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Simulations and the analysis of fake trigger events background in JEM-EUSO experiment

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Abstract: The goal of the trigger system is to detect the occurrence of scientifically valuable signal among very huge background noise detected by JEM-EUSO telescope. The UV background registered by JEM-EUSO is randomly distributed. We study if these random processes produce fake pattern, which could be mistakenly interpreted as extreme energy cosmic rays events. For this purpose very huge amount of measurements on one photo detection module with only detector noise were simulated. To distinguish between such simulated fake events and real extreme energy cosmic rays events we have applied several pattern recognition methods. The presented results obtained by one of them - Hough transformation provide reasonable ....

Keywords: EECR, JEM-EUSO, Trigger, Fake trigger events, Pattern recognition.

1 Introduction

The JEM-EUSO [1] is an Extreme Energy Cosmic Rays (EECR) experiment whose main purpose is the study of the End of Cosmic Rays spectrum above the GZK cut-off. The detector is basically a large field of view UV camera, pointing toward the earth atmosphere, to detect and measure the fluorescence light imprint produced by development at speed of light of Extensive Air Showers (EAS). Typically, for a $10^{20}eV$ EAS, a few thousands photons are expected on the JEM-EUSO detector focal surface (FS). However, the background photons are much more than those of signal. Therefore the background reduction is essential for such space observatory of EECRs. It is the aim of the trigger to try to extract the signal from the background sea. The electronics will have to reject as much counts as possible without rejecting the signal itself. Fortunately the signal has some peculiar characteristics that can be used to distinguish it. The shower generate a spot moving on the focal surface. On the other hand, the background is distributed randomly. Despite of it is necessary to assess, if the random processes do not produce fake patterns, which could be mistakenly interpreted as EECR events. For this purpose a huge amount of measurements with only background events have to be simulated. The obtained results would be consequently analysed by several pattern recognition algorithms to verify the probability of registration a fake trigger events in several trigger conditions.

2 Trigger

The role of the trigger is to select EAS events rejecting the random background. The random hits come from the fluorescence photons having undergone Mie and Rayleigh scattering in the atmosphere induced by the night glow, the air glow, the moon light and light cities and the reflected stars light. This background is strongly variable and ranges from $100-600\ photons\ m^{-2}ns^{-1}sr^{-1}$. It provides a photon rate on the pixel of $1.7-10MHz$ and it needs to be greatly reduced. To reject the background, JEM-EUSO electronics operate with several trigger levels. The trigger scheme relies on the partitioning of the FS in subsections.

The FS is covered by a large numbers of photo-detector tubes mechanically structured in series of similar pieces, the one embedded in the others. The largest piece is a photodetector module (PDM). The whole FS is made of 137 such PDM's. Each PDM structure is itself a squared matrix of 3x3 smaller elements called elementary cells (EC). Each EC is a squared matrix of 2×2 multianode photomultipliers. An EC is a 12×12 pixel matrix, corresponding to 144 channels. A PDM is a 36×36 pixel matrix corresponding to 1296 channels. Each PDM probe a squared pad of $27km\times 27km$, which is large enough tocontain a substantial part of the imaged trace under investigation (this depends on the zenith and eenergy of the EAS). The FS has in total 177600 channels.

The Table 1 gives a possible reduction of the trigger rates that could be achieved at various trigger levels [2], [3].

General JEM-EUSO trigger philosophy asks for a system trigger organized into two main trigger levels. The system trigger works on the statistical properties of the incoming photon flux in order to detect the interesting events hindered in the background, basing on their position and time correlation.

The 1^{st} trigger level mainly operates to remove most of the background fluctuations by requiring a locally persistent signal above over a few GTU's duration. GTU is the gate time unit of the value $2.5\mu s$, which is the temporal time resolution of detector electronics. In the 1^{st} level trigger named also PTT (Persistency Track Trigger) are the pixels grouped in boxes of 3×3. A trigger is issued if for 5 consecutive GTU's there is at least one pixel in the box

Level	**Triggers rate at PDM level [Hz]**	**Triggers rate at FS level [Hz]**
Photon trigger (channel)	$\sim 9.2 \times 10^8$	$\sim 1.4 \times 10^{11}$
Counting trigger (EC)	$\sim 7.1 \times 10^5$	$\sim 1.1 \times 10^8$
1^{st} level (PDM) Persistency trigger	~ 7	$\sim 10^3$
2^{nd} level (PDM cluster) Linear track trigger	$\sim 6.7 \times 10^{-4}$	$\sim 10^{-1}$
Expected rate of EECRs	$\sim 6.7 \times 10^{-6}$	$\sim 10^{-3}$

