ENUBET: a monitored neutrino beam for high precision cross section measurement

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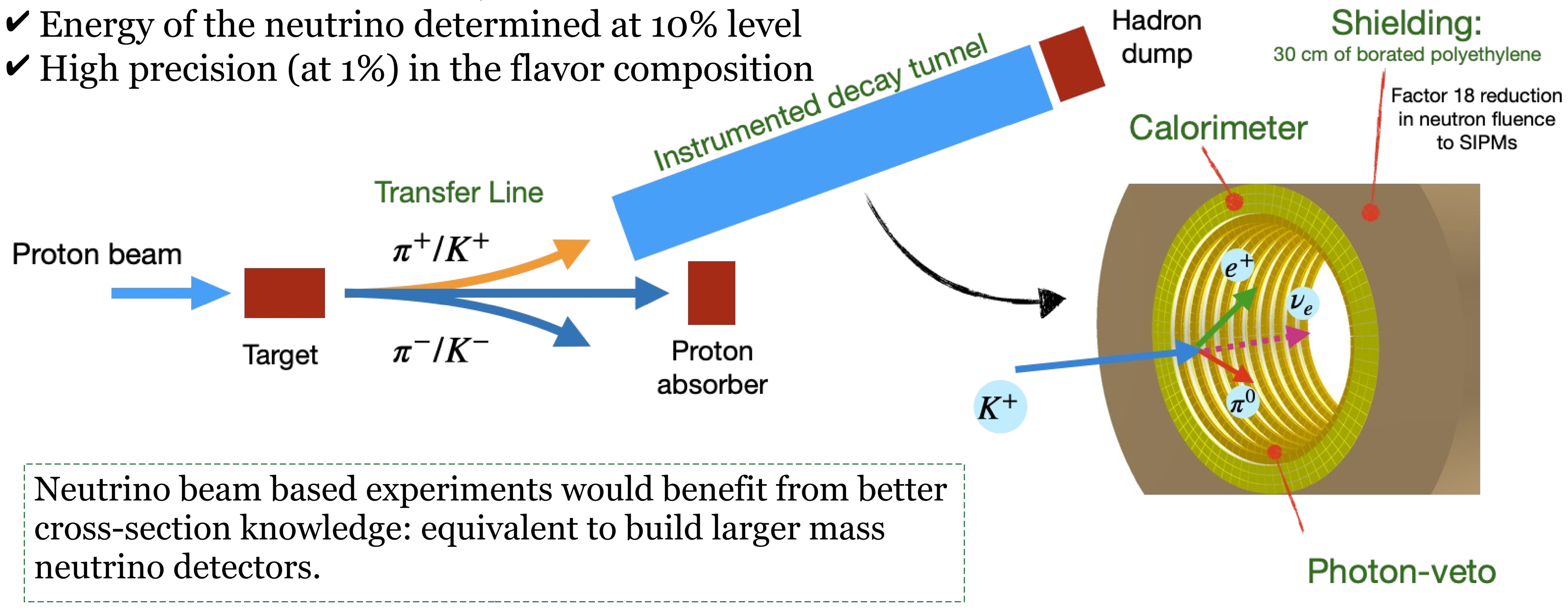
The concept: monitored neutrino beams

ENUBET (**E**nhanced **N**e**U**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 (at 1%) in the flavor composition



Neutrino beam based experiments would benefit from better cross-section knowledge: equivalent to build larger mass neutrino detectors.

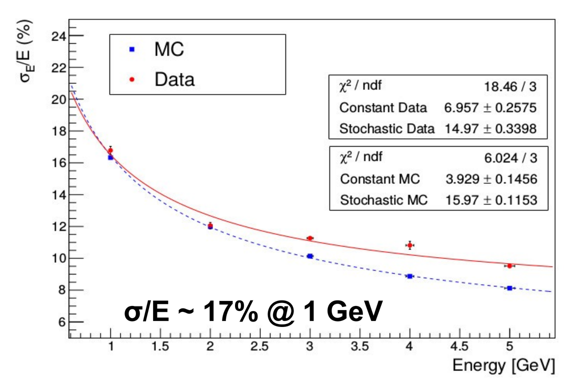
- The instrumented decay tunnel (tagger) allows to monitor positrons from K_{e3} **decay** → ν_e **flux** determination from **e⁺ counting**
- Extend to the monitoring of muons from $K_{\mu\nu}$ **and** $\pi_{\mu\nu}$ **decays** for the ν_μ **flux** determination
- Avoids uncertainties from Protons-on-Target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

The instrumented decay tunnel: prototype and the final demonstrator

Calorimeter ($e^+/\pi^\pm/\mu$ 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 and SiPM.

