The ERC ENUBET project

high precision neutrino flux measurements in conventional neutrino beams

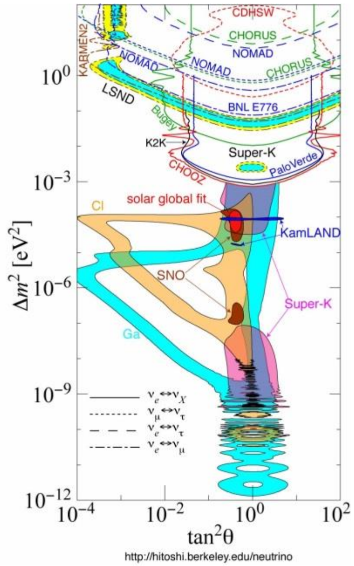
- High precision flux measurement with the ENUBET technique
  [A. Longhin, L. Ludovici, F. Terranova, Eur. Phys. J. C75 (2015) 155]
- The ENUBET project: goals and plans (2016-2021)
- Most relevant achievements in 2016:
  - Particle identification with calorimetric techniques in the decay tunnel
  - Shashlik calorimeters with longitudinal segmentation (SCENTT R&D)
  - Full simulation of the instrumented tunnel
- Proton extraction scheme, focusing and transfer line
- Forthcoming activities and conclusions

F. Terranova on behalf of the ENUBET Collaboration

European Research Council
Established by the European Commission

A striking paradox in precision neutrino physics…

… very well known to NuFact participants and already mentioned by many speakers!



from discovery to precision physics →

Known

(pre-ν2016)

δm^2	2.4%
Δm^2	1.8%
$\sin^2\theta_{12}$	5.8%
$\sin^2\theta_{13}$	4.7%
$\sin^2\theta_{23}$	$\sim$ 9%

Detectors have grown in size, resolution and complexity.

BUT

Neutrino beams grew “just” in intensity. No major conceptual breakthrough since the 70s.

Experiments in the precision era of neutrino physics have exquisite knowledge of the final state interactions but a quite rough (>5%) knowledge of initial fluxes and beam contamination.

As a consequence, the physics reach of precision physics experiments is strongly linked to the systematic reduction programme currently underway.

nuSTORM

ν_μ and ν_e from muon decay in flight

Flux: muon counting in the decay ring

nuPIL

ν_μ from pion decay

Flux: beamline instrumentation

ENUBET (*)

