Proceedings of the 30th International Cosmic Ray Conference
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Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 5 (HE part 2), pages 1009–1012

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Mérida, México

Characteristics and Performances of the electronics for the fluorescence detectors of the Telescope Array experiment

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Abstract: The three stations of the Telescope Array fluorescence detectors(FDs) contain 12 telescopes each, and each of the telescopes has a 256 pixel PMT camera with a field of view of $18^\circ \times 15.6^\circ$. The fluorescence signals of each pixel are digitized with their waveforms by the Signal Digitizer and Finder(SDF) modules. The results of signal finding from the SDFs are sent to the Track Finder(TF) module to fine air shower tracks. When a shower track image is found in the field of view, the Central Trigger Distributor(CTD) module sends the final trigger signal to all the telescopes to store their data. Here we will describe the characteristic features and performances of the electronics, which are developed and measured through laboratory tests and actual fluorescence light measurements.

Introduction

The telescope array(TA) project[1] has been started to solve the origin of ultra high energy cosmic rays(UHECRs). The TA achieves the hybrid observation with three fluorescence detector(FD) stations and the surface detector(SD) array located in the western desert area in Utah, USA(39.1°N, 112.9°W). TA FD has spherical mirror optics and PMT camera system. The spherical mirror with a diameter of 3.3m consists of 18 segment mirrors whose curvature radius is 6m. The PMT camera has 256 PMTs of 16×16 matrix. The field of view of one telescope is $18^\circ \times 15.6^\circ$.

To record atmospheric fluorescence signals, we use three different electronics modules. The Signal Digitizer and Finder(SDF) module digitizes PMT output and find large excess signals over the night-sky background. The Track Finder(TF) module searches air shower fluorescence tracks by examining the result of SDF. Finally, the Central Trigger Distributor(CTD) decides whether to acquire the event data or not and distributes the final level trigger pulse to all the telescopes.

TA FD electronics

Figure 1 shows the block diagram of TA FD electronics for the FD station. The PMT camera consists of 256 PMTs, which are DC coupled. The signal caused by fluorescence photon is amplified by pre-amplifier attached on the PMT and send to SDF via twist pair cables. The gain of the PMT and the pre-amplifier are adjusted 8×10^4 and 50, respectively.

There are three types of trigger electronics modules: SDF, TF and CTD [2][3]. 16 SDFs and TF

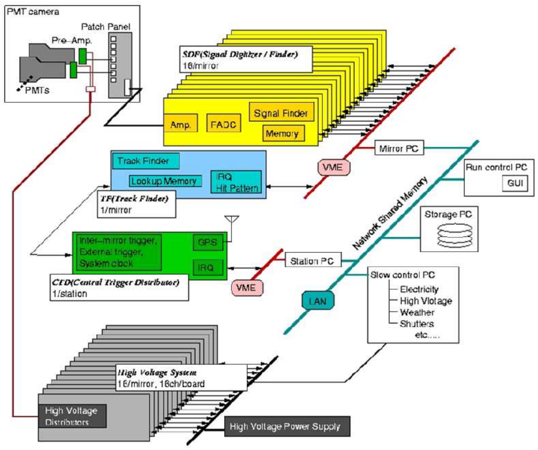

Figure 1: The block diagram of TA FD electronics.

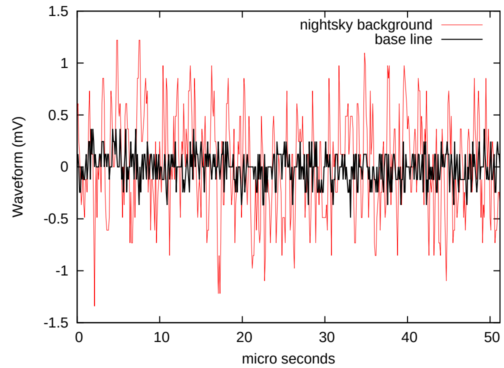

Figure 2: Typical waveform of nightsky background(red) and base line noise(black).

are mounted with one telescope and one CTD is in each FD station. All of them work synchronized with one 40MHz system clock supplied by CTD. Time scale of the fluorescence signals caused by air showers is about $\sim \mu$s. Therefore the trigger judgment process is achieved every 12.8μs time frame.

