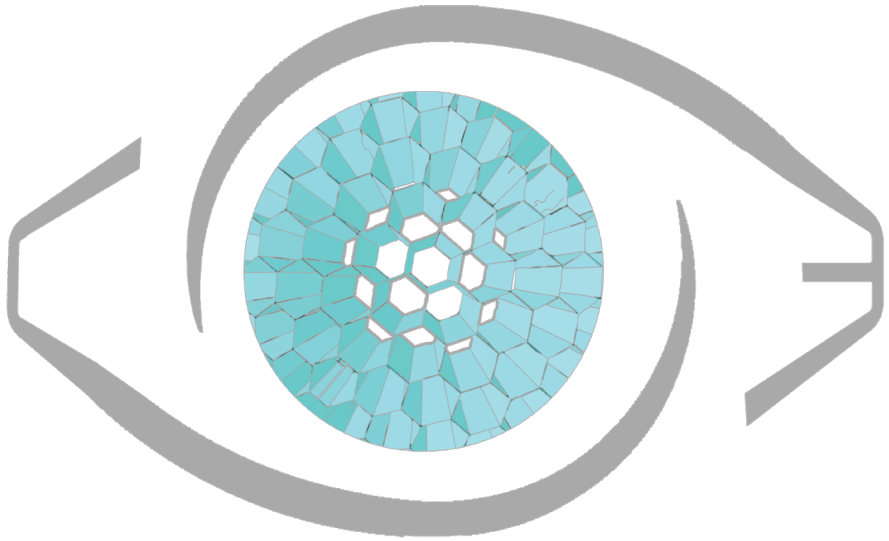
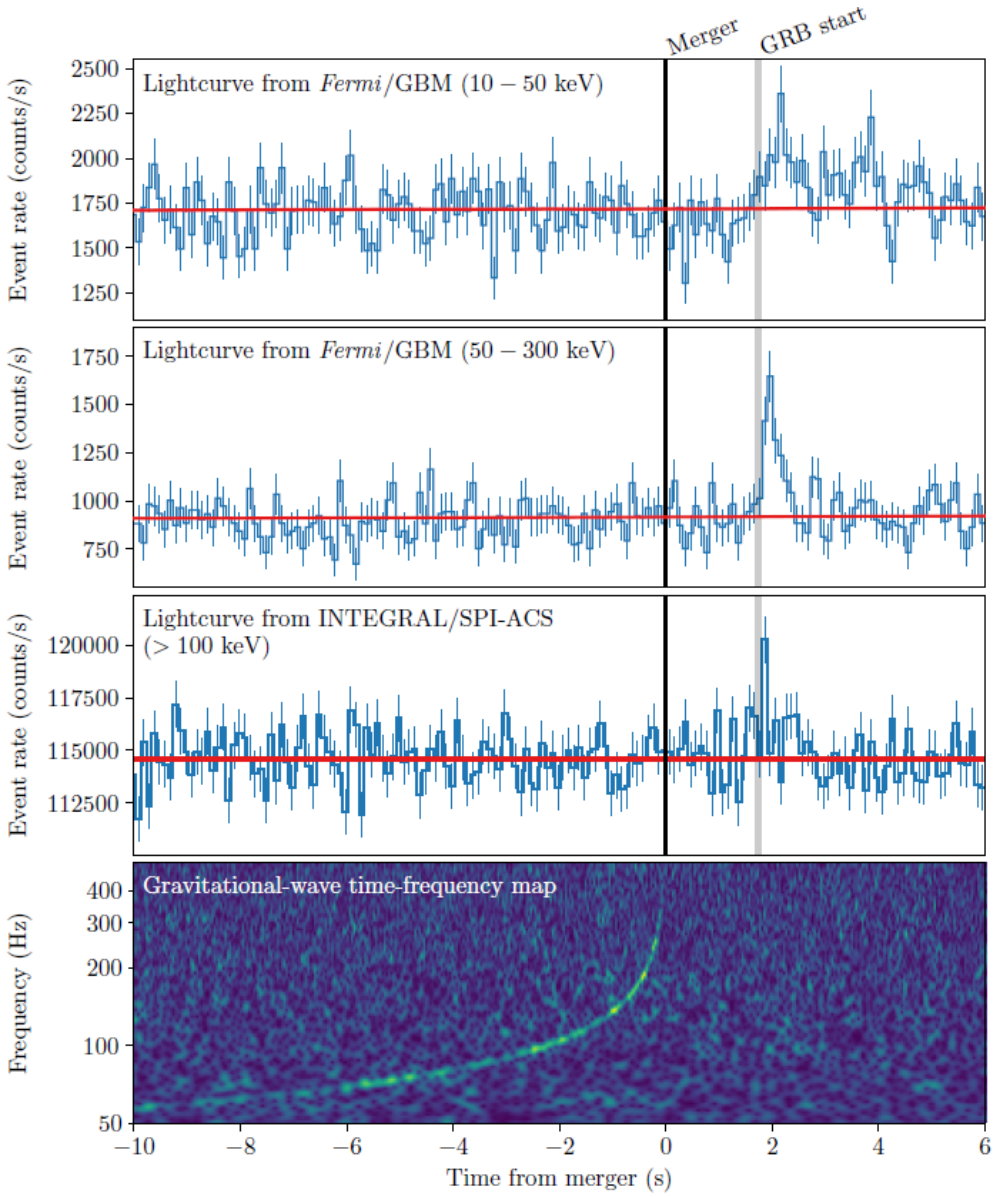
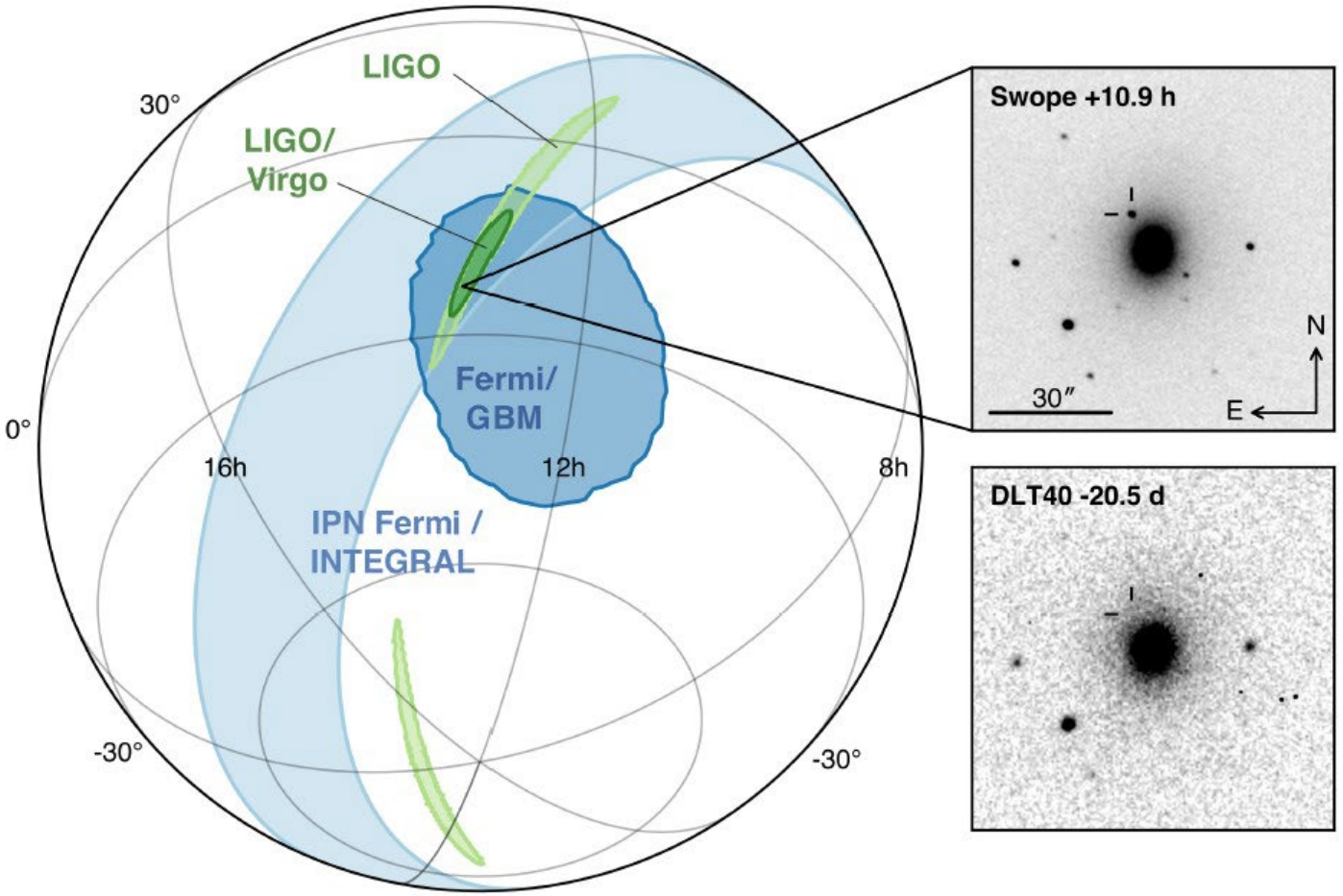


