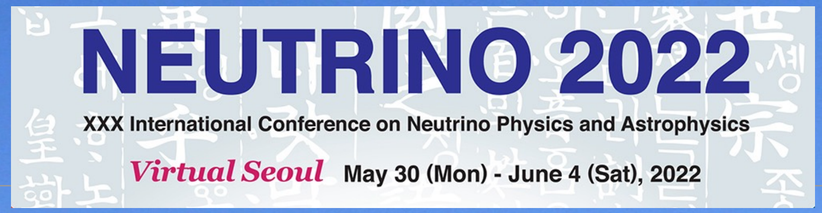
Gaseous detectors for neutrinoless double beta decay searches: NEXT and PandaX-III



Michel Sorel, on behalf of the NEXT Collaboration

With many thanks to: Ke Han (PandaX Collaboration)

High-pressure xenon gas time projection chambers for 0νββ in ^{136}Xe

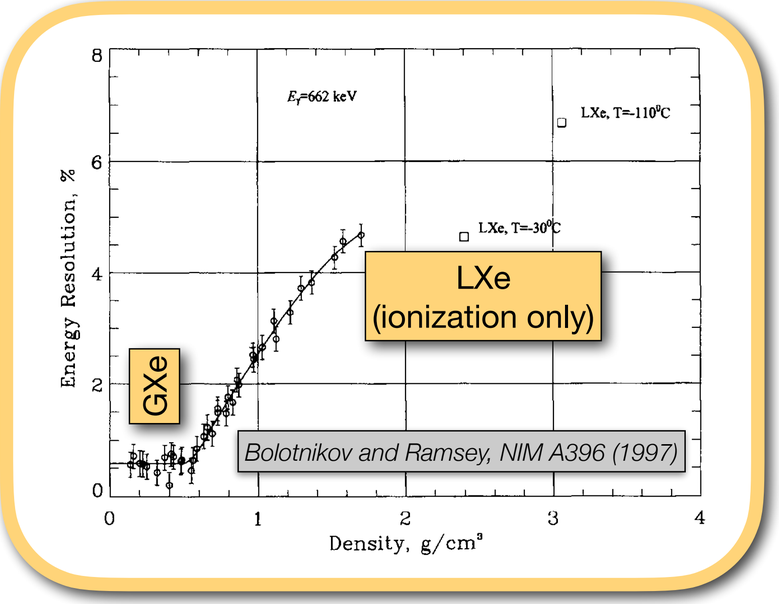
Precise energy resolution of <1% FWHM

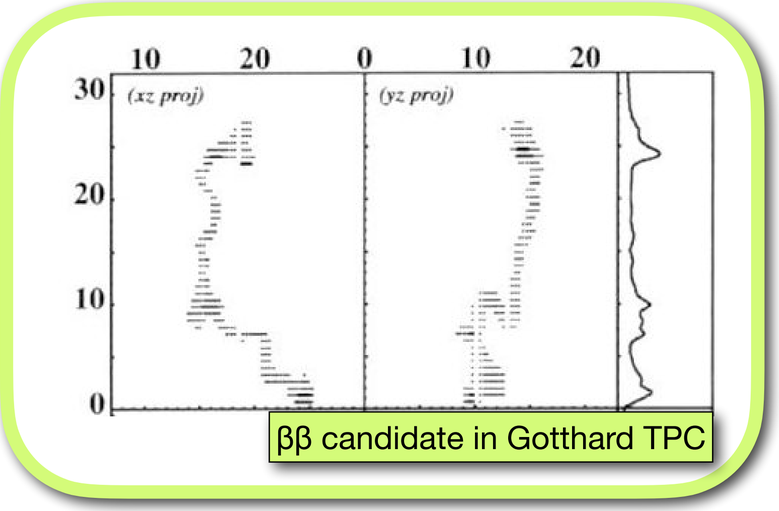
Topological event identification distinguishes 2e from 1e events

Scalability to large masses of isotopically-enriched ^{136}Xe

Possibility to detect $^{136}Ba^{++}$ daughter ion in coincidence with decay electrons

- Experimental programs: Gotthard, **NEXT**, PandaX-III, AXEL



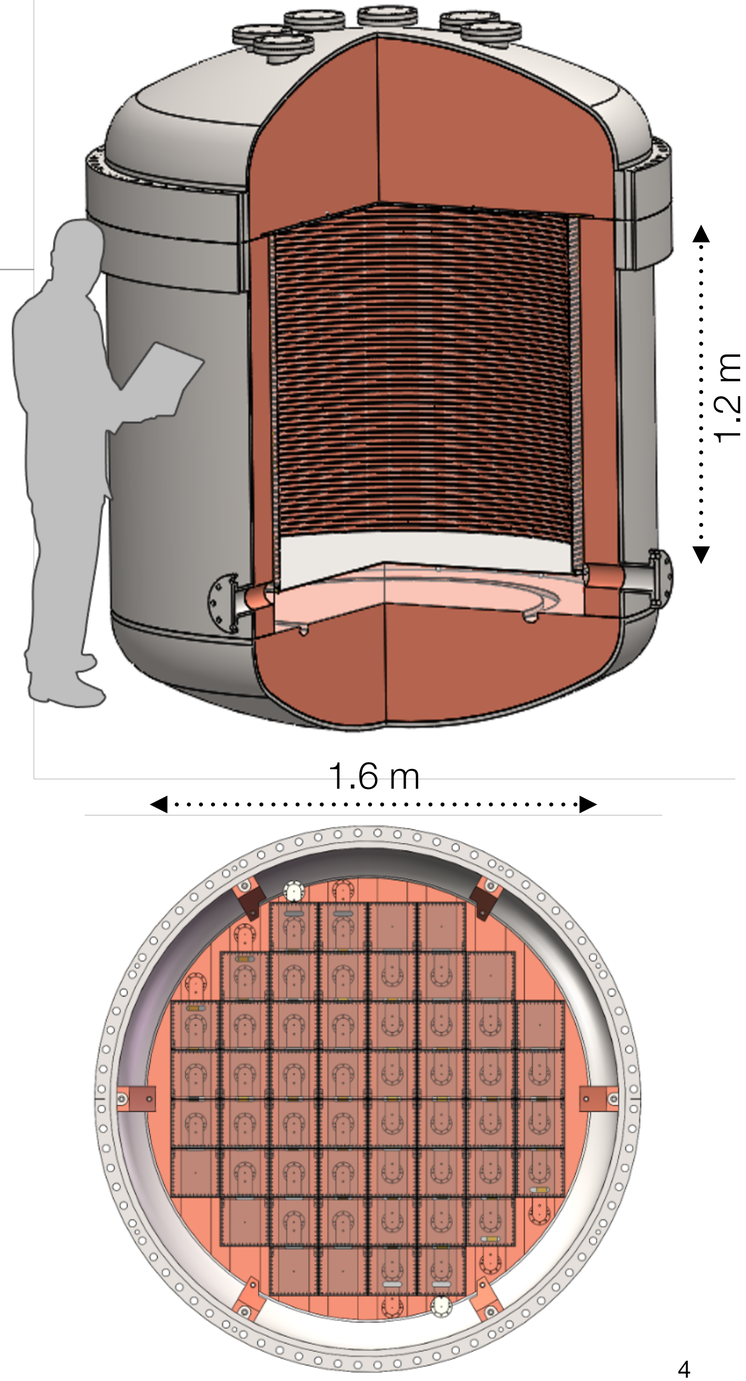


See poster #197, B. Sugashima

PandaX-III

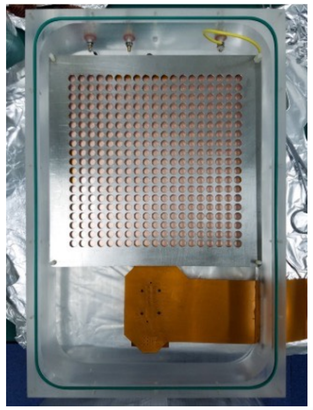
PandaX-III

- **140 kg** high pressure TPC at 10 bar at CJPL-II
  - *Active volume: 1.6 m diameter, 1.2 m drift*
  - *Xenon mixed with TMA quencher gas to reduce diffusion*
- One charge-only readout plane with mm-level spatial resolution
  - *20×20 cm^2 Micromegas modules, 52 in total*
- Good energy resolution and tracking capability
- Half-life sensitivity with 3 years of data: **9×10^{25} yr** (90% CL)
  - *Detailed tracking features can further improve this sensitivity*



From prototypes to full vessel and field cage

1 Micromegas



MiniTPC: 1 Micromegas, 16 bar

Prototype TPC: 7 Micromegas, 10 bar

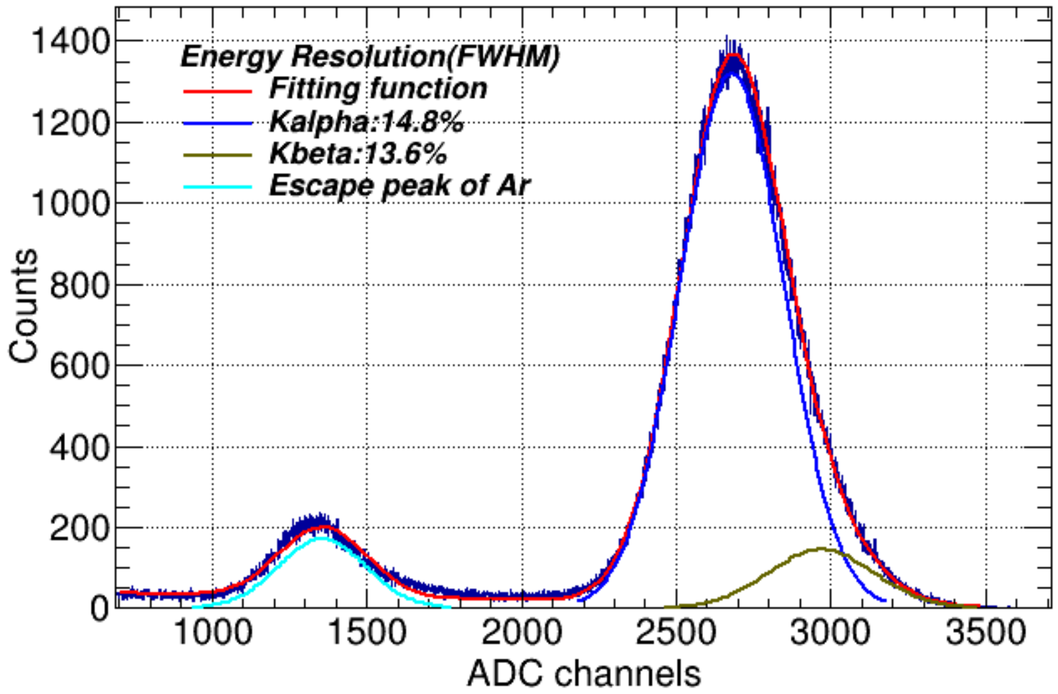
Full vessel: low-background SS, 4 m^3 inner volume

Field cage: tiled Kapton flexible PCB + SMD resistors

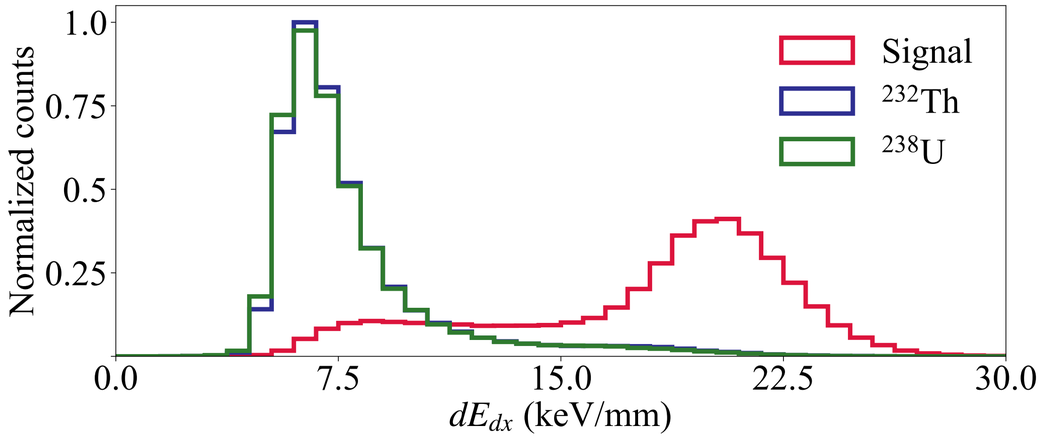
- Aim to complete installation on surface: late 2022. Moving underground to CJPL-II: TBD.

