Status of hybrid-trigger system of the Telescope Array experiment

H. TOKUNO[1,2], S. KITAMURA[1], R. ISHIMORI[1], T.NONAKA[3], D. IKEDA[3], T. FUJII[4], S. OGIO[4], J. SMITH[5], A. TAKETA[6], Y. TSUNESADA[1], Y. YAMAKAWA[3], FOR THE TELESCOPE ARRAY COLLABORATION.

[1] *Graduate School of Science and Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan*
[2] *Interactive Research Center of Science, Graduate School of Science and Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan*
[3] *Institute for Cosmic Ray Research, The University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[4] *Graduate School of Science, Osaka City University, Sumiyoshi, Osaka 558-8585, Japan*
[5] *Department of Physics and High Energy Astrophysics Institute, University of Utah, Salt lake city, Utah 84112, USA*
[6] *Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo, Japan*

htokuno@cr.phys.titech.ac.jp

Abstract: The Telescope Array is a hybrid detector which consists of a surface detector array with ∼700 km^2 area, and three air fluorescence detectors (FDs) surrunding the SD array. In October 2010, we have installed an external trigger for the SD array to obtain footprints of extensive air showers with the primary energy below $10^{18.5}$ eV efficiently. This trigger is provided from FD (called as "hybrid-trigger"), and additional SD information is recorded during FD observation since that time. In this paper, we introduce the simulation results for the performance of the FD mono analysis with one SD information.

Keywords: ultra-high energy cosmic rays, composition, hybrid trigger system

1 Introduction

The cosmic ray composition makes transition between heavier at 10^{16} eV to lighter $10^{18.5}$ (e.g. [1]).This transition may be caused by differences in their origin or propagation processes. To study these differences in detail, a more precise determination of the transition is needed in this energy range.

1.1 Hybrid Trigger

The Telescope Array (TA) experiment has been observing ultra-high energy cosmic rays (UHECRs) since May 2008. To observe extensive air showers (EASs), we installed a Surface Detector (SD) array and three air Fluorescence Detector (FD) stations in the west desert of Utah, USA [2]. Fig. 1 shows the schematic view of the detector positions. These different type of detectors are operated with thier own trigger independently. We installed newly developed FDs at the BRM and LR stations, and FDs from HiRes experiment at the MD station.

Longitudinal development of EASs, especially thier maximum development point (X_{max} [g cm^{-2}]), are measured by FD to estimate the primary particle type. In the FD analysis below $10^{18.5}$ eV, adding the SD information (EASs position and hit timing on the ground) improves reconstruction accuracies of longitudinal development of EASs significantly [3]. More than 90% EAS above $10^{17.0}$ eV make signals in at least one SD, however, our normal trigger efficiencies of the SD array is less than 1% below $10^{17.5}$ eV. To collect small SD signals, which are untriggered by the SD array itself, we have installed an external trigger, called "hybrid-trigger", for the SD array provided by FD. This trigger is thrown from the FD stations to the nearest SD sub-array, and all the signals of the SDs in the sub-array are stored. The specification of the hybrid-trigger system is described in the previous paper [4].

We have installed the hybrid-trigger system at BRM and LR stations in October 2010, and the system are operated

