http://enubet.pd.infn.it

Istituto Nazionale di Fisica Nucleare

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681647).

The physics of ENUBET

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

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

F. Pupilli
(INFN)

FIP Physics Centre: meeting with experiments

24/06/2021

on behalf of the

ENUBET Collaboration: 62 physicists, 13 institutions

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

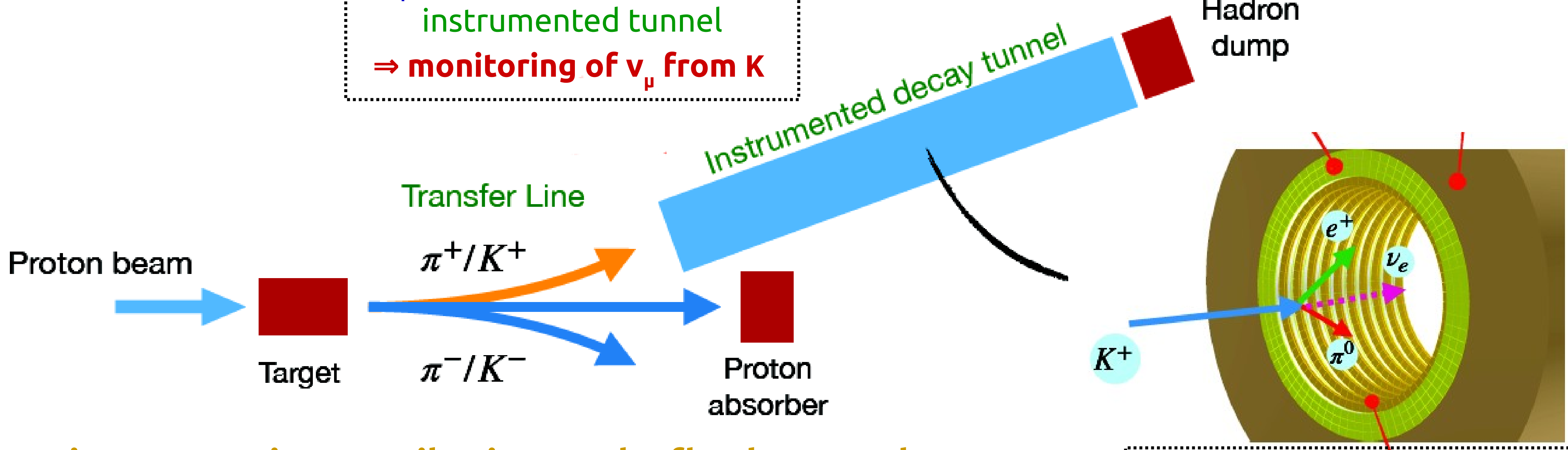
ENUBET: the first monitored neutrino beam

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

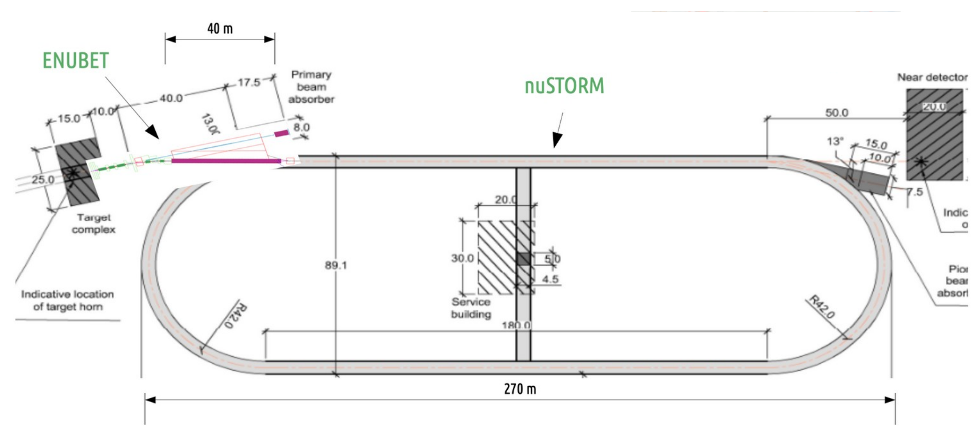
Since 2021 ENUBET is included in the PBC effort with peculiar goals:

- 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



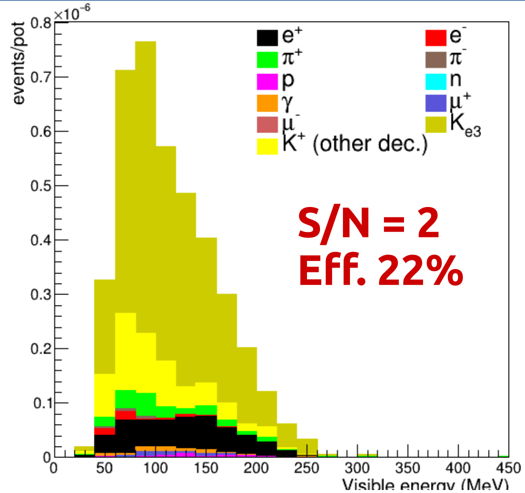
- Extend and quantify the physics reach of ENUBET beyond the original goal of 1% flux precision, involving CERN EP and TH divisions

→ FIP physics centre

ENUBET: ν_e and ν_μ monitoring

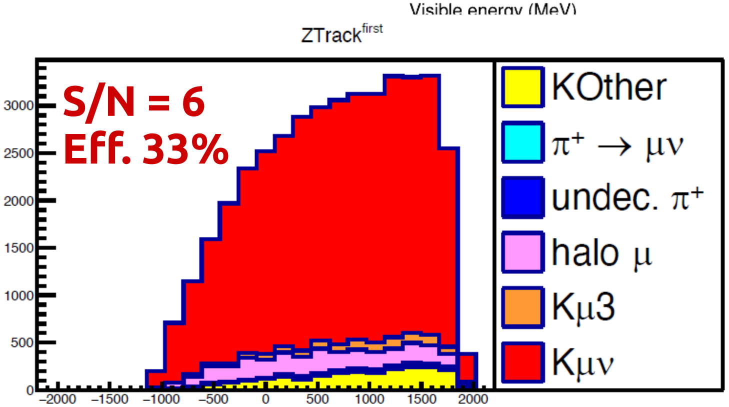
Assuming a 6x6 m², 500 t LAr detector @ 50 m from dump

Large angle leptons in tagger



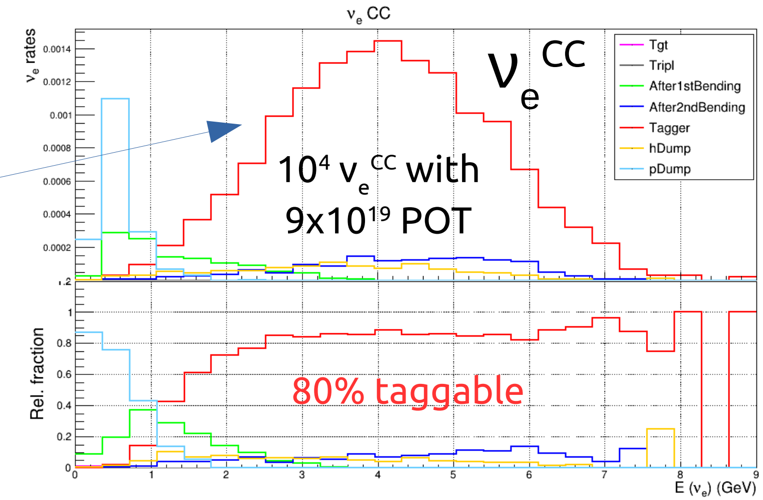
S/N = 2
Eff. 22%

e^+ from K_{e3} ($\sim\nu_e$)

