The NUSES space mission

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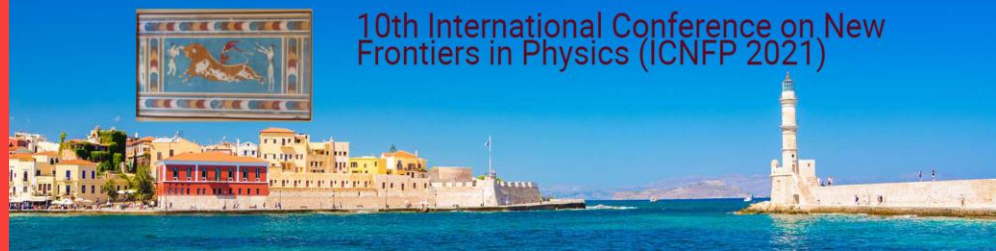
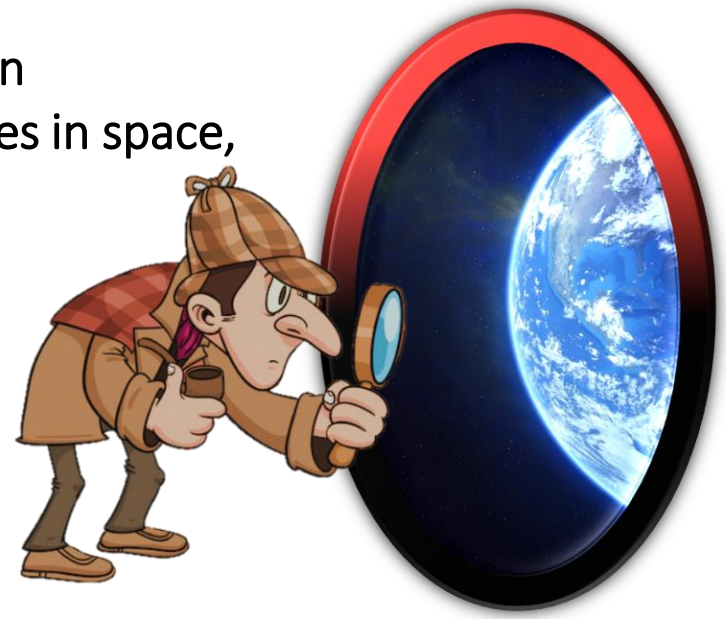


The NUSES space mission

NUSES is a new space mission project with different scientific purposes:

- **technology pathfinder** dedicated to the detection of high-energy astrophysical neutrinos as probes of the deep universe of extreme astrophysical phenomena;
- monitoring of the **variations in the EM field and the particle flux** both in the ionosphere and in the earth's magnetosphere induced by natural sources, such as seismic activities or anthropogenic emitters;
- study of the **cosmic radiation variability** (fundamental for the effects on space missions with/without crew) and introduction of new technologies in space, paving the way for future research and applications.



✓ The NUSES proposal was approved by the Italian government as a flagship initiative to relaunch the economy of the **L'Aquila (AQ)** area.

✓ NUSES is funded by the Italian government and the Italian Minister for economic development.

✓ The NUSES industrial partner is **Thales Alenia Space Italy (TAS-I).**

The NUSES Collaboration

People coming from many institutions.
Large expertise on space missions/R&D : AMS, DAMPE, eASTROGAM, FERMI, GAPS, HERD, LIMADOU, PAMELA, POEMMA, SPB2 , …

Current list of the italian groups:
Gran Sasso Science Institute (GSSI)
INFN – Laboratori Nazionali del Gran Sasso
Università dell'Aquila
Università di Roma "Tor Vergata" & INFN-Roma2
Università di Torino & INFN Torino
Università di Trento & INFN-TIFPA
Università di Bari & INFN
Università di Padova & INFN
Università di Napoli & INFN

The Collaboration is being setup in these months.
Also interests from non-italian groups…

The NUSES detectors

The NUSES payload will host two main experiments:

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

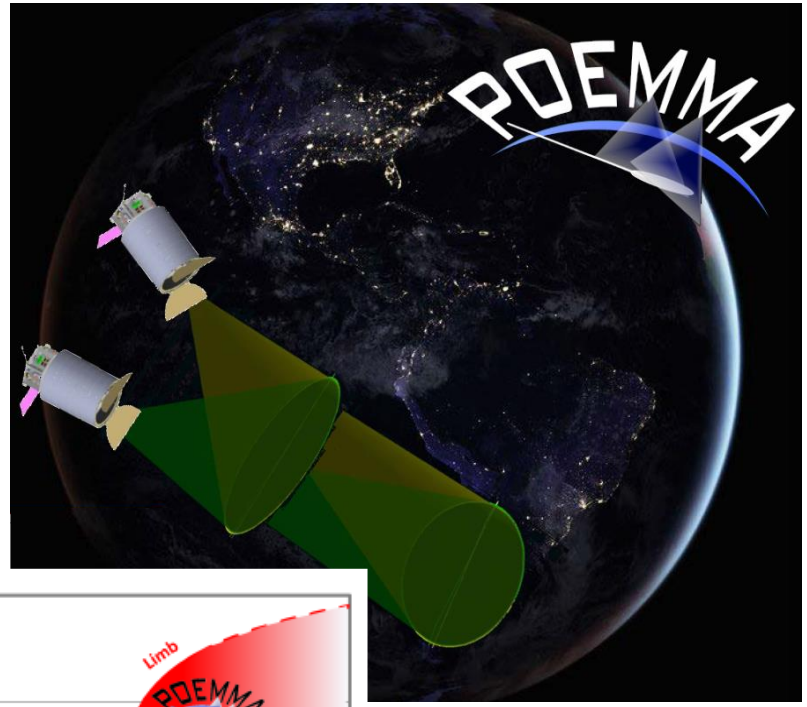
ZIRÉ ▶ Monitor the fluxes of low energy (<250 MeV) CRs, mainly electrons and protons, to study Van Allen belts, space weather and the lithosphere-ionosphere-magnetosphere couplings. It will detect 0.1 MeV – 10 MeV photons for the study of transient (GRB, e.m. followup of GW events, SN emission lines,…) and steady gamma sources.

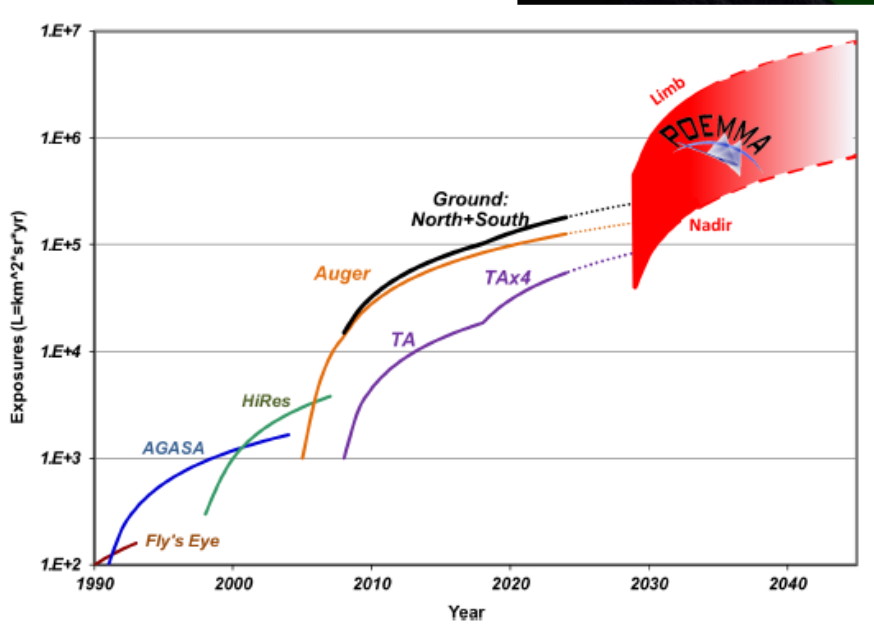
New technologies will be developed together with new observational techniques , sensors (e.g. SiPM) and related electronics/DAQ for space missions.

