HAWC Progress Report PY3 Q2

This is a quarterly summary of the progress on the construction of the HAWC Gamma-Ray Observatory. This summary is accompanied by a quarterly financial report that will cover spending through PY3Q2, which ended on July 31, 2013. For completeness, this narrative report describes developments in the HAWC construction project through August 2013.

During this reporting period tanks were continuously added, filled and instrumented. The period began with 77 tanks incorporated into the DAQ then 95 tanks and culminated with 111 tanks. On August 1, 2013 we transitioned from engineering operations to science operations.

During June of 2013, the HAWC project underwent a mid-construction review. The review focused on technical progress and the project's funding. HAWC is on-schedule and on-cost. The reviewers wrote a highly favorable report. We have implemented all the recommendations of the review panel.

Since the transition to operations, the sensitivity of the HAWC detector is sufficient to observe TeV gamma-ray sources. The figure below shows the a map of the entire sky from the same data set. Even though this data represents only about 2 months of data (~6 weeks of engineering data from HAWC-95 and ~3 weeks from HAWC-111), many sources are clearly visibly, including the Crab plearion, Markarian 421, Markarian 501, and many near-threshold sources along the Galactic ridge. This data set achieves a sensitivity of about 3% of the final HAWC sensitivity.

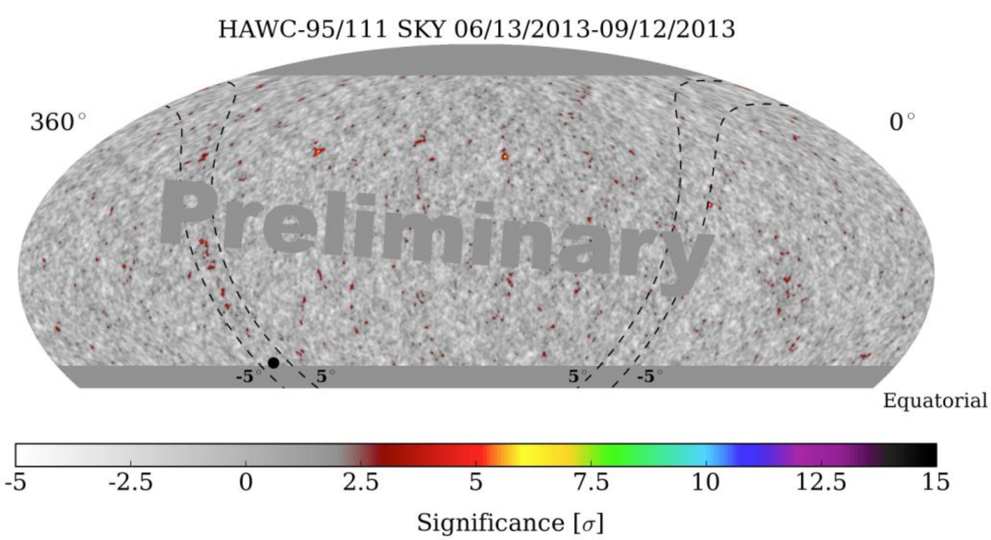

Figure 1 - Initial map of the sky showing the Crab (5h35m,22.0) at 7.5σ, Mrk 421 (11h04m, 38.2) at >6, Mrk 501 (16h54m, 29.8) at >6σ and a clear excess along the galactic ridge from ~(18h,-20) to ~(21h,+50). This data set achieve a sensitivity of about 3% of HAWC's final sensitivity.

Funding & Schedule

The project overall is on schedule and on budget. In August 2013, we began science operations with the 111-tank detector, which satisfies the high level milestone of operations commencing with a “100-tank” detector. We chose to operate with 111 tanks since the tanks are added in groups to the DAQ, with each group including about 12 to 15 tanks. The development of HAWC included stages of 29, 43, 77, 95 and 111 tanks.

Technical Status

WBS 1 Calibration & Verification:

The HAWC calibration system consists of a pulsed laser that delivers light to diffusers that are suspended in the center of each tank. The laser light is routed through a network of optical fibers. The calibration system has been assembled and is being verified. In addition, the verification tasks will confirm the detector performance through the measurement of cosmic-ray rates and distributions, gamma-ray rates from the Crab plerion and through a data challenge that simulates high level data as a test for analysis tools.

