The ENUBET neutrino beam

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on behalf of ENUBET Collaboration

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A narrow-band beam for the precision era of ν physics

Absolute flux of ν_e and ν_μ at the 1% level

↓

Remove the leading source of uncertainty in **neutrino cross section measurement**

Energy of the neutrino known at the 10% level

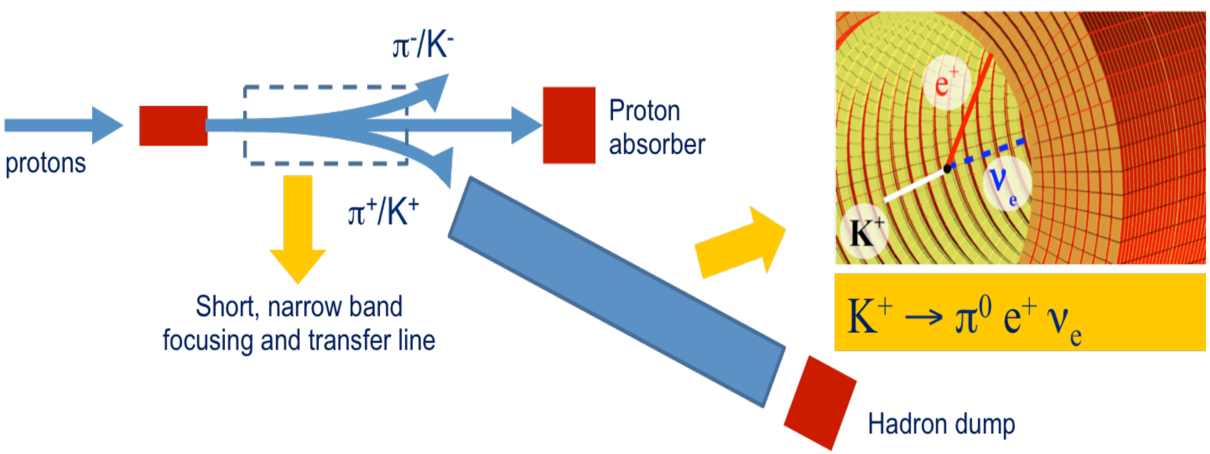
↓

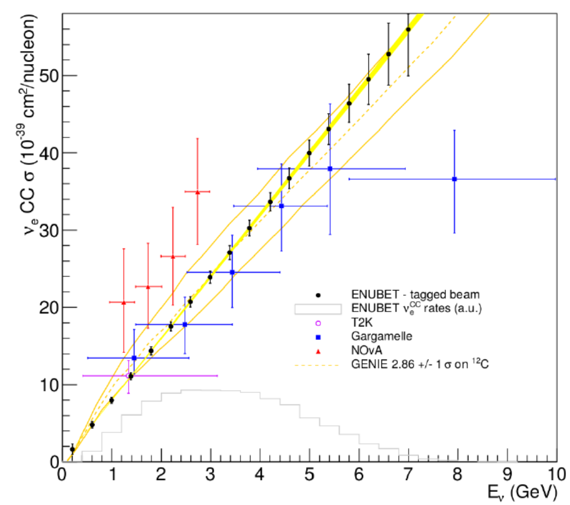
The ideal tool to study neutrino interactions in nuclei

Flavor composition known at the 1% level

↓

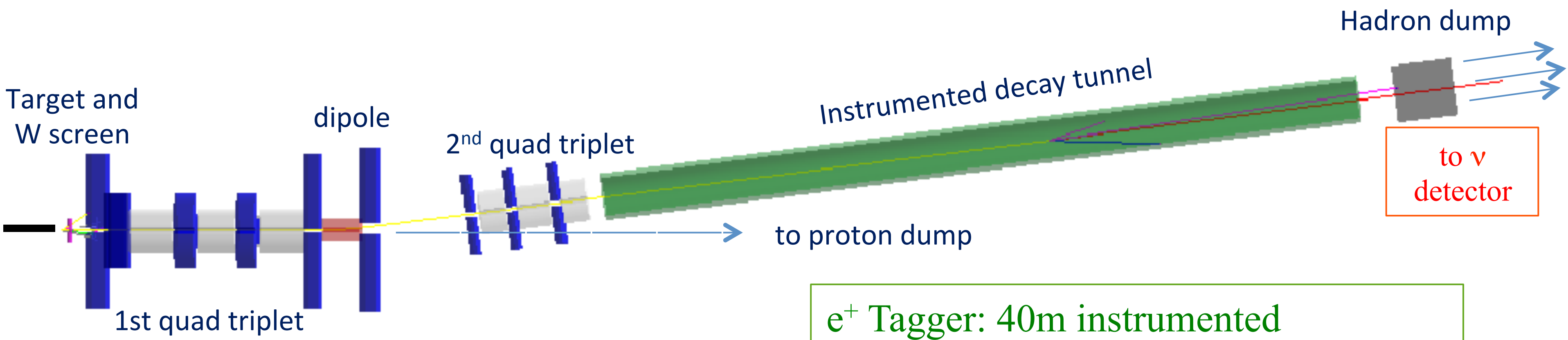
The ideal tool to study NSI and sterile neutrinos at the GeV scale





