

# Preliminary stereo results from the High Resolution Fly's Eye cosmic ray observatory

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**Abstract.** The High Resolution Fly's Eye Cosmic Ray Observatory consists of two detector sites located on hilltops in the western desert of Utah. The two sites are separated by 12.6 km. Stereoscopic observations from the two sites enable the location of air showers to be more accurately reconstructed by using triangulation. The improved geometrical reconstruction provides for a more precise measurement of both the energy of the primary cosmic ray particle and the depth of the shower maximum. Preliminary results from approximately 1000 hours of stereo on-time will be shown.

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## 1 Introduction

The High Resolution Fly's Eye detector, HiRes, is designed to detect and measure the characteristics of cosmic ray particles with energies above 1 EeV ( $10^{18} eV$ ). The first generation Fly's Eye detector observed a cosmic ray particle whose energy was measured to be 320 EeV (D.J. Bird, 1995). More recently, the AGASA air shower array has observed several events whose energies were above 60 EeV (S. Yoshida, 1999). The observed energy spectrum of cosmic rays is expected to be cut off above 60 EeV. This cutoff in the energy spectrum, known as the GZK cutoff (T. Zatsepin, V.A. Kuzmin, 1966)(K. Greissen, 1966), would result if the sources of cosmic rays with energies above 60 EeV were isotropically located at distances greater than 50 Mpc. Protons above 60 EeV are not expected to propagate further than this distance due to inelastic collisions with photons from the cosmic microwave background.

The aperture for stereo event reconstruction of the recently completed HiRes detector is  $10,000 km^2$  steradian, which is approximately 10 times greater than the original Fly's Eye detector. This large aperture will enable the clear determination of whether the energy spectrum continues above the GZK cutoff. The angular resolution afforded by the stereo reconstruction of the air showers will also be beneficial in

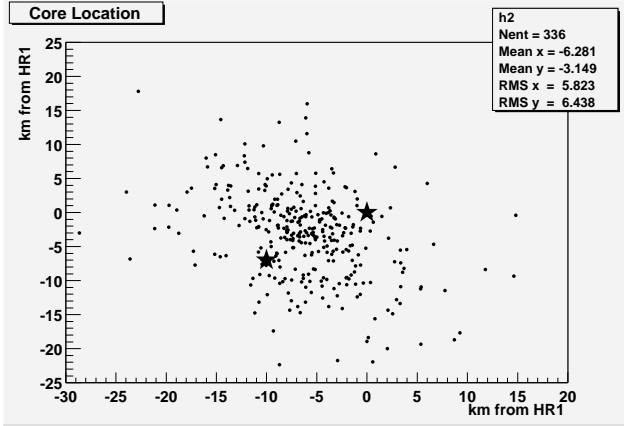
searches for point sources of ultrahigh energy cosmic rays.

## 2 Experiment Description

The HiRes detector utilizes the air fluorescence technique first proposed in the 1950's and developed by the Fly's Eye group in the 1980's (D.J. Bird, 1994). 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 which emit ultraviolet photons through fluorescence. 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 in the atmosphere. The depth of shower maximum in the atmosphere, known as  $X_{max}$ , occurs when the initial particle energy has been distributed to enough secondary particles so that number of secondary particles reaches a maximum. The energy of the cosmic ray can be determined by integrating this longitudinal shower curve if one knows the following information:

- Relationship between amount of UV fluorescence to energy deposition in atmosphere.
- Light transmission characteristics of the atmosphere.
- Absolute PMT Calibration.
- Distance to the air shower.

The relationship between the number of UV photons and the energy deposition of the air shower has been determined by beam test measurements at ICRR where the UV fluorescence yield of electrons propagating through air at various pressures was measured (F. Kakimo, 1996). One must also understand the propagation of UV photons in the atmosphere. Atmospheric monitoring is a major concern at HiRes due to the relatively large distance to the air shower.



