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NP06/ENUBET

F. Terranova (Univ. of Milano-Bicocca and INFN) on behalf of
the ENUBET Collaboration

ENUBET: ERC Consolidator Grant. Jun 2016 - May 2021. PI: A. Longhin.
Since April 2019, ENUBET is also **a CERN Neutrino Platform experiment: NP06**

The ENUBET Collaboration:
60 physicists, 12 institutions

The rationale of

The precision era of accelerator neutrino physics needs a new generation of high precision short baseline experiments for the measurement of cross sections and a detailed knowledge of neutrino interaction in matter.

ENUBET is

- a narrow band beam at the GeV scale with a **superior control of the neutrino flux, flavor** and **energy** of the neutrinos produced at source

It is designed

- to serve a new generation of short-baseline experiments in order to reach 1% precision measurement of the ν_e and ν_μ **neutrino cross sections**
- It is the ideal neutrino source for the study of neutrino interactions at the GeV scale **with "low" mass, high-granularity detectors**
- It is the **most natural follow up** of the MINERvA, ArgoNeuT and the ProtoDUNE physics programme

A narrow-band beam for the precision era of ν physics

Absolute flux of ν_e and ν_μ at the 1% level

↓

Remove the leading source of uncertainty in **neutrino cross section measurement**

Energy of the neutrino known at the 10% level

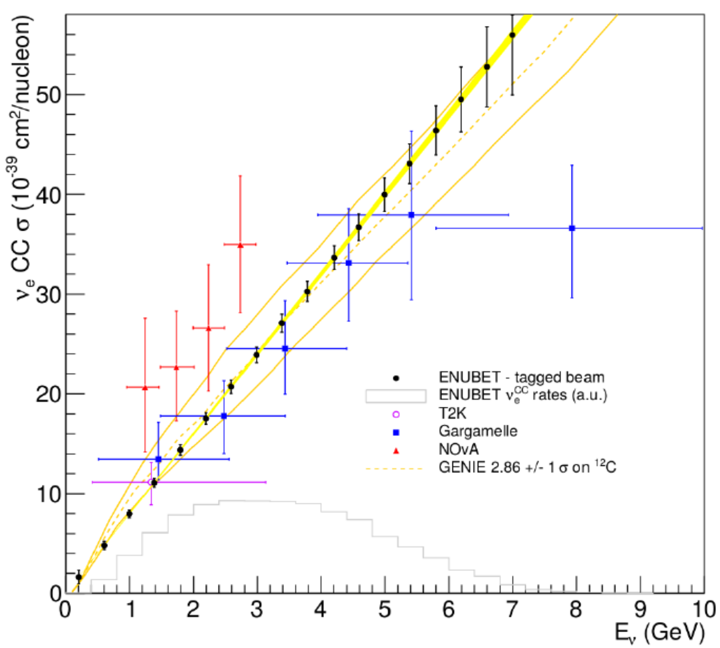
↓

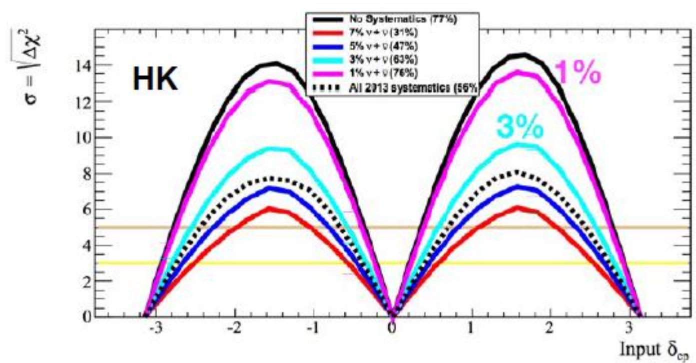
The ideal tool to study neutrino interactions in nuclei

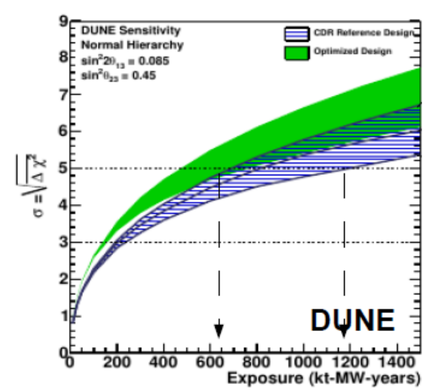
Flavor composition known at the 1% level

