The ENUBET project: high precision neutrino flux measurements in conventional neutrino beams

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on behalf of the ENUBET Collaboration

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The problem of flux uncertainty

Indirect technique to estimate neutrino flux (current generation cross-sextion experiment):

- Monitoring of protons on target (pot), horn currents, muons after the beam dump
- Hadro-production data
- Full simulation of beamline, secondary reinteractions etc.

BUT STILL…

Neutrino experiments affected by an intrinsic limitation:

large uncertainty of the overall neutrino flux (~7-10%) directly reflecting to the cross section measurements.

In addition to the flux uncertainty for $\sigma(\nu_e)$ → beam contamination.

$\sigma(\nu_\mu) \leftrightarrow \sigma(\nu_e)$ not simple especially @ low-E (Mc. Farland, 2012)

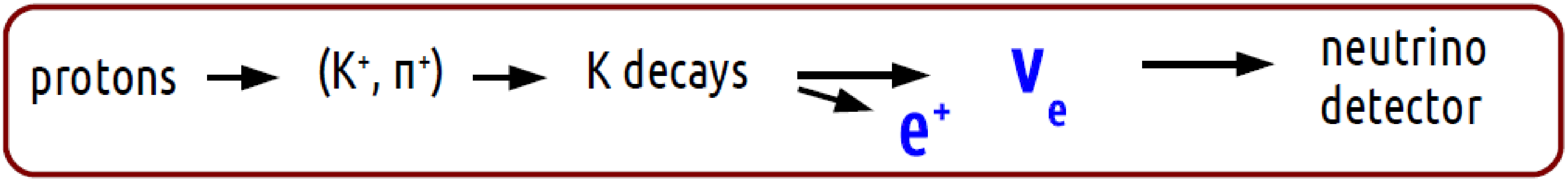
Poor knowledge of $\sigma(\nu_e)$ can spoil :

the CPV discovery potential

the insight on the underlying physics (standard vs exotic)

Monitored neutrino beams

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



Traditional

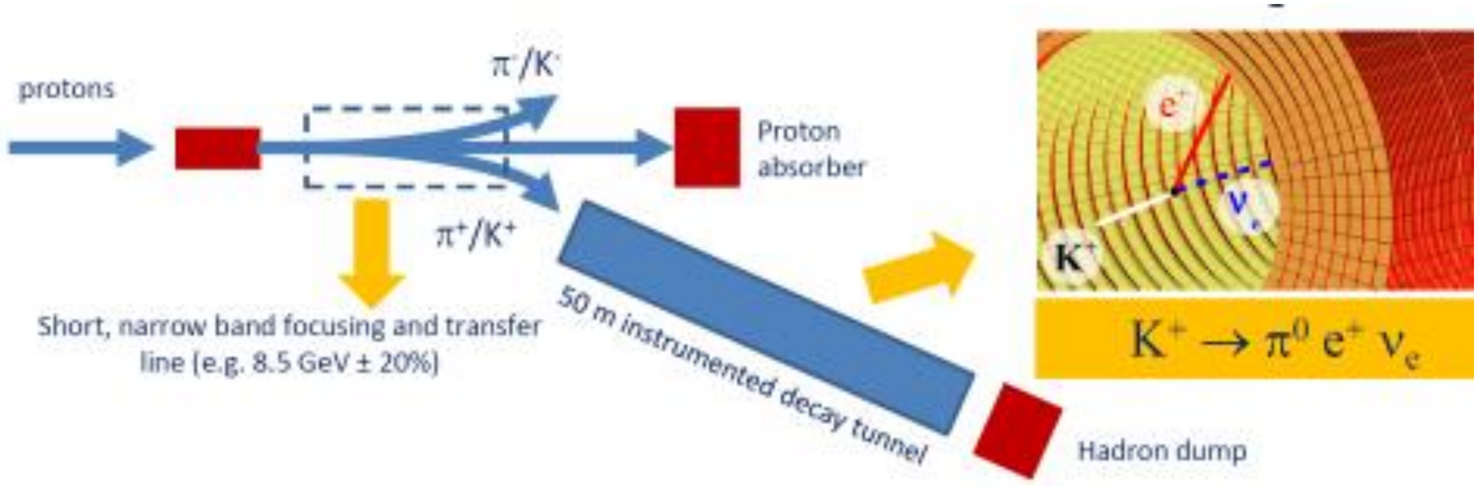
- Passive decay region
- ν_e flux relies on ab-initio simulations of the full chain
- large uncertainties

Monitored

- Fully instrumented
- ν_e flux prediction = e+ counting ($K^+ \rightarrow e^+ \nu_e \pi^0$)
- "By-pass" hadro-production, PoT, beam-line efficiency uncertainties

<u>**ENUBET**, ERC Project (Consolidator Grant, PI A.Longhin, Host Institution: INFN)</u> aims to **enable the technology of monitored neutrino beams** for the next generation of experiments (technical challenges / physics reach)

Challenges and Requirements



CHALLENGES:

