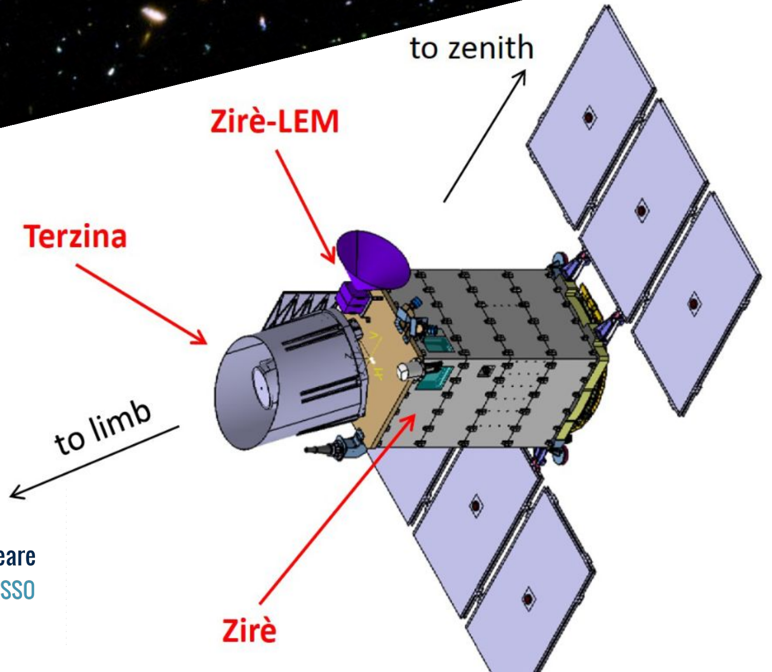
Detector characterization for the upcoming NUSES space mission

Students:
Stefano Amoroso, Luigi Ernesto Ghezzer,
Francesco Rossi, David Schledewitz

Supervisors:
Dimitrios Kyratzis
Pierpaolo Savina

GRAN SASSO SCIENCE INSTITUTE

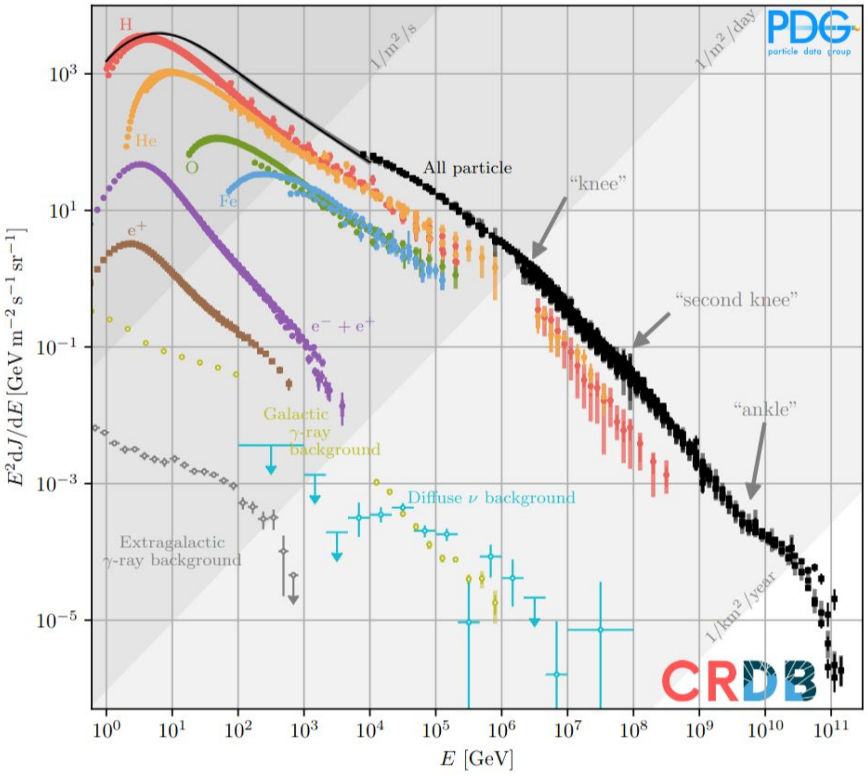


GRAN SASSO hands-on 2025
PhD school on experimental astroparticle physics
September 8th - 18th, 2025

