http://enubet.pd.infn.it

Istituto Nazionale di Fisica Nucleare

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ENUBET status

ERC consolidator grant (2016-2022) – P.I. A. Longhin

Since 2019 **CERN Neutrino Platform Experiment** as **NP06/ENUBET**

F. Pupilli

(INFN)

PBC General Working Group meeting

3/12/2021

on behalf of the

ENUBET Collaboration: 62 physicists, 13 institutions

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

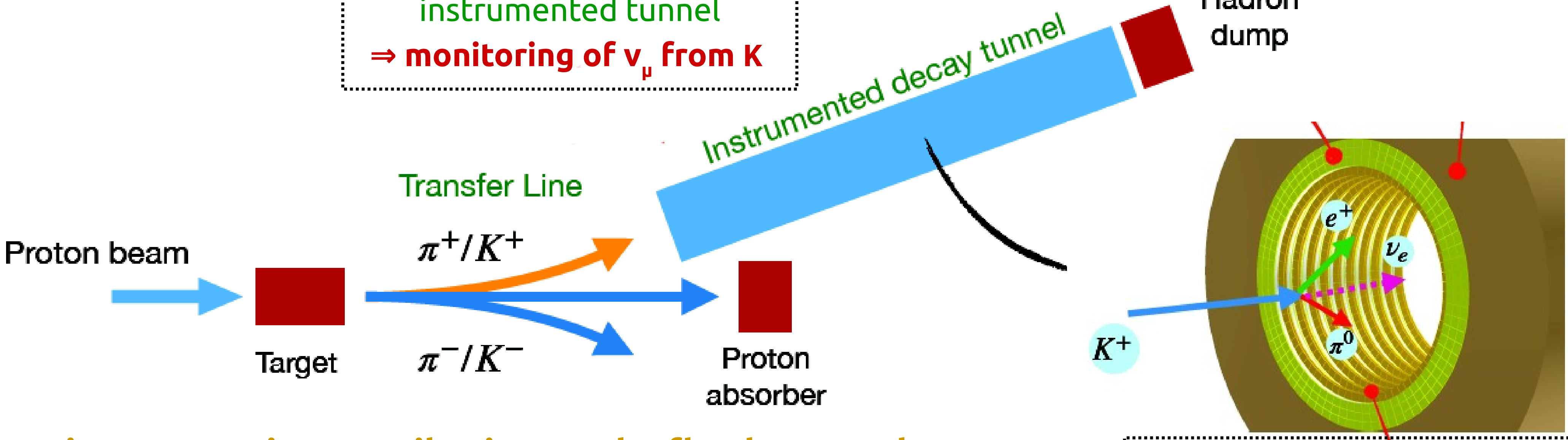
ENUBET: the first monitored neutrino beam

Monitored ν beams

Measure rate of leptons ⇔ monitor ν flux

muons measured by a range meter in the hadron dump
⇒ monitoring of ν_μ from π

$K_{\mu\nu}$ muons measured in the instrumented tunnel
⇒ monitoring of ν_μ from K



K_{e3} positrons measured in the instrumented tunnel
⇒ monitoring of ν_e

Main systematics contribution on the flux bypassed:
- Hadron production, beamline geometry and focusing, POT

Pillars of the ERC project:
- ✓ Built/test a demonstrator of the instrumented decay tunnel (tagger)
  → sampling calorimeter with segmentation in Z, φ, R
- ✓ Design/simulate the layout of the hadronic beamline

Latest update:
SPSC Annual Report 2021

ENUBET in Physics Beyond Colliders

Since 2021 ENUBET is included in the PBC effort with peculiar goals:

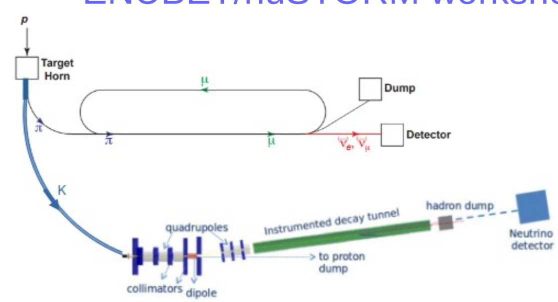
- Cost assessment of the facility and detailed accelerator/engineering studies

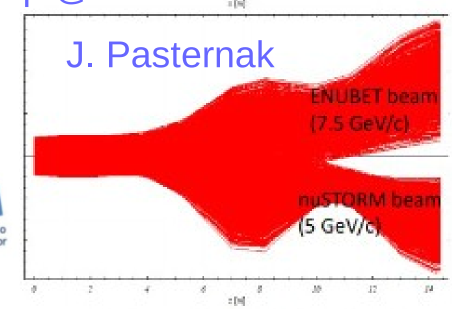
  → Investigate the possibility to serve with ENUBET a set of ν Xsec experiments (LAr, Water Cerenkov, HP-TPC with Ar, low Z targets...) in the CERN NA

- Study possible synergies at facility level with nuSTORM

  → Focus on proton extraction, target station, meson beamline, proton dump

ENUBET/nuSTORM workshop @ NuFACT2021

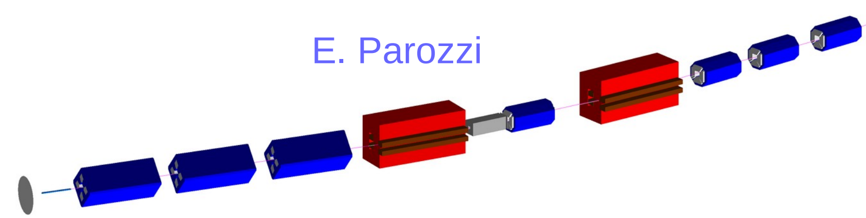




- Parallel study (in PBCacc - CBWG) for the hadron beamline to focus **8.5**, **6** or **4** GeV/c mesons <u>by changing the magnetic fields only</u>

- → Allow a set of <u>different neutrino spectra</u> **from Hyper-K to Dune** regions of interest