The decay tunnel is a **harsh environment:**

- **particle rates: > 200 kHz/cm^2**
- **backgrounds:** pions from K$^+$ decays
  → **need to veto 98-99 % of them**
- **instrument region: ~ 50 m**
- grazing incidence
- significant spread in the initial direction

REQUIREMENTS:

e$^+$ tagger key points:

- longitudinal sampling
- perfect homogeneity
  → integrated light-readout

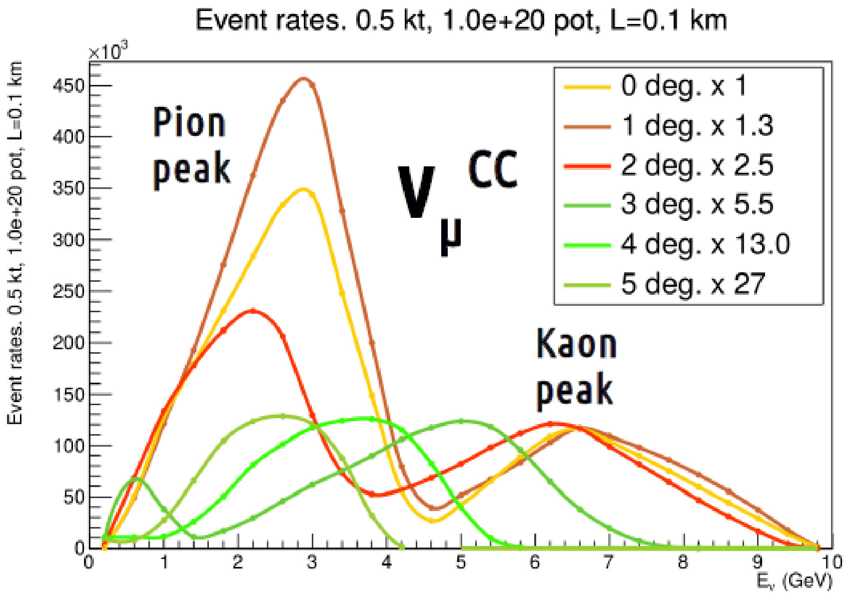
Photon veto key points:

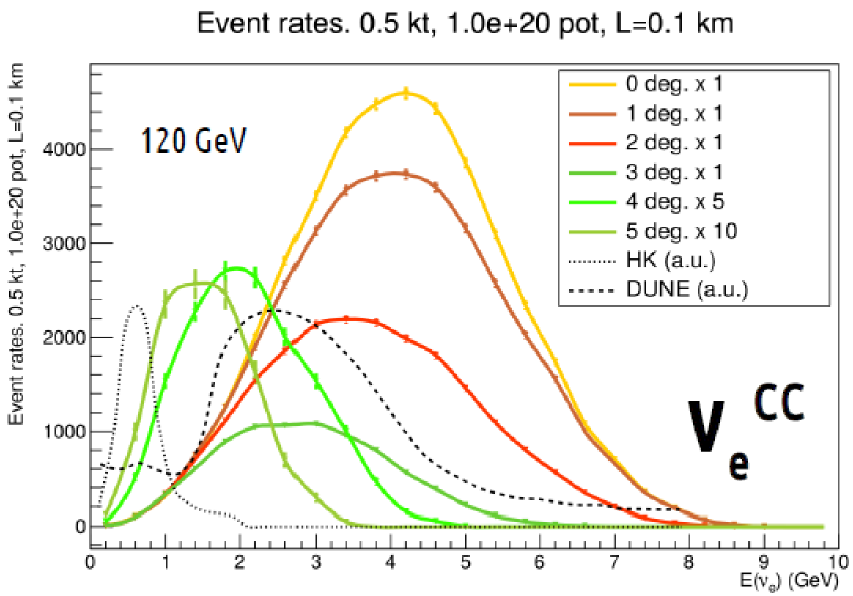
- photon identification capabilities
- precise timing of the particles
- Exploit 1 mip – 2 mip separation

Neutrino fluxes in the reference design

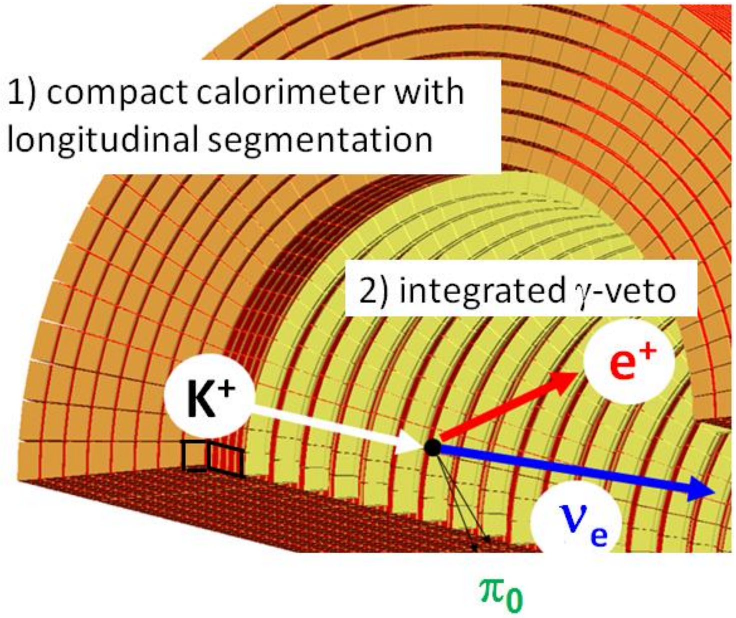
The **ENUBET design is optimized** to reach a 1% systematic error on the ν_e flux and a <1% statistical error **for a 500 ton neutrino detector located ~100 m from the hadron dump.**

