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On site calibration for new fluorescence detectors of the telescope array experiment

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ABSTRACT

The Telescope Array experiment is searching for the origin of ultra-high energy cosmic rays using a ground array of particle detectors and three fluorescence telescope stations. The precise calibration of the fluorescence detectors is important for small systematic errors in shower reconstruction. This paper details the process of calibrating cameras for two of the fluorescence telescope stations. This paper provides the operational results of these camera calibrations.

1. Introduction

In 1966 Greisen, Zatsepin, and Kuzmin predicted that the energy spectrum of ultra-high energy cosmic rays (UHECRs) will have a cutoff [1]. Detailed measurement of the UHECR flux in the GZK cutoff region is important when studying the origin and propagation of UHECRs. Currently, the energy spectra of UHECRs have been reported by Volcano Ranch, Suger, Haverah Park, Yakutsk, Fly's Eye, HiRes, Akeno, AGASA, and Pierre Auger [2–10]. The energy spectra around 10^{19} eV have been obtained with small statistical error [7–10]. However, these energy spectra are not consistent. These inconsistencies can be explained by including the estimated systematic error. Accordingly, the degree of systematic error is comparable to the difference between energy spectra. In order to obtain a definitive UHECR energy spectrum, a new experiment is needed with small systematic and statistical error.

In order to take detailed measurements of the northern hemisphere UHECR flux, we have constructed the Telescope Array (TA) in Utah, USA [11]. This experiment has a hybrid detector, which consists of a surface detector (SD) array and fluorescence detectors (FDs). The SD array measures extensive air shower (EAS) particles on the ground while FDs detect air fluorescence photons induced by EAS particles.

Each SD has two 1.2 cm thick layers of 3 m^2 plastic scintillator. The SD array consists of 507 SDs with 1.2 km spacing covering a total 700 km^2. This is seven times larger than the AGASA array. The expected trigger efficiency from our simulation studies is 100% for primary protons with energies above 10^{19} eV and zenith angles within 45° [12].

The three FD stations (known as BR, LR, and MD) have been installed surrounding the SD array. BR is located at the southeast corner of the SD array while LR is to the southwest. Both stations are new detectors designed specifically for the TA experiment. Each station has 12 telescopes. MD is located at the northeast corner of the array and has 14 telescopes [13]. The MD telescopes consist of the cameras and electronics formerly used in the HiRes-I experiment and the mirrors from the HiRes-II experiment.

In the TA experiment, the SD array and the FDs observe EASs independently. Events measured by both SD array and FDs provide crucial data in studying the systematic differences of the reconstructed shower parameters. Our FDs are operated on moonless clear nights. Accordingly, the expected duty factor of FDs is about 10%, whereas that of SD is almost 100%. From our simulation studies, expected FD's stereo detection area is 1000 km^2 for primary protons with energies above 10^{19} eV and zenith angles below 45° [14]. Thus, this expected observation area covers the whole area of the SD array. The expected observation

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efficiency of the SD array is 100% for the same air showers. Therefore, the showers with primary energies above 10^{19} eV are measured by SD and are simultaneously observed by multiple FDs. Using these events we estimate the systematic error of the fluorescence (HiRes type) and the surface (AGASA type) detectors. The expected detection rate of these events is 70 events/year for primary energies above 10^{19} eV [14].

For shower reconstructions to have small systematic error, the precise calibration of FDs is important. For this purpose, we have developed the following calibration systems [15–18]: (a) absolute calibrations of PMT gains including temperature dependence, (b) monitoring of absolute PMT gains using alpha-ray light sources, (c) adjusting and monitoring of relative PMT gains, (d) response uniformity on the photo cathode for every PMT, (e) end to end detector calibration including the fluorescence yield, (f) measurement of the reflectivities, the focal lengths and the blurs of images of segment mirrors and the combined mirrors, and (g) monitoring of the atmospheric transparency.

In this paper we describe the calibration of (c) and (d) in the BR and LR stations. The brief descriptions of other calibrations are in the previous papers [15–18]. The details will be provided in forthcoming publications. In Section 2, we introduce the PMT cameras in the BR and LR stations. A method for the absolute calibration of PMTs is briefly reviewed in Section 3. We show the results of the calibration of relative PMT gains and the measurement of uniformities of PMT responses in Sections 4 and 5, respectively. In Section 6, we summarize this paper.

