An end-to-end in-flight calibration of Mini-EUSO detector

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Abstract

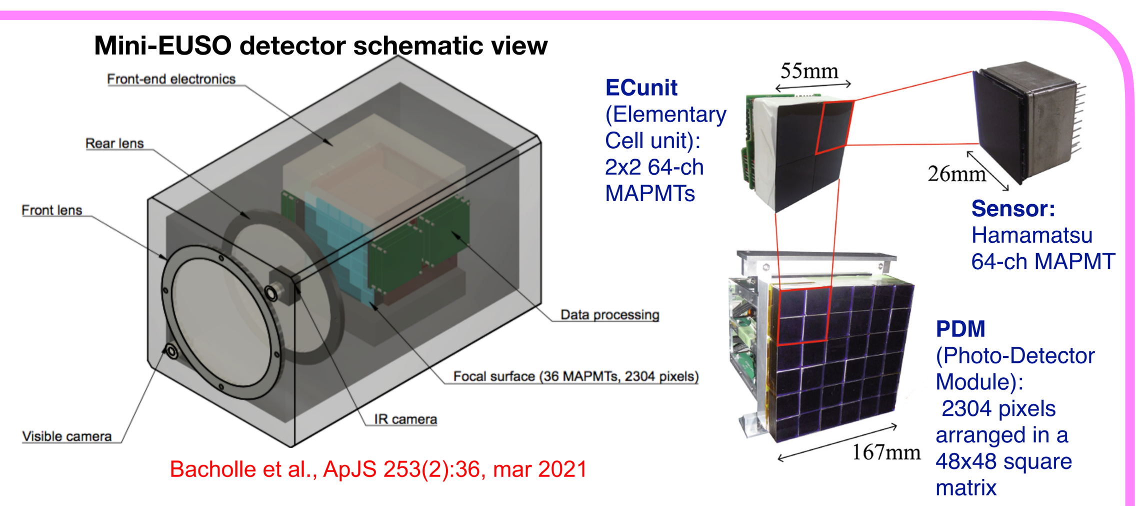
Mini-EUSO is a wide Field-of-View (FoV, ±22 deg) telescope currently in operation from a nadir-facing UV-transparent window in the Russian Zvezda module on the International Space Station (ISS). It is the first detector of the JEM-EUSO program deployed on the ISS. Mini-EUSO is mostly sensitive in the 290 - 430 nm bandwidth. Light is focused by a system of two Fresnel lenses of 25 cm diameter each on an array of 36 Multi-Anode Photomultipliers Tubes (MAPMTs) for a total of 2304 pixels working in photon counting mode, in three different time resolutions of 2.5 µs, 320 µs and 40.96 ms at the same time. In the longest time scale, the data is continuously acquired without a trigger system, and allows a continuous monitoring of the UV emission of the Earth, which is best suited for the observation of atmospheric and ground sources. For this reason, it has been used to observe the signal produced by two UV flasher systems assembled on ground and fired in two different observational campaigns in order to perform an end-to-end calibration of Mini-EUSO.

In this contribution, the assembling of the UV ground flasher, the operation of the field campaign and the analysis of the obtained data is presented. The result is compared with the overall efficiency computed from the expectations which take into account the atmospheric absorption and the parametrisation of different effects such as the optics efficiency, the MAPMT detection efficiency, BG3 filter transmittance and the transparency of the ISS window.

Mini-EUSO

- Compact detector (37 × 37 × 62 cm^3)
- 48x48 pixels, single photon counting
- UV wavelength (300-400 nm)
- Optical system: two Fresnel lenses, 25 cm diameter
- Large FOV (±21°). Pixel size at sea level ~6.3km
- **Three different timescales**:
  - D1: 2.5 µs - EECRs and fast events (elves) - dedicated trigger logic (L1 trigger)
  - D2: 320 µs - atmospheric events - dedicated trigger logic (L2 trigger)
  - **D3: 40.96 ms** - slow events and UV maps - continuous data taking
- Ancillary cameras

