Shashlik calorimeters: novel ultra-compact design prototypes for the ENUBET Project

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ENUBET (Enhanced NeUtrino BEams from kaon Tagging)

- New-concept ν_e source based on tagging of large angle e^+ from $K^+ \to e^+ \pi^0 \nu_e$ decays in an **instrumented decay tunnel**
- Reduction of the systematic uncertainties on the knowledge of the initial neutrino flux to O(1%) level

Physics implications

- Unprecedented high precision measurement ν_e of and $\bar{\nu}_e$ cross sections (short baseline neutrino experiments)
- Highly beneficial for tackling the main open neutrino-related problems: mass hierarchy, θ_{23} octant, leptonic CP violation
- First step towards a time tagged neutrino beam: direct ν production/detection correlation

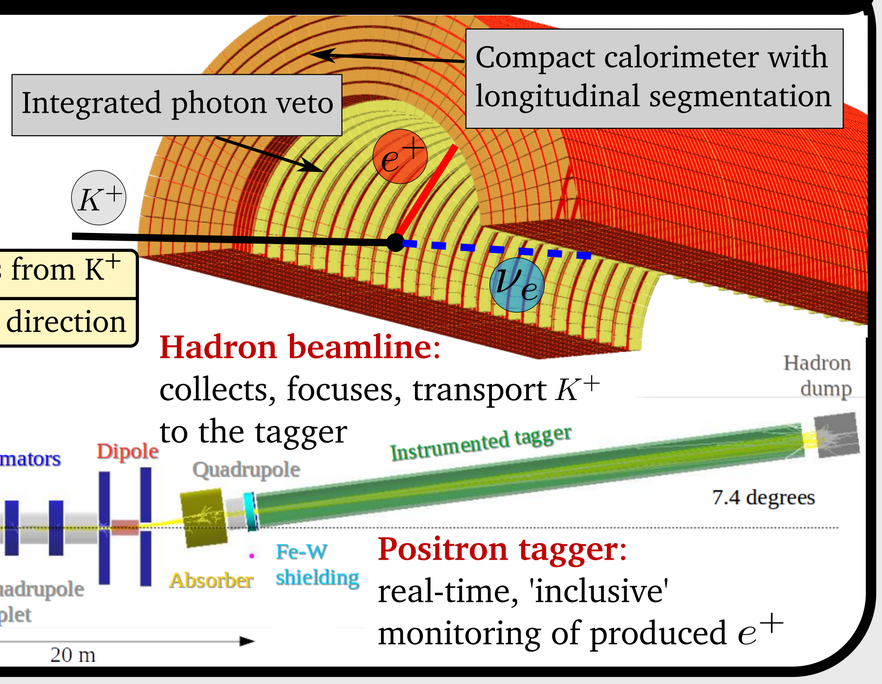
Experiment design

- **Monitored neutrino beam**: hadron beamline followed by an instrumented decay tunnel
- **Positron tagger requirements**:

rates $>$ 200 kHz/cm^2	main bkg: pions from K$^+$
source length $\sim$ 50 m	spread in initial direction

- **Implementation challenges**:

Radiation hard components
Recovery time O(10 ns)
Granularity $\simeq 10$ cm^2:
scalable/cheap technology
(up to 10^5 channels)
Readout triggerless ≥ 10 ms



Hadron beamline: collects, focuses, transport K^+ to the tagger

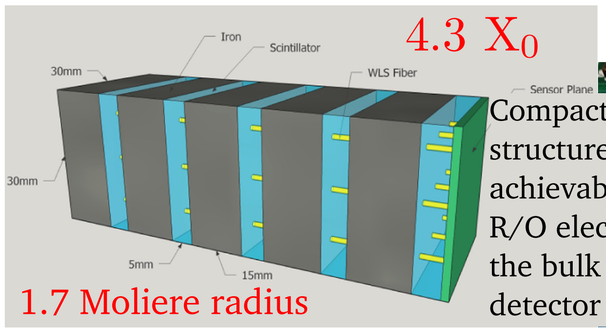
Positron tagger: real-time, 'inclusive' monitoring of produced e^+

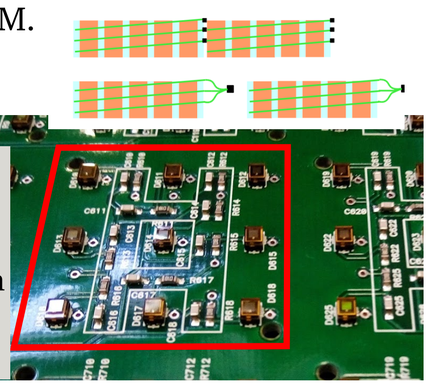
Ultra-Compact Shashlik Calorimeter Prototypes

Ultra-Compact Module (UCM)

