The NUSES space mission

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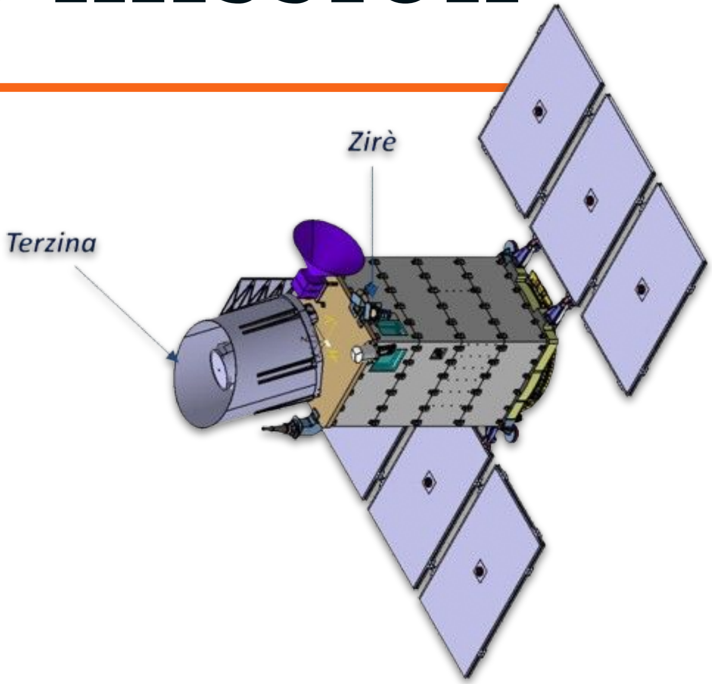


TeV Particle Astrophysics
TeVPA 2026
Tendo Japan
August 30 - September 4, 2026

GSSI
GRAN SASSO SCIENCE INSTITUTE

INFN
Laboratori Nazionali del Gran Sasso

THE NUSES SPACE MISSION

Research Institutes:

- **Gran Sasso Science Institute**
- Laboratori Nazionali del Gran Sasso
- Università dell'Aquila
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari, Politecnico di Bari and INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce
- University of Geneva
- Columbia University
- NASA Goddard Space Flight Center
- Pennsylvania State University
- New York University Abu Dhabi

Industrial partners:

- Thales Alenia Space Italy (TAS-I)
  [Platform development and satellite integration]
- Fondazione Bruno Kessler
- Officina Stellare
- Nuclear Instruments
- AGE Scientific
- Sophia HighTech

Industrial Partners:

The NUSES payloads

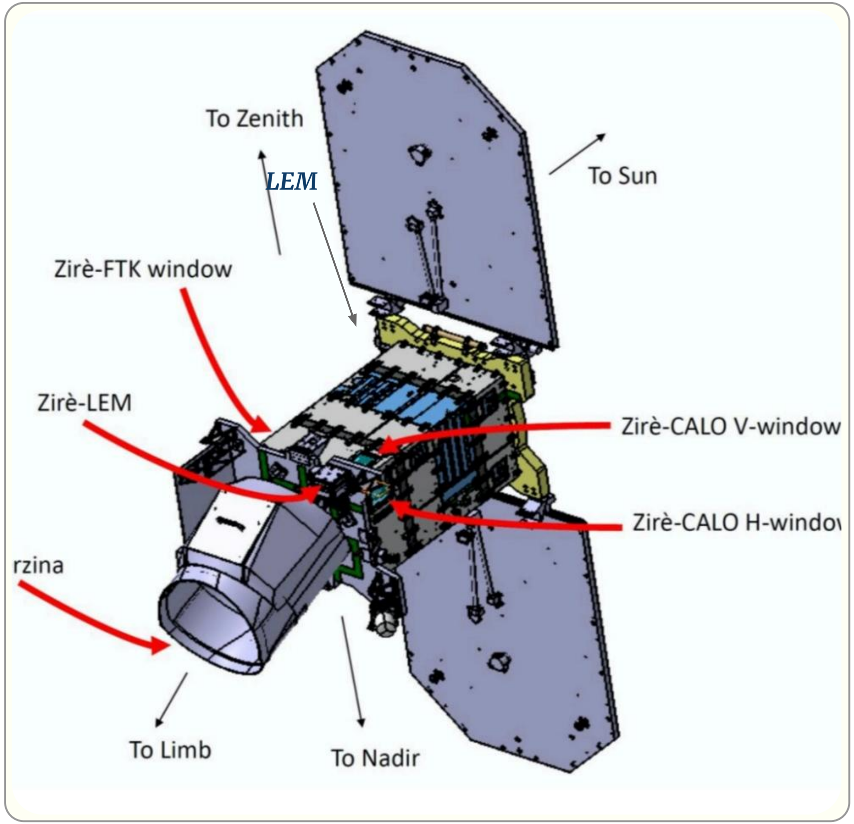
Italian pathfinder mission for exploring new observation methods and technologies for the study of high and low energy radiations from space.

Payload-1: Terzina (High Energy)

- Pathfinder for future Ultra-High Energy Cosmic rays and Neutrino astronomy from space by detecting the atmospheric Cherenkov radiation
- First detection of UHE cosmic rays and neutrino from space?

