The ENUBET project

high precision neutrino flux measurements in conventional neutrino beams

- Beams for precision physics in the ν sector
- The ENUBET Project (Jun 2016 – May 2021) and the Reference Design
- Achievements of the first year:
  - First prototype of the instrumentation for the decay tunnel successfully tested at the CERN East Area
  - Full simulation of the instrumented decay tunnel: particle identification, doses, pile-up
  - Precise assessment of all flavor fluxes at the neutrino detector
  - Progress on beamline simulation, photon veto development, front end electronics

F. Terranova (Univ. of Milano-Bicocca and INFN)
on behalf of the ENUBET Collaboration

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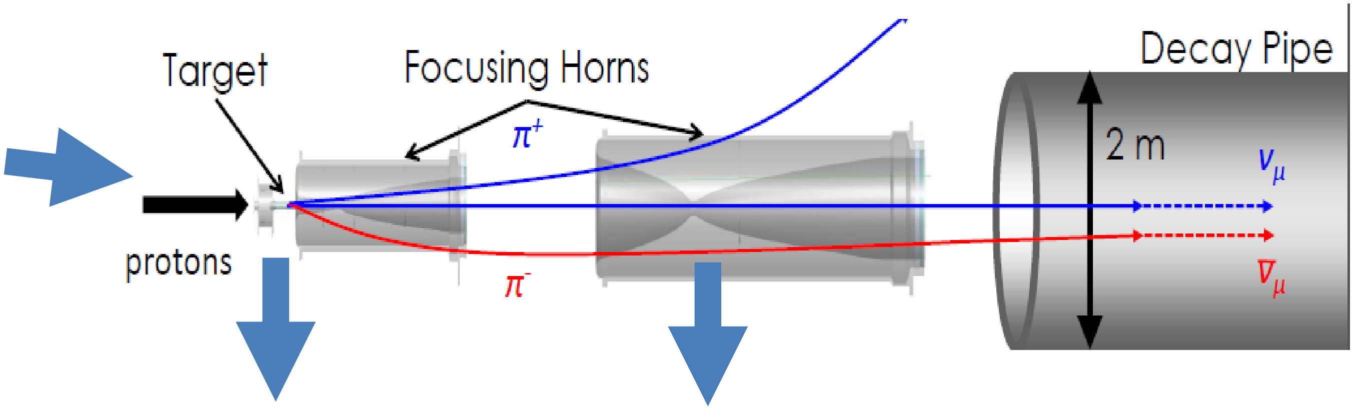
Beams for the precision era of ν physics

In neutrino physics, we get "as many neutrinos as possible" but…
we do not know "how many"

Monitoring of protons on target (pot), horn currents, muons after the beam dump

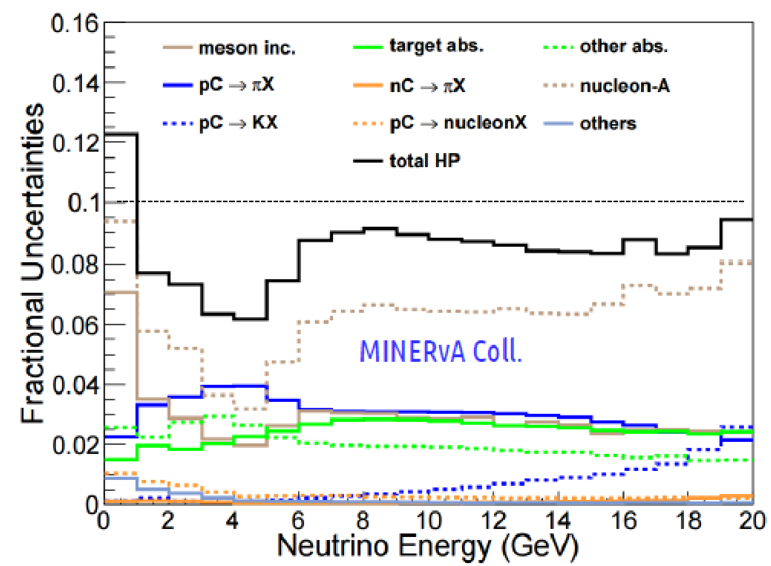


Hadro-production data

Full simulation of beamline, secondary reinteractions etc.

