Crystal Eye: a wide Field of View instrument for the study of astrophysical MeV photons

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(on behalf of the Crystal Eye collaboration)

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Outline

- Why a “MeV” mission ?

- The Crystal Eye concept

- Detector layout

- Main figures and sensitivities

- “Pathfinder” missions: NUSES and WINK

- Outlook

Outline

- **Why a "MeV" mission ?**

No need to convince the audience in this session.
So, let's skip this…

- **The Crystal Eye concept**

- **Detector layout**

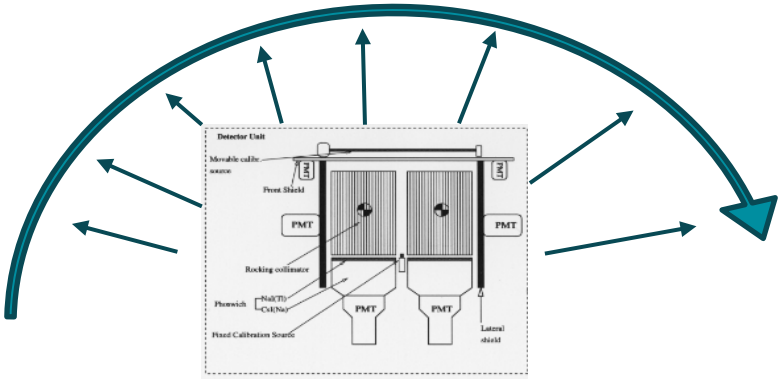
- **Main figures and sensitivities**

- **"Pathfinder" missions: NUSES and WINK**

- **Outlook**

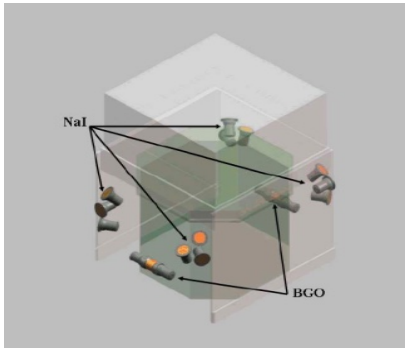
The Crystal Eye idea

Beppo-Sax (PDS)



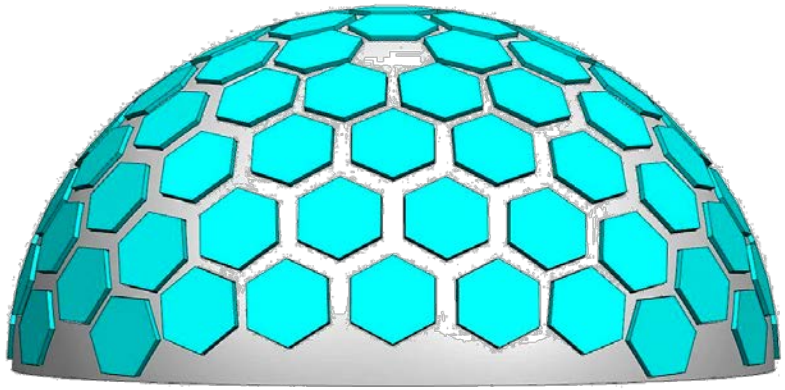
- Phoswich technique with collimators
- Orientable mechanics
- One module

Fermi-GBM



- Triangulation over 12 pixel (ø 12.7 cm)
- Different orientation
- One module

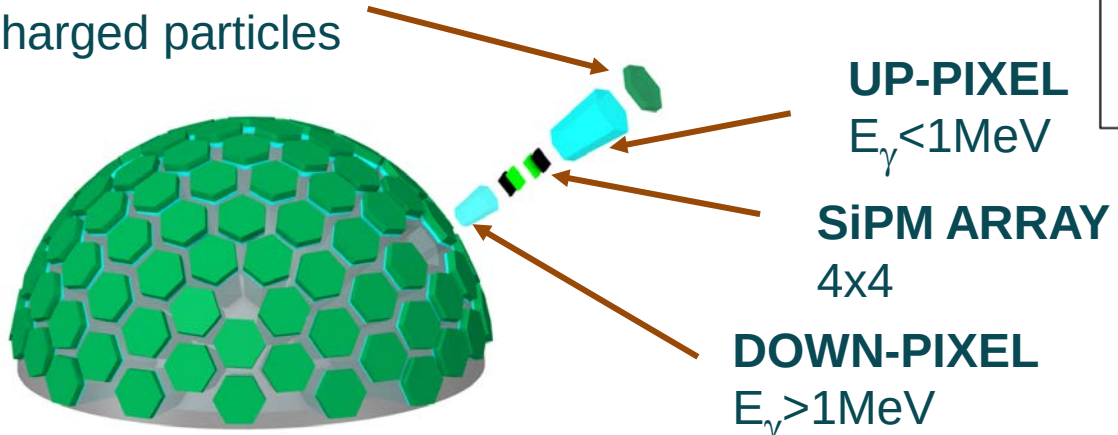
Crystal Eye



- Charge distribution over 112 pixel (ø ~ 5cm)
- Compact photosensors (simplified phoswich)
- Compact hemispherical design
  (no need for orientable mechanics)
- 3-4 modules in orbit for a full time coverage

The detector layout

VETO
Charged particles

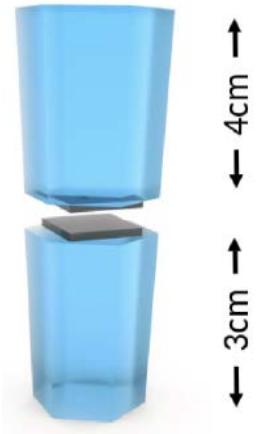


UP-PIXEL
E_γ<1MeV

SiPM ARRAY
4x4

DOWN-PIXEL
E_γ>1MeV

Radius: ~20 cm
Mass: <50 kg
Energy range: 10keV - 30MeV
Material: GAGG/LYSO
Photodetectors: SiPM-array
FOV: 2π



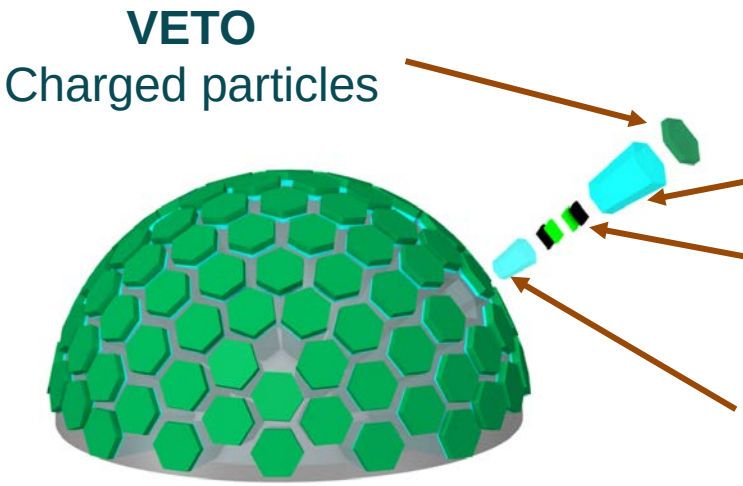
COMPACT SIZE:

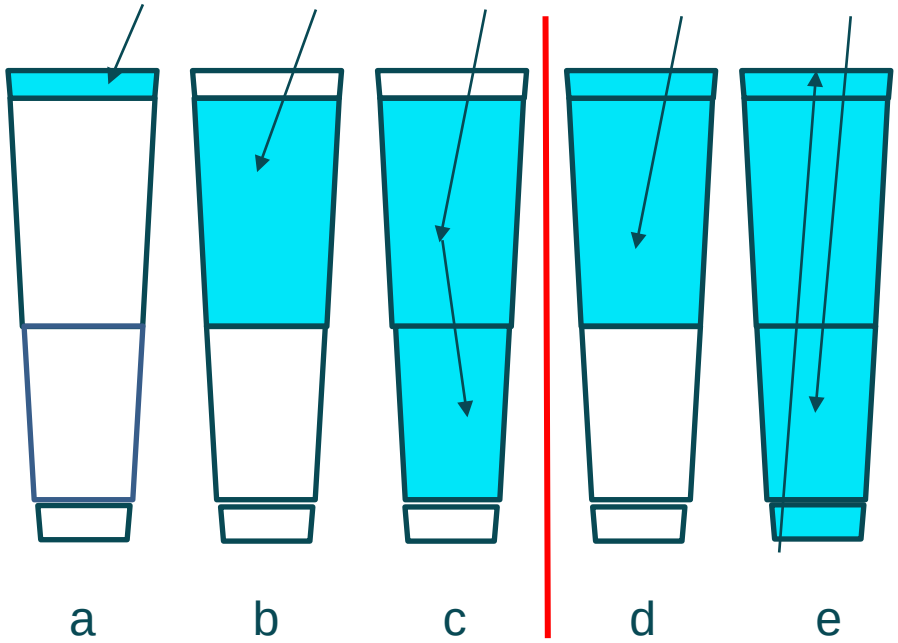
- Free-flyer
- Onboard of space stations
- GBM module of larger satellites

A smart configuration

- **Compactness**
- **Symmetry**
- **Thermal protection of the SiPMs**
- **Radiation protection of the SiPMs**

Topological discriminations





a – Down-going hard X-ray
b – Down-going LE γ-ray
c – Down-going ME γ-ray

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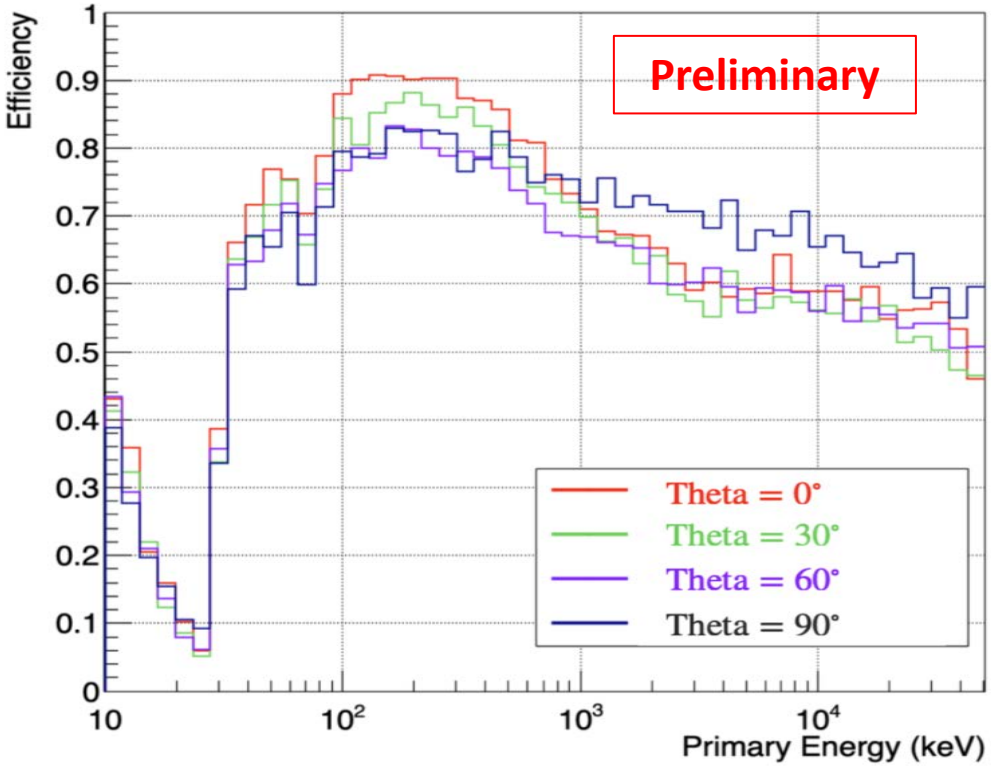
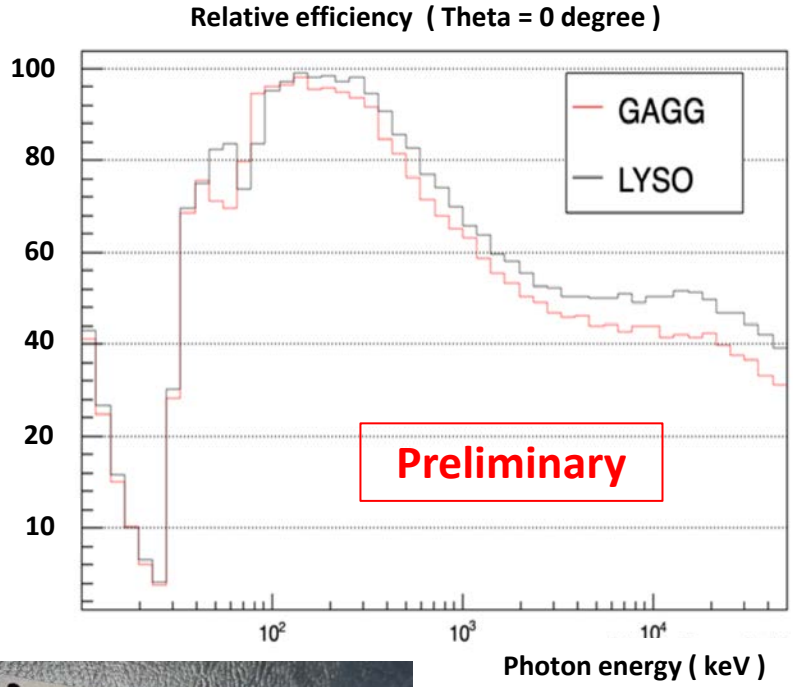
d – Down-going LE charged particle
e – HE charged particle

