Extremely High Energy Cosmic Rays—Experiments, Theories and Future Direction—
J. Phys. Soc. Jpn. Vol. **70** (2001) Suppl. B pp. 195–198

EUSO System Electronics

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EUSO (Extreme Universe Space Observatory) has been selected by the ESA (European Space Agency) as a mission to be accommodated on the Columbus external facilities module of the ISS (International Space Station). EUSO, currently in phase A study, is scheduled to be launched as from the end of 2007. The system electronics acting as the "brain" of the EUSO telescope is described in the paper. The front-end, read-out, on board data handling and trigger electronics specifically designed for the experiment are presented. The solutions adopted have been introduced to maximize the signal-to-noise ratio and minimize the requirements for power consumption, weight and volume. The characteristic faint fluorescence signals seen by the telescope from an altitude of 400 km, averaged altitude of the ISS, are taken into account to study the response function of the EUSO instrument.

INTRODUCTION

The very low event rate of EECRs (Extreme Energy Cosmic Rays) imposes extremely large sensitive areas. In spite of the big efforts lavished in the last 40 years, no more than a handful of events of energy greater than 10^{20} eV has been reported by the ground based experiments. The Earth atmosphere, viewed from space by EUSO [1] aboard of the ISS, with a geometrical factor of 5 x 10^5 km^2 sr and target mass of the order of 10^{12} tons, constitutes an ideal absorber/detector for the EECRs and Neutrinos. EECRs, including Gamma Rays and Neutrinos, colliding with air nuclei, produce secondaries that in turn collide with the air molecules giving rise to a propagating cascade of particles (Extensive Air Showers, EAS). A high energy EAS forms a significant streak of scintillation light over 10-100 km in length along its passage in the atmosphere, depending on the energy of the Primary and the angle with the vertical axis. Ĉerenkov light moving nearly with the same direction of the shower axis is also produced and diffused backward at the impact point on ground, sea or clouds. The observation of this fluorescence and Ĉerenkov light with a detector at distance from the shower axis is the best way to control the cascade profile of the EAS. A schematic representation of the EUSO detection concept is depicted in fig. 1. The resulting event seen by the detector looks like a narrow track in which the recorded

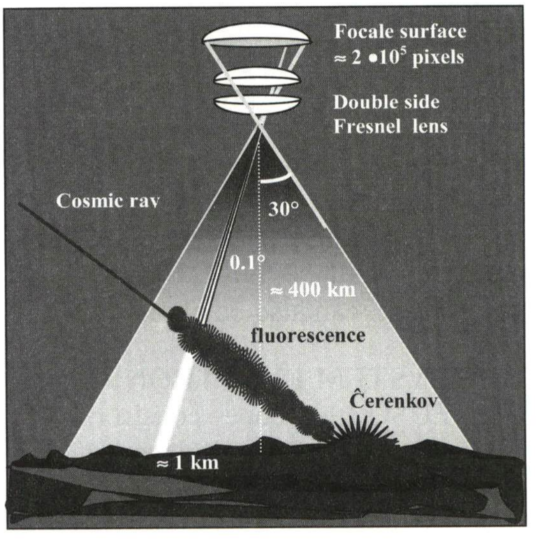

Fig.1– Artistic representation of Fluorescence (left) and Ĉerenkov (right) lights as imagined by the ***EUSO*** telescope (not on scale).

amount of light is proportional to the shower size at the various penetration depths in the atmosphere. The integral of light recorded in the track (as well as the light signal at the shower maximum) is proportional to the Primary energy. The cascade shape (especially the position of the shower maximum as a function of the penetration depth) gives an indication about the nature of the Primary. A different shape for the cascade curve is expected for different particles initiating the EAS. Showers initiated very deep in the atmosphere indicate an origin by neutrinos because the neutrino-air nuclei interaction cross section is several orders of magnitude lower than the cross section for hadrons or photons.

The fluorescence method has been successfully implemented at operational level by the "Fly's Eye" [2] in the past and presently by "HiRes" [3] in Utah; it is planned, in combination with an array of Water Cherenkov particle detectors, as baseline for the Auger project [4]. From the ISS the UV fluorescence induced in the atmospheric nitrogen by the incoming radiation can be monitored and studied; the luminescence coming from EAS produced by the Cosmic Ray (protons, nuclei, gamma rays, neutrinos,...) can be disentangled from the general background and measured. Other phenomena such as meteors, lightning, atmospheric flashes and distribution of minor components in the atmosphere, can also be observed.

