ENUBET: a monitored neutrino beam for the precision era of neutrino physics

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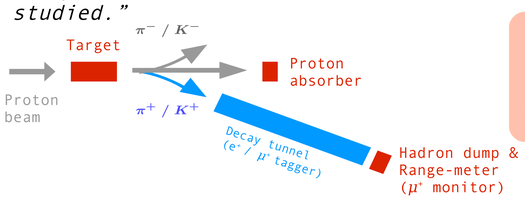
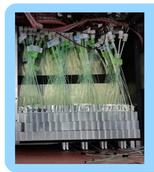
NP06/ENUBET OVERVIEW

NP06: CERN Neutrino Platform experiment number 6
ENUBET: Enhanced NeUtrino BEams from Kaon Tagging

GOAL: developing a new narrow-band neutrino beam in which the flux and flavor composition are known at 1% level, and the energy with O(10%) precision.
MOTIVATION supported by the European Strategy for Particle Physics Deliberation document (page 5):
"To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. [...]. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied."





Shashlik to lateral readout design migration for attenuating SiPM radiation damage. Hadronic cal + γveto prototype beam exposure at CERN-PS

Start of ERC grant & initial shashlik design beam exposure at CERN-PS

Systematics budget finalization & demonstrator construction

1979 | 2016 | 2017 | 2018 | 2019 | 2021 | 2022

SiPM irradiation campaign at INFN-LNL and beam exposure of irradiated sensors at CERN-PS

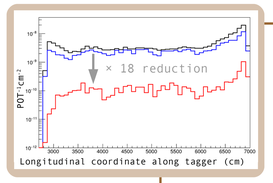
"The possibility of using tagged-neutrino beams in high-energy experiments must have occurred to many people." B. Pontecorvo, Lett. Nuovo Cimento, 25 (1979) 257

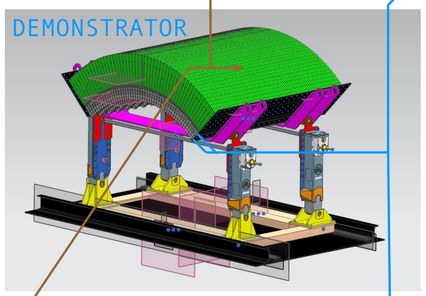
Demonstrator beam exposure at CERN-SPS & conceptual design report

ENUBET becomes a CERN Neutrino Platform experiment

THE DEMONSTRATOR

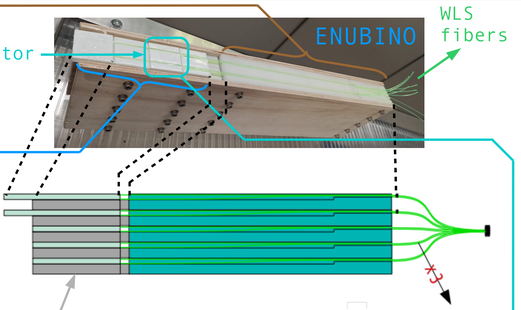
Deliverable of the ENUBET ERC project is the tagger demonstrator, a portion of the instrumented decay tunnel:
- Under construction, to be finished in 2022 for beam exposure at CERN.
- Dimensions: azimuthal quarter-of-circle, length 1.65 m.
- Instrumented with electronics in central 45 degrees.



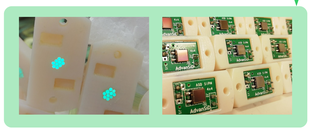


Neutron shield
(30 cm 5% borated polyethylene)
- Neutron reduction factor = 18

Calorimeter + γ-veto
(11 cm radial iron part)

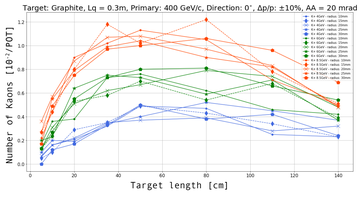


The ENUBINO prototype is a single azimuthal portion (3 radial LCM) of the demonstrator:
- Scintillator tiles frontally coupled to WLS-fibers.
- 10-fibers bundle (1 LCM) read by a 4 x 4 mm² RGB SiPM.



THE PROTON TARGET

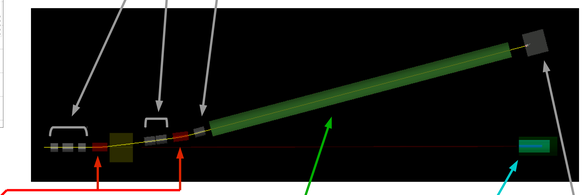
The design of the cylindrical target has been studied to optimize the challenging trade-off between heat dissipation and yield loss due to re-interactions in the target.



