Performance of the Fluorescence Detector of the Telescope Array

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Abstract: The Telescope Array experiment operates three fluorescence detector (FD) stations on the periphery of the surface detector array. All three stations have been in routine observation on clear, moonless nights since November of 2007. In this presentation, we will report on the data taking efficiency and cumulative observation time of the three detectors. We will also discuss the on-going optometric calibration at each site, and cross-calibration between the three sites. For these, we employ a combination of several techniques including UV LED and xenon flashers, as well as YAP sources. In addition, we will report on progress of the atmospheric monitoring from the mono-static LIDAR, IR cloud monitors and inter-site calibrations using from the central laser (CLF). The calibration of the FDs and monitoring of atmospheric conditions are important for control of systematic uncertainties in shower reconstruction.

Keywords: UHECR, fluorescence, technique, extensive air shower,

1 Introduction

The air fluorescence technique of observing extensive air showers (EAS) is perhaps the most powerful method for measuring ultrahigh energy (UHE) cosmic rays ever devised. The technique was originally suggested independently by Greisen [1] in the U.S. and by Suga [2] in Japan. The first successful fluorescence detector (FD) that produced measurements on the energy spectrum[3], composition [4] and arrival direction anisotropy [5] was the Ely's Eye [6] of University of Utah. Refinement of the Fly's Eye technique led to the construction of the High Resolution Fly's Eye (HiRes) experiment that was the first to observe [7] the predicted Greisen-Zatsepin-Kuz'min (GZK) cutoff [8] [9] in the UHE cosmic ray spectrum.

The Telescope Array (TA) experiment is a joint effort of groups from Japan, U.S., Russia, South Korea, and Belgium. The core of the new collaboration consists of the former leading institutions of the HiRes and the Akeno Giant Air Shower Array (AGASA) group [10]. The new experiment also combined the two major techniques for UHE cosmic ray measurements: the fluorescence technique used by HiRes, and the scintillation counter ground array used by AGASA. The main advantage of the ground array is that it can be operated both day and night. The TA ground array, for instance, operates at better than 99% on-time. The Fluorescence detector on the other hand, is limited to operating on clear, moonless nights (10% duty cycle). Whereas the ground array has a well-defined fiducial area that is mostly independent of energy down to its threshold, the aperture of a fluorescence detector varies continuously with energy. The fluorescence detector, however, is able to view the longitudinal development of the air shower, which then gives it good statistical power to discern light and heavy components of the cosmic ray flux. A fluorescence detector together with a well-matched scintillation array produces reconstruction resolutions that are superior to both techniques alone, and comparable to that of stereo fluorescence observations.

2 The Telescope Array experiment

The TA experiment is located in the West Desert of Utah near the town of Delta. The site is about 240 km southwest of Salt Lake City and the University of Utah. The primary components of the experiment are three fluorescence detector stations placed at the periphery of a 730 km^2 ground array of scintillation counters. The scintillation counters each consist of two 3m^2 layers of plastic scintillators with extruded grooves. Wavelength shifting optical fibers embedded in these grooves collect the light from each layer into a single photo-tube (two per counter). The counters are linked by 2.4 GHz wireless system to three main antennae located near the FD sites.

At the two southern sites, Black Rock and Long Ridge, new FD telescopes designed specifically for the TA experiment were constructed. Each site houses 12 telescopes with 3m diameter mirrors. Each camera consists of an array of 256 pixels instrumented with Hamamatsu R9508 2-inch diameter photomultiplier tubes (PMTs). Each pixel covers about a 1.1° cone of the sky. The signals from the PMTs are recorded by an FADC operating at 10 MHz. A centralized track finder system is used to look for track-like hit patterns in time coincidence. Once a trigger is activated, 51.2 μs (12.8 μs before, and 38.4 μs after the trigger) of recorded data are read out for every PMT at the site.

The northern most FD site at Middle Drum (MD) was constructed from 14 refurbished telescopes from the HiRes-1 site of the High Resolution Fly's Eye (HiRes) Experiment. Each of these telescopes has a 2m diameter mirror, and a closed packed array of 1-inch EMI 9974KAFL (telescopes 1-6) and Photonis (formerly Philips) XP3062/FL (telescope 7-14) PMTs. Here each pixel views a 1.0° cone of the sky. The time and pulse area information from each channel is readout using traditional TDC and sample-and-hold charge integrator through an ADC. The 14 telescopes trigger individually, with a reduced trigger condition if a neighboring telescope registered a full trigger. Only those telescopes that trigger are read out and data from groups of triggered telescopes within 100 μs from one the next are combined as a single event. The use of refurbished HiRes-1 telescopes reduced the cost and construction time of TA, but also allows TA to make a direct comparison to the HiRes experiment.

