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Description of the High Resolution Fly's Eye Detector

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Abstract.
The High Resolution Fly's Eye experiment measures properties of the highest energy cosmic rays. The air fluorescence technique used in HiRes was previously demonstrated by the original Fly's Eye detector. The HiRes Observatory is the realization of the next stage of air fluorescence observation of ultra high energy cosmic rays. The observatory has been operating in various sub-configurations since spring of 1997. HiRes has been operating in its full design configuration utilizing two detector sites to provide stereoscopic observations since the fall of 1999. A brief description of the detectors as well as the techniques used to observe and measure ultra high energy cosmic ray showers are the subject of this paper.

1 The Technique

Above 10^{17} eV, the flux of cosmic ray particles is so low that direct detection of the primary particles becomes in-feasible. The traditional method to extend measurements into this region has been to observe Extensive Air Showers (EAS), produced in the Earth's atmosphere, by the primary cosmic ray particles. An Ultra High Energy Cosmic Ray (UHECR) collides with a nucleus (nitrogen or oxygen) in the atmosphere resulting in the formation of an EAS containing billions of secondary particles. The EAS is a cascade of charged particles that develops over 10's of km eventually becoming a pancake a few hundred meters wide and a few meters thick moving at nearly the speed of light.

As the EAS traverses the atmosphere, it excites air molecules. The molecules fall back into their ground state emitting light. The light is emitted almost exclusively from nitrogen molecules in the wavelength region from 300-400 nm. The amount of light emitted corresponds to roughly 4 - 5 photons per meter per ionizing particle. (Kakimoto 1996) There are such an enormous number of ionizing particles (billions at shower maximum) that even this low efficiency process yields measurable amounts of light. (Sokolsky 1989)

The HiRes Program dates back to Ken Greisen's first attempt to detect such signals at Cornell University in 1965. (Greisen 1960,P) However, the first successful coincidence detection of an EAS via air fluorescence and a ground array was not achieved until 1976 by a group at the University of Utah operating optical detectors in coincidence with the Volcano Ranch ground array (Bergeson 1970). This group went on to complete the original Fly's Eye experiment, utilizing the air fluorescence technique, which began to take data in 1981. (Cady 1983)

2 The Goals

The original Fly's Eye experiment published results indicating a) a lightening in the cosmic ray composition (from predominantly iron-like to predominantly proton-like) from 3×10^{17} eV to 10^{19} eV that is correlated with a hardening of the differential spectrum near 3×10^{18} eV (Bird 1985); b) a well measured event with an energy of 3.2×10^{20} eV, well beyond the expected GKZ cut-off energy (Bird 1995); and c) a weak anisotropy towards the galactic plane at energies $1 - 3 \times 10^{18}$ eV (Bird 1999). The goals of the HiRes experiment are based on the results of the original Fly's Eye experiment. These include: a) measurement of the UHECR energy spectrum, b) measurement of composition and arrival direction anisotropy, and c) search for neutrino flux and exotic particles.

3 The Observatories

The HiRes Observatories are located within the U.S. Army's Dugway Proving Ground, about two hours drive south-west of Salt Lake City, Utah. The experiment is comprised of two stations (HiRes-I and HiRes-II) separated by 12.6 km. HiRes-I, located at Little Granite Mountain, consists of 21 detector elements and has almost full azimuthal coverage

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Fig. 1. *Two detectors are housed in a single metal building. The large roll-up garage door opens for nocturnal observation. A door opened in daylight with the mirrors and clusters exposed is the researcher's worst nightmare.*

over a range of elevation angles from 3° to 17°. HiRes-II, located at Camel's Back Ridge, has two detector rings with nearly full azimuthal coverage. It is composed of 42 detectors and views elevation angles from 3° to 31°.

4 The Detectors

The detector elements are configured two to a building (figure 1), with each building about the size of a two car garage. Each detector element consists of a large spherical mirror, a 256 pixel photomultiplier (PMT) camera, and associated electronics. The spherical mirror is composed of four segments arranged in a clover-like pattern. The on-axis effective area of the mirror is ∼3.8 m^2 (taking into account the shadowing of the camera) and the radius of curvature is 474 cm. The spherical mirror collects fluorescence light from an EAS and focuses it onto the pixels of the camera.

The camera consists of a 16x16 rectangular array of hexagonal photo-multiplier tubes (figure 2). The apothem of each PMT is ∼40 mm and they are arranged in a 41.8 mm center-to-center honeycomb pattern. In this configuration each PMT views about 1° of sky and the camera (aka cluster) views a segment of sky about 16° in azimuth and 14° in elevation. Each PMT has an attached preamplifier that plugs into the back-plane of the cluster. Signal cables run from each cluster to a rack of electronics located in the same building.

At HiRes-I, the signals from the PMTs are processed by common-stop, sample and hold (S&H) system that integrates the observed light pulses over a 5.2 μs time window. The digitized PMT signal information includes the integrated area of the light pulse and the trigger time. HiRes-II, the newer of the two sites, uses Flash Analog to Digital Conversion (FADC) electronics. It continuously samples the signal in 100 ns time bins. This gives the advantage of a) more detailed observation of the signal shape, b) multiple samples of the signal as it crosses each PMT, and c) more precise timing information.

