The Fluorescence Camera of the POEMMA-Balloon with Radio (PBR): Design and Scientific goals

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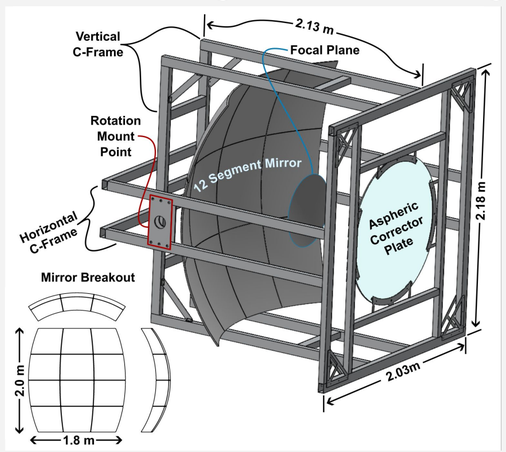
The POEMMA-Balloon with Radio (PBR) is a proposed payload to fly on a NASA Super Pressure Balloon. It will act as a pathfinder of the Probe Of Extreme Multi-Messenger Astrophysics (POEMMA). PBR will consist of an innovative hybrid focal surface featuring a Fluorescence Camera (FC, based on Multi-Anode Photomultiplier Tubes (MAPMTs), 1 μs time resolution) and a Cherenkov Camera (CC, based on SiPMs, 10 ns time resolution), both mounted on the same tiltable frame that can point from nadir up to 13° above the horizon. The FC's main scientific goal is to observe, for the first time, the fluorescence emission of Extensive Air Showers (EASs) produced by Ultra-High Energy Cosmic Rays from sub-orbital altitudes. This measurement will validate the detection strategy for future space-based missions, such as POEMMA. As a secondary goal, the FC will perform a search for macroscopic dark matter through slowly evolving showers that will leave a signal similar to (but distinct from) a meteor. The PBR FC design is based on the technology developed over the last decade within the JEM-EUSO collaboration. PBR targets a launch in 2027 as a payload of an ultra-long duration balloon flight with a duration of up to 100 days.

Fluorescence Camera (FC)

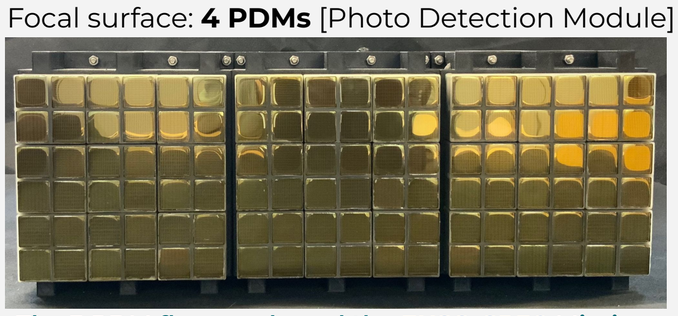
Based upon the EUSO-SPB2 Fluorescence Telescope

- **Schmidt optics** (common to the CC)
  - Entrance pupil of 1.1 m diameter
  - 12 mirror segments in 3×4 configuration



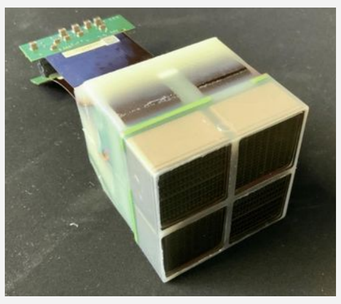
Design of the tiltable frame that host the optic system and the FC and CC focal planes.

- Focal surface: **4 PDMs** [Photo Detection Module]



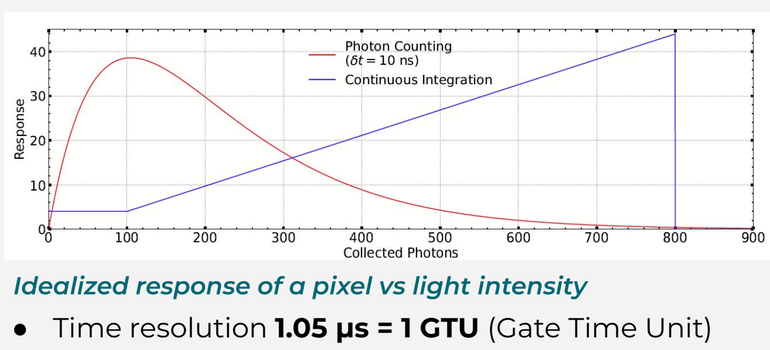
The 3 PDM flown onboard the EUSO-SPB2 Mission

