The ENUBET monitored neutrino beam: a progress report

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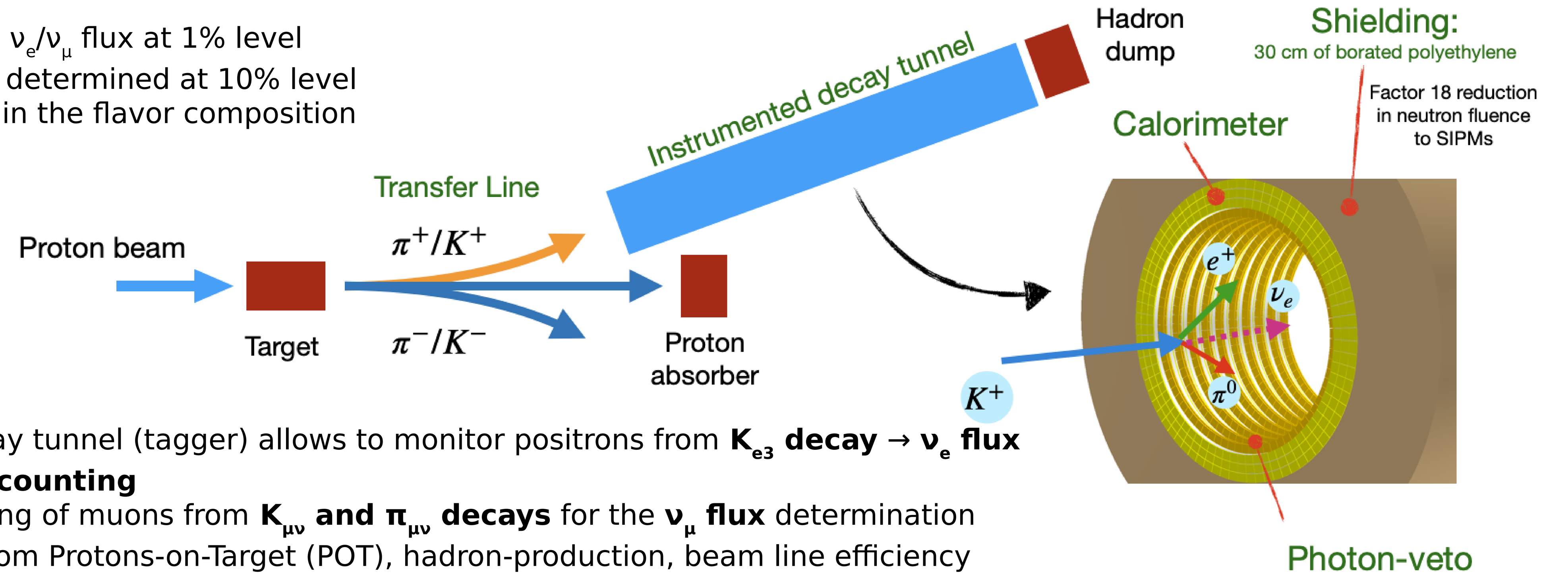
The idea of monitored neutrino beams

ENUBET (**E**nhanced **NeU**trino **BE**ams from kaon **T**agging): a narrow-band beam for the precision era of ν physics:

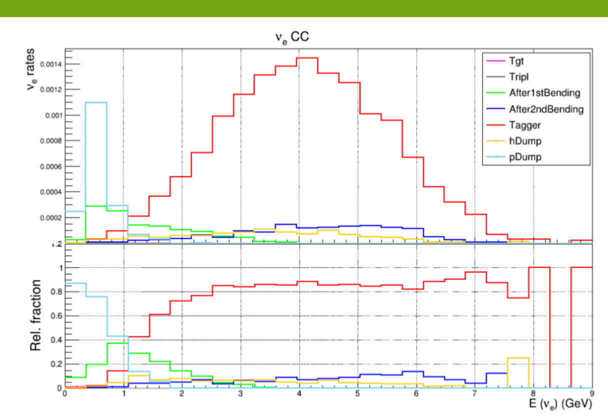
- Knowledge of absolute ν_e/ν_μ flux at 1% level
- Energy of the neutrino determined at 10% level
- High precision (@ 1%) in the flavor composition