Achievements this period for laser calibration system:

• The laser calibration system has been run weekly and we have found that the detector shows no signs of drift over time scales as large as a month. Since the volume of the HAWC tanks is very large, the PMTs are in an extremely stable environment. Also, HAWC’s tropical location means that little seasonal temperature variation is anticipated.

• The 4-fiber bundles that we have run to each tank pair, were found to include fibers of different lengths wrapped in the same jacket. The difference is small, about 2ns RMS on a 550’ optical path, but our timing requirements demand < 1ns tank-to-tank timing. With our current data sets, we use cosmic-ray showers to adjust the PMT timing instead of the absolute timing from the laser system. This deficiency is being remedied by measuring the length of all the fibers already deployed and measuring the length of the fibers yet to be deployed in a lab. The measurements are made by comparing the timing to a reference fiber.

WBS 2 HAWC Site:

With the platform and buildings complete, the only tasks remaining for the Site WBS are the deployment of tanks and the delivery and filtration of water. Tank construction rates of ~3-5 tanks per week have been achieved and maintained and we filled about 3 tanks per week with water. The tank construction rate can be as high as 5 per week, but is often effectively lower since the tank construction crew is used for other tasks, such as moving materials and cabling as needed. The key to maintaining the pace of construction is keeping the tank construction rate ahead of the water delivery rate, ~3.5 tanks per week, which defines the critical path for construction.

Achievements this period for HAWC Site:

• Completed the construction and filled more than 135 tanks since the inception of the project. At a pace of 3-5/week, we should have no problem completing the HAWC detector on schedule by August 2014.

• We are currently in the wet season and we have been working to collect water from a natural spring near the HAWC site. If this water is usable, the cost per tank is less than half of the trucked water. We have found that initial tests of the spring water indicate the presence of a yellow contaminant that we believe to be due to lichens, which grow on the mountain rocks. The yellow color indicates absorption in the blue, which is deadly for a water Cherenkov detector. We have not used this water. Later samples seem to show that the yellow contaminate is not present, though we are proceeding slowly and revising our testing procedures.

Figure 2 - Construction status of HAWC from early September 2013. In this image, there are 139 constructed tanks. The completed (as funded) HAWC detector will include 250 tanks. The platform was designed to accommodate 300 tanks.

