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Observation of ultra high energy cosmic rays with the surface detector array of the TA experiment

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Abstract: The Telescope Array (TA) experiment is a surface array of 512 plastic scintillation detectors in a grid with 1.2 km spacing with three fluorescence telescope stations in Utah, USA, to study the origin of the highest energy cosmic rays. We started the major deployment of the surface detectors in October 2006 and 485 detectors were deployed by March 2007. Each surface detector is outfitted with double layer scintillators of 3m^2 area, readout electronics, and wireless LAN communication system, which are powered by solar system. In this talk, we present the performance of the surface detectors and the shower data observed by the surface detector array, and discuss the prospect.

Introduction

The main purpose of the TA experiment [1] is the measurement of the cosmic ray spectrum beyond 10^{20}eV decisively to solve an outstanding puzzle about the existence or the nonexistence of the GZK cutoff [2] which originated from the discrepancy reported by AGASA and HiRes experiments.

The TA experiment is a hybrid of a surface detector array and three fluorescence detector (FD) stations. The TA site is located in the desert at about 1400 m above sea level near Delta City in Millard County, about 200 km southwest of Salt Lake City in the state of Utah in USA. The surface detector (SD) array consists of 512 plastic scintillation detectors in a grid with 1.2 km spacing covering the ground area of about 700 km^2. For energies greater than 10^{20}eV, more than 90% of the primary energy is transferred to the electromagnetic component (e^+, e^- and γ) at the end of the shower development. The plastic scintillator is sensitive to the charged particles, and the energy measurement is less affected by the difference of the detail of unkown hadronic interactions and the primary composition. The TA experiment uses plastic scintillators like AGASA, and it is expected to understand more for the energy scale by AGASA.

An anisotropy of arrival directions of ultra high energy cosmic rays will be studied in the northern hemisphere where the effect of the galactic disturbance is small.

Surface detector array

Each surface detector consists of plastic scintillators, wave length shifter (WLS) fibers, photomultipliliers (PMTs), electronics, wireless LAN communication system, and a solar power system.

The scintillation counter consists of two layers of plastic scintillator 1.2 cm thick with the area of 3 m^2. The WLS fibers 1 mm in diameter (Kuraray Co.) are installed in the grooves at 2 cm interval on the surface of the plastic scintillator (C.I. Industry Inc.). Both ends of the fibers from each layer are optically connected to a PMT (Electrontubes 9124SA). The scintillation counter is contained in a 2.3m$\times$1.7m$\times$10cm stainless steel box.

Signals from the PMTs are continuously digitized using 12-bit flash ADCs with 50 MHz sampling. For the case that a PMT signal exceeds 1/3 of the single muon peak, the rate of local buffering is about 1 kHz. The wave form is stored locally in a memory with a time stamp supplied by a GPS

(Motorola M12+ Timing Oncore Receiver). The relative timing between remotely separated surface detectors should be maintained within 20 ns by the GPS for the good resolution of arrival direction.

Each surface detector is equipped with a commercially produced wireless LAN modem board using 2.4 GHz spread spectrum technology. To cover communication in the whole surface detector array, the array is divided into three regions. For each region, one communication tower equipped with one host SD electronics is built around the edge of the array. Each surface detector is assigned to one of the three host SD electronics at the towers. A colinear antenna which is indirectional in azimuth is connected to each host SD electronics. The planar-type antenna is used for most of the surface detectors while the parabolic antenna with higher gain is used for the detectors far from the tower.

When one of the PMT signals exceeds a trigger threshold of three muons, the trigger timing information is locally stored in a trigger list, which is transmitted to the corresponding host SD electronics at 1 Hz. The host SD electronics decides the final coincidence trigger based on the trigger table with the requirement of adjacent position condition and a certain time window to take wave forms from the surface detectors as a shower event. The trigger efficiency is expected to be about 100% for cosmic rays with energies beyond 10^{19}eV with zenith angles below 45°. The data are transimitted to a central data acquisition system via commercially available tower-to-tower wireless LAN communication system. More details on SD data acquisition system are found in [3].

The total electrical power consumed by all the electronics is ∼6W. It is locally generated by a solar panel (Kyocera, KC120J or KC125TJ) of ∼120W and stored in a deep cycle battery (C&D Technologies, DCS-100L) of 100 Ah and supplied by a custom-made charge controller.

To check on the stability and detection efficiency of each surface detector, we monitor single muon peak and trigger rate. For the quick check of dynamic range and linearity, we have two LEDs (NICHIA Corp., NSPB320BS) attached to the side of each scintillator layer. The detail on SD calibration is described in [4].

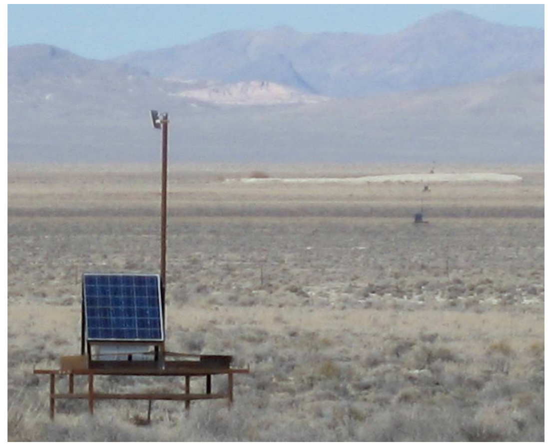

Figure 1: A photograph of a surface detector deployed in the field. A few other detectors can be seen in the distance (in the right side of the photograph).

