# The NUSES space mission

Ivan De Mitri

Gran Sasso Science Institute

INFN-Laboratori Nazionali del Gran Sasso

# NUSES

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

The NUSES proposal has been approved by the Italian government as a flagship initiative to relaunch the economy of the L'Aquila area.
It is a joint GSSI-Thales Alenia Space Italy (TAS-I) project.

The NUSES payloads are funded (to GSSI) by the Italian government and the Italian Minister for economic development.
Thales Alenia Space Italy (TAS-I) has been funded for the OASIS project, providing the NIMBUS platform to host the NUSES payloads.

A joint GSSI-INFN effort is currently ongoing for the design and construction of the NUSES payloads.

Participation of 60+ persons from many italian universitites/INFN units and the University of Geneva. Strong interest from US / NASA groups, most probably joining the collaboration, currently involved in the POEMMA and EUSO-SPB2 projects.

Ongoing work also with other industrial partners, e.g. FBK , Officina Stellare,…

# The NUSES mission: two payloads

## Terzina

Pathfinder for future missions devoted to **UHE cosmic ray and neutrino astronomy** throught space-based atmospheric **Cerenkov light** detection.

## Zirè

Monitor the fluxes **of low energy (<250 MeV) CR**, mainly electrons and protons, to study Van Allen belts**, space weather** and the magnetosphere-ionosphere-litosphere couplings (MILC) in case of seismic / vulcanic activities.
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.

## New technologies

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

# The NUSES Collaboration

60+ persons from many institutions.

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

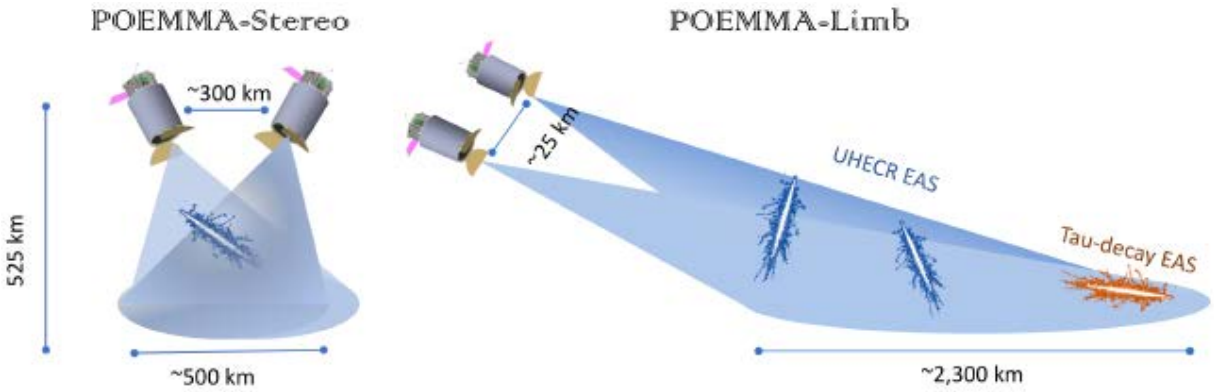
Current list of the italian groups:

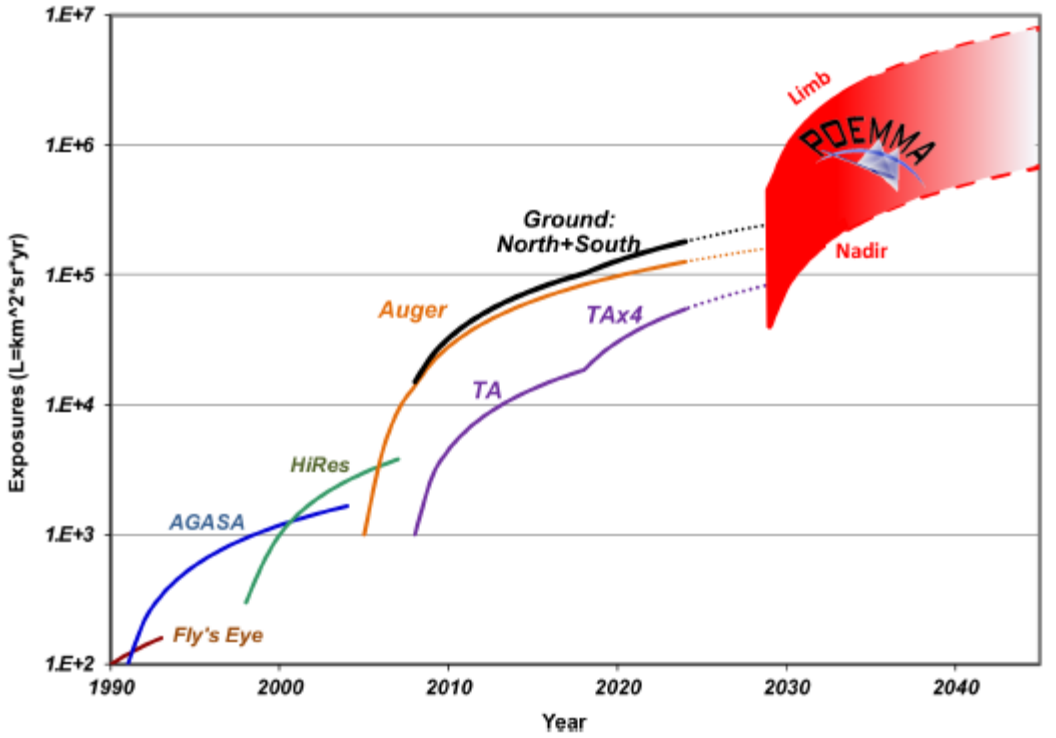
- Gran Sasso Science Institute
- INFN – Laboratori Nazionali del Gran Sasso
- Università dell'Aquila
- Università di Roma "Tor Vergata" and INFN-Roma2
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari and INFN
- Università di Padova and INFN
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN

University of Geneva +
Possible interests from:
- US institutions
- Spanish institutions
-……

# Probe of Extreme Multi Messenger Astrophysics

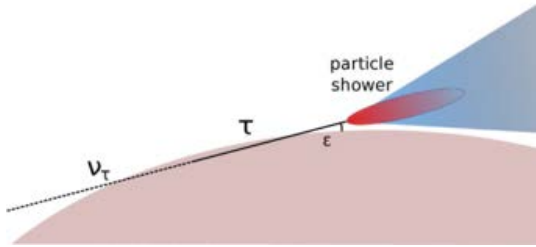
- ✓ Ultra High Energy Cosmic Rays.
- ✓ Astrophysical Neutrinos.
- ✓ International collaboration (lead by U. Chicago) . Main participants: USA, Italy, Germany, France, Denmark, Japan.

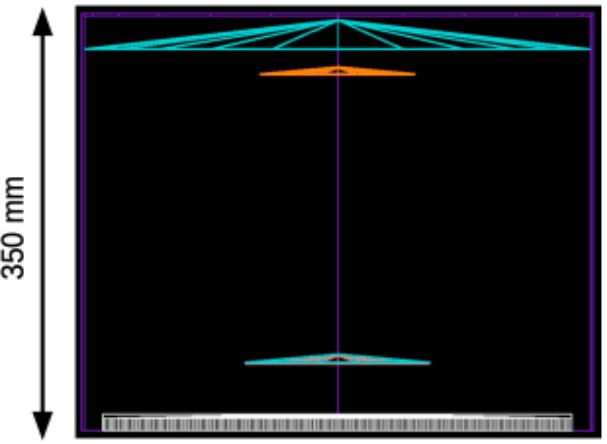


# Terzina

Detect Cherenkov radiation from the Earth limb.
UHE CR and neutrino detection. Background studies.

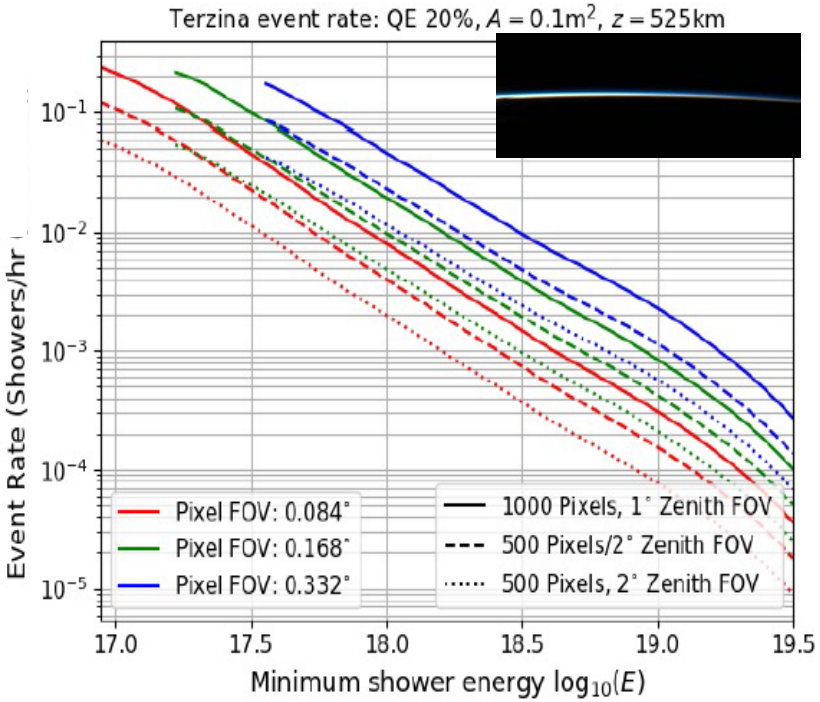



Double mirror optics
Area ~0.1 m$^2$

SiPM focal surface

Roughly 1 event/day

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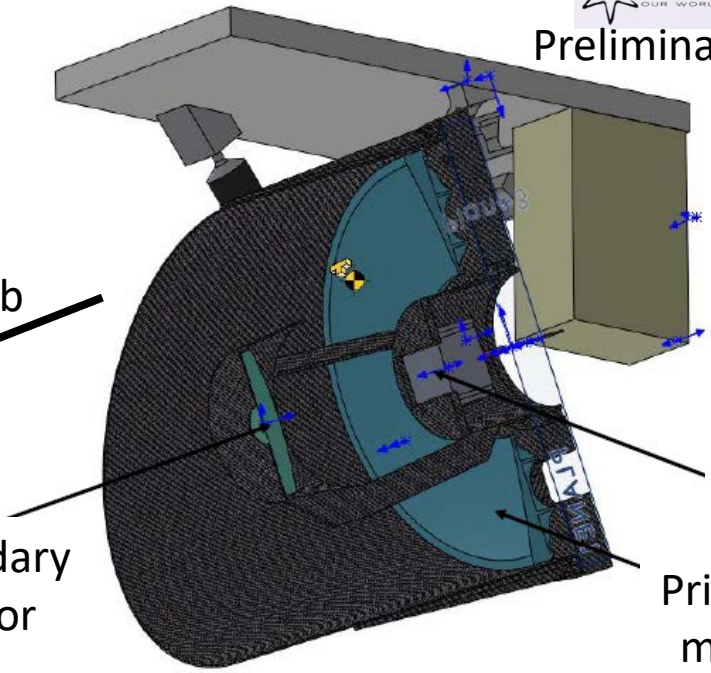
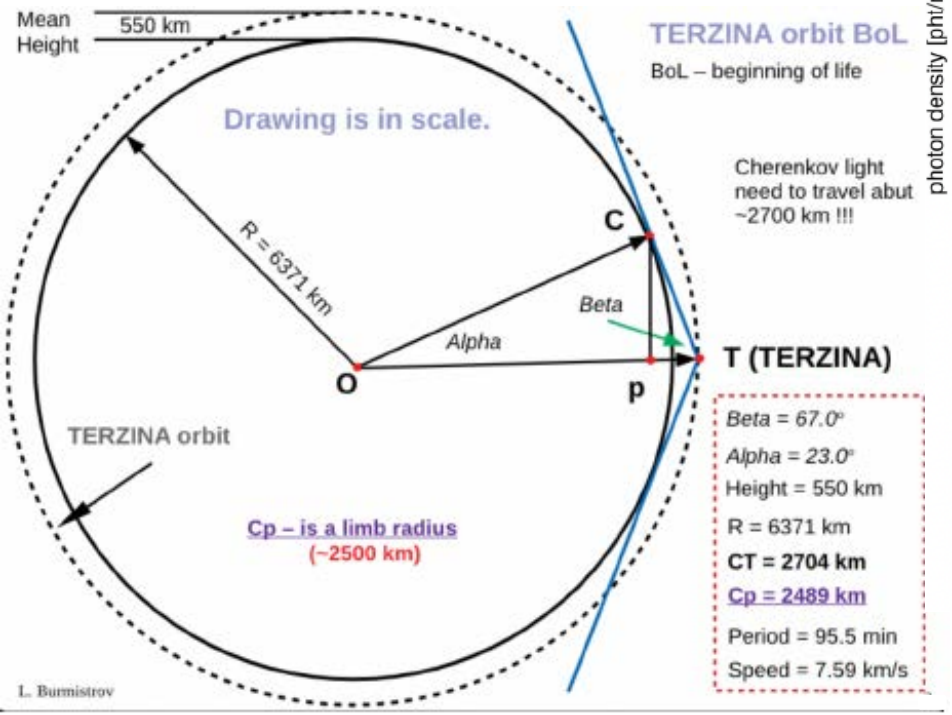
Preliminary design

