Ultra High Energy Cosmic Rays in the North

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Abstract—**The High Resolution Fly's Eye (HiRes) observatory has been collecting Ultra High Energy Cosmic Ray (UHECR) data since 1997. The experiment observes cosmic ray air showers via the air fluorescence technique and consists of two observatory sites separated by 12.6 km in the western Utah desert. The two stations can each measure the cosmic rays in monocular mode. In addition, the data from the two stations can also be combined to form a stereo measurement of the air showers. The experiment measures such properties as the energy spectrum, chemical composition, and proton-air cross-section of these cosmic rays. It also searches for point sources and other anisotropy. The spectrum is measured above ~3×10^{17} eV and shows significant structure including the "ankle" and a steep fall off which is consistent with the expectation of the GZK threshold. The spectrum is inconsistent with a continuing spectrum at the 5σ level. The composition is measured using the X_{max} technique. It was found to be predominantly light and unchanging over the range from 10^{18} to 3×10^{19} eV. Finally, several different styles of searches for anisotropy in the data were performed. There are some tantalizing hints including potential correlation with BL Lac objects and the "AGASA triplet'", however these will need to be confirmed with an independent data set.**

I. Introduction

The High Resolution Fly's Eye (HiRes) Experiment was constructed, in stages, between 1994-1999 at the U.S. Army Dugway Proving Ground (DPG) in the West Desert of Utah, with funding from the US National Science Foundation (NSF). The HiRes observatory was operated between 1997-2006. The experiment was optimized to study the energy spectrum, arrival anisotropy and the composition of Ultra High Energy Cosmic Rays with energies above $10^{18.5}$ eV. The detector system was divided into two sites with a 12.6 km separation and was designed to measure fluorescence light from cosmic ray extensive air showers on clear, moonless nights[1, 2].

The HiRes experiment ceased routine observations at the end of the March-April run of 2006. All of the HiRes mirrors and PMT clusters will be redeployed to the Telescope Array (TA) Project[3, 4], which is jointly funded by the U.S. NSF, the governments of Japan, South Korea, The State of Utah, and the University of Utah. The Telescope Array Project will begin data collection in 2007.

II. HiRes Results

At the cessation of routine observation in April 2006, the HiRes-1 detector had accumulated 5839 hours of monocular data. In addition, HiRes-2 had collected 4205 hours of data in monocular mode and a total of 3737 hours of data observations were in full stereo. While there is significant overlap, these three data sets have all been analyzed independently.

With its three year head start in data collection operations, the HiRes-1 monocular data has the largest exposure and provides the best statistical power. The HiRes-2 monocular data, with its greater span of zenith angle observations, has the lowest energy reach of the three sets, allowing for reliable event reconstruction down to $10^{17.2}$ eV. The stereo data provides the most precise measurement of all aspects of individual air-showers.

The physics topics for the HiRes data analysis are divided into five major areas: (1) Energy Spectrum, (2) Anisotropy, (3) Composition, and (4) Search for exotics. A significant number of publications have already resulted from on-going analysis on the UHE cosmic ray spectrum, on large- and small-scale anisotropy, and on cosmic ray composition. We will discuss the individual topics in the following subsections.

A. UHE Cosmic Ray Energy Spectrum

HiRes has published three papers based on the combined monocular spectrum[5-7], which include HiRes-1 data through March, 2003 and HiRes-2 data up to Sept. of 2001. Figure 1 shows the most recent UHE cosmic ray spectrum obtained from the HiRes-1 and HiRes-2 monocular data. The solid lines show the result of a three-power-law fit with two floating breaks. This *tri-linear* fit gives an excellent χ^2 of 34.7 over 37 degrees of freedom[8]. The breaks in the spectrum are found at $10^{18.46}$ eV (ankle) and at $10^{19.75}$ eV (GZK threshold). The latter, representing a change in spectral index from 2.88 to 5.1, occurs at an energy that is consistent with the expected GZK suppression[9, 10]. In comparison, a *bi-linear* fit with one floating break yields χ^2/ d.o.f.=59.3/36, and a linear fit to a single unbroken power law gives χ^2/ d.o.f.=162/39[8].

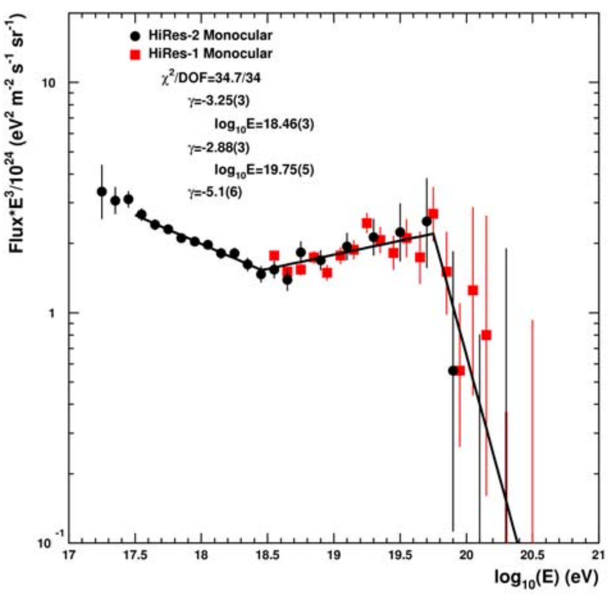

Figure 1: The UHE cosmic ray spectrum obtained from the HiRes-1 and HiRes-2 monocular data. The solid lines show the result of a three-power-law fit with two floating breaks. As seen in the plot, this *tri-linear* fit gives a good χ^2 of 34.7 over 37 degrees of freedom. The breaks in the spectrum are found at $10^{18.46}$ and $10^{19.75}$ eV. The latter, which represents a change in spectral index from 2.88 to 5.1, occurs at an energy which is consistent with the expected GZK suppression.

