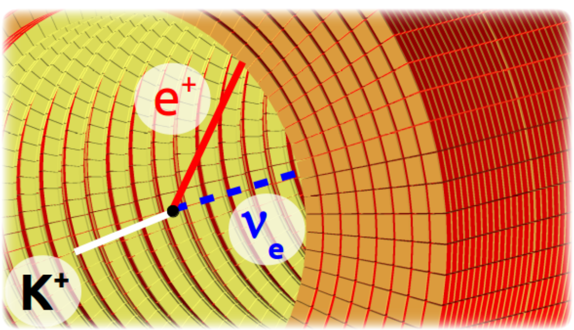
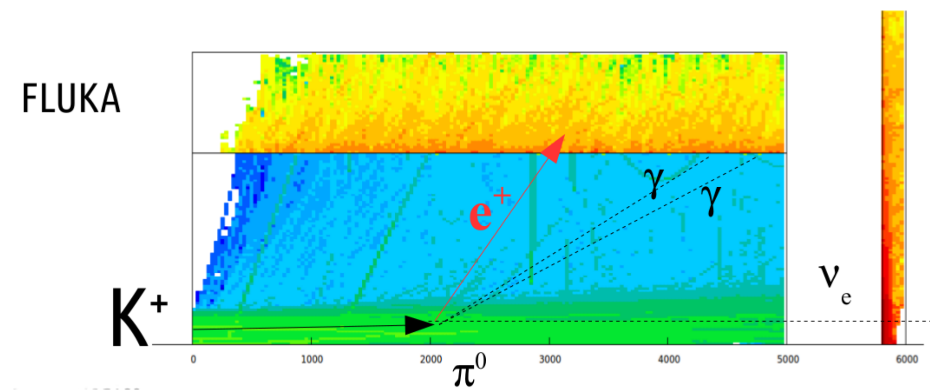
CALOR 2018 - 18th International Conference on Calorimetry in Particle Physics
21-25 May, 2018. Eugene, USA

Shashlik calorimeters for the ENUBET tagged neutrino beam





Claudia Brizzolari on behalf of the ENUBET collaboration

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681647).

Neutrino cross sections and flux uncertainties

- Precise knowledge of $\sigma(\nu)$ → important for future neutrino oscillation experiments
- $\sigma(\nu_\mu)$: remarkable improvement in the last 10 years (MiniBooNE, SCIBooNE, T2K, MINERνA, NOνA...), but still not absolute measurements below 7-10%
- $\sigma(\nu_e)$: $\sigma(\nu_\mu) \leftrightarrow \sigma(\nu_e)$ delicate at low energies, no intense/pure source of GeV ν_e available

Poor knowledge of $\sigma(\nu_e)$ can spoil the CPV discovery potential and the insight on the underlying physics (standard vs exotic)

Main limiting factor: **systematic uncertainties in the initial flux determination**

Monitored neutrino beams

Direct measurement of the neutrino flux inside the decay tunnel with conventional technologies

Aiming for a ν_e source pure and precise (1%) from a kaon-based beam

Protons → (K^+, π^+) → K decays → ν_e → neutrino detector

K decays → e^+

Traditional
- Passive decay region
- ν flux inferred from hadro production data
- Large uncertainties

→

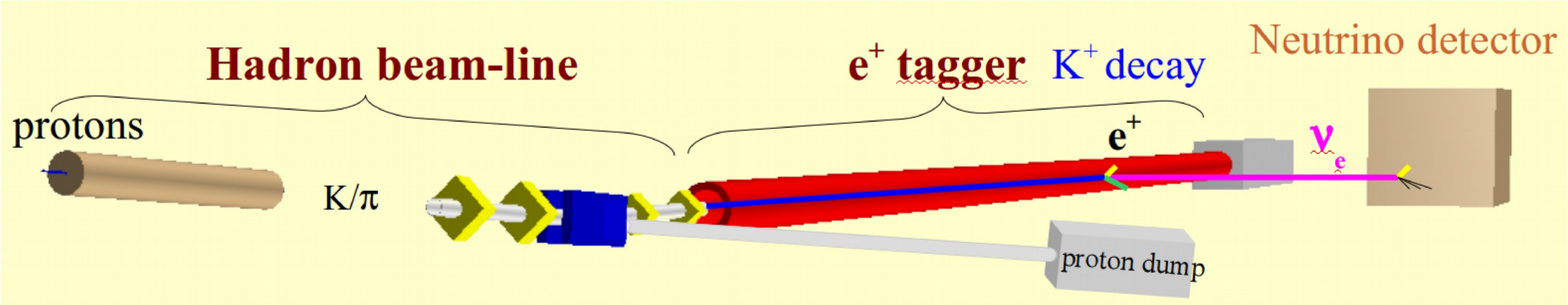
Monitored
- Fully instrumented decay region
- $K^+ \rightarrow e^+ \nu_e \pi^0$ (K_{e3})
- large angle e^+ (~90 mrad)
- ν_e flux prediction = e^+ counting

↓

The ENUBET approach

The ENUBET project

Enhanced **N**e**U**trino **BE**ams from kaon **T**agging project
- ERC-Consolidator Grant-2015, n° 681647 (PE2)



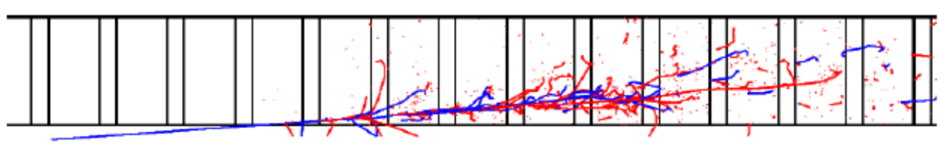
Longhin, L. Ludovici, F. Terranova, Eur. Phys. J. C75 (2015) 155

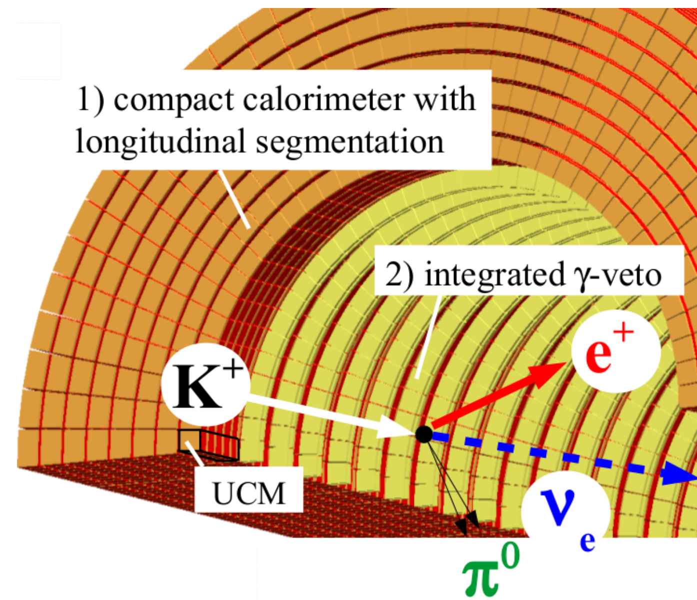
Hadron beam-line: collects, focuses, transports K^+ to the e^+ tagger (WP1 Giulia Brunetti)

e^+ tagger: monitors produced e^+
If ~ 50 m at 8 GeV K_{e3} is the only source of ν_e

