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UHECR Composition Measurements Using the HiRes-II Detector

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While stereo measurements of extensive air showers allow a more precise determination of the depth of shower maximum and hence the composition of UHECR's, monocular measurements allow one to go much lower in energy. Since the composition of UHECR seems to constant throughout the HiRes stereo energy range but changing just below it, this is not a trivial lowering of the energy threshold. We fit the observed X_{max} distribution to a combination of expected proton and iron X_{max} distributions, using two different interaction models, to determine the relative fraction of light and heavy components throughout the HiRes monocular energy range. Using a two component fit allows both the mean X_{max} and the width of the X_{max} distribution to contribute composition measurement and allows us to deal with the X_{max} acceptance bias caused by limited elevation coverage. An updated analysis from a larger data set will be presented in Pune.

1. Introduction

Recent measurements of the UHECR composition by the HiRes Prototype/MIA experiment[1] (HiRes/MIA) and by HiRes in stereo mode[2] (HiRes Stereo), seem to indicate that the cosmic ray composition is changing from heavy to light below 10^{18} eV, and then remains light above 10^{18} eV. This interpretation depends on the fact that HiRes/MIA measures a large elongation rate, larger than expected from an unchanging composition, while HiRes Stereo measures an elongation rate consistent with an unchanging composition. The two measurements barely overlap in energy range, and the change in the elongation rate is in just this overlapping range. One would like to observe the low energy, changing composition becoming constant at higher energies, all in one experiment. To do so with the HiRes detector one must go lower in energy, which also requires that one look at monocular data; lower energy showers will only be observed from one site, if at all.

Unfortunately, the limited elevation coverage of the HiRes-II detector biases the X_{max} acceptance, with the bias increasing at lower energies. The bias stems from the requirement that one find X_{max} within that extent of the shower observed in the detector. Events that are closer to the detector are more likely to have X_{max} above the visible range, and thus be cut. Furthermore, because lower energies can only be observed close to the detector, events at these energies will have a larger acceptance bias than those at higher energies. Iron showers at a given energy, will be more affected than proton showers. This bias precludes performing an elongation rate analysis at energies below 10^{18} eV.

2. The Two Component Fitting Method

Instead of performing an elongation rate analysis, we have chosen to fit the X_{max} distribution to a combination of X_{max} distributions from proton and from iron primaries. The proton and iron X_{max} distributions are generated by Monte Carlo (MC) simulation. The X_{max} distribution, in a given energy bin, is stored in a histogram, and the data histogram is then fit to a combination of the proton and iron MC histograms to find the proportion of each. The fit is performed using the binned maximum likelihood technique as implemented in the HBOOK[3] routine HMCLNL. The statistical uncertainty of the fit is taken from the width of $-2\log L$ as fit to a quadratic in the region about the minimum.

Once the proton fraction in an energy bin is determined, one must correct for the fact that proton and iron

showers have different acceptances at a given energy. This is done using the acceptances calculated from the same MC samples used to make the $X_{\max}$ distributions for fitting the data. The observed events at a given energy are split up into the proton events and the iron events according to the proton fraction. Each of these samples is then corrected for the acceptance, giving the number of proton events and the iron events one would see with a fixed aperture and no $X_{\max}$ bias. These corrected numbers of events are then used to calculate the true proton fraction.

3. Preliminary Results

We generated three sets of Monte Carlo (MC) data using Corsika/QGSJet01[4, 5]. These three sets all use the broken power law fit to the Fly's Eye[6] stereo spectrum as an input spectrum. The sets differ according to the composition, with one being pure proton, one being pure iron, and one having the mixed composition implied by the elongation rate measurements compared to QGSJet expectations. This last set is also the one used in the HiRes-II monocular spectrum analysis. The fitting procedure itself only uses the pure composition sets; the mixed composition set is used for cross checking.

The results of the fits for proton fraction in the various energy bands are shown in Figures 1.