Payload-2: Zirè (Low Energy)

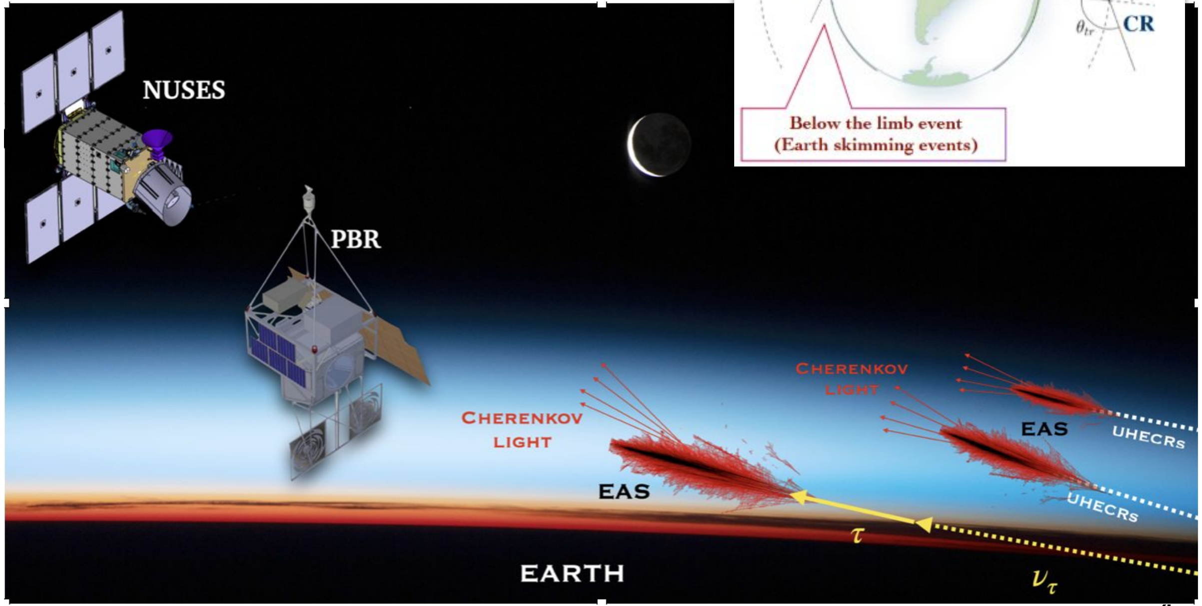
- Measure flux (E < 300 MeV) of cosmic e-, p and lighter nuclei
- Detection of 0.1 - 50 MeV photons for transient gamma ray source (GRBs) study
- Exploring new technologies in space: SiPM based readout system, new NIMBUS satellite platforms
- Possible Magnetosphere-Ionosphere- Lithosphere Coupling (MILC) (?)

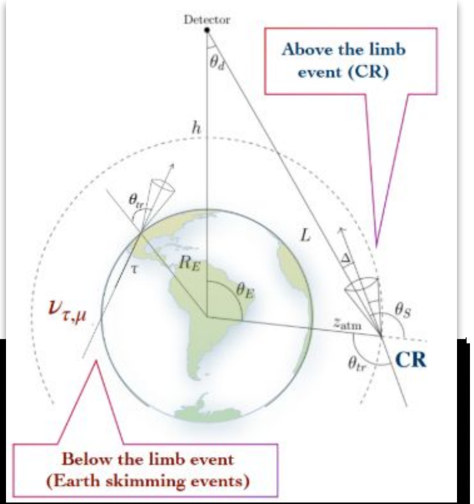


The TERZINA telescope

TERZINA mission includes:

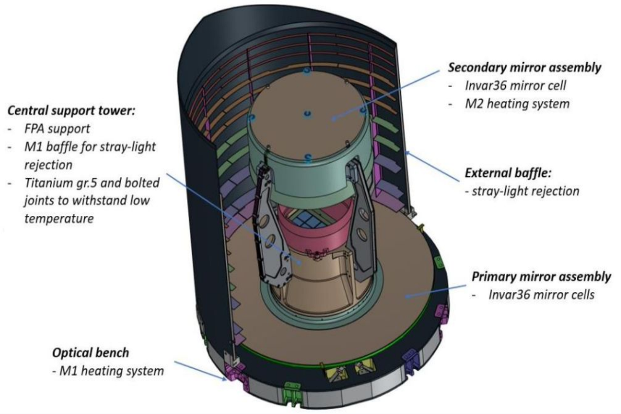
- Detection of Cherenkov light produced by the EAS from space
- Detection of UHE (> 100 PeV) cosmic rays
- Detection of Earth skimming neutrinos
- Technological advancement towards SiPM based photon detection

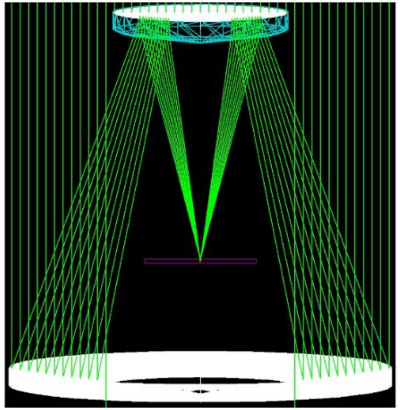


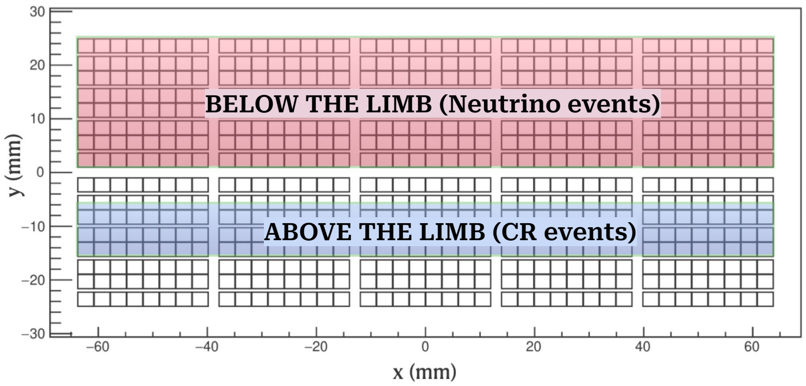


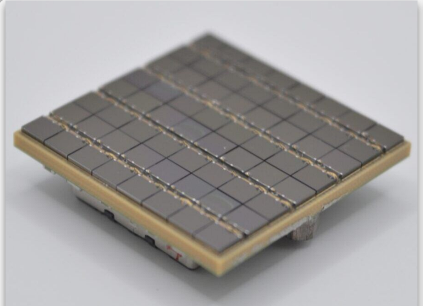
The TERZINA telescope

Double mirror telescope constituting an **Optical Telescope Assembly, Focal Plane Assembly (FPA), Thermal Control Assembly** and **Front End Electronics.**