THE SYSTEM ELECTRONICS

The EUSO telescope consists of three main parts: optics, focal plane detector and system electronics. A schematic representation of the telescope is shown in fig. 2. An exhaustive overview of the EUSO telescope can be found in ref. [5]. The purpose of this contribution is to present a general description of the proposed system electronics for the EUSO telescope.

The development of a suitable front-end, read-out, data handling techniques and trigger has been one of the major contributions to the EUSO project. The very wide field of view of the optics (±30°) requires a large numbers of image-sensors (pixels) of the order of $2x10^5$. The complexity of the electronics, demanding a huge amount of channels, makes conventional solutions not generally suitable for mission based on space vehicles, where stringent limitations are present for power, weight and telemetry. To overcome such a problem, in the assumption of using a fast detector capable of detecting single photoelectrons, it is necessary to reduce the number of position and timing channels without significant loss of information. A modular Fluorescence Image Read-out Electronics (FIRE) and an On-board Unit System Trigger (OUST) have been designed specifically for such experiment. The modular hierarchical organization of FIRE, assisted by OUST, allows to register X-Y position and arrival time at level of the single photoelectron. The system electronics is constituted by the two main

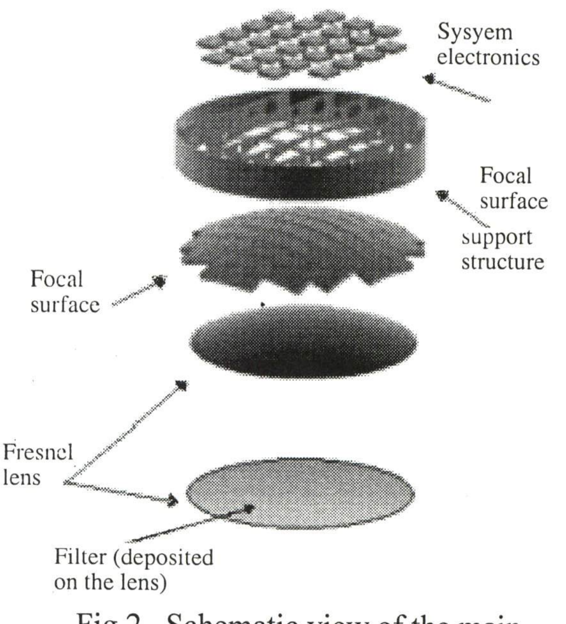

Fig.2 . Schematic view of the main components of the EUSO telescope.

modules, which orchestrate the major functions of the system as binary readout of the detector signals, data handling, trigger decision and data validation and compression [6].

A simplified block diagram of the system electronics is shown in fig. 3. Pixels detector front–end and macrocell (n x n pixels matrix) units constitute the **FIRE** system whereas control and trigger module forms the **OUST** module.

The pixel front-end level constitutes the very front-end of the instrument. It is also the only analog section of the Pixel Front-End. A fast comparator is directly coupled to the anode of the MAPMT (Multi Anode Photomultiplier) with sensitivity to the single-photoelectron pulses. Double pulse resolution of the order of 10 ns is required for optimization of dynamic range. The fast comparator generates a fast pulse every time the analog threshold is exceeded. The pulse is routed to a counter and compared with a pre-set value. When pre-set counter value is reached within a GTU (Gate Time Unit), the set X,Y lines of the wired-ored pixels are stored in the X,Y ring memories and the pulse counting output is enabled until the successive starting phase of GTU signal generating the reset of the counters and writing of memories. At macrocell level the pulses coming from all the enabled pixel circuits are counted and compared with a pre-set value calculated to be of statistical significance for event triggering. Exceeding of the pre-set value is sent as one-bit information (one per macrocell) to the system trigger and the content of the macrocell counter stored in an additional ring memory. Fig. 4 shows the contents of the position ring–memories for a simulated shower track. The X and Y projections show the track as memorized respectively in the X and Y memories. Dots represent the pixel background related to the time (GTUs) involved in the shower–event developing process. The system trigger elaborates the incoming macrocell-trigger information seeking a persistency of activity in one or more macrocells lasting for a minimum to a maximum time (30 to 300 μs approximately), expected time of traveling trough the atmosphere of a shower event. The system trigger is software re-configurable for better performances of the trigger operations. A track length persistency algorithm is used to control the save operation starting a data

