# Measurement of the Flux of UHE Cosmic Rays by the HiRes Detectors Observing in both Monocular and Stereoscopic Modes

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## Abstract

The High Resolution Fly's Eye Detector (HiRes) detects and measures properties of ultra high energy cosmic rays (UHECR). The HiRes detector exploits the air fluorescence technique that uses the atmosphere as a calorimeter. A brief description of this technique and how it is used by the HiRes detector will be given in this paper. The HiRes detector has been operational with two detector sites separated by 12.6 km since the fall of 1999. The two separated "eyes" enable the HiRes detector to obtain stereoscopic observations of the air showers. We also have a data set obtained with the first of the 2 sites from a total of 4.0 years of observations in monocular mode. Preliminary results from both the monocular and stereo analysis will be described.

## Introduction

The dependence of the flux of cosmic rays on energy is roughly described by a power law, $flux = E^{-n}$, where the spectral index, n, is approximately 3. Structure in the energy spectrum is manifested by changes in the spectral index. The energy spectrum of ultra-high energy cosmic rays is expected to be cut off above an energy of 60 EeV[1][2]. The first generation Fly's Eye detector, however, observed a cosmic ray particle whose energy was measured to be 320 EeV [3]. The AGASA air shower array has observed several events whose energies were above 60 EeV [4].Many interesting theoretical explanations for the existence of purported "super-GZK" particles have been proposed.

The HiRes detector utilizes the air fluorescence technique[5]. This technique uses the atmosphere as a calorimeter to measure the energy of cosmic ray particles. The initial primary particle interacts with atoms in the atmosphere and produces a cascade of secondary particles. As the secondary shower particles pass through the atmosphere they excite nitrogen atoms in the atmosphere that emit ultraviolet photons through fluorescence [6]. The longitudinal development of the air shower can be determined by measuring the amount of UV light produced by

pp. 413–416 

the air shower along its length. The energy of the cosmic ray can be determined by integrating this longitudinal shower development profile.

This article will discuss the measurement of the UHECR spectrum in the energy range from $2 \times 10^{17}$ eV to above $10^{20}$ eV by the HiRes detector. More detailed descriptions of the monocular [7] and stereoscopic [8] spectrum measurements as well as descriptions of the HiRes collaboration measurements of the anisotropy of arrival directions [9] and chemical composition [10] can be found in additional papers submitted to this conference. Further details about detector calibration [11][12], atmospheric monitoring [13], detector survey [14] and Monte Carlo simulation [15] can also be found in papers submitted by the HiRes collaboration to this conference.

**Detector Description**

The two HiRes detector sites, HiRes-I and HiRes-II, are located in the west desert of Utah at the U.S. Army Dugway Proving Grounds and are separated by 12.6 km. The optical elements of both sites are nearly identical and consist of 5 $m^2$ spherical mirrors that collect light that is focused onto clusters of 256 photo-multiplier tubes. Each photo-multiplier tube views approximately a $1°$ cone of the sky. There are 21 mirrors at the HiRes-I site providing nearly full azimuthal coverage for elevation angles between 3 ° to 17 °. The readout system of the HiRes-I site performs a "sample-and-hold" integration in a $5.6 \mu s$ time window. The HiRes-I site has been operational since June 1997. The HiRes-II site has 42 mirrors covering nearly twice the range of elevation angles from 3 ° to 17 °. HiRes-II uses an FADC based detector readout operating at 10 MHz [16]. HiRes-II began operating in late 1999.

Two significant design considerations of the HiRes detector were to maximize detector aperture and realize good energy resolution, in particular for energies above $10^{18}$ eV . The flux of particles at energies above $6 \times 10^{19} eV$ is such that apertures of approximately 10,000 $km^2$ steradian are required to either detect or rule out the existence of particles with energies in excess of the GZK cutoff. Good energy resolution is required to ensure that poorly measured events do not mimic a "super-GZK" event. An additional benefit of good energy resolution is the possibility of observing "structure" in the cosmic ray spectrum.

The aperture for both monocular and stereoscopic event reconstruction of the HiRes detector approaches 10,000 $km^2$ steradian for energies above $10^{20}$ eV. The HiRes aperture for energies greater than the GZK cutoff is approximately 10 times greater than the original Fly's Eye detector. The actual detector aperture depends on atmosphere conditions. Measured variation of the atmospheric parameters are used in the stereo analyses when available. For the monocular analysis, average measured atmospheric conditions were assumed to determine the aperture as well as energy reconstruction. The sensitivity of the estimated aperture for the monocular spectrum measurement was determined to be ±15% for a reasonable variation in atmospheric conditions.

The sensitivity of the flux measurement, especially above the GZK cutoff, improves as more data is collected. The HiRes detector continues to collect data and is expected to operate until at least 2006. With the amount of data that will be collected over the full operating lifetime of the HiRes detector the ability to either detect or rule out the existence of particles with energies in excess of the GZK cutoff should be realized.

The intrinsic energy resolution for monocular reconstruction using the HiRes-I detector is 25% at an energy of $3 \times 10^{18}$ eV. The intrinsic energy resolution for monocular reconstruction using the HiRes-II detector is 20% at an energy of $10^{18}$ eV. The HiRes-II detector can attempt to measure lower energy UHECR air showers because the elevation angle range covered by the HiRes-II detector is twice that of the HiRes-I detector. The FADC based readout system of HiRes-II also helps to improve the energy resolution. The intrinsic energy resolution above $10^{18}$ eV for the HiRes stereo detector is better than 15%. The stereoscopic based energy measurement has improved resolution principally due to the reduction in the uncertainty in the geometry of the air shower. The stereoscopic energy resolution should enable the measurement of the spectral index with sufficient precision to observe changes in the spectral index over the range of energy $10^{18}$ eV and above.

## Summary and Conclusion

We have collected over 1500 hours of stereoscopic data. We have approximately an additional 2000 hours of data taken in monocular mode with the HiRes-I detector. Results for the measurement of the UHECR energy spectrum from both the monocular and stereoscopic analysis techniques will be presented at the 2003 International Conference on Cosmic Rays.

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