E. Parozzi



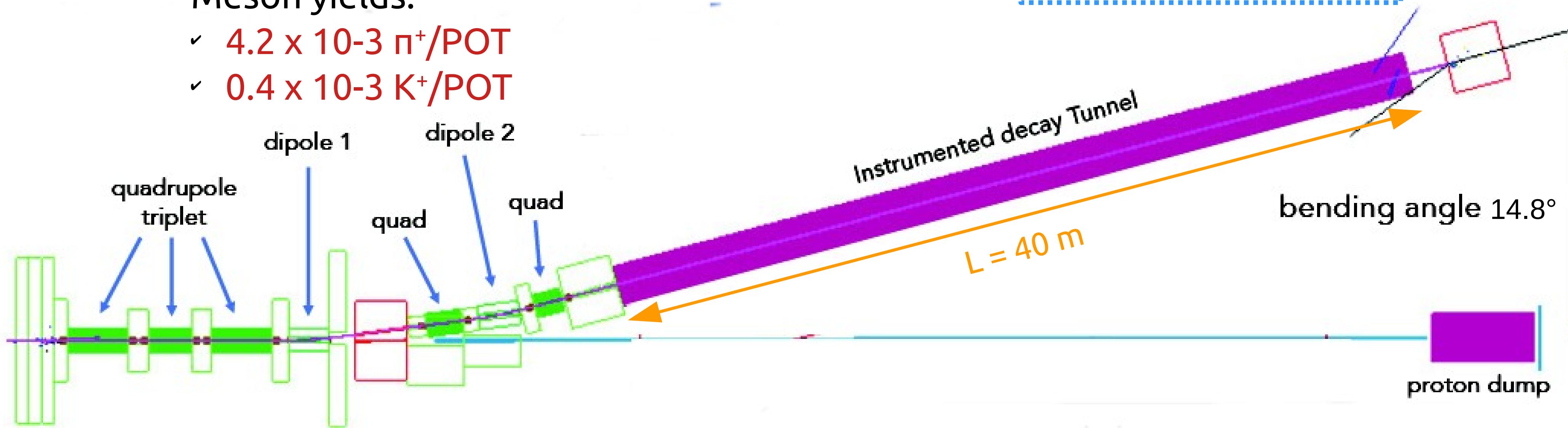
- Extend and quantify the physics reach of ENUBET beyond the original goal of 1% flux precision → BSM Working Group

The ENUBET hadron beamline

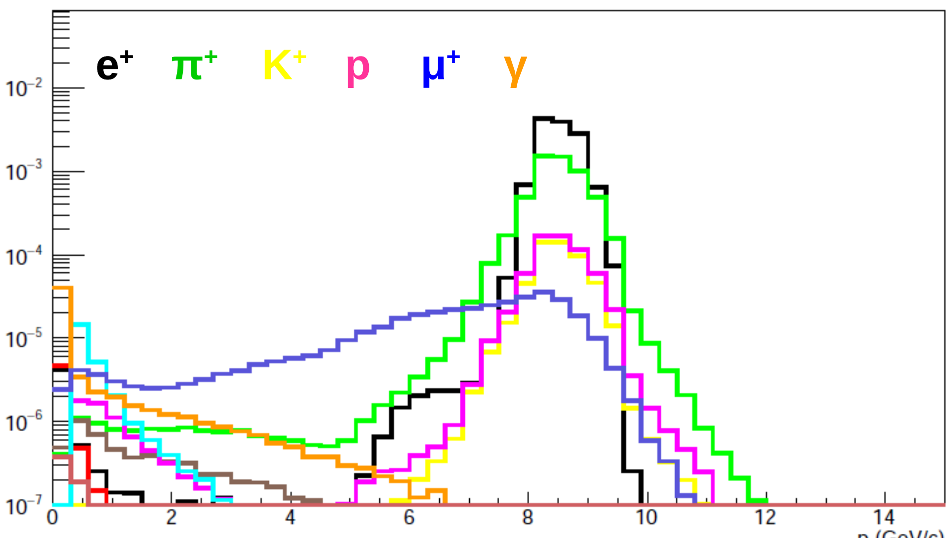
- Standard warm magnets. Max aperture 15 cm.
- **Momentum bite**: 8.5 ± 10% GeV/c
- Meson yields:
  - ✓ 4.2 x 10-3 π^+/POT
  - ✓ 0.4 x 10-3 K^+/POT

Assuming SPS as proton driver:

4.5×10^{13} POT @ 400 GeV for each extraction



Collimators and shieldings tuned to keep under control backgrounds in the tunnel while retaining large enough meson yields



Static focusing (with 2 s proton extraction)

- Mitigation of pile-up effects in the tunnel
- Muon monitoring at the h-dump at 1% level
  → flux of ν_μ from pions
- Pave the way for time-tagged ν beams:
  → time correlation of the interacted neutrino with the associated lepton in the tunnel

Working in parallel on horn + "bursted" slow extraction

The instrumented decay tunnel

Requirements:

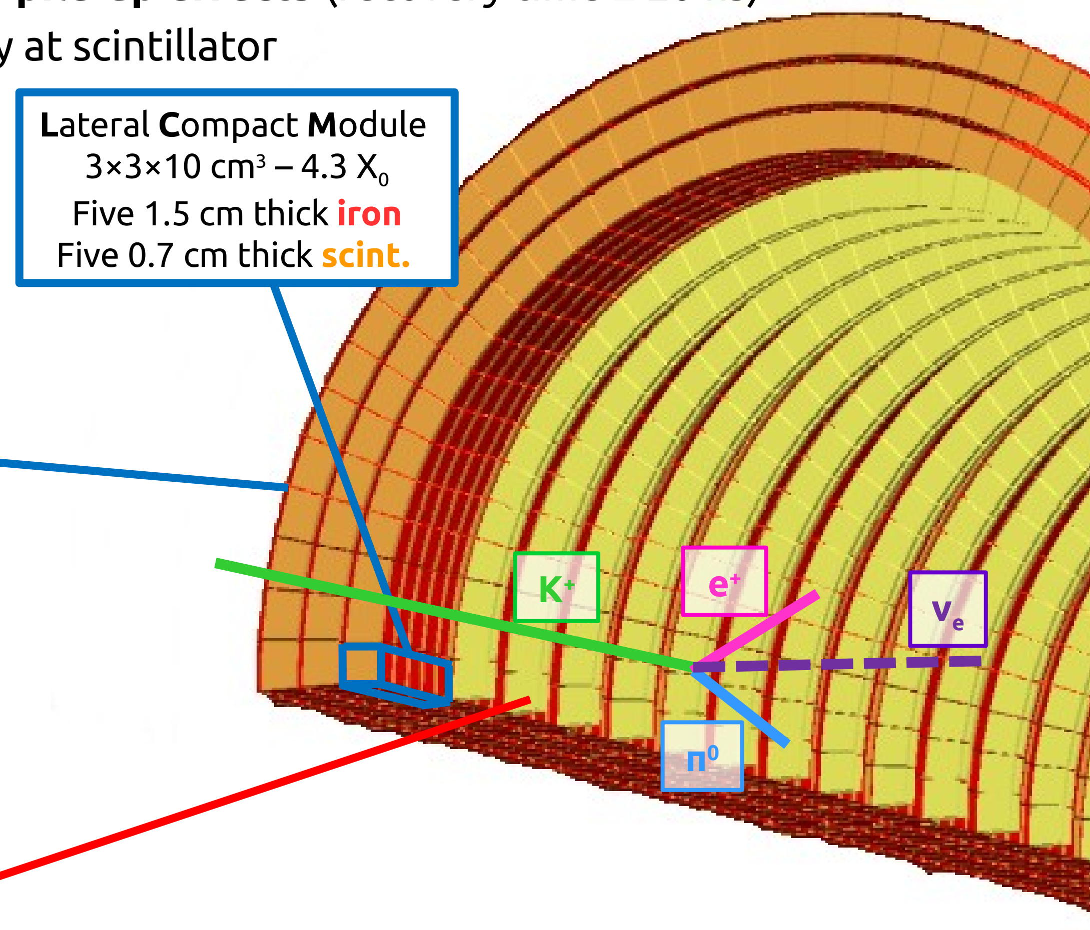
- Allow **$e^+/\pi^{\pm,0}$ separation** in the GeV energy region
- **Suppress** background from **beam halo** (μ, γ, non collimated hadrons)
- Sustain O(MHz) rate and **suppress pile-up effects** (recovery time ≤ 20 ns)
- **Doses**: <10^{10} n/cm^2 at SiPMs, 0.1Gy at scintillator

Calorimeter
Longitudinal segmentation
Plastic scintillator + Iron absorbers
Lateral light readout with WLS+SiPM

→ $e^+/\pi^\pm/\mu$ separation

Integrated photon veto (t0-layer)
Plastic scintillators
Rings of 3×3 cm^2 pads readout by SiPM

→ π^0/γ rejection

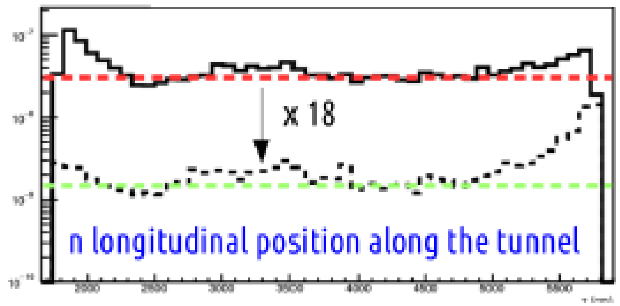


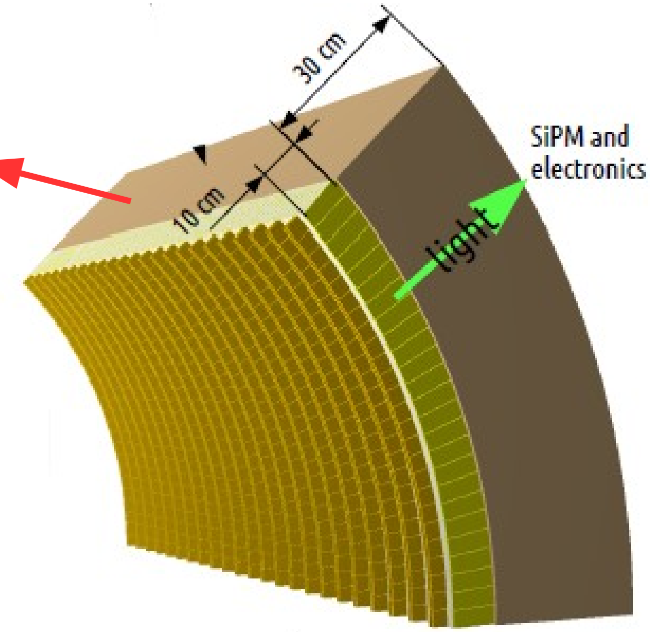
The tagger demonstrator

Larger scale prototype:

- 1.7 m long
- 45° coverage in φ
- To be tested @ CERN PS-T9 in 2022
- Demonstrate physics, scalability and cost effectiveness

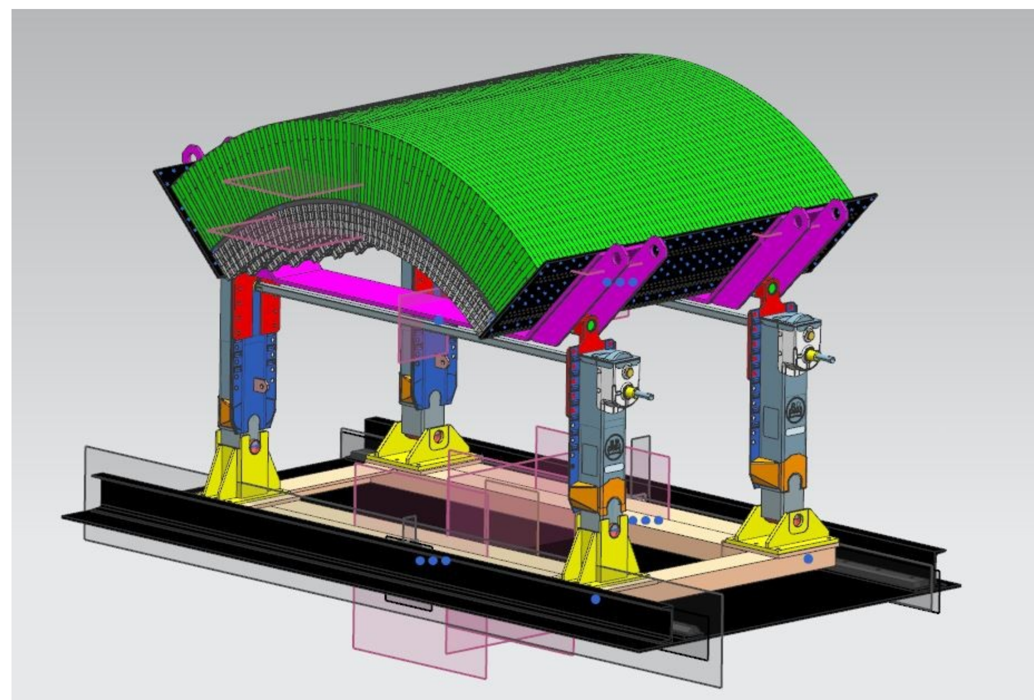
30 cm borated polyethylene
→ ~ **x18 neutron reduction**
Add safety margin for SiPM





