The Surface Detectors of the Pierre Auger Observatory

Peter O. Mazur[1] for the Pierre Auger Collaboration[2]
(1) Fermi National Accelerator Laboratory, Batavia, Illinois, 60510, USA
(2) Observatorio Pierre Auger, Av. San Martin, (5613) Malargüe, Argentina

Abstract

The Pierre Auger Observatory will study ultrahigh energy cosmic rays by measuring extensive air showers with both surface detectors and fluorescence detectors. The surface detectors are deployed on a 1.5-km triangular grid covering 3000 km^2 and must operate with minimal maintenance for 20 years. Cylindrical water Cerenkov detectors of 12000 liters have been designed, fabricated, deployed, and operated in a modest engineering array. Refined through this experience, optimized versions of the surface detectors are now under construction and are being deployed to make up the full array of 1600 detectors. Each detector includes a rotationally molded polyethylene water tank that contains ultrapure water and photomultipliers for signal detection. The tank also serves as the main support and protective structure for the electronics, communications system, and solar power system. Among the virtues of the water Cerenkov detector are the ability to be calibrated by cosmic ray muons and a sensitivity to showers at very large zenith angles. Performance of the surface detectors exceeds our expectations. We discuss their design, construction and operation.

1. Introduction

The water Cerenkov detectors consist of a cylindrical volume of ultrapure water 3.6 m in diameter and 1.2 m in height, contained within a reflective liner with an inner layer of Tyvek$^{(R)}$ spun-bonded polyolefin. Features of the design [2] and implementation [1] for the Engineering Array have been described previously. The detector includes the water volume and liner, three photomultipliers (PMTs), a solar power system, an electronics system, and a communications system. All are either supported by or enclosed in a rotationally molded polyethylene tank. Fig. 1 shows a completed surface detector at the Observatory site in Argentina.

The design challenges for the system include the need to survive in a hostile outdoor environment for 20 years. The site is corrosive (due to high salt levels), subject to high winds and dust, high ultraviolet light levels in summer and wide temperature extremes, typically -10°C to 40°C during the year with surface temperatures exceeding 50°C on hot, sunny days.

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2. The Tank

The tank provides the housing and structure for the detector. It is rotationally molded from a hexene-based high density polyethylene resin, Exxon-Mobil Escorene HD 8660 as compounded by A. Schulman Inc. This is a premium quality resin to insure long life. The thickness is 13 mm. The 4.3-mm thick exterior layer is a light beige color to minimize heating in the sun on hot days, and to blend in with the environment. The inner layer is black and has been compounded with 1% carbon black to provide complete opacity and to absorb the damaging UV component of sunlight. In addition, both the black and beige resins have been compounded with hindered-amine light stabilizers (HALS) to provide further UV protection by a radical-trapping mechanism rather than by absorption.

The tanks produced up to now have a UV protection rating (on the industry-standard scale) of UV-8, for 8000 hours of operation. Given the considerable thickness of the tank wall, this is considered adequate by most industry experts consulted. For further assurance, we are testing a UV-15 (15000 hours) beige layer compounded with a higher HALS concentration to insure against cracking in the outer, most exposed layer.

Fig. 1. A Surface Detector of the Pierre Auger Observatory.

The complex shape on the top of the tank has three purposes: 1. To provide rigidity to the top (supporting the weight of equipment and workers) without adding very much to the height of the tank, which is limited to 1.6 m by shipping regulations; 2. To provide support for the external components: solar panels, antenna mast, the electronics package enclosed under the aluminum dome visible on the top of one of the access hatches; 3. To provide space for the three PMT assemblies, located 120° apart on the top of the water volume/liner at a radius of 1.2 m.