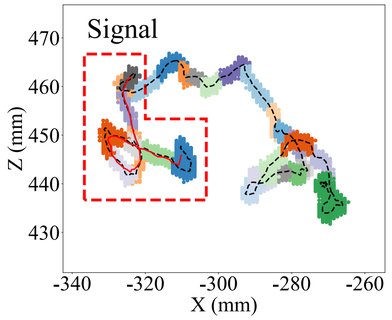
Energy resolution and tracking capabilities

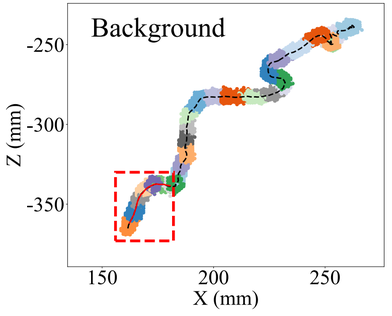
- Thermal bonding Micromegas tested in 1/8/10 bar Ar mixture gases.
- Best energy resolution at 6 keV (^{55}Fe) is **15%** FWHM in 1 bar argon/CO_2.



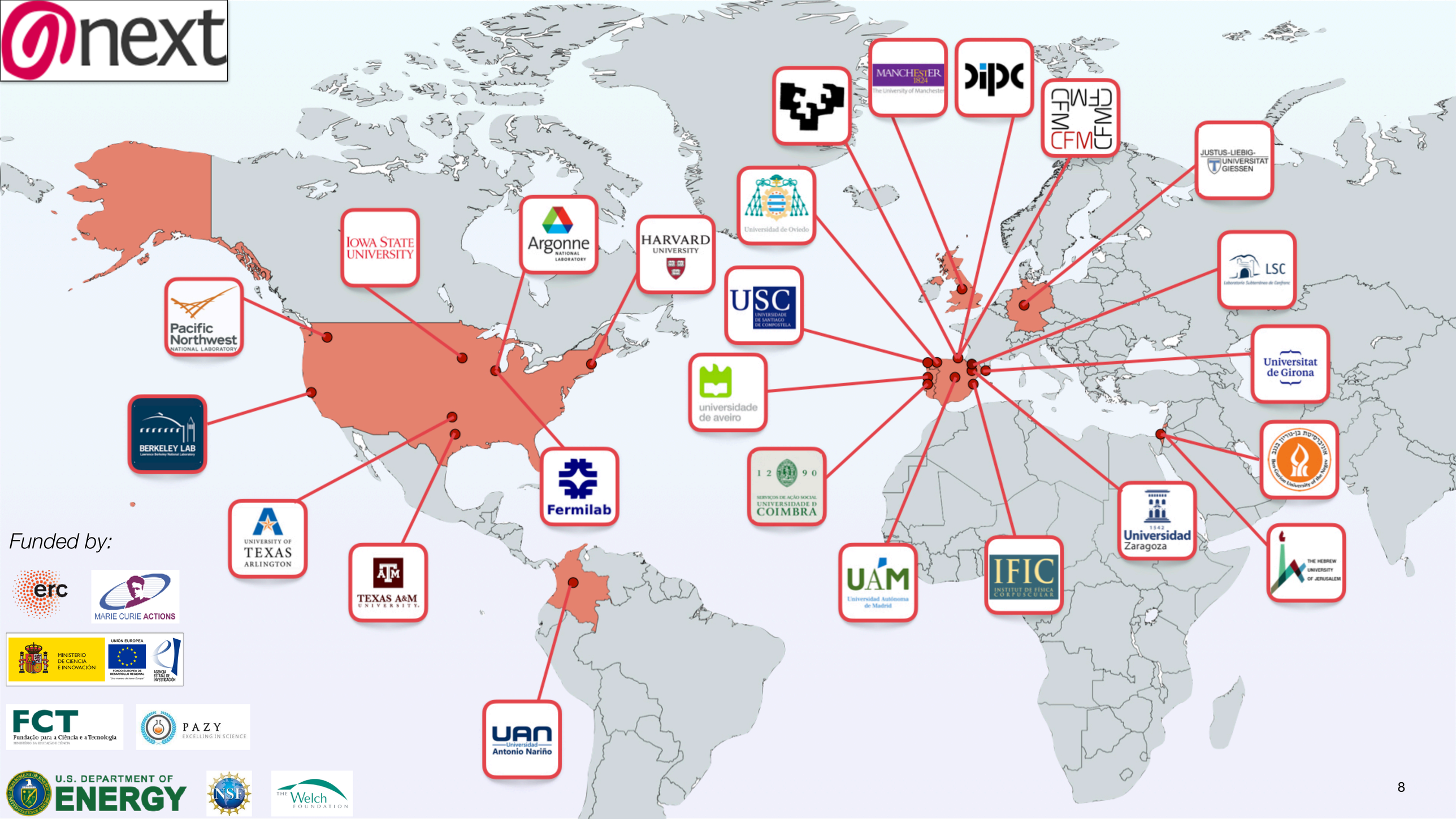
- Kalman filter based track reconstruction on simulated data.
- Improve sensitivity to **2.7×10^{26} yr** after 5 yr.







NEXT

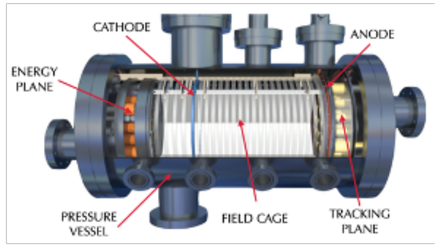

next
Iowa State University
Argonne National Laboratory
Harvard University
Pacific Northwest National Laboratory
Berkeley Lab
Fermilab
University of Texas Arlington
Texas A&M University
UAN Universidad Antonio Nariño
Universidad de Oviedo
USC Universidade de Santiago de Compostela
universidade de aveiro
1290 Serviços de Ação Social Universidade de Coimbra
Manchester 1824 The University of Manchester
DIPC
CFM
Justus-Liebig-Universität Giessen
LSC Laboratorio Subterráneo de Canfranc
Universitat de Girona
Universidad Zaragoza
The Hebrew University of Jerusalem
UAM Universidad Autónoma de Madrid
IFIC Institut de Física Corpuscular
Funded by:
erc
Marie Curie Actions
Ministerio de Ciencia e Innovación
Unión Europea
Fondo Europeo de Desarrollo Regional
Agencia Estatal de Investigación
FCT Fundação para a Ciência e a Tecnologia
PAZY Excelling in Science
U.S. Department of Energy
NSF
The Welch Foundation

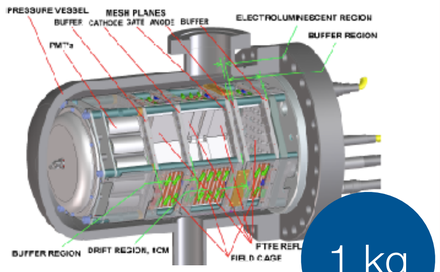
The NEXT program

Prototypes

2008-2015

- Demonstration of detector concept



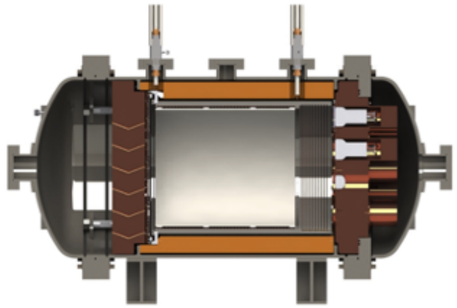


1 kg

NEXT-White

2016-2021

- Det. performance near $Q_{\beta\beta}$
- Background measurement
- 2νββ measurement

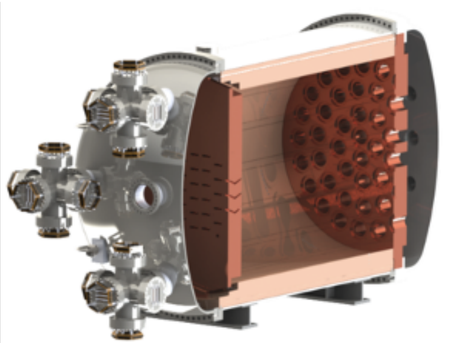


4 kg

NEXT-100

2022-2025

- Background measurement
- 0νββ search



100 kg

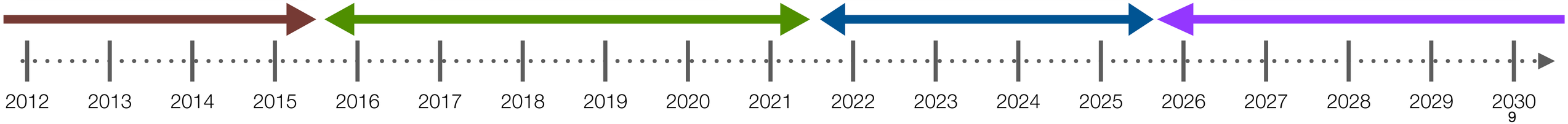
NEXT-HD

2026?

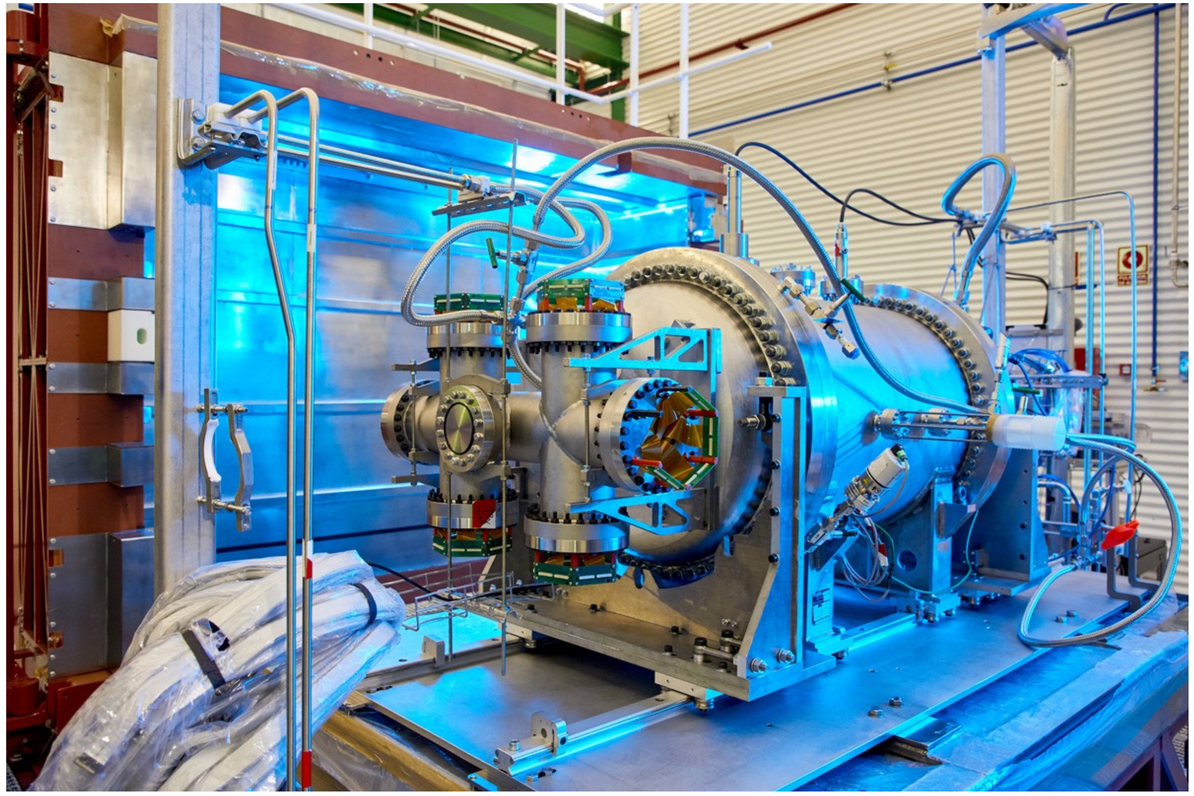
- 0νββ search through inverted ν mass ordering

