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Calibration of The Telescope Array Air Fluorescence Detector

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We are constructing 18 air Fluorescence Detectors (FD) in three stations for Telescope Array (TA) experiment (each station contains 6 detectors). The telescopes measure longitudinal developments of EAS by air fluorescence lights associated with extensive air shower EAS of ultra high energy cosmic rays. From the reconstructed EAS developments the primary energy of the cosmic rays and arrival direction can be determined. To observe the primary cosmic ray with high accuracy, we have to study air fluorescence yield, atmospheric monitoring, absolute calibration and performance monitoring of FD equipment carefully. For latter ones, we calibrate the components of FD: reflectance and curvature radius of segment mirrors; the characteristics of PMT and preamplifier (their gain, linearity, dynamic range); uniformity of the camera surface. Also we have plans of FD performance monitoring and adjusting: absolute PMT gain, mirror reflectance, and transmittance of the front window of camera etc. In this paper these calibrations and the plans of performance monitoring for FD of TA experiment are described.

1. Introduction

The AGASA energy spectrum of the primary cosmic rays shows that there is no indication of GZK cut-off expected by the photo-pion production of the ultra high energy cosmic rays[1]. In contrast, Hires group reported that there is a GZK cut-off in their observed energy spectrum [2]. It seems that a part of the inconsistency is due to the systematic error of both experiments in the determination of primary cosmic ray energies. To make clear the difference we plan to observe extensive air showers EAS with an AGASA type surface detector (SD) array [3] and with a Hires type air fluorescence detector (FD) [4]simultaneously as the first step of the Telescope Array (TA) experiment [5].

FD measures the UV fluorescence light of molecular nitrogen generated by EAS particles. The observation of the whole shower longitudinal development in the atmosphere enables the unbiased determination of the energy by the total absorption calorimetry. A telescope consists of upper and lower pairs of camera and spherical mirror. The mirror with a radius of curvature R=3.3 m which is composed of 18 hexagonal shape segment mirrors. The spot size on the focal plane is about 30 mm in FWHM according to a ray tracing calculation. We install Xenon-flasher (L2461 HAMAMATSU) system which is light source for camera calibration in the location of the central segment mirror. The camera consists of 256 hexagonal shape PMT (R9508 HAMAMATSU) with 60 mm opposite side distance and each PMT has 1.1×1 field of view (FOV). A FD station consists of 6 units of telescope. The FOV of one telescope unit is 18.0° in azimuth 15.5° in elevation. Totally 18 telescopes will be installed on three stations near Delta, Utah, USA. To observe a single EAS event by multi telescopes, which allows an accurate determination of the EAS axis geometry by the stereo event reconstruction, these FOV of stations will be overlapped[4].

To obtain a result from FD with high accuracy we have to study the air fluorescence light yield, atmospheric monitoring, and absolute calibration and performance monitoring of FD equipment carefully. For the latter ones, absolute calibration of PMT and individual equipment test are being studied in our laboratory. Moreover we have plans for the calibration and monitoring in situ (for PMT gain and mirror reflectance etc.).

2. PMT camera calibration

To reduce Night Sky Background (NSB) PMT are equipped with an optical filter, Schott BG3 with 4mm thickness (transmittance=95% at 350 nm). Photocathode is impressed negative voltage typical -900V with absolute gain 8×10^4. Pre-amplifier outputs a semi-differential signal into electronics via 20 m twist pair cable. Each channel of the electronics has a differential receiver and a stretcher.

