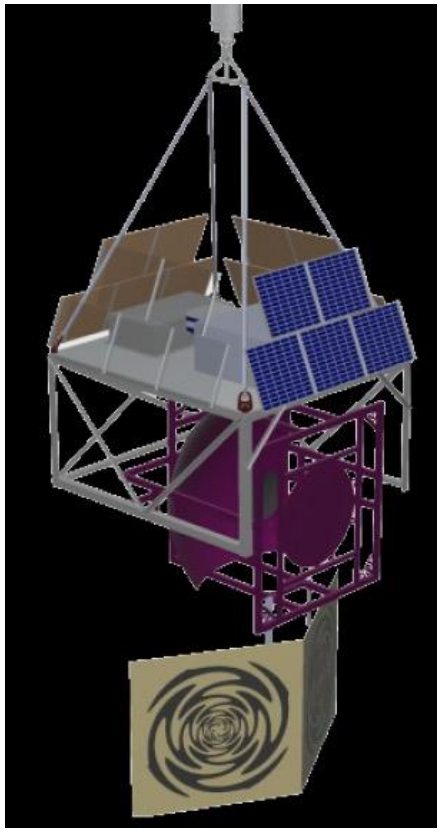


JEM-EUSO/PBR
ITALY Report
First half 2025



Marco Ricci

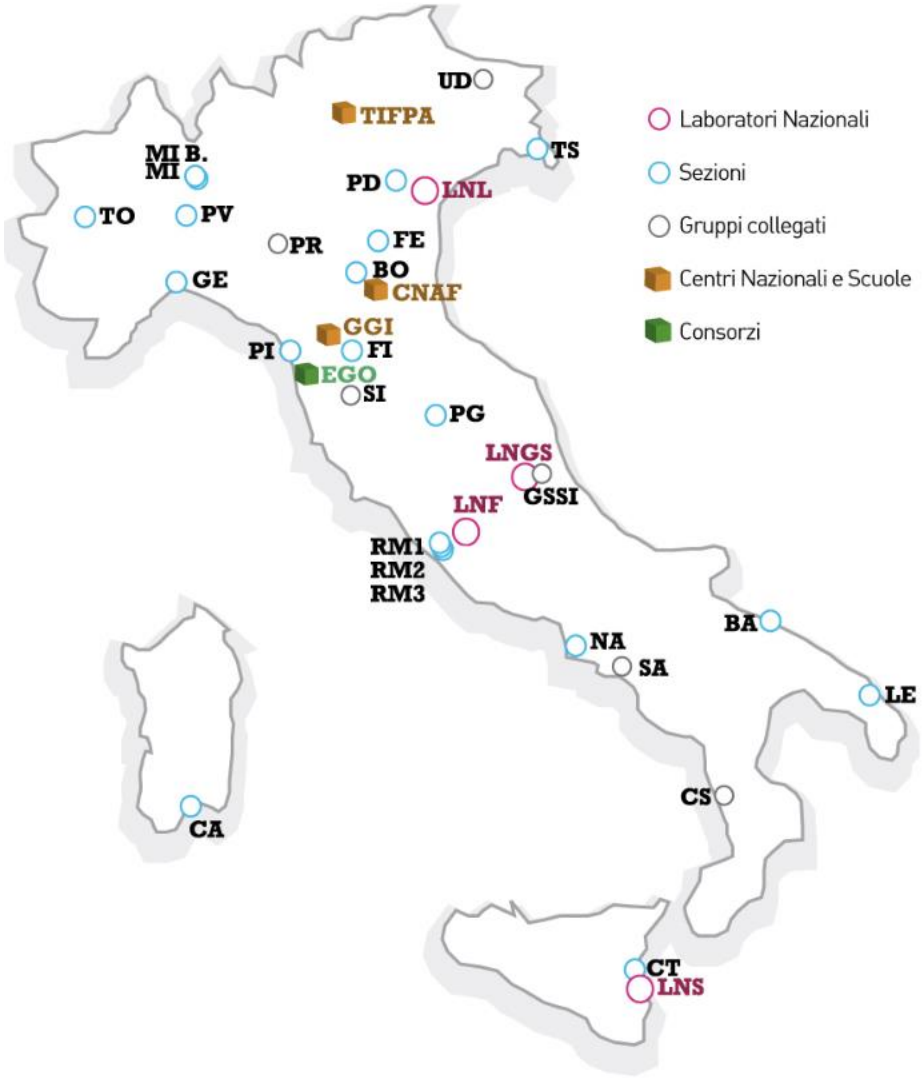
37th International JEM-EUSO Collaboration Meeting

Paris APC, 2 -6 June 2025

THE TEAM - INSTITUTIONS AND UNIVERSITIES

People officially involved in the JEM-EUSO activities for 2024 (SPB2, Mini-EUSO, EUSO TA, PBR, etc):

- **51 → 64 people (30 FTE) + 25% since last year**
  - 58 researchers
  - 6 technologists
  - 9 Institutions
- **Bari (Resp. F. Cafagna)**
- **Catania (R. Caruso)**
- **Gran Sasso Science Institute (GSSI/LNGS) (A. Di Giovanni)**
- **Lecce (V. Scherini)**
- **Napoli (G. Osteria)**
- **Roma Tor Vergata (Roma2) (M. Casolino)**
- **Trento (TIFPA) (F. Nozzoli)**
- **Torino (M. Bertaina)**
- **Trieste (Resp. R. Munini) started 2025**



Main activities in Italy focused on

- EUSO-SPB2 (analysis)
- Mini-EUSO (mission control, ground flashes campaigns, analysis)
- EUSO-TA (operations on site in Utah, analysis, upgrades)
- PBR
  - CC, FC, γ and X cameras, DAQ&DP, software, simulations,
  - INFN-ASI agreements, MoUs
  - During the last months: common participation in the preparation of the response to ESA 2025 M8&F3 calls that resulted in the submission of the M-EUSO proposal

What follows is a quick and synthetic report on the activities

carried out in the

INFN Structures and in the Universities in the 1st half of 2025

that will be thoroughly detailed during this week

TORINO - Current Activities and Responsibilities
Coord. Mario Bertaina

* **EUSO-SPB2/PBR:**
- Development of new ASIC chip for Cherenkov measurements within the ASI/INFN contract (A. Rivetti, A. Disalvo, S. Garbolino, M. Mignone, G. Dellacasa, R. Wheadon, S. Zugravel, G. Mazza, E. Trossarello, M. Bargelli)
- Study of the cloud conditions during EUSO-SPB2 flight (S. Ferrarese, M. Manfrin)

* **Mini-EUSO:**
- Weather studies along orbits (M. Manfrin, A. Golzio)
- Meteor analysis (D. Barghini, A. Coretti, F. Reynaud, I. Savioli, A. Bowaire)
- Simulation of nuclearites (R. Pullano, D. Barghini & M. Bertaina)
- Mini-EUSO calibration (M. Bertaina, M. Abrate, F. Reynaud, A. Coretti)

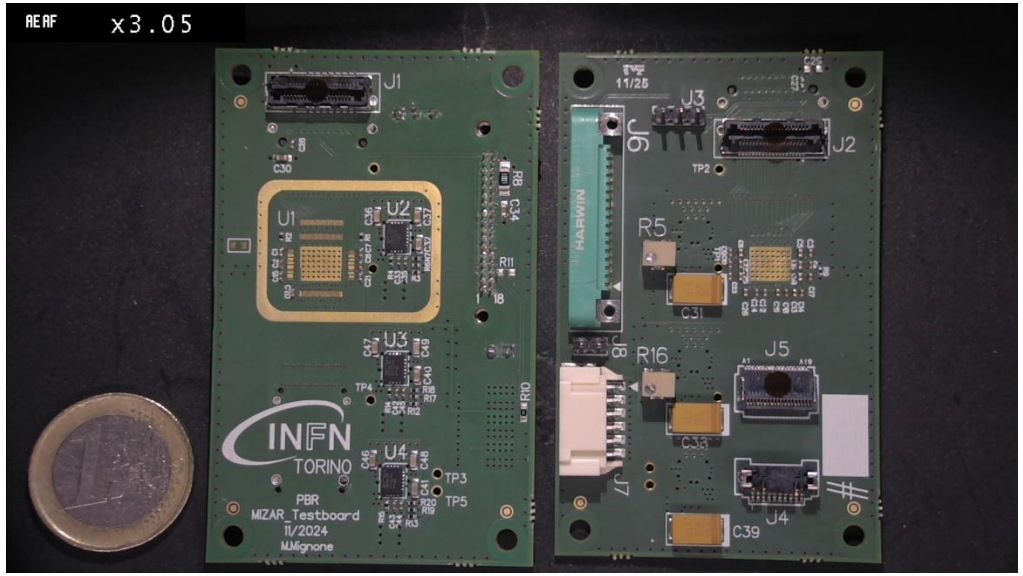
Others:
- Implementation of Stack-CNN on FPGA (M. Abrate, F. Reynaud & A. Coretti)
- CubeSat mission for space debris (M. Abrate, F. Reynaud, A. Coretti)
- Participation to the ESA Call for M mission (M. Bertaina)

* **GLOBAL ANALYSIS MEETINGS**:
- M. Bertaina (overall chair)

* ***PUBLICATION & CONFERENCE COMMITTEE:***
- M. Bertaina

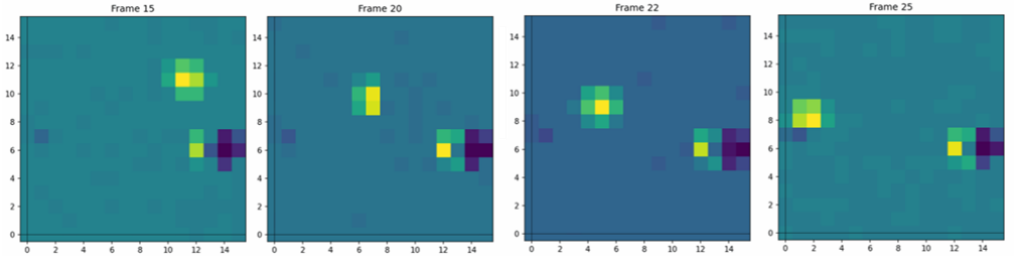
ASIC development for PBR

MIZAR ASIC back from foundry under test on ASIC test board



A. Di Salvo/S. Garbolino/M. Mignone/R. Wheadon

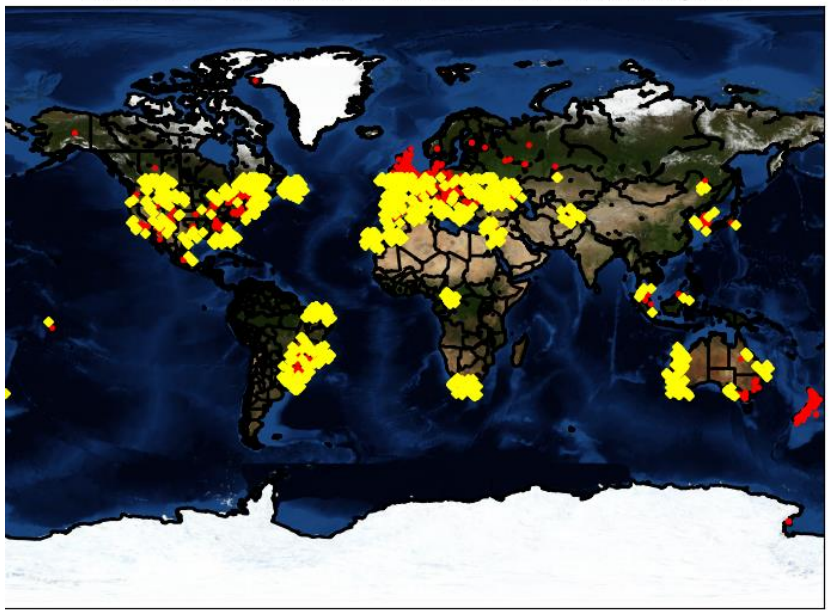
DISCARD project - Stack-CNN in FPGA



Demonstration of the technique observing Starlink satellites

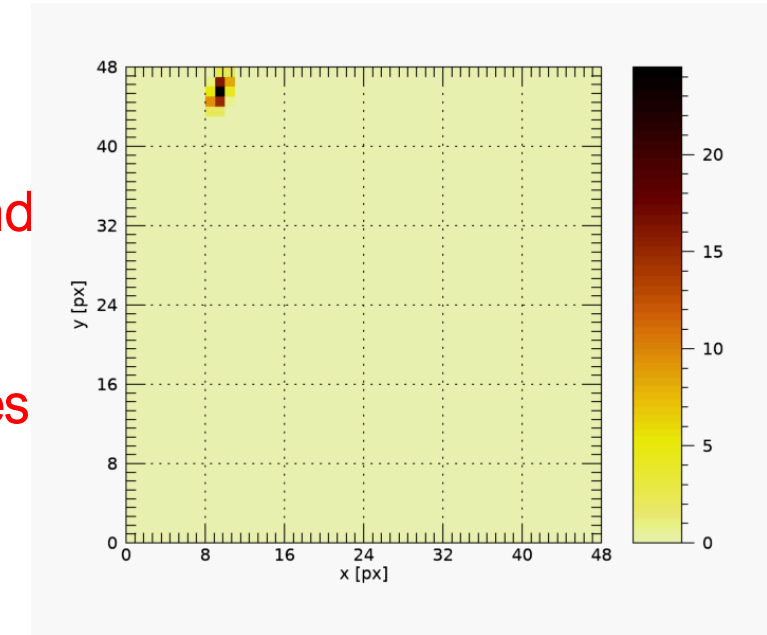
M.Abrate/A.Coretti/A.Frasson/F.Reynaud

Global Meteor Network stations in red, Mini-EUSO meteor in yellow



Search for coincident detection of meteors between Mini-EUSO and ground network
&
Simulation of nuclearites

