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Recent Results from the Telescope Array Project

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Abstract

The Telescope Array Project (TA) is the largest cosmic ray observatory in the northern hemisphere and has entered its eighth year of data collection exploring astrophysical phenomena at the highest ends of the cosmic ray energy spectrum. New additions to TA have expanded its reach down to lower parts of the energy spectrum, thus allowing it to probe over an unprecedented 4.5 decades of energy via hybrid detection techniques. Recent results suggestive of anisotropy in the arrival direction of cosmic rays are presented as well as updated measurements of the spectrum, primary source composition, new measurement of the inelastic proton-air cross section, and the first ever quantitative radar cross section upper limit measurement.

Keywords: UHECR, Cosmic Rays, Telescope Array, Proton-Air Cross Section, Proton-Proton Cross Section, Anisotropy, Composition, Spectrum, Radar Cross Section

1. Introduction

The Telescope Array Project (TA) is the largest cosmic ray observatory in the Northern Hemisphere, covering approximately 700 km^2 in Millard County, Utah (centered at 39.3°N and 112.9°W, 1400 m above sea level). It is a joint international collaboration of 33 institutions located in Belgium, Japan, Russia, South Korea, and the United States and is the successor to the AGASA and HiRes experiments. Expertise from the AGASA ground array and HiRes air fluorescence techniques have been combined in TA to build a hybrid cosmic ray detector designed to probe the properties of cosmic rays with primary energies near the "ultra high energy" regime ($E \gtrsim 10^{18}$ eV). The TA observatory is composed of 507 scintillation surface counters sensitive to muons and electrons spaced 1.2 km apart in a grid-like manner which make up the surface detector (SD) array, and 48 fluorescence detector (FD) telescopes distributed in 3 separate detector stations which are spaced in a roughly equiangular manner on the perimeter of the SD array looking towards its center. This configuration allows for independent cosmic ray detection by either just the SD or FD array as well as coincident detection by both, also called hybrid detection. While the fluorescence detectors are restricted to running during clear moonless hours reducing their duty cycle to about 10%, the surface array runs continuously day and night under all weather conditions. Data collection started during the first quarter of 2008 and TA has entered it's 8th year of data collection. Figure 1 shows the physical layout of the TA observatory.

Each surface detector is made up of 2 layers of plastic scintillator material measuring 3 m^2 x 1.2 cm. Embedded in grooves in each layer of scintillator is 5 m of wavelength shifting fiber, which transmits light to a photomultiplier tube, 1 for each scintillator layer, and associated electronics to record the passage of charged particles through the detector. The analog PMT signal is digitized by FADC electronics with 50 MHz clock rate and stored in a local buffer. Onboard electronics implement a triggering system to determine if detected signals represent the passage of particles by an air shower

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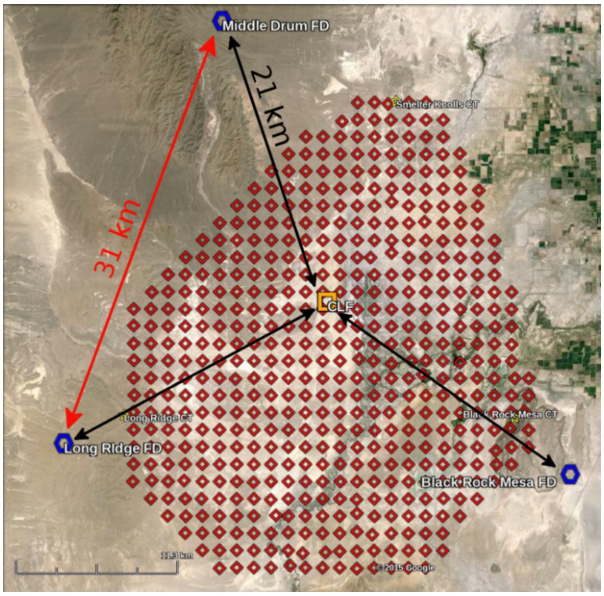

Figure 1: Location of the Telescope Array SDs and FD stations. Each red diamond is one of 507 surface counters and the blue hexagons show the locations of the FD stations which all look in toward the SD array. Yellow stars indicate SD communication towers and the CLF is a calibration laser located equidistant from each FD station.

based upon the signal expected from a minimum ionizing particle. When the trigger threshold for a single SD station is passed, the SD communicates via wireless LAN to one of three communication towers placed around the ground array. Event level triggers are generated by electronics in the communication towers which can direct all SDs that have detected a low level trigger to send their data for storage and event construction. Event data is sent from the communications towers to a central computing facility located nearby and the data is then collected and written to computer hard drives for further analysis. GPS timing is used by each SD station to record the time of each trigger and to record the relative timing of triggers between other SDs and the FD stations as well in the event of a hybrid event. The SD array trigger efficiency is nearly 100% for air showers with energies in excess of 10^{19} eV and zenith angles below 45°[1].

Three FD stations, named Middle Drum FD, Black Rock FD, and Long Ridge FD, overlook the SD array. Each FD station is located about 35 km away from each other around the perimeter of the array. Near the center of the SD array is a central laser facility (CLF) and each FD station is located 21 km away from it. The CLF is used for energy scale calibration between the different stations and to study aerosol distributions in the atmosphere.

Middle Drum FD uses the mirrors and electronics of the HiRes1 fluorescence detector from the HiRes experiment, while Black Rock FD and Long Ridge FD were constructed as new FD stations for the TA project. Reutilizing the HiRes1 equipment allows TA to relate the energy scale of previous measurements from the HiRes experiment to new results measured by TA. There are 14 telescopes viewing 112° in azimuth arranged in 2 rings of zenith angle coverage. Ring 1 telescopes observe between 3° - 17° and ring 2 telescopes observe between 17° - 31° in zenith angle. Each telescope's 5.2 m^2 mirror collects and reflects light onto a cluster of 256 PMTs arranged into a tightly packed 16x16 hexagonal array with each pixel viewing about a 1° cone of the sky. Black Rock FD and Long Ridge FD utilize 12 telescopes at each station with similar sky coverage as Middle Drum. Black Rock and Long Ridge FDs utilize FADC electronics to digitize and record light they observe, while Middle Drum employs a sample and hold electronics design.

Operation of the Telescope Array Low Energy Extension (TALE) began in May 2013. TALE uses 10 FD telescopes pointed up into a higher zenith angle configuration than the other TA FD stations. 5 mirrors each make up a ring 3 and ring 4 viewing a total zenith angle range of 31° - 57° and 100° in azimuth. TALE is colocated with the Middle Drum FD effectively giving that station a zenith angle coverage of 3° - 57° zenith angle coverage of some low energy events. A closeby infill array of SD counters with 400 m spacing is also part of the TALE detector design. There are 31 counters are in place with 16 counters currently operational. TALE was designed to record events in the cosmic ray spectrum down to the region just above the knee ($\sim 10^{16.5}$ eV) and as high as the ankle ($\sim 10^{18.5}$ eV). TALE can also be operated as a hybrid detector combining coincident events measured by the infill array as well as the FD station or independently as only an FD station.

2. Spectrum

The cosmic ray energy spectrum can be observed by TA either independently by the SD array or the FD array. Observations can also be combined between the SD array and the FD array (hybrid observation) or can also be combined between multiple independent FD stations (so-called stereo or triple events). Measurements made by combining the different elements can greatly improve the determination of important air shower parameters such as event timing and geometry, thereby