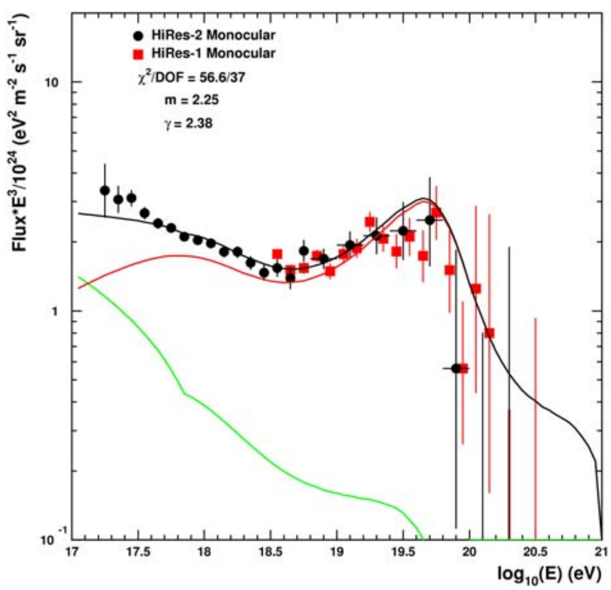

Figure 2: Fit of the HiRes UHECR spectrum to a simple two-component model. The first component (red line) consists of extra-galactic cosmic rays of light (proton) composition with age/distance evolution of $(1+z)^m$ and a universal injection spectral index γ. Both m and γ are free parameters of the fit. The second, heavier (Fe) galactic component (shown in green) is required to fit the spectrum below $\sim 10^{18}$ eV. The overall fit is shown by the solid black curve.

In addition to probing the trans-GZK region, our measurement of the shape of the spectrum in the energy range covered by the HiRes monocular data ($\sim 10^{17.5}$-$10^{20.5}$ eV) also contains information on the distribution of the sources of UHE cosmic rays. Figure 2 shows a fit of the HiRes spectrum to a simple two-component model (update to similar plot in reference [7]). While the fit appears to give a good account of the overall shape of the measured spectrum, this simple model predicts more GZK pile-up (spectral hardening at $>10^{19}$ eV) than is observed. A possible explanation of this may be that the model uses a universal upper injection energy limit of 10^{21} eV, whereas the end of the injection spectrum might vary from source to source. Collaborative work is on-going between HiRes and a number of theorists to explore these possibilities.

Figure 3 shows a preliminary HiRes stereo spectrum[11], where only very loose cuts have been applied. As can be seen in the overlay, both the shape and normalization of this spectrum are clearly in agreement with that of the monocular result. In addition, the stereo spectrum is clearly consistent with the monocular results in the paucity of events above the GZK threshold.

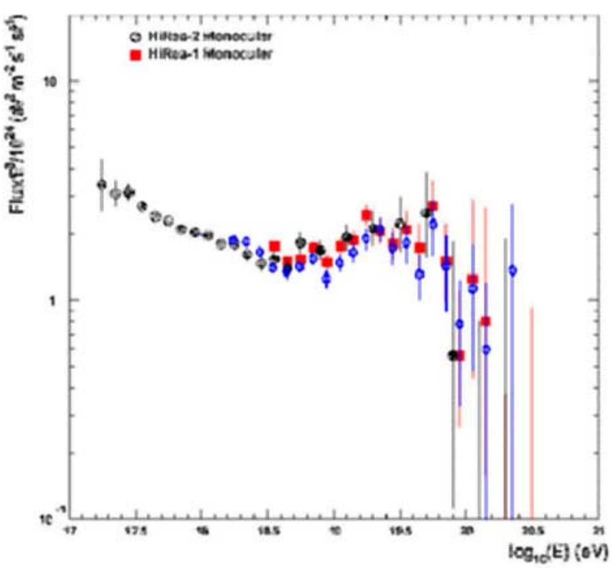

Figure 3: Preliminary HiRes stereo spectrum (with loose cuts), shown in blue circles, overlaid with the HiRes-1 and -2 monocular spectra.

As noted above, the ankle structure seen in the monocular spectrum, in addition to the observation of the GZK suppression, is also an indication of a predominant protonic composition. Some theorists, such as Berezinskii[12], have suggested the occurrence of a “dip” structure to be a more robust indicator of protonic composition than the GZK suppression. It is therefore very important for HiRes to try to extend the spectrum to the lowest energy possible. However, due to the limited stereo overlap of the apertures of the two detector sites for showers below 3×10^{18} eV, the systematic uncertainties in the stereo aperture calculation are expected to be large in this region. This is one of the primary motivations for the Telescope Array Low-Energy extension (TALE) of the TA Project which will be discussed in more detail below.