NEXT-BOLD

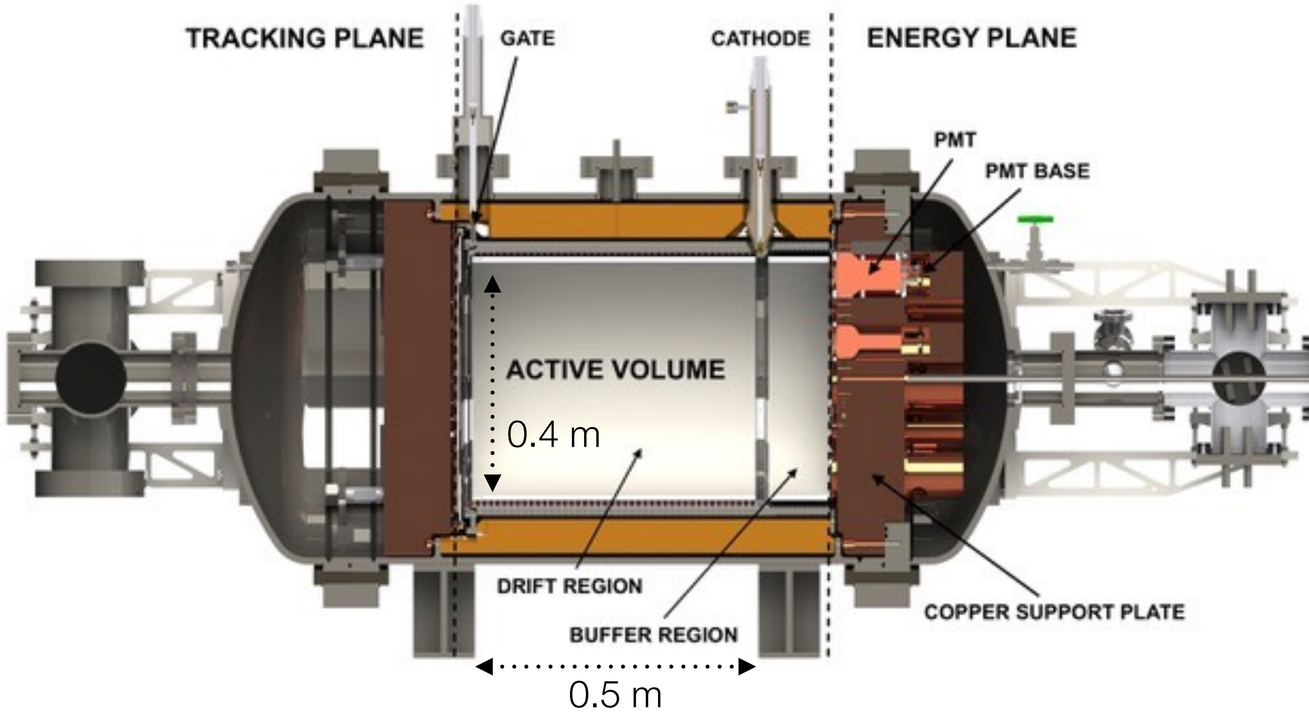
- Barium tagging for bgr-free experiment



NEXT-White



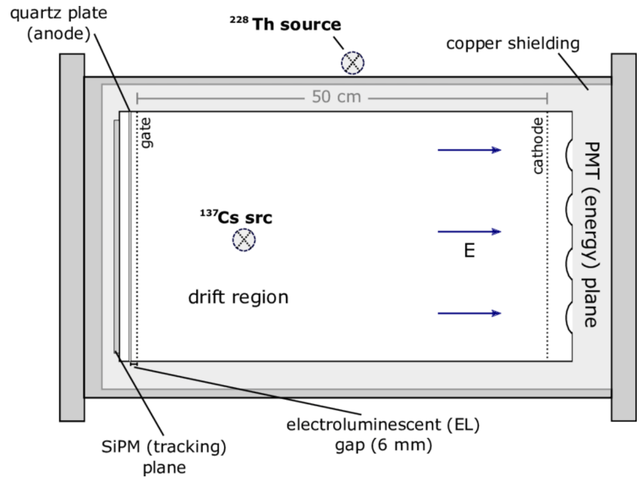
JINST 13 (2018) 12, P12010



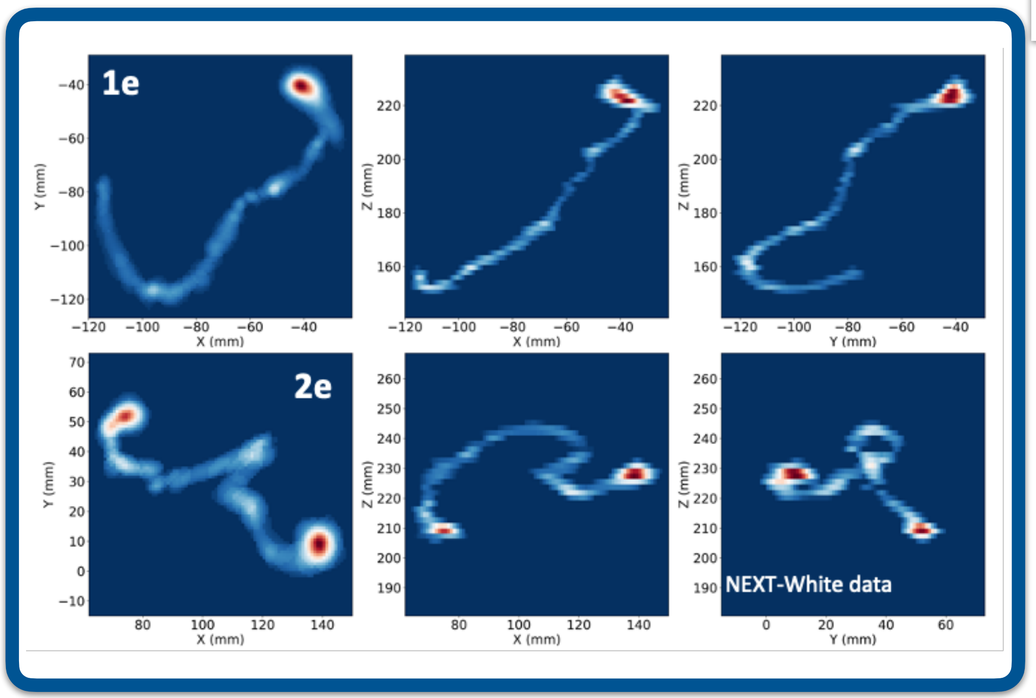
- Operated at the LSC, 2016-2021.
- ^{enr}Xe and ^{dep}Xe gas. Calibration and low-background data.

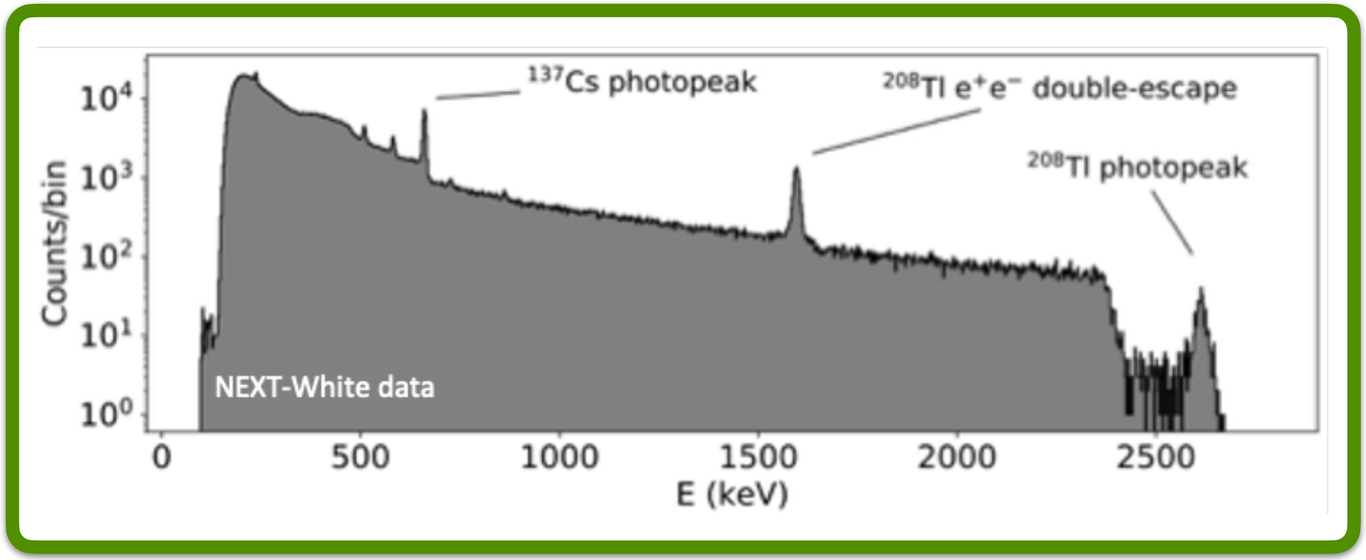
NEXT-White calibration data results

- ^{137}Cs (662 keV) and ^{228}Th (2615 keV) calibration gamma sources
- **Energy resolution**: **0.91±0.12%** FWHM at 2.6 MeV *JHEP 10 (2019) 230*
- **Topology**: 1e background rejection factor of **27** for 57% 2e signal efficiency at 1.6 MeV *JHEP 07 (2021) 146*



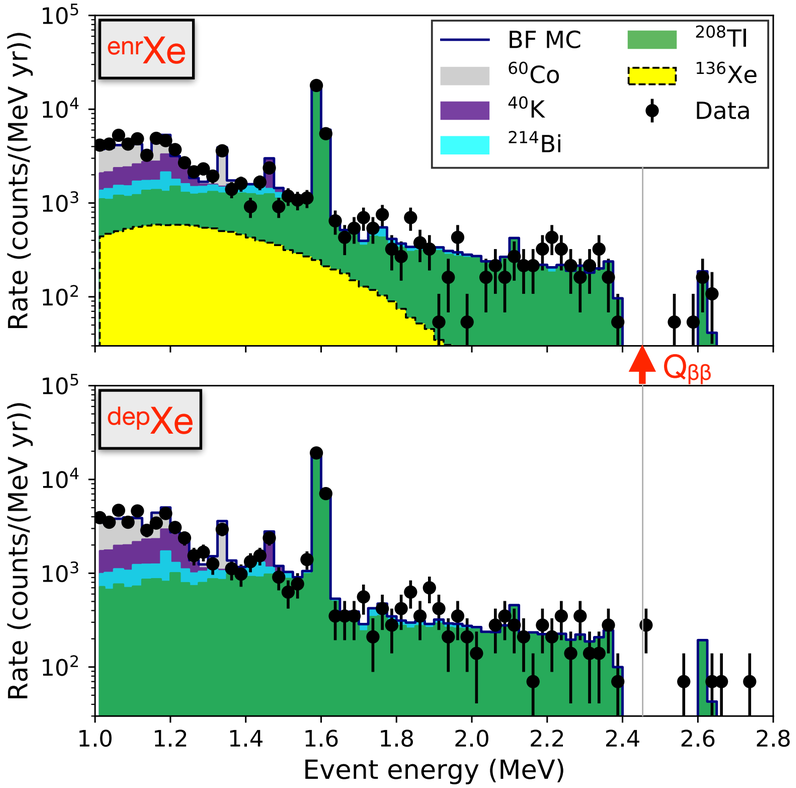
See poster #602, A. Redwine

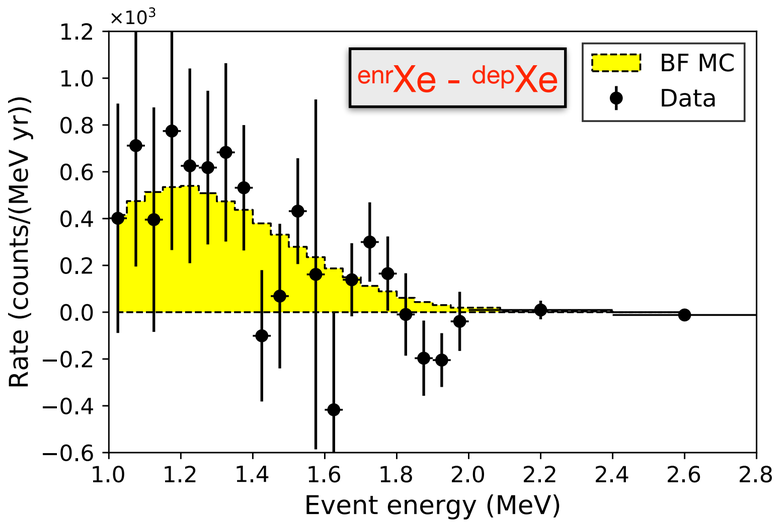




NEXT-White low-background data results

- Low-bgr data samples: **271.6 d** ^{136}Xe-enriched (90.9%), **208.9 d** ^{136}Xe-depleted (2.6%).
- Select 2e-like events in **3.5 kg** Xe fiducial mass.
- Direct background subtraction technique, ~independent of background model assumptions.