Signal Digitizer and Finder module

The SDF module digitizes signals from PMT by 12bit 40MHz FADC and records the output of FADC added up with 4 bins as a waveform. The standard deviation of the base line is less than $\sim 200\mu$V(0.6p.e.), which is small enough against that of the nightsky back ground(1.8p.e.)(Fig. 2). Nightsky back ground can be measured directly because we use DC coupled PMTs.

In order to find large excess signals over the nightsky background, SDF calculates moving average in several time windows of 1.6, 3.2, 6.4 and 12.8μs. Average and standard deviation are also calculated from past 1.6ms, to normalize moving average counts. The SDF module examines the moving average counts to find fluorescence signals by comparing with a preset sigma threshold level.

Track Finder module

The TF module finds air shower tracks based on the result of the signal finding by SDF. In order to find air shower tracks, TF examines the 256ch hit pattern, which is the 16$\times$16 size map of the result of the signal finding sent from SDFs. The TF module clips the 5$\times$5 sub matrixes out of the hit pattern and compares them with the complete track trigger patterns, in which there are 5 or more adjoining fired PMTs(Fig. 3:upper).

There might be shower events such that track of air shower crosses two cameras and length of that in each camera are too short to be triggered. Not to lose such events, TF also cuts out the 4$\times$4 sub matrixes from the side of the hit pattern and compare the partial track trigger patterns, in which there are 3 or more adjoining fired PMTs along the side of the PMT camera(Fig. 3:lower). The total processing time to find tracks is $12^2 \times 25$ns. Both the complete and partial track trigger patterns are memorized in static RAMs.

Finally, TF sends a result of the track finding and the time frame ID to CTD.

Central Trigger Distributor module

The CTD module decides whether the system acquires the event data or not. Accumulating the result of the track finding, if there are complete tracks, partial tracks crossing two cameras or external trigger pulses, CTD generates the final trigger

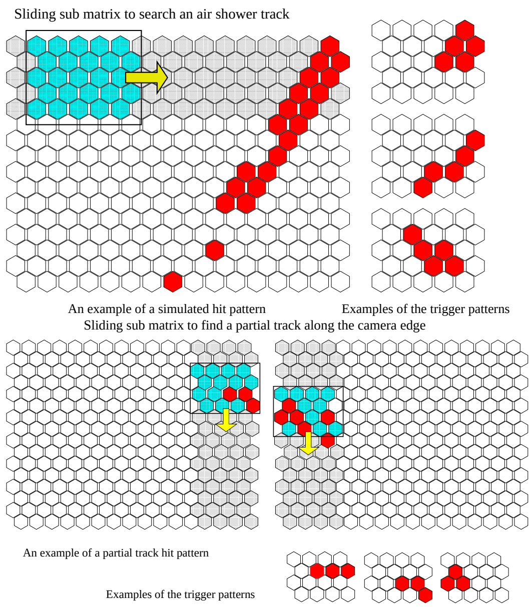

Figure 3: Examples of the hit pattern map and the complete(upper) and partial(lower) track trigger patterns.

pulse for data acquisition. The final trigger pulse is distributed to all the FD trigger electronics.

The CTD module supplies 40MHz system clock pulse to all the trigger electronics modules and sends the reset pulse to synchronize the all of them. If TF misses to receive the system clock, TF switches to the TF inner clock and stands the error bit. The clock is monitored by counting the number of the clock pulses in the interval of the 1PPS from GPS mounted on CTD. After 1PPS become stable, the standard deviation of the number of the clock pulse is about less than 1clock, which equivalents 25ns(Fig. 4). We can know the absolute time information about each triggered event data by GPS time information and the number of clock pulses from the latest 1PPS. This time information is important in analysis stereo event with other FD station or hybrid event with SD array.

The CTD module can calculate the accurate dead time. The buffer is prepared, which enable to store 8 event data. The maximum rate to be able to acquire the air shower data is about 30Hz. This is fast enough against the expected trigger rate, which is less than 0.1Hz. If the trigger rate become more

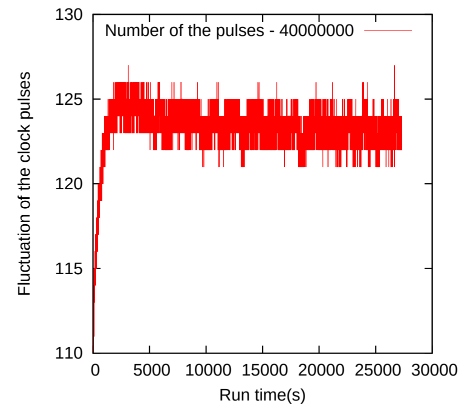

Figure 4: The fluctuation of the number of the clock pulses.