INFN
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DEL GRAN SASSO

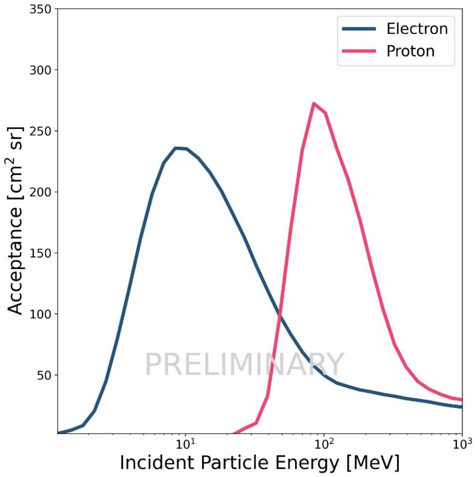
The Cosmic Ray Spectrum

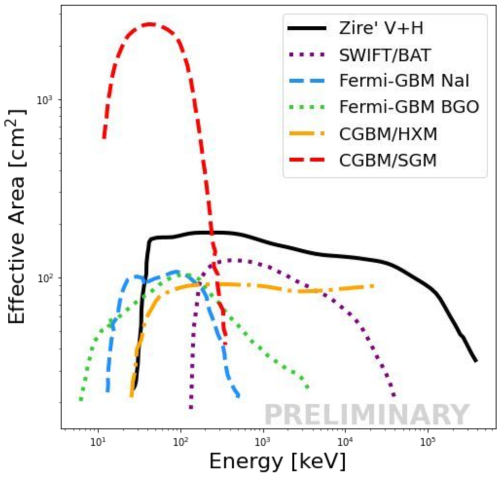
- CRs are particles that populate the whole universe.
- Different for composition, energy spectrum, arrival direction, rate of arrival.
- Separation between space-borne and ground experiments is around the knee (1 PeV).

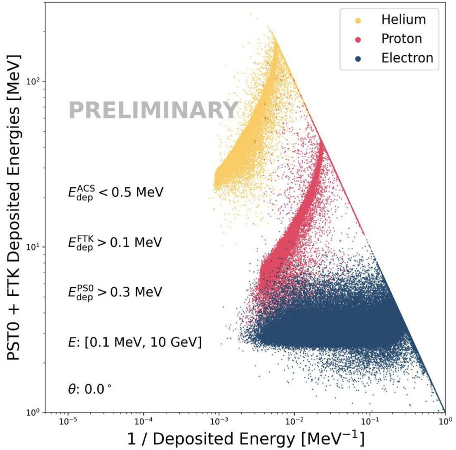


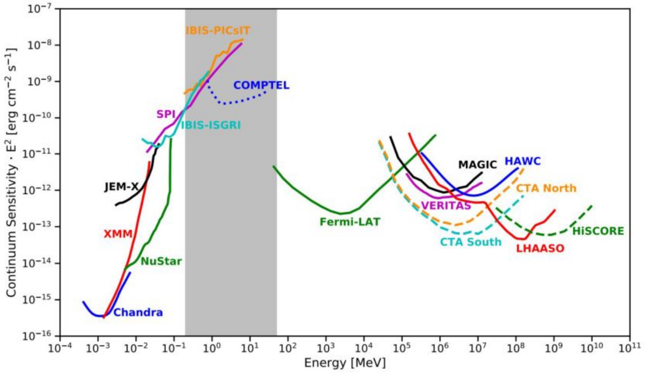
NUSES goals

- Measuring flux of low energy CR (E < 300 MeV)
  - Cosmic e, p, and solar/cosmic light nuclei.
- Studying cosmic radiation variability.
- Investigating the possible Magnetosphere-Ionosphere-Lithosphere-Coupling.
- Detection of 0.1 - 30 MeV photons (GRBs).
- Pathfinding for future UHECR and neutrino space missions using Cherenkov light.
- Testing new detectors (e.g. SiPMs) and related electronics for space missions.

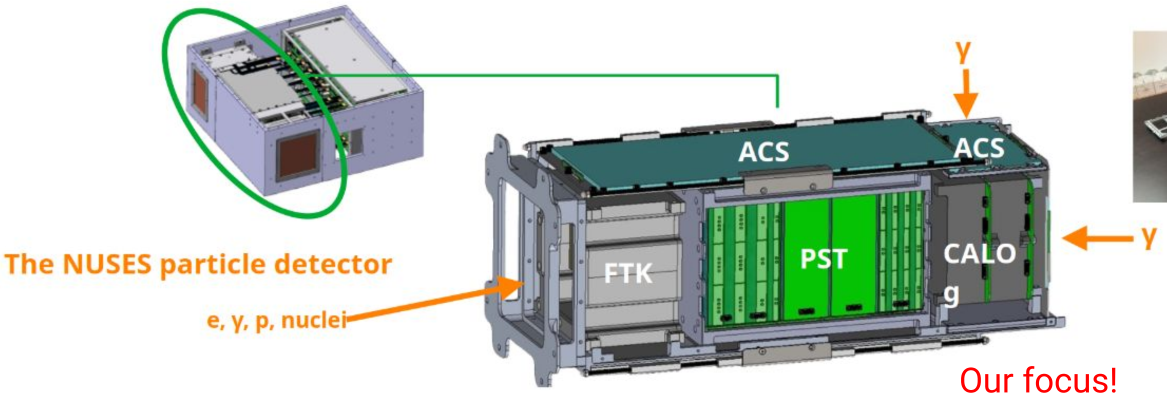




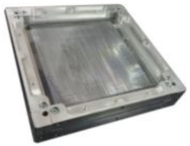




The Zirè payload



Our focus!



FTK

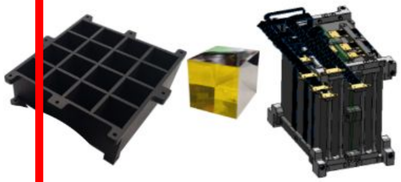
Fiber TracKer: track reco w/ scint. fibers.
3 modules in X-Y read by SiPMs.
Readout: 9.6 x 9.6 cm^2.