Last Updated 10/7/13

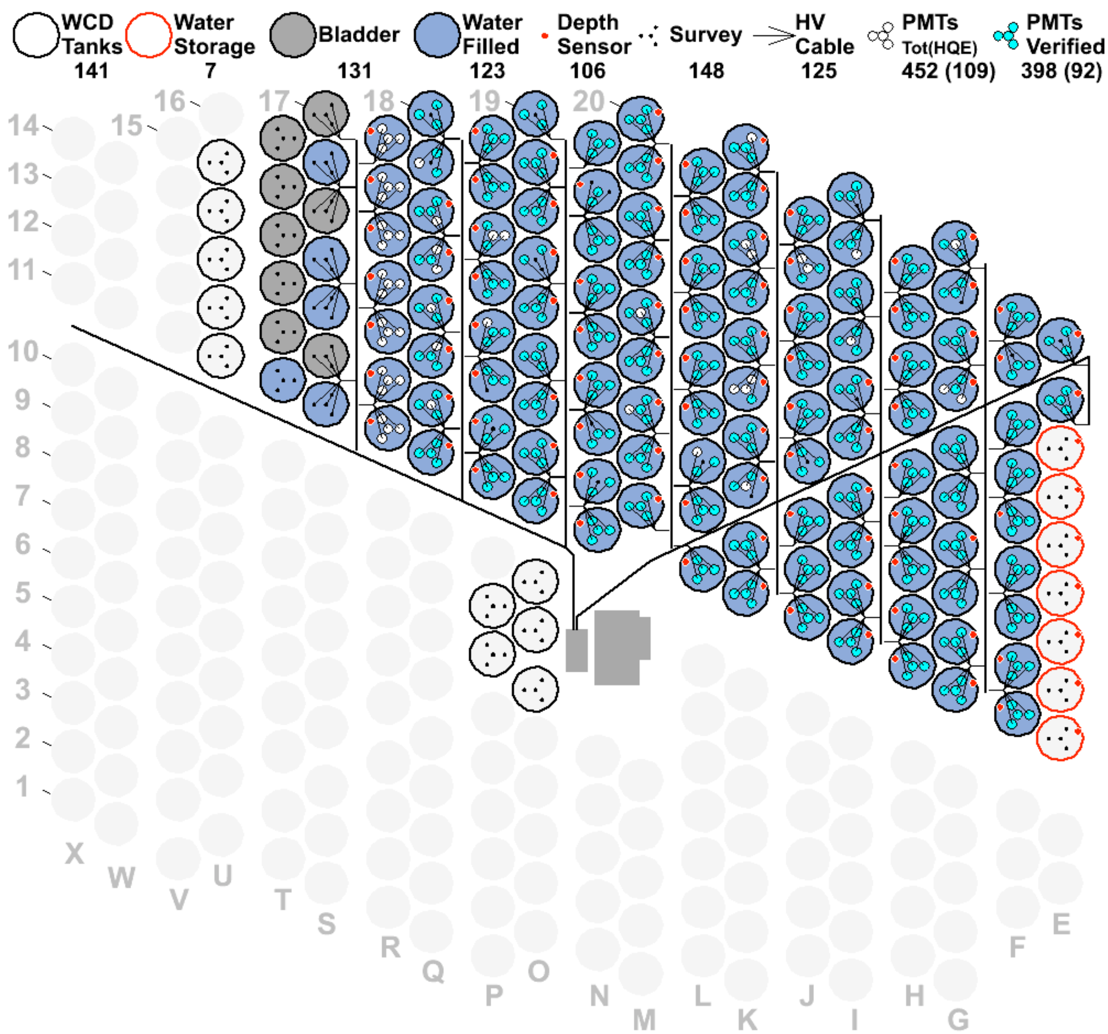

Figure 3. HAWC Progress Web Page is updated daily and shows construction and deployment status on Sept 28, 2013. 148 tanks were completed by this date.

<u>WBS 3 Water Cherenkov Detectors (WCDs):</u>

The Water Cherenkov Detectors (WCDs) consist of a cylindrical metal tank with a convex roof, the plastic bladder, the PMTs and the cables and the spark-gap lightning protection system.

Cabling

We have completed all the cabling main lines North of “10th Avenue”, the diagonal road running through the center of the HAWC detector. Work has began on the cabling for the radial cable run which will service tanks in the south-west region of the detector.

PMTs

The Photomultiplier Tubes (PMTs) are deployed by the same crew that deploys and fills the bladders under the supervision of Arturo Iriarte of UNAM using a system designed by David Warner of CSU. The PMTs are lowered into place using a clothes-line-like string with a plastic ball to a mount point on the bottom of the bladder. PMTs can be deployed and recovered as needed to effect repairs. Figure 11 shows the PMT anchoring system (top) and a snapshot of an underwater camera monitoring the deployment of a PMT (bottom).

About 40 of the 444 PMT in the HAWC-111 detector have known problems. In most cases, the encapsulation has leaked under the pressure or there was a problem with the deployment string. In October, we will have personnel on site to repair these channels. Note that we had similar deployment and “infant mortality” issues with the first 30 tanks (in the eastern triangle). After repairs were done to correct the problems, only 1 of the 120 channels has encountered recurring failures. The PMTs, once in place are quite stable.

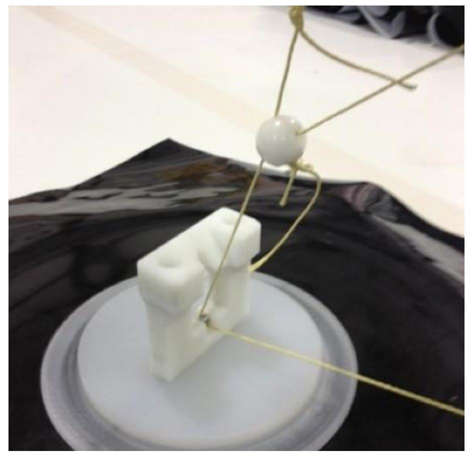

Figure 4. HAWC remote PMT anchor system (top). TV image of PMT capture.

Achievements and developments during this period:

- Completed and began science operations with the HAWC-111 detector.

<u>WBS 4 Electronics:</u>

The HAWC electronics system includes the front-end boards, which distribute high voltage to the PMTs and shape and discriminate the PMTs pulses, main DAQ (sometimes referred to as the TDC DAQ), which digitizes the PMTs pulses using a multi-level time over threshold method, a GPS clock and control system that provides a uniform clocked trigger signal to the TDCs, a scaler DAQ, which is an independent readout that records the PMT rates every 10ms, and an environmental monitoring system to monitor temperatures, voltages and other critical parameters.

