The HAWC observatory and its synergies at Sierra Negra Volcano

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***Abstract*. The High Altitude Water Cherenkov (HAWC) observatory is currently at early stages of development at 4100 m.a.s.l. site of Sierra Negra, in the state of Puebla, Mexico. The geographical location of the site allows visibility of two thirds of the sky and the Galactic plane.**
The HAWC basic infrastructure is an extension of that of the Large Millimeter Telescope, located at the 4600 m.a.s.l. summit of Sierra Negra, a site now shared facilities like a Solar Neutron Telescope, the RT5 solar radio telescope and the LAGO cosmic-ray array. The installation and testing of the HAWC prototype provides a first sample on the synergic projects that will be feasible between HAWC and the rest of the facilities at Sierra Negra. We will present the HAWC site as well as the possible synergies with the other local projects.

***Keywords*: New experiments, water Cherenkov detectors and energy spectrum**

I. Introduction

HAWC, the High Altitude Water Cherenkov observatory is a proposal for surveying and monitoring the high energy gamma ray sky. Water Cherenkov detectors like Milagro and HAWC function as wide field monitors of photons and cosmic rays of energies from 100 GeV to 100 TeV, operating continuously day and night without interruptions due to weather conditions. Their field of view extend up to 45 degrees from the zenith, allowing to make a shallow survey of more than 7 sr every sidereal day.

The continuous accumulation of homogeneous data permits a deep exposure of up to 2/3 of the sky after a few years of operation.
The operating principle of these detectors has been demonstrated with the successful 8 years of operation of Milagro in New Mexico, at an altitude of 2650 m.a.s.l, and its detection of the Crab, Mrk 421 and the extended emission from the Cygnus region. The list of sources and potential TeV emitters is growing from the updated data analysis.
Milagro has also acted as a gamma ray burst (GRB) monitor, setting physically constraining upper limits for some events. As wide field low energy cosmic ray monitor, Milagro found localized anisotropy pointing to the possibility of nearby sources of cosmic rays. All these results exhibit the need for an all sky survey instrument.
The knowledge and resources are already available to build HAWC, a detector more than an order of magnitude more sensitive than Milagro at a reasonable cost (about 8 MUSD). The science case for HAWC include mapping and continuous monitoring of the TeV sky; the study of the Galactic interstellar medium, together with the properties of cosmic rays throughout the Milky Way; the study of extended emission from Galactic nebulae; the persistent and transient emission of active galaxies; monitoring prompt emission and searching high energy afterglows of GRBs; cosmological pair attenuation and the intergalactic infrared background.

HAWC can also be used for studying the sun, dark matter searches and coincident gamma ray and neutrino emission, in close synergy with Ice Cube (see fig. 1)

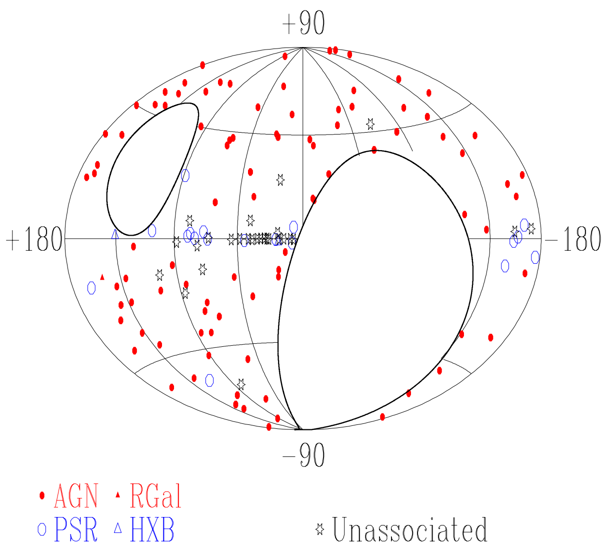

Fig. 1. Gamma-ray sources from the *Fermi*[1] bright source list displayed on the sky available to HAWC. Open (blue) octagons and triangles show Galactic sources, namely pulsars and X-ray binaries, while (red) closed figures show extragalacticsources, blazars and radiogalaxies. Stars (in black) show *Fermi* sources with nocounterpart associated.

Two basic conditions are needed to achieve a more sensitive water Cherenkov detector:

- A higher site and
- A larger area detector.

Further improvements can be made in the design of the detector.
Under these considerations HAWC is conceived to have a 200 m $\times$ 110 m = 22000 m^2 detection area at an altitude of 4100 m.a.s.l.
The optimized detector design still under consideration[2] and first stage of tests will incorporate an array of individual detectors of depth of 4.5 m of water, arranged in a grid of 22$\times$16 cylindrical cells of 7.3 m diameter, each one optically isolated from the others (see fig. 3). This arrangement allows direct rejection of atmospheric muons and an effective hadron-photon discrimination (see figs. 2,3).

