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First Results from the High Resolution Fly's Eye Experiment

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The High Resolution Fly's Eye Experiment (HiRes) is the only operational experiment of it's kind in the world. HiRes is the direct descendent of the original Fly's Eye experiment. HiRes is designed to make stereo observations of Ultra High Energy Cosmic Rays (UHECR) via atmospheric fluorescence. HiRes will measure the energy spectrum, composition, and anisotropy of UHECR. The first of two sites, HiRes-1, has been in operation since June, 1997. Over 1000 hours of good weather data has been taken, monocularly, and analyzed. A preliminary energy spectrum is presented based on this data set and compared to the results from the original Fly's Eye experiment. The second site, HiRes-2, began limited data-taking in April, 1999. The installation of the HiRes-2 detector is now complete and commissioning is underway. Some high energy events have already been observed in stereo.

The High Resolution Fly's Eye (HiRes) experiment consists of two sites located 12.6 km apart. Each site consists of multiple detectors. Each detector employs a 3.7 m^2 spherical mirror instrumented with a camera composed of 256 photomultiplier tubes (PMTs). Each hexagonal PMT views a 1° segment of the sky.

HiRes-1 consists of 22 detectors instrumented with sample-and-hold electronics. The detectors cover the full range of azimuth over elevation angles from 3° to 17°. HiRes-2 consists of 42 detectors instrumented with a 10 MHz flash-ADC (FADC) system covering elevation angles from 3° to 31°.

1. HiRes-1 Monocular Results

The HiRes-1 detector, began observation in June, 1997. At the end of June, 1999, about 2000 hours of data had been collected, of which 1070 hours of good weather data have been analyzed.

The HiRes detectors are designed specifically to operate in stereo mode. Events observed only by HiRes-1 are short, typically less than 20° in angular span and do not have the time curvature necessary for a good monocular reconstruction. They also do not have the stereo constraint for a precise measurement of geometry. A solution to this problem is to include a constrained fit to the shower profile with the timing fit. This method of reconstruction is called a profile-constrained time fit. A Gaisser-Hillas profile is assumed and the shower parameters are constrained to reasonable values as determined by previous experiments[1] and Monte Carlo [2–4]. Reconstruction of simulated events using this procedure shows a resolution which improves with energy. At energies greater than 3×10^{19} eV, this resolution is found to be better than 20%.

1.1. Monocular Spectrum

The monocular reconstruction aperture is evaluated, using simulations, to be 9100 km^2-str for showers with energies of 10^{20} eV. Thus, the 1070 hours of good weather monocular data analyzed so far corresponds to an integrated exposure of 970 km^2-str-yr at 5×10^{19} eV, and 1090 km^2-str-yr at 10^{20} eV.

After the events are reconstructed, the aperture is folded in and the spectrum, figure 1, is obtained. The measured flux in this plot is multiplied by the cube of the nominal shower energy to reveal details otherwise masked by the dominant E^{-3} power law. Also shown in figure 1, are the parameterized monocular and stereo spectra from the original Fly's Eye Experiment [5–7].

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The plot clearly shows the new HiRes-1 monocular spectrum to be in good agreement with both of the Fly's Eye spectra.

It should be noted that the energy determination used in the construction of figure 1 assumes a static *Standard Desert Atmosphere*, corresponding to an aerosol layer of 1.2 km scale height and a horizontal aerosol extinction length of 12 km. Event-by-event atmospheric corrections have not yet been applied. The monocular data set does contain calibration events from both xenon flashers and bi-static lidar. This sub-set of data will be analyzed to characterize the nightly aerosol variations, which will be included later in energy reconstruction. Nevertheless, the atmospheric clarity is bounded on the clearest nights by pure molecular atmospheric conditions. Therefore a lower bound on the energies of the showers can be calculated by assuming zero aerosol content during reconstruction.

1.2. The GZK Cut-off

HiRes-1 has observed events with nominal energies above the theoretical Greisen-Zatsepin-K'uzmin (GZK) Cut-off of 6×10^{19} eV. However, in the case of a rapidly falling spectrum, events in the high-energy tail of the energy resolution function can contribute to a possible false signature of events above the GZK cut-off, should they actually exist. It is therefore necessary to compare the observed spectrum to one reconstructed from simulated data. Figure 2 shows such a comparison. Three simulated scenarios are presented in this plot: (a) a cut-off at 6×10^{19} eV, (b) a cut-off at 10^{20} eV and (c) no cut-off. For the simulation, events are generated according to the Fly's Eye stereo spectrum extrapolated above 6×10^{19} eV.

The number of events in the data sample with reconstructed energies greater than 6×10^{19} eV was 13. This compares with a) 2.5±1.1 events predicted with a 6×10^{19} eV cut-off, b) 12.8±2.5 event with a 1×10^{20} eV cut-off, and c) 21.7±3.3 events predicted by simulation with no spectrum cut-off. In addition, seven of the HiRes events were reconstructed with energies greater than 1×10^{20} eV. The numbers predicted in the three cut-off cases were a) <1, b)1.9±1.0, and 10.2±2.3 events. The data, uncorrected for atmospheric variations, appears to be inconsistent with a 6×10^{19} eV cut-off.

