Water Cherenkov Detection of (gamma ray and cosmic ray) Air Showers
The High Altitude Water Cherenkov Experiment

- Move Milagro PMTs and front-end electronics to 4100 meter site at Sierra Negra, Mexico
- Existing infrastructure for Large Millimeter Telescope
- 2500 square meter area.
- 300 water tanks. 3 PMTs per tank.
  - 7.5 meter diameter
  - 4.0 meter water above PMTs
- Overall 15x sensitivity improvement over Milagro.
- See sources 225x faster.
  - See 1 Crab every day.
Water Cherenkov Detectors
HAWC Improvements over Milagro

- Higher altitude. 4100 meters over 2600 meters.
- Larger triggering area. 22500 vs 4800 m$^2$.
- Larger area of muon discrimination. 22500 vs 4000 m$^2$.
- Overall 15x increase in sensitivity to a Crab-like source.
  - Observe Crab at 5 sigma in one day rather than several months.
HAWC Improvements over Milagro

- Additional particles on the ground improves angular resolution.
- Additional area of “deep” muon detection area gives much better gamma/ hadron discrimination.
- Higher altitude gives much higher low-energy response.
\[
N_{\text{events}} = \int A_{\text{eff}}(E, \theta)\phi(E)\,dEd\theta
\]
\[
A_{\text{eff}}(E, \theta) = A_{\text{thrown}} \frac{N_{\text{observed}}(E, \theta)}{N_{\text{thrown}}(E, \theta)}
\]
Gamma Ray

Cosmic Ray

e\pm \text{ or gamma}

\mu\pm
• Shower fronts are curved.
• Shower fronts are thick.
• 1 ns timing error over 50 meters results in 0.3 degree pointing error.
• Need to accurately resolve core location limits the high-energy area to the physical area of the array.
- Tendancy of low-energy showers to result in 0 ground level particles gives lower-than-geometric effective area.
HAWC Improvements over Milagro

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Gamma / Hadron Separation

Gamma Rays
- ntop/cxpe: 12.0
- ntop/cxpe: 16.3
- ntop/cxpe: 7.5
- ntop/cxpe: 9.7

Protons
- ntop/cxpe: 0.6
- ntop/cxpe: 0.6
- ntop/cxpe: 3.2
- ntop/cxpe: 1.6
Significance on the Crab

\[ \Phi_{crab} = 3.45 \times 10^{-11} \left( \frac{E}{\text{TeV}} \right)^{-2.63} \frac{\text{photons}}{\text{cm}^2 \cdot \text{s} \cdot \text{TeV}} \]

\[ \Phi_{proton} = 8.9 \times 10^{-2} \left( \frac{E}{\text{TeV}} \right)^{-2.65} \frac{\text{protons}}{\text{m}^2 \cdot \text{s} \cdot \text{TeV} \cdot \text{sr}} \]

- Assume 20000 square meter effective area over 1 TeV.
- Assume 5 hours transit time
- Assume a 0.5 degree bin on the sky (2x10^{-4} sr)
- About 75 photons / 3900 protons before gamma / hadron separation
- Approximate 38 photons / 39 protons after gamma / hadron separation cuts.
- Bump up protons by 1.3 to account for other species of cosmic rays.
- About 5\( \sigma \) per day.

See HESS & ATIC Results
Summary and Outlook

- This summer: VAMOS prototype array (7 WCDs)
  - Hopeful detection of Moon Shadow
- Early next year: 30 WCDs and sensitivity comparable to Milagro.
- 300 WCDs in 2014.