Adriano Di Giovanni on behalf of the NUSES collaboration

The NUSES* space mission

__Ne____U__**trino and **S**eismic **E**lectromagnetic **S**ignals*

A joint Gran Sasso Science Institute -Thales Alenia Space Italy (TAS-I) mission conceived as a pathfinder for new observation methods and technologies in the study of high and low energy radiations enabling new sensors, tools and detection techniques.

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EPS-HEP 2023, 20-25/08/2023- Universität Hamburg - Hamburg - Germany

NUSES in a nutshell

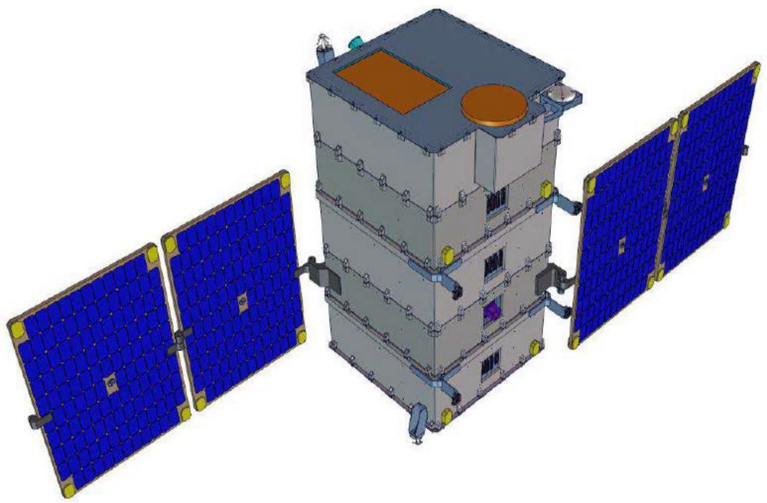
Mission Players

- NUSES is a joint GSSI-Thales Alenia Space Italy (TAS-I) project approved by the Italian government as a flagship initiative to relaunch the economy of the L'Aquila area.
- >60 scientists from Italian Universities and INFN sites, international research and academic institutions and industrial partners. Large expertise (and synergies) from space missions/R&D programs: AMS, DAMPE, ASTROGAM, FERMI, GAPS, HERD, LIMADOU, PAMELA, POEMMA, SPB2 , …
- The NUSES mission has been approved by ASI and the required funding for the launch and ground segment operations have been secured.

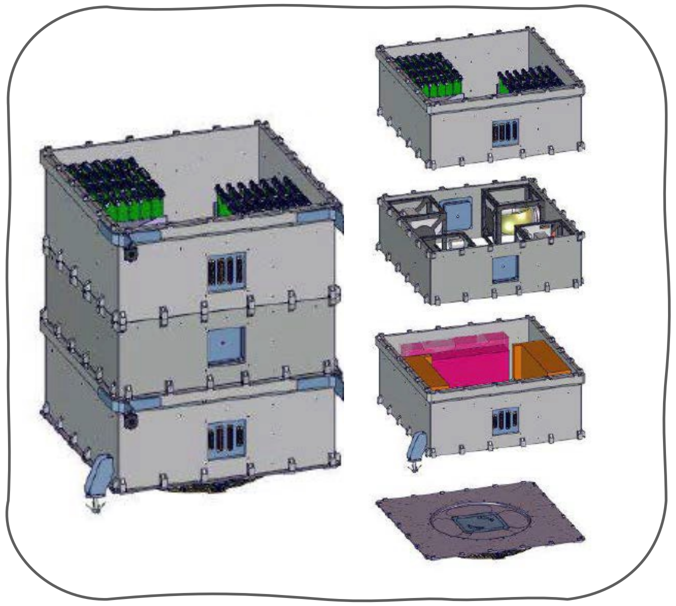
Mission Goals

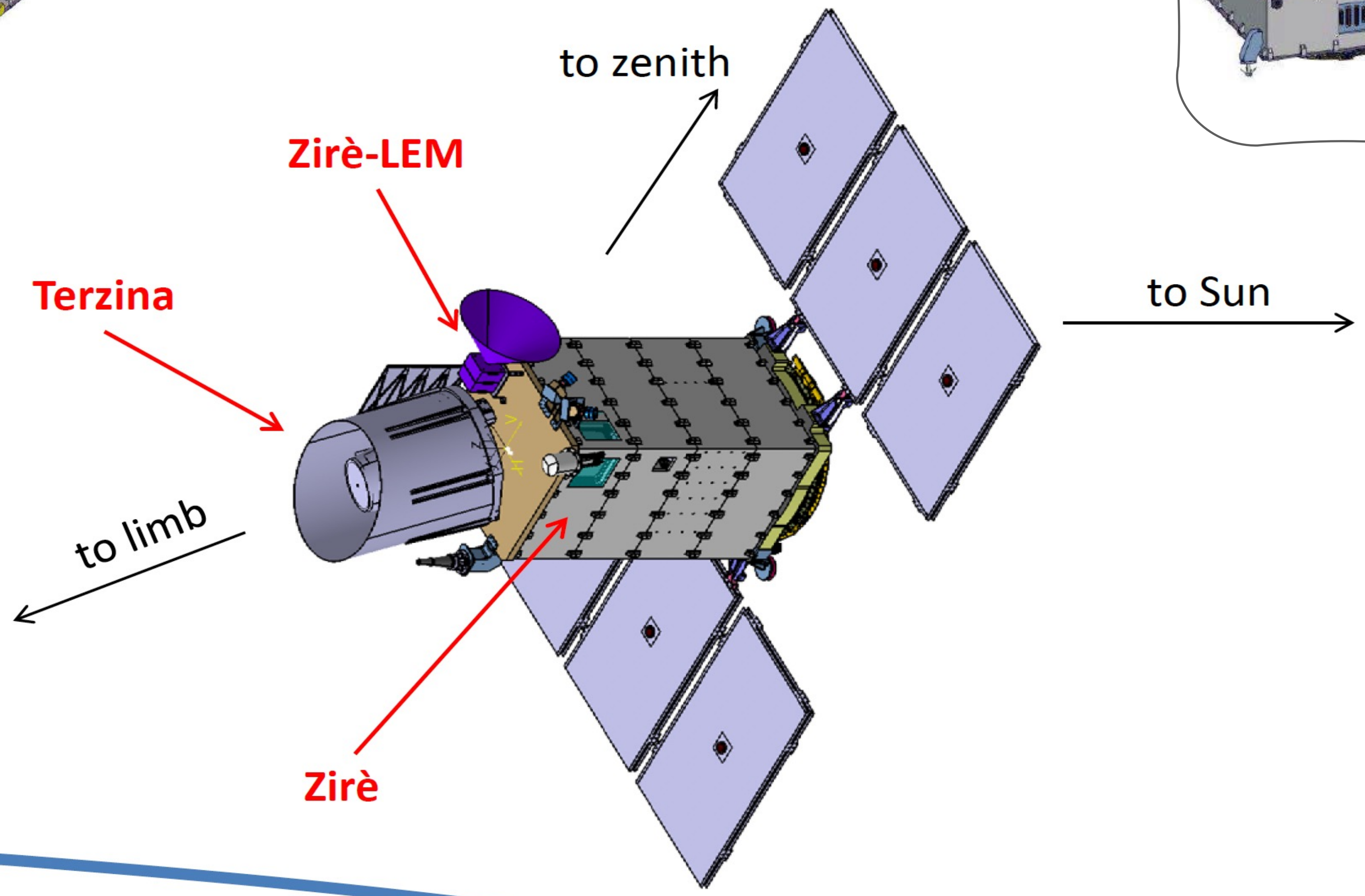
- To measure UHE cosmic rays and enable neutrino astronomy through **space-based atmospheric Cerenkov light detection**.
- To **monitor the fluxes of low energy (<250 MeV) e, p, CR** to study Van Allen belts, space weather and the magnetosphere-ionosphere-litosphere couplings (**MILC**) in case of seismic / volcanic activities.
- To detect 0.1-10 MeV photons for the study of **transient** (GRB, e-m follow up of GW events, SN emission lines,…) and **steady gamma sources**.
- To develop new observational techniques, to test sensors (e.g. Silicon PhotoMultiplier, SiPM) and related electronics/DAQ for space missions.

The NUSES scientific instruments: Terzina & Ziré



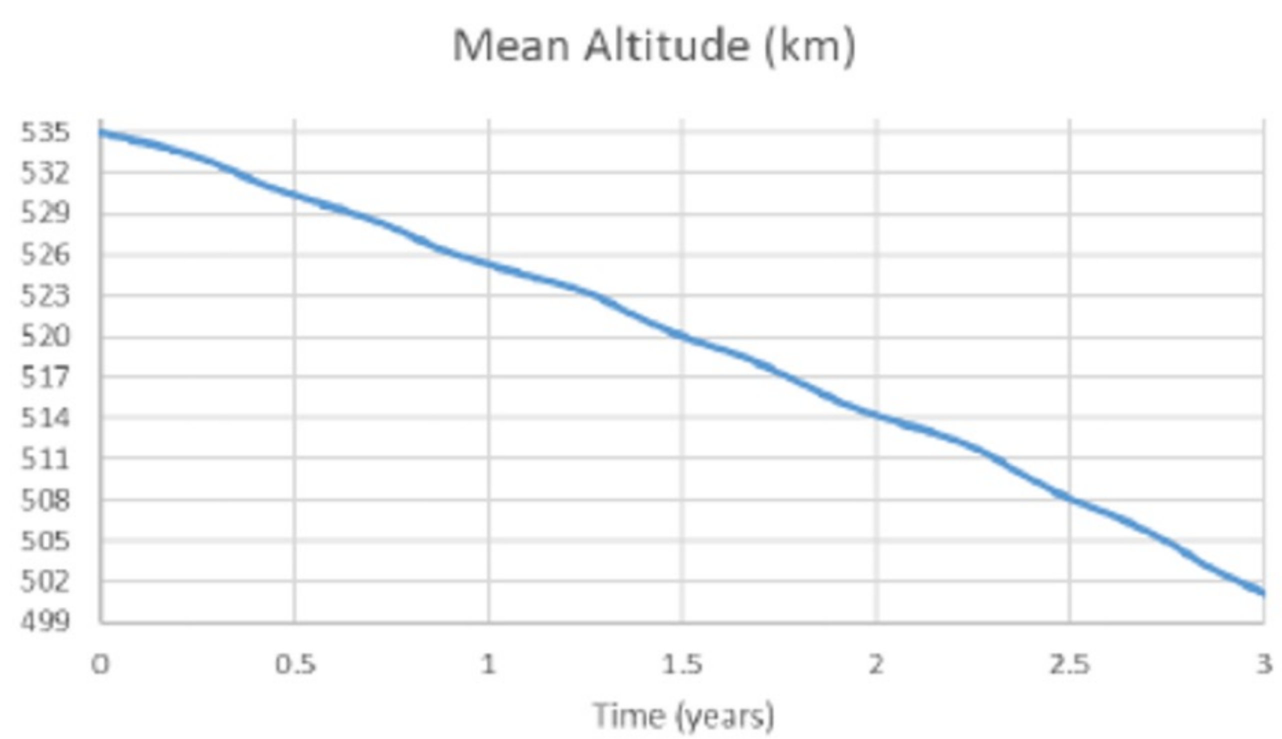
NIMBUS (**N**ew **I**talian **M**icro **BUS**) is based on a new satellite bus concept which foresees a modular approach relying on standard trays.