Mini-EUSO detector schematic view



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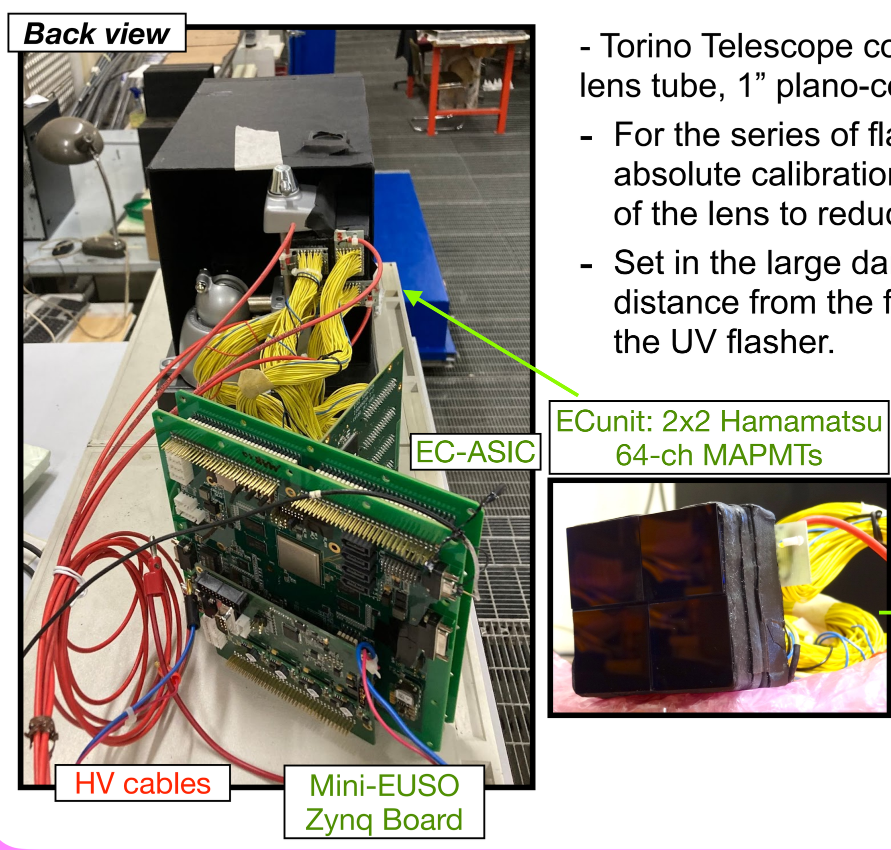
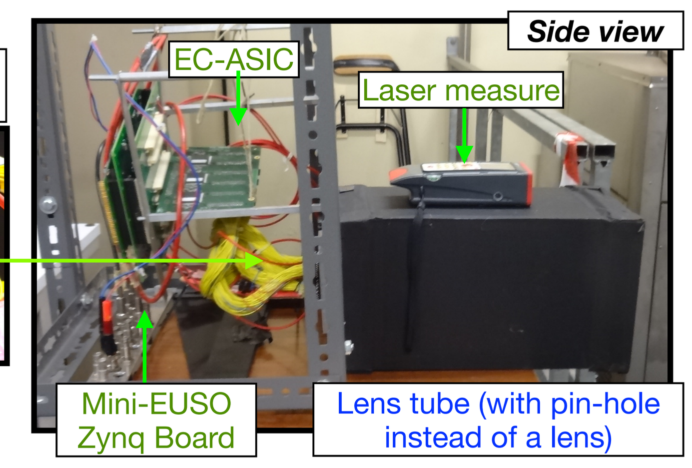
Mini-EUSO onboard the ISS