Bending dipoles
- Normal conducting
- 1.5 T field
- 14.8° total bend from proton beam-line

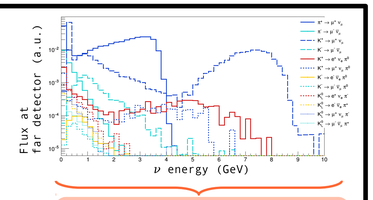
THE MESON TRANSFER LINE

Focusing quadrupoles
- Aperture radius 15 cm



Instrumented decay line

Proton dump



Assuming a realistic operation at CERN-SPS corresponding to 4.5×10^{19} POT/year, the newly simulated transfer line TLR6 would ensure, in a far detector displaced 50 m downstream its end, the occurrence of 10^4 ν_e-CC interactions in about 2 years.

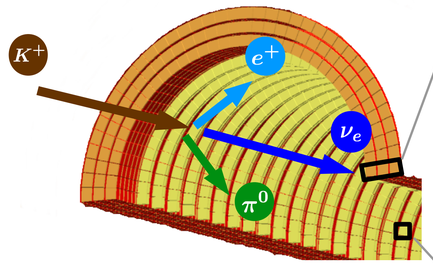
Hadron dump
- 3 radial layers: graphite core, iron coating, and outer borated concrete
- Neutron backscattering attenuation of 0.2

THE DECAY TUNNEL

NP06/ENUBET will be the first "monitored neutrino beam":
- ν_e flux monitored by tagging positrons in instrumented decay channel.
- ν_μ flux monitored by tagging muons in instrumented decay channel and range-meter in the hadron dump.

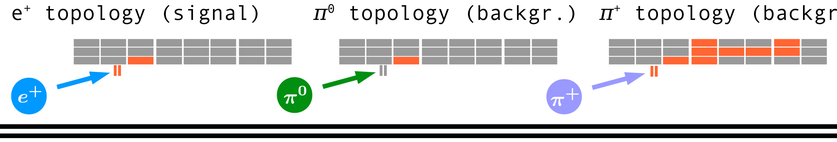
Lepton tagging e^+ μ^+
- Lepton deposited energy in innermost layer:
  - > 28 MeV for e^+
  - in [5, 15] MeV range for μ^+
- γ suppression from t0-layer
- hadronic bkg suppression permitted by longitudinal, transverse, and radial segmentation of calorimeter.
- Neural Network is applied for optimal signal-background discrimination.

Calorimeter functional block is the LCM:
- LCM = Lateral Compact Module
- LCM dimensions: 3 × 3 × 10 cm³ (4.3 X_0)
- Made of scintillator and iron
- $e^+/\mu^+/\pi^+$ discrimination capabilities

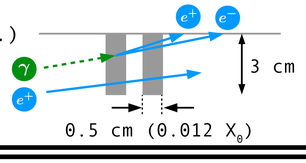


K^+ decay mode			Branching ratio (%)	
μ^+	ν_μ		63.55	Tagged in decay tunnel
π^+	π^0		20.66	
π^+	π^+	π^-	5.59	
π^0	e^+	ν_e	5.07	
π^0	μ^+	ν_μ	3.353	
π^+	π^0	π^0	1.761	
$\pi^+ \longrightarrow \mu^+ \nu_\mu$				Tagged in range-meter

Photon veto rings are made of scintillator doublets:
- Scintillator dimension 3 × 3 × 0.5 cm³ (0.012 X_0)
- Rejects gammas from π^0 decay



Photon veto working principle

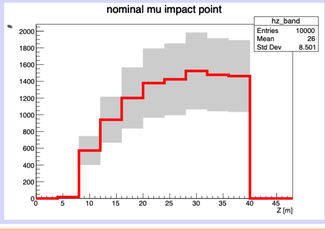


ν-FLUX SYSTEMATICS

Lepton monitoring data coming from the calorimeter and range-meter can constrain the hadro-production and beamline parameters, implying a reduction of the systematic uncertainty on the neutrino flux.

EXAMPLE: consider as observable the position Z along the calorimeter of the muons from K-decays.

1 Construct from MC simulation the PDF of Z,and store it as a histogram $PDF(Z;\vec{\alpha})$

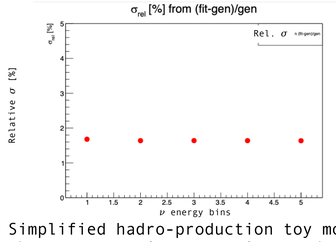


2 Given the lepton monitoring data-set $\{Z\}_i$ compute the likelihood for various values of the hadro-production parameters α

$$\log \mathcal{L}(\vec{\alpha}) = \sum_{i \in \{DATA\}} \log PDF(Z_i;\vec{\alpha})$$

3 The hadro-production parameters are constrained to the values maximizing the likelihood

$$\max\left(\log \mathcal{L}(\vec{\alpha})\right) \Longrightarrow \text{constrained } \vec{\alpha}$$



Simplified hadro-production toy model shows systematic uncertainty reduction from initial 15% down to 1.8%. Complete study of systematics budget ongoing.

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