The TALE Tower Detector

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Abstract: The Telescope Array Low Energy Extension (TALE) is a set of detectors to be added to the Telescope Array (TA) experiment to increase its aperture at high energies and extend the range of its energy coverage to lower energies. One of the TALE detectors is a "tower" detector. This is a fluorescence detector designed to be sensitive to extensive air showers from primary cosmic rays with energies between $10^{16.5}$ and 10^{18} eV. To achieve this low-energy sensitivity the tower detector will use much larger mirrors than any previous fluorescence experiment and will have an elevation coverage extending much higher from the horizon than in HiRes, TA or Auger.

Introduction

The Telescope Array (TA), currently being deployed in Utah, will consist of 516 surface array detectors covering 750 km^2, overlooked by three sets of fluorescence detectors. It will be sensitive to extensive air showers from primaries with energies above $10^{18.5}$ eV. To extend the coverage of the detector to lower energies and to increase the total aperture at high energies, a set of detectors called the TA Low Energy Extension (TALE) is planned. TALE will consist of two sets of fluorescence detectors and an associated infill array. The TALE fluorescence detectors will be placed 6 km away from existing TA fluorescence detectors. This is the optimum spacing for studying the ankle region of the UHECR spectrum by viewing air showers in stereo with fluorescence detectors. The TALE fluorescence detectors will also look outward from TA surface array, adding exposure at high energies.

Most of the TALE fluorescence detectors will have an elevation coverage of 3 to 31 degrees above the horizon, similar to the TA fluorescence detectors. However, one of the TALE fluorescence detector sites will also contain fluorescence detectors viewing elevation angles from 31 to 71 degrees, but with limited azimuthal coverage of about 90 degrees. This is the TALE Tower Detector.

The purpose of the Tower Detector is to observe air showers from cosmic rays with energies between $10^{16.5}$ and 10^{18} eV. It will achieve this reduction in the threshold for fluorescence detectors by using larger mirrors than previously used in fluorescence detectors and by looking high into sky where most of the low energy showers develop.

The range of energies covered by the Tower Detector is interesting because it must contain the transition between galactic and extra-galactic cosmic rays. At the low end of the region the flux is dominated by galactic sources, as manifested by the heavy elemental composition seen in the results of KASCADE [1] and the HiRes Prototype/MIA measurements [2]. At the upper end of the region, a light composition is observed by HiRes [3]. The HiRes Prototype/MIA measurement also shows a changing composition, heavy-to-light, throughout this region. One can thus imagine doing a composition-tagged analysis of the events in this energy range to study the galactic cosmic rays by picking out the heavy part of the composition.

In addition, the extragalactic component of cosmic rays in this energy range is dominated by those coming from extremely distant sources. At energies below $10^{17.5}$ eV, the flux is dominated by sources with redshift $z > 1.5$. Two candidate sources of extra-galactic cosmic rays, QSO's and AGN's, exhibit a break in their evolution at about this redshift. A break in the evolution of the sources of extra-galactic cosmic rays, should thus be visible in the spectrum in this region.

The combination of TA and TALE will result in a experiment that is sensitive to nearly four orders of magnitude in energy. This wide dynamic range will allow the robust measurement of the features of the UHECR energy spectrum and their relative positions.

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Fluorescence detectors designed for observations at the highest energies such as those in HiRes, TA and Auger are typically only instrumented up to an elevation angle of about 30 degrees. At these energies, most showers are far enough away that the whole shower is visible within this window. At lower energies, below about 10^{18} eV, this reduced elevation coverage causes a bias in the acceptance of the detector: only showers with a maximum in the field-of-view can be well reconstructed. This bias interacts with composition measurements because cosmic rays of different types give rise to showers with maxima at different heights. Thus, below 10^{18} eV, the aperture for proton induced showers in a fluorescence detector is greater than that for iron showers, where above 10^{18} eV the apertures are identical.

Thus, to observe low energy showers using the fluorescence technique with good statistics and with little composition bias, one must cover a large elevation range. The HiRes Prototype/MIA Experiment [2] is an example of just such a fluorescence detector arrangement. That experiment had a low energy threshold of about 10^{17} eV. To go to lower energies, one must use larger mirrors in order to improve the signal-to-noise ratio and observe events over greater distances.

