

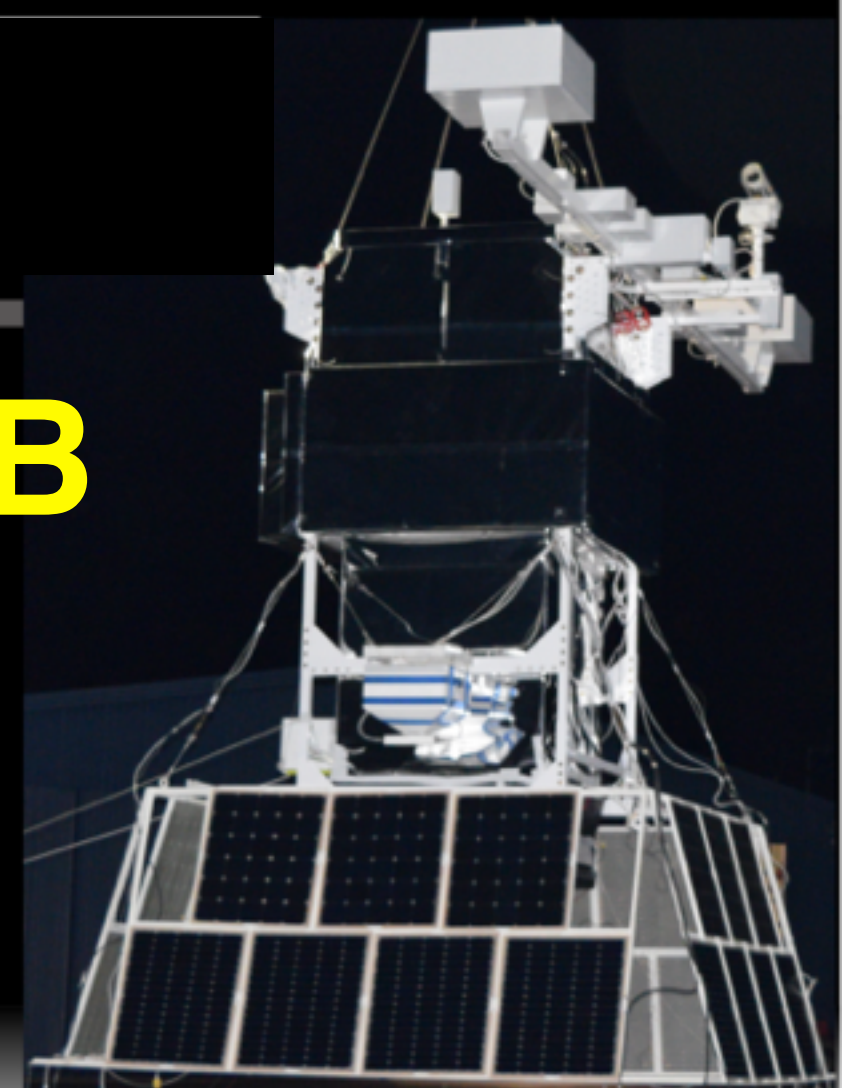
EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon



Performance results of the trigger logic implemented in EUSO-SPB

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INTRODUCTION

EUSO-SPB (Extreme Universe Space Observatory - Super Pressure Balloon) is the first pathfinder mission of the JEM-EUSO program with the aim of detecting for the first time from the edge of space Ultra-High Energy Cosmic Rays by means of the fluorescence technique. EUSO-SPB is the first instrument hosting a trigger logic following the concept envisaged for the main mission.

EUSO-SPB launched from Wanaka New Zealand on April 25th on a NASA Super Pressure Balloon and flew 12 days and 4 hours before sinking in the South Pacific ocean on May 6th. During the flight EUSO-SPB collected around hundred thousands events. Most of them were successfully downloaded on ground and are being processed. The Focal Surface (FS) of EUSO-SPB was based on MAPMTs (Hamamatsu Photonics R11265-03-M64) which have 8x8 pixels and for readout purposes 2x2 MAPMTs are grouped into one Elementary Cell (EC). The First Level Trigger (FLT) works at the level of these ECs. Nine ECs form one Photo-Detector Module (PDM), which is the entire FS of EUSO-SPB and is the basic unit for the Second Level Trigger (SLT).

