

## Trigger system for the TA fluorescence detector

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### Abstract

The Telescope Array (TA) is a hybrid detector system consisting of fluorescence detectors (FDs) and a surface detector (SD) array to study ultra high energy cosmic rays. In this paper, we describe the development and status of the trigger system for the TA FDs. The trigger system consists of three components, those are the Signal Digitizer and Finder (SDF) module, the Track Finder (TF) module and the Central Trigger Distributor (CTD) module. The SDF module recognizes the fluorescence signal, TF finds air shower tracks and CTD controls data acquisition. We also report the first engineering run carried out in 2007.

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### 1. Introduction

Cosmic rays are high energy particles traveling throughout the universe. Since the discovery by V.F. Hess in 1912, cosmic ray observations have been carried out by a number of researchers. However, the origin of cosmic rays are still unknown. In particular, the possible existence of ultra high energy cosmic rays (UHECRs) with energies above  $10^{20}$  eV is the most important problem in cosmic ray physics. Soon after the discovery of the cosmic microwave background (CMB) radiation, it was predicted that UHECRs cannot travel long distances greater than 100 Mpc because they interact with CMB photons, therefore they cannot reach the earth [1,2]. There are two experimental results on the energy spectrum of UHECRs, which lead to a controversy:

the AGASA group reported 11 events of cosmic rays with energies above  $10^{20}$  eV [3], on the other hand, no convincing evidence are found on the existence of UHECRs from the result of the HiRes group [4].

In order to solve the origin of UHECRs, we need a new detector with higher energy and angular resolution and statistics. For this purpose, the Telescope Array (TA) [5] project has been started. The TA consists of fluorescence detectors (FDs) and a surface detector (SD) array and located in the western desert area in Utah, USA ( $39.1^\circ\text{N}$ ,  $112.9^\circ\text{W}$ ). FD is the same type detector as HiRes, and the SD array is the same type as AGASA. A hybrid observation using FDs and the SD array enables us to improve the energy and angular resolution. The TA is expected to achieve statistics about 10 times better than AGASA's and an energy scale error less than 10%.

Cosmic ray particles incident to the Earth interact with nuclei in the atmosphere to form a shower of particles

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(mainly electrons and positrons) through the cascade phenomena. The ionizing particles in an air shower excite  $N_2$  molecules in the atmosphere, the excited molecules emit fluorescence light with wavelengths of 300–400 nm. The TA FDs measure these fluorescence photons to determine energies and masses of the primary cosmic rays. We have constructed three FD stations with separations about 40 km. In each station there are 12 telescopes, each of which has a spherical mirror optics and a PMT camera system. The spherical mirror optics with a diameter of

3.3 m consists of 18 segment mirrors. The PMT camera has 256 PMTs of  $16 \times 16$  pixels, and the field of view (FOV) of each PMT is  $1^\circ \times 1^\circ$ . In total, the FOV of one telescope is  $18^\circ \times 15.6^\circ$ . We can detect shower tracks of dozens of km away (Fig. 1).

To record atmospheric fluorescence signals, we use three different electronics modules. The Signal Digitizer and Finder (SDF) module records PMT output digitized with 12 bit 40 MHz FADC into RAM. It has the first level trigger logic, i.e., searches large amplitude signals above a