↓

The ideal tool to study NSI and sterile neutrinos at the GeV scale

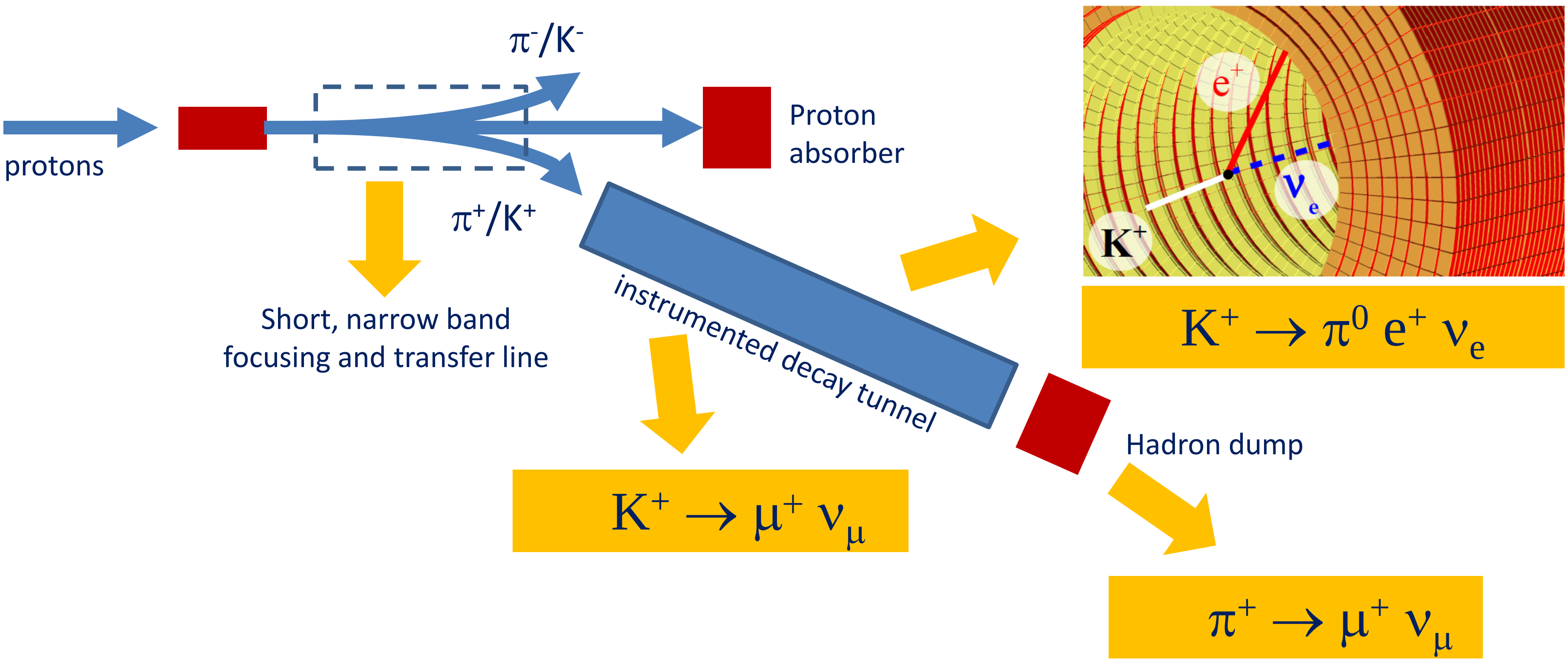






ENUBET: the first monitored neutrino beam

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



The challenges of ENUBET:

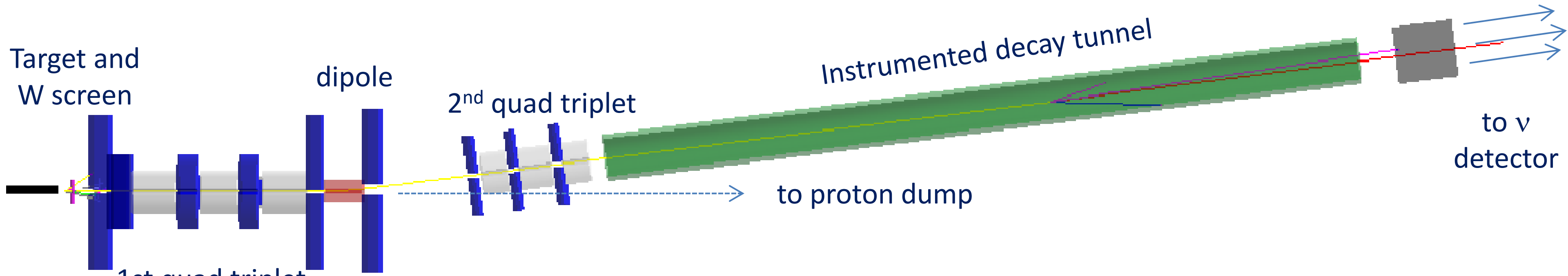
Addressed in 2016-2019

- Flux
- Radiation hardness
- Particle monitoring
- ν at detector

- Beamline engineering
- Assessment of systematics
- Cost (site specific)

Flux

The ENUBET beamline (baseline option)



- Proton driver: CERN SPS (400 GeV), Fermilab Main Ring (120 GeV), JPARC (30 GeV)
- Target: 1 m Be, graphite target. FLUKA
- Focusing
  - [Horn: 2 ms pulse, 180 kA, 10 Hz during the flat top] [not shown in figure]
  - **Static focusing system**: a quadrupole triplet before the bending magnet
- Transfer line:
  - Optics: optimized with TRANSPORT to a 10% momentum bite
  - Particle transport and interaction: full simulation with G4Beamline
  - All normal-conducting, numerical aperture <40 cm, Two quadrupole triplet, one bending dipole
- Decay tunnel
  - Radius: 1m. Length 40 m [re-optimized after beam envelope determination]
  - Low power hadron dump at the end of the decay tunnel
- Proton dump: position and size under optimization

Flux

Yields

Focusing system	π/pot (10^{-3})	K/pot (10^{-3})	Extraction lenght	π/cycle (10^{10})	K/cycle (10^{10})	Proposal [c]
Horn	97	7.9	2ms [a]	438	36	x2
No horn	19	1.4	2 s [b]	85	6.2	**x4**

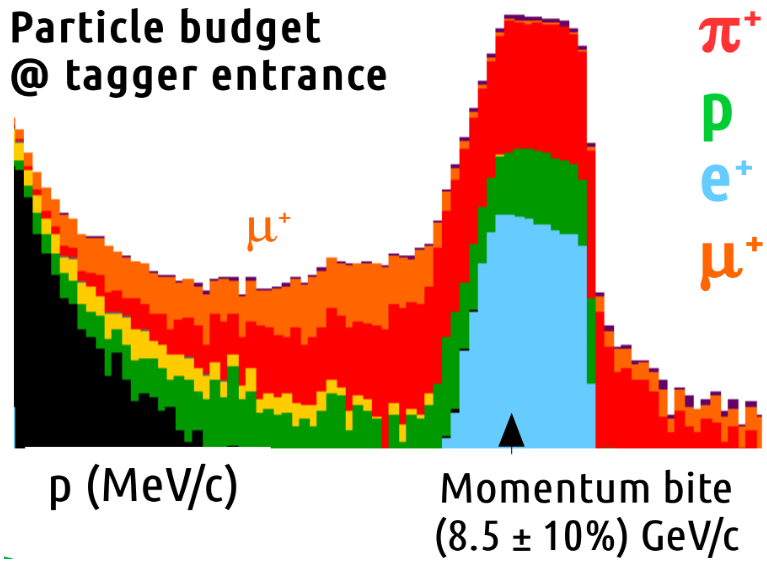
(a) 2 ms at 10 Hz during the flat top (2 s) to empty the accelerator after a super-cycle: this extraction scheme is currently under test at CERN
(b) Slow extraction. Detailed performance and losses currently under evaluation at CERN
(c) A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155