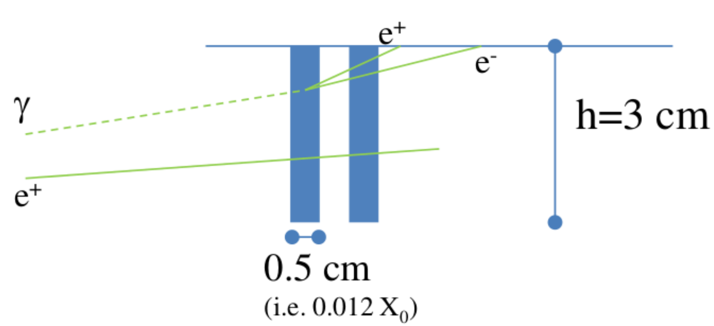
Particle identification

$e^+/\pi^+/\mu^+$ separation → Longitudinally segmented calorimeter



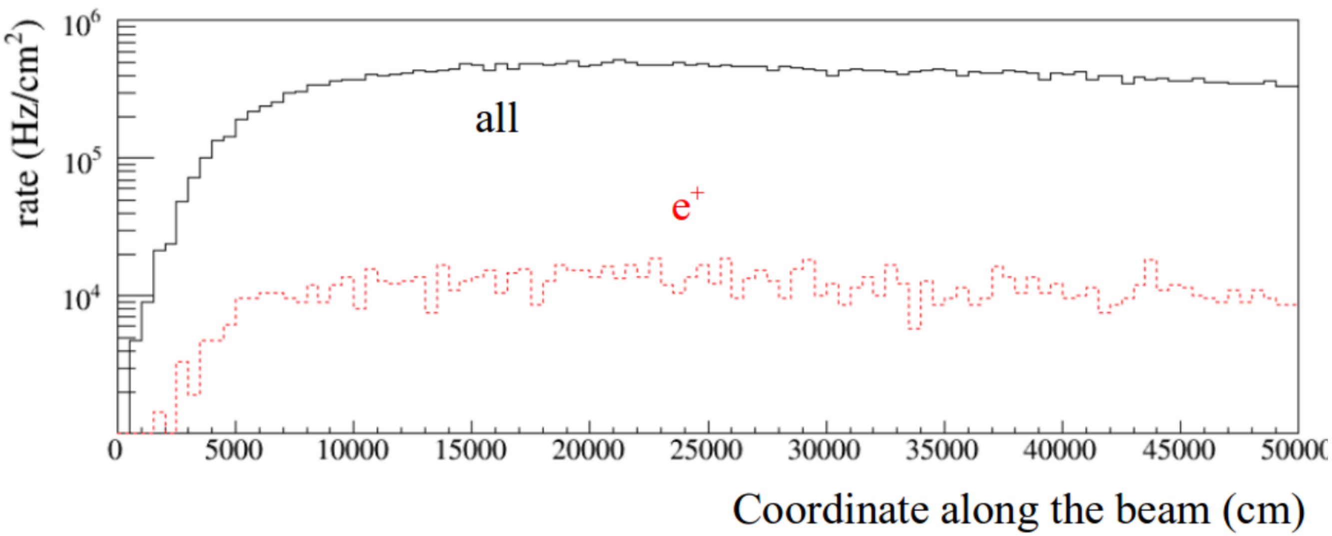


e^+/γ separation → Plastic scintillator exploiting 1 mip – 2 mip separation



The e^+ tagger challenges

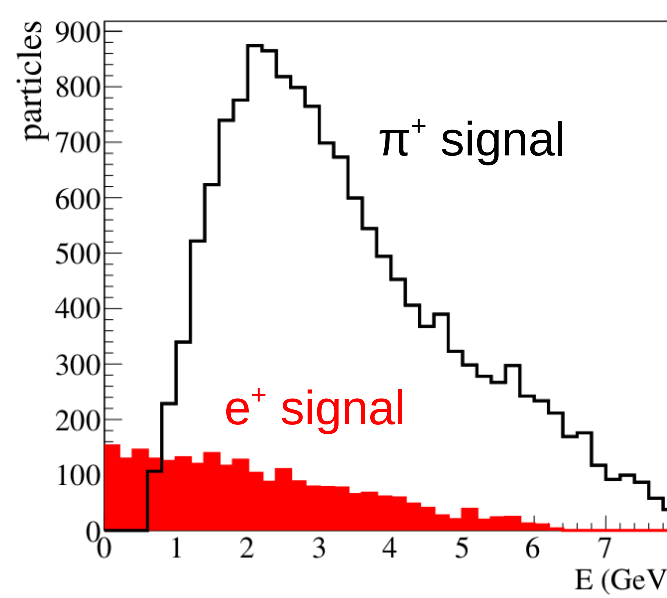
Injecting 10^{10} π^+ in a 2 ms spill →



	Max rate (kHz/cm²)
μ^+	190
γ	190
π^+	100
e^+	20
all	500

The decay tunnel, a harsh environment:

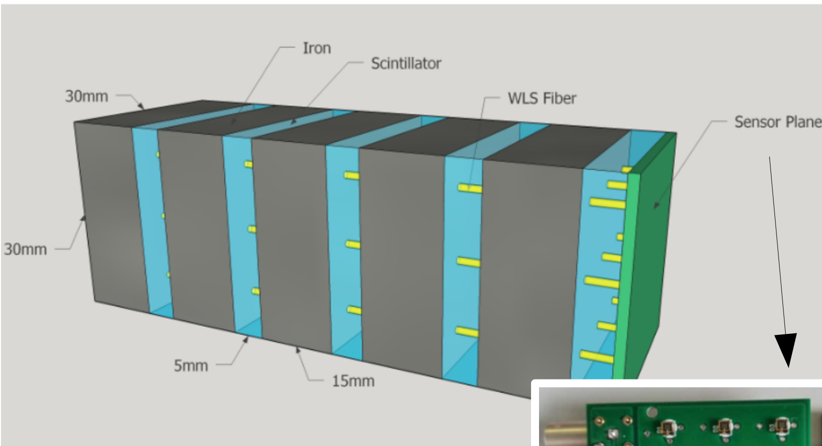
- Particles rate > 200 kHz/cm²
- Background: pions from K^+ decay →

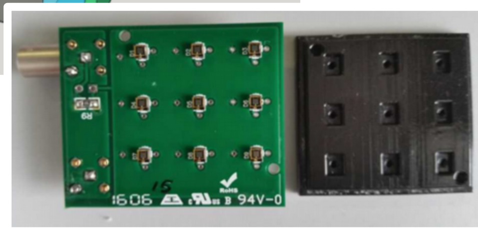


Moreover:

- Dimensions! (~50 m) → cost effectiveness

The e$^+$ tagger calorimeter

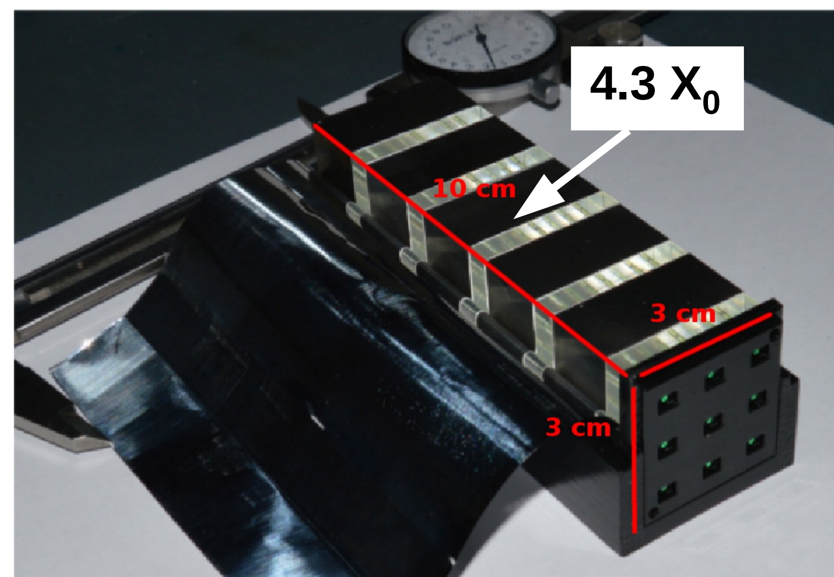




- Longitudinally segmented
- Cost effective
- E resolution < 20%/√E

→ shashlik calorimeter + compact readout based on SiPMs

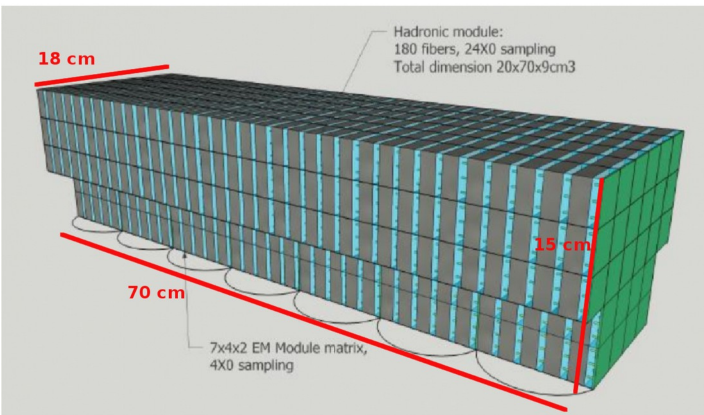
Ultra Compact Module (UCM)

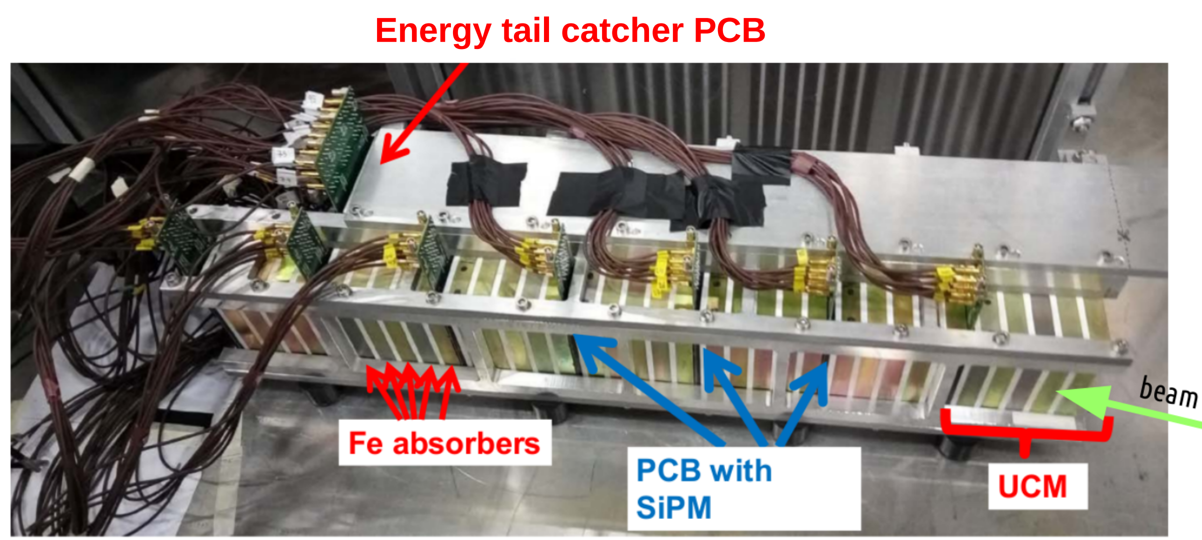


No bundling of fibres, readout embedded in the calorimeter bulk → longitudinal segmentation

“Supermodule” prototype

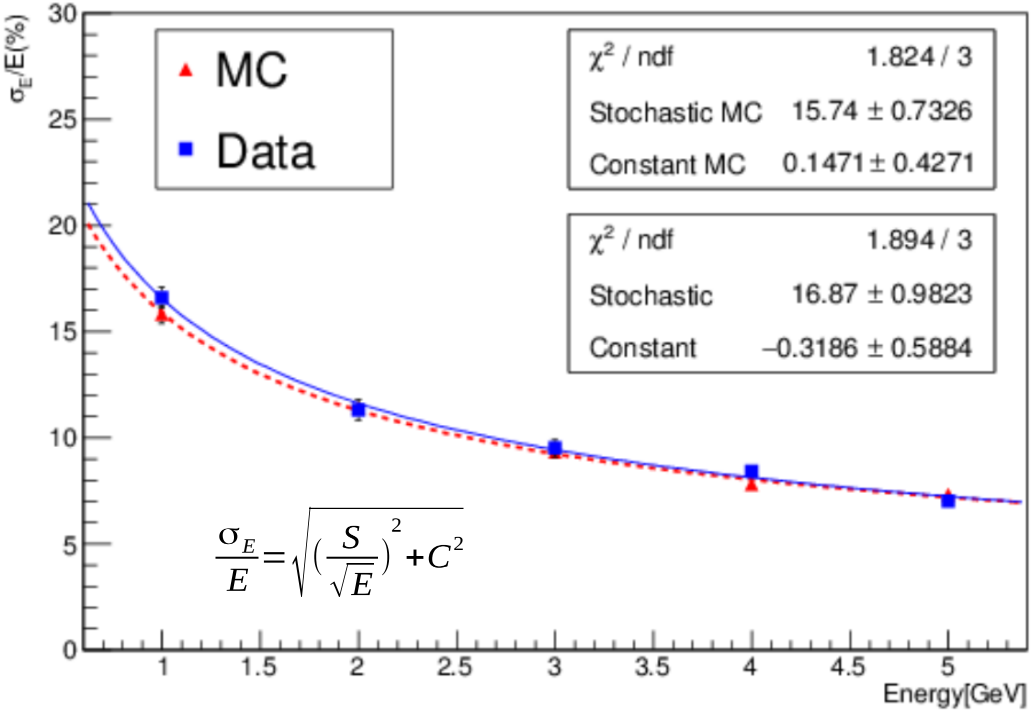
G. Ballerini et al, JINST 13 (2018) P01028