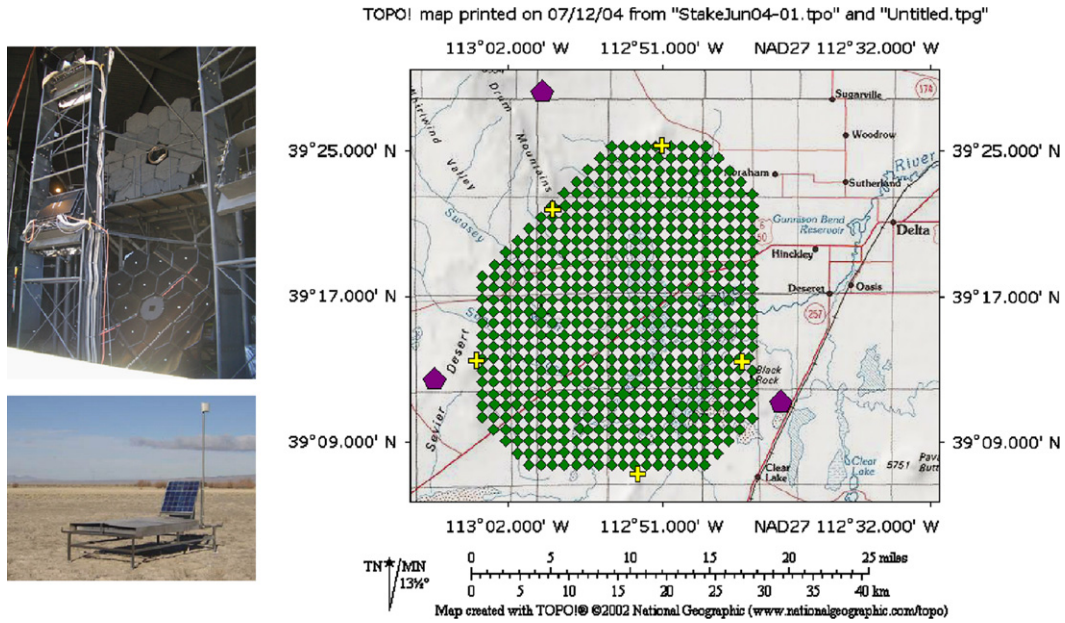


Fig. 1. Telescopes in the FD station (upper left), a surface detector (lower left) and location of the TA FD stations (purple pentagon) and the SD (green diamond) array.

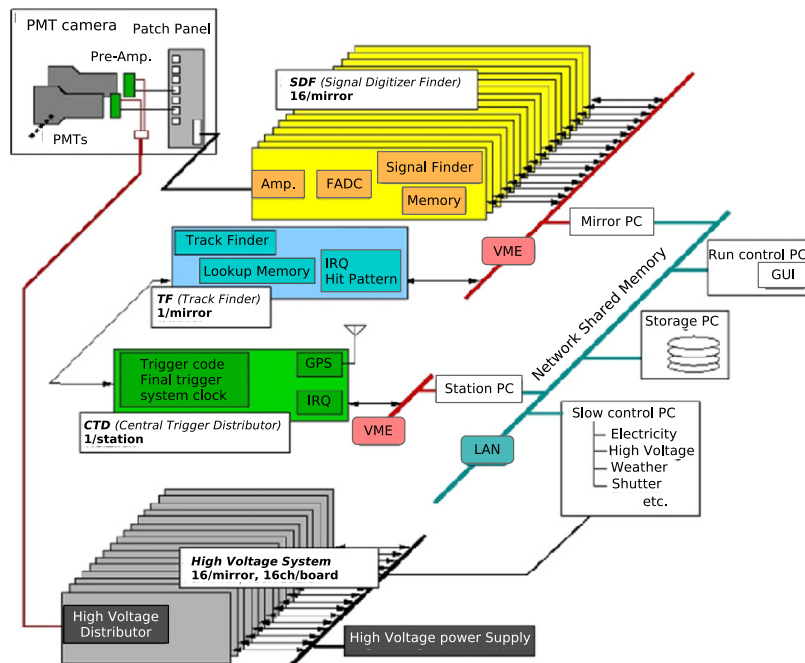


Fig. 2. Block diagram of electronics and trigger system of the TA FD.

threshold level, which is programmable, and discriminates the signal to 0 (not hit) or 1 (hit). For a whole camera, SDFs make a  $16 \times 16$  size map of 0/1 in each  $12.8 \mu\text{s}$  interval, and they transferred this map to the Track Finder (TF) module. The TF module searches air shower fluorescence tracks on the map as the second level trigger, and the result is sent to the Central Trigger Distributor (CTD) module. Finally, CTD decides whether to acquire the event data or not and distributes the final level trigger pulse to all the telescopes.

In this paper we describe the TA FD trigger system, especially TF and CTD, in detail.

## 2. Trigger system for the TA FD

Fig. 2 shows the block diagram of the TA FD electronics and trigger system in an FD station. The time scale of the fluorescence light emissions associated with air showers is an order of  $\sim \mu\text{s}$ . The triggering criteria are examined every  $12.8 \mu\text{s}$ .

The SDF module searches fluorescence signal from PMT output waveform [6]. The SDF module calculates moving average in each time window of 1.6, 3.2, 6.4 and  $12.8 \mu\text{s}$  to find large excess signals over the nightsky background. The average and the standard deviation are also calculated from past 1.6 ms, to normalize moving average counts. The SDF module examines the moving average counts to find fluorescence signals by comparing with a predetermined threshold.