The Crystal Eye X and gamma ray detector for space missions

F. Garufi – UNINA and INFN-NA on behalf of the Crystal Eye collaboration – Sept. 12th 2022

WHY AND FROM WHERE WE STARTED

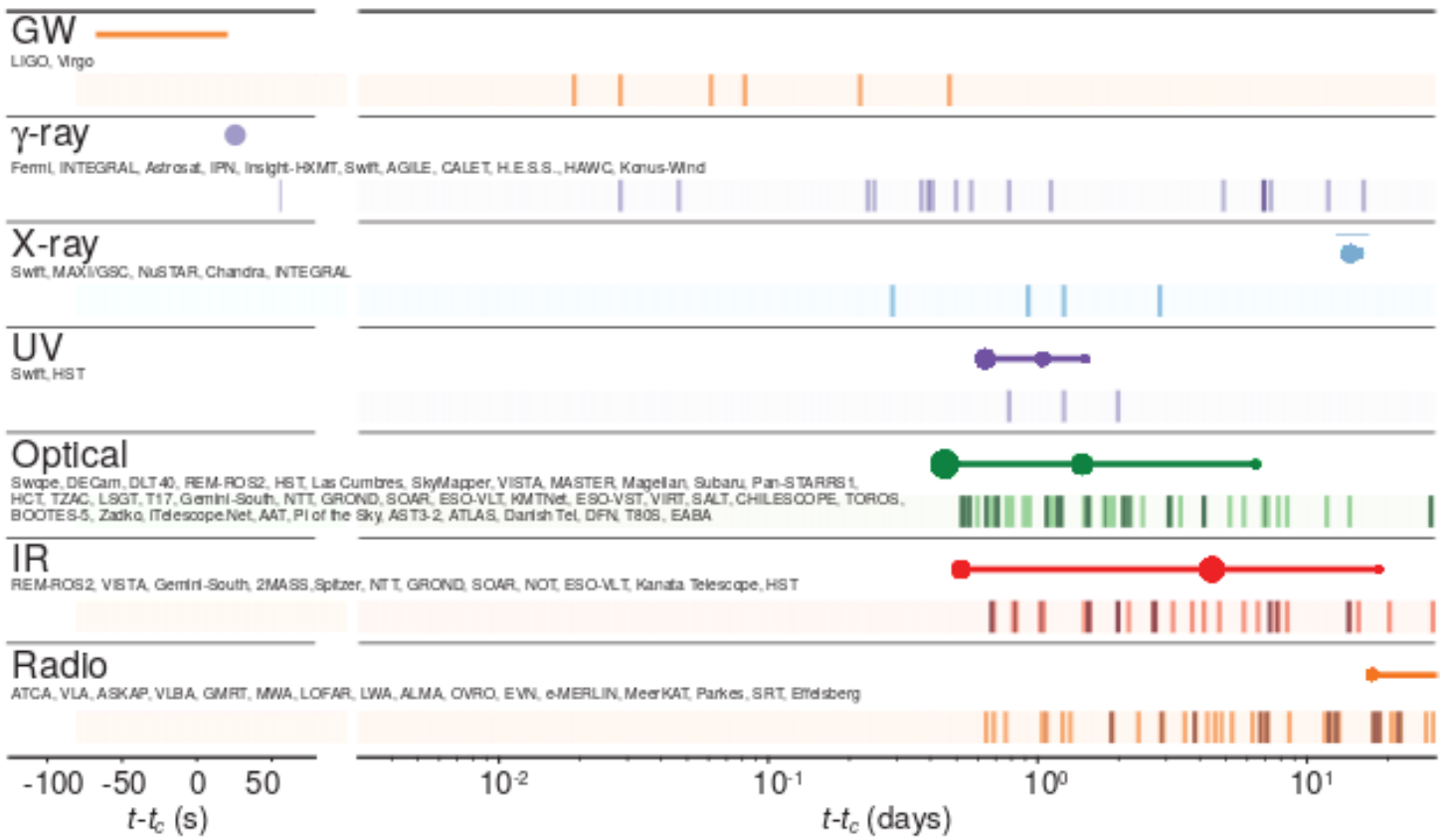




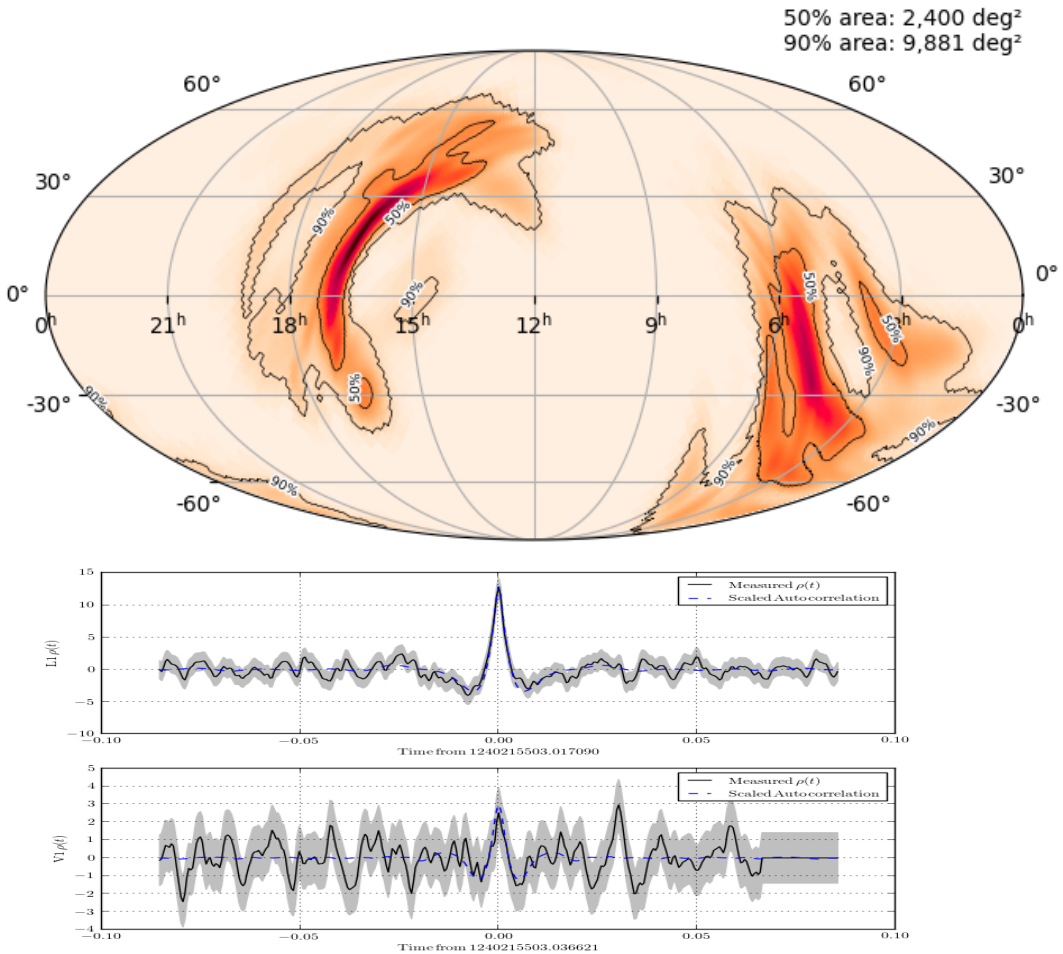
GW170817

Optical, UV, IR, Radio, X

- Several other observatories followed the source evolution for many days. Apparently it is a kilonova.
- It is the first time an astronomical object is studied with so many information from different messengers
- The multi-messenger GW astronomy has born.



GW190425



Single LHO event (SNR 12.8 in L1, 2.52 in V1 – consistent with sensitivity difference), faint localization.

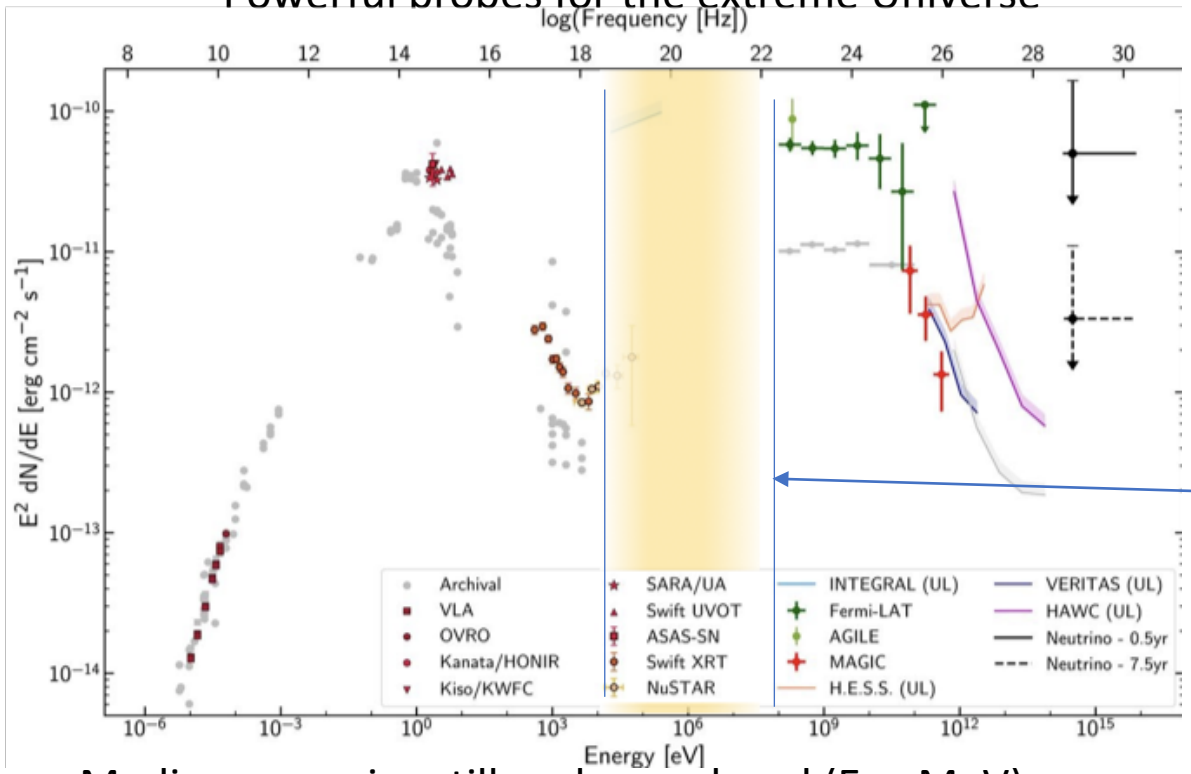
TITLE: GCN CIRCULAR
NUMBER: 24170
SUBJECT: LIGO/Virgo S190425z: INTEGRAL SPI-ACS prompt observation
DATE: 19/04/25 10:27:09 GMT
[…]
After trigger time of S190425z (G330561) we found two pulses with time since trigger, duration, significance and fluence (in counts) above a background as following

+0.5 s, 0.4 s, 3.6 sigma, 900 +/- 250
+6 s, 1 s, 4 sigma, 1620 +/- 400

GCN CIRCULAR NUMBER: 24185
SUBJECT: LIGO/Virgo S190425z: Fermi GBM Observations
[…]
There was no Fermi-GBM onboard trigger around the event time of the LIGO/Virgo detection of GW trigger S190425z (GCN 24168).

THE MEDIUM/LOW ENERGY GAMMA RANGE

Powerful probes for the extreme Universe



There is a «hole» in the 10keV – 100MeV range

Medium energies still under-explored (E ~ MeV)

Primary Scientific Goal: Monitoring the electromagnetic counterpart of gravitational waves

Exploit a constellation of satellites

Improve the detection method

THE SCIENCE CASE

Primary scientific goals

1) Monitoring/prompt triggering the electromagnetic counterpart of gravitational waves

2) Multimessenger observations with GW and Neutrinos

Progress in understanding mechanism that power jets (like GRBs, AGNs)

3) Observation of gamma ray lines from supernovae

Progress in understanding the mechanism of element formation in extreme environment