- The instrumented decay tunnel (tagger) allows to monitor positrons from **K_{e3} decay → ν_e flux** determination from **e^+ counting**
- Extend to the monitoring of muons from **$K_{\mu\nu}$ and $\pi_{\mu\nu}$ decays** for the **ν_μ flux** determination
- Avoids uncertainties from Protons-on-Target (POT), hadron-production, beam line efficiency

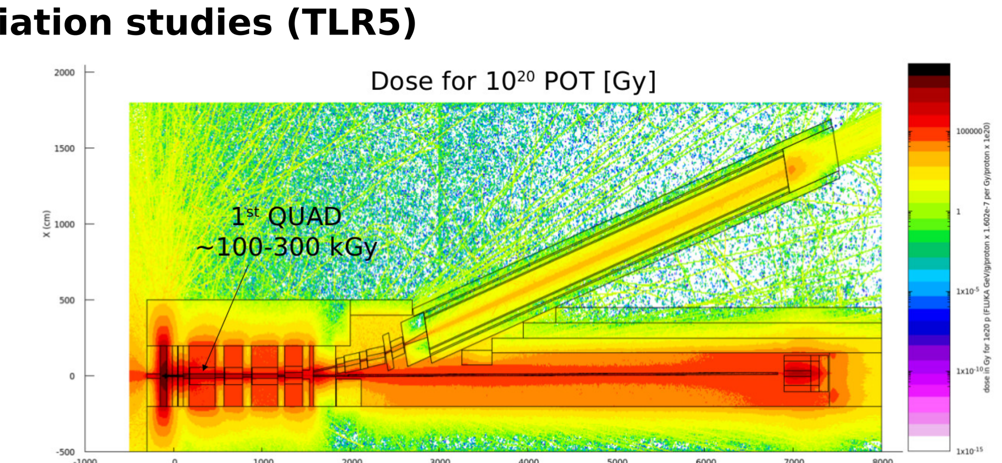
Beamline design

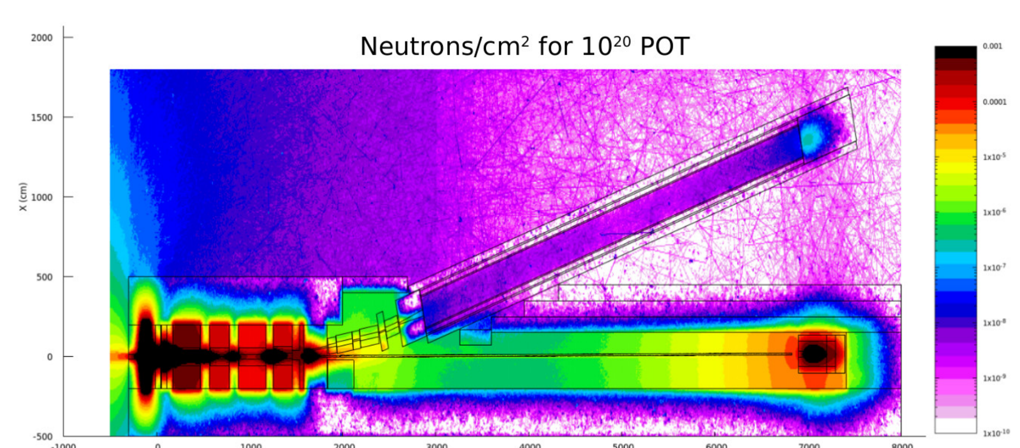
- A new design ("TLR6") worked out
- Optimizes length, optics and collimation
- Implements the optimized target
- Significant suppression of **ν_e from the target region** at low-E
- With 4.5×10^{19} POT/y → 10^4 ν_e ^{CC} on 500 t @ 100m from target



