# Performance of the Surface Detector of the Telescope Array experiment

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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 for supplying power to SD 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

## 1 TA Surface Array

Telescope Array(TA) experiment was designed to have both fluorescence detectors (FD) and surface detector(SD) array using plastic scintillator. To investigate origin of Extreme highenergy cosmic ray, the experiment observes EHECR to confirm energy spectrum above $4 \times 10^{19}\mathrm{eV}$ [1] [3] [6] ,chemical composition and its anisotropy of arrival direction. Those detectors have been constructed and deployed in desert of western Utah,USA (N39.3°,W112.9°,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 the area of deployed surface detectors and positions of air fluorescence detectors. The total area of the SD array is $700\mathrm{km}^2$ approximately. The observed anisotropy and correlation between arrival direction of cosmic ray and astronomical objects 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.

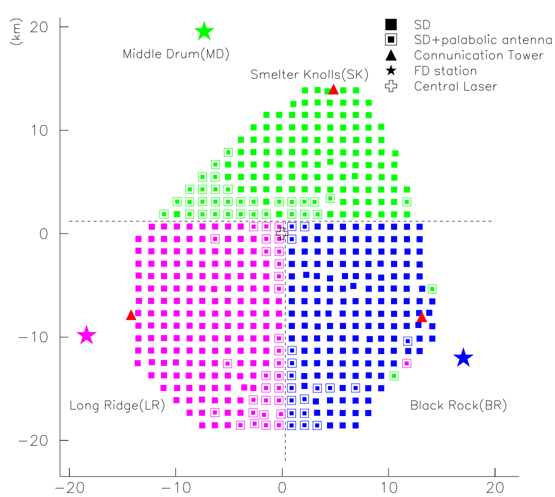


Figure 1: Area of completed 507 SD array surrounded by 3 FD stations($\star$). $\triangle$ represents communication tower where the trigger judgment electronics for sub-array are installed. The distance between tower at Long Ridge and Black Rock is 27km.

Figure 2: A picture of deployed SD. Electronics box and scintillator are on the iron flame. An electronics exists under the solar panel and scintillator box exists under the roof visible at the picture. Each SD are deployed in $1.2\mathrm{km}$ of separation.

## 2 TA surface detector

Fig.2 shows one of the SDs which have deployed at one of the communication towers placed at hill called Smelter Knolls(SK). The SD communication antenna is mounted at the 3m of iron pole and the height is adjustable. There a 1m$\times$1m 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. Each surface detector consists of two layers of plastic scintillators. Each layer of scintillator has $3\mathrm{m}^2$ of area and 1.2cm thick. Scintillation light is collected through 104 of 5m long Wave-Length Shifting fibers (WLSfiber Y-11 Kuraray make) are laid for each layer. Both ends of the fiber are bundled and connected to a PMT (Electron tubes : 9124SA). Installed PMTs were calibrated for relation of high voltage to gain and linearity curve [8]. Two LEDs(Nichia: NSPB320BS) are also installed for each layer to calibrate the output linearity for input light. 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.

The output signal from PMTs are recorded with a 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. The pedestals of FADC trace are monitored inside monitoring loop and corrected every second interval to keep threshold count for trigger. All SD clocks are synchronized by 1pps signal received from a GPS unit (Motorola M12+ oncore module) and run at 50 MHz for 20 nsec time resolution. A scaler pulsed by the 50 MHz oscillator and reset by the 1 PPS signal is used for time stamps for all saved triggers, and the trigger list and time stamps are sent to the communication tower as level 1 triggers. Total count of the scaler between 1pps pulses are also sent to trigger judgment electronics along with Level-1 event list for correction of time stamp of wave form in later analysis. The power requirements of each SD (4 watts) is supplied by a special low current deep cycle gel-cell lead acid battery (DCS 100IT, C&D Technologies) and the battery is re-charged by a solar panel (KC125J,Kyocera) The power system provides sufficient power required from system($4 \sim 5$ W).

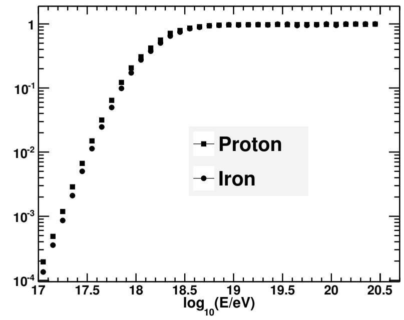


Figure 3: Trigger efficiency as a function of primary proton energy [7].

### 2.1 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 Knolls(SK) array respectively. The LR array covers west side of the entire array.The SK and BR coveres noth and east side,respectively. Each sub-array is controlled from its 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 that 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 $8\mu$ 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. To obtain uniform trigger condition including bondary between sub-arrays inter site trigger process is running at SK communication tower. Fig.3 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]

### 2.2 SD Array Monitor

A monitoring process is running on each SD with 10 min cycle. The monitor items that have been collected are summarized at Table1. The monitoring data are sent along with Level-1 trigger table each 16byte. One data set of monitoring data is sent using 600 sec. The detail of monitor information are as following.