Table 1: The trigger rate reduction on different trigger levels

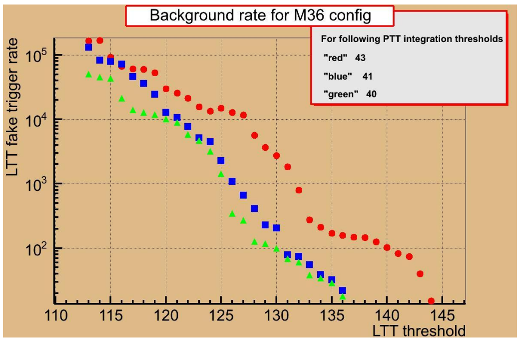

Fig. 1: Thresholds for M36 configuration

with an activity higher than a preset threshold (N_{th}) and the total number of detected photoelectrons in the box is higher than a preset value M. N_{th} and M are set as a function of the average noise level in order to keep the rate of triggers on fake events at a few Hz per PDM.

The role of the 2^{nd} trigger level - Linear Track Trigger (LTT) is to find some tracks segments in three dimensions from the list of pixels provided by the first level, for each GTU time bin. The track speed has to be compatible with a point travelling at speed of light in whatever direction it propagates. So it follows the movement of the EAS spot inside the PDM over some predefined time, to distinguish this unique pattern of an EAS from the background. From a PTT trigger, the PDM electronics will send a starting point, which contains the pixel coordinates and the GTU which generated the trigger. The LTT algorithm will then define a small box around it, move the box from GTU to GTU and integrate the photon counting values. When the excess of integrated value above the background exceeds the threshold, an LTT trigger will be issued. Currently it is foreseen to have a total of 67 starting points for the integration, which are distributed equally over time and position around this box. Each integration will be performed over ±7 GTU's for a predefined set of directions. The background-dependent threshold on the total number of counts inside the track is defined to reduce the level of fake events to a rate of 0.1 Hz per FS. These two trigger levels combined together reduce therefore the rate of signals on the level of 10^9 at PDM level.

3 Simulations

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As already pointed, a crucial aspect of each simulation is the background. In presence of background a certain number of Fake Trigger Rates (FTR) is expected. Aim of a trigger algorithm is to reduce this rate without affecting too much the real events rate. The PTT and LTT trigger algorithms were implemented in ESAF - general simulation and analysis framework of JEM-EUSO experiment [4]. However, these algorithms are optimized using stand alone Monte Carlo simulations to minimize the fake trigger rate against average background level. The standalone simlations are much faster and coud be performed in parallel in comparison with ESAF. Very huge amount of simulations is needed, and due to CPU capcaity it is impossible perform it inside the ESAF framework.

In general, the massive simulation results of FTR obtained by fast and standalone simulation code, which contains the trigger algorithm together with background generation input were performed and the results from obtained data will be presented. In the code one PDM was simulated. The PTT and LTT trigger algorithms were implemented.

The background source is the Poisson distribution of average 500 $photons\, m^{-2} s^{-1} sr^{-1}) = 2.1\, photons/pixel/GTU$.

Code is fast, but since to produce very huge statistics, it has to be run in parallel. The Kosice JEM-EUSO PC cluster was used for these calculations [5]. Minimal needed statistics obtained by a year of continuos computing on nearly full PC cluster (over 200 CPU cores), optimally several years (not possible to run continuosly).

Firstly, the threshold levels for triggers has to be adjusted to fit within the permissible fake trigger rates by a large amount of background simulations. This was done for two possible configurations of PDM, for M36 configuration (36 × 36 pixels) and M64 configuration (64 × 64 pixels), too. However, it has to be noticed here, that we hjave consequently performed simulations for both cvonfigurations, only analysis of M36 configuration results are presented in this paper. In Figures 1 and 2 these results for the FTR depending on threshold values for PTT and LTT trigger are shown.

The PTT and LTT threshold values of $PTT_{integr} = 43$, $LTT_{integr} = 145$ for M36 configuration and $PTT_{integr} = 52$, $LTT_{integr} = 115$ for M64 configurtion have been setup and used in massive simulations. The accumulated amount of data for M36 configuration is 10^{12} GTU's actually and among them 12000 LTT triggers and 750000 PTT triggers have been obtained. The statistics for M64 configuration is 5×10^{11} upto now.

Stored are events filtered on PTT and LTT levels. Corresponding two files with an information on pixel positions, time and number of counts are written, when the thresholds are reached. Average size of the LTT output used in following analysis is 250 MB per 10^9 GTU's. They were reprocessed to root ntuples with average sizes of 10 MB per 10^9 GTU's.

