The HAWC Observatory

Tyce DeYoung
Department of Physics
Penn State University

GeV and TeV Sources in the Milky Way
Aspen Summer Workshop
June 14, 2010
From Milagro to HAWC

• The High Altitude Water Cherenkov Observatory

• Redeploy Milagro detectors at Volcán Sierra Negra, México
  • Increase altitude from 2650 m to 4100 m
  • Increase area from 3,600 m² (pond) to 20,000 m²
  • Segment the Cherenkov medium: separate tanks instead of a single pond
  • Better angular resolution and background rejection, lower energy threshold

• Achieve 10-15 x sensitivity of Milagro
  • Detect Crab at $5\sigma$ in 6 hours instead of 3 months

• Cost: ~$10M
The HAWC Collaboration

USA

- University of Maryland
- Los Alamos National Laboratory
- University of California, Irvine
- University of California, Santa Cruz
- Colorado State University
- George Mason University
- Georgia Institute of Technology
- Goddard Space Flight Center
- Harvey Mudd College
- Michigan State University
- Michigan Technological University
- University of New Hampshire
- University of New Mexico
- Pennsylvania State University
- University of Utah
- University of Wisconsin, Madison

México

- Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)
- Universidad Nacional Autónoma de México (UNAM)
- Universidad Autónoma de Chiapas
- Universidad de Guadalajara
- Universidad de Guanajuato
- Universidad Michoacana de San Nicolás de Hidalgo
- Centro de Investigación y Estudios Avanzados (CINVESTAV)
- Benemérita Universidad de Puebla
HAWC

Pico de Orizaba, altitude 4100 m, latitude 18° 59’ N
Two hours drive from Puebla, four from México City
Site of Large Millimeter Telescope (infrastructure exists)
HAWC

Site is a saddle point between Sierra Negra & Orizaba National park, existing scientific consortium
Temperatures mild, wind/rain patterns known
Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m² area, >60% active Cherenkov volume
Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m² area, >60% active Cherenkov volume
Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m² area, >60% active Cherenkov volume
HAWC Tanks

- Prefabricated steel cylinders
  - Light-tight, black plastic bladder to hold water
  - Attenuate scattered light so that photons not promptly detected are efficiently absorbed
  - Reduces late tails in the PMT photon distribution and reduces noise rate

- 900 8” Hamamatsu PMTs re-used from Milagro
Benefits of Higher Altitude

• Number of particles in the shower reaches maximum, then declines exponentially due to atmospheric absorption

• Higher altitude means more particles survive to reach the ground
  • More information about the air shower

• Lower energy threshold, better angular resolution, better energy resolution, better background rejection
Higher altitude leads to a lower energy threshold

- Stochastics of shower development lead to very soft threshold

HAWC will be fully efficient above ~2 TeV

- Still >100 m$^2$ effective area at 100 GeV

- Improvements even more significant after hadron cuts

![Energy Threshold and Effective Area](chart.png)
Energy Resolution

• Uncertainty from two sources:
  • Measurement of energy deposited at ground level
  • Fluctuations in shower development in atmosphere (naturally log-normal)

• Higher elevation means HAWC has a big advantage over Milagro
  • HAWC resolution very close to theoretical limit due to shower stochastics

Resolutions are log-normal: 50% resolution indicates 1σ range [0.67, 1.5] times measured value
Angular Resolution

- Significant increase over Milagro – limited by information in the particles that reach the ground
  - Based on Milagro algorithms – improvements expected (esp. at higher E)
Cosmic ray background rejection based on search for substructure in air showers

S. Funk, from Aharonian, Buckley, Kifune & Sinnis 2008
Algorithm looks for high-amplitude hits more than 40 m from the reconstructed core location.
Gamma-Hadron Separation

- Currently use parameter $C = \frac{n\text{Hit}}{c\text{xPE}}$
  
  $c\text{xPE} =$ largest hit (in PEs) >40m from shower core

- Already gives ~10x better rejection than Milagro at fixed energy

- Conservative: more sophisticated algorithms possible

G-H separation at 50% gamma efficiency

![Graph](image.png)
Sensitivity to Crab-like Point Sources

- Long integration times lead to excellent sensitivity at highest energies (> few TeV)

- $5\sigma$ sensitivity to:
  - 10 Crab in 3 minutes
  - 1 Crab in 5 hr (1 transit)
  - 0.1 Crab in $\frac{1}{3}$ year

- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Better angular resolution
  - Better rejection of cosmic rays

50 hr observation time assumed for IACTs, HAWC source transit 15° off zenith
Field of View

- Wide field of view, limited by atmospheric depth
  - 45° from zenith (Milagro standard analysis)
  - 50 mCrab survey in 1 yr

![Graph showing 1 yr Survey Sensitivity (mCrab) vs Declination]

- 2.6π sr (64%)
- 1.8π sr (44%)

![Diagram showing HAWC all-sky Sensitivity (mCrab)]

- HESS Galactic Ridge Strip Survey
- VERITAS-4 Galactic Plane Strip Survey

Tyce DeYoung
Aspen GeV-TeV Galactic Workshop
June 14, 2010
Measuring Spectra at the Highest Energies

- **HESS J1616-508**
  - 0.2 Crab @ 1 TeV, $\alpha=-2.3$
  - Highest energy $\sim$20 TeV

- Simulated HAWC data for 1 year with no cutoff

- ...or with a 40 TeV exponential cutoff


**Transient Sensitivity**

Assumed $E^{-2}$ emission spectrum

Full HAWC simulation

Fermi-LAT assumed 0.8 m$^2$ effective area, no background
Harder spectra give significant increase in sensitivity

Fluxes normalized at 10 GeV

Transient Sensitivity
HAWC Construction Schedule

• **VAMOS**
  - Verification Assessment Measuring Observatory Subsystems (3 months)

• **HAWC-30**
  - Implementation of all subsystems (6 months)

• **HAWC-100**
  - Science operations with 2 times Milagro’s sensitivity (12 months)

• **HAWC-300**
  - Full detector (15 months)
HAWC Construction Schedule

- VAMOS: Verification Assessment Measuring Observatory Subsystems (3 months)
- HAWC-30: Implementation of all subsystems (6 months)
- HAWC-100: Science operations with 2 times Milagro's sensitivity (12 months)
- HAWC-300: Full detector (15 months)
Questions for Discussion

• What else should we be thinking about?
  • Sky survey
  • High energy observations
  • Extended/diffuse emission
  • Transients/variable sources

• We plan to alert the community to transients via GCN – are there other types of rapid communications that would be useful?

• Is there a way to exploit better the relative advantages of HAWC (extended/HE emission) and IACTs (angular resolution) to understand complex areas such as the Cygnus region?