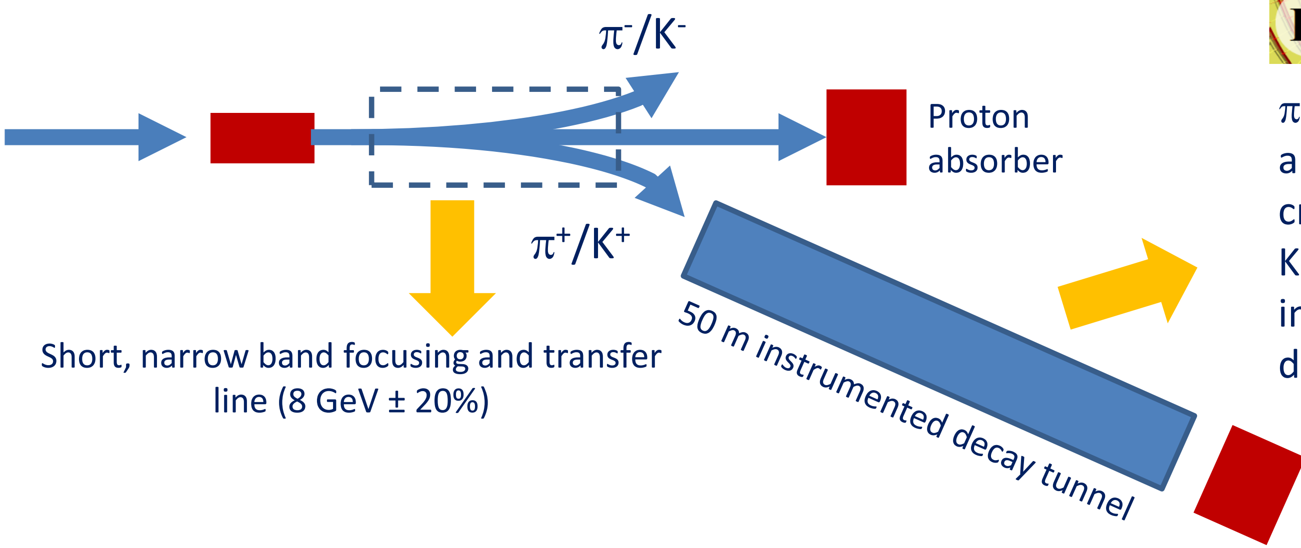
ν_e from kaon decay

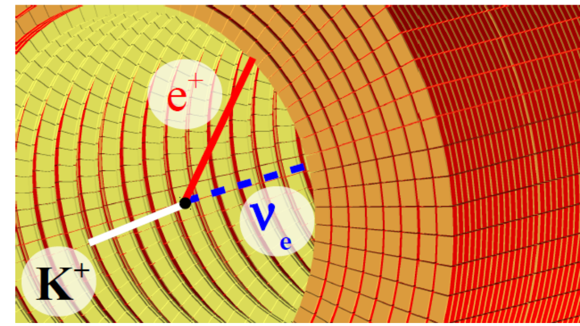
Flux: large angle positron monitoring

(*) **Enhanced Neutrino Beams from Kaon tagging.**

Inspired by the “tagged neutrino beam” concept.

Hand, 1969, S. Denisov, 1981, R. Bernstein, 1989, Ludovici, Zucchelli, 1999, Ludovici, Terranova, 2010





π^+ and μ decay at small angles and reach the dump without crossing the wall of the tunnel. K decay products cross the instrumented walls and are detected.

<u>Pros</u>: a pure ν_e source from K decay (μ DIF negligible)

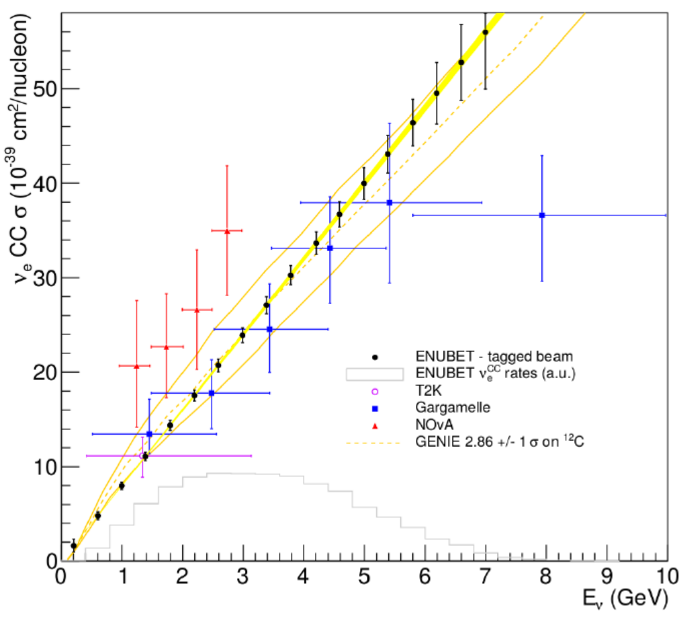
Flux determined from e^+ monitoring at large angle

<u>Cons</u>: large reduction of flux compared to nuSTORM/nuPIL

Why to develop the ENUBET technology?

This technology is well suited for short baseline experiment where the intensity requirement are less stringent. There are three major applications:

- A new generation of cross section experiment operating with a neutrino source that is controlled at the <1% level. A unique tool for the precision era of neutrino physics and a new opportunity for the cross-section community. This is the main aim of ENUBET as funded by ERC.
- A phase II sterile neutrino search, especially in case of positive signal from the Fermilab SBL program
- The first step toward a real tagged neutrino beam where the ν_e CC interaction at the detector is time-correlated with the observation of the lepton in the decay tunnel



Impact on ν_e cross section measurement assuming the parameters of EPJ C75 (2015) 115 (see below)

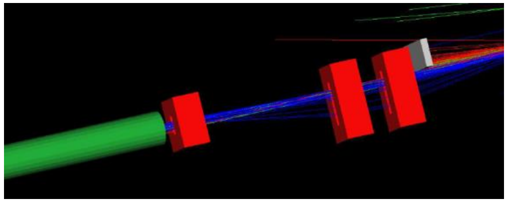
The ENUBET Collaboration

ENUBET is a project approved by the European Research Council (ERC) for a 5 year duration (Jun 2016 – May 2021) with an overall budget of 2 Meuro.