The current generation of cross section experiments is based on this time-honored (but indirect) technique to estimate the neutrinos produced in the decay tunnel. Hence,

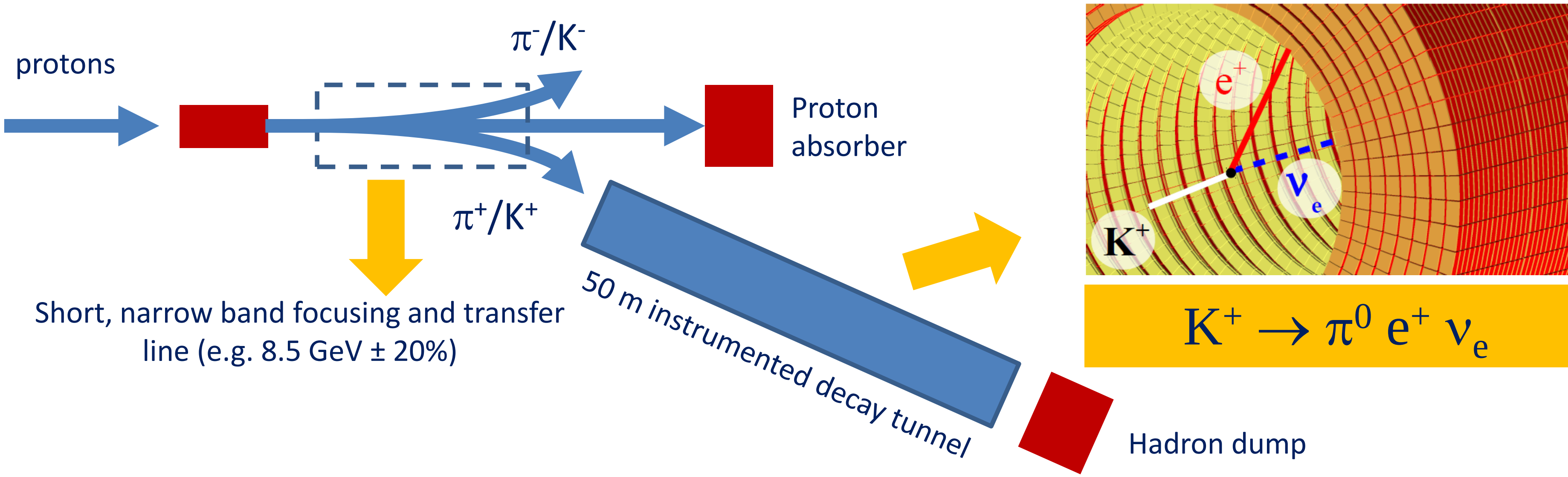
- ✓ all absolute cross section measurements are limited to >6% by flux uncertainties
- ✓ No precise measurement of ν_e available in spite of the great relevance for CPV, NSI, precision oscillation physics



Monitored neutrino beams

The new generation of short baseline experiment for cross-section measurement and, in general, for precision ν physics at short baseline (e.g. sterile neutrinos and NSI) should rely on a **direct measurement of the neutrino fluxes**.

Kaon-based monitored neutrino beams (A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155) are a very appealing candidate since provide a pure and precise source of ν_e



π^+ and μ decay at small angles and reach the hadron dump without crossing the wall of the tunnel. Kaon decay products cross the instrumented walls and are detected. **The e^+ rate is a direct measurement of the ν_e flux** and, in the ENUBET reference design, ν_e from kaon decay represents 97% of the overall ν_e flux.

ENUBET: Enhanced NeUtrino BEams from kaon Tagging

This **ERC Project** (Consolidator Grant, PI A.Longhin, Host Institution: INFN) will enable the technology of monitored neutrino beams for the next generation of experiments addressing **both the technical challenges and the physics reach**.