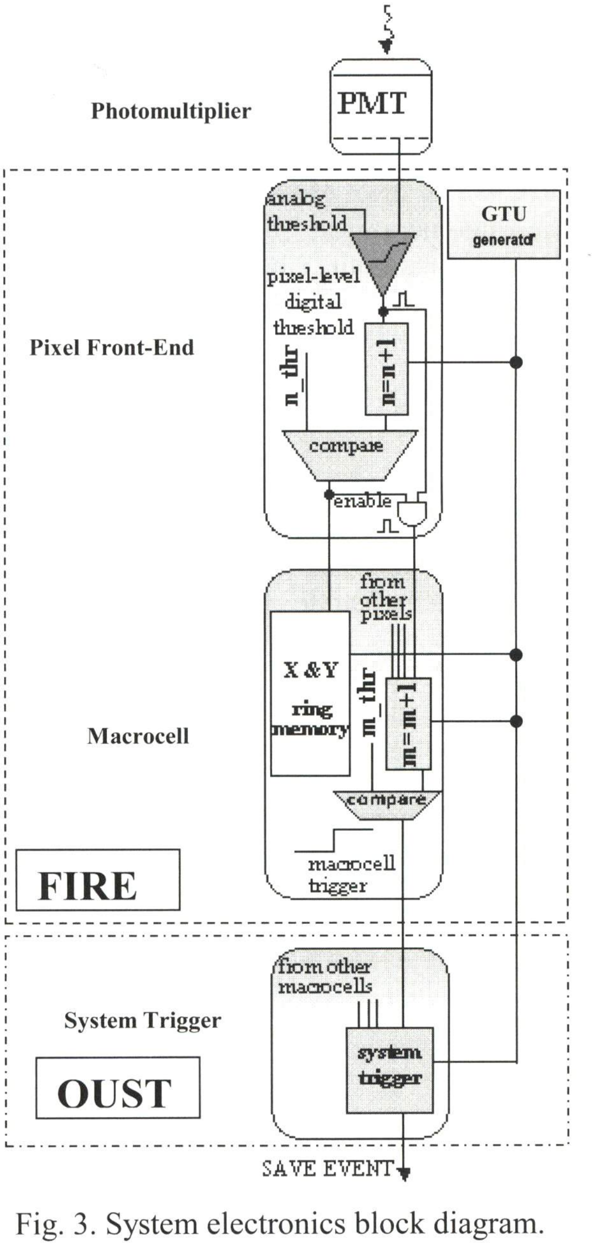

Fig. 3. System electronics block diagram.

read-out sequence. At this stage all the information from the relevant memories are sent to the
telemetry buffer memory for successive downlinks.

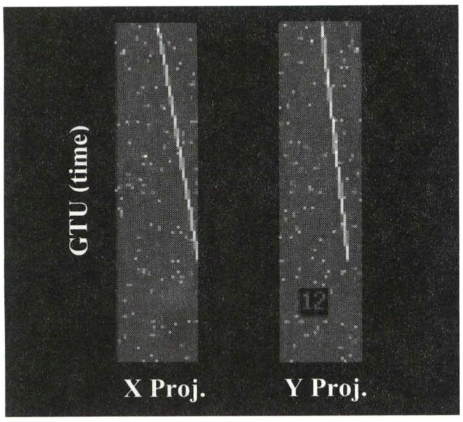

Figure 4: The track as recorded, after triggering, in the ring–memories. The X and Y projections shown graphically the ring-memories contents in terms of binary digital information.

CONCLUSIONS

The EUSO system electronics has been described. Only the conceptual design has been presented while are currently in progress phase A study aiming to demonstrate the feasibility of the overall system.
The method described is applied to the reconstruction of fluorescence UV tracks with a trigger efficiency, angular resolution and energy resolution comparable to the conventional ground fluorescence experiments. This method has been developed specifically for the system electronics of EUSO. The highly demanding conditions of the space environment have imposed an optimized ad-hoc solution for the design. The system proposed merges several stringent requirements as those to keep the total power consumption of the system electronics within the power budget available on the pallet facility of the ISS; handle hundreds of thousands of pixels with a reasonable simplified hardware implementation; provide a reliable and prompt trigger to the system supporting different event-trigger levels; introduce flexibility and redundancy in the design, segmenting the focal surface and relative associate electronics (macrocells).

References

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