3 Photometric Calibration

The absolute photometric calibration of the PMTs is the most basic measurement required for the proper setting of the cosmic ray energy scale. For the Hamamatsu R9508 tubes, an absolute light source named CRAYS (Calibration using RAYleigh Scattering) [11] was used. The scattered light from a 337 nm nitrogen laser in a N_2 filled chamber was used to calibrate three primary PMTs for each camera. Each primary PMT is also equipped with a alpha-ray scintillation light source mounted on top of its detection surface. These YAP sources consist of a 50 Bq ^{241}Am source embedded in $YAlO_3$:Ce scintillator [12][13]. The YAP sources monitor the stability and temperature dependence of the primary tubes. The primary calibration is transferred from calibrated to uncalibrated PMTs using an in-situ xenon flasher [14].

The PMTs at the MD site are calibrated in the same way as the HiRes telescopes. The gains of all PMTs are calibrated using a portable, high-stability xenon flash tube referred to as the roving xenon flasher (RXF) [15]. These pulsers have been found to be stable to better than 2% over the course of a night. The RXF itself is calibrated against NIST-calibrated photo-diodes. RXF calibrations are run about once per dark period (lunar month). UV LED pulsers are used for nightly relative calibration and to track short term stability.

Cross calibration between FD sites was made using both the RXF device and one of the UV-LED modules carried to all three sites. In addition, a vertical energy-tripled YAG laser at the central laser facility (CLF) [16] fires a series of 355 nm shots every 30 minutes that can be viewed simultaneously by all three detectors. The CLF is also located at the same distance from all three sites, and any variation in aerosol concentration in the air is to first order common to all three detectors. Therefore the intensity of the scattered light seen by each FD is the same. The combination of RXF and CLF have proven to be very effective in eliminating measurement and analysis errors in the calibration process, and bringing the optometric calibration of the three FD sites into agreement.

Most recently, the TA collaboration is carrying out an end-to-end calibration effort using the ”Electron Light Source” (ELS) [17]. This facility places a small linear accelerator that directs a pulses of 40 MeV electron vertically upward into the air. The vertical beam is located at a 100m distance in front of the BR telescopes. Its design intensity is to give pulses that are equivalent to an extensive air shower of 10^{20} eV in energy at 20 km viewed at 20 km away from the FD. This device will provide a real test beam calibration which have not been available to any fluorescence detector until now. In this way, the ELS is a unique feature of TA.

4 Atmospheric Monitoring

Because the air showers are viewed by the FD from a distance of up to 40km or more, absorption and scattering of the UV light through the atmosphere is another important factor to our understanding of the energy scale. The attenuation comes from two components: Rayleigh scattering from the constituent molecules of air, and from scattering through the particulate (aerosol) contaminants suspended in the air.

For the molecular scattering, a good knowledge of the vertical atmospheric profile is needed, especially for the precise determination of shower maximum depth (X_{max}), which gives the primary measurement of composition. The data used by TA is collected twice daily via radiosonde balloons from the two major airports in the vicinity of TA: KSLC (Salt Lake City International), and KEKO (Elko Regional Airport in Nevada) [18]. The measurements from the two airports are typically in excellent agreement with one another. The TA site is located at the downwind end of the Great Basin, which is largely free of significant orographic features that might stir up the atmosphere. The radiosonde from these two airports thus provide excellent representation of the atmospheric profile for the entire region.

Whereas the atmospheric density profile varies relatively slowly with time, the aerosol concentration can vary dramatically from night to night, based on wind and other weather conditions. The monitoring of the aerosols at TA relies primarily on the data collected from the LIDAR system located at the BR site [16]. The LIDAR measures backscattered light from a dedicated 355 nm YAG laser. The results of more than three years of measurements show an average aerosol density and profile that are essentially the same as that measured at the old HiRes sites 150 km north of TA. The details will be presented in a separate paper at the 2011 ICRC [19]

Cloud cover in the field of view of a fluorescence detector can reduce the detector, aperture in ways that are difficult, if not impossible to calculate. Scattering of light by clouds can also lead to anomalous shower profiles during reconstruction. To identify the presence of cloud cover, an IR camera (AVIO TVS-600S) is used to continuously image the sky. For the MD site, seven IR sensors measure the sky temperature relative to the ground as an additional indicator of cloud cover (clouds are significantly warmer than clear sky). Finally, the observers at the MD site also make visual observations of the field of view about once every 60 minutes, and more frequently in case of unstable weather conditions. Correlation studies have shown excellent agreement between the IR camera and the visual observations.