ACS

Anti-Coincidence System: veto for charged particles.
9 layers (0.5 cm thick) of plastic scintillators read by SiPMs.

PST

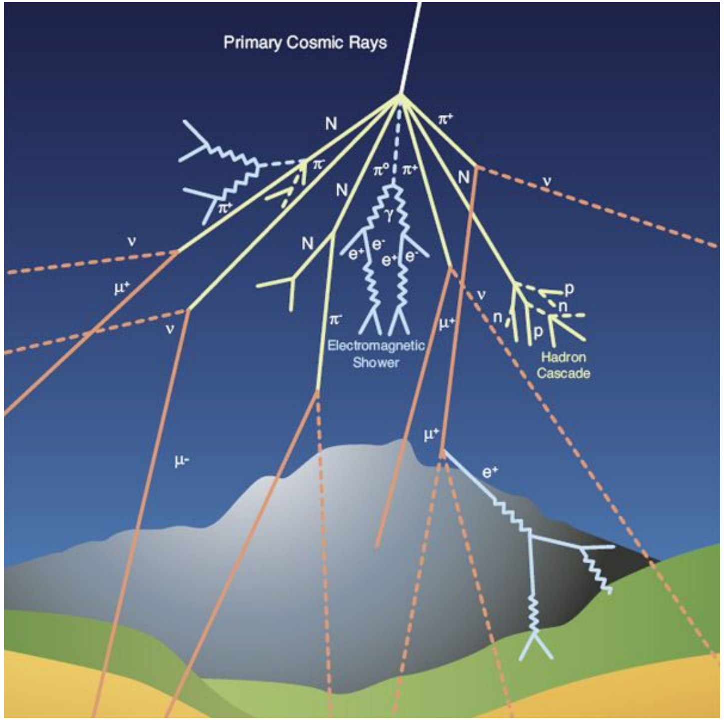
Plastic Scintillation Tower: particle identification.
32 PS layers in X-Y, 12x4x0.5 cm^3 and 12x4x1 cm^3, read by SiPMs.



CALOg

Calorimeter for energy measurement.
4 x 4 x 2 matrix of GAGG crystal cubes of 2.5 x 2.5 x 3.0 cm^3, read by SiPMs.

Cosmic muons as triggers



We want to characterize 2 PST prototype bars of dimensions **12x4x0.5 cm^3** and **12x4x1 cm^3**. We need a source and an external trigger.

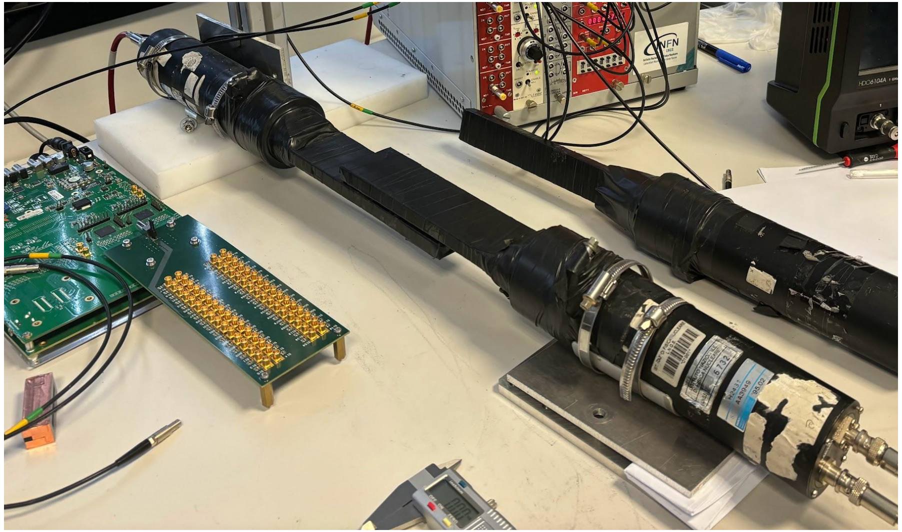
Our source: cosmic muons (mainly produced by pion decays).

