PROCEEDINGS OF SCIENCE

An end-to-end calibration of the Mini-EUSO detector in space

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Mini-EUSO is a wide Field-of-View (FoV, 44°) telescope currently in operation from a nadia-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, launched in August 2019. The main goal of Mini-EUSO is to measure the UV emissions from the ground and atmosphere, using an orbital platform. Mini-EUSO is mainly sensitive in the 290-430 nm bandwidth. Light is focused by a system of two Fresnel lenses of 25 cm diameter each on the Photo- Detector-Module (PDM), which consists of an array of 36 Multi-Anode Photomultiplier Tubes (MAPMTs), for a total of 2304 pixels working in photon counting mode, in three different time resolutions of 2.5 μs, 320 μs, 40.96 ms operation in parallel. In the longest time scale, the data is continuously acquired to monitor the UV emission of the Earth. It is best suited for the observation of ground sources and therefore has been used for the observational campaigns of the Mini-EUSO. In this contribution, we present the assembled UV flasher, the operation of the field campaign and the analysis of the obtained data. The result is compared with the overall efficiency computed from the expectations which takes into account the atmospheric attenuation and the parameterization of different effects such as the optics efficiency, the MAPMT detection efficiency, BG3 filter transmittance and the transparency of the ISS window.

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1. Introduction

Mini-EUSO, a fluorescence telescope with a wide FoV of 44° currently in operation onboard the ISS, is the first detector in space of the JEM-EUSO program [1], launched in August 2019. The main goal of Mini-EUSO is to measure the UV emissions from the ground and atmosphere and to assess the feasibility and performance of the measurement of ultra-high energy cosmic rays by means of a space-based detector. Fig. 1 shows schematic views of the full Mini-EUSO telescope (left) and the PDM (right). A more detailed explanation of the Mini-EUSO detector and data acquisition chain is reported in [2].

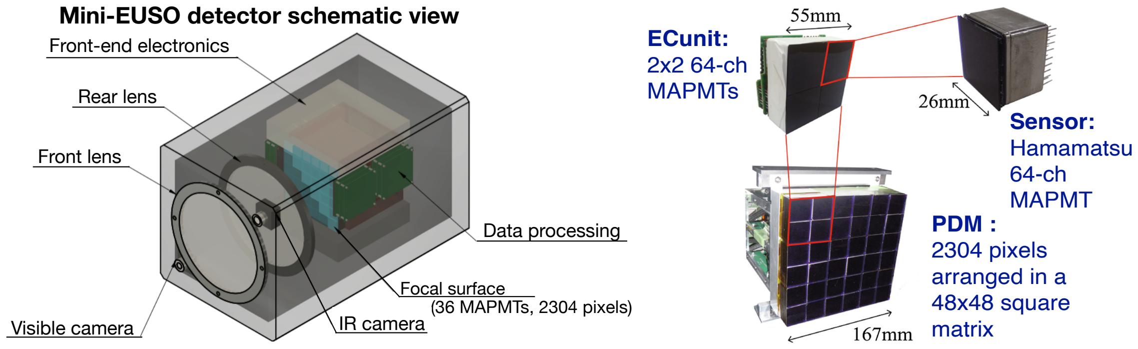

Figure 1: Schematic view of Mini-EUSO telescope (left) and the PDM (right).

Several kinds of ground-based flashers have been developed in different groups of the JEM-EUSO collaboration such as in Japan, Italy and France. One of such flashers has been developed in Turin (namely "Torino UV flasher"), and calibrated with the Torino EC telescope, a telescope based on a Mini-EUSO EC and electronics. The flasher consists of an array of 9 100W COB-UV LEDs, batteries and an Arduino circuit (see the left panel of Fig. 3). LEDs were programmed to pulse 6 times in 12 s with a pulse duration of 1600 ms on and 400 ms off each, followed by 12 pulses in 9.6 s with 400 ms on and 400 ms off each. The durations were decided taking into account that a pixel FoV of Mini-EUSO moves completely to neighboring pixel every ~800 ms as it corresponds to ~6.3 km on ground and the ISS speed is ~7.5 km/s. In this way, it was guaranteed to have a light signal lasting the entire transit of the flasher in a pixel FoV (1600 ms on) and the possibility to measure the flasher light and the background (400 ms on).