Advantages of the static extraction:

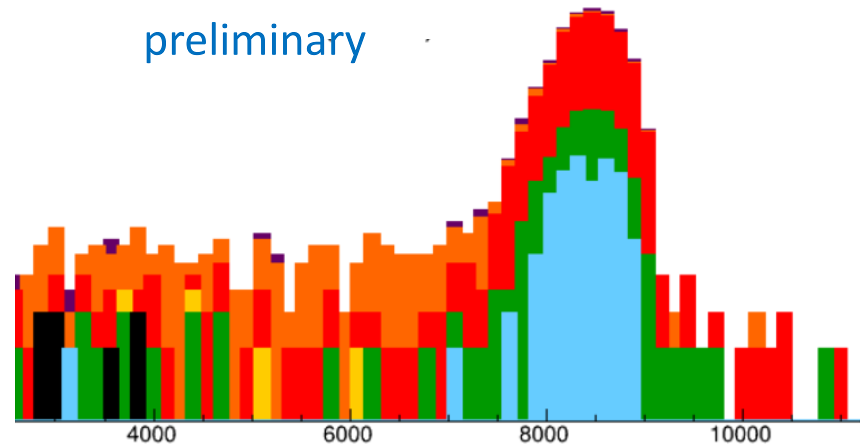
- No need for fast-cycling horn
- Strong reduction of the rate in the instrumented decay tunnel
- Possibility to monitor the muon rate after the dump at 1% level (flux of ν_μ from pion decay) [**NEW: under evaluation**]
- Pave the way to a «tagged neutrino beam», namely a beam where the neutrino interaction at the detector is associated in time with the observation of the lepton from the parent hadron in the decay tunnel

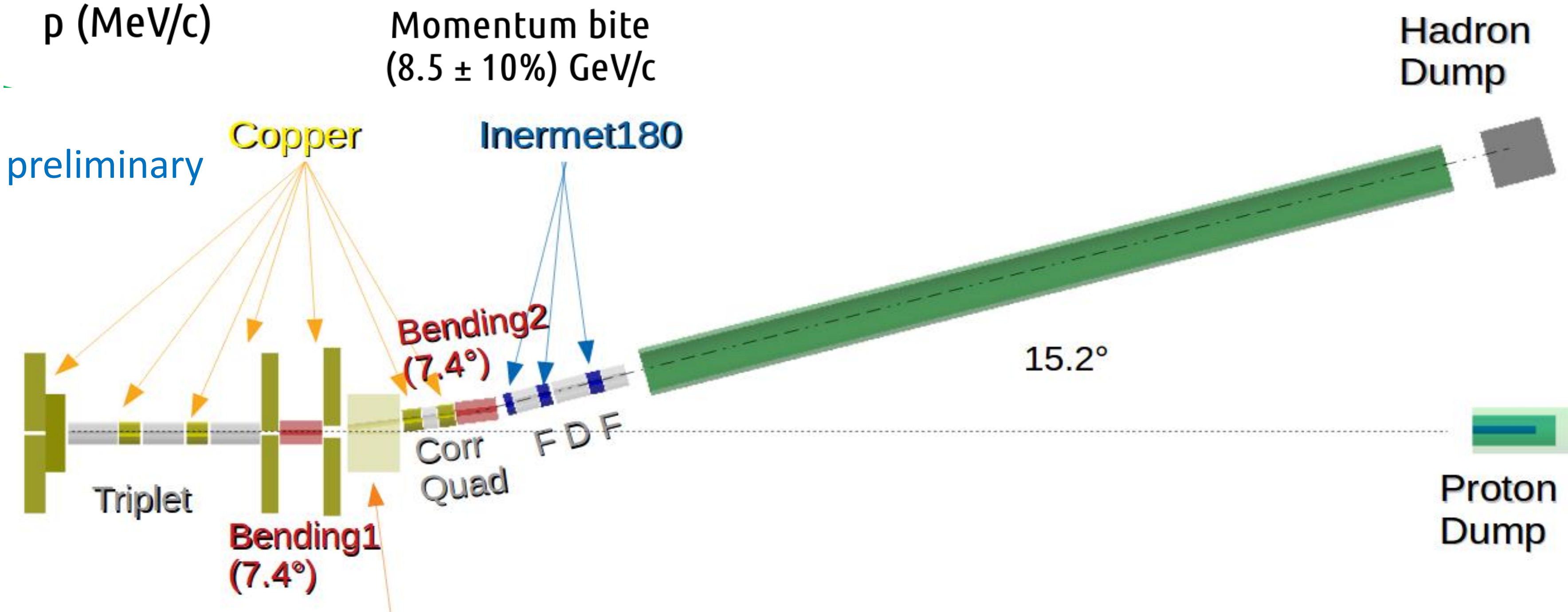
A more sophisticated design

One dipole beamline (baseline)

