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Surface detector calibration for the Auger Observatory

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Abstract. The ground array of the Pierre Auger Observatory will consist of 1600 water Cherenkov detectors arranged in a triangular grid with a spacing of 1.5 km. Each detector station contains 12 tons of clean water as Cherenkov radiator in a cylindrical volume of 3.6 m diameter and 1.2 m height. The detector walls are lined with tyvec as a diffuse reflector to homogenize the Cherenkov light. The light detection occurs via three photo-multipliers of 20 cm diameter facing downward and arranged symmetrically on the water surface. The performance of the radiator, the reflector and the readout electronics have to be calibrated regularly. Due to the extent of the ground array and the rough terrain all detector stations have to be autonomous and maintenance free. This implies that the calibration method has to be simple and robust. It also has to be cost-effective since it will be implemented 1600 times. The electronics of the surface detector has high- and low-gain channels which have to be calibrated differently. The high-gain channels are calibrated using the signal from cosmic ray background muons as an absolute reference. The relative calibration between high-and low-gain channels is done using LED pulses. We present the details of the calibration and diagnosis scheme as well as first results obtained from the engineering array installed at the southern site of the Pierre Auger Observatory in Malargüe, Argentina.

1 Introduction

The purpose of the Pierre Auger Observatory is the study of the origin and the nature of the highest energy cosmic rays, with energies above 10^{19} eV (Auger collaboration, 1997; Dova, 2001). To this end, the observatory is designed to determine the energy, the arrival direction, and nature of the primary particle as well as possible. In order to collect sufficient events, required to improve the statistics compared to the total world sample available today, the Pierre Auger Observatory is designed to have two sites, each with an aperture of $7360\,\mathrm{km}^2\mathrm{sr}$, covering an area of $3000\,\mathrm{km}^2$ (Ave et. al., 2001). The observatory consists of two sub-systems: a surface array of approximately 1600 water Cherenkov stations and a fluorescence detector with 3 or 4 eyes per site. The extend of the surface array requires that it be operated remotely and that the components require no or only minimal maintenance. For the calibration method, this implies that a simple, reliable and cost-efficient method has to be used. The Pierre Auger Collaboration decided to use the signals of through-going or stopping muons, which naturally arrive with a rate of more than $250\,\mathrm{m}^{-2}\mathrm{s}^{-1}$. No special hardware is required for this method, only some calibration triggers have to be implemented in the front-end electronics. Additionally, there will be LED flashers for monitoring installed in each tank. The calibration methods presented here will be tested in the engineering array for the Pierre Auger Observatory, which is currently under construction (Allekotte et. al., 2001).

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2 Surface detector station

Each detector station of the surface array of the Pierre Auger Observatory consist of a cylindrical tank with a surface of $10\,\mathrm{m}^2$ and a height of $1.2\,\mathrm{m}$. The tank is lined with Tyvec as a diffuse reflector on the walls. It contains $12\,\mathrm{tons}$ of water as a Cherenkov radiator (Escobar, 2001). The light is detected by 3 photo-multiplier tubes (PMTs), each connected to the local station data acquisition system by a low-gain and a high-gain channel with a nominal relative amplification of 32 (Suomijärvi, 2001). Each channel is digitized by a $10\,\mathrm{bit}$ FADC running at $40\,\mathrm{MHz}$, giving an effective dynamical range of $15\,\mathrm{bits}$ per PMT. The local station electronics takes the level 1 and level 2 trigger decisions, including special triggers for the calibration of the detector station. The communication of each detector station with the central control and data acquisition system takes place via a special, custom designed wireless LAN (Clark and Nitz, 2001).

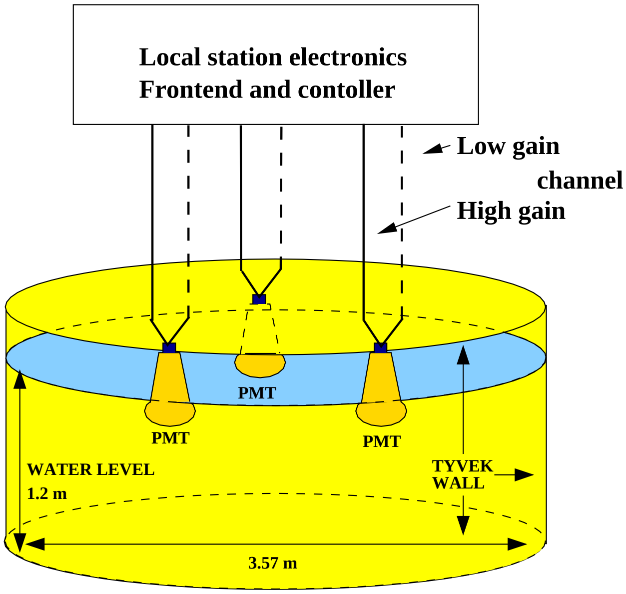

Fig. 1. Water Cherenkov tank schematics. Each tank contains 12 tons of water as a radiator. The light is detected by three photomultiplier tubes, each connected to a high- and a low-gain channel in the local station electronics.

