OBSERVATIONS OF EXTENSIVE AIR SHOWERS NEAR THE MAXIMUM OF THEIR LONGITUDINAL DEVELOPMENT*

J. Hersil and I. Escobar
Laboratorio de Fisica Cosmica, Universidad Mayor de San Andres, La Paz, Bolivia

and

D. Scott, G. Clark, and S. Olbert
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
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Extensive air showers have been studied at an altitude of 4200 m (atmospheric depth 630 g/cm^2) with apparatus previously used at sea level.[1-3] Their characteristics are found to differ markedly from those of showers at sea level, and demonstrate that vertical showers with about 30×10^6 particles are near their maximum development. These results were derived from data on approximately 400 selected showers with sizes greater than 15×10^6 particles.

The experimental method[2] employs the techniques of fast-timing and density sampling with eleven 1-m^2 scintillation detectors in an array with outside diameter 700 m. The apparatus is located on the Altiplano at El Alto near La Paz, Bolivia. For each shower event the arrival direction is determined from the timing data to within 5°. The size and core location are determined by a least-squares fitting of the density data to a trial function representing the lateral distribution. Tests of the analysis procedure on artificial shower data generated by a Monte Carlo method demonstrate that the average error displacement in the core location is about 10 m, and that the fractional error in the size determination is about 8%, provided the trial function is an accurate representation of the lateral distribution. The function used throughout the analysis was the Greisen representation[4] of the Nishimura-Kamata function (NKG) with the age parameter $s = 1.0$ and the Molière unit equal to 132 m.

We first compared the observed average lateral distributions with the trial function, for showers grouped according to their sizes and zenith angles. A part of these results for one size group (18×10^6-25×10^6) are shown in Fig. 1, where the ratios of the observed particle densities to the densities calculated from the fitted trial function are plotted versus the distance from the core. Also plotted are the ratios found for artificial shower data generated using the NKG function with values of s equal to 0.8, 1.0, and 1.2. The results for artificial showers indicate that the method of analysis can reveal a systematic trend in the steepness of the lateral distribution. The results for real showers therefore support the conclusion that the steepness of the lateral distribution decreases with zenith angle. (By comparison, at sea level the lateral distribution shows little or no variation with zenith angle and can be fitted by the NKG function for $s = 1.3$).[3] Note that our results are essentially limited to core distances from about 40 m to 400 m.

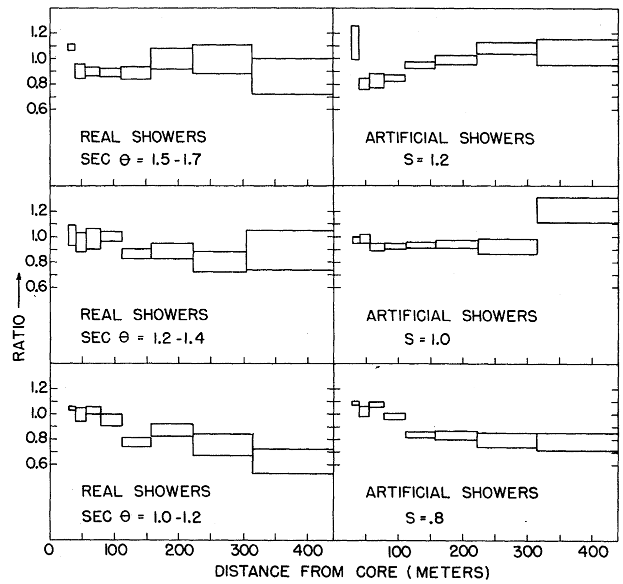

FIG. 1. Comparison of the observed lateral distributions with the trial function NKG 1.0 for three groups of real events with sizes from 18×10^6 to 25×10^6, and for three groups of artificial events. The abscissa represents the distance from the calculated core position. The ordinate represents the ratio between the average observed particle density and the average density calculated according to the fitted trial function. The height of each box indicates the statistical and instrumental uncertainty.

