The Mexican Participation at the Pierre Auger Observatory: Recent Results


Abstract. In this work we present the participations of the Mexican group at development of the Pierre Auger Observatory. We have been working in both parts of the hybrid proposed for the Auger detector, the fluorescence and the surface detectors. In the part of fluorescence, we have analyzed the resolution of the Hi-Res optical design of the fluorescence detector observatory. We have found a heterogeneous image resolution. We propose to use a lensless Schmidt camera (with spherical image surface) to duplicate the field of view to 30x30 degrees and simultaneously guarantee a resolution of one degree over the whole field of view.

By the Surface Detector, a water Čerenkov detector (WCD) prototype of reduced dimensions (cylinder 1.54 diameter filled with purified water up to 1.20 m high) is used to obtain preliminary experimental results that validate the concept of remote calibration and monitoring of WCDs. We use muons that stop and decay inside the WCD and, in a complementary way, muons that cross the WCD. We used a moun telescope trigger in order to study the charge distribution of vertical muons, their pulse amplitude decay and the Čerenkov light attenuation length of those secondary cosmic muons we include the bacteria population content for the four months of operation to validate the monitoring method.

INTRODUCTION

The Auger Observatory is to be a hybrid detector, employing two complementary techniques to observe extensive air showers. A giant array of particle counters will measure the lateral and temporal distribution of shower particles
at ground level. An optical air-fluorescence detector (FD) will measure the air shower development in the atmosphere above the surface array. Operating together, the surface detector (SD) array and fluorescence detector characterize showers to a greater degree than either technique alone. Both methods are well established by prior experiments. The surface array resembles the array successfully employed by the Havera Park group for over twenty years (ref. [1]), although on much larger scale. The optical device uses the fluorescence technique pioneered by the University of Utah's Fly's Eye (ref. [2]). Measurement of atmospheric fluorescence is possible only on clear, dark nights.

The decision to use the two techniques together is based upon in this aspects, Intercalibration, Enhanced composition sensitivity, Hadronic interactions, Uniform exposure and Cost.

Auger's hybrid configuration is the most economical and robust way to obtain the necessary data, including a subset with specially high reconstruction resolution and independent cross checks.

Each of the two surface arrays of the Auger Observatory will consist of about 1600 detectors spaced on a grid with about 1.5 km separation between individual detectors. Each array encompasses an area of 3000 km$^2$. The angular and energy resolution of a ground array (without coincident fluorescence data) are typically less than 1.5° and less than 20%, respectively. If an event trigger is assumed to require five detectors above threshold, the array is fully efficient at $10^{19}$ eV. New technologies are employed, making it practical to operate thousands of detectors spread over such an area. Each detector will be solar powered (consuming less than 10 watts) and will communicate via modern wireless techniques. Inter-detector relative timing is accomplished by individual Global Positionating Satellite (GPS) receivers.

The fluorescence detectors consist of many meter-sized mirrors, each of which is equipped with a cluster of hundred or more photomultipliers. Each mirror and associated cluster will view its own segment of the sky. Together, the system of mirrors observes most of the sky above the surface array. The magnitude of the photomultipliers signals gives the number of electromagnetic particles in the shower, and hence the energy. Fast timing of the sequence of signals yield the trajectory of air showers passing in the field of view of the detector. In the hybrid mode of operation, the surface and fluorescence detectors together have a directional reconstruction resolution of about 0.3° for events near $10^{20}$ eV (ref. [3]).

In this paper we present the work done for the Mexican Auger collaboration. We will describe briefly the main objectives and principal results of our effort in the fluorescence and surface detectors development. In the second section we will detail our optical design proposal for the FD, including the correspondent values of its optics parameters. The third section will be dedicated to the description of our results on the water Cerenkov plastic tanks which is operating since March 1997 in Mexico. Finally we present the conclusions in the Section 4.
OPTICS AT THE FLUORESCENCE DETECTOR

In the optical design in order to improve the Hi-Res telescope, the optical group (Cordero et al) to use a lensless Schmidt camera. A spherical with an aperture-stop at its center of curvature, "C", would give uniform images over a wide spherical field-surface concentric with itself, each image affected from a large amount of spherical aberration.