The ENUBET Collaboration

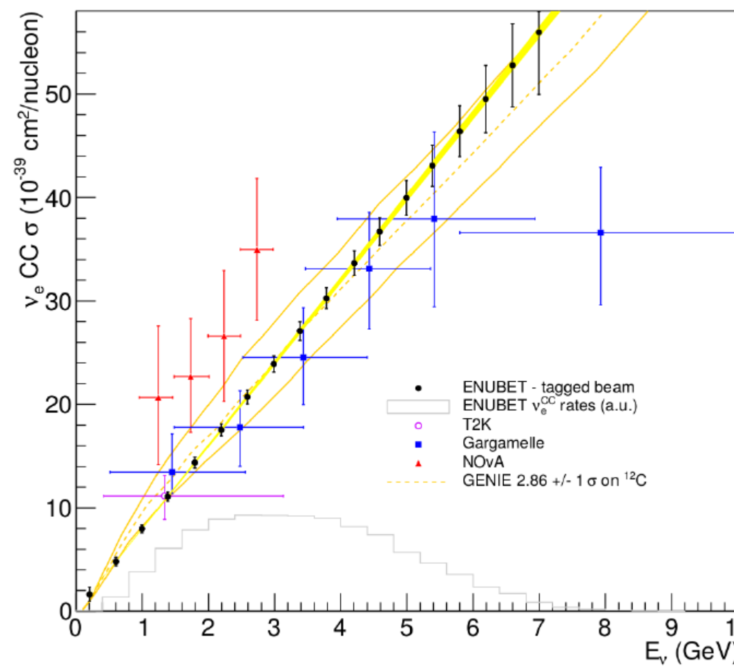
Enabling precise measurements of flux in accelerator neutrino beams: the ENUBET project

A. Berra[a,b], M. Bonesini[b], C. Brizzolari[a,b], M. Calviani[m], M.G. Catanesi[l], S. Cecchini[c], F. Cindolo[c], G. Collazuol[k,j], E. Conti[j], F. Dal Corso[j], G. De Rosa[p,q], A. Gola[o], R.A. Intonti[l], C. Jollet[d], M. Laveder[k,j], A. Longhin[j(*)], P.F. Loverre[n,f], L. Ludovici[f], L. Magaletti[l], G. Mandrioli[c], A. Margotti[c], N. Mauri[c], A. Meregaglia[d], M. Mezzetto[j], M. Nessi[m], A. Paoloni[e], L. Pasqualini[c,g], G. Paternoster[o], L. Patrizii[c], C. Piemonte[o], M. Pozzato[c], M. Prest[a,b], F. Pupilli[e], E. Radicioni[l], C. Riccio[p,q], A.C. Ruggeri[p], G. Sirri[c], F. Terranova[b,h], E. Vallazza[i], L. Votano[e], E. Wildner[m]

CERN-SPSC-2016-036: SPSC-EOI-014
CERN Neutrino Platform: NP03 Plafond

The ENUBET design is optimized to reach a 1% systematic error on the ν_e flux and a <1% statistical error **for a 500 ton neutrino detector located 50 m from the hadron dump**.

If achieved, it would represent a major breakthrough in experimental neutrino physics.



