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TALE FD Cosmic Rays Composition Measurement

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The Telescope Array (TA) cosmic rays detector located in the State of Utah in the United States is the largest ultra high energy cosmic rays detector in the northern hemisphere. The Telescope Array Low Energy Extension (TALE) fluorescence detector (FD) was added to TA in order to lower the detector's energy threshold, and has succeeded in measuring the cosmic rays energy spectrum down to PeV energies. In this contribution we describe a measurement of the cosmic rays composition using TALE FD data collected over a period of ~ 4 years. TALE FD data is used to measure the X_{max} distributions of showers seen in the energy range of $10^{15.3}$ - $10^{18.3}$ eV. An increase in the X_{max} elongation rate is observed at energies just above 10^{17} eV indicating a change in the cosmic rays composition from a heavier to a lighter mix of primaries.

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1. Introduction

The Telescope Array (TA) experiment was designed for the study of ultra high energy (above $\sim 10^{18}$ eV) cosmic rays. TA is the successor to the AGASA/HiRes experiments [1, 2] with the goal of improving on both. TA is composed of three fluorescence detectors (FDs) [3, 4] and a large array of surface detectors [5]. TA is located in Millard County, Utah, $\sim$ 200 km southwest of Salt Lake City. The surface detector array is made up of 507 scintillation counters with 1.2 km spacing on a square grid. The three fluorescence detectors have an elevation coverage of about 30°, and an azimuthal coverage of about 110° overlooking the SD array.

The TA Low Energy extension (TALE) detector [6] aims to lower the energy threshold of the experiment to well below 10^{17} eV. This is mainly motivated by the interest in the galactic to extra-galactic transition in cosmic ray flux.

Located at the TA Middle Drum FD site at the northern edge of the main SD array, TALE provides an additional set of telescopes with high-elevation angle view to the site. These complement the existing telescopes at Middle Drum, resulting in an elevation coverage range of 3°-59° for the full detector. In addition, an infill surface detector (SD) located closer to the FD site than the main TA array, and with closer spacing between the SD counters themselves, forms the second component of the “hybrid detector”. TALE operates as a hybrid detector (FD/SD) for best event quality in the intended range of operation, but can also operate as two separate detectors. GPS timing allows for an observed cosmic ray shower (an event) observed separately by the FD and SD to be merged into a single event. Events recorded by the FD which fail to trigger the SD, or if we choose to ignore the SD data, are referred to as monocular events.

2. Data Analysis

TALE FD data collected between June 2014 and November 2018 is included in the analysis. The total, good-weather, detector on-time in this period is $\sim$ 2700 hours. Air showers register in the detector as events, which are calibrated and reconstructed to obtain the shower geometry, total energy, and the depth of maximum development, X_{max}. Quality cuts are applied to the reconstructed data to reduce it to a data set usable for energy spectrum measurement or for cosmic rays composition analysis, the subject of this proceeding.

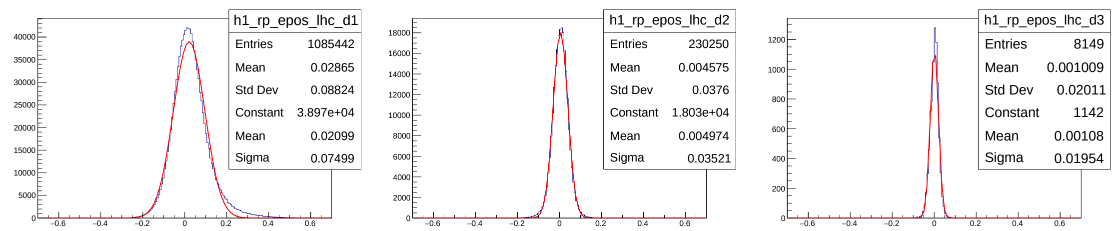

Figure 1: Track impact parameter, R_p, resolution. The histograms show the fractional error, $\Delta R_p/R_p$. The three plots are for events reconstructed in different energy ranges; from the left: $10^{15.3}$ - $10^{16.3}$ eV, $10^{16.3}$ - $10^{17.3}$ eV, and $10^{17.3}$ - $10^{18.3}$ eV

