The NP06/ENUBET experiment: a monitored neutrino beam

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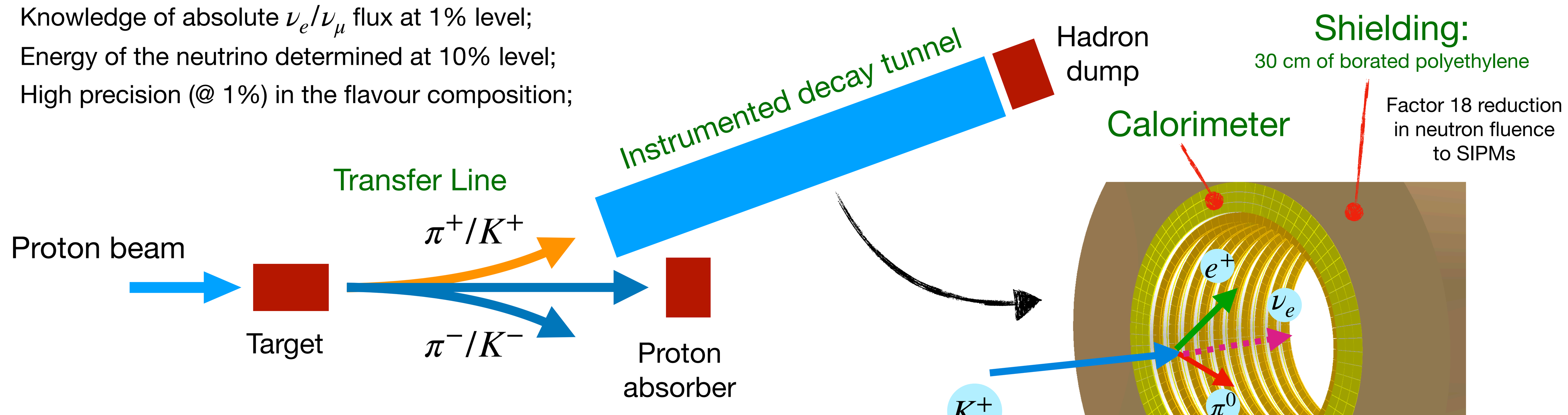
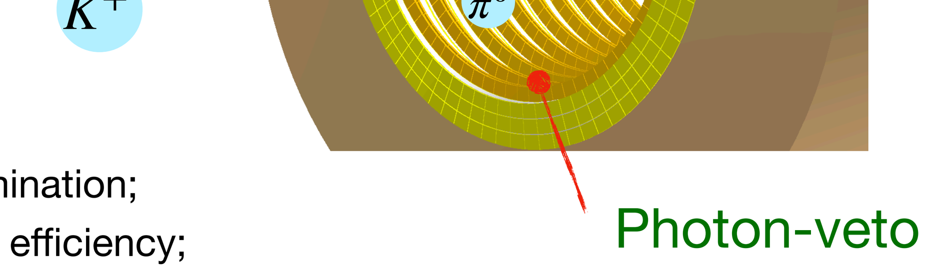
The idea of monitored ν-beams

ENUBET (Enhanced NeUtrino BEams from kaon Tagging): 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 flavour composition;

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





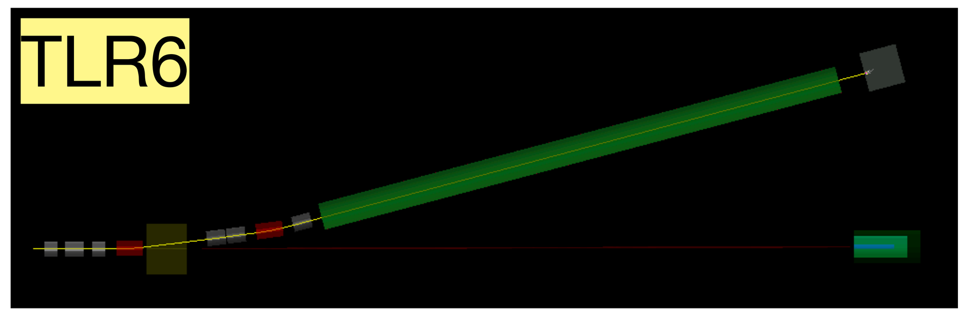
- Monitor positrons from K_{e3} decays with a fully instrumented decay tunnel (tagger): ν_e flux determination from e^+ counting;
- Extend to the monitoring of muons from $K_{\mu\nu}$ and $\pi_{\mu\nu}$ decays for the ν_μ flux determination;
- Avoids uncertainties from Protons-on-Target (POT), hadron-production,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