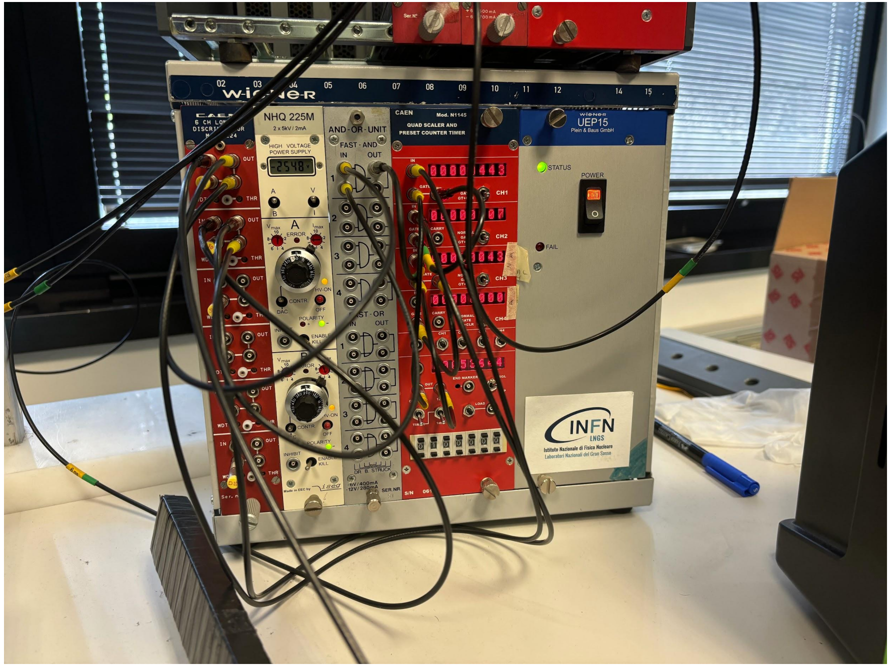
Expected rate at sea level: 1 muon /(cm^2 min).

Angular distribution at sea level: $\propto \cos^2(\theta)$.

Our trigger: two plastic scintillators + PMTs in coincidence.

External trigger setup



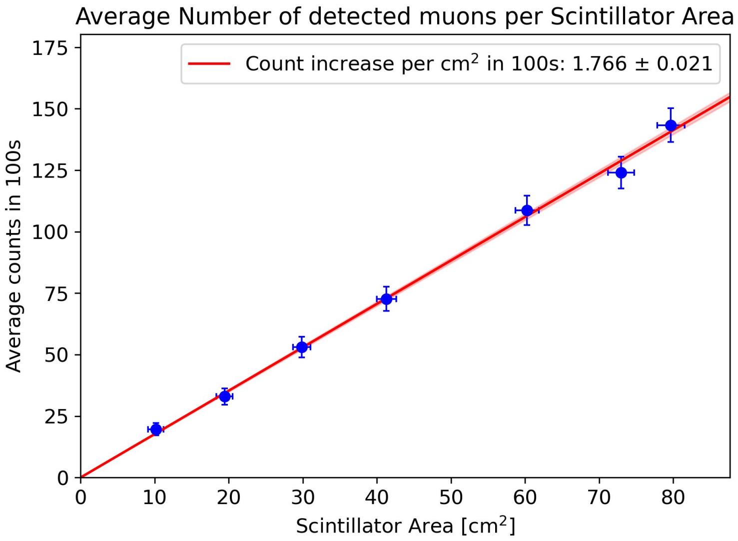


Specifics (front PMT, back PMT):

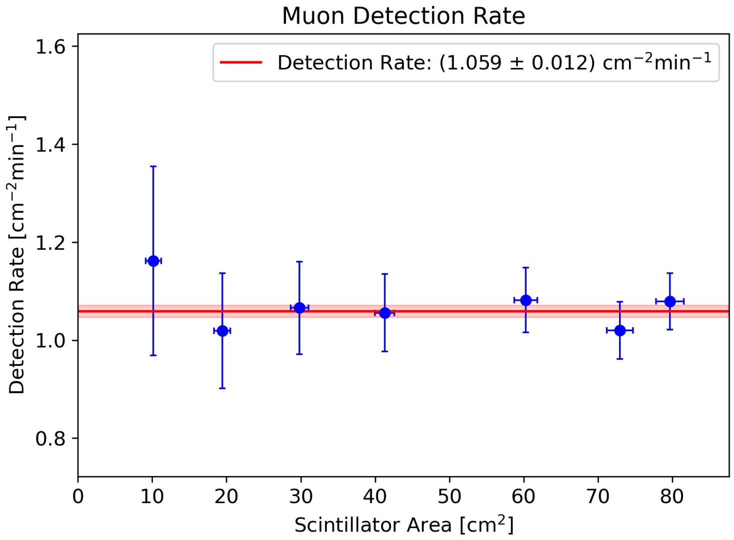
- HV (V): 2548, 2604
- Threshold (mV): 40, 40
- Coincidence window (ns): 100, 100

Reliability test of external trigger

- Linear increase of detection rate while increasing the active area of the coincidence: scintillators are reliable over full area



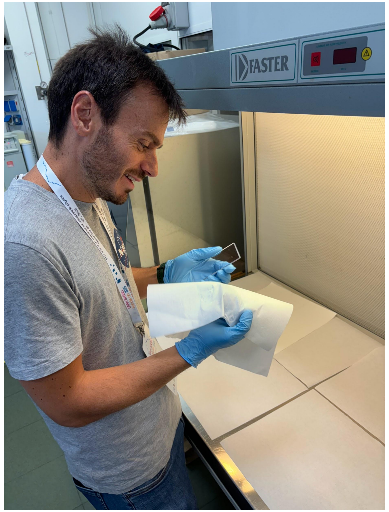
- Expected rate of cosmic muons: approximately 1 cm^{-2} min^{-1} .
- Measured detection rate in agreement with expectations!

