Calibration and Monitoring of the Pierre Auger Surface Detectors

Xavier Bertou,[1] for the Pierre Auger Collaboration[2]
(1) University of Chicago, (IL 60637) Chicago, USA
(2) Observatorio Pierre Auger, Malargüe, (5613) Mendoza, Argentina

Abstract

The ground array of the Pierre Auger Observatory will consist of 1600 water Cerenkov detectors. They will be deployed over 3000 km^2 at Pampa Amarilla, near Malargüe, in the state of Mendoza, Argentina. A prototype of 32 detectors, the engineering array (EA), has been continuously taking data since 2001.
The remoteness and difficulty to access each detector imposed an automatic remote calibration procedure. The main parameter to determine is the average charge deposited by central muons crossing the water volume vertically.

1. Introduction

The Auger water Cerenkov detectors are equipped with three photomultiplier tubes (PMTs) overlooking 12 tons of ultra pure water, enclosed in a highly diffusive Tyvek liner [2].

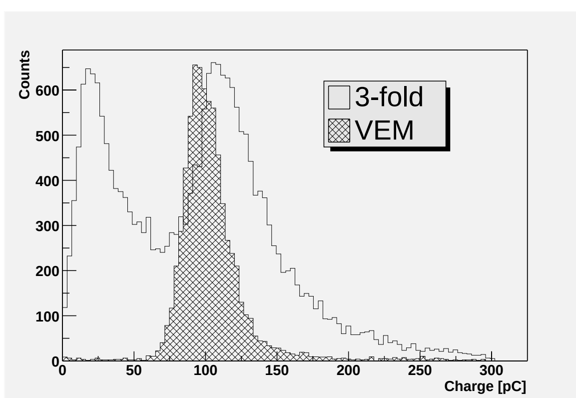

Fig. 1. Charge histogram of signals seen by a detector under the flux of atmospheric muons. The first hump is due to the triggering (3-fold). The second very clear hump corresponds to the signal of single muons going through the tank. Superposed in hatches events triggered by a muon telescope as vertical and centered.

The signal processed by the surface detector local station electronics (LS) is the final readout of a long chain depending on many parameters: water quality, liner, optical coupling of the PMT, gain of the PMT, electronic gain of the dynode

pp. 813–816

and anode amplifiers, the dynode being amplified by a factor 32 with respect to the anode. Atmospheric muons provide a well known physics quantity to match the end-to-end signal at the LS, as they are constantly available and easy to measure [1].

The key parameter to measure for each detector is the average charge deposited by a centered and vertical high energy muon traversing a tank (1 VEM). This value is measured indirectly by plotting the distribution of charge deposited by muons crossing in all directions (see figure 1). Measurements with test detectors equipped with a muon telescope allow us to conclude that the peak position of the second hump in this distribution is located approximately at the position of the peak in the charge distribution of vertical muons.

2. Online calibration

Gain matching phototubes

To get a rough gain match of all phototubes, a rate-based method was implemented. It calibrates each PMT individually, allowing its use on detectors with less than three operating PMTs.

It was determined from a test detector installed in the central campus that the rate of triggers above 2.8 VEM for an Auger tank was approximately 100 Hz. All PMTs are therefore calibrated by setting a threshold of 2.8 times the desired value for a VEM (50 ADC counts) above baseline, and high voltages are adjusted until 100 Hz is reached on that PMT. One then moves to next PMT.

An algorithm has been developed to automatize this method and make sure it converges. After such a calibration, all PMTs are gain matched within a few percent. However, in the EA phase a few bad PMTs showed deviation of up to 10% after a few days. This method is used once upon installation of the LS, and in case a PMT gets unmatched after a few months of operation.

VEM monitoring

To follow PMT fluctuation, be it for bad PMT or, for example, temperature effects, an online monitoring of individual PMT rate has been implemented. It is done on the first level triggers, T1. These events are 3-fold above 1.75 VEM on each phototube (in case of a tank with less then 3 working PMTs, thresholds are adapted). They occur at a rate of 110 Hz.