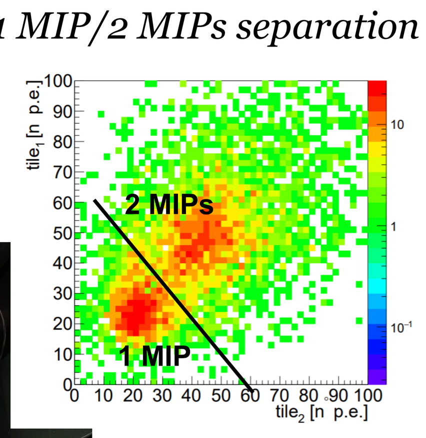
Calorimeter energy resolution



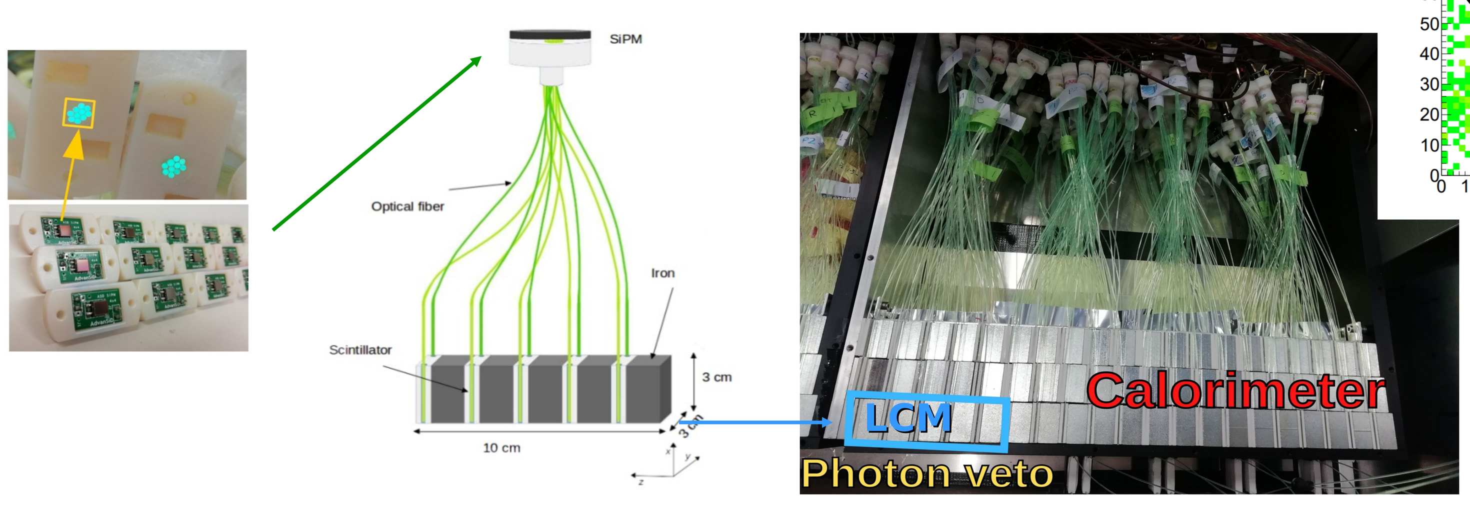
Photon veto (π^0 rejection)

- Plastic scintillator tiles: 3×3 cm² tiles arranged in doublets forming an inner ring below the calorimeter;
- time resolution of ≃ 400 ps.

