Other future accelerator experiments

M. Mezzetto, INFN Padova

The talk has been prepared in collaboration with A. Blondel
13 posters related to this argument (mentioned in the slides)
12 projects described in the talk

Thanks to: J. Conrad, F. Terranova, A. Longhin, M. Dracos, T. Ekelof, K. Long, C. Vallee, R. Jacobsson, A. Golutvin, J. Brunner, A. Bross, J. Tang, N. Vassilopoulos

Outline

Alternative configurations for LBL experiments: P2O, Pacific, Chips

Ancillary setups for LBL experiments: Enubet, NuStorm, (Hadroproduction: next talk by A. Marino)

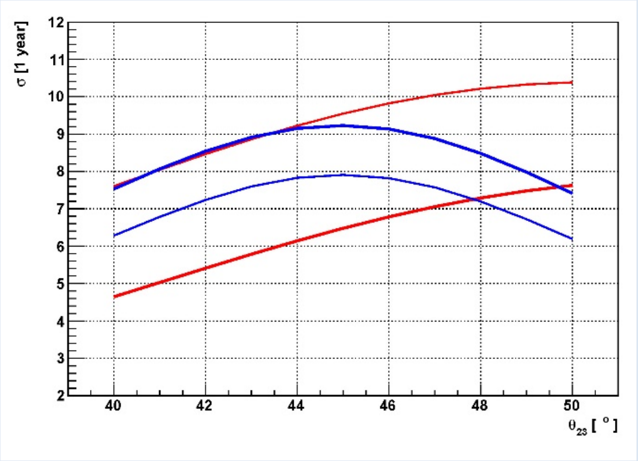
Measurements not covered by LBL experiments: Heavy neutrinos

New concepts for neutrino beams (and their first stages): ESSnuBeam, DAEδALUS (IsoDAR), Nufact (nuSTORM), Moment (EMuS)

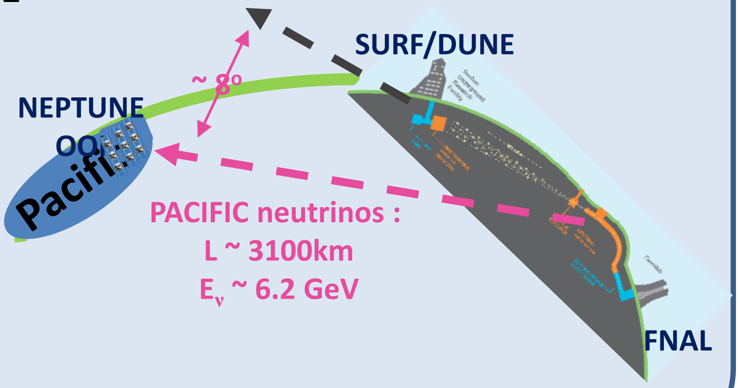
Alternative configurations of LBL experiments

P2O (Adv. High Energy Phys.2013, 782538 (2013)):
Use ORCA as far detector and create a neutrino beam at Protvino (Omega project, 70 GeV, 450 kW).
Baseline: 2590 km.
Excellent sensitivity on MH, mild sensitivity on CP

J. Brunner, Poster #74



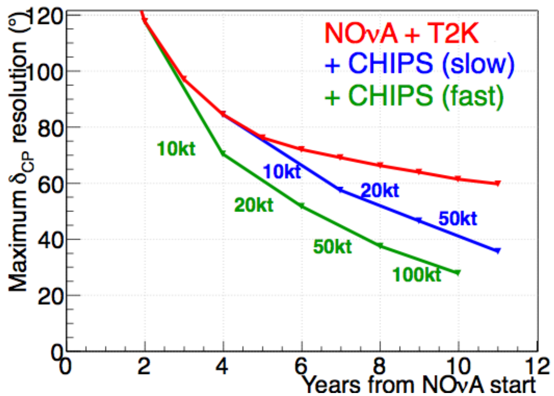
Pacific (arXiv:1610:08655):neutrino beam from FNAL similar to NUMI medium energy tune, fired to a 10 Mton KM3NeT-like detector placed at a baseline of 3100 km (Neptune/OOI deep sea observatories). E_ν ~ 6.2 GeV. It would accumulate 100 more events than Dune for the same number of pot.

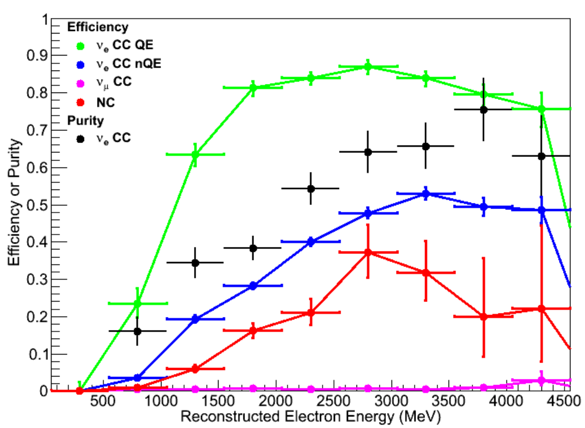


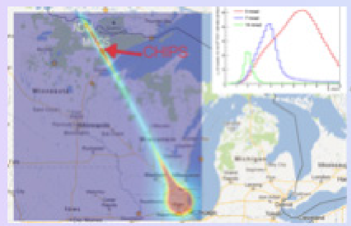
CHIPS(Cherenkov Detectors In mine PitS)

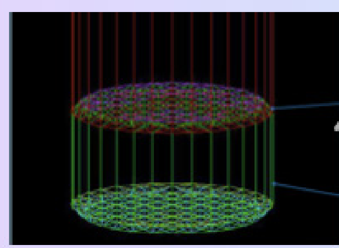
UCL, Nikhef, UW, UMn, U.Alberta, UC. arXiv:1307.5918

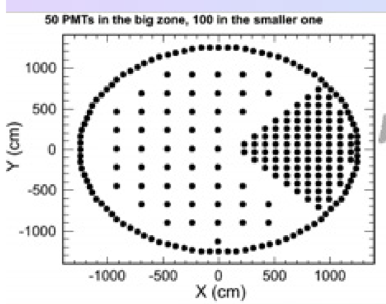
- CHIPS has two goals: to prove that a detector costing **$200-300k/kiloton** is viable for measuring accelerator produced neutrinos
- To contribute to world knowledge of the mixing parameters **$\sin^2 2\theta_{23}$**, **$\sin^2\theta_{13}$** and to **δ_{CP}**, **MH**







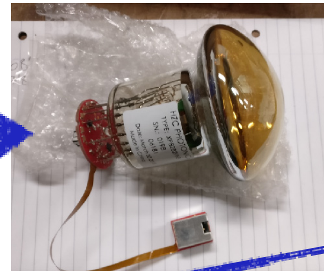


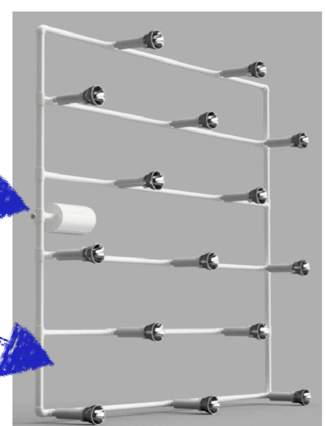


1) **Location**
   sunk in a flooded mine pit in the path of the NuMI neutrino beam, will make use of the water for cosmic overburden and mechanical support;
2) **Structure design**
   will allow it to grow in size with time but with no financial penalty beyond the instrumentation costs
3) **PMT choice and layout**
   3” PMT’s good position and time resolution and beam optimized layout
4) **Electronics**
   will make use of ubiquitous mobile phone and communications technology and already developed KM3Net Solutions
5) **Simple water purification plant**
   will use straightforward filtering to maintain water clarity.

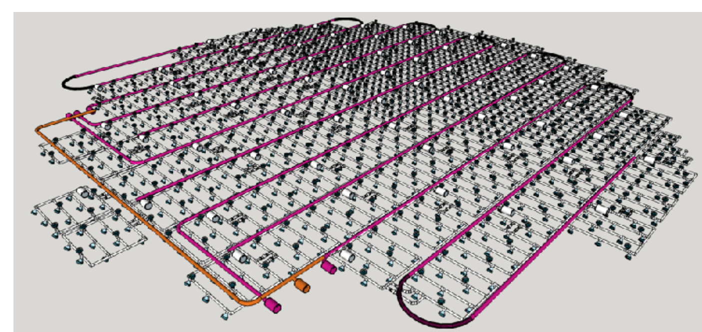
Progress and Status

- **Downstream part of detector will use**
  - 5500 HCZ 80mm XP82B2FN PMTs
  - Km3Net electronics
  - Light cones for improved light collection
- **Upstream wall will use donated**
  - PMTs (NEMO-III)
  - Madison designed electronics
    - +ve HV CW
    - microprocessor on each PMT for TOT
    - Beaglebone single board computer
- **Detector planes made from standard PVC fittings**
- **Cables inside and dry!**





- **5 kiloton detector will be deployed this summer**
- **Procurement and production on-going**
- **Goal to have data in October 2018**



Heavy neutrinos searches

Some bibliography

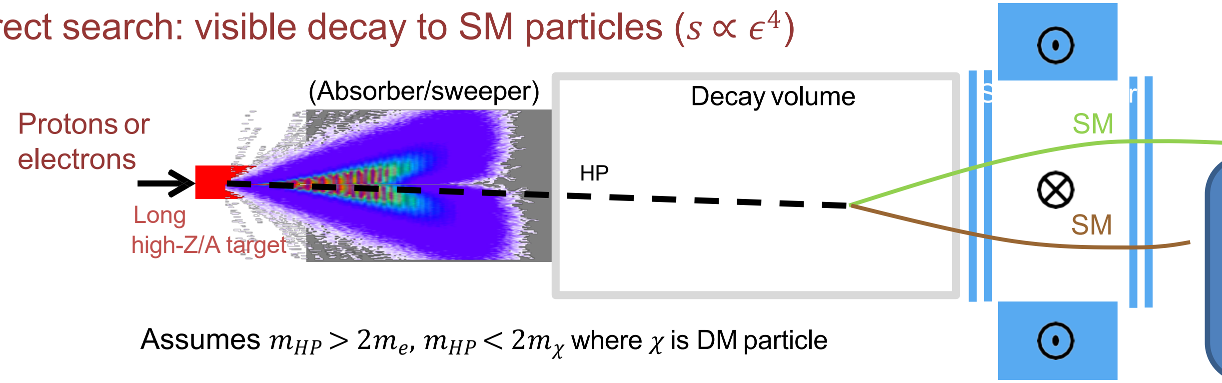
- SHiP Physics Paper: Rep.Progr.Phys.79(2016) 124201 (137pp),
- SLAC Dark Sector Workshop 2016: Community Report – arXiv: 1608.08632,
- Maryland Dark Sector Workshop 2017: Cosmic Visions – arXiv:1707.04591

M. Lamoureux, Poster # 43 (Search for heavy neutrinos in T2K)

O. Fischer, Poster # 91 (Sterile Neutrinos at the FCC)

Experimental techniques

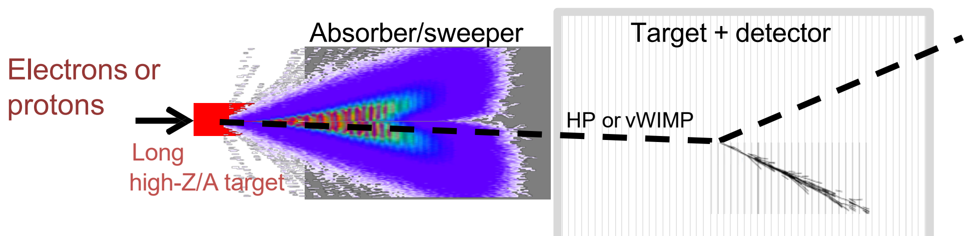
- Direct search: visible decay to SM particles ($s \propto \epsilon^4$)