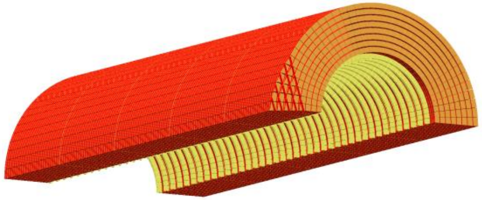
Grant: ERC Consolidator Grant, 2015 (PE2)
Principal Investigator: Andrea Longhin
Host Institution: Italian Institute for Nuclear Research (INFN)
Collaboration (as for Aug 2016): ~40 physicists from 10 institutions (INFN, CERN, IN2P3, Univ. of Bologna, Insubria, Milano-Bicocca, Napoli, Padova, Roma, Strasbourg)

Activities include:

- Design of the beamline



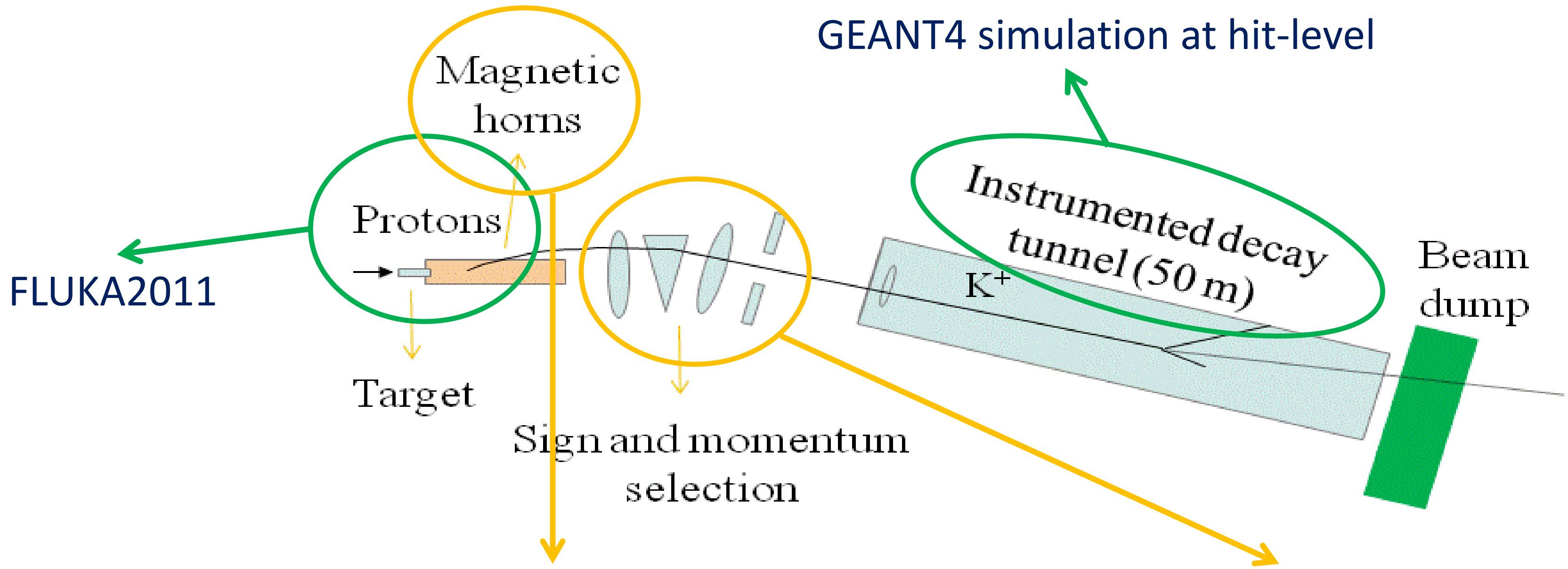
- Construction of a 3 m section of the instrumented decay tunnel



