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The Telescope Array Low Energy Extension: the Tower Detector

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The Telescope Array Low Energy Extension (TALE) is a series of detectors to be added to the Telescope Array (TA) experiment to increase its aperture at high energies and extend its energy coverage to lower energies. One of the TALE detectors is a "tower" detector. This is a fluorescence detector designed for sensitivity to low energy cosmic rays, from $10^{16.5}$ to 10^{18} eV. To achieve this low-energy sensitivity the detector's mirrors will be larger than those of any previous fluorescence experiment, and they will point higher in the sky than those of HiRes, TA, or Auger.

1. Introduction

The TA and TALE experiments are being built by a collaboration of research groups from Japan and the United States. The experiment is designed to study the spectrum, composition, and anisotropy of ultrahigh energy cosmic rays, over a wide energy range, with a large aperture, and with good control of systematic uncertainties.

The experiment will be located in Millard County, Utah. It will consist of TA detectors (a ground array of 576 scintillation counters separated by 1.2 km, and three fluorescence detectors overlooking it), two TALE fluorescence detectors, and an infill array. The TALE fluorescence detectors will be located a distance of 6 km from two of the TA fluorescence detectors. This spacing is optimum for studying the ankle of the cosmic ray spectrum with a nearly flat stereo aperture. All these fluorescence detectors will observe at elevation angles from 3 to 31 degrees above the horizon.

Associated with one of the TALE detector sites will be a "tower detector" which will observe at higher elevations, from 31 to 71 degrees. The tower detector will have larger mirrors and be able to detect cosmic rays from about $10^{16.5}$ eV to 10^{18} eV. A ground array of about 110 scintillation counters, of 400 m spacing, will be deployed in front of the tower detector for hybrid coverage at low energies.

Important physics occurs in this energy range. The galactic - extragalactic transition occurs here: at the lower end the cosmic ray flux is dominated by galactic sources, and at the upper end extragalactic sources dominate. HiRes-MIA [1] and HiRes stereo [2] data show a change in composition in this energy range, from heavy to light, indicative of this transition. One can perform a composition-tagged analysis to study galactic sources by picking out the heavy part of the composition, and extragalactic using the light part.

In the region below about $10^{17.5}$ eV most extragalactic cosmic rays come from redshifts greater than z=1.5. Two candidate sources, QSO's and AGN's, show a break in their evolution near this redshift [3], in that QSO and AGN luminosity densities stop increasing with redshift and become almost flat at larger redshifts. If these astronomical objects are sources of ultrahigh energy cosmic rays, then this break in source intensity should be visible in the cosmic ray spectrum also, where it should provide a feature in the extragalactic spectrum in the middle of the 10^{17} eV decade. An experiment that can detect cosmic rays from well below this point up to the energy of the GZK suppression is needed to study this question, which is a test of the nature of the sources of ultrahigh energy cosmic rays. Fits to the spectrum measured by TA and TALE, taking galactic and extragalactic sources into account, should be sensitive to this break.

Together the TA and TALE detectors will make an experiment that has good sensitivity over four orders of magnitude in energy, from well below the second knee through the area of the GZK suppression [4]. The same events will seen by different detectors and cross normalization of energy scales will be possible.

2. The TALE Tower Detector

Fluorescence detectors such as those deployed by the HiRes, TA, and Auger experiments, that observe fluorescence light from showers at elevation angles up to 31 degrees, suffer a bias for cosmic ray showers below an energy of about 10^{18} eV. This is because lower energy events can be seen only if they are close to the detector, and the point of maximum shower development, X_{max}, most often occurs above the elevation angle coverage of the detector. Since seeing X_{max} is important for good energy resolution, events must be selected where X_{max} is visible, and the bias results.

