Adriano Di Giovanni on behalf of the NUSES collaboration

The scientific payload of the NUSES space mission

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

In charge of the scientific payload

In charge of the spacecraft platform

NUSES in a nutshell

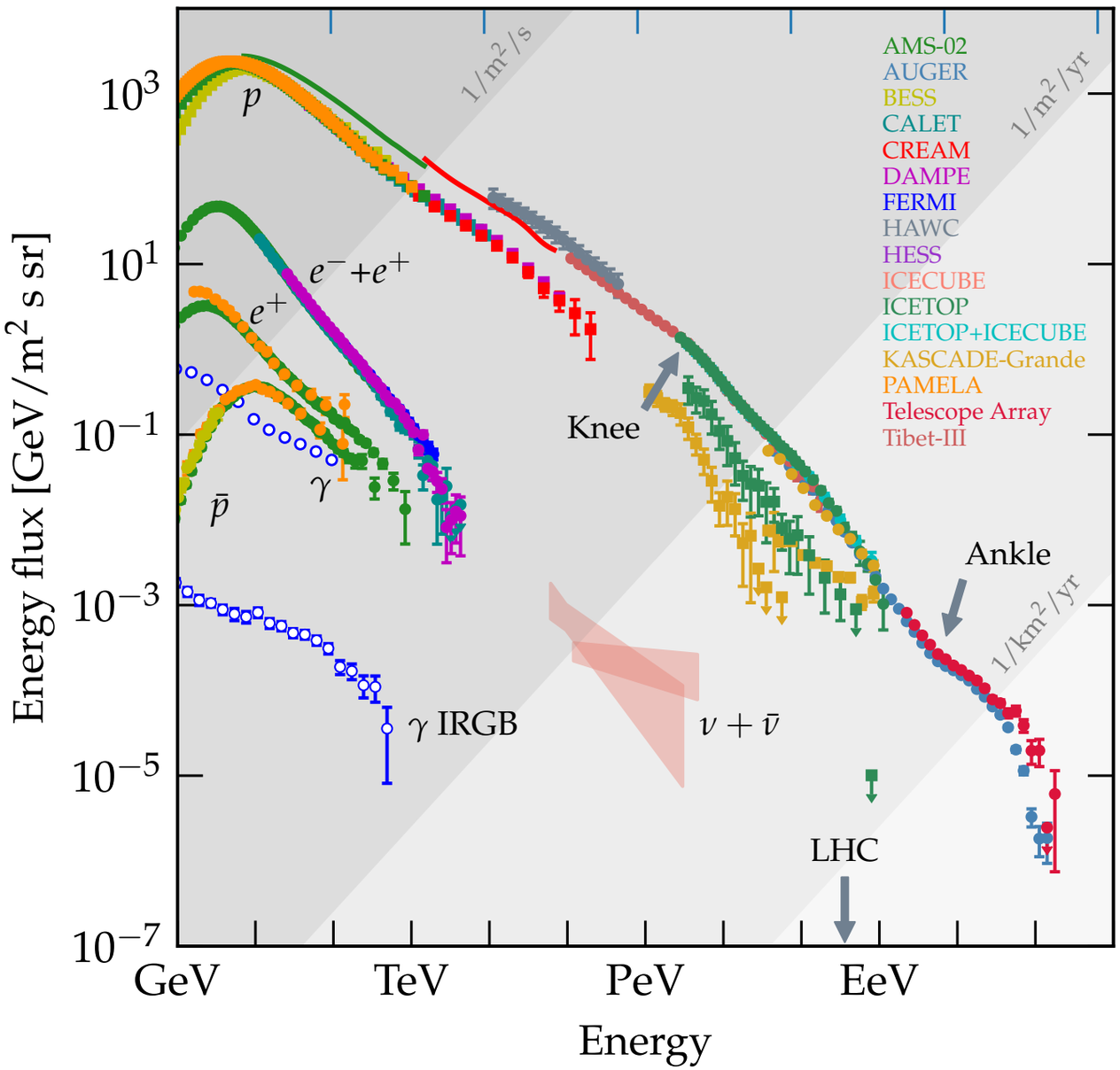
- >60 scientists from Italian Universities and INFN sites, international research and academic institutions and industrial partners. Large expertise (and synergies) from space missions/R&D programs: AMS, DAMPE,FERMI, GAPS, HERD, LIMADOU, PAMELA, POEMMA, SPB2 , . . .
- Approved by the Italian Space Agency (ASI)
- Five industrial partners

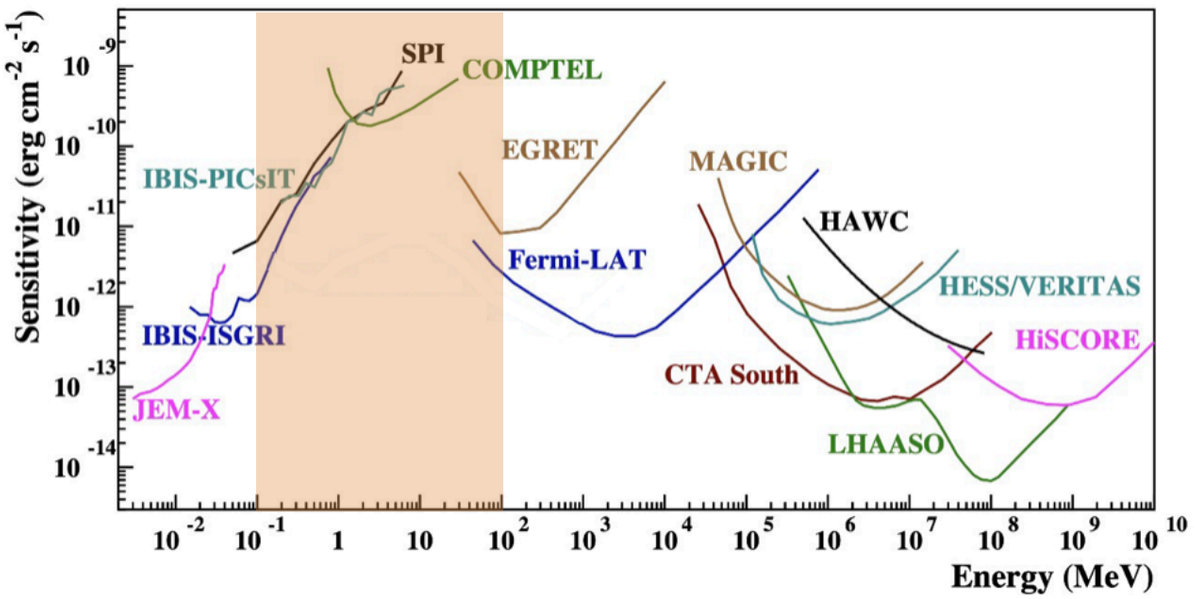
Gran Sasso Science Institute
Gran Sasso National Laboratory
University of L'Aquila
University of Turin and INFN Turin
University of Trento and INFN-TIFPA
University of Bari and INFN Bari
University of Padua and INFN Padua
University "Federico II" and INFN Napoli
University of Salento and INFN Lecce
University of Geneva
University of Chicago

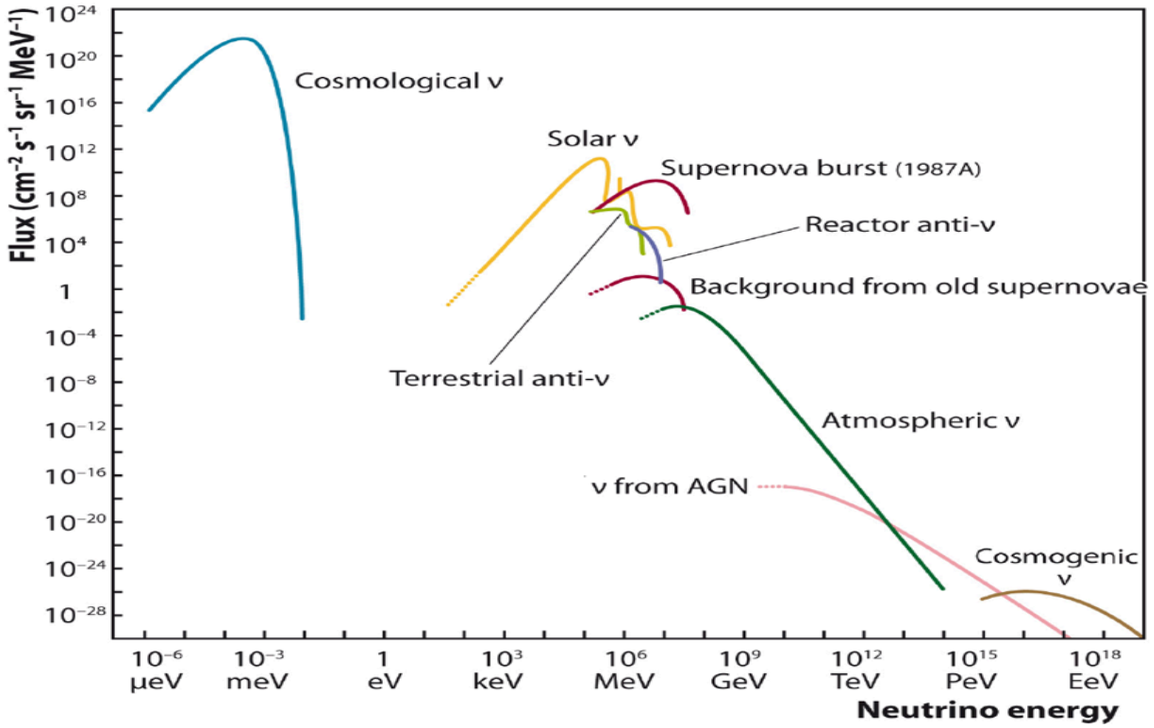
Mission Goals

- To measure UHE cosmic rays and enable neutrino astronomy through space-based atmospheric Cherenkov light detection;
- to monitor the fluxes of low energy (<300 MeV) e, p, and light nuclei of solar/galactic origin;
- to study the cosmic radiation variability (Van Allen belts);
- to detect [0.1-50] MeV photons for the study of transient (GRB, e-m follow up of GW events, SN emission lines,. . .) and steady gamma sources;
- to look for possible correlation with seismic activity due to Magnetosphere-Ionosphere-Lithosphere Coupling (MILC);
- to develop new observational techniques, to test Silicon PhotoMultiplier (SiPM) and related electronics/DAQ for space missions.

