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Observation of the Long Term Stability of Water Stations in the Pierre Auger Surface Detector

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The results of a study examining the long-term behavior of Pierre Auger surface detectors is presented. The station properties, such as water quality, liner reflectivity and the water level must be continuously monitored. Such monitoring provides information on the long-term stability of the detectors, which have been designed to operate for twenty years. Using pulse height and shapes of cosmic ray muons, water quality changes are monitored and a technique developed to identify and monitor long-term trends in the array.

1. Introduction

The Pierre Auger Surface Detector is a water Cherenkov detector that will consist of 1600 stations when construction is complete. Each station contains 12 tons of ultra pure water sealed in a light-tight Tyvek[1] bag. The bag is in turn contained within a cylindrical plastic station 3.6 meters in diameters and 1.2 meters in height. Three 9 inch photomultiplier tubes look downward through the water from windows placed at the top of the bag. The array as a whole is designed to have an operational lifespan of at least twenty years. We review the performance of the 75 stations that have been in operation since 1 September 2003.

The stations function as water-based calorimeters for the purpose of measuring the energy deposited by an extensive air shower. The charge deposited by a single vertical muon provides the energy calibration for each station [1]. The amount of this charge (hence referred to as Q_{VEM} - Vertical Equivalent Muon Area [2]) is a fluctuating value dependent on a convolution of quantities ranging from static, such as the particular photomultiplier tubes in a station, to cyclic quantities like temperature. On a daily basis the most important of these is temperature which results in a daily modulation of Q_{VEM}. This type of behavior was expected and is handled by the calibration and monitoring system which recomputes Q_{VEM} for each station every minute [3]. In principle, this system can measure the energy deposited in a station regardless of the calibration value obtained from vertical muons, none-the-less tracking the changes is important for a thorough understanding of the surface detector as well as information in the case of undesirable performance. The current state of the detector can also by used as input for a complete simulation of the surface detector [4].

2. Monitoring of the Calibration Stability

Two critical factors in determining a stations Q_{VEM} calibration value are the transparency of the water and the reflectivity of the Tyvek[1] bag. The signal decay constant is a parameter obtained by fitting the trailing edge of the pulse from a single muon with an exponential function. This is done because a decrease in water purity or poor Tyvek[1] reflectivity would cause the signal decay constant to decrease as Cherenkov light is absorbed more readily. The Tyvek[1] reflectivity and the water absorption length can then be passed to the simulation as input to reproduce the currently observed signal from vertical muons. The signal decay constant has been simulated for various reflectivites and absorption lengths (see figure 1), the effects of increased absorption are evident. Approximately the same information can be obtained by dividing the total charge of a muon by its maximum

[1] Tyvek® is a registered trademark of the Dupont Corporation

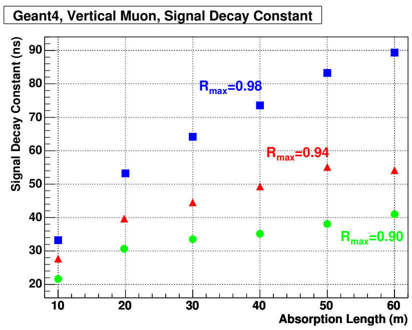

Figure 1. Effect of Different Tyvek Reflectivity (R_{MAX}) and Absorption Length on the Signal Decay Constant for one Vertical Muon.

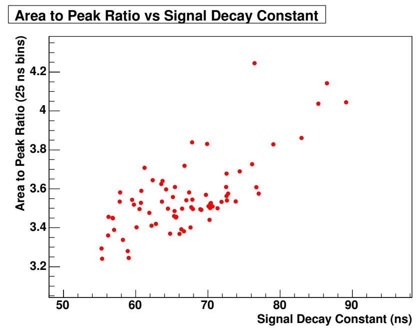

Figure 2. Correlation Between the Area to Peak Ratio and the Signal Decay Constant for one Vertical Muon.

amplitude, *the area to peak ratio*, which has the advantage of not being subject to the details of the fit used to obtain it. Figure 2 is the correlation between the area to peak ratio and the signal decay constant from the stations used in this study.