In May 2021, an observational campaign was performed at Piana di Castelluccio in central Italy at the altitude of ~ 1550 m a.s.l. The place was chosen based on the very low light pollution in an area of several km radius. In this campaign, photons from the Torino UV flasher were detected and we preliminarily estimated the overall efficiency of Mini-EUSO telescope. However, the flasher signal was detected by Mini-EUSO at the edge of the FoV of an MAPMT. Therefore, some light was missing as it was focused in the gap between two PMTs, which is making the calibration effort more uncertain.

Prior to the measurement by Mini-EUSO, the flasher was tested with the Torino EC telescope at the TurLab facility [3]. As shown in the right panel of Fig. 3, this facility allows one to place the telescope at 40 m distance from a light source in a dark environment.

An EC based telescope, so-called "Torino EC telescope" (Fig.2), has been originally built in Turin for fundamental functionality tests, the study and development of the trigger for the Mini-

EUSO telescope at the TurLab facility and open-sky conditions [4]. It consists of a 30 cm lens tube with a 1-inch plano-convex lens, an Elementary Cell unit (ECunit), which consists of the 2×2 MAPMTs, front-end electronics based on SPAICROC3 ASICs (EC_ASIC), and the Zynq Board connected to a PC via ethernet cable, where dedicated software for the Mini-EUSO data processing system is installed. MAPMTs and electronics boards are powered by external High, and Low Voltage DC Power Supply (HVPS, LVPS), respectively.

Fig.4 shows examples of the Torino flasher data taken by the Torino EC telescope (top) and by the Mini-EUSO detector in space (bottom), where one can see the image of one frame (integration of 40.96 ms) on the left and the light curves of the UV flasher signal (right) after the background subtraction.

The overall efficiency of Mini-EUSO telescope can be estimated as:

$$Eff = N_{\rm det}/N^{window}_{photons}, \tag{1}$$

where $N_{\rm det}$ is the photon counts detected by Mini-EUSO telescope and $N^{window}_{photons}$ is the number of photons arriving at the UV transparent window on the ISS. For the analysis, we selected two pixels, pixel[31,5] and pixel[31,13], which are located at 18° and 12° from nadir, respectively, where the flasher is flashing in the center of a pixel according to the following methods for each:

- method 1: Search for a pixel with flasher signal when the neighboring top, bottom and left pixels have the same counts (the right pixel belongs to a different MAPMT and gaps exist between MAPMTs).

- method 2: Estimate the geographical position from the orbital information (UTC time, distance and the angle)

As a result, $N_{\rm det}$ are 9.7 cts/GTU (pix[31,5]) and 8.3 cts/GTU (pix[31,13]), respectively. In the following we describe how $N^{window}_{photons}$ has been estimated.

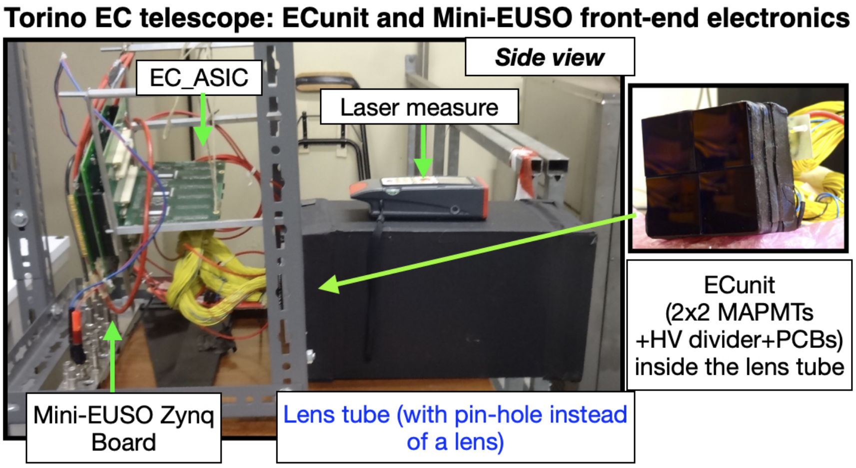

Figure 2: The Torino EC Telescope consists of an ECunit, EC_ASIC, Zynq Board, lens tube, 1" plano-convex lens, CPU (PC), external LV and HV power supplies. For the flasher measurements in the lab, a pin-hole of 0.1 mm in diameter, instead of the lens, is used to reduce light from the flasher LEDs.