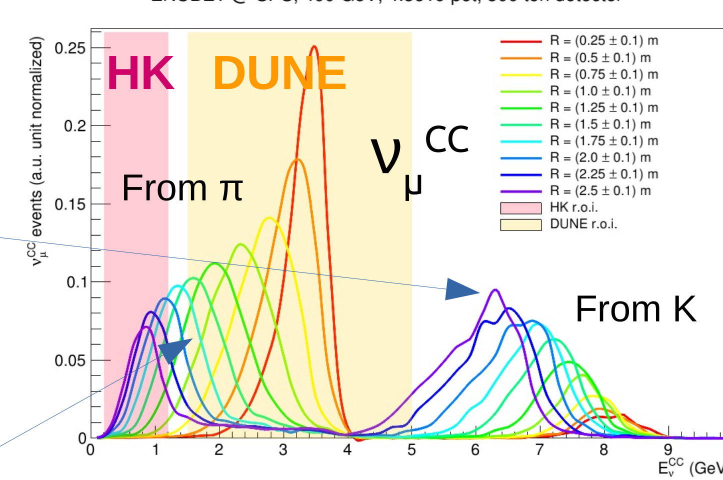


S/N = 6
Eff. 33%

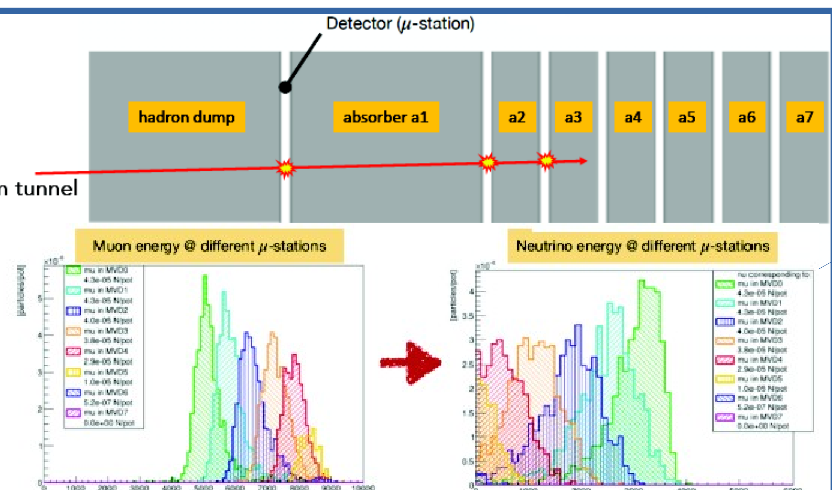
μ^+ from $K_{\mu2}$ ($\sim\nu_\mu$)



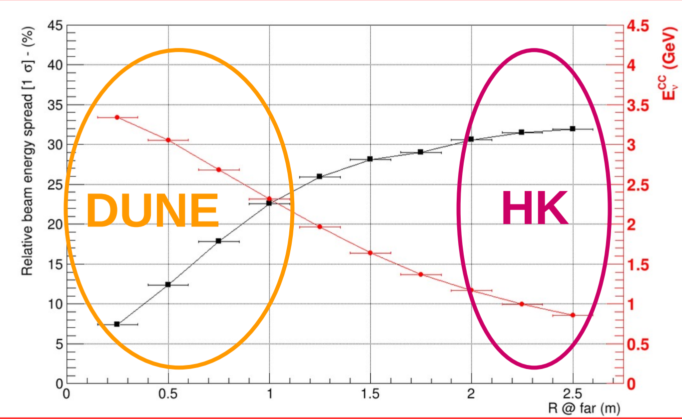
ENUBET @ SPS, 400 GeV, 4.5e19 pot, 500 ton detector



Low angle μ^+ from π in the range meter



Extra - NBOA:
E_ν with O(10-20%) precision from its correlation with radial interaction coordinate



Cross section measurements

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

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

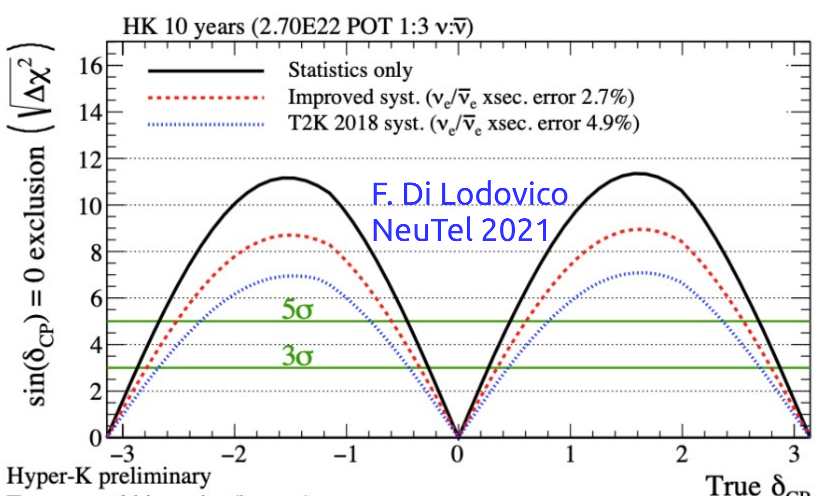
- Absolute normalization and flavour content know at ~1%
- Abundant source of ν_e (the appearing species in LBL experiments)

- 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:

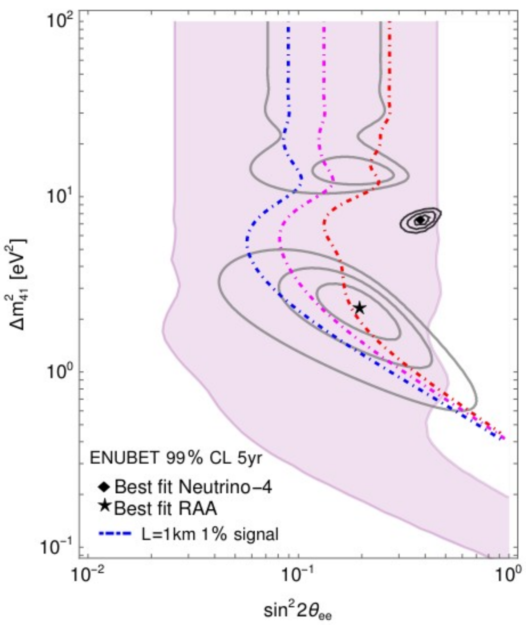
To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure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

