Performance and Operational Status of Muon Detectors in the Telescope Array Experiment

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Abstract: The Telescope Array (TA) experiment, located in the western desert of Utah, USA, at 39.38° north and 112.9° west, is collecting data of ultra high energy cosmic rays in the energy range 10^{18} - 10^{20} eV. The experiment has a Surface Detector (SD) array surrounded by three Fluorescence Detectors (FD) to enable simultaneous detection of shower particles and fluorescence photons. Measurement of shower particles at ground level, with different absorber thickness, enables a more detailed study of the experiment's energy scale and of hadron interaction models. In this report, we present a design and first observation result of a surface muon detector using lead plate and concrete absorbers.

Concept of Detector

It is planned to have multiple types of detector with different thicknesses of absorber,
One type is the lead inserted segmented detector , which will have the capability to measure muon and electro magnetic (EM) components separately. And the second type is a concrete shielded detector to find high energy (E > 600 MeV) muons.

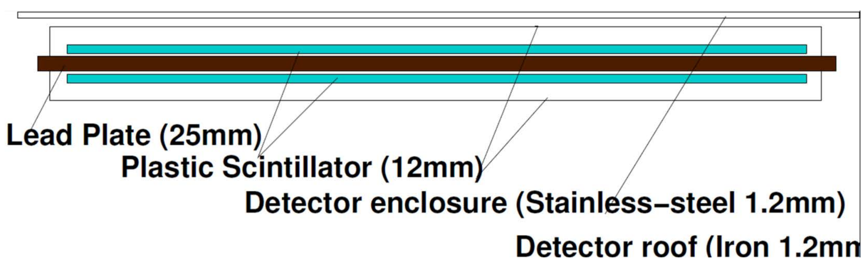

Fig. 1: Side view of Lead inserted detector.

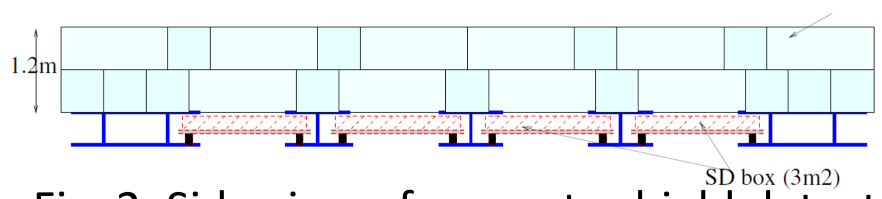

Fig. 2: Side view of concrete shield detector.

Fig. 3:Constructed concrete shield. 8 of 3m^2 detector will be inserted under the shield.

Lead detector:
Fig.1 shows a schematic of side view of the concept of the detector in TA. The detector has two layers of scintillator with 12 mm thickness and lead plates are inserted between scintillators to have the thickness of 25 mm. Scintillation light is collected through WLS fibers layed in grooves in the surface of scintillator with 20 mm spacing.

Concrete shield detector:
The detector is designed to have 1.2 m of absorber. Concrete absorber was assembled from concrete blocks. The dimensions of each block are are 60x60x140 cm^3. It is removable with a crane if necessary. Eight scintillator segment units are stationed under the concrete absorber. Each unit has surface area of 3m^2. The scitillator unit is the same with the one which is used as TA SD [5]. Each unit has two layers of scintillator, each 1.2 cm thick.

