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

Published version:

DOI:10.1016/j.nima.2022.167601

(Article begins on next page)

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

M. Bertaina[a,b,*], D. Barghini[a,b,c], M. Battisti[b], A. Belov[d,e], M. Bianciotto[a,f], F. Bisconti[a,b], C. Blaksley[g], K. Bolmgren[f], G. Cambiè[h,i], F. Capel[j], M. Casolino[g,h,i], T. Ebisuzaki[g], F. Fenu[k], M.A. Franceschi[l], C. Fuglesang[f], A. Golzio[a,b], P. Gorodetzky[m], F. Kajino[n], P. Klimov[e], M. Manfrin[a,b], L. Marcelli[h,i], W. Marszał[o], M. Mignone[b], H. Miyamoto[b,p], T. Napolitano[l], E. Parizot[m], P. Picozza[h,i], L.W. Piotrowski[q], Z. Plebaniak[o], G. Prévôt[m], E. Reali[h,i], M. Ricci[l], N. Sakaki[g], S. Sharakin[e], J. Szabelski[o], Y. Takizawa[g], M. Vrabel[o], I. Yashin[e], M. Zotov[e]

[a] *Dipartimento di Fisica, Università di Torino, Torino, Italy*
[b] *INFN, Sezione di Torino - Torino, Italy*
[c] *INAF, Osservatorio Astrofisico di Torino - Torino, Italy*
[d] *Faculty of Physics, M.V. Lomonosov Moscow State University - Moscow, Russia*
[e] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State Univ. - Moscow, Russia*
[f] *KTH Royal Institute of Technology - Stockholm, Sweden*
[g] *RIKEN - Wako, Japan*
[h] *INFN, Sezione di Roma Tor Vergata - Roma, Italy*
[i] *Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
[j] *Technical University of Munich - Munich, Germany*
[k] *Karlsruhe Institute of Technology - Karlsruhe, Germany*
[l] *INFN, Laboratori Nazionali di Frascati - Frascati, Italy*
[m] *APC, Univ Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, Sorbonne Paris Cité, France*
[n] *Konan University, Kobe, Japan*
[o] *National Centre for Nuclear Research - Lodz, Poland*
[p] *Gran Sasso Science Institute - L'Aquila, Italy*
[q] *Faculty of Physics, University of Warsaw - Warsaw, Poland*

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

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 μs 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 μs. The other modes are designed for Transient Luminous Events (TLEs) and meteor detection and have a time resolution of 25.6 μs (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^{st} level trigger is activated. The persistency of such a signal excess on a moving

*Corresponding author
Email address: bertaina@to.infn.it (M. Bertaina)

matrix of 3×3 contiguous pixels is tested each 16 frames. Once the persistency is longer than a predetermined value, the 2^{nd} level trigger is issued. At the issuance of a 2^{nd} 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 μs time resolution (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 time frames of D1 while the average background level is updated every 320 μs. 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 ~6.3 km. This is the TL designed for fast signals like UHECRs or fast TLEs. The 2^{nd} TL operates at 320 μs time resolution (D2) and has a dedicated TL similar to the 1^{st} 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 ~7×10^4 and Mini-EUSO so far ~5×10^4 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 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. 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 ∼1550 km^2 sr yr in EAS mode, while the current estimation for Mini-EUSO is of a few hundreds km^2 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.

Acknowledgments

This work was supported by ROSCOSMOS, by ASI through the agreements ASI-INAF n.2017-14-H.O and ASI-INFN n.2020-26-Hh.0, by CNES, by the National Science Centre in Poland grant 2017/27/B/ST9/02162. This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University "Fundamental and Applied Space Research" and it is based on research materials carried out in the space experiment "UV atmosphere".

References

[1] D. Barghini, et al., UV telescope TUS on board Lomonosov satellite: Selected results of the mission, Advances in Space Research In Press (2021) Corrected Proof. doi:10.1016/j.asr.2021.11.044.

[2] S. Bacholle, et al., Mini-EUSO Mission to Study Earth UV Emissions on board the ISS, The Astrophysical Journal Supplement Series 253:36 (2021) 1–17. doi:10.3847/1538-4365/abd93d.

[3] M. Ricci, JEM-EUSO Collaboration, The JEM-EUSO Program, Journal of Physics: Conference Series 718 (2016) 052034. doi:10.1088/1742-6596/718/5/052034.

[4] P. Klimov, et al., Status of the K-EUSO Orbital Detector of Ultra-High Energy Cosmic Rays, Universe 8/2 (2022) 88. doi:10.3390/universe8020088.

[5] A. Olinto, et al., The POEMMA (Probe of Extreme Multi-Messenger Astrophysics) observatory, Journal of Cosmology and Astroparticle Physics 06 (2021) 007. doi:10.1088/1475-7516/2021/06/007.

[6] L. Anchordoqui, et al., Prospects for macroscopic dark matter detection at space-based and suborbital experiments, EPL 135/5 (2021) 51001. doi:10.1209/0295-5075/ac115f.

[7] G. Abdellaoui, et al., Cosmic ray oriented performance studies for the JEM-EUSO first level trigger, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 866 (2017) 150–163. doi:10.1016/j.nima.2017.05.043.

[8] M. Battisti, et al., Performance results of the trigger logic implemented in EUSO-SPB, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 936 (2019) 349–350. doi:10.1016/j.nima.2018.11.002.

[9] G. Filippatos, et al., Development of a cosmic ray oriented trigger for the fluorescence telescope on EUSO-SPB2, Advances in Space Research In Press (2021) Correct Proof. doi:10.1016/j.asr.2021.12.028.

[10] P. Klimov, et al., The TUS Detector of Extreme Energy Cosmic Rays on Board the Lomonosov Satellite, Space Science Reviews 212/3 (2017) 1687–1703. doi:10.1007/s11214-017-0403-3.

[11] A. Belov, et al., The integration and testing of the Mini-EUSO multi-level trigger system, Advances in Space Research 62/10 (2018) 2966–2976. doi:10.1016/j.asr.2017.10.044.

[12] F. Bisconti, et al., Pre-flight qualification tests of the Mini-EUSO telescope engineering model, Experimental Astronomy 53/1 (2022) 133–158. doi:10.1007/s10686-021-09805-w.

[13] B. Khrenov, et al., An extensive-air-shower-like event registered with the TUS orbital detector, Journal of Cosmology and Astroparticle Physics 2020/03 (2020) 033. doi:10.1088/1475-7516/2020/03/033.