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The Telescope Array Low Energy Extension (1): the 6-km Stereo Detector

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We plan to build a series of detectors to extend the energy coverage of the Telescope Array (TA) experiment to lower energies, called the TA Low energy extension (TALE). We plan to cover the energy range $10^{16.5}$ – $10^{20.5}$ eV with this experiment. Here we present the design of a double-stereo detector to be constructed by redeploying 50 of the existing mirror units from the High Resolution Fly's Eye (HiRes) Experiment in conjunction with two of the fluorescence detector (FD) stations of the TA experiment. This arrangement will extend the threshold for stereoscopic fluorescence measurements of ultrahigh energy cosmic ray (UHECR) showers down to 10^{18} eV.

1. Introduction

The Telescope Array (TA) Experiment, now under construction in Millard County, Utah, U.S.A., is a hybrid array consisting of three fluorescence detector (FD) stations and 576 scintillation surface detector (SD) units. The SD units are arranged in a square grid with 1.2 km spacing and the FD stations are located at the corners of the surface array. This arrangement of the surface array gives TA an effective physics threshold of 10^{19} eV. Its fiducial area of 800 km^2 above this threshold is fully-efficient, and is completely covered by the three fluorescence stations in hybrid mode. The standard TA detectors are optimized for the measurement of the ultrahigh energy cosmic ray (UHECR) spectrum in the region of the GZK suppression [1].

The TA Low energy extension (TALE) plans to make hybrid and stereo fluorescence measurements of cosmic rays down to an energy of $10^{16.5}$ eV, using additional fluorescence stations from the redeployment of existing detector units from the High Resolution Fly's Eye (HiRes), plus additional equipment to be constructed. The HiRes experiment has been operating since spring, 1997 with one detector site (monocular mode), and since the end of 1999 with two detector sites (stereo mode). HiRes is scheduled to suspend operation in Dugway, Utah during the summer season of 2006. We plan then to move the detector units to the TA site. With 50 of the HiRes mirror units spread over two sites located 6km from standard TA FD stations, we can achieve total stereo aperture about an order of magnitude larger than that of HiRes at 10^{18} eV, while maintaining an aperture equal to that of HiRes at 10^{19} eV. This will allow us to make significantly better stereo measurements of the *ankle* or *dip* region than was previously possible. The significance of the physics of the ankle region is discussed elsewhere[2], as is the details of the *tower* detector for extending the observations down to $10^{16.5}$ eV[3]. The layout and performance of the 6km TALE detectors will be described in the following sections.

2. Motivation

Both the Fly's Eye and HiRes experiments have observed the ankle structure at $10^18.5$ eV[4, 5, 6]. It should be noted, however, that the ankle was resolved only in the stereo energy spectrum of Fly's Eye, whereas the Fly's Eye monocular measurement did not have sufficiently fine energy resolution to reveal this feature. The monocular spectrum of HiRes, as shown in figure 1, did confirm the occurrence and location of the ankle feature seen in the Fly's Eye stereo spectrum. The HiRes experiment,however, was designed for stereo observations above 3×10^{18} eV. From 10^{19} to 10^{18} eV, the stereo aperture of HiRes drops by more than two orders of

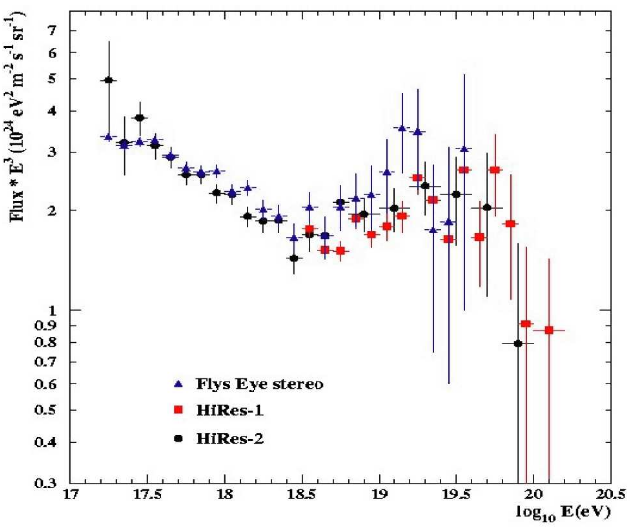

Figure 1. HiRes monocular spectra[6] overlaid with the Fly's Eye stereo spectrum[4] showing the ankle/dip structure near $10^{18.5}$ eV. As is usually done for UHECR spectra, the differential flux has been multiplied by E^3 to reveal the finer structures.