4) Searching for magnetars

Understanding possible correlation with FRB

5) TGF, space weather

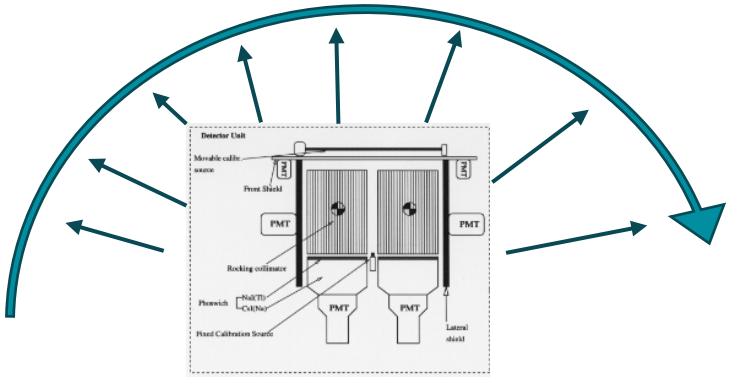
Technological requirements

- Wide FOV
- Good sensitivity
- Localization capability
- Fast response

- Wide FOV in X-rays
- Good sensitivity in X-rays

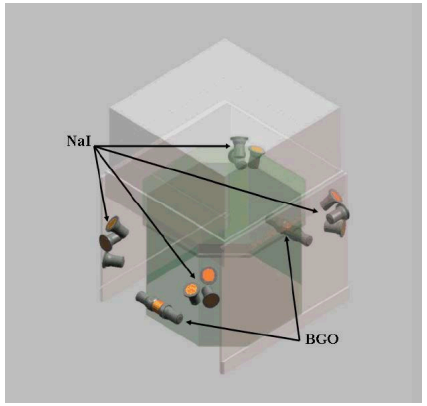
FROM FERMI-GBM TO CRYSTAL EYE

Beppo-Sax



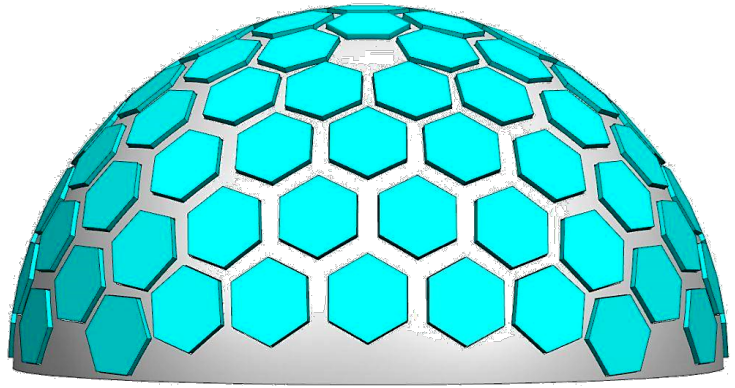
- Phoswich technique with collimators
- Orientable mechanics
- One module

Fermi-GBM



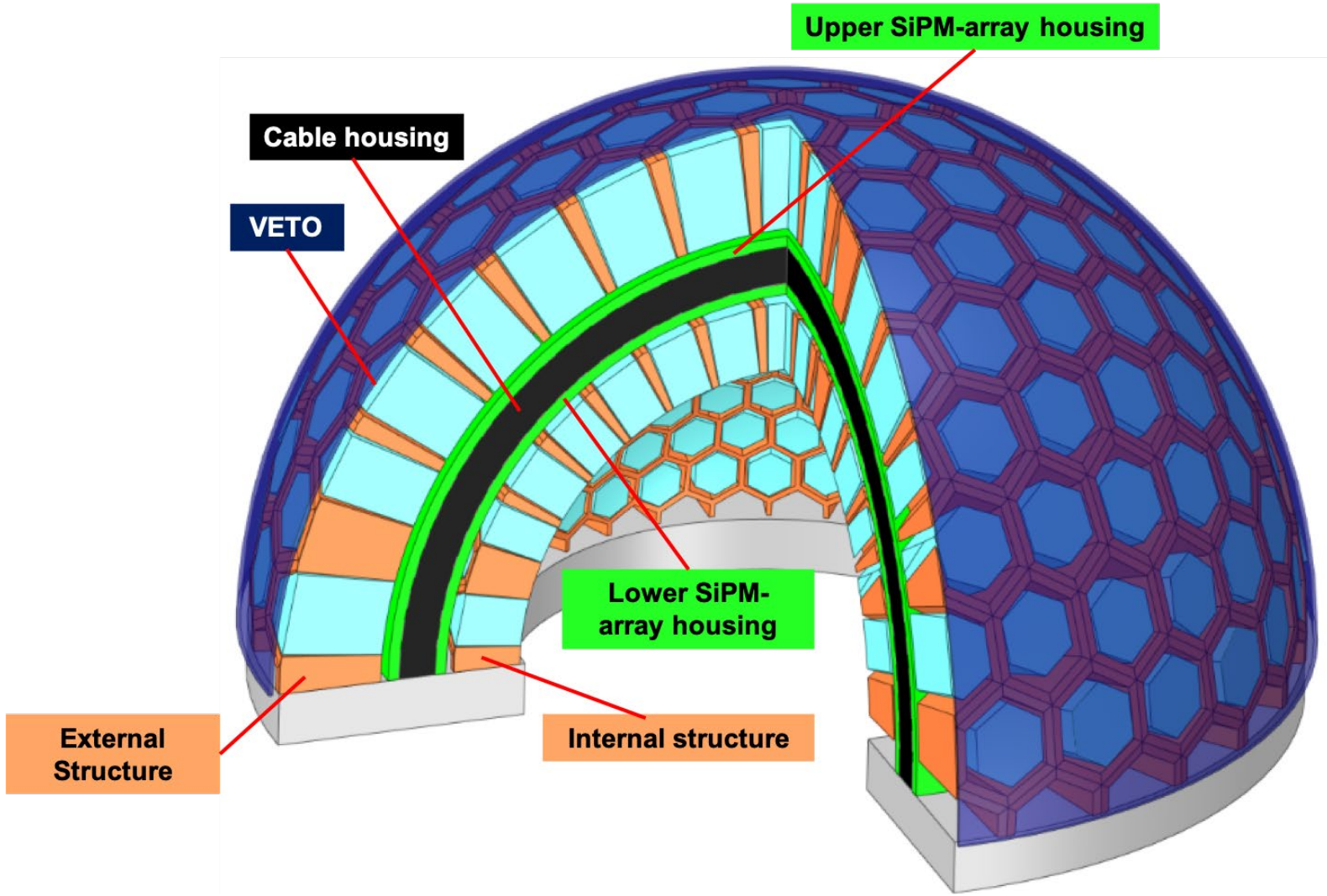
- Triangulation over 12 pixel (ø 12.7 cm)
- Different orientation
- One module

Crystal Eye

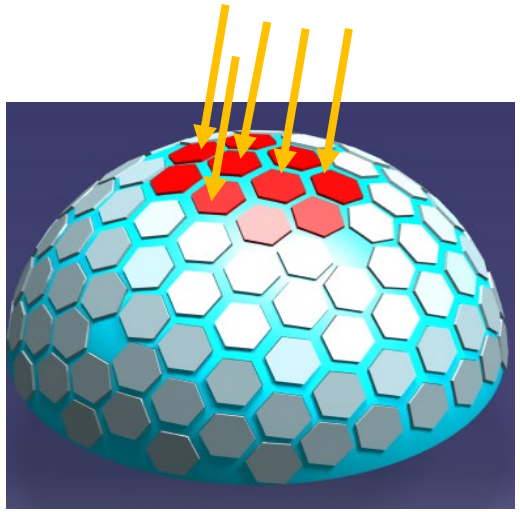


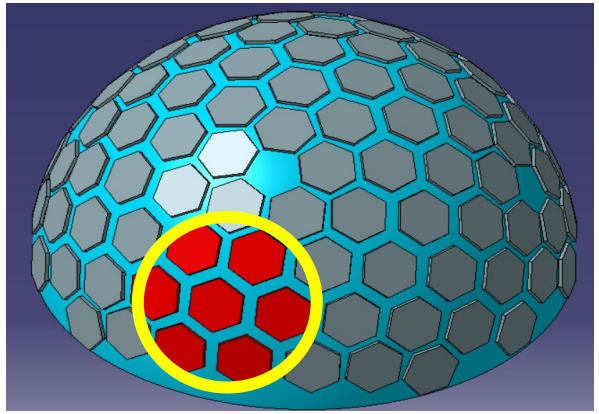
- Charge distribution over 112 pixel (ø ~ 5cm)
- Compact photosensors (simplified phoswich)
- Compact hemispherical design (no need for orientable mechanics)
- 3-4 modules in orbit for a full time coverage

TIME IS NOW!

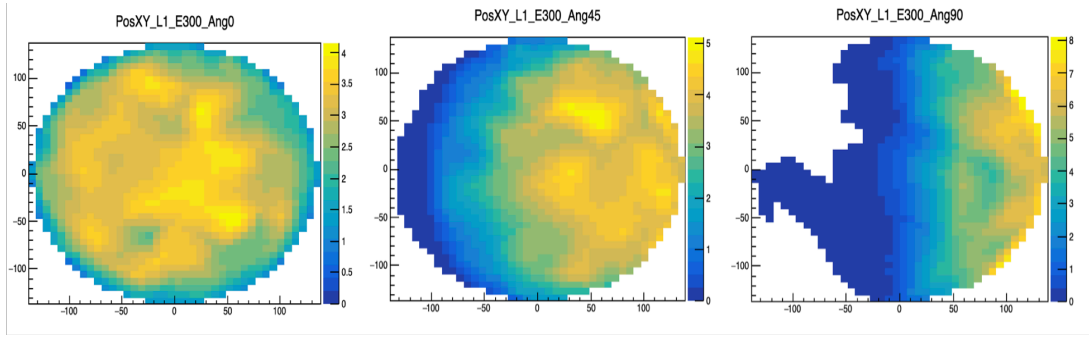

Upper SiPM-array housing
Cable housing
VETO
Lower SiPM-array housing
External Structure
Internal structure

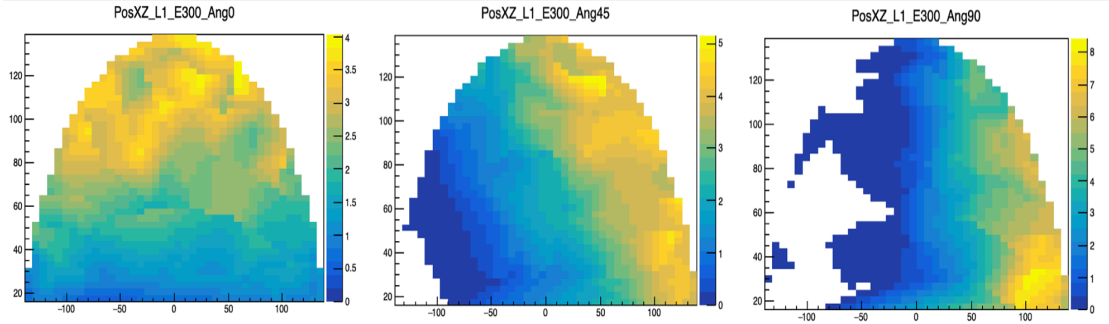
THE CHARGE DISTRIBUTION



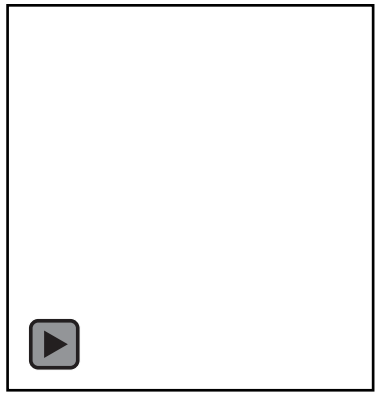


The localization is possible by following the charge distribution on the detector