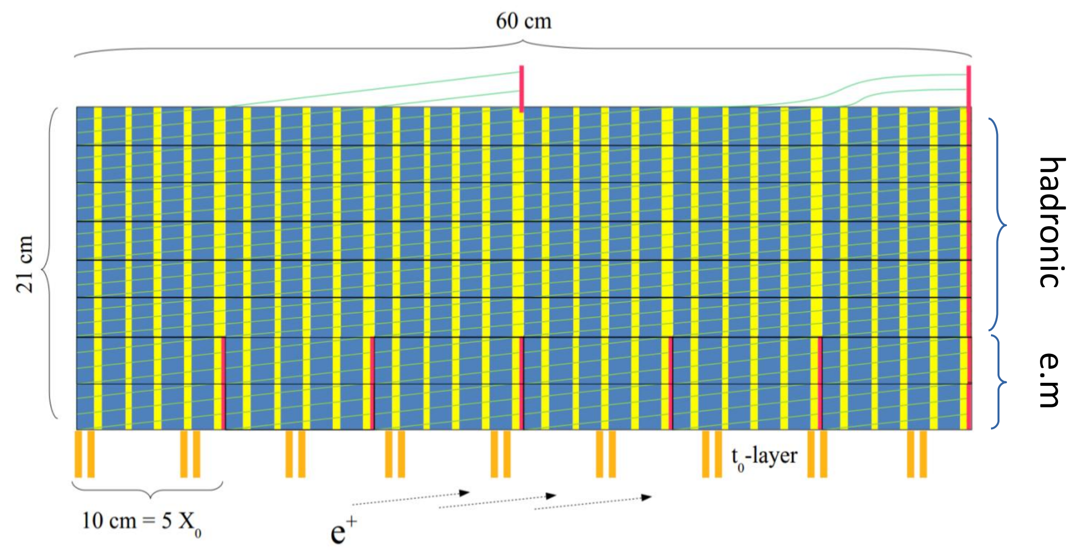
Proton Energy	Pot for 10^4 ν_e CC	Run nominal duration
30 GeV [JPARC]	1.0 10^{20}	~ 3 months at nominal JPARC intensity
120 GeV [Fermilab]	0.24 10^{20}	~2 months at nominal NuMI intensity
400 GeV [CERN]	0.11 10^{20}	~3 months at nominal CNGS intensity





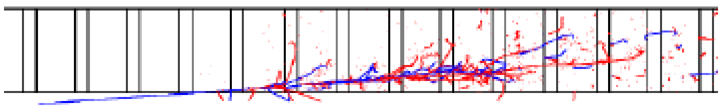
PID – Tagger technology





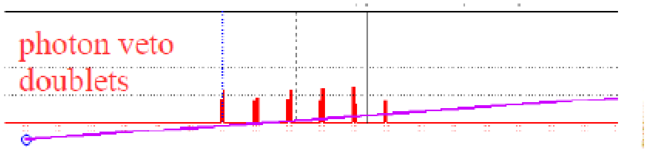
(1) Compact shashlik calorimeter (UCM) with longitudinal (4 X_0) segmentation.

- $3x3x10\ cm^3$ Fe + scint. modules
- SiPM embedded in the bulk of the calorimeter



Separate e^+, π^+, μ

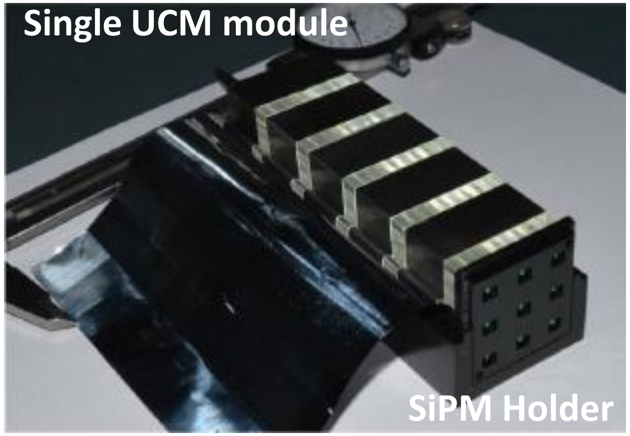
(2) Photon Veto Rings of $3 \times 3\ cm^2$ pads of plastic scintillator