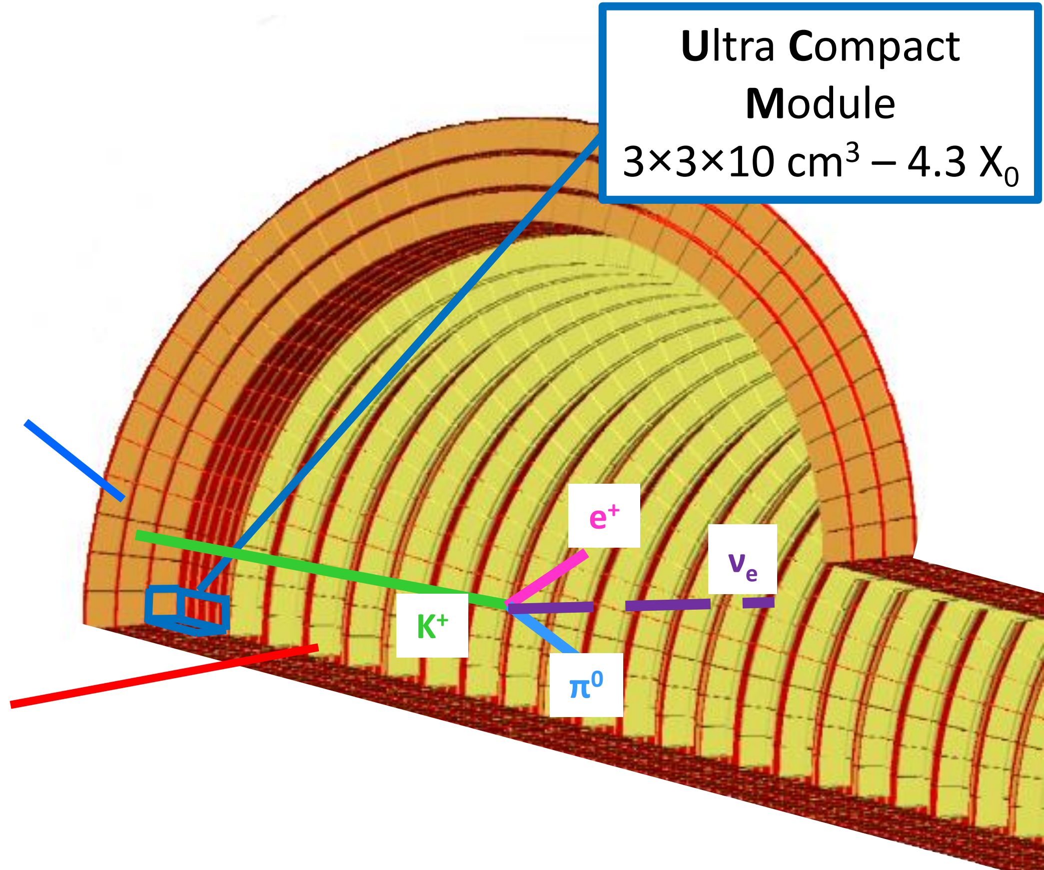


Two dipole (achromat focusing) beamline





Instrumentation



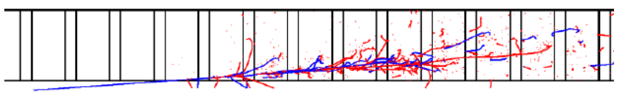
Calorimeter

Longitudinal segmentation

Plastic scintillator + Iron absorbers

Integrated light readout with SiPM

→ $e^+/\pi^\pm/\mu$ separation

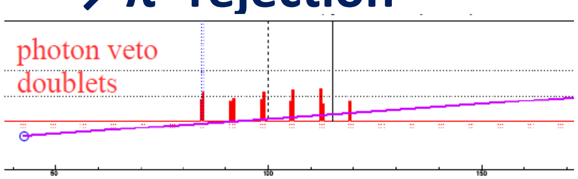


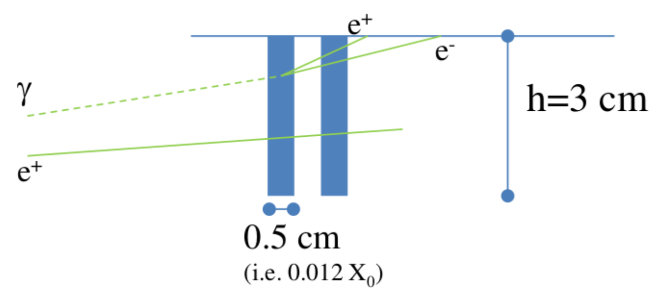
Integrated photon veto

Plastic scintillators

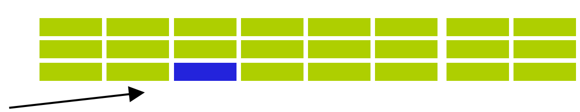
Rings of 3×3 cm^2 pads

→ π^0 rejection

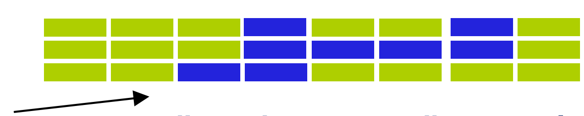




e^+ (signal) topology



π^0 (background) topology



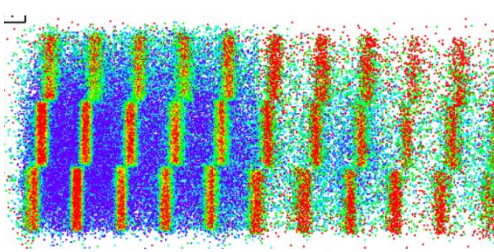
π^+ (background) topology

Calorimeter

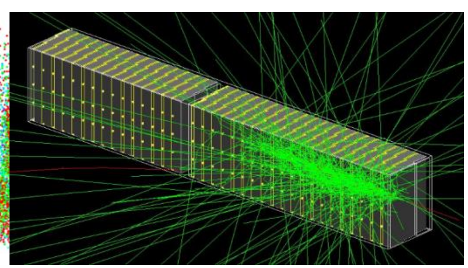
Several options studied in 2016-2019. Final choice: **sampling calorimeter with lateral light readout (WLS fibers + SiPMs)**

- ✓ Validation performed at CERN in fall 2018
- ✓ Construction of a 3 m full fledged instrument (**ENUBET demonstrator**) in 2020)