The POEMMA mission

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.
- Selected by NASA as probe study for the next decade missions.
- hybrid Class B Mission
- 3-year Prime Mission, 5-year Mission Goal
- LEO 525 km, 28.5o inclination
- From 300 km to 25 km separation among satellites
- Phase A start 10/2023 (NASA HQ guidance)
- Launch 11/2029 (MDL forecast)





NUSES: TERZINA

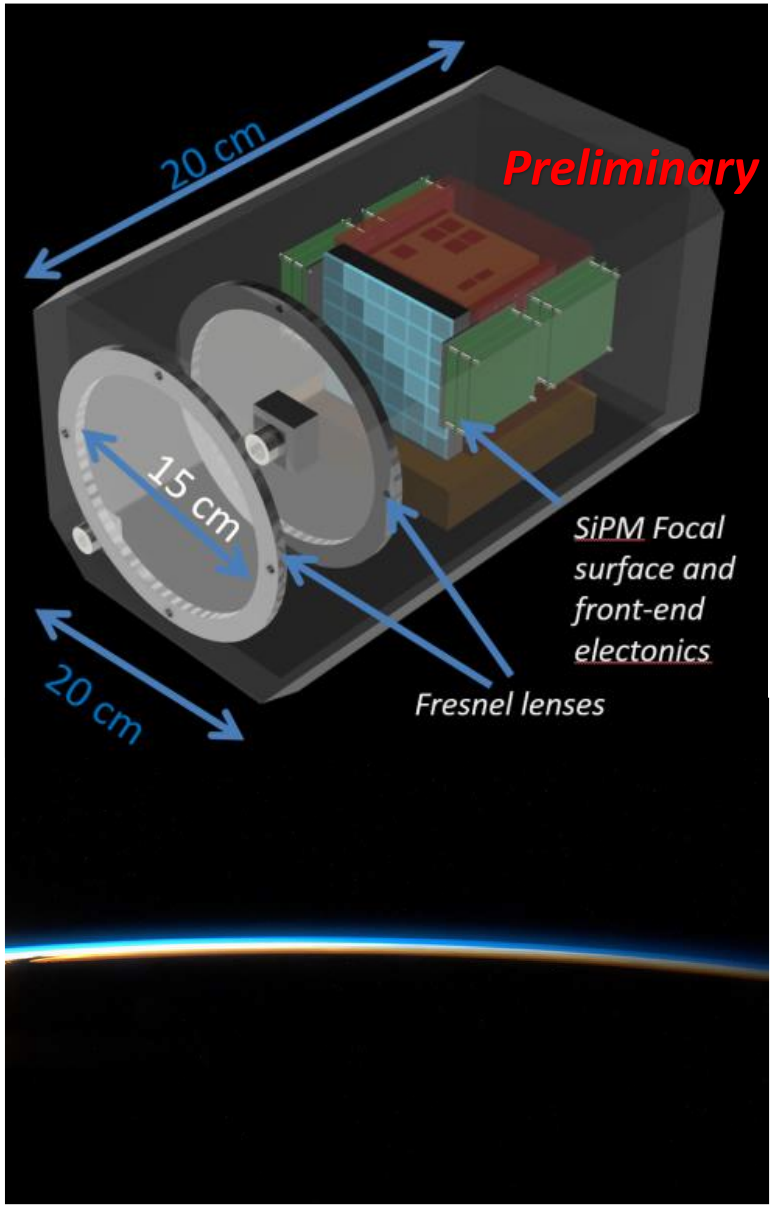
Characterization of the background in the observation of astrophysical neutrinos (E>1 PeV) with Cherenkov telescopes from space. (TERZINA will experience the same background intensity for pixels expected in future large area Cherenkov telescopes from space such as POEMMA).

The preliminary design of the TERZINA experiment includes:

- ❑ two optical systems with a double-sided Fresnel lens (diameter = 25 cm)
- ❑ multi-pixel focal surface detector based on SiPM technology.

TERZINA will point to the dark side of the earth's limb by detecting, in the frequency range of visible, the expected background for a large area Cherenkov telescope in Space.

By orienting it at the limb, where CRs can produce cascades of particles into the atmosphere (EAS), it will be possible to test the detection technique of tau neutrinos which, as discussed above, produce EAS resulting in Cherenkov light emission.



Earth's observations

Observations on ground and with satellites at Low Earth Orbit altitudes have revealed:

- anomalies in the ionosphere (electromagnetic and plasma density perturbations,…)

French micro-satellite dedicated to the study of ionospheric perturbations (measurement of electromagnetic waves and their effects), caused by natural phenomena, such as earthquakes and volcanic eruptions, or resulting from human activities

ANNALS OF GEOPHYSICS, 55, 1, 2012; doi: 10.4401/ag-5356

Special Issue: EARTHQUAKE PRECURSORS

Extremely low frequency plasma turbulence recorded by the DEMETER satellite in the ionosphere over the Abruzzi region prior to the April 6, 2009, L'Aquila earthquake

Jan Błęcki[1,*], Małgorzata Kościesza[1], Michel Parrot[2], Sergey Savin[3], Roman Wronowski[1]

[1] *Space Research Centre PAS, Warsaw, Poland*

[2] *Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, Université d'Orléans, CNRS, Orléans, France*

[3] *Space Research Institute, Russian Academy of Sciences, Moscow, Russia*

Possible correlation with earthquakes or eruption?

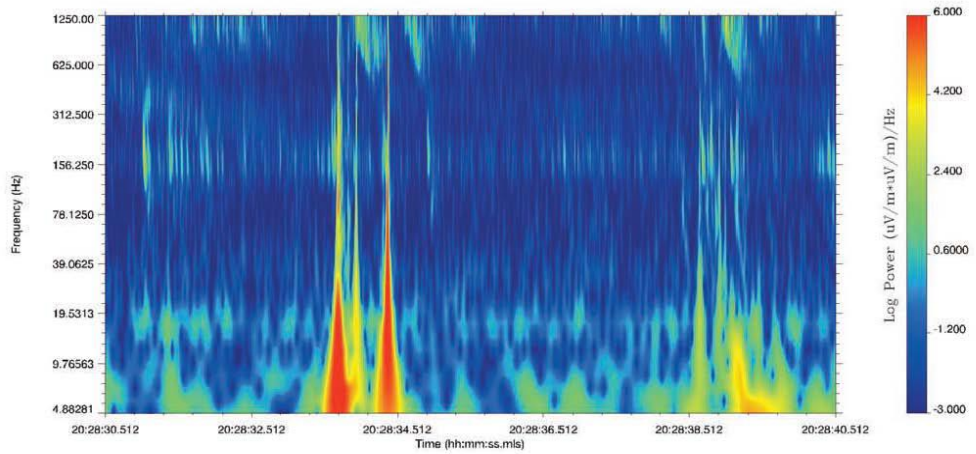


Figure 7a. Wavelet spectrogram of the broad-band emission in the ELF range recorded on April 4, 2009. The distance of the footprint of the satellite to the epicenter was about 280 km. The color scale is as in Figure 2.

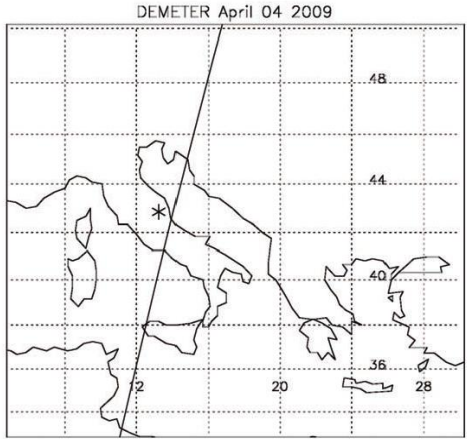
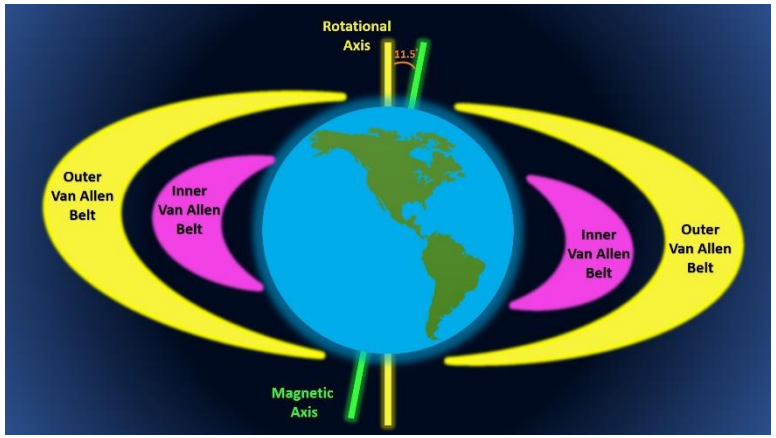


Figure 6. Map showing the epicenter of the April 6 L'Aquila earthquake (*) and the orbit of the DEMETER satellite on April 4, 2009. The point of closest approach from the epicenter was 125 km.

Earth's observations

Observations on ground and with satellites at Low Earth Orbit altitudes have revealed:

- anomalies in the ionosphere (electromagnetic and plasma density perturbations,…)
- anomalous increase of low-energy electron and proton counting rate (with energies of few MeV to several tens of MeV) trapped in the VABs



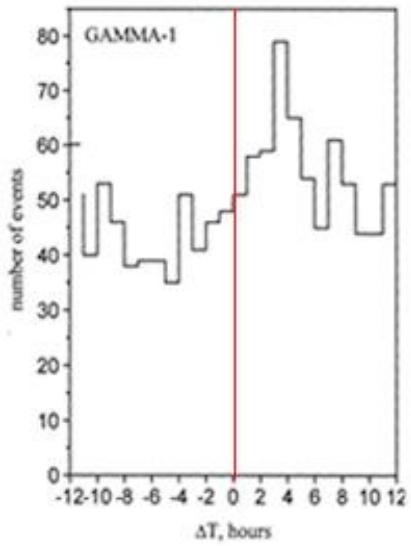
Inner Van Allen belt:
electrons and protons O(100 keV) – O(100 MeV)
(enhanced proton flux on the South Atlantic Anomaly)

