29th International Cosmic Ray Conference Pune (2005) **5**, 339–342

Detection of Atmospheric Cherenkov Images of Air Showers using High-Resolution and High-Speed Camera System with Image Intensifiers

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We developed a detection system of Cherenkov images of air showers using a 10 cm aperture image intensifier (I. I.) tube. The trigger pulses are generated by 64ch multi-anode photomultiplier tubes (MAPMT). This system was installed to a focal plane of a 3m diameter reflector composed of 18 segment mirrors in which 12 segment mirrors are focussed to I. I. tubes and 6 mirrors to MAPMTs. Air shower images are taken by a high speed CCD camera. Trigger signals are generated by an FPGA logic system which identify image patterns of the air showers. The CCD camera can be randomly triggered, and the system can record the data directly onto hard disks on a PC with a maximum rate of 250Hz. As a result, many images of air shower events were obtained in the energy region around a few 10 TeV. These images are very fine grained, which corresponds to an angler resolution of at least 0.012 degrees.

1. Introduction

Imaging Atmospheric Cherenkov Telescopes (IACT) are the most effective experiments for TeV gamma-ray observations. The angular resolution of the IACT systems are today limited to be about 0.1 degree. This limitation is due to the resolution of telescope optics made of a principal reflector consisting of many segment mirrors, and due to camera system with limited number of pixels made of photomultiplier tubes. It is suggested that the high-resolution Cherenkov telescopes are effective for the observation of high-energy gamma rays around 100 GeV or less energies [2]. To achieve it, a better resolution of telescope optics and imaging cameras than the present ones are required. Photo-multiplier tubes are popular devices used for the camera system of the IACT experiments. A test experiment to detect atmospheric Cherenkov light in ultraviolet region using an image intensifier was carried out at Mt. Norikura from 1991 to 1993 [3]. In order to show that the idea of the high-resolution Cherenkov telescope for observing high-energy gamma rays, we have been developing a new telescope optics and high-resolution camera using image intensifier devices[2]. Design principle of this new camera system and some observation results measured by cosmic-ray sources are described in this paper.

2. Camera System with Image Intensifiers

The new camera system is designed to install to the Cherenkov telescope with 3m diameter in Konan University for testing the idea of the high-resolution Cherenkov telescope. The reflector is composed of 18 segment mirrors and a focal length of about 3m. A field of view of the camera system corresponds to 2 degrees. Cherenkov light emitted by air showers are focussed by the telescope on the camera surface at the focal plane. The telescope is designed to focus at two positions. Twelve segment mirrors of the reflector are focused to the I.I. to take the Cherenkov images, and six mirrors are focused to MAPMTs to make trigger signals.

Basic elements of the camera system are shown in Figure 1. The camera system consists of a large image

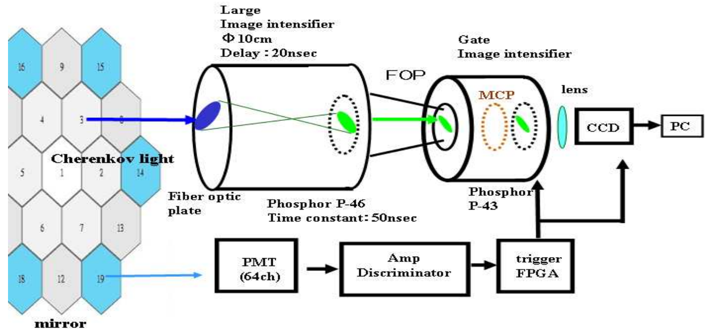

Figure 1. Schematic illustration of the camera system using 2 image intensifiers, a high-speed CCD camera and a trigger system.

intensifier (HAMAMATSU V4440U-01X) with 10cm diameter, a high-speed gate image intensifier (HAMAMATSU C4078-01), a high-speed CCD camera (DALSA DA-D6) and a trigger circuit.

Table 1. Details of the image intensifiers

	ent	exit	phosphor	gain	Q.E.
Large I.I. (HAMAMATSU V4440U-01X)	100mm	20mm	P-46	100	20%at 430nm
Gate I.I. (HAMAMATSU V4078-01)	17.5mm	17.5mm	P-43	10^7	7%at 550nm

The trigger system is composed of MAPMTs, amplifiers, discriminators, and the FPGA. When four adjacent pixels of the MAPMTs fire at the limited time interval, a trigger signal is generated later at 110nsec. The maximum trigger rate of the camera system is 250Hz.

3. NSB cut

Night sky background (NSB) photons are overlapped with Cherenkov photons generated by the air showers in the observed image data. The NSB photons are distinguished from the Cherenkov photons by the group of photo-electrons in the present analysis. Figure 2 shows the schematic diagram which explains how to reject the NSB photons. A criterion is set to the number of bright pixels in the circle of radius 0.2 degrees to extract the Cherenkov photons from the NSB photons. The Cherenkov images of the air showers are well extracted from the simulation data by this method.