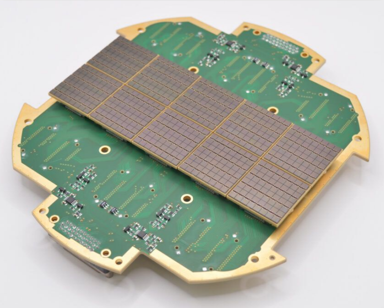




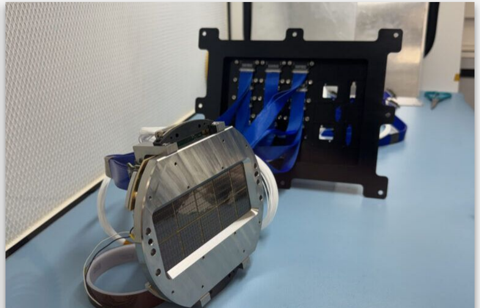




Single SiPM Tile



FPA

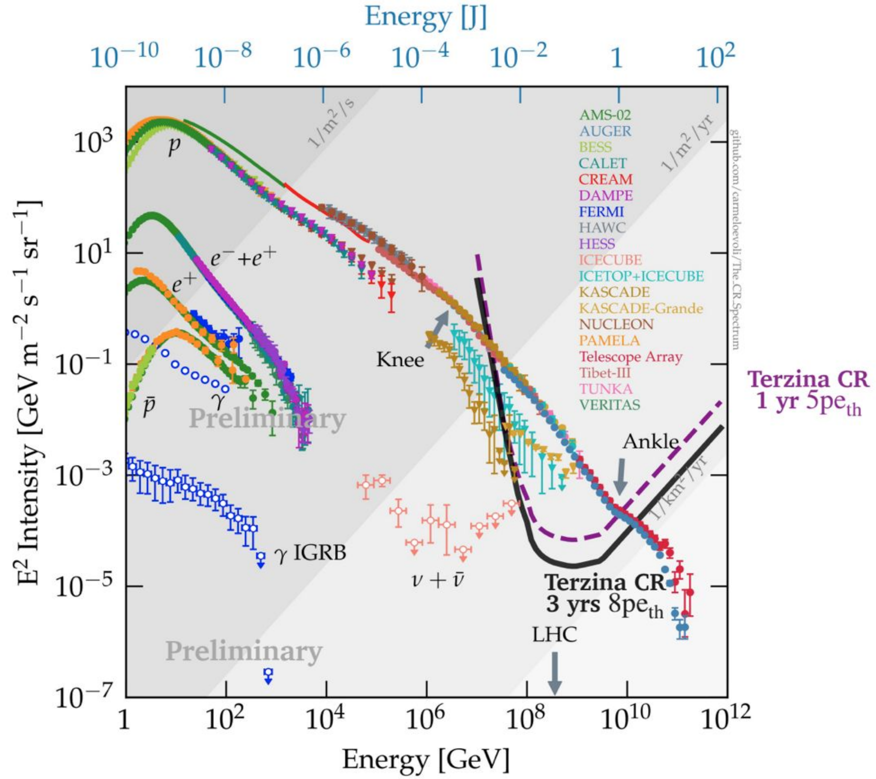


Fully assembled FPA

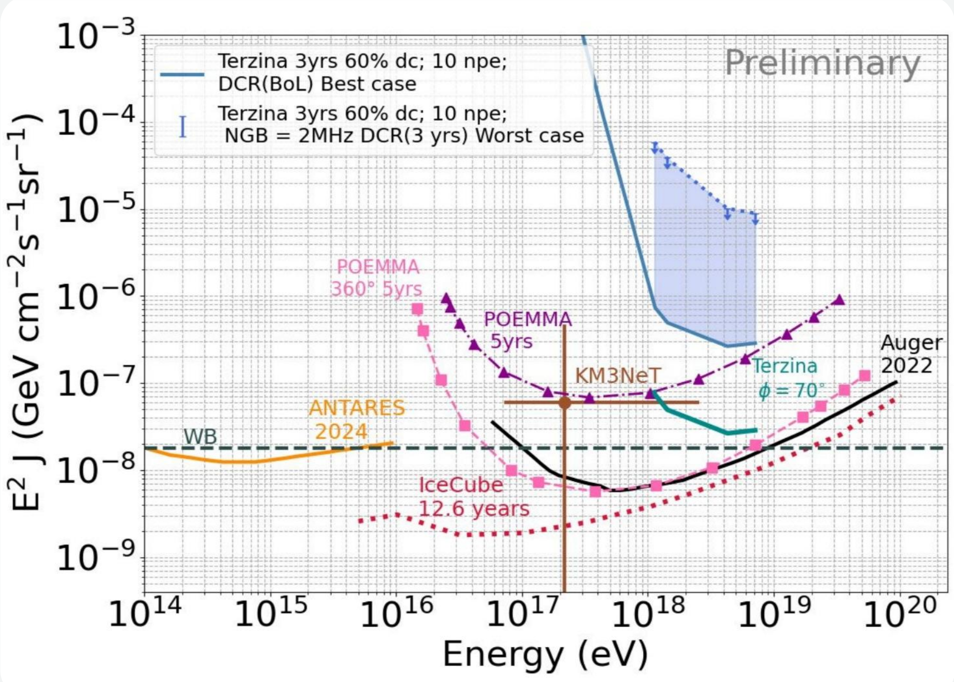
- Each SiPM tile consists of 8x8 grid of 2.3 mm x 2.7 mm sensors (FBK NUV-HD_MT).
- The FPA, telescope's camera, constitutes 10 SiPM tiles with a total of 640 pixels.
- The FPA full assembly was completed in June-2025.