The items of PMT calibration are input-output linearity, PMT-gain, PMT-response, 2-dimensional uniformity. All PMT will be checked its DC input-output linearity etc. by HAMAMATSU before making delivery. Moreover we check PMT absolute gain, and QE×CE for 5% PMT. To obtain absolute gain of PMT single p.e. measurement is necessary. However operational gain of our PMT 8×10^4 is too low to measure a single p.e. Therefore we have to use a stable light source for checking the absolute PMT gain on an operation. As the stable light source we use YAP light pulser (Radiation Instruments and New Components Ltd.) [6, 7]. YAP light pulser consists ($YAlO_3$: Ce) + Am^{241} alpha radiation source (50Bq) in an aluminium cylinder with 4mm diameter and 1mm thickness, and radiates UV light (Its peak wave length is 370 nm. A light intensity is 2000-3000 p.e.. FWHM is 20 ns. The deviation of that light intensity is typical 10%.). In our assumed operational temperature range from -20 degree to 20 degree, YAP has some temperature dependence which is ±1% from -20 to 10 degree, and temperature coefficient is -0.2%/degree from 10 to 20 degree [6]. To compensate the temperature dependence we have to monitor the ambient air temperature.

To calibrate PMT and YAP pulser we made an absolute light source which called CRAYS. CRAYS has a scatter box filled in molecular nitrogen. Light of laser (N_2 laser 337.1 nm 300 μJ, VSL-337ND-S, Laser Science) goes through the box, and that light is scattered (by Rayleigh scattering) by the nitrogen in the box. We measure the laser intensity using Silicon energy probe (RjP-465, Laser Probe Inc.). This probe has a determination accuracy of energy is ±5% for the laser pulse absolutely. The intensity of Rayleigh scattering light can be calculated by theoretical simulation and ray tracing calculation. Using CRAYS we measure light intensity of YAP pulse and QE×CE of PMT. For the QE×CE measurement it is necessary to improve single p.e./noise ratio by making an additional amplifier for this measurement. Using the QE×CE, the light intensity of CRAYS will be converted to number of photo-electron. Finally we obtain the light intensity of YAP pulser by comparing the light intensity of CRAYS and YAP pulser. If single p.e. can measure by operational PMT correctly, QE×CE measurement and the prediction of the light intensity of Rayleigh scattering will be confirmed. We study it now. For total calibration checking for light intensity / FADC count is important. Now we are making a test bench for the total calibration from PMT to electronics on a wide range of wave length using a variable laser wave length.

Each PMT gain will be adjusted in the each camera. Moreover we have to monitor it on the fluorescence light observation period, because PMT gain is affected by the variation of temperature, NSB, and PMT aging. For these purpose we install Xenon-flasher covered with teflon diffuser (light intensity is $\sim4\times10^4$ p.e. and FWHM 2 μs, the deviation of the light intensity is typical 1%) at the center of the mirror and YAP pulser on the front

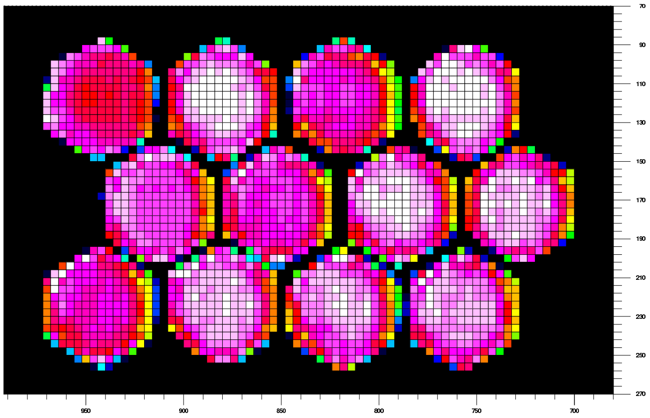

Figure 1. Contour map of 2-dimensional uniformity of QE×CE for 12 PMT in arbitrary unit.

of 9 PMT/camera. PMT with YAP pulser can measure its absolute gain. All PMT can measure relative gain using Xenon-flasher and these also can be compared absolute gain from the PMT with YAP pulser.

