

Scientific Program of the Fourth International Conference on Advances in Radioactive Isotope Science (ARIS)

David Lunney¹, Aurélie Bonhomme², Wolfram Korten³, and Ulli Köster⁴

¹Université Paris-Saclay, CNRS-IN2P3, IJCLab

²Université de Strasbourg, CNRS-IN2P3, IPHC

³Université Paris-Saclay, CEA-IRFU, DPhN

⁴Institut Laue-Langevin, Grenoble

Abstract. A summary is given of the 4th international conference on Advances in Radioactive Isotope Science (ARIS), held 4-9 June 2023 in Avignon, France. All abstracts presented at the conference are included as an appendix.

1 Introduction

The fourth international conference on **Advances in Radioactive Isotope Science**, ARIS 2023, was held last June in Avignon, France. ARIS 2023 was organized by members of France's nuclear physics laboratories of the CNRS/IN2P3 (Bordeaux, Caen, Orsay and Strasbourg), CEA/IRFU (Saclay) and the ILL (Grenoble).

ARIS is the flagship research conference in nuclear physics devoted to the study and applications of exotic nuclides, taking place every three years in a cycle with two other major meetings: INPC (International Nuclear Physics Conference) and EMIS (Electromagnetic Isotope Separators and Related Topics).

The first ARIS, held in Leuven (Belgium) in 2011, resulted from the merger of RNB (Radioactive Nuclear Beams, which ran from 1989 to 2009) and ENAM (Exotic Nuclei and Atomic Masses, 1995 to 2008). ENAM itself resulted from combining the conferences NFSS (Nuclei Far From Stability) and AMCO (Atomic Masses and Fundamental Constants). The antecedents of ARIS can therefore be traced back to 1956. Alternating between Europe, Asia and North America (ARIS 2014 was held in Tokyo and ARIS 2017 in Keystone, near Denver) ARIS has now returned to Europe and started its second cycle. Originally scheduled for 2020, the Covid-19 pandemic contrived to delay it, finally for three years. We proposed hosting ARIS in France to highlight the commissioning of the SPIRAL2 project at GANIL.

ARIS 2023 was held in the stunning *Palais des Papes* in Avignon, which lies on the banks of the Rhone River at the gateway to the lush lavender fields of Provence. The French pope Clément V settled in Avignon in the year 1309 and was succeeded by six other popes until the Great Schism from 1378-1417, during which the popes in Rome and Avignon coexisted. Pope Benedict XIII fled Avignon in 1403 and the fourth ARIS meeting was held 620 years later, attended by 258 scientific delegates, from 28 different countries. The break-down is shown Fig. 1.

Overview

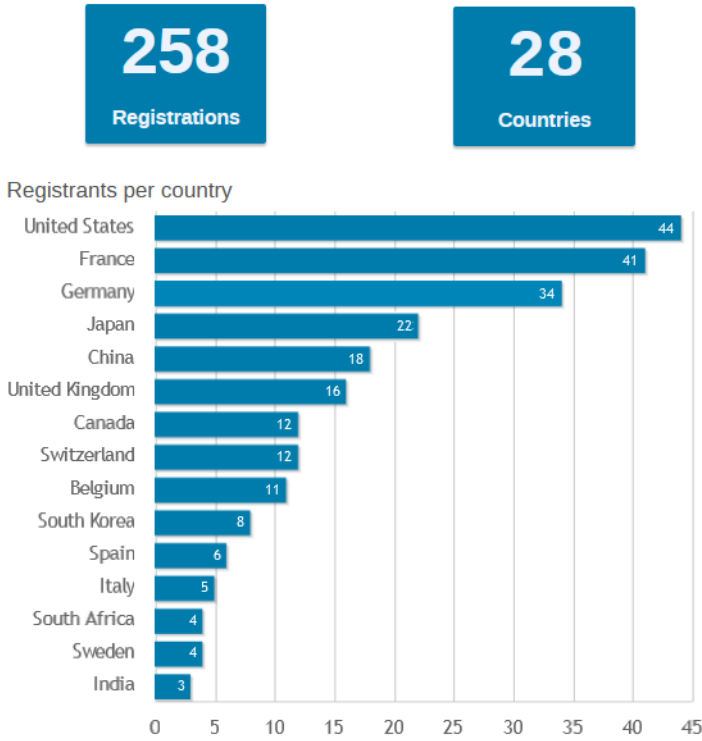


Figure 1. Registered scientific delegates by country. The countries not listed are: Botswana (1); Brazil (2); Bulgaria (2); Czech (1); Denmark (1); Finland (2); Hong Kong (1); Hungary (1); Netherlands (1); Poland (3); Portugal (1); Slovakia (1); and Vietnam (1).

Over four and a half days, our delegates could enjoy lively exchanges around a program highlighting the most recent advances in radioactive isotope science, including:

- Nuclear structure and reactions
- New approaches in nuclear theory
- Nuclear astrophysics including nucleosynthesis and compact objects
- Ground-state properties and fundamental interactions in nuclei
- Drip-line nuclei, heavy elements and fission
- Radioactive ion beam production and experimental developments
- Applications of radioisotopes in medicine and material science

The timetable and most of the presentations can be viewed via the website: <http://aris2023.eu/> (or by its indico URL: <https://indico.in2p3.fr/event/19688/>)

We processed a total of 360 abstracts submitted for ARIS. Through the parallel sessions, 81 (mostly) younger scientists (31% of them female) were able to highlight their contributions through oral presentations, nicely complementing the 38 invited speakers (24% female) in the plenary sessions. ARIS also included a public lecture, delivered by the “pope” of medical isotopes for theranostics (a contraction of therapy + diagnostics), Prof. Dr. Richard Baum, from the Curanosticum in Wiesbaden, Germany. Two lively, pastis-fueled poster sessions were held where all of the 103 posters were on display (29% by women). A panel of senior scientists ranked the 48 posters presented by doctoral students with cash prizes awarded to:

- 1st place: Magdalena Kaja, Mainz University
- 2nd place: Anjali Ajayakumar, GANIL
- 3rd place: Jinti Barman, Indian Institute of Technology (Roorkee) and Eleanor Ronning, Michigan State University

The conference abstract booklet is available via the ARIS2023 website but we have decided to publish it as an appendix to this report in lieu of conference proceedings, with its own DOI for citation purposes.

We thank the sponsors shown in Fig. 2 who made important financial contributions.



Figure 2. ARIS2023 sponsors

We deeply appreciate the help of our International Advisory Committee:

A. Aprahamian, Notre Dame, USA
R. Bark, iThemba Labs, South Africa
B. Blank, LP2I, France
C. Cutler, BNL, USA
M. Dasgupta, Australian National University
P. Fallon, LBNL, USA
S. Freeman, ISOLDE, CERN
A. Gade, NSCL, USA
A. Garnsworthy, TRIUMF, Canada
M. Gorska, GSI, Germany
V. Guimaraes, University of São Paulo, Brazil
K. I. Hahn, Institute for Basic Science, Daejeon, Korea
R.-D. Herzberg, University of Liverpool, U.K.
A. Jokinen, University of Jyväskylä, Finland
A. Jungclaus, IEM-CSIC Madrid, Spain
Y. Kanada-En'yo, Kyoto University, Japan
S. Leoni, INFN, Milan, Italy
M. Lewitowicz, NuPECC
T. Motobayashi, RIKEN, Japan
A. Navin, EUROLABS
G. Neyens, KU-Leuven, Belgium
T. Nilsson, Chalmers University, Sweden
T. Otsuka, University of Tokyo, Japan
R. Palit, TIFR, Mumbai, India
T. Papenbrock, ORNL, USA
M. Pfützner, University of Warsaw, Poland
K. Riisager, Aarhus University, Denmark
P. Roussel-Chomaz, GANIL, France
G. Savard, ANL, USA
S. Siem, University of Oslo, Norway
C. Svensson, Guelph University, Canada
I. Tanihata, RCNP, Osaka, Japan
P. Thirolf, LMU, Munich, Germany
P. Van Duppen, KU-Leuven, Belgium
D. Vretenar, University of Zagreb, Croatia
F. Xu, Peking University, China
S. Yennello, Texas A&M University, USA
Y. Zhang, IMP-Lanzhou, China

and our Local Organizing Committee members who were not able to attend:

Marlène Assié (IJCLab-Orsay), Ferid Haddad (Arronax/U. Nantes), Beatriz Jurado (LP2I-Bordeaux), Nigel Orr (LPC Caen), Kamila Sieja (IPHC-Strasbourg) and Jean-Charles Thomas (GANIL-Caen)

The next, fifth, ARIS is scheduled for 2026 and will be held in Fukushima, Japan. We look forward to the continuing success of this flagship conference.

Contents

High-resolution gamma-ray spectroscopy at a neutron beam: news from ILL 294	1
Nuclear Structure investigations of most exotic nuclei via mass measurements at TITAN 295	1
Complex-energy based description of alpha-tunneling in intense laser fields 296	2
Measurement of the bound-state beta decay of highly charged ions $^{205}\text{Tl}^{81+}$	3
Electromagnetic Dipole Response of Nuclei: Exploring Nuclear Structures and Constraining Nucleosynthesis Processes 298	3
Studies of Weakly-Bound, Neutron-Rich Nuclei using HELIOS and SOLARIS 299	4
β -decay of ^{36}Mg and ^{36}Al : Identification of a long-lived isomer in ^{36}Al 300	5
New Technique of Injecting Radioactive Ions into Charge Breeding ECR Ion Source 301	5
Breakdown of the Isobaric Multiplet Mass Equation at $A = 54, T = 3$ 303	6
Performance Test of Beam Drift Chamber for LAMPS 304	6
Development of LAMPS Time Projection Chamber at RAON 305	7
Searching for CP-violation in nuclear beta decay: First results of the MORA experiment 306	7
Electromagnetic moments of the antimony ($Z = 51$) isotopic chain $^{112-133}\text{Sb}$ in comparison to shell-model ab initio calculations 307	8
A systematic analysis of nucleon emission in deuteron-induced reactions 308	9
Evolution of single-particle structure along the Mg isotopic chain: the $d(30\text{Mg,p})31\text{Mg}$ reaction measured with the ISOLDE Solenoidal Spectrometer 309	9
CERN-MEDICIS: a unique facility for the production of non-conventional radionuclides for medical research 311	10
Observation of the radiative decay of the low energy thorium-229 isomer: En route towards a nuclear clock 312	11
High-resolution in-beam γ -ray spectroscopy at RIBF 313	12
Microscopic study of nuclear monopole excitations 315	13

Spectroscopic Factor Investigation in the N=40 Island of Inversion 318	13
Extremely neutron-rich nuclei beyond the drip line 319	13
Production of Tb-155 with highly enriched targets : first results 320	14
Production and characterization of ^{111}Ag radioisotope in a TRIGA Mark II nuclear reactor for medical use in the framework of the Italian ISOLPHARM project 321	15
Design of the High Rigidity Spectrometer at the Facility for Rare Isotope Beams 322 . . .	15
Laser Spectroscopy of the Hyperfine Splitting in $^{208}\text{Bi}^{82+}$ 324	16
Materials Science with radioactive isotopes –results from emission Mössbauer Spectroscopy 328	17
Beta-delayed fission of neutron-rich actinides 330	18
Cross-shell interactions at the N=28 shell closure via $^{47}\text{K}(\text{d,p})$ and $^{47}\text{K}(\text{d,t})$ with MUGAST + AGATA + VAMOS. 331	18
Study of ^{11}Be excited states via the $^{10}\text{Be}(\text{d,p})$ reaction in SOLARIS with the AT-TPC 332 .	20
From Tensor Currents to Solar Neutrinos: Precision Beta-Decay Studies of ^8Li and ^8B 334	20
Solar Neutrinos and Physics Beyond the Standard Model Probed through Boron-8 Beta Decay 335	21
Mass Measurement of the ^{123}Pd with the Rare-RI Ring in RIKEN 336	22
Charge polarization on the fission fragments from U-236 calculated with a time-dependent mean-field model 337	22
Production of highly charged and molecular thorium ions for fundamental physics 339 .	23
The new Atomic Mass Evaluation (AME2020) 340	24
First characterization of Short-Range Correlations in an exotic nucleus at R3B 341	25
Is there a dark decay in ^6He ? 342	25
Study of alpha particle production in the $^6\text{He}+^9\text{Be}$ collision 343	26
Deformed two-body models for exotic nuclei applied to transfer reactions 346	27
Microscopic models of nuclear structure at scale 347	27
Shape coexistence studies of Pb-186 employing the SAGE spectrometer 350	28
Characterization of the participant zone in Xe+Sn collisions 351	29
Total Absorption Spectroscopy of Ground and Isomeric States in ^{70}Cu 352	29
Microscopic study of alpha, two-alpha and cluster decays 353	30
Nuclear astrophysics at storage rings 355	31

Towards N=126 shell closure using multi-nucleon transfer reaction between ^{136}Xe and ^{198}Pt 358	31
Nuclear and molecular physics studies with laser spectroscopy of radioactive molecules 360	32
β -delayed proton decay of ^{23}Si and isospin symmetry breaking 361	33
β -decay studies of A = 107 nuclei using the Modular Total Absorption Spectrometer (MTAS) 362	34
Studies of astrophysically important reactions using rare isotope beams at TRIUMF 363	35
High-precision collinear laser spectroscopy - An all-optical nuclear charge radius of ^{12}C 364	35
Effect of Halo and Bubble Nuclei in Limited Abundance Calculations Relevant for the r-process 368	36
Fission, gamma rays and the r-process 371	37
Storage ring facilities for radioactive ions -New detectors and upgrade plans 372	37
Investigation of the atomic and nuclear structures of $^{244-248}\text{Cm}$ 373	38
Testing ab-initio calculations in light nuclei via high-precision spectroscopy 374	39
Detecting fission fragments at ISS 375	40
In-beam gamma-ray spectroscopy of the exotic ^{79}Cu with HiCARI 376	40
Li-8 and He-8 beams for hadrontherapy 377	41
A DESIRable radiofrequency cooler and buncher: the GPIB 378	42
Constraining the electron-capture rates of neutron-rich nuclei with the ($d, ^2\text{He}$) reaction in inverse kinematics. 381	42
Study of the tensor force contribution in the N isotopic chain using QFS reactions 382	43
Searching for Alpha-Cluster States in ^{126}Te 383	44
Determination of the Neutron Dripline at F and Ne and Discovery of the Heaviest Na Isotope: ^{39}Na 384	44
Alpha-clustering in atomic nuclei from first principles 385	45
Towards implantation of pure Fe-55 for radioactivity standardization by low temperature devices 386	46
Search for ^{22}Na in novae supported by a novel method for measuring femtosecond nuclear lifetimes 387	46
Visualization of nuclear many-body correlations in microscopic wave functions 388	47
Discovery of isotopes and first time broadband measurements of neutron-deficient light lanthanides via high precision mass spectrometry 389	47

Measurements with the FRS Ion Catcher in the region below ^{100}Sn and on the ^{252}Cf spontaneous fission fragments 390	49
Nuclear structure of Pd isotopes via optical spectroscopy 391	50
Determination of fission barrier height of ^{210}Fr via neutron measurement 392	51
Search for near-threshold multi-neutron resonances in (p,2p) reactions with neutron-rich nuclei at R3B 394	51
Spectroscopy of ^{12}Be using TexAT TPC 395	52
Highlights of GANIL-SPIRAL2 facilities 397	53
Axial Shape Asymmetry and Configuration Coexistence in Neutron-Rich ^{74}Zn 398	53
Study of $^{70,72}\text{Se}$ nuclear shapes with SPICE and TIGRESS 402	54
β -decay spectroscopy of ^{28}S 403	54
The ISOLDE RILIS at 30 405	55
Measurement of reaction cross section for ^{17}F with a solid hydrogen target 407	55
Extracting β -decay strengths from ^{73}Co using the Summing NaI (SuN) Total Absorption Spectrometer 413	56
Study of the Pygmy Dipole Resonance using neutron inelastic scattering at GANIL-SPIRAL2/NFS 415	57
What are the fingerprints of nucleosynthesis? 416	58
Harvesting Hf-172 from heavy-ion beam irradiated tungsten beam-blocker for generating Lu-172 419	59
Strongly isospin-mixed doublet in ^{26}Si observed by β decay of ^{26}P 420	59
The NEXT setup to study Neutron-rich EXotic nuclei produced in multinucleon Transfer reactions 422	60
Hyperfine structure and isotope shift in the atomic spectrum of neptunium 423	61
Development of a Thick Solid Deuterium Target 425	61
Developments in muonic x-ray spectroscopy 426	62
Cluster structure of neutron-rich beryllium isotopes probed by cluster knockout reactions in inverse kinematics 427	63
Spectroscopy of heavy neutron-rich $N > 126$ nuclei at RIKEN 428	64
Towards in-gas-jet studies of isomeric $^{229}\text{Th}^+$ 430	64
Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings 435	65
Recent results with the Active Target Time Projection Chamber 436	66

Light-exotic nuclei studied with the (t,p) reaction in inverse kinematics using HELIOS 437	66
Study of muon capture reaction on Si via in-beam muon activation 438	67
Determination of electromagnetic moments within nuclear DFT 439	68
Collinear laser spectroscopy in medium-mass elements at BECOLA 440	69
Statistical and shell effect in beta-delayed neutron emission 441	70
Doubly magic ^{78}Ni as a beta-delayed neutron precursor 442	70
Gas Cell Development using a ^{248}Cm Fission Source at the ZD MRTOF Mass Spectrograph at RIBF 445	71
Evolution of the neutron $1d$ spin-orbit splitting in ^{35}S and ^{39}Ca 446	72
Mass measurement of neutron-deficient $T_z=3/2$ nuclides at CSRe 447	73
Resonance Ionization Mass Spectroscopy on Americium 448	74
Investigation on Isomeric ratio of ^{211}Po produced via MNT approach using $^{136}\text{Xe} + ^{209}\text{Bi}/$ ^{nat}Pb at the IGISOL facility 449	75
Recent highlights from high-precision atomic mass measurements using MRTOF-MS at RIKEN/RIBF 451	75
Recent progress of mass measurements for short-lived nuclides at CSRe-Lanzhou 453 . .	76
Two-centre self-consistent approach to fission with arbitrary distance, deformations and orientations of fragments 455	77
The nuclear charge radius of ^{13}C 456	77
First study of proton capture reaction on stored radioactive ^{118}Te beam 458	78
Mass measurement in the neutron-rich Mo region using the new ZD MRTOF system 459	79
Production of medical grade Ac-225 with resonant laser ionization and mass separation at CERN MEDICIS 460	80
Onset of deformation in the neutron-rich krypton isotopes via transfer reactions with the ISOLDE Solenoidal Spectrometer 466	81
Systematic nuclear-DFT calculations of electromagnetic moments of $\pi 7/2^+$ and $\nu 11/2^-$ configurations in heavy deformed open-shell odd nuclei with $50 \leq Z \leq 64$ 468 . . .	82
Charge-current and neutral-current quasielastic (anti)neutrino scattering on ^{12}C and ^{40}Ar targets with realistic spectral and scaling functions 469	83
First in-gas-jet laser spectroscopy with $\text{S}^3\text{-LEB}$ 470	83
Ab initio calculation of the $^3\text{He}(\alpha, \gamma)^7\text{Be}$ astrophysical S factor 471	85
$B\rho$ -defined isochronous mass spectrometry using two TOF detectors at CSRe-Lanzhou 472	85
Direct mass measurement of neutron-deficient Fe isotopes 473	86

Development of Ti:Sapphire laser system for resonance ionization laser ion source, PALIS RIKEN 474	86
Precision velocity measurements of ions in the storage ring CSRe-Lanzhou 475	87
Measurements of β -delayed one and two neutron emission probabilities south-east of ^{132}Sn within the BRIKEN project at RIKEN 477	87
The Super Separator Spectrometer (S^3) at GANIL/SPIRAL2 478	88
Recent Nuclear Structure Studies at $N=50$ Through Masses of Isomeric States 480	89
Development of ^{14}C cavity ring-down spectroscopic system for biomedical tracer and en- vironmental applications 482	89
Shape studies in neutron-rich cerium isotopes 484	90
Technical progress at the double Penning trap PIPERADE 487	91
MEASUREMENTS OF ^{161}Tb PRODUCTION CROSS SECTION FOR NUCLEAR DATA AND NUCLEAR MEDICINE 491	92
Latest results from MARA 494	93
Isospin-symmetry breaking in the $B(E2)$ transitions of $T = 1$ isotriplets 495	93
Structure of $A=22$ analogue states revealed through mirrored-transfer 497	94
Study of medium-mass and heavy hypernuclei produced through spallation and fission reactions in inverse kinematics 498	95
Is $^{70}\text{Zn}(d,x)^{67}\text{Cu}$ the best way to produce ^{67}Cu for medical applications? 501	96
The $N=126$ Factory: A new multi-nucleon transfer reaction facility at Argonne National Laboratory 503	96
The role of tensor forces in polarised nuclear matter 505	97
Study of the $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction with the SOLARIS spectrometer 506	98
Towards the r-process path at $N=126$ 507	98
Elucidating the structure of the 16.6 - 16.9 MeV doublet of ^8Be through β -decay feeding 508	99
Surrogate Reactions in the FRIB Era – New Challenges and Opportunities 509	100
Conversion coating method development for thin-film vanadium targetry 510	100
KDK: first measurement of the rare electron-capture decay of ^{40}K to the ground state of ^{40}Ar 512	101
Super-allowed alpha decay to doubly-magic ^{100}Sn 513	101
Gamma-ray spectroscopy of the neutron-rich $^{55,57,59}\text{Sc}$ isotopes 514	102
The ALTO facility of IJCLab 515	102

Beta-neutrino angular correlation measurements of mirror transitions with St. Benedict 516	103
Core-breaking effects around 100Sn: lifetime measurements in the most neutron-deficient Sn isotopes. 517	103
Exploring low-lying states in ^{136}Cs and ^{136}Ba relevant for ^{136}Xe neutrinoless double beta decay 519	104
Elastic scattering of $^6\text{He}+d$ at 26 MeV/A 520	104
Precision half-life measurements of mirror transitions at Notre Dame 521	105
Possible Existence of Extremely Neutron-Rich Superheavy Nuclei in Neutron Star Crusts Under a Superstrong Magnetic Field 524	106
First results from ATLANTIS - A new collinear laser spectroscopy setup at Argonne Na- tional Laboratory 525	106
Precision Lifetime Measurements of Excited States in ^{38}Si and ^{36}Si 526	107
Present status and future prospect of the SCRIT electron scattering facility 527	108
New structure features revealed in isomeric spectroscopy in the $Z \sim 82, N \sim 104$ region 529	108
Initial RI Beam Commissioning of the RAON ISOL Facility 530	110
Investigation of negative-parity band in ^{130}Cs 531	110
Beta-Delayed Neutron Spectroscopy of Californium-252 Fission Fragments with BEARtrap at Argonne National Laboratory 532	111
Medical Radioisotope Production Using Inverse Kinematics 537	112
First measurement of a p-process reaction using a radioactive ion beam 538	113
Ξ hypernuclei $^{15}_{\Xi}\text{C}$ and $^{12}_{\Xi}\text{Be}$, and the ΞN two-body interaction 539	113
First results with the Advanced Rare Isotope Separator (ARIS) at FRIB 540	114
Isospin symmetry in the $A=78$ triplet - gamma-ray spectroscopy of ^{78}Y and ^{78}Zr 544 . . .	114
Investigation of axial shape in ^{130}La through lifetime measurements 545	115
Cross-section measurement in proton-, deuteron- and carbon-induced reactions on ^{136}Xe in inverse kinematics 547	116
Recent Progress with the MLLTRAP double Penning Trap Mass Spectrometer at ALTO 548	117
Laser spectroscopy of the Heaviest Elements 550	118
Simultaneous pH sensing and gamma-ray imaging via angular correlation measurement using cascade nuclides 553	118
High-precision mass measurements of ground and isomeric states of (super)heavy nuclides with SHIPTRAP 558	119

New Super-pulse Fitting Algorithms for Decomposing Pile-up Pulses and Application to the α -decay of ^{222}U 559	120
Study of the $N = 32$ and $N = 34$ shell gap for Ca and Ar isotopes with quasi-free scattering reactions 560	120
Gamow-Teller Giant Resonance in ^{11}Li neutron drip line nucleus 561	121
The South African Isotope Facility and Low-Energy Radioactive-Ion Beam Project 563	122
Penning-trap mass measurements of neutron-rich Rh and Ru nuclei at IGISOL/JYFL 565	123
Beta decay of neutron rich bromine isotopes studied by means of Modular Total Absorption Spectrometer 566	124
First beta-delayed spectroscopy of neutron-rich Cl isotopes with FDSi 568	125
High-resolution spectroscopy of exotic silver with a cw OPO injection-seeded PDA. 571	126
Indium Energy Spectrum Shape (InESS) at WISArD 573	126
First beta-delayed neutron spectroscopy of doubly-magic ^{24}O . 574	127
b-STILED: Search for Tensor Interactions in nuclear beta Decay 577	127
Island of inversion at the $N=Z$ line 578	128
Spectroscopy of ^{128}In and ^{128}Sn from the beta-decay of ^{128}Cd 579	129
Advances in TRIUMF's resonant ionization laser ion source 581	130
Probing the $N = 152$ neutron shell gap by laser spectroscopy of fermium isotopes 584	130
Radiation-detected NMR for chemistry and life-science studies using unstable nuclei 587	132
Collinear Laser Spectroscopy on Neutron Rich Palladium Isotopes 588	133
Development of the polarizer facility at TRIUMF 589	134
The AGATA γ -ray tracking array at the LNL TANDEM-ALPI-PIAVE facility 590	134
Magnetization distribution from hyperfine anomaly measurements 591	134
Evaluation of metal-organic frameworks for room temperature noble gas harvesting at the Facility for Rare Isotope Beams 592	135
β -decay of ^{68}Mn : Probing the $N=40$ island of inversion 593	136
Higher rare isotope yields at ISAC TRIUMF using proton beam rastering 594	137
A new technique for direct (n,p) reaction measurements of astrophysical interest using radioactive beams with SECAR 597	137
Decay spectroscopy around neutron-rich ^{33}Mg to probe an 'island of inversion' 598	138
Combined Mass and Half-life Measurements with TITAN's MR-TOF-MS 600	139

Advanced Spectrometer and Separator Tuning for Commissioning or New Operational Modes 603	139
Probing the rapid onset of deformation below ^{68}Ni through the beta decay of ^{67}Mn 609	140
Measurement of the Fierz interference term in ^{20}F decay 611	141
β -decay studies of neutron-rich isotopes in the region around double-magic ^{132}Sn 613	142
The PUMA experiment at CERN 618	143
The Decay Spectroscopy Setup at the GSI-FAIR facility and the physics results from FAIR-0 620	143
The Future of the GANIL facility 622	144
Structure of ^{13}Be using TexAT active target. 627	144
Improved procedures for La-135 cyclotron production and purification 629	145
Charge exchange as a quantum state detector to study exotic Calcium isotopes 630	145
Evolution of single-particle properties probed with the ISOLDE Solenoidal Spectrometer 631	146
Study of proton and neutron excitations along Silicon Isotopes between $N=20$ and $N=28$ 632	147
RF timer based time-of-flight spectrometer for the measurement of the absolute energy of alpha particles 635	147
OEDO-SHARAQ system: Its multifaceted performance and recent experimental achievements 639	148
Towards a cyclotron production of Ac-225 for targeted alpha therapy 640	149
Emission channeling investigations of impurities with interesting quantum properties in single crystals 641	149
Unravelling the mysteries of the atomic nucleus via high resolution laser spectroscopy at COLLAPS 643	150
FRIB and the Neutron-Rich Mg Isotopes 644	150
Global ab initio calculations for the structure of exotic and heavy nuclei 645	151
Nuclear collectivity studied with the newly refurbished Miniball spectrometer at HIE-ISOLDE 646	151
Synthesis of cold highly charged radionuclei using antiprotons 648	151
Accessing nuclear structure with high-energy nuclear collisions (presentation sponsored by NUPECC) 649	153
r process and supernova signatures in deep-sea archives 650	153
Prevailing triaxial shapes in exotic and heavy nuclei 651	154

Observation of a correlated free four-neutron system 652	154
Studies of exotic isotopes using laser ionization techniques and trapped ion techniques 653	154
Proton radioactivity studies with ACTAR TPC 654	155
Probing Nuclear and Particle Physics Phenomena with Radioactive Molecules 655	155
Reactor Antineutrino Spectral Excess: Cumulative Fission Yield Measurement Using Gamma-Ray Spectroscopy 656	156
Treatment of metastatic cancer by Radiomolecular Precision Oncology - an ongoing revolution 657	156

plenary / 294

High-resolution gamma-ray spectroscopy at a neutron beam: news from ILL

Auteur: Caterina Michelagnoli¹¹ *Institut Laue-Langevin***Auteur correspondant** michelagnolic@ill.fr

Thermal neutron capture gamma-ray spectroscopy and prompt gamma-ray spectroscopy of fission fragments are powerful tools to obtain detailed nuclear structure information for nuclides close to stability and medium mass neutron-rich isotopes. The power of coupling a high-efficiency Ge detector array with an intense pencil-like neutron beam provided by the ILL reactor, has been recently demonstrated by the success of the EXILL (EXogam at ILL) campaign. This success led to the installation of permanent setup at ILL, the new instrument FIPPS (Fission Product Prompt Spectrometer). In its first phase, it consists of a halo-free pencil neutron beam incident on a target surrounded by an array of 8 HPGe clovers. This setup has recently been exploited for a variety of (n,γ) experiments on stable (rare) and radioactive targets. Additional HPGe clovers from IFIN-HH were added during the last year allowing for a higher efficiency and granularity. Recently, targets consisting of $^{235,233}\text{U}$ diluted in a liquid scintillator has been used to study the spectroscopy of neutron-rich nuclei with a fission tag. In a second phase, the instrument will be complemented with a fission-fragment identification setup, based on diamond detectors. This will increase the sensitivity and selectivity for nuclear spectroscopy of fission products and enable fission studies of the correlation between excitation energy, angular momentum and kinetic energy.

After a general introduction to the nuclear physics activity at ILL, the details of the FIPPS instrument, its performance and first physics results will be shown. An overview on the physics cases investigated in last years, together with the techniques used, will be given. The future developments foreseen, in particular for fission studies, will be also reported.

plenary / 295

Nuclear Structure investigations of most exotic nuclei via mass measurements at TITAN

Auteurs: Moritz Pascal Reiter¹; TITAN Collaboration²¹ *University of Edinburgh*² *TRIUMF***Auteur correspondant** mreiter@ed.ac.uk

High precision mass measurement using ion trapping continue to play an important role in shaping our understanding of the nucleus. State-of-the-art spectrometers nowadays are able to reach far from the valley of beta stability, where new phenomena, as e.g. shell quenching, weakening or disappearance of classical and appearance of new magic numbers can be observed and studied via their characteristic signatures in the mass surface.

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) [1] located at the Isotope Separator and Accelerator (ISAC) facility, TRIUMF, Vancouver, Canada is a multiple ion trap system specialized in performing fast high-precision mass measurements and in-trap decay spectroscopy of short-lived radioactive species. Since its installation in 2017, the new Multiple-Reflection Time-Of-Flight Mass Spectrometer (MR-TOF-MS) has been in routine operation [2] and has expanded TITANs reach to even more exotic nuclei.

Mass selection is achieved using dynamic re-trapping of the ions of interest after a time-of-flight analysis in an electrostatic isochronous reflector system [3]. Re-using the injection trap of the device for the selective re-trapping, the TITAN MR-TOF-MS can operate as its own high resolution

isobar separator prior to a mass measurements within the same device. This unique combination of operation modes boosts the dynamic range and background handling capabilities of the device, enabling high precision mass measurements with ion of interests to contaminant ratios of $1:10^7$. Among other, we will discuss recent results of mass measurements of neutron-deficient Yb and Tm isotopes investigating the persistence of the $N=82$ neutron shell closure far from stability, made possible by online mass-selective re-trapping suppressing strong isobaric background. On the opposite side of the nuclear chart, we will investigate the evolution of the $N=40$ island of inversion in the neutron-rich Mn to Fe isotopic chains and give an outlook towards future mass measurements for nuclear structure investigations.

References:

- [1] J. Dilling et al., NIM B 204, 2003, 492–496
- [2] M. P. Reier et al., NIM A 1018, 2021, 165823
- [3] T. Dickel et al. J. Am. Soc. Mass Spectrom. (2017) 28: 1079

296

Complex-energy based description of alpha-tunneling in intense laser fields

Auteur: Réka Szilvási¹

¹ *Budapest University of Technology and Economics, Institute of Nuclear Techniques, Department of Nuclear Energy*

Auteur correspondant szilvasi.reka@ttk.bme.hu

Abstract

Several attempts have been made to investigate the case when an alpha-decaying nucleus is coupled to an external time-dependent potential field, in particular coherent electromagnetic fields (lasers). The main question is how the time-dependent laser field alters the half-life of the decay, or correspondingly, the lifetime of the alpha cluster in the nuclei.

There are two crucial aspects of the problem: how to treat the time-dependence of the external field and how to describe the alpha-particle states.

In this research alpha decay is studied in the frame of quasi-stationary states which are associated with complex energy ($E_{qs} = E_0 - i\frac{\Gamma}{2}$), the imaginary part of which is proportional to the lifetime of the state ($\Gamma \propto \frac{1}{\tau}$). Using the quasi-stationary description of alpha-decay, in order to determine a quantitative effect of a time-dependent coherent electromagnetic field on the complex energy of a quasi-stationary state the procedure of the (t,t') -perturbation calculation is followed which provides a way to perform formally time-independent perturbation calculation on the time-dependent system, in an extended Hilbert space. The (t,t') -formalism requires the wavefunction-centered description of decaying states, although due to the complex nature of the alpha energy the corresponding eigenfunctions diverge in coordinate representation. To treat this problem, alpha decay is studied within the framework of non-Hermitian quantum theory, which, I argue, might be regarded as the natural coordinate system of decaying states. The special complex scaling transformation renders the divergence of the quasi-stationary eigenfunctions and allows one to apply the (t,t') -method.

From the nuclear theory perspective, as an additional gain, the formalism guaranties that the complex spectrum of a non-Hermitian (complex-scaled) operator representing an alpha-decaying system can be determined by non-Hermitian spectral calculations numerically, using the complex variational calculus, hence the lifetime of the alpha decay can be elicited directly from the spectrum of a non-Hermitian operator.

During this research, to demonstrate the appliance of the non-Hermitian formalism, the lifetime of the alpha particle of a specific isotope was extracted from the complex-scaled, mean-field Hamiltonian operator of the nuclear system and was determined upon finite numerical error, considering only spherically symmetric nucleus. I computed the laser-field-induced correction to the lifetime of the alpha-particle $\varepsilon^{(1,p)}$ by first-order (t,t') -perturbation calculation in regards of different polarization states (p) and control parameters of the external laser field, and also examined the limit of the non-relativistic approximation of the problem.

Related publications:

Réka Szilvási and Dániel P Kis, *J. Phys. A: Math. Theor.* **55**, 275301 (2022)

Réka Szilvási and Dániel P Kis, Computation of the complex-energy shift of decaying states in intense laser fields (Researchgate, preprint)

parallel / 297

Measurement of the bound-state beta decay of highly charged ions $^{205}\text{Tl}^{81+}$

Auteurs: G. Leckenby¹; R. Mancino²; R. S. Sidhu²; Rui-Jiu Chen³; Yu. A. Litvinov²

¹ TRIUMF

² gsi

³ GSI

Auteur correspondant r.chen@gsi.de

Neutrinos are produced as a result of the nuclear fusion reactions happening inside the Sun. Precise measurement of the solar neutrino flux is crucial for a better understanding of the various nuclear reactions taking place in the Sun but also gives us important information about the Sun's core [1]. The geochemical experiment LOREX (LORandite EXperiment) [2], proposed by Freedman and collaborators aims to determine the long-time average (over ~4.3 million years) of the solar pp-neutrino flux Φ_ν through the neutrino-capture reaction. The interaction cross-section of ν_e and ^{205}Tl nucleus is important for the determination of the neutrino flux in the LOREX project. To determine the interaction cross-section, the half-life of bound state β^- decay of bare $^{205}\text{Tl}^{81+}$ nuclei is required as the two processes share the identical nuclear matrix element.

In this talk, we report on the first direct measurement of the bound-state beta decay of $^{205}\text{Tl}^{81+}$ ions [3]. The experiment was performed at GSI, Darmstadt in 2020, wherein the entire accelerator chain was employed. Highly charged ions $^{205}\text{Tl}^{81+}$ ions were produced with the projectile fragmentation of ^{206}Pb primary beam on ^9Be target, separated in the fragment separator (FRS), accumulated, cooled, and stored for different storage times (up to 10 hours) in the experimental storage ring (ESR). The experimentally measured half-life value agrees with the theoretically predicted values by E. Braun [3] and deviates from the theoretically predicted values [4,5]. The interaction cross-section between neutrino and ^{205}Tl nucleus is determined. The impact of our result on LOREX project will be discussed in this talk.

This research has been conducted in the framework of the SPARC, ILIMA, LOREX, NucAR collaborations, experiment E121 of FAIR Phase-0 supported by GSI. The authors received support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (Grant Agreement No. 682841 "ASTRUM").

[1] Wurm, Michael: Solar neutrino spectroscopy. *Physics Reports* 685, 1-52 (2017).

[2] Melvin S. Freedman et al., Solar Neutrinos: Proposal for a New Test. *Science* 193, 4258: p. 1117 (1976).

[3] Ragandeep Singh Sidhu, Ph.D. Thesis, Ruprecht-Karls-Universität, 2021.

[4] Proceedings of the International Symposium, Weak and Electromagnetic Interactions in Nuclei, Heidelberg, edited by H. V. Klapdor (Springer, Berlin, 1986), p. 47.

[5] K. Takahashi et al., *Phys. Rev. C*, 36, 1522, 1987.

[6] S. Liu et al., *Phys. Rev. C*, 104, 024304, 2021.

parallel / 298

Electromagnetic Dipole Response of Nuclei: Exploring Nuclear Structures and Constraining Nucleosynthesis Processes

Auteur: Mathis Wiedeking¹

¹ *iThemba LABS and University of the Witwatersrand*

Auteur correspondant wiedeking@tlabs.ac.za

The gamma-ray decay of nuclear states in the quasi-continuum provides important insights into nuclear structure effects and constraints to nucleosynthesis processes. In particular, measurements of Nuclear Level Densities (NLDs) and Photon Strength Functions (PSFs) have and will continue to play a central role as we are entering an era of incredible potential for novel measurements. This is due to many institutes across the world having established programs to provide enhanced, state-of-the-art research infrastructure. These range from significant increases in efficiencies for particle and gamma-ray detectors, to new or upgraded radioactive ion beam facilities. In parallel, several new experimental and analytical techniques were developed which allow for more reliable PSF and NLD studies, even on nuclei away from stability. All this progress will undoubtedly lead to unprecedented insight into the structure of nuclei and provide reaction rates of relevance to nucleosynthesis processes.

In this talk, I will provide an overview of the most significant advances made and how these have laid the foundation for novel and ambitious measurements of PSFs and NLDs at radioactive and stable ion beam facilities. I will further discuss recent progress in exploring the underlying nuclear structure of resonances from PSF measurements, focusing on the scissor's mode and the low-energy enhancement, whose mechanisms are still not fully understood. Our understanding of observed isotopic abundances can be improved greatly through the measurement of PSFs and NLDs as will be demonstrated.

This work is supported by the National Research Foundation of South Africa under grant number 118840.

plenary / 299

Studies of Weakly-Bound, Neutron-Rich Nuclei using HELIOS and SOLARIS

Auteur: Ben Kay¹

¹ *Argonne National Laboratory*

Auteur correspondant kay@anl.gov

The solenoidal-spectrometer technique developed at Argonne some 15 years ago in the form of HELIOS continues to evolve, adding new capabilities. A similar device has been recently installed at the Facility for Rare Isotope Beams (FRIB), called SOLARIS, for use with reaccelerated (ReA) beams. SOLARIS operates as a dual-mode spectrometer, both in a vacuum with position-sensitive silicon arrays and in Active-Target Time Projection Chamber (AT-TPC) mode. This allows for reaction studies across a broad dynamic range in terms of beam intensities (hundreds of particles per second to nano-Ampere beams), masses, and incident beam energies. SOLARIS has been used in both modes of operation during the operation of ReA with long-lived radioisotopes. The capabilities of these two devices will be demonstrated via a series of recent highlights: for HELIOS, the role of quenching in weakly-bound systems using the (d,p) reaction [1], and for SOLARIS studies using the (t,p) reaction [2] where the inverse kinematics technique allows for almost background-free measurements and a determination of branching ratios of unbound states.

*This material is based upon work supported the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357. SOLARIS is funded by the U.S. Department of Energy, Office of Science, under the FRIB Cooperative Agreement DE-SC0000661.

References

- [1] B. P. Kay et al., Phys. Rev. Lett. 129, 152501 (2022).
- [2] A. Muñoz-Ramos, in preparation.

parallel / 300

β -decay of ^{36}Mg and ^{36}Al : Identification of a long-lived isomer in ^{36}Al

Auteur: Rebeka Sultana Lubna¹

Co-auteurs: Aaron Chester²; Adam Hartley²; Alexander Volya³; Amelia Doetsch²; Andrea Richard⁴; Augusto Macchiavelli⁵; Axel Frotscher⁶; Benjamin Crider⁷; Brenden Longfellow⁴; Carlotta Porzio⁸; Christopher Campbell⁶; Christopher Morse⁹; Christopher Prokop¹⁰; Dariusz Seweryniak¹¹; Eleanor Ronning²; Elizabeth Rubino²; Filip Kondev¹¹; Heather Crawford⁶; Ian Connor Cox¹²; J. A. Winger⁷; James Allmond⁵; Jason Harke¹³; Kay Kolos¹³; Kevin Siegl¹²; Krzysztof Rykaczewski⁵; Maninder Singh¹²; Mejdi Mogannam²; Michael Carpenter¹¹; Miguel Madurga¹²; Noritaka Kitamura¹²; Paul Fallon⁶; Rahul Jain²; Robert Grzywacz¹²; Robert Janssens¹⁴; Ruchi Mahajan²; Ryan Tang³; Samuel Tabor³; Sapan Luitel¹⁵; Sean Liddick¹⁶; Shree Neupane¹⁷; Soumik Bhattacharya³; Tawfik Gaballah⁷; Tim Gray⁵; Timilehin Ogunketu²; Toby King⁵; Tyler Wheeler²; Vandana Tripathi³; Wei-Jia Ong¹³; Zhengyu Xu¹²

¹ FRIB, Michigan State University

² Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA

³ Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

⁴ National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA

⁵ Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

⁶ Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

⁷ Department of Physics and Astronomy, Mississippi State University, Mississippi State, Mississippi 39762, USA

⁸ Università Degli Studi di Milano/TRIUMF

⁹ Brookhaven National Laboratory, Upton, New York 11973, USA

¹⁰ Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

¹¹ Argonne National Laboratory, Argonne, Illinois 60439, USA

¹² Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA

¹³ Lawrence Livermore National Laboratory, Livermore, California 94550, USA

¹⁴ Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA

¹⁵ Department of Physics and Astronomy, Mississippi State University, Mississippi State, MS 39762, USA

¹⁶ Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA. Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA

¹⁷ Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA

Auteur correspondant lubna@frib.msu.edu

A long-lived isomeric state in ^{36}Al has been identified for the first time via β -decay of ^{36}Mg and ^{36}Al . Neutron-rich ^{36}Mg and ^{36}Al were produced at the Facility for Rare Isotope Beams (FRIB) via projectile fragmentation of a ^{48}Ca beam of energy 172.3 MeV/u. The beam was impinged on a 8.89 mm thick ^9Be target. The fragmented beam was delivered to the β -decay station after being resolved by the Advanced Rare Isotope Separator (ARIS). A fast timing scintillator of 2mm thickness followed by two Si PIN detectors, each 500 μm thick, were placed in the upstream side for the particle identification (PID). The energies lost by the ions in PIN2 were plotted against the time-of-flight between the ARIS scintillator and the scintillator at the decay station in order to generate the PID. At the heart of the decay station, a 5mm thick YSO scintillator implantation detector was placed. The β -delayed γ -rays were identified with 11 clover detectors and 15 LaBr₃ detectors. The half-lives of the two parent nuclei were determined and were compared to the previous measurements. The β -delayed γ -ray transitions were observed in ^{36}Al and ^{36}Si for the first time and their level schemes were built from the correlated β -decays of ^{36}Mg and ^{36}Al . Excited energy states of ^{36}Al populated by the β -decay of ^{36}Mg are proposed, whereas only the ground state information was available prior to this work. A long-lived isomer in ^{36}Al was identified which undergoes β -decay to an excited state of ^{36}Si . The experimental results were interpreted by using the nuclear configuration interaction studies with the FSU shell-model Hamiltonian. The results will shed light in our understanding of the structure of more exotic neutron-rich nuclei to be produced with the new generation facilities like FRIB.

301

New Technique of Injecting Radioactive Ions into Charge Breeding ECR Ion Source

Auteur: Gabriel Tabacaru¹

Co-auteurs: Juha Arje¹; Veli Kolhinen²; Don May¹; Brian Roeder¹; George Kim¹; Henry Clark¹; Hyo-In Park¹; Fred Abegglen¹

¹ Cyclotron Institute, Texas A&M University

² Texas A&M

Auteur correspondant tabacaru@tamu.edu

Cyclotron Institute at Texas A&M University started a project to develop the reacceleration of radioactive ions using the two operational cyclotrons and a Charge Breeding ECR ion source. The radioactive ions are produced primarily via (p,n) reactions using the well-known IGISOL technique. The reaction products are transported into a Charge Breeder ECR ion source where their charge state is boosted from 1+ to higher, depending on the product of interest and the operational state of the Charge Breeder ECR ion source. The transport of the products and the injection into the ion source are essential for the efficiency of charge breeding. Two techniques have been used: acceleration-deceleration method (classic) and low - energy RF-only sextupole ion guide transport and injection method (innovative technique). The last method appears to be very efficient and excellent charge breeding efficiency was observed. The presentation of the entire project, the new injection technique, experimental results, and future plans will be discussed.

303

Breakdown of the Isobaric Multiplet Mass Equation at $A = 54$, $T = 3$

Auteur: Xing XU¹

Co-auteurs: Chaoyi Fu¹; Hongfu Li¹; Meng Wang ; Wenjia Huang²; Yuhu Zhang¹

¹ Institute of Modern Physics, Chinese Academy of Sciences

² Advanced Energy Science and Technology Guangdong Laboratory

Auteur correspondant xuxing@impcas.ac.cn

The determination of basic properties of the so-called isobaric analog states(IASs) which are states with the same isospin T and spin-parity $J\pi$ in a fixed A isobar has long been an important research subject in nuclear physics. A famous and simple formula, isobaric multiplet mass equation (IMME), which is derived 60 years ago on the basis of the perturbation theory in Quantum Mechanics and the isospin symmetry, can successfully describe the masses of IASs.

Using the recently-measured mass of ^{52}Ni and the two-proton decay energy of ^{54}Zn , the ground-state mass excess of ^{54}Zn is deduced to be $-6504(83)$ keV. A cubic fit to the existing mass data of the $A = 54$, $T = 3$ isospin multiplet yields a surprisingly large d -coefficient of IMME, i.e., $d = 18.6(27)$ being 6.9σ deviated from zero, with the $|b/c|$ -ratio significantly deviated from the systematics. This phenomenon is analyzed and we conclude that the breakdown of the quadratic form of IMME could be most probably due to mis-assignment of the $T = 3$ isobaric analog state (IAS) in the $T_z = 1$ nucleus ^{54}Fe or extremely strong isospin mixing. To confirm and further investigate the breakdown, accurate determination for masses of corresponding $A = 54$, $T = 3$ IASs states and dedicated theoretical calculations are highly recommended.

304

Performance Test of Beam Drift Chamber for LAMPS

Auteur: CheongSoo LEE¹

Co-auteurs: Hyo Sang LEE¹; Young Jin KIM¹; Jaein HWANG²; Yunseul BAE³; Hyunchul KIM³

¹ *Institute for Basic Science, KOREA*

² *Korea University*

³ *Chonnam National University*

Auteur correspondant cslee@ibs.re.kr

Large Acceptance Multi-Purpose Spectrometer (LAMPS) which is designed for studying equation of state(EoS) and symmetry energy of nuclear matter above the saturation density ρ_0 , is under construction at Institute for Basic Science, Korea. LAMPS detection system consists of Start Counter(SC), Beam Drift Chamber(BDC), Time Projection Chamber(TPC), Time-of-Flight/Trigger Detector, Neutron Detector Array, and Superconducting Solenoid Magnet. Each part of the detection system has been tested individually to assure its performance, and most of the results so far meet the requirements from the experimental design well. In this presentation, detection system of LAMPS will be briefly introduced and beam line detectors, in particular BDCs are focused to be explained in detail.

305

Development of LAMPS Time Projection Chamber at RAON

Auteurs: HyoSang Lee¹; Young Jin Kim¹; Cheong Soo Lee¹

¹ *Institute for Basic Science, Korea*

Auteur correspondant hslee@ibs.re.kr

Rare isotope Accelerator complex for ON-line experiments (RAON) is the rare isotope (RI) beam accelerator facility in Korea. Large Acceptance Multi-Purpose Spectrometer (LAMPS) is the nuclear science facility to study a nuclear equation of state (EoS) via heavy-ion collisions at RAON. At the end of the In-Flight separator, LAMPS will be located for completing an event reconstruction by detecting all particles produced in heavy-ion collisions within a large acceptance angle to measure particle spectrum, yield, ratio and collective flow of pions, protons, neutrons, and intermediate fragments at the same time. LAMPS consists of a solenoid spectrometer and a forward neutron wall. A Time Projection Chamber (TPC) and a time-of-flight (ToF) detector will be placed inside cylindrical solenoid magnet of 0.5 T for charged particle tracking and particle identification. The forward neutron wall will be made of 8 layers of plastic scintillators for neutron tracking. TPC is the main tracking detector of the LAMPS solenoid spectrometer to identify particle species and reconstruct the momentum of each track with high precision over a large acceptance. Development and test result of LAMPS TPC will be presented.

306

Searching for CP-violation in nuclear beta decay: First results of the MORA experiment

Auteur: Sacha Daumas¹

¹ *CNRS(LPC Caen)*

Auteur correspondant daumastschopp@lpccaen.in2p3.fr

The “Matter’s Origin from RadioActivity” (MORA) project focuses on ion manipulation in traps and laser orientation methods for the searches for New Physics (NP) in nuclear beta decays, looking for possible hints to explain the matter-antimatter asymmetry observed in the Universe.

Located in Finland within the JYFL Accelerator Laboratory, the IGISOL facility delivers the right ion beam, the $^{23}\text{Mg}^+$, for the initial phase of the MORA experiment. It is an ideal candidate to extract the so-called D correlation parameter which is sensitive to Time reversal violation and, according to the CPT theorem, to CP violation.

A measurement of the D parameter to the 10^{-5} level is sensitive to the existence of leptoquarks and/or to a right-handed W boson. By using an innovative in-trap laser polarization technique, we will be able to reach a sensitivity below 10^{-4} on D, according to simulations. This sensitivity should allow us to probe not only NP but also the Final State Interaction process.

After an offline commissioning has been carried out by using a $^{23}\text{Na}^+$ spark source, the first tests with $^{23}\text{Mg}^+$ have been conducted in the IGISOL facility. An efficient trapping process has been achieved up to 11s. Despite a large contamination of the radioactive beam with the stable ^{23}Na , around 30h of data have been registered in November 2022, using a trapping cycle of 3s and alternating 1h run with cloud laser polarization (sigma +, sigma -) and without. The analysis is currently ongoing.

In this talk, a short introduction of the commissioning performed followed by a detailed presentation of the first results will be presented.

parallel / 307

Electromagnetic moments of the antimony ($Z = 51$) isotopic chain $^{112-133}\text{Sb}$ in comparison to shell-model *ab initio* calculations

Auteur: Simon Lechner¹

Co-auteurs: Agota Koszorus²; Anastasios Kanellakopoulos²; Bradley Cheal³; Charles S. Devlin³; Deyan Yordanov⁴; George Sanamyan⁵; Gerda Neyens²; Hanne Heylen¹; Jacinda S. M. Ginges⁵; Jason Holt⁶; Klaus Blaum⁷; Liss Vazquez Rodriguez⁸; Mark L. Bissell⁹; Peter Plattner¹⁰; Phillip Ingram¹¹; Rainer Neugart¹²; Ronald Fernando Garcia Ruiz¹³; Stephan Malbrunot¹⁴; Takayuki Miyagi⁶; Wilfried Nörtershäuser¹¹; Xiaofei Yang²; Yutaka Utsuno¹⁵; Zhengyu Xu²

¹ CERN

² KU Leuven

³ University of Liverpool

⁴ IPN

⁵ University of Queensland

⁶ TRIUMF

⁷ MPIK

⁸ CERN, MPIK

⁹ University of Manchester

¹⁰ Universität Innsbruck

¹¹ TU Darmstadt

¹² MPIK, Universität Mainz

¹³ MIT

¹⁴ CERN, TRIUMF, University of Toronto

¹⁵ Japan Atomic Energy Agency

Auteur correspondant simon.lechner@cern.ch

Antimony (Sb) contains 51 protons, one proton above the magic $Z = 50$ proton shell closure. Therefore, its nuclear magnetic moments serve as an ideal candidate to probe the proton single particle behavior along the Sb isotopic chain, while its quadrupole moments shed light on collective effects as a function of neutron number towards the shell closure at $N = 82$.

Phenomenological shell-model calculations work well in the mass region around magic tin. Moreover, *ab initio* methods such as the valence-space in-medium similarity renormalization group (VS-IMSRG) have recently expanded their scope and are now capable of computing nuclear properties around $Z = 50$. Following collinear laser spectroscopy measurements of the antimony isotopic chain from $^{112-133}\text{Sb}$, the experimental magnetic and quadrupole moments are compared to their calculation in the phenomenological shell-model and VS-IMSRG. Since both nuclear models employ the same valence-space diagonalization, their full comparison as well as the artificial use of the shell model's effective g -factors and charges in VS-IMSRG allows to investigate the operator-evolution within VS-IMSRG separated from the obtained wave functions.

This contribution will present the new experimental results from collinear laser spectroscopy and discuss the underlying physics with the help of state-of-the-art shell-model and *ab initio* calculations.

parallel / 308

A systematic analysis of nucleon emission in deuteron-induced reactions

Auteurs: Brett Carlson¹; Fatemeh Torabi¹

¹ Instituto Tecnológico de Aeronáutica

Auteur correspondant brett@ita.br

Considering its weakly-bound nature, a complete description of deuteron-induced reactions remains a challenging problem for theoretical studies. To examine this problem, we perform a systematic analysis of inclusive nucleon emission cross sections for deuterons incident on a wide range of nuclei at different energies up to 100 MeV. The local-energy approximation to the post form DWBA is used to calculate the elastic and nonelastic breakup cross sections [1,2]. The breakup cross sections are integrated into the EMPIRE nuclear reaction code [3] in order to take into account the pre-equilibrium and equilibrium decay of the three compound nuclei formed in the reaction. Theoretical double differential and integrated nucleon emission cross sections are compared with the experimental ones. Our investigations demonstrate a general good agreement between the theoretical and experimental integrated cross sections. The comparisons of the experimental data with the calculated double differential cross sections show that the general behavior of the experimental spectra is reproduced at small angles and for the lighter systems, but that systematic discrepancies between the calculations and the data occur for heavier targets. Possible reasons for the disagreements are discussed.

References

- [1] M. Ichimura, N. Austern, and C. M. Vincent, Phys. Rev. C 32, 431 (1985).
- [2] N. Austern, Y. Iseri, M. Kamimura, M. Kawai, G. Rawitscher, M. Yahiro, Phys. Rep. 154, 125 (1987).
- [3] M. Herman, R. Capote, B. V. Carlson, P. Obložinský, M. Sin, A. Trkov, H. Wienke, V. Zerkin, Nucl. Data Sheets 108, 2655 (2007).

parallel / 309

Evolution of single-particle structure along the Mg isotopic chain: the $d(30\text{Mg},p)31\text{Mg}$ reaction measured with the ISOLDE Solenoidal Spectrometer

Auteurs: David Sharp¹; Liam Gaffney²; Patrick MacGregor³; Sean Freeman⁴

Co-auteurs: Annie Dolan²; Bruno Olaizola³; Calem Hoffman⁵; Charlie Paxman⁶; Chris Cousins⁶; Chris Everett²; Chris Page⁷; Connor O'Shea⁶; Dan Judson²; Daniel Clarke¹; Daria Zemilianskya⁸; Jie Chen⁵; Joonas Ojala²; Katie Garrett¹; Magda Satarazani²; Marc Labiche⁹; Oleksii Poleshchuk¹⁰; Philippos Papadakis⁹; Riccardo Raabe¹⁰; Samuel Bennett¹; Samuel Reeve¹; Thorsten Kröll¹¹; Wilton Catford⁶; Zixuan Yue⁷

¹ *The University of Manchester*² *University of Liverpool*³ *CERN*⁴ *CERN, The University of Manchester*⁵ *Argonne National Laboratory*⁶ *University of Surrey*⁷ *University of York*⁸ *Moscow Institute of Physics and Technology*⁹ *STFC Daresbury*¹⁰ *KU Leuven*¹¹ *TU Darmstadt***Auteur correspondant** patrick.macgregor@cern.ch

The $N = 20$ “island of inversion” is a neutron-rich region of the nuclear chart which is of particular importance for understanding the evolution of nuclear structure. In this region, deformed intruder configurations (particle-hole excitations) dominate at ground-state and low-excitation energies which is facilitated by the weakening of the $N = 20$ shell closure. Additionally this shell gap weakens as protons are removed, leading to a new shell closure emerging at $N = 16$, which produces doubly-magic properties in ^{24}O .

The magnesium isotopes exhibit a swift transition into the island between ^{30}Mg and ^{31}Mg , and thus are a useful measure of how single-particle structure evolves into the island. Data on isotopes in this region can be used to test the validity of current nuclear models, and be used to further refine them for other nuclei in the island.

The ISOLDE Solenoidal Spectrometer (ISS) collaboration published results on the nuclear structure of ^{29}Mg recently [1], measuring its neutron occupancies from the $d(^{28}\text{Mg},p)^{29}\text{Mg}$ reaction (9.47 MeV/u) performed before CERN’s long shutdown. An analogous $d(^{30}\text{Mg},p)^{31}\text{Mg}$ reaction (8.52 MeV/u) has been performed at the ISS to examine the neutron occupancies of ^{31}Mg , which can be compared to the measurement of ^{29}Mg to understand this transition into the island. This measurement was performed with a new on-axis silicon developed specifically for ISS. Preliminary results from this new measurement will be presented, with reference to the previous measurement on ^{29}Mg .

[1] P. T. MacGregor et al., Phys. Rev. C 104, L051301, Nov 2021

plenary / 311

CERN-MEDICIS: a unique facility for the production of non-conventional radionuclides for medical research

Auteur: CHARLOTTE DUCHEMIN¹

Co-auteurs: Alexandre Dorsival¹; Aurore Boscher²; Benjamin Juif²; Bernard Crepieux¹; Bruce Marsh¹; Cyril Bernerd³; Edgars Mamis⁴; Elodie Aubert¹; Eric Chevallay¹; Fabio Pozzi¹; Francesco Riccardi¹; Giuseppe Prete²; Jean-Louis Grenard¹; Jean-Yves Rinchet¹; Joachim Vollaie¹; Julien Thiboud¹; Klaus Wendt⁵; Laura Lambert¹; Matthieu Deschamps²; Maxime Munos¹; Moazam Khan⁶; Nabil Menaa¹; Pascal Fernier¹; Philippe Bertreix¹; Qaiser Khan⁶; Ralf Rossel¹; Reinhard Heinke¹; Ricardo Martinez¹; Richard Catherall¹; Sebastian Rothe¹; Simone Gilardoni¹; Stefano Marzari¹; Thierry Stora¹; Thomas Elias Cocolios⁷; Umair Khalid⁶; Valentin Fedosseev¹; Vincent Barozier¹; and the MEDICIS collaboration

¹ *CERN, Meyrin, Switzerland*² *CERAP, Meyrin, Switzerland*³ *CERN, Meyrin, Switzerland & KU Leuven, Institute for Nuclear and Radiation Physics, Heverlee, Belgium*⁴ *CERN, Meyrin, Switzerland & Institute of Chemical Physics of the University of Latvia, Riga, Latvia*⁵ *Johannes Gutenberg-Universität, Mainz, Germany*⁶ *Pakistan Atomic Energy Commission, Islamabad, Pakistan*

⁷ *KU Leuven, Institute for Nuclear and Radiation Physics, Heverlee, Belgium*

Auteur correspondant charlotte.duchemin@cern.ch

The MEDICIS facility is a unique facility located at CERN dedicated to the production of non-conventional radionuclides for research and development in medical imaging, diagnostics and radiation therapy. Located in a laboratory equipped to safely handle unsealed radioactive samples, it comprises a dedicated isotope separator beam line, a target irradiation station at the 1.4 GeV Proton Synchrotron Booster (PSB), or alternatively receives activated targets from external institutes e.g. during CERN Long Shut-Downs. The target is heated up at high temperatures to allow for the diffusion and effusion of the produced atoms out of the target that are subsequently ionized. The ions are accelerated and sent through an off-line mass separator. The radionuclide of interest is mass-separated and implanted into a thin metallic collection foil. After collection, followed by a radiochemistry process when necessary, the batch is prepared to be dispatched to a research center for further processing and usage. Since its commissioning in December 2017, the facility has provided novel radionuclides including, but not limited to, Ba-128/Cs-128, Tb-149, Sm-153, Tb-155, Tm-165/Er-165, Er-169, Yb-175 and Ac-225 with high specific activity values, some for the first time, to research institutes part of the collaboration. CERN-MEDICIS' research and development around the topics of production, extraction and mass-separation is in constant evolution. The facility also contributes in the education and training of young researchers. Moreover, MEDICIS is one of the pillars of PRISMAP, a network of world-leading European facilities including nuclear reactors, medium- and high-energy accelerators, radiochemical laboratories and biomedical facilities. PRISMAP acts as a European platform for medical radionuclides and supports the ongoing research on nuclear therapy and molecular imaging by providing immediate access to novel radionuclides.

plenary / 312

Observation of the radiative decay of the low energy thorium-229 isomer: En route towards a nuclear clock

Auteur: Sandro Kraemer¹

Co-auteurs: Janni Moens²; Michail Athanasakis-Kaklamanakis³; Silvia Bara¹; Kjeld Beeks⁴; Premaditya Chhetri¹; Katerina Chrysalidis³; Arno Claessens¹; Thomas Coccolios¹; João M. Correia³; Hilde De Witte¹; Rafael Ferrer¹; Sarina Geldhof¹; Reihard Heinke³; Niyusha Hosseini⁴; Mark Huyse¹; Ulli Köster⁵; Yuri Kudryavtsev¹; Mustapha Laatiaoui⁶; Razvan Lica³; Goele Magchiels²; Vladimir Manea¹; Clement Merckling⁷; Lino Pereira²; Sebastian Raeder⁸; Thorsten Schumm⁴; Simon Sels¹; Peter Thirof⁹; Shandirai Malven Tunhuma²; Paul Van Den Bergh¹; Piet Van Duppen¹; André Vantomme; Matthias Verlinde¹; Renan Villareal²; Ulrich Wahl¹⁰

¹ *Instituut voor Kern- en Stralingsfysica, KU Leuven*

² *Quantum-Solid-State Physics, KU Leuven*

³ *CERN*

⁴ *Atominstytut, TU Wien*

⁵ *Institut Laue-Langevin*

⁶ *Helmholtz-Institut Mainz*

⁷ *imec*

⁸ *GSI*

⁹ *LMU Munich*

¹⁰ *ULisboa*

Auteur correspondant sandro.kraemer@kuleuven.be

The radioisotope thorium-229 features a nuclear isomer with an exceptionally low excitation energy of ≈ 8 eV and a favourable coupling to the environment, making it a candidate for a next generation of optical clocks allowing to study fundamental physics such as the variation of the fine structure constant [1,2]. While first indirect experimental evidence for the existence of such a nuclear state dates from almost 50 years ago, the proof of existence has been delivered only recently by observing the isomer's internal electron conversion decay [3]. This discovery triggered a series of successful measurements using the α -decay of uranium-233 of several properties, including its energy, an

important input parameter for the development of laser excitation of the nucleus. In spite of recent progress, the difficulties to observe the isomer's radiative decay remains a dark spot of this research field. The development towards a “nuclear clock” is further hindered by a too large uncertainty on the isomer energy.

In order to overcome limitations of previous experiments and to increase the population of the isomer while easing at the same time background contributions, a novel approach is used to populate the isomeric state in radioactive decay [4]. It is based on the β -decay of actinium-229 and uses radioactive ion beams provided by the ISOLDE facility at CERN implanted into large-bandgap crystals.

In this contribution, a dedicated setup for the implantation of a francium/radium/actinium-229 beam into large-bandgap crystals and the vacuum-ultraviolet spectroscopic study of the emitted photons will be presented. From the results obtained during a first measuring campaign using MgF₂ and CaF₂ crystals as host material it can be concluded that the radiative decay of the thorium-229 isomer has been observed for the first time, the excitation energy of the isomer has been determined with a factor of 5 improved uncertainty.

References

- [1] E. Peik et al., *Europhys. Lett.* 61, 2 (2003).
- [2] E. Peik et al. *Quantum Sci. Technol.* 6 (3), 034002 (2021).
- [3] L. von der Wense et al. *Nature* 533 (7601), 47–51 (2016).
- [4] M. Verlinde et al., *Physical Review C*, 100, 024315 (2019).

plenary / 313

High-resolution in-beam γ -ray spectroscopy at RIBF

Auteur: Byul Moon¹

Co-auteurs: Pieter Doornenbal²; Kathrin Wimmer³

¹ *Center for Exotic Nuclear Studies, Institute for Basic Science*

² *RIKEN Nishina Center*

³ *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

Auteur correspondant mb0316@ibs.re.kr

In-beam gamma-ray spectroscopy experiments have been actively performed at Radioactive Isotope Beam Factory (RIBF) of the RIKEN Nishina Center owing to the high secondary beam intensities from the BigRIPS fragment separator [1]. These experiments mostly employed the DALI2 NaI array with the very high γ -ray detection efficiency [2], and the Zero Degree Spectrometer [1] and the SAMURAI spectrometer [3] for reaction product identifications. Among the abundant scientific achievements from in-beam γ -ray spectroscopy experiments, the first spectroscopy of ⁵⁴Ca [4], ⁷⁸Ni [5], and ⁷⁰Kr [6] are examples of the capability of the RIBF facility.

Despite the notable accomplishments, experiments have been mostly limited to even-even nuclei in the vicinity of shell closures due to the moderate energy resolution of the DALI2 array. For the new capability in spectroscopy, a germanium-based high-resolution γ -ray detector array was constructed in 2019 under the High-resolution Cluster Array at RIBF (HiCARI) project [7]. The HiCARI array was comprised of several different types of high-purity germanium detectors, six segmented triple clusters from the Miniball collaboration, four segmented Clover detectors from the IMP, a quad-type tracking detector from the RCNP, and a triple-cluster tracking detector P3 from the LBNL. Through the improved position and energy resolution, the spectroscopy capabilities could be extended to further regions of interest such as odd-mass and deformed nuclei. Moreover, the HiCARI array was capable to measure level lifetimes based on the line-shape method [8].

In 2020 and 2021, 8 experiments were successfully carried out during 31.5 day of beam times with ²³⁸U and ⁷⁰Zn primary beams. The campaign included a wide range of exotic neutron-rich nuclei covering various physics motivations, such as shell and shape evolutions. An overview of the HiCARI project and first preliminary results from the rich physics program will be presented.

- [1] T. Kubo et al., Prog. Theor. Exp. Phys. 2012, 03C003 (2012).
- [2] S. Takeuchi et al., Nucl. Instrum. And Methods Phys. Res. A 763, 596 (2014).
- [3] T. Kobayashi et al., Nucl. Instrum. And Methods Phys. Res. B 317, 294 (2013).
- [4] D. Steppenbeck et al., Nature 502, 207 (2013).
- [5] R. Taniuchi et al., Nature 569, 52 (2019).
- [6] K. Wimmer et al., Phys. Lett. B 785, 441 (2018).
- [7] K. Wimmer et al., RIKEN Accel. Prog. Rep. 54, S27 (2021).
- [8] P. Doornenbal et al., Nucl. Instrum. Methods Phys. Res. A 613, 218 (2010).

315

Microscopic study of nuclear monopole excitations

Auteur: Mitko Gaidarov¹

Co-auteurs: Martin Ivanov ; Yordan Katsarov ; Anton Antonov

¹ *Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences*

Auteur correspondant gaidarov@inrne.bas.bg

A systematic study of the isoscalar giant monopole resonance (ISGMR) in spherical and deformed nuclei from various isotopic chains is performed within the microscopic self-consistent Skyrme HF+BCS method and coherent density fluctuation model. The calculations for the incompressibility in finite nuclei are based on the Brueckner and Skyrme energy density functionals for nuclear matter. The good agreement achieved between the calculated centroid energies of the ISGMR and their recent experimental values for various nuclei demonstrates the relevance of the proposed theoretical approach. The latter can be applied to analyses of neutron stars properties, such as incompressibility, symmetry energy, slope parameter, and other astrophysical quantities.

parallel / 318

Spectroscopic Factor Investigation in the N=40 Island of Inversion

Auteur: Carlotta Porzio¹

¹ *Lawrence Berkeley National Laboratory*

Auteur correspondant cporzio@lbl.gov

The focus of this work is on the Fe and Mn neutron-rich isotopes with $N \sim 40$, which lie within one of the so-called Islands of Inversion. Here, a quenching of the $N = 40$ shell gap allows deformation to develop in the ground-state configurations. Limited spectroscopic information is available in the region of $N \sim 40$ below the Ni isotopes. For the even-even nuclei, this consists of systematics of 2_1^+ and 4_1^+ state energies and, for the Fe and Cr isotopes, of $B(E2; 2_1^+ \rightarrow 0_1^+)$ values up to ^{68}Fe and ^{64}Cr . Large-scale shell-model calculations well reproduce the energy systematics of the observed low-lying states of the even-even Fe and Cr isotopes around $N = 40$. A good agreement is found also within the rotational Nilsson model. Such two descriptions, however, provide different predictions for proton spectroscopic factors. A measurement of such quantity would thus allow us to probe the validity of the considered models.