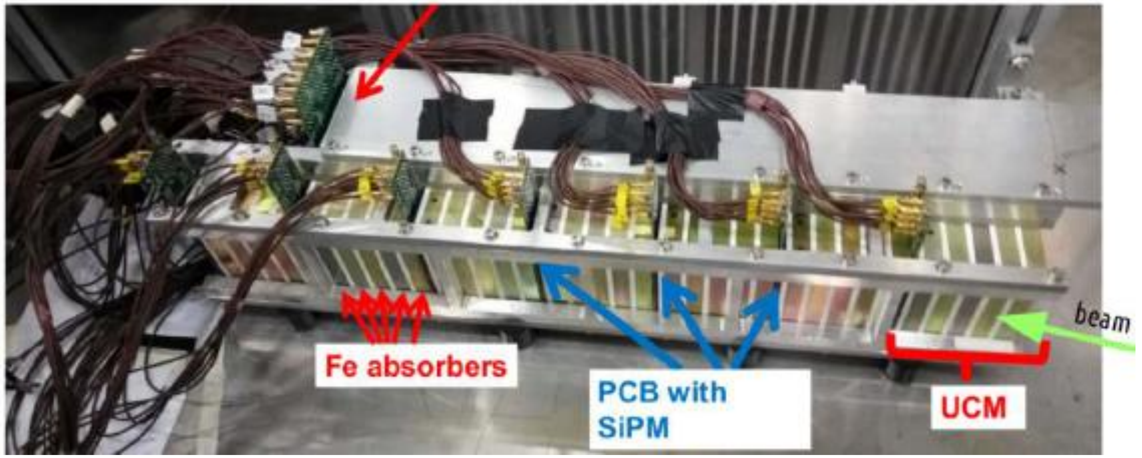


Separate e^+, γ

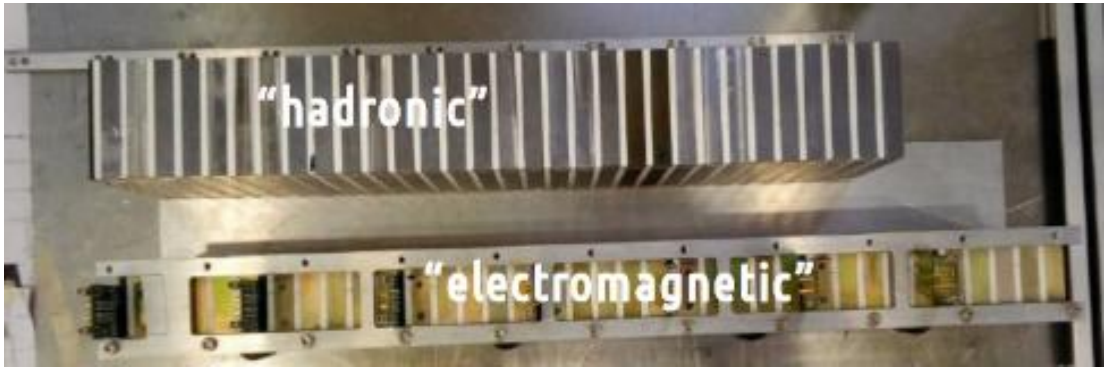
1) Hadronic + e.m. calorimeter prototype