Proton target & Transfer Line design

Layout (G4Beamline) of the two latest static transfer lines (8.5 GeV particle beam optimisation) + tagger + dumps:

Large bending angle of 14.8° (2 dipoles):

- better collimated beam and reduced background from muons;
- reduced ν_e from early decays in detector;



Legend: quadrupole, dipole (B =1.8 T), copper block, tungsten block, tagger, hadron-dump, proton-dump

Shielding:

- absorbers & rock volumes included in complete simulation (optimised with FLUKA and GEANT4);
- tungsten block at tagger entrance for TLR5;
- in progress: optimisation/design of collimators + absorbers of last section of TLR6;
- tungsten foil downstream target to suppress positron background;

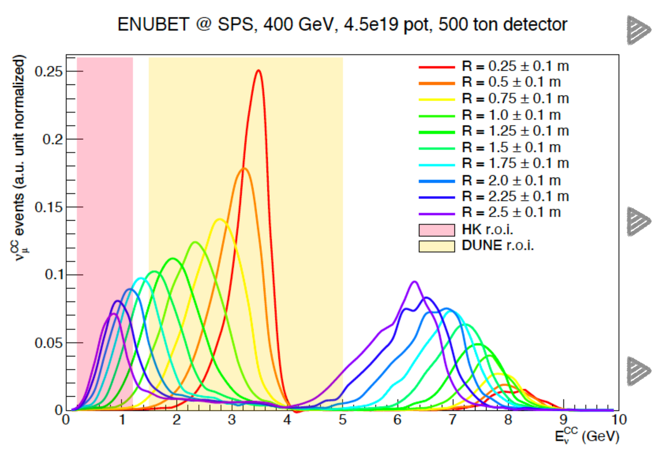
Increased Kaon flux w.r.t. previous Transfer Lines

Transfer line	π^+ $[10^{-3}/POT]$ $[8.5 \pm 5\%]$ GeV/c	K^+ $[10^{-3}/POT]$ $[8.5 \pm 5\%]$ 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

Target optimisation (FLUKA & G4Beamline):

- scan in the geometry parameter space and test of different materials (graphite, beryllium, inconel) to maximise K/π production in region of interest;
- TLR6 employs optimised graphite target ($L = 70\ cm$ / $R = 3\ cm$);
- inconel target ($L = 50\ cm$ / $R = 3\ cm$) under consideration;

