

# Una nuova tecnica di segmentazione longitudinale per calorimetri shashlik

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# Il progetto SCENTT-ENUBET

Shashlik Calorimeters for Electron Neutrino Tagging and Tracing, part of Enhanced NeUtrino BEams from kaon Tagging project - ERC-Consolidator Grant-2015, no.681647 (PE2)

## Scopo scientifico

Predominanza materia su antimateria  $\rightarrow$  ruolo dei neutrini?

$(\nu_\mu \rightarrow \nu_e) \neq (\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$  ? Trovare evidenza sperimentale di violazione di CP nel settore leptonico



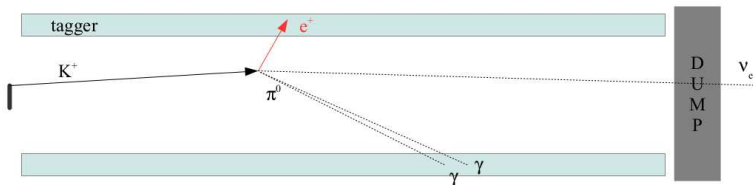
Effetti piccoli  $\rightarrow$  Conoscenza dell'interazione di  $\nu_e$  con la materia

## Obiettivo

Sorgente pura di  $\nu_e$ , conoscenza  $\sigma_\nu$  a  $\sim$ GeV con precisione 1%  
**al momento 10-20%** perché flusso iniziale  $\nu$  sconosciuto

# Il progetto SCENTT-ENUBET

- Flusso di neutrini misurato direttamente all'interno del tunnel di decadimento  $K^+ \rightarrow \pi^0 + e^+ + \nu_e$  ( $K_{e3}$ )
- $e^+$  emessi a grande angolo (88 mrad)
- Flusso neutrini  $\nu_e$  da conteggio  $e^+$
- Se tunnel  $\sim 50$  m a 8 GeV,  $K_{e3}$  è l'unica sorgente di  $\nu$
- Segmentazione longitudinale  $\rightarrow$  separazione  $e^+/\pi$



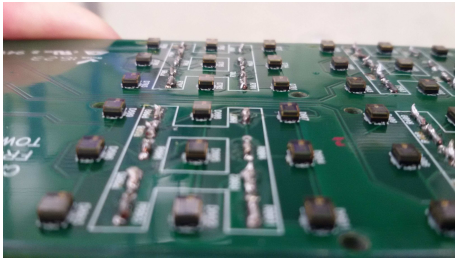
# Il detector: calorimetro

## Calorimetro "Shashlik":

- costo limitato
- buona risoluzione energetica
- tecnologia consolidata



## Il detector: sistema di lettura



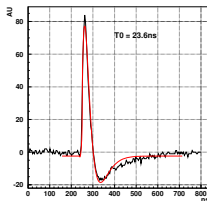
### Sistema di lettura compatto basato su SiPM:

- accoppiamento diretto fibra-SiPM
- sistema di lettura incorporato nella struttura del calorimetro → segmentazione longitudinale
- rate  $> 500 \text{ kHz/cm}^2$

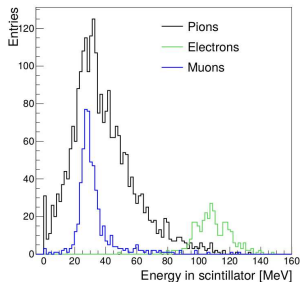
# Test Beam Novembre 2016 @ CERN PS-T9 beamline: prototipo



- Calorimetro EM + H
- EM 70 cm, letto ogni 10 cm (4  $X_0$ )
- H 60 cm
- Fe + EJ-200
- SiPM accoppiati in AC, tempo di risposta  $\sim 25$  ns



