The Telescope Array Low Energy Extension

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Abstract: The Telescope Array observatory has been collecting ultra high energy cosmic ray data since 2007. It consists of three telescope stations at the corners of a 30km triangle and an array of 507 scintillator detectors filling the central part of this area. The scintillator detectors measure the footprint of the extensive air show generated when a cosmic ray interacts with the atmosphere. The 38 telescopes at the three stations observe the longitudinal development of the showers above the scintillator array. However, the existing experiment was designed with a threshold of 10^{19} eV. While we have been able to extend analysis down to about 10^{18} eV, this is insufficient to fully observe the galactic to extra galactic transition. In addition, it is optimal to observe cosmic rays from LHC energies through the second knee and up to the GZK cutoff with one well cross-calibrated detector. TALE, the low energy extension to the Telescope Array, is designed to lower the energy threshold to about $10^{16.5}$ eV. To do this, we installed an additional 10 telescopes viewing up to 57 degrees in elevation and a new graded array of scintillator detectors. This extension will enable the Telescope Array to measure the energy and composition of cosmic rays to much lower energies while cross calibrated with the detectors of the main Telescope Array. By pushing the energy threshold down to $10^{16.5}$ eV, we hope to sort out the galactic and extragalactic contributions to the cosmic ray flux. The detectors, their status, and first measurements will be presented.

Keywords: GCR to EGCR transition, source evolution, cosmic ray composition, spectrum, anisotropy, below ankle.

1 Introduction

The Telescope Array (TA) experiment is designed to study ultrahigh energy cosmic rays of energies above about 10^{18} eV, and the equipment, which is located in Millard county, Utah, is the largest such experiment in the northern hemisphere[1]. TA consists of a Surface Detector (SD) of 507 scintillation counters deployed on a square grid of 1.2 km spacing, and three fluorescence detectors (FD) overlooking the SD.

These existing detectors observe cosmic ray showers in independent, stereo, and hybrid modes. The ground array has 100 % detection efficiency and an aperture of about 1500 km^2 sr above 10^{19} eV. Above 10^{19} eV, the three FD stations cover the full ground array and operate in hybrid and stereo modes. Routine observations by TA FD began in late 2007, and the ground array in the spring of 2008.

The TA Low Energy Extension (TALE) project consists of a set of detectors to be added to TA which will lower the energy threshold of the experiment to about $10^{16.5}$ eV. The TALE fluorescence detector consists of 10 new telescopes which cover elevation angles between $30°$ and $57°$ (Fig. 1). The TALE surface detector will include an infill array of 76 scintillation counters (40 with 400 m spacing and 36 with 600 m spacing) and an addition to the TA SD of an additional 25 counters. The TALE detectors will operate as one experiment with those of TA. Cross calibrations of the energy scale and resolution, pointing accuracy, and Xmax reconstruction will be carried out for each of the TA/TALE detectors. This experiment will have the widest energy range in the ultra high energy field. They will operate with a single energy scale and will observe cosmic rays seamlessly from below 10^{17} eV to above 10^{20} eV.

The physics aims of TALE are to study the second knee of the cosmic ray spectrum, the galactic-extragalactic transition, the iron knee and the evolution parameter of the cosmic ray sources. In addition, we will characterize cosmic ray showers at 10^{17} eV to compare with LHC measurements at the equivalent center of mass energy.

2 TALE Physics

2.1 Galactic to Extragalactic Transition

There is a great deal of information potentially available to us in the form of several structures in the flux of cosmic rays. From low energy to high, the knee of the spectrum occurs at about $10^{15.5}$ eV, the second knee in the middle of the 10^{17} eV decade, the ankle at $10^{18.66}$ eV, and a suppression at $10^{19.73}$ eV[2].

The knee of the cosmic ray spectrum has been interpreted as the start of a rigidity-dependent cutoff, where protonic cosmic rays are being effected. If it is true, then the process would continue through helium, carbon and continue through iron. The iron knee or cutoff would be a factor of 26 higher, at 8×10^{16} eV. If this feature exists, it should be found in the heavy component of the spectrum.

