Performance of TA Surface Array

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for The Telescope Array collaboration

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***Abstract*. The Telescope Array(TA) experiment, located in the western desert of Utah, USA, at $39.3°$ north and $112.9°$ west, is designed for observation of air showers from ultra high energy cosmic rays. The experiment has a Surface Detector (SD) array surrounded by three Fluorescence Detectors (FD) to enable simultaneous detection of shower particles at ground level and fluorescence photons along the shower track. The SD array consists of 507 scintillation detectors (each consisting of 2 layers of scintillator of area $3\mathrm{m}^2$) deployed with $1.2\mathrm{km}$ of separation. Total coverage of the array is $\sim 700\mathrm{km}^2$. Full hybrid observation was started using the entire array in March,2008. Detailed monitoring of the detector has been dedicated to confirm the stability of detector response and system operation. The variation of detector response due to outdoor environment needs to be monitored carefully. Stability of power cycles of the solar panels and batteries is also maintained. Here we present what has been achieved in long term stability of observation. Prospects for analysis will also be discussed.**

***Keywords*: Surface detector , Extensive Air Shower ,Ultra high energy cosmic rays**

I. Introduction

There exists two major method of observation for detecting EHECRs. One is the method which were taken at the High Resolution Fly's Eye (HiRes) experiment that detects air fluorescence light along air shower track using fluorescence detector(FD). Another is that taken at the AGASA experiment that detects air shower particles at ground level using surface detectors(SD) deployed in wide area($\gtrsim 100\mathrm{km}^2$).

The energy spectrum reported from the AGASA experiment shows that there are 11 events beyond the GZK cut off [1] [3]. However the High Resolution Fly's Eye (HiRes) experiment report the existence of the GZK cut off [5]. The Pierre Auger experiment reported a suppression on the cosmic ray flux at energy above $4{\times}10^{19}\mathrm{eV}$ [6]. But still the contradiction between results from fluorescence detector and surface array remains to be investigated by having independent energy scale at both technique. At same time, anisotropy and correlation between arrival direction of cosmic ray and astronomical objects at this energy region also gives a key to limit the origin of EHECR. The observation with surface array has advantage for the purpose since near 100% of duty cycle can be obtained.

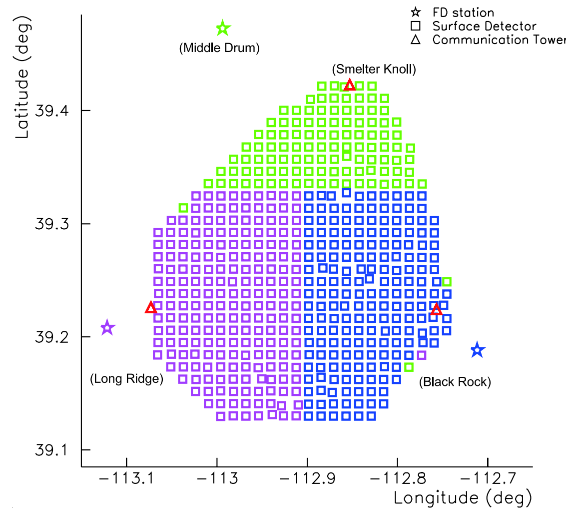

Fig. 1. Area of completed 507 SD array surrounded by 3 FD stations(⋆). △ represents communication tower where the trigger judgment electronics for sub-array are installed. The distance between tower at Long Ridge and Black Rock is 27km.

II. TA Surface Array

Telescope Array(TA) experiment was designed to have both fluorescence detectors (FD) and surface detector(SD) array using plastic scintillator. Those detectors have been constructed and deployed in desert of western Utah,USA (N39.3^o,W112.9^o,1500m asl). At this moment,three fluorescence telescopes and 507 surface detectors have been constructed and deployed. Each SD is deployed in $1.2\mathrm{km}$ of separation. Fig.1 shows area of deployed surface detectors and position of air fluorescence detectors. Total area of the SD array is $700\mathrm{km}^2$ approximately. Fig.2 shows one of the SDs which have deployed one of the communication tower placed at hill called Smelter Knoll(SK). The SD communication antenna is mounted at the 3m of iron pole and the height is adjustable. There $1\mathrm{m}{\times}1\mathrm{m}$ square solar panel is seen. Front end electronics and a battery are contained in the box made of 1.2mm of thick stainless steel under the solar panel. Scintillators and PMTs are contained in the 1.2mm thick of stainless box which is mounted under the roof made of 1.2mm thick of iron. Fig.3 shows schematic views of inside of surface detector. Each surface detector consists of two layers

Fig. 2. A picture of deployed SD. Electronics box and scintillator are on the iron flame. Electronics exists under the solar panel and scintillator box exists under the roof visible at the picture. Each SD are deployed in 1.2km of separation.