TERZINA - Performance based on simulation

TERZINA sensitivity for Cosmic Rays



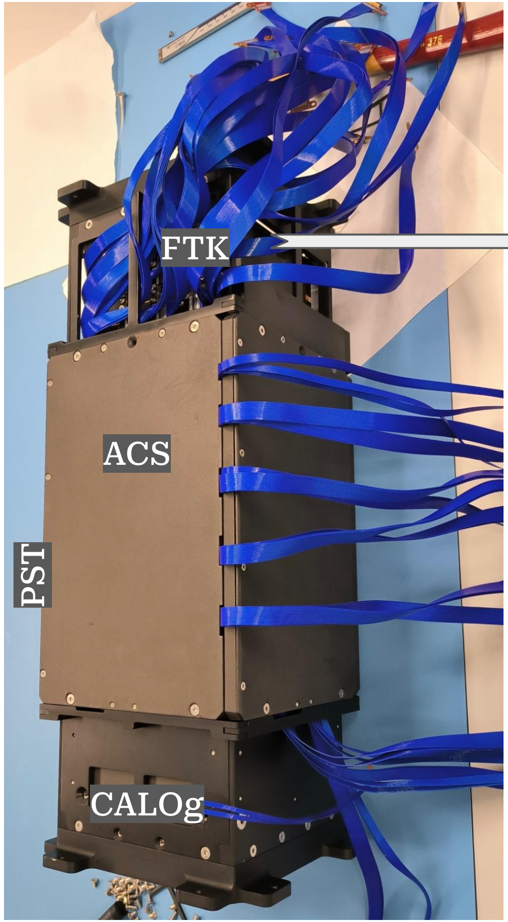
TERZINA sensitivity for Neutrinos

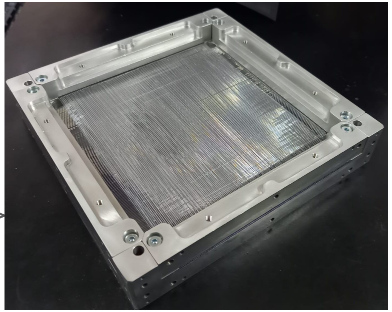


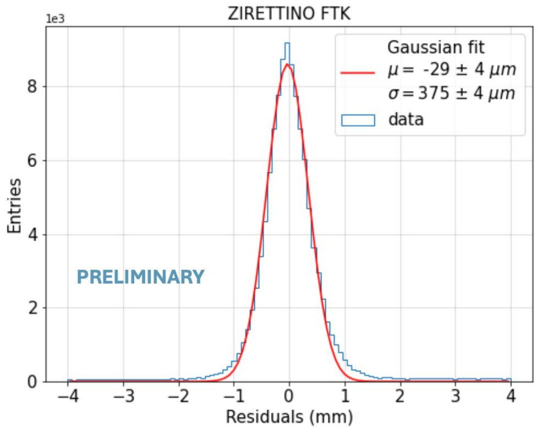
TERZINA: Current status

- **Model Integration & Qualification**
  Structural and Thermal Model (Telescope + FPA EQM) has been integrated and qualified (TVAC, Vibrational and environmental tests).
- **EQM FPA Characterization**
  EQM FPA is now fully characterized.
- **PFM FPA Integration (May 2026)**
  Integration complete, tested, and initial TVAC cycle successfully completed.
- **PFM Payload Integration (Sept 2026)**
  Scheduled to be started from September-2026.
- **Validation Activities**
  FPA functionality and trigger logic validation activities are currently ongoing.

Zirè - Fiber Tracker (FTK)





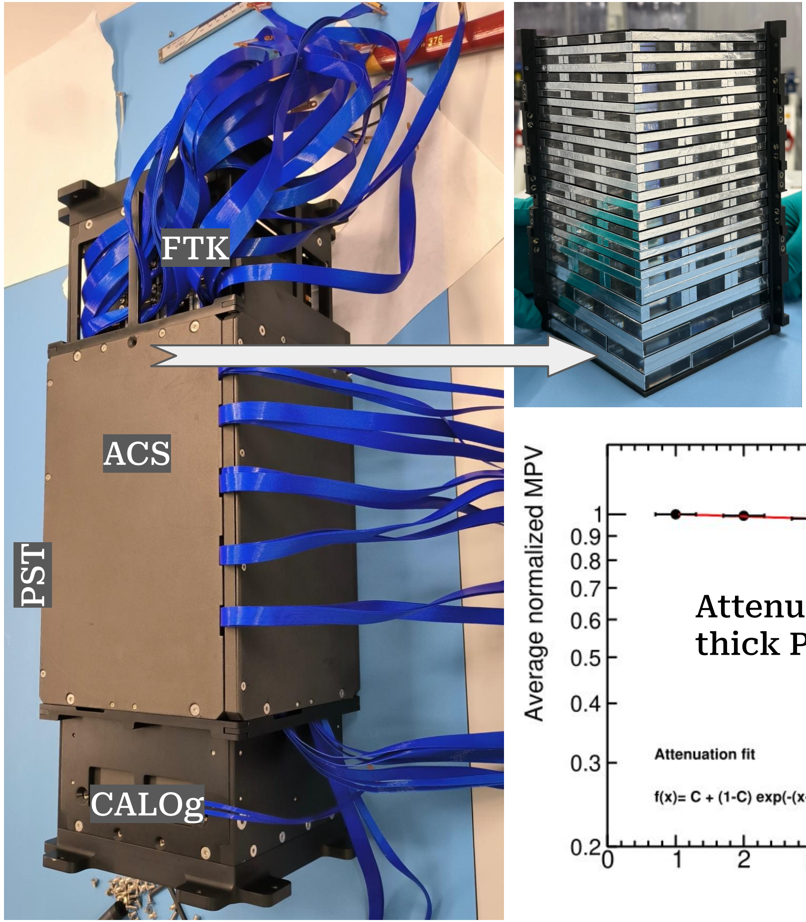


Spatial resolution of a single FTK module measured with the CERN PS test-beam using Zire prototype (Zirettino)

FIBER TRACKER (FTK)