Assumes $m_{HP} > 2m_e$, $m_{HP} < 2m_\chi$ where χ is DM particle

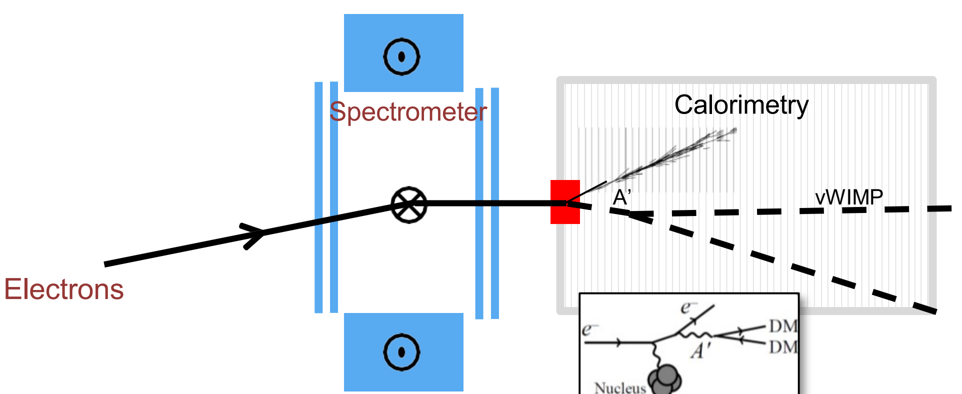
NA62++@CERN (p@400, 10^{18})
HPS, APEX, DarkLight@JLAB (e@1-10)
SHiP@CERN (p@400, 2×10^{20}),
SeaQuest@FNAL (p@120, 10^{18}–10^{20})
(LBNF@FNAL)

- Direct search: Scattering off atomic electrons and nuclei ($s \propto \epsilon^4$)



BDX@JLAB (e@11, 10^{22}),
MiniBooNE@FNAL (p@8.9, 10^{20}),
SHiP@CERN (p@400, 2×10^{20})
PADME (LNF)
(interest for BDX-like experiments at Mainz (MESA), SLAC, Cornell…)

- Indirect search: Missing mass/energy ($s \propto \epsilon^2$)



NA64@CERN (e@100, 10^{12}),
LDMX@SLAC (e@10, 10^{16})

➔ *Operating with electrons assumes vector portal*

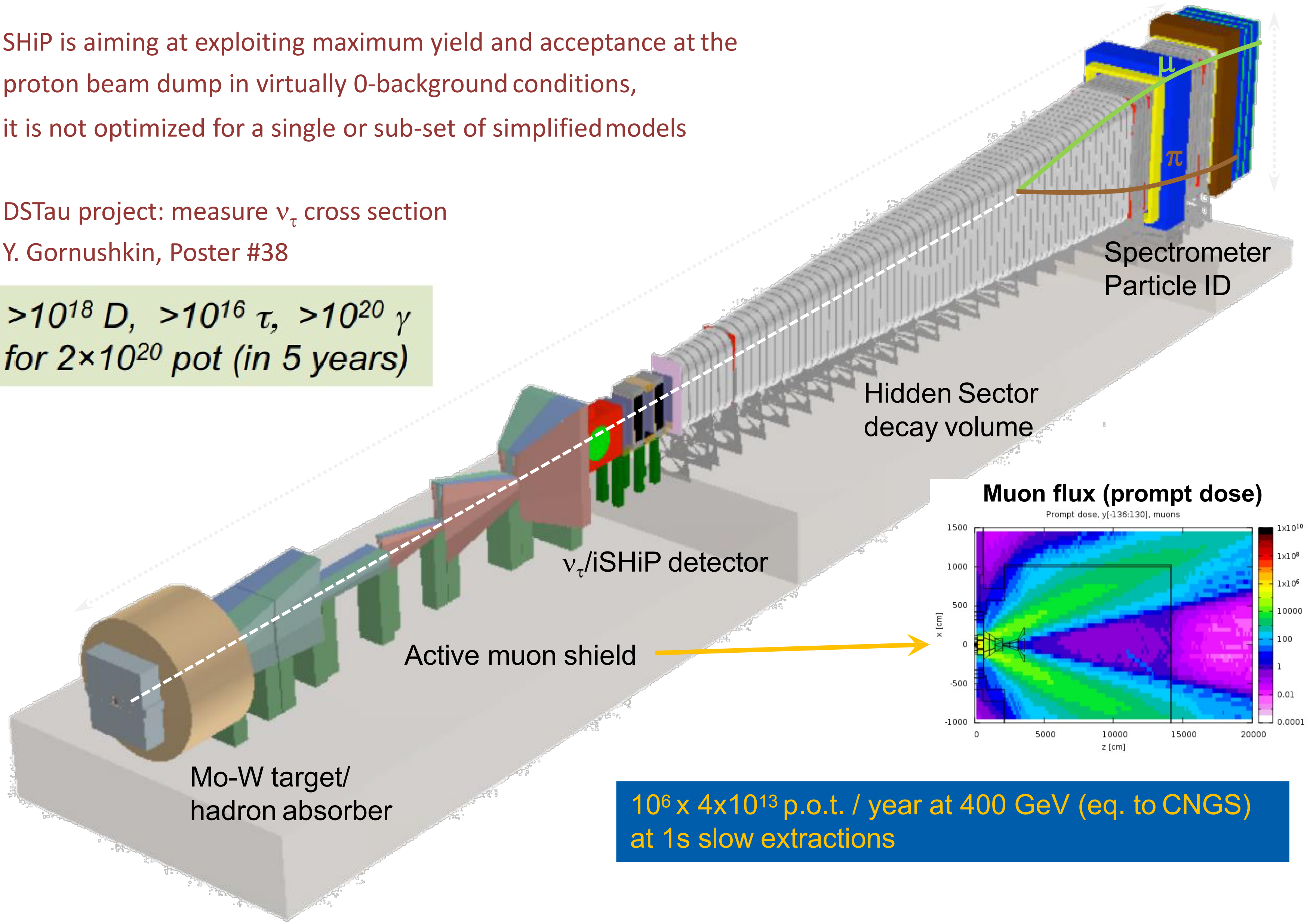
Courtesy of R. Jacobsson

Ship Experiment

SHiP is aiming at exploiting maximum yield and acceptance at the proton beam dump in virtually 0-background conditions,
it is not optimized for a single or sub-set of simplified models

DSTau project: measure ν_τ cross section
Y. Gornushkin, Poster #38

*$>10^{18}$ D, $>10^{16}$ τ, $>10^{20}$ γ
for 2×10^{20} pot (in 5 years)*

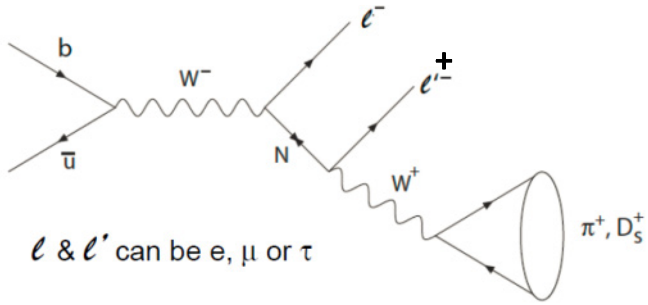


10^6 x 4×10^{13} p.o.t. / year at 400 GeV (eq. to CNGS)
at 1s slow extractions

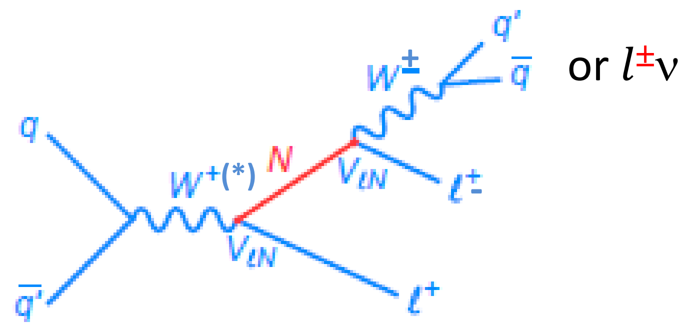
Search for heavy right-handed neutrinos in collider experiments.

Phys. Rev. D 92, 075002 (2015)

B factories

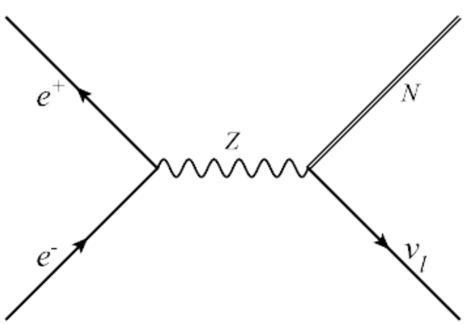


Hadron colliders

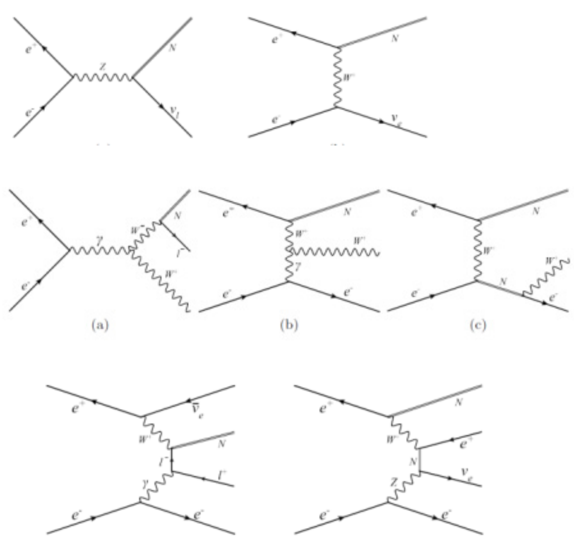


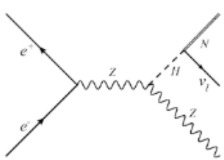
Z factory (FCC-ee, Tera-Z)

arXiv:1411.5230

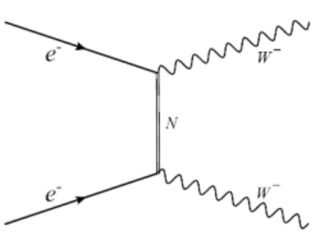


HE Lepton Collider (LEP2, CEPC, CLIC, FCC-ee, ILC, μμ)



