The photo-detector for the EUSO experiment

Alessandro Petrolini
on behalf of the EUSO Collaboration

The EUSO experiment
The EUSO Photo-Detector
The *EUSO* objective and observational approach

**Objective**

Observation of Extreme High Energy Cosmic Rays (EHECR): $E \gtrsim 3 \cdot 10^{19}$ eV.

**Experimental approach**

- Observation, from a space-based experiment, of the Extensive Air Showers, (EAS) produced by the interaction of the primary EHECR with the atmosphere, by looking down to nadir from the ISS (*AirWatch* concept).
- An EAS can be detected by observing the atmospheric scintillation light, isotropically produced during the EAS development.
- The observation of the forward beamed Cherenkov light diffusely reflected at the Earth surface can help the EAS reconstruction.
The observational technique: key points

- Large distance and large FoV $\Rightarrow$ Large geometrical aperture.
- The scintillation light is isotropic and proportional, at any point, to the number of charged particles in the EAS: record the EAS development.
- Observation of EAS from primary particles interacting deeply in the atmosphere (EAS development).
- All sky coverage is possible.
- Approach complementary to the observation from the Earth surface: different energy range (partially overlapping), different systematic effects.

The EUSO approach
The *EUSO* project (ESA) phase A: the feasibility study

The design of an *EUSO*-like Instrument is a challenge. No *R\&D* was allowed by ESA for the AO after which *EUSO* was pre-selected.

- Collaboration: Europe (Italy, France, Portugal and ...), US and Japan.
- ESA phase A just started (payload).
- Instrument phase A: many nationally funded activities support the Instrument phase A studies (Agencies and Institutes).
- Non trivial technical problems have to be faced.
- A baseline conceptual design has been done (to be completed and refined).
- During phase A (from March 2002 to March 2003) a detailed conceptual Instrument design will be carried on, mainly focusing on critical points.
Signal production: air scintillation

The air scintillation spectrum

Air scintillation yield versus height
Signal transport: atmospheric transmission

Transmission versus starting point

Transmission versus wavelength
The signal to *EUSO*

Average number of photons reaching *EUSO* per $\mu$s *(red curves)*: proton with $E = 10^{20}$ eV, $\theta_z = 50^\circ$, US standard atmosphere, LOWTRAN7 atmospheric transmission code.

---

Photon arrival times (on sea, clear atmosphere)

Photon arrival times (thick cloud at 2 km height)
The background: night-glow, ...

- The characteristics of the EAS, including the kinematic ones, allow one to distinguish an EAS from the various backgrounds, because those have a typically different space-time development.
The Earth from Space at night
Accommodation of *EUSO* on the Columbus ESA module

The accommodation must be compatible with the ISS/Columbus resources: mass ($\lesssim 1.5$ ton), volume ($\lesssim 2.5 \times 2.5 \times 4.5$ m$^3$), power ($\lesssim 1$ kW) and telemetry.
The main optics: requirements

Main requirements for the optics

- **Large aperture**: $\approx 2 \text{ m}$ diameter (large photon collection area);
- **large FoV**: $\pm 30^\circ$ (large mass of atmosphere observed);
- **angular resolution**: $\Delta \alpha \approx 0.1^\circ$;
- **good transparency** in the wavelength range: $330 \text{ nm} < \lambda < 400 \text{ nm}$;
- **suitable for space operation**:
  (e.g. low mass, rad-hard, stable and reliable operation, ...).
The main optics: baseline design

The optics baseline design

- Two double-sided Fresnel lens system made of light-weight polymers;
- filter: absorption or interference;
- preliminary optics design is done (spot size ≈ 3 mm ÷ 6 mm);
- engineering design is in progress (lenses supported by a light-weight structure).
The photo-detector: main requirements

- **Single photon sensitivity** in the $330\,\text{nm} \div 400\,\text{nm}$ wavelength range (good efficiency): expect $\approx 20$ detected photons per pixel in a few $\mu\text{s}$ at the maximum of a $E = 10^{20}\,\text{eV}$ proton induced EAS.

- **Fast response** (below $\approx 0.1\,\mu\text{s}$) to follow the EAS space-time development.

- **A moderate space resolution** (of the order of a few $\text{mm}$) is required.

