Composition Measurements near the Second Knee with the Telescope Array Low-Energy Extension (TALE)

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Abstract: Cosmic rays with energies between $10^{16.5}$ and $10^{18.5}$ eV exhibit a rich range of features. The energy spectrum changes index at at least two points, known as the "second knee" and the "ankle". There may be a composition change in this energy regime as well, perhaps indicative of a shift in predominance from galactic to extragalactic sources. The Telescope Array Low-Energy Extension — planned for construction in Millard County, Utah, USA — stands well poised to make decisive simultaneous measurements of cosmic ray energy spectra and composition in this transition region. Here, we present the results of simulation studies relevant to the design of the TALE detectors, and estimate the sensitivity of TALE to composition changes in the 10^{17} eV decade.

Introduction

While a consensus is emerging on the features of the ultra-high energy cosmic ray spectrum, the chemical composition of the primary cosmic rays is unclear [4]. Historically, the most commonly used technique for determining composition utilizes the fact that — at a given energy — airshowers generated by light primaries tend to reach their peak at a greater depth in the atmosphere. Cosmic ray observatories measure the average location of the shower peak, known as X_{max}, and observe how the average X_{max} varies with energy. Changes in the *elongation rate* or slope of X_{max} plotted against $\log E$ are taken as evidence of shifting composition.

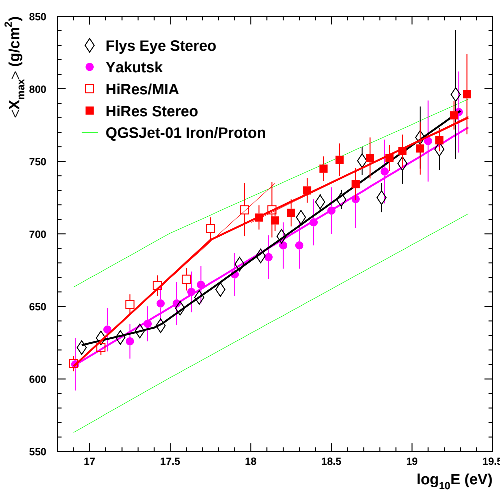

Figure 1: Measurements of the average X_{max} as a function of energy [4].

The current experimental picture with regard to X_{max} is shown in Figure 1. While some experiments appear to indicate changes in elongation rate, not all do, and there is no consistency among experiments as to the location or nature of the change.

The Telescope Array (TA) observatory — currently being commissioned in Millard County, Utah — and its Low Energy extension (TALE), will perform composition studies with greatly improved sensitivity in the critical $10^{16.5}$ to $10^{18.5}$ eV energy range. In addition to improved measurements of X_{max}, TALE will simultaneously investigate shower width and muon density at ground level, both additional observational handles on the primary cosmic ray composition. In so doing, and in conjunction with spectral measurements, TALE

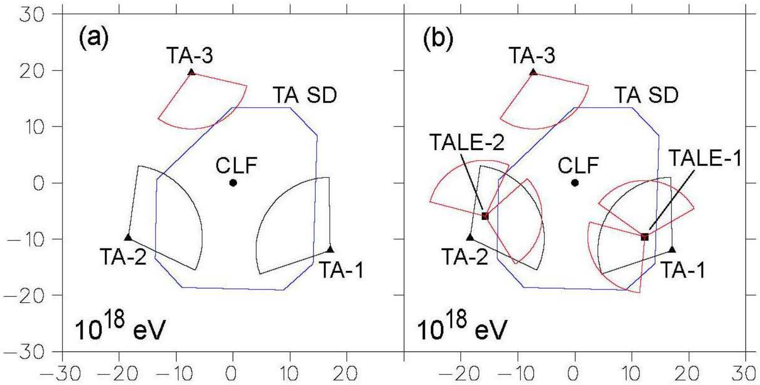

Figure 2: Left: Approximate FOV (pie wedges) of TA fluorescence detectors at 10^{18} eV. Right: Corresponding FOV for TALE-enhanced observatory, showing maximal stereo overlap at this energy.

will seek to determine the cosmic ray galactic to extragalactic transition.

