Test of the Telescope Array Low-energy Extension Tower Prototype

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***Abstract*. The second knee, located in the middle of the 10^{17} eV decade is the most poorly known feature of the ultrahigh energy cosmic-ray spectrum. Because the fluorescence signals become small in this energy region and shower development occurs high in the atmosphere, an accurate measurement of this feature requires large mirrors pointing at high elevations. A prototype of the proposed TALE (Telescope Array Low-energy Extension) Tower fluorescence detector, a 12.2 m^2 mirror which observes at elevation angles between 44 and 58 degrees, has been built in Dugway, Utah. The prototype has been tested in coincidence with the 5.1 m^2 HiRes-I telescopes which observe from 3 to 17 degrees. Coincidence events have signals in the Tower prototype consistent with expectations from simulations, confirming expectations for the performance of the proposed Tower fluorescence detectors.**

***Keywords*: UHECR, fluorescence, Telescope Array**

I. Introduction

The Telescope Array experiment (TA), a system of 3 fluorescence telescope sites and 507 surface detectors located in Millard County, Utah, has been taking data for a little over a year. The experiment was designed to measure the energies, composition and arrival directions of the ultrahigh energy cosmic rays (UHECR). The TA experiment is sensitive to UHECRs with energies in excess of about 10^{18} eV.

We propose a set of detectors known as the TA Low Energy Extension (TALE) to increase the total aperture of the experiment and extend its energy range down into the 10^{16}-eV decade. The TALE fluorescence detectors (FD) will be located 6 km from the currently operating FD located at Long Ridge to the southeast of the array, thereby obtaining better stereoscopic measurements of UHECRs in the region near the ankle. While most TALE FDs will observe with the same elevation angles as the TA FD sites (3 to 31 degrees), one TALE FD, known as the TALE Tower Detector will have three-times larger mirrors and observe from 31 to 71 degrees. With its larger mirrors and higher elevation angles, the Tower will measure cosmic rays with energies from $10^{16.5}$ to 10^{18} eV whose air showers are much dimmer and develop higher in the atmosphere.

This energy range is the least-studied region of the cosmic-ray spectrum and contains the so-called "second knee" feature located in the middle of the 10^{17} decade. This region likely contains the transition from galactic to extra-galactic cosmic rays as can be seen by the change from a heavier to lighter elemental composition with increasing energy. Near around $10^{16.5}$ eV, the KASCADE [1] and the HiRes Prototype/MIA [2] experiments have found a heavy elemental composition in this region, due to sources of primarily galactic origin. The HiRes experiment observed a mostly light, composition in the region near 10^{18} eV [3]; the HiRes Prototype/MIA experiment measured a changing composition from heavy to light in in this region.

The TA/TALE experiment will be sensitive to UHECRs across nearly four decades in energy. Measurements of several features in the UHECR spectrum with a single experiment will be integral to gaining a better understanding of the sources and composition of cosmic rays.

II. The TALE Tower Detector Prototype

A prototype for the Tower detector was built and tested in conjunction with the HiRes-I detector located in Dugway, Utah. Of primary importance in testing the apparatus were studies of the photomultiplier tube (PMT) thresholds, trigger rates of the mirror and the quality of event reconstruction. An FD was constructed at the HiRes-I site that observes at elevation angles from 44 to 58 degrees with twice the mirror area of the HiRes mirrors. The detector used the same electronics and PMTs as the HiRes-I detector; the PMTs were fit with Winston cones to increase their acceptance. Figure 1 shows a drawing of this detector.

Data was collected with this mirror during July and August, 2007 in coincidence with data collected with six mirrors of the HiRes-I experiment, observing from 3 to 17 degrees. The Tower prototype ran in a stable manner with a trigger rate of around 2 Hz (roughly a factor of 4 higher than the typical HiRes-I trigger rate, but well within the capability of the electronics).

Real cosmic-ray events collected were analyzed with the standard HiRes analysis routines. Figure 2 shows

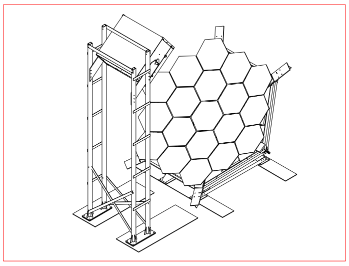

Fig. 1. Drawing of the TALE Tower detector prototype.

