A. Smirnov (GSSI and INFN-LNGS)
on behalf of the NUSES Collaboration

*P. Savina (GSSI and INFN-LNGS)
on behalf of the NUSES Collaboration

THE NUSES MISSION

RICAP 2024, Frascati, Italy

THE NUSES MISSION

Italian led mission conceived as a **pathfinder** for **new observation methods and technologies** in the study of high and low energy radiations from space enabling new sensors and tools

60+ persons from many institutions.

Large **expertise** (and **sinergies**) from space missions/R&D: AMS, DAMPE, eASTROGAM, Fermi, LIMADOU, GAPS, HERD, PAMELA, POEMMA, SPB2, …

Italian 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 and INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce

Other Institutes:

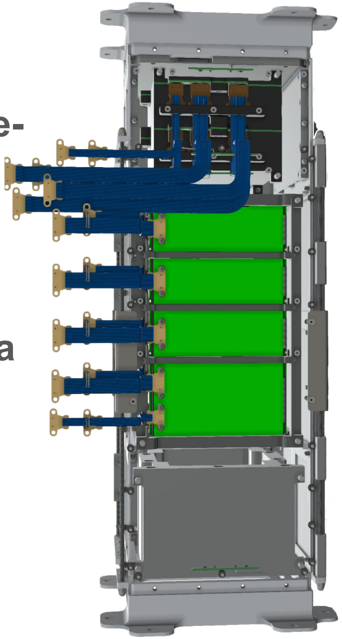
- University of Geneva
- University of Chicago
- Interests from other US institutions, …

Industrial Partners:

NUSES: **TWO PAYLOADS**

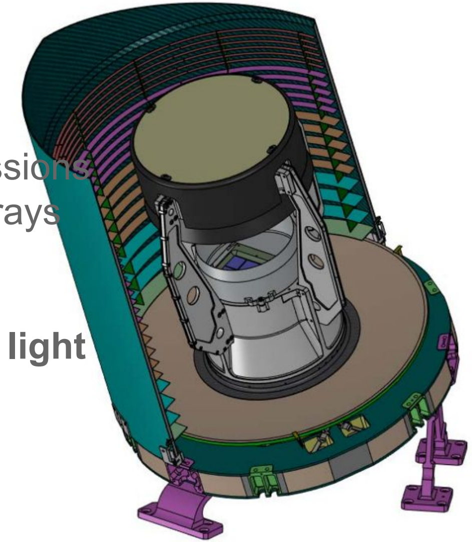
Zirè

- **Measure the flux (E<300 MeV) of cosmic e$^-$, p** and light nuclei of solar/galactic origin;
- Study of the cosmic radiation variability (Van Allen belt system);
- Possible correlation with seismic activity due to **Magnetosphere-Ionosphere-Lithosphere Coupling** (MILC);
- Detection of 0.1 - 30 MeV photons for **study of transient and stable gamma sources**;
- Paving the way for future **applications of new technology** (SiPM, …);



Terzina

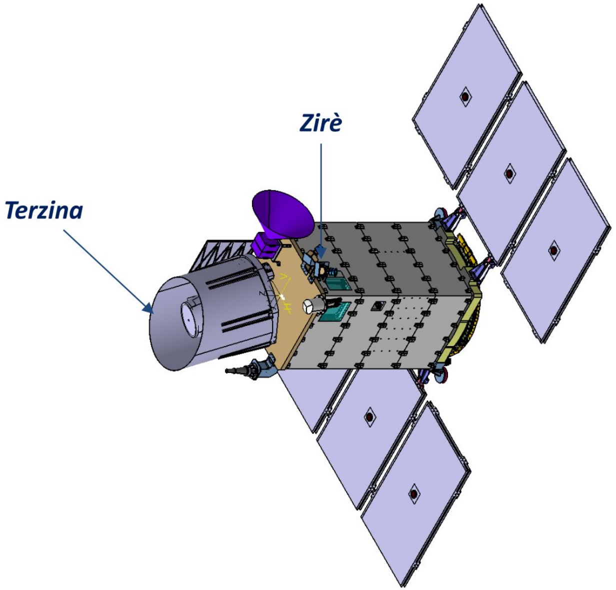
Pathfinder for future missions devoted to UHE cosmic rays and neutrino astronomy through **space-based** atmospheric **Cherenkov light** detection.



New Technologies and approaches

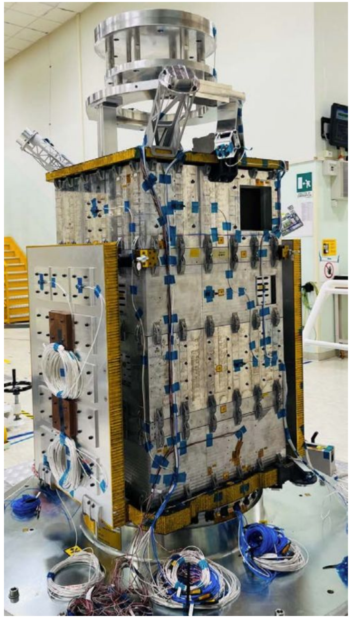
Development of new observational techniques, testing new sensors (e.g. **SiPM**) and related electronics/DAQ for space missions. New solutions for the satellite platform.