To see lower energy showers with good statistics and good energy resolution one must align one's fluorescence detectors to look higher in elevation angle. An example of this was the HiRes prototype - MIA hybrid experiment [1], where the fluorescence detectors were arranged to observe from 3 to 71 degrees in elevation. This experiment observed down to an minimum energy of about 10^{17} eV. To go even lower in minimum energy one must improve one's signal to noise ratio, for example to collect more light by using larger mirrors. Thus the strategy we adopt in the TALE tower detector is to build mirrors three times larger in area than HiRes', point them from 31 to 71 degrees in elevation, and deploy them with one of the TALE detectors, whose mirrors point lower in the sky, to provide overall coverage from 3 to 71 degrees.

3. Tower Detector Simulations

The detectors being simulated are shown in Figure 1. The diameter of the mirror is 4.0 m, with a 7.50 m radius of curvature. Winston cones will be used to collect the light onto the phototubes, and a drawing of the Winston cone is shown in the inset in this figure.

We have used the full Monte Carlo simulation for the HiRes-II detector, including analysis cuts, to simulate the TALE tower detector. HiRes-II is the newer of the two detectors in the High Resolution Fly's Eye (HiRes) experiment, which has a flash ADC readout system and is deployed on top of Camel's Back Ridge in the U.S. Army Dugway Proving Ground in Utah. The agreement between this Monte Carlo and the HiRes-II data was excellent, so we believe that the prediction for the tower detector will be excellent as well.

Figure 2 shows the arrangement of detectors used for the simulation. A full two-ring detector (identical to HiRes-II) observing from 3 to 31 degrees in elevation, plus 15 large mirrors observing between 31 and 71 degrees was used.

Figure 3 shows the aperture of several TA and TALE detectors: the TA surface detector (SD), the TALE tower detector, with the HiRes-II detector monocular aperture for comparison. Figure 4 shows the number of events that will be collected per year by these three detectors.

It can be seen from these figures that the TALE tower detector has a minimum energy that is an order of magnitude lower than a standard fluorescence detector like those of the HiRes, TA, and Auger experiments. The tower detector will produce a good-statistics measurement of the flux and composition of cosmic rays from $10^{16.5}$ to 10^{18} eV.

We plan to deploy an infill array of 110 scintillation counters in front of the TALE tower detector. These counters will be in a grid of spacing 0.4 km, 1/3 of that of the TA surface detector. These counters will be used for hybrid observations with the tower detector. This will improve the energy resolution for spectrum measure-

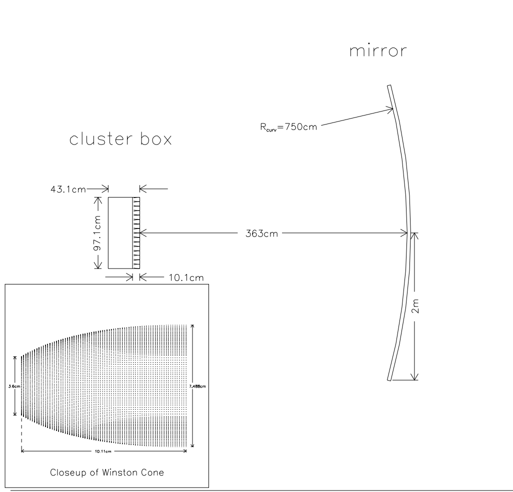

Figure 1. Drawing of the large mirrors that will be used for the TALE Tower Detector. The inset shows the outline of the Winston cones to be used to channel light to the phototubes.

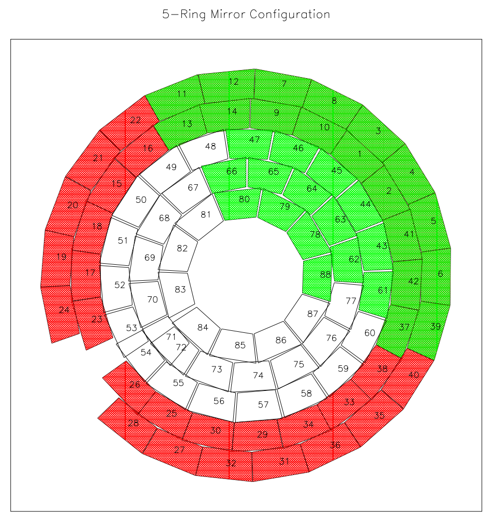

Figure 2. How the TALE detector might look. The mirrors in the outermost two rings (that observe from 3 to 31 degrees in elevation) are identical to HiRes mirrors, and the mirrors in the inner rings are the large mirrors that will be used for the TALE Tower Detector.