WLS collecting light from each module through grooves on the frontal face of scintillator tiles

Tested @PS-T9 in Nov 2021!



Custom digitizers @ 500 MS/s

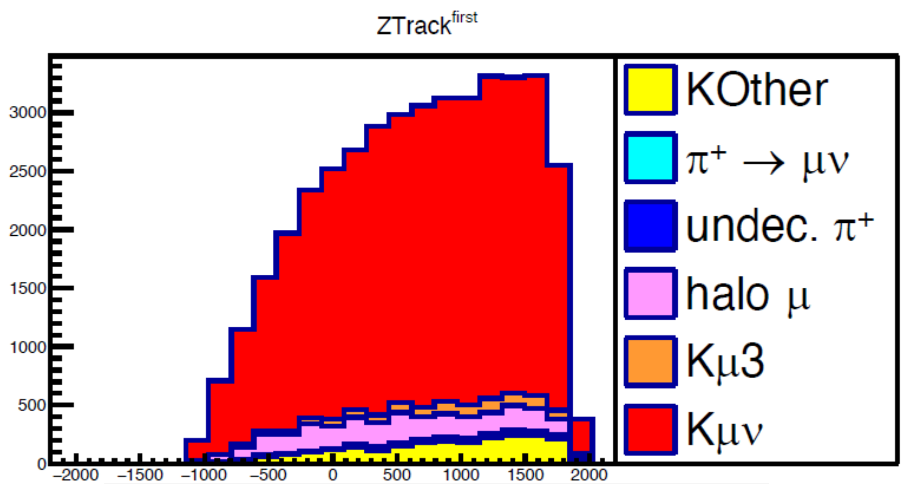
Lepton identification

Full GEANT4 simulation of the detector: validated by prototype tests @ CERN; hit-level detector response; pile-up effects included (through waveform simulation and reconstruction)

- Large angle muons and positrons from kaon decays identified exploiting the energy pattern in the tagger
- Event selection based on 19 variables for positrons (13 for muons) employed by a Neural Network

Muons from $K_{\mu 2}$ ($\sim\nu_\mu$)

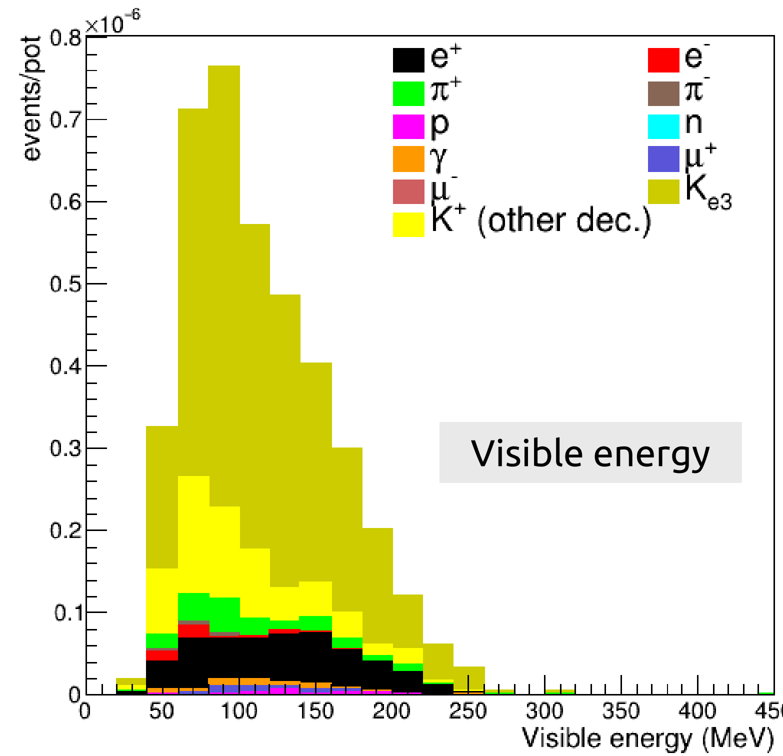
S/N = 6
Efficiency: 33% (~ half geom.)



Longitudinal position along tunnel

Positrons from K_{e3} ($\sim\nu_e$)

S/N = 2
Efficiency: 22% (~ half geom.)



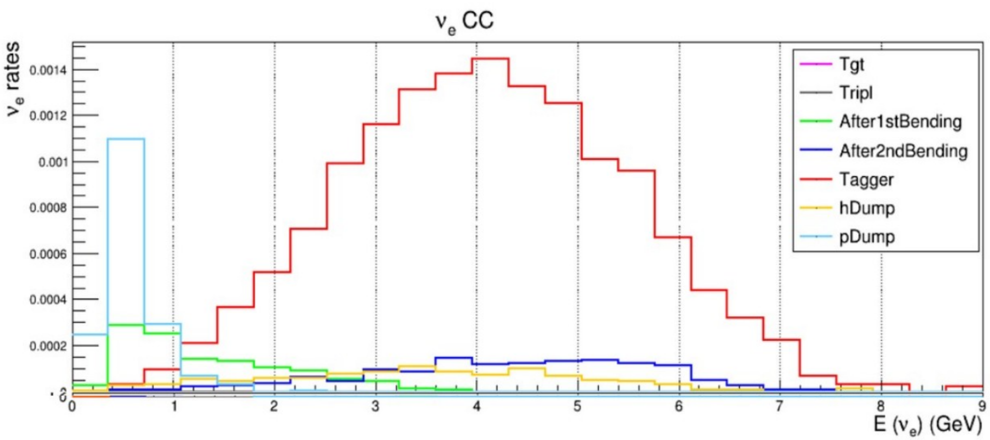
Visible energy

Neutrino spectra

Assuming:
- 4.5×10^{19} pot/year
- 500 ton Lar ν-detector (6x6 m^2) @ 50 m from h-dump