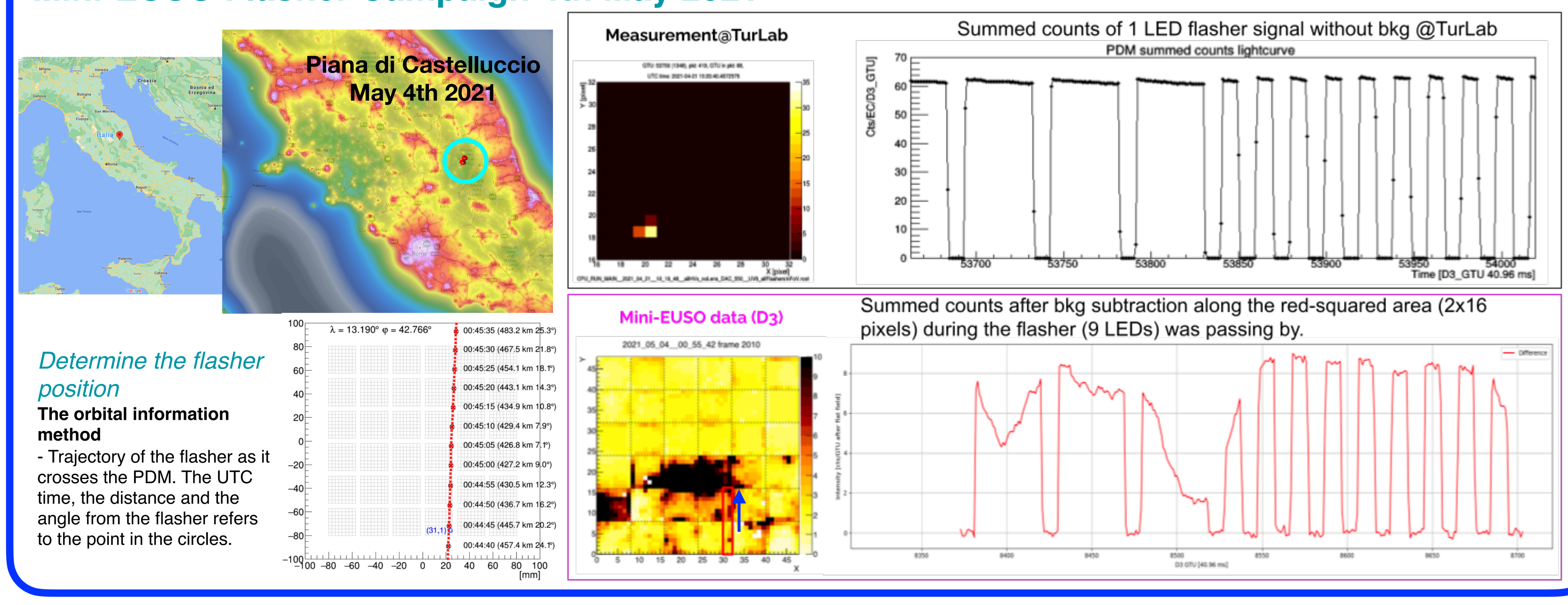
Torino telescope: ECunit and Mini-EUSO front-end electronics



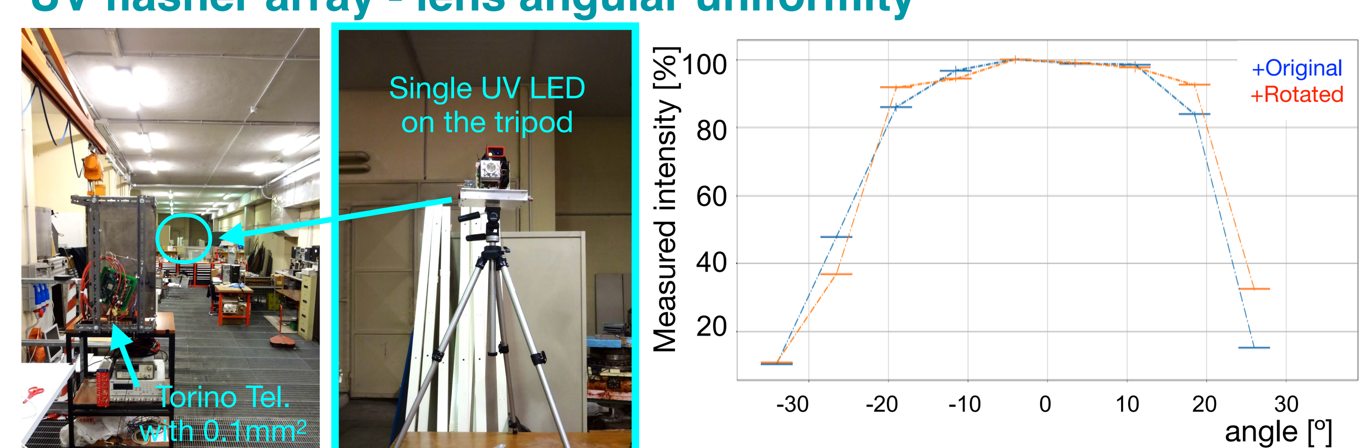
- Torino Telescope consists of an ECunit, EC-ASIC, Zynq Board, lens tube, 1" plano-convex lens, LVPS, HVPS and CPU (PC).
- For the series of flasher measurements for Mini-EUSO absolute calibration, 0.1 mm sized pin-holes are used instead of the lens to reduce the light.
- Set in the large dark room at TurLab facility@-4F at ~40 m distance from the flasher LEDs to estimate the light intensity of the UV flasher.