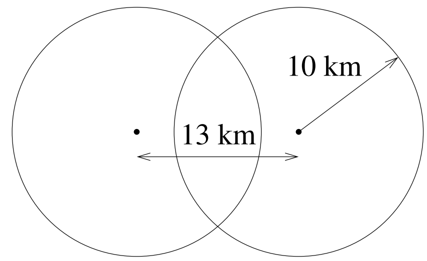

Figure 2. Illustration of the limited stereo aperture for the HiRes detector at 10^{18} eV.

magnitude. This precipitous drop will make it difficult to make systematically reliable aperture calculation and stereo flux measurement in the ankle region.

Figure 2 illustrates this limitation of HiRes at 10^{18}eV. To first order approximation, the collection area of a fluorescence station can be modeled as a circle whose radius is determined by the largest distance at which it can detect a vertical cosmic ray shower of a particular energy. For the HiRes detectors, the effective radius at 10^{18} eV is 10 km. The two HiRes detectors are located at a distance of 13 km apart. The overlap (stereo) region between the two circles is limited and shrinks much more quickly in area than either circle with decreasing energy.

3. Simulation Study of the TALE 6 km Configuration

The standard TA mirrors are about 50% larger than the HiRes mirrors and have an effective radius of 13 km at 10^{18} eV. However, each TA FD only covers 108 degrees in azimuth, as required for hybrid operations. A number of different locations are available at between 4-6 km from the two TA FD sites to the south of the array. A simulation study was made of HiRes mirrors placed at 6 km in the center of the field of view of a TA FD site. Not surprisingly, we found that most of the stereo aperture at 10^{18} eV occurs in those HiRes mirrors facing away from the TA sites. However, those mirrors facing directly away from TA sites capture mostly events with small opening angles between the two shower-detector planes and result in poor geometrical reconstruction. Removing these, we arrive at a two-site configuration shown in figure 3.

The intended optimization of the stereo aperture at 10^{18} eV is evident in the left panel of figure 4, in which we have represented the collection areas of the five TA/TALE FD sites by wedges. In the right panel of figure 4, we also see the overlap at 10^{19} eV, which demonstrates that the TALE 6 km upgrades will also provide TA

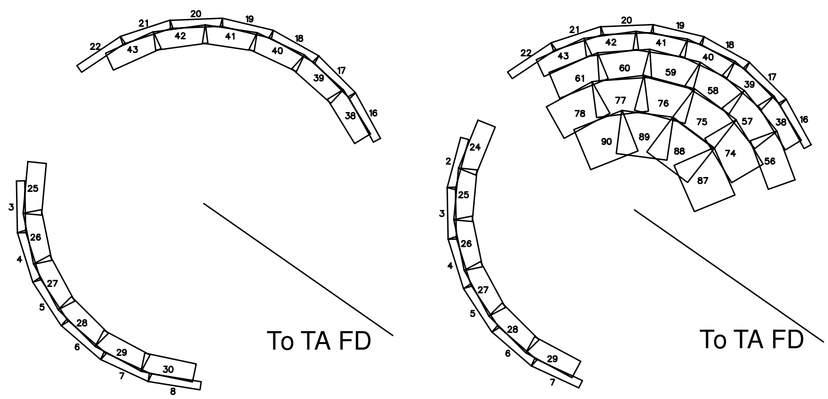

Figure 3. Arrangement of HiRes mirrors at 6 km, in the center of view of the TA FD sites. The individual mirrors are seen in top-projection view, covering elevation angles from $3 - 31°$. The site on the right also shows the 15 tower mirrors placed to view higher elevations

with stereo-hybrid coverage over essentially the entire surface array at above 10^{19} eV. The expected angular resolution for stereo-hybrid events is about $0.1°$. The combination of the large collection area and the extra-fine angular resolution will make TA/TALE a uniquely powerful tool for searching for point-sources of UHE cosmic ray.