A.Bowaire/D.Barghini/
R. Pullano



National Aeronautics and Space Administration

NASA

INTERNATIONAL SPACE STATION

ANNUAL HIGHLIGHTS of RESULTS

2024

BENEFITS FOR HUMANITY

The Roscosmos-ASI-ESA investigation **Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory (Mini-EUSO)** is a state-of-the-art multipurpose telescope designed to examine terrestrial, atmospheric, and cosmic ultraviolet emissions entering Earth's atmosphere. Its optical system of 36 multianode photomultiplier tubes capable of detecting single photons allows exceptional imaging during day/night and night/day transitions (Figure 15). Mini-EUSO has been onboard station since August 2019 and is the first mission of a larger program (JEM-EUSO) that includes about 300 scientists from 16 countries.

Figure 15. Digitized image of space debris around Earth. *Image adopted from Mini-EUSO research team video.*

Data from Mini-EUSO has recently been used to test a new machine learning algorithm to detect space debris and meteors when space objects move across the field of view of the telescope. The study, published in the *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, reports that the highly sensitive algorithm, called **Refined Stacking Method and Convolutional Neural Network (R-Stack-CNN)**, is an improved version of a previous machine learning method expected to become more significant and useful as increasing traffic of satellites and spacecraft sharing the same orbits add to the risk of collisions.[14] Millions of unidentified pieces of space debris could be removed from their orbit once detected.

The R-Stack-CNN model showed precision of 88.2%, a 2% improvement over the standard method used before, and detected 63.4% more events. Researchers improved the detection of space debris and meteors by using many instances of simulated and real data, enabling offline detection, and including light curves that provide information about the rotation rates of the objects and their physical characteristics. These upgrades allowed researchers to reduce false positives and increase the reliability of the algorithm.

Despite the challenges of detecting opaque objects with a moving telescope, a changing background of clouds, light emissions from cities, Moon reflections, and the small fraction of optimal conditions during twilight, researchers employed an advanced neural network used in computer vision that allowed them to classify information more accurately.

The R-Stack-CNN algorithm could be implemented on ground-based telescopes or satellites to identify space debris, meteors, or asteroids and increase the safety of space activities.

Napoli – Coord. Giuseppe Osteria

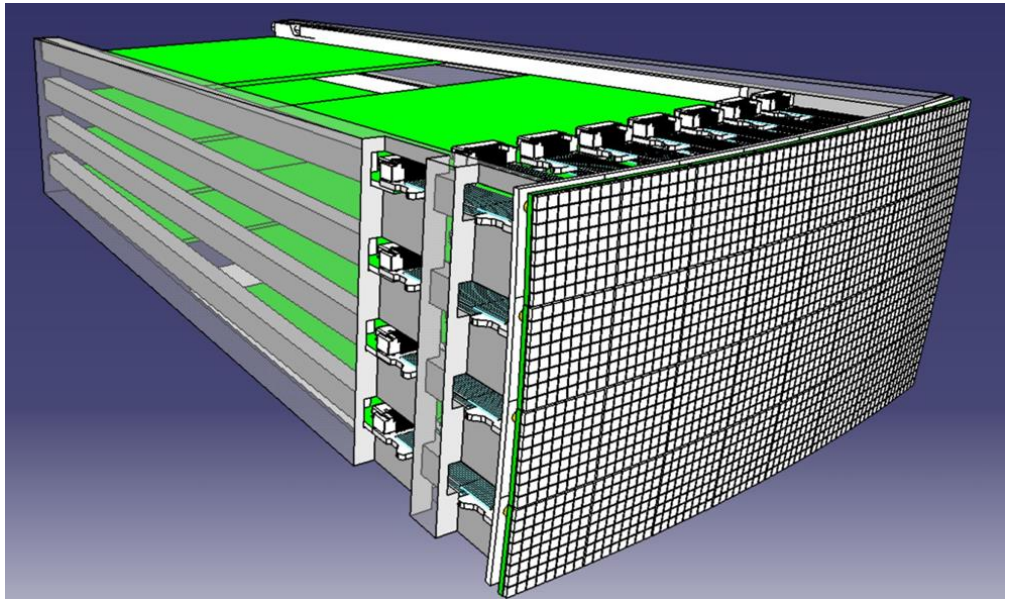
- **PBR Telescope DAQ & Control architecture**
- **Trigger architecture**
- **Data Processor**
  - design, procurement and MAIT:
    - Flight Model (SPB2 DP “Spare” and “Prototype” models modified and adapted)
    - Spare Model (procurement and MAIT)
  - **CPU and data storage** (procurement, design of the housing and cooling mechanics)
  - **GPS receivers** (procurement, design of the housing and cooling mechanics)
  - **TRG&CLK boards** (design, manufacturing, design of the housing and cooling mechanics)
  - **HK** (design, manufacturing, design of the housing and cooling mechanics)
  - **Ethernet Switches** (procurement, design of the housing and cooling mechanics)
  - **Telescope Power distributor** (procurement, design of the housing and cooling mechanics)

SPB2 DP Flight Model

SPB2 DP Prototype

Napoli

- **Cherenkov Camera**
  - **System design**
  - **SiPM procurement**
  - **Mechanics**
  - **Cooling**
  - **ASIC & FPGA board (B option)**
  - **Simulation studies for the electronic chain**
- **FC MAPMT procurement (one PDM)**
- **Termo Vacuum test (@CIRA) of DP, FC, and CC**
- **European shift center**



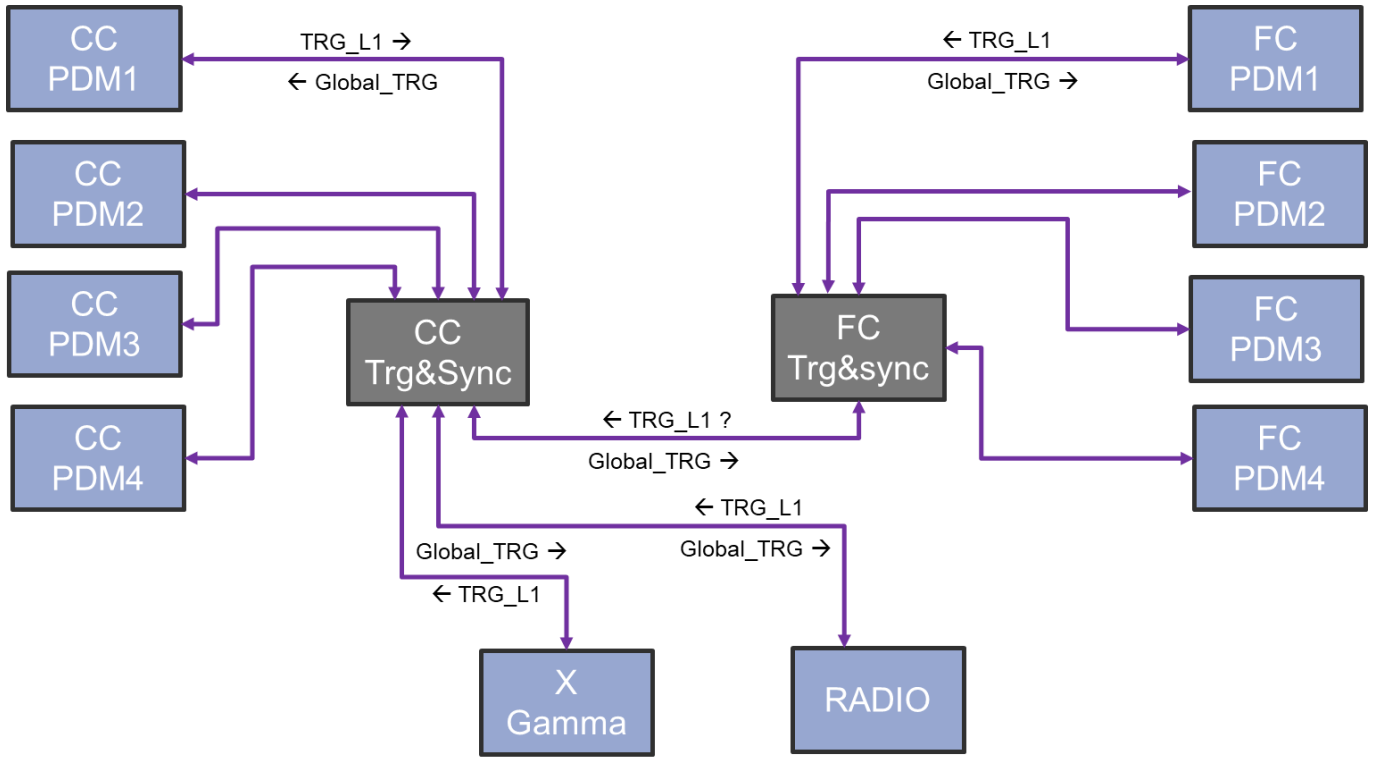
PBR Cherenkov Camera (CAD view)

COMBINED CHAMBER
(Angelantoni UD 1000 C VT)

SPB2 European shift center

Napoli

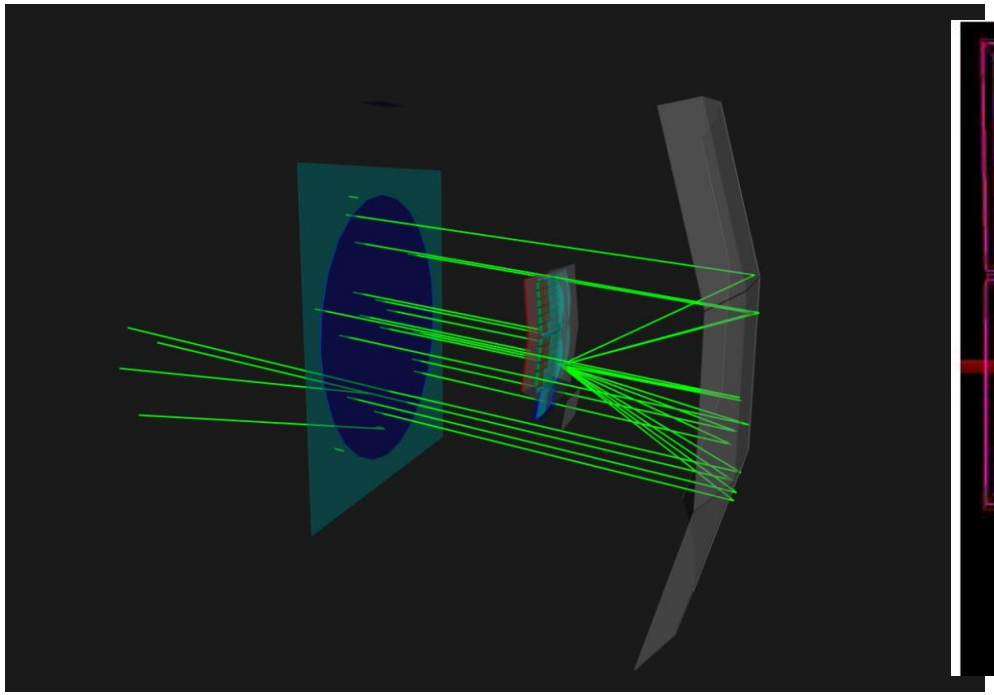
- **Trigger architecture**
  - **L1 trigger signals management**
  - **Global trigger signal distribution**