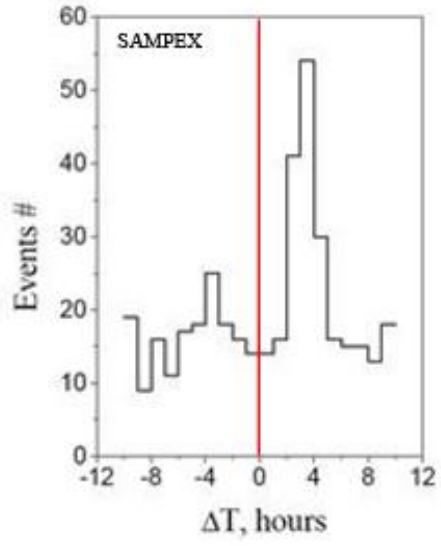
Outer Van Allen belt: mostly electrons

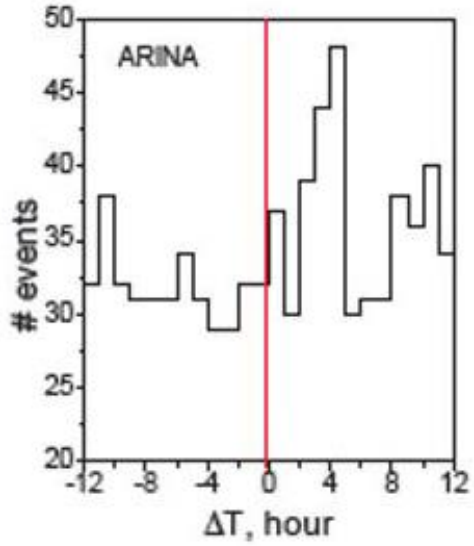
Any electromagnetic perturbation determines sizeable effects on particle trajectories in Van Allen belts:

- from the Earth (VLF/ULF emitters, seismic activity…)
- from the outer space (solar activity)

3







Time Difference Distribution. Zero is the current time of the particle burst. ΔT is the time difference between earthquake and the detected electron burst.
a) GAMMA-1 mission, 1990-1992, Altitude 350 km, Inclination 51°, E > 50 MeV
b) SAMPEX/PET mission 1992-1999, Altitude 520-740 km, Inclination 82°, 4≤E≤15 MeV
c) ARINA mission 2006-in operation, 3≤E≤30 MeV

A possible model for MILC

remote sensing

MDPI

Article

Magnetospheric–Ionospheric–Lithospheric Coupling Model. 1: Observations during the 5 August 2018 Bayan Earthquake

Mirko Piersanti [1,*,†], Massimo Materassi [2,†], Roberto Battiston [3,†], Vincenzo Carbone [4,†], Antonio Cicone [5,†], Giulia D'Angelo [5,†], Piero Diego [5,†] and Pietro Ubertini [5,†]

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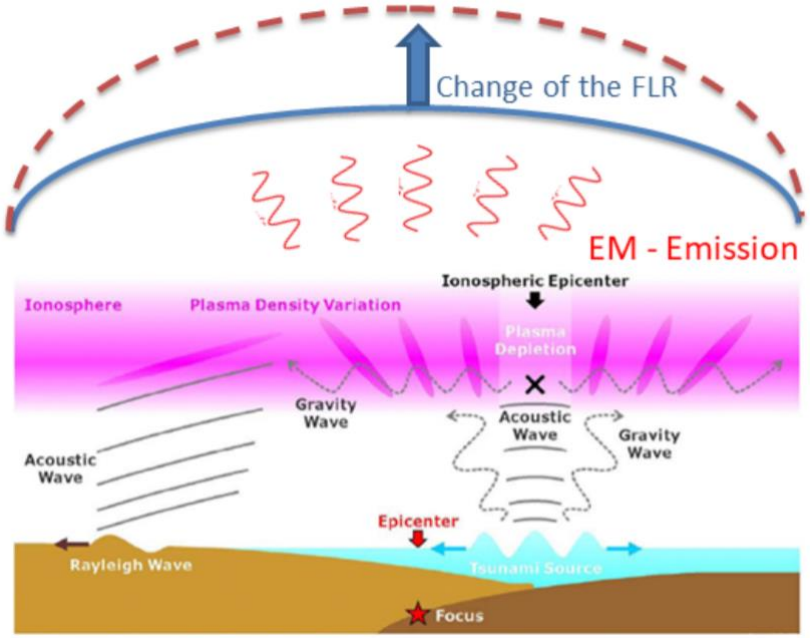
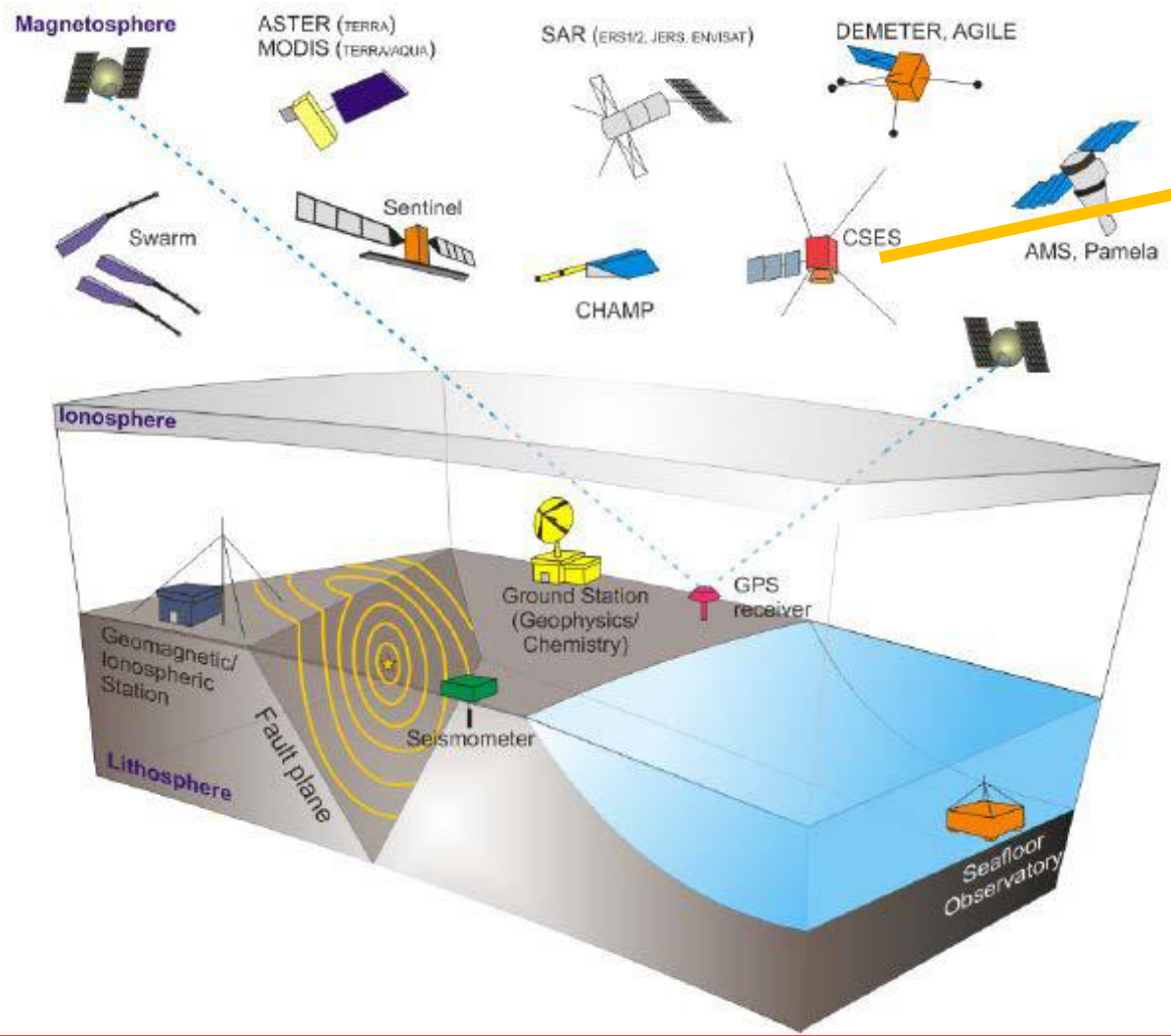
Abstract: The short-term prediction of earthquakes is an essential issue connected with human life protection and related social and economic matters. Recent papers have provided some evidence of the link between the lithosphere, lower atmosphere, and ionosphere, even though with marginal statistical evidence. The basic coupling is hypothesized as being via the atmospheric gravity wave (AGW)/acoustic wave (AW) channel. In this paper we analyze a scenario of the low latitude earthquake (Mw = 6.9) which occurred in Indonesia on 5 August 2018, through a multi-instrumental approach, using ground and satellites high quality data. As a result, we derive a new analytical lithospheric–atmospheric–ionospheric–magnetospheric coupling model with the aim to provide quantitative indicators to interpret the observations around 6 h before and at the moment of the earthquake occurrence.