**Fig. 1.** Core locations of stereo events (impact with  $z=0$  plane)  
Stars represent the locations of the HiRes-1 and HiRes-2 detectors

Many of our atmospheric considerations will be described in other talks at this conference (Lawrence Wienke and Mike Roberts, 2001)(Reid Mumford, 1999).

It is also necessary to know the absolute calibration of the light measuring equipment. An extensive calibration program using lasers, Xenon flashers, etc., is utilized by the HiRes experiment to determine absolute calibration. This program is described in a poster session at this conference (John N. Matthews, 2001). Finally, one also needs to know the distance from the detector to various segments of the air shower. An indication of distance can be extracted from the timing information gathered from the hits in the PMT array. For instance, the known speed of propagation of the shower, namely the speed of light, enables one to determine the product of the distance and slant angle from the inverse angular speed measured by the time required to cross 1 degree of the sky. A stereo view of the shower simplifies the task of distance determination enormously by reducing the problem to one of geometry.

The location of our detector is ideal due to the quality of the desert atmosphere. Additionally, with our two sites located on hilltops approximately 500-700 feet above the valley floor, we are able to view above most of the aerosol layer. The HiRes-1 site has been in operation since May 1997 and has been collecting monocular data. Talks describing results from this data set can be found in this conference (Charles Jui and John Belz, 2001). The optical systems at both sites consist of spherical mirrors of  $3.8 \text{ m}^2$  effective area. The light collected by these mirrors are focused onto clusters of 256 hexagonal photo-multiplier tubes closed packed into 16 rows by 16 columns. Each tube views a 1 degree cone in the sky. The HiRes-1 site consists of 21 mirrors that view nearly the full 360 degree azimuthal range from 3 degrees to 17 degrees above the horizon. The HiRes-2 site consists of 42 mirrors that view almost full azimuthal range with from 3 degrees to 31 degrees above the horizon. The electronics used to measure the light from the PMTs differs between the two sites. The HiRes-1 site uses a sample and hold technique

that integrates the pulse from the PMT. The HiRes-1 trigger is based upon coincidences of combinations of tubes whose signals exceeded a variable threshold. The electronics at the HiRes-2 site is based upon 10 MHz Flash ADCs. The PMT signals are therefore sampled every 100ns. Additional timing information of the development of the shower is thereby obtained. The FADC electronics used at HiRes-2 have been described at a prior conference (Bruce Knapp, 1999). Timing of the two sites is synchronized through the use of the Global Positioning System. This timing information is necessary to match the events observed at one site with the corresponding events at the other site. The difference in the absolute time of observation of an air shower from each of the two sites can also be used in the geometrical reconstruction of the air shower.

### 3 Preliminary Results

The HiRes group has been collecting monocular data for four years with the HiRes-1 detector. Our full stereo detector has been operating stably for over 18 months. As of May 22, 2001, we have collected almost 1000 hours of stereo data consisting of some 700,000 stereo triggers.

The stereo triggers are dominated by our calibration light sources. These sources include one portable and two fixed steerable laser systems and an array of xenon flashers on the desert floor (Lawrence Wienke and Mike Roberts, 2001). After filtering known sources from our data well over 1000 stereo cosmic ray candidates remain. Identification of these known sources has been dramatically simplified by the use of GPS modules which provide firing at known offsets from the GPS second (Jeremy Smith, 2001).

Cosmic rays have been observed at distances of closest approach of up to 30 km from our detector sites. Segments of these air showers are observed at distances of even greater than 30 km. Figure 1 shows the core location (impact of  $y=0$  plane) of a select portion of our stereo data set. Figures 2 and 3 show the impact parameter, or distance of closest approach, of the same events. Atmospheric attenuation corrections become important for the distances from which these air showers are observed. Hence a considerable effort in atmospheric monitoring has been undertaken by the HiRes collaboration (Lawrence Wienke and Mike Roberts (2001)).