See poster #219,A. Usón

$T_{1/2}^{2\nu} = (2.34\ ^{+0.85}_{-0.49}) \times 10^{21}$ yr

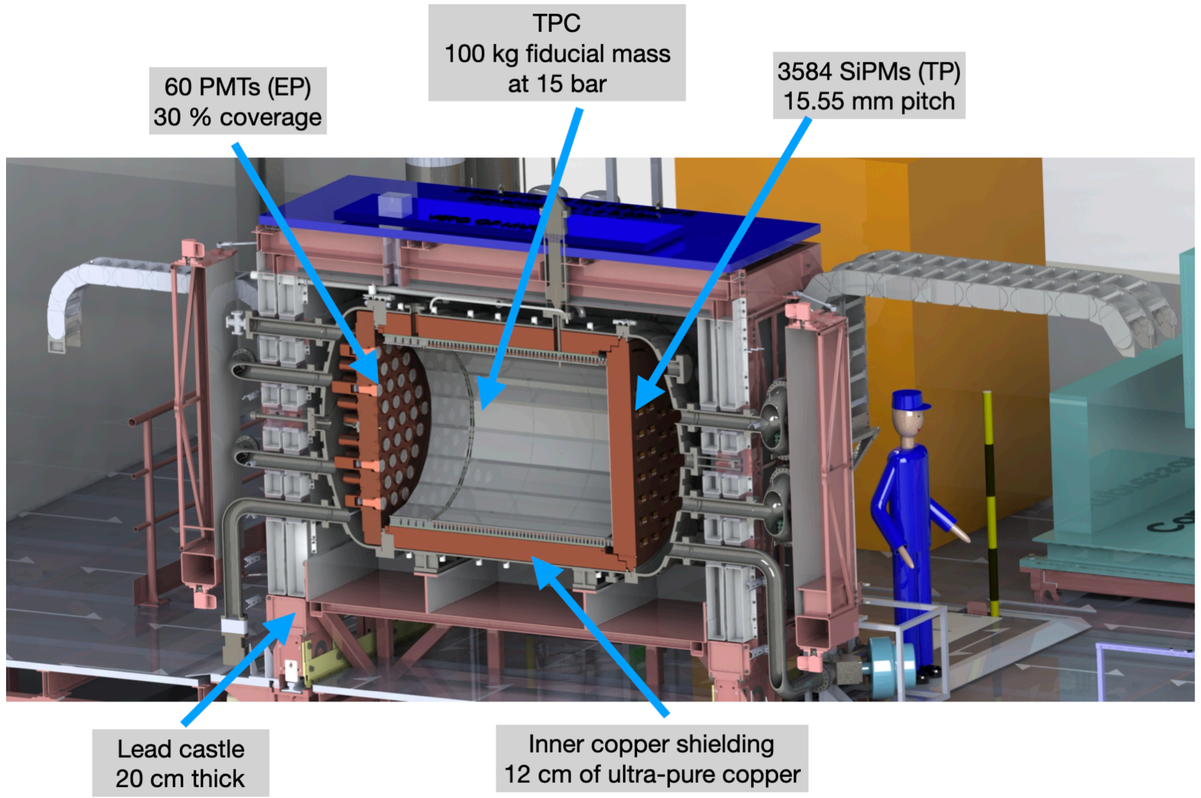
Phys.Rev.C 105 (2022) 5, 055501

$T_{1/2}^{0\nu} > 0.6\text{-}1.3 \times 10^{24}$ yr at 90% CL

PRELIMINARY

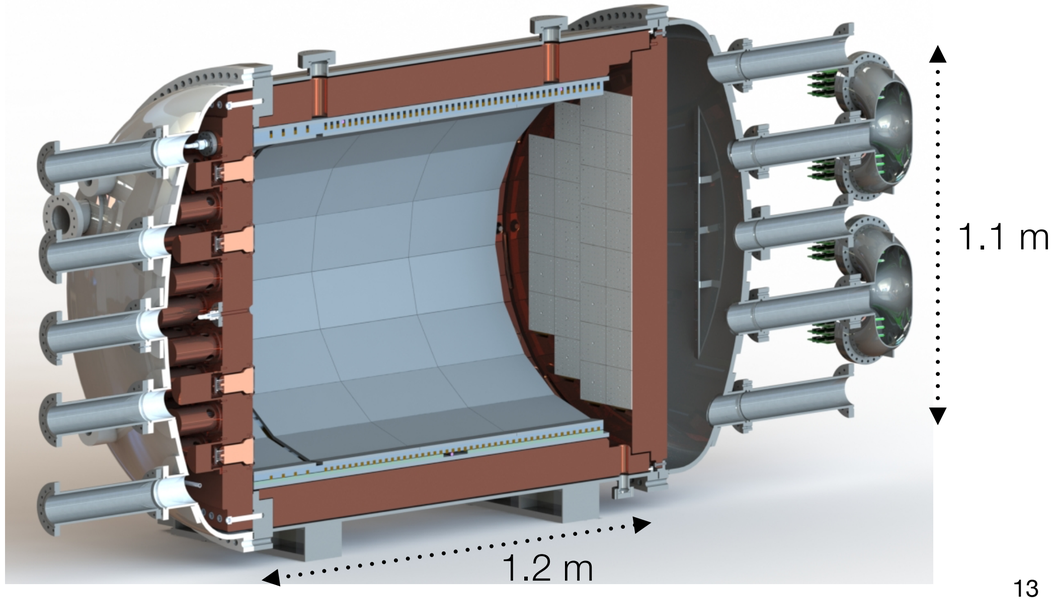
NEXT-100

- Demonstrate ~bgr-free conditions at 100 kg scale, 0νββ search, tonne-scale demonstrator.
- Target background rate of 5×10^{-4} counts/(keV·kg·yr) or **1 count/(ROI·yr)** *JHEP 05 (2016) 159*
- Status: in advanced construction stage, to be installed at the LSC in late 2022.



See poster #140, K. Mistry

See poster #143, G. Diaz



NEXT-100: external shield and gas system infrastructures

- **External shield**: refurbishing of lead castle completed. Now with more radiopure steel!

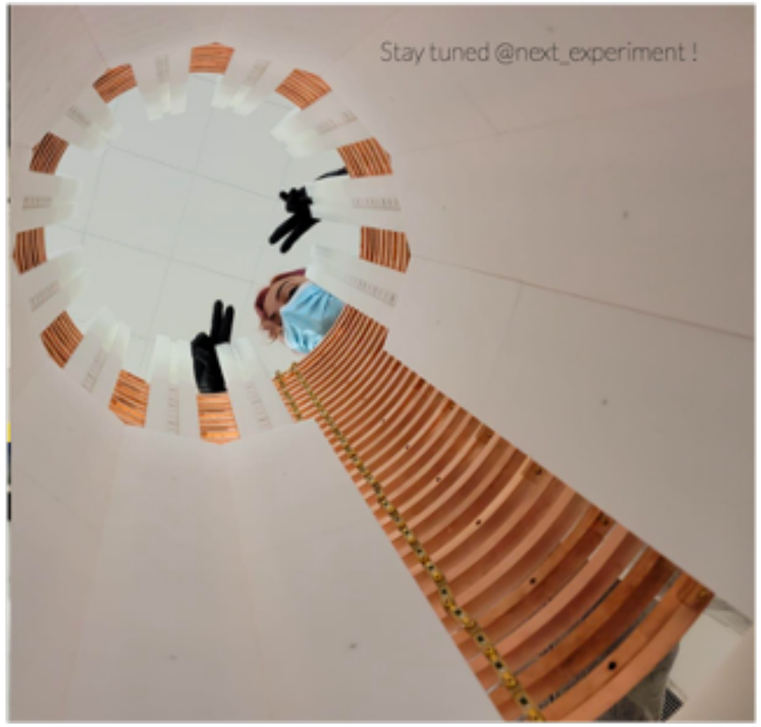
- **Gas system**: upgrades with respect to NEXT-White completed.

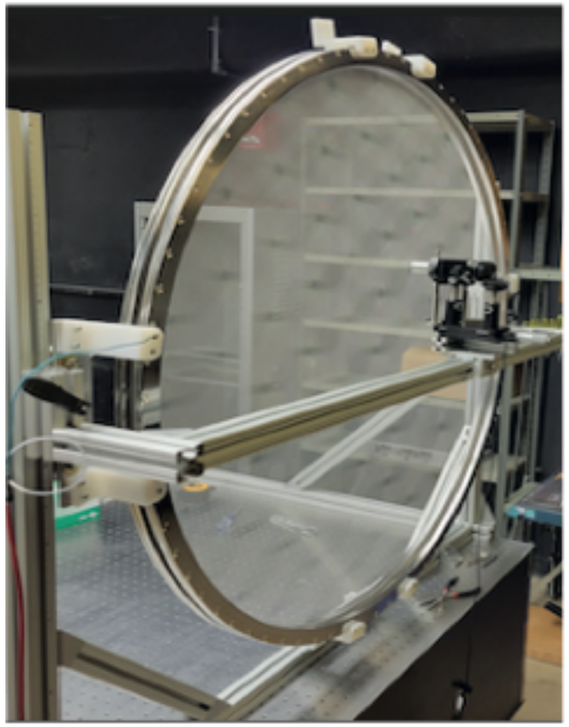
NEXT-100: pressure vessel and inner copper shield

- **Pressure vessel**: stainless steel, **13.5 bar** operational pressure. Status: completed.
- **Inner shield**: radiopure copper, **12 cm** thick. Status: forged & machined, cleaning ongoing.

NEXT-100: time projection chamber

- **Field cage**: copper rings on HDPE staves, PTFE panels for increased light collection. Status: design and prototyping completed, production orders ongoing.
- **EL** (anode, gate) and **cathode**: stainless steel rings with wire meshes. Status: design and prototyping completed, production orders ongoing.

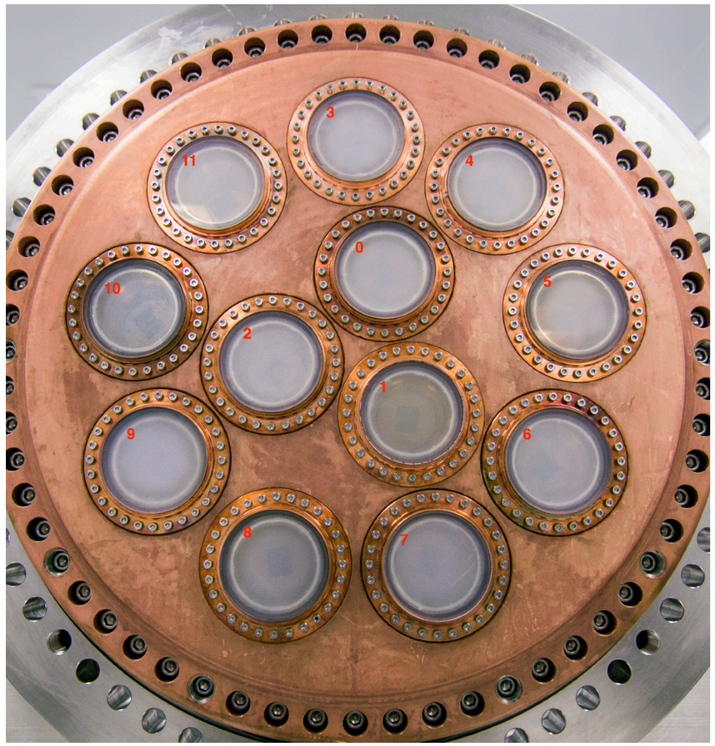


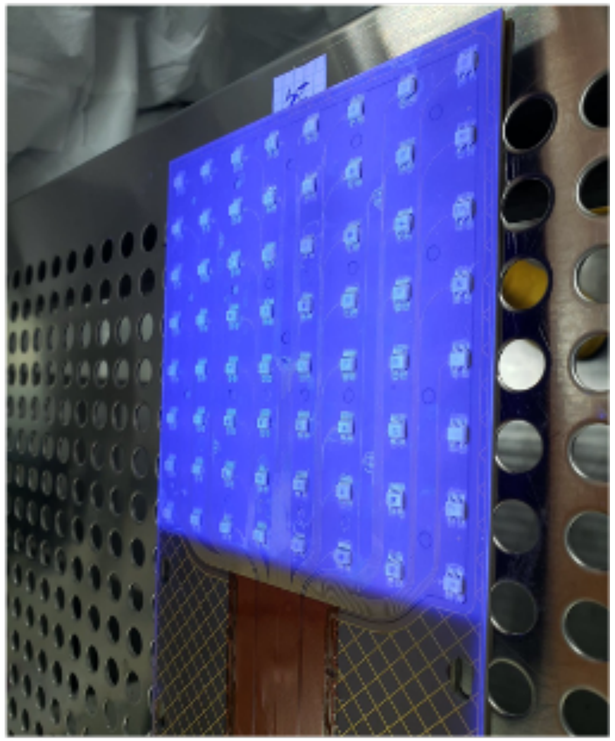


See poster #140, K. Mistry

NEXT-100: readout planes and associated electronics

- **Energy plane**: **60** PMTs behind sapphire windows. Status: PMTs procured, PMT bases built, electronics completed, windows' coating ongoing.
- **Tracking plane**: 56 boards with 64 SiPMs each, for a total of **3584** SiPMs. Status: boards built and TPB-coated, electronics completed and tested.