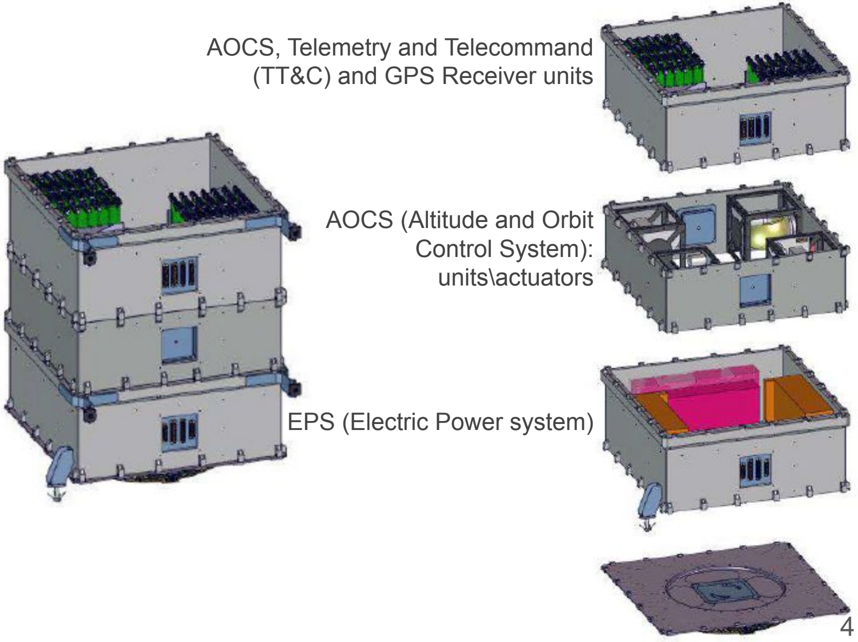
NUSES: **THE SATELLITE**



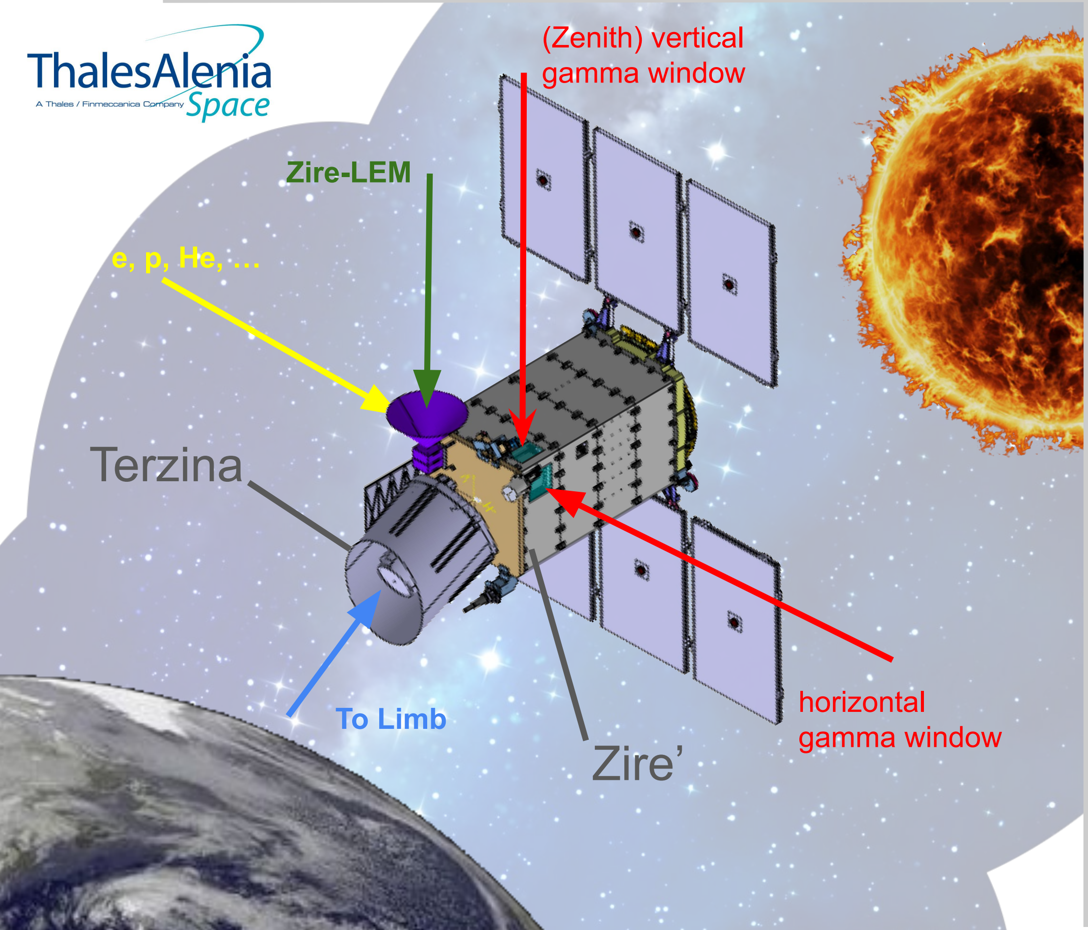
New Italian Micro **BUS**

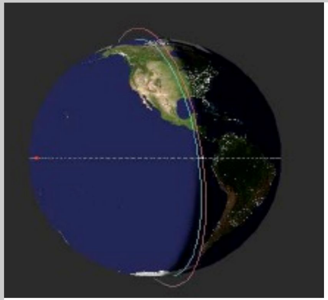
New platform concept which foresees a modular approach relying on standard trays.





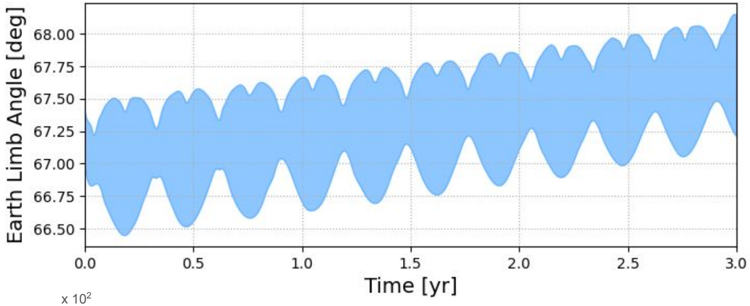
NUSES: **THE ORBIT**

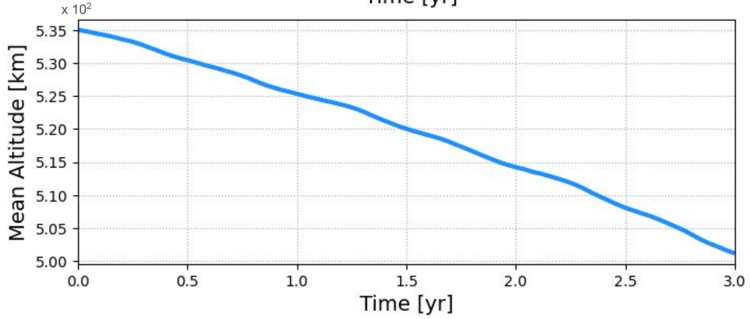




Low Earth Orbit (LEO) with high inclination, **sun synchronous orbit on the day-night border.**

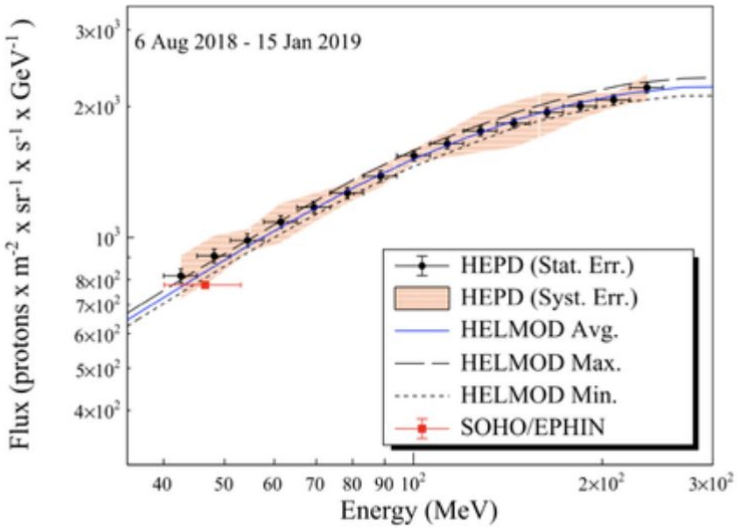
- Altitude ~550 km
- Inclination = 97.8 deg
- LTAN = 18:00)