TALE Composition Methods

TALE will seek to measure primary cosmic ray composition in the $10^{16.5}$ to $10^{18.5}$ eV energy range by three methods:

1. X_{max} measurements
2. Shower width (Gaussian in shower age) measurements
3. Muon density measurements at the Earth's surface.

The first two methods involve the calorimetric sampling of airshowers by the nitrogen fluorescence technique. TALE will add to the standard TA array a set of 6 km stereo fluorescence detectors, to allow stereo reconstruction of airshowers to energies as low as 10^{18} eV (Figure 2). To push the fluorescence measurements down to $10^{16.5}$ eV, TALE will also employ a fluorescence "tower" detector [3]. This tower detector will have more than twice the elevation-angle coverage of the standard TA fluorescence detectors and the 6 km stereo detectors.

To enhance the X_{max} and shower width measurements, by providing *hybrid* coverage of airshowers down to $10^{16.5}$ eV, as well as to provide a means of counting particles of different species on the ground, TALE will also consist of a two-component ground array [2]. A surface scintillator array on a 0.4 km grid will provide hybrid detector coverage by detecting primarily the electromagnetic component of the shower, while a second scintillator array with a sand/gravel overburden will count exclusively muons.

The resultant TALE detector will thus extend many of the ideas pioneered in the HiRes Prototype/CASA-MIA hybrid airshower detector [1].

Simulation Results

In the work presented here, we employ the use of CORSIKA [5] simulations to categorize how airshowers of different primary species, energy, and zenith angle will be distributed in X_{max}, shower width, and muon density. As an example, Figure 3 contains a scatter plot of X_{max} versus N_{μ}/N_e (the muon to electron ratio at TA ground, 100 meters from the core) for 10^{17} eV proton- and iron-induced showers at a zenith angle of $30°$. We also employ a TALE detector Monte Carlo to estimate the sensitivity of TALE to composition transitions for different exposure times.

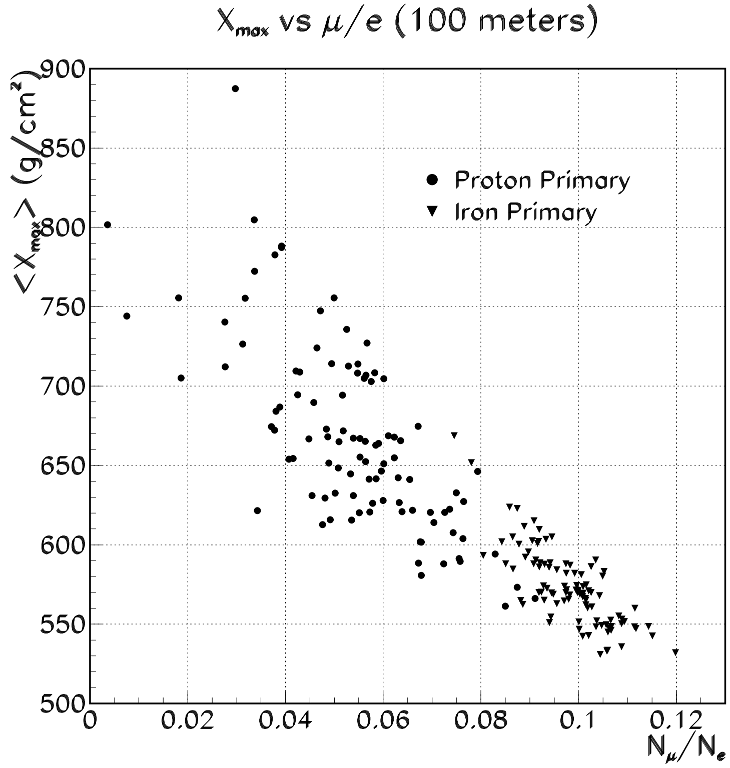

Figure 3: Scatter plot of X_{max} versus N_μ/N_e (the muon to electron ratio at TA ground, 100 meters from the core) for 10^{17} eV proton (circles) and iron (triangles) induced showers at a zenith angle of $30°$.

Conclusions

The results of these studies will be presented by the author at the 2007 International Cosmic Ray Conference.

Acknowledgements

This work was supported in part by the U.S. National Science Foundation under grants PHY-0307098 and PHY-0636162. We thank colleagues from the AGASA, HiRes and TA collaborations for valuable discussion.

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