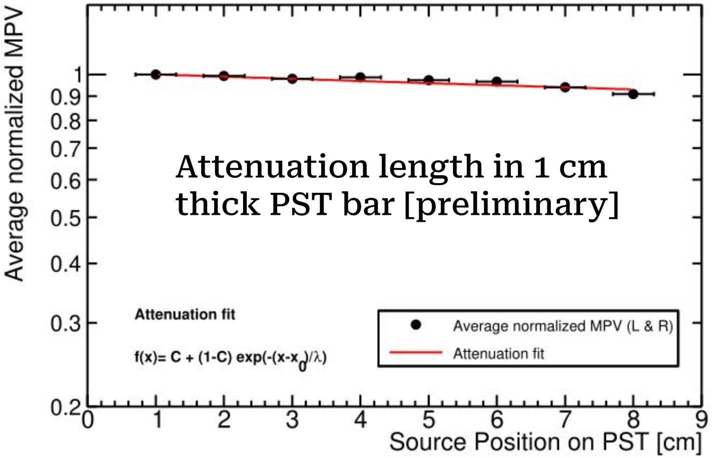
- 3 X-Y modules (9.6 x 9.6 cm^2) of scintillating fibers
- Kuraray SCSF78-MSJ fiber (750 μm diameter)
- Photon yield ~ 8000 / MeV
- SiPM based readout system
- Ideal for precision track reconstruction and particle identification

Zirè - PST



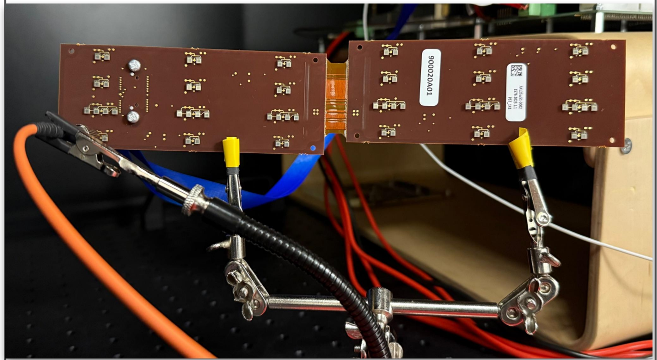
Plastic Scintillator Tower (PST)

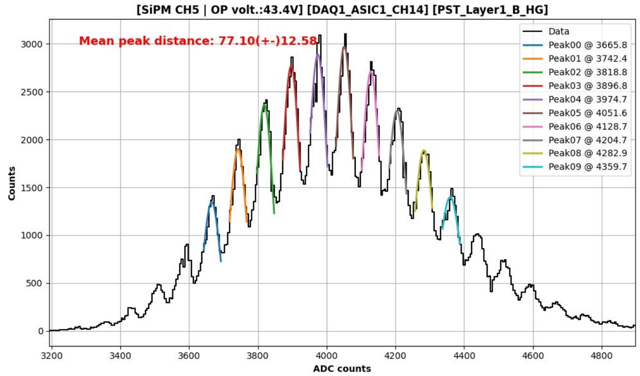
- 32 layers of plastic scintillators bars (EJ 204)
- 3 bars in each layer
- First 6 layers: 4 x 12 x 1 cm^3
- Next 26 layers: 4 x 12 x 0.5 cm^3



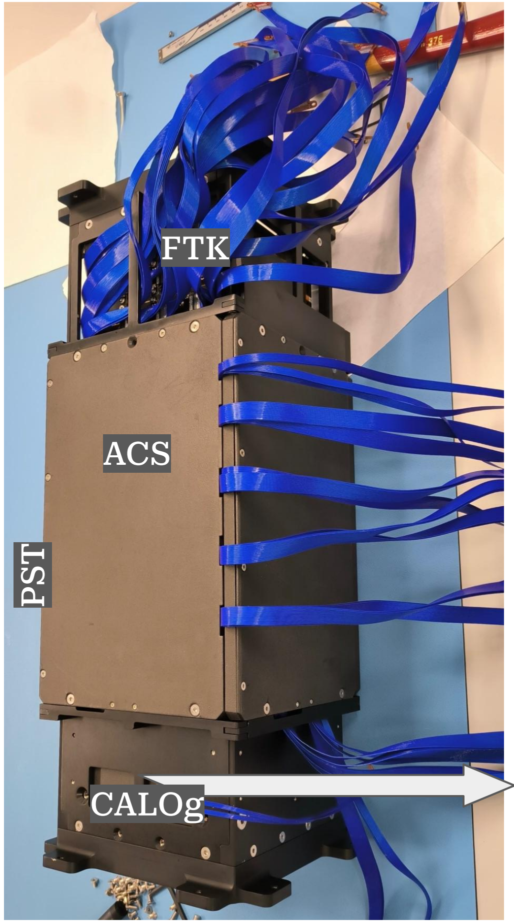
Calibration of SiPM using LASER source

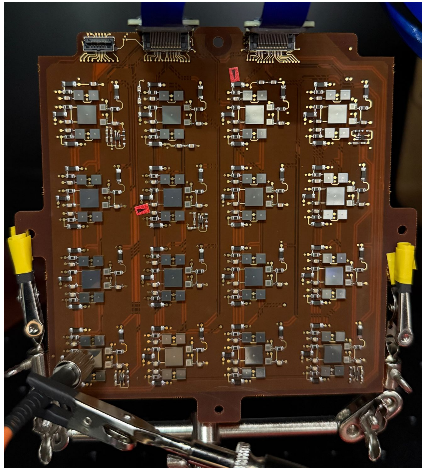
- Wavelength: 405 nm
- Rate: 5 kHz

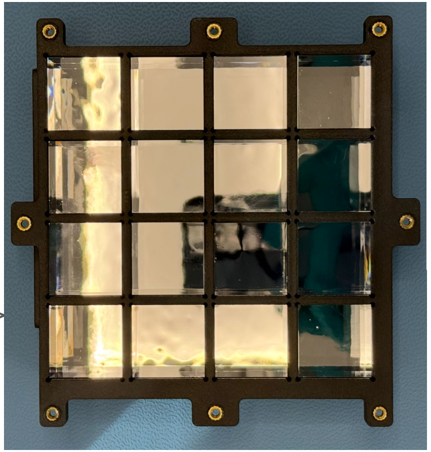




Zirè - CALOg

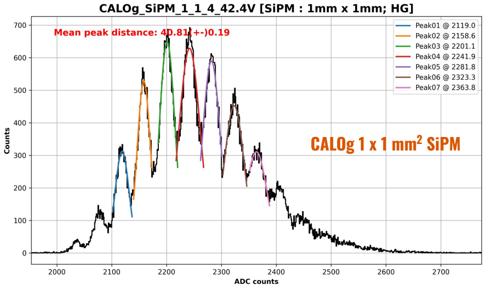


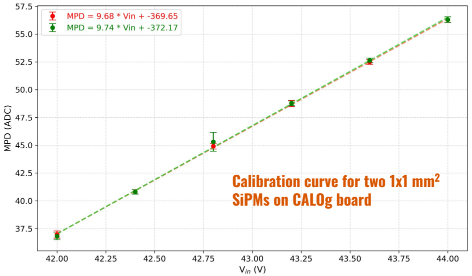




CALORIMETER (CALOg)