Mini-EUSO Flasher Campaign 4th May 2021

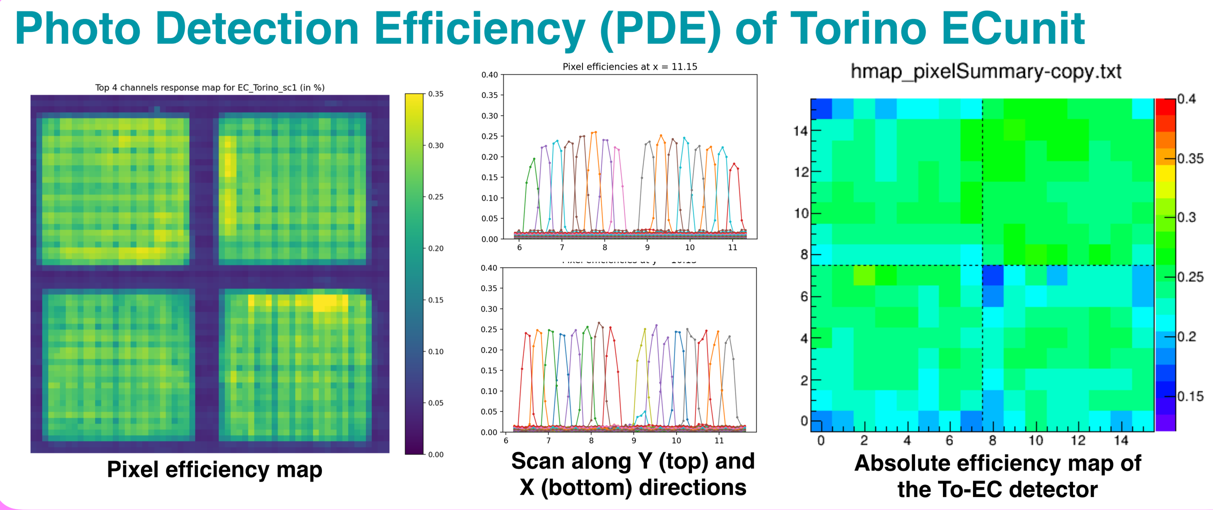


UV flasher array - lens angular uniformity



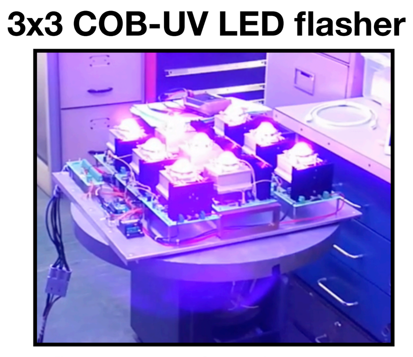
- Single UV LED positioned 40 m away from the detector
- LED pointed at a specific angle
- Output compared with the "on-axis" value

