The High Altitude Water Cherenkov Detector

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Abstract.

The high altitude water Cherenkov observatory (HAWC) is an instrument for the detection of high energy cosmic gamma-rays. Its predecessor Milagro has successfully proven that the water Cherenkov technology for gamma-ray astronomy is a useful technique. HAWC is currently under construction at Sierra Negra in Mexico at an altitude of 4100 m and will include several improvements compared to Milagro. Two complementary DAQ systems of the HAWC detector allow for the observation of a large fraction of the sky with a very high duty cycle and independent of environmental conditions. HAWC will observe the gamma-ray sky from about 100 GeV up to 100 TeV. Also the cosmic ray flux anisotropy on different angular length scales is object of HAWC science. Because of HAWC’s large effective area and field of view, we describe its prospects to observe gamma-ray bursts (GRBs) as an example for transient sources.

1. Introduction

HAWC is an air shower detector array for the observation of TeV gamma-rays and the direct successor of the Milagro experiment [1, 2]. Several instruments have observed over a hundred TeV gamma-ray sources so far [3]. These include galactic supernova remnants, microquasars and active galactic nuclei (AGN). Some of these sources show very hard spectra. Among them are sources detected by Milagro like MGRO J1908+06 ($\gamma = 2.1$) [4, 5] and MGRO J2019+37 ($\gamma \approx 2.2$ between 100 MeV and 12 TeV) [6]. The Cygnus region source MGRO J2019+37 has not been detected by air Cherenkov telescopes (IACTs) [7]. The missing detection can be explained by a spatial extension of the source or its very hard spectral index shifting the spectrum into an energy band that is favored by HAWC and Milagro but above the IACT sensitive energy region. Compared to IACTs, HAWC is better suited for spatially extended sources because of its large field of view of about 10% of the full $4\pi$ sr sky. HAWC is extending the observable gamma-ray energy towards 100 TeV [8] and, therefore, opens a complementary energy window.

HAWC’s large field of view also allows for measuring the diffuse galactic gamma-ray spectrum as well as the large and medium scale cosmic ray (CR) anisotropies [9]. The medium scale CR anisotropy was discovered by Milagro [10]. Results of the Milagro measurements of the galactic plane diffuse gamma-ray emission and the Cygnus region [11] can be confirmed by HAWC and the corresponding spectra extended to higher energies. High energy gamma-ray observation are a hint towards hadronic particle acceleration in the Cygnus region because the resulting pion decay can explain the observed TeV gamma-ray excess [12].

The very high duty cycle of $> 95\%$ and large field of view qualify HAWC for transient source observation. Gamma-ray burst (GRB) photons with energies above 30 GeV [13, 14] have
been measured by Fermi LAT. Together with the discovery of a subclass of GRBs containing an additional hard power law (PL) spectral component [15, 16] a GRB detection with HAWC seems to be possible.

2. The HAWC Detector

HAWC is located in the Pico de Orizaba National Park in Mexico at an altitude of 4100 m. The instrument itself is currently under construction and scheduled to be completed by 2014.

Like its predecessor Milagro, HAWC is an air shower array, looking for the particle cascades induced by high energy CRs or gamma-rays hitting Earth’s atmosphere. In its final state, the detector will consist of 300 light insulated and densely packed water Cherenkov detectors (WCDs) with a diameter of 7.3 m and a water height of 4.5 m each. The area included by the outer boundary of the detector is about 22000 m². The HAWC layout is presented in Fig 1. A small set of WCDs, the VAMOS test array, is operational since summer 2011.

In the baseline construction plan every tank contains three 8” PMTs. The funding for a fourth high quantum efficiency PMT in each tank has been granted but in this document only simulation results with three PMTs per WCD are presented.