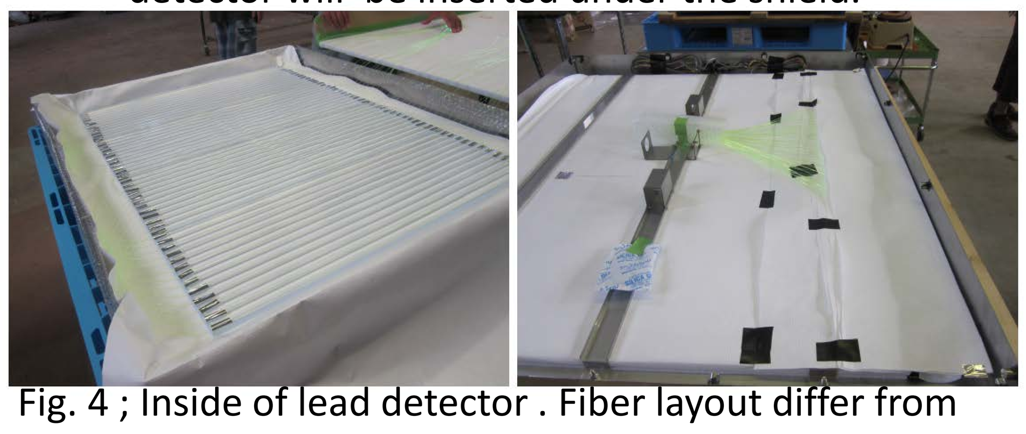

Fig. 4 ; Inside of lead detector . Fiber layout differ from standard TASD.

Estimation of accuracy of muon counting

Lead detector:

Simulation studies with air shower Monte Carlo simulation were done to estimate accuracy of muon counting. For the lead detector. We count the coincident of the rising edge within 20 nsec between the top and bottom layer.
Fig. 5 shows lateral distribution of simulated muon from vertical proton shower (10^{19} eV). The ★ represents the number of thrown muons. The ■ represents the counted number of coincidences in the rising edge of the wave form. The □ represents the number of thrown muons counted via coincidence of the rising edge. The EM component is also injected while the simulation. Fig. 6 shows fraction of counted muon number to thrown number of muon as a function of core distance. The ■ is the fraction of counted number of coincidences. The □ is the fraction of thrown muon counted coincidences. When the core distance is 1200 m , the detector and counting method gives 20 % of accuracy in the average number of muons.

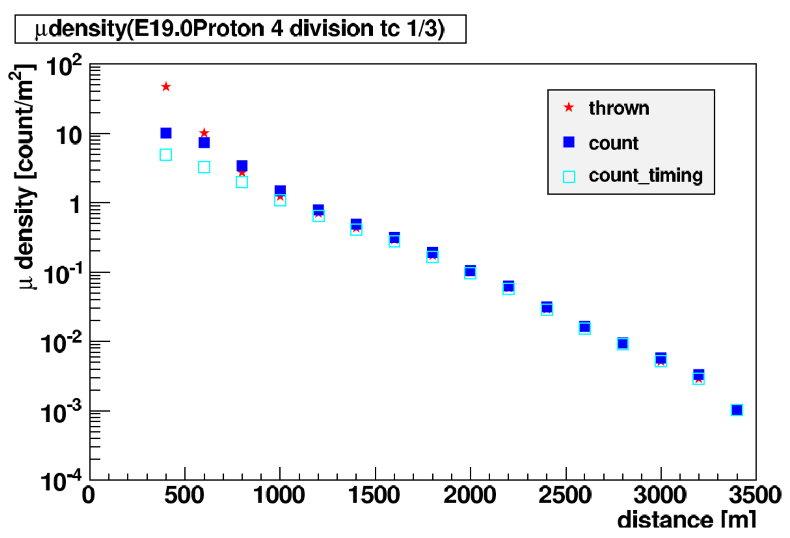

Fig. 5: shows lateral distribution of simulated muon count at vertical proton shower(10^{19}eV)