Goal: demonstrate the technical feasibility and physics performance of a neutrino beam where **lepton production at large angles is monitored at single particle level** ⇒ direct measurement of the flux

ENUBET Beamline



Hadron beam line: collection, focusing, transport K^+ to the e^+ tagger

e^+ Tagger: 40m instrumented **decay tunnel**
→ real-time monitoring of produced e^+

Traditional Beam
- Passive decay region
- ν_e flux from ab-initio simulation of full chain
- Large uncertainties from hadro-production, K/π ratio, POT

Monitored/Tagged Beam
- Fully Instrumented decay region
- $K^+ \rightarrow e^+ \pi^0 \nu_e$ → large angle e^+
- ν_e Flux = e^+ counting
- → O(1%) systematic error achievable

Yields (ref: CERN SPS, 400 GeV[d])

Focusing system	π/pot (10^{-3})	K/pot (10^{-3})	Extraction lenght	π/cycle (10^{10})	K/cycle (10^{10})	Proposal [c]
Horn	97	7.9	2ms [a]	438	36	x2
No horn	19	1.4	2 s [b]	85	6.2	**x5**

(a) 2 ms at 10 Hz during the flat top (2 s) to empty the accelerator after a super-cycle: this extraction scheme is currently under test at CERN
(b) Slow extraction. Detailed performance and losses currently under evaluation at CERN
(c) A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155
(d) Similar performances for other proton accelerators (FNAL/J-PARC)

Advantages of the static extraction:

- No need for fast-cycling horn
- Strong reduction of the rate in the instrumented decay tunnel
- Possibility to monitor the muon rate after the dump at 1% level (flux of ν_μ from pion decay) **[NEW: under evaluation]**
- Pave the way to a «tagged neutrino beam», namely a beam where the neutrino interaction at the detector is associated in time with the observation of the lepton from the parent hadron in the decay tunnel

