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## The Status of the Telescope Array experiment

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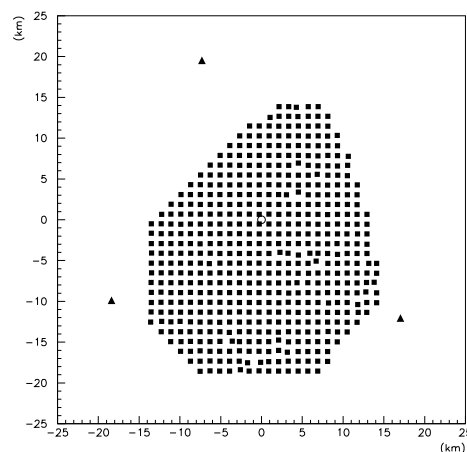
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**Abstract.** The purpose of The Telescope Array experiment is to identify origin of the ultra high energy cosmic rays. The Telescope Array is a hybrid detector consists of a surface detector array and air fluorescence detectors. This hybrid detector is observing extensive air showers to measure the energy spectrum, anisotropy and composition of Ultra High Energy Cosmic Rays. The detector construction has been completed in March 2008, and the hybrid observation with the full configuration has been running since that time. In this talk, the status of observation and our prospects are described.

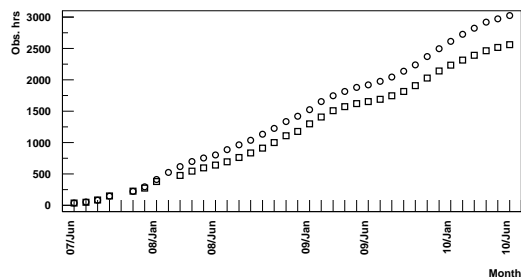
## 1. Introduction

The main purpose of the Telescope Array experiment is to identify sources of Ultra High Energy Cosmic Rays (UHECRs). UHECRs must interact with the cosmic microwave background, and a cutoff (GZK cutoff) in their energy spectrum is expected around its energy  $10^{19.5}$  eV by Greisen, Zatsepin and Kuzmin [1, 2]. HiRes and Auger experiment reported that there is a cut-off structure in their observed energy spectrum [3, 4]. In contrast, the AGASA result shows that there are 11 events above  $10^{20}$  eV [5]. These three experimental groups claim their systematic uncertainty in energy determination is about 20% respectively [3, 4, 5]. The rescaling energy spectra of AGASA, HiRes, and Auger within their uncertainties are in agree well below  $10^{20}$  eV [6]. It seems that the inconsistency is due to the systematic uncertainties of these experiments in energy determination. To resolve this situation, we compare the response of AGASA type detector (plastic scintillation counter array) with that of HiRes type detector (air fluorescence light detector) directly using observed same EAS events.

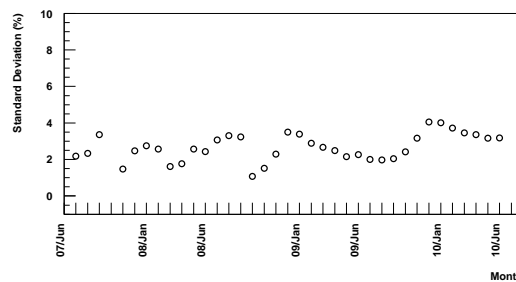
The Telescope Array is a hybrid detector consists of a surface detector (SD) array and fluorescence detectors (FDs) [7, 8]. This detector is located in Delta, Utah, USA (39.3 N, 112.9 W) with an



**Figure 1.** Layout of SD array (squares), and FD sites (triangles).



**Figure 2.** Total observation hours of FD from 2007/June to (circle: BR, square: LR).



**Figure 3.** Standard deviation of relative PMT gains (Mean value of gain is equaled to 1 for each camera).

average altitude of 1400 m. The SD array has 507 detectors, each 3 m<sup>2</sup> in area, with 1.2 km spacing, and its total area is 700 km<sup>2</sup>. Layout of SD array is shown in Fig. 1 (squares). Each SD consist of two layers of plastic scintillators with 1.2 cm thickness.

Three FD stations are surrounding the SD array, and observe the night sky above the SD array. Triangles in Fig. 1 show the location of FD site (South East: Black Rock Mesa, South West: Long Ridge, North West: Middle Drum). The each field of view (FOV) of these FD stations is 108 degree (114 degree for the third station) in azimuth and 3–31 degree in elevation. These FOVs in azimuth cover the whole region of SD array. More details of our detector configuration are described in our previous papers [7, 8]. The detector construction has been completed by March 2008, and the hybrid observation with the full configuration has been running since that time.