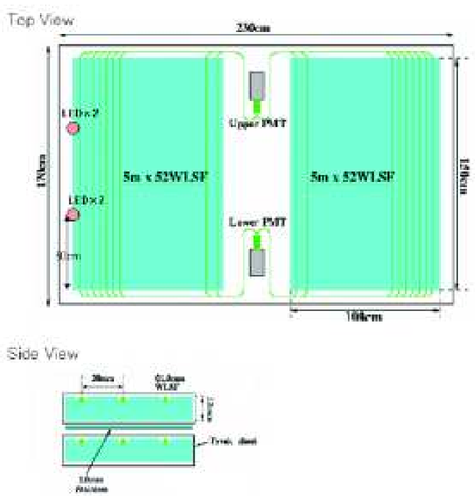

Fig. 3. Top view and side view of inside scintillator and WLS fiber. Total 104 WLS fibers on each layer are laid to collect and transmit scintillation light to PMT. [9]

of plastic scintillators. Each layer of scintillator have $3\mathrm{m}^2$ of area and 1.2cm thick. Scintillation light are collected through 104 of 5m long Wave-Length Shifting fibers (WLSfiber Y-11 Kuraray make) are laid for each layer. Both end of the fiber are bundled and connected to a PMT (Electron tubes : 9124SA). Installed PMTs are calibrated for relation of high voltage to gain and linearity curve [8]. Two LED(Nichia: NSPB320BS) are also installed for each layer to calibrate the output linearity for input light.

The output signal from PMTs are recorded with CPU board equipped with 12bit FADC which is running with 50 MHz of sampling rate. At the current setup, signals greater than 0.3$\times$MIPs equivalent are stored to memory buffer as Level-0 trigger data. And signals greater than 3.0$\times$MIPs equivalent are stored as Level-1 trigger event which is to be sent to trigger judgment electronics via wireless LAN modem using custom made protocol for communication. Trigger judgment electronics are mounted at communication tower for each sub-array.

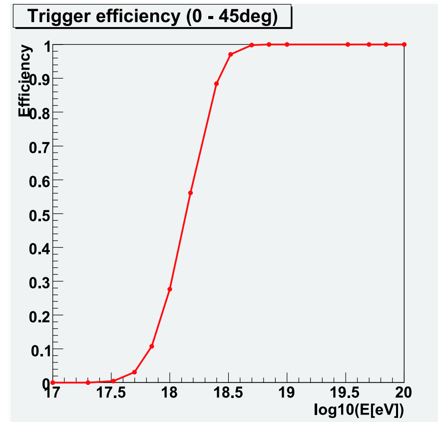

Fig. 4. Trigger efficiency as a function of primary proton energy [7].

The pedestals of FADC trace are monitored inside monitoring loop and corrected every second interval to keep threshold count for trigger. All electronics are synchronized by 1pps signal received by GPS unit (Motorola M12+ oncore module). 20nsec of resolution of time stamp are cleared by 50 MHz of the sub clock on the system board. Total count of the sub clock between 1pps pulses are sent to trigger judgment electronics along with Level-1 event list for correction of time stamp of wave form. Entire system described adove is powered a pair of solar panel(KC125J,Kyocera make) and a commercial car battery (DCS100lT C&Dtechnorogies make). The power system provides sufficient power for required from system(4 W).

A. *SD Array Trigger*

The SD array is divided into three sub-arrays of 207,190 and 110 SDs. The sub-arrays are named Long Ridge(LR) array , Black Rock(BR) array and Smelter Knool(SK) array respectively. The LR array covers west side of entire array and SK and BR coveres noth and east side. Each sub-array is controlled from it's trigger judgment electronics installed at communication tower. Every second,the control electronics collect list of recorded Level-1 trigger event and total count of the sub clock in the period of 1pps from all SDs. Level-1 trigger from SDs those are deployed at the edge of sub-array are also sent to boundary trigger judgment process running at SK tower. From the event lists, air shower trigger is generated when adjacent three SDs are coincident within 8μ sec. After trigger is generated, trigger signal is distributed to all control electronics and they collect wave forms coincidences within $\pm 32\mu sec$ from the trigger timing from SDs. Fig.4 shows trigger efficiency as a function of energy of primary particles(Proton). At energy of $10^{18.7} eV$ the trigger efficiency of SD array reaches 100%. [7]