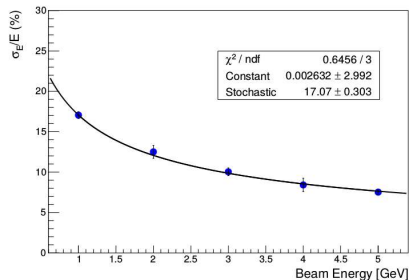
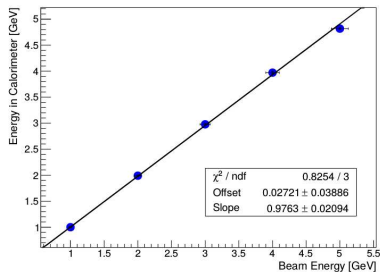
# Test Beam Novembre 2016 @ CERN PS-T9 beamline: test effettuati



- Fascio misto di  $e^-$ ,  $\mu^-$  e  $\pi^-$
- Scan in energia 1-5 GeV + run a 7 GeV per calibrare
- Calorimetro tiltato a 100 e 200 mrad per simulare l'emissione di positroni all'interno del tunnel di decadimento
- Due Cherenkov counter della linea T9 usati per identificazione di particelle

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# Test Beam Novembre 2016 @ CERN PS-T9 beamline: linearità e risoluzione

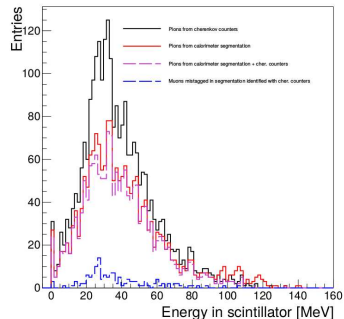
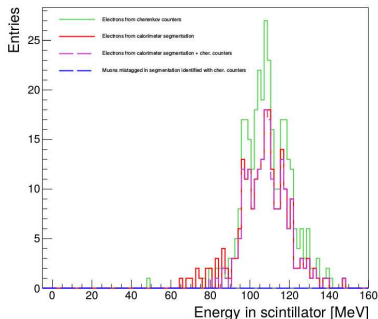


Calorimetro EM + H, 3 GeV,  
100 mrad  
OV = 36(8) V Y11  
OV = 37(9) v BCF92

$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{S}{\sqrt{E(\text{GeV})}}\right)^2 + C^2}$$



# Test Beam Novembre 2016 @ CERN PS-T9 beamline: separazione $e^-/\pi^-$



	Da Cher.	Da segmentazione	Segm. + Cher.	Efficienza	Purezza
$e^-$ 0-160 MeV	332	234	214	70 %	91 %
$\pi^-$ 0-160 MeV	2547	1832	1624	72 %	89 %

# Conclusioni e studi futuri

## Conclusioni:

- questo schema di readout non degrada linearità e risoluzione energetica
- la risoluzione energetica =  $17\%/\sqrt{E} \rightarrow \text{OK!}$
- è possibile lavorare su separazione  $e^-/\pi^-$  tramite segmentazione longitudinale

## Studi futuri:

- migliorare i tagli per separazione  $e^-/\pi^-$
- confronto dati - simulazione

## Appendix: publications

- A. Berra et al., “*Silicon photomultipliers as readout system for a scintillator-lead Shashlik calorimeter*”, IEEE Trans. Nucl. Sci. 58 1297, 2011.
- A. Berra et al., “*Characterization of a DAQ system for the readout of a SiPM based shashlik calorimeter*”, Nucl. Instrum. Meth. A 735 422, 2014.
- A. Longhin, L. Ludovici, F. Terranova, “*A novel technique for the measurement of the electron neutrino cross section*”, Eur. Phys. J. C 75 155, 2015.
- A. Berra et al., “*A non-conventional neutrino beamline for the measurement of the electron neutrino cross section*”, Proceedings, 17th International Workshop on Neutrino Factories and Future Neutrino Facilities (NuFact15): Rio de Janeiro, Brazil, August 10-15, 2015. SLAC-econf-C1508102, arXiv:1512.08202 [hep-ex]
- A. Berra et al., “*A compact light readout system for longitudinally segmented shashlik calorimeters*”, Nucl. Instrum. Meth. A 830 345, 2016.
- A. Berra et al., “*Enabling precise measurements of flux in accelerator neutrino beams: the ENUBET project*”, CERN-SPSC-2016-036; SPSC-EO I-014
- A. Berra et al., “*Shashlik calorimeters with embedded SiPMs for longitudinal segmentation*”, submitted to IEEE Trans. Nucl. Sci.

