Focal Surface Detector for Extreme Universe Space Observatory

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The Extreme Universe Space Observatory (EUSO) is a wide angle refractive telescope in near UV wavelength region to detect extreme energy cosmic rays by observing time-resolved air-fluorescence images induced by the airshowers from the International Space Station. The focal surface detector of the EUSO is designed to be segmented into 2.5×10^5 pixels with single photon counting capability as a mosaic of multianode photomultipliers. We describe the current status of the studies together with the experimental results using a small-scale prototype of the wide angle refractive telescope.

KEYWORDS: extreme energy cosmic rays, space observatory, multianode photomultiplier

§1. Introduction

Extreme Universe Space Observatory (EUSO) is the space observatory of extreme energy cosmic rays and neutrinos to be installed on the International Space Station about 400 km above sea level.[1)] The EUSO observes airshowers induced by the cosmic rays by detecting the near-ultraviolet photon emission from nitrogen molecules excited along the airshowers in the earth atmosphere. The EUSO telescope views the area of about 400 km in diameter on the earth surface with the 60° field of view using a double-sided Fresnel lenses with a 2 m diameter entrance pupil aperture and it is capable of detecting 800 extreme energy cosmic rays of $E \geq 10^{20}$ eV per year. The angular resolution of 0.1° corresponds to 800 m spatial resolution on the earth surface.

The time evolution of airshower is observed by the time-resolved imaging of the air fluorescence every 0.8μs and the energy of the primary cosmic ray is measured from the time profile of the air fluorescence yield. The neutrino induced airshower can be distinguished from the atmospheric depth at the shower maximum. The arrival direction of primary cosmic rays is determined by measuring the apparent velocity of the air fluorescence moving on the focal surface. The Čerenkov photons beamed along the airshower reflected on the earth surface gives additional information of landing position of the airshower improves the determination accuracy of the primary particle arrival direction.

§2. Focal Surface Detector of EUSO

The EUSO telescope has a curved focal surface segmented into 2×10^5 pixels to realize the 0.1° angular resolution 1. The shower front of a 10^{20} eV primary proton airshower amounts about 7×10^{10} electrons and positrons and emits about 3×10^{11} photons per meter in ultraviolet region dominated by 337 nm, 357 nm and 391 nm emission lines. About 130 ultraviolet photons are delivered in the time interval of 0.8μs to a 2 m diameter aperture located 400 km away from the shower maximum of a 10^{20} eV airshower. Assuming the atmospheric attenuation of 0.4, telescope transmittance of 0.8 and photon detector quantum efficiency of 0.2, the EUSO focal surface detector receives 8 photoelectrons per 0.8μs. The photon counting capability at a single photoelectron level is strongly desired. The counting capability at the shower maximum of 5×10^{20} eV airshower corresponds to the counting rate of 1 photoelectron per 20 ns. On the other hand, the 0.1° angular resolution corresponds to about 5 mm on the focal plane in the current optics design. Following these requirements, a mosaic of

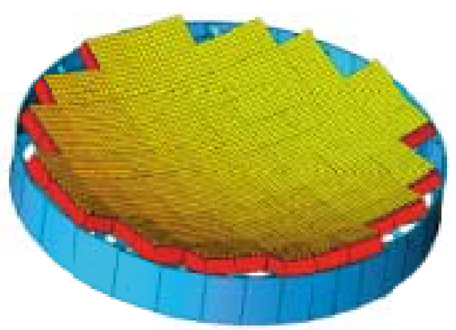

Fig. 1. Focal surface of EUSO telescope is segmented into 2×10^5 pixels and is capable of single photon counting.

segmented photomultiplier array is proposed as the candidate configuration of EUSO focal surface detector.

2.1 Multianode Photomultiplier

A multianode photomultiplier of Hamamatsu R7600-M64 with UV glass entrance window is proposed in the primary design. The multianode photomultiplier has the single photoelectron counting capability with the timing characteristics of ns. It has the bialkali photocathode and is sensitive to photons in the wavelength region of $\lambda = 300 - 650$ nm with the quantum efficiency of 20% at $\lambda = 390$ nm. The anode size is 2mm $\times$ 2mm and 64 anodes are distributed in the 8×8 format. A typical gain of photoelectron amplification is 5×10^5 with a 12-stage dynode stack and the typical gain uniformity among anodes in a multianode photomultiplier unit is 1:3.