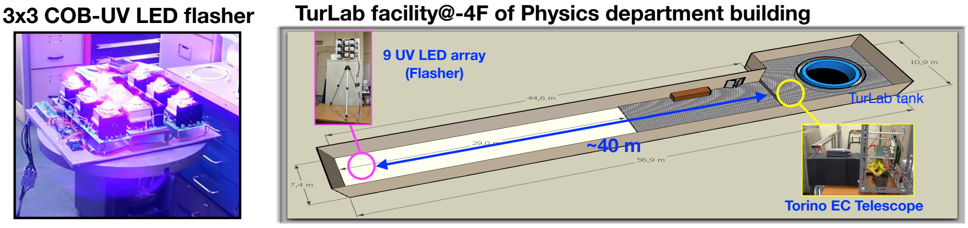

Figure 3: Left: 3 × 3 COB-UV LED flasher built in Turin. Right: schematic view of TurLab facility where the positions of the flasher and Torino EC telescope are indicated.

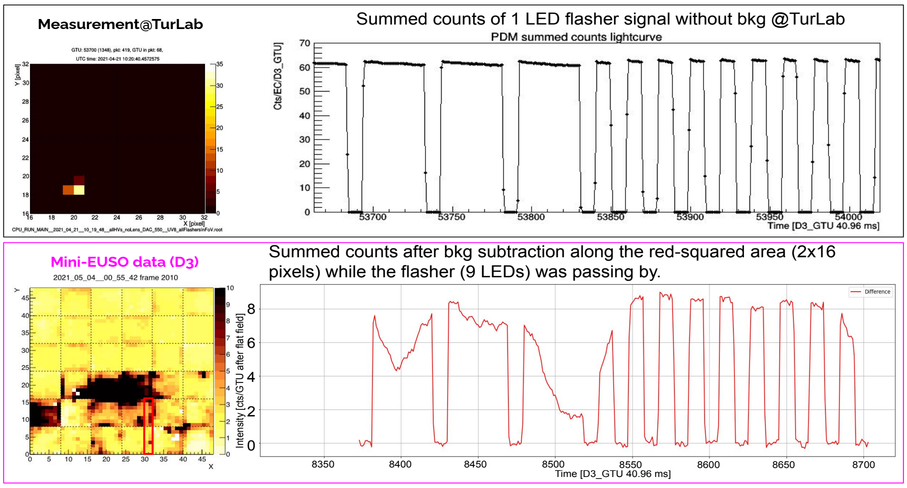

Figure 4: Image of a frame (left) and the lightcurve (right) of the flasher LED photons detected by the Torino EC at 40 m distance (top) and by Mini-EUSO on the ISS (bottom).

2. Calibration of the Flasher

For the end-to-end calibration, it is possible to compare the flasher signals in the same Focal Surface (FS) detector, data acquisition system and electronics on the ground and in space, taking into account the factors of distance, incident angles, atmospheric attenuation, the transmittance of the optics and the ISS window. The Torino ECunit together with EC_ASIC front-end board were absolutely calibrated in France (APC/Univ. Paris Cité) using the method and equipment for the standard JEM-EUSO FS detector calibration [5]. The left plot of Fig. 5 shows the resulted absolute Photo Detection Efficiency (PDE) map of the Torino EC. The telescope is set at 40 m distance from the flasher LEDs to estimate the light intensity of the UV flasher in the large dark room of the TurLab facility located at the fourth basement of the Physics department building of University of Turin. A high precision 0.1 mm pin-hole is attached to the lens tube instead of the lens to reduce light from the flasher. We repeated the measurement at different times to verify that no significant difference in the measurement exists depending on the time or setup conditions. The number of emitted photons is estimated from the detected photon counts by the Torino EC telescope as following:

1. Apply pile-up correction (pixel by pixel) [6].

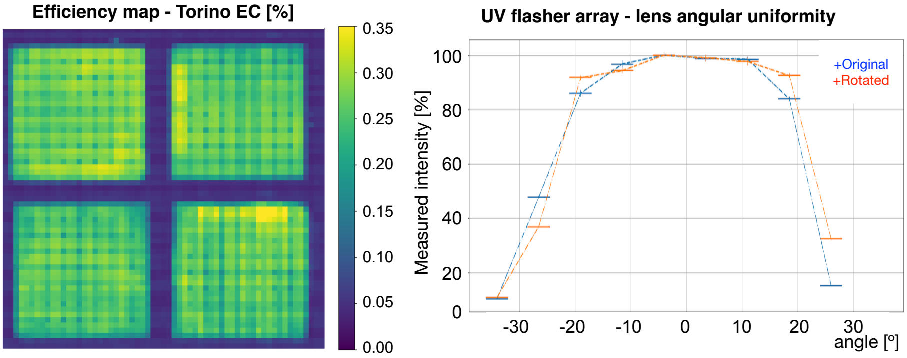

Figure 5: Left: PDE map of Torino EC. Right: Results of the flasher angular measurement.

2. Apply the absolute efficiency of the EC taking into account of a correction factor of 2% as it is calibrated at 395 nm in wavelength, while the flasher is of ~ 395–400 nm in wavelength.
3. Sum all the counts of the pixels with dominant signal.
4. Average peak counts.

As a result, the total number of photons obtained from the measurements performed in Apr 2022 and Jun 2022 are 3564±304 photons/GTU and 3400±296 photons/GTU, respectively.

Table 1: List of the obtained parameters of the flasher and the quadratic sum of the errors

	N_{det}	$N^{TurLab}_{photons}$	PDE	Lens uniformity	$Attn_{atm}$	Angle ($\cos^3\theta$)
Value	9.7–8.3	3482	/	0.9–0.95	0.22	18.6–12.3
Error [%]	10	6	10	5	10	2

The same measurement was repeated at different emission angles between the flasher and the telescope to study the angular response of the flasher. In this measurement, we used a single UV LED which is of the same type as the ones employed in the UV flasher. The right plot of Fig. 5 shows the light intensity at each angle comparing the obtained photon counts with "on-axis" value (red dotted curve). The measurement was then repeated after rotating the lens of flasher LED to check the dependency on the uniformity of the lens (blue dotted curve).

Table 2: Parameters for the arrival photons at ISS window.

	$pix[31,5]$	$pix[31,13]$
θ [°]	18	12
$Angular_{lens}$ [%]	0.9	0.95
$Distance(ToEC)/Distance(ME)$	$9.26\times10^{-9}\cos^2\theta$	
$\cos^3\theta$	0.86	0.94

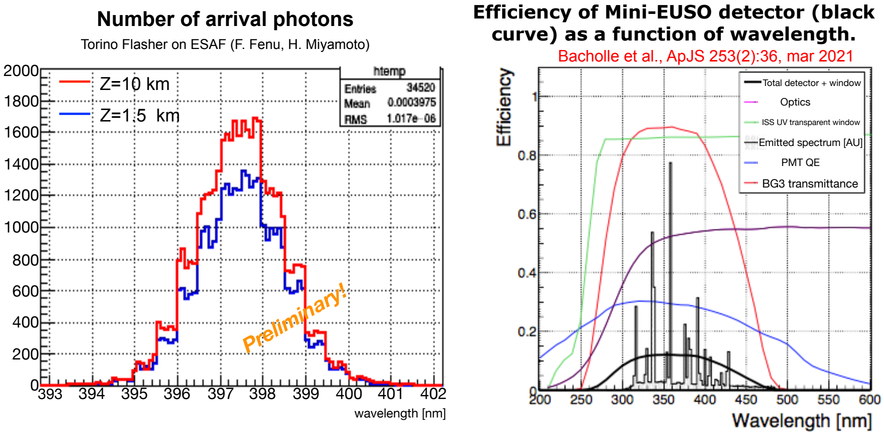

Figure 6: Left: The number of arrival photons at the ISS window as a function of the emitted wavelength as simulated with ESAF for two different heights of the flasher. Right: Efficiency of the Mini-EUSO detector (black curve) as a function of wavelength, resulted from the Optics transmittance (purple), transmission of the BG3 bandpass filter (red), PMT detector efficiency (blue) and ISS UV transparent window (green). The histogram shows the fluorescence light from extensive air showers.