- Testbeams at CERN-T9 and INFN-LNF

- Design and test of the proton extraction schemes (CERN-SPS)

Results in the preparatory phase (Nufact 2015)



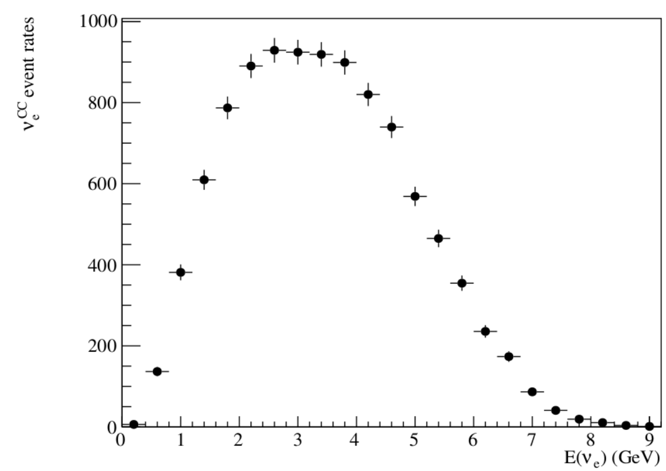
Assuming 85% efficiency for secondaries inside the ellipse $\varepsilon_{xx'}=\varepsilon_{yy'}=0.15$ mm rad in the (x,x',y,y') phase space

Assuming 20% momentum bite at 8.5 GeV and flux reduction due to decay (15 m).

The neutrino beam

Since the decay tunnel is short and the secondary momentum is 8.5 GeV, 97% of the ν_e are from K decay.

the e^+ rate is a direct measurement of the ν_e flux



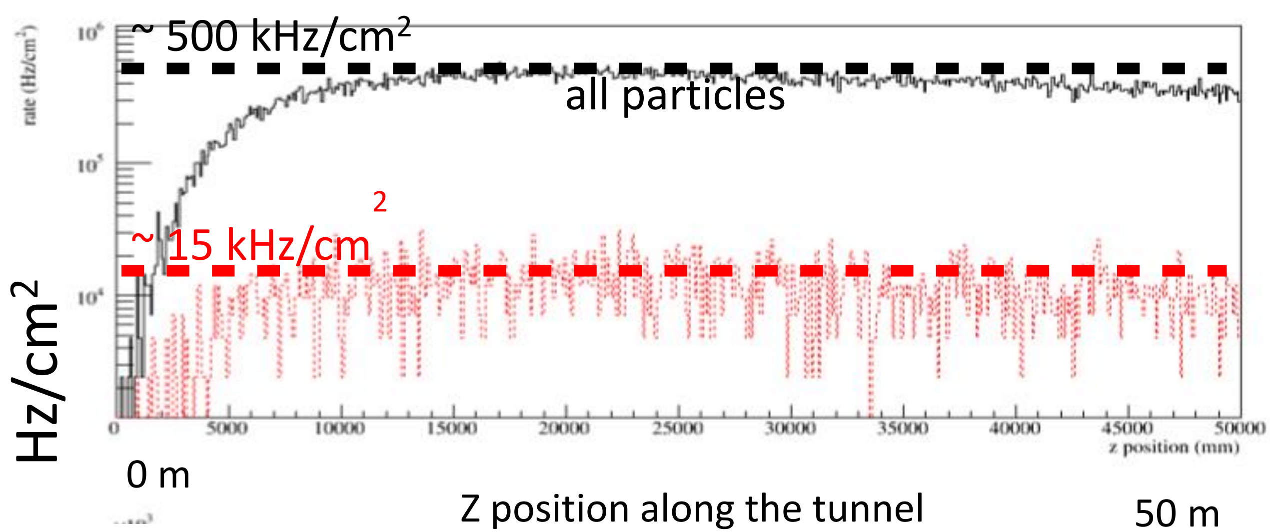
A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155, NIM A824 (2016) 693; A. Berra et al., NIM A830 (2016) 345, A. Berra et al., NuFact15 Proceedings, arXiv:1512.08202

Reference parameters: 10^{10} π^+/spill (1.02×10^9 K^+/spill). **500 ton neutrino detector(*)** at 100 m from the entrance of the tunnel. How many protons-on-target are needed to observe 10^4 ν_e CC events in the detector (1% statistical uncertainty on cross section)?