Transfer line	π^+ [10^{-3}/POT] [8.5 ± 5%] GeV/c	K^+ [10^{-3}/POT] [8.5 ± 5%] GeV/c	Ratio w.r.t previous results
previous TL	2.05	0.185	
TLR5	3.4	0.28	1.5
TLR6	4.2	0.4	2

Irradiation studies (TLR5)



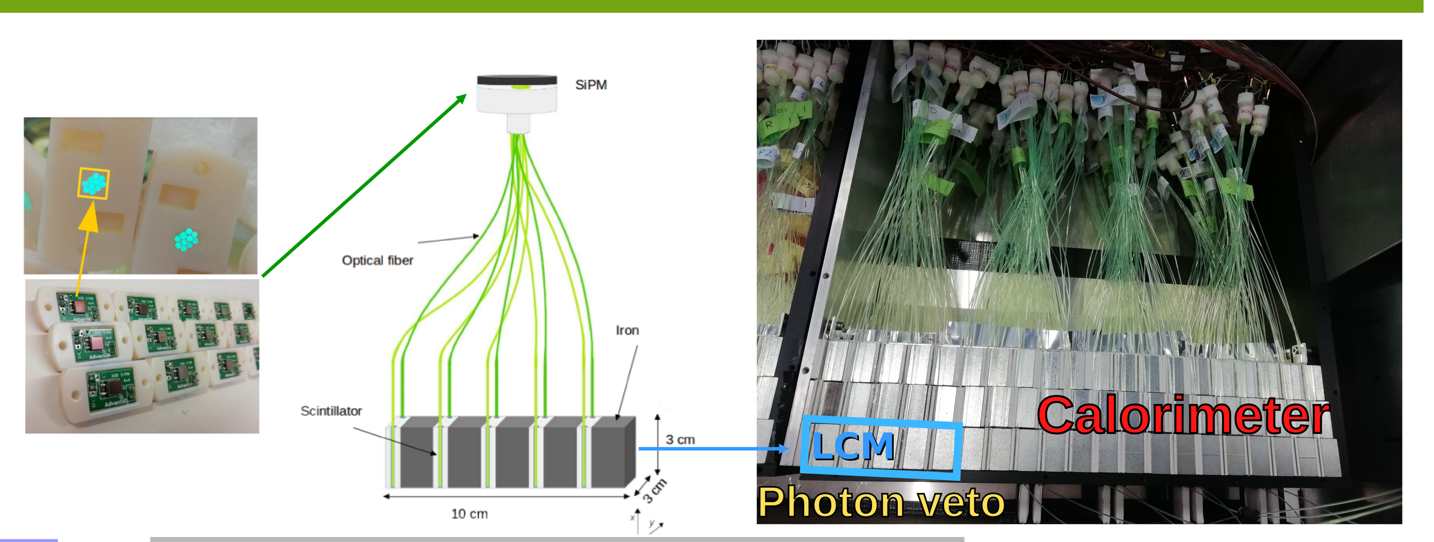


Focus on the instrumented decay tunnel, where scintillators and SiPMs are located.

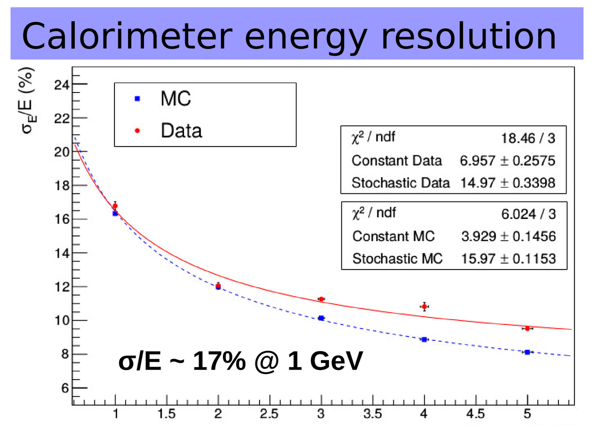
Monitoring instrumentation

Calorimeter (e^+ /$\pi^\pm$ /μ separation)
- Sampling calorimeter: plastic scintillator (0.5 cm) + Iron absorbers (1.5 cm);
- three radial layers of Lateral Compact Modules (LCM: 3×3×10 cm³ ~4.3 X_0) with longitudinal segmentation;
- light collection/readout: WLS fibers & SiPM.

