

Performance of the Pierre Auger Observatory Surface Array

The Pierre Auger Collaboration

Presenter: X. Bertou (bertou@auger.org.ar), arg-bertou-X-abs1-he14-oral

The surface detector of the Pierre Auger Observatory is a 1600 water Cherenkov tank array on a triangular 1.5 km grid. The signals from each tank are read out using three 9" photomultipliers and processed at a sampling frequency of 40 MHz, from which a local digital trigger efficiently selects shower candidates. GPS signals are used for time synchronization and a wireless communication system connects all tanks to the central data acquisition system. Power is provided by a stand-alone solar panel system.

With large ambient temperature variations, that can reach over 20 degrees in 24 hours, high salinity, dusty air, high humidity inside the tank, and remoteness of access, the performance and reliability of the array is a challenge. Several key parameters are constantly monitored to ensure consistent operation.

The Surface Array has currently over 750 detectors and has been in reliable operation since January 2004. Good uniformity in the response of different detectors and good long term stability is observed.

1. Introduction

The Pierre Auger Observatory aims at unveiling the secrets of Ultra High Energy Cosmic Rays (UHECR) through the observation of the Extensive Air Showers (EAS) they produce in the atmosphere. It combines four fluorescence detector (FD) sites with a ground array to achieve hybrid detection of the EAS [1]. The fluorescence detectors, however, operate only at night, with limited moon light contamination, affecting the statistics of the hybrid data set. To achieve high exposure, the surface array, with an uptime close to 100 %, is fundamental.

An Auger Surface Detector (SD) station is a 10 m² base, 1.5 m tall cylindrical rotomolded plastic tank. It encloses a Tyvek[®] liner filled with locally produced purified water (resistivity: 15 M Ω cm) up to a 1.2 m level. Three 9" Photonis XP1805 photomultiplier tubes are used to collect the Cherenkov light emitted by particles crossing the tank. Signal is extracted both from the anode and the last dynode, the latter being amplified to achieve a larger final dynamic range extending from a few to about 10⁵ photoelectrons. All channels are connected to a 5 pole anti-aliasing filter with a cutoff at 20 MHz, digitized at 40 MHz by 10 bit FADC, a digital trigger is operated by a local CPU. Timing is obtained by a GPS Motorola unit, and communication to the Central Data Acquisition System (CDAS) is done via a custom built wireless communication system. Two solar panels charging two 12 V batteries provide the 10 W used by the electronics. Each detector is therefore independent and can start operating upon installation, independently of other detectors in the array. More details about the SD can be found in [2].

The Auger Surface Array will consist of 1600 of these detectors, on a 3000 km² triangular grid of 1.5 km spacing. Since January 2004, the array has been in stable operation and has grown at a steady rate of about 9 tanks per week. Figure 1 shows the status in June 2005. Each tank is deployed and its position is verified with differential GPS technique. Even if the landscape sometimes forces some displacements from the perfect triangular geometry, 50 % of the tanks are at less than 5 m from the theoretical position, and 90 % at less than 20 m. The exact position is used to operate the GPS in position hold mode, achieving better than 20 ns time resolution.

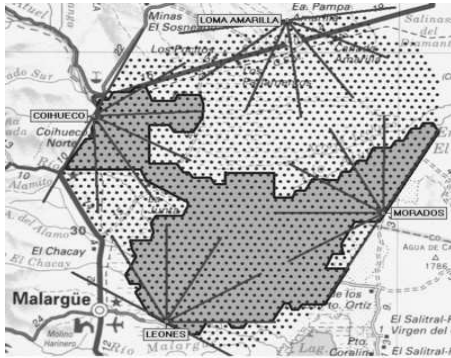


Figure 1. SD Array status on June 2005. The map is roughly 70 km by 50 km, close to the Malargüe city (lower left corner). Each dot represents one station, and the array is surrounded by the 4 FD buildings, displayed with the field of view of their 6 bays. The hatched region corresponds to the currently deployed stations, one half of the final 1600 stations array. The shape was driven by two main concerns: install stations close to the FD buildings to improve the hybrid acceptance, and take advantage of dry summer to install them in areas difficult to access.