For the attenuation by the atmosphere, we refer to the simulation result. The left panel of Fig. 6 shows the UV flasher simulated by the EUSO Simulation and Analysis Framework (ESAF) setting the flasher position at the altitude of 1.5 km (blue) as for the campaign, and 10 km (red), where no attenuation by the atmosphere occurs [7]. This result indicates that the number of arrival photons from the flasher is reduced to ~78% due to the attenuation. The number of arrival photons at the ISS window is:

$$N^{window}_{photons} = N^{TurLab}_{photons} \times Angular_{lens} \times (1 - Attn_{atm}) \times \frac{Area(ME)}{Area(ToEC)} \times \left(\frac{Distance(ToEC)}{Distance(ME)}\right)^2 \times \cos(\theta),$$

where $N^{TurLab}_{photons}$ is the number of photons emitted by the flasher estimated by the TurLab measurement, θ and $Angular_{lens}$ are the incident angle and the Mini-EUSO lens efficiency of the corresponding angle, $Attn_{atm}$ is the atmospheric attenuation, $Area(ME)$ and $Area(ToEC)$ are the lens and pin-hole areas of Mini-EUSO and Torino EC respectively, $Distance(ToEC)$ and $Distance(ME)$ are the distances between the flasher and each detectors. Applying parameters shown in Table 2, $N^{window}_{photons}$ for pix[31,5] and pix[31,13] are 120.4 cts/GTU and 139.3 cts/GTU. The estimated efficiencies as indicated in Eq. (1) for those pixels are 8.1 ± 1.5% and 6.0 ± 1.5%, respectively. The total error (19%) comes from the quadratic sum of the errors listed in Table 1. Note that there is no value of "PDE" in the table as the error is independent from it.

3. Comparison with theoretical value

The right panel of Fig. 6 shows the theoretical overall efficiency of the Mini-EUSO detector (black curve) as a function of wavelength. It 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 system has been designed to optimize observations of the fluorescence light emitted by nitrogen atoms excited by the extensive air shower of cosmic rays (grey histogram). The theoretical efficiency for perpendicular light emitted at 397.5 nm is 11%. Applying the optical efficiency of 96% and 98% at 18° and 12°, the theoretical efficiency for those angles are 10.6% and 10.8%, respectively.

4. Conclusions and perspectives

An in-flight end-to-end calibration procedure for the Mini-EUSO detector has been developed. The Torino UV flasher signal was detected by Mini-EUSO in orbit. However, the signal was close to the gap between MAPMTs in this campaign, increasing the uncertainty in the measurement. The number of photons produced by the flasher is measured in the laboratory, then finally experimental value for the Mini-EUSO efficiency has been derived, which indicates the Mini-EUSO overall efficiency of 8.1 ± 1.5% and 6.0 ± 1.5%. A couple of more new campaigns are done and the analysis of part of the data arrived on the ground are in progress, which includes the data of a good condition, i.e., detected in the center of the pixel, of the PMTs as well as of the PDM. The preliminary analysis indicates the consistency with the results described in this report. The further analysis of other campaigns and different pixels will improve our flat fielding technique and to complete the end-to-end calibration of the entire PDM consequently.

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References

[1] M. Casolino et al. (JEM-EUSO COll.), ”Overview and latest results of the JEM-EUSO program for the study of ultra-high-energy cosmic-rays from space", in this conference (2023)

[2] S. Bacholle et al., ApJ Supplement Series **DOI 10.3847/1538 – 4365/abd93d** (2021) Also, L. Marcelli et al. (JEM-EUSO Coll.), ”Results and performance of the Mini-EUSO telescope on board the ISS", in this conference (2023)

[3] P. Barrillon et al. (JEM-EUSO Coll.), Exp. Astr. **https : //doi.org/10.1007/s10686 – 022 – 09871 – 8** (2022)

[4] F. Bisconti et al. (JEM-EUSO Coll.), Exp. Astr. **53** 133-158 (2021)

[5] D. Trofimov et al. (JEM-EUSO Coll.), EPJ Web of Conferences, **https : //doi.org/10.1051/epjconf/202328306016** (2022)

[6] M. Casolino et al., Remote Sensing of Environment, **https : //doi.org/10.1016/j.rse.2022.113336** (2023)

[7] H. Miyamoto et al. (JEM-EUSO Coll.), PoS (ICRC2021) **334**

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