## Appendix: $K^+$ decay

$$K^+ \rightarrow \pi^0 e^+ \nu_e$$

$$K^+ \rightarrow \mu^+ \nu_\mu$$

$$K^+ \rightarrow \pi^+ \pi^- \pi^+$$

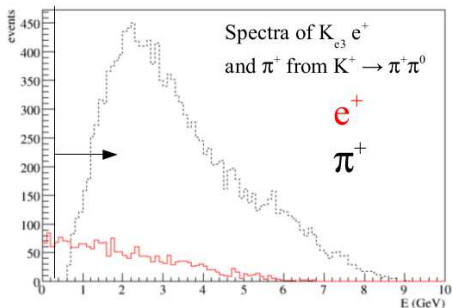
$$K^+ \rightarrow \pi^+ \pi^0$$

## Appendix: radiation

In critical areas of the detector for  $10^4 \nu_e$ :

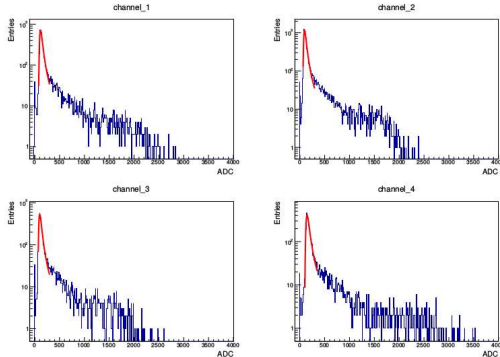
- 1.3 kGy
- Neutron flux  $10^{12}/\text{cm}^2$

## Appendix: $e^+/\pi^+$ ratio



[Andrea Longhin]

# Appendix: calibration



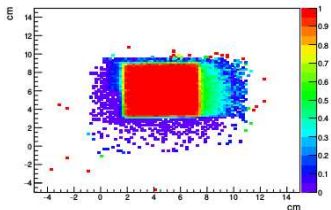
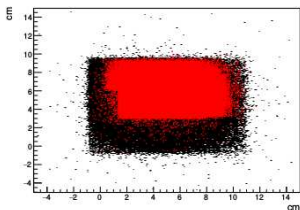
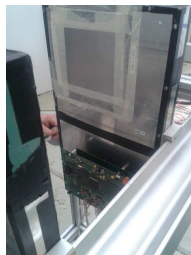
Each channel has a slightly different response



- fit MIPs peak with Landau function
- equalize MIPs peak positions for all channels

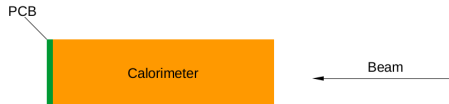
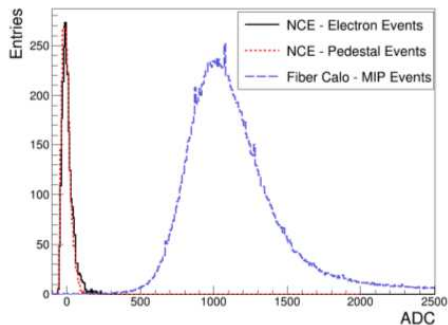
## Appendix: track reconstruction

- two silicon beam chambers
- each chamber two single side silicon microstrip detectors, x-y geometry
- active area  $9.5 \times 9.5 \text{ cm}^2$
- spatial resolution  $\sim 30 \mu\text{m}$





## Appendix: Nuclear counter effect (NCE)



Nuclear counter effect studied in August 2015.