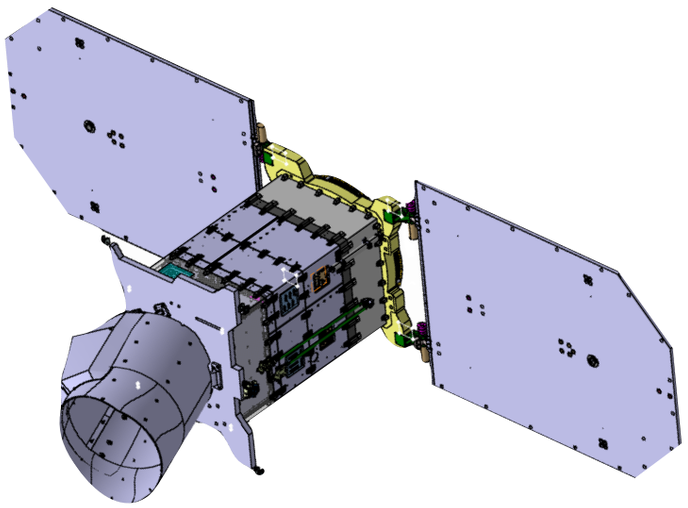
The current (particle) landscape



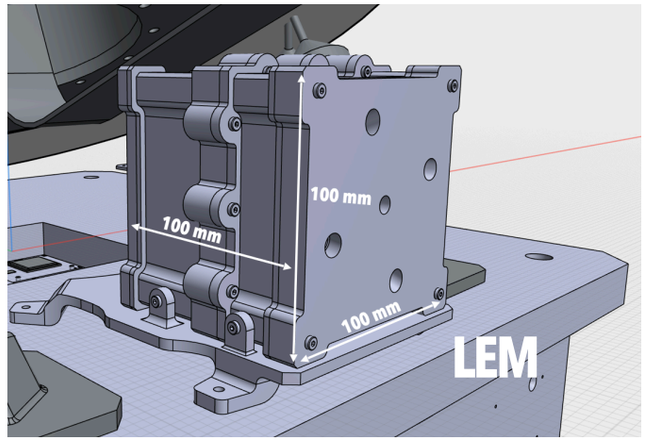


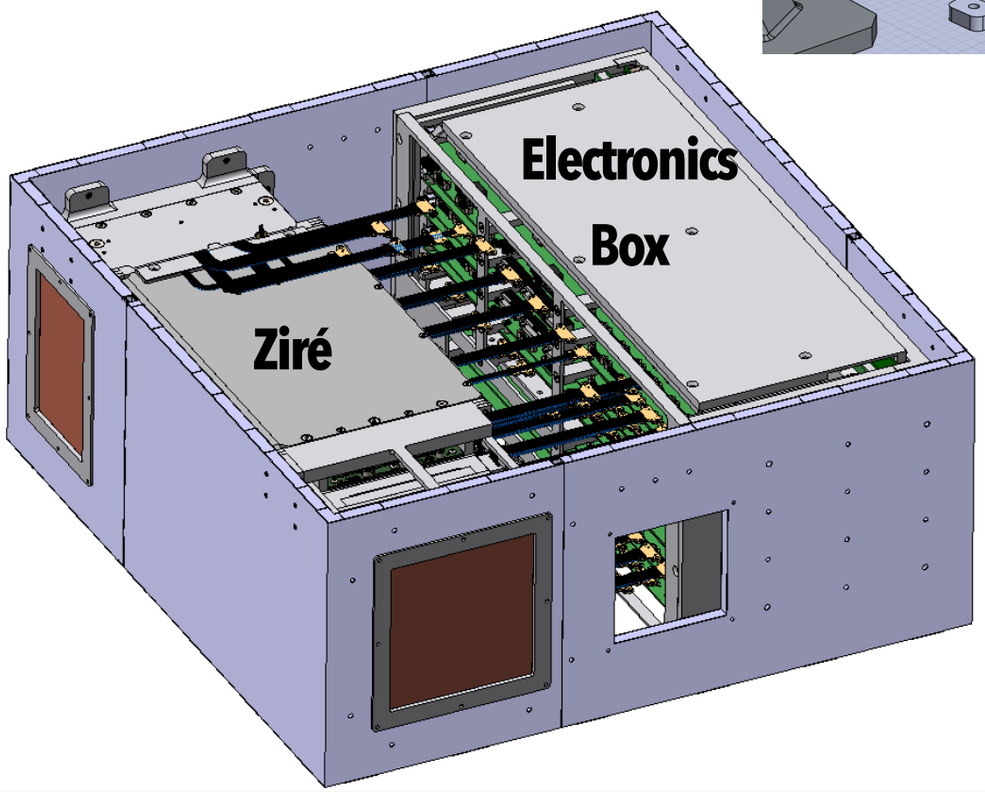


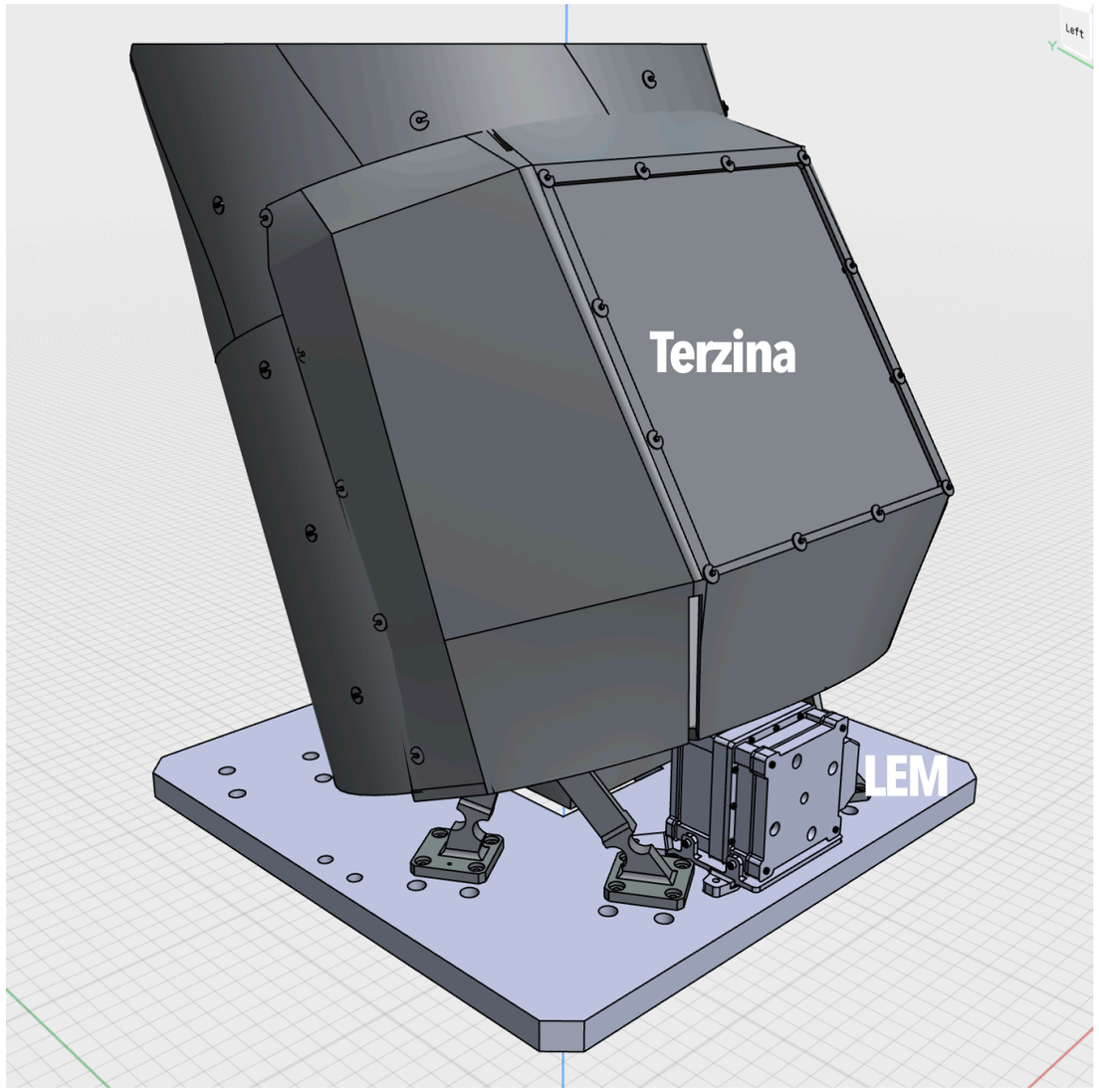
The NUSES scientific instruments: Terzina & Ziré



NIMBUS (**N**ew **I**talian **M**icro **BUS**), the IRIDE SAR and Optical missions (Italian PNRR) platform is based on a new satellite bus concept which foresees a modular approach relying on standard trays.

