

# Characterization of a outer detector (outriggers) for HAWC

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**Abstract.** The High Altitude Water Cherenkov (HAWC) Observatory is a ground-based air-shower array deployed on the hillside of the Sierra Negra Volcano in the state of Puebla, Mexico. HAWC comprises of 300 water Cherenkov detectors (WCDs), each WCD is equipped with four photomultiplier tubes (PMTs) to detect secondary particles of the air-showers that are produced by the interaction of a primary particle (gamma-rays and cosmic rays) with the atmosphere. HAWC is able to reconstruct gamma-ray showers in the 100 GeV - 100 TeV energy range, but suffers from a lack of sensitivity when the particle showers core develop outside the WCD array. A proposed upgrade to fix this issue is to build an external array of smaller water detectors, called outriggers. A Outrigger comprises a PMT on the bottom of the tank. In this work the instrumentation and characterizing an Outrigger is presented, in order to know the behavior of this detector with as function of threshold voltage.

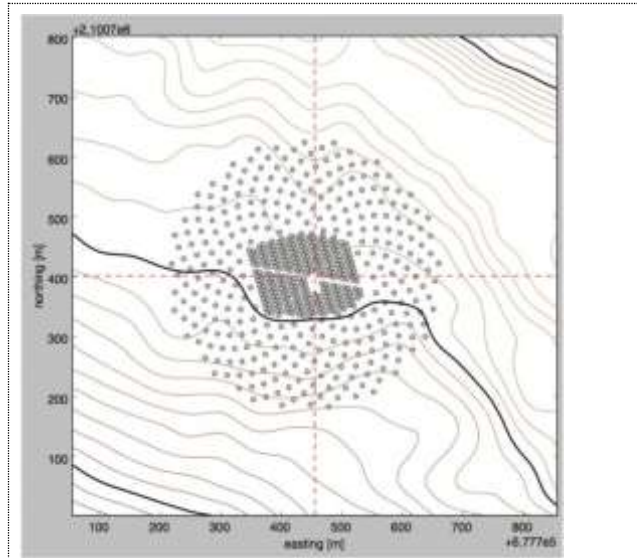
## 1.Introduction

The high altitude water Cherenkov (HAWC) is a gamma-ray observatory located at 4,100 meters above sea level on the hillside of the Sierra Negra volcano in the state of Puebla, Mexico. HAWC is an array of 300 water Cherenkov detector (WCDs) that began full operation in March of 2015 [2]. Each WCD consists of a metal cylindrical structure of 7.3 in diameter, and 4.5 in height, a dark bag (called bladder), high-purity water, and 4 photomultiplier tubes (PMTs) on the bottom. When a primary particle arrives in the Earth's atmosphere, they interact with the atoms of the air, and this interaction produces secondary particles that depend on the kind of primary particle (for example if a gamma ray is the primary particle, these secondary particles are made up of electrons). These particles penetrate the WCDs, and emit Cherenkov light that can be detected by the PMTs [3].

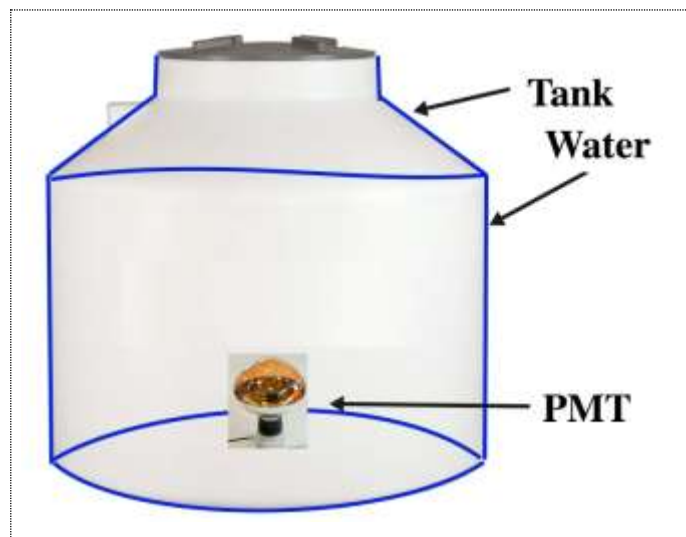
One event is considered when a primary particle arrives at the atmosphere, then it has developed an air-shower, finally it is detected by HAWC. Sandoval in [1] said "The PMTs activated during an event depends mainly upon the primary particle's energy. If the latter has a high energy, the most of the PMTs are activated. However, the shower may be poorly reconstructed if the shower core falls outside the array". Therefore an array of smaller detectors, called outriggers, is currently being deployed around HAWC (see the Figure 1). These outrigger will be comprised of a cylindrical polyethylene



tank with approximate 2 m of diameter, filled with purified water and equipped with a single PMT at the bottom (see Figure 2). These outrigger will be able to detect the secondary particles which land outside of HAWC, which will improve the core reconstruction and improve 3-4 times the sensitivity to gamma-rays above 10 TeV [1]. In this work, we present a test for characterizing one of outrigger, and understand the behavior of the rate and charge distribution of the new detector as a function of threshold voltage.