We then plotted the integral intensity S of showers with sizes greater than N as a function of secθ. We selected events according to criteria which permitted accurate evaluation of the detection efficiency. The calculated sizes were corrected for errors caused by the systematic change with θ in the lateral distribution function as discussed previously.

Whereas, at sea level, S for fixed N can be expressed as an exponential function of secθ (which is proportional to the slant thickness of the atmosphere), at 4200 m we find that S (for N near 30×10^6) is approximately stationary with respect to changes in secθ near sec$\theta = 1.0$. This is the behavior expected if showers with $N\approx30\times10^6$ are near their maximum longitudinal development.

The same data can be used to determine directly the longitudinal development. For this purpose we plotted S versus N for events grouped according to zenith angle. For each group we evaluated the average slant thickness of the atmosphere, $x=x_0$ secθ, where $x_0=630$ g/cm^2. We then read from these plots the values of N at several given values of S. In this way we obtained the data on the variation of N with x at constant S which are shown in Fig. 2. If the primary flux is isotropic, and if there were no fluctuations in shower development, then each set of points in Fig. 2 would represent the dependence of size on depth for showers initiated by primaries of a certain specific energy. Even with fluctuations present, Fig. 2 should indicate the general features of the dependence on secθ of the average size of showers initiated by primaries of a given energy. We wish to emphasize that the important feature of these curves is the presence of the maximum near 630 g/cm^2.

Also shown in Fig. 2 is the analogous result from the earlier sea level experiment[3] on the variation of N with x at one of the same absolute values of S. The discrepancy in size at equivalent atmospheric depth is not yet understood.

A more complete report on this work including results on showers with sizes less than 10^7 particles is in preparation.

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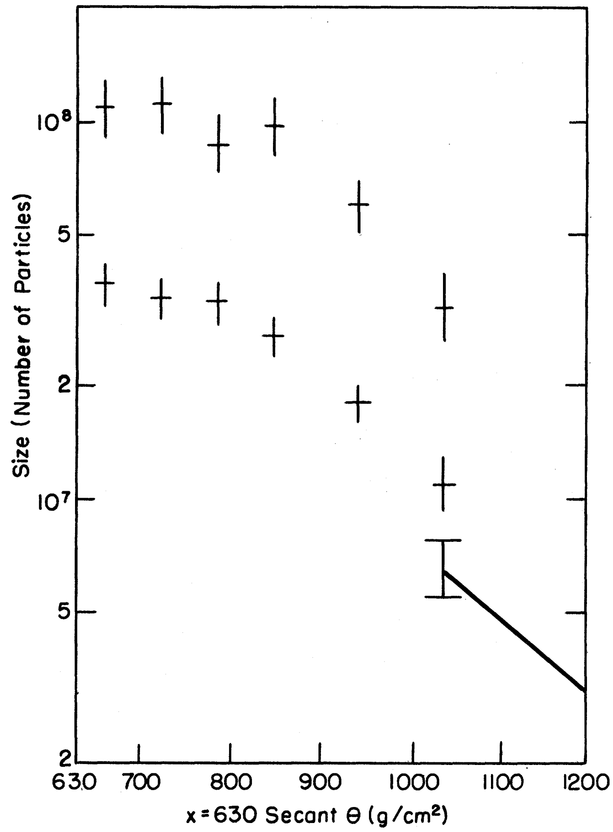

FIG. 2. Experimental results on the longitudinal development of extensive air showers. The plot is derived from the observed integral size spectra at various zenith angles and represents the dependence of N on x at constant S. The upper and lower sets of points are for $S=10^{-14}$ cm^{-2} sec^{-1} sr^{-1} and $S=10^{-13}$ cm^{-2} sec^{-1} sr^{-1}, respectively. The straight line with an error indicator represents the analogous results derived from sea level data for $S=10^{-13}$ cm^{-2} sec^{-1} sr^{-1}.

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