A photo-detector for UHECR observation from space

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Abstract

It is most likely that the next generation of experiments for the study of the Ultra High-Energy Cosmic Radiation (UHECR), that is cosmic particles reaching the Earth with energies in excess of 10^{19} eV, will consist of space-based experiments. The observation from space of the Extensive Atmospheric Showers (EAS) produced by UHECR is a big challenge, because the faint signal must be extracted from a large background by an experimental apparatus operating in space.

The requirements for the photo-detector for such a kind of space missions will be briefly discussed and the solutions adopted for the design of the photo-detector of the EUSO experiment will be presented.

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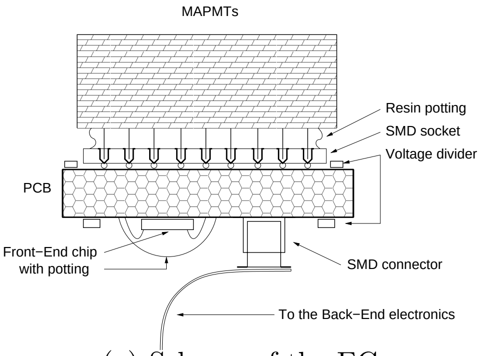
1 Scientific Motivations and the required apparatus

The interpretation of the phenomenology of the Ultra High-Energy Cosmic Radiation (UHECR) is one of the most challenging topics of modern astroparticle physics [1]. UHECR reach the Earth with a very low flux (of the order of $\mathcal{F} \approx 0.01$ particle year^{-1} km^{-2} sr^{-1} for particles with an energy $E \gtrsim 10^{20}$ eV) and therefore a huge target as well as a complex and sophisticated experimental apparatus is required to observe them.

One approach with great potentialities was first proposed by John Linsley in 1982 [2]: the observation, by means of a space-borne apparatus, of the Extensive Air Showers (EAS) produced by the interaction of primary UHECR with the atmosphere, by looking down to the Earth atmosphere from Space at night (*AirWatch* concept).

An EAS can be detected by observing the faint atmospheric scintillation light isotropically produced all along the EAS development. Moreover the observation of the forward beamed Cherenkov light diffusely reflected by the Earth (land, sea or clouds) can help the EAS reconstruction. The atmosphere is thus used as a calorimeter, which is passive, continuously changing and outside human control. The required apparatus is basically a fast digital camera for near-UV faint signals in a large background, capable of space operation. However the design of such an apparatus is challenging, due to the many requirements and constraints.

The main requirements for the apparatus, photo-detector and associated electronics are: large aperture and large field-of-view optics, with high throughput and angular resolution of the order of one tenth of degree; an optical filter to improve the signal to background ratio by selecting the wavelength range; single photon sensitivity in the 330 nm $\div$ 400 nm wavelength range with good overall efficiency, as the signal is very low; low noise and good signal to noise ratio to detect the faint signal produced by the less energetic EAS and to discriminate it from the huge background; a moderate spatial resolution of the order of a few mm; suitable fast and pixelized sensors to cover the large area curved focal surface of the optics, with large geometrical acceptance and filling factor; fast response, with single photon counting at about ten MHz, to follow the EAS space-time development; a modular photo-detector architecture, to handle the large number of channels ($10^5 \div 10^6$); a fast and low-power front-end electronics; an efficient and selective trigger, which must be fast, reconfigurable (for EAS, Calibration and slow phenomena), parametric (setting according to the expected background), self adapting (to fast changes of the local background conditions); compliance with the tight resource limitations, including (in the case of EUSO): mass $\lesssim$ 1.5 ton; power $\lesssim$ 1 kW; volume $\lesssim$ (2.5 × 2.5 × 4.5) m^3 and telemetry $\lesssim$ 180 Mbits/orbit. Finally the whole



(a) Scheme of the EC.

(b) Front-view of the prototype EC, with three of the MAPMT installed.

apparatus has to be compatible with the requirements imposed by a Space mission including: mechanical robustness and compactness, resistance to environmental factors (including radiation, chemical contamination and thermal excursions), high reliability and low ageing.

2 The EUSO photo-detector

In order to handle six thousands MAPMT in a space mission within the tight resource limitations the EUSO photo-detector is based on Elementary-Cells (EC) housing four Hamamatsu MAPMT, all the associated electronics (including the front-end ASIC) and the ancillary components in a totally autonomous assembly [3,4]. The EC implements a highly modular architecture and combines different functions together to save on resources by integrating mechanical, thermal, electrical, electronics and data extraction functions together. The EC is thus a highly flexible and general purpose device for building arrays of MAPMT (see [3]). The scheme of the EC and a picture of one prototypes are shown in figures 1(a) and 1(b)

Prototypes of all the elements were built and an extensive test campaign was started. Mechanical tests of the EC with the expected levels for a space mission were successful. Heat dissipation tests, with the expected thermal environment, proved that the prototype were working according to the specifications.

A dedicated front-end ASIC (MARS: Multi-Anode Readout System) was designed to cope with the following main requirements: preamplify the MAPMT signal; discriminate the signals with a programmable threshold on a channel-by-channel basis to recover the MAPMT gain spread; count the photons detected by each channel during an externally driven time interval of $\approx$ μs (parametric); activate asynchronously the trigger signals when the count exceeds a programmable digital threshold; mask noisy or bad channels; provide the logical signals and storage capabilities required by the triggering system; accept commands, parameters and settings from a serial line; average power consumption $\approx$ one mW/channel; radiation tolerant technology and space qualification.

A third generation prototype in the AMS S35 Si-Ge BiCMOS 0.35 μm technology was delivered in February 2005 (18 independent channels); tests are just starting. Tests on the previous generation of prototypes had showed a power consumption within the requirements, acceptable channel-to-channel uniformity and low noise.

A complete test system was also developed (IEFE, Interface to EUSO Front-End) featuring: interface to the Front-End ASIC; USB link to a PC and fully programmable logic and functions, in order to control up to 8 MARS.

3 Conclusions and Acknowledgements

The understanding of the space-based approach to UHECR observation, more than 20 years old, is now reaching its maturity, and it is now ready to pass into the implementation phase. The problem of operating six thousands of MAPMT in space has been faced for EUSO: it was found to be technically feasible, but very challenging. Tests on prototypes have validated the preliminary design of the EUSO photo-detector, which proved to be totally successful, for a path-finder/pioneer experiment such as EUSO. UHECR observation from space (like many other applications) is photon-hungry. Future projects might benefit (actually they might require): better detection efficiency in the near-UV; capability to fill a large curved focal surface with negligible dead areas and good uniformity; robust, stable and reliable sensors with low ageing.

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