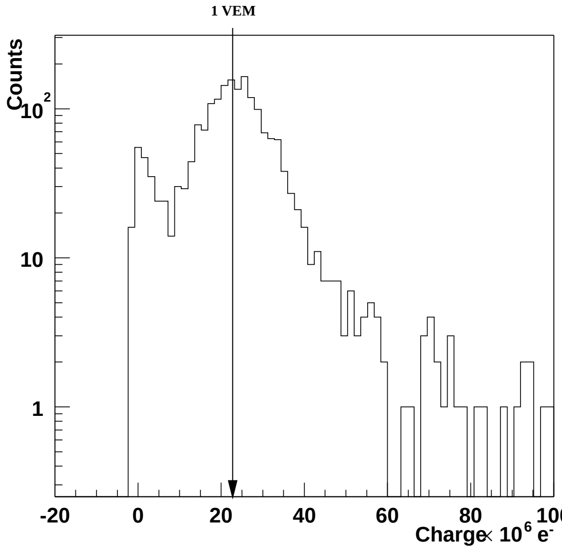

Fig. 2. Vertical muon data taken on a test tank on the souther Auger site in Malargüe, Argentina. Due to mechanical constraints, both scintillators of the muon telescope had to be placed above the tank. Absorbing material was put between the scintillators to eliminate the soft, electromagnetic background. The small rise of the count rate for low charges (less than $10^7 e$) is due to a remaining part of this background. One VEM in this setup corresponds to $\approx 2.3 \times 10^7 e$.

3 Water Cherenkov detector calibration

The aims of the calibration of each individual detector station are:

- Balance the individual PMTs such that they produce (on the average) the same output signal in the high gain channel,
- Obtain the calibration constants needed to convert the registered FADC signal into an equivalent signal produced by vertical muons,
- Measure the exact attenuation of the low-gain channel relative to the high-gain channel.

3.1 PMT gain matching

The first calibration step during the activation of a detector station is the balancing of the PMTs in order to get a uniform response of all three. Initially, the high voltage of each PMT is set to a known, fixed value determined previously. Next, the high voltage of PMT 1 is adjusted such that on the average we obtain $\bar{Q}_1 = (\bar{Q}_2 + \bar{Q}_3)/2$. This requires the collection of a few hundreds to thousand events per adjustment cycle. In the next step, we match separately PMTs 2 and 3 to PMT 1 such that $\bar{Q}_1 = \bar{Q}_2$ and $\bar{Q}_1 = \bar{Q}_3$. Once this is completed, the gains of the three PMTs are matched to each other. Only the high-gain channels of the PMTs are used in this step.

This procedure exploits the cylindrical symmetry of the tank and the relative uniformity of the detector response over the whole area together with the almost uniform flux of the cosmic rays over the whole azimuth.

3.2 Absolute calibration

The reference for the absolute calibration of a detector station is the average signal produced by vertical muons crossing the tank. In a laboratory setup, one uses a muon telescope consisting of a pair of scintillators above and below the tank to trigger in coincidence on vertical muons. This procedure defines the signal of a vertical equivalent muon (VEM, see figure 2).

The absolute calibration of each detector station uses the signal produced by muons from the cosmic ray background to obtain the signal corresponding to 1 VEM. The majority of the muons cross the tank and stay relativistic all the way, emitting a constant amount of Cherenkov light throughout the tank. A fraction of the muons, those with momenta below $300\,\mathrm{MeV}/c$, can stop and decay inside the tank.

Calibration based on the signal generated by muons crossing the tank was proposed for the Pierre Auger Observatory by Kutter et. al. (1997). This method uses the fact that the charge distribution of events taken using a simple threshold trigger on one PMT shows a peak (see figure 3), which can be enhanced using quality cuts (see figure 4). One can see that the peak in figures 2 and 4 is, within errors, at the same position of about $2.5 \times 10^7 e$. This corresponds to the production of about 25 photoelectrons in the PMT. This calibration method has also been evaluated using test tanks operated by the Pierre Auger Collaboration (AGASA: Pryke (1997), Buenos Aires: Bauleo et. al. (1997, 2001), Fermilab: Ravi-

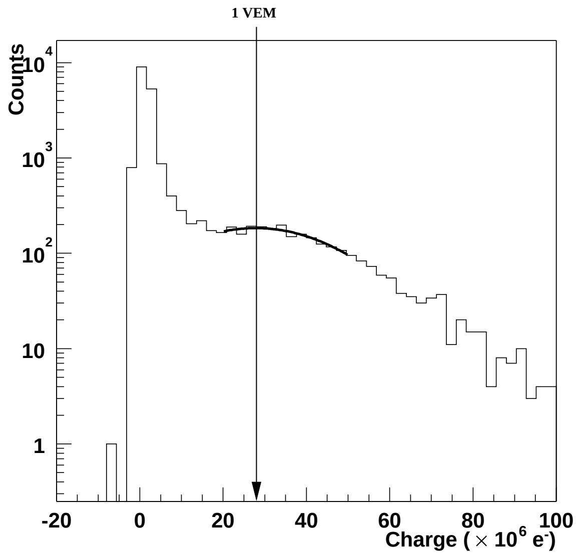

Fig. 3. Crossing muon data taken on a test tank on the souther Auger site in Malargüe, Argentina. The data was taken using a simple threshold trigger on the anode of the PMT. One VEM in this setup corresponds to $\approx 2.7 \times 10^7 e$.