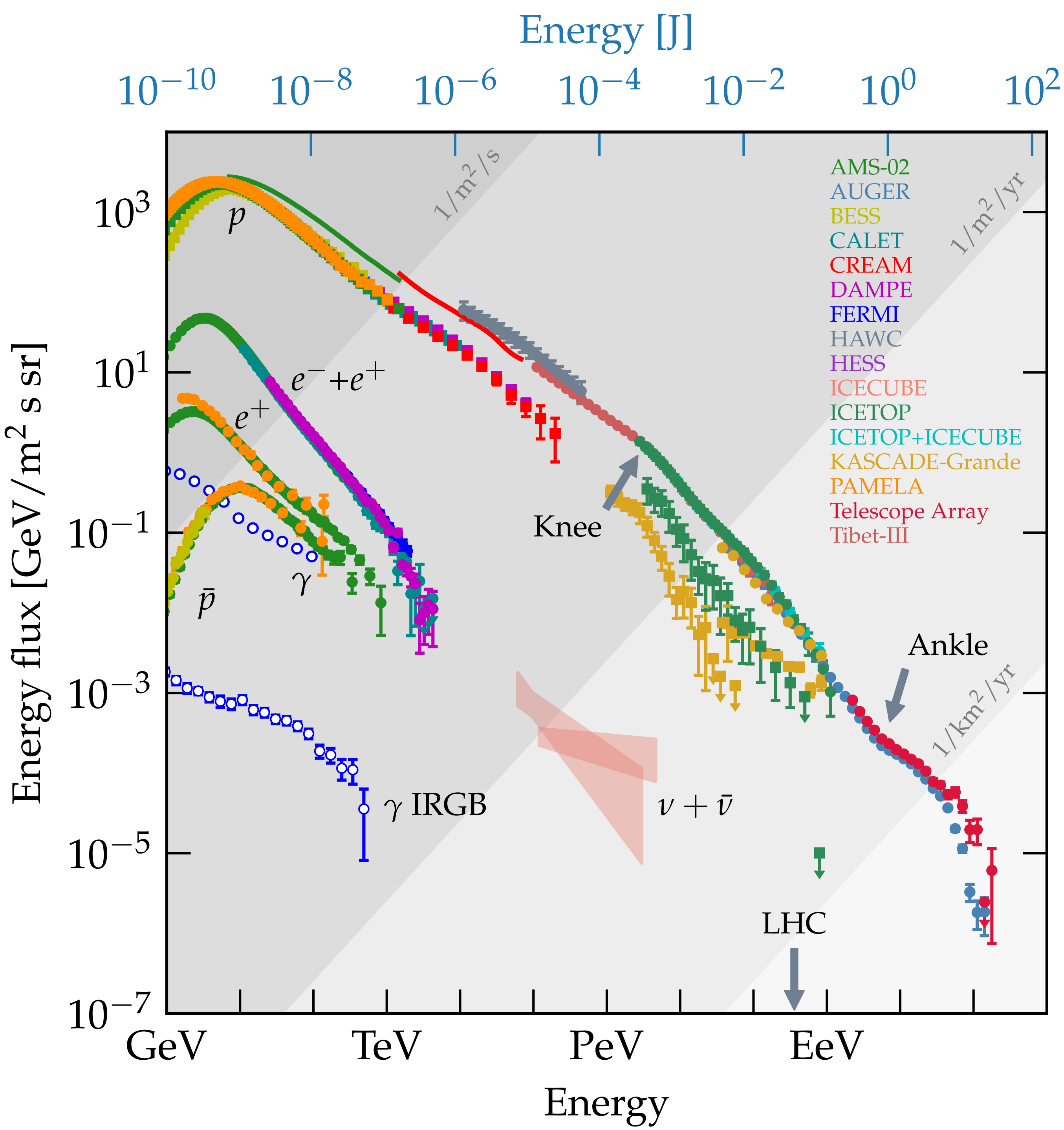
The NUSES orbit

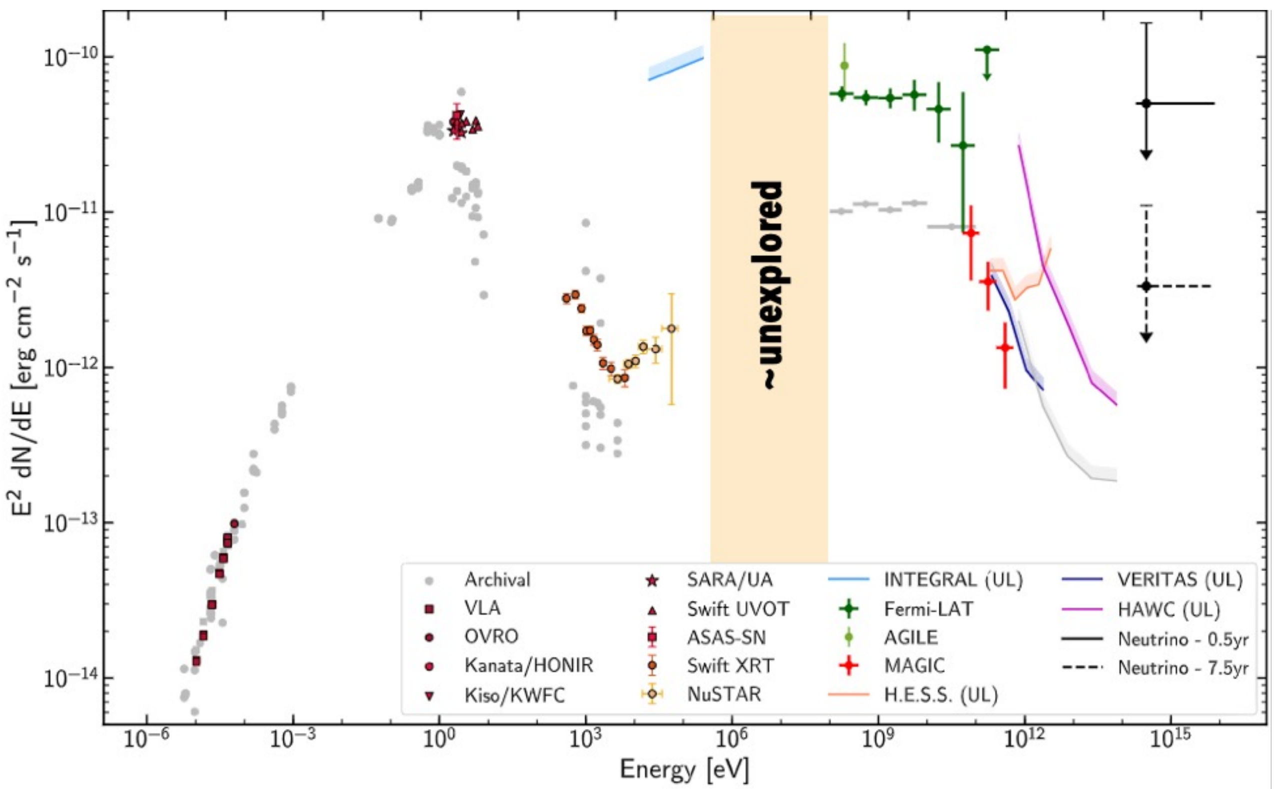
Mission Lifetime	3 y
Mean Altitude	550 km, LEO
Semi-major axis (km)	6928 km
Eccentricity	0
Inclination (deg)	97.6 deg, SunSync
LTAN	18:00:00
Pointing	< 0.1 deg

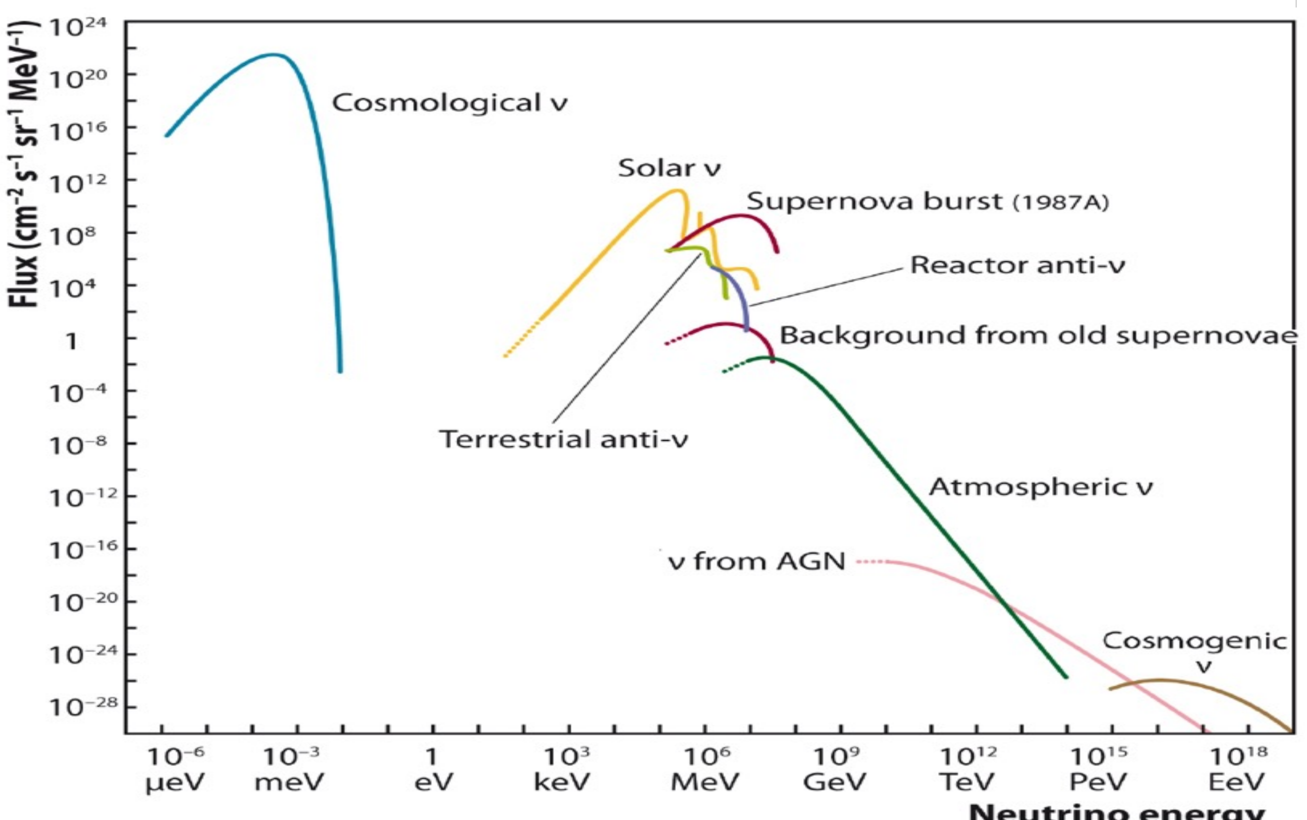


- Low Earth Orbit at high inclination, Sun-Sync orbit on the day-night border
- The orbit has been tailored around the requirement for the optimal detection of the Cherenkov light
- "Ballistic" mission (no propulsion for orbital elevation corrections)