Fig. 2. HAWC site at Parque Pico de Orizaba.

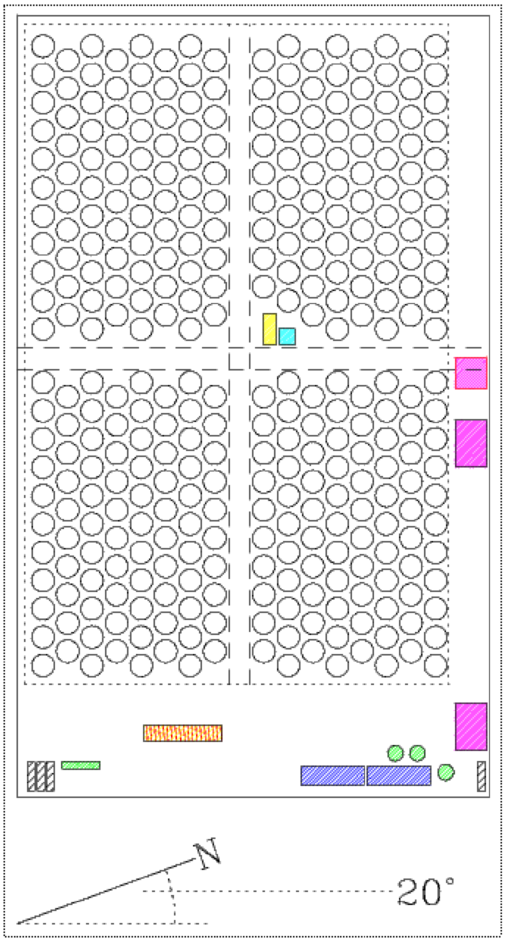

Fig. 3. HAWC at Parque Pico de Orizaba and layout, individual detectors of depth of 4.5 m of water, arranged in a grid of 22$\times$16 cylindrical cells of 7.3 m diameter, each one optically isolated from the others.

HAWC will be able to achieve 5σ detections of the Crab nebula in single transits and detections of fluxes down to 50 mCrab after 1 year.

In April 2006 a group of astrophysicists and high energy physicists held a workshop on high energy astrophysics at Tonantzintla and as a result decided to jointly support the installion of HAWC in Mexico and to participate in its scientific operation. Early this year, environmental authorities in Mexico (SEMARNAT) gave the permit for road and design modification, complenting the site permit obtained in 2007.

II. The Sierra Negra site

Suitable sites above 4000 meters are hard to find. HAWC requires a flat area of about 220 m $\times$ 150 m, manageable weather conditions for human builders and operators, the availability of about 90000 m^3 of water and of support infrastructure, namely an access road, electricity and internet.

The Sierra Negra volcano is the site of the Large Millimeter Telescope / Gran Telescopio Milimetrico (LMT/GTM), the largest scientific project ever in Mexico. LMT/GTM is a 50 m antenna for millimeter wave astronomy[3] located at the top of Sierra Negra also known as Tliltepetl at 4600 m. The development of the LMT/GTM site started in 1997 with the construction of the access road, followed with the installation of a power line and an optical fiber link to the Internet, both currently functional.

Sierra Negra is inside the Parque Nacional Pico de Orizaba, named after Pico de Orizaba or Citlaltepelt, the highest mountain in Mexico with 5610 m.a.s.l. The National Park has an extension of 197.5 km^2, which comprises both stratovolcanoes, whose summits are separated by 7 km. The valley between them is at 4000 m.a.s.l. We selected as the HAWC site a relatively flat area at the base of Sierra Negra at 4100 m.a.s.l., which has an area of about 90000 m^2 comprised within variations of $\pm$10 m in altitude. We performed a topographic survey of a favorable location for HAWC with an area of about (210 m)^2, a mean altitude of 4099 m and a slope of 5 degrees. The site is at 1 km from the LMT road and power line, from where access, electricity and Internet can be extended to HAWC with very little cost and effort.

III. WATER FOR HAWC

Due to the modularity aspect of this project, the acquisition of water in a few years (3-4) is not a big issue. The national park is located in the limits between the Mexican states of Puebla and Veracruz, in a transition zone from a high altitude dry region (Puebla) to low altitude wet region influenced by the Gulf of Mexico (Veracruz).
The precipitation in the park amounts to 1000 mm/year, with a very marked seasonal modulation: 83% of the precipitation falling in the six months between 1st of May and 31st of October.
We performed geoelectrical studies in the zone, some 500 meters N of the HAWC site, which indicate water flows some 150 m underground along the geological structure of a former glacier. Suitable locations for water extraction wells have been defined and we are currently working on an exploratory well. Complementary water studies used a 3D model of the region to find natural nozzles where water converges during precipitation. One point identified through these studies corresponds to the convergence of precipitation falling in a physical area of just around 100 m^2. A concrete trap and pipe system can be used to capture and transport for low cost water from this point to the HAWC site (see fig. 4). A very promising complementary method for water collection is the drainage system of the 2000 m^2 Large Milimeter Telescope.

