Telescope Array Measurements of Ultra High Energy Rays

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The Telscope Array is the largest ultra high energy cosmic ray observatory in the northern hemisphere. It is a hybrid detector including three telescope stations and a large array of scintillator surface detectors. It covers about 700 sq.km. in central Utah, USA. We discuss some of the most recent measurements made with this detector as well as the future plans of the collaboration.

1 Introduction

The high energy component of the Telescope Array (TA) is composed of an array of 507 scintillator detectors. Three fluorescence telescope stations (12-14 telescopes each) view the sky above scintillator array. It was operational as of 2008.

The three telescope stations are located on a ~30km triangle. The northern station is composed of 14 telescopes from the HiRes-I site of the High Resolution Fly's Eye (HiRes) experiment. The mirrors are $5.2m^2$ in area. The southern two telescope stations are each composed of 12 telescopes with $6.8m^2$ mirrors. In both cases the telescopes are instrumented with cameras made of 256 PMTs (~1o FOV each). Each station views 3-31o in elevation and ~112o in azimuth. The older HiRes cameras are read out with sample and hold electronics. The newer, southern, telescopes are read out with FADC electronics. The telescopes observe the longitudinal development of the cosmic ray induced extensive air shower.

The surface detectors are each $3m^2$ in area and are composed of two layers of 1.2cm thick scintillator. Optical fibers run through groves in the plastic and bring the light from traversing particles to PMTs, one per layer. The detectors are deployed on a 1.2km square grid and they sample the footprint of the extensive air shower when it reaches the Earth's surface.

Each of the telescope stations and the surface detector array operates separately and the data from each can be analyzed separately or in conjunction with other detectors. Monte Carlo simulations of air showers and the detectors simulated response to these showers was injected into the same actual reconstruction code as the real data. The distributions were then compared to those for real data for a wide variety of signals and reconstructed parameters. These comparisons were in excellent agreement, giving us confidence that the simulations are a good representation

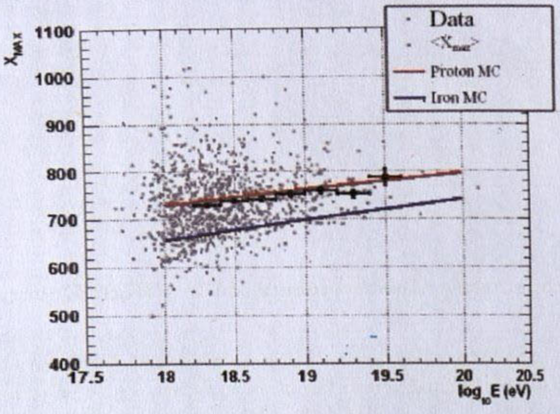

Figure 1 – The Composition as measured in hybrid mode using the first 4 years of Telescope Array data. The gray dots represent the measurement of Xmax of the individual events, while the black points with error bars indicate the mean Xmax for an energy slice. The red/blue lines mark the reconstructed proton/iron Monte Carlo. The data looks very much like the reconstructed protons.

of the data and ensuring that we can trust the resulting aperture calculations.

2 Spectrum and Composition

The Scintillator Array has a duty cycle near 100% and has the largest statistic data set. The five year data set (5/2008-5/2013) has an exposure of ~4500km·str·yr. In fitting the resulting spectrum, we find the break of the "ankle" at $5.40 \cdot 10^{18}$eV and that marking the beginning of the GZK suppression at $5.68 \cdot 10^{19}$eV is in good agreement with predictions and the HiRes measurements. We confirm the HiRes observation of the GZK suppression with 5.7σ significance, expecting 68 events above the break for a continuing spectrum, but only observing 26.

Measurement of chemical composition requires stereo or hybrid measurement of the air shower to constrain the geometry and know Xmax, the maximum in the longitudinal development of the shower. The depth of Xmax results in a distribution of measurements. However, the mean Xmax depends upon the primary particle and is the clearest indicator of chemical composition. This also evolves with the energy of the primary particle. The HiRes measurement of mean Xmax indicates a composition that is light/protonic from $10^{18.25}$ to $10^{19.75}$ eV. The Auger measurement is indicative of a light composition around 10^{18}eV, but appears to become heavier and heavier with energy starting around $4 \cdot 10^{18}$eV.

The HiRes measurement was made using two telescope stations in a stereo method, while the Auger measurement was made using a hybrid technique with surface detectors and one telescope station. In the Telescope Array, we made both stereo and hybrid measurements of the mean Xmax and they are both consistent with the light/protonic composition models. See Figure 1. When the events are divided into energy slices and again compared to the proton and iron simulations, they again look much more like protons than iron at all energies. See Figure 2.