4. Observation of Cherenkov Images

We observed cosmic ray air showers in January 2005. The observation site was near the top of Mt. Oya at 720m above sea level in Hyogo Prefecture in Japan. During total observation time at 220 minutes, we observed 13,841 events in total. The trigger rate was set to about 1Hz. The telescope was fixed to the direction of the zenith.

Figure 3 shows some examples of the observed data. It is clear that the present high resolution camera system

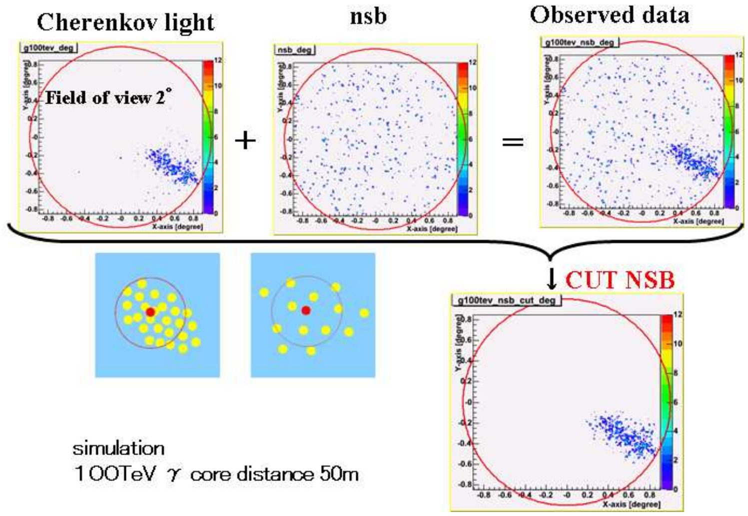

Figure 2. The Cherenkov images of the air showers are well extracted from the simulation data which includes the NSB photons by using a method to count the number of bright pixels within a circle of radius with 0.2 deggree.

using the image intensifiers is possible to take pictures of detailed Cherenkov images of the air showers than those of the conventional cameras using the PMTs.

Figure 4 shows a brightness distribution in which the NSB photons are removed from the observed data, where the brightness is defined as a total number of CCD values of the images. Number of events as a function of the brightness is shown in the figure. The power index of the solid line in this figure is -2.7.

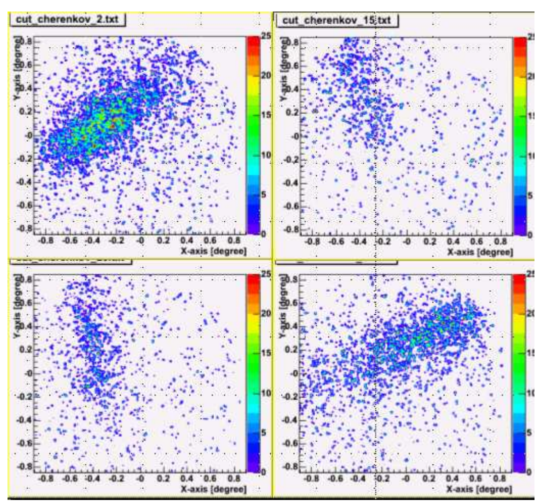

Figure 3. Typical observed data taken by the image intensifier system. Each bright point shows a single photo-electron. Detail images of the air showers are well shown.

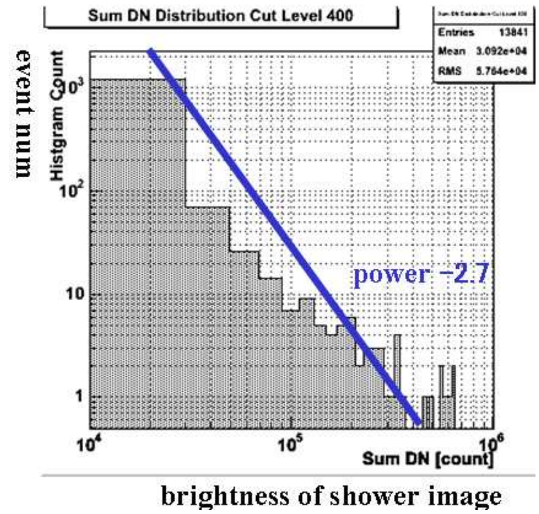

Figure 4. Brightness distribution of the observation data. The power index of the solid line is -2.7.

5. Summary

We have observed high-resolution Cherenkov images of the air showers which are generated by high-energy cosmic rays by using the image intensifier system. It is confirmed that the observation of cosmic rays by using the I.I. is quite promising. This result is a encouraging step for the high-resolution Cherenkov telescope of the next generation. Furthermore we are developing a new camera system with a new trigger system and an optical system with Fresnel lenses which will be attached in front of the I.I. system.

6. Acknowledgements

This study is partially supported by Grant-in-Aids of the Ministry of Education, Culture, Sports, Science and Technology, and the Promotion and Mutual Aid Corporation for Private School of Japan.

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