Photo Detection Efficiency (PDE) of Torino ECunit

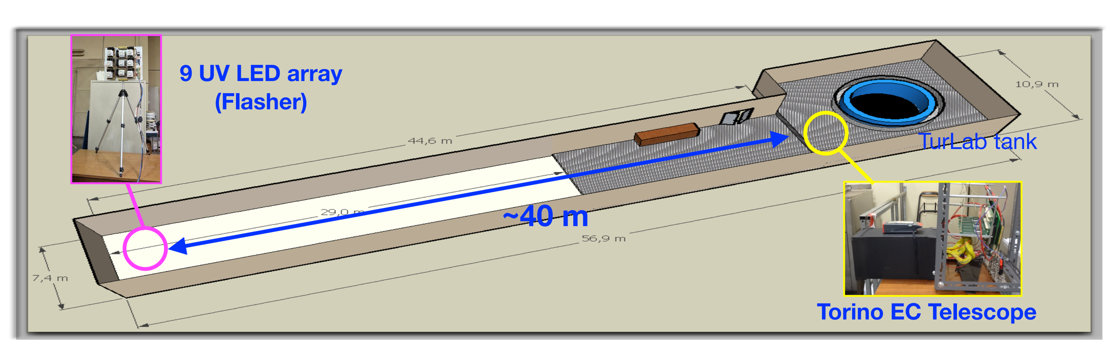


Flasher measurements in the large dark room@-4F (TurLab facility)

3x3 COB-UV LED flasher



- Commercial High-Power 100W UV LED
- 395~400 nm



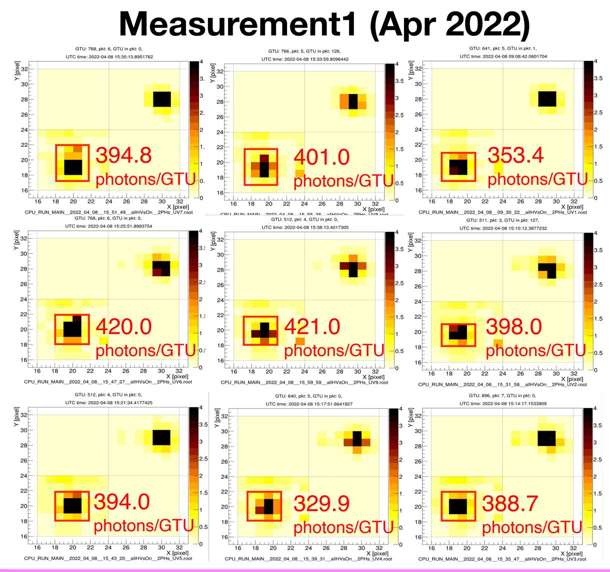
The TurLab facility is a laboratory at the Physics Department of the Torino University. It hosts a 5 m diameter rotating tank in a room more than 40 m long, that can be used as a large black box.

Two different types of 0.1 mm pin-holes: high-precision (indicated by red squares) and hand-manufactured as a reference (another light spot in each frame below)

Measurement repeated at different times.

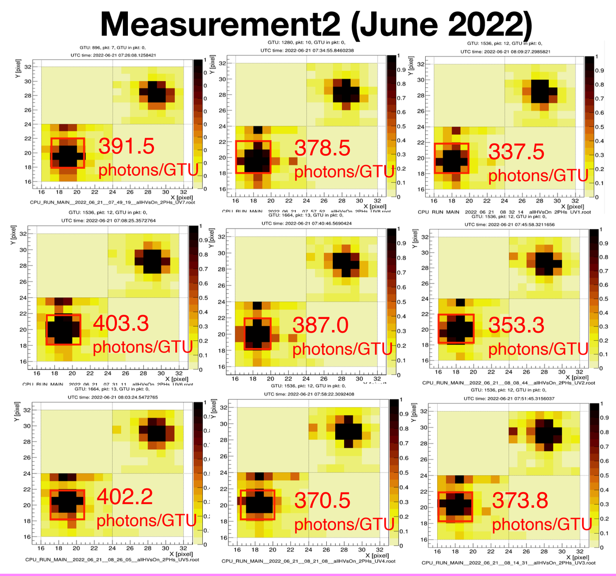
1. Pile-up correction (pixel by pixel)
2. Apply absolute calibration [measured at APC with an LED of 395 nm, while flasher between 395-400 nm, correction factor of 2%]
3. Sum all the pixels with dominant signal (red or blue box)
4. For each lightcurve, find the peaks and compute the average of the peaks

