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First Stereo Results from the High Resolution Fly's Eye Air Fluorescence Detector

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Abstract

The second site of the High Resolution Fly's Eye air flourescence detector,known as HiRes2, located at Camel's Back Ridge in Dugway, Utah has been in operation since Spring 1999. Stereo observations of cosmic ray air showers have been made using the HiRes2 site in conjunction with the HiRes1site located at a distance of 13 km. Stereo observations enable the location of air showers to be more reliably determined using geometrical considerations. The determination of the energy of the primary cosmic ray particle and the depth of the shower maximum, which is useful for composition studies, are thereby improved. First results from the stereo observation of cosmic ray air showers using both detector sites will be described.

1 Introduction

The High Resolution Fly's Eye detector, HiRes, is an air flourescence detector designed to detect and measure the characteristics of cosmic ray particles with energies above 1 EeV (1 x10^{18} eV). The first generation Fly's Eye detector observed a cosmic ray particle whose energy was measured to be 320 EeV [1]. More recently, the AGASA air shower array has observed several events whose energies were above 60 EeV [2]. The observed energy spectrum of cosmic rays is expected to be cut off above 60 EeV. This cut-off in the energy spectrum, known as the GZK cut-off [3], would result if the sources of cosmic rays with energies above 60 EeV were 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-str., 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 should also be beneficial for searches for point sources of ultra high 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 [4] group in the 1980's. This technique uses the atmosphere as a calorimeter to measure the energy of the extensive air shower produced by the cosmic ray particle interacting with the Earth's atmosphere. As the secondary shower particles pass through the atmosphere they excite nitrogen atoms in the atmosphere which emit ulraviolet 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 energy of the cosmic ray can be determined by integrating this longitudinal shower curve if one knows the following:

1 Relationship between amount of UV fluorescence to energy deposition in atmosphere.
2 Light transmission characteristics of the atmosphere.
3 Absolute PMT Calibration.
4 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 KEK where the UV fluorescence yield of electrons propagating through air at various pressures was measured [5]. One must also understand the propagation of UV photons in the atmosphere. Atmospheric monitoring is a major concern at HiRes and will be described in other talks at this conference [6]. 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 [7]. 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 HiRes detector consists of 2 sites, known as HiRes1 and HiRes2, separated by approximately 13 km. The sites are located in the West Desert of Utah at the Dugway Proving Grounds. This location is ideal for the quality of the desert atmosphere. The 2 sites are located on hilltops approximately 500-700 feet above the valley floor. The HiRes1 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 [8]. The optical systems at both sites consist of spherical mirrors of $3.8m^2$ area. The light collected by these mirrors are focused onto clusters of 256 hexagonal photomultiplier tubes closed packed into 16 rows by 16 columns. Each tube views a 1 degree by 1 degree patch of sky. The HiRes1 site consists of 21 mirrors that view nearly the full 180 degree azimuthal range from 3 degrees to 17 degrees above the horizon. The Hires2 site consists of 42 mirrors that view about 80% of the 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 2 sites. The HiRes1 site uses a sample and hold technique that integrates the pulse from the PMT. The HiRes1 trigger is based upon coincidences of combinations of tubes whose signals exceeded a variable threshold. The electronics at the HiRes2 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 trigger for the FADC system is based upon the digitized information. The FADC electronics used at HiRes2 is described in another talk at this conference[9]. 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 2 sites can also be used in the geometrical reconstruction of the air shower.

3 Preliminary Results

At the time of writing this article, data was only available for an observation time of less than 100 hours with approximately 50% of the HiRes2 site operational. Problems concerning the GPS timing of the HiRes2 site have only been more recently rectified. Therefore the results reported on in this article are very preliminary and rather sparse. Nevertheless many major milestones have been reached at this early date:

1 As of Feb 3, 1999, the HiRes1 site has collected 1600+ hours of monocular data. Calibration techniques for the HiRes1 detector are now well established [7]. Preliminary results from this data set have been described elsewhere in this conference [8].

2 As of May 1, 1999 24 of the 42 mirrors at the HiRes2 site are fully operational and taking data. These 24 PMT clusters have been calibrated and balanced using a "roving xenon flasher" such that the output of the FADC system is calibrated in units photoelectrons [9]. 36 of the 42 PMT clusters are in the field and are in various stages of commissioning.

3 Software for event reconstruction of the HiRes2 detector and event matching with HiRes1 events well under development. Cosmic ray events have been observed in the partially completed HiRes2 site. Extensive use of radio-controlled xenon flashers distributed on the desert floor have enabled the synchronization of the 2 sites to be established.