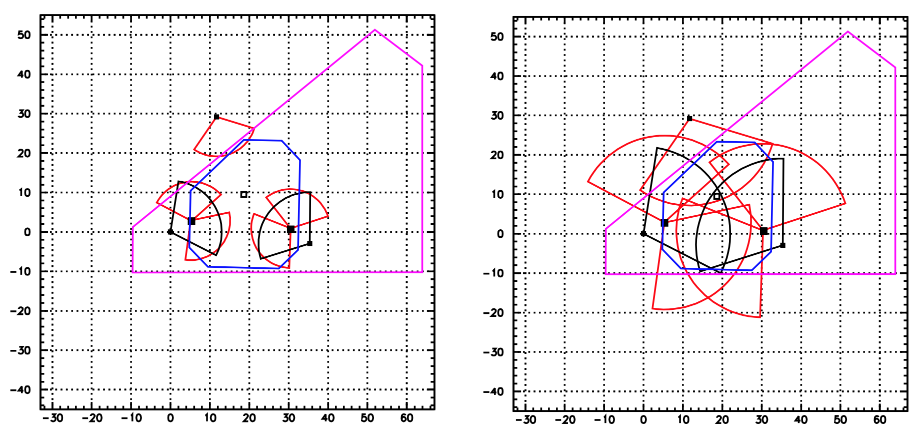

Figure 4. Illustration of the overlap of the collection areas between the TALE mirrors (located at squares) and the TA FD stations at 10^{18} eV (left) and at 10^{19} eV (right). The blue octagon in both panels represents the extent of the TA surface array, and the outer magenta pentagon shows the proposed Northern AUGER site in Utah.

The simulations also show the stereo angular and X_{max} resolutions of TA/TALE to be equivalent to that of HiRes. The combined stereo aperture, plotted in figure 5, is roughly equal to that of HiRes at 10^{19} eV, and decreases six-fold to 10^{18} eV. This represents an improvement of about an order of magnitude over HiRes at the low end of the ankle region.

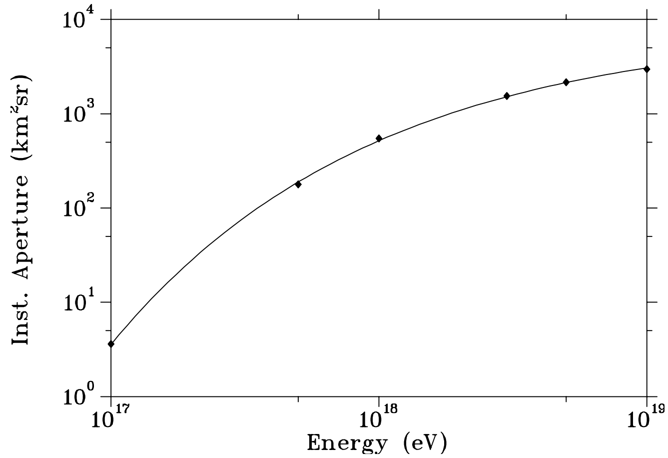

Figure 5. Total calculated stereo aperture of the TALE 6 km detectors between $10^{17} - 10^{19}$ eV.

4. Summary

With the modest investment of refurbishing and moving existing HiRes detectors from Dugway to Millard County, TA/TALE will be able to extend stereo fluorescence observations for TA down to 10^{18} eV. By locating the stereo pairs 6 km apart, the resulting aperture over the ankle region will increase by about a factor of six between $10^{18} - 10^{19}$ eV, which is significantly flatter than that of HiRes. In addition, this arrangement will also result in the world's largest stereo-hybrid detector with a collection area of 800 km^2 at above 10^{19} eV and an anticipated angular resolution of about $0.1°$.

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