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The Telescope Array Low-Energy Extension (TALE) Infill Ground Array

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Abstract: The physics goals of the The Telescope Array Low-Energy Extension (TALE) include the hybrid measurement of spectrum and composition of cosmic rays down to energies below 10^{17} eV. To achieve composition measurements from observation of extensive air showers, a ground array detector must have the ability to distinguish the muonic and electromagnetic components of a shower. Here, we consider the design issues relevant to the infill ground array component of the TALE hybrid detector, and present results of prototype studies as well as preliminary detector designs and the envisioned array layout.

Introduction

Telescope Array (TA) is a hybrid observatory for UHECR air showers currently being commissioned in Millard County, Utah U.S.A. [1]. Its goal is to measure the energy spectrum, composition and arrival directions of cosmic rays with energy above $10^{18.5}$ eV, using three air fluorescence observatories [2, 3] operated in conjunction with a surface scintillator array [4] on a 1.2 km square grid.

The TA Low Energy extension or TALE will extend the physics reach of this observatory downward by two orders of magnitude, to $10^{16.5}$ eV. It will accomplish this by adding additional fluorescence detectors, including a "tower" detector viewing elevation angles up to 72° [5]. TALE will also add a more tightly-packed infill array on the ground. In this paper, we discuss the plans for the infill array.

Requirements for Infill Array

Physics goals motivating the TALE infill array are:

1. Hybrid reconstruction of extensive air shower events down to energies of a few $\times 10^{16}$ eV.
2. Determination of composition of the primary cosmic rays by measuring the muon richness of the shower.

In designing a surface array capable of achieving these goals, the expected lateral distributions of shower particles are important. Consider Figure 1.

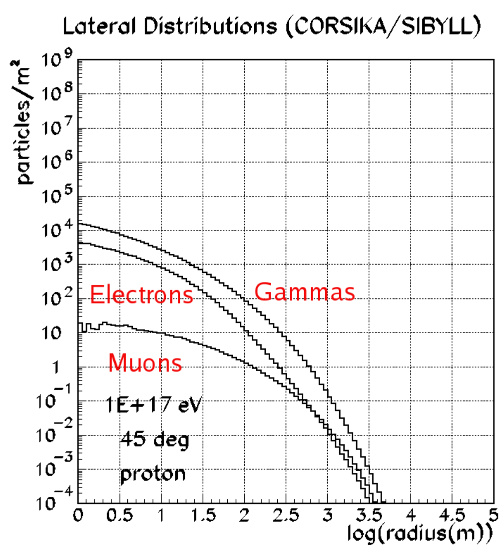

Figure 1: CORSIKA particle densities at TALE ground level for a 10^{17} eV proton-induced shower at 45° zenith angle.

Figure 1 shows the lateral distributions at TA ground level of muons, electrons, and gamma rays for an unthinned CORSIKA [6] shower, initiated by a 10^{17} eV proton at $45°$ zenith angle. Note that at distances of 300-100 meters from the core of the shower, one can expect of order 1-10 electrons per square meter and 10-100 gamma rays per square meter. Thus to satisfy the hybrid reconstruction objective of the infill array, it is clear that a detector sensitive to the electromagnetic portion of the shower is the appropriate choice.

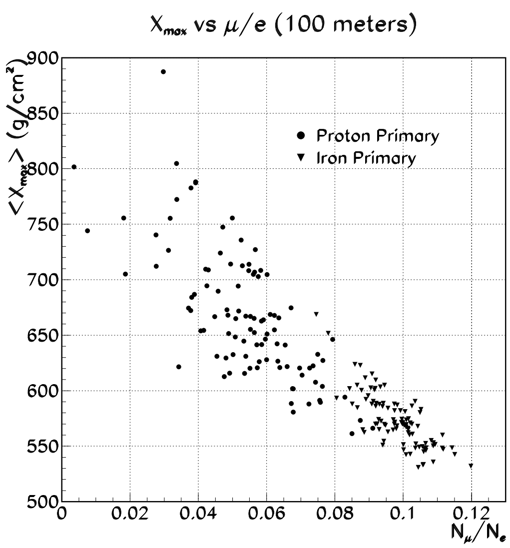

Figure 2: Scatter plot of X_{max} versus N_μ/N_e (the muon to electron ratio at TA ground, 100 meters from the core) for 10^{17} eV proton (circles) and iron (triangles) induced showers at a zenith angle of $30°$.

Additionally however, we are interested in complementing the composition measurement by X_{max} using the fluorescence detector with muon counting at ground level [7]. Figure 1 shows that we can expect only about 1 muon per square meter at "infill array scale" distances (approximately 100 meters) from the core of the shower. However, as shown in Figure 2, in distinguishing protons from iron by the muon counting method we will need counting uncertainties of better than 20%. Thus it will be very important to filter electromagnetics from the muon counting signal, as well as to have a detector element of sufficient size — greater than 25 m^2 — that adequate muon counting uncertainties are obtained.