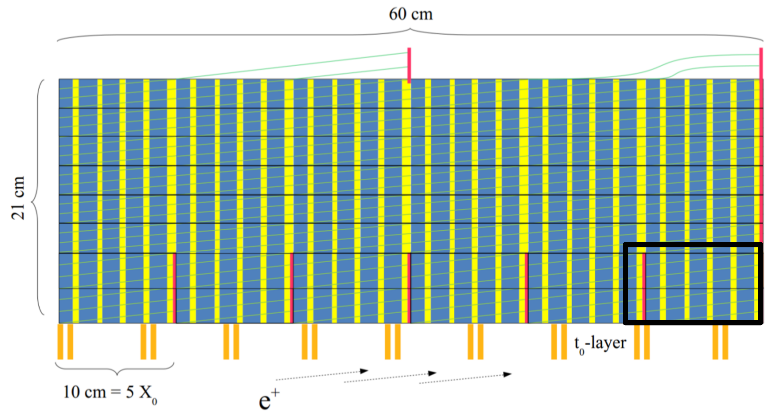
Instrumented decay tunnel

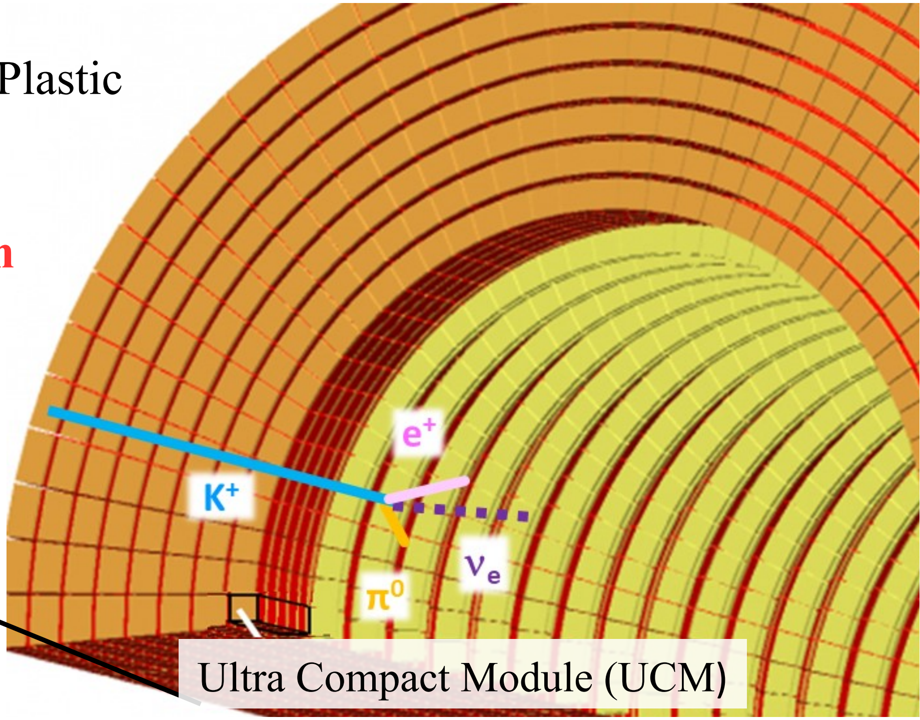
Longitudinally Segmented Calorimeters

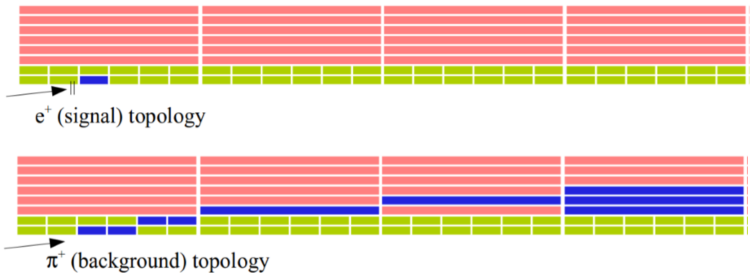
1) Ultra Compact Module (UCM) (Fe absorber+Plastic scintillator)

2) Light Readout with SiPM

→ $4X_0$ Longitudinal sampling: **e+/π± separation**



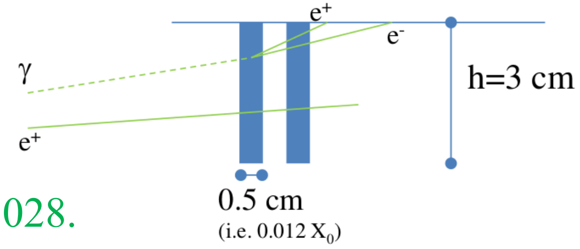




Integrated Photon-veto

3) 3x3 cm^2 plastic scintillator pads

→ **e+/π^0 separation** (π^0 rejection)