- **Low noise and good signal to noise ratio** to detect the faint signal produced by the less energetic EAS and to discriminate it from the background.

- **Large area** (a few square meters), due to the large aperture and FoV.

- **A large number of channels** is required (hundreds of thousands).

- **Compatibility with the requirements** imposed by a **Space mission** including: low mass and power consumption, mechanical robustness and compactness, environmental factors resistance, ......

- **Ready to use** devices are required (Space missions development is long ...
The photo-detector: sensors

- Requirements $\implies$ multi-anode PMT (well-established technology).
- **R7600 multi-anode PMT (64 pixels) from Hamamatsu** (already used by AMS). Weakness: low geometrical acceptance $\implies$ light collector system.
- Possible improvement of the geometrical acceptance: weakly focused version. It is under test to evaluate its suitability. Weakness: small number of pixels.

R5900 series MAPMT

The weakly-focused R8900 MAPMT
Light Collector Systems for the MAPMT

Different types are possible (trade-off is on-going): lenses-based and tapered light pipes (normal or total internal reflection).
Sensors characterization: magnetic field

ISS orbit (top), Vertical component of the Earth magnetic field (bottom).

Fraction of pixels showing a relative gain change smaller than 0.1:
R5900M64 (top), R8900M16 (bottom).
Elementary-cell (2 × 2 MAPMTs): functional design
The photo-detector architecture: the elementary cell

The PD elementary-cell (front)

The PD elementary-cell prototype (back-side)
The photo-detector architecture: layout and supporting structure

Type 1 proposal

Edge interface with EUSO «cylinder»

Lens
The photo-detector support

**Static and dynamical analysis** of the supporting structure (typical loads).

**Loads on Z axis:**
Von Mises maximum stress:
\[ \sigma_{\text{vm}} = 22 \text{ Mpa} \]
Maximum deflection (in the centre):
\[ d = 0.48 \text{ mm} \]

**Loads on X axis:**
Von Mises maximum stress:
\[ \sigma_{\text{vm}} = 14 \text{ Mpa} \]
Maximum deflection:
\[ d = 0.17 \text{ mm} \]

**First modes of vibration:**
Mode 1 = 121 Hz
Mode 2 = 139 Hz
Mode 3 = 144 Hz
Mode 4 = 185 Hz

**Shape of the first two modes:**
The front-end, trigger and data-handling electronics

Front-end, trigger and data-handling electronics

- Large number of channels \((\text{up to } \approx 4 \cdot 10^5)\) and resource limitations.
- An efficient and selective trigger is required.
- Modular architecture: independent macro-cells plus a central trigger unit.
The auxiliary atmospheric sounding Instrumentation

- An auxiliary telescope for atmospheric sounding is under study.
- It has a significant impact on the resource requirements to Columbus/ISS.
- A detailed study will be carried out during phase A.
## The *EUSO* Instrument: main baseline parameters

<table>
<thead>
<tr>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desired pixel size at the Earth surface</td>
</tr>
<tr>
<td>ISS average orbit height</td>
</tr>
<tr>
<td>Observation duty cycle</td>
</tr>
<tr>
<td>Orbital period</td>
</tr>
<tr>
<td>Operational lifetime</td>
</tr>
<tr>
<td>Geometrical aperture</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optics maximum diameter</td>
</tr>
<tr>
<td>Optics aperture (entrance pupil diameter)</td>
</tr>
<tr>
<td>Optics $f#$</td>
</tr>
<tr>
<td>Optics field of view (half-angle)</td>
</tr>
<tr>
<td>Optics spot size diameter on the FS</td>
</tr>
<tr>
<td>Average transmission of the optics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Photon detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisional geometry of the FS</td>
</tr>
<tr>
<td>Overall photo-detector detection efficiency</td>
</tr>
<tr>
<td>Pixel dimensions</td>
</tr>
<tr>
<td>Number of channels</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall atmospheric transmission ($330$ nm $\leq \lambda \leq 400$ nm)</td>
</tr>
<tr>
<td>Background ($330$ nm $\leq \lambda \leq 400$ nm at $\approx 400$ km height)</td>
</tr>
</tbody>
</table>
EUSO preliminary simulated performance: trigger efficiency

- Preliminary simulations: trigger efficiency as a function of the EHECR energy.
How to get there ...