In table 1, the parameters of the design telescope are shown.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curvature Radius of the mirror</td>
<td>2415 mm</td>
</tr>
<tr>
<td>Diameter of the mirror from the mirror vertex</td>
<td>2566.4 mm</td>
</tr>
<tr>
<td>Best image plane</td>
<td>1161.5 mm</td>
</tr>
<tr>
<td>Effective focal distance</td>
<td>1207.5 mm</td>
</tr>
<tr>
<td>Detector array size</td>
<td>628.37 mm</td>
</tr>
<tr>
<td>Spot size</td>
<td>20.29 mm</td>
</tr>
</tbody>
</table>

The main advantage of this proposal is that the image quality can be guaranteed even when the field of view is extended from 15x15 degrees to 30x30 degrees, 40x40 degrees and 45x45 degrees and so on.

This method offers several important advantages: (1) Coma aberration is eliminated and the spot size image is uniform over the larger field of view. (2) The reduction in the number of buildings, electronics crates, calibration devices, etc., can reduce the cost of each eye. (3) The opening to the outside is only the diaphragm with UV transparent material (like thin mylar), it may be possible to keep dust and dirt out of the telescopes and maintain them at nearly constant temperature, thereby eliminating important causes of sensitivity variation. However, what is the prize that we must pay for extending the field of view? If we increase the field of view and if we do not want the vignetting effect then the diameter of the mirror must be increased. However if the field of view goes from 15x15 degrees to 30x30 degrees, then the constructed area of the mirror goes from 3696367 mm² to 5869603 mm², i.e. the area increases only 1.6 times: while the explored area on the sky grows 4 times. On the other hand we lose energy when we increase the field of because the detector area grows and it obstructs the pass of light. This is a serious problem because we must increase the diameter of diaphragm. Then we must increase the diameter mirror and must re-analyze the optical design for spherical aberration, which grows as the cube of the radius of diaphragm.

Because it is desirable to have a plane image surface instead of the spherical one, then we can make a small modification of our initial optical design. The
first step was reached locating the focal plane at the vertex of spherical image surface. We found the spot sizes grow to 5 times at the end of the field with respect to the image axis. Then, in the second step, we reached the optimal defocus and we found in this case the spot sizes only grow 1.6 times with respective to the image on axis (see fig. 1). So, we showed that even with a plane image surface we improve the Hi-Res results.

If we increase the curvature radius we find several spot sizes for one degree on the sky. We found that if the curvature radius is equal to 3500 mm then the spot size is equal to 28 mm and the image size for one degree on the sky is equal to 30 mm. In this case the diameter of the mirror is equal to 3183 mm and the new area is 4 times the area of the Hi-Res telescope. Remember that we should need four Hi-Res telescopes to cover a field of view 30x30 degrees. The very important difference is that the image quality is four times better than Hi-Res.

Finally we have constructed a 1/10 scaled Schmidt camera prototype at Puebla. We built a segmented spherical mirror. We obtained a uniform image over the whole field of view. With this experience in mind, we could make a full scale Schmidt lensless camera (ref. [4]).