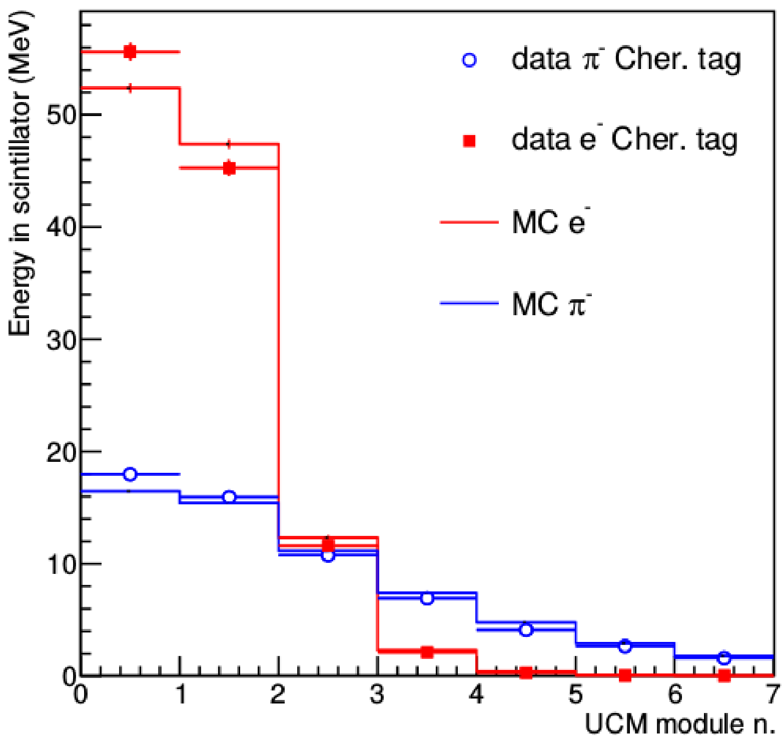
- Electromagnetic calorimeter: 56 UCMs
- Energy tail catcher (“hadronic” calorimeter): readout 18 channels, no longitudinal or transversal segmentation
- Fe (15 mm) + EJ200 (5 mm)
- Y11 and BCF92 WLS fibres, 1mm diameter
- SiPMs 20 x 20 μm^2 cell size, sensitive area 1 x 1 mm^2, breakdown = 28 V, AdvanSiD
- Voltage (OV) = 36(8) V Y11 - Voltage (OV) = 37(9) V BCF92

“Supermodule” prototype



Stochastic term **~17%/√E**
Requirements: <20%/√E → **ok!**

Comparison of the calorimeter response for π^- and e^-

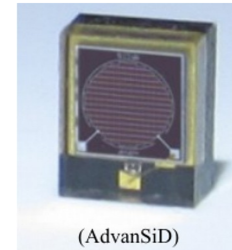


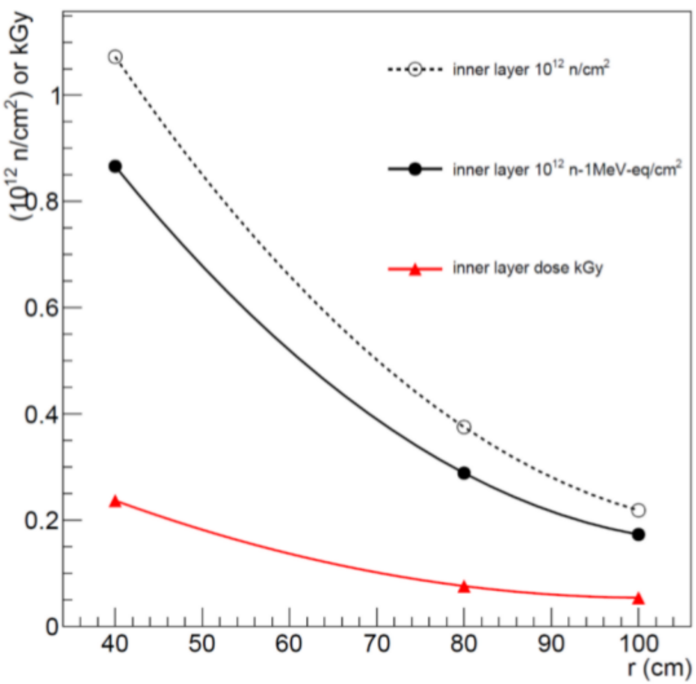
The longitudinal energy profiles of partially contained pions is reproduced by MC with a precision of 10%

Irradiation tests

Test @ INFN-LNL CN, May 2017

- SiPM RGB-HD (High Density)
- Sensitive area 1 x 1 mm2
- Cell size 20 x 20 μm^2, 15 x 15 μm^2, 12 x 12 μm^2
- Breakdown: 28 V

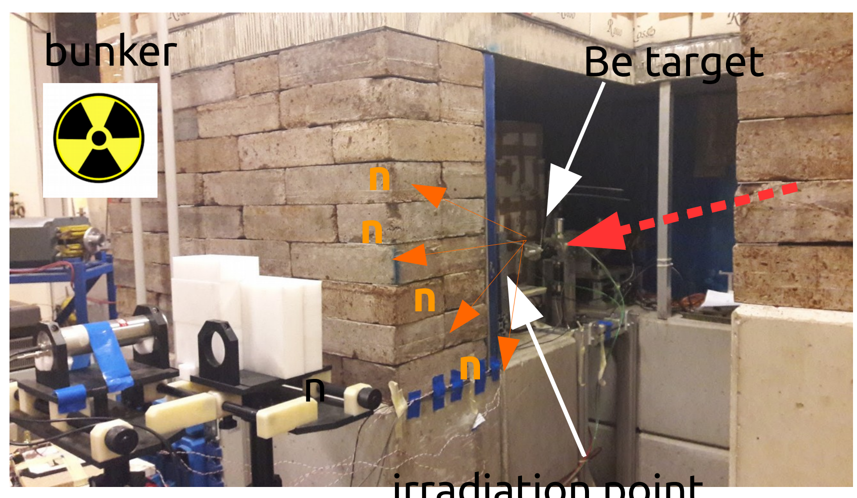


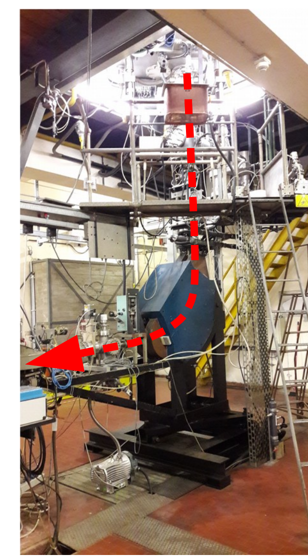


- Van de Graaff CN accelerator
- p (5 MeV) + ^{9}Be → n + X
- p currents ≤ 5 μA
- N spectrum ~ 1-3 MeV

