ENUBET: a monitored narrow-band neutrino beam

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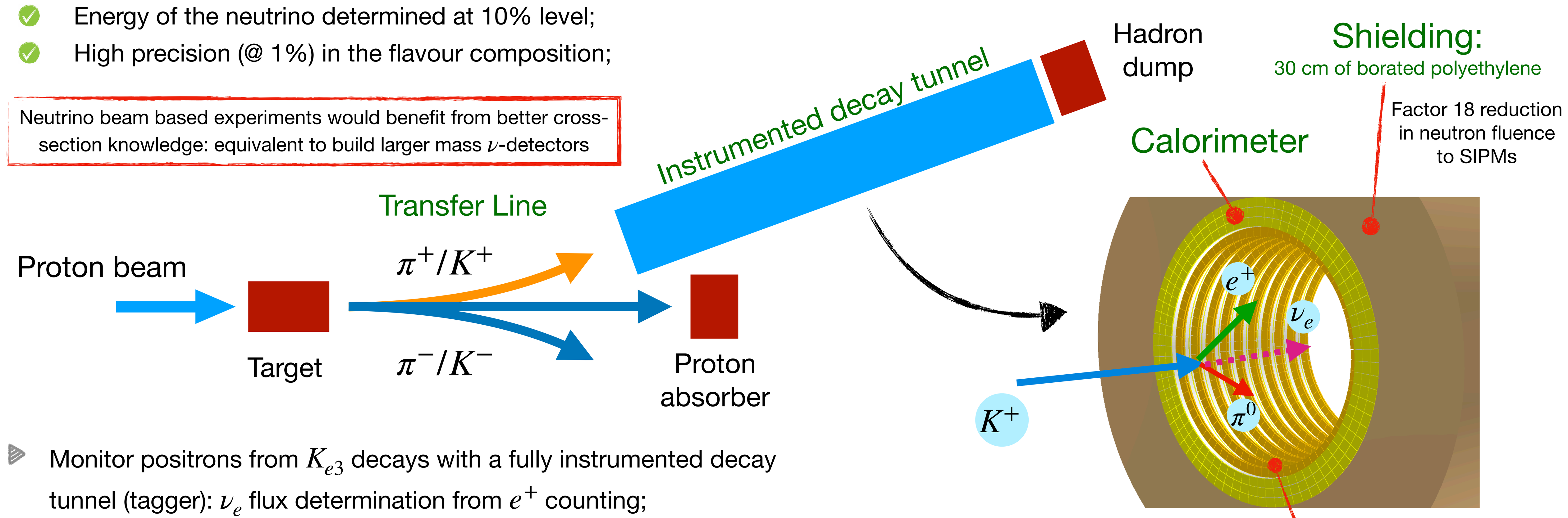
The idea of monitored ν-beams

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 flavour composition;

