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The First Observation with the Fluorescence Detectors of the Telescope Array Experiment

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Abstract: The fluorescence measurement is the key in observations of ultra high energy cosmic rays and in determinations of their primary energies in the TA experiment. Almost all fluorescence detectors of TA is in operation from June 2007. Here, we describe the characteristics of the telescopes and the status of the associated systems, and also present preliminary results from the first observation run with the full telescope configurations.

Introduction

The Telescope Array(TA) Project[1] is designed to study cosmic rays with energies above 10^{19} eV. The TA observatory will measure the energy spectrum, the arrival direction distribution (anisotropy) and the composition of Ultra-High Energy Cosmic Rays (UHECRs). It will look for super–GZK events[2] and event clusters[3] observed by AGASA(the Akeno Giant Air Shower Array) and will resolve the discrepancy between the AGASA results and those of HiRes(the High Resolution Fly's Eye)[4].

The TA observatory has a hybrid detector system consisting of both a Surface Detector (SD) array[5](ala AGASA) as well as a set of Fluorescence Detectors(FD)(ala HiRes). The array consists of 512 scintillation SDs which measure distribution of charged particles at the ground with an coverage area nine times greater than the AGASA detection area. Three FD stations are installed around the array and observe night skies above the SD array. With this hybrid system we can observe both the longitudinal development and the lateral distribution of air showers simultaneously. Thus, we will use the measured parameters for complementary calibrations and can improve the energy and the angular resolutions of each component of the hybrid system.

The TA observatory is located in Millard County, Utah, USA($39.3°$N, $112.9°$W). The site is about 1400 m above sea level. As with the AGASA and the HiRes experiment the TA observatory is located in the northern hemisphere, and then this allows the TA collaboration to directly compare with AGASA and HiRes measurement and to compare with southern experiments to search for a potential north–south asymmetry in energy spectra or the source distribution.

Fluorescence Detector

The TA observatory has three FD stations. The stations are located on a triangle with about 35 km separation and consists of 12-14 telescopes. Each station is centered on the central laser facility(CLF)[6] in the middle of the array and views 3°-33° in elevation and $\sim$108° in azimuth, and thus each one views nearly the entire array at high energies.

We have completed installation of telescopes for all the FD stations. For the first and the second station at the south-east and the south-west corner, we installed 12 newly developed telescopes, 12 cameras and the associated DAQ electronics, which we describe here in this paper. However the third station at the north-west corner has 14 HiRes-I telescopes and will have HiRes-I cameras and their electronics[7].

The telescopes (Figure 1) at the first two sites have a combined spherical mirror with a diameter of 3.3 m, a focal length of 3.0 m and a spot size of less than 30 mm on the focal plane. The pointing accuracy of the telescopes is $0.07°$.

Each telescope has a fluorescence light camera which consists of 256 PMTs (HAMAMATSU R9508). The sensitive area of the camera is 1 m $\times$ 1 m, which corresponds to the field of view of $15°$ in elevation times $18°$ in azimuth. Thus the pixel size of the camera is nearly equal to $1°$.

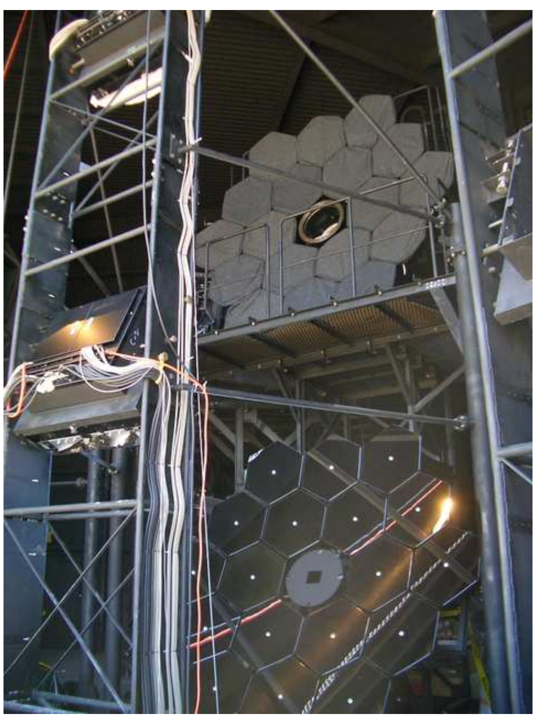

Figure 1: Telescopes and cameras in the first TA FD station. Every segment mirror of the upper mirror has a cover to avoid dust at the time.

