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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.

TUS [1] and Mini-EUSO [2] are aimed at demonstrating the detection principle of UHECRs from space in view of the planned K-EUSO [3] and POEMMA [4] missions. TUS operated in 2016–17 as a part of the Lomonosov satellite orbiting at 500 km from ground while Mini-EUSO is operational since 2019 on the ISS. Both telescopes are based on an Fresnel optical system (mirrors for TUS and 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 TL with sampling time (ST) ranging from μs to tens of ms to search for UHECRs and slower phenomena occurring in the atmosphere such as Transient Luminous Events (TLEs), meteors and dark matter [5]. These TLs are fine-tuned versions of the one designed for a large space-based mission [6] similarly to what is done for the balloon missions EUSO-SPB1/2 [7,8].

A description of the TUS acquisition logic is reported in [9] and Fig. 1. The readout operates in 4 modes specifically designed for different classes of events. However, they cannot operate simultaneously, therefore, the operation mode is defined at start run. Normally, it is changed every few weeks or months. The Extensive Air Shower (EAS) mode is aimed at the detection of UHECRs. The ST is 0.8 μs. The other modes are designed for TLEs and meteor detection and have a ST of 25.6 μs (or 0.4 ms) and 6.6 ms, respectively. A software TL is structured in 2 steps to allow background rejection and the acceptance of EAS events. A fast ADC digitizes the signals in each time frame (TF). The

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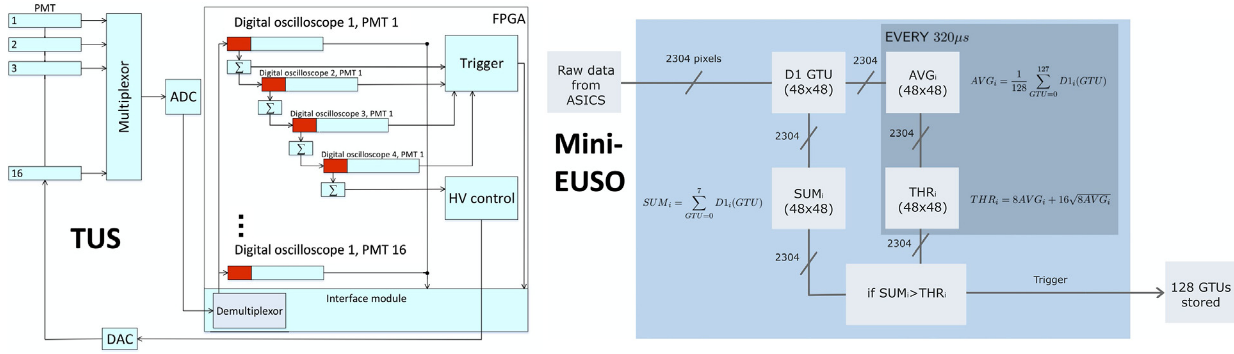

Fig. 1. Block schemes of TUS (left) Photo Detector Module (PDM) electronics (cluster of 16 PMTs) and of Mini-EUSO (right) 1st level TL.

digitized signals are summed up on a sliding window of 16 TFs for each PMT. The integrated values are then compared with a preset threshold (this is done at PDM FPGA level). If the threshold is overcome, the 1st level TL is activated. The 2nd level TL is a pixel mapping TL implemented in the central processor board, which acts as a contiguity trigger. This procedure selects cases of sequential triggering of spatially contiguous pixels that are also adjacent in time, allowing for the selection of events with different spatial–temporal patterns. The preset value of the number of neighbouring pixels (N) sequentially activated by a signal from a given event is set to $N = 3$ but can be changed by command during flight. Once the persistency is longer than N, the 2nd level TL is issued, the acquisition procedure is stopped and data transfer is started. For 50–60 s the detector is in dead time before restarting the acquisition. A description of the Mini-EUSO TL is reported in [10] and Fig. 1. Mini-EUSO adopts the photon counting technique. The data acquisition operates simultaneously at 3 different STs and stores the data in 3 different timescales (D1, D2 and D3). The 2.5 μs ST (D1 data) is the fastest one and has a dedicated TL based on signal excess at pixel level of at least 16σ above the average background level due to nightglow or other natural and/or artificial sources on ground and/or in atmosphere. The excess is estimated integrating 8 consecutive TFs of D1 while the average background level is updated every 320 μs. The system can acquire up to 4 packets of 128 D1 TFs every 5.24 s, then it is in dead time 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 at ground (like 16 TFs in TUS). This is the TL designed for fast signals like UHECRs or fast TLEs. The 2nd TL operates at 320 μs ST (D2) and has a dedicated TL similar to the 1st 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 ST (D3) is performed. Data are grouped in blocks of 128 D3 TFs 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 (i.e. meteors). Prior to flight the TL was successfully tested in laboratory and in open-sky conditions [11].

The expected performance of TUS and Mini-EUSO for EAS detection was tested by means of ESAF simulations [1,10]. 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 few hundreds had characteristic light curve with a pronounced maximum and full duration at half-maximum from 40 to 80 μs, 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. Mini-EUSO revealed 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 US [12], however, an UHECR origin is highly unlikely. TUS collected a total geometric exposure of ~ 1550 km^2 sr yr in EAS mode, while the current estimation for Mini-EUSO is of ~ 400 km^2 sr yr. The amount of events of different nature collected by TUS and Mini-EUSO demonstrate a multifunctionality of an orbital fluorescent observatory and its usefulness for various astrophysical and geophysical studies, and provide an invaluable experience in view of K-EUSO and POEMMA.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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