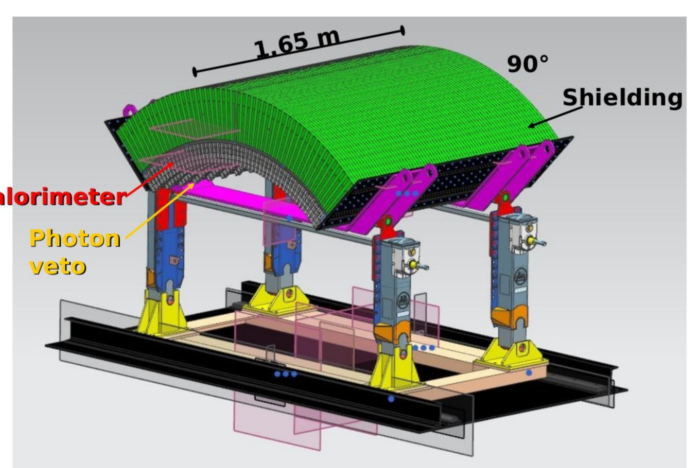
1 MIP/2 MIPs separation



Prototype tested during test-beams runs at CERN TS-P9.



- New light readout scheme with frontal grooves instead of lateral grooves driven by large scale scintillator production → safer production and more uniform light collection.
- **Pre-demonstrator** prototype with 3 LCMs (ENUBINO) tested at CERN PS-T9 in November 2021 to study the uniformity of response and efficiency maps;
- **Final demonstrator** by 2022 at CERN: ENUBET part of the Neutrino Platform as NP06/ENUBET.



Lepton reconstruction and PID performance

Full Geant4 simulation of the detector (validated by prototype tests at CERN during 2016-2018):

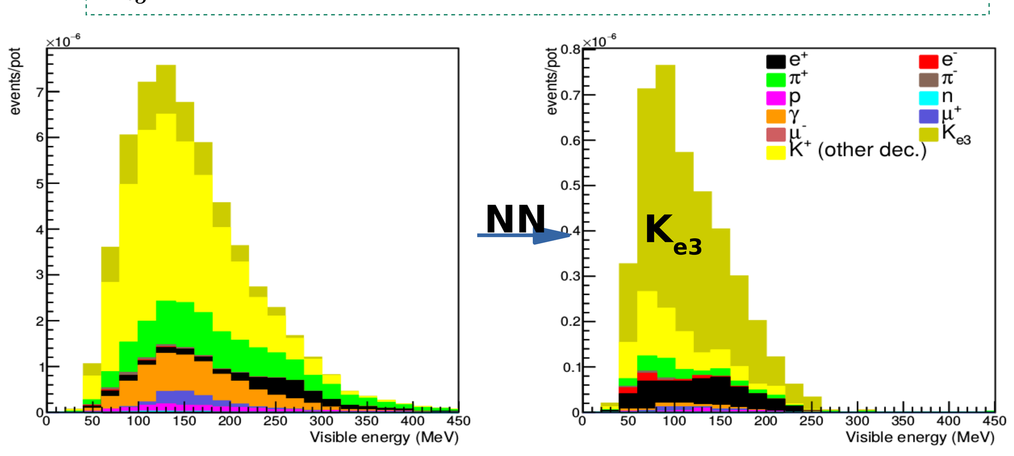
- particle propagation and decay from TL to detector;
- hit level detector response;
- pile-up effects included;

Analysis chain:

1. **Event builder**: identify LCM with energy deposit as seed of the event. Cluster neighbour LCM deposits compatible with particle.

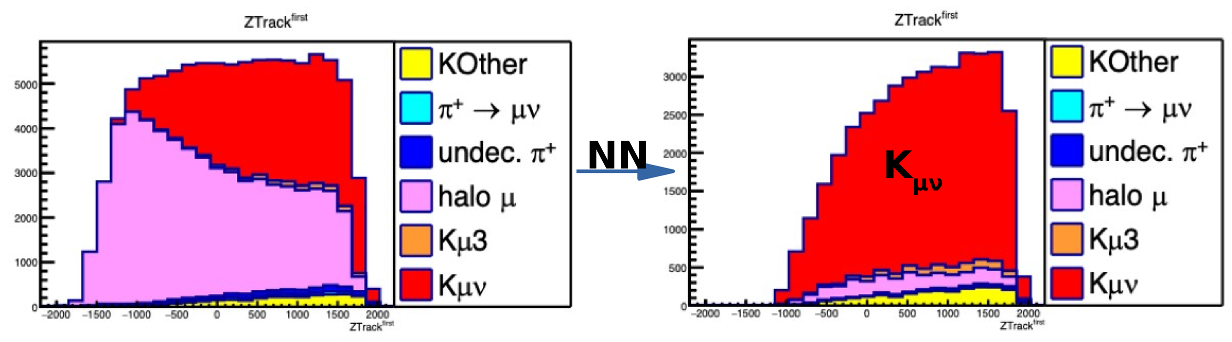
2. **Signal/background separation**: multivariate analysis (MLP-NN from TMVA) exploiting energy pattern deposition in calorimeter, event topology and photon-veto energy deposition variables