In each camera three PMTs (currently one PMT) among the 256 are absolutely calibrated with a standard light source[8]. Moreover, the gain of each calibrated PMT is monitored through the constant measurements using a YAP light pulsar[9] attached on the photo cathode. The YAP pulsar consists of $^{241}\mathrm{Am}$ and a $\mathrm{YAlO_3}$:Ce scintillator, and its dimension are 4 mm in diameter and 2 mm in thickness. The gains of other PMTs are calibrated relative to the absolutely calibrated ones by comparing output signals of PMTs when they are exposed to a Xe flasher installed at the center of a mirror. The accuracy of the absolute and the relative gain determination is 7% and 2.5%, respectively. Finally, the PMT–gain is set at 8×10^4, and the gain of pre–amplifiers attached on the PMTs is about 52.

The FD electronics[10][11] consists of the following three main components: Signal Digitizer/Finder (SDF), Track Finder (TF), and Central Trigger Distributer (CTD). Each component fits on a single width VME–9U module. The effective dynamic range and the sampling frequency of SDF are equivalent to 14 bits at 10MHz. The signal finder logic searches excess signals above night sky background(NSBs) and calculates the significance of the found excess number of photoelectrons in every 12.8 μs window, which we call "frames". Finally, SDFs send the signal finding results to TF module belonging to same camera.

Each TF processes hit patterns on one camera in every frame. The TF recognizes a 5–fold hit pixel pattern as a track and a 4–fold hit on the edge of the camera as a partial track, and sends the track recognition result to the CTD. The processing time for a cycle of track finding routine is 5.4 μs.

The CTD which is only one module in each station processes the track recognition results of all the cameras in a FD station. When one or more TFs find tracks, CTD distributes final trigger signals to start data recording procedures for all the SDFs, the TFs and the data acquisition (DAQ) system[12]. Moreover, when each of two neighboring TFs finds a partial track, the CTD also distribute final trigger signals . The total triggering time including SDF and TF processing is 9.8 μs.

Observation

We had finished installation of the telescopes during March 2007 for the first and the second FD station, and made a observation for a test operation of the electronics and the DAQ system in the first (Black Rock Mesa, BRM) station. We measured signals induced not only by air showers but also by the Xe flashers and the LIDAR laser[13] in order to confirm performances of the electronics as expected in the specifications and to select channels which had an initial failure. In April, we developed DAQ softwares and make a test observation for the DAQ system. For the preparation of stereo operations, we tested the electronics and the DAQ system installed at the second (Long Ridge, LR) station in May. In the following month we started a stereo observation with the BRM and LR stations. In this observation season (from July 13th to 20th(UTC)), we had an opportunity to make simultaneous detections of scattered photons which radiated by a Nd:YAG laser at the CLF, which provided evidence for the correctness of the synchronization of the DAQ systems based on GPS in two separated stations.

As one of the performance tests for the electronics, we measured an electrical noise for every channel, and we show a result for a certain camera in Figure 2(a). The averaged electrical noise is equivalent to about 0.5 $\mathrm{p.e./100ns}$. In Figure 2(b) we show a typical waveform recorded at a channel which observed NSB. From our observations, the typical number of photo-electrons of NSB is 7.7 $\mathrm{p.e./100ns}$ on average.