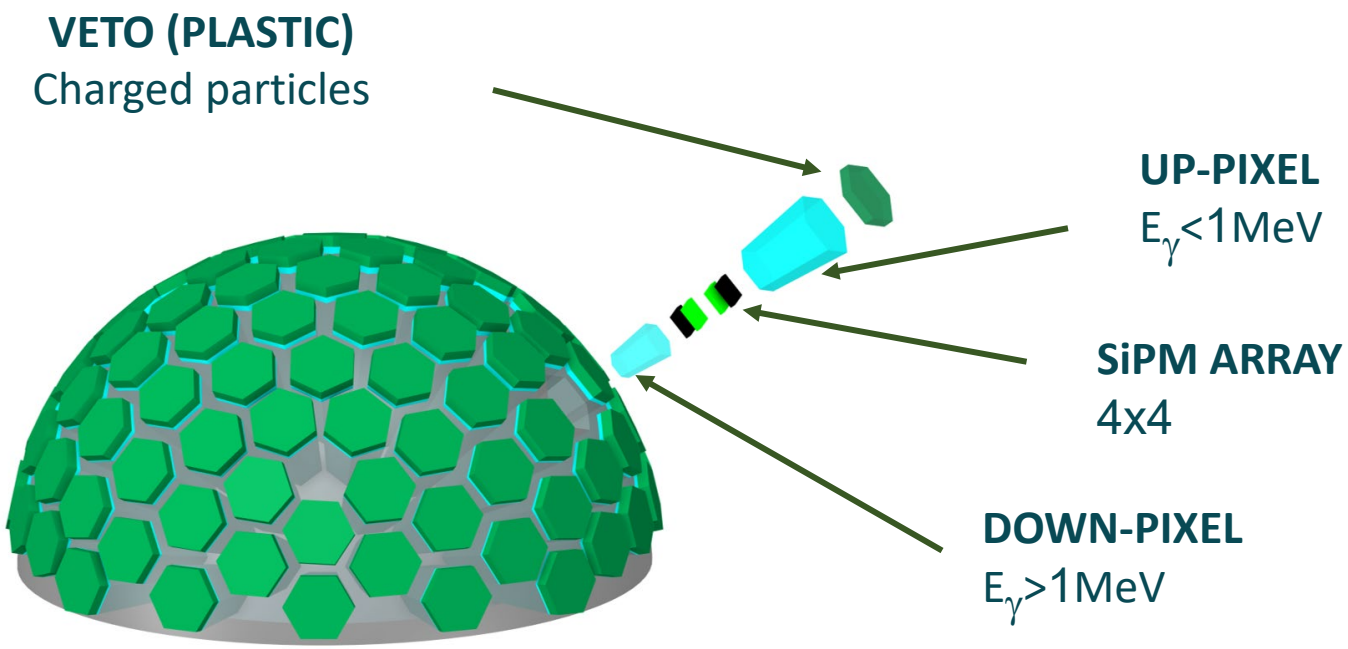


PRELIMINARY SIMULATIONS



Angular resolution ~1deg

THE CRYSTAL EYE METHOD



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

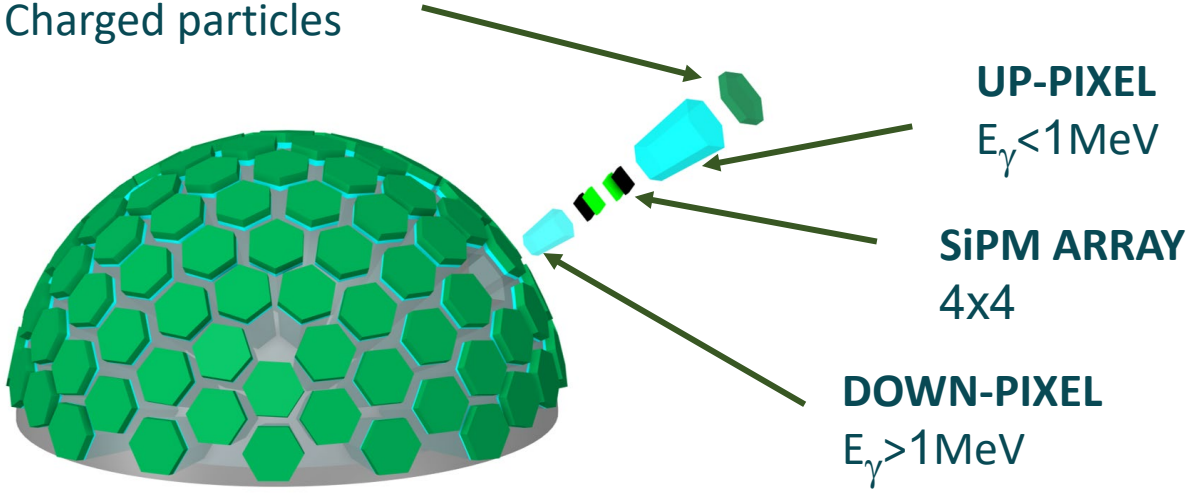
COMPACT SIZE:

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

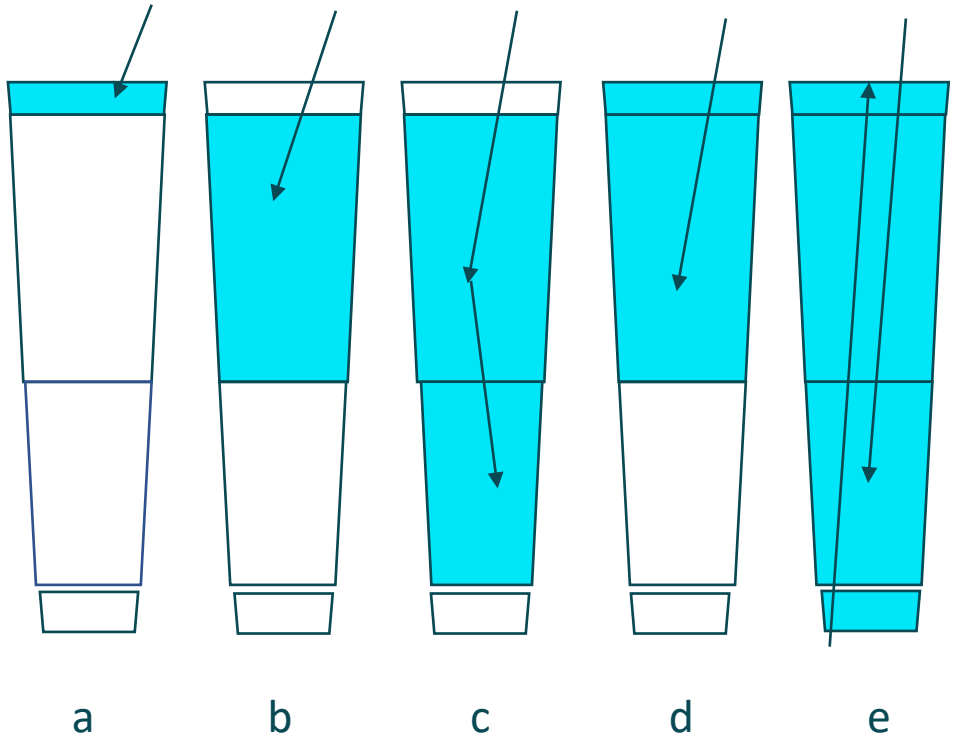
A smart configuration

- Compactness
- Symmetry
- Thermal protection of the SiPMs
- Radioprotection of the SiPMs

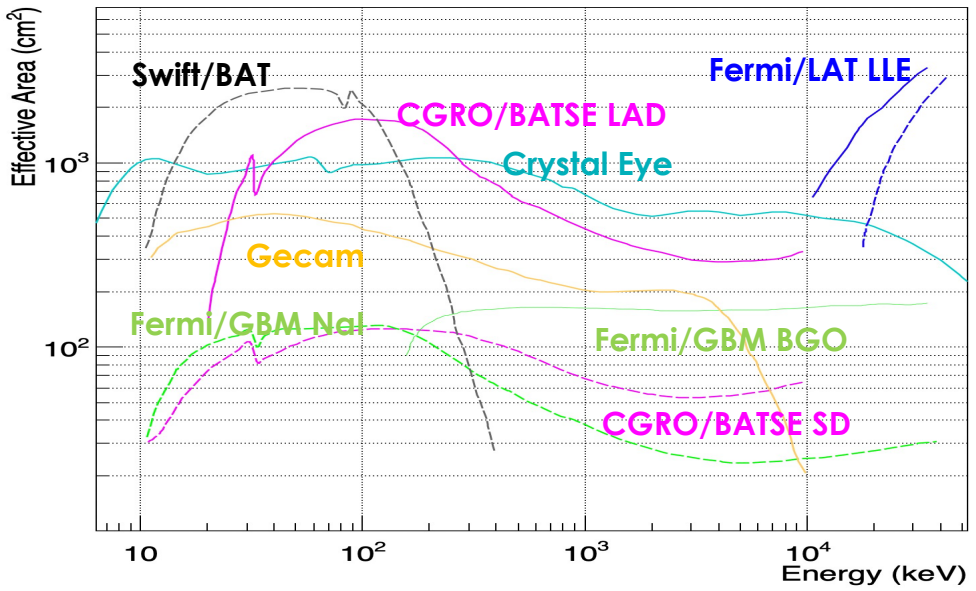
THE CRYSTAL EYE METHOD

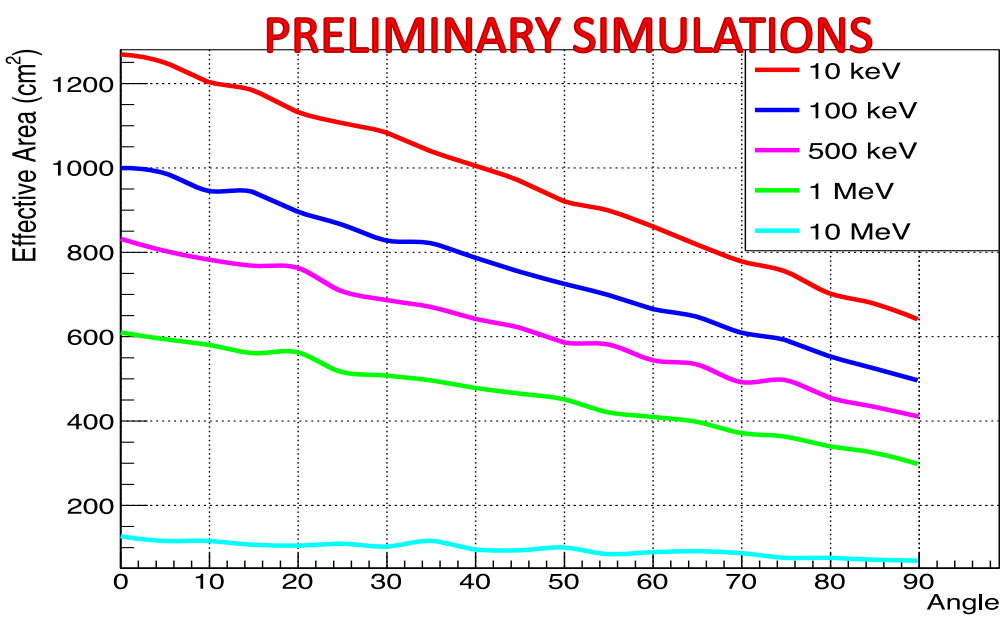


a – Down-going hard X-ray (E < 30 keV)
b – Down-going LE γ-ray (30keV<E<1MeV)
c – Down-going ME γ-ray (E>1MeV)
d – Down-going LE charged particle
e – HE charged particle



