# Performance of the Fluorescence Detector of the Telescope Array experiment

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***Abstract*. Three fluorescence detector (FD) stations overlook the surface detector of the Telescope Array. The FD stations have been operating on clear moonless nights since November 2007. The calibration of the FDs and monitoring of atmospheric conditions are important for control of systematic uncertainties in shower reconstruction. We have developed an atmospheric monitoring system which is comprised of laser facilities for the measurement of atmospheric transparency, and an infrared cloud monitoring camera. We employ a variety of FD calibration systems for PMT absolute gain measurements, monitoring of relative PMT gains, and measurements of mirror reflectance. We will present the status of FD observation, atmospheric monitoring, and FD calibration.**

***Keywords*: Ultra high energy cosmic rays, Extensive Air Showers, Fluorescence Light**

## I. Introduction

Detailed measurement of the ultra high energy cosmic rays (UHECRs) flux in the GZK [1] cutoff region is important when studying the origin and propagation of UHECRs. The energy spectra around $10^{19}$ eV have been obtained with small statistical error [2], [3], [4], [5]. 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.

For this purpose, the Telescope Array (TA) have been constructed in Utah, USA [6]. 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. This array consists of 507 SDs with 1.2 km spacing covering a total 700 km$^2$. The three FD stations (called as BR, LR, and MD) have been installed surrounding the SD array. The FDs detect air fluorescence photons induced by EAS particles.

At BR and LR, we have constructed new detectors designed specifically for the TA experiment. Each station has twelve telescopes. Their field of view is 15° in elevation × 18° in azimuth. The total FOV of a station is $3°-33°$ in elevation and 108° in azimuth. This FOV covers the whole area of the SD array. MD station has fourteen telescopes [7]. The MD telescopes consist of the cameras and electronics formerly used in the HiRes-I experiment and the mirrors from the HiRes-II experiment. The total FOV also covers the whole area of the SD array. 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° [8].

The FD stations have been operating on clear moonless nights since November 2007. The total observation time more than 1500h, and the duty factor of FDs is about 10%. During observation, the FD trigger rates, and PMT gains are stable.

For shower reconstructions to have small systematic error, the precise calibration of FDs and atmospheric monitoring are important. Therefore, we have developed calibration and monitoring systems: (I) absolute calibrations of PMT gains including temperature dependence [9], [10], (II) monitoring of absolute PMT gains using alpha-ray light sources [11], (III) adjusting and monitoring of relative PMT gains [12], [11], (IV) response uniformity on the photo cathode for every PMT [12], (V) end-to-end detector calibration including the fluorescence yield [13], (VI) measurement of the reflectivities, the focal lengths and the blurs of images of segment mirrors and the combined mirrors [11], (VII) monitoring of the atmospheric transparency [14]. In this paper we describe a brief overview of the status of calibration and monitoring of FD performance.

## II. Calibration

The cameras at BR/LR station consist 256 HAMAMATSU photomultiplier tubes (PMTs) R9508. These PMTs have a 2 in. diameter hexagonal photon sensitive area. In order to reduced night sky background light, a UV transparent filter (SCHOTT BG3) with 4mm thickness is mounted on the photo cathode of every PMT. In order to calibrate PMT gains, we developed an absolute light source called CRAYS (Calibration using RAYleigh Scattering) [9]. It consists an $N_2$ filled chamber and an

$N_2$ pulse laser (wavelength: 337.1 nm). An energy meter monitors the intensity per laser shot with the absolute accuracy of $\pm 5\%$. We achieved systematic uncertainty for the intensity estimation to be $\pm 8\%$. Using this system, three PMTs per camera have been calibrated in the laboratory. We obtained the output response of a PMT for 337.1 nm photons from this calibration. We measured the wavelength dependence of transmittance of BG3 filter, and PMT quantum efficiencies. Using these values we obtain a PMT output response function for any given wavelength. An alpha-ray light source called YAP is mounted on the top of the PMT surface. This light source consists of an $YAlO_3$:Ce scintillator and a 50 Bq alpha ray source of $^{241}$Am [15], [16]. The photon intensity and its YAP stability is calibrated comparing its intensity with CRAYS. For more detail on the CRAYS calibration, please refer to the paper [9] in this proceedings. PMT gains and light intensity of YAP have temperature dependence, which are $-0.7\%$/degree and $-0.2\%$/degree respectively [10]. These temperature dependence have been measured in the laboratory, and these effects are corrected on off-line analysis. On the sites, the gains of the un-calibrated PMTs are adjusted to that of the calibrated PMTs in the same camera using a Xe flasher [12].

