29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

Measurements of UHECR Spectrum with the HiRes detector

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The High Resolution Fly's Eye Detector (HiRes) has measured the flux of ultra high energy cosmic rays in both monocular and stereoscopic modes. The stereoscopic measurement has better resolution of air shower observables, such as energy and arrival directions. However, the monocular measurements of the spectrum have a lower energy threshold as well as larger exposure than the stereoscopic measurement. The monocular measurement from the HiRes-2 site has better resolution than the HiRes-1 monocular measurement due to larger elevation angle coverage and improved readout electronics. This talk will summarize the measurements of the UHECR spectrum using the HiRes detector. The systematic uncertainties and the statistical power of each of the spectrum measurements will be discussed.

1. 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].

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 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 various measurements of the UHECR spectrum in the energy range from 2×10^{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 and previous ICRC conferences.

2. 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 $^\circ$ to 17 $^\circ$. The readout system of the HiRes-I site performs a "sample-and-hold" integration in a 5.6μs 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 [18]. 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 $\pm 15\%$ 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. A paper [11] based on the monocular spectrum measurement to be presented at this conference indicates that the HiRes data already favors the existence of the so-called GZK cutoff.

The intrinsic energy resolution for monocular reconstruction using the HiRes-I detector is 25% at an energy of 3×10^{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.

3. Summary and Conclusion

Much effort has been recently placed in calibration and atmospheric monitoring. The time dependence of the calibration of the PMTs has been measured using episodic calibrations with a standard Xenon Flasher light source as well as continuous monitoring through the illumination of the clusters with light from a YAG laser via fiber optics. Atmospheric monitoring was carried out to determine the amount of aerosols in the atmosphere on an hourly basis. The calibration measurement of the approximately 15000 PMTs as well as the hourly measurements of the atmospheric parameters were stored in a calibrations database. This database was used in the reconstruction of the stereo events. This database was also used to generate a sample of Monte Carlo events that were used to determine the aperture for every hour of operation based upon the existing detector and atmospheric conditions. For the purpose of aperture determination the simulation also included information about trigger thresholds to simulate the detector response for the varying trigger conditions. An absolute calibration of the photometric scale has been carried out through a campaign that illuminated many of the individual HiRes mirrors from a distance of 4km. This distance was chosen to minimize sensitivity to the effects of aerosol absorption and scattering. This program verified that the piecewise calibration used to obtain a measurement of photon flux impinging upon a mirror from the DAQ readout values was correct and known to within an uncertainty of less than $/pm10\%$. A program of measurement of Fluorescence yield has also been carried out by the Flash experiment and will be described in a paper [17] submitted to this conference. Further details about detector calibration [12][13], atmospheric monitoring [14], detector survey [15] and Monte Carlo simulation [16] can also be found in papers submitted by the HiRes collaboration to this and previous ICRC conferences.

We have collected approximately 3000 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 2005 International Conference on Cosmic Rays.

4. Acknowledgements

This work is supported by US NSF grants PHY-9321949, PHY-9322298, PHY-9904048, PHY-9974537, PHY-0098826, PHY-0140688, PHY-0245428, PHY-0305516, PHY-0307098, and by the DOE grant FG03-92ER40732. We gratefully acknowledge the contributions from the technical staffs of our home institutions. The cooperation of Colonels E. Fischer and G. Harter, the US Army, and the Dugway Proving Ground staff is greatly appreciated.

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