

Development of SiPM based radiation detectors for space

Candidate: Matteo Tambone

Innovative Technologies for Space Missions and Radiation Detection program



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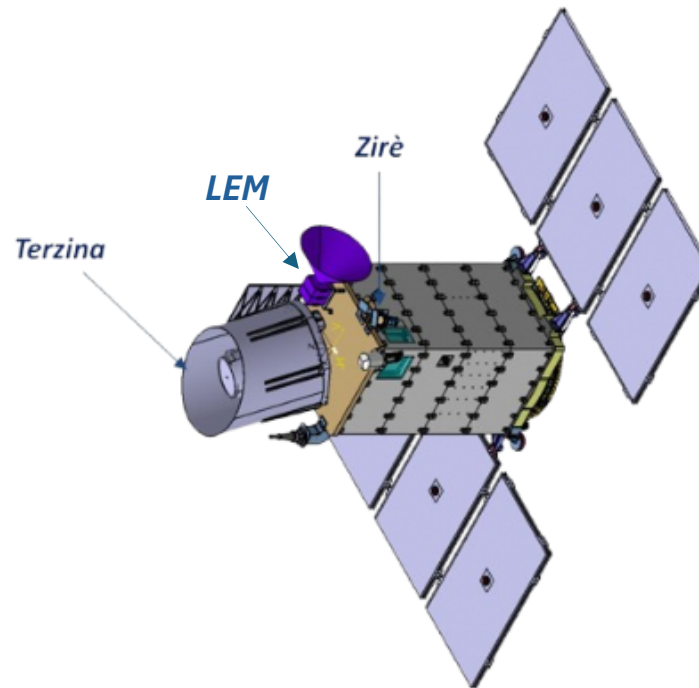
1.1 – NUSES, Overview

Italian pathfinder mission for exploring new observation methods and technologies for the study of high and low energy radiations from space & exploring new technologies in space: SiPM based readout system, new NIMBUS satellite platforms



ZIRE'

Measure flux ($E < 300$ MeV) of cosmic e^- , p and lighter nuclei
Detection of 0.1 – 30 MeV photons for study of transient gamma ray source (GRBs)



LEM

Monitor energetic particle fluxes and investigate precipitation events in the near-Earth environment, contributing to the understanding of particle dynamics driven by solar and geomagnetic activity, while exploring potential connections with terrestrial geophysical phenomena



TERZINA

Pathfinder for future Ultra-High Energy Cosmic rays and Neutrino astronomy from space by detecting the atmospheric Cherenkov radiation.



1.1 – NUSES, Overview

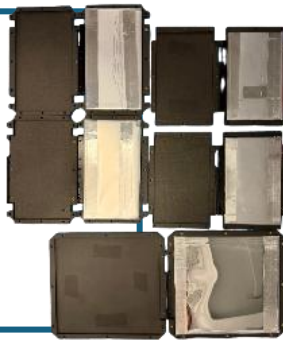
FIBER TRACKER (FTK)

3 X-Y modules ($9.6 \times 9.6 \text{ cm}^2$) of scintillating fibers
 Kuraray SCSF78-MSJ fiber ($750 \mu\text{m}$ diameter)
 Photon yield $\sim 8000 / \text{MeV}$
 SiPM based readout system
 Ideal for precision track reconstruction and particle identification.



Anti-Coincidence Shield (ACS)

9 Plastic scintillator tiles (EJ 208)
 4 Tiles cover the PST ($0.6 \times 16.5 \times 27.0 \text{ cm}^3$)
 5 Tiles cover the CALOg from the sides and bottom.



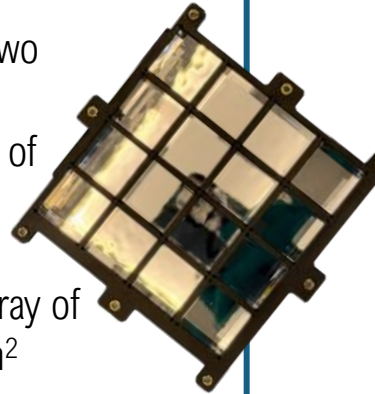
Plastic Scintillator Tower (PST)

32 layers of plastic scintillators bars (EJ 208)
 3 bars in each layer
 First 6 layers: $4 \times 12 \times 1 \text{ cm}^3$
 Next 26 layers: $4 \times 12 \times 0.5 \text{ cm}^3$



CALORIMETER (CALOg)

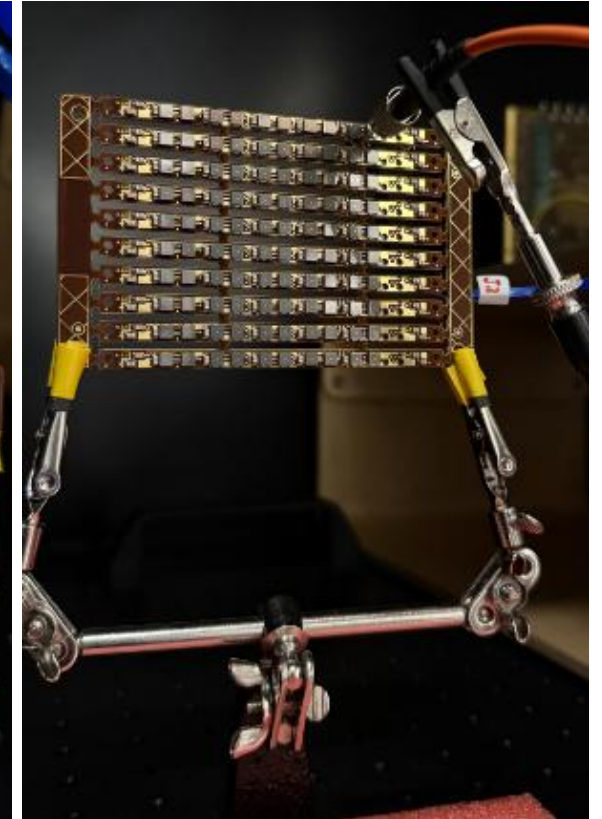
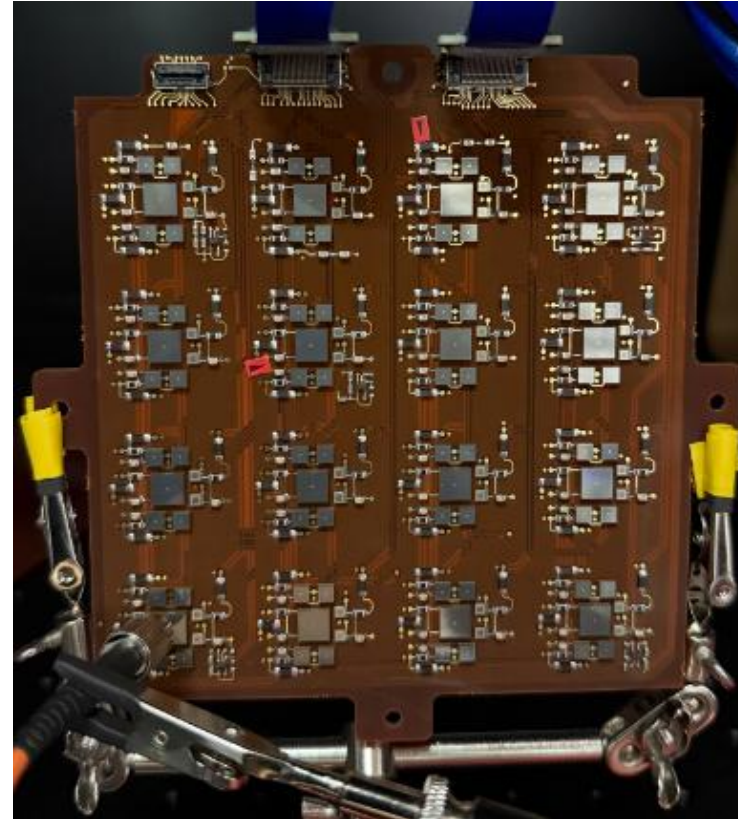
32 crystals (GAGG) arranged in two layers.
 Each layers consists of 4×4 grids of crystal ($2.5 \times 2.5 \times 3.0 \text{ cm}^3$)
 Crucial for energy measurement
 The signals are read out by an array of $6 \times 6 \text{ mm}^2$, $3 \times 3 \text{ mm}^2$, and $1 \times 1 \text{ mm}^2$ SiPMs.