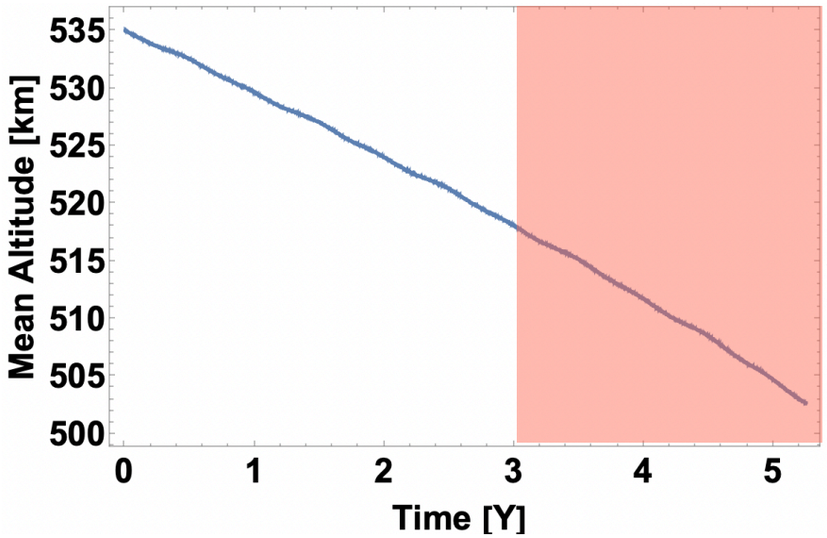


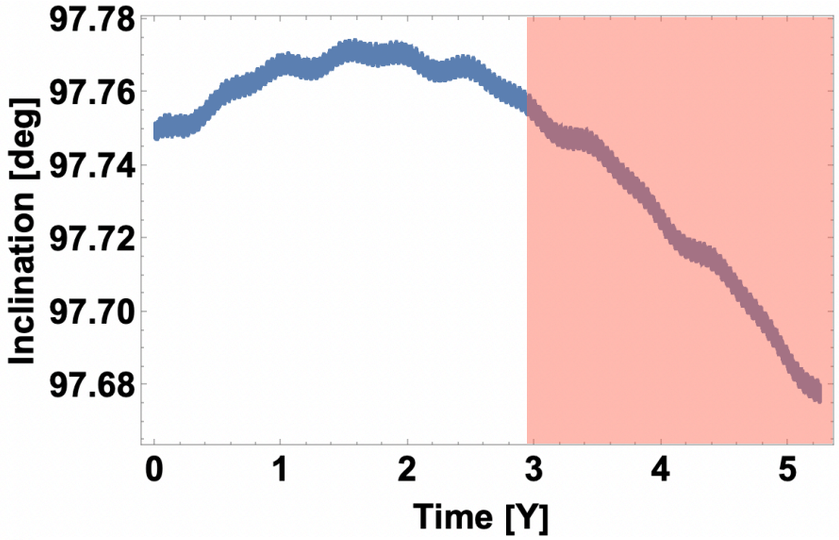


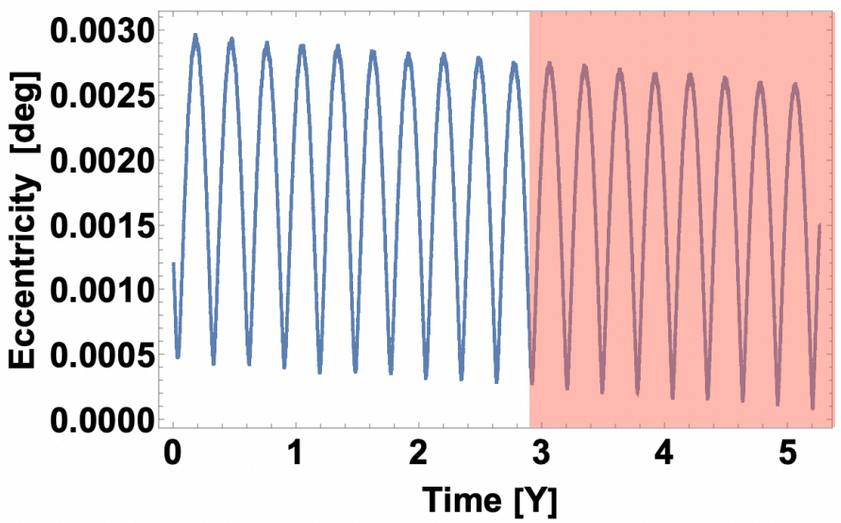


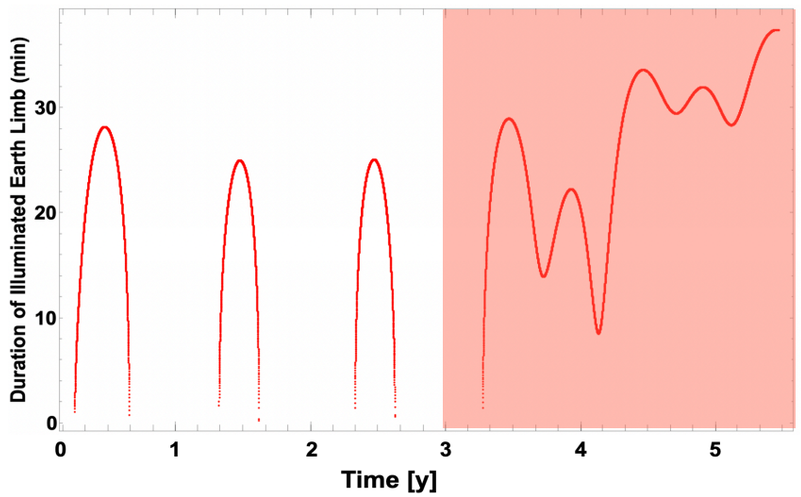
The NUSES orbit

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

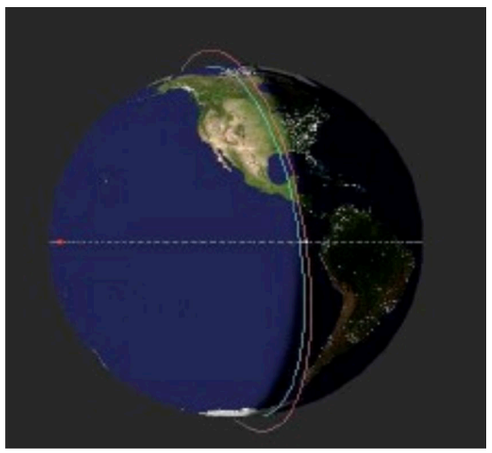




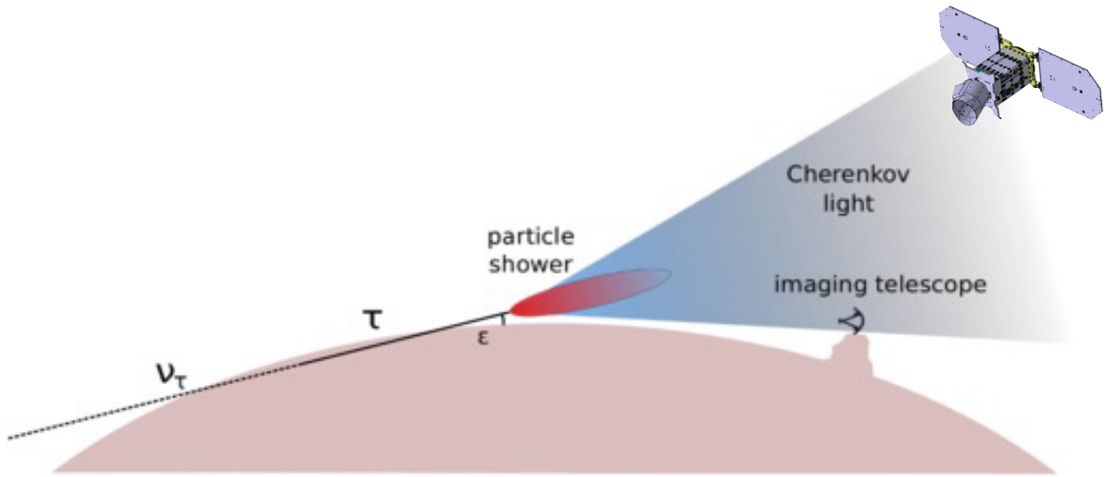


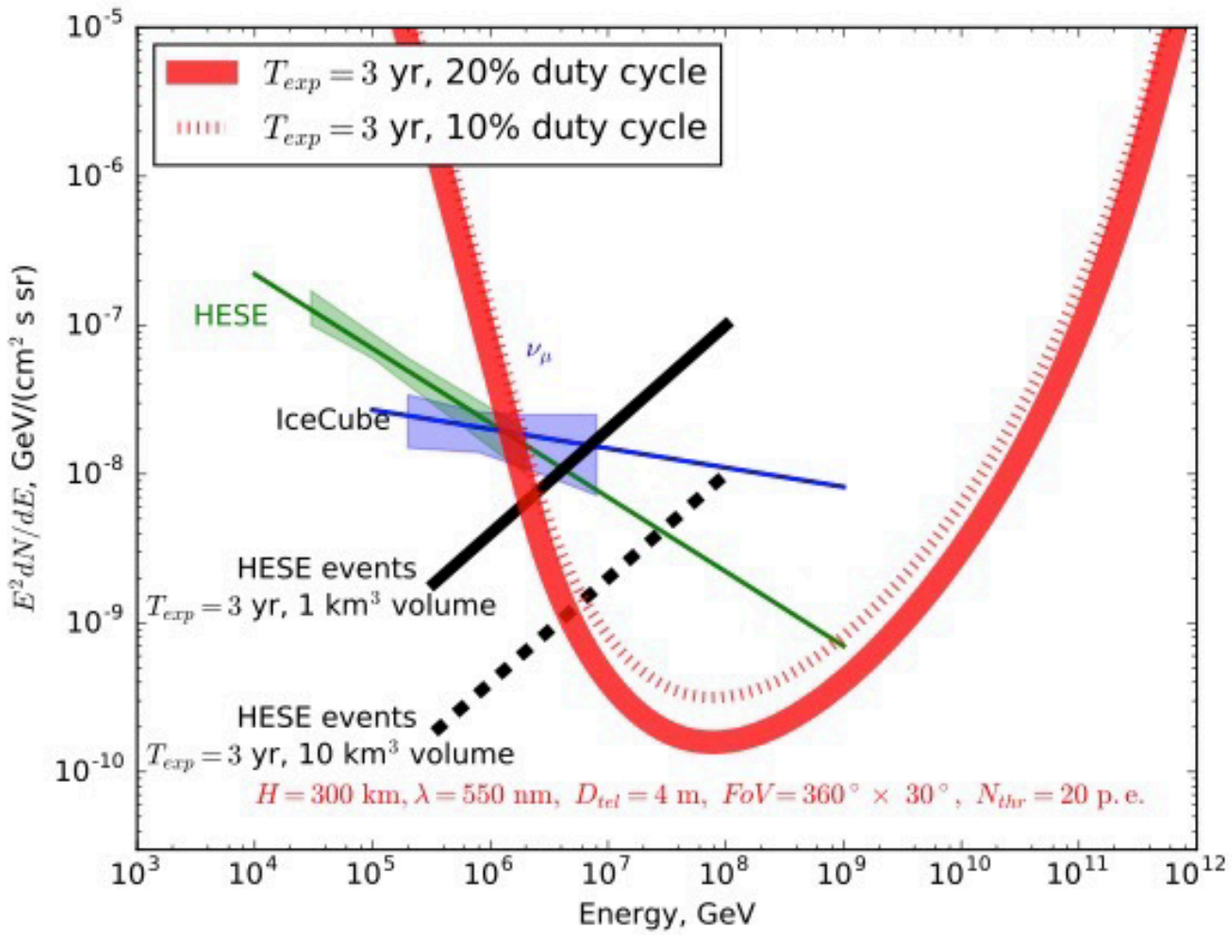


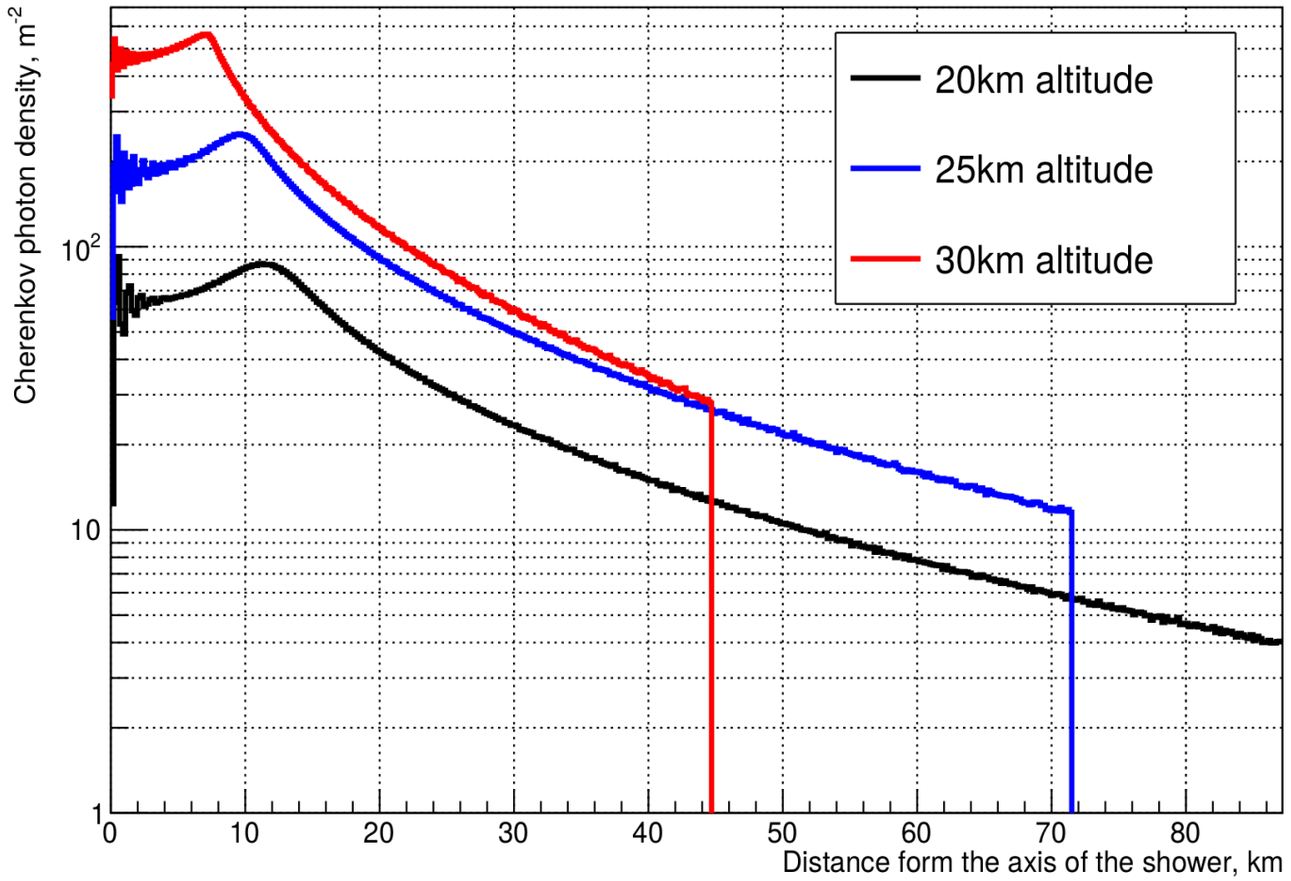
- Low Earth Orbit at high inclination, Sun-Sync orbit on the day-night border
- The orbit has been tailored around the requirement for the optimal detection of the Cherenkov light
- "Ballistic" mission (no propulsion for orbital elevation corrections)
- Expected launch window Q3 2026



