Stereo Spectrum of UHECR showers at the HiRes Detector

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Abstract

We present a measurement of the energy spectrum of UHECR showers. This measurement uses the two HiRes detector sites separated by 12.6 km to perform stereoscopic observations of UHECR air showers. The technique of stereoscopic reconstruction of the shower geometry and longitudinal profile is described. The resolution of reconstructed shower parameters using these techniques has been estimated using a detector simulation. Using the independently measured shower profiles from each detector site the energy resolution has also been measured. The detector aperture has been estimated by using the detector simulation. The energy distribution and resultant energy spectrum will be shown.

Introduction

A brief description of the background information describing the physics of UHECR as well as the air fluorescence technique can be found in the HiRes summary paper [3] submitted to this conference. A slightly more detailed description of the HiRes detector as well as references to the other papers submitted by the HiRes collaboration may also be found there. This article will focus on describing the techniques and benefits of the stereoscopic measurement.

Stereo Detector Requirements and Description

The stereoscopic HiRes detector needs to maintain a large aperture to have a sensitivity to fluxes at and beyond the GZK cutoff energy. The flux of particles at energies above $E_{GZK} = 6 \times 10^{19} eV$ is such that an aperture of approximately 10,000 km^2 steradian is required to either detect or rule out the existence of particles with energies in excess of the GZK cutoff. It should be noted that for lower energies, the stereoscopic aperture is less than the corresponding monocular aperture due to the requirement that the air shower be seen by both detectors. The aperture for stereoscopic reconstruction rapidly falls to zero for energies less than $10^{17.8}$ eV.

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Good energy resolution is required to ensure that poorly measured lower energy events do not mimic a "super-GZK" event. An additional benefit of good energy resolution is the possibility of observing "structure" in the cosmic ray spectrum. It is also necessary to correctly ascertain the absolute energy scale. To do this one must 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[6] [7].

The HiRes detector consists of two detector sites separated by 12.6 km. This separation allows the UHECR induced air showers to be viewed stereoscopically. A stereoscopic view of the shower simplifies the task of distance determination enormously by reducing the problem to one of geometry. The precision of the energy determination is thereby greatly improved by reducing the uncertainty in the distance to the air shower. The stereoscopic determination of the geometry also eliminates any need to make assumptions about the shower profile to help determine distance. The intrinsic energy resolution above 10^{18} eV for the HiRes stereo detector is better than 15% and improves with increasing energy. This energy resolution provides for a measurement of the spectral index with sufficient precision to observe structure in the spectrum.

Monte Carlo Simulation and Detector Aperture

A Monte Carlo simulation of UHECR air showers and the response of the HiRes detector has been developed and is described in more detail in another HiRes collaboration paper submitted to this conference [9]. A simulation of the charged particles of air showers that subsequently produce fluorescence UV photons as well as photons from Cerenkov light is performed. The photons that are produced from the air shower are propagated through the atmosphere to the optical system of the detector. A ray tracing procedure is used to simulate the optical elements of the detector. The Monte Carlo software also simulates the photomultiplier tubes as well as the detector electronics and trigger.

This Monte Carlo simulation software package has been used to develop the shower reconstruction software. The resolution of the measurement of shower parameters has been evaluated using this Monte Carlo software package. It is possible to vary the parameters that describe the atmosphere in this MC simulation. This feature of the MC simulation has allowed us to study the impact of the variability of the atmosphere on both the reconstruction of the UHECR shower parameters as well as the detector aperture. Resolution distributions will be shown at 2003 International Conference on Cosmic Rays. Distributions for observables such as those describing the shower geometry obtained from the Monte Carlo simulation have been compared to the corresponding distributions seen in the data. Generally good agreement has been observed. This good agreement between the MC simulation and the data gives confidence in the use of this MC simulation package to determine the detector aperture. The estimated aperture for stereo event reconstruction of the HiRes detector approaches 10,000 km^2 steradian for energies above the GZK cutoff. This aperture is approximately 10 times greater than the original Fly's Eye detector.

Reconstruction

The fundamental signal from the hires detector is the number of observed photoelectrons from individual photo-tubes. Shower detector planes are determined for each site using the individual tube directions and signals. The HiRes-I detector readout only provides the integrated number of photoelectrons for the event. The air shower profile is measured by binning these individual tube signals into angular bins. To use individual tubes as angular bins a detailed correction for the measurement of the air shower from that tube must be performed. This correction accounts for the acceptance of that tube for light produced by the air shower. Detailed knowledge of the tube locations and the shower detector plane is needed to determine these corrections. To reduce sensitivity to acceptance corrections we bin together several tubes into a larger angular bin. These angular-based binning reconstruction techniques can also be used on the HiRes-II data. The HiRes-II FADC based detector readout provides the number of photoelectrons for each 100 ns time slice. A time based binning technique is also used for reconstructing the shower using HiRes-II. In this technique, the direction to the air shower at that time is estimated by performing an amplitude weighted average of the tube directions. The amount of light arriving at the detector per time slice is measured by averaging the noise suppressed tube signals. Corrections associated with acceptance of the optical system for the time-based binning is typically smaller than the corrections for the angular based binning. The air shower parameters can be reconstructed by performing fits of these measured bin signals to simulated shower profiles using the shower geometry determined from the intersection of the two shower-detector planes.

Summary and Conclusion

The stereo detector has been operating stably since December 1999. As of April 1, 2003, we have collected approximately 1500 hours of stereo data. We continue to collect data. Results for the measurement of the UHECR energy spectrum from the stereoscopic analysis technique will be presented at the 2003 International Conference on Cosmic Rays.

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