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The High Altitude water Cherenkov (HAWC) Observatory

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Abstract

HAWC is a continuously operated, wide field of view detector comprised of three hundred 188,000 liter water Cherenkov detectors, each instrumented with four photomultipliers providing charge and timing information. HAWC covers approximately ~22,000 m2 at an altitude of 4100m and reliably estimates the energy and arrival direction of gamma and cosmic rays with significant sensitivity over energies from several hundred GeV to several hundred TeV. With an instantaneous field of view of 2 steradians, HAWC observes 2/3 of the sky in 24 hours. HAWC has been optimized to study transient and steady emission from both galactic and extragalactic sources of gamma rays and serves as a survey instrument for multi-wavelength studies. HAWC has significant discovery potential, including the possibility of indirect detection of dark matter through the observation of gamma rays produced via dark-matter particle annihilation. HAWC has been making observations since summer 2012 and officially commenced data-taking operations with the completed detector on March 20, 2015. This paper will describe the detector design, science capabilities, first scientific results and future plans of the HAWC observatory.

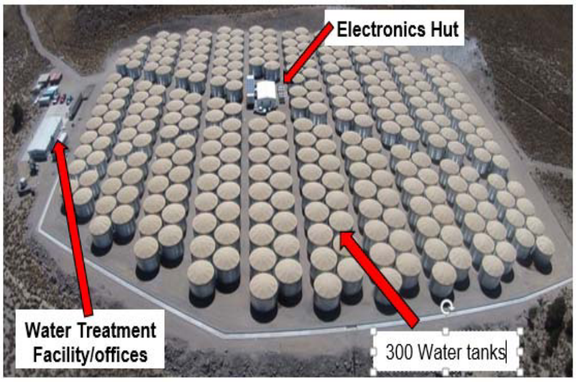
Keywords: gamma-ray astronomy, instrumentation

1. Design of the HAWC Observatory

1.1. Observatory Site

The High Altitude Water Cherenkov (HAWC) observatory, shown in figure 1, is a continuously operated, wide field of view detector principally designed to observe astrophysical sources of gamma rays. HAWC, is based upon the technology developed by the Milagro detector [1] that uses the Earth's atmosphere as a calorimeter to sample extensive air showers (EAS) produced by the primary gamma or cosmic ray. The measurement of the energy and arrival direction of gamma rays, as well as cosmic rays, impinging on the Earth's atmosphere is achieved by sampling the resulting extensive air

Figure 1 Aerial photograph of HAWC observatory



showing the three hundred 7.3m diameter 4.5m deep water tanks and the electronics hut and water treatment facility.

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showers using an array of 300 closely spaced water tanks. This array covers an area of approximately 22,000m^2 and is located at an altitude of 4100 m on Sierra Negra Mountain in Mexico (18^0 59' N, 97^0 18' W) resulting in a detector with significant sensitivity to gamma rays and cosmic rays with energies from several hundred GeV up to several hundred TeV. Milagro was located at an altitude of 2600m and had an effective area approximately 10 times smaller. The increased area and higher altitude of HAWC results in more than an order of magnitude increase in sensitivity of HAWC over Milagro. The higher altitude of 4100m allows HAWC to sample vertical showers at an atmospheric slant depth of slightly less than 600 g/cm^2, closer to the depth of shower maximum for lower energy extensive air showers.

1.2. Water Cherenkov Detectors

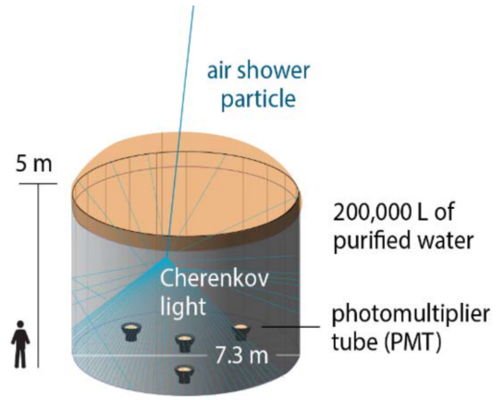

Figure 2 A HAWC Water Cherenkov Detector indicating the layout of the 4 PMTs that measure the Cherenkov light produced by charged particles from extensive air showers.

Each water Cherenkov detector (WCD), as shown in figure 2, consists of a commercially available corrugated galvanized steel water storage tank, 7.3m in diameter and 5.4 m high. A light-tight plastic bladder custom manufactured by HAWC collaborators contains approximately 188,000 liters of purified water inside each tank. Four upward-looking photomultiplier tubes provide timing and charge information by observing Cherenkov light produced by charged particles as they traverse each 4.5m deep pool of water. HAWC can reliably estimate the energy and arrival direction of cosmic and gamma rays arriving from zenith angles of up to 45^0 , resulting in an instantaneous field of view of approximately 2 steradians. As the Earth rotates over one day, HAWC observes a swath of the sky from 26^0 to 64^0 in Declination and 0 to 24 hours in Right Ascension, roughly 2/3 of the sky.

1.3. Readout Electronics and Data Acquisition

HAWC reuses the 900 Milagro Hamamatsu 8" Hamamatsu R5912 PMTs, and added 300 larger and higher quantum e□ciency PMTs, Hamamatsu R7081HQE 10" PMT, to further increase HAWC's sensitivity to lower energy gamma rays. A block diagram of the recycled Milagro Time-Over-Threshold (ToT) discriminator based front end electronics is shown in figure 3. In addition to providing precise timing information for the shower front from the leading edge of the discriminated signal, the width or time-over-threshold of the discriminated signal is proportional to the charge. A VME-based high speed data acquisition system using CAEN VX1190 TDCs with a precision of 0.1ns is used to record time stamps of the pulse edges. Each PMT is connected to the central electronics building through equal length, ~145m, Belden 8241 RG-59 cable through which high-voltage is provided and signals are read. A laser-based system providing light to each WCD through a network of optical fibers is used to perform timing and charge calibration.

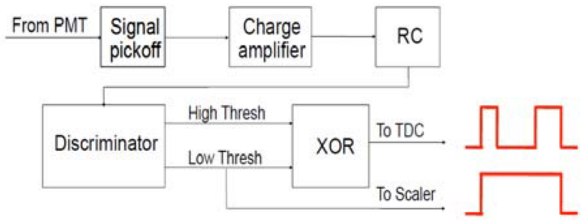

Figure 3 Block diagram of Time-Over-Threshold (TOT) front-end electronics used to provide timing and charge information from the WCDs.

A schematic diagram of the DAQ and online processing is shown in figure 4. The rate of signals from each PMT is typically between 10 to 20 kHz. At the TDC level there is no hardware trigger and the online processing farm treats all incoming hits. Approximately 24 kHz of events are identified as air showers, mainly from cosmic rays, and stored on disk at a raw data rate of ~20 MB/sec or 700 TB/year. Reconstruction and analysis is done within a few seconds of triggering with an online processing farm of ~ 200 cores. The raw data is transported via disk