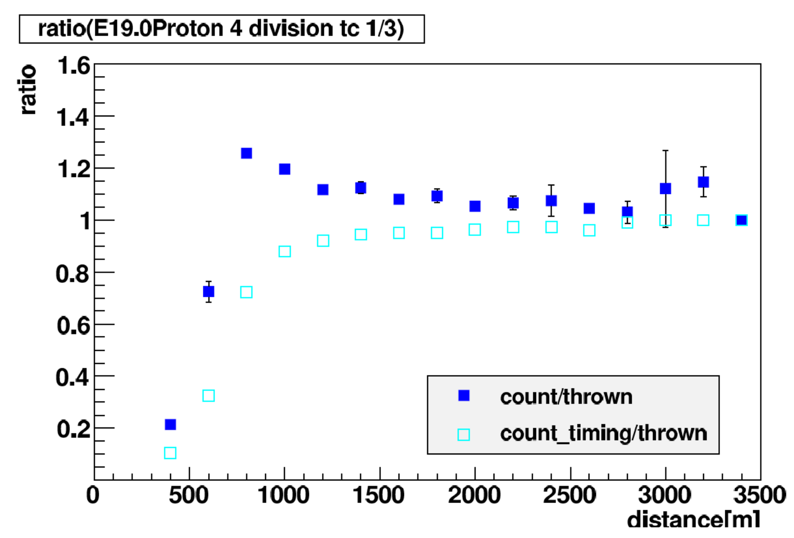

Fig. 6: shows lateral distribution of simulated muon count at vertical proton shower(10^{19}eV)

Concrete shield detector:

Because of 1.2m of concrete shield 600 MeV is the threshold energy. Accuracy of counted number of muon depends on counting method. Fig .7 shows counting accuracy for two method of counting.
Left side is the scatter plot of the thrown and counted number of muons in a case counting of the muons using wave form rising edge.
(Same method which used for lead detector)
Right side is the same plot in a case counting Of the muon using charge amount of signal (VEM).

Primary Energy(eV)	distance (m)
$10^{18.0}$	> 1000
$10^{18.4}$	> 1000
$10^{18.7}$	> 1200
$10^{19.0}$	> 1200
$10^{19.4}$	> 1400

Table. 1: Estimated distance for which the detector can measure number of muons with about 20% of accuracy greater than 80 % purity in the muon fraction.