While the highest energy galactic cosmic rays (GCRs) are expected to be heavy nuclei, extragalactic cosmic rays (EGCRs) are expected to be light, so the galactic-to-extragalactic transition should show up as a heavy to light change in composition. This transition feature may be reflected in the second knee, which has been observed by four previous experiments[3]. Their energy scales differ by about a factor of two, so the energy at which the second knee occurs is quite uncertain, except that it occurs some-
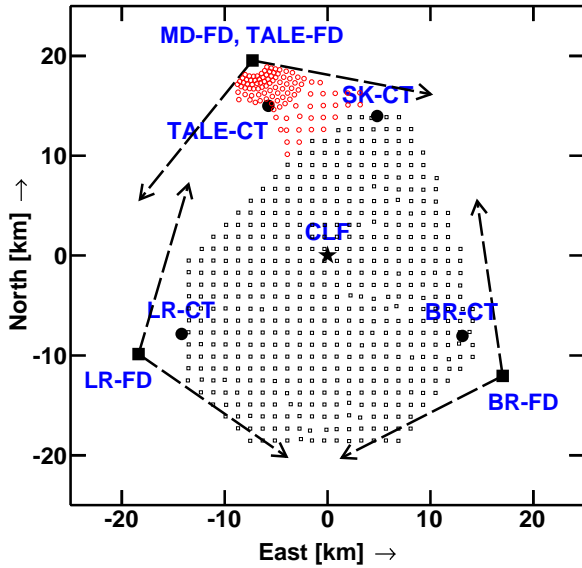
Fig. 1: The TA and TALE experiment layout. Open squares represent the positions of the TA scintillation counters and open circles show the positions of the TALE counters.

where in the middle of the 10^{17} eV decade. Important information can be learned about the second knee by performing a correlated spectrum + composition study. It is necessary to emphasize the importance of the width of the Xmax distribution at a constant energy. In the region of the galactic-extragalactic transition, if the composition is galactic iron plus extragalactic protons, the distribution of Xmax values will be very wide. This will be an unmistakable signature.

2.2 Evolution of Cosmic Ray Sources

Interactions between cosmic ray protons and the cosmic microwave background photons, as well as the expansion of the universe, cause cosmic rays to lose energy in a way that depends on the distance from the cosmic ray source to the Earth. The energy loss mechanisms cause there to be a correlation between cosmic ray energies and the average redshift of their origin. This correlation can be exploited to measure the evolution of cosmic ray sources. The details of the spectral shape, measured with sufficient precision, have the potential of giving us the maximum energy, spectral index and evolution parameter of the sources. Previous studies [4] indicate that the region of the middle of the 10^{19} eV decade is sensitive to the average spectral index at the source, and the region just below the ankle is sensitive to the evolution parameter. Therefore, these important parameters of the sources are separated in the fit, and can be measured as well.

2.3 Air Showers at LHC energy

The Large Hadron Collider (LHC) is running at a center-of-mass energy of 14 TeV, which is equivalent to 1×10^{17} eV in fixed target mode. LHC experiments continue to measure cross sections that can be used in air shower Monte Carlo simulations. As the new information is included in the models, experiments like TALE will provide very use-

ful measurements to test the models. In particular, since the proton-proton total cross section will be known at 1×10^{17} eV, a more accurate simulation of Xmax can be made. This will be very important for ultrahigh energy cosmic ray experiments.

2.4 Anisotropy

The hybrid TALE instruments, in particular, will be able to study anisotropy in conjunction with composition. Composition tagged studies could see the anisotropy of galactic origin in the heavier component. Because of large magnetic deflections, however, such signals would likely be manifested in the form of large scale harmonic distortions rather than in point correlations.

3 TALE Detectors

3.1 Fluorescence Detector

Fig. 2: Photos of TALE FD building(*upper*), telescopes(*lower left*), the Middle Drum TA FD and the TALE FD(*lower right*).In the lower right figure, the left building, which has the opened seven windows, is the Middle Drum TA station. The left is the TALE FD station.
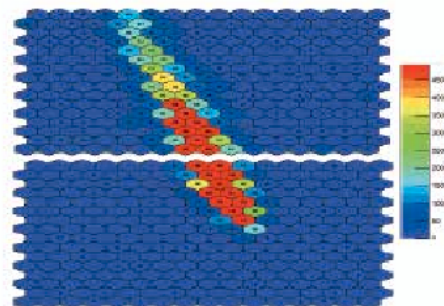
Fig. 3: An event from the first hours of TALE FD operation.

The TALE fluorescence detector will observe from $30°$ to $57°$ above the previous Middle Drum telescopes. Hence
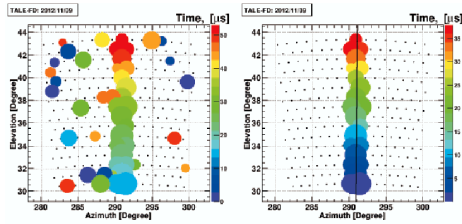
Fig. 4: A vertical laser image from the central laser facility. (*left*)The combined raw data image after signal processing. (*right*)The image after noise tube filtering and plane fitting.

the full FOV is 3° to 57° in elevation. This will enable this site to see Xmax for the lower energy events which is higher in the sky. Reconditioned HiRes Telescopes are being used for the TALE fluorescence detector. They are coming from the HiRes-II detector, and have FADC readout with 10 MHz sample rate.

