

Performance of the 1st prototype of the HAWC Gamma Ray Observatory

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ABSTRACT

The 1st prototype of 3 water Cherenkov detectors of HAWC was successfully built and tested but lead to design changes in the layout of the observatory.

I. INTRODUCTION

The High Altitude Water Cherenkov observatory (HAWC) [1] is a second-generation gamma ray detector that will survey the sky continuously from its site at 4100 m altitude and 19° northern latitude at the Sierra Negra volcano in the state of Puebla, 200 km in a straight line from Mexico City. The baseline detector design was 900 large water tanks (4m diameter x 5m depth) each instrumented with a single 20 cm photomultiplier tube looking up at the water volume from the bottom of the tank but as a result of this investigation it was changed to 300 metallic pipes 7.3m diameter with a water and light tight inner bladder and 3 photomultiplier tubes. The tanks will be densely packed to cover an area of ~ 25,000 m². The array detects atmospheric cascades through the Cherenkov light produced in the water and has a good gamma/hadron discrimination of the primary cosmic ray in the energy range below hundred of GeV to hundreds of TeV and an angular resolution between 0.5° and 0.25°.

HAWC is designed to monitor AGN for variability and measure the high energy behavior of galactic gamma-ray sources and look for GRBs. To validate the conceptual design, face the reality of commercial vs custom built water tanks, prove the strength and commitment of the US-Mexican collaboration and evaluate the performance of a small array it was decided to build a prototype consisting of 3 large commercial water tanks in an environment like the one of the final observatory.

II. THE PROTOTYPE ARRAY

As the HAWC site is being developed it was decided to place the prototype array higher up in the mountain at 4530m close to the top of Sierra Negra, where the Large Millimetric Telescope has been built (LMT), a radio telescope with a 50m antenna. The LMT collaboration has developed the site, which counts with road access, electricity, internet, security and teams of engineers and skilled workers going daily up the mountain.

With funds from the Physics Institute at UNAM and the University of Chiapas we bought 3 tanks of 3m diameter and 3.6m height which were delivered between November and December 2008. These are the largest tanks that are made commercially in Mexico (3.6m diameter in the US). We learned that there are no ovens or moulds large enough to make 5m diameter plastic tanks and that 3.6m is the largest width of objects that can be transported on the highways. Therefore we had to change our base design to 7.3m metallic pipes that can be assembled on the site.



Fig. 1: Left, installation of the first tank of the HAWC prototype in the volcano Sierra Negra, Mexico at an altitude of 4530m (February 2009). Right, prototype of one of the metallic pipes that will hold the 60 m³ of water of the final HAWC water Cherenkov detectors (October 2009).

In five field trips to the mountain between November 2008 and March 2009, for a total of 14 days, we cleaned and set up the 3 tanks, filled them with filtered and softened water and instrumented them with photomultipliers that have been recycled from the Milagro gamma ray observatory, see Fig. 1.

The tanks have been set up in a triangular pattern see Fig. 2 and named T1, T2 and T3. Table 1 gives their coordinates.

TABLE I: Positions of the three prototype tanks.

| | X (m) | Y (m) | Z (m) |
|----|--------|--------|---------|
| T1 | 0.0 | 0.0 | 4531.29 |
| T2 | -14.59 | -27.76 | 4531.12 |
| T3 | -33.19 | 0.60 | 4531.05 |

Each tank holds 25,000 l of water, which had to be carried up from a well at the bottom of the mountain by trucks. To supply the water for the HAWC array a well will be dug near the site. The tanks were filled with filtered and softened water. A manhole of 80cm diameter allows access to the interior of the tank and is closed with a light tight screwed lid.

The site of roughly 80x80 m² had been leveled by the contractors building the LMT to put a concrete plant for the structure supporting the antenna. It contains still some leftover structures like a ramp near the T1 tank and a small stone warehouse also next to T1 that served us as a counting room.

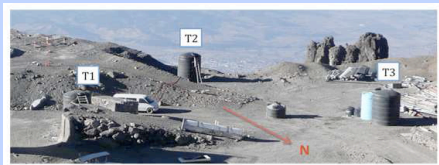


Fig. 2: three water tanks of the HAWC prototype array named T1, T2 and T3

The T1 tank was instrumented with three 8i Hamamatsu R5912 photomultipliers that had been used in Milagro [2]. The voltage divider of the PMTs is encased in a water tight plastic cylinder from which emerges the high voltage cable carrying also the signal. One PMT was placed looking down on the top of the water, a second was placed centered at the bottom of the tank and the third sat at the side close to the tank wall, see Fig 3. Two scintillator paddles 60 x 60 cm² were used to select vertical muons by being placed one at the top and the other at the bottom of the tank. The other two tanks, T2 and T3, were instrumented with only one photomultiplier centered at the bottom of the tank.



Fig. 3: While the place for the T2 tank is being prepared (left), the water of T3 is being purified.

The HAWC array is optimized to obtain the best timing resolution for the arrival of the shower signals rather than to collect the maximum amount of the Cherenkov light produced in each tank. Therefore the walls and bottom of the tanks are absorbing in contrast to the case in the Auger tanks. The signals are consequently faster.