Test Beam @ T9 - CERN 2016

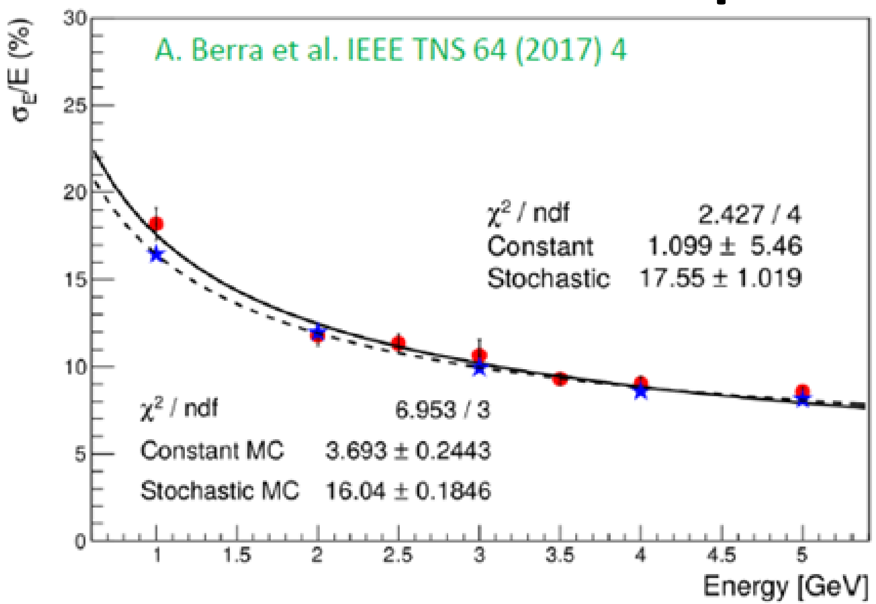


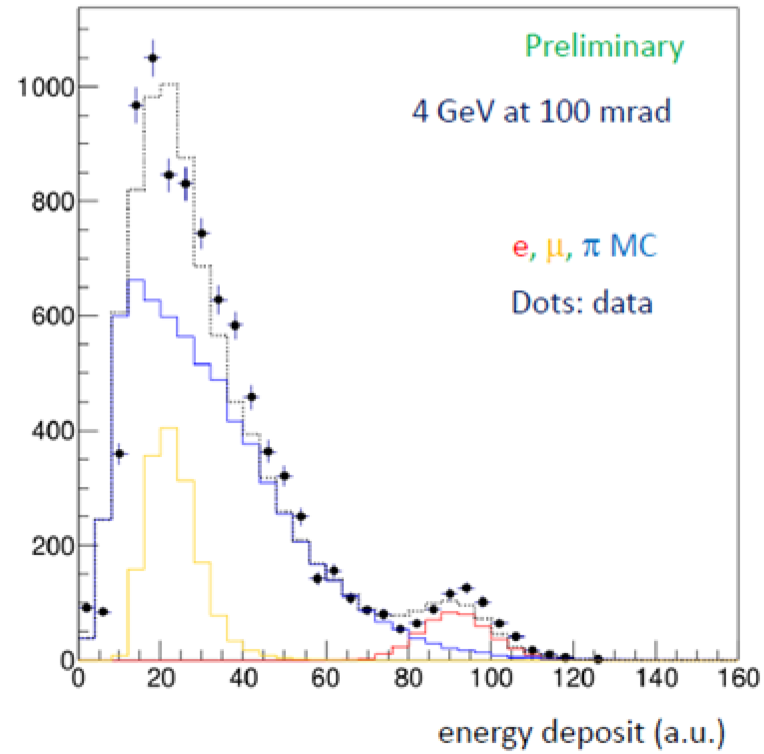


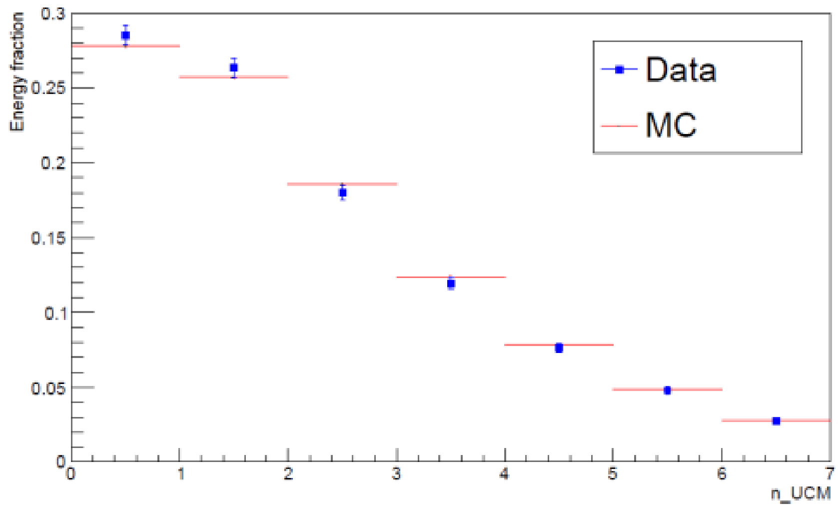
56 (e.m) + 18 (had) UCM modules → 666 SiPM (FBK)



Prototypes: resolution and e/π separation







The obtained results also validate the GEANT4 ENUBET simulation

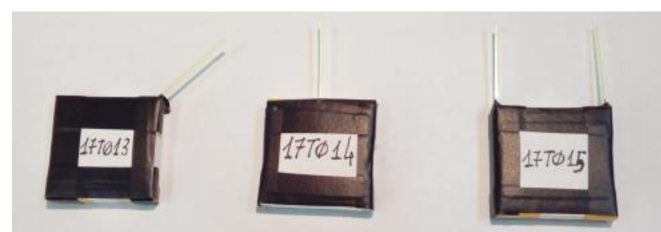
testBeam @ T9 CERN 2017

Setup shashlik calorimeter (1) :
Scintillator: EJ204 scintillator (double thickness)
WLS Fiber: BCF92 MC
14 X_0 shashlik calorimeter using plastic Scintillators: new configuration promising a higher light yield and fast response

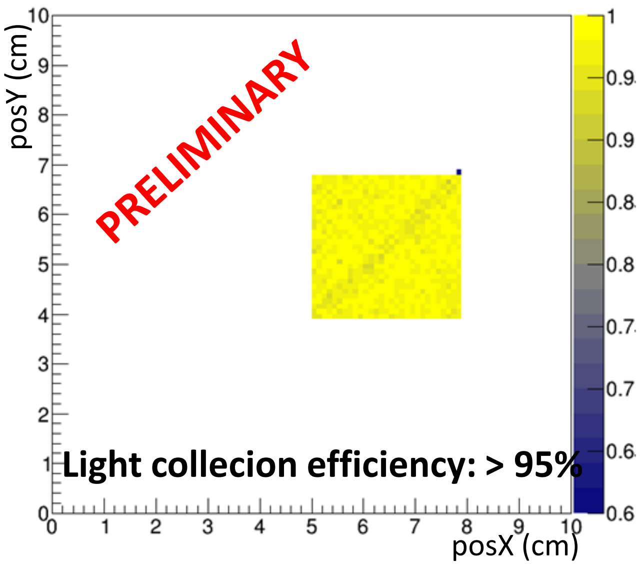
Goal:
Study calorimeter response (light collection efficiency, linearity response, energy resolution…)