Astrophysical neutrinos and High Energy CRs





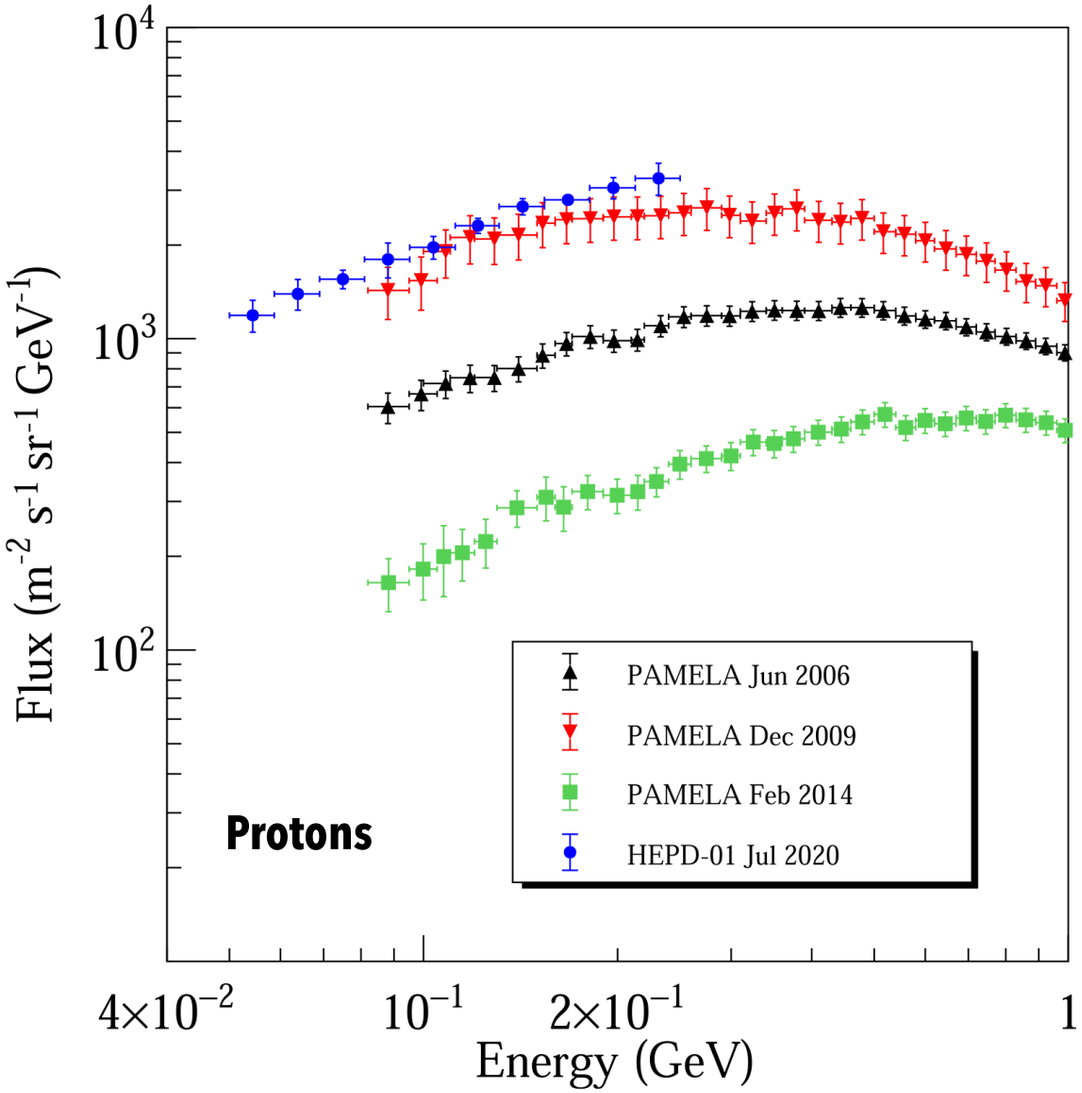


- The observation of astrophysical neutrinos at energies larger than few PeV can be achieved only from space.
- High energy CR (E>1 PeV) can be efficiently observed through EAS Cherenkov emission.

Measurements of low Energy CRs

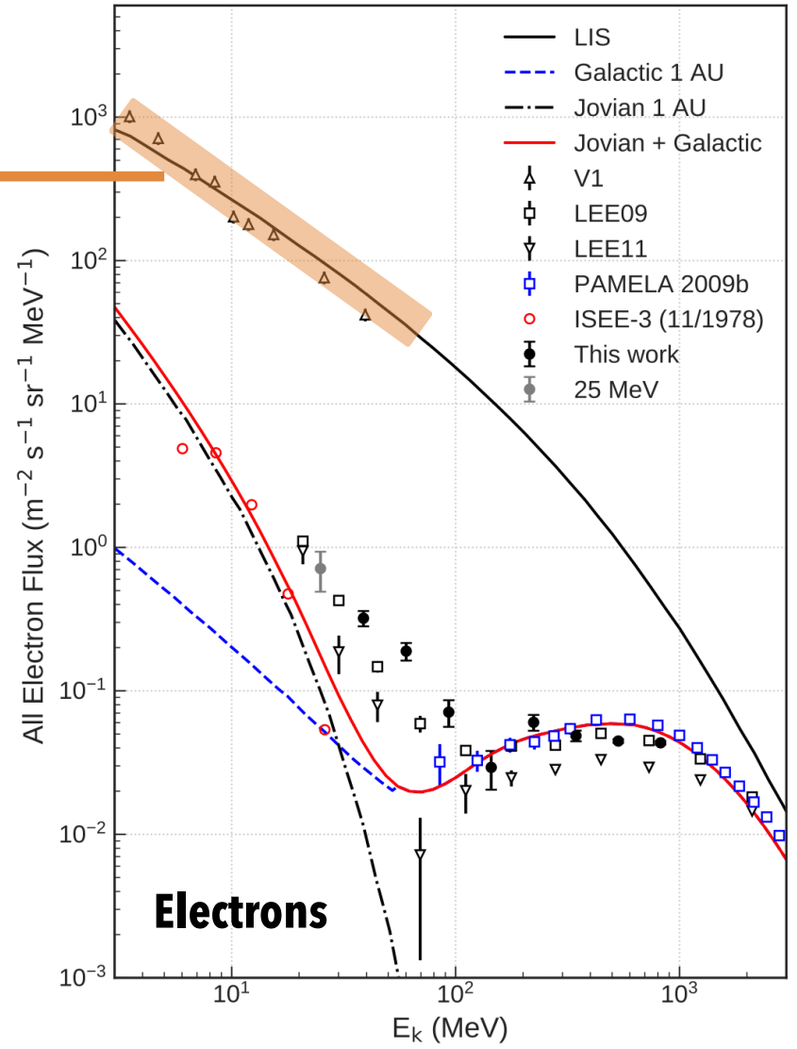
Measuring CR fluxes with energy E < 300 MeV:

- Energy spectrum of low energy charged cosmic particles is different with respect to the Local Interstellar Spectra: the Sun influences the propagation of cosmic rays within the heliosphere, altering their energy spectra.
- Magnitude is strictly dependent on the time of the measurements (governed by the magnetic field of the heliosphere)



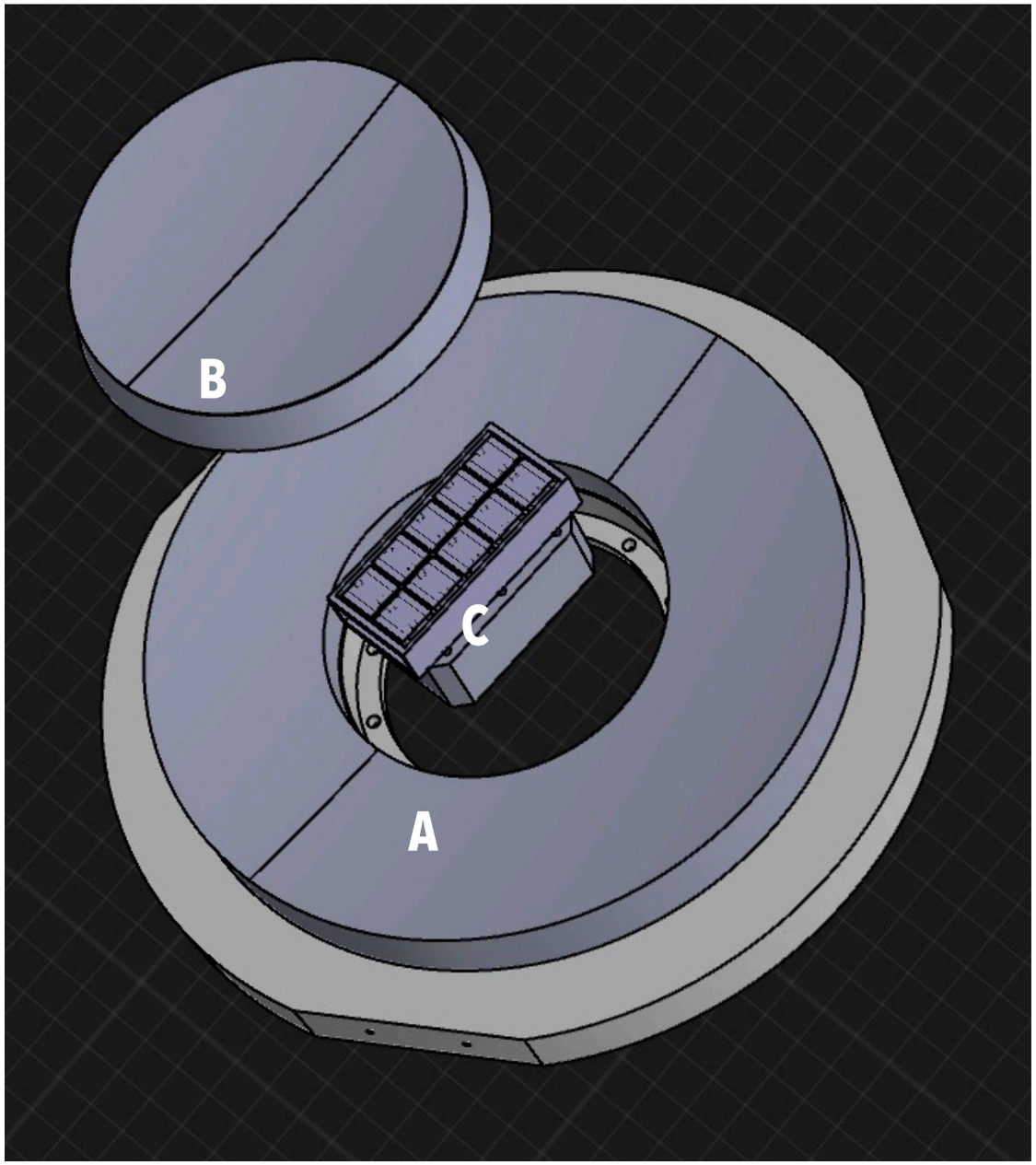
M. Martucci et al 2023 ApJL 945 L39

Outside heliosphere

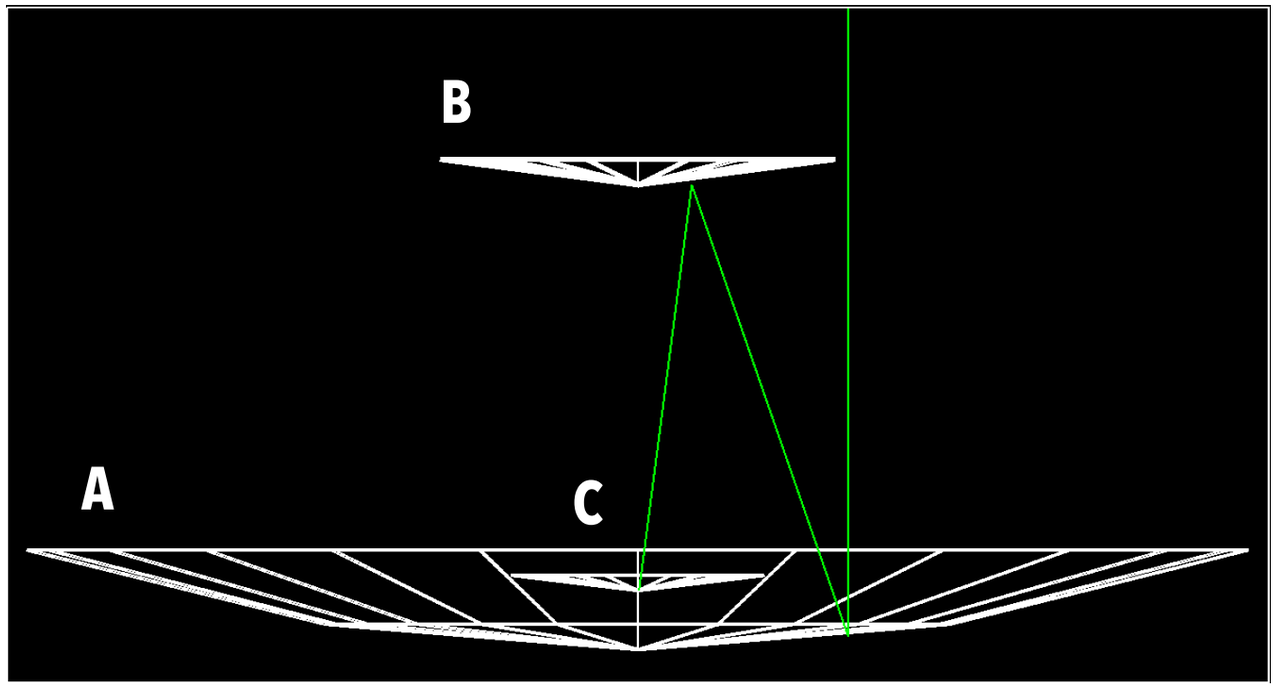


Mechbal S., et al. 2020 ApJ 903 21 (data 2018)

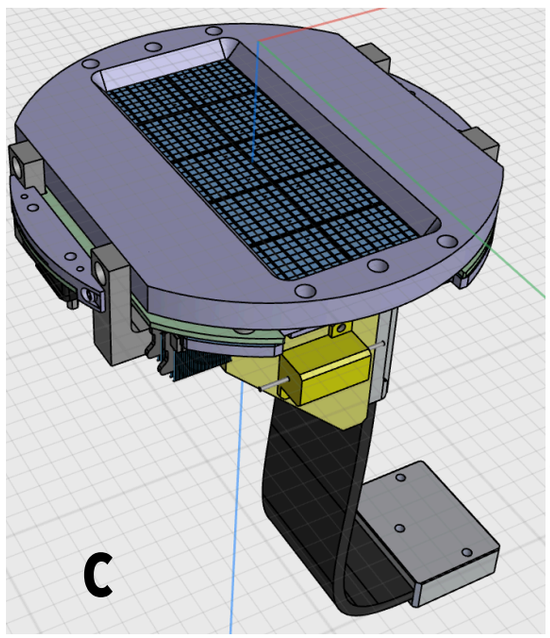
The Terzina payload



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).



