29th International Cosmic Ray Conference Pune (2005) 7, 361–364

Cross-checks of the HiRes Monocular Flux Measurements

T. Abu-Zayyad[a] and D. R. Bergman[b] for the HiRes collaboration
(a) University of Utah, Salt Lake City, UT USA
(b) Rutgers University, Piscataway, NJ USA
Presenter: J.N. Mathews (jnm@cosmic.utah.edu), usa-matthews-John-abs1-he14-poster

The HiRes Collaboration has published results on the flux of the ultra-high energy cosmic rays, based on monocular observation by the two sites comprising the stereo detector. The main advantage of stereo observation is the superior geometrical reconstruction as compared with monocular reconstructed tracks. A combined analysis of the two monocular data sets makes it possible to use stereo reconstructed shower track geometry as the input to the monocular analysis for each site now with the benefit of accurate geometrical reconstruction. Results of the new flux measurement will be presented.

1. Introduction

The High Resolution Fly's Eye (HiRes) detector is an air fluorescence detector located in the state of Utah [1, 2]. The detector was designed to measure the properties of ultra high energy cosmic rays by observing the extensive air showers (EAS) generated when a high energy cosmic ray particle interacts with the atmosphere. The detector began data collection in the spring of 1997 and remains in operation in 2005.

Two air fluorescence stations, HiRes-1 and HiRes-2, make up the detector. An extensive air shower which is detected by both stations is said to be observed in stereo mode. If only one station triggers, then the shower is recorded in monocular mode. Stereo observation has a distinct advantage over monocular when it comes to reconstructing the shower geometry. Uncertainty in the shower's geometry propagate to uncertainties in the energy estimation of the primary particle, therefore shower energies measured in stereo are considered more reliable and accurate than those measured in mono. However, the HiRes collaboration has performed two independent measurements of the spectrum using monocular reconstruction of data from each of the two stations [3, 4]. The motivation for this is explained next.

The HiRes-1 station began operations in the spring of 1997, more than two years before the HiRes-2 station did. The latter employs newer FADC electronics and took longer to construct than HiRes-1 which uses an older charge-integrating electronics system carried-over from the HiRes prototype detector. Since the HiRes-1 data from the first two years of operation was monocular data with no stereo counterpart, monocular reconstruction was the only option. HiRes-2 began data collection in December of 1999 and it was always operated in conjunction with HiRes-1. Thus, stereo data is available for the entire HiRes-2 data taking period. However, not all events are observed in stereo. In particular, lower energy events, especially those below 10^{18} eV, are likely to trigger only one of the two detectors. The two HiRes sites are separated by a distance of 12.6 km. This distance determines the energy threshold for stereo observation. The stereo trigger aperture is a very steep function of the shower energy near and below 10^{18} eV, in fact the "physics energy threshold" for HiRes is close to 3×10^{18} eV. The advantage of the HiRes-2 monocular measurement is that it has a much lower energy reach than stereo. In monocular mode, HiRes-2 can be used to measure and reconstruct EAS with energies above $\sim 3 \times 10^{17}$. The trigger aperture for HiRes-2 mono, while still steep is much less so than the stereo aperture.

Currently the HiRes collaboration is working on a stereo measurement of the energy spectrum. The stereo analysis uses a Monte Carlo simulation of the detector and reconstruction software that is different than that used for the monocular analysis. In addition, the stereo analysis uses atmospheric and detector calibration data bases which represent the actual detector settings and running conditions as recorded by the detector monitoring and calibration systems. In contrast, the monocular analysis used detector calibration information based on measurements performed once every few months and assumed an average atmosphere in the treatment of light attenuation due to aerosols.

Because of the differences between the stereo and monocular analyses, it is useful to quantify the effects of the various assumptions on the reconstructed shower geometries. For this reason, a procedure called "tandem stereo analysis" was developed. The initial goal was to look at HiRes-1 events and compare the monocular reconstructed shower energies with those obtained with the stereo geometry, but otherwise using the calibration, atmospheric parameters, and the reconstruction programs of the monocular analysis.

Tandem stereo analysis extends the event-by-event comparison between stereo and monocular reconstructions (see for example, figure 14 of reference [4]) to a cross check of the measured monocular spectra themselves. This is accomplished by repeating the monocular analysis from each site, but with only those events which were seen by the other site as well. Details of the procedure and description of the data used in this analysis are presented in the next section.

2. Data and Analysis

The data set used for the tandem stereo analysis is a subset of that used in the HiRes-2 monocular measurement. Starting from the latter we searched for any corresponding HiRes-1 trigger for each Hires-2 event in the set. Data collected between December 1999 and September of 2001 comprises the data set. In all, the tandem data set contains some 1100 stereo events, collected over 124 nights with a total detector on-time of 573 hours.

