Signal Fluctuations in the Auger Surface Detector

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Abstract

We measured the Čerenkov signal fluctuations in the water tanks of the Pierre Auger Observatory (PAO). Two stations located near the center of the 32-tank Engineering Array (EA) separated by 11 m were used for the purpose. At this separation the stations sample nearly the same region of the air shower. Sources of the signal fluctuations are discussed.

1. Introduction

The PAO is currently under construction in Mendoza Province, Argentina. Its main objective is the study of cosmic rays above 10 EeV. The Surface Detector (SD) will consist of 1600 water tanks (10 $m^2\times$ 1.2 m deep) spaced 1.5 km apart to register the Čerenkov signal of a sample of the Extensive Air Shower (EAS) particles. The fluctuations in the signal recorded by the detectors directly affect the reconstruction of the physical parameters.

The contributions to the total signal at ground level of the electromagnetic and muon components of the shower depend on the distance of the shower maximum to ground level and the lateral distance of the tank from the core of the air shower. The response of water Čerenkov tanks is different for these two components. Therefore, the Poisson fluctuations will depend not only on the total signal, but also on primary energy, zenith angle, and distance of the shower core to the tank. We call this “sampling” fluctuations.

The fluctuations we study depend not only on the physical processes in the EAS but also on properties of the detector including stability and calibration. Therefore an analysis of the signal characteristics is basic to understanding the detector response and the data analysis.

We investigated the signal fluctuations based on the data obtained by two closely located stations in the EA of the PAO. Details of this analysis and the sources of signal fluctuations are discussed in this paper.

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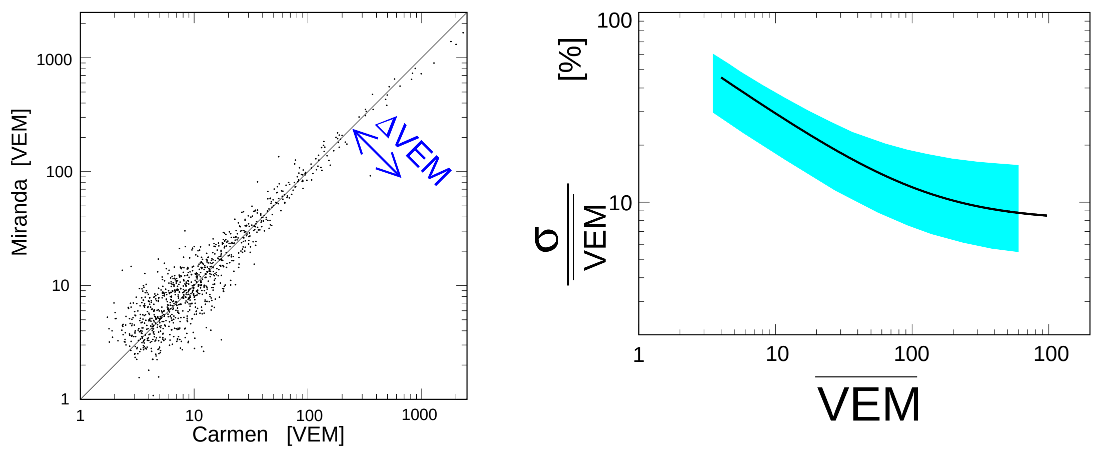

Fig. 1. Left: Correlation of the signals recorded in Carmen and Miranda. The distance of each point to the solid line is the fluctuation of each particular event. Right: Signal fluctuation between Carmen and Miranda as a function of the average of the two signals. The shaded area shows the uncertainty due to event selection. The solid line is representative of the data on average and indicates a fit using Equation (1) resulting in $A = 0.08$ and $B = 0.80$.

2. Experiment

The EA of the SD consists of 32 instrumented tanks separated by 1.5 km on a triangular grid. It was successfully operated throughout most of 2002. Near the center of this array two stations are located at 11 m separation. The stations are named Carmen and Miranda. This pair of stations samples essentially the same region of the shower and therefore is a useful tool for the study of the signal fluctuations performed in this work. In addition to this pair there are two tanks on a 800 m spacing forming an equilateral triangle with the pair enabling triggers at lower energies than with the standard 1500 m spacing.

To detect the Čerenkov light produced in the water each station has 3 PMTs located on the water surface. Calibration of each PMT is done with single muon signals[1].

3. Analysis

We have analyzed all of the events recorded from May through October, 2002. About 1000 events with 4 or more stations triggered, including Carmen and Miranda, survived after this event selection, about half of which were triggered only by the 800 m triangle. If the requirement is set for 5 or more stations triggered, the number of events is reduced to less than 500.