THE MEXICAN WATER ČERENKOV DETECTOR PROTOTYPE

The mexican tank is made of a polyethylene cylinder, white on the inside and black on the outside wall, 1.54m in diameter, filled with purified water (commercially available as drinkable water in 20-liter bottles) up to height of 1.2m.
A single Hamamatsu 8" PMT looking downwards was located at the center of the tank with the PMT slightly immersed in the water. The inner wall of the tank and the water surface were covered with a tyvek sheet cut to a cylindrical shape and kept in place by circular PVC hoses stretched tight against the wall of the tank. We used a Hamamatsu R5912 during the first three months of operation; then we replaced it for a Hamamatsu R1408. In the trigger system, it is consisted of two scintillation counters, one on the top and the second formed the bottom trigger. Both counters forming a vertical telescope which accepted vertical muons in a cone of almost 2 degrees with respect to the vertical with an active area of 0.073 m². The high voltage of the top (bottom) PMT paddle was 1.87 (1.60) kV., and the corresponding provided pulse rates were 3.80 Hz and 3.60 Hz, respectively. In the data acquisition system we have that the signal from the PMT was discriminated with a commercial NIM module using a threshold of -30 mV. A custom made TDC CAMAC module was used to trigger with two scintillation paddles in coincidence to measure the vertical muon pulse shape as a function of time (hundreds of nanoseconds). The signal from all the PMT’s (the Hamamatsu and the small paddle’s PMTs) were transmitted via RG58 coaxial cables to the digital oscilloscope and the NIM module. The charge was obtained integrating the pulse shape. A pentium PC running at 75 MHz. and a DAQ program written in LabView were used to store pulses and the charge as recorded by a Tektronix TDS220 digital scope for a large number of events (see figure 2) [ref. [5]].

By the calibration we used also a custom-made CAMAC TDC module, referred to as muon module from hereafter, was used to measure the time interval between consecutive pulses coming out of the discriminator. And the
CONCLUSIONS

In the optical part is possible to build an optimized Schimdt camera without correcting plate, i.e. a spherical mirror and a diaphragm located at the center of curvature plane of that mirror. This will warranty a homogeneous image size of 20.3 mm over the detectors on all the 30 by 30 degrees field. Moreover we have analyzed flattening the image surface and we found that it is possible to use a flat or segmented flat surface in which cases the image quality is guaranteed too.

In the surface part, the average number of photoelectrons produced by the decay electron coming from stopping muons is found to be 0.18 times the average number produced by vertical muons that cross the WCD coming from the background flux of secondary cosmic ray muons. Likewise, the charge distribution of the first pulse for the events that satisfy the cut $C_2 < C_1$, which we associate with crossing muons (in the sense that this cut is the complement of the stopping-muon cuts), shows a clear peak which is slightly displaced to the right of the peak corresponding to vertical muons. The peak positions of the charge distributions of the decay electron and the crossing muons can be used to calibrate the WCD and to monitor the gain of its PMT's.

In the figure 3.a shows the charge distribution of the first pulse for events that pass the cuts $C_2 < C_1$ and time between pulses < 8μs. The solid line is a gaussian fit to the data. Figure 3.b shows the charge distribution of the first pulse for the events that satisfy the cut $C_2 < C_1$, which selects crossing-muon events. The vertical arrow indicates the position of the peak for vertical muons.

This method can be applied even in the case that the WCD is segmented in three sectors in such a way that the Čerenkov light emitted in each sector is collected only by one PMT and not by the three PMT's as in the unsegmented case. In the case that the WCD's are unsegmented this method can be complemented with the requirement of double or triple coincidences among the three PMT's to reduce the background noise from the PMT's. Another important conclusion is that the calculated average attenuation length (9.7 m.) and the number of photoelectrons were practically constant during our four month data taking period. We believe that this result is very dependent on plastic tank material. From the report of the bacteria population in the inner water, we could see that the number of bacteria becomes very low with respect to the bacteria content when the tank was filled. We think that it is because of lack of air in the interior of our tank. It is also a consequence of the intrinsical hygenic properties of the plastic material. It is clear that this result is good news for the Auger Čerenkov tanks final design because we have shown that
FIGURE 3. Distribution of the charge of the first pulse. Upper plot: for events satisfying charge(pulse$_2$) > charge(pulse$_1$) and time between pulses < 8μs. The curve is a gaussian fit to the data. Lower plot: distribution of the charge of the first pulse for the events satisfying charge(pulse$_2$) < charge(pulse$_1$), the arrow indicates the position of the peak for vertical muons, the solid curve is a gaussian fit to the data.
the plastic material could conserve pure the inner water for a long period of time. The final conclusions will be obtained from the results of the full size plastic tank which is already working in Puebla.

REFERENCES