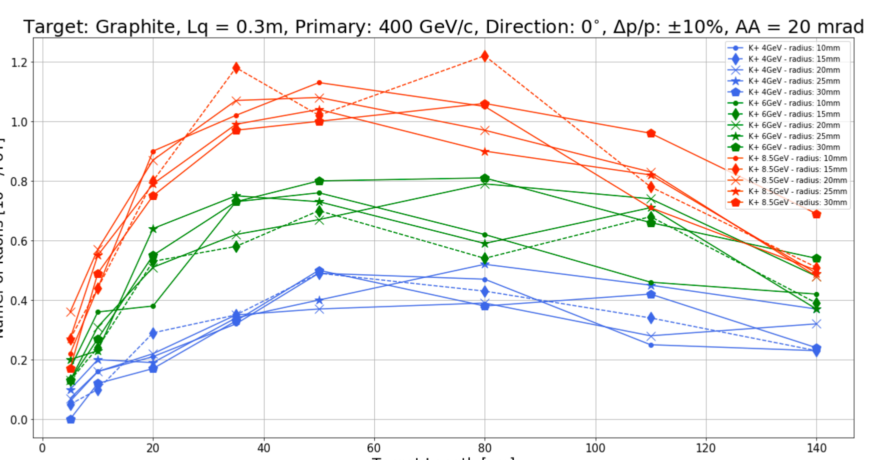
Narrow band off-axis technique



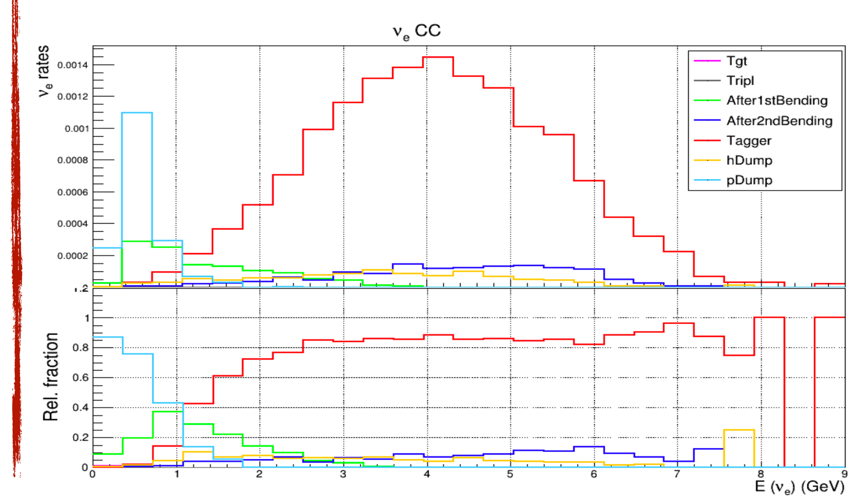
High energy ν_μ from kaons are well separated from low energy neutrinos from pions

- narrow momentum beam allows a precise estimate of ν_μ-energy exploiting correlation w/ interaction vertex @ detector: high precision in differential cross section measurement;
- 8-25% ν_μ-energy resolution from pions in the DUNE energy range & 30% in the Hyper-K energy range (DUNE optimised TL w/ 8.5 GeV beam);
- Ongoing R&D: develop a Multi-Momentum Beamline (4.5, 6 and 8.5 GeV beam) to populate and enhance resolution in the low ν_μ-energy region (Hyper-K & DUNE optimised beamline);

Graphite target length/radius scan



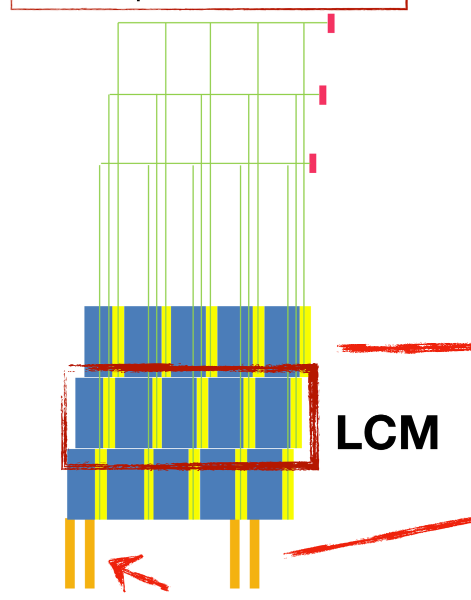
ν_e^{CC} interactions @ detector ($6 \times 6\ m^2$ area / $50\ m$ from tagger end)



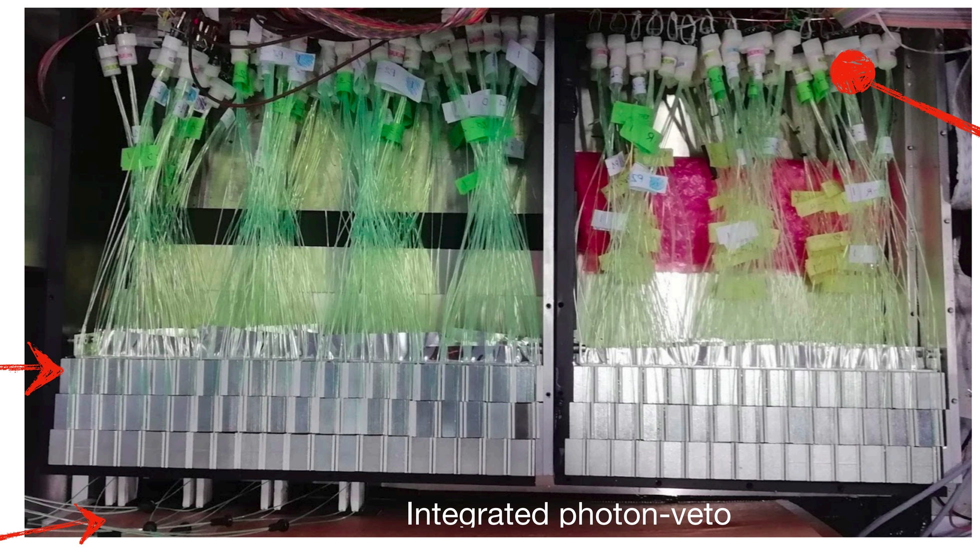
- clear separation of ν_e generated inside tagger (red) from ones from proton dump (cyan) and first section of TL (green);
- w.r.t. previous TL: increase ν_e^{CC} events of 2.5 for TLR6 and 1.4 for TLR5;
- 10^4 ν_e^{CC} in 2 years w/ TLR6 and 3.5 years w/ TLR5 (4.5×10^{19} $POT/year$ @ SPS);

