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HiRes Stereo Cosmic Rays Composition Measurements

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Abstract: The High Resolution Fly's Eye (HiRes) fluorescence detectors have been collecting extensive air shower (EAS) data for more than 6 years . The obtained statistics allows us to more precisely estimate the mass composition of the ultra high energy cosmic rays (UHECR). In this study we summarize the stereo shower parameters measurements, especially X_{max} measurements. The sensitivity limitations of our detector, the effect of the hadronic model choice on the estimate, and systematic errors of our measurements are also presented.

Introduction

Knowledge of the chemical composition of the UHECR is essential to our understanding the nature of this phenomenon. The particle's mass sets certain restrictions on the acceleration mechanisms and, as a consequence, the physical conditions at the CR origin. Propagation effects are also important. For example, the observation of GZK cutoff requires that most of the UHECR flux be protonic. Recent theoretical models [1] assume a transition from particles originating in our Galaxy to extragalactic particles with the latter being dominant at energies above $3 \cdot 10^{18}$eV. This transition should be reflected in a composition change.

We observe UHECR through their interactions with the Earth's atmosphere which result in extensive air showers. Analyzing these showers gives us an estimates of the incident particle energy and its position in the atmosphere. However, we can not determine the type of the element we observe on event by event basis. A statistical approach allows us to make estimates of the presence of different elements in the collected data.

Method

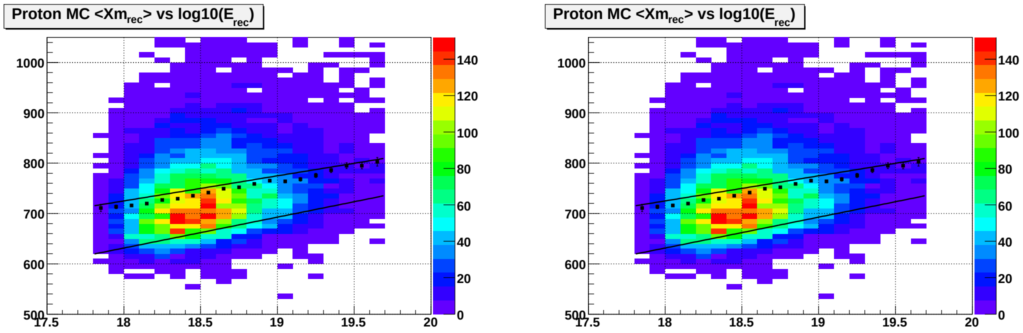
X_{max} analysis

The standard statistical method of mass composition analysis consists of measuring the slant depth at the EAS maximum (X_{max}) and studying its distribution with respect to the particle's energy. There are noticeable differences in the distribution parameters (mean and width) for different elements. Namely, EAS associated with lighter particles develop deeper in atmosphere and have wider distributions. For example, X_{max} for proton is greater by approximately 100 g/cm^2 than for iron, while the distribution width is almost three times bigger.

While at the first glance these differences are quite significant, the selection of the sample for analysis presents a rather tough balancing act. Our measurements should not have any preference for the type of particle we observe, the quality cuts we apply should not distort the elongation rate, and at the same time we need to have enough data for statistical studies.

Monte Carlo simulations and Reconstruction

The main source of the distortions of the X_{max} distributions is the limited field of view of the detec-



(a) (b)

Figure 1: Reconstructed proton (a) and iron (b) Monte Carlo datasets. Black lines indicate input proton and iron elongation rates. Black square points correspond to $<$X$_{max}$$>$ at given energy.

tor which covers up to 30° in elevation. This design introduces a strong bias in observing EAS associated with low energy iron particles as well as systematic errors in reconstructing shower parameters. We use MC simulations to investigate this effect and to estimate our reconstruction biases. Two datasets simulating the detector response to the proton and to the iron air showers respectively were used. This is the simulation which is also used in the stereo spectrum analysis ([2]). It includes hourly atmospheric corrections and up to date calibrations. The extensive air shower development is generated by CORSIKA v6.003 with QGSJET01 hadronic interaction model.

We expect to get good energy and X$_{max}$ measurements when the EAS profile we observe is long enough for the maximum to be in detector' FOV and clearly pronounced. Additionally, energy reconstruction also depends on the quality of the measurements of shower position in atmosphere. The following cuts take into account these requirements:

- 450 g/cm^2 $<$ X$_{max}$ $<$1300g/cm^2
- FOV$>$250g/cm^2
- Gaussian-in-age width 0.11$<$ σ_s $<$0.29
- Rp1$>$2 km; Rp2$>$5 km
- Stereo opening angle$>$3.6°

To compensate for unbalanced acceptance for proton and iron at energies below $3 \cdot 10^{18}$eV, we introduce an energy depended cut on the measured shower track zenith angle. Proton showers tend to be reconstructed better then iron at larger zenith angles, where shower maximum for iron is usually out of field of view. After applying such a cut we are able to avoid the detector efficiency bias. The final cut is an energy depended Rp2 cut for events below 10^{19}eV to preserve the elongation rate for both species after all previous cuts.

After these cuts, we have

- X$_{max}$ resolution between 25 g/cm^2 and 30 g/cm^2 with a systematic shift of about -10 g/cm^2.
- The iron/proton trigger and reconstruction efficiency is 09$\pm$0.1 over the entire energy range.
- Input elongation rates for both species are well reproduced (see Figure 1) .

Real Data Analysis

The HiRes stereo fluorescence detector has been collecting the data from December 1999 through March 2006. All the data was processed using the same atmospheric and calibration databases as for MC datasets. After application of the cuts, the sample contains 3641 events, which were used in this study. The Figure 2 shows (X$_{max}$ vs Energy) distribution of the sample. The black lines on the plot are the elongation rates for proton and iron, dots denote $<X_{max}>$.

Conclusions

We validate the method to select a composition unbiased sample using MC data sets. These cuts are than applied to our collected data. The obtained sample is at least 4 times larger than the dataset, which was previously used by HiRes ([3]). The measured elongation rate and X_{max} distribution are consistent with a light composition. The result is also in a good agreement with previous HiRes measurements above 10^{18}eV (see Figure 3). Detailed comparisons with other hadronic models and composition mixtures is proceeding.

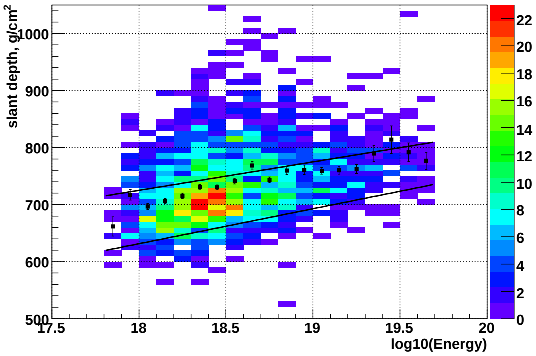


Figure 2: Real data distribution.

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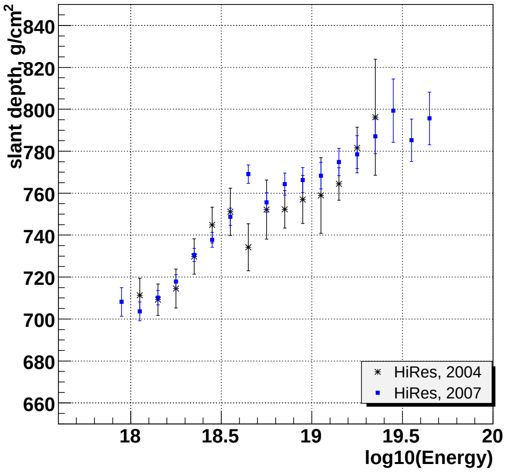

Figure 3: Comparison $<X_{max}>$ measurements. The errors for the new measurement are statistical.

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