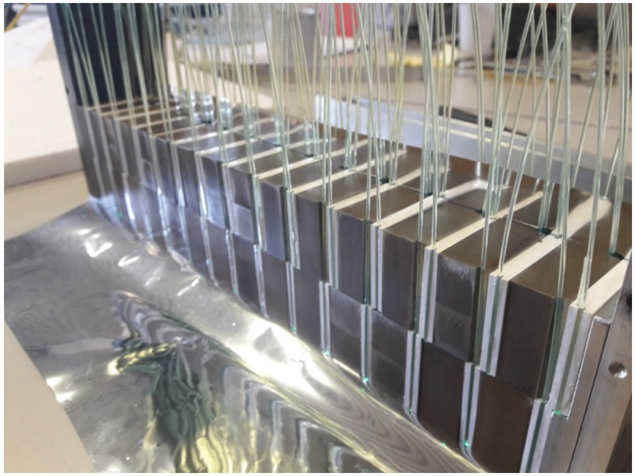


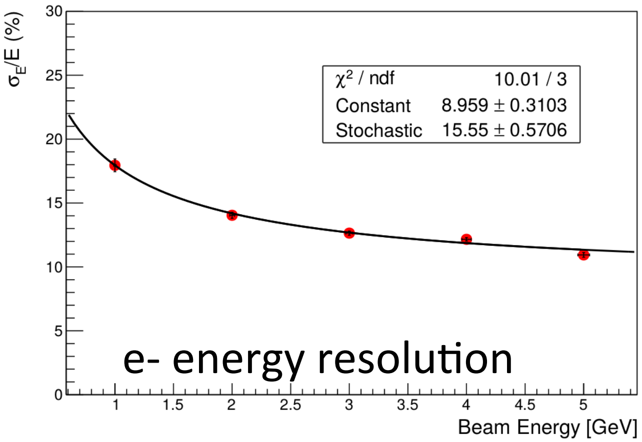
2016/2017 tested → G. Ballerini et al., JINST 13 (2018) P01028.

Instrumented decay tunnel – Test beam 2018

Calorimeter prototype performance with test-beam data @ CERN-PS T9 line – May 2018

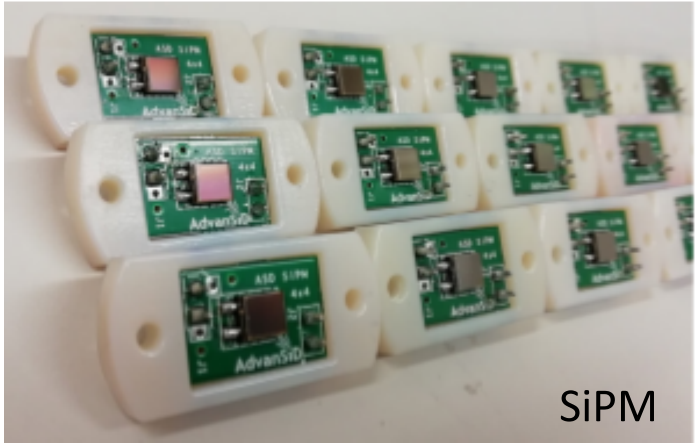
Sampling calorimeter with lateral WLS light collection



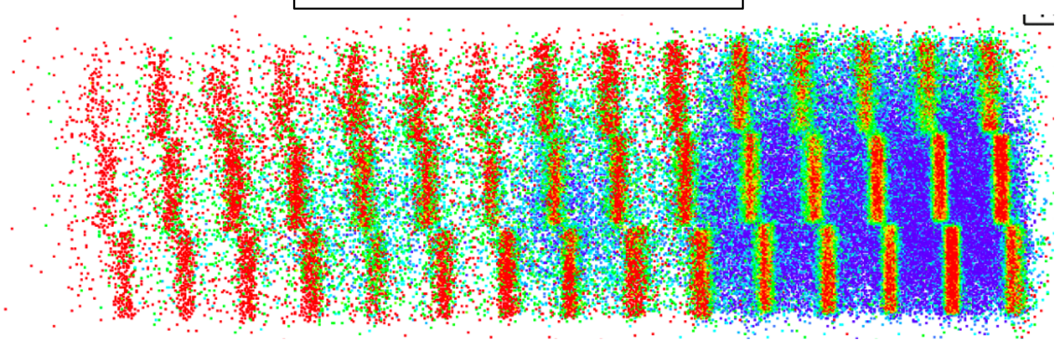


Test of:

- Light yield
- Uniformity
- Resolution
- Optical coupling to photosensors



Efficiency map



Instrumented decay tunnel – Test beam 2018

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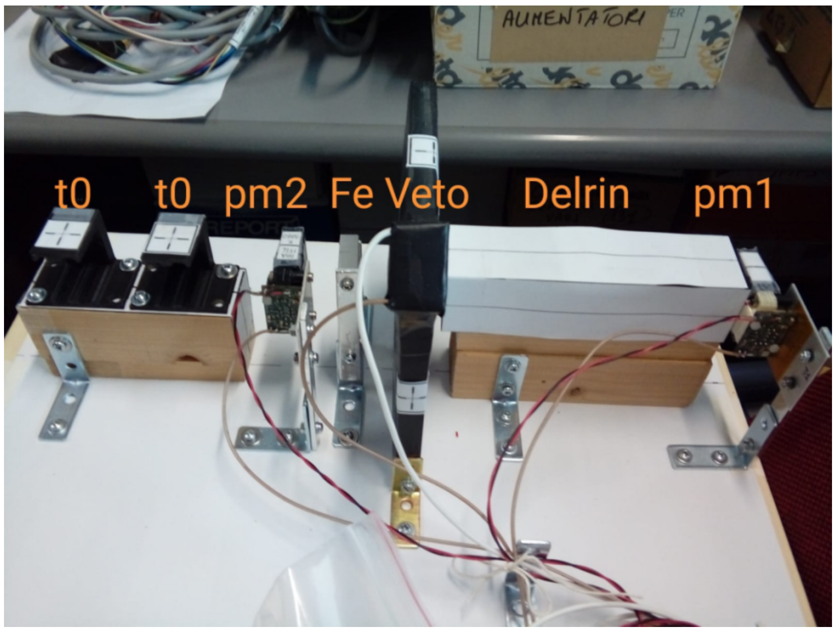
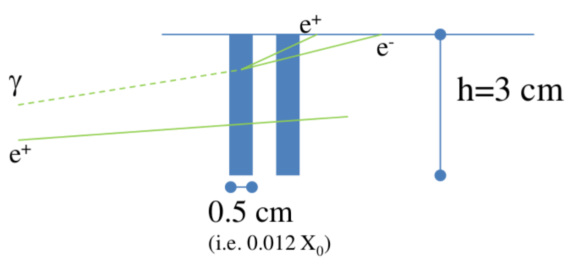
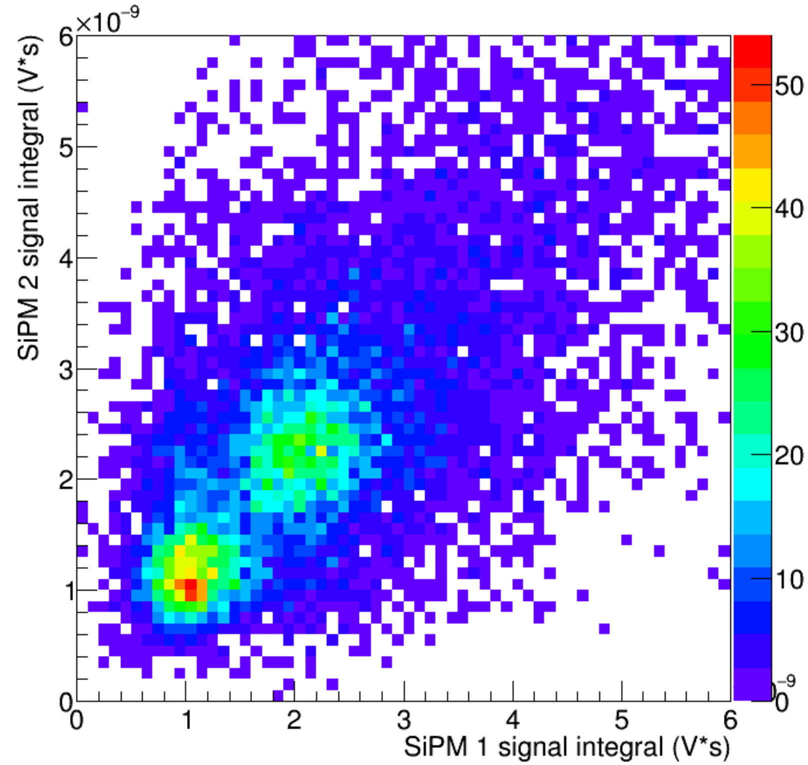
Preliminary results of test of photon veto in standalone mode: 1 mip/2 mip separation using converted photon from π^+ N -> π^0 X (charge exchange)