2.2 Characterization

We measured the position dependence of the gain of the multianode photomultiplier Hamamatsu R5900-M64 with UV entrance window.[2)] R7600 and R5900 have the same configuration and differ only in the package metal can. The UV light source was a light emission diode which emits photons in the wavelength region of $\lambda = 350 - 400$ nm with the emission peak at $\lambda = 370$ nm. We obtained a 0.22 mm diameter spot of UV light on the photomultiplier entrance window using a pinhole collimator. We mounted the collimated UV light source on an xy scanning stage and measured the anode output levels as a function of UV spot position as shown in Fig. 2. The applied high voltage was -800 V. The crosstalk was evaluated to be 3% in average. Anodes on the edge had the crosstalk of 4% while inside anodes had the crosstalk of 2%. More detailed study of the dependence of the gain distribution and crosstalk on the UV light incident angle and high voltages applied to dynodes and cathode is in progress.

2.3 Uniform Sensitivity

The large non-uniformity of the gain over the sensitive area must be corrected to realize the uniform sensitivity of the EUSO focal surface. The gain adjustment without using amplifier is suitable because of the limitation of power available to EUSO. A possible solution is the fine adjustment of the termination resistance at the input of the comparator to discriminate single photoelectron signals.

A simple array of R7600 has a non-uniformly distrbuted dead area since the sensitive area of R7600 is about 45% of the physical dimension of the entrance window and concentrated in the central region. Optical adaptors to reduce optical images on the focal surface onto the sensitive area of the multianode photomultiplier is being studied using tapered light guides, small lens array and the their combination. However, the increase of sensitive area is more suitable to maximize the detection efficiency. Thus, a new type of detectors such as the flat panel photomultipliers and the multianode with electron focusing are studied in parallel.

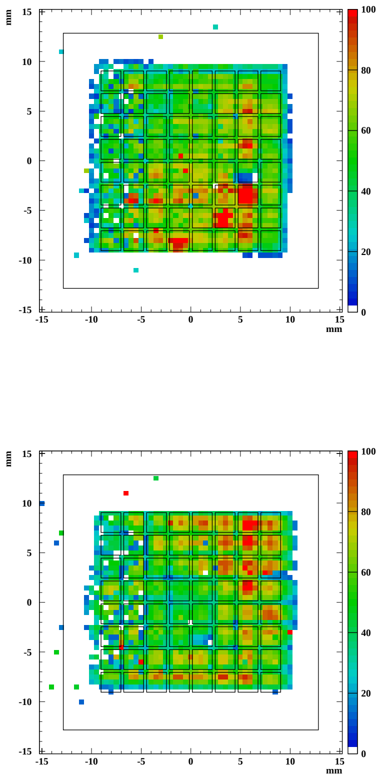

Fig. 2. Anode output levels of two different units of R5900-M64 with UV entrance window measured as a function of UV light spot position. Applied high voltage was -800 V. All output levels measured separately are superimposed in the figure. The anode segmentation and the entrance window are also superimposed in the figure.

§3. A 40 cm Prototype Telescope

We constructed a small-scale prototype of a wide field-of-view refractive telescope as the test bench of the focal surface detector.[3)] The optics design is shown in Fig. 3.[4)] The design value of the spotsize in root-mean-square is shown in Fig. 3.

wavelength [nm]	spot size [mm R.M.S.]				
	0°	10°	20°	25°	30°
337	1.8	1.9	2.1	2.1	1.6
351	0.2	0.5	0.9	1.0	0.7
391	1.9	1.9	1.6	1.5	1.8

Table I. Spot sizes of the 40 cm prototype telescope in root-mean-square for incident angles of 0°, 10°, 20°, 25° and 30°.

