29th International Cosmic Ray Conference Pune (2005) 7, 307–310

Monocular UHECR Spectrum Measurements from HiRes

D.R. Bergman for the HiRes Collaboration

Rutgers - The State University of New Jersey, Department of Physics and Astronomy, Piscataway, New Jersey, USA

Presenter: D.R. Bergman (bergman@physics.rutgers.edu), usa-bergman-D-abs1-he14-poster

Monocular measurements of the UHECR flux with the HiRes detector give the largest statistical significance and the largest range of energies available. The spectrum from each of the two HiRes sites will be presented. The statistical significance of agreement or disagreement between the HiRes monocular measurements and other measurements and expectations will be discussed.

1. Introduction and Motivation

While the High Resolution Fly's Eye (HiRes) detector was designed to view UHECR showers in stereo, there are good reasons to reconstruct showers from each site independently and to calculate the UHECR flux observed in this way. First, the first HiRes detector began to take data more than two years before stereo mode operations began in December of 1999. This is the largest sample of UHECR's obtained by any detector to date and, likewise, has the best statistical power for determining features in the spectrum.

The second reason to use monocular data is energy range. Since an event has to trigger only one of the detectors, it can have a much lower energy. This fact allows us to extend the energy range covered by an order of magnitude for low energies. This is especially important because the Ankle is expected to be just at the lower edge of the stereo energy range, while it is right in the middle of the HiRes-II monocular range.

2. Analysis Techniques

One determines the geometry of an extensive air shower in monocular mode by fitting the photo-tube trigger times to their viewing angles. With the geometry determined, the photo-electron count is then converted to a shower size at each atmospheric depth, using the known geometry of the shower, and corrected for atmospheric attenuation. We integrate the resulting function over X (using the determined values of $N_{\max}$ and $X_{\max}$) and then multiply by the average energy loss per particle to give the visible shower energy. A correction for energy carried off by non-observable particles to give the total shower energy ($\sim 10\%$)[1] is then applied.

HiRes-I events are too short in angular spread for reliable determination of the angle and impact parameter by timing alone. For the HiRes-I analysis, the expected form of the shower development itself is used to constrain the time fit to yield realistic geometries. The shower profile is assumed to be described by the Gaisser-Hillas parameterization[2], which is in good agreement with previous HiRes measurements[3] and with CORSIKA/QGSJET simulations[1, 4, 5]. This technique is called the Profile-Constrained Fit (PCF).

Monte Carlo (MC) studies were performed to assess the reliability of the PCF method. The simulated events were subjected to the same selection criteria and cuts imposed on the data. Not including atmospheric fluctuations, an RMS energy resolution of better than 20% was seen above $10^{19.5}$ eV. However, the resolution degrades at lower energies to about 25% at $10^{18.5}$ eV. These MC results were cross-checked by examination of a smaller set of stereo events where the geometry is more precisely known. Comparing the energies reconstructed using monocular and stereo geometries, we obtained resolutions similar to those seen in MC.

The analysis of HiRes-II monocular data is similar to that for HiRes-I. With the greater elevation coverage at HiRes-II, it is feasible to reconstruct the shower geometry from timing alone.

The MC is also used to calculate the detector aperture. Simulated events were subjected to the same reconstruction algorithm and cuts applied to the data. To verify the reliability of this calculation, we compared, at different energies, the zenith angle and impact parameter distributions, which define the detector aperture. The MC predictions for these are very sensitive to details of the simulation, including the detector triggering, optical ray-tracing, signal/noise, and the atmospheric modeling.

3. Flux

We calculated the cosmic ray flux for HiRes-I above 3×10^{18} eV, and for HiRes-II above 2×10^{17} eV. This combined spectrum is shown in Fig. 1, where the flux $J(E)$ has been multiplied by E^3. The data sample for HiRes-I includes data between June 1997 and May 2005. The data sample for HiRes-II includes dates between December 1999 and May 2003. The error bars represent the 68% confidence interval for the Poisson fluctuations in the number of events, including bins with no observed events.

The largest systematic uncertainties are the absolute calibration of the photo-tubes ($\pm 10\%$)[6], the yield of the fluorescence process ($\pm 10\%$)[7], the correction for unobserved energy in the shower ($\pm 5\%$)[1], [8], and the modeling of the atmosphere[9].

Our spectrum contains four events which reconstruct with energies greater than 10^{20} eV, measured at 1.0, 1.0, 1.2 and 1.5×10^{20} eV. The fitted geometries were insensitive to variations in aerosol parameters. Assuming a purely molecular atmosphere ($\tau_A = 0.0$), we obtain a lower energy limits of 0.9–1.2×10^{20} eV.

In the energy range where both detectors' data have good statistical power, the results agree with each other very well. The data are consistent with previous experiments which observed the second knee at about $10^{17.6}$ eV, and the ankle at about $10^{18.6}$ eV[10].

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.