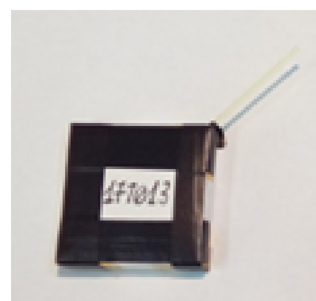
Setup Photon Veto (2):
Scintillator: 3x3x0.5 cm^3 EJ200/EJ204
WLS Fiber: Kuraray Y11 MC / BCF92 MC
SiPM: SenSL

Goal:
Study light collection efficiency
First measure of time resolution
First trial of 1 mip / 2mip separation



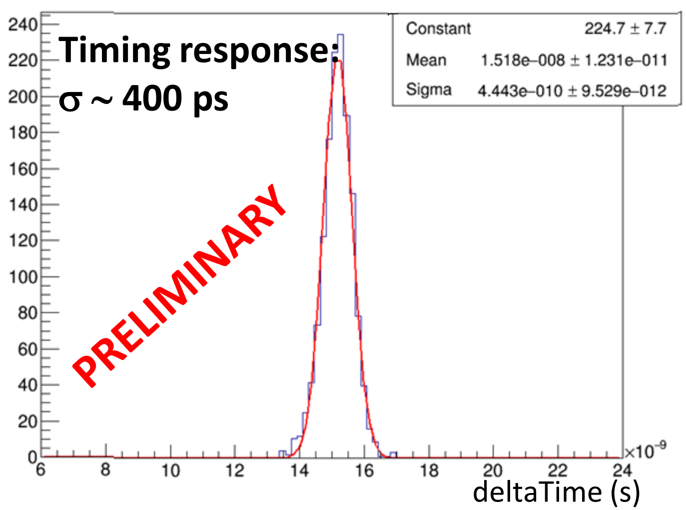
Photon veto@ CERN-PS T9 2017

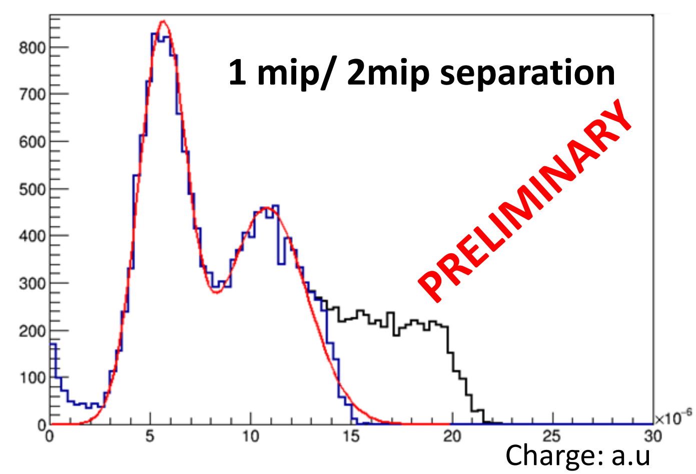




1 mip signal is ~ **20 p.e**

Testing **1 mip/2mip** separation, exploiting a **Delrin cylinder** on the beam **to enhance** the π^0 production **and an iron γ-converter** (~ 0.8 X0) for pair produciton





Ongoing activities (1)
Irradiation studies

ENUBET works after a transfer line (narrow band beam) and the instrumentation is located only at large angles. BUT still the doses are significant and will drive the final detector choice.

- Neutron and ionizing doses have been studied for a tagger radius of 40, 80 and 100 cm with FLUKA and crosschecked with GEANT4.
- Doses at 1 m radius for 10^4 ν_e CC 0.05 kGy (ionizing dose) $2 \cdot 10^{11}$ neutrons /cm^2 (1 MeV equivalent).
- Test irradition with 1-3 MeV neutrons performed at INFN-LNL CN Van de Graaff on 12-27 June 2017.
- Characterise rad-hard SiPM with 12-15-20 μm cell size (FBK, SensL) up to 10^{11-12} 1 MeV-eq n/cm^2.
- Test viability of self-calibration with m.i.p.

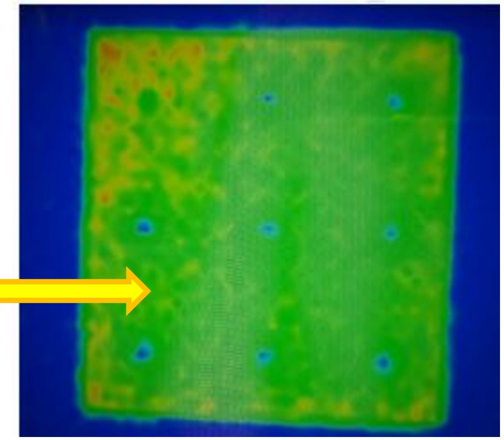
Ongoing activities (2)