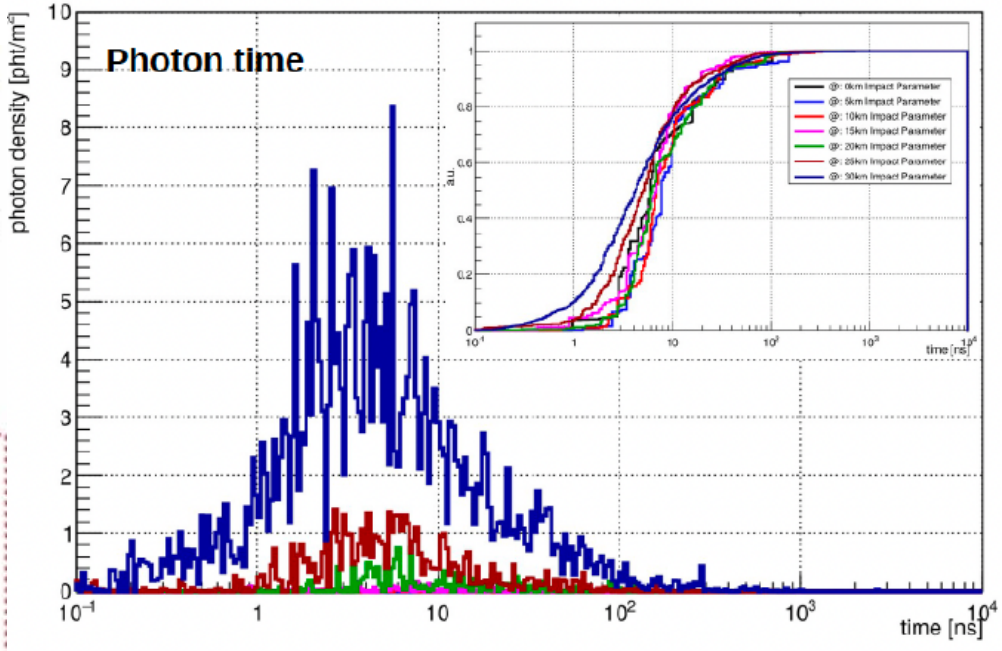


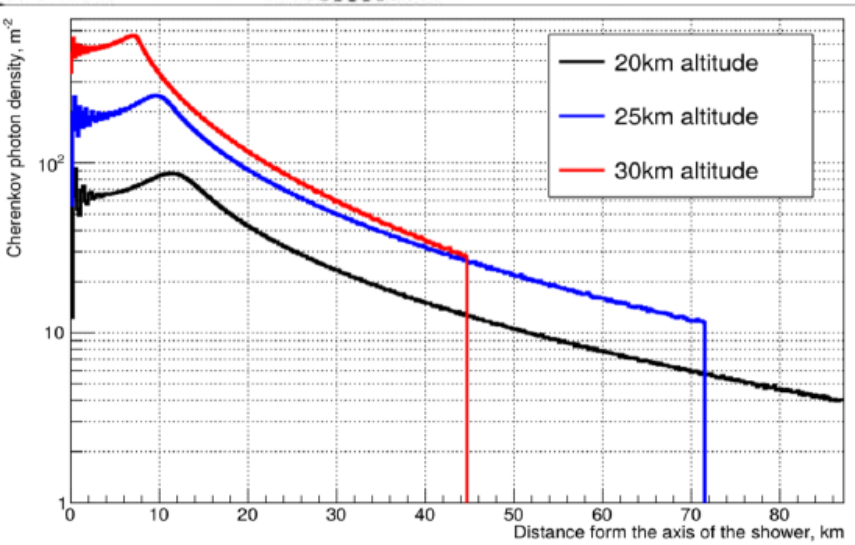

- ✓ Needed the same intensity per pixel expected in future large area IACT in space (POEMMA).
- ✓ Test of new technologies for Astroparticles studies in space.

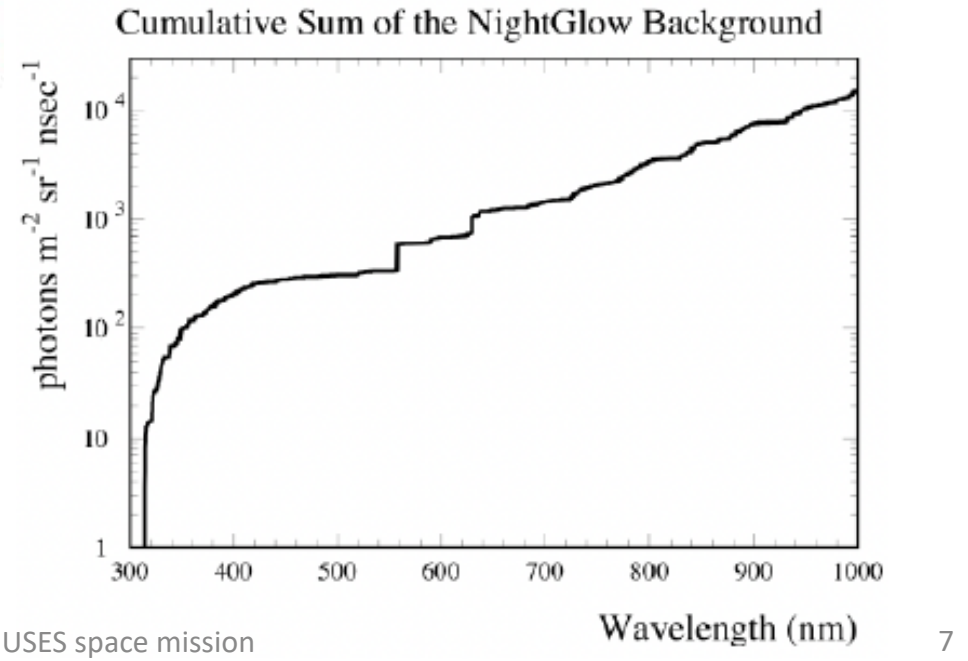
# TERZINA: S & N



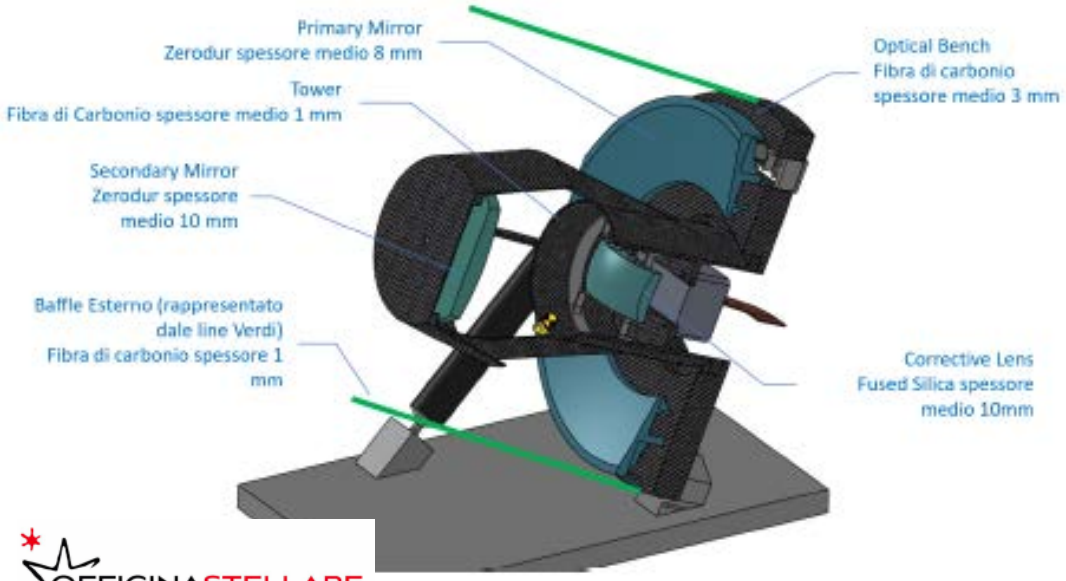

Most photons for 100 PeV promaries at ~25-35 km altitude.
>75% of photons collected in the first 10 ns (but on axis)



# TERZINA: mechanics & optics

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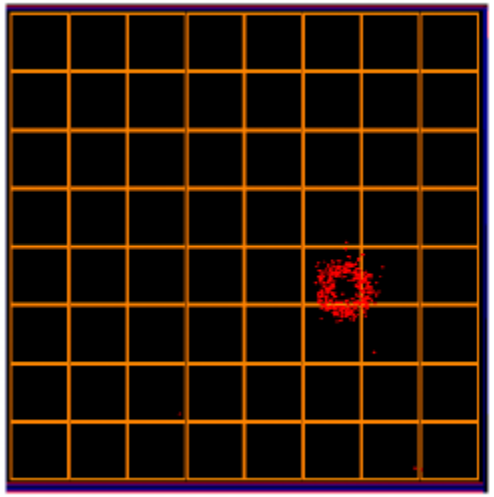
3mm pixels



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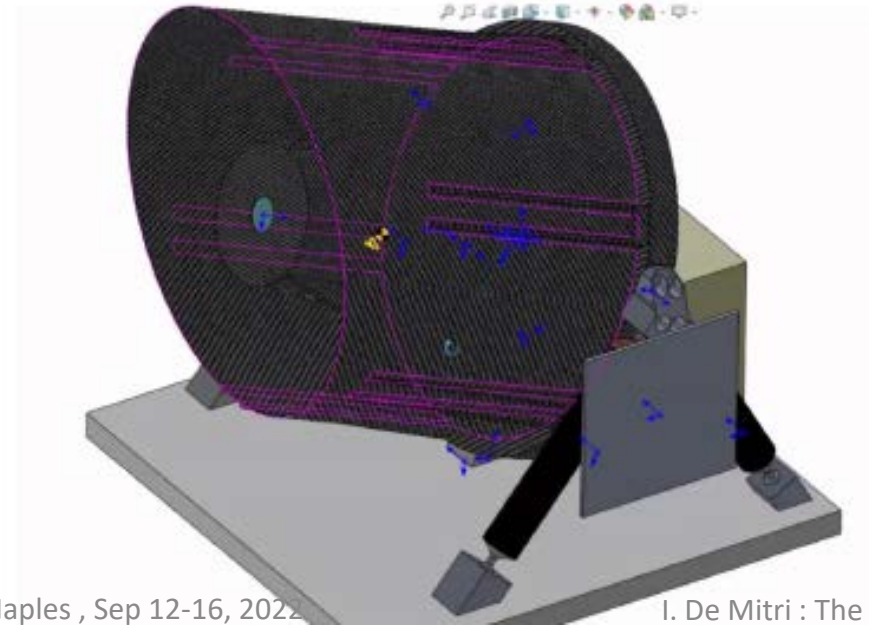
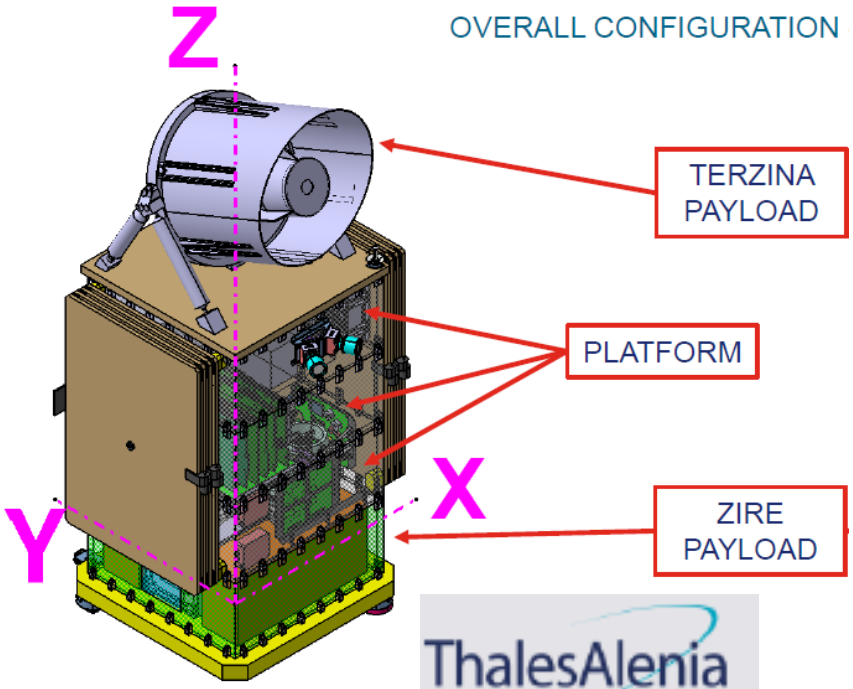
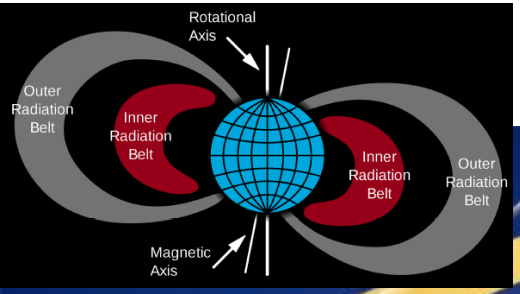


