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The energy spectrum of Telescope Array's Middle Drum detector and the direct comparison to the High Resolution Fly's Eye experiment

T. Abu-Zayyad [a], R. Aida [b], M. Allen [a], R. Anderson [a], R. Azuma [c], E. Barcikowski [a], J.W. Belz [a], D.R. Bergman [a], S.A. Blake [a], R. Cady [a], B.G. Cheon [d], J. Chiba [e], M. Chikawa [f], E.J. Cho [d], W.R. Cho [g], H. Fujii [h], T. Fujii [i], T. Fukuda [c], M. Fukushima [j,t], D. Gorbunov [k], W. Hanlon [a], K. Hayashi [c], Y. Hayashi [i], N. Hayashida [l], K. Hibino [l], K. Hiyama [j], K. Honda [b], T. Iguchi [c], D. Ikeda [j], K. Ikuta [b], N. Inoue [m], T. Ishii [b], R. Ishimori [c], D. Ivanov [a,n], S. Iwamoto [b], C.C.H. Jui [a], K. Kadota [o], F. Kakimoto [c], O. Kalashev [k], T. Kanbe [b], K. Kasahara [p], H. Kawai [q], S. Kawakami [i], S. Kawana [m], E. Kido [j], H.B. Kim [d], H.K. Kim [g], J.H. Kim [d,r], K. Kitamoto [f], S. Kitamura [c], Y. Kitamura [c], K. Kobayashi [e], Y. Kobayashi [c], Y. Kondo [j], K. Kuramoto [i], V. Kuzmin [k], Y.J. Kwon [g], S.I. Lim [s], S. Machida [c], K. Martens [t], J. Martineau [a], T. Matsuda [h], T. Matsuura [c], T. Matsuyama [i], J.N. Matthews [a], I. Myers [a], M. Minamino [i], K. Miyata [e], Y. Murano [c], S. Nagataki [u], T. Nakamura [v], S.W. Nam [s], T. Nonaka [j], S. Ogio [i], M. Ohnishi [j], H. Ohoka [j], K. Oki [j], D. Oku [b], T. Okuda [i], A. Oshima [i], S. Ozawa [p], I.H. Park [s], M.S. Pshirkov [w], D.C. Rodriguez [a,*], S.Y. Roh [r], G. Rubtsov [k], D. Ryu [r], H. Sagawa [j], N. Sakurai [i], A.L. Sampson [a], L.M. Scott [n], P.D. Shah [a], F. Shibata [b], T. Shibata [j], H. Shimodaira [j], B.K. Shin [d], J.I. Shin [g], T. Shirahama [m], J.D. Smith [a], P. Sokolsky [a], T.J. Sonley [a], R.W. Springer [a], B.T. Stokes [a], S.R. Stratton [a,n], T.A. Stroman [a], S. Suzuki [h], Y. Takahashi [j], M. Takeda [j], A. Taketa [x], M. Takita [j], Y. Tameda [j], H. Tanaka [i], K. Tanaka [y], M. Tanaka [h], S.B. Thomas [a], G.B. Thomson [a], P. Tinyakov [k,v], I. Tkachev [k], H. Tokuno [c], T. Tomida [b], S. Troitsky [k], Y. Tsunesada [c], K. Tsutsumi [c], Y. Tsuyuguchi [b], Y. Uchihori [z], S. Udo [i], H. Ukai [b], G. Vasiloff [a], Y. Wada [m], T. Wong [a], M. Wood [a], Y. Yamakawa [j], R. Yamane [i], H. Yamaoka [h], K. Yamazaki [i], J. Yang [s], Y. Yoneda [i], S. Yoshida [q], H. Yoshii [aa], R. Zollinger [a], Z. Zundel [a]

[a] *University of Utah, High Energy Astrophysics Institute, Salt Lake City, UT, USA*
[b] *University of Yamanashi, Interdisciplinary Graduate School of Medicine and Engineering, Kofu, Yamanashi, Japan*
[c] *Tokyo Institute of Technology, Meguro, Tokyo, Japan*
[d] *Hanyang University, Seongdong-gu, Seoul, South Korea*
[e] *Tokyo University of Science, Noda, Chiba, Japan*
[f] *Kinki University, Higashi Osaka, Osaka, Japan*
[g] *Yonsei University, Seodaemun-gu, Seoul, South Korea*
[h] *Institute of Particle and Nuclear Studies, KEK, Tsukuba, Ibaraki, Japan*
[i] *Osaka City University, Osaka, Japan*
[j] *Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba, Japan*
[k] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia*
[l] *Kanagawa University, Yokohama, Kanagawa, Japan*
[m] *Saitama University, Saitama, Saitama, Japan*
[n] *Rutgers University, Piscataway, NJ, USA*
[o] *Tokyo City University, Setagaya-ku, Tokyo, Japan*
[p] *Waseda University, Advanced Research Institute for Science and Engineering, Shinjuku-ku, Tokyo, Japan*
[q] *Chiba University, Chiba, Japan*
[r] *Chungnam National University, Yuseong-gu, Daejeon, South Korea*
[s] *Ewha Womans University, Seodaaemun-gu, Seoul, South Korea*
[t] *University of Tokyo, Institute for the Physics and Mathematics of the Universe, Kashiwa, Chiba, Japan*
[u] *Kyoto University, Sakyo, Kyoto, Japan*
[v] *Kochi University, Kochi, Japan*
[w] *University Libre de Bruxelles, Brussels, Belgium*
[x] *Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo, Japan*
[y] *Hiroshima City University, Hiroshima, Japan*
[z] *National Institute of Radiological Science, Chiba, Japan*
[aa] *Ehime University, Matsuyama, Ehime, Japan*

* Corresponding author.
E-mail address: doug@cosmic.utah.edu (D.C. Rodriguez).