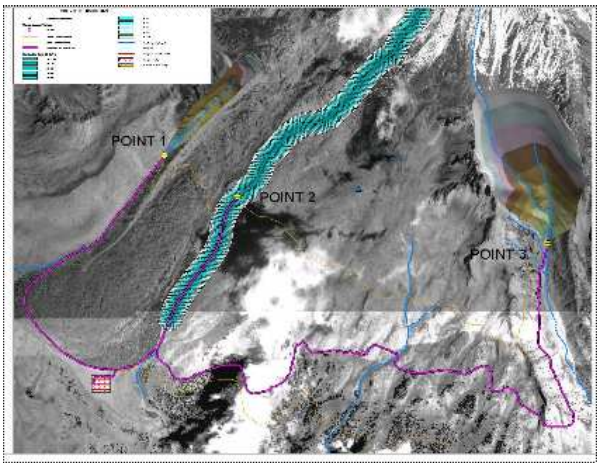

Fig. 4. Hydroelectrical studies for well or locations of potentials capture points for water (1,2,3).

IV. HAWC ASTROPHYSICS AT SIERRA NEGRA

HAWC will benefit from much more than a high altitude site. Sky survey coverage dependence on geographical latitude meaning that HAWC at 19^0 N will cover 8.4 sr, gaining 17% more sky than the 7.2 sr reachable from the Milagro site.
Fig.1 shows the important coverage of the Galactic plane, even grazing the Galactic Center at 46^0 from the zenith. The longitude of the site ensures synchronization with US, Mexican and South American observatories for rapid follow up studies, including daytime LMT/GTM observations.
A first step in HAWC operation as Enginering array is Proto-HAWC, which is running since the middle of March of this year at the top of the Sierra Negra Volcano. Proto-HAWC consist of 3 cylindrical detectors of 3 m diameter and 3.9 m height see fig. 5

Fig. 5. Proto-HAWC at the top of Sierra Negra Volcano.

The radiator system is purified water and one upward-facing photosensor (Hamamatsu 8 inches) in the bottom converting the Cherenkov photons in signals. Two alternative DAQ systems have been used in these first stage[4]. Fig. 6 shows the signal coming from the detector when a 200 MSPS DAQ system was used[5].

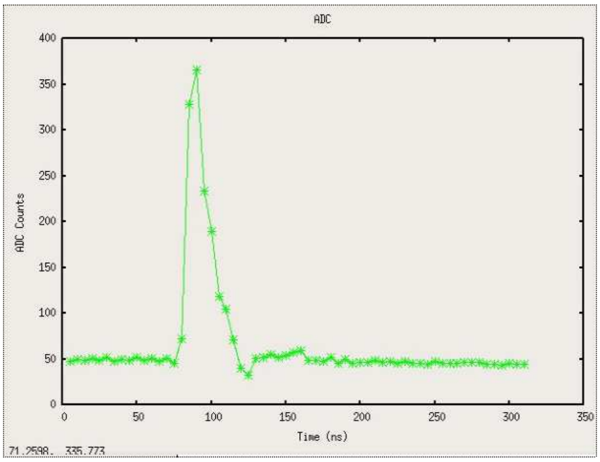

Fig. 6. Signal coming from the detector when a 200 MSPS DAQ system was used in one of the Proto-Hawc detectors.

All site HAWC operations will be coordinated by the Consorcio Sierra Negra, which groups the scientific experiments in the site, including the largest single dish mm telescope in the world (LMT), the 5 m RT5 radio telescope, a solar neutron telescope (TNS), two atmospheric Cherenkov telescopes, a cosmic ray surface detector array (LAGO) and a fluorescence telescope

Fig. 7. Google Earth view of the local experiments at SN. Solar Neutron Telescope, the RT5 solar radio telescope, LAGO cosmic-ray observatory and Proto-HAWC.

and Proto-HAWC (see figs. 7,8).

Fig. 8. Local experiments at SN. Solar Neutron Telescope, the RT5 solar radio telescope, LAGO cosmic-ray observatory and Proto-HAWC.

HAWC will form part of an unique multiwavelength multidisciplinary scientific complex able to perform combined astrophysical studies (LMT + ACTs), high energy solar physics (RT5 + TNS) and cross calibrated cosmic and gamma ray event reconstructions.
Sierra Negra will provide HAWC with the required infrastructure added with extraordinary synergy and the support of Mexican scientists experienced in geophysics, astrophysics, solar and high energy physics.

V. ACKNOWLEDGEMENTS

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