See also the ESPP Physics Briefbook
arXiv:1910.11775

FIB physics

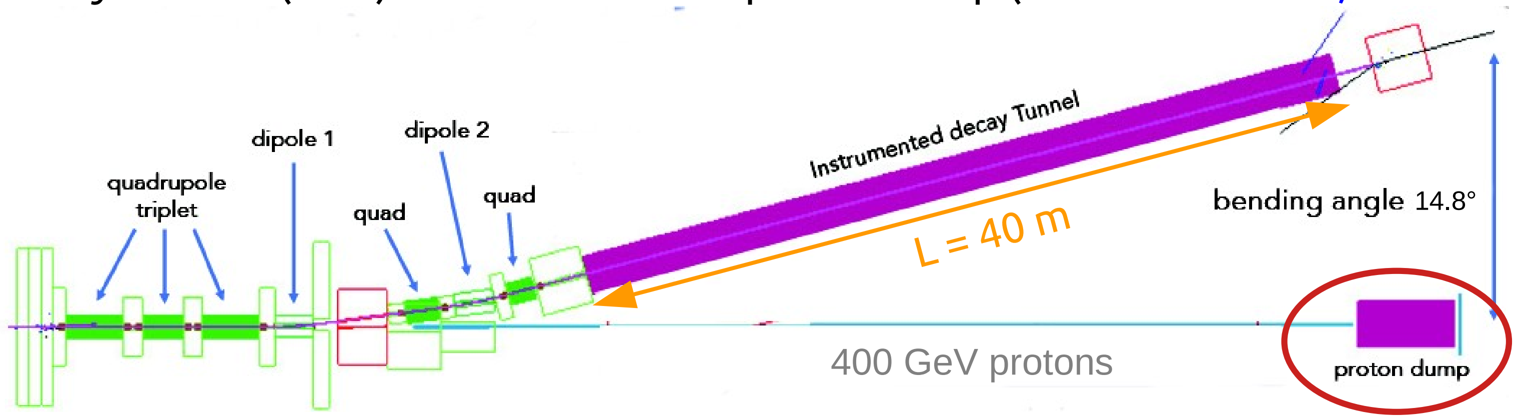
1) Low normalization errors on the flux allow for further constraints on **sterile neutrinos** or to study them in the scenario of having them discovered at FNAL

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, …)



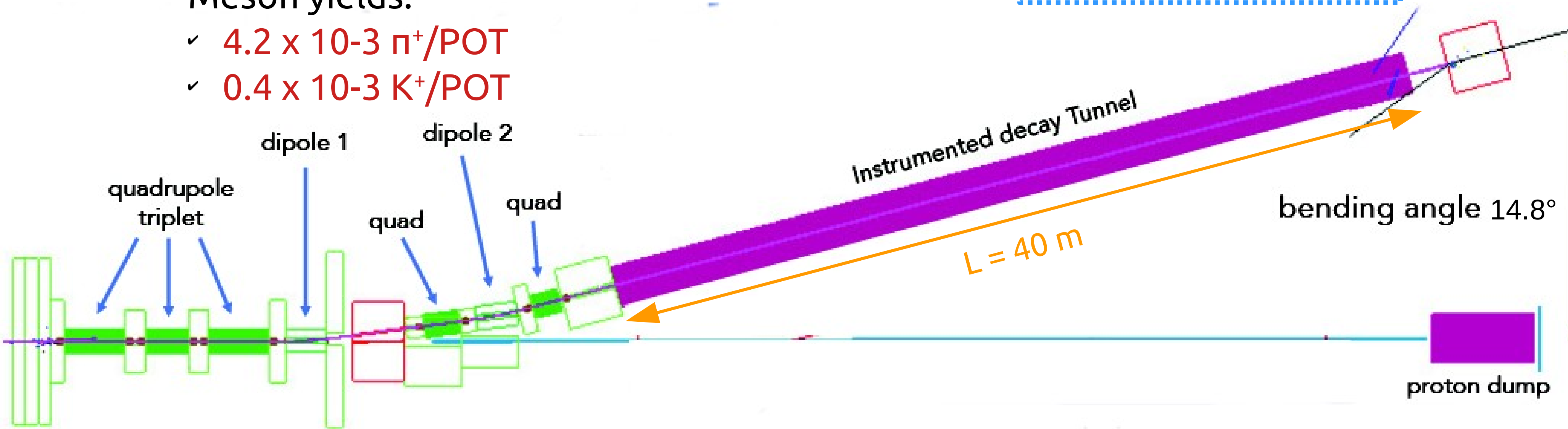
3) Explore the Dark portal through Kaon tagging in the transfer line and decay kinematics reconstruction in the instrumented decay tunnel