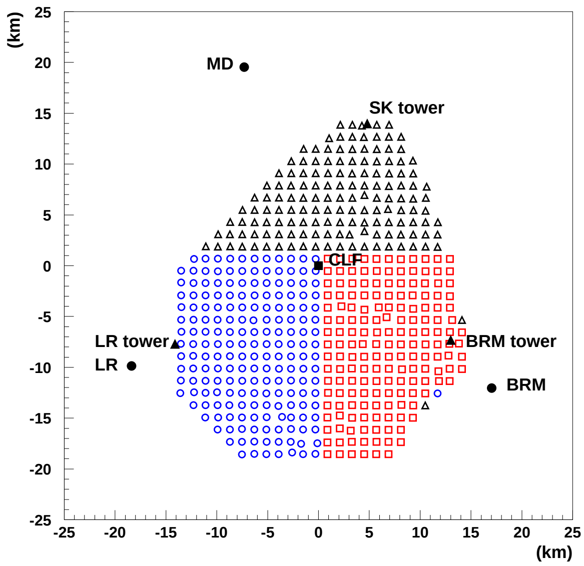

Figure 1: Schematic view of the detector positions. Filled circles: the position of FD station. Filled triangles: the SD control tower. Filled square: Central Laser Facility (CLF) [5]. Open circles, open squares, and open triangles represent SD positions belonging to the LR, the BRM, and the SK sub-array respectively. The hybrid-trigger is thrown from a FD to the nearby SD sub-array.

since that time. Fig. 2 shows the cumulative operation time of hybrid-trigger from October 2010 to November 2012. For safety reasons, the operation time of LR is shorter than that of BRM systematically. The operation time is growing up continuously except several times of maintenance.

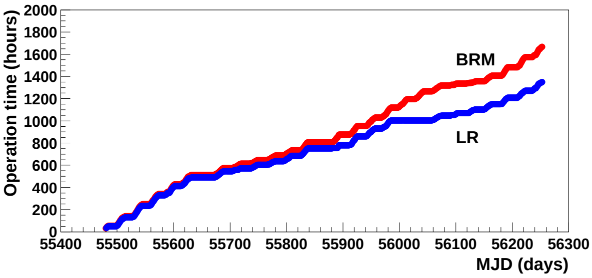

Figure 2: Cumulative operation time of the hybrid-trigger mode. For safety reasons, the operation time of LR is shorter than that of BRM systematically.

2 Simulation

In order to reconstruct EAS geometries, observed photon arrival timings are compared with expected ones in the monocular FD analysis. There are three fitting parameters to determine the shower axis on the Shower Detector Plane: the elevation angle of the air shower axis (Ψ), the hit timing of shower core on the ground, and the shower core distance from the FD [3]. In this fitting procedure, adding SD information can make a strong anchor of these fitting parameters of the shower core, and reconstruction accuracies of EAS geometries are drastically improved [3].

We are studying the reconstruction accuracies of the hybrid-trigger events using CORSIKA Monte Carlo (MC) [6] simulation with QGSJET-II-03 [7]. In this study we assume proton primaries and the slope of the energy spectrum of −3.25. We simulated EAS events in a circle with 25 km radius from the Central Laser Facility (CLF) [5], and with the zenith angle smaller than 60 degree. In this simulation studies, we applied minimum event selection criteria, for example, reconstructed zenith angle smaller than 57 degree, reconstructed X_{max} should be located in the field of view of the FDs. Fig. 3 shows the determination accuracies of the primary energy (upper panel) and X_{max} (lower panel), and there are no strong energy dependence on these accuracies. We are studying quality cut conditions to get robust reconstruction result of EAS longitudinal development.

3 Performance of Data

To check the consistencies between results from MC simulation events and those from observed events, we compared the distribution of the reconstructed geometrical parameters. In this procedure we applied the same quality cut conditions used in Sec 2. Fig. 4 shows comparison between the distribution of reconstructed zenith angle (in the upper panel) and azimuth angle (in the lower panel) for the observed events and their expected distribution from Monte-Carlo (MC) simulation. In addition, Fig. 5 shows comparison between the distribution of reconstructed the elevation angle of the EAS axis on the shower detector plane (Ψ) and impact parameter (R_p) for the observed events and their expected distribution from Monte-Carlo (MC) simulation. The figures show that there are no large systematic differences on the reconstructed geometrical parameters between MC events and observed events.