(*) e.g. ICARUS@Fermilab , Protodune SP/DP @CERN

	E (GeV)	π^+/PoT (10^{-3})	K^+/PoT (10^{-3})	PoT for a 10^{10} π^+ spill (10^{12})	PoT for 10^4 ν_e CC (10^{20})
JPARC	30	4.0	0.39	2.5	5.0
	50	9.0	0.84	1.1	2.4
Protvino	60	10.6	0.97	0.94	2.0
	70	12.0	1.10	0.83	1.76
Fermilab	120	16.6	1.69	0.60	1.16
CERN-SPS	450	33.5	3.73	0.30	0.52

For 10^{10} π^+ in a 2 ms spill at the entrance of the tunnel **rates are well below 1 MHz/cm²**

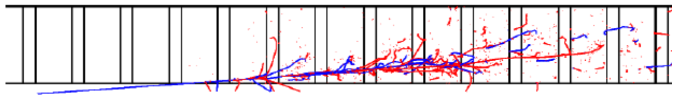


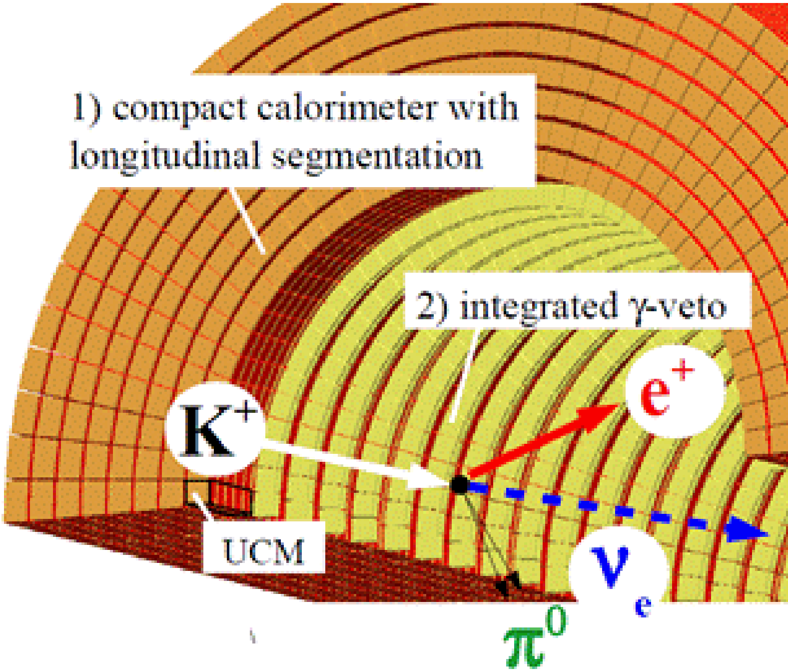
New results: (I) Simulation

- Setting up of the general software framework hosted at CC-IN2P3 (Lyon) and coordinated by A. Meregaglia (IN2P3, Strasbourg)
- Full GEANT4 simulation of the baseline detector of choice for the instrumented tunnel

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

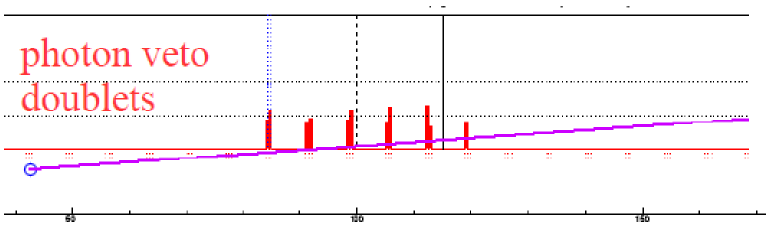
(1) Compact shashlik calorimeter (3x3x10 cm^2 Fe+scint. modules + energy catcher) with longitudinal (4 X_0) segmentation and SiPM embedded in the bulk of the calorimeter (see below)