Additional slides

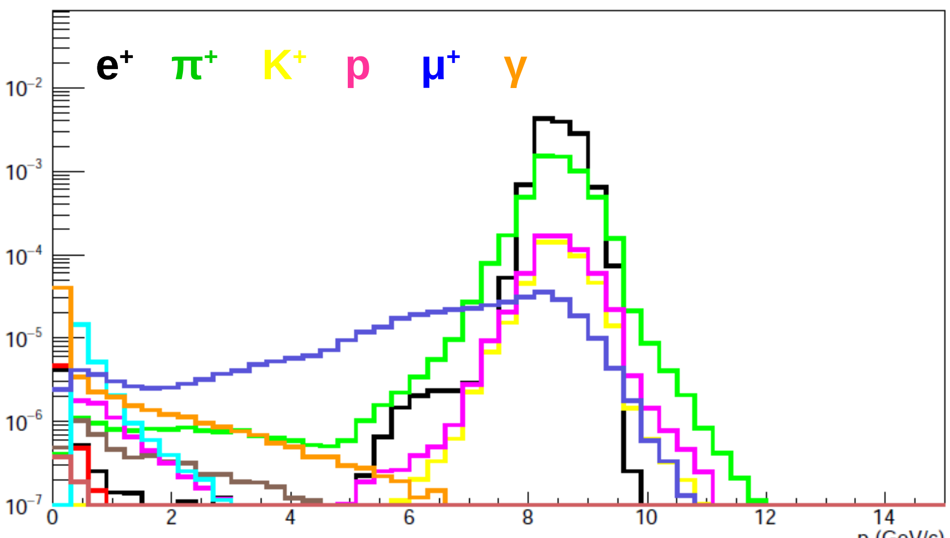
The ENUBET hadron beamline

- 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 (I)