Efficiency

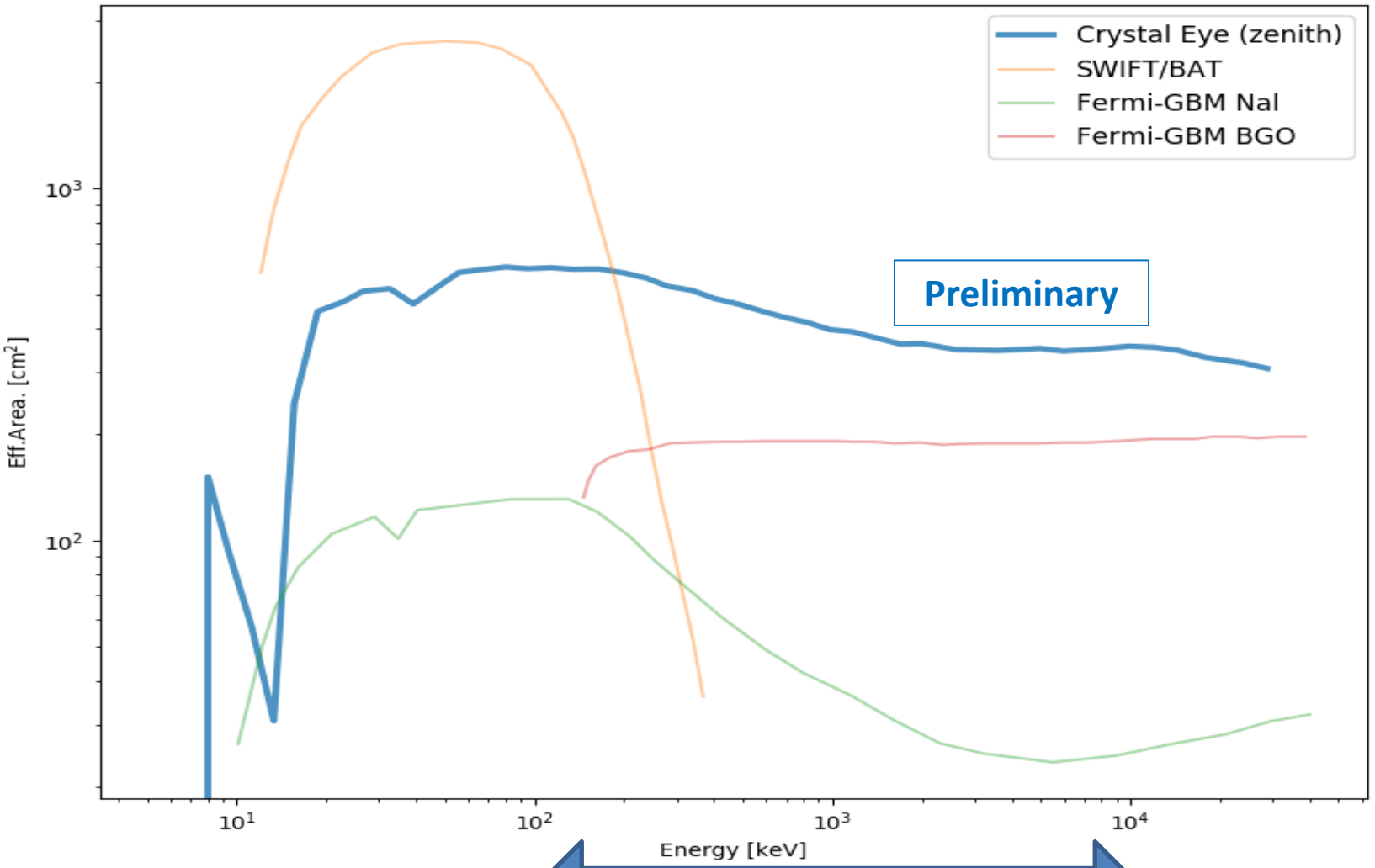
Preliminary estimates: this really depends on the final detector layout and analysi cuts





No large dependence on incidence angle and crystal type

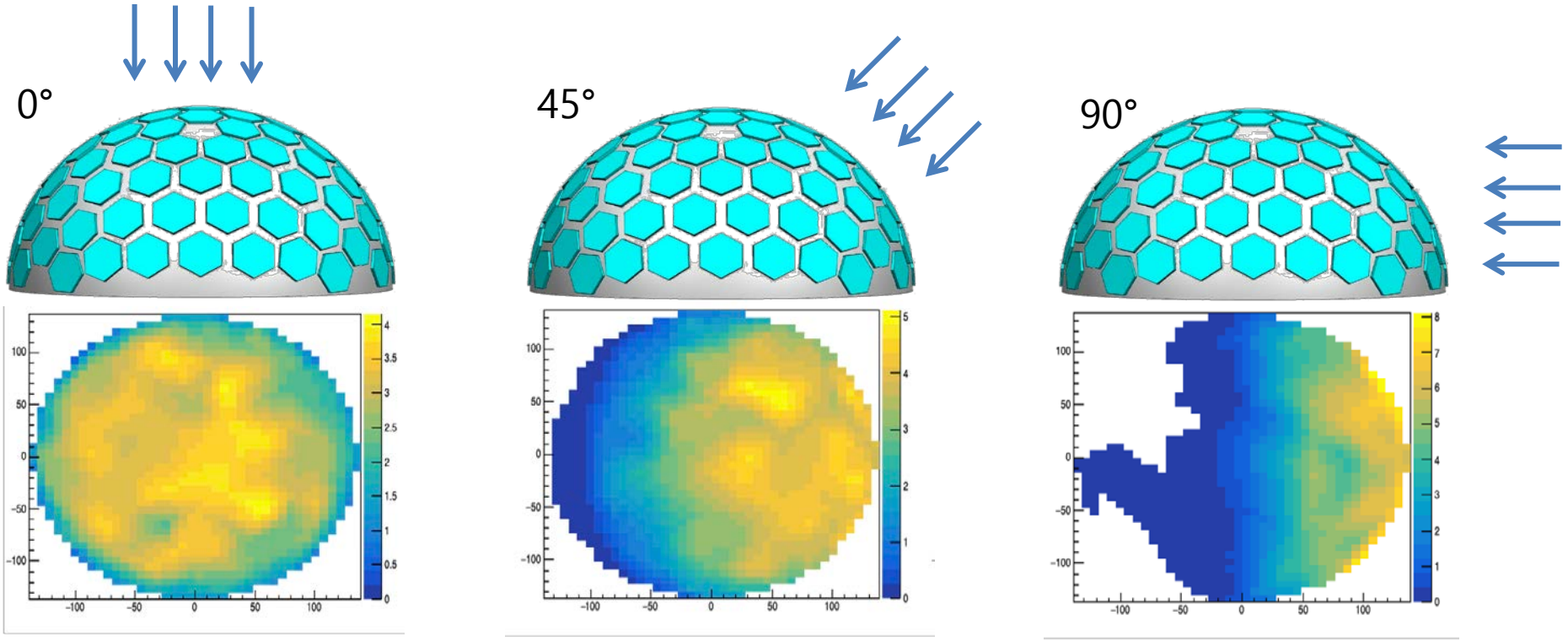
Effective area and energy range



0.1-10MeV ("Ultra Safe")

10keV-50MeV ("Extended")

Sky localization (GRBs,…): the method



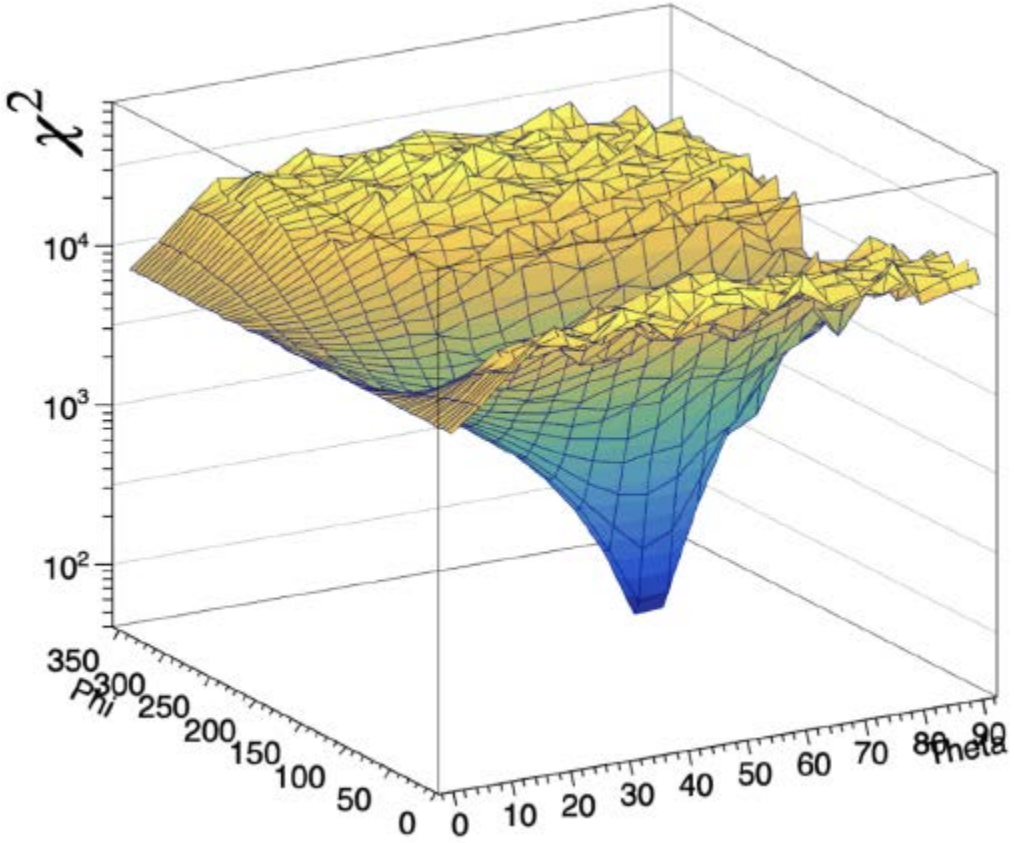
The (GRB) localization algorithm is based on a minimization process that compares a simulated signal in a particular direction, with a template map containing expected counts with multiple directions in the sky.

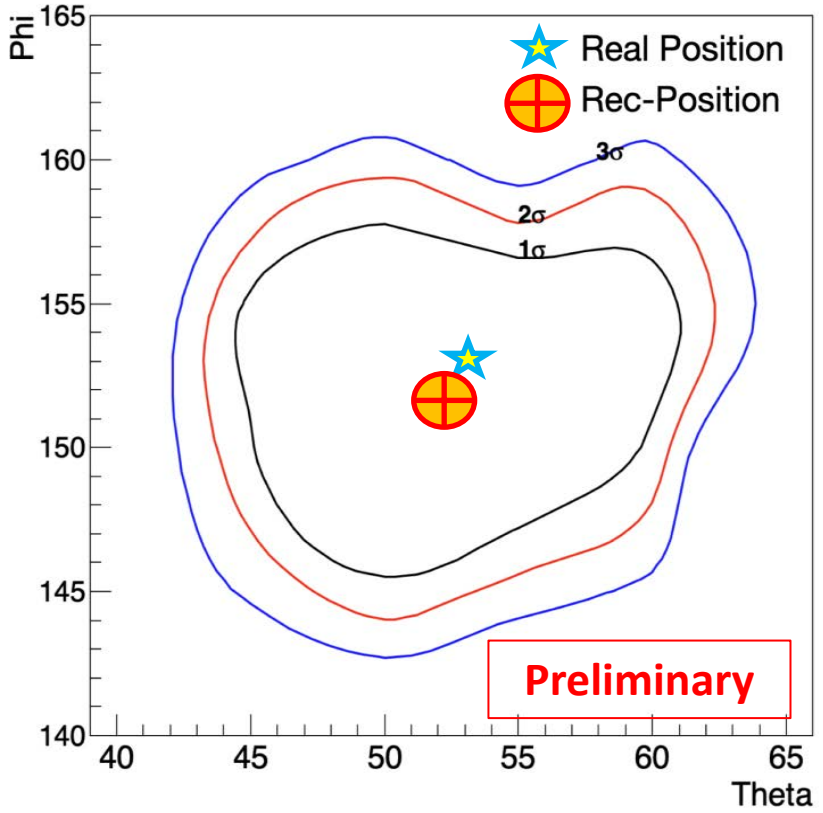
The method would work in real time, and allows to reconstruct the direction of the event and the corresponding uncertainty.

Sky localization (GRBs,…): an example

Example:
GRB170817A (GW followup)
incoming direction $\theta=53°$ $\phi=153°$

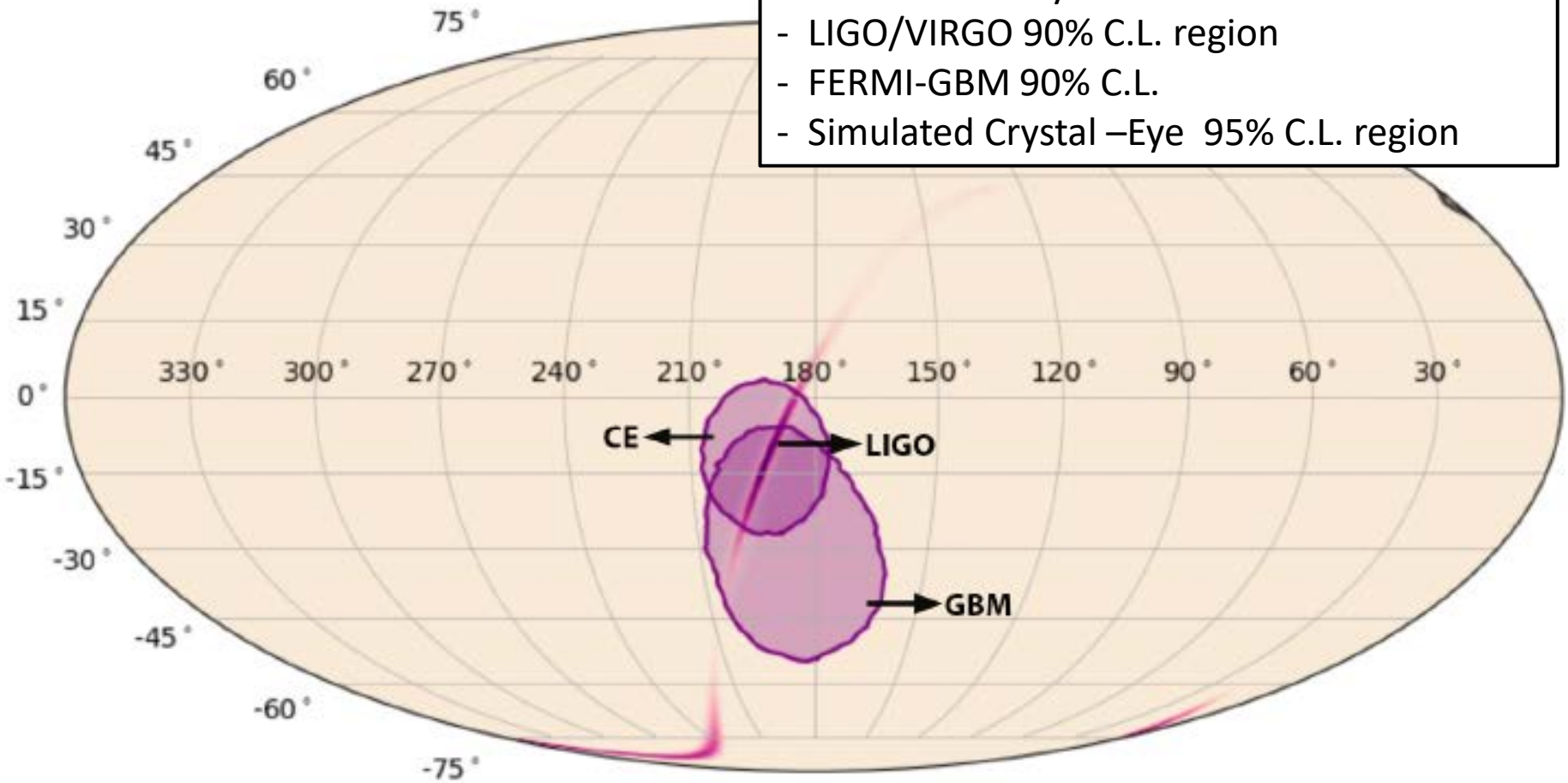
The 68% and 95% C.L. regions are at about 8° and 9° respectively