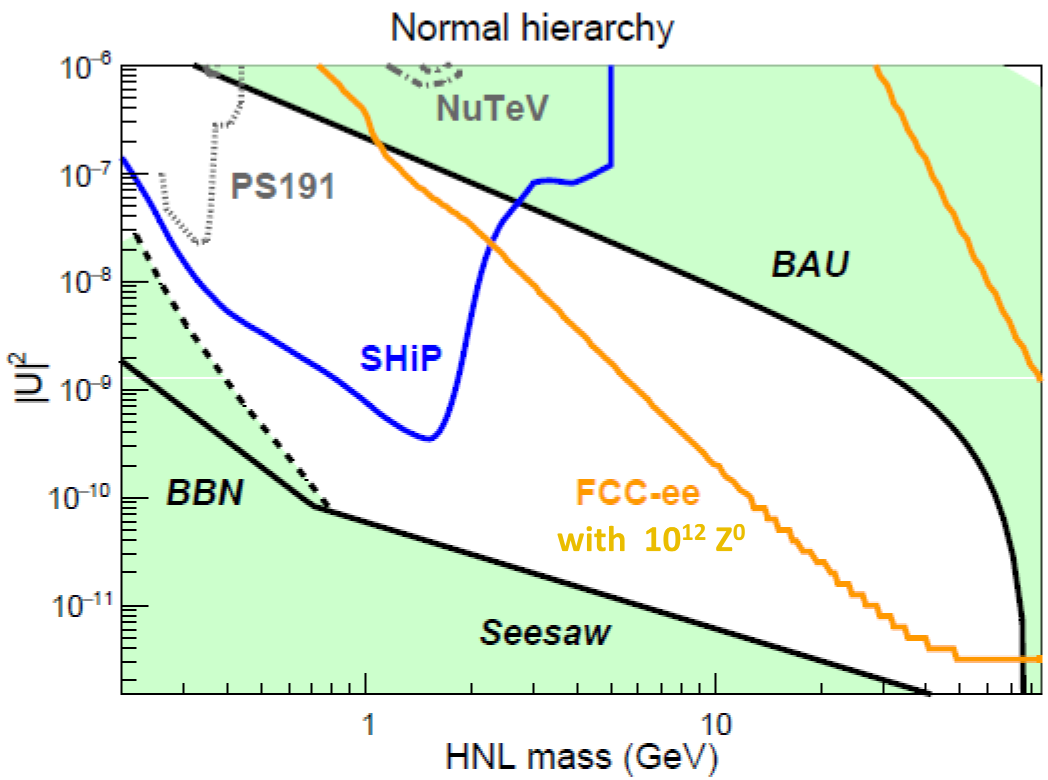


E. $e^-e^- \to W^-W^-$



Physics reach in the HNL parameter space

E. Graverini, arXiv:1611.07215



(a) Decay length 500 μm to 2 m

Neutrino beams for precision physics: the ERC ENUBET Project

Enhanced **Ne**U**t**rino **BE**ams from kaon **T**agging

ERC-CoG-2015,
G.A. 681647 (2016-21)
A. Longhin, INFN

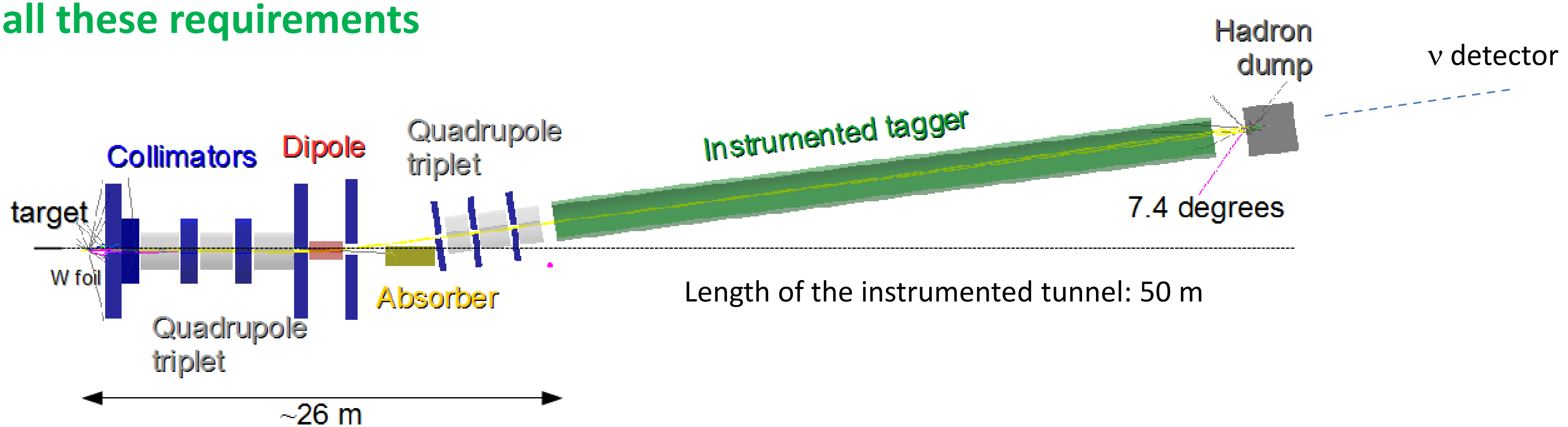
CERN-EoI: 41 physicists, 10 institutions:
CERN, IN2P3 (Bordeaux), INR, INFN (Bari, Bologna, Insubria, Milano-Bicocca, Napoli, Padova, Roma-I)

+ NUTECH funding from the Italian Min. of Research (MIUR)

The next generation of short baseline experiments for cross-section measurement and for precision ν physics at short baseline (e.g. sterile neutrinos and NSI) should rely on:

- ✓ a high precision, **direct measurement of the fluxes**
- ✓ a beam covering the region of interest **from sub- to multi-GeV**
- ✓ a narrow band beam where **the energy is known a priori** from the beam width

the ENUBET facility fulfills simultaneously all these requirements



Reference parameters: **100 m baseline, 500 t detector** (e.g. ICARUS@FNAL or Protodune-SP/DP@CERN)

End-to-end simulation of the ENUBET beamline

see G. Brunetti, Poster Wall #84

Flux and rates at the far detector:

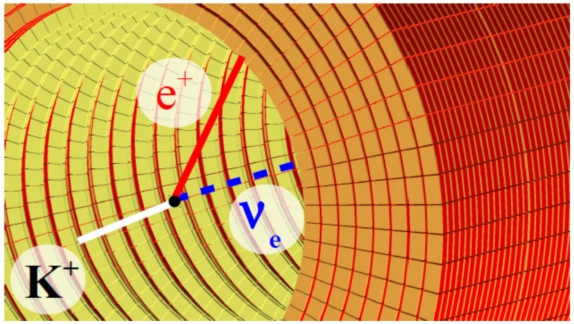
focusing system	π+/pot (10^{-3})	K+/pot (10^{-3})	increase w.r.t. the ENUBET proposal (*)
horn	77.3	7.9	2.2
static focusing system	19.0	1.37	5.2 (π), 3.2 (K)

Rates at the far detector: O(10^4) ν_e CC events, O(10^6) ν_μ CC events in about 1 year of data taking at CERN SPS (400 GeV protons) even **without the horn**

Static system: slow extraction (2 s, ~ 3 10^{13} pot/spill), strong reduction of rates in the instrumented decay tunnel, pave the way to the "tagged neutrino beams"

Flux monitoring:

kaon yield (main source of ν_e in ENUBET)
pion yield: conventional techniques + constraints from kaons



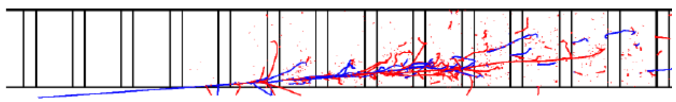
$K^+ \rightarrow \pi^0 e^+ \nu_e$

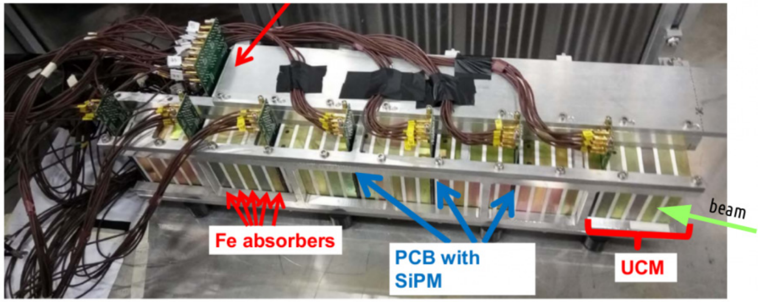
(*) A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155

Particle identification in the decay tunnel

$e^+/\pi^+/\mu$ separation

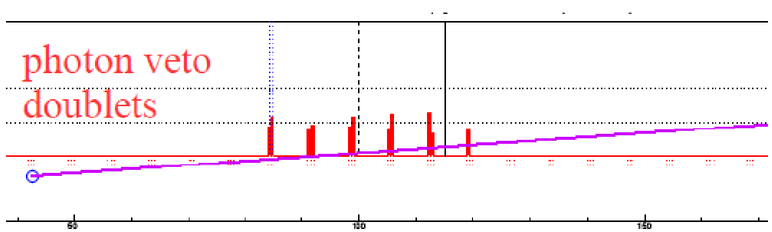
(1) Compact shashlik calorimeter (3x3x10 cm^2 Fe+scint. modules + energy catcher) with longitudinal (4 X_0) segmentation and SiPM embedded in the bulk of the calorimeter





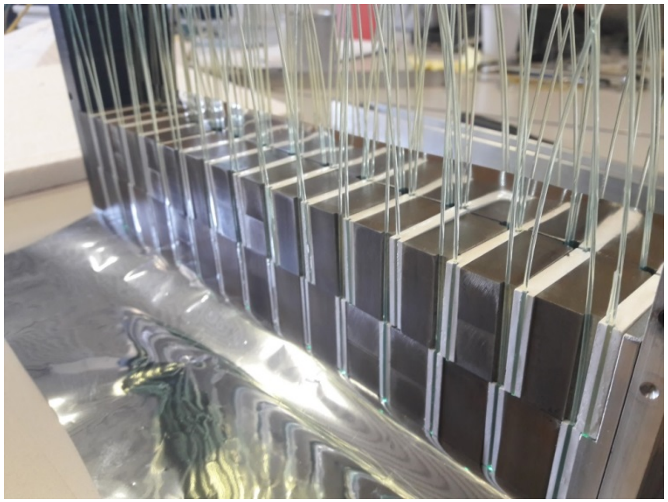
e^+/γ separation

(2) Rings of 3 x 3 cm^2 pads of plastic scintillator



G. Ballerini et al., JINST 13 (2018) P01028

A. Coffani et al., arXiv:1801.06167

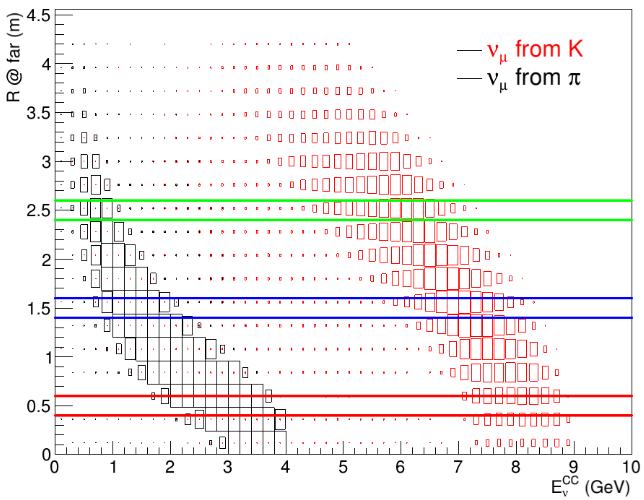


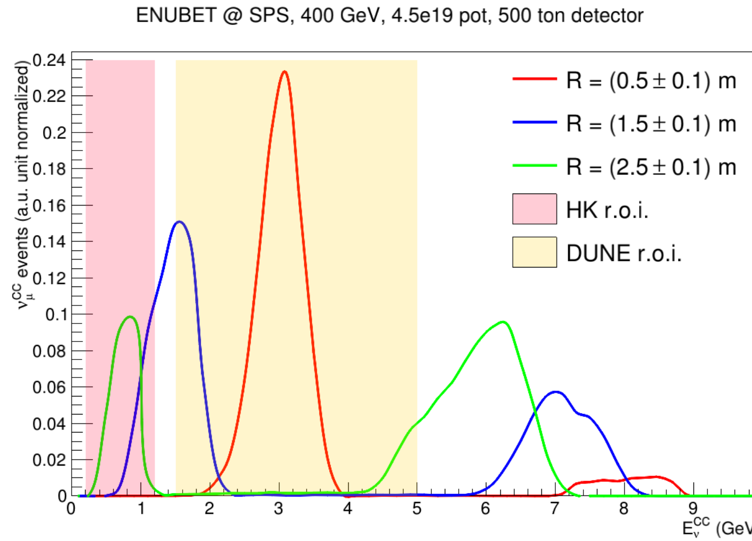
Tested in 2017-2018:

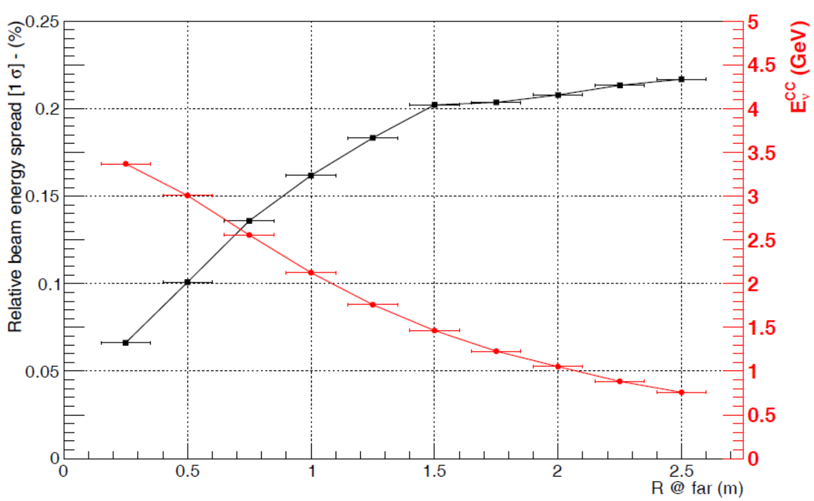
- ✓ Both calorimeter options (shashlik and lateral readout)
- ✓ Photon veto
- ✓ Radiation hardness up to nominal ENUBET doses (both ionizing and non-ionizing)