Measurement1 (Apr 2022)



High Precision PinHole
Total: **3564 photons/GTU**
Error: 9 x (Max-Min)/2
= 304 photons/GTU
[8.5%]

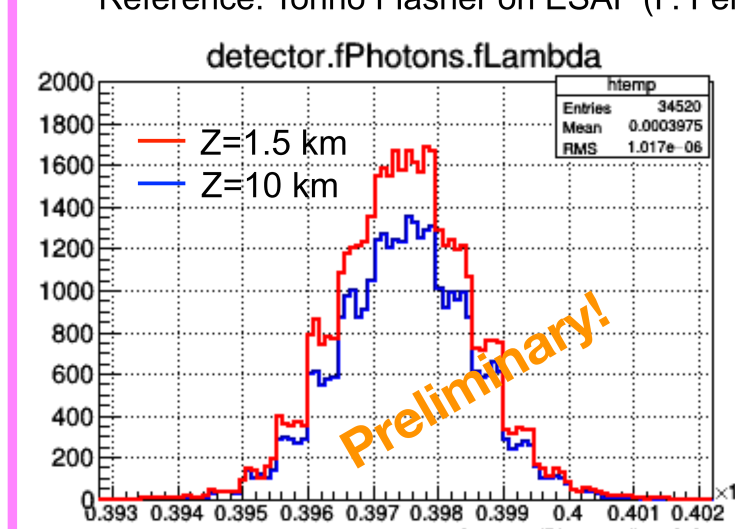
Measurement2 (June 2022)



High Precision PinHole
Total **3400 photons/GTU**
Error: 9 x (Max-Min)/2
= 296 photons/GTU
[8.7%]

Absorption by atmosphere

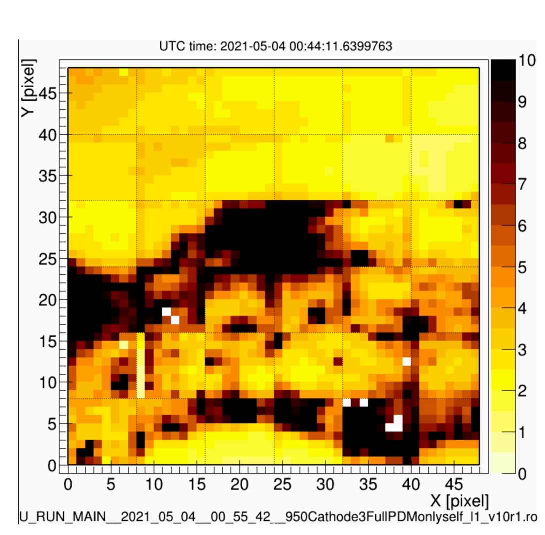
Reference: Torino Flasher on ESAF (F. Fenu, H. Miyamoto)



- UV Flasher simulated by ESAF
- Setting Flasher altitude at 1.5 km (actual altitude for the flasher campaign) and 10 km where no absorption by the atmosphere (mainly ozone) expected
- Comparison between each results of remaining photons on the pupil indicates that the overall absorption by atmosphere is ~0.78 (preliminary)

Mini-EUSO Overall Efficiency

Searching for the pixels where flasher is flashing in the center in the following methods:
- method1: search for a pixel with flasher signal and surrounding 3 pixels have the same counts -> **pixel [31,5]**
- method2: Estimate geographical position by orbital information and the UTC time, distance and the angle from the flasher -> **pixel [31,13]**



$$\mathbf{Eff_{ME} = Nph_{det}/Nph_{window}}$$

$Nph_{det}[31,5] = 9.7$ cts/GTU

$Nph_{det}[31,13] = 8.3$ cts/GTU

$$\mathbf{Nph_{window} = Nph_{TurLab} \times Eff_{IncidentAngle} \times Abs_{Atm} \times Area_{ME}/Area_{ToEC} \times (Dist_{ToEC}/Dist_{ME})^2 \times \cos(\theta)}$$