Sky localization (GRBs,…): an example

GRB170817A sky localization:
- LIGO/VIRGO 90% C.L. region
- FERMI-GBM 90% C.L.
- Simulated Crystal –Eye 95% C.L. region



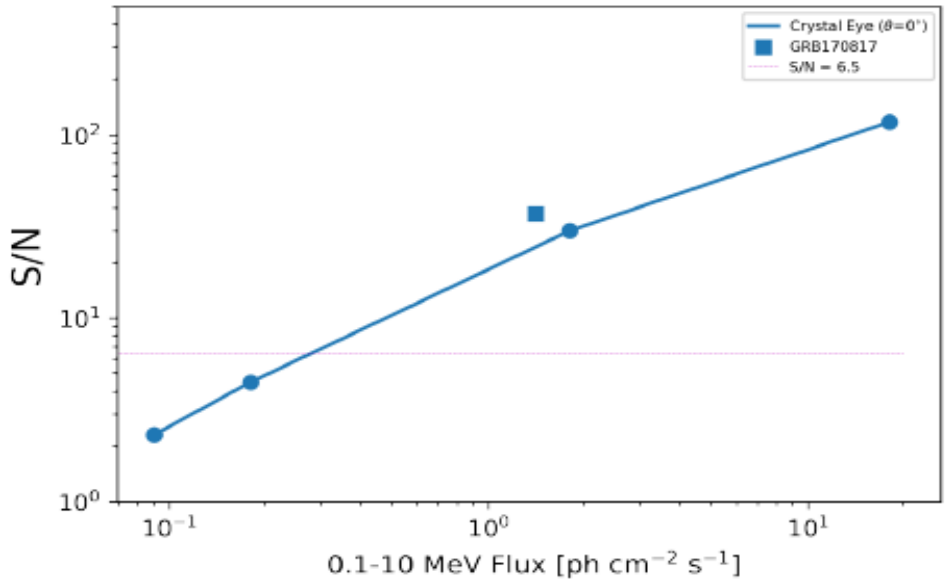
Possible substantial improvement improvement with a 3-4 modules constellation

Transient sensitivity

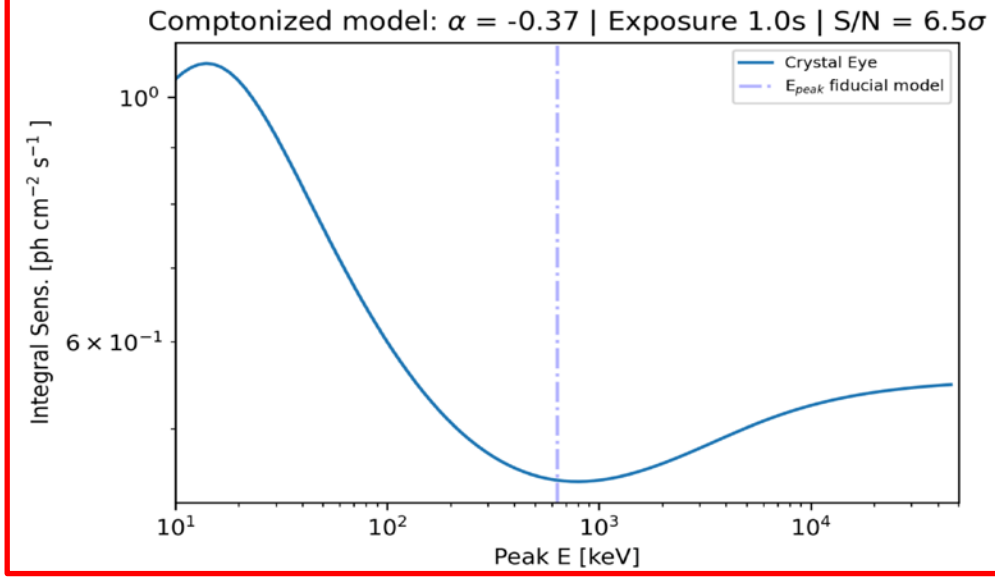
Signal-to-noise ratio vs integrated GRB flux:

S/N =6.5 corresponds to 1 false alarm/year

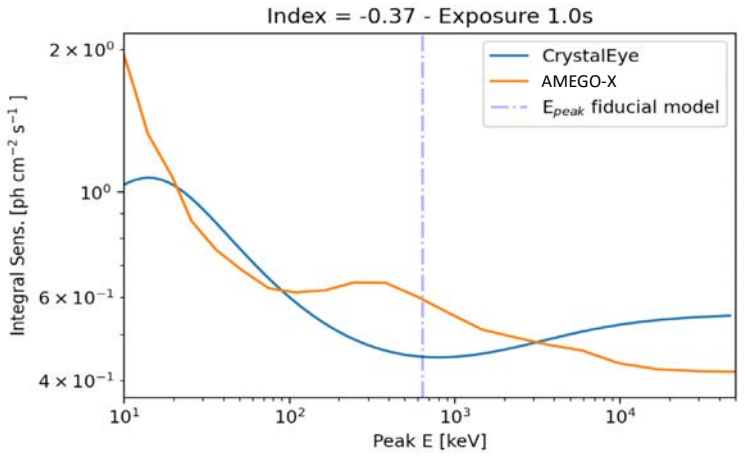
→ Integrated sensitivity threshold
at 0.27 photons /cm2 /s for 1s bursts



Preliminary



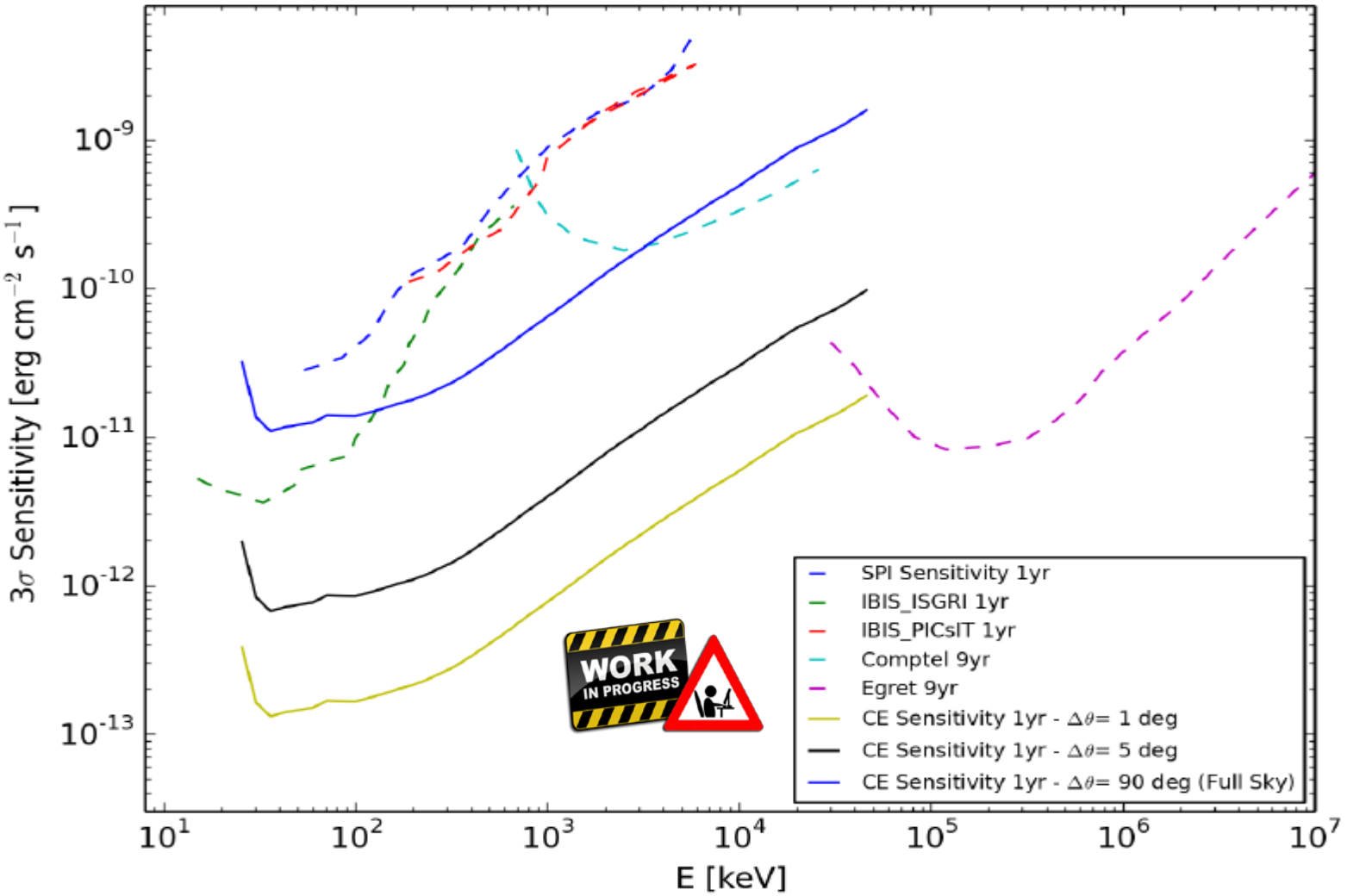
Scan vs peak energy , etc…..



Continuum sensitivity

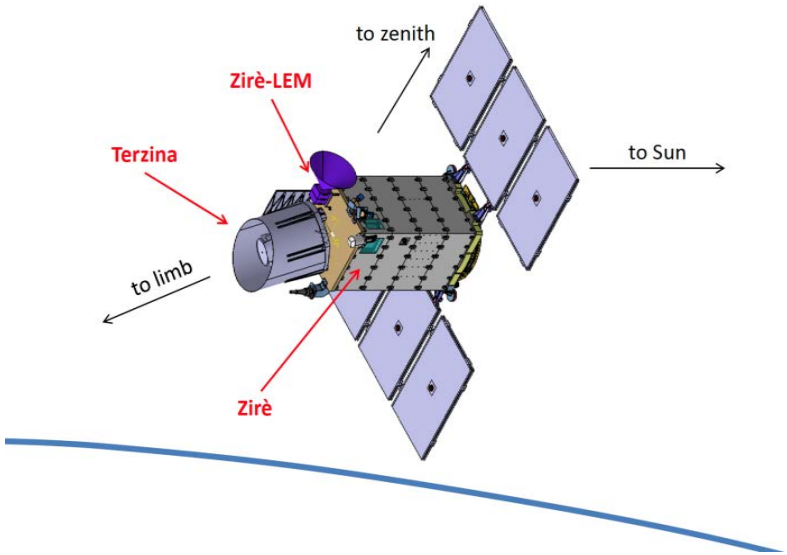
The final curve will depend on the observational technique and the energy dependence of the angular resolution. Detailed simulations are in progress.

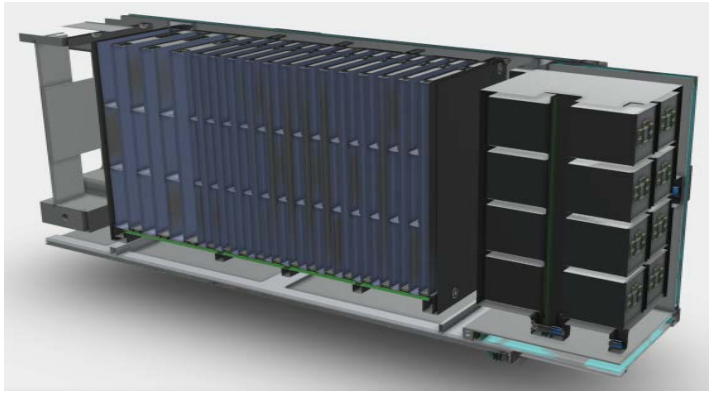
A least one order of magnitude improvement wrt previous missions



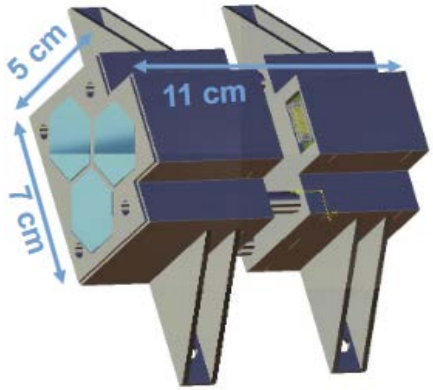
Flight opportunities for CE prototypes

NUSES/Zirè





WINK
Onboard Space Rider



NUSES

An italian led mission conceived as a pathfinder for new observation methods and innovative technologies in the study of high and low energy cosmic 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.

GSSI-INFN collaboration for detector design and operation.

The NUSES mission has been approved by ASI : funds for launch and ground segment.

Participation of 60+ persons from many italian universitites/INFN units , the University of Geneva, the University of Chicago and other US institutions.