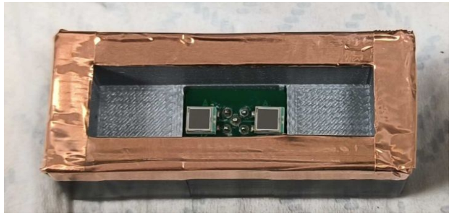


Preparing the detectors

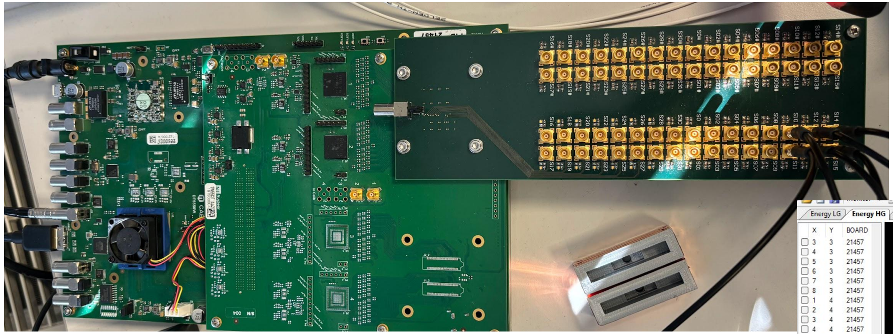
2 PST prototype bars, 0.5 and 1 cm thickness.

- Cleaning
- Teflon wrapping (internal reflection)
- Aluminium wrapping (outside reflection)
- Positioning the SiPMs (3x3 mm^2 Hamamatsu S14160-3015PS)
- Endcaps + black tape

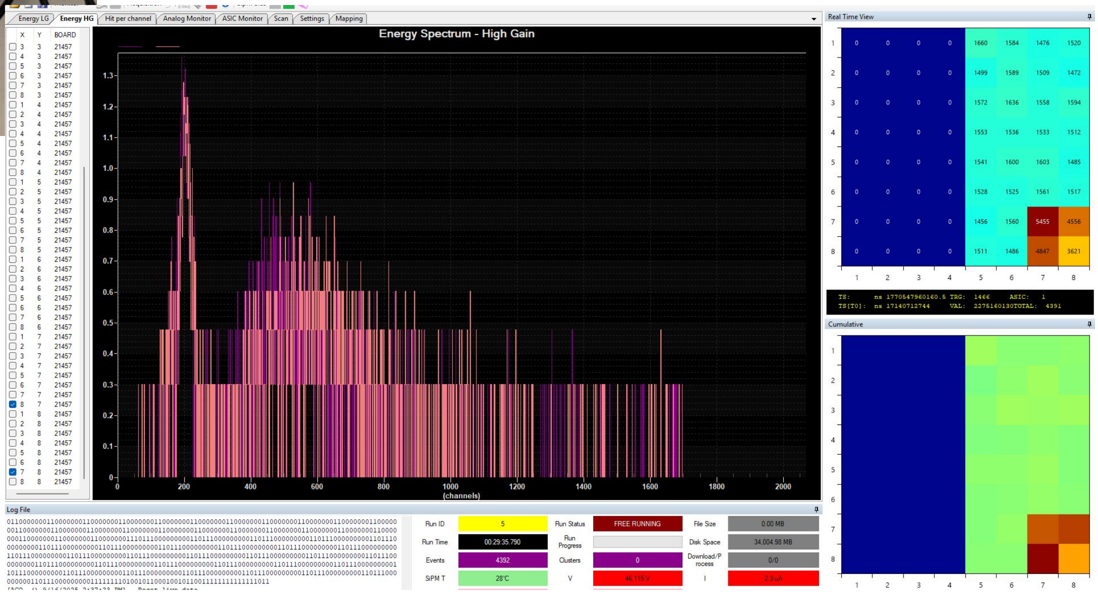




DAQ setup

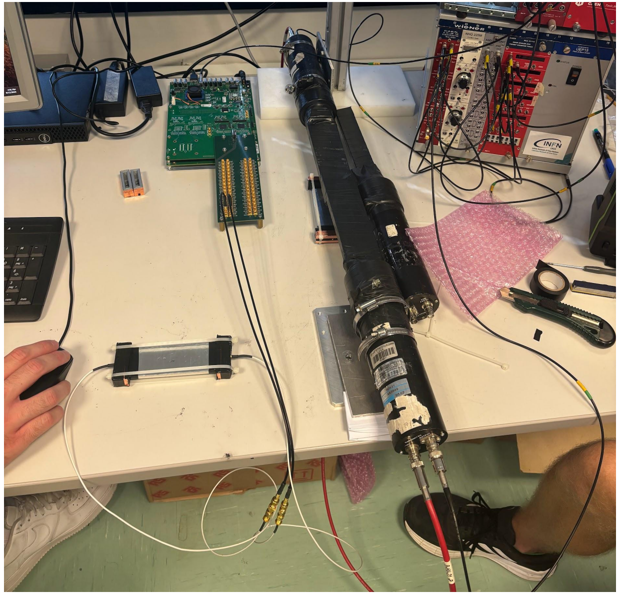


- DAQ Board: CAEN DT5550W
  - Full ready-to-use Readout system
- 80 MHz readout: Energy, time and position for all channels □ generating one event.

