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Data acquisition system of air fluorescence detectors for the Telescope Array experiment

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Abstract: The construction of the fluorescence detectors (FDs) of the Telescope Array (TA) experiment have been completed in June 2007, and the stereo observation have been started in June 2007. In this paper, we describe the development of the data acquisition (DAQ) system for the TA FD observations. The DAQ system of each TA FD station is comprised of 16 CPUs: 13 for controls of the FD front-end electronics and 1 for data storage and 1 for environment monitoring, and 1 for the central control of the whole system. We employ the Network Shared Memory system (NSM) for communication of the CPUs. We will present the detail of the system and the performance in the test observations and the first stereo observation.

Introduction

In order to get a definite answer on the origin of ultra high energy cosmic rays, it is important to measure the energy spectrum, the distribution of arrival direction and the composition more accurately. The Telescope Array (TA) is a hybrid detector consists of a Surface Detector (SD) Array which contains 512 plastic scintillator detectors [1] and Fluorescence Detectors (FD) in three stations [2, 3]. It is located in the West Desert of Utah, USA. The three air Fluorescence stations surround the SD array. The separation of the station is 30 km. Primary cosmic rays above $10^{19.0}$ xv falling SD coverage will be detected with Stereo, and FD and SD Hybrid measurements [4, 1]. The hybrid detector measures both the longitudinal development and the lateral distribution of extensive air showers (EASs). Since both SD and FD measures electromagnetic components of EAS mainly, robust estimators of primary cosmic ray energy by the hybrid analysis will be available. From the hybrid measurements, we will determine the primary energy and species with satisfactory accuracy from event by event analysis.

The construction of the fluorescence detectors has been completed in Mar 2007. After that construction, calibrations and adjustments of FD are now in progress. In June 2007, stereo observation has been started with 10 cameras at the first station, and 6 cameras at the second station. In July 2007, in addition 2 cameras were adjusted and taking data at the first station. Other telescopes are calibrated and adjusted continuously in summer 2007. The third station have been constructed. HiRes-I mirror and electronics were transfered from HiRes-site to the third station [3], and assembled. The performance check of equipments and test run is now in progress.

FD DAQ system

Figure 2 shows the schematic view of TA FD DAQ system at the first two sites.

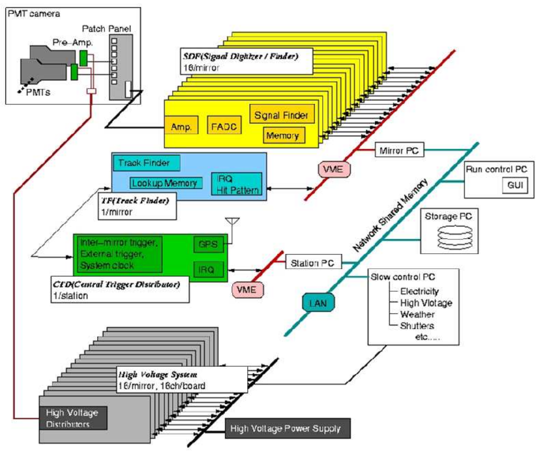

Figure 1: The schematic vie of TA FD DAQ system

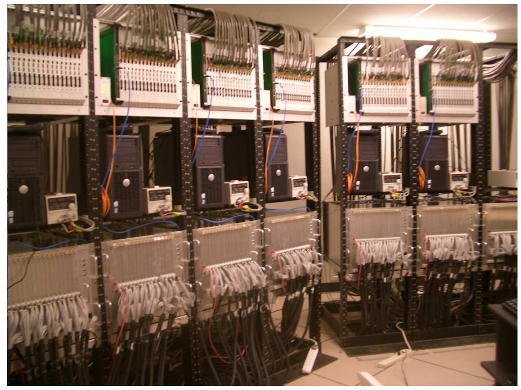

Figure 2: Overview of FD electronics room.

Each fluorescence camera has 256 PMTs (HAMAMATSU R9508). Their signals are measured by the Signal Digitizer/Finder (SDF) with 10MHz, 12 bit resolution and 14 bit dynamic range. Hit patterns of each camera are found by Track Finder (TF) module. The Central trigger distributor (CTD) module recognizes a signal even though a signal across multiple cameras, and distributes trigger signals to store data for all the SDFs and TFs. Digitized waveform and additional information (statistical information, counts of an internal clock, and hit pattern etc.) will be transfered to Personal Computer (PC) via Bit3 interface. Total time of trigger judgment process is within 10 μs. This trigger judgment and signal digitizing process run in parallel. Otherwise data transfer time for each event is $\sim$ 30ms, which is not parallel process. Thus total estimated dead time is 3% at 1Hz from data transfer. In order to reduce the dead time a memory buffer will be installed. By that improvement the dead time will be free if DAQ rate is less than 30Hz.

To take calibration data using some light sources effectively, there are some trigger mode.

One PMT calibration mode: each camera has three PMTs are calibrated absolutely. These PMTs have a calibrated light source on their surface. In order to calibrate absolute PMT-gain, the waveforms of the calibrated light source are measured during the observation period under this trigger mode.

