# STUDY OF THE COMPOSITION OF COSMIC RAYS WITH ENERGY .7<E<3. EeV

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ABSTRACT

The longitudinal shower development of EAS observed in the Fly's Eye is used to determine the distribution of $X_{max}$, the depth in the atmosphere of the EAS maximum. Work in progress to compare data and Monte Carlo simulations of proton and iron primaries is described. Preliminary evidence is in favor of a substantial contribution from light primaries.

1. Introduction. The overall longitudinal development of the EAS detected by the Fly's Eye(1) can be used to determine the depth in the atmosphere in gm/cm$^2$ of the EAS maximum $X_{max}$. The distribution in $X_{max}$ is in principle sensitive to the composition of the primary particles since iron nuclei and protons will give rise to $X_{max}$ distributions that peak at shallower and deeper depths and have narrower and wider widths, respectively. It also follows that a mixed composition will have a broader $X_{max}$ distribution than any single source.

In what follows, we discuss the reconstruction of longitudinal shower profiles and the systematics of determining $X_{max}$ distributions and then discuss work in progress on Monte Carlo simulations, which include the details of the Fly's Eye acceptance, for pure protons, iron, and a mixed composition.

2. Shower Size Measurement. A fit to the relative time of arrival of light to succeeding phototubes in the event-detector plane yields $R_p$, the impact parameter of the shower to the detector, and the zenith and azimuthal angles of the EAS. Measured values of optical gathering power, efficiencies and electronic gains and pedestals are used to convert photoelectron yields into apparent brightness, i.e., numbers of photons arriving at the detector from the source. This can be converted into intrinsic source fluorescent brightness after correcting for: (a) directly produced Cerenkov light beamed in the direction of the detector; (b) Cerenkov light scattered in the direction of the detector due to Rayleigh and Mie scattering; and (c) atmospheric attenuation of light. The details of these corrections are described in reference 1. The intrinsic fluorescence brightness can be translated directly into a shower size using the known nitrogen fluorescence efficiency.

The Cerenkov light production model, and in particular, the dependence of the Cerenkov light intensity on emission angle has been checked by using a sample of events seen by both Fly's Eye I and Fly's Eye II, a smaller station situated 3.3 km from Fly's Eye I. We find good consistency in size estimates of sections of EAS viewed simultaneously at different emission angles by the two eyes.

The size versus depth distributions are fitted with a Gaussian form and the $X_{max}$ and energy of the event determined(1). The Gaussian form fits most showers well. Figure 1 shows a typical shower profile.

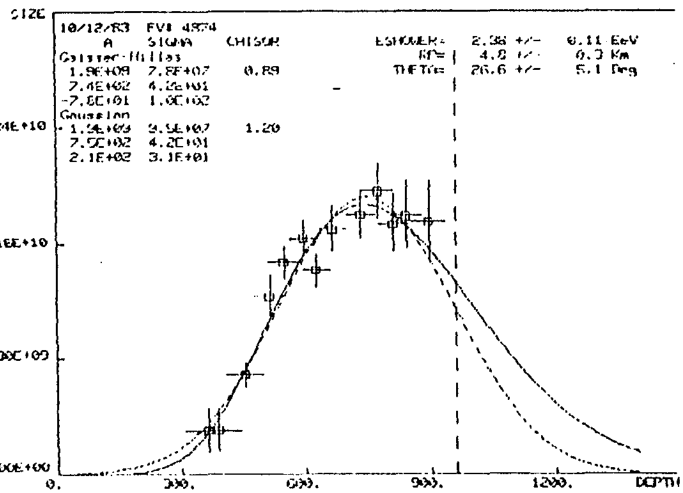


Figure 1. Typical Longitudinal Shower Profile

3. Systematics of Shower Maximum Distributions The absolute depth of $X_{max}$ is the parameter most sensitive to systematic errors of any that we measure. Symmetric random errors in the zenith angle, $\theta_z$, result in non-symmetric errors in $X_{max}$. Symmetric errors in $R_p$ also yield non-symmetric errors in $X_{max}$ because of the exponential atmospheric density distribution. There is also an intrinsic correlation between $X_{max}$ and the shower energy. Showers whose reconstruction err to smaller $R_p$ and larger $\theta_z$ will have systematically deeper $X_{max}$ and smaller estimated energy while errors that lead to larger $R_p$ and smaller $\theta_z$ yield smaller $X_{max}$ and larger energy estimates. This is a direct consequence of random errors and the exponential nature of the atmosphere. Any additional systematic bias in $\theta_z$ or $R_p$ will shift the $X_{max}$ distributions accordingly.