10^4 ν_e^{CC} interactions in ~2y of data taking

<E> ≈ 4 GeV



- Taggable component:

80% monitored by measuring positrons in the decay tunnel

- Non-taggable component 1:

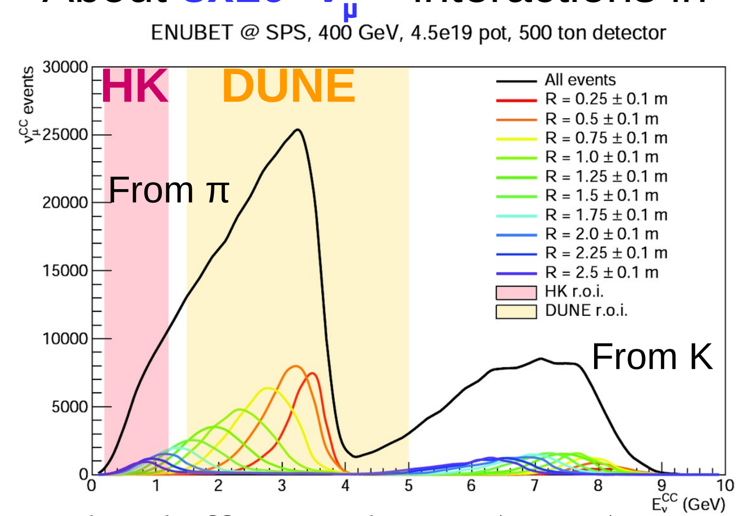
5-10% low-E ν from p-dump

Can be removed with energy cut

- Non-taggable component 2:

10% from decays in the transfer line

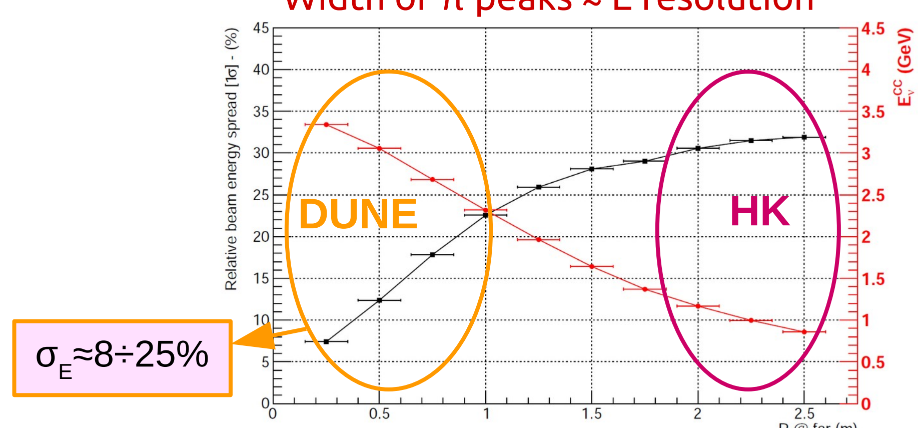
About 8×10^5 ν_μ^{CC} interactions in ~2y



Narrow-band off axis technique (NBOA):
- Narrow p width (O(10%))
- Finite dimesion of near ν-detector

→ Strong correlation between E_ν and radial vertex pos (R)

Width of π peaks ≈ E resolution



The "core business": X-sec measurements

ENUBET is an ideal facility for high precision ν-N cross section measurements at the GeV scale

$$N \sim \int \phi(E)\,\sigma(E)\,\epsilon(E)\,dE$$

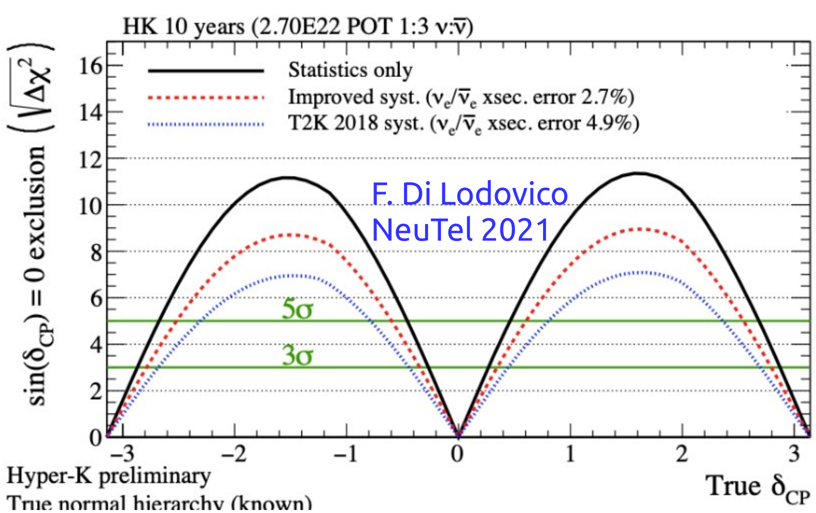
- Absolute normalization and flavour content know at ~1%
- Abundant source of ν_e (the appearing species in LBL experiments)

- ν energy known a priori at 10-20% on an event by event basis
- Remove biases from nuclear effects and FSI that are affecting the energy reconstruction through final state particle kinematics

- Measure σ x ε for the oscillation program with "replica" detector technologies
- Decouple σ and ε with complementary high efficiency detectors

A variety of detector concepts is desirable

- W-Cherenkov, LAr
- High Eff. (HP-TPC, FGD)
- Low Z targets
- ...