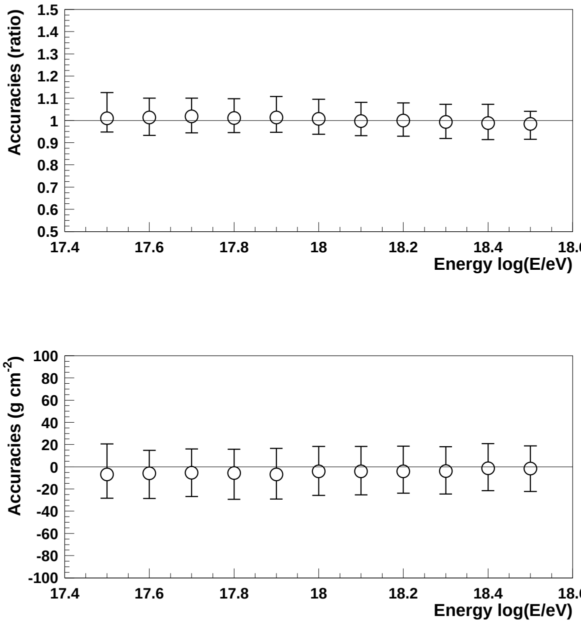

Figure 3: Accuracies of Energy and X_{max} determination. The plots and bars show the median value and the region of 68% C.L. respectively. Upper panel: the determination accuracies of the primary energy, lower panel: the determination accuracies of X_{max}.

4 Summary

Adding SD information improves determination accuracies of EAS geometries in the mono FD analysis. We installed the hybrid-trigger system to collect small signals of the SDs un-triggered by the normal SD trigger itself. The hybrid-trigger events have been observed continuously since 2010 October. The comparison between reconstructed geometrical parameters from MC events and observed events shows that there are no systematic differences. Optimization of quality cut conditions is now understudying to get robust reconstruction results of EAS longitudinal development such as the primary energy and X_{max}.

Acknowledgment: HT is supported by JSPS KAKENHI Grant Number 24740153. The Telescope Array experiment is supported by the Japan Society for the Promotion of Science through Grants-in-Aid for Scientific Research on Specially Promoted Research (21000002) "Extreme Phenomena in the Universe Explored by Highest Energy Cosmic Rays", and the Inter-University Research Program of the Institute for Cosmic Ray Research; by the U.S. National Science Foundation awards PHY-0307098, PHY-0601915, PHY-0703893, PHY-0758342, PHY-0848320, PHY-1069280, and PHY-1069286 (Utah) and PHY-0649681 (Rutgers); by the National Research Foundation of Korea (2006-0050031, 2007-0056005, 2007-0093860, 2010-0011378, 2010-0028071, R32-10130); by the Russian Academy of Sciences, RFBR grants 10-02-01406a and 11-02-01528a (INR), IISN project No. 4.4509.10 and Belgian Science Policy under IUAP VI/11 (ULB). The foundations of Dr. Ezekiel R. and Edna Wattis Dumke, Willard L. Eccles and the George S. and Dolores Dore Eccles all helped with generous donations. The State of Utah supported the project through its Economic Development Board, and the University of Utah through the Office of the Vice President for Research. The experimental site became available through the cooperation of the Utah School and Institutional Trust Lands Administration (SITLA), U.S. Bureau of Land Management and the U.S. Air Force. We also wish to thank the

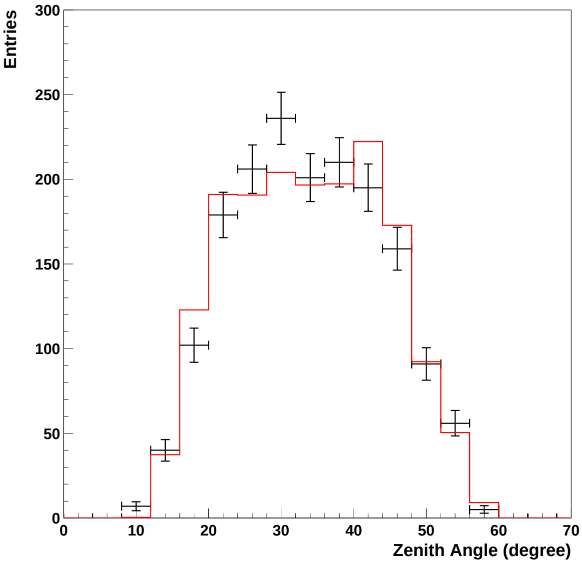

Figure 4: Distribution of Zenith (upper) and Azimuth (lower) angles. In each panel, histogram shows the results from proton simulation, and plots show the observed event distributions.

people and the officials of Millard County, Utah, for their steadfast and warm support. We gratefully acknowledge the contributions from the technical staffs of our home institutions as well as the University of Utah Center for High Performance Computing (CHPC).