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

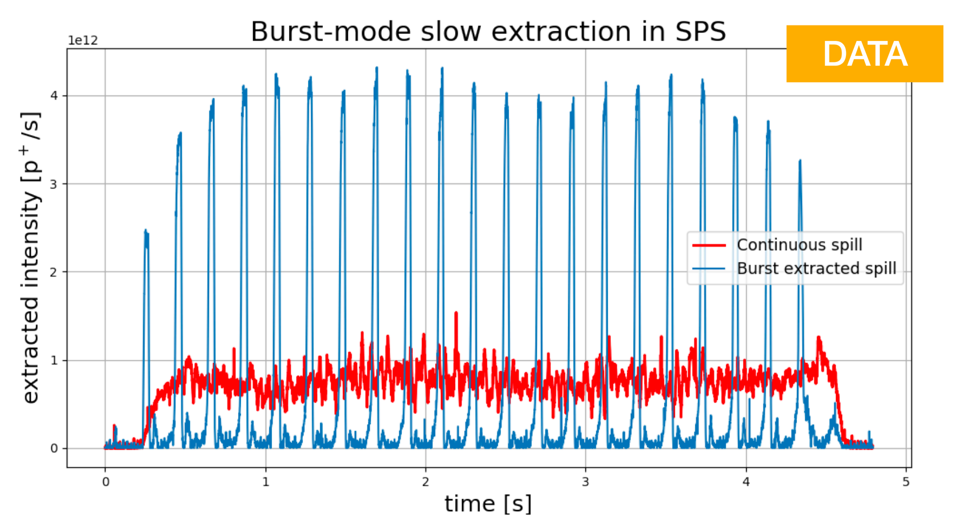


- Monitor positrons from K_{e3} decays with a fully instrumented decay tunnel (tagger): ν_e flux determination from e^+ counting;
- Extend to the monitoring of muons from $K_{\mu\nu}$ and $\pi_{\mu\nu}$ decays for the ν_μ flux determination;
- Avoids uncertainties from Protons-on-Target (POT), hadron-production,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

Meson Transfer Line

Two possibilities for the slow proton extraction scheme (~2 s) from the proton-beam accelerator:

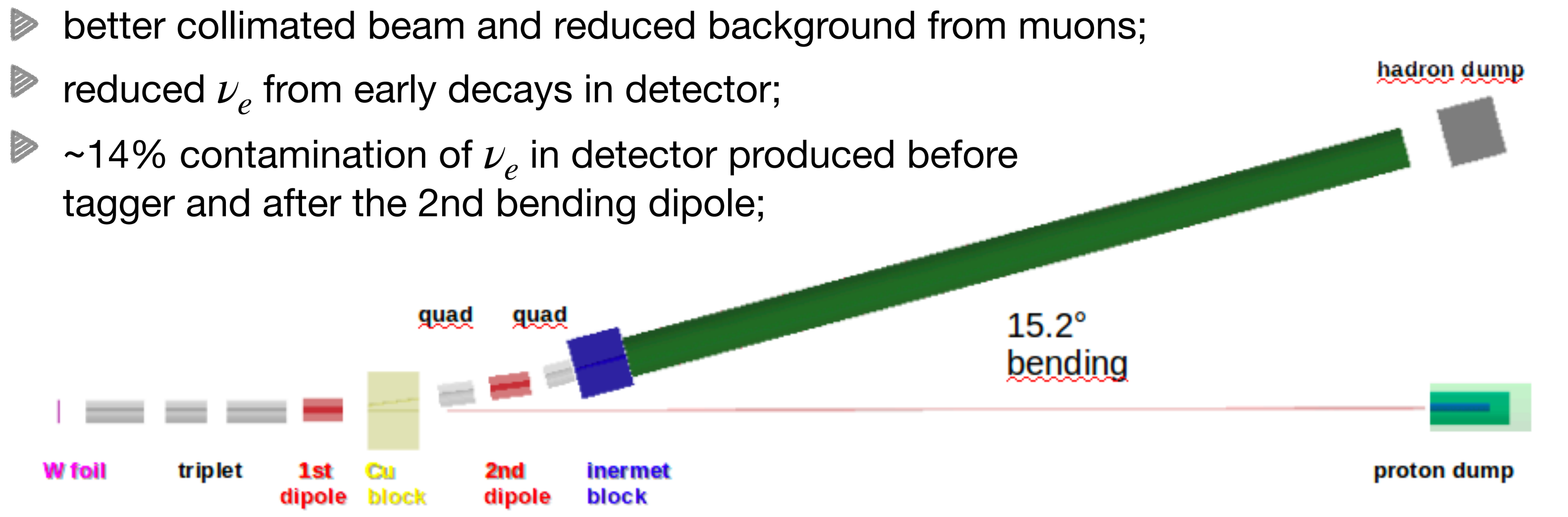
1. continuous spill: advantages in terms of costs, technical implementation, higher performance of particle ID and possibility to operate a time-tagged neutrino beam;
2. burst extracted spill: advantage in term of intensity (horn); same integrated POT extracted; no increase in measured losses; obtained pulses ~20 ms of length; a reduction to ~5 ms could be achieved (ongoing simulation studies)



First option (continuous spill): layout (G4Beamline) of the static transfer line. In sequence starting from the left, quadrupole triplet - dipole - quadrupole - dipole - quadrupole