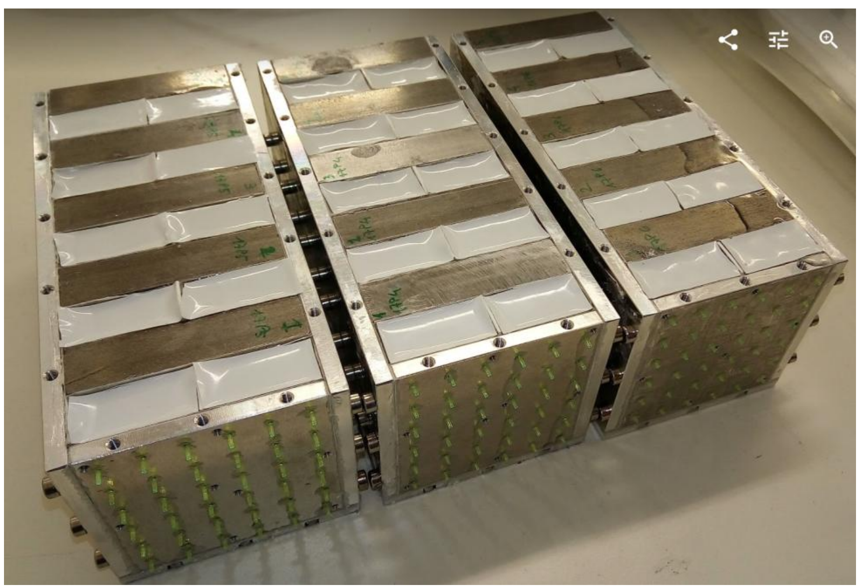
Tests:

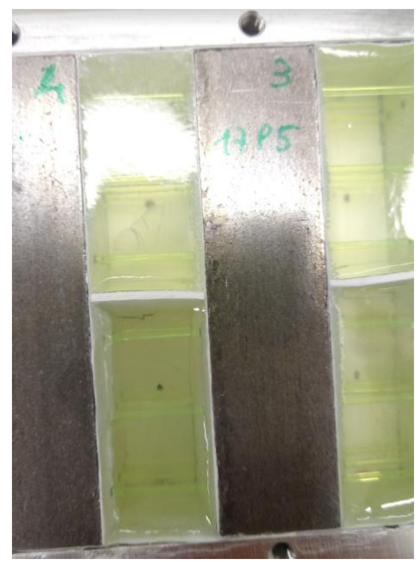
- Response of irradiated SiPM (FBK, SenSL)
- Custom digitizers electronics
- photon veto prototypes with plastic scintillators
- recovery time (to cope with pile-up)

Scalable/reproducible technological solutions under study:

- Molded scintillators, water-jet holes machining for absorbers
- Polysiloxane scintillators/powder absorbers



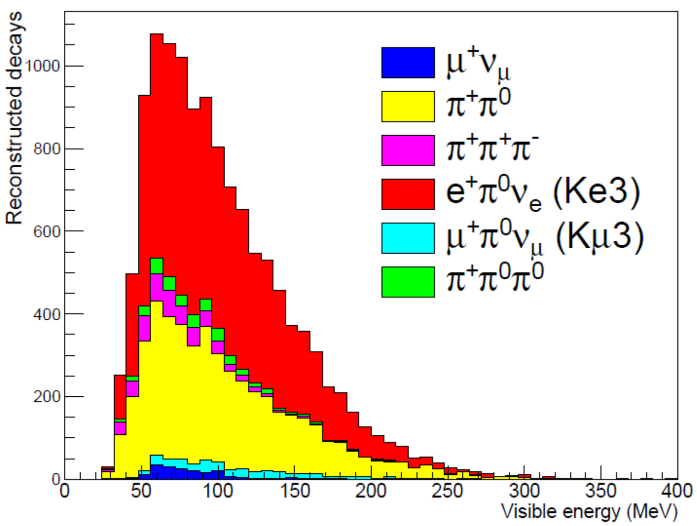




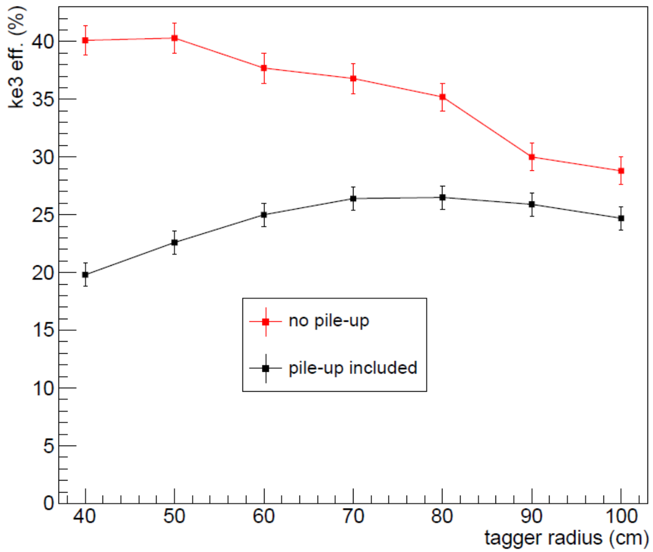
Ongoing acrtivities (3)
Simulation of the decay tunnel