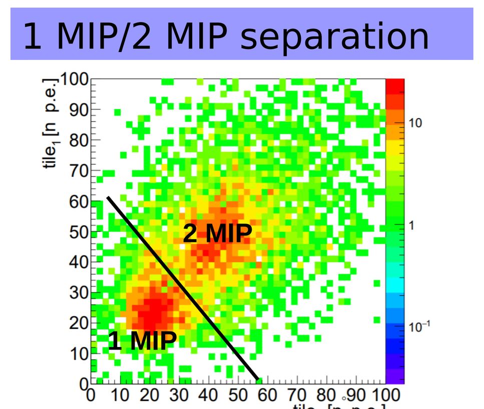
Photon veto (π^0 rejection)
- Plastic scintillator tiles;
- 3×3 cm² tiles arranged in doublets forming inner ring;
- time resolution of ≃ 400 ps.



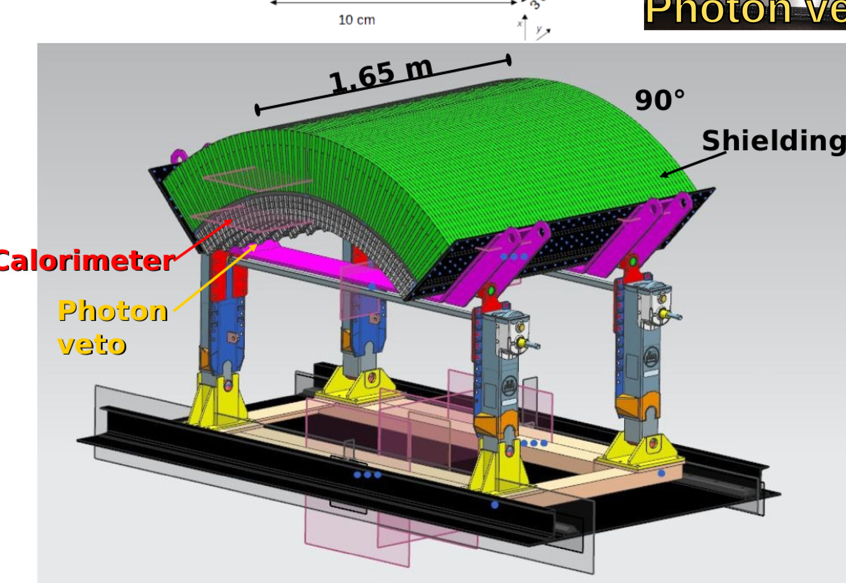
Calorimeter energy resolution



1 MIP/2 MIP separation



Results published in "F.Acerbi *et al.*, The ENUBET positron tagger prototype: construction and testbeam performance, 2020, JINST 15 P08001"



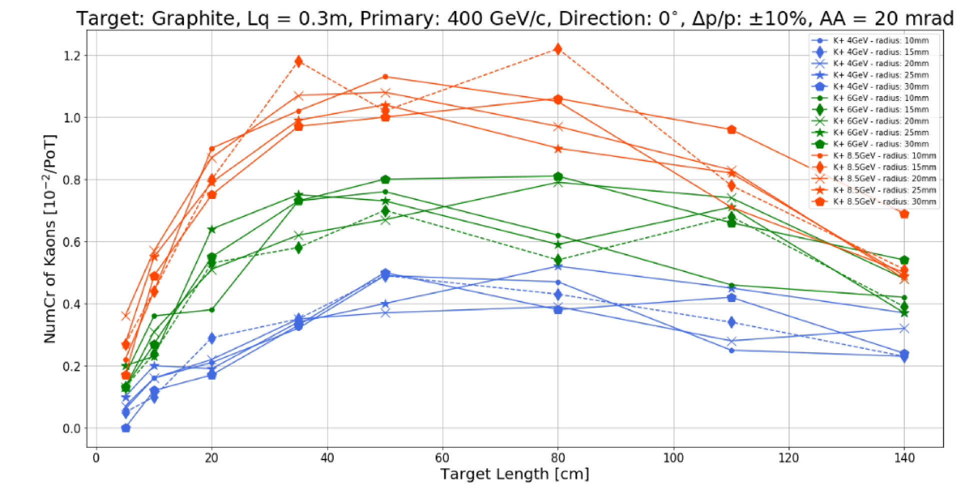
Pre demonstrator small prototype to be soon characterized at INFN-LNL