OVERALL CONFIGURATION



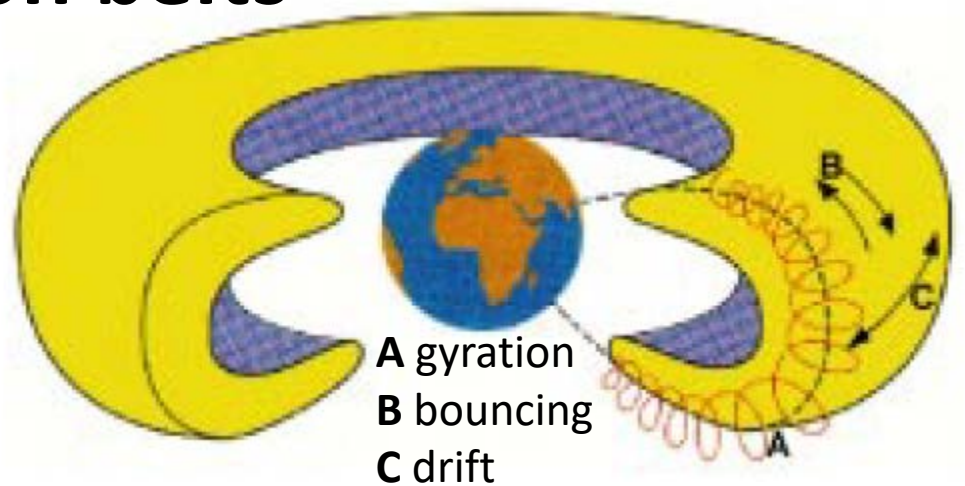

ThalesAlenia Space

# (Van Allen) radiation belts

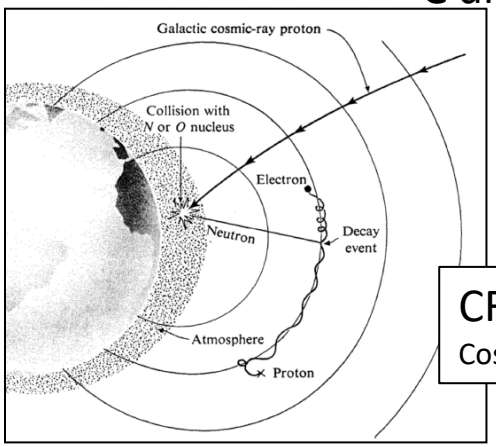









**A** gyration
**B** bouncing
**C** drift



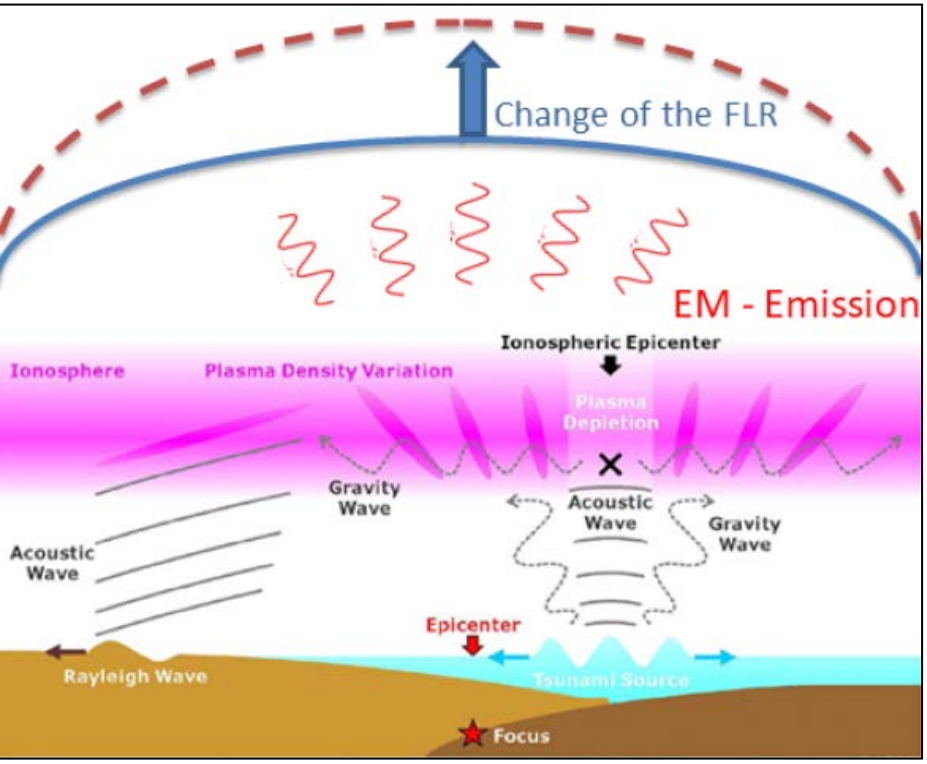

**CRAND**
Cosmic Ray Albedo Neutron Decay

| Belt type | Composition | Rigidity [MeV/n] | Filling mechanisms | L | Residence time [d] |
|---|---|---|---|---|---|
| Van Allen (inner) | $p$<br>$e^-$ | $0.1-100$<br>$0.01-1$ | $n \to pe^-\overline{\nu}_e$,<br>external belts | $< 2.5$ | $10-1000$ |
| Van Allen (outer) | $e^-$<br>$p$ | $1-10$<br>$0.1-1$ | solar wind | $> 2.5$ | $1-10$ |
| SAMPEX | $N^{+x}, O^{+x}$,<br>$Ne^{+x}$ | 10<br>$10-100$ | Anomalous CR | 2 | $10-100$ |

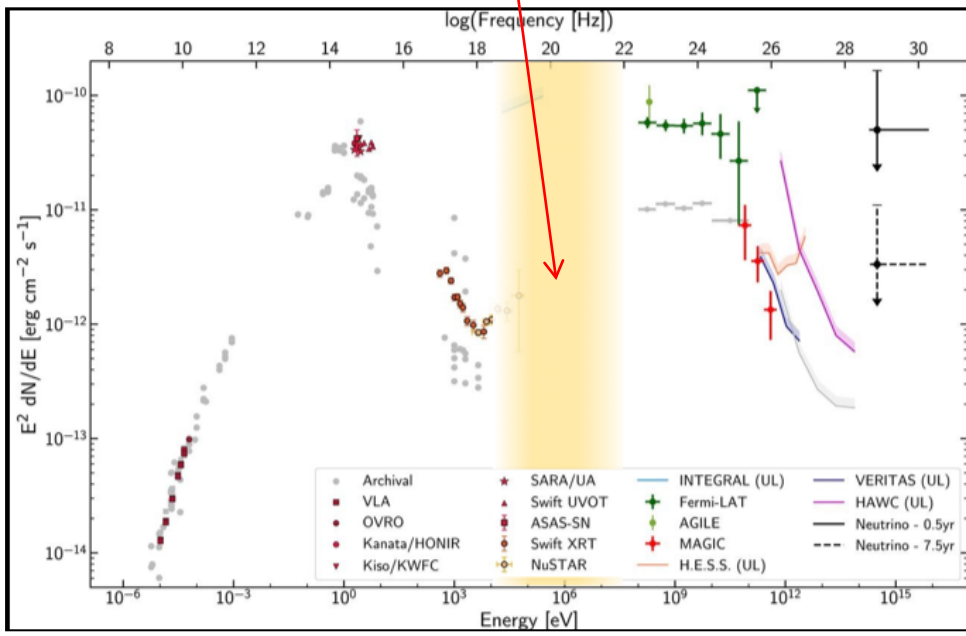
# Magnetospheric Ionospheric Lithospheric Coupling

# Steady and transient gamma ray sources

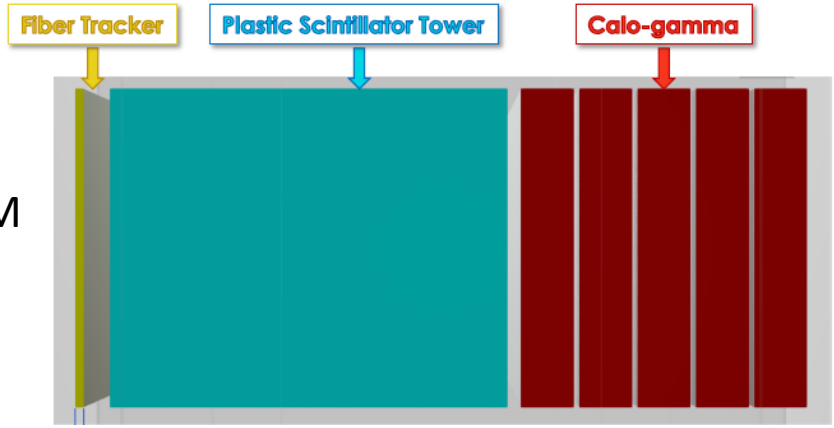
Electrons and protons




MeV photons

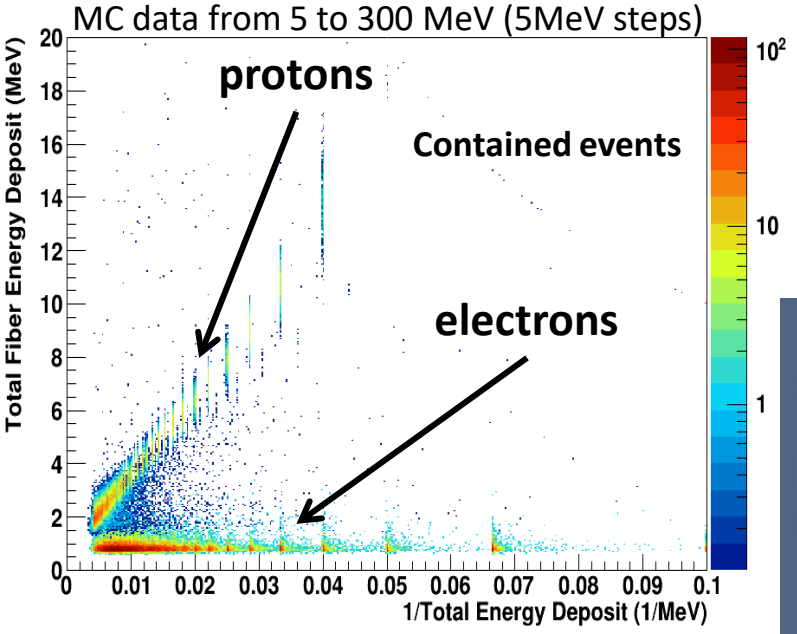


# ZIRE’

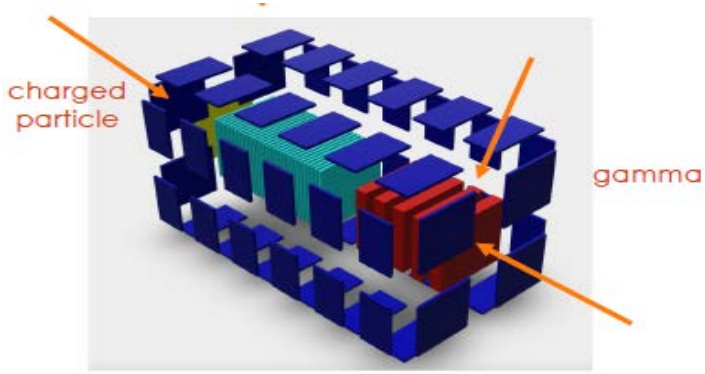


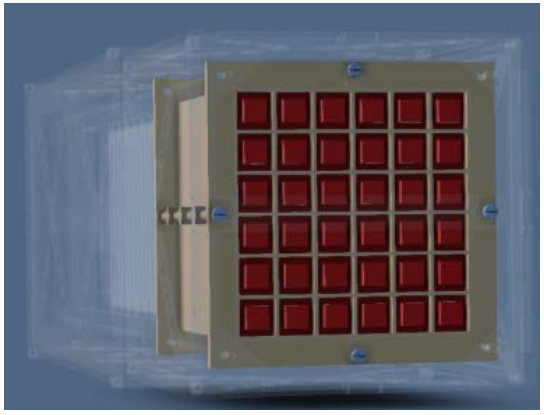

- A fiber tracker, readout by SiPM arrays
- Layers of plastic scintillators X-Y bars, readout by SiPM
- Absorption calorimeter (LYSO cubes radout by SiPM)
- A surrounding active veto system

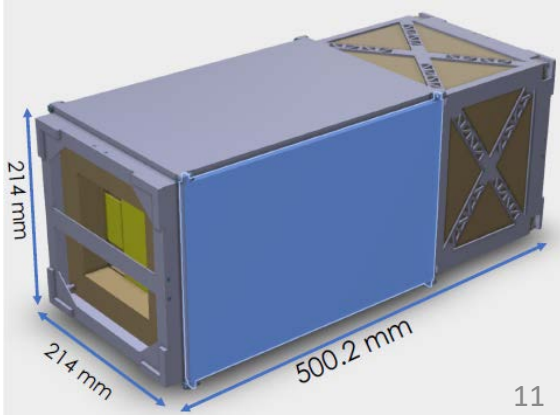
Energy ranges:
- From few up to hundreds MeV for electrons and protons / nuclei + Low Energy electrons
- 0.1 – 10 MeV for gammas