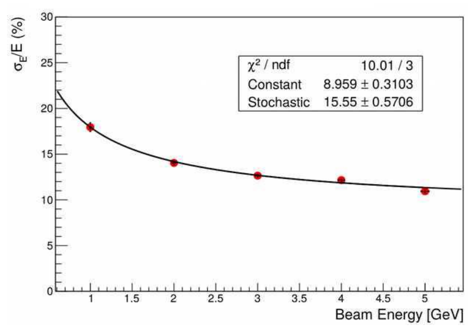
Efficiency maps



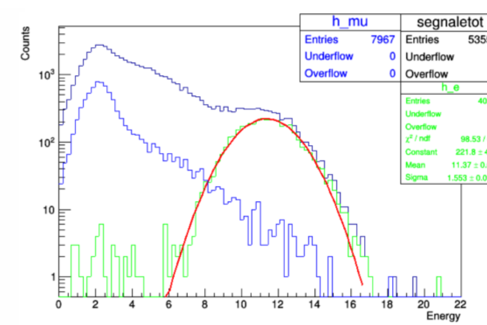
Simulation



Resolution



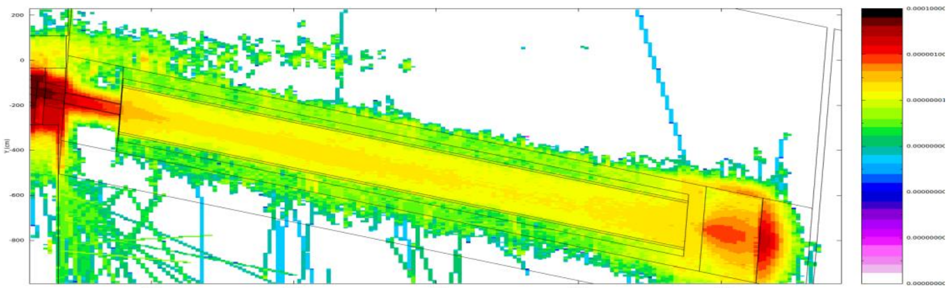
PID

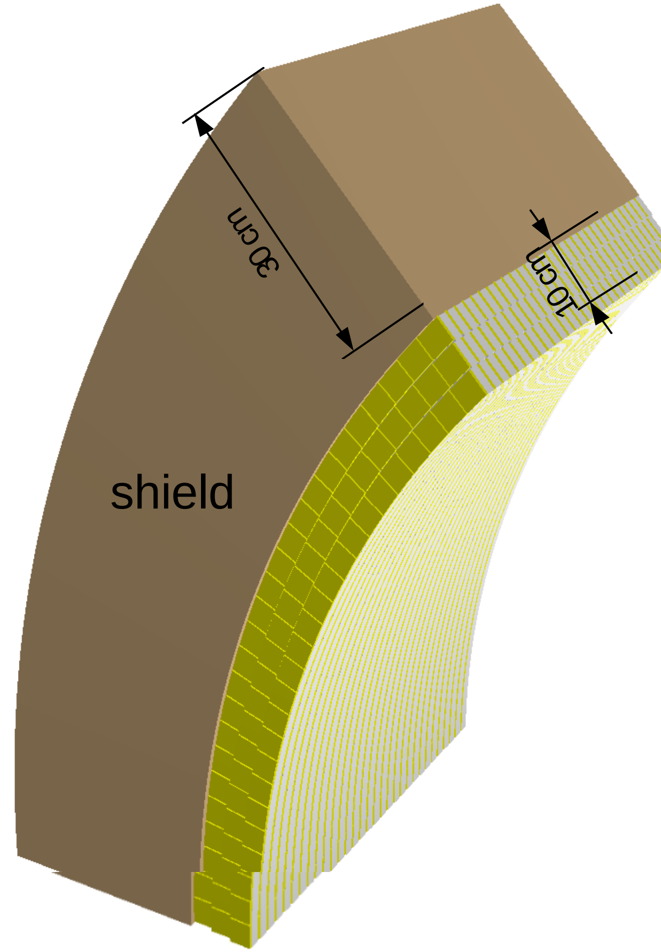


Radiation damage

FLUKA simulation of the whole beamline

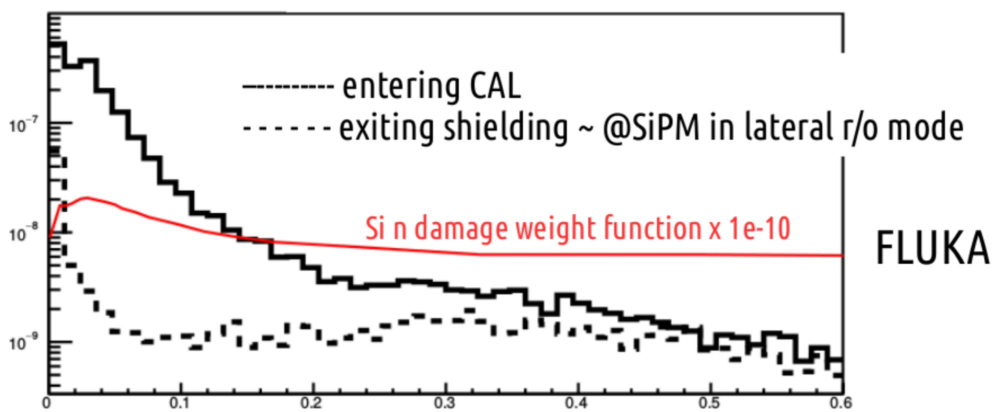
Special emphasis on neutron-induced damage in photosensors ($<10^{11}$ n/cm^2) for the entire lifetime of the experiment