The First Level Trigger (FLT) logic has been coded and implemented in the PDM. The performance of the implemented logic has been then verified by means of dedicated tests carried out in a field campaign at the Telescope Array site where the EUSO-SPB detector was exposed to the night sky luminosity and to a variety of point-like and diffused light sources such as stars, meteors, airplanes and lightnings. Moreover, dedicated tests were performed using the Central Laser Facility of Telescope Array and a mobile laser system of the Colorado School of Mines with variable intensity to mimic up-going cosmic ray showers and determine experimentally the triggering performance of EUSO-SPB.

The First Level Trigger Logic

The FLT rejects the fluctuations of the UV night-glow as well as electronic noise by requiring a locally persistent signal that lasts a few GTUs above the average background. In the FLT, pixels are grouped in cells of 3x3 pixels with one pixel overlap. When a pixel in a cell detects a number of counts equal, or higher than, a preset threshold $N=n^{thr}_{pix}$, the FLT logic checks if for a certain number of following GTUs ($R=N_{GTU}$) in a slot of consecutive GTUs ($P=N_{PST}$), 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 $S=n^{thr}_{cell}$. If this condition is verified a trigger is issued. R and P define the trigger mode suitable for the JEM-EUSO path-finder. In case of TA-EUSO 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 to keep the rate of triggers on false positives < 1 Hz/EC. An EAS is visible in one EC for less than 45 GTUs. This is much shorter than the minimum fraction of time that lightning (ms), meteors (hundreds ms) and cities/airplanes (s) will illuminate 1 EC. Starting from the GTU in which the FLT fires, a confirmation counter is activated. For a preset number of consecutive GTUs (N_{GTU}), the confirmation counter is increased by 1 count for each GTU in which the FLT is fired. After N_{GTU} , if the confirmation counter has passed a certain threshold N^{thr}_{GTU} , the trigger is not activated because it indicates that the FLT fired for a fraction of time that exceeded the expected duration of an EAS. If it is lower than N^{thr}_{GTU} , the trigger confirmation is issued. The FLT parameters are set according to the average background level on the MAPMTs. Thresholds are set at MAPMT level. For each pixel an average background level is calculated every 128 GTUs (320 μ s). The pixel with the highest average count determines the thresholds for the entire MAPMT. This method takes into account the non-uniformity among pixels, as well as the presence of man-made sources with very limited spatial extension. Artificial sources such as cities, planes, ships can be considered static at this level. The trigger logic has been implemented on a Xilinx Virtex6 model XC6VLX240T FPGA.