The calculation of an energy spectrum requires three basic pieces of information. The first is the energy distribution of the observed events. The second is the instantaneous reconstructible aperture of the detector as a function of event energy. The third is the time interval during which the data was collected, i.e. the detector on-time. To get an energy distribution, the event reconstruction programs developed for the monocular analysis are used. The calculation of the aperture requires a Monte Carlo simulation of the detector response to simulated showers. Since the Monte Carlo programs used for the two monocular analyses are different, the simulation of each detector response was carried out sequentially and thus the name tandem analysis. Finally, the HiRes-2 detector on-time already calculated for mono was corrected for overlap with HiRes-1 data taking periods.

The detailed steps of the aperture calculation are as follows:

1. Simulation begins with the generation of HiRes-2 monocular events. This defines the "thrown" aperture. The input spectrum and composition of the thrown events is based on the Fly's Eye stereo spectrum and the HiRes/MIA and HiRes composition.

2. Triggered events are processed through event selection and HiRes-2 Shower Detector Plane (SDP) determination as performed for HiRes-2 monocular data.

3. Events with successful HiRes-2 SDP reconstruction are at this point passed to the HiRes-1 Monte Carlo.

4. If HiRes-1 triggers, then that event is processed through HiRes-1 SDP determination and event selection process.

5. Events with SDP's from both sites are merged and the stereo geometry is determined.

6. The stereo geometry determination is the only stage of the analysis that uses data from both sites. Once the geometry is determined, the two analyses continue separately as in mono.

7. Shower profile and energy reconstruction is the next step and is done for each site.

8. final event selection and quality cuts are applied separately for each site.

3. Discussion

The reconstructible aperture calculated as described in the previous section is shown in figure 1 for both detectors. The differences in aperture between the two sites are due to the different reconstruction efficiencies. The HiRes-2 detector viewing angle extends to 31^o in elevation, while HiRes-1 sees up to only 17^o, therefore HiRes-2 can successfully reconstruct a higher fraction of close-by events than HiRes-1.

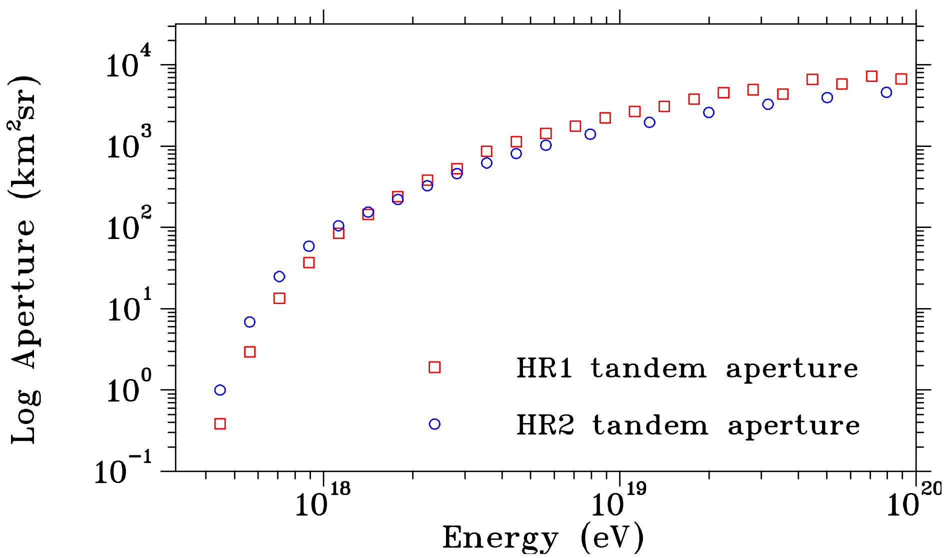

Figure 1. The reconstructible apertures for the HiRes1 and HiRes2 tandem stereo analyses.

After application of quality cuts, the energy resolution for reconstructed Monte Carlo events energies is $\sim 10\%$ for both sites. A comparison of the Monte Carlo and real data distributions for a large number of reoconstructed parameters shows a good agreement for all the important paramters. The energy spectra calculated from both sites will be shown at the conference.

4. Acknowledgments

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 FG03-92ER407 32. 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] T. Abu-Zayyad *et al.*, Proc. 26th Int. Cosmic Ray Conf. (Salt Lake City) 5 (1999) 349
[2] J.H. Boyer *et al.*, Nucl. Instr. Meth. A 482 (2002) 457-474
[3] R. U. Abbasi *et al.*, Phys. Rev Lett. 92 (2004) 151101
[4] R. U. Abassi *et al.*, Astroparticle Physics 23 (2005) 157-174