Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 61 (2015) 399 – 408

Physics Procedia

First Results from the High-Altitude Water Cherenkov Observatory

Segev BenZvi, for the HAWC Collaboration

Wisconsin IceCube Particle Astrophysics Center and Department of Physics, University of Wisconsin-Madison, Madison, WI, USA

Abstract

The High-Altitude Water Cherenkov (HAWC) Observatory is designed to observe extensive air showers produced by cosmic rays and gamma rays between 50 GeV and 100 TeV. HAWC is unique among existing TeV detectors because it can be used to observe air showers from a wide range of arrival directions, enabling us to perform a synoptic survey of the TeV sky. HAWC is also designed to have a high livetime (> 90%), making the detector ideal for observations of transient sources such as gamma-ray bursts and flaring active galactic nuclei. While the observatory is only partially built, we have already accumulated one of the largest data sets of TeV air showers ever recorded. Using these data, we have observed a significant anisotropy in the arrival directions of the cosmic rays on angular scales > 60° and < 20° at the 10^{-3} level. We discuss the origin of the anisotropy and compare the data to previous observations by other cosmic-ray experiments. We also describe our ongoing program to observe gamma-ray bursts and flares in the TeV band and report current upper limits. Finally, we discuss prospects for the observation of point-like and diffuse emission of TeV gamma rays when HAWC is completed in 2014.

Selection and peer review is the responsibility of the Conference lead organizers, Frank Avignone, University of South Carolina, and Wick Haxton, University of California, Berkeley, and Lawrence Berkeley Laboratory

Keywords: cosmic rays, gamma rays, anisotropy, astrophysics, cosmology

1. Introduction

The High-Altitude Water Cherenkov (HAWC) observatory, currently under construction near Puebla, Mexico, is a water Cherenkov detector built to observe extensive air showers produced by TeV gamma rays and cosmic rays. HAWC is located 4100 m above sea level at 18°59.7′N latitude and 97°18.6′W longitude. The site is a 150 m × 150 m graded square located in the relatively flat saddle point between the volcanic peaks Sierra Negra and Pico de Orizaba, near the eastern end of the trans-Mexican volcanic belt. When complete, the detector will consist of 300 close-packed cylindrical steel water tanks lined with light-tight plastic bladders. Each tank is 7.3 m in diameter and 5 m tall and contains 200,000 L of purified water. The bottom of every tank is instrumented with four upward-facing photomultiplier tubes: one 10” Hamamtsu R7081HQE PMT in the center of the tank, and three 8” R5912 PMTs displaced 1.85 m from the center. Signals from the 1200 PMTs are digitized by CAEN model VX1190 time-to-digital converters located in a counting house at the center of the tank array.

Water Cherenkov detectors such as HAWC sample air showers at ground level. When an air shower reaches the ground, the PMTs record the Cherenkov light produced by charged particles passing through the tanks. Air showers are identified in software using a simple multiplicity trigger on the number of PMTs with

1875-3892 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Selection and peer review is the responsibility of the Conference lead organizers, Frank Avignone, University of South Carolina, and Wick Haxton, University of California, Berkeley, and Lawrence Berkeley Laboratory
doi:10.1016/j.phpro.2014.12.084

signal during a short coincidence window. The relative timing and amplitude of the signals observed in the PMTs are used to reconstruct the initial arrival directions of the primary cosmic rays or gamma rays which produced the air showers. The accuracy of the direction reconstruction depends on the number of triggered PMTs, and hence improves as a function of energy. From simulations of extensive air showers we expect the angular resolution of the complete HAWC detector to improve from $\sim 1^\circ$ at 100 GeV to $< 0.1^\circ$ above 10 TeV [1]. The water Cherenkov technique can also be used to discriminate gamma rays from cosmic rays, because hadronic air showers tend to produce large isolated regions of charge far from the shower core. A topological cut on the pattern of hits in the detector is thus sufficient to remove 99% of the cosmic-ray showers above $\sim$ 2 TeV [1].

The sensitivity of HAWC to point sources of gamma rays is moderate in comparison to pointed measurements by Imaging Air Cherenkov Telescopes (IACTs), which have superior angular resolution and gamma-hadron discrimination at TeV energies. However, with > 90% uptime and an instantaneous field of view of 2 sr, HAWC can observe 2/3 of the sky in every 24 hour period. As a result the detector is ideally suited to observe transient sources of gamma-ray emission, as well as extended sources, the diffuse flux of gamma rays, and weak anisotropies in the arrival directions of the cosmic rays.

The construction of HAWC is expected to be complete in summer 2014. We review the first gamma-ray and cosmic-ray results from HAWC in Sections 2 and 3 collected using the 30-, 95-, and 111-tank configurations of the detector. We summarize future work in Section 4.

2. Observations of Cosmic Rays

The flux of TeV cosmic rays at Earth is nearly isotropic and roughly three orders of magnitude larger than the flux of gamma rays from the brightest TeV gamma-ray sources. As a result hadronic showers are the major source of background in the analysis of gamma rays. However, the cosmic rays are themselves of significant interest, not only as a calibration source for the detector (Section 2.1) but also because they exhibit a significant 10^{-3} anisotropy that is not well understood (Section 2.2).

2.1. Cosmic-Ray Shadow of the Moon and Sun

Objects in the solar system such as the Sun and Moon absorb Galactic cosmic rays and can produce observable deficits in the flux of TeV cosmic rays at Earth. Because the location and amplitude of the deficits can be simulated, they are useful for testing the accuracy and precision of the detector reconstruction independent of the effectiveness of gamma-hadron separation.

To estimate the amplitude and statistical significance of the shadow of the Moon, we bin the sky into a fine grid with 0.1° resolution. As a function of position on the sky, we compare the observed counts of cosmic-ray events to the expected number of cosmic rays in the absence of the shadow. The expected counts are estimated from the data themselves using the "direct integration" technique described in [3].

The shadow of the Moon, observed with 10% of the complete array (HAWC-30), is plotted in Moon-centered equatorial coordinates in Fig. 1. The data include 6×10^9 well-reconstructed cosmic-ray air showers recorded between January and April 2013, with the condition that at least 32 PMTs were triggered by each shower. Using the detector simulation we estimate the median energy of the data set to be about 2 TeV. The statistical significance of the shadow is -15.5σ, and due to the deflection of cosmic rays in the geomagnetic field its center is offset from the true position of the Moon by $-0.35^\circ \pm 0.11^\circ$ in right ascension. The offset can be be simulated by backtracing cosmic rays through a model of the geomagnetic field [4], which yields a predicted offset of $-0.56^\circ \pm 0.15^\circ$ [2], consistent with observations. A Gaussian fit to the shadow indicates that its width in data is 50% wider than in simulation, largely due to a mismatch between the angular resolution used in data and in simulation (corrected in subsequent versions of the reconstruction). It is in this sense that the Moon shadow can be used as a diagnostic of the reconstruction of primary cosmic rays and gamma rays.

Due to the high rate of cosmic rays in HAWC-30, it is also possible to observe the shadow of the Sun in the cosmic-ray background. The solar shadow is of interest because it can be used to infer the strength and orientation of the magnetic field in the solar corona [5], which is otherwise very difficult to measure. This