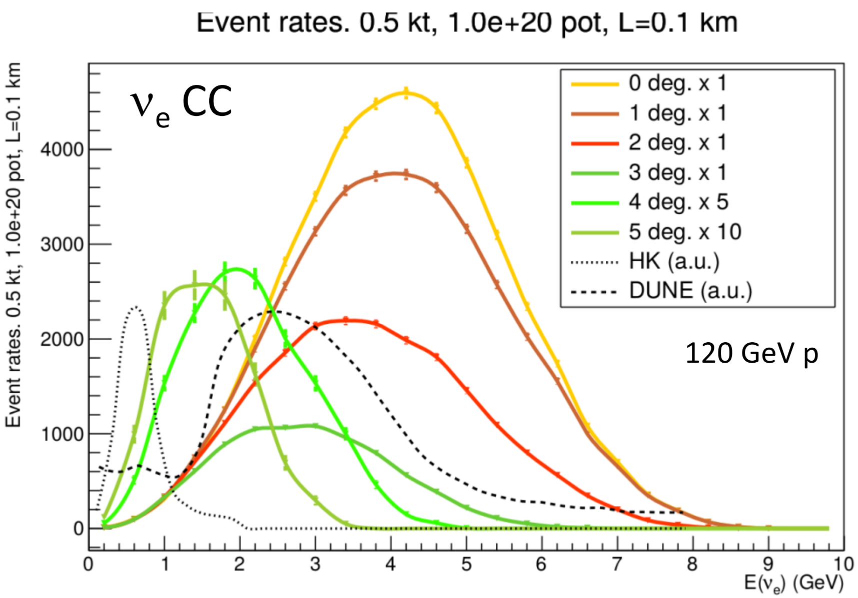
The ENUBET Reference Design

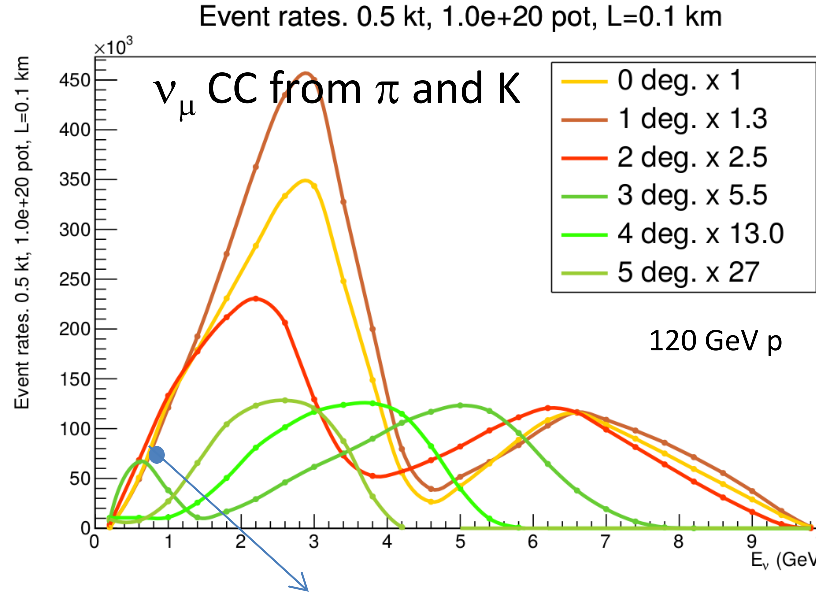
In about one year we moved from a conceptual study (EPJC 75 (2015) 155) to a concrete Reference Design that we are validating:

	baseline option	other options	status
Proton extraction	Few ms spill at O(10 Hz) during the flat top (2 s)	slow extraction	not tested yet
Focusing	Horn based	quad based	conductor optimization ongoing
Transfer line	Quad+dipoles		just started
Detector for e/π separation	Shaslik calorimeters with SiPM readout	polysiloxane scintillators, non-shashlik readout	full simulation and prototyping ongoing
Photon veto	Scint. pads with fiber readout	direct light readout, large area APD	full simulation and prototyping ongoing
Particle identification and detector optimization	3x3x10 cm^2 ultra compact modules (UCM)	different radii and granularities	full simulation and prototyping ongoing
Systematic assessment	Positron monitoring	enhanced with other K decay mode	just started

Neutrino fluxes in the Reference Design

Proton Energy	pot for 10^4 ν_e CC	nominal duration of the run (actual duration will depend on max horn repetition rate)
30 GeV [JPARC]	$1.0\ 10^{20}$	~3 months at nominal JPARC intensity
120 GeV [Fermilab]	$2.4\ 10^{19}$	~2 months at nominal NuMI intensity
400 GeV [CERN]	$1.1\ 10^{19}$	~3 months at nominal CNGS intensity





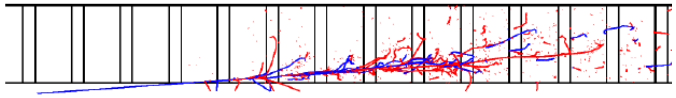
10^5 ν_μ CC events from π decay

The reference design mostly optimized for multi-GeV (e.g. DUNE). The HyperK region is accessible lowering the secondary energy and/or exploiting the huge statistics of the ν_μ CC from pion decay: work in progress.

