

## THE HIRES FLY'S EYE PROJECT

G.L. Cassiday, R. Cooper, S.C. Corbato, B.R. Dawson, J.W. Elbert,  
D.B. Kieda, S. Ko, E.C. Loh, M.H. Salamon, J. Smith, P. Sokolsky,  
S. B. Thomas, B.M. Wheeler

Dept. of Physics, University of Utah,  
Salt Lake City, UT 84112

## I. INTRODUCTION

We report the status of the High Resolution Fly's (Hi Res) Eye detector which is being prototyped. Our desire to build a new detector is motivated by the possibilities indicated in a series of results obtained by the present Fly's Eye.<sup>1</sup> These results and the implications are briefly stated below:

1 Energy spectrum of cosmic rays above 0.5 EeV.<sup>2</sup> The differential energy spectrum exhibits an  $E^{-3}$  power law below 10 EeV and what appears to be a cut-off of 60 EeV. The cut-off could be explained by the GreisenZatsepin-Kuz'min hypothesis<sup>3</sup>.

2 Chemical composition of cosmic rays between 0.5 and 5 EeV.<sup>4</sup> Analysis of data obtained since 1987 indicate that the chemical composition of cosmic rays in the stated energy region is a mixture of protons, light elements, and heavy elements. A detector with much larger aperture and capable of making a more precise shower cascade maximum determination is needed to determine cosmic ray composition above 10 EeV. Such measurements would play an essential part in determining the cosmic ray acceleration mechanism in this energy region.

3 Evidence of a point source above 0.5 EeV.<sup>5</sup> Emissions of neutral from the direction of Cygnus X-3 have been observed. With a detector of greater aperture and improved angular resolution, one could measure the flux with greater signal to noise sensitivity and at a higher energy. Such information is critical in establishing sources of galactic cosmic rays and explaining the acceleration mechanisms in the binary star systems.

4 Measurement of inelastic proton *nucleon cross section* at a center of mass energy of greater than 30 TeV.g

## II. OPTIMIZATION OF DETECTOR PARAMETERS OF THE HIGH RESOLUTION DETECTOR

The central question in ultra-high energy cosmic ray physics is the search for the Greisen-Zatsepin-Kuz'min cut-off in the energy spectrum. The implications of whether the cut-off exists or not are profound, since they relate to the mechanisms of cosmic ray acceleration and of the existence of the 2.7 degree microwave radiation.<sup>7</sup> The high resolution detector currently being prototyped is optimized to locate the cut-off and to measure the spectrum and the chemical composition near the cut-off. For that purpose, the new detector not only must be designed to have sufficient aperture (a product of the sensitive area and the solid angle) to carry out this goal but it also must have resolution in shower cascade maximum ( $X_{\max}$ )determination close to  $30 \text{ g cm}^{-2}$ , a resolution which will enable us to separate light elements(P,He) from the intermediate elements (CNO group) and the heavy elements (Fe).

We now have several years of data reconstructed using both the monocular (timing) technique and purely geometrical (stereo) technique. Several important conclusions can be drawn from a comparison of the two reconstruction techniques.

The most obvious advantage of stereo is the improvement in geometrical reconstruction of the event (determination of zenith angle and  $R_p$ ). Stereo data have much smaller tails in the error distributions of these variables. Since the uncertainty in  $X_{\max}$  is largely a function of the geometrical reconstruction, the fraction of stereo events with small  $X_{\max}$  uncertainties is significantly higher in stereo than in mono, even though the peak value of the  $X_{\max}$  uncertainty is 'not very different. This is a result of the fact that the quality of the timing fit is a strong function of the track length of the event, whereas stereo reconstruction is only a weak function of track length (it is a stronger function of the opening angle between the two track-detector planes). Evidently, although stereo aperture is smaller than mono aperture, the fraction of useful events is larger.

Another advantage of the stereo technique is the stability of the reconstruction with respect to detector imperfections. This is particularly crucial for the measurement of composition where instrumentally induced tails or broadening must be adequately modeled.

Yet another advantage of stereo is the inherent internal consistency checks available. These include the comparison of purely geometric and timing reconstruction for an event, and the possibility of checking the contribution of Cherenkov and scintillation light by measuring light yields at large and small angles to the shower simultaneously.

In addition to all these advantages, the detector aperture and resolution is a slow function of nearly all design parameters and hence predictions of the final performance of a high resolution detector can be made with confidence.

The following different designs were considered:

- 1 An array of detectors with  $1^\circ \times 1^\circ$  aperture phototubes and 2 meter diameter mirrors with four variations of different azimuthal and elevation angular coverage.
- 2 An array of detectors with  $1.5^\circ \times 1.5^\circ$  aperture phototubes and 2 meter diameter mirrors with four variations of azimuthal and elevation angular coverage.
- 3 Retro-fit our present Eyes and complete the second Eye with a cluster of the same size but with 64 tubes, reducing the aperture of each tube from  $5.5^\circ \times 5.5^\circ$  to  $2.9^\circ \times 2.9^\circ$ .