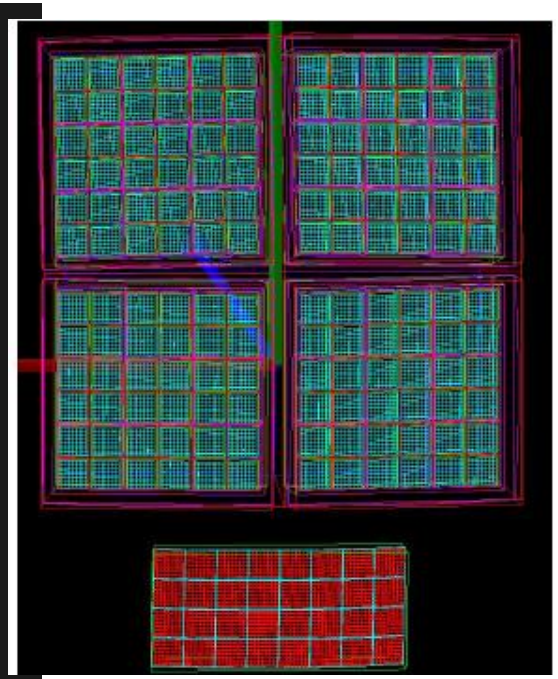


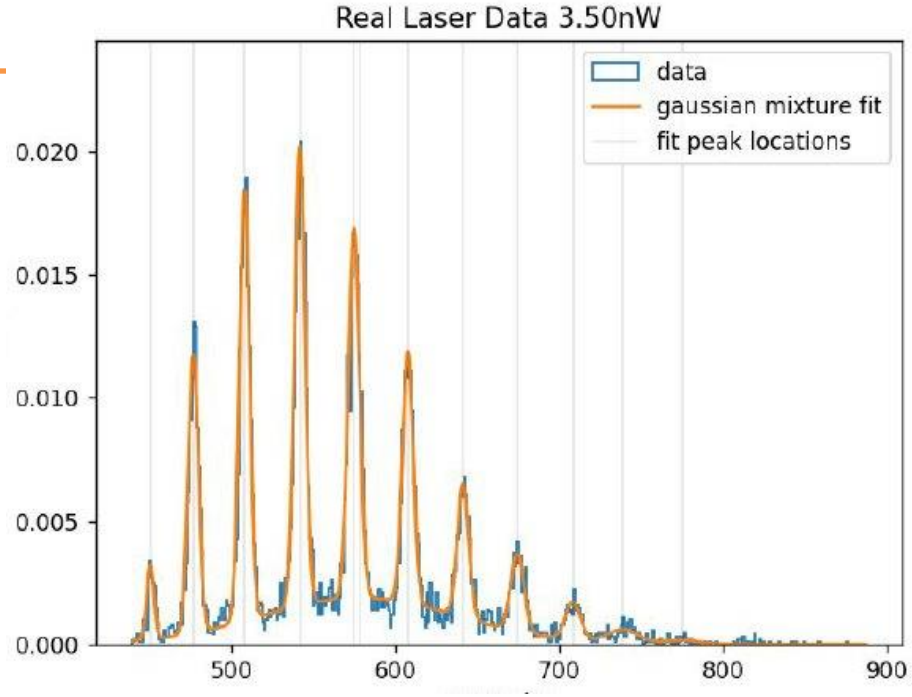
Napoli

Simulations

- Simulation with CAD files for mirrors and mechanical structures
- Offline structure defined
- Example in progress
- Together with I.Buckland studying the implementation of the electronic chain starting from real data measured in the laboratory of Naples

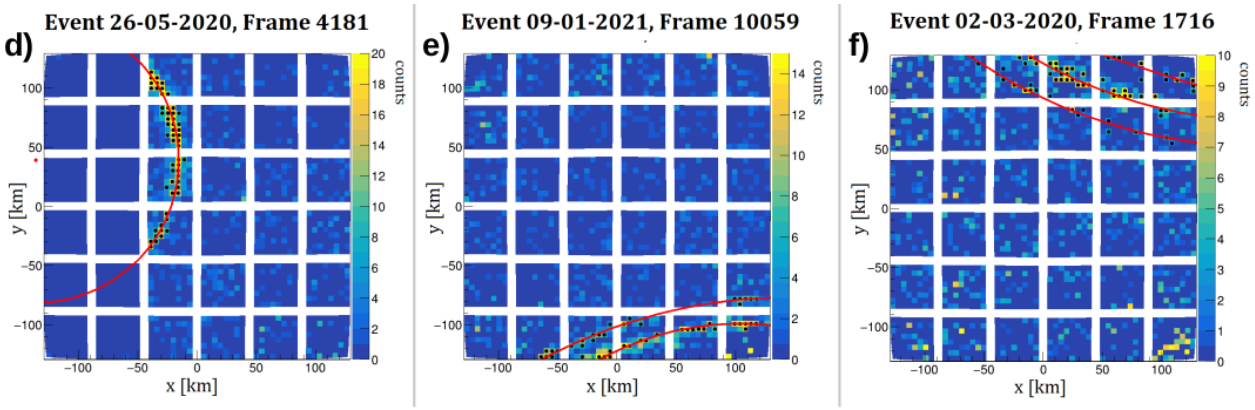






Roma Tor Vergata

Coord. Marco Casolino



Mini-EUSO:

- >5yrs and >150 sessions;
- mission control (on-board and on-ground operations);
- data handling and data processing;
- ELVES analysis and ELVES paper (submitted to *“Science Advances”*);
- UV ground flasher operations;
- ASI-SSDC website (UV maps published, meteors (and ELVES) to be published);

EUSO-TA:

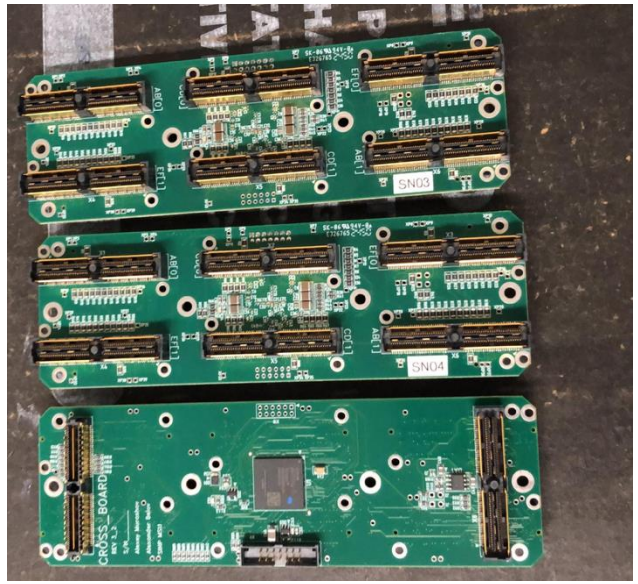
- PDM + Zynq + CPU in Rome to be fixed

Roma Tor Vergata

PBR:

Fluorescence Telescope:

- Zynq board (built upon the Russian project for SPB2):
  - 2x boards assembled, to be tested with 3x Cross boards and PDMs for verification;
  - 6x boards to be assembled after verification;
  - Firmware upgrade planned;
- Cross board (built upon the Russian project for SPB2):
  - 3x boards assembled, to be tested with one brand new Zynq board and PDMs for verification;
  - 15x boards to be assembled after verification.

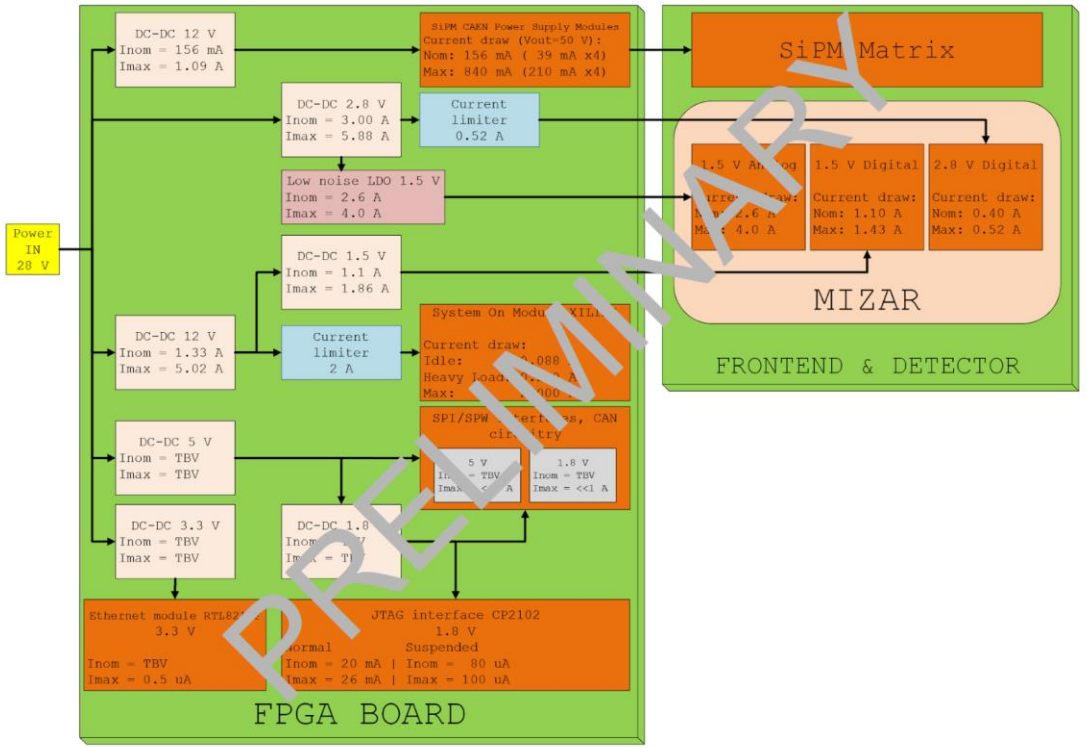


Roma Tor Vergata

PBR:

Cherenkov Telescope:

- FPGA board:
  - Electronic circuit diagram development ongoing;
  - FPGA: Xilinx Artix Ultrascale+ XCAU15P-2FFVB676I;
  - Developed around Alinx System on Module (SoM) ACAU15;
  - Testbed with Alinx AXAU15;
  - Firwmare development ongoing.