2. FDs of the TA experiment

Each FD telescope consists of a spherical mirror, a PMT camera, and readout electronics. Fig. 1 shows a cross-sectional view of a station. Our 3 m aperture spherical mirror consists of 18 segment mirrors, each of which has a hexagonal shape, opposite side distance of 660 mm, and a curvature radius of 6067 mm. The camera has $16 \times 16 (= 256)$ PMTs and is mounted at the prime focus of the mirror. The sensitive area of a camera is 860 mm $\times$ 992 mm, corresponding to a field of view (FOV) of 15° in elevation $\times$18° in azimuth. Each camera views a different area of the sky above the SD array, but overlaps its FOV with its neighbors. In total, the FOV of a station is 3°–33° in elevation and 108° in azimuth.

For dust control, we use a UV-transparent acrylic panel (PARAGLAS-UV00 by KURARAY Co. Ltd.) for the front window of the cameras. Fig. 2 shows the typical spectral transmittance of this window measured with a HITACHI-U-1100 spectrophotometer. In addition to these manufacturer specifications, we measured the transmittance for the camera windows on site by comparing the differences between PMT outputs for a stable light source with the windows opened to those with windows closed. The light

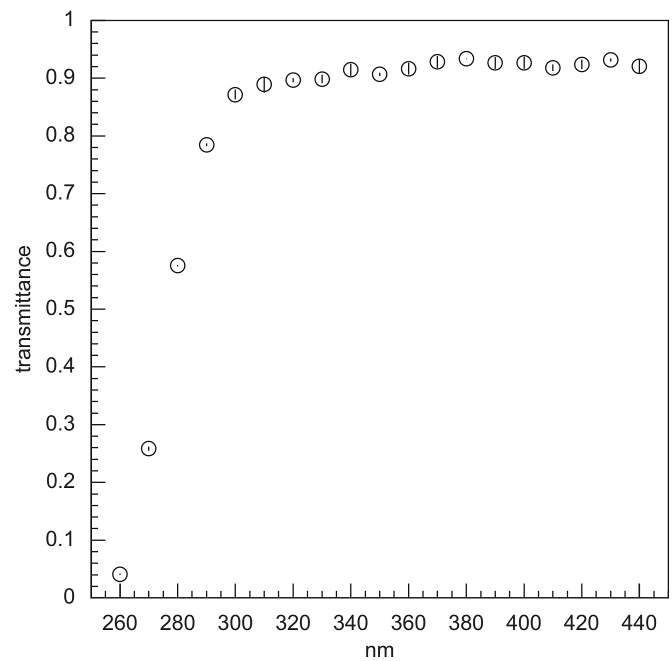

Fig. 2. The typical transmittance of the acrylic window panel on the FD camera. Open circles are the median value of three measurements. Error bars are the difference between the median value and the other two measurements.

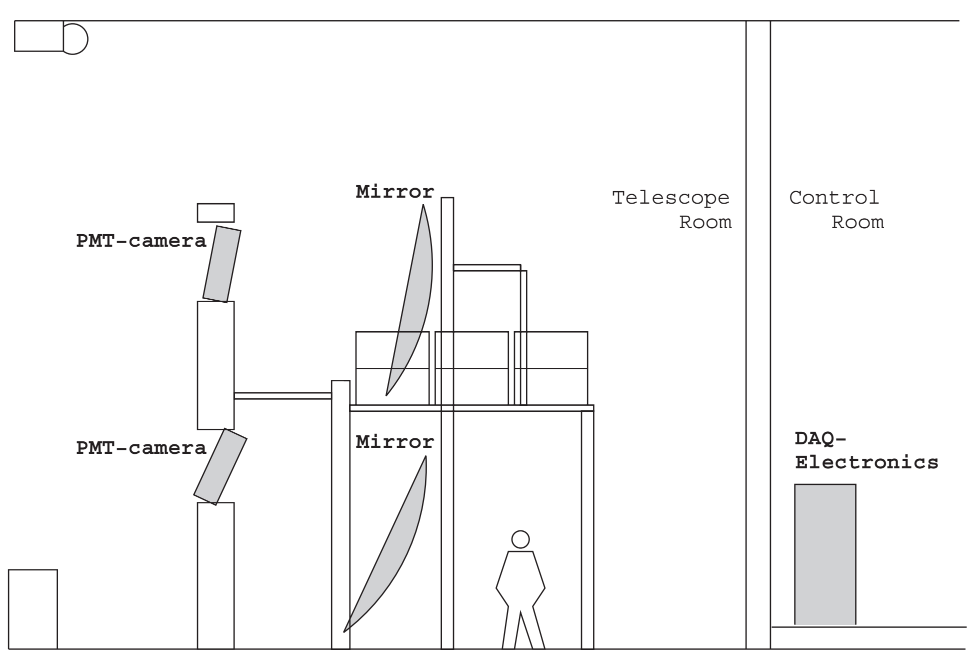

Fig. 1. The cross-sectional view of a fluorescence detector station.