Final demonstrator by 2022 @ CERN: ENUBET part of the Neutrino Platform as NP06/ENUBET

Improved design of the proton target

Explored the parameter space of the geometry (also tronco-conical) and some materials (graphite, beryllium, Inconel) to maximise the yields of mesons in our region of interest with FLUKA and G4beamline.

Studies on secondary target production confirm nominal energy of SPS (400 GeV/c) fits the requirements for ENUBET.



New baseline targets:

Graphite: L/ø = 700/60 mm
Inconel: L/ø = 500/60 mm

Simulation of the facility

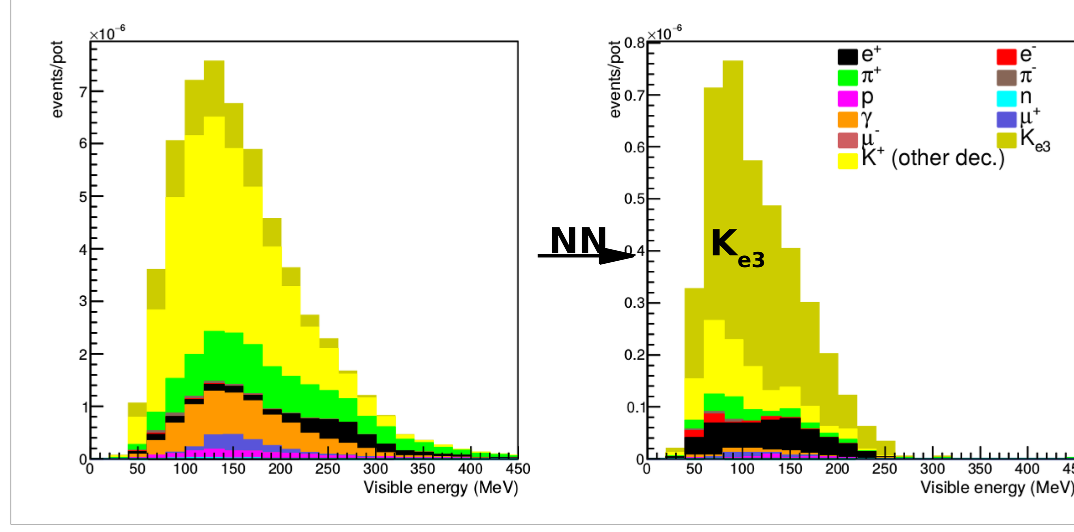
Positron monitoring

Multivariate analysis exploiting a set of variables describing the energy deposition pattern in the tagger from the longitudinal, transverse and radial segmentation of the calorimeter + photon veto.