In this context, proton knockout reactions on the neutron-rich $N = 38$ and $N = 40$ isotopes $^{64,66}\text{Fe}$ and $^{63,65}\text{Mn}$ have been performed to investigate the proton spectroscopic factors of the parent nuclei. The experiment took place at the NSCL laboratory in the US and exploited the γ -ray tracking array GRETINA coupled to the S800 spectrograph to perform an in-beam γ -ray spectroscopic study. Preliminary results of the data analysis will be presented.

plenary / 319

Extremely neutron-rich nuclei beyond the drip line

Auteur: Yosuke Kondo¹

¹ *Tokyo Institute of Technology*

Auteur correspondant kondo@phys.titech.ac.jp

The limit of the nuclear stability, called neutron drip line, reflects structure of atomic nuclei with extremely proton-neutron asymmetry. It is known that the neutron drip line of oxygen isotope is ^{24}O ($Z=8, N=16$), while that of fluorine is ^{31}F ($Z=9, N=22$). This sudden change of the neutron drip line is called oxygen anomaly. Theoretical study [1] suggests that three-nucleon forces play an important role in the binding of the oxygen isotopes especially for $N>16$. This region is also interesting in terms of the island of inversion. It is well known that the $N=20$ shell closure disappears for magnesium and neon isotopes in the vicinity of $N=20$ while the shell structure for fluorine and oxygen is not clear. Recent experimental studies [2,3] suggest that the island of inversion extends to ^{29}F ($Z = 9, N = 20$). It is a question whether the ^{28}O nucleus, having the canonical magic numbers $Z=8$ and $N=20$, shows doubly magic characters or not. In these contexts, experimental study on the neutron-rich oxygen isotopes located beyond the neutron drip line is strongly desired.

Series of experiment for the unbound oxygen isotopes $^{25-28}\text{O}$ has been performed with the SAMURAI setup [4] at RI Beam Factory (RIBF). Results of the experiments and related studies will be presented in the talk.

References

- [1] T. Otsuka et al., Phys. Rev. Lett. 105, 032501 (2010).
- [2] P. Doornenbal et al., Phys. Rev. C 95, 041301(R) (2017).
- [3] S. Bagchi et al., Phys. Rev. Lett.124, 222504 (2020).
- [4] T. Kobayashi et al., Nucl. Instrum. Methods Phys. Res., Sect. B 317, 294 (2013).

320

Production of Tb-155 with highly enriched targets : first results

Auteur: Morgane BOUTECULET¹

Co-auteur: Charles-Olivier BACRI¹

¹ *IJCLab/CNRS*

Auteur correspondant morgane.bouteculet@ijclab.in2p3.fr

The PRISM (PRoduction d' Isotopes et Séparation pour le Médical) project's objective is to optimize the production and the vectorization of radio-isotopes of medical interest, especially for internal vectorized radiotherapy. The aim is to develop a complementary method to those already used, based on the use of an electromagnetic isotope separator before production of the radio-isotope of interest. A study of the functionalization of the radio-isotope by a biological vector at room temperature completes this project. *

The production of radio-isotopes of medical interest is accompanied by the production of other radio-isotopes. These contaminants can induce additional and unnecessary radiations to the patient. The use of more enriched targets that is currently available will make it possible to reduce the number of reaction channels and then limit production of these contaminants while maintaining production of the radio-isotope of interest.

The PRISM project, which will be briefly described, applies this method to the production of Tb-155 from Gd. A production target with an isotopic enrichment superior to 99% has been produced with

the electromagnetic isotope separator SIDONIE at IJCLab, Orsay, then irradiated at Nantes with the cyclotron ARRONAX. First results will be presented, as well as some perspectives.

**This project is partially financed by the contract ANR-21-CE19-0037.*

321

Production and characterization of ^{111}Ag radioisotope in a TRIGA Mark II nuclear reactor for medical use in the framework of the Italian ISOLPHARM project

Auteurs: Luca Morselli¹; Antonietta Donzella²; Alberto Arzenton³; Mattia Asti⁴; Silva Bortolussi⁵; Stefano Corradetti³; Giancarlo D'Agostino⁶; Marco Di Luzio⁶; Matteo Ferrari⁷; Andrea Gandini⁸; Marcello Lunardon⁹; Valerio Villa²; Andrea Salvini⁸; Lisa Zangrando¹⁰; Aldo Zenoni²; Alberto Andrighetto³

¹ *Università degli Studi di Ferrara, Italy*

² *Università degli Studi di Brescia and INFN di Pavia, Italy*

³ *INFN, Laboratori Nazionali di Legnaro, Padova, Italy*

⁴ *AUSL-IRCCS di Reggio Emilia, Italy*

⁵ *Università degli Studi and INFN di Pavia, Italy*

⁶ *INRIM, Università degli Studi and INFN di Pavia, Italy*

⁷ *Universit'e Jean Monnet F-42000, Saint-Etienne, France*

⁸ *Laboratorio per l' Energia Nucleare Applicata and INFN, Pavia, Italy*

⁹ *Università degli Studi and INFN di Padova, Italy*

¹⁰ *INFN di Padova, Italy*

Auteur correspondant antonietta.donzella@unibs.it

Nowadays radiopharmaceuticals represent a fundamental aid in nuclear medicine. They contain a radionuclide bound to a ligand, which selectively accumulates into a target tissue allowing either a precise imaging or a focalized treatment, without significantly damaging neighboring healthy tissues. ISOLPHARM is an Italian project that aims to develop innovative radiopharmaceuticals prototypes. It exploits the capability to produce high specific activity carrier-free radioisotopes at the SPES (Selective Production of Exotic Species) facility of the INFN-LNL (Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali di Legnaro, Pd, Italy), through the ISOL (Isotope Separation On Line) technique. In the framework of the ISOLPHARM method, ^{111}Ag was proposed as a very promising radionuclide for internal radiotherapy. It is a β - emitter with medium half-life, convenient β - energy and medium tissue penetration, and low percentage of associated γ -emission. A study on the production and characterization of the ^{111}Ag radioisotope in a TRIGA Mark II nuclear research reactor, for its utilization in the ISOLPHARM research activities, will be presented. Experimental results of the radioactivity coming from ^{nat}Pd and ^{110}Pd -enriched samples irradiated in the reactor main irradiation facility are collected and spectroscopically characterized with a cost-effective, robust and easy-to-use detection system, based on a Lanthanum Bromo-Chloride (LBC) inorganic scintillator. The radioisotope production is simulated starting from an MCNP6-based reactor model producing the neutron spectrum and flux in the selected irradiation facility. A comparison between experimental results of the activity of irradiated targets and theoretical predictions obtained with MCNPX and PHITS Monte Carlo codes, coupled with inventory calculation programs, allows models to be normalized to experimental data. In this way a reliable planning of the ^{111}Ag production for the aims of the ISOLPHARM project is achieved.

322

Design of the High Rigidity Spectrometer at the Facility for Rare Isotope Beams

Auteur: Shumpei Noji¹

Co-auteurs: A. M. Amthor²; A. Stolz¹; B. M. Sherrill³; D. Bazin³; D. H. Potterveld⁴; E. E. Burkhardt⁵; G. P. A. Berg⁶; J. C. DeKamp¹; M. Cortesi¹; M. Hausmann¹; M. Portillo¹; O. B. Tarasov¹; R. C. York¹; R. G. T. Zegers³; T. Baumann¹

¹ Facility for Rare Isotope Beams, Michigan State University

² Department of Physics and Astronomy, Bucknell University

³ Facility for Rare Isotope Beams & Department of Physics and Astronomy, Michigan State University

⁴ Physics Division, Argonne National Laboratory

⁵ Facility for Rare Isotope Beams, Michigan State University & Fusion Energy Division, Oak Ridge National Laboratory

⁶ Department of Physics, University of Notre Dame

Auteur correspondant noji@frib.msu.edu

A High Rigidity Spectrometer (HRS) [1] has been designed in support of the scientific program at the newly constructed Facility for Rare-Isotope Beams (FRIB) at Michigan State University. The HRS will allow experiments to be performed with the most exotic neutron-rich isotopes at high beam energies ($\gtrsim 100$ MeV/ u). The HRS consists of an analysis beamline called the High-Transmission Beamline (HTBL) and the spectrometer proper called the Spectrometer Section. The maximum magnetic rigidity of the HRS is 8 Tm, which corresponds to the rigidities at which rare-isotope beams are optimally produced at FRIB. The resolving power, angular acceptance, and momentum acceptance are set to match the anticipated scientific program. An ion-optical design developed for the HRS will be presented along with those of the specifications of the associated magnet and detector systems.

*Work supported by the U.S. Department of Energy Office of Science, Office of Nuclear Physics under grant Nos. DE-SC0014554 and DE-SC0000661 (FRIB) and contract No. DEAC02-06CH11357 (ANL).

[1] S. Noji et al.: Nucl. Instrum. Methods Phys. Res., Sect. A 1045 (2023) 167548.

parallel / 324

Laser Spectroscopy of the Hyperfine Splitting in $^{208}\text{Bi}^{82+}$

Auteurs: Max Horst¹; Zoran Andelkovic²; Carsten Brandau³; Rui Jiu Chen²; David Freire Fernández⁴; Christopher Geppert⁵; Guy Gleckenby⁶; Jan Glorius²; Volker Hannen⁷; Regina Heß²; Phillip Imgram⁸; Sebastian Klammes²; Kristian König¹; Yury Litvinov²; Bernd Lorentz²; Sergey Litvinov²; Johann Meisner⁹; Konstantin Mohr¹; Patrick Müller⁸; Wilfried Nörtershäuser¹; Stephan Passon⁹; Tim Ratajczyk⁸; Simon Rausch¹; Jon Rossbach²; Rodolfo Sánchez²; Shahab Sanjari¹⁰; Ragandeep Singh Sidhu¹¹; Felix Sommer⁸; Uwe Spillmann²; Markus Steck²; Thomas Stöhlker¹²; Ken Ueberholz⁷; Christian Weinheimer⁷; Danyal Winters²

¹ TU Darmstadt, HFHF Darmstadt

² GSI Darmstadt

³ GSI Darmstadt, Justus-Liebig-Universität Gießen

⁴ MPIK Heidelberg, Ruprecht-Karls-Universität Heidelberg

⁵ Johannes Gutenberg-Universität Mainz

⁶ TRIUMF, Vancouver

⁷ Westfälische Wilhelms-Universität Münster

⁸ TU Darmstadt

⁹ Physikalisch-Technische Bundesanstalt, Braunschweig

¹⁰ GSI Darmstadt, University of Applied Sciences, Aachen

¹¹ GSI Darmstadt, University of Edinburgh

¹² GSI Darmstadt, Helmholtz-Institut Jena

Auteur correspondant ma.horst@gsi.de

We present results of a laser spectroscopy experiment on the hyperfine splitting of hydrogen-like $^{208}\text{Bi}^{82+}$ at the Experimental Storage Ring (ESR) at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt. This is the first time that an artificially produced isotope is successfully targeted by laser spectroscopy in a storage ring.

During the campaign in May 2022, the ions of the radioactive isotope were produced in-flight before injection into the ESR. After isotope separation, a few 10^5 $^{208}\text{Bi}^{82+}$ -ions were stored with $\beta = 0.72$ ($E_{\text{ion}} = 408$ MeV/u). To excite the hyperfine transition ($\lambda_0 = 221$ nm) the ion beam was superimposed with a counterpropagating beam of a pulsed dye laser at $\lambda_{\text{lab}} = 548$ nm. Fluorescence detection was realized spatially separated from the laser interaction with a new detection region to obtain the required low background.

The result is compared to the theoretical and semi-empirical predictions in [1]. It will later be combined with a measurement on lithium-like $^{208}\text{Bi}^{80+}$, which is in preparation, to provide the so-called specific difference between the two hyperfine splittings [2,3]. This will constitute the most stringent test of QED in strong magnetic fields.

[1] S. Schmidt, et al., Phys. Lett. B, 779, 324 (2018).

[2] V. M. Shabaev, et al., Phys. Rev. Lett. 86, 3959 (2001).

[3] Ullmann et al., Nat. Comm., 8, 15484 (2017).

Funding by BMBF under contract 05P21RDEFA1 is acknowledged.

plenary / 328

Materials Science with radioactive isotopes –results from emission Mössbauer Spectroscopy

Auteur: Hilary Masenda¹

¹ University of the Witwatersrand

Auteur correspondant hilary.masenda@wits.ac.za

The intentional incorporation of foreign atoms in semiconductors, with the aim to realize new and/or novel functionalities with potential applications in optoelectronic and spintronic devices, gives rise to structural changes that profoundly affect their electronic, magnetic, and optical properties. Consequently, information on material properties and on dynamic processes such as dopants diffusion and relaxation processes are necessary and can be determined using a wide variety of techniques. Of particular importance are techniques employing radioactive isotopes implanted in materials as probes as they combine a two-fold function: (a) material modification and (b) material characterization at the atomic level. The latter is achieved through utilizing the isotopes mainly as “spies” via the radiation/particles they emit in their decay. This provides knowledge on lattice sites of desired dopants, lattice location changes with thermal annealing, and the defects/complexes formed with host atoms.

Mössbauer Spectroscopy (MS) is a very sensitive technique capable of detecting minor shifts in energy levels that emanate from hyperfine interactions between the nuclear moments of the probe/dopant and any local electric and magnetic fields in their immediate environment. A novel extension is emission Mössbauer Spectroscopy (eMS) employing short-lived radioactive isotopes developed at ISOLDE, CERN. eMS studies have been undertaken mainly using $^{57}\text{Mn}^*$ ($t_{1/2} = 1.5$ min) which is produced via proton-induced fission in a UC_2 target followed by multistage laser ionization[1], mass separation and acceleration to 40-60 keV. In addition, other precursor isotopes such as $^{57}\text{Co}^*$ ($t_{1/2} = 272$ days) and $^{119}\text{In}^*$ ($t_{1/2} = 2.4$ min) have also been applied for offline ^{57}Fe studies and for online ^{119}Sn measurements, respectively.

Over the years, eMS has been applied in several different material systems at ISOLDE, with investigations initially on the role of Fe in silicon to recent studies on the nature and origin of magnetic effects observed in transition metal doped semiconductors[2-5] envisaged for spintronic applications.

Special features of the technique will be presented and discussed, together with representative results in binary[4] and ternary III-nitrides. The results will mainly focus on investigations of the lattice sites of the probes, their charge and spin states, and the magnetic interactions of dopants in ternary-nitrides (virgin and Mn pre-doped)[6] and metal halides[7].

- [1] Fedoseyev et al., *Nucl. Instrum. Meth. B*, **126** (1997) 88.
- [2] Gunnlaugsson et al., *Appl. Phys. Lett.* **97** (2010) 142501.
- [3] Mølholt et al., *Phys. Scr.* **T148** (2012) 014006.
- [4] Masenda et al. *J. Magn. Magn. Mater.* **401** (2016)1130.
- [5] Mantovan et al. *Adv. Electron. Mater.* **1** (2015) 1400039.
- [6] Masenda et al. *New J. Phys.* **24** (2022) 103007.
- [7] Gunnlaugsson et al., *Phys. Rev. B* **106** (2022) 174108.

330

Beta-delayed fission of neutron-rich actinides

Auteur: Silvia Bara¹

Co-auteurs: Ahmed Youssef¹; Alberto Camaiani²; Andrei Andreyev³; Boris Andel⁴; Carlos Mario Fajardo Zambrano¹; Chris Page³; Fedor Ivandikov¹; Hilde De Witte⁵; Jake Johnson¹; James Cubiss³; Jozef Klimo¹; Michael Heines⁶; Piet Van Duppen⁷; Razvan Lica⁸; Riccardo Raabe⁶; Stanislav Antalic⁴; Stéphane Goriely⁹; Thomas Elias Cocolios¹⁰; Viktor Van Den Bergh¹; Zixuan Yue³; Zoe Favier⁸

¹ IKS, KU Leuven, Belgium

² IKS - KU LEUVEN

³ University of York

⁴ Comenius University in Bratislava

⁵ Instituut voor Kern- en Stralingsfysica, KU Leuven

⁶ KU Leuven

⁷ KU Leuven, Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium

⁸ CERN

⁹ UInstituut d' Astronomie et d' Astrophysique, ULB-CP226, 1050 Brussels, Belgium

¹⁰ KU Leuven - Instituut voor Kern- en Stralingsfysica

Auteur correspondant silvia.bara@kuleuven.be

Beta-delayed fission (β DF) is a two-step process where a parent nucleus β -decays into excited states of the daughter nucleus that are high enough with respect to the fission barrier and can therefore potentially lead to the daughter's fission [1]. Besides its relevance in understanding the nuclear structure, this process, as any other type of fission, may have a strong impact on the termination of the r-process. β DF has been only partially studied experimentally, especially in the neutron-rich side of the nuclide chart important to nucleosynthesis.

In order to expand the knowledge on β DF in the neutron-rich region, a recent campaign was carried out at ISOLDE (CERN) with the purpose of measuring β DF in $^{230,232,234}\text{Ac}$ [2] (LOI216, May 2022). From this campaign upper limits for the β DF probabilities of ^{230}Ac and ^{232}Ac were preliminarily estimated, and the value for ^{230}Ac was found to be at least two orders of magnitude lower than the one reported in literature [3].

This contribution will discuss in more details the systematics of β DF, the preliminary results obtained during the LOI216 experimental campaign, as well as a comparison with theory, and present some of the future plans of the β DF campaign.

- [1] A. N. Andreyev et al., *Rev. Mod. Phys.*, Vol. 85, 1541 (2013).
- [2] A. N. Andreyev et al., *INTC-I-216* (2020).
- [3] Y. Shuanggui et al., *Eur. Phy. J. A* 10, 1 (2001).

parallel / 331

Cross-shell interactions at the $N=28$ shell closure via $47\text{K}(\text{d},\text{p})$ and $47\text{K}(\text{d},\text{t})$ with MUGAST+AGATA+VAMOS.

Auteurs: Charlie Paxman¹; Adrien MATTA²; Wilton Catford¹; Marlène Assié³; Emmanuel CLEMENT⁴; Antoine Lemasson⁵; Diego Ramos⁶; Franco Galtarossa⁷

Co-auteurs: Lynda Achouri⁸; Dieter Ackermann⁶; Didier Beaumel⁹; Laetitia Canete¹; Pierre DELAHAYE⁶; Jeremie Dudouet¹⁰; Beatriz Fernandez Dominguez¹¹; Daniel Fernandez Fernandez¹²; Freddy FLAVIGNY⁸; Chloé Fougères¹³; Gilles de FRANCE¹⁴; serge franchoo¹⁵; Julien Gibelin¹⁶; Nishu GOYAL¹⁷; Faïrouz Hammache¹⁸; Djamilia Sarah Harrouz¹⁹; bertrand Jacquot²⁰; Louis Lalanne²¹; Cyril Lenain⁸; Juan Lois-Fuentes¹²; Taras Lokotko⁶; Ismael Martel²²; Nigel Orr²³; F.M. Marques⁶; Leo Plagnol⁶; Daniel Regueira Castro¹²; Nicolas de Séréville⁹; Jean-Charles THOMAS²⁴; Ablaihan Utepov⁶

¹ University of Surrey

² LPC Caen, CNRS-IN2P3

³ IPNO

⁴ {CNRS}UPR3266

⁵ GANIL / CNRS UPR3266

⁶ GANIL

⁷ Università di Padova and INFN LNL

⁸ LPC Caen

⁹ IPN Orsay

¹⁰ IP2I

¹¹ USC

¹² IGFAE

¹³ GANIL CEA/DRF - CNRS/IN2P3

¹⁴ GANIL/IN2P3/CNRS

¹⁵ ipn

¹⁶ LPC CAEN/Université de Caen

¹⁷ Grand Accélérateur National d'ion Lourds

¹⁸ IPN-Orsay

¹⁹ IJCLab

²⁰ CNRS

²¹ IPN

²² University of Huelva

²³ LPC-Caen

²⁴ Grand Accélérateur National d'Ions Lourds

Auteur correspondant c.paxman@surrey.ac.uk

Shell evolution in the region around the magic numbers $N = 28$ and $Z = 20$ is of great interest in nuclear structure physics. Moving away from the doubly-magic isotope ^{48}Ca , in the neutron-rich direction there is evidence of an emergent shell gap at $N = 34$ [1], and in the proton-deficient direction, the onset of shape deformation suggests a weakening of the $N = 28$ magic number [2]. The $^{47}\text{K}(\text{d},\text{p})^{48}\text{K}$ reaction is uniquely suited to investigating this region, as the ground state configuration of ^{47}K has an exotic proton structure, with an odd proton in the $\pi(1s_{1/2})$ orbital, below a fully occupied $\pi(0d_{3/2})$ orbital [3]. As such, the selective neutron transfer reaction (d,p) will preferentially populate states in ^{48}K arising from $\pi(1s_{1/2}) \otimes \nu(fp)$ cross-shell interactions. The implications of this extend both down the proton-deficient $N = 28$ isotonic chain, where these interactions are expected to dominate the structure of the exotic, short-lived ^{44}P nucleus [4], and across the neutron-rich region, where the relative energies of the $\nu(fp)$ orbitals is the driving force behind shell evolution.

The first experimental study of states arising from the interaction between $\pi(1s_{1/2})$ and the orbitals $\nu(1p_{3/2})$, $\nu(1p_{1/2})$ and $\nu(0f_{5/2})$ has been conducted, by way of the $^{47}\text{K}(d,p)$ reaction in inverse kinematics. A beam of radioactive ^{47}K ions was delivered by the GANIL-SPiRAL1+ facility, with a beam energy of 7.7 MeV/nucleon. This beam was estimated to be $> 99.99\%$ pure, with a typical intensity of 5×10^5 pps, and was impinged upon a 0.3 mg/cm^2 CD_2 target. The MUGAST+AGATA+VAMOS detection setup [5] allowed for triple coincidence gating, providing a great amount of selectivity. An analysis based both on excitation and gamma-ray energy measurements has revealed a number of previously unobserved states in ^{48}K , and preliminary differential cross sections for the most strongly populated of these states will be presented. Spectroscopic factors for these states will be discussed in the context of shell model calculations, with regard to the N=28, 32 and 34 shell gaps. Additionally, results for positive and negative parity states in ^{46}K , measured simultaneously via the $^{47}\text{K}(d,t)$ reaction, will also be presented.

- [1] D. Steppenbeck et al., Nature 502, 207 (2013).
- [2] O. Sorlin and M.-G. Porquet, Prog. Part. Nucl. Phys. 61, 602 (2008).
- [3] J. Papuga et al., Phys. Rev. C, 90 034321 (2014).
- [4] L. Gaudefroy, Phys. Rev. C, 81, 064329 (2010).
- [5] M. Assié et al., Nucl. Instrum. Methods A 1014, 165743 (2021).

332

Study of ^{11}Be excited states via the $^{10}\text{Be}(d,p)$ reaction in SOLARIS with the AT-TPC

Auteurs: Daniel Bazin¹; Jie Chen²; Michael Serikow^{None}; Nabin Rijal³; Saul Beceiro-Novo⁴; Wolfgang Mittig⁵; Yassid Ayyad⁶; Clementine Santamaria⁴

¹ Michigan State University

² Argonne National Laboratory

³ JINA-CEE, FRIB, Michigan State University

⁴ MSU/FRIB

⁵ MSU

⁶ USC

Auteur correspondant serikow@frib.msu.edu

The commissioning of transfer reaction measurements in inverse kinematics in SOLARIS with the Active Target Time Projection Chamber (AT-TPC) was successfully completed in the summer of 2021 at the NSCL. The goal of this experiment was to demonstrate the possibility of performing transfer reaction measurements at low beam intensities (between 100 Hz - 1 kHz) using the high luminosity provided by the AT-TPC. A beam of ^{10}Be was accelerated to about 9 MeV/u in the ReA6 linac and delivered to the AT-TPC placed in a 3 Tesla magnetic field provided by the SOLARIS solenoid. The AT-TPC was filled with pure deuterium gas at 600 Torr. Although multiple reaction channels were simultaneously detected, in this presentation we focus on the $^{10}\text{Be}(d,p)$ channel that populates bound and unbound states in ^{11}Be , with a particular interest towards a 3.41 MeV resonance for which the parity is still an open question. We present the preliminary analysis of the $^{10}\text{Be}(d,p)$ channel, including angular momentum transfer identification and determination of spectroscopic factors from comparison with DWBA calculations. The AT-TPC's ability to perform transfer reaction measurements at low intensities opens the door to further study neutron-rich nuclei using the rare isotope reaccelerated beams available at FRIB in the near future.

plenary / 334

From Tensor Currents to Solar Neutrinos: Precision Beta-Decay Studies of ^8Li and ^8B

Auteur: Aaron Gallant¹

Co-auteurs: Mary Burkey ; Brenden Longfellow ¹; Nicholas Scielzo ¹; Guy Savard ²; Jason Clark ²; Barbara Alan ¹; Maxime Brodeur ³; Fritz Buchinger ⁴; Daniel Burdette ²; Tsviki Hirsh ⁵; Kay Kolos McCubbin ¹; Bernhard Maaß ⁶; Scott Marley ⁷; Peter Mueller ²; Rodnet Orford ⁸; Dwaipayana Ray ⁹; Grigor Sargsyan ¹; Ralph Segel ¹⁰; Kumar Sharma ¹¹; Kevin Siegl ¹²; Adrian Valverde ¹³; Louis Varriano ¹⁴; Gemma Wilson ⁷

¹ Lawrence Livermore National Laboratory

² Argonne National Laboratory

³ University of Notre Dame

⁴ McGill University

⁵ SOREQ NRC

⁶ Technische Universität Darmstadt

⁷ Louisiana State University

⁸ McGill University

⁹ Univeristy of Manitoba

¹⁰ Northwestern University

¹¹ University of Manitoba

¹² Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA

¹³ Argonne National Laboratory/University of Manitoba

¹⁴ University of Chicago

Auteur correspondant gallant3@llnl.gov

The β -decays of ^8Li and ^8B provide an important playground to search for physics beyond the Standard Model, and, additionally, a detailed study of ^8B β -delayed α -particles provides key insights needed to constrain the spectrum of high energy neutrinos emitted by the Sun. To accomplish both these aims, the β -decays of ^8Li and ^8B were studied with the Beta-decay Paul Trap (BPT) at the ATLAS facility of Argonne National Laboratory. The BPT traps a cloud of ions at rest in a volume of $\sim 1 \text{ mm}^3$ for extended periods of time, allowing for a backing-free measurement of the emitted particles. The trapping volume is surrounded by segmented, 1 mm thick DSSDs, from which the decay kinematics can be fully constrained by a β - α - α triple coincidence measurement. This enables both a nearly background-free measurement of the β - ν angular correlation coefficient $a_{\beta\nu}$, while a α - α double coincidence measurement enables a determination of the ^8B neutrino energy spectrum.

We will present (1) recent results in ^8Li , showing the most precise measurement of $a_{\beta\nu}$ in a GT decay and highlighting both the possibility of a $\sim 9 \text{ MeV } 2^+$ “intruder state” in ^8Be and the importance of accurate values for the recoil-order terms, (2) the first measurement of $a_{\beta\nu}$ in ^8B and a method to constrain C_T and C'_T in the decay of mirror systems, and (3) the preliminary analysis of a high statistics ^8B dataset to determine $a_{\beta\nu}$, and a new determination of the neutrino spectrum following ^8B β -decay, which is important for the next generation of solar neutrino experiments.

We acknowledge the U.S. DOE Contract No. DE-AC02-06CH11357 [ANL] and DE- AC52-07NA27344 [LLNL], the Argonne National Laboratory ATLAS facility, which is a DOE Office of Science User Facility, and NSERC, Canada, Contract Nos. SAPPJ-2015- 00034 and SAPPJ-2018-00028.

335

Solar Neutrinos and Physics Beyond the Standard Model Probed through Boron-8 Beta Decay

Auteur: Brenden Longfellow¹

Co-auteurs: Aaron Gallant ¹; Tsviki Hirsh ²; Mary Burkey ¹; Guy Savard ³; Nicholas Scielzo ¹; Louis Varriano ⁴; Maxime Brodeur ⁵; Daniel Burdette ⁵; Jason Clark ³; Daniel Lascar ⁶; Peter Mueller ³; Dwaipayana Ray ⁷; Kumar Sharma ⁷; Adrian Valverde ⁸; Gemma Wilson ⁹; Xinliang Yan ³

¹ Lawrence Livermore National Laboratory

² Soreq Nuclear Research Center

³ Argonne National Laboratory⁴ University of Chicago⁵ University of Notre Dame⁶ Northwestern University⁷ University of Manitoba⁸ Argonne National Laboratory/University of Manitoba⁹ Louisiana State University**Auteur correspondant** longfellow1@llnl.gov

⁸B beta decay is the dominant source of the high-energy neutrinos generated in the Sun and observed in solar neutrino astrophysics measurements on Earth. Consequently, these experiments require the ⁸B neutrino energy spectrum to be known to high precision. In addition, the large Q value of the ⁸B beta decay and the fact that the unbound daughter ⁸Be breaks up into two alpha particles make a particularly sensitive probe to physics beyond the standard model. Preliminary results from a high-statistics experiment performed at Argonne National Laboratory using the Beta-decay Paul Trap (BPT) will be presented. The energies and relative angles of the alpha and beta particle were precisely measured with four 32x32 double-sided silicon strip detectors surrounding the BPT. The kinematics of the decay products were leveraged to reconstruct the undistorted ⁸B neutrino energy spectrum, an important input for solar neutrino astrophysics. At the same time, high-fidelity simulations of the decay were performed to set limits on the exotic tensor current contribution to the weak interaction.

parallel / 336

Mass Measurement of the ¹²³Pd with the Rare-RI Ring in RIKEN

Auteur: HONGFU LI¹¹ Institute of Modern Physics, Chinese Academy of Sciences**Auteur correspondant** lihongfu@impcas.ac.cn

The rapid neutron capture process (r-process) is considered to be responsible for the synthesis of about one-half of the elements heavier than iron up to bismuth and all of thorium and uranium. To model the r-process, nuclear properties of neutron-rich nuclides are needed. Nuclear mass is one of the most important input properties for the r-process calculation. However, some of the neutron-rich nuclides involved in the r-process lie far away from the stability line and are hard to produce in the laboratory. Therefore, r-process calculations have to rely on theoretical mass predictions. Thus, the mass measurements for the neutron-rich nuclei not only provide reliable data for the r-process calculations but also can help validate and improve the theoretical mass models.

The Rare-RI Ring (R3) is a recently commissioned isochronous mass spectrometer dedicated at Radioactive Isotope Beam Factory (RIBF) in RIKEN. Based on the Isotope-Selectable Self-triggered Injection technique, the pre-identified ions can be selected and injected into R3 event by event. The mass precision of 10^{-6} is expected to be achieved within less than 1-ms. In this contribution, the first application of mass measurements with the Rare-RI Ring will be reported. In the experiment, 5 isotones, ¹²⁷Sn, ¹²⁶In, ¹²⁵Cd, ¹²⁴Ag, and ¹²³Pd, were injected into R3 and extracted from it successfully. The mass uncertainty of ¹²³Pd is improved and the final relative uncertainty is 2.3×10^{-6} . The impact of the new ¹²³Pd mass result on the solar r-process abundances in a neutron star merger event is investigated by performing PRISM reaction network model. The A=122 and A=123 element abundance ratios in twenty r-process trajectories are calculated with varying electron fraction Y_e . We found that if our new mass value is used instead of the FRDM value, the r-process abundances at A=122 and A=123 are modified toward being more consistent with solar values.

Charge polarization on the fission fragments from U-236 calculated with a time-dependent mean-field model

Auteur: Shuichiro Ebata¹

Co-auteurs: Shin Okumura²; Chikako Ishizuka³; Satoshi Chiba³

¹ Graduate School of Science and Engineering, Saitama University

² IAEA Nuclear Data Section

³ Tokyo Institute of Technology

Auteur correspondant ebata@mail.saitama-u.ac.jp

The charge distribution of fission fragments is a significant quantity to estimate and evaluate the yields of the emitted neutron from fission fragments.

The distribution has been evaluated as the deviation from the unchanged charge distribution assumption in which the fragments keep the neutron-proton ratio of the fissile parent nucleus.

It is called charge polarization (CP).

For the major fission reactions in the reactor, their CP have been compiled in a library called Wahl's systematics.

The library is designed for the nuclear engineering field, which is unsuitable for predicting the fission fragments from unmeasured fissile nuclei.

We suggest a theoretical method based on the microscopic nuclear theory to provide the CP of fragments generated from unknown fissile nuclei without empirical ways.

We employ the mean-field theories, which are the constrained Skyrme Hartree-Fock+BCS theory and the canonical-basis time-dependent Hartree-Fock-Bogoliubov theory, represented in three-dimensional space.

For the evaluation of the theoretical results, we compare several statistical quantities of the experimental data and the results deduced through the Hauser-Feshbach calculation.

In the presentation, we report on the CP of the fission products on the ²³⁶U, which is assumed as the reaction of ²³⁵U absorbing a thermal neutron.

We will discuss the effectiveness of our method and will mention the dynamical effects on the CP through the comparison between results calculated by static and dynamic mean-field models.

339

Production of highly charged and molecular thorium ions for fundamental physics

Auteur: Jonas Stricker¹

Co-auteurs: Azer Trimeche²; Can Leichtweiß³; Leonard Fendel⁴; Valerii Andriushkov⁵; Dennis Renisch⁶; Dmitry Budker⁷; Ferdinand Schmidt-Kaler⁸; Christoph E. Düllmann⁹

¹ Johannes Gutenberg-Universität Mainz; Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz, Germany

² QUANTUM, Institute for Physics, JGU Mainz, 55099 Mainz; PRISMA+ Cluster of Excellence, JGU Mainz

³ QUANTUM, Institute for Physics, JGU Mainz, 55099 Mainz, Germany

⁴ Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany

⁵ Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz, Germany

⁶ Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany; Helmholtz-Institute Mainz, 55099 Mainz, Germany

⁷ Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz, Germany; Department of Physics, University of California, Berkeley, California 94720, USA

⁸ PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz, Germany; QUANTUM, Institute for Physics, JGU Mainz, 55099 Mainz, Germany

⁹ Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany; Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz; GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany.

Auteur correspondant jstricke@students.uni-mainz.de

Thorium isotopes became of high interest in the search for fundamental physics and for testing of the standard model of particle physics because of their unique nuclear and atomic properties [1,2]. In the project *Trapping And Cooling of Thorium Ions via Calcium* (TACTiCa), ion trapping and spectroscopic techniques are developed for a precise determination of nuclear moments, hyperfine intervals, and isotope shifts with different Th isotopes [3]. Two methods are used to produce atomic thorium ions, i. e., laser ablation of macroscopic thorium samples [3] and thin layers of alpha-decaying uranium isotopes which produce thorium daughter nuclei that recoil from the sample with the momentum imparted by the alpha decay [4]. While the former process yields predominantly singly charged ions, the latter also leads to substantially more highly charged ions [4]. Within this project, laser ablated thorium-232 ions were trapped in a linear Paul trap [3], a recoil ion source providing electrostatically decelerated Th ions [4] has been built and commissioned, and an apparatus for systematic studies of the laser-ablation production of atomic and molecular Th ions has been developed.

Laser ablation and in-flight reactions are used for the production of molecular thorium ions. Molecules including ThF [5] are of interest in the search for scalar dark matter [6] and could be used as quantum sensors to search for CP violations [7]. For this, further experiments are aimed at investigating the laser ablation behavior of different thorium isotopes in salt-based form and the formation and delivery of different thorium molecules from chemically different Th samples.

- [1] V. V. Flambaum, *Physical Review Letters* 97, 1–3 (2006).
- [2] V. V. Flambaum et al., *Physical Review A* 97, 1–12 (2018).
- [3] K. Groot-Berning et al., *Phys. Rev. A* 99, 023420 (2019)
- [4] R. Haas et al., *Hyperfine Interact.* 241, 25 (2020)
- [5] V. V. Flambaum, *Phys. Rev. C* 99, 35501 (2019).
- [6] D. Antypas et al., *Quantum Sci. Technol.* 6, 034001 (2021).
- [7] N. R. Hutzler et al., <https://arxiv.org/abs/2010.08709> (2020).

parallel / 340

The new Atomic Mass Evaluation (AME2020)

Auteur: Wenjia Huang¹

Co-auteurs: Filip Kondev²; Georges Audi²; Meng Wang²; Sarah Naimi³

¹ Institute of Modern Physics, Chinese Academy of Sciences

² Universite Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

³ IJCLab

Auteur correspondant huangwj@impcas.ac.cn

Systematic study of the masses of exotic nuclei far from the valley of stability reveals interesting phenomena such as new decay models, disappearance of traditional shell gaps and emergence of new magic numbers, and breakdown of isospin symmetry. With the advent of the new radioactive ion beam facilities built worldwide, numerous projects of mass measurements of short-lived nuclei have been carried out and reshape our understanding of how nuclei are formed. The latest Atomic Mass Evaluation (AME2020) [1,2] was recently published, which provides the most up-to-date knowledge for nuclear masses. In this conference, the evaluation procedure will be briefly reviewed and the main influence of new mass data on the AME will be discussed. Some mass data deviating from the smooth trends of the mass surface will also be mentioned and pertinent experiments are called for.

[1] W.J. Huang, M. Wang, F.G. Kondev, G. Audi, S. Naimi, *Chin. Phys. C* 45, 030002 (2021)

[2] M. Wang, W.J. Huang, F.G. Kondev, G. Audi, S. Naimi, *Chin. Phys. C* 45, 030003 (2021)

This work is supported in part by the National Key Research and Development Program of China (Grant No.2016YFA0400504), the Strategic Priority Research Program of Chinese Academy of Sciences (CAS, Grant No.XDB34000000), the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No.DE-AC02-06CH11357 and the RIKEN Pioneering Project Funding (SN).

parallel / 341

First characterization of Short-Range Correlations in an exotic nucleus at R3B

Auteur: Andrea Lagni¹

¹ *CEA Saclay*

Auteur correspondant andrea.lagni@cea.fr

Most of the knowledge we have to date about Short-Range Correlations (SRC) in nuclei comes from electron induced quasi-free scattering (QFS) experiments in large momentum transfer kinematics. Experiments performed at Jefferson Lab with a ^{12}C nucleus showed that the high-momentum tail of the nuclear momentum distribution is dominated by SRC and that the neutron/proton pairs are about 20 times more abundant than isospin-like pairs due to the tensor part of the nucleon-nucleon (NN) interaction [1]. Moreover, indications of a possible dependence of the high momentum fraction of protons and neutrons with the N/Z ratio was proposed from measurements on stable nuclei [2]. In this talk, I will present a novel experiment performed at the GSI accelerator facility with the R³B setup [3]. For the first time we made use of a short-lived nucleus scattering off a proton probe in inverse kinematics, allowing a more direct and systematic access to SRC properties as function of the N/Z ratio. The study of ^{16}C will add a new measurement at N/Z = 1.67, above the largest available N/Z (^{208}Pb) and at a much smaller mass, close to the one of the reference system ^{12}C measured in the same experiment. Furthermore, we aim to extract the ratio of np/pp pairs as function of missing momentum and thus gain information about the NN interaction in comparison to different NN interaction theories. The concept of this experiment and some preliminary results will be discussed.

[1] R. Subedi, R. Shneor, *Science*, 1156675, 2008.

[2] M. Duer et al. (CLAS Collaboration), *Nature*, 560:617, 2018.

[3]https://www.gsi.de/work/forschung/nustarenna/nustarenna_divisions/kernreaktionen/activities/r3b.

parallel / 342

Is there a dark decay in ^6He ?

Auteur: Marius Le Joubioux¹

Co-auteurs: A. Grillet²; A. Singha¹; CATALIN BORCEA³; Christelle STODEL¹; Damien THISSE⁴; David Verney⁵; Dieter Ackermann¹; Dmitry Testov⁶; Dominique Durand⁷; Francois DIDIERJEAN⁸; Hervé Savajols⁹; Jean-Charles THOMAS¹⁰; Lucia Caceres¹¹; Matthieu Lebois¹²; O. Navillat⁷; Pierre DELAHAYE¹; Serge Franchoo¹³; V. Smirnov¹⁴; Wolfgang Mittig¹⁵; Xavier Flechard⁷; Xavier Ledoux¹; Yu. E. Penionzhkevich¹⁴; Bertrand Jacquot¹⁶

¹ *GANIL*

² *IPHC, Strasbourg*

³ *IFIN-HH Bucharest, Romania*

⁴ CEA⁵ IPN Orsay⁶ Extreme Light Infrastructure-Nuclear Physics (ELI-NP)⁷ LPC Caen⁸ Université de Strasbourg - IPHC⁹ GANIL/CNRS¹⁰ Grand Accélérateur National d'Ions Lourds¹¹ CEA-GANIL¹² Institut de Physique Nucléaire d'Orsay¹³ IJCLab¹⁴ Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna 141980, Russia¹⁵ MSU-FRIB¹⁶ CNRS**Auteur correspondant** marius.lejoubioux@ganil.fr

The neutron lifetime discrepancy between beam and bottle experiments of 4σ could be interpreted as a possible sign of the neutron into dark particles [1]. If such a decay exists, it could also occur in unstable nuclei with sufficiently low neutron binding energy, a quasi-free neutron decay into a dark matter particle χ ; as is the case of ${}^6\text{He}$ with $S_{2n} = 975.45\text{keV} < m_n - m_\chi$ [2]. This quasi-free neutron dark decay would be as followed ${}^6\text{He} \rightarrow {}^4\text{He} + n + \chi$ which is the only way to have the emission of a free neutron in the decay of ${}^6\text{He}$. The SPIRAL1 facility at GANIL was used in June 2021 in order to produce a pure ${}^6\text{He}^{1+}$ radioactive beam at 25 keV to observe an excess of neutrons in the decay of ${}^6\text{He}$ which would be a unique signature for dark matter creation. In this presentation, we report the (preliminary) results of this experiment to set an upper limit for this dark decay mode in ${}^6\text{He}$.

[1] Bartosz Fornal and Benjamin Grinstein, “Dark Matter Interpretation of the Neutron Decay Anomaly,” *Phys. Rev. Lett.* 120, 191801 (2018); <https://link.aps.org/doi/10.1103/PhysRevLett.120.191801>.

[2] M. Pfützner and K. Riisager, “Examining the possibility to observe neutron dark decay in nuclei,” *Phys. Rev. C* 97, 042501 (2018); <https://link.aps.org/doi/10.1103/PhysRevC.97.042501>

parallel / 343

Study of alpha particle production in the ${}^6\text{He}+{}^9\text{Be}$ collision

Auteurs: Bruno P. Monteiro¹; Kelly C. C. Pires¹**Co-auteurs:** Rubens Lichtenthäler¹; Osvaldo C. B. dos Santos¹; André Serra¹; Uiran Umbelino¹¹ Universidade de São Paulo**Auteur correspondant** kelly@if.usp.br

A study of reaction mechanisms involved in the production of alpha particles in reactions induced by a ${}^6\text{He}$ radioactive beam on a ${}^9\text{Be}$ target nuclei is presented. Experimental data [1] was obtained using the RIBRAS (Radioactive Ion Beams in Brasil) facility of the Institute of Physics of the University of São Paulo, Brazil [2-4]. It is the first RIB facility in the southern hemisphere and is presently the only experimental equipment in South America capable of producing secondary beams of rare isotopes. The RIBRAS system consists of two superconducting solenoids used to select and focus light secondary beams of nuclei out of the stability valley. ${}^6\text{He}+{}^9\text{Be}$ angular distributions were measured at $E_{\text{lab}}=16.2\text{MeV}$ and $E_{\text{lab}}=21.3\text{MeV}$ bombarding energies. A large yield of alpha particles was observed, that is absent with gold target measurements, indicating that they come from reactions with the ${}^9\text{Be}$ target. The ${}^6\text{He}$ secondary beam had many kind of particles (cocktail beam) like ${}^7\text{Li}$ and light particles such as α , p and t. In particular, these ${}^7\text{Li}$ and α -particles can also contribute to the production of the observed alpha particles, in addition to the breakup of the ${}^9\text{Be}$ target, since the ${}^9\text{Be}$ nucleus has $(\alpha+\alpha+n)$ cluster configuration with binding energy of 1.564 MeV. Energy and

angular distributions of those events were obtained taking into account these alpha particle production possibilities. The results were compared with theoretical calculations performed using the Continuum Discretized Coupled Channel (CDCC), the Ichimura-Austern-Vincent (IAV) formalisms [5,6], in addition to the fusion-evaporation calculations.

References

- [1] K. C. C. Pires et al. Phys. Rev. C83, 064603, (2011).
- [2] R. Lichtenthäler Filho, et al. Eur. Jour. of Phys., 25, 733, (2005).
- [3] A. Lépine-Szily, et al. Nuclear Physics News, v. 23, p. 5-11, (2013).
- [4] R. Lichtenthäler, et al. Eur. Phys. J. A57, 92 (2021).
- [5] Jin Lei, A. M. Moro. Phys. Rev. C92, 044616 (2015).
- [6] O. C. B. Santos et al. Phys. Rev. C103, 064601 (2021).

346

Deformed two-body models for exotic nuclei applied to transfer reactions

Auteurs: Pedro Punta¹; José Antonio Lay¹; Antonio Moro¹

¹ *Universidad de Sevilla*

Auteur correspondant ppunta@us.es

Light exotic nuclei are usually described within few-body models made of an inert spherical core and one or two weakly bound nucleons. However, for some exotic nuclei like ^{11}Be or ^{17}C , deformation is especially relevant and should be included in the structure models.

Hence, the structure of ^{11}Be and ^{17}C is described using two-body models where a neutron moves under the action of a deformed potential generated by the core. Two different models have been used according to the coupling limit of the fragments: the semi-microscopic particle-plus-AMD (PAMD) model from [Phys. Rev. C 89 (2014) 014333] for weak-coupling and a model based on Nilsson for strong-coupling.

Energies and associated wave functions are obtained by diagonalizing the Hamiltonian in a transformed Harmonic Oscillator basis (THO) [Phys. Rev. C 80 (2009) 054605]. This basis has been successfully applied to the discretization of the continuum of two-body and three-body weakly bound nuclei for the analysis of break up and transfer reactions [Phys. Rev. Lett. 109 (2012) 232502, Phys. Rev. C 94 (2016) 054622].

The structure models are tested by studying transfer reactions $^{11}\text{Be}(p,d)^{10}\text{Be}$ and $^{16}\text{C}(d,p)^{17}\text{C}$. Good agreement is found for these transfer reactions to bound states by comparing with the experimental data from [Chinese Phys. Lett. 35 (2018) 082501],[Phys. Lett. B 811 (2020) 135939] respectively. The transfer to the continuum is also studied for $^{16}\text{C}(d,p)^{17}\text{C}$ using our two models.

plenary / 347

Microscopic models of nuclear structure at scale

Auteur: Wouter Ryssens¹

Co-auteurs: Guilherme Grams²; Michael Bender³; Stéphane Goriely⁴

¹ *Université Libre de Bruxelles*

² *Astronomy and Astrophysics Institute (I.A.A.) - ULB*

³ *IPN Lyon*

⁴ *Institut d'Astronomie et d'Astrophysique, ULB-CP226, 1050 Brussels, Belgium*

Auteur correspondant wouter.ryssens@ulb.be

The diversity of atomic nuclei is enormous: the number of possible species is estimated to be 7000 while we know that adding a single nucleon to one nucleus can dramatically change its properties. This diversity renders nuclear structure interesting in itself, but it is also crucial to the progress in several other fields of research: from searches for beyond-the-standard-model physics to the chemistry of (possibly long-lived) superheavy nuclei. The need for nuclear data is particularly large in astrophysics: answering fundamental questions about the Universe (What is the origin of the elements? What is the composition of the core of neutron stars?) requires data on many properties of thousands of nuclei at the extremes of isospin, temperature and angular momentum.

Since exotic nuclei are hard to produce and handle, the only realistic way to provide all required nuclear data is nuclear theory. To maximize predictive power, models should incorporate as much of the relevant physics ingredients as current computers can handle while describing the maximum number of properties simultaneously with a limited number of parameters. Models based on energy density functionals (EDFs) offer an attractive compromise: starting from an effective interaction they rely on the mean-field approximation to render the many-body problem tractable and can provide a microscopic description of all relevant quantities in terms of individual neutrons and protons and a modest amount of parameters across the scale of the nuclear chart. The success of EDF-based models is largely due to spontaneous symmetry breaking: by considering deformed configurations, these models can account for large parts of the effects of nuclear collectivity at the mean-field level.

In this contribution, I will introduce the recent EDF-based models constructed in Brussels: the BSkG-series. Fitted to over two thousands binding energies, they all achieve a root-mean-square error on the known masses of less than 800 keV which is competitive with simpler models. What sets the BSkG-series apart from other large-scale models based on EDFs is the sophistication of their representation of the nucleus: a three-dimensional coordinate representation results not only in a well-controlled numerical accuracy but also allows us to exploit the power of spontaneous symmetry breaking fully. All BSkG-models allow the nucleus to explore triaxial deformation, while the most recent ones also allow in addition for (i) non-zero angular momentum in the ground-states of odd-mass and odd-odd nuclei through time-reversal breaking and (ii) reflection asymmetry, i.e. octupole deformation.

I will discuss the performance of the BSkG-models for a diversity of (pseudo-)observables relevant to nuclear structure and astrophysical applications: from bulk properties such as masses, charge radii and deformations to the large-scale description of nuclear fission; from fine-grained aspects of ground states such as moments of inertia and magnetic moments to statistical properties such as nuclear level densities. Throughout the presentation, I will explain the impact of spontaneous symmetry breaking and underline its importance to achieve a state-of-the-art simultaneous description of all these quantities. Finally, I will discuss ongoing refinements of these models and the challenges we intend to tackle in the long run.

parallel / 350

Shape coexistence studies of Pb-186 employing the SAGE spectrometer

Auteurs: Joonas Ojala¹; Janne Pakarinen²

Co-auteurs: Juha Sorri²; Mikael Sandzelius³; Daniel M. Cox²; Kalle Auranen²; Hussam Badran²; Paul Davies⁴; Rolf-Dietmar Herzberg¹; Joshua Hilton²; Ulrika Jakobson²; David T. Joss¹; Rauno Julin²; Sakari Juutinen²; Joonas Konki²; Matti Leino²; Jarkko Liimatainen²; Christopher G. McPeake²; Olavi Neuvonen²; Robert D. Page¹; Edward Parr¹; Jari Partanen²; Pauli Peura²; Jan Sarén²; Scholey Catherine²; Sanna Stolze²; Juha Uusitalo²; Andrew Ward¹; Robert Wadsworth⁴; Panu Rahkila²; John Revill¹; Tuomas Grahn²; Paul Greenlees²; Jack Henderson⁴; Andrej Herzán²; David G. Jenkins⁴; Tibor Kibédi⁵; Gregory J. Lane⁵; Panu Ruotsalainen²; Papadakis Philippos²

¹ University of Liverpool

² University of Jyväskylä

³ University of Jyväskylä

⁴ University of York

⁵ *Australian National University*

Auteur correspondant joonas.k.ojala@jyu.fi

Shape coexistence is a phenomenon in which the same nuclei can possess different macroscopic shapes. The alpha-decay study for Pb-186 have shown a unique triplet of 0+ states which has been associated with spherical, prolate and oblate shapes [1]. Collective bands built upon these deformed 0+ states have been observed in in-beam gamma-ray spectroscopy experiments [2; 3]. However, gamma-ray spectroscopy can not probe E0 transitions which proceed primarily through internal conversion. These transitions are typically present in nuclei featuring shape coexistence.

Simultaneous conversion electron and gamma-ray studies for Pb-186 have been conducted exploiting the SAGE spectrometer [4] and the recoil-decay tagging technique, employing a $^{106}\text{Pd}(^{83}\text{Kr},3n)^{186}\text{Pb}$ fusion-evaporation reaction. The experiment was performed in 2013 at the Accelerator Laboratory of the University of Jyväskylä.

As a result of this experiment, direct feeding of the first excited 0+ state, which allowed us to reassign the shapes of the excited 0+ states in the Pb-186. Also, the 0+ \rightarrow 0+ transitions from the excited 0+ states to ground state, the E0 transitions of the 2+ \rightarrow 2+ and the 4+ \rightarrow 4+ transitions were observed. These results have been published in Communication Physics [5]. This work introduces a way to have systematic studies of E0 transitions in this region.

References

- [1] A. N. Andreyev et al. Nature, 405:430 (2000).
- [2] J. Heese et al. Phys. Lett. B, 302, 4:390 (1993).
- [3] J. Pakarinen et al. Phys. Rev. C, 72:011304 (2005).
- [4] J. Pakarinen et al. Eur. Phys. J. A, 50, 3:53 (2014).
- [5] J. Ojala et al. Commun. Phys.5:1 (2022).

351

Characterization of the participant zone in Xe+Sn collisions

Auteur: Tom Génard¹

¹ *GANIL*

Auteur correspondant tom.genard@ganil.fr

Collisions of heavy ions are the best tools at our disposal to probe nuclear matter. It allows us to reach extreme densities, giving us the possibility to constraint transport models. In particular at incident energies around 100 MeV/nucleon a participant zone is formed by a part of projectile and target nuclei.

The aim of this work is to characterize the participant zone. We will focus on the characteristics of cluster production (chemical composition, energy, angular distributions, multiplicities, and their correlations). These analysis reveal the neutron richness of the emitted particles, and their yield gives an insight on the mixing of target and projectile contributions. Furthermore, a systematic analysis of the transverse energy of the emitted clusters shows a link between incident energy, compression energy, and density during the reaction.

For this study, INDRA datasets for $^{124,129}\text{Xe}+^{112,124}\text{Sn}$ collisions at 100 AMeV has been used to study the effect of neutron richness on the production of light particles. The kinematic study has been done using the datasets for $^{129}\text{Xe}+^{124}\text{Sn}$ at 65, 80, 100 and 150 AMeV collisions, and using the $^{136}\text{Xe}+^{124}\text{Sn}$ collision dataset for 32 and 45 AMeV.

The results of this analysis were compared to the semi-classical event generator ELIE. This work has been done with the goal of expanding it to a lighter system, $^{58,64}\text{Ni}+^{58,64}\text{Ni}$, measured at 32 and 52 AMeV during the E789 INDRA-FAZIA campaign.

352

Total Absorption Spectroscopy of Ground and Isomeric States in ^{70}Cu

Auteur: Eleanor Ronning¹

Co-auteurs: Aaron Chester²; Alec Hamaker¹; Alyssa Palmisano³; Andrea Richard⁴; Artemis Spyrou¹; Caley Harris¹; Chandana Sumithrarachchi⁵; Daniel Puentes¹; Isaac Yandow¹; Jordan Owens-Fryar¹; Kasey Lund⁶; Katie Childers⁷; Mathis Wiedeking⁸; Paul DeYoung⁹; Rebecka Lewis¹; Ryan Ringle⁵; Sean Liddick¹⁰; Stephanie Lyons¹¹; Youngchi Xiao¹²

¹ Michigan State University

² Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA

³ University of Tennessee Knoxville

⁴ National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA

⁵ Facility for Rare Isotope Beams

⁶ National Superconducting Cyclotron Laboratory

⁷ Nevada National Security Site

⁸ iThemba LABS and University of the Witwatersrand

⁹ Hope College

¹⁰ Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA. Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA

¹¹ Pacific Northwest National Laboratory

¹² University of Kentucky

Auteur correspondant ronning@frib.msu.edu

Theoretical models studying the origin of elements in the universe and stellar nucleosynthesis processes such as the rapid neutron capture process (r-process), require physics information such as beta-decay properties and neutron-capture reaction rates [1]. Nuclei with larger β -decay Q -values have decay schemes with many weak de-excitation pathways to the ground state and β -decay branches, which are difficult to measure without high efficiency detectors. Further, information about the production mechanisms and conditions of the r-process can be investigated by considering the importance of “astromers,” which are nuclear isomers with astrophysical significance [2]. Astromer calculations rely on experimental β -decay information such as half-lives, $\log(ft)$ values, and beta-feeding (I) intensities [3]. Here, we use the method of total absorption spectroscopy to investigate the β -decay of ^{70}Cu which has three β -decaying spin-parity states (6^- ground state, and two isomeric states: 3^- , and 1^+) [4]. In an experiment performed at the National Superconducting Cyclotron Laboratory ^{70}Cu was produced and delivered to the Summing NaI (SuN) Total Absorption Spectrometer [5]. Spectra from the β -decay of each spin-parity state were isolated using different beam on/off periods. I values from total absorption spectroscopy following the β -decay of each of the three β -decaying spin-parity states will be presented.

[1] M. R. Mumpower, et al. Prog. in Particle and Nucl. Phys 86, (2016) 86-126.

[2] G. W. Misch, et al. ApJ 525, 2 (2021).

[3] G. W. Misch, et al. Symmetry 13, 1831 (2021).

[4] P. Vingerhoets et al. Phys. Rev. C 82, 064311 (2010).

[5] A. Simon et al. Nucl. Inst and Meth. Phys. Res. A 703, (2013) 16.

parallel / 353

Microscopic study of alpha, two-alpha and cluster decays

Auteur: Elias Khan¹

Co-auteurs: Louis Heitz¹; Florian Mercier¹; Tamara Niksic²; Dario Vretenar³; Jie Zhao⁴; Jean-Paul Ebran⁵

¹ IfJCLab

² *Department of physics, Faculty of science, University of Zagreb*

³ *University of Zagreb*

⁴ *Center for Circuits and Systems*

⁵ *CEA*

Auteur correspondant elias.khan@ijclab.in2p3.fr

Using covariant energy density functional approach, it was recently possible to describe alpha decay, on both medium mass and heavy nuclei [1]. Using the same formalism, a new mode of radioactivity was predicted [2]. In such a mode, 2 alpha particles are emitted back-to-back, contrary to a ^8Be -like cluster mode. Cluster decay will also be analyzed with this approach [3].

Information brought by such a formalism on the preformation and the localization of the alpha particle in the nuclei will be discussed [4]. Indications on possible favorable candidates to experimentally search for 2 alpha decays with radioactive beams will also be given.

[1] F. Mercier, J. Zhao, R.-D. Lasserri, J. P. Ebran, E. Khan, T. Nikšić, and D. Vretenar, *Phys. Rev. C* 102, 011301(R) (2020)

[2] F. Mercier, J. Zhao, J.-P. Ebran, E. Khan, T. Nikšić, D. Vretenar, *Phys. Rev. Lett.* 127, 012501 (2021)

[3] J. Zhao, J. P. Ebran, L. Heitz, E. Khan, F. Mercier, T. Nikšić, and D. Vretenar, arXiv:2211.14135 (2022)

[4] E. Khan, L. Heitz, F. Mercier, J. P. Ebran, *Phys. Rev. C* 106, 064330 (2022)

plenary / 355

Nuclear astrophysics at storage rings

Auteur: Rene Reifarh¹

¹ *Goethe University Frankfurt*

Auteur correspondant reifarh@physik.uni-frankfurt.de

Most of the time, stars gain their energy from fusion of the very light left-overs of the Big Bang into heavier elements over long periods of time. The observation of radioactive isotopes in different regions of the Universe is an indicator of this ongoing nucleosynthesis. In addition, short-lived nuclei are often intermediate steps during the nucleosynthesis in stars. A quantitative analysis of these relations requires a precise knowledge of reaction cross sections involving unstable nuclei. The corresponding measurements are very demanding and the applied techniques therefore manifold.

Ion storage rings offer unprecedented possibilities to investigate radioactive isotopes of astrophysical importance in inverse kinematics. During the last years, a series of pioneering experiments proofed the feasibility of this concept at the Experimental Storage Ring (ESR) at GSI. I will present recent experiments and ideas for future setups for the investigation of capture reactions with astrophysical motivation.

parallel / 358

Towards N=126 shell closure using multi-nucleon transfer reaction between ^{136}Xe and ^{198}Pt

Auteurs: Alahari Navin¹; Andrey Andreev²; Antoine Lemasson¹; Chole Fourgeres¹; Diego Ramos¹; Dieter Ackerman¹; Francesco Recchia³; Gille de France¹; Hiroari Miyatake⁴; Jason Park⁵; Jean-charle Thomas¹; Jeremy Dudouet⁶; Kyungyuk Chae⁷; M. Rosenbusch⁴; Mauricy Rejmund¹; Peter Schury⁴; Sarmi Bhattacharya⁸; Seonho Choi⁹; Sunchan Jeong⁴; Sunghan Bae⁵; Wolfram Korten¹⁰; Yonghyun Son⁹; Yoshikazu Hirayama⁴; Youngju Cho⁹; Yung Hee KIM¹¹; Yutaka Watanabe⁴

¹ GANIL² York University³ University of Padova⁴ KEK⁵ Center for Exotic Nuclear Studies⁶ Institut de Physique Nucléaire de Lyon⁷ Sungkyunkwan University⁸ VECC⁹ Seoul National University¹⁰ CEA¹¹ Center for Exotic Nuclear Studies, Institute for Basic Science**Auteur correspondant** yunghee.kim@ibs.re.kr

The neutron-rich unstable nuclei in the vicinity of neutron magic numbers are relatively well studied, far from the stability lineup to the neutron magic number $N = 82$. However, for the neutron-rich nuclei to the south of ^{208}Pb , there is limited knowledge of the excited states of these nuclei. This arises from the difficulty in producing these nuclei using conventional methods. Even for nuclei that have already been produced only limited information is known. The recent multi-nucleon transfer reaction showed promising results with several orders of magnitude larger cross-sections than those for fragmentation reactions.

A new experiment was carried out at GANIL to explore these isotopes of interest using multi-nucleon transfer reactions of $7\text{MeV/u } ^{136}\text{Xe}$ beam and ^{198}Pt target. Large acceptance VAMOS++ magnetic spectrometer and AGATA Ge tracking array were used to measure excited states of nuclides of interest. And several new experimental techniques were implemented in this experiment. First, a second arm detector was newly installed, which is composed of a vacuum chamber and multi-wire proportional counter to measure the velocity vector of the target-like fragments. Second, four EXOGAM HPGe clover array was installed at the end of the second arm to measure the delayed gamma rays from the excited states of the produced nuclei. Finally, a new method to determine particle identification is under development using a machine learning algorithm, where energy and charge states are determined using supervised machine learning and atomic numbers are determined by the unsupervised learning method. The preliminary result of the experiment such as particle identification with the help of machine learning and gamma-ray spectroscopy neutron-rich nuclei will be presented.

parallel / 360

Nuclear and molecular physics studies with laser spectroscopy of radioactive molecules

Auteur: Michail Athanasakis-Kaklamanakis¹

Co-auteurs: Abigail McGlone²; Aleksander Oleynichenko³; Aleksandra Kiuberis⁴; Alexander Breier⁵; Anais Dorne⁶; Anastasia Borschevsky⁴; Andrei Zaitsevskii⁷; Bram van den Borne⁶; Carlos Fajardo-Zambrano⁶; Carsten Zülch⁸; Dag Hanstorp⁹; Fabian Pastrana¹⁰; Gerda Neyens⁶; Holly Perrett²; Ivana Belošević¹¹; Jochen Ballof¹²; Jordan Reilly²; Julius Wessolek²; Kara Lynch²; Katerina Chrysalidis¹; Kieran Flanagan²; Konstantin Gaul⁸; Leonid Skripnikov³; Louis Lalanne¹; Lukas Nies¹; Mark Bissell¹; Mia Au¹; Miranda Nichols⁹; Qunjun Wang¹³; Reinhard Heinke¹; Robert Berger⁸; Ronald Garcia Ruiz¹⁰; Ruben de Groot⁶; Sarina Geldhof¹⁴; Serge Franchoo¹⁵; Shane Wilkins¹⁰; Silviu-Marian Udrescu¹⁰; Sonja Kujanpää¹⁶; Thomas Cocolios⁶; Thomas Giesen⁵; Timur Isaev⁷; Xiaofei Yang¹⁷; Yongchao Liu¹⁷; Ági Koszorús⁶

¹ CERN² The University of Manchester³ St Petersburg State University⁴ University of Groningen⁵ University of Kassel⁶ KU Leuven

⁷ *Lomonosov Moscow State University*

⁸ *Philipps-Universität Marburg*

⁹ *University of Gothenburg*

¹⁰ *MIT*

¹¹ *TRIUMF*

¹² *FRIB*

¹³ *Lanzhou University*

¹⁴ *GANIL*

¹⁵ *IJCLab*

¹⁶ *University of Jyväskylä*

¹⁷ *Peking University*

Auteur correspondant m.athkak@cern.ch

The research potential of radioactive molecules for both fundamental and applied science has recently been recognized [1,2] and significant progress has been marked at ISOLDE on both the production [3] and the spectroscopy [4-7] of radioactive molecules.

In addition to the first laser spectroscopy of RaF at the collinear resonance ionization spectroscopy (CRIS) experiment [4,5] and its subsequent high-resolution study [6], the CRIS collaboration recently performed the first laser spectroscopy of AcF [8]. AcF has been proposed as a promising system for the first measurement of a nuclear Schiff moment across the nuclear chart, which is a symmetry-violating property that is predicted to be easier to measure in AcF than in RaF, YbF, ThO, and other diatomic molecules that are currently under investigation in the search for an electron electric dipole moment.

Simultaneously, experimental and theoretical progress in the excited electronic states of RaF [7] and the manifestation of nuclear observables in molecular spectra [9] carried out by members of the CRIS collaboration has highlighted the potential of laser spectroscopy of radioactive molecules at radioactive ion beam facilities to probe nuclear and molecular observables that are not easily accessible by other methods and systems.

In this talk, recent results by the CRIS collaboration on the laser spectroscopy of RaF and AcF will be presented, along with the spectroscopy of lighter radioactive molecules that can provide access to nuclear and molecular observables that cannot be studied via other methods. The future directions of laser-spectroscopic studies of radioactive molecules at CRIS will also be discussed.

[1] Opportunities for Fundamental Physics Research with Radioactive Molecules, In preparation (2023)

[2] M. Athanasakis, S. G. Wilkins, G. Neyens, Radioactive molecules at ISOLDE, Letter of Intent to the ISOLDE and n-ToF Committee at CERN. No. CERN-INTC-2021-017 (2021)

[3] M. Au et al., In-target, in-source, and in-trap formation of molecular ions in the actinide mass range at CERN-ISOLDE, Submitted to NIM B (2023)

[4] R. F. Garcia Ruiz et al., Spectroscopy of short-lived radioactive molecules, *Nature* 581, 396 (2020)

[5] S. M. Udrescu et al., Isotope Shifts of Radium Monofluoride Molecules, *Physical Review Letters* 127, 033001 (2021)

[6] S. M. Udrescu, S. G. Wilkins et al., Precision spectroscopy and laser cooling scheme of a radium-containing molecule, Under review at *Science* (2023)

[7] M. Athanasakis-Kaklamanakis, S. G. Wilkins, L. V. Skripnikov et al., Pinning down electron correlations in RaF towards searches for new physics, In preparation (2023)

[8] M. Athanasakis-Kaklamanakis et al., Laser ionization spectroscopy of AcF, Proposal to the ISOLDE and n-ToF Committee at CERN. No. CERN-INTC-2021-053 (2021)

[9] M. Athanasakis-Kaklamanakis, S. G. Wilkins, A. A. Breier, and G. Neyens, King-plot analysis of isotope shifts in simple diatomic molecules, Accepted at *Physical Review X* (2023)

Auteurs: Hao Jian¹; Xinxing Xu¹; Jianguo Li¹

¹ *Institute of Modern Physics*

Auteur correspondant jianhao19@mails.ucas.ac.cn

The elegant concept of isospin symmetry was first applied to nuclei by Wigner[1] as a charge independence operator based on the nucleon-nucleon (NN) interaction. Nevertheless, the approximate isospin symmetry is broken, which is mainly attributed to the Coulomb force and charge dependent parts of nuclear force. Far from the stability line, various exotic decay modes of the proton-rich nuclei, especially the β -delayed particle emission, are demonstrated as an intriguing phenomena which have played a significant role of testing for the isospin symmetry[2-4]. Our research team has found that the largest value of mirror asymmetry $\delta = 209(96)\%$ occurs in low-lying states of the β decay of mirror nuclei $^{22}\text{Si}/^{22}\text{O}$, supporting the existence of a halo structure in ^{22}Al [5]. Systematical research on the origin of breaking is of great importance to understand the nuclear force and nuclear structure.

The proton-rich nucleus ^{23}Si , with an isospin projection of $T_z = -5/2$, was produced, identified and selected by the Radioactive Ion Beam Line in Lanzhou (RIBLL1) at the Heavy Ion Research Facility in Lanzhou (HIRFL). The ions of ^{23}Si were finally implanted into double-sided silicon strip detectors (DSSDs) surrounded by clover-type high-purity germanium (HPGe) detectors. The energy levels and the decay branching ratios populated to the low-lying excited states of ^{23}Al were extracted to construct the partial decay scheme by coincidence measurement of β -delayed protons and gamma rays. Comparing to the mirror β decay of ^{23}F , a large value of mirror asymmetry $\delta = 201(108)\%$ and mirror energy difference $\text{MED} = -569(8)$ keV are found in the transition to the second $5/2^+$ state.

The ab initio valence-space in-medium similarity renormalization group (VS-IMSRG)[6-8] calculations based on chiral two-body and three-body force, in which charge-symmetry and charge-independence breakings are included, are performed to explain the large mirror asymmetries in the low-lying state of ^{22}Al and ^{23}Al . Our calculations give that the large mirror asymmetries are mainly caused by the large occupations of $s_{1/2}$ wave, which is weakly-bound or unbound in proton-rich nuclei and deeply-bound in neutron-rich nuclei. Moreover, isospin asymmetries in the sd -shell nuclei are also extensively investigated based on ab initio VS-IMSRG calculations.

[1] Wigner, E. Phys. Rev. 51, 106-119 (1937).

[2] B. Blank and M. Borge, Progress in Particle and Nuclear Physics 60, 403 (2008).

[3] B. Blank and M. Ploszajczak, Reports on Progress in Physics 71, 046301 (2008).

[4] M. Pfützner, M. Karny, et al, Rev. Mod. Phys. 84, 567 (2012).

[5] J. Lee, X. X. Xu, et al, Phys. Rev. Lett. 125, 192503 (2020).