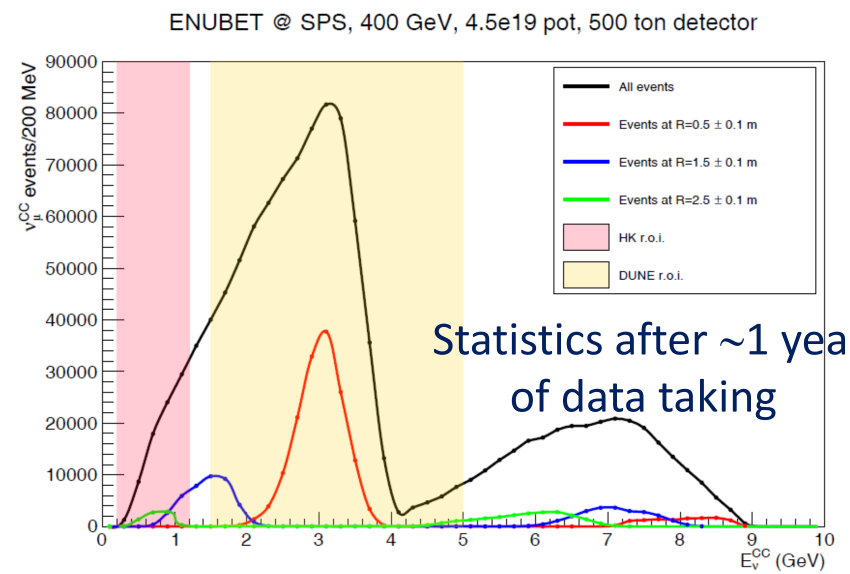
ν_μ CC events at the ENUBET narrow band beam

The neutrino energy is a function of the distance of the neutrino vertex from the beam axis (R). The beam width at fixed R (≡ neutrino energy resolution at source) is 8-22%









New concepts in neutrino beams

Few well known considerations

The high value of θ_{13} made possible to design powerful setups to look for leptonic CP violation based on conventional neutrino beams.

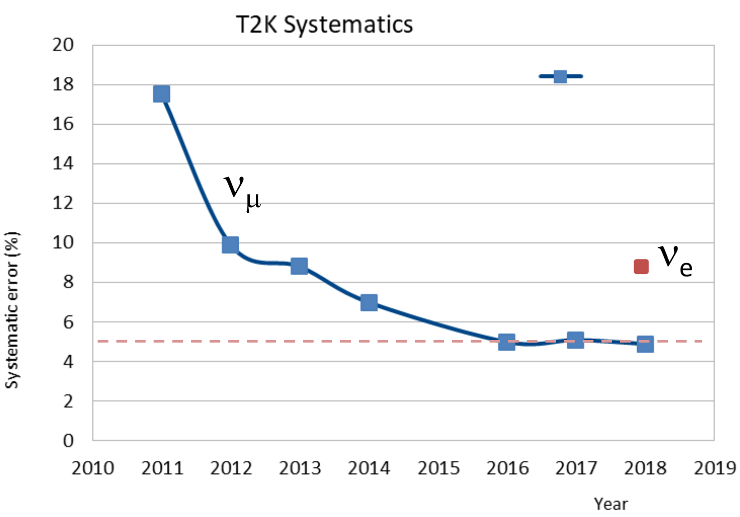
Conventional neutrino beams have severe limitations:

- Intrinsic ν_e contamination
- Neutrino parents are secondary particles and their production is not entirely described (next talk)
- The strong correlation among flux and cross section uncertainty makes very difficult to keep systematic errors below 4-5%

Solutions:

- Short term(*): Better and better close detectors, hadroproduction and ancillary experiments
- Long term: New concepts in neutrino beams, where neutrino parents are under control and intrinsic backgrounds smaller

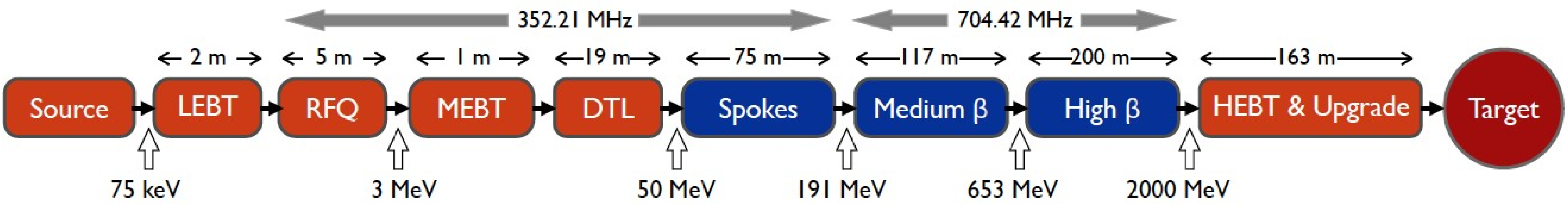
(*) In neutrino physics metrics short term could be 20 years …



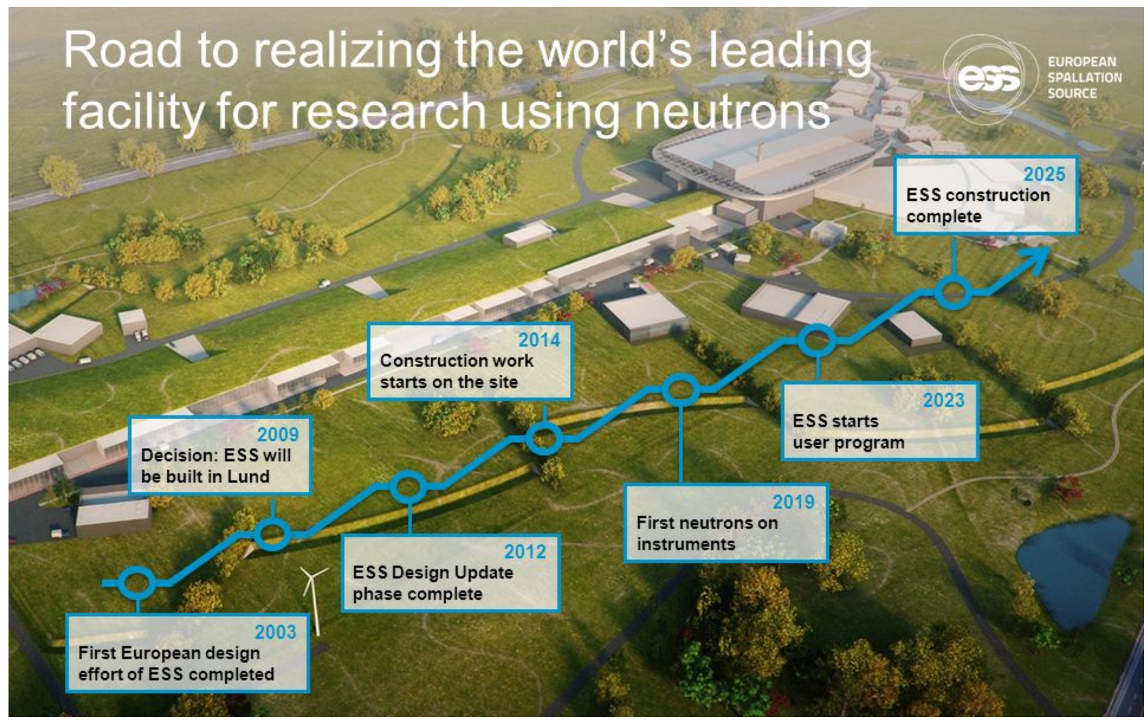
New concepts for ν beams

- More powerful proton driver, breaking the MW wall: ESSnuSB
- Different concepts:
  - π-DAR neutrinos: DAEδALUS (first stage: IsoDAR)
  - Neutrinos from muon decays: Nufact (first stage: nuSTORM) and Moment (first stage: EMuS)
  - Not discussed here: pure ν_e ($\bar{\nu}_e$) beams from accelerated radioactive ions: Beta Beams (but see O.Titov, Poster #118)

The European Spallation Source Linac



- The ESS will be a copious source of spallation neutrons.
- **5 MW** average beam power.
- 125 MW peak power.
- 14 Hz repetition rate (2.86 ms pulse duration, 10^{15} protons).
- Duty cycle 4%.
- 2.0 GeV protons
  - up to 3.5 GeV with linac upgrades
- **>2.7x10^{23} p.o.t/year.**



How to add a neutrino beam line to ESS: ESSnuSB

ESSnuSB Design Study funded by H2020: 23 sites, 15 European countries

M. Dracos, Poster # 39

The neutron program must not be affected modifications.

Linac: double the pulse rate (14 Hz→ 28 Hz), from 4% duty cycle to 8%.

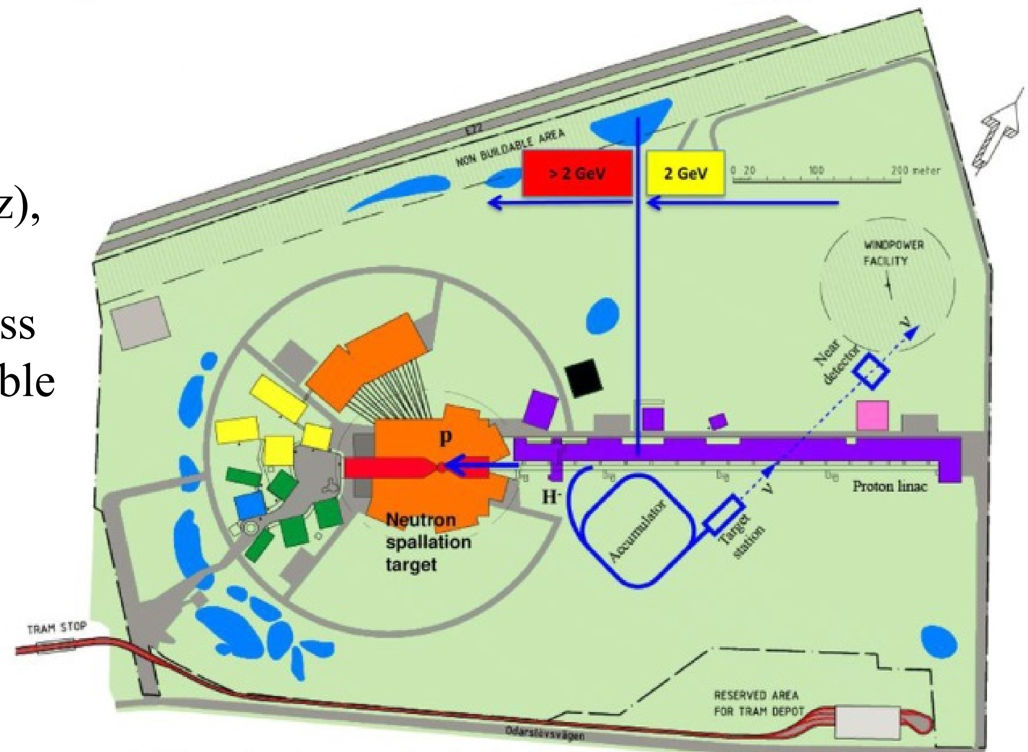
Accumulator (C~400 m) needed to compress to few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA)

- H^- source (instead of protons),
- space charge problems in the accumulator ring to be solved.

Target station (studied in EUROν).

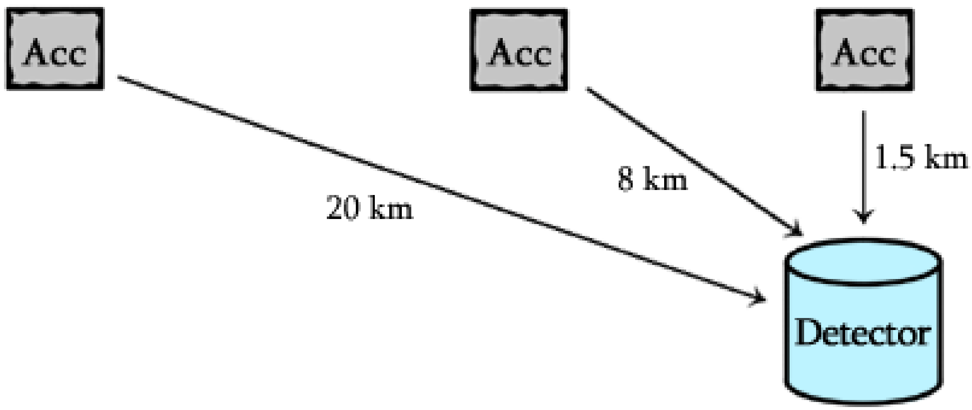
Underground detector (WC à la Hyper-K studied in LAGUNA).