The building to house the TALE FD, which generally resembles the previous Middle Drum FD building, was placed right next to that building(Fig. 2). The telescopes have been deployed, and test operations are continuing from November 2012. The TALE FD is now in a commissioning phase, and we continue to adjust and to reconfigure triggering electronics. An event and a laser image taken by the TALE FD are shown in Fig. 3 and Fig. 4.

A large telescope, which has a primary mirror of about 5 m diameter, is currently under development. The large telescopes will be additionally installed in the TALE FD station and arranged to cover elevation angles up to 72° to see lower energies.

3.2 Surface Detector Array

In front of the TA+TALE FD detectors an infill air shower array of about 100 scintillation counters will be deployed(Fig. 5). This detector is designed to operate from 3×10^{16} eV, up to the highest energies. All of the scintillation counters of the infill array will be similar to those of the TA SD. The infill array consists of three parts. The first part has 40 counters with a spacing of 400 m. This part is closest to the TALE FD (1.5 km at its closest point), and is designed to have 10 % efficiency at 3×10^{16} eV. Since most events in the 10^{16} eV decade that are seen by the FD fall within 3 km of the FD, in order to cover more area, for distances between 3 and 5 km we change the spacing to 600 m. At this spacing the infill array is 10 % efficient at 1×10^{17} eV. The excellent TA analysis and simulation techniques have been used to predict these efficiencies. We have shown that these techniques are bias-free at this efficiency level. For larger distances we use the spacing of the main TA SD array, 1200 m to join the TALE SD array to the main TA SD array. In October 2012 the WLAN communications tower was installed, and 35 counters were deployed with 400 m spacing in April 2013(Fig. 6).

The TALE infill array is designed to work as a standalone detector, or in hybrid mode (as is the TA SD). It will make a measurement of the spectrum and composition of cosmic rays for energies above 3×10^{16} eV. The expected number of events per year are shown in Fig. 7 and Fig. 8.
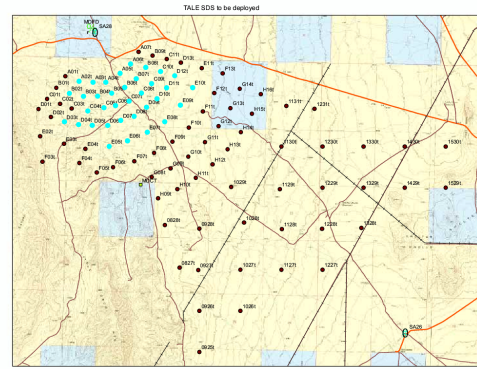
Fig. 5: The planned alignment of the TALE SD. The brown and light blue points indicate planned and deployed SD locations. The green marker labeled "MD FD" is the location of the Middle Drum station. "SA" indicates the staging areas for surface detectors before deployment.
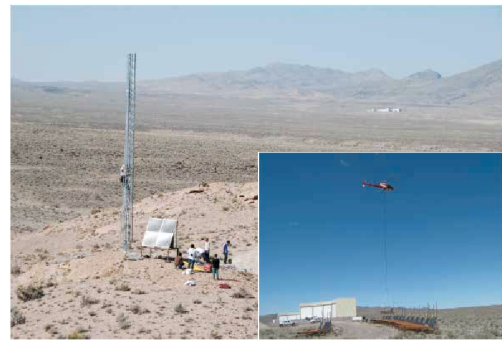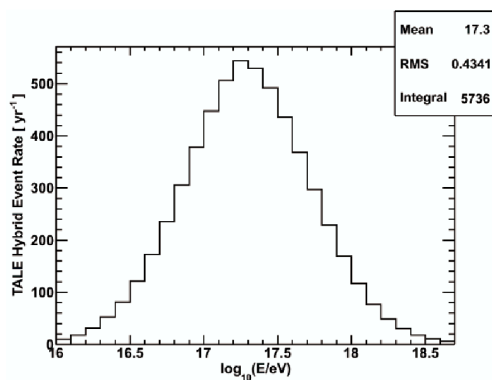

Fig. 6: The WLAN communications tower for TALE. In upper right of the photo, we can see the Middle Drum station in the distance. The over-wrapped photo shows the deployment work with a helicopter in April 2013 for surface scintillation detectors at the Middle Drum FD station.

Fig. 7: The expected number of events per year detected with TALE SD array.

Fig. 8: The expected number of hybrid events per year detected with TALE.

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