[6] S. K. Bogner, H. Hergert, et al, Phys. Rev. Lett. 113, 142501 (2014).

[7] S. R. Stroberg, A. Calci, et al, Phys. Rev. Lett. 118, 032502 (2017).

[8] H. H. Li, Q. Yuan, J.G. Li, et al, Phys. Rev. C. 107, 014302 (2023).

362

β -decay studies of $A = 107$ nuclei using the Modular Total Absorption Spectrometer (MTAS)

Auteur: Peng Shuai¹

¹ *Institute of Modern Physics, Chinese Academy of Sciences*

Auteur correspondant shuai620@impcas.ac.cn

Determination of the true feeding intensities (I_β) in β -decay of fission products is very important in addressing the reactor antineutrino anomaly and modeling the reactor decay heat. β -decay measurements with high-resolution but low-efficiency detectors may be affected by the Pandemonium effect. This effect may lead to underestimation of the feeding to high excited levels, thus systematically biases the calculation of reactor antineutrino spectrum and decay heat calculation.

Modular Total Absorption Spectrometer (MTAS), which has almost 99% gamma detection efficiency, is an ideal spectrometer to determine not only the true β feeding intensities free from Pandemonium

effect, but also the intensity of ground state to ground state feeding. MTAS has been utilized to measure the beta decay pattern of several fission products that are high-priority contributors to reactor decay heat and antineutrino spectrum.

In this talk, we will present some preliminary results of $A = 107$ decays measured at CARIBU (ANL) in March, 2020. The β -branchings of ^{107}Tc and ^{107}Mo , which have incomplete data in current nuclear dataset, is determined experimentally using MTAS. We found the Pandemonium Effect in the β -decay measurements of ^{107}Tc and ^{107}Mo . Plenty of new levels with high excitation energy are required to reproduced the experimental spectra. This suggests a large shift of the antineutrino spectrum of ^{107}Tc and ^{107}Mo towards lower energy.

plenary / 363

Studies of astrophysically important reactions using rare isotope beams at TRIUMF

Auteur: Annika Lennarz¹

¹ TRIUMF

Auteur correspondant lennarz@triumf.ca

Determining the stellar origin of the elements observed in our Galaxy today poses one of the key challenges in the field of nuclear astrophysics. Thus, we seek to understand the nuclear processes involved in stellar evolution, as their details give us insight into the fusion pathways and routes to the synthesis of heavy elements. The investigation of radiative capture reactions involving the fusion of hydrogen or helium is crucial for the understanding of said nucleosynthesis pathways as these reactions govern nucleosynthesis and energy generation in a large variety of astrophysical burning and explosive scenarios. However, direct measurements of the associated reaction cross sections at astrophysically relevant low energies are extremely challenging due to the vanishingly small cross sections in this energy regime. Continuous advances in the production of accelerated rare isotope beams provide an opportunity to simulate and study the reactions occurring inside stars. However, many astrophysically important reactions involve radioactive isotopes, which still pose challenges for beam production and background reduction.

To overcome these challenges, dedicated facilities, such as the DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) recoil separator, SONIK (Scattering Of Nuclei in Inverse Kinematics), TUDA, the TRIUMF UK Detector Array for charged particle detection as well as the EMMA (ElectroMagnetic Mass Analyser) recoil mass spectrometer at the TRIUMF-ISAC Radioactive Ion Beam Facility have been designed to experimentally determine nuclear reaction rates of interest for nuclear astrophysics in inverse kinematics.

In this contribution, I will introduce the experimental facilities - with focus on the DRAGON recoil separator - before presenting recent experimental highlights involving the use of radioactive and high-intensity stable ion beams. Finally, I will report on recent and future facility upgrades to extend the experimental capacities and versatility.

parallel / 364

High-precision collinear laser spectroscopy - An all-optical nuclear charge radius of ^{12}C

Auteur: Phillip Imgram¹

Co-auteurs: Bernhard Maaß¹; Kristian König¹; Patrick Müller¹; Wilfried Nörtershäuser¹

¹ Institute for Nuclear Physics, Technical University Darmstadt

Auteur correspondant pimgram@ikp.tu-darmstadt.de

The size of an atomic nucleus is a fundamental observable and can be used to benchmark nuclear structure theory and therefore test our fundamental knowledge of matter. In contrast to matter and neutron radii, the nuclear charge radius can be probed through the well-known electromagnetic interaction. Typically, charge radii of stable nuclei are extracted from elastic electron scattering or muonic atom spectroscopy, and collinear laser spectroscopy resonance ionization spectroscopy are used to measure differential charge radii of radioactive isotopes relative to a stable reference nucleus. In a few cases, the uncertainty of the charge radius of the stable isotope limits the uncertainties of the radioactive species. To overcome this limit in light mass nuclei like $^{10,11}\text{B}$, an all-optical approach for the charge radius determination purely from laser spectroscopy measurements and non-relativistic QED calculations [1] was tested with the well-known nucleus of ^{12}C . Thereby, helium-like $^{12}\text{C}^{4+}$ was laser excited from the metastable $1s2s\ ^3\text{S}_1$ state with a lifetime of 21 ms to the $1s2p\ ^3\text{P}_J$ states and the respective transition frequencies were determined with less than 2 MHz uncertainty. The high-precision collinear laser spectroscopy was performed at the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA), situated at the Institute for Nuclear Physics at the TU Darmstadt.

This contribution will present the first high-precision laser spectroscopy in the isotopic chain of carbon and the first all-optical nuclear charge radius determination of ^{12}C . This project is supported by the German Research Foundation (Project-ID 279384907 –SFB1245).

[1] V.A. Yerokhin et al., Phys. Rev. A 106, 022815 (2022)

368

Effect of Halo and Bubble Nuclei in Limited Abundance Calculations Relevant for the r-process

Auteur: Jinti Barman¹

Co-auteurs: Rajdeep Chatterjee¹; Ranojit Barman¹; Shahariar Sarkar¹

¹ Indian Institute of Technology Roorkee, India

Auteur correspondant j_barman@ph.iitr.ac.in

Nuclei away from the valley of stability, and typically near the drip lines, have challenged our understanding of nuclear structure. For example, ^{11}Be , ^{19}C , or ^{37}Mg have a long tail in their matter density distribution –popularly known as a halo. Another exciting development in this arena is the existence of bubble nuclei such as ^{20}N , ^{22}O , and ^{24}Si , which have a marked depression in their central densities and are shaped as a biconcave spheroid.

The question, therefore, we pose is what effect they have on stellar reaction rates and nucleosynthesis, which in turn can affect the astrophysical abundance pattern relevant for the r-process by a considerable margin [1]. Thus, in this work, we have considered a limited network of neutron-rich C, N, and O isotopes, taking proper structures of ^{19}C , ^{20}N , and ^{21}N into consideration. The neutron capture rates of $^{18}\text{C}(n, \gamma)^{19}\text{C}$ and $^{19}\text{N}(n, \gamma)^{20}\text{N}$ are taken from finite range distorted wave Born approximation (FRDWBA) calculations [2,3] and $^{20}\text{N}(n, \gamma)^{21}\text{N}$ from [4]. The required beta decay rates are calculated in the interacting nuclear shell model framework [5] using the shell model code KSHELL [6]. The shell model Hamiltonian *psdmk* was used to calculate the necessary wave functions of the isotopes of interest for the C, N, and O series for beta-decay rate calculations. Other rates have been taken from the JINA REACLIB database and statistical model calculations. An abundance calculation has been carried out at an equilibrium temperature and a constant density in core collapse supernova [1].

We will highlight how the improved nuclear structure and reaction rate calculations, including exotic properties like nuclear halo and bubble structure, can affect radiative capture rates associated with light and medium mass nuclei. Without the inclusion of proper structural inputs, one is often limited with the statistical estimates which are possibly uncertain. We can see how even with a limited network, the elemental abundances can change drastically with the inclusion of proper structure. We will show that the time evolution of the abundances of nuclei close to the above mentioned exotic nuclei (^{19}C , ^{20}N , and ^{21}N), show a large difference as compared to those calculated with statistical model rates.

- [1] M. Terasawa *et. al.*, *ApJ* **562**, 470 (2001).
- [2] M. Dan *et. al.*, *Phys. Rev. C* **99**, 035801 (2019).
- [3] G. Singh *et. al.*, *J. Phys.: Conf. Ser.* **1643**, 012065 (2020).
- [4] M. Roder *et. al.*, *Phys. Rev. C* **93**, 065807 (2016).
- [5] E. Caurier *et al.*, *Rev. Mod. Phys.* **77**, 427 (2005).
- [6] Noritaka Shimizu *et al.*, *Comput. Phys. Commun.* **244**, 372 (2019).

371

Fission, gamma rays and the r-process

Auteur: Anna Kawęcka¹

¹ *Chalmers University of Technology*

Auteur correspondant anna.kawecka@chalmers.se

Nuclear fission plays a key role in the astrophysical r-process which is responsible for creating heavy nuclei in astrophysical scenarios, such as neutron star mergers. Data on fission of nuclei populated by the r-process are with current experimental techniques not accessible. However, it is possible to extend our knowledge on fission of isotopes which are as neutron rich as state-of-the-art radioactive beam facilities can reach, to improve fission models and thereby r-process model calculations.

The ISOLDE facility at CERN offers unique conditions to perform fission experiments in inverse kinematics. By using the ISOLDE Solenoidal Spectrometer (ISS), fission can be investigated in inverse kinematics. Here, plans and simulation results for the measurement of gamma rays in coincidence with fission fragments will be presented.

Such data are of importance for the observation of gamma rays emitted by neutron star mergers and r-process model calculations. However, the experimental conditions, namely the high kinetic energy of the two fission fragments in an inverse kinematics experiment and the detection inside a 2.5 T magnetic field pose challenges. Doppler correction is complicated by the fact that gamma rays can be emitted from either of two different moving sources at an angle with respect to the incoming beam axis. The impact of those conditions and the total gamma efficiency for different geometrical arrangements of 40 CeBr3 detectors will be presented.

This work is supported by the Knut and Alice Wallenberg Foundation Dnr. KAW 2020.0076.

parallel / 372

Storage ring facilities for radioactive ions -New detectors and upgrade plans

Auteur: Takayuki Yamaguchi¹

¹ *Saitama University*

Auteur correspondant yamaguti@ribf.riken.jp

I will overview storage-ring nuclear physics at GSI/FAIR and RIKEN with a focus on recent technical developments with future perspectives. The experimental storage ring ESR at GSI has pioneered

mass measurements of exotic nuclei and decay studies of highly charged ions (HCI)[1]. Radioactive ions produced at the fragment separator FRS are in-flight separated and are stored into the ESR where two methods of mass spectrometry have been established. One is the time-resolved Schottky mass spectrometry where stored ions, cooled with the stochastic and/or electron cooling techniques, are frequency analyzed by non-destructive Schottky detectors, and the other is the isochronous mass spectrometry where revolutions of short-lived ions are directly measured by an in-ring dedicated time-of-flight detector under a specific optical condition. The FRS-ESR facility features relativistic energy and cooled heavy ions, highlighted by the discovery of new isotopes, new long-lived isomers, and the observation of bound-state beta decays, hyperfine effects of HCI. The facility will be upgraded to the FAIR ring branch based on the Isomeric beams, Lifetimes and Masses (ILIMA) collaboration.

The RI Beam Factory (RIBF) at RIKEN features the largest cyclotron facility complex. Taking advantage of the highest intensities of radioactive ions, a new mass spectrometer, Rare-RI Ring (R3) [2], for exotic nuclei has recently been launched. The spectrometer consists of a cyclotron-like storage ring coupled with the fragment separator BigRIPS. The isochronous mass spectrometry is employed, where only dipole magnets form a weak focusing lattice to realize the precise isochronous optical condition with a large momentum acceptance. Because of the beam characteristic, exotic nuclei of interest are individually, in-flight selected to be stored in the storage ring. Thus, single-ion mass spectrometry with the individual injection scheme has been accomplished. The first application for neutron rich Pd isotopes has recently been published [3].

Both facilities are unique and complementary. Collaborative technical studies are proceeding toward common goals; a position-sensitive transverse Schottky detector has been designed at GSI and will be tested at RIKEN. A high-resolution GAGG(Ce) crystal telescope (~50 ps time and ~1% energy resolution) was tested with heavy ions at the Heavy Ion Medical Accelerator in Chiba (HIMAC) facility in Japan and has been installed as a decay study pocket detector at the ESR. Additionally, new specific detectors: a time-of-flight detector based on delta-ray readout technique (~80 ps time resolution) and low-cost position-sensitive plastic scintillation detectors with fiber readout techniques (~1 mm spatial resolution) have been developed in Japan, which can be extended as a general purpose as well. With these instruments, the facilities will be upgraded for decay and reaction studies, beyond conventional mass measurements, of exotic nuclei available at both facilities.

[1] F. Bosch et al., Prog. Part. Nucl. Phys. 73, 84 (2013).

[2] A. Ozawa et al., Prog. Theor. Exp. Phys. 2012, 03C009 (2012).

[3] H. F. Li et al., Phys. Rev. Lett. 128, 152701 (2022).

373

Investigation of the atomic and nuclear structures of $^{244-248}\text{Cm}$

Auteur: Nina Kneip¹

Co-auteurs: Christian M. Marquardt²; Christoph E. Düllmann³; Christoph Mokry⁴; Clemens Walther⁵; Dominik Studer⁶; Felix Weber⁶; Jörg Runke⁷; Klaus Wendt⁸; Petra J. Panak²; Sebastian Raeder⁹

¹ Johannes Gutenberg University Mainz and Leibniz University Hannover

² Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

³ Johannes Gutenberg University Mainz, 55099 Mainz, Germany, Helmholtz Institute Mainz, 55099 Mainz, Germany, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

⁴ Johannes Gutenberg University Mainz, 55099 Mainz, Germany, Helmholtz Institute Mainz, 55099 Mainz, Germany

⁵ Leibniz University Hannover, 30060 Hannover, Germany

⁶ JGU Mainz

⁷ Johannes Gutenberg University Mainz, 55099 Mainz, Germany, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

⁸ Johannes Gutenberg-Universität, Mainz, Germany

⁹ GSI Darmstadt

Auteur correspondant nina.kneip@uni-mainz.de

The transuranium element curium ($Z = 96$) was discovered 1944 by Glenn T. Seaborg and coworkers [1]. Curium is one of the minor actinides beyond plutonium, contained in spent nuclear fuel (SNF) at about 20 g/t. It is produced during power reactor operation in a series of nuclear reactions starting from ^{238}U . The isotopes $^{242-248}\text{Cm}$ and ^{250}Cm have the longest half-lives of the 18 known curium isotopes, ranging from 1 to 10^7 years [2]. Especially after the Chernobyl reactor accident in 1986, curium isotopes have become more relevant in the context of radioanalytics and radiation protection. The isotope ^{242}Cm ($T_{1/2} = 162.88$ d) is the largest contributor to gross alpha activity and is thus one of the strongest alpha particle emitters in fresh SNF [3].

Resonance Ionization Mass Spectrometry (RIMS) was used at the RISIKO mass separator at Johannes Gutenberg University Mainz for off-line studies of the complex and dense atomic structure of curium. The RIMS method is ideally suited for the identification of minute amounts of rare isotopes due to its high ionization efficiency and excellent element selectivity. In preparation for the identification of curium isotopes in fresh SNF, highly efficient and element-selective ionization schemes have been developed using two different excited levels with the electron configurations $5^7 6^7 7^7 9^3$ and $5^8 6^7 7^9 3$. First demonstrations of the identification of curium in environmental hot particles have already been performed [5].

Apart of that, curium is of special interest for studies of atomic and nuclear structures of actinides by laser spectroscopy. For this a mixed curium sample with the isotope ratios of $^{244}\text{Cm} : ^{245}\text{Cm} : ^{246}\text{Cm} : ^{247}\text{Cm} : ^{248}\text{Cm} = 0.40 : 0.06 : 0.13 : 0.004 : 0.39$ was used at the RISIKO mass separator. A narrow band Ti:sapphire laser system was used for high-precision measurements of the $^{244-248}\text{Cm}$ isotope shift. The hyperfine structure was resolved for the two odd-A isotopes of $^{245,247}\text{Cm}$ with 15 hyperfine transitions each. Finally, the modified King plot was used to determine the missing mean square charge radius of ^{247}Cm .

[1] G.T. Seaborg, Science 104 (1946).

[2] A. Habibi et al., Radioanal. Nucl. Chem. 329 (2021).

[3] E. Horn et al., Radioanal. Nucl. Chem. 252 (2002).

[4] N. Kneip et al., Eur. Phys. J. D 76 (2022).

[5] H. Bosco et al., Sci. Adv. 7 (2021).

parallel / 374

Testing *ab-initio* calculations in light nuclei via high-precision spectroscopy

Auteur: Irene Zanon¹

Co-auteurs: Emmanuel CLEMENT²; Alain Goasduff¹

¹ INFN-LNL

² {CNRS}GANIL

Auteur correspondant irene.zanon@lnl.infn.it

The development and improvement in terms of performances of accelerator facilities and detectors has paved the way for extending the study of nuclear structure towards more exotic nuclei and experimental quantities that have been, until now, less accessible. In parallel, theoretical methods have advances in precision and prediction capabilities.

In recent years, *ab-initio* calculations in particular have proven to be powerful tools to address open questions in nuclear structure; one example is the role of three-body forces in the evolution of nuclear structure far from stability. The importance of their contribution is evident in the case of the oxygen isotopic chain. In fact, only by including these forces in the calculations it is possible to correctly reproduce the neutron dripline in correspondence of ^{24}O , instead of ^{28}O as predicted by standard calculations. However, in order to quantify the contribution of these forces, spectroscopic information is crucial.

In this context, the ^{20}O nucleus is a perfect playground for these measurements; in fact, the properties of the 2_2^+ and 3_1^+ states of this nucleus are expected to be influenced by three-body forces. By measuring the spectroscopic properties of these nuclei, such as the excitation energy, the branching ratio and the lifetime, and comparing them to theoretical calculations, it is possible to understand the depth of their influence.

For these reasons, an experiment aimed at studying the ^{20}O was performed in GANIL. The radioactive beam of ^{19}O , provided by the SPIRAL1 complex, impinged on a deuterated target, populating the nucleus of interest by means of a (d, p) reaction. The target was deposited on a layer of gold in order to measure the lifetime of the states by using the Doppler-Shift Attenuation Method. The recoils of the binary reaction were detected using the MUGAST array and the VAMOS++ magnetic spectrometer, while the γ rays emitted were detected using AGATA.

The nucleus was first investigated via particle- γ spectroscopy to reconstruct the level scheme and measure the branching ratios. Then the lifetimes of the 2_2^+ and 3_1^+ states were measured. To do so, the experimental lineshapes were compared to realistic Monte Carlo simulations and the lifetimes were extracted by using the least- χ^2 method. Finally the reduced transition probabilities, B(E2) and B(M1) deduced from the lifetime measurements, were compared to *ab-initio* calculations.

In this contribution, the results of the particle- γ spectroscopy and the lifetime measurements of the 2_2^+ and 3_1^+ states are reported. An interpretation of the nature of the excited states of ^{20}O is presented as well as the future perspectives for further investigation in this region.

375

Detecting fission fragments at ISS

Auteur: Maria Vittoria Managlia¹

Co-auteurs: Andreas Heinz¹; Hakan T. Johansson¹; Bjorn Jonson¹; Anna Kawecka¹; Thomas Nilsson¹; Hans T. Tornqvist¹

¹ Chalmers University of Technology

Auteur correspondant mariavittoria.managlia@chalmers.se

Recent advances in the production of radioactive beams and spectrometer design allow for the measurement of fission barrier heights in inverse kinematics, also for neutron-rich nuclei. Fission reactions in inverse kinematics result in a forward focusing of the two fission fragments which can be exploited.

The complex network of nuclear reactions known as the r-process is responsible for the nucleosynthesis of the heaviest elements in the universe. It is believed to occur in astrophysical scenarios like neutron-star mergers. In this process, nuclear fission plays a key role since it limits the maximum element number that can be produced. However, our knowledge on the fission of neutron-rich nuclei, relevant for the r-process, is very limited and lacks experimental information.

Simulations of such experiments using the ISOLDE Solenoidal Spectrometer (ISS) at CERN will be presented. By detecting the fission fragments in coincidence with a proton from a (d, pf) reaction, fission probabilities can be extracted as a function of the excitation energy. Ways of optimizing the acceptance of fission fragment detectors located inside or near a 2.5 T magnetic field have been investigated. Different detector configurations will be discussed and compared.

This work is supported by the Knut and Alice Wallenberg Foundation Dnr. KAW 2020.0076.

376

In-beam gamma-ray spectroscopy of the exotic ^{79}Cu with HiCARI

Auteur: MASSYL KACI¹

¹ *IjCLab PhD*

Auteur correspondant massyl.kaci@ijclab.in2p3.fr

An experiment aiming at performing an in-beam γ -ray spectroscopy of ^{79}Cu after a one-proton knock-out from ^{80}Zn was carried out at the Radioactive Isotope Beam Factory of the Riken laboratory during the 2021 HiCARI campaign [1]. An incident primary beam of ^{238}U at 345 MeV/nucleon produced a wide range of exotic nuclei including ^{80}Zn , after in-flight fission. These nuclei were sent through the BigRIPS separator onto a beryllium target, in which the knock-out reactions took place. The outgoing fragments including ^{79}Cu were subsequently identified in the ZeroDegree spectrometer. The emitted γ -rays were detected by the HiCARI germanium detector array placed around the target. The particle identification of the nuclei of interest for $^{80}\text{Zn}(9\text{Be},X)^{79}\text{Cu}$ reaction channel has been achieved in the ongoing analysis after optical corrections and background removal. We present here the preliminary γ -spectra of ^{79}Cu de-excitation, which we compare with the results of our previous campaign where a scintillator array was used [2].

1. K. Wimmer et al., HiCARI: High-resolution Cluster Array at RIBF, RIKEN Accel. Prog. Rep. 54, S27 (2021).
2. L. Olivier et al., Persistence of the $Z = 28$ shell gap around ^{78}Ni : first spectroscopy of ^{79}Cu , Phys. Rev. Lett. 119, 192501 (2017).

377

Li-8 and He-8 beams for hadrontherapy

Auteur: Emil Traykov¹

Co-auteurs: Christian Finck²; Laurine Schnelzauer; Marie Vanstalle¹; Nicolas Arbor³; Quentin Raffy⁴; Samuel VALENTIN⁵

¹ *IPHC*

² *CNRS - IPHC*

³ *IPHC-Strasbourg*

⁴ *IPHC / Radiochimie*

⁵ *University of Strasbourg*

Auteur correspondant emil.traykov@iphc.cnrs.fr

Radiotherapy with light ion beams is beneficial for treatment of tumors that are resistant to chemotherapy and radiotherapy. In addition, hadrontherapy is the preferred choice of treatment for tumors that are inoperable, e.g. due to their proximity to vital organs.

One of the advantages of hadrontherapy over conventional X-ray radiotherapy is the possibility to target the tumor site with a higher precision, both radially and longitudinally. Due to the high-energy transfer at the Bragg peak, one can increase the dose in the tumor while preserving the surrounding healthy tissue.

The high precision of the dose deposition requires also a high accuracy of deposition that is presently hindered due to the dependence on modelling and due to the current limitations of dose monitoring. A possible improvement of the latter can be achieved by using short-lived ion beams, which allows evaluation of the dose distribution by measuring the decay radiation.

An additional advantage of using specific short-lived isotopes, such as Li-8 and He-8, is the presence of beta-delayed particle emissions that are expected to increase further the dose delivery in the tumor. Moreover, in the case of He-8, a single 980 keV gamma is emitted in 84% of the beta decays, which allows delayed, background-free detection for online dose monitoring. The possible advantages of Li-8 and He-8 for hadrontherapy supported by simulation results and the upcoming experimental verification at GANIL will be discussed.

There are various schemes for production of short-lived radioactive ion beams, which are based on “isotope separation on-line” (ISOL) and/or on “In-flight production and separation” (IF). The main

advantages and disadvantages of the production in various scenarios will be presented. A kinematic advantage in the case of IF production and separation of neutron-rich beams will be discussed as a possible way to reduce costs of future hadrontherapy centers.

378

A DESIRable radiofrequency cooler and buncher: the GPIB

Auteur: Mathias Gerbaux¹

Co-auteurs: Antoine de Roubin²; Audric Husson³; Benjamin THOMAS⁴; Benoit LACHACINSKI⁴; Bertram Blank⁵; David Lunney⁶; Dinko Atanasov³; Hugo Guérin³; Laurent Daudin⁷; Marjut Hukkanen⁸; Mathieu FLAYOL⁹; Mehdi AOUADI¹⁰; Pauline Ascher²; Philippe Alfaut³; Sean Pérard³; Soufiane El Abbeir³; Stéphane Grévy²

¹ LP2iB - Université de Bordeaux

² CENBG

³ LP2iB

⁴ {CNRS}UMR5797

⁵ CEN Bordeaux-Ggradignan

⁶ CNRS/IN2P3

⁷ CNRS/IN2P3/CENBG

⁸ University of Jyväskylä and CENBG

⁹ CNRS-LP2IB-CENBG

¹⁰ CENBG-CNRS

Auteur correspondant mathias.gerbaux@u-bordeaux.fr

A gas-filled radiofrequency quadrupole (RFQ) named the General Purpose Ion Buncher (GPIB) has been designed to be the beam cooler and buncher located at the entrance of the soon-to-be-built DESIR* experimental hall at GANIL. The GPIB will both cool the beams coming from the SPIRAL1 and SPIRAL2 facilities from the few-10 π .mm.mrad emittance typical of the accelerators down to a few π .mm.mrad at energies ranging from 60 to 3 keV and also bunch them if needed by the experiment further downstream in the hall while maintaining a high transmission.

The mechanical design is an upgrade of the existing ISCOOL RFQ located on the HRS beamline at ISOLDE, CERN but the new radiofrequency system based on a balun transformer enables a much stronger radial confinement of the ions inside the cooler so as to handle the high production rates expected at DESIR: around 10^8 ions per second for most nuclides but up to 10^{10} ions per second in some specific cases.

The GPIB has been assembled at LP2i-Bordeaux and is currently being commissioned in parallel with the PIPERADE double Penning trap that has been installed on the same beamline and makes use of the cooled beam of the GPIB. We will demonstrate that a transmission of 80% or higher can be maintained in continuous mode (cooling only) up to a few nA of incoming ions while the transverse emittance is lowered down to 3 π .mm.mrad at 30 keV. Preliminary results concerning energy and time dispersions will also be shown.

* Standing for Decay, Excitation and Storage of Radioactive Ions

parallel / 381

Constraining the electron-capture rates of neutron-rich nuclei with the ($d, {}^2\text{He}$) reaction in inverse kinematics.

Auteurs: Simon Giraud¹; Zarif Rahman¹

Co-auteurs: Alex Brown ¹; Alexander Carls ; Cavan Maher ¹; Charlie Hultquist ¹; Daniel Bazin ¹; Felix Ndayisabye ¹; Gaute Hagen ²; Jaclyn Schmitt ¹; Jason Surbrook ¹; Jie Chen ³; Jorge Pereira ¹; Juan Carlos Zamora ¹; Lijie Sun ¹; Marco Cortesi ¹; Michael Serikow ¹; Miles DeNudt ; Nathan Watwood ¹; Remco Zegers ¹; Sam Novario ²; Saul Beceiro Novo ⁴; Shumpei Noji ¹; Sonia Bacca ⁵; Tyler Wheeler ¹; Wolfgang Mittig ¹; Yassid Ayyad ⁶

¹ MSU-FRIB

² UT-ORNL

³ ANL

⁴ Universidade da Coruña

⁵ Helmholtz-Institut Mainz

⁶ Universidade de Santiago de Compostela

Auteur correspondant giraud@frib.msu.edu

Nuclear charge-exchange reactions can be used to estimate the electron-capture rates which are key quantities in various astrophysical scenarios, such as the final evolution of intermediate-mass stars, core-collapse supernovae (CCSN), cooling of the neutron star crust, and nucleosynthesis in thermonuclear supernovae. Over the past decades, great progress has been made to constrain electron-capture rates on stable nuclei by using reactions in forward kinematics. However, the unstable neutron-rich nuclei that play an important role during, for example, the core-collapse supernovae ($N \approx 50$, $Z \approx 28$), remained inaccessible. The use of the ($d, {}^2\text{He}$) charge-exchange reaction in inverse kinematics with the Active-Target Time-Projection Chamber and the S800 Spectrograph was developed at NSCL/FRIB, for extracting Gamow-Teller strengths in the β^+ direction on unstable nuclei. This makes it possible, for the first time, to constrain electron-capture rates on neutron-rich nuclei. In this talk I will discuss recent results of the pilot ${}^{14}\text{O}(d, {}^2\text{He})$ experiment.

This work is supported by the National Science Foundation under Grants PHY-2209429, “Windows on the Universe: Nuclear Astrophysics at FRIB”

382

Study of the tensor force contribution in the N isotopic chain using QFS reactions

Auteurs: Antoine Barrière¹; Olivier Sorlin¹; Nikhil Mozumdar²; and the R³B Collaboration

¹ Grand Accélérateur National d'Ions Lourds (GANIL)

² Technische Universität Darmstadt

Auteur correspondant antoine.barriere@ganil.fr

In the shell model framework, the two-body nuclear force can be divided into a central, spin-orbit (SO) and tensor parts. The vast majority of studies performed so far in the chart of nuclides shows that the amplitude of the SO splitting scales with the function presented by G.Mairle [1], from systematics of nuclei studied so far in the valley of stability. Two exceptions to this trend have been found so far for the ${}^{133}\text{Sn}$ [2,3] and ${}^{35}\text{Si}$ [4] nuclei. As for the first, deviation to the trend has been attributed to the effect of the continuum, while the second to the effect of the central proton depletion that induces a strong reduction of the SO splitting of orbits probing the interior of the nucleus [5,6]. There is not so far striking evidence of the effect of the tensor force that should induce a change in the SO splittings that depends on its strength.

An experiment has been recently performed using the R³B setup at GSI, within the FAIR Phase-0 program. One of the scientific goals is to study the role of the tensor force when approaching the neutron drip-line. During this experiment a “cocktail” of nuclei, among which ${}^{22}\text{O}$ was sent on a 5 cm LH2 target surrounded by tracking detectors and the CALIFA calorimeter [7]. This calorimeter allows to detect γ -rays and light particles from the QFS reactions in inverse kinematics. To study the spectroscopy of unbound states with an unprecedented energy resolution, this new setup includes the high resolution and granularity neutron detector NeuLAND [8].

In this work, the $^{22}\text{O}(p, 2p)$ and $^{21}\text{N}(p, pn)$ QFS knockout reactions provide us information on the tensor force contribution to the $0p_{1/2}$ - $0p_{3/2}$ SO splitting in the N isotope chain, from N=8 to N=14 shell closure, when the neutron $0d_{5/2}$ orbital is filled. The first reaction gives access to the $1/2^-$ and $3/2^-$ states in ^{21}N , and the second allows to check that 6 neutrons are indeed populating the $0d_{5/2}$ orbital in ^{21}N .

Preliminary results from this study will be presented.

- [1] G. Mairle, Phys. Lett. B **304**, (1993) 39.
- [2] K. L. Jones et al., Nature **465**, (2010) 454.
- [3] R. Orlandi et al., Phys. Lett. B **785**, (2018) 615.
- [4] G. Burgunder et al., Phys. Rev. Lett. **112**, (2014) 042502.
- [5] O. Sorlin et al., Phys. Lett. B **809**, (2020) 135740.
- [6] A. Mutschler et al. Nature Phys. **13**, (2017) 152.
- [7] A. Knyazev et al., Nucl. Instr. and Meth. A **940**, (2019) 393-404.
- [8] K. Boretzky et al., Nucl. Instr. and Meth. A **1014**, (2021) 165701.

383

Searching for Alpha-Cluster States in ^{126}Te

Auteurs: Corina Andreoiu¹; Costel Petrache²; Frank (Tongan) Wu¹; Jose Javier Valiente Dobon³

¹ Simon Fraser University

² CSNSM, Université Paris Sud and CNRS/IN2P3

³ Laboratori Nazionali di Legnaro (INFN)

Auteur correspondant twa73@sfu.ca

Clustering in nuclei provides an alternative description to their nuclear structure in addition to the Nuclear Shell Model. Although alpha-cluster configurations are widely accepted to be essential to the understanding of the structure of light nuclei, such as the Hoyle state in ^{12}C , it was experimentally reported in heavy nuclei only recently in ^{212}Po . The study showed that ^{212}Po had mixed shell and cluster configurations, where the structure of ^{212}Po could be explained by an alpha cluster coupled to the doubly-magic ^{208}Pb core. However, very recently another study of ^{212}Po showed that the enhanced E1 transitions depopulating the claimed cluster states are in fact M1 transitions and thus questioned the existence of the predicted cluster states, which remain to be discovered.

Another recent experiment performed at INFN Legnaro observed an excess cross section for the $^{122}\text{Sn}(^{13}\text{C}, ^9\text{Be})^{126}\text{Te}$ reaction. Because the fusion-evaporation cross section for this channel was negligible in PACE4 calculations, the ^{126}Te was likely populated through an alpha-transfer/incomplete-fusion reaction, which suggests alpha-clustering in its structure. In this experiment gamma rays were detected with the GALILEO array which is composed of 25 Compton-suppressed HPGe detectors, while charged particles with particle identification were detected in the EUCLIDES $E - \Delta E$ 4π Si-ball array. Gamma-ray spectroscopy with coincidence techniques, such as particle-particle, particle-gamma, and gamma-gamma, is underway to extract previously unobserved transitions and levels in ^{126}Te from this data set. Preliminary results from the Legnaro data, together with plans for a future experiment, will be presented and discussed.

plenary / 384

Determination of the Neutron Dripline at F and Ne and Discovery of the Heaviest Na Isotope: ^{39}Na

Auteur: Toshiyuki KUBO¹

Co-auteurs: DeukSoon AHN²; Junki AMANO³; Hidetada BABA¹; Naoki FUKUDA¹; Hans GEISSEL⁴; Naohito INABE¹; Shunki ISHIKAWA⁵; Naohito IWASA⁵; Tetsuro KOMATSUBARA¹; Kensuke KUSAKA¹; David J. MORRISSEY⁶; Daichi MURAI³; Takashi NAKAMURA⁷; Masao OHTAKE¹; Hideaki OTSU¹; Takahiro SAKAKIBARA

⁵; Hiromi SATO ¹; Brad M. SHERRILL ⁸; Yohei SHIMIZU ¹; Toshiyuki SUMIKAMA ¹; Hiroshi SUZUKI ¹; Hiroyuki TAKEDA ¹; Oleg B. TARASOV ⁶; Hideki UENO ¹; Yoshiyuki YANAGISAWA ¹; Koichi YOSHIDA ¹

¹ RIKEN Nishina Center

² Center for Exotic Nuclear Studies, KOREA

³ Rikkyo University

⁴ GSI

⁵ Tohoku University

⁶ NSCL/MSU

⁷ Tokyo Institute of Technology

⁸ FRIB/MSU

Auteur correspondant hsuzuki@ribf.riken.jp

The location of the neutron dripline is crucial to understand the stability of nucleonic many-body systems with extreme neutron-to-proton ratios. It provides a benchmark for nuclear theories and mass models, and an important key to understand underlying nuclear structure and interactions. The neutron dripline has been experimentally determined up to oxygen (atomic number $Z = 8$) as ^{24}O [1-4] more than 20 year ago, while no experimental confirmation has been reported for $Z \geq 9$.

We have searched for the neutron driplines, the heaviest new isotopes, of fluorine ($Z = 9$), neon (10), and sodium (11) by the BigRIPS separator at the RIKEN RI Beam Factory. The neutron-rich isotopes were produced by projectile fragmentation of a 345-MeV/u 450~500-pnA $^{48}\text{Ca}^{20+}$ beam impinging on a 20-mm-thick Be target. No events were observed for $^{32,33}\text{F}$, $^{35,36}\text{Ne}$, and ^{38}Na [5]. Comparison with predicted yields excludes the existence of bound states of these unobserved isotopes with high confidence levels, which indicates that ^{31}F and ^{34}Ne are the heaviest bound isotopes of fluorine and neon, respectively. We have confirmed the fluorine and neon neutron driplines for the first time. We have observed the new isotope of ^{39}Na , which is the most neutron-rich isotope with $N = 28$ neutron magic number [6].

The locations of the neutron dripline from oxygen to neon isotopes and the bound nature of ^{39}Na could be explained by evolution of nuclear deformation. By the recent large-scale shell-model calculation with *ab initio* effective NN interaction [7], the oxygen dripline is determined by a new magic number of $N = 16$, emerging by tensor force and repulsive 3 nucleon forces. From $Z = 9$ to 12, quadrupole deformation leads to a larger binding energy for neutrons and affects the location of the driplines. The discovery of ^{39}Na suggests that its ground state is deformed and the magicity of $N = 28$ is lost.

In this talk, the experimental results will be presented to discuss the location of the neutron driplines as well as the underlying nuclear structure.

- [1] D. Guillemaud-Mueller *et al.*, Phys. Rev. C **41**, 937 (1990).
- [2] M. Fauerbach *et al.*, Phys. Rev. C **53**, 647 (1996).
- [3] O. B. Tarasov *et al.*, Phys. Lett. B **409**, 64 (1997).
- [4] H. Sakurai *et al.*, Phys. Lett. B **448**, 180 (1999).
- [5] D.S. Ahn, T. Kubo *et al.*, Phys. Rev. Lett. **123**, 212501 (2019).
- [6] D.S. Ahn, T. Kubo *et al.*, Phys. Rev. Lett. **129**, 212502 (2022).
- [7] N. Tsunoda *et al.*, Nature (London) **587**, 66 (2020).

plenary / 385

Alpha-clustering in atomic nuclei from first principles

Auteur: Takashi Abe¹

¹ CNS, the University of Tokyo

Auteur correspondant tabe@cns.s.u-tokyo.ac.jp

Owing to recent computational and methodological advances, ab-initio approaches in low-energy nuclear theory have been developed rapidly in recent years. As one of such approaches, the no-core Monte Carlo shell model (MCSM) is briefly introduced in this presentation. After verifying the capability of the no-core MCSM on actual computations, the alpha-cluster structure of light nuclei is discussed from an ab-initio point of view, especially focusing on the appearance of molecular-orbital structure of valence neutrons in Be isotopes and the intrinsic shapes of the C-12 nucleus.

386

Towards implantation of pure Fe-55 for radioactivity standardization by low temperature devices

Auteur: Thorben Niemeyer¹

Co-auteurs: Christoph E. Düllmann²; Dennis Renisch³; Dominik Studer²; Holger Dorrer¹; Jung Bog Kim⁴; Klaus Wendt¹; Nina Kneip⁵; Sebastian Berndt¹; Tom Kieck⁶

¹ Johannes Gutenberg University Mainz

² Johannes Gutenberg University Mainz, Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH

³ Johannes Gutenberg University Mainz, Helmholtz-Institut Mainz

⁴ Johannes Gutenberg University Mainz, Korea National University of Education

⁵ Leibniz University Hannover

⁶ Johannes Gutenberg University Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH

Auteur correspondant thniemey@students.uni-mainz.de

Radionuclide activity metrology techniques currently used for activity standardization show a huge variety of measurement uncertainty - from permille accuracy, e.g. for the α -decaying Am-241 ($T_{1/2} = 432$ a) up to several percent for Fe-55 ($T_{1/2} = 2.73$ a) which decays by electron capture. To reduce such uncertainties, a new standardization technique using direct implantation of a radionuclide on low-temperature calorimeters is being developed within the EU project PrimA-LTD. The results will have impact on theoretical models on the decay spectra and in this way contribute to the nuclear power industry, nuclear medicine and radiopharmacy.

The implantation of 5 Bq of Fe-55 into the absorbers of microcalorimetric detectors will be performed at the RISIKO mass separator at Mainz University via resonance ionization mass spectrometry. This technique is used due its outstanding elemental selectivity and overall implantation efficiency. A new 2-step ionization scheme is being developed, where the first excitation step to 39.625 cm^{-1} demands third-harmonic generation and the second step at around 24.112 cm^{-1} implies second-harmonic-generation of the pulsed Ti:Sa laser radiation used at RISIKO. The optical excitation scheme was characterized by spectroscopy studies in the atomic spectrum below and above the ionization potential. Strong auto-ionizing states were localized, which will be used for implantation, while the measurement of Rydberg states is carried out to verify the ionization potential and extend the data on even parity Rydberg states in Fe adding to results of Page and Gudeman [1]. The identification of the ionization scheme and the spectroscopy is performed on the stable Fe-56.

[1] Ralph H. Page and Christopher S. Gudeman, "Completing the iron period: double-resonance, fluorescence-dip Rydberg spectroscopy and ionization potentials of titanium, vanadium, iron, cobalt, and nickel," J. Opt. Soc. Am. B 7, 1761-1771 (1990), <https://doi.org/10.1364/JOSAB.7.001761>

parallel / 387

Search for ^{22}Na in novae supported by a novel method for measuring femtosecond nuclear lifetimes

Auteurs: Chloé Fougères¹; François de Oliveira Santos²

¹ GANIL CEA/DRF - CNRS/IN2P3

² GANIL

Auteur correspondant oliveira@ganil.fr

Astrophysical simulations predict that ^{22}Na is produced in novae explosions. With its half-life of 2.6 years and its characteristic γ -ray of 1.275 MeV, it could be easily identified and measured with γ -ray space telescopes, which has not been the case yet. The amount of ^{22}Na produced in novae depends on the rate of nuclear reactions, and in particular on the $^{22}\text{Na}(p, \gamma)^{23}\text{Mg}$ reaction rate. It has been shown that the amount of ^{22}Na ejected from novae is directly proportional to the lifetime of the excited state at $E_x=7.785$ MeV in ^{23}Mg .

We have measured this lifetime in an experiment at GANIL-France, associating the VAMOS++ magnetic spectrometer, the AGATA γ -ray tracking spectrometer and a silicon detector. The analysis of angle-integrated velocity-difference profiles allowed us to obtain a femtosecond sensitivity.

The obtained result places strong limits on the amount of ^{22}Na produced in novae, explains its non-observation to date in γ rays (flux $< \sim 2.5 \times 10^{-4} \sim \text{ph.cm}^{-2}\text{s}^{-1}$), and constrains its detectability with future space-borne observatories.

Ref: <https://arxiv.org/abs/2212.06302>

388

Visualization of nuclear many-body correlations in microscopic wave functions

Auteur: Moemi Matsumoto¹

Co-auteur: Yusuke Tanimura¹

¹ Tohoku University

Auteur correspondant moemi@nucl.phys.tohoku.ac.jp

In general, the quantum many-body wave function obtained by theoretical calculation contains an enormous amount of information about many-body correlations. However, theoretical analyses in nuclear physics are mainly performed for quantities such as one- and two-body densities, which are obtained after integrating out most of the information in a many-body wave function.

On the other hand, in the field of quantum chemistry, methods have been developed to visualize the information on the correlations among all the electrons and applied to the structure studies of molecular systems [1]. We are attempting to apply such a method to nuclear systems. As the first step, we start with finding the most probable arrangement of nucleon coordinates, i.e, the set of position and spin coordinates that maximizes the square of the many-body wave function.

In this presentation, we apply this method to Hartree-Fock and Hartree-Fock+BCS wave functions of p-shell and sd-shell nuclei [2]. We find some alpha-cluster-like correlations out of the wave functions obtained without any assumption of cluster structure. Effects of pairing correlation on the cluster structure are discussed by comparing the results between HF and HF+BCS. We also investigate the relationship between deformation and the cluster structure with constrained HF+BCS wave functions. We believe that this study gives a new viewpoint to the microscopic nuclear wave function.

[1] Yu Liu, Terry J. Frankcombe, and Timothy W. Schmidt, Phys. Chem. Chem. Phys. 18, 13385 (2016).

[2] Moemi Matsumoto and Yusuke Tanimura, Phys. Rev. C 106, 014307 (2022).

Discovery of isotopes and first time broadband measurements of neutron-deficient light lanthanides via high precision mass spectrometry

Auteur: Christine Hornung¹

Co-auteurs: Daler Amanbayev²; Samuel Ayet San Andrés³; Soumya Bagchi⁴; Sönke Beck⁵; Dimiter Balabanski⁶; Julian Bergmann²; Ziga Brencic⁷; Paul Constantin⁸; Masoumeh Dehghan¹; Timo Dickel¹; Tayemar Fowler-Davis⁹; Hans GEISSEL¹⁰; Florian Greiner¹; Lizzy Gröf²; Emma Haettner¹; Oscar Hall⁹; Muhsin N. Harakeh¹¹; Jan-Paul Hucka¹²; Nasser Kalantar-Nayestanaki¹³; Anu Kankainen¹⁴; Daria A. Kostyleva¹⁵; Gabriella Kripko-Koncz²; Erich Leistenschneider¹⁶; Isreal Mardor¹⁷; Nikolay Minkov¹⁸; Ivan Miskun²; Ali Mollaebrahimi⁵; Ivan Mukha¹; Gottfried Münzenberg¹; Stephane Pietri¹; Wolfgang R. Plass⁵; Christophe Rappold¹; Moritz Pascal Reiter⁹; Heidi Roesch¹⁹; Christoph Scheidenberger⁵; Anamaria Spataru⁸; Suraj Kumar Singh⁵; Yoshiki K. Tanaka²⁰; Matjaz Vencelj⁷; Helmut Weick¹; Jianwei Zhao²¹

¹ GSI Helmholtzzentrum für Schwerionenforschung

² Justus-Liebig-Universität Gießen

³ GSI Helmholtzzentrum für Schwerionenforschung, Justus-Liebig-Universität Gießen, Gießen

⁴ GSI Helmholtzzentrum für Schwerionenforschung, Indian Institute of Technology (Indian School of Mines), Jharkhand, Saint Mary's University, Halifax

⁵ GSI Helmholtzzentrum für Schwerionenforschung, Justus-Liebig-Universität Gießen

⁶ ELI-NP, IFIN-HH

⁷ Jozef Stefan Institute, Ljubljana

⁸ Extreme Light Infrastructure-Nuclear Physics (ELI-NP), Bucharest-Magurele

⁹ University of Edinburgh

¹⁰ GSI

¹¹ GSI/KVI

¹² GSI Helmholtzzentrum für Schwerionenforschung, Technische Universität Darmstadt

¹³ Nuclear Energy Group, ESRIG, University of Groningen

¹⁴ University of Jyväskylä

¹⁵ GSI Helmholtzzentrum für Schwerionenforschung, Justus-Liebig-Universität Gießen

¹⁶ National Superconducting Cyclotron Laboratory, East Lansing

¹⁷ Tel Aviv University, Soreq Nuclear Research Center, Yavne

¹⁸ Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences

¹⁹ GSI Helmholtzzentrum für Schwerionenforschung, Technische Universität Darmstadt

²⁰ High Energy Nuclear Physics Laboratory, RIKEN, Wako

²¹ GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)

Auteur correspondant c.hornung@gsi.de

Approaching the limits of nuclear binding, the structure and properties of drip-line nuclei is of great interest and draws a lot of attention from both, experiment and theory. The nuclear properties in the light lanthanide region are shaped by the interplay between large beta-decay Q-values, low or negative proton separation energies, and the confining effects of the Coulomb barrier. From precise mass values, differential quantities, such as the proton and neutron separation energies, can be determined, and different phenomena, including a variety of beta-delayed particle emission channels, proton radioactivity, and two-proton radioactivity as well as exotic pairing phenomena, can be addressed.

Nuclei in the region of between ¹⁰⁰Sn and ¹⁵⁰Lu were produced at relativistic energies and separated in-flight with the fragment separator FRS at GSI as part of the FAIR Phase-0 experiments. They were identified by their proton number and mass-to-charge ratio in the FRS, before being slowed down, thermalized in the Cryogenic Stopping Cell (CSC) of the FRS Ion Catcher and transported to a Multiple-Reflection Time-Of-Flight Mass Spectrometer (MR-TOF-MS) for high-resolution mass measurements. In order to calibrate and verify the particle identification at the FRS, a novel method, tagging by high resolution mass spectrometry using the MR-TOF-MS of the FRS Ion Catcher, was successfully applied.

In the experiment, new isotopes towards the proton drip-line, in the region between Nd and Tb, could be identified by the FRS particle identification. For the mass measurements a new technical

approach was applied, the so called mean range bunching. The combination of achromatic ion optics of the FRS with a new variable wedge-shaped degrader system at the final focal plane allows to “correct” the range-position dependence, which enables efficient stopping of many nuclides in the CSC simultaneously. This novel technical approach was proven by the simultaneous measurement of more than 35 nuclides in a single setting. It opens up the possibility to cover large regions on the chart of the nuclides in a single measurement with stopped or thermalized nuclides, aside from mass measurements also for decay and laser spectroscopy. The masses of more than 10 nuclides were measured for the first time, and the mass uncertainties of more than 10 nuclides were significantly reduced. These results give an insight into the nuclear structure and for the first time allow tracking of the proton drip line between ^{100}Sn and ^{150}Lu . In this contribution, these recent results and the new technical approaches will be reported.

390

Measurements with the FRS Ion Catcher in the region below ^{100}Sn and on the ^{252}Cf spontaneous fission fragments

Auteur: Jianwei Zhao¹

Co-auteurs: Daler Amanbayev²; Dimiter L. Balabanski³; Samue Ayet San Andrés⁴; Sönke Beck⁴; Andrey Blazhev⁵; Julian Bergmann²; Ziga Brencic⁶; Paul Constantin³; Timo Dickel⁴; Tayemar Fowler-Davis⁷; Zhuang Ge⁸; Hans Geissel⁴; Magdalena Górska⁸; Florian Greiner²; Emma Haettner⁸; Oscar Hall⁷; Christine Hornung⁴; Nasser Kalantar-Nayestanaki⁹; Ivan Miskun²; Frédéric Nowacki¹⁰; Anu Kankainen¹¹; Gabriella Kripkó-Koncz²; Israel Mardor¹²; Ali Mollaebrahimi¹³; Wolfgang R. Plaß¹⁴; Ilkka Pohjalainen¹⁵; Moritz Pascal Reiter⁷; Christoph Scheidenberger¹⁴; Anamaria Spataru³; Alexandru State³; Peter Thierolf¹⁶; Nazarena Tortorelli¹⁷; Matjaz Vencelj⁶; Jiajun Yu⁸; Alexandra Zadornaya²

¹ GSI Helmholtzzentrum für Schwerionenforschung GmbH(GSI)

² Justus-Liebig-Universität Gießen, Gießen, Germany

³ ELI-NP, Bucharest, Romania

⁴ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany;Justus-Liebig-Universität Gießen, Gießen, Germany

⁵ Universität zu Köln, Köln, Germany

⁶ Jozef Stefan Institute, Ljubljana, Slovenia

⁷ University of Edinburgh, Edinburgh, United Kingdom

⁸ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

⁹ ESRIG, University of Groningen, Groningen, The Netherlands

¹⁰ Universitéde Strasbourg, CNRS, IPHC UMR, Strasbourg, France

¹¹ University of Jyväskylä, Jyväskylä, Finland

¹² Tel Aviv University, Tel Aviv, Israel

¹³ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany;Justus-Liebig-Universität Gießen, Gießen, Germany;ESRIG, University of Groningen, Groningen, The Netherlands

¹⁴ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany; Justus-Liebig-Universität Gießen, Gießen, Germany

¹⁵ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany;University of Jyväskylä, Jyväskylä, Finland

¹⁶ Ludwig-Maximilians-Universität München, München, Germany

¹⁷ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany;Ludwig-Maximilians-Universität München, München, Germany

Auteur correspondant j.zhao@gsi.de

Masses of exotic nuclei provide key information for the understanding of nuclear structure and astrophysics. At GSI, exotic nuclei have been produced at relativistic velocities by projectile fragmentation or fission at the entrance of the fragment separator FRS, separated in-flight, identified, and transported to the FRS Ion Catcher [1,2], where they were slowed down and thermalized in

a Cryogenic Stopping Cell (CSC). Subsequently, their masses were measured by using a Multiple-Reflection Time-Of-Flight Mass-Spectrometer (MR-TOF-MS). Masses of nuclides with production cross sections down to a few nb and rates down to two counts per hour have been measured with the FRS Ion Catcher. The MR-TOF-MS features mass resolving powers of up to one million and relative mass measurement accuracies of down to 2×10^{-8} with measurement times of merely a few tens of milliseconds [3]. Moreover, the broadband and non-scanning properties make it an effective tool for mapping large-scale mass surfaces and searching for long-lived isomeric states.

Direct mass measurements of neutron-deficient nuclides around the $N = 50$ shell closure below ^{100}Sn , including the first direct mass measurements of ^{98}Cd and ^{97}Rh [5] and the discovery of new isomeric states in ^{97}Ag [4], shed light on the nuclear structure in this region and on the “ ^{100}Sn mass riddle” [6]. The Gamow-Teller strength $B(\text{GT})$ values obtained with the new Q_{EC} values can be well understood by the large-scale shell model (LSSM) calculations. Contradictory results on ^{100}Sn investigated by the shifted empirical two-neutron shell gap and by the $B(\text{GT})$ call for further experiments. Additionally, mass measurements of neutron-rich nuclei from a ^{252}Cf spontaneous fission source reveal evidence for shape transitions in the $N \sim 90$, $Z = 56\text{--}63$ region, and provide direct determination of independent isotopic fission yields [7]. These recent results and technical advances, as well as further measurements performed in the vicinity of the $N = Z$ line, which are currently under analysis, will be reported in this contribution.

References

- [1] W.R. Plaß et al., Nucl. Instrum. Methods B 317 (2013) 457.
- [2] W.R. Plaß et al., Hyperfine Interact. 240 (2019) 73.
- [3] I. Mardor et al., Phys. Rev. C 103 (2021) 034319.
- [4] C. Hornung et al., Phys. Lett. B 802 (2020) 135200.
- [5] A. Mollaebrahimi et al., arXiv:2209.13713.
- [6] M. Mougeot et al., Nature Phys. 17 (2021) 1099.
- [7] A. Spataru et al., Bulgarian Journal of Physics 48 (2021) 535.

parallel / 391

Nuclear structure of Pd isotopes via optical spectroscopy

Auteur: Sarina Geldhof¹

Co-auteurs: Alejandro Ortiz-Cortes²; Andrea Raggio³; Antoine de Roubin³; Bradley Cheal⁴; Charles S. Devlin⁴; Felix Sommer⁵; Frédéric Nowacki⁶; Hervé Savajols⁷; Iain Moore³; Ilkka Pohjalainen³; Jorge Romero⁴; Katerina Chrysalidis⁸; Laetitia Canete⁹; Lucia Caceres¹⁰; Luis Robledo¹¹; Markus Kortelainen³; Mikael Reponen³; Olga Beliuskina³; Paul Campbell¹²; Ruben de Groot¹³; Sonja Kujanpää³; Tommi Eronen³; Tomás Rodríguez¹⁴; Wouter Gins³; Zhuang Ge¹⁵; Ági Koszorús¹³

¹ GANIL

² Grand Accélérateur d' Ions Lourds (GANIL)

³ University of Jyväskylä

⁴ University of Liverpool

⁵ TU Darmstadt

⁶ Université de Strasbourg, CNRS, IPHC UMR, Strasbourg, France

⁷ GANIL/CNRS

⁸ CERN

⁹ University of Surrey

¹⁰ CEA-GANIL

¹¹ Universidad Autonoma de Madrid

¹² University of Manchester

¹³ KU Leuven

¹⁴ Technische Universität Darmstadt

¹⁵ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

Auteur correspondant sarina.geldhof@ganil.fr

High-resolution laser spectroscopy has been proven to be a powerful tool to extract nuclear structure data in an nuclear-model-independent manner. The isotope shift which can be extracted from the hyperfine spectra gives direct access to changes in mean-square charge radii, while the extracted hyperfine parameters give access to the nuclear spin, nuclear magnetic dipole moment and electric quadrupole moment. All this provides information on e.g. deformation and shape coexistence, proton-neutron pairing correlations, evolution of nuclear shells and the presence of shell closures. In recent years, measurements of nuclear ground state properties have also been proven exceptionally potent in testing state-of-the-art nuclear Density Functional Theory (DFT) and ab-initio approaches.

The Pd isotopes are located in a transitional area in between chains which display smooth parabolic trends in the changes in mean-square charge radii (Sn, In, Cd and Ag), and a region where the changes in mean-square charge radii and corresponding electric quadrupole moments show evidence of a dramatic shape change at $N=60$, maximized and centred around the yttrium system. In the transitional area between both regions however, i.e. the Tc, Ru, Rh and Pd isotopes, no optical spectroscopic information has been available for radioactive nuclei so far. This is in part due to the refractory character of these nuclei, which makes their production challenging for many facilities, but also due to their complex atomic structure.

At the IGISOL facility, these difficulties were overcome thanks to the chemically insensitive production method, and the installation of a charge-exchange cell and addition of a cw Ti:sapphire laser. Collinear laser spectroscopy was performed on unstable Pd isotopes, which are known to be deformed from decay spectroscopy studies, although there is disagreement on the origin and character of the (possible) change in deformation. The measured nuclear charge radii [1], spins and nuclear moments [2] will be presented in this contribution, and the implication on the deformation/shape of the isotopes will be discussed. In addition, the results will be compared to state-of-the-art DFT calculations using Fayans Energy Density Functionals (EDFs), and using Gogny EDF including beyond mean-field calculations within the Symmetry Conserving Configuration Mixing (SCCM) framework. As all recent benchmarks of nuclear DFT were performed on spherical systems, close to (doubly-)magic systems, this presents the first test of the performance of the Fayans functionals for well-deformed isotopes.

[1] S. Geldhof et al., Phys. Rev. Lett. 128, 152501 (2022).

[2] A. Ortiz-Cortes et al., to be submitted.

parallel / 392

Determination of fission barrier height of ^{210}Fr via neutron measurement

Auteur: Martin Veselský¹

¹ *Czech Technical University Prague*

Auteur correspondant martin.veselsky@cvut.cz

Fission of ^{210}Fr , produced by (d,p)-transfer reaction of the ^{209}Fr beam was investigated at HIE-ISOLDE. Four Timepix3 pixel detectors were installed on the body of Actar TPC demonstrator chamber. Polyethylene converters were used for the detection of fast neutrons. Since no significant background was observed, it was possible to measure the spatial distribution of emitted neutrons. Subsequent simulations employing the results of Talys code and available data on fission fragment distributions allowed to estimate directly the value of fission barrier height for neutron-deficient nucleus ^{210}Fr , which confirmed the reduction of the fission barrier compared to theoretical models by 15 - 30 % for such extremely neutron-deficient unstable nuclei.

Search for near-threshold multi-neutron resonances in (p,2p) reactions with neutron-rich nuclei at R3B

Auteurs: Nikhil Mozumdar¹; Thomas Aumann²; Olivier Sorlin³; Antoine Barrière⁴; R3B Collaboration⁵

¹ *1. Technische Universität Darmstadt Institut für Kernphysik. 2 Helmholtz Forschungsakademie Hessen für FAIR*

² *1. Technische Universität Darmstadt Institut für Kernphysik. 2. GSI Helmholtz-Zentrum für Schwerionenforschung. 3 Helmholtz Forschungsakademie Hessen für FAIR.*

³ *GANIL*

⁴ *Grand Accélérateur National d'Ions Lourds (GANIL)*

⁵ *GSI Helmholtz-Zentrum für Schwerionenforschung*

Auteur correspondant nmozumdar@ikp.tu-darmstadt.de

In order to constrain the largely unknown multi-neutron interactions, it is necessary to measure the relevant observables sensitive to them. One such property is the possible existence of narrow resonances related to multi-neutron cluster structures and correlations^{[1][2]}. This can be investigated by studying multi-neutron resonances close to the corresponding neutron removal thresholds in neutron-rich light nuclei. Progress over the recent years have presented several evidences of such narrow resonances^{[3][4][5]}, which provides an indication for the generalization of the Ikeda conjecture.

With the aim of systematically studying and characterizing such resonances, an experiment has been recently concluded at the R³B setup in GSI, within the FAIR Phase-0 program. Quasi-free scattering (*p, 2p*) reactions are studied in inverse kinematics where a radioactive ion “cocktail” beam is impinging on a 5cm LH₂ target. The resulting reaction products are measured in the state-of-the-art setup using a large combination of detector systems providing information of the full reaction kinematics. This includes in addition to detection of fragments, the detection of the γ -rays and protons in the CALIFA^[6] calorimeter. Relevant to the current work, is the neutron detector NeuLAND^[7], which thanks to its high resolution and granularity provides access to the detailed study of multi-neutron resonances.

Among the nuclei populated in this cocktail beam, of specific interest is the case of ¹⁷B populated via ¹⁸C(*p, 2p*)¹⁷B QFS reaction. This is thanks to its lower 1 neutron ($S_{1n} = 1.41$ MeV), 2 neutron ($S_{2n} = 1.33$ MeV) and 4 neutron ($S_{4n} = 5.1$ MeV) separation energies and an indication of a possible near threshold state^[8]. In this communication some of the preliminary results of the analysis will be discussed.

[1] K. Ikeda et al. Progress of theoretical physics supplement, E68(1968) 464-475.

[2] J. Okolowicz et al. Progress of theoretical physics supplement, 196(2012) 230-243

[3] T. Sugimoto et al. Phys. Lett. B, 654,(2007) 160.

[4] Y. Kondo et al. Phys. Rev. Lett., 116,(2016).

[5] A. Revel et al. Phys. Rev. Lett., 124,(2020).

[6] A. Knyazev et al. Nucl. Instr. and Meth. A, 940,(2019) 393-404.

[7] K. Boretzky et al. Nucl. Instr. and Meth. A, 1014,(2021) 165701.

[8] J. Gibelin. États résonants de noyaux loin de la stabilité. Physique Nucléaire Expérimentale. Université de Caen Normandie, 2018. <tel-01729016>

395

Spectroscopy of ¹²Be using TexAT TPC

Auteur: Michael Roosa¹

Co-auteurs: Gregory Christian ; Grigory Rogachev¹

¹ *Texas A&M University*

Auteur correspondant roosa@tamu.edu

The detailed spectroscopic data that can be extracted from single nucleon transfer reactions provide a useful experimental probe of nuclear structure. This work aims to complement existing data for the ^{12}Be system by measuring the proton removal spectroscopic factors to low-lying states in ^{12}Be with the $^{13}\text{B}(d,^3\text{He})^{12}\text{Be}$ reaction in inverse kinematics. This experiment was done at the Texas A&M University Cyclotron Institute (TAMU-CI) where a ^{13}B beam was delivered to the TEXas Active Target (TexAT) Time Projection Chamber (TPC) filled with CD_4 gas. By reconstructing reaction vertices and tracks in TexAT, differential cross sections and thus spectroscopic data can be extracted. Experimental details and preliminary results will be discussed.

plenary / 397

Highlights of GANIL-SPIRAL2 facilities

Auteur: Patricia Roussel-Chomaz¹

¹ CEA

The SPIRAL2 Phase 1 LINAC moved from project status to full operation on December 31st 2021, after the important milestone of acceleration of 45 μA deuteron beam at 40 MeV. Beams of protons and alpha particles were also accelerated. These beams were sent to the Neutron For Science (NFS) experimental cave. Two NFS campaigns have been performed with neutron beams in Fall 2021 and 2022. The S3 spectrometer installation is progressing well and the commissioning should start at the end of 2024. The first heavy ion beams were already accelerated by the LINAC with the dedicated ion source, to prepare for the S3 physics program. The presentation will give an overview on these different achievements together with an update of the DESIR project status. The new project NEWGAIN will also be presented. It will increase the capabilities of SPIRAL2 LINAC with the construction of a second injector able to produce and accelerate ion beams with mass to charge-state ratios ranging from $A/q=3$ up to $A/q=7$. This second injector will be designed to be fully compatible with the existing facility and to further enhance its ‘multi-user’ capabilities.

In parallel to SPIRAL2 developments, a refurbishing program of the GANIL cyclotrons is being planned. New beams are under development with SPIRAL1 target-ion sources. Selected results will be presented, together with the vision for the medium and long term plans.

plenary / 398

Axial Shape Asymmetry and Configuration Coexistence in Neutron-Rich ^{74}Zn

Auteur: Marco Rocchini¹

¹ INFN - Firenze division

Auteur correspondant marco.rocchini@fi.infn.it

Results from recent experiments studying nuclei in the ^{78}Ni region suggest that the $N = 50$ shell closure persists, in agreement with state-of-the-art shell model calculations. However, how collectivity manifests and evolves in this region of the Segrè chart is still an open question, particularly concerning phenomena such as vibrational modes, triaxiality and shape coexistence. This is especially true in the Zn isotopic chain in the neutron-rich region, in which even definitive spin assignments are unavailable except for the very low-lying states.

In this talk, I will present the results of a recent experiment performed at the TRIUMF laboratory (Vancouver, Canada) using the GRIFFIN γ -ray spectrometer. The excited states of ^{74}Zn were investigated via γ -ray spectroscopy following ^{74}Cu β -decay. By exploiting γ - γ angular correlation analysis, the 2_2^+ , 3_1^+ , 0_2^+ and 2_3^+ states in ^{74}Zn were firmly identified. The γ -ray branching and $E2/M1$

mixing ratios for transitions de-exciting the 2_2^+ , 3_1^+ and 2_3^+ states were measured, allowing for the extraction of relative $B(E2)$ values. In particular, the $2_3^+ \rightarrow 0_2^+$ and $2_3^+ \rightarrow 4_1^+$ transitions were observed for the first time. The levels observed were organized into rotational-like bands and the results were compared with large-scale shell-model calculations from which the shapes of individual states were determined. Enhanced axial shape asymmetry (triaxiality) is suggested to characterize ^{74}Zn in its ground state. Furthermore, an excited $K = 0$ band with a different shape is identified. A shore of the $N = 40$ island of inversion appears to manifest above $Z = 28$, previously thought as its northern limit in the nuclide chart.

402

Study of $^{70,72}\text{Se}$ nuclear shapes with SPICE and TIGRESS

Auteur: James Smallcombe¹

Co-auteurs: Adam Garnsworthy²; Purnima Singh³; Wolfram KORTEN⁴

¹ *Japan Atomic Energy Agency*

² *TRIUMF*

³ *IRFU, CEA, Université Paris-Saclay*

⁴ *CEA Paris-Saclay*

Auteur correspondant smallcombe.james@jaea.go.jp

The phenomenon of shape coexistence is prevalent in the $Z \sim 34$ region, with isotopes of neutron-deficient even Ge, Se and Kr each exhibiting the characteristic low-lying coexisting 0^+ bands which display quadrupole deformation different to that of the ground states. In the selenium isotopes, $^{72-78}\text{Se}$ seem to show a prolate ground structure with shape coexisting oblate excitation, while in ^{68}Se the oblate structure appears to have become the ground state. The exact nature of the low-lying structure ^{70}Se and any shape coexistence remains uncertain.

Combining the Spectrometer for Internal Conversion Electrons (SPICE) with the TIGRESS HPGe Array, a full electron and gamma-ray experimental study of $^{70,72}\text{Se}$ was undertaken at the TRIUMF ISAC-II facility to unveil the low-lying structure of these nuclei. Details of the device and experiment will be presented, alongside the experimental results and possible structural interpretations for both isotopes.

403

β -decay spectroscopy of ^{28}S

Auteurs: Xinxing Xu¹; Yufeng GAO²

¹ *The Institute of Modern Physics*

² *Institute of Modern Physics, CAS*

Auteur correspondant gaoyf0923@impcas.ac.cn

As a member of the $T_z = -2$ family, ^{28}S is a nucleus rather light near the proton drip line, and has high β -delayed proton (βp) branching ratio. Precise β -decay spectroscopy of proton-rich nucleus ^{28}S serves as a powerful tool to study the isospin symmetry breaking [1], and to test the unitarity of CKM matrix through the superallowed Fermi transition between isobaric analog states [2, 3]. Nevertheless, only one experimental study was previously published by Pougheon et al. without detecting γ rays in 1989 [4]. The present work was conducted at the Heavy Ion Research Facility in Lanzhou (HIRFL) in Lanzhou. The interested nucleus ^{28}S was produced through projectile fragmentation (PF) method where $^{32}\text{S}^{16+}$ beam (about 80 MeV/u) bombarded ^9Be target, and subsequently implanted into a detector system [5] composed of double-sided silicon strip detectors (DSSD), quadrant silicon detectors (QSD), and clover-type high-purity germanium detectors. Based on this detector system,

our team has achieved excellent results for ^{22}Si [6], ^{26}P [7, 8], and ^{27}S [9] in recent years. By measuring p and γ following β decay, the half-life and energy with higher accuracy were obtained. Different decay channels were clearly identified through the coincidence method to construct complete decay scheme, and the results were consistent with shell model calculations. The mirror nuclei ^{28}S - ^{28}Mg [10] was also studied, which gave no evidence for existence of isospin symmetry breaking. Moreover, the correction terms proposed in [3] are to be given to deduce V_{ud} (the element describing the trend of flavor change between up and down quark of CKM matrix) with theoretical calculations.

- [1] B. Blank, and M. Borge. *Progress in Particle & Nuclear Physics*, 2008. 60(2): p. 403-483.
- [2] M. Bhattacharya, D. Melconian, A. Komives, et al.. *Physical Review C*, 77(2008)065503.
- [3] J. C. Hardy and I. S. Towner. *Physical Review C*, 102(2020)045501.
- [4] F. Pougheon, V. Borrel, J. Jacmar, et al.. *Nuclear Physics A*, 500(1989)287-300.
- [5] L. J. Sun, X. X. Xu, C. J. Lin, et al.. *Physical Review C*, 99(2019)064312.
- [6] J. Lee, X. X. Xu, K. Kaneko, et al.. *Physical Review Letters*, 125(2020)192503.
- [7] P. F. Liang, L. J. Sun, J. Lee, et al.. *Physical Review C*, 101(2020)024305.
- [8] J. J. Liu, X. X. Xu, L. J. Sun, et al.. *Physical Review Letters*, 24(2022)242502.
- [9] L. J. Sun, X. X. Xu, S. Q. Hou, et al.. *Physics Letters B*, 802(2020)135213.
- [10] D. E. Alburger, and E. K. Warburton. *Physical Review C*, 20(1979): 793-798.

parallel / 405

The ISOLDE RILIS at 30

Auteur: Katerina Chrysalidis¹

Co-auteurs: Asar Jaradat ¹; Bruce Marsh ¹; Cyril Bernerd ²; Ralitsa Mancheva ¹; Reinhard Heinke ¹; Valentin Fedosseev ³

¹ CERN

² CERN, Meyrin, Switzerland & KU Leuven, Institute for Nuclear and Radiation Physics, Heverlee, Belgium

³ CERN, Meyrin, Switzerland

Auteur correspondant katerina.chrysalidis@cern.ch

The Resonance Ionization Laser Ion Source (RILIS) has been the principal ion source at ISOLDE for the majority of the past three decades. Unmatched selectivity, coupled to high efficiency, has been the main reason for RILIS being requested in more than half of the proposals submitted for review to the ISOLDE scientific committee (INTC). What started as a home-made system of 3 tunable dye lasers pumped by a single Copper vapor laser system with a Master oscillator/ Power amplifier configuration has now become a suite of state-of-the-art collection of >13 lasers: Ti:Sapphire and commercial dye lasers pumped by industrial solid state lasers. Over 35 chemical elements have been ionised within a variety of specially-designed laser ion source configurations and simultaneous operation at both ISOLDE front-ends is possible.