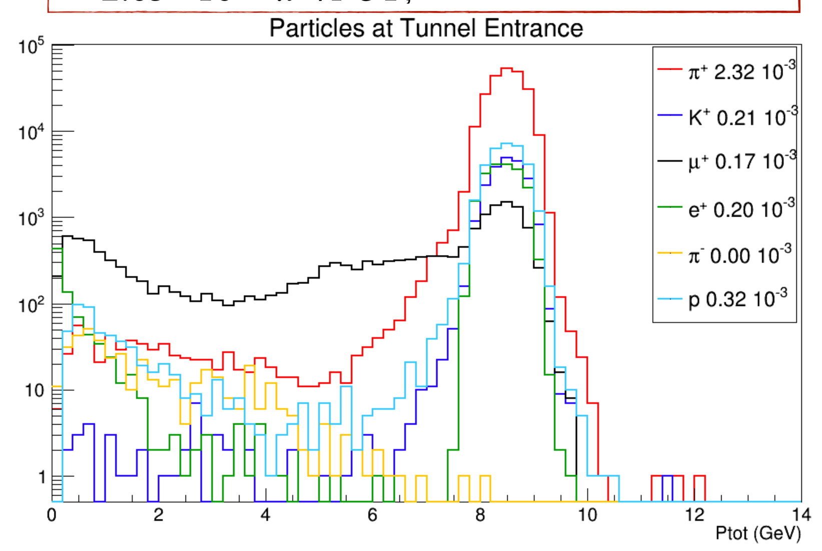
Large bending angle of 15.2° (2 dipoles):

- better collimated beam and reduced background from muons;
- reduced ν_e from early decays in detector;
- ~14% contamination of ν_e in detector produced before tagger and after the 2nd bending dipole;

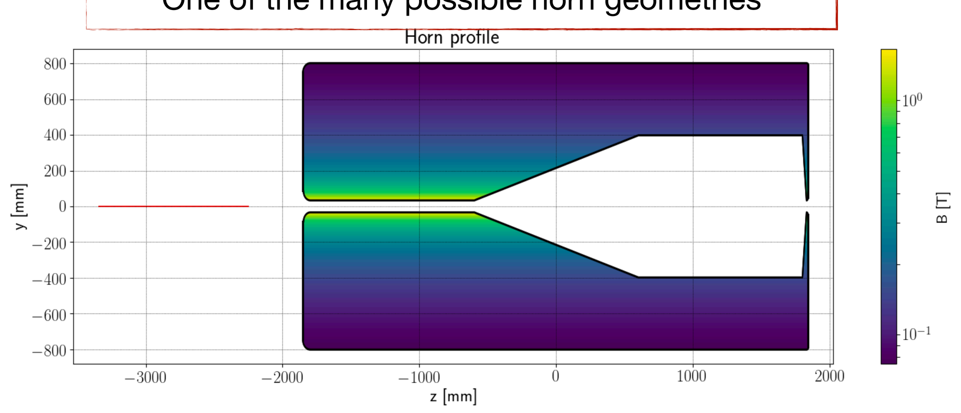


Expected K^+ and π^+ at tagger entrance in the 8.5 ± 5% GeV momentum range:

- $0.185 \cdot 10^{-3}\ K^+/POT$;
- $2.05 \cdot 10^{-3}\ \pi^+/POT$;



One of the many possible horn geometries



Second option (burst extracted spill): a strong focusing device, horn magnet, is used;

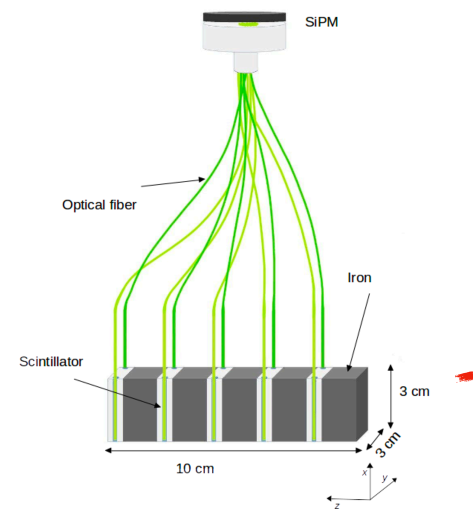
- a larger collection efficiency for K^+ and π^+ can be achieved, thus higher neutrino flux can be reached;
- shorter beamline could be possible;