PCBs under test:

- Single SiPM 12 x 12 μm^2 cell size
- 9 SiPMs 20 x 20 μm^2 (current normalized to 1 in plot in following slide)

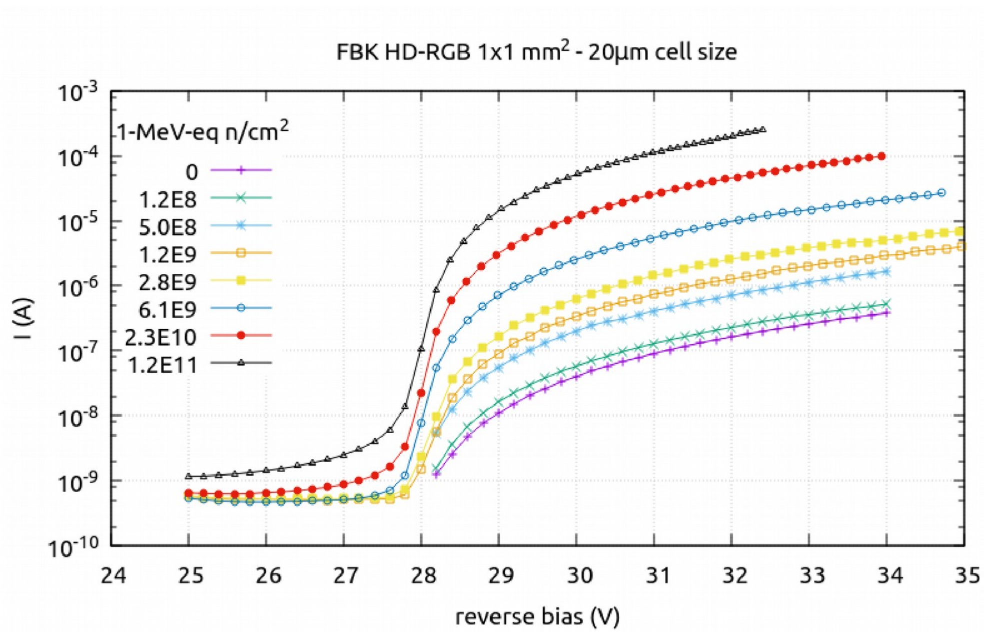


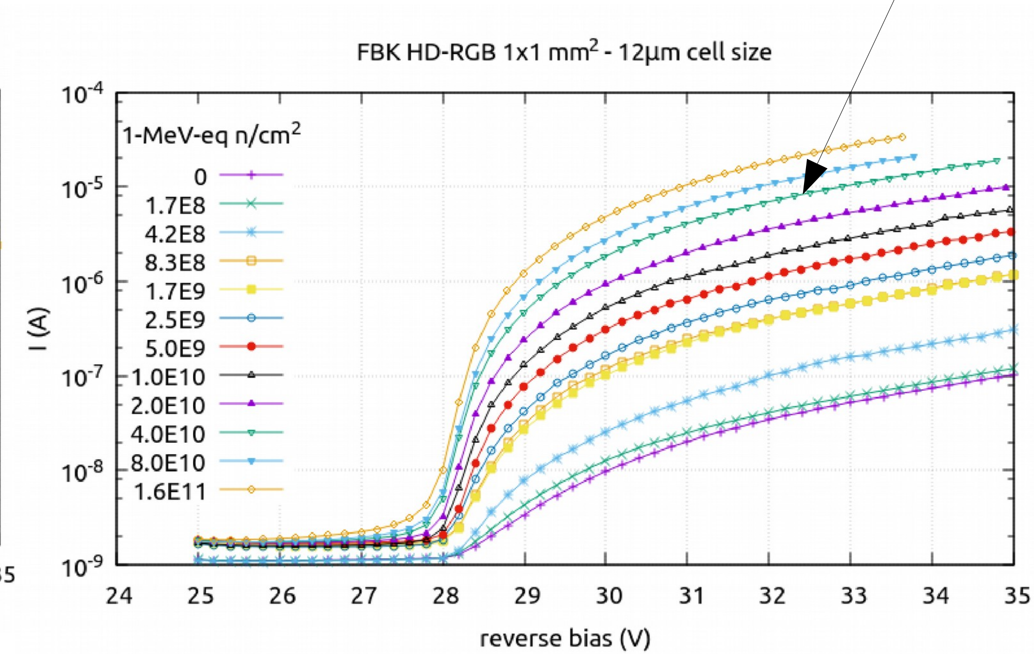


Irradiation tests

Test @ INFN-LNL CN, May 2017

Lower currents





SiPMs currently used for the prototypes

Smaller cell size, more rad-hard but lower gain

Signal collected by non irradiated and irradiated board

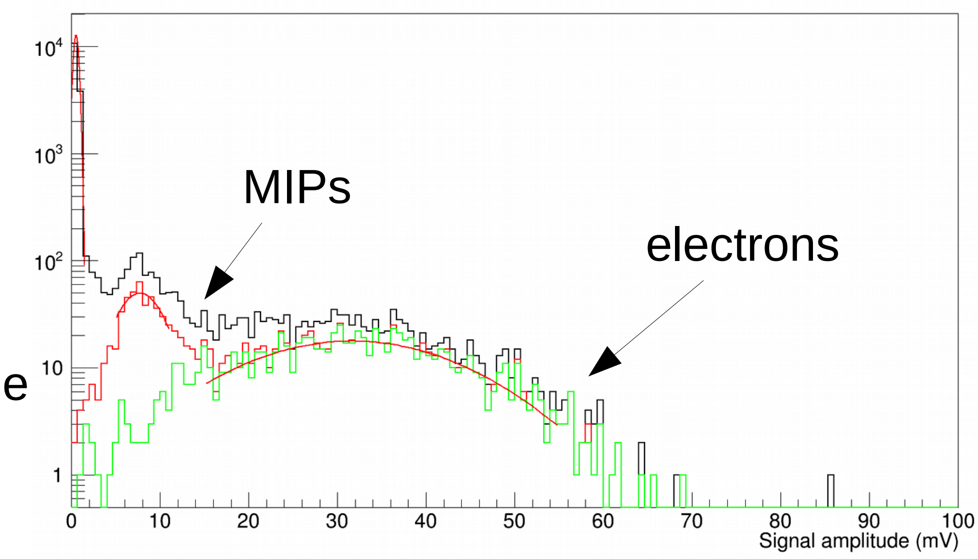
Tested @ CERN-T9 beamline, Oct 2017

UCM equipped with non irradiated and irradiated (10^{11} n/cm^2) board.