A joint effort is ongoing for the design/construction of the payloads.
Ongoing work also with other industrial partners, e.g. FBK , Officina Stellare, Nuclear Instruments, AGE Scientific, Sophia HigTech

The NUSES mission: two payloads

Terzina

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

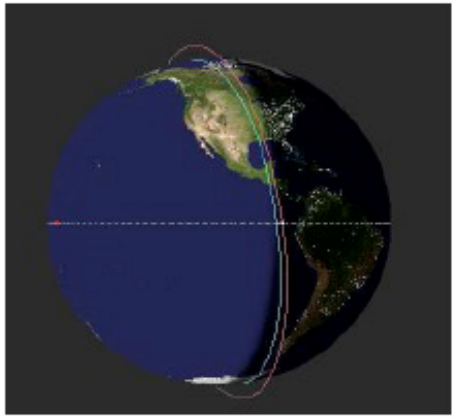
Zirè

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

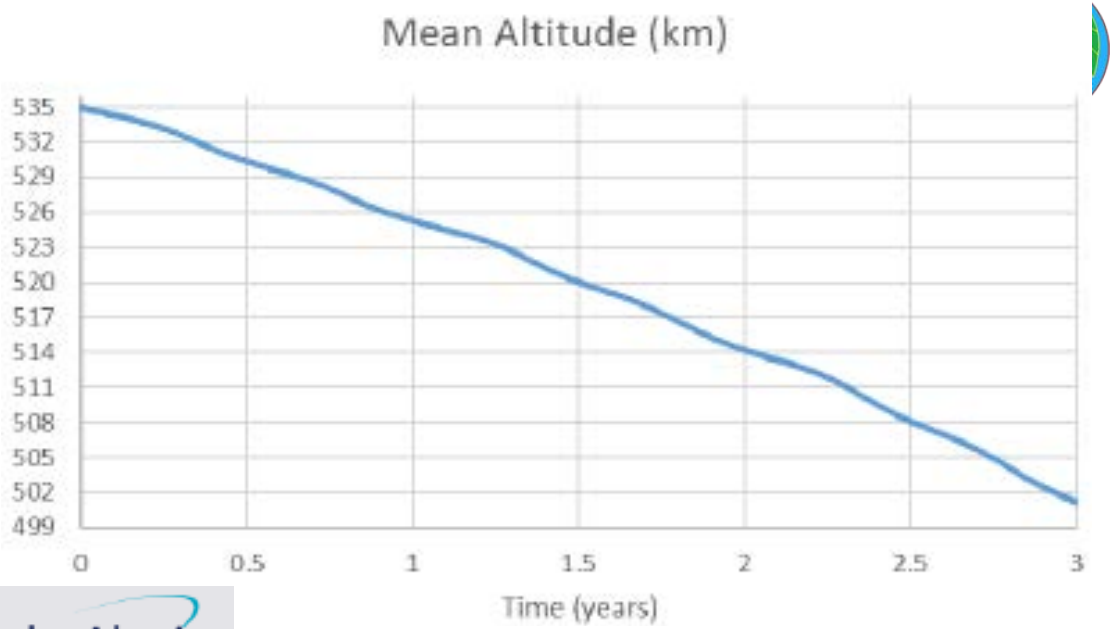
New technologies and approaches

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

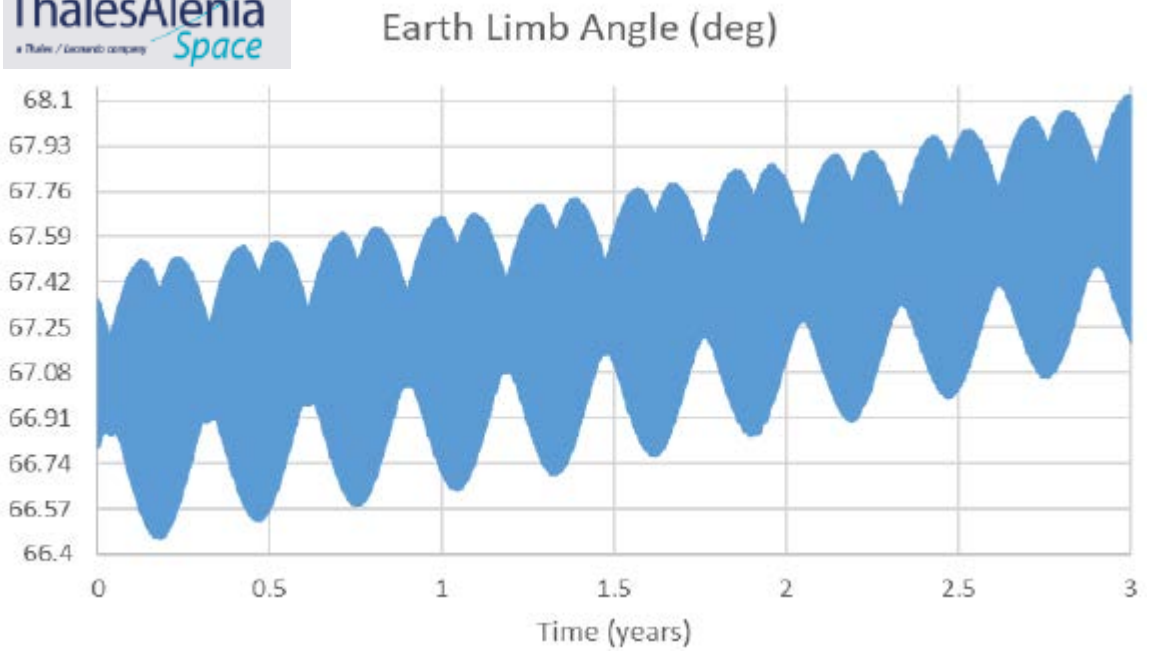
The orbit



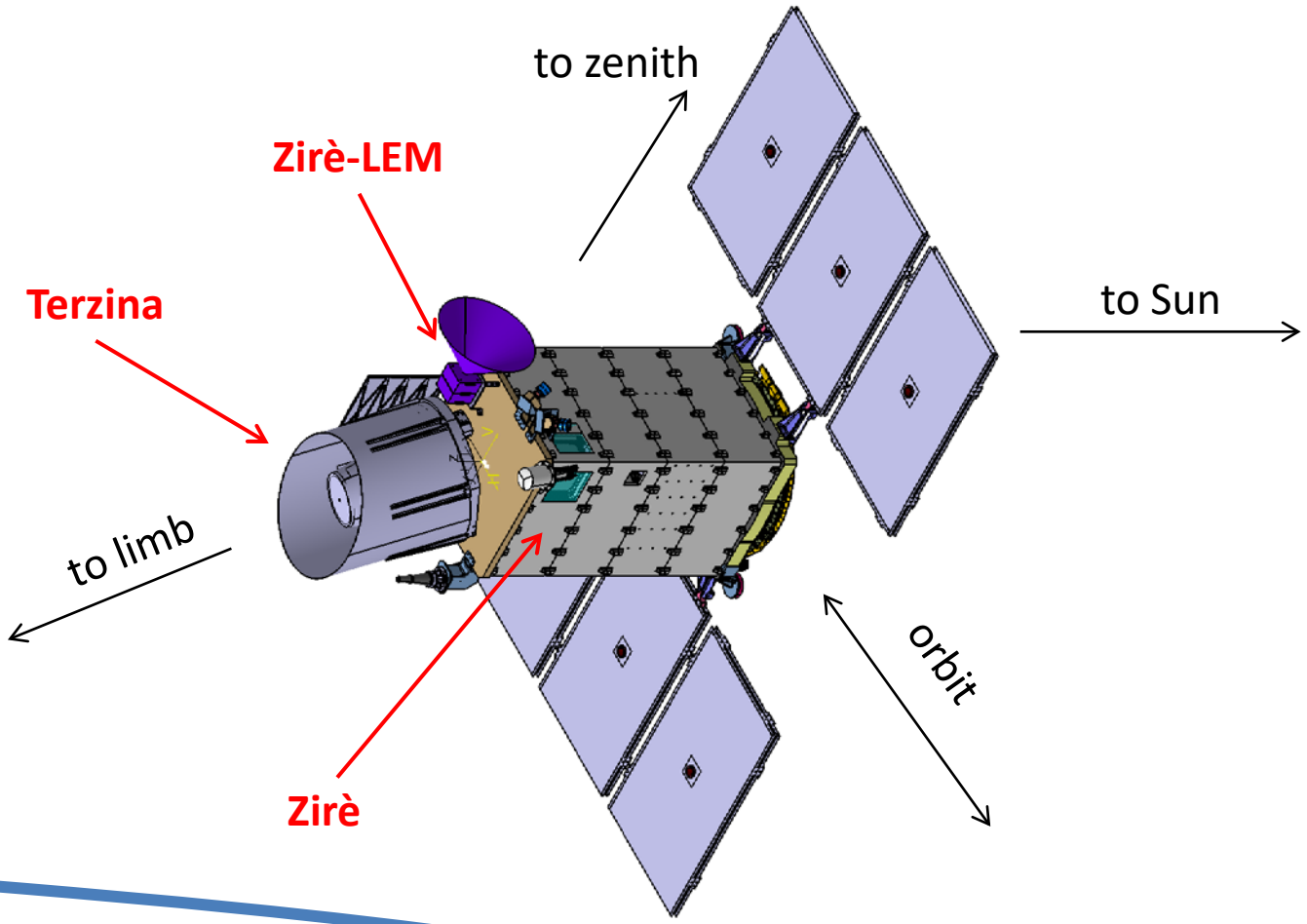
- Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (mean altitude ~ 600 Km, inclination = 97.8°, LTAN = 18:00);
- Orbit optimization for Cherenkov photons detection;
- Ballistic mission (no propulsion for orbital control).



ThalesAlenia Space

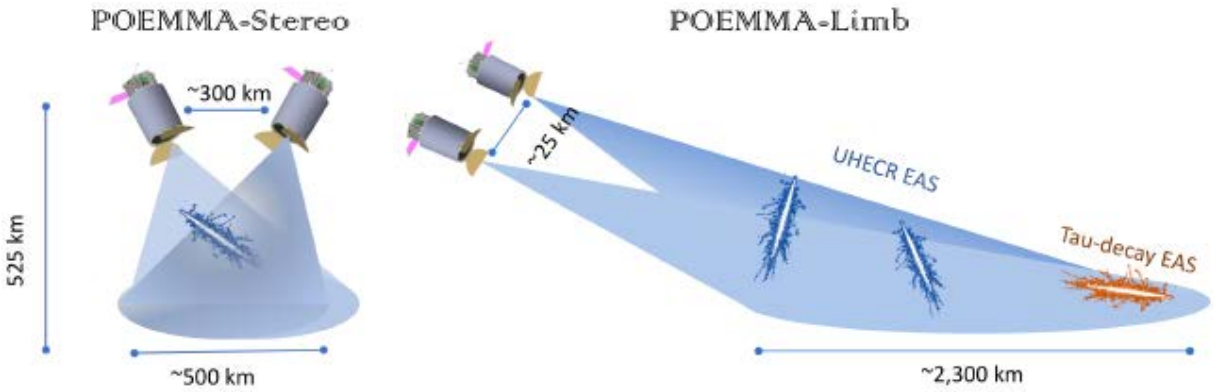


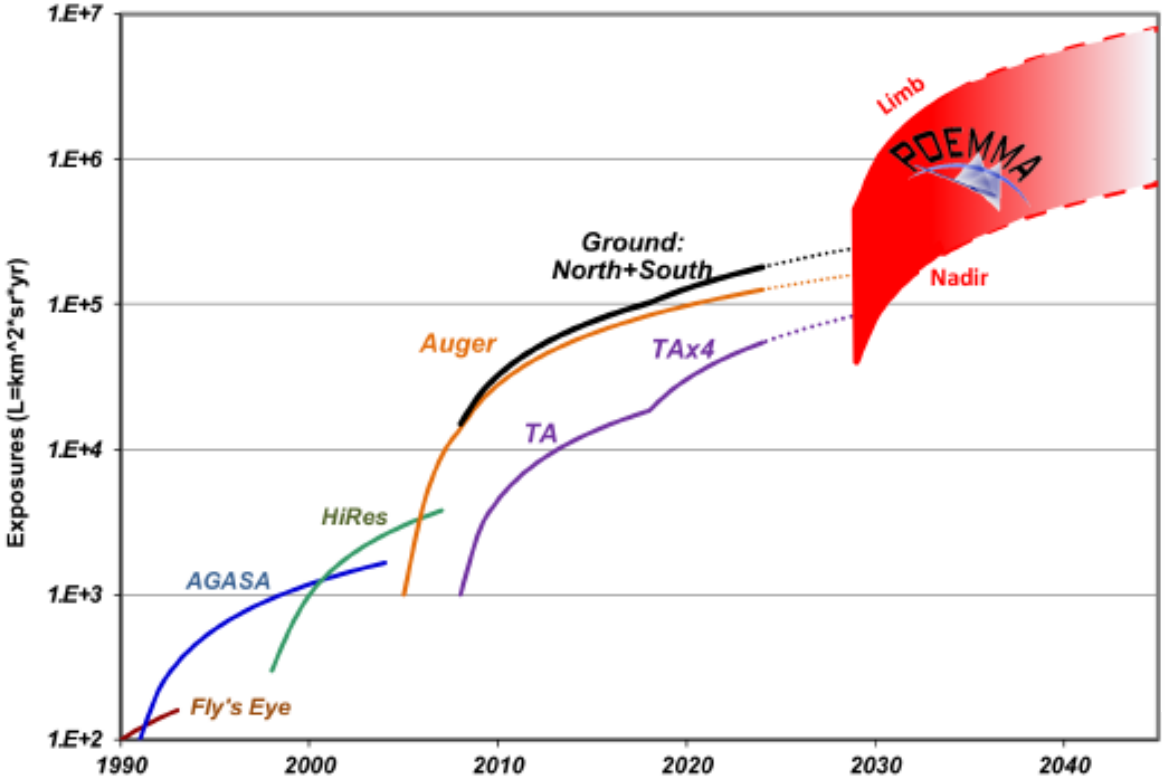
The satellite / payloads layout

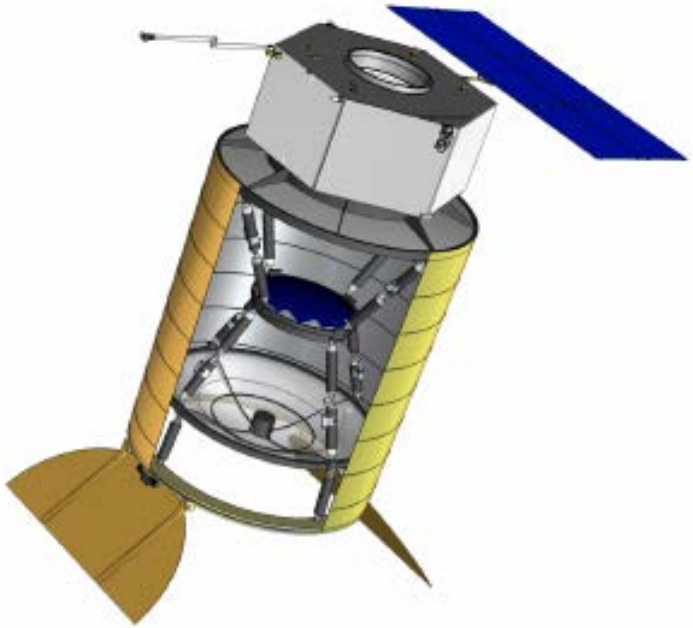


Extensive Air Shower detection from space

- ✓ Ultra High Energy Cosmic Rays.
- ✓ Astrophysical Neutrinos.
- ✓ Big jump in exposure: POEMMA proposal
- ✓ Fluorescence + Cerenkov light