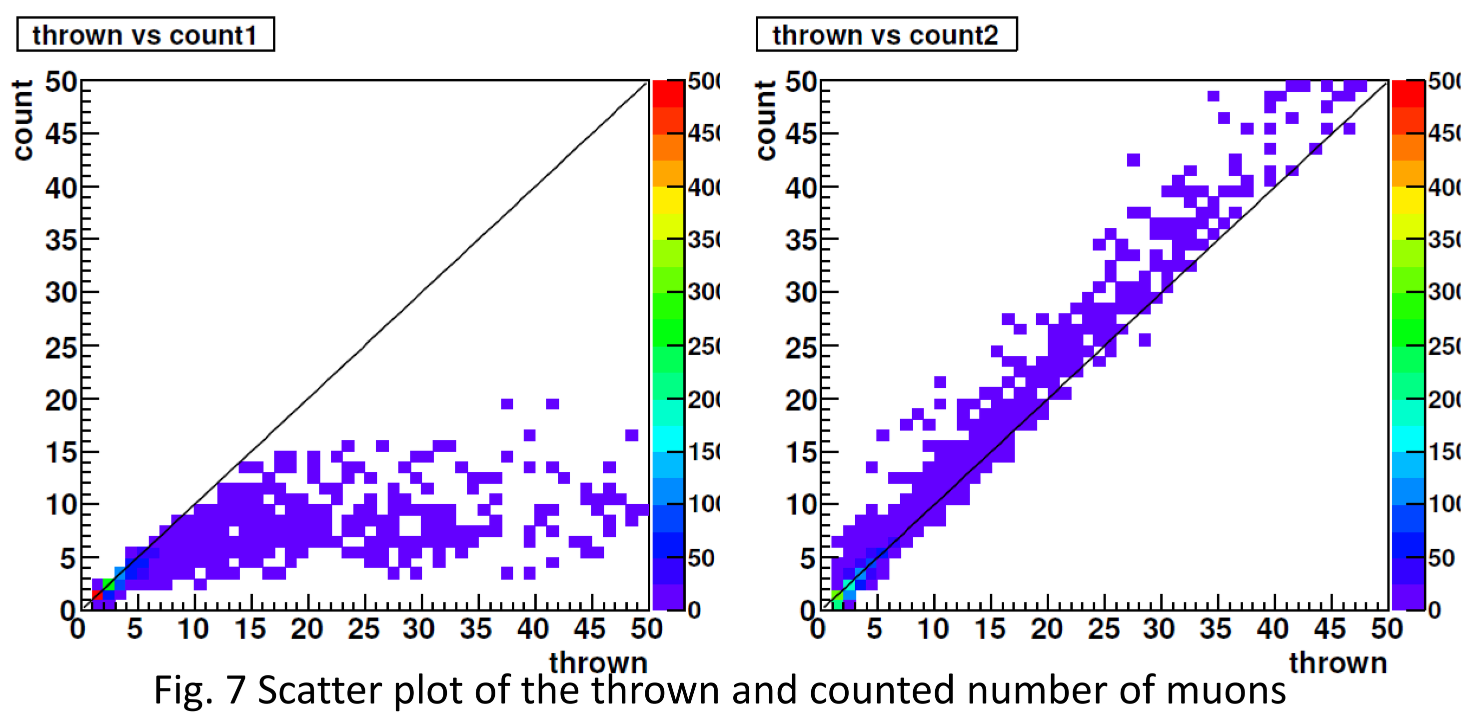

Fig. 7 Scatter plot of the thrown and counted number of muons (left:using waveform right:using charge).

Performance of assembled detector and prototype observation

Lead detector assembly:
For the lead detector, 12 modules (top and bottom pair) are assembled, each of 0.75 m^2. The Npe for 1mip was 18.3 pe. The average Npe for 1 mip at TA SD is 24.6 $\pm$7.2 with same type of PMTs. The position dependence of the response for the mip were checked at 35 positions to cover entire segment which is 15x15 cm^2. The RMS of the distribution of 1mip value is about 5% of the average 1mip value.

Concrete detector assembly:
For the concrete shield detector, a total of 8 modules of 3 m^2 TA SD are assembled. Construction of concrete stack is completed at end of March 2015.

Test observation of air shower :
We started test observation with a prototype lead detector in December 2013. Fig. 8 shows the distribution of energies of observed air showers from Dec. 2013-May.2014. Red histogram shows showers which left signal on deployed detector. Fig. 9 and 10 show one of observed events in this time period. The reconstructed energy is 17 EeV and zenith angle is 37°. Fig. 9 and 10 shows the recorded VEM at top layer of the prototype detector and signal timing at each detector respectively. The lead detector's signal is plotted as red color. Both are well aligned along other detectors. So recorded waveform at the lead detector can be considered as a signal associated with this shower.

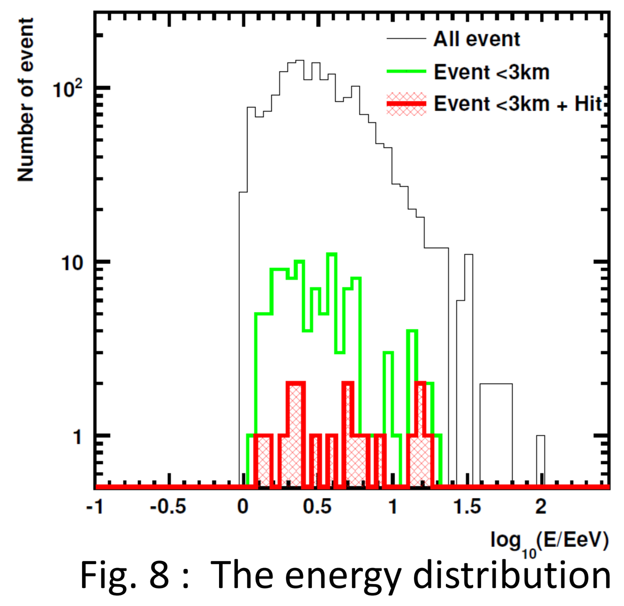

Fig. 8 : The energy distribution of observed showers.