1.1 – NUSES, *Overview*

The complete sensor system of Ziré is SiPM based. Different combinations of Hamamatsu MPPC (Multi-Pixel Photon Counter) are integrated in board or tile solutions, each tailored on the specific subdetector requirements.

PST board	{ Hamamatsu MPPC S14160 - 1310 S14160 - 3050
CALog board	{ Hamamatsu MPPC S14160 - 1310 S14160 - 3050 S14160 - 6050
ACS tile	{ Hamamatsu MPPC S14160 - 3050



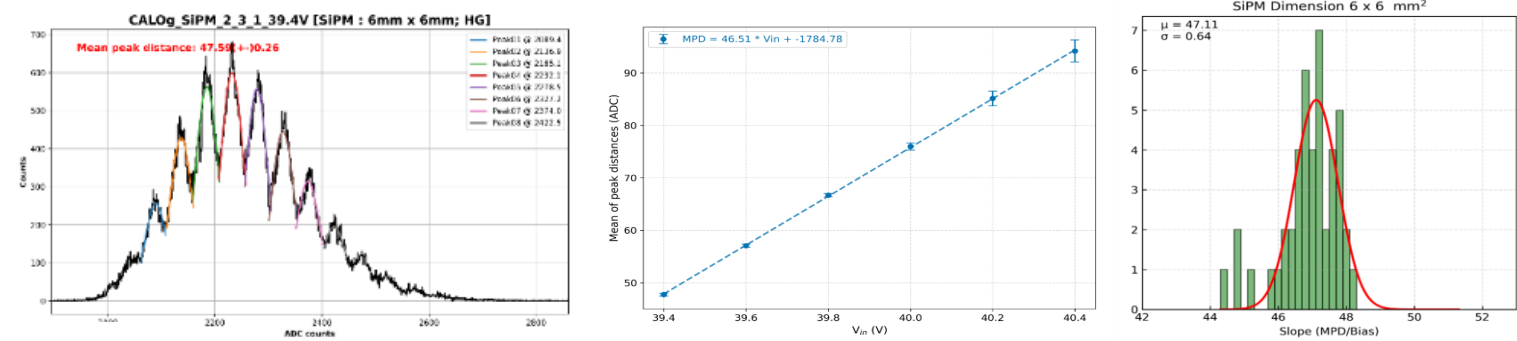
MY CONTRIBUTION

Involved in Ziré EQM and PFM SiPM characterization.

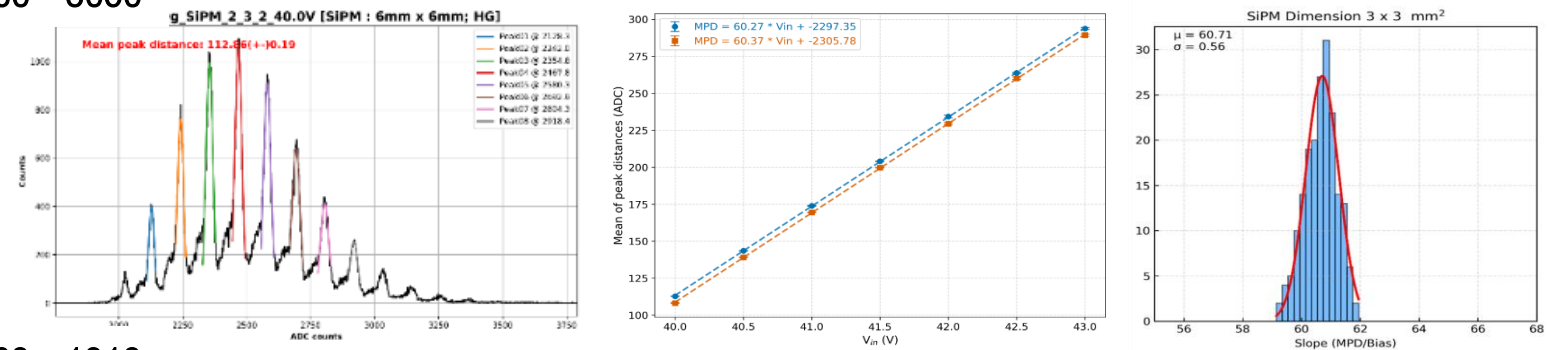
**800+ SiPM
characterized overall!**

1.2 – NUSES, *My contribution*

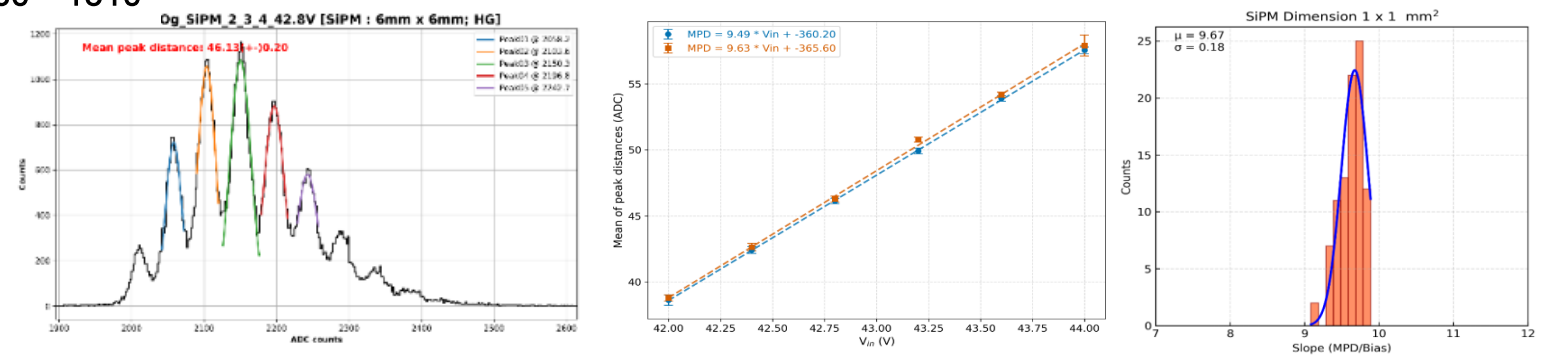
HAMAMATSU S14160 – 6050



HAMAMATSU S14160 – 3050



HAMAMATSU S14160 – 1310



2.1 – SpaceltUp!, Overview



SpaceltUp! is a strategic partnership funded by the **Italian Space Agency (ASI)** and the **Italian Ministry for University and Research (MUR)** for the development of new technologies and solutions for Space.

