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# Description and performance results of the trigger logic of TUS and Mini-EUSO to search for Ultra-High Energy Cosmic Rays from space

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## Abstract

The Trigger Logic (TL) of the Tracking Ultraviolet Setup (TUS) and Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory (Mini-EUSO) space-based projects of the Joint Experiment Missions - EUSO (JEM-EUSO) program is summarized. The performance results on the search for Ultra-High Energy Cosmic Rays (UHECRs) are presented.

**Keywords:** Front End, Trigger, DAQ and Data Management, JEM-EUSO

**PACS:** 29.85.Ca, 96.50.sd

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## 1. Introduction and trigger logic

TUS [1] and Mini-EUSO [2] are the first two space experiments of the JEM-EUSO program [3] devoted to demonstrate the detection principle of UHECRs from space in view of the planned K-EUSO [4] and POEMMA [5] missions. TUS operated in 2016 – 2017 as a part of the Lomonosov satellite orbiting at 500 km from ground while Mini-EUSO is operational since 2019 on the International Space Station. Both telescopes are based on an optical system (Fresnel mirrors for TUS and Fresnel lenses for Mini-EUSO) which focus near-UV light (290 – 430 nm) on an array of PhotoMultiplier Tubes (256 PMT channels for TUS and 2304 pixel channels for Mini-EUSO). Both instruments adopt a multi-mode trigger scheme with time resolutions ranging from  $\mu\text{s}$  to tens of ms to search for UHECRs and slower phenomena occurring in the atmosphere such as transient luminous events, meteors and macroscopic dark matter

(MACRO) [6]. These TLs are fine-tuned versions of the one designed for a large space-based mission devoted to UHECR science [7] similarly to what has been done for the balloon missions EUSO-SPB1 [8] and EUSO-SPB2 [9].

A detailed description of the TUS acquisition logic is reported in [10]. The readout operates in 4 modes specifically designed for different classes of events. However, the different modes can not operate simultaneously, therefore, the operation mode has to be defined at start run. The Extensive Air Shower (EAS) mode is aimed at the detection of UHECRs. The time sampling is  $0.8 \mu\text{s}$ . The other modes are designed for Transient Luminous Events (TLEs) and meteor detection and have a time resolution of  $25.6 \mu\text{s}$  (or 0.4 ms) and 6.6 ms, respectively. The trigger scheme is structured in two steps to allow background rejection and the acceptance of EAS events. A fast ADC digitizes the signals in each time frame. The digitized signals are summed up on a sliding window of 16 frames for each PMT. The integrated values are then compared with a preset threshold. If the threshold is overcome, the 1<sup>st</sup> level trigger is activated. The persistency of such a signal excess on a moving

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matrix of  $3 \times 3$  contiguous pixels is tested each 16 frames. Once the persistency is longer than a predetermined value, the 2<sup>nd</sup> level trigger is issued. At the issuance of a 2<sup>nd</sup> level trigger the acquisition procedure is stopped and data transfer is started. For 50-60 s the detector is blind before restarting the acquisition.

A detailed description of the Mini-EUSO TL is reported in [11]. Mini-EUSO adopts the photon counting technique. The data acquisition operates simultaneously at 3 different time resolutions and stores the data in 3 different timescales (D1, D2 and D3). The 2.5  $\mu$ s time resolution (D1 data) is the fastest one and has a dedicated TL based on signal excess at pixel level of at least  $16\sigma$  above the average background level due to night-glow or other natural and/or artificial sources on ground and/or in atmosphere. The excess is estimated integrating 8 consecutive time frames of D1 while the average background level is updated every 320  $\mu$ s. The system can acquire up to 4 packets, of 128 D1 frames every 5.24 s, then it becomes blind till the end of the 5.24 s period. Each pixel operates independently and the 8 D1 integration time matches the time required by a light signal to cross diagonally the pixel's Field of View (FoV) corresponding to a linear scale at ground of  $\sim 6.3$  km. This is the TL designed for fast signals like UHECRs or fast TLEs. The 2<sup>nd</sup> TL operates at 320  $\mu$ s time resolution (D2) and has a dedicated TL similar to the 1<sup>st</sup> TL which runs in parallel. Up to 4 packets of 128 D2 data can be acquired every 5.24 s. D2 TL is suitable for TLEs. Finally a continuous data taking at 41 ms time resolution (D3) is performed. Data are grouped in blocks of 128 D3 frames corresponding to 5.24 s. These data are used offline to produce UV maps needed to compute the exposure for UHECR observation, and search for slow events such as meteors. Prior to flight the TL was successfully tested in laboratory and in open-sky conditions [12].

## 2. Performance results for UHECR search

The expected performance of TUS and Mini-EUSO for EAS detection was tested by means of detailed simulations using the ESAF software [11, 1]. The sensitivity of both detectors turned out to be around (for TUS) or above (for Mini-EUSO)  $10^{21}$  eV. TUS collected  $\sim 7 \times 10^4$  and Mini-EUSO so far  $\sim 5 \times 10^4$  events in EAS mode. Among them a small fraction had characteristic light curve with a pronounced maximum and full duration at half-maximum (FDHM) from 40 to 80  $\mu$ s, which is quite consistent with the simulated detector response to the EAS signal. However, the amplitude of all EAS-like events corresponds to UHECR energies well above  $10^{21}$  eV. Moreover, the majority of EAS-like events were registered above continents, several times close by airports. Thanks to Mini-EUSO's capability of triggering on consecutive events it was possible to reveal their association with ground flashers due to their repetitive occurrence. The non repetitive ones were excluded from an EAS origin by comparing at the same time their light profile and track image with simulated EAS. TUS detected a few events characterized by a moving light spot. The most interesting one was registered above Minnesota, US [13]. However, an UHECR origin of this event is highly unlikely. TUS collected a total geometric exposure of  $\sim 1550$  km<sup>2</sup> sr yr in EAS mode, while the current estima-

tion for Mini-EUSO is of a few hundreds km<sup>2</sup> sr yr. The amount of events of different nature collected by TUS and Mini-EUSO, documented in [1] and [2], demonstrate a multifunctionality of an orbital fluorescent observatory and its usefulness for various astrophysical and geophysical studies. They provide an invaluable experience for the implementation of K-EUSO and POEMMA missions.

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