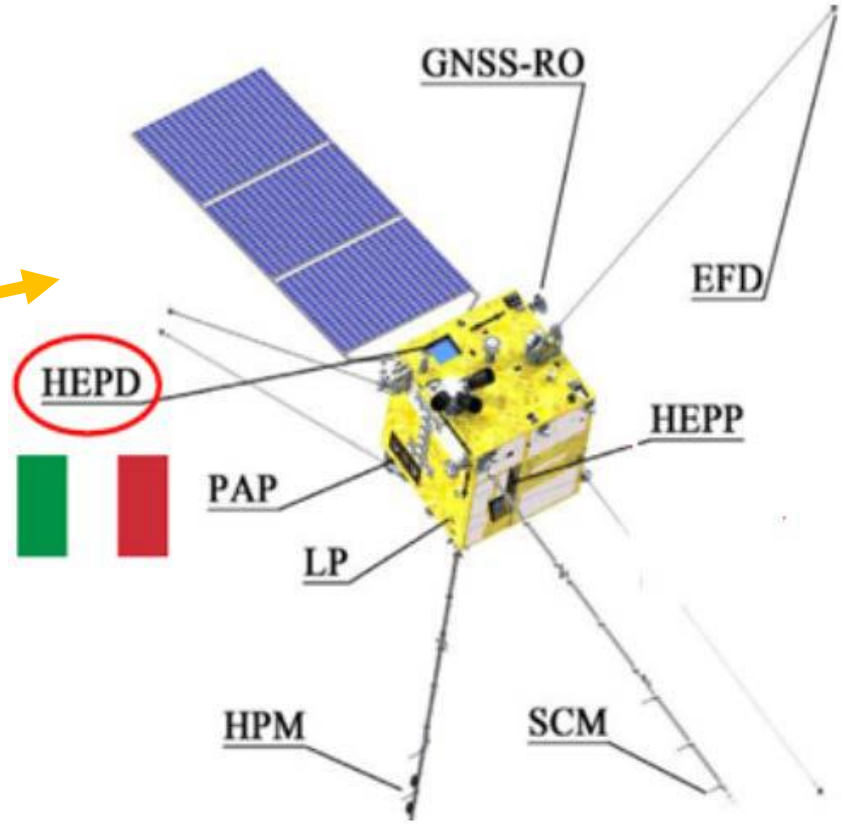
"quantitatively explain the experimental observations about 6h before and at the moment of " (Aug 5, 2018 Indonesia) *"earthquake observation"*



"…the observations of the CSES-01 satellite flying over the EE around 6 h before the EQ, confirms both the presence of EM wave activity, coming from the lower ionosphere, and plasma density variation …"

Ground and space-based detectors





CSES China Seismic Electromagnetic
HEPD (High Energy Particle Detector)

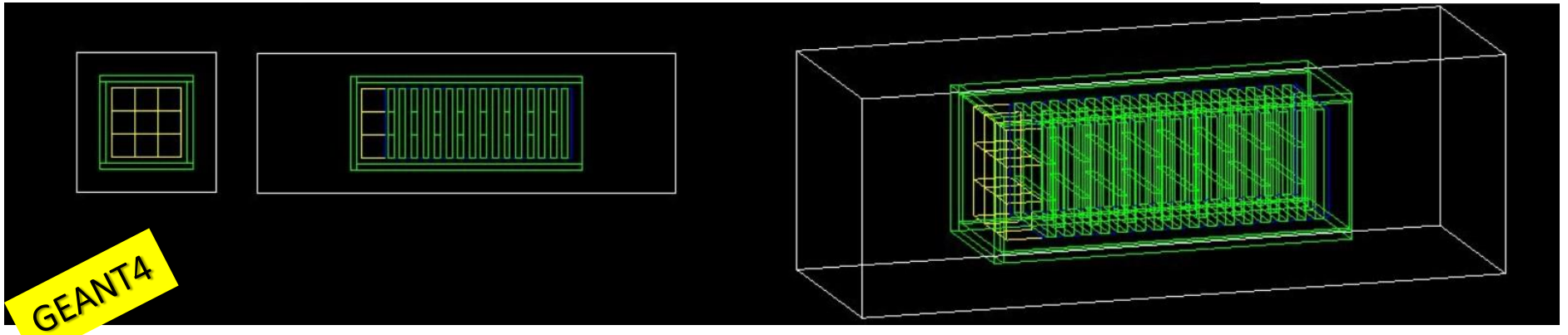
CSES-01 on orbit since February 2018
CSES-02 launch (2022)

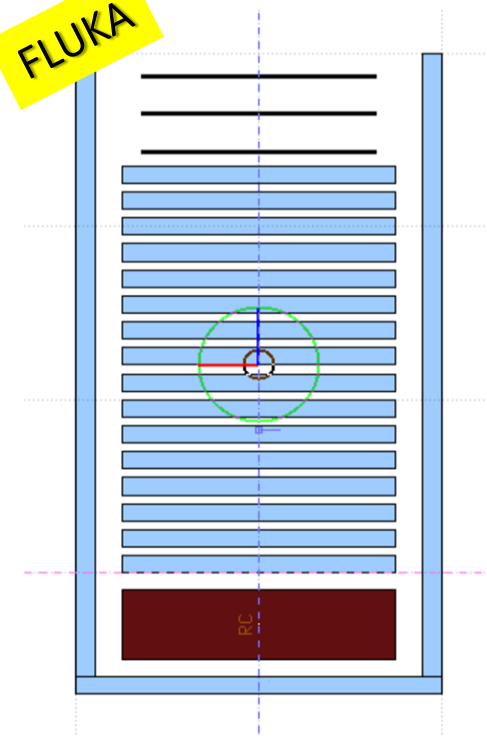
NUSES: ZIRÉ

ZIRÉ is basically a small calorimeter for electron and proton spectral measurements, adopting new technological solutions:

- Use SiPM instead of standard PMT
- Optimize the tracker and test new technologies (e.g. Fiber Tracker, …..)
- Possible new design for the calorimeter readout

- ❑ First simple layout considered (3 fiber X-Y planes, 16 *1cm tiles, LYSO array, VETO)
- ❑ FLUKA simulation of electrons and protons from 5 up to 300 MeV
- ❑ GEANT4 simulation starting…

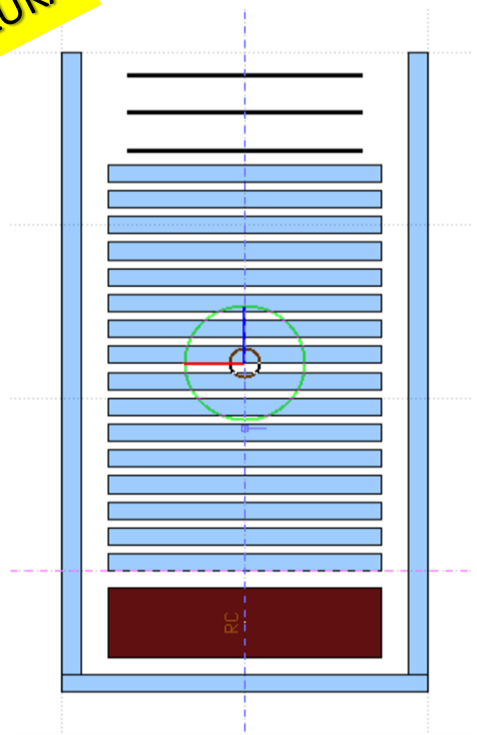


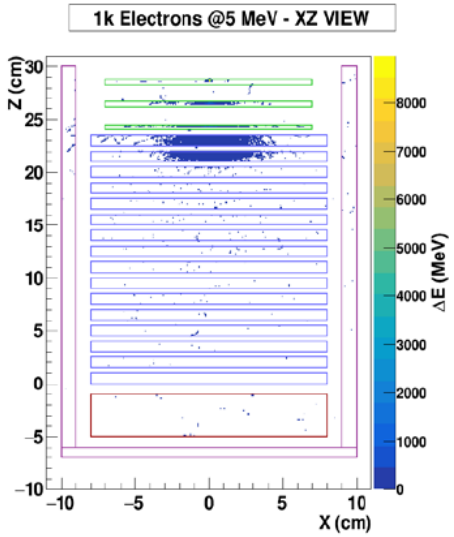


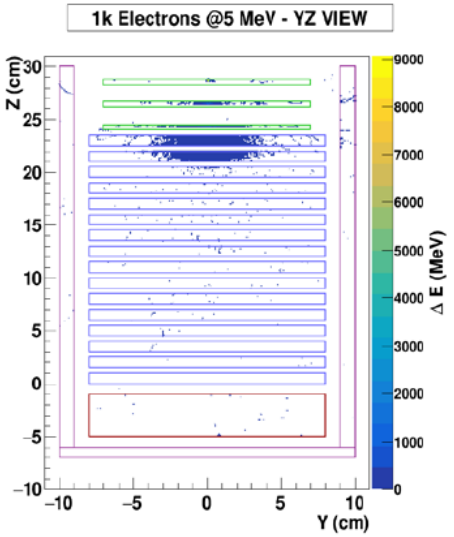
ZIRÉ SIMULATION STARTING POINT

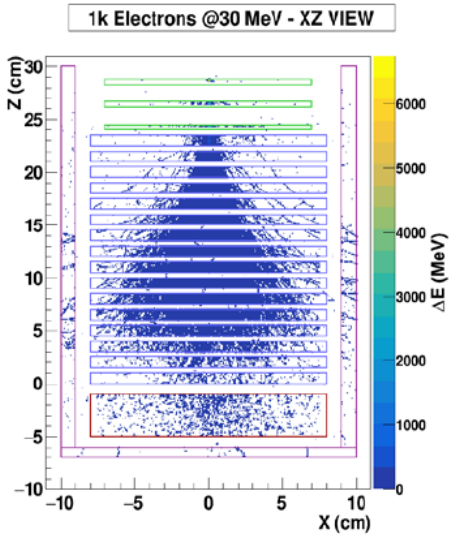
FLUKA simulation of electrons from 5 up to 300 MeV
(5 MeV steps, normal incidence, flat spectrum, no absolute flux normalization)