Each FD at MD has also 256 PMTs. The gains of the all PMTs are calibrated every month on the site using a portable high stability Xenon flash lamp called Roving Xenon Flasher (RXF) [17]. The pulse to pulse variation in intensity is $\sim 0.3\%$ and the stability over a night is better than 2%. The absolute light intensity of RXF are measured using NIST traceable reference detectors. This calibration scheme is the same as that of HiRes experiment [17].

## III. Observation and monitoring

BR and partly LR operation have been started from June 2007. MD operation started from November 2007, and the full FD operation have been started from this time. The recent total observation time of BR is 1650 h at the end of March 2009 (Fig. 2). There are some differences of total observation time between the sites, which are caused by system maintenances or different weather conditions mainly.

During observation, the gains of PMT at BR/LR stations are being monitored using YAP pulser and Xe flasher every hour. Fig. 1 shows that the standard deviation of the gain instability distribution for all the PMTs is 1 %. The gains of PMT at MD stations are also being monitored using the pulse of YAG laser via quartz optical fibers at the beginning and end of every observation night.

Atmospheric monitoring is also important for a precise EAS reconstruction. To monitor atmospheric conditions, we employ laser equipments called Central Laser Facility (CLF) [14], Light Detection And Ranging (LIDAR) [14], and a cloud monitor using an infra-red camera (AVIO TVS-600S) [18].

CLF is located at the same distance from the three FD stations. It consists of a 355 nm Nd:YAG laser, optical system and energy probes. CLF makes vertical laser shots every 30 min in the observation periods. These shots can be measured by the three FDs if the atmospheric condition is not so bad. The atmospheric condition between CLF to each FD site can be monitored using the recorded data of CLF shots by FDs. These also have a potential to be assumed calibrated light source if Mie-scattering is not dominant. These events are selected with Mie-scattering condition measured by LIDAR. Using CLF, GPS timing calibration between each FD and SDs is also planned. This scheme is as follows: CLF provides a signal to a SD when CLF shot a laser simultaneously, and it will be recognized as a special trigger for SD DAQ. Otherwise, FD can detect this laser shot from CLF in the normal DAQ mode. We can compare analysis results of absolute shooting time at CLF from FD's and SD's data.

We have a LIDAR system [14] at BRM. It consists of a 355 nm Nd:YAG laser, an energy probe and a PMT attached a 30 cm dia. astronomical telescope. LIDAR observes back scattered lights of laser shots by air (Rayleigh scattering) and aerosol (Mie scattering). If one-dimensional atmospheric is supposed, the effect of Mie scattering will be separated from that of Rayleigh scattering. Our preliminary result shows that the one-dimensional atmospheric density model is reasonable assumption on a limitative condition in our observation site [19]. Now we are checking the applicable days of the one-dimensional atmospheric assumption. For more detail, please refer to the paper [14] in this proceedings.

The cloudiness of the night sky is measured using an IR camera (AVIO TVS-600S). IR data provides a sky map of temperature distribution. We can recognize cloudiness of the sky contrasted with clear region from this distributions. An analysis to determinate cloudiness have been progressed [18]. We are studying a correlation between this cloudiness and the results from LIDAR and CLF. The correlation studies provide more robust results of the atmospheric conditions.