Left panel of Fig.1 shows the clear correlation of the signals recorded in

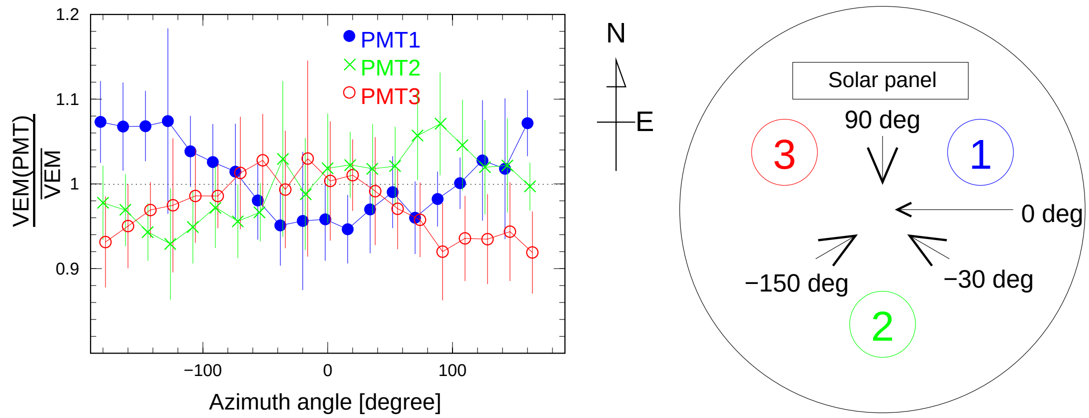

Fig. 2. Ratio of the signal of each PMT to the average of 3 PMTs as a function of azimuth angle of the air shower. Primary cosmic ray zenith angle smaller than 60 degrees and 10 or more $\overline{VEM}$ are required. In this plot, a clear azimuthal effect is evident.

Carmen and Miranda. The units are VEM, Vertical Equivalent Muons, where 1 VEM is the average signal produced by a muon vertically traversing the center of the tank. The distance of each point to the solid line is the fluctuation of each particular event ($\Delta VEM[i]$). The RMS of ΔVEM corresponds to the signal fluctuation in one tank.

The sources of the signal fluctuations include: (1) photo-statistics; (2) calibration including detector stability and electrical noise; (3) azimuthal effect; (4) sampling fluctuations in the number of particles that hit each tank.

The Auger tanks have three measurements of the signal given by the 3 PMTs. Particles from an air shower plunge into the tank and emit Čerenkov light. The Čerenkov light is then diffusively reflected by the walls of the tank liner and detected by the PMTs located at the top of the tank (Fig.2). Then the spread of the signal in the 3 PMTs will be driven by Poisson fluctuations in the number of photoelectrons arriving to the PMTs. These fluctuations are called "Photo-statistic".

If the tank is not a perfect diffuser, the number of Čerenkov photons arriving at each PMT will be different depending on the incident angle of the particles. Čerenkov photons falling directly onto the PMT without reflection from the tank walls also contribute to this effect (Fig.2), which we call the "azimuthal effect".

Another source of fluctuation is what we called the "lateral distribution effect". The lateral distribution of particles per square meter is very steep close to the core, and therefore the density changes very rapidly even in distances as short as 11 m. Because of the uncertainty of the estimated core location, this effect represents an additional uncertainty in our measurements of the fluctuations near the core. This is one of the difficulties of this preliminary study.

Right panel of Fig.1 shows the fluctuations in the signal between Carmen and Miranda as a function of the average of the signal ($\overline{VEM}$). We have analyzed the data based on different event selection criteria. The shaded area represents the uncertainty due to using these different event selection criteria. The fluctuations of smaller signals are dominated by the "sampling" fluctuations whereas for higher signals the fluctuations approach a constant fraction. It should be noted that the trigger efficiency will suppress the fluctuations in lower $\overline{VEM}$ since the threshold of the local trigger is adjusted to 3 VEM and we require both Carmen and Miranda to trigger in this analysis. The anode output with a low amplification is used for large signals (close to the shower axis) whereas the out from the last dynode is strongly amplified (factor 30) to detect weaker signals. Accuracy of the dynode to anode ratio, which is about 5 %, may dominate the constant fraction. Future on-line calibration system will reduce this fluctuation.

The functional form we propose to fit the signal fluctuations as a function of VEM is the following:

$$\sigma_{\Delta VEM} = \sqrt{(VEM \times A)^2 + (\sqrt{VEM} \times B)^2} \tag{1}$$

where A is a constant parameter which is related to calibration accuracy or detector stability and may be dominated by the accuracy of the Dynode to Anode ratio. B is the parameter associated with the "sampling" fluctuations. Actually it should be a function of zenith angle and distance to the shower core. Our preliminary result, where we do not bin in angle or core distance, gives $A = 0.08$ and $B = 0.80$.

4. Conclusions

We have analyzed the data recorded by the Carmen and Miranda pair. We have shown that the fluctuations of the mean signal in the tank can be explained with the functional form given by Equation (1).

The current statistics of the data are not large enough to fit the parameters of Equation (1) as a function of zenith angle and distance to the shower core. To investigate more detail, additional Carmen and Miranda pairs and a larger data set are necessary. Both of them will be available in the next stage of the Pierre Auger Surface Array.

1. Bertou X. for the Pierre Auger Collaboration, these proceedings