33 entities between universities, research institutes and industries:



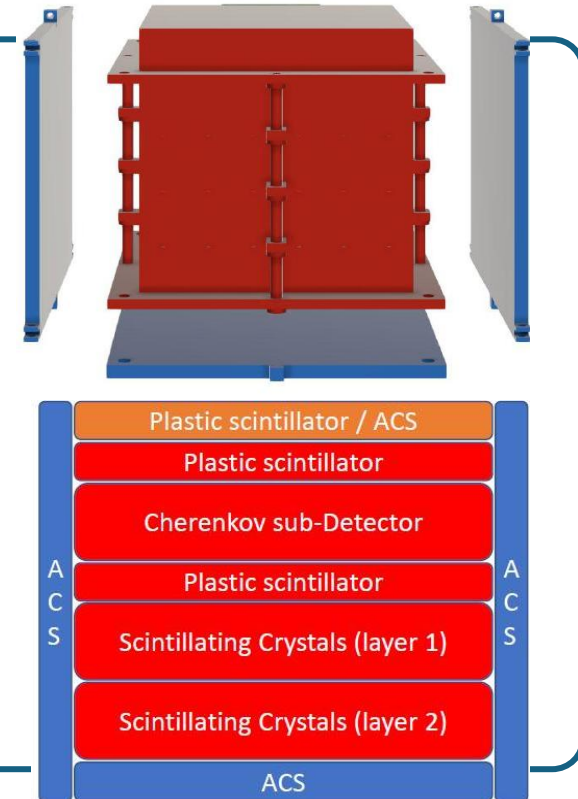
Within this context, GSSI is leading WP4.3, whose goal is to **design, test and characterize SiPM-based ionizing radiation detectors**.



2.1 – SpaceltUp!, Overview

THE DETECTOR

- **HDT** (*Hybrid Detection Tower*): particle tracking and ID with Cherenkov detection for electron tagging, realized with plastic scintillator and Cherenkov detector bars organized in 8 layers (6x1 cm thick and 2x0.5 cm thick)
- **ACS** (*Anti-Coincidence System*): Photon tagging with duly segmented active veto systems realized with plastic scintillator
- **CALO** (*Calorimeter*): Two layers of scintillating crystals for energy measurements
- **CHD** (*Cherenkov Detector*): Optional standalone Cherenkov detector made of a 4x4 array of single parallelepiped-shaped ($2,5 \times 2,5 \times 3 \text{ cm}^3$) each read out by a Silicon Photomultiplier (SiPM) array. *This detector is an alternative to the Cherenkov bars contained in the HDT.*



TARGET MEASUREMENTS

- **Electrons and Protons** below 100-200 MeV : space weather, solar flares, magnetosphere-ionosphere-lithosphere coupling
- **Photons** (0.1-10 MeV) : gamma transients, Terrestrial Gamma Ray Flashes (TGFs).

2.2 – SpaceltUp!, Overview

CALO

For the CALO subdetector, different scintillating crystals—**BGO**, **LYSO**, and **GAGG**—are being characterized and compared.

Current studies mainly on LYSO and GAGG (F & T types):

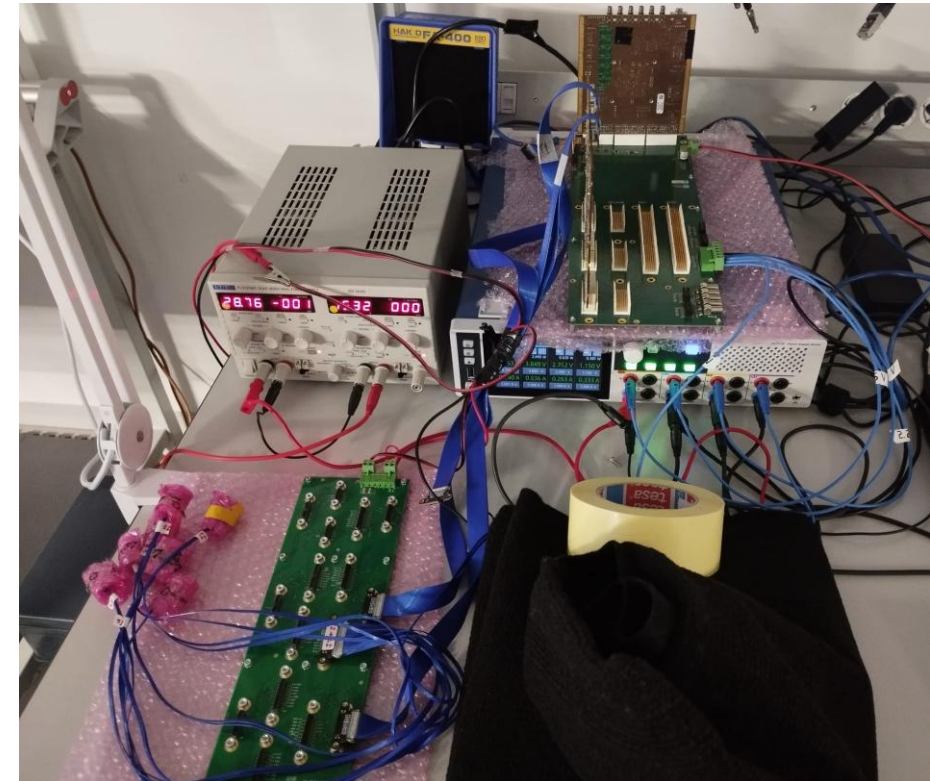
- LYSO offering higher density, larger effective Z, and faster decay time.
- GAGG avoids the intrinsic self-emission associated with the radioactive decay of lutetium present in LYSO.

Crystal	BGO	LYSO
Density (gm/cm ³)	7.13	7.1
Rad. Length (cm)	1.18	1.1
Peak Emission (nm)	480	420
Light Yield (ph / keV)	8-10	25
Melting point (°C)	1050	2050
Decay Time (ns)	300	40
Hygroscopicity	None	None
Energy Res. (% @662 keV)	12	8
Refractive Index	1.90-2.15	1.81-1.85

General parameters	GAGG-F	GAGG-T
Density	6.6	6.6
Hardness	8	8
Refractive Index	1.91	1.91
Light Output	30,000	42,000
Energy Resolution	7%	6%
Decay Constant	50	90
Wavelength of Emission Peak	520	530

MY CONTRIBUTION

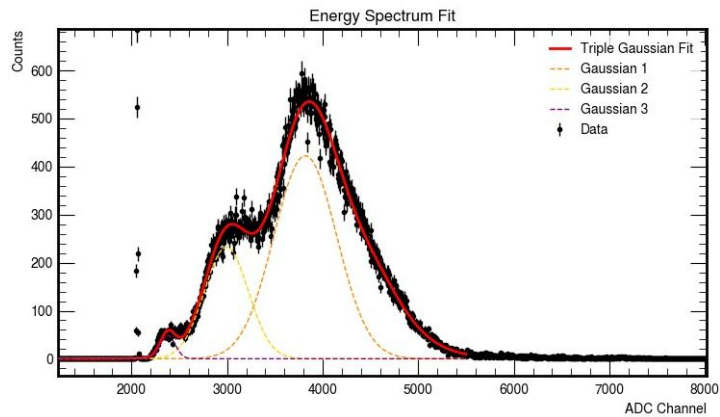
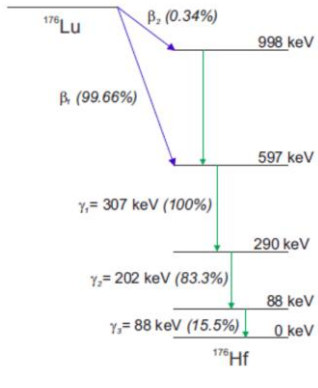
Performed data acquisition for LYSO and GAGG energy characterization by using Hamamatsu SiPM and custom DAQ system coupled to the different crystals.