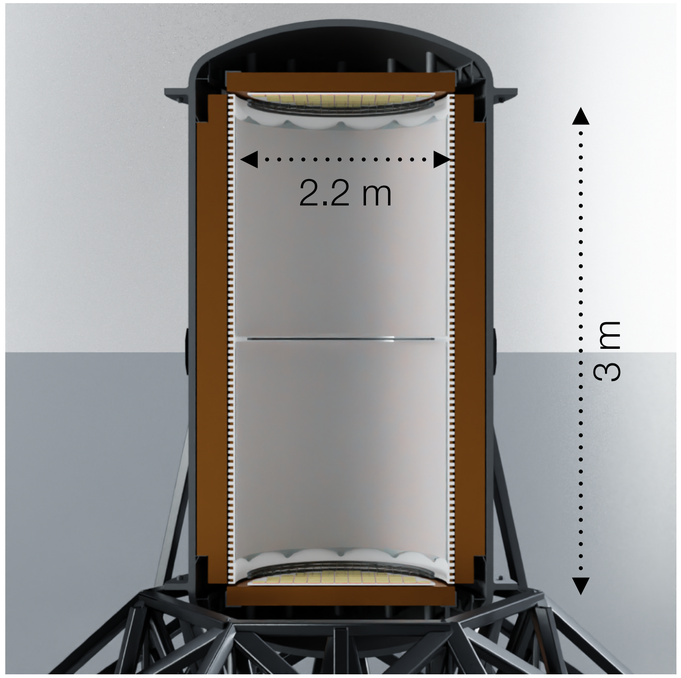
NEXT at the tonne scale: NEXT-HD

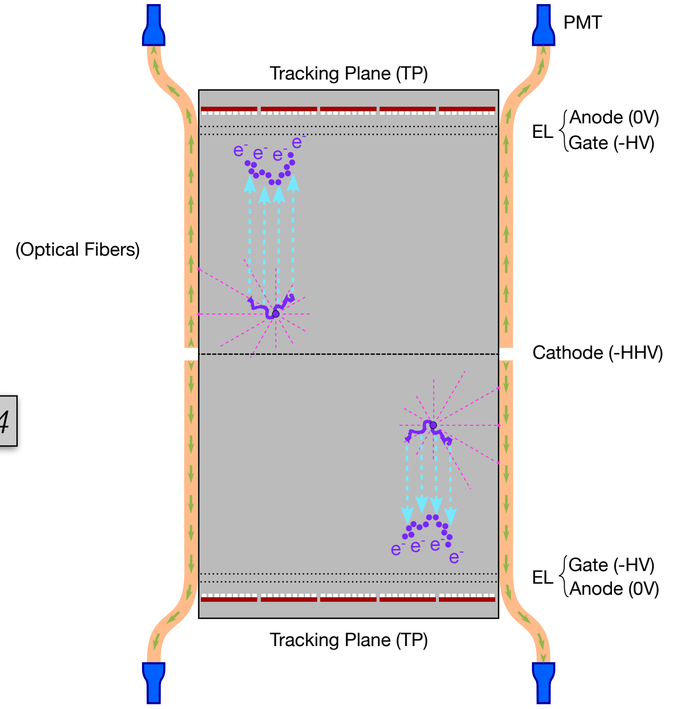
- Multi-module system with first module at Laboratorio Subterráneo de Canfranc (Spain)

- Baseline concept:

  - *Symmetric TPC with central cathode*
  - *Two dense SiPM tracking plane readouts*
  - *Barrel fibre detector for energy measurement*
  - *Gas additives (eg, ^{4}He) to reduce diffusion*
  - *Estimated background **0.09-0.27** counts/(ton·yr·ROI)*

- Other advanced readout options explored, and cosmogenic background mitigation using ^{3}He





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See poster #452, J. Martín-Albo, H. Almazan, L. Arazi

See poster #70, L. Rogers

Barium tagging R&D and NEXT-BOLD

- **Idea**: single molecule fluorescent imaging to detect Ba^{2+} produced in double beta decay.
- **Status**: NEXT has developed custom barium chemosensing molecules with demonstrated single ion response in dry environments.
- Two approaches:
  - *Turn-on* 
  - *Bicolor* 

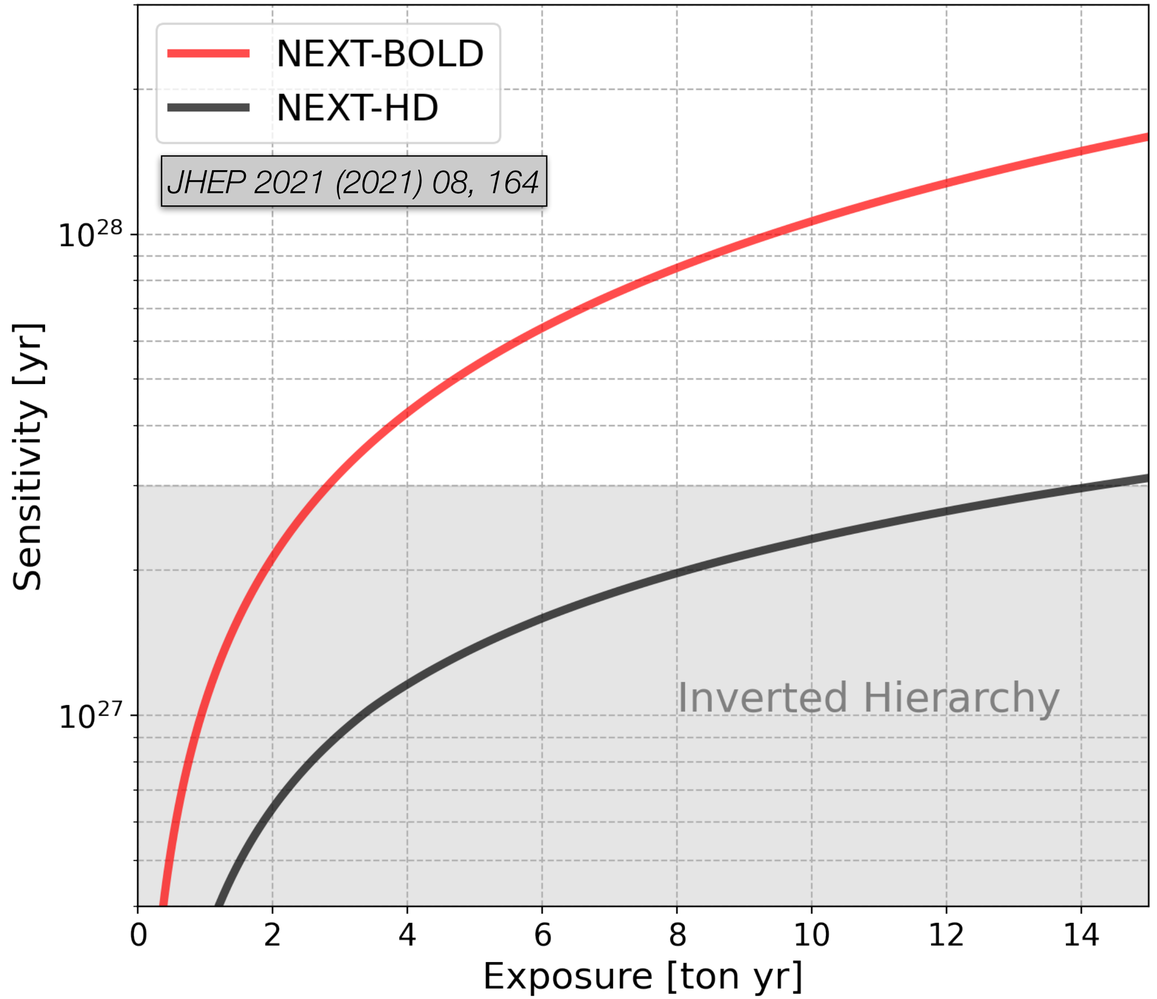
See poster #323, K. Navarro

See poster #51, P. Herrero

For recent barium tagging R&D achievements in NEXT: see talk by Stefan Schönert in S5!

NEXT 0νββ sensitivity prospects at the tonne scale

- NEXT-HD first module can reach **10^{27} yr** sensitivity with **4 ton·yr** exposure.
- To explore **10^{28} yr** sensitivity, further background reduction and higher signal efficiency are essential.
- Both may be achieved with NEXT-BOLD, implementing Barium Tagging.



Summary

- The three aces and the joker up our sleeves for 0νββ searches in ^{136}Xe gas detectors:

♠ energy resolution, ♦ topological identification, ♣ scalability,  barium tagging

- **Recent past**: detector performance, backgrounds and 2νββ with NEXT-White (~4 kg)
- **Short-term future**: 0νββ searches at the 100 kg scale with PandaX-III and NEXT-100
- **Medium term**: 0νββ searches at the tonne scale with NEXT-HD
- **Longer term**: NEXT-BOLD, a tonne-scale detector implementing barium tagging

Related NEUTRINO 2022 posters to check out!

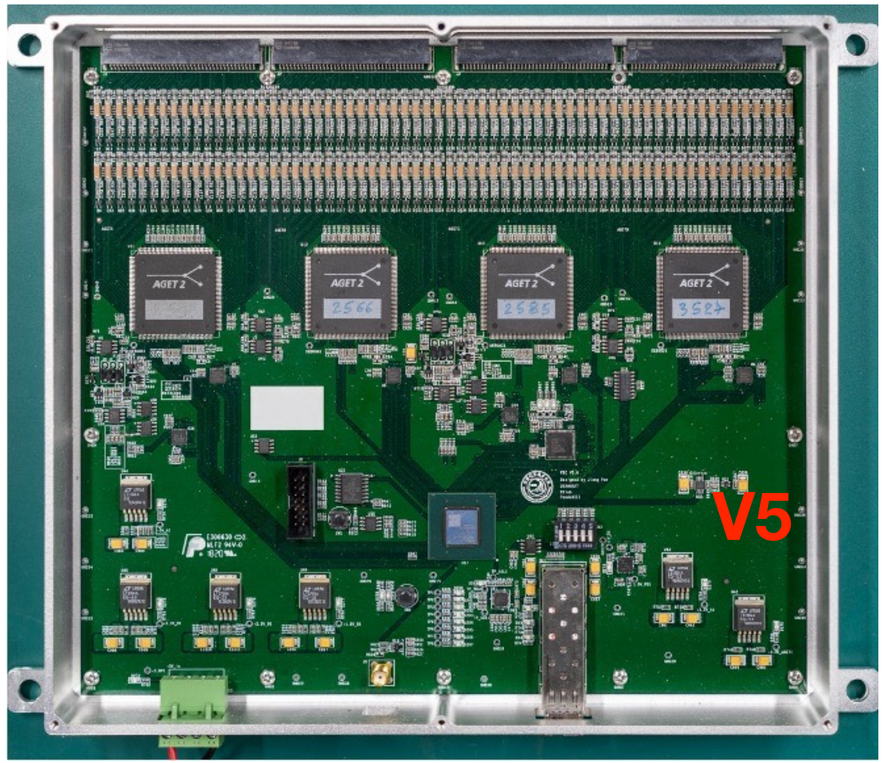
Poster #	Title	Presenter	Collaboration
51	*Demonstration of Barium ion trapping by organic submonolayer in ultra-high vacuum: toward a barium tagging sensor for NEXT, an ultra-low background 0νββ decay detector*	P. Herrero	NEXT
70	*NEXT-CRAB: A High Pressure Xenon Gas Time Projection Chamber with Camera Readout for Neutrinoless Double Beta Decay Searches*	L. Rogers	NEXT
140	*The NEXT-100 time projection chamber and electroluminescent region*	K. Mistry	NEXT
143	*Simulation of NEXT-100 detector*	G. Diaz	NEXT
197	*AXEL Xenon gas TPC for neutrinoless double beta search: prototype performance and status of 1,000L detector construction*	B. Sugashima	AXEL
219	*Xe-136 double beta decay searches with the NEXT-White detector*	A. Usón	NEXT
323	*Progress towards single barium ion capture and imaging in high pressure xenon gas: a prototype barium tagging sensor for NEXT neutrinoless double beta decay searches*	K. Navarro	NEXT
452	*NEXT-HD, a tonne-scale detector for neutrinoless double beta decay searches*	J. Martín-Albo, H. Almazan, L. Arazi	NEXT
602	*Advances in topological studies in NEXT-White and beyond*	A. Redwine, L. Arazi, Y. Ifergan, A. Simon, H. Almazan	NEXT

