

The High Resolution Fly's Eye Project

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Abstract

Two prototype stations of the High Resolution Fly's Eye (HiRes) detector are currently operational. The HiRes1 Prototype is currently measuring cosmic rays in coincidence with the HiRes 2, CASA/MIA, Fly's Eye 2, and DICE detectors. We describe the goals of the HiRes project, the expected detector resolution and the current operational status. The HiRes detector construction schedule is discussed.

1 Introduction

Measurements of the primary cosmic ray energy spectrum above 10^{17} eV by the Fly's Eye indicate the existence of steepening of the spectrum above $10^{17.6}$ eV, and a subsequent flattening above $10^{18.5}$ [1]. This fine structure is suggestive of a 'two-source' model of the cosmic ray origin in this energy region. The lower energy source is presumably due to a Galactic contribution from a rigidity-limited acceleration mechanism. The higher energy source may be an extragalactic source, which can contain only protons since heavier nuclei will be quickly photo dissociated through interactions with the universal 2.7' microwave background. The Fly's Eye experiment has recently observed a correlation between the energy spectrum structure and a change in the primary composition[2] over this energy region which supports this hypothesis.

In order to examine the validity of various proposed models of cosmic origin in this energy region, additional experimental information will be necessary. Specifically, the observed energy structure and primary composition correlation must be studied with better statistics to improve confidence in the previous results. The unambiguous measurement of a Greisen cutoff in the primary energy spectrum above 6×10^{19} eV would provide additional confidence in the extragalactic origin hypothesis for the highest energy cosmic rays.

Excellent energy and primary composition resolution will be needed to avoid experimental artifacts that could invalidate the results.

Recent measurement of three cosmic rays with primary energies above 100 EeV [3,4,5] have also provided serious challenges to canonical acceleration mechanisms. More events in this energy range are needed in order to provide sufficient experimental input for the theoretical discussion of possible acceleration processes.

Based upon these requirements, we have designed and are constructing a High Resolution Fly's Eye (HiRes) detector.

The HiRes detector uses a Nitrogen fluorescence technique to observe cosmic rays with energies above 5×10^{16} eV. The HiRes detector will

- Increase the data rate above 10 EeV by an order of magnitude from the present Fly's Eye to more than 200 events per year.
- Improve the depth of shower X_{\max} resolution to a mean of 15 to 20 g cm^{-2} from 90 g cm^{-2} for the monocular Fly's Eye and 45 g cm^{-2} for the Stereo Fly's Eye.
- Improve the angular resolution and acceptance in the EeV range to increase sensitivity to point sources.

2 Detector Description

The HiRes detector, located at the Dugway proving Grounds, USA, consists of two sites which provide stereo images of the atmospheric fluorescence light generated by extremely high energy extensive air showers. The two sites are located at the Dugway Proving Grounds, USA. The first site, HiRes1, is at the location of the original Fly's Eye detector (Five Mile Hill, $40^{\circ}9'55''$ latitude, $112^{\circ}50'9''$ W longitude, 1593 meters a.s.l.) The second site, HiRes2, is located at the Camel's back ridge location ($40^{\circ}7'55''$ latitude, $112^{\circ}57'32''$ W longitude, 1550 meters a.s.l.). The HiRes2 site is approximately 12.6 km to the west of the HiRes1 site.

We have chosen to divide the detector construction into two stages to maximize the physics output of the experiment. Stage 1 construction will deploy a total of 56 mirror detection units[6]. These will be distributed on both the Camel's back site and the Five Mile Hill site to maximize the stereo aperture for cosmic ray events. The completion of two independent detectors first (instead of one full site) allows observation of air showers in stereo provides the best energy resolution and depth of shower maximum resolution as well as measurement redundancy. The two-site configuration also allows collection of high quality data without having to wait for the completion of two full detectors at each site. After several years of cosmic ray observation with the Stage 1 detector, the optimal mirror locations and orientations will be determined for Stage 2 deployment, based in part on the observed cosmic ray energy spectrum.

Energy (EeV)	X_{\max} Resolution (g cm ⁻²)	Energy Resolution ÅE/E (%)	Aperture (km ² sr)
1.0	19.9	6.3	780
3.0	14.5	6.0	1950
10.0	14.7	6.5	3380
30.0	13.5	6.5	5060

Table 1: Calculated X_{\max} , Energy resolution, and Reconstructable triggering aperture for a two site, 28 mirror/site HiRes Stage 1 detector. The energy resolution neglects atmospheric fluctuations and fluctuations in the charged particle intensity of the EAS.