I will talk about the changes made over the past years to get to the modern RILIS system we use today and deliver a performance review. In addition I will give a summary of ongoing developments and how they might improve RILIS efficiency, applicability and selectivity further. I will conclude by presenting the work towards making RILIS a viable option for high-resolution laser spectroscopy, future-proofing the highly sensitive in-source laser spectroscopy method at ISOLDE.

parallel / 407

Measurement of reaction cross section for ^{17}F with a solid hydrogen target

Auteur: Tetsuaki Moriguchi¹

¹ Univ. of Tsukuba

Auteur correspondant moriguchi@tac.tsukuba.ac.jp

T. Moriguchi¹, R. Kagesawa¹, A. Ozawa¹, W. Horiuchi², Y. Abe³, M. Amano¹, D. Kamioka¹, A. Kitagawa⁴, M. Mukai³, D. Nagae⁵, M. Sakaue⁶, S. Sato⁴, B. H. Sun⁷, S. Suzuki⁸, T. Suzuki⁶, T. Yamaguchi⁶, A. Yano¹, K. Yokota⁶

¹University of Tsukuba, ²Osaka Metropolitan University, ³RIKEN Nishina Center, ⁴National Institutes for Quantum Science and Technology, ⁵Tokyo Institute of Technology, ⁶Saitama University, ⁷Beihang University, ⁸Japan Synchrotron Radiation Research Institute

Measurement of reaction cross section (σ_R) is an effective method for investigations of nuclear size properties such as radii and density distributions. In particular, σ_R on a proton target has the possibility to extract the proton and neutron density distributions separately because of the asymmetry of the nucleon–nucleon total cross sections. However, only a few experimental σ_R for unstable nuclei on a proton target are reported at this time. It is important to understand collisions between unstable nuclei and a proton from both experimental and theoretical sides. In this study, we measured σ_R for ^{17}F , which is the proton drip-line nucleus of fluorine isotopes, with a solid hydrogen target (SHT) in a wide energy range. So far, the existence of the proton skin in the ground state of ^{17}F has been discussed because of the small one-proton separation energy ($S_p=0.6$ MeV), but the skin thickness of ^{17}F is not reported yet experimentally. Experiment has been performed in the Heavy Ion Medical Accelerator in Chiba (HIMAC). Our SHT was developed for σ_R measurements, and its effective area and maximum thickness are $\phi 50$ mm and 100 mm, respectively. From the present experiment, we found that σ_R 's for ^{17}F on a proton target are almost the same as those of ^{17}Ne , which is known to be a two-proton halo nucleus. These experimental results are very interesting because, in the case of proton-rich nuclei, the decrease of σ_R on a proton target was reported theoretically despite the increase of the root-mean-square matter radius towards the proton dripline. In this presentation, we will explain the details of the experiment, and discuss the energy dependence of σ_R for ^{17}F on a proton target with the Glauber model calculation.

413

Extracting β -decay strengths from ^{73}Co using the Summing NaI (SuN) Total Absorption Spectrometer

Auteur: Mejd J. Mogannam¹

Co-auteurs: Aaron Chester²; Adriana Sweet³; Alex Dombos⁴; Alyssa Palmisano⁵; Andrea Richard⁶; Ann-Cecilie Larsen⁷; Anna Simon-Robertson⁸; Artemis Spyrou⁹; Benjamin Crider¹⁰; Caley Harris⁹; Darren Bleuel¹¹; Debra Richman¹²; Katie Childers¹³; Magne Guttormsen⁷; Mallory K. Smith¹⁴; Nicholas D. Scielzo¹¹; R. G. T. Zegers¹⁵; Rebecca Lewis¹⁶; Sean Liddick¹⁷; Stephanie Lyons¹⁸

¹ Department of Chemistry, Michigan State University (MSU)/Facility for Rare Isotope Beams

² Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA

³ Lawrence Livermore National Laboratory (LLNL)

⁴ Department of Physics, University of Notre Dame

⁵ University of Tennessee Knoxville

⁶ National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA

⁷ University of Oslo

⁸ University of Notre Dame

⁹ Michigan State University

¹⁰ Department of Physics and Astronomy, Mississippi State University, Mississippi State, Mississippi 39762, USA

¹¹ Lawrence Livermore National Laboratory

¹² Michigan State University (MSU)

¹³ Nevada National Security Site

¹⁴ Facility for Rare Isotope Beams

¹⁵ Facility for Rare Isotope Beams & Department of Physics and Astronomy, Michigan State University

¹⁶ Zeno Power

¹⁷ *Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA. Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA*

¹⁸ *Pacific Northwest National Laboratory*

Auteur correspondant mogannam@frib.msu.edu

Knowledge of the β -decay properties of neutron-rich isotopes far from stability is critical for improving stellar nucleosynthesis and β -decay models, as well as structural information. Calculations of the abundance of elements produced via the rapid neutron capture process (r- process) require information such as β -decay rates and β -delayed neutron emission probabilities. β -feeding intensities are used to calculate β -decay strengths, which can be compared to theoretical Gamow-Teller strength (B(GT)) values to rigorously test and validate models of β - decay far beyond stability. One method used to obtain β -feeding intensities is Total Absorption Spectroscopy (TAS), which requires the use of a dedicated detector such as the Summing NaI (SuN) detector [1] based at FRIB/MSU. In this presentation, the TAS analysis of ^{73}Co will be presented. Ions of ^{73}Co were implanted into a DSSD whereby the subsequent β -decay electrons were detected in conjunction with the β -delayed γ -rays detected in SuN. β -feeding intensities are determined from a chi2 analysis between the experimental data from SuN and simulated data using a combination of the RAINIER and Geant4 software packages. This information will be compared with theory as well as the results of neighboring isotopes that have been previously studied using the same experimental setup for systematic comparison of β -decay properties across the $Z = 28$ shell closure [2-3].

[1] A. Simon, et al. NIM Phys. Res. A 703, 16 (2013)

[2] S. Lyons, et al. Physical Review C 100.2 (2019): 025806

[3] A. Spyrou, et al. Physical Review Letters 117.14 (2016): 142701

plenary / 415

Study of the Pygmy Dipole Resonance using neutron inelastic scattering at GANIL-SPIRAL2/NFS

Auteur: Marine Vandebrouck¹

Co-auteurs: ANNA CORSI ²; Adam Maj ³; Antoine Bogenschutz ⁴; Christophe THEISEN ⁵; Damien THISSE ⁶; Daniel Cano Ott ⁷; David Etasse ⁸; Diane Doré ⁹; Didier Beaumel ¹⁰; Diego Ramos ¹¹; Emmanuel Rey-herme ¹²; Eric Berthoumieux ¹³; Fabio Crespi ¹⁴; Frank Gunsing ¹⁵; Guillem Tocabens ¹⁶; Iolanda MATEA ¹⁰; Jeremie Dudouet ¹⁷; Julien Gibelin ¹⁸; Lama Al Ayoubi ¹⁹; Loïc THULLIEZ ¹²; Lynda Achouri ⁸; Marc Dupuis ⁶; Marek Lewitowicz ¹¹; Maria Kmiecik ²⁰; Marion MacCormick ²¹; Matthieu Lebois ²²; Michał Ciemala ²³; Mihai Stanoui ²⁴; Muhsin N. Harakeh ²⁵; Olivier DORVAUX ²⁶; Olivier Stezowski ¹⁷; Périne Miriot-Jaubert ⁴; Sophie PERU ⁶; Stefana Calinescu ²⁴; Trino Martinez ⁷; Valérie Lapoux ¹; Wenling Dong ²⁷; Xavier Ledoux ¹¹; Yasmine Demane ²⁸; Yorick Blumenfeld ¹⁶; anne-marie frelin ¹¹; christelle schmitt ²⁹

¹ CEA Saclay DPhN

² CEA Saclay

³ IFJ PAN

⁴ CEA Irfu/DPhN

⁵ CEA SACLAY

⁶ CEA

⁷ CIEMAT

⁸ LPC Caen

⁹ CEA/Saclay, IRFU/Service de Physique Nucléaire

¹⁰ IPN Orsay

¹¹ GANIL

¹² CEA-Saclay

¹³ CEA Irfu, Université Paris Saclay

¹⁴ University of Milan - INFN

¹⁵ CEA Saclay, Irfu/DPhN¹⁶ IPNO¹⁷ IP2I¹⁸ LPC CAEN/Université de Caen¹⁹ University of Jyväskylä / University of Paris Saclay²⁰ IFJ PAN Krakow²¹ CNRS-IJCLab²² Institut de Physique Nucléaire d'Orsay²³ IFJ PAN Kraków, Polska²⁴ IFIN-HH²⁵ GSI/KVI²⁶ IPHC-DRS/University of Strasbourg²⁷ IJCLab²⁸ IP2I of Lyon²⁹ IPHC Strasbourg**Auteur correspondant** marine.vandebrouck@cea.fr

The pygmy dipole resonance (PDR) is a vibrational mode described as the oscillation of a neutron skin against a core symmetric in number of protons and neutrons. The PDR has been the subject of many studies, both experimental and theoretical [1,2]. Indeed, the study of the PDR has been and still is of great interest since it allows to constrain the symmetry energy, an important ingredient of the equation of state of nuclear matter that describes the matter within neutron stars [3]. Moreover, the PDR is predicted to play a key role in the r-process via the increase of the neutron capture rate [4]. However, despite numerous experiments dedicated to the study of the PDR, a consistent description could not be extracted. In this context, we propose to study the PDR using a new probe: the neutron inelastic scattering reaction ($n, n' \gamma$).

An experiment to study the pygmy resonance in ^{140}Ce using the ($n, n' \gamma$) reaction has just been carried out. This experiment has been made possible thanks to the high-intensity proton beam of the new accelerator SPIRAL2 at GANIL and the NFS (Neutron For Science) facility. The experimental setup consisting of the new generation multi-detectors PARIS [5], for the detection of gammas coming from the de-excitation of the PDR, and MONSTER [6], for the detection of scattered neutrons, was used.

[1] D. Savran, T. Aumann, A. Zilges, Prog. Part. Nucl. Phys. 70, 210-245 (2013)

[2] A. Bracco, E.G. Lanza, A. Tamii, Prog. Part. Nucl. Phys. 106, 360-433 (2019)

[3] A. Carbone et al., Phys. Rev. C 81, 041301(R) (2010)

[4] S. Goriely, E. Khan, M. Samyn, Nucl. Phys. A 739, 331-352 (2004)

[5] A. Maj et al., Acta Phys. Pol. B40, 565 (2009)

[6] A. R. Garcia et al., JINST 7, C05012 (2012)

plenary / 416

What are the fingerprints of nucleosynthesis?

Auteur: Wei Jia Ong¹¹ Lawrence Livermore National Laboratory**Auteur correspondant** ong10@llnl.gov

Disentangling the different components and astrophysical sites of various nucleosynthesis processes is challenging for many reasons. Observations of metal-poor stars currently provide some of the cleanest signatures of the rapid neutron-capture process (r-process) but are sparse. Isotopic analyses of presolar grains originating from Asymptotic Giant Branch (AGB) stars give strong insight into the slow neutron-capture process (s-process) but rely on assumptions that the grains are unaltered

between formation and laboratory analysis. To correctly interpret such observations, the nuclear physics in nucleosynthesis models need to be accurate and of high enough precision. Currently the characteristic fingerprints of different processes only loosely constrain the astrophysical conditions under which the elements form. In the recent past, significant advancements in constraining the nuclear physics uncertainties, together with increased availability of ‘ground-truth’ data have improved our understanding of how the elements are made in the cosmos.

parallel / 419

Harvesting Hf-172 from heavy-ion beam irradiated tungsten beam-blocker for generating Lu-172

Auteur: Samridhi Satija¹

Co-auteurs: Chirag Vyas²; Chloe Kleinfeldt¹; Greg Severin¹; Jose Blanco¹; Katharina Domnanich²; Scott Essenschacher¹; Vlad Bodnar¹

¹ Michigan State University/Facility for Rare Isotope Beams

² Facility for Rare Isotope Beams

Auteur correspondant satija@frib.msu.edu

During the routine operation of radioactive heavy-ion beam facilities, tremendous quantities of radioisotopes get deposited or produced at multiple sites throughout the accelerator parts and beam-line components. This presents an opportunity to harvest the long-lived radioisotopes that have wide ranging applications once these components and parts are decommissioned and often, considerable activities will have built up by then. One such decommissioned component from the National Superconducting Cyclotron Laboratory (NSCL) was the tungsten beam-blocker that acted as the beam-dump for the primary heavy-ion beams while NSCL was in operation. This work elucidates the radioanalytical separation techniques and methodologies used in the extraction and purification of Hf-172 from the tungsten beam-blocker and the other co-embedded radionuclides such as Lu-173, Lu-172, Na-22, Co-56, Co-57, Co-58, Co-60 amongst others. The harvested Hf-172 was used for generating Lu-172 employing the use of an extraction chromatographic resin and radiolabeling studies were carried out with the generated Lu-172.

420

Strongly isospin-mixed doublet in ²⁶Si observed by β decay of ²⁶P

Auteurs: Jiajian Liu¹; Xinxing Xu²; Lijie Sun³; Cenxi Yuan⁴; Kazunari Kaneko⁵; Yang Sun⁶; Pengfei Liang⁷

¹ Institute of Modern Physics

² The Institute of Modern Physics

³ Shanghai Jiao Tong University

⁴ Sun Yat-Sen University

⁵ Kyushu Sangyo University

⁶ Shanghai Jiaotong University

⁷ University of Hong Kong

Auteur correspondant liujj@impcas.ac.cn

In 1932, W. Heisenberg proposed the concept of isospin to interpret the symmetry in atomic nuclei based on nearly identical properties between protons and neutrons with respect to strong interaction [1]. However, due to proton-neutron mass difference, Coulomb interaction, and charge-dependent parts of nuclear force, isospin is not strictly symmetric. Such asymmetry leads to Fermi strength

fragmented between the isobaric analog state (IAS) and its neighboring states via strong isospin mixing, instead of being contributed into only one state. Probing isospin mixing has gained considerable traction in β -decay studies.

We have performed the β -decay experiment of ^{26}P [2] at the Heavy Ion Research Facility in Lanzhou (HIRFL), using double-sided silicon strip detectors operating in conjunction with high-purity germanium detectors [2,3,4,5]. The IAS at 13055 keV and two new high-lying states at 13380 and 11912 keV in ^{26}Si were determined via β -delayed two-proton emission of ^{26}P . The abnormal $\log ft$ values of IAS and 13380-keV state indicate a strong isospin mixing between these two states. The isospin mixing matrix element is determined to be 130(21) keV, representing the strongest mixing ever observed in β -decay experiments [6].

[1] W. Heisenberg, *Z. Phys.* 77, 1 (1932).

[2] P. F. Liang, et al. (RIBLL collaboration), *Phys. Rev. C* 101, 024305 (2020).

[3] L. J. Sun, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* 804, 1 (2015).

[4] L. J. Sun, et al. (RIBLL Collaboration), *Phys. Rev. C* 99, 064312 (2019)

[5] G. Z. Shi, et al., *Phys. Rev. C* 103, L061301 (2021).

[6] J. J. Liu, et al. (RIBLL collaboration), *Phys. Rev. Lett.* 129, 242502 (2022).

422

The NEXT setup to study Neutron-rich EXotic nuclei produced in multinucleon Transfer reactions

Auteur: Julia Even¹

Co-auteurs: Arif Soylu¹; Briain D. Hartigan¹; Frank Wienholtz²; Jan Sarén³; Jennifer Brigitte Cipagauta Mora¹; Juha Uusitalo³; Lutz Schweikhard⁴; Marko Brajkovic¹; Moritz Schlaich²; Nathanael N. Moorrees⁵; Paul Fischer⁴; Xiangcheng Chen¹

¹ *University of Groningen*

² *Technical University Darmstadt*

³ *University of Jyväskylä*

⁴ *University Greifswald*

⁵ *UMC Groningen*

Auteur correspondant j.even@rug.nl

Neutron-rich, heavy, EXotic nuclei around the neutron shell closure at $N=126$ and in the transfermium region are accessible via multinucleon Transfer reactions which feature relatively high cross sections. However, the wide angular distributions of the multinucleon transfer products lead to experimental challenges in their separation and identification.

In order to overcome these obstacles, we are building the NEXT experiment [1] at the PARTREC facility in Groningen. The AGOR cyclotron at PARTREC delivers high intense heavy ion beams at energies suited for transfer reactions. The production target for the transfer reactions is placed inside a 3-T solenoid magnet with The bore of 157-cm length and 86-cm width. Within this volume the transfer products are separated according to their magnetic rigidities. The ions of interest are focused by the magnet towards a gas catcher where they are slowed down. From the gas catcher the ions are transferred and bunched by a newly developed stacked-ring ion guide [2] into a Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) [3]. The MR-ToF MS allows for precision mass measurements and provides isobaric separation. Thus, background free spectroscopy will be feasible.

In the contribution, we will present an overview of the NEXT setup, its current status and the planned experimental program.

[1] J. Even, X. Chen, A. Soylu, P. Fischer, A. Karpov, V. Saiko, J. Saren, M. Schlaich, T. Schlathölder, L. Schweikhard, J. Uusitalo, and F. Wienholtz, *The NEXT Project: Towards Production and Investigation of Neutron-Rich Heavy Nuclides*, *Atoms* 10, 59 (2022).

[2] X. Chen, J. Even, P. Fischer, M. Schlaich, T. Schlathölder, L. Schweikhard, and A. Soylu, *Stacked-Ring Ion Guide for Cooling and Bunching Rare Isotopes*, *Int. J. Mass Spectrom.* 477, 116856 (2022).

[3] M. Schlaich, Development and Characterization of a Multi-Reflection Time-of-Flight Mass Spectrometer for the Offline Ion Source of PUMA, Master's thesis, Technische Universität Darmstadt, (2021).

423

Hyperfine structure and isotope shift in the atomic spectrum of neptunium

Auteurs: Dominik Studer¹; Felix Berg¹; Felix Weber¹; Klaus Wendt¹; Korbinian Hens²; Magdalena Kaja¹; Matou Stemmler¹; Mitzi Urquiza-González²; Tobias Reich¹

¹ Johannes Gutenberg University, 55099 Mainz, Germany

² Hübner GmbH & Co. KG, Kassel, Germany

Auteur correspondant mkaja@uni-mainz.de

Neptunium, with atomic number 93, is a radioactive actinide and the first transuranic element. In particular, the isotope ^{237}Np is generated quantitatively within the nuclear fuel cycle with typical amounts of ~ 10 kg in each conventional pressurized water reactor per year [1]. Due to its long half-life of $2.1 \cdot 10^6$ years and high radiotoxicity in the up to 12 subsequent decays along the neptunium series, it represents a major hazard in the final disposal of nuclear waste. Under environmental conditions, Np can be present in four different oxidation states +III to +VI, and can form soluble species. In this context ultra-trace analysis of Np in environmental samples is of high relevance [2]. The development of efficient and selective non-radiometric determination methods using laser mass spectrometry relies on the identification of ionization schemes and detailed atomic spectroscopy [3]. For example, for quantitative isotope ratio determination by resonance ionization mass spectroscopy (RIMS), it is important to take into account the isotope-related effects stemming from hyperfine structures (HFS) and isotope shift (IS). For this purpose, new two-step excitation schemes were investigated for their suitability for neptunium analytics.

Narrow bandwidth spectroscopy on ^{237}Np and ^{239}Np was carried out at the high transmission mass separator RISIKO using the PI-LIST laser ion source geometry [4]. Optical transitions were studied using a cw Ti:sapphire laser system [5] for seeding and injection locking of a pulsed Ti:sapphire amplifier [6]. The injection-seeded Ti:sapphire laser has a spectral bandwidth of 20 MHz, providing pulsed operation at a repetition rate of 10 kHz and high-power density as required with 150 mW average power after frequency doubling.

The HFS of the atomic ground-state transitions to the levels at $25\,075.15\text{ cm}^{-1}$ ($J = 13/2$) and at $25\,277.63\text{ cm}^{-1}$ ($J = 9/2$) have been measured and hyperfine coupling constants for both isotopes, as well as the isotope shifts between ^{237}Np and ^{239}Np have been determined. Additionally, the HFS of the atomic transition between the atomic ground state, as well as the thermally excited state at $2\,033.94\text{ cm}^{-1}$ and the level at $25\,342.55\text{ cm}^{-1}$ ($J=11/2$), has been measured for ^{237}Np . Experiment and data are discussed in the framework of the analysis of the atomic structure of the lighter actinide elements.

[1] Krachler, M; Alvarez-Sarandes, R; et. al.; Microchem. J., 117, 225-232, (2014)

[2] Raeder, S; Stoebener, N; et al.; Spectrochim. Acta B, 66, 242 - 247, (2011)

[3] Bosco, H; Hamann, L; et al.; Sci. Adv., 7, 44, (2021)

[4] Heinke, R; Kron, T; et al.; Hyperfine Interact 238, 6 (2017)

[5] Sonnenschein, V; Tomita, H; et al.; Hyperfine Interact 241, 32 (2020)

[6] Sonnenschein, V; Moore I D; et al.; Laser Phys. 27, 8 (2017)

425

Development of a Thick Solid Deuterium Target

Auteur: Asahi Yano¹

¹ *Institute of Physics, University of Tsukuba*

Auteur correspondant s2120190@s.tsukuba.ac.jp

A. Yano¹, T. Moriguchi¹, A. Ozawa¹, S. Ishimoto^{2,3}, M. Fukuda⁴, M. Mihara⁴, M. Tanaka³, D. Nishimura⁵, T. Yamaguchi⁶, T. Suzuki⁶, T. Izumikawa⁷, T. Ohtsubo⁸, S. Sato⁹, S. Fukuda⁹, A. Kitagawa⁹, M. Fukutome⁴, F. Hayashi⁴, Y. Honda⁴, N. Kaname¹, M. Kanda⁶, Y. Kimura⁴, N. Noguchi⁸, H. Seki⁶, N. Shinozaki⁶, S. Sugawara⁵, R. Taguchi⁴, H. Takahashi⁵, G. Takayama⁴ and C. Une⁵

¹ Institute of Physics, University of Tsukuba

² High Energy Accelerator Research Organization

³ RIKEN Nishina Center

⁴ Department of Physics, Osaka University

⁵ Department of Natural Sciences, Tokyo City University

⁶ Department of Physics, Saitama University

⁷ Institute for Research Promotion, Niigata University

⁸ Institute of Science and Technology, Niigata University

⁹ National Institutes for Quantum Science and Technology

Deducing the neutron skin thicknesses of atomic nuclei is important for studies of the equation of state of neutron matter.

A recent theoretical work suggested that the measurements of the reaction cross sections (σ_R 's) with proton and deuteron targets can be used for determining the skin thickness accurately [1]. In this study, we developed a thick solid deuterium target (SDT) based on a thick solid hydrogen target (SHT) for σ_R measurements [2]. The utilization of a thicker target in RI beam experiments provides a statistical advantage, and the employment of solidified deuterium further enhances the statistics due to its higher density.

The SDT fabrication system is almost same as the SHT one [2]. In order to make thick SDT, it was necessary to optimize two key fabrication conditions. Initially, we systematically varied the temperature of the target cell to determine the optimum. Once the optimal temperature was established, the gas supply pressure was altered to further fine optimization. Through these optimizations, we succeeded in fabricating SDT with a diameter of 50 mm and a thickness of 50 mm with few voids without cracks. Subsequently, we performed an irradiation test of SDT using a ¹⁸O beam with an energy of 250 MeV/nucleon at the Heavy Ion Medical Accelerator in Chiba to investigate the uniformity of solidification. From this test, it was found that there were no significant density defects inside SDT.

In this presentation, I will describe in detail on the SDT fabrication system and the irradiation test.

[1] W. Horiuchi et al., PRC 102 (2020) 054601.

[2] T. Moriguchi et al., NIMA 624-1 (2010) 27.

parallel / 426

Developments in muonic x-ray spectroscopy

Auteur: Michael Heines¹

Co-auteurs: Andreas Knecht²; Frederik Wauters³; Katharina von Schoeler⁴; Nilesh Deokar³; Randolph Pohl³; Silvia Bara¹; Stergiani Marina Vogiatzi⁴; Thomas Elias Cocolios¹

¹ *IKS, KU Leuven, Belgium*

² *Paul Scherrer Institute*

³ *Johannes Gutenberg-Universität Mainz*

⁴ *ETH Zürich*

Auteur correspondant michael.heines@kuleuven.be

Muonic x-ray spectroscopy is a technique that utilizes the properties of the muon to obtain information about the structure of the atom and the nucleus. When a muon interacts with an atom, it can

be captured in a high principal atomic quantum number state, after which it will fall towards the ground state emitting high energy characteristic x rays. Due to the heavy mass of muons compared to that of electrons ($m_\mu \approx 207m_e$, the muon's orbitals are closer to the nucleus with that same factor. Hence, the muonic energy levels are more sensitive to nuclear effects. In particular, the finite size correction is increased by a factor close to 10^7 . Consequently, muonic x rays can provide valuable input for laser spectroscopy in the form of high-precision absolute charge radii (10^{-3} relative precision).

While muonic x rays have been extensively studied at the end of the twentieth century, it was limited to target quantities above 10 mg. However, in 2017, our collaboration investigated the use of a high-pressure hydrogen cell with a small deuterium admixture in order to enhance the transfer of the muon to the target atom of interest [1]. With this advancement, measurements on targets of ~ 5 μg became possible, opening the door to long-lived radioactive isotopes (>20 years) [2]. At low-to-medium atomic numbers, a high isotopic purity is required in order to reliably extract the nuclear charge radius. This purity can only be obtained by using magnetic mass separation for certain isotopes. Therefore, we investigated the feasibility of using implanted targets during a beamtime in September 2022. Besides measurements on implanted targets, the attenuation of the muonic x-ray signal through graphite was quantified. These advancements will allow for absolute charge radii measurements of medium-Z elements that are not available in sufficiently large quantities and/or isotopic purity.

In this contribution, we will report on the recent advancements of the muX collaboration as well as their implications for future research.

[1] Knecht, Andreas, Alexander Skawran, and Stergiani Marina Vogiatzi. "Study of nuclear properties with muonic atoms." *The European Physical Journal Plus* 135.10 (2020): 1-18.

[2] Adamczak, A., et al. "Muonic atom spectroscopy with microgram target material." *EPJA* in print (2023).

427

Cluster structure of neutron-rich beryllium isotopes probed by cluster knockout reactions in inverse kinematics

Auteurs: Pengjie Li¹; Didier Beaumel²; Jenny Lee³

¹ *Institute of Modern Physics, China*

² *IJC lab*

³ *HKU*

Auteur correspondant lipengjie@impcas.ac.cn

The emergence of cluster structures within the nucleus is a fascinating phenomenon that requires a complete understanding of the nuclear structure and the fundamental nuclear interactions. So far α -clustering has dominated cluster state studies among all other possible partitioning due to the large binding energy of the α -particle and its inert character. The famous Ikeda diagram conveyed the idea that cluster states appear near α threshold in stable $N=Z$ nuclei [1]. However, clustering in the ground-state of exotic nuclei with large imbalance of proton and neutron number is still a question. Neutron-rich beryllium isotopes ^{10}Be , ^{12}Be , ^{14}Be are the very appealing candidates of clustering studies as being built on the well-developed alpha-alpha rotor of ^8Be ($N=4$, $Z=4$). It is predicted by calculations in antisymmetrized molecular dynamics model that alpha clustering in the ground-state develops from ^{10}Be going to the dripline [2].

The SAMURAI-12 experiment performed at the Radioactive Isotope Beam Factory (RIBF) in RIKEN aims to investigate the cluster structure of neutron-rich beryllium isotopes using the cluster quasifree scattering reaction ($p,p\alpha$) in inverse kinematics. The reaction of interest was induced by radioactive $^{10,12,14}\text{Be}$ beams at 150 MeV/u impinging on a 2-mm-thick pure solid hydrogen target. Recoil protons were detected using the Recoil Proton Spectrometer (drift chamber, plastic scintillator, and NaI(Tl) rods) in a two-arm configuration, covering an angular range of 50° - 70° . Two telescopes composed of silicon strip detectors and CsI(Tl) modules were placed at forward angles for detecting alpha

clusters. The detection of helium residues was performed by using the SAMURAI spectrometer and its standard detectors. Experimental results concerning missing mass spectra and triple differential cross-sections will be presented. The latter will be compared to calculations using a microscopic description of the reactions of interest implemented in the distorted wave impulse approximation, allowing to probe the alpha cluster structures directly and quantitatively.

- [1] K. Ikeda, N. Takigawa, and H. Horiuchi, *Prog. Theor. Phys. Suppl. Extra Number*, 464 (1968).
 [2] Y. Kanada-En'yo and H. Horiuchi, *Phys. Rev. C* 68, 014319 (2003).

parallel / 428

Spectroscopy of heavy neutron-rich $N > 126$ nuclei at RIKEN

Auteurs: Anabel Morales López¹; Jin Wu²; Jose L. Tain³; Lewis Sexton⁴; Naoki FUKUDA⁵; Oscar Hall⁶; Shunji Nishimura⁵; Tik Tsun Yeung⁵; Tom Davinson⁴; Vi Ho Phong^{None}

¹ IFIC (CSIC-UV)

² Brookhaven National Lab

³ Instituto de Fisica Corpuscular

⁴ U. Edimburgh

⁵ RIKEN Nishina Center

⁶ University of Edinburgh, Edinburgh, United Kingdom

Auteur correspondant ana.morales@ific.uv.es

The experimental information available to test shell-model calculations south of 208Pb is almost non-existent at present due to the challenges in accessing the exotic neutron-rich region around and beyond $N=126$. Such information are essential not only for understanding how the shell structure evolves below and beyond $N=126$, and if deformation or new shell gaps develop in the region, but to calculate more complex configurations in the more exotic, inaccessible nuclei on the r-process pathway towards the trans-bismuth fissile elements [Hol19].

In the present contribution, we will show for the first time new isomeric transitions observed in the “south-east” quadrant of 208Pb in an experiment carried out during the 2021 spring campaign of the BRIKEN collaboration at the RIBF factory in RIKEN (Japan) [Wu17,Tol19]. The level schemes will be discussed in terms of the latest shell-model calculations in the region [Yuan22]. Future perspectives to continue with the investigation of isomerism around and beyond 208Pb exploiting the BigRIPS spectrometer at RIKEN will be discussed as well.

[Hol19] E.M. Holmbeck et al., *Ap. J.* 870, 23 (2019)

[Tol19] A. Tolosa-Delgado et al., *Nucl. Instr. And Methods A*, 925-133 (2019)

[Wu17] J. Wu et al., β -decay spectroscopy in the vicinity of the $N=126$ closed shell. RIBF NP-PAC Proposal NP1712-RIBF158

[Yuan22] Cenxi Yuan et al., *Phys. Rev. C* 106, 044314 (2022)

parallel / 430

Towards in-gas-jet studies of isomeric $^{229}\text{Th}^+$

Auteur: Arno Claessens¹

Co-auteurs: Andreas Dragoun²; Antoine de Roubin³; Christoph E. Düllmann⁴; Dennis Renisch⁵; Fedor Ivandikov⁶; Jekabs Romans¹; Paul Van den Bergh⁷; Piet Van Duppen⁷; Premaditya Chhetri⁸; Rafael Ferrer⁸; Sandro Kraemer⁸; Silvia Bara⁶; Thorsten Schumm⁹; Veronika Rosecker⁹; Yens Elskens³; Yuri Kudryavtsev⁸

¹ KU Leuven

² Johannes Gutenberg University Mainz, 55099 Mainz, Germany; Helmholtz-Institut Mainz, 55099 Mainz, Germany

³ *KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium*

⁴ *Johannes Gutenberg University Mainz, 55099 Mainz, Germany, Helmholtz Institute Mainz, 55099 Mainz, Germany, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*

⁵ *Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany; Helmholtz-Institute Mainz, 55099 Mainz, Germany*

⁶ *IKS, KU Leuven, Belgium*

⁷ *KU Leuven, Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium*

⁸ *Instituut voor Kern- en Stralingsfysica, KU Leuven*

⁹ *Atominstytut, TU Wien, 1020 Vienna, Austria*

Auteur correspondant arno.clæssens@kuleuven.be

Short half-lives, low production rates and the need to produce them by fusion-evaporation reactions all complicate laser spectroscopy studies of (trans)actinides. The In-Gas Laser Ionization and Spectroscopy (IGLIS) technique has been successfully employed in studies on short-lived actinides (see for instance [1,2]). The addition of a convergent-divergent (de Laval) nozzle to create a cold hypersonic gas jet combines efficiency with sub-GHz spectral resolution. The new generation of nozzles with a Mach number of 8 enables laser spectroscopy studies of actinides with spectral resolutions around 200 MHz [3].

The light actinide ²²⁹Th and its nuclear clock isomer have attracted significant attention in the last years. A remarkable feature is the suggested short half-life (< 10 ms) of the isomer in its, not-yet observed, singly charged state [4]. We report on the design of a fast-extraction gas cell (evacuation time of ~ 1 ms) and tailor-made recoil ion sources of ²³³U prepared by TU Vienna and JGU Mainz which are installed inside the gas cell to provide the isomeric thorium ions. A new set of de Laval nozzles was designed and characterized to operate under the required low-stagnation-pressure conditions of the recoil sources as well as for spectroscopy studies of (trans)actinides in the JetRIS experiment at GSI [5]. A level search above the second ionization potential of thorium revealed several auto-ionizing states which are used to improve laser ionization efficiency for future in-gas-jet laser spectroscopy studies of ^{229m}Th⁺.

[1] C. Granados et al. Phys. Rev. C, 96:054331, 2017.

[2] S. Raeder et al. Phys. Rev. Lett., 120:232503, 2018.

[3] R. Ferrer et al. Physical Review Research, 3:043041, 2021.

[4] L. von der Wense et al. Nature, 533:47–51, 2016.

[5] S. Raeder et al. Nucl. Instrum. Methods Phys. Res. B, 463:272–276, 2020.

parallel / 435

Indirect measurements of neutron-induced reaction cross-sections at heavy-ion storage rings

Auteur: Michele Sguazzin¹

Co-auteurs: Beatriz Jurado²; Jérôme PIBERNAT³; Jacobus Swartz³; Manfred Grieser⁴; Jan Glorius⁵; Yury Litvinov⁵; Rene Reifarth⁶; Klaus Blaum⁷; Camille Berthelot³; Marc Dupuis⁸; Bertrand THOMAS³; Philippe Alfaut³

¹ *CNRS/LP2iB*

² *IN2P3/CENBG*

³ *LP2iB*

⁴ *Max-Planck Institut für Kernphysik*

⁵ *GSI Darmstadt*

⁶ *Goethe University Frankfurt*

⁷ *MPIK*

⁸ *CEA*

Auteur correspondant sguazzin@cenbg.in2p3.fr

Obtaining reliable cross sections for neutron-induced reactions on unstable nuclei is crucial to our understanding of the stellar nucleosynthesis of heavy elements and for applications in nuclear technology. However, the measurement of these cross sections is very complicated due to the radioactivity of the targets involved. The NECTAR (NuclEAR reaCTions At storage Rings) project aims to circumvent this problem by using the surrogate-reaction method in inverse kinematics. A heavy, radioactive nucleus in the beam is to interact with a light, stable nucleus in the target to produce the compound nucleus formed in the neutron-induced reaction of interest via an alternative or surrogate reaction such as transfer or inelastic scattering. This compound nucleus may decay by fission, neutron or gamma-ray emission, and the probabilities for these modes of decay are to be measured as a function of the excitation energy of the compound nucleus. This information is used to constrain model parameters and to obtain much more accurate predictions of neutron-induced reaction cross sections [1].

Yet, the full development of the surrogate method is hampered by numerous long-standing target issues. The objective of the NECTAR project is to solve these issues by combining surrogate reactions with the unique and largely unexplored possibilities at heavy-ion storage rings. In these storage rings, heavy radioactive ions revolve at high frequency passing repeatedly through an electron cooler, which greatly improves the beam quality and restores it after each passage of the beam through the internal gas-jet serving as ultra-thin, windowless target. This way, excitation energy and decay probabilities can be measured with unrivaled accuracy.

In this contribution, we will present the technical developments and the methodology, which we are developing within NECTAR to measure for the first time simultaneously the fission, neutron and gamma-ray emission probabilities at the heavy-ion storage rings of the GSI/FAIR facility. In particular, we will present the first results of the proof of principle experiment, which we successfully conducted in June 2022 at the ESR storage ring of GSI/FAIR.

[1] R. Pérez Sánchez, B. Jurado et al., Phys. Rev. Lett. 125 (2020) 122502

436

Recent results with the Active Target Time Projection Chamber

Auteur: Daniel Bazin¹

Co-auteurs: Clementine Santamaria²; Jie Chen³; Michael Serikow⁴; Saul Beceiro-Novo²; Tan Ahn⁵; Wolfgang Mittig⁴; Yassid Ayyad⁶

¹ Michigan State University

² MSU/FRIB

³ ANL

⁴ MSU-FRIB

⁵ University of Notre Dame

⁶ USC

Auteur correspondant bazin@nscl.msu.edu

The Active Target Time Projection Chamber (AT-TPC) has been used in experiments aimed at the exploration of structural effects in radioactive nuclei using one step reactions such as transfer or resonant scattering. The high luminosity of this type of detector allows to perform this type of measurement in inverse kinematics with much reduced beam intensities, while preserving a good resolution, hence extending their reach towards the most rare isotopes. This presentation will feature recent results obtained as a proof of principle on several reaction channels observed between a 10 MeV/u ¹⁰Be beam and a pure deuterium target. The methodology used to analyze the complex data recorded by the AT-TPC will be presented, as well as its performance in extracting the physical quantities of interest for structure studies of nuclei far from stability.

parallel / 437

Light-exotic nuclei studied with the (t,p) reaction in inverse kinematics using HELIOS

Auteur: Alan Wuosmaa¹

Co-auteurs: Augusto Macchiavelli²; Benjamin Kay³; Catherine Deibel⁴; Daniel McNeel¹; David Sharp⁵; Gemma Wilson⁴; Jeremy Smith⁶; Jie Chen³; John Schiffer³; Jonathon Lighthall⁴; Robert Janssens⁶; Roderick Clark²; Scott Marley⁴; Sean Kuvin¹; Tsz Leung Tang³

¹ *University of Connecticut*

² *Lawrence Berkeley National Laboratory*

³ *Argonne National Laboratory*

⁴ *Louisiana State University*

⁵ *University of Manchester*

⁶ *University of North Carolina*

Auteur correspondant alan.wuosmaa@uconn.edu

We report on studies of ^{14}B and ^{10}Li using the (t,p) reaction in inverse kinematics with HELIOS at Argonne National Laboratory. Two-neutron transfer provides information complementary to that obtained with one-neutron transfer. The selective nature of (t,p) is ideal for studying neutron pairing, configuration mixing and shape-coexistence, effects necessary to understand regions where the shell-model orbitals are changing rapidly with N/Z. Here, we have studied the $^{12}\text{B}(t,p)^{14}\text{B}$ and $^8\text{Li}(t,p)^{10}\text{Li}$ reactions. In ^{14}B , data for ^{14}Be beta-decay [1] and the $^{14}\text{Be}(p,n)^{14}\text{B}$ reaction [2] suggest a 1^+ excitation at $E_X(^{14}\text{B})=1.27$ MeV interpreted as a low-lying intruder state with strong $\nu(1s_{1/2})^2$ character. The properties of this and other $\nu(sd)^2$ states in ^{14}B that can be populated in (t,p) provide information about the changing nature of the p-sd splitting in this mass region that is important, for example, in understanding the disappearance of the N=8 shell gap suggested in ^{12}Be . In ^{10}Li , the nature of the low-lying structure remains controversial with conflicting interpretations of data from the $^9\text{Li}(d,p)^{10}\text{Li}$ reaction[3,4] suggesting the dominance of either s-wave or p-wave excitations. The selectivity of (t,p) can shed more light on this behavior, but also identify two-neutron (sd)² excitations that, due to their small overlap with $^9\text{Li}_{g.s.}+n$, may be narrow despite ^{10}Li being unbound. The properties of such states in ^{10}Li can provide information that is important for a detailed understanding of the two-neutron halo structure of ^{11}Li .

Secondary ^{12}B and ^8Li beams produced using the RAISOR separator at the ATLAS facility at Argonne National Laboratory bombarded a ^3H target consisting of ^3H adsorbed into a $450 \mu\text{g}/\text{cm}^2$ Ti foil. Protons transported by the HELIOS uniform magnetic field were detected using an array of position-sensitive silicon detectors, and recoiling beam-like reaction products were detected at forward angles using a set of $\Delta E - E$ silicon-detector telescopes. We will present the results of first measurements of the $^{12}\text{B}(t,p)^{14}\text{B}$ and $^8\text{Li}(t,p)^{10}\text{Li}$ reactions, and compare the observations with predictions of shell-model calculations for two-neutron transfer leading to states in ^{14}B and ^{10}Li .

This research was supported by the US Department of Energy, Office of Nuclear Physics, under Grants No. DESC0014552, (UConn), No. DE-FG02-96ER40978 (LSU), and No. DE-AC02-06CH11357 (ANL).

[1] N. Aoi et al., Phys. Rev. C 66, 014301 (2002).

[2] Y. Satou et al., Phys. Lett. B 697, 459 (2011).

[3] H. B. Jeppesen et al., Phys. Lett. B 642, 449 (2006).

[4] M. Callavaro et al., Phys. Rev. Lett. 118, 012701 (2017).

438

Study of muon capture reaction on Si via in-beam muon activation

Auteurs: Megumi Niikura¹; Rurie Mizuno²; Takeshi Y. Saito³; Teiichiro Matsuzaki¹

Co-auteurs: Akira Sato⁴; Hiroya Fukuda⁵; Izumi Umegaki⁶; Katsuhiko Ishida¹; Koichiro Shimomura⁶; Masanori Hashimoto⁷; Masaya Oishi⁵; Naritoshi Kawamura⁶; Patrick Strasser⁶; Shinichiro Abe⁸; Shoichiro Kawase⁵; Soshi Takeshita⁶

¹ *RIKEN Nishina Center*

² *University of Tokyo*

³ *The University of Tokyo*

⁴ *Osaka University*

⁵ *Kyushu University*

⁶ *High Energy Accelerator Research Organization*

⁷ *Kyoto University*

⁸ *Japan Atomic Energy Agency*

Auteur correspondant mizuno@nex.phys.s.u-tokyo.ac.jp

The muon capture reaction is a capture of a negative muon by a proton in the nucleus via the weak interaction. This reaction produces an excited Z-1 nucleus having the same mass as the original nucleus. Although the existence of the muon nuclear capture event has been well known since the 1950s, the measurement data of the excitation energy of the nuclei or the branching ratio of particle emissions from this excited state are sparse, and there is no established model of muon capture. The production branching ratio of each daughter nucleus produced by the muon capture of Si isotopes, which gives information on the energy distribution of the excitation states populated by the muon nuclear capture, was measured with some methods [1-4]. But these methods contain several assumptions, and they show some discrepancies in the production branching ratio. Therefore, to obtain accurate data and evaluate the excitation state of the nuclei after the muon capture, we measured the absolute production branching ratio of the muon capture of Si isotopes with a new method, the in-beam activation method.

The experiment was performed at the Materials and Life Science Experimental Facility (MLF), J-PARC [5]. In the facility, the pulsed muon beam is produced by decay of pions, which are generated by irradiating the graphite target with the 3-GeV proton beam. The pulsed beam has a quiet time period between any neighboring pulses, suited for the β -decay measurement without beam background. In the in-beam activation method, β -delayed γ -rays are simultaneously measured during the beam irradiation thanks to the time structure of the pulsed muon beam. The negative muon beam at 38 MeV/c irradiated targets at 25 Hz. The targets were enriched 28,29,30Si powders and a natural Si plate. Two Ge detectors were used for gamma-ray detection, and a thin plastic scintillator was used for the muon counter. The response function of the plastic scintillator was also measured with the proposed in-beam activation method of the Al target by changing the intensity of the muon beam.

From this experiment, some β -delayed γ -ray peaks from Na, Mg, and Al isotopes were observed. The absolute production branching ratio of muon capture of Si isotopes is obtained from the counts of these gamma-ray peaks and the number of irradiated muons. This result is also compared with the PHITS simulation. The result of the experiment will be reported in this presentation.

[1] G.G. Bunatyan et al., *Sov. J. Nucl. Phys.* 11, 444 (1970).

[2] B. MacDonald, J. A. Diaz, S. N. Kaplan, and R. V. Pyle, *Phys. Rev.* 139, B1253 (1965). [3] S. E. Sobottka and E. L. Wills, *Phys. Rev. Lett.* 20, 596 (1968).

[4] D.F. Measday et al., *Phys. Rev. C* 76, 035504 (2007)

[5] Y. Miyake et al., *Nucl. Instrum. Meth. A* 600, 1 (2009)

parallel / 439

Determination of electromagnetic moments within nuclear DFT

Auteurs: Jacek Dobaczewski¹; Jérémy Bonnard²; Gauthier Danneaux³; Ronald Fernando Garcia Ruiz⁴; Markus Kortelainen³; Paolo Sassarini¹; Herlik Wibowo¹

¹ *University of York*

² *Institut de Physique des 2 infinis de Lyon*

³ *University of Jyväskylä*

⁴ *MIT*

Auteur correspondant jacek.dobaczewski@york.ac.uk

Nuclear electromagnetic moments provide essential information in our understanding of nuclear structure. Observables such as electric quadrupole moments are highly sensitive to collective nuclear phenomena, whereas magnetic dipole moments offer sensitive probes to test our description of microscopic properties such as those of valence nucleons. Although great progress was achieved in the description of electromagnetic properties of light nuclei and experimental trends in certain isotopic chains, a unified and consistent description across the Segré chart of nuclear electromagnetic properties remains an open challenge for nuclear theory.

In our nuclear-DFT methodology, we align angular momenta along the intrinsic axial-symmetry axis with broken spherical and time-reversal symmetries. This allows us to explore fully the self-consistent charge, spin, and current polarizations. Spectroscopic moments are then determined for symmetry-restored wave functions and compared with available experimental data.

We determined the nuclear electric quadrupole and magnetic dipole moments in all one-particle and one-hole neighbours of eight doubly magic nuclei [1]. Such a dataset allowed us to adjust the time-odd mean-field channel of nuclear functionals to experimental data. Without further adjustments, we then determined the electromagnetic moments in paired nuclear states corresponding to the proton (neutron) quasiparticles blocked in the $\pi 11/2^-$ ($\nu 13/2^+$) intruder configurations [2]. We performed calculations for all deformed open-shell odd nuclei with $63 \leq Z \leq 82$ and $82 \leq N \leq 126$.

We obtained good agreement with data without using effective π -factors or effective charges in the dipole or quadrupole operators, respectively. We also showed that the intrinsic magnetic dipole moments, or those obtained for conserved intrinsic time-reversal symmetry, do not represent viable approximations of the spectroscopic ones, see the results plotted in the figure.

In this talk, I will review recent nuclear-DFT results obtained in the unpaired odd near doubly magic nuclei [1], heavy paired odd open-shell nuclei [2], and indium [3], silver [4], and tin [5] isotopes.

[1] P.L. Sassarini *et al.*, *J. Phys G* **49** (2022) 11LT01

[2] J. Bonnard *et al.*, arXiv:2209.09156

[3] A.R. Vernon *et al.*, *Nature* **607** (2022) 260; A.R. Vernon *et al.*, to be published; L. Nies *et al.*, accepted in *Phys. Rev. Lett.* (2023)

[4] R.P. de Groot *et al.*, to be published

[5] T.J. Gray *et al.*, to be published

This work was partially supported by the STFC Grant Nos. ST/P003885/1 and ST/V001035/1, by the Polish National Science Centre under Contract No. 2018/31/B/ST2/02220, by a Leverhulme Trust Research Project Grant, by the Academy of Finland under the Academy Project No. 339243, and by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under award numbers DE-SC0021176 and DE-SC0021179. We acknowledge the CSC-IT Center for Science Ltd., Finland, for the allocation of computational resources. This project was partly undertaken on the Viking Cluster, which is a high performance compute facility provided by the University of York. We are grateful for computational support from the University of York High Performance Computing service, Viking and the Research Computing team.

Collinear laser spectroscopy in medium-mass elements at BECOLA

Auteur: Kristian König¹

Co-auteurs: Andrew Klose²; Felix Sommer¹; Gaute Hagen³; Jason Holt⁴; Jeremy Lantis⁵; Kei Minamisono⁶; Paul-Gerhard Reinhard⁷; Robert Powel⁵; Skyy Pineda⁵; Stephan Fritzsche⁸; Takayuki Miyagi⁴; Thomas Papenbrock⁹; Wilfried Nörtershäuser¹; Witold Nazarewicz¹⁰

¹ *TU Darmstadt*

² *Augustana University, Sioux Fall*

³ *UT-ORNL*

⁴ *TRIUMF*

⁵ *Michigan State University*

⁶ *NSCL/MSU*

⁷ *Friedrich-Alexander Universität Erlangen*

⁸ *Helmholtz Institut Jena*

⁹ *The University of Tennessee*

¹⁰ *Facility for Rare Isotope Beams*

Auteur correspondant kkoenig@ikp.tu-darmstadt.de

Collinear laser spectroscopy in medium-mass elements was performed at the NSCL/FRIB facility at Michigan State University at the BECOLA setup to investigate the nuclear structure in the proximity of the neutron shell closures at $N = 20$ and 28 . The extracted nuclear charge radii were compared to state-of-the-art density functional and ab initio theories yielding a surprisingly similar behavior between the strong/soft shell closures in ^{48}Ca and ^{56}Ni , respectively, [1] and a restoration of the $N = 20$ kink in Sc that absent in K, Ar and Ca.

In this talk, we will present and discuss the experimental findings and give an outlook of the capabilities of BECOLA in the FRIB era to further explore this fascinating region of the nuclear chart.

This work was supported in part by US NSF Grant No. PHY-21-11185 and DOE Office of Science Award No. DE-SC0000661 and by the DFG –Project-Id 279384907*SFB 1245.

[1] F. Sommer, et al., Phys. Rev. Lett. 129, 132501 (2022).

parallel / 441

Statistical and shell effect in beta-delayed neutron emission

Auteur: Robert Grzywacz¹

¹ *University of Tennessee*

Auteur correspondant rgrzywac@utk.edu

With access to very neutron-rich isotopes, the neutron emission from excited states populated after beta decay becomes a dominant decay mode. The neutron energy measurement informs about beta-decay strength distribution, which is driven by shell effects. The neutron emission is considered to be statistical. Discrete neutron and gamma-ray spectroscopy measurements performed in nuclei ranging from ^{240}In to ^{134}In were performed with hybrid neutron arrays at RIBF, ISOLDE, NSCL, and FRIB. In addition to providing the first measurement of the strength distribution for many nuclei with a large beta-n energy window, we found evidence for non-statistical neutron emission process. It forced us to revisit a conventional picture of neutron emission thought to proceed via a compound nucleus phase. A model which connects nuclear structure and neutron emission was developed to explain the observed phenomena [1].

[1] J. Heideman et al. submitted to Phys. Rev. C.

parallel / 442

Doubly magic ^{78}Ni as a beta-delayed neutron precursor

Auteur: Krzysztof Rykaczewski¹

Co-auteurs: Bertis Rasco¹; James Allmond¹; Nathan Brewer¹; Rin Yokoyama²; Robert Grzywacz³

¹ Oak Ridge National Laboratory

² CNS, University of Tokyo, Japan

³ University of Tennessee

Auteur correspondant fpr@ornl.gov

^{78}Ni is a unique doubly magic nucleus far from beta stability line, the only one decaying with β -delayed neutron emission channel. Its decay properties influence the early r-process nucleosynthesis and the beta decays of exotic nuclei north-east of $Z=28$ and $N=50$. Nuclei in the ^{78}Ni region were created with the 345 MeV/u ^{238}U beam reaching nearly 70 part*nanoAmp. Fragmentation products were separated by means of BigRIPS spectrometer at RIKEN (Wako, Japan). The spectroscopy of radiation emitted by beta-delayed neutron precursors was performed using BRIKEN ^3He array [1] modified to achieve larger gamma efficiency [2]. ORNL contributions included 87% of ^3He neutron detection volume and two Ge clovers. The fragment implantation and decay array were consisting of four smaller double-sided Si-strip counters of WASABI complemented by a position sensitive YSO scintillator developed at the UTK. The BigRIPS setting was maximized for the transmission of ^{82}Cu . Isotopes between ^{61}V - ^{69}V up to ^{95}Br - ^{97}Br were produced and identified. The total rate of identified ^{78}Ni ions was around 65,000, with about 40,000 ions implanted for decay study. Beta-gamma and beta-neutron-gamma decay channels were identified for ^{78}Ni precursor. The P_{1n} branching ratio of about 27(4)% was determined from the analysis [3] of β - $1n$ decay pattern. New levels in ^{78}Cu as well as new level associated with proton $p_{3/2}$ state in $Z=29$ ^{77}Cu were observed. The accepted proposal to study ^{78}Ni decay with the recently commissioned ORNL's Modular Total Absorption Spectrometer at the Facility for Rare Isotopes Beams will be briefly presented.

[1] A. Tarifeño-Saldivia et al., Jour. of Instrum. 12, P04006 (2017).

[2] R. Yokoyama et al., Phys. Rev. C 100, 031302(R) (2019).

[3] B. C. Rasco et al., Nucl. Instrum. Methods. Phys. Res. A 911, 79 (2018).

Supported by the U.S. DOE Office of Nuclear Physics under contracts DE-AC05-00R22725 (ORNL) and DE-FG02-96ER40983 (UTK)

445

Gas Cell Development using a ^{248}Cm Fission Source at the ZD MRTOF Mass Spectrograph at RIBF

Auteur: Jinn Ming Yap¹

Co-auteurs: Aiko Takamine²; D. Hou; Hironobu Ishiyama²; Jenny Lee³; Marco Rosenbusch⁴; Michiharu Wada⁵; Peter Schury⁶; Phong Vi⁷; Shuji Nishimura⁸; Shun Iimura⁹; Sidong Chen³; Sota Kimura⁶; T. Sonoda¹⁰; T.M. Kojima¹⁰; Ting Gao¹; Toshitaka Niwase⁶; Wenduo Xian¹¹; Yutaka Watanabe⁶

¹ Department of Physics, The University of Hong Kong

² RIKEN

³ the University of Hong Kong

⁴ WNSC-IPNS-KEK, Tsukuba, Japan

⁵ KEK

⁶ KEK, WNSC

⁷ RIKEN Nishina Center, Japan

⁸ RIKEN, Nishina Center

⁹ Rikkyo University

¹⁰ RIKEN Nishina Center

¹¹ *HongKong University*

Auteur correspondant jmyap@connect.hku.hk

To perform high-precision experiments on exotic nuclei, efficient capture and transport of radioactive isotope (RI) beams in accelerator facilities are required, leading to many efforts over the years [1, 2, 3, 4]. Downstream from the ZeroDegree spectrometer at RIKEN, RIBF, we employ a cryogenic He filled gas catcher [5] for ion capture and transport to the multi-reflection time-of-flight mass spectrograph (ZD MRTOF-MS) [6] for high precision mass measurements. To study ion transport from the gas catcher to the ZD MRTOF-MS, we have installed a fission source to perform offline mass measurement of fission products. The capture of the fission products in the gas catcher was optimized by rotating a thin Ti degrader attached to the fission source. Recently, mass measurements of fission products, such as $^{104-106}\text{Nb}$, Mo, Tc, and Ru, from ^{248}Cm were performed. The transport efficiency was evaluated based on the stopping efficiency obtained from Monte Carlo simulations of the gas cell and well-known fission yields of ^{248}Cm provided by JAEA [7]. In this presentation, we report the transport efficiency investigations of the gas cell, mass measurements of the fission products, and our gas catcher development.

[1] H. Raimbault-Hartmann, Nucl. Instrum. Methods Phys. Res. B 126, 378 (1997).

[2] M. Wada, Nucl. Instrum. Methods Phys. Res. A 532, 40 (2004).

[3] G. Bollen *et al.*, Eur. Phys. J. Spec. Top. 150, 265 (2007).

[4] W. R. Plaß *et al.*, Nucl. Instrum. Methods Phys. Res. B 317, 457 (2013).

[5] A. Takamine *et al.*, RIKEN Accel. Prog. Rep. 53, 108 (2019).

[6] M. Rosenbusch *et al.*, Nucl. Instrum. Methods Phys. Res. A 1047, 167824 (2023).

[7] J. Katakura, F. Minato, K. Ohgama, EPJ Web of Conferences 111, 08004 (2016).

parallel / 446

Evolution of the neutron $1d$ spin-orbit splitting in ^{35}S and ^{39}Ca

Auteur: Sandile Jongile^{None}

Co-auteurs: Retief Neveling¹; Mathis Wiedeking²; Olivier Sorlin³; Antoine Lemasson⁴; Paul Papka⁵; Philip Adsley⁶; Luna Pellegrini⁷; Frederick Smit⁵; Lindsay Michelle Donaldson⁸; Nicholas Keeley⁹; Freddy FLAVIGNY¹⁰; Vittorio Somà¹¹; Thomas Duguet¹²; JEAN-PAUL EBRAN¹³; Cenxi Yuan¹⁴; Sinegugu Mthembu¹⁵; Pete Jongile⁵; Thuthukile Khumalo⁵; Harshna Jivan¹⁶; Abraham Aava⁵; Doris Kenfack⁵; Fhumulani Nemulodi⁵; Kgashane Malatji⁵; Adivhaho Netshiya⁵

¹ *iThemba Laboratory for Accelerator Based Sciences*

² *iThemba LABS and University of the Witwatersrand*

³ *GANIL*

⁴ *GANIL / CNRS UPR3266*

⁵ *iThemba LABS*

⁶ *IPN Orsay*

⁷ *University of Milan - INFN Milan*

⁸ *iThemba Laboratory for Accelerator Based Science*

⁹ *National Centre for Nuclear Research*

¹⁰ *LPC Caen*

¹¹ *IRFU, CEA, Université Paris-Saclay*

¹² *CEA/Saclay/SPhN*

¹³ *CEA*

¹⁴ *Sun Yat-Sen University*

¹⁵ *University of the western cape & iThemba LABS*

¹⁶ *University of Witwatersrand*

Auteur correspondant sandilej@tlabs.ac.za

Nuclei along $N=20$ provide an excellent region to investigate the change in nuclear structure and interactions. From their evolution from the doubly magic nucleus ^{40}Ca through to the $Z=16$ and $Z=14$ nuclei ^{36}S and ^{34}Si , respectively, to ^{32}Mg with a deformed $2p - 2h$ intruder ground state [1]. The mechanism responsible for the change in shell structure is not well understood and is suspected to be a subtle combination of the different components of the nuclear force namely the central, spin-orbit (SO), and tensor parts. A significant reduction of the neutron $d_{5/2}$ and $d_{3/2}$ spin-orbit splitting between ^{40}Ca and ^{36}S , as protons are removed from the $d_{3/2}$ orbital, would be indicative of the proton-neutron tensor force. By comparing the neutron $d_{5/2}$ hole strength between these nuclei, the strength of the tensor force is probed in an unprecedented manner.

The centroids of the hole states in ^{35}S have been inferred from a $^{36}\text{S}(p,d)^{35}\text{S}$ experiment performed at iThemba LABS. A $^{36}\text{S}(p,d)^{35}\text{S}$ reaction is a useful tool to probe the neutron spin-orbit splitting in ^{36}S , provided a reliable ^{36}S target is available. This was achieved by specifically developing a new target system at iThemba LABS which allows for a cost-effective ^{36}S target without heavy contaminants to be used. This novel target encapsulates sulfur between two Mylar foils and has been shown to be an effective way to produce targets with a significant amount of material ($0.5\text{-}1\text{ mg/cm}^2$). Using this moving ^{36}S target with 66 MeV incident protons, states in ^{35}S were measured with the K600 magnetic spectrometer at iThemba LABS. States up to 20 MeV were observed, identifying the neutron single-particle strength below and above the Fermi surface using the detection of the deuterons at the focal plane of the K600 spectrometer with an energy resolution of approximately 30 keV [2]. The results from the $^{36}\text{S}(p,d)^{35}\text{S}$ experiment were compared to the $^{40}\text{Ca}(p,d)^{39}\text{Ca}$ study by Matoba *et al.* [3]. The results show an increase of the neutron $1d_{5/2} - 1d_{3/2}$ SO splitting between ^{35}S and ^{39}Ca by 0.411 MeV. This is contrary to the universal trend of SO splitting with increasing mass number which would predict a decrease of ~ 0.450 MeV. This deviation is highly indicative of the effect of tensor forces. At present, the tensor force is not implemented in the vast majority of the available mean field and relativistic mean field calculations, whereby the amplitude of the SO splitting is solely attributed to the spin-orbit force. This study provides an unambiguous result indicating the role of the tensor force. It is shown that the strength of the tensor force is, however, lower than predicted by the shell model and ab-initio theory.

[1] O. Sorlin and M.-G. Porquet, *Progress in Particle and Nuclear Physics* 61, 602 (2008), ISSN 0146-6410

[2] R. Neveling, H. Fujita, *et. al Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 654, 29 (2011), ISSN 0168-9002

[3] M. Matoba, *et. al Phys. Rev. C* 48, 95 (1993)

This work is supported by the National Research Foundation of South Africa grant 118846.

447

Mass measurement of neutron-deficient $T_z=3/2$ nuclides at CSRe

Auteur: Yuanming Xing²

Co-auteurs: Cenxi Yuan¹; Meng Wang²; Yuhu Zhang²; Yury Litvinov³

¹ Sun Yat-Sen University

² IMP-Lanzhou

³ GSI Darmstadt

Auteur correspondant xym@impcas.ac.cn

Masses of neutron-deficient $T_z=3/2$ nuclides, from ^{69}As through ^{103}Sn , have been measured by using the experimental storage ring CSRe at the Institute of Modern Physics (IMP), Lanzhou, China. The nuclides of interest were produced by projectile fragmentation of a ~ 400 MeV/u ^{112}Sn beam on a ^9Be target. The neutron-deficient projectile fragments were injected into CSRe and their revolution times

were precisely measured and accumulated to form spectra. In our data analysis, the well-separated revolution time peak shapes corresponding to certain ion species were systematically described by exponentially modified Gaussian functions. Then the overlapped peaks from different ion species with similar m/q values were properly deconvoluted and the mass values were accurately determined. The masses of ^{69}As , ^{73}Br , ^{75}Kr , ^{79}Sr , and ^{81}Y were redetermined with mass uncertainties of a few keV, which is comparable to the results obtained from MR-TOF or Penning-trap mass spectrometry. The mass excesses of ^{103}Sn as well as the low-lying $1/2^-$ isomers in ^{87}Mo , ^{91}Ru , and ^{95}Pd were directly measured for the first time. With the help of the new obtained isomer masses, systematics of the excitation energies of the low-lying $1/2^-$ isomers in the $N = 45, 47, 49$ isotones are presented. By employing the state-of-the-art shell model calculations including tensor forces, such systematic trends are well reproduced. For more details, see Phys. Rev. C 107, 014304 (2023).

448

Resonance Ionization Mass Spectroscopy on Americium

Auteur: Matou Stemmler¹

Co-auteurs: Anjali Ajayakumar²; Christoph E. Düllmann³; Christoph Mokry⁴; Felix Weber⁵; Hideki Tomita⁶; Jörg Runke⁷; Klaus Wendt⁸; Magdalena Kaja⁸; Nina Kneip⁹; Sebastian Berndt⁸; Volker Sonnenschein¹⁰

¹ Johannes Gutenberg-Universität Mainz, Institut für Physik

² Grand Accélérateur National d'Ions Lourds, 1400 Caen, France

³ Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany; Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz; GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany.

⁴ Department of Chemistry – TRIGA Site, Johannes Gutenberg University Mainz, Germany; Helmholtz Institute Mainz, Germany

⁵ Johannes Gutenberg University, 55099 Mainz, Germany

⁶ Nagoya University

⁷ Department of Chemistry – TRIGA Site, Johannes Gutenberg University Mainz, Germany; GSI Helmholtzzentrum für Schwerionenforschung mbH, Darmstadt, Germany

⁸ Johannes Gutenberg-Universität Mainz

⁹ Johannes Gutenberg University Mainz and Leibniz University Hannover

¹⁰ HÜBNER GmbH & Co. KG, 34123 Kassel, Germany

Auteur correspondant mastemml@uni-mainz.de

Americium (Am, $Z=95$) is a transuranic member of the actinide series and was discovered in 1944 by the group led by Glenn T. Seaborg. All its isotopes are radioactive. The two most long-lived ones are ^{241}Am with a half-life of $t_{1/2} = 432.2$ a and ^{243}Am with a half-life of $t_{1/2} = 7370$ a. As any primordial americium has decayed by now, these isotopes are produced artificially by neutron irradiation, also in nuclear power reactors. One ton of spent nuclear fuel contains about 100 g of Am. Applications for americium have been proposed, e.g., as fuel for spaceships with nuclear propulsion, and ^{241}Am is routinely used today in ionization-type smoke detectors and - when mixed with Be - as a neutron source. Regarding fundamental atomic and nuclear data obtained in optical spectroscopic studies, only few have been reported to date and the accumulated knowledge on atomic and nuclear properties in literature is rather scarce.

Resonance ionization spectroscopy (RIS) was used as a very sensitive technique to precisely study atomic excitation schemes and level positions in the spectrum of americium, both for fundamental studies as well as in preparation of laser mass spectrometric ultra-trace analysis.

Here we report on two-step high resolution RIS in Am at the RISIKO off-line radioactive ion beam facility. About $3 \cdot 10^{13}$ atoms of both isotopes ^{241}Am and ^{243}Am were prepared on zirconium foil and loaded into a resistively heated tantalum oven. A wide-range tuneable, frequency doubled, continuous wave Ti:sapphire laser was used for spectroscopy by injection locking of a high power pulsed Ti:sapphire ring laser setup. Hyperfine structures of the two isotopes $^{241,243}\text{Am}$ were investigated in two different ground state transitions at 23437.0 cm^{-1} and 25409.5 cm^{-1} , which served as first excitation steps for resonant ionization via suitable autoionizing states. In addition, the isotope shift was measured. Results regarding the atomic structure of Am as well as hyperfine parameters extracted will be discussed.

449

Investigation on Isomeric ratio of ^{211}Po produced via MNT approach using $^{136}\text{Xe} + ^{209}\text{Bi}/^{nat}\text{Pb}$ at the IGISOL facility

Auteur: Deepak Kumar¹

Co-auteurs: Timo Dickel²; Alexandra Zadornaya³; Olga Beliuskina⁴; Anu Kankainen⁵; Paul Constantin⁶; Christine Hornung¹; Alexander Karpov⁷; Sivaji Purushothaman¹; Vyacheslav V Saiko⁷; Anamaria Spătaru⁶; Marek Stryczyk⁵

¹ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

² GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany; Justus-Liebig-Universität Gießen, Gießen, Germany

³ Justus-Liebig-Universität Gießen, Gießen, Germany; University of Jyväskylä, Jyväskylä, Finland

⁴ University of Jyväskylä

⁵ University of Jyväskylä, Jyväskylä, Finland

⁶ Extreme Light Infrastructure – Nuclear Physics (ELI-NP), National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)

⁷ Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia

Auteur correspondant de.kumar@gsi.de

Investigations on Multi-Nuclear Transfer (MNT) reaction processes are currently a hot topic for theorists as well as experimentalists [1-3]. The MNT reaction processes facilitate access to very neutron-rich rare-earth nuclei, nuclei around the shell closure $N = 126$, and neutron-rich actinides, which are highly relevant for understanding the nucleosynthesis process of heavier elements [4,5]. The MNT approach provides the advantage of extensive production of isotopic distributions over a wide mass range around target-like and projectile-like fragments, along with the possibility of significant production of isomers [4].

In this endeavor, experiments were performed at the Ion-Guide Isotope Separator On-Line (IGISOL) facility in the JYFL Accelerator Laboratory of the University of Jyväskylä, Finland [5]. The neutron-rich actinides were produced through the MNT reaction process using the 945 MeV ^{136}Xe beam from the K-130 cyclotron on ^{209}Bi and ^{nat}Pb targets. The energetic MNT fragments were thermalized within a new dedicated MNT Ion Guide (IG) by penetrating through a nickel/havar window of the gas cell. The thermalized ions were extracted from the gas cell using a sextupole ion guide, accelerated to 30 keV, and mass-separated using a dipole magnet [4]. Finally, the alpha spectroscopy of the produced isotopes was carried out. Different isotopes of Bi, Po, and At were identified using a Si-detector placed at the Switch Yard (SW) of the IGISOL facility.