Fig. 2. *A 256 pixel HiRes-I PMT cluster. The reflection of the photographer can be seen in the ultraviolet filter that has been swung open to expose the PMTs. The UV filter would normally cover the PMTs to filter out all but the 300-400 nm fluorescence light from the EAS.*

At the HiRes-I site the resolution of the EAS development is limited to fixed 1° pixels. At the HiRes-II site the development of a distant EAS can be still be resolved into 100 ns (∼30 meter) bins. At both HiRes-I and HiRes-II, once a trigger is formed, the digitized event information is transferred from the individual clusters to a central facility at that site where the data is written to disk for offline processing and analysis.

An EAS initiated by a cosmic ray forms a track across the pixels of the camera face. The width of the EAS is typically a few hundred meters and it's distance is typically 10-30 km or greater. Thus, the tracks appear basically linear. The position of the detector and this line determine the shower-detector plane. Using timing information recorded at a single detector site, the full three dimensional EAS geometry can be reconstructed. However, the uncertainties can be large and difficult to determine. As shown in figure 3, using simultaneous observations of the same EAS from two physically separated detectors (stereo observation), the geometry of the EAS can be determined precisely simply by calculating the intersec-

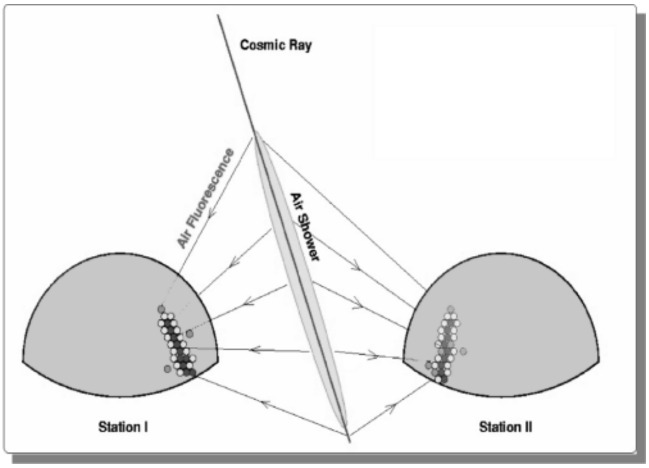

Fig. 3. *An EAS appears as a line of illuminated pixels (PMTs) at each detector site. The line of the pixels determines the plane containing the detector and the EAS. For stereo observations, the intersection of the shower-detector planes from the two sites fixes the three dimensional geometry of the EAS.*

tion of the two shower detector planes. The addition of precise timing information from both sites further constrains the EAS reconstruction. Simultaneous observations of the EAS also provides model independent checks of the reconstructed EAS parameter resolutions.

5 Calibration Equipment

Each site is equipped with a single 355 nm tripled YAG laser for the purpose of system wide detector calibration. The light from the laser is routed via quartz optical fibers to each of the detectors. Some fibers are used to directly illuminate the clusters for their calibration, and other fibers are used to illuminate the cluster via reflection off of the spherical mirror to monitor the mirrors' reflectivity. Additionally, a highly stable and portable light source, the Roving Xenon Flasher (RXF), is periodically taken from camera to camera, and even site-to-site to monitor the detector calibration. A basic description of the calibration systems, methods, and of the long term stability of HiRes is presented elsewhere in these proceedings (Matthews et al. 2001a).

6 Calibrating the Atmosphere

In the air fluorescence technique, the atmosphere is the calorimeter. Understanding it's optical properties is a critical calibration for HiRes. Although the molecular component of the atmosphere can be described by Rayleigh scattering and a small seasonal variation, effects of aerosols such as haze, ground fog, smoke, and clouds require a dedicated calibration effort. This calibration must be performed throughout the time the detector is collecting data because the distribution of aerosols in the aperture varies with time. Each site is instrumented with a steerable laser system (Wiencke et al. 1999b). Scattered light from these lasers is observed by the same HiRes detectors that measure light from air showers. The lasers produce light at 355 nm which is near the 351nm line of nitrogen fluorescence in air. The polarization, energy, direction, and firing times of these laser beams can be controlled remotely. These laser beams are the nearest approximation to a test beam and can be used to study the detector response to a known source of light. An array of xenon "flashers" (Wiencke et al. 1999a) located between the HiRes detectors also generates tracks similar to acctual events. Like the tracks from the lasers the profiles of these "flasher" tracks are are also sensitive to scattering and attenuation effects of atmospheric aerosols. Measurements from these systems are described in other proceedings of this conference (Roberts et al. 2001a), (Wiencke et al. 2001a).

7 Operations

The first HiRes site, HiRes-I began operations in June of 1997 and has accumulated about 2800 detector-hours of data with 2270 detector-hours being good weather data. The second HiRes site, HiRes-II began limited operations in August of 1999 and was in full operation by the end of that year. HiRes-II has accumulated about 1000 detector-hours of data. HiRes-I has observed 2880 events over 1EeV and there are now over 1000 candidate events observed in stereo.

8 Conclusions

The HiRes stereo instrument, consisting of the two HiRes detector sites, HiRes-I & II is essentially complete. Operations have stabilized and the emphasis of researchers within the collaboration is shifting from construction and debugging to refining the calibration and analysis of the data. As the statistics continue to improve we expect to produce a number of new results.

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