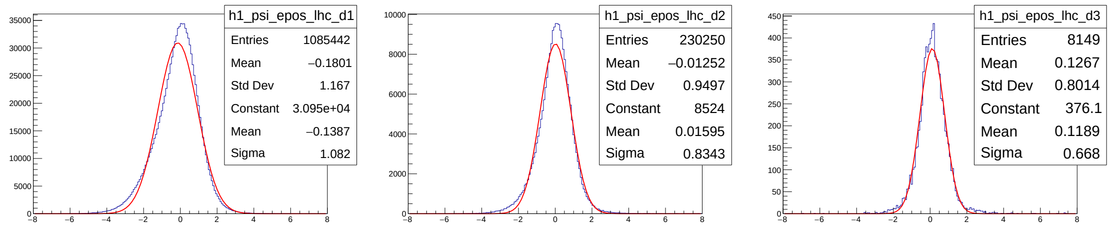

Figure 2: Track "angle in the plane", ψ, resolution. The histograms show the error, $\Delta\psi$. Along with R_p, the ψ angle error determines the accuracy of the shower track reconstruction. The three plots are for events reconstructed in different energy ranges; from the left: $10^{15.3}$ - $10^{16.3}$ eV, $10^{16.3}$ - $10^{17.3}$ eV, and $10^{17.3}$ - $10^{18.3}$ eV

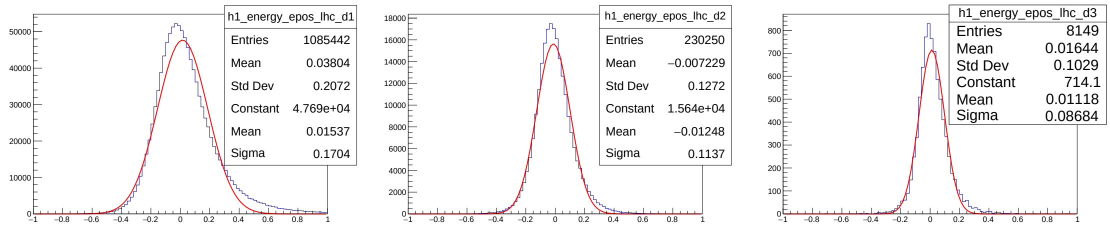

Figure 3: Shower Energy, E, resolution. The histograms show the fractional error, $\Delta E/E$. The three plots are for events reconstructed in different energy ranges; from the left: $10^{15.3}$ - $10^{16.3}$ eV, $10^{16.3}$ - $10^{17.3}$ eV, and $10^{17.3}$ - $10^{18.3}$ eV

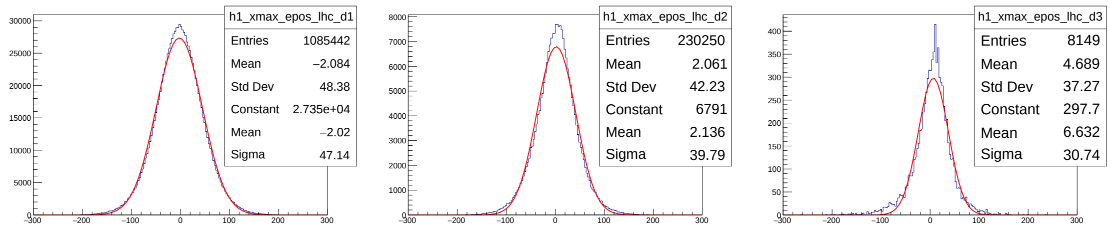

Figure 4: Shower X_{max}, resolution. The histograms show the error, $\Delta X_{max} gcm^{-2}$. The three plots are for events reconstructed in different energy ranges; from the left: $10^{15.3}$ - $10^{16.3}$ eV, $10^{16.3}$ - $10^{17.3}$ eV, and $10^{17.3}$ - $10^{18.3}$ eV

A detailed description of the data reconstruction and selection can be found in [7]. Here we show resolution plots for the track-geometry, energy, and X_{max}, for the data set used in this analysis.

Observed air showers comprising the "composition" data set used for this study were required to meet the condition that at least 35% of the total observed light signal of the detected event should be direct Cherenkov light. Direct in the sense of not scattered. This condition was found to be sufficient for good geometrical reconstruction of the events seen by the TALE FD operating in monocular mode.