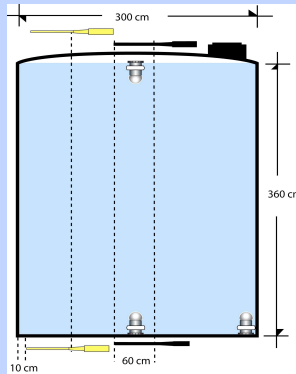


Fig. 4: Layout of the T1 tank with 3 PMTs, one on the top floating and looking down, one on the bottom centered and one on the bottom on the side of the tank. Two scintillator paddles with 60x60 cm² area were used to trigger on vertical muons at two different positions.

III. MEASUREMENTS

The photomultiplier signals were split by a linear fan out with one of them fed to a discriminator and a gate generator to make the trigger signal, the other went into a 4 channel CAEN V1729 FADC that digitized the signal shape taking up to 2Gsamples/s. Offline analysis provided the amplitude, integrated charge and arrival time of the Cherenkov light produced by the incoming particles as seen by the photomultiplier. Typical pulse shapes for air showers detected by the three tanks in coincidence are shown in Fig. 5. The time difference between the arrival times of the signals in the three tanks gives the direction of the shower, permitting to obtain a rough sky map of cosmic rays. The count rate of signals was of the order of 16 KHz with the trigger set at a fraction of a single photo electron. Amplitude spectra for one single tank are shown in Fig. 6 for the central photomultiplier in T1.

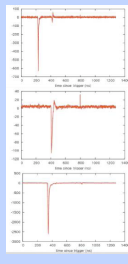


Fig. 5: Pulse shapes from the 3-tank prototype array detecting an air shower.

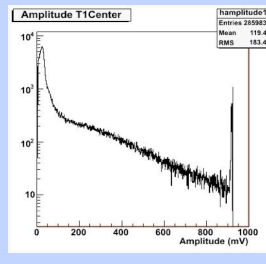


Fig. 6: Spectra of the signal detected by the central photomultiplier in tank T1 when triggered by the Cherenkov light.

In order to use the array to trigger on air showers, the output of the discriminators were broadened to 250 ns and a triple coincidence was required. The resulting trigger rate was 1 Hz. The amplitude spectra and distribution of the arrival time differences between two tanks are shown in Fig. 7.

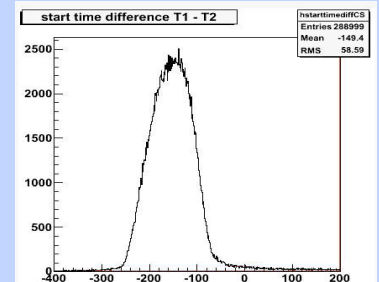


Fig. 7: Time difference between the T1 and T2 tanks.

From the arrival times of the shower particles at the three tanks the direction of the primary cosmic ray was reconstructed and the resulting sky map is shown in Fig. 8.

As it was to be expected, the distribution of the arrival directions of the detected air showers shows a marked deficit in the direction of the summit of the Sierra Negra volcano, where the mountain in the direction of the LMT absorbs the showers.

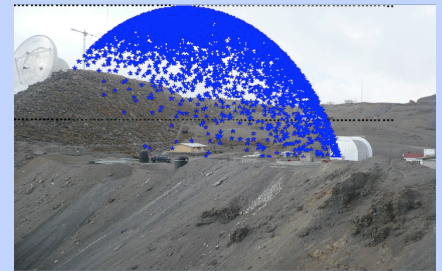


Fig. 8: Sky map of primary cosmic rays obtained with the prototype array.

IV. CONCLUSIONS

The design of the HAWC gamma ray observatory is based on a large number of water Cherenkov detectors, installed at 4100m altitude and covering an area of 25,000 m². The array is optimized for gamma/hadron discrimination and sub-nanosecond timing for reconstruction of the shower direction with good accuracy. By the end of 2008 this called for 900 high density polyethylene water tanks of 4m diameter and 5 m height with one upwards looking photomultiplier at the center bottom of the tank.

To test the feasibility of this solution, a prototype consisting of three water Cherenkov detectors of the HAWC gamma ray observatory has been constructed and made operational near the chosen site at the Sierra Negra volcano in Mexico, at 4530m altitude.

As these large water tanks of 4m diameter and 5m height are not commercially available, the prototype array was made with three roto-molded plastic tanks of 3m diameter and 3.6m height. They were filled with purified water and instrumented with 8" Hamamatsu R-5912 photomultipliers able to detect single photons.

Data with a single tank was obtained with a trigger PMT at the bottom center of the tank. Air showers were recorded by the triple coincidence of the tank signals within a 250ns time window. From the arrival time differences of the signals in the three tanks the direction of the shower was reconstructed and a sky map of the primary cosmic rays was produced.

This exercise amalgamated the collaboration between Mexican and US groups and demonstrated that the infrastructure exists at the Sierra Negra site to be able to build the HAWC gamma ray observatory. It also showed that the 4m diameter polyethylene tanks were not a viable solution as it required the installation of a casting factory very near to the site, then the largest objects that are allowed on the highways have to have less than 3.6m width. Also new larger ovens and molds had to be constructed, making the solution too expensive.

The new layout consists of larger water containers made out of pipes of corrugated steel sheets and having 7.3 m diameter and 5.5 m height. They have a water and light-tight bag and three photomultipliers at the bottom. They are more economical than the plastic tanks and can be assembled on the site, which solves the problem of transportation of such large objects.

The next stage of the observatory to construct an array of 7 large metallic tanks, 7.3m diameter at the site of the HAWC observatory is starting now.

V. ACKNOWLEDGEMENTS

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