$(dE / dX)_{NR} \propto 1/\beta^2 \propto 1/E_{kin}$





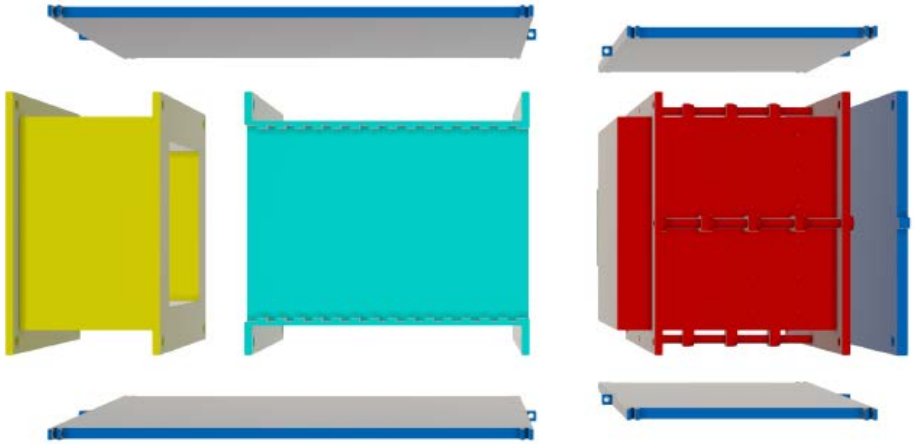
# ZIRE': general layout

FTK - Fibre Tracker

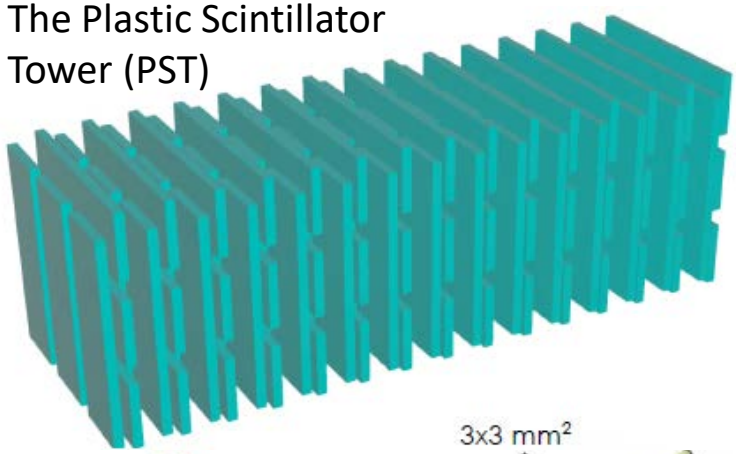
PST – Plastic Scintillating Tower

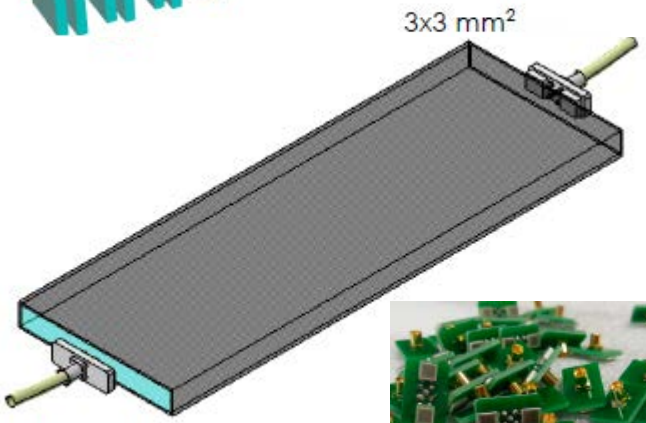
CALOg Calorimeter

ACS – AntiCoincidence System



## The Plastic Scintillator Tower (PST)

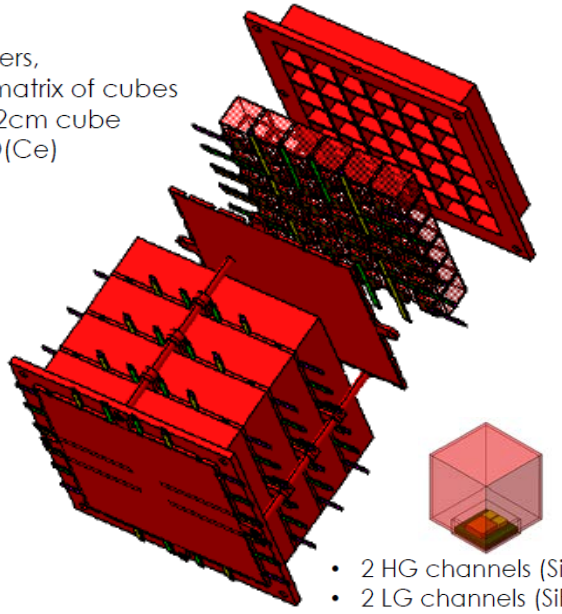






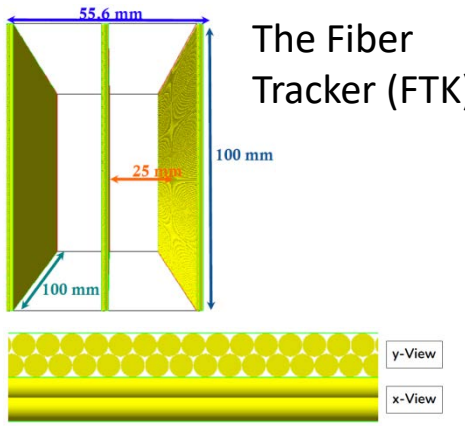

## The calorimeter (CALO)

- 5 layers,
- 6x6 matrix of cubes
- 2x2x2cm cube
- LYSO(Ce)

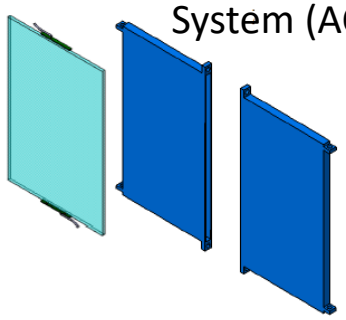


- 2 HG channels (SiPM 6x6 mm)
- 2 LG channels (SiPM 1x1 mm)

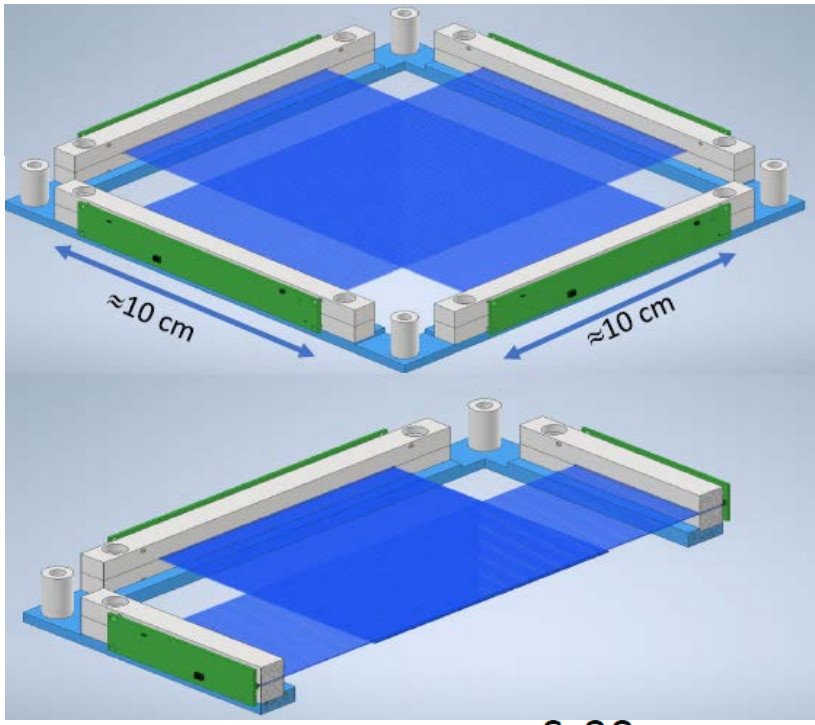
## The Fiber Tracker (FTK)




## The Anti-Coincidence System (ACS)

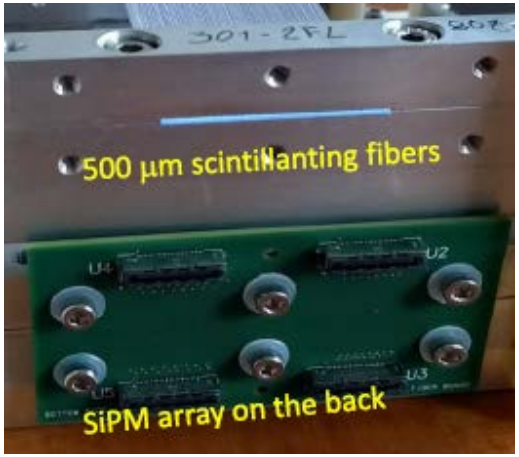


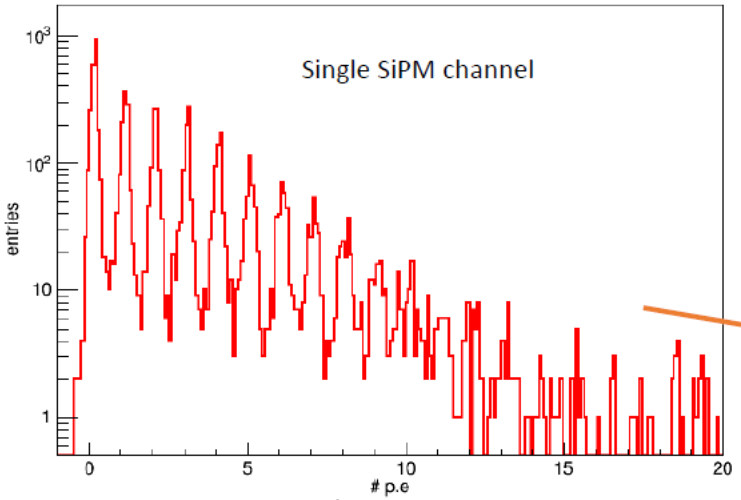
# ZIRE': The Fiber Tracker (FTK)

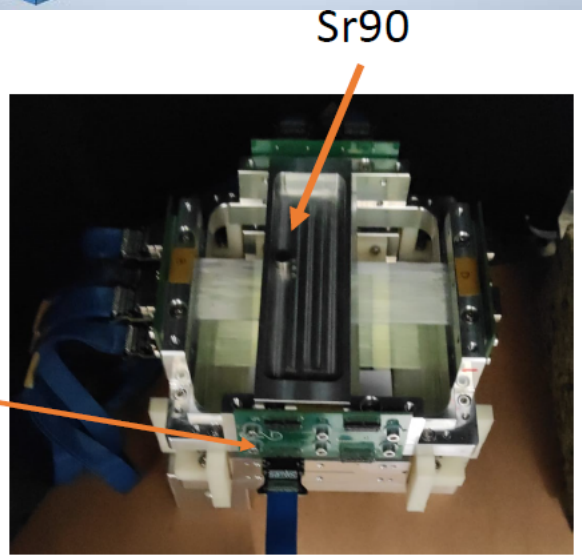



## A test module

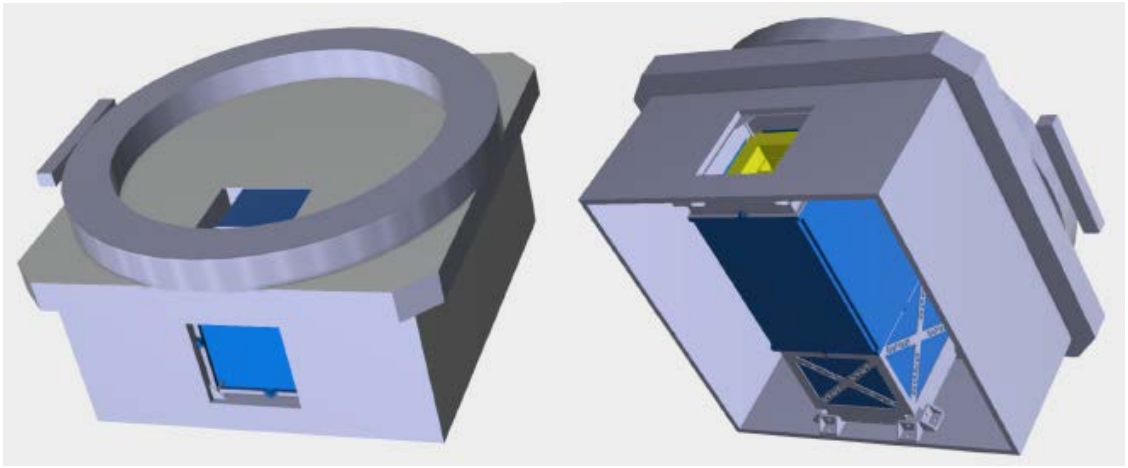
- X-Y module with Saint Gobain BCF12 500 μm diameter fiber
  - Two staggered layers in each view
- SiPM: Hamamatsu 128-channel 250 μm strip pitch
  - The odd channels (top pads) and the even ones (bottom pads) are connected to two different FE ASICs
  - In this way the trigger can be implemented requiring the coincidence between the signals from the two ASICs
- Read-out board
  - 4 Petiroc 2A ASICs
  - CAEN A7585D SiPM voltage module
  - Kintex-7 FPGA module
- DAQ based on the Raspberry Pi4