than 30Hz temporally, the data are left in the buffer not to be acquired. At this time the buffer become full (predetermined limit(max:8) event data are stored) and we can not acquire the air shower data any more, even though there is triggered air shower event. This interval should be add up as a dead time. The TF modules send the buffer status which means the buffer is full or not to CTD. The CTD module counts the number of dead time frames(Fig. 5) and records the start and end frame ID of dead time interval. By this information we can know the accurate dead time.

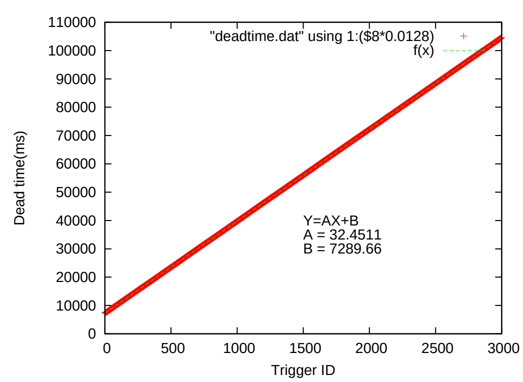

Figure 5: Dead time when the limit of buffer is set as one.

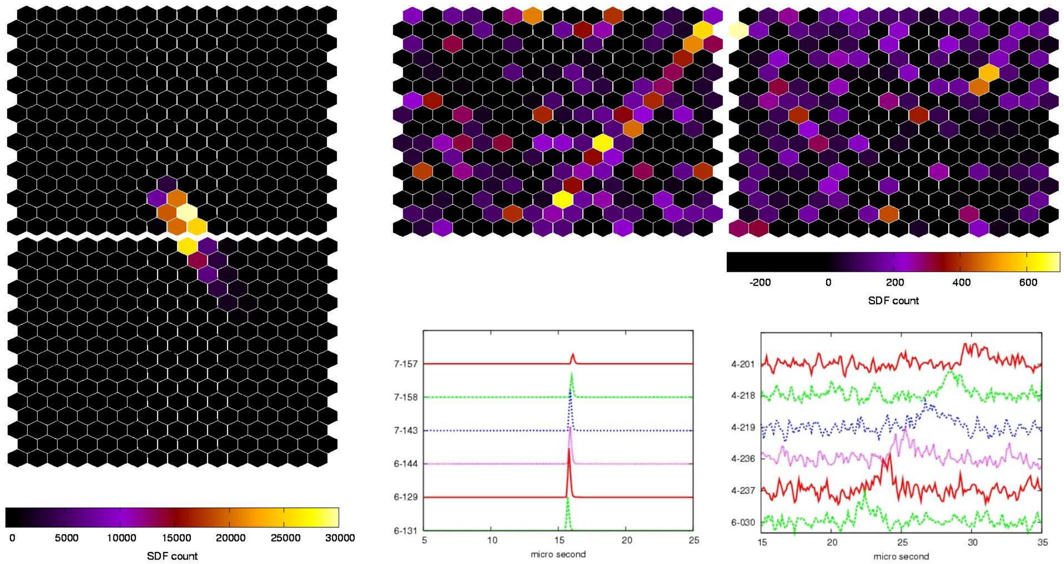

Figure 6: Stereo shower images and waveforms(left:LR,right:BRM).

Test observation

In May 2007, we carried out a test run for the trigger electronics and data acquisition system at each station. In June 2007, we operated 2 FD stations and also investigated whether stereo events can be acquired using the laser shoot located temporally in the future site of the Central laser facility[4].

Figure 6 is the example of stereo event observed at the Long Ridge(LR) and the Black Rock Mesa(BRM) FD station on June 14 2007. The left side and right upper images are intensity maps triggered by LR and BRM respectively. The lower left and right images are some waveforms picked up from channels discriminated at LR and BRM respectively.

In autumn 2007, we will start full operation with 3 FD stations.

Acknowledgements

The TA is supported in part by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan. This work was supported by a 21st Century COE Program at TokyoTech ”Nanometer-Scale Quantum Physics” by the Ministry of Education, Culture, Sports, Science and Technology.

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