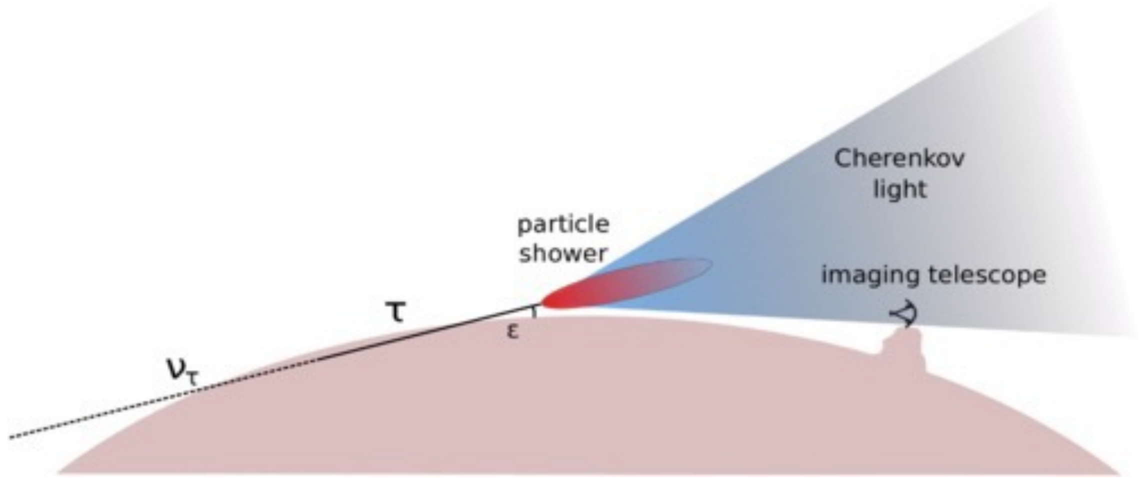
The current (particle) landscape

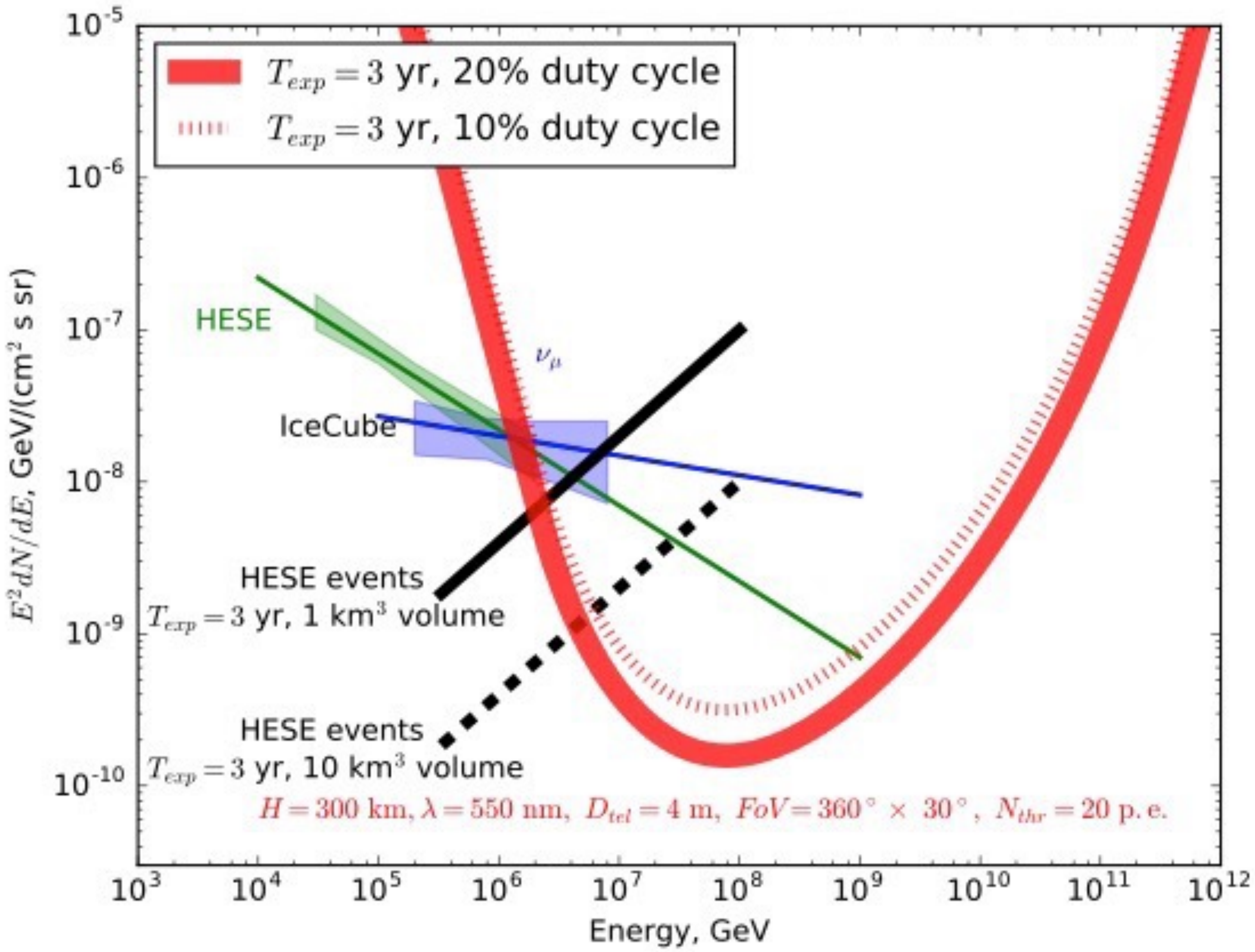


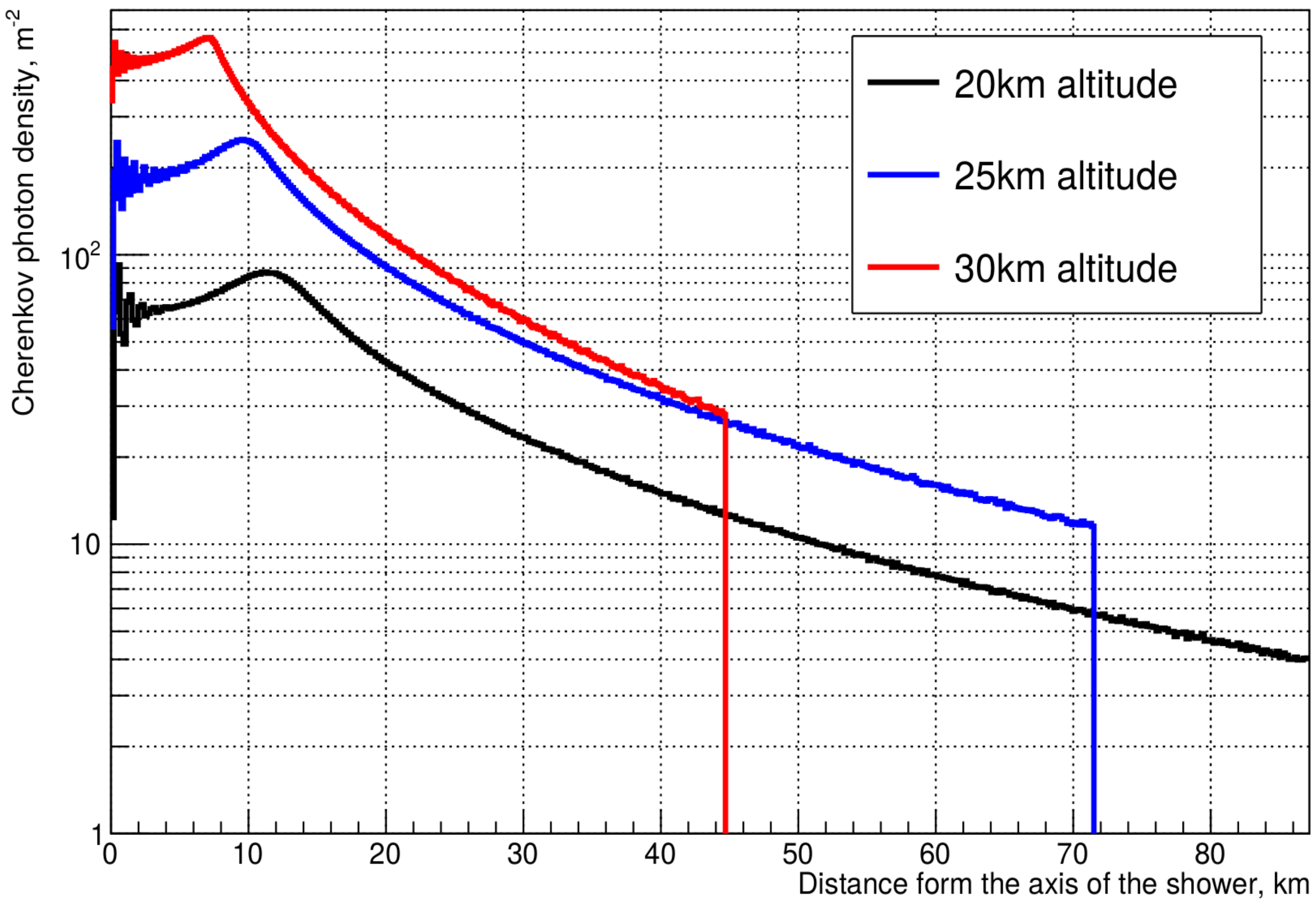




Astrophysical neutrinos and High Energy CR

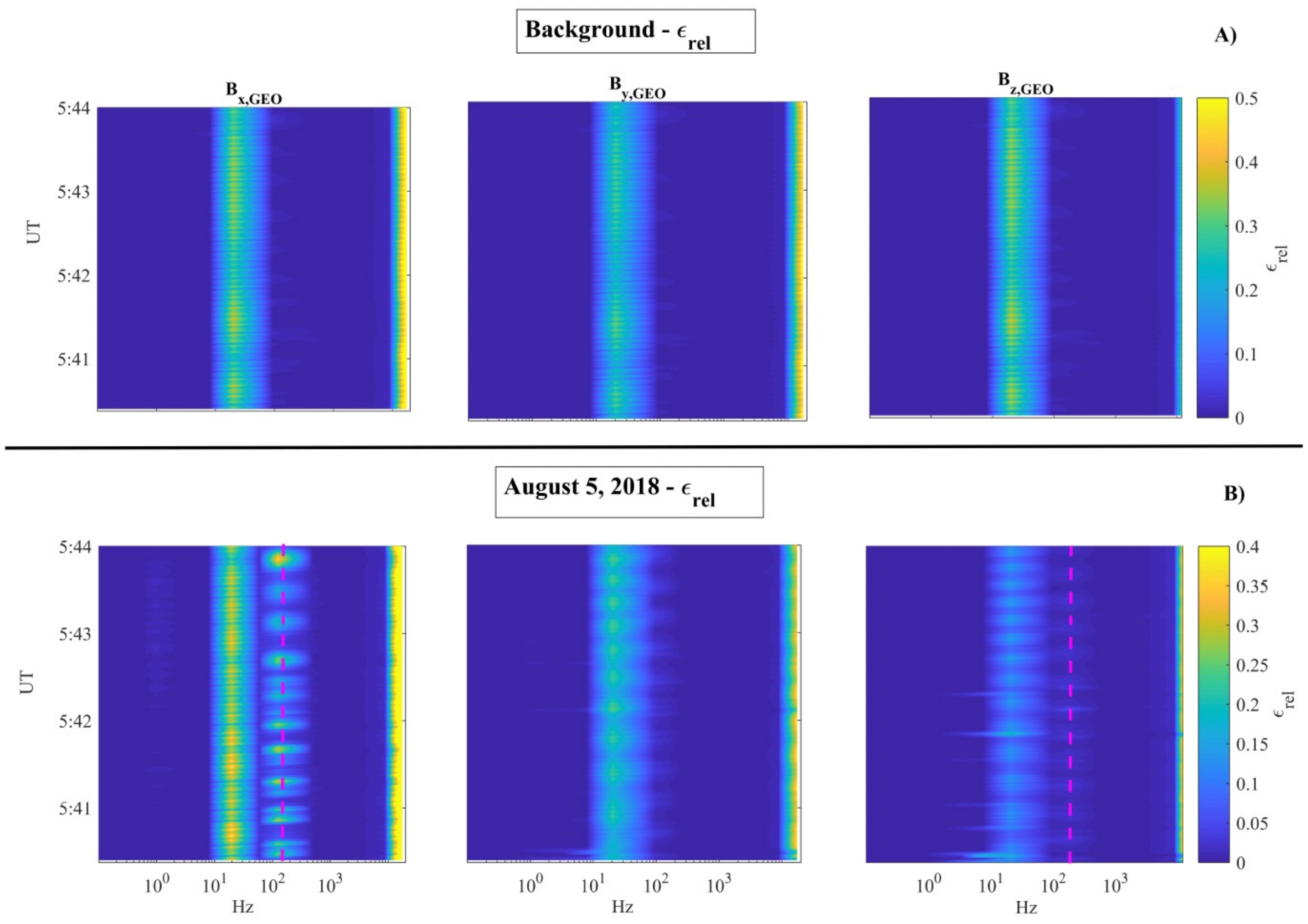


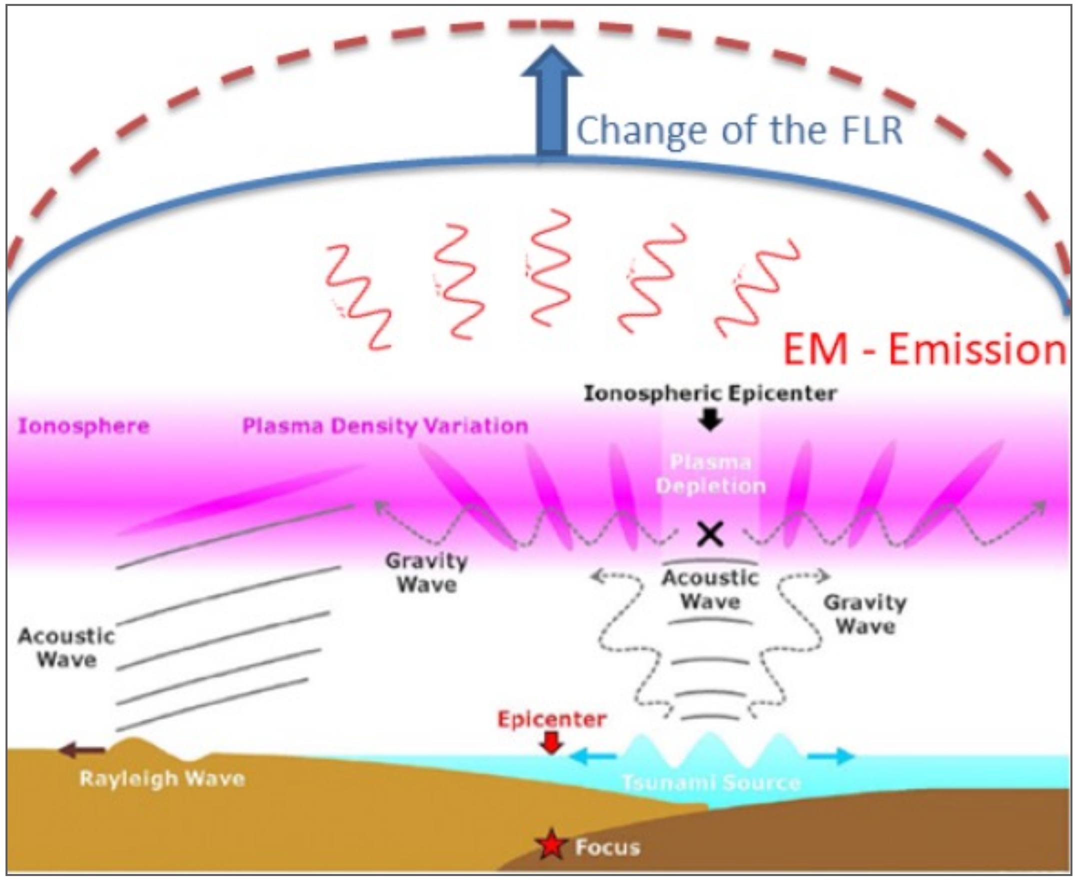




- The observation of astrophysical neutrinos at energies larger than few PeV can be achieved only from space.
- High energy CR (E>1 PeV) can be efficiently observed through EAS Cherenkov emission.

Magnetospheric Ionospheric Lithospheric Coupling (MILC)

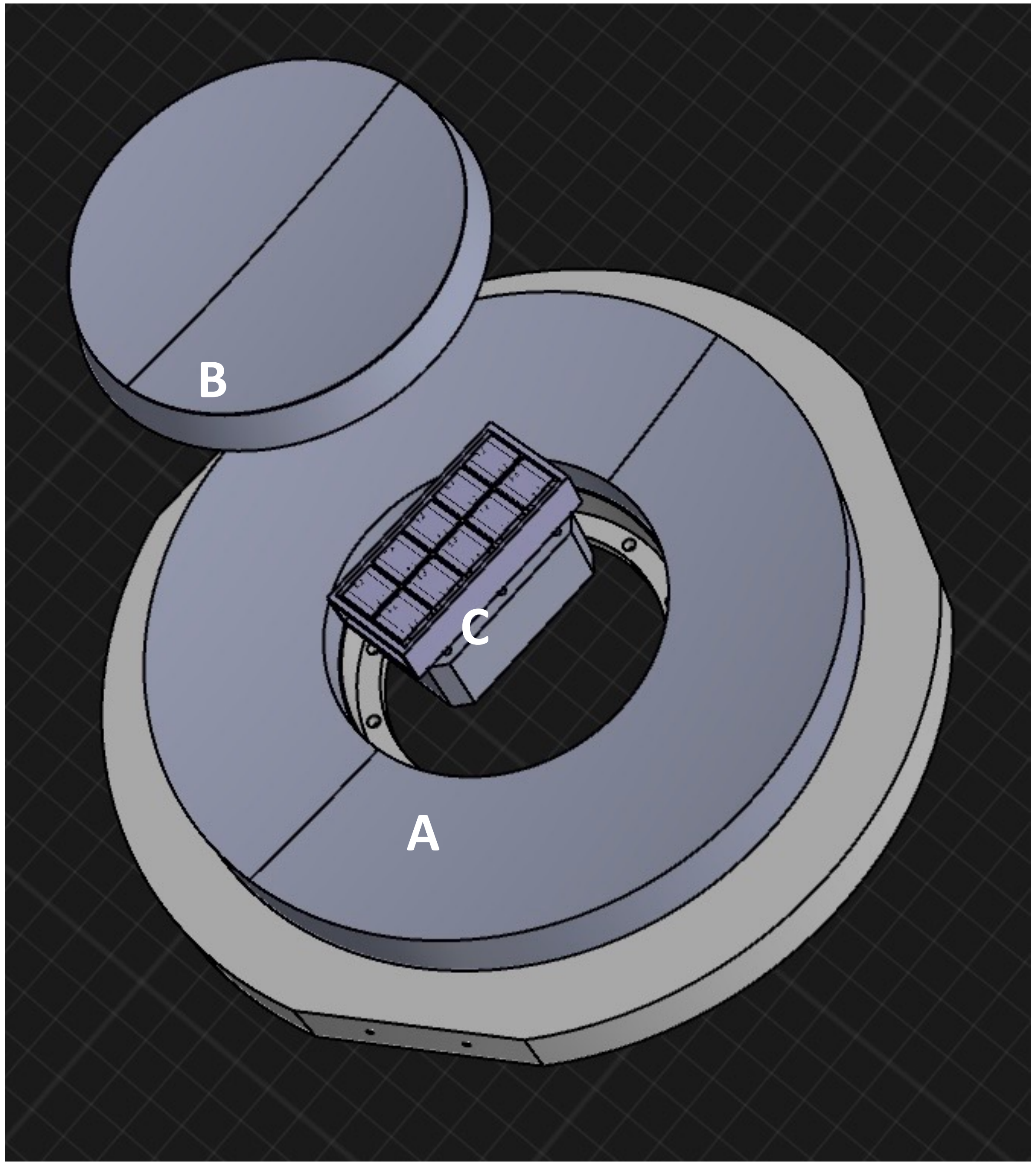




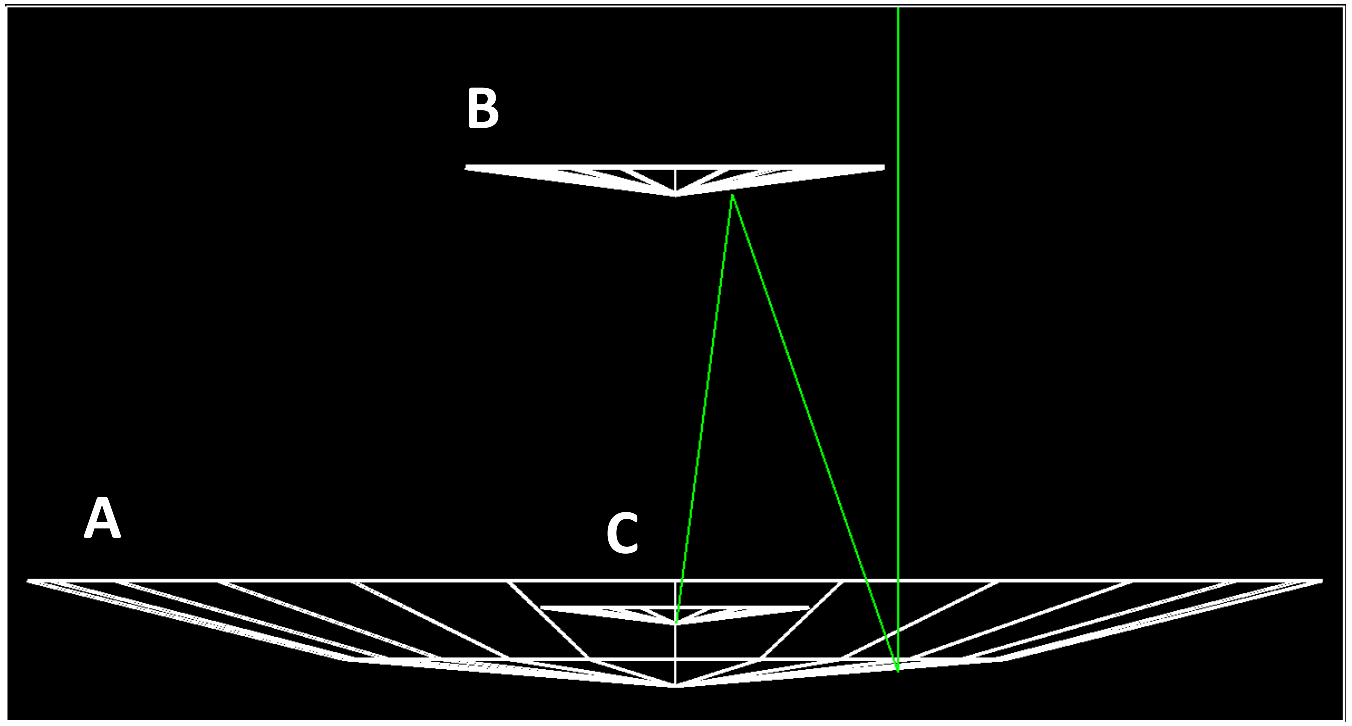
https://doi.org/10.3390/rs12203299

Study of possible time correlations between earthquakes and variations of the orbital particle background