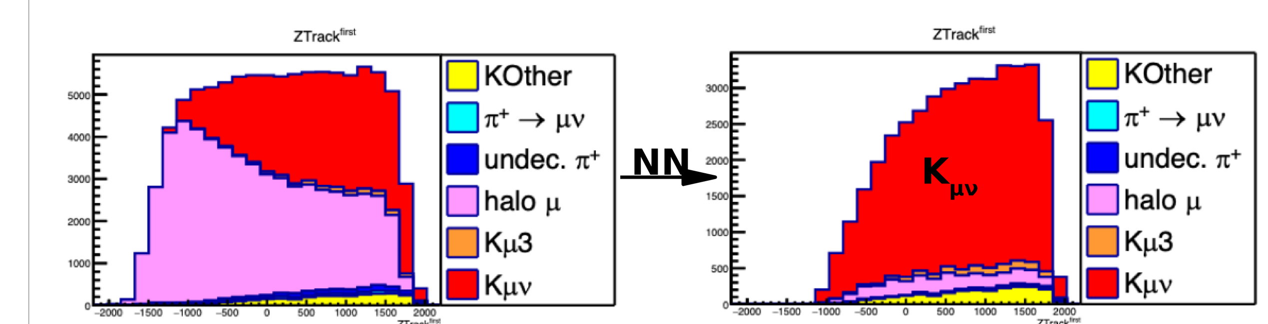
In inner layer **E>28 MeV**

Based on Multilayer perceptron **Neural Network (NN)**.

Positrons monitored with **efficiency ~22% and S/N of ~2**



Muon monitoring



Tagger: discrimination of μ from $K_{\mu 2}$ and $K_{\mu 3}$ by clustering of the energy deposit **(NN).**
If in inner layer **5<E<15 MeV** → compatible with MIP.
Signal/background muons discrimination from impact point position along the calorimeter.

Muons monitored with **efficiency ~34% and S/N of ~6**

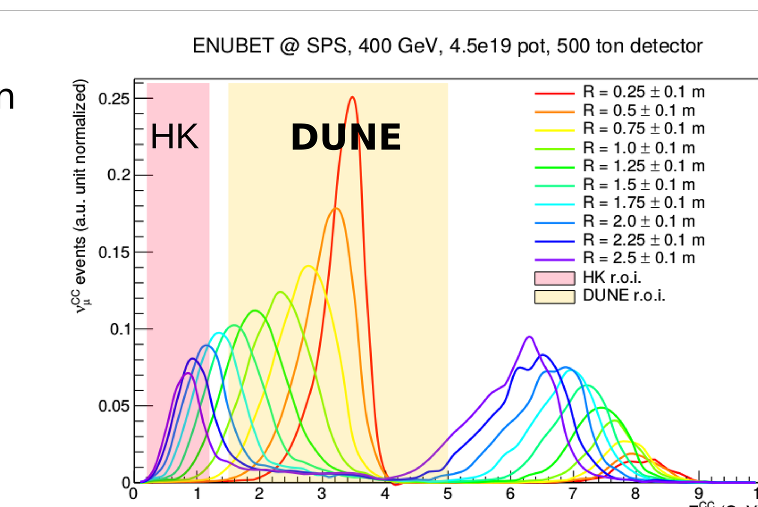
Instrumented hadron dump: reconstruct energy and spatial distributions of μ from π → monitor low-E ν_μ.

Narrow band off-axis technique

Slow extraction → combine the information from the tagger to the one of muons after hadron dump → **complete monitoring of ν_μ**

Narrow momentum width of the beam (O(5-10%)) → neutrino energy correlated with the position of the interaction vertex in a detector (500 ton LAr, cross-area 6x6 m²) placed at short distance (90 m from entrance of decay tunnel, 50 m from hadron dump).

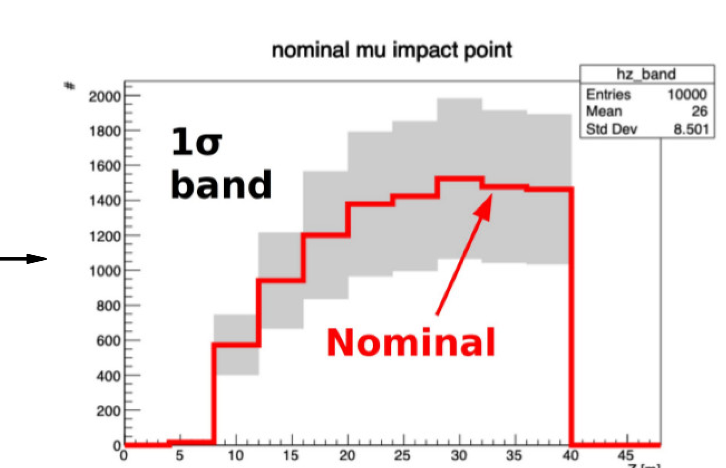
Precision of neutrino energy: **8%-25% in DUNE energy domain**, 30% for HyperK