e^+/γ separation

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



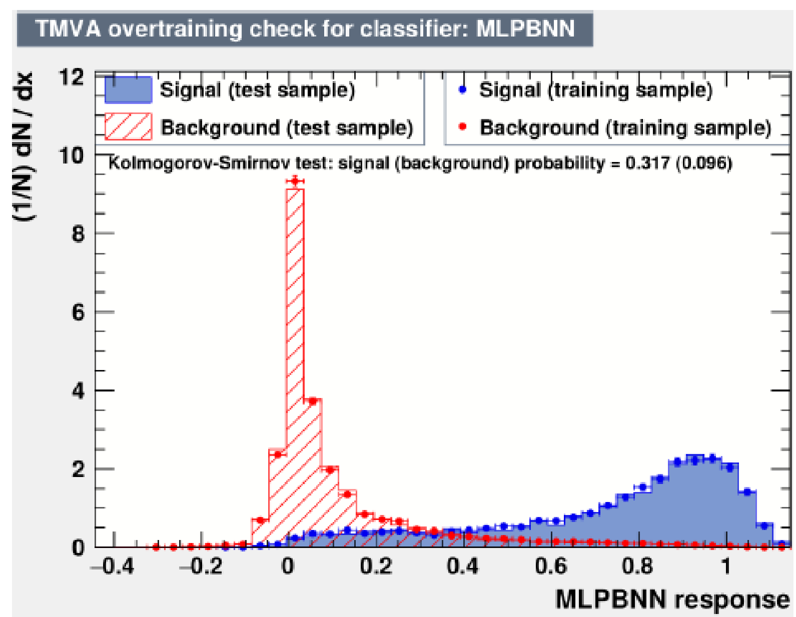
New results: (I) Simulation

The identification algorithms separate positrons from charged and neutral pions combining info from the calorimeter modules and γ veto. Clustering and event building is limited to neighboring modules to avoid pile-up effects and mismatch due to time resolution

$(e^+ + \gamma)/\pi^+$ separation → **Artificial Neural Network** (5 variables employing the pattern of E deposited in the calorimeter) → e/γ separation → **Sequential cuts** (Info from the γ veto) → e^+ signal

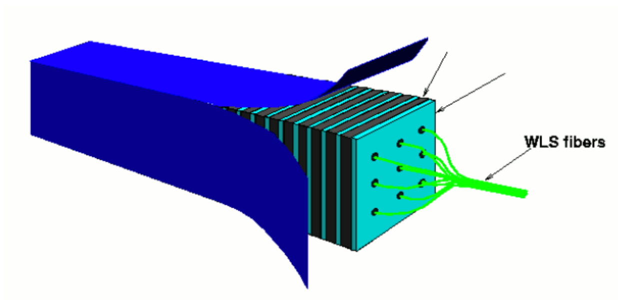
	ε_{geom}	ε_{sel}
e^+	90.7 %	49.0 %
π^+	85.7 %	2.9 %
π^0	95.1 %	1.2 %

Confirm early results from fast simulation but with a **realistic** and **very cost-effective** setup!



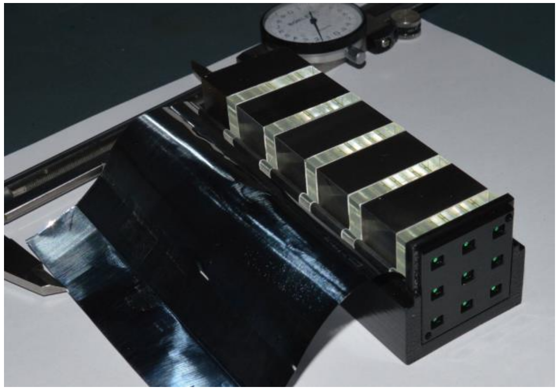
New results: (II) Prototyping

Detector prototyping for shashlik calorimeter with longitudinal segmentation ongoing since 2015 and funded by an INFN R&D programme (SCENTT).