ZIRÈ: **LOW ENERGY MEASUREMENTS**

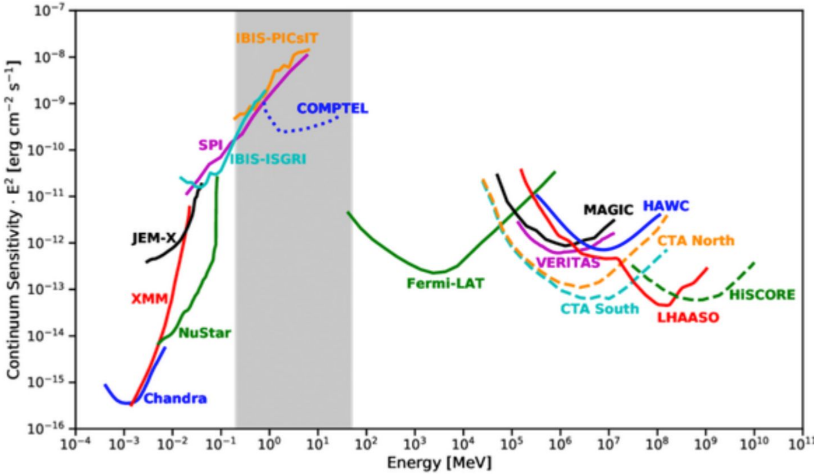
Measuring CR fluxes with energy E < 300 MeV:



Energy spectrum of low energy charged cosmic particles is different with respect to the Local Interstellar Spectra (the spectra that would be measured outside the heliospheric boundaries)

Magnitude is strictly dependent on the time of the measurements

Study of the astrophysical photons in the 100 keV up 50 MeV region which is to date not extensively measured.



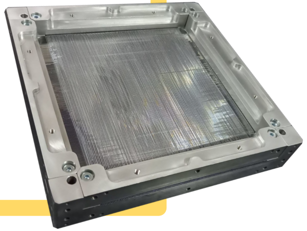
Other goals:

- Monitoring near-Earth space environment
- Study of fluxes of high- & low-energy charged particles from the Van Allen radiation belts
- Measurements of magnetospheric and solar activity
- Analysis of the ionospheric and plasmaspheric fluctuations & possible correlations with seismic phenomena

ZIRÈ: LAYOUT

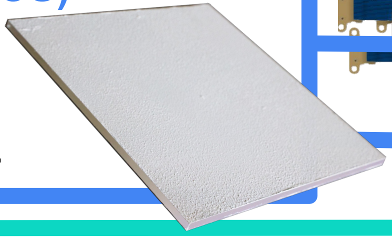
Fiber TracKer (FTK)

3 double layer XY modules of fibers to be used for track identification.



Anti-Coincidence System (ACS)

9 PS layers surrounding the detector.



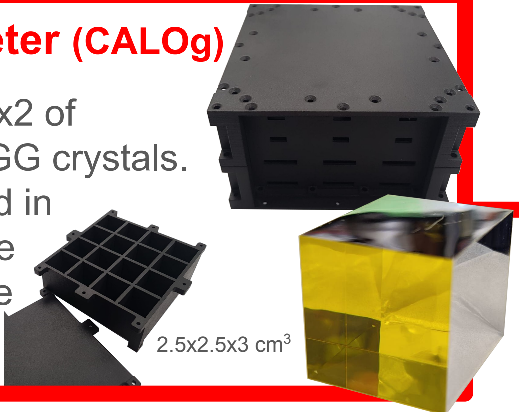
Plastic Scintillator Tower (PST)

Tower of 32 Plastic Scintillator layers. Each layer is composed by 3 bars.

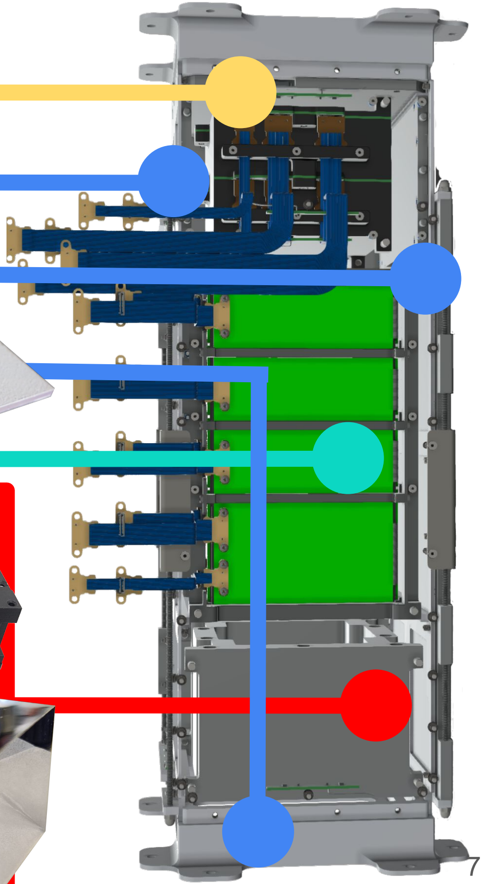
6 layers: $4x12x1\ cm^3$
26 layers: $4x12x0.5\ cm^3$

Calorimeter (CALOg)

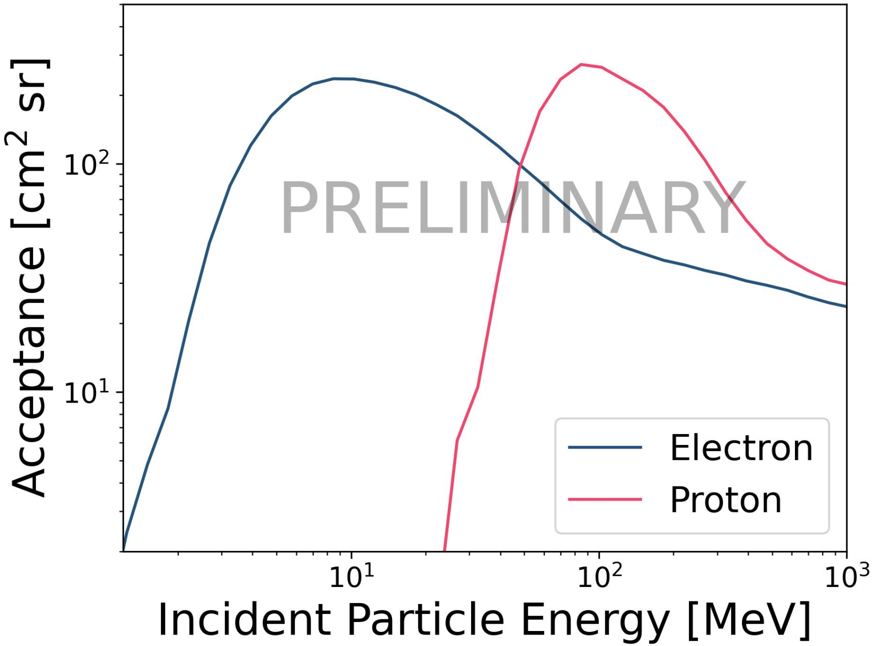
Matrix 4x4x2 of LYSO/GAGG crystals. Segmented in cubes to be Crystal Eye pathfinder.