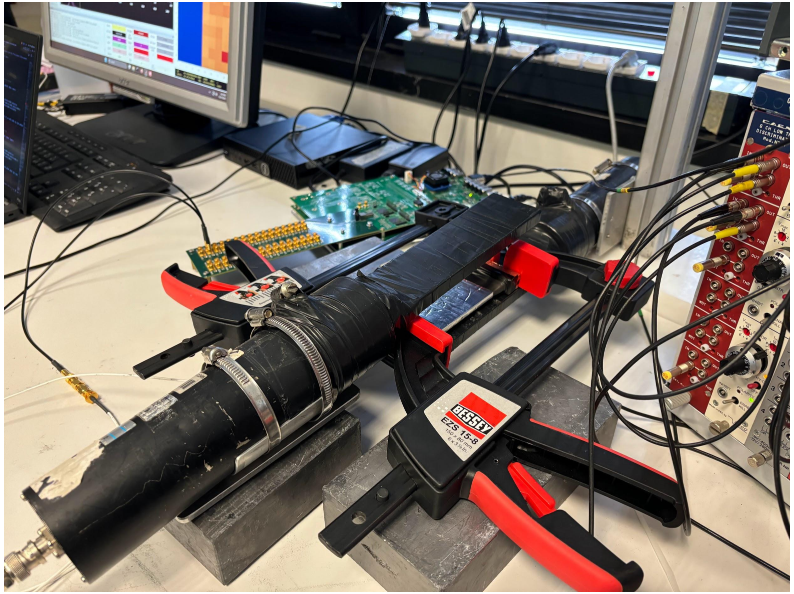


- Potential readout of up to 64 Channels
  - We are using 4, triggered by external PMTs
- Overview:
  - ADC Energy Spectrum
  - Event and accumulated map
- 32 channels masked (dark blue)

0.5cm PST bar setup



Background measure: random trigger.

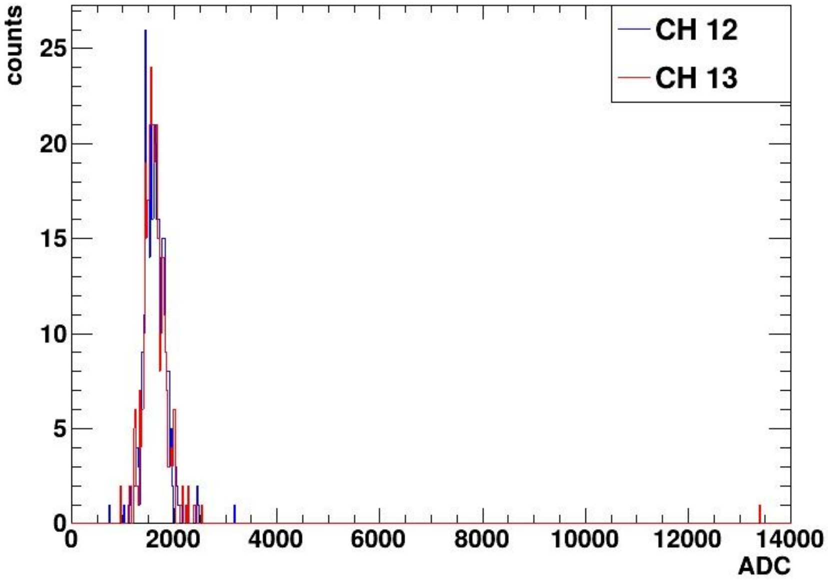


Signal measure: coupled to the trigger.

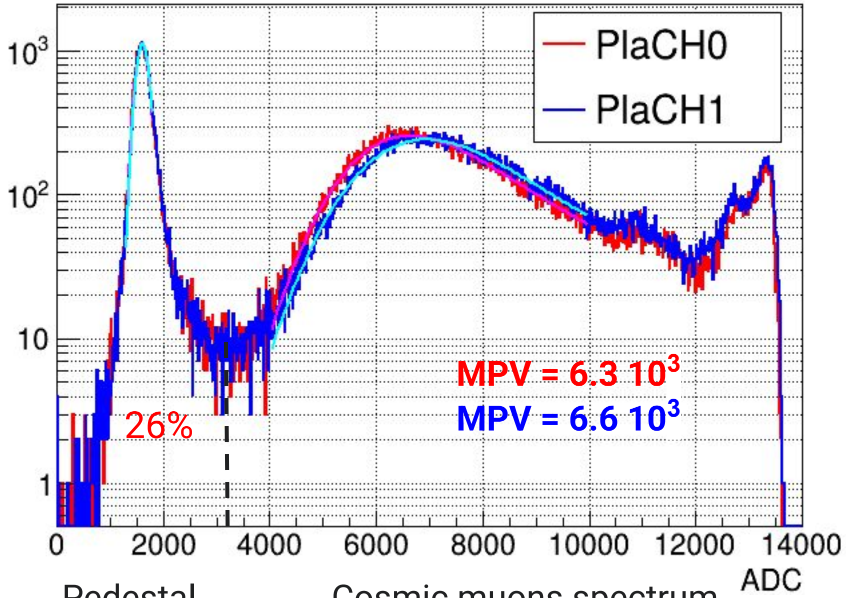
Specifics: HV=45.5V, HG=60.