The averaged hit rate measured in May 18th and 20th is 71 Hz per channel with a threshold of 6.0 σ, and the final trigger rate is about 0.9 Hz, which includes surging trigger rates of frequent occurrence induced by the passages of air planes in the field of the stations. In figure 3 we show an example of air shower events detected in July. Figure 3(a) is a map of the shower image lying on the two cameras, in different colors according to integrated signal ADC values of every channel. We can see a clear shower track with a variation of signal strength along the track. Figure 3(b) is waveforms recorded at 10 channels of the cameras of the image map (a). The peak timings of signals shifted because of the passage of the shower front in the field of view. In Figure 3(c) we show a time variation of the light intensity along the shower track calculated with figuring out a sum of signals over the two cameras at each sampling time bin. The horizontal scale is relative time in the unit of micro second and the vertical is the number of excess photo-electrons above the NSB level. This figure is a pseudo longitudinal development curve of the air shower, and we can obviously see a shower maximum between the smooth transition of the intensity.

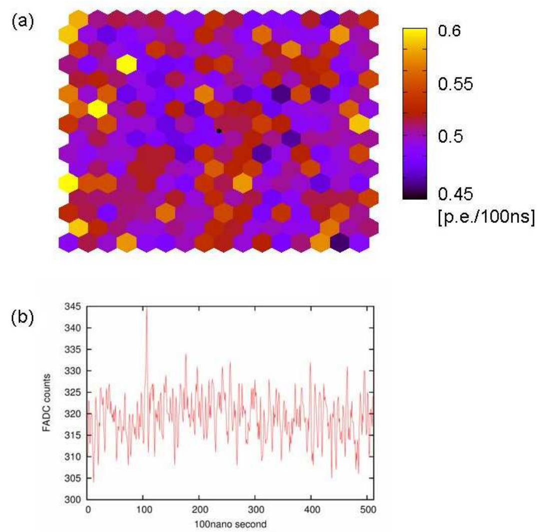

Figure 2: (a)A map of the electrical noise levels on a camera. (b)A typical waveform recored in a channel which observed the night sky background.

In Figure 4 we show one of the candidates of stereo events. The time difference between the maximum light intensities recorded by two stations is about 10 μs, equivalent to about 3 km difference. However the stereo reconstruction for this event has not been finished yet, so that this event is not confirmed as an assured stereo event. It would appear that the image observed at the LR station has a huge contamination of Čerenkov photons, but the details are not understood.

The third site will be operational in September 2007. We will soon be collecting stereo–hybrid data at the Telescope Array.

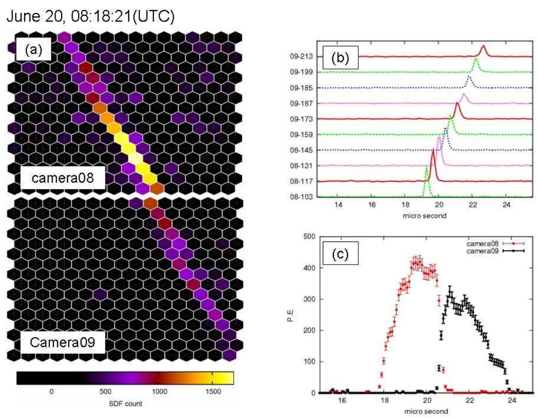

Figure 3: An example of observed multi mirror shower events: (a)the intensity map recorded by the FD cameras, (b)the waveforms recorded at 10 channels of the cameras of the image map, (c)a time variation of light intensities along the track.

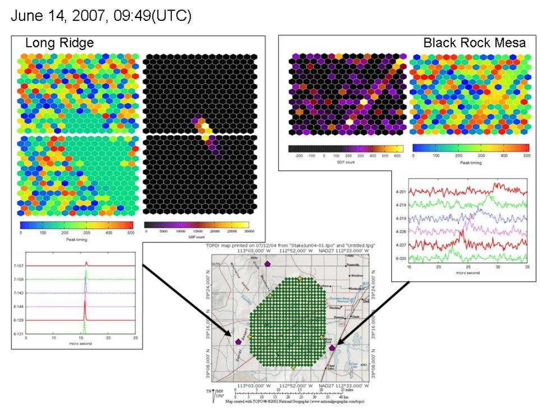

Figure 4: One of the candidates of stereo events observed with BRM and LR station.

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