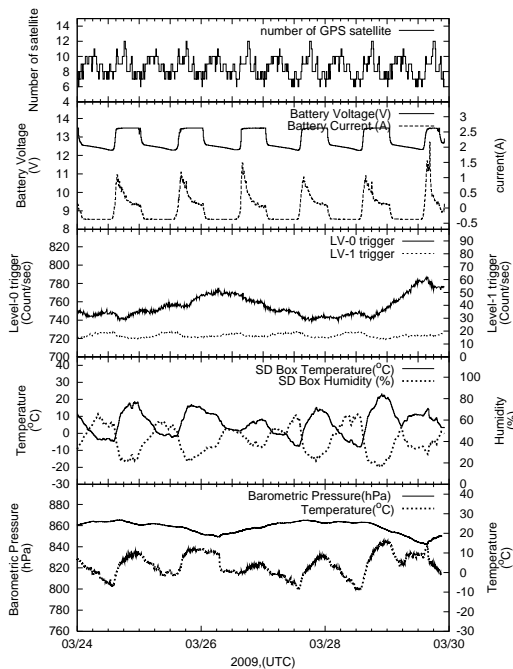
## 2. Observation Status

### 2.1. Fluorescence Detector

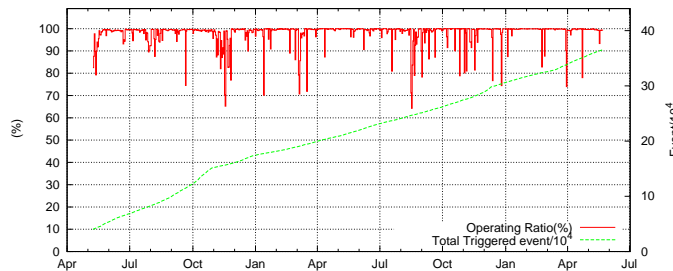
The first FD station (BR) and a half of the second station (LR) are running from May 2008, and the another half of the second station has been started from December 2008. The trigger rate for a station is about 2 Hz with 6% dead time. The total running time of the first and second station is 3020, 2560 hours respectively at 2010 June (Fig. 2). The running time of the second station is reduced for safety backup procedures, because the second FD station is operated remotely from the first station since May 2009.

FD performances (PMT gain, mirror reflectance, window transmittance, etc.) are monitoring continuously [9]. To monitor PMT gains, we employ absolute light pulsars on three PMTs each camera, and Xe-flashers for relative PMT gain monitoring mounted on each mirror. Fig. 3 shows the standard deviation of relative PMT gains (mean values of PMT gain at each camera are equaled to 1) through all the observation periods. The relative PMT gain are stable within 4% differences as shown in this figure. Using these monitor data, PMT gains are corrected in our analysis.

Atmospheric condition monitoring is important for FD analysis, because fluorescence light will be attenuated by aerosol components between generating point and FD. To monitor atmospheric conditions, we employ three special devices: a Central Laser Facility located on the same distance from the three FD stations (CLF location in Fig. 1: the circle), LIDAR (LIght Detection And Ranging), and an infrared camera for cloud monitoring at the first station ([10, 11], and Y. Tsunesada et al., T. Tomida et al., Proc. of 31th International Cosmic Ray Conference, 2009). LIDAR measures back scattered light of laser by air molecules and by aerosols in the air, and FDs measure side scattered lights from CLF laser. From CLF and LIDAR, atmospheric



**Figure 4.** Plots of SD performance monitoring (status of GPS, Batteries, Low voltage power supply, Temperature, Humidity, Pressure).



**Figure 5.** Plots of SD performance monitoring (Number of total Triggered event, Detector operating Ratio).

parameters are obtained, which include Vertical Aerosol Optical Depth (VAOD), extinction coefficients caused by Rayleigh scattering and Mie scattering. Clouds cause a strong attenuation of fluorescence light, therefore cloudiness in FOVs of FD is monitored by IR camera every 30 min.

The FDs at the third station were moved from HiRes-I, and this station have been running from December 2008. These FDs are calibrated and monitored by the same procedures of HiRes experiments and new additional equipments will provide for verification of their calibration and monitoring accuracies [12].

## 2.2. Surface Detector array

We installed 503 SDs in March 2008, and installed 4 additional SDs in November 2008. The trigger condition of the SD array is three adjacent detectors with more than three particle's equivalent signal within 8 usec. The average trigger rate is 20 triggers/hour under this condition. DAQ of SD was running with three sub-arrays from March 2008, and these three sub-arrays were integrated as a whole array in November 2008. This integration reduced array boundary, and increases number of useful events under our data quality cut in the analysis procedure. The total exposure will be comparable to that of AGASA with 13 years by 2010 Summer. SD performances are monitored every minutes independently of main DAQ. These information include the following items: Detector gain, accuracy of internal clock, charge level of battery, trigger rate, temperature and humidity inside the detectors, and accuracy of GPS clock (T. Nonaka et al., Proc. of 31th ICRC, 2009). Samples of the performance monitor are shown in Fig. 4,5. From this monitoring, the average number of available SD is more than 98 %, and down time of SD observation is less than 4% (Fig. 5). This on-line monitoring system help us to keep a stable DAQ running.

### 3. Prospects

We have obtained the following preliminary results: energy spectrum by FD + one SD analysis, photon limits,  $X_{\max}$  distribution of air shower from FD experiments (see the presentation slides on the conference web page: <http://bes3.ihep.ac.cn/conference/calor2010/>). The FDs at the third station (MD) also provide a preliminary result of energy spectrum, which are consistent with HiRes-I experimental result (C.C.H. Jui et al. Proc. of 31th ICRC, 2009). In order to obtain energy spectrum from SD array, we have been studying its energy scale and robust procedures of energy determination by Monte Carlo simulation.

