Detecting Cosmic Ray Muons at Suffolk County Community College

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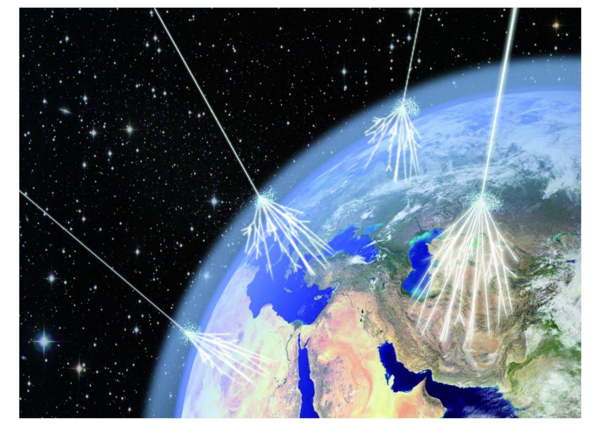
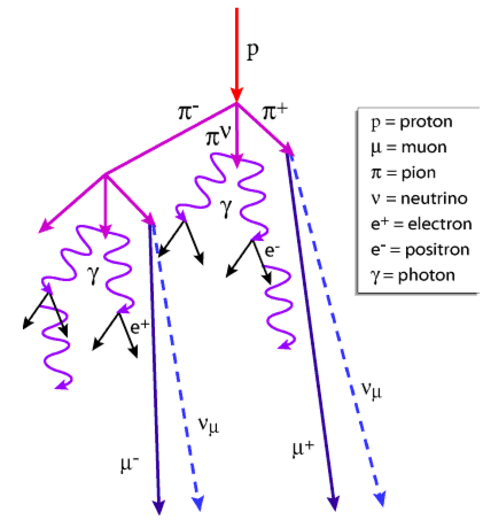
Introduction

Cosmic rays are high energy particles emitted by the sun, supernovae, and black hole regions; about 90% of the cosmic ray flux consists of protons and 9% of heavier particles, principally alpha particles. When a cosmic ray proton collides with a nucleon in earth's atmosphere pions are produced; charged pions decay producing muons which are detectable as they hit earth's surface. Cosmic rays are studied in particle physics, space weather, astrophysics, solar activity, lightning, and earth's magnetic field. At the Suffolk County Community College Ammerman Campus three MARIACHI cosmic ray detector counters each, with an ADIT brand photomultiplier tube, were retrofitted with a QuarkNet DAQ board from