### 2.1. TF module

The TF module is a trigger module (Fig. 3) to find air shower tracks and installed for each of the 12 telescopes. It is mounted on a VME crate, and connected to 16 SDFs through the VME back plane. It is also connected to CTD via an external shielded twist pair cable.

The track findings are carried out every time frame of  $12.8 \mu\text{s}$  by examining the 256 ch hit pattern map, which is a  $16 \times 16$  size map of result of signal recognition of each PMT by SDF. The TF module clips  $5 \times 5$  array maps out of the hit pattern map (see Fig. 4) and compares them with the complete track trigger patterns. The complete track trigger pattern is a  $5 \times 5$  array map which has five or more adjoining hit PMTs and the number of hit PMT

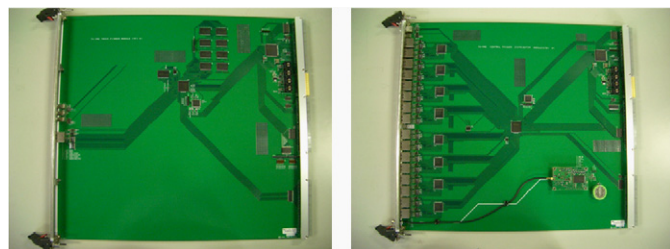


Fig. 3. Track Finder module (left) and Central Trigger Distributor module (right). Both of them are VME 9U boards.

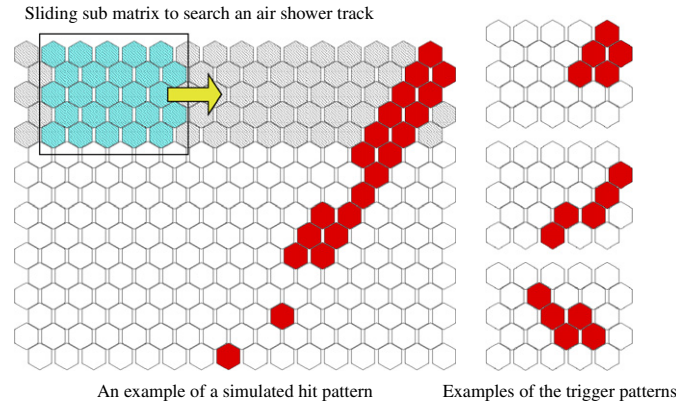


Fig. 4. Examples of the hit pattern map and the complete track trigger patterns.

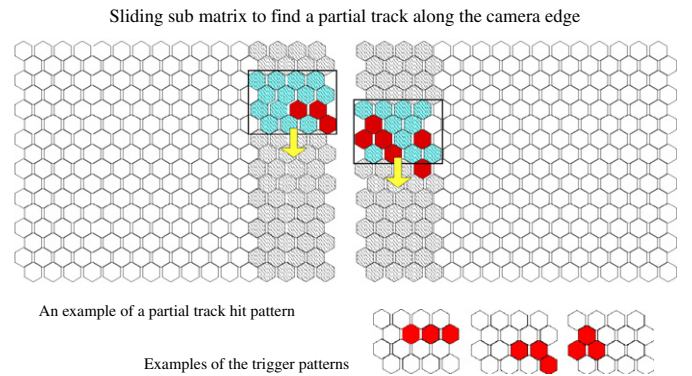


Fig. 5. Examples of the hit pattern map crossing two cameras and the partial track trigger patterns.

combinations is  $2^{25}$ . These patterns are memorized in eight static RAMs ( $512 \times 8 \text{ KB}$ ). The time required to find the complete tracks is  $12^2 \times 25 \text{ ns}$ .

There are shower events such that two cameras are fired and the track lengths in each camera are shorter to be triggered by the complete track trigger pattern. In order not to lose such events, TF cuts out  $4 \times 4$  array maps from the edge of the hit pattern map (see Fig. 5) and compares them with the partial track trigger patterns which are also memorized in a static RAM. The partial track trigger pattern is a  $4 \times 4$  array map which has three or more adjoining hit PMTs along the edge of the hit pattern map, i.e., edge of the FOV of each telescope.

Finally, TF sends a result of the track finding and the time frame ID to CTD. All the logics above are written in a Field Programmable Gate Array (FPGA), Xilinx Spartan 2E.

### 2.2. CTD module

The CTD module is a trigger module (Fig. 3) to decide whether the system acquires the event data or not, which is installed in each station and communicates with all TFs in a station.