4 Analysis

4.1 Pattern recognition

To verify whether the data obtained by simulation of random background could not contain random fake patterns whose can be mistaken as real events, we have applied pattern recognition methods for signal tracks. The signal track on the FS contains information about the observed air shower and consequently about the primary UHECR particle itself. It is a distribution of counts in space and time. There are

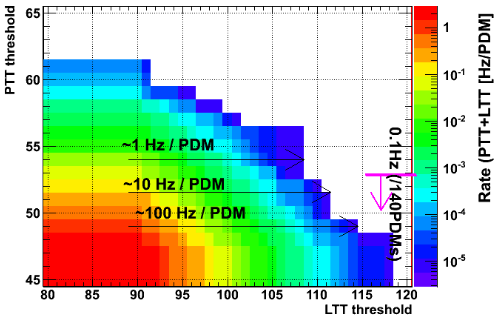

Fig. 2: Thresholds for M64 configuration

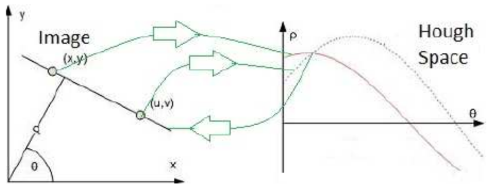

Fig. 3: Hough transform.

possible several algorithms for the pattern recognition and among them we have tried following two:

- Clustering of data points in space and time to disentangle causally related data points from those distributed randomly.
- Hough Transform (HT), developed to identify prefixed shapes within noise by transforming the relevant parameters to Hough space and back.

The presented analysis have been performed by using the second method (HT), which we briefly describe here.

The HT is an algorithm for the discrimination of certain shapes (even incomplete ones) from others, e.g. noise [6]. Longish pattern can be abstracted as a straight line. For each data point the HT assumes a number of lines passing through it. These lines can be parametrized by their distance from the origin of the coordinate system ρ and the angle Θ between its normal and the x-axis (Fig. 3, left). Transformed into the Hough space, a two dimensional parameter space spanned by ρ and Θ each data point represents a sinusoidal curve (Fig. 3, right). The intersection points of the many sinusoidals are summed up in an accumulator. The intersection point that drews in most of the counts is then transformed back into the image space, where it corresponds to a straight line passing through as many data points as possible.

4.2 Results

The simulation results described in section 3 have been analyzed by HT i and consequently by modified HT.

Firstly, we have developed and checked the method on purely uniformly distributedd random values. A large number of matrices 8×8 (like PMT) were generated. Two pattern characteristics are of interest:

- $pattern\ length = No\ of\ pixels\ over\ threshold$
- $average\ pattern\ value = \sum pixel\ values/\ pattern\ length$

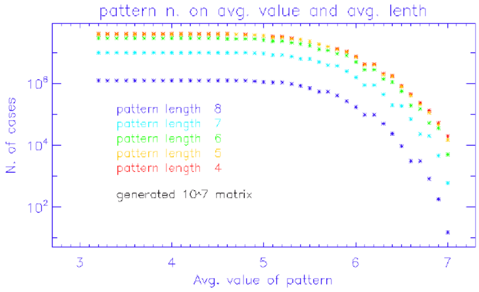

Fig. 4:

Method was firstly tested by putting by hand small amount of patterns to huge amount of generated background. The method reliably detected artificial patterns. In Figure 4 it shown the number of detected patterns dependence over selected average pattern value for several pattern lengths (4 - 8). It can be seen, that for 10^7 generated 8×8 matrices, around 20 matrices with fake pattern with the length of 8 pixels with average pixel value (all pixels at maximum) will be found. It could simply verified. The probabillity that matrix pixel has some value is 1/8. Any 8 pixel configuration lineal pattern 8 pixel long appears with a probability $(1/8)^8 = 5.96 \times 10^{-8}$. Such lineal patterns are 32, then the result is 19.07, compatible with the simulation result.

However, classic HT cannot distinguish between continuos and disconnected patterns. Thus it overloaded the number of recognized patterns. It was needed to improve the algorithm for the JEM-EUSO purpose to be able to differ between such patterns. It was done on the basis of pixel distance.

In the next step we have tested modified HT algorithm on the LTT triggers obtained in section 3. For each LTT trigger we have 31 matrices of 36×36 (M36 configuration) - the actual snapshot and for 15 anterior and 15 posterior in GTU.

The real shower appear as a light speed moving point. On the basis of this we have developed a strategy of folding above mentioned matrices to recognition the moving patterns. We have divided atmosphere to cells equivalent to pixel projection of JEM-EUSO PMT pixels on Earth surface (i.e. $0.51 \times 0.51 km$ in nadir mode of detector). For a set of zenith and axial angles of incoming particle direction we evaluate a projection of moving light point created by shower on Earth surface and time when pixel is observed in GTU unit.

Every direction of incoming EECR particle is equivalent to set of projections in consequetive GTUs. Then for one incoming direction we can take only columns where for this directions will be moving light point visible from stored 31 matrices and combine from these columns a new matrix. Pattern recognition method is then applied to this new matrix. We build over the stored 31 matrices a set of new matrices for selected incoming angles of primary cosmic rays. Such analysis is applied to all simulated sets of 31 matrices passed LTT trigger.