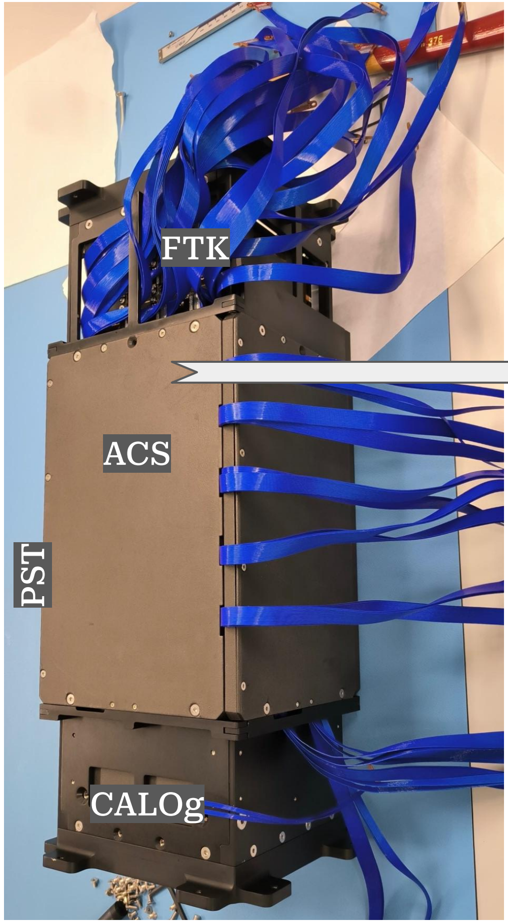
- 32 crystals (GAGG) arranged in two layers.
- Each layers consists of 4x4 grids of crystal (2.5 x 2.5 x 3.0 cm^3)
- Crucial for energy measurement
- Also vital for the performance study for the upcoming Crystal Eye experiment.
- The signal are read out by an array of 6x6 mm^2, 3x3 mm^2 and 1x1 mm^2 SiPMs.

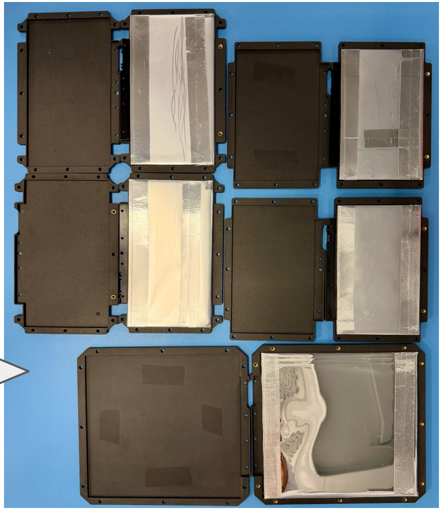




The EQM is equipped with LYSO crystals while the PFM will be equipped with GAGG.

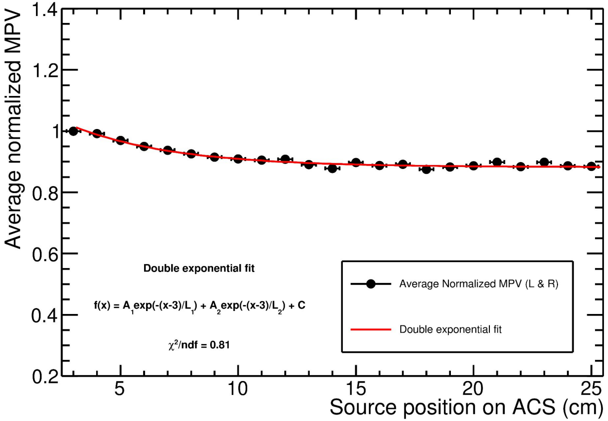
Zirè - ACS



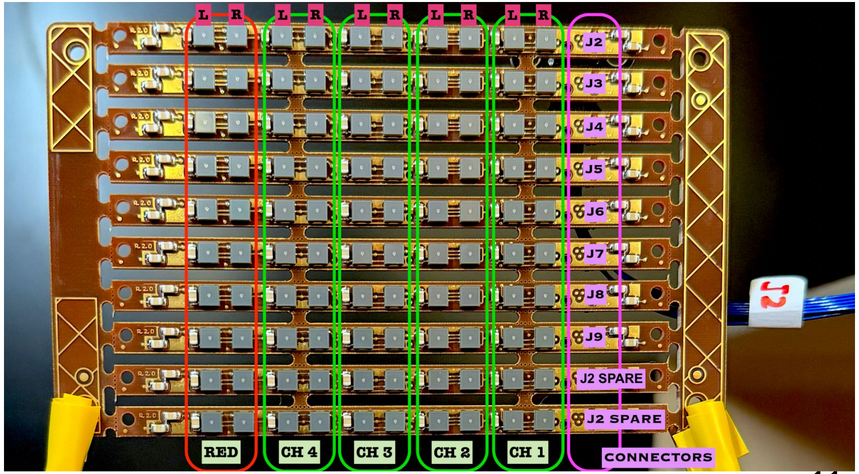


Anti-Coincidence Shield (ACS)

- 9 Plastic scintillator tiles (EJ 208)
- 4 Tiles covers the PST (0.6 x 16.5 x 27.0 cm^3)
- 5 Tiles covers the CALOg from sides and bottom