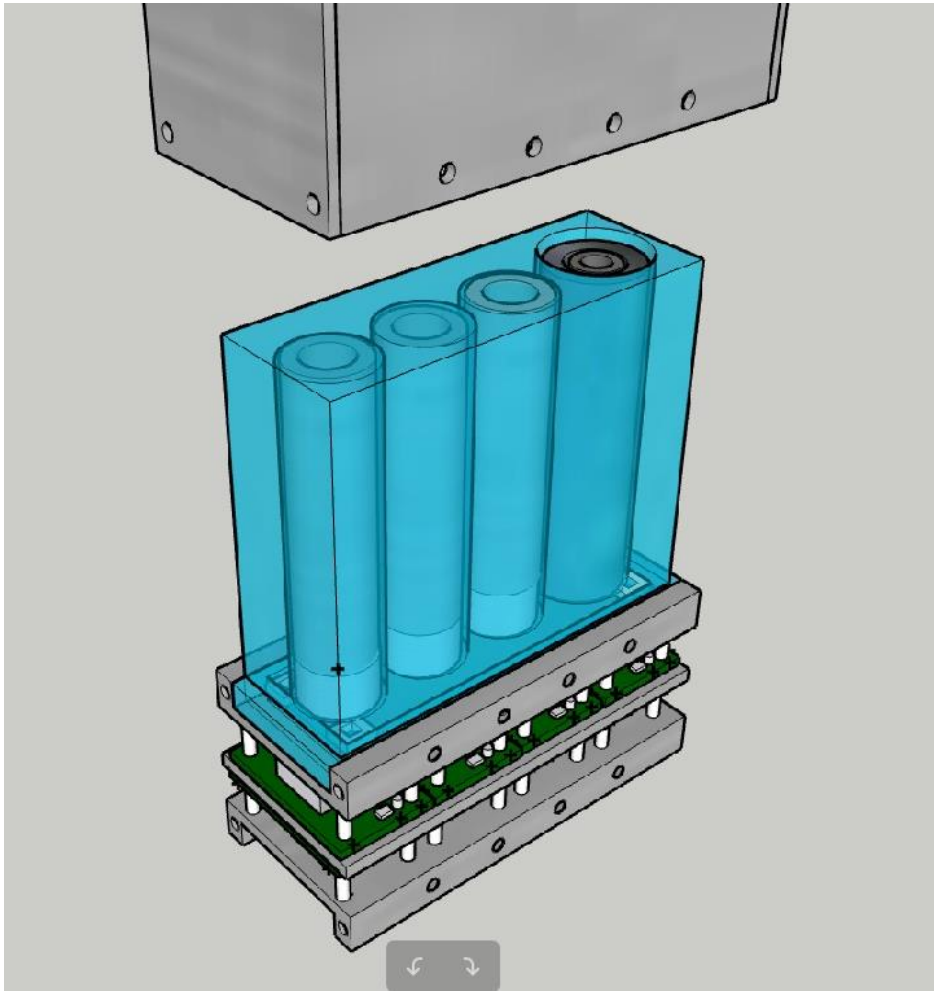


Roma Tor Vergata

PBR:

X- and Gamma- Ray detector:

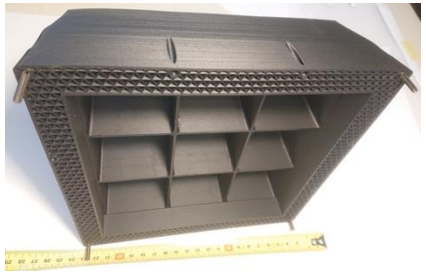
- detector design;
- read-out front-end board produced and under test;
- sensors (scionix detectors) under test;
- payload computer: project done;
- mechanics: procurement ongoing.



Bari Activities (Coord. Francesco Cafagna)

- Participation to the design of the PBR instrument.
- Design and construction of the PDM mechanical frames.
- Co-chairing the software group.

PDM prototype under test



A printed frame

Printing the prototype

Prof. Roberto Belotti (member of the JEM-EUSO Collaboration) is the new Rector of the University of Bari

UNIVERSITÀ degli STUDI di CATANIA

Dipartimento di Fisica e Astronomia "Ettore Majorana"

INFN CATANIA
Istituto Nazionale di Fisica Nucleare
Sezione di Catania

Agenzia Spaziale Italiana

CATANIA JEM-EUSO Group

Coord. Rossella Caruso

Members:

Anzalone Anna [c,b], Caruso Rossella [a, b],Pagliaro Antonio [c,b], Petta Catia [a, b]

Brio* Vanessa [a], Crocco**Anna [a]

(a) Dipartimento di Fisica ed Astronomia "E. Majorana" – Università di Catania

(b) INFN Sezione di Catania

(c) INAF-IASF – Palermo

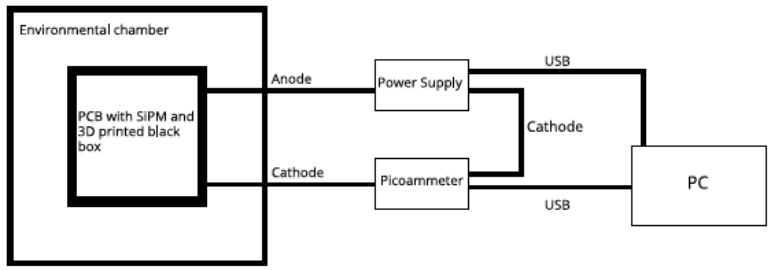
***Fellowship University of Catania**

****Master's Degree student**

Activities: **a) Test & Calibration of Elementary Cell units for PBR Cherenkov Camera**

involved members: R. Caruso, C.Petta, V.Brio, A.Crocco

See Talk by R. Caruso on Thursday, June 5th 2025 – PBR Session – this Meeting



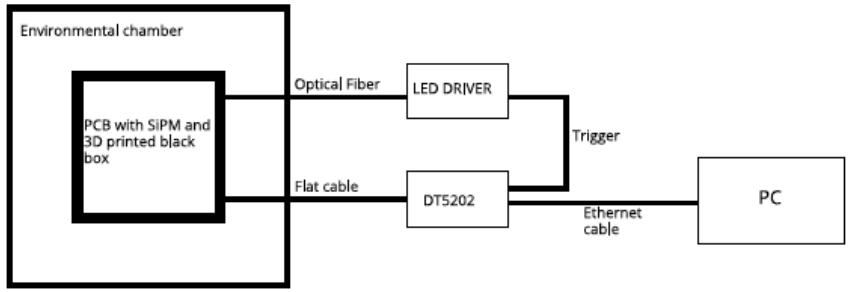
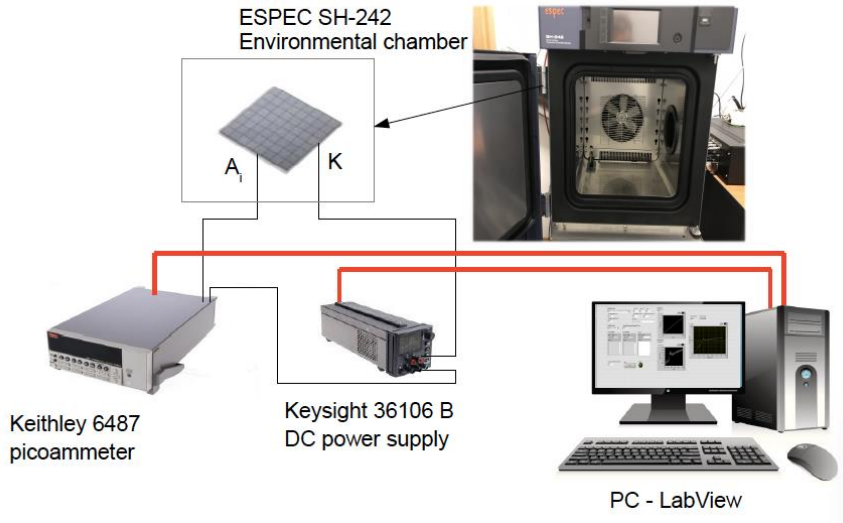
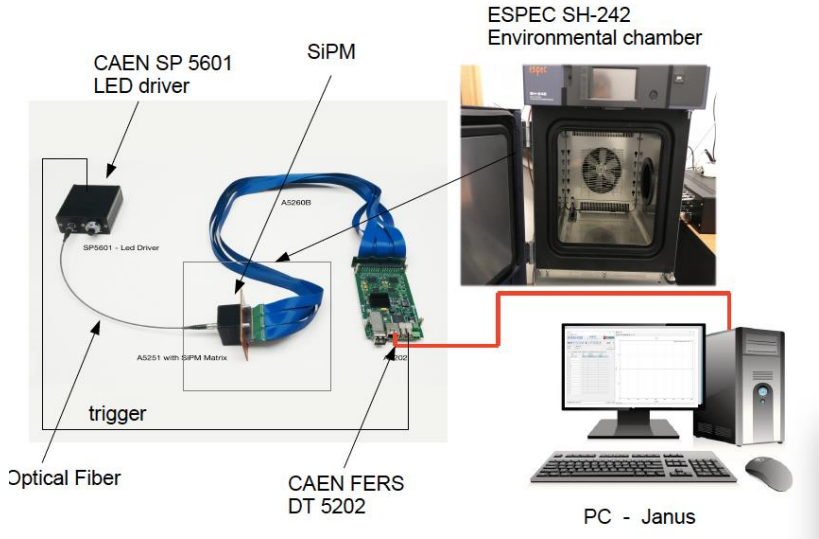


Fig. 1. Schematic view of the set-up used for I-V measurements.

I-V measurement setup



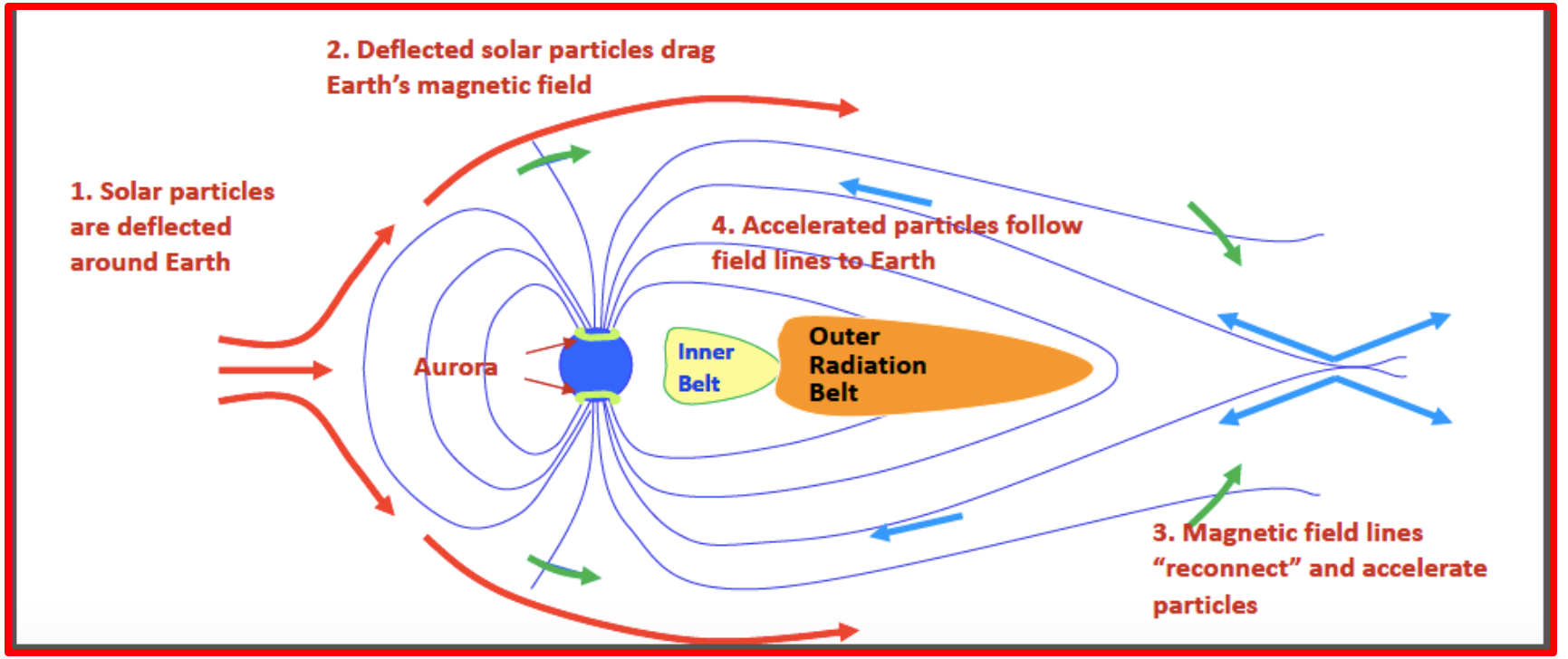
Multiphoton & staircase setup



Activities: b) *CME (*) solar events and U.V. Transient Luminous Events in MiniEUSO data*