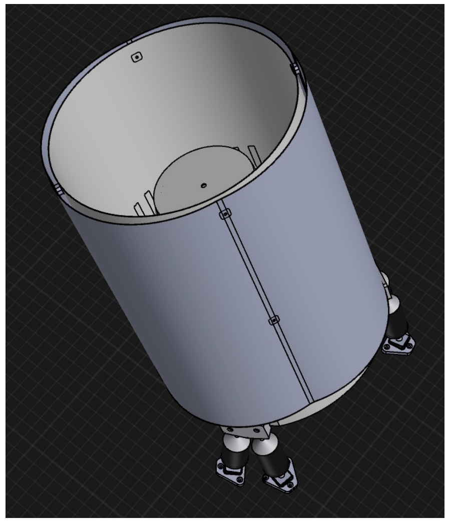
The Terzina payload



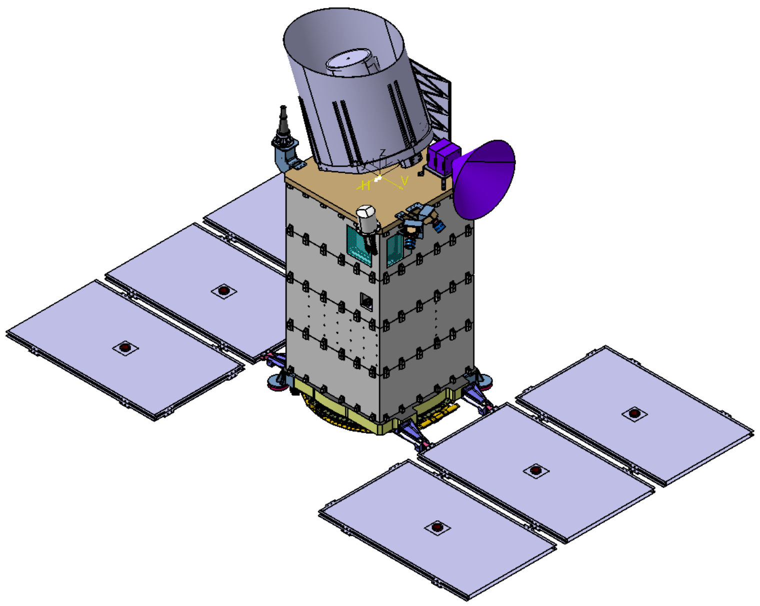
C is the SIPM based camera that composes the Focal Plane Assembly (FPA)



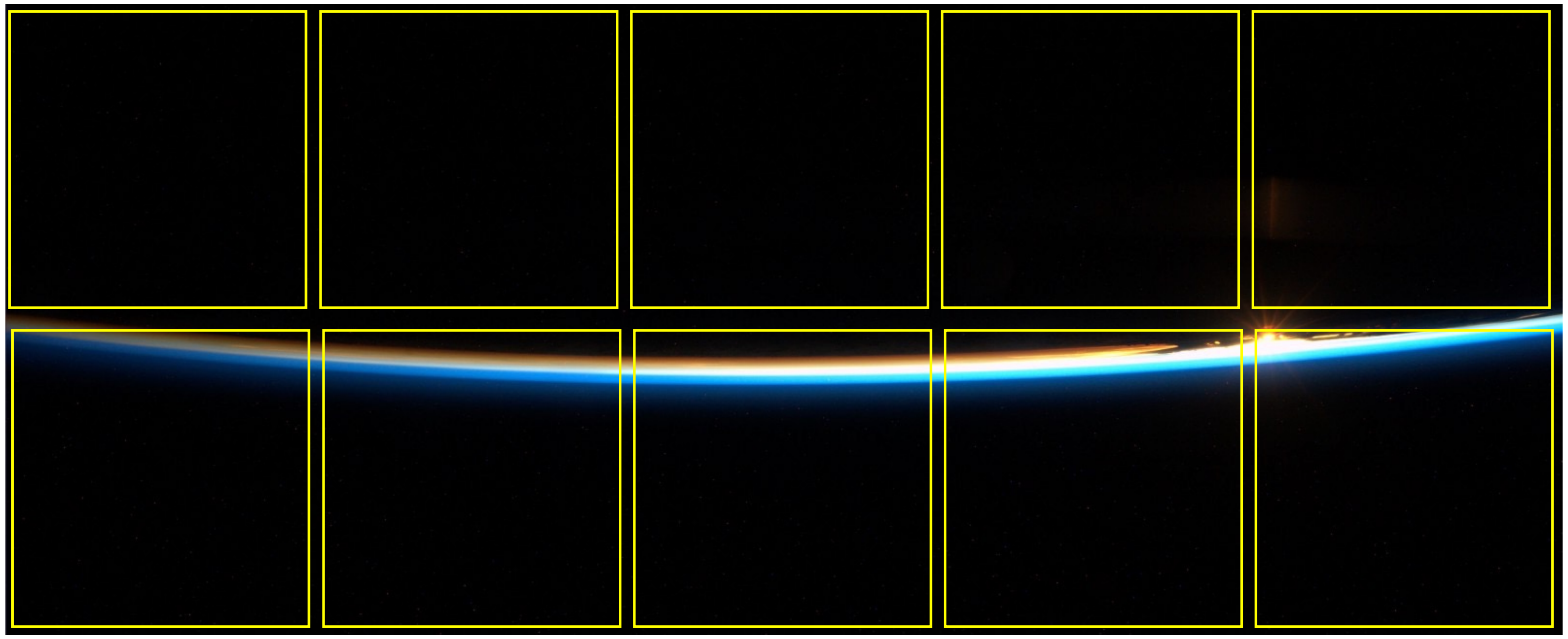
A and B are the primary and secondary mirrors composing the Terzina optical system (Cassegrain).



External Baffle



The Terzina telescope focal plane



N.10 8x8 SiPM arrays

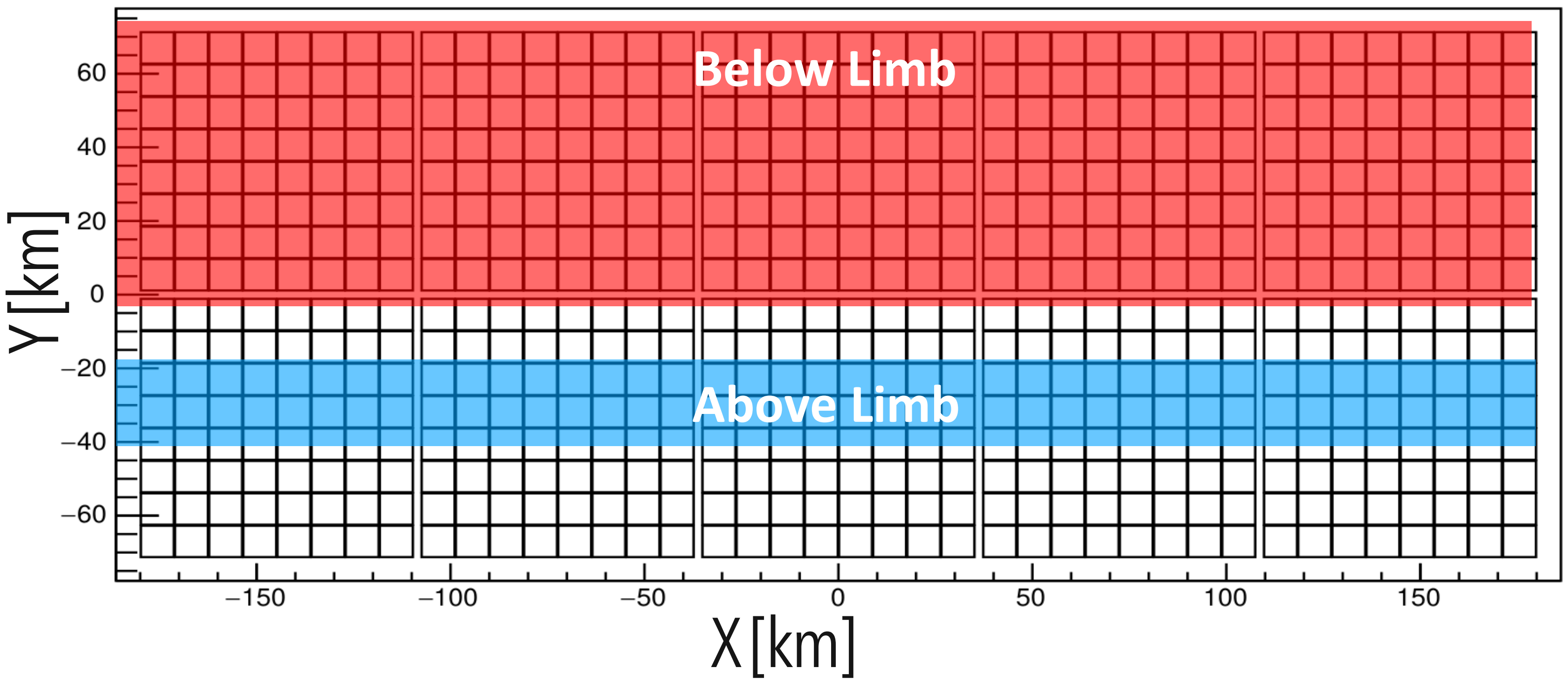
640 pixels/channels/SiPMs in total

Each is SiPM is 3 x 3 mm^2

Pixel F.O.V. 0.18^o

24 x 24 mm^2 effective area per array

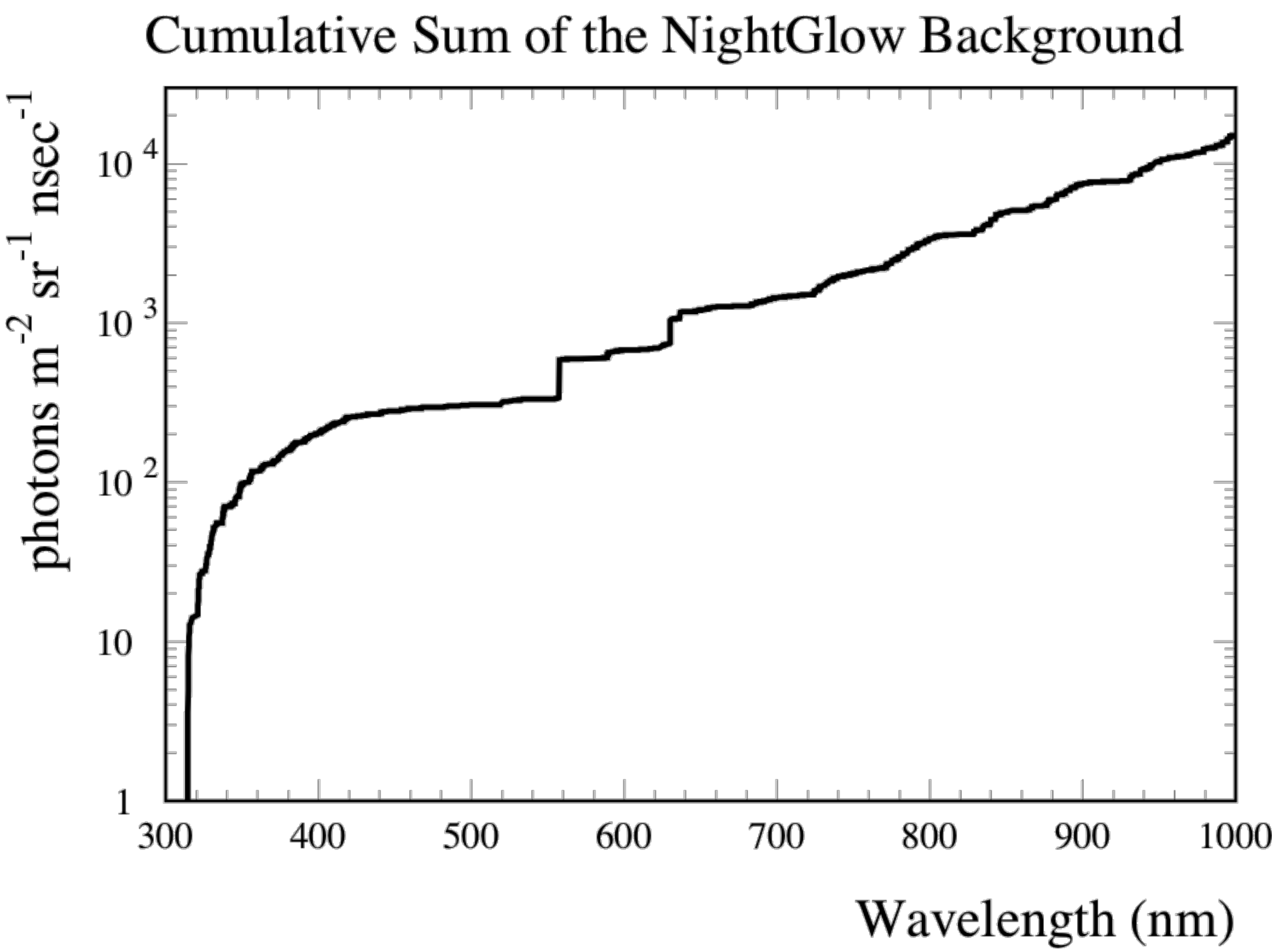
- Looking at the atmosphere limb (just above) for CR detection and (just below) for neutrino detection.