0.5cm PST bar results

Background only



Signal + background

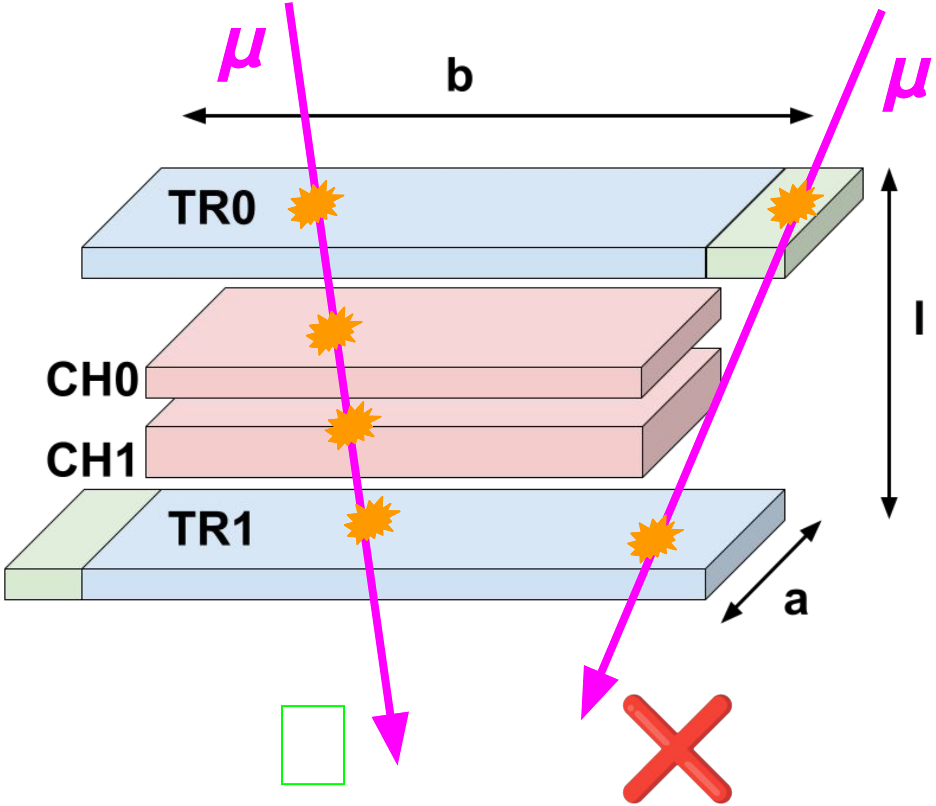


We used HG=60.

Pedestal   Cosmic muons spectrum

- Both SiPMs MPVs are in agreement → Good optical coupling, justification of manufacturing procedure
- Saturation at the end of the spectrum → reduce the gain
- 26% of events don't detect muons, is that expected?

Estimation of missed muons



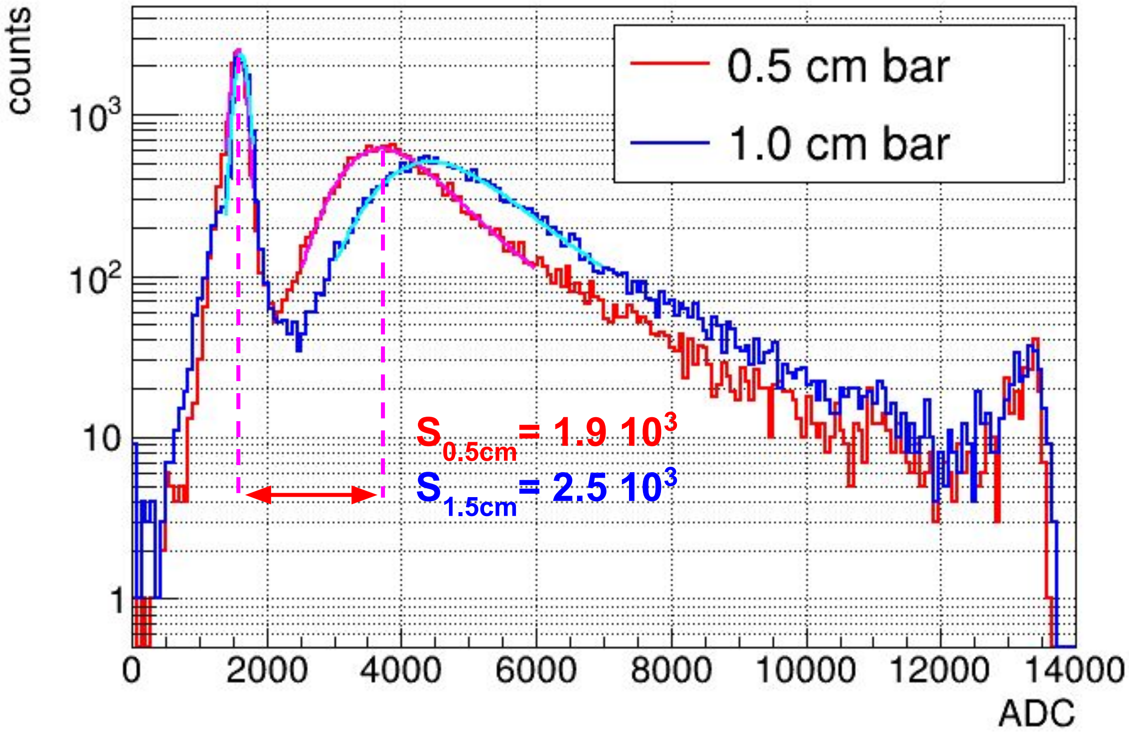
Percentage of triggers without detection in plastic scintillators because of the different geometric acceptances G (triggers are larger)