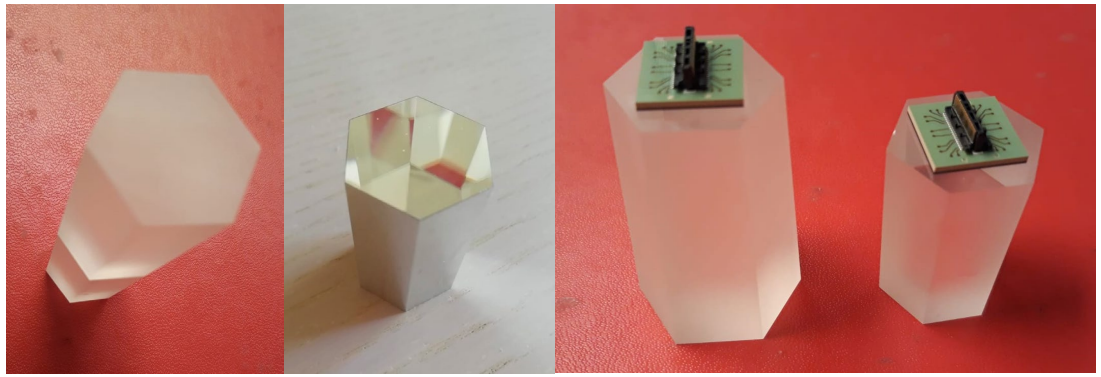
Effective area and sensitivity (preliminary)

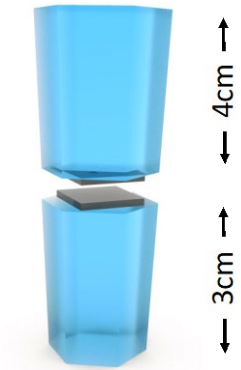




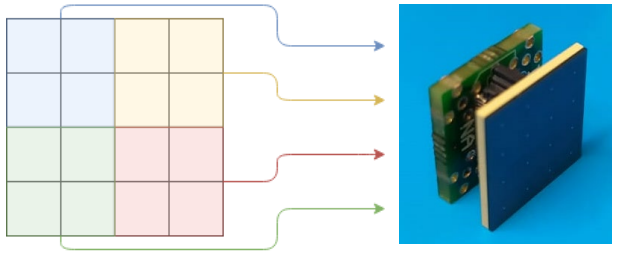
Larger effective area than competitors in the 300keV-10MeV range

THE PIXELS





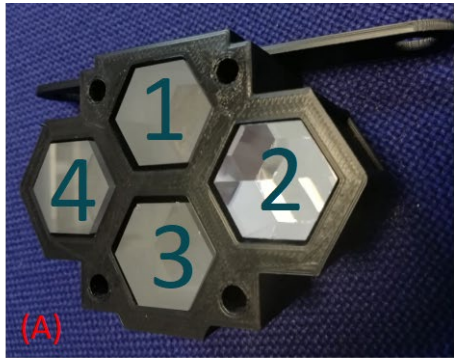
Array-Sum

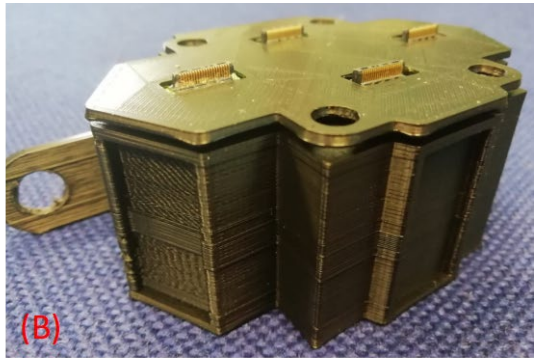


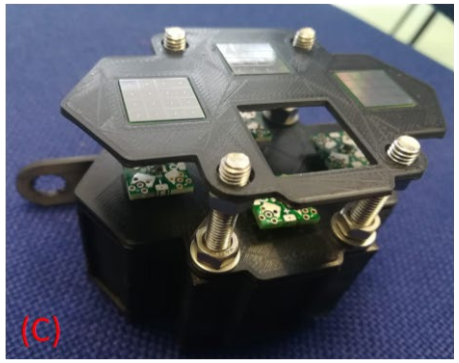
Front-end board

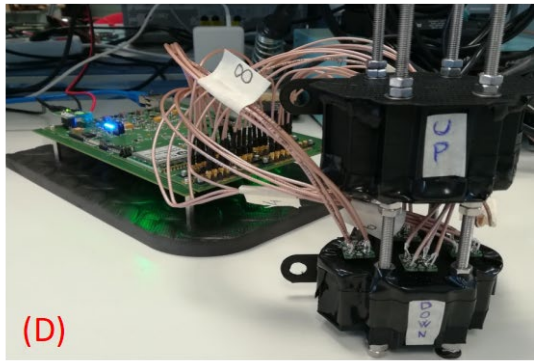
Properties Mechanical	Units	Value
Density	g/cm^3	7.15
Atomic Number (Effective)		65
Melting Point	°K	2070
Thermal Expansion Coeff.	C^{-1}	7.0×10^{-6}
Crystal Structure		Mono
Hardness	Moh	5.8
Hygroscopic		No
Solubility	$g/100gH_20$	N/A

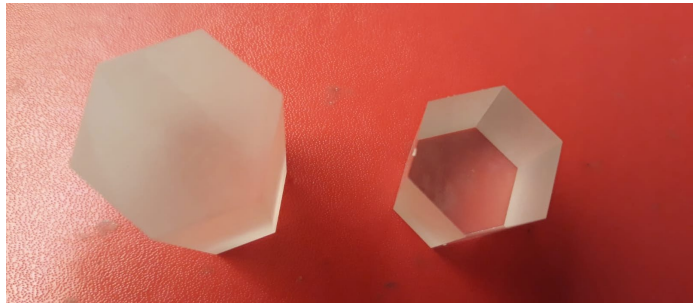
THE PROTOTYPE

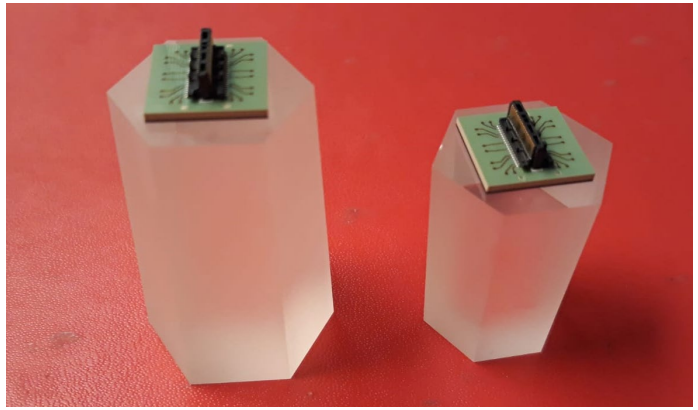


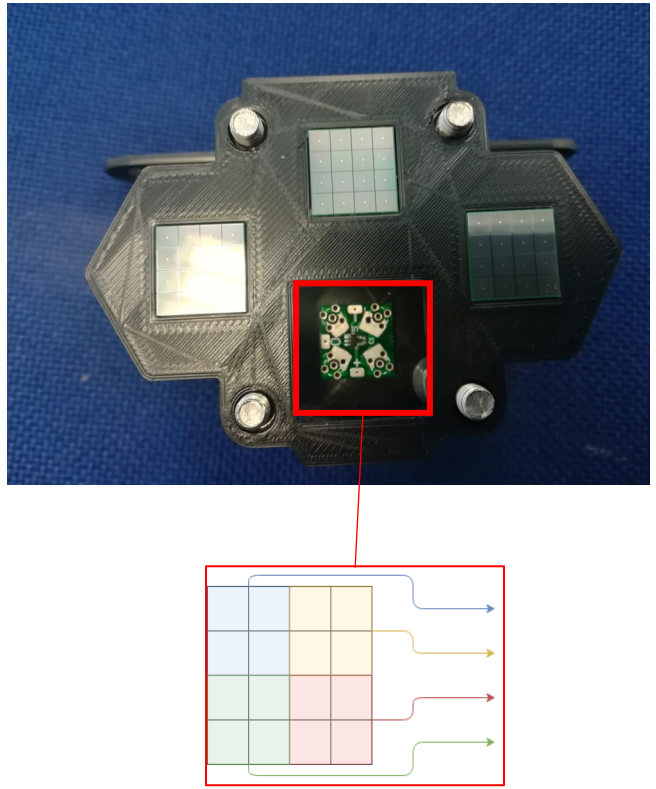








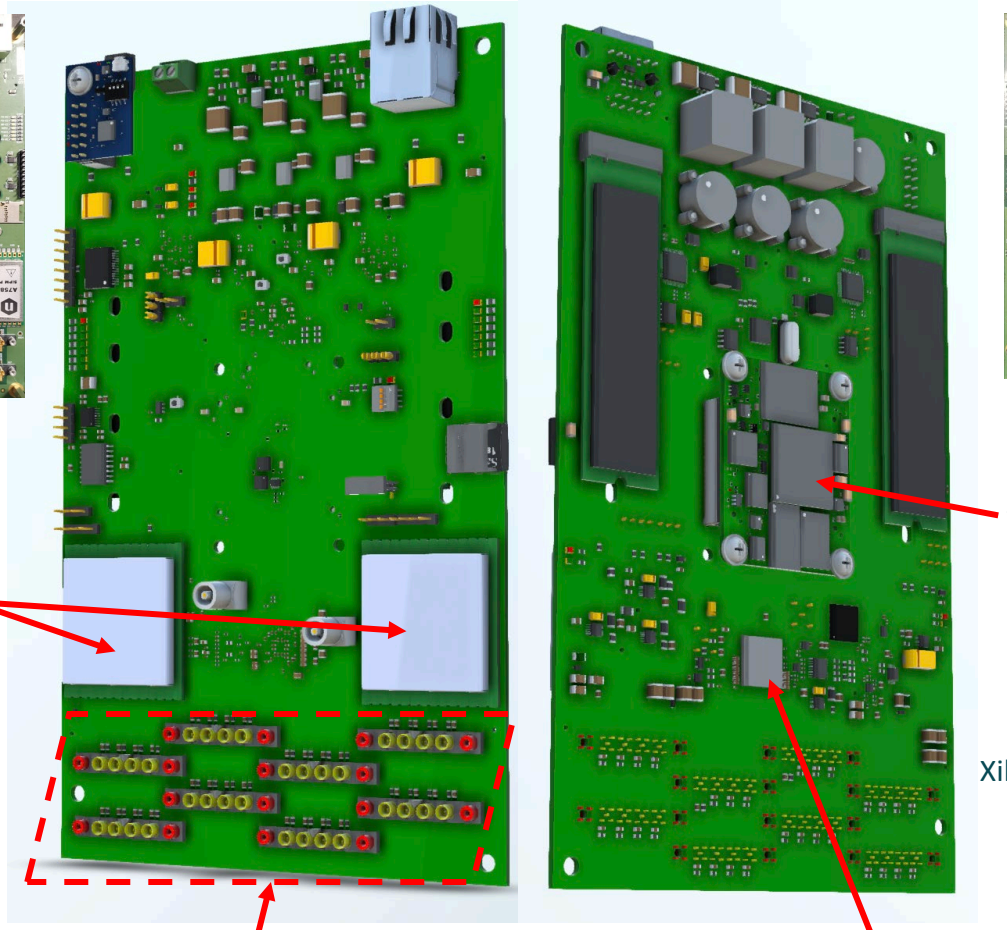


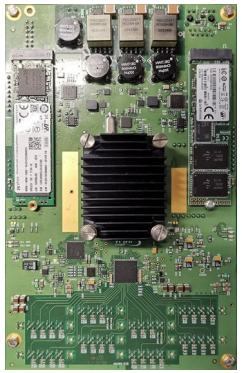


1 – LYSO by OST (ground surface)
2 – LYSO by EPIC Crystals (polished surfaces with ESR)
3 – BGO by OST (ground surfaces)
4 – LYSO by EPIC Crystals (ground surfaces)