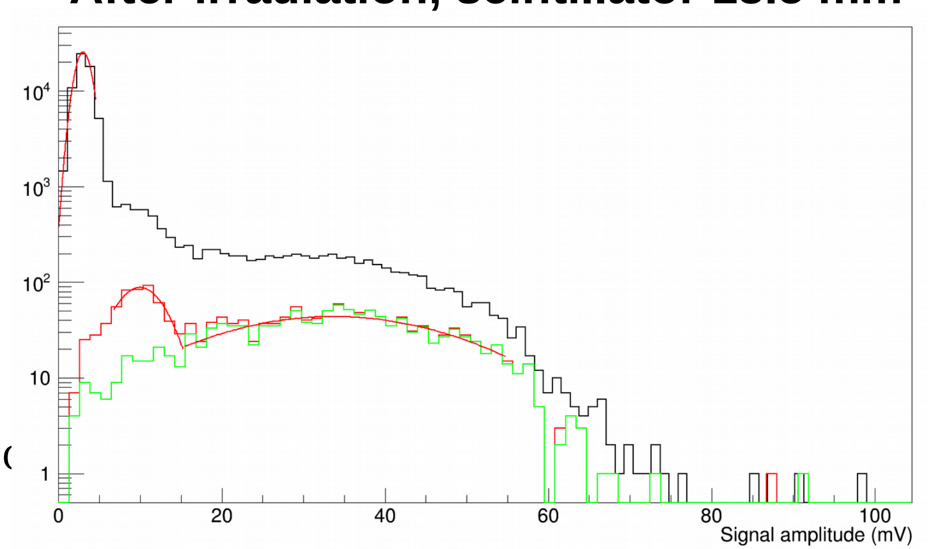
Irradiated board:

- Electron peak still distinguishable from pedestal
- Ratio between e^- and MIP constant after irradiation → no SiPM saturation effect due to the reduction of working pixels

Before irradiation, scintillator 5 mm



After irradiation, scintillator 13.5 mm

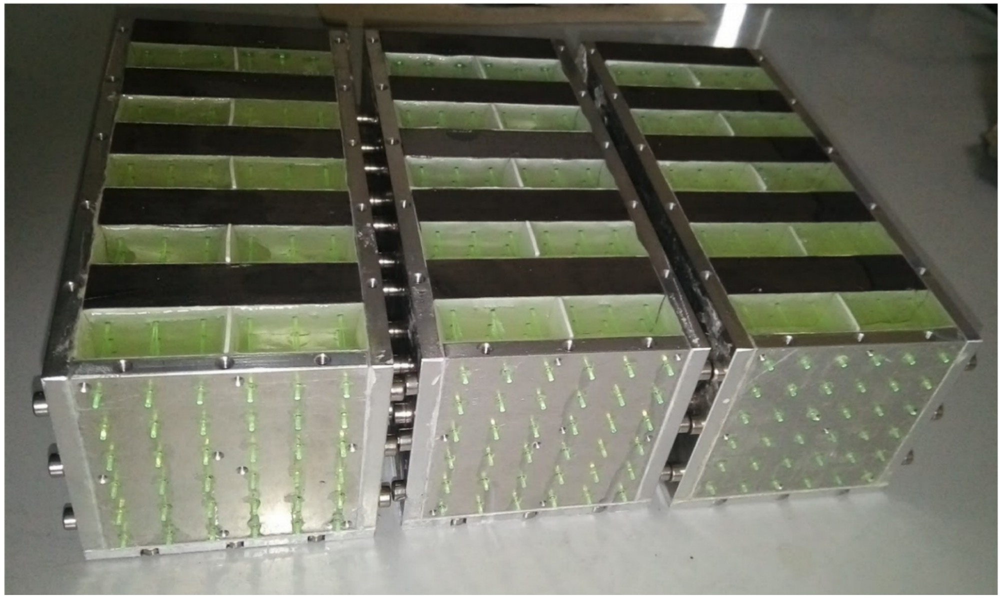


- MIP useful for channel equalization and to identify e.g. $K^+ \rightarrow \mu^+ \nu_\mu$
- If scintillator thickness > 10 mm and number of p.e. ≳ 150, MIP peak distinguishable from pedestal

Polysiloxane calorimeter

Tested @ CERN-T9 beamline, Oct 2017

- Fe (15 mm) + polysiloxane (15 mm)
- Y11 WLS fibres, 1 mm diameter, Kuraray
- SiPMs 20 x 20 μm^2 cell size, sensitive area 1 x 1 mm^2, breakdown = 28 V
- 12 UCM