The mirrors at each site will be deployed to view the night sky at elevation angles between 3-43.5°. Each mirror detection unit consists of a 2.0 m diameter mirror, a 256 pixel cluster of photomultiplier tubes, and a data acquisition system. A UV bandpass filter in front of each photomultiplier tube cluster restricts the spectral sensitivity of the detector to the 300-400nm waveband. The data acquisition system uses a Flash ADC system which continuously records the signals from each photomultiplier tube pixel. The FADC system records a detailed time evolution of the signal and deep buffering can be provided to store all information until detailed computations determine what to keep permanently. The prompt conversion to digital information means that we can readily use the precise digital measurements in a flexible manner that allows modification of trigger, signal processing and diagnostic monitoring.

3 Expected Performance

Monte Carlo simulations, based upon our experience with the Fly's Eye and HiRes prototype detectors, have been used to estimate the Stage 1 detector energy and X_{\max} resolution, and the reconstructable detection aperture. Table 1 lists the expected X_{\max} and energy resolution as a function of energy for a typical Stage 1 detector deployment. Here we assume an equal number of mirrors are located at each HiRes site. This table also lists the expected reconstructable detection aperture (neglecting on-time efficiency). The Stage 1 deployment should provide 70% of the desired stereo aperture for the full HiRes detector, with excellent directional, energy and X_{\max} resolution.

4 Construction Schedule

At the present time, a 14 mirror prototype of the HiRes detector has been operational at the HiRes1 site since March 1993. This detector overlooks the volume of atmosphere above the CASA/MIA extensive air shower array[7] the Fly's Eye 2 detector, and the DICE imaging Cerenkov detectors[8]. Extensive air showers observed in coincidence with these detectors[9,10] are currently under study to examine the energy and primary composition spectrum just above the knee the spectrum. It is anticipated that these coincident measurements will overlap with the DICE composition /spectrum measurement at the

lower energy end, and the HiRes Fly's Eye measurements at the energy end, giving a continuous, intercalibrated spectrum measurement extending from below 100 TeV up to over 100 EeV.

A 4 mirror prototype has also been constructed at the Hires2 site. This prototype has been operational since September 1994, and is being used to study the stereo reconstruction of showers for the full Hires detector[11].

A LIDAR system has been constructed at the Fly's Eye 2 detector to monitor atmospheric conditions[12]. The pulsed light beam is simultaneously visible by both prototype HiRes sites, and is currently being used to study the stereo reconstruction resolution.

The present plan for Stage 1 HiRes construction is to add 24 mirror detection units to the existing 4 mirrors at the HiRes2 by the end of 1996. Stage 1 will be completed by the end of 1998, deploying additional 14 mirrors detection units among the two sites. At that time, the final Stage 1 detector will provide more than an order of magnitude increase in aperture for stereo reconstruction over the original Fly's Eye detector.

Acknowledgements

We are indebted to Colonel Eugene Fuzy and the staff of the U.S. Army Dugway Proving Grounds for their continued cooperation and assistance. It is also a pleasure to acknowledge the support of the technical staffs at our home institutions. This work is funded by NSF Grants PHY 93-22298, PHY 93-21949, PHY 9115987, and the Australian Research Council.

References

- [1] Bird, D.J. *et al.*, *Astrophys. J.* 424 (1994) 497.
- [2] Bird, D.J. *et al.*, *Phys. Rev. Letters* 71, 3401 (1993).
- [3] Bird, D.J. *et al.*, *Astrophys. J.* 441 (1995) 144.
- [4] Hayashida, N. *et al.*, *Phys. Rev. Lett.* 73 (1994) 3491.
- [5] Efimov, N. *et al.*, in: *Proc. Intl. Wrkshp. on Astrophysical Aspects of the Most Energetic Cosmic Rays*, Kofu, Japan (World Scientific, Singapore, 1991) 20.
- [6] Clay, R. W. *et al.*, *Staged Construction Proposal for the High Resolution Fly's Eye (HiRes) Detector*, NSF Proposal (1993).
- [7] Borione, A. *et al.*, *Nucl. Inst. Meth.* **A346**, 349 (1994).
- [8] Boothby, K. *et al.*, *A Dual Imaging Cerenkov Experiment (DICE for Examining Primary Composition near the Knee of the All Particle Spectrum*, **OG 10**, *ibid.*
- [9] Bird, D. J. *et al.*, *Multi-Component Observations of 101 eV EAS with the CASA-MIA and HiRes Detectors*, **OG 6**, this conference.
- [10] Bird, D. J. *et al.*, *Cosmic Rays Shower Maximum in the 0.01 to 1 EeV Region -Results from HiRes/FE2 Coincident Data*, **OG 6**, *ibid.*
- [11] Bird, D. J. *et al.*, *The HiRes2 Prototype and Coincident Measurements with HiRes1*, **OG 6**, *ibid.*
- [12] Bird, D. J. *et al.*, *Monitoring Atmospheric Extinction for Air Fluorescence Experiments*, **OG 10**, *ibid.*