

## The High Resolution Fly's Eye ( HiRes ) Project

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### ABSTRACT

At the present time, the origin of cosmic rays in the EHE region ( Energy  $> 10^{18}$  eV ) remains uncertain. The major limitation to progress in determination of the source of these particles is the low event statistics and poor directional, energy, and primary composition resolution of present cosmic ray observatories in this energy range. We describe the capabilities and status of the High Resolution Fly's Eye detector ( HiRes ), a proposed ground-based cosmic ray observatory with substantial improvements in detection area and resolution over present-day detectors.

#### 1. SOURCES OF EHE COSMIC RAYS

There are several models for the sources of cosmic rays in the EHE region. Table 1 lists the various types of EHE cosmic ray sources and their predictions for energy spectrum, anisotropy and composition. Notice that many of the models have similar predictions for many of the characteristics. In particular, measurement of the correlation between structure in the CR energy spectrum and cosmic ray composition seems vital in discovering the sources of these particles. Predicted variations in anisotropy are small for all but Galactic sources. In order to determine which, if any, of these models are valid, it will be necessary to measure all of the characteristics with excellent resolution. The idea of correlated measurements of spectrum, composition and anisotropy without reliance on a hadronic interaction model is the driving force behind the HiRes detector.

#### 2. HIGH RESOLUTION FLY'S EYE ( HIRES ) DETECTOR

The main goal of the HiRes detector is to determine the sources of cosmic rays above  $10^{19}$  eV. At the present time, there are two well developed approaches to the measurement of cosmic rays in this energy range: large ground arrays ( Area  $> 100$  km<sup>2</sup> ), and the Nitrogen Fluorescence technique. The ground array measures the size of the extensive air shower at ground level, and reconstructs direction and primary energy from particle density and arrival times. The Nitrogen Fluorescence technique is currently employed by the Fly's Eye Experiment ( Baltrusaitis *et al.* 1985 ).

The Nitrogen Fluorescence technique has the very strong advantage that it directly measures the electromagnetic cascade down to ground level, thereby providing a calorimetric measurement of shower energy on an event by event basis, independent of hadronic model, primary composition and fluctuations in the depth of the cascade maximum. Typical energy resolution for a Nitrogen fluorescence experiment ( Cooper *et al* 1990 ) is better than 20%. The position of the maximum shower development,  $X_{\max}$  is also directly measured with this technique. The distribution of  $X_{\max}$  can constrain the primary composition. Such constraints are critical in ruling out or confirming certain source models ( see Table 1 ).

Ground arrays infer the primary energy from particle density measurements at ground level through a Monte Carlo calculation relating  $\rho_{600}$  to the primary particle energy. This typically leads to an energy resolution

Model	Energy Spectrum	Anisotropy	Composition
Galactic Wind	$7-10 \times 10^{19}$ eV Energy Cutoff	Slight ( $\sim 5\%$ ) Enhancement	Light — Heavy
Multiple SNR	$10^{18} - 10^{20}$ eV Cutoff	Isotropic	Light — Heavy
Compact Object (Accr. Disk)	$10^{18} - 10^{19}$ eV Energy Cutoff	Galactic Plane Enhancement	Protons Only
Compact Object (Nebula)	$10^{18} - 10^{19}$ eV Energy Cutoff	Galactic Plane Enhancement	Light — Heavy
Extragalactic Cosmic Strings	$6 \times 10^{19}$ eV Cutoff, Bump Before Cutoff	No Enhancement (Isotropic)	Protons Only
Extragalactic EGRJ's (< 100 Mpc)	$6 \times 10^{19}$ eV Cutoff, Bump Before Cutoff	No Enhancement (Isotropic)	Light — Heavy
Extragalactic AGN's, EGRJ's (> 100 Mpc)	$6 \times 10^{19}$ eV Cutoff, Bump Before Cutoff	No Enhancement (Isotropic)	Protons Only

Table 1: Summary of Various EHE Cosmic Ray Source Model Predictions.

of 40% in the EeV energy range ( Chiba *et al.* 1992 ). Although some cross-calibration with Cherenkov light measurements exist, changes in the nature of the cosmic ray flux or the hadronic interactions may change the assumed relation in unknown ways. Changes in the cascade development curve, such as the LPM effect on gamma ray primaries near  $10^{20}$  eV, can make the energy resolution of these arrays substantially worse. Since the arrays do not measure cascade development, they have little information to indicate an erroneous energy extrapolation.

From the construction and operational point of view, the Nitrogen Fluorescence technique has many advantages. The detectors are located at compact sites, typically the detectors and the main operations center are located within 100 m, and are accessible by improved gravel roads. Since the detectors are centralized, high data rates can be accomplished as the bandwidth is limited only by the quality of the cables to the detectors. Electrical and emergency power is easily accessible. Maintenance logistics are simplified as travel time to the individual detectors is negligible, and travel is not affected by bad weather.

The Nitrogen Fluorescence technique has the disadvantage that it can only operate on clear, moonless nights. This limits the detector duty cycle to 10-15%. This is compensated by the very large detection volume. The duty cycle also provides other advantages over continually running systems. In the continuously running system, calibrations and maintenance must be minimized as they directly reduce detector operation time. In the Nitrogen Fluorescence apparatus, detector calibration and maintenance time do not affect duty cycle.

A second difficulty with the Nitrogen Fluorescence technique is that the atmosphere must be well characterized as the EAS track characteristics are modulated by atmospheric effects. This problem is solved using automated laser beams and LIDAR systems to examine atmospheric clarity and aerosol scattering. Atmospheric characteristics can automatically be measured many times per hour by rapid slewing of the laser beams throughout the entire atmospheric detection volume.