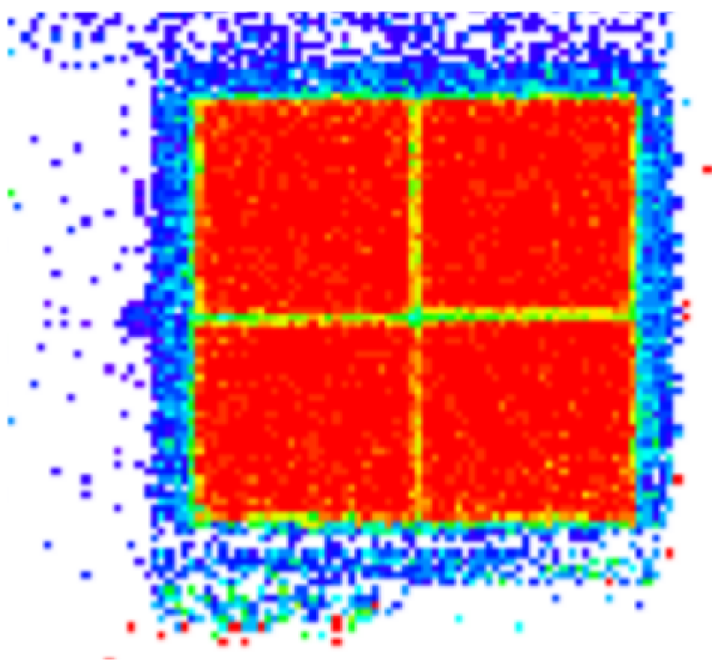


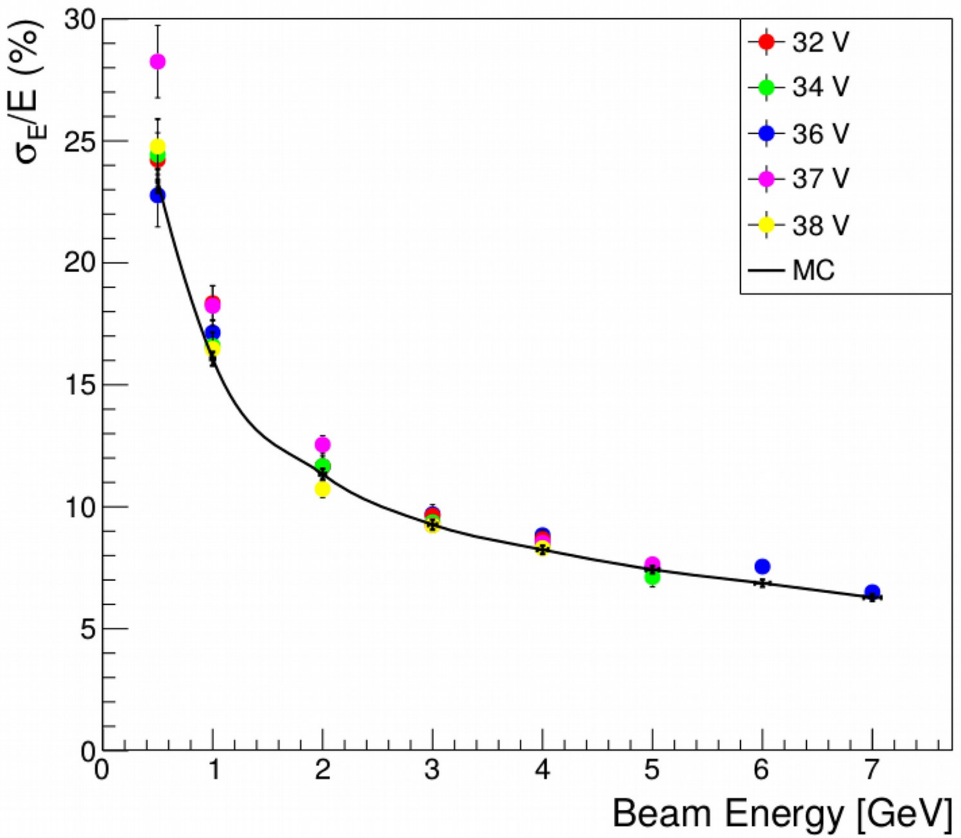
- Higher radiation hardness
- No necessity to drill or cast the scintillator tiles
- Optimal optical contact with the fibres

Polysiloxane calorimeter

Explored different bias voltages on the SiPMs:

- Energy resolution ~17%/√E for all voltage values
- Possible to work with lower overvoltage on SiPMs





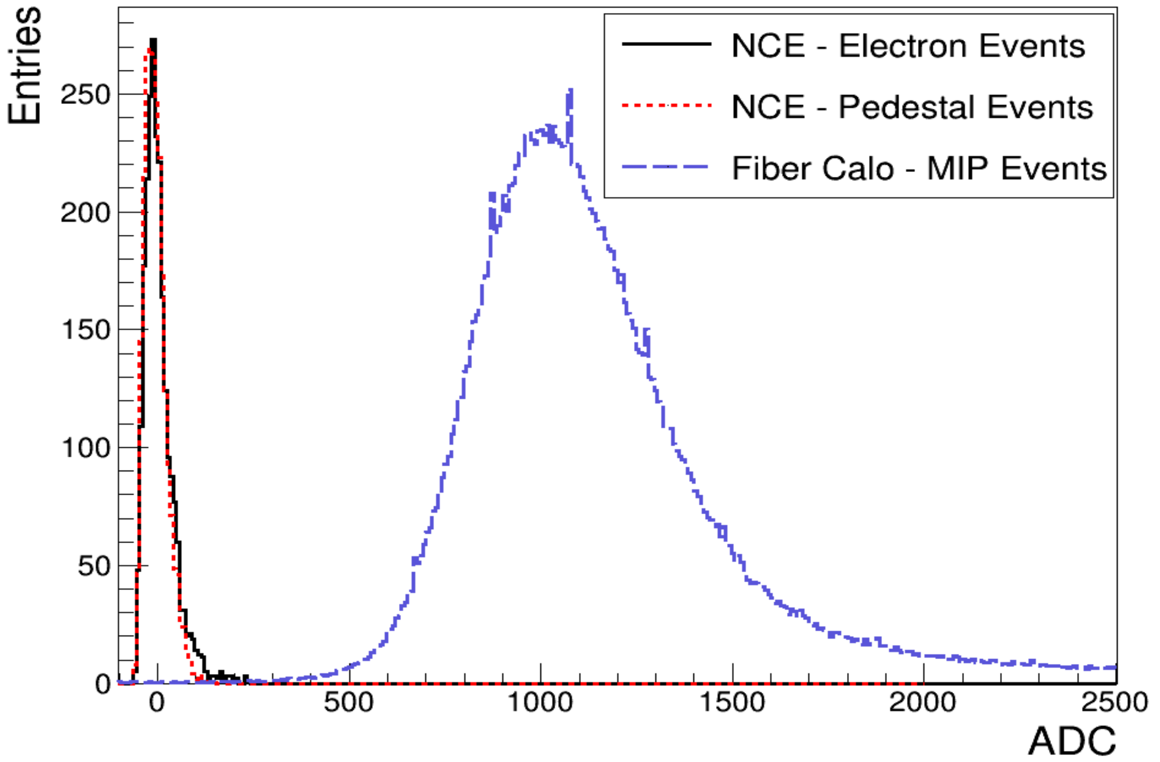
- Polysiloxane light yield ~ 1/3 EJ200 light yield
- The interface polysiloxane – fibre does not impact on light yield

Conclusions

- The UCM technique is within ENUBET requirements for E resolution, e^+/π^+ separation, MIP sensitivity
- For irradiation $\leq 10^{11}$ n/cm^2: $e^{-(+)}$ peak properties unmodified, MIP visible if p.e. for UCM $\gtrsim 150$
- Polysiloxane can be used for shashlik calorimeters, as the coupling fibres-gel does not deteriorate the light yield

Backup

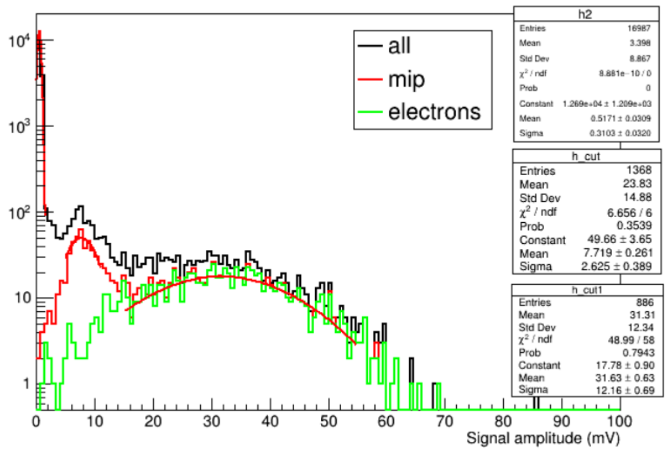
Nuclear Counter Effect

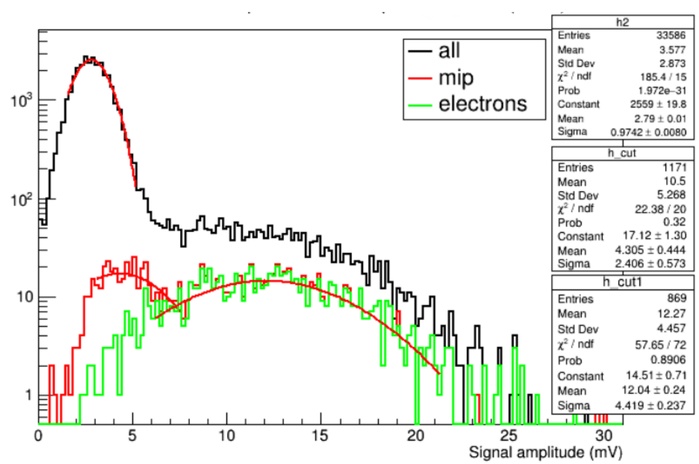


Nuclear counter effect studied in August 2015 on another prototype.
Red and black lines: run at 5 GeV without WLS fibres
Blue line: standard run at 5 GeV
[from: "A compact light readout system for longitudinally segmented shashlik calorimeters", published on Nuclear Instruments and Methods in Physics Research: Section A]