Preliminary result show a factor 5 gain in the flux

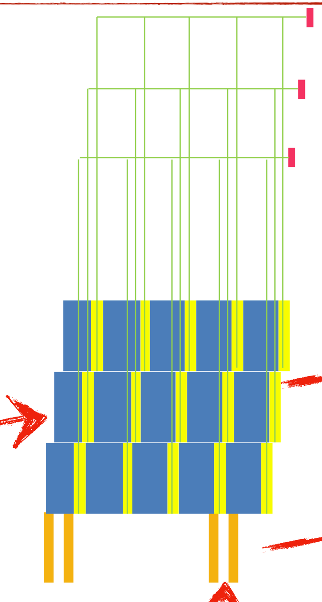
Ongoing studies to maximise the flux by exploring the horn parameter space and different designs.

Calorimeter prototyping and testing

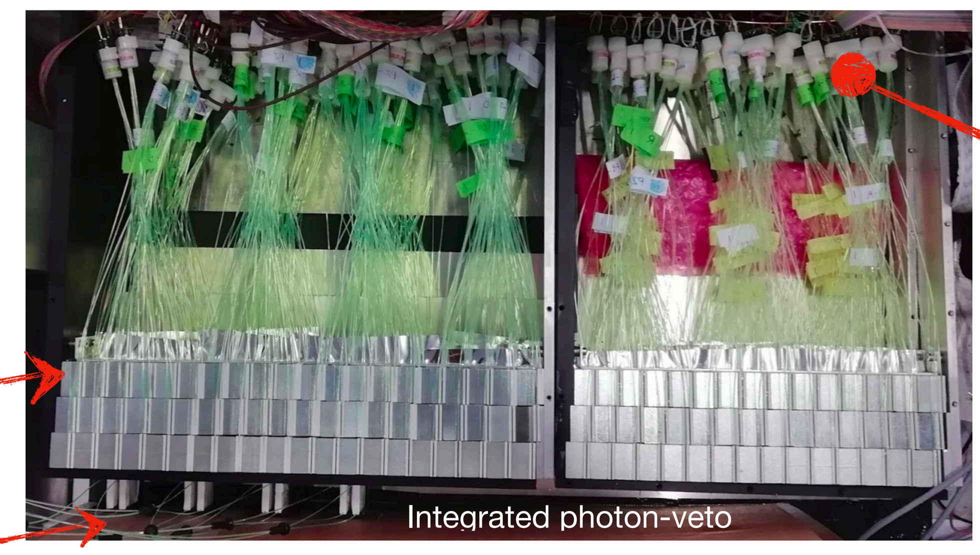
A Lateral readout Compact Module (LCM)



Lateral readout schematic representation

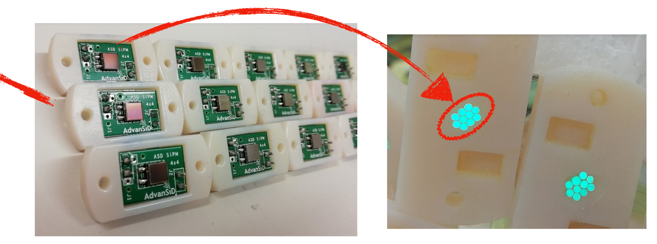


Sampling calorimeter with lateral WLS fibers for light collection



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

Large SiPM area ($4 \times 4\ cm^2$) for the readout of 10 WLS (a single LCM)



- SiPM will be installed outside of the shielding, thus they will not be immersed in the hadronic shower;
- Less compact arrangement, but with the benefit of: **reduced neutron damage, better accessibility, possibility of replacement, better reproducibility of WLS-SiPM optical coupling;**