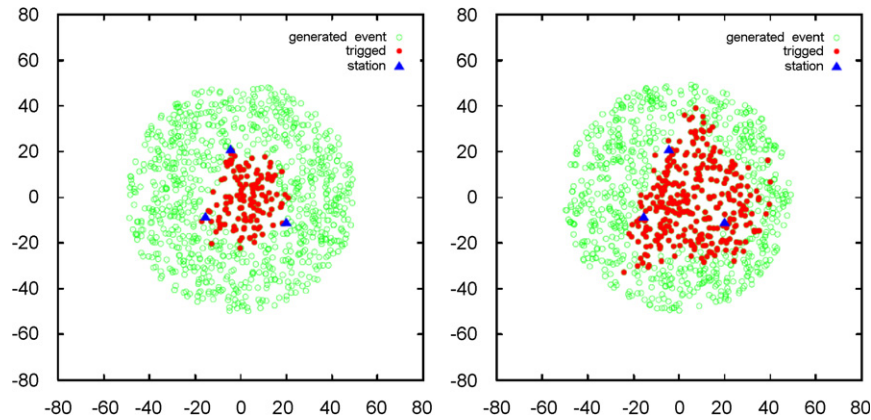


Fig. 6. The core locations of the simulated cosmic rays (green) and triggered by more than two FD stations (red). The FD stations are located at blue triangle. Primary is proton with incident angle of  $30^\circ$  and energy  $10^{19}$  eV (left) and  $10^{20}$  eV (right).

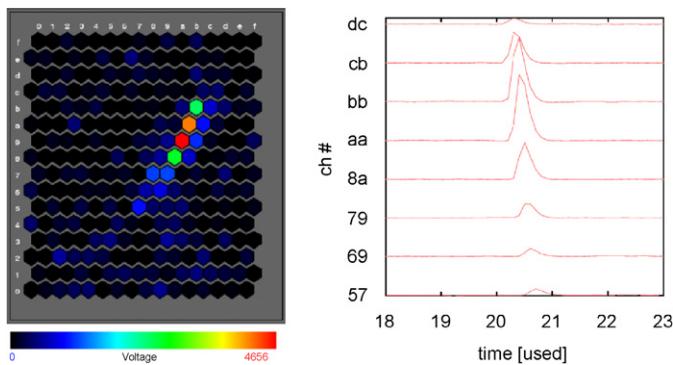


Fig. 7. An example of the shower events (left). Wave forms of a fluorescence signal (right).

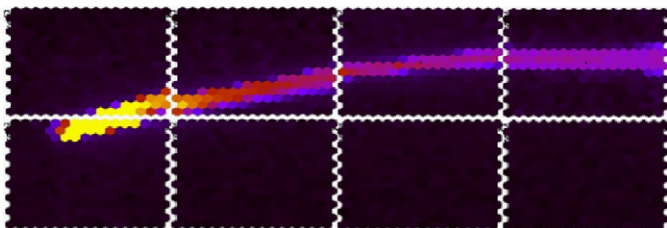


Fig. 8. An image of an ultraviolet laser shoot event with eight PMT cameras.

The CTD module accumulates results of track finding from all TFs every time frame. If there are complete tracks, partial tracks crossing two cameras or external trigger pulses, CTD generates the final trigger pulse for data acquisition. The final trigger pulse is distributed to all the FD trigger electronics.

The CTD module also provides the system clock to synchronize all the FD trigger electronics by distributing reset pulses. A GPS receiver module (Motorola M12+) is installed, so that CTD can record absolute time for each triggered event in the accuracy of  $\pm$  a few ns. This time information is important in analysis other FD station's and the SD array's triggered events.

After the final trigger pulse is distributed, CTD and TFs send IRQ to each VME control PC to start data

acquisition. All the logics above are written in an FPGA (Xilinx Spartan 2E), and CPLD (Xilinx XC9500XL).

The trigger efficiencies of the TA FD with this trigger system is evaluated by a Monte-Carlo simulation. The detection range of the FDs for cosmic rays with energies above  $10^{19}$  eV covers the whole SD area as shown in Fig. 6.

### 2.3. Test observation

A test observation using one telescope was performed in July 2005 at the Black Rock Mesa FD station. An example of the shower events obtained in the test observation is shown in Fig. 7.

Installation of other telescopes has been started from July 2006. In March 2007, we carried out a test run for the data acquisition system including trigger system for multi-telescopes by detecting an ultraviolet (355 nm) laser shoot (Fig. 8). We plan to complete the installation of the telescopes of the two stations in April 2007, and will start stable observations from this summer.

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