K_{e3} reconstruction: ε ~ 22 % and S/N ~ 2



$K_{\mu\nu}$ reconstruction: ε ~ 34 % and S/N ~ 6

- Instrumenting the hadron-dump will allow to monitor also muons from pion decays: evaluating detector background in collaboration with Thessaloniki University.

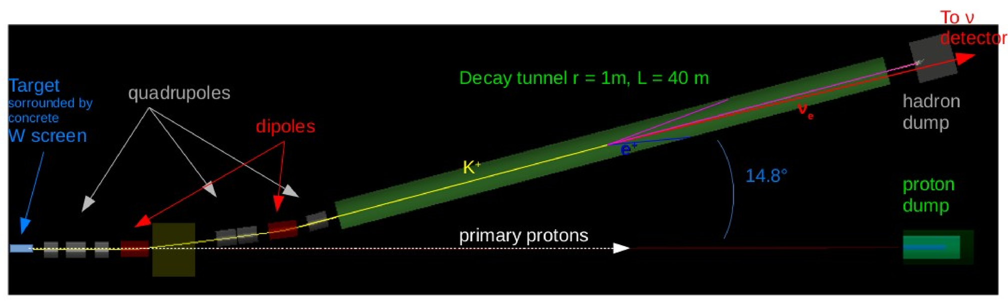


Beamline design and optimisation

The optimization of the beamline is a crucial task in order to produce an intense and well collimated beam of K / π at the tagger entrance.

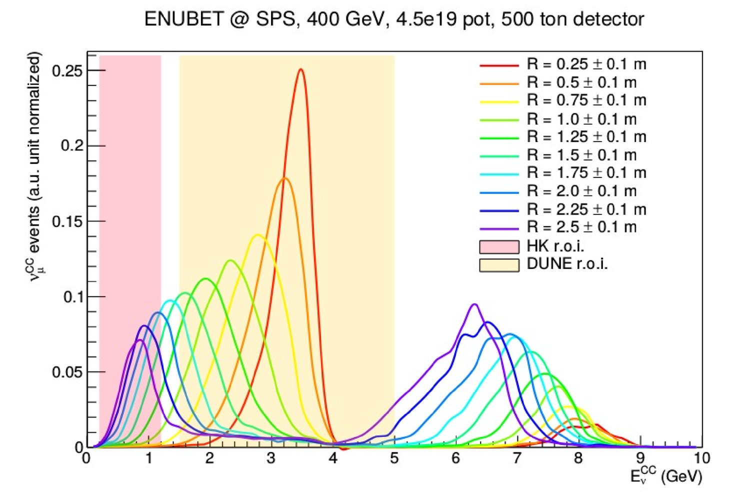
Layout of the Static Transfer Line (TLR6):

- Selection of secondary K^+/π^+ with momentum p = 8.5 GeV/c ± 10%;
- Large bending angle of 14.8° (2 dipoles);
- Optimised (FLUKA and G4Beamline) graphite target (L = 70 cm, R = 3 cm);
- Tungsten foil downstream target to suppress e^+ background;
- Significant suppression of ν_e **from the target region** at low-E.