References

[1] C. Song, Z. Cao *et al.*, Astropart. Phys. **14**, 7, (2000).
[2] T. Gaisser and A.M. Hillas, Proc. 15th Int. Cosmic Ray Conf. (Plovdiv), **8**, 353, (1977).
[3] T. Abu-Zayyad *et al.*, Astropart. Phys. **16**, 1, (2001).
[4] D. Heck *et al.*, "CORSIKA : A Monte Carlo Code to Simulate Extensive Air Showers", Report FZKA 6019 (1998), Forschungszentrum Karlsruhe.
[5] N.N. Kalmykov, S.S. Ostapchenko and A.I. Pavlov, Nucl. Phys. B (Proc. Suppl.) **52B**, 17, (1997).
[6] T. Abu-Zayyad *et al.*, to be submitted to NIM.
[7] F. Kakimoto *et al.*, NIM **A 372**, 527 (1996).
[8] J. Linsley, Proc. 18th Int. Cosmic Ray Conf. (Bangalore), **12**, 135, (1983).
[9] T. Abu-Zayyad *et al.*, in preparation, and http://www.cosmic-ray.org/atmos/.
[10] D.J. Bird *et al.*, Phys. Rev. Lett. **71**, 3401, (1993).
[11] R. Abbasi *et. al.*, To appear in Phys. Lett. B., astro-ph/0501317; see also http://www.physics.rutgers.edu/ dbergman/HiRes-Monocular-Spectra.html.

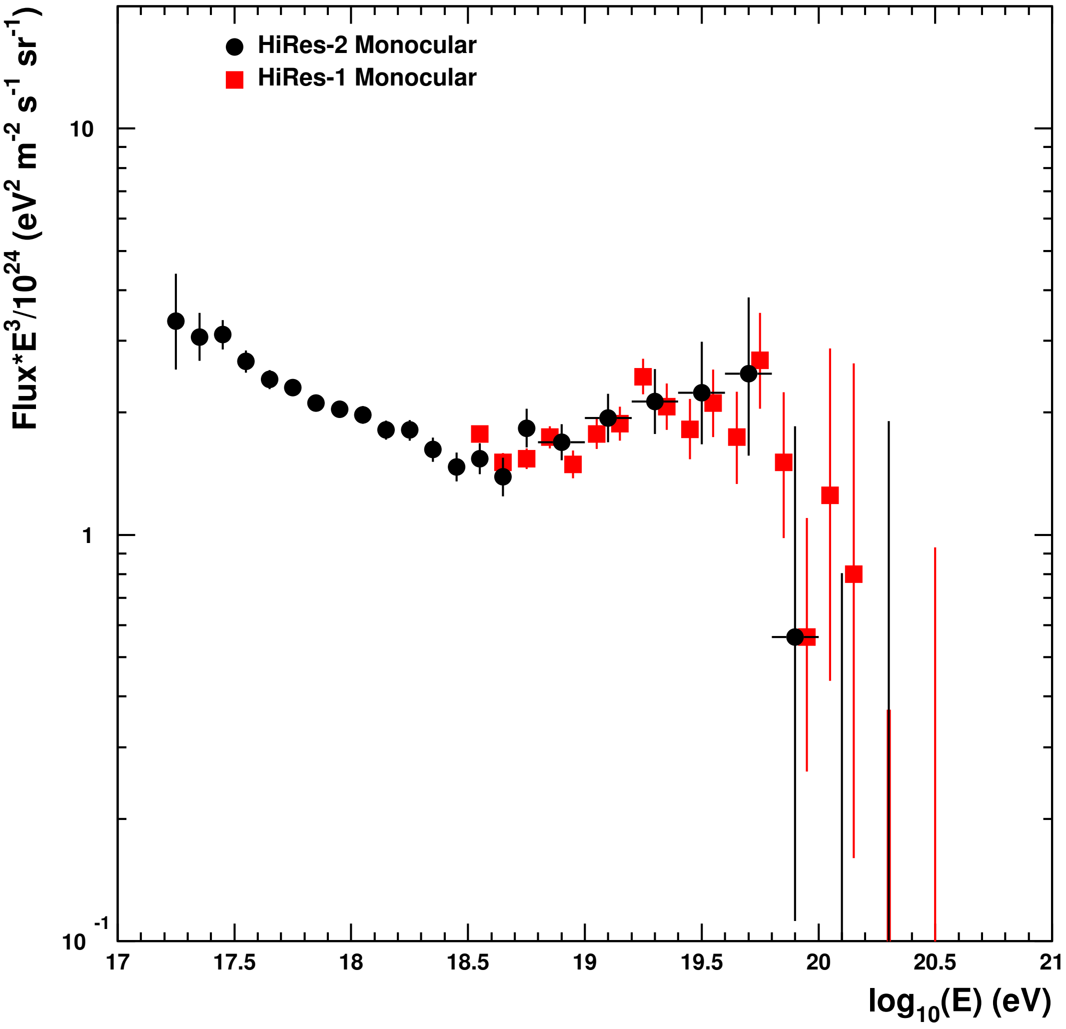

Figure 1. The two HiRes monocular spectra.