B. UHE Cosmic Ray Composition and Particle Physics

A fluorescence detector like HiRes is unique in having the capability to measure the longitudinal development of air showers. The distribution of X_{MAX}, the slant depth of the shower maximum, contains a wealth of statistical information on the composition of the parent nuclei in the case of hadronic showers. The basic underlying physics is that a larger nucleus, such as iron, suffers its first collision higher up in the atmosphere, which also results in larger multiplicity in the product particles than a lighter nucleus such as a proton. Both effects contribute to earlier shower development in heavier nuclei leading to a significantly shallower average shower maximum (i.e. smaller $< X_{MAX} >$ values) than a lighter nucleus of the same energy. The evolution of the measured $< X_{MAX} >$ values with energy thus constitutes the simplest observable related to the composition of the primary cosmic ray.

Figure 4 shows the published HiRes result for the development of $< X_{MAX} >$ values vs. energy (elongation) in the range $10^{18.0}$-$10^{19.4}$ eV[14], measured from the stereo data. The predictions for QGSJet[15] and SIBYLL[16, 17] protons and iron are shown for comparison. In the energy region covered by the HiRes data, ~10^{18} to $3\text{x}10^{19}$ eV, the elongation rate is 54.5 ± 6.5(stat) $\pm$ 4.5(sys) gm/cm^2 per decade in energy. This is significantly different from the measurement of the HiRes Prototype/MIA (stars in the plot) in the energy range just below this - 10^{17} to 10^{18} eV. There, the elongation rate was found to be 93.0 ± 8.5(stat) $\pm$ 10.5(sys) gm/cm^2 per decade in energy. The uncertainties in both measurements are significantly smaller than the proton-iron separation and the two measurements are in good agreement in the range where they do overlap.

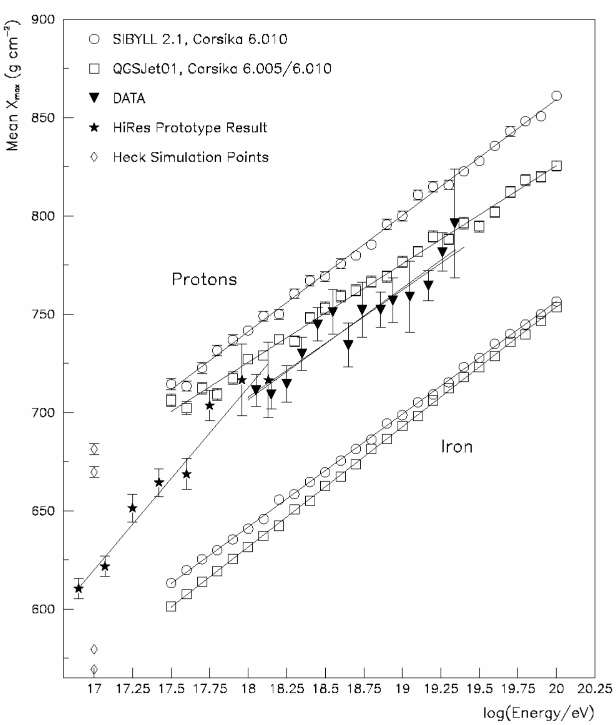

Figure 4: The HiRes measurement of <XMAX> in the energy range of $10^{18.0}$-$10^{19.4}$ eV, shown as inverted triangles. The predictions for QGSJet and SIBYLL protons and iron are shown for comparison. The stars show the HiRes Prototype result. The diamonds show simulation points calculated by Heck[13].

The HiRes/MIA measurements have a significantly different slope from either constant composition model. This implies that the composition starts out heavy and transitions to light in the decade between 10^{17} and 10^{18} eV. Based on comparisons with the models, the current HiRes results indicate a predominantly light composition from 10^{18} eV to the upper limit of this study. A quick study of additional events collected beyond this data set indicates that the elongation rate remains constant and that composition remains light at least up to the GZK threshold.

Note that the change is complete by about 10^{18} eV, well below the “ankle” in the energy spectrum. The inference of proton predominance in Figure 4 is also supported by the measured fluctuations in the X_{MAX} distributions as well as by the observation of the “ankle” and the GZK suppression in the HiRes data.

An alternate observable, which is less model-dependent than $<X_{MAX}>$, is the shape of the X_{MAX} distribution. Because of its longer interaction length and lower particle multiplicity from the first collision, lighter nuclei like protons are subject to greater fluctuations which results in broader X_{MAX} distributions than heavy nuclei. We have been studying, in simulation, the feasibility of a maximum likelihood method of measuring the cosmic ray composition based on the shape of the measured X_{MAX} distribution. The result of this study, summarized in a recent publication[18], shows that this technique can be applied reliably to measure the fractional composition of a mixture of protons and iron with meaningful uncertainty estimates. The application of this technique to HiRes stereo data is in progress. A publication is expected from this work in the summer of 2007.