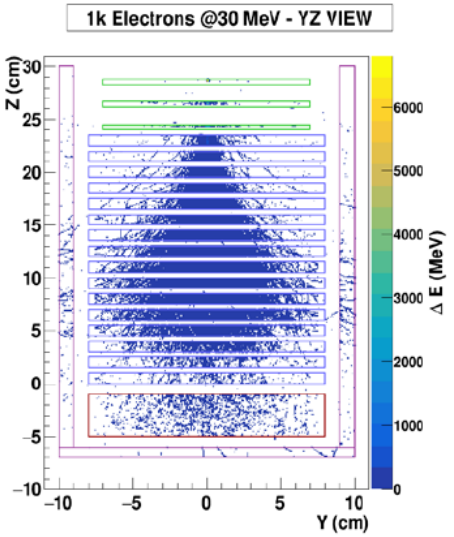
FLUKA

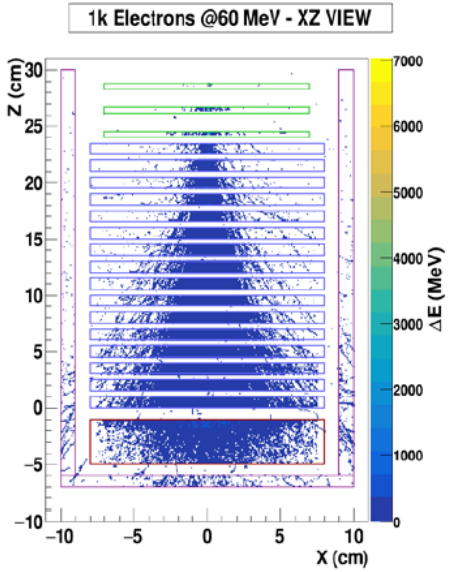


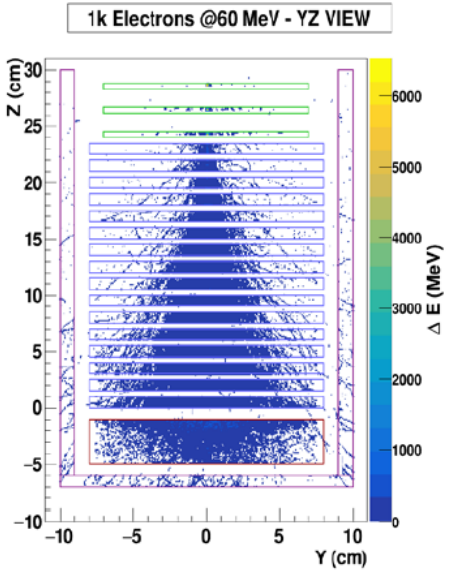


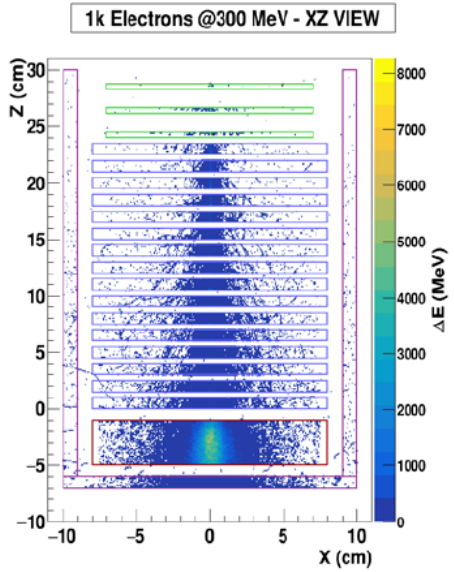


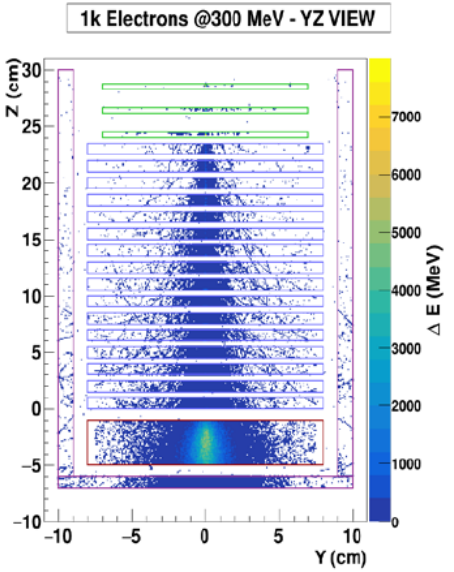








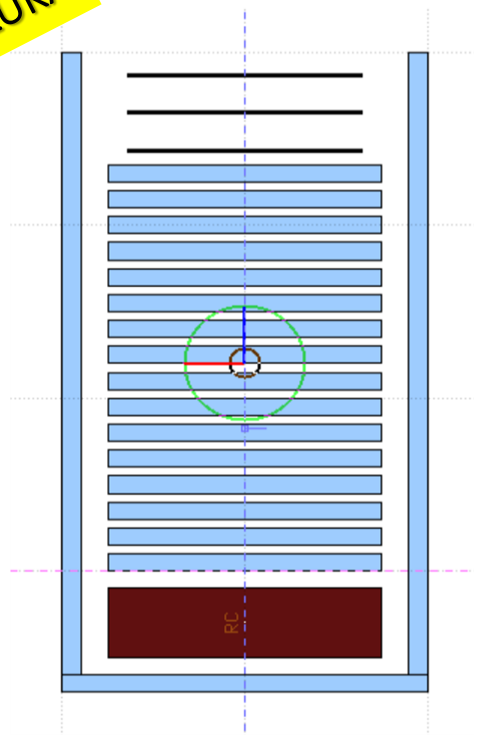


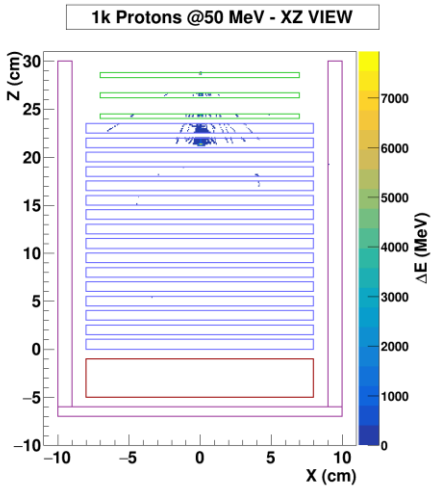


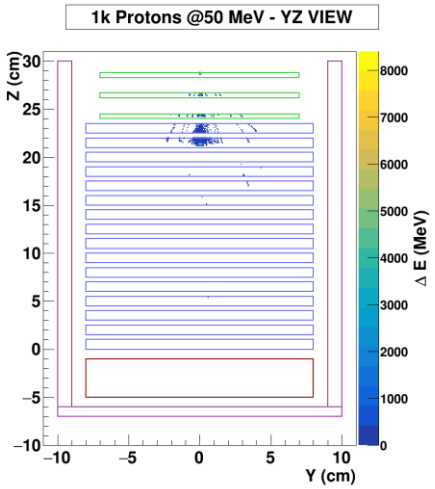
ZIRÉ SIMULATION STARTING POINT

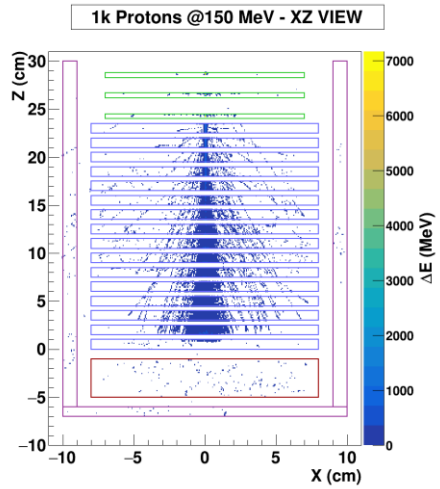
FLUKA simulation of protons from 5 up to 300 MeV
(5 MeV steps, normal incidence, flat spectrum, no absolute flux normalization)