Cheap, fast (<10 ns), rad-hard
(ENUBET needs: 1.3 kGy – not critical)

e^+/π^+ separation needs longitudinal segmentation

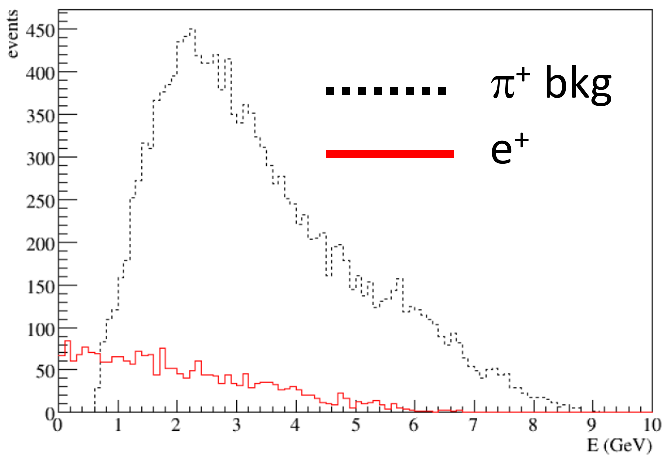


One SiPM for each fiber in the back of each module. Summed signals (9 SiPM per ADC) to reduce cost

Requirements for ENUBET:

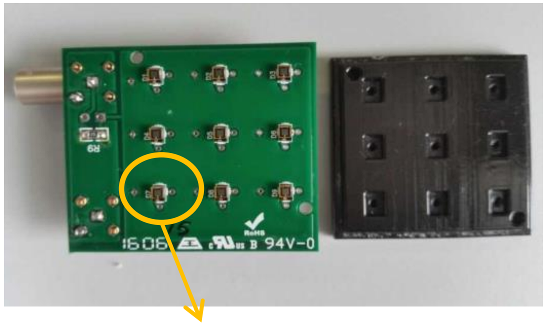
- mip sensitivity but no saturation for e.m. showers up to 4 GeV — done
- energy resolution $<25\%/E^{1/2}$ — done
- recovery time ~10 ns
- validation of MC for e/π separation

→ nov 2016

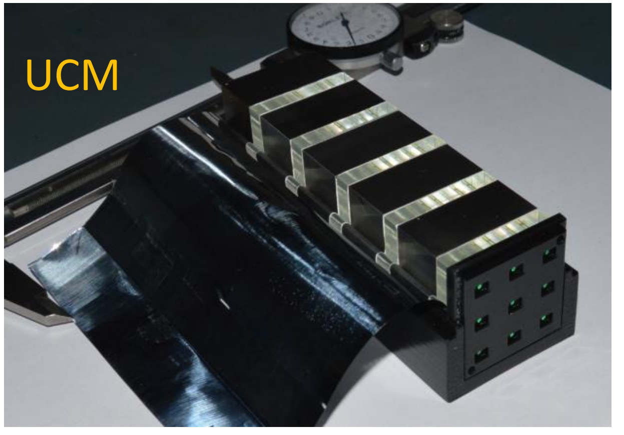


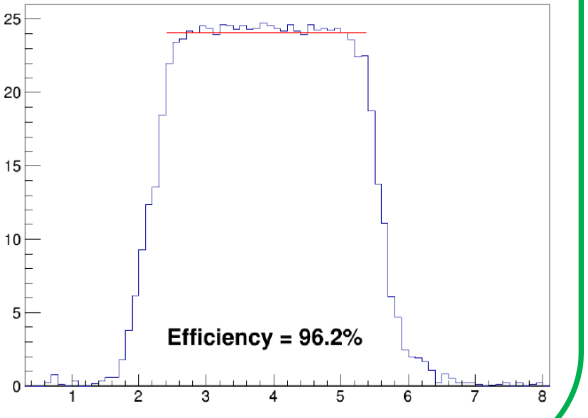
New results: (II) Prototyping

Apr-Jun 2016: construction and test with cosmics of ultra-compact modules (UCMs)

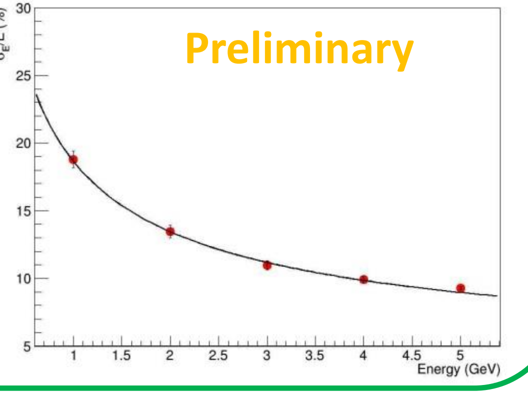


SiPM holder
(PCB+ plastic mask)





Characterization of 12 UCMs at CERN PS-T9 (1-5 GeV, e and π, 28 June -13 July).