3. Results

We use Monte Carlo simulations to study the detector efficiency and reconstruction resolution.

Two sets of simulations were used for the analysis. One based on the EPOS-LHC[8] hadronic model and one based on QGSJetII-03[9]. The first model is a post-LHC model, while the second was the model used for the TALE energy spectrum measurement [7].

Due to time constraints, the QGSJetII-03 model shower simulations were run at energies greater than 3×10^{15} eV, as such, results based on these simulations are presented at energies greater than $\sim 5 \times 10^{15}$ eV. EPOS-LHC based shower simulations start at 10^{15} eV, and results are shown from $\sim 2 \times 10^{15}$ eV.

In both cases, four primary cosmic rays particle types were simulated: proton, helium, nitrogen (CNO), and iron. Equal numbers of each primary type were thrown. Simulated showers were processed through the event reconstruction and event selection procedure used for TALE data. The resulting shower X_{max} distributions for each primary type were used to fit the observed data X_{max} distribution, using the TFractionFitter [10, 11] utility.

The results of these fits and the values of the "Mean log(A)" derived from them will be presented at the conference; this proceeding will be updated to include these results post conference.

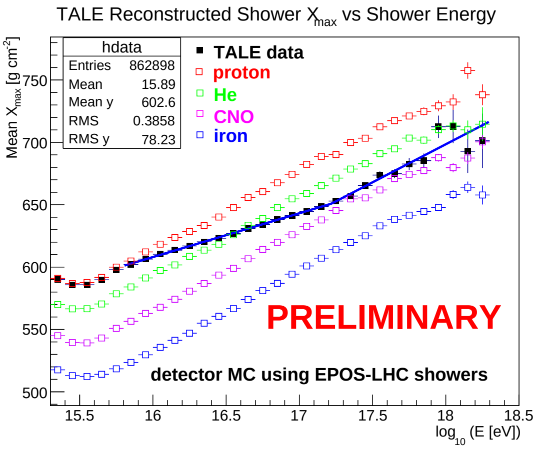

Figure 5: Reconstructed TALE events mean X_{max} as a function of shower energy. Shower energy estimate using EPOS-LHC missing energy correction. Reconstructed X_{max} values for four MC primaries shown alongside the data for comparison.

An alternative analysis to estimating primary fractions is to examine the mean X_{max} values of TALE data. A comparison of these observations with those of different MC primaries is shown in Figure 5. A change in the elongation rate of the mean X_{max} as a function of energy can be interpreted as a change in composition and we look for such change by using a broken line fit (one floating break point). The results of the fit are shown in Figure 6. This figure also shows the mean X_{max} measured by the Telescope Array detectors at higher energies [12]

4. Summary

We presented the results of a measurement of the cosmic rays composition in the energy range of $10^{15.3}$ - $10^{18.3}$ eV using data collected by the TALE detector over a period of roughly four years. An examination of the mean X_{max} versus energy, shows a change in the X_{max} elongation rate at an

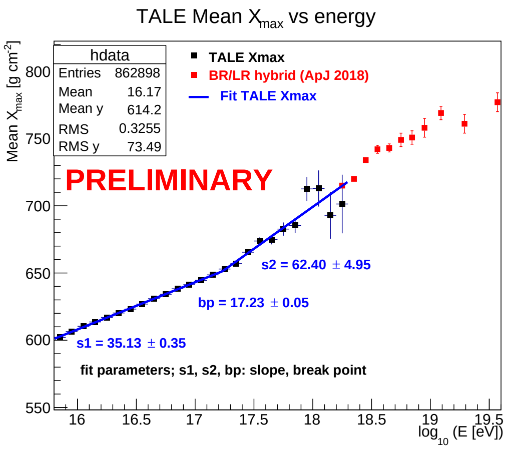

Figure 6: Reconstructed TALE events mean X_{max} as a function of shower energy. Shower energy estimate using EPOS-LHC missing energy correction. A broken line fit with fit parameters displayed on the figure also shown. Red points at higher energies come from a hybrid measurement by TA [12].

energy of $\sim 10^{17.2}$ eV. This “break” in the elongation rate is likely correlated with the observed break in the cosmic rays energy spectrum [7].

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