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Performance results of the trigger logic implemented in EUSO-SPB

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Abstract

EUSO-SPB (Extreme Universe Space Observatory - Super Pressure Balloon) [1] is the first path-finder mission of the JEM-EUSO program which hosted a trigger logic to detect Ultra-High Energy Cosmic Rays (UHECRs) following the concept envisaged for the main mission. The performance of the implemented logic was verified by means of dedicated tests carried out in a field campaign at the Telescope Array (TA) site where the EUSO-SPB detector was exposed to the night sky luminosity and to a variety of point-like light sources such as stars, meteors, and laser shots to mimic UHECR tracks. Finally, the logic was tested on board the EUSO-SPB flight. Results satisfied the requirements conceived for the First Level Trigger (FLT) envisaged for JEM-EUSO as described in [2].

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

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1. Introduction and trigger logic

EUSO-SPB launched from Wanaka New Zealand on April 25th 2017 on a NASA Super Pressure Balloon and flew more than 12 days. During the flight EUSO-SPB collected ~100k events. Most of them were successfully downloaded on ground and processed. EUSO-SPB mounted on-board an autonomous FLT similar to the one foreseen for JEM-EUSO [2]. The Focal Surface (FS) of EUSO-SPB was based on MAPMTs (Hamamatsu Photonics R11265-03-M64) which have 8×8 pixels and for readout purposes 2×2 MAPMTs are grouped into one Elementary Cell (EC). The FLT works at the level of these ECs. Nine ECs form one PDM [3].

The FLT [2] rejects most of the fluctuations of the UV night-glow as well as electronic noise by requiring a locally persistent signal that lasts a few Gate Time Units (GTUs, 1 GTU = 2.5 μs) above the average background. In the FLT pixels are grouped in cells of 3 × 3 pixels. When a pixel in a cell detects a number of counts equal, or higher than, a preset threshold N , the FLT logic checks if for a certain number of following GTUs (R) in a slot of

consecutive GTUs (P), there is at least one pixel in the same cell with an activity equal to, or higher than N , and the total number of photo-electrons integrated in the cell is higher than a preset value S . If this condition is verified a pre-trigger is issued. In case the pre-trigger activation persists for less than 73 GTUs the event is finally triggered. If the persistence lasts longer the event is considered not to be compliant with an UHECR duration and the trigger is not issued. R and P define the trigger mode suitable for the JEM-EUSO path-finder. In case of EUSO-TA [4] or EUSO-SPB where the location of the Extensive Air Shower (EAS) can vary between 1 to 30 km, P values such as 0 or 1 are the most appropriate; consequently, R can be 0 or 1. On the other hand, for JEM-EUSO, looking at 400 km distant EAS, $P = 4$ and $R = 2$. Having fixed P and R , the N and S parameters are set as a function of the average background level on each MAPMT independently to keep the rate of triggers on false positives at ~1 Hz/EC. The parameters can also be set via an external command. For each pixel an average background level is calculated every 128 GTUs (320 μs). The pixel with the highest average count determines the thresholds for the entire MAPMT. This method takes more precisely into account the non-uniformity among pixels, as well as the presence of man-made sources with very limited spatial extension. All the

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artificial sources such as cities, ships can be considered static at this level. The FLT and all the control logic and interfaces was implemented on a Xilinx Virtex 6 model XC6VLX360T FPGA and it used around 34%-43% of the available resources.