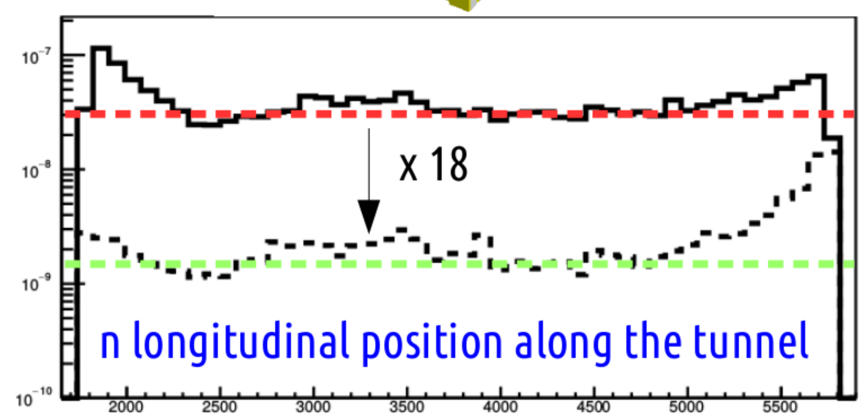




Neutron energy

preliminary

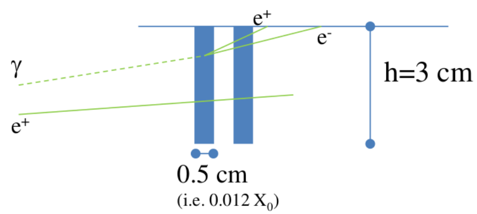


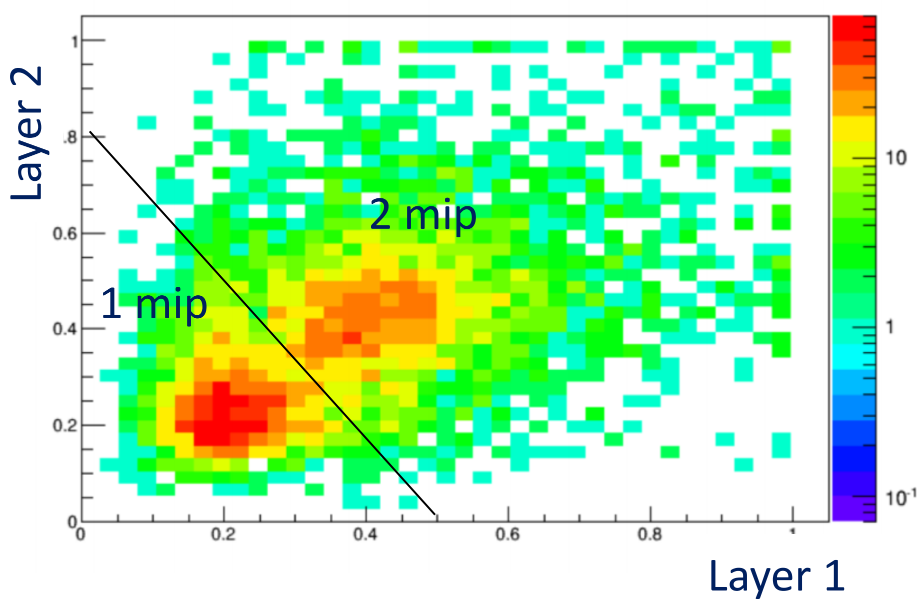


The photon veto

Scintillator ($3\times3\times0.5$ cm^3) + WLS Fiber (40 cm) + SiPM

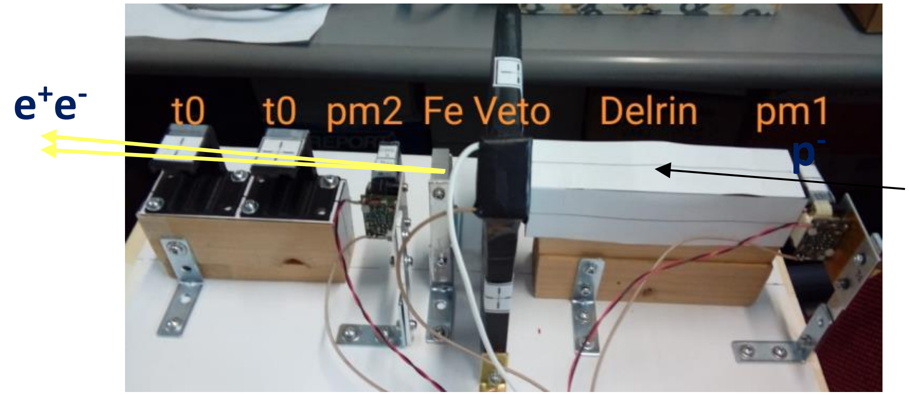
- ✓ light collection efficiency → >95%
- ✓ time resolution → **σ_t ~ 400 ps**
- ✓ 1mip/2mip separation

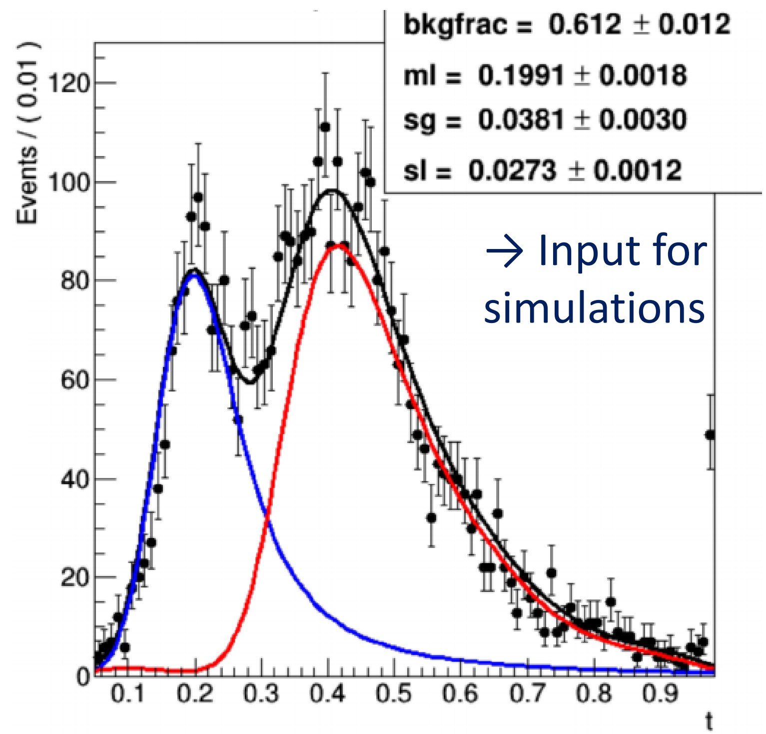




charge exchange: **$\pi^- p \rightarrow n\, \pi^0$ (→ gg)**

Trigger: PM1 + VETO +PM2





→ Input for simulations

Particle monitoring

Positron identification from K decay

Full GEANT4 simulation of the detector, validated by prototype tests at CERN in 2016-2018. The simulation include particle propagation and decay, from the transfer line to the detector, hit-level detector response, pile-up effects.