Particle identification in the decay tunnel

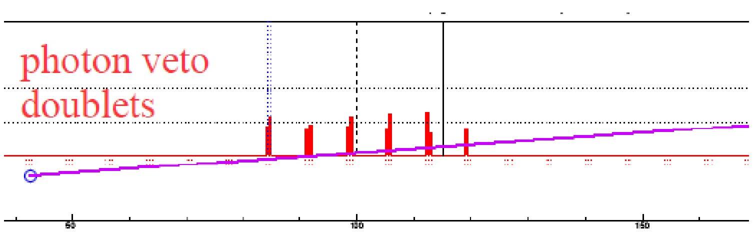
$e^+/\pi^+/\mu$ separation

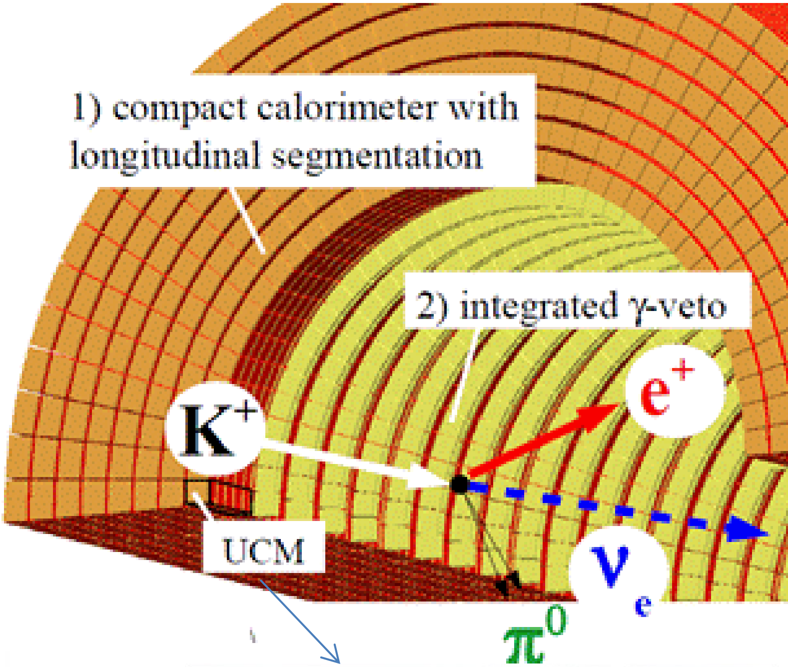
(1) Compact shashlik calorimeter (3x3x10 cm^2 Fe+scint. modules + energy catcher) with longitudinal (4 X_0) segmentation and SiPM embedded in the bulk of the calorimeter (see below)