The front-end boards are custom electronics boards that distribute high voltage to the PMTs and receive the PMT pulses through a single co-axial cable. The PMT pulses are shaped and discriminated at 2 levels (~0.25 PE and ~5 PE) and transmit ECL square wave pulses to the TDCs and scalers. These boards are working well. We currently have sufficient boards installed at the site for the 111-tank detector. Tests operating a full crate of boards indicates that cooling is not a problem despite the high elevation.

The DAQ consists of 128 channel TDCs (CAEN VX1190A) each read with a single board computer (GE SBC), each on a separate VME backplane. Each TDC/SBC pair operates independently of each other aside from the shared 40 KHz trigger signal and 40MHz internal clock. The TDCs readout all PMT hits without deadtime, which corresponds to a data rate of 40-50 MB/s per TDC/SBC. This data is logged by the SBC and forwarded to the online system for sorting, triggering, and processing.

We currently have all electronics materials needed to operate the 111-Tank array at the site or approved for shipment.

Achievements and developments during this period:

• Multi-TDC DAQ has been running stably for several months with no major problems. There seem to be no rate limitations which should limit our scientific goals in any way.

• Collecting data at >150MB/s using 4 TDCs.

<u>WBS 5 Software and Computing:</u>

The Software and Computing system includes all software and the computing hardware.

HAWC maintains 2 comprehensive data centers, one in Mexico at UNAM-ICN and the other in the US at the University of Maryland. We have budgeted for a full triggered data rate of 20MB/s with 24/7 operations. At this rate, we will need to archive ~700TB of data per year. We will keep identical copies at both sites and not backup the data to tape or some other archival media.

The HAWC online computing system includes a 30TB disk array, which acts as a local data archive, and sufficient computing to assemble the TDC data streams, apply a software trigger, reconstruct and analyze the data. We have purchased and installed in the HAWC counting house 4 computers with a total of 176 cores. This should be sufficient for all of HAWC.

In the current 111-tank configuration, we operate HAWC with a trigger that is satisfied by ~20 PMTs being hit within a 150ns window. With this trigger, we readout about 16,000 events per second (about 10x the rate of Milagro) and log data at a rate of ~6MB/s to disk. Event building and reconstruction utilizes about 80 computer cores operating in parallel. The interprocess communication is handled by a socket layer library called “zeromq”, which has been tested well beyond the full design rates and found to work well.

Data is transferred from the site to the UNAM-ICN archive weekly using portable disk drives that are driven from the site to Mexico City. We have a network to the site, but the bandwidth is insufficient for anything but monitoring, control and interactive work. An upgrade of the network is being performed by INAOE to improve the access to all the experiments at the Sierra Negra site.

Achievements and developments during this period:

• Achieved full 1Gb bandwidth in US-Mexico link. This will be sufficient to maintain data archive synchronization between UNAM-ICN and UMD.

• INAOE has installed a fiber from the HAWC office Atzizintla to Ciudad Serdan where it can join the Mexican Internet. This is the first step toward a high speed connection from the site to INAOE and then UNAM and the US. This cost is being covered by INAOE, and it will substantially reduce the cost of internet at the site. This would increase our bandwidth to the site from its currently level of 1Mb to 100Mb or higher.

<u>WBS 6 Cost, Schedule, Management</u>

WBS 6 includes project management, technical and engineering personnel, shipping travel safety and outreach.

Andrew Smith (UMD) is the project manager for HAWC and Brenda Dingus (LANL) is the deputy project manager. The site is managed by the INAOE under an agreement with the Mexican national park system.

In the Summer of 2013, the US embassy in Mexico notified us that the shipping method that we have been using is no longer available. In the future, materials will either need to be subject to taxation, donated or imported under a temporary importation grant. This change impacts our shipping of materials and has kept us from shipping many of the electronics components needed to expand beyond HAWC-111. We will pursue the donation route for NSF-purchased materials and materials which are disposable. LANL rules prohibit donation of capital equipment, so temporary importation will used for these items.

The next major milestone in the project execution plan is the 10-sigma detection of the Crab by February 1, 2014. As we currently have 7.5 sigma on this source and the quality and quantity of data is rapidly increasing, we anticipate having no trouble reaching this milestone earlier than scheduled.