We have adopted these strategy two strategies in the design of the TALE Tower Detector. We will use mirrors with a 3 times larger light collection area. These mirrors will be arranged so as to cover elevation angles from 31 to 71 degrees in elevation, while only covering about 90 degrees in azimuth. Because of the steeply falling UHECR energy spectrum, the flux of cosmic rays at lower energies is fairly high, so having full azimuthal coverage is not necessary. The elevation range from 3 to 31 degrees will be covered by the co-located TALE Stereo fluorescence detectors. Thus we will have nearly full elevation coverage over about a quarter of the sky. The arrangement of the mirrors is shown in Figure 1

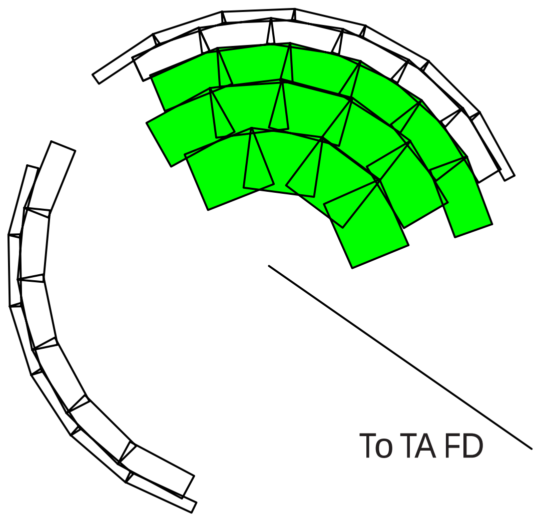

Figure 1: The layout of mirror units for the Tower Fluorescence Detector (in green). The mirrors are displayed schematically with elevation angle coverage displayed radially with small elevation angle displayed on the outside. The lower (outer) two rings are provided by one of the TALE Stereo detector, while the upper (inner) three layers, in green, are the Tower Fluorescence Detector proper.

We have performed a simulation of this detector using both HiRes-sized mirrors, and mirrors three times the size of HiRes (only above 31 degree elevation). The simulation uses the fluxes and spectral indices found by Fly's Eye [4]. The expected event distributions after one year of running with either sized mirrors are shown in Figure 2. The event distribution for a full two-ring HiRes detector is also shown. One can see that the full HiRes rings have a large aperture at high energies, but that the tower arrangement with the same size mirrors reduces the low energy threshold by half an order-of-magnitude. The number of events below $10^{17.5}$ eV is then dramatically increased by enlarging the mirror size.

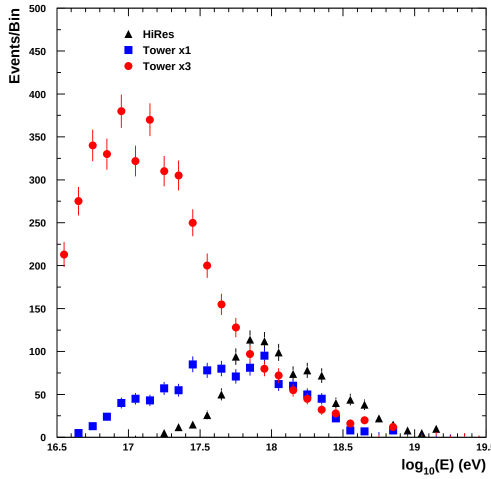

Figure 2: The number of events expected in one year of running with various tower detectors is shown. The same expectation for two full rings of HiRes mirrors is also shown.

Figure 3: A drawing of the prototype Tower Detector mirror on its stand in the building where it has been deployed. The cluster box is also shown. The mirror stand is designed to also hold the full size mirrors.

Prototype Mirror

We have constructed a prototype mirror for the Tower Detector, and in the process of deploying it in Dugway, Utah, for testing at the HiRes-I site. The prototype mirror is smaller than the final planned mirror, with a 6 m radius of curvature and an aperture 3 m in diameter, but it still has twice the collecting area of the HiRes mirrors. The mirror is pointed up at an angle of 52 degree, just in the middle of the planned elevation coverage. A drawing of the prototype mirror, the cluster box and the surrounding building is shown in Figure 3.

The light from the mirror is collected onto a cluster of PMT's at the focal plane. Because the Tower Detector will use the same model PMT's as in HiRes, but the mirrors and the pixel spacing is larger, Winston cone's are used to give a relatively uniform sensitivity to light in the focal plane. A picture of the assembled PMT cluster is shown in Figure 4, while the assembled panel of Winston cones which goes over it is shown in Figure 5. We expect to have test data from the prototype shortly.

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Figure 4: A picture of the assembled PMT cluster box awaiting the addition of the Winston cone frame.

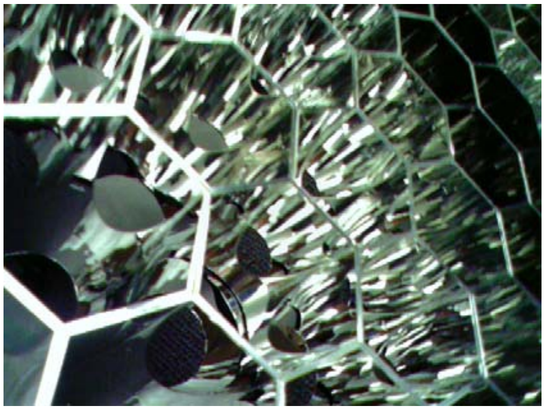

Figure 5: A picture of the assembled Winston cone frame.

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