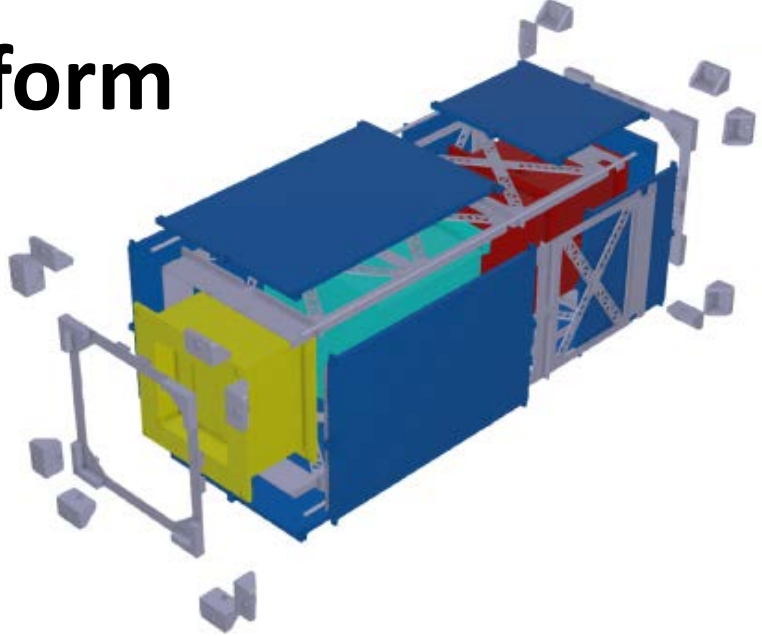


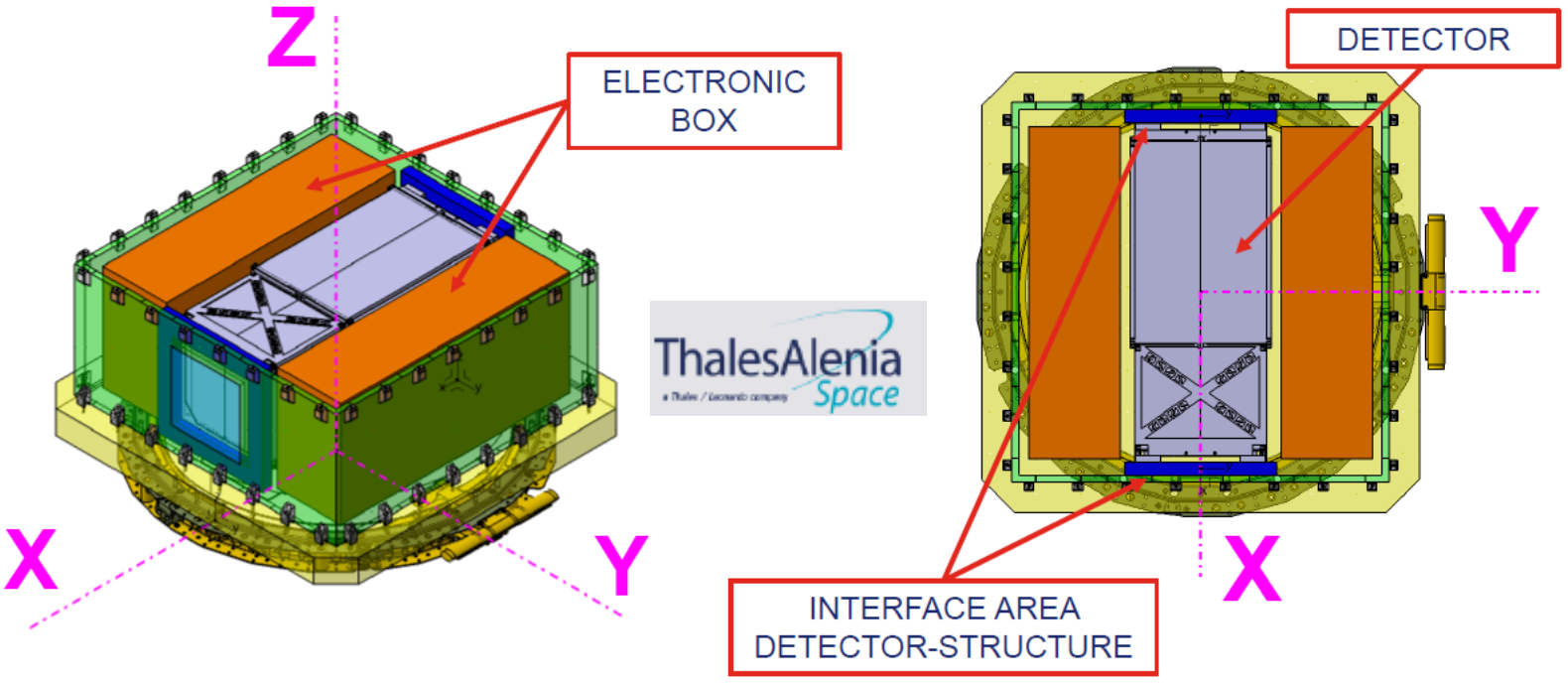



# ZIRE': mechanics / platform



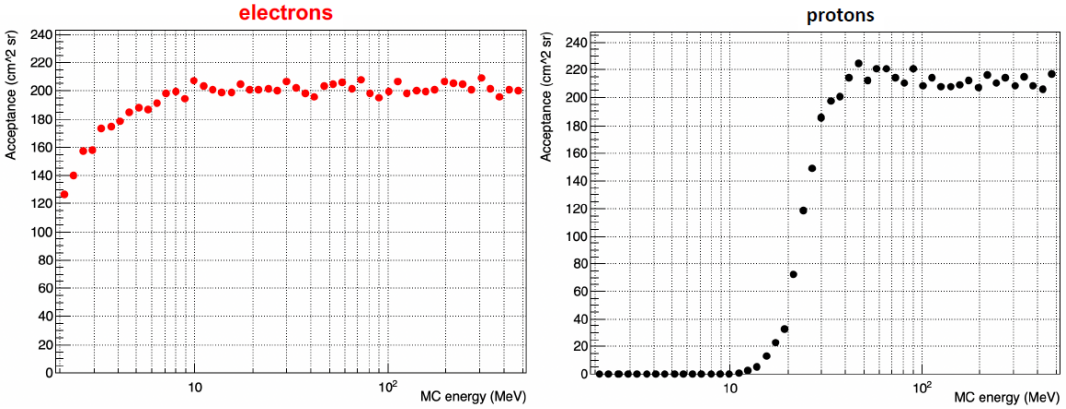


OVERALL CONFIGURATION - PLATFORM – ZIRE PL



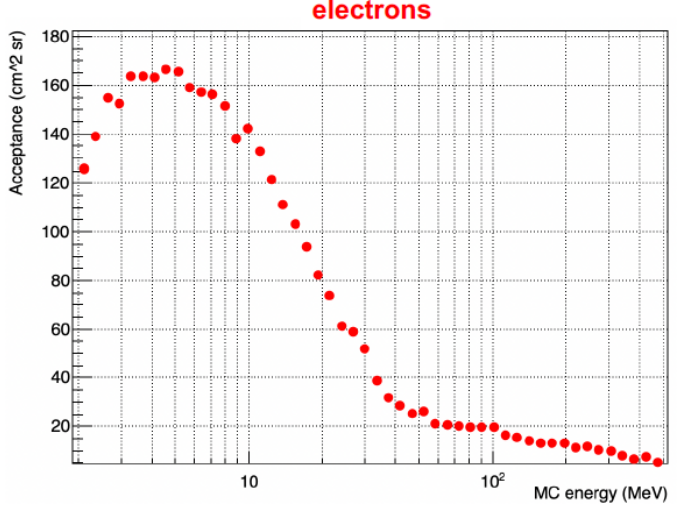
# ZIRE': G4 simulation

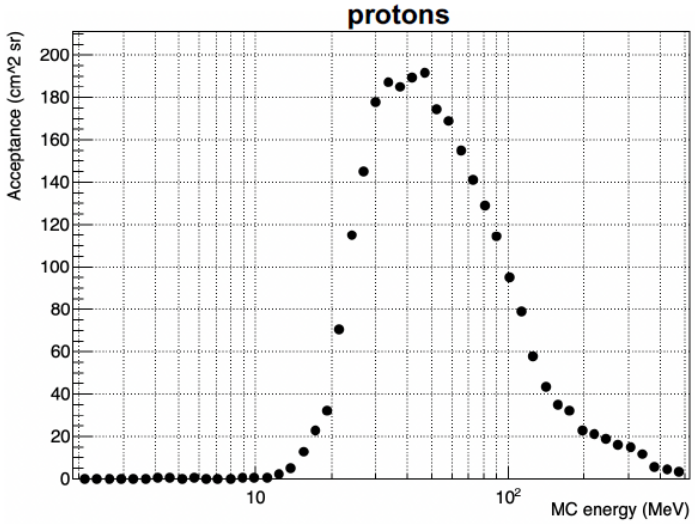
Ready for acceptance , efficiency, PID,… evaluations and detector layout optimization