3. The Liner

The liner is a cylindrical "bag" with dimensions slightly larger than the water volume and is made of a custom laminate [1] of metallocene-catalyzed polyethylenes and DuPont Tyvek. The laminate is opaque due to carbon black loading in one layer, provides a tough container for the water due to the polyethylenes selected, and provides a high diffuse reflectivity for ultraviolet light ($\lambda \gtrsim 350$ nm) due to the Tyvek inner surface. There are three polyethylene frames with windows of thin (0.5 mm), transparent metallocene polyethylene welded into the liner for the PMTs. The windows are formed into a curved shape to approximate the PMT envelope shape, and the PMTs are bonded into place with General Electric RTV 6136-D1 silicone rubber. Tests with freezing water indicate that this assembly will survive ice formation without damage if a very small amount of insulation is used at the perimeter of the PMT assembly. The entire liner and PMT assembly water enclosure is welded together without adhesives. Not only does this provide the most reliable seal, but also there are no chemicals from adhesives that could contaminate the ultrapure water Cerenkov radiator. After each liner has been manufactured, it is subject to tests to determine if it is light tight and gas tight. The liner is inflated into a nearly spherical shape, and a soap-bubble test can then be performed on the external surface. By shining a light through a PMT port, light from the inside of the liner can be clearly seen in a darkened room, revealing any light leaks. These tests easily detect holes $< 35\ \mu$m, which would leak water at 1/3 the maximum tolerable leakage rate of 7 ml/hr.

4. Water

We require good light transmissivity over a long period of time for proper operation of the detector. This is accomplished by providing ultrapure water, which has very little particulate matter (because of extensive filtration) and very little dissolved solids (because of extensive purification and deionization) or non-polar organic compounds because of a Total Organic Carbon (TOC) destruct stage in the water plant. The conductivity of the water in the detectors typically varies from 0.10 to 0.15 μS and the TOC level is less than 200 ppb. Initial water clarity is excellent and samples taken at intervals of several months do not indicate significant quantities of free-floating bacteria or other biological activity.

5. Solar Power

The electronics average power consumption budget of 10 W is satisfied by a 24 V solar power system using two 50–60 Wp (watts under standard solar illumination) photovoltaic modules mounted on the tank, a standard charge regulator and two 12 V lead acid batteries of 100 Ah capacity each, mounted in a thermally insulated polyethylene battery box that can be seen to the left in Fig. 1. The system is controlled by special circuitry that monitors the state-of-charge of the batteries and reports it to the Observatory campus. If, during extended cloudy periods, a sufficient number of batteries approach a low state of charge, the on-shift operator can shut down, via software command, the entire surface detector array to allow the batteries to recharge. It is turned on again after a suitable state of charge has been reached. This allows the array to operate without "holes" caused by individual detectors shutting down one at a time when their batteries are at a low state of charge.

6. Electronics and Communications

The custom electronics and communications systems are largely within the aluminum dome mounted over one of the access hatches. Heat conduction through the 13-mm polyethylene hatch cover between the electronics and the water in the detector moderates the diurnal temperature variation so effectively that neither thermal insulation nor ventilation is required. All cabling except antenna and solar panel cables are enclosed within the dome, tank, or battery box.

The arrival time of the signal at each detector is used to form a trigger and to determine the direction of incoming showers. Time signals are obtained from the Global Positioning System (GPS) through an antenna and receiver at each detector. The quality of the time coincidence can be evaluated by looking at signals from the same shower in two Engineering Array detectors that are separated by only 11 m, called Carmen and Miranda. Fig. 2 shows the time difference between their signals.

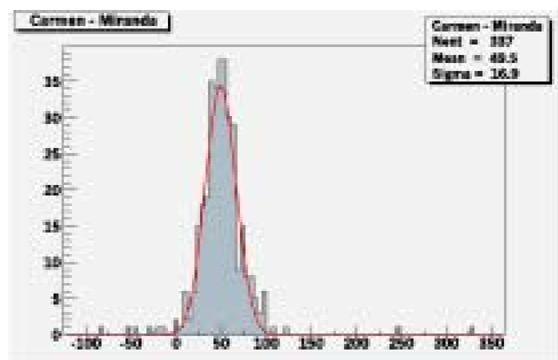

Fig. 2. Time difference (ns) of shower arrival between two detectors separated by 11 m. Data have not been corrected for detector separation distance. Raw data binning is 25 ns.

Data are communicated between each surface detector and an intermediate station located typically at the Fluorescence Detectors, and from there to the Observatory Campus with a custom communications system. The Yagi antenna and the small white GPS receiving antenna are visible on the top of the mast in Fig. 1.

References

1. C. O. Escobar et al., Surface detector construction and installation at the Auger Observatory, in *Proceedings of ICRC 2001*
2. *Pierre Auger Project Technical Design Report*, available at http://tdpc01.fnal.gov/auger/org/tdr/index.html