$Eff_{incidentAngle}[31,5] = 0.9$

$Eff_{incidentAngle}[31,13] = 0.95$

$Abs_{atm} = 0.78$ (ESAF simulation)

$Area_{ME}/Area_{ToEC} = 6.25\times10^6$

$(Dist_{ToEC}/Dist_{ME})^2 = 9.26\times10^{-9}\cos^2(\theta)$

$\cos(\theta)[31,5] = 0.85$

$\cos(\theta)[31,13] = 0.93$

$Eff_{ME} = Nph_{det}/Nph_{window} = 9.7/120.4 = (8.0\pm1.5)\%$

$Eff_{ME} = Nph_{det}/Nph_{window} = 8.3/139.3 = (6.0\pm1.1)\%$

Estimated efficiency. The total error (19%) comes from the quadratic sum of the errors listed in the table below

	Photoelectrons	Photons@TurLab	PDE	$Angular_{lens}$	Abs_{atm}	Angle ($\cos^3(\theta)$)
Value	9.7 - 8.3	3482	/	0.9 - 0.95	0.74	18.6 - 12.3
Error	10%	6%	10%	5%	10%	2%

Comparison with the theoretical value

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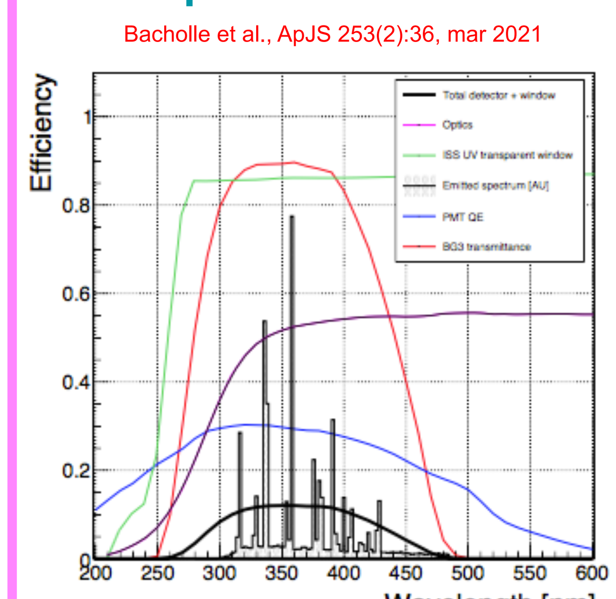

- Theoretical efficiency for perpendicular light emitted at 397.5 nm: **11%**
- Optical efficiency at 18° and 12°: 96% and 98% respectively

Incident angle [°]	Theoretical efficiency [%]	Experimental efficiency [%]
18	10.6	8.0±1.5
12	10.8	6.0±1.1

Modeled efficiency of the Mini-EUSO detector (**black** curve) as a function of wavelength. The total detector efficiency is the result of the optics transmittance (purple curve), the transmission of the BG3 bandpass filter (red curve), the PMT detector efficiency of the photocathodes (blue curve) and of the UV-transparent window of the ISS (green curve). The efficiency is **fairly constant in the range 320 nm - 400 nm**, it is **maximum** around 360 nm where it reaches **~12%**. The system has been designed to optimize observations of the fluorescence light emitted by nitrogen atoms excited by the extensive air shower of cosmic rays (gray histogram).

Conclusions and perspectives

An in flight end-to-end calibration procedure for Mini-EUSO has been developed

- Assembled a UV flasher
- UV flasher signal detected by Mini-EUSO
- Unfortunately, the signal was close to the gap between MAPMTs
- Procedure to estimate the amount of light lost has been developed
- Number of photons produced by the flasher measured in the lab
- Experimental value for the Mini-EUSO efficiency has been derived