Development of Multi-Anode Photomultipliers for the EUSO Focal Surface Detector

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Abstract

The focal surface of the EUSO telescope consists of a few hundred thousand of pixels of photo-detectors and detects air showers as mosaic images. Since the EUSO telescope observes air showers from high altitude (∼400km), the expected number of photons is small. Therefore uniform and efficient photon detection and small contamination of background photons are very important. We have developed a new multi-anode photomultiplier tube (MAPMT) of weak electron focus type and achieved increase of sensitive area from ∼ 45% to ∼ 83% of physical area.

1. Introduction

To make an imaging detector with huge number of pixels, a MAPMT of 64 pixels (HAMAMATSU R7600-03-M64) or of 16 pixels (R7600-03-M16) with UV glass window is the original candidate detector in the proposal [3]. The advantages of these MAPMT are commercial product, good availability, and widely used. However, its sensitive area is only 45% of the physical area. To overcome this difficulty, many kinds of adaptive optics were proposed [1] and some of them can improve the efficiency up to 60–70%. But practically manufacturing more efficient optics was found to be very difficult. We have developed a new type of MAPMT to increase the sensitive area, which are referred by HAMAMATSU R8900. R8900 is a modified version of R7600 series, by adding a grid between the photocathode and the first dynode for concentrating photoelectrons onto the first dynode. This feature can make a MAPMT sensitive to photons even nearly at the edge of the photocathode. The dimension of R8900 is similar to that of R7600 (26mm×26mm) except for the larger height due to the additional grid and the space for concentrating photoelectrons. We have developed R8900-M16 (4×4 anodes) first, and then R8900-M25 with finer anode format (5×5).

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2. Experiment and Results

A similar measurement system described in Ref.[4] was used. The light of a UV LED (NICHIA NSHU-590E, peak wavelength 370 nm) was collimated to $\sim 100\mu$m in diameter and illuminate a photocathode. This light source is mounted on a steerable stage with four axes, xyzθ, so that the response at any position on the photocathode can be examined. A PMT, the light source and the 4-axis stage were installed in a blackout box with $\sim$ 1m cubic. The signals from a MAPMT were taken by a CAMAC ADC (REPIC RPC-022) system controlled by a Linux PC after amplification. To study the sensitive area, a pulse of 300 ns width is fed to the LED typically, which corresponds to a few thousand photons. The measured MAPMTs were R8900-03-M25 which has anode format 5×5 and R7600-03-M64 which has anode format 8×8.

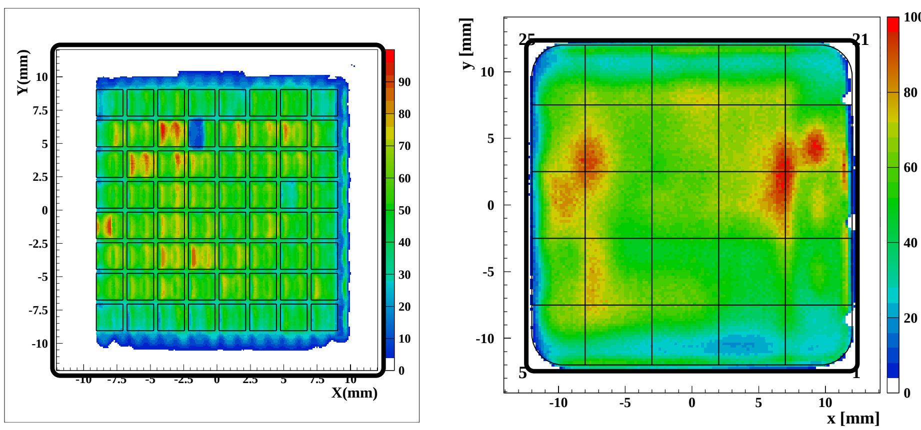

Fig. 1. Comparison of sensitive area. The left panel shows that of R7600-03-M64 and the right panel shows that of R8900-03-M25.

$g_i(x, y)$ is defined as the output of i-th channel of the MAPMT, where (x, y) is the position where the LED illuminate on the photocathode. Fig. 1 shows a sample sensitivity maps ($\sum_{i=1}^{N} g_i(x, y)$, $N = 64$ for R7600-M64, $N = 25$ for R8900-M25) of R7600-03-M64 and of R8900-03-M25. The thick square surrounding the sensitive area in each panel represents the physical size of each MAPMT and the grids show the physical size of each anode. It is clear that R8900 is sensitive to photons even at the edge of the photocathode and the response is almost uniform all over the photocathode, while R7600 isn't sensitive in the surrounding part and the structure of dynodes are seen. This electron focus feature improves sensitive area ratio up to $\sim 83\%$ by simple estimation. The pixel-to-pixel variation of gain for R8900-M25 is around 1:4. There still remains insensitive area mainly due to the packaging material. We estimate simple tapered UV transparent filter such as BG3 on the photocathode will increase sensitive area ratio up to ≥90% all over the focal surface.