involved members: R. Caruso, A. Crocco

(*) CME = Coronal Mass Ejection



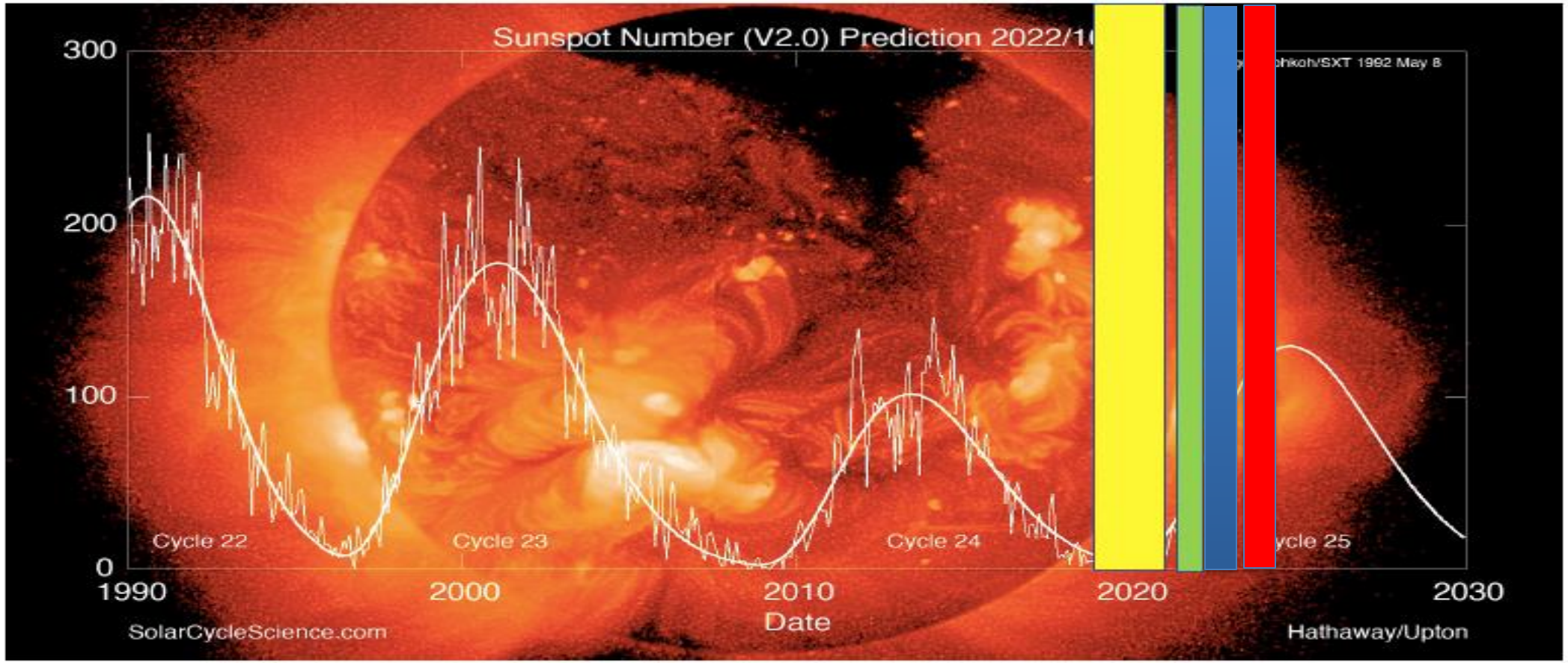
Sequence of Events leading to Geo-Effective CMEs

- Active Region on the Sun Erupts
  1. Solar Flare (Visible, UV, EUV, X-ray)
  2. Shock (energetic particles)
  3. Coronal Mass Ejection (particles and fields)
- Radiation reaches Earth in 8 minutes (speed of light)
- Energetic Particles reach Earth in 15 min to 24 hours
- **Coronal Mass Ejection reaches Earth in 1-4 Days**

A CME is **geo-effective** when:

- It takes place close to the solar disk center
- The source AR is located in the western side of the solar disk
- It is a Halo CME
- The magnetic field embedded in the plasma cloud has a component opposite to the Earth magnetic field.

The first Mini-Euso dataset was acquired during the phase of minimum of solar activity (Nov 2019 – Aug 2021), indicated by the yellow box.
The second dataset was acquired during the growing phase of Cycle 25 (Nov 2021 – Aug 2022), indicated by the green box.



The third dataset was acquired during the more growing phase of Cycle 25 (Sep 2022 – Nov 2023) indicated by the blue box.
The fourth dataset was acquired during the maximum phase of Cycle 25 (Dec 2024 – Jan 2025) indicated by the red box.

FLOW-CHART - Data Analysis CME vs MiniEUSO

1. **Compilation of candidate geo-effective CME** events using different catalogues:

- https://www.helcats-fp7.eu/catalogues/wp2_cat.html
- http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm
- https://wind.nasa.gov/ICME_catalog/ICME_catalog_viewer.php
- https://helioforecast.space/arrcat

2. **determination of CME arrival time** in the Earth atmosphere in order to correlate with MiniEUSO events;
3. **determination of the CME angular width** in order to evaluate its geo-magnetic effectiveness;
3. **dowload MiniEUSO data e lista Sessioni dati utili** ("Sessions" i.e. ROOT files);

3. **comparison** between geo-effective **CME arrival time at Earth** with **data acquistion time of MiniEUSO data** in order to search for possible candidates;

6. **analysis of possible candidate files using ETOS** code searching for signature in the data (i.e. no new or strange signal) ;

7. **cross-check** by means of comparison between CME arrival time at Earth **with the DST index**;

- https://www.ngdc.noaa.gov/stp/GEOMAG/dst.html
- https://wdc.kugi.kyoto-u.ac.jp//dstdir/
- https://web.archive.org/web/20120209110443/http://www.esa-spaceweather.net/swenet/login cmd=swenet_latest_alerts

8. **further cross- check** for any evidence of significance in the **Kp index level**

- https://www.spaceweatherlive.com/en/auroral-activity/top-50-geomagnetic-storms/year/2022.html

MiniEUSO Data Sets:

- **44 Sessions (n.1 ÷ n. 44)**

November 6, 2019 ÷ August 12, 2021;

- **19 Sessions (n.45 ÷ n. 63)**

November 6, 2021 ÷ August 26, 2022;

- **42 Sessions (n.64 ÷ n. 101)**

September 30, 2022 ÷ November 28, 2023;

- **39 Sessions (n.102 ÷ n. 141)**

December 21, 2023 ÷ January 2, 2025;

A) Possible CME candidates in MiniEUSO Sessions **(n.1 ÷ n. 114):**

- **June 24, 2020**
- **June 29, 2020**
- **February 3, 2022**
- **July 3, 2022**

RESULTS: NO CORRELATION!

B) 4 CME candidates in MiniEUSO Sessions **(n.115 ÷ n. 141)**

RESULTS: CORRELATION NOT EXCLUDED!

Cross checks ongoing

INAF - IASF Palermo
ISTITUTO DI ASTROFISICA SPAZIALE E FISICA COSMICA DI PALERMO

INFN CATANIA
Istituto Nazionale di Fisica Nucleare
Sezione di Catania

Activities:
b) Atmospheric and Cloud Monitoring

Involved members: **Anna Anzalone, Antonio Pagliaro**

Mini-EUSO Data Analysis:

3D reconstruction of meteor trajectory

- Test of the computer vision method on the real meteor data

Cloud Masking:

Application of Machine and Deep Learning methods for Cloud Mask Retrieval

TRENTO (Coord. Ester Ricci)

Thermal Tests with climate chamber

SiPM bias proposed solution

- Developing of the **bias system** of PBR Cherenkov camera
- Best candidate: **CAEN A7585D**
- Issues: the component is not validated for temperatures higher than 60ºC
- Circuit and component test **currently ongoing**
- We have the expertise and the infrastructure to do that **in house** from CSES –LIMADOU HEPD-02 tracker

People involved:
E. Ricci (researcher)
R. Iuppa (associate professor)
P. Zuccon (associate professor)
D. Schledewitz (PhD student)

Setup until now

- Proposed setup thermal test:
  - Arduino controlled SiPM PS
  - SiPM readout over multiple thermal cycles
- Setup ready for testing the SiPM PS module in climate chamber:
  - 25.5 Thermal cycles from -35°C to 90°C
  - Arduino responsiveness (serial communication, timing)
  - Output voltage from PS module across temperature
  - Power-on stability and cold start behavior

Activities in Lecce (Viviana Scherini (Resp.) & Lorenzo Perrone)

CORSIKA simulation productions

Test set

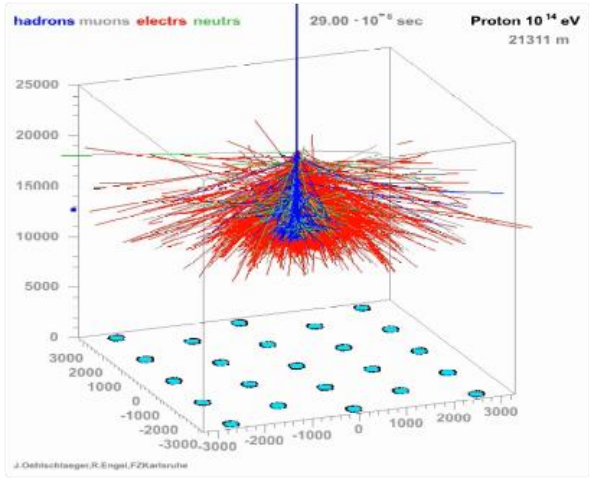
- fixed energy 10^{17}, zenith angle 79° – 89°
  100 showers per bin (1° steps)
- different primaries P – Fe – O

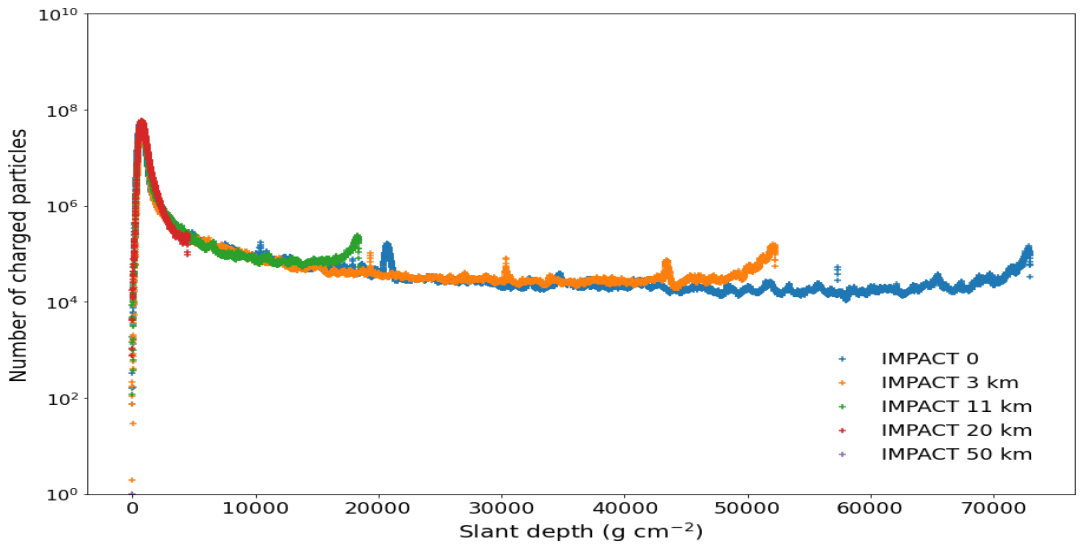
Energy dependence set

- energy bins lg(E/eV) 15 – 20
  100 showers per bin (0.5 in log steps)
- fixed angle 89°, Proton

Impact parameter option ~15000 sh/prim

- Corsika v 77500 with Fluka 2021-2
- P – He– O – Fe
- energy spectrum E^{-1} log(E/eV) [15.5,20],
  different impact parameter (horizontal shower)
- impact parameter [0, 1.5, 2.2, 3.2, 4.8, 7.1,
  10.5, 22.9, 33.8, 50] km