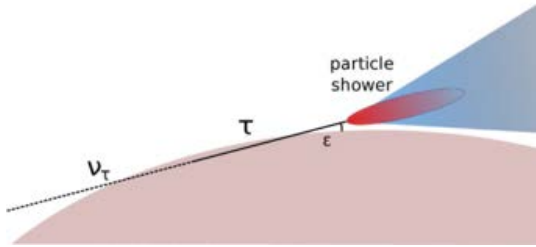


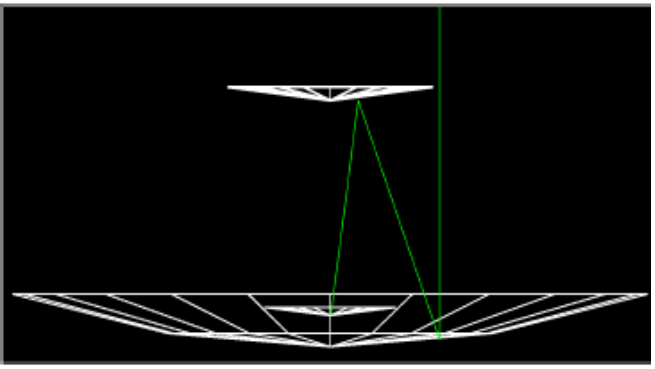




Terzina

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

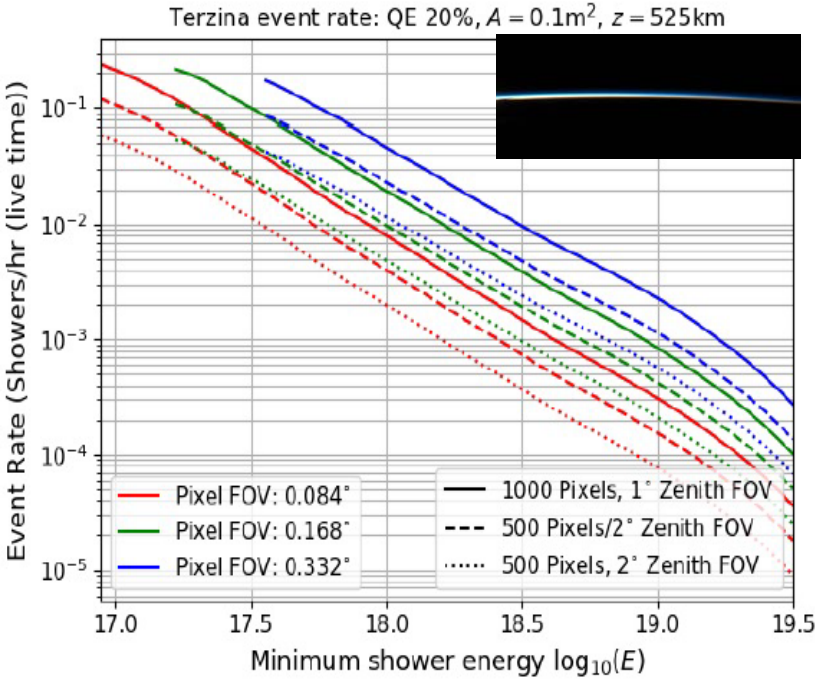


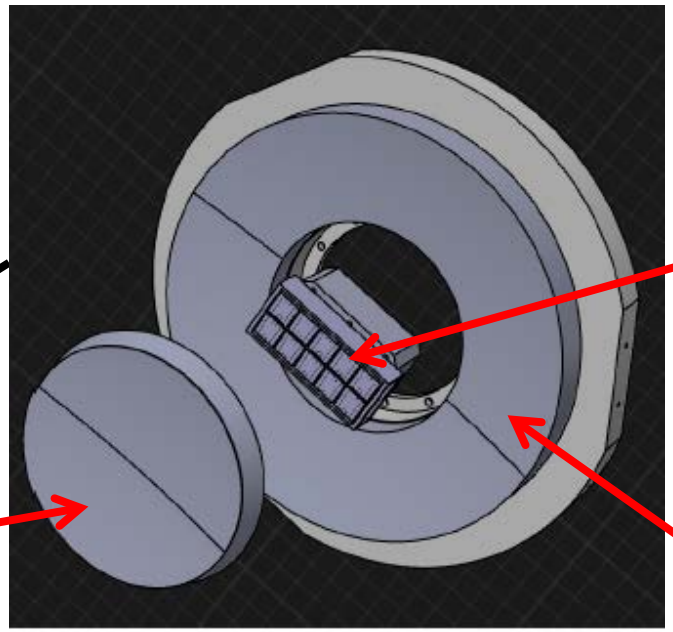


Double mirror optics
Area ~0.1 m²

SiPM focal surface

Roughly 1 event/day





To limb

Focal plane

Secondary mirror

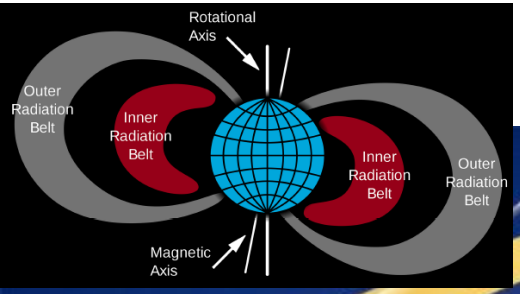
Primary mirror

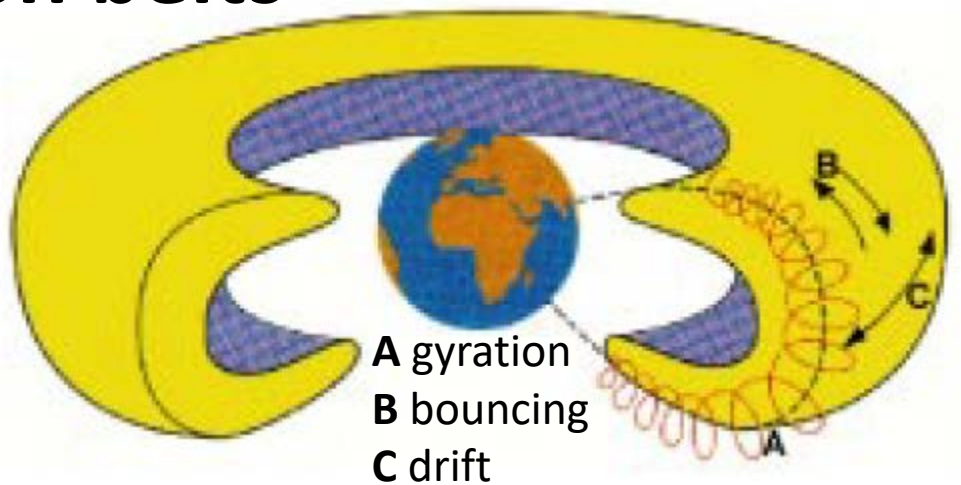
SiPM arrays: **8 x 8 channels**
Pixel: **3 x 3 mm²**
Pixel FoV: **0.18°**

5 x 2 = 10 SiPM arrays In total
(8 x 8) x 10 = 640 pixels (channels)

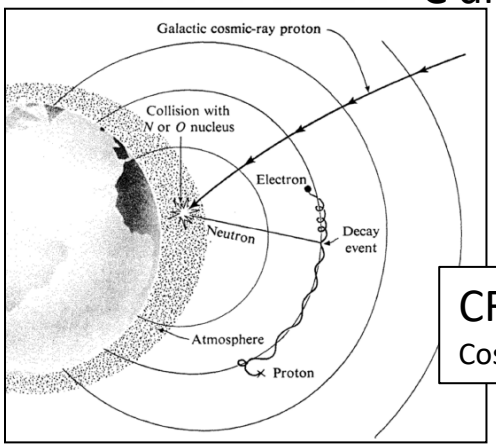
Array dim. : 25.3 x 25.3 mm²
Array Eff. area : 24 x 24 mm²

(Van Allen) radiation belts





A gyration
B bouncing
C drift



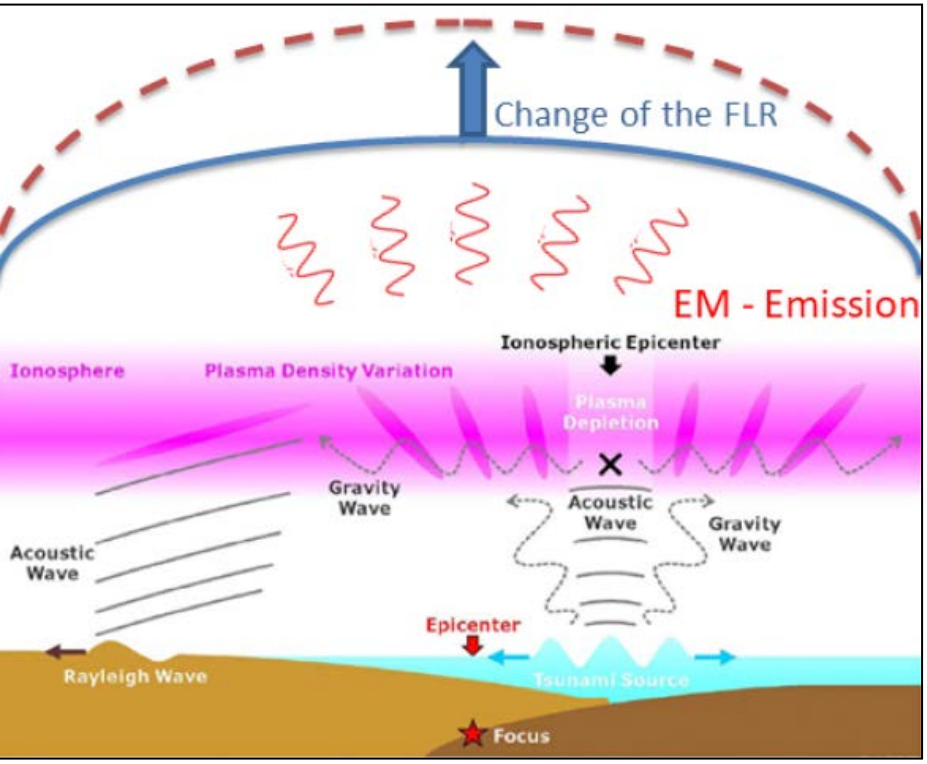
CRAND
Cosmic Ray Albedo Neutron Decay

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

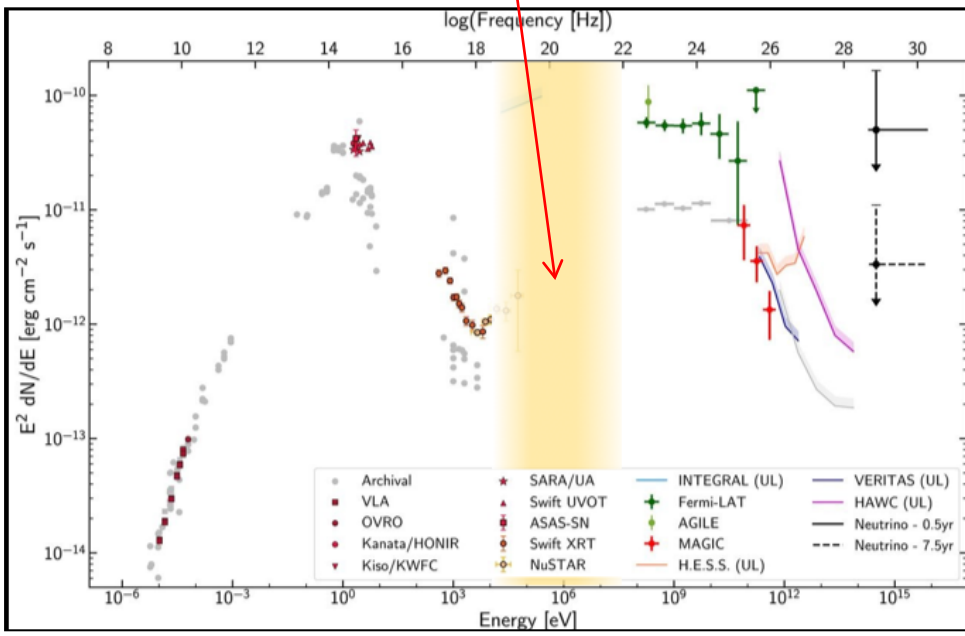
Magnetospheric Ionospheric Lithospheric Coupling

Steady and transient gamma ray sources

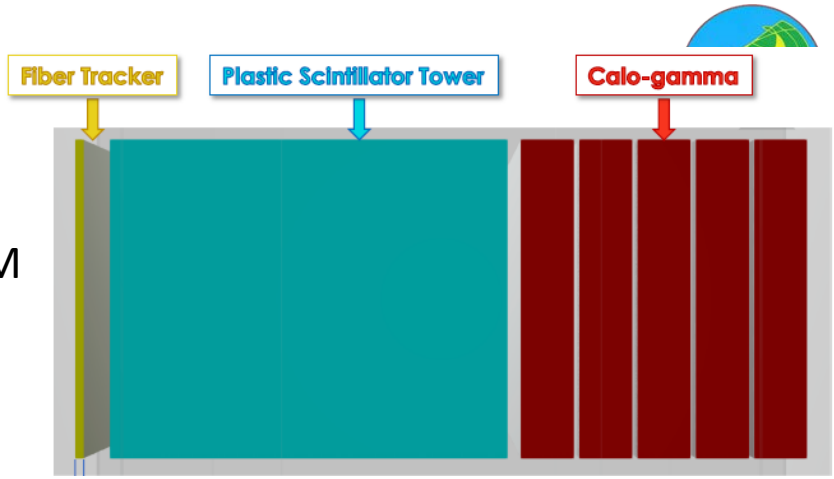
Electrons and protons



MeV photons



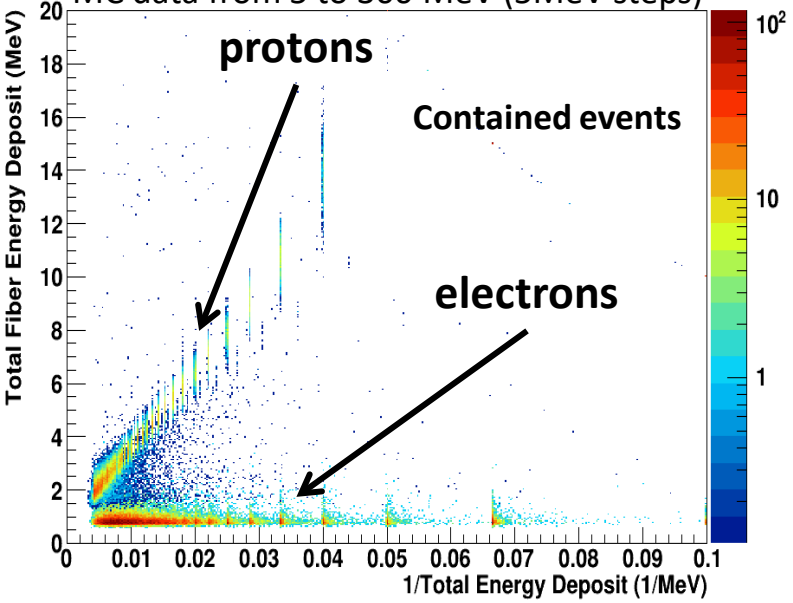
Zirè layout - 1



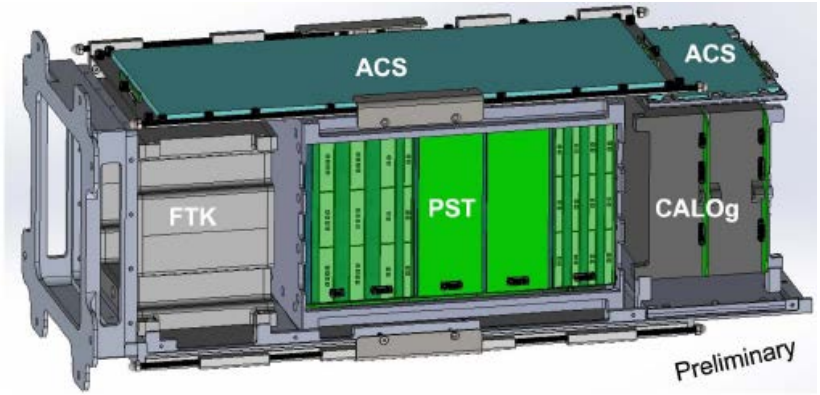
- A fiber tracker, readout by SiPM arrays
- Layers of plastic scintillators X-Y bars, readout by SiPM
- Absorption calorimeter (LYSO cubes radout by SiPM)
- A surrounding active veto system