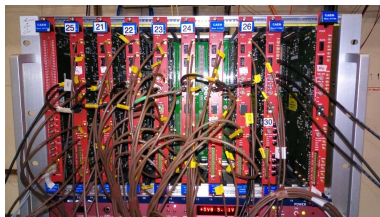
Red and black lines: run at 5 GeV without WLS fibers

Blue line: standard run at 5 GeV

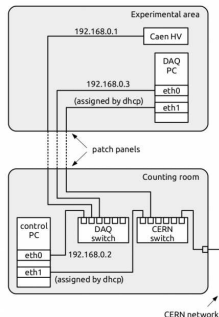
*[from: "A compact light readout system for longitudinally segmented shashlik calorimeters", published on Nuclear Instruments and Methods in Physics Research: Section A]*

## Appendix: Data Acquisition

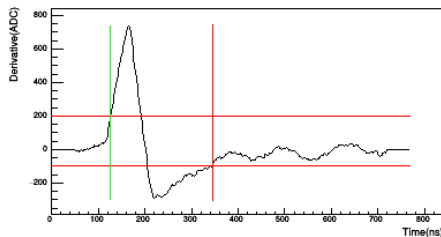
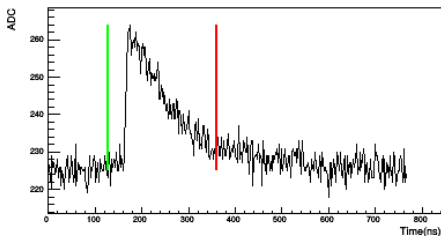
Neutrino physics requires triggerless acquisition + high rate →  
**waveform digitizers**  
Sampling extended up to 2 ms.



SCENTT testbeam Nov 2016, network configuration



## Appendix: Data acquisition: waveform analysis



- Waveform Digitizer CAEN V1730
- Sampled 384 times every 2 ns

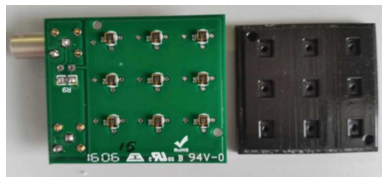
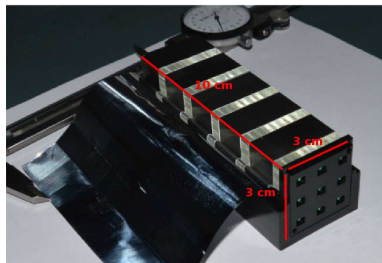
For each waveform, smoothed derivative  $\delta_i$  of the  $i$ -th waveform is computed

$$\delta_i(N) = \sum_{k=1}^N s_{i+k} - \sum_{k=1}^N s_{i-k}$$

Positive threshold: 200 ADC

Negative threshold: -100 ADC

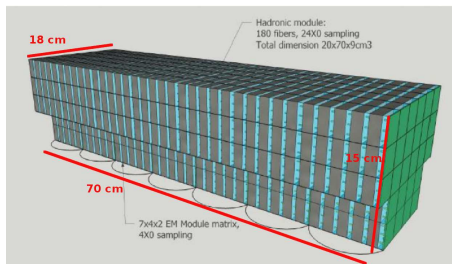
## Appendix: Prototypes Ultra Compact Module (UCM)



- $4 X_0$
- tested with cosmic rays
- Fe + plastic scintillator
- 9 SiPM arranged in arrays on custom PCBs
- SiPM signal summed together

## Appendix: Prototypes supermodule

- Hadronic + EM
- confinement of hadronic shower
- readout EM every  $4 X_0$
- readout H at the end of the supermodule



# Silicon PhotoMultipliers

- FBK (Fondazione Bruno Kessler)
- SiPM RGB-HD (High Density)
- Sensitive area  $1 \times 1 \text{ mm}^2$
- 2500 cells  $20 \times 20 \mu\text{m}^2$
- Breakdown: 28 V

