Future High-Energy Solar and Heliospheric Measurements with the HAWC TeV Gamma-Ray Observatory

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Abstract

Following up on the successful and revealing ground level enhancement (GLE) measurements performed with the Milagro TeV gamma-ray observatory, the High Altitude Water Čerenkov (HAWC) Observatory will be used to perform similar measurements of GLE particles. Milagro was located in the Jemez Mountains near Los Alamos, while HAWC will be operating at a lower latitude near Puebla, Mexico. At the time of this SHINE meeting, a limited version of HAWC is being deployed. HAWC is at a much higher altitude with a much much larger geometrical area—all optimized for cosmic gamma-ray observations. For GLE detection and measurements, this implies a greater geomagnetic cutoff but with a much greater effective area that partially compensates for the cutoff effect. Because of lower latitude, HAWC will also be sensitive to direct solar neutrons when the Sun is in the northern hemisphere. HAWC will also register Forbush decreases at its higher cutoff.

Big Science Questions

- ***How does the high end of the solar interplanetary proton spectrum behave?***
    - The most energetic protons and ions exhibit a short lifetime when measured at Earth, e.g., tens of minutes rather than hours or days, as at 10 MeV.
    - The spectrum exhibits an exponential-like roll off. This roll off is produced by the available particle acceleration time, the finite size of the acceleration region and/or the divergent plasma flow associated with the accelerating agent, e.g., shock. Thus, this spectrum roll off carries much information about the acceleration process.
    - The decay of the enhancement also reveals transport phenomena between the Sun and Earth, e.g., the upstream diffusion coefficient.
- ***How do the solar neutrons relate to the solar protons, putatively accelerated remotely in a coronal shock?***
- ***Do the solar neutrons arise from the same solar protons detected at Earth, but striking the solar atmosphere instead of the Earth's atmosphere?***
- ***How are galactic cosmic rays at 100 GeV and above modulated by heliospheric phenomena?***

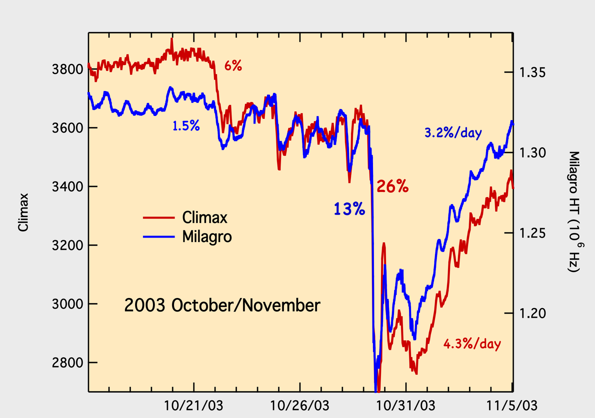
The Instrument

The HAWC instrument is an array of water-filled tanks. Each tank is light tight and is equipped with photomultiplier tubes at the bottom (looking up). Each tank detects energetic charged particles as those particles enter the tank and emit Čerenkov light. To measure TeV γ rays that produce air showers, the moving front of electrons and positrons sweeps over the array and the timing of the signals from the different tanks defines the trajectory of the air shower. The uniformity, or lack thereof, identifies the shower as being either electronic or hadronic.

Showers produced by galactic cosmic rays are identified and recorded too if they are sufficiently energetic (>100 GeV).