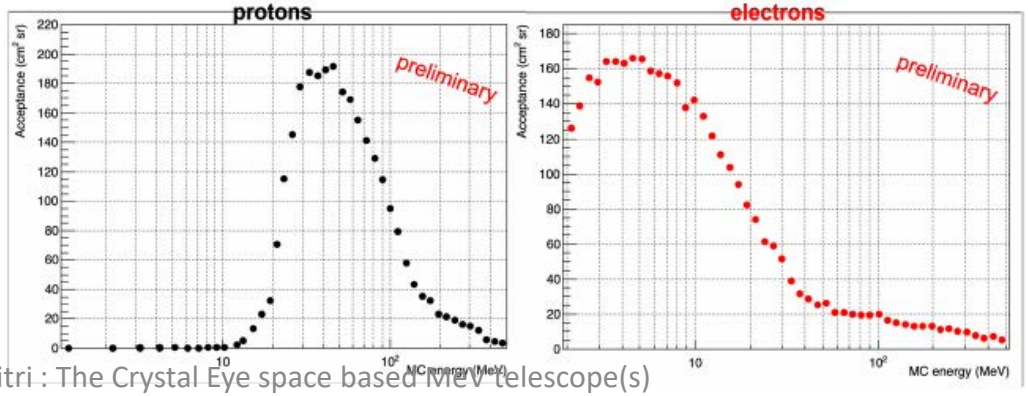
Energy ranges:
- From few up to hundreds MeV for electrons and protons / nuclei + Low Energy electrons
- 0.1 – 10 MeV for gammas

MC data from 5 to 300 MeV (5MeV steps)

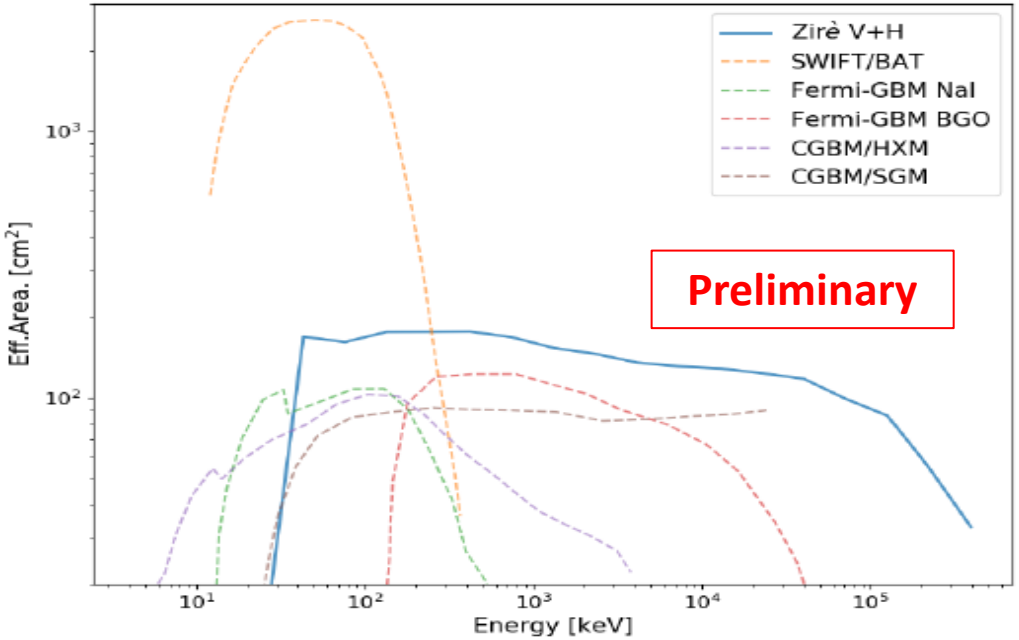


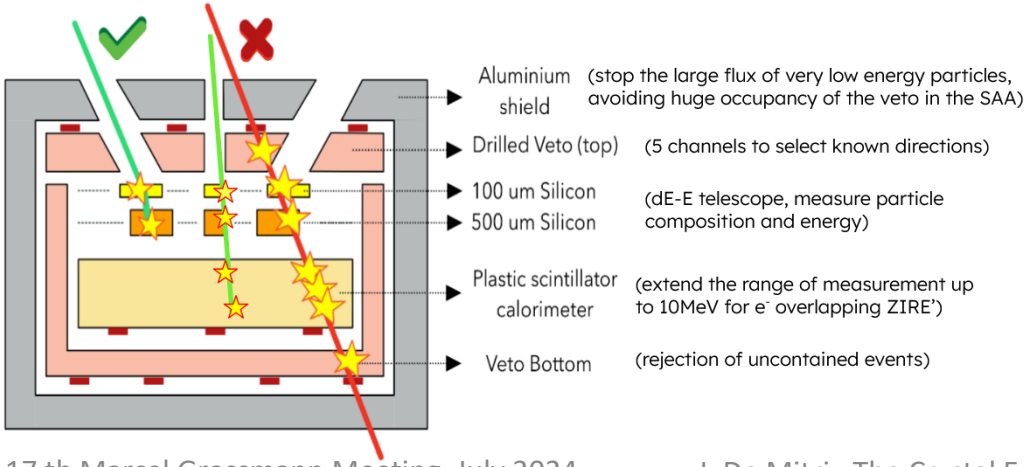
$(dE / dX)_{NR} \propto 1/\beta^2 \propto 1/E_{kin}$

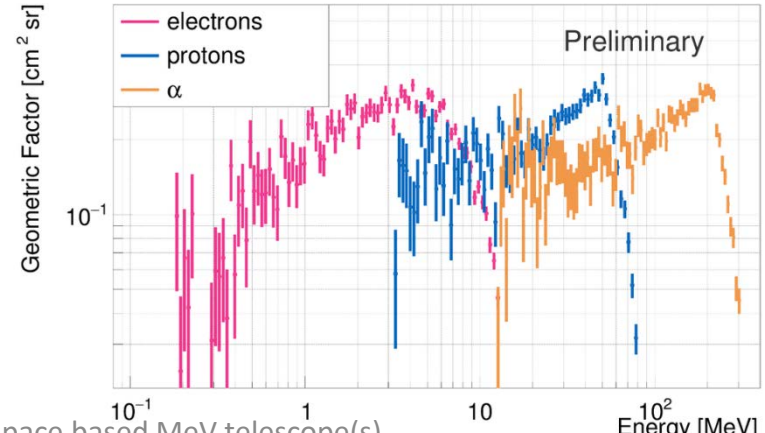




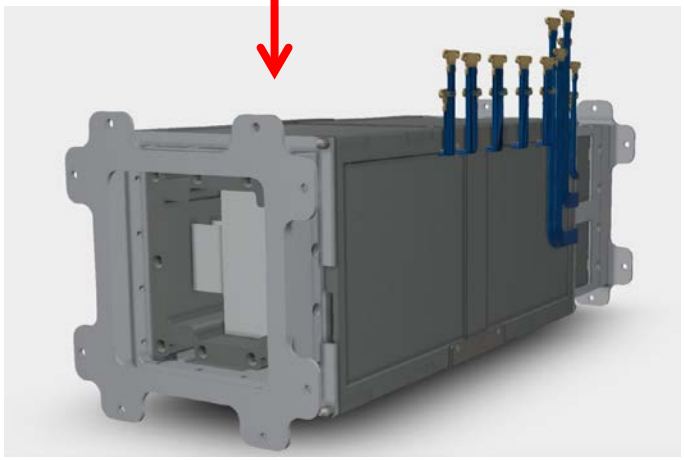
Zirè-CALOG: MeV γ rays (GRBs, etc)
Zirè-LEM: very low energy e, p, α

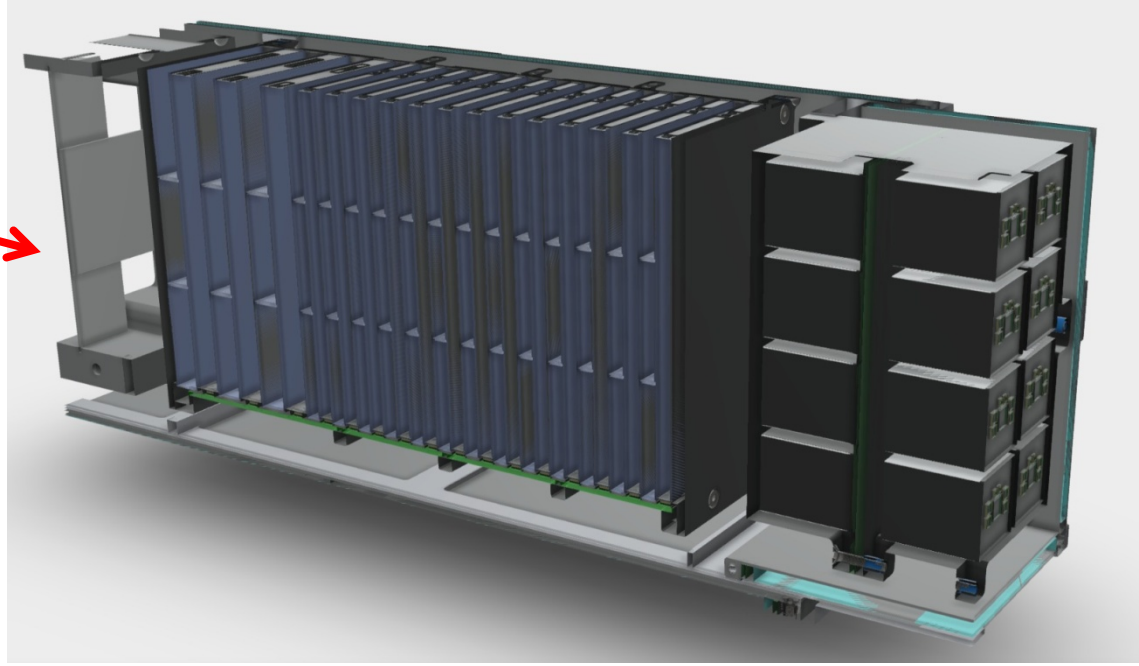






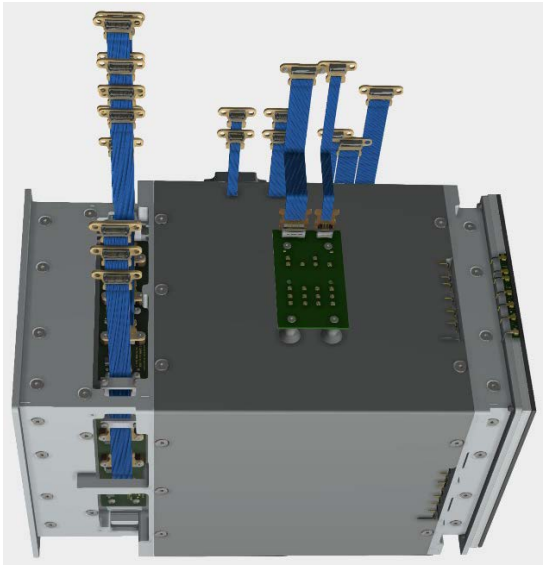
Zirè final design

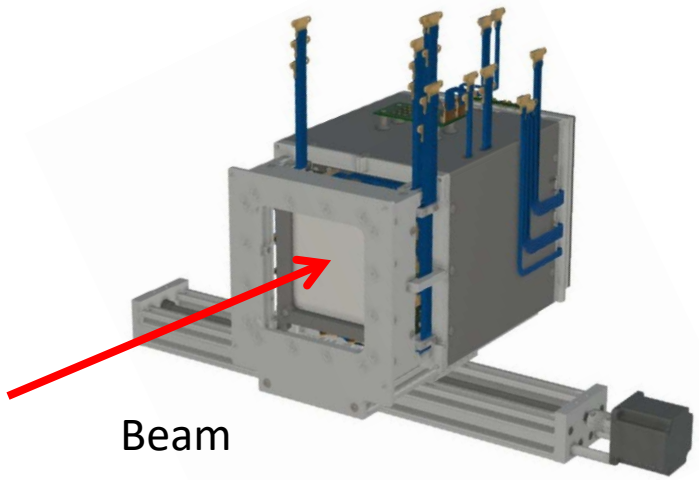




Zirèttino

(for tests and calibrations)