The alpha spectra exhibiting ^{211}Bi as a dominant peak in the $^{136}\text{Xe} + ^{209}\text{Bi}$ reaction were consistent in the three independent runs performed in different experimental conditions. The isomer of ^{211}Po (i.e., 7225 keV of ^{211m}Po) was observed as a dominant peak in the case of the $^{136}\text{Xe} + ^{nat}\text{Pb}$ reaction. The isomer-to-ground state ratio (IR) of ^{211}Po obtained in $^{136}\text{Xe} + ^{209}\text{Bi}/^{nat}\text{Pb}$ was determined. The results were deduced from the experiments performed in 2019 and 2021. Interestingly, the IR of ^{211}Po produced in the $^{136}\text{Xe} + ^{nat}\text{Pb}$ reaction was two times higher than that observed in $^{136}\text{Xe} + ^{209}\text{Bi}$, indicating the dominant role of entrance channel parameters in the MNT process. Moreover, the measured data were compared with the theoretical calculations that qualitatively explain the deduced results. This talk will focus on the discussion of the production of MNT ions and the entrance channel effect on the MNT process via IR measurements.

parallel / 451

Recent highlights from high-precision atomic mass measurements using MRTOF-MS at RIKEN/RIBF

Auteur: Marco Rosenbusch¹ on behalf of the RIBF-MRTOF collaboration and the KISS collaboration

¹ RIKEN, KEK-WNSC

Auteur correspondant rosmar@post.kek.jp

Multi-reflection time-of-flight (MRTOF) mass spectrometry [1] has become a new powerful tool for fast and precise measurements of atomic masses. It is a breakthrough-technology considering the required duration of a measurement and the small number of rare events needed to reach a relative mass precision of $\delta m/m \leq 10^{-7}$. This mass spectrometry technology has been developed at RIKEN's RIBF facility for about two decades. Presently, three independent systems are running at different access points to radioisotopes, where gas cells built the essential hub for low-energy access. Recent achievements like high mass resolving power [2] and installations like α/β -TOF detectors [3] and in-MRTOF ion selection have tremendously increased the selectivity of the systems and improved the reduction of background. This makes us capable to distinguish between a rare radioactive ions and unwanted molecules or dark counts.

In this contribution, I will give an overview about recent MRTOF atomic mass measurement highlights achieved at RIBF. Among other measurements presented, these results include new mass values for neutron-rich titanium and vanadium isotopes revealing a vanishing of the empirical two-neutron shell gap at $N = 34$, which is known to be pronounced in Ca isotopes [4]. Furthermore, I will present the discovery of the isotope ^{241}U using the KISS facility [5], and the present status of MRTOF mass measurements of superheavy nuclides using the MRTOF setup at the GARIS-II separator [6].

References:

- [1] H. Wollnik, M. Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990).
- [2] M. Rosenbusch et al., Nucl. Instrum. Meth. A 1047, 167824 (2023).
- [3] T. Niwase et al., Theo. Exp. Phys. 2023(3), 031H01 (2023).
- [4] S. Iimura et al., Phys. Rev. Lett. 130, 012501 (2023).
- [5] T. Niwase et al., Phys. Rev. Lett. 130, 132502 (2023).
- [6] P. Schury et al., Phys. Rev. C 104, L021304 (2021).

plenary / 453

Recent progress of mass measurements for short-lived nuclides at CSRe-Lanzhou

Auteurs: Meng Wang¹; Yuhu Zhang¹; Yuri. A. Litvinov²

¹ IMP-Lanzhou

² GSI Helmholtzzentrum für Schwerionenforschung

Auteur correspondant wangm@impcas.ac.cn

Accurate nuclear masses not only provide indispensable information on nuclear structure, but also deliver important input data for applications in nuclear astrophysics. The challenge today is to obtain accurate masses of nuclei located far away from the valley of stability. In the past few years, we have devoted to the mass measurements of exotic nuclei below $A=100$ using the isochronous mass spectrometry (IMS) at the heavy ion storage ring CSRe in Lanzhou. New mass values have been obtained including ^{27}P , ^{29}S [1], ^{407}Ti , ^{44}Cr , ^{46}Mn , ^{48}Fe , ^{50}Co , ^{52}Ni [2], $^{44g,m}\text{V}$, ^{46}Cr , ^{48}Mn , ^{50}Fe , $^{52g,m}\text{Co}$, ^{54}Ni , ^{56}Cu [3,4], ^{79}Y , $^{81,82}\text{Zr}$, $^{83,84}\text{Nb}$ [5], $^{101g,m}\text{In}$ [6], ^{87m}Mo , ^{91m}Ru , ^{95m}Pd , ^{103}Sn [7]. Some physics issues have been addressed using our new and improved mass data. In this talk, the experiment details and some selected topics in nuclear structure and in nuclear astrophysics are presented and discussed. We also outline the plans and the technique improvements in our future experiments.

- [1] C. Y. Fu et al., Phys. Rev. C 98, 014315 (2018)
- [2] C. Y. Fu et al., Phys. Rev. C 102, 04311 (2020)
- [3] Y. H. Zhang et al., Phys. Rev. C 98, 014319 (2018)
- [4] M. Wang et al., Phys. Rev. C 106, L051301 (2022)
- [5] Y. M. Xing et al., Phys. Lett. B 781, 358 (2018)
- [6] X. Xu et al., Phys. Rev. C 100, 051303(R) (2019)
- [7] Y. M. Xing et al., Phys. Rev. C 107, 014304 (2023)

455

Two-centre self-consistent approach to fission with arbitrary distance, deformations and orientations of fragments

Auteur: Adrian Sanchez Fernandez¹

Co-auteurs: Herlik Wibowo¹; Jacek Dobaczewski¹; Xuwei Sun¹

¹ *University of York*

Auteur correspondant adrian.sanchezfernandez@york.ac.uk

Fission is one of the most challenging processes to describe in nuclear physics. Contrary to most of the nuclear properties, which can be explained in terms of a smaller set of valence nucleons out of an inert core, in fission all the particles are involved. Because of this, many-body approximations and theoretical assumptions that simplify the problem are mandatory when trying to describe mathematically the whole process. For connecting the properties of the nascent fragments to the structure of the initial compound nucleus, it seems adequate to consider a two-centre basis to build the single particle states of the nuclear wave functions [1-3]. Even though there are some existing results computed with that approach, in all of them axial symmetry was preserved [4], which appears as a limitation for describing more complex phenomena. In the present work, for the first time, symmetry-unrestricted two-centre harmonic oscillator states are used within the density functional solver HFODD [5] to solve the Hartree-Fock-Bogoliubov equations.

The effects of the separation and orientations between centres are analysed in super-deformed states (as doorway states to scission configurations) and the results are compared to the usual one-centre calculations as a benchmark.

This novel work opens the door to developing more sophisticated theoretical technologies in the near future. Time-dependent methods will allow computing properties relevant to both spontaneous and neutron-induced fission (collective inertia, mass distributions or angular momenta of the fragments) without the classical assumptions about adiabaticity or thermalisation[2].

[1] N. Schunck and L. M. Robledo, *Rep. Prog. Phys.* 79 (2016) 1163011.

[2] J. Dobaczewski (2019), arXiv:1910.03924.

[3] M. Bender et al 2020, *J. Phys. G: Nucl. Part. Phys.* 47 113002.

[4] J.F. Berger and D. Gogny (1980). *Nuclear Physics A.* 333. 302-332.

[5] J. Dobaczewski et al 2021 *J. Phys. G: Nucl. Part. Phys.* 48 102001.

[6] J. N. Wilson et al., *Nature* 590, 566–570 (2021).

This work was partially supported by the STFC Grant No. ST/W005832/1, ST/P003885/1 and ST/V001035/1 and by the Polish National Science Centre under Contract No. 2018/31/B/ST2/02220. We acknowledge the CSC-IT Center for Science Ltd., Finland, for the allocation of computational resources. This project was partly undertaken on the Viking Cluster, which is a high-performance computing facility provided by the University of York. We are grateful for computational support from the University of York High-Performance Computing service, Viking and the Research Computing team.

456

The nuclear charge radius of ¹³C

Auteur: Patrick Müller¹

Co-auteurs: Bernhard Maaß²; Kristian König³; Phillip Imgram⁴; Wilfried Nörtershäuser³

¹ *Institut für Kernphysik, Technische Universität Darmstadt*

² *ANL*

³ *TU Darmstadt*

⁴ *Institute for Nuclear Physics, Technical University Darmstadt*

Auteur correspondant pamueller@ikp.tu-darmstadt.de

Nuclear charge radii extracted from collinear laser spectroscopy are often used to benchmark nuclear structure models. Light nuclei, such as ^{11}Be and ^8B , which have a well known neutron-halo or are expected to have a proton-halo, respectively, are of particular interest. Unfortunately, for boron there is insufficient knowledge of the charge radius of the stable isotopes from elastic electron scattering or muonic atom spectroscopy, to extract reliable nuclear charge radii of radioactive isotopes using collinear laser spectroscopy. However, recent developments in atomic structure calculations enabled us to directly extract absolute nuclear charge radii from laser spectroscopy measurements in helium-like systems [1]. As a starting point for this effort, the isotopic chain of carbon was chosen due to the relatively well-known nuclear charge radius of ^{12}C .

We have now measured the $1s2s^3S_1 \rightarrow 1s2p^3P_{0,1,2}$ transitions in helium-like $^{12,13}\text{C}^{4+}$ at the Collinear Apparatus for Laser Spectroscopy and Applied Science (COALA), located at the Institute for Nuclear Physics at TU Darmstadt. In combination with state-of-the-art mass-shift calculations, we are able to determine the differential nuclear charge radius $\delta\langle r^2 \rangle^{12,13}$ with unprecedented precision. This is the first step towards an extraction of absolute all-optical nuclear charge radii, which require more sophisticated atomic structure calculations. Particularly challenging are systems such as $^{13}\text{C}^{4+}$ or the helium-like ions of the halo-candidates $^8\text{B}^{3+}$ and $^{11}\text{Be}^{2+}$ whose electronic excited states are affected significantly by hyperfine-induced mixing.

In this contribution we report on our measurements in $^{13}\text{C}^{4+}$ and the extraction of the isotope shift from the mixed hyperfine structure which is used to determine $\delta\langle r^2 \rangle^{12,13}$. This project is supported by the German Research Foundation (Project-ID 279384907 –SFB1245).

[1] Yerokhin *et al.*, Phys. Rev. A **106**, 022815 (2022)

parallel / 458

First study of proton capture reaction on stored radioactive ^{118}Te beam

Auteur: Sophia Florence Dellmann¹

Co-auteurs: Alexandre Gumberidze²; Andrey Surzhykov³; Bastian Löher²; Beatriz Jurado⁴; Benjamin Brückner⁵; Bernd Alfred Lorenz²; C. Griffin⁶; Carlo Bruno⁷; Christoph Langer⁸; Christoph Scheidenberger⁹; Christophor Kozhuharov²; Claudia Lederer-Woods⁷; Diego Vescovi⁵; Dmytro Dmytriev²; Emma Haettner¹⁰; Enis Lorenz¹¹; Esther Menz²; Guy Gleckenby¹²; Hans Geissel¹³; Hans T. Tornqvist¹⁴; Helmut Weick¹⁵; Iris Dillmann¹⁶; Ivan Kulikov²; Jacobus Swartz¹⁷; Jan Glorius¹⁸; Jordan Marsh⁷; Jérôme PIBERNAT¹⁹; Kafa Al-Khasawneh⁵; Kathrin Göbel²; Laszlo Varga²; Lukas Bott⁵; Marialuisa Aliotta⁷; Mario Weigand⁵; Markus Steck¹⁸; Michael Heil²; Michael Lestinsky²; Michele Sguazzin²⁰; Nikolaos Petridis²; Oliver Forstner²; Philip Woods⁷; Philipp Erbacher⁵; Pierre-Michel Hillenbrand²; Ragandeep Singh Sidhu²¹; Regina Heß¹⁸; Rene Reifarth¹; Robert Grisenti²; Ronald Joseph²; Rui Jiu Chen¹⁸; Sergey Litvinov¹⁸; Shahab Sanjari²²; Siegbert Hagmann²; Takayuki Yamaguchi²³; Thanassis Psaltis¹¹; Thomas Stöhlker²⁴; Timo Dickel¹³; Tino Morgenroth²; Tom Davinson²⁵; Ulrich Popp²; Uwe Spillmann¹⁸; Yuanming Xing²; Yury Litvinov¹⁸

¹ Goethe University Frankfurt

² GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Germany

³ Physikalisch Technische Bundesanstalt Braunschweig, Germany

⁴ IN2P3/CENBG

⁵ Goethe University Frankfurt, Germany

⁶ TRIUMF

⁷ University of Edinburgh, United Kingdom

⁸ University of Applied Science Aachen, Germany

⁹ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany; Justus-Liebig-Universität Gießen, Gießen, Germany

¹⁰ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

¹¹ TU Darmstadt, Germany

¹² TRIUMF, Vancouver

¹³ GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany; Justus-Liebig-Universität Gießen, Gießen, Germany

¹⁴ Chalmers University of Technology

¹⁵ GSI Darmstadt, Germany

¹⁶ TRIUMF, Canada

¹⁷ Centre Etudes Nucleaires de Bordeaux Gradignan

¹⁸ GSI Darmstadt

¹⁹ CENBG

²⁰ CNRS

²¹ GSI Darmstadt, University of Edinburgh

²² GSI Darmstadt, University of Applied Sciences, Aachen

²³ Saitama University

²⁴ GSI Darmstadt, Helmholtz-Institut Jena

²⁵ U. Edinburgh

Auteur correspondant dellmann@iap.uni-frankfurt.de

For the first time, the proton capture reaction for a stored radioactive isotope has been directly measured. This measurement became possible by combining two unique facilities at GSI (Helmholtz Centre for Heavy Ion Research), the fragment separator (FRS) and the experimental storage ring (ESR). The combination of sharp ion energy, ultra-thin internal gas target, and the ability to adjust the energy of the beam in the ring enables precise, energy-differentiated measurements of the (p,γ) -cross-sections. This provides a sensitive method for measuring (p,γ) and (p,n) reactions relevant for nucleosynthesis processes in supernovae, which are among the most violent explosions in the universe and are not yet well understood.

The cross section of the $^{118}\text{Te}(p,\gamma)$ reaction was measured at energies of astrophysical interest. The heavy ions were stored with energies of 6~MeV/u and 7~MeV/u and interacted with a hydrogen gas-jet target providing the protons. A Double-sided silicon strip detector was used in order to detect the produced ^{119}I ions. The radiative electron capture process occurring in collisions of the fully stripped ^{118}Te ions with electrons from the hydrogen target were used as a luminosity monitor.

These measurements follow a proof-of-principle experiment which was performed in 2016 to validate the method on the stable isotope ^{124}Xe [1].

An overview of the experimental method and preliminary results from the ongoing analysis will be presented.

[1] J. Glorius et al., Phys. Rev. Lett. 122, 092701 (2019)

459

Mass measurement in the neutron-rich Mo region using the new ZD MRTOF system

Auteurs: D. Hou¹; A. Takamine²; S. Iimura³; M. Rosenbusch⁴; Z. Liu¹; C. Chen⁵; W. Xian⁶; S. Yan⁷; M. Wada⁴; P. Schury⁸; Y. Hirayama⁴; H. Ishiyama²; Y. Ito⁹; S. Kimura²; J. Lee⁹; J. Liu¹; H. Liang¹⁰; T.M Kojima²; S. Michimasa¹¹; H. Miyatake⁴; S. Naimi²; S. Nishimura²; Z. Niu¹²; T. Niwase⁴; T. Sonoda¹³; Y.X. Watanabe⁴; H. Wollnik¹⁴

¹ Institute of Modern Physics, Chinese Academy of Sciences

² RIKEN Nishina Center

³ Rikkyo University

⁴ Wako Nuclear Science Center (WNSC), IPNS, KEK

⁵ School of Physics, Engineering and Technology, University of York

⁶ Department of Physics, The University of Hong Kong

⁷ *Jinan University*

⁸ *Wako Nuclear Science Center (WNSC), IPNS, K*

⁹ *Advanced Science Research Center, JAEA Ibaraki*

¹⁰ *Department of Physics, Graduate School of Science, The University of Tokyo*

¹¹ *Center for Nuclear Studies (CNS), The University of Tokyo*

¹² *School of Physics and Optoelectronic Engineering, Anhui University*

¹³ *RIKEN Nishina Cen*

¹⁴ *New Mexico State University*

Auteur correspondant houdongsheng@impcas.ac.cn

The ZD MRTOF system at RIKEN BigRIPS is a new high-precision multi-reflection time-of-flight (MRTOF) mass spectrograph for low-energy radionuclides, which is located downstream of the ZeroDegree spectrometer. A novel helium-filled gas-catcher cell based on radiofrequency (RF) ion guides has been developed to thermalize and transport radioisotopes (RIs) produced via in-flight fission and fragmentation at relativistic energies [1]. The stopped RI ions were extracted from the gas cell as atomic or molecular ions and transported to the MRTOF mass spectrograph [2,3] for direct mass measurements with high resolving power. The first online commissioning experiment was performed in winter 2020. During the commissioning, many atomic masses were measured in a series of parasitic experiments, which provides valuable input for nuclear astrophysics and nuclear structure studies [3]. In this contribution, we would like to report the mass measurement results of $^{111,113}\text{Ag}$, $^{111-113}\text{Pd}$, $^{111,113}\text{Rh}$, $^{111-113}\text{Ru}$, and $^{111,112}\text{Mo}$. We have obtained a good agreement with the previously known data (AME2020), and have achieved the first mass measurement of the isotope ^{112}Mo . Based on the systematics of two-neutron separation energies (S_{2n}) around $N = 70$, we discuss our results in the context of the sudden onset of nuclear deformation in this region visible by S_{2n} values, which maximizes for Sr, Y, and Zr isotopes [4]. Furthermore, we compare our data with global mass models and present new results from a Bayesian machine-learning approach.

[1] M. Wada et al., Nucl. Instrum. Methods Phys. Res. B. 204, 570 (2003).

[2] H. Wollnik and M. Przewloka, Int. J. Mass Spectrom. Ion Proc., 96, 267 (1990).

[3] M. Rosenbusch et al., Nucl. Instrum. Methods Phys. Res. A 1047, 167824 (2023).

[4] S. Naimi et al., Phys. Rev. Lett. 105, 032502 (2010).

parallel / 460

Production of medical grade Ac-225 with resonant laser ionization and mass separation at CERN MEDICIS

Auteur: Jake Johnson¹

Co-auteurs: Benji Leenders²; Bruce Marsh³; CHARLOTTE DUCHEMIN⁴; Cyril Bernerd⁵; Eric Chevallay³; Frank Bruchertseifer⁶; Laura Lambert³; Mia Au⁴; Michael Heines¹; Ralf Rossel³; Silvia Bara⁷; Sophie Hurier⁸; Thierry Stora³; Thomas Elias Cocolios⁷; Viktor Van Den Bergh⁷; Wiktoria Wojtaczka¹

¹ *KU Leuven*

² *SCK CEN, Gent Universiteit*

³ *CERN, Meyrin, Switzerland*

⁴ *CERN*

⁵ *CERN, Meyrin, Switzerland & KU Leuven, Institute for Nuclear and Radiation Physics, Heverlee, Belgium*

⁶ *JRC Karlsruhe*

⁷ *IKS, KU Leuven, Belgium*

⁸ *SCK CEN, KU Leuven*

Auteur correspondant jake.johnson@kuleuven.be

The medical radioisotope Ac-225 is produced at a handful of accelerator facilities by high energy proton irradiation of thorium-based targets. The current standard separation protocol of this isotope

and its generator parent Ra-225 from irradiated targets is based on radiochemistry. This method can recover Ac-225 and Ra-225 with high radiochemical yields of >90%. Nonetheless, a major issue is that the recovered Ac solutions contain the long-lived Ac-227 with an activity potentially unsafe for medical use. In order to address this, the method of resonant laser ionization and mass separation can instead be performed on Ac-225-containing samples including irradiated ThO₂ matrices, or as solutions dried on refractory foils. This contribution will provide a comprehensive overview of the multiple collections of Ac-225 that have been performed with this method at CERN MEDICIS from different starting samples. For each collection, the total separation efficiency as measured by complementary alpha- and gamma-spectroscopy techniques will be reported and discussed. Furthermore, the separation factor of Ac-225 compared to Ac-227 through this method and hence its suitability for producing medically relevant Ac-225 samples will be reported where applicable. During the discussion, emphasis will be placed on the systematics of the laser ionization efficiency, as well as Ac-225 release as a function of its chemical environment and temperature. The contribution will conclude by recommending an optimum method for separating medical grade Ac-225 from thorium-based targets irradiated with protons.

parallel / 466

Onset of deformation in the neutron-rich krypton isotopes via transfer reactions with the ISOLDE Solenoidal Spectrometer

Auteur: Annie Dolan¹

Co-auteurs: Andreas Ceulemans²; Ben Jones¹; Betoool Alayed¹; Bruno Olaizola³; Chris Page⁴; Daniel Clarke⁵; David Sharp⁶; Frank Browne³; Ian Lazarus⁷; Joonas Ojala¹; Liam Gaffney¹; Magda Satrazani¹; Marc Labiche⁸; Oleksii Poleshchuk⁹; Peter Butler¹; Riccardo Raabe²; Robert D. Page¹; Samuel Bennett⁵; Sean Freeman¹⁰; Thorsten Kröll¹¹; Zixuan Yue⁴

¹ *University of Liverpool*

² *KU Leuven*

³ *CERN*

⁴ *University of York*

⁵ *The University of Manchester*

⁶ *University of Manchester*

⁷ *Daresbury Laboratory*

⁸ *STFC Daresbury Laboratory*

⁹ *KU Leuven, Institute for Nuclear and Radiation Physics*

¹⁰ *CERN, The University of Manchester*

¹¹ *TU Darmstadt*

Auteur correspondant adolan@liverpool.ac.uk

In the $A = 100$ region, the dramatic shape change observed for Zr [1-3] and Sr [4-7] ($Z = 40$ and 38 , respectively) is not present in Kr ($Z = 36$) isotopes [8-10]. The 2_1^+ energies and the $B(E2; 2_1^+ \rightarrow 0_1^+)$ values vary smoothly across the Kr isotopes but Sr and Zr isotopes display a large jump at $N = 60$, indicating a significant increase in the ground state deformation of these isotopes. The $\nu g_{7/2}$ orbital is filled in the ground states of the krypton isotopes around $N = 59$ and is thought to lower the energy of the $\pi g_{9/2}$ orbital and help to drive deformation in this region.

Previous studies in this region have shown a smooth onset of deformation in Kr isotopes at $N = 60$ [9,10] and evidence of a new oblate structure coexisting with the prolate ground state [11]. Accurately predicting ground-state spins and parities of odd-mass isotopes in this region is challenging due to the large valence space, and lack of ESPE data and accurate shell-model interactions. The single-particle energy differences and spectroscopic factors extracted from neutron adding reactions will provide a more complete experimental picture of the underlying single-particle configurations, which will allow for comparison to modern shell-model calculations [12] that try to describe the onset of deformation around $A = 100$.

The evolution of neutron single-particle properties and their role in the onset of deformation towards $N = 60$ in the neutron-rich Kr isotopes has been studied via the one-neutron transfer reactions $^{92,94}\text{Kr} (d,p)$. These were performed in inverse kinematics at an energy of 7.5 MeV/u using the ISOLDE Solenoidal Spectrometer at ISOLDE, CERN. The main goals are to determine the energy difference between the $2\nu s_{1/2}$ and $0\nu g_{7/2}$ orbitals below $N = 60$ using the $^{92,94}\text{Kr} (d,p)$ reactions to identify the likely $\Delta\ell = 4$ transfer to the $7/2^+$ state. Preliminary results obtained from the October 2022 experiment will be presented.

- [1] F. Browne et al., Phys. Lett. B **750**, 448 (2015).
- [2] J. E. García-Ramos and K. Heyde, Phys. Rev. C **100**, 044315 (2019).
- [3] P. Spagnoletti et al., Phys. Rev. C **100**, 014311 (2019).
- [4] F. Buchinger et al., Phys. Rev. C **41**, 2883 (1990).
- [5] E. Clément et al., Phys. Rev. Lett. **116**, 022701 (2016).
- [6] A. Chester et al., Phys. Rev. C **96**, 011302 (2017).
- [7] S. Cruz et al., Phys. Rev. C **100**, 054321 (2019).
- [8] M. Keim et al., Nucl. Phys. A **586**, 219 (1995).
- [9] M. Albers et al., Phys. Rev. Lett. **108**, 062701 (2012).
- [10] M. Albers et al., Nucl. Phys. A **899**, 1 (2013).
- [11] T. R. Rodríguez, Phys. Rev. C **90**, 034306 (2014).
- [12] T. Togashi et al., Phys. Rev. Lett. **117**, 172502 (2016).

468

Systematic nuclear-DFT calculations of electromagnetic moments of $\pi 7/2^+$ and $\nu 11/2^-$ configurations in heavy deformed open-shell odd nuclei with $50 \leq Z \leq 64$

Auteur: Herlik Wibowo¹

Co-auteurs: David Muir¹; Adrián Sánchez-Fernández¹; Xuwei Sun¹; Jacek Dobaczewski¹

¹ University of York

The study of nuclear electromagnetic moments can provide detailed information on nuclear structure [1]. While the quadrupole moments serve as an excellent tool to probe nuclear deformation and collective behavior, the magnetic moments are significantly affected by the single-particle orbits of unpaired nucleons. The shell model [2] has been successfully applied to describe the experimental electromagnetic moments, albeit with the necessity to introduce the g -factors and effective charges in the dipole and quadrupole operators, respectively. In our recent work [3,4], systematic calculations of the electric quadrupole and magnetic dipole moments were performed using the nuclear-density-functional-theory (nuclear-DFT). The spectroscopic moments of angular-momentum-projected (AMP) wave functions were determined and compared with the available experimental data. It was shown that a good agreement with data can be achieved without the use of effective g -factors and charges. In the present contribution we consider triaxial deformations. As the triaxial deformations strongly modify the single-particle orbits, it is instructive to investigate its effects on nuclear magnetic moments. The nuclear magnetic dipole properties of ground and Z -vibrational bands in Dy and Er isotopic chains have been studied using the triaxial projected shell model [5]. The study has found that the N -factor ratio of the γ state in ground bands to that of g -bands varies as a function of triaxiality. This result motivates us to investigate the effects of triaxial deformations on the properties of nuclear magnetic moments both for even-even and odd nuclei. Specifically, we perform systematic calculations of magnetic dipole and electric quadrupole moments for paired nuclear states associated with the proton (neutron) quasiparticles blocked in the 2^+ (γ) configurations of deformed open-shell odd nuclei shown in Fig 1. The self-consistent shape and spin core polarizations are established in the self-consistent calculations based on the spherical and time-reversal symmetry breaking. Calculations are performed using code HFODD. To consider the triaxiality, we first perform the potential energy surface (PES) calculations $7/2^+$ in the gamma-unstable region around $11/2^-$ Ba nucleus. For the obtained triaxial shapes, we then determine the spectroscopic moments of the AMP wave functions.

- [1] G. Neyens, Rep. Prog. Phys. **66**, 633 (2003)
- [2] A. Klose *et al.*, Phys. Rev. C **99** 061301(R) (2019)
- [3] P. L. Sassarini *et al.*, J. Phys. G: Nucl. Part. Phys. **49**, 11LT01 (2022)
- [4] J. Bonnard, J. Dobaczewski, G. Danneaux, and M. Kortelainen, arXiv:2209.09156v1
- [5] Y. Sun, J. A. Sheikh, and G-L. Long, Phys. Lett. B **533**, 253 (2002)

We acknowledge the support from a Leverhulme Trust Research Project Grant. This work was partially supported by the STFC Grant Nos. ST/P003885/1 and ST/V001035/1 and by the Polish National Science Centre under Contract No. 2018/31/B/ST2/02220. We acknowledge the CSC-IT Center for Science Ltd., Finland, for the allocation of computational resources. This project was partly undertaken on the Viking Cluster, which is a high performance compute facility provided by the University of York. We are grateful for computational support from the University of York High Performance Computing service, Viking and the Research Computing team.

469

Charge-current and neutral-current quasielastic (anti)neutrino scattering on ^{12}C and ^{40}Ar targets with realistic spectral and scaling functions

Auteur: Martin Ivanov¹

Co-auteurs: Anton Antonov¹; Maria Barbaro²; Juan Caballero³; Guillermo Megias⁴; Carlotta Giusti⁵; Raul González-Jiménez⁶; Andrea Meucci⁵; Elvira Moya de Guerra⁶; Jose Udias⁶

¹ *Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia 1784, Bulgaria*

² *Dipartimento di Fisica dell'Università di Torino and INFN – Sezione di Torino, via Pietro Giuria 1, 10125 Turin, Italy*

³ *Departamento de Física Atómica, Molecular y Nuclear, Universidad de Sevilla, 41080 Sevilla, Spain*

⁴ *Research Center for Cosmic Neutrinos, Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan*

⁵ *Dipartimento di Fisica, Università degli Studi di Pavia and INFN – Sezione di Pavia, via Bassi 6 I-27100 Pavia, Italy*

⁶ *Grupo de Física Nuclear, Departamento de Estructura de la Materia, Física Térmica y Electrónica and IPARCOS, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, CEI Moncloa, Madrid 28040, Spain*

Auteur correspondant martin@inrne.bas.bg

Charge-current (CC) and neutral-current (NC) quasielastic (anti)neutrino scattering cross sections on ^{12}C and ^{40}Ar targets are analyzed using a realistic spectral function $S(p, \text{cal}E)$ that gives a scaling function in accordance with the (e, e') scattering data. The spectral function accounts for the nucleon-nucleon correlations and has a realistic energy dependence. The standard value of the axial mass $M_A = 1.03$ GeV is used in the calculations. The role of the final-state interaction on the spectral and scaling functions, as well as on the cross sections is accounted for. Our results in the CC case are compared with those from other theoretical approaches, such as the Superscaling Approach and the relativistic Fermi gas, as well as with those of the relativistic mean field and the relativistic Green's function in the NC case. Based on the impulse approximation our calculations for the CC scattering underpredict the MiniBooNE and Minerva data but agree with the data from the NOMAD experiment. The NC results are compared with the empirical data of the MiniBooNE and BNL experiments. The possible missing ingredients in the considered theoretical methods are discussed.

470

First in-gas-jet laser spectroscopy with $\text{S}^3\text{-LEB}$

Auteur: Anjali Ajayakumar¹

Co-auteurs: Alejandro Ortiz-Cortes²; Alexandre Brizard¹; Antoine Drouart³; Antoine de Roubin⁴; Arno Claessens⁴; Benoit OSMOND; Christophe Vandamme⁵; Dominik Studer⁶; Emil Traykov⁷; Fedor Ivandikov⁸; Franck Lutton

⁹; Frederic Boumard ⁵; Hervé Savajols ¹⁰; Iain Moore ¹¹; Jean-François Cam ⁵; Jekabs Romans ⁴; Juha Uusitalo ¹¹; Julien Lory ; Julien Piot ¹; Klaus Wendt ⁶; Lucia Caceres ¹²; Martial Authier ³; Nathalie LECESNE ¹; Olivier POCHON ¹³; PATRICIA DUCHESNE ¹⁴; Patrice Gangnant ¹; Paul Van den Bergh ¹⁵; Philippe Desrués ⁵; Pierre DELAHAYE ¹; Piet Van Duppen ¹⁵; Rafael Ferrer ¹⁶; Renan Leroy ¹; Ruben de Groot ⁴; Sarina Geldhof ¹; Sebastian Raeder ¹⁷; Serge Franchoo ¹⁸; Vladimir Manea ¹⁹; Wenling Dong ¹⁸; Xavier Flechard ⁵; Yazeed Balasmeh ⁴; Yvan MERRER ⁵

¹ GANIL

² Grand Accélérateur d' Ions Lourds (GANIL)

³ CEA

⁴ KU Leuven

⁵ LPC Caen

⁶ Johannes Gutenberg University, 55099 Mainz, Germany

⁷ IPHC

⁸ IKS, KU Leuven, Belgium

⁹ CNRS

¹⁰ GANIL/CNRS

¹¹ University of Jyväskylä

¹² CEA-GANIL

¹³ IJCLAB.IN2P3

¹⁴ IPNO

¹⁵ KU Leuven, Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium

¹⁶ Instituut voor Kern- en Stralingsfysica, KU Leuven

¹⁷ GSI Darmstadt

¹⁸ IJCLab

¹⁹ IJCLab, Orsay

Auteur correspondant anjali.ajayakumar@ganil.fr

The Superconducting Linear Accelerator (SPIRAL2-LINAC) facility of GANIL will extend the capabilities of studying exotic nuclei by producing beams of rare radioactive isotopes with highest intensities achieved so far [1,2]. The SPIRAL2-LINAC coupled with the Super Separator Spectrometer (S^3) recoil separator will allow the production of neutron-deficient nuclei close to the proton dripline and super heavy nuclei via fusion-evaporation reactions and separate them from the intense background contamination [3]. The S^3 -Low Energy Branch (S^3 -LEB), currently under commissioning at LPC Caen, will sit at the focal plane of S^3 and stop, thermalize, and then neutralize the radioactive isotopes using a buffer gas cell set-up. The S^3 -LEB is dedicated to the study of ground state and isomeric state properties using laser ionization with high efficiency and high selectivity.

Development work has been ongoing at the S^3 -LEB setup [4, 5]. It uses in-gas-jet laser ionization, to resonantly ionize the neutralized atoms, and ion guides to send them to the Piège à Ions Linéaire du GANIL pour la Résolution des Isobares et la mesure de Masse (PILGRIM), a Multi-Reflection Time Of Flight Mass Spectrometer (MR-TOF-MS), or to a decay spectroscopy study station, SEASON. A buffer gas cell with 400 ms extraction time has been coupled to the ion transport ensemble and a de-Laval nozzle of Mach number $M \sim 8$ (developed at KU Leuven) has been installed at the gas cell aperture, which can create a hypersonic jet of narrow velocity distribution in a reduced collision environment. The hypersonic jet environment reduces the Doppler and pressure broadening by at least an order of magnitude compared to the gas cell [6,7]. Laser spectroscopy with suitable atomic transition schemes at S^3 -LEB offers improved spectral resolution (≤ 300 MHz) while maintaining high efficiency, enabling access to isotope shifts and hyperfine constants measurements and thus to nuclear structure such as nuclear spin, moments and difference in nuclear charge radii for the exotic nuclei.

Here, we present the results from the offline commissioning of S^3 -LEB with first in-gas-jet ionization and high-resolution laser spectroscopy in-gas-jet results for erbium, performed to validate the potential of the setup. Measurements of the isotope shifts and hyperfine constants in the hypersonic gas jet will be compared to literature and measurements in an Atomic Beam Unit (ABU). Characterization of the pressure broadening effects in gas cell will be reported. Additionally, first optimization of the overall transport efficiency for the setup with laser-produced ions will be presented.

- [1] Grand Accélérateur National d'Ions Lourds, URL: <https://www.ganil-spiral2.eu/en/>
- [2] F. Déchery, et al., Eur. Phys. J. A 51, 66 (2015)
- [3] F. Déchery, et.al., NIMS B, 376125 (2016)
- [4] J. Romans, et al., Atoms, 10, 21 (2022)
- [5] J. Romans, et.al., NIM B, 536, 72 (2023)
- [6] R. Ferrer, et.al., NIMS B, 317570 (2013)
- [7] R. Ferrer, et.al., Nat. Comm. 8, 14520 (2017)

parallel / 471

Ab initio calculation of the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ astrophysical S factor

Auteur: Mack Atkinson¹

Co-auteurs: Guillaume Hupin²; Konstantinos Kravvaris³; Petr Navratil⁴; Sofia Quaglioni³

¹ Lawrence Livermore National Laboratory

² IN2P3

³ LLNL

⁴ TRIUMF

Auteur correspondant atkinson27@llnl.gov

The ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ reaction is an important part of ongoing processes occurring in stars like our very own sun. In the fusion reaction network of the sun, the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ reaction is key to determining the ${}^7\text{Be}$ and ${}^8\text{B}$ neutrino fluxes resulting from the pp-II chain. In standard solar model (SSM) predictions of these neutrino fluxes, the low-energy ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ S factor, $S_{34}(E)$, is the largest source of uncertainty from nuclear input. The SSM uses $S_{34}(E)$ near the Gamow peak energy, roughly 18 keV, which cannot be experimentally measured since the Coulomb force between ${}^3\text{He}$ and ${}^4\text{He}$ suppresses the fusion reaction at such low energies. Theoretical calculations are needed to guide the extrapolation to the solar energies of interest. To this end, I will present *ab initio* calculations of the ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$ reaction using the no-core shell model with continuum starting from two- and three-nucleon chiral interactions. To demonstrate that the NCSMC provides an accurate S factor, I will also compare NCSMC ${}^3\text{He} + {}^4\text{He}$ elastic-scattering cross sections with those recently measured by the SONIK collaboration.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC.

472

$B\rho$ -defined isochronous mass spectrometry using two TOF detectors at CSRe-Lanzhou

Auteur: Yu Hu Zhang¹

Co-auteurs: Meng Wang¹; Yuri. A. Litvinov²

¹ Institute of Modern Physics, Chinese Academy of Sciences

² GSI Helmholtzzentrum für Schwerionenforschung

Auteur correspondant yhzhang@impcas.ac.cn

A novel isochronous mass spectrometry, termed as $B\rho$ -defined IMS, has been established at the experimental cooler-storage ring CSRe in Lanzhou. Its potential has been studied through high precision

mass measurements of ^{58}Ni projectile fragments. Two time-of-flight detectors were installed in one of the straight sections of CSRe, thus enabling simultaneous measurements of the velocity and the revolution time of each stored short-lived ion. This allows for calculating the magnetic rigidity $B\rho$ and the orbit length C of each ion. The accurate $B\rho(C)$ function has been constructed, which is a universal calibration curve used to deduce the masses of the stored nuclides. The sensitivity to single stored ions, fast measurement time, and background-free characteristics of the method are ideally suited to address nuclides with very short lifetimes and smallest production yields. In the limiting case of just a single particle, the achieved mass resolving power allows one to determine its mass-over-charge ratio m/q with a remarkable precision of merely ~ 5 keV. Masses of $T_z = -3/2$ fp-shell nuclides are re-determined with high accuracy, and the validity of the isospin multiplet mass equation is tested up to the heaviest isospin quartet with $A = 55$. The new masses are also used to investigate the mirror symmetry of empirical residual proton-neutron interactions.

473

Direct mass measurement of neutron-deficient Fe isotopes

Auteur: Shutaro Hanai¹

Co-auteurs: Nobu Imai¹; Rin Yokoyama¹; Shin'ichiro Michimasa¹

¹ Center for Nuclear Study (CNS), The University of Tokyo

Auteur correspondant hanai@cns.s.u-tokyo.ac.jp

The two-proton radioactivity, so-called $2p$ decay, is a decay mode where two protons are simultaneously emitted from a ground state of nuclei with a large proton excess, such as ^{45}Fe and ^{48}Ni . Theoretical models suggest that the valence two protons in the $2p$ decay process are strongly correlated due to the pairing effect and paired protons tunnel through the Coulomb potential [1, 2]. Although some events of $2p$ decay and half-lives are reported in recent studies [3, 4], the pairing energies of two protons in $2p$ emitters are not investigated experimentally and the mechanism of $2p$ decay is still not fully understood.

We, therefore, performed direct mass measurements around ^{45}Fe to reveal the development of energy structure towards the $2p$ -decay nucleus.

Two-proton separation energies and proton-pairing energies of neutron-deficient nuclei will be evaluated by using experimentally-obtained mass differences from this experiment.

The experiment was performed at RI beam Factory in RIKEN, Japan. In this study, the TOF-Brho technique was used to measure the masses of short-lived nuclei. The ions produced by fragmentation reactions of ^{78}Kr were separated through the BigRIPS separator and transported to the OEDO-SHARAQ beamline. We confirmed that the cocktail beam included a two-proton emitter ^{45}Fe nucleus even with a small fraction and many Fe, Cr, and Ti isotopes around ^{45}Fe . The data analysis is still underway, but we will determine these masses from the presently-obtained data.

In this talk, details of the experiment and the preliminary results of the analysis will be reported.

[1] B. A. Brown, Phys. Rev. C **43**, R1513 (1991).

[2] B. J. Cole, Phys. Rev. C **54**, 1240 (1996).

[3] C. Dossat et al., Phys. Rev. C. **72**, 054315, (2005).

[4] K. Miernik et al., Eur. Phys. J. A. **42**, 431-439 (2009).

474

Development of Ti:Sapphire laser system for resonance ionization laser ion source, PALIS RIKEN

Auteur: Hideki Tomita¹

Co-auteurs: Hiroki Miura¹; Volker Sonnenschein²; Tetsu Sonoda³; Hironobu Ishiyama⁴; Klaus Wendt⁵

¹ Nagoya University, Japan

² Nagoya University (Current affiliation Hübner Photonics)

³ RIKEN, Japan

⁴ RIKEN

⁵ Johannes Gutenberg-Universität Mainz, Germany

Auteur correspondant tomita@nagoya-u.jp

A parasitic low-energy RI-beam production system (PALIS) at BigRIPS, RIKEN has been developed to allow effective use of the RI species surrounding the main beam. We confirmed resonance ionization of stable Bi atoms in the gas catcher of PALIS using broad bandwidth dye and Ti:Sapphire laser systems. Toward high-resolution resonance ionization spectroscopy in gas jet at PALIS, we developed a narrow bandwidth injection-locked Ti:Sapphire pulsed laser system using a direct diode-pumped continuous wave Ti:Sapphire laser as a single-frequency seed source. Output powers of up to 2.8 W and 150 mW were achieved at a repetition rate of 10 kHz in the fundamental and second harmonic generation, respectively. High-resolution resonance ionization spectroscopy of stable Cs and Ga atoms in a graphite furnace was demonstrated by the injection-locked laser system coupled with a time-of-flight mass spectrometer.

Acknowledgment: This research was partially supported by JST SCORE University Promotion Type JPMJST2076, JST, PRESTO JPMJPR19G7, and JSPS KAKENHI: Grant-in-Aid for Transformative Research Areas (B) 22H05023, Japan.

475

Precision velocity measurements of ions in the storage ring CSRe-Lanzhou

Auteurs: Xu Zhou¹; Meng Wang¹; Yu Hu Zhang¹

¹ Institute of Modern Physics - Lanzhou, Chinese Academy of Sciences

Auteur correspondant zhouxu@impcas.ac.cn

Storage-ring-based isochronous mass spectrometry (IMS) is a powerful tool for mass measurements of short-lived nuclei. The IMS [1] depends on precision measurements of the mean revolution times of stored ions in a given acceptance of magnetic rigidity of $\sim \pm 0.2\%$ [2]. The mean revolution times are considered to be associated with a reference orbit that all ions move around. For a limited ion species with similar mass-to-charge ratios, m/q , the time spreads due to different path lengths are eliminated or minimized by the so-called isochronous conditions [1], while the revolution times for most of the stored ions with different m/q values have broadened distributions due to their velocity spreads (or equivalently the different path lengths). In order to have a high-resolution time spectrum associated with a specific path length (or equivalently a given magnetic rigidity), a pair of identical TOF detectors of 18 m apart are installed in a straight section of the storage ring CSRe, from which the ion's velocity and revolution time can be simultaneously measured. We have developed a novel method to precisely determine the velocity of each stored ion by considering its Betatron oscillations in the ring [3]. A test experiment showed that the relative precision of $\delta v/v \sim 10^{-5}$ could be achieved for the relativistic heavy ions within a velocity spread of $\Delta\beta \sim 10^{-3}$. The velocity information allows us to construct a high-resolution revolution-time spectrum at a fixed orbital, which is crucial for the following precision mass determinations [4].

[1] M. Hausmann et al., Nucl. Instr. Meth. A446 (2000) 569

[2] Y. H. Zhang et al., Phys. Rev. C 98, 014319 (2018)

[3] X. Zhou et al., Phys. Rev. AB 24, 042802 (2021)

[4] Y. H. Zhang et al., a contribution to this Conference

parallel / 477

Measurements of β -delayed one and two neutron emission probabilities south-east of ^{132}Sn within the BRIKEN project at RIKEN

Auteur: Phong Vi¹

Co-auteurs: Alfredo Estrade²; Fernando Monte³; Giuseppe Lorusso⁴; Shunji Nishimura⁵

¹ RIKEN Nishina Center, Japan and University of Science, Vietnam National University, Hanoi, Vietnam

² Central Michigan University, USA

³ National Superconducting Cyclotron Laboratory, USA

⁴ National Physical Laboratory, UK, University of Surrey, UK and RIKEN Nishina Center, Japan

⁵ RIKEN Nishina Center

Auteur correspondant phong@ribf.riken.jp

Recent observations of metal-poor star elemental and isotopic abundances [Roe22, Wen18] have sparked new interest in the nucleosynthesis of elements around the second r -process abundance peak, as it may shed light on the r -process conditions. To understand the r -process conditions and link these observations to astrophysical models, it is crucial to have information on the nuclear properties of the radioactive progenitors of the second r -process peak.

Following r -process freezeout, the final abundances of the second peak are the result of various competing reactions, such as neutron capture, photodisintegration, fission, and β -delayed neutron emission. The latter has been the main focus of our experiment, conducted within the BRIKEN project [Tol19] at the RIBF facility of RIKEN (Japan).

In the present contribution, we will present new experimental results on β -delayed one and two neutron emission probabilities of very neutron-rich nuclei located south-east of ^{132}Sn [Pho20] and compare them with recent macroscopic-microscopic and self-consistent global models with the inclusion of the statistical treatment of neutron and γ emission [Kaw08, Min21]. The impact of our results on the odd-even staggering of the final r -process abundance around the second r -process peak, as well as the observed odd-mass isotopic fractions of Ba in metal-poor stars [Wen18] will be presented. Continuing our experimental program on r -process nuclei, we will present a new experimental setup that will allow β -decay and β -delayed neutron spectroscopy studies to be conducted in parallel with MR-TOF mass measurements program at RIKEN RIBF.

[Roe22] I. U. Roederer et al., *Astrophys. J. Suppl. Ser.* 260, 27 (2022).

[Wen18] C. Wenyuan et al., *Astrophys. J.* 854, 131 (2018).

[Pho20] V. H. Phong, *Phys. Rev. Lett.* 129, 172701 (2022)

[Tol19] A. Tolosa-Delgado et al., *Nucl. Instr. And Methods A*, 925, 133 (2019)

[Kaw08] T. Kawano, P. Möller, and W. B. Wilson, *Phys. Rev. C* 78, 054601 (2008).

[Min21] F. Minato et al., *Phys. Rev. C* 104, 044321 (2021).

[Ros22] M. Rosenbusch et al., *Nucl. Instr. And Methods A*, 1047, 167824 (2023)

478

The Super Separator Spectrometer (S^3) at GANIL/SPIRAL2

Auteur: Hervé Savajols¹

¹ GANIL/CNRS

Auteur correspondant savajols@ganil.fr

The Super Separator Spectrometer S^3 [1] is, with the NFS (Neutrons For Science) facility, a major experimental system developed for SPIRAL2. It is designed for very low cross section experiments at low ($<15\text{MeV/u}$) energy. It will receive the very high intensity (more than $1\text{p}\mu\text{A}$) stable ion beams

accelerated by the superconducting LINAC accelerator of SPIRAL2. S^3 will be notably used for the study of rare nuclei produced by fusion evaporation reactions, such as superheavy elements and neutron-deficient isotopes. Such experiments require a high transmission of the products of interest but also a separation of these nuclei from unwanted species. Hence S^3 must have a large acceptance but also a high selection power including physical mass resolution. These properties are reached with the use of seven large aperture superconducting quadrupole triplets which include sextupolar and octupolar corrections in a two-stage separator (momentum achromat followed by a mass spectrometer) that can be coupled to the SIRIUS implantation-decay spectroscopy station [2] or to a gas cell with laser ionization to provide very pure beams for low energy experiments [3,4]. S^3 is now in the installation and tests phases. We will present the scientific objectives of S^3 as well as the current status of the facility.

[1] F. Déchery, et al., NIMS B, 376125 (2016)

[2] J. Piot and the S3 collaboration, Acta Phys. Pol. B 43 (2012) 285

[3] J. Romans, et al., Atoms, 10, 21 (2022)

[4] J. Romans, et al., NIM B, 536, 72 (2023)

parallel / 480

Recent Nuclear Structure Studies at N=50 Through Masses of Isomeric States

Auteur: Lukas Nies¹

Co-auteurs: Anu Kankainen ²; David Lunney ³; Klaus Blaum ⁴; Lutz Schweikhard ⁵

¹ CERN / University of Greifswald (DE)

² University of Jyväskylä

³ CNRS/IN2P3

⁴ MPIK

⁵ University Greifswald

Auteur correspondant lukas.nies@cern.ch

The nuclear binding energy arises from various effects that govern nuclear properties. Different nucleon configurations within nuclear isomers lead to modified binding energies, often resulting in mass differences of tens to hundreds of kilo-electronvolts. These isomeric excitation energies can be directly accessed by measuring the difference in atomic masses of ground and isomeric states. Here, we present such measurements performed through multi-reflection time-of-flight [1] and ion-cyclotron resonance mass spectrometry [2]. By evaluating the excitation energies of neutron-deficient indium isotopes down to the shell closure at N=50 against state-of-the-art shell model, DFT, and ab initio calculations, we contrast the performance of these theories applied to several nuclear properties [3,4]. We further present evidence for shape-coexistences close to N=50 through independent excitation energy measurements of the $1/2^+$ state in ^{79}Zn with JYFLTRAP at IGISOL and ISOLTRAP at ISOLDE, supported by accurate large-scale shell model calculations [5].

[1] Wienholtz, F. et al. (2013). Masses of exotic calcium isotopes pin down nuclear forces. *Nature*, 498(7454), 346–349. <https://doi.org/10.1038/nature12226>

[2] Dilling, J., Blaum, K., Brodeur, M., & Eliseev, S. (2018). Penning-Trap Mass Measurements in Atomic and Nuclear Physics. *Annual Review of Nuclear and Particle Science*, 68, 45–74.

[3] Mougeot, M. et al. (2021). Mass measurements of 99–101In challenge ab initio nuclear theory of the nuclide 100Sn. *Nature Physics*, 17(10), 1099–1103. <https://doi.org/10.1038/S41567-021-01326-9>

[4] L. Nies et al., Isomeric excitation energy for ^{99m}In from mass spectrometry reveals contrasting trends next to doubly magic ^{100}Sn , *Physical Review Letters* (2023) accepted

[5] L. Nies et al., Further Evidence for Shape Coexistence in ^{79m}Zn near Doubly Magic ^{78}Ni , *Physical Review Letters* (2023) submitted

482

Development of ^{14}C cavity ring-down spectroscopic system for biomedical tracer and environmental applications

Auteur: Keisuke Saito¹

Co-auteurs: Ryohei Terabayashi²; Kazuki Iwamoto¹; Volker Sonnenschein³; Shinichi Ninomiya⁴; Yuta Kawashima⁴; Kazune Mano⁴; Tetsuo Furumiya⁴; Koji Tojo⁴; Kenji Yoshida⁵; Norihiko Nishizawa¹; Hisashi Abe⁶; Hideki Tomita¹

¹ Nagoya University

² Nagoya University, The University of Tokyo

³ Nagoya University (Current affiliation Hübner Photonics)

⁴ Shimadzu Corp.

⁵ Sekisui Medical Co. Ltd.,

⁶ National Institute of Advanced Industrial Science and Technology (AIST)

Auteur correspondant saito.keisuke.u1@s.mail.nagoya-u.ac.jp

Long-lived radioactive carbon isotopes ^{14}C are widely used as a tracer in environmental and biomedical studies. We are developing a ^{14}C analytical system based on highly sensitive cavity-enhanced laser absorption spectroscopy, i.e. cavity ring-down spectroscopy (CRDS). Using a distributed feedback diode laser stabilized by optical feedback from a V-shape cavity, a single detection limit of $1 \times 10^{-9} \text{ cm}^{-1} \text{ Hz}^{-1/2}$ corresponding to a detectable abundance of 0.2 in fraction modern ^{14}C for a 10 second averaging time was demonstrated. To achieve further abundance sensitivity, the ^{14}C analytical system was combined with a mid-infrared optical frequency comb. In this presentation, we will show an overview of the ^{14}C analytical system based on CRDS and recent results in ^{14}C determinations for bio-tracer applications.

Acknowledgment: This work was partially supported by JST PRESTO JPMJPR19G7, JST CREST JPMJCR2104, JST SPRING program JPMJSP2125, JSPS KAKENHI: Grant-in-Aid for Early-Career Scientists 20K15205, and JSPS KAKENHI: Grant-in-Aid for Transformative Research Areas (B) 22H05023, Japan.

484

Shape studies in neutron-rich cerium isotopes

Auteur: Magda Satrazani¹

Co-auteurs: A. Diaz Varela²; A. Fuad²; A. J. Radich²; A.B Garnsworthy³; B. C. Olaizola Mampaso³; B. K. Luna⁴; C. Andreoiu⁵; C. Petrache⁶; C. Svensson²; D. Yates⁷; E. Timakova³; F. H. Garcia⁵; G. Grinyer⁸; J. Keatings⁹; J. L. Mitchell⁸; J. Smallcombe³; J.F. Smith⁹; K. Mashtakov⁹; K. Whitmore⁵; L. Sexton¹⁰; L.P. Gaffney¹¹; M. Bowry³; M.M Rajabali⁴; M.P. Hladun⁸; N. Bernier⁷; P. Siuryte¹⁰; P. Spagnoletti⁹; R. Cabellero-Folch³; R. Coleman²; R. Lefleur²; S. S. Bhattacharjee³; Y. Saito⁷

¹ University of Liverpool

² University of Guelph

³ TRIUMF

⁴ Tennessee Technological University

⁵ Simon Fraser University

⁶ Paris Sud

⁷ TRIUMF/UBC

⁸ University of Regina

⁹ UWS

¹⁰ TRIUMF/University of Surrey

¹¹ CERN**Auteur correspondant** maria-magdalini.satrazani@cern.ch

Octupole correlations are the result of the long-range octupole-octupole interaction between nucleons occupying pairs of orbitals which differ by 3 units in both orbital and total angular momentum. This interaction gives rise to an asymmetric pear-shaped form that can be manifested by the appearance of low-lying negative-parity states [1]. The presence of octupole deformation has only been observed in localized regions of the nuclear chart and more specifically in the mass region around $Z = 88$, $N = 134$ [2-5] with the next promising region to be around $Z = 56$, $N = 88$ [6]. Isotopes with their Fermi surfaces close to these particle numbers are predicted to possess an octupole collectivity [7] which can be characterized by enhanced $B(E3)$ values, as observed in recent experiments on $^{144,146}\text{Ba}$ [8-9]. The neighbouring cerium isotopes with $146 \leq A \leq 152$ are also considered to be excellent candidates to study this kind of deformation [10-11]. Studying the electromagnetic properties of excited states is essential in our understanding of the magnitude and mode of octupole deformation, whether it is static or vibrational in nature [3].

A β -decay experiment has been performed at the radioactive ion beam facility ISAC-I at the TRIUMF particle accelerator center in Vancouver, Canada, aiming to look for low-lying negative-parity states in neutron-rich cerium isotopes. Beams of Cs were initially produced from a UC_x target and implanted on an aluminized mylar moving tape collector. The population of states in $^{146,148,150,152}\text{Ce}$ was possible through the decay of the grand-daughter La isotopes. Spectroscopy measurements have been performed using the GRIFFIN spectrometer, which consists of an array of 16 Compton-suppressed HPGe clover detectors for the detection of gamma-rays, 5 scintillators for conversion electron spectroscopy and 8 LaBr_3 detectors to allow for fast-timing measurements of excited-state lifetimes.

In this talk, preliminary results of this experimental campaign will be presented including the identification of new excited levels in ^{148}Ce . Additionally, from angular distribution measurements, the assignment of spin and parity of the proposed low-lying 1^- and 3^- states in $^{146,148}\text{Ce}$ [12] will be discussed.

- [1] W. Phillips et al., Phys. Lett. B **212**, 402 (1988)
- [2] L.P Gaffney et al., Nature, **497**, 199 (2013)
- [3] P.A. Butler et al., Phys. Rev. Lett. **124**, 042503 (2020).
- [4] P. Spagnoletti et al., Phys. Rev. C **105**, 024323 (2022)
- [5] P.A. Butler et al., Nat. Commun. **10**, 2473 (2019).
- [6] P.A. Butler, J. Phys. G Nucl. Part. Phys. **43**, 073002 (2016).
- [7] P.A. Butler and W. Nazarewicz, Rev. Mod. Phys. **68**, 349 (1996).
- [8] B. Bucher et al., Phys. Rev. Lett. **116**, 112503 (2016).
- [9] B. Bucher et al., Phys. Rev. Lett. **118**, 152504 (2017).
- [10] Y. Chen et al., Phys. Rev. C **73**, 054316 (2006).
- [11] K. Nomura, R. Rodriguez-Guzman, and L.M. Robledo, Phys. Rev. C **104**, 054320 (2021).
- [12] R.L. Gill, et al., Phys. Rev. C **27**, 1732 (1983).

487

Technical progress on the double Penning trap PIPERADE

Auteur: Dinko Atanasov¹

Co-auteurs: Antoine de Roubin²; Audric Husson¹; Benoit LACHACINSKI¹; Laurent Daudin¹; Marjut Hukkanen³; Mathias GERBAUX¹; Mathieu FLAYOL¹; Pauline Ascher¹; Philippe Alfaut¹; Sean Pérard¹; Stéphane Grévy¹; Yan Langlois¹

¹ LP2iB-CNRS/Université de Bordeaux² KU Leuven³ University of Jyväskylä and LP2iB**Auteur correspondant** atanasov@lp2ib.in2p3.fr

The double Penning trap PIPERADE (Pièges de Penning pour les Radionucléides à DESIR) [1] for the DESIR facility has been advancing in its commissioning phase at the LP2i-Bordeaux laboratory. The traps were designed with the objective of performing high-precision mass measurements and high-resolution mass purification of strongly contaminated ion beams. The latter will be produced by the existing SPIRAL1 facility and the S3 spectrometer. In order to push the limits of existing devices, PIPERADE is equipped with a new type of high-capacity large trap that aims to separate up to $10^4 - 10^5$ ions per bunch.

The purified samples will be re-injected in the main DESIR beam line for downstream setups to perform trap-assisted spectroscopy. Alternatively, the purified samples will be utilized to perform high-precision mass measurements. In this context, standard ion-beam manipulation techniques are now being routinely demonstrated, i.e. the sideband buffer gas cooling (BGC) [2] and the time-of-flight ion-cyclotron-resonance (ToF-ICR) [3], while others are being implemented - phase-imaging ion-cyclotron-resonance (PI-ICR) [4]. Last year, as part of the implementation process of PI-ICR, an imaging system consisting of a microchannel-plate detector coupled to an anode constructed of helical wire delay lines was installed. RoentDek Handels GmbH has developed the delay-line anode with a specific three-layer geometry (“Hexanode”) [5] to improve the ambiguity of multi-hit position and time encoding on the detector.

In this contribution, we will present the latest achievement from the BGC technique, the first mass measurement by using ToF-ICR and finally, the detector installation to allow the position encoding for future PI-ICR measurements.

[1] P. Ascher et al., Nucl. Instrum. Methods. Phys. Res. A 1019 (2021) 165857

[2] G. Savard, et al., Phys. Lett. A 158 (1991) 247

[3] M. Koenig, et al., Int. J. Mass Spectrom. 31 (1995) 95

[4] S. Eliseev et al., Phys. Rev. Lett. 110 082501 (2013)

[5] O. Jagutzki et al., IEEE Trans. Nuc. Sci. 49 (2002) 5

491

Measurements of the ^{161}Tb production cross section for nuclear data and nuclear medicine

Auteurs: Arnaud Guertin¹; Etienne Nigrón²

Co-auteurs: Alexandre Rintaud³; Maxence Rayer³; Lucas Granger³; Thomas Sounalet¹; Férid Haddad⁴

¹ CNRS/IN2P3/SUBATECH

² GIP ARRONAX

³ SUBATECH

⁴ SUBATECH, GIP ARRONAX

Auteur correspondant arnaud.guertin@subatech.in2p3.fr

^{161}Tb has interesting physical properties for therapeutic applications in nuclear medicine. It has a half-life of 6.88 days and it is a β^- emitter with a mean energy of 154 keV and a maximum energy between 42.85 and 593.1 keV. It corresponds to an electron range of 3 millimeters in water. Its coordination chemistry and energy range, comparable to that of ^{177}Lu used in vectorized radiotherapy, allow a stable coordination with a DOTA chelator, a localized effect on targeted cells and limits the dose received by the surrounding healthy tissues. The therapeutic effect of ^{161}Tb may be enhanced due to the co-emission of a larger number of conversion and Auger electrons as compared to ^{177}Lu . In a theranostic approach, it could be coupled at another terbium isotope dedicated to diagnostic.

Production cross section of various β^- and α emitters dedicated to therapy were measured by the PRISMA team of the Subatech laboratory at the GIP ARRONAX using a multiparticle C70XP cyclotron, the stacked-foil technique and gamma spectroscopy. From irradiated stacks, composed of natGd foils, Ni monitors and Al degraders, we are able to obtain the natGd(d,x) ^{161}Tb cumulative production cross section coming from the reactions $^{160}\text{Gd}(d,p)^{161}\text{Gd}$ and $^{160}\text{Gd}(d,n)^{161}\text{Tb}$

between 6.69 and 16.47 MeV. Previous data sets published in the literature by Tarkanyi et al. [1] and Szelecsenyi et al. [2] are not in accordance, one objective of this work is to better define the shape and the maximum of the excitation function. Additional data have also been collected for the natGd(d,x)155Tb, 156Tb, 160Tb. Results are presented along with values extracted from TENDL-2019.

The only three series of published experimental data have been complemented in the energy region, near 12 MeV, of the maximum cross section, around 50 mb. This production cross section is of interest for nuclear models as it fixes the shape and the amplitude associated to this nuclear reaction and for nuclear medicine as it allows to defined optimized irradiation parameters to produce 161Tb that can be beneficial for vectorized radiotherapy to take advantage of its β^- and Auger electron emissions.

[1] Tarkanyi, F., Hermanne, A., Tackacs, S., Ditroi, F. Csikai, J. & Ignatyuk, A. V. (2013). Cross-section measurement of some deuteron induced reactions on 160 Gd for possible production of the therapeutic radionuclide 161 Tb. *Journal of Radioanalytical and Nuclear Chemistry*, 298(2), 1385-1392. <https://doi.org/10.1007/s10967-013-2507-x>

[2] Szelecsenyi, F., Kovacs, Z., Nagatsu, K., Zhang, M-R. & Suzuki, K. (2016). Investigation of deuteron-induced reactions on natGd up to 30 MeV: possibility of production of medically relevant 155Tb and 161Tb radioisotopes. *Journal of Radioanalytical and Nuclear Chemistry*, 307(3), 1877-1881. <https://doi.org/10.1007/s10967-013-2507-x>

plenary / 494

Latest results from MARA

Auteur: Juha Uusitalo¹ for the nuclear spectroscopy group collaboration

¹ *Accelerator Laboratory, Department of Physics, University of Jyväskylä*

Auteur correspondant juha.uusitalo@jyu.fi

A new vacuum-mode separator, MARA (Mass Analyzing Recoil Apparatus) [1, 2], has been completed and has extended the research possibilities whit the existing gas-filled recoil separator, RITU [3] at JYFL-ACCLAB. The ion-optical configuration of MARA is QQQEDM, differing significantly from the other existing in-flight separators around the world. MARA has turned out be a very reliable separator and easy to operate. The studied nuclei of interest have been produced using fusion-evaporation reactions, mainly employing symmetric or inverse kinematics. In-beam studies, isomeric studies as well as production of new isotopes have been performed at and beyond the proton dripline starting from a mass number 66 up to a mass number 180. In this work some highlights of the latest results using the JYFL in-flight separator MARA will be given.

[1] J. Uusitalo et al., *Acta Physica Polonica B* 50 (2019) 319

[2] J. Sarén et al., *Research Report No. 7/2011*, University of Jyväskylä

[3] M. Leino et al., *NIMB* 99 (1995), 653

parallel / 495

Isospin-symmetry breaking in the $B(E2)$ transitions of $T = 1$ isotriplets

Auteurs: Betania Camille Tumelero Backes¹; Michael Bentley¹; Jacek Dobaczewski¹; David Jenkins¹; David Muir¹; Witold Nazarewicz²; Paul-Gerhard Reinhard³; Robert Wadsworth¹

¹ *University of York*

² *Michigan State University*

³ *Friedrich-Alexander Universität Erlangen*

Auteur correspondant betania.backes@york.ac.uk

The study of $T = 1$ triplets plays an important role in our understanding of isospin physics. A linear dependence of the proton matrix elements (M_p) with respect to isospin projection T_Z indicates the isospin purity of states, an effect that has been studied and observed for triplets of $22 \leq A \leq 50$ [1]. As measurements of reduced electromagnetic transition probabilities become available for heavier $T_Z = -1$ nuclei, some studies suggest that beyond-Coulomb isospin symmetry-breaking (ISB) effects affect this observable in mirror nuclei [2].

In this work, we investigate all even-even $T = 1$ mirrors with $42 \leq A \leq 98$ within the nuclear-density-functional-theory (nuclear-DFT) approach and analyse systematic properties of the obtained $B(E2 : 0^+ \rightarrow 2^+)$ values. For this purpose, we use the numerical software HFODD [3] to identify the deformed minima and to perform angular momentum projection. In addition, we employ the Generalised Bohr Hamiltonian [4, 5] to study effects of the quadrupole collectivity. For both methods, we utilise the Skyrme energy density functional with the UNEDF1 parameterisation [6]. We compare the obtained results with the available experimental data. Our results show significant differences between the mirror pairs without considering beyond-Coulomb ISB effects.

Furthermore, for the $A = 70$ and $A = 78$ triplets, including the odd-odd $N = Z$ nuclei, we perform calculations utilising a variety of nuclear-DFT parameterisations. The $A = 70$ triplet is the heaviest one for which the $B(E2)$ are known for all members, whereas the $A = 78$ triplet is the subject of interest for further experimental measurements. To obtain the $B(E2)$ of the odd-odd $N = Z$ nuclei, we performed the angular-momentum projection of the Hartree-Fock-Bogoliubov states with pair-blocked configurations. Our results allow for a full investigation of the linearity of M_p in function of T_z .

[1] A. Boso *et al.*, *Physics Letters B* **797** (2019) 134835;

[2] K. Wimmer *et al.*, *Physical Review Letters* **126** (2021) 072501;

[3] J. Dobaczewski *et al.*, *J. Phys. G: Nucl. Part. Phys.* **48** (2021) 102001;

[4] L. Próchniak and S. G. Rohoziński, *J. Phys. G: Nucl. Part. Phys.* **36** (2009) 123101;

[5] D. Muir, PhD thesis, University of York (2021);

[6] M. Kortelainen *et al.*, *Phys. Rev. C*, **85** (2012) 024304.

parallel / 497

Structure of $A = 22$ analogue states revealed through mirrored-transfer

Auteurs: Jack Henderson¹; Philip Adsley²

Co-auteurs: A Wen³; Barry Davids⁴; Ben Reed¹; C. Griffin⁴; C. Svensson⁵; C.R. Natzke⁴; Calem Hoffman⁶; Cameron Angus⁷; Corina Andreoiu⁸; Daniel Doherty¹; Daniel Yates⁴; David G. Jenkins⁹; Gemma Wilson¹⁰; Greg Hackman⁴; Guy Gleckenby⁴; Heinz Asch⁸; J Williams⁴; Jacob Heery¹; James Smallcombe¹²; K Pak¹³; Kevan Hudson⁸; Kyle Leach¹⁴; Laetitia Canete¹; M.S. Martin⁸; Matthew Williams¹⁵; Nicholas Esker¹⁶; P. Spagnoletti⁸; Reuben Russell¹; Robert Wadsworth⁹; Roger Caballero-Folch⁴; S Upadhyayula⁴; Samantha Buck⁵; Sophia Devinyak⁴; Steven Pain¹⁷; V Vedia⁴; Wilton Catford¹

¹ *University of Surrey*

² *Texas A&M*

³ *University of British Columbia*

⁴ *TRIUMF, Vancouver*

⁵ *University of Guelph*

⁶ *Argonne National Laboratory*

⁷ *TRIUMF/University of York*

⁸ *Simon Fraser University*

⁹ *University of York*

¹⁰ *Louisiana State University*

¹² *Japan Atomic Energy Agency*¹³ *Hanyang University*¹⁴ *Colorado School of Mines*¹⁵ *LLNL*¹⁶ *San Jose State*¹⁷ *ORNL***Auteur correspondant** jack.henderson@surrey.ac.uk

The isospin formalism describes protons and neutrons as two projections of the nucleon and provides a powerful tool for identifying and classifying states in the vicinity of the line of $N = Z$. Under the assumption that isospin is a good quantum number, a number of relations arise to describe isobaric analogue states their properties. This provides access wealth of information, from tests of the isospin-symmetry conserving nature of the nuclear interaction, to applications in nuclear astrophysics. In truth, however, this assumption is known to be false, broken by the Coulomb interaction and components of the nucleon-nucleon interaction.

Here, we employ mirrored transfer reactions using beams of radioactive ^{21}Na and stable ^{21}Ne delivered by the ISAC-II facility at TRIUMF. These are used to populate isobaric analogue states in ^{22}Na and ^{22}Ne , respectively, through (d,p). Making use of proton- γ coincidences, we are able to selectively probe the single-particle nature of individual states, and probe their isospin purity. I will present initial findings, focusing on the role of isospin mixing in 2^+ states through single-particle transfer, as well as future directions involving (d,n) data taken simultaneously to the (d,p).

498

Study of medium-mass and heavy hypernuclei produced through spallation and fission reactions in inverse kinematics

Auteur: Jose Luis Rodriguez Sanchez¹**Co-auteurs:** Aleksandra Kelic-Heil²; Jason Hirtz³; Jean-Christophe David⁴; Joseph Cugnon⁵¹ *University of Coruña*² *GSI, Darmstadt, Germany*³ *DRF/Irfu/SPhN, CEA-Saclay*⁴ *CEA*⁵ *University of Liège***Auteur correspondant** j.l.rodriguez.sanchez@udc.es

Innovative experiments using the inverse kinematics technique to accelerate light, medium-mass, and heavy nuclei at relativistic energies have become excellent tools to produce and study hypernuclei [1]. In this work, we investigate hypernuclei created in spallation reactions, where multifragmentation, particle evaporation, and fission processes play an important role in the formation of final hypernuclei residues. For the description of spallation reactions, we couple the Liège intranuclear cascade model, extended recently to the strange sector [2], to a new version of the ablation (ABLA) model that accounts for the evaporation of Λ -particles from hot hyperremnants produced during the intranuclear cascade stage [3,4]. These state-of-the art models are then used to study the production of hypernuclei close to the drip lines through spallation-evaporation and fission reactions. Moreover, we will also present the recent results obtained for the study of hypernuclei dynamics, in particular, for the constraint of the viscosity parameter involved in hyperfission reactions [5].

