Calibration of the Auger Fluorescence Telescopes

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Abstract. Thirty fluorescence telescopes in four stations will overlook the detector array of the southern hemisphere experiment of the Pierre Auger project. The main aim of these telescopes is tracking of EHE air showers, measurement of the longitudinal shower development (Xmax) and determination of the absolute energy of EHE events.

A telescope camera contains 440 PMTs - each covering a 1.5 x 1.5 degree pixel of the sky. The response of every pixel is converted into the number of charged particles at the observed part of the shower. This reconstruction includes the shower/observer geometry and the details of the atmospheric photon production and transport. The remaining experimental task is to convert the ADC counts of the camera pixel electronics into the light flux entering the Schmidt aperture.

Three types of calibration and control are necessary : a) Monitoring of time dependent variations has to be performed for all parts of the optics and for all pixels frequently. Common illumination for all pixels of a camera allows the detection of individual deviations. Properties of windows, filters and mirrors have to be measured separately. b) Differences in pixel-to-pixel efficiency are mainly due to PMT gain and to differences in effective area (camera shadow, mirror size limits). Homogeneous and isotropic illumination will enable cross calibration. c) An absolute calibration has to be performed once in a while using trusted light monitors.

The calibration methods used for the Pierre Auger FD telescopes in Argentina are discussed.

1 Introduction

The southern hemisphere experiment of the Pierre Auger Observatory will contain 1600 particle detectors on a hexagonal grid of 1.5 km spacing covering an area of nearly 60 km x 60 km. On the boundaries of this array observatory stations with optical telescopes are used to watch the atmosphere above the detector array for the fluorescence light from the interaction

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of the avalanche of secondary particles in the EHE extensive air showers with the Nitrogen molecules.

Simulations show that the number of charged particles produced in an air shower at the maximum of its development depends only slightly on the detailed knowledge of the interaction at extremely high energies, which is limited due to the low energies available at terrestrial accelerators. The determination of the differential energy loss of these particles in their passing through the atmosphere is realized by the measurement of the showers fluorescence light with high sensitivity telescopes. The fluorescence measurements offer the possibility to reconstruct the energy of the primary cosmic ray particle with less ambiguity than it is possible by the determination of the lateral and longitudinal distribution of secondary shower particles only. Hybrid operation with the ground array detector system will yield best accuracy and enable excellent cross calibration.

The determination of the shower/observer geometry is a rather simple first task in the FD reconstruction chain. A more severe problem is the precise knowledge of the fluorescence yield as function of particle type and energy, and of atmospheric density, temperature and composition. Dedicated laboratory measurements of the fluorescence yield have yet to be performed to reduce the existing errors. Another limiting factor is the uncertainty connected with the photon transport in the atmosphere which may depend strongly on the local weather conditions, height above ground, and other variables. Large effort is devoted to the precise determination of atmospheric conditions during the fluorescence measurements. These activities of the Pierre Auger Collaboration are presented in a separate contribution to this conference.

The remaining task is the thorough understanding of detector properties, which may be changing with time. An absolute detector calibration has to be performed in order to enable the conversion of the ADC counts in the data into the photon flux entering the detector. This calibration has to be checked frequently to detect any changes and individual deviations.
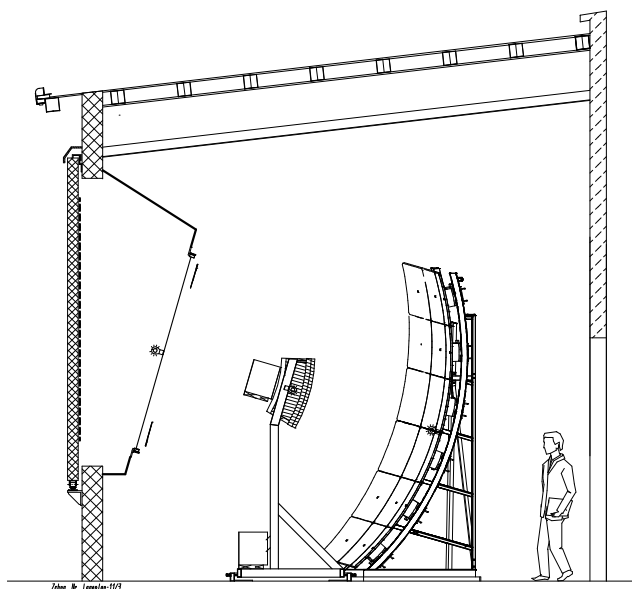
Fig. 1. Layout of the telescope system showing the Xenon flasher positions for 3 types of calibration procedures: a) at the centre of the mirror, b) on both sides of the camera body, and c) on both sides of the centre of the aperture box illuminating a Tyvek reflector on the shutter surface.