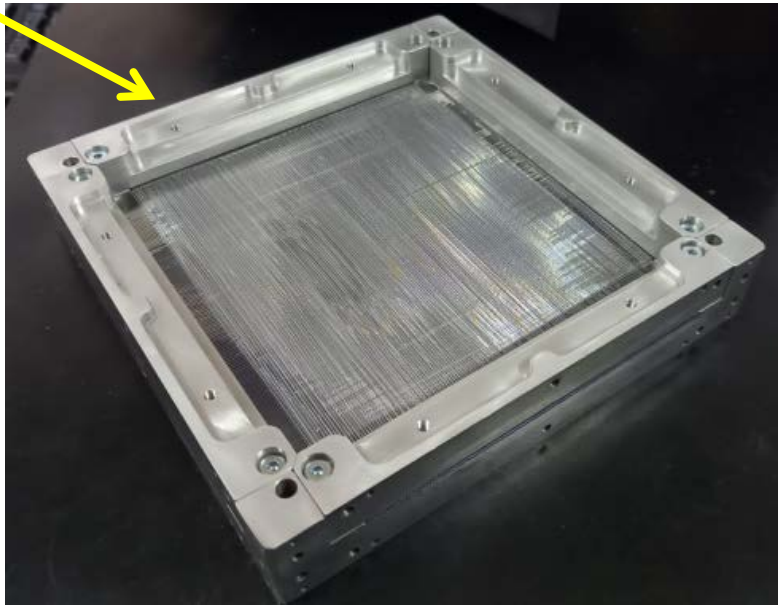




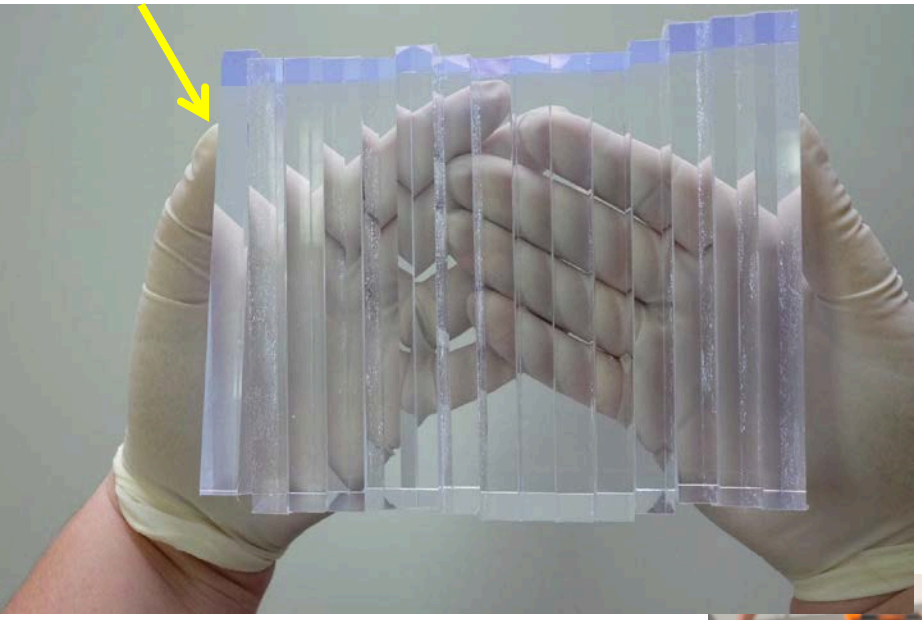
Beam

Zirèttino construction

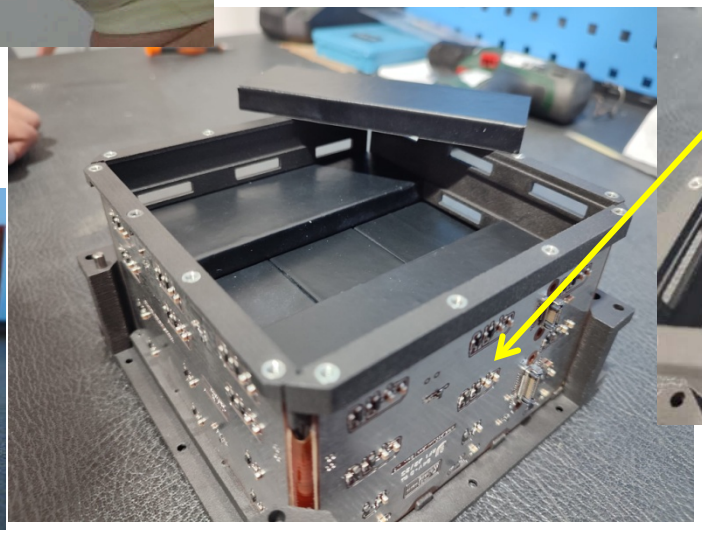
The fiber tracker (FTK)

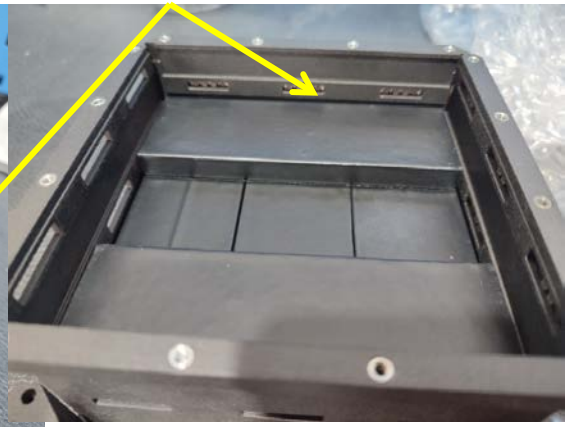


Plastic Scintillator Tower (PST) bars

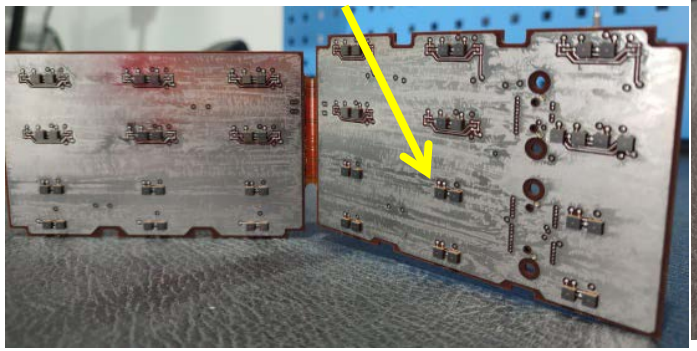


PST layout and readout board/ windows

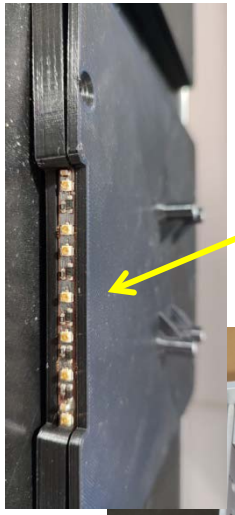




The readout PCB hosting SiPM
Plastic Scintillator Tower (PST)

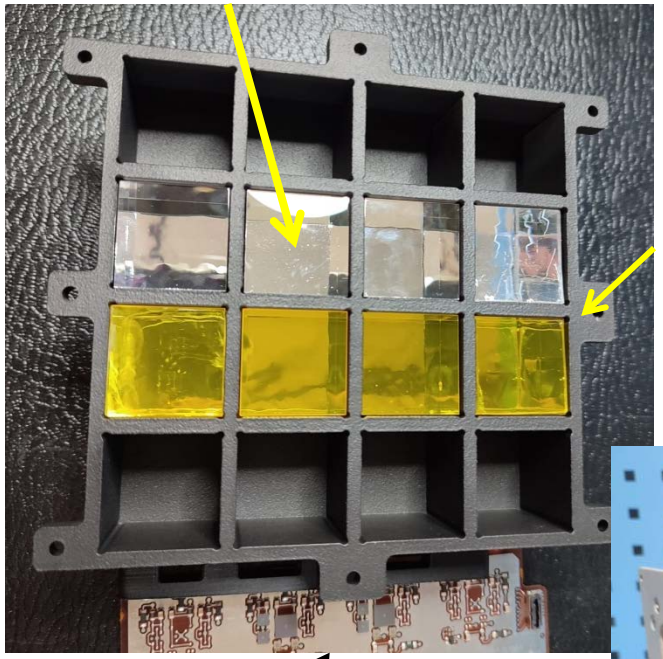


Zirèttino construction

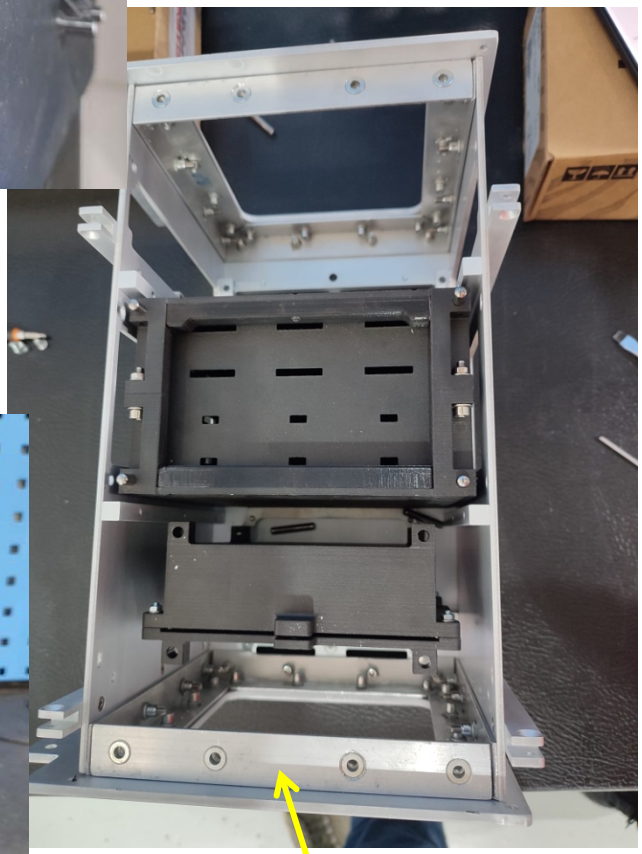


Anti-conicidence tile
and SiPM readout

LYSO and GAGG crystals in the CALO



3D printed
Windform case



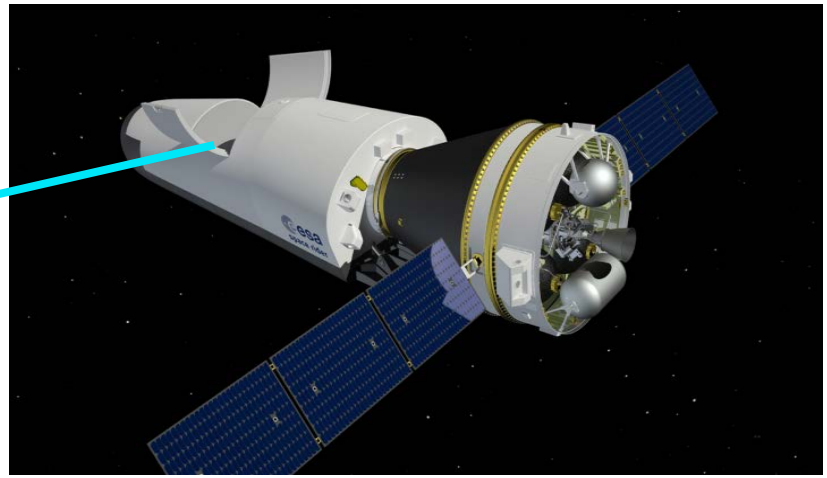
PCB hosting SiPMs
for CALO readout

Al 6061-T6 external case

WINK onboard the Space Rider

A few pixels Crystal Eye prototype (WINK) will fly onboard Space Rider
Space Rider is an uncrewed robotic laboratory. After launch on Vega-C it will stay in low orbit for about two months. Payloads will be hosted inside its cargo bay (1.2 m^3) .

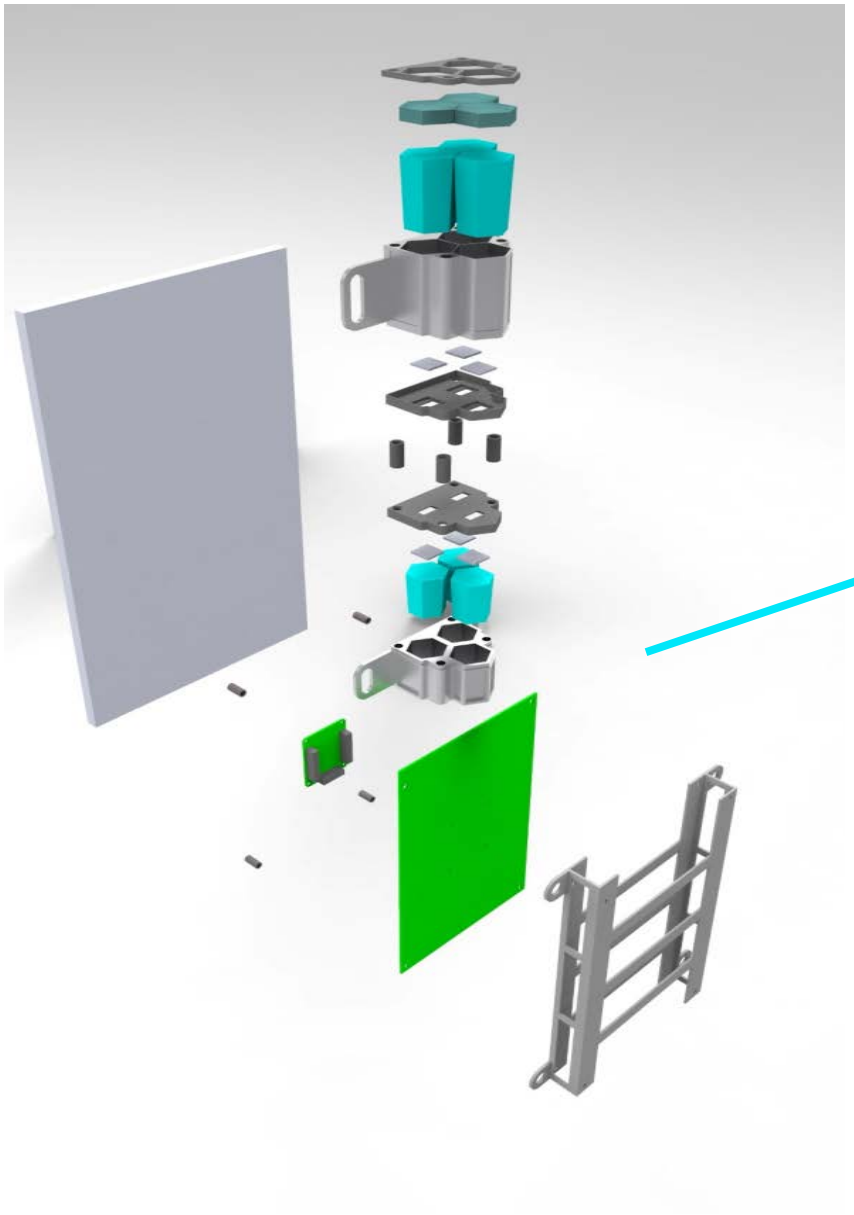
At the end of its mission, Space Rider will return to Earth with its payloads and land on a runway to be unloaded and refurbished for another flight.