[1] A. Gal et al., *Rev. Mod. Phys.* 88, 035004 (2016)[2] J. Hirtz et al., *Phys. Rev. C* 101, 014608 (2020)[3] J.L. Rodríguez-Sánchez et al., *Phys. Rev. C* 98, 021602(R) (2018)[4] J.L. Rodríguez-Sánchez et al., *Phys. Rev. C* 105, 014623 (2022)[5] J.L. Rodríguez-Sánchez et al., accepted in *Phys. Rev. Lett.* (2023)

501

Is $^{70}\text{Zn}(d,x)^{67}\text{Cu}$ the best way to produce ^{67}Cu for medical applications?

Auteur: Etienne NIGRON¹

Co-auteurs: Arnaud Guertin ²; Férid Haddad ³; Thomas Sounalet ⁴

¹ GIP ARRONAX

² CNRS/IN2P3

³ SUBATECH, GIP ARRONAX

⁴ CNRS/IN2P3/SUBATECH

Auteur correspondant nigron@arronax-nantes.fr

The theranostic approach combines diagnostic and therapy towards personalised treatment for patients. Among the different possibilities, associating two radionuclides of the same element is appealing, one for imaging purpose and the other for therapy. Copper offers such a pair of radionuclides with ^{64}Cu ($T_{1/2}=12.7$ h) allowing PET imaging and ^{67}Cu ($T_{1/2}=61.8$ h) for targeted beta therapy. If for ^{64}Cu the production route is well defined (a biomedical cyclotron delivering protons on a ^{64}Ni target), this is not the case for ^{67}Cu . Many production routes have been explored using neutrons, charged particles or photons. For charged particles, the main challenge relies on the limitation of ^{64}Cu co-production, even if its real impact on the patient and staff radioprotection needs to be studied and clarified. This work aims at identifying and studying an optimized production route for ^{67}Cu while limiting the impact of ^{64}Cu .

Within this frame, a preliminary research identified the production route $^{70}\text{Zn}(d,x)$. We have measured its production cross sections for ^{67}Cu up to 30 MeV. Measurements were done using the well-known stacked foils technique on 97.5 % enriched ^{70}Zn homemade electroplated targets. Beam intensity has been obtained using an instrumented Faraday cup. Cross sections were also measured for the monitor reactions $\text{natTi}(d,x)^{48}\text{V}$ and $\text{natNi}(d,x)^{61}\text{Cu}$. They complement at higher incident energies the only set of data available in nuclear databases. The maximum of the cross section is reached for an incident energy of 23 MeV. Its value, 30 mb, is twice higher than the one obtained with a proton irradiation. With deuterons below 26 MeV, ^{64}Cu production is limited and directly connected to the enrichment of the target. Using this data, the production yield was calculated and production optimization parameters were proposed (energy incident of the deuteron, thickness crossed by the particles, irradiation time, waiting time).

This production route is of great interest as it limits strongly the production of ^{64}Cu that is directly linked to the level of ^{68}Zn impurity in the target. Using a 26 MeV deuteron beam and an enriched ^{70}Zn target, it is then possible to produce high purity ^{67}Cu . Activity of 16.4 GBq can be obtained for 26 MeV and 80 μA beam crossing 576 μm of ^{70}Zn thickness during 40 hours. By waiting 70 minutes after irradiation for decays, the activity of ^{67}Cu reaches 99.99 % of the total copper activity and, at this time, the specific activity is 1.87 GBq/nmol or 27.9 TBq/mg. This specific activity value is very close to the theoretical maximum (28 TBq/mg). This production route can be of interest for future linear accelerators under development where mA deuteron beams can be available if adequate targetry is developed.

parallel / 503

The $N = 126$ Factory: A new multi-nucleon transfer reaction facility at Argonne National Laboratory

Auteur: Adrian Valverde¹

Co-auteurs: Maxime Brodeur ²; Jason Clark ¹; Alicen Houff ²; Russell Knaack ¹; Biying Liu ³; Guy Savard ¹; Kumar Sharma ⁴; John Rohrer ¹; Bruce Zabransky ¹

¹ Argonne National Laboratory

² University of Notre Dame

³ University of Notre Dame/Argonne National Laboratory

⁴ *University of Manitoba*

Auteur correspondant avalverde@anl.gov

Multi-nucleon transfer (MNT) reactions between two heavy ions offer an effective method of producing heavy, neutron-rich nuclei that cannot currently be accessed efficiently using traditional projectile-fragmentation, target-fragmentation or fission production techniques [1]. These nuclei are important for understanding many astrophysical phenomena. For example, properties of the neutron-rich nuclei near the $N = 126$ shell closure are critical to the understanding of the r -process pathway and the formation of the $A \sim 195$ abundance peak [2]. The $N = 126$ Factory currently under construction at Argonne National Laboratory's ATLAS facility will make use of these reactions to allow for the study of these nuclei [3]. Due to the wide angular distribution of MNT reaction products, a large-volume gas catcher will be used to convert these reaction products into a continuous low-energy beam. This beam will undergo preliminary separation in a magnetic dipole of resolving power $R \sim 10^3$ before passing through an RFQ cooler-buncher and MR-TOF system of resolving power $R > 10^5$, sufficient to suppress isobaric contaminants. These isotopically separated, bunched low energy beams will then be available for experimental systems at ATLAS such as the CPT mass spectrometer for precision mass measurements. Results of commissioning the component devices will be presented, as will the status of the final assembly and commissioning of the facility, which is expected to be operational this year.

This work is supported in part by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357; by NSERC (Canada), Application No. SAPPJ-2018-00028; by the National Science Foundation under Grant No. PHY-2011890; by the University of Notre Dame; and with resources of ANL's ATLAS facility, an Office of Science User Facility.

[1] V. Zagrebaev and W. Greiner. PRL 101, 122701 (2008)

[2] M.R. Mumpower, R. Surman, G.C. McLaughlin, and A. Aprahamian. PPNP 86, 86–126 (2016)

[3] G. Savard, M. Brodeur, J.A. Clark, R.A. Knaack, and A.A. Valverde. NIM-B, 463, 258–261 (2020)

505

The role of tensor forces in polarised nuclear matter

Auteur: Paul Proust¹

Co-auteurs: Dany Davesne¹; Michael Bender¹

¹ *Institut de Physique des Deux Infinis (IP2I-Lyon)*

Auteur correspondant p.proust@ip2i.in2p3.fr

In the last decades, standard Skyrme functionals have reached their limits with respect to experimental data. To overcome this issue, people started to develop extensions for such functionals. For example, some groups reconsidered the use of the so-called tensor forces in calculations[1-4]. However, the terms introduced by these interactions are of a different nature from others. In particular, as well as spin-orbit terms, they couple momenta and spins.

These recent studies were focalised on the impact of the tensor interactions on nuclear shell structure and, more precisely, on the orbital-dependent correction it brings to nuclear spin-orbit splittings. However, unlike spin-orbit terms, the aforementioned interaction also contributes to the properties of infinite spin polarised nuclear matter, as expected to be found in compact astrophysical objects. Most importantly, the presence of the tensor interaction changes the formalism for the description of infinite matter, as single particle energies depend on the relative orientation between the momentum of each particle and the direction of spin polarisation.

In this work, we investigate these non trivial effects which are expected to modify the phenomenology of infinite polarised matter by going further than some exploratory studies of the past[5].

[1]Brown et al, Phys. Rec. C, 74, 061303 (2006)

[2]Colo et al, Phys. Lett. B, 646, 227 (2007)

- [3]Lesinski et al, Phys. Rev. C, 76, 014312 (2007)
 [4]Anguiano et al, Phys. Rec. C, 83, 064306 (2011)
 [5]Dabrowski et al, Ann. Phys., 97, 452 (1976)

parallel / 506

Study of the $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction with the SOLARIS spectrometer

Auteurs: Alicia Muñoz Ramos¹; Benjamin Kay²; Héctor Alvarez Pol³; Yassid Ayyad⁴

¹ IGFAE-USC

² Argonne National Laboratory

³ Universidade de Santiago de Compostela

⁴ USC

Auteur correspondant alicia.munoz@rai.usc.es

The $^{10}\text{Be}(t,p)^{12}\text{Be}$ reaction has been studied with the SOLARIS solenoidal spectrometer. This measurement was carried out in inverse kinematics using a 9.6 MeV/u ^{10}Be beam provided by the ReA6 re-accelerator in stand-alone mode. SOLARIS provides excellent resolution (about 150 keV FWHM) and background rejection capabilities via recoil detection. A titanium tritide target was used. The advantages of this approach, contrasted to the classic study of this reaction in normal kinematics, are higher bombarding energies coupled with recoil detection, allowing for a clean Q-value spectrum and insights into the decay of unbound states in ^{12}Be . We observed the well-known bound states of ^{12}Be and known states above the one- and two-neutron separation energies along with some additional, weakly populated states. Using angular distributions and coincident recoils (^{10}Be , ^{11}Be), we favor spin-parity assignments of 3- and 4+ for the states at 4.58 and 5.72 MeV, respectively. We observe states at approximately 5.0 MeV and 5.4 MeV which have not been clearly observed before. The SOLARIS device, the analysis procedure, and the preliminary results are discussed.

This material is based upon work supported by NSF's National Superconducting Cyclotron Laboratory which is a major facility fully funded by the National Science Foundation under award PHY-1565546; the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract Number DE-AC02-06CH11357 (Argonne) and under Award Number DE-SC0014552 (UConn); the Spanish Ministerio de Economía y Competitividad through the Programmes "Ramón y Cajal" with the grant number RYC2019-028438-I; the UK Science and Technology Facilities Council (Grant No. ST/P004423/1); and the International Technology Center Pacific (ITC-PAC) under Contract No. FA520919PA138. SOLARIS is funded by DOE Office of Science under the FRIB Cooperative Agreement DE-SC0000661. The Paul Scherrer Institut is acknowledged for their provision of the ^{10}Be isotope.

parallel / 507

Towards the r-process path at $N = 126$

Auteur: Zsolt Podolyak¹

¹ University of Surrey

Auteur correspondant z.podolyak@surrey.ac.uk

The ^{208}Pb nuclide is the heaviest known doubly-magic nucleus. Information on its neutron-rich neighbourhood is rather scarce, due to the limited mechanisms by which these nuclei can be populated. However, experimental information on neutron-rich $N=126$ nuclei is of paramount importance not only for nuclear structure physics, but also for implications for astrophysics. Theoretical

predictions for exotic nuclei in this region are essential inputs into nucleosynthesis calculations, influencing the yields in the A-195 r-process peak.

Neutron-rich nuclei around 208Pb are under intense scrutiny. However, no $B(E2;2^{+} \rightarrow 0^{+})$ transition strength was extracted on any of the N=126 nuclei below 208Pb. This quantity, connected to the wave functions of the involved states, often provide the first hint of the erosion of the magicity by exhibiting enhanced collectivity.

The radioactive semi-magic two proton-hole 206Hg nucleus was Coulomb excited for the first time at a safe beam energy using the HIE-ISOLDE facility at CERN [1]. Two gamma rays depopulating low-lying states in 206Hg were observed. The determined reduced transition strength $B(E2;2^{+} \rightarrow 0^{+})$ of the 1068 keV transition is in line, but slightly lower, than the shell-model predictions. Furthermore, a collective octupole state was identified, and the corresponding transition strength of was extracted. The obtained results were confronted with large scale shell model and time-dependent Hartree-Fock calculations, and are crucial for furthering understanding of both quadrupole and octupole collectivity in the neutron-rich vicinity of the heaviest doubly-magic nucleus 208Pb.

The most exotic N=126 nuclei studied so far were populated in fragmentation reactions at GSI (see e.g. [2,3]). Within the FAIR-0 experimental campaign a number of such studies will be performed within the DESPEC (Decay Spectroscopy) collaboration in spring 2022. An experiment aimed at the beta decay and isomeric decays of the most neutron-rich N=126 nuclei presently accessible, 202Os and 203Ir took place May 2022. The obtained statistics is an order of magnitude higher than previously [2].

The status of knowledge on neutron-rich N=126 nuclei will be presented. This will include the new results on the Coulomb excitation of 206Hg, and hopefully isomeric decays in 202Os, as well as recent works on the competition between allowed and first-forbidden beta decays [4].

[1] L. Morrison et al., Phys. Lett. B 838, 137675 (2023)

[2] S.J. Steer et al., Phys. Rev. C 84, 044313 (2011).

[3] A.I. Morales et al., Phys. Rev. Lett. 113, 022702 (2014).

[4] R.J. Carrol et al., Phys. Rev. Lett. 125, 192501 (2020)

508

Elucidating the structure of the 16.6 - 16.9 MeV doublet of ${}^8\text{Be}$ through β -decay feeding

Auteurs: Daniel Fernandez Ruiz¹; Maria José Garcia Borge²

Co-auteurs: Karsten Riisager³; Olof Tengblad²; Sílvia Viñals Onsès² for the IS633 collaboration

¹ Instituto de Estructura de Materia (IEM-CSIC)

² IEM-CSIC

³ Aarhus University

Auteur correspondant daniel.fernandez@csic.es

The β -decay of the proton halo nucleus ${}^8\text{B}$ is a precise probe to study the structure of ${}^8\text{Be}$. This decay has been studied via several experiments due to its interest in astrophysics, as ${}^8\text{B}$ is the main source of high-energy solar neutrinos above 2 MeV, i. e. the main contributor to what was known as the “solar neutrino problem” [1]. On the nuclear structure side, the 2^{+} isospin doublet formed by two narrow levels at 16.6 and 16.9 MeV, with respectively dominant configurations of ${}^7\text{Li}+p$ and ${}^7\text{Be}+n$, has not been reached in β -decay. This doublet is the best case of predicted full isospin mixing between nuclear states [2].

The β -decay of ${}^8\text{B}$ ($J^{\pi} = 2^{+}$, $Q_{EC} = 17980(1)$ MeV) proceeds mainly (>88%) through the 2^{+} state at 3 MeV [3] being this feeding the main source of neutrinos. The remaining decay occurs through the doublet and can be modelled assuming that Fermi strength only goes to the T=1 component and Gamow-Teller strength only to T= 0. Employing this assumption, a B_{GT} of 2.06 can be deduced. In addition, within the Q_{EC} window, the 17.640 MeV 1^{+} state can be factorised [4] as a p-halo around the ${}^7\text{Li}$ -core. This EC-decay can be modelled as occurring in the core ${}^7\text{Li}$ with the halo proton as a spectator. The strength of this branch is then estimated from the β -decay of ${}^7\text{Li}$ giving a B_{GT} of 1.83 [5].

The ${}^8\text{Be}$ nucleus is unbound and breaks up into two α -particles. Theoretically, the transition is dominated by the Gamow Teller contribution up to 15 MeV, however, experimentally this has only been observed up to 8 MeV. The decay of ${}^8\text{B}$ into the 16.626(3) MeV state has been observed previously, but the (mainly EC) decay into the 16.922(3) MeV state was first hinted at, with only 5 events, in an experiment at JYFL [6].

The MAGISOL (Madrid-Aarhus-Goteborg at ISOL)-collaboration has conducted several beta-decay experiments to study the structure of ${}^8\text{Be}$ [6,7]. In the IS633 experiment at ISOLDE, a compact 4 particle-telescope setup [7] formed by a Double-Sided Silicon strip Detector (DSSD) of 40 and 60 μm thickness stacked with a 1000 μm thick Si-PAD detector was used. At the centre of the setup, a carbon foil catcher of 30 g/cm^2 was placed to stop the mass-separated 50 keV ${}^8\text{BF}_2$ beam.

The two orders of magnitude higher statistics than any previous 8B experiment, allowed us to resolve the feeding to the 16.6-16.9 MeV doublet for the first time in a beta-decay work. Using these high-statistics data, the feeding of the 2^+ states in ${}^8\text{Be}$ was studied using the R-Matrix formalism. This has allowed for the first time to experimentally verify whether the 16.6 and 16.9 MeV states of ${}^8\text{Be}$ are completely isospin mixed [7].

In this contribution, we will present the results of these experiments with special emphasis on the Gamow Teller and Fermi contribution of the ${}^8\text{B}$ decay. The B_{GT} distribution strength and the isospin mixing the character of the doublet will be addressed.

509

Surrogate Reactions in the FRIB Era – New Challenges and Opportunities

Auteur: Andrew Ratkiewicz¹

¹ *Lawrence Livermore National Lab*

Auteur correspondant ratkiewicz1@llnl.gov

Neutron-induced reactions play an important role in the synthesis of heavy elements in stars. However, many of the nuclei involved in these processes are unstable, so the most important reactions often cannot be measured directly. The Surrogate Reactions Method was developed to indirectly constrain the properties of these elusive nuclei. In it, an experimentally-tractable reaction which forms the “same” compound nucleus as is created in the desired reaction is chosen. The decay of the compound nucleus is measured as a function of its excitation energy, and its properties are used to constrain calculations of the desired reaction.

The advent of FRIB will make many exotic beams and important reactions accessible for the first time. I will discuss the Surrogate Reactions Method, give some experimental highlights, and share ideas about opportunities and challenges in the FRIB era.

510

Conversion coating method development for thin-film vanadium targetry

Auteur: Chloe Kleinfeldt¹

Co-auteurs: Gregory Severin¹; Hye Young Lee²; Scott Essenmacher¹; Vladyslav Bodnar¹

¹ *Michigan State University/Facility for Rare Isotope Beams*

² *Los Alamos National Laboratory*

Auteur correspondant kleinfe3@msu.edu

Nuclear reactions studies provide data that are important for a variety of disciplines and applications. However, experimentally measured neutron reaction cross-section data for radionuclides are limited. Having the capability to produce radioactive targets would enhance the ability to obtain accurate nuclear data which leads to improved computational models for studies predicting yields from stellar nucleosynthesis or for nuclear validation applications. One radioisotope of vanadium, V-48, is important for nuclear validation purposes and currently lacks experimentally measured neutron-induced charged particle reaction cross-section data. Targets for such studies must be thin and durable during irradiation. A vanadium chemical conversion coating onto an aluminum foil may provide a method to produce radioactive vanadium targets that meet the specifications demanded from neutron-induced charged particle cross-section studies. The efforts to develop these thin-film vanadium targets will be discussed.

parallel / 512

KDK: first measurement of the rare electron-capture decay of ^{40}K to the ground state of ^{40}Ar

Auteur: Philippe Di Stefano¹

¹ *Queen's University, Kingston*

Auteur correspondant distefan@queensu.ca

Potassium-40 (^{40}K) is a naturally-occurring radioactive isotope. It is a background in searches for exotic subatomic particles, plays a role in geochronology, and has a nuclear structure of interest to theorists. This radionuclide decays mainly by beta emission to calcium, and by electron-capture to an excited state of argon. The electron-capture decay of ^{40}K directly to the ground state of argon has never been measured, and predicted intensities are highly variable (0–0.22%). This poorly understood intensity may impact the interpretation of a controversial claim of dark matter discovery [1]. The KDK (potassium decay) experiment has carried out the first measurement of this electron-capture branch, using a novel setup at Oak Ridge National Labs [2]. KDK deployed a very sensitive inner detector to trigger on the $\sim\text{keV}$ radiation emitted by both forms of electron capture, surrounded by a very efficient veto to distinguish between the decays to ground state and those to the excited state. We present result of the experiment [3] and implications for various fields.

[1] Pradler et al, *Physics Letters B* 720 (2013) 399–404, <http://dx.doi.org/10.1016/j.physletb.2013.02.033>

[2] Stukel et al, *Nuclear Inst. and Methods in Physics Research, A* 1012 (2021) 165593, <https://doi.org/10.1016/j.nima.2021.165593>

[3] Stukel et al, <https://doi.org/10.48550/arXiv.2211.10319>

plenary / 513

Super-allowed alpha decay to doubly-magic ^{100}Sn

Auteur: Dariusz Seweryniak¹

¹ *Argonne National Laboratory*

Auteur correspondant seweryniak@anl.gov

The proton-rich doubly-magic self-conjugate nucleus ^{100}Sn and neighboring nuclei are a site of unique nuclear phenomena and a test bed for modern nuclear models. The ^{100}Sn nucleus is one of the fastest known Gamow-Teller β emitters. Due to close proximity of the proton drip line, nuclei with $Z>50$ and $N>50$ near ^{100}Sn form an island of α and proton emitters which decay towards ^{100}Sn . Alpha decays of proton-rich Te isotopes were proposed to terminate the astrophysical rp-process. Consequently, despite small production cross sections, this region of nuclear chart has been an aim of numerous experimental studies.

In an experiment with the Fragment Mass Analyzer at ATLAS, the super-allowed α -decay chain ^{108}Xe - ^{104}Te to doubly-magic ^{100}Sn was observed [1] using the recoil-decay correlation technique. This was the first time that evidence was found for production of ^{100}Sn in a fusion-evaporation reaction. This observation is an important stepping-stone towards developing a microscopic model of α decay, since it is only the second case of α decay to a doubly-magic nucleus besides the benchmark ^{212}Po α decay to ^{208}Pb , and it triggered a flurry of theoretical activity. The decay properties of ^{108}Xe and ^{104}Te indicate that in at least one of them the reduced α -decay width is a factor of 5 larger than in ^{212}Po , which confirms their super-allowed character. This could be explained by an enhanced α -particle preformation probability due to a stronger interaction between protons and neutrons, which occupy the same orbitals in $N=Z$ nuclei. The Q_α -values deduced for the very exotic ^{108}Xe and ^{104}Te nuclei are consistent with the doubly-magic nature of ^{100}Sn . Interestingly, a weak proton-decay branch in ^{108}I was found in the same experiment. The deduced ^{104}Sb Q_p value rules out the formation of the Sn-Sb-Te cycle at ^{103}Sn .

Further experiments to observe more ^{108}Xe - ^{104}Te α -decay chains and to better characterize the properties of other α emitters in the ^{100}Sn region are planned. Tests with the recently constructed Argonne Gas-Filled Analyzer, which offers much higher efficiency, will be discussed.

[1] K.Auranen, D.Seweryniak, M.Albers, A.D.Ayangeakaa, S.Bottoni, M.P.Carpenter, C.J.Chiera, P.Copp, H.M.David, D.T.Doherty, J.Harker, C.R.Hoffman, R.V.F.Janssens, T.L.Khoo, S.A.Kuvin, T.Lauritsen, G.Lotay, A.M.Rogers, J.Sethi, C.Scholey, R.Talwar, W.B.Walters, P.J.Woods, and S.Zhu, *Phys. Rev. Lett.* 121, 182501 (2018)

This material is based upon work supported by the U.S Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

parallel / 514

Gamma-ray spectroscopy of the neutron-rich $^{55,57,59}\text{Sc}$ isotopes

Auteur: Radostina Zidarova¹

Co-auteurs: Martha Liliana Cortes Sua²; Volker Werner³; Pavlos Koseoglou⁴; Norbert Pietralla¹; Pieter Doornenbal²; Alexandre Obertelli¹

¹ TU Darmstadt

² RIKEN

³ TU Darmstadt, HFHF

⁴ IKP TU-Darmstadt, GSI

Auteur correspondant rzidarova@ikp.tu-darmstadt.de

Experimental data have shown that far from the valley of stability the nuclear shell structure evolves. New magic numbers can emerge and the traditional ones can disappear. In particular, two new magic numbers at $N=32$ and $N=34$ have been suggested in the vicinity of $Z=20$ based on gamma-ray spectroscopy and mass measurements. In order to assess the impact of a single valence proton outside of the $Z=20$ shell on the shell-evolution mechanism in this region, it is necessary to study the neutron-rich Sc isotopes around, and even beyond, neutron number $N=34$. Investigation of exotic nuclei in this region was the goal of the third SEASTAR campaign at RIKEN-RIBF. Neutron-rich isotopes in the vicinity of ^{53}K were produced by fragmentation of a primary ^{70}Zn beam on a ^9Be target. Known and new γ -ray transitions of the isotope ^{55}Sc were observed and γ -rays from $^{57,59}\text{Sc}$ were identified for the first time. Observed γ spectra from $^{55,57,59}\text{Sc}$ will be presented together with preliminary level schemes. They will be discussed in the framework of the tensor-driven shell evolution.

Supported by BMBF under Grant Nos. 05P19/21RDFN1.

515

The ALTO facility of IJCLab

Auteur: Enrique Minaya Ramirez¹

¹ *IJCLab*

Auteur correspondant enrique.minaya@ijclab.in2p3.fr

The ALTO (Accélérateur Linéaire et Tandem d'Orsay) research platform of IJCLab consists of two accelerators : a 15 MV Tandem electrostatic accelerator for stable beams from proton to heavy ions, clusters and neutron production, and a 50-MeV 10- μ A electron linear accelerator for the production of low energy radioactive beams by photofission. These machines are surrounded by a large variety of experimental instruments/devices located on 10 different beam lines. The diversity of the beams produced facilitates wide-ranging research in nuclear physics, nuclear astrophysics and interdisciplinary activities such as health physics. ALTO has some unique features: It delivers low-energy radioactivity beams from the photofission of ²³⁸U, it can provide rare heavy-ion beams such as ³He and ¹⁴C, and is also unique in its capacity to provide high-flux naturally directional neutron beams with the LICORNE neutron converter. An overview of the ALTO facility as well as some of the highlights and prospects of the experimental schedule will be given.

516

Beta-neutrino angular correlation measurements of mirror transitions with St. Benedict

Auteur: Sam Porter¹

Co-auteurs: Maxime Brodeur¹; Daniel Burdette²; Jason Clark²; Aaron Gallant³; Alicen Houff¹; Biying Liu¹; Patrick O'Malley¹; Fabio Rivero¹; Guy Savard²; Adrian Valverde⁴; Regan Zite¹

¹ *University of Notre Dame*

² *Argonne National Laboratory*

³ *Lawrence Livermore National Laboratory*

⁴ *Argonne National Laboratory/University of Manitoba*

Auteur correspondant wporter@nd.edu

Precise measurements of nuclear beta decays provide a unique insight into the Standard Model due to their connection to electroweak interactions. These decays can provide constraints on the unitarity or non-unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix, where non-unitarity would signal potential physics Beyond the Standard Model. The most precise of these tests involves the matrix element V_{ud} as determined from superallowed pure Fermi beta decays, and indicates a deviation from unitarity on the order of 2.4σ . As such, cross-checks from additional methods, including superallowed mixed mirror beta decays, are necessary. V_{ud} precision from mirror decays is currently limited by the absence of precise Fermi-to-Gamow Teller mixing ratios, which are most sensitively determined via the angular correlation of the neutrino and beta particle emitted during the decay. At the Nuclear Science Laboratory (NSL) at the University of Notre Dame, the Superallowed Transition Beta-Neutrino Decay Ion Coincidence Trap (St. Benedict) is being constructed to determine the beta-neutrino angular correlation parameter of various mirror decays. We plan on measuring this correlation parameter for the beta decays of nuclei ranging from ¹¹C to ⁴¹Sc using radioactive ion beams from the NSL's TwinSol separator, which will result in significantly improved precision of the V_{ud} element of the CKM matrix from superallowed mirror transitions. The status of the development of St. Benedict, including its beam preparation and measurement stages, will be presented.

Core-breaking effects around 100Sn : lifetime measurements in the most neutron-deficient Sn isotopes.

Auteurs: Guangxin Zhang¹; Daniele Mengoni¹; Marta Polettini²; Giovanna Benzoni³

¹ *University and INFN - Padova*

² *University of Milano & INFN Milano*

³ *INFN*

Auteur correspondant marta.polettini@unimi.it

The long Sn isotopic chain is a formidable testing ground for nuclear models aiming at describing the evolution of the shell structure. Low-lying excited states roughly exhibits the typical behavior predicted by the generalized seniority scheme. However, the corresponding $B(E2; 0^+ \rightarrow 2^+)$ values, approaching the $N=Z=50$ shell closure, have shown a presumed deviation from the expected parabolic behavior [1]. From a theoretical point of view, various attempts have been done to explain such experimental results, in particular by including core-breaking excitations in the shell-model calculations and promoting protons and neutrons from the $g_{9/2}$ orbital across the shell gap [2]. From the experimental side, limited data are available beyond 104Sn and no lifetime information are known in this extremely neutron-deficient region, leading to a difficulty in a firm evaluation of any core-breaking effects.

In this contribution, we will report recent results on lifetime measurements in $102,103\text{Sn}$. The experiment was performed in May 2021 at GSI using the AIDA Si active stopper surrounded by the EUROBALL HPGe and the FATIMA LaBr₃ array. The nuclei of interest were identified in the FRS separator, following the production via fragmentation reactions of a 124Xe beam on a ^9Be target. The Sn isotopes have been stopped in the AIDA array and the decaying gamma rays collected by the FATIMA array, which allowed for a direct lifetime measurement with a precision up to few tens of ps. The analysis is ongoing and the preliminary results will be presented, together with their possible implications.

[1] G. Guastalla et al., Phys. Rev. Lett. 110, 172501 (2013); V.M. Bader et al., Phys. Rev. C 88, 051301(R) (2013); P. Doornenbal et al., Phys. Rev. C 90 (R), 061302 (2014).

[2] T. Togashi et al., Phys. Rev. Lett. 121, 062501 (2018).

519

Exploring low-lying states in 136Cs and 136Ba relevant for 136Xe neutrinoless double beta decay

Auteur: Bernadette Rebeiro¹

¹ *GANIL and University of the Western Cape*

Auteur correspondant bernadette.m.rebeiro@mcgill.ca

Benchmarking against experimental data is critical for nuclear matrix element (NME) calculations of various neutrinoless double beta decay (0nbb) candidates. As next-generation xenon-based detectors are expected to scale up in size and enhance their sensitivity to probe the inverted neutrino mass hierarchy region and beyond, it is increasingly important to accurately calculate the matrix element for 136Xe 0nbb decay. This talk will focus on recent spectroscopic studies of low-lying states in 136Cs and 136Ba , and discuss their impact on calculations of the 136Xe 0nbb NME.

520

Elastic scattering of $6\text{He}+d$ at 26 MeV/A

Auteur: Bogumił Zalewski¹

Co-auteurs: Krzysztof Rusek ¹; Mikhail Golovkov ²; Sergey Belogurov ²; Andrey Bezbakh ²; Vratislav Chudoba ²; Andrey Fomichev ²; Elvira Gazeeva ²; Alexander Gorshkov ²; Grzegorz Kamiński ²; Sergey Krupko ²; Bakytbek Maueyev ²; Ivan Muzalevskii ²; Paweł Napiorkowski ¹; Yuri Nikolskii ²; Wojciech Piątek ¹; Adilzhan Serikov ²; Sergey Sidorchuk ²; Roman Slepnev ²; Pavel Sharov ²; Natalia Sokołowska ³; Gurgen Ter-Akopian ²; Agnieszka Trzcńska ¹; Roman Wolski ²

¹ *Heavy Ion Laboratory, University of Warsaw*

² *Joint Institute for Nuclear Research*

³ *Faculty of Physics, University of Warsaw*

Auteur correspondant zalewski@slcj.uw.edu.pl

Nuclei far away from the stability line are at the center of attention of modern nuclear physics. With the considerable imbalance between neutron and proton numbers, they are a great testing point for theoretical models. Neutron halo nuclei are the most prominent examples of such nuclei. They consist of a stable core and one or two loosely bound neutrons orbiting the core. The lightest halo nucleus is Helium-6 which due to the small number of nucleons is among the most straightforward systems to treat from a theoretical point of view. Experimental studies of such an unstable nucleus are complex due to the low intensities of produced beams. One of the solutions for this problem is using high cross-section processes such as elastic scattering.

For ${}^6\text{He}$, many experiments have been performed investigating the coupling of the elastic scattering with the breakup channels. At low energies, the method of continuum-discretized coupled channels (CDCC) is one of the most effective for the interpretation of experimental results [1]. This presentation will review the most recent results for the ${}^6\text{He} + d$ elastic scattering measurement, in inverse kinematics, at 26MeV/n beam energy. The experiment was performed in 2018. Such a scattering, involving these two weakly bound nuclei, was performed for the first time. The results could be useful for expanding the CDCC method for a four-body framework [2].

The obtained data set was analyzed in two steps. First, an effective optical model potential was derived from the analysis of ${}^6\text{He} + p$ elastic scattering data measured at the same energy. This potential accounts for the effects due to the ${}^6\text{He}$ breakup [3]. In the second step, this potential was used to derive the optical model potential for ${}^6\text{He} + d$ by means of the single folding (SF) method [4]. The wave function of the deuteron ground state included the S- and D- state contributions [5]. The nuclear part of the ${}^6\text{He} + n$ optical model potential used in the SF calculations was assumed to be the same as that for ${}^6\text{He} + p$. A comparison of the optical model calculations involving the SF ${}^6\text{He} + d$ potential showed good agreement with the experimental data. This result suggests that the effects due to deuteron breakup on the ${}^6\text{He} + d$ elastic scattering are small. In the same experiment differential cross-section for the ${}^6\text{He}(d, t){}^5\text{He}$ reaction was obtained. The results of the analysis with DWBA and Coupled Reactions Channels will be presented.

1. N. Austern et al., Phys. Reports 154, 125 (1987)
2. P. Descouvemont, Phs.Rev. C97, 064607 (2018)
3. R.S. Mackintosh, K. Rusek, Phys. Rev. C67, 034607 (2003)
4. P.W. Keaton Jr, D.D. Armstrong, Phys. Rev. C 8, 1692 (1973)
5. M. Lacombe et al., Phys. Rev. C 21, 861 (1980)

parallel / 521

Precision half-life measurements of mirror transitions at Notre Dame

Auteur: Maxime Brodeur¹

Co-auteurs: Adrian Valverde ²; Alicen Houff ¹; Biying Liu ¹; Catherine Nicoloff ³; Dan Bardayan ¹; Daniel Burdette ⁴; Fabio Rivero ¹; Jacob Long ¹; James Kolata ¹; Patrick O'Malley ¹; Regan Zite ¹; Sam Porter ¹

¹ *University of Notre Dame*

² *Argonne National Laboratory/University of Manitoba*

³ *Facility for Rare Isotope Beams*

⁴ *Argonne National Laboratory*

Auteur correspondant mbrodeur@nd.edu

Despite its success, the Standard Model (SM) is currently being scrutinized on multiple fronts as it fails to explain many features of nature including the matter/anti-matter asymmetry, dark matter and even gravity. One probing mechanism for new physics is the unitarity test of the Cabibbo-Kobayashi-Maskawa matrix. A series of recent transition-independent radiative corrections resulted in a reduction of the V_{ud} matrix element creating a 2.4 sigma tension with unitarity. Consequently, the determination of this matrix element, derived from the fit-value of superallowed beta decays, is under scrutiny. While superallowed pure Fermi transitions currently allow for the most precise determination of V_{ud} , there is currently a growing interest in obtaining that matrix element from superallowed mixed transitions to test the accuracy of V_{ud} and the calculation of isospin symmetry breaking corrections. In the past few years, a research program aimed at solidifying the determination of V_{ud} from mirror transitions was initiated using radioactive ion beams from the Twin Solenoid (TwinSol) separator at the Nuclear Science Laboratory of the University Notre Dame. As part of this program, several half-lives have been measured, some for the first time in 40 years, to relative uncertainties in the 0.01% range. These range from ^{11}C to ^{33}Cl and include the measurement of ^{20}F and, more recently, ^{28}Al , which are also both of interest for searches of second-class currents. These recent measurements as well as future measurements will be presented.

parallel / 524

Possible Existence of Extremely Neutron-Rich Superheavy Nuclei in Neutron Star Crusts Under a Superstrong Magnetic Field

Auteur: Kazuyuki Sekizawa¹

Co-auteur: Kentaro Kaba¹

¹ *Tokyo Institute of Technology*

Auteur correspondant sekizawa@phys.titech.ac.jp

We investigate outer crust compositions for a wide range of pressures (densities) and magnetic-field strengths, adopting the latest experimental masses (AME2020) supplemented with various theoretical mass models. By exploring the optimal composition of nuclei in the entire nuclear chart, we find emergence of neutron-rich heavy nuclei, which are much heavier than previously thought (that was at most $Z \approx 50$), mainly because of the increasing electron density with the magnetic field strength, which allows nuclei to exist at higher densities without leakage of neutrons. We point out a clear manifestation of neutron magic numbers, e.g. $N = 50, 82, 126$, as well as 184, and possibly those around the next spherical magic number $N \approx 258$. Furthermore, surprisingly enough, for $B \geq 4 \times 10^{18}$ G, we find that superheavy nuclei with $Z > 110$, including the unknown element 119, naturally emerge as optimal compositions that minimize the Gibbs energy. In this talk, we will explain the aforementioned findings and discuss possible consequences.

parallel / 525

First results from ATLANTIS - A new collinear laser spectroscopy setup at Argonne National Laboratory

Auteur: Bernhard Maaß¹

Co-auteurs: Alex Brinson²; Daniel Burdette¹; Jason Clark¹; Adam Dockery³; Max Horst⁴; Phillip Imgram⁵; Kristian König⁴; Kei Minamisono⁶; Patrick Müller⁷; Peter Mueller¹; Wilfried Nörtershäuser⁴; Skyy Pineda⁸; Simon Rausch⁹; Laura Renth¹⁰; Brooke Rickey³; Daniel Santiago-Gonzalez¹; Guy Savard¹; Felix Sommer¹⁰; Adrian Valverde¹¹

¹ *Argonne National Laboratory*

² *Massachusetts Institute of Technology*

³ Facility for Rare Isotope Beams

⁴ TU Darmstadt

⁵ Institute for Nuclear Physics, Technical University Darmstadt

⁶ NSCL/MSU

⁷ Institut für Kernphysik, Technische Universität Darmstadt

⁸ Michigan State University

⁹ TU Darmstadt, HFHF Darmstadt

¹⁰ Technische Universität Darmstadt

¹¹ Argonne National Laboratory/University of Manitoba

Auteur correspondant maass@anl.gov

The region of refractory metals, below the magic number $Z = 50$ is of particular interest for nuclear physics studies and exhibits phenomena such as deformations, shape coexistence and hints of triaxial nuclei. Laser spectroscopy has provided valuable and complementary input, providing information about the shape, size and electromagnetic moments of radioactive isotopes and isomers in this region. The CARIBU californium-252 fission source at Argonne National Laboratory can uniquely produce sufficiently intense low-energy ion beams of neutron-rich isotopes in this part of the nuclear chart. Therefore, the new collinear laser spectroscopy setup, ATLANTIS –the Argonne Tandem hall LAsEr beamline for aTom and Ion Spectroscopy–was installed at the low-energy branch of CARIBU.

The setup includes a dedicated open-gate cooler-buncher that prepares and delivers cooled ion beams with minimal energy and time spread and a laser ablation source to produce stable isotope beams. The laser spectroscopy beamline is fitted with a low-energy charge exchange cell suited for high-temperature application to also allow spectroscopy on atomic beams and a highly efficient 4π mirror system to collect fluorescence ions.

In this talk, the results of the first measurements of short-lived isotopes of palladium and ruthenium obtained at ATLANTIS will be discussed, and an outlook of future laser spectroscopy endeavors at Argonne National Laboratory will be given.

This work was supported by DFG –Project-Id 279384907-SFB 1245, BMBF 05P19RDFN1 and NSF Grant No. PHY-21-11185, and by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357, with resources of ANL’s ATLAS facility, an Office of Science User Facility.

parallel / 526

Precision Lifetime Measurements of Excited States in ^{38}Si and ^{36}Si

Auteur: Mara Grindler¹

Co-auteurs: A. Dewald ; ALDRIC REVEL²; Alexandra Gade²; Brandon Elman²; Brandon Longfellow²; Charles Loelius²; Daniel Bazin²; Dirk Weisshaar³; Eric Lunderberg²; Hironori Iwasaki⁴; J. Belarge²; John Ash⁵; Kenneth Whitmore⁶; M. Mathy ; Nobu Kobayashi²; Peter Bender²; Robert Elder⁷; S. Heil ; T. Haylett ; Tea Mijatovic²

¹ Rutgers University

² NSCL

³ FRIB

⁴ Michigan State University

⁵ TRIMUF

⁶ NSCL

⁷ Washington and Lee University

Auteur correspondant mg1916@physics.rutgers.edu

Rapid shape transitions are predicted by the shell model calculations as a result of the nuclear shell structure significantly evolving in the neutron-rich region at the traditional magic numbers $N=20$ and 28. The energy ratios between the first $2+$ and $4+$ states in the even-even silicon isotopes from $N=20$ to 28 suggest a variety of collectivity evolving from vibrational, to possible triaxial, to rotational modes. The systematic behavior of the level schemes along the silicon isotopic chain suggests ^{38}Si as the turning point in this transition. The lifetime measurements of ^{38}Si and ^{36}Si were performed at the National Superconducting Cyclotron Laboratory based on the Recoil-Distance Method using the Gamma-Ray Energy Tracking In-Beam Nuclear Array (GRETINA). The data was used to extract the $B(E2)$ ratios for the yrast $2+$ and $4+$ states in ^{38}Si and the yrast $4+$ and $6+$ states in ^{36}Si . These ratios were then compared to theoretical models.

parallel / 527

Present status and future prospect of the SCRIT electron scattering facility

Auteur: Kyo Tsukada¹

Co-auteurs: Akitomo Enokizono²; Clement Legris³; Daiki Abe³; Hikari Wauke³; Kazushi Ishikura³; Kazuyoshi Kurita²; Masahiro Hara⁴; Masamitsu Watanabe⁴; Masanori Wakasugi¹; Rika Danjo³; Ryo Obara³; Ryo Ogawara¹; Satoru Yoshida¹; Shin'ichi Ichikawa⁴; Shun Imura²; Tadaaki Tamae³; Tadatoshi Hori⁴; Taiga Goke³; Tetsuya Ohnishi⁴; Toshimi Suda³; Tsubasa Yamano²; Yasushi Abe⁴; Yoshiki Maehara¹; Yuki Honda³; Yuki Ito¹; Yuma Ishikura³

¹ *Kyoto University, ICR*

² *Rikkyo University*

³ *Tohoku University, ELPH*

⁴ *RIKEN Nishina Center*

Auteur correspondant tsukada.kyo.5x@kyoto-u.ac.jp

The SCRIT (Self-Confining RI Ion Target) electron scattering facility [1] was constructed to realize electron scattering from short-lived unstable nuclei at RIKEN in Japan. Electron scattering is one of the most powerful tools for structure studies of atomic nuclei because of the well-understood mechanism of electromagnetic interaction. It has, however, never been applied to short-lived unstable nuclei because of the difficulty in preparing thick target although it has been long-desired to investigate exotic features of unstable nuclei by electron scattering [2].

Recently, we succeeded in realizing the world's first electron scattering from online-produced unstable nuclei at the SCRIT facility after years of developments. Caesium nuclides were produced via photo-fission of uranium by irradiating 28-g uranium with 15-W electron beam and were ionized with the surface ionization type ion source at an ISOL system [3]. Thanks to a high production rate of caesium nuclides and the development of beam stacking methods in the ISOL and a Cooler-Buncher [4] systems, approximately 10^7 of ^{137}Cs ions/pulse beams were delivered into the SCRIT system, the averaged luminosity of $0.9 \times 10^{26} \text{ cm}^{-2}\text{s}^{-1}$ was achieved. The obtained angular distribution of elastically scattered electrons is consistent with a calculation. This experiment perfectly mimics the experiment of electron scattering from short-lived unstable nuclei produced online after the power of the ISOL driver is upgraded.

In this contribution, we will report recent results and future prospect of the SCRIT electron scattering facility.

[1] M. Wakasugi et al., Phys. Rev. Lett. 100, 164801 (2008)

[2] T. Suda and H. Simon, Prog. Part. Nucl. Phys. 96, 1 (2017)

[3] T. Ohnishi et al., Nucl. Instr. Meth. B317 (2013) 357

[4] M. Wakasugi et al., Rev. Sci. Instrum. 89 (2018) 095107

529

New structure features revealed in isomeric spectroscopy in the Z~82, N~104 region

Auteurs: Wenqiang Zhang¹; Andrei Andreyev²; Zhong Liu³; Dariusz Seweryniak⁴; Hao Huang^{None}; Zhihuan Li⁵; Jianguo Li⁶; Chengyu Guo⁵; Daniel Doherty⁷; A. E. Barzakh⁸; Piet Van Duppen⁹; James Cubiss²; Boris Andel¹⁰; Stanislav Antalic¹⁰; Michael Block¹¹; A. Bronis¹²; M. Carpenter¹³; P. Copp¹³; Bing Ding^{None}; Zoe Favier¹⁴; Francesca Giacoppo¹⁵; Tianheng Huang^{None}; B Kindle¹⁶; Filip Kondev^{None}; Torben Lauritsen¹⁷; Guangshun Li¹⁸; M. A. Monthery¹⁹; P. Mosat¹²; Yifei Liu²⁰; Zhiheng Wang²⁰; C. Raison¹⁹; W. Reviol¹³; Guy Savard⁴; Gemma Wilson²¹; H.Y. Wu⁵; F.R. Xu⁵; X. H. Yu¹; Quanbo Zeng¹; X. H. Zhou¹⁸

¹ Institute of Modern Physics, Chinese Academy of Sciences

² University of York

³ IMP,CAS

⁴ Argonne National Laboratory

⁵ State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China

⁶ Institute of Modern Physics

⁷ University of Surrey

⁸ Petersburg Nuclear Physics Institute, NRC Kurchatov Institute, 188300 Gatchina, Russia

⁹ KU Leuven, Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium

¹⁰ Comenius University in Bratislava

¹¹ GSI/HIM/JGU

¹² Department of Nuclear Physics and Biophysics, Comenius University in Bratislava, 84248 Bratislava, Slovakia

¹³ Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

¹⁴ CERN

¹⁵ GSI Helmholtzzentrum für Schwerionenforschung GmbH

¹⁶ GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Darmstadt, 64291, Germany

¹⁷ ANL

¹⁸ Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

¹⁹ Department of Physics, University of York, York, YO10 5DD, United Kingdom

²⁰ Lanzhou University, Lanzhou 730000, China

²¹ Louisiana State University

Auteur correspondant zwqzwq@impcas.ac.cn

Neutron-deficient nuclei around mid-shell at $N \sim 104$ in the lead region provide many examples of shape coexistence and shape isomers [1]. In order to study shape coexistence in this region, prompt and delayed γ -ray spectroscopy of the ^{187}Pb and ^{183}Hg isotopes produced in the reaction $^{50}\text{Cr} + ^{142}\text{Nd} \rightarrow ^{192}\text{Po}^*$ has been performed at the Argonne Gas-Filled Analyzer.

In ^{187}Pb , a new 5.15(15)- μs isomeric state at 308 keV above the spherical $3/2^-$ ground state was identified. A strongly-coupled band is observed on top of this isomer, which is nearly identical to the one built on the prolate $7/2^-$ -[514] Nilsson state in the isotone ^{185}Hg . Based on this similarity and on the result of the potential-energy surface calculations, the new isomer in ^{187}Pb was proposed to be prolate with $J^\pi = 7/2^-$ and classified as a shape isomer. The retarded character of the 308-keV $(7/2^-) \rightarrow 3/2^-$ gs transition with a deduced $B(E2) = 5.6(2) \times 10^{-4}$ W.u. can be well explained by the significant difference between the prolate parent and spherical daughter configurations, leading to the shape isomerism [2].

In ^{183}Hg , the decay of the nearly spherical $13/2^+$ isomeric state was first observed following the α decay of the $13/2^+$ isomer in ^{187}Pb . By the α - γ correlation measurement, the half-life of this isomer was measured to be $T_{1/2} = 290(30)$ μs . This isomer was proposed to deexcite by retarded $M2$ transition, which can be explained by the notable shape change between the initial and the final states [3].

[1] P. Möller *et al.*, Phys. Rev. Lett. 103, 212501 (2009).

[2] W. Q. Zhang *et al.*, Phys. Lett. B 829, 137129 (2022).

[3] H. Huang *et al.*, Phys. Lett. B 833, 137345 (2022).

parallel / 530

Initial RI Beam Commissioning of the RAON ISOL Facility

Auteur: Jinho Lee¹

Co-auteurs: Hee-Joong Yim ¹; Wonjoo Hwang ¹; Takashi Hashimoto ¹; Jae-Won Jeong ¹; Yeong-Heum Yeon ¹; Sung-Jong Park ¹; Dong-Joon Park ¹; Jaehong Kim ¹; Byoung-Hwi Kang ¹; Seongjin Heo ¹; Kyoung-Hun Yoo ¹; Young-Ho Park ²; Taeksu Shin ¹

¹ *Institute for Basic Science*² *Korea Research Institute of Standards and Science*

Auteur correspondant jinhlee@ibs.re.kr

The ultimate goal of RAON (Rare Isotope Accelerator Complex for Online Experiments) is to combine the Isotope Separator On-Line (ISOL) and In-Flight Separator (IF) systems to produce more exotic rare isotope (RI) beams and access unexplored regions of the nuclear landscape. As the first step, we completed the installation of the ISOL facility in June 2021. The RAON ISOL facility consists of a driver accelerator, a target/ion source (TIS) capable of full remote handling, a pre-mass separator, a Radio Frequency Quadrupole Cooler Buncher (RFQ-CB), an Electron Beam Ion Source Charge Breeder (EBIS-CB) and an A/q separator. The driver accelerator utilizes an H- Cyclotron with an energy of 70 MeV. The primary proton beam of up to 0.75 mA is delivered to the ISOL target/ion source (TIS) module, producing relatively pure and low-energy rare isotopes. The existing TIS module can accommodate up to 10 kW beam power, and it is expected that neutron-rich isotope ions will be produced by uranium fission reaction processes with the rates of 10^{13} fission/s from the maximum beam power. The development of a high-power target and module system that can be operated reliably up to 70 kW proton beam power without compromising the yield of rare isotopes will be a future challenge.

The RI ion beams extracted from the TIS can be transported to the pre-mass separator and cooled in the RFQ-CB. Cooled ion beams can be sent to either a mass measurement system (MMS) or collinear laser spectroscopy (CLS) for the investigation of the fundamental properties of exotic nuclei in the ISOL experimental hall. Alternatively, RI beams can be transported to an A/q separator after charge breeding with the energy of 10 keV/u through RFQ-CB and EBIS-CB and later sent to the RAON injector system for post-accelerator.

The beam commissioning of the 70 MeV proton cyclotron was completed in January 2023, and the first RI beam commissioning using the SiC target for RAON ISOL has started.

parallel / 531

Investigation of negative-parity band in ^{130}Cs

Auteur: Chandrani Majumder¹

Co-auteurs: Pragma Das ¹; Himanshu Kumar Singh ¹; Umakant Lamani ¹; B. Bhujang ¹; V. Pasi ¹

¹ *Indian Institute of Technology Bombay*

Auteurs correspondants: 20002432@iitb.ac.in, hksingh@phy.iitb.ac.in

Odd-odd Cs isotopes have been extensively studied by means of in-beam γ -ray spectroscopy, especially the positive-parity band based on $\pi h_{11/2} \otimes \nu h_{11/2}$ for the chiral symmetry and signature inversion [1,2]. Our present study focuses on a negative-parity band based on $\pi h_{11/2} \otimes \nu g_{7/2}$ valence particle configuration in ^{130}Cs [3]. We have studied the band structure by measuring lifetimes (in ps) of excited states using Doppler shift attenuation method (DSAM). Our new results on reduced transition probabilities (B(E2) and B(M1)) established the triaxial nature of the band consistent with the total Routhian surface (TRS) calculation.

We utilized the fusion-evaporation reaction $^{124}\text{Sn}(^{11}\text{B}, 5n)^{130}\text{Cs}$ to populate the high spin states of ^{130}Cs . Energetic ^{11}B beam at 70 MeV was delivered by the Pelletron accelerator facility at the Tata Institute of Fundamental Research, Mumbai, India. We utilized a self-supporting target (^{124}Sn) of

thickness $\sim 2.2 \text{ mg/cm}^2$ sufficient to stop most of the recoiling nuclei. The emitted γ -rays were detected by the 21 Compton suppressed HPGe Clover detectors of Indian National Gamma Array (INGA) [4]. The valid two- and higher-fold coincident γ -events were recorded in list mode using PIXIE-16 based digital data acquisition system. The standard procedure of data analysis was adopted as described in our earlier work [5]. For the concerned negative-parity band, we first confirmed the decay scheme and spins up to $22 \hbar$ by finding the Directional Correlation ratios. To extract the lifetimes, we fitted the DSAM lineshape profiles using the code LINESHAPE [6] for detectors located at angles of 23° , 90° , 157° .

From our DSAM analysis, we determined the lifetimes of four states (14^- to 20^-) within the range of 0.4 to 1.2 ps, with an average $B(E2)$ value of $0.4 e^2 b^2$. There seems to be a slight decrease in $B(E2)$ values with increasing spin. Interestingly, the band exhibits some striking features. Only the even spin states are populated above the bandhead 8^- , so the M1 transitions are missing. Above the backbend at around $\hbar\omega \simeq 0.38 \text{ MeV}$, both signature spins are observed with M1 transitions. However, the M1 is much weaker than the E2 transitions. The band shows the decoupling behaviour up to $16 \hbar$, with energy spacings similar to the neighboring even-even and odd-even nuclei – the ground state band of ^{128}Xe [7] and $\pi h_{11/2}$ band of ^{129}Cs [5].

We performed the total Routhian surface (TRS) [8] calculation to study various features of the band. Firstly, we determined the deformation parameters values (β , γ) for the minimum energy configuration, from the contour plots for the band configuration $\pi h_{11/2} \otimes \nu g_{7/2}$. In addition, we identified the first band-crossing for the neutron alignment in $h_{11/2}$ orbit from the quasi-particle Routhian diagram. The theoretical crossing frequency (0.40 MeV) was in agreement with the experimental observation. The proton alignment was ruled out because of the high values of the band-crossing frequencies for both positive and negative-parity orbits. Furthermore, we confirmed the neutron alignment by comparing the experimental $B(M1)$ values with those obtained from the geometrical model of Donau and Frauendorf [9,10]. We extracted the experimental $B(M1)$ values from the $B(M1)/B(E2)$ ratios determined from the γ -ray intensity measurements, and $B(E2)$ estimated from the DSAM analysis. Again, the proton alignment was ruled out by comparing the estimated and experimental $B(M1)$ values.

In summary, we have investigated thoroughly the structure of the negative-parity band through lifetime measurement near and above the band-crossing region. A triaxial nuclear shape was inferred with deformation parameter values $\beta = 0.16$ and $\gamma = -30^\circ$ (in Lund convention) using the total Routhian surface calculation. We also established the neutron alignment with configuration $\pi h_{11/2} \otimes \nu g_{7/2} (h_{11/2})^2$.

[1] E. Grodner *et.al.* Phys. Rev. Lett. 97, 172501 (2006).

[2] Y. Liu *et.al.* Phys. Rev. C 54, 719 (1996).

[3] R. Kumar *et.al.* Eur. Phys. J. A 11, 5 (2001).

[4] R. Palit *et.al.*, Nucl. Instrum. Methods A 680, 90 (2012).

[5] U. Lamani *et.al.*, Nucl. Phys. A 1014, 122220 (2021).

[6] J. C. Wells and N. R. Johnson ORNL report 6689, 44 (1991).

[7] J. N. Orce *et.al.* Phys. Rev. C 74, 034318 (2006).

[8] T. Bengtsson, Nucl. Phys. A 512, 124 (1990).

[9] F. Dönau and S. Frauendorf, in Proceedings of the International Conference on High Angular Momentum Properties of Nuclei, Oak Ridge, 1982, edited by N. R. Johnson (Harwood, New York, 1983), p. 143.

[10] F. Dönau, Nucl. Phys. A 471, 469 (1987).

532

Beta-Delayed Neutron Spectroscopy of Californium-252 Fission Fragments with BEARtrap at Argonne National Laboratory

Auteur: Daniel Burdette¹

Co-auteurs: Aaron Gallant²; Gemma Wilson³; Graeme Morgan³; Guy Savard¹; Jason Clark¹; Nicholas D. Scielzo²; Scott Marley⁴

¹ Argonne National Laboratory

² Lawrence Livermore National Laboratory

³ Louisiana State University, Argonne National Laboratory

⁴ Louisiana State University

Auteur correspondant dburdette@anl.gov

Beta-delayed neutron emission properties are important to both basic science and applications-driven nuclear physics research. Branching ratios for these decays of neutron-rich nuclei play a role in r-process nucleosynthesis calculations as they are needed to determine final abundance patterns. The energy spectra of beta-delayed neutron precursors are also of interest to the development of advanced fuel cycles for nuclear reactors. A new recoil-ion technique has been developed to measure these properties without direct neutron detection. This method involves trapping the parent nucleus at the center of a Paul trap, and then measures the time of flight of the recoiling ion relative to the beta particle following beta decay. This allows for identification of beta-delayed neutron events, as well as a kinematic reconstruction of the neutron energy. This technique was conducted on various fission fragments generated by the californium-252 source of the CARIBU facility at Argonne National Laboratory using the Beta-decay Paul Trap (BPT), which was designed for precision measurements of beta decay on lighter nuclei. These measurements allowed for the determination of branching ratios and energy spectra for various beta-delayed neutron precursors, however, they also provided a good learning benchmark in how the trap and detector systems could be improved to perform future measurements. As a result, a dedicated trap and detector array, referred to as the BEtA Recoil-ion trap (BEARtrap), have been developed. The experimental setup is located in CARIBU's low-energy experimental area to study the large number of unmeasured beta-delayed neutron precursors generated by both the current source, and the forthcoming nuCARIBU upgrade. An overview of the experimental method, ion trapping, and detector systems as well as the first science case of the new apparatus will be presented.

This work is supported by the U.S. DOE under contract No. DE-AC02-06H11357 (ANL), and DE-AC52-07NA27344 (LLNL), and the U.S. DOE Office of Science Award No. DE-SC0021315 (LSU).

parallel / 537

Medical Radioisotope Production Using Inverse Kinematics

Auteurs: Aldo Bonasera¹; Brian Roeder²; Dustin Scriven²; Gabriel Tabacaru³; Georgios Souliotis⁴; Jedidiah Romo²; Justin Mabiala⁵; Kang Wang³; Marcia Dias Rodrigues³; Meixiang Yu⁶; Ninel Nica³; Njeri Edwards⁵; Nolan Tenpas³; Paulo Zanotti-Fregonara⁶; Victor Iacob³

¹ Cyclotron Institute, Texas A&M University, USA and Laboratori Nazionali del Sud, INFN, Italy

² Cyclotron Institute, Texas A&M University, USA

³ Cyclotron Institute, Texas A&M University, USA

⁴ Laboratory of Physical Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, Greece

⁵ Department of Chemistry and Physics, Prairie View A&M University, USA

⁶ Houston Methodist Research Institute, USA

Auteur correspondant mrodrigues@tamu.edu

A novel approach to produce medically important radionuclides using inverse kinematics [1-3] has been developed at the Cyclotron Institute at Texas A&M University. The methodology involves a heavy-ion beam of appropriate energy impinging on a light gas target (e.g., H_2 , D_2 , ${}^3\text{-}^4\text{He}$, ...) and collecting the isotope of interest, focused along the beam direction, on a foil catcher after the target. In addition, secondary emitted particles such as neutrons from the primary nuclear reaction can be used to irradiate a secondary target for further radionuclide production. As the quantity of the material required to prepare the heavy-ion beam is considerably smaller than that used in the standard solid target approach, material costs are expected to be reduced via this methodology. The theranostic radionuclide ${}^{67}\text{Cu}$ ($T_{1/2} = 62h$) was produced through the reaction of a ${}^{70}\text{Zn}$ beam at 15 MeV/nucleon with a hydrogen gas target [1-2]. The ${}^{67}\text{Cu}$ radionuclide alongside other coproduced

isotopes, was collected after the gas target on an aluminum catcher foil. Their radioactivity was measured by off-line γ -ray analysis. In addition, the forward-focused neutrons from the primary reaction were used to irradiate a ^{nat}Zn target in order to produce more ^{67}Cu . Pursuing this initial investigation, the well-known $^{99}Mo/^{99m}Tc$ generator system [3] was also investigated with a beam of ^{100}Mo at 12MeV/nucleon on 4He gas cell target for three different gas pressures. The methodology was tested with success. The production of the ^{67}Cu and ^{99}Mo were predominant in comparison with the various radio-impurities. In order to achieve production appropriate for preclinical studies, high-intensity heavy-ion primary beams are necessary.

[1] Souliotis, G. et al. A novel approach to medical radioisotope production using inverse kinematics: A successful production test of the theranostic radionuclide ^{67}Cu . *Applied Radiation Isotopes* 149, 89–95, DOI: <https://doi.org/10.1016/j.apradiso.2019.04.019> (2019).

[2] Rodrigues, M.R.D. et al. A novel approach to medical radioisotope production using inverse kinematics, *EPJ Web of Conferences* 252, 08002, DOI: <https://doi.org/10.1051/epjconf/202125208002> (2021).

[3] Mabila J. et al. Enhanced production of ^{99}Mo in inverse kinematics heavy ion reactions, *EPJ Web of Conferences* 252, 08003. DOI: <https://doi.org/10.1051/epjconf/202125208003> (2021).

[4] Rodrigues M.R.D. et al., *Radiation Physics and Chemistry* submitted.

parallel / 538

First measurement of a p-process reaction using a radioactive ion beam

Auteurs: Barry Davids¹; Gavin Lotay²; Matthew Williams³; Thomas Rauscher⁴

¹ TRIUMF

² University of Surrey

³ Lawrence Livermore National Laboratory

⁴ University of Basel

Auteur correspondant williams328@llnl.gov

Approximately 30 stable nuclides on the neutron-deficient side of stability cannot be produced via the same neutron-capture driven mechanisms responsible for synthesizing all other elements heavier than iron. These “p-nuclei” are instead thought to originate from photodisintegration reactions on s- and r-process seed nuclei, which can occur in the extreme high-temperature environments of core-collapse supernovae. However, significant discrepancies exist, in some cases extending to orders of magnitude, between observed p-nuclei abundances obtained via isotopic analysis of meteorite samples, and supernovae model predictions. Improving on the available nuclear reaction data is an essential part of solving the puzzle of the p-nuclei, but experimental efforts in this regard must overcome significant technical challenges. This talk will describe the first ever measurement of a p-process reaction cross-section obtained with a radioactive ion beam. The $^{83}Rb(p,\gamma)^{84}Sr$ reaction was investigated at the TRIUMF-ISAC facility using a radioactive ^{83}Rb beam impinging on CH₂ foil targets. The recoiling reaction products were selected by m/q using the newly commissioned Electromagnetic Mass Analyser (EMMA), with γ -rays detected in-coincidence using the TIGRESS HPGe array. The high sensitivity of the combined EMMA-TIGRESS set-up allowed detection of low-lying transitions in ^{84}Sr populated by $^{83}Rb(p,\gamma)^{84}Sr$. The measured partial cross-section was then combined with statistical model calculations to obtain a total reaction cross-section that is 4x smaller than predicted, in-turn affecting the abundance of the ^{84}Sr p-nucleus predicted by massive-star models.

539

Ξ hypernuclei $^{15}_{\Xi}C$ and $^{12}_{\Xi}Be$, and the ΞN two-body interaction

Auteur: Yusuke Tanimura¹

Co-auteurs: Emiko Hiyama ²; Hiroyuki Sagawa ³; Tingting Sun ⁴

¹ *Tohoku University*

² *RIKEN*

³ *RIKEN/University of Aizu*

⁴ *Zhengzhou University, China*

Auteur correspondant tanimura@nucl.phys.tohoku.ac.jp

The study of interaction in the strangeness $S = -2$ sector is important in hypernuclear physics for unified understanding of baryon-baryon interaction. To this end, it is crucial to study structure of double-strangeness hypernuclei such as double- Λ and Ξ hypernuclei.

In this work [1], we focus on the new experimental data, which is named “IRRAWADDY” event, of $^{15}_{\Xi}\text{C}$ nucleus observed at $B_{\Xi} = 6.27 \pm 0.27$ MeV. We estimate the strengths of the ΞN interaction and give a consistent interpretation for all the existing events of the Ξ hypernucleus including IRRAWADDY. In addition to our previous work [2] based on the relativistic mean-field (RMF) model, we introduce an ΞN residual interaction and infer that KINKA ($B_{\Xi} = 8.00 \pm 0.77$ or 4.96 ± 0.77 MeV) and IRRAWADDY events are the ground-state spin doublet with the Ξ particle in the s orbit, and that IBUKI ($B_{\Xi} = 1.27 \pm 0.21$ MeV) and KISO ($B_{\Xi} = 3.87 \pm 0.21$ or 1.03 ± 0.18 MeV) events are members of the excited-state multiplets with the Ξ particle in the p orbits.

[1] Y. Tanimura, H. Sagawa, T.-T. Sun, and E. Hiyama, *Phys. Rev. C* **105**, 044324 (2022).

[2] T.-T. Sun, E. Hiyama, H. Sagawa, H.-J. Schulze, and J. Meng, *Phys. Rev. C* **94**, 064319 (2016).

parallel / 540

First results with the Advanced Rare Isotope Separator (ARIS) at FRIB

Auteurs: Oleg Tarasov¹; Roman Chyzh¹; Kei Fukusima¹; Simon Giraud¹; Marc Hausmann¹; Elaine Kwan¹; Peter Ostroumov¹; Mauricio Portillo¹; Bradley Sherrill¹; Mallory Smith¹

¹ *FRIB/MSU*

Auteur correspondant tarasov@frib.msu.edu

Commissioning of the Facility for Rare Isotope Beams (FRIB) in-flight separator system Advanced Rare Isotope Separator, ARIS, began in early 2022. The system consists of up to three stages of achromatic separation based on large superconducting magnets and can deliver beams to various experimental stations for nuclear and astrophysics studies, as well as other societal needs. ARIS is designed to be able to work with 400kW of primary beam power. The conceptual design and the comparison to commissioning studies will be presented.

In this contribution we summarize first results of rare beam isotopes production, and then to focus on high Z isotopes production in the recent commissioning experiment, that demonstrates ARIS abilities to separate and identify isotopes produced in the energy range of 100-200 MeV/u. Isotope production results and comparison with production models will be presented.

Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.

parallel / 544

Isospin symmetry in the $A=78$ triplet - gamma-ray spectroscopy of ^{78}Y and ^{78}Zr

Auteurs: Panu Ruotsalainen¹; George Zimba²

Co-auteurs: Robert Wadsworth³; David G. Jenkins³; Jesus Pereira Lopez⁴; University of Jyväskylä Nuclear Spectroscopy Group²

¹ University of Jyväskylä

² University of Jyväskylä

³ University of York

⁴ Center for Exotic Nuclear Studies (CENS), Institute for Basic Science (IBS)

Auteur correspondant panu.ruotsalainen@jyu.fi

The isospin symmetry concept has its origins in the charge-symmetry and charge-independence characteristics of the strong nuclear force. This implies that the strong interaction has an equal strength between the proton-proton, neutron-neutron and proton-neutron pairs. Therefore, the isobaric analog nuclei of the same mass $A = N + Z$, but with the neutron and proton numbers differing as $N = Z - 2$, $N = Z$ and $N = Z + 2$, should contain the same set of excited states at similar excitation energies. This assumption holds in the absence of the electromagnetic effects, but in practice the isobaric analog states (IAS) manifest energy differences resulting, e.g., from the Coulomb interaction. Investigations of the Coulomb, mirror and triplet energy differences have proven to be an effective probe for the nuclear structure, but have also provided information on the conservation of the isospin symmetry. During the past two decades a wealth of evidence has been collected for an isospin-breaking two-body interaction in the $A = 50 - 70$ mass region. This additional schematic interaction, in combination with the Coulomb force, appears to be required to reproduce the experimental data on the triplet energy differences.

Since the $N = Z$ line approaches the proton-drip line in the $A > 70$ mass region, spectroscopic data for these triplets are scarce, which in turn prevents the investigations of the energy differences between IAS. This is particularly true for the mass $A = 78$ triplet (^{78}Zr , ^{78}Y and ^{78}Sr). The excited states in ^{78}Zr are not currently known at all, while only two excited states have been tentatively assigned in ^{78}Y . Recently, an experiment was performed at the Accelerator Laboratory of the University of Jyväskylä to investigate the structures of ^{78}Zr and ^{78}Y . This study employed the $^{40}\text{Ca}(^{40}\text{Ca}, 2n/pn)^{78}\text{Zr}/^{78}\text{Y}$ fusion evaporation reaction, the JUROGAM 3 Ge-array coupled to the vacuum-mode recoil separator MARA and the recoil-beta tagging technique. The preliminary analysis of this data has resulted in the discovery of several new excited states in ^{78}Y and a candidate for the $2^+ \rightarrow 0^+$ transition in ^{78}Zr observed via recoil-beta-beta correlations. This presentation discusses the new experimental results obtained for the mass $A = 78$ triplet in the context of the predictions obtained from nuclear theory.

545

Investigation of axial shape in ^{130}La through lifetime measurements

Auteur: Himanshu Kumar Singh¹

Co-auteurs: Pragma Das¹; Indu Bala²; Rakesh Kumar²; R. P. Singh²; S Muralithar²

¹ Indian Institute of Technology Bombay

² Inter-University Accelerator Centre, New Delhi, INDIA

Auteurs correspondants: pragma@phy.iitb.ac.in, hksingh@phy.iitb.ac.in

The shape coexistence in a collective excitation mode of atomic nuclei is widely discussed in the last decades [1]. In mass region ≈ 130 , the doubly odd nuclei are the excellent examples because of their γ -soft core as well as the presence of valence particles (protons and neutrons) in unique parity $h_{11/2}$ orbitals. The case of ^{130}La is a beautiful example of shape coexistence [2-6]. Many different shapes – triaxially deformed, axially deformed, excited collective oblate structure, and superdeformation – were seen in ^{130}La . In the present study, we focus on the axially deformed (prolate) band based on the valence particle configuration $\pi h_{11/2} \otimes \nu g_{7/2}$. The band shows signature splitting and backbending.

Our motivation has been to test experimental values of reduced transition probability (B(E2)) over two-quasiparticle plus rotor model as well as cranking calculations. We extracted the B(E2) values by measuring lifetimes (in ps) of the excited states using the Doppler shift attenuation method (DSAM). We have indeed found a near axial symmetry in nuclear shape, and neutron alignment above the band crossing.