Infill Array Detector Components

In past experiments at these energies (*e.g.* Reference [8]), large-area scintillators have been buried to depths of three meters to satisfy the above requirements. To meet the muon counting requirements for TALE, we are investigating the novel idea of placing large-area scintillator at the bottom of sand- or gravel-filled shipping containers or "Connex boxes" (Figure 3). The container fill would range-out the electromagnetic portion of the shower to allow muon counting, with substantially less environmental impact than buried scintillator.

Figure 3: $20 \times 8 \times 8$ ft^3 "Connex box" (shipping container).

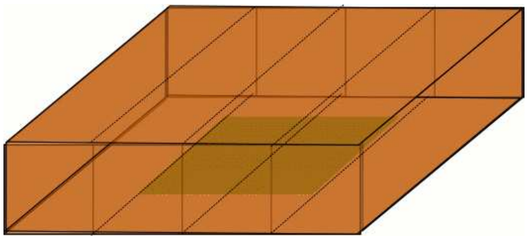

Figure 4: Schematic of four $40 \times 8 \times 8$ ft^3 Connex containers arranged to range out electromagnetics incident on a 25 m^2 scintillator patch. Such an arrangement will comprise a single TALE muon detector station.

A single large shipping container is not sufficiently large to shield electrons from showers at large an-

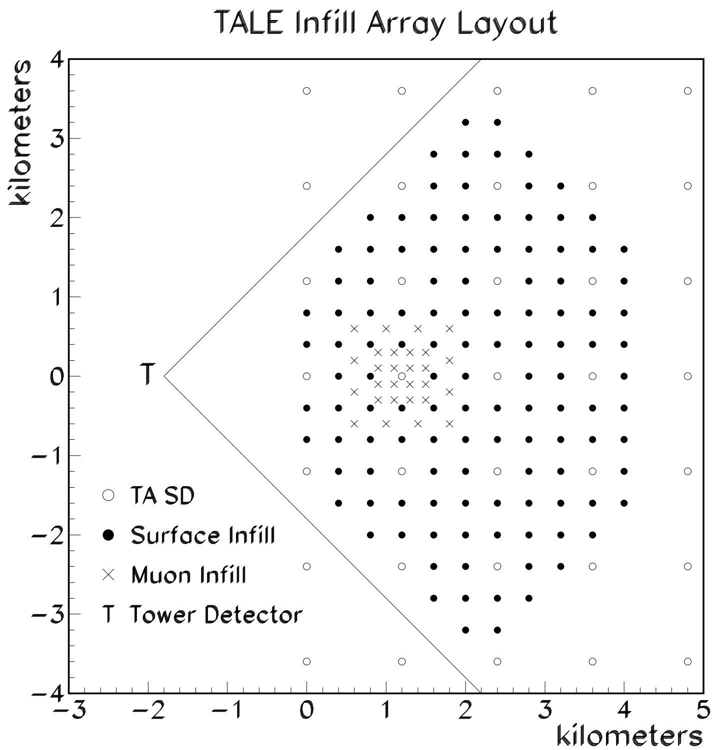

Figure 5: Planned layout of TALE infill array, showing standard TA surface detectors (open circles), TALE surface infill (closed circles), the TALE muon detectors (×'s), and the "tower" fluorescence detector (T). The tower detector field of view is represented by the two perpendicular lines.

gles. Thus we ultimately envision the use of four 40' shipping containers arranged as shown in Figure 4, with the scintillator beneath a false floor in the two central boxes. Such an arrangement constitutes a single muon detector "station", of which several dozen may ultimately be deployed in the TALE experiment.

Infill Array Layout

The planned layout of the TALE infill array is shown in Figure 5. Roughly 100 "surface" scintillator detectors will be deployed at 400 meter spacing, likely recycled counters from the AGASA experiment. 28 muon stations will be located with a centroid about 3 km from the tower fluorescence detector. The central muon stations will be packed at 200 meter spacing to allow adequate muon counting for proton-iron separation at 10^{17} eV. Outer detectors will be spaced 400 meters apart to push the muon-counting into the 10^{17} eV decade.

Conclusions

The TALE infill array will consist of surface scintillator detectors at 400 meter spacing and gravel-filled Connex box muon detectors at 200 meter spacing. This arrangement will allow both hybrid reconstruction of airshowers at energies below 10^{17} eV, and muon counting for an additional handle on primary cosmic ray composition.

Acknowledgements

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