The HiRes detector has been described in detail in many other articles ( Cooper *et al.* 1990, Y. Au *et al.* 1991 ). Briefly, the detector consists of 152 individual detection units which are oriented to observe the night sky and record data when a cosmic ray enters the atmosphere and creates a track of nitrogen fluorescent light across the sky. The 152 detection units are distributed among three independent sites, each site contains 54 detection units. The detectors are pointed to maximize the number of cosmic ray events viewed in stereo. The

Parameter	HiRes
Point source resolution at 1 EeV	0.3°
Primary Energy Range (EeV)	0.1 to > 200
Energy resolution at 1 EeV	< 20%
$X_{max}$ resolution at 1 EeV	20-30 g cm <sup>-2</sup>
Detection aperture at 100 EeV with < 30 g cm <sup>-2</sup> resolution	7000 km <sup>2</sup> sr
Events / year > 10 EeV with < 30 g cm <sup>-2</sup> $X_{max}$ resolution	270

Table 2: High Resolution Fly's Eye Detector Capabilities.

detector will be constructed at the Dugway Proving Grounds, USA ( 40.2° N, 112.8° W ), at an elevation of 1500 m above sea level. Table 2 summarizes the expected detection aperture, energy, angular, and  $X_{max}$  resolution.

### 3. STATUS

The HiRes detector is presently in the Prototype Development / Operation stage. The modular design of the HiRes detector allows the operation of individual detector units to occur as soon as each is completed. The first two detector units became operational in January 1991, and acquired cosmic ray data for several hundred hours of night sky operation. Based upon these observations, an upgraded electronics system was developed ( Bird *et al.* 1993a ). The original two units were upgraded, and an additional 4 detector units were instrumented and brought into operation by August 1992. By March 1993, 8 more detector units were brought into operation ( Bird *et al.* 1993b ). By April 1 1993 the full 14 detector prototype had logged nearly 100 hours of night sky operation.

The prototype detectors overlook the atmospheric volume above the CASA-MIA air shower array. In a single years' operation, we expect to measure several hundred events which will have useful information from both HiRes and CASA-MIA ( Bird *et al.* 1993c ). These events will provide detailed measurements of extensive air shower characteristics which may allow examination of the energy spectrum and primary composition in the 10-100 PeV range.

The prototype detector has been used to compare the capabilities of a Flash ADC ( FADC ) system with a Sample-and-Hold ( S/H ) system. The FADC system has the advantage that it directly measures the PMT signal pulse shape, thereby allowing optimization of the night-sky background subtraction to increase the signal-to-noise ratio.

To examine the usefulness of the PMT signal shape for event reconstruction, a FADC system was installed on one of the detector units ( Bird *et al.* 1993e ). This system "tapped" into the PMT signals from a PMT cluster that was also instrumented with a S/H system. Figure 1 illustrates the theoretical and experimental photoelectron resolution of the FADC and the S/H systems. The FADC system shows good improvement over the S/H system at low  $n_{pe}$ . Based upon this analysis, the HiRes experiment is pursuing a FADC data acquisition system for use with the full HiRes detector.

The purpose of the prototype is to examine the operation / reliability of a system which is approximately 10% of the full HiRes design. System performance is being evaluated through examination of event tracks generated by high power Nitrogen and YAG laser beams fired at various orientations and distances up to 50 km distant. Analysis of this data has shown the HiRes experiment can define the plane of the laser beam track to better than 0.1 °. Extrapolation of this monocular accuracy to a stereo HiRes system predicts a track directional reconstruction to better than 0.3° ( Bird *et al.* 1993d ). This accuracy is substantially better than the typical 3° accuracy of an EeV surface array ( Chiba *et al.* 1992 ).

An additional 4 HiRes detector units are currently under construction at the Camel's Back Site,

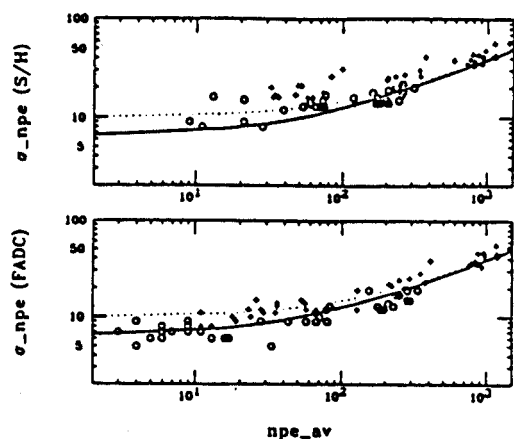


Figure 1: Experimental and theoretical photoelectron resolution for two different electronics systems for the HiRes Fly's Eye. Horizontal axes: Photoelectron Number. Vertical axes: Photoelectron resolution. Points: Experimental Data. Upper plot: Experimental data for S/H system. Lower Plot: Experimental data for FADC system. Dotted Line: Theoretical expectation for S/H system. Solid Line: Theoretical expectation for FADC system.

approximately 13 km west of the present Fly's Eye 1 site. These units will allow the first stereo track measurements of extensive air showers by HiRes detectors, and therefore will provide a powerful tool for examining the stereo directional and energy reconstruction accuracy predicted by the monocular HiRes data. The Camel's Back detectors will be instrumented with an FADC system, thereby allowing examination of the full capabilities of the HiRes detectors, and allowing further optimization of the site layout to maximize event statistics. We expect the Camel's Back prototype to become fully operational by January 1994.

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