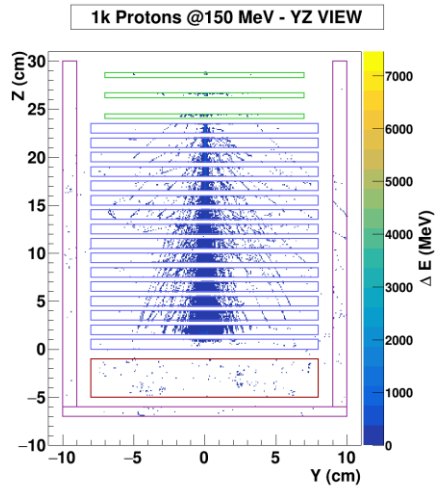
FLUKA

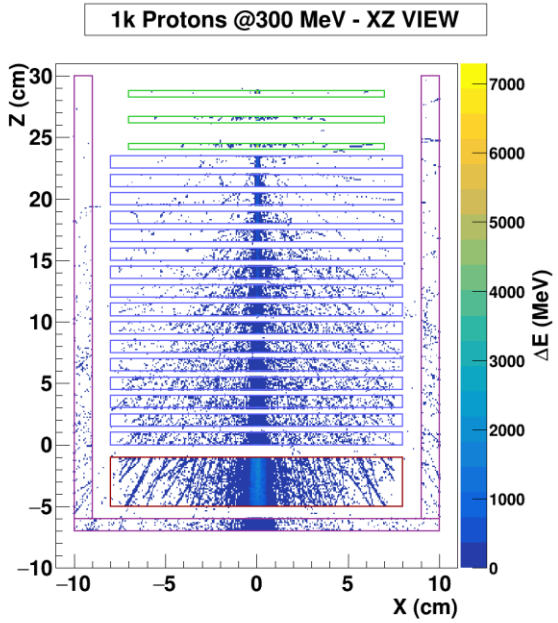


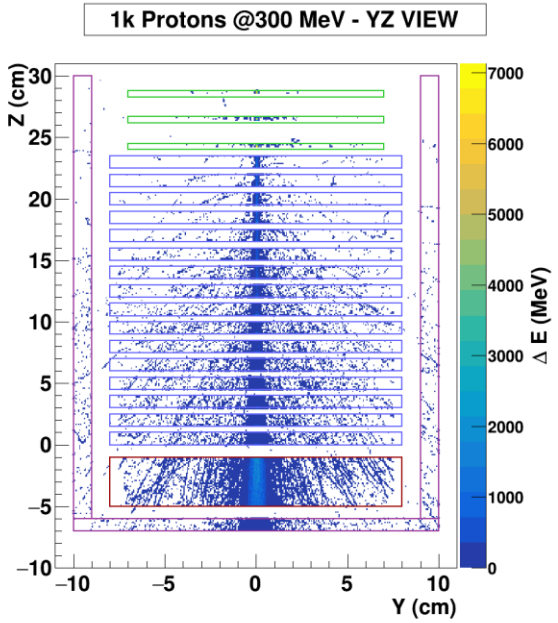








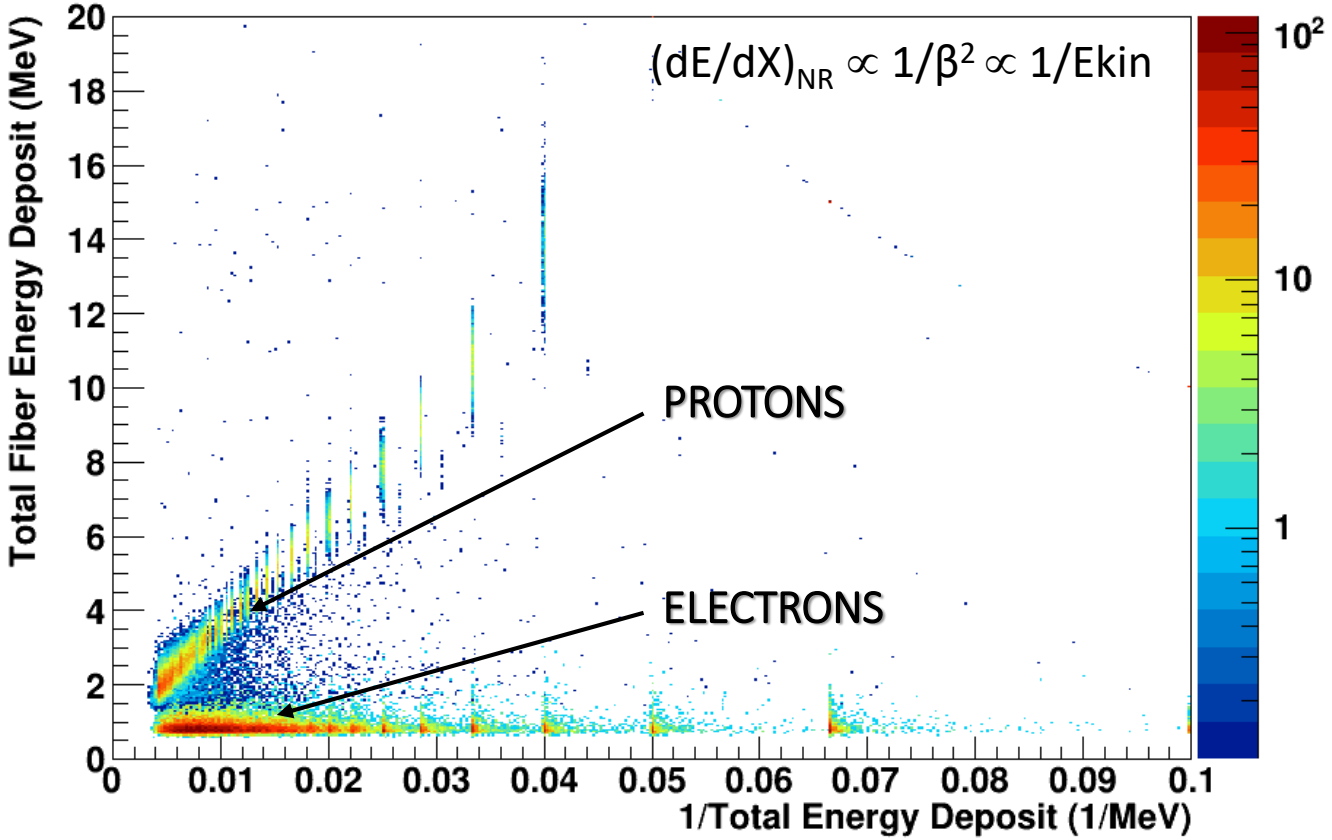


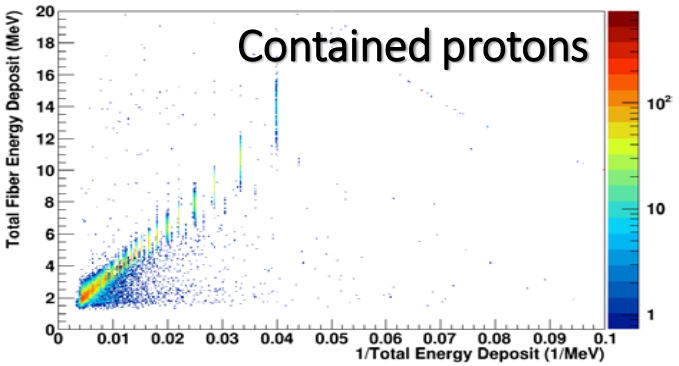


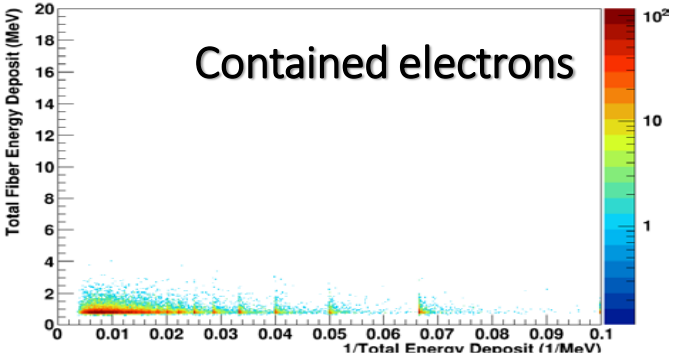
ZIRÉ SIMULATION STARTING POINT

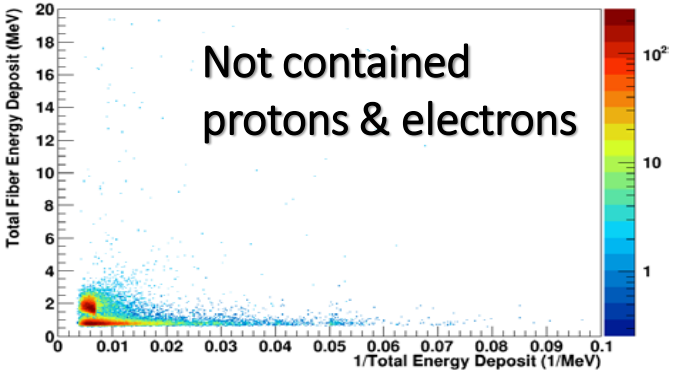
FLUKA simulation of protons and electrons from 5 MeV to 300 MeV.
(5 MeV steps, normal incidence, flat spectrum, no absolute flux normalization)

e/p DISCRIMINATION – VETO ENERGY < 0.25 MIP







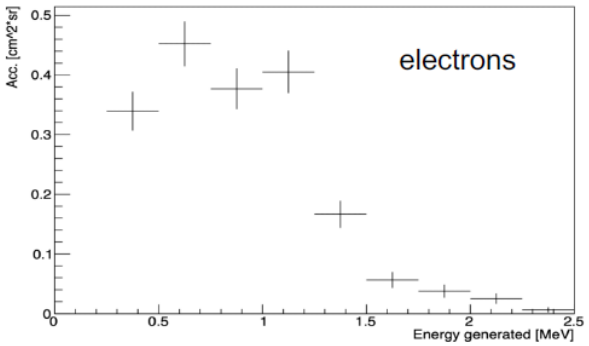


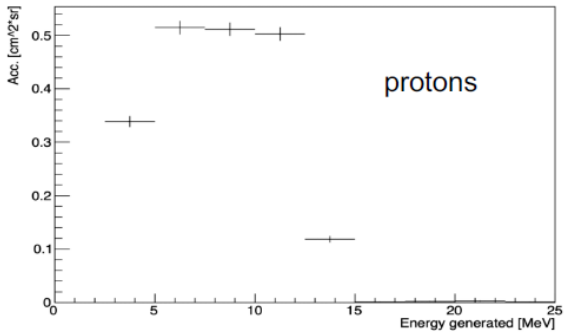
A Low Energy Module (LEM) for electrons

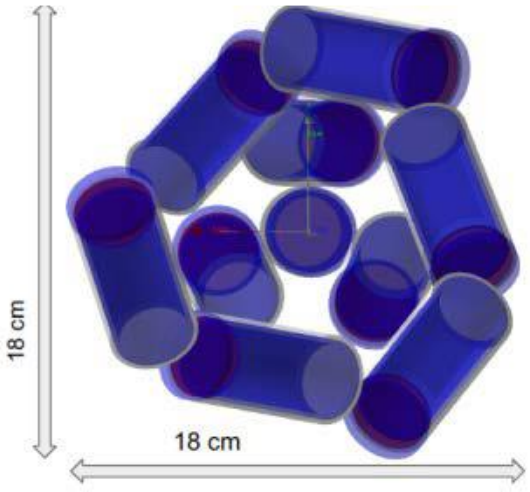
Current data suggest larger sensitivity for MILC studies using very low energy electrons (< 5 MeV) from the zenith .

