Calibration of the Pierre Auger fluorescence detector

M. D. Roberts[1] for the Auger Collaboration[2]
(1) Dept. of Physics, University of New Mexico, Albuquerque, NM 87131-1156, USA
(2) Observatorio Pierre Auger, Av. San Martin Norte 304, (5613) Malargue, Argentina

Abstract

The absolute calibration of an air fluorescence detector (FD) is an important element in correctly determining the energy of detected cosmic rays. The absolute calibration relates the flux of photons of a given wavelength at the detector aperture to the electronic signal recorded by the FD data acquisition system. For the Auger FDs, the primary absolute calibration method uses a diffusive surface which is placed in front of a telescope aperture to uniformly illuminate the telescope field of view with a known light signal. This single-wavelength measurement (375 nm) will be made at intervals of several months until the stability of the telescopes is determined. The relative wavelength dependence of the calibration is determined through independent measurements. The error in absolute calibration at a single wavelength is estimated to be less than 10%. Two other absolute calibration methods are used to provide an independent verification of the primary measurement. The stability of the calibration with time is monitored nightly by a relative calibration system. In this paper we will provide descriptions of the absolute and relative calibration methods used by the Auger air fluorescence observatory. Results from the calibration of the Auger Engineering Array telescopes will also be presented.

1. Introduction

The absolute calibration of the Auger fluorescence detectors is determined by the wavelength dependent photon detection efficiency of the FD optical system. The components of this system are described in detail in [3]. The interaction between these components makes it difficult to determine the calibration of the system by measuring the efficiencies of individual components. Two "end to end" methods, described below, are used to determine the absolute calibration. Also described are the relative calibrations which monitor the time and wavelength variability in the calibration.

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2. The "Drum" calibration

The drum calibration is designed to provide an end to end calibration of the FD using an illuminated surface covering the entrance aperture of an FD telescope. Ideally, each part of this surface would be uniformly illuminated and would emit as a Lambertian source over the angular range viewed by the camera (21°). The mechanical structure of the drum is made from a lightweight aluminum frame 2.8 m in diameter and 1.5 m deep. The frame supports the illuminated front surface of the drum, the reflective back and side surfaces of the drum and the light source. The frame has coupling points that accurately position and hold the drum over the telescope aperture during calibration measurements. The illuminated front surface of the drum is made from 0.38 mm thick Teflon and has a diameter of 2.5 m. The light source consists of 2 pulsed UV LEDs (375 ± 12 nm). The LEDs are embedded in a Teflon cylinder that sits on top of a 15 cm disk of diffusively reflective Tyvec. A UV enhanced silicon detector at the top of the Teflon cylinder monitors the relative light output of the LEDs and also prevents the direct illumination of the drum by light from the Teflon cylinder. The Tyvec disk is held by struts on the inside of the drum near to the front surface but facing to the back of the drum. The light from the disk illuminates the back and sides of the drum, also made of Tyvec, which diffusively reflect light on to the front surface of the drum.

The angular and spatial uniformity of the drum front surface were measured by powering the UV LEDs continuously and measuring the surface brightness with a CCD camera. The illumination of the area of the surface corresponding to the telescope aperture was found to be spatially uniform to $\pm 1\%$. The angular dependence of the surface brightness followed the expected cosine (viewing angle) dependence to within $\pm 2\%$. The reference standard for the calibration of the drum was a UV-enhanced Si detector (UDT sensors UV100 photodiode) calibrated at the National Institute for Standards and Technology (NIST). This device was not sensitive enough to detect the pulsed LED signal from the drum so it was used to calibrate a light source which in turn was used to calibrate a photomultiplier tube (PMT) and its readout ADC. This PMT/ADC was used to measure the light flux from the drum front surface.