**Figure 1.** Contour lines of the terrain at the HAWC site, with the HAWC array and the layout of a 300 tank outrigger array in the geometry of a sunflower spiral [1] .



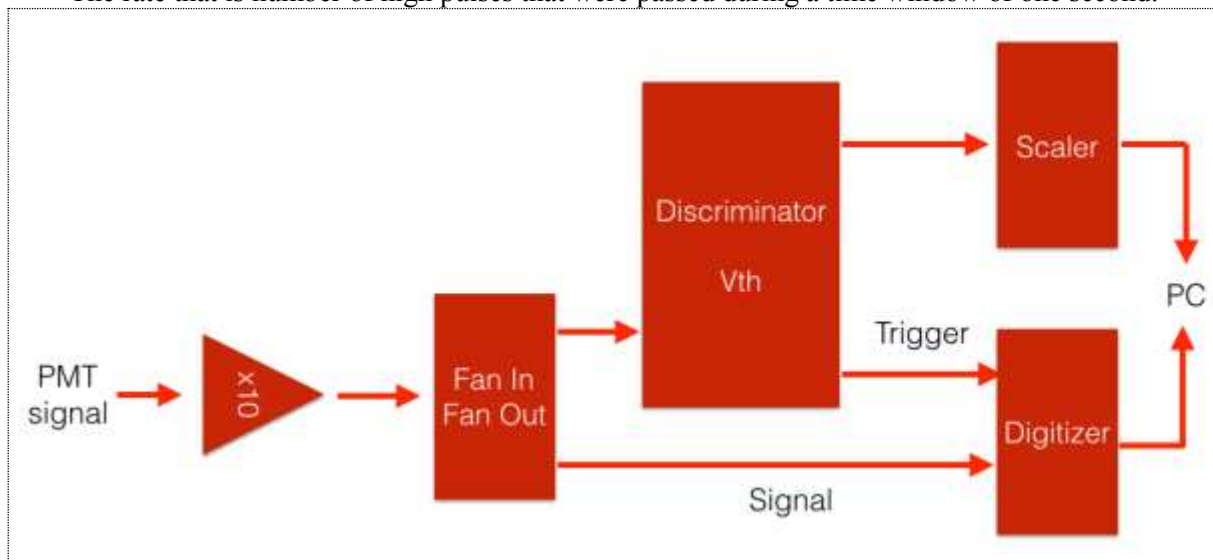
**Figure 2.** An outside detector, called outrigger, is comprised of one tank, purified water, and PMT on the bottom.

## 2. Experimental setup

The experimental setup is shown in Figure 3 in the form of block diagram illustrating the flow the information from PMT to the data acquisition module. CAEN electronics were used for collecting these informations basen on VME and an amplifier basen on NIM. First the PMT is powered by a CAEN V6533 High-voltage VME module, at an optimal tension of 1617 V. The signal cable of the PMT is isolated from the HV supply with the help of a decoupler, and fed through a 10x amplifier. The resulting output signal is then connected to an N625 Fan-In/Fan-Out Unit, because this unit output generates the sum of the input signals (in this case only one) times the gain that is 1. Therefore, there are four independent output signals: one is plugged in as input of a V1751 digitizer, and the other is connected to a discriminator (V812) for distinguishing between the low signal and high signal: a high signal is defined as the signal that is bigger than a threshold voltage ( $V_{th}$ ), and the discriminator sends a pulse when a high signal is at the input. A high signal pulse will be sent at two locations: a V820 Scaler and a V1751 digitizer. The Scaler counts the number of pulses in a time windows of one second. Data is only acquired by the digitizer when the system detects a high-signal pulse.

Upon Data acquisition, two measurements are saved in a data file.