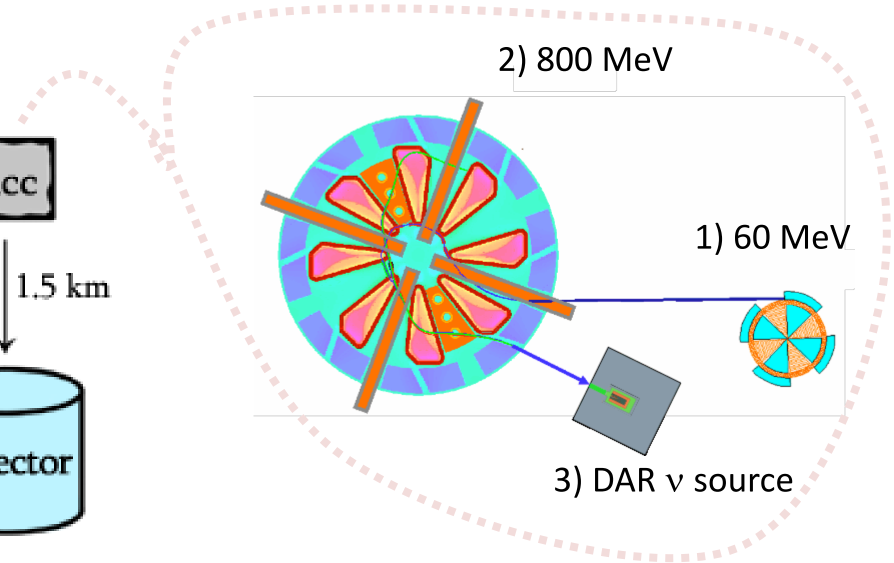
Short pulses (~μs) will also allow DAR experiments (as those proposed for SNS) using the neutron target.



~1 BEuros for the neutrino facility including detector

The DAEδALUS concept





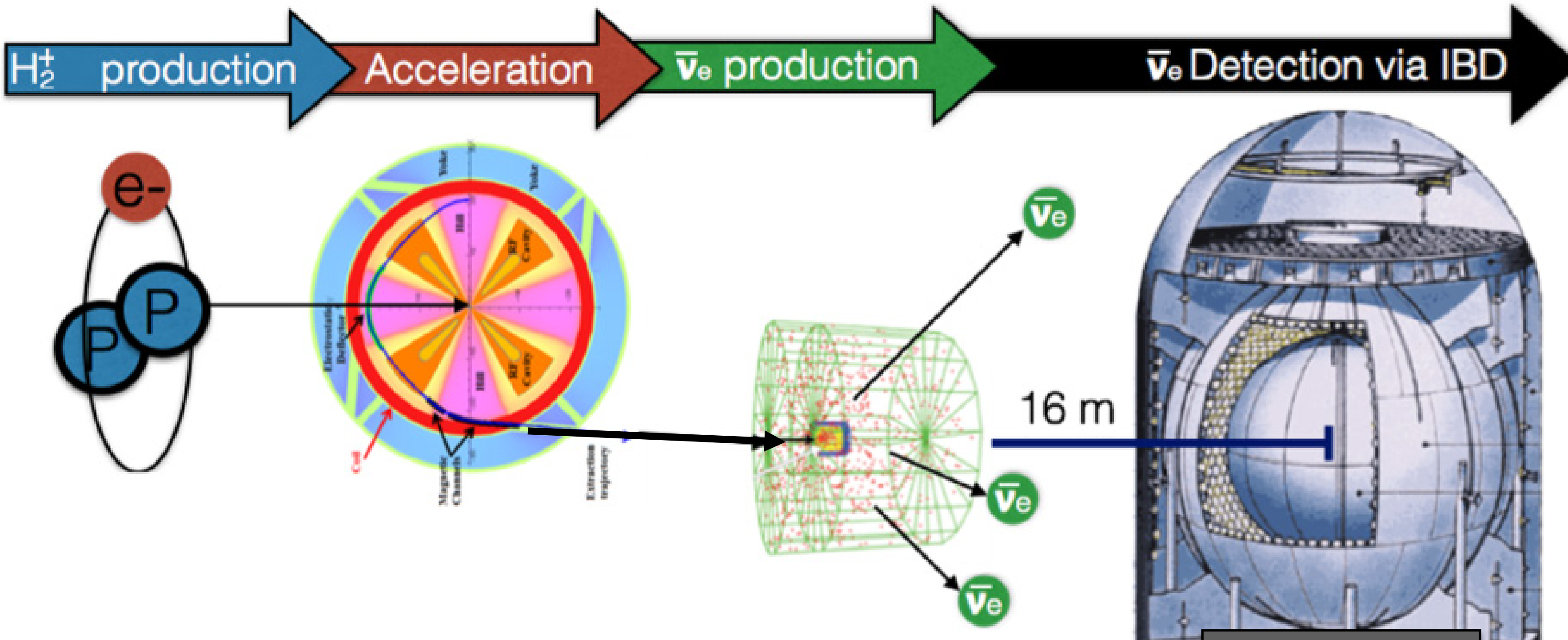
- π-DAR neutrino beams are free from $\bar{\nu}_e$
- Powerful searches for CP violation can be performed looking for $\bar{\nu}_\mu$-$\bar{\nu}_e$ oscillations at different distances …
- … requiring LS or GD-doped WC detectors
- First stage of DAEδALUS is IsoDAR

Principle operation of IsoDAR

IsoDAR
@KamLAND

S. Axani, Poster # 127

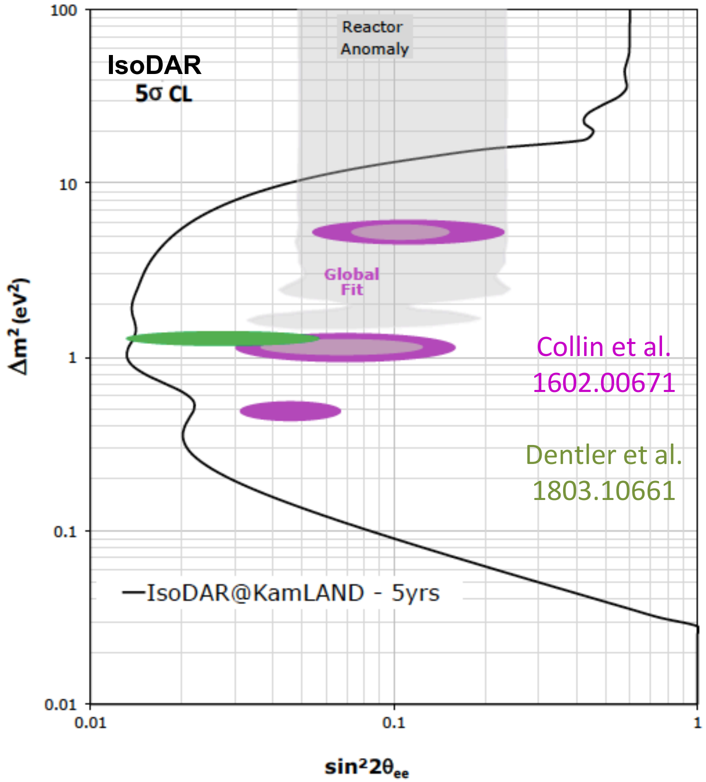
The IsoDAR (Isotope Decay-A-Rest) experiment is a high-intensity neutrino factory paired with a kiloton scale detector, that is able to make a **definitive statement about the existence of light sterile neutrinos**.



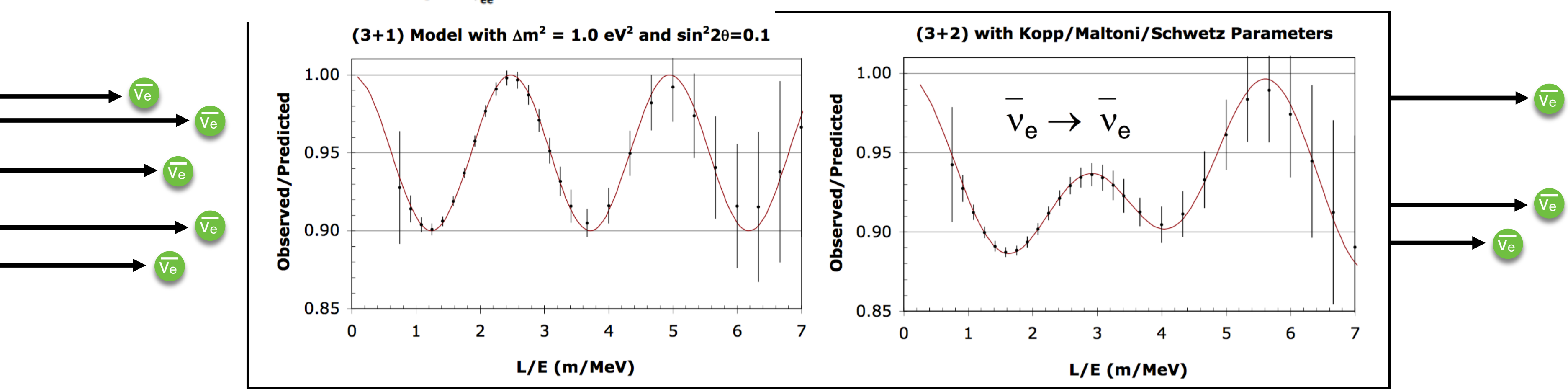
1. Produce and inject H_2^+ into a compact cyclotron.
2. Accelerate and extract 5 mA of H_2^+ at 60 MeV/amu.
3. Impinge H_2^+ on a ^{9}Be target to produce neutrons
4. Capture neutrons : $^7\text{Li}+n \rightarrow {}^8\text{Li} \rightarrow {}^8\text{Be} + e^- + \bar{\nu}_e$
5. Measure the $\bar{\nu}_e$ disappearance via IBD within a kiloton scale detector like KamLAND.

Expected sensitivity of IsoDAR

IsoDAR @KamLAND



- Probe the 3+1 global allowed region:
  - 5σ in 4 months
- Distinguish between different sterile models.
  - 3+1 versus 3+2
  - sterile neutrino decay
- Collect the worlds largest sample of low energy $\bar{\nu}_e$ - e^- elastic scattering events.
- IsoDAR makes innovations in:
  - High current cyclotrons
  - Axial injection into cyclotrons
  - Ion source development
  - Medical isotope production



Progress on the Design

IsoDAR @KamLAND

Two Conceptual Design Reports available:

The neutrino source design (accelerator and target): https://arxiv.org/abs/1511.05130