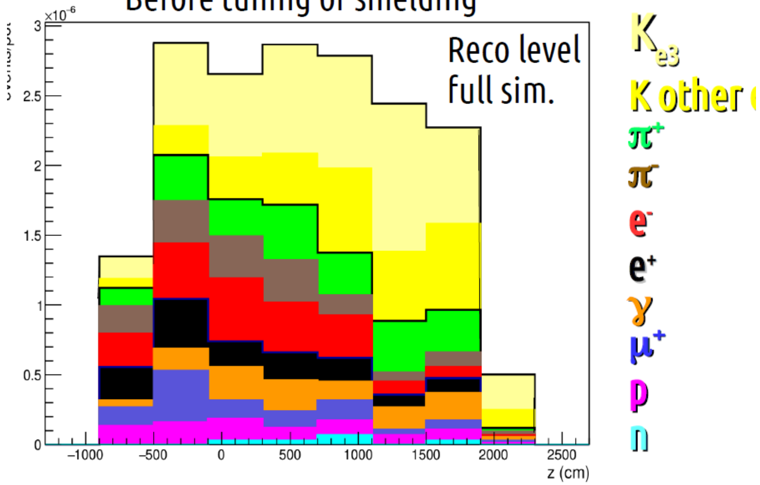
Analysis chain

Event Builder → Identify the seed of the event (UCM with large energy deposit) and link neighboring modules

$e/\pi/\mu$ separation → (**Neural Network**) TMVA multivariate analysis based on 5 variables (pattern of the energy deposition in the calorimeter)

e/γ separation → Signal on the tiles of the photon veto

Before tuning of shielding



after E and z-cut

ε_{geom}	**0.36**
ε_{sel}	0.55
ε_{tot}	0.20
purity	0.26
S/N	0.36

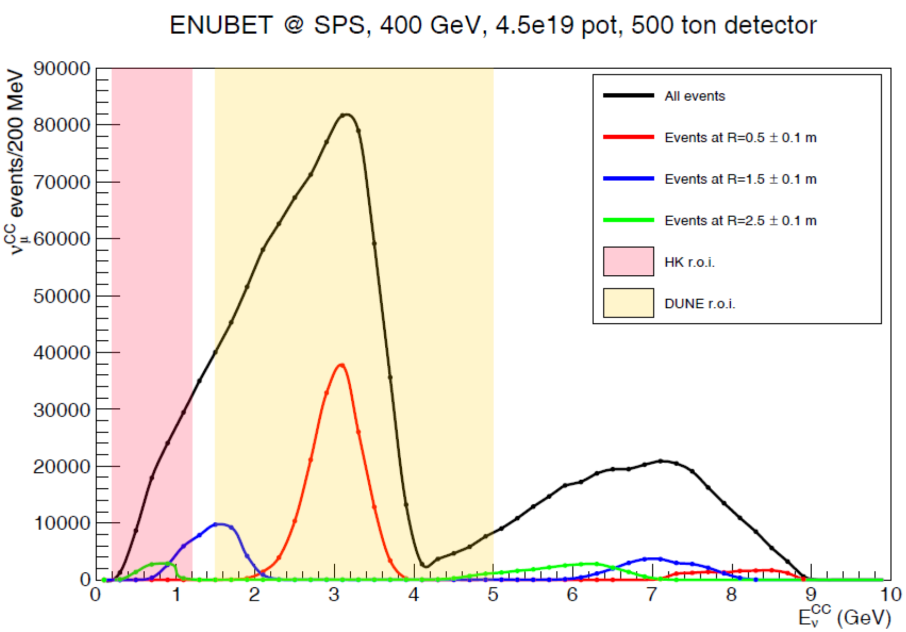
φ-cut → **0.46**

Instrumenting half of the decay tunnel we identify positrons from K decay at single particle level with a S/N = 0.46

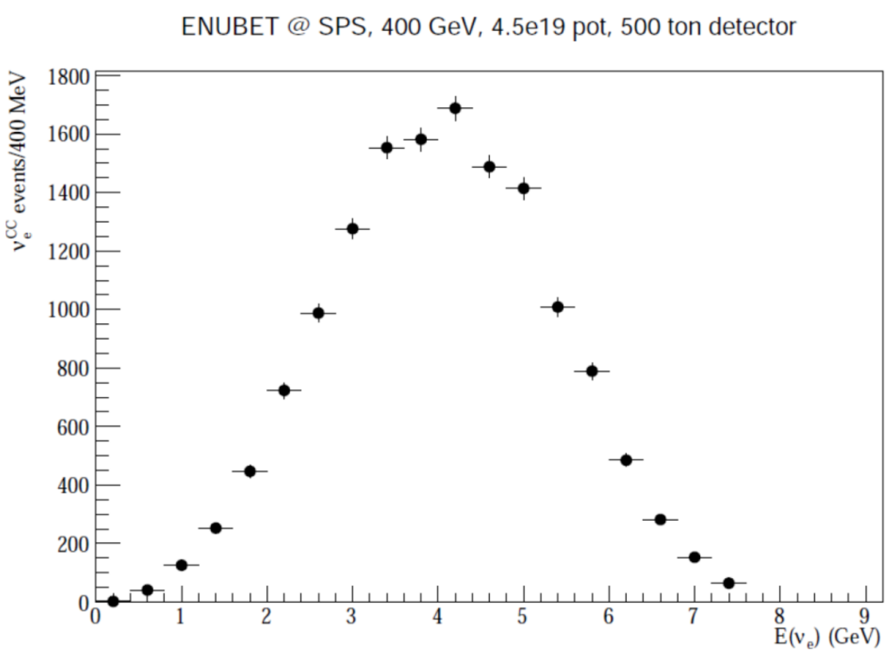
ν at detector

Neutrino events per year at the detector

Detector mass: 500 tons (e.g. Protodune-SP or DP @ CERN, ICARUS @ Fermilab)
Baseline (i.e. distance between the detector and the beam dump) : 50 m
Integrated pot: 4.5 10^{19} at SPS (6 months in dedicated mode, ~**1 year in shared mode**) or, equivalently, 1.5 10^{20} pot at the Fermilab Main Ring.
Warning: detector response not simulated!