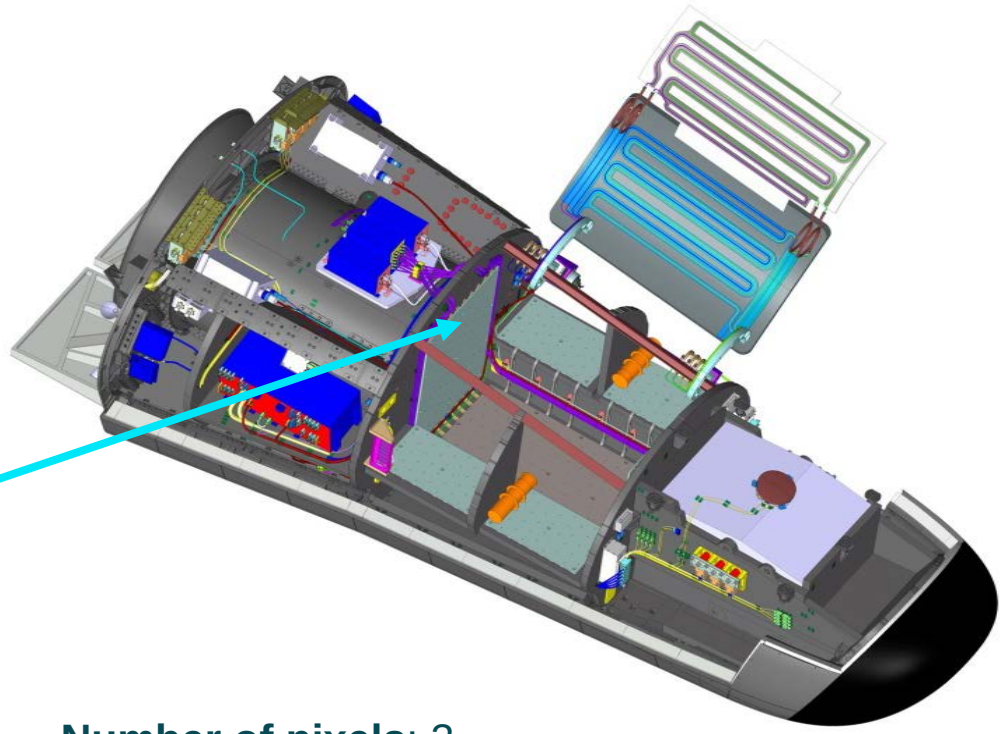


WINK for the first flight of the Space Rider
launched by ESA in 2025

GOALS:
- Background studies
- TGF detection
- Technology test

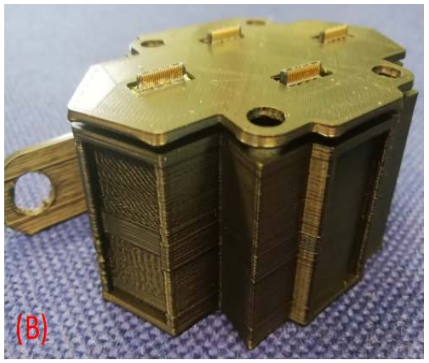
WINK onboard the Space Rider

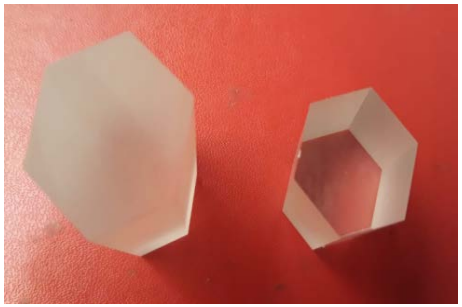


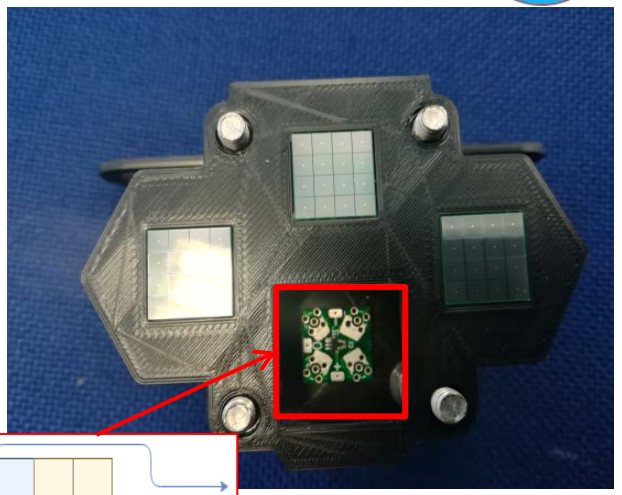


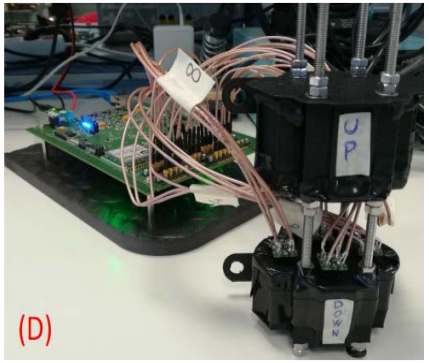
Number of pixels: 3
Material: LYSO
Photodetectors: SiPM-array
Weight: 1.7kg
Power consumption: <6 W
FOV: 30°
Observation Mode: Zenith + Nadir

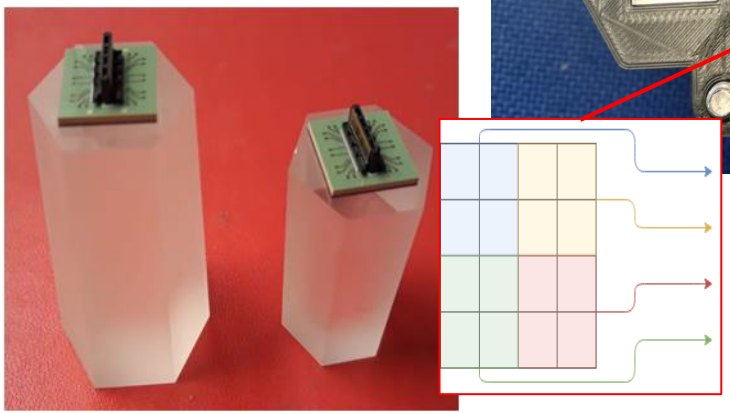
Crystal Eye / WINK breadboard model(s)





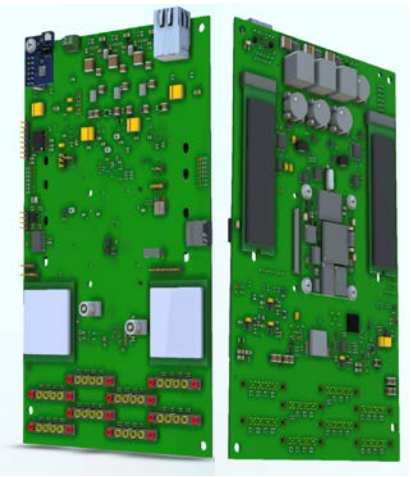


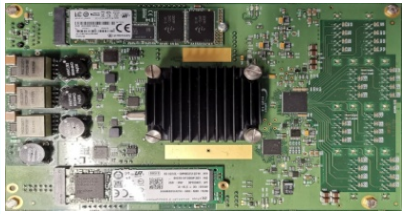


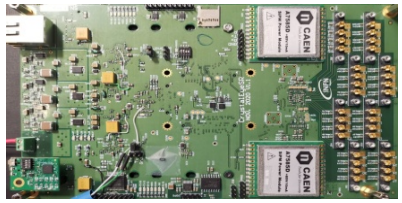


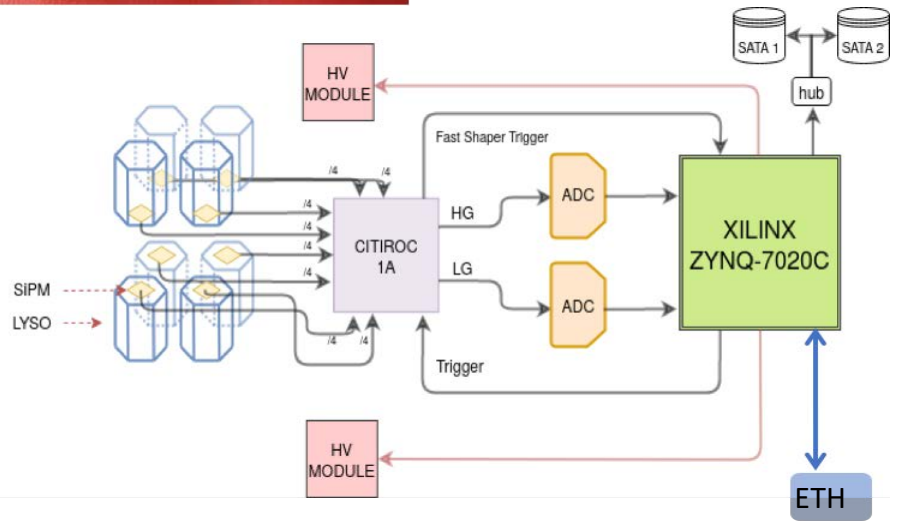
Trigger options:

- Majority: >3 quadrants
- OR of the crystals



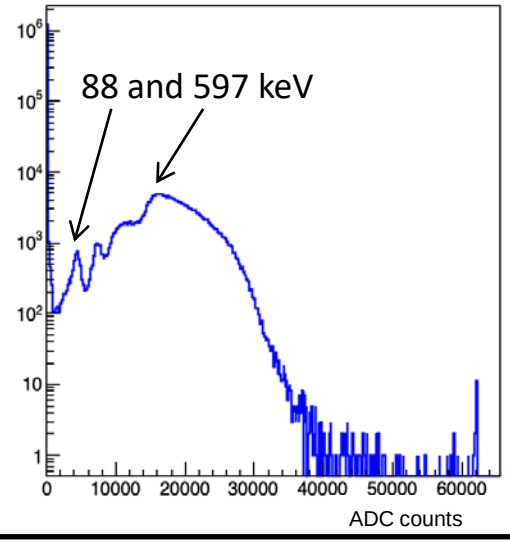




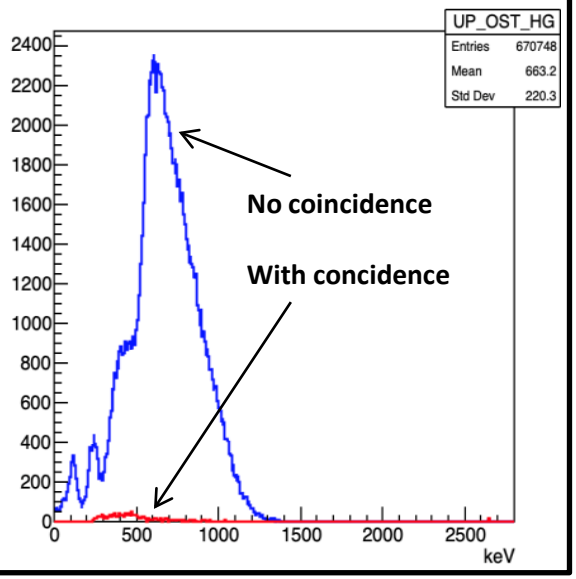


Energy calibration and resolution

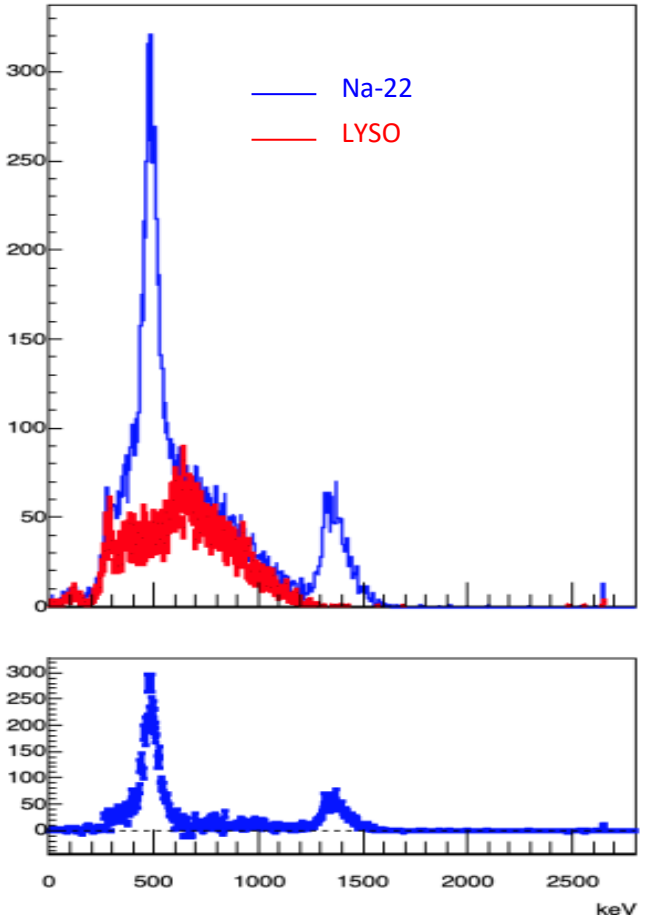
Use intrinsic LYSO radioactivity as a tool of calibration

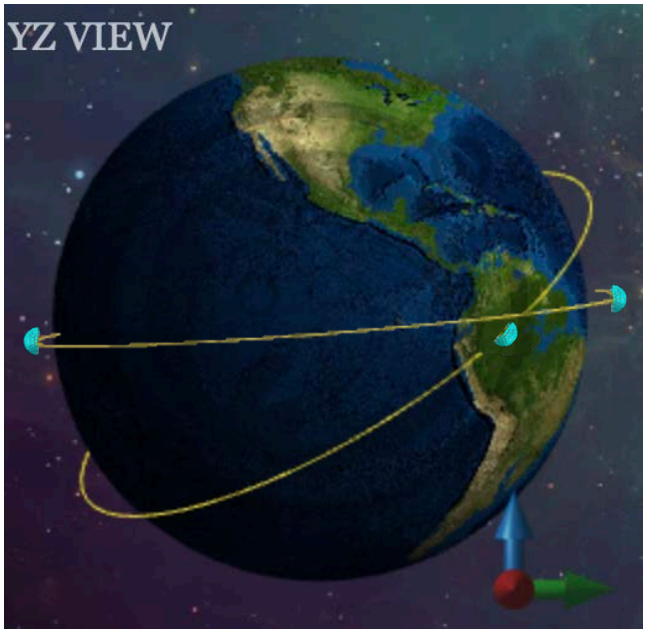


Intrinsic LYSO radioactivity easily removed by fast concidence among 2 crystals



Further background removal can be done offlline using template histograms





MACBETH

Multi-messenger Astrophysics with Crystal eye for Burst Events and Transients Hunting

4 Crystal Eyes in LEO orbit

- Full sky coverage
- High effective area
- Improved localization capabilities
- Use of NIMBUS spacecraft developed by TAS-I for NUSES mission
- Low weight (<150 kg)
- Possible networking with other experiments (e.g. nanosatellites constellations)

Summary

- The Crystal Eye concept will provide 0.1-10 MeV coverage, with extensions to (50keV – 50 MeV) depending on the final setup.

- The main detector components have been designed and tested. Prototypes are being built and operated.

- Funding for one full scale module.

- WINK prototype onboard first Space Rider flight.

- The NUSES mission will give important inputs.

- The collaboration is open to new countries/istitutions