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

Narrow band off-axis technique

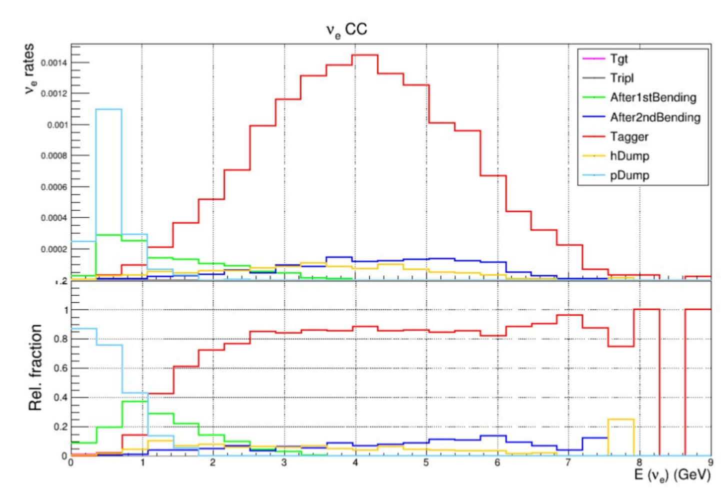


High energy ν_μ from kaons are well separated from low energy ν from pions

- Narrow momentum beam allows a precise estimate of ν_μ energy exploiting correlation with respect to interaction vertex at the detector: high precision in differential cross section measurement;
- 8 - 25% ν_μ energy resolution from pions in the DUNE energy range and 30% in the Hyper-K energy range.
- DUNE optimised TLR w/ 8.5 GeV beam;
- Optimization for Hyper-K in progress.

ν_e CC interactions at detector (6 × 6 m² area / 50 m from tagger end)

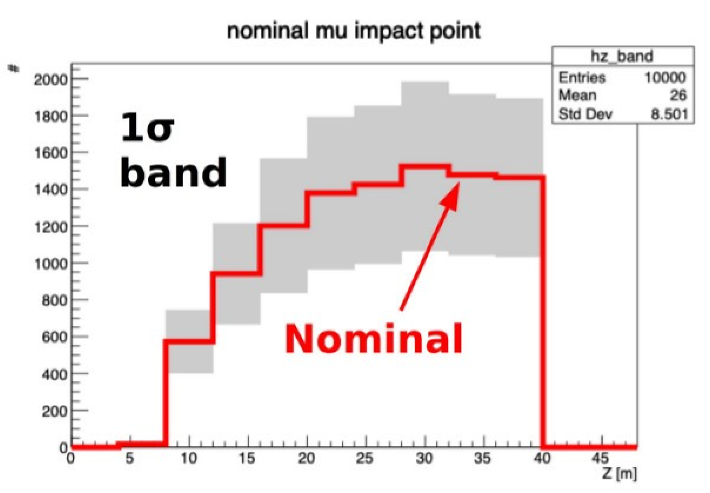
- Clear separation of ν_e generated inside the tagger (red) from ones from the proton dump (cyan) and first section of the TLR (green);
- w.r.t. previous TLR: increase ν_e CC events of 2.5 for TLR6 and 1.4 for TLR5;
- 10 4 ν e CC in 2 years w/ TLR6 and 3.5 years w/ TLR5 (4.5 × 10 19 POT/year at SPS).

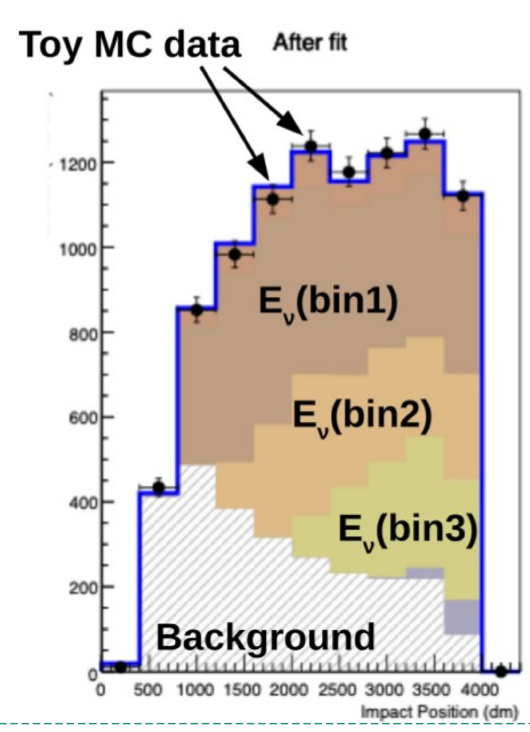


The assessment of flux systematic uncertainties

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 E_ν → **flux constraint**.
NEXT STEP: built a model based on real hadro-production data.

References

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

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