All the necessary equipment for a surface detector is mounted on a platform constructed of 2 inch square tubular steel legs and frame as shown in figure 1. A scintillation counter in a stainless steel box lies on the platform and is covered with a thin steel roof to avoid sunlight and rain. A solar panel is installed on the platform at a 60 degree angle. Behind and below the solar panel is a metal enclosure containing a 12V battery and most of the electronics. An antenna pole is attached to the frame supporting the solar panel.

Status and prospect

In December 2004, 18 surface detectors were placed as an engineering array to test the deployment and technical designs. The scintillation counters in the stainless steel boxes were assembled in Japan in mass production, and transported to Delta City where all the surface detectors were finally assembled. They were transported by trucks with a flatbed trailer to the staging areas in the TA site, which are accessible by existing roads. Each surface detector was transported by helicopter from the staging area to the position to be deployed. We constructed three communication towers about 12 m high in September 2006. In October 2006,

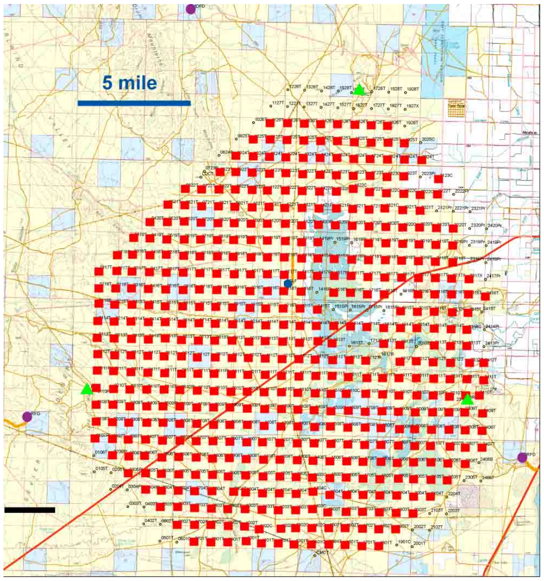

Figure 2: Layout of the surface detector array and telescope stations. The filled red squares show 485 surface detectors which were deployed. The filled green triangles around the edge of the array are for three communication towers and the filled purple circles outside the array are for three FD stations.

we started major deployment of the surface detectors. By the end of February in 2007, 485 surface detectors were deployed as shown in figure 2. Remaining 27 surface detectors will be deployed this fall and the full array is expected to be operational.

The deployed surface detectors are being calibrated and tuned. We can see a clear single muon peak in the integrated ADC distribution. The dependence of the peak value of the single muons on temperature is about $-0.7\%/^{\circ}$C. After subtracting temperature effect, the single muon peak is stable within 5%. A 3-fold coincidence trigger is set up with a trigger level of three muons for the SD data acquisition. An example of an air shower event observed by the surface detectors is shown in figure 3. The detail on the reconstruction of air shower events with the surface detectors is found in [5].

Conclusions

The surface detector array of the TA experiment consists of 512 plastic scintillation detectors. Major deployment of the surface detectors started in October 2006, and we deployed 485 surface detectors by March 2007. The deployed detectors are being calibrated and tuned. Clear single muon signals from the deployed detectors can be seen and the detectors are basically stable. The observed shower data by the surface array are demonstrated. Remaining surface detectors will be deployed this fall and the full array is expected to be operational.

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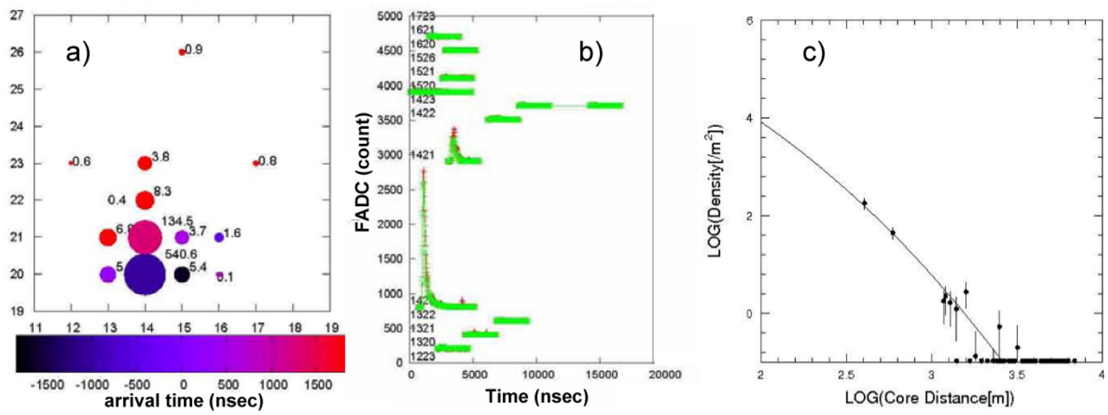

Figure 3: An example of an air shower event observed by the surface detectors. a) Map of the number of charged particles with arrival time in color. The vertical axis and the horizontal axis are the row number and the column number which show the SD position, respectively. The area of each circle is proportional to the logarithm of the number of charged particles. b) The wave form distributions for the surface detectors with data more than about 1/3 muons. c) Lateral distribution of the charged particle density.

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