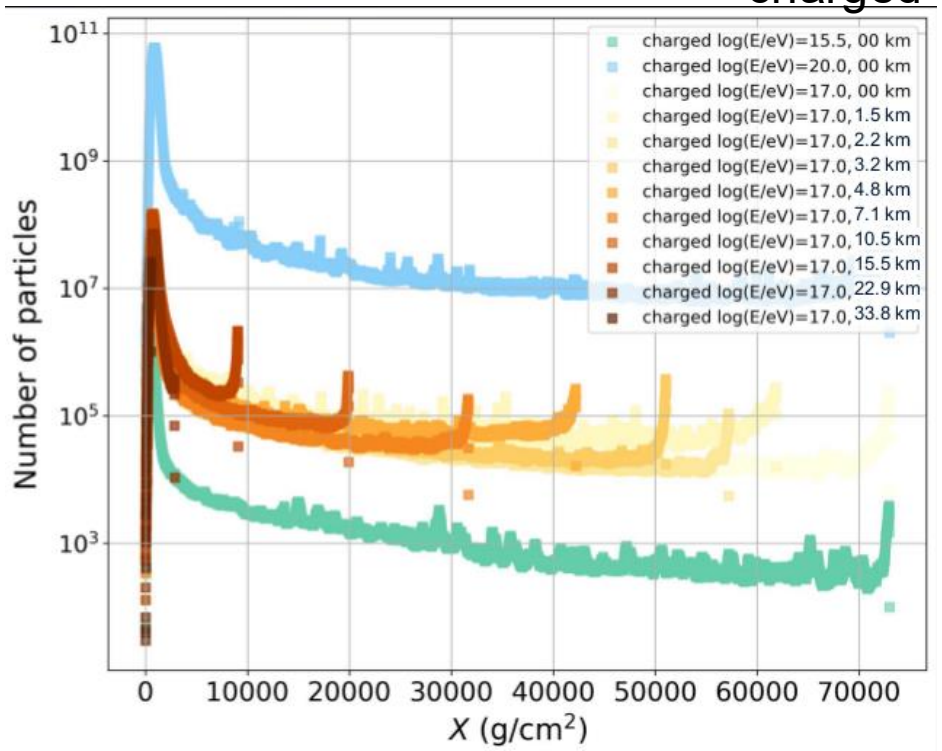


Longitudinal profile checks

Check on test productions

- particle distributions (charged – gamma – hadrons - nuclei)
- different primaries P – He – O – Fe
- energy bins lg(E/eV) 15.5 – 20
- different impact parameter (for horizontal showers)
  [0, 1.5, 2.2, 3.2, 4.8, 7.1, 10.5, 22.9, 33.8, 50] km

charged

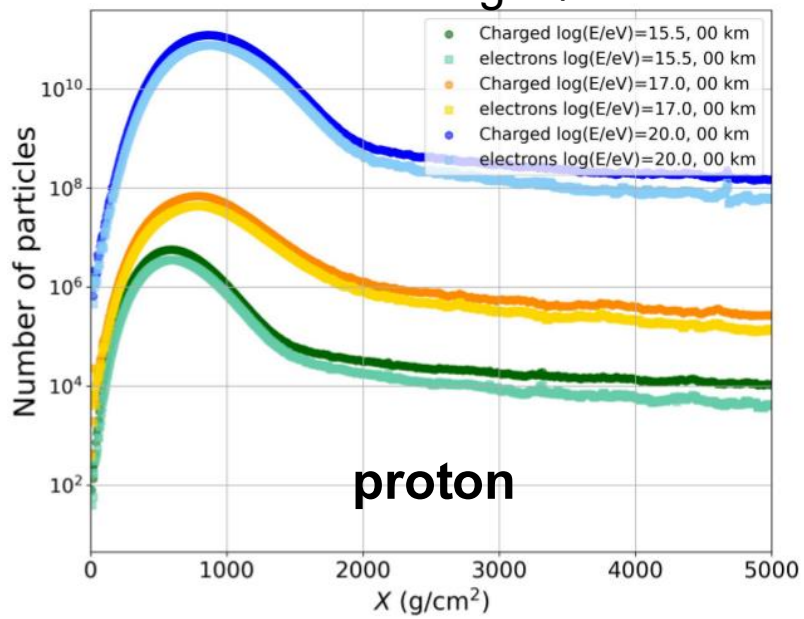


10^{20} eV

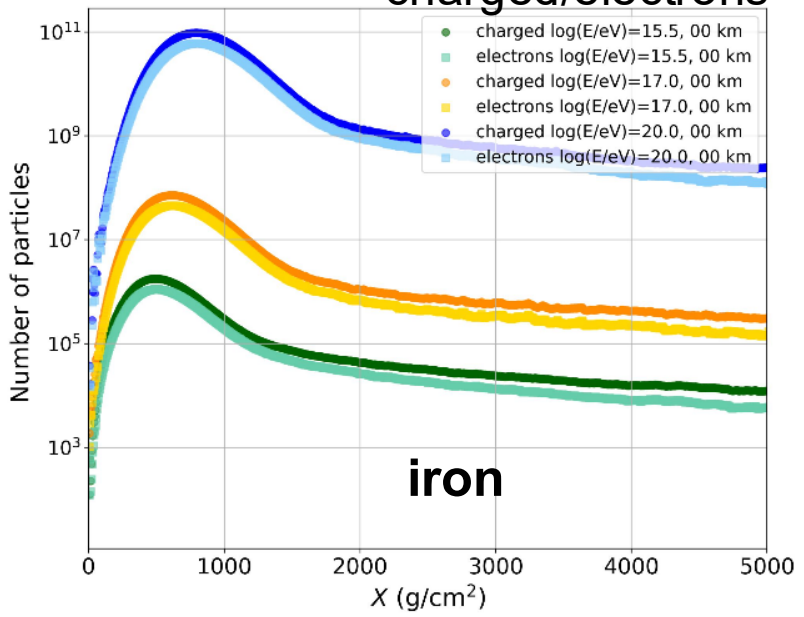
10^{17} eV

$10^{15.5}$ eV

charged/electrons



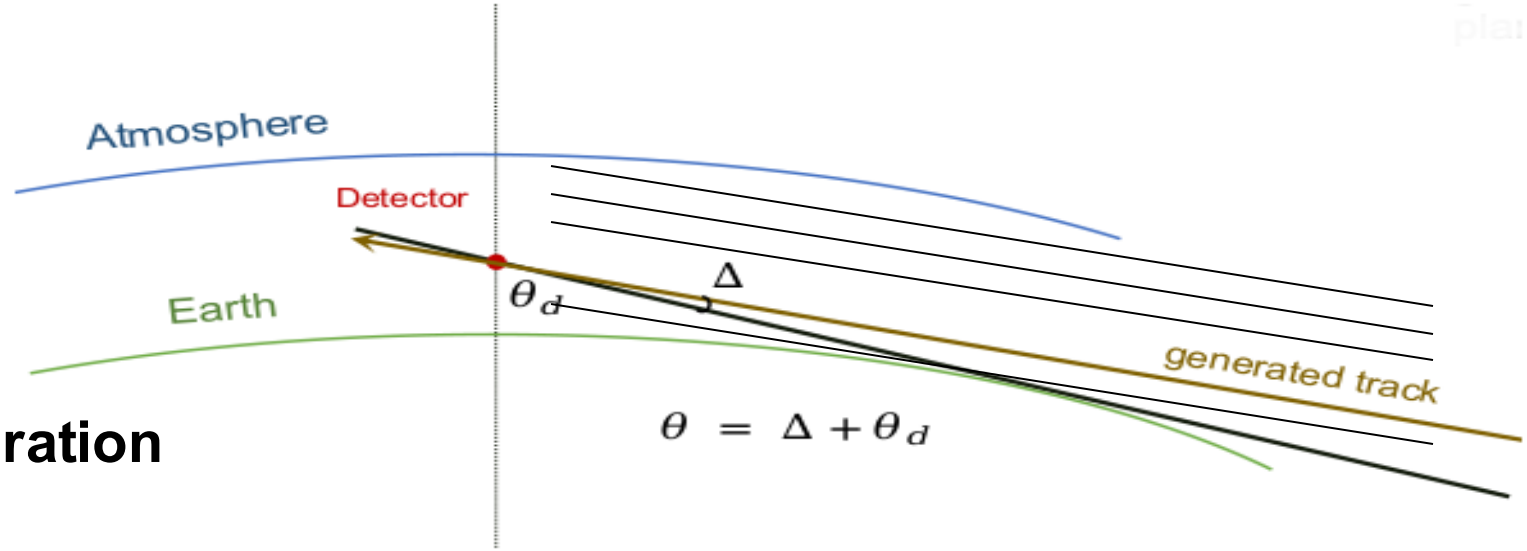
charged/electrons



Next productions in the pipeline

Extend statistics on previous test productions

- 90° zenith
- different impact parameters
- energy spectrum
- different primaries



Lower Altitude / Balloon configuration

- zenith downward-going very inclined (80°-90°)
- energy spectrum
- different primaries

JEM-EUSO Update from GSSI

R. Aloisio, A. Di Giovanni (Coord.), A. Roy, R. Torres, C. Trimarelli

The NUSES Mission

Italian led mission conceived as a **pathfinder** for **new observation methods and technologies** in the study of high and low energy radiations from space, enabling new sensors and tools.

60+ persons from many institutions.

Large **expertise** (and **synergies**) from space missions/R&D: AMS, DAMPE, Fermi, LIMADOU, GAPS, HERD, PAMELA, SPB, newASTROGAM, POEMMA, …

Italian Institutes:

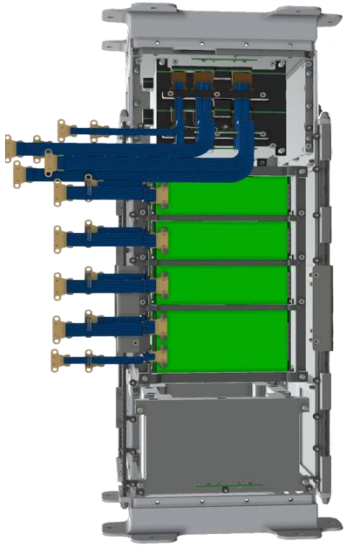
- Gran Sasso Science Institute
- Laboratori Nazionali del Gran Sasso
- University dell'Aquila
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari, INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce

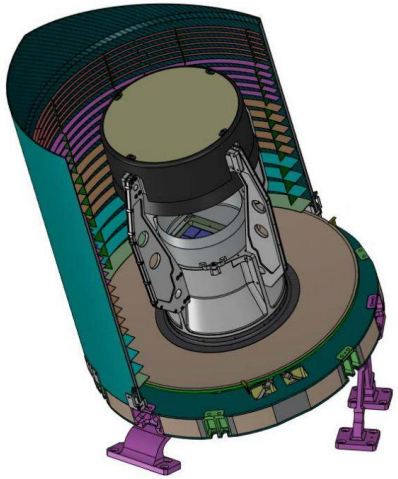
Other Institutes:

- University of Geneva
- Columbia University
- NASA Goddard Space Flight Center
- Pennsylvania State University