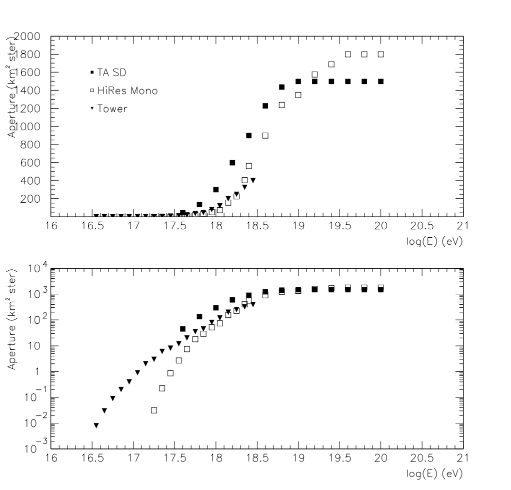

Figure 3. The aperture of TALE tower detector and the TA surface detector (SD). The monocular aperture of the HiRes-II detector is shown for comparison.

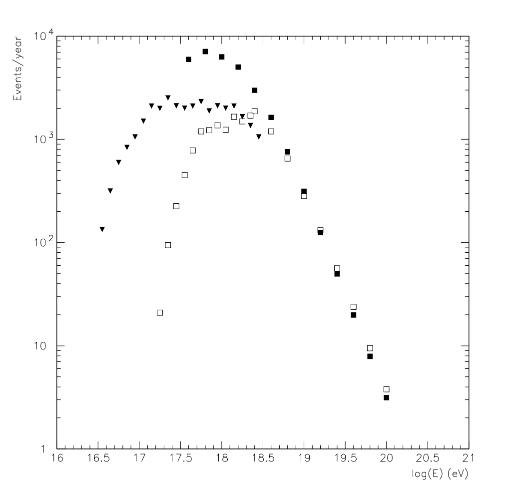

Figure 4. Histogram of the energy of events that will be collected per year by the TALE tower detector and the TA surface detector (SD). The number of events collected per year by the HiRes-II detector in monocular mode is shown for comparison. The symbols used are the same as in the previous figure.

ments, and will be particularly important for measuring X_{max} of showers (and hence their composition). A hybrid measurement of X_{max} has better resolution than a monocular measurement by about a factor of 2.

4. Conclusions

The TALE tower detector with its infill array, the TALE 6-km stereo detector [5], the TA fluorescence detectors, and the TA surface detector will be a powerful experiment for the study of ultrahigh energy cosmic rays.

The physics of ultrahigh energy cosmic rays in the energy range above $10^{16.5}$ eV is very rich. Three spectral features are present, in contrast to the single feature in the spectrum at all lower energies. In addition the galactic - extragalactic transition occurs here.

The composition of the primaries at the lower end of this energy range should be heavy and of galactic origin, then at higher energies make a transition to become light and of extragalactic origin. This will occur just where the TALE detectors are at their optimum efficiency. The highest energy events should continue this light composition.

QSO's and AGN's, two types of astronomical objects which are expected to be sources of extragalactic cosmic rays, show a break in their evolution at a redshift of about 1.5. The effect of this break should appear in the flux of cosmic rays in the middle of the 10^{17} eV decade. To understand cosmic ray sources it is important to search for this break. An experiment to carry out this search must cover a wide energy range, from an order of magnitude below the break, all the way to the threshold for the GZK suppression.

The TALE tower detector will extend the fluorescence technique to lower energies than previously explored. The minimum energy of $10^{16.5}$ eV is perfect for fits to the cosmic ray spectrum to search for the break in the extragalactic spectrum from QSO and AGN sources. The composition of cosmic rays will be studied by the TALE tower detector (and by the TALE 6-km stereo detector) in a model-independent way.

5. Acknowledgements

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