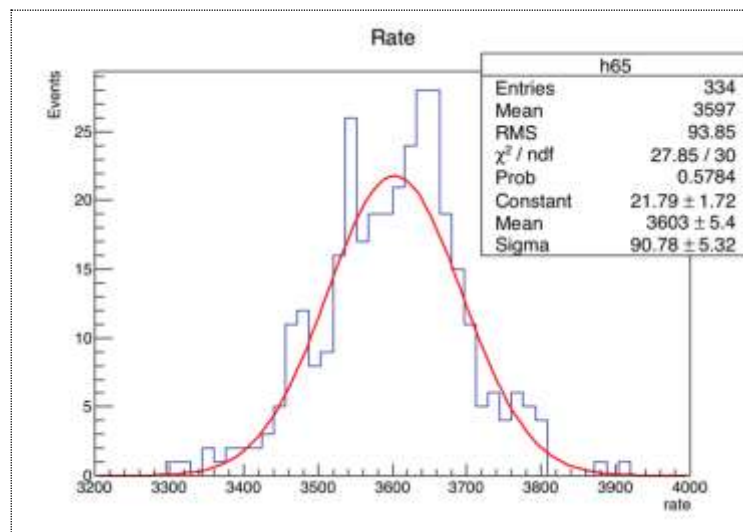
- The high pulses is shown in the Figure 5.
- The rate that is number of high pulses that were passed during a time window of one second.



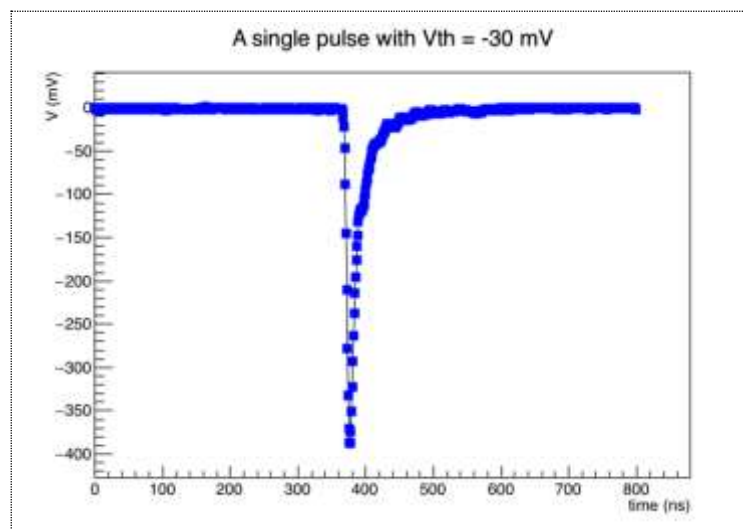
**Figure 3.** Schematic diagram of the CAEN electronic that were used for collecting the data.

Different values of threshold voltage were used from -5 mV to -100 mV with a step of 5 mV. Each  $V_{th}$ , the next informations were saved:

- In the case of Scaler: approximate 300 rate were measured, that is about 5 minutes of data. These measurements of rate were put into a histogram and fit a gaussian function (see the Figure 4), and exported the mean and sigma for an analysis.
- In the case of Digitizer: 50,000 pulses were saved with a time window of 800 ns (see in the Figure 5). Each pulse was integrated to obtain its charge.



**Figure 4.** This is a histogram of the rate. 334 measurements were taken with a  $V_{th}$  of -65 mV. The red line is a gaussian fit.