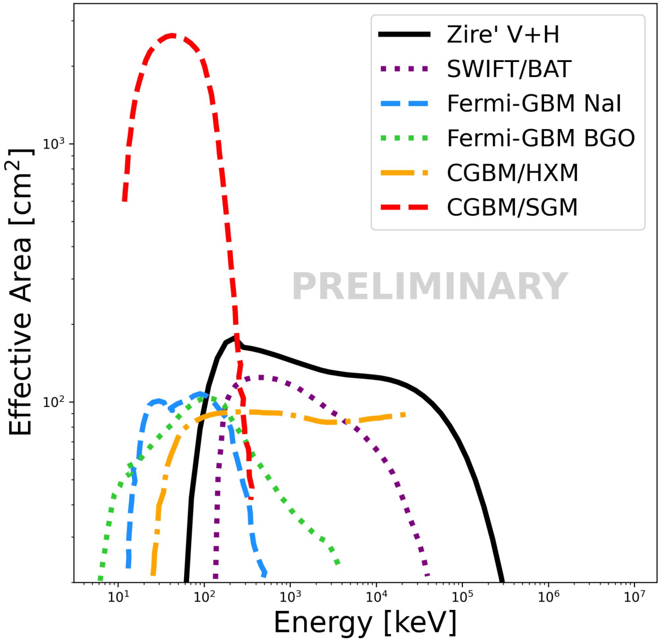


$2.5x2.5x3\ cm^3$



ZIRÈ: e, p ACCEPTANCE AND γ EFFECTIVE AREA





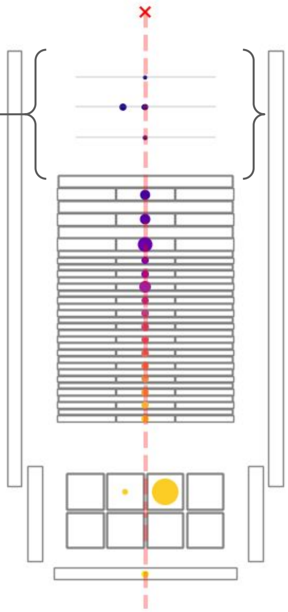
CALOg will be also used for the study of **low energy γ-rays** between 10 keV and 50 MeV.

Two windows surrounding the CALOg are included for this purpose.

ZIRÈ: **P**ARTICLE **ID**ENTIFICATION

Particle Identification by studying the correlation between the energy deposit inside FTK+PS0 and the inverse of the total energy deposition in the whole detector.

FTK + PS0
Energy deposit

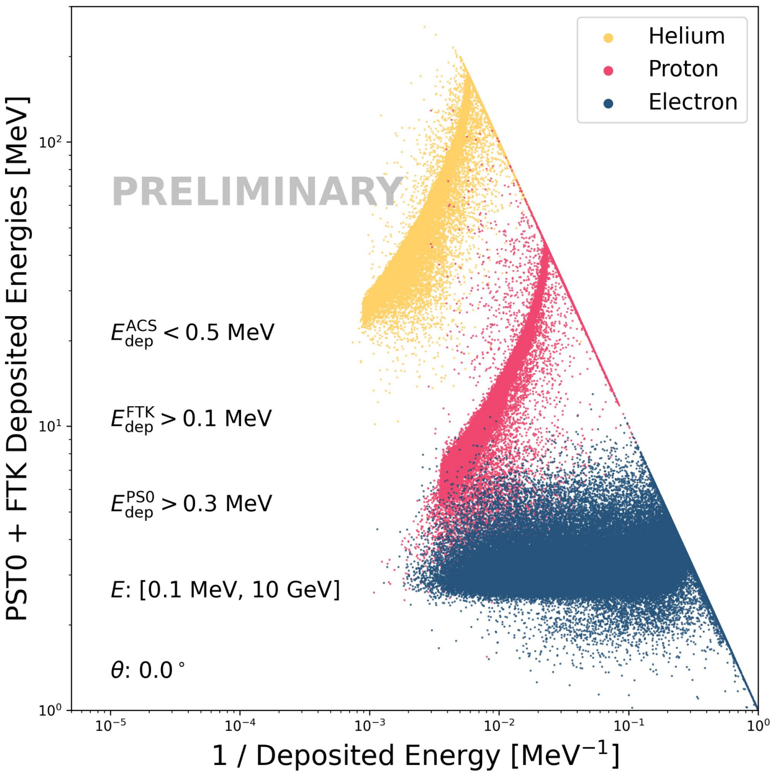


$$\Delta_0 = \Delta E_{\mathrm{FTK+PS0}} \simeq \frac{dE}{dX} \propto \frac{z^2}{\beta^2} F(\gamma\beta)$$

$$E_{\mathrm{dep}} \simeq E_k \propto \beta^2$$

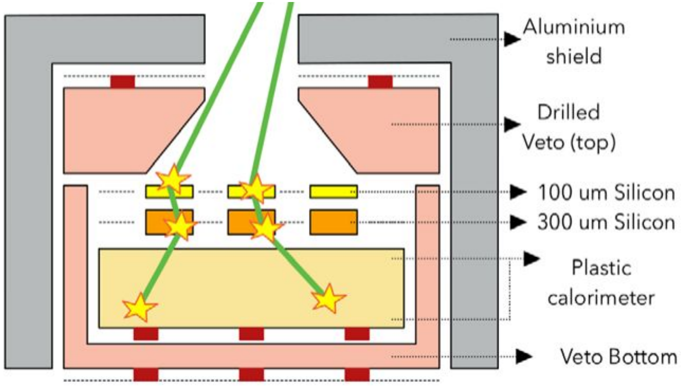
$$\Delta_0 \propto \frac{z^2 F(\gamma\beta)}{E_{\mathrm{dep}}}$$

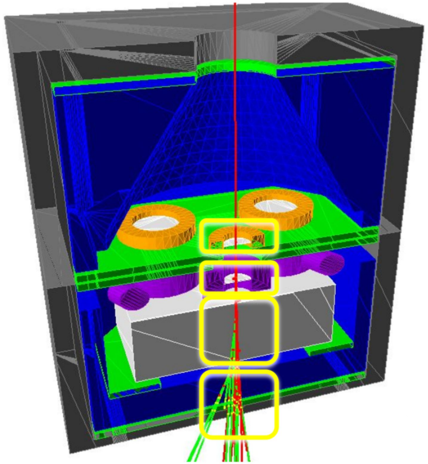
For non-relativistic and contained nuclei