CERN-NA could become a hub for detailed cross sections experiments, boosting the LBL programs in Japan and USA, in the spirit of the European Strategy for Particle Physics:

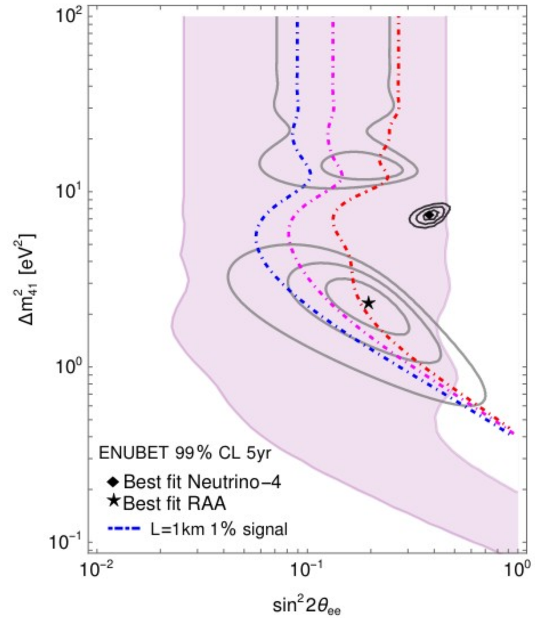
To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied. Other important

See also the ESPP Physics Briefbook arXiv:1910.11775

BSM physics

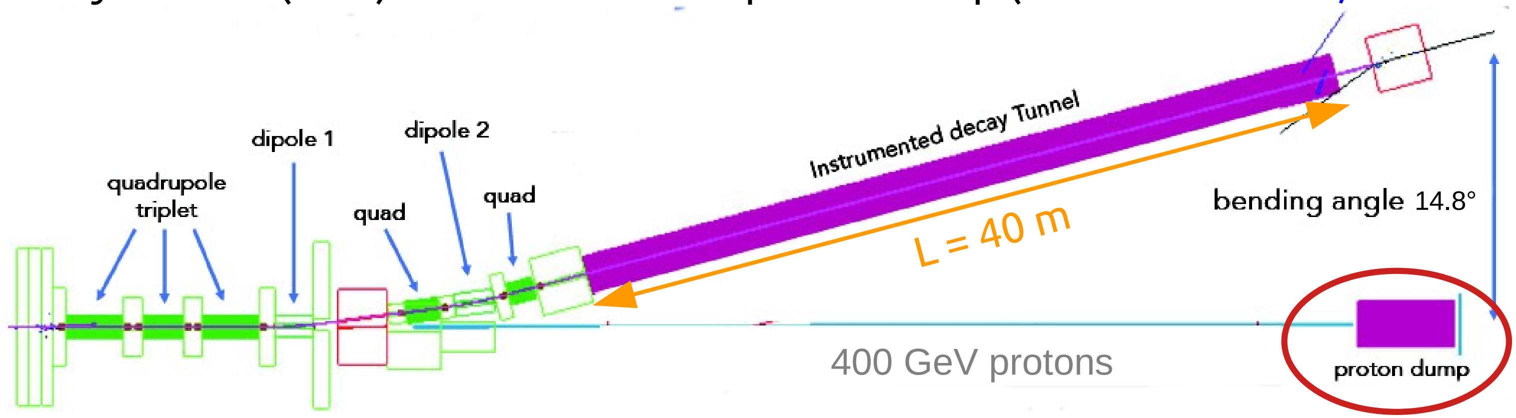
1) Low normalization errors on the flux allow for further constraints on **sterile neutrinos** or to study them in the scenario of having them discovered at FNAL

Update and further extend this study to the current beamline implementation and performance



P. Huber, L. Delgadillo
Phys. Rev. D 103 (2021)

2) Decay-At-Rest (DAR) measurements at proton dump (sterile neutrinos, coherent ν-scattering, …)



3) Explore the Dark portal through Kaon tagging in the transfer line and decay kinematics reconstruction in the instrumented decay tunnel

BSM physics

4) associating the decay and the interaction at an event-by-event basis could open up for new ways of testing non-standard couplings

(i.e.: what if a ν_μ interaction in the neutrino detector is associated to a K_{e3} decay in the tagger)

Tagged neutrino beams

Profit of advances/affordability of excellent **timing capabilities over large areas** →

→ time coincidences of ν_e and e^+

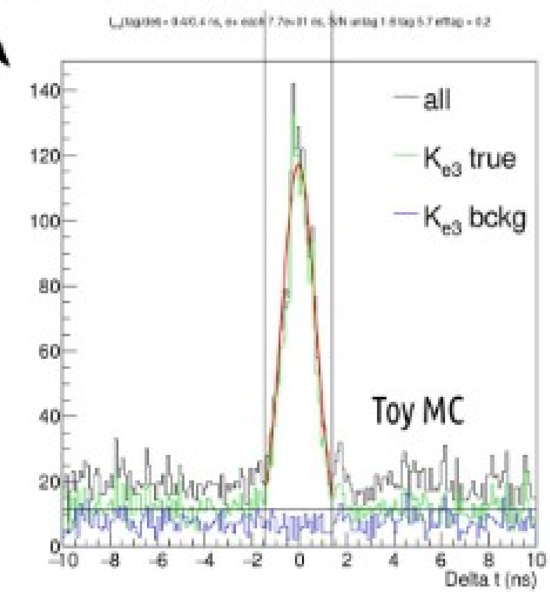
Example with reconstructed e^+
2.5×10^{13} pot / 2s with 20% eff. S/N 1.6

genuine K_{e3} cand. : → **1 every ~ 77 ns**
background K_{e3} cand. ~ 0.6 x → 1 cand / ~ 130 ns

Assumed time resolution: 0.4 ⊕ 0.4 ns

Flavour and energy determination at **interaction level** are enriched by information at the **decay level.**

Distance corrected Δt between tagged leptons and neutrino interactions



Pros:
- one to one association
- Low backgrounds
- Not degenerate with effects driven by sterile states (?)

Cons:
- Likely not such a large statistics

Final remarks

- So far a lot of work has been done to prove to impact of ENUBET on the precise measurement of cross sections to fit the needs of the neutrino community.
  Detailed studies of technical feasibility, performances.

- It is a rather peculiar experimental situation
  → large room to explore new ideas to constrain new physics.