2 The telescope system

For the design of the fluorescence telescopes the principle of a wide angle Schmidt camera is adapted. The system contains a large spherical mirror with a radius of curvature of 3.4 m, a pixel camera with 440 PMTs in the focal surface, and a diaphragm with an entrance glass window and an opening of 1.7 m diameter, which can be enlarged to 2.2 m diameter in combination with an annular Schmidt corrector lens. This design is cost effective and combines a large field of view of 30 degree both in elevation and azimuth with a modest resolution which is dominated by spherical aberration. Due to the complete enclosure the telescopes are operated under controlled ambient conditions leading to an improved stability of the PMTs and the electronics. The entrance window will keep dust and moisture away from the optical elements. An external shutter protects the window against environmental influences between the periods of measurements.

Figure 1 shows the principal layout of the telescope system with the external shutter, the aperture box holding the window, UV filter, and corrector ring, the 440 PMT pixel camera, and the large spherical mirror with its central line-of-sight pointing 16 degrees above the horizon.

3 Sources of variations

In the telescope system, pixel-to-pixel differences are present which have to be determined experimentally with high accuracy. In addition, time dependent changes may occur for the overall system or in individual channels. Some sources of

these possible variations are listed here.

The UV light transmission through the window, the UV filter, the corrector lens, and the PMT windows as well as the reflectivity of the mirrors and the PMT light guides may decrease slowly with a growing deposit of dust and other dirt on the surfaces and may be much higher again after cleaning.

The transmission through the optical elements depends slightly on the angle of incidence of the photon beam, i.e. on the pixels individual direction of view. The effective area illuminated on the mirror shows this angular dependence to a larger extent. The variation is mainly due to the geometrical acceptance and to the shadow of the camera body and support structure which varies substantially from the center to the corners of the field of view. In addition, at the mirror gaps and edges, a small part of the light may be missing due to the limited mirror size. These effects are of the order of a few percent only and can be simulated quite accurately but should be determined experimentally in any case.

The individual PMTs are slightly different in gain, naturally. 22 phototubes (selected for similar gain) are using a common HV power supply. PMTs are subject to aging effects of the photocathode, the dynodes and the anode structure. These effects on the gain can be dependent on the wavelength of the detected light. Gain changes from HV instabilities or varying load (background light) are reduced considerably by a well designed supply chain. Temperature effects may also occur, but will probably be small due the controlled ambient room temperature.

The conversion factor for the PMT current signal into ADC counts through the electronics chain can be tested completely using an internal test pulse system. However, the full chain should also be checked frequently with calibrated light pulses.

4 Central calibration system

For frequent tests of the detector properties a central light pulse system with fiber optic distribution is used. The light source system consists of a Xenon flash tube with appropriate beam optics, a beam splitter with source monitor, spectral filters for the selection of certain wavelengths, neutral density filters for intensity variation, and a 1:7 optical splitter. It is located in a central calibration room of the observatory building. The computer controlled light source is connected to the Slow Control system of the building. Remote control is the normal way of operation.

Six UV transmitting optical fibers are used for the supply of the 6 telescope systems in the building. The 7th fiber goes to an output light monitor with a calibrated radiometer. In the telescope bays the light is split again to be used with different Teflon diffusers as can be seen in figure 1.

The first diffuser is positioned at the center of the mirrors. It is used to illuminate the full camera. By this method the individual PMTs are tested for stability only. An example of raw data from such full camera test is shown in figure 2. The measurement was made at Rome university during the functionality test of the first PMT camera in March 2001.
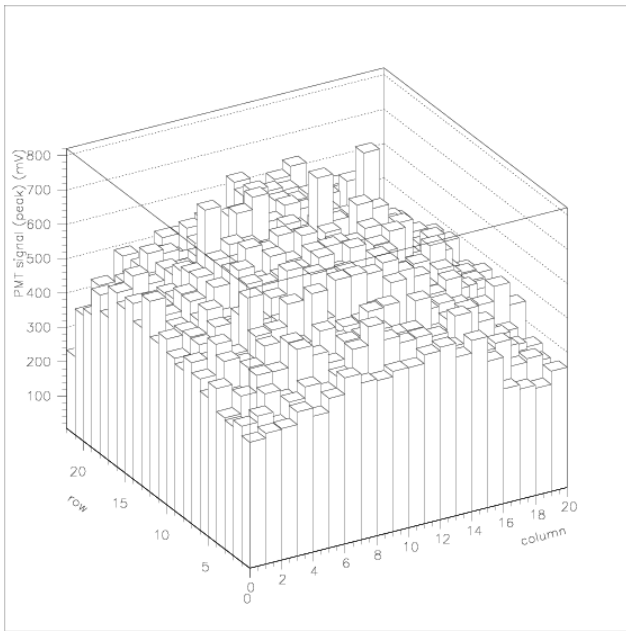
Fig. 2. Test results of illumination of the full PMT camera with a Xenon flasher plus Teflon diffuser at 1.7 m distance. The raw data show the response of the individual PMTs.