Basic shashlik calorimeter: Scintillator / absorber sampling calorimeter, read out by Wavelength Shifter (WLS) optical fibers, routed to PMT

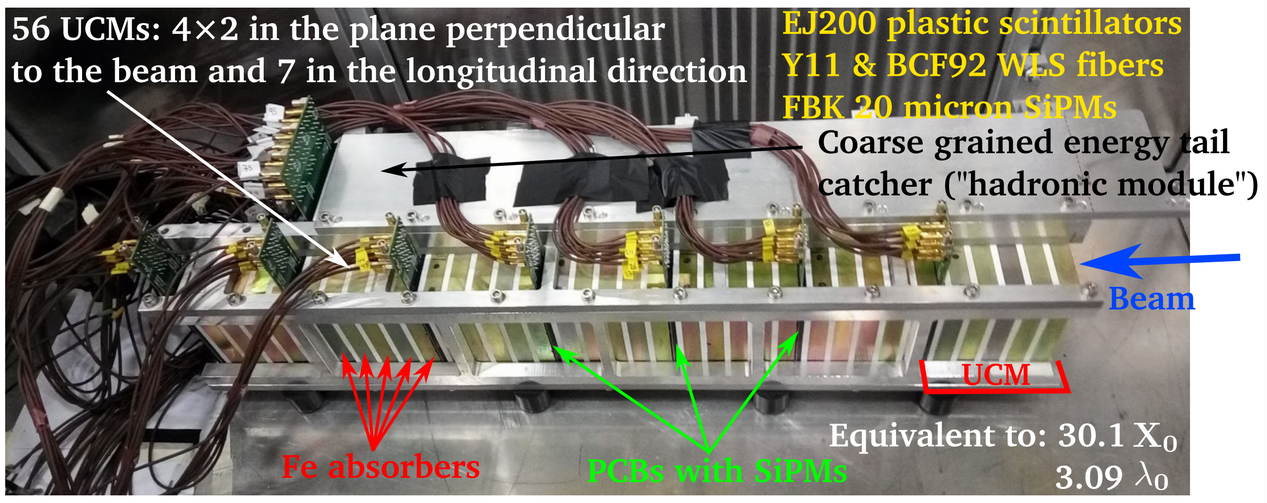
Ultra-Compact shashlik prototype: basic iron/scintillator shashlik where each WLS fiber is read out by one single SiPM.





Compact structures achievable. R/O electr. in the bulk of detector

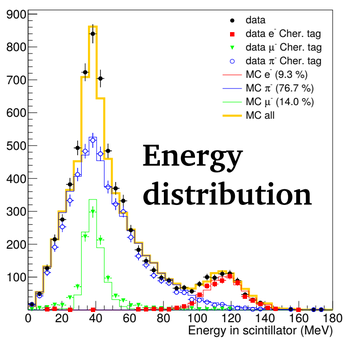
Tagger prototype tested at CERN (PS-T9)

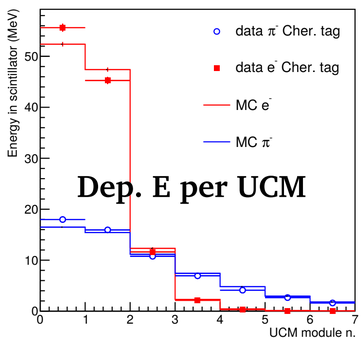


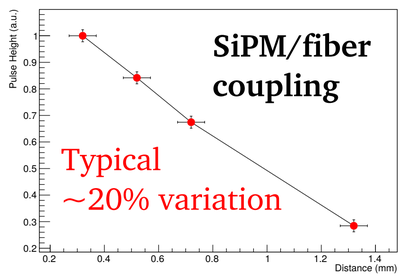
Results from CERN PS-T9 test beam

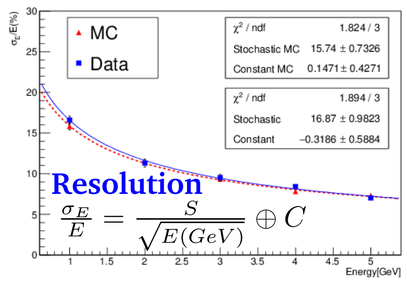
Analyzed data has been compared with a GEANT4 simulation of the detector (**doesn't** include photon generation and transport)

- Measures repeated with different tilt angles (from 0 to 200 mrad)
- e/π^+ discrimination based on longitudinal segmentation (misid. $<$ 3%)