Assessment of neutrino flux systematics

Constrain the neutrino flux from the reconstructed leptons by using a software framework written within RooFit.

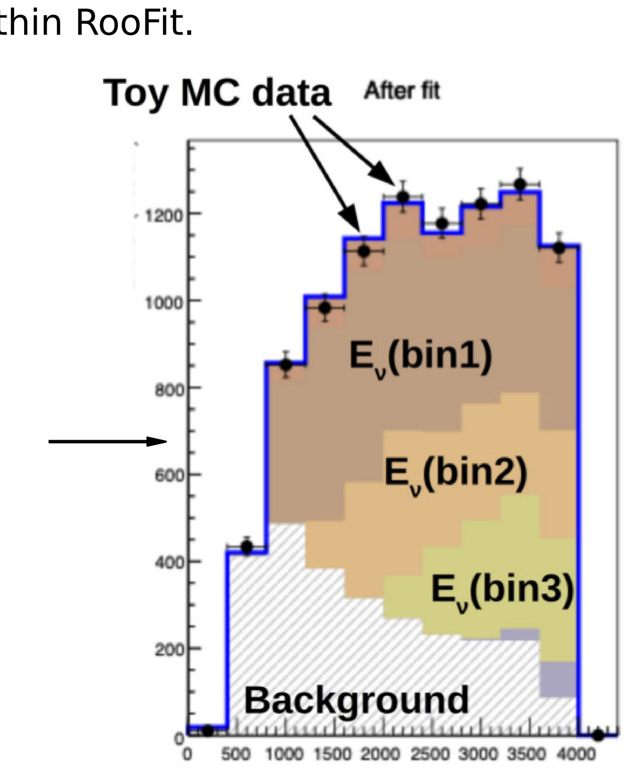
To validate the machinery: impact point along the tagger of muons from kaon decays (starting from simulation).
Uncertainty envelope of 1σ created by sampling hadroproduction parameters of a toy model (multiverse method).



Outcome from a 500 toy MC test.

Model built from signal templates for different neutrino energies + background template.

Performed extended likelihood fit with nominal nuisances.



Fit the relative normalizations of the templates in Eν → **flux constraint**.
NEXT STEP: built a model based on real hadroproduction data.

References

1)ENUBET Collaboration, Enabling precise measurements of flux in accelerator neutrino beams: the ENUBET project, CERN-SPSC-2016-036; SPSC-EOI-014.
2)F. Acerbi et al., CERN-SPSC-2018-034, SPSC-I-248, Geneva, 2018
3)A. Longhin, L. Ludovici, F. Terranova, A novel technique for the measurement of the electron neutrino cross section, Eur. Phys. J. C (2015) 75:155;
4)F. Acerbi et al., NP06/ENUBET annual report for the CERN-SPSC, CERN-SPSC-2020-009. SPSC-SR-268, Geneva, 2020
5)ENUBET Collaboration, Enabling precise measurements of flux in accelerator neutrino beams: the ENUBET project, CERN-SPSC-2016-036; SPSC-EOI-014;
6)N. Charitonidis, A. Longhin, M. Pari, E. G. Parozzi and F. Terranova, "Design and Diagnostics of High-Precision Accelerator Neutrino Beams," Appl. Sciences 11 (2021) 1644.
7)F.Acerbi *et al.*, The ENUBET positron tagger prototype: construction and testbeam performance, 2020, JINST 15 P08001

Please visit http://enubet.pd.infn.it for more information