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.**



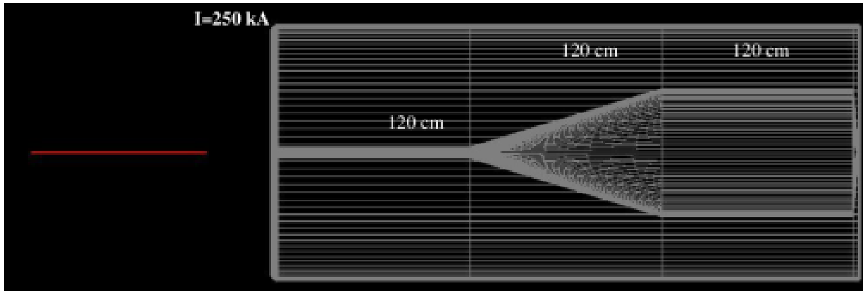
composition of the reconstructed sample

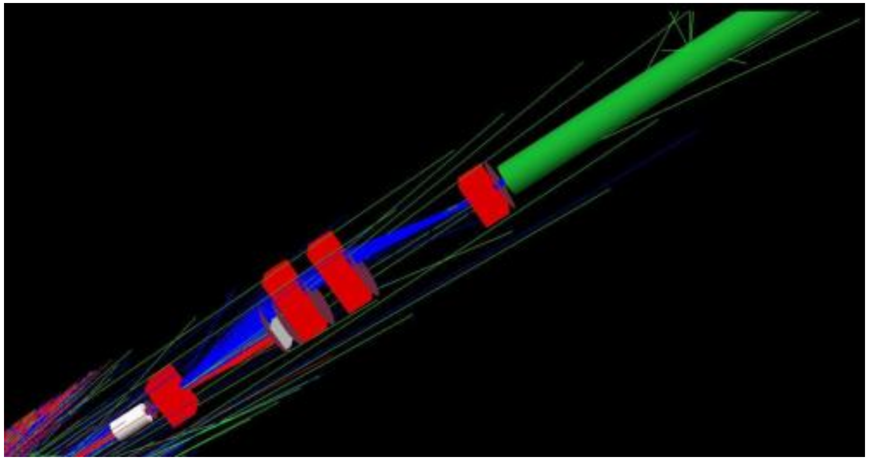


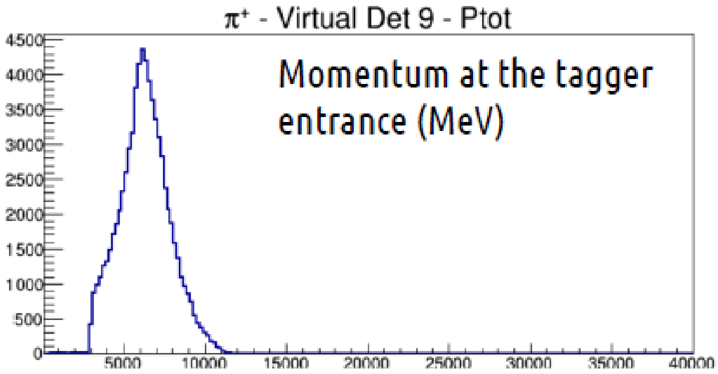
Pile-up effect on Ke3 efficiency seen at nominal rates. Mitigation enlarging the radius: ~ 25 % (~ 50 % purity).

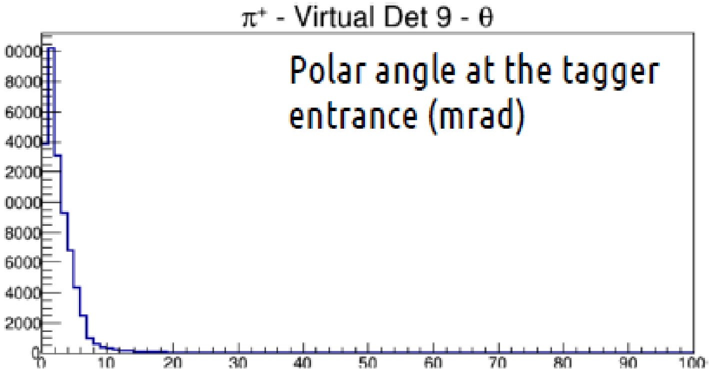
Ongoing Activities (4)
Hadron beamline studies

- A realistic implementation of the beam-line/focusing layout.
- Site-independent. We are considering existing proton driver energies.
- FLUKA/G4Beamline simulations in progress. Support early estimates.
- Assess beam-related backgrounds.
- Machine studies of multi-Hz slow resonant extraction at CERN-SPS









Conclusions

- At **GeV scale** the limited **knowledge on the initial flux** is the **dominant contribution to cross section uncertainties** → exploiting the $K^+ \rightarrow \pi^0 e^+ \nu_e$ channel (Ke3)

- **ENUBET is investigating this approach** and its application to a new generation of neutrino experiments.: enabling a technology to directly **monitor neutrino production at source → major breakthrough in experimental neutrino physics.**

- 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