

THE COSMIC RAY SPECTRUM AT E>1017eV

B. Cady, G. Cassiday, J. Elbert, P. Gerhardy, E. Loh,  
Y. Mizumoto, M. Salamon, P. Sokolsky, D. Steck

Department of Physics, University of Utah  
Salt Lake City, UT 84112 USA

ABSTRACT

Extensive air showers (EAS) have been recorded by the Fly's Eye detector for approximately 1000 hours during 1981 and 1982. Observed rates have been used to infer the primary cosmic ray spectrum. At E > 10<sup>17</sup> eV the integral spectrum slope and intensity obtained are  $\tilde{\alpha} = 2.04 \pm .05$  and  $I(>E) = 2.02 \pm 17 \times 10^{-10} \text{ m}^{-2}\text{sr}^{-1}\text{s}^{-1}$  respectively. The rates of showers above 10<sup>19</sup> eV are used to assess the probability of spectral "flattening."

1. Introduction

The complete Fly's Eye detector<sup>1,2</sup> (67 mirrors, 880 PMT's) has operated since November 1981 and has accumulated 791 hours of clear, moonless and cloud-free hours of data-taking. Thus far, we have analyzed only 439 hours of data and during that time approximately 6,000 EAS with energies exceeding 310<sup>16</sup>eV were recorded with 1755 of those events geometrically reconstructed well enough to permit a measurement of the longitudinal development profile of the shower. (See EA4-22 for an example of a shower profile.) A shower's energy is estimated by fitting the data with the Gaisser-Hillas functional parameterization of shower development whose expression is:<sup>3</sup>

$$N(E,x) = N_0 \frac{E}{\epsilon} \exp \left( p \left( \frac{x-x_0}{x_{\max}-\lambda} \right) \right)^p \exp^{-(x-x_0)/\lambda}$$

where E = shower energy; x<sub>0</sub> = location of 1st interaction.

x<sub>max</sub> = location of shower maximum; N<sub>0</sub> = .045  
 $\tilde{\alpha} = .074 \text{ GeV}$ ;  $\tilde{\epsilon} = 70 \text{ g cm}^{-2}$ ,  $p = (x_{\max} - \tilde{\epsilon}) / \tilde{\epsilon}$

2. Method of Calculation

Shown in Figure 1 is the observed distribution of events as a function of shower energy. The spectrum can be extracted from this distribution by calculating the integral  $R(>E) = A_{\text{tot}} \int I(>E) dA_{\text{E}}(E)$  over the Fly's Eye energy dependent aperture  $A_{\text{E}}(E)$ . A simple power law,  $a (E/10^{17} \text{ eV})^{\tilde{\alpha}}$ , has been assumed for I(>E). Correct evaluation of the integral obviously involves an accurate assessment of the Fly's Eye aperture  $A_{\text{E}}(E)$ . Two methods of assessment are in progress.

The first essentially models the Fly's Eye on computer, divides its aperture into a small number of differential bins and uses Monte Carlo techniques to generate air showers whose energies are taken from a test spectrum. When a shower is generated that satisfies Fly's Eye triggering conditions a "hit" is stored in the appropriate aperture bin. The final tally of hits and misses are used to calculate rates as a function of energy, impact parameter, zenith angle, etc. This method should yield the best results since different primary components with differing spectra and fluctuating longitudinal development can readily be incorporated. Ultimately, a complete "global" fit to all relevant distributions will be obtained. This program is not yet complete although we do have preliminary results based upon the assumption of proton primaries, a single power-law spectrum, Gaisser-Hillas shower development with first point fluctuations allowed.

The second method numerically evaluates the rate integral over the Fly's Eye aperture using a single power law spectrum. In this case, a shower of a particular geometry is picked and the energy found which satisfies Fly's Eye triggering. Rates are then calculated by forming the sum  $\int_{E}^{\infty} \frac{dN}{dE} dE$  (AU). This method has the disadvantage that fluctuations are not easily included. However, we base our current results upon this calculation since it is simpler to carry out than the former.

### 3. The Spectrum at $10^{17}$ - $10^{19}$ eV.

Shown in Figures 1-3 are the differential data distributions vs. energy, impact parameter and zenith angle along with the result of the Monte-Carlo. The values used in the Monte-Carlo ( $\tilde{a} = 2.04 \pm 0.05$ ;  $a = 2.02 \pm 0.17 \times 10^{-10} \text{ m}^2 \text{sr}^{-1} \text{s}^{-1}$ ) were the result of the analytic evaluation described above. As an additional check on our calculations we note that the impact parameter distribution can be simply parameterized if we assume that the Fly's Eye triggering is optimized over a wide dynamic time range.<sup>1,2</sup> We have:  $\frac{dN}{dR_p} \propto e^{-0.065 \tilde{a} R_p / R_p} (1.5 \tilde{a} - 1)$