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ABSTRACT

The Telescope Array's Middle Drum fluorescence detector was instrumented with telescopes refurbished from the High Resolution Fly's Eye's HiRes-1 site. The data observed by Middle Drum in monocular mode was analyzed via the HiRes-1 profile-constrained geometry reconstruction technique and utilized the same calibration techniques enabling a direct comparison of the energy spectra and energy scales between the two experiments. The spectrum measured using the Middle Drum telescopes is based on a three-year exposure collected between December 16, 2007 and December 16, 2010. The calculated difference between the spectrum of the Middle Drum observations and the published spectrum obtained by the data collected by the HiRes-1 site allows the HiRes-1 energy scale to be transferred to Middle Drum. The HiRes energy scale is applied to the entire Telescope Array by making a comparison between Middle Drum monocular events and hybrid events that triggered both Middle Drum and the Telescope Array's scintillator ground array.

1. Telescope Array

The Telescope Array (TA) is the largest cosmic ray experiment in the northern hemisphere. It was designed to help resolve physics differences between the High Resolution Fly's Eye (HiRes) experiment, the Akeno Giant Air Shower Array (AGASA) [2], and the Pierre Auger Observatory [3]. TA consists of three HiRes-like fluorescence telescope stations overlooking 507 AGASA-like scintillator surface detectors (see Figs. 1 and 2). The surface detector (SD) array was deployed in a square grid with a 1.2 km separation, covering $\sim 700\ \mathrm{km}^2$ [1]. Each SD unit is composed of two layers of $3\ \mathrm{m}^2 \times 1.2$ cm scintillating plastic sheets separated by a thin steel sheet. The light from each layer is collected by wavelength-shifting optical fibers and directed into separate photo-multiplier tubes (PMTs).

Three telescope stations view the sky over the scintillator array. The northernmost fluorescence station, known as the Middle Drum (TAMD) site, consists of 14 telescopes refurbished from the HiRes experiment's HiRes-1 site. These were deployed between November, 2006 and October, 2007 and were arranged to view $\sim 120^\circ$ in azimuth and $3^\circ - 31^\circ$ in elevation. Compared to HiRes-1 [4], the Middle Drum site has only 1/3 of the azimuthal coverage but observes twice the elevation, as it was deployed into two rings, each covering 14° in elevation. Each telescope unit uses sample-and-hold electronics with a 5.6 μs gate. Each telescope camera consists of 256 PMTs covered with an ultra-violet band-pass filter. The Black Rock (TABR) and Long Ridge (TALR) telescope stations were described by Tokuno et al. [5].

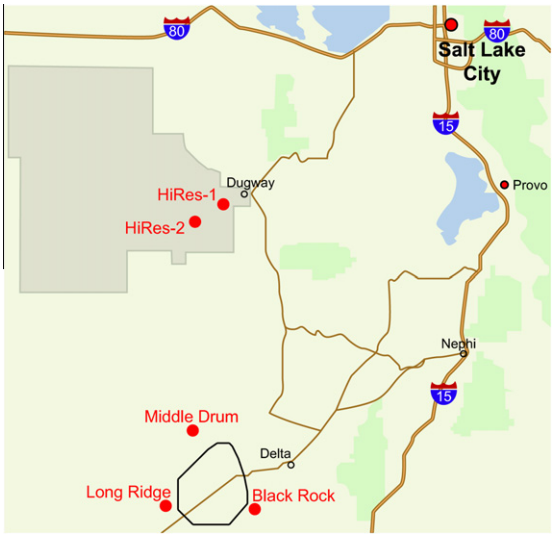

Fig. 1. Map showing the location of Telescope Array relative to Salt Lake City and Dugway, Utah (the location of the high resolution fly's eye). The route from Salt Lake City to Delta is 136 miles.

The goals of the Middle Drum spectral analysis are threefold. The primary goal of this analysis is to determine the flux of particles using the same calibration and analysis processing tools used to produce the monocular spectrum from the HiRes-1 data. The second goal is to compare the spectrum measured by the Middle Drum detector with that of HiRes-1. Since the telescope units used in both of these detectors are composed of the same equipment, the results of this comparison produce a direct link in the energy scale between these two experiments. Finally, by comparing events observed by Middle Drum and any of the other TA detectors, the energy scale of the entire Telescope Array experiment can be compared to that of the HiRes experiment. In this paper, this comparison is performed between the geometries of the events observed by Middle Drum and reconstructed using the monocular technique to those events that triggered both Middle Drum and the SD array and analyzed using a hybrid technique. The results of this approach are expected to show the direct difference between the energy scales of Middle Drum and HiRes-1. It is expected that this will be the only method required to transfer the energy scale of HiRes to TA.

2. Event reconstruction and selection

The Middle Drum data and Monte Carlo events (described in Section 3) were processed using the same programs created for HiRes-1 analysis [6]. The only changes made were for the location and pointing directions of the telescopes. The HiRes-1 analysis was unique in that there was limited elevation coverage and a traditional monocular reconstruction could not be performed on the data. Instead, a combined geometrical-profile reconstruction was developed by Abu-Zayyad [7] which improved the resolution of the observed showers. In this technique, the energy and the geometry are reconstructed concurrently, only needing to vary the angle between the shower axis and the direction of the core position, ψ. This ensures that the reconstruction of the observed signal improves the accuracy of the pointing direction and primary energy of the cosmic ray. This technique was not required in the analysis of Middle Drum data since the increase in elevation angle coverage would allow an accurate geometrical reconstruction based on a fit to the arrival time of light for the tubes in the shower-detector plane. However, the profile-constrained geometry reconstruction was used for consistency in order to limit the differences for the energy scale comparison.