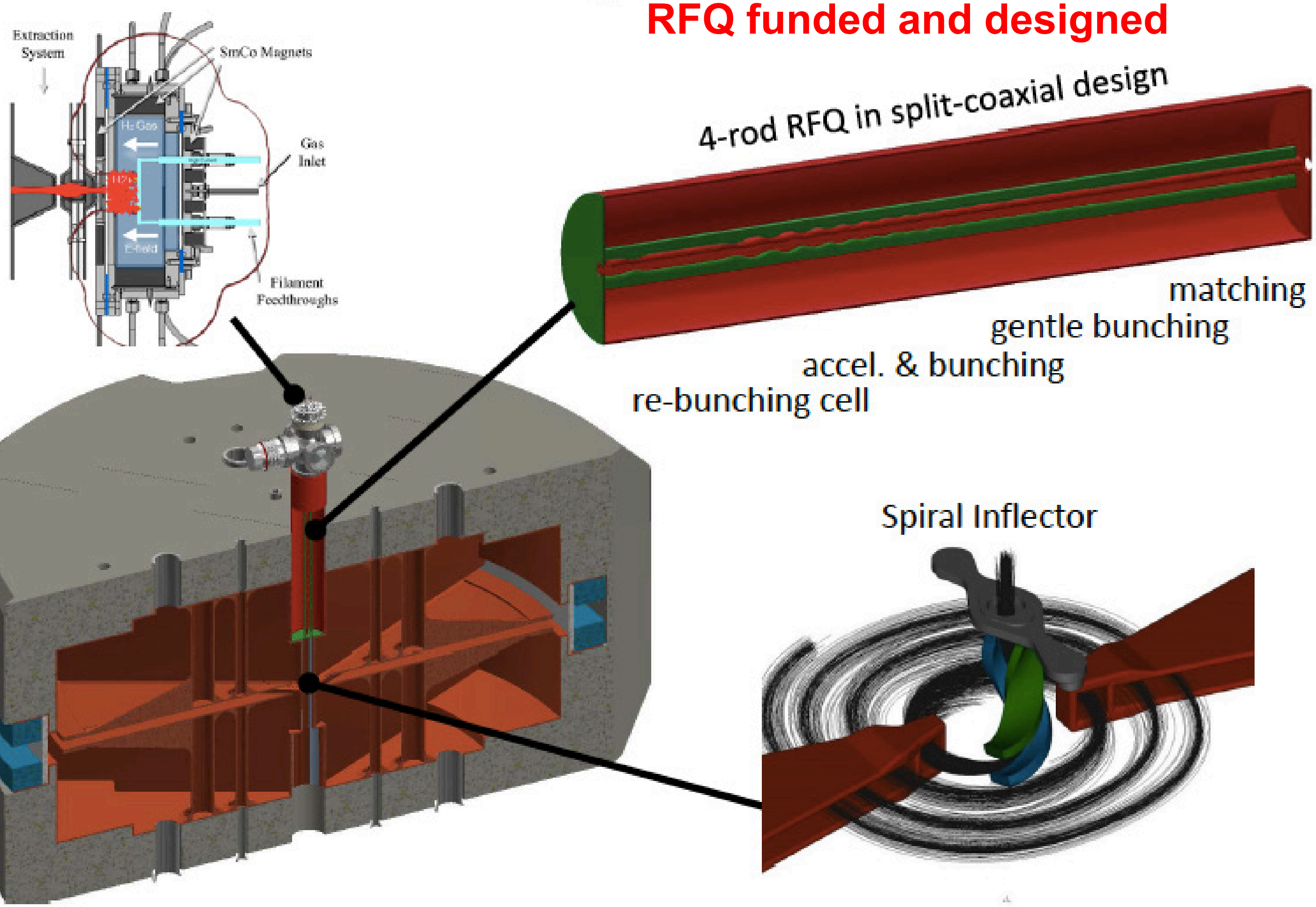
The facility design at KamLAND: https://arxiv.org/abs/1710.09325

Accelerator:

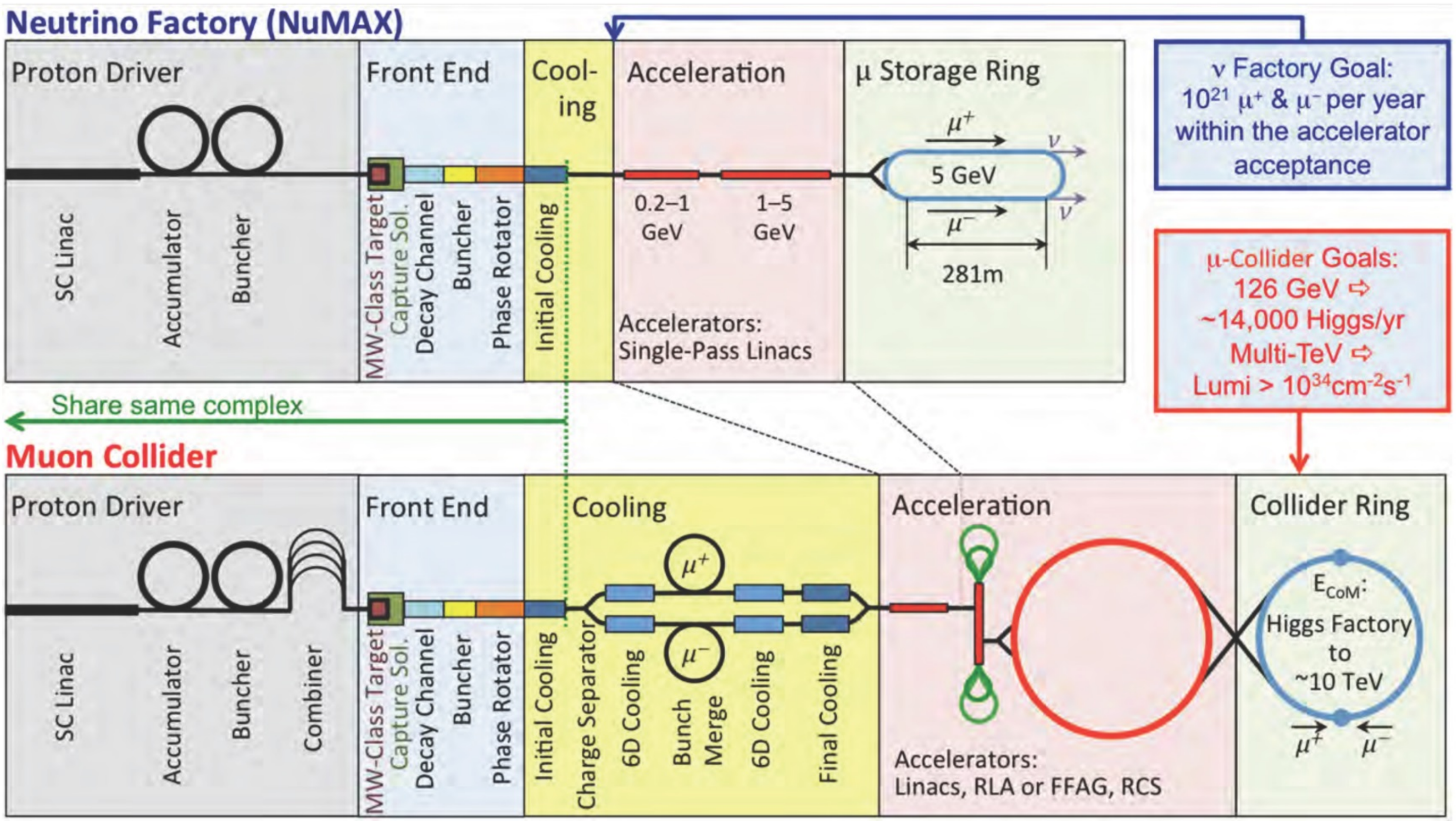
Ion source constructed

RFQ funded and designed

Cyclotron design **well underway** by **MIT,** AIMA, **IBA,** INFN, **PSI**



Neutrino Factory

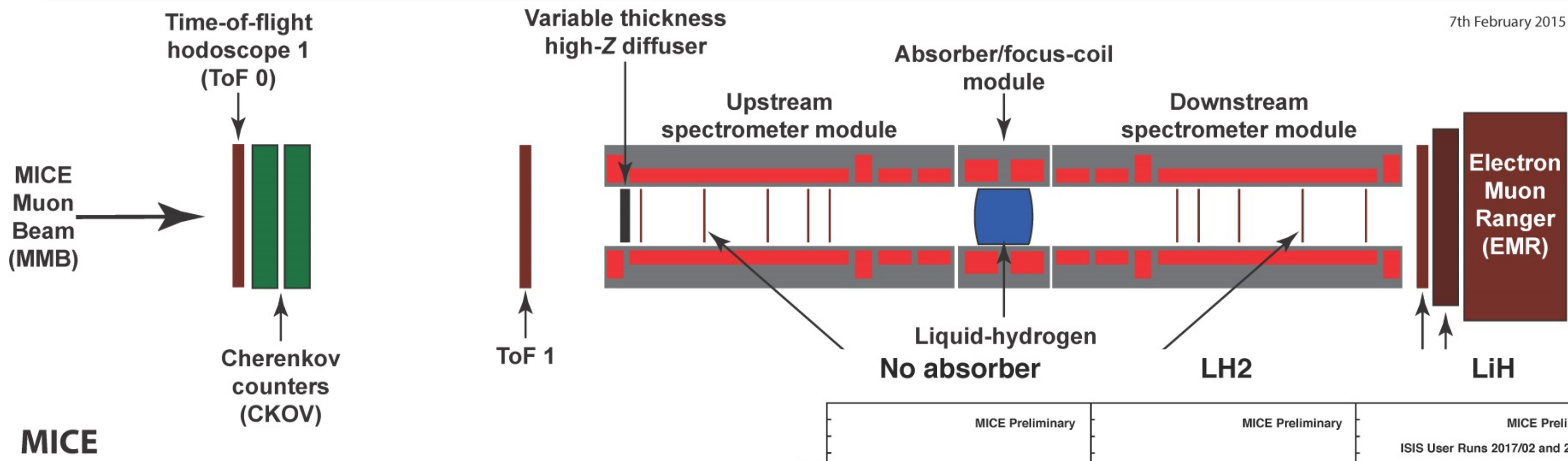


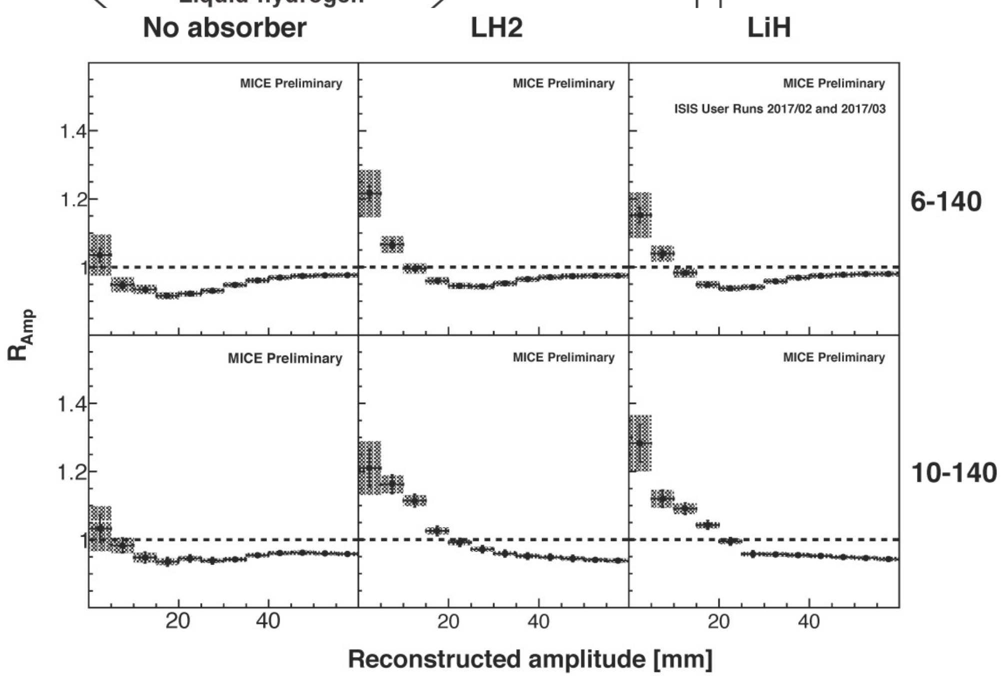
- ν parents (μ) have all the same energy, same direction and are well counted
- ν beam known at % level (before any close detector constrain)
- Signal events are wrong sign muons
- The first stage of a Muon Collider …
- … but still very expensive (and challenging)

FIRST DEMONSTRATION OF IONIZATION COOLING IN MICE

C. White, Poster #59; F. Drielsma, Poster #64; A. Young Poster #61; S. Boyd, Poster #62

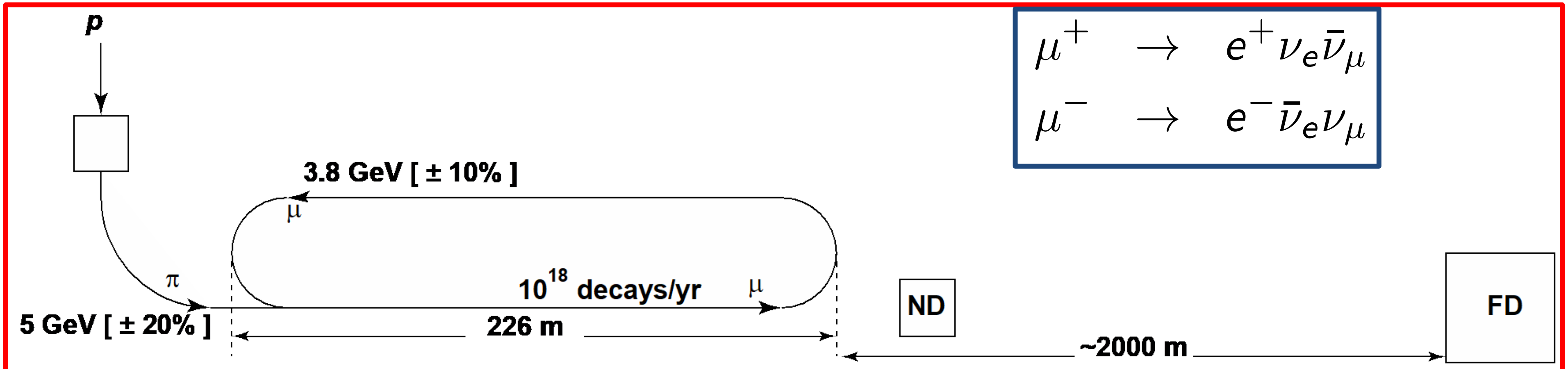
MICE is a single particle experiment where single muons are selected upstream of the absorber and formed into ensembles to represent a muon beam.