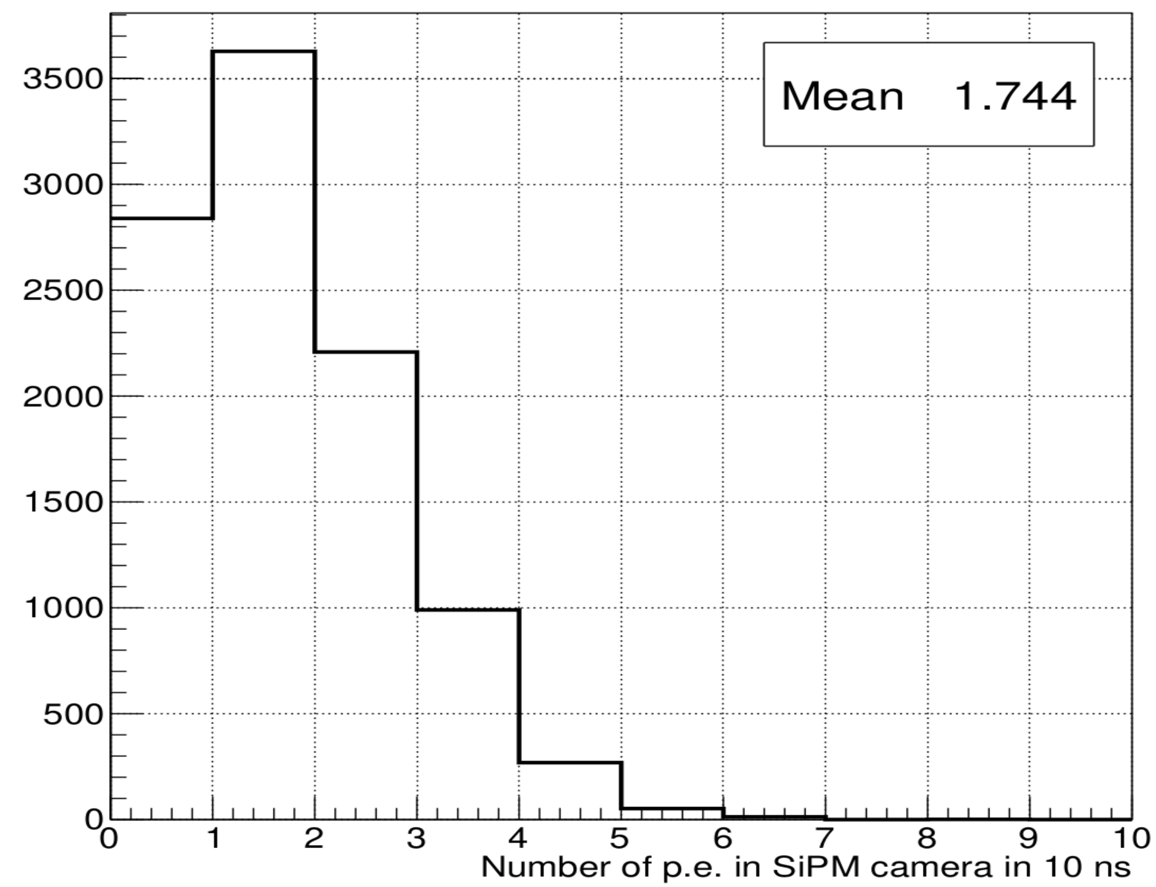


Background Evaluation
Earth Skimming Neutrino Shower

ROI: CR EAS

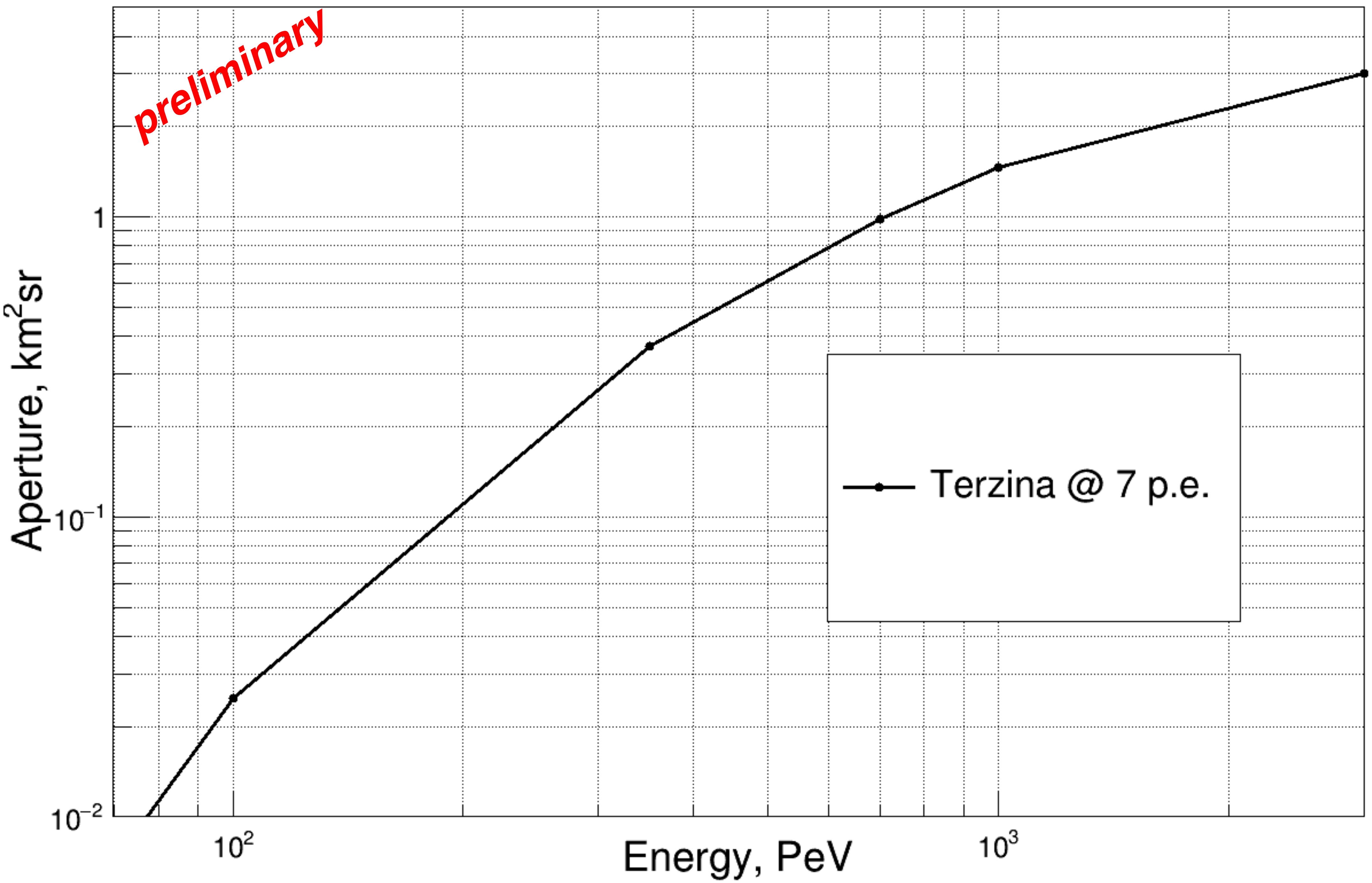
The Terzina fight against BKG





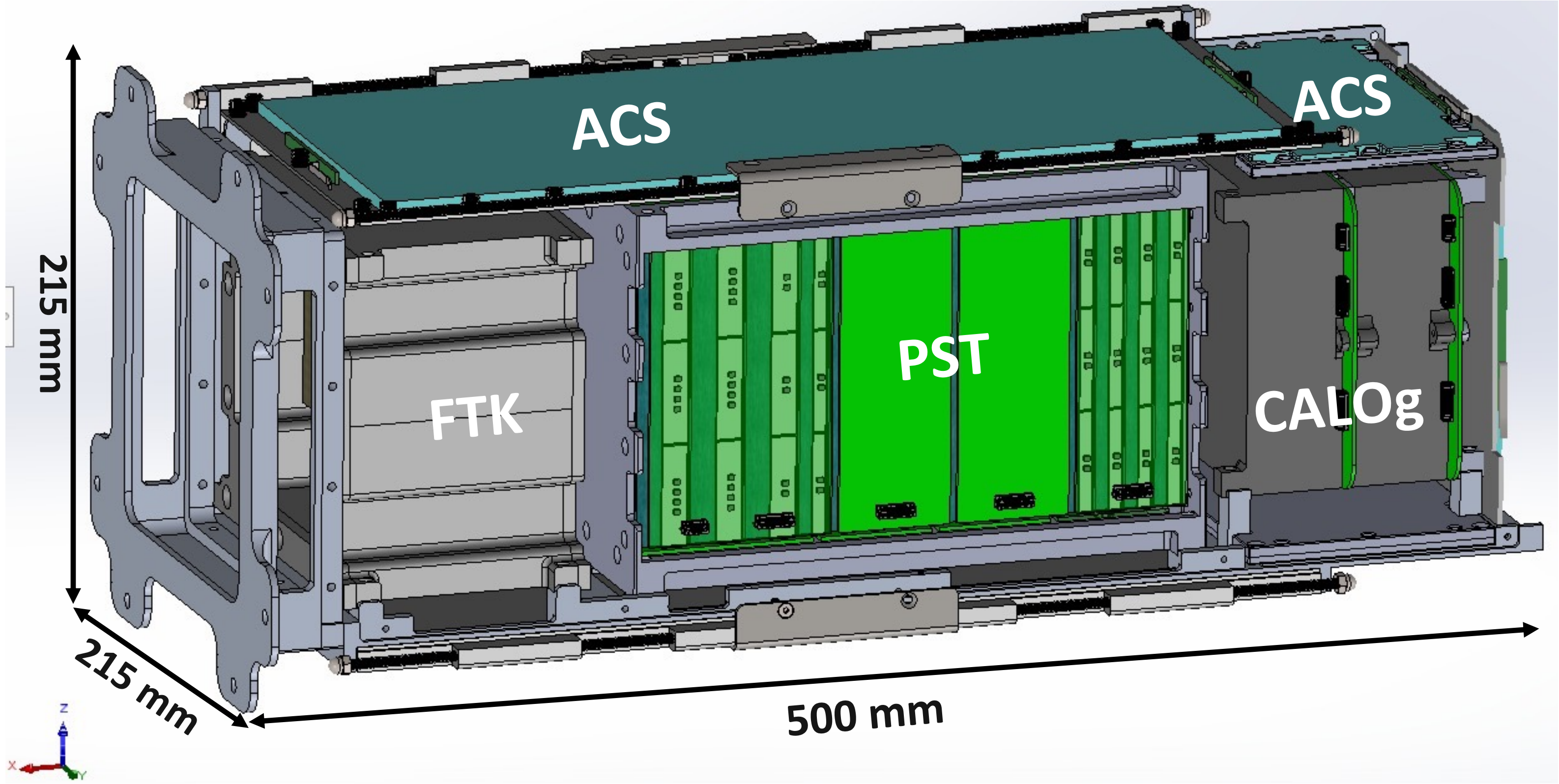
Night Glow Background: in the order of slightly less than 10 MHz per SiPM: a high detection threshold (in p.e.) is therefore required.

The Terzina aperture (HECR)



Around 100 events of HECR with energy larger than 100 PeV are expected per year of Terzina operation