B. *SD Array Monitor*

A monitoring process is running on each SD with 10 min cycle. The monitor item those have been collected

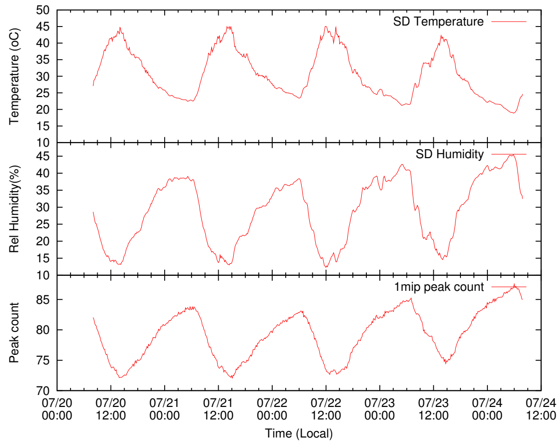

Fig. 5. Example of 1 MIP peak count variation plotted with environmental data taken at SD. Top: variation of temperature at inside of scintillator box. Middle: variaion of relative humidity. Bottom: variation of muon peak.

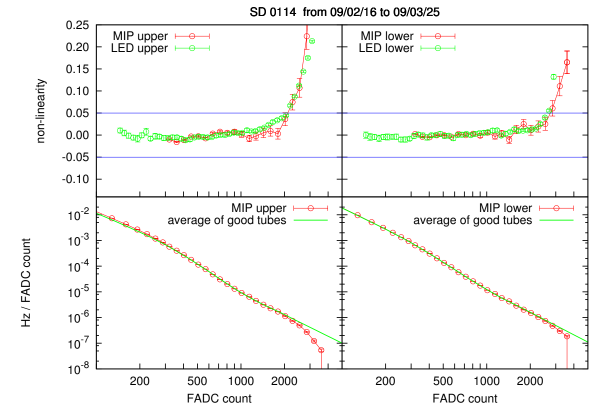

Fig. 6. Preliminary result of comparison of linearity calibration using LED and estimated from monitor data [11] Top left panel shows deviation from estimated linear response at LED calibration and pulse height monitor for upper layer of a SD.Top right panel shows the same plot for lower layer. Bottom left panel shows scaled pulse height histogram observed at upper layer and it's average from good tubes. Bottom right panel shows the same plot for lower layer.

are summarized at TableI. The monitoring data are sent along with Level-1 trigger table each 16byte. One data set of monitoring data are sent using 600 sec. The detail of monitor information are as following.

1) 1MIP monitor: The most frequent charge output by atmospheric muons is used to estimate total energy deposit induced by shower particles. For that purpose, at TA surface detector, the integrated FADC count of Level-0 trigger are collected as a monitoring data. Here the time window for the integration are 240 nsec. Temperature coefficient of gains of TA SDs is -0.8($\%/^{\circ}C$) [10],and diurnal variation of temperature reaches up to $25^{\circ}C$.By this monitor, it is possible to evaluate the change of detector response due to variation of outside environment continuously with 10 min of time resolution.

Fig.5 shows example of 1 MIP peak count variation plotted with environmental data taken at inside of the scintillator box.

2) Linearity monitor: Using LEDs equipped at each layer of scintillator, linearity check were done for all detector before it was deployed. To check the linearity break and its variation in long term of operation, pulse height (FADC peak) histogram and charge output(FADC sum) histogram are taken as a monitor data. Fig.6 shows preliminary comparison of pulse height linearity obtained from LED calibration and the one estimated using pulse height monitor. It shows fairly good agreement and it was confirmed that the histogram can be used for monitoring stability.

3) Power cycle,GPS and environmental monitor: Since the SD is operated by solar panel and battery charge, it is very important to monitor status of solar panel output voltage and current. At GPS module, the 1pps pulse are generated from signals from satellites which is visible through the GPS antenna. To understand the status of GPS module, the number of satellites visible at GPS module and conductivity of the antenna are read out every 600 sec and monitored. Additionally,inside SD ,five temperature sensors and two of humidity sensors are equipped to understand the environment of the detector and electronics box. Fig.7 is an example of plot of monitoring data showing detected GPS satellite, battery voltage and its charging current and Level-0,Level-1 trigger rate plotted with SD enviroinment monitor. The bottom panel shows barometric pressure and air temperature observed at Central Laser Facility(CLF) [4] site located near center of SD array.