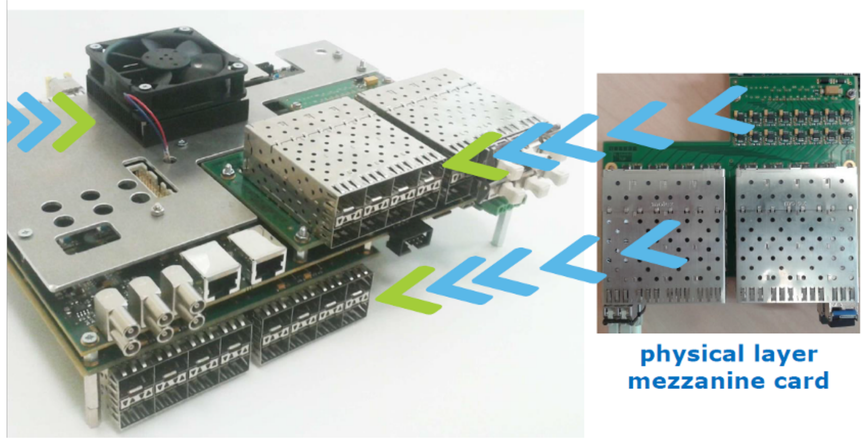
Backups

PandaX-III electronics

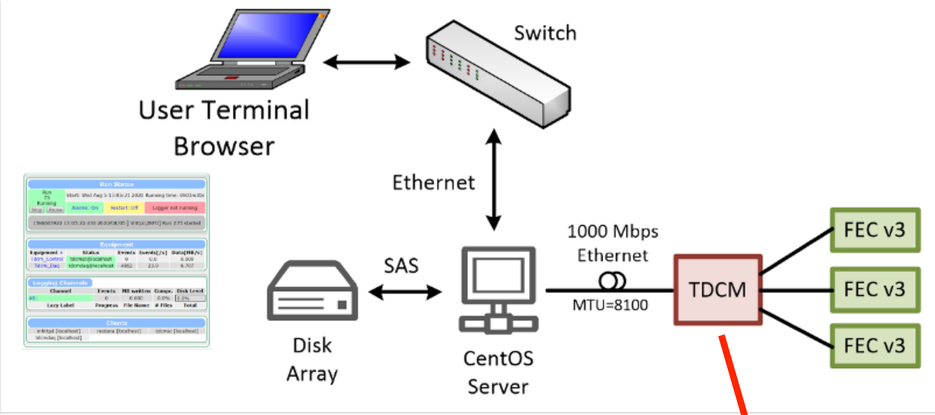
- Frontend electronics based on AGET ASIC chips
  - Kapton-based low background FEC
  - Mass production in progress

- Backend: The Trigger and Data Concentrator Module – TDCM
  - Designed by Saclay for PandaX-III and T2K-II
  - A custom-made 6U form factor carrier board with two physical layer mezzanine cards for 32 FECs

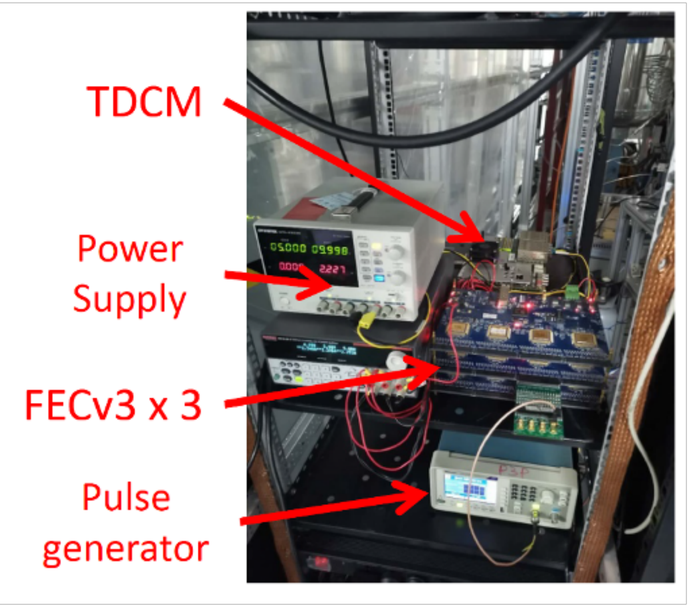


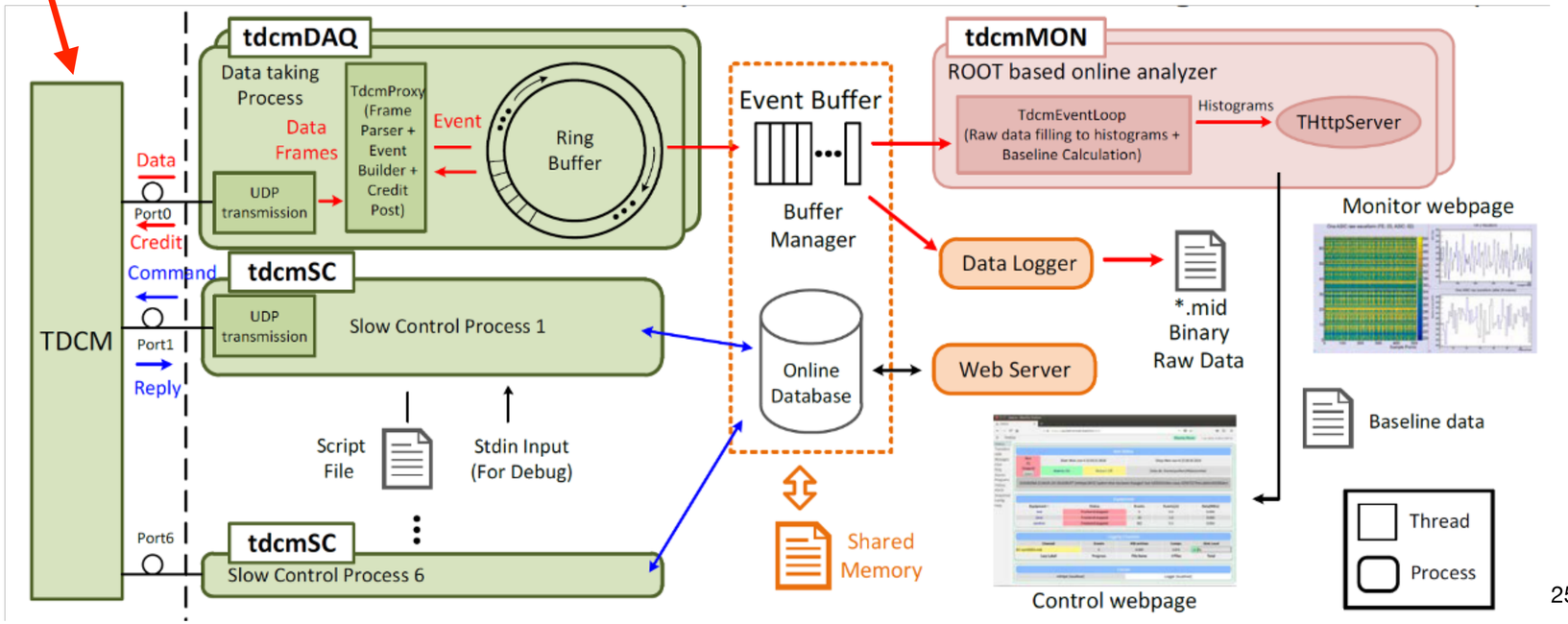


PandaX-III DAQ chain



- DAQ chain joint test is on-going with promising results
- DAQ software based on MIDAS reaches stable state



