A Higher Altitude Water Chernkov Detector for TeV gamma-rays

Michael DuVernois
University of Wisconsin-Madison
WIPAC & Physics

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Starting from the HAWC Observatory, thinking about the Southern Hemisphere
Outline

Going to Higher Altitude & Southern Hemisphere
- Science
- Simulations

Where?
- Site Options
- Building from HAWC experience

How?
- First sketches of detectors
- …and electronics
TeV Sky

TeV Catalog (2012)
• ~140 sources (~90 Galactic).
• Not an all-sky survey - catalog is strongly biased.

http://tevcat.uchicago.edu
Altitude Effects

- Higher altitude leads to lower energy threshold
  - Higher in the air shower
  - Improves ability to cross-check with IACTs
  - EBL cutoff becomes negligible at lower energy
  - Better to determine spectral shape
- Higher backgrounds, still on the exponential decay of the showers
  - Need to be able to deal with rates

- Simulate a strawman water Cherenkov detector at differing altitudes
  - Includes work of Asif Imran & Gus Sinnis & Andy Smith (UMD)

- Show this is plausible with real sites
Implementation

- Use CORSIKA (v6990) capability to save particle output for 10 different observation levels
  - 6600m, 6000m, 5200m, 4100m
- QGSJET for high-energy interactions
- GHEISHA for low-energy hadronic interactions
- Followed electrons to 3 MeV, muons and hadrons to 300 MeV
- CORSIKA atmospheric model (US standard):
  - 6600m = 445 g/cm²
  - 6000m = 483 g/cm²
  - 5200m = 538 g/cm²
  - 4100m = 623 g/cm²
- Gammas thrown on $E^{-2.3}$ spectrum
- Protons thrown on $E^{-2.7}$ spectrum
- Fixed zenith angle runs (0, 20, 30, 40, 45, 50)
Energy at Ground (gamma & proton)
Array Simulation

- Dense array 30x30 tanks
- Each tank 1.5m radius and 1.5m tall
- Tank separation 3m
- 1 10" High QE PMT in each tank
- Converge PMT QE curve with Cherenkov spectrum: 35 PE/MeV for high QE (27 PE/MeV for R5912)
- Results in ~4 MeV/detected PE (ratio of PMT:tank area)
- Simulation:
  - Throw core over 200mx200m area (800mx800m for protons)
  - Translate each particle position by core location (and array center)
  - Loop over particles in shower at each elevation
    - Determine if particle hits a tank
    - \[ <\text{detected PES}> = \frac{\text{MAX}(\text{particle energy}/2 \text{ MeV, 75 MeV})}{4} \]
    - detected PES = Poisson(mu=\(<\text{detected PES}>\))
  - Enforce trigger - 30 tanks with \(\geq1\) detected PE

20deg South
Moving detector around…

Effective Area for varying altitudes and zenith angles

- 4100 m
- 5200 m
- 6000 m
- 6600 m

Energy [GeV] vs. Area [$m^2$] for different altitudes z = 0, 10, 20, 30, 40.
Sensitivity to a Crab-like Point Source

![Graph showing sensitivity to a Crab-like point source per day. The graph plots Integrated Flux (E>100 GeV) [cm^-2 sec^-1] against Declination [°]. Different curves represent different altitudes: 4100m, 5200m, 6000m, and 6600m.]
Adding some sources (per month)
Softer spectrum (per day)
HAWC REMINDER
HAWC Site: Pico de Orizaba/Sierra Negra

N 18°59'
W 97°18'
8 GeV geom. cutoff
The HAWC Detector

- 4,100 altitude meter site at Sierra Negra, Mexico (~19º N), near the Large Millimeter Telescope.
- 22,000 m² area (57% coverage).
- 300 water tanks:
  - 7.3 m diameter × 4.5 m depth.
  - 3 upward-facing 8” PMTs and one upward-facing 10” PMT (with high quantum efficiency) on the bottom of each tank.
- 1 Crab (5σ) per day.
The HAWC Detector

- HAWC tank construction, bladder, and 8” photomultiplier.
Milagro
HAWC
5400m
Milagro

How Altitude Sickness Works
©2008 HowStuffWorks

At 8,000 feet, altitude sickness can afflict travelers
## Highest permanent observatories

Permanent observatories above 3,000 m:

<table>
<thead>
<tr>
<th>Observatory Name</th>
<th>Elevation</th>
<th>Observatory Site</th>
<th>Location</th>
<th>Coordinates</th>
<th>Established</th>
<th>Type of Observatory</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Tokyo Atacama Observatory (TAO)</td>
<td>5,640 m (18,500 ft)¹⁰</td>
<td>Cerro Chajnantor</td>
<td>Atacama Desert, Chile</td>
<td>22°59′12″S 67°44′32″W</td>
<td>2009¹⁰</td>
<td>Optical, infrared</td>
</tr>
<tr>
<td>Chacaltaya Astrophysical Observatory</td>
<td>5,230 m (17,160 ft)⁹</td>
<td>Chacaltaya</td>
<td>Andes, Bolivia</td>
<td>16°21′12″S 68°07′53″W</td>
<td>1946⁸</td>
<td>Cosmic ray, gamma ray</td>
</tr>
<tr>
<td>James Ax Observatory</td>
<td>5,200 m (17,030 ft)</td>
<td>Cerro Toco</td>
<td>Atacama Desert, Chile</td>
<td>22°57′30″S 67°47′10″W</td>
<td>2011</td>
<td>Microwave</td>
</tr>
<tr>
<td>Atacama Cosmology Telescope</td>
<td>5,190 m (17,030 ft)</td>
<td>Cerro Toco</td>
<td>Atacama Desert, Chile</td>
<td>22°57′31″S 67°47′16″W</td>
<td>2007</td>
<td>Microwave</td>
</tr>
<tr>
<td>Llano de Chajnantor Observatory</td>
<td>5,104 m (16,745 ft)</td>
<td>Llano de Chajnantor</td>
<td>Atacama Desert, Chile</td>
<td>23°01′22″S 67°45′17″W</td>
<td>1999</td>
<td>Millimeter wave, submillimeter</td>
</tr>
<tr>
<td>Shiquanhe Observatory (NAOC All Observatory)¹¹</td>
<td>5,100 m (16,700 ft)¹²</td>
<td>Shiquanhe, Ngari Plateau</td>
<td>Tibet Autonomous Region, China</td>
<td>32°19′N 80°01′E</td>
<td>2011</td>
<td>Optical</td>
</tr>
</tbody>
</table>
Road to 5600m…
Back in 2005
Chacaltaya, with long cosmic ray history
Detector ideas
Electronics synergy with Next Generation IceCube & PINGU

- New PDOM electronics are being produced
- These are fairly general purpose, digital readouts with feature extraction, good for all environments, closely coupled to a 10” PMT
- Power consumption <2W (could be <0.5W)
- Built in communications, capable of 1Mb over random wire
- FADC with >100MHz bandwidth & >14b resolution
- Timing to <5ns either cabled or via Ethernet/White Rabbit
Strawman PINGU “PDOM” Design

Keep these parts/designs:
- Sphere
- Penetrator
- PMT, Collar, Gel
- Harness
- HV generator and Base
- Quad Cable technology

Keep/upgrade these Designs:
- DOMAPP
- CONFIGBOOT (Built into FPGA now)
- DAQ
- DOR FUNCTIONALITY

Develop new:
- Digitizer (ADC)
- Comms circuitry
- Flasher
- FPGA logic
- Power Supply
- PCB & packaging
## Rough Cost: IC DOM vs. PDOM

<table>
<thead>
<tr>
<th>ITEM</th>
<th>High QE IC DOM</th>
<th>PDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMT</td>
<td>2000</td>
<td>2000</td>
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<tr>
<td>PMT Base Board</td>
<td>130</td>
<td>130</td>
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<tr>
<td>Sphere/Harness</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Penetrator</td>
<td>400</td>
<td>400</td>
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<tr>
<td>Main Board</td>
<td>1900</td>
<td>1000</td>
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<tr>
<td>ATWD Test /pkg</td>
<td>500</td>
<td>0</td>
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<tr>
<td>Delay Board</td>
<td>130</td>
<td>0</td>
</tr>
<tr>
<td>Engineering (project)</td>
<td>(3mo)</td>
<td>(36mo)</td>
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<tr>
<td>Flasher Board</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>Flasher Parts</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>HV Supply Board</td>
<td>190</td>
<td>0</td>
</tr>
<tr>
<td>HV Module</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>Mu Metal</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>$ 6630 (+6mo)</strong></td>
<td><strong>$ 4760 (+36mo)</strong></td>
</tr>
</tbody>
</table>
Inexpensive and Compact muon detection

10 cm of scintillator yields $2\times10^5$ photons for a through-mu
~ 40 PE detected in a 2” PMT
0.75 m³ of LAB scintillator
~$850/detector (~1/4$ cost of plastic scintillator)
Much easier to construct and deploy
Not exactly conclusions

• Going higher is possible, quite desirable, and plausible for a Southern Hemisphere experiment using WCD
• Probably needs a different construction technique than HAWC, build lower and bring units up, tanks more like Auger perhaps
• Electronics could have significant synergies with Next Generation IceCube and other experiments
BACKUP SLIDES