The Ziré payload

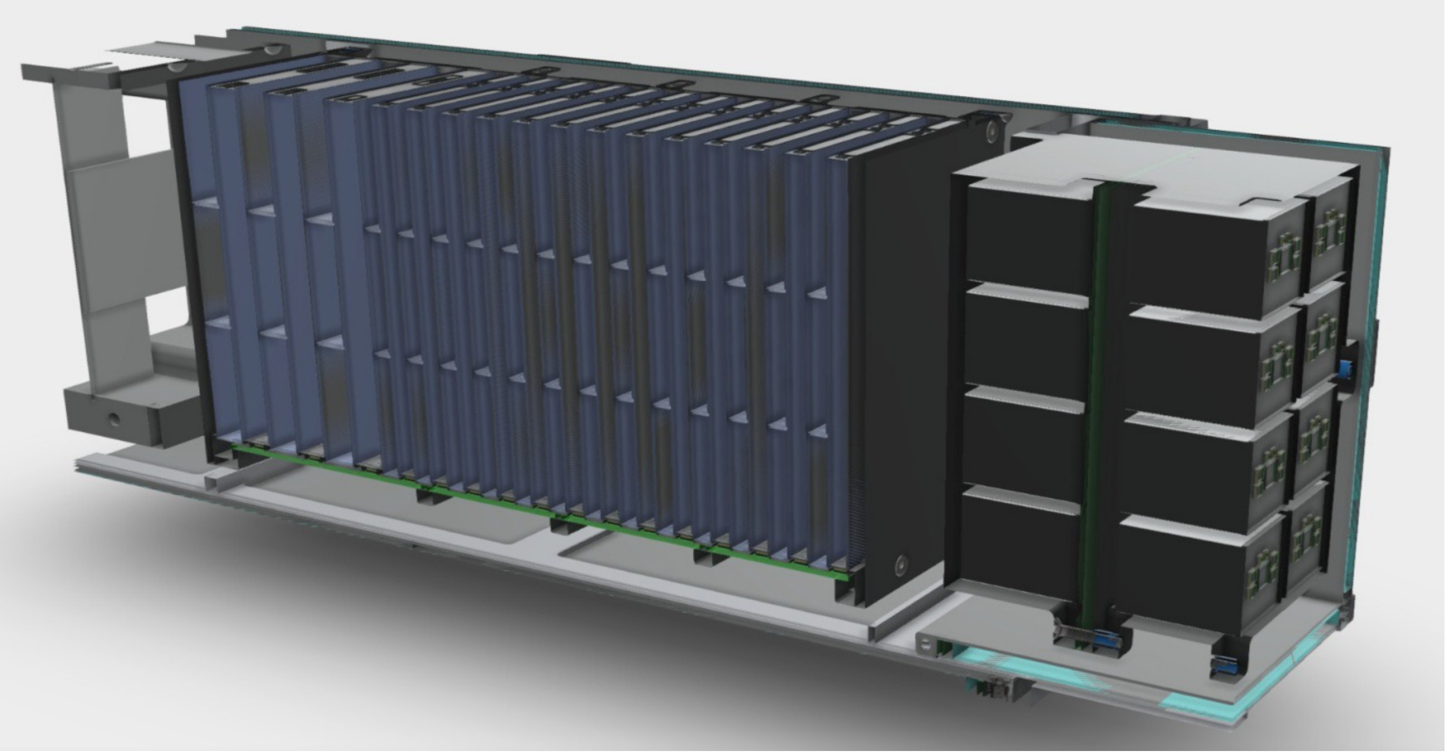


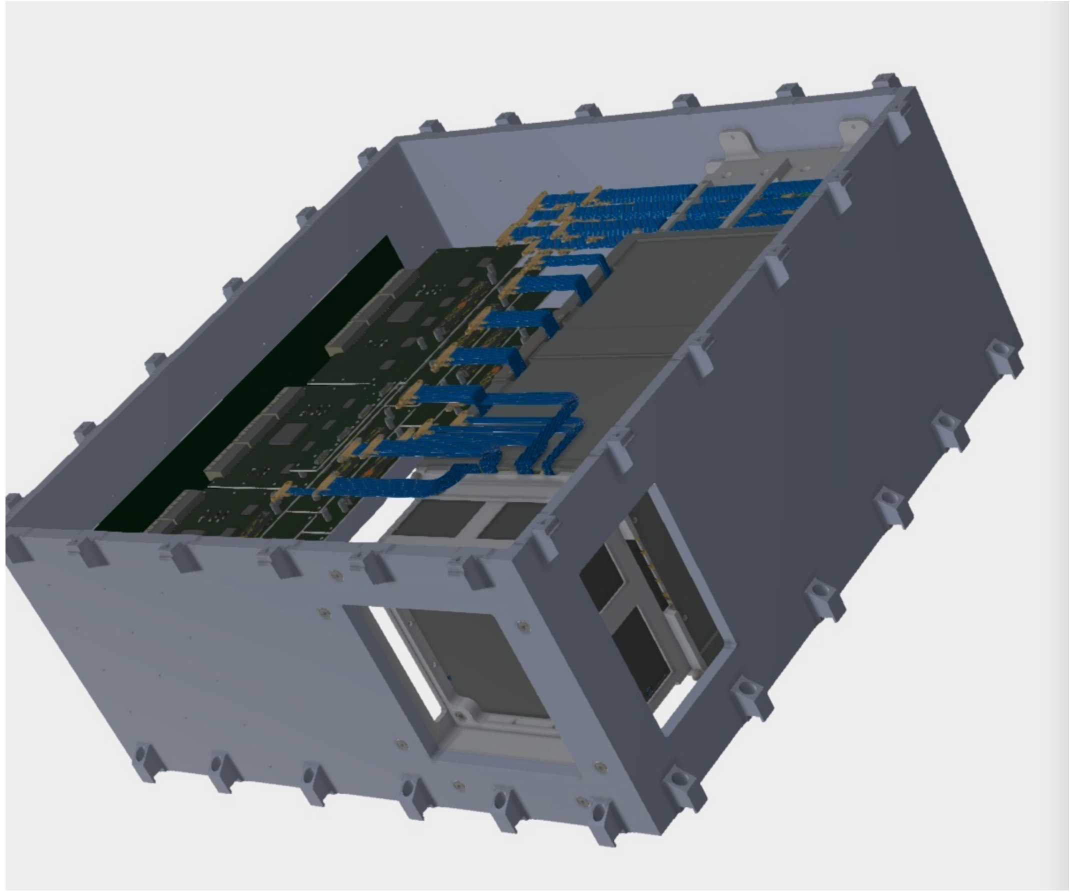
ACS (Anti-Coincidence System): a VETO for charged particle induced events made of plastic scintillator tiles and read out by SiPMs

FTK (Fiber TracKer): N.3 X-Y modules made of scintillating fibers read out by linear arrays of SiPMs

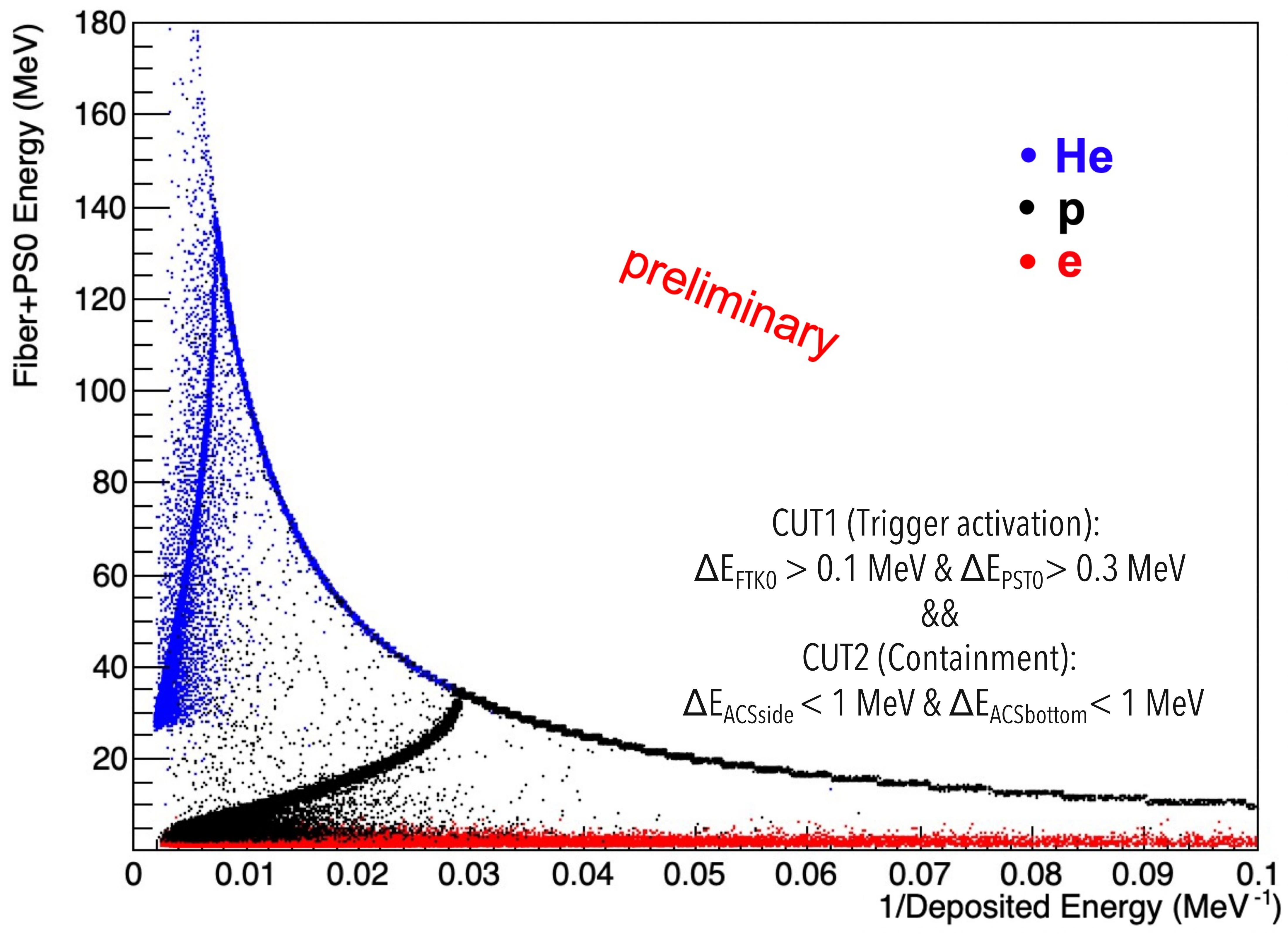
PST (Plastic Scintillator Tower): N. 16 X-Y modules made of scintillating tiles read out by two sets of SiPMs of different sensitive area

CALOg: N.2 4X4 matrices of LYSO (GAGG) crystals read out by three sets of SiPMs of different sensitive area



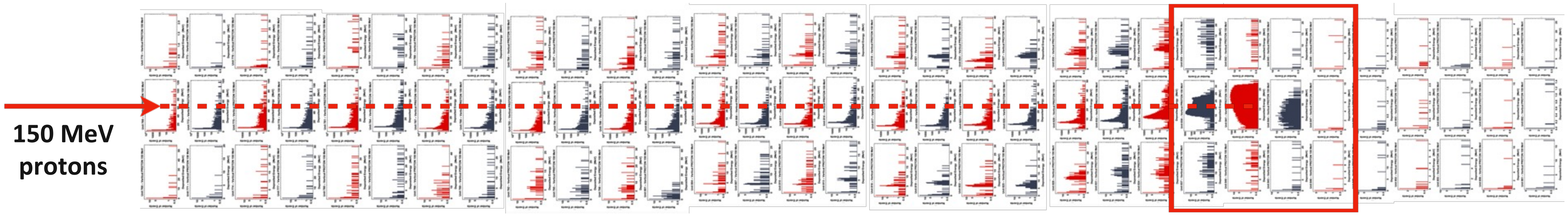


The Ziré Particle Identification (PID)

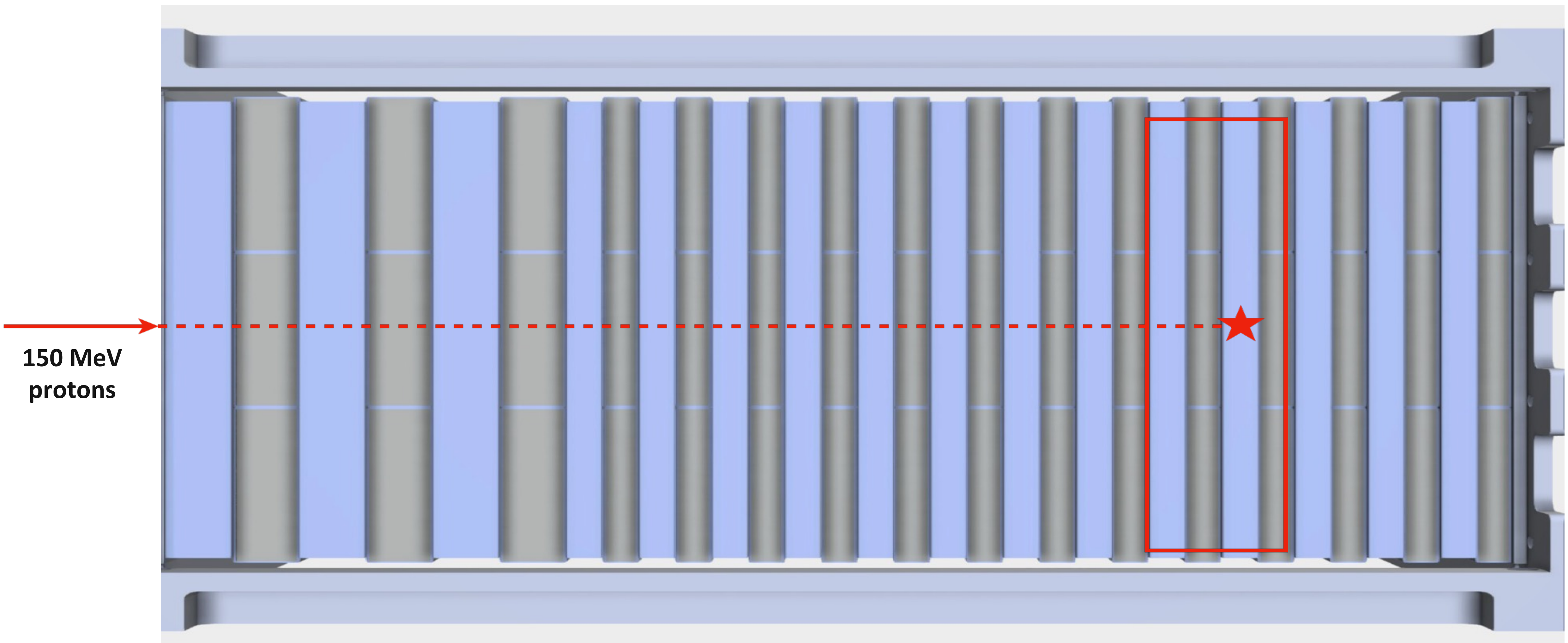


A case study (G4): 150 MeV (KE) protons

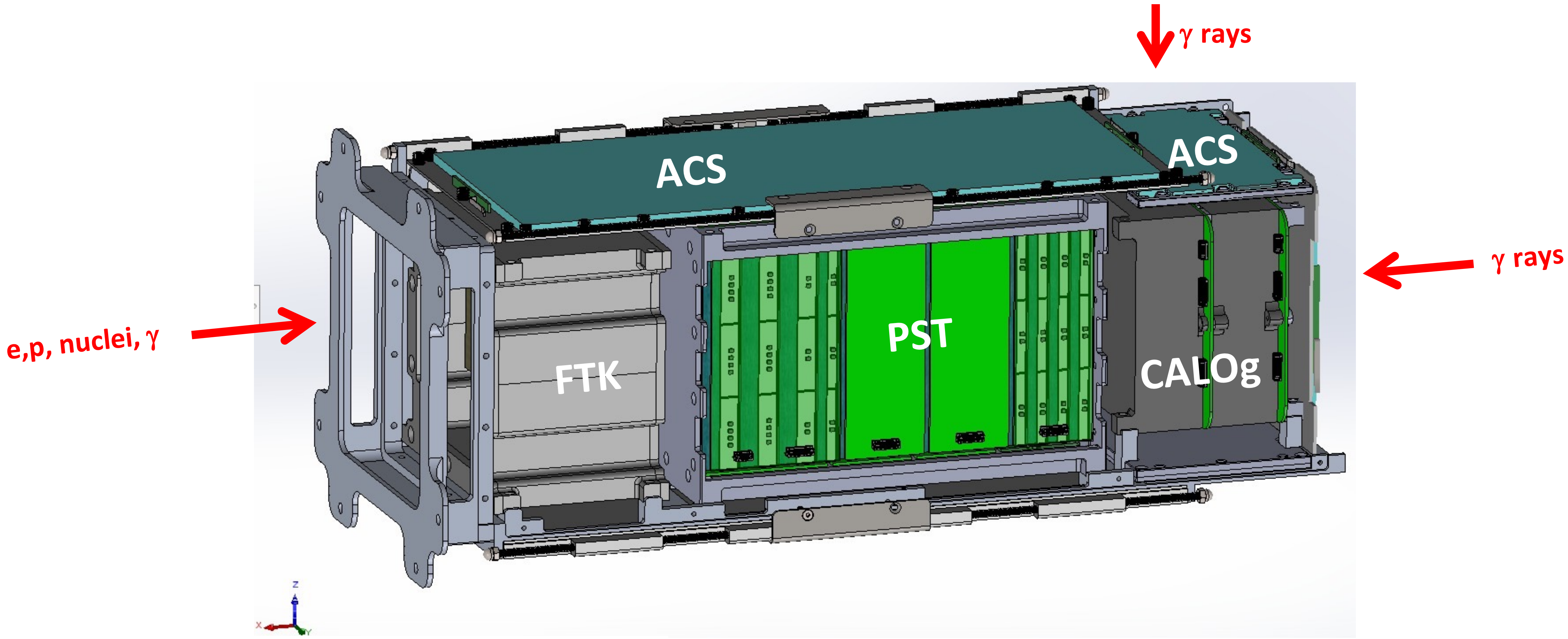
150 MeV protons

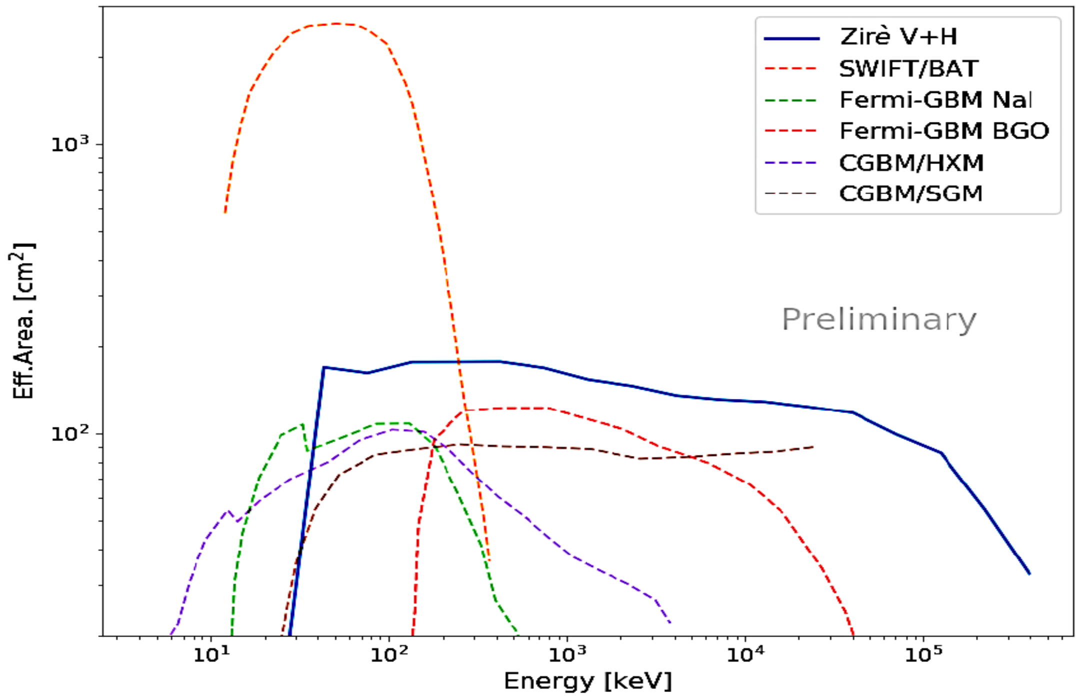


150 MeV protons



The Zirè CALOg for gamma rays (GRBs,..)