2.2 – SpaceltUp!, *My contribution*

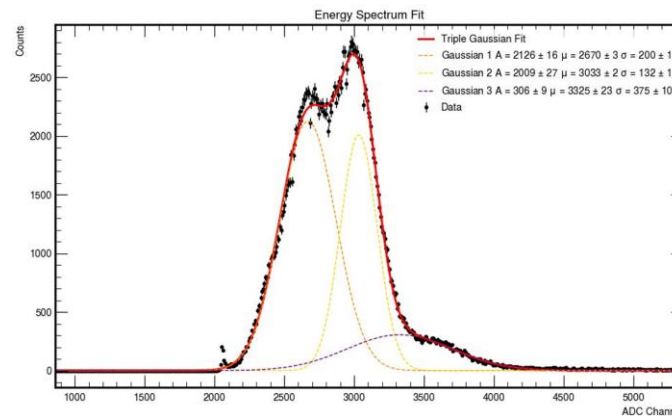
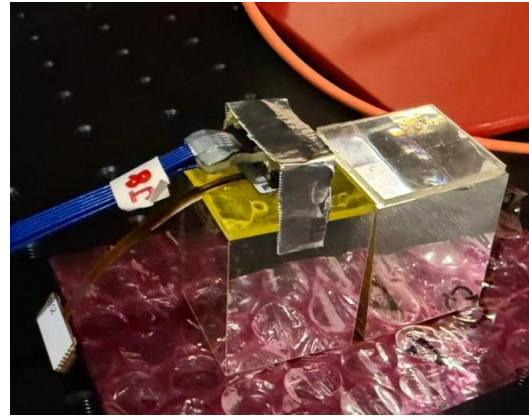
LYSO

Performed cubic $2,5 \times 2,5 \times 3$ cm LYSO crystals self-emission acquisitions



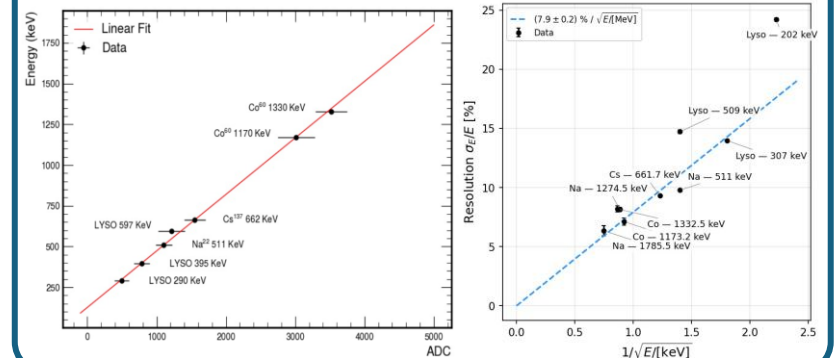
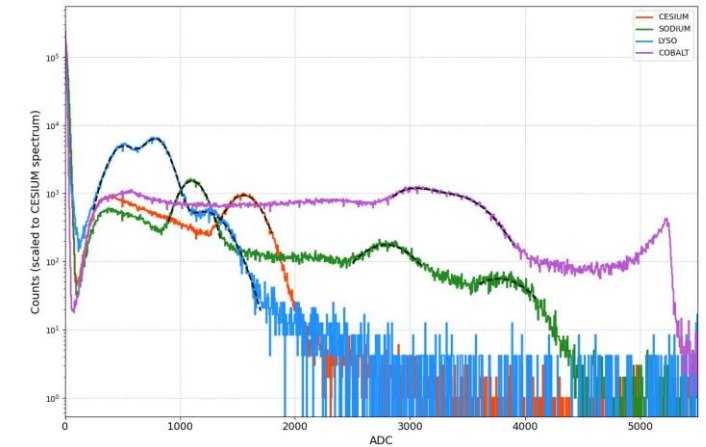
GAGG-F

LYSO spectra seen by $2,5 \times 2,5 \times 3$ cm GAGG-F crystal



SOURCES

Energy characterization and resolution of $2,5 \times 2,5 \times 3$ cm GAGG-F crystal with different radioactive sources

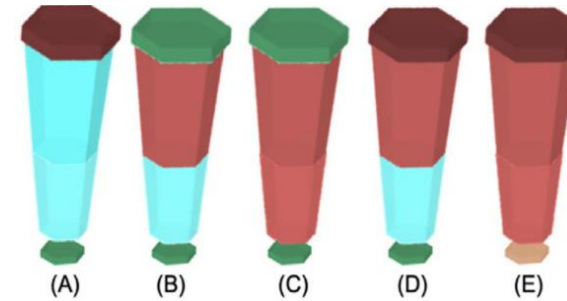
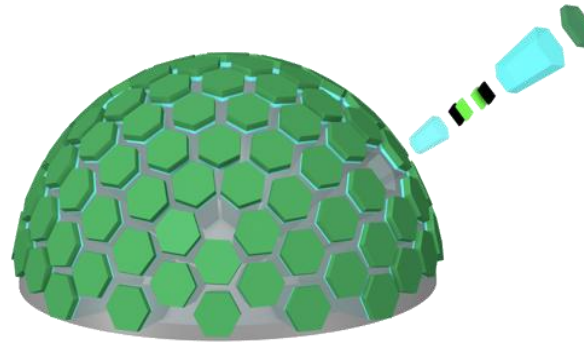


3.1 – Crystal Eye, Overview

THE DETECTOR

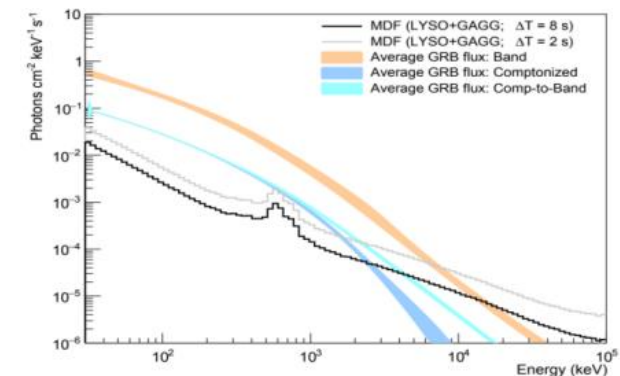
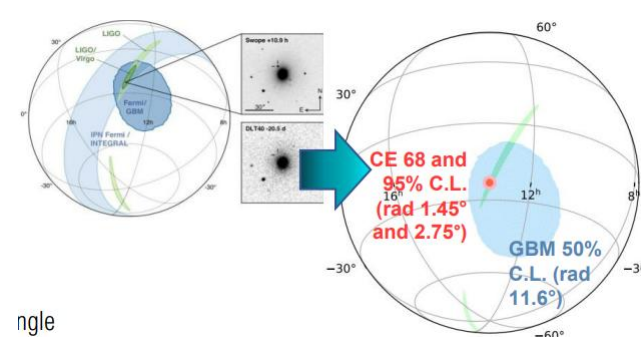
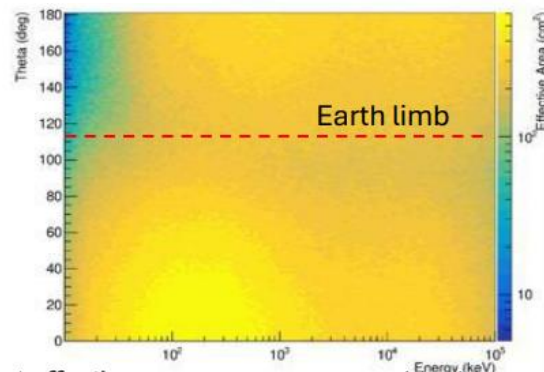
Crystal Eye is a **space-based, all-sky monitor, wide FoV detector 0.01-30 MeV** designed for LEO environment and compatible with different mission profiles: Free Flyer (equatorial orbit, 550 Km altitude), hosted payload on bigger satellite or space station.

- FOV: 2π sr
- hemispherical structure (D: 32 cm. ~13 in)
- 126 pixels (concept design)
- Scintillating crystals: LYSO down pixels, GAGG up pixels
- High prompt localization capability ($\sim 1^\circ$, ~ 1 ms).