One Camera calibration mode: each camera has a light source mounted on the center of the mirror for adjustment of the relative PMT-gain.

Normal operation mode: The CTD at each station is operating independently of other stations. Thus stereo events will be searched by offline analysis using GPS time stamps.

From FD to SD trigger: we have a plan to install that trigger mode, and the trigger criteria of FD are now studying. The CTD divides a special trigger to Central SD controller. This SD controller broadcasts a command to SDs for getting the coincidence events. Each SD records waveform and timing information.

Other trigger: Triggers from SD to FD and FD station to other FD station are not installed because of limitation of data transfers speed via long-distance wireless LAN. We can search a fluorescence event which is corresponding SD and other FD events by an off-line analysis. Another trigger from FD to Lidar will be installed. When interesting EAS shower is observed, Lidar shoot the laser along the shower axis. For this measurement, we need a fast semi-online analysis direction and primary energy of cosmic rays with some accuracies. The trigger and shooting direction of laser are divided from FD to Lidar.

The following items are recorded event by event:

- SDF waveform
- TF track pattern
- CTD GPS clock, trigger code
- statistical information of each electronics etc.

Measurement conditions are also recorded: trigger condition, the temperature at each camera, and electronics, the relation between the internal clock of electronics and GPS clock etc. during observation. From these information FD events have been reconstructed.

Run control PC communicate with CTD-PC, SDF/TF-PC, via Network Shared Memory (NSM) written by Dr. Nakao (KEK). Network Shared Memory provides a method of sending status and commands with each other. Graphical user interface (GUI) which helps users to operate FD smoothly is preparing. Users can get the information of electronics, environmental, operation setups, and command the devices from the GUI. One of our final goal of DAQ is to achieve a remote control of FDs from a single place (*e.g.* first station) through the Internet. If they cannot be controlled remotely, night observation at different sites needs a lot of manpower. For that purpose, long distance wireless network are installed on FD stations. We check the stability of it, and have to install safety backup system. For example we have to protect camera from sunshine, when a shutter opened has some problems. Integrated test of these softwares and hardware for remote control is now in progress.

FD Stereo Observation

Installation of FD has been finished in Mar 2007, and test observation have been progressed with single station (FD-Mono) [2]. We confirmed the electronics and DAQ system have the expected quality and performance by test operation. Stereo observation using first and second station has been running in June 2007.

The total PMT gain were adjusted before observation season with $1\sigma = \pm 1\%$ level [5]. During the observation we monitored the PMT gain variation in every hours. The main source of the fluctuations can be explained in terms of the variations in temperatures. Temperature dependence of PMT gain will be corrected using monitored temperature in each camera on the offline analysis. Number of PMTs have some trouble is five, which is less than 0.1 % of total number of PMTs in those season. This is because of lower PMT gain, defective soldering of connectors etc. We are checking those PMTs and repairing them. Trigger rate is stable during the observation is 1 Hz. Dominant component of trigger source is the flash of aircraft exterior lights in sky. Photo-cathode of PMT is impressed negative voltage typical -900 V with DC coupling. Therefore we can measure DC component of night sky directory. DC level of star-lights will be used to check arraignments of telescopes. Moreover, deviation of night sky background to check PMT stability, etc.

A temporary laser system was installed at the predetermined point of Central Laser Facility (CLF) is located on the same distance from the three FD stations. It aims for monitor of the atmospheric condition between CLF to each FD site, and GPS timing calibration between each FD sites and SDs [6]. In these observation season, fluctuation of GPS timing stamp is studied using the laser system. The result shows that fluctuation of GPS timing stamp between the first station and the second station is smaller than interspace of 40 MHz internal clock [7]. The relation between internal clock of electronics and GPS clock are modified by offline analysis. A typical value of this relation is 40M$\pm$ 100 in 1 PPS of GPS clock. Also stereo detection have been confirmed using CLF. After that confirmation, we observed EAS events with stereo measurement. From our preliminary analysis, we have some stereo air shower events [7]. These events are being analyzed now.

Conclusion

Installation of FD has been finished in Mar 2007, and stereo observation have been started from June 2007. The stereo measurements are confirmed with CLF events and we observed air shower events with stereo measurement. Integrated test of

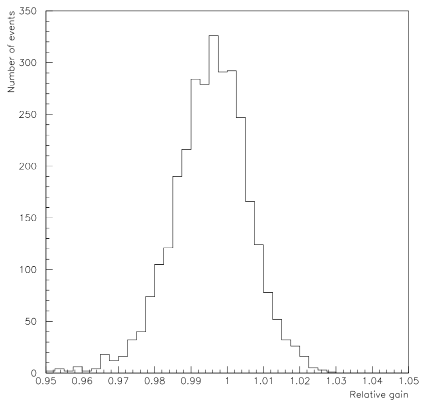

Figure 3: Histogram of the relative gain during observation period.

softwares and hardware for remote control is now in progress.

Acknowledgments

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