THE CUSTOM ELECTRONICS

Custom DAQ developed with INFN-Na and Nuclear Instruments





Power Supply & temperature feedback by CAEN

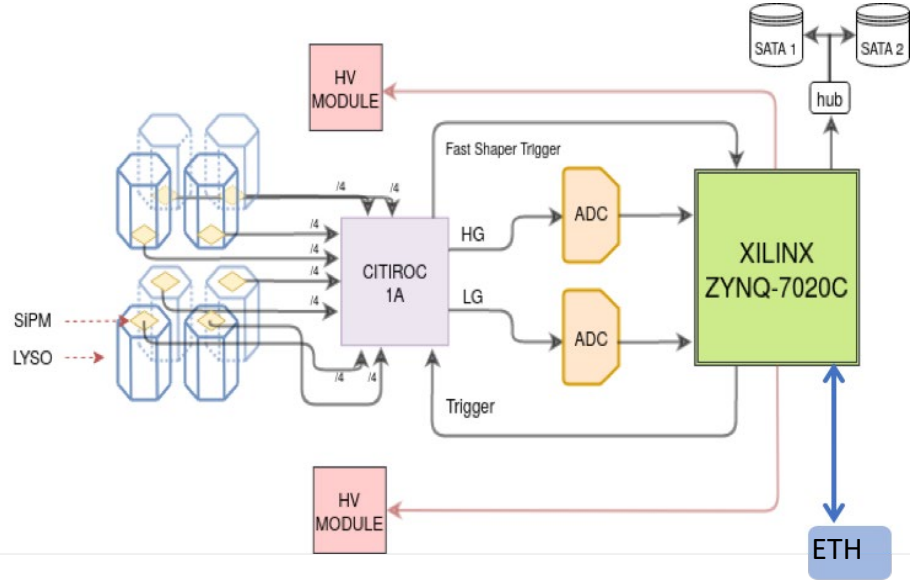
TRENZ module for high shocks and vibrations

Xilinx Zynq XC7Z020-2CLG484I

MMCX connectors by Samtec (Military & Aerospace)

CITIROC 1A

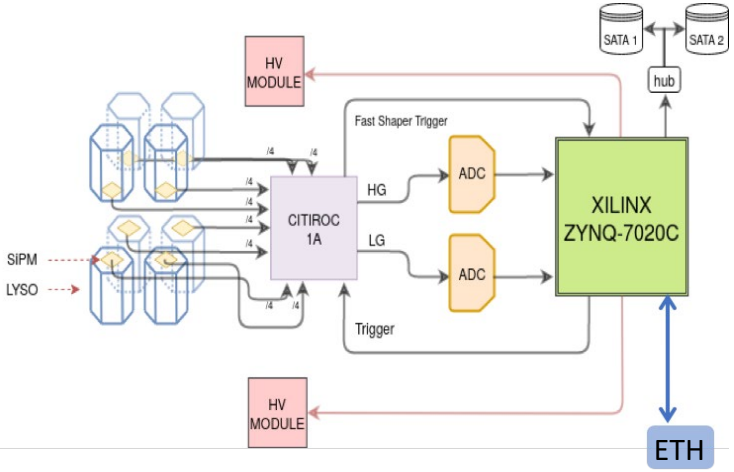
DAQ modes

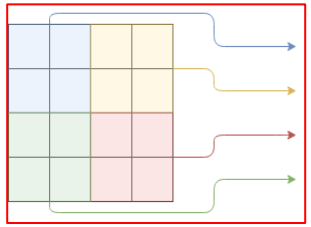


Calibration Mode

Observation Mode

CALIBRATION MODE





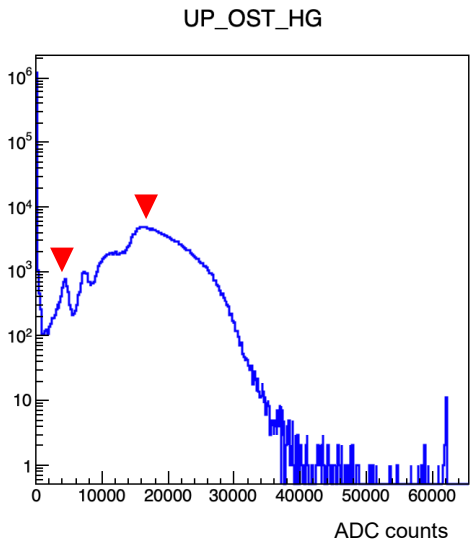
Trigger options:

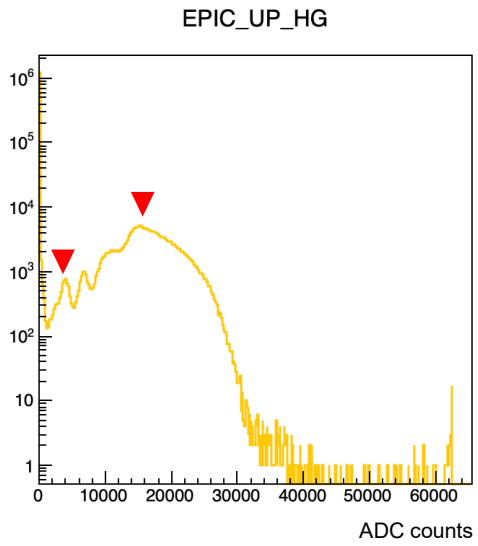
- Majority (>3 quadrants)
- OR of the crystals

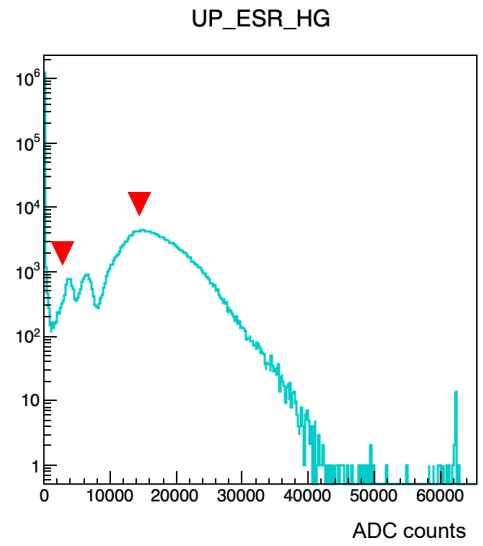
Calibration from LYSO Spectrum 88, 597 keV after each good event

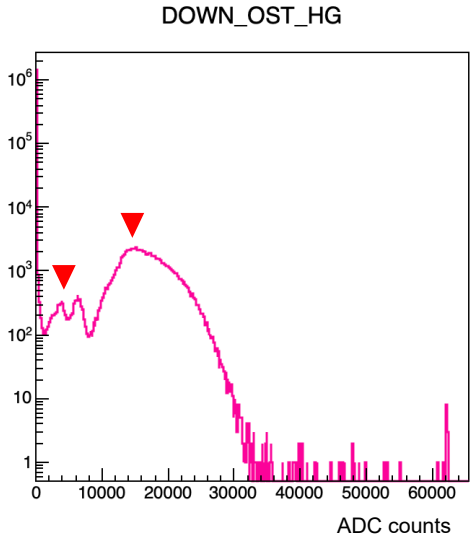
+

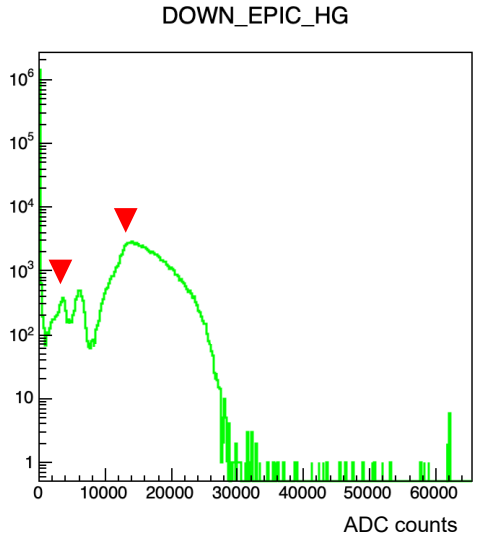
Calibration from LYSO Spectrum 88, 597 keV 3 times in the orbit