A drum calibration of telescopes 4 and 5 of the Los Leones Engineering Array FD was made during February/March of 2002. The calibration of telescope 4 was found to be 4.0 ± 0.3 photons at the front of the aperture per FADC count. For telescope 5 the calibration was found to be 5.6 ± 0.4 photons at the front of the aperture per FADC count. A complete description of the prototype drum and of the calibration of the Los Leones Engineering Array telescopes can be found in [1]. A number of new drums are being built to calibrate the FDs of the full Auger Observatory. The physical construction of the drums has been changed to provide a more robust mechanical structure that can be transported easily between sites within the Auger Observatory. The drums will be used to calibrate the telescopes of the Auger FD observatories as they come on line starting mid-2003. Initially, each telescope of each observatory will be calibrated every 2-3 months. The time interval between drum calibrations will be adjusted according to the stability of the calibration. There is currently a development effort underway to make the drums a multi-wavelength calibration source. The LED light sources will be replaced with optical fibers which bring light from a monochromator.

3. Atmospheric laser scattering calibration

Artificial tracks, generated from a 355 nm laser located 3-4 km from the FD, are used to confirm the FD calibration obtained by the drum. If the energy and polarization state of the laser beam are well known, Rayleigh scattering from the molecular atmosphere provides an accurately calculable flux of photons arriving at a telescope aperture from each part of the track. An advantage of this calibration method over the drum calibration is that it produces a track image that is very similar to the cosmic ray tracks measured by the FD. A description of a laser system used for this type of measurement can be found in [4] . A set of laser measurements was made on March 17^{th} 2002 to calibrate telescope 4 of the Engineering Array FD at Los Leones. An analysis of these laser shots gave a calibration for telescope 4 of 4.1 ± 0.5 photons at the front of the aperture per FADC count at 355 nm. The two main sources of uncertainty are the measurement of the absolute energy of the laser shots and the contribution of aerosol scattering and extinction to the measurement. The absolute calibration of the laser energy , traceable to NIST standards, is better than 10%. The calibration value found by the laser method agrees very well with that of the drum measurement made two weeks earlier. Although the drum and laser calibrations were made at different wavelengths, the wavelength dependence of the FD filters and that of the PMTs cancel almost exactly between 375 nm and 355 nm. A full description of the March 17^{th} laser calibration can be found in [4].

A new roving laser system is being built for use with the Auger Observatory which will have smaller uncertainty in laser energy than the prototype laser system. It is planned to use the laser beam calibration as an occasional cross-check of the drum calibration. If serious discrepancies are found between the drum and laser calibrations a more comprehensive program of laser calibrations will be undertaken.

4. Monitoring of the wavelength and time dependence of the calibration

The relative wavelength dependence of the calibration will be determined through "piece by piece" measurements of samples from components of the FD telescopes. Using a ray tracing simulation of the FD optics these measurements can also be used to estimate the absolute calibration of the FD. Preliminary measurements have shown that this calibration is consistent with measurements made by the drum and laser methods, but the uncertainty is large (20%).

To monitor changes in the FD response, a relative calibration system has been implemented. This relative calibration system uses 3 xenon flash light sources located at each FD site. Light from each source (denoted A,B or C) is distributed to the six telescopes through optical fibers. Light from the A source goes to a diffuser at the center of each mirror and directly illuminates the camera. The A source includes a broadband Johnson-U filter and a filter wheel with 5 different neutral density filters. The wavelength dependence of the Johnson-U filter transmission is roughly matched to that of the FD. The purpose of the A source is to measure the stability and linearity of the camera system. Light from the B source is reflected from the mirror on to the camera to monitor the combined stability of the mirror reflectivity and camera gain. The B source also includes a Johnson-U filter. Light from the C source illuminates diffusively reflective Tyvec targets on the inside of the telescope doors. The light from the Tyvec goes through the aperture to the mirror and on to the camera. The C light source includes 5 narrow band interference filters at wavelengths of 330 nm, 350 nm, 370 nm, 390 nm and 410 nm. This light source monitors the end-to-end stability of the telescopes at all 5 wavelengths. The A,B and C calibrations are made at least once for each night that the FD takes data. Calibration data taken during the running of the FD Engineering Array has shown that the overall stability of the camera gain, as well as pixel to pixel variation in relative gain, is better than 5%. Further details of the relative wavelength and time dependent calibrations can be found in [2].

5. Conclusion

The absolute calibration of the Engineering Array FD telescopes has been measured using three independent techniques: drum calibration, laser calibration and piece by piece calibration. Within the estimated uncertainties the calibration of FD telescopes measured by all three techniques agree.

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