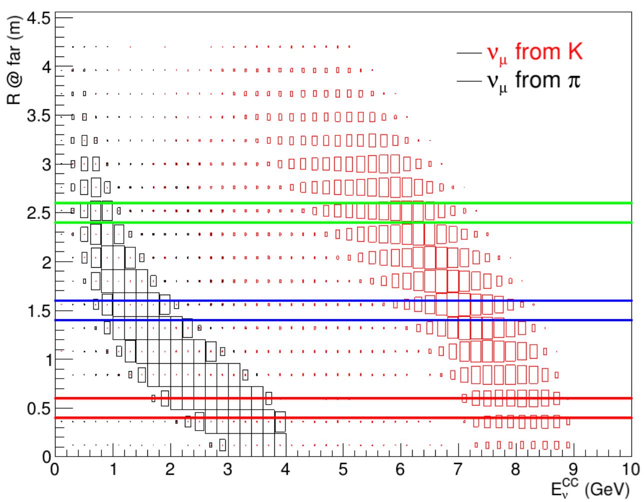
1.2 10^6 ν_μ charged current events per year

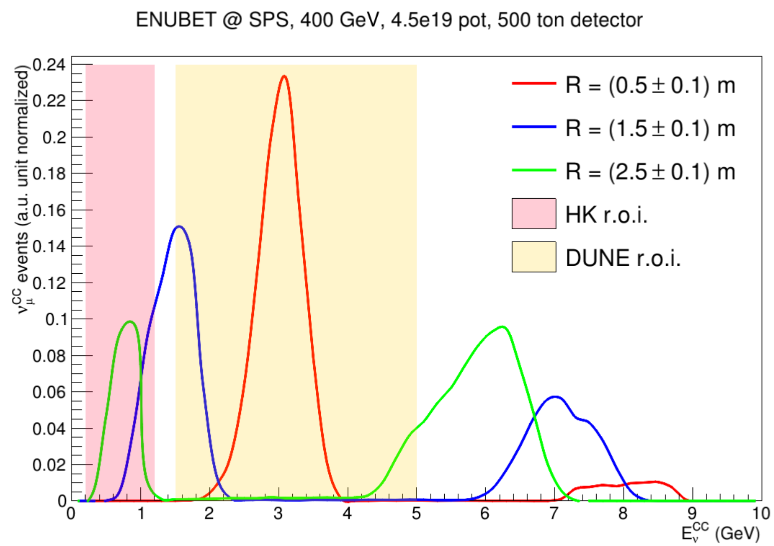


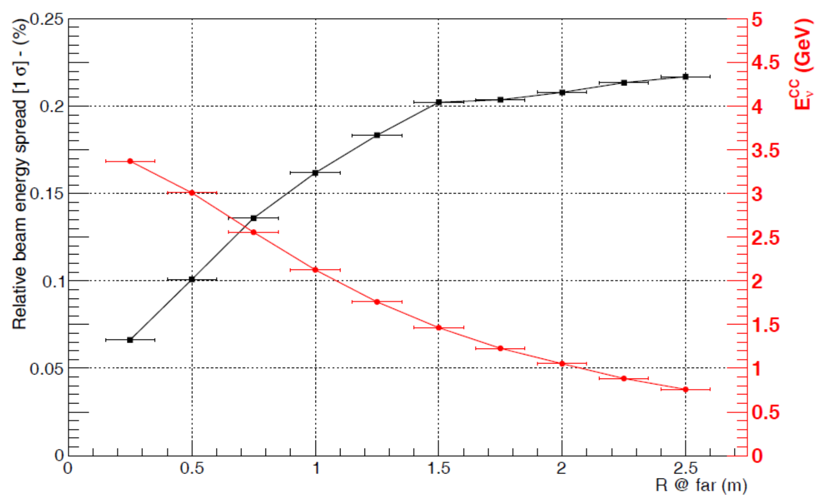
1.4 10^4 ν_e charged current events per year

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%

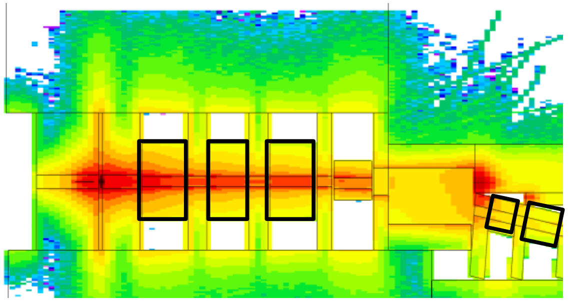






Ongoing in 2019

Beamline engineering



Proton extraction scheme for ENUBET: M. Pari, M. A. Fraser, B. Goddard, V. Kain, L. S. Stoel, and F. M. Velotti, doi:10.18429/JACoW-IPAC2019-WEPMP035

Optimization of the beamline to achieve a higher S/N

Doses at the first quad triplet

Assessment of systematics

Adapt the T2K (BANFF) approach to reduce the flux uncertainty using as input the measured positron spectra in the instrumented decay tunnel

NEW!

Muon monitoring before and after the hadron dump

Funded by an ENUBET satellite grant (NUTECH, Italy)

Exploit the static focusing option to transform ENUBET from a monitored to a tagged neutrino beam

Conclusions

- ENUBET is a narrow band beam with a high precision monitoring of the flux at source (1%), neutrino energy (20% at 1 GeV $\rightarrow$ 8% at 4 GeV) and flavor composition (1%)
- In the last year, we
  - completed the **end-to-end simulation** of the beamline in the baseline option
  - identified the best technology for the instrumentation of the decay tunnel after a **complete testbeam validation at CERN-PS**
  - solved the problems of **radiation hardness** of the instrumentation
- We are proceeding toward the Conceptual Design (2021) that will include the full assessment of the systematics , the monitoring of the other decay modes of K and of pions, the outline of the physics performance for cross-section measurement and cost estimates
- We are fostering a **white paper** on a new generation of cross section experiments together with physicists working on high precision neutrino detectors (in particular the Near detectors for DUNE/HK)

We look forward to seeing these experiments up and running in the DUNE/HyperK era!