SD DAQ will be installed an additional trigger from FD in 2010 September. The SD trigger efficiencies is lower than 10% for  $10^{18}$  eV from our simulation studies. In contrast, FD trigger efficiencies are higher than that for SD. However FD Mono analysis power for lower energetic events around  $10^{18}$  eV is relatively lower. To improve analysis power, additional SD information is quite important. The FD mono analysis with SD information provides a better angular resolution and energy estimation accuracies than FD mono analysis. In this analysis, only information from one SD is enough to improve analysis power (D. Ikeda et al. 31th ICRC, 2009). For example, number of events which can be reconstructed by FD + one SD analysis will be 7 times larger than that of FD-Mono at  $10^{18}$  eV. Estimated angler resolution of this analysis is also improved (e.g. better than  $2^\circ$  at  $10^{18}$  eV).

Various equipments are applied to calibrate FDs optics and monitor for transparency of the atmosphere [10, 11, 12, 20]. Using these devices, we are monitoring FD performance, and atmospheric conditions continuously during observation periods. Estimation accuracy of FD aperture will also be studied carefully using these monitor data. We have obtained typical values of atmospheric parameters (e.g. VAOD, and extinction coefficient). We are studying the differences from typical values of these atmospheric parameters with various time scales, and their affect on FD analysis.

Uncertainty of fluorescence light yield is an issue of primary energy determination in air fluorescence experiments. Fluorescence light yield have been measured by some authors (e.g. [14, 15, 16, 17, 18]). However their experimental results cannot compare directly, because their experimental setting and units of results are different from each other. J. Rosado et al. [13] compared these results from different experiments, and their result suggests that there are 15% difference between the experiment results (Table 1 in [13]). Also some experimental results differ from estimated value by J. Rosado et al. about 10%. In order to obtain correct value of fluorescence yield, we need to understand these differences of experimental results, and the difference between experimental results and estimated values. To reduce this uncertainty, we have a plan to measure fluorescence light from controlled electrons in air using our FDs [19]. The module of electron light source will makes  $10^9$  electron bunch with their energy 40 MeV, and this pulse width is 2 us. This electron bunch will provide a standard candle of fluorescence light. This module has been installed at the front of the BR station with the distance 100 m between FD and the light axis. We are adjusting its setting to get stable electron bunches. This measurement will provide an End to End calibration which includes the energy loss rate of electron in air, fluorescence yield, and electronics performances of our FDs. From this measurement, our systematic uncertainties of primary energy estimation by FD will be reduced.

### 4. Summary

The hybrid detector of the Telescope Array has been measured EAS events since March 2008. Monitoring system of SD and FD performance and atmospheric condition is also running. The total exposure of SD array will be comparable to that of AGASA with 13 years by 2010 Summer. Some preliminary results were presented in this conference. In order to obtain robust analysis results, we are studying the energy scale comparison between SD and FD, FD-mono analysis comparison between the three station, etc. Also we will employ new devices: a standard candle

of fluorescence light emitted from controlled electron bunch, an additional SD trigger from FD, etc in 2010.

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### References

- [1] K.Greisen, 1966, Phys. Rev. Lett., v16, 748,
- [2] T.Zatsepin and V.A.Kuzmin,1966, JETP Lett., v4, 78
- [3] J. Abraham et al., 2008, Phys. Rev. Lett., v101, 061101
- [4] R.U. Abbasi et al., 2008, Phys. Rev. Lett., v100, 101101
- [5] M. Takeda et al., 2003, Astropart. Phys., v19, 447
- [6] V. Berezhinsky, 2009, Proc. of 30th ICRC, v6, 21
- [7] H. Kawai et al., 2008, Nucl.Phys.B Proc.Suppl,v175-176, 221
- [8] H. Kawai et al., 2009, J.Phys.Soc.Jpn. Suppl. A ,v78, 108
- [9] H. Tokuno et al., 2009, NIM A, v601, 364
- [10] S. Udo et al., 2008, Proc. of 30th ICRC, v5, 1021
- [11] M. Chikawa et al., 2008, Proc. of 30th ICRC, v5, 1025
- [12] J. N. Matthews et al., 2007, Proc. of 30th ICRC, v5, 1157
- [13] J. Rosado et al., 2010, Astropart. Phys. in press (doi:10.1016/j.astropartphys.2010.06.007)
- [14] F. Kakimoto et al., 1996, NIM A, v372, 527
- [15] M. Nagano et al., 2004, Astropart. Phys. v22, 235
- [16] R. Abbasi et al., 2008, Astropart. Phys. v29, 77
- [17] M. Bohacova et al., 2009, Nucl. Phys. B Proc. Suppl. v190, 266
- [18] P. Colin et al., 2007, Astropart. Phys. v27, 317
- [19] T. Shibata et al., 2008, NIM A, v597, 61
- [20] H. Tokuno et al., 2008, Proc. of 30th ICRC, v5, 1013