$R_{AMP}>1$ indicates cooling.

Neutrinos from stored muons



$$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$$
$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

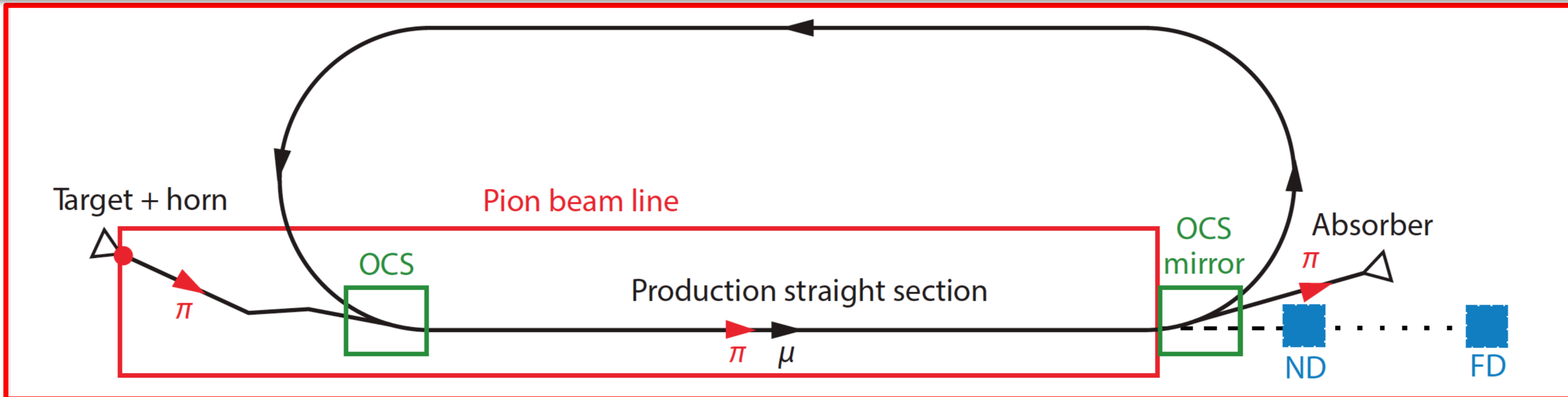
Fast extraction at >~ 100 GeV

Conventional pion production and capture (horn)
Quadrupole pion-transport channel to decay ring

1. %-level ($\nu_e N$)cross sections
   - *Double differential*
2. Sterile neutrino search
   - *Beyond Fermilab SBN*

- **Precise neutrino flux:**
  - **Normalisation: < 1%**
  - **Energy (and flavour) precise**
- **π → μ injection pass:**
  - **"Flash" of muon neutrinos**

CCQE measurement at nuSTORM

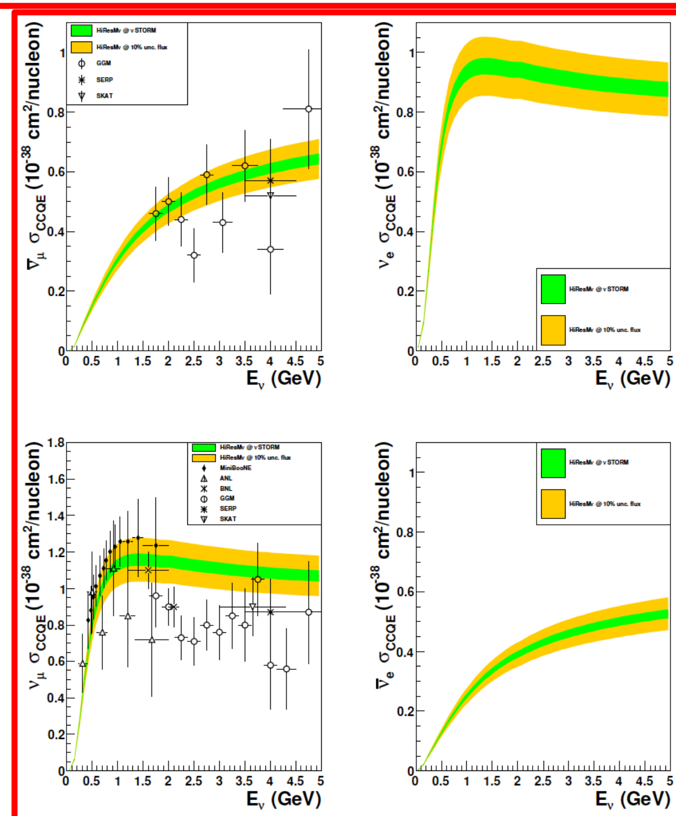


10.1103/PhysRevD.89.071301; arXiv:1305.1419

CCQE at nuSTORM:

- Six-fold improvement in systematic uncertainty compared with “state of the art”
- Electron-neutrino cross section measurement **unique**

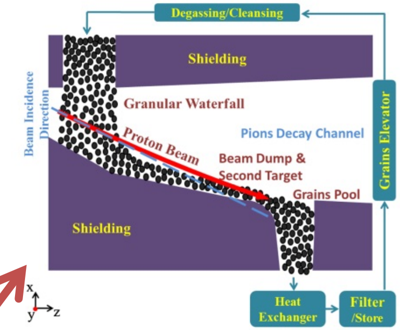
- Require to demonstrate: ~<1% precision on flux

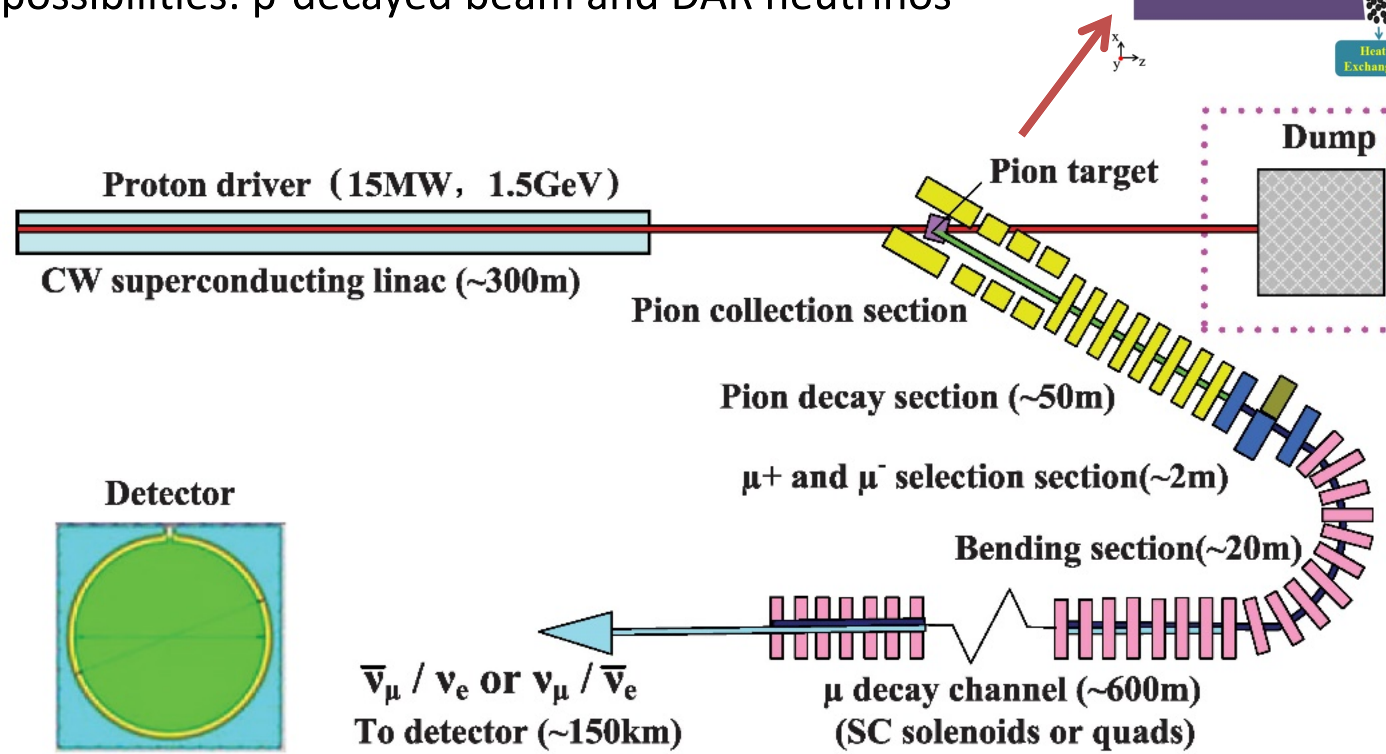


Individual ν_e measurements from T2K and MINERvA [10.1103/PhysRevLett.113.241803, 10.1103/PhysRevLett.116.081802]

Moment (China)

- Concept: fire Juno with an accelerator neutrino beam
- Use a CW proton Linac: 15 MW, 1.5 GeV
- Derived from China-ADS Linac development
- Fluidized target in high-field SC solenoid
- Muon transport and decay channel
- Other possibilities: p-decayed beam and DAR neutrinos





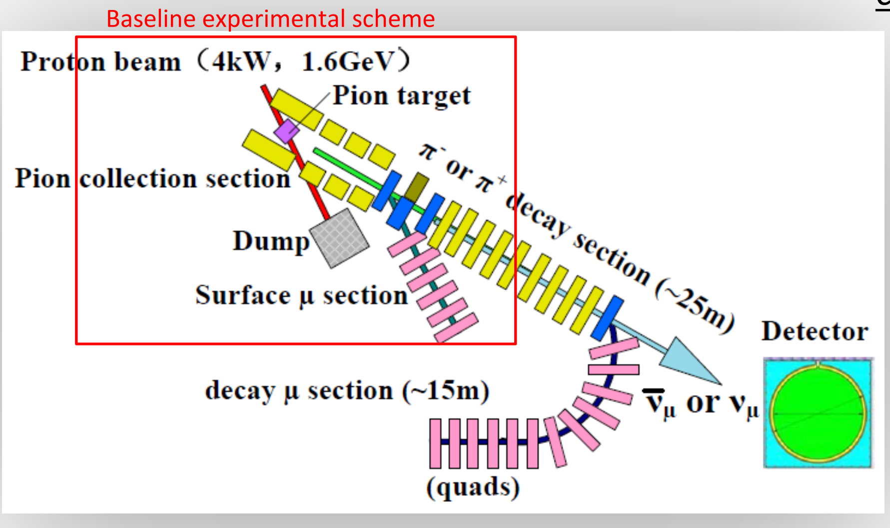
First stage of Moment: EMuS

Poster #46 by N. Vassilopoulos

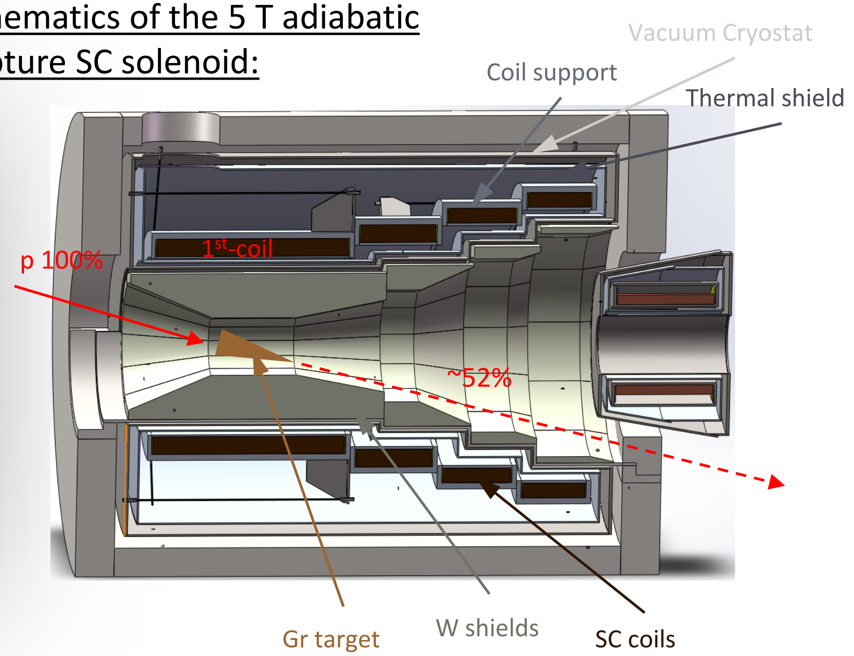
Description
- The experimental muon source project EMuS is foreseen at China Spallation Neutron Source and is being optimized for both muon and neutrino experiments
- It is primarily intended for muon science as µSR techniques in matter physics and chemistry while its neutrino beam is an option for cross section measurements if valuable
- Staged and cost-conscious design approach