The actual measurements of mean Xmax of HiRes and Telescope Array are not all that different from those of Auger. However, the HiRes and Telescope Array experiments are interpreted in comparison to Monte Carlo simulated protons and iron nuclei after the effects of reconstruction and event selection are taken into account. The Auger collaboration, on the other hand, believes their event reconstruction and event selection do not result in any effect on the distribution of Xmax. Therefore, their measurements are compared to the initial Monte Carlo thrown distributions. This difference gives rise to the difference in the interpretation of

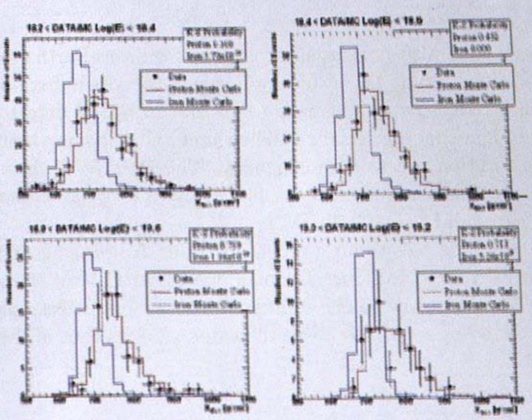

Figure 2 – The Composition as measured in hybrid mode using the first 4 years of Telescope Array data for four energy slices. The energy band included is indicated at the top of each histogram. The black points with error bars indicate the data Xmax distribution for the energy slice. The red/blue lines mark the reconstructed proton/iron Monte Carlo for the same energy slice. In the top right corner of each histogram, the results of a K-S test comparing the data to protons and iron are indicated. In each case, the comparison to protons is highly probable, while comparison to iron is highly improbable. This holds true to the highest energies.

the measurements.

3 Exotic Events and Anisotropy

We have searched for photon induced showers by looking for deep showers with large curvature. We have also searched for neutrino induced showers by looking at extremely deep, very inclined, showers. Both searches found no candidate events and event rate limits have been set.

SPELLING and CITATIONS In 2007, the Auger collaboration announced it had $\sim 3\sigma$ correlation with AGNs in the Veron-Cetti-Veron catalog. Using the same event and AGN selection criteria as the Auger collaboration, we searched the TA data for correlations. The data correlate with the selected AGNs at a rate only slightly higher than random background expectations, but about 2σ lower than the 2007 Auger rate measurement. If there is any correlation in the north, it is much weaker than the original 2007 report from Auger. In the time since 2007, the Auger collaboration has also indicated that the correlation they have since observed is much weaker than the original report.

4 New Developments

The initial construction of the Telescope Array was optimized for events with energies greater than 10^{19}eV. The trigger efficiency of the scintillator array drops rapidly below $\sim 5 \cdot 10^{18}$eV and there is no overlap of the fluorescence exposure at this low energy. In addition, the distance at which a telescope can observe a lower energy event is smaller since the number of particles in the shower is smaller and the amount of light generated less. The closer distance pushes the elevation angle of Xmax is higher in the sky. In order to push the energy threshold of the experiment down towards the "knee" of the cosmic ray spectrum as well as towards LHC energies, we have installed a new telescope building at the northern telescope site. The addition is composed of 10 telescopes from the HiRes-II site and have FADC electronics. The additional telescopes view the sky above the initial 14 telescopes, hence the site now views 3-59° in elevation. The new telescopes have all been installed and the first events have already been observed in unison with the original telescopes

Lower energy air showers also have smaller footprints on the Earth's surface. Therefore, we are in the process of adding a graded array of scintillator detectors in front of the newly improved telescope station. The graded array adds more than one hundred detectors to the array. The closest detectors have 400m spacing. In the middle range, the spacing is 600m. This extends to 1200m spacing as the addition meets the main array. The first 35 of these detectors have been deployed and are being commissioned. The combined low energy extension to Telescope Array will lower the energy threshold to $\sim 3\times 10^{16}$eV.

This fall the group intends to submit a proposal to our funding agencies to expand the size of the Telescope Array by a factor of four. The plan would add about 500 additional scintillator detectors on a 2km grid and would add one additional fluorescence telescope station. This would increase theTelescope Array aperture to about the same size as that of the Auger experiment.

5 Summary

The Telescope Array is a large cosmic ray detector working to carefully control systematic uncertainties. It has picked up where the High Resolution Fly's Eye, HiRes, left off in measuring ultra high energy cosmic rays in the northern hemisphere. There are multiple analyses going on for each of the data sets from each detector system, telescope stations and scintillator array. The ankle and GZK suppression have been confirmed. The composition is determined to be light/protonic over the full energy region measured to the highest energies. There are no signs of photons or neutrinos yet in the data. While the correlation with AGNs, if there is any, appears very weak, there are some hints of anisotropy with the large scale structure. Finally, we are in the process of adding a low energy extension to the Telescope Array which will lower its energy threshold to better understand the transition from galactic to extra-galactic cosmic rays.

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