Two Payloads

Ziré and Terzina

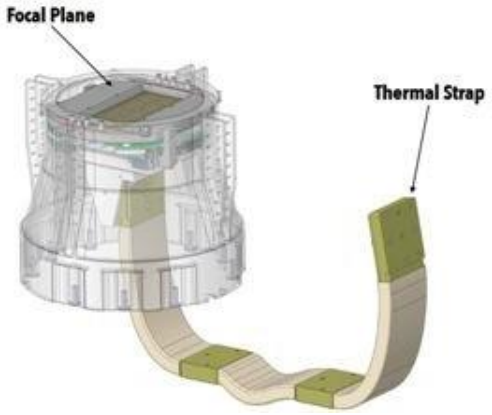


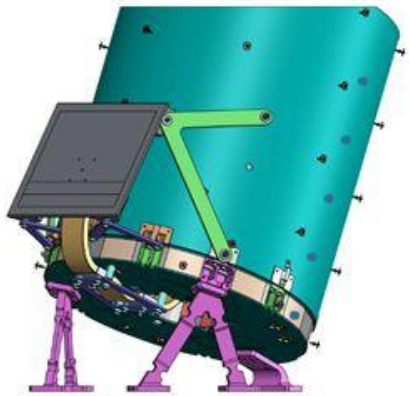


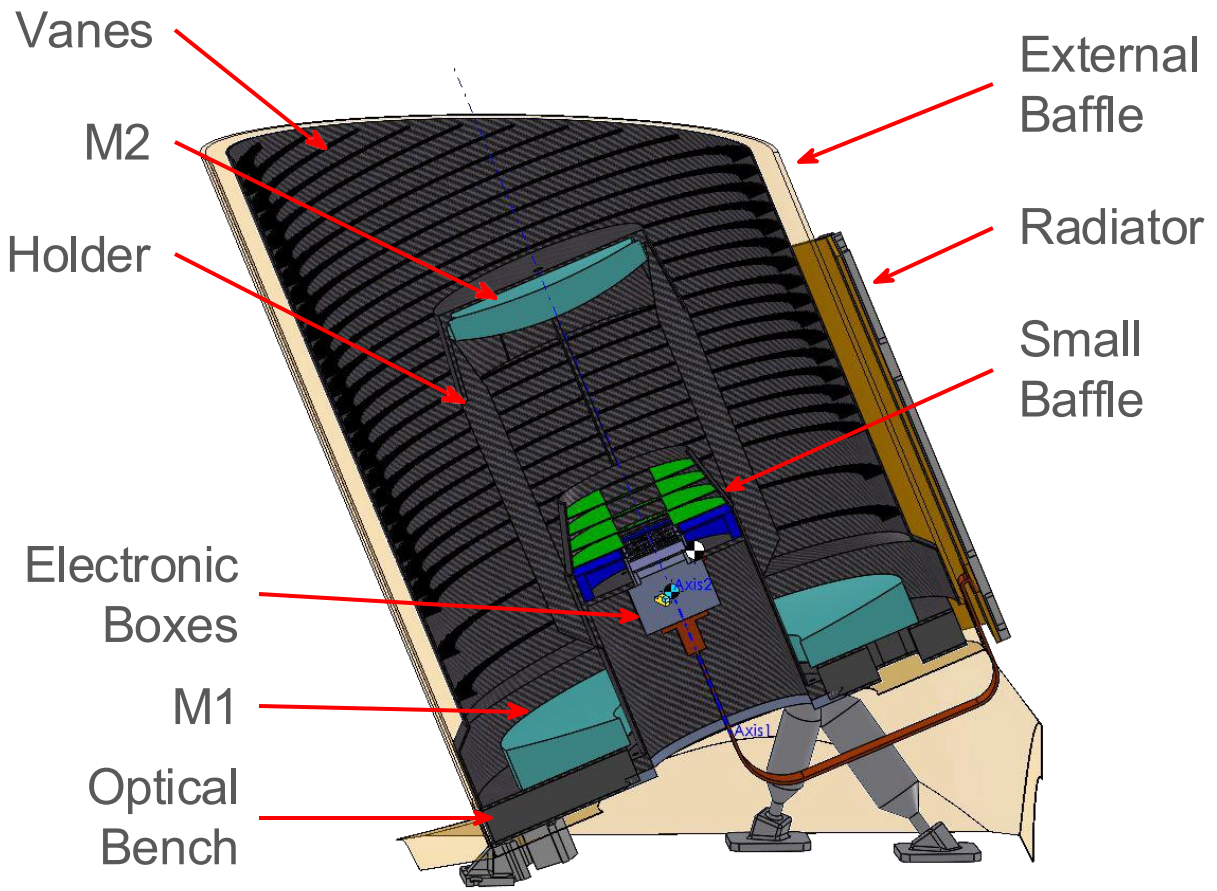
Terzina: **Overview** (see talk by R. Aloisio Friday 6 June)

A near-UV-optical telescope composed of:

1. the structural (mechanics) and thermal control (TC) assembly,
2. the optical head unit,
3. the focal plane assembly (FPA),
4. the front-end electronics (FEE) and data acquisition (DAQ) boards.







Terzina: **Software**

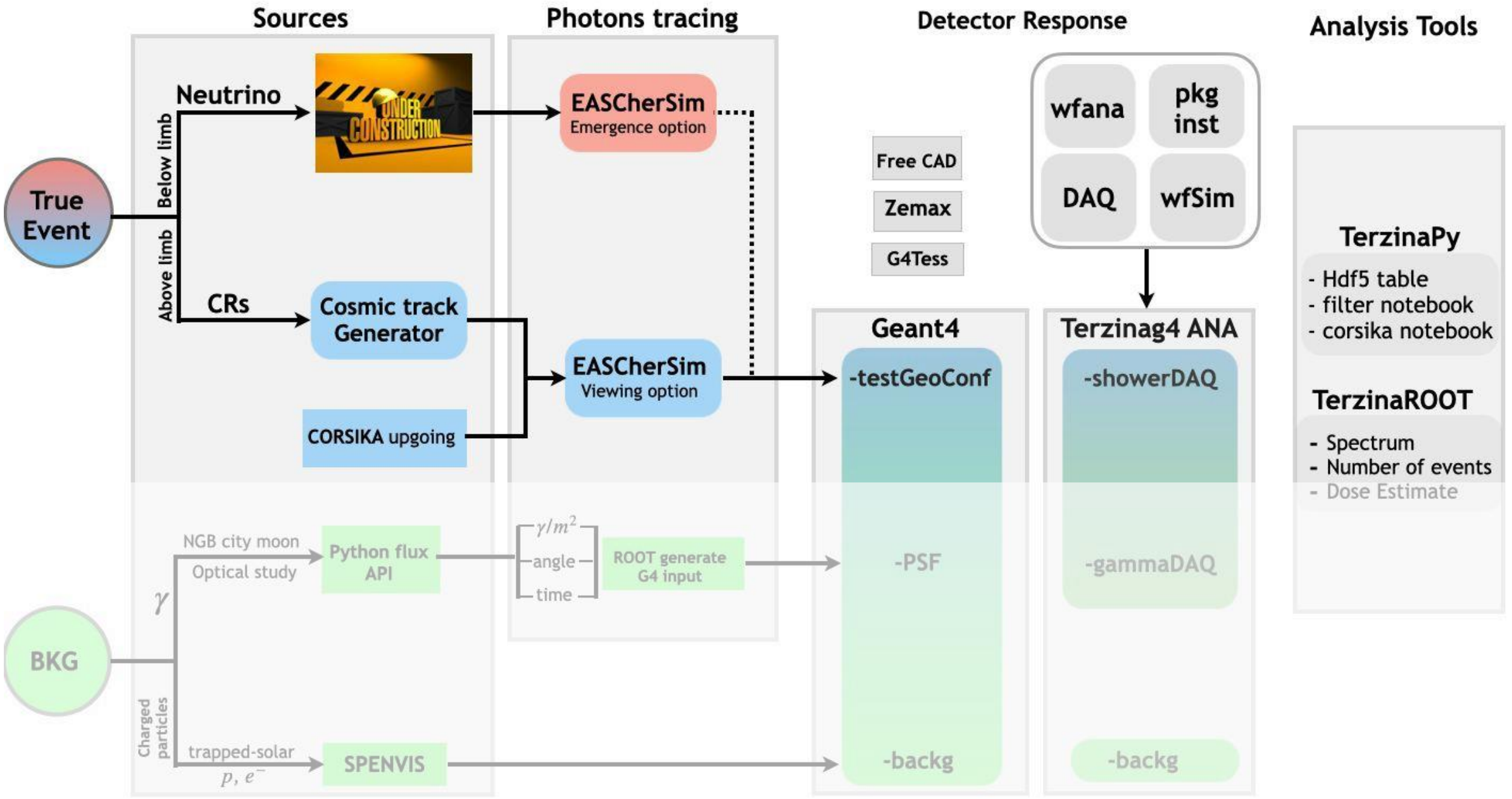
The simulation chain has been fully developed for both expected events and background in Terzina.

Specifically for “true events”, the simulation chain includes:

- A generator for the directions of the primary particles.
- The expected number of Cherenkov photons for the given trajectory, calculated using the EASCHerSim program.
- The optical and mechanical response of the detector, with a complete simulation of the detector geometry within Geant4.
- The expected response of the SiPMs and trigger module for a comprehensive estimation of the number of events and expected performance at both Beginning of Life (BoL) and End of Life (EoL).

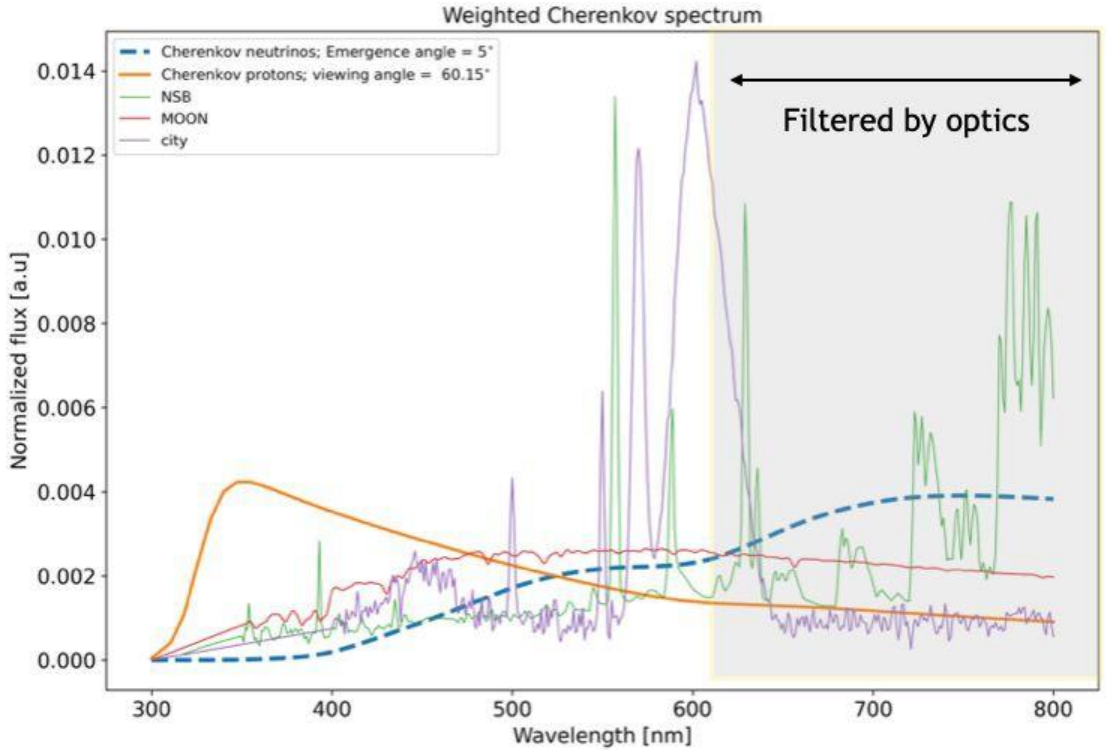
The listed simulation chain is fully operational for Cosmic Rays (above the limb events).
It is currently being updated for the neutrino component (below the limb events).

Terzina Simulation Chain



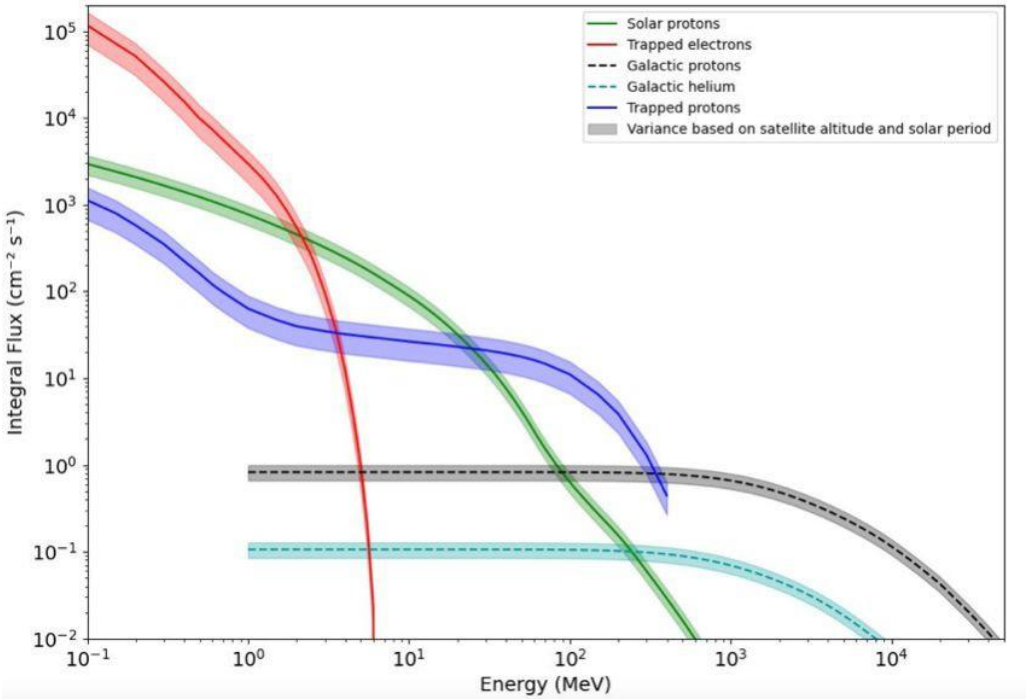
Terzina: **Software**

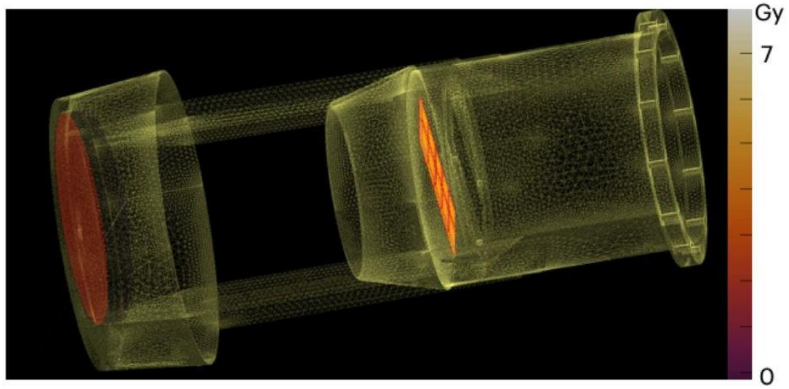
For the expected background, it is possible to simulate both the anticipated noise from NGB sources, such as city lights, the Moon, and auroras.