To reduce these effects to a minimum, we consider events that are very well reconstructed, with $R_p$>2.0 km, projected track length >50°, $SR_p/R_p$<.1, $S\theta_z$<10° and relative uncertainties in Gaussian width, $X_{max}$, and energy of <.4. These cuts also have the effect of reducing the Cerenkov subtractions to a level where 50% variation in the Cerenkov light model parameters do not significantly affect the $X_{max}$ distributions. Since any residual reconstruction bias will affect data near the tails of the energy distribution, we cut on .7<E<3 EeV, around the maximum of our energy acceptance. We believe residual systematic effects in this data sample will produce less than a ± 50 gm/cm$^2$ shift in the average $X_{max}$. We note that the width of the $X_{max}$ distribution is much less sensitive to systematic errors. We estimate the systematic error in the width to be ± 10 gm/cm$^2$. The resultant distribution in $X_{max}$ is shown in Figure 2. The average $X_{max}$ for this sample is 730±60 gm/cm$^2$ while the width (standard deviation) is 120±40 gm/cm$^2$.

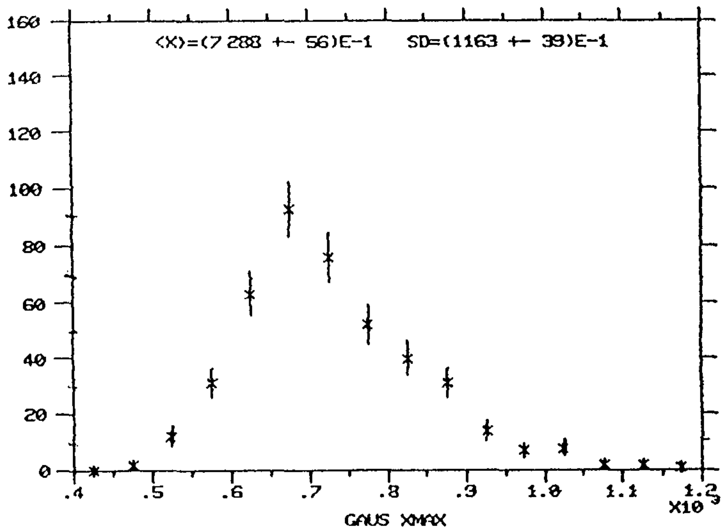


Figure 2. Distributions of $X_{max}$ in $gm/cm^2$.

4. Monte Carlo Generation

Proton and iron induced showers are generated in a Monte Carlo program with the following input. Protons are assumed to obey Hillas pure scaling with the only scale violating effects being rising cross-sections as parameterized by Gaisser and Yodh(2). The mean inelasticity is assumed to be .5. For the case of iron primaries a superposition model is assumed. The Monte Carlo follows hardons and electromagnetic particles down to 1/30th of the primary energy after which parameterizations of shower development are used. We use these showers to predict the number of photoelectrons and relative time delays observed in the detector and generate fake events which are then passed thru the same reconstruction and analysis programs as the real data. This work is in progress but preliminary indications are that the depth of maximum distribution for heavies is substrantially narrower than that for protons. It is important to note that comparing the observed $X_{max}$ distributions to theoretical predictions without taking into account the details of detector response can lead to misleading conclusions.

5. Conclusions. Although we are not yet ready to quote quantitative comparisions between the data and Monte Carlo simulations, preliminary evidence based on comparisons of the widths of the $X_{max}$ distribution to Monte Carlo is in favor of a substantial contribution from light primaries to the cosmic ray composition at these energies. Detailed comparisons will be forthcoming.

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References.

1. Baltrusaitis, R.M., et al., Nuclear Instruments Methods (to be published).
2. Gaisser, T.K., and Yodh, G.B., Ann., Rev. of Nucl. and Particle Science, 30 (1980), p.475.