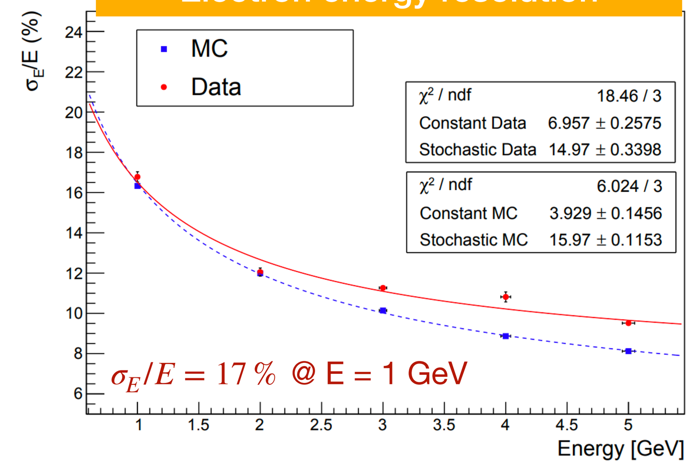
Calorimeter with $e/\pi/\mu$ separation capabilities

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

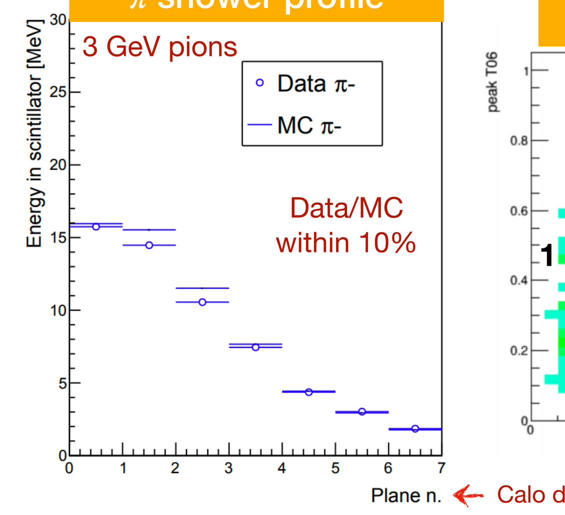
Photon-veto allows π^0 rejection

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

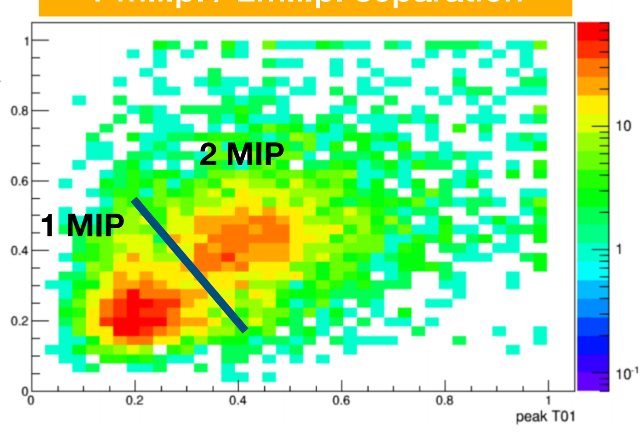
Electron energy resolution



π shower profile



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



Final demonstrator by 2021 @ CERN: ENUBET part of the Neutrino Platform as NP06/ENUBET

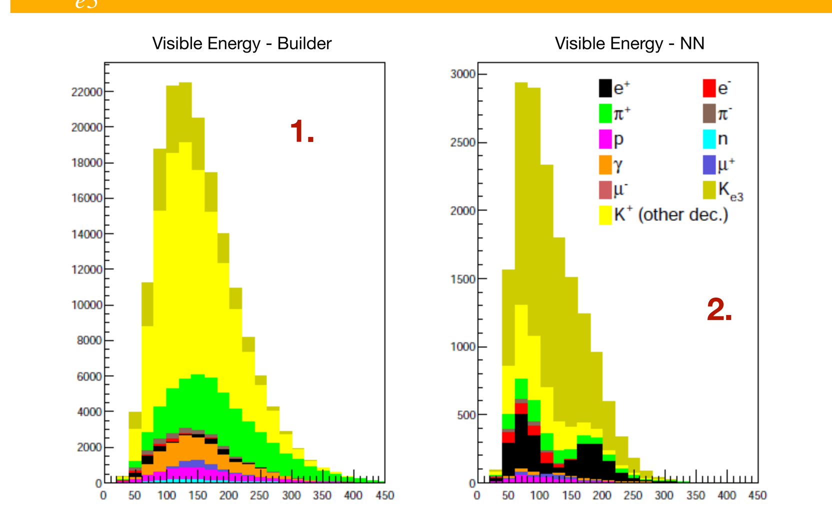
Given the good energy resolution, shower profile differences and 1 vs 2 m.i.p. separation capabilities, we can achieve a good e/π discrimination