  - PDM (Multi-Anode PMTs) → **2304 pixels**
  - Based upon stand-alone elements called Elementary Cells (**ECs**) integrating the following elements:
    - **4 MAPMTs** (Hamamatsu R11265, 4×64 pixels)
    - **High Voltage** provider, based on CW circuit delivering **up to 1100 V**
    - **4 SPACIROC-3 ASICs** mounted on 2 ASIC boards



A packaged Elementary Cell (EC). All the electronic components are hosted in the shadow of the 4 MAPMTs.

- Peak Sensitivity ~**300-400 nm (BG3 filter)**
- **Single photon counting** (primary mode)
  - Secondary mode with charge integration (**KI**)



Idealized response of a pixel vs light intensity

- Time resolution **1.05 μs = 1 GTU** (Gate Time Unit)
  - double pulse resolution ~5-10 ns
- **FoV: 24°×24°. Pixel size on ground: 115 m**

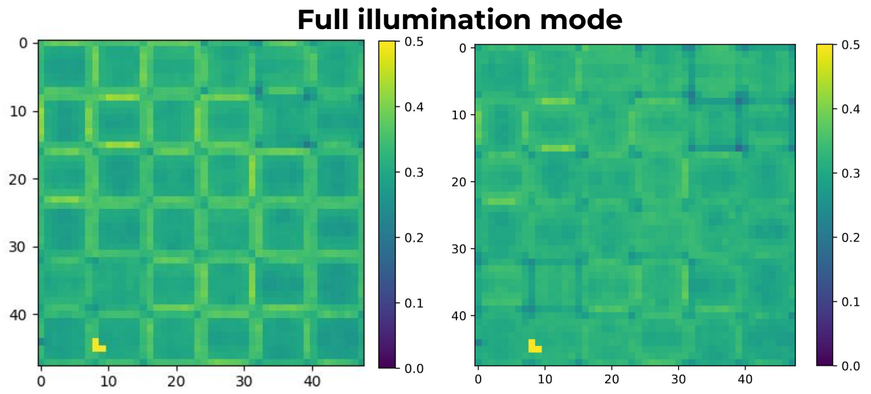
Calibration

Calibration at MAPMT, EC and PDM level. For each pixels it is measured:

- Efficiency
- Gain
- Physical size
- Uniformity
- Wavelength dependence
- High-Voltage dependence
- Doble pulse resolution
- Crosstalk (negligible)

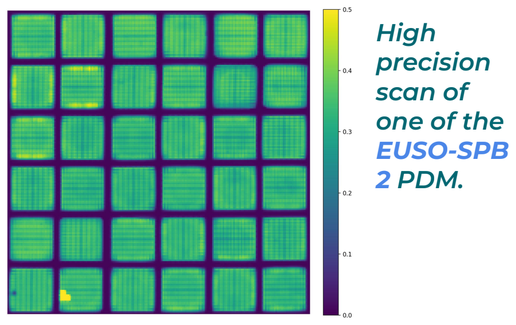
Two main mode of operation:

Full illumination mode

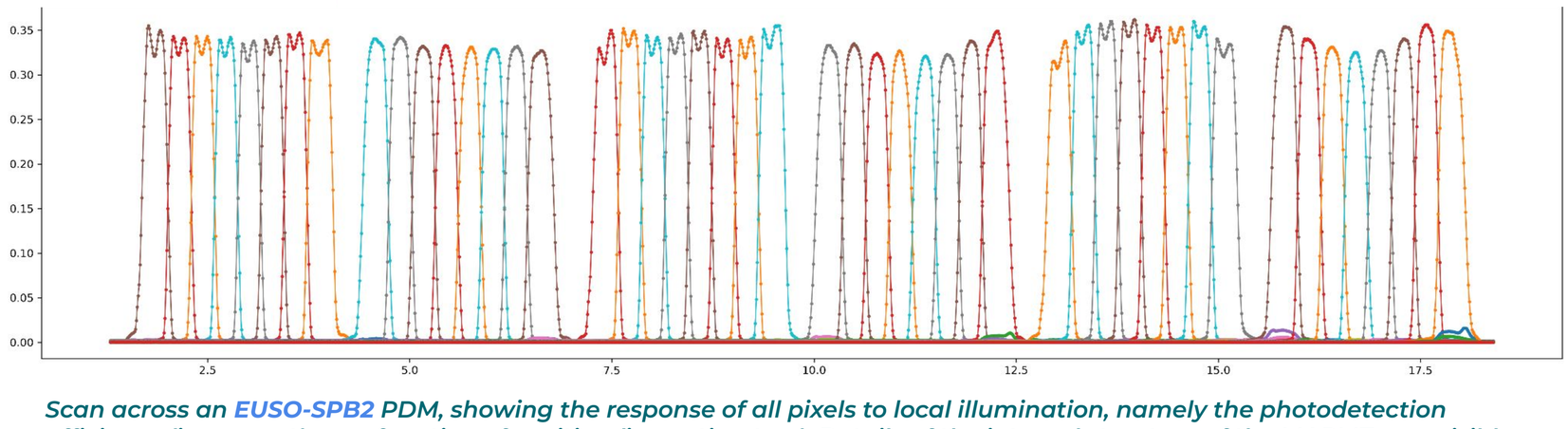


Left: (Apparent) Efficiency map of an EUSO-SPB 2 PDM. Right: Efficiency rescaled for the pixel size.

Scan mode



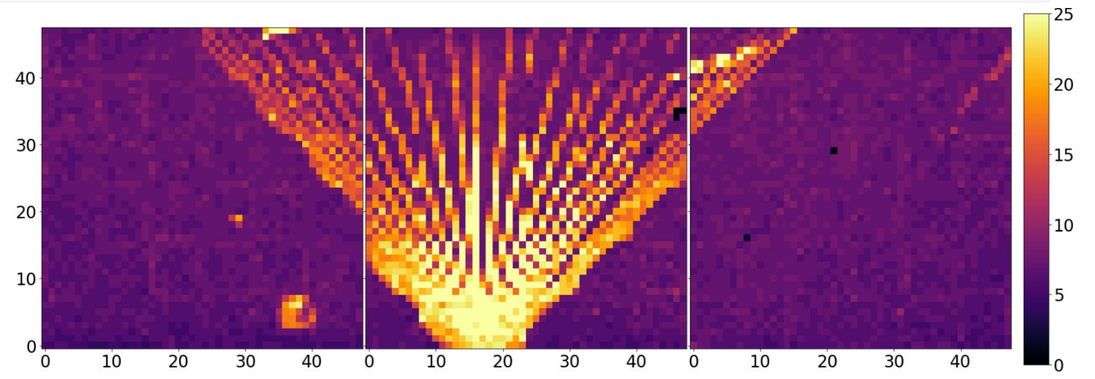
High precision scan of one of the EUSO-SPB 2 PDM.



Scan across an EUSO-SPB2 PDM, showing the response of all pixels to local illumination, namely the photodetection efficiency (in percent), as a function of position (in centimeters). Details of the internal structure of the MAPMTs are visible

Field test

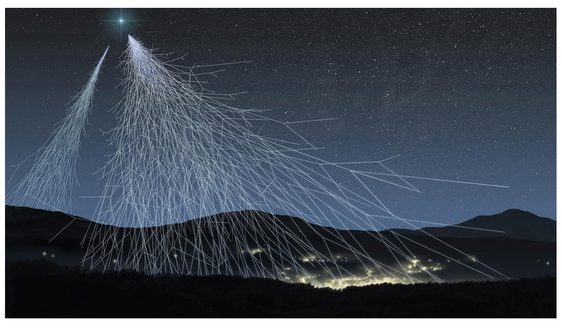
- Scheduled for **Summer 2026** at Black Rock Mesa site (Utah, USA) next to Telescope Array, **together with the CC**.
- Last test before shipping to New Zealand, **2 months** long
  - Functioning and stability
  - Trigger efficiency
  - End-to-end efficiency
  - UHECR observation from ground



Example of a series laser shot fired at different azimuth angle, detected during the field campaign of EUSO-SPB2 in 2022. The laser was fired from 28 km away, pointing at 45° zenith angle. The bright spot is due to a lamp in the field of view of the instrument