The flux spectrum of cosmic ray particles is defined as

$$\Phi(dE) = \frac{dN}{dE} \frac{1}{\sigma \Delta t}$$

or the number of events per energy bin per unit aperture,  $\sigma$ , per unit exposure time,  $\Delta t$ .

In order to study the spectrum, we are currently tuning our stereo Monte Carlo simulation and studying our real atmospheric parameters. We will use the simulation to perform studies to determine the energy and  $X_{max}$  resolutions of our detector. The simulation will also be used to calculate the aperture (volume covered by detector) as a function of energy. Higher energy events produce more light and can therefore be seen further away.

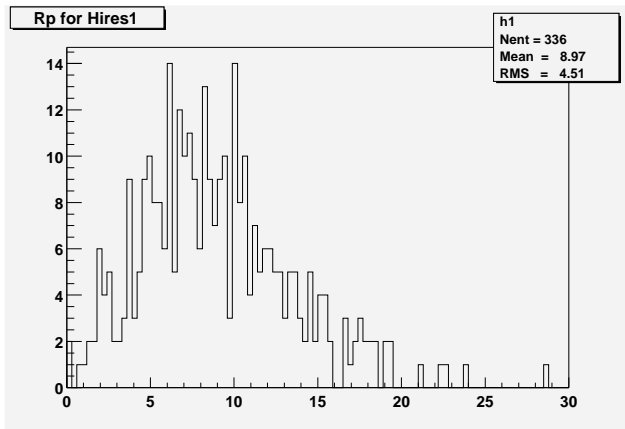


Fig. 2. Impact Parameter of Stereo Events for HiRes-1

The aperture also varies with changing atmospheric conditions (Lawrence Wienke and Mike Roberts, 2001). Since the aperture varies with atmosphere, we must calculate exposure time as a function of atmosphere. A full description of the Monte Carlo and atmospheric efforts will be presented during separate talks at this conference (Zhen Cao, 2001) (Lawrence Wienke and Mike Roberts, 2001). Finally, a study to determine efficiency of noise, known source and quality cuts will be carried out.

At the time of this writing, we are not prepared to provide a spectrum. It is sufficient to say that we have recorded several events with measured energies at and above the GZK cutoff.

#### 4 Summary and Conclusion

We have collected over 1000 stereo cosmic ray candidates. These include some over the GZK cutoff. By combining our efforts in Monte Carlo and atmospheric parameterization, we hope to have full results soon.

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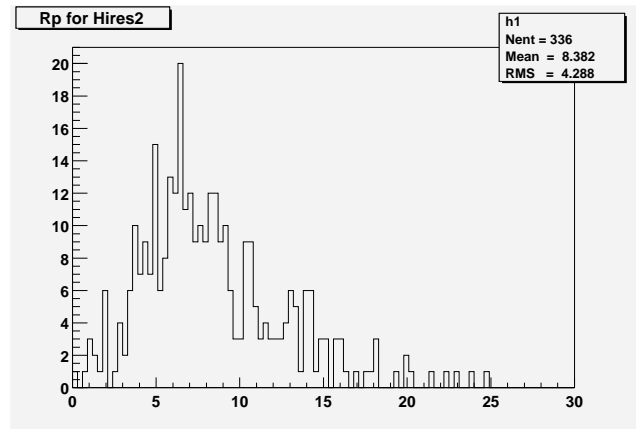


Fig. 3. Impact Parameter of Stereo Events for HiRes-2

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HiRes Monte Carlo: Proc of 27th ICRC (2001), Zhen Cao *et al.*

HiRes GPSY Board: Proc of 27th ICRC (poster) (2001), Jeremy Smith *et al.*

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HiRes Atmospheric Hardware: Proc of 27th ICRC (posters)(2001), Lawrence Wiencke, Mike Roberts *et al.*

HiRes Public URL: <http://www.cosmic-ray.org/>