End-to-end calibrations are also important to understand our FD performance totally. For the calibrations we employ CLF [14], RXF [11]. The total FD gains are checked using these calibration source. For a calibration includes air fluorescence light yield, we will install a electron light source (ELS) at the 100 m away from the BR FDs. Air fluorescence lights are generated by the electrons shot by ELS [13]. The designed light intensity is equal to that generated by EAS 20 km away with the primary energy $10^{20}$ eV. Reported fluorescence light yield are difference from each other (ex. [20], [21]). There are various efforts to determine the yield and to parameterize a lot of measurement conditions, and to get realistic assumptions. In contrast, we can obtain the relation between $\mathrm{d}E/\mathrm{d}x$ and ADC counts of PMT output includes fluorescence light yield using calibrated light from ELS on site. Uncertainties of estimated primary

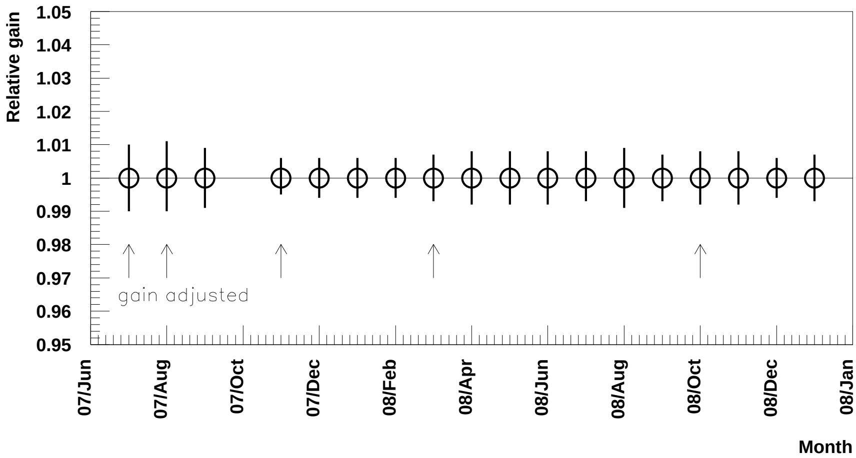


Fig. 1. The variation of relative gains of all PMTs at BR/LR through all the observation periods.

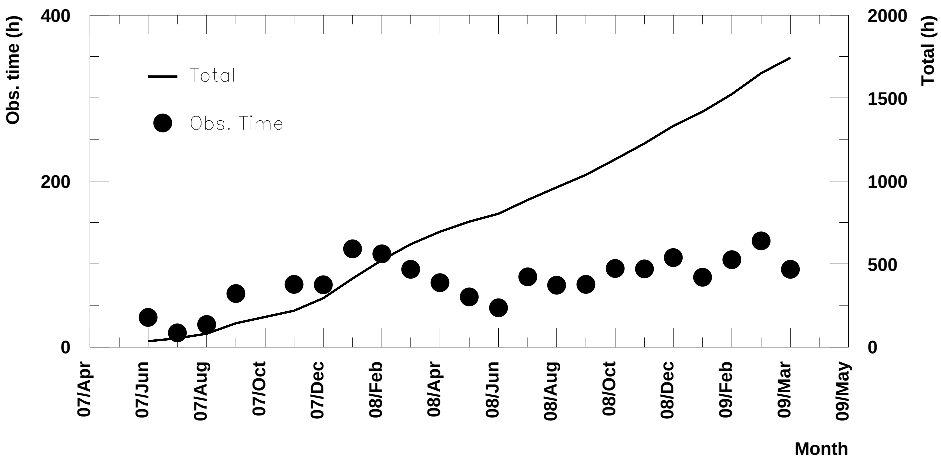


Fig. 2. The total and monthly observation time of the BR site.

energy caused by that of fluorescence light yield can be reduced drastically by this ELS calibration.

## IV. Summary

The full FD operation have been started from November 2007. Our each FD components have been calibrated, and the FD performance and atmospheric conditions are monitoring during observation. To calibrate the total FD performance, end-to-end calibrations using RXF, CLF, and ELS are planed. To estimate FD aperture, and FD performances, which include trigger and selection efficiencies, energy and angular resolution, have been calculating using our simulation. Our simulation results are being checked now, these will be shown on our presentation of ICRC. In the near future, we will take an answer for cause of the differences between the previous experimental results on the UHRCR energy spectrum.

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