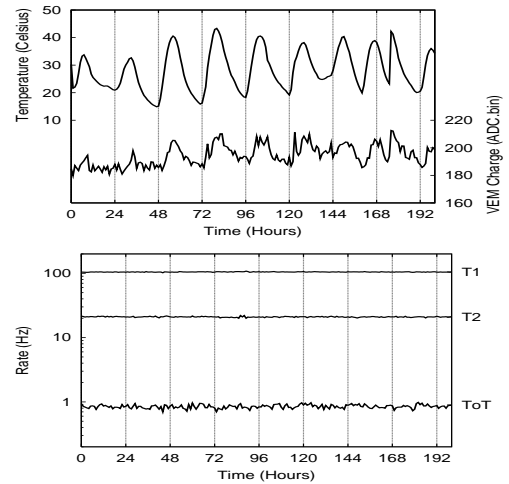


Figure 2. Top: evolution of the electronics temperature (top curve) and of the VEM charge (bottom curve) of station 102 over a week in April 2005. The correlation is clear. Bottom: trigger rates (T1: first level trigger, T2: second level trigger, ToT: Time over threshold trigger rate [4]) for the same station 102 over the same period.

2. Environment monitoring and Calibration stability

The environment to which an Auger Surface Detector is exposed is somewhat hostile for the electronics. At 1400 m a.s.l. and with clear skies, day-night temperature variations are of the order of 20°C . The terrain properties vary on the 3000 km^2 of the array, and some detectors have to face high salinity corrosive air, while others face dusty air from sandy ground. Humidity is present both in the ground (rivers, groundwater) and in the tank due to condensation.

To monitor the whole array accurately various sensors are installed in each tank. This information is sent to the CDAS every 6 minutes. Temperature is measured on each PMT base, on the electronics board, and on each battery. PMT voltage and current are also monitored, as well as solar panel voltages, individual battery voltage, and charge current. These data are used to detect a wide range of failures, from broken solar panels to discharging batteries, and correlations like unstable PMT behavior related to temperature.

Weather stations reporting temperature, pressure, humidity, wind speed and direction are installed at each fluorescence site and in the center of the array, to complete the environmental monitoring. These data allow extra checks such as the influence of the pressure on the calibration.

The calibration is operated online every minute [3], and sent to CDAS every 6 minutes for monitoring. A number of quantities are available to check the behavior of the tank: baseline values, single muon peak signal, single muon average charge, dynode/anode ratio, and PMT stability. In addition, high statistics histograms of the charge distribution from muons (150 000 counts) and average pulse shapes are sent every time a station records an event.

This information allows detailed monitoring of the evolution of the calibration and various cross-checks. Figure 2 shows the evolution of the VEM (Vertical Equivalent Muon, average charge deposited by a vertical and

central through going muon) and its correlation with temperature for a specific detector. The online calibration takes into account most temperature fluctuations at the local trigger level as reflected in the same figure by the stability of the trigger rate over time [4]. Over the whole array, correlation of the trigger rate with temperature are -0.04 ± 0.03 % per degree for first trigger level (T1), 0.08 ± 0.05 % per degree for the second level trigger (T2), and 0.2 ± 0.5 % per degree for the Time over Threshold trigger (ToT). The SD array therefore operates with stable trigger threshold even with 20 degrees daily temperature variations. It is clear from the plots of figure 2 that calibrating the array only once per day would introduce a significant bias in the trigger threshold, of the order of 10 %.

issue	fraction of stations
PMT connector	0.9 %
PMT unstable	2.5 %
PMT various	1.4 %
Electronics generic	4 %
Power issue	5 %
Baseline	0.3 %
VEM	5 %
Charge/Peak	0.9 %
Dynode/Anode	0.5 %

Cause	Dead time
Power cut	0.9 %
Communication shortout	0.9 %
Acquisition deadtime	1.1 %
Software Updates	0.6 %
Individual detector failure	2.2 %
Total	5.7 %
On-time	94.3 %

Table 1. Left: fraction of poorly performing detectors. First part of the table describes electronics related issues, and second part its impact on calibration values (fraction of stations with the calibration parameter outside of established range or with fluctuations above 5 %). Right: dead times of the SD array in 2004. See text for details.