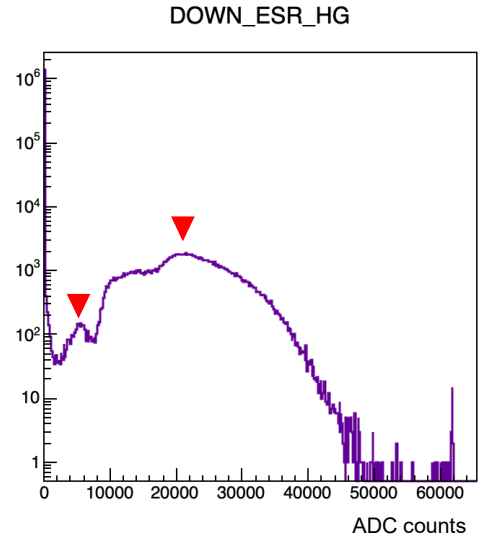




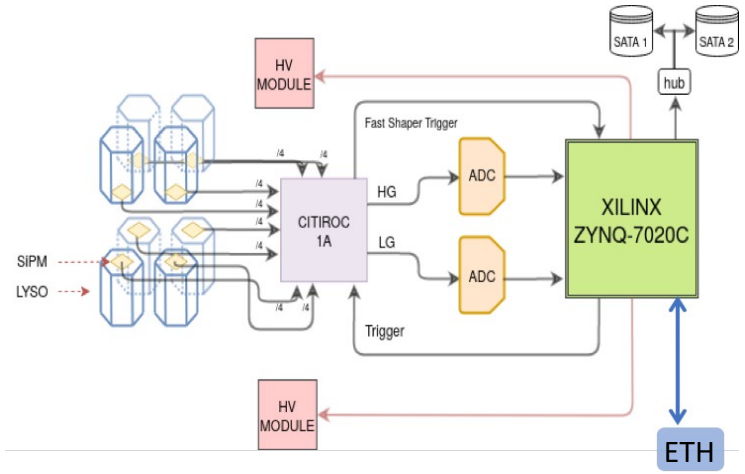






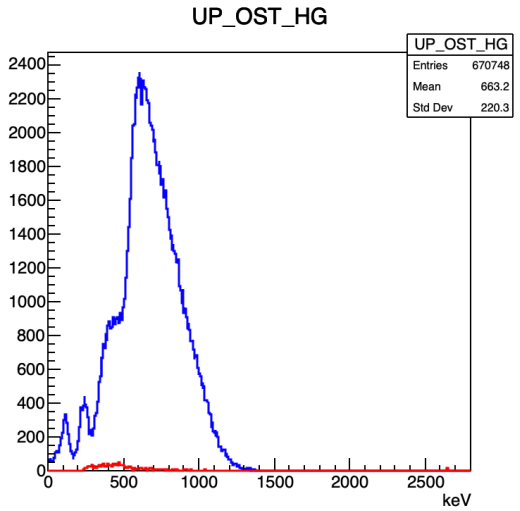


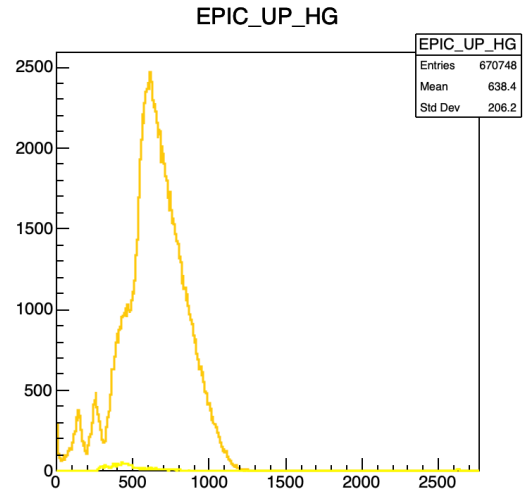
FROM CALIBRATION TO OBSERVATION MODE

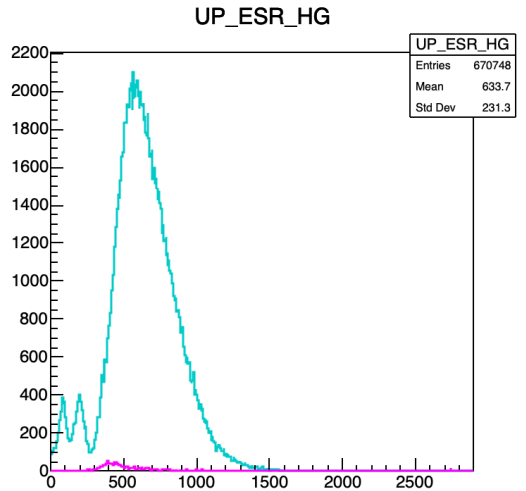


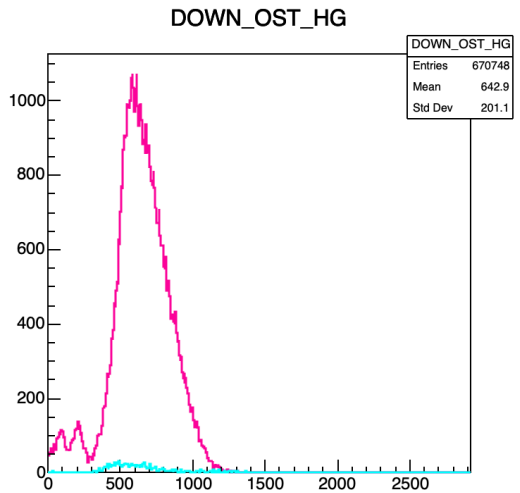
100 s

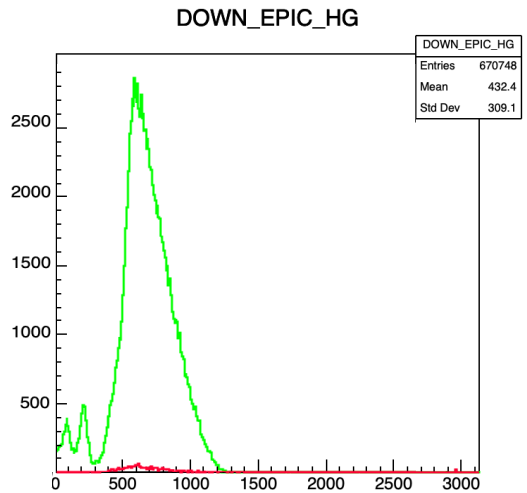
CALIBRATION MODE 670748 triggers
OBSERVATION MODE 6281 triggers

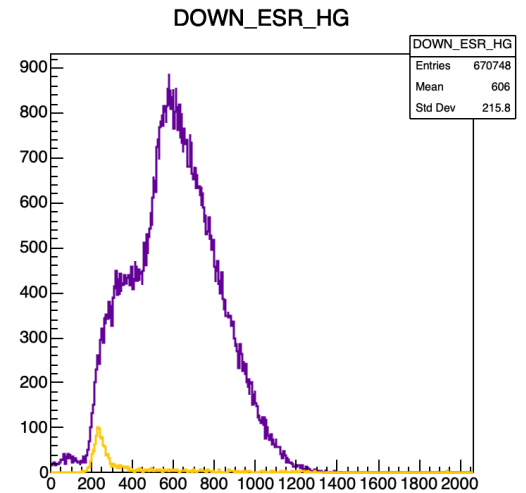




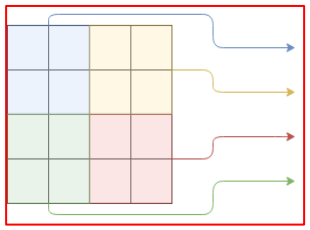






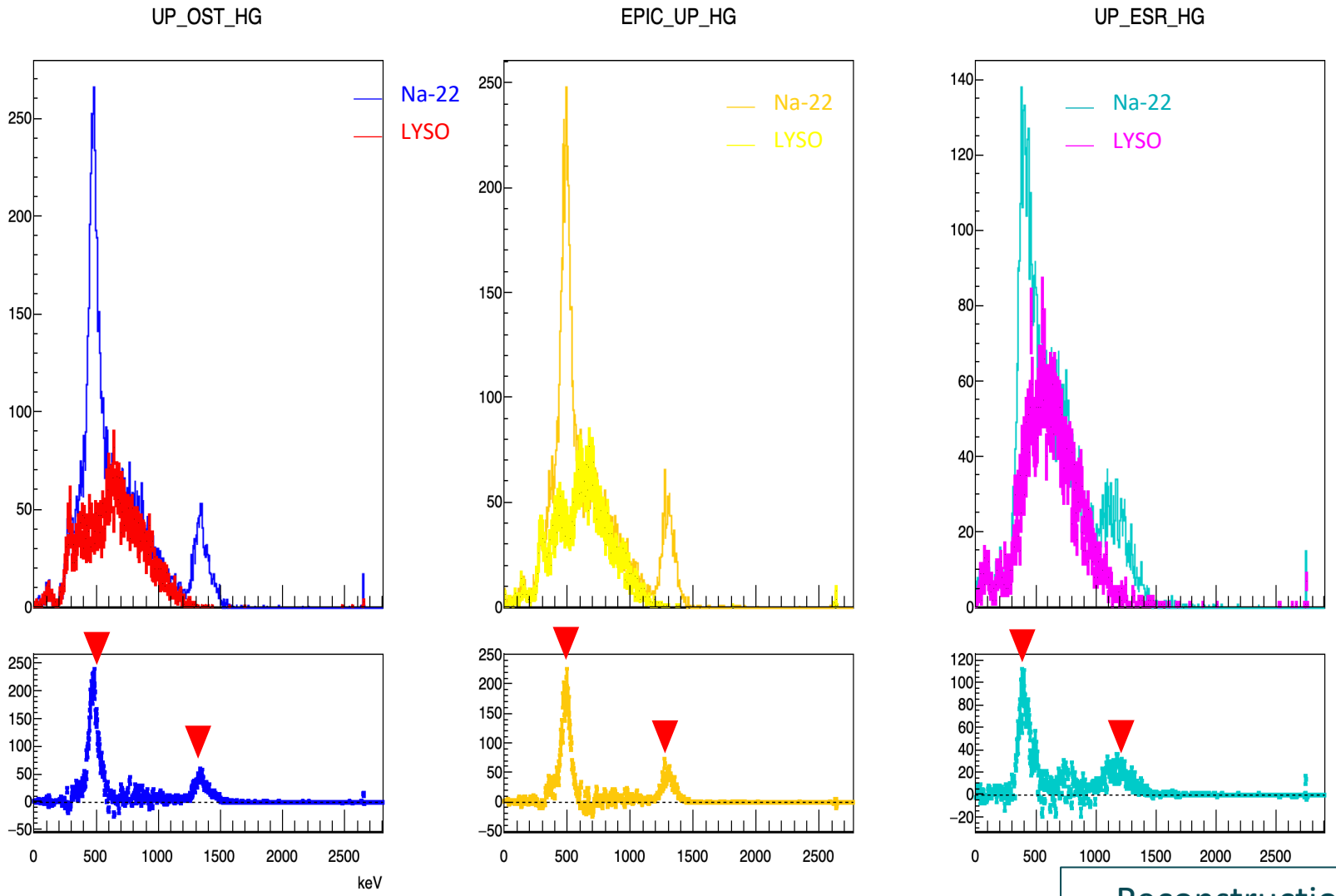


OBSERVATION MODE (Na-22 on OST UP)



Trigger options:

- Majority (>3 quadrants)
- AND of the crystals

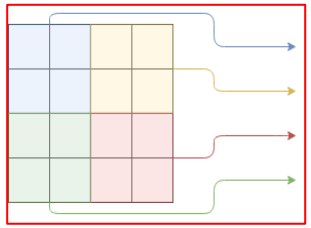


Reconstruction

γ_{511keV} 6.2%

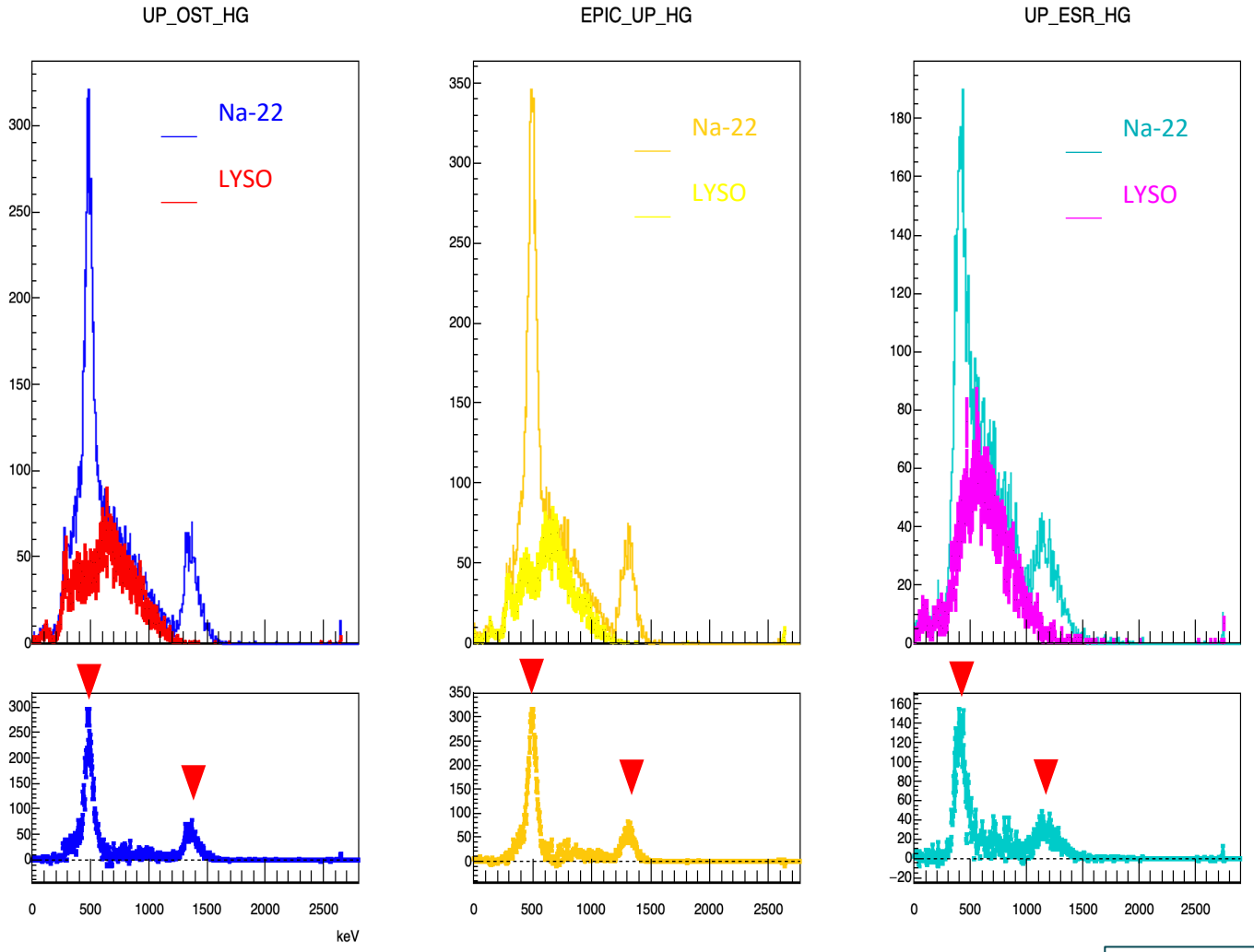
$\gamma_{1275keV}$ 5.3%

OBSERVATION MODE (Na-22 on EPIC UP)