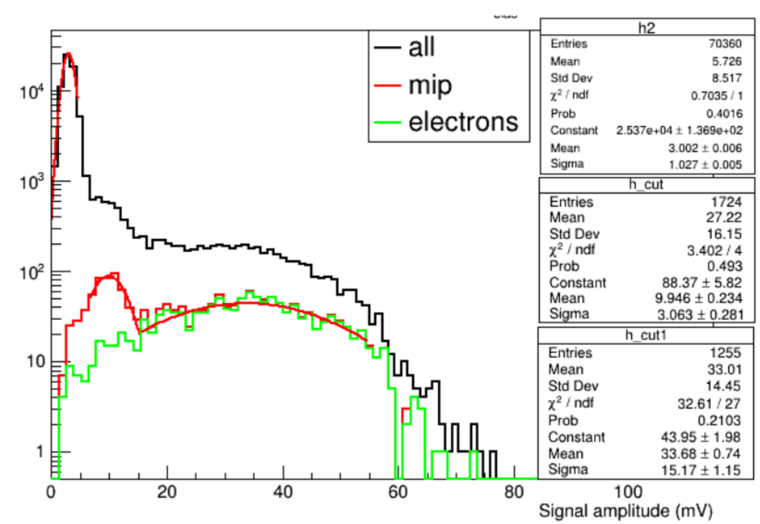
Irradiation tests

- Fe (15 mm) + EJ200 (5 mm)





- Fe (15 mm) + Uniplast (1.35 mm)

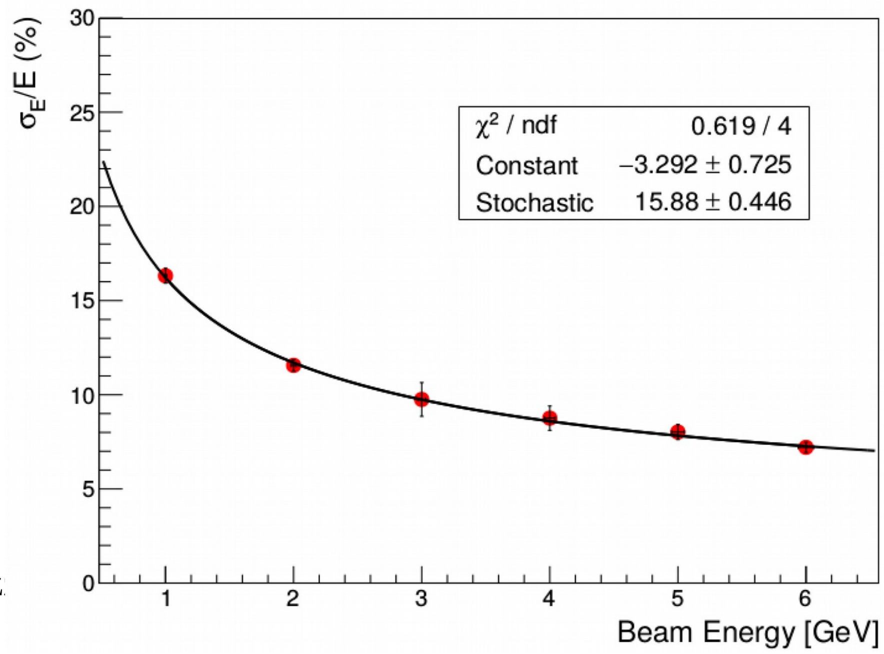


A "fast" calorimeter: EJ204+BCF92

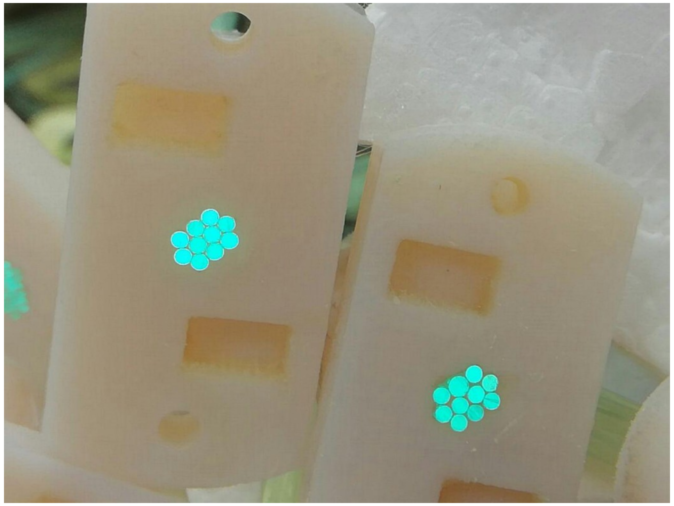
Tested @ CERN-T9 beamline, Oct 2017

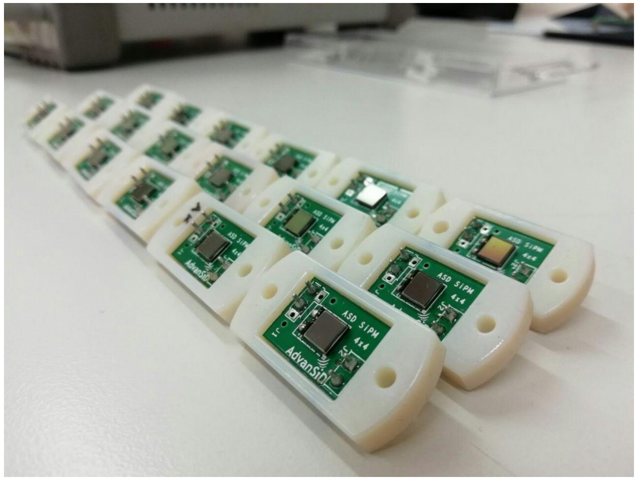
- Fe (15 mm) + EJ204 (10 mm)
- BCF92 WLS fibres, 1 mm diameter (Saint-Gobain)
- SiPMs 20 x 20 μm^2 cell size, sensitive area 1 x 1 mm^2, breakdown = 28 V, AdvanSiD
- 12 UCM

- EJ204 (Eljen): high scintillation efficiency, high speed
- BCF92: fast blue to green shifter



Non-shashlik prototype





Various prototypes tested

UCM
- Fe + Polysiloxane + Y11 WLS
- Pb powder + Polysiloxane + Y11 WLS
- Fe + EJ200 + Y11 WLS
- Fe + Ej200 BCF92
- Fe + Uniplast + Y11 WLS

12 UCM calorimeters
- Fe + EJ204 + BCF92 WLS
- Fe + Polysiloxane+Y11 WLS