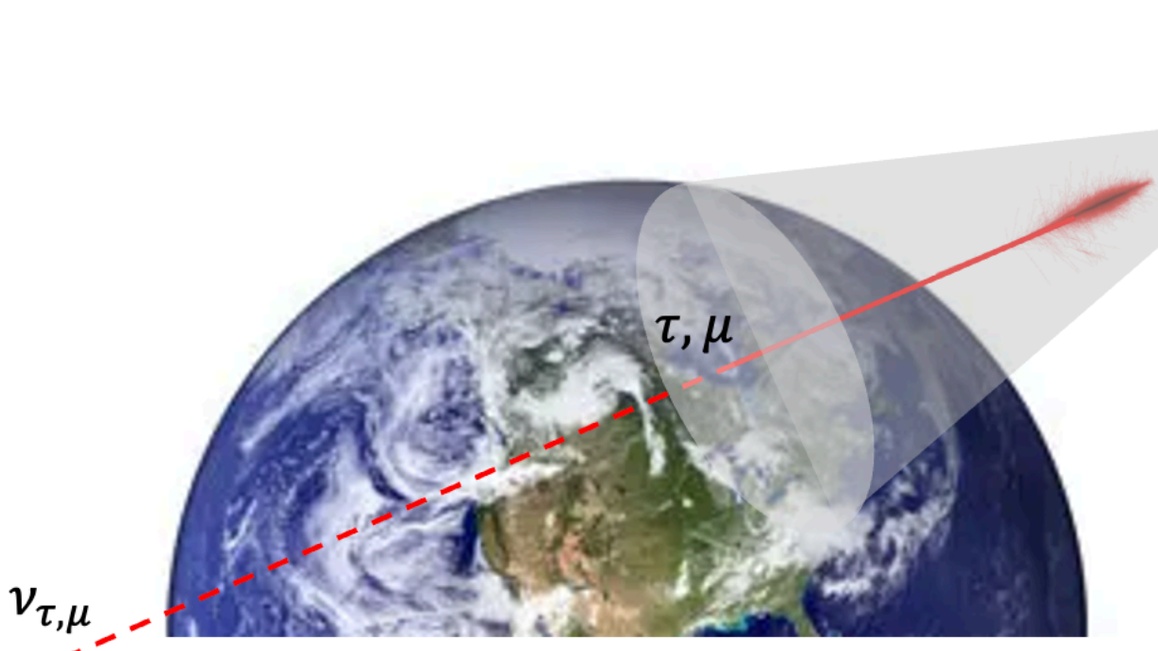
- Equivalent focal length F_L= 925 mm
- FP Field of View (FoV) : 7.2^0x 2.88^0
- Point spread function (PSF) : <1.0 mm
- Effective area of the primary mirror: 0.1 m^2
- M1 paraboloid, M2 hyperbole

The Terzina payload

Event signatures of Earth Skimming Neutrinos and CRs

Looking at the atmosphere limb (just below) for neutrinos detection and (just above) for CR, γ detection a tiny layer of the atmosphere shines in Cherenkov.

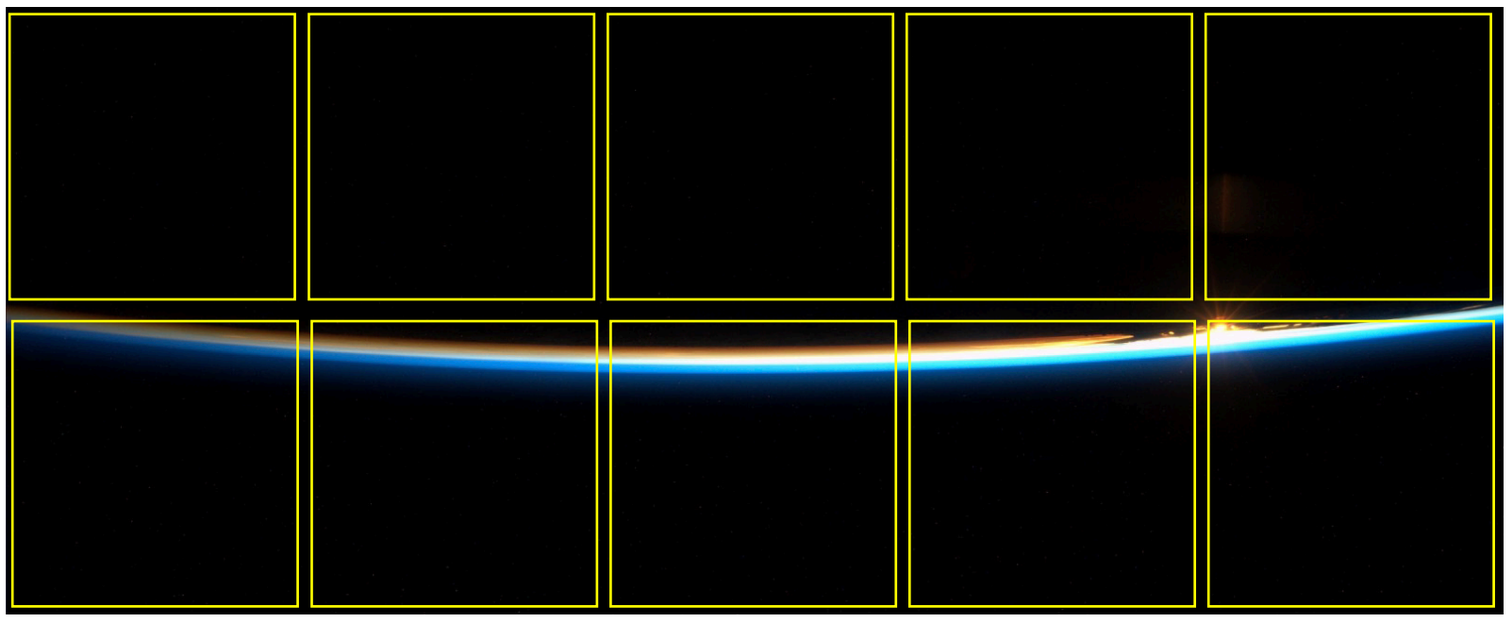
Both orbital and high altitudes are suitable to detect the EAS Cherenkov emission.



Below Limb Events

Above Limb Events

The Terzina telescope focal plane



N.10 8x8 SiPM arrays

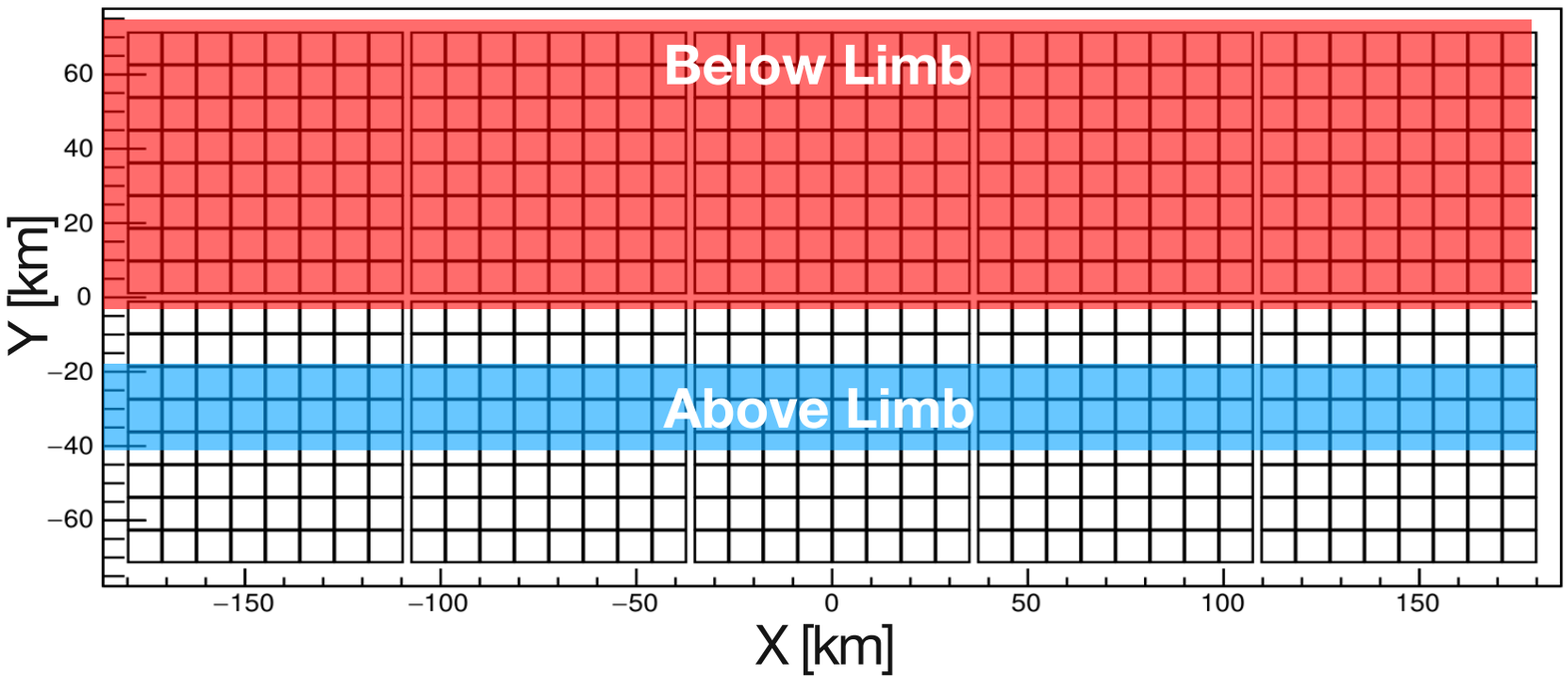
640 pixels/channels/SiPMs in total

Each is SiPM is 3 x 3 mm^2

Pixel F.O.V. 0.18º

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.