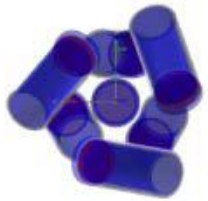
A specific Zire' payload extension (LEM) is being designed for the detection of such electrons.

A modular geometry would allow covering a large FoV with a compact object.

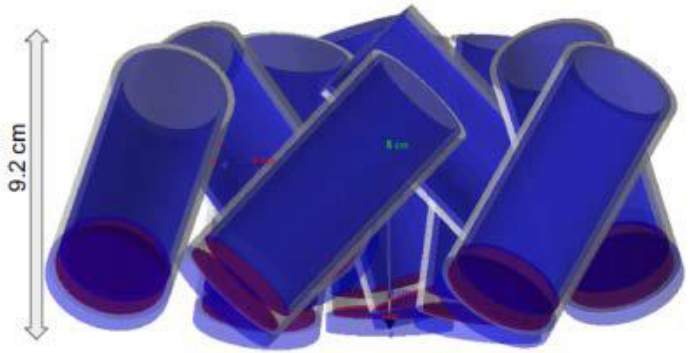




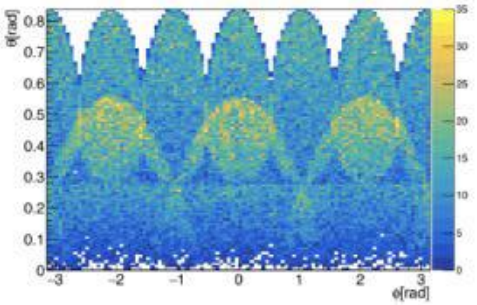




other layouts under study… aiming at 10x10x10 cm3 aluminum structure 3D printed (prototype to be manufactured at ProM Rovereto)



~ 3 cm2*sr

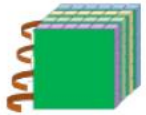


LYSO array as gamma detector

The LYSO array can be used as gamma detector in the 50keV -100 MeV, depending on the specific optimization, using a specific veto system. The whole readout will be done by SiPMs.

3 designs

Zirè-ECC



Extension with compact LYSO cubes

Weight/Layer (kg)	4,3
Total Weight (kg)	17,1
N. citiroc	9
Readout power consumption (W)	2,0
N. Beta chip	2,3
Readout power consumption (W)	0,1
Total Sensitive surface (cm2)	375
Energy range (MeV)	0,1-100

Super-compact
Easy mechanics
High energy range

Larger weight
Larger power consumption

Zirè-ESC

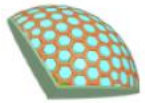
Extension with staggered LYSO cubes

Weight/Layer (kg)	4,1
Total Weight (kg)	16,3
N. citiroc	5
Readout power consumption (W)	1,1
N. Beta chip	1,3
Readout power consumption (W)	0,1
Total Sensitive surface (cm2)	375
Energy range (MeV)	0,1-100

High hermeticity for CRs
High energy range

Larger weight
Complicated mechanics

Zirè-CE



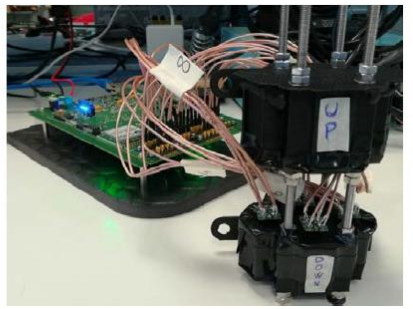
Crystal Eye slice side detector

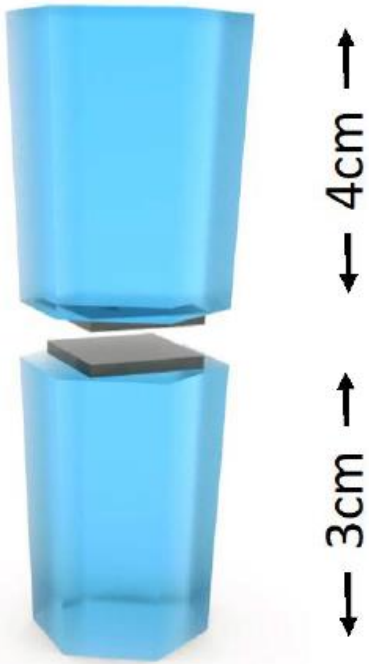
Weight/Layer (kg)	6,8
Total Weight (kg)	13,5
N. citiroc	6
Readout power consumption (W)	1,4
N. Beta chip	2
Readout power consumption (W)	0,1
Total Sensitive surface (cm2)	196
Energy range (MeV)	0,01-30

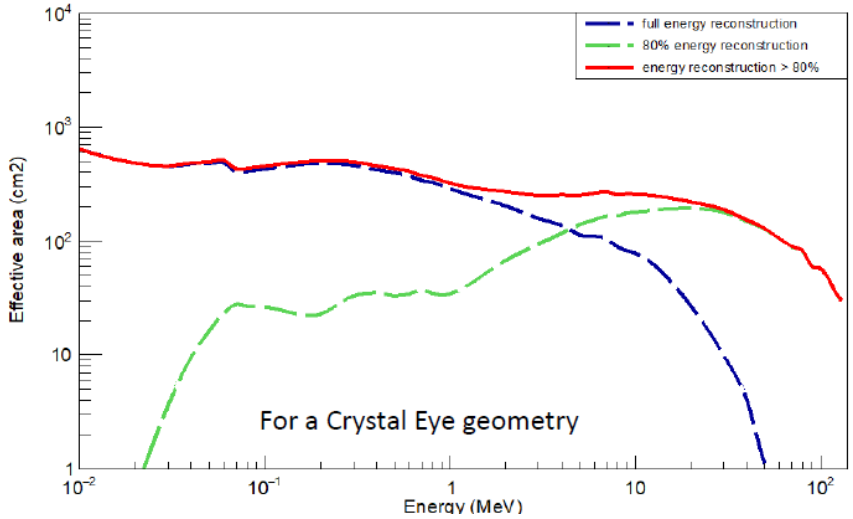
Optimized for GRBs
Uniform response to directions
Lower weight