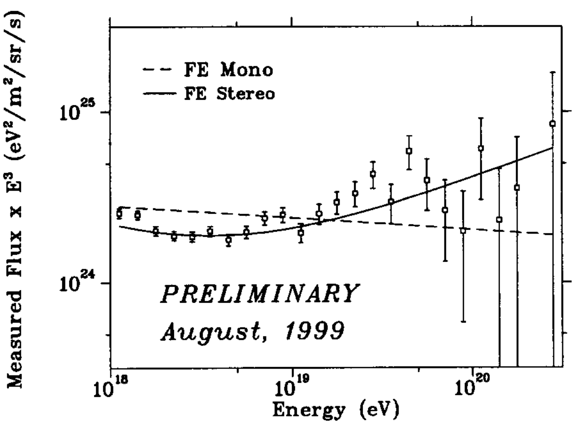

Figure 1. The cosmic ray flux measured by HiRes-1 times the cube of energy vs. energy. The dashed and solid curves show the monocular and stereo spectra from the original Fly's Eye Experiment.

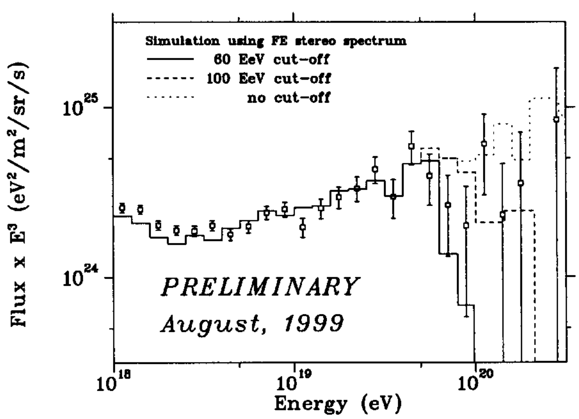

Figure 2. A comparison between the measured HiRes-1 spectrum and various simulated cut-off spectra.

1.3. The Highest Energy Monocular Event

The HiRes-1 monocular data set also contains an event with a reconstructed energy in excess of 2×10^{20} eV. Its best-fit energy and X_{max} values are 2.8×10^{20} eV, and 790 g/cm^2, respectively. Although parts of the HiRes-2 detector had begun night-sky tests of the night sky at that point, it was not operating at the time of this event. We therefore have no stereo confirmation of the reconstructed geometry. Nevertheless, a number of systematic checks were performed on this event. First, we repeated the geometrical fitting procedure, but with the X_{max} values fixed at 35 g/cm^2 intervals from 685 to 860 g/cm^2. These results show that the geometrical fit is stable with respect to variations in the assumed shower profile.

In addition, the event was also analyzed using a timing fit without a profile constraint. In this case the energy and X_{max} values are 3.6×10^{20} eV and 687 g/cm^2, respectively. We have assumed, however, a standard desert atmosphere in the reconstruction as in the above systematic checks. Changing the assumptions about the atmosphere itself will also vary the reconstructed energy. In particular, if the aerosol content is significantly lower than assumed, then we would have over-estimated the energy in the reconstruction. For instance, changing the aerosol horizontal extinction length from 12 to 15 km lowers the reconstructed energy from 2.8×10^{20} eV to 2.5×10^{20} eV. Removing the aerosol completely from the reconstruction, a lower bound of 1.6×10^{20} eV is obtained for this event.

2. HiRes-2 Status

The second site, HiRes-2, began limited data taking with a partially completed detector in April, 1999. The installation was completed at August, 1999 and commissioning is underway.

2.1. A First Look at Stereo Events

By the end of July, 1999, HiRes-2 had collected about 40 hours of stereo data in coincidence with HiRes-1. Analysis codes are being developed specifically to take advantage of the FADC system. For a preliminary analysis, only the reconstructed shower-detector planes from HiRes-2 are used in conjunction with HiRes-I information to determine the shower geometry. The shower energy is reconstructed using HiRes-1 information. Of the subset of data that had been scanned for coincidence with HiRes-1, ten events were observed above 10^{18} eV and two events were reconstructed above 10^{19} eV. These events provide an opportunity to cross-check the monocular reconstruction using a subset of the data. The first look is very encouraging. The monocular energy and geometrical reconstruction are in good agreement with the stereo results.

3. Summary

The HiRes experiment is now well underway. We have already accumulated an exposure which exceeds that of the original Fly's Eye. Preliminary results from two years of monocular observation are taking shape and the monocular energy spectrum is in good agreement with the old Fly's Eye results. Our second site, HiRes-2, is turning on and some stereo observation has already begun. Verification of the monocular resolution with stereo data as well as as many other exciting results will soon be available.

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