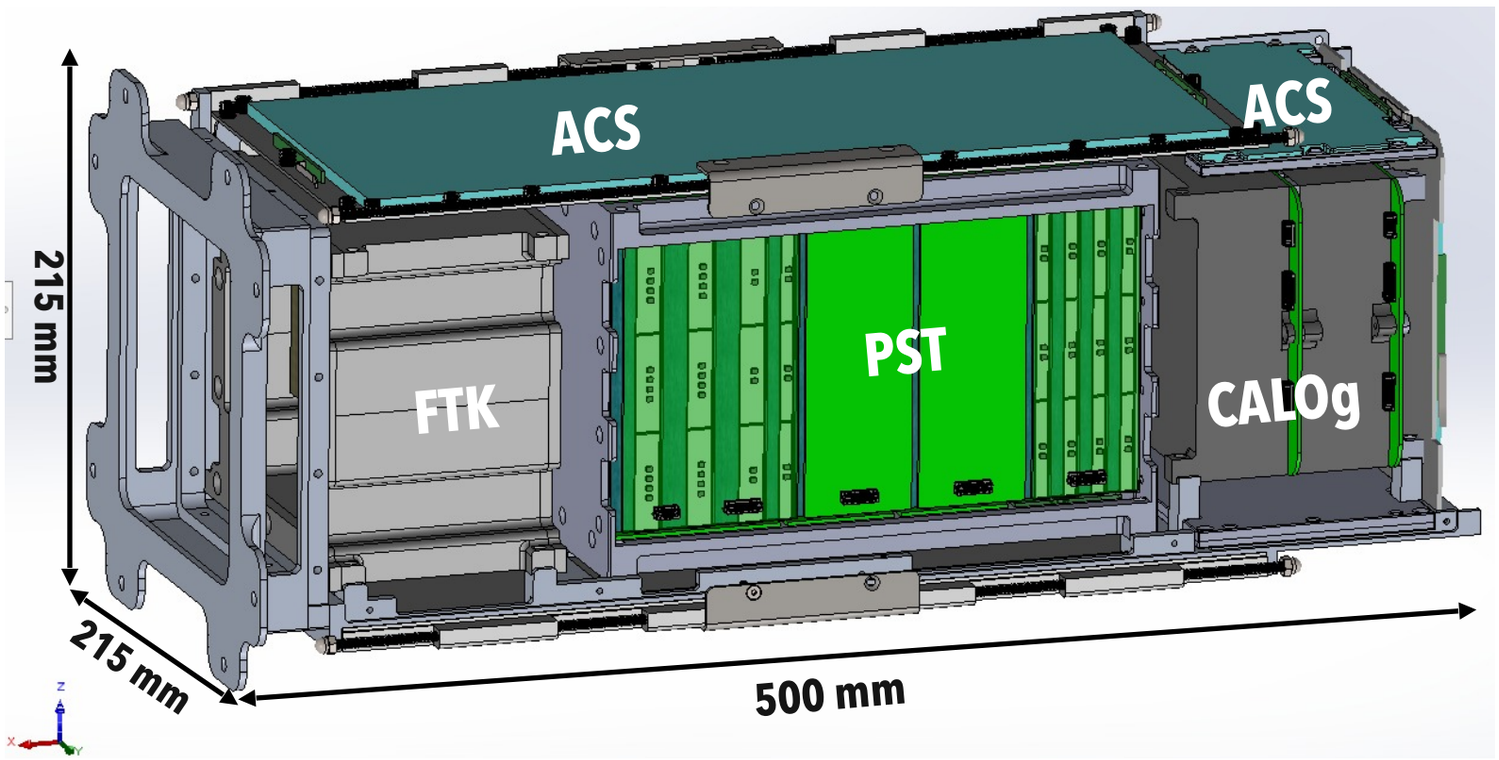


Background Evaluation

Earth Skimming Neutrino Shower

ROI: CR EAS

The Ziré payload

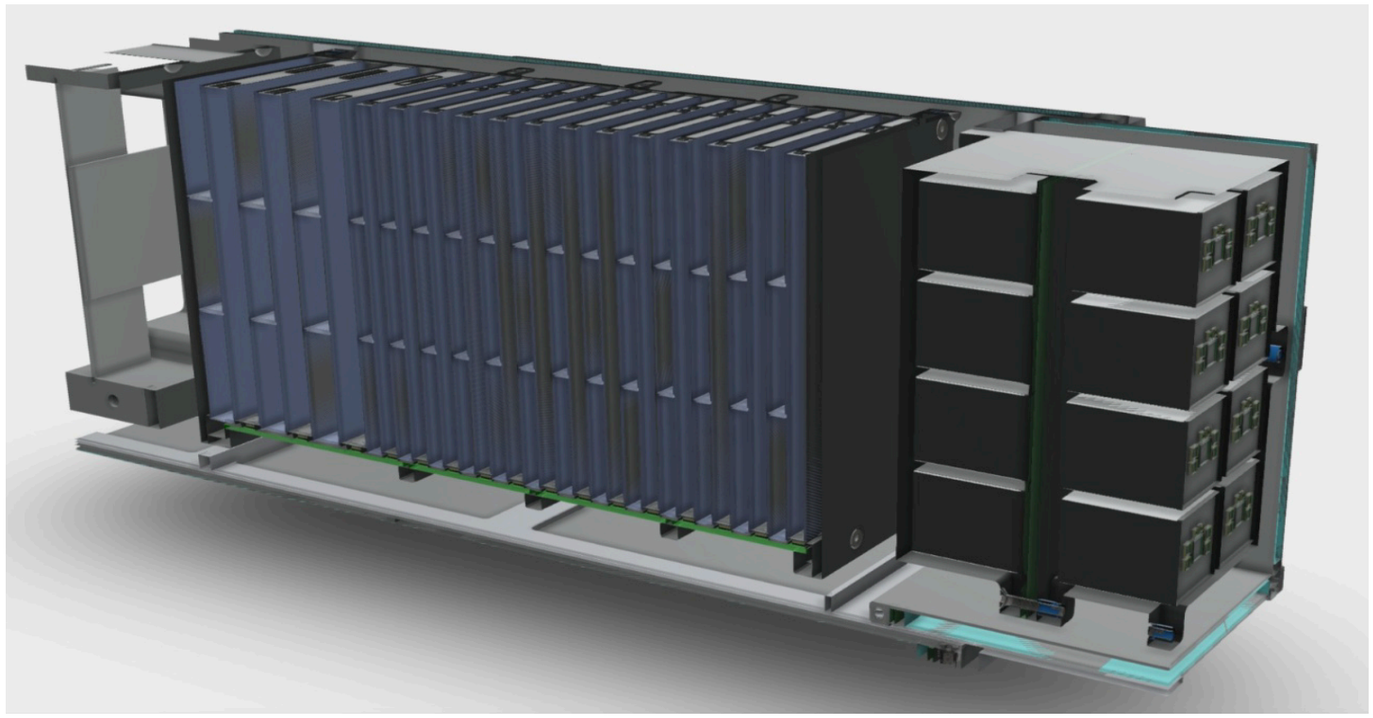


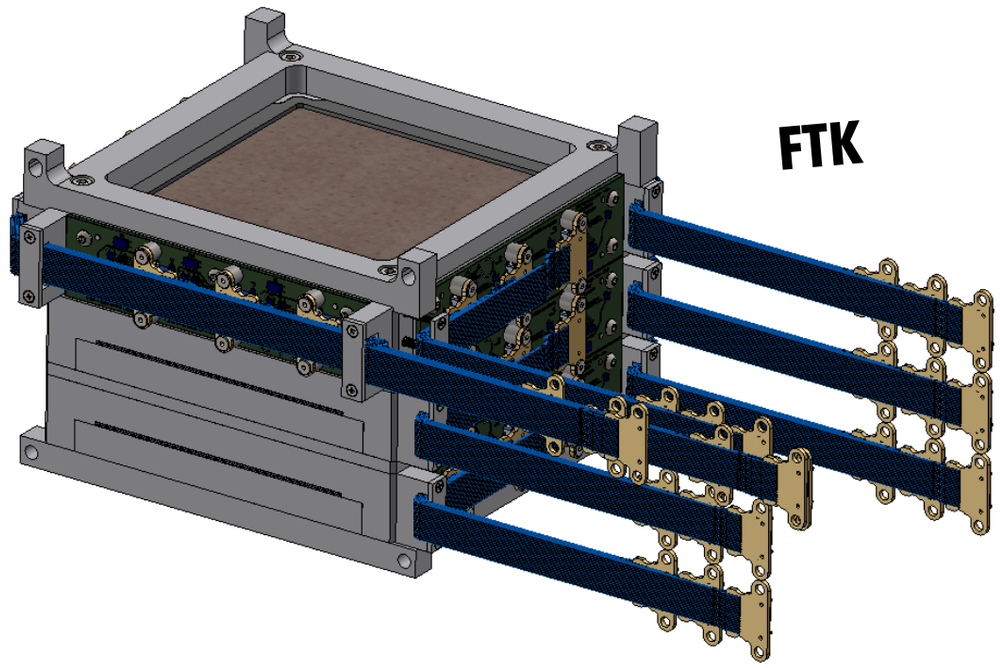
ACS (Anti-Coincidence System): a VETO for charged particle induced events made of plastic scintillator tiles and read out by SiPMs

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 setsof SiPMs of different sensitive area

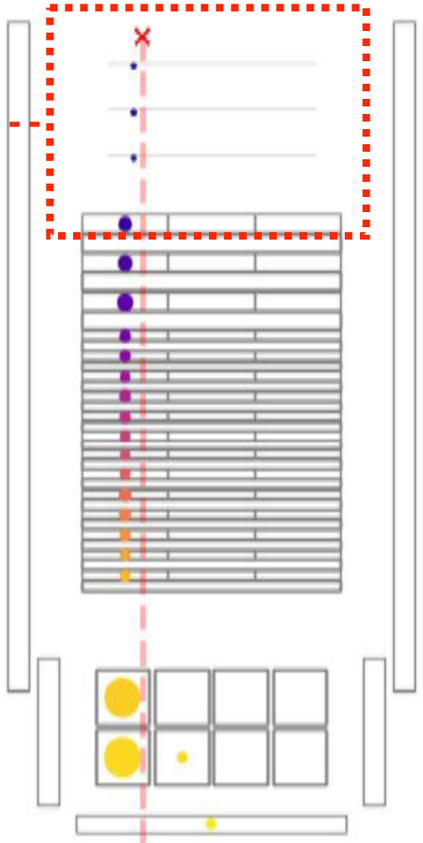
CALOg: N.2 4X4 matrices of LYSO (GAGG) crystals read out by three sets of SiPMs of different sensitive area





The Ziré Particle Identification (PID)

FTK + PS0 Energy deposit

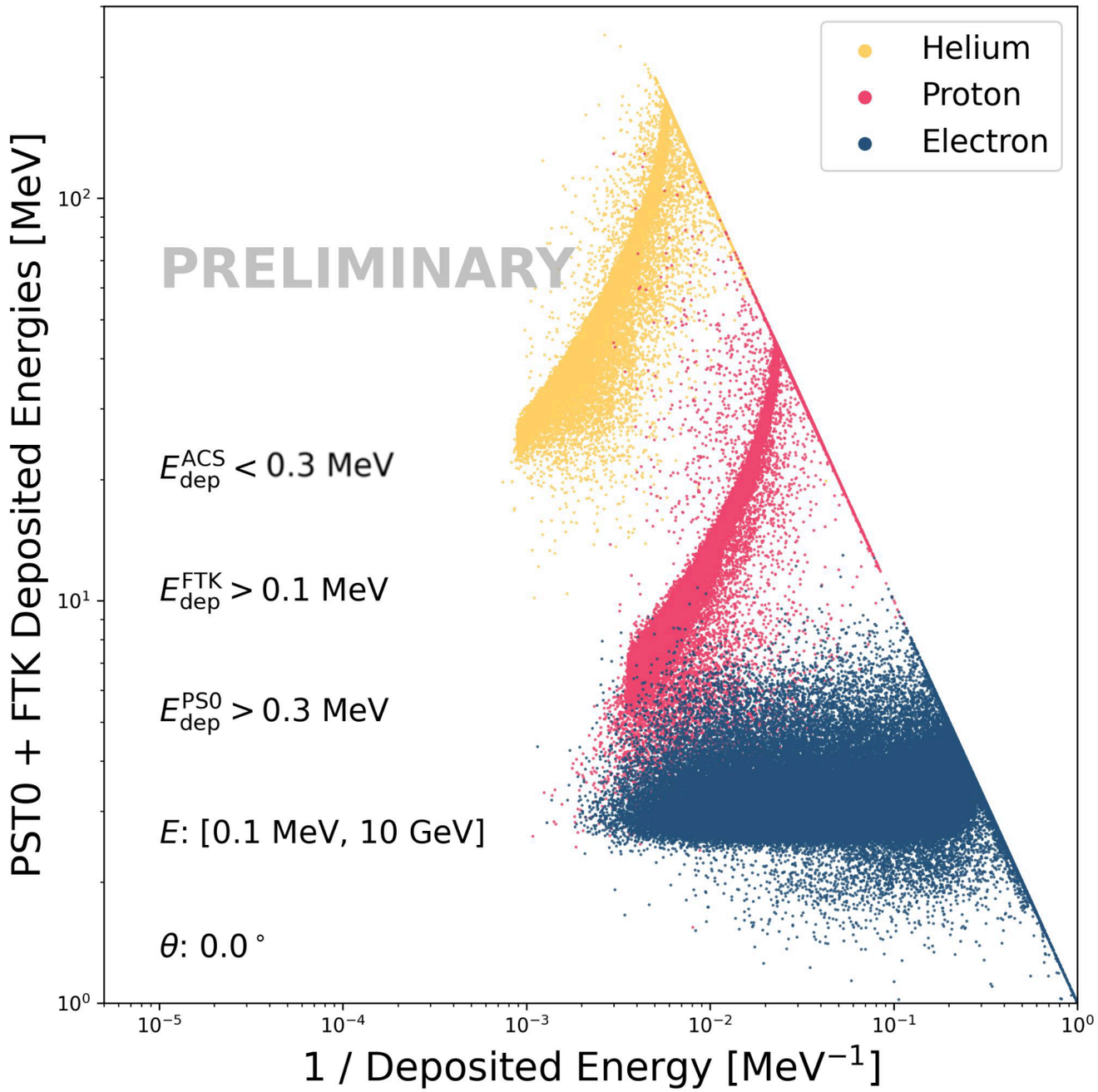


$$\Delta_0 = \Delta E_{\mathrm{FTK+PS0}} \simeq \frac{dE}{dX} \propto \frac{z^2}{\beta^2} F(\gamma\beta)$$