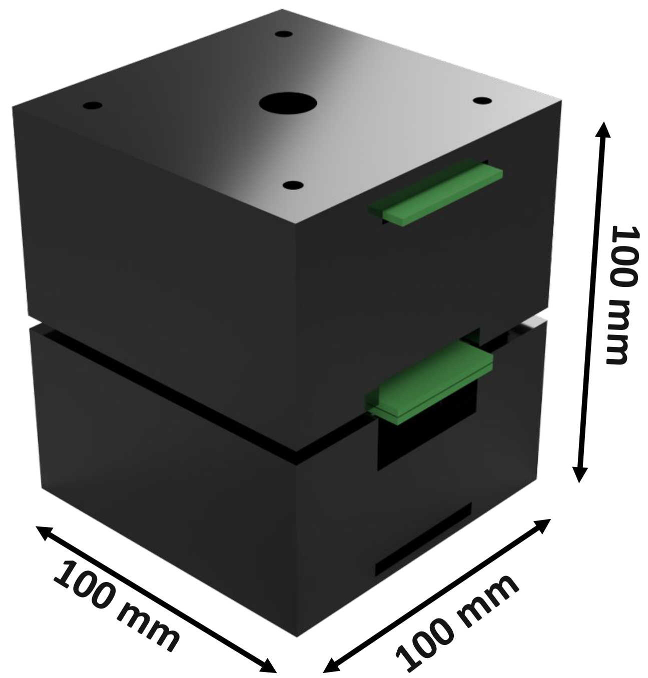


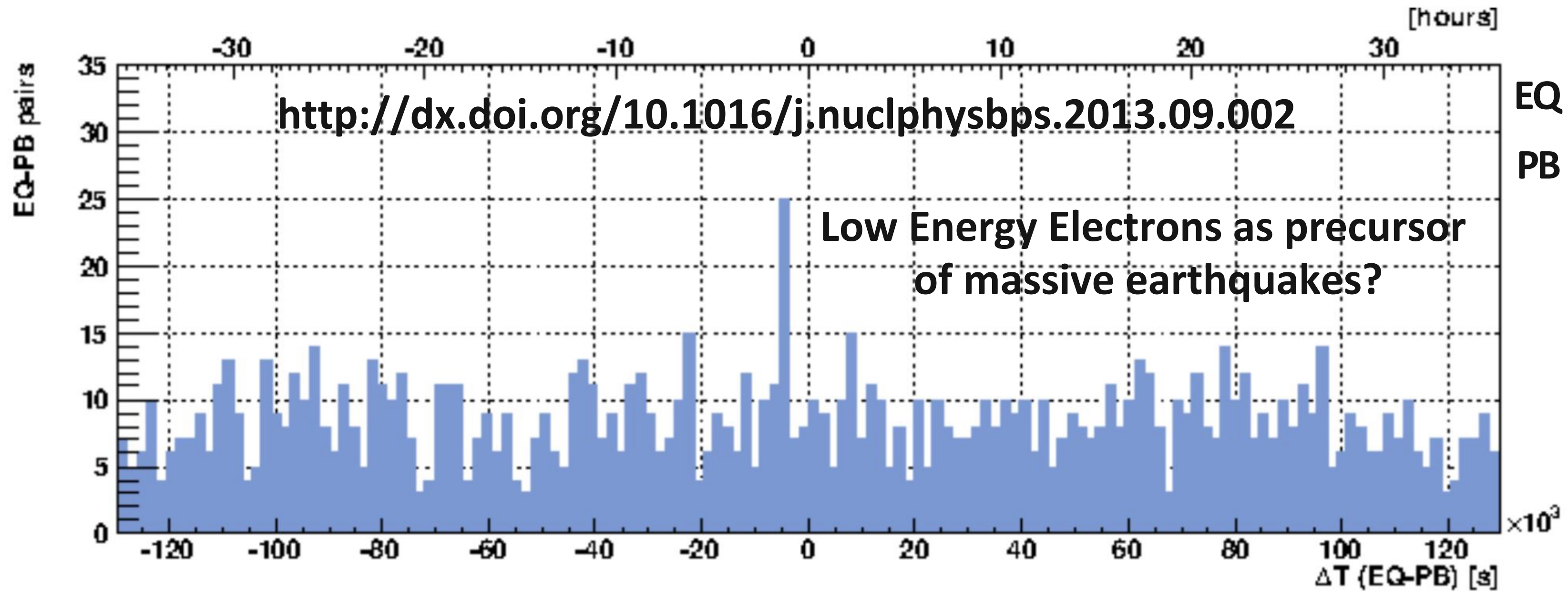
Detection of photons in the 0.1 MeV - few tens MeV energy range allowing for the study of transient (Gamma Ray Bursts, em follow-up of GW events, SN emission lines,...) and steady γ sources;

Pathfinder for future missions such as Crystal Eye;

Possible observation of high intensity GRB by measuring variations of the local flux of charged particles .

The Ziré payload – LEM (Low Energy Module)

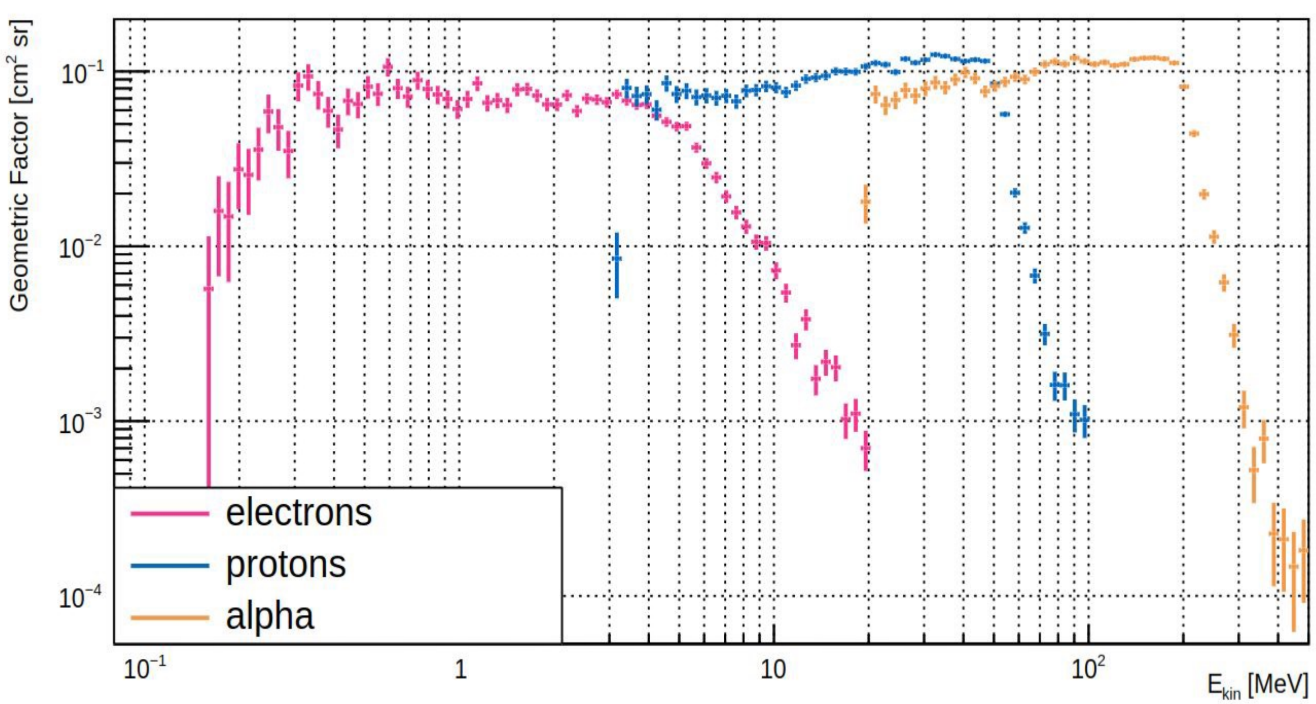


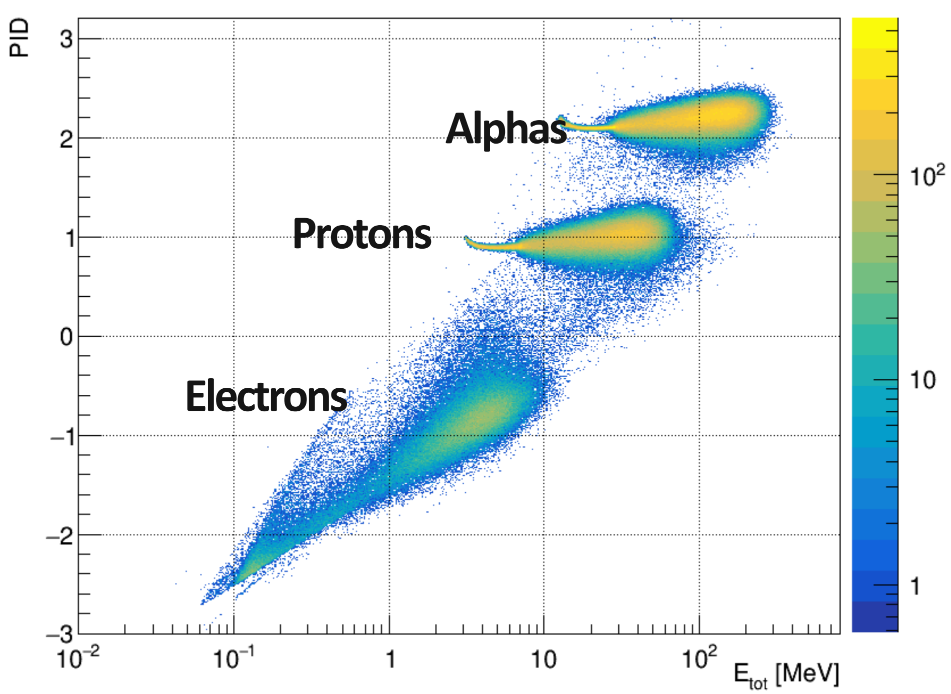


EQ = t of Earthquake

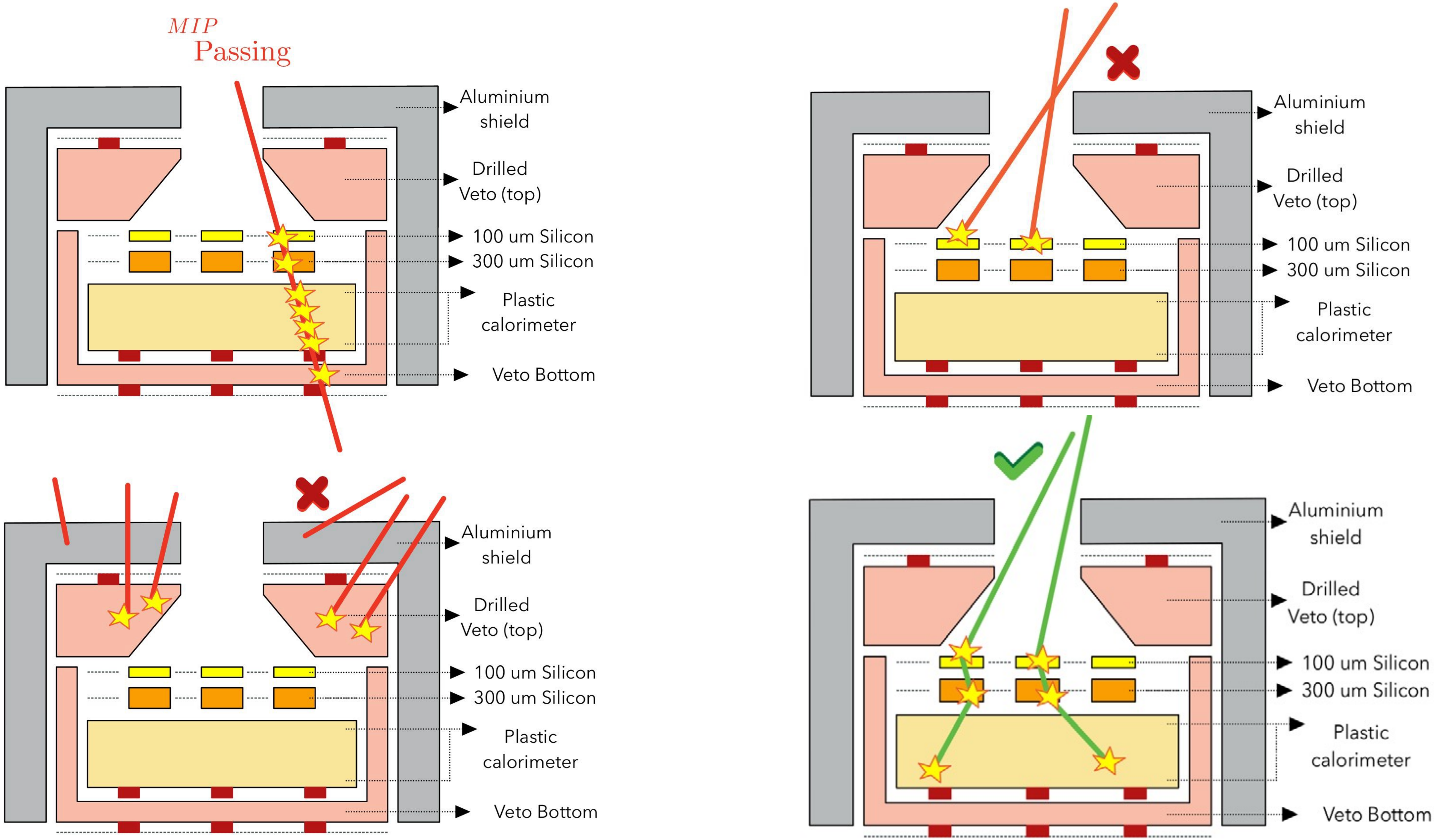
PB = Particle Bursts @ t

A compact particle spectrometer for time resolved measurement of differential flux distribution of low-energy charged particles