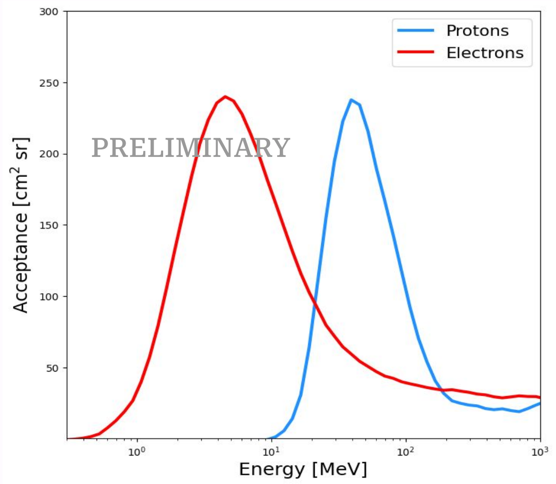
Attenuation length measured in the 27 cm long ACS tile designed to cover the PST

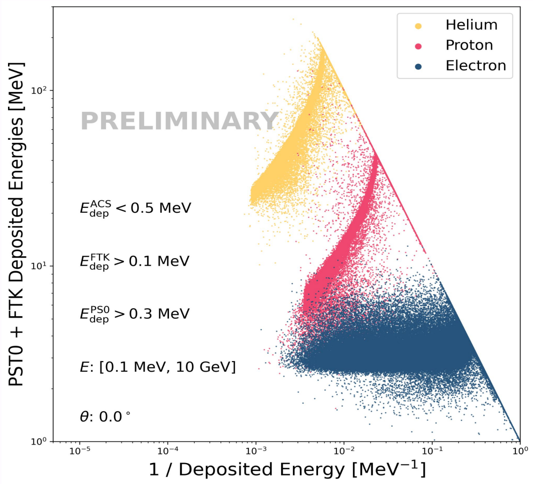


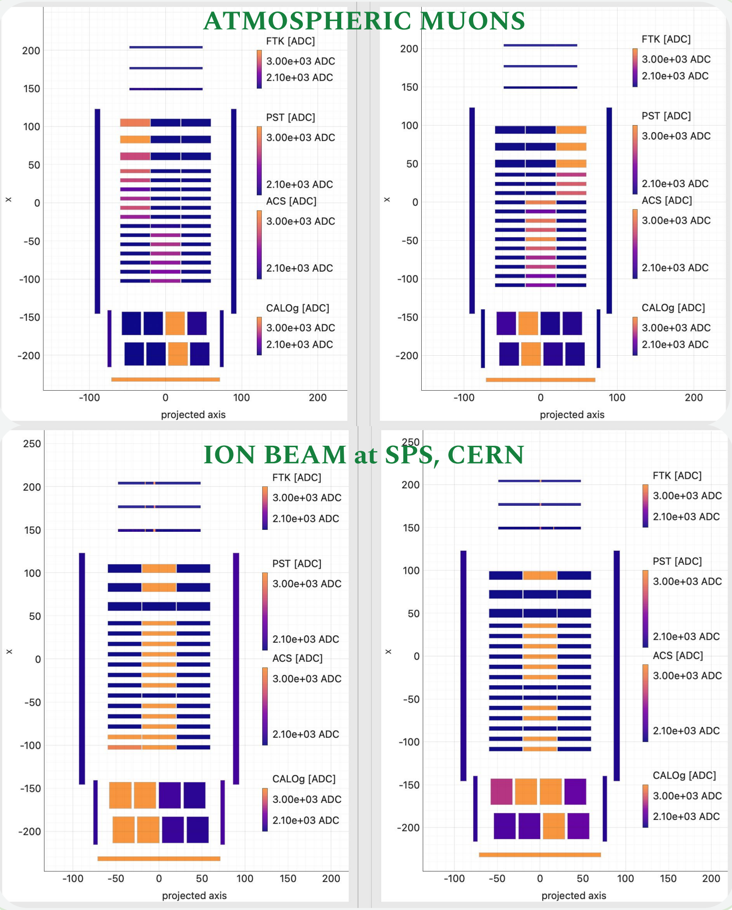
SiPM boards designed for the ACS

Zirè - performance

SIMULATION







Zirè event display

Integration of Zirè-EQM had been completed and the detector performance was studies using the test beam at CERN.

Campaign 1:

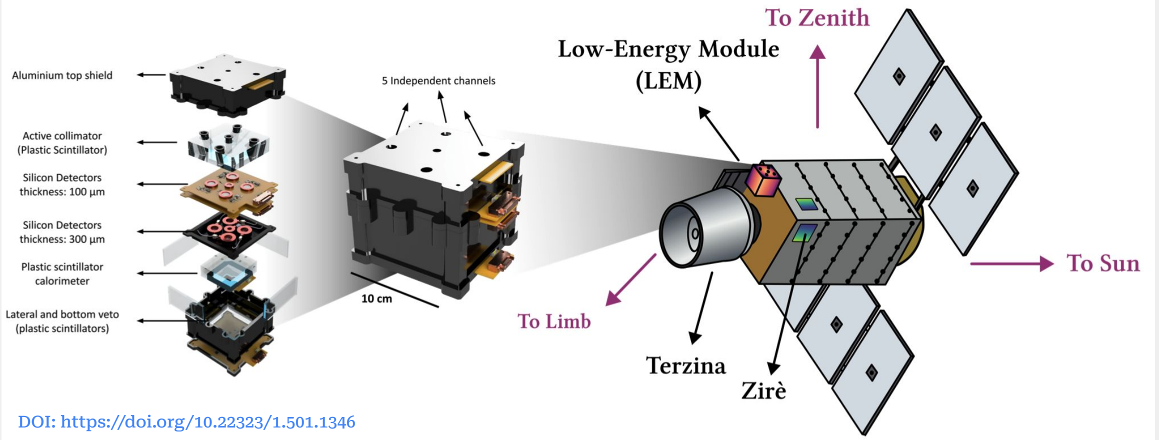
- At CERN PS facility

Campaign 2:

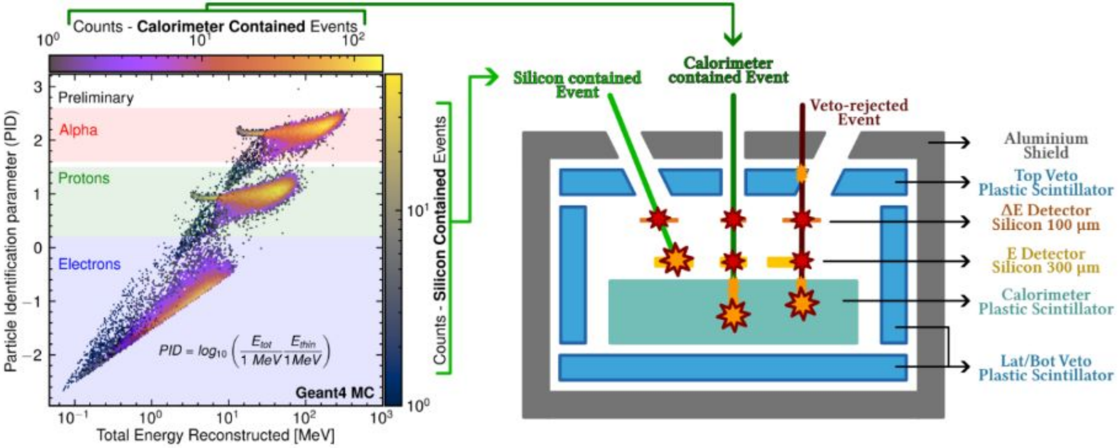
- At CERN SPS facility

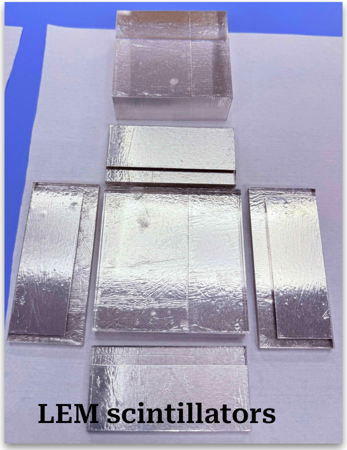
Zirè - Low Energy Module (LEM)

- LEM, a compact (10 x 10 x 10 cm^3) spectrometer, is designed to measure direction, energy and composition of low-energy charged particles.
- Compact design and limited acceptance, provide particle identification on event-by-event basis.



DOI: https://doi.org/10.22323/1.501.1346





LEM is dedicated to measure low-energy

- electrons : 0.1–7 MeV
- Protons : 3–50 MeV

Zirè-Current status

Zirè-EQM

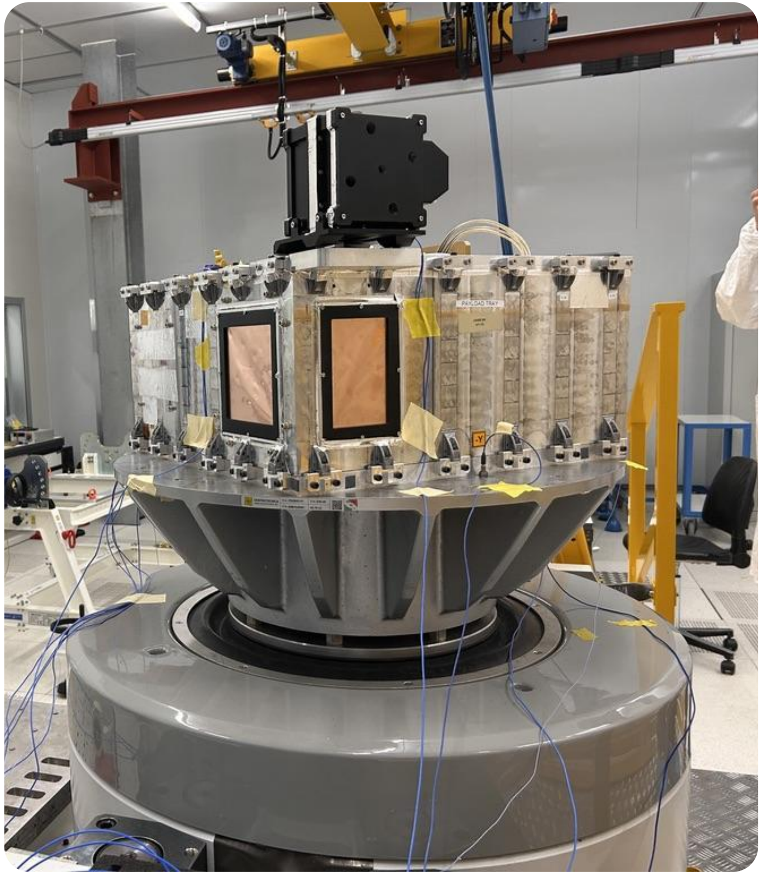
- EQM integration completed
- Qualification campaign at its final stage
- Beam test campaign at CERN (PS and SPS) was completed in August 18.

Zirè - Proto Flight Model (PFM)

- SiPM characterization completed
- Individual sub-detector preparation is underway
- Final integration : Second week of September

Payload integration timeline

- Complete the EQM qualification campaign
- Deliver the PFM by the end of 2026



Summary

Science

- Test HE neutrino detection feasibility using the Earth skimming geometry and Cherenkov light
- Measure electrons, protons and nuclei up to a few hundreds of MeV
- Measure [0.1-50 MeV] photons for the detection of transient and steady gamma sources
- Monitor very low energy (< 10 MeV) electron flux to study possible correlation with seismic activity due to Magnetosphere-Ionosphere-Lithosphere Coupling (MILC)
- Characterize the near-UV-optical background in the region close to the limb, crucial for next-generation payloads like POEMMA

Technology

- Space qualification of new technologies (SiPMs, onboard data reduction, additive manufacturing,...)
- Cherenkov telescope based on a SiPM focal plane
- Design/qualification/use of low power/COTS electronics (~few mW/ch)
- New observational methods: Cherenkov light from the limb

Thank you