"Topological" trigger: A) Down-going hard-X ($E < 30$ KeV)
 B) Low-energy down-going γ ($30 \text{ KeV} < E < 1 \text{ MeV}$);
 C) Medium-energy down-going γ ($E > 1 \text{ MeV}$);
 D) Low-energy down-going charged particle;
 E) Charged particle

PERFORMANCE

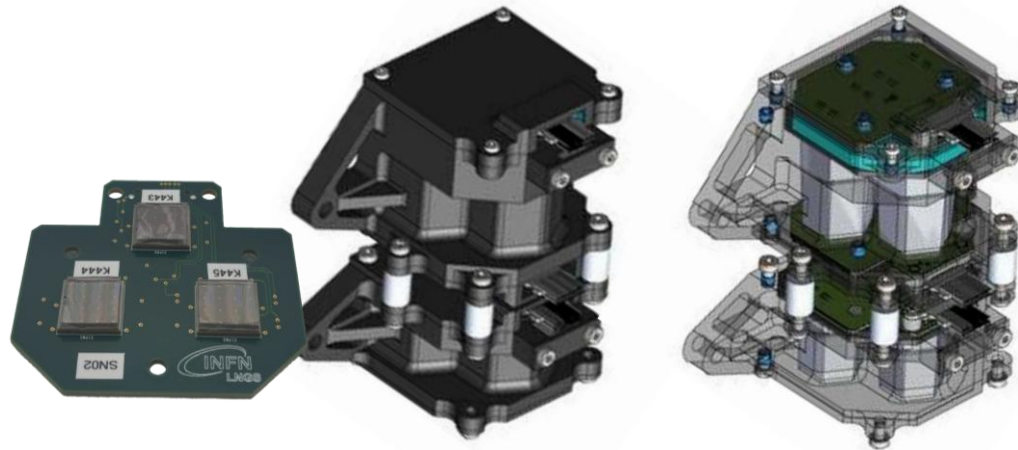


3.1 – Crystal Eye, Overview

WINK

WINK is the **technological pathfinder** of the **Crystal Eye** detector for the in-orbit validation of the key technologies of Crystal Eye, alongside background characterization and ancillary science support.

Three full size pixels from Crystal Eye (30° FoV tot.) of two layers of LYSO scintillating crystals read out with Silicon Photomultipliers (SiPMs) and top anticoincidence system (T-ACS).



Dedicated DAQ board based on Citiroc1A ASIC and a ZynQ SoM and built using Automotive-Grade Commercial Off-The-Shelf (COTS) components.



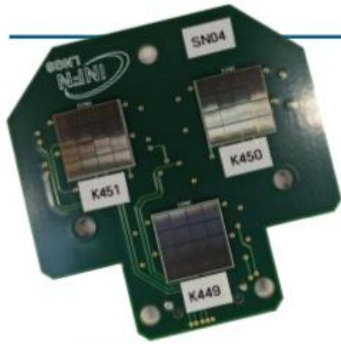
SPACE RIDER

Set to fly on board of Space Rider, ESA uncrewed reusable vehicle whom maiden flight is scheduled for Q1 - 2028 aboard the Vega-C vector. Two months of operations in LEO —380 to 450 km above Earth— before re-entry. PFM funded on PRIN2022 funds, flight funded by ASI.



3.1 – Crystal Eye, Overview

SiPM



Scintillating crystals are read by **Hamamatsu S13361-3050NE MPPCs** mounted on custom PCBs called **SiPM holders** equipped with temperature sensors.

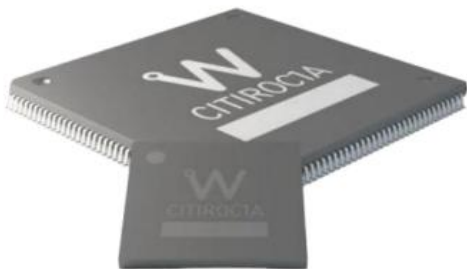
ZYNQ



All the operations are managed by a **SoM (System on Module)** which integrates base components in a single module to create a processing system.

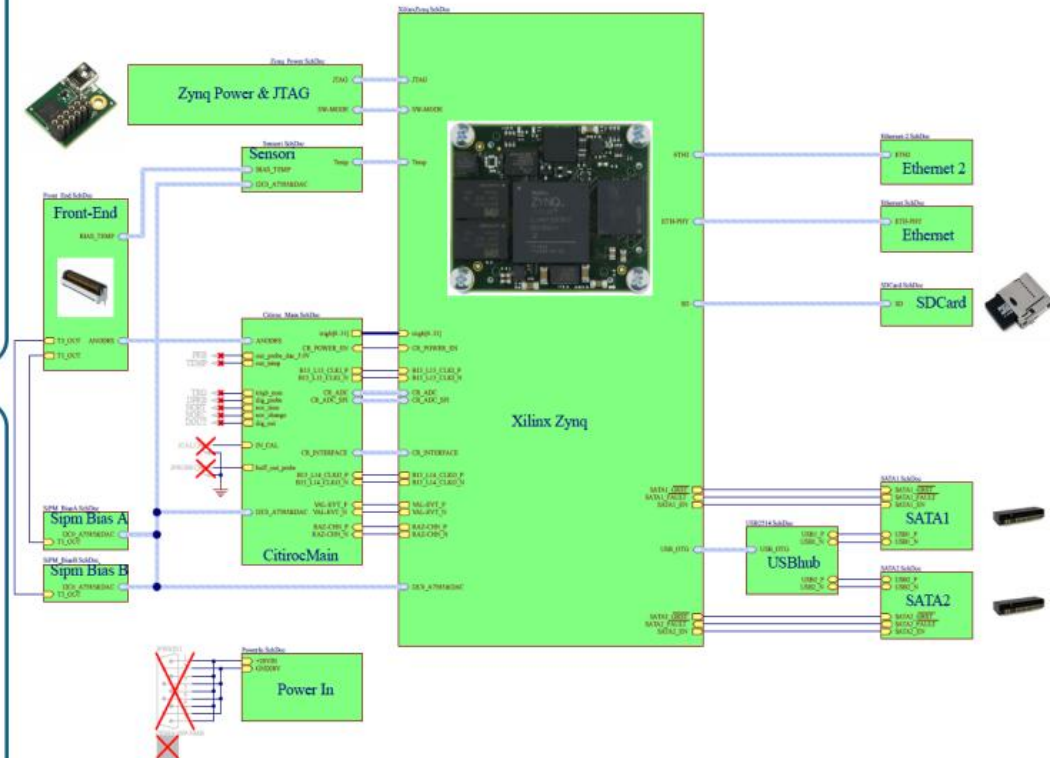
DAQ

WINK DAQ chain revolves around the synergy between the **Citiroc1A ASIC** produced by WeeRoc and a **14bit ADC** to convert its analogue output.