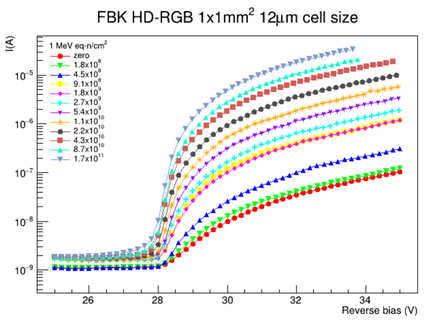


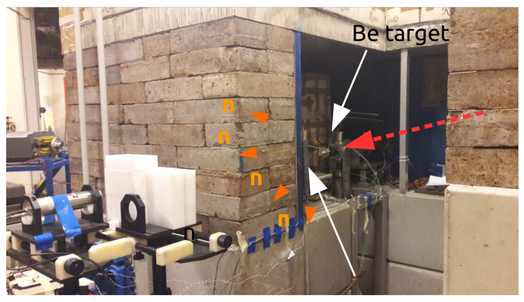


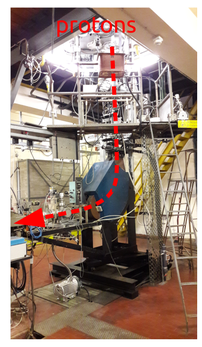


Tests of SiPM radiation-hardness

Van de Graaff CN accelerator at **L**aboratori **N**azionali di **L**egnaro
p (5 MeV) + ^{9}Be $\longrightarrow$ n + X, (p currents $\lesssim 1$ μA, n $\sim$ 1-3 MeV)

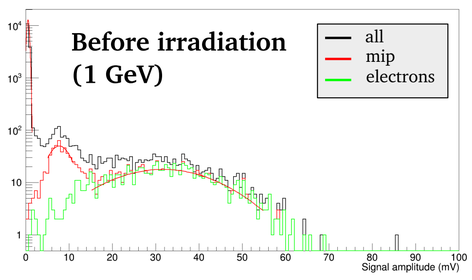


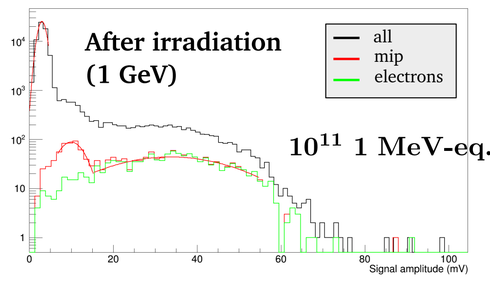




Neutron irradiation @LNL and test beam @CERN PS-T9

- Sensitivity to single p.e. is lost after $3 \cdot 10^9$ n/cm^2
- Ratio MIP peak/e constant. Equalization can be achieved with overvoltage

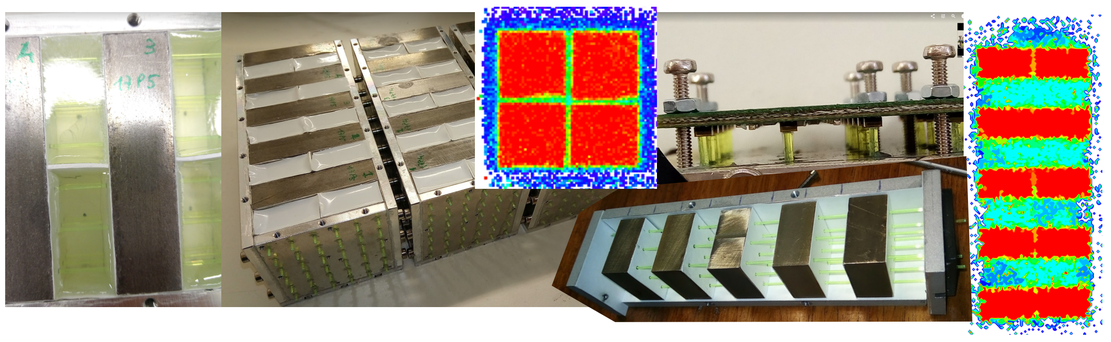




Polysiloxane shashlik calorimeters

First use in HEP. Elastometric material with interesting properties:

- Superior radiation hardness
- Easier fabrication process: initial liquid form. No drilling of the scintillator.
- Optimal optical contact with fibers
- Test beam of the prototypes at CERN PS-T9



http://enubet.pd.infn.it

[1] Eur. Phys. J. C (2015) 75:155
A novel technique for the measurement of the electron neutrino cross section. A. Longhin, L. Ludovici, F. Terranova

[2] CERN-SPSC-2016-036; SPSC-EOI-014
Enabling precise measurements of flux in accelerator neutrino beams: the ENUBET project. ENUBET Collaboration

[3] IEEE Trans. Nucl. Sci. 64 (2017) 1056
Shashlik Calorimeters With Embedded SiPMs for Longitudinal Segmentation. A. Berra et al.

[4] JINST 13 (2018) P01028 arXiv:1801.06167
Testbeam performance of a shashlik calorimeter with fine-grained longitudinal segmentation. G. Ballerini et al.