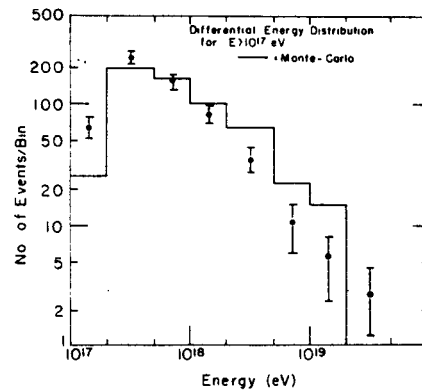


Figure 1

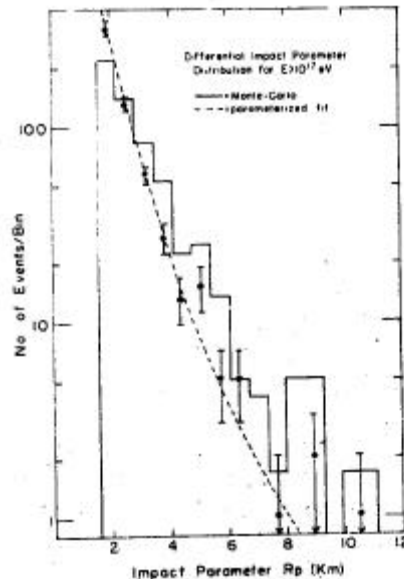


Figure 2

This function is plotted as a dashed curve in Figure 2. The agreement with the data and the Monte-Carlo is quite extraordinary which implies that the triggering conditions are well-understood.

The distributions of Figures 1-3 contain only 570 of the "best geometry" events selected from the 1755 fully reconstructed events.

These are events whose energies have been-determined directly from the Gaisser-Hillas fit. The remaining events, although well-reconstructed, do not consist of a long enough shower development profile to which a Gaisser-Hillas fit can be reliably applied. Their energy can be assessed by other means of interpolation, however, and

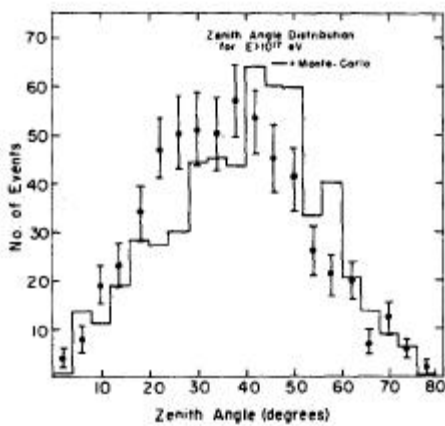


Figure 3

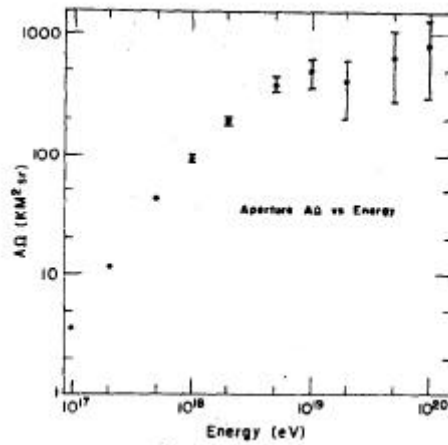


Figure 4

eventually, all these events will be included in a final spectrum analysis. The Monte-Carlo histograms have been normalized to the 570 event total and have error bars (not plotted) comparable to the data error bars. The aperture calculated by the Monte-Carlo for the collection of 1755 events in 439 hours is shown in Figure 4. Its value at  $E > 10^{17}$  eV is  $AU = 3.6 \pm 0.4 \text{ km}^2 \text{ sr}$

#### 4. $E > 10^{19}$ eV?

The aperture of the Fly's Eye detector can be modified by changing electronic triggering requirements as well as signal input filter characteristics. During the past year, the detector has been optimized in so far as possible to detect showers at distances ranging from about 1.5-10-km. To a large extent, this choice has been dictated by our desire to detect and accurately reconstruct as many events as possible in the  $10^{17}$ - $10^{19}$  eV range. At some future time, the detector will be "retuned" in hopes of optimizing the detection of events with energies  $E > 10^{19}$  eV. Unfortunately, an increase of high energy aperture can only be accomplished with a loss of the lower energy aperture with the current detector. Given these qualifications, it is still worth an attempt to assess the probability of spectral flattening at  $E > 10^{19}$  eV with the existing data.

The Monte-Carlo calculation was rerun by fixing the spectral index to a value  $\tilde{\alpha} = 1.5$  for  $E > 10^{19}\text{eV}$ . The likelihood analysis of Orear5 was then applied in order to assess the probability of such a flattening. The results of the likelihood analysis are shown in Table I .

Table I. Spectrum Above  $10^{19}\text{eV}$

Integral Spectral Index Y	Intensity I(>E) @ 10 <sup>19</sup> eV 10-14(M-2sr-is-1)	Likelihood Value	Relative Odds
2.1	$2.0 \pm 0.8$	$3.3 \cdot 10^{-4}$	3.7
1.5	$1.8 \pm 0.7$	$0.9 \cdot 10^{-4}$	1

Our normalization at  $10^{19}\text{eV}$  agrees reasonably well with the Haverrah Park value<sup>4</sup> of  $I = 2.5 \cdot 10^{-14} \text{ m}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$  but do not support a flattening of the spectrum by odds of 3.7 to 1. We point that this result is based upon only 9 events at  $E > 10^{19}\text{eV}$ . Strong support for or against a flattened spectrum must await the inclusion of the remaining data as well as the data taken with a "retuned" Fly's Eye.

### 5. Acknowledgements

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### 6. References

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