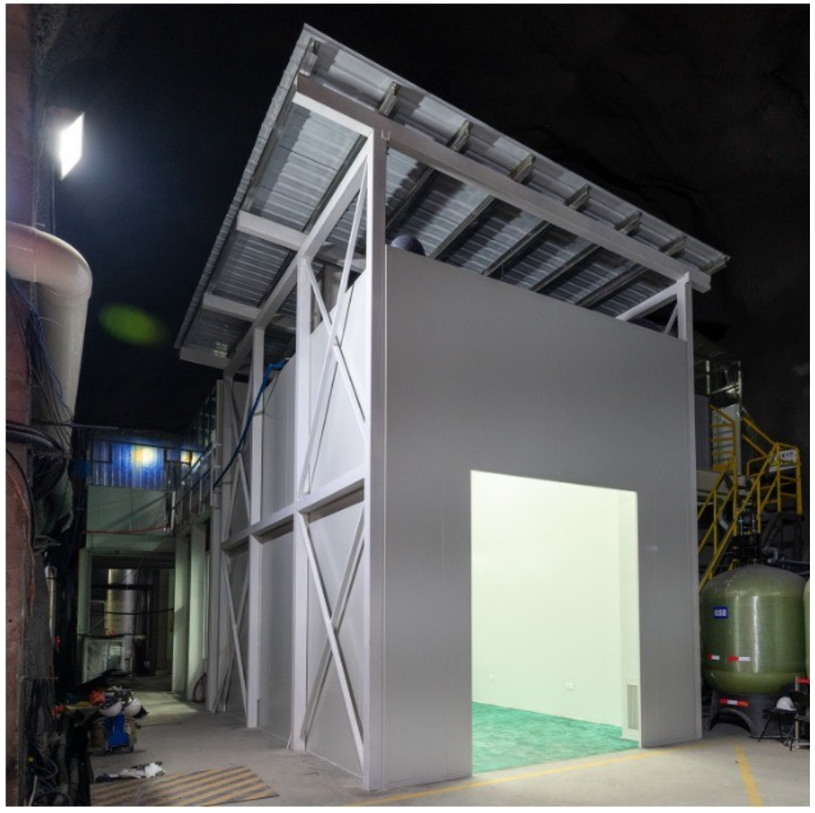


PandaX-III infrastructures

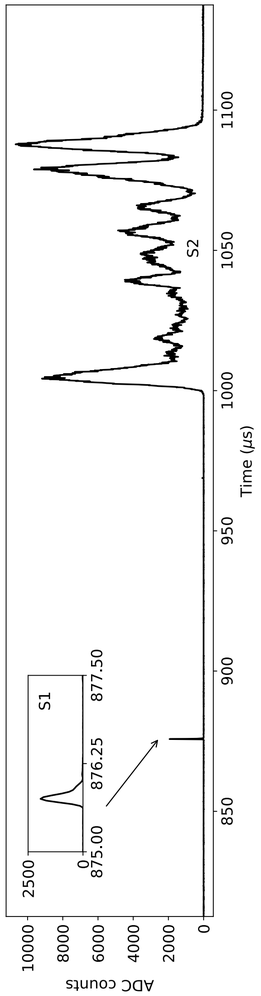
Gas circulation and purification system

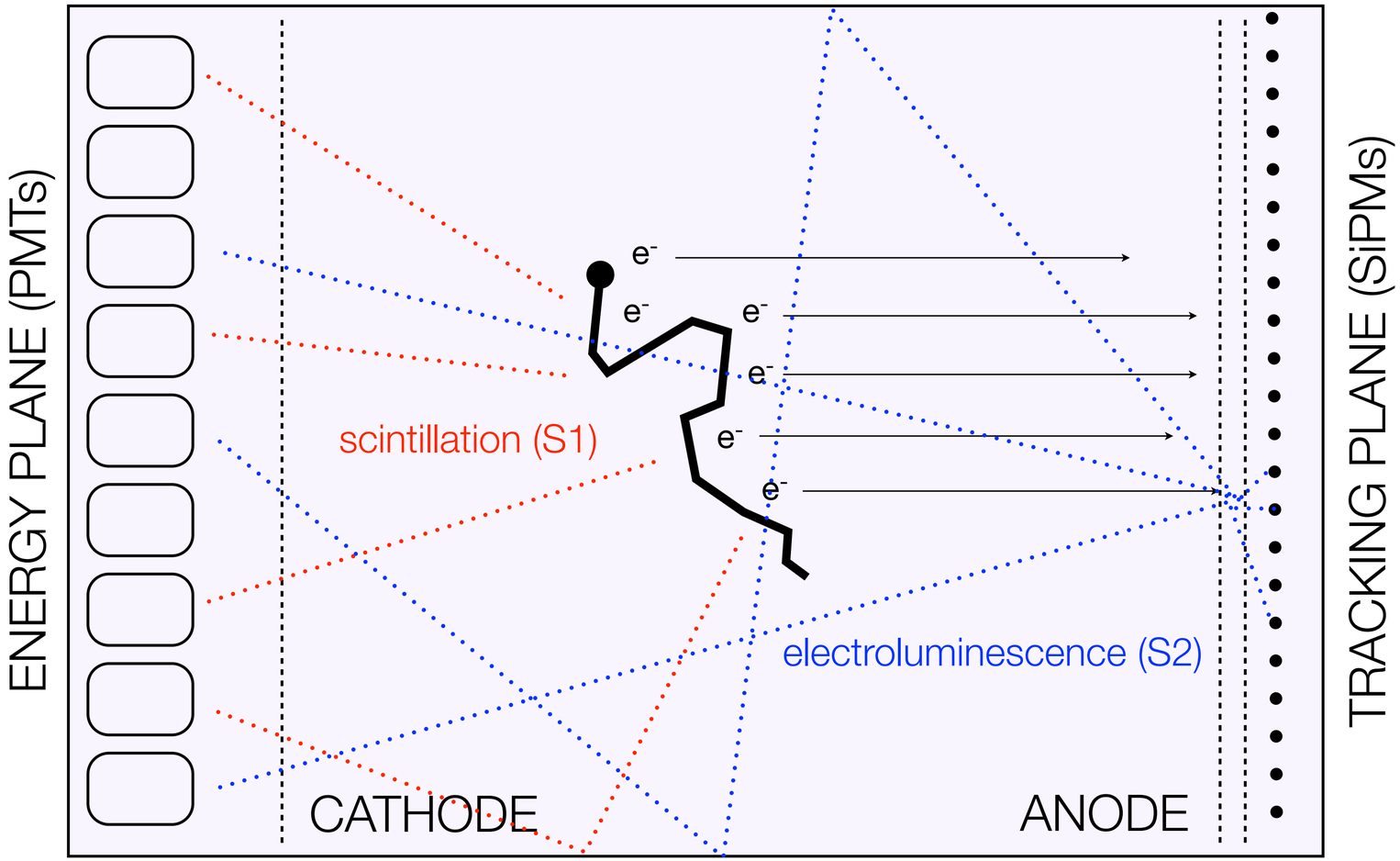
Detector installation fixture

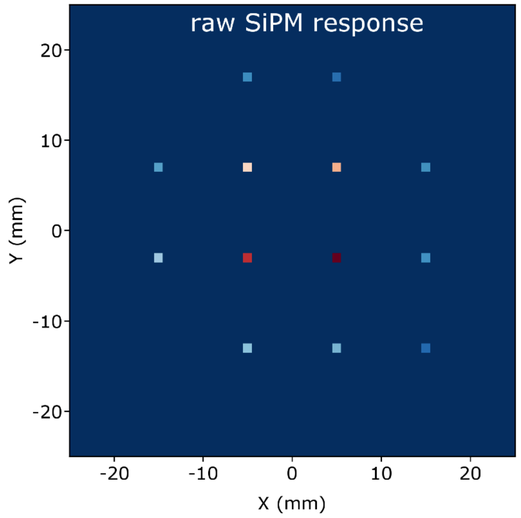
Clean room at CJPL-II



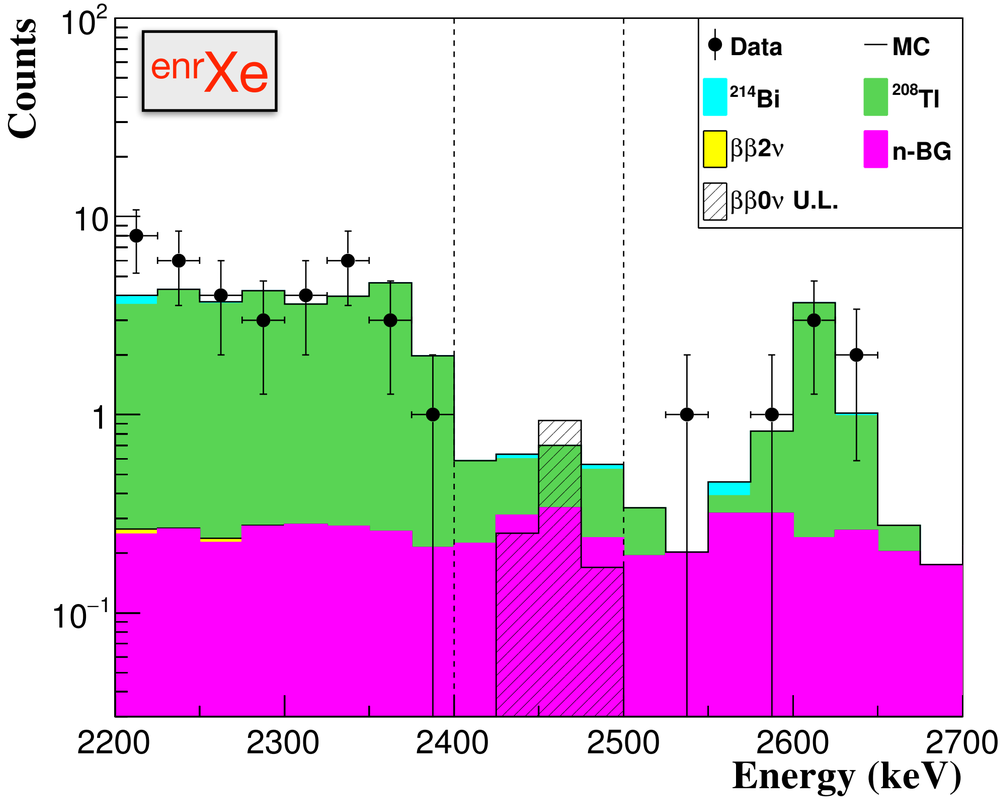
NEXT detection concept

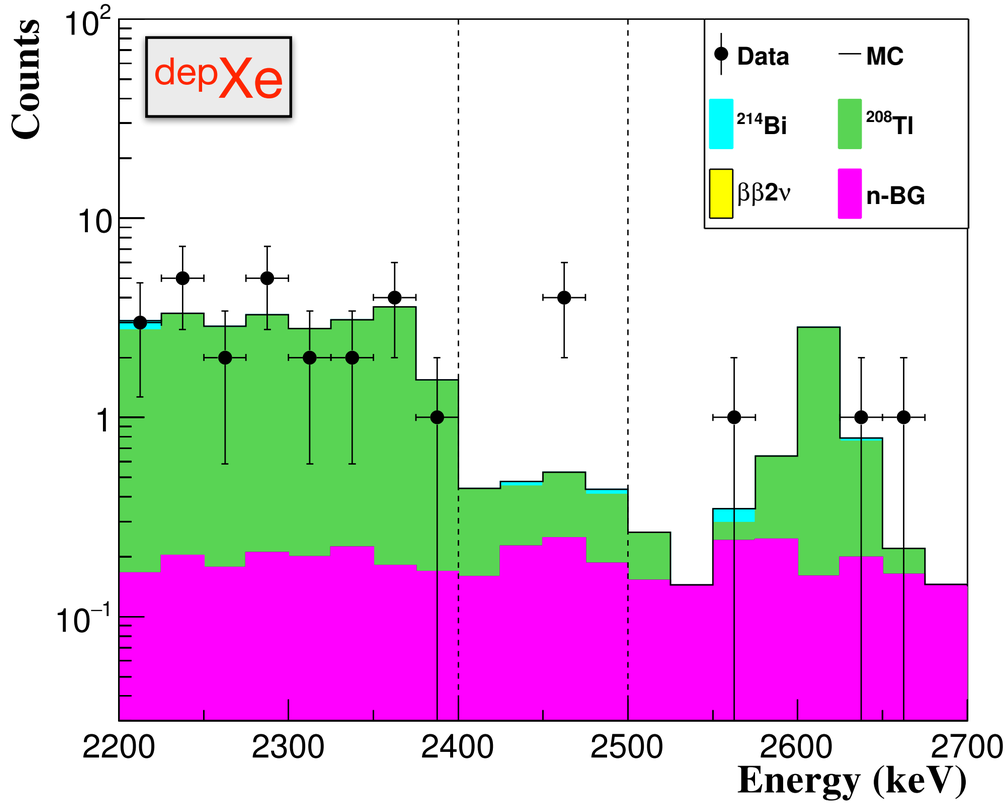






0νββ search in NEXT-White





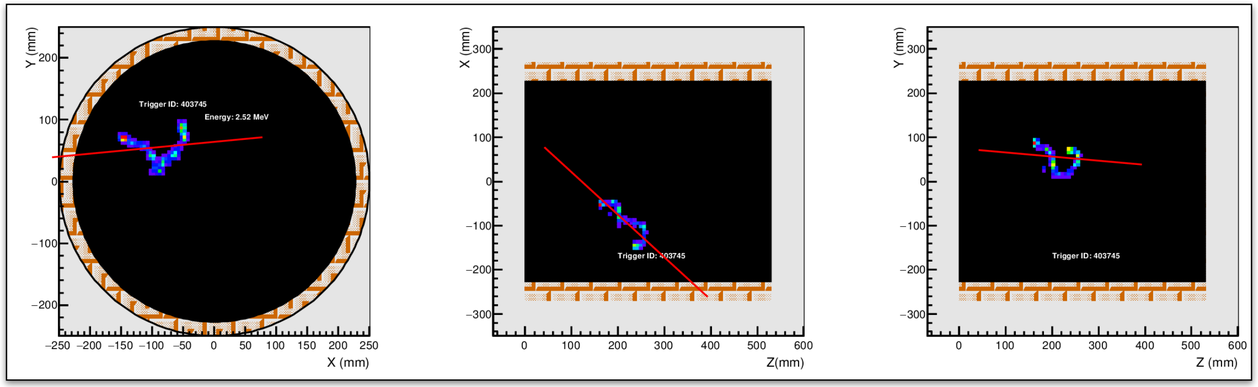
- In 100 keV wide energy ROI near $Q_{\beta\beta}$: **0** events in ^{enr}Xe run, **4** events in ^{dep}Xe run

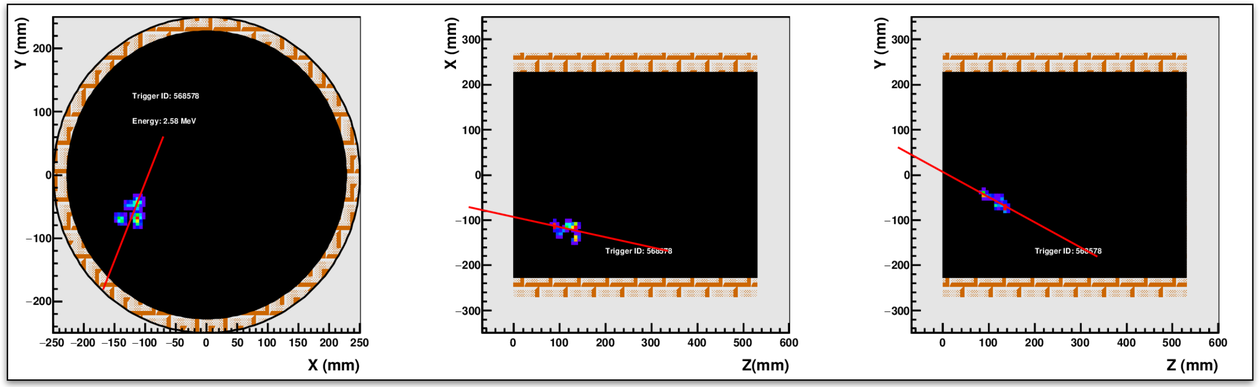
PRELIMINARY

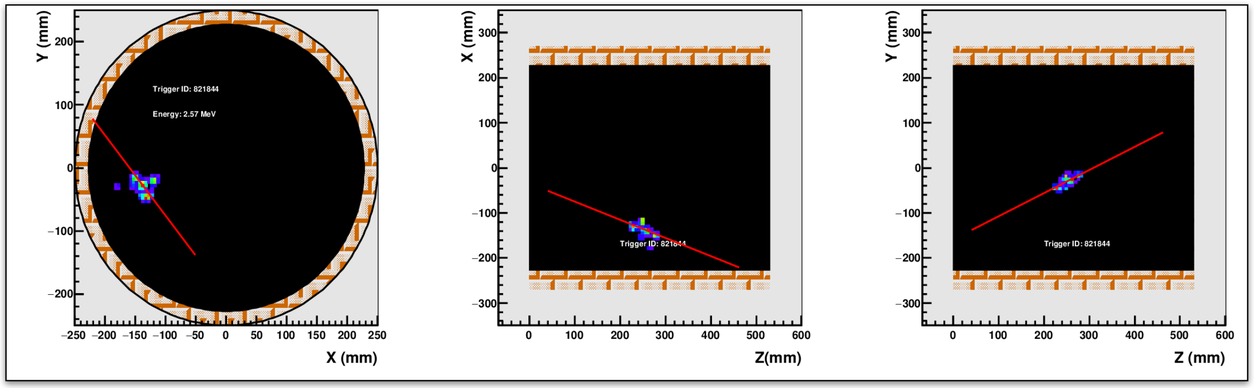
- Background expectation: 1.8±0.3 yr^{-1} radiogenic, 1.5±0.9 yr^{-1} cosmogenic