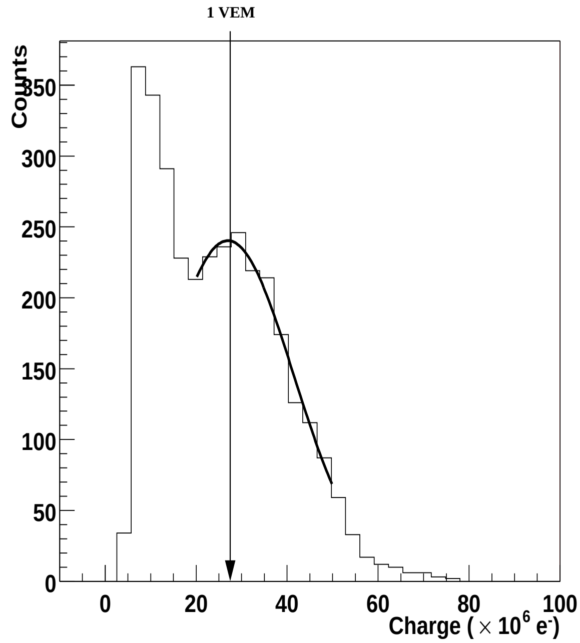

Fig. 4. Crossing muon data. Compared to the data in figure 3, one requires an additional coincidence of 2 PMTs. The value of one VEM does not change, it still corresponds to $\approx 2.7 \times 10^7 e$. However, the muon peak is much more pronounced.

gnani and Hojvat (1996), and Puebla: D'Olivo et al. (1999); Fernández (1999)).

One can also use the signal from the electrons produced in the decay of muons which stopped inside the tank for calibration (Alarcón et. al., 1999; D'Olivo et al., 1999). The peak of the charge distribution is at about $0.2\,\mathrm{VEM}$.

The absolute calibration can be done relatively quickly, since the rate of background events is about $2\,\mathrm{kHz}$. Both methods for the absolute calibration of the detector station will be evaluated at the engineering array and are likely to be used in the full Pierre Auger Observatory.

3.3 Calibration of the low-gain channels

The low-gain channels will be obtained from a dynode tap in order to obtain a signal when the anode of the PMT is saturated. The relative gain, nominally 32, between the low- and the high-gain channel has to be measured in order to obtain an absolute calibration of the low-gain channels from the calibration of the high-gain channels. The pulses generated by single muons will not be visible in the low-gain channels. Instead, we need signals of 20 to $50\,\mathrm{VEM}$. Those signals do not saturate the high-gain channel, and at the same time they are visible in the low-gain channel. Comparing the signal in the overlap region allows us to extract the relative gain of the two channels.

One possibility for generating signals of a few VEM is to inject light into the tank using a LED flasher. This method is under development and will be fully tested using the engineering array. Another possibility is to use the naturally occurring events from the cosmic ray background. Small air showers which land near to a detector station deposit several VEM in the detector. The rate of those events, however, is much lower than the rate of cosmic ray muons. As a consequence, the calibration of the low-gain channels can take $15\,\mathrm{min}$ or more. Fortunately, this is not a problem as this calibration procedure can run in parallel to the normal data taking operation of the detector station.

3.4 Continuous calibration

The aim of the Pierre Auger Collaboration is to have the surface detector running continuously. Operating parameter, such as high voltages of the PMTs, will only be adjusted if the monitoring information indicates that it is necessary, or if a detector station is restarted for some other reason, such as local maintenance. As a consequence, we have to verify the calibration of the detector continuously. For this, the muon triggers are taken all the time to verify the absolute calibration and the gain matching of the gains of the PMTs. Some of the normal event data will be used to re-compute the relative gain of the low- and high-gain channels.

4 Monitoring

The calibration data also serves for monitoring the individual detector stations. Changes in the calibration constants indicate potential problems. Calibration and slow control information will be used to perform remote diagnosis of a limited number of possible problems with the detector stations. The details will be developed and tested using the engineering array. Possible failure modes and their signals in the calibration data are:

– Water contamination: Reduced values for $1\,\mathrm{VEM}$ and simultaneously shorter pulses due to the extra absorption for photons traveling longer distances in the tank.

– Window contamination: Reduced values for $1\,\mathrm{VEM}$ without affecting the average pulse shape since the extra absorption takes place just before the photons reach the PMT.

– PMT failures show up in changes of the value for $1\,\mathrm{VEM}$ together with changes in the slow control data.

5 Conclusion

The surface detector calibration for the Pierre Auger Observatory uses several simple, robust, and cost-efficient methods. The methods have been developed using several test installations operated by the Pierre Auger Collaboration. Further tests and refinements are expected during the operation of the engineering array.

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