$$G \approx \frac{4\pi A_1 A_2}{2l^2 + a_1^2 + a_2^2 + b_1^2 + b_2^2}.$$

$$\Gamma_{miss} = \frac{(G_T - G_{pla})}{G_T} \sim 30\%$$

[https://doi.org/10.1016/0029-554X(71)90033-4]

0.5cm vs 1.0cm PST bars

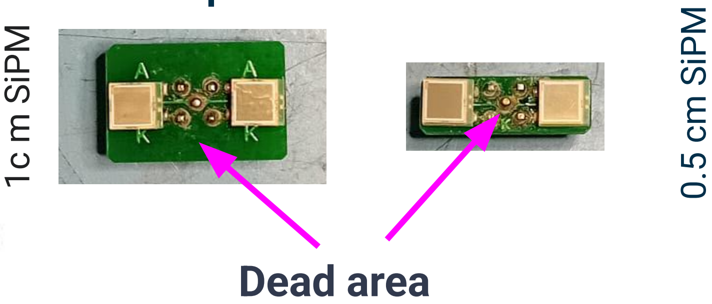


We used HG=55 (lower saturation).

- **Expected 2 times more scint photons ➡ two times the signal S**
- **we obtain:**

$$\frac{S_{1\mathrm{cm}}}{S_{0.5\mathrm{cm}}} \sim 1.3$$

BUT there is more dead area in the SiPM coupled to the 1 cm thick bar



Summary and Outlook

- Main Objective: Characterization of PST bar prototypes for the Zirè detector of NUSES
- Validated PMT coincidence setup as cosmic muon trigger
- Prepared 2 PST bars of 1.0 cm and 0.5 cm thickness
- Isolated muon signal from the background by acquiring triggered and untriggered data
- Investigated impact of the geometric acceptance on the signal-to-background ratio
- Characterized detector response with respect to scintillator thickness

Thank you for your attention!

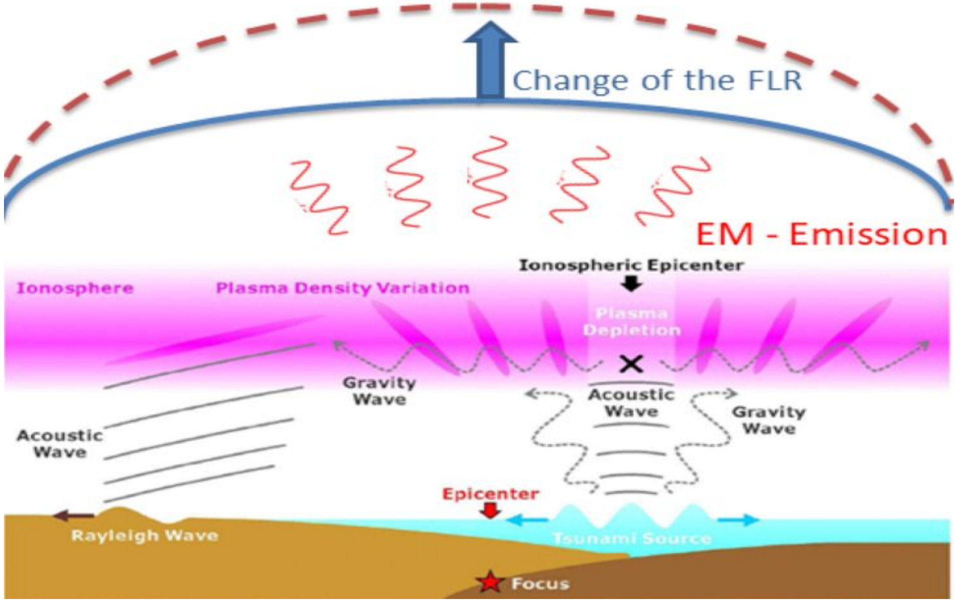
BACKUP SLIDES

What is MILC?

- So far only a conjecture
- Possibility to detect earthquakes before they reach land and alert the population.

Magnetosphere
Ionosphere
Lithosphere
Coupling

protons and electrons



Dark counts

- Dark counts: Random SiPM Signal trigger by thermal excitation in the absence of light
- Dark Count Rate (DCR) evolves with temperature and internal threshold
  ➡Calibration needed
- 43.5V reverse bias
  ➡5.5V Overvoltage