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

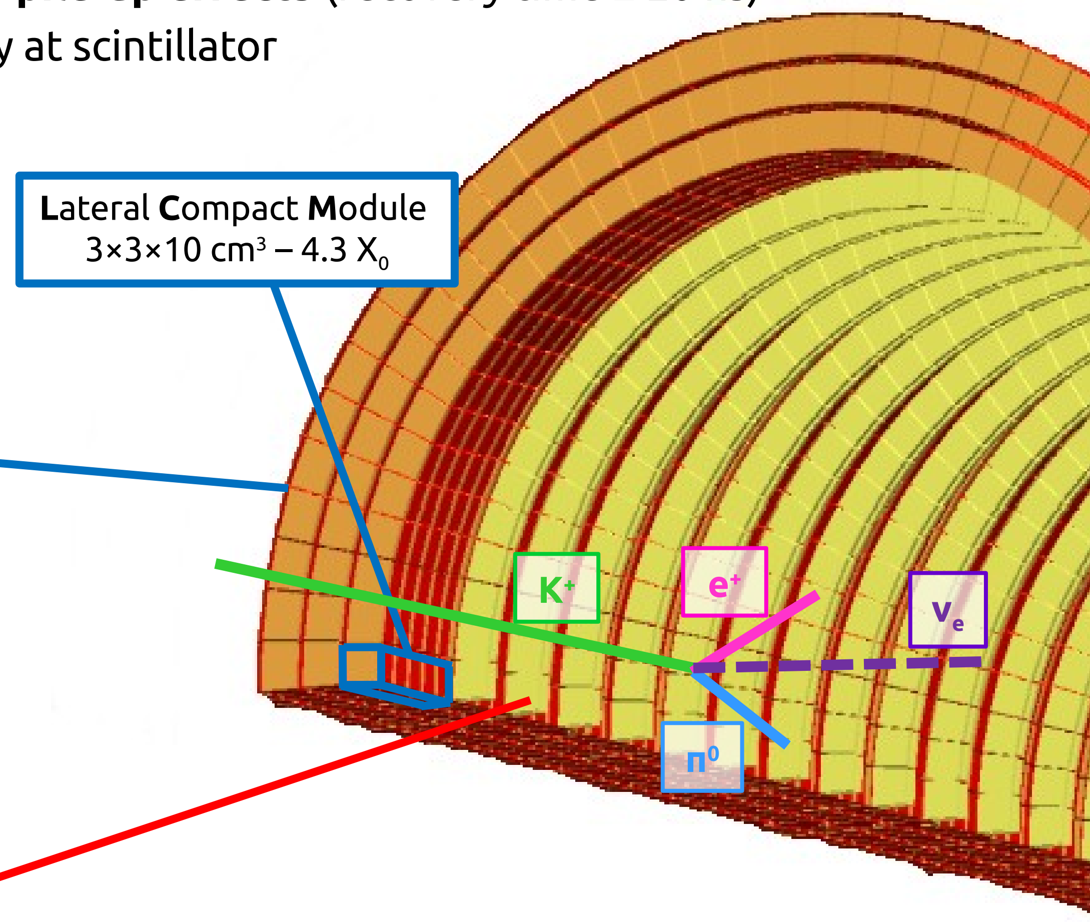
→ $e^+/\pi^\pm/\mu$ separation

Integrated photon veto (t0-layer)

Plastic scintillators

Rings of 3×3 cm^2 pads readout by SiPM

→ π^0/γ rejection

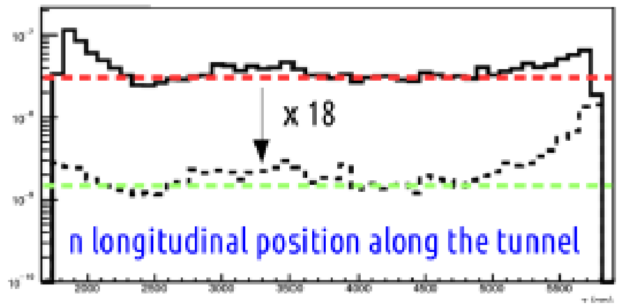


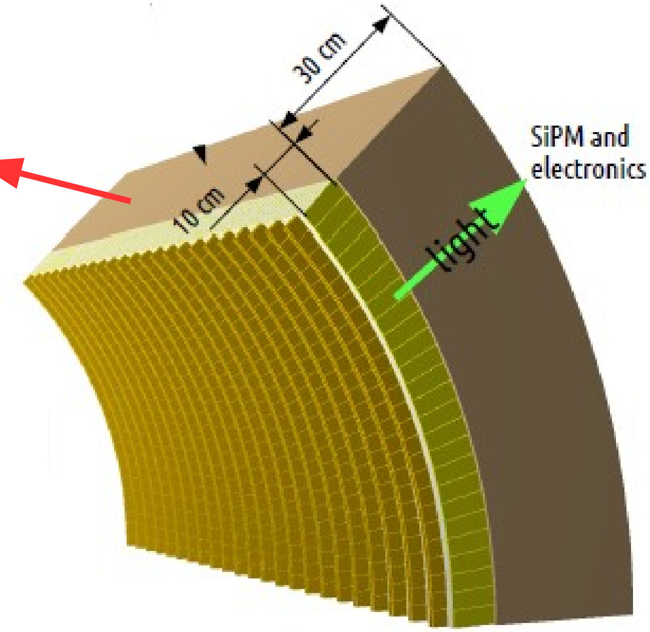
The tagger demonstrator

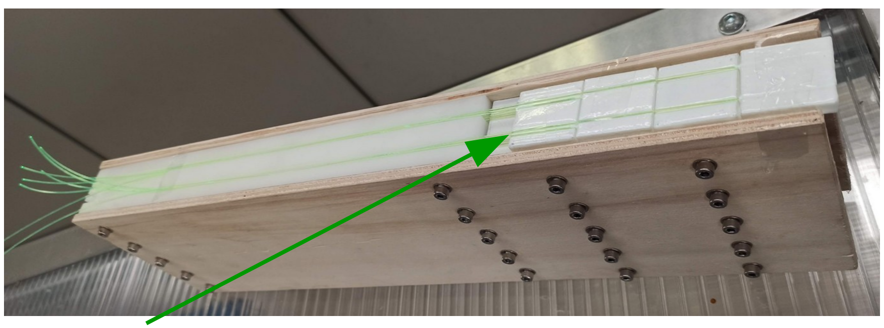
Larger scale prototype:

- 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

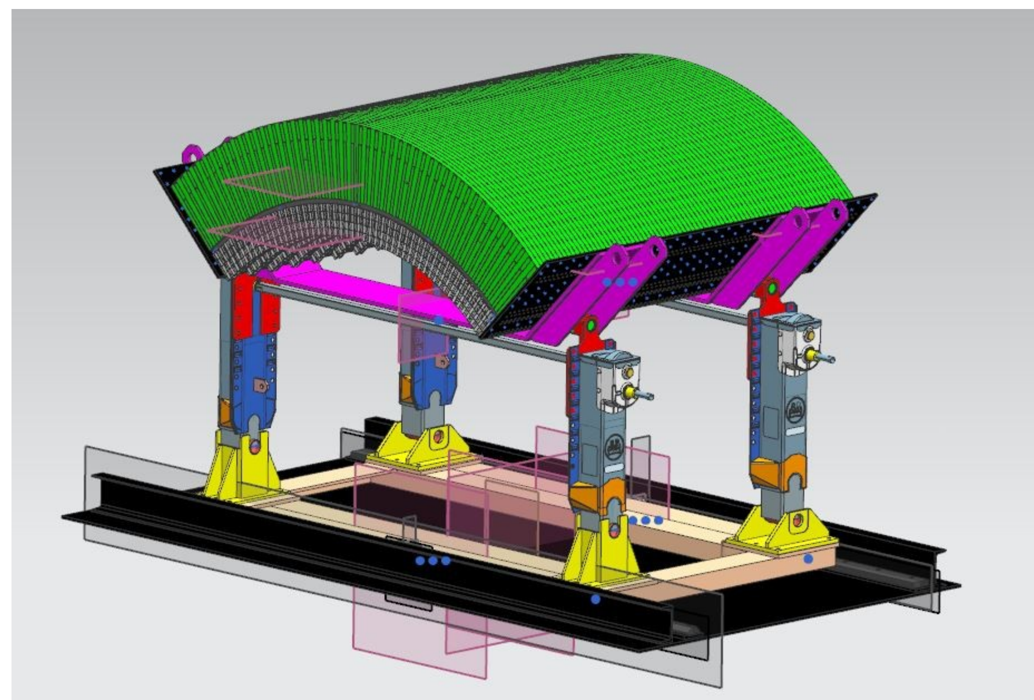






WLS collecting light from each module through grooves on the frontal face of scintillator tiles

Custom digitizers
@ 500 MS/s



ν_μ flux

Constrain on flux:

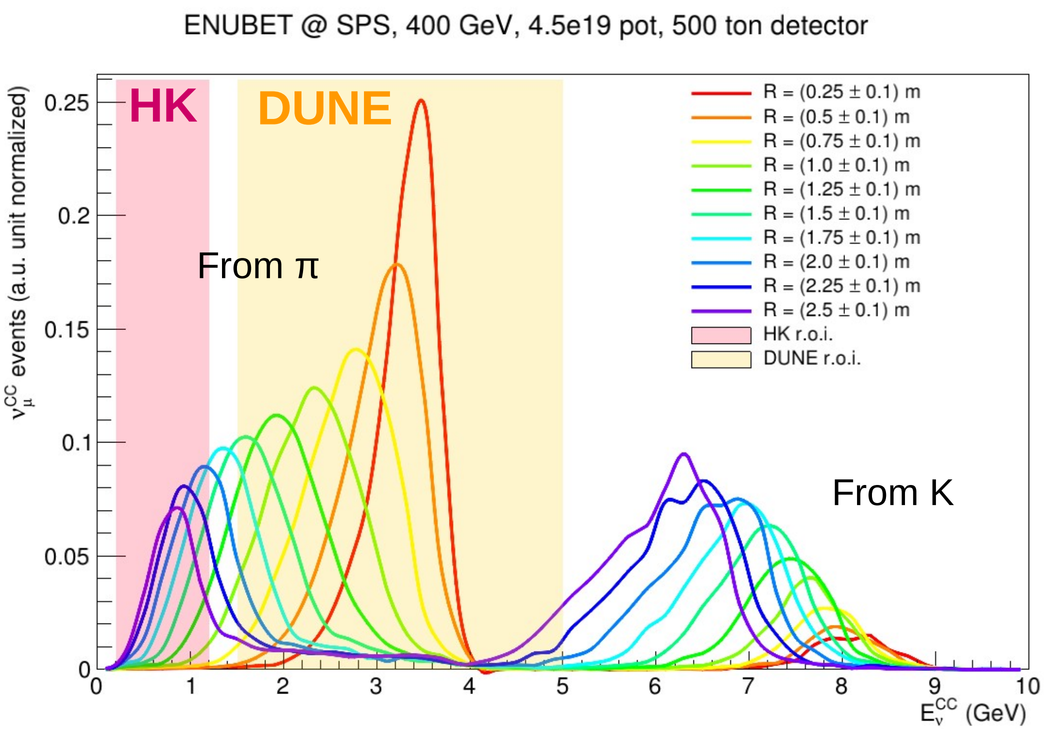
- Muons from π monitored by the range-meter (low energy part of the ν flux)
- Muons from $K_{\mu 2}$ monitored in the instumented tunnel (high energy part)