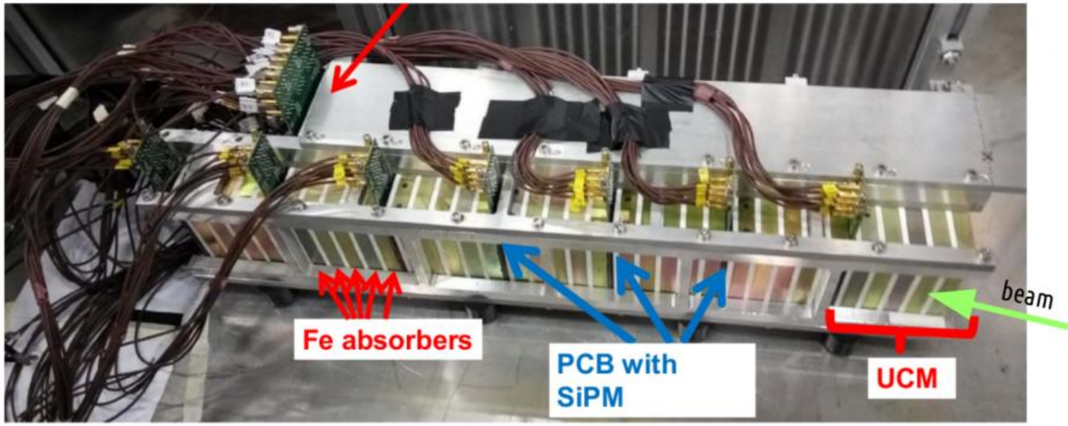


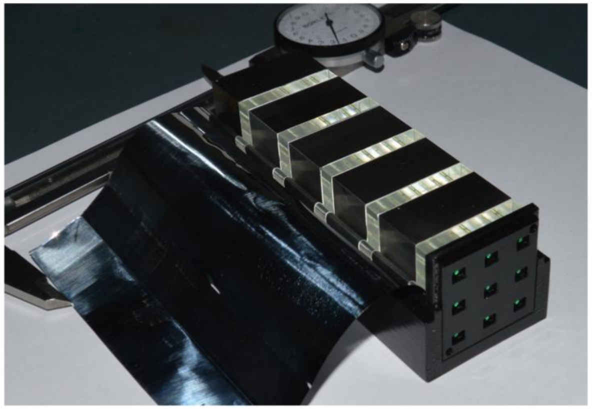
e^+/γ separation

(2) Rings of 3 x 3 cm^2 pads of plastic scintillator

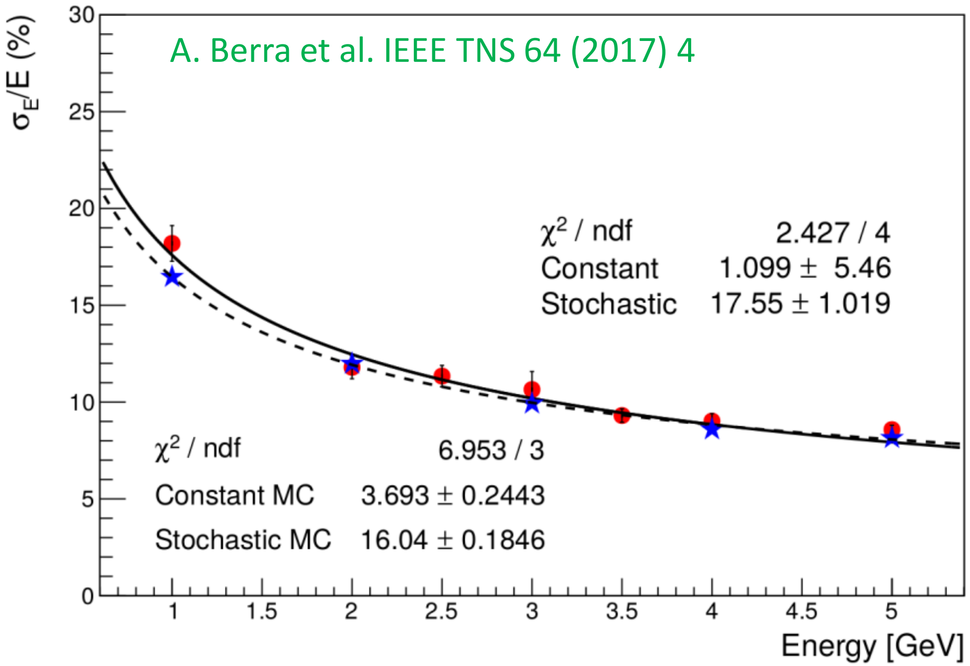


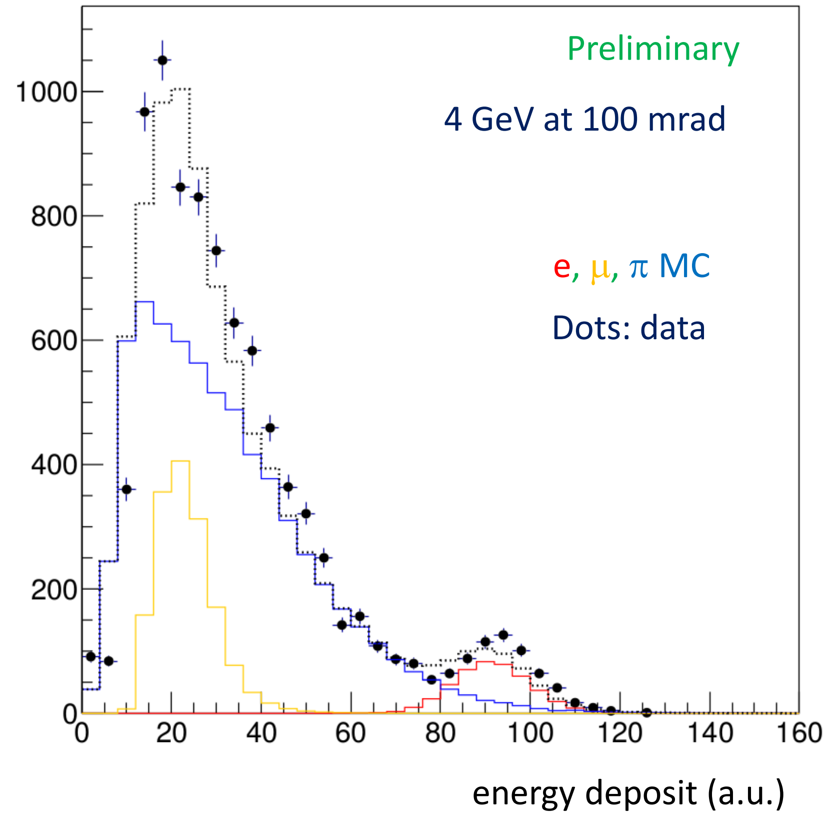