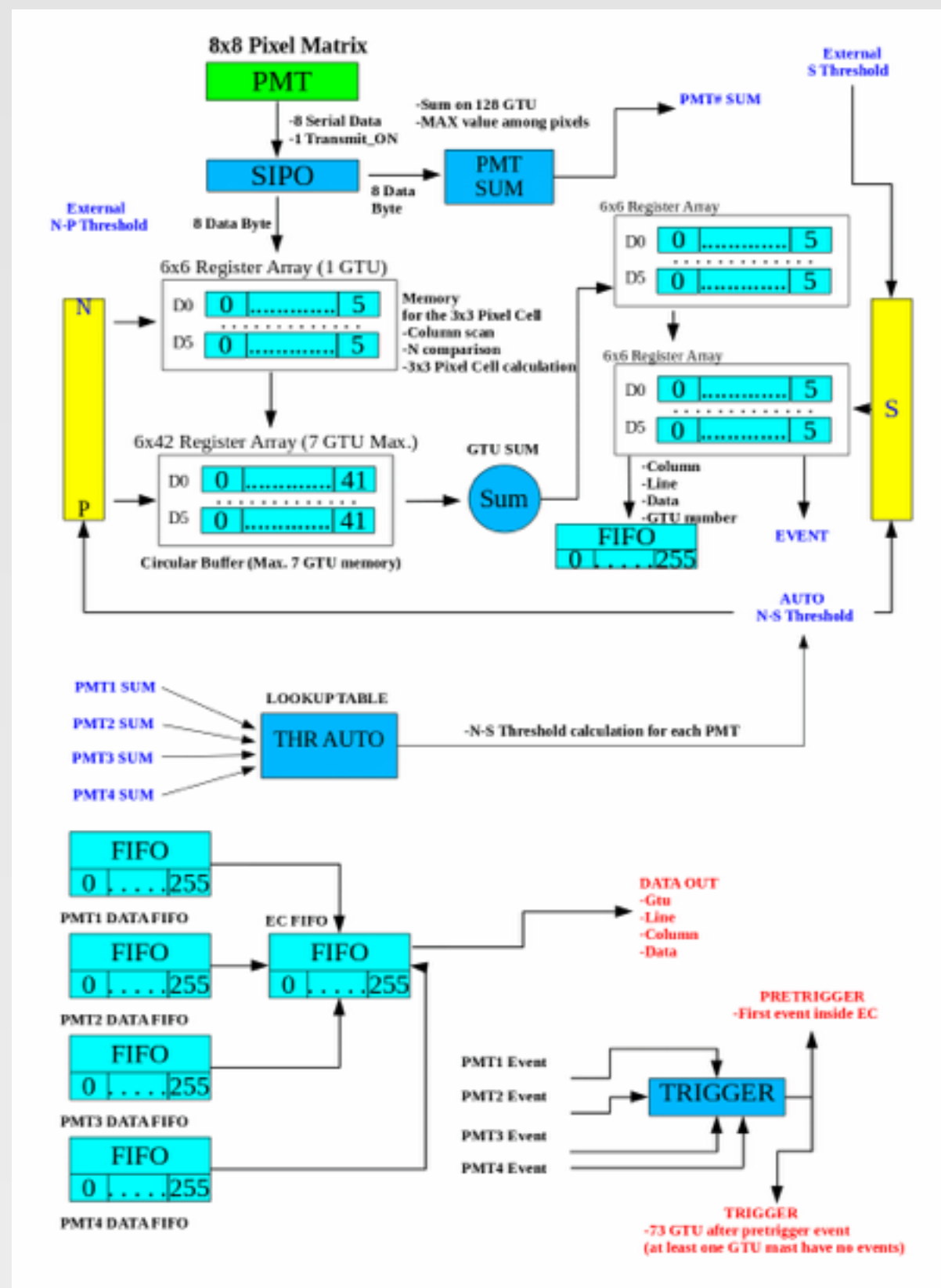


Figure 1: Top: Schema of the VHDL implementation of the FLT logic. Bottom right: The FLT trigger logic. PDM board.

Hardware implementation of FLT

FLT main components are:

Serial Pixel in to Column out (SIPO): This is the interface module towards the ASIC and receives the serial data from the single MAPMT channels, checks the data integrity and hands the pixel counts over to the next modules.

PMT AVG: This module calculates the average of 128 GTUs which is used to estimate the current background level and to set the N - and S -thresholds accordingly.

6x6 Register Array (1 GTU): The received data is compared to the N -threshold and if above, the integration of the various 3x3 pixel boxes is performed.

