Hybrid Measurement of the Telescope Array Experiment

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***Abstract*. The Telescope Array is the largest hybrid detector in the northern hemisphere. It consists of fluorescence detectors and an array of surface detectors to explore the origin of ultra high energy cosmic rays (UHECRs). The fluorescence detectors make calorimetric measurement of the primary UHECR energy. The surface detectors are plastic scintillation counters, which are less sensitive to hadronic interaction models and mass composition in determining the energies of air showers in an independent way. Hybrid measurement is the key to cross-checking the energy scales by simultaneous detection of UHECR air showers with these two complementary methods. The hybrid technique is also expected to provide improved reconstruction resolution than that by either method alone. We present the hybrid performance evaluated from the observations in the Telescope Array experiment.**

***Keywords*: Ultra High Energy Cosmic Rays, Telescope Array, Hybrid**

I. Introduction

The important role of the Telescope Array (TA) experiment is to measure the energy spectrum, arrival direction distribution, and mass composition of UHECRs. Whether super-GZK particles exist or not is a long-standing problem which has been raised by the discrepancy in energy spectra between the Akeno Giant Air Shower Array (AGASA) and High Resolution Fly's Eye (HiRes) [1][2]. In 2008, HiRes and Auger published the results of the energy spectra, which are consistent with GZK suppression [3][4]. The spectra multiplied to E^3 measured by AGASA, HiRes, Auger, and Yakutsk experiments differ from each other. V. Berezinsky emphasized that the measured spectra by the different experiments are in good agreement after energy shift at the dip, which is a feature predicted by electron-positron pair production in collisions of protons with CMB photons [5]. It can be an evidence that the energy scales of some experiments are not correct.

The TA detector [6] is the hybrid detector composed of an array of surface detectors (SDs) and fluorescence detectors (FDs) to observe air showers induced by UHECRs in the atmosphere (See Fig. 1).

The surface detector array consists of 507 plastic scintillation counters, deployed on a square grid with 1.2 km spacing to sample air shower particles on the ground. The array is located in the western desert of Utah, USA, and covers an area of about 700 km^2. We use AGASA-type plastic scintillation counters because they allow us energy estimation relatively insensitive to hadronic interaction models and mass composition of primary cosmic rays. Thus we can determine the energy of air showers by the surface detectors alone with the help of air shower Monte Carlo (MC) simulations independently of the fluorescence detectors. Full operation of the surface detector array started in March 2008. The performance of the surface detector array is mentioned in [7].

The fluorescence detectors record air fluorescence photons induced by air shower particles. There are three FD stations with HiRes-type telescopes, overlooking the central TA site. We constructed 24 new telescopes. The half of them are installed at Black Rock Mesa (BRM) to the southeast of the surface detector array, and the rest are at Long Ridge (LR) to the southwest. To the north, the Middle Drum (MD) site is instrumented with 14 telescopes previously used at the HiRes-1 site. The inclusion of the MD site makes possible a direct comparison between the fluorescence energy scales and spectra between TA and HiRes. All the three FD stations have been operating since November 2007. The performance of the fluorescence detectors is described in [8].

The fluorescence detectors observe the longitudinal shower development and make calorimetric measurement of the primary UHECR energy. On the other hand, the surface detectors measure lateral distribution of shower particles on the ground and make indirect measurement of the shower energy. Hybrid measurement is the key to cross-checking energy scales by detecting air showers simultaneously using these two independent and complementary methods. The fluorescence detectors are operational only on clear moonless nights ($\sim$10% duty cycle), and the surface detectors run continuously for 24 hours ($\sim$100% duty cycle). The surface detectors provide the largest statistical sample at the highest eneriges. We use the subset ("the hybrid events") of the SD data which were detected coincidentally with the

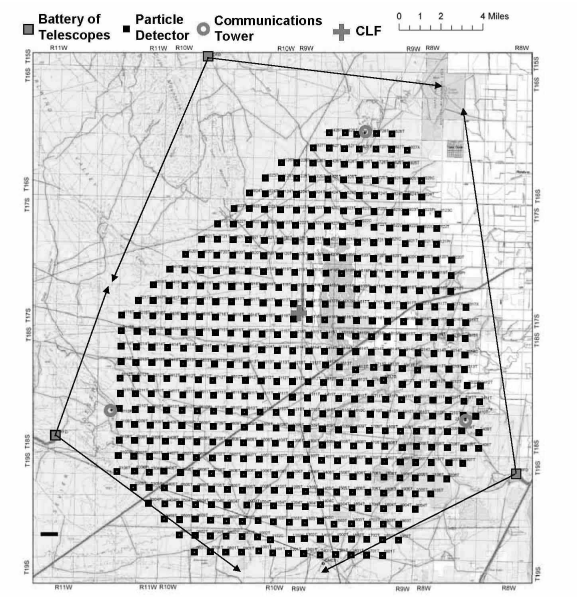

Fig. 1. Configuration of the TA detector, showing the positions of 507 deployed surface detectors surrounded by the three FD stations. The cross mark in the center of the TA site shows the position of the Central Laser Facility (CLF).

fluorescence detectors. Using the hybrid technique, we can improve reconstruction resolution than that by either technique alone.