Positron identification from K decay

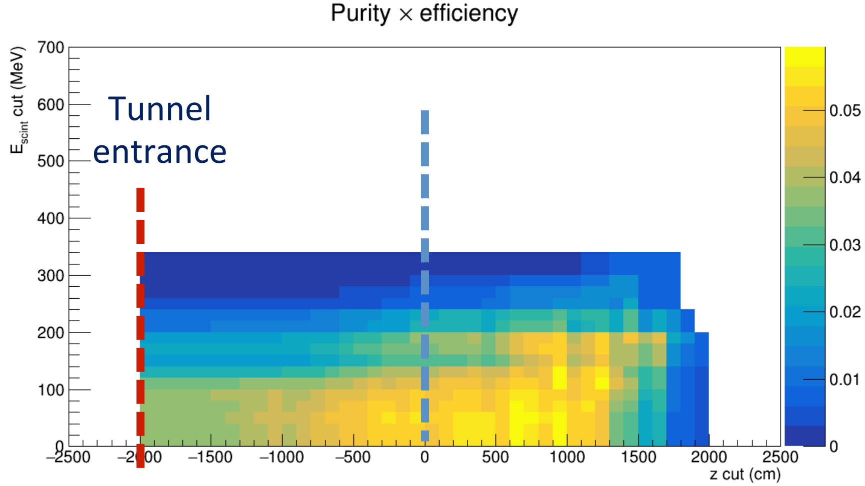
Full GEANT4 simulation of the detector, validated by prototype tests at CERN in 2016-2018. The simulation includes particle propagation and decay from the transfer line to the detector, hit-level detector response, pile-up effects.

Analysis chain

Event Builder → Identify the seed of the event (UCM with large energy deposit) and link neighboring modules

e/π/μ separation → (**Neural Network**) TMVA multivariate analysis based on 5 variables (pattern of the energy deposition in the calorimeter)

e/γ separation → Signal on the tiles of the photon veto



after E and z-cut

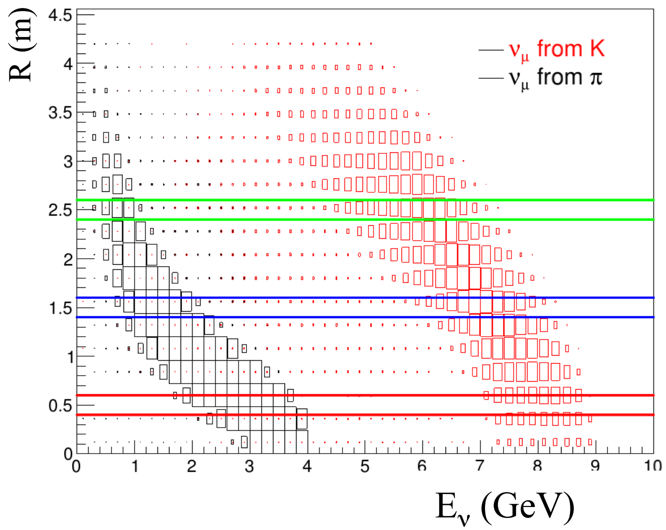
ε_{geom}	**0.36**
ε_{sel}	0.55
ε_{tot}	0.20
purity	0.26
S/N	0.36

