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TUS space detector as a pathfinder for the next generation space detectors

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Abstract: Space detectors of UV fluorescence and Cherenkov light radiated by ultra high energy extensive air showers (UHECR EAS) have advantages of high EAS detection aperture in observing the whole sky by one instrument and will be able to get statistically rich results on the UHECR arriving directions. At the same time the space environment and particularly variable UV background intensity put some restrictions to EAS measurements from the satellites. Before making and launching the full scale fluorescence detectors like JEM-EUSO and TUS-M for UHECR measurements the TUS detector is planned to be launched in 2010. Results of the TUS detector will help to make final design of the next generation of space UHECR detectors.

Introduction

At extreme energies $E>5x10^{19}$ eV the near UV fluorescence signal from the EAS particle disc is high enough to be observed from space, by the detector comprising a moderate size light collectors (2-3 m in diameter). Two kind of optics are being developed for the space EAS detectors: 1) narrow field of view (FOV) reflective mirror- concentrator optics and 2) wide FOV complex transparent lenses optics. The advantage of the first option is a possibility to develop a large area reflective mirror and put it at high orbit (up to geostationary orbit) so that it will cover area in the atmosphere comparable to the Earth disc area. The same detector at moderate height orbits (400-500 km) will have the advantage of low energy threshold which is important for developing the ultra high energy neutrino astronomy. The second option has an advantage of covering a large area in the atmosphere from the "economy" orbits of 400-500 km height, particularly from ISS. The first option is developed in the "TUS" collaboration and the second option – in the "JEM-EUSO" collaboration. The TUS project was planned as a step-by-step progress in space instrumentation with the first step (already achieved, see [1]) of checking the photo receiver sensor operation in space and getting data on the near UV atmosphere background radiation. The second step is the operation in space of the pilot fluorescence imaging detector with the mirror area of about 2 m^2 and photo receiver of 256 pixels. In the final

TUS-M detector the mirror area has to be 10 m^2 and number of pixels of about 5000. The pilot TUS detector expected to be launched on 2010- before the JEM-EUSO detector will be constructed- and both collaborations decided to use this detector for testing some of the JEM-EUSO technology in space.

Instrumentation

In the pilot TUS detector the EAS fluorescence (and backscattered Cherenkov) radiation is collected to the photo receiver by the mirror- concentrator shown in Fig. 1. The mirror concentrator has 6 standard Fresnel segments and one central parabolic mirror. All of them are made as carbon plastic replica of the corresponding 2 steel molds, see [2] for details. At focal distance 1.5 m from the mirror surface the mosaic of pixels (PM tubes with square window light guides) are placed, Fig. 2. In the original TUS photo receiver all pixels are PM tubes of Hamamatsu R1463 type, 13 mm diameter. The light guide window has the size 15 mm, so the pixel angular size is 0.01 rad. The tube anode integration RC is equal to the ADC time sample t_s =0.8 μs. One ADC is used for 16 pixels, the multiplexer for 16 channels is operating with the frequency 20 MHz. Digital information comes to the FPGA unit serving one cluster. Digital information from 16 clusters is gathered in the central FPGA in which the trigger system for the full photo receiver is organized. The cluster of 16 pixels has also a common high voltage supply, so the cluster of 16 tubes is a standard unit of the photo receiver. The tube voltage is corrected by the control circuit measuring the background UV atmospheric intensity so that the tube gain is at its maximum when the UV intensity is at its minimum of ~4 10^7 ph/cm^2 s sr. The UV intensity is determined by two code numbers: M- code of the voltage and N-code of the ADC proportional to the anode signal. With atmospheric UV intensity increasing the voltage (gain) is decreased as a root square of intensity. Correction is done every second. This approach allows to operate the TUS detector in all range of UV intensities of the night atmosphere (from moonless to full moon nights). It was tested in operation of the MSU satellite “Tatiana”. In analysis of the selected events the pixel signal is measured in number of photo electrons (p.e.) defined as ratio of the signal value to value of one p.e. signal measured for every pixel before the flight as a function of PM tube voltage and controlled at flight in measurement of the background ADC distribution, see [3].

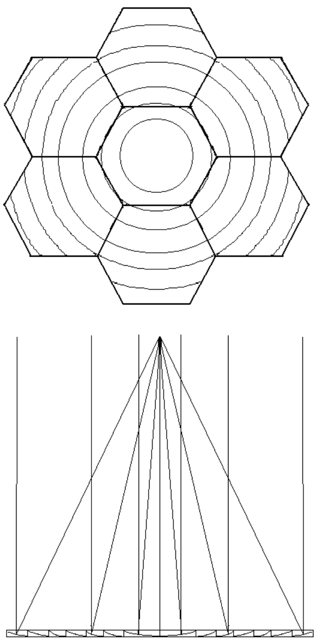

Figure 1: TUS mirror-concentrator.

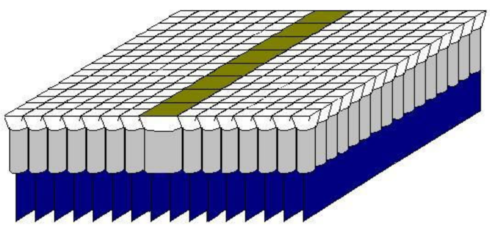

Figure 2: TUS photo receiver. Two central lines of PM tubes are replaced by multi- anode tubes of the JEM-EUSO type.

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In the JEM-EUSO the other approach to measurement of the EAS signal is implemented. In every pixel (which is one anode of multi-anode PM tube) the rate of single p.e. is counted and p.e. number measured in a time sample is recorded. This sampling time is set at 2.5μs which is called a Gate Time Unit (GTU). The voltage on the multi-anode tube is basically constant and the threshold for a single electron counting is selected for every pixel before the flight, though they can be variable on the flight. The JEM-EUSO approach has an advantage of low power consumption for a large number of pixels of about $2x10^5$, see [4],[5]

The p.e. counting rate of the JEM-EUSO pixel of size 4.5 mm, of quantum efficiency 0.3 in the focal plane of the 4 m^2 with the focal distance 2.5 m is on moonless nights (UV intensity 4 10^7 -10^8 ph/cm^2 s sr): 0.6-1.4 MHz. This background rate is order of magnitude less than expected p.e. rate in the EAS signal (for primary energy 10^{20} eV, the p.e. rate at shower maximum is ~20 MHz). On nights with moon the UV intensity is growing with moon phase and at full moon it is $2x10^9$ ph/cm^2 s sr s. The JEM-EUSO detector is not supposed to operate at full moon nights as the PM tube anode current will exceed the operation limit and because the background p.e. rate (>100 MHz) will exceed the limit of the counting rate for time sample of p.e. pulses 10 ns.

To check a real duty cycle of the JEM-EUSO pixels and a performance of JEM-EUSO electronics in space conditions we decided to incorporate a line of multi-anode tubes (of size 30 mm) instead of two lines of the TUS pixels (of size 15 mm) as it is shown in Fig. 2. In this part the lateral resolution of observing the EAS disc will be higher but because of limited area of TUS mirror the signal in one pixel would be significant only in the largest EAS. The pixel high resolution will be useless at the periphery of the receiver where the mirror aberration is high. The p.e. rate of JEM-EUSO pixel in the TUS detector will close to presented above estimates.

A difficult problem of the simultaneous operation of the TUS and JEM-EUSO pixels is the triggering by events observed in both parts of the receiver.
At present we are working on the design of the electronics for the joint TUS-JEMEUSO photo receiver. This design would be presented at the conference.

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