Finally, analysis of all these parameters allows to detect poorly performing detectors. Table 1 shows the fraction of detector in which some monitoring parameters fall outside of the expected range or exhibit large fluctuations. While this fraction is already small, it is important to remember that most of the detectors have been recently deployed and infancy problems are the major cause of improper functioning. As a reference, out of 96 PMT issues, only 2 manifested problems after 18 months of correct behavior. The remaining 94 showed problems in the first days of operation.

3. Central Data Acquisition

The last step monitored to ensure the quality of the Auger SD data set is done at the system acquisition level. The second level trigger rate for each station are registered every second allowing a precise knowledge of the dead time of the detectors.

The acquisition is fully automated and no operator is needed for data taking. A “watchdog” restarts the system in case of failure and an UPS guarantees operation in case of power cut. Information from the CDAS processes are kept to diagnose possible crashes.

Simple quantities such as the number of stations in operation and the event rate, and more complex ones such as the rate of physics events are checked daily to validate the data acquisition period. Over 2004, the total on-time of the system has been ~ 94 %, including all kinds of dead time (individual detectors down, general power cuts, software upgrades, etc.). Table 1 summarizes the various contributions. It should be noted that this on-time was obtained while priority was being given to the building of the Observatory (deploying new detectors) over its operation (repairing failing ones), and with evolving software for the detectors, the communication system,

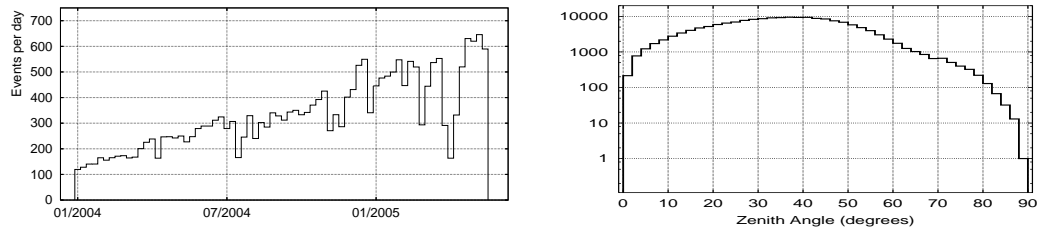


Figure 3. Left: Evolution of event rate with time. An average event rate of about one physics event per day per station is observed. The consequence of a major software upgrade in April 2005 is visible as a dip in the plot. Right: Zenith angle distribution for all events observed up to June 2005. Large zenith angle events manifest themselves as high multiplicity (20 tanks or more) due to the compact aspect of the array when viewed at large zenith angle.

and the CDAS. It seems clear that once the Observatory is completed and the software stabilized, an on-time above 95 % should be achievable.

Figure 3 shows the evolution of the physics event rate as a function of time. It is roughly related to the number of active stations by 0.9 event per day per station. The zenith angle distribution of these events is also plotted. A significant number of very horizontal events is observed [5].

4. Conclusion

The surface array of the Pierre Auger Observatory has been in operation for more than a year and has shown very stable behavior. On-time for 2004 is above 94 %. Detectors have been shown to be able to compensate important daily temperature fluctuations. A small number of poorly performing stations have been identified, and most failures appear in the first days of operation. Fraction of stable detectors is increasing and reached 97 % at the time of writing.

Up to June 2005, more than 180 000 events were recorded with an average rate of about 0.9 per station per day. Once the array is completed, a rate of about 1500 physics events per day is expected. A significant number of very horizontal events are detected, offering a novel view of EAS. For events above 10^{19} eV, reconstruction accuracy is around 1.4 degree for direction [6] and around 10% for the SD energy estimator (signal at 1000 m from the core [7]).

The SD array has shown its potential in the period from January 2004 to June 2005, achieving below 60 degrees of zenith angle a total exposure of $1750 \text{ km}^2 \text{ sr yr}$. It will reach its full size, and gain one order of magnitude exposure within the next two years, hopefully unveiling the secrets of the UHECR.

References

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