The configuration of the prototype is shown in Fig. 4. The prototype consists of two double-sided Fresnel lenses of 40 cm in diameter and 2.3 cm in thickness. Both lenses were fabricated by the direct cut on the polymethylmethacrylate (PMMA) using a ultraprecision cutting/grinding machine in RIKEN. The grooves were made with the constant pitch of 1 mm and the groove depth ranging from 0 to 0.73 mm. An absorptive UV

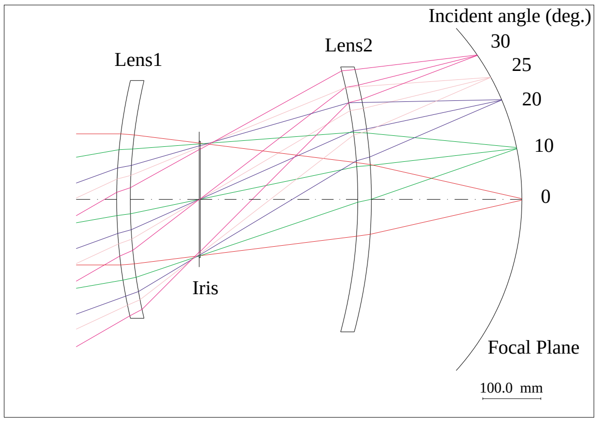

Fig. 3. Optics design of the 40 cm prototype telescope. Total field of view is 60°.

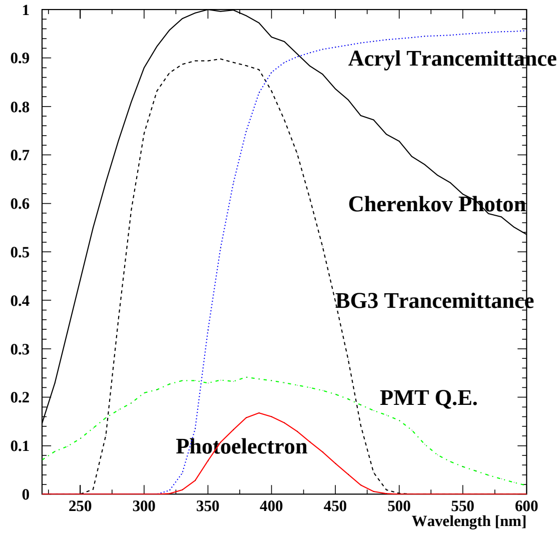

Fig. 5. Overall efficiency for the airshower Čerenkov photons plotted as a function of photon wavelength, together with the two Fresnel lenses, BG3 filter and photomultiplier quantum efficiency.

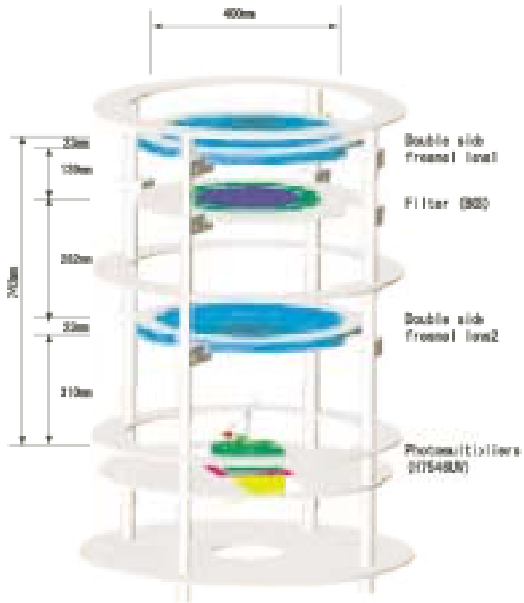

Fig. 4. Configuration of the 40 cm prototype telescope. It consists of two double-sided Fresnel lenses of 40 cm in diameter with the f/#=1.8. An absorptive UV filter (BG3) is placed at the entrance pupil.

Fig. 6. 40 cm prototype telescope.

filter BG3 was placed at the entrance pupul. The overall efficiency for the airshower Čerenkov photons is shown in Fig. 5 together with the transmittance of two lenses, that of BG3 filter and photomultiplier quantum efficiency.

3.1 Airshower Čerenkov Observation

We carried out an observation of the atmospheric Čerenkov image for the test of the small-scale prototype.[5)] The prototype is shown in Fig. 6.