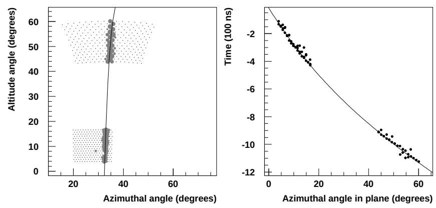

Fig. 2. Event seen in both the TALE Tower prototype and the HiRes-I detector. *Left panel*: Image of a cosmic-ray event in altitude and azimuth as seen by the Tower and a HiRes-I mirror. *Right panel*: Time vs. angle plot with best-fit event geometry overlaid. The impact parameter for this event was found to be 3.82 ± 0.04 km.

an image of an event seen in both the Tower prototype mirror and one of the HiRes mirrors, in addition to the measured time of the event as a function of angle in the shower-detector plane. From a fit to the time vs. angle plot, this event was found to have an impact parameter, R_P, of 3.82 ± 0.04 km.

A Xenon flasher located 3.4 km from the site was fixed so that its beam crossed the fields of view of both the Tower and HiRes-I. Taking into account the geometry of the beam, the mirror solid angles and atmospheric absorption, we estimated the ratio of pulse heights from the two detectors to be 0.94, and found 0.86 ± 0.18, in good agreement with expectation. We found the test of the Tower prototype to be an overall success.

III. Tower electronics

The Tower detectors will observe cosmic rays with energies in the range from $10^{16.5}$ to 10^{18} eV. In order to be detected, events in this energy range will be relatively dim and must pass close to the detector. With three-times larger mirrors than their HiRes predecessors, we expect the signal-to-noise ratio to be about a factor of 3 higher than that for HiRes. Since events that occur close to the detector will be seen in only a small number of FADC bins in a given PMT, we plan to increase the FADC readout system by a factor of 4 in order to further increase the signal-to-noise ratio. We modified the existing HiRes full-detector Monte Carlo simulation to test the effect of decreasing the HiRes sampling rate from 100 ns to 25 ns per FADC bin. It was found that using a sampling rate of 25 ns and an FADC shaping time of 50 ns greatly increased our ability to reconstruct the geometries of events below 10^{17} eV. Figure 3 shows the improvement in resolution in the shower impact parameter, R_p and the angle in the shower-detector plane, ψ [4].

IV. Conclusion

We have tested a prototype for the TALE Tower detector, an important component of the proposed low-energy extension to the Telescope Array experiment. The prototype behaved as expected; the light-gathering power of its larger mirror agreed with simulations. We have simulated an FADC system with a 25-ns sampling rate and a 50-ns shaping time and have found that it greatly increases the ability to reconstruct cosmic-ray-induced air showers in the energy range from 10^{16} to 10^{17} eV.

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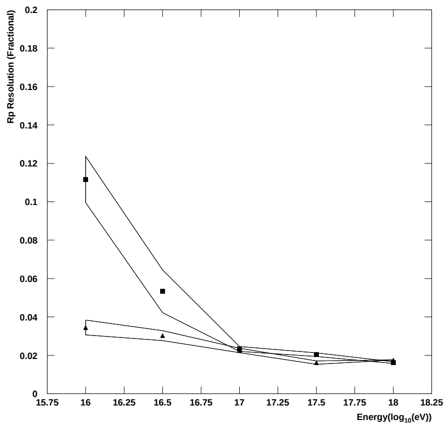
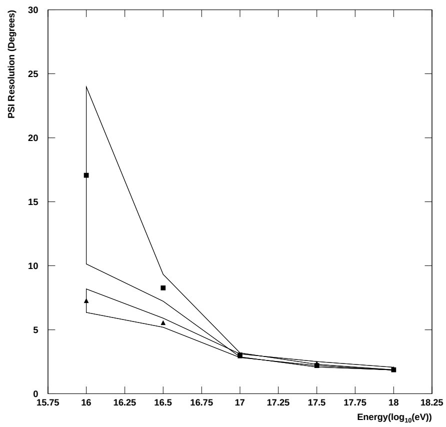


(a) R_p resolution



(b) ψ resolution

Fig. 3. Resolution for reconstructing the impact parameter, R_p and the angle in the shower-detector plane, ψ from simulations using an FADC with a 100-ns sampling rate (*squares*) and a 25-ns sampling rate (*triangles*). The ability to reconstruct cosmic rays with energies less than about 10^{17} eV is greatly enhanced using a 25-ns sampling rate.