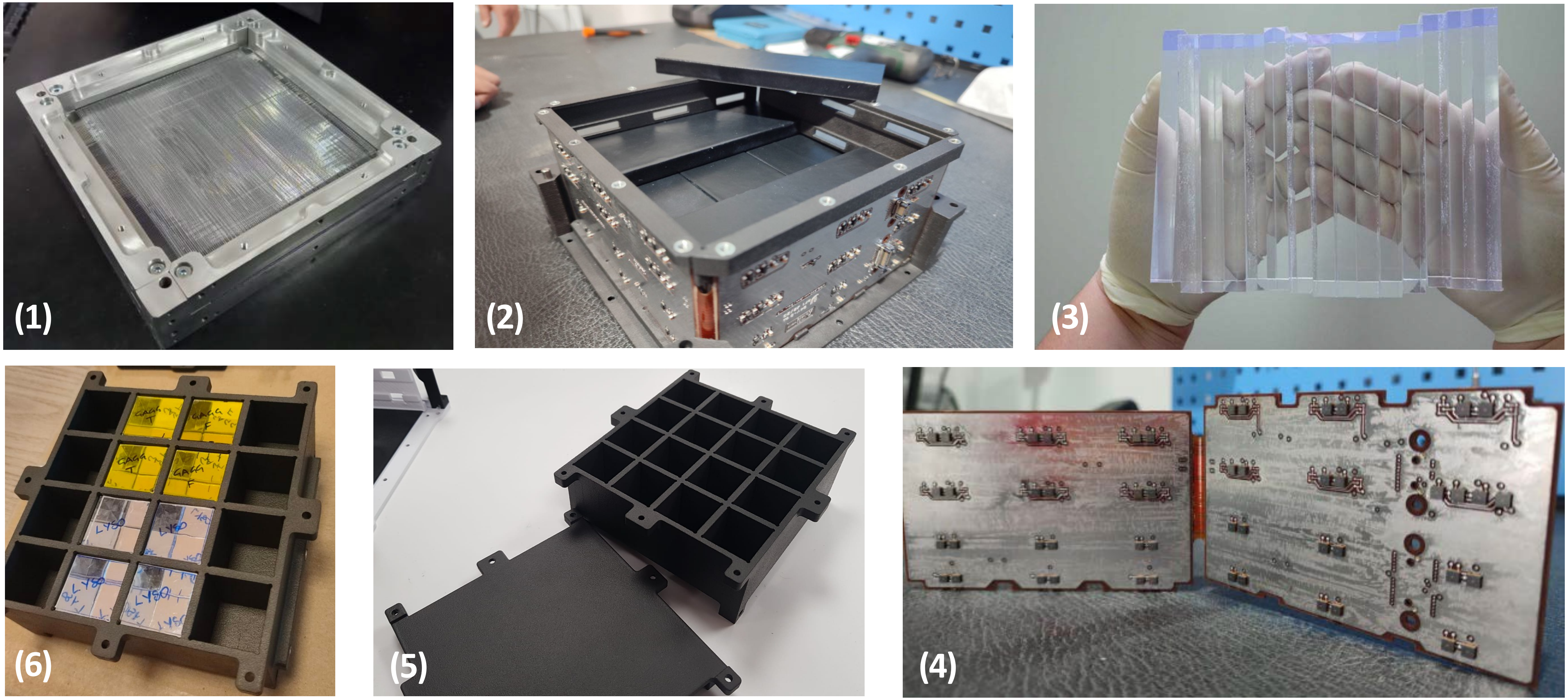




The Ziré payload – LEM (Low Energy Module)



The Ziré prototype: Zirettino



(1) The assembled FTK (1 X-Y module)

(2) The assembled PST (4 X-Y modules)

(3) The scintillator bars used in the PST

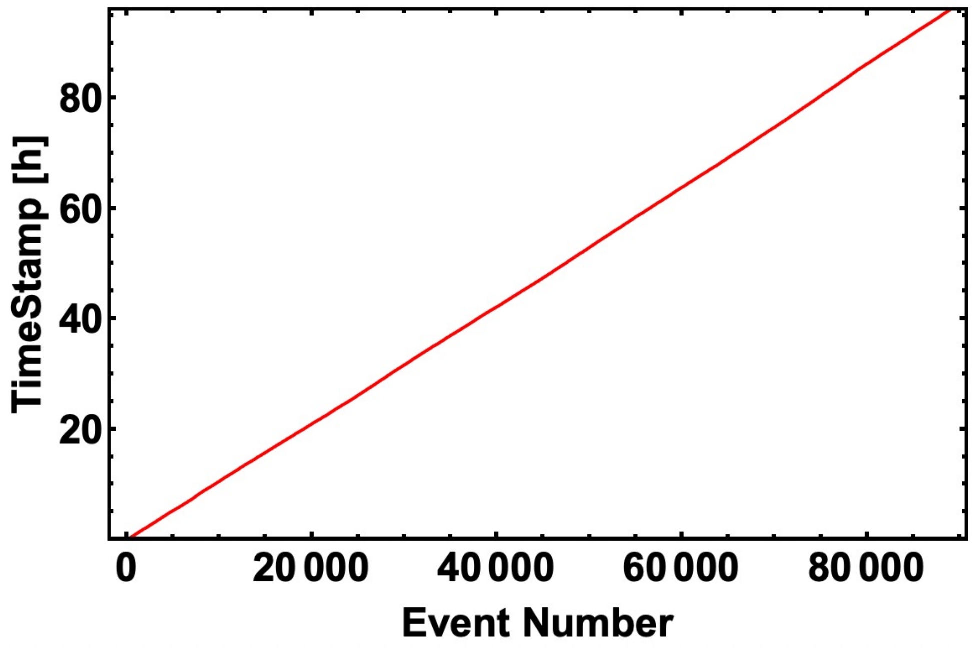
(4) The Rigid-Flex PCB readout hosting the SiPMs of the Plastic Scintillator Tower (PST)

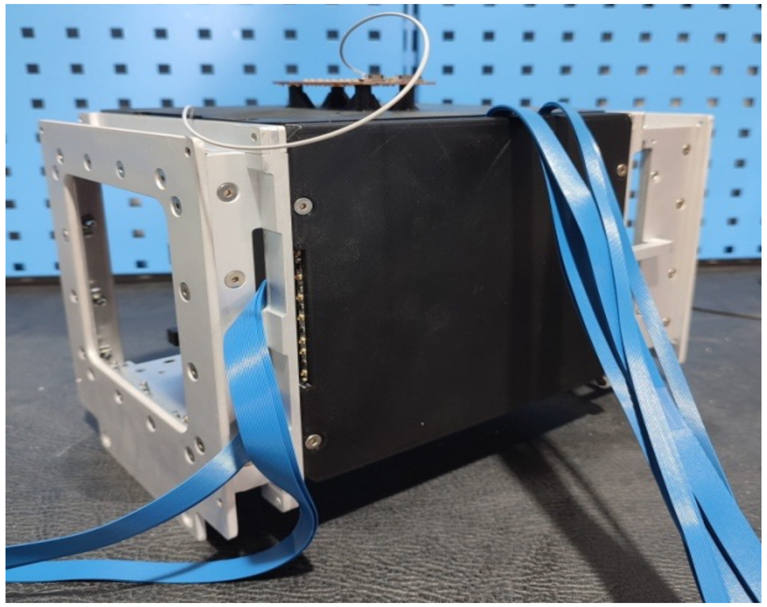
(5) The CALOg enclosure made of 3D printed windform

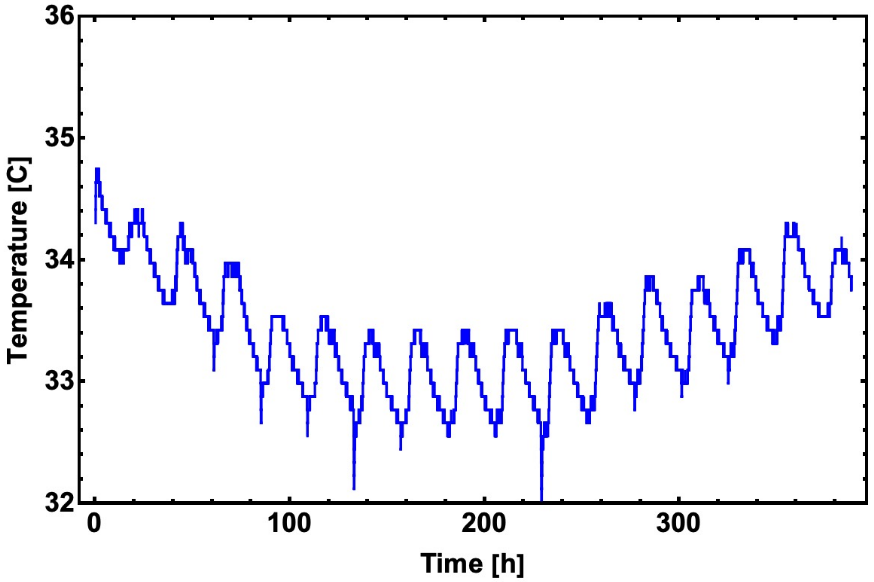
(6) The CALOg enclosure hosting N.4 LYSO and N. 4 GaGG scintillating crystals

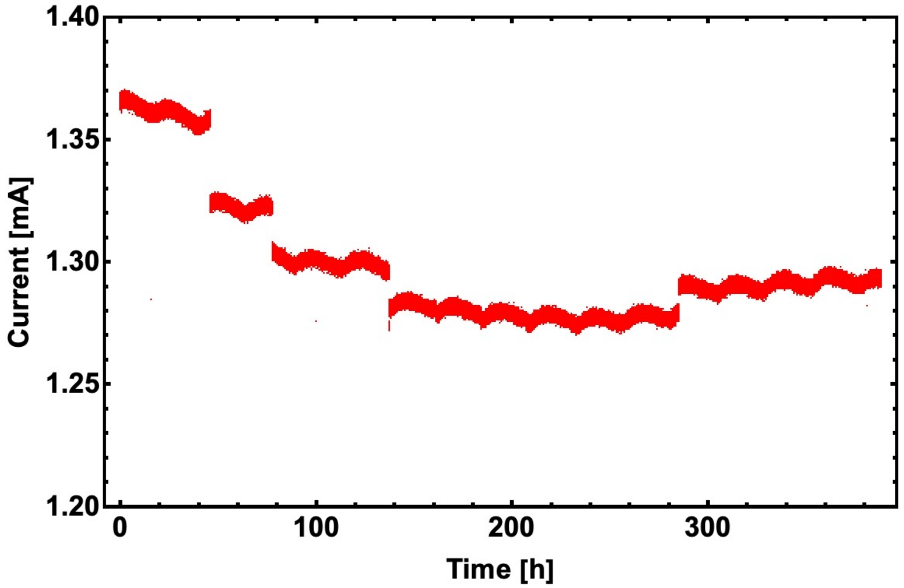
Zirettino in commissioning

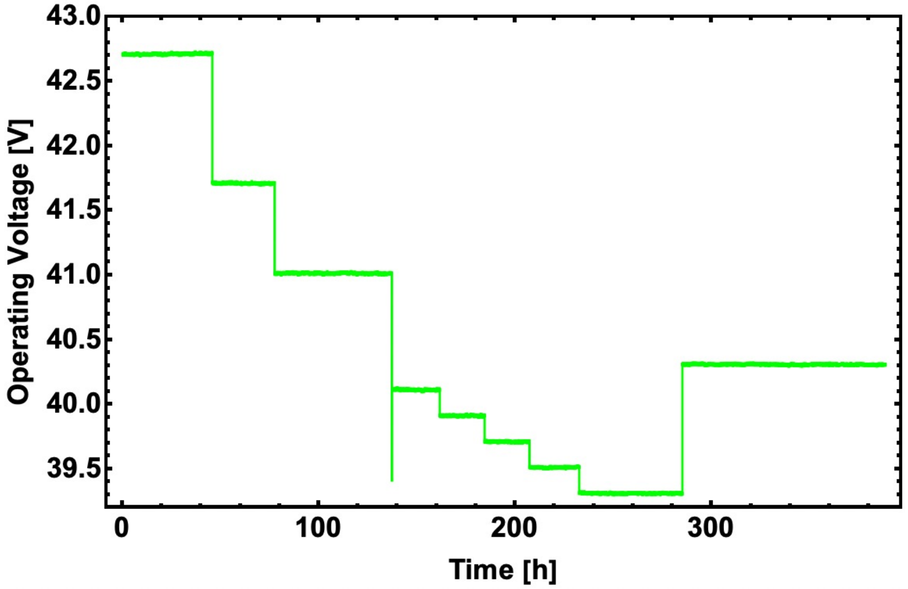
Running in "Muon" mode











(1) Each SiPM output gives one High Gain and Low Gain ADC value (to increase the dynamic range)

(2) We are currently improving the optical readout of the system and performing the long-term monitor of working parameters (Biasing stability, Absorbed currents, etc …)

Summary of science and technological goals

SCIENCE:

- **First Observation** of High Energy cosmic ray showers **from space through Cherenkov signals**
- **Test HE neutrino detection** feasibility using the **Earth skimming** geometry and Č light
- (UV - near visible) background characterization from the Earth limb
- **Measure electrons, protons and nuclei up to hundreds of MeV**
- Study **particle flux correlation with seismic activity** and space weather phenomena
- Monitor very low energy (< 10 MeV) electron flux
- **Measure 0.1-10 MeV photons for the detection of transient and steady gamma sources** (GRB, e.m. follow up of GW events, SN emission lines, TGFs, …)

TECHNOLOGY:

- Space qualification of new technologies (Photosensors, onboard data reduction, 3D printing,…)
- Setup a Č telescope based on a SiPM focal plane
- Design/qualification/use of low power/**COTS** electronics (~few mW/ch)

MISSION PATHFINDER:

- New observational methods: Cherenkov light from the limb
- Networking with other missions: GRB, space weather, MILC effects,
- **Precursor for larger missions: Crystal Eye, POEMMA like**, ….
- Super Pressure Balloons (POEMMA-B). Discussions started to a possible scaling of the **Terzina design for the POEMMA-B Cherenkov Telescope**.