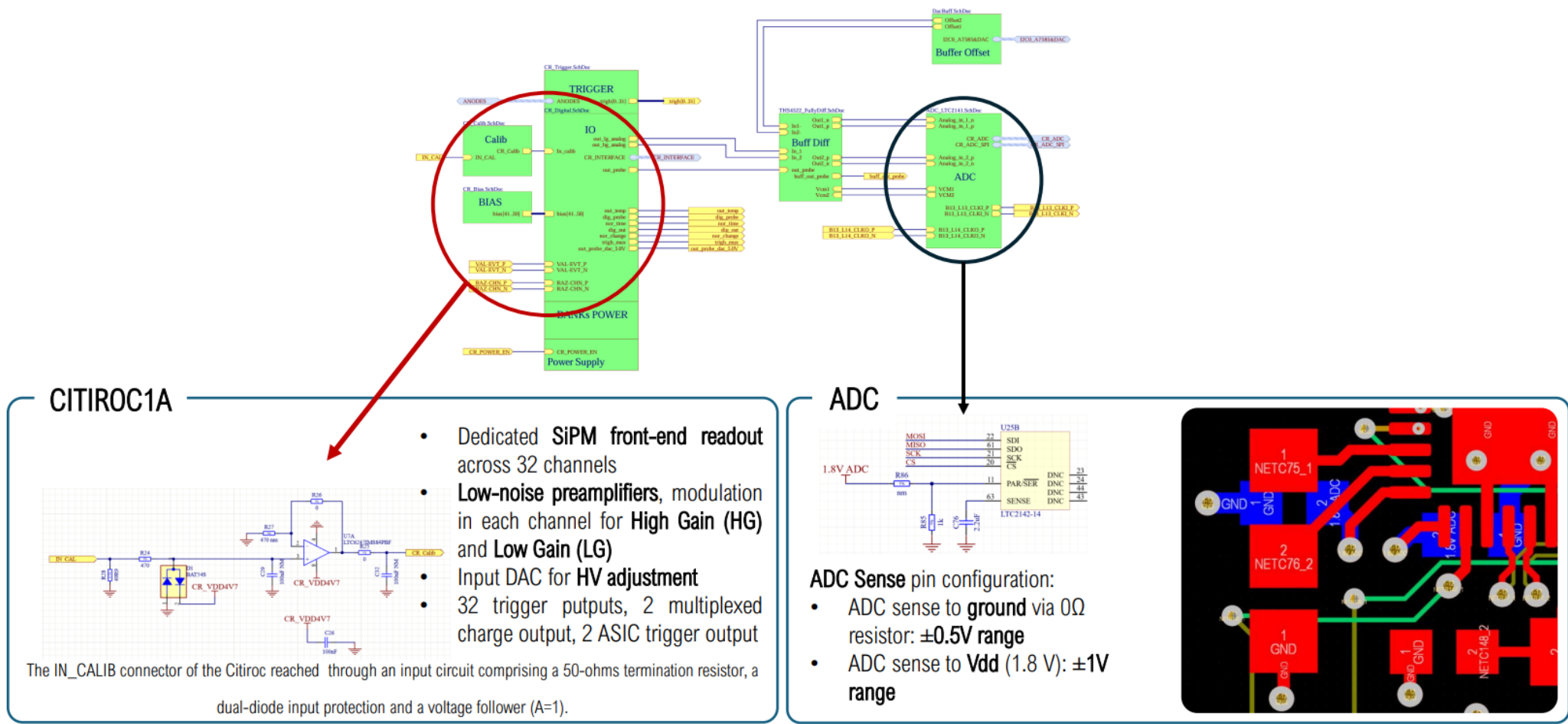


POWER

Main Power is provided by **SR**, while the **SiPMs biasing** is carried out through two **CAEN SiPM Power Modules**



3.1 – Crystal Eye, Overview

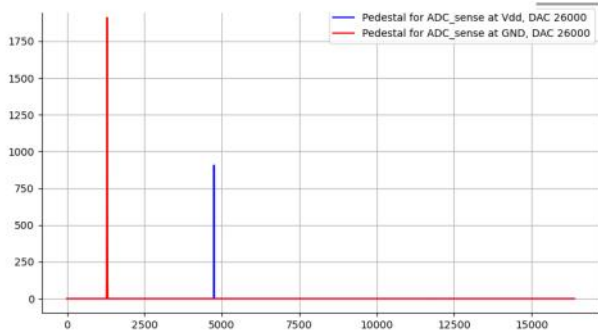


MY CONTRIBUTION

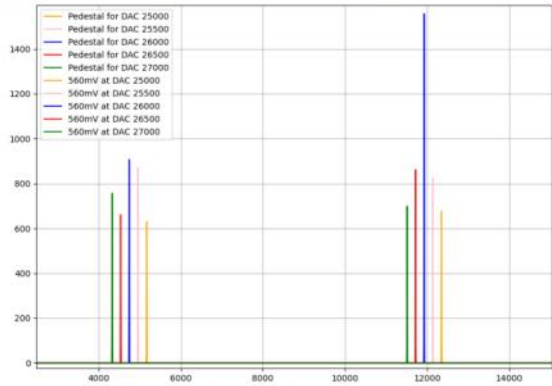
Performed different ADC configurations characterization

3.2 – Crystal Eye, *My contribution*

PEDESTAL CHARACTERIZATION



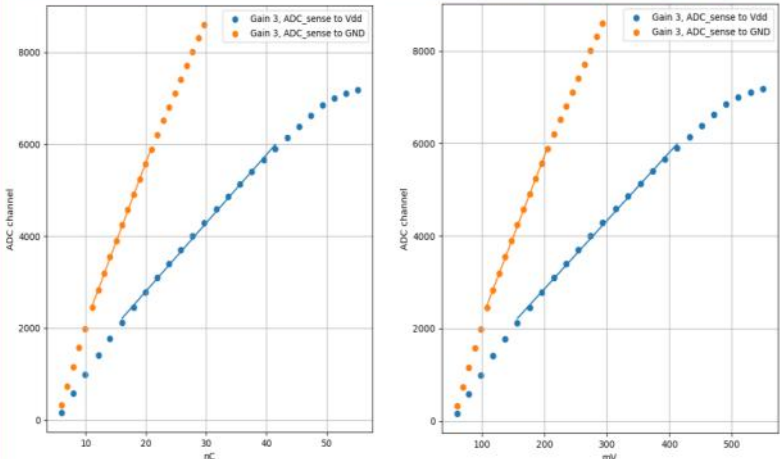
	ADC_sense to GND	ADC_sense to Vdd
Pedestal (26000 DAC value)	1295 ± 7	4746 ± 4



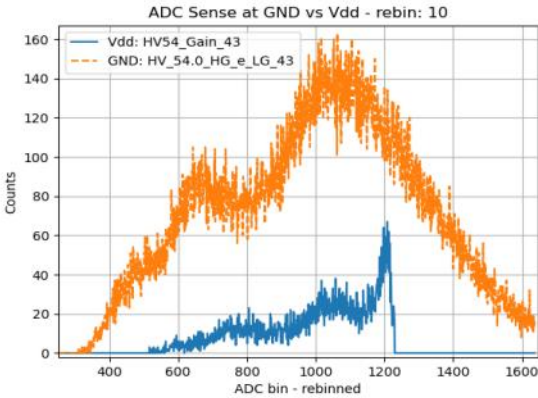
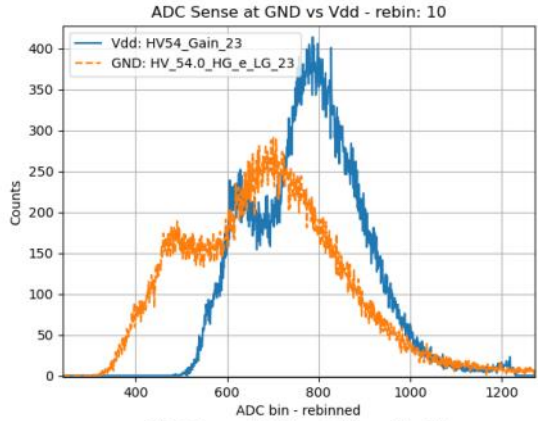
Pedestal ADC value - DAC25000: 5170.69 +/- 11.83
 Pedestal ADC value - DAC25500: 4959.76 +/- 16.11
 Pedestal ADC value - DAC26000: 4746.21 +/- 17.45
 Pedestal ADC value - DAC26500: 4538.65 +/- 11.91
 Pedestal ADC value - DAC27000: 4331.75 +/- 14.90
 Distance between Ped and Sat - DAC25000: 7182.27 +/- 15.06
 Distance between Ped and Sat - DAC25500: 7181.02 +/- 19.49
 Distance between Ped and Sat - DAC26000: 7182.97 +/- 20.77
 Distance between Ped and Sat - DAC26500: 7182.31 +/- 15.14
 Distance between Ped and Sat - DAC27000: 7183.34 +/- 18.33

SIGNAL CHARACTERIZATION

Known signal from functions generator characterized with oscilloscope and then injected into DAQ board



LYSO SPECTRA COMPARISON



ADC sense pin put at **GND** to ensure dynamical coverage within Citiroc saturation and compliance with Mission Prime requests about grounding