In a second X_{MAX}-based analysis, we used the trailing tail of the measured X_{MAX} distribution to extract the inelastic proton-air collision cross-section. For this study, a new de-convolution technique was developed which fits the tail of the measured X_{MAX} distribution using the proton interaction depth, $\lambda_{p\text{-}air}$ as a parameter. Previous measurements, such as the one published by the original Fly’s Eye experiment[19], makes linear regression fit for the logarithmic slope Λ of the X_{MAX} distribution itself and extracts $\lambda_{p\text{-}air}$ using a multiplicative k factor ($\Lambda = k\lambda_{p\text{-}air}$) determined from shower and detector simulations. The k factor turned out to be extremely sensitive to the modeling of the hadronic interactions. Simulation studies with QGSJet and Sybyll-2.have shown that this method is able to accurately reproduce input values of $\lambda_{p\text{-}air}$, independent both of the hadronic interaction model and of energy.

The result of the de-convolution analysis applied to the HiRes stereo data (up to Jan. 2004) is shown in Figure 5. The best-fit value of $\lambda_{p\text{-}air} = 52.7 \pm 2.0$ g/cm^2 was obtained which gives a value of $\sigma_{p\text{-}air}(\text{inel}) = 456 \pm 17(\text{stat}) + 39(\text{sys}) - 11(\text{sys})$ mb (at $10^{18.5}$ eV) for the proton-air cross section[20]. The

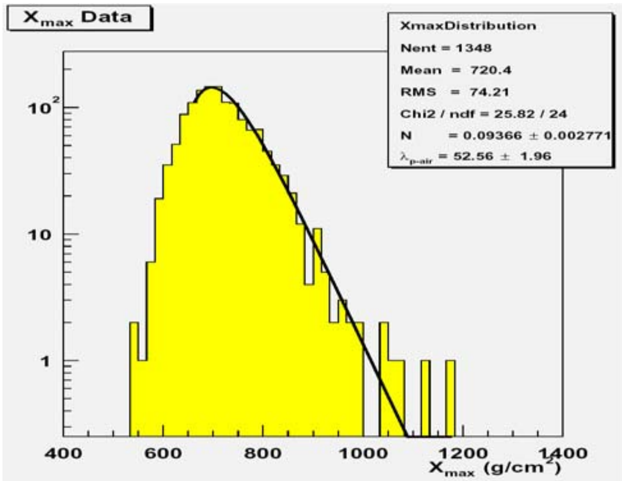

Figure 5: Histogram showing the measured X_{MAX} distribution and the result of the de-convolution to the exponential tail, which resulted in a measured value of $\lambda_{p\text{-}air}$ = 52.7±2.0 g/cm^2.

dominant contributions to the overall systematic errors were the uncertainties in the mirror pointing direction and the uncertainty in the fraction of photon contamination in the dataset. Using the Glauber Method[21], this cross-section was translated to a proton-proton cross-section, which is shown in Figure 6[22]. The figure also shows accelerator-based pp and $p\bar{p}$ data selected by M. Block and fitted to a parametric model[23, 24]. The extrapolation of this model gives a prediction that lies within the error bars of the HiRes result. The figure also shows the results from the Fly's Eye experiment [25]and the old Akeno Array[26], renormalized with a k-factor of 1.33 obtained from CORSIKA[27] simulations (using both QGSJet and Sibyll).

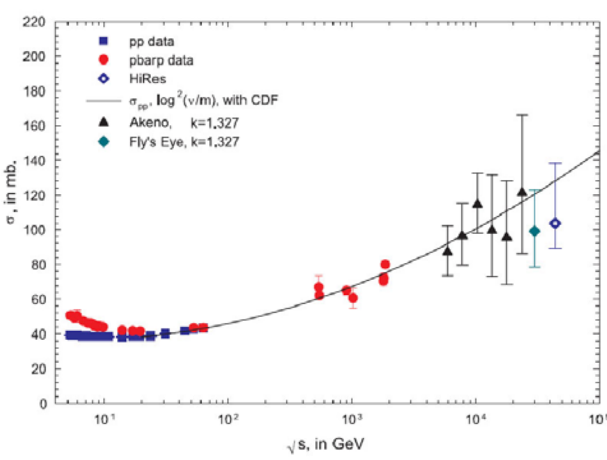

Figure 6: The measured inelastic cross section $\sigma_{p\text{-}air}$(inel) = 456 ± 17(stat) + 39(sys) − 11(sys) mb (at $10^{18.5}$ eV) converted, using Glauber Theory to a proton-proton cross-section. The HiRes data point is shown with an extrapolation of lower-energy pp data, which gives a prediction that lies within the error bars of the HiRes result. Also shown are the Fly's Eye and Akeno results re-normalized using a *k* factor of 1.32 obtained from CORSIKA simulations (with QGSJet and Sibyll); previously *k* factor values of 1.6-1.8 were used in the original publications.