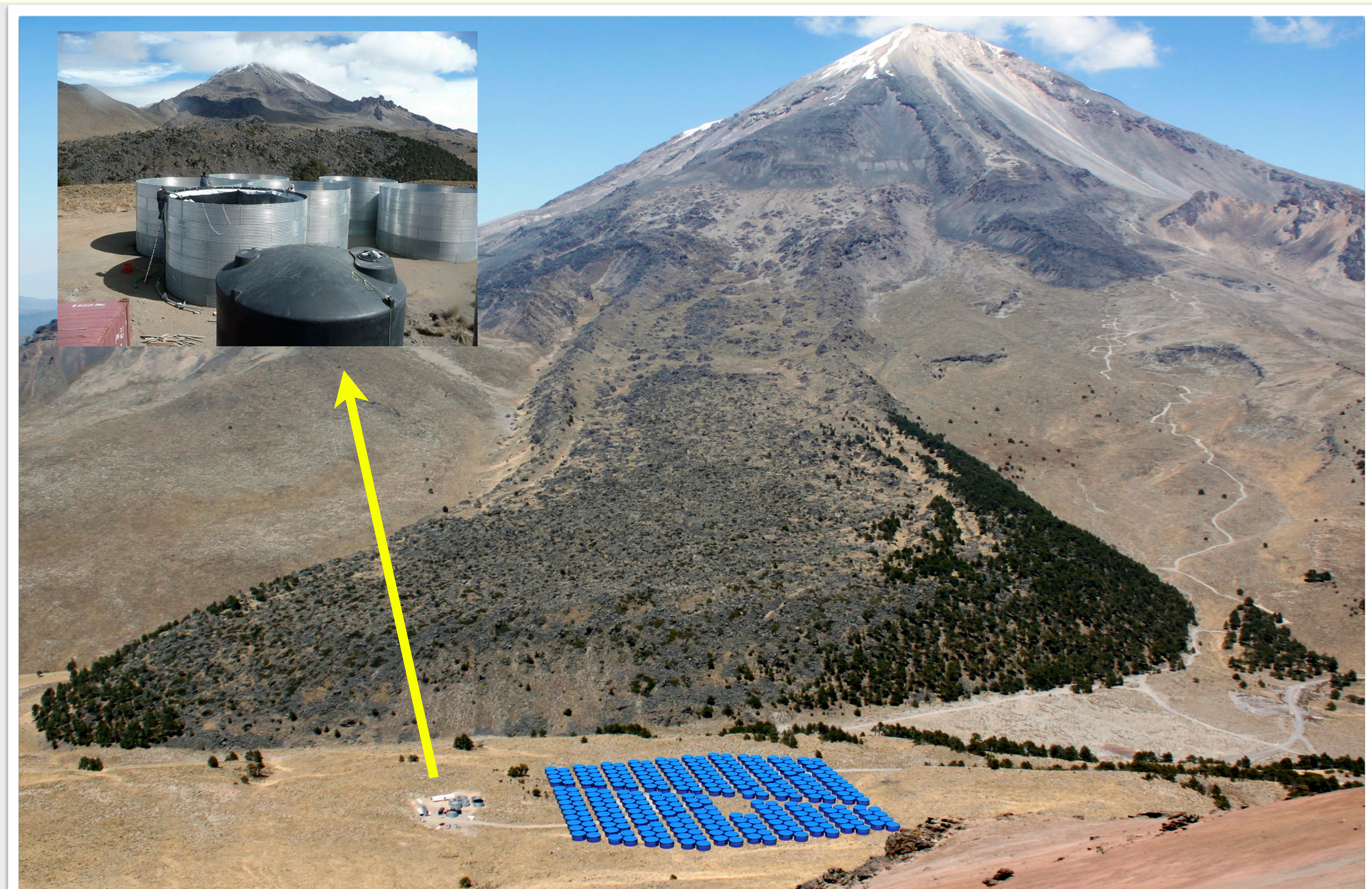
Lower energy (<100 GeV) particles at the top of the atmosphere produce muons with signals in a single or a few tanks. Solar protons or neutrons will produce muons that will hit and be sensed by one or a few tanks without a full shower. HAWC monitors the rate of these hits, for various levels of multiplicity, i.e., one, two, six, ... photomultiplier tubes. Thus, HAWC is a muon detector, but behaves simultaneously like several neutron monitors with differing atmospheric cutoffs. HAWC is much like Milagro, except that Milagro used a single large pond of water equipped with many PMTs.

Milagro successfully detected several GLEs, two of which are shown at the right, as well as significant Forbush decreases. See below.



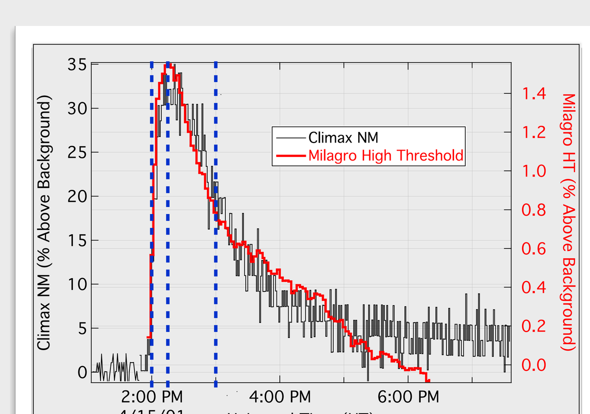
Although located near the Climax neutron monitor, Milagro responded differently than Climax to the Halloween 2003 Forbush decreases, because of its greater rigidity threshold as a muon detector.