However, one of expected disadvantages of electron focusing feature is influence of surrounding magnetic field. We studied this effect by putting a MAPMT in the Helmholtz electromagnet. The MAPMT was more sensitive to the magnetic field perpendicular to the photocathode (hereafter referred as z-direction) than other directions. The gain of R8900-M16 starts to decrease around 0.2 mT in z-direction and half number of pixels deviate down by more than 10% at 1 mT. In the case of R7600, more than 90% of pixels are within 10% deviation under the same condition. In the geomagnetic field on the International Space Station (ISS) orbit, the magnetic field strength varies in the range of $\sim \pm 50\mu$T at 400 km high. It doesn't matter for R7600, and it is still acceptable for R8900.

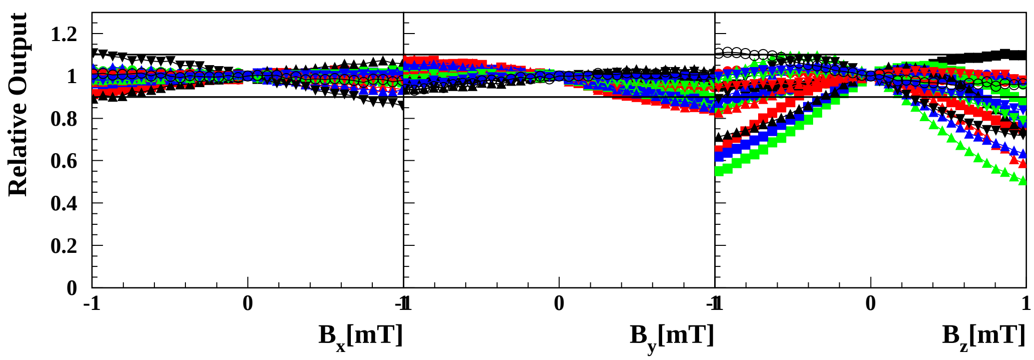

Fig. 2. Relative gain variation of R8900-M16 as a function of magnetic field strength. z axis is perpendicular to the photocathode surface, and x and y axes are parallel to the photocathode.

As mentioned above, small number of signal photons ($< 10/\mu$s·pixel) is expected even for 10^{20}eV showers. Therefore the photon counting method is more preferable than the analog method and is employed. The photon counting method has advantages in the stability for the variation of gain (or high voltage) and better signal to noise ratio. Fig. 3 shows a single photoelectron distribution for R8900-M25 with a faint UV LED light. The detection efficiency (D.E.), defined as product of the quantum efficiency and the collection efficiency, was studied with the photon counting method by comparing with a calibrated PMT (H7195PX) by HAMAMATSU photonics. The preliminary result of D.E. for R8900-M16 and R8900-M25 is 13–15%.

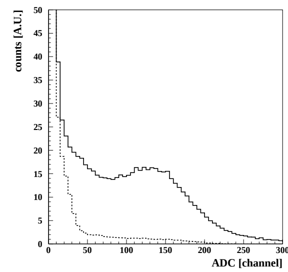

Fig. 3. Sample of single photoelectron distribution for R8900-M25. Solid histogram shows the distribution with LED on, and dashed one shows that with LED off.

3. Further Development

Since finer pixel size is preferable in the point of S/N, we have been developing R8900-03-M36 which has anode format 6×6. They will be delivered to us in the near future. Another solution to increase sensitive area is a flat-panel MAPMT (HAMAMATSU R8400 series, 52mm$\times$52mm in dimension). The advantages are light weight and large sensitive area ratio ($\sim 90\%$) without electron focusing feature. R8400-M256 with borosilicate glass window has already developed for the medical purpose [2]. We are now developing a UV glass window version. There is also possibility to achieve more efficiency by making use of single crystal photocathode such as GaAsP, which has high quantum efficiency in the visible region, with the combination of wavelength-shifter and multi-layer mirror. The development is in progress and the status is reported in Ref. [5].

Acknowledgments

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