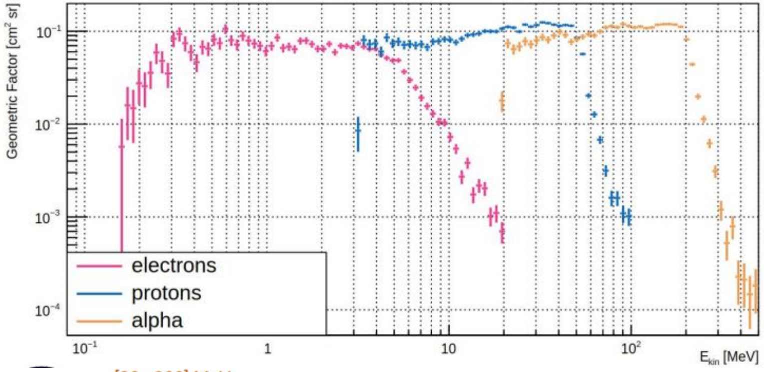


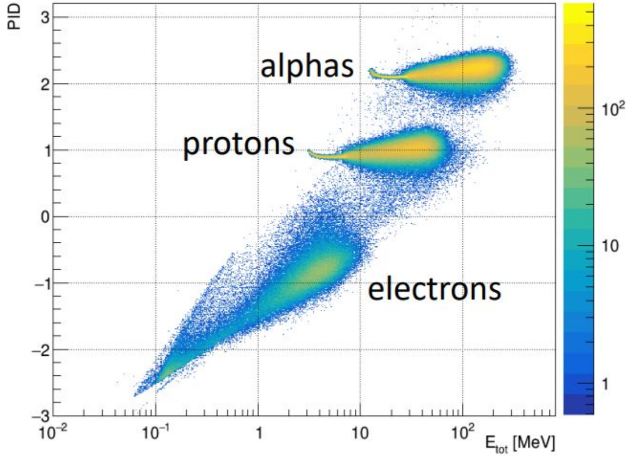
ZIRÈ: LOW ENERGY MODULE

Contained Event: **Selected**

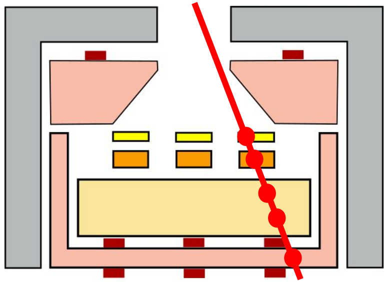




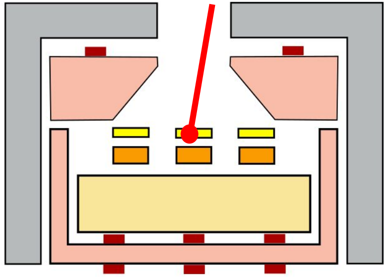




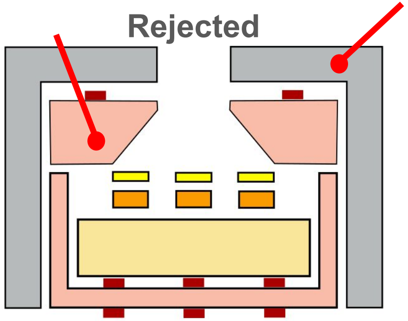
Through-going:
MIP - Calibrations



Low-energy:
Single silicon spectra

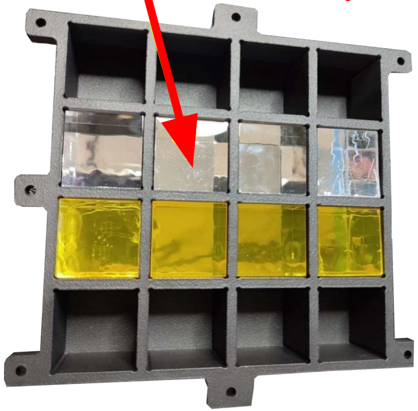


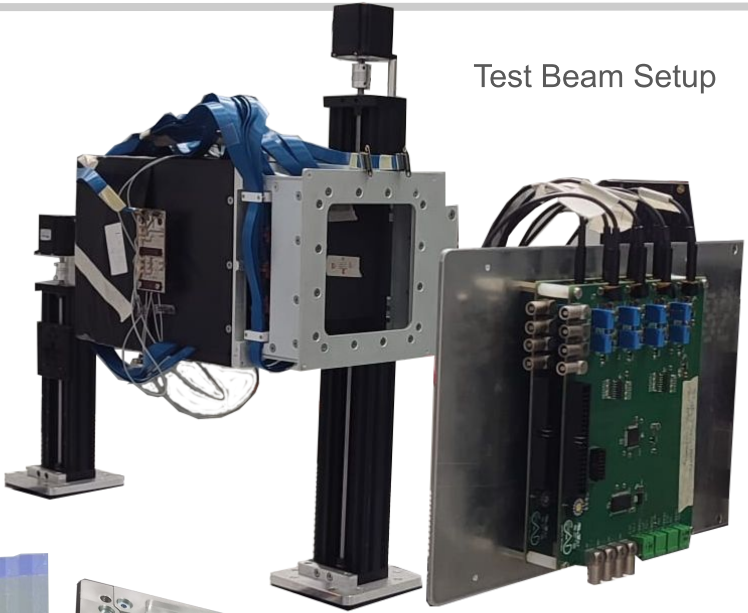
Shielded/Vetoed:
Rejected



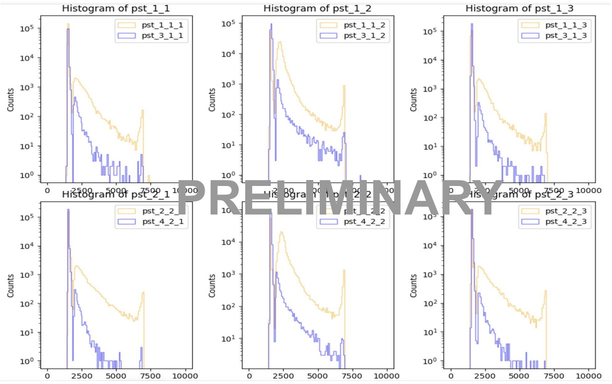
ZIRETTINO (TEST AND CALIBRATIONS)