C. UHE Cosmic Ray Anisotropy

A third major analysis topic is the search for large- and small-scale anisotropy. HiRes results have already been published for both large- and small-scale searches using the HiRes-1 monocular data. For these papers we used the early HiRes-1 monocular data set on which the Physical Review Letter monocular spectrum was based [5]. We developed a statistical sampling technique in order to account for the elongated, asymmetric error ellipses of monocular events. We reported null results in the search for dipole-enhancement where upper limits for the dipole amplitude, $|\alpha|$ (the dipole distribution is assumed to follow the form $1+\alpha\cos\theta$) is at the ~0.05 level[28]. We also reported a null result in an autocorrelation study [29], where the histogram of the cosine densities between pairs of events (using the sampling technique) showed no significant excess at small angles. In the autocorrelation study we also repeated the same analysis with AGASA data, both with AGASA errors and simulated HiRes-like errors; in both cases we were able to reproduce the enhancement seen by AGASA[30, 31], thus demonstrating comparable sensitivity for the two experiments. A search for point sources based on the same data set has been completed and has been submitted for publication[32]. No point sources were found and upper limits were set on the flux of cosmic rays from point sources as a function of position in the sky.

Anisotropy studies were also performed using the HiRes stereo dataset, which has better than 0.6° resolution for the arrival direction of the primary cosmic rays. An initial study showed the stereo events above 10^{19} eV to be consistent with isotropy at all small angular scales[33, 34]. A joint search for point sources with AGASA data showed one HiRes stereo

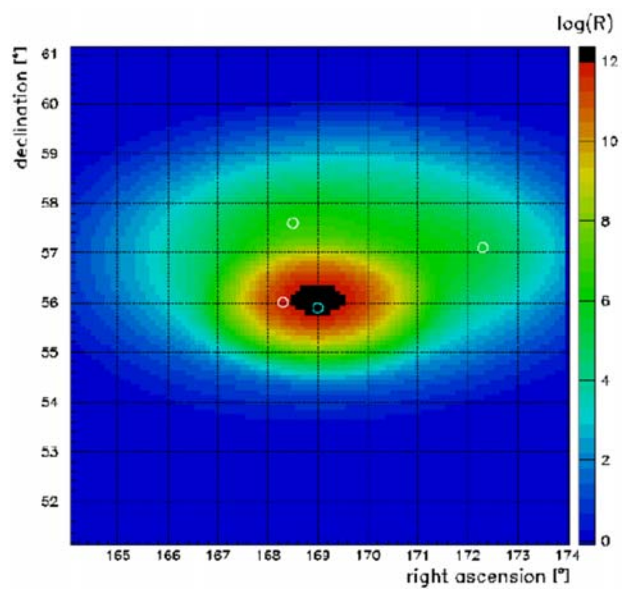

Figure 7: Sky-map, in the vicinity of the AGASA triplet, of the Relative likelihood ratio for the location of a point source that would give the both the AGASA triplet and the one HiRes event. Because of its smaller uncertainty, the point nearest the centroid of the distribution is the HiRes event.

event in coincidence with the AGASA triplet[33, 34]. This result is shown in Figure 7, which plots the relative likelihood ratio for the location of a point source that would give the both the AGASA triplet and the one HiRes event. However, a simulation study using 10^4 random, isotropic HiRes datasets with identical statistics yielded 47 sets which gave a coincidence with greater significance, consistent with a ~2.5σ fluctuation. Moreover, this chance probability of $\sim 5\times10^{-3}$ does not take into consideration the statistical penalty associated with the *a posteriori* nature of the AGASA cuts, which would further weaken the significance of the observed overlap.

A possible correlation between HiRes stereo events and BL-Lacertae (BL-Lac) objects was first reported by Gorbunov *et al*[35]. Using a binned analysis, they compared the positions of HiRes stereo events above 10^{19} eV , extracted from previous HiRes publications[33], to those of the 156 “BL” objects in the Veron Catalog[36]. They found 11 HiRes events to lie within 0.8° of a “BL” object, with a chance probability estimated at $\sim 10^{-3}$. An independent analysis by the HiRes group using an un-binned maximum-likelihood method reproduced the apparent correlation with a chance probability of $\sim 10^{-4}$[37].

Anisotropy work has also begun on the HiRes-2 monocular data. Because of the low energy reach (down to $\sim 10^{17}$ eV) of this data set, it has the advantage of having the highest statistics. We have concentrated in searching for enhancements associated with the Galactic and Super-Galactic planes. Thus far, no significant excesses have been found. We have been unable to reproduce the enhancement toward the Galactic Center reported by AGASA, but it should be noted that the HiRes exposure in that direction is limited. We do, however, see a small deficit, as did AGASA, toward the Galactic Anti-Center. This represents the most significant feature in the HiRes-2 monocular sky-map. The chance similarity between the two distributions (HiRes-2 monocular and AGASA) is estimated at the $\sim 10^{-3}$ level.

III. The Telescope Array (TA)

After the completion of HiRes analysis, the primary project for the Utah cosmic ray group will be the Telescope Array (TA) Project[3, 4]. The TA is an international collaboration involving research and educational institutions from Japan, U.S., China, Taiwan, and South Korea.

The main goal of TA is to study the sources of UHE cosmic rays by measuring their characteristics (spectrum, composition, and anisotropy). The experiment is designed to cover a wide energy range ($10^{16.5}$-$10^{20.5}$ eV), with a large (relatively flat) aperture, good resolution, and good control of systematic uncertainties. The physics issues (what is the nature of the sources? and how do they accelerate particles to such high energies?) are among the most important questions in physics today, as identified by the Turner Panel[38].