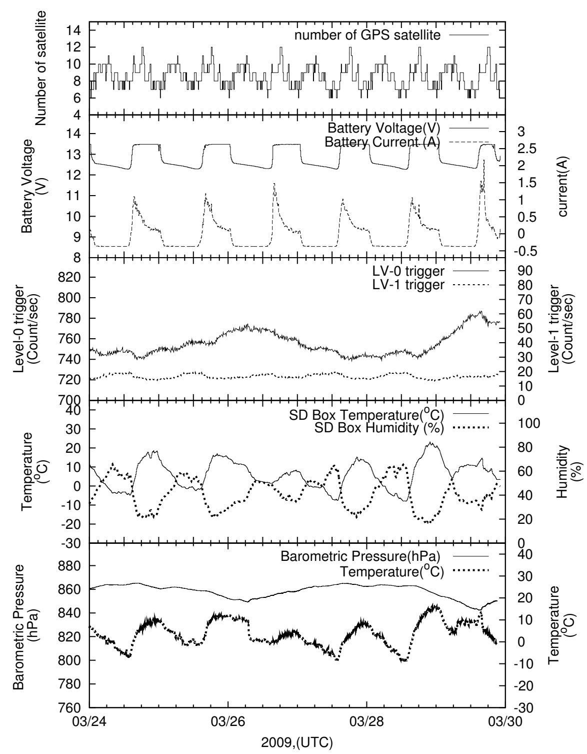

Fig. 7. An example of monitoring data of GPS,Battery voltage and charging current and local trigger rate (Level-0,1) plotted with environmental data(Barometric Pressure and Atmosphelic temperature at CLF site)

TABLE I
ITEMS AND RESOLUTION OF TA SURFACE DETECTOR MONITOR

Item	Data	Resolution
MIP histogram	12bin sum of FADC count	1FADC count 10min
Pedestal histogram	8bin sum of FADC count	1FADC count 10min
Pulse height histogram	Maximum FADC count	32FADC count 10min
Total charge histogram	128bin sum of FADC cont	$\Delta \log_2(FADCsum) = 0.2$
Power Cycle data	Battery,Solar Panel (voltage , current)	1min
Environmental data	temp($^{\circ}C$,)hum($\%$) at SD	1min
Trigger rate	Level-0 , Level-1 trigger rate	1min
GPS status	number of satellite, Antenna status	10min

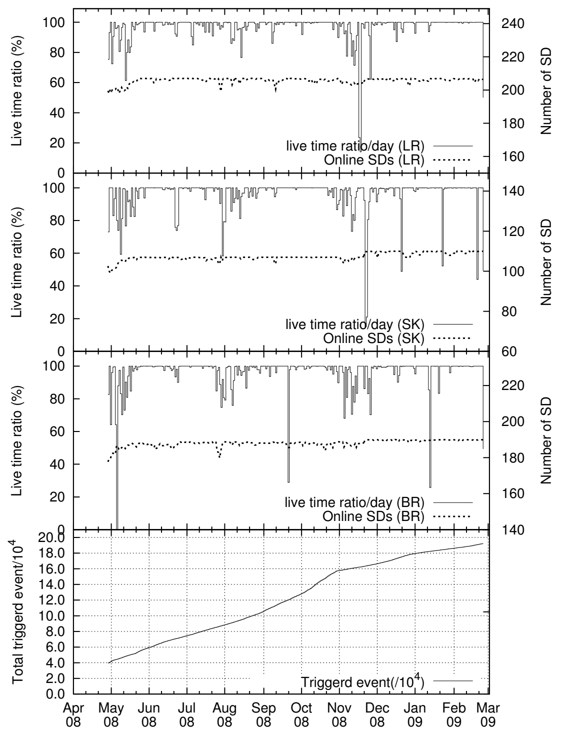

Fig. 8. Running status of all SD array. Top panel: Daily duty ratio of running and average number of active detector at LR array.Second panel: Third panel : same data for SK and BR array.Bottom panel : evolutution of number of triggerd event.

III. RUNNING STATUS AND SUMMARY

Fig.8 shows running status of 1year of SD operation. Status of three sub-arrays is shown in three upper panels. Evolution of number of collected shower trigger event are shown at bottom panel. There, effect of majour daq system upgrade and additional deployment performed in November 2008 is seen.
Including maintainance period, since May 2008 the array has been stable ,and 99% of the detector were on-line on average. At all three sub-array data are collected with 97% of duty cycle as average.

The TA surface detector started operation using full array since March 2008. And for more than one year,events of air shower from EHECR are collected with detailed monitoring data. The variation of detector response and status are well known in $\sim 10\text{min}$ of resolution. Number of event collected untill Mar.2009 has reached 2×10^5 event.

IV. ACKNOWLEDGEMENT

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