Constrain on energy:

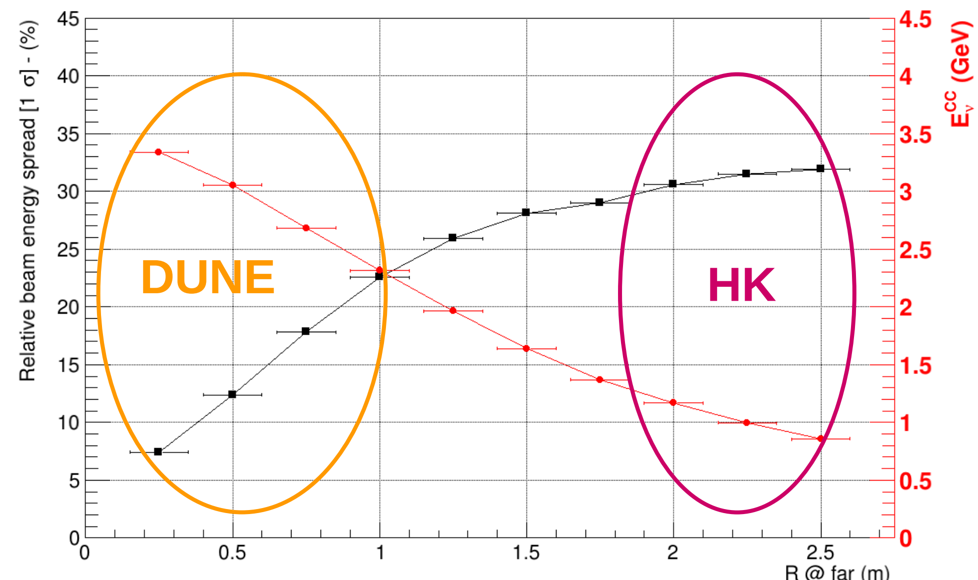
*F. Acerbi et al., CERN-SPSC-2018-034

- Since the momentum bite is <10% and the detector distance is small, strong correlation between the position of the neutrino vertex and its energy
- Technique dubbed "**narrow-band off-axis**" *
- ν energy available on a event-by event basis without relying on the reconstruction of the final state in ν_μ^{CC} interactions

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



Width of π peaks ≈ E resolution



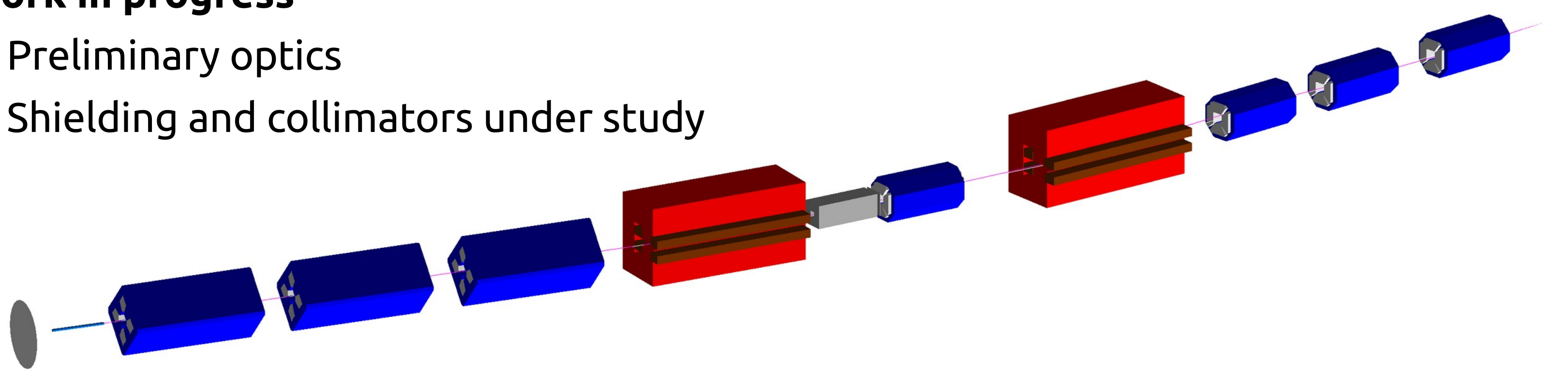
ENUBET beam optimized for DUNE

ENUBET multi-momentum transferline

- A parallel study ongoing for the hadron beamline to focus **8.5**, **6** or **4** GeV/c secondaries by changing the magnetic fields only

Work in progress

- Preliminary optics
- Shielding and collimators under study



- Add flexibility and allow a set of different neutrino spectra **from Hyper-K to Dune** regions of interest