The method validity was verified by artificial patterns with known incoming direction added to tested data set. All artificial patterns were found by the method.

Finally we go through 10^{12} simulated GTU's on one PDM. This is equivalent to 3.3 hours measurement of all

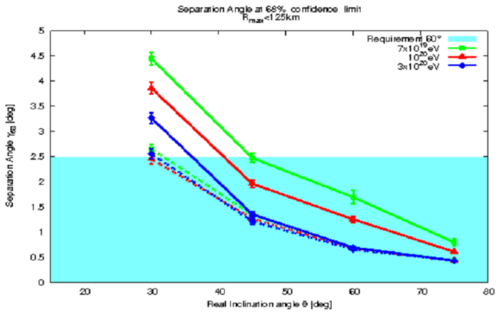

Fig. 5:

137 PDMs of JEM-EUSO detector. The number of founded patterns as a function of pattern length is presented on the Figure 6.

Example of analysis result for 10^9 GTU's run equivalent to 2500 second measurements at one PDM of detector is presented by blue line with diamonds. The result from full analysis of 3.3 hours measurements of all detector is presented by magenta line with triangles. We fit both of them by statistically motivated function:

$$N_p\left(L_p\right) \sim (1/N_{pix})^{L_p}, \tag{1}$$

where N_p is number of recognized patterns, L_p is the patern length and N_{pix} is number of possible pixel values. We set a number of possible pixel values to 8 following a histogram of pixel values. This approximation conservatively estimate number of patterns for longer patterns founded in analysed data set. Conservatively because ... mozno doplnime ...

If we scale approximation to one day measurement of all detector (green line on Figure 6.), we can find the few patterns with length of 11 and maybe one with length of 12 pixels. Further approximation scalling to full planned 3 years of JEM-EUSO operation, we will find only one pattern with the length of 15 pixels. This 15 pixels on ground means 7.65 km long projection of shower. Showers created by more inclined and higher energetic particles are more easy to recognize and reconstruct. Let's assume the worst case when we will have particle with energy $5 \times 10^{19} eV$ and with maximum zenith angle. Particle with such energy can create first pixel visible by detector at altitude 13 km. If fake pattern will be 7.65 km long with first visible point at altitude 13 km, then zenith angle of primary particle is 30.5 degrees. In another words, fake pattern during 3 years of measurement can be mistaken by particle with zenith angle maximaly 30.5 degrees. If we look to our ability to reconstruct real events we can see that under 30 degrees we are not able to reconstruct events in defined mission requirements (i.e. with error less than 2.5 degree). This is upper limit for fake event to appear in measurements. We can conclude that during 3 years of measurement we cannot mistake fake trigger to real event.

5 Conclusions

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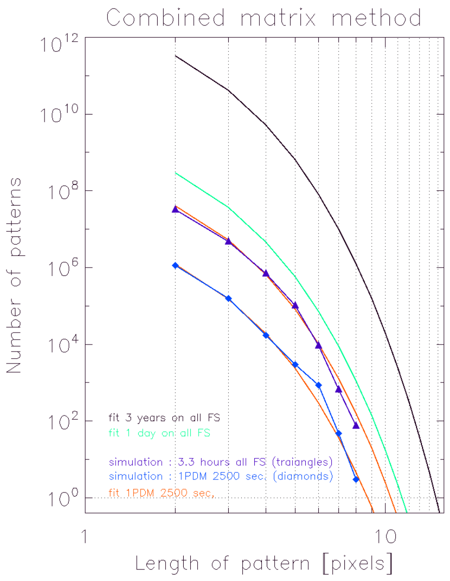

Fig. 6:

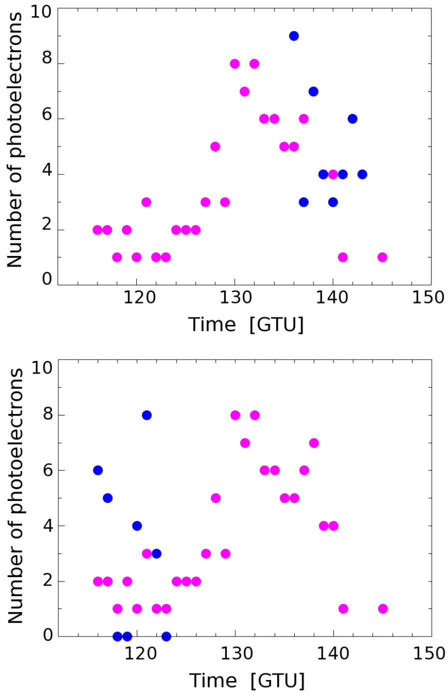

Fig. 7:

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