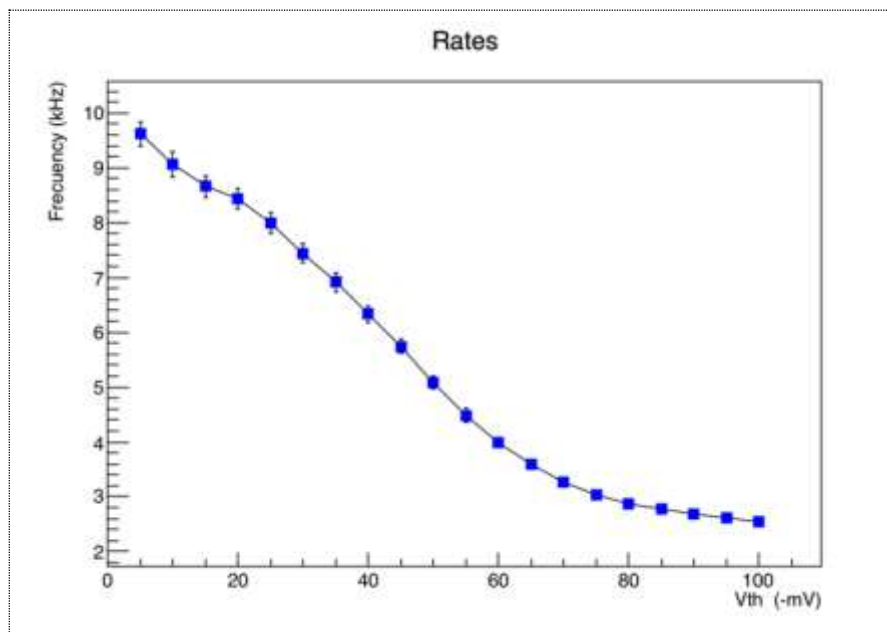


**Figure 5.** Is shown a high signal with a time window of 800 ns.

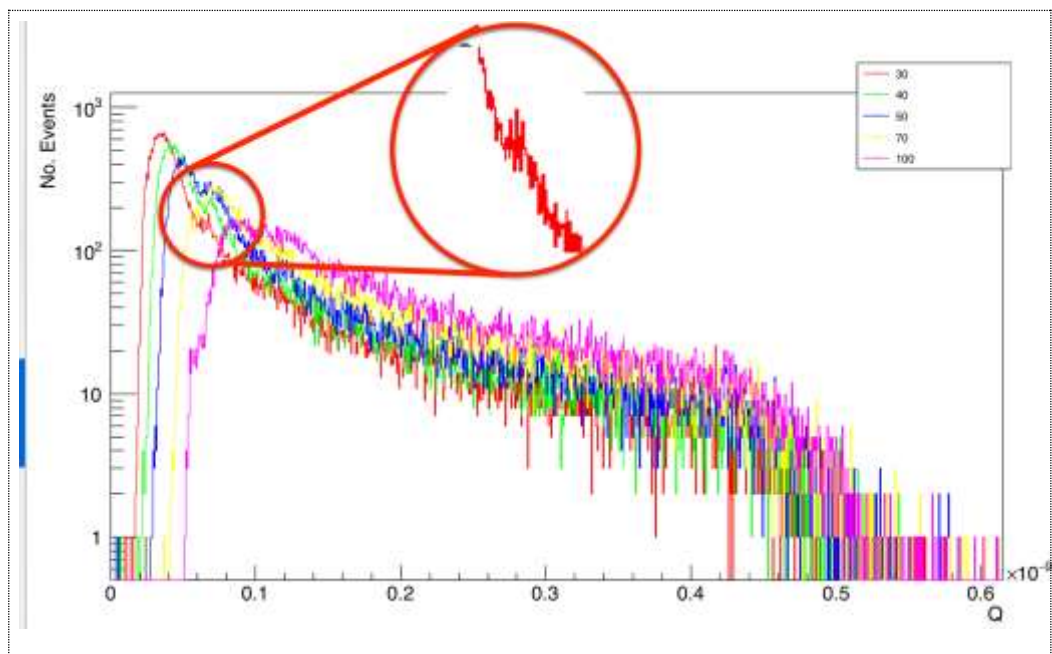
### 3.Results

In the Figure 6 is shown the rate Vs  $V_{th}$ . In this graph, the response of single photoelectron (PE) could be found, it is around 20 mV, but more measurements with step smaller will have to be made. On other hand when a  $V_{th}$  is bigger, the rate is lower, due to there are less signal with big energy that was detected by the PMT.

Figure 7 shows the histogram of the integrated pulse charge (Q) as a function of threshold voltage. When  $V_{th}$  is -30 mV (red histogram), there is a small peak between 0.05 and 0.1 nC, there are a possibility that will be vertical muons, but more analysis will need to do.



**Figure 6.** Bias curve of an outrigger tank. The plot shows rate vs  $V_{th}$ . When the voltage is low, that is, close to zero, the rate is increased. Because there are more signal with low energy were detected by the PMT.



**Figure 7.** There are some histograms with different  $V_{th}$ . If the threshold voltage is increased, the small signal does not pass the trigger and is not saved therefore the numbers of events is smaller. A zoom of the -30 mV histogram is made because it is possible that are vertical muons but it is necessary make more analysis.

#### 4. Conclusion

In this work, we started analyzing the response of an outrigger detector to various trigger threshold voltage, which is the first step in understanding the behavior of the new instrument. In addition to the measurements presented, a thorough inspection of the tank seals and light shielding needs to be made, in order to avoid flawed detector which would systematically trigger at a very high rate.

Measurements of the bias curves for one outrigger shows that the events rate increases when the  $V_{th}$  is low because of there are less particles with high energy. Finally, the integrated charge distribution hint at a possible contamination of the signal by muons, although more analysis needs to be done to confirm this hypothesis.

#### Acknowledgments

We acknowledge the support from: the US National Science Foundation (NSF); the US Department of Energy Office of High-Energy Physics; the Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia y Tecnología (Mexico (grants 239762,260378, 55155, 105666, 122331, 132197, 167281, 167733); Red de Física de Altas Energías, Mexico; DGAPA-UNAM (grants IG100414-3, IN108713, IN121309, IN115409, IN111315); VIEP-BUAP (grant 161-EXC-2011); the University of Wisconsin Alumni Research Foundation; the Institute of Geophysics, Planetary Physics, and Signatures at Los Alamos National Laboratory; the Luc Binette Foundation UNAM Postdoctoral Fellowship program.

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