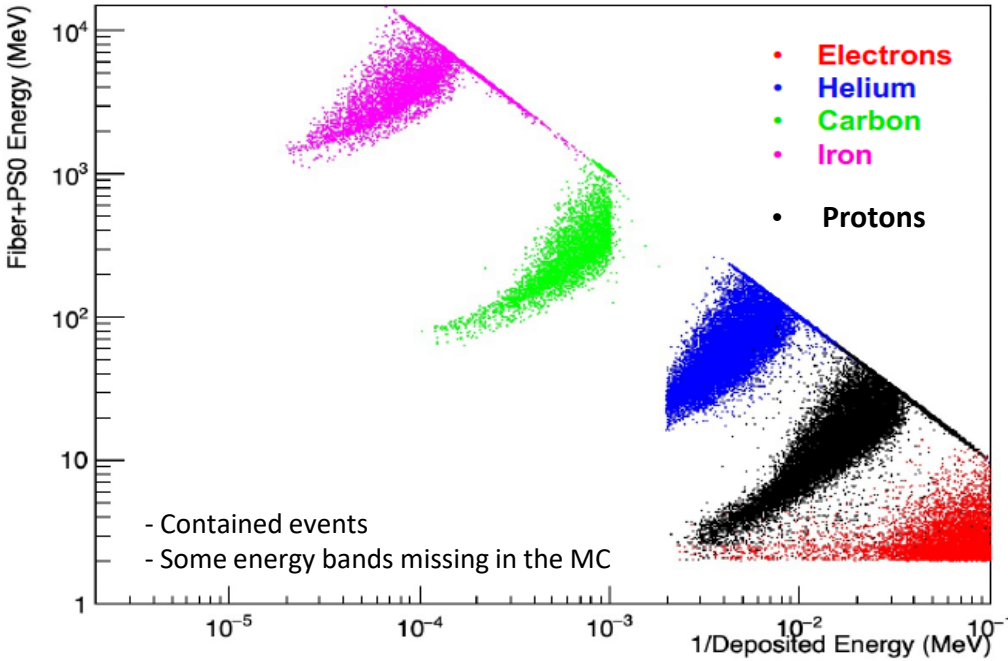


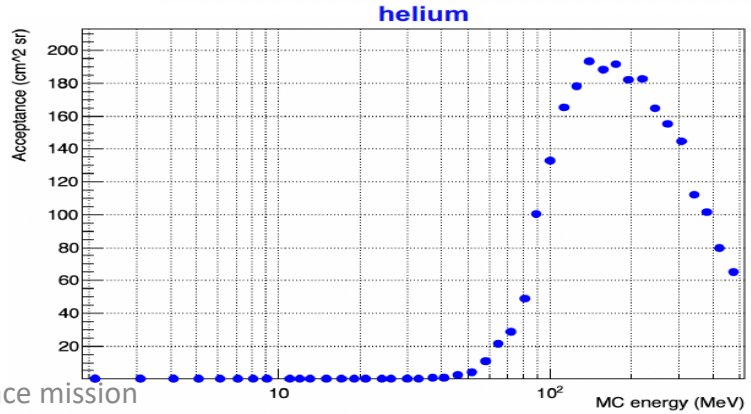




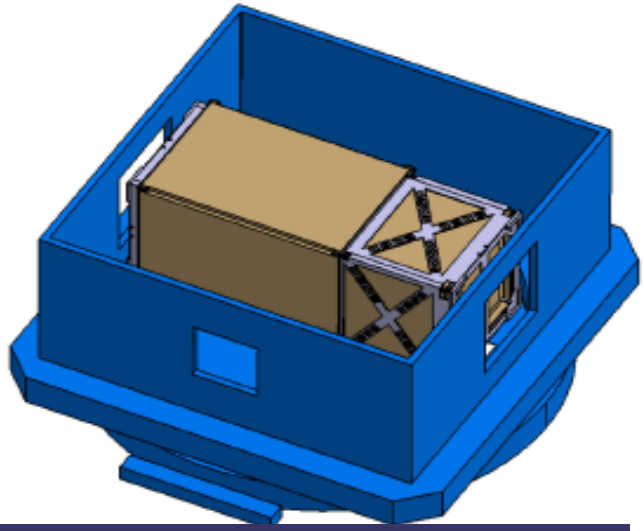


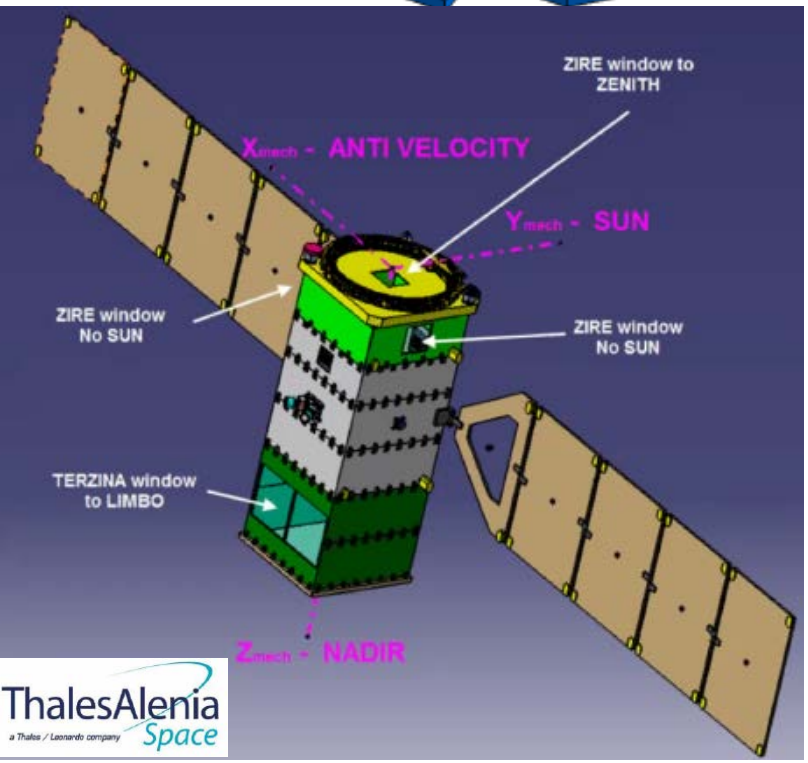



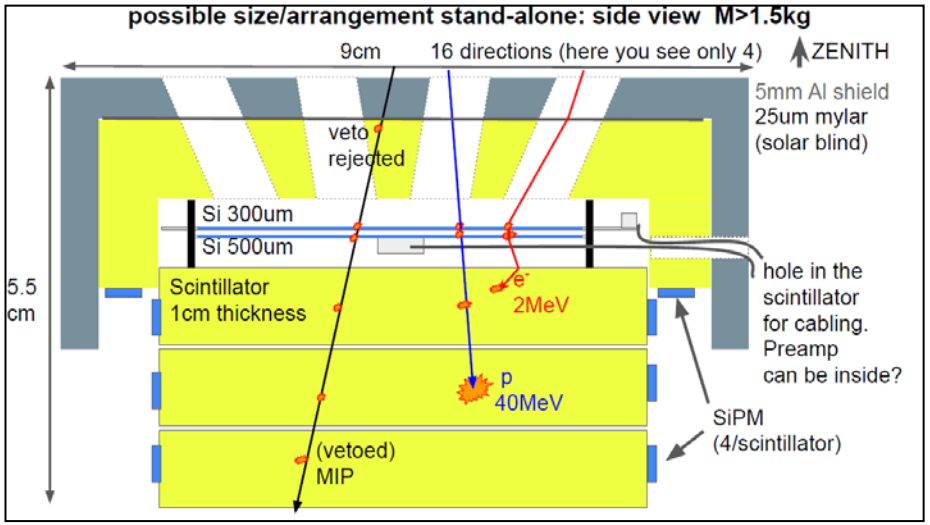



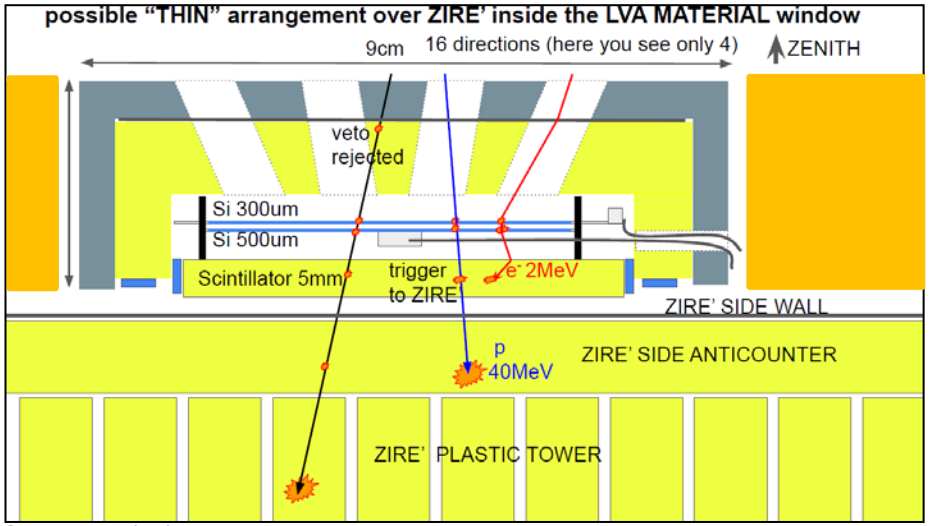
# ZIRE' onboard the platform + LEM



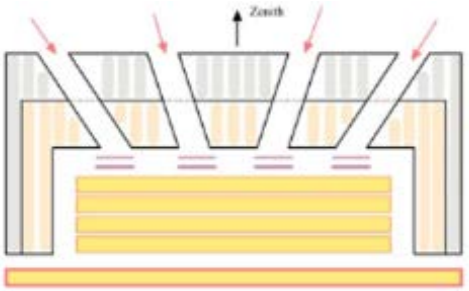



For the study of correlations with seismic activity, it's important to lower the energy threshold for electrons down to hundreds keV, looking at the zenith. Two possible geometries for the LEM.

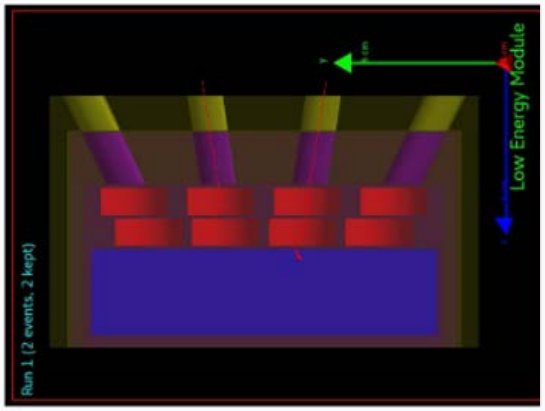


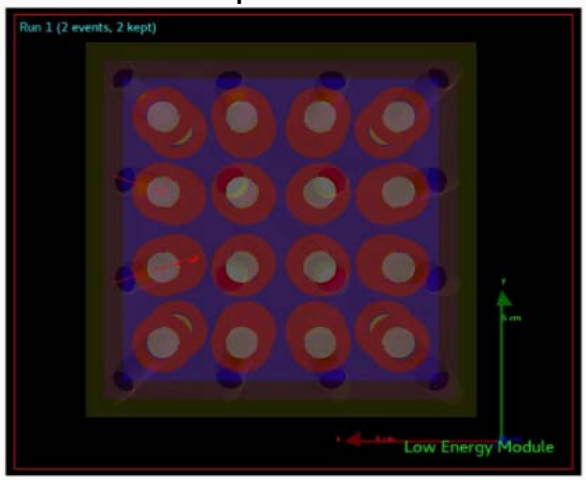
# ZIRE': the LEM layout




side view



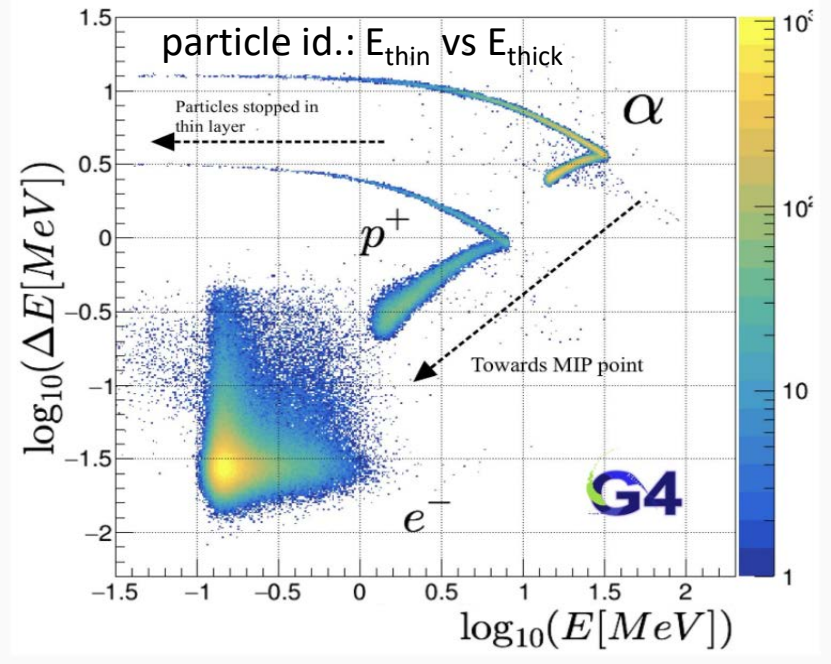

top view

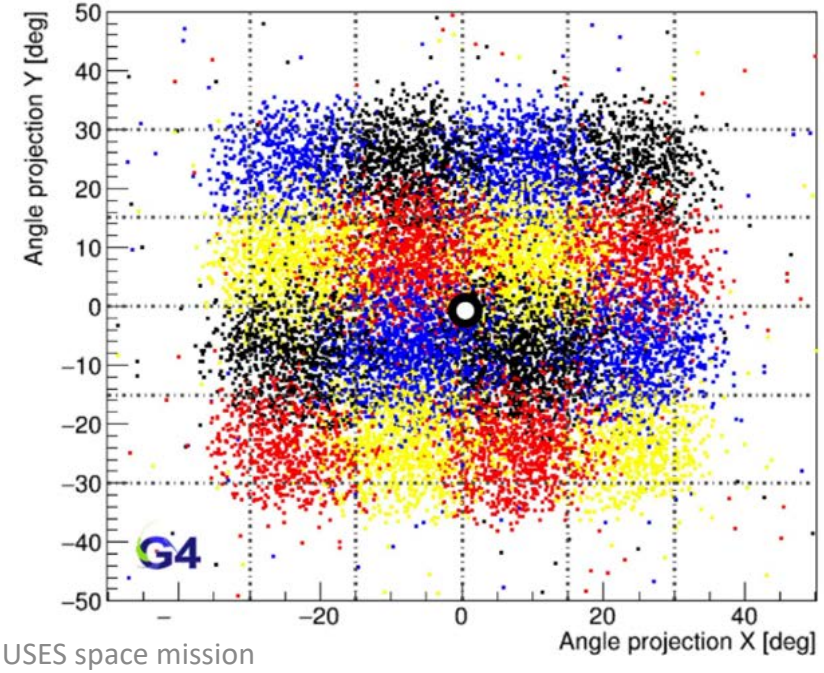



-16 channels spanning the ±35° FOV

-16 "thin" top detectors (ΔE) +
16 "thick" bottom detectors (E)

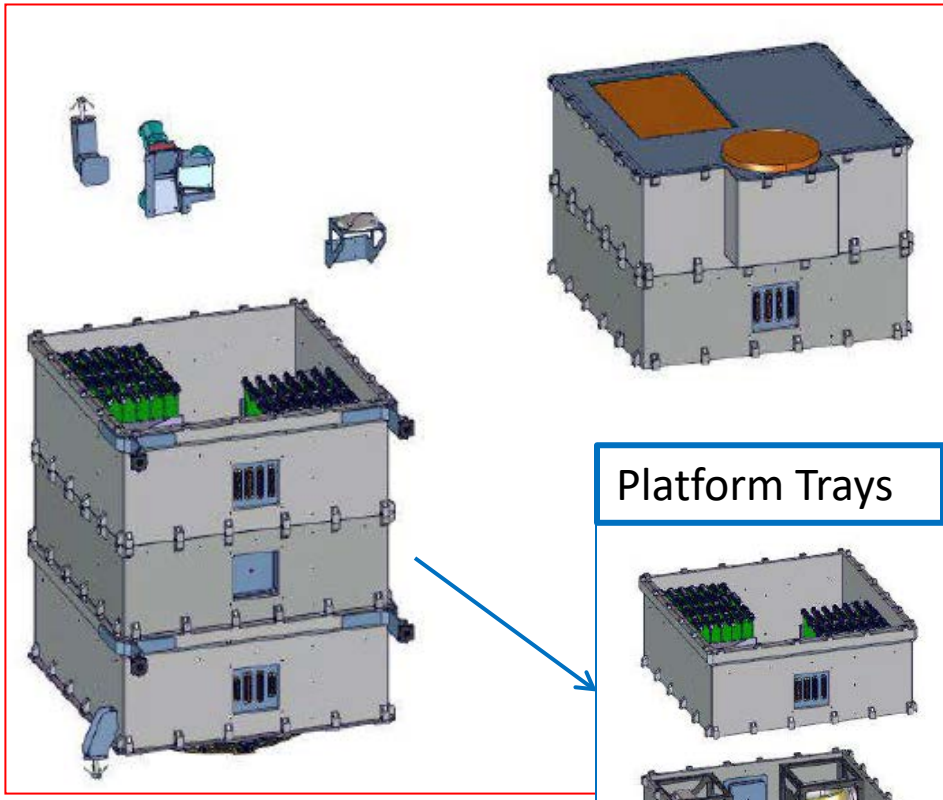
-maximum acceptance 0.5cm$^2$sr
(imply ≈kHz rate for trapped
electrons detected by silicon PIPS)



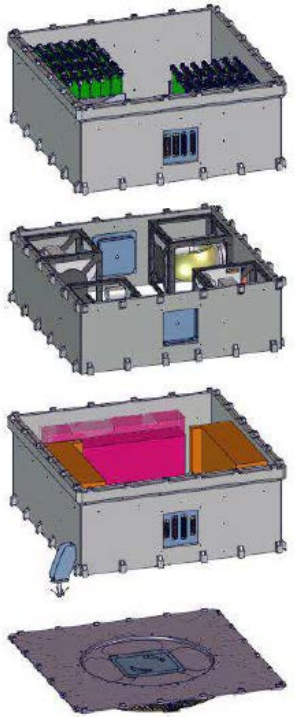



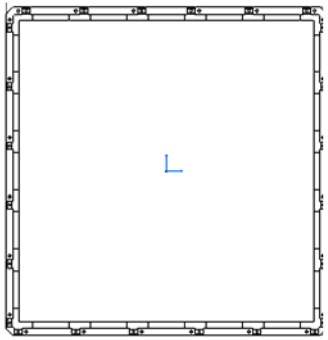
# The satellite / platform

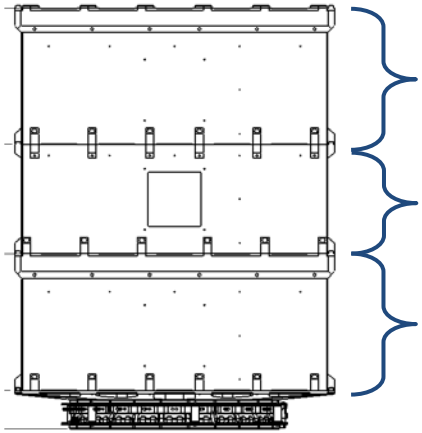

**NIMBUS** (**N**ew **I**talian **M**icro **B**US)
is a new Platform concept which foresees a modular approach relying on standard trays.