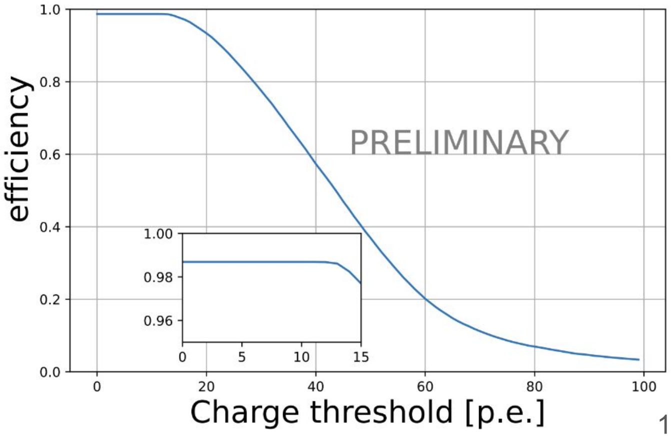
4 LYSO and 4 GAGG crystals



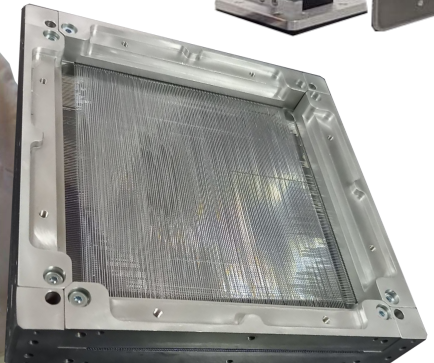


Test Beam Setup





8 layers of PST Bars

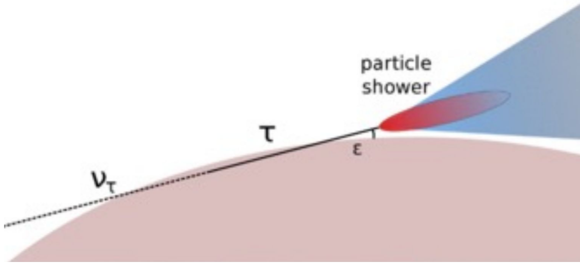


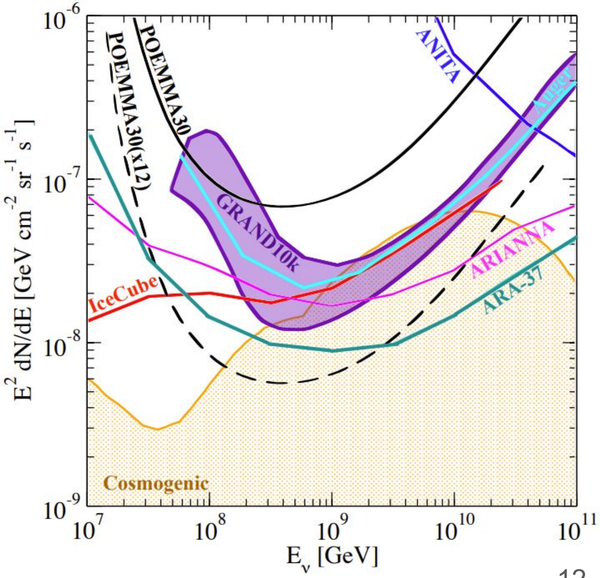
Single FTK layer

TERZINA: **Astrophysical neutrinos** and **CR**

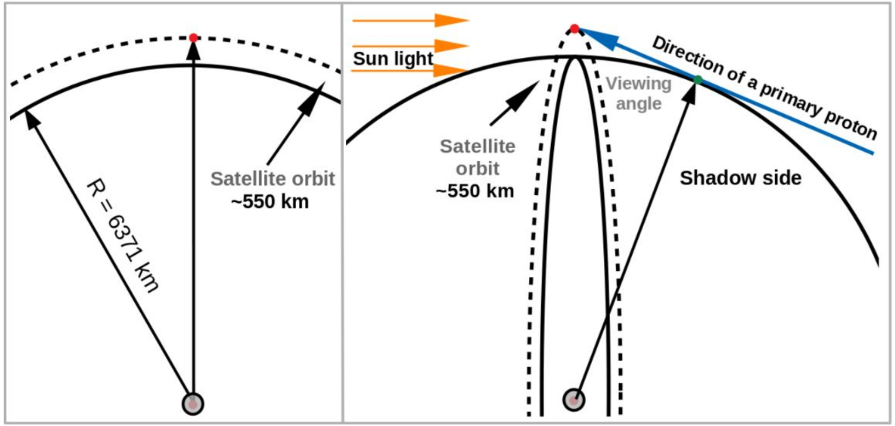
The observation of **astrophysical neutrinos** at energies > **few PeV** can be achieved only by detecting EAS produced by Earth skimming events. The Cherenkov emission of these cascades provides a **unique signal for space based (LEO) instruments**.

Similar signals are produced by high energy **CR (E>1 PeV)** impinging the atmosphere from **above the Earth's limb**. Thus, also CR with E>1 PeV can be efficiently observed through EAS's Cherenkov emission from space.