For each design, we calculate the aperture for events which are reconstructed with an  $X_{\max}$  uncertainty less than or equal to  $30 \text{ g cm}^{-2}$ . Since the Greisen-Zatsepin-Kuz'min cut-off is expected to appear about 60 EeV, we ask that the experiment conclusively show that the spectrum above 30 EeV is not a continuation of the lower energy power law spectrum. We propose, as a simple test of this, that the number of events above 30 EeV, for a continuing spectrum, and a spectrum with a cut-off at 60 EeV, be different by five standard deviations. Experiment durations to achieve the I five sigma significance have been evaluated for the following two scenarios:

- 1 The differential energy spectrum obeys an  $E^{*-3.1}$  power law up to the cut-off.
- 2 The differential energy spectrum obeys an  $E^{*-3.1}$  power law up to 10 EeV at which point the spectrum flattens to a  $E^{*-2.4}$  power law and continues to the cut-off. This scenario is the one that most closely matches existing data.

The results of the aperture calculations are shown in Table I.

Design Scenario	Number of Detectors	Azimuthal Angular Coverage	Elevation Angular Coverage	Number of Mirrors	Number of PM tubes	A*Û# in km <sup>2</sup> sr	Years## of Running
1	3 (1°)	2/3	55°	174	44,544	4,900	8 , 2
2	3 (1°)	2/3	29°	90	23,040	3,850	10 , 2
3	3 (1.5°)	Full	55°	264	29,697	3,800	10 , 2
4	2 (1°)	2/3	55°	116	29,696	3,300	12 , 3.5
5	2 (1°)	2/3	42°	86	22,528	3,130	13 , 4
6	3 (1.5°)	2/3	55°	174	19,797	2,900	14 , 4
7	2 (1°)	2/3	29°	60	15,360	2,540	17 , 5
8	2 (1.5°)	Full	55°	176	19,788	2,500	17 , 5
9	2 (1.5°)	2/3	55°	116	13,198	1,900	>20 , 6
10	2 (2.9°)	Full	Full	134	8,576	1,700	>20 ,10

# A\* Û is evaluated at 30 EeV for events with less than 30 g cm<sup>-2</sup> X<sub>max</sub> uncertainty.

## The first number denotes the number of years it takes to attain a 5 sigma significance if the spectrum follows an E<sup>\*\*</sup>-3.1 power law up to the cut-off. The second number denotes the time it takes to perform the S sigma measurement if the spectrum takes the less steep slope as discussed earlier.

Detector design scenario 1 is our choice. With the addition of this detector, we will be able to study a number of physics topics at the Dugway facility. Some of these are outlined below:

1 Physics of the production of ultra high energy cosmic rays. This includes measurement of the spectrum, anisotropy, and composition above 10 EeV and the search for an associated neutrino flux and photon flux.

2 Physics of high energy interactions. This includes the extension of the measurement of the measurement of  $\sigma_{p-air}$  from the SSC region to 150 TeV center of mass energies. Because of Am-1 air aperture, our present measurement is performed at one energy region of 30 TeV in the center of mass system. With the larger aperture of the High Resolution Eye and better angular resolution, we will be able to study the energy dependence of the total inelastic cross section from 30 TeV to 150 TeV in the center of mass system.

3 Ultra-high-energy gamma ray/neutral particle astronomy. The new detector will have an aperture at 1 EeV about nine times our present aperture and an average angular uncertainty of 0.4°x 3° instead of our present uncertainty of 2°x 9°. We will be able to measure with a five sigma significance a flux as low as 2 times 10<sup>-17</sup> cm<sup>-2</sup> s<sup>-1</sup> within a period of ten observation days.

4 Composition in the 10 PeV to EeV region The high resolution detector will be built near the Michigan muon array and the Chicago surface detector array. The combination of detectors will also be utilized to study cosmic ray composition in the energy range 10 PeV to 1 EeV. The surface and sub-surface arrays will be utilized to measure shower muon/electron ratios as a function of energy (when the HiRes Eye detector is operating). The key to such a measurement is the independent determination of the energy, provided by the Fly's Eye. Otherwise, fluctuations will wash out the differences between Fe and protons. The composition, as measured by  $X_{\max}$  techniques, can be compared to the one determined by muon and electron size measurements. These measurements, clearly interesting in themselves since they will be made in the region of the spectral "knee" and above, will also provide confidence in the Fly's Eye composition measurements obtained alone at higher energies (where the electron and muon arrays are too small to provide any information) using the different technique of shower maximum distributions.

### III. ACKNOWLEDGMENTS

We gratefully acknowledge the financial support of the National Science Foundation and the help of Colonel Van Prooyen and the staff of Dugway Proving Ground.

1. R. M. Baltrusaitis et al., NIM A20, 410 (1985).
2. R. M. Baltrusaitis et al., P.R.L. 54, 1875, (1985).
3. K. Greisen, Phys. Rev. Lett. 16, 748 (1966). G. T. Zatsepin, V. A. Kuz'min, Pis'ma Zh. Eksp. Teor. Fiz. 4, 114 (1966).
4. Submitted to ICRC
5. G. L. Cassiday et al., P.R.L. 62 383 (1989).
6. R. M. Baltrusaitis et al., P.R.L. 51, 1380 (1984).
7. C. T. Hill, D. N. Schramm, and T. P. Walker, Phys. Rev. D36, 1007 (1987).