Lower weight
Lower effective area

LYSO array as gamma detector



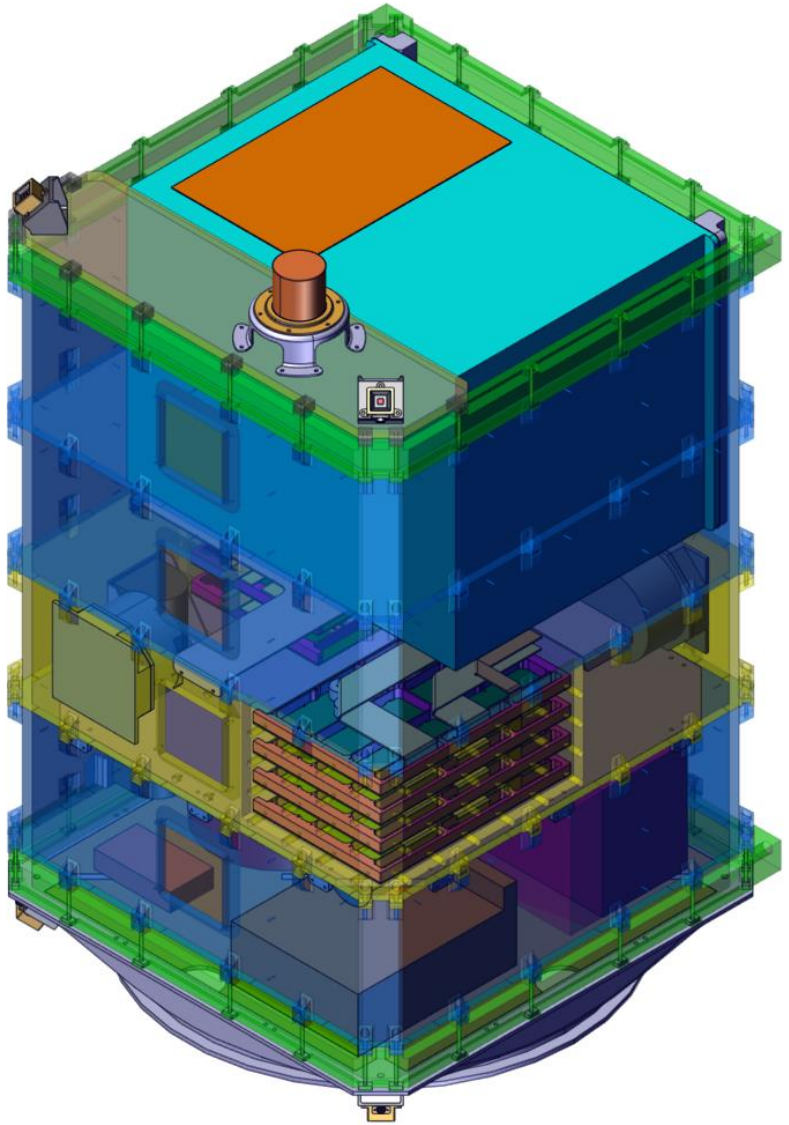


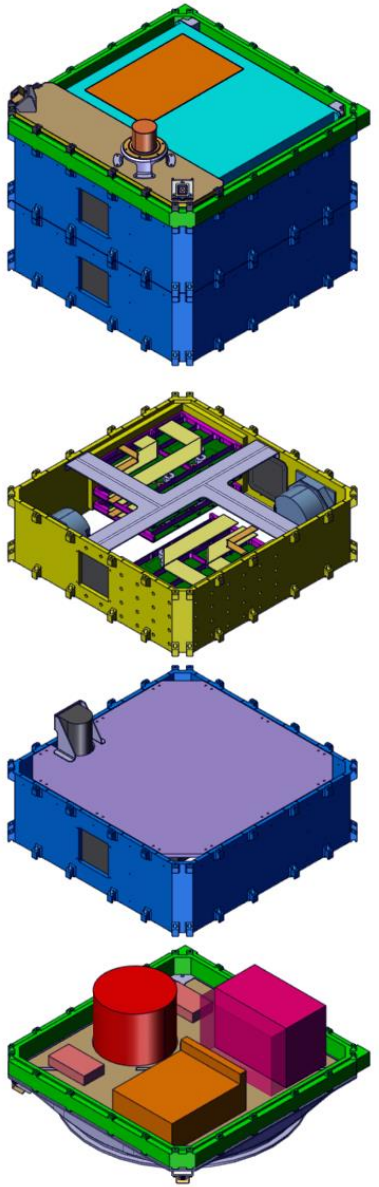


NUSES: the satellite

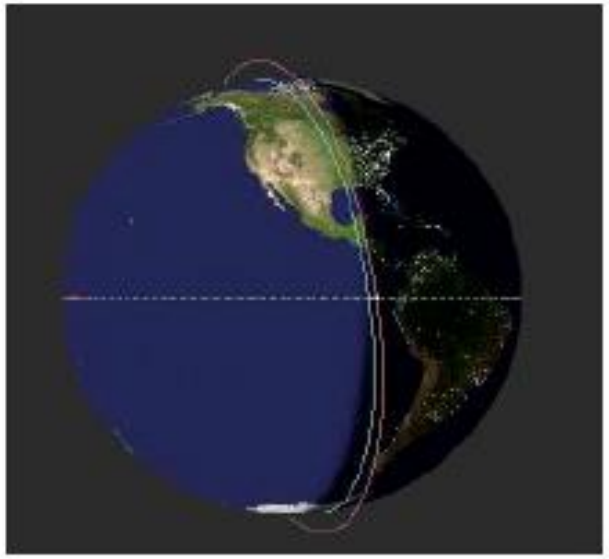
NIMBUS (New Italian Micro BUS)
new Platform concept for low orbit microsatellites (LEO) which foresees a modular approach relying on standard trays.

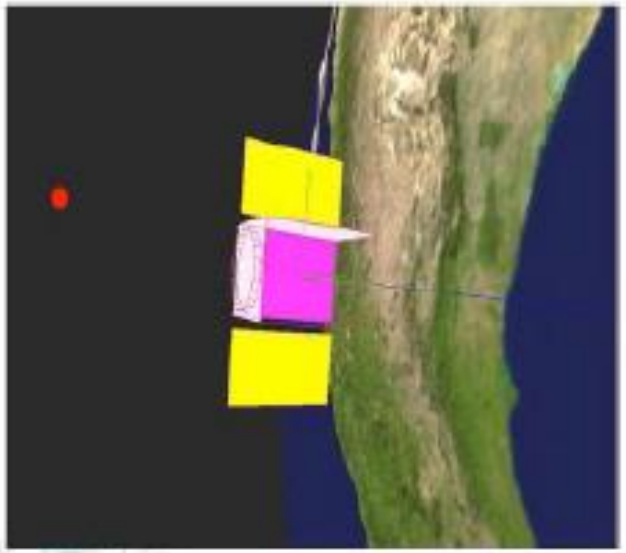
ThalesAlenia Space
a Thales / Leonardo company

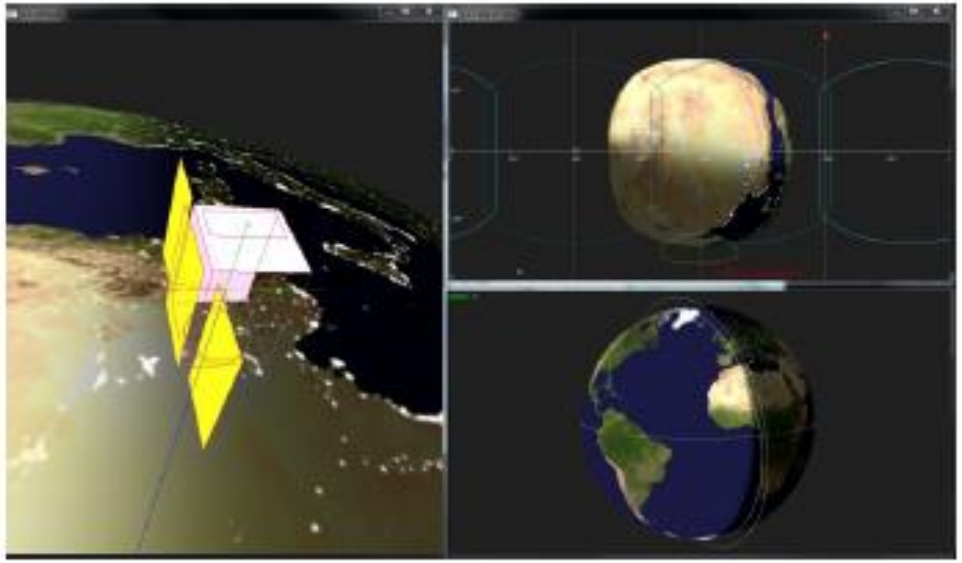




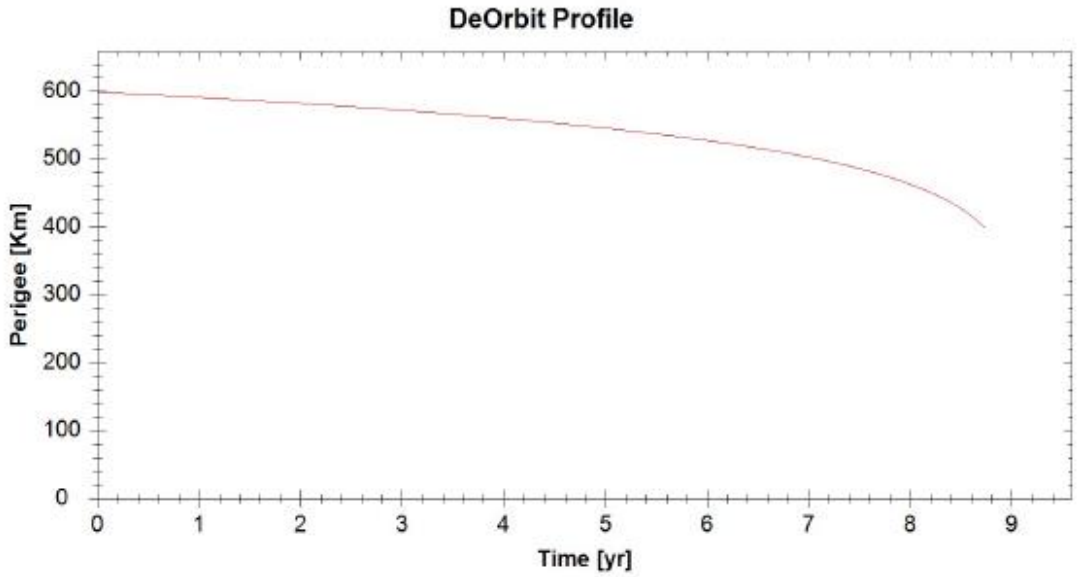
NUSES: the orbit







- Low Earth Orbit (LEO) with high inclination, sunsynchronous orbit on the day-night border (mean altitude = 600 Km, inclination = 97.8°, LTAN = 18:00);
- Orbit optimization for neutrino detection, still under discussion because of the interplay between Terzina-Zirè orbit requirements;
- Ballistic mission (no propulsion for orbital control);
- Terzina will point to the Limbo, while Zirè to the zenith.



Conclusions

- **NUSES will be a technological pathfinder for future space missions with the introduction of new technologies/approaches**
- **First simulations of the detectors are currently on-going**
- **The design of satellite and detectors is under optimization**


Thank you!