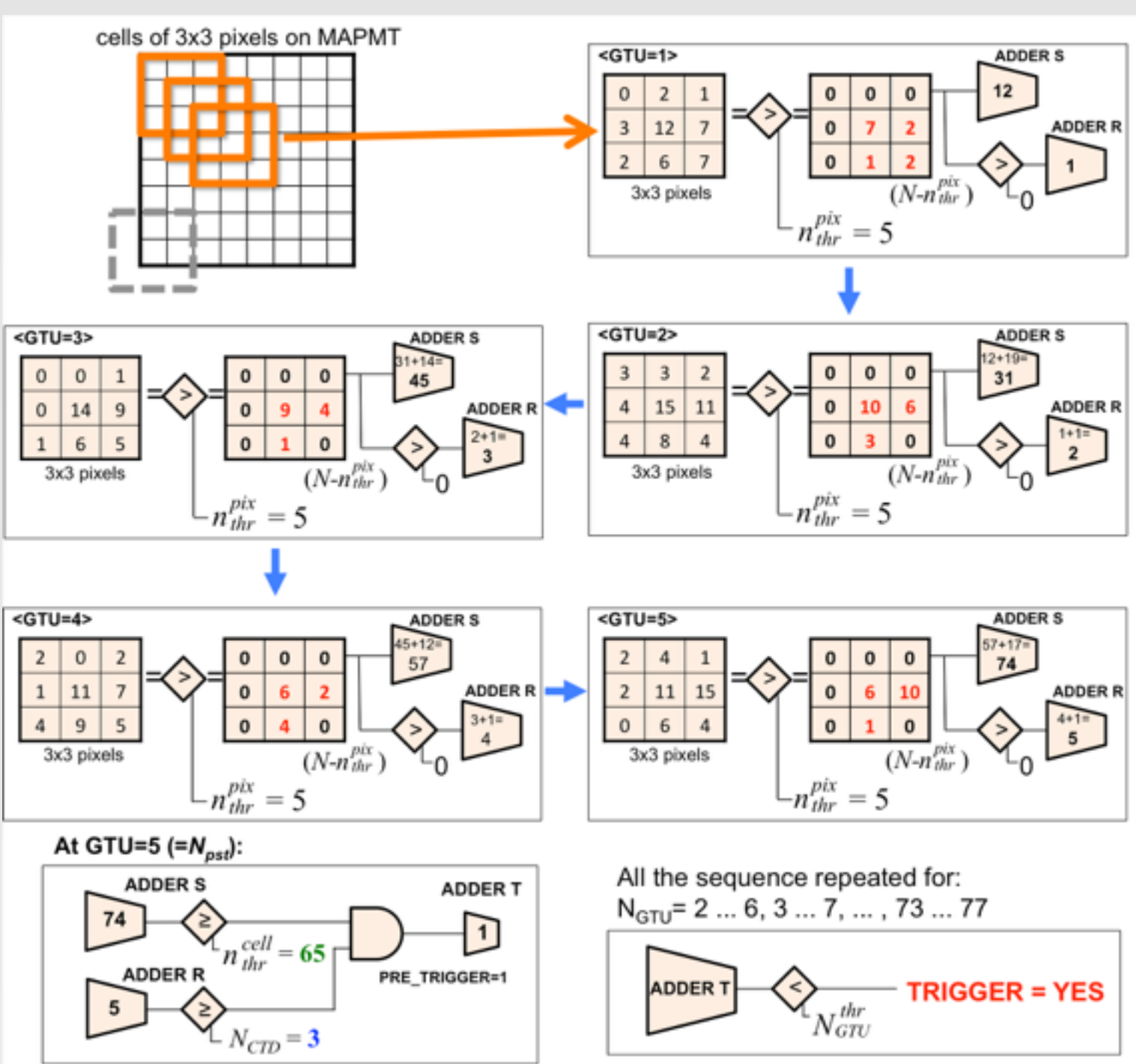
6x42 Register Array (7 GTU Max.): This data buffer is used to apply the P - and R -thresholds together with the 'GTU SUM' module. In the current implementation it buffers the data for a maximum of 7 GTUs.

6x6 Register Arrays: The last two data buffers are used to compare the integrated 3x3 boxes to the S -threshold and to store the information (position, integrated value and GTU number) to a FIFO and issue a pre-trigger.

EC FIFO: This module simply collects the data from the single MAPMTs by reading them out in a round-robin fashion.

TRIGGER: The trigger module finally collects the single cell triggers and checks that the pre-triggers are not lasting for more than 72 GTUs. This is done to remove triggers coming from slow and persisting events.

The main optimizations done in the implementation of the FLT for EUSO-SPB were on one hand the adaption of the VHDL to the specific hardware architecture of the Virtex-6 to make use of various dedicated hard-macros and on the other hand by doubling the internal clock speed and to serialize the processing of the FLT. This way, the resource utilization was greatly reduced via several steps. For example, due to the serialization of some processes and re-using the internal memories to total usage of the internal BRAM blocks was reduced by 85%.



The Utah Campaign

In October 2016, the fully assembled EUSO-SPB detector was tested 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 Telescope Array and the 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 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 in some cases the FLT was not pre-triggered for N^{thr}_{GTU} GTUs, failing to recognize it as a slow event. 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 a few Hz, which means that the logic successfully avoided too high trigger rates. It is worth remembering that the JEM-EUSO requirement on the FLT is to have a trigger rate < 7 Hz to make sure that the SLT is capable of processing the data on time.