3. Long Term Stability of Water and Tyvek Quality

The time period analyzed is 1 September 2003 to 4 February 2005 and uses only those 75 stations that have been in continuous operation for that period. A graph of the area to peak ratio is produced for each photomultiplier tube of every station. For the purposes of fitting, each point is taken as a 5 day average so that the daily fluctuations have minimal impact. The area to peak ratio has a small positive correlation coefficient with temperature [1], therefore we expect a slight oscillation coupled to the annual temperature modulation. Examination of the histograms also revealed that many stations have an initial period of decrease. Because of these combined factors we fit the observed behavior with a combined exponential and sine function:

$$p_0\left[1 - p_1(1 - e^{\frac{-t}{p2}})\right] \times \left[1 + p_3 \sin(2\pi(\frac{t}{T} - \phi))\right]$$

The fit parameters are p_0 through p_3 with the following definitions; p_0 is the normalization with units of 25 ns bins, p_1 is the fractional loss (fraction of initial signal lost due to decay) and is a dimensionless quantity, p_2 is the characteristic time (time for the initial signal to decrease by $\frac{1}{e}$) with units of years, p_3 is the seasonal amplitude (amplitude fraction after signal reaches a stable point) and is also a dimensionless quantity. The function contains two additional parameters that have fixed values; T which forces the period to be one year as we expect, and ϕ a fixed phase angle that adjusts the oscillation to coincide with the annual temperature oscillation. The independent variable t is the time in years.

Parameters p_0 through p_3 are collected and saved for every photomultiplier tube and then analyzed for any commonalities and/or correlations for the array as a whole. Figure 3 is an example histogram for the normalization parameter (p_0) from the 75 stations. The mean of the distribution is 3.7 σ 0.3 [25 ns bins]. The distribution of fractional losses is characterized by a mean of 0.071 σ 0.027 for stations whose characteristic time (p_2) is less than 0.7 years (54 out of 75 stations). The remainder have much longer decay times ranging to a maximum of 2.8 centuries. Therefore, the majority of stations do experience a period of signal loss after

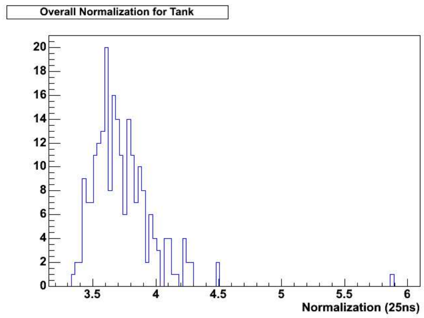

Figure 3. Distribution of the Normalization (p_0) from the Fits.

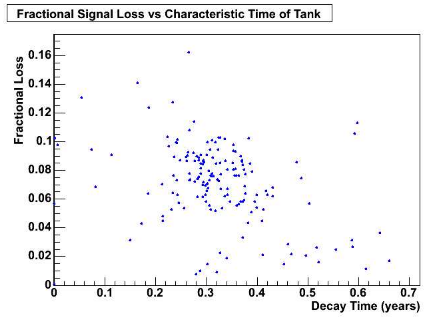

Figure 4. Scatter Plot of the Fractional Loss (p_1) vs the Characteristic Time (p_2).

they are deployed but the net result is a decrease on the order of 0.10. Figure 4 above is a scatter plot of fractional loss (p_1) versus the characteristic times for those stations with a characteristic time of less than 0.7 years. These stations have a mean decay time of 0.32 σ of 0.12 [years]. Following the period of decay we found a stable condition characterized by an annual modulation dependent on seasonal changes. The amplitude of the oscillation is given by the distribution of seasonally induced amplitudes (mean 0.005, σ 0.005).