Calorimeter prototyping: test-beams and final demonstrator

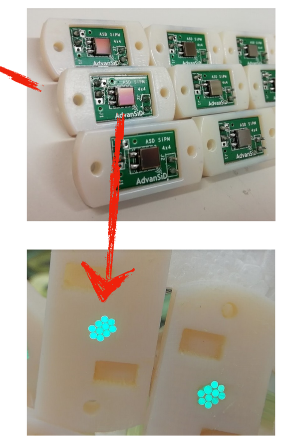
Lateral readout schematic representation



Sampling calorimeter with lateral WLS fibers for light collection

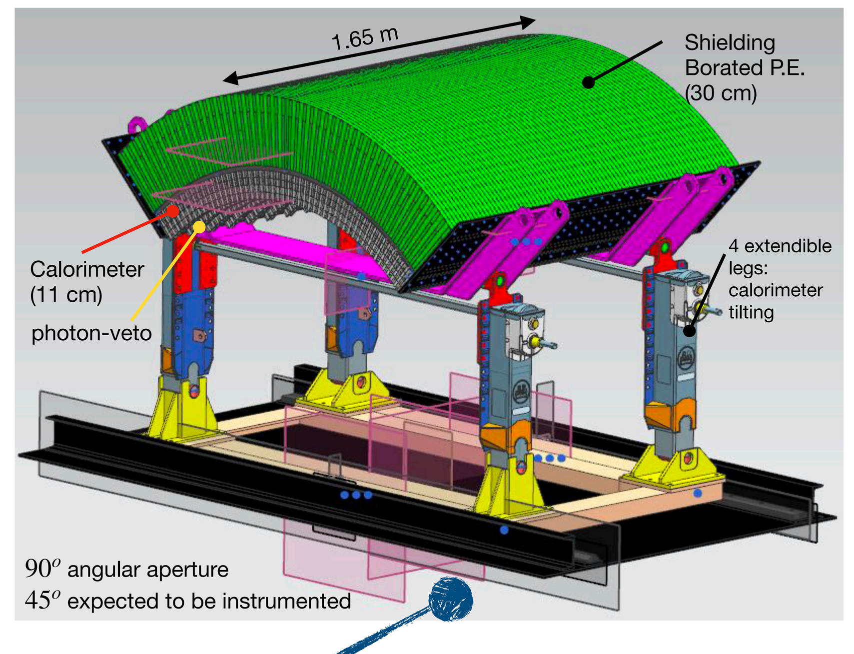


SiPM ($4 \times 4\ cm^2$) for the readout of 10 WLS (single LCM) installed outside shielding