Fig. 3. Absolute calibration of the entire telescope system is performed using a Tyvek/Teflon diffuse reflector outside the entrance window with a stabilized UV light source (LED) and a calibrated light sensor.

Two Teflon diffusers are located at the camera, one on each side, pointing towards both halves of the mirror area. With these diffuse light sources a different illumination of the pixels is achieved and, in addition, also changes of mirror reflectivity can be detected.

Two additional light diffusers are mounted at the sides of the aperture box pointing out towards a large sheet of Tyvek reflector on the inside of the shutter doors. The Tyvek acts as a rather uniform and diffuse reflector for the Xenon light pulses. This third type of camera illumination enables tests of the full light transport through the aperture window, filter and corrector lens, including the effects of the mirrors and the PMT light guides. However, also these will be relative measurements and stability checks only.

In addition to the Xenon flash tubes in special measurements UV emitting LEDs will be used which are commercially available with a narrow line width around 375nm and higher intensity compared to the flasher/fiber system. These LEDs have the advantage of an easily variable pulse length for detailed tests of the camera trigger system. Simultaneous pulsed and DC illumination of the PMTs is possible to study the effects of increasing background light quantitatively.

5 Absolute calibration

To achieve an absolute conversion factor for ADC counts into photon flux for each pixel it is necessary to use a precisely known light source and a stable detection system with calibrated and trusted light sensors. For this purpose at present two different approaches are investigated intensively. The first method is using bright stars as external light sources,
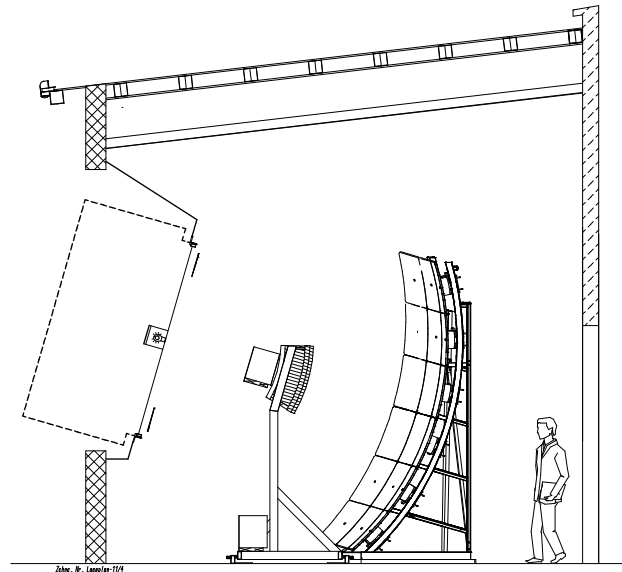
well measured by astronomers and the second method relies mainly on the highly accurate absolute calibration of stable and trusted light sensors.

5.1 Star monitor telescope

Bright stars with a well known photon flux in the UV can be used to determine the absolute efficiency of a 10 inch star telescope when the position of the star is nearly vertical and atmospheric uncertainties are rather small. Pointing the telescope immediately to another star in the field of view of a camera pixel enables a comparison of pixel response and star monitor sensitivity. This is quantitatively possible when the effective aperture is known precisely enough for both detectors. A remaining problem is a possible difference in the pixel response to DC and pulsed light which has to be studied carefully with the calibration system. In addition, if the brightness of the star in the field of view is also well known by astronomers, its apparent brightness in the UV at low elevation enables a cross check on the atmospheric monitoring data measured by other means.

5.2 Calibration dome

A sufficiently homogeneous and isotropic local light source has been developed for the absolute calibration of all pixels of the PMT camera. The light output of this device is monitored by trusted light sensors during the measurements and calibrated routinely in a separate experimental set up using light sensors with NIST certification. It consists of a lightweight frame covered with a Tyvek laminate reflector bag. The shape of this "light dome" resembles a large pillbox with about 2.6 m diameter and 1.4 m height. During the

calibration runs (about once every month) it is brought to a telescope bay and mounted outside the aperture window on a support ring in the aperture box as indicated in figure 3. This method of absolute calibration is enabled only by the use of a Schmidt camera design with a well defined optical aperture.

The bottom of the box is closed by a thin Teflon diffuser sheet. The primary light source is a stabilized UV emitting LED with a small Teflon sphere as first diffuser. The forward angles are partly blocked by the monitor detector for the LED, a NIST calibrated Silicon sensor. Trusted PMTs are used for the monitoring of the output of reflected light from the dome. Each time before the dome is brought into operation, an absolute calibration of its photon flux is performed in a separate room and the response of the monitor detectors is determined. By this chain of procedures a total error of less than 5% for the absolute calibration parameters can be achieved.

Relative differences in pixel-to-pixel efficiency can be measured with much better accuracy by several different methods including the dome illumination. Time dependent variations of the full system between the calibration runs and deviations of individual pixels will be determined on the 1% level by the Xenon flasher/fiber system.