The TA Project is located in Millard County, Utah, near the city of Delta. The location and layout of the TA site is shown in Figure 8 The overall observatory will consist of a ground array of 576 scintillation counters, whose locations are indicated by the blue diamonds. The ground array is accompanied by three exterior fluorescence stations, each with a field of view that covers 3°-31° in elevation, and 108° in azimuth. These are shown by the three squares in. The southeastern station is located at Black Rock Mesa and designated TA-1. The southwestern station is sited at Long Ridge and designated TA-2. The northern station sits on Middle Drum Hill and is designated TA-3. The azimuthal range of each station is centered on the Central Laser Facility (CLF), which is shown by the cross in the interior of the

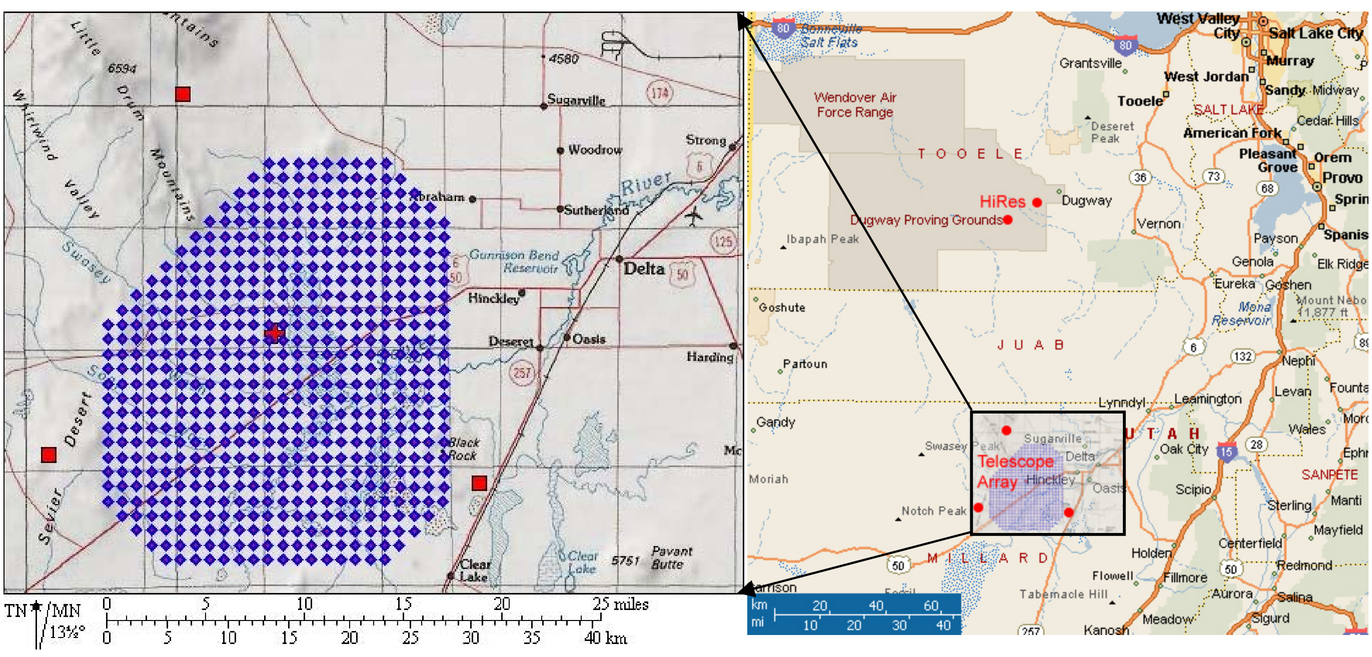

Figure 8: Map of the Telescope Array site showing the locations of the three exterior fluorescence stations (squares), the central laser facility (cross), and the positions of the scintillation counters (diamonds). The panel on the right shows the scale of the site in the context of a roadmap of north-central Utah, in which the two HiRes sites are indicated as circles.

ground array. This combination of detectors is designed to measure cosmic rays above 10^{19}eV in hybrid mode, and with the fluorescence detectors or ground array alone.

A. Telescope Array Detector

One of the 50 ground array stations already deployed in Millard County is shown in the photograph of Figure 9. Each station consists of two layers of 1.0cm thick plastic scintillators covering 3.0 m^2 in area. Light collection is accomplished using wavelength-shifting optical fibers that are embedded in extruded grooves on the surface of the plastic. Both ends of the fibers from each layer are glued together and coupled to a PMT. The use of the fibers gives good readout uniformity. The two layers give redundant coincidence signals from charged particles.

Each ground array station is powered by a 240W solar power panel (shown in the rear of Figure 9) with deep cycle batteries. To minimize the impact on plant and animal life, the counters sit on an elevated frame, and are lifted into place by helicopters during deployment. The analog signal from each PMT is digitized by a 50MHz, 12-bit Flash analog-to-digital converter (FADC). Each counter is set to trigger at a signal equivalent to 1/3 Minimum Ionizing Particle (MIP), and coincidence triggers (within 10 μs) involving at least three adjacent counters constitute an event trigger initiating a readout of the ground array. Each ground array station is also equipped with a GPS clock and a communication system. Four communications towers are used to relay control signals and data between the central facility at Black Rock Mesa and the individual counters.