The online VEM monitoring algorithm aims at determining the real value of the VEM of each PMT. This VEM is the one used for the triggering by the LS. Once set, the LS is used to check that from all the T1, each individual PMT has a counting rate above 2.3 VEM of 70 Hz. A PMT not conforming to this 70 Hz is unmatched. For example, a higher gain PMT would not increase significantly T1 rate as it is a 3-fold, but would have a much higher rate above 2.3 VEM than the other PMTs. The LS would modify the VEM value for the faulty PMTs and iterate. In the end, the LS has 110 Hz of T1, with each individual PMT above 2.3 VEM at 70 Hz, and the value of the peak of the VEM determined for each PMT.

The charge of the VEM is determined by integrating the signal of one PMT over 625 ns when its signal peaks exactly at the threshold (1.75 VEM), and then dividing by 1.75 (we use this threshold as the rate at 1 VEM is too high to allow such a processing). This method is very accurate and gives a precision better than 2% on the position of the hump in the histograms.

Calibrated events

The VEM peak and charge as defined above were used to calibrate the EA data. Starting in May 2003, the triggering system was programmed to handle slow buffers, which are filled with low energy events. These buffers can handle rates of events of up to 8 kHz, allowing to take histograms in real time, while the station is still running in real data acquisition.

Using the values of the VEM peak from above, the LS sets thresholds at 0.1 VEM and takes events in 3-fold at a rate of about 3 kHz. Peak and charge histograms are obtained from 20 bins (500 ns) of FADC trace, including 3 pre-trigger bins. This allows to get histograms with more than 150 000 counts of the amplitude and charge of each PMT, of the sum of all three PMTs, and average muon pulse shapes every minute. These pulse shapes are determined averaging signals with total charge within 10% of the VEM charge.

Two LEDs are used to to get the dynode to anode gain ratio – an important parameter as muons are seen in the dynode while the anode is used to obtain the full dynamic range when close to the core of an EAS – and check the linearity of the PMTs by comparing the sum of the signals obtained upon firing the first and then the second LED to the signal obtained upon firing both at the same time, at various increasing voltages.

We therefore have pulse shapes and 150 000 entries histograms measured the previous minute to the occurrence of a high energy extensive air shower to determine the calibration constant (VEM) of each surface detector in the event.

3. Offline calibration and monitoring

VEM determination

Once one has determined with great accuracy the hump of the charge histogram, one has to relate it to the real VEM. The hump is close to the value of the VEM, as the flux is dominated with muons at small angles. However, photostatistics will blur this result, moving the hump to higher VEM values. Also, while muon deposits in a tank a total energy proportional to its track length (this

can be checked by using the sum of the signals of all PMTs), each individual PMT has a different signal histogram, seeing usually less than 1/3 of the summed signal (on a typical muon, one nearby PMT will have a large signal and the 2 PMTs further away a small one). This effect will move the hump toward lower VEM values.
Various measurements of the position of the hump in the 3-fold histogram with respect to the real position of the VEM (determined by triggering with a muon telescope) have been done and show that the hump of individual PMTs is around 1% below the VEM, while the hump in the sum is 13% above it. These results are in good agreement with analytic models and Monte Carlo simulations.

Monitoring

To check the long term performance of the system and the accuracy of the online calibration, each LS sends every 6 minutes a block of monitoring data. Various temperature, current and voltage measurements are added to the already defined calibration constants. This information can be used to shut down the whole array for a short period should the weather be bad for more than a week and the batteries be low (this never happened in the first two years of EA operation). Every 4 hours, 1000 raw traces at low threshold (0.15 VEM) are taken and sent to the central campus without any processing, allowing checks of online calibration, and testing new algorithms before implementing them in the LS.

4. Conclusion

The Pierre Auger surface detectors are constantly monitored to update the values of their calibration constants every minute from the 2 kHz background rate of atmospheric muons. This allows a precise determination of the hump in individual PMT charge histogram at a level better than 1%. The position of the hump is converted into a VEM value for each detector by using the ratio of these two parameters as measured previously with a detector equipped with a muon telescope. All the surface detectors are calibrated remotely with an overall 5% precision with respect to their absolute VEM value.
While the VEM is the essential calibration constant, other ones are determined as well. The dynode to anode gain ratio and the linearity of all PMTs are computed by using two LED signals, while water and liner quality are determined from the fall time of the average muon pulse shape, and water level is derived from the slope of the histogram of individual PMTs in the [1.5-2.5] VEM range. These parameters allow an overall excellent understanding of each individual detector.

1. Bauleo P. et al., NIM A 463 (2001) 175
2. Pierre Auger Design Report, Fermilab (1997)