At the time of writing this article, event matching between the 2 sites was verified through the use of the vertical flashers. These flasher produce vertical tracks of light in the volume of atmosphere between the 2 sites at known positions. By firing the various flashers in a sequence, individual flashes can be used to synchronize the 2 sites. The observed time differences for matched events from the HiRes1 and HiRes2 sites for several hours of data collection is shown in figure 1. The peaks correspond to the observation of tracks produced by vertical flashers [10]. The time differences are consistent with expected variations due to the various locations of the flashers on the desert floor

4 Summary and Conclusion

A program to reconstruct cosmic ray air showers viewed in stereo by the 2 sites of the High Resolution Fly's Eye detector is now underway. One of the first tasks in this program is to cross-check the monocular reconstruction techniques that have been applied to the 1600+ hours of monocular data collected by the HiRes1 site. At the time of writing this article these checks have not yet been completed. It is, however, likely that first results of these checks and others will be available at the time of the conference.

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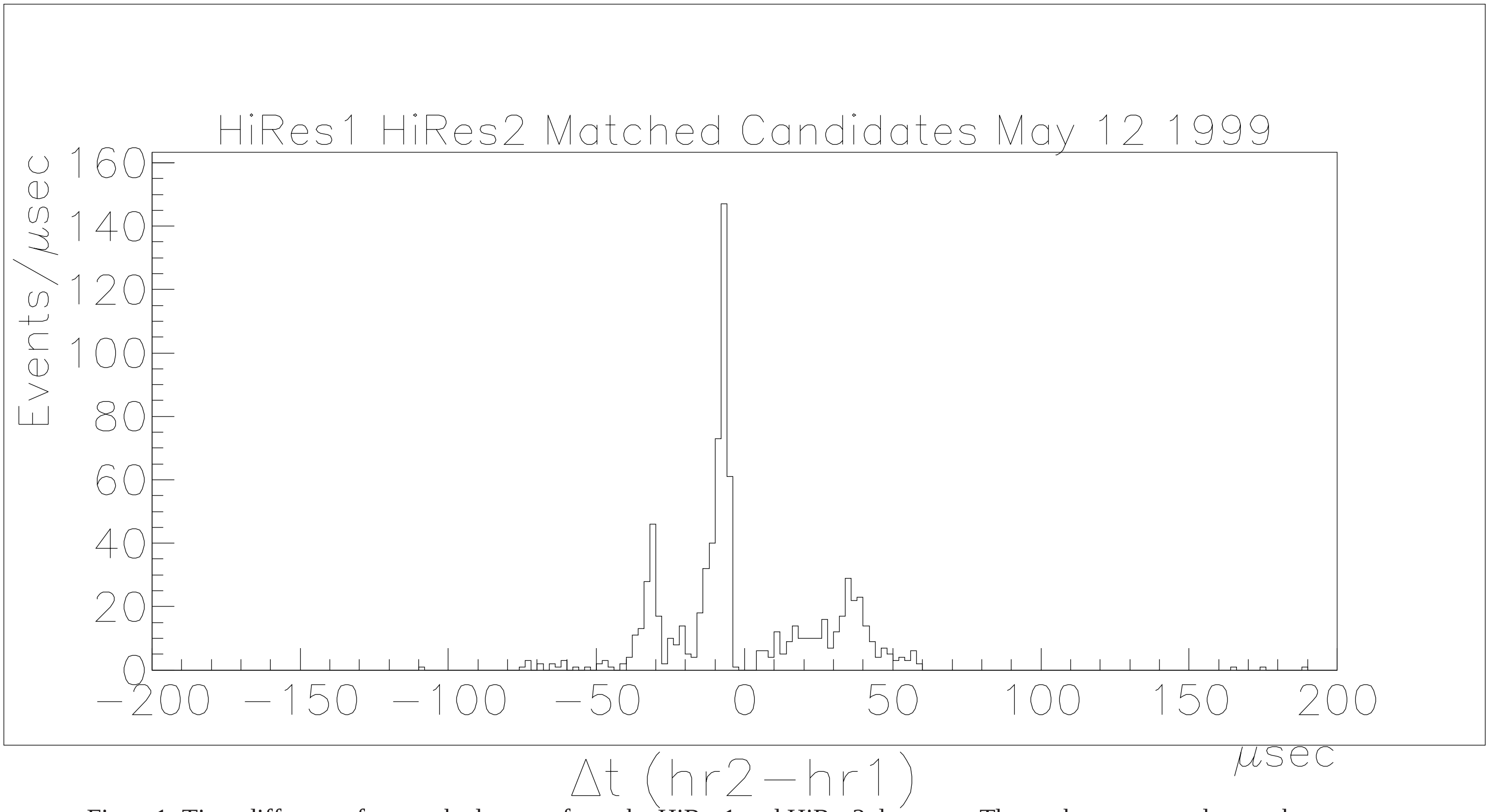

Figure1: Time difference for matched events from the HiRes1 and HiRes2 detectors. The peaks correspond to tracks produced by vertical flashers located at various positions between the 2 detector sites.

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