3.2 – Crystal Eye, *My contribution*

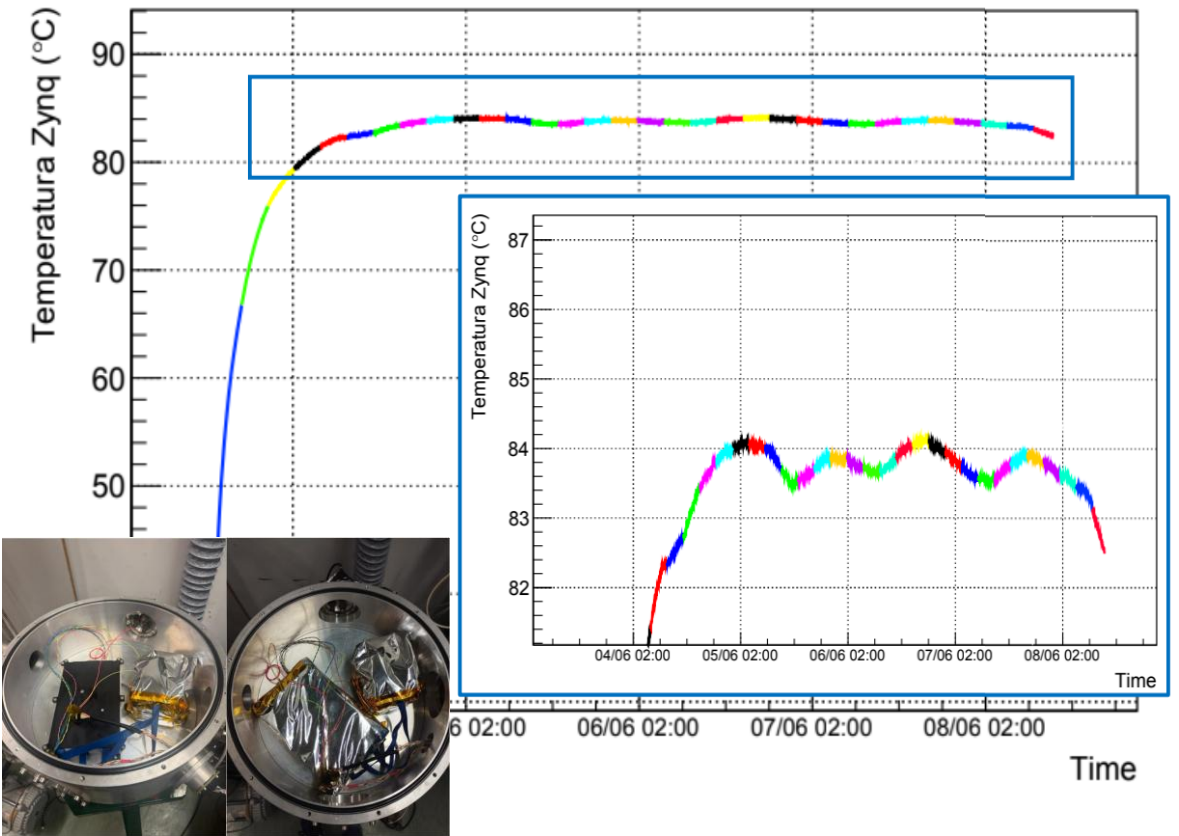
EQM

Partecipated in **WINK EQM assembly** in LNGS clean room in preparation for Qualification Tests run



FIRST TESTS

Performed **preliminary tests** in relevant conditions in Federico II University (Naples)

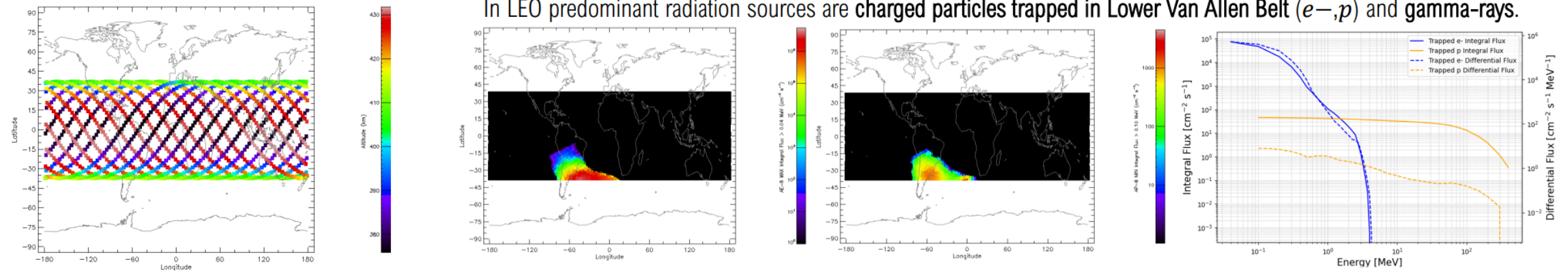


3.2 – Crystal Eye, *My contribution*

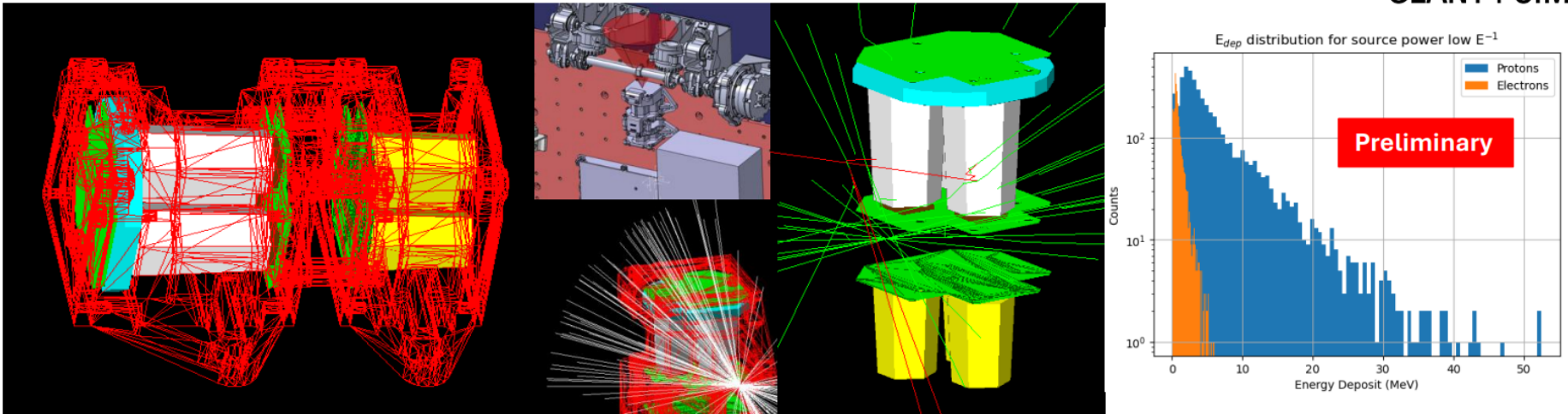
SiPMs are subject to **performance degradation** caused by prolonged exposure to ionizing and non-ionizing radiation. The energy transfer produce defects in the Si lattice that results in **higher Dark Current and Dark Count rate**. MULTITOOL analysis for RadHard Assessment.

SPENVIS ANALYSIS

In LEO predominant radiation sources are charged particles trapped in Lower Van Allen Belt (e^- , p) and gamma-rays.