Lepton reconstruction performance from simulation

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;

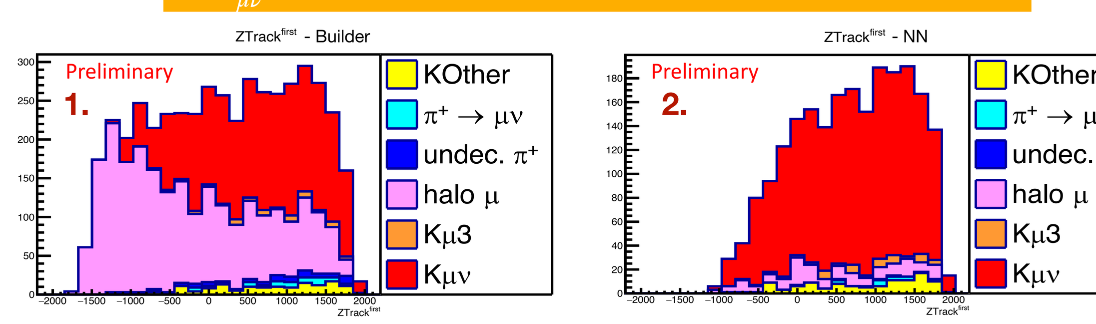
K_{e3} reconstruction: Eff. = 23.7±0.2% & S/N = 2.04



Analysis chain:

1. Event builder: identify seed of the event (inner layer LCM with energy deposit of E>28 MeV). Cluster neighbour LCM deposits compatible with propagation of shower;
2. $e/\pi/\mu/\gamma$ separation: multivariate analysis (MLP-NN from TMVA) exploiting 19 variables (energy pattern deposition in calorimeter, event topology and photon-veto energy deposition);

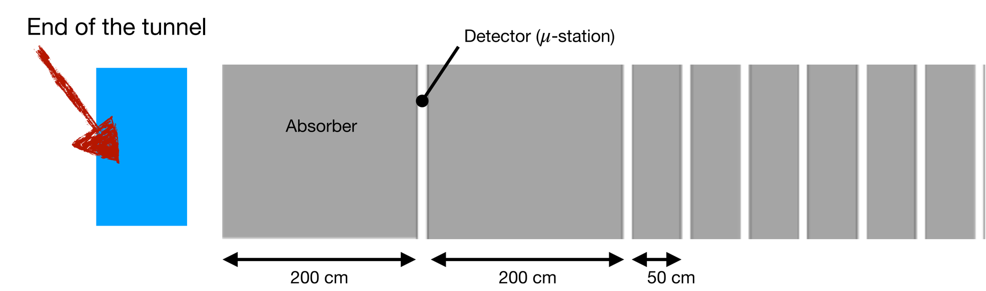
$K_{\mu\nu}$ reconstruction: Eff. = 33.5±0.6% & S/N = 6.1



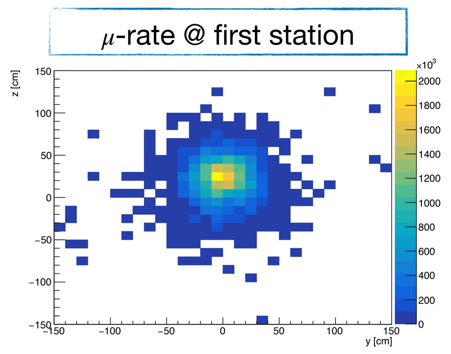
Analysis chain:

1. Event builder: identify seed of the event (inner layer LCM with E = [5, 15] MeV). Cluster all LCM deposits compatible with muon-track topology and propagation;
2. μ-like background separation (especially halo-μ): multivariate analysis (MLP-NN from TMVA) exploiting 13 variables (energy deposition, track isolation and topology);

$\pi_{\mu\nu}$ detection system under investigation



μ-rate @ first station



Design of detection system:

1. Muon stations after hadron dump: pions have a large forward boost, thus muons from π decays exit the tunnel;
2. Ongoing studies to estimate muon and neutron rates for the determination of the detector technology to employ;

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