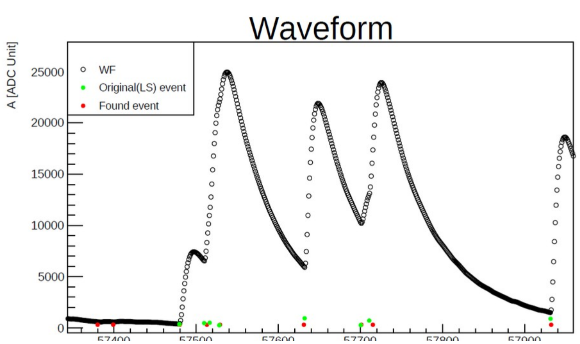
- Still vastly unexplored, hope to take advantage of the “pool of expertise” of this WG to get further insight on the full potential of the ENUBET-BSM program

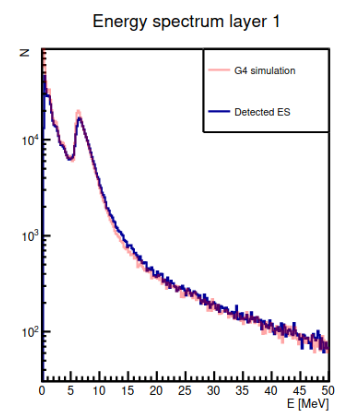
Backup slides

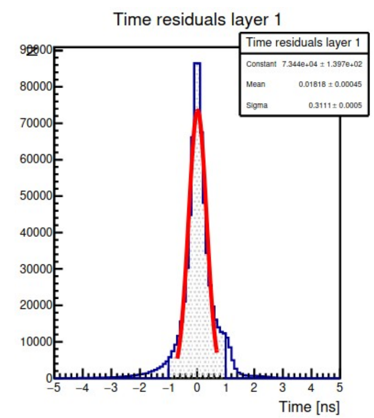
Waveform simulation and reconstruction

Software framework implemented to simulate tagger response at single channel level
→ fully realistic treatment of pile-up effects

Conversion of energy deposits in p.e. Conversion factor (15p.e./MeV) from test beam data	→	SiPM response simulated using the GosSiP software Waveform digitization	→	Pulse detection algorithm → Peak amplitude and time determination	→	Standard analysis chain

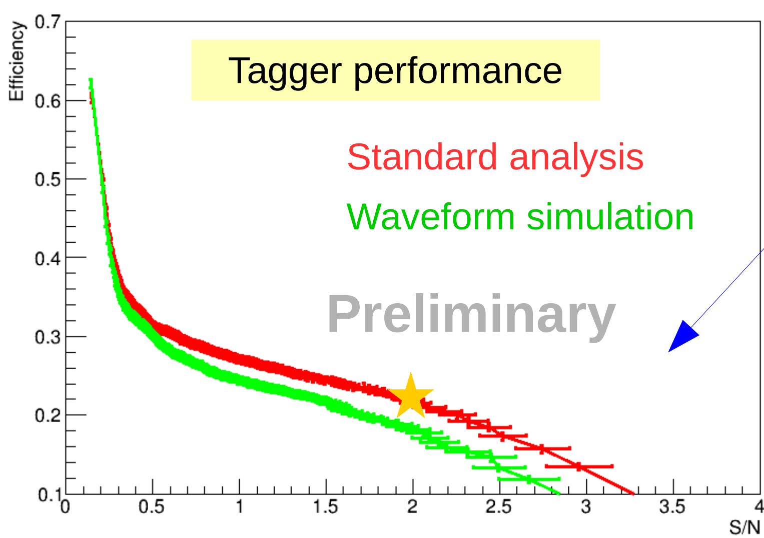






Eff.: 95÷98%

σ_t: 0.3÷0.4 ns



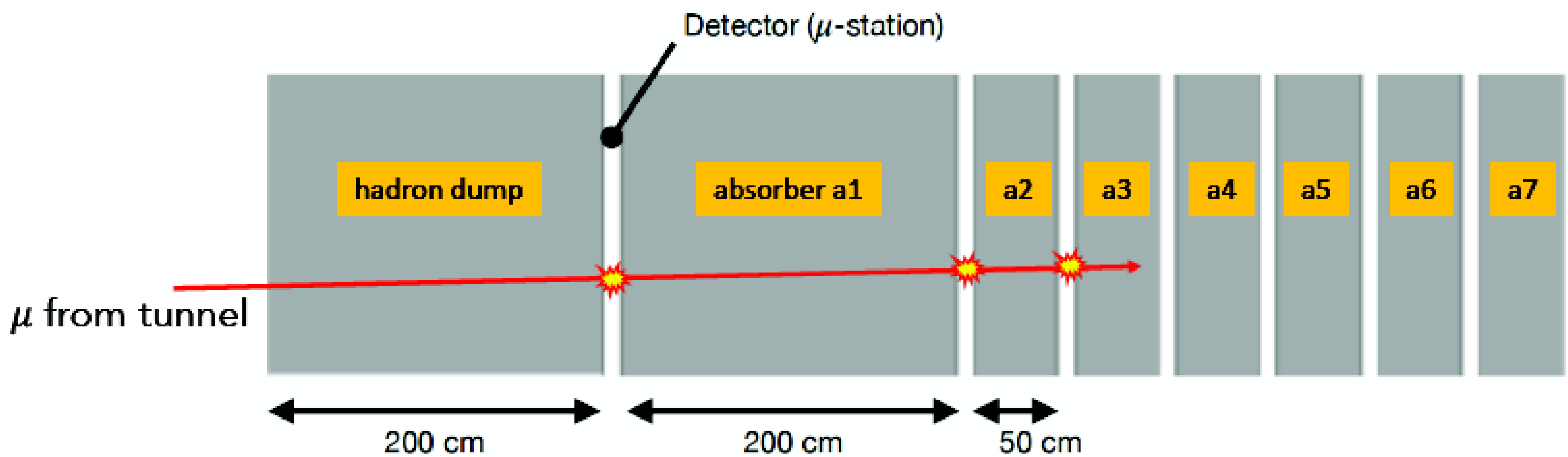
Efficiency vs S/N for different cuts on the NN classifier