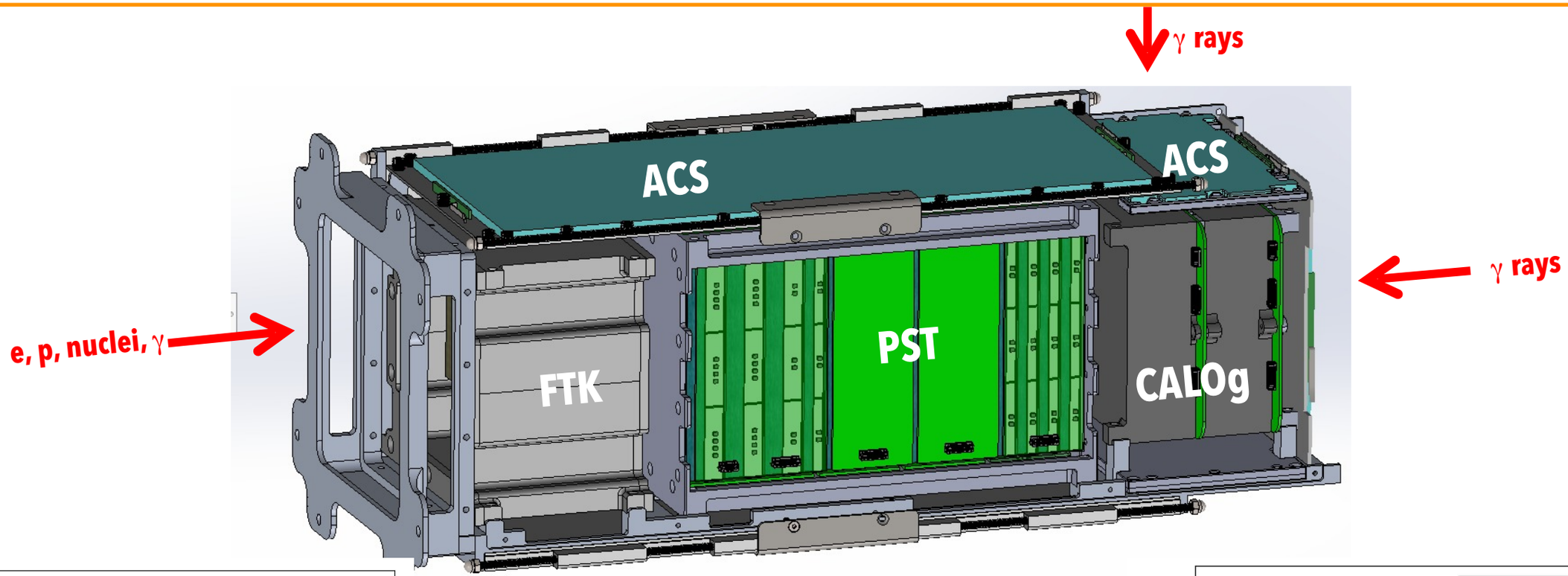
$$E_{\mathrm{dep}} \simeq E_k \propto \beta^2$$

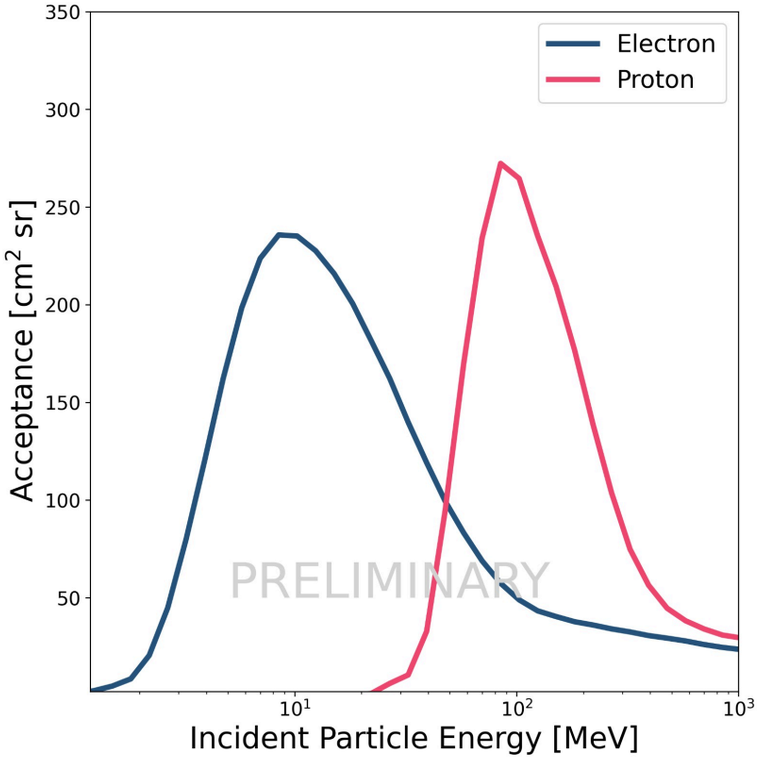
$$\Delta_0 \propto \frac{z^2 F(\gamma\beta)}{E_{\mathrm{dep}}}$$