The HAWC Experiment



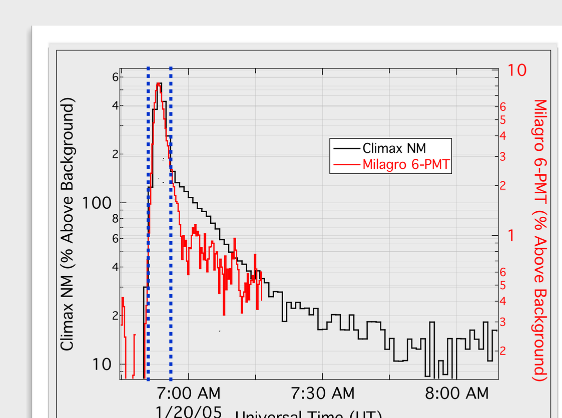
Heritage—Milagro 2000-2008

2001 April 15 GLE



A

2005 January 20 GLE

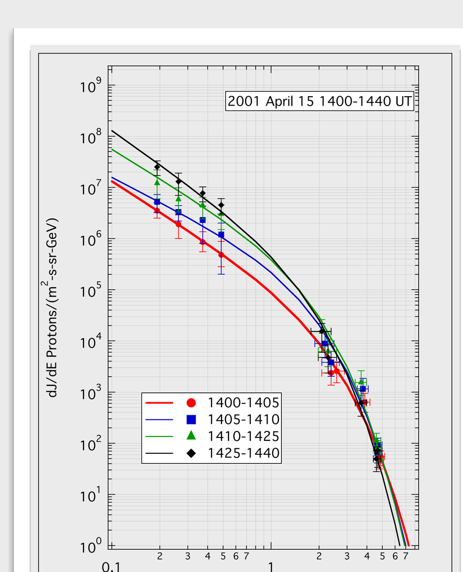


F

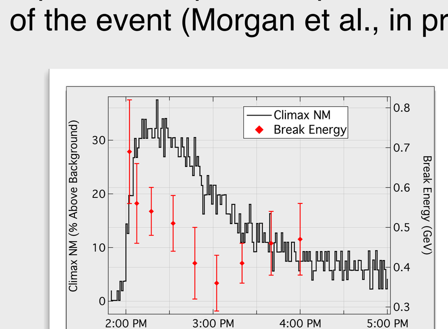
Shown at the left and right on top (A,F) are the count rates seen in Milgaro and the Climax neutron monitor. The Climax profile matches well that from Milagro for both events, except that decay of the 2005 January 20 event is less rapid in the Climax data.

At the bottom (B,E) in the corners are the time-resolved spectra obtained with Milagro, Climax and IMP (2001, left) and ERNE (2005, right). Both events exhibit significant spectral softening. For the 2005 event, the softening occurs after the initial impulsive spike, while the for the 2001 event, it occurs after the leading edge of the enhancement. The time integration used here is enough to integrate over velocity dispersion effects. Both events also exhibit a spectrum roll over that reflects the spectral evolution. At the bottom (C,D), the characteristic energy of the exponential break is plotted as a function of time with the Climax count rate as a reference.

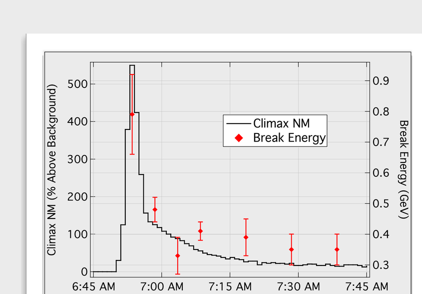
The evolution of the spectrum is rapid and stark in the 2005 event. After the impulsive spike the spectrum settles down to a stationary form as one can see in the break energy plot as well as the time-resolved spectrum. For the 2001 event, only the leading edge of the event appears to be much different than the remainder of the event, although poorer statistics qualify that statement. However, if true, the 2005 event distinguishes itself by having an impulsive spike of much greater relative intensity than that of the 2001 event. As is, any equivalent impulsive spike for the 2001 event would be buried beneath the rest of the event (Morgan et al., in preparation).



B



C



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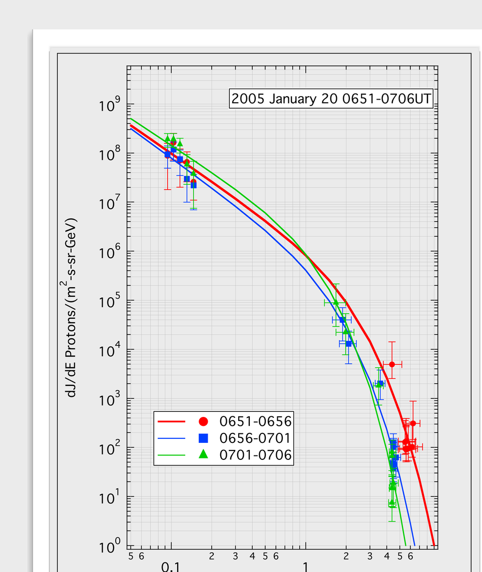

E

HAWC Details

HAWC Advantages

- **Covers the high end of the proton or neutron spectrum**, but with enormous collecting area for excellent statistics.
- **Many data channels (different multiplicity channels) probe different energy or rigidity bands.**
- Ideally supported with its own neutron monitor—yet to be proposed. Close to Mexico City NM-64 station. **The proximity of a neutron monitor with a much different response allows us to perform spectroscopy at a single location with minimal concern for anisotropy effects between stations.**
- **Taking test and engineering data now!**
- **Low latitude—great for solar neutrons and gammas** for much of northern hemisphere summer.
- **High altitude—great for both solar protons, neutrons and maybe gammas.**

HAWC Parameters

- Location: between Mexico City and Veracruz
- 608 g-cm^{-2} overburden vs. 735 g-cm^{-2} for Milagro
- 12500 m^2 geometrical area vs. ~2000 m^2 for Milagro
- 8.2 GV cutoff vs. ~4 GV for Milagro
- 19˚ latitude vs. 36˚ for Milagro
- ~5 GeV Threshold detection energy, protons or neutrons
- 2-s readout of all scalers to resolve fast time structure in GLEs.

Deployment Schedule

Stage	Tanks	Completion Date
VAMOS 7	7	Done
HAWC 30	30	Spring 2012
HAWC 100	100	Summer 2013
HAWC 300	300	Fall 2014

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