4. Monitoring the Water Level in the Stations

A system for monitoring the water level in the stations has also been developed. The calibration obtained by the charge deposit of vertical muons [3] adjusts itself constantly based on the amplitude of I_{VEM} (*Vertical Equivalent Muon Peak*). That signal is a function of the mass of water that the muon passes through and will decrease if less water is present in the station. This is not a problem for muons as that effect cancels between calibration and the detection of shower muons, however it does not cancel for electro-magnetic showers. It is the relative signal between muons and the electro-magnetic component that will be affected. It is therefore important to monitor the water level in order to check there is no evolution (water leak in the liner for short term changes, transpiration through the liner for long term changes). Various parameters are linked to the water level, and one could use for example the ratio of the signal of an electron from a muon decay to a normal muon [5]. However in this study we investigate a parameter linked to the shape of cosmic ray muon pulses.

Studies on test stations [6] have shown that the slope obtained by fitting cosmic ray muon pulses for an individual PMT in the 1.5-2 VEM range is strongly correlated with the water level. It is in fact a measurement of the uniformity of a station: with a higher water level, a PMT will receive the same amount of light whatever the entry point of the muon, as its light will be isotropized by the reflections on the Tyvek[1]. With a lower water level, the light will be less isotropized and will give a stronger signal on a nearby PMT, while a smaller signal will be recorded at a PMT farther away. This will give an extra spread to the signals recorded, hence a flatter slope after the muon peak.

Figure 5 shows this slope parameter for all the stations over more than a year. The error bars are the RMS fluctuations for the station (or stations) indicated. A slight yearly modulation due to the temperature effect on the electronics can be seen. Superimposed on the same graph is the slope obtained only from station 254. Station 254 is a test bed on which an artificial leak was produced by draining the water during a 4 day period. The water was allowed to drain 30 cm in this 4 day period to prove the validity of the method and its sensitivity. From this measurement, a 0.027±0.002 change in the slope is found to correspond to 1 cm change in the water level. The right hand graph again shows all the stations, but this time with station 376 superimposed. Station

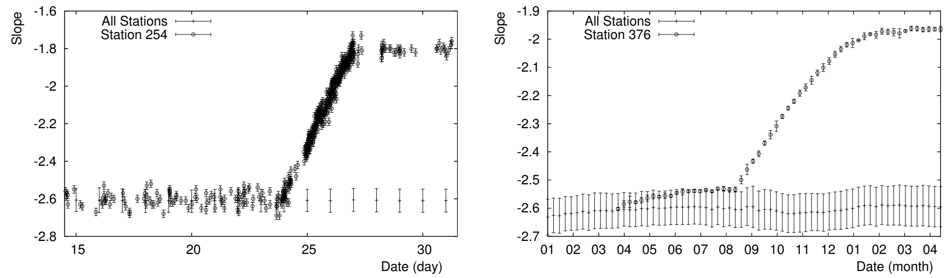

Figure 5. Evolution of the slope of the muon histogram as a function of time for all the stations, compared with 2 specific cases: station 254 and station 376. See text for details.

376 started leaking without warning and without this monitoring tool we would not have been able to detect the leak. Over the next seven months, the station had leaked about 23 cm. Applying this technique to the whole array, a limit of 0.5 cm leak per year due to transpiration can be set.

5. Conclusion

Two techniques have been developed to help us monitor the status of the water stations in the Pierre Auger surface detector. One method will allow us to track the absorption of light in the station, and the other method will be used to track the water level in the station. Using the area to peak ratio it is possible to monitor the quality of the detectors and it has been found that water stations first lose signal and then stabilize. The mean loss of 0.071 in the area to peak ratio will not adversely affect the operation of the surface detector and should be interpreted as a settling period. After this period, the water stations enter into a stable annual modulation (of <0.01) coupled to seasonal changes. The slope obtained by fitting the traces produced from naturally occurring muons has been applied to monitor the water level inside a station. Careful tracking of this fit parameter will allow leaks to be found. Using this method a limit on water loss rate has been established at 0.5 cm per year. We will continue to monitor the area to peak ratio for any further changes in the water quality and Tyvek[1] reflectivity, however aside from the annual modulation none are expected. In the case of water level, any changes detected will be dealt with by fixing the leak and/or adding more water.

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