Most of the time, EUSO-SPB trigger logic was tested using CLF and GLS laser shots. The CLF, placed at a distance of 21 km from EUSO-TA and EUSO-SPB, fires 300 vertical laser pulses of 3 mJ and 355 nm at 10 Hz every half hour. 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. Left side of figure shows an example of a 2 mJ GLS laser event detected by EUSO-SPB. In this condition the trigger efficiency was 100%. This test was performed adopting two different lens configurations: a 2-lens system, without a diffractive lens in between which would correct the chromatic aberrations; a 3-lens system which is the basic configuration for JEM-EUSO. The measurements were performed on different nights but with similar sky conditions to avoid major systematic effects in the comparison. Same figure shows the efficiency in triggering vertical laser shots in both conditions as a function of the laser energy. The two-lens configuration turned out to be much better performing, despite a larger spot size on the focal surface. By comparing the laser signal on the FS and the expectation from simulations of EAS performed with ESAF and OffLine simulation codes, the result was that laser intensity giving 50% trigger efficiency is equivalent to that expected from 3×10^{18} eV and 45° inclined EAS as seen from EUSO-SPB at an altitude of 33 km. This was a positive result because it confirmed within 30-50% uncertainty the energy threshold assumed for EUSO-SPB in simulations.

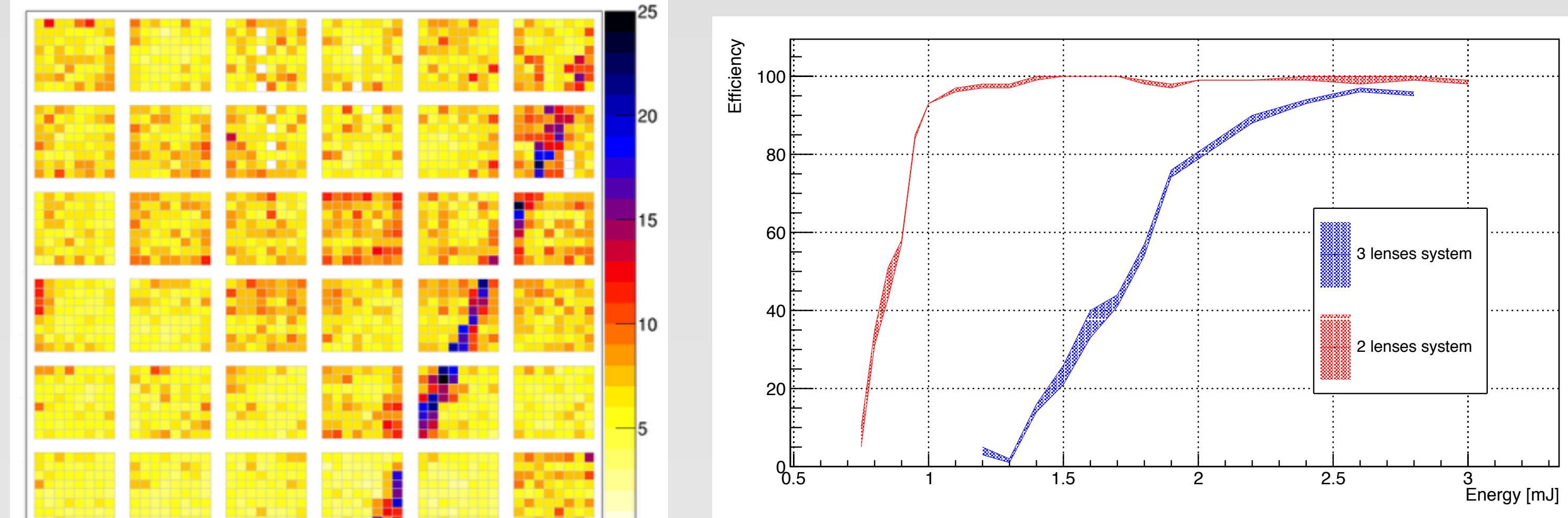


Figure 2: GLS laser event (2 mJ) going through the FoV of the PDM adopting the 2 lens system (left) and trigger efficiency as a function of laser energy (right) with 2 and 3 lens system for vertical shots. The 3 lens system was only tested up to 2.7 mJ.