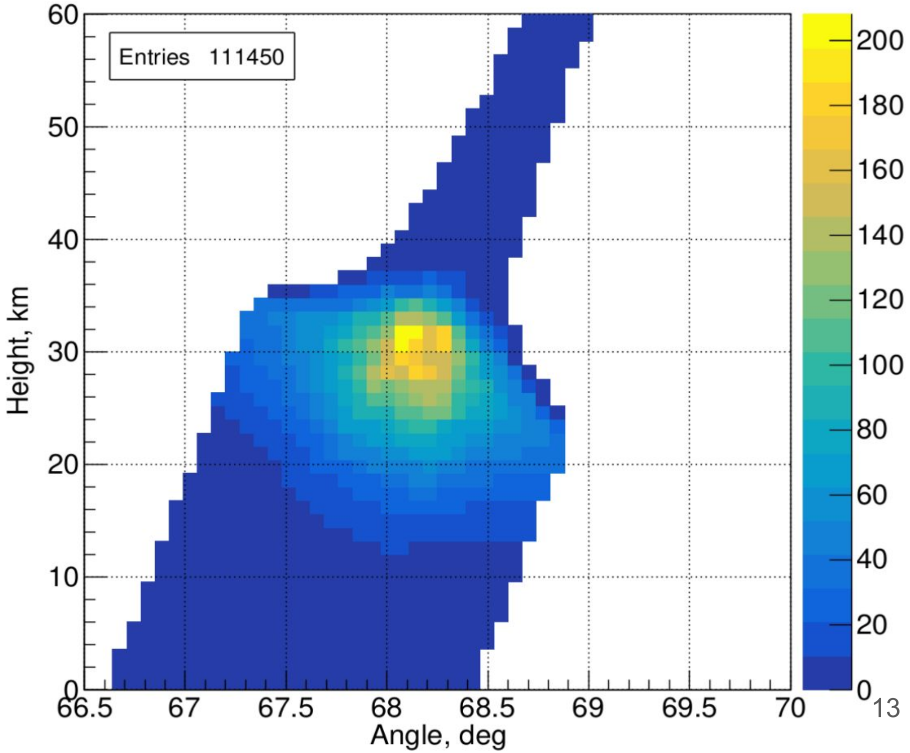




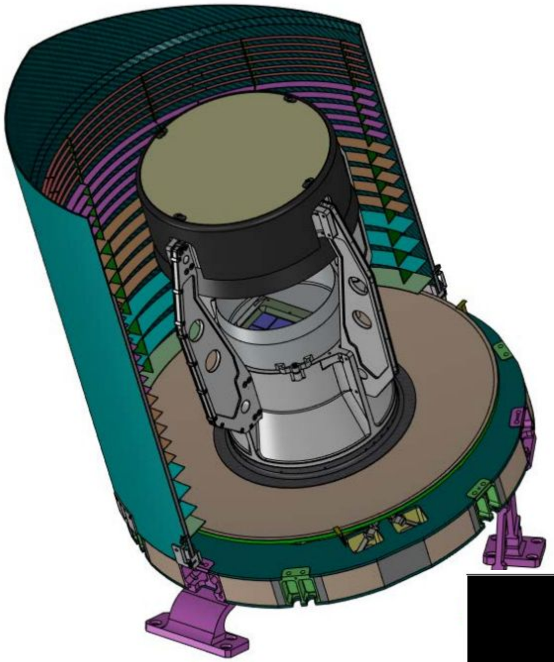
TERZINA: **CHERENKOV SIGNAL**

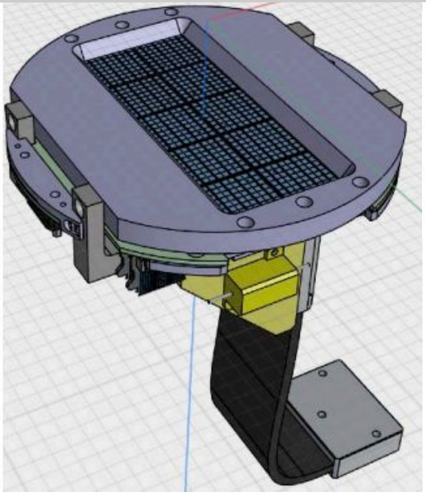


Most contributing atmosphere layers @ 550 km: between 20 - 40 km altitude



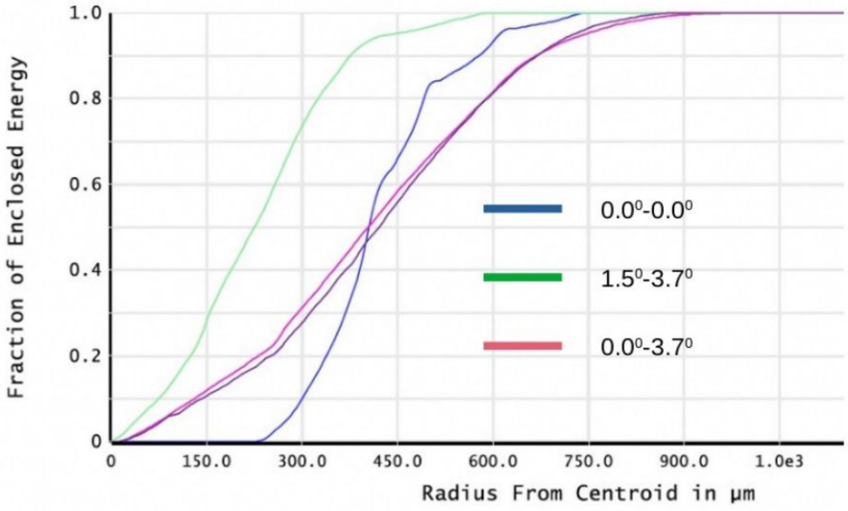
TERZINA: **LAYOUT**

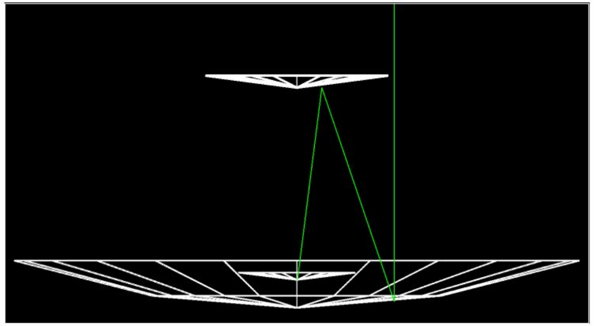




- ✓ Equivalent focal length 925 mm
- ✓ Field of View (FoV) : 7.2º
- ✓ Point spread function (PSF) : <1.0 mm
- ✓ Effective area of the telescope : 0.1 m²
- ✓ M1 paraboloid, M2 hyperbole

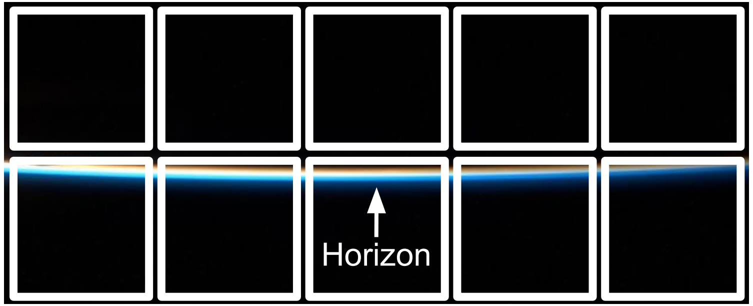
Point spread function for different inclination angles





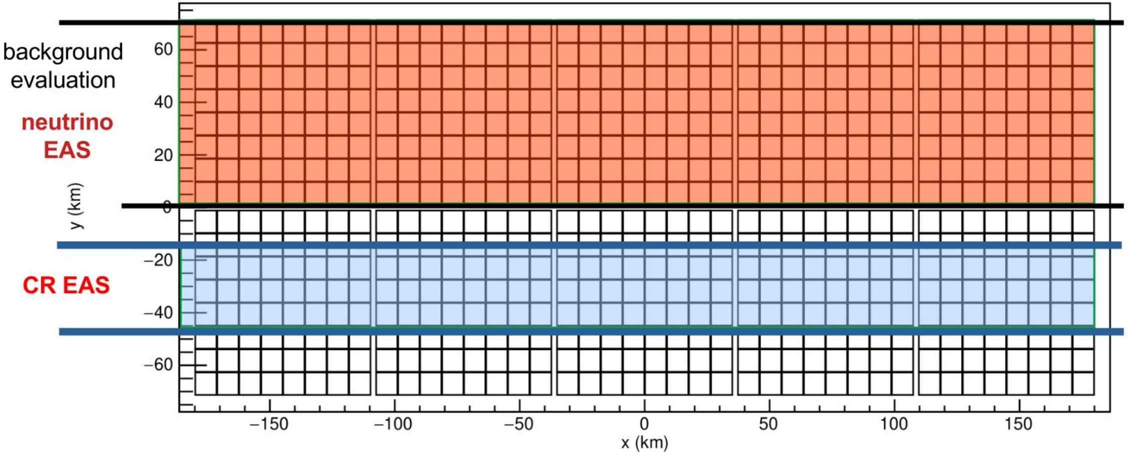
A and B are the primary and secondary mirrors composing the Terzina optical system (Cassegrain).