Prototype tested during 2018 test-beams runs @ CERN TS-P9

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

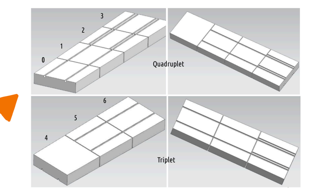


Calorimeter with $e/\pi/\mu$ separation capabilities

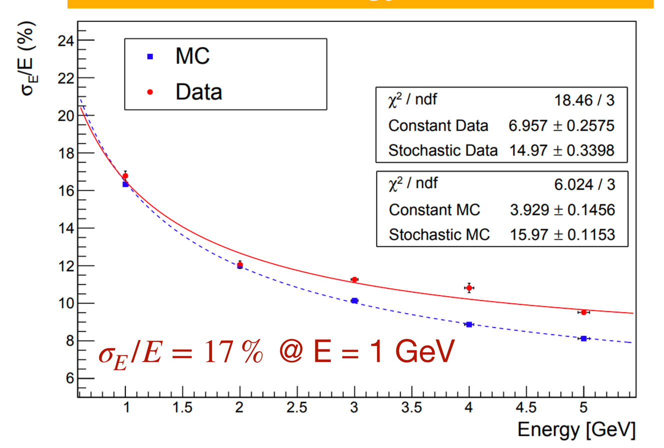
- Sampling calorimeter: plastic scintillator (0.5 cm) + Iron absorbers (1.5 cm);
- Three radial layers of Lateral Compact Modules (**LCM**: $3 \times 3 \times 10\ cm^3 - 4.3X_0$) with longitudinal segmentation;
- light collection/readout: WLS fibers & SiPM;

Photon-veto allows π^0 rejection

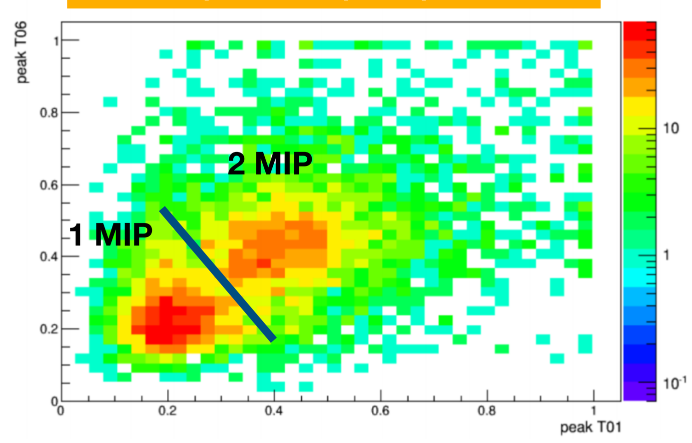
- plastic scintillator tiles;
- $3 \times 3\ cm^2$ tiles arranged in doublets forming inner rings;
- time resolution of $\simeq 400\ ps$;



Electron energy resolution



1 m.i.p. / 2m.i.p. separation



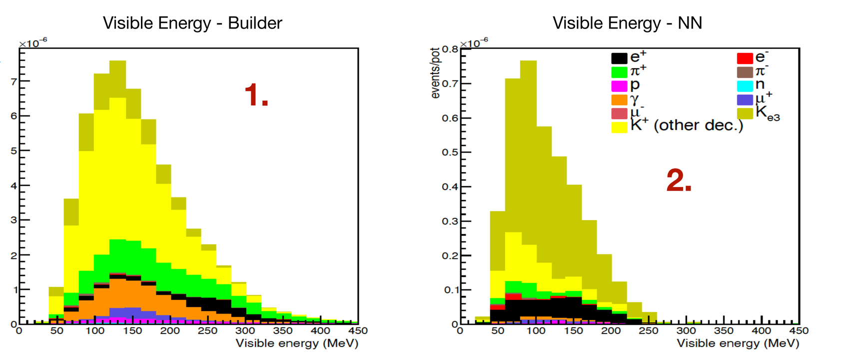
- new light readout scheme with frontal grooves instead of lateral grooves driven by large scale scintillator production (safer production and more uniform light collection):
  - validated with GEANT4 optical simulation;
  - measuring efficiency maps of tiles with similar geometry ongoing @ INFN-Bologna;
- scintillators in production phase (~10000 pieces) with UNIPLAST in collaboration with INR group;
- pre-demonstrator prototype w/ 3 LCMs (ENUBINO): under test with cosmic-rays @ INFN-LNL;

Lepton PID performance and ν-flux systematics assessment

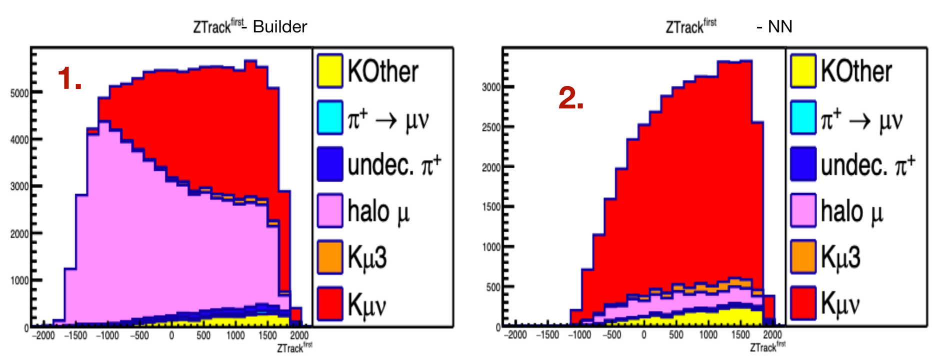
Full Geant4 simulation of the detector (validated for e^+ reconstruction by prototype tests at CERN during 2016-2018)**:**