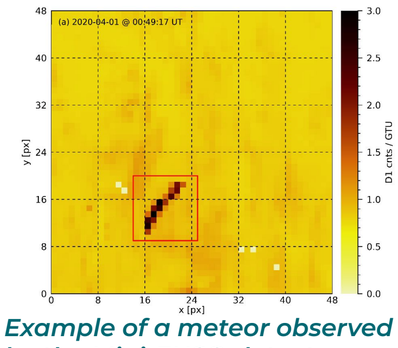
Expected results in UHECR detection

- **EUSO-SPB2** expected performance:
  - 0.12 events/live hour (~1 event every 2 nights)
  - 10% of the events reconstructable (geometry, energy, Xmax)
  - Energy threshold at ~2×10^{18}eV
- **PBR FC**:
  - increase in FoV (25%, 4 PDMs instead of 3)
  - increase in light collection (16%, larger entrance pupil) → lower energy threshold
- Overall increase of 50% in the number of expected events
- Titling possibility: increase energy threshold and exposure



Artistic view of Extensive Air Showers initiated by two UHECRs.

Search for Macroscopic dark matter

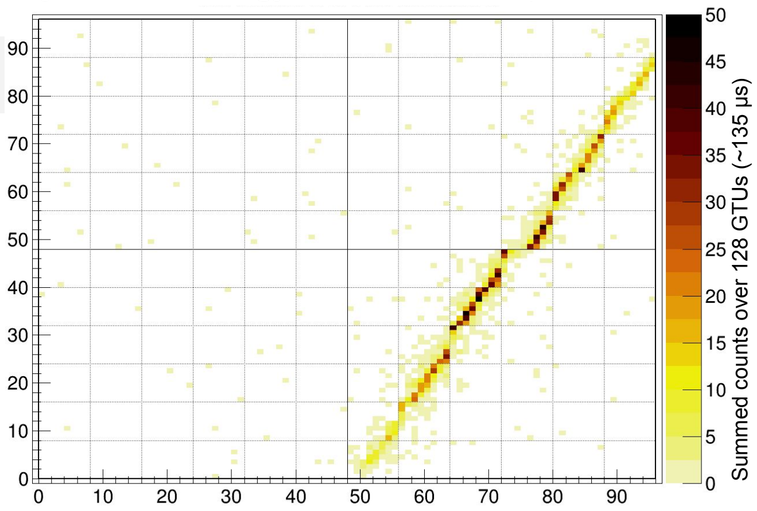


Example of a meteor observed by the Mini-EUSO detector looking nadir from the ISS

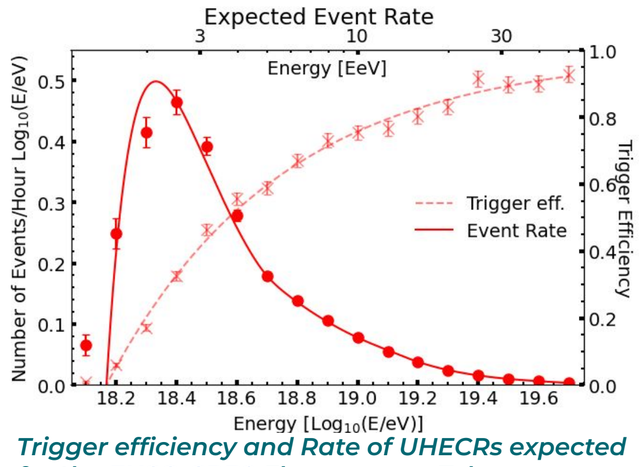
namely **nuclearites**, **strange quark nuggets**, **primordial black holes**, … (high mass and low density in the universe)

- Move at speeds well below the speed of light
- Deposit significant amounts of energy in the atmosphere as they traverse it
- Leave a signal similar to meteors, but
  - different speed
  - develop at different altitude

PBR will set limits on slow-moving objects like macrospopic dark matter candidates



Simulation of a $2x10^{19}$ UHECR observed by PBR FC. The color scale represents the sum of the counts



Trigger efficiency and Rate of UHECRs expected for the EUSO-SPB2 Fluorescence Telescope as a function of energy, based on simulation results