Prototypes of the tunnel instrumentation

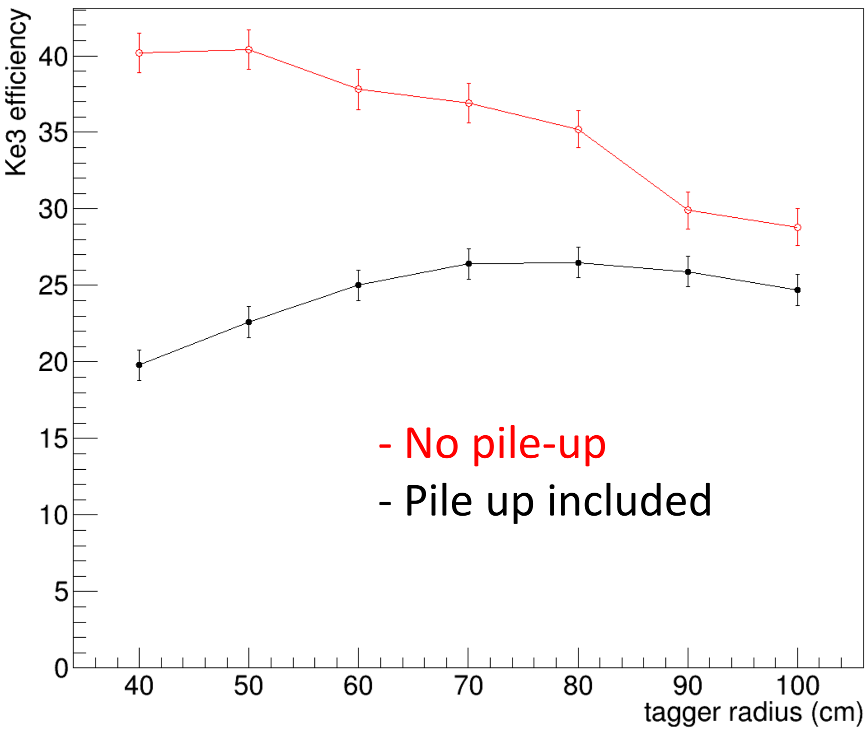


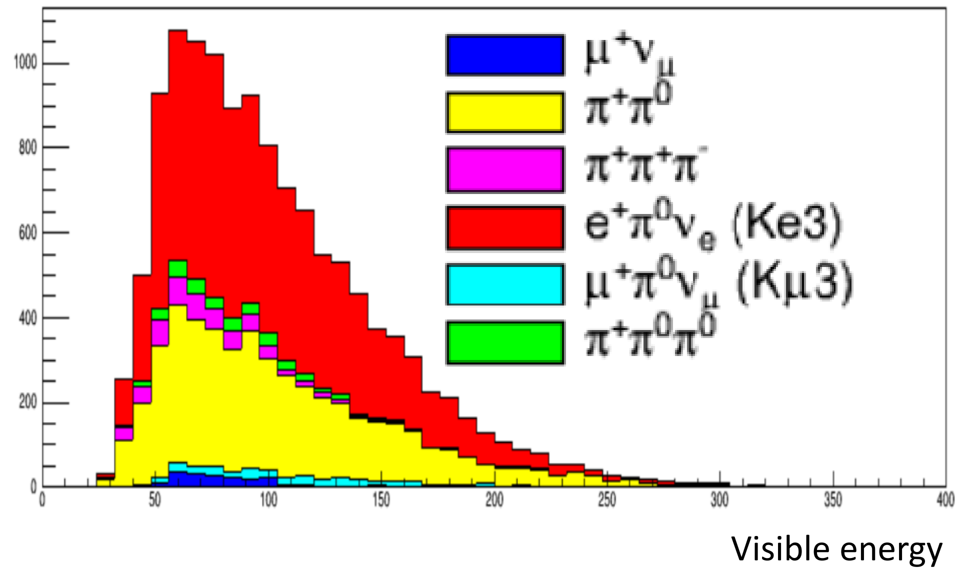


The results obtained in the 2016 test-beams on small size prototypes of the instrumentation for the decay tunnel also validate the GEANT4 ENUBET simulation.