Trigger options:

- Majority (>3 quadrants)
- AND of the crystals

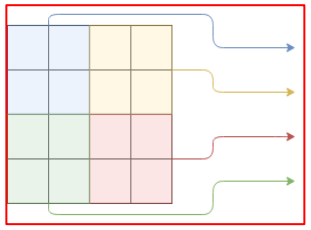


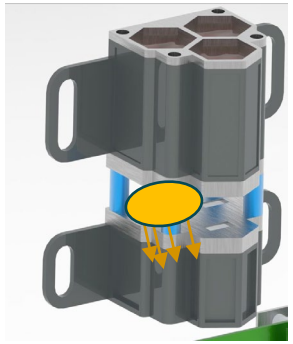
Reconstruction

γ_{511keV} 3.9%

$\gamma_{1275keV}$ 2.6%

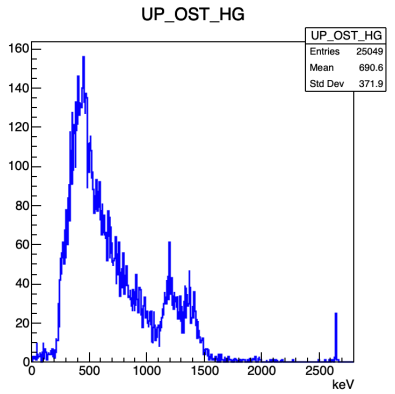
OBSERVATION MODE (Co-60)

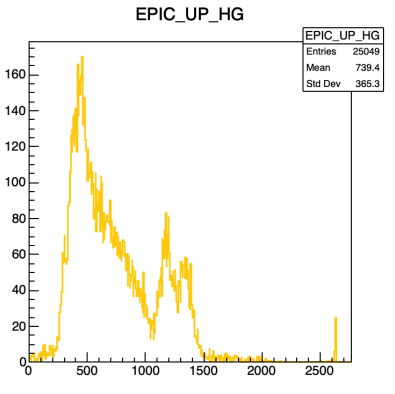


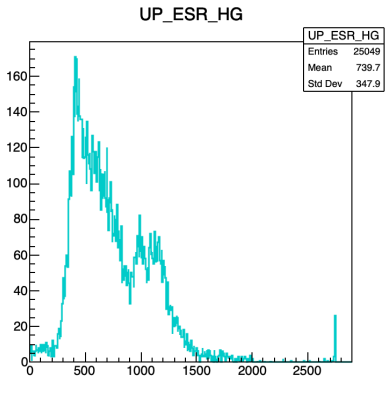


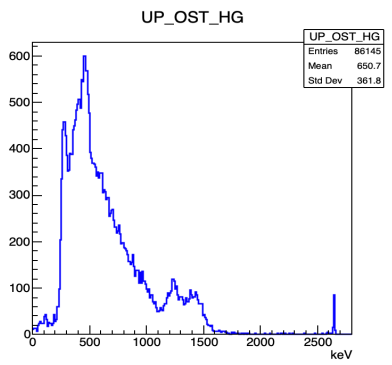
Trigger options:

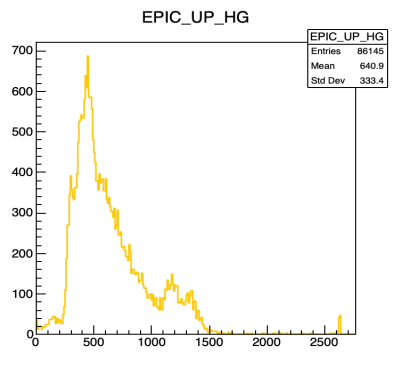
- Majority (>3 quadrants)
- AND of the crystals

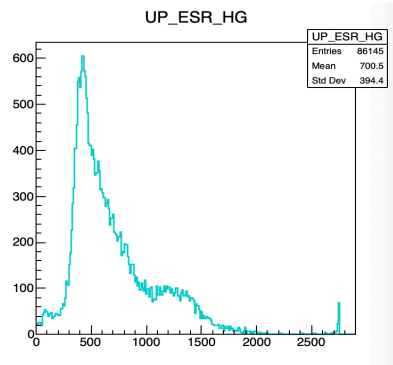


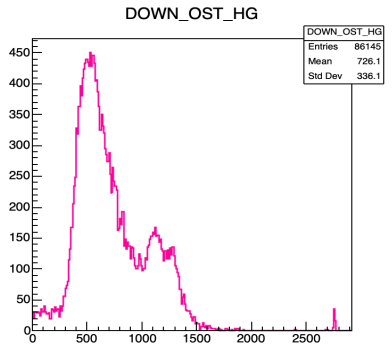


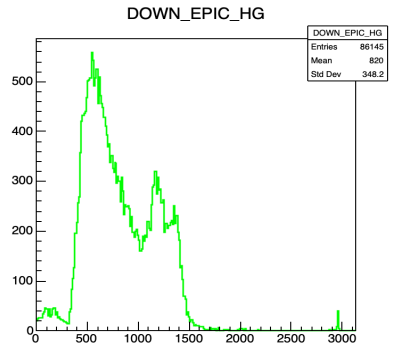


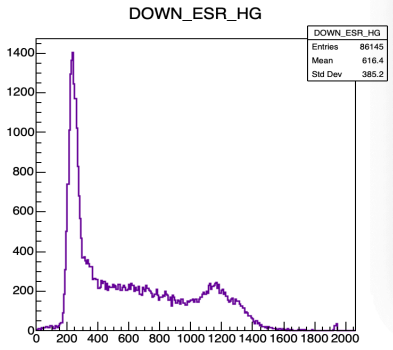










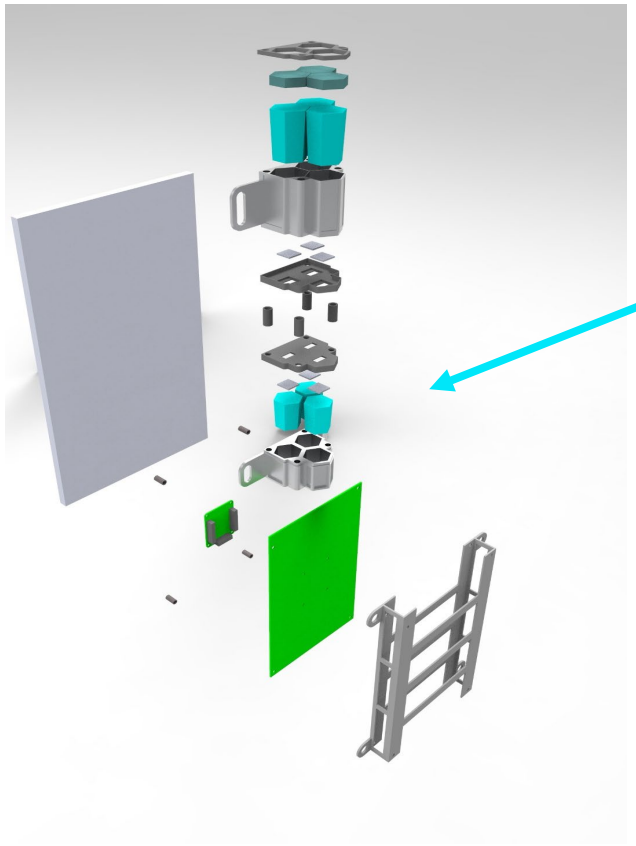


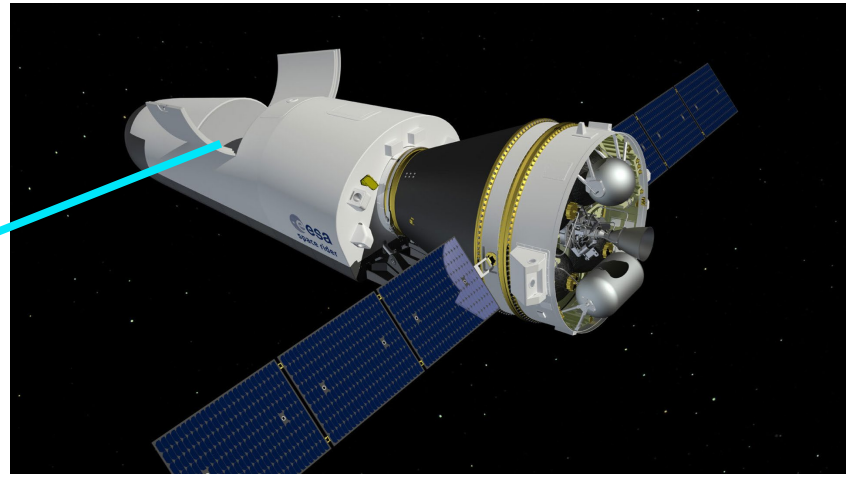
Reconstruction

γ 1.17MeV ~1%

γ 1.33MeV ~1%

THE SPACE RIDER FLIGHT





Technological pathfinder for maiden flight of the Space RIDER by ESA in 2024

GOAL:
- Background characterization
- TGF detection
- Technology test

Number of pixels: 3
Material: LYSO
Photodetectors: SiPM-array
Weight: 1.5kg
Power consumption: <6 W

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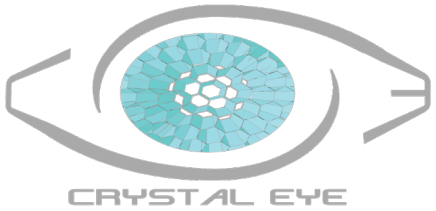
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

INFN NAPOLI

Nuclear Instruments

ALTEC

Concluding



Collaboration today consists of:
University of Naples Federico II – INFN-NA
Gran Sasso Science Institute (GSSI)

Submitted a PRIN

Looking for collaborations

Applying to various financing calls

…the best Is yet to come…