TERZINA: **FOCAL PLANE**



Upside-down image in the telescope

Camera plane with projection on the Earth (total area **360 x 140 km^2**)

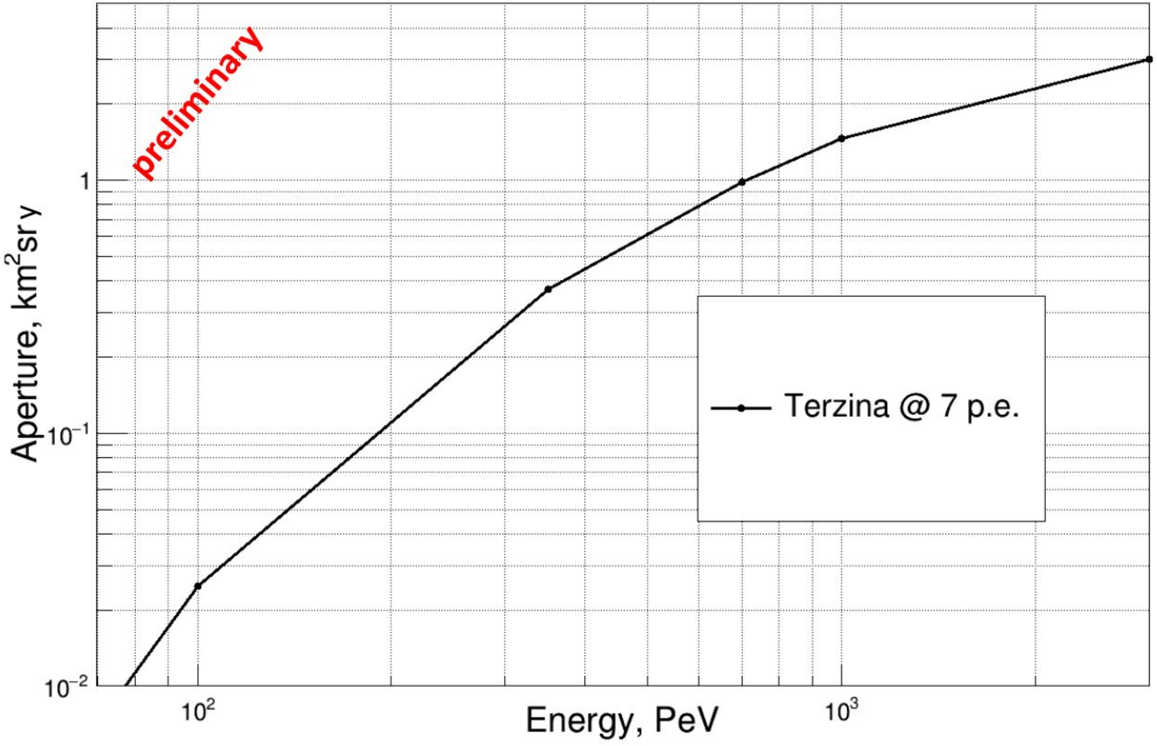


SiPM arrays: 8 x 8 pixels
5 x 2 arrays (640 pixels)
Pixel: 3 x 3 mm2
Pixel FoV: ~0.18°
Array dimension: 25.3 x 25.3 mm^2

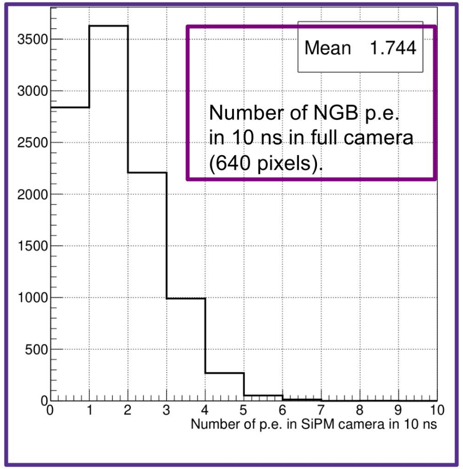
Array Effective Area: 24 x 24 mm^2

See Poster from: S. Davarpanah

TERZINA: **APERTURE**



Night Glow Background



More than 20 CR events per year with E > 100 PeV expected

CONCLUSIONS

Science Goals:

- **Measure electrons, protons and nuclei up to hundreds MeV;**
- Study particle flux correlation with seismic activity and space weather phenomena;
- Monitor very low energy (0.5-5 MeV) electron flux;
- **Photon detection from 100 keV up to 30 MeV; (Crystal eye pathfinder)**
- Cross correlations among low-energy-electrons, protons-alpha, photons in coincidence with (high-intensity) GRBs;
- First observation of high energy cosmic ray showers from space through Cherenkov signal.
- Certify HE neutrino detection feasibility through Cherenkov emission in the Earth skimming geometry.

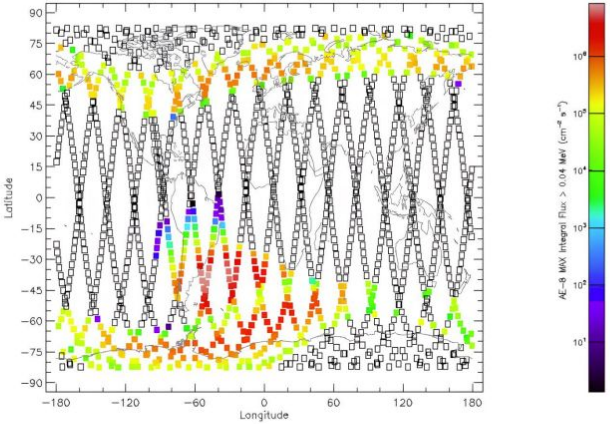
New Technologies:

- Use of SiPM in space;
- Use a scintillating fiber tracker (~300μm) readout by SiPM arrays;
- Optimize a LYSO/GAGG crystal array to act as a (astrophysical) γ detector (0.1-30 MeV);
- Design/use low power electronics (try to go down to ~few mW/ch);
- Test / Optimize onboard (Standard and/or Machine Learning) techniques for data reduction;
- Test new approaches for the satellite platform.

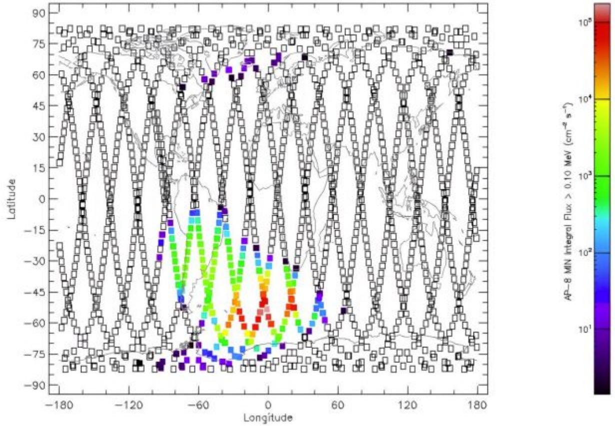
Thank you

BACK UP

Electrons



Protons



- Solar model: CREME96 peak flux