We placed an H7546UV, which is a R5900-M64 with UV glass entrance window equipped with the standard assembly, at the center of the focal surface. The pixel size of 2mm × 2mm corrresponded to about 0.2° × 0.2° and one H7546UV unit covered the field of view of 1.8° × 1.8°. The block diagram of the data acquisition system is shown in Fig. 7. Photomultiplier outputs were integrated using charge sensitive preamplifiers with the time constant of 1μs and input to peak-hold circuits. The output voltage levels were kept by the peak-hold circuits on the trigger generated by the majority coincidence of discriminators operated at a common threshold level. They were

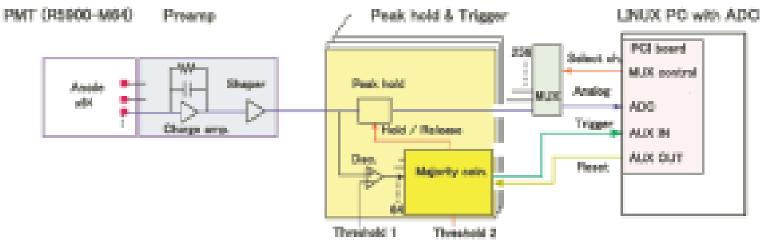

Fig. 7. Block diagram of data acquisition system for the observation of Čerenkov images using the small-scale prototype.

convereted to digital values by a 16 bit ADC through an analog multiplexer (MUX in the figure). Effective dynamic range of the conversion was 10 bits. The readout time for a trigger was about 1 ms for 64 channels.

We placed the prototype at the Akeno Observatory of The Institute for Cosmic Ray Research of the University of Tokyo located 900 m above sea level. An Čerenkov image obtained with the prototype is shown in Fig. 8. The event histogram is shown in Fig. 9 as a function of the sum of ADC values (SumADC in the figure). The threshold energy is estimated to be several hundreds of TeV. The SumADC is proportional to the primary energy of the cosmic rays and the calibration of the SumADC to the primary energy is in progress by measuring the back scattering of a laser shot.

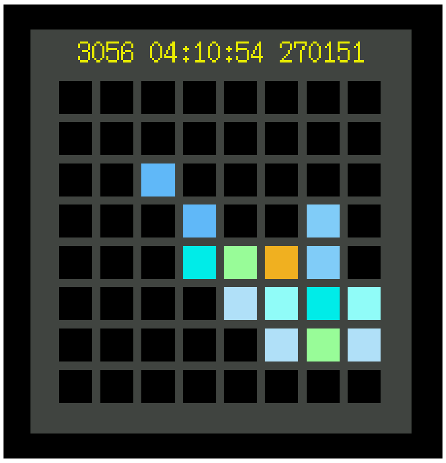

Fig. 8. An image of atmospheric Čerenkov image obtained with the 40 cm prototype.

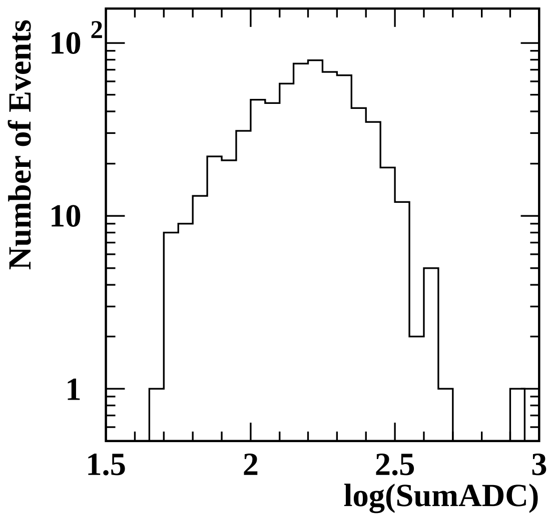

Fig. 9. Histogram of atmospheric Čerenkov events as a function of the sum of ADC values (SumADC).

§4. Summary

The characteristics of the multianode photomultiplier which is a candidate of the EUSO focal surface detector is in progress. A small-scale prototype of the wide angle refractive telescope has been developed for the test bench of the EUSO focal surface detector. We carried out the performance test of the prototype by observing atmospheric Čerenkov images.

For a better uniformity and detection efficiency, studies of new types of focal surface detectors which are multianode photomultipliers with larger sensitive area are in progress.

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