The first of the TA fluorescence stations, located at Black Rock Mesa, is shown in Figure 10. Each building is equipped with three garage-style doors which open on clear, moonless nights to permit observations by the mirrors. A total of 12 mirror units are deployed in each building. An identical building is already located on the TA-2 site and construction recently began at the Middle Drum, TA-3, site.

Figure 9: One of 50 TA ground array stations deployed in Millard County.

Figure 10: The fluorescence detector housing at Black Rock Mesa. A pick-up truck near the bottom left of the photograph serves to set the scale of the building.

The TA mirrors are 3m in diameter and are subdivided into 18 segments. These have an effective collection area that is about 50% larger than the HiRes mirrors. Like the HiRes telescopes, each is instrumented with a cluster of 16×16 PMTs in a hexagonal close pack geometry. Also like HiRes each PMT views a 1.1° cone of the sky. The newer cameras, however, are instrumented with 4" PMT pixels. The new mirrors are physically placed in two stories, with those viewing the lower elevations placed in the upper layer. A prototype PMT cluster, mirror, and support structures are shown in Figure 11. The TA-3 site at Middle Drum will be instrumented with 14 reconditioned 2m diameter mirrors, and 16×16 clusters of 2" PMT clusters reclaimed from the HiRes experiment. The HiRes PMT's have a 1.0° field-of-view.

The readout electronics for the TA-1 and TA-2 fluorescence detectors are similar in concept to those of the HiRes systems. Each PMT channel is digitized by a 14-bit, 10MHz FADC

Figure 11: Upper Left: prototype 16×16 4" PMT cluster for TA. Lower Left: Prototype of 18-segment, 3m diameter TA mirror. Right: Two-story TA mirror support structure showing one fully mounted mirror in the lower layer and empty brackets for the PMT clusters.

system. This sampling rate is identical to that used by the HiRes-2 detector. The mirror trigger module (the so called Track-Finder, or TF module) uses a coincidence pattern search similar to that used at HiRes-1.

B. Low Energy Extension: TALE

Two additional fluorescence sites will be constructed at about ~6km from the TA-1 and TA-2 sites. These sites, together with an additional infill ground array, will extend the low energy reach of TA down to $10^{16.5}$ eV. These two TA Low Energy-extension (TALE) sites are designated TALE-1 and TALE-2. Their locations are shown in the left panel of Figure 12.

The two TALE sites will be instrumented with reconditioned HiRes mirrors, PMT clusters, and electronics. The layout of the TALE-1 and TALE-2 sites are shown in the right and middle panels of Figure 12, respectively. The unshaded mirrors in these panels have a FOV from 3°-31°, identical to the HiRes-2 configuration. Their azimuthal placements are designed to provide optimal stereo overlap with the TA fluorescence stations at Black Rock Mesa and Long Ridge, with the goal of extending the total stereo fluorescence aperture at 10^{18} eV by a factor of 10 over that of HiRes.

In addition, 15 new mirrors of 3.5m diameter will be constructed and placed at the TALE-1 to form a new "tower" detector. These mirrors, shown in shade on the right panel of Figure 12, will view events from elevation angles of 31°-73°. Coupled with an infill ground array (~400m spacing), the tower detector will provide hybrid detection of air UHECR showers down to an energy threshold of $\sim 10^{16.5}$ eV, with the goal of increasing the hybrid aperture at $\sim 10^{17}$eV by an order of magnitude over that of the HiRes-MIA experiment (see, for example, [39]).

C. The Physics of TA

The TA experiment will make excellent measurements of spectrum, composition, and anisotropy at the highest energies. In a five-year run TA will observe the GZK cutoff at the 7σ level, and accumulate very significant statistics in the "clear window" region below. The presence of the GZK cutoff means that all experiments, proposed, building, or running, will not be able to do much above 10^{20} eV. The TA will measure the composition up to this energy, and will perform anisotropy searches at the highest energies much better than HiRes or AGASA could.

TA, because of its hybrid nature which makes use of both HiRes fluorescence detectors and AGASA-like scintillators, is perfectly positioned to resolve the difference between HiRes[5-7] and AGASA results[40, 41]. While an energy scale shift has been proposed to explain the normalization difference in spectra[42, 43], the true cause of the difference may be a result of resolution, not energy scale. Recent re-analysis of AGASA events using hadronic models instead of fits to data shows that assumptions about the attenuation of EAS in the atmosphere can affect the energy scale of surface detectors significantly, and non-linearly[44]. However, there is no reason to believe that the specific hadronic models used to simulate this new attenuation represent reality either. What is clear is that the energy determination by AGASA has larger systematic errors than initially thought. TA will resolve these issues by direct, event by event comparison with air fluorescence measurements.

Note that the Auger experiment, because it uses water as a detection medium, is much more sensitive to the muon content of EAS and hence their hybrid measurement addresses a very different problem in understanding systematics. They have shown that shower simulation programs do poorly in predicting the ratio of muons to the electromagnetic parts of the shower[45]. Hence, it is probable, that Auger data will not be helpful in understanding the HiRes/AGASA discrepancy.