2. Trigger tests during the Utah campaign

In October 2016, the fully assembled EUSO-SPB detector was tested for a week at the EUSO-TA site to measure the overall response of the detector and to calibrate it by means of the Central Laser Facility (CLF) of TA and a portable Ground Laser System (GLS) of Colorado School of Mines. This time the FLT trigger was tested on the entire PDM for about a week. The trigger logic was set with $P=1$ and $R=1$. In normal sky conditions, the FLT rate was below 1 Hz on the entire PDM, increasing to few Hz during thunderstorms outside the FoV (the system could not have been operated with thunderstorms in the FoV) or during the passage of airplanes. This was due to the fact that the strobe lights of airplanes have very sharp raising phase of the signal, with longer time decay. Being just above threshold, they failed to be recognized as slow events. The fact that in normal conditions stars were not creating huge bursts of triggers proved that the logic is capable of dealing with very slow but bright moving objects. Only rarely, when a bright star was passing through different MAPMTs and the light was scattered in an irregular way from the filters, a slight increase in the trigger rate was observed. Similar situation occurred in presence of meteoroids. A few of them triggered EUSO-SPB but at the level of no more than 10 Hz, which means that the logic successfully avoided too high trigger rates. Most of the time, EUSO-SPB trigger logic was tested using CLF and GLS laser shots. The GLS laser is a mobile system which was set at a distance of 25 km from EUSO-SPB and EUSO-TA with a laser intensity in the range of 1 to 86 mJ. As the laser itself is steerable, the geometry of the laser track can be varied more freely, mimicking EAS of different energy and direction. The GLS turned to be essential to provide a first estimation of the energy threshold of the FLT to trigger on EAS-like events. By comparing the laser signal on the FS and the expectation from simulations of EAS, the result was that laser intensity giving $\sim 50\%$ trigger efficiency is equivalent to that expected from $\sim 3 \times 10^{18}$ eV and 45° inclined EAS as seen from EUSO-SPB at an altitude of 30 km. This was a positive result because it confirmed within 30-50% uncertainty the energy threshold assumed for EUSO-SPB in simulations.

3. Trigger performance on flight

On April 25th, EUSO-SPB was lifted by a Super Pressure Balloon of NASA and flew for about 12 days and operated during all nights without moon. Hundred thousands of packets of data were recorded. About 75% of them was downloaded before the flight terminated. Data were acquired in nominal runs of 120 seconds. Every hour a much shorter run (40 seconds) was started and data immediately downloaded to understand the general performance of the detector. Fig. 1 shows the overall trigger rate during the entire flight. An indication of the trigger

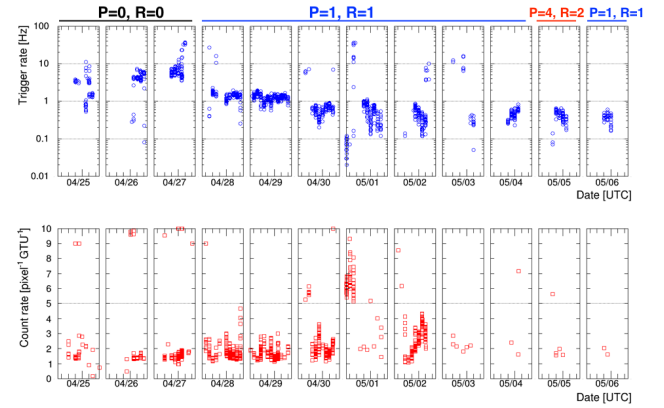


Figure 1: Top: EUSO-SPB trigger rate in flight. Bottom: average count rate measured at pixel level.

modes as a function of time is reported. For the first three nights EUSO-SPB operated in the $P=0$ and $R=0$ mode, which means single GTU trigger. In normal condition the trigger rate was around ~ 1 Hz/EC, however, this was too high for the down-link telemetry requirements. During all the rest of the flight, except for one night, the $P=1$ and $R=1$ mode, as used in Utah, was operated. In this case the overall trigger rate was below 2 Hz/PDM. The peaks above 10 Hz during the flight are often due to electronics disturbances on one specific EC in some cases related to interference with other add-on units. This situation didn't occur during the Utah tests. The night of May 5th, the $P=4$ and $R=2$ mode (JEM-EUSO trigger mode) was tested. The trigger rate was always below 2 Hz/PDM. In general, the FLT triggered within the JEM-EUSO requirements (below 7 Hz/PDM). A certain number of events compatible with cosmic rays directly impacting in the detector have been recognized. Simulations are planned to understand and cross-check the rate. The analysis to search for EAS candidates is in progress. Simulations indicate that the number of expected events is of the order of 1 or less in the available data sample.

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