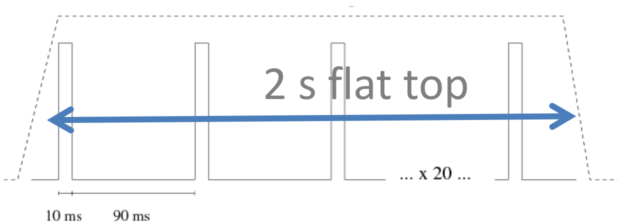
Test with a 28 UCMs + energy catcher at CERN PS-T9, November 2016.

A long way to go….

Claiming an overall systematic budget <1% requires an end-to-end simulation of the neutrino beamline. Such simulation work (currently based on CERN-SPS) has just started.

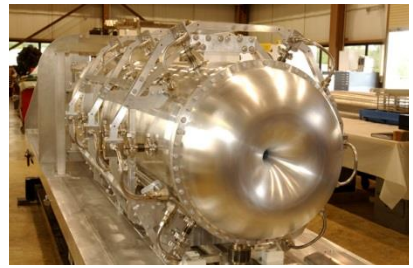
ENUBET horn-based option:

Proton extraction scheme



several few-ms extractions during the 1.2 s flat top

Horn



I(t) profile matching the extraction scheme (few ms, ~10 Hz during flat top)

Pros: large acceptance (flux)

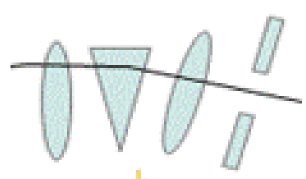
Cons: unconventional parameters for p extraction and focusing of secondaries

ENUBET static focusing-based option:

Proton extraction scheme

Identical to the one of SHIP@CERN

Focusing



Static (quad, dipoles)

Pros: very low rates at the decay tunnel. Tagged neutrino beams

Cons: small acceptance (flux). Cosmic ray background at the neutrino detector.

Systematics on the flux

Source of uncertainties	Size and mitigation
Statistical error	<1%
kaon production yield	**irrelevant (positron tag)**
uncertainty on integrated pot	**irrelevant (positron tag)**
geometrical efficiency	<0.5%
uncertainty on 3-body kinematics and mass	<0.1%
uncertainty on the ν_e contam. from μ DIF	<0.5%
uncertainty on phase space at entrance	**can be checked directly with low intensity pion runs**
uncertainty on Branching Ratios	**irrelevant (positron tag)** except for background estimation (<0.1%)
e/π^+ separation and detector stability	**can be checked directly at test-beams**

The claim of <1% uncertainty is very likely but has to be firmly grounded if ENUBET has to become the standard flux monitoring technique for short baseline neutrino beams.

Conclusions

- The precision era of neutrino oscillation physics requires better control of its artificial sources. 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})**
- In the next 5 years ENUBET will investigate this approach and its application to a new generation of **cross section, sterile and time tagged neutrino experiments**.
- The results obtained in 2015-2016 are very promising:
  - **Full simulation** of the decay tunnel supports the effectiveness of the **calorimetric approach** for large angle lepton identification
  - First prototypes demonstrate that shashlik calorimeters with longitudinal segmentation can be built without compromising energy resolution (19% at 1 GeV) and provide the **performance requested by the ENUBET technology**
- The final goal of the ENUBET Collaboration is to demonstrate that:
  - a "positron monitored" ν_e source based on K_{e3} can be constructed using existing beam technologies and can be implemented at CERN, Fermilab or JPARC
  - a 1% measurement of the absolute ν_e cross section can be achieved with detector of moderate mass (500 ton)