Platform Trays





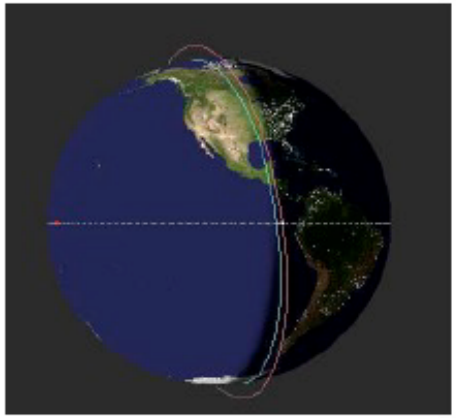


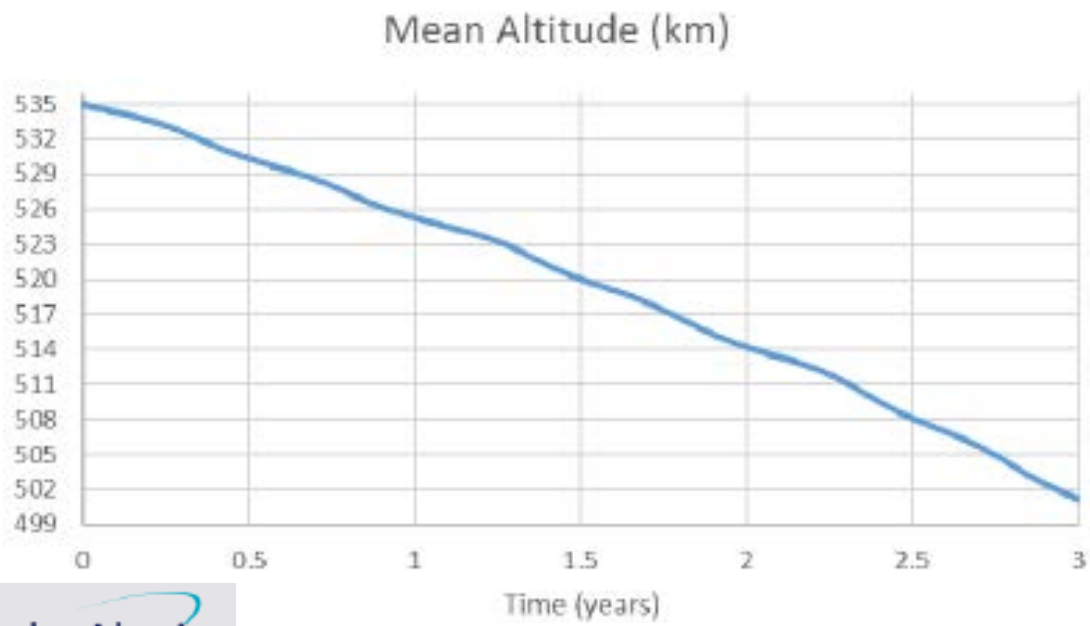
AOCS, Telemetry and Tele-command (TT&C) and GPS Receiver units

AOCS (Attitude and Orbit Control System): units\actuators

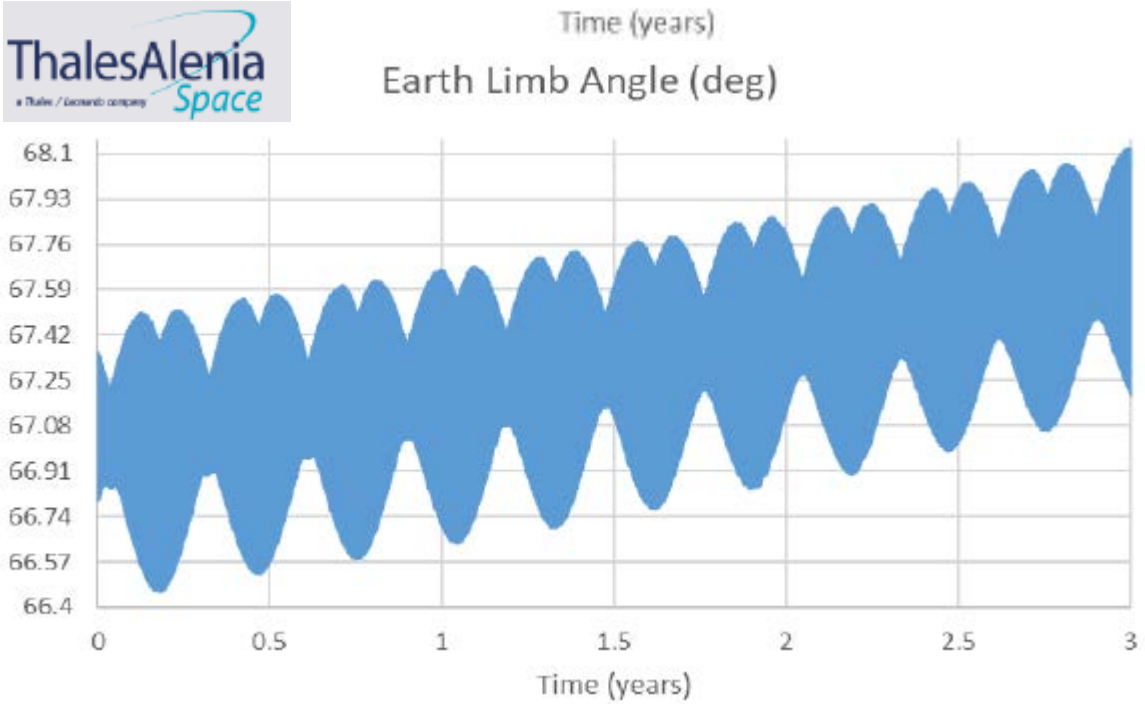
EPS (Electric Power system)

# The orbit

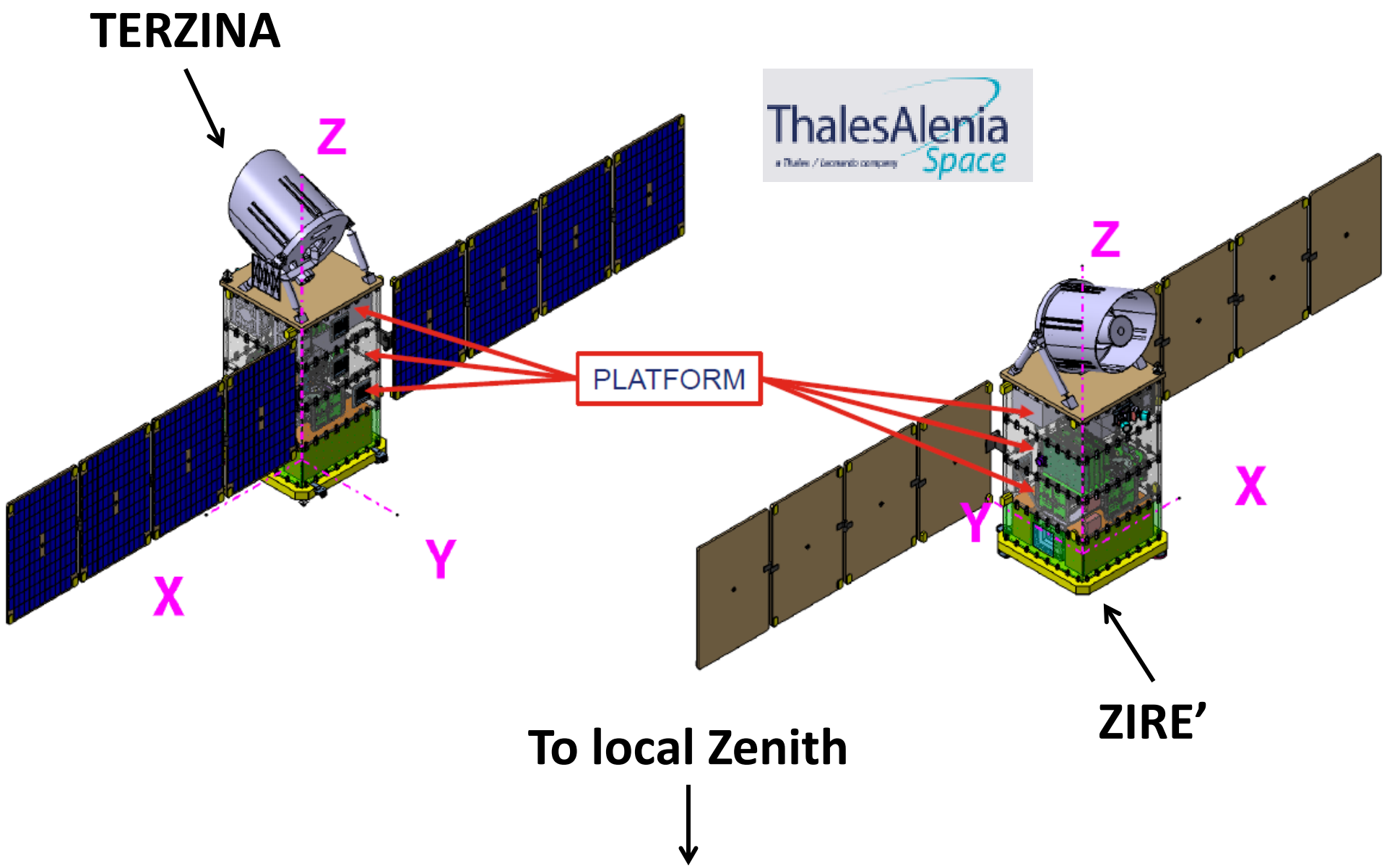





- Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (mean altitude ~ 600 Km, inclination = 97.8°, LTAN = 18:00);
- Orbit optimization for Cherenkov photons detection;
- Ballistic mission (no propulsion for orbital control).



# The platform/payload layout



# Summary of science goals

- New observation methods : Cherenkov light from the limb
- Networking with other missions : MILC effects, GRB, space weather
- Precursor for larger missions: POEMMA like, Crystal Eye, ….

- First Observation of High Energy cosmic ray showers from space through Cherenkov signal
- Certify 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 MeV
- Study particle flux correlation with seismic activity and space weather phenomena
- Monitor very low energy (0.5-5 MeV) electron flux
- Measure photons in the 0.1-10 MeV for transient and steady gamma source detection
- ……..

# New technologies/approaches (in space)

- Go from PMT to SiPM (fully testing them for future missions)
- Use a scintillating fiber tracker (~300μm) readout by SiPM arrays
- Optimize a LYSO crystal array to act as a (astrophysical) gamma ray detector (0.1-10 MeV)

*e.g. Crystal Eye*

- Setup a Cerenkov telescope with SiPM focal plane
- Design/space-qualify of the whole related electronics
- 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
- Use 3D printing technologies for payload mechanics
- ….
- **…….and interdisciplinary applications of the technologies and of the observations**

# First “in person” General Meeting. GSSI May-Jun 2022

Four half-day sessions, about 25 talks, more than 80 registrants (academy and industry)

# UHECR2022 at GSSI




Contact
uhecr2022@gssi.it

## General information

The UHECR2022 symposium will be held at the Gran Sasso Science Institute (GSSI) and jointly organized by GSSI, INFN - Laboratori Nazionali del Gran Sasso (LNGS) and the University of L'Aquila.

It will be the sixth edition of the series of meetings that started in Nagoya in 2010 and continued in CERN (2012), Springdale, Utah (2014), Kyoto (2016) and Paris (2018).

The event is dedicated to the discussions of the latest UHECRs observations and theoretical developments, also reviewing future plans in the field.

Topics will include the following subjects:

- Acceleration to the highest energies
- Source scenarios and CR propagation
- Galactic and extragalactic magnetic fields
- Transition from galactic to extragalactic CRs
- Hadronic interactions related to EAS interpretation
- Multi-messenger connections of UHECRs, neutrinos, gamma rays and gravitational waves
- Physics beyond the standard model

Invited reviews, contributed talks and posters will be presented.

You are invited to submit your abstract by July 25 (**postponed to August 5**).

The symposium will be held in person, in compliance with the relevant COVID-19 regulations at the time of the meeting.

Due to possible COVID-19 restrictions, the participation to the workshop might be limited to the first registrants. We then recommend you to register as soon as possible, and anyway not later than August 31 (**postponed to September 9**).