For non-relativistic nuclei

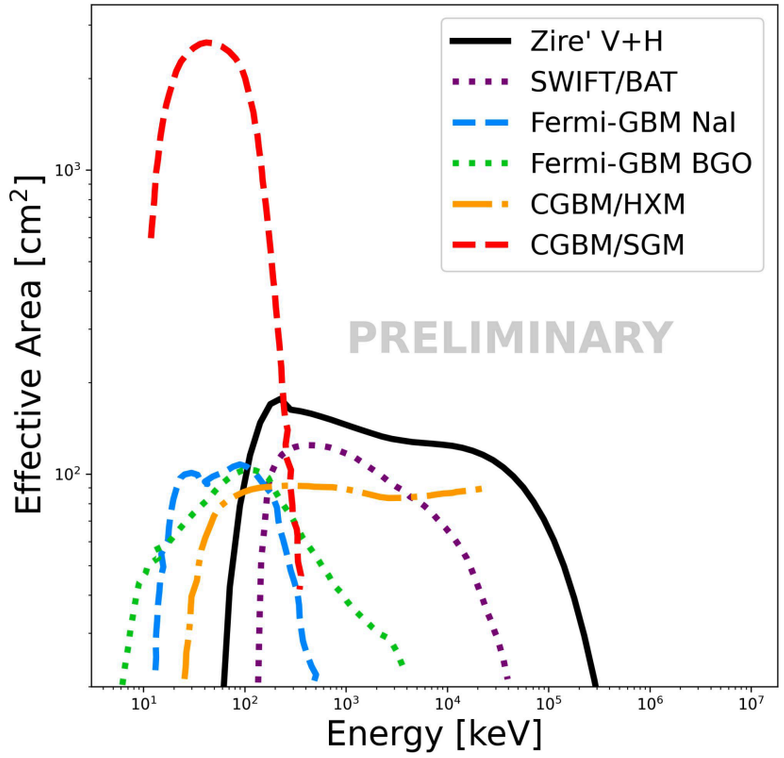


ZIRÈ: e, p ACCEPTANCE AND ɣ EFFECTIVE AREA

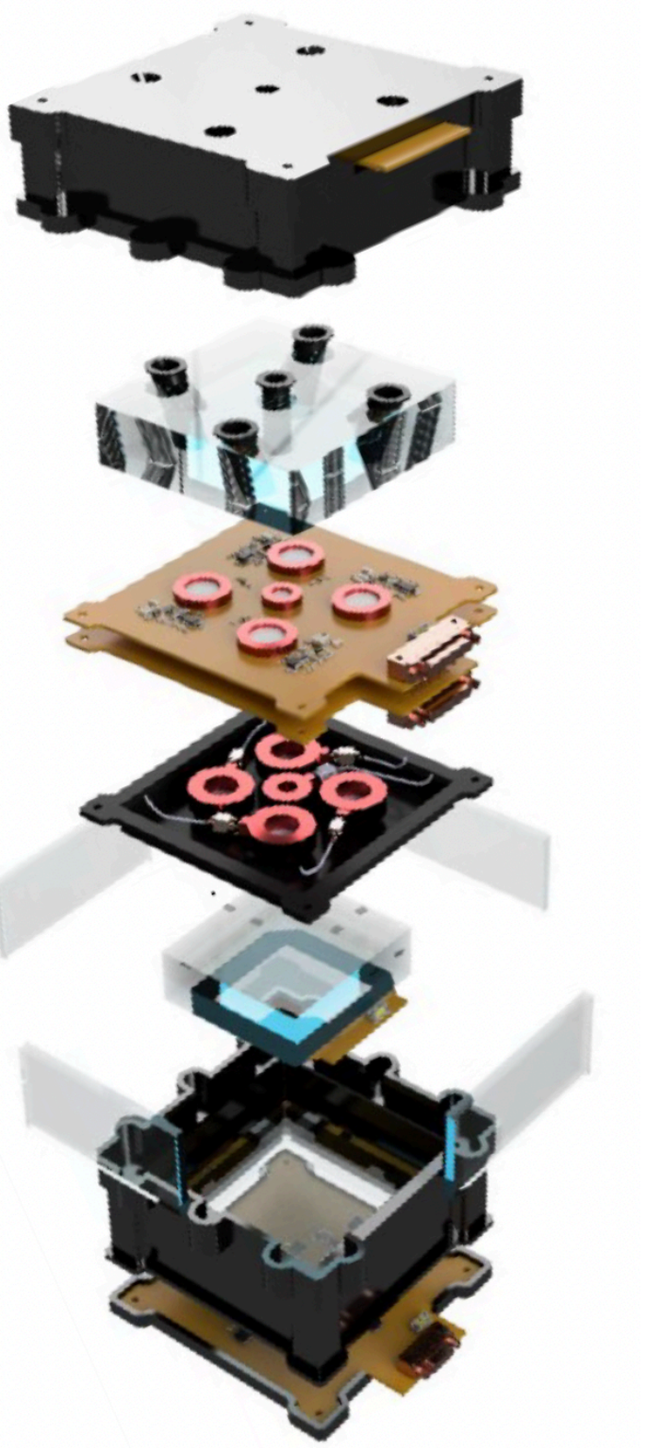


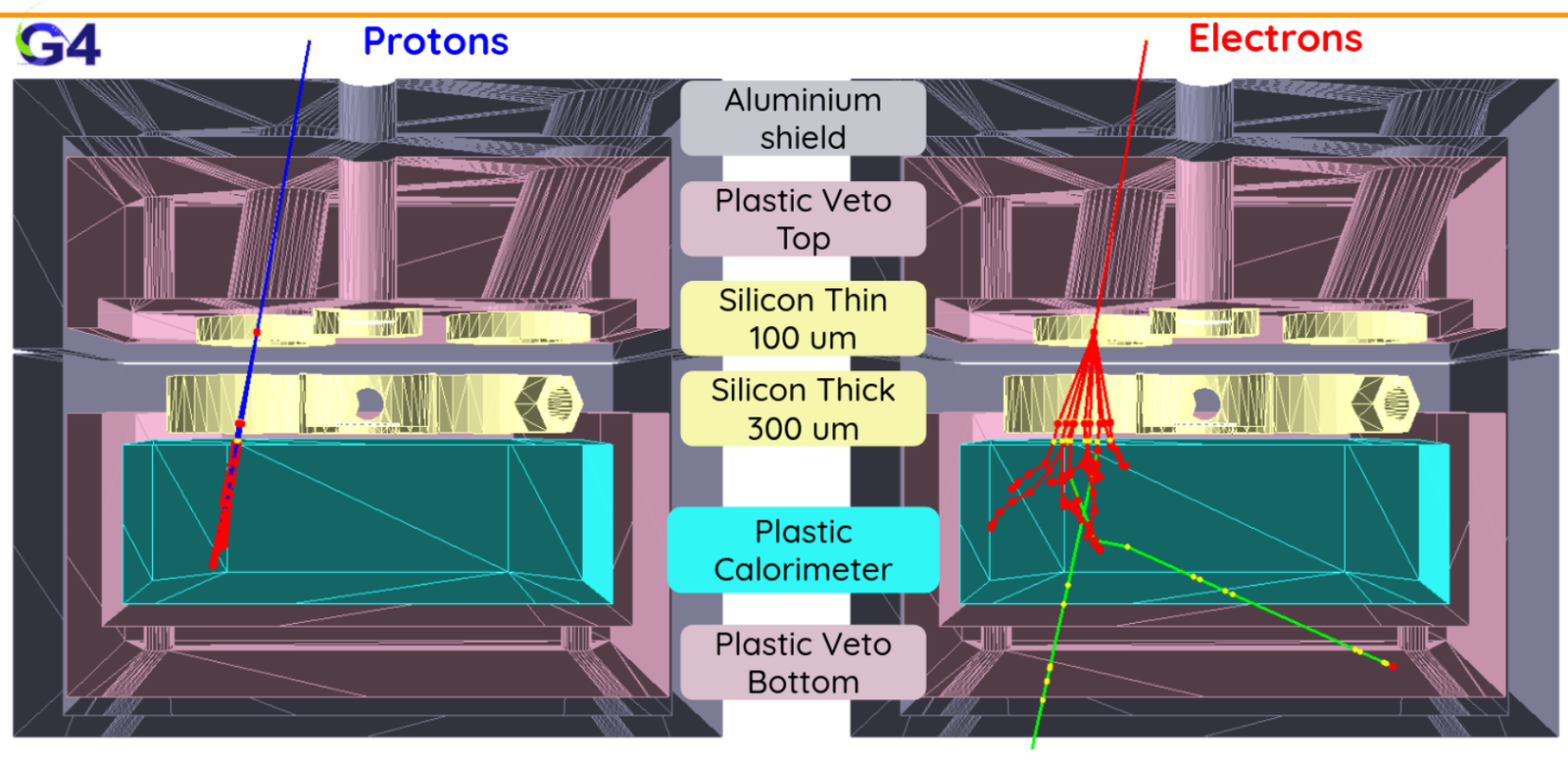


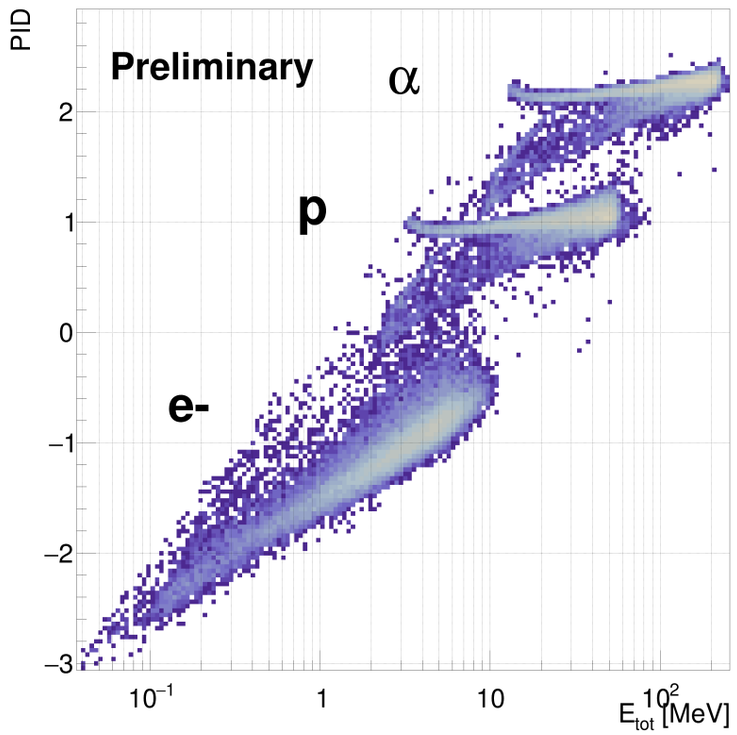
CALOg will be also used for the study of X and **ɣ**-rays from several tens of keVs up to 50 MeV (**preliminary estimates**)

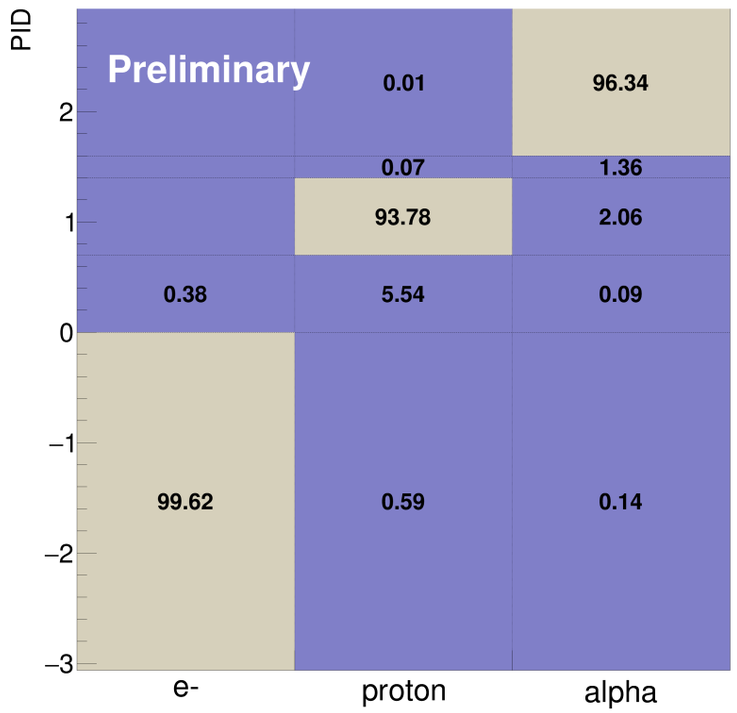


The Ziré payload – LEM (Low Energy Module)

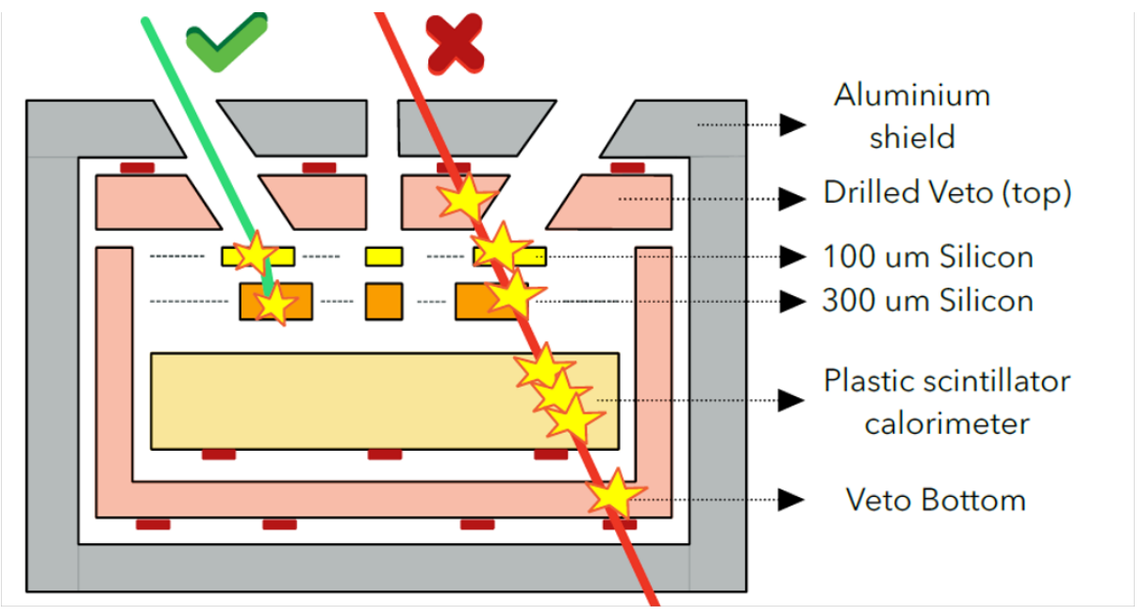


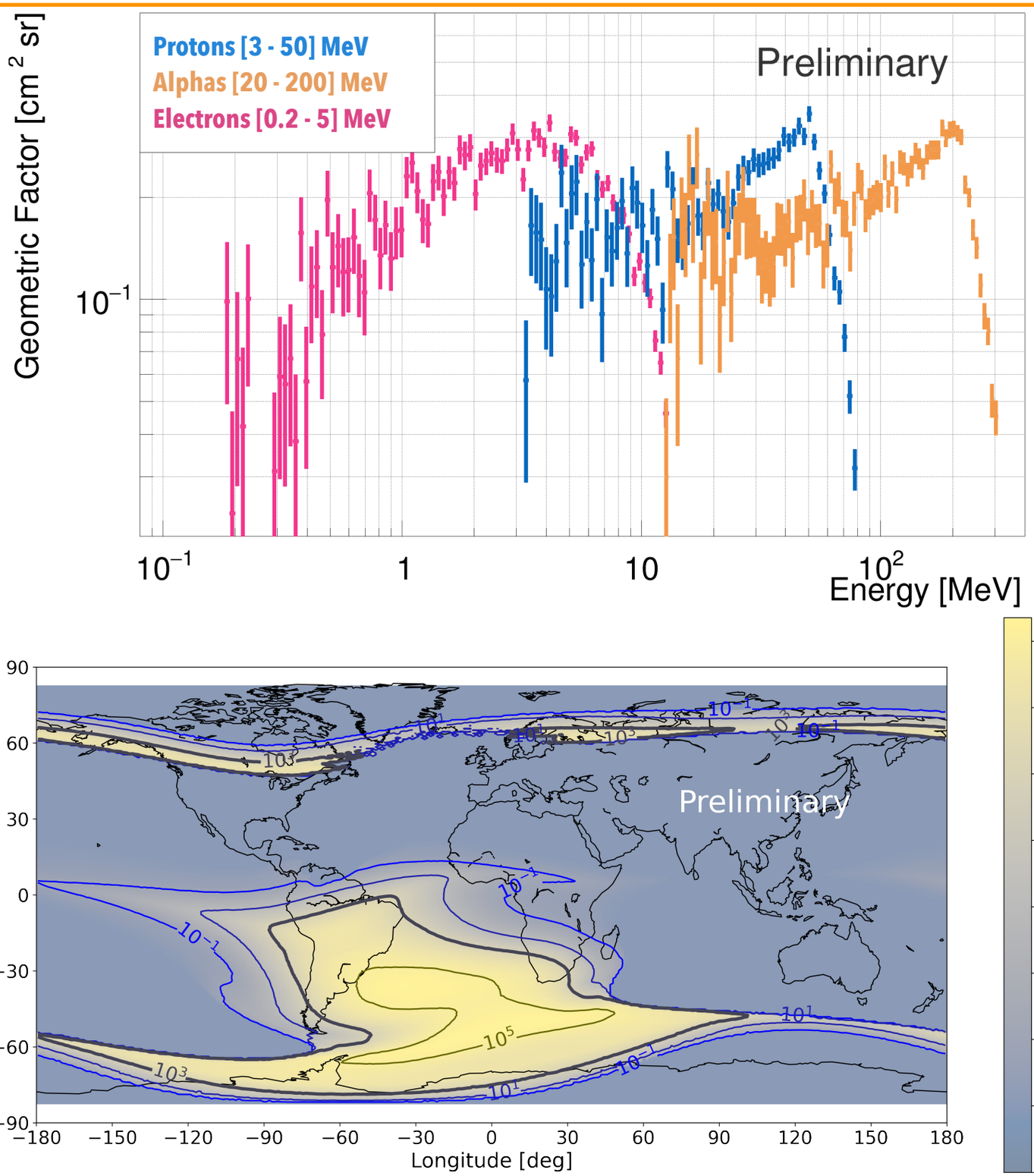






The Ziré payload – LEM (Low Energy Module)





Simulated orbital particle rate map for a 3-year of mission at nominal sensitivity.

Summary of science and technological goals

SCIENCE:

- Test HE neutrino detection feasibility using the Earth skimming geometry and Č light
- (UV - near visible) background characterisation from the Earth limb
- Measure electrons, protons and nuclei up to a few hundreds of MeV
- Measure [0.1-50] photons for the detection of transient and steady gamma sources (GRBs, e.m. follow up of GWs, SN emission lines, TGFs, …)
- Monitor very low energy (< 10 MeV) electron flux to study possible correlation with seismic activity due to Magnetosphere-Ionosphere-Lithosphere Coupling (MILC)

TECHNOLOGY:

- Space qualification of new technologies (SiPMs, onboard data reduction, additive manufacturing,…)
- 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, etc …