We performed an experiment at the Inter-University Accelerator Center (IUAC) (New Delhi, India) to populate the high spin states of ^{130}La . The Indian National Gamma Array [7], consisting of eighteen Compton-suppressed clover HPGe detectors placed at the angles 32° , 57° , 90° , 123° , and 148° , was utilized. We decided a self-supporting target ^{116}Cd of thickness 4.6 mg/cm^2 sufficient to stop most of the recoiling nuclei. It was bombarded with ^{19}F beam at energy 94 MeV using the 15UD pelletron accelerator, forming ^{130}La via the reaction $^{116}\text{Cd}(^{19}\text{F}, 5n)^{130}\text{La}$ with maximum cross-section. We constructed symmetric as well as asymmetric matrices to determine lifetimes by fitting the DSAM lineshape profiles corresponding to detectors in the forward (32°), backward (148°), and 90° .

The gamma transitions belonging to the negative-parity band were observed in the gated spectra of two low-lying transitions 177 keV and 118 keV. The nicely spaced gamma transitions are the characteristics of a prolate deformed shape. The Doppler-shifted lineshapes were globally fitted for eight transitions via the gate on transition below (GTB). The gate on transition above (GTA) was also used to cross-check the lifetime values, and were found in good agreement. The value $K = 6$ was used considering the Gallagher-Mozzowski rule. The lifetime values were found within the range of 0.5 to 1.5 ps for states below the backbending. There was a smoothly decreasing trend in experimental B(E2) values. At high spins, the average B(E2) value experimentally found was $0.33 \pm 0.05 (e^2b^2)$.

We performed total Routhian surface (TRS) calculation and obtained the deformation parameters ($\beta, \gamma = 0.2, 7^\circ$) from the contour plot for the minimum energy configuration. The band configuration was confirmed to be $\pi h_{11/2} \otimes \nu g_{7/2}$, with mixing from other positive-parity neutron orbital ($\nu d_{5/2}$). Also, the first band-crossing frequency (0.46 MeV) for the neutron alignment obtained from the quasi-particle Routhian diagram, matched well with the experimental value (0.47 MeV). For the two-quasiparticle plus rotor model (PRM) calculations, we utilized the TRS results on β, γ values. The signature splitting were well reproduced. However, the theoretical B(E2) values agreed only at high spins, and remained roughly constant for the entire spin range.

In summary, we measured lifetimes using DSAM for eight states of a negative-parity band in ^{130}La . The band was known to be prolate and we confirmed it from our TRS result. Our experimental results on B(E2) were limited to only levels below backbend, and the values agreed with the PRM calculation at high spins. The particle configuration $\pi h_{11/2} \otimes \nu (h_{11/2})^2 g_{7/2}$ was established above the band-crossing.

[1] K. Heyde, et al. *Coexistence in odd-mass nuclei*, Phys. Rep. 102, 291-393 (1983).

[2] M. J. Godfrey, et al. *The competition between collective and single particle behavior in the odd-odd isotopes $^{128,130}\text{La}$* , J. Phys. G: Nucl. Part. Phys. 15, 487-508 (1989).

[3] M. J. Godfrey, et al. *Collective oblate structure in the odd-odd isotopes $^{128,130}\text{La}$* , J. Phys. G: Nucl. Part. Phys. 15, 671-686 (1989).

[4] M. Ionescu-Bujor, et al. *Lifetime measurements in the chiral-candidate doublet bands of ^{130}La* , Phys. Rev. C 98, 054305 (2018).

[5] M. Ionescu-Bujor, et al. *Band structures, lifetimes, and shape coexistence in ^{130}La* , Phys. Rev. C 102, 044311 (2020).

[6] P. Das et al. *Nuclear shapes and symmetries seen through measurement of short lifetimes*, Acta Phys. Pol. B51, 103 (2020).

[7] S. Muralithar et al. *Indian National Gamma Array at IUAC*, J. Phys.: Conf. Ser. 312, 052015 (2011).

Cross-section measurement in proton-, deuteron- and carbon-induced reactions on ^{136}Xe in inverse kinematics

Auteur: Xiaohui Sun¹

Co-auteurs: Hideaki Otsu²; He Wang²

¹ *Huzhou University*² *RIKEN***Auteur correspondant** xhsun@zjhu.edu.cn

Spallation/fragmentation reactions are promising in the production of both the proton-rich and neutron-rich nuclei. In order to optimize the production of the radioactive ion beams, a comprehensive understanding of the reaction mechanisms is required. In particular, the energy and target dependence is essential. Therefore, a large amount of high-quality experimental data has to be obtained. Many studies have been conducted to investigate on the reaction mechanisms of the spallation/fragmentation reaction, such as ^{76}Ge , ^{107}Pd , ^{137}Cs , ^{197}Au , and so on. As a primary beam used in worldwide for the radioactive beam generation, the reactions on the stable nuclei ^{136}Xe attracted much interest. However, the study of the ^{136}Xe on deuteron and heavy-ion is limited, only the reactions at high energy is performed. In order to gain more information on the energy dependence of deuteron- and heavy-ion- induced reactions, and to investigate the target dependence, we have measured the cross sections in the reactions of ^{136}Xe induced by proton, deuteron and carbon at 168 MeV/nucleon.

The experiment was performed at the RIKEN Radioactive Isotope Beam Factory. By using the inverse kinematics method, the production cross sections over a wide range of isotopes including stable isotopes, can be obtained. The secondary beams including ^{136}Xe were produced by the in-flight fission of ^{238}U beam at 345 MeV/nucleon. The particles in the secondary beams were identified event by event in the BigRIPS separator. CH_2 , CD_2 and C targets were used to induce the secondary reactions. The reaction products were analyzed and identified unambiguously by the ZeroDegree spectrometer. The cross sections for the reactions of ^{136}Xe on proton, deuteron and carbon will be presented as well as the target dependence. The energy dependence was also investigated by the comparison of these experimental results to previous studies for ^{136}Xe at higher reaction energies. These results were compared with the DEURACS calculations, the PHITS code including both the intra-nuclear cascade/dynamical and evaporation processes, and with empirical SPACS and EPAX parameterization. In the presentation, the detailed results will be discussed.

548

Recent Progress with the MLLTRAP double Penning Trap Mass Spectrometer at ALTO

Auteur: Sophie Morard¹**Co-auteurs:** Amelia Leite ¹; Elodie Morin ¹; Enrique Minaya Ramirez ¹; Luc Perrot ¹¹ *IJCLAB - Laboratoire de Physique des 2 Infinis Irène Joliot-Curie***Auteur correspondant** sophie.morard@ijclab.in2p3.fr

The double Penning trap mass spectrometer (PTMS) MLLTRAP is currently being setup at the Accélérateur Linéaire et Tandem à Orsay (ALTO facility) in France. The ISOL facility ALTO provides neutron-rich radioactive ion beams from the interaction of a γ -flux induced by a 50 MeV 10 μA electron beam in a uranium carbide target. A magnetic dipole mass separator and a resonance ionization laser ion source allow selecting the ions of interest. A new beamline dedicated for MLLTRAP will transport the 30 keV monocharged radioactive beams to a linear segmented Paul trap (RFQCB) where the ions are cooled and bunched. When ejected from the RFQCB, the bunched beam is decelerated to 100 eV before being injected into the PTMS. The goal of the MLLTRAP project at ALTO is to perform high precision mass measurements of silver isotopes toward the $N = 82$ neutron shell closure prior to its move to SPIRAL2/DESIR at Caen.

In order to ensure a good beam transmission from the target-ion source vault to the PTMS, detailed simulations of the transport and preparation areas have been started. Currently, calculations focus on the beam transport up to the entrance of the RFQCB. The transport and the preparation area are being finalized to be ready for off-line and on-line commissioning. New diagnostics has been installed in the new beamline such as beam profilers, faraday cup, and MCP. Moreover an emittance meter is expected to be placed as close as possible to the target-ion source vault and in front of the RFQCB as a way to characterize the transverse beam Twiss parameters. The off-line commissioning will include the characterization of a new high voltage ion source located few meters upstream

to the RFQCB. This source will also produce the ions of reference for the mass measurements. An overview of the project and a report on the recent progress will be given.

plenary / 550

Laser spectroscopy of the Heaviest Elements

Auteur: Sebastian Raeder¹

¹ *GSI Darmstadt*

Auteur correspondant s.raeder@gsi.de

The heaviest elements are of interest to nuclear and atomic physicists due to their peculiar properties. While nuclear shell structure effects are responsible for their very existence stabilizing them against spontaneous disintegration, the structure of their electronic shells is affected by strong relativistic effects leading to different atomic and chemical properties compared to their lighter homologs. The atomic structure can be probed by laser spectroscopy. This is a powerful tool to unveil fundamental atomic and, from the determination of subtle changes in atomic transitions, nuclear properties. The lack in atomic information on the heavy element of interest, the low production rates, and the rather short half-lives make experimental investigations challenging and demand very sensitive experimental techniques.

Laser spectroscopy of accelerator produced heavy nobelium (No, $Z=102$) isotopes in atom-at-a-time quantities became accessible in the pioneering experiment employing the Radiation Detected Resonance Ionization Spectroscopy (RADRIS) technique at the velocity filter SHIP at GSI, Darmstadt. More recent measurements with additional advancements of the setup and employing a novel mode of the RADRIS technique, where the desired nuclides are bred by radioactive decay on the capture filament, extended the reach of the method to ^{251,255}No and, for the first time, to on-line produced fermium (Fm, $Z=100$) isotopes. These on-line experiments are complemented by off-line laser spectroscopy measurements at the RISIKO mass separator at Mainz University on reactor-bred heavy actinides with suitable long lifetimes. Hot-cavity laser spectroscopy on radio-chemically purified samples enabled the investigation of isotopes of the heavy actinides curium (Cm, $Z=96$), californium (Cf, $Z=98$), einsteinium (Es, $Z=99$), and fermium. This experimental endeavor is accompanied by improvements of theoretical atomic calculations enabling the determination of nuclear ground state properties from the extracted atomic observables of isotope shifts and hyperfine structure parameters. This provides insight to the peculiar nuclear nature and especially the deformation of the heaviest elements. The obtained results will be discussed in view of nuclear theory predictions together with the perspectives for laser spectroscopic investigations in even heavier elements.

parallel / 553

Simultaneous pH sensing and gamma-ray imaging via angular correlation measurement using cascade nuclides

Auteur: Mizuki Uenomachi¹

Co-auteurs: Taisei Ueki²; Kenji Shimazoe²; Hideki Tomita³; Ryohei Terabayashi²; Tetsu Sonoda⁴; Momo Mukai⁴; Yudai Shigekawa⁴; Akira Sugiyama²; Sachiyo Nomura²; Takeshi Sato²

¹ *Kyoto University*

² *The University of Tokyo*

³ *Nagoya University*

⁴ *RIKEN*

Auteur correspondant uenomachi.mizuki.6a@kyoto-u.ac.jp

Gamma-ray imaging techniques such as positron emission tomography and single photon emission computed tomography (SPECT) have been utilized in nuclear medicine for diagnosis. The radioactive tracer imaging can provide functional or metabolic information non-invasively at the molecule

or cellular level. However, nuclear medicine imaging techniques cannot extract the local molecule or cellular environment information. While single photon emission radionuclides are conventionally used for SPECT, some of them emits two or more cascade photons with a short duration of intermediate state; for example, In-111 emits 171 keV and 245 keV gamma-rays with 84.5 ns time constant. An angular correlation between cascade photons that originates from the nuclear spin state is perturbed by the external fields. We have proposed a novel simultaneous gamma-ray imaging and local environment sensing method via the angular correlation measurement, which provides radionuclide position and its local environmental information simultaneously. In this study, we demonstrated simultaneous measurements of angular correlation and gamma-ray imaging using 8 x 8 array high-resolution Gd₃(Ga,Al)5O₁₂(Ce) scintillator detectors coupled with silicon photo multipliers (Hamamatsu, S13361-3050). We succeeded to obtain the local pH information of In-111 solution and the accumulation image simultaneously. We will report the detail in our presentation.

parallel / 558

High-precision mass measurements of ground and isomeric states of (super)heavy nuclides with SHIPTRAP

Auteur: Manuel J. Gutiérrez¹

Co-auteurs: Alexander Yakushev¹; Andrew Mistry²; Brankica Anđelić³; Christoph E. Düllmann⁴; Daniel Rodríguez⁵; Dennis Neidherr⁶; Elisabeth Rickert⁷; Elodie Morin⁸; Enrique Minaya Ramirez⁹; Francesca Giacoppo²; Fritz-Peter Heßberger¹; Jessica Warbinek¹⁰; Joaquín Berrocal⁵; Julia Even¹¹; Klaus Blaum¹²; Lennart Blaauw¹¹; Luisa Arcila González¹¹; Lutz Schweikhard¹³; Michael Block¹⁴; Nasser Kalantar-Nayestanaki¹⁵; Oliver Kaleja¹⁶; Peter Thierolf¹⁷; Pierre Chauveau¹⁸; Sebastian Raeder⁶; Stanislav Chenmarev¹²; Steffen Lohse⁷; Steven Nothhelfer¹

¹ GSI Darmstadt / HIM Mainz

² GSI Helmholtzzentrum für Schwerionenforschung GmbH

³ University of Groningen & Helmholtz Institut Mainz

⁴ Johannes Gutenberg University Mainz, 55099 Mainz, Germany, Helmholtz Institute Mainz, 55099 Mainz, Germany, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

⁵ Universidad de Granada

⁶ GSI Darmstadt

⁷ GSI Darmstadt / HIM Mainz / JGU Mainz

⁸ IJC Lab

⁹ IJCLab

¹⁰ GSI Helmholtz Centre

¹¹ University of Groningen

¹² MPIK

¹³ University Greifswald

¹⁴ GSI/HIM/JGU

¹⁵ ESRIG, University of Groningen, Groningen, The Netherlands

¹⁶ GSI Darmstadt / MPIK / JGU Mainz / University of Greifswald

¹⁷ Ludwig-Maximilians-University Munich

¹⁸ GANIL

Auteur correspondant m.j.gutierrez@gsi.de

Quantum shell effects stabilize heavy nuclei against spontaneous fission, making the existence of superheavy elements possible. Direct mass measurements performed with Penning traps provide information on the nuclear shell structure via binding energies, as well as excitation energies of low-lying, long-lived isomers obtained from the directly measured masses.

The SHIPTRAP experiment is devoted to the study of heavy and superheavy nuclei produced via fusion-evaporation reactions at rates well below one particle per hour. Thanks to the Phase-Imaging

Ion-Cyclotron-Resonance technique, the resolving power has been increased beyond 10^7 , bringing many low-lying isomeric states within reach for mass spectrometry. In this contribution the latest results, obtained as part of the FAIR Phase-0 campaign, will be discussed. These encompass ground-state masses and isomeric-state-energy measurements of several nuclides, ranging from ^{241}Cf to ^{258}Db . The alpha-decay chain ^{206}Fr - ^{202}At - ^{198}Bi was also studied, with the aim to pin down the excitation energies of several isomers for the first time.

559

New Super-pulse Fitting Algorithms for Decomposing Pile-up Pulses and Application to the α -decay of ^{222}U

Auteur: Zhong Liu¹

Co-auteurs: Hong-yang Lu²; Xiang Wang³; Zhi-huan Li³; and the SHANS collaboration

¹ IMP,CAS

² Institute of Modern Physics,CAS,China

³ State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University

Auteur correspondant liuzhong@impcas.ac.cn

The region to the “north-east” of ^{208}Pb , with $Z \geq 84$ and $N=128-130$, hosts the shortest-lived α -emitters, with half-lives in the range of nanoseconds to microseconds. The implantation and subsequent α -decay signals result in pile-up events in the charged particle spectroscopy with Doublesided Silicon Strip Detector (DSSD) detector, which were successfully resolved with digital pulse processing (DPP) technique by recording the waveform of the signals [1]. This technique introduces much flexibility as the digitized waveforms can be analyzed offline using different algorithms and has demonstrated significant advantage over conventional analog systems. Following the super-pulse scheme proposed in [2], we developed two new algorithms [3,4] to decompose pile-up events by fitting the super-pulse to the experimental traces. In [3], with proper baseline correction and plateau-region fitting, the spectroscopic information of piling-up signals with time separation down to 80 ns and amplitude of subsequent pulse down to 70 keV, can be readily extracted. In our latest algorithm development, a more general one based on the least square fitting method [4] shows better performance with higher sensitivity and energy resolution. The details of the algorithms will be presented in this contribution.

The α -decay of ^{222}U was studied at GSI recently [5], however the reduced decay width obtained was found to deviate exceptionally from the systematics in the $N_p.N_n$ scheme in the $N>126$ region (see Fig 3b in [6]). ^{222}U was also produced in our recent experiment [7] performed at the gas-filled recoil separator SHANS [8]. The α energy of ^{222}U was revised to be 9246(6) keV using the new algorithms, the precision much improved compared with the GSI results (9.31(5) MeV) [5], though with lower statistics. Using the present α energy, the α -decay reduced width of ^{222}U was revised and fit in the systematics in the $N>126$ region very well, removing the anomaly in δ^2 at ^{222}U [6].

[1] R. Grzywacz, Nucl. Instrum. Methods Phys. Res. B 204, 649 (2003)

[2] S.N. Liddick, et al., Nucl. Instrum. Methods Phys. Res. A 669, 70 (2012)

[3] X.Wang, Z.H.Li, Z.Liu et al., Nucl.Instrum.Methods Phys.Res. A971, 164068 (2020)

[4] H.Y. Lu, Z.Liu, X.Wang, Z.H.Li et al., in preparation

[5] J. Khuyagbaatar et al., Phys. Rev. Lett. 115, 242502 (2015)

[6] Z.Y. Zhang, et al., Phys. Rev. Lett. 122, 192503 (2019)

[7] T.H. Huang et al., Phys. Rev. C 98, 044302 (2018)

[8] Z.Y. Zhang et al., Nucl. Instrum. Methods Phys. Res., Sect. B 317 (2013) 315

parallel / 560

Study of the $N = 32$ and $N = 34$ shell gap for Ca and Ar isotopes with quasi-free scattering reactions

Auteur: Hongna Liu¹

¹ *Beijing Normal University*

Auteur correspondant hongna.liu@bnu.edu.cn

Shell gaps represent the backbone of nuclear structure and are a direct fingerprint of the in-medium many-body interactions. The nuclear shell structure is found to change, sometimes drastically, with the number of protons and neutrons, revealing how delicate the arrangement of interacting nucleons is. The neutron-rich *pf*-shell nuclei have received much attention on both experimental and theoretical fronts with the possible appearance of new subshell closures at $N = 32$ and 34 . The $N = 32$ subshell closure has been reported in the region from Ar to Cr isotopes based on $E(2_1^+)$, transition probability, and mass measurements. However, the laser spectroscopy of Ca and K isotopes reveals an increase of the charge radii with a slope larger than expected from $N = 28$ to $N = 32$ and 33 , which were interpreted to challenge the magic character of $N = 32$. For the $N = 34$ subshell closure, experimental evidence favors a new doubly-magic nucleus ^{54}Ca with a neutron subshell closure at $N = 34$, although the systematics of $E(2_1^+)$ and $B(E2; 0_1^+ \rightarrow 2_1^+)$ in Ti and Cr isotopes does not show any evidence for the $N = 34$ magicity. It is natural to ask how the $N = 34$ subshell evolves below $Z = 20$ towards more neutron-rich systems, such as ^{52}Ar .

In this presentation, I will present the quasi-free one-nucleon removal measurements performed at the RIBF facility using the MINOS and DALI2 set up to study the $N = 32$ and 34 shell gaps in Ca and Ar isotopes. The $^{52}\text{Ca}(p, pn)$ reaction in inverse kinematics was performed at ~ 230 MeV/nucleon. The measured partial cross sections and momentum distributions support the doubly-magicity of ^{52}Ca . The analysis of the momentum distributions leads to a difference of the root-mean-square radii of the neutron $1f_{7/2}$ and $2p_{3/2}$ orbitals of $0.61(23)$ fm, in agreement with the modified-shell-model prediction of 0.7 fm suggesting that the large root-mean-square radius of the $2p_{3/2}$ orbital in neutron-rich Ca isotopes is responsible for the unexpected linear increase of the charge radius with the neutron number. The low-lying structure of ^{52}Ar was extracted using the $^{53}\text{K}(p, 2p)$ reaction. The 2_1^+ excitation energy is found at $1656(18)$ keV, the highest among the Ar isotopes with $N > 20$. This result is the first experimental signature of the persistence of the $N = 34$ subshell closure beyond ^{54}Ca . Shell-model calculations with phenomenological and chiral-effective-field-theory interactions both reproduce the measured 2_1^+ systematics of neutron-rich Ar isotopes and support a $N = 34$ subshell closure in ^{52}Ar .

parallel / 561

Gamow-Teller Giant Resonance in ^{11}Li neutron drip line nucleus

Auteur: László Stuhl¹

Co-auteurs: Masaki Sasano²; Gao Jian³; Y. Hirai⁴; Kentaro Yako⁵; T. Wakasa⁴; DeukSoon AHN⁶; Hidetada BABA²; A. I. Chilug⁷; Serge Franchoo⁸; Y. Fujino⁹; Julien Gibelin¹⁰; K.I. Hahn¹; Z. Halász¹¹; T. Harada¹²; Muhsin N. Harakeh¹³; D. Inomoto⁴; Tadaaki Isobe¹⁴; H. Kasahara⁴; D. Kim¹; G.G. Kiss¹¹; T. Kobayashi¹⁵; Yosuke Kondo¹⁶; Zeren Korkulu¹; Shumpei KOYAMA¹⁷; Yuki Kubota¹⁴; A. Kurihara¹⁸; H.N. Liu¹⁹; M. Matsumoto¹⁸; S Michimasa²⁰; H. Miki¹⁸; M. Miwa²¹; T. Motobayashi²; Takashi NAKAMURA¹⁶; M. Nishimura²; Hideaki OTSU²; Valerii Panin²²; A.T. Saito¹⁸; Hideyuki Sakai²³; Hiroshi SATO²; T. Shimada¹⁸; Yohei SHIMIZU²; Susumu Shimoura²⁴; A. Spiridon⁷; I.C. Stefanescu⁷; X. Sun²; Y.L. Sun¹⁹; Hiroshi Suzuki²⁵; Y. Togano²; T. Tomai¹⁸; L. Trache⁷; D. Tudor⁷; T. Uesaka²; H. Yamada¹⁸; M. Yasuda¹⁸; K. Yoneda²; Koichi YOSHIDA²; Juzo Zenihiro²⁶; N. Zhang²⁷

¹ *Center for Exotic Nuclear Studies, Institute for Basic Science*

² *RIKEN Nishina Center*

³ *State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, No. 5 Yiheyuan Road, Haidian district, 100871, Beijing, China*

⁴ *Department of Physics, Kyushu University*

⁵ *CNS, University of Tokyo*

⁶ *Center for Exotic Nuclear Studies, KOREA*

⁷ *Horia Hulubei Nat. Inst. of Phys. and Nucl. Eng.*

⁸ *IfJLab*

⁹ *Department of Physics, Rikkyo University*

¹⁰ *LPC Caen*

¹¹ *ATOMKI, Eötvös Loránd Research Network (ELKH), Debrecen, Hungary*

¹² *Department of Physics, Toho University*

¹³ *GSI/KVI*

¹⁴ *RIKEN*

¹⁵ *Department of Physics, Tohoku University*

¹⁶ *Tokyo Institute of Technology*

¹⁷ *University of Tokyo*

¹⁸ *Dept. of Physics, Tokyo Institute of Technology*

¹⁹ *Dépt. Physique Nucl., CEA, Univ. Paris-Saclay*

²⁰ *Center for Nuclear Studies (CNS), The University of Tokyo*

²¹ *Dept. of Physics, Saitama University*

²² *CEA Saclay*

²³ *Riken Nishina Center*

²⁴ *Center for Nuclear Study, the University of Tokyo*

²⁵ *RIKEN Nishina Center, RIKEN*

²⁶ *Kyoto University*

²⁷ *Institute of Modern Physics, Chinese Acad. of Sci.*

Auteur correspondant stuhl@ins.re.kr

At the RIKEN Radioactive Isotope Beam Factory, the spin-isospin response of ^{11}Li was measured in charge-exchange (p, n) reaction at 182 MeV/nucleon beam energy. There is no available data for isovector spin-flip giant resonances in nuclei with large isospin asymmetry factors, where $(N-Z)/A > 0.25$ [1]. Our work aims to investigate this unexplored region up to $(N-Z)/A = 0.5$.

The charge-exchange (p, n) reactions in inverse kinematics combined with the missing-mass technique are powerful tools to extract the B(GT) strengths of unstable isotopes up to high excitation energies, without Q-value limitation of the β decay [1]. In our previous work on ^{132}Sn [2], we demonstrated that accurate information about giant resonances can be obtained for unstable nuclei by using this probe. The combined setup [3] of PANDORA low-energy neutron spectrometer [4] and SAMURAI large-acceptance magnetic spectrometer [5] together with a thick liquid hydrogen target allowed us to perform the experiment with high luminosity. The recoil neutrons with kinetic energy of 0.1–10 MeV were identified with PANDORA, while the SAMURAI was used for tagging the decay channels of the reaction residues.

The β decay of ^{11}Li is complex. The ^{11}Li β -decay involves the largest number of decay channels ever detected [6] and experimental results have been reported for cases, when the daughter breaks into fragments, and emission of one, two, and three neutrons, α particles and ^6He , tritons, and deuterons has been observed in several β -decay studies [8,9]. However, the B(GT) values were not clearly deduced as these studies were effected by the Q value.


In this talk, the final results of our analysis will be presented. Deduced double differential cross section up to about 40 MeV, including the Gamow-Teller (GT) Giant Resonance region in ^{11}Li will be reported, as well as the comparison of the obtained B(GT) values with those from β -decay studies. We will discuss the nature of several newly identified decay channels of ^{11}Be also.

Our observation, that the GT peak occurs below the Isobaric Analog State in ^{11}Li , will be discussed in connection with the variation of residual spin-isospin interaction in exotic nuclei.

[1] K. Nakayama, et al., Phys. Lett. B 114, 217 (1982).

[2] M. Sasano et al., Phys. Rev. Lett. 107, 202501 (2011). 

[3] J. Yasuda et al., Phys. Rev. Lett. 121, 132501 (2018).

[4] L. Stuhl et al., Nucl. Instr. Meth. B 463, 189 (2020). 

[5] L. Stuhl et al., Nucl. Instr. Meth. A 866, 164 (2017).

[6] T. Kobayashi, et al., Nucl. Instr. Meth. B 317, 294 (2013).

[7] M. Madurga et al., Nucl. Phys. A 810, 1 (2008).

[8] M.J.G. Borge et al., Nucl. Phys. A 613 199 (1997).

[9] R. Raabe et al., Phys. Rev. Lett. 101, 212501 (2008).

563

The South African Isotope Facility and Low-Energy Radioactive-Ion Beam Project

Auteur: Robert Bark¹

Co-auteurs: Faiçal Azaiez¹; Shadley Baard¹; Lowry Conradie¹; Pieter Van Schalkwyk¹; Skye Segal¹; Le Roux Strydom¹

¹ *iThemba LABS*

Auteur correspondant bark@tlabs.ac.za

The iThemba Laboratory for Accelerator Based Sciences is based around a K=200 Separated Sector Cyclotron (SSC) which is used for radionuclide production, for research in nuclear physics and radiobiology.

Radionuclides are currently produced with the SSC for local and export markets, with only longer-lived isotopes available for export. iThemba LABS recently supplied 20% of the world's ⁸²Sr, 40% of the world's ⁶⁸Ge/⁶⁸Ga generator and all of its ²²Na. The first phase of its flagship project, the "South African Isotope Facility" (SAIF), is nearing completion at iThemba LABS, with the installation of an IBA C70 cyclotron. This machine will be capable of accelerating protons to 70 MeV and delivering currents of up to 700 μA. It will be dedicated to isotope production, which will increase by more than a factor of two once the facility is commissioned.

With the release of the SSC from isotope production, it can be dedicated to physics research. The Low-Energy Radioactive-Ion Beam (LERIB) project of iThemba LABS will use 66 MeV protons from the SSC to produce radioactive-ion beams using the ISOL method, with non-actinide, carbide targets. The target/ion-source "Front-End" is identical to the SPES Front-end, which in turn owes its heritage to the target/ion-sources at ISOLDE. It is presently installed in an off-line test facility where the ion-source is being developed using stable beams.

The first stage of the LERIB project will see the front-end placed on an SSC beam line which will be used to produce RIBs using a low-intensity (< 10 μA) 66 MeV proton beam. The construction of LERIB Phase 0 is presently in the hands of consulting engineers who are doing the final detailed design work.

565

Penning-trap mass measurements of neutron-rich Rh and Ru nuclei at IGISOL/JYFL

Auteur: Pauline Ascher¹

Co-auteurs: Antoine de Roubin²; Anu Kankainen³; Dinko Atanasov¹; Marek Stryjczyk⁴; Marjut Hukkanen⁵; Mathias GERBAUX⁶; Mathieu FLAYOL⁷; Michael Bender⁸; Stéphane Grévy⁹; Tommi Eronen³; Wouter Ryssens¹⁰

¹ *LP2iB*

² *KU Leuven*

³ *University of Jyväskylä*

⁴ *University of Jyväskylä*

⁵ *University of Jyväskylä and CENBG*

⁶ *CENBG - Université de Bordeaux*

⁷ *CNRS-LP2IB-CENBG*

⁸ *IPN Lyon*

⁹ *CENBG*

¹⁰ *Université Libre de Bruxelles*

Auteur correspondant ascher@lp2ib.in2p3.fr

The nuclear mass is a key observable to guide and constrain the theoretical descriptions of the nucleus. The evolution of binding energy differences can also reveal specific structure effects, such as shape changes or shell closure evolutions. The drastic deformation change in the A-100 region is an example, where a strong kink in the two-neutron separation energy surface has been observed and attributed to the effect of the tensor force between the neutron $g_{7/2}$ and the proton $g_{9/2}$ orbitals. Above this region, where the prolate deformation dominates the ground state, the nuclei are expected to exhibit triaxial shapes [1], with an expected additional contribution to the binding energy compared to axially symmetric configurations.

Experimentally, the region between $Z = 38$ and $Z = 46$ is particularly difficult to explore in terms of ground-state properties, as the elements of interest are refractory, thus are difficult to extract from ISOL-type sources. The IGISOL facility of the Accelerator Laboratory at the University of Jyväskylä is one of the very few places, where they can be produced and studied with the high-precision Penning trap technique. A mass measurement campaign has been conducted at IGISOL using the JYFLTRAP mass spectrometer [2], and allowed to measure the ground-state masses of odd-odd 110-120Rh [3] and 115,117Ru [4]. In the case of the odd-odd 110-118Rh and 115Ru, the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique [5][6] was used to separate low-lying isomeric states from the ground states. This high-resolution separation allowed, on one hand to measure clean ground-state masses and on the other hand to determine the isomer excitation energies, in most of the cases for the first time.

The experimental techniques and the results will be presented, as well as comparisons with the predictions of the state-of-the-art global mass model BSkG1 [1].

- [1] G. Scamps et al., Eur. Phys. J. A 57 333 (2021)
- [2] T. Eronen et al., Eur. Phys. J. A 48 46 (2012)
- [3] M. Hukkanen et al., Phys. Rev. C. 107 014306 (2023)
- [4] M. Hukkanen et al., in preparation
- [5] S. Eliseev et al., Phys. Rev. Lett. 110 082501 (2013)
- [6] D.A. Nesterenko et al. Eur. Phys. J. A (2021) 57:302

566

Beta decay of neutron rich bromine isotopes studied by means of Modular Total Absorption Spectrometer

Auteur: Michał Stepaniuk¹

¹ *University of Warsaw*

Auteur correspondant michal.stepaniuk@fuw.edu.pl

This work was partially supported by the National Science Centre, Poland (NCN), under grant 2016/23/B/ST2/03559, and by the Office of Nuclear Physics, U.S. Department of Energy under Contracts No. DE-AC05-00OR22725 and FOA 18-1903 (ORNL), No. DEFG02-96ER40983 (UTK) and by the Office of Science.

M. Stepaniuk¹, M. Karny¹, A. Fijalkowska^{1,2}, K. P. Rykaczewski³, B. C. Rasco³, R. Grzywacz^{2,3,4}, C. J. Gross³, M. Wolinska-Cichocka⁵, K. C. Goetz^{2,6}, D. W. Stracener³, R. Goans⁷, J. H. Hamilton⁸, J. W. Johnson³, C. Jost², M. Madurga², K. Miernik^{1,3}, P. Shuai^{2,3,4,9}, D. Miller², S. W. Padgett², S. V. Paulauskas², A. V. Ramayya⁸, E. F. Zganjar¹⁰

¹Faculty of Physics, University of Warsaw, PL-02-093 Warsaw, Poland ²Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA ³Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

⁴JINPA, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

⁵Heavy Ion Laboratory, University of Warsaw, PL-02-093 Warsaw, Poland

⁶CIRE Bredesen Center, University of Tennessee, Knoxville, Tennessee 37966, USA

⁷Oak Ridge Associated Universities, Oak Ridge, Tennessee 37831, USA

⁸Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, USA

⁹Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China

¹⁰Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA

Results of the β decay of neutron rich bromine isotopes from mass $A=87$ to $A=91$ measured with Modular Total Absorption Spectrometer (MTAS) will be presented. Neutron rich bromine isotopes have high ^{235}U cumulative fission yields and large Q_β energies, therefore they make substantial contributions to the reactor decay heat and may create many detectable reactor anti-neutrinos. These large contributions means a complete knowledge of the decay schemes, including β -n branches, is of the utmost importance.

Decay schemes from ENSDF database of all discussed bromine isotopes have been found to be insufficient and incomplete, compared to the results of MTAS measurements. For example, even though the decay of ^{87}Br is a relatively well studied case (161 known levels, 226 known γ -transitions), our analysis shows a missing β -feedings to highly excited levels as well as incomplete γ -decay patterns for the known levels. Published ^{91}Br decay scheme lacks information on all β -feedings and γ -transitions intensities. Based on existing decay schemes, we present suggestions on how to improve them, using known levels and introducing so-called pseudo-levels where needed. Average β and γ -transitions energies are calculated as a result. Our analysis uses a multi spectra simultaneous fitting technique, which fits β -decay branches to the experimental spectra from different modules (or their sums) in parallel with the total MTAS energy spectrum.

Large Q_β energies lead to wide $Q_{\beta n}$ energy windows, what makes all isotopes in question a delayed neutron emitters. Modular Total Absorption Spectrometer, because of its volume, allows for a direct neutron measurements, thanks to neutron scatterings and captures inside NaI(Tl) crystals. Analysis results consist of estimation of P_n values, neutron energy spectra and neutron transitions to excited energy states in corresponding daughter nuclei. In the decay of ^{91}Br four β delayed neutron transitions to the excited states in ^{90}Kr have been observed for the first time.

In summary, analysis results of the MTAS data for neutron-rich, β -delayed neutron emitting bromine isotopes from mass $A=87$ to $A=91$ will be shown. Beta-neutron transitions to excited states in daughter nuclei will be discussed, as they are clearly visible in MTAS spectra. The impact of the evaluated isotopes on reactor decay heat calculations as well as on the reactor anti-neutrino anomaly will also be presented.

parallel / 568

First beta-delayed spectroscopy of neutron-rich Cl isotopes with FDSi

Auteur: Ian Cox¹

Co-auteurs: Bertis Rasco ²; Bradley Sherrill ³; Hendrik Schatz ⁴; James Allmond ²; Krzysztof P. Rykaczewski ²; Noritaka Kitamura ⁵; Oleg Tarasov ³; Robert Grzywacz ¹; Wei Jia Ong ⁶; Zhengyu Xu ¹

¹ *University of Tennessee, Knoxville*

² *Oak Ridge National Laboratory*

³ *FRIB / MSU*

⁴ *Michigan State University*

⁵ *Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA*

⁶ *Lawrence Livermore National Laboratory*

Auteur correspondant icox2@vols.utk.edu

The first experimental campaigns with FRIB Decay Station Initiator [1] at FRIB focused on the spectroscopy of very neutron-rich isotopes. They provided a wealth of data on beta-delayed neutron emitters. We will present the first results on the beta-delayed neutron emission spectroscopy near $N=28$ shell closure, such as $^{45,46,47}\text{Cl}$. Using a combination of neutron and gamma-ray data, we extracted the beta decay strength distribution to neutron unbound states and compared the results with the large-scale shell model calculations by Yoshida et al. [2], providing the first test of these predictions for the dominant Gamow-Teller transitions in this region. We also extracted the neutron-emission branching ratios to excited states in Ar isotopes and compared them with those predicted by the statistical model [3]. The importance of the discrepancies between model predictions and experimental data will be discussed.

[1] <https://fds.ornl.gov/initiator/>

[2] T. Kawano et al., *Journal of Nuclear Science and Technology*, 47(5),462, (2010), .

[3] S. Yoshida, Y. Utsuno, N. Shimizu, and T. Otsuka, *Phys. Rev. C* 97, 054321 (2018).

571

High-resolution spectroscopy of exotic silver with a cw OPO injection-seeded PDA.

Auteur: Mitzi Urquiza-González¹

Co-auteurs: Bram van den Borne²; Bruce A. Marsh³; Katerina Chrysalidis³; Klaus Wendt⁴; Korbinian Hens¹; Michael Heines²; Omorjit S. Khwairakpam⁵; Ruben P. de Groot⁶; Volker Sonnenschein¹; Ágota Koszorus²

¹ Division HÜBNER Photonics, Hübner GmbH Co KG, Germany

² KU Leuven, Belgium

³ CERN, Switzerland

⁴ Johannes Gutenberg Universität, Germany

⁵ Istituto Nazionale di Fisica Nucleare LNL, Italy

⁶ KU Leuven, Belgium. University of Jyväskylä, Finland

Auteur correspondant mitzi.urquiza@cern.ch

Short-lived radioisotopes are of special interest for nuclear structure studies, as their characteristic provide valuable reference points for theoretical predictions far from stability. By using lasers, hyperfine transitions can be accessed, allowing direct measurement of nuclear observables. For such high-resolution spectroscopy, narrow-band pulsed lasers can be created by the pulsed amplification of a cw seed laser, keeping the amplifier's high power and short time profile whilst acquiring the seeder's spectral properties. Spectroscopy on exotic silver was performed at the CRIS experiment at ISOLDE, CERN. A tunable cw single-mode OPO was employed as injection-seed for a two-stage pulsed dye amplifier. The hyperfine splitting of the ground-state $^2S_{1/2}$ to the level $^2P_{3/2}$ was measured and the hyperfine coupling constants were determined. For this work $^{109,111,117}\text{Ag}$ are presented, showcasing this laser system's applicability for future high-resolution spectroscopy studies.

573

Indium Energy Spectrum Shape (InESS) at WISArD

Auteur: Simon Vanlangendonck³

Co-auteurs: Dinko Atanasov¹; Bertram Blank²; Federica Cresto; Lennert De Keukeleere³; Xavier Flechard⁴; Leendert Hayen⁴; Nathal Severijns⁵; Maud Versteegen⁶

¹ LP2iB

² CEN Bordeaux-Giradignan

³ KU Leuven, Instituut voor Kern- en Stralingsfysica

⁴ LPC Caen

⁵ Instituut voor Kern- en Stralingsfysica, Katholieke Universiteit Leuven, B-3001 Leuven, Belgium

⁶ CENBG

Auteur correspondant simon.vanlangendonck@kuleuven.be

High-precision measurements of the beta spectrum shape and beta-neutrino angular correlation parameter allow to test for exotic scalar and tensor currents in the weak interaction. These measurements are the goal of the WISArD collaboration at ISOLDE/CERN. When experiments aim for the highest precision, even small Standard Model effects, usually called corrections, become important. The present work focuses on one such effect, i.e. the recoil-order correction, on the beta spectrum shape.

To overcome the effect of backscattering, an intrinsic limitation for this type of measurement, two detectors have been installed face-to-face in the high magnetic field of the WISArD set-up. This

effectively forms a closed system with a 4π solid angle thus mitigating the effect of backscattering. The detector set-up was characterized using conversion-electron sources as well as a continuous-spectrum beta source.

We will present the details of the experimental approach and report the first results for the determination of the recoil-order correction, which is dominated by the weak magnetism form factor, on the beta energy spectrum of $^{114}_{49}\text{In}$. Previously, weak magnetism has only been experimentally determined for specific isotopes up to $A = 75$, which makes its determination for $^{114}_{49}\text{In}$ the first within uncharted territories.

parallel / 574

First beta-delayed neutron spectroscopy of doubly-magic ^{24}O .

Auteurs: Shree Neupane¹; Noritaka Kitamura²; Zhengyu Xu³; Robert Grzywacz³; Joseph Heideman⁴; Toby King⁵; Miguel Madurga^{None}; Kevin Siegl²; Philipp Wagenknecht¹; Aaron Chester⁶; Andrea Richard⁷

¹ University of Tennessee

² Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA

³ University of Tennessee, Knoxville

⁴ University of Tennessee Knoxville

⁵ Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

⁶ Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA

⁷ National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA

Auteur correspondant sneupan4@vols.utk.edu

Located at the neutron drip-line, ^{24}O is the heaviest doubly-magic isotope of the oxygen isotopic chain. As the Q_β value increases and the neutron separation energy in the daughter nucleus decreases for the neutron-rich nucleus, beta-delayed neutron emission becomes a dominant decay mode, and neutron energy measurement is vital in studying the beta decay to the neutron unbound states. Also, spectroscopy of such drip-line nuclei may provide important information regarding the effects of nuclear interactions and many-body correlations in determining the limits of nuclear stability [1].

The neutron energy spectrum measurement of the beta-delayed neutron precursor ^{24}O was performed for the first time at National Superconducting Cyclotron Laboratory (NSCL) using a neutron time-of-flight array (VANDLE[2]) accompanied by gamma spectroscopy setup. New half-life and beta decay branching ratios are extracted. The beta-gamma and beta-delayed neutron measurements following the decay of ^{24}O provided the excitation energies and beta decay strength distribution to both neutron-bound and unbound states in ^{24}F . The decay of “doubly-magic” ^{24}O is an excellent case to test the quality of the state-of-the-art calculations of the beta-decay strength distribution near the neutron drip line. The experimental results are compared with the shell model calculation using the standard, empirical USDB interaction, and state-of-the-art ab initio calculations such as those using the valence-space in-medium similarity renormalization group (VS-IMSRG), coupled cluster model or shell-model embedded in the continuum.

[1] T.L. Tang et al. Phys. Rev. Lett. 124, 212502 (2020).

[2] W. A. Peters et al., Nucl. Instrum. Methods Phys. Res. A 836, 122 (2016).

577

b-STILED: Search for Tensor Interactions in nuclear beta Decay

Auteur: Mohamad Kanafani¹

Co-auteurs: Etienne Liénard ¹; Gilles Quemener ²; Jean-Charles Thomas ³; Oscar Naviliat-Cuncic ⁴; Sylvain Leblond ⁵; Xavier Flechard ¹; Xavier Mougeot ⁶

¹ *LPC Caen*

² *CNRS/IN2P3 - LPC Caen*

³ *GANIL*

⁴ *Laboratoire de Physique Corpusculaire de Caen*

⁵ *LNE/LNHB*

⁶ *CEA / LIST / LNHB*

Auteur correspondant kanafani@lpccaen.in2p3.fr

Precision measurements in beta decay play an essential role in the search for new physics beyond the standard model (SM), by probing “exotic” phenomena such as scalar and tensor interactions. The existence of such interactions induces deviations on certain observables away from their SM predictions. The study of the full beta energy spectrum offers a sensitive property to probe these interactions.

The goal of this work is to perform the most precise measurement of the beta-energy spectrum in ⁶He decay, in order to extract the Fierz interference term b with a precision in the order of $4 \cdot 10^{-3}$. This term depends linearly on exotic coupling constants, allowing to search for or to constrain the presence of tensor interactions in nuclear beta decay.

The main instrumental effect observed in previous measurements of the beta energy spectrum resides in the energy loss due to electrons backscattering outside the detector volume. A new technique is used to overcome this effect. It consists of using a very low energy beam of ⁶He⁺ ions (25 keV) deposited between two scintillation detectors forming a 4π calorimeter. The use of this technique ensures the deposition of the entire energy of the detected beta particles. An experiment with this setup was performed at the Grand Accélérateur National d’ Ions Lourds (GANIL) in 2021.

This contribution will introduce the general context of the project, describe the experimental setup, report the status of the data analysis and present the preliminary results.

parallel / 578

Island of inversion at the N=Z line

Auteur: Frederic NOWACKI¹

Co-auteurs: Duy Duc Dao ¹; alfredo povos ²

¹ *IPHC Strasbourg*

² *Departamento de Física Teórica and IFT UAM-CSIC, Universidad Autónoma de Madrid*

Auteur correspondant frederic.nowacki@iphc.cnrs.fr

The development of collectivity along the $N = Z$ is one of the subjects that has recently attracted great experimental efforts. In particular, heavy $N = Z$ nuclei in the mass region $A = 80$ are expected to be some of the most deformed ground states which have been found [1] in mid-mass nuclei, typically $8p - 8h$, $12p - 12h$ for e.g. the cases of ⁷⁶Sr, ⁸⁰Zr. This strong enhancement of collectivity with respect to lighter $N = Z$ nuclei has its origin in cross shell excitations across the $N = 40$ shell gap to $g9/2$, $d5/2$ and $s1/2$ which are intruder quadrupole partners generating deformations.

These structures can be interpreted in terms of algebraic Nilsson-SU3 self-consistent model to describe the intruder relative evolution in the vicinity of ⁸⁰Zr [2]. In this presentation, we will expose some of the latest developments in microscopic nuclear structure calculations for exotic nuclei far from stability at the N=Z [3].

The new theoretical calculations for the very region of ⁸⁰Zr will be presented for the first time within

the interacting shell model framework using an enlarged model space outside a ^{56}Ni core comprising the pseudo-SU3 $p_{\frac{3}{2}} f_{\frac{5}{2}} p_{\frac{1}{2}}$ and quasi-SU3 $g_{\frac{9}{2}} d_{\frac{5}{2}} s_{\frac{1}{2}}$ orbitals for both protons and neutrons. We will present and compare results from both exact Shell Model diagonalization [4] and our newly developed DNO Shell Model approach employing beyond mean field techniques [5]. These theoretical calculations allow a very good description of the rapid transition ($A = 60 - 100$) from spherical to deformed structures which can be interpreted in terms of “simple” many particles - many holes configurations. Emphasis will be put on the intimate relationship between shell evolution far from stability at the neutron-rich AND proton-rich edges.

[1] R. D. O. Llewellyn et al., Phys. Rev. Lett. 124, 152501 (2020).

[2] A. P. Zuker et al., Phys. Rev. C 92, 024320 (2015)

[3] D. D. Dao, F. Nowacki, A. Poves in preparation

[4] E. Caurier, G. Martínez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker, Rev. Mod. Phys. 77, 427 (2005).

[5] D. D. Dao and F. Nowacki, Phys. Rev. C 105, 054314 (2022).

579

Spectroscopy of ^{128}In and ^{128}Sn from the beta-decay of ^{128}Cd

Auteurs: Marcos Llanos Expósito¹; Luis Fraile²; Jaime Benito Garcia³

Co-auteurs: Zsolt Podolyak⁴; Zoe Favier⁵; Zixuan Yue⁶; Víctor Sánchez-Tembleque⁷; Ushashi Datta Pramanik⁸; Ulli Köster⁹; Thorsten Kröll¹⁰; Sorin Ujenuc; Razvan Lica⁵; Pete Jones¹¹; Monika Piersa¹²; Marek Karny¹³; Martin von Tresckow¹⁰; Priyabrata Das⁸; Michal Stepaniuk¹⁴; Maria José Garcia Borge¹⁵; Marcos García Távora¹⁵; Krzysztof Solak¹⁴; Krzysztof Miernik¹³; José Antonio Briz¹⁶; Javier Rodríguez Murias¹⁶; Janne Pakarinen¹⁷; Jaime Acosta¹⁵; Daniel Fernández Ruiz¹⁸; Carlos Ferrera¹⁵; Andrés Illana Sison¹⁷; Alejandro Algora¹⁹; Dennis Bittner²⁰; Esmaylzadeh Arwin Esmaylzadeh²⁰; Gabriel Turturica²¹; Georgi Georgiev²²; Enrique Nácher²³; Chris Page⁶; Bruno Olaizola⁵; Andrei Turturica²¹; Agnieszka Korgul¹⁴

¹ *Complutense University of Madrid*

² *Universidad Complutense*

³ *Universidad Complutensa & Universidad di Padova and INFN Padova*

⁴ *University of Surrey*

⁵ *CERN*

⁶ *University of York*

⁷ *HEPIA/HES-SO, University of Applied Sciences of Western Switzerland*

⁸ *Saha Institute*

⁹ *Institut Laue-Langevin*

¹⁰ *TU Darmstadt*

¹¹ *iThemba*

¹² *University of Warsaw*

¹³ *U Warsaw*

¹⁴ *Faculty of Physics, University of Warsaw*

¹⁵ *IEM-CSIC*

¹⁶ *Universidad Complutense de Madrid*

¹⁷ *University of Jyväskylä*

¹⁸ *Instituto de Estructura de Materia (IEM-CSIC)*

¹⁹ *IFIC (CSIC-Univ. Valencia)*

²⁰ *IKP Cologne*

²¹ *IFIN-HH*

²² *CSNSM, Orsay, France*

²³ *IFIC, CSIC-University of Valencia)*

Auteur correspondant marcllan@ucm.es

Over the last decades, the area close to the doubly-magic nucleus ^{132}Sn has played a prominent role in spectroscopy studies of exotic nuclei. Their aim is to obtain a better understanding of shell evolution in nuclei with large N/Z ratios, providing critical information to test theoretical models. In addition, the information on the nuclear structure and decay properties of neutron-rich nuclei in this region provides input to calculations for astrophysical r-process.

In the IS685 experiment, performed at the ISOLDE facility at CERN, high purity ^{128}Cd ($Z=48$, $N=80$) beams were produced after the fission of a thick UC_x target, selectively ionized by the ISOLDE Resonance Ionization Laser Ion Source (RILIS) and separated in mass using the General Purpose Separator (GPS) ISOLDE mass separator. A temperature-controlled quartz transfer line hinders the transmission of surface-ionized species, yielding extremely pure beams. The beam was taken to the ISOLDE Decay Station (IDS) where high-resolution gamma spectroscopy using six clover-type HPGe detectors were employed. The Advanced Time-Delayed $\beta\gamma\gamma(t)$ method [1] was employed to access lifetimes down to the 10 ps range. We made use of a compact fast-timing setup with 2 γ -LaBr₃(Ce) detectors and 3 fast β -detectors.

The excited structures of the odd-odd ^{128}In ($Z=49$, $N=79$) and even-odd magic ^{128}Sn ($Z=50$, $N=78$) isotopes were populated via the $^{128}\text{Cd} \rightarrow ^{128}\text{In} \rightarrow ^{128}\text{Sn}$ β -decay chain. The level schemes for both ^{128}In and ^{128}Sn isotopes were constructed and largely expanded, profiting from the high-resolution spectroscopy measurement. Lifetimes of excited states were determined and reduced transition probabilities were obtained. The presentation will highlight the preliminary results together with a comparison with available shell model calculations.

[1] H. Mach, R.L. Gill, and M. Moszynski, Nucl. Instrum. Methods Phys. Res. A 280 (1989) 49.

581

Advances in TRIUMF's resonant ionization laser ion source

Auteur: Jens Lassen¹

Co-auteurs: Alexander Gottberg¹; András Gacsbaranyi¹; Carla Babcock¹; Friedhelm Ames; Peter Kunz¹; Ruo-hong Li¹

¹ TRIUMF - Canada's particle accelerator centre

Auteur correspondant lassen@triumf.ca

The COVID19 pandemic required TRIUMF to operate with reduced personnel interaction while continuing to provide access to radioactive ion beams. To that end new ways of laser ion source operation had to be implemented, to reduce in-person interactions, yet maintain information flow and functionality to delivery a full spectrum of radioactive ion beams to users. In addition, development and complex beam delivery modes still are at the heart of radioactive ion beam facilities - therefore upgrades to and implementation of the ion guide - laser ion source were completed at the ISAC west target station. The results are such that the prototype IG-LIS on the ISAC east target station will also be upgraded to reflect improvements. The contribution will describe recent beams, beam delivery modes, laser system and IG-LIS improvements and capabilities.

parallel / 584

Probing the $N = 152$ neutron shell gap by laser spectroscopy of fermium isotopes

Auteur: Jessica Warbinek¹

Co-auteurs: Elisabeth Rickert²; Sebastian Raeder³; Thomas Albrecht-Schönzart⁴; Brankica Anđelić⁵; Julian Auler⁶; Benjamin Bally⁷; Michael Bender⁸; Sebastian Berndt⁹; Michael Block¹⁰; Pierre Chauveau¹¹; Bradley Cheal¹²;

Premaditya Chhetri ¹³; Arno Claessens ¹⁴; Antoine de Roubin ¹⁴; Charlie Devlin ¹²; Holger Dorrer ⁹; Christoph E. Düllmann ¹⁵; Julie Ezold ¹⁶; Rafael Ferrer ¹³; Vadim Gadelshin ⁶; Alyssa Gaiser ⁴; Francesca Giacoppo ¹⁷; Stéphane Goriely ¹⁸; Manuel J. Gutiérrez ¹⁹; Ashley Harvey ¹⁶; Reinhard Heinke ²⁰; Fritz-Peter Heßberger ¹⁹; Stéphane Hilaire ²¹; Magdalena Kaja ⁶; Oliver Kaleja ²²; Tom Kieck ²³; EunKang Kim ⁶; Nina Kneip ²⁴; Ulli Köster ²⁵; Sandro Kraemer ¹³; Mustapha Laatiaoui ²⁶; Jeremy Lantis ²⁶; Nathalie Leceste ¹¹; Andrew Mistry ¹⁷; Christoph Mokry ²⁷; Iain Moore ²⁸; Tobias Murböck ²⁹; Danny Münzberg ³⁰; Witold Nazarewicz ³¹; Steven Nothhelfer ³²; Sophie Peru-Desenfans ²¹; Andrea Raggio ²⁸; Paul-Gerhard Reinhard ³³; Dennis Renisch ³⁴; Emmanuel Rey-herme ³⁵; Jekabs Romans ¹⁴; Elisa Romero Romero ³⁶; Jörg Runke ³⁷; Hervé Savajols ¹¹; Fabian Schneider ³²; Joseph Sperling ⁴; Matou Stemmler ³⁸; Dominik Studer ³⁸; Petra Thörle-Pospiech ³⁴; Norbert Trautmann ³⁹; Shelley Van Cleve ¹⁶; Piet Van Duppen ⁴⁰; Marine Vandebrouck ³⁵; Elise Verstraelen ¹³; Thomas Walther ⁴²; Felix Weber ³⁸; Klaus Wendt ³⁸

¹ GSI Helmholtzzentrum für Schwerionenforschung GmbH; Johannes Gutenberg-Universität Mainz

² GSI Darmstadt / HIM Mainz / JGU Mainz

³ GSI Darmstadt

⁴ Florida State University

⁵ University of Groningen & Helmholtz Institut Mainz

⁶ Johannes Gutenberg-Universität Mainz

⁷ CEA - ESNT

⁸ IPN Lyon

⁹ Johannes Gutenberg University Mainz

¹⁰ GSI/HIM/JGU

¹¹ GANIL

¹² University of Liverpool

¹³ Instituut voor Kern- en Stralingsfysica, KU Leuven

¹⁴ KU Leuven

¹⁵ Johannes Gutenberg University Mainz, 55099 Mainz, Germany; Helmholtz Institute Mainz, 55099 Mainz, Germany; GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

¹⁶ Oak Ridge National Laboratory

¹⁷ GSI Helmholtzzentrum für Schwerionenforschung GmbH

¹⁸ Institut d'Astronomie et d'Astrophysique, ULB-CP226, 1050 Brussels, Belgium

¹⁹ GSI Darmstadt / HIM Mainz

²⁰ CERN

²¹ CEA DAM

²² GSI Darmstadt / MPIK / JGU Mainz / University of Greifswald

²³ Johannes Gutenberg University Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH

²⁴ Johannes Gutenberg University Mainz and Leibniz University Hannover

²⁵ Institut Laue-Langevin

²⁶ HIM/JGU

²⁷ Department of Chemistry – TRIGA Site, Johannes Gutenberg University Mainz, Germany; Helmholtz Institute Mainz, Germany

²⁸ University of Jyväskylä

²⁹ GSI Helmholtzzentrum für Schwerionenforschung GmbH, Helmholtz-Institut Mainz

³⁰ GSI Helmholtzzentrum für Schwerionenforschung GmbH, Helmholtz-Institut Mainz, Johannes Gutenberg-Universität Mainz

³¹ Michigan State University

³² HIM / GSI

³³ Friedrich-Alexander Universität Erlangen

³⁴ Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany; Helmholtz-Institute Mainz, 55099 Mainz, Germany

³⁵ CEA-Saclay

³⁶ Johannes Gutenberg Universität Mainz

³⁷ Department of Chemistry – TRIGA Site, Johannes Gutenberg University Mainz, Germany; GSI Helmholtzzentrum für Schwerionenforschung mbH, Darmstadt, Germany

³⁸ *Johannes Gutenberg University, 55099 Mainz, Germany*

³⁹ *Department of Chemistry – TRIGA Site, JGU Mainz, 55099 Mainz, Germany*

⁴⁰ *KU Leuven, Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200D, 3001 Leuven, Belgium*

⁴¹ *TU Darmstadt*

Auteur correspondant j.warbinek@gsi.de

Determining the limits of existence of the heaviest nuclides is a forefront topic in nuclear-physics research [1]. Nuclides with proton numbers $Z \geq 100$ are stabilized by shell effects that retard spontaneous fission and they feature properties distinctly different from those of lighter nuclei. However, our understanding of such shell effects in the region of the heaviest elements is limited as predictions by state-of-the-art nuclear models are challenging and experimental studies are hampered by production capabilities. Recent mass measurements confirmed the location and the size of such a shell gap leading to an increased nuclear stability at neutron number $N = 152$ in a region of strong prolate deformation [2,3].

Here, laser spectroscopy can serve as a powerful tool to extract experimental information on nuclear parameters such as the change in the mean-square charge radii and nuclear moments in a nuclear-model independent manner [4,5]. Access to the heaviest elements however is limited by production yields, their short half-lives and sparse information on atomic levels. The recent findings in the heavy actinide element nobelium ($Z = 102$) with the RADRES method paved the way for such observations [6,7].

New studies of fermium (Fm, $Z = 100$) isotopes allowed the determination of the isotope shift in an atomic transition for a long chain of eight isotopes ranging from the accelerator-produced ^{245}Fm to the reactor-bred ^{257}Fm . On-line and off-line laser spectroscopy techniques were significantly advanced to access these isotopes via various production methods down to minute production rates. The investigated isotopic chain spans across the known deformed shell gap at $N = 152$ allowing to probe its effect on changes in the mean-square charge radii. The experimental results revealing a discontinuity in the evolution of mean-square charge radii around the neutron shell gap will be discussed. These observations will trigger new developments in theoretical models which will eventually improve their predictive power towards the heaviest elements.

[1] W. Nazarewicz et al., *Nat Phys* 14, 537–541 (2018).

[2] E. Minaya Ramirez et al., *Science* 337, 1207–1210 (2012).

[3] C. Theisen et al., *Nucl Phys A* 944, 333–375 (2015).

[4] X. Yang et al., *Prog Part Nucl Phys* 129, 104005 (2023).

[5] M. Block et al., *Prog Part Nucl Phys* 116, 103834 (2021).

[6] M. Laatiaoui et al., *Nature* 538, 495–498 (2016).

[7] S. Raeder et al., *Phys Rev Lett* 120, 232503 (2018).

parallel / 587

Radiation-detected NMR for chemistry and life-science studies using unstable nuclei

Auteurs: A. Antušek¹; A. Hurajt²; Beatrice Karg³; D. Zakoucky⁴; Danila Barskyi⁵; Dmitry Budker⁶; I. Michelon⁷; M. Baranowski⁸; M. J. Chojnacki⁷; M. Jankowski⁷; M. Pešek⁷; M. Piersa-Silkowska⁷; Magdalena Kowalska⁷; Mark Bissell⁷; Miguel Madurga; N. Azaryan⁷; Raphael Kircher⁵; T. P. Treczoks⁷; Werner Lindberg⁹

¹ *Slovak University of Technology*

² *Comenius University in Bratislava*

³ *CERN, UNIGE*

⁴ *Nuclear Physics Institute, Czech Academy of Science*

⁵ *JGU Mainz*

⁶ *Helmholtz-Institute Mainz, 55099 Mainz, Germany; PRISMA+ Cluster of Excellence, JGU Mainz, 55099 Mainz, Germany; Department of Physics, University of California, Berkeley, California 94720, USA*

⁷ *CERN*

⁸ Adam Mickiewicz University, Poznań

⁹ CERN, U Tampere

Auteur correspondant kowalska@cern.ch

Radiation-detected Nuclear Magnetic Resonance (RD-NMR), especially in the form of beta-NMR in solids hosts, is an extremely sensitive NMR approach, which has been used in nuclear structure studies over the last few decades, allowing to determine magnetic and quadrupole moments of selected unstable nuclei.

RD-NMR applications in chemistry, biology, or medical diagnosis –performed on short-but also long-lived spin-polarised nuclei in liquid or gaseous samples –are much more recent but growing. Such studies are performed by our ISOLDE team as part of interdisciplinary collaborations with colleagues from other institutes. Beta-NMR on laser polarised short-lived sodium and potassium nuclei has already allowed us to study the arrangement of low-vapour ionic liquids which might be suitable for car-battery material and is being used to investigate binding of DNA G-quadruplex structures around alkali metals. A development of beta-NMR on longer-lived isotopes polarised using chemical methods known in conventional NMR in zero-to-ultra-low fields (ZULF) might lead to ultrasensitive and highly portable NMR devices. Finally gamma-detected MRI signals after spin-exchange optical pumping of long-lived Xe isomers might be used as a new medical imaging modality.

This contribution will cover the principles of RD-NMR, followed by the description of selected experimental setups and examples of ongoing studies from across the fields.

588

Collinear Laser Spectroscopy on Neutron Rich Palladium Isotopes

Auteur: Laura Renth¹

Co-auteurs: Adam Dockery ²; Adrian Valverde ³; Alex Brinson ⁴; Bernhard Maaß ⁵; Brooke Rickey ²; D. Santiago-Gonzalez ⁶; Daniel Burdette ⁵; Felix Sommer ¹; Guy Savard ⁵; Kei Minamisono ⁷; Kristian König ⁸; Max Horst ⁸; Patrick Müller ⁹; Peter Müller ¹⁰; Phillip Imgram ¹¹; Simon Rausch ¹²; Skyy Pineda ¹³; Wilfried Nörtershäuser ⁸

¹ Technische Universität Darmstadt

² Facility for Rare Isotope Beams

³ Argonne National Laboratory/University of Manitoba

⁴ Massachusetts Institute of Technology

⁵ Argonne National Laboratory

⁶ Physics Division, Argonne National Laboratory, USA

⁷ NSCL/MSU

⁸ TU Darmstadt

⁹ Institut für Kernphysik, Technische Universität Darmstadt

¹⁰ 2Physics Division, Argonne National Laboratory

¹¹ Institute for Nuclear Physics, Technical University Darmstadt

¹² TU Darmstadt, HFHF Darmstadt

¹³ Michigan State University

Auteur correspondant laura.renth@tu-darmstadt.de

Collinear laser spectroscopy gives access to hyperfine parameters and isotopes shifts at high precision. From these, nuclear charge radii, moments and spins can be determined. At the new collinear laser spectroscopy setup ATLANTIS (Argonne Tandem hall LAsEr beamline for aTom and Ion Spectroscopy) laser fluorescence spectroscopy was performed on neutron rich refractory metals below Z=50, produced by the Californium Rare Isotope Breeder Upgrade (CARIBU). Palladium is 4 protons below the nuclear shell closure Z=50 and therefore of particular interest for nuclear physics. Neutron rich palladium isotopes and all stable palladium isotopes were investigated by ATLANTIS.

First results on the measurements of $^{110,112-116}\text{Pd}$ and all stable Pd isotopes are presented.

This work was supported by DFG –Project-Id 279384907-SFB 1245, BMBF 05P19RDFN1 and NSF Grant No. PHY-21-11185 and by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357, with resources of ANL’s ATLAS facility, an Office of Science User Facility.

589

Development of the polarizer facility at TRIUMF

Auteur: Ruohong Li¹

Co-auteurs: Jens Lassen¹; Philip Levy¹; Gerald Morris¹; Alexander Gottberg¹

¹ TRIUMF - Canada’s particle accelerator centre

Auteur correspondant ruohong@triumf.ca

The polarizer facility at TRIUMF-ISAC provides nuclear-spin polarized radioactive isotope beams via optical pumping in collinear laser fast-beam geometry. Polarized ^8Li and ^{31}Mg are routinely delivered for material science, biochemistry, nuclear physics, and fundamental symmetry studies. To enhance the facility’s capabilities and provide novel beams for cutting-edge research, an upgrade and development program is ongoing on laser systems, fluorescence and ion detection, auxiliary systems, and user stations. An overview of the polarizer facility, including recent developments on polarized beams and current capabilities for collinear laser spectroscopy, will be presented.

plenary / 590

The AGATA γ -ray tracking array at the LNL TANDEM-ALPI-PIAVE facility

Auteur: Daniele Brugnara¹

¹ University of Padova - LNL INFN

Auteur correspondant daniele.brugnara@lnl.infn.it

The AGATA γ -ray tracking array represents the state-of-the-art of in-beam gamma-ray detection. Its capabilities rely on the high segmentation of its High Purity Germanium detectors to provide position sensitivity and, as a result, the ability to track gamma rays.

In this contribution, we will present an overview of the experiments performed during the first phase of AGATA’s installation at the TANDEM-ALPI-PIAVE accelerator complex in the “Laboratori Nazionali di Legnaro” in Italy. The gamma-ray array was initially coupled to the PRISMA magnetic spectrometer, to study the spectroscopy of isotopes produced from multinucleon transfer and fission reactions.

Moreover, part of the experimental campaign was devoted to the study of Coulomb excitation experiments that saw the array coupled to silicon detectors (SPIDER and EUCLIDES).

A brief overview of the performance and recent achievements will be presented, with a future perspective of the spectrometer at Legnaro, also in view of the future delivery of radioactive beams provided by the SPES facility.

591

Magnetization distribution from hyperfine anomaly measurements

Auteurs: A. Antušek¹; A. Hurajt²; A. Takamine³; D. Zakoucky⁴; G. King⁵; G. Sanamyan⁶; I. Michelon⁷; J. Dobaczewski⁸; J. Ginges⁶; M. Baranowski⁹; M. J. Chojnacki⁷; M. Jankowski⁷; M. Kowalska⁷; M. Pešek⁷; M. Piersa-Siłkowska⁷; Mark Bissell⁷; N. Azaryan⁷; R.P. de Groot¹⁰; S. Pastore⁵; T. P. Trezczok⁷

¹ *Slovak University of Technology*

² *Comenius University in Bratislava*

³ *RIKEN*

⁴ *Nuclear Physics Institute, Czech Academy of Science*

⁵ *Washington University*

⁶ *University of Queensland*

⁷ *CERN*

⁸ *University of York*

⁹ *Adam Mickiewicz University, Poznań*

¹⁰ *KULeuven*

Auteur correspondant mark.lloyd.bissell@cern.ch

At the VITO beamline at the CERN-ISOLDE facility we have begun a new programme of hyperfine anomaly measurements. This interesting, but tiny observable will provide a new way to look at nuclear structure due to its sensitivity to the magnetization distribution. This distribution is sensitive to the unpaired valence nucleons and thus can give information on both the proton and neutron special distribution.

By performing β -NMR in vacuum compatible liquids, it has been shown recently that we can measure the magnetic moments of short-lived radioactive isotopes with ppm precision. The first results of these measurements will be presented. The remaining ingredient of precision hyperfine anomaly measurements - the Hyperfine *A* factor will be addressed by the installation of a laser-rf double resonance setup. Progress in this new research theme will be presented along with future plans.

592

Evaluation of metal-organic frameworks for room temperature noble gas harvesting at the Facility for Rare Isotope Beams

Auteur: Vladyslav Bodnar¹

Co-auteurs: Ate Visser²; Gregory Severin³; Noelle Catarineu²; Sun Ho Kim²

¹ *Michigan State University - Facility for Rare Isotope Beams*

² *Lawrence Livermore National Laboratory*

³ *Michigan State University/Facility for Rare Isotope Beams*

Auteur correspondant bodnar@frib.msu.edu

The Facility for Rare Isotope Beams (FRIB) is a unique accelerator laboratory for nuclear science research at Michigan State University. During its operation, only a fraction of the produced isotopes will be utilized for fundamental nuclear research, leaving significant amounts of radioisotopes unused and discarded into a water beam dump. The isotope harvesting group is interested in collecting and separating numerous by-product radionuclides from the water beam dump system at FRIB. Some of the radionuclides that will be produced in the beam dump are noble gases such as Kr-77/76 and Rn-211. The decay products of the above-mentioned radioisotopes are of a high value for nuclear medicine. Therefore, the ability to collect those by-product radionuclides that otherwise would be left unused will greatly benefit the field of nuclear medicine. Consequently, an effort to develop a noble gas tuned microporous metal organic framework (MOF)-based method for noble gas harvesting at room temperature will be discussed.