**3-7 October at GSSI**
**More than 145 participants**
**About 70 talks + 35 posters**

**www.uhecr2022.gssi.it**

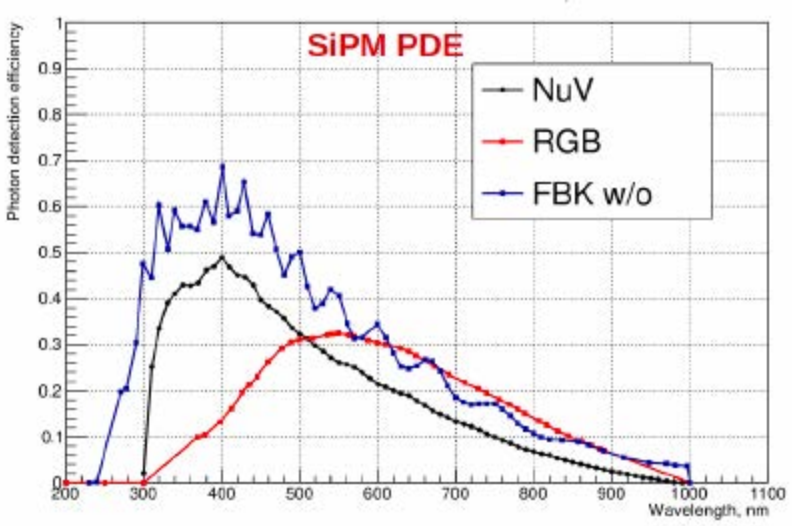
GRAN SASSO SCIENCE INSTITUTE

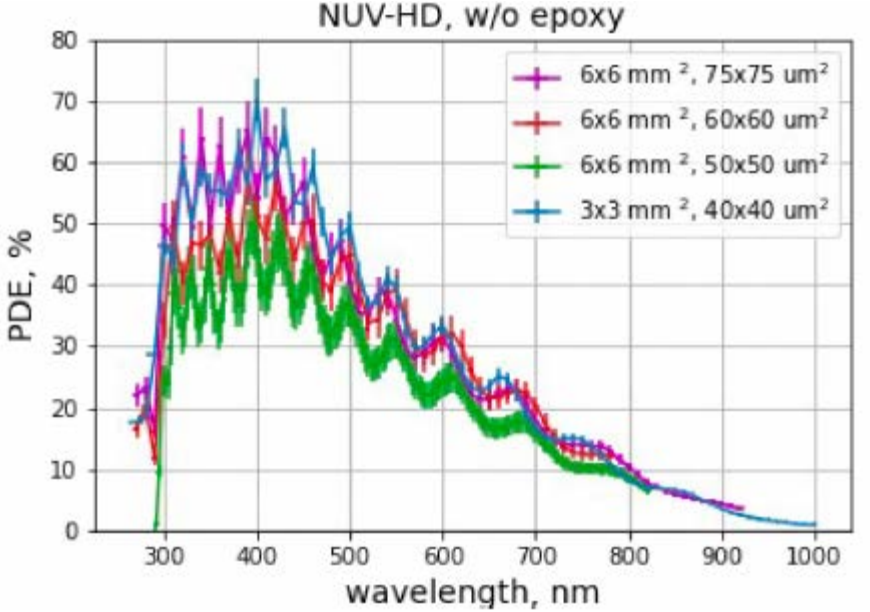
INFN LNGS

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

# MORE STUFF

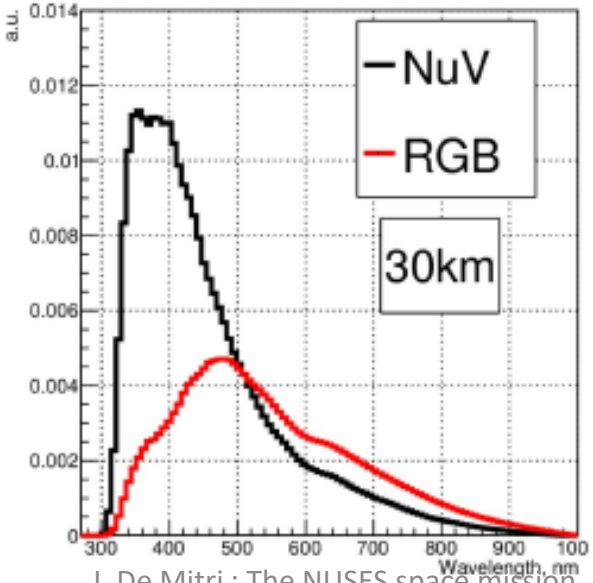
# TERZINA: testing SiPMs

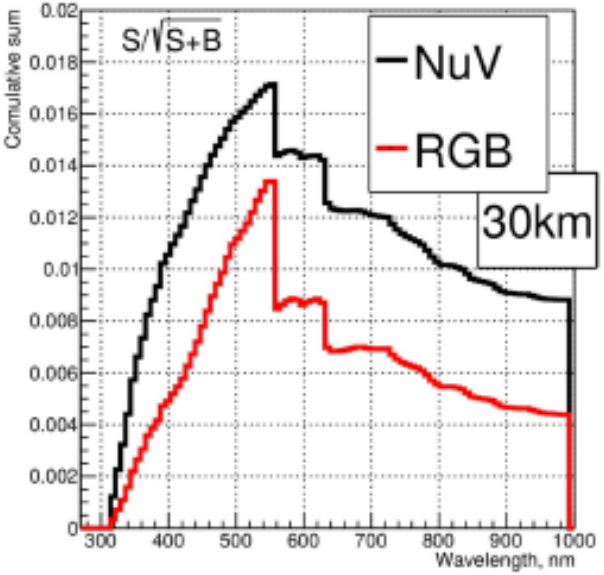



Testing different sensors:
- Cell size
- NUV vs RGB
- temperature dependence
- epoxy coating
-……..

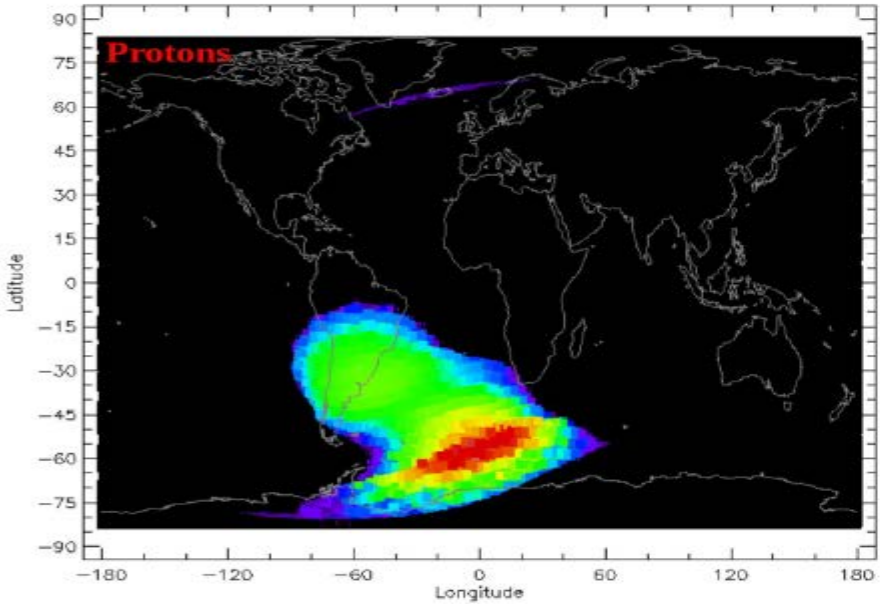
NUV clearly preferred

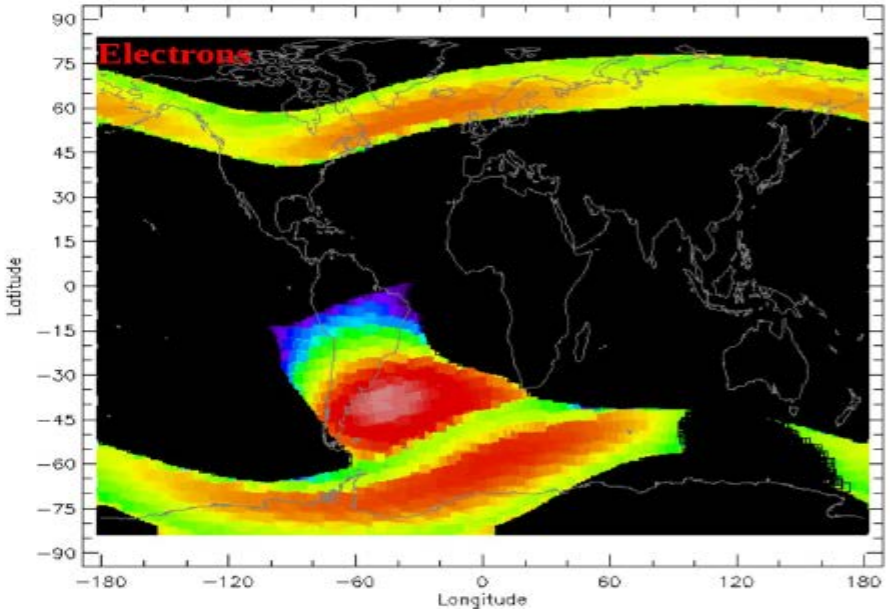


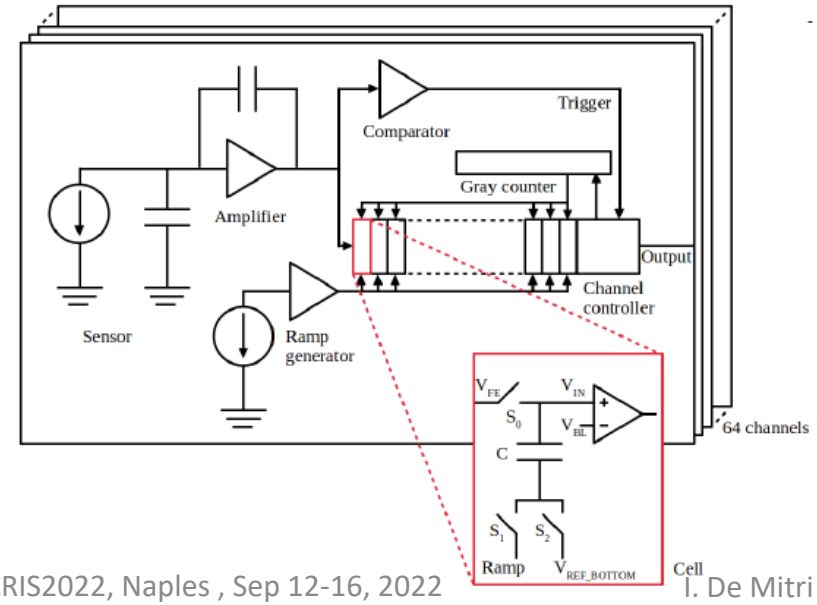



# TERZINA: sensors and electronics

Background radiation simulation studies with SPENVIS (on SiPMs)



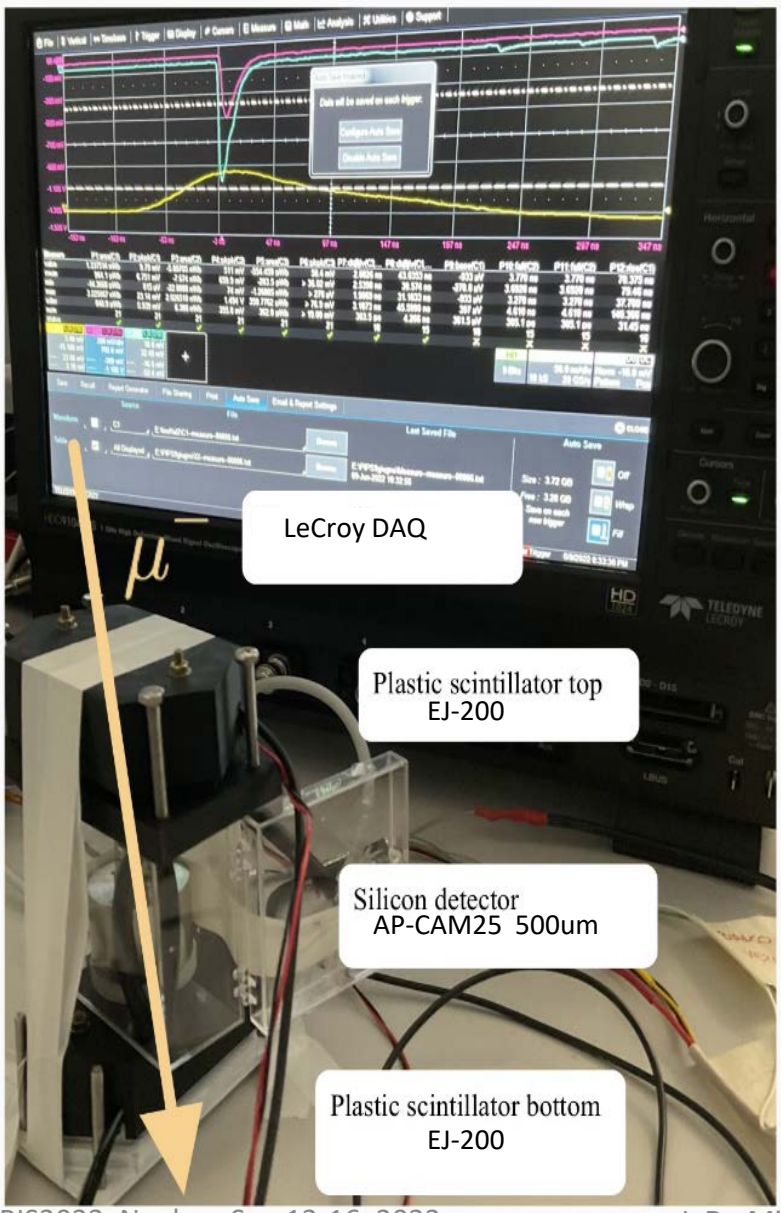

ASIC architecture

- 64 channels
  - Channel controller
  - 256 cells
    - Sections
    - Section controller
      - 5 states

Design status:

- Mode:
  - Sparse
  - Imaging
- Segmentation:
  - 32 cells
  - 64 cells
  - 256 cells
- Resolution:
  - 8 - 12 bits
- Trigger:
  - Internally generated
  - Externally provided
- 8-channels readout
- Cell layout ongoing
- SiPM modelling

# ZIRE': testing AP-CAM25 for the LEM




Preliminary results:

AP-CAM25 signal timing: $\tau$ ~100ns
(good: allows MHz particle rates)
AP-CAM25 signal amplitude: ~35mV/MeV
(quite small since it is already preamplified)