References

[1] K.H. Kampert, and M. Unger, Astropart phys., 35 (2012) 660-678
[2] H. Kawai et al., Nucl.Phys.B Proc.Suppl, 175-176 (2008) 221-226
[3] D. Ikeda et al., proceedings of ICRC2011, 2 (2011) 238-241
[4] H. Tokuno et al., proceedings of ICRC2011, 3 (2011) 317-320
[5] T. Tomida et al., proceedings of ICRC2011, 3 (2011)

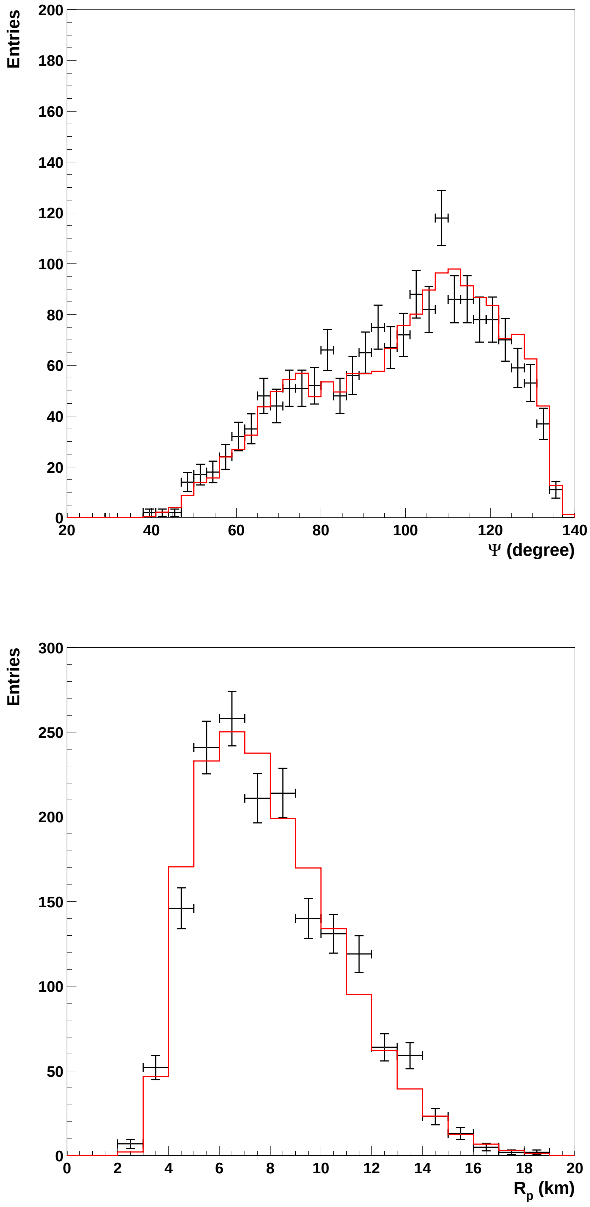

Figure 5: Distribution of geometrical parameters. Upper panel: the elevation angle of the air shower axis on the shower detector plane (Ψ), Lower panel: impact parameter (R_p). In each panel histogram shows the results from proton simulation, and plots show the observed event distributions.

329-332
[6] D. Heck et al., FZKA, (1998) 6019
[7] S. Ostapchenko, Nucl. Phys. Proc. Suppl. 151 (2006) 143-146