Table 1: 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 |

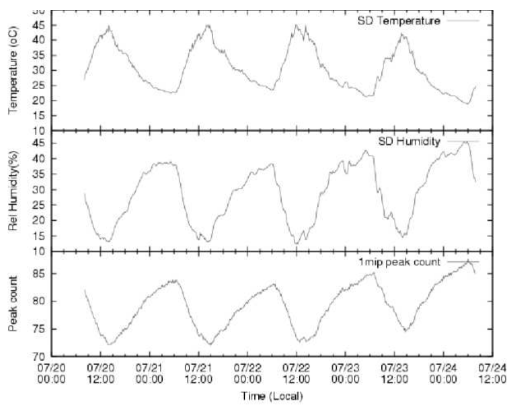


Figure 4: An example of 1 MIP peak count variation plotted with environmental data taken at SD. Top: variation of temperature inside the scintillator box. Middle: variaion of relative humidity. Bottom: variation of muon peak.

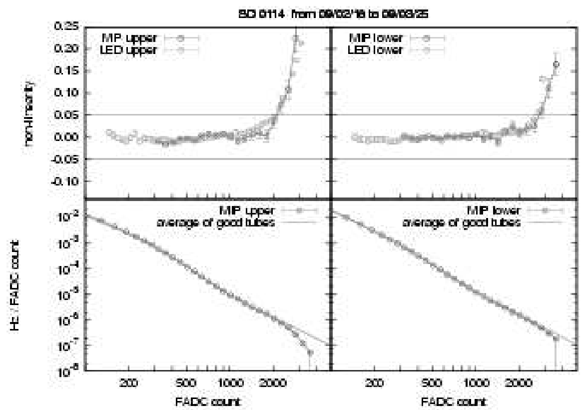


Figure 5: Preliminary result of comparison of linearity calibration using LED and estimated from monitor data [11] Top left panel shows deviation from estimated linear response at LED calibration and pulse height monitor for upper layer of a SD.Top right panel shows the same plot for lower layer. Bottom left panel shows scaled pulse height histogram observed at upper layer and its average from good tubes. Bottom right panel shows the same plot for lower layer.

#### 2.2.1 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 is 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.4 shows example of 1 MIP peak count variation plotted with environmental data taken at inside of the scintillator box.

#### 2.2.2 Linearity monitor

Using LEDs equipped at each layer of scintillator, linearity check was 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.5 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.

#### 2.2.3 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 pulses are generated from signals from satellites which are 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.6 is an example of the 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

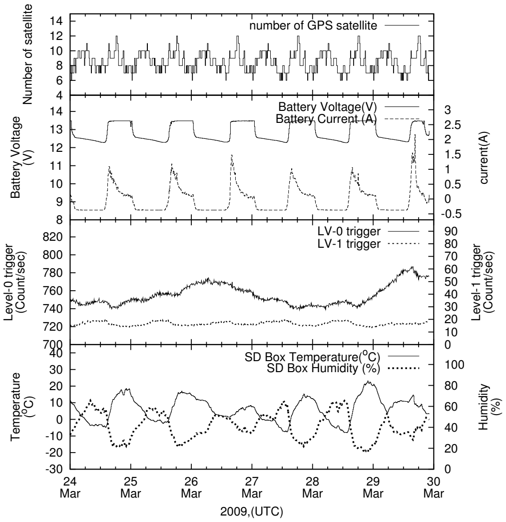


Figure 6: An example of monitoring data of GPS,Battery voltage and charging current and local trigger rate (Level-0,1) plotted with environmental data

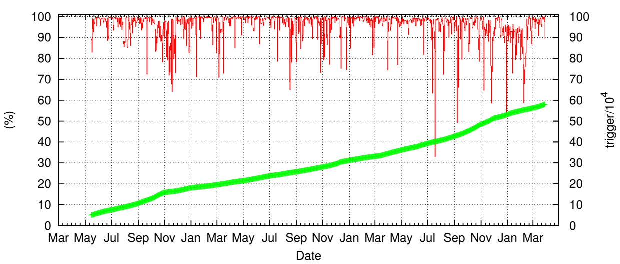


Figure 7: Running status of SD array. Daily duty ratio of running .Evolutution of number of triggerd event is also shown using right vertical axis.

pressure and air temperature observed at the Central Laser Facility(CLF) [4] site located near center of SD array.

## 3 Running status and Summary

Fig.7 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 98% of the detectors were on-line on average. At all three sub-arrays data are collected with 95% of duty cycle as average. The TA surface detectors started operation using full array in 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 $\sim$ 10min of resolution. The Number of event collected untill Mar.2011 has reached $6 \times 10^5$ event.

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