Simulation of the decay tunnel

Particles are identified by the energy deposit pattern in the calorimeter modules and in the photon veto using a multivariate analysis.
The clustering of energy deposits ("event builder") is based on position and timing of the signal waveforms in the modules. **Pile up is now fully included**.

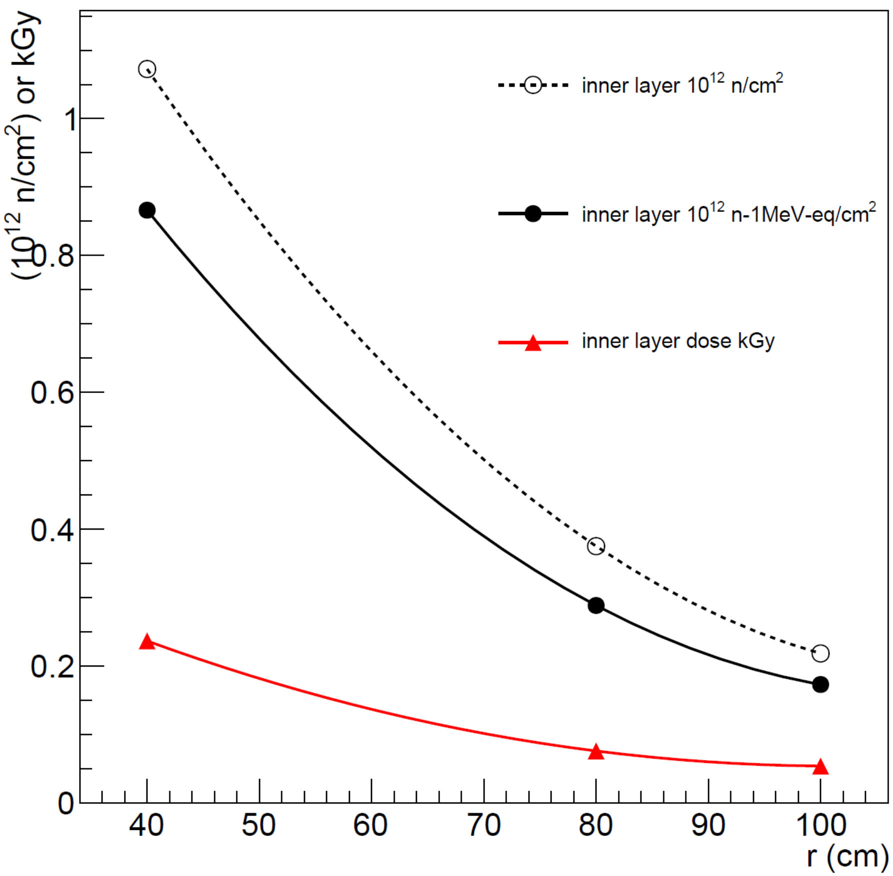




For the granularity of the calorimeter (3x3x10 cm^2 modules) of the Reference Design, instrumenting the tunnel at 1 m radius allows for positron identification with S/N > 1.

Doses

The decay tunnel is a harsh radiation environment but ENUBET works after a transfer line (narrow band beam) and the instrumentation is located only at large angles. Still the doses are significant and will drive the final detector choice.



Doses at 1 m radius for 10^4 ν_e CC
0.05 kGy (ionizing dose)
2 10^{11} neutrons /cm^2 (1 MeV equivalent)

Irradiation tests are ongoing to evaluate the best option for the type and location of SiPM

Conclusions

- Enabling a technology to monitor **in a direct manner** the neutrino production at source would represent a major breakthrough in experimental neutrino physics.
- In fact, at the GeV scale the limited knowledge on the initial flux is **the dominant contribution to cross section uncertainties**
- Such limit **can be reduced by one order of magnitude exploiting the $K^+ \to \pi^0 e^+ \nu_e$ channel (K_{e3})**
- ENUBET is investigating this approach and its application to a new generation of **cross section, sterile and time tagged neutrino experiments**.
- The results obtained in the first year of the project are very promising:
  - ✓ The Reference Design has been established
  - ✓ The detector technology was studied with dedicated prototypes and testbeams, and performance fulfills the expectations
  - ✓ The simulation of the decay tunnel is now complete and include particle identification, pile up and assessment of ionizing and non-ionizing doses
  - ✓ The work on the beamline simulation and systematics assessment has started

We're just at the beginning of the Project (2016-2021) but… we are off to a great start ☺