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Using two-photon statistical contribution in the detection of telescopes EUSO

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Abstract

The Extreme Universe Space Observatory onboard Japanese Experiment Module (JEM-EUSO) is the future space observatory will be installed on the International Space Station (ISS) to study the comic rays of ultra high energy (UHECR). The Photo detector module (PDM) of telescope (JEM-EUSO) is characterized by high sensitivity detection that allows you to detect single photons of UV backgraund. The telescope EUSO-Balloon was the first prototype to validate JEM-EUSO chain detection in extreme environmental conditions. The post flight analysis of the efficiency of EUSO-Balloon detection showed that only 30 % of the pixels met the technical requirements for the study of EAS et detection of UV background (required efficiency of photo-detection > 12%). The next prototypes of JEM-EUSO have as their mission the Extensive Air Shower (EAS) detection of UHECR with energies $> 10^{20} eV$. An requirement for this, it is the validation of the systems trigger, which distinguish this luminescence over background noise UV. These systems trigger requires that all pixels are operational, this means, these pixels must be able to detect events corresponding to one photo-electron (pe) per gate time unit (GTU=$2, 5\mu s$). This work is about a method to offset, to some extent, the problem of efficiency loss of detection channels. The formation of a pulse signal corresponding to 1 pe is governed by the Poisson distribution, this means that there are pulses formed by the pil-up of two or more pulses. That may eventually be used to estimate the efficiency of pixels with weak performance.

Keywords: JEM-EUSO, EUSO-Ballon, photo detection, EAS, UHECR

1. Introduction

The mission EUSO-Balloon was about the flight of 5 hours at 38 km altitude of a stratospheric balloon which payload was a telescope which observed the ground in nadir mode. This mission took place on August 24, 2014 at the base of stratospheric flights of the ASC (Canadian Space Agency) in Timins Ontario. The launch and recovery of the balloon payload was in charge of CNES-France (Centre National d'tudes Spatiales).

This telescope have a Field of View (FOV) of 12° (observation area ~ 50 km^2) and its objective was the detection of background UV emitted by different sources on the ground. The telescope showed the ability to detect photon flux of UV background (500 $photons/m^2/ns/sr$ in moonless condition) which corresponds to ~ 1 photo-electron per GTU per pixel. On the other hand, the parameters that modulate the sensitivity of the detector must be well chosen to detect the simulation of a EAS. This simulation consists of a pulse laser beam fired from a helicopter flying below the altitude balloon at 20 km. These objectives were achieved, allowing the validation of the concept and some devices of chain detection. Also, the mission gave knowledge to improvements in hardware and software of the new telescopes EUSO family.

The post-flight EUSO-Balloon calibration showed that only 30% of pixels meet the detection efficiency. > 12% [1].

Trigger systems used persistent photons detected within a sub-array of pixels neighboring lapse of certain time [3]. Therefore triger system requires these pixels (within the sub-matrix) are efficient enough to detect single photons detection. And with it, not to lose the op-

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portunity of a detection of an EAS. The problem arises when the amplification gain of the photomultiplier is small and the generated pulse is indistinguishable from electronic noise.

Another critical point is the ability of the electronic system to discriminate the signal. This discrimination efficiency decreases when the electronic noise increases or when the linearity between the discriminated counts versus detected events (pe) decreases for reasons of pilup pulse. These impairments are progressive and increases with use and / or hostile space environment.

In summary, the values affected: The trigger system efficiency, the energy presition ($\Delta E < 30\%$) and the slant depth presition ($\Delta X_{max} < 120 g/cm^3$) [2]. At present the new ASIC-SPACIROC 3 (Application Specific Integrated Circuit-Space Readout Chip) has a linearity count $> 100 pe/GTU$ outperforming the SPACIROC 1 of $20 pe/GTU$ which were used in TA-EUSO and EUSO-Balloon. But the slow loss of profit in the photomultiplier still not resolved.

2. The photo-detection with the Photo Detector Module of Euso Balloon

2.1. Description of PDM [6]

El Photo Detector Module (PDM) is the UV camera located on the focal surface of the diffractive optical of the telescope. This is the prototypo basic unit detection JEM-EUSO. Its front-end is formed by 36 Multi anode Photomultipliers (MAPMT) where the anode matrix represent 64 pixels [7]. These MAPMTs are grouped in elementary cells (EC-Units) in groups of 4. Each EC-Unit has a high voltage supply based on a Crockroft-Walton circuit (CW). The surface of the MAPMTs are covered by a UV filter that allows the passage of only photons with wavelengths between 290 – 430 *nm*. Each MAPMT is connected to an ASIC. These ASICs are grouped together in groups of 6 in a borad called EC-ASIC. The EC-ASICs communicate with the PDM-board whose main component an programmable logic device FPGA (field-programmable gate array) and is responsible for management of the PDM. The ASIC trigge the analog signal in function to an threshold V_{th}. It is also responsible for the digitization of date. The FPGA has among many of its functions to performer the algorithm trigger L1 or persistent track Trigger (PTT). In total it has 2304 pixels which corresponds to each channel signal transmission extending from the MAPMTs pins to into the ASIC. Inside of ASICs this channel through the amplifiers, the system of discrimination of the analog signal called Photo-Counting and Digital Part that digitizes the trigger signal.

2.2. Le processus de photo-detection

The distance between two photons emitted by an EAS is greater than the wavelength of the photons. Then the photons are incoherents and we be consider than photon flux obeys the Poisson distribution (Apendix G [4]). When a photon hits the surface of a pixel, there is a probability that this release an electron in the photocathode (photoelectric effect) called photo-electron (pe) This process is governed by a binomial distribution whose probability of success is known as quantum efficiency ϵ_q. The pe released then stimulates the formation of a multiplicative electronic cascade in a configuration 12 dynodos. Thanks to a potential difference between dynodos. The last stage of the electronic cascade is collected at the anode of MAPMT. The gain amplifier depends on the voltage supplied to MAPMT and our case is 10^6 to 950 V. This mean than for each pe released into the photo-cathode, the charge accumulated in the anode is 160 fC [8]. The statistics of the amplification process in the diode is a complex process and studied with many mathematical models ([5], [9]). The advantage is that the gain of the first The analysis of the SNR for dynodos chains show that the gain of the first dynode is the main determining factor. Finalment the statistical law of charge accumulation process at the anode will be the combination of photon flux distribution with the binomial distribution of emission in the photocathodo and the process of multiplication of dynodos. Then, the signal-to-noise ratio for the anode is (equation G-73 [4]):

$$SNR_a = \sqrt{\frac{\epsilon_q \cdot \bar{n}_{ph}}{\left(\frac{\delta}{\delta-1}\right)}} \tag{1}$$

Where $\bar{n}_{ph}$ is the average photon arrival rate of a source (eg:EAS or UV background) and δ is the gain of first dynode. For very large gain values we can say that the dependence of the SNR is clearly of quantum eficaidad. This allows us to state that the number of pulses at the output of the anode is practically the number of PEs that are released into the photocatodo. Restricting the analysis to the processes: arrival of photons to photocatodo and release of pe from photo-cathode, this means that the distribution to consider is the combination of the distribution of these two processes (Poisson and binomial respectively). This type of combination is a new poisson distribution with mean $\lambda = \epsilon_q \times \bar{n}_{ph}$. Keep in mind that lambda is a average rate. Then the number of events (pulses or pe) depends on a temporary