HAWC uses two independent data acquisition (DAQ) systems. The main DAQ consists of time to digital converters to measure, digitize and store the arrival times and the time over threshold (ToT) information of the PMT pulses. Therefore, the main DAQ is able to reconstruct direction and energy of the primary. The angular and energy resolution of the main DAQ are plotted in Fig. 2 and Fig. 3. The second DAQ system is based on scaler modules. This scaler

![HAWC layout](image)
Figure 1: **HAWC layout.** The 7 upper left tanks are part of the VAMOS test array.

![Angular Resolution](image)
Figure 2: **Angular Resolution for HAWC and Milagro** using a 68 % containment radius.

![Energy Resolution](image)
Figure 3: **Energy Resolution for HAWC and Milagro.** The ground energy resolution is plotted to illustrate the shower fluctuation component contributing to the resolution. 100 % means that standard deviation equals mean value.
DAQ is counting the number of pulses from each PMT individually in 10 ms time intervals. The system is part of the detector monitoring but is also capable of delivering science data. The scaler DAQ is able to see transient signals as statistical fluctuations above the background count rate of the PMTs and has sensitivity at lower energies than the main DAQ.

To measure (variable) offsets due to electronics effects, cable lengths or the slewing due to the pulse charge, the detector will have a laser based timing calibration system [17].

The baseline concept for HAWC uses a hardware triggering system for the main DAQ working at a rate of about 5 kHz. However, advanced triggering options, including a pure software triggering, are currently under investigation.

To separate gamma-rays from the dominant hadronic background, a gamma/hadron (G/H) filter algorithm is applied. It uses the increased granularity of hadron shower footprints due to the higher probability of spatially separated secondary showers in hadron showers.

3. HAWC’s Response to Gamma-Ray Bursts

In order to obtain the sensitivity of HAWC to GRBs, simulation studies using CORSIKA [18] and a custom made software based on Geant4 [19] have been performed. This included detailed background studies which also provided values for the Fano factor [20] for the scaler DAQ data. The Fano factor describes the widening of a statistical distribution due to event correlation. The main DAQ shower data is reconstructed by applying a 2D Gaussian fit to obtain the shower core location. Fitting a plane to the leading edge times of the PMT pulses delivers the shower axis. A shower curvature correction algorithm has been derived from simulation and is applied to the leading edge times prior to the plane fit.

To obtain the HAWC sensitivity to GRBs, a GRB with a known time, a known position in the sky and a duration of 1 second is assumed. This time scale has been chosen because HAWC has the highest detection probability for short GRBs. Several cuts are applied to the simulated main DAQ data. These include G/H separation, angular distance between reconstructed shower axis and source position, and the usage of a restrictive time window based on the known timing of the GRB.

Fig. 5 shows the effects of different GRB spectra on the expected sensitivity of the two HAWC DAQs. The GRB spectrum is described by a simple PL function with various Heavyside cutoffs, $dN/dE \propto E^\gamma \times \Theta(E_{\text{cut}} - E)$.

The main DAQ sensitivities towards lower energies can be improved by advanced trigger techniques. However, the scaler DAQ sensitivity extends to lower energies than the sensitivity of the main DAQ even in this improved scenarios. Consequently, the scaler DAQ is an important complementary system to the main DAQ for low energy transients.

4. Conclusion

The HAWC detector is a new instrument for the detection of high energy gamma-rays. It is using the water Cherenkov technique for detecting atmospheric particle showers induced by high energetic primaries. This technique has been successfully implemented in the HAWC predecessor.
Figure 5: **HAWC Sensitivity to Short GRBs.** The plots show the $5\sigma$ discovery potential of the main and the scaler DAQ as a function of spectral index $\gamma$ for various values of a sharp high-energy spectral cutoff. The plots assume a 1 s GRB duration. The example GRB fluxes are normalized to the corresponding flux for a 1 s GRB.

Milagro. With respect to Milagro many conceptual improvements in HAWC allow for better angular resolution, energy resolution and G/H separation. HAWC will extend measurements of other detectors towards higher energies and resolve spatially extended sources. Due to its high duty cycle and wide field of view, HAWC has the potential to observe the prompt phase of GRB photon emission.

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