593

β -decay of ^{68}Mn : Probing the $N=40$ island of inversion

Auteur: Rashmi Umashankar¹

Co-auteurs: Bruno Olaizola²; Victoria Vedia³; Adam Garnsworthy³; Corina Andreoiu⁴; G.C. Ball³; S. S. Bhattacharjee³; Eleanor Dunling⁵; Iris Dillmann⁶; Roger Caballero-Folch³; S. Buck⁷; F.H. Garcia⁸; Paul Garrett⁷; Shaun Georges³; C. Griffin³; Gwen Grinyer⁹; Eric Gyabeng Fuakye⁹; Tammy Zidar⁷; Greg Hackman³; Kushal Kapoor⁹; G. Leckenby³; Rebeka Sultana Lubna¹⁰; M.S. Martin⁴; C.R. Natzke³; Marco Rocchini¹¹; Nastaran Saei⁹; Y. Saito¹²; Magda Satrazani¹³; J. Smallcombe³; Dhruval Shah⁹; P. Spagnoletti¹⁴; C. Svensson⁷; Daniel Yates³

¹ University of British Columbia/TRIUMF

² CERN

³ TRIUMF

⁴ Simon Fraser University

⁵ TRIUMF/University of York

⁶ TRIUMF, Canada

⁷ University of Guelph

⁸ LBNL

⁹ University of Regina

¹⁰ FRIB, Michigan State University

¹¹ Università degli Studi Di Firenze e INFN Sezione di Firenze

¹² TRIUMF/UBC

¹³ University of Liverpool

¹⁴ UWS

Auteur correspondant rumashankar@triumf.ca

Although the shell model forms the backbone of our understanding of nuclear structure, the breakdown of traditional magic numbers far from stability gives insight into the nature of the underlying nuclear interactions and acts as a tool to test existing models. Islands of inversion (IoI) in the nuclear landscape are characterized by the presence of deformed multi-particle multi-hole (*npnh*) ground states instead of the *0p0h* configurations predicted by spherical mean-field calculations. In the $N=40$ region, the relatively large energy gap separating the *pf* shell from the neutron $g_{9/2}$ orbital points towards a strong sub-shell closure at $N=40$ which has been supported by the observation of a high-lying 2^+ state and low $B(E2)$ value in ^{68}Ni ($Z=28$) [1]. However, systematics of $E(2^+)$ and $B(E2)$ values have indicated a sudden increase in collectivity below $Z=28$ when approaching $N=40$, seen especially in the rapid drop of $E(2^+)$ in Fe ($Z=26$) and Cr ($Z=24$) isotopes [2,3]. This increase in collectivity around $N=40$ and $Z<28$ is thought to be due to the neutron occupation of intruder states from a higher shell, similar to the island of inversion around $N=20$ [4,5]. Recent studies also suggest the occurrence of a new IoI at $N=50$ and a proposed merging of the $N=40$ and $N=50$ IoIs, equivalent to the one observed between $N=20$ and $N=28$ [6,7]. Detailed spectroscopic information of the Fe, Co, and Ni isotopes will be crucial to understand the structure of nuclei near and inside the $N=40$ IoI and map the bridge between $N=40$ and $N=50$. To this end, an experiment was performed at TRIUMF-ISAC using the GRIFFIN spectrometer that utilized the β and β_n decay of ^{68}Mn to populate excited states in $^{67,68}\text{Fe}$, $^{67,68}\text{Co}$ and $^{67,68}\text{Ni}$. Preliminary results from the analysis will be presented which include an expanded ^{68}Fe level scheme and spin-parity assignments from a gamma-gamma angular correlation analysis.

[1] O. Sorlin et al. In: *Phys. Rev. Lett.* 88 (9 Feb. 2002), p. 092501.

[2] S. Naimi et al. In: *Phys. Rev. C* 86 (1 July 2012), p. 014325.

[3] M. Hannawald et al. In: *Phys. Rev. Lett.* 82 (7 Feb. 1999), pp. 1391–1394.

[4] S. M. Lenzi et al. In: *Phys. Rev. C* 82 (5 Nov. 2010), p. 054301.

[5] Y. Tsunoda et al. In: *Phys. Rev. C* 89 (3 Mar. 2014), p. 031301.

[6] C. Santamaria et al. In: *Phys. Rev. Lett.* 115 (19 Nov. 2015), p. 192501.

[7] E. Caurier, F. Nowacki, and A. Poves. In: *Phys. Rev. C* 90 (1 July 2014), p. 014302.

594

Higher rare isotope yields at ISAC TRIUMF using proton beam rastering

Auteur: Aurelia Laxdal¹

Co-auteurs: Peter Kunz¹; Friedhelm Ames¹; Jens Lassen¹; Thomas Planche¹; Lige Zhang¹; Alexander Gottberg¹; Yasser Beilouni¹; Matthew R. Pearson²; Bradley Cheal²; Andrzej Wolski²; Christopher Charles¹; Thomas Day Goodacre¹; Carla Babcock¹; Yi-Nong Rao¹; Louis Moskven¹; Brad Schultz¹; Aaron Schmidt¹; Anders Mjos¹; John Wong¹; Laura Lambert³; Tiffany Angus¹

¹ TRIUMF

² University of Liverpool

³ CERN

Auteur correspondant aureliat@triumf.ca

An AC rastering system has been implemented at TRIUMF's Isotope Separation and Acceleration facility (ISAC) to rotate the 500 MeV proton beam from TRIUMF's H- cyclotron onto targets for rare isotope production at a frequency of up to 400Hz. Rastering enables a more uniform beam power deposition in the target allowing higher proton beam intensities (up to 50% over the stationary beam), reduces the temperature gradients across the target, and enhances the diffusion and effusion of the short-lived isotopes.

The rastering system at ISAC was successfully tested for several targets and ion sources. In depth thermal models of the targets were developed for stationary and rotating proton beams, and correlated with yield results and in-target production rates. New isotopes were extracted and yields of short-lived isotopes, such as ¹¹Li and a wide range of lanthanides, were increased. This contribution summarizes the technical implementation, thermal modelling of the rotating beam and experimental isotope yields in relation to static beam operation.

597

A new technique for direct (n,p) reaction measurements of astrophysical interest using radioactive beams with SECAR

Auteur: Pelagia Tsintari¹

Co-auteurs: Ashley Hood²; Caleb Marshall³; Catherine Deibel⁴; Cavan Maher⁵; Fernando Montes⁶; Georg P. A. Berg⁷; Georgios Perdikakis⁸; Hendrik Schatz⁹; Jeffery C. Blackmon²; Jorge Pereira⁵; Kelly Chipps¹⁰; Kiana Setood-ehnia¹¹; Kirby Hermansen¹²; Louis Wagner¹³; Manoel Couder⁷; Michael S. Smith¹⁰; Nikolaos Dimitrakopoulos⁸; R. G. T. Zegers¹⁴; Rahul Jain¹⁴; Ruchi Garg¹¹; Sara A. Miskovich¹²; Thomas Ruland⁴; Uwe Greife¹⁵; Zach Meisel³

¹ Central Michigan University

² Department of Physics and Astronomy, Louisiana State University

³ Department of Physics and Astronomy, Ohio University

⁴ Louisiana State University

⁵ MSU-FRIB

⁶ NSCL and Department of Physics and Astronomy, Michigan State University

⁷ Department of Physics and Astronomy, University of Notre Dame

⁸ Department of Physics, Central Michigan University

⁹ Michigan State University

¹⁰ Physics Division, Oak Ridge National Laboratory

¹¹ Facility for Rare Isotope Beams, Michigan State University

¹² Department of Physics and Astronomy, Michigan State University

¹³ Michigan State University

¹⁴ Facility for Rare Isotope Beams & Department of Physics and Astronomy, Michigan State University

¹⁵ Department of Physics, Colorado School of Mines

Auteur correspondant tsint1p@cmich.edu

The nucleosynthesis of elements above the iron peak highly depends on neutron-induced reactions. Studies have shown that key (n,p) reactions such as the $^{56}\text{Ni}(n,p)^{56}\text{Co}$ and $^{64}\text{Ge}(n,p)^{64}\text{Ga}$ can accelerate the so-called neutrino-p process (νp -process), contributing to the creation of elements between nickel (Ni) and tin (Sn) in type II Supernovae. The νp -process occurs in slightly proton-rich regions in the neutrino-driven wind of core-collapse supernovae via a sequence of proton-capture and (n,p) reactions. The small abundance of neutrons that drives the (n,p) reactions originates from anti-neutrino captures on free protons.

Such (n,p) reactions can be studied via the measurement of the reverse (p,n) reactions followed by the application of the detailed balance principle [1]. We present a new approach for such measurements, using a heavy radioactive beam impinging on a hydrogen target. Reaction recoils are separated from the unreacted beam and detected using SECAR, the SEparator for CAPture Reactions [2] at FRIB. Measurements of (p,n) reaction are particularly challenging, as the recoils and the unreacted projectiles have almost identical masses. However, an appropriate separation level can still be achieved using neutron tagging along with SECAR. In a recent experiment, the first direct measurement of the $p(^{58}\text{Fe},n)^{58}\text{Co}$ reaction at 3.7 MeV/u was possible by the in-coincidence detection of the emitted neutrons close to the target location and the ^{58}Co ions at the end of the SECAR system. The neutron detection was achieved with a combination of liquid and plastic scintillators, while for the heavy ions the SECAR's ΔE -E detection system, which consists of an IC (Ionization Chamber) and a DSSD (Double-sided Silicon Strip) detector, was used. This direct measurement of the $^{58}\text{Fe}(p,n)^{58}\text{Co}$ reaction will complement an earlier one obtained via activation. In addition, it will likely improve the cross-section data available and pave the path for many other (p,n) reaction measurements of significant astrophysical interest using radioactive beams. Preliminary results along with experimental details for the technique will be presented.

[1] P. Gastis, et al., Nucl. Inst. Meth. Phys. Res. A, 985, 164603, (2021) [2] G. P. A. Berg, et al., Nucl. Inst. Meth. Phys. Res. A, 877, 87–103 (2018)

parallel / 598

Decay spectroscopy around neutron-rich ^{33}Mg to probe an ‘island of inversion’

Auteur: Tammy Zidar¹

Co-auteurs: Adam Garnsworthy²; Bruno Olaizola³; C. Griffin²; C. Paxman²; C.E. Svensson¹; C.R. Natzke²; Carlotta Porzio⁴; G. Carpenter²; G.C. Ball²; Greg Hackman²; Iris Dillmann⁵; K. Whitmore⁶; Mustafa Rajabali⁷; R.S. Lubna²; S.S. Bhattacharjee²; V Vedia²; Vinzenz Bildstein¹; Y. Saito⁸

¹ University of Guelph

² TRIUMF

³ CERN

⁴ Lawrence Berkeley National Laboratory

⁵ TRIUMF, Canada

⁶ Simon Fraser University

⁷ Tennessee Technological University

⁸ TRIUMF/UBC

Auteur correspondant tzidar@uoguelph.ca

The term ‘island of inversion’ is used to refer to a region of the nuclear landscape in which deformed intruder configurations dominate nuclear ground states over the spherical configurations naively expected from the shell model. Theoretical models of the inversion mechanism can be tested through

detailed studies of the nuclear structure of transitional nuclei, in which the normal and intruder configurations compete. One such transition occurs along the $N = 20$ isotones, where neutron-rich ^{32}Mg is known to have a deformed ground-state configuration, while ^{34}Si displays a normal ground state configuration. Previous studies of the intermediate $N = 20$ isotope ^{33}Al have yielded conflicting results regarding its structure. In the present work, ^{33}Al was studied through the β -decay of ^{33}Mg to clarify these discrepancies. A low-energy radioactive beam of ^{33}Mg was delivered at a rate of $10\text{e}3$ ions/s by the Isotope Separator and Accelerator (ISAC-I) facility at TRIUMF. Data were collected with the GRIFFIN high-purity germanium γ -ray spectrometer coupled with the SCEPTAR plastic scintillator array and the ZDS (zero degree) β particle detectors. The majority of the data were collected in a cycled mode (with a period of 2 s beam on, 1.5 s beam off) to provide sensitivity to all of the ^{33}Mg , ^{33}Al , ^{32}Al (β -n daughter) and ^{33}Si half-lives. The high efficiency of the GRIFFIN detector provided new γ - γ coincidences to elucidate the excited state structure of ^{33}Al , and the capability of GRIFFIN to detect weak transitions has provided more complete β -decay branching ratios for the ^{33}Mg - ^{33}Al - ^{33}Si decay chain. Results following the β -decay of neutron-rich ^{33}Mg are presented. Approximately 10^8 γ - γ coincidences were used to build level schemes for ^{33}Al and ^{32}Al . The γ -gated time spectra were fit to calculate half-lives of ^{33}Mg , $^{32,33}\text{Al}$ and ^{33}Si , β counts were used to calculate β -feeding to the levels of the scheme of ^{33}Al , including the ground state. Clarification of ^{33}Al level scheme, and expansion of ^{32}Al are presented.

parallel / 600

Combined Mass and Half-life Measurements with TITAN's MR-TOF-MS

Auteurs: Coulter Walls¹; Chris Chambers²; Andrew Jacobs³; Ali Mollaebrahimi⁴; Gerald Gwinner¹; Ania Kwiatkowski⁵

¹ *University of Manitoba*

² *TRIUMF*

³ *University of British Columbia*

⁴ *GSI Helmholtzzentrum für Schwerionenforschung, Justus-Liebig-Universität Gießen*

⁵ *University of Victoria*

Auteur correspondant cwalls@triumf.ca

TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) operates several ion traps for high-precision mass measurements and spectroscopy. Among these traps is a Multi-Reflection Time-Of-Flight Mass Spectrometer (MR-TOF-MS) for mass measurement and isotope selective cleaning of beam for other traps. TITAN's MR-TOF-MS has demonstrated excellent dynamic range ($\sim 10^8$) and high-precision ($\frac{\delta m}{m} \approx 10^{-7}$) allowing for measurement of very exotic isotopes. Presented here are a set of mass measurements clarifying the nuclear structure near $N=34$ in potassium.

Recently we developed new techniques enabling the measurement of half-lives using the MR-TOF-MS. This has allowed for half-life measurements of isotopes ranging from ~ 10 ms and ~ 5 min. In addition to providing supplementary data for identification of species, this new measurement technique has allowed for several first time half-life measurements and improved half-life uncertainties. The TITAN MR-TOF-MS's re-trapping and ion by ion mass and decay measurement abilities have proven to be powerful tools for half-life and mass measurements of exotic low rate species in a high background environment. The implications of these and future half-life measurements for nuclear structure and nucleosynthesis will be discussed.

603

Advanced Spectrometer and Separator Tuning for Commissioning or New Operational Modes

Auteur: Matt Amthor¹

Co-auteurs: Shumpei Noji ²; D. H. Potterveld ³; George Sun ¹; Yicheng Wang ¹; R. C. York ²; R. G. T. Zegers ⁴

¹ *Bucknell University*

² *Facility for Rare Isotope Beams, Michigan State University*

³ *Physics Division, Argonne National Laboratory*

⁴ *Facility for Rare Isotope Beams & Department of Physics and Astronomy, Michigan State University*

Auteur correspondant m.amthor@bucknell.edu

Two complementary methods have been developed—and tested in Monte Carlo simulations—to more reliably achieve the desired ion optical properties in large acceptance spectrometer, separator, or beam transport systems by automatically tuning first order and higher order magnetic elements. The High Rigidity Spectrometer (HRS) [1] has been used as a test case for these developments. Detailed ion optical models typically allow systems to be tuned to the neighborhood of a well-performing optical tune, after which manual tuning is used to ultimately achieve the desired optical properties. The increasing complexity of these optical systems and their increasingly complex operational requirements make current approaches to bridging the gap between model-derived tunes and performant operational tunes more time consuming and less reliable. For the correction of first order optical properties (e.g. focus conditions, dispersion, etc.), once the system has had a model-derived tune applied to arrive within the neighborhood of the correct tune, we use in-system measurements to extract a quadrupole coupling matrix. The inverse of the coupling matrix then allows the direct calculation of the corrections that must be applied to each quadrupole to achieve the desired first order tune properties. For the correction of higher order optical properties, we apply a global optimization algorithm, the Particle Swarm Optimizer (PSO), to tune the sextupole and octupole degrees of freedom and report on a study of which values of the algorithm's two controlling parameters (for acceleration and inertia) will most reliably produce improvement in a complex optimization objective. The optimization objective in our simulated online optimization includes the minimization of the final spot size on the reaction target and also beam properties at intermediate, dispersive planes that will enhance the momentum resolution of the analysis line.

[1] S. Noji et al. in these proceedings.

parallel / 609

Probing the rapid onset of deformation below ^{68}Ni through the beta decay of ^{67}Mn

Auteur: Victoria Vedia¹

Co-auteurs: Adam Garnsworthy ¹; Bruno Olaizola ²; C. Griffin ¹; C. Svensson ³; C.R. Natzke ¹; Corina Andreoiu ⁴; Daniel Yates ¹; Dhruval Shah ⁵; Eleanor Dunling ⁶; Eric Gyabeng Fuakye ⁵; F. H. Garcia ⁷; G. Grinyer ⁵; G. Leckenby ¹; G.C. Ball ¹; Greg Hackman ¹; Iris Dillmann ⁸; James Smallcombe ⁹; Kushal Kapoor ⁵; M.S. Martin ⁷; Magda Satrazani ¹⁰; Marco Rocchini ¹¹; Nastaran Saei ⁵; P. Spagnoletti ¹²; Paul Garrett ³; R.S. Lubna ¹; Rashmi Umashankar ¹³; Roger Caballero-Folch ¹; S.S. Bhattacharjee ¹; Samantha Buck ³; Shaun Georges ¹; Tammy Zidar ³; Y. Saito ¹³

¹ *TRIUMF*

² *CERN*

³ *University of Guelph*

⁴ *Simon Fraser University*

⁵ *University of Regina*

⁶ *TRIUMF/University of York*

⁷ *Simon Fraser University*

⁸ *TRIUMF, Canada*

⁹ *Japan Atomic Energy Agency*

¹⁰ *University of Liverpool*

¹¹ *Università degli Studi Di Firenze e INFN Sezione di Firenze*

¹² *UWS*

¹³ University of British Columbia/TRIUMF

Auteur correspondant vvedia@triumf.ca

One of the best-known divergences from the independent-particle shell model description is the existence of islands of inversion [1]. The IoI of the region N=40 draws particular attention since the neutron number 40 was postulated as a non-traditional “magic” number and N = 40 represents the boundary between the negative-parity pf shell and the positive-parity g shell. In stable nuclei, the neutron $g_{9/2}$ orbital is close enough to the pf shell to reduce this shell gap resulting in a more stable subshell closure at N = 50. Measurements of B(E2) values and E(2⁺) in the neutron-rich region show increased collectivity through the N = 40 shell gap, with the clear exception of ⁶⁸Ni [2,3]. Deformation and shape coexistence have been identified in the area, LNPS calculations predict triple shape coexistence for ⁶⁷Co (N=40), with three rotational bands [4]. And, recent experiments on ⁶⁷Fe (N=41) propose a spin-parity of 5/2⁺ or 1/2⁻ for its ground state [5] which indicates a significant deformation. In addition, shape coexistence is also expected for ⁶⁷Fe. Despite the high interest in the region, very limited information is available, to this end, an experiment was performed at the TRIUMF-ISAC facility utilizing the GRIFFIN spectrometer [6], where the β and βn decay of ⁶⁷Mn populated the ^{67,66}Fe, ^{67,66}Co and ^{67,66}Ni isotopes.

This data set contains orders of magnitude more statistics than previous studies allowing us to build for the first time a complete level scheme of ⁶⁷Fe and ⁶⁷Ni, and to improve upon the known β- decay level schemes of ⁶⁷Co, by expanding the number of transitions and levels, as well as by improving the precision of branching ratios and ground-state half-life measurement. In addition, measurements of level lifetimes down to the picosecond range will allow us to investigate the band structure in these nuclei. For the ⁶⁷Fe isotope, the good level of statistics will make it possible to measure the energy of the identified isomeric state and improve the lifetime measurement.

These results can provide further insight into the detailed structure of the states by comparison to simple models and large-scale shell model calculations in order to confirm or refute the shape coexistence picture predicted by LNPS calculations and the shrinking of the N=40 gap just one proton below ⁶⁸Ni.

Preliminary results from the analysis will be presented and discussed.

[1] B. A. Brown. Physics, 3:104 (2010).

[2] S. Naimi et al., Phys. Rev. C 86 (2012), p. 014325

[3] M. Hannawald et al., Phys. Rev. Lett. 82 (1999), pp. 1391–1394.

[4] F. Recchia et al., Phys. Rev. C, 85:064305 (2012)

[5] M. Sawicka et al., The European Physical Journal A - Hadrons and Nuclei, 16(1):51–54, 2003

[6] Garnsworthy et al., Nucl. Inst. Meths. A 918, 9 (2019)

parallel / 611

Measurement of the Fierz interference term in 20F decay

Auteur: O. Naviliat-Cuncic (1,2,5,6)

Co-auteurs: A. Gade (1,2,5) ; D. Weisshaar (2,5) ; E.A. George (3) ; K. Minamisono (1,2,5) ; M. Hughes (1,2) ; P.A. Voytas (3) ; S.N. Liddick (2,4,5) ; S.V. Paulauskas (2,&) ; T. Chuna (1,3,%); X. Huyan (1,2,#)

(1) Department of Physics and Astronomy, Michigan State University, East-Lansing, MI, USA

(2) National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI, USA

(3) Department of Physics, Wittenberg University, Springfield, OH, USA

(4) Department of Chemistry, Michigan State University, East Lansing, MI, USA

(5) Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA

(6) LPC-Caen, ENSI-CAEN, CNRS-IN2P3, Universite de Caen Normandie, Caen, France

Precision measurements in nuclear beta decay offer a sensitive means to search for new physics beyond the standard electroweak model. The new physics signatures are parametrized in terms of exotic phenomenological scalar and tensor interactions, which induce deviations on observables relative to their standard model predictions. It has been recognized that the Fierz interference term

is the most sensitive parameter to probe the presence of exotic couplings since it depends linearly on them. This term can directly be accessed through measurements of the beta-particle energy spectrum. These are notoriously difficult to perform with high precision due to distortions generally induced by back- and out-scattering of beta particles.

We report here on the measurement of the energy spectrum of beta particles emitted in 20F decay to extract the Fierz term in this decay for the first time. A 132 MeV/nucleon 20F beam was implanted in a CsI(Na) detector and beta-gamma coincidences were recorded between the implantation detector and four other CsI(Na) surrounding detectors. This configuration enabled us to implement a calorimetry technique such that the dominant distortion of the beta-energy spectrum was due to the bremsstrahlung radiation escaping the implantation detector. The measured decay is the 99.9913(8)% Gamow-Teller branch and the Fierz term is sensitive to exotic tensor couplings.

This contribution will describe the experimental conditions and will provide details on the systematic effects in the data analysis of the spectrum shape. It will also discuss the role of the weak magnetism form factor in the extraction of the Fierz interference term.

This work was supported in part by the US National Science Foundation under grants PHY-1102511, PHY-1506084, PHY-1565546, and PHY-2013557, and by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, operated by Michigan State University, under Award Number DE-SC0000661.

(*) Present address: Max Planck Institute for Physics, Munich, Germany

(%) Present address: College of Engineering, Michigan State University, East Lansing, MI, USA

(#) Permanent address: LeoLabs Inc., Menlo Park, CA, USA

(&) Permanent address: XIA LLC, Knoxville, TN, USA

plenary / 613

β -decay studies of neutron-rich isotopes in the region around double-magic ^{132}Sn

Auteurs: Agnieszka Korgul¹; Monika Piersa-Silkowska²; Luis Mario Fraile³; Jaime Benito³

¹ Faculty of Physics, University of Warsaw, Poland

² CERN, Geneva, Switzerland

³ Grupo de Física Nuclear and UPARCOS, Universidad Complutense de Madrid, Spain

Auteur correspondant korgul@fuw.edu.pl

In a simple picture, nuclei in the vicinity of double magic isotopes are of great interest from both experimental and theoretical points of view. Such nuclei have a spherical shape and the excitation-energy spectrum is dominated by single-particle excitation. This simple approach may need to be revised for nuclei that are significantly off the stability path on the neutron-rich side. The study of the evolution of single-particle states, interaction energies and β -decay properties (half-lives, β -decay strength, and β -delayed neutron emission probability) are important for understanding the structure of such exotic nuclei, as well as for its relevance in understanding the astrophysical r-process.

In this particular, understanding the nuclear structure near the doubly-magic ^{132}Sn is important for validating theoretical models that predict properties of more exotic nuclei, which are not experimentally accessible. In the specificity, the single-particle energy of the neutron state $i_{13/2}$ is still not firmly established [1,2] and it was suggested that nuclear structure affects the neutron versus γ -ray competition in the decay of neutron-unbound states [3]. The n - γ competition in the de-excitation of excited states of these nuclei is relevant in the framework of the astrophysical r-process, since ^{135}In is a so-called waiting point [4]. β -decay studies of neutron-rich indium isotopes provide excellent conditions to investigate such effects since their decays are characterized by large energy windows for the population of neutron-unbound states ($Q_{\beta n} > 10$ MeV).

Excited states in $^{132-135}\text{Sn}$ were investigated via β decay of the respective precursors, $^{133-135}\text{In}$, at ISOLDE Decay Station [5,6]. Isomer-selective ionization using the Resonance Ionization Laser Ion Source enabled the β decays of ^{133g}In ($I^\pi=9/2^+$) and ^{133m}In ($I^\pi=1/2^-$) to be studied independently for the first time [5]. Owing to the large spin difference of those two β -decaying states, it is possible to investigate separately the lower- and higher-spin states in the daughter ^{133}Sn and therefore to probe independently different single-particle transitions relevant in the ^{132}Sn region. The single-particle $i_{13/2}$ neutron state was tentatively identified in the decay of ^{134}In and ^{135}In .

A review of the most recent results will be given and discussed in the framework of state-of-the-art shell model computations.

- [1] P. Hoff *et al.*, Phys. Rev. Lett. **77**, (1996) 1020.
- [2] A. Korgul *et al.*, Phys. Rev. C **91**, (2015) 027303.
- [3] V. Vaquero *et al.*, Phys. Rev. Lett. **118**, (2017) 202502.
- [4] I. Dillmann *et al.*, Eur. Phys. J. A **13**, (2002) 281.
- [5] M. Piersa, A. Korgul *et al.*, Phys. Rev. C **99**, (2019) 024304.
- [6] M. Piersa, A. Korgul *et al.*, Phys. Rev. C **104**, (2021) 044328.

parallel / 618

The PUMA experiment at CERN

Auteur: Frank Wienholtz¹ for the PUMA Collaboration

¹ TU Darmstadt

Auteur correspondant fwienholtz@ikp.tu-darmstadt.de

The main goal of the PUMA [1] (antiProton Unstable Matter Annihilation) experiment is to use antiprotons as a tool to investigate properties of exotic nuclei. For this, antiprotons produced at the AD/CERN and decelerated by the ELENA storage ring will be captured, cooled and transported to the ISODLE facility where the antiprotons will be mixed with short lived isotopes. During this process, an antiproton can be captured by the nucleus and will subsequently annihilate with a neutron or a proton at the surface of the nucleus itself. The fingerprint of this annihilation will be measured using a time-projection-chamber. With this knowledge of the ratio of protons to neutrons on the outermost part of the nuclei distribution, phenomena like a neutron or a proton halo or neutron or proton skins can be investigated.

This contribution will give an overview of the PUMA experiment, present its status and highlight some of the main physics goals.

- [1] Aumann *et al.*, Eur. Phys. J. A (2022) 58: 88

plenary / 620

The Decay Spectroscopy Setup at the GSI-FAIR facility and the physics results from FAIR-0

Auteur: Biswarup Das¹

Co-auteur: Magda Gorska¹

¹ GSI Helmholtzzentrum für Schwerionenforschung

Auteurs correspondants: b.das@gsi.de, m.gorska@gsi.de

The DEcay SPECTroscopy (DESPEC) setup assembled for the future GSI-FAIR facility in Darmstadt, Germany, aims to study the nuclear footprint mainly through gamma ray spectroscopic measurements.

As a part of the NUSTAR project, the DESPEC collaboration aims to search for the exotic nuclear

structure phenomena such as shell evolution in nuclei which take part in the astrophysical r-processes. The FAIR “Phase-0” programme has already been started. In pursuit of characterising the exotic nuclei, the gamma-spectroscopy was combined with charge particle spectroscopy using an array of DSSSD’s of the AIDA. AIDA could also sort out the implanted ion position and time, with precision. The filtered out gamma-rays could be used to measure nuclear energy levels precisely by the high resolution HPGe detectors, while the nuclear level lifetimes could be measured using LaBr3 scintillator detectors of the FATIMA array. Some interesting development in the Phase-0 programme has already been observed by studying the basic nuclear structure phenomena in exotic nuclei south west to the “N=Z=50” line. In future, the neutron delayed gamma-ray spectroscopic studies would be possible using the MONSTER detectors. In summary, with a multidimensional system for particle and gamma spectroscopy, the DESPEC setup once placed at the final focal plane of FRS/SUPER-FRS of the GSI-FAIR accelerator complex, is a robust tool to explore the nuclear landscape.

parallel / 622

The Future of the GANIL facility

Auteur: Hanna Fränberg¹

Co-auteur: Stéphane Grévy²

¹ GANIL

² CENBG

Auteur correspondant hanna.franberg@ganil.fr

The first experiment performed at GANIL (Grand Accélérateur National d’Ions Lourds) was scheduled 40 years ago to study the reactions induced by a 44 MeV/u Ar beam on Ni and Au targets through the mass, charge and energy distributions of the fragments. The projectile fragmentation was found to be the dominant process at this intermediate energy and this pioneer work paved the way to the successful studies of exotic nuclei performed at GANIL in the domain of halo nuclei, magic numbers, exotic radioactivities among others.

In the years 2000, the SPIRAL1 facility gave access to ISOL type beams mainly for light and medium masses nuclei whereas the new SPIRAL2 facility will, in the coming years with S3 and DESIR, open unique opportunities for the study of medium and heavy N=Z nuclei and superheavy nuclei. In addition to nuclear physics experiments, many studies are performed in the domain of interdisciplinary researches such as atomic physics, material science, medical science, biology... Part of the beam time is also dedicated to industrial applications.

In 2020, the GANIL scientific community participated to the national prospectives that produced the “French roadmap for Nuclear, Particle and Astroparticle physics, and associated technical developments and applications”. In the framework of the national landscape, particular focus was done on the future of the GANIL facility that has also been afterwards intensively discussed in the frame of a committee of international experts. Four major objectives have been expressed: i- the study of neutron rich fission fragments requiring to construct a dedicated production building; ii- a post-acceleration for the radioactive ions up to 150 MeV/u; iii- the study of electron scattering on radioactive ions and iv- the increase of beamtime for the interdisciplinary activities and industrial applications. We are now in the process of starting a preliminary project in order to define possible scenarios that will account for the four aforementioned objectives. The ARIS conference will be a unique occasion to discuss these objectives with international experts.

parallel / 627

Structure of ¹³Be using TexAT active target.

Auteur: Grigory Rogachev¹

Co-auteurs: Curtis Hunt¹; Jack Bishop¹

¹ Cyclotron Institute, Texas A&M University

Auteur correspondant rogachev@tamu.edu

^{13}Be is the first neutron-unbound isotope of beryllium on the neutron-rich side. Its structure has been the subject of many experimental and theoretical studies with often conflicting results. Even the spin-parity of the ground state is still uncertain. We performed an experiment in which the $T=5/2$ states in ^{13}B , the isobaric analogs of ^{13}Be , were populated in $^{12}\text{Be}+p$ resonance elastic scattering. The experiment was performed at TRIUMF using Texas Active Target (TexAT). New constraints on the structure of low-lying resonances in ^{13}Be will be discussed.

629

Improved procedures for La-135 cyclotron production and purification

Auteur: Claire Deville¹

Co-auteurs: Kristina Søborg Pedersen¹; Ursula Søndergaard²; Mikael Jensen¹; Andreas I. Jensen¹

¹ Technical University of Denmark

² University Hospital of North Norway, Arctic University of Norway

Auteur correspondant cldev@dtu.dk

For application in radiotherapy, the production procedure of a radionuclide has to be both reliable and scalable. Lanthanum-135 (^{135}La) is an Auger emitter with very few secondary emissions making it a promising candidate for Auger therapy. However, achieving a scalable production for ^{135}La comes with some challenges. In most previously reported cases, metallic natural barium was used as target material; it has the drawback of being sensitive to moisture and oxidation, making it difficult to handle. Barium carbonate (BaCO_3) is more stable as target material, but it suffers from poor thermal conductivity. In order to avoid a BaCO_3 target to burn during irradiation, the current that can be applied has to remain low and only currents up to 10 μA have been reported.¹ We have developed a new target made of a pressed mixture of enriched [^{135}Ba] BaCO_3 ² and aluminum powder as filling material.³ Aluminum is a light element with a low stopping power and high thermal conductivity. It increases the thermal conductivity of the target, which can then withstand irradiation at 16.5 MeV and 20 μA current without visible damage. After 4 h irradiation, an average of 1.62 ± 0.18 GBq was produced, corresponding to a saturation yield of $11.91 \text{ GBq} \pm 1.31 \text{ GBq}$. We developed a subsequent purification procedure involving an initial precipitation step, followed by one single column containing two different commercial resins. After purification, 97.1 ± 3.6 % of the ^{135}La activity was recovered with a radionuclidic purity over 99.9%. The effective molar activity was suitable for radiolabeling: 79.6 ± 25.3 MBq/nmol was measured for the DOTA chelator, while 104.0 ± 40.4 MBq/nmol was obtained with the chelator DTPA.

(1) J. Jastrzebski, N. Zandi, J. Choinski, M. Sitarz, A. Stolarz, A. Trzcinska, M. Vagheian, Acta Phys. Pol. B, 2020, 51, 861. b) R. Chakravarty, S. Patra, K. C. Jagadeesan, S. V. Thakare, S. Chakraborty, Sep. Purif. Technol., 2022, 280, 119908.

(2) A. Mansel, K. Franke, Radiochim. Acta, 2015, 103 (11), 759. b) B. J. B. Nelson, S. Ferguson, M. Wuest, J. Wilson, M. J. M. Duke, S. Richter, H. Soenke-Jans, J. D. Andersson, F. Juengling, F. Wuest, J. Nucl. Med., 2022, 63 (4), 584.

(3) K. S. Pedersen, C. Deville, U. Søndergaard, M. Jensen, A. I. Jensen, Appl. Radiat. Isotopes, 2023, 192, 110612.

630

Charge exchange as a quantum-state detector to study exotic Calcium isotopes

Auteur: Tim Enrico Lellinger¹

¹ CERN (EP-SME-IS), Technische Universitaet Darmstadt (DE)

Auteur correspondant tim.enrico.lellinger@cern.ch

Collinear laser spectroscopy (CLS) has been a reliable technique to probe nuclear structure for more than 40 years. However, both fluorescence detection and resonant ionization methods are limited in their sensitivity due to beam contamination and laser induced background. Here, an upgraded experimental setup of an existing realization of “radioactive detection of optically pumped ions after state-selective charge exchange” (ROC) is presented. With this technique, the ions are optically pumped into a metastable state. The probability for the following charge exchange within a sodium vapor cell is then greatly enhanced if this pumping was successful. After separation, the ion and atom beam respectively are implanted into a tape within a plastic scintillator detector and identified through their β -decay. This combination of optical pumping, state-selective charge exchange and β -decay identification inherently immunizes the method to stable and long-lived beam contamination as well as laser induced background, drastically improving sensitivity to a few ions/s. The technique is tested now on a new CLS setup, which was primarily optimized for rapid offline development. After moving back to the main COLLAPS beamline, the increase in sensitivity will enable optical spectroscopy of the so far unreached $^{53,54}\text{Ca}$ to probe the potential subshell closure at $N=52$ that has long been theorized and also confirmed by mass- and nuclear excitation energy measurements.

plenary / 631

Evolution of single-particle properties probed with the ISOLDE Solenoidal Spectrometer

Auteur: David Sharp¹

¹ The University of Manchester

Auteur correspondant david.sharp@manchester.ac.uk

The ISOLDE Solenoidal Spectrometer (ISS) has been built for measuring direct reactions in inverse kinematics with radioactive beams (RIBs) from HIE-ISOLDE, with a focus on obtaining excellent charged particle resolution. ISS was fully commissioned in 2021 with a new silicon array developed by the University of Liverpool. This array makes use of double-sided silicon strip detectors, with ASIC readout, to determine the position of interaction and the energy of light ejectiles from reactions of RIBs with a light-ion target, when they return to the beam axis in the solenoid field. ISS has now completed two full physics campaigns focussing on measurements of the (d,p) reaction to probe single-neutron behaviour in various systems. This talk will give an overview of ISS and a summary of the physics campaigns from the last two years with a focus on evolving single-particle structure.

The study of single-particle structure in light neutron-rich systems has led to discoveries of dramatic changes which are otherwise gradual near stability, leading to the weakening and appearance of shell closures. For example, the disappearance of $N = 20$ and emergence of $N = 16$ [1, 2] as well the emergence of $N = 32, 34$ in calcium isotopes [3]. Pronounced trends have also been observed in stable heavier nuclei, in the changes in high- j states as high- j orbitals are filling. Studies of chains of stable, closed-shell isotopes [4] and isotones [5] have pointed to robust mechanisms for these changes, such as the importance of a tensor interaction [6]. The beams available at ISOLDE allow an extension of these studies both in light neutron-rich systems but also in heavier systems such along $N = 126$. Measurements looking at the properties of the single neutron outside both $N = 16$ and $N = 126$ will be covered here.

[1] A. Ozawa et al., Phys. Rev. Lett. 84, 5493 (2000).

[2] C. R. Hoffman et al., Phys. Lett. B 672, 17 (2009).

[3] D. Steppenbeck et al., Nature 502, 207 (2013).

[4] J. P. Schiffer et al., Phys. Rev. Lett. 92, 162501 (2004).

[5] B. P. Kay et al., Phys. Lett. B 658, 216 (2008), D. K. Sharp et al., Phys. Rev. C 87, 014312 (2013).

[6] T. Otsuka et al., Phys. Rev. Lett. 95, 232502 (2005).

632

Study of proton and neutron excitations along silicon Isotopes between N=20 and N=28

Auteur: Quentin DELIGNAC¹

Co-auteur: Stéphane Grévy¹

¹ LP2I Bordeaux

Auteur correspondant delignac@cenbg.in2p3.fr

The main subject of this study is the experimental investigation of the nuclear structure of exotic neutron-rich nuclei in the vicinity of shell closures in order to constrain the description of the nucleon-nucleon interaction, and in particular its tensor term. Previous studies have shown that a deformation region develops along the N=28 isotonic chain between the doubly magical and spherical ⁴⁸Ca nucleus (20 protons/28 neutrons) and the ⁴²Si nucleus which is extremely deformed in spite of its semi-magical character (14 protons/28 neutrons). It has been shown that this deformation results from neutron excitations above N=28 and proton excitations above Z=14, both made possible by the reduction of these shell closures under the effect of the tensor component of the nuclear interaction. The goal is now to follow the evolution of the deformation along the Si isotopic chain, between ³⁴Si (N=20) and ⁴²Si (N=28) by measuring for the first time and in a **simultaneous** way through the **E823** experiment at GANIL (Grand Accelerator National d'Ions Lourds):

- The contribution of neutrons to the excitation of the 2⁺ state of ^{34–36–38}Si nuclei by inelastic proton scattering.
- The contribution of protons and neutrons to the excitation of the 2⁺ state of ^{34–36–38}Si nuclei by Coulomb excitation on a gold target.

The experiment E823 has been set up during the 2022 campaign of LISE spectrometer (Ligne d'Ions Super Epluchés) at GANIL. This spectrometer allowed to produce and select ³⁴Si, ³⁶Si and ³⁸Si nuclei. In order to measure the proton and neutron contributions, the experimental setup was composed of two independent experiments on the same beamline with the same radioactive beam.

The first experiment was performed with ACTAR-TPC detector (ACTif TARget-Time Projection Chamber). The purpose of this experiment was to measure the inelastic scattering of ^ASi(p,p')^ASi* reactions, with (A=34,36,38). The analysis of this part is in progress by one of the thesis students of the ACTAR collaboration.

The second experiment was the CoulEx part (Coulomb Excitation). The goal of this experiment was to measure the effective cross section of coulomb excitations. Several types of detectors composed the CoulEx setup. The work of this thesis is mainly based on the analysis of this experiment.

635

RF timer based time-of-flight spectrometer for the measurement of the absolute energy of alpha particles

Auteur: Ani Aprahamian¹

Co-auteur: Amur Margaryan²

¹ U. Notre Dame

² A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute)

Auteurs correspondants: mat@mail.yerphi.am, aapraham@nd.edu

The knowledge of the absolute and accurate energies of the alpha particles emitted in the radioactive decay of a nuclide is a key factor in the construction of its decay scheme and play an important role

in the evolution of the atomic-mass scale and comprise nearly 60% of the input data of atoms with $A > 200$. Virtually all existing data are based on a few absolute measurements made by magnetic spectrometry, to which most other measurements are traced. The combined statistic and systematic errors of these measurements in the best cases amount to be about 0.1 keV. Recently an advanced RF timing technique of single electrons has been developed at the A. I. Alikhanyan National Science Laboratory. Test studies demonstrated ~ 10 ps time resolution and 0.2 ps/hour stability of the technique. This 10 ps resolution is mainly due to the technical parameters of the prototype device and could be reduced essentially by suitable optimization of its parameters. In this paper we propose to develop, construct and operate time-of-flight spectrometer based on this new timing technique. By using this technique, it will be possible to measure the absolute energy of alpha particles with precision of about or better than 0.1 keV. The proposed approach is an alternative to magnetic spectrometry and will help to evaluate its possible systematic error. Meanwhile this table-top experimental setup can be used at high energy particle beams to carry out alpha spectroscopy of produced short lifetime nuclear isotopes.

parallel / 639

OEDO-SHARAQ system: Its multifaceted performance and recent experimental achievements

Auteur: Shin'ichiro Michimasa¹

Co-auteurs: Daisuke Suzuki²; Jongwon Hwang¹; Masanori Dozono; Nobuaki Imai; Rin Yokoyama¹; Shinsuke OTA¹; Susumu Shimoura¹; Thomas Chillery

¹ Center for Nuclear Study, The University of Tokyo

² RIKEN Nishina Center

Auteur correspondant mitimasa@cns.s.u-tokyo.ac.jp

The OEDO-SHARAQ system at RIBF in RIKEN was primarily started to promote high-resolution nuclear spectroscopy with radioactive isotope (RI) beams. It was recently upgraded as the world's first beamline characterized by the energy-degrading of RI beams with a followed magnetic spectrometer for fragment analysis.

The high-resolution property of the system was fully demonstrated in the direct atomic mass measurements by using the TOF-B ρ method. We recently reported the atomic masses of ^{55–57}Ca and ^{58–62}Ti for the first time using the OEDO-SHARAQ system in RIBF [1,2]. In this talk we would like to discuss the shell evolution in the neutron $p_{1/2}$, $f_{5/2}$ and $g_{9/2}$ orbitals in this region and the similarities or differences to a region around ²⁴O and ³²Mg.

The energy-degrading operation of the system began experiments in the spring of 2017. This beamline was designed to decelerate the intermediate-energy RI beam produced by the BigRIPS separator down to 10-50 MeV/u. A radio-frequency electric ion-optical element is installed in the beamline, which provides unique ion optics of time-dependent beam focusing [3]. Additionally, an angle-tunable wedge-shaped energy degrader is utilized for the compression of RI-beam energy [4]. The combination of these key equipment enables OEDO to achieve simultaneously good beam focusing and energy compression on the secondary target. Thus, the RI beams provided by the OEDO-SHARAQ system widely cover the energy range for pre-compound, pre-equilibrium, and/or direct reactions.

After OEDO's construction, we performed measurements utilizing such reaction mechanisms. Recent achievements include low-energy cross-section studies of spallation reactions on RIs, especially long-lived fission products (LLFPs) ⁹³Zr and ¹⁰⁷Pd. The results report the lowest beam energy measurements for these LLFPs and are essential when designing reduction schemes for nuclear waste management [5]. Also, experimental studies on the astrophysical neutron-capture process were done. Amplitudes of neutron-capture processes are essential for nucleosynthesis in explosive sites. OEDO-SHARAQ provides the experimental opportunity to determine survival probabilities from unbound states via a pre-compound neutron-transfer reaction. We recently measured ¹³⁰Sn(d,p) and

$^{56}\text{Ni}(d,p)$ reactions to study the neutron captures in r - and νp -processes, respectively. Data analyses are ongoing. We will show here tentative achievements mainly regarding the experimental technique.

This presentation will introduce the multifaceted performances of the OEDO-SHARAQ system in intermediate-energy high-resolution spectroscopy and low-energy inverse-kinematics reaction measurements and report the recent experimental results of the system. We also discuss perspectives about future physics programs.

640

Towards a cyclotron production of Ac-225 for targeted alpha therapy

Auteur: Erika Jajčišinová¹

Co-auteurs: Alban Kellerbauer²; Carlos De Almeida Carrapiço²; Rikard Malmbeck²

¹ *KU Leuven (BE)+JRC Karlsruhe (DE)*

² *European Commission, Joint Research Centre*

Auteur correspondant erika.jajcisinova@kuleuven.be

Targeted alpha therapy using the radionuclide Ac-225 has shown remarkable benefit in clinical trials to patients suffering from various cancer types. Currently most Ac-225 is produced from a few sources of Th-229 existing worldwide. However, the total amount available is only sufficient for a few thousand patient doses. Given a projected demand that is several orders of magnitude higher, alternative paths for the production of Ac-225 must be developed. We are investigating the route using the Ra-226(p,n)Ac-225 reaction, which can be readily employed at a large number of cyclotron facilities. Its highest cross-section is near 17 MeV proton energy. The excitation function of this reaction has been previously measured by us for a few energies¹, but discrepancies with calculations remain. Hence, we are planning new irradiation experiments to improve the knowledge of the excitation function to support the industrial production of Ac-225 via this route. We have produced radium targets by electrodeposition from a mixed organic/aqueous solution in view of proton irradiation at a 30-MeV proton cyclotron. In the process, we have quantitatively determined the deposition efficiency as well as the homogeneity of deposition, which is crucial for highly precise cross-section measurements. In this talk, we will describe our electrodeposition setup and process, and report on the properties of the prepared Ra-226 targets.

¹ C. Apostolidis et al., *Appl. Rad. Isot.* 62 (2005) 383

plenary / 641

Emission channeling investigations of impurities with interesting quantum properties in single crystals

Auteur: Ulrich Wahl¹

¹ *Instituto Superior Técnico, Universidade de Lisboa*

Auteur correspondant ulrich.wahl@cern.ch

As we enter the second quantum revolution, where non-classical properties of quantum systems are being explored for practical applications, the interest in impurity atoms embedded in crystalline materials has been extended, going far beyond previous, more conventional applications like doping to modify electrical, optical or magnetic properties of semiconductors or other materials. For instance, systems composed of a single impurity atom in a crystalline matrix, like the nitrogen vacancy (NV)

center in diamond, which is already finding applications in nanoscale magnetometry, or of small ensembles of such defects, could be at the base of future quantum communication, computation and metrology devices. In that respect, one of the crucial issues is the targeted creation of specific configurations of impurity atoms in the lattice, where ion implantation plays a critical role, however, competing with other techniques.

In this talk I will discuss two examples where emission channeling experiments with radioactive ion beams at the CERN-ISOLDE facility contributed to investigating the microscopic structure of impurity configurations that may play a role in future quantum applications based on ion-implanted single crystals. The first example will address the lattice location of the “nuclear clock” isotope ^{229}mTh in CaF_2 , where for the observation of the emitted 8.3 eV photons it was crucial to have the radioactive isotope occupy substitutional Ca sites [1,2]. Another set of examples addresses the structure and formation mechanism of ion implanted colour centers in diamond based on impurities like Sn [3], Ge, or Mg [4]. For these defects with desired quantum properties it is vital to incorporate the foreign atom in the center of a double vacancy, the so-called split-vacancy configuration.

[1] M. Verlinde, S. Kraemer, J. Moens, et al., “Alternative approach to populate and study the ^{229}Th nuclear clock isomer” , Phys. Rev. C 100 (2019) 024315.

[2] S. Kraemer, J. Moens, et al., “Observation of the radiative decay of the ^{229}Th nuclear clock isomer” , accepted by Nature.

[3] U. Wahl, et al., “Direct structural identification and quantification of the split-vacancy configuration for implanted Sn in diamond” , Phys. Rev. Lett. 125 (2020) 045301.

[4] E. Corte, et al., “Magnesium-vacancy optical centers in diamond” , ACS Photonics 10 (2023) 101.

plenary / 643

Unravelling the mysteries of the atomic nucleus via high resolution laser spectroscopy at COLLAPS

Auteur: Liss Vazquez Rodriguez¹

¹ CERN, MPIK

Auteur correspondant liss.vazquez.rodriguez@cern.ch

plenary / 644

FRIB and the Neutron-Rich Mg Isotopes

Auteur: Heather Crawford¹

¹ Lawrence Berkeley National Laboratory

Auteur correspondant hlcrawford@lbl.gov

The study of nuclei far from stability is one of the most active and challenging areas of nuclear structure physics. The neutron-proton imbalance in nuclei approaching the dripline(s) affects the detailed impacts of the residual interaction, modifying single-particle energies and potentially leading to altered ground and excited-state properties. In addition, at the very edge of stability, the proximity of the continuum to the bound states may modify wavefunctions further. I will discuss a range of recent experimental measurements exploring different aspects of the structure in the most neutron-rich isotopes. I will present recent work in the region of neutron number $N=28$, below the Ca isotopes. There is a breakdown of the $N=28$ harmonic oscillator magic number as protons are removed from the sd shell, and the isotones below Ar are understood to be dominated by multi-particle-multi-hole excitations and deformation in their low-lying structure. I will discuss results from the first experiment at FRIB on half-lives in this region. I will also explore the specific case of

Mg-40, which sits along the $N=28$ isotones and very near (or possibly at) the neutron dripline, where first spectroscopy resulted in an unexpected excitation spectrum.

plenary / 645

Global ab initio calculations for the structure of exotic and heavy nuclei

Auteur: Jason Holt¹

¹ TRIUMF

Auteur correspondant jholt@triumf.ca

Breakthroughs in our treatment of the many-body problem and nuclear forces are rapidly transforming modern nuclear theory into a true first-principles discipline. This allows us to address some of the most exciting questions at the frontiers of nuclear structure and physics beyond the standard model.

In this talk I will highlight recent advances which now allow for global converged calculations of open-shell nuclei to the 208Pb region and beyond. In particular, I will focus on key topics in nuclear structure such as predictions of the proton and neutron driplines and evolution of magic numbers throughout the light and medium-mass regions, including new insights on the nature and existence of 28O including continuum degrees of freedom. In addition, I will discuss how correlation of the neutron skin and dipole polarizability in heavy nuclei to 208Pb provide first ab initio constraints on symmetry energy parameters for determining neutron star properties.

plenary / 646

Nuclear collectivity studied with the newly refurbished Miniball spectrometer at HIE-ISOLDE

Auteur: Liam Gaffney¹

¹ University of Liverpool

Auteur correspondant liam.gaffney@liverpool.ac.uk

The Miniball spectrometer has been utilised for the study of collectivity in nuclei for two decades, exploiting post-accelerated radioactive ion beams at the ISOLDE facility. The workhorse technique has been Coulomb excitation, but few-nucleon and multi-nucleon transfer-reactions have also been exploited with the addition of ancillary devices such as the T-REX charged-particle detector.

Miniball came back to life at HIE-ISOLDE in 2022 following the second long shutdown at CERN (2018-2021), during which time it has undergone a total transformation. There has been a refurbishment of the HPGe detectors, including new cryostats, electronics and preamplifiers, as well as a newly developed data acquisition system.

In this talk, I will present some recent physics highlights from Miniball in the HIE-ISOLDE era, focusing on studies of nuclear collectivity and shapes. I will also detail the current status of the spectrometer and show preliminary results from the first experiments of the new era; including the first use of the SPEDE spectrometer for conversion electron spectroscopy in the Coulomb excitation of ¹⁸²Hg.

Synthesis of cold highly charged radionuclei using antiprotons

Auteur: Fredrik Parnefjord Gustafsson¹

Co-auteurs: A Farricker²; A Camper³; B Bergmann⁴; F Castelli⁵; F Guatieri⁶; G Kornakov⁷; G Consolati⁸; L Graczykowski⁹; Lisa Glogglér¹; L. K. Graczykowski⁷; M Auzins¹⁰; M. Grosbart¹; Michael Doser¹; N Gusakova¹¹; P Burian⁴; R Ciurylo¹²; R. S. Brusa⁶; R Caravita⁶; S Huck¹; S Haider¹; T Sowiński¹³; M Janik⁹; G Kasprowicz⁹; G Khatri¹; L Klosowski¹²; Valts Kruminis¹⁰; L Lappo¹⁴; J Malamant³; S Mariazzi⁶; D Nowicka⁷; L Penasa⁶; V Petracek¹⁵; M Piwinski¹²; S Pospisil⁴; L Povolò⁶; F Prelz⁵; S Rangwala¹⁶; Benjamin Rienacker²; V Rodin²; O.M. Rohne³; H Sandaker³; P Smolyanskiy⁴; D. Tefelski⁹; C.P. Welsch²; M. Zawada¹⁷; J Zielinski⁷; N Zurlo¹⁸

¹ CERN

² University of Liverpool, UK and The Cockcroft Institute, Daresbury, UK

³ University of Oslo (NO)

⁴ Institute of Experimental and Applied Physics, Czech Technical University in Prague, Husova 240/5, 110 00, Prague 1, Czech Republic

⁵ INFN Milano, via Celoria 16, 20133-Milano, Italy

⁶ TIFPA/INFN Trento, via Sommarive 14, 38123-Povo, Trento, Italy

⁷ Warsaw University of Technology (PL)

⁸ Department of Aerospace Science and Technology, Politecnico di Milano, via La Masa 34, 20156-Milano, Italy

⁹ Warsaw University of Technology, Faculty of Physics ul. Koszykowa 75, 00-662, Warsaw, Poland

¹⁰ University of Latvia, Department of Physics Raina boulevard 19, LV-1586, Riga, Latvia

¹¹ Department of Physics, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

¹² Institute of Physics, Faculty of Physics, Astronomy, and Informatics, Nicolaus Copernicus University in Toruń, Grudziadzka 5, 87-100 Torun, Poland

¹³ Institute of Physics, Polish Academy of Sciences

¹⁴ [Warsaw University of Technology, Faculty of Physics ul. Koszykowa 75, 00-662, Warsaw, Poland

¹⁵ Czech Technical University, Prague, Brehov'ska 7, 11519-Prague-1, Czech Republic] \address[IAEP][Institute of Experimental and Applied Physics, Czech Technical University in Prague, Husova 240/5, 110 00, Prague 1, Czech Republic

¹⁶ Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bangalore 560080, India

¹⁷ Institute of Physics, Faculty of Physics, Astronomy, and Informatics, Nicolaus Copernicus University in Torun, Grudziadzka 5, 87-100 Torun, Poland

¹⁸ INFN Pavia, via Bassi 6, 27100-Pavia, Italy

Auteur correspondant fredrik.parnefjord.gustafsson@cern.ch

At CERN's Antimatter Decelerator (AD) cold beams of antiprotons are routinely generated for a wide range of precision experiments. The Antimatter Experiment: Gravity, Interferometry, Spectroscopy (AEGIS) at AD aims at performing studies of the gravitational influence on a horizontal beam of cold antihydrogen atoms. AEGIS has achieved remarkable performance in trapping antiprotons and successfully demonstrated the pulsed production of Rydberg excited antihydrogen [2,3]. The production process is achieved through the charge exchange reaction using laser-excited Rydberg positronium (a hydrogen like bound system of a positron and electron) interacting with cold antiprotons stored within a Penning-Malmberg trap.

This technique is currently being adapted for the synthesis of antiprotonic atoms of medium-heavy nuclei [4]. So far, antiprotonic atoms were formed in beam-on-target experiments, primarily focusing on light systems such as antiprotonic helium [5,6]. Due to the great mass of the antiproton, nearly 1836 times heavier than the electron, the antiproton naturally forms orbits inside the electron cloud and rapidly annihilates on the nuclear surface. However, using the charge exchange procedure developed at AEGIS for antihydrogen, cold trapped antiprotonic atoms can be selectively formed in highly excited Rydberg states bound outside the electron cloud. The relaxation of the bound antiproton leads to Auger electron and photon emission, eventually forming a fully or nearly fully stripped nucleus with the bound antiproton. Subsequent annihilation on the nuclear surface results in the formation of exotic, highly charged radioactive nuclei within the trap. This technique will open avenues for exploring a variety of nuclear structure phenomena, allowing the novel formation of highly charged radionuclei and enable the search for new physics [7,8].

Recent upgrades of the AEGIS apparatus will explore the first co-trapping of iodine anions with cold antiprotons, allowing the study of antiprotonic iodine formation as a proof-of-principle of this technique.

- [1] M. Doser et al. 2012 *Class. Quantum Grav.* 29 184009
- [2] D. Krasnický et al. 2016 *Phys. Rev. A* 94 022714
- [3] C. Amsler et al. 2021 *Commun. Phys.* 4 19
- [4] Kornakov, G., et al. *Phys. Rev. C* 107.3 (2023): 034314.
- [5] Hori, Masaki, et al. *PRL* 87.9 (2001): 093401.
- [6] Sótér, Anna, et al. *Nature* 603.7901 (2022): 411-415.
- [7] Doser, M. *Progress in Particle and Nuclear Physics* (2022): 103964.
- [8] Doser, M., G. Farrar, and G. Kornakov. *arXiv preprint arXiv:2302.00759* (2023).

plenary / 649

Accessing nuclear structure with high-energy nuclear collisions

Auteur: Giuliano Giacalone¹

¹ *Universität Heidelberg*

Auteur correspondant giulianogiacalone@gmail.com

High-energy nuclear collisions are conducted in the world's largest accelerators, the BNL RHIC and the CERN LHC, to characterize the hot phase of strong-interaction matter, the quark-gluon plasma. Following two decades of phenomenological studies and the availability of data from several different species, a picture has been established according to which high-energy nuclear scattering works as an imaging process giving access to spatial distributions of nucleons in the ground states of the colliding ions. These experiments provide, thus, complementary evidence of nuclear deformations, as well as a new means to determine neutron skins.

I present recent activities that have gathered together low-energy nuclear structure physicists and high-energy heavy-ion physicists to address these issues, and I highlight the advances that they have brought for both communities. I discuss the prospects for future experimental and theoretical studies at the intersection of these two areas aimed at improving our knowledge of the strong nuclear force across energy scales.

plenary / 650

r process and supernova signatures in deep-sea archives

Auteur: Anton Wallner¹

¹ *Helmholtz Center Dresden-Rossendorf / Australian National University*

Auteur correspondant a.wallner@hzdr.de

Half of the heavy elements are produced in r-process nucleosynthesis, which is exclusively responsible for actinide production, such as Pu-244 ($t_{1/2}=81$ Myr). The r-process requires an explosive scenario but is far from being fully understood; in particular, its sites and history.

The solar system moves through the interstellar medium (ISM) and collects interstellar dust particles that contain such signatures, including the radionuclides Fe-60 ($t_{1/2}=2.6$ Myr) and Pu-244. These nuclides are incorporated into terrestrial archives over millions of years and once recovered can be measured with Accelerator Mass Spectrometry (AMS) with high sensitivity.

Recent technical developments have seen an exceptional gain in measurement efficiency and sensitivity, in particular for actinides, including Pu-244. On the other hand, very large accelerators

with >10 million volts allow for effective isobar separation using techniques derived from nuclear physics research. Such AMS systems are unique but required for the identification of small traces of interstellar Fe-60.

New data demonstrate a global Fe-60 influx and is evidence for exposure of Earth to recent (<10 Myr) supernova explosions. In addition, the recent finding in deep-sea archives of ISM-Pu-244, exclusively produced by the r-process, allows to link supernovae and r-process signatures. The low concentrations of Pu-244 measured in deep-sea archives suggest a low abundance of interstellar Pu and supports the hypothesis that the dominant actinide r-process nucleosynthesis is rare. However, the data allow some actinide production in supernovae while implying r-process contributions from additional sources.

plenary / 651

Prevailing triaxial shapes in exotic and heavy nuclei

Auteur: Takaharu Otsuka¹

¹ *University of Tokyo / RIKEN*

Auteur correspondant otsuka@phys.s.u-tokyo.ac.jp

Shapes of heavy deformed nuclei are discussed from the viewpoint of the Monte Carlo Shell Model with realistic effective NN interactions. The prevailing triaxial shapes then emerge due to the nuclear tensor force, in contrast to the conventional picture of the prolate-shape dominance since 1950's. The triaxiality with $\gamma \sim 9^\circ$ arises commonly for rare-earth nuclei around ^{166}Er . The mechanism for the low-lying second 2^+ state is presented, and the relation to the Davydov model is mentioned. Possible new M1 mode due to the triaxiality is pointed out. Triaxial shapes of exotic Ne, Na and Mg isotopes are also discussed with the *ab initio* EEdf1 interaction for the sd-pf combined shell.

plenary / 652

Observation of a correlated free four-neutron system

Auteurs: Valerii Panin¹; Meytal Duer²; Thomas Aumann²

¹ *GSI, Darmstadt*

² *TU Darmstadt*

Auteur correspondant v.panin@gsi.de

An isolated system of four neutrons is studied in the SAMURAI experiment at the Radioactive-Ion Beam Factory at RIKEN [1]. The key reaction $8\text{He}(p,p\alpha)4n$ in inverse kinematics populates the final state of four neutrons through a prompt quasi-free-scattering process close to 180 degrees in the p- α centre-of-mass frame. The resulting energy spectrum of the free 4n system reveals a distinct peak-like structure with positive energy centered at 2.4 MeV in addition to a more broad distribution associated with the continuum. The details of the experimental method and the analysis results will be presented along with the further perspectives of studying multi-neutron systems.

[1] M. Duer et al., Nature 606, 678 (2022)

plenary / 653

Studies of exotic isotopes using laser ionization techniques and trapped ion techniques

Auteur: Ruben de Groot¹

¹ *KU Leuven*

Auteur correspondant ruben.degroot@kuleuven.be

Laser spectroscopy techniques provide nuclear-model independent access to nuclear electromagnetic moments, spins and charge radii. Advances in radioactive ion beam instrumentation and laser technologies have enabled the study of a wide range of elements and isotopes, pushing out far from the valley of stability towards the drip lines. In this contribution, I will present experimental progress along two important frontiers. I will discuss the use of methods based on laser ionization spectroscopy and how they have allowed us to reach exotic nuclei such as ⁹⁴Ag and ⁵²K. Crucially, these measurements relied on the use of decay detection or ultra-selective mass separation tools to provide low-background measurement conditions.

Besides using efficient laser ionization and particle detection methods, another important area of research relies on the use of ion traps. I will show a recent example of how ions trapped in a linear Paul trap can be optically pumped into a beneficial metastable state. In particular, I will show how this approach enabled fluorescence spectroscopy of neutron-deficient singly-charged cobalt isotopes. Finally, I will conclude with a discussion on the next logical step, which entails doing optical and radiofrequency spectroscopy of radioactive ions while they are trapped in a linear Paul trap. I will discuss the status of a new setup currently under construction at the KU Leuven.

plenary / 654

Proton radioactivity studies with ACTAR TPC

Auteur: Jérôme Giovinazzo¹ (for the E690 and E791 collaborations)

¹ *LP2IB (CENBG) CNRS / Univ. Bordeaux*

Auteur correspondant giovinaz@cenbg.in2p3.fr

For nuclear systems that are slightly unbound with respect to the nuclear strong interaction, the 1- and 2-proton radioactivity decay channel opens [1,2]. The experimental study of these radioactivities offers a unique access to the structure properties of the emitting states. Such data can represent real challenges in terms of theoretical interpretations.

This kind of exotic decay modes is part of the physics program that motivated the development of the ACTAR TPC (Active Target and Time Projection Chamber) device [3], as well as several other TPC detectors worldwide. ACTAR TPC has been successfully used in recent experiments, related to proton(s) radioactivity in the A-50 mass region.

The first experiment allowed for the imaging of the proton emission from the ^{53m}Co and the (short-lived) ^{54m}Ni isomeric states [4,5,6]. In both cases, the observation of the high angular momenta proton branches allowed for the determination of the complete decay pattern of these states. The second experiment aimed at the direct observation of the ground state 2-proton radioactivity of ⁴⁸Ni [7]. The scientific context and the experimental results will be presented, and compared to state of the art theoretical interpretations.

[1] B. Blank and M.J.G. Borge, *Progress in Particle and Nuclear Physics* 60 (2008) 403–483

[2] M. Pfützner *et al.*, *Review of Modern Physics*, vol. 84 (2012)

[3] B. Mauss *et al.*, *Nuclear Inst. and Methods in Physics Research, A* 940 (2019) 498–504

[4] J. Giovinazzo *et al.*, *Nature Comm.* 12, (2021) 4085

[5] D. Rudolph *et al.*, *Physics Letters B* 830 (2022) 137144

[6] L.G. Sarmiento *et al.*, accepted for publication in *Nature Comm.*

[7] A. Ortega Moral *et al.*, proceedings of Zakopane 2022 conf.

plenary / 655

Probing Nuclear and Particle Physics Phenomena with Radioactive Molecules

Auteur: Ronald Garcia Ruiz¹

¹ MIT

poster session / 656

Reactor Antineutrino Spectral Excess: Cumulative Fission Yield Measurement Using Gamma-Ray Spectroscopy

Auteur: Samuel Kim¹

Co-auteurs: David Glasgow ²; Mike Dion ²; Jeff Martoff ³

¹ Brookhaven National Laboratory

² Oak Ridge National Laboratory

³ Temple University

Auteur correspondant skim3@bnl.gov

Recent measurements of the reactor antineutrino emission show that there exists a spectral excess in the 5-7 MeV region when compared to the Huber-Muller prediction based on the conversion method. Analysis within an alternate prediction technique, the summation method, suggests that the bump could be due to excess contributions from a certain few of the beta-decaying fission products. However, it has been shown that when updated fission yield values are used in the summation method, the predicted excess vanishes. In the present preliminary study, fission yields for nuclides suspected of causing the neutrino spectral bump are investigated using gamma-ray spectroscopy of ²³⁵-U and ²³⁹-Pu samples freshly irradiated using the High Flux Isotope Reactor. For several of the suspect nuclides, the derived fission yields are consistent with JEFF3.3 fission yield library. The exception is the case of ¹⁴⁰-Cs from ²³⁹-Pu, where the discrepancy between the fitted and expected values suggests a potential error in the fission yield library. This highlights the importance of using accurate nuclear data libraries in the analysis of the reactor antineutrino spectra, and the need for ongoing efforts to improve these libraries.

public lecture / 657

Treatment of metastatic cancer by Radiomolecular Precision Oncology - an ongoing revolution

Auteur: Richard P Baum (baumrp@gmail.com)

The radiopharmaceuticals toolbox has expanded dramatically over the last few years. Isotopes with well-established chemistries continue to be used routinely, while newer isotopes have grown more available, with a wider variety of chemistries, decay modes and in vivo behaviors, making it easier to pair radiopharmaceuticals for imaging and therapy, a pairing referred to as radiomolecular theranostics. In much the same way that the development of targeted agents and immunotherapy revolutionized medical therapies for cancer, the rapid development and availability of these new isotopes and agents has fundamentally changed the landscape for radiopharmaceutical therapy.

Radiomolecular Precision Oncology is being driven by rapid advances in novel diagnostics and therapeutic interventions. As part and integral in the current era of precision oncology, theranostics aims to identify the appropriate molecular targets in neoplasms (diagnostic tool), so that the optimal ligands and radionuclides (therapeutic tool) with favorable labeling chemistry can be selected for

personalized management of a specific disease, taking into consideration the specific patient, and subsequently monitor treatment response for personalized cancer care.

Peptide receptor radionuclide therapy (PRRT) and PSMA Radioligand Therapy (PRLT): Over the past two decades, the use of ^{68}Ga labeled peptides for somatostatin receptor (SSTR)-targeted PET imaging followed by beta emitters like ^{177}Lu and ^{90}Y or alpha-emitters like ^{225}Ac and ^{212}Pb labeled SSTR-analogues for peptide receptor radionuclide therapy (PRRT) has demonstrated remarkable success in the management of neuroendocrine neoplasms and paved the way to other theranostics indications.

Targeted Alpha radioligand therapy (ART): While beta-emitters have demonstrated efficacy, alpha-emitters have a 100-fold higher LET. Remarkable results have been achieved by switching non-responders from ^{177}Lu to alpha therapies. Our experiences indicate that the combination of ^{225}Ac and ^{177}Lu labeled PSMA and somatostatin receptor antagonists ligands for TANDEM treatments are feasible, safe, and effective, and suggest a potential synergistic effect.

FAP-targeted peptide targeted radionuclide therapy (PTRT)

FAP is overexpressed on cancer-associated fibroblasts (CAFs) in over 90% of epithelial. We recently published the worldwide first clinical experience using ^{177}Lu -FAP-2286. We are now performing PTRT using 3BP-3940 to explore the theranostic approach applying ^{68}Ga -3BP-3940 for PET/CT imaging and selection of the patients for PTRT with ^{177}Lu , ^{90}Y , ^{225}Ac and combinations of the radioisotopes for TANDEM-PTRT.

RadioVakzination - Combination of radioligand therapy with immunotherapy: By combining molecular targeted radioligand therapy with immune check-point inhibitors (ICPI), e.g. PD-L1 mAb like pembrolizumab, a promising paradigm of cancer immunotherapy has been developed that could re-program TME from “cold” to “hot”, to make low immunoactivity tumors sensitive to therapy.

Conclusions: PRRT lends a significant benefit in progression-free survival in metastasized NENs as compared to other treatment modalities. Quality of life is significantly improved. The combination of ^{177}Lu and/or ^{90}Y , ^{225}Ac (DUO-PRRT) may be more effective than either radionuclide alone.

^{177}Lu -PSMA RLT is safe and effective with appropriate selection/follow-up of patients by ^{68}Ga -PSMA PET/CT. ^{225}Ac -PSMA or TANDEM-ART is prolonging overall survival for end-stage mCRPC. The initial clinical results of PTRT provide evidence for the feasibility of radiomolecular precision theranostics in a number of advanced, therapy-refractory adenocarcinomas. New targets, novel radionuclides (^{225}Ac , ^{212}Pb and Terbium radioisotopes), tumor microenvironment with optimized peptide and optimal isotopes (^{177}Lu , ^{225}Ac , ^{90}Y , TANDEM) and administration schedules, RadioVax (combination of radioligand with immunotherapy), radioprotectors and radiosensitizers will be systematically explored in future. Personalized, molecular radiotherapy of malignancies, tailored to the individual patient in a PRECISION ONCOLOGY setting (including genomics) is moving from innovation to implementation in real-world, and large patient populations are expected to be in the mainstream of future applications.