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. Figure shows the overall trigger rate during the entire flight. In the figure, an indication of the trigger modes as a function of time is also indicated. For the first three nights EUSO-SPB operated in the $P=0$ and $R=0$ mode, which means single GTU operation. This was expected to be the most effective one to detect EAS. In normal condition the trigger rate was ~ 1 Hz/EC, however, this was too high for the downlink 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. 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). However, the trigger rate on flight was typically higher than what observed on ground. A preliminary analysis of the data seem to indicate that the periods with high trigger rate are related to electric noise. 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 has started. Simulations indicate that the number of expected events is of the order of 1-2 in the available data sample.

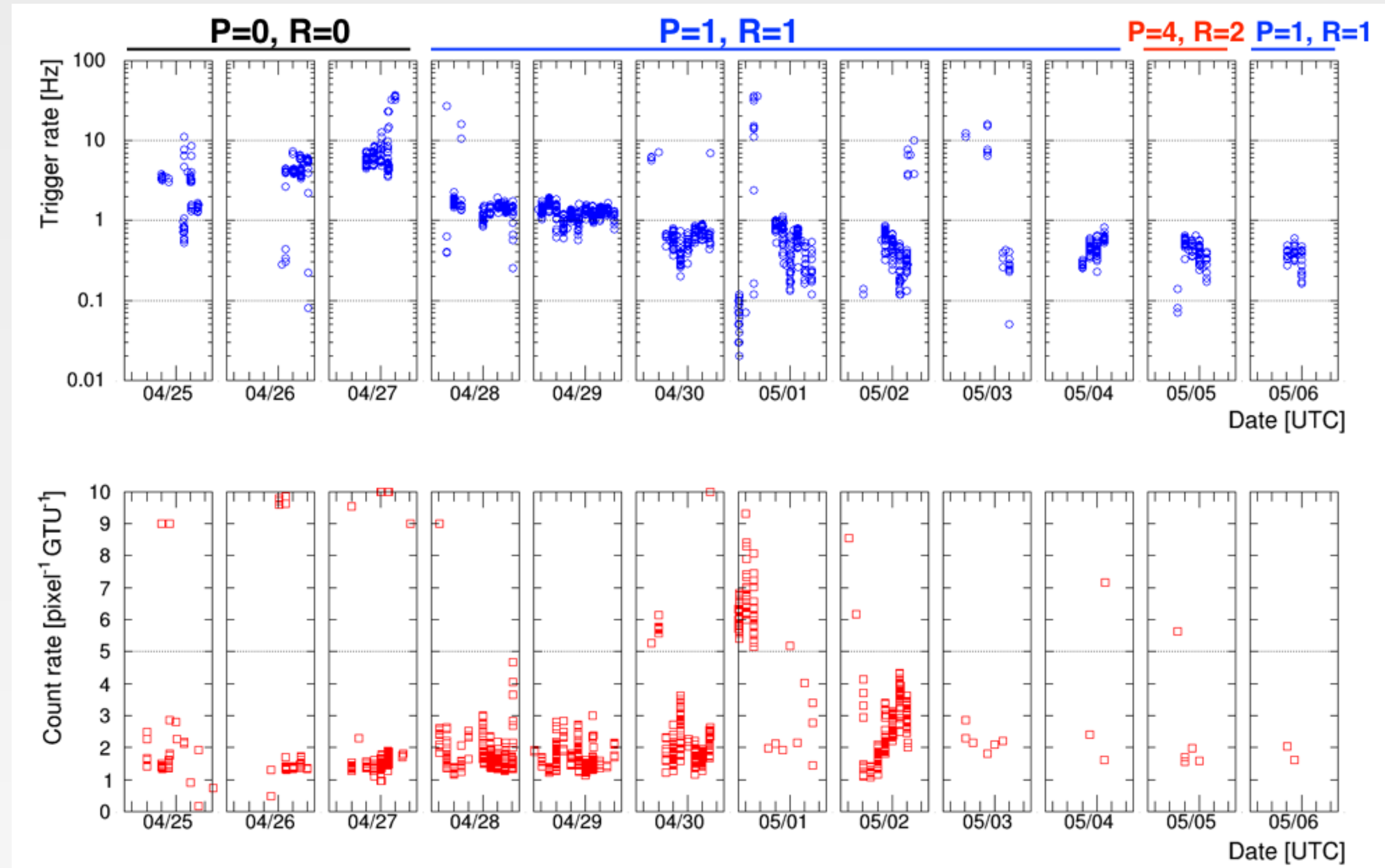


Figure 3: Top: EUSO-SPB trigger rate in flight. Bottom: average count rate measured at pixel level.