5 Observations

The FD stations at BR and LR were constructed first, and began observations in June of 2007. Figure 1 shows the cumulative good weather data during the hybrid observation period starting in June of 2008, when the surface array became operational. The accounting in this plot ends in the September dark period of 2010. The four curves show, starting on top, the total number of hours of operation where at least one of the BR or LR sites was observing, the stereo data hours (when both BR and LR were taking data), the number of hours when only BR data was selected, and the hours where only LR data was selected, respectively. The selection criteria at each site are subject to local weather variations, since the two sites are more than 20 km apart. During this period of about 800 days, about 1300 hours of good weather data were collected at BR, and 1100 at LR. The overall data collection under all weather conditions where it was safe to open the shutters were about 2200 hours at BR, and 1900 at LR. These correspond to a duty factor of over 11% for BR and just under 10% for LR. It should be noted that observations at the LR site is done entirely by remote control from the main BR control room, and thus the operators tend to be more conservative about opening the shutters and exposing the detectors to potential precipitation and wind damage.

The Middle Drum site completed construction just before the 30th ICRC. After one month of shakedown running starting in the November 2007 dark period, routine data collection began in December of 2007. Figure 2 shows the number of telescope-hours of operation accumulated during the three year period of Dec. 2007 through Dec. 2010. The three curves show, starting from top, the total number of dark telescope-hours available (black), the number of telescope-hours of data collected under all weather conditions (red), and the number of telescope-hours of good weather data selected for analysis (blue). As the efficiency for 13 of the 14 telescopes are above 99%, and the remaining telescope at better than 98%, one can simply devide the telescope-hours by 14 to determine the site on-time. Through the three year period, 2400 hours of good weather data was collected from MD, which corresponds to just over 9% duty factor. This is roughly 10% larger in intergated exposure than the AGASA experiment at 10^{20} eV, and about 1/3 of HiRes-1 exposure. The corresponding all-weather duty factor was about 11%.

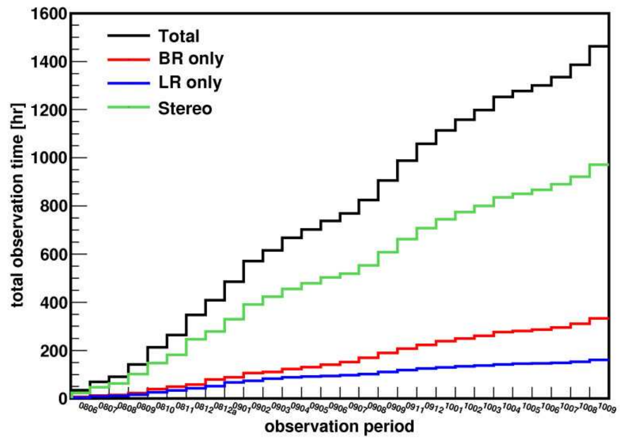
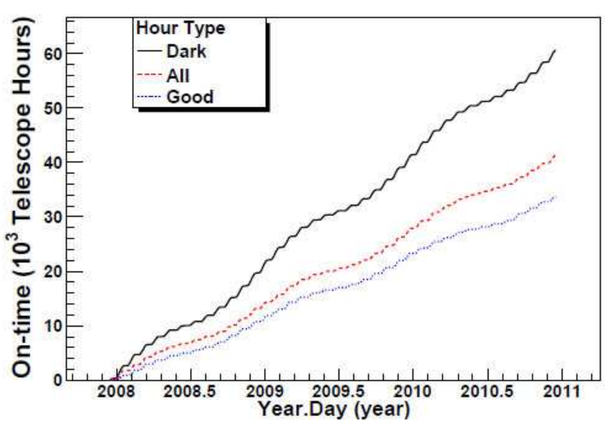


Figure 1: Cumulative data collection at BR and LR FD sites from June 2008 through September 2010: Starting on top, the total number of hours of operation where at least one of the BR or LR sites was observing (black), the stereo data hours (green), the number of hours when only BR data was selected (red), and the hours where only LR data was selected (blue), respectively.



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6 Summary

FD operations at TA began in June of 2007. By December of 2007, all three FD stations were in routine observation. With the surface scintillation counter array coming on-line in June of 2008, we have now accumulated close to three years of hybrid data as well. These observations have continued without pause through March of 2011. Individually each of the three FD's have each achieved roughly the same exposure as the AGASA experiment. The three FD sites have been cross-calibrated using the RXF and the CLF light sources, and analysis of the data from the first runs of electron light source is well under way to provide a true test beam energy calibration. Monocular and hybrid FD spectra will be shown at the 32nd ICRC, along with results of composition studies using both stereo and hybrid reconstructions.

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