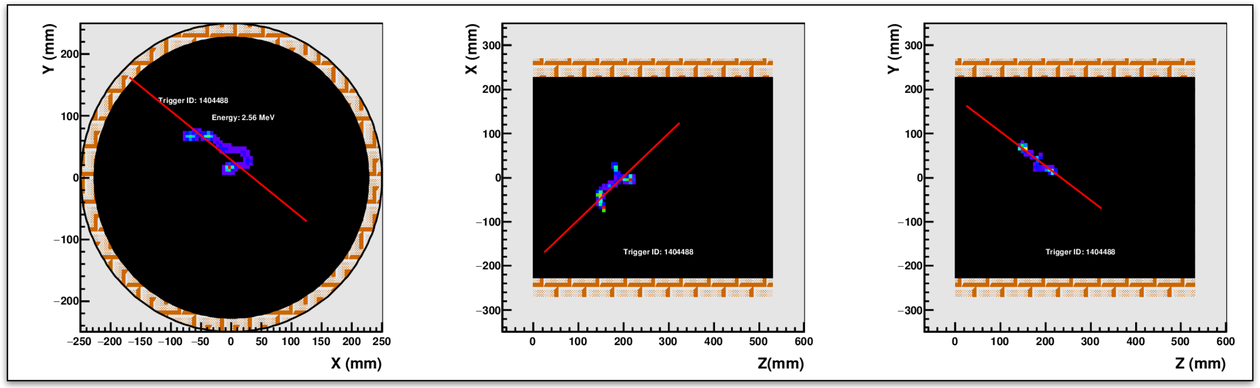
NEXT-White four ββ candidates in ROI, ^{dep}Xe run

PRELIMINARY









NEXT-100 projected sensitivity

- Target background budget: 5×10^{-4} counts/(keV·kg·yr), or 1 count/(ROI·yr)
  - *Estimated main contributors (preliminary): copper shield, tracking readout connectors, PMT bases*
- Global 0νββ efficiency: 28%
- For a 3-yr exposure and at 90% CL:
  - $T_{1/2} > 6\times10^{25}$ yr
  - $m_{\beta\beta} < 80\text{-}160$ meV

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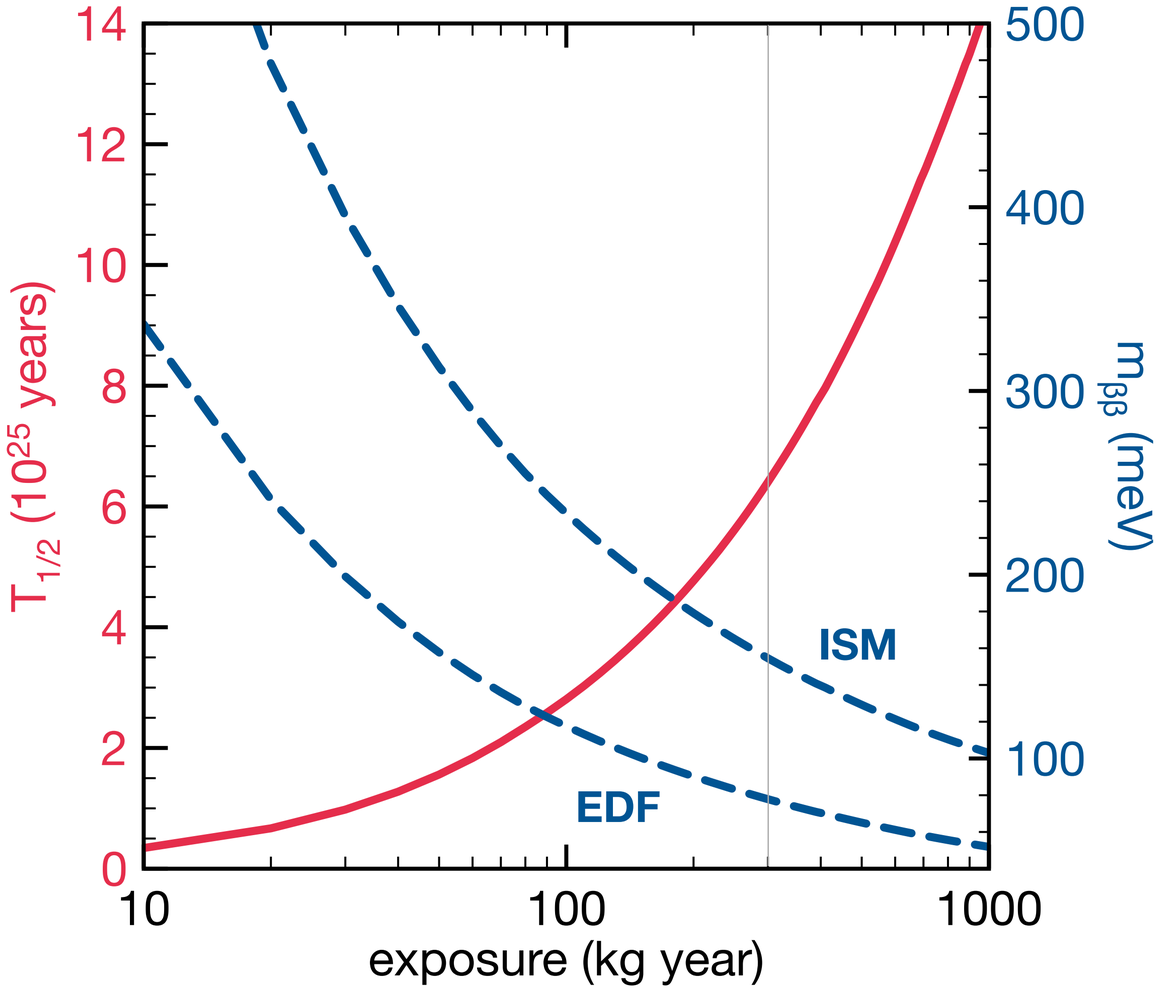


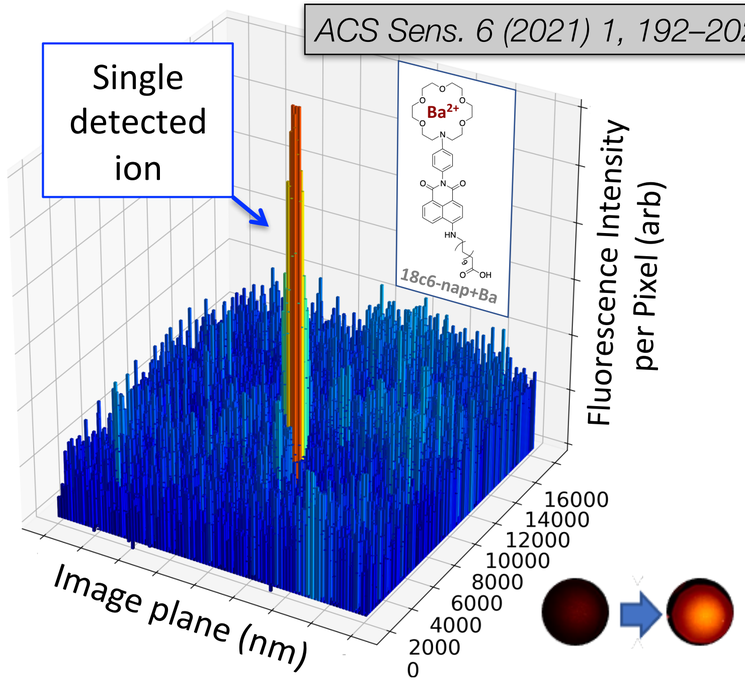
Barium tagging R&D and NEXT-BOLD

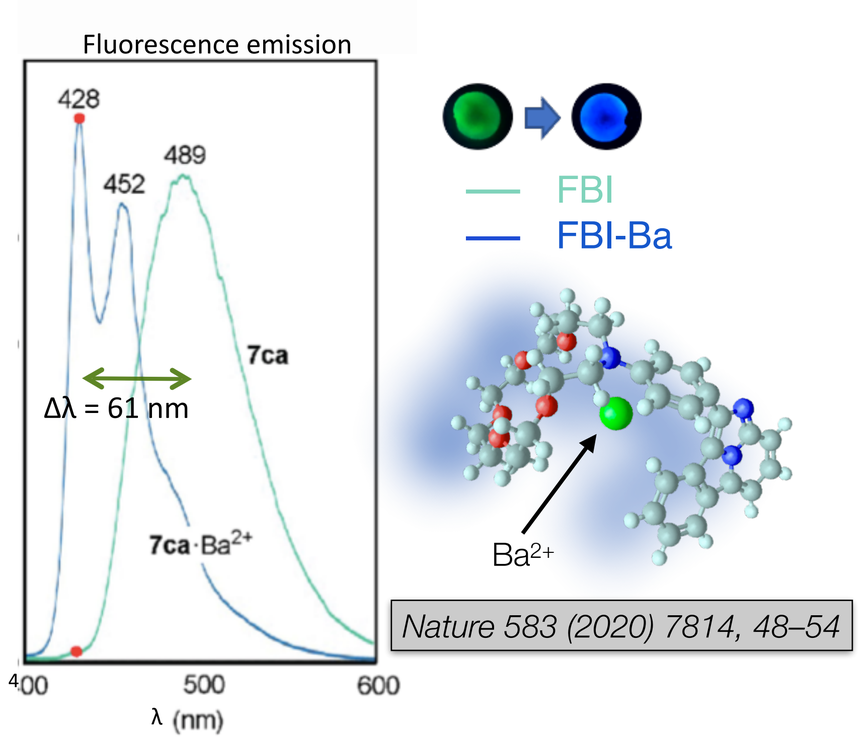
- Idea: single molecule fluorescent imaging to detect Ba^{2+} produced in double beta decay.
- NEXT has developed custom barium chemosensing molecules with demonstrated single ion response in dry environments.
- Two approaches:
  - *Turn-on* 
  - *Bicolor* 

See poster #323, K. Navarro

See poster #51, P. Herrero

ACS Sens. 6 (2021) 1, 192–202





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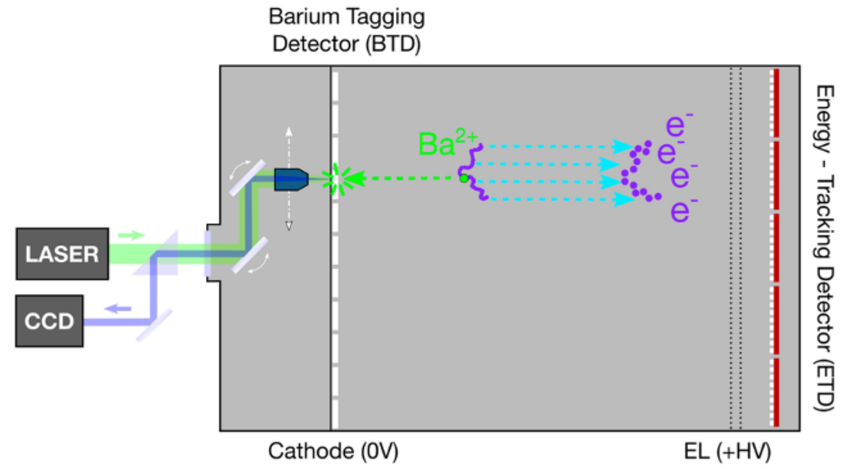
NEXT barium tagging demonstrator phases

- Single ion sensor concepts fairly advanced
- Important R&D remains for ion concentration and collection

Sensor-to-ion (BTD concept)



Ion-to-sensor (CRAB concept)