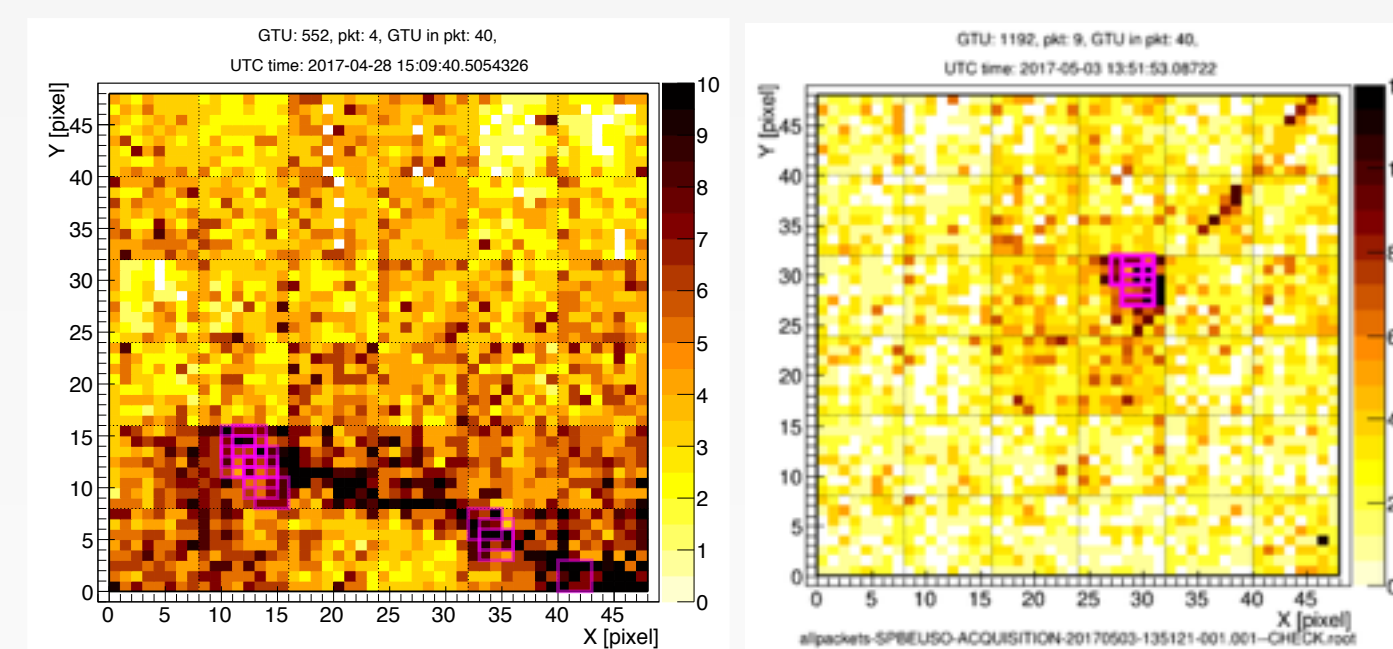


Figure 4: Examples of CRs interacting in the detector.

Conclusions

The FLT was tested for the first time on board a JEM-EUSO instrument. In general, its performance turned out to be within the requirements, even though for EUSO-SPB slightly lower trigger rate would have been more appropriate due to the telemetry bandwidth. The data collected with EUSO-SPB will be extremely important to test the performance of Mini-EUSO FLT logic which is slightly different from EUSO-SPB, to make sure that the trigger rate remains within the constraints imposed by the mission.

JEM-EUSO collaboration

16 Countries, 93 Institutes, 351 People