II. Hybrid measurement

In order to understand the discrepancy between the AGASA and HiRes energy spectra, it is important to compare the SD and FD energies measured for the hybrid events candidates. We compare the time stamps on SD events with those on FD events to find the hybrid events. Fig. 2 shows the time differences between the SD and FD events. We chose the combinations of the SD and FD events with the time differences below 200 μs as the hybrid event candidates. Fig. 3 shows an example of a hybrid event which was detected with surface detectors and fluorescence detectors at BRM and LR.

We use a calorimetric technique for measuring UHECR energies with the fluorescence detectors. The monocular FD aperture increases with energy and the monocular FD spectrum can cover a very large energy range. The monocular FD analysis at the BRM and LR sites is explained in [9], and the analysis at the MD site is mentioned in [10]. The stereo FD analysis [11] using two FD stations simultaneously leads to better determination of the air shower geometry and the primary energy than the monocular FD analysis.

The surface detectors provide the energy parameter $S_\theta(r)$ which is defined as the total energy deposition in a surface detector at a distance of r from the shower core. Here the incident zenith angle of the primary cosmic ray is defined as θ. When we convert $S_\theta(r)$ to the cosmic ray primary energy, it is imperative to use air shower MC simulation. However, our energy estimation

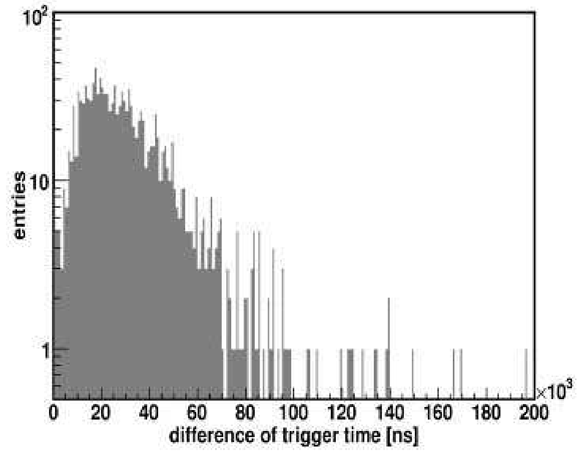

Fig. 2. Event time differences between the SD and FD events for the hybrid events.

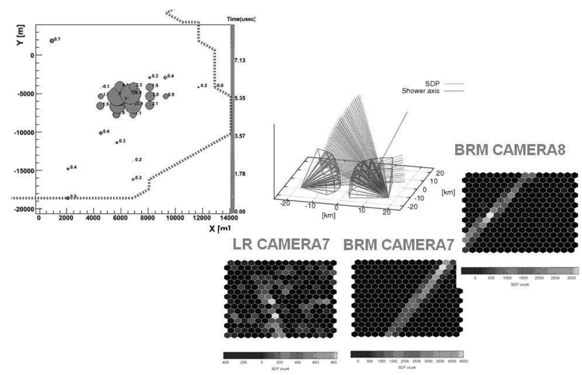

Fig. 3. An example of a hybrid stereo event. Left figure shows the data taken by the surface detectors. Right figure shows the shower reconstruction from the data taken by BRM FD and LR FD.

is rather insensitive to hadronic interaction models and mass composition of primary cosmic ray because the TA surface detectors are plastic scintillation counters. The details of the SD calibration and energy measurement with the surface detectors are described in [12].

It is important to estimate the energy deposition in the surface detector array properly for each event when we evaluate the primary energy of the cosmic ray. The energy deposition in the surface detector is caused not only by the charged particles but also by the neutral components such as much abundant soft gamma rays and delayed neutrons produced in the air shower. In order to take the effects of all the particles into account properly, we study the detector response by using GEANT4 simulation [13] with the detailed structure of the surface detector. We use and compare air shower MC simulations using COSMOS code [14] and CORSIKA code [15] including surface detector simulation to quantify the SD response.

It is also expected that the hybrid technique provides improved reconstruction resolution. In anisotropy studies, precise arrival directions of air showers are provided from analyses of hybrid data, which are used to cross-check the directions measured with surface detectors and to evaluate the SD angular resolution directly. The Central Laser Facility (CLF) is located equidistantly from three FD stations. The location of the CLF and the direction of the laser beam are known with better accuracy than those measured with the fluorescence detectors.

In the conference, we will present the comparisons between the shower parameters measured with the surface detectors and those with the fluorescence detectors. We also present the prospect of the improvement of FD event reconstruction with the help of the SD information.

For the precise determination of energy scale, we built Electron Light Source (ELS) [16] to perform end-to-end absolute energy calibration of the fluorescence telescopes including everything from the air fluorescence yield through the telescope optics and electronics. The ELS is a compact electron linear accelerator, and was constructed at KEK in Japan. We performed a series of beam tests. At the beginning of 2009, the ELS was moved to the BRM FD site. The beam operation will start this summer.

III. SUMMARY

The Telescope Array is the hybrid detector with a variety of components and methods to measure the energy of UHECRs in the northern hemisphere. We present the comparison of SD and FD energies for the hybrid events, which is the key for the precise measurement of the energy spectrum. We also present the prospect of the hybrid measurement to improve the reconstruction of air shower events.

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