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

K_{e3} reconstruction: $\epsilon \sim 22\,\%$ & $S/N \sim 2$



$K_{\mu\nu}$ reconstruction: $\epsilon \sim 34\,\%$ & $S/N \sim 6\,\%$



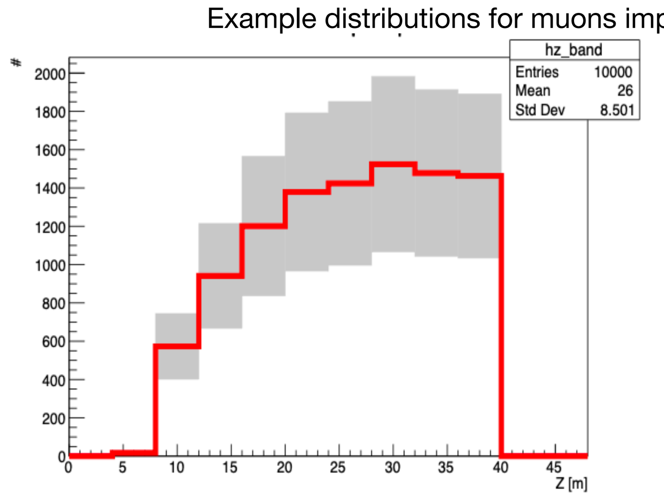
Instrumenting the hadron-dump will allow to monitor also muons from pion decays: evaluating detector technology in collaboration with Thessaloniki University

Analysis chain:

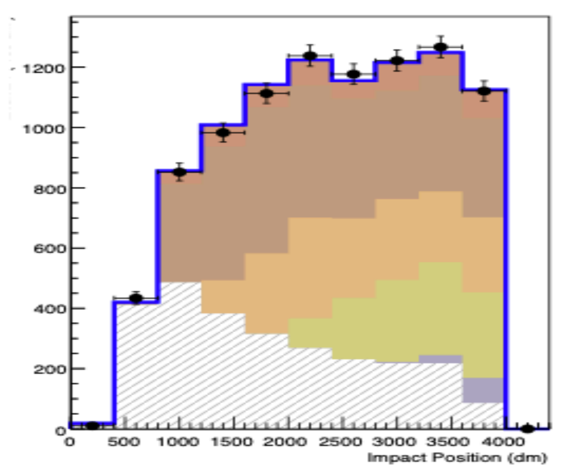
1. Event builder: identify LCM with energy deposit as seed of the event. Cluster neighbour LCM deposits compatible with particle;
2. signal/background separation: multivariate analysis (MLP-NN from TMVA) exploiting energy pattern deposition in calorimeter, event topology and photon-veto energy deposition variables;

ν-flux systematics assessment: leptons measured @ calorimeter are related to neutrinos flux @ detector

Example distributions for muons impact point along calorimeter wall



Template distribution for fit model: nominal distribution (red) and 1σ band (grey)



Toy-MC experiment: fit muon data (**black points**) with signal templates (coloured) and background (dashed)

- exploit Monte-Carlo (MC) simulations to compute template distributions for lepton physics observables measured by calorimeter;
- build a signal+background model (using RooFit): include a priori hadro-production (HP) and TL related systematic uncertainties;
- perform fit of toy-MC experiments to study the a posteriori systematic uncertainties and asses the corresponding uncertainties reduction;
- propagate the a posteriori systematic uncertainties to the ν-flux;
- ☑ built templates from toy HP model & mock kinematic observables: multiverse method to propagate systematics from HP to observables;
- ☑ tested RooFit model on 500 toy-MC experiments: after fit $\sim 1.8\,\%$ error on ν-flux, starting from a $\sim 15\,\%$ initial error (preliminary result on toy-model);
- ✱ next: build model based on real HP data and MC templates (work in progress!);

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Checkout more @ http://enubet.pd.infn.it