Motivations
- lack of recent cross section measurements at lower energies
- R&D platform for MOMENT, a future muon-decay medium-baseline neutrino beam facility in China
  - EMuS as high power targetry and accelerator R&D platform

EMuS full scheme:



Schematics of the 5 T adiabatic capture SC solenoid:



Conclusions

- DUNE and Hyper-K are the first priority for the future of accelerator neutrino physics and must be pursued with the maximum support
- Any possibility of optimization should anyway be studied with great attention
- And other topics in neutrino physics exist that require different accelerator experiments to be addressed
- In the long term (neutrino physics has always been an exercise of patience) new concepts in neutrino beams will become necessary. It is important that the R&D is kept alive and first stage experiments are welcome.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 777419

Additional slides

Target and Sleeve:

New result on arXiv:

arXiv.org > physics > arXiv:1805.00410

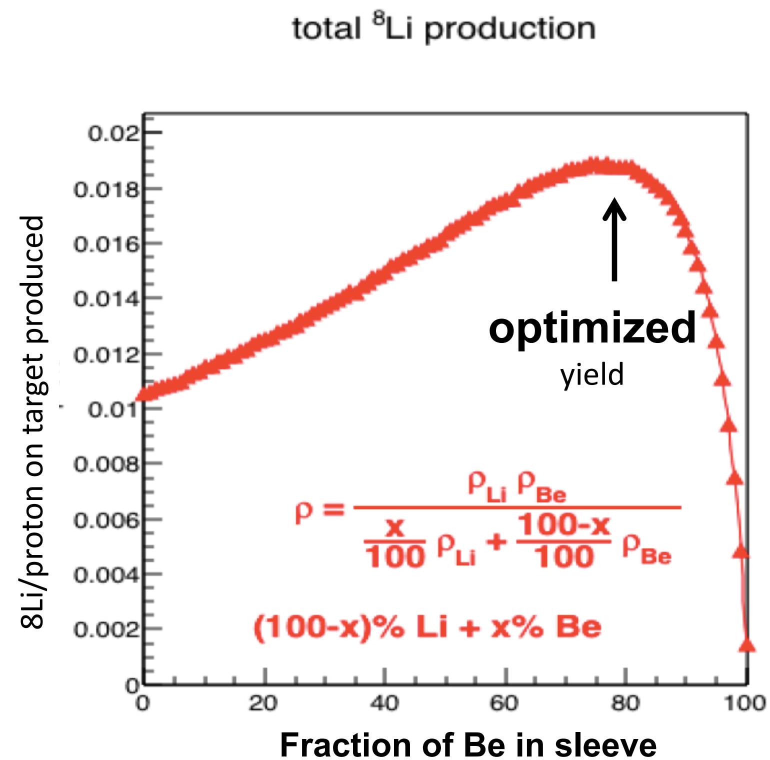
Physics > Instrumentation and Detectors

Optimizing the ^{8}Li yield for the IsoDAR Neutrino Experiment

Adriana Bungau, Jose Alonso, Larry Bartoszek, Janet Conrad, Michael Shaevitz, Joshua Spitz

Sleeve is now ^{7}Li with embedded beryllium to multiply neutrons

High yield for much less ^{7}Li !



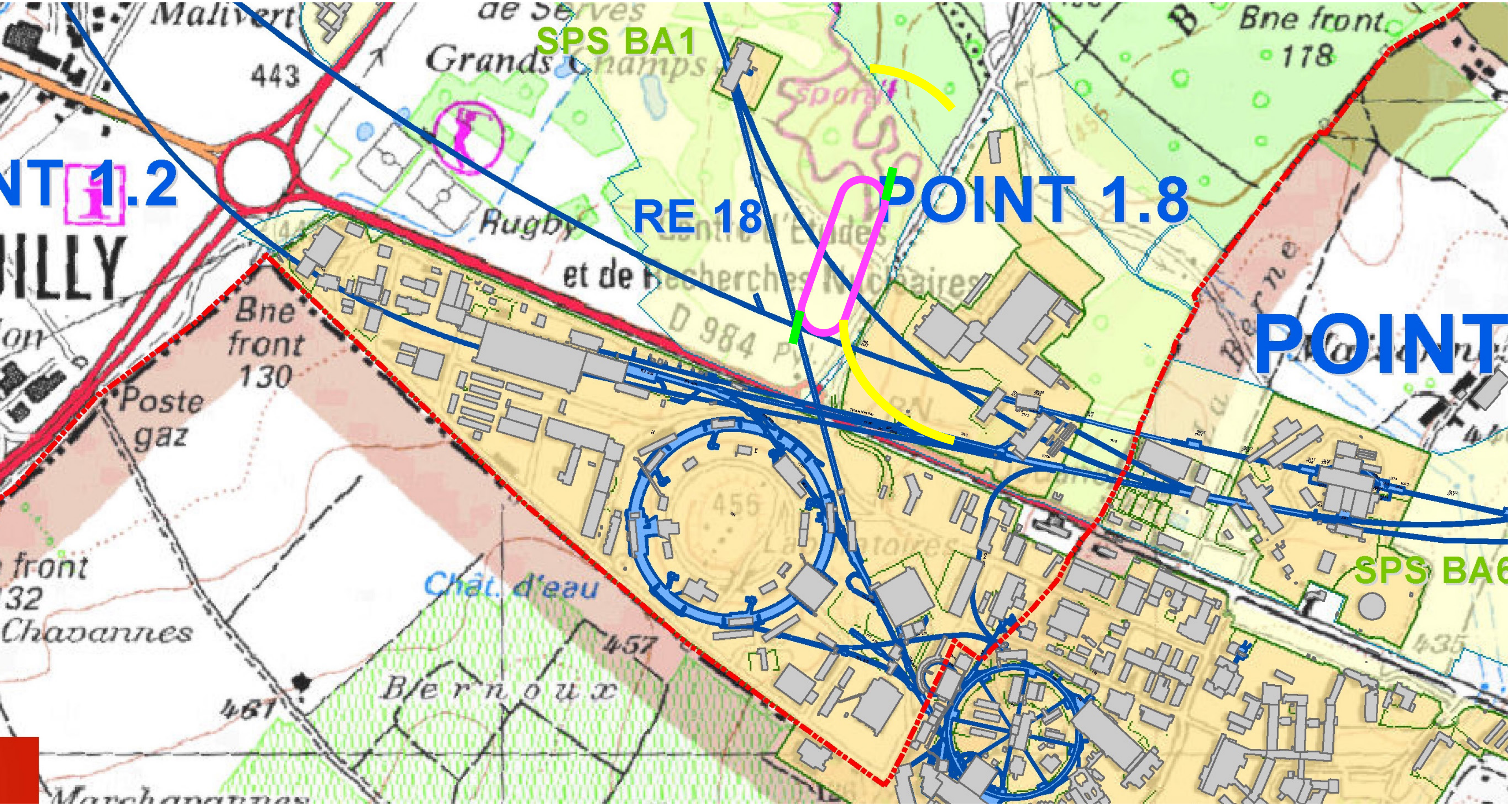
Target design:
Columbia, Bartoszek Engineering

Sleeve design:
U. Michigan, Huddersfield

Shielding design:
Huddersfield

Development of NSF proposal for
neutrino source (accelerator and target/sleeve) underway

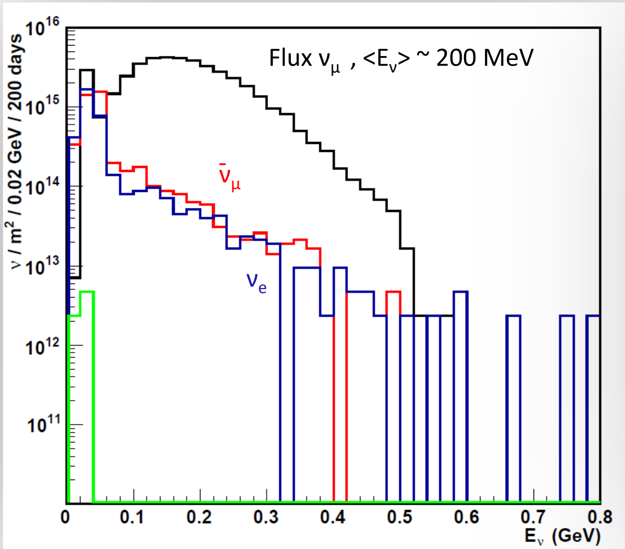
A possible site at CERN

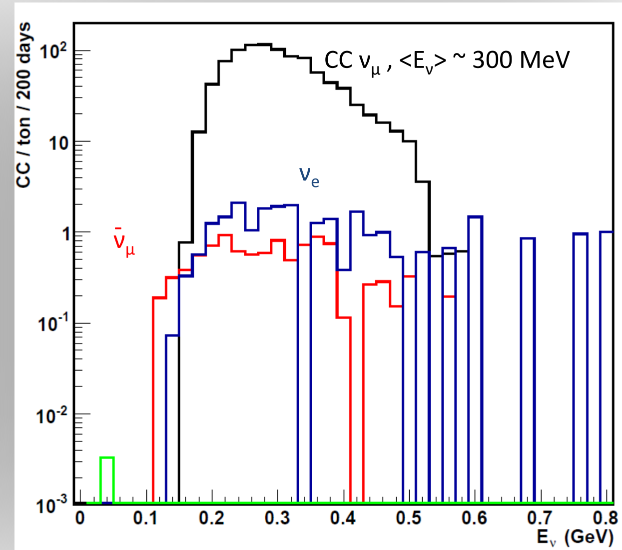


Results for the neutrino beam

Simulation parameters

- Neutrino beam from pions at 3 m downstream of decay tunnel
- 100 % π^+/π^- separation
- Decay tunnel: L = 25 m, aperture = 30 cm





1-8% stat. error, FLUKA	N_ν ($x10^{16}$) / m² / 200 days		CC / ton / 200 days	
	> 53 MeV	%		%
ν_μ	3.78	94.5	959	96.5
$\bar{\nu}_\mu$	0.13	3.2	10	1
ν_e	0.09	2.3	25	2.5
$\bar{\nu}_e$	-	-	0.004	

Detector performance analysis needed in order to investigate its value

1. CC ν_μ at $<E_\nu>$ = 300 MeV at EMuS
2. ~ 1000 CC events / ton / year at CSNS – I
3. x 50 with capture system and decay channel upgrades at CSNS-II
4. Preliminary study for the muon beam shows severe reduction in neutrino flux

Muon collider dead?

- Yes, according to P5
- Community is proposing it in the process of the CERN strategy discussion
- With original new configurations
- Workshops happen in Europe