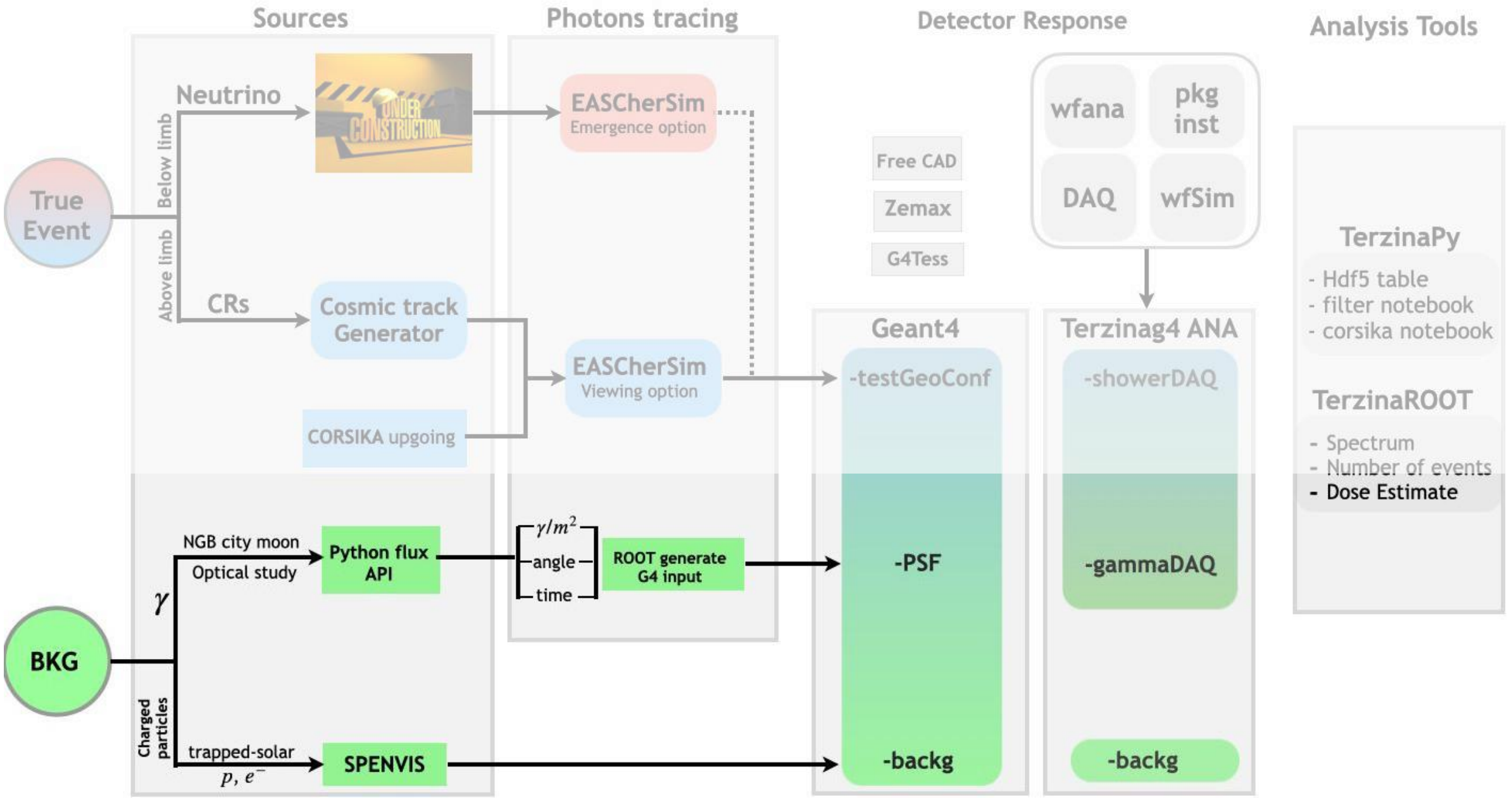
Terzina: **Software**

- Additionally, a precise estimation of the dose released in various volumes of the geometry was performed, assessing the radiation hardness of the sensors.
- This includes the effects of trapped, solar, and galactic particles, whose fluxes have been derived for the specific mission timeline and conditions (using SPENVIS).





Terzina Simulation Chain



TRIESTE (Coord. R. Munini)

Simulation of the PBR Cherenkov Camera

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riccardo.munini@ts.infn.it

SiPM response to incoming light:

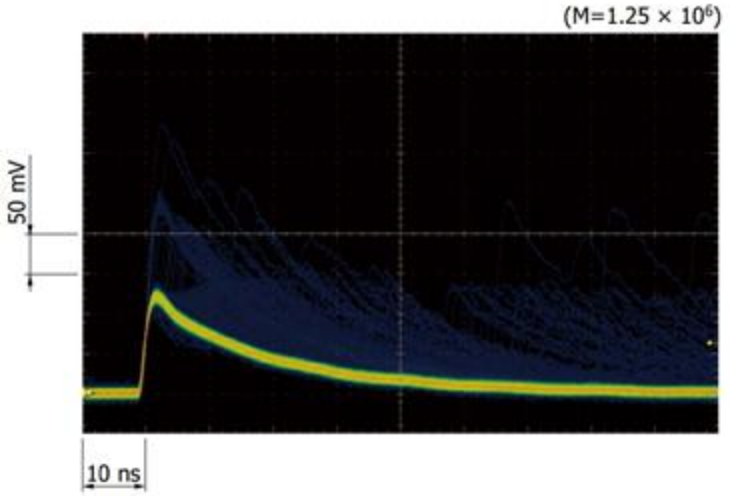
- Pedestal -> dark current + dark counts
- Incoming light releases PE in a SiPM pixel according to w.l.
- Each released PE cause avalanche breakdown in a microcell
  - 3584 microcells per pixel (64 pixels per matrix)
  - Digitized integral current from 1 breakdown ~= gain (ADC/PE)
- Each avalanche breakdown (regardless of source) can cause:
  - Crosstalk -> breakdown in adjacent microcell
  - Afterpulses -> additional breakdown in same cell
- Each microcell may have multiple avalanches -> More contribution than gain
- Integration time may complete before pulse current diminishes -> Less contribution than gain

Analysis of Finger Plots with Gaussian Mixture Expectation Maximization:

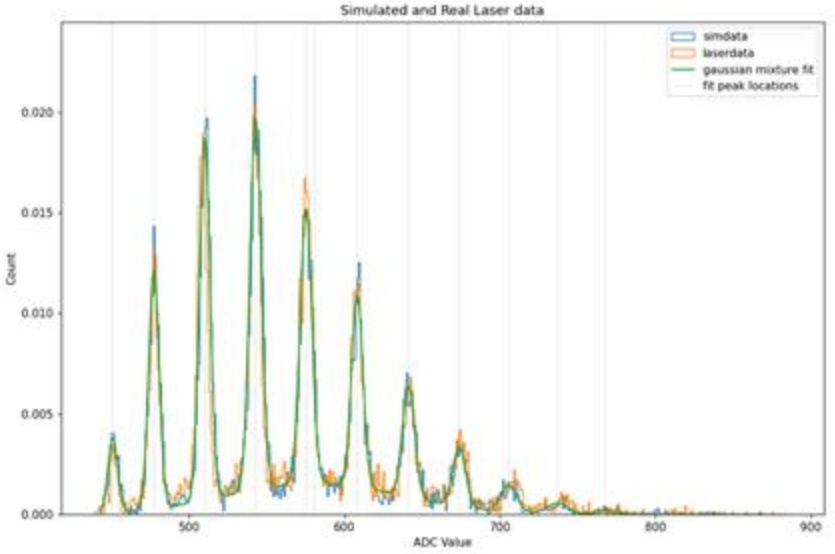
- Variance of ADC contribution vs #PE
- Relative contribution of incomplete pulses
- Validation of simulation data
- Standalone repo implemented in Python -> useful for others analyzing finger plots

Implementation in JEM EUSO Offline (2 Options):

1. Variance of ADC count recorded as function of #PE
   a. Noise treated to first order
   b. Faster for large numbers of PE
   c. Microcell saturation treated statistically
2. Each PE ADC contribution treated individually
   a. Spurious avalanches can also cause noise
   b. More true to life simulation of a complete SiPM pixel
   c. Fewer parameters for calibration / can calibrate just from pedestal data
   d. Correct ADC contribution variance arises naturally



Scope trace of SiPM Pedestal data showing crosstalk and afterpulses



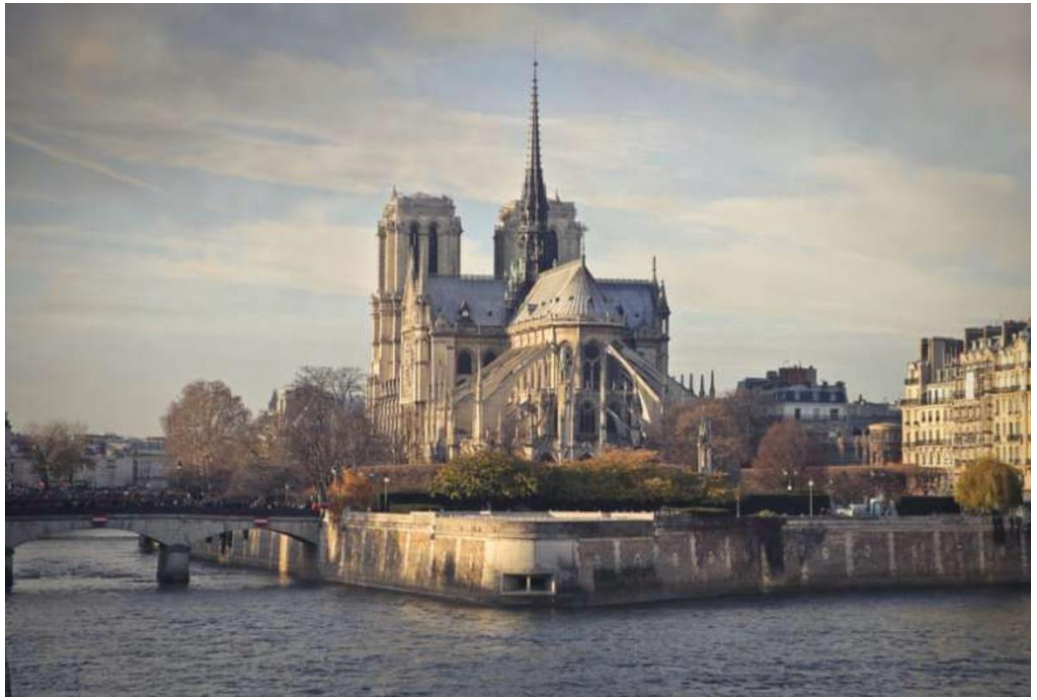
Comparison between real (from INFN Naples) and simulated SiPM data

RECENT NEWS ON ASI AGREEMENTS FOR SPB2 AND PBR

- Agreement ASI-INFN for SPB2:
  - non-onerous extension to May 2025
  - start of Addendum 3

- 14 May 2025: official closing of the agreement ASI – Univ. of Chicago for SPB2

- The text of the agreement between ASI and Univ. of Columbia for PBR is being defined, currently under the control of ASI's International Affairs Office.



Magnifique 1 !
(7 December 2024)

THANK YOU

Magnifique 2 !
(31 May 2025)

37th International JEM-EUSO

Collaboration Meeting, Paris APC 2-6 June 2025