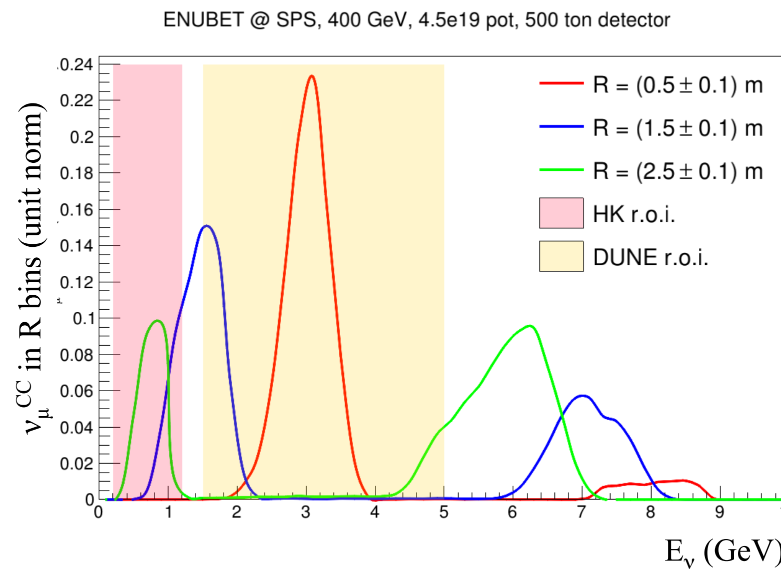
φ-cut → **0.46**

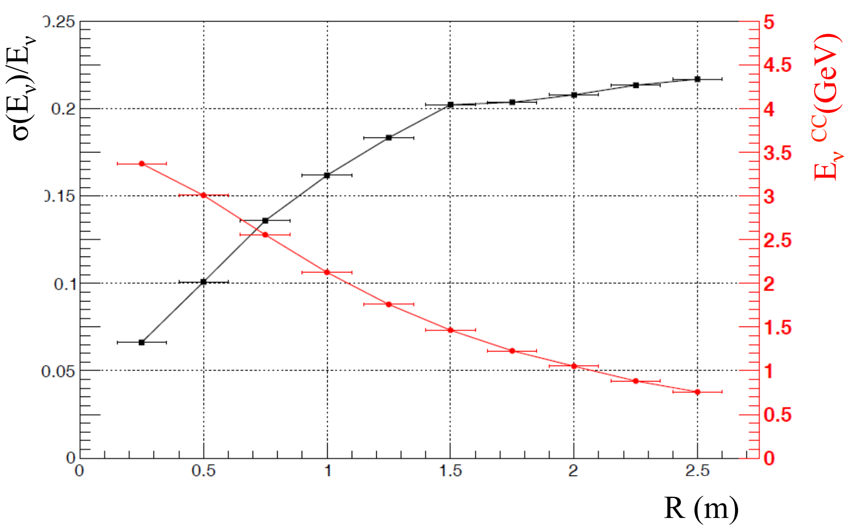
Instrumenting half of the decay tunnel we identify positrons from K decay at single particle level with a S/N = 0.46

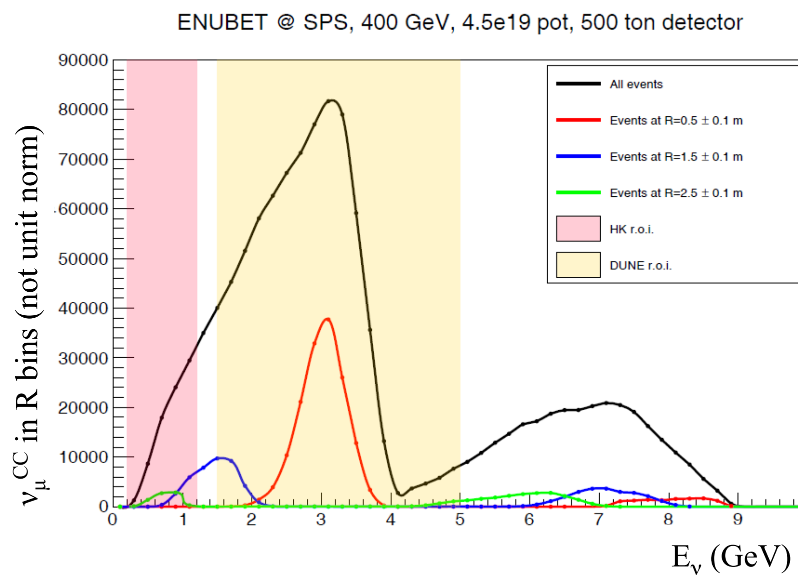
ν_μ CC events at the ENUBET narrow band beam

The neutrino energy is a function of the distance of the neutrino vertex from the beam axis (R). The beam width at fixed R (~ neutrino energy resolution at source) is 8-22%









Conclusions

- ENUBET is a narrow band beam with a high precision monitoring of the flux at source (1%) and neutrino energy (20% at 1 GeV → 8% at 4 GeV)
- In the last year, we
  - provided the first **end-to-end simulation** of the beamline
  - proved the feasibility of a **purely static focusing system** (10^6 ν_μ CC per year, 10^4 ν_e CC per year with a 500 ton detector)
  - identified the best options for the instrumentation of the decay tunnel (shashlik and lateral readout: final decision in 2019)
  - completed the **full simulation of the positron reconstruction**: the results confirm that monitoring at the single particle level can be performed with S/N = 0.5
- We are proceeding toward the **Conceptual Design** (2021) that will include the full assessment of the systematics , the monitoring of the other decay modes of K and of pions, the outline of the physics performance for cross-section measurement and cost estimates

The ENUBET technique is very promising and the results we got in the last twelve months exceeded our expectations.

We look forward to seeing ENUBET up and running in the DUNE/HyperK era!

Thank you!