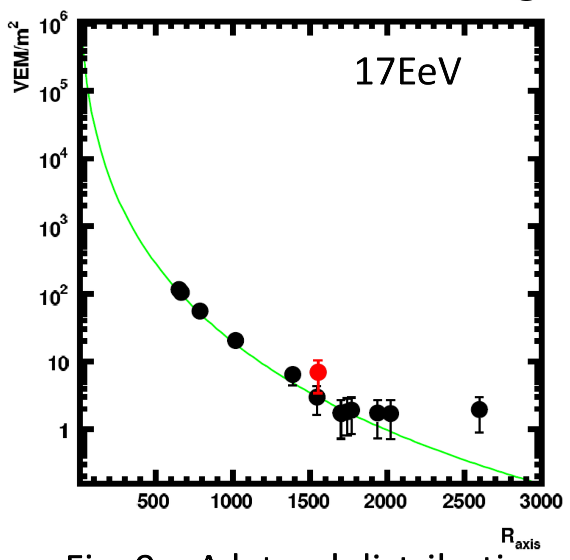

Fig. 9 : A lateral distribution ov VEM along axis distance .

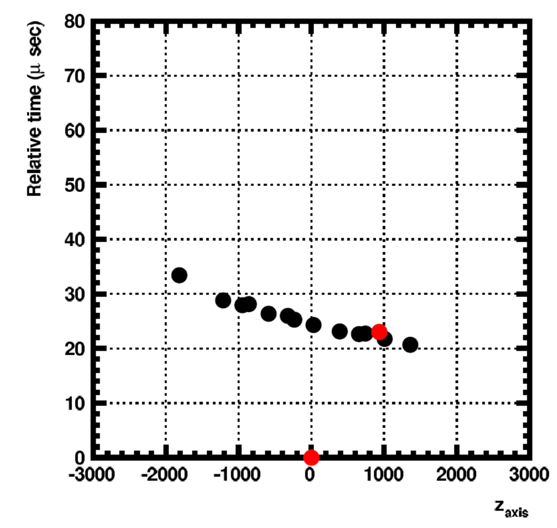

Fig. 10 : Relative timing of first particle hit.(same event with Fig. 9)

Fig. 11 shows scatter plot of amount of signal(VEM) observed at lower and upper scintillator. Data point from standard TASD and lead detector are displayed in Blue and Red respectively. It is seen the TASD (Blue) shows symmetric response between upper and lower layer.
In case of lead detector, the response is not symmetric between upper and lower layer.
The comparison of observed events and MC is under way.

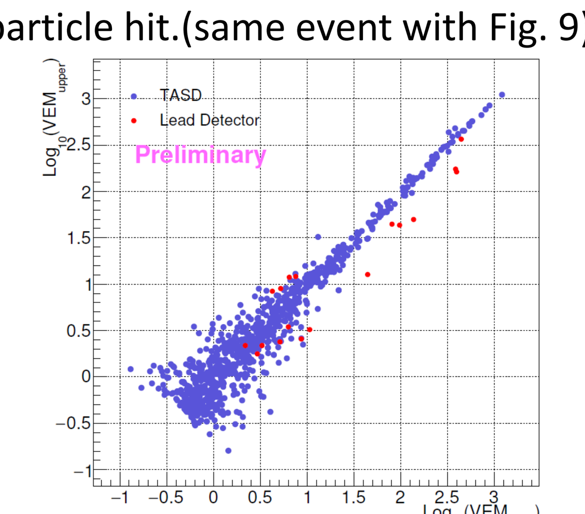

Fig. 11 : The scatter plot of VEM between upper and lower signal.

Summary

Performance and operation status of TA muon detector is presented. The detectors are currently being installed for the test observations in the TA array. The detector has good stability and sensitivity and uniformity. The detector collects the data of air showers in association with the TASD. With more statistics, detailed comparison with existing MC will be done. Currently 8 of 3 m^2 detector segment are being installed.

Reference

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