We make a XY-scanner for measuring 2-dimensional relative uniformity of QE×CE of camera. This XY-scanner consist of a UV LED (wave length λ =360 nm, NSHU590B NICHIA) with optical lens for light source and a XY-stage mounted on the front of camera. The source makes a ∼1 mm diameter spot on the PMT surface. By comparing absolute QE×CE of PMT obtained by CRAYS and relative one, we will obtain absolute QE×CE of all PMT. We have a test model of XY-scanner, and we measured 2-dimensional uniformity for 9 PMT (Fig.1). Now we try to improve the speed of measurements for making final version of it.

3. Mirror calibration, monitor

The spherical mirror with a radius of curvature R=3.3 m which is composed of 18 hexagonal shape segment mirrors. These mirrors have anodized surface which is stable and the estimated degradation of the reflectivity is ∼ 1 %/year. We purchased the 216 segment mirrors for a station and done acceptance test. When diffusion light is emitted at the same distance from the mirror as the curvature radius, the reflected light makes the minimum spot at the axisymmetrical point. We measured the spot size of the reflected light at 6067 ± 100 mm, and we checked the curvature radius of the mirrors. From our ray-tracing calculation, it is necessary that curvature radius and the diameter of minimum spot fill the following specification: curvature radius is 6067 ± 100 mm, and the diameter of the minimum spot is less than 20 mm. Figure 2 shows the histogram of the curvature radius for the mirrors and the histogram of the spot size of reflected light at the curvature radius. From the figures it is confirmed that all mirrors fill our specifications. By our calculation the spot size for a parallel light is less than 30 mm at PMT surface under that condition. It is sufficiently small because that spot size is half of the PMT dimension. The reflectivity of the 18 segment mirrors were measured using Spectrophotometer (CM-2500d, KONICA-MINOLTA) on the wave length from 360 nm to 450 nm. The reflectivity of these mirrors is more than 90% at 360nm, and its deviation by location dependency on the mirror surface is less than ±1%. Now we make a reflect-meter for measuring shorter wave length from 200 nm. At the operation period the reflectivity will be monitored using these reflect-meters. That monitored data is used for a simulation and reconstruction procedure of EAS events.

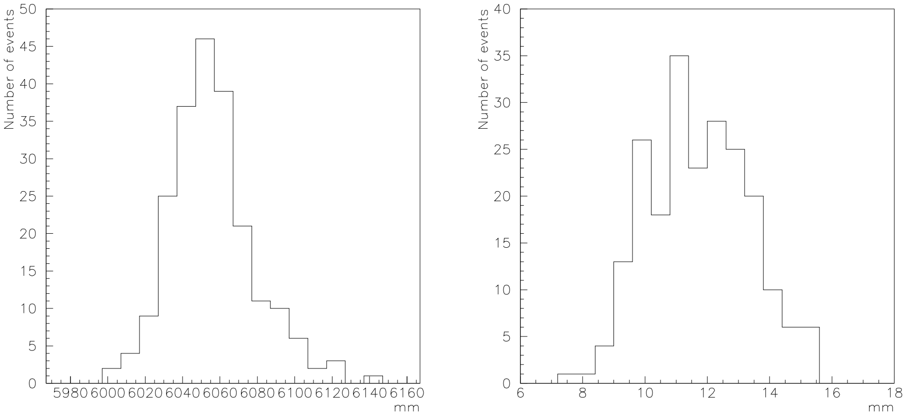

Figure 2. Left panel: histogram of the curvature radius of segment mirror, Right panel: histogram of the spot size of reflected light at the curvature radius.

4. End To End calibration

Individual FD equipment is being calibrated in our laboratory. In parallel the first FD telescope is being installed at the Black Rock Mesa site[5]. Then calibrations and performance monitoring for FD in situ will be started. End to end (the mirrors to FADC data) calibration is also important to understand our FD system totally. For the purpose we are also studying the various measurable light sources by the telescopes, which are Rayleigh scattering lights by a portable laser, lateral scattering lights by a steerable laser at the center of our experimental site, air fluorescence lights of generated by low energy electrons radiated by Linac, etc.

5. Acknowledgements

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