As shown by the Auger experience, monocular events that also trigger the ground array have excellent geometrical reconstruction and hence shower profile resolution[46]. TA stereo and monocular hybrid data will allow a careful study of the cosmic ray composition in the region above the ankle to the GZK, using the X_{MAX} technique.

While the complete TA with low energy extension (TALE) will study cosmic rays over a very wide energy range, from well below the second knee through the GZK, only the high-energy part of the experiment will be operational initially

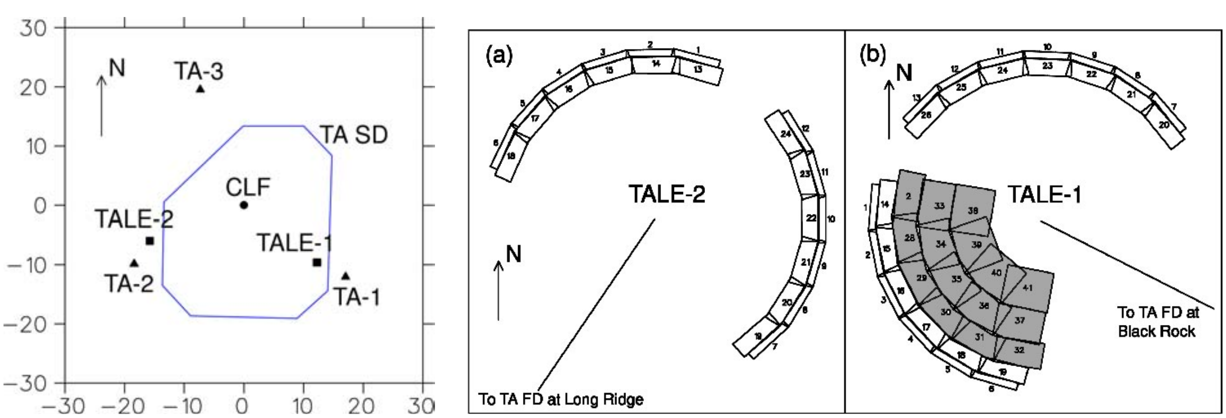

Figure 12: Left: Physical layout of the Telescope Array Project showing the boundaries of the ground array in blue, the Central Laser Facility as a circle, the three exterior fluorescence detectors (TA-1, -2 and -3) as triangles, the stereo fluorescence sites (TALE-1 and -2) as squares. The scale on the map is in kilometers. Right: Layout of the TALE-1 and TALE-2 sites, showing 24 and 26 reconditioned

(starting in 2007). Here, in addition to spectrum and composition studies, TA has unique capabilities in the search for point sources of cosmic rays because of its much improved angular resolution.

At this point, there are only three hints of anisotropy coming from the HiRes and AGASA data: (1) the direction of the AGASA triplet with one HiRes event atop it[34]; (2) the possible correlation between stereo events and BL Lac objects reported by HiRes[37]; and (3) the report by AGASA of an excess of events near the direction of the Galactic center and a deficit near the galactic anti-center[47]. The TA experiment will be able to test these hints of anisotropy with much improved sensitivity and to search for others. In particular, a confirmed correlation of UHE cosmic rays with BL-Lacs will require high statistics follow-up measurements in the northern hemisphere. Because of obscuration by the galactic plane, most identified BL-Lacs are in the north and understanding the nature of these sources and the neutral particles they may produce would require multi-wavelength correlation studies as well as improved composition measurements. Given that most BL-Lacs are 50 Mpc or more distant, the survival of photons over these distances is highly problematic.

Based on relative exposures and improved angular resolution, the TA experiment will have the highest sensitivity for high-resolution anisotropy studies of any experiment. The figure of merit for this sensitivity is the time-averaged aperture divided by the square of the resolution. Table 1 below lists the aperture, resolution and figure of merit for HiRes stereo, TA stereo, TA ground array, Auger ground array and TA hybrid stereo, all at 10^{19} eV, the energy at which the correlation of HiRes data with the observed BL Lac's is maximized.

Table 1: Comparison of the figure of merit (aperture/resolution^2) of sensitivity to point sources between TA and other experiments

Experiment	Aperture (km2 ster)	Resolution	Aper/Resolution^2
HiRes stereo	300 (avg)	0.5 deg	1200
TA/TALE stereo	340	0.5	1360
TA SD	1500	1.5	667
S. Auger SD	6600	1.5	2933
TA/TALE hybrid stereo	260	0.1	**26000**

IV. CONCOLUSIONS

After nearly nine years of observations, the HiRes Experiment has accumulated the largest Ultra High Energy Cosmic Ray dataset to date. The analysis efforts, thus far, have produced strong evidence for the expected GZK suppression, expected for a predominantly protonic composition, which is confirmed by our $<X_{MAX}>$ measurements. We have also measured the proton-air cross-section at the highest energy yet achieved, which has been shown to give a pp cross-section consistent with extrapolations from lower energy accelerator data. A most tantalizing correlation has been observed also between the arrival direction of stereo HiRes events and identified BL-Lac objects.

The next step for many members of the HiRes experiment is the Telescope Array Project. This collaboration of some HiRes members and some AGASA members is building a hybrid cosmic ray detector, fluorescence and scintillator ground array, in central Utah. Construction of the Telescope Array is already well underway and normal data collection will begin in mid-2007.

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