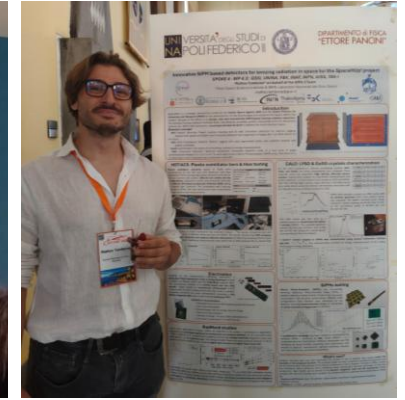
GEANT4 SIMULATIONS



4 – Schools, Conferences & Papers

In 2026 attended:

- **22th IFAE 2026**, Incontri di Fisica delle Alte Energie, Bologna, 8 to 10 April 2026. **ORAL CONTRIBUTION:** «Sviluppo di detector compatto ed innovativo per il progetto SpaceltUP! dedicato alla detezione di radiazione ionizzante attraverso un readout basato su SiPM»
- **14th CRIS-MAC 2026**, Cosmic-Ray International Studies and Multimessenger Astroparticle Conference, Sorrento, 13 - 17 July 2026. **POSTER CONTRIBUTION** «Innovative SiPM based detectors for ionizing radiation in space for the SpaceltUp! project»
- **46th COSPAR 2026**, Scientific Assembly of the Committee on Space Research, Florence 1 - 9 August 2026. **ORAL CONTRIBUTION** «WINK: Pathfinder for an innovative X-ray and gamma-ray detector in space»



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PROCEEDING
SUBMITTED

PROCEEDING
SUBMITTED

FULL ARTICLE IN
WRITING

IL NUOVO CIMENTO Vol. ?, N. ?

Innovative space-based ionizing radiation detectors with SiPM readout in the SpaceltUp! project

F. ACERBI^(*), S. ASHUROV⁽¹⁾⁽²⁾, M. BAIOCCHI⁽¹⁾⁽²⁾, F.C.T. BARBATO⁽¹⁾⁽²⁾, L. DE MITRI⁽¹⁾⁽²⁾, A. DI GIOVANNI⁽¹⁾⁽²⁾, S. FARINA⁽⁶⁾⁽⁷⁾, G. FONTANELLA⁽¹⁾⁽²⁾, A. GOLA⁽⁷⁾, F. GUARINO⁽³⁾⁽⁴⁾, D. KYRATZIS⁽¹⁾⁽²⁾, L. LAVITOLA⁽³⁾⁽⁴⁾, D. PATTANAIK⁽¹⁾⁽²⁾, F. PERFETTO⁽³⁾⁽⁴⁾, M. RUZZARIN⁽³⁾, F. SANSONE⁽³⁾⁽⁴⁾, P. SAVINA⁽¹⁾⁽²⁾, M. TAMBONE⁽¹⁾⁽²⁾, A. TIENGO⁽⁶⁾⁽⁷⁾, C. TRIMARELLI⁽¹⁾⁽²⁾, L. VALORE⁽³⁾⁽⁴⁾

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⁽³⁾ INFN Sezione di Napoli - Napoli, Italy
⁽⁴⁾ Università degli Studi di Napoli Federico II - Napoli, Italy
⁽⁵⁾ Fondazione Bruno Kessler, FBK - Trento, Italy
⁽⁶⁾ Istituto Nazionale di Studi Superiori, IUSS - Pavia, Italy
⁽⁷⁾ Istituto Nazionale di Astrofisica, Istituto di Astrofisica Spaziale e Fisica Cosmica di Milano - Milano, Italy

Summary. Within the framework of the multidisciplinary SpaceltUp! project, WP4.3 proposes new detector technologies for future missions in Earth orbit. The prototype is designed to detect photons in the 0.1-30 MeV energy range of interest for Terrestrial Gamma-ray Flashes (TGFs), gamma-ray transients, and high-energy atmospheric phenomena - as well as cosmic electrons and protons with energies up to approximately 100-200 MeV, relevant to space-weather and magnetosphere-ionosphere-lithosphere coupling (MILC) studies. Based on the integration of scintillating materials - i.e. plastic scintillators and scintillating crystals - and Silicon Photomultipliers (SiPMs), it comprises in a modular architecture a coarse tracker, a calorimeter and an active anticoincidence systems, enabling the investigation and assessment of different detector configurations. A removable Cherenkov submodule, that can be also operated separately, is integrated to test the capability of the discrimination of relativistic electrons from protons and heavier nuclei. Signal readout is performed using Hamamatsu MPPCs and FBK NUV-HD SiPMs provided in similar CSP packages and mounted on custom dedicated boards, leveraging the distinct characteristics, different solutions will be tailored according to the requirements of the various subdetectors. The data acquisition system, based on modular front-end electronics incorporating a System-on-Module and a low-power ASIC (RADIOROC2), enables simultaneous charge and timing measurements with low electronic noise. This work focuses on system-level design, prototype development, and preliminary performance validation of the proposed detector.

(*) Presenting Author

Innovative SiPM based detectors for ionizing radiation in space for the SpaceltUp! project

Fabio Acerbi⁵, Sindorjon Ashurov^{1,2}, Melissa Baiocchi^{1,2}, Felicia Carla Tiziana Barbato^{1,2}, Ivan De Mitri^{1,2}, Adriano Di Giovanni^{1,2}, Serena Farina^{6,7}, Giulio Fontanella^{1,2}, Alberto Gola⁷, Fausto Guarino^{3,4}, Dimitrios Kyrtatzis^{1,2}, Luigi Lavitola^{3,4}, Dipiranjjan Pattanaik^{1,2}, Francesco Perfetto^{3,4}, Maria Ruzzarin³, Fabio Sansone^{3,4}, Pierpaolo Savina^{1,2}, Matteo Tambone^{1,2,*}, Andrea Tiengo^{6,7}, Caterina Trimarelli^{1,2}, and Laura Valore^{3,4}.

¹Gran Sasso Science Institute, GSSI - L'Aquila, Italy
²INFN Laboratori Nazionali del Gran Sasso - Assegi, Italy
³Università degli Studi di Napoli Federico II - Napoli, Italy
⁴INFN Sezione di Napoli - Napoli, Italy
⁵Fondazione Bruno Kessler, FBK - Trento, Italy
⁶Istituto Universitario di Studi Superiori, IUSS - Pavia, Italy
⁷Istituto Nazionale di Astrofisica, Istituto di Astrofisica Spaziale e Fisica Cosmica di Milano - Milano, Italy

Abstract. Within the SpaceltUp! multidisciplinary project, the WP4.3 proposes a compact, modular, and low-power detector to test new techniques for the detection of cosmic electrons and protons up to approximately 100-200 MeV, and for photons in the 0.1-30 MeV energy range. The prototype is based on the integration of scintillating materials and Silicon Photomultipliers (SiPMs) in a modular architecture that allows for the integration of different types of subdetector. Signal readout is performed using Hamamatsu Multi-Pixel Photon Counters (MPPCs) and next-generation FBK NUV-HD SiPMs, provided in similar CSP packages and mounted on custom dedicated boards. The data acquisition system, based on modular front-end electronics and a flexible architecture incorporating a System-on-Module (ARM + FPGA) and low-power ASICs (RADIOROC2), provides simultaneous charge and timing measurements with low electronic noise. This work focuses on the system-level design, prototyping and preliminary performance validation of the setup.

1 Introduction

SpaceltUp[1] is a strategic partnership funded by the Italian Space Agency (ASI) and the Italian Ministry for University and Research (MUR) for the development of new technologies and solutions for Space. Within this context, the goal of the WP4.3 is to design, test and characterize SiPM-based ionizing radiation detectors. The activities include, among others, radiation hardness tests, new detector assembly system, new solutions for the electronics readout. Within this framework, a prototype, whose structure is shown in Figure 1, is being

*e-mail: matteo.tambone@gssi.it

4 – Schools, Conferences & Papers



Attend **ISOTDAQ 2026**, *International School of Trigger and Data Acquisition*, Bucharest 1 – 10 July 2026.



5 – Future work

NUSES

PFM assembly participation, characterization measurements

SPACEITUP

Prototype assembly, characterization and debugging firmware involvement

WINK

Space qualification campaign, PFM assembly