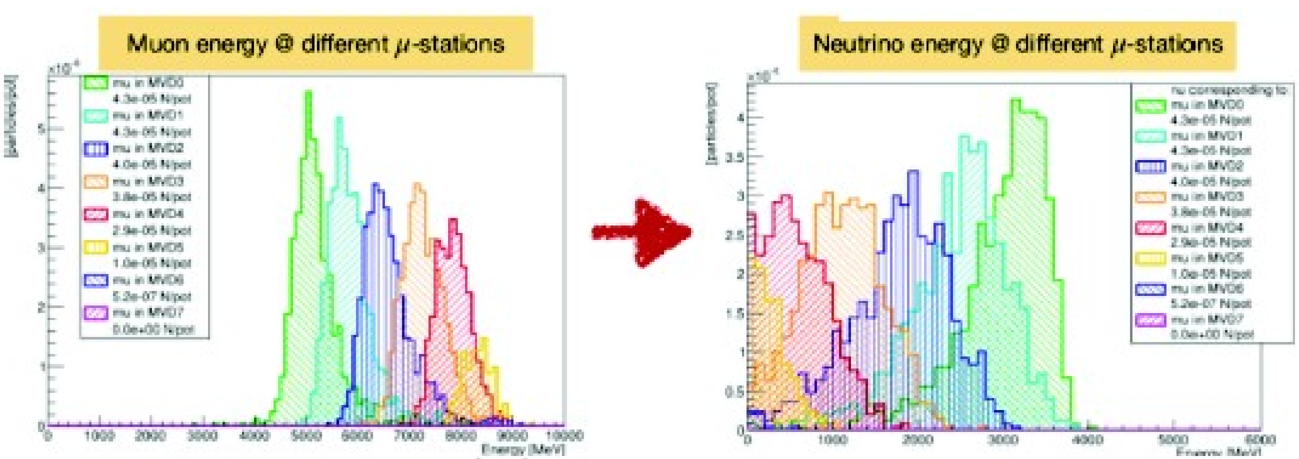
- Improvement to close the gap expected when processing the NN training sample with the same chain
- Full control on the pile-up effects and on the reconstruction chain up to the signal processing level

$\pi_{\mu 2}$ muon identification

$\pi_{\mu 2}$ muon reconstruction to constrain low energy ν_μ

Low angle muons, out of tagger acceptance → need muon stations after the hadron dump





Work in progress

Exploit:

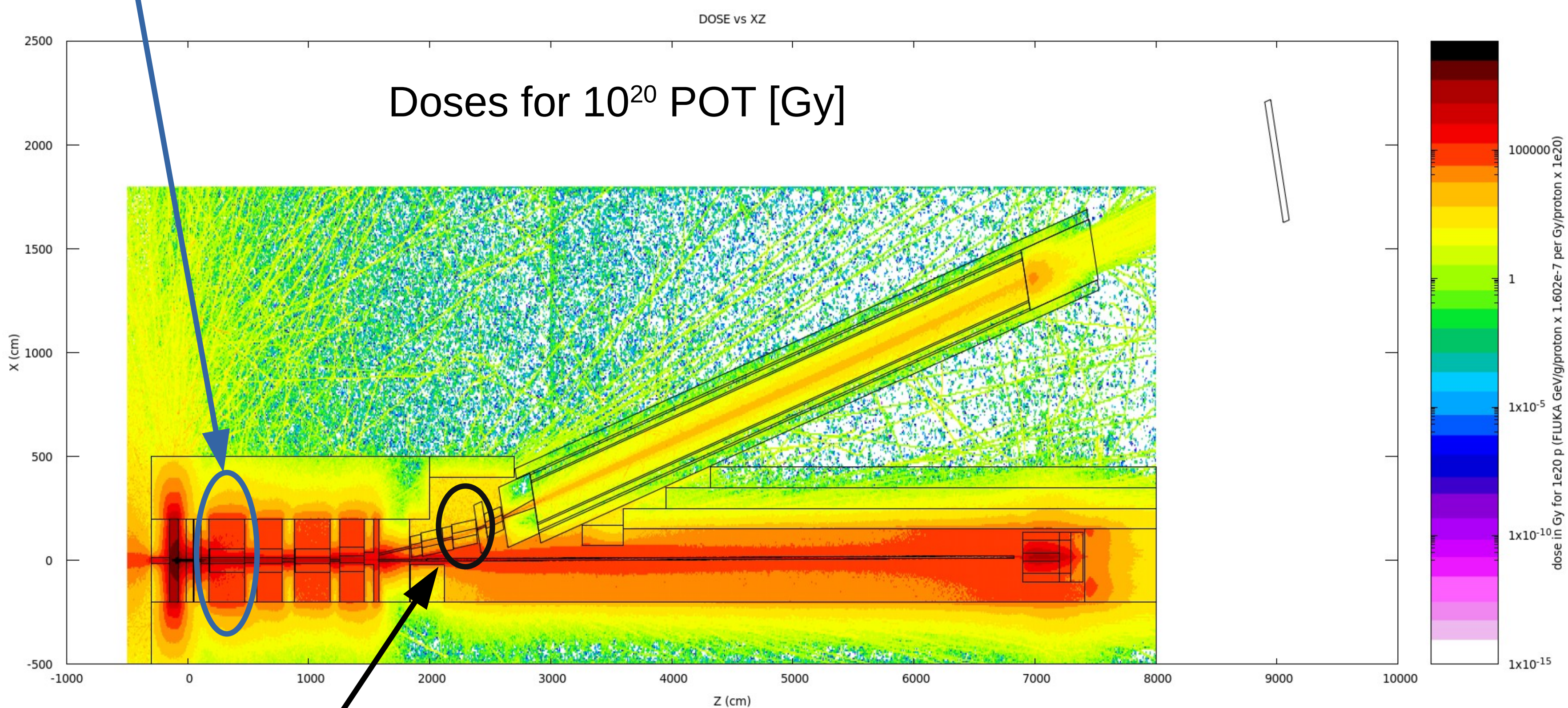
- Correlation btw number of transversed stations (μ energy from range-out) and ν energy;
- Difference in distribution to disentangle signal from halo-muons

Detector technology to be assessed

Max μ rate: 2 MHz/cm^2
Max n fluence: 10^{12} 1-Mev-neq/cm^2

Irradiation studies – add a SC dipole?

- Full FLUKA model of the entire beamline
- The hottest point on the quadrupole closest to the target has a “safe” dose of 100-300 kGy



Doses at the second dipole could allow to place a **Super Conducting magnet**:

- Easily double/triple the bending angle
- Further **reduction** of the non-taggable component from decays in the trasfer line