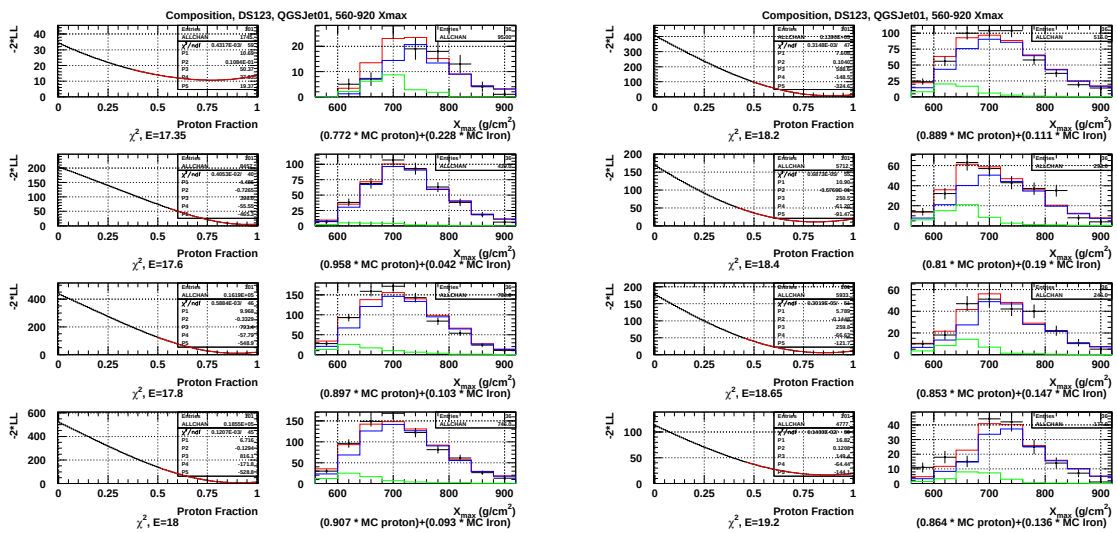

Figure 1. Two component composition fits of the $X_{\max}$ distribution in bins centered at $\log_{10} E = 17.35$, 17.6, 17.8, 18, 18.2, 18.4, 18.65 and 19.2 (E in eV). The left side shows the quality-of-fit versus the proton fraction. The right side shows the best fit (red) against the data (black points) along with the two components, protons (blue) and iron (green).

The best fit proton fraction in each bin is plotted in the top half of Figure 2, along with the statistical uncertainty. After adjusting for the different acceptances of protons and iron, one finds the corrected composition as shown in the bottom of Figure 2. The measurement indicates that the composition is dominated by protons above an energy of $\log_{10} E = 17.6$. The composition lower energies, but there are large uncertainties.

As a cross check of our procedure, we have performed the same analysis using the mixed MC. The results, before and after the acceptance correction, are shown in Figure 3. In the MC case, we can know the particle

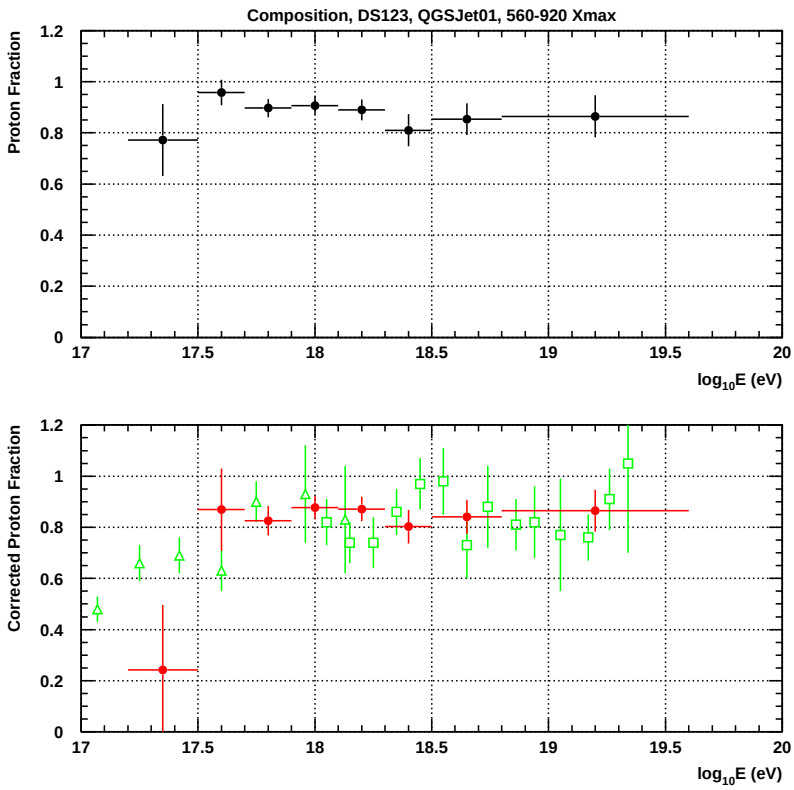

Figure 2. The top plane shows the measured proton fraction in each energy bin. The bottom plane shows the proton fraction after the acceptance correction. The HiRes/MIA and Hires Stereo $X_{\rm max}$ measurements, interpreted as a proton fraction using the QGSJet01 expectations, are shown in green.

type of each shower that passes the analysis cuts. This is used to calculate the exact proton fraction, which is shown as the blue points in the top plane of Figure 3. These points agree well with the proton fractions obtained from fitting. Likewise, the corrected MC composition matches very well the HiRes/MIA and HiRes Stereo proton fractions which were used as inputs.

4. Conclusion

We have made a preliminary measurement of the UHECR composition using the HiRes-II detector. This measurement indicates a light composition above $\log_{10} E = 17.6$. Measurements using an enlarged data set and both QGSJet and Sibyll shower simulations will be presented in Pune.

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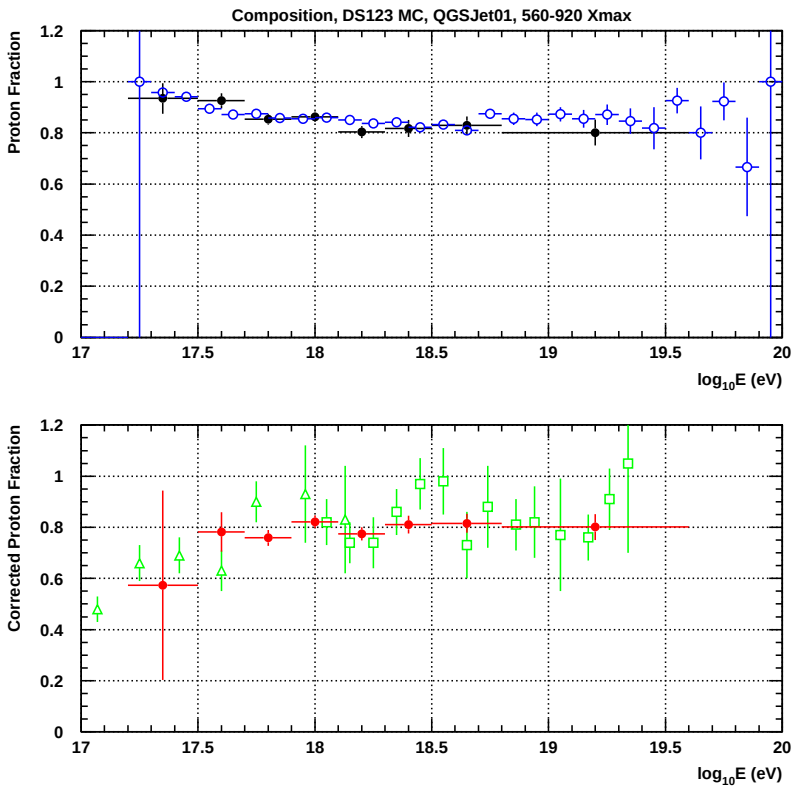

Figure 3. The top plane shows the measured proton fraction of a MC sample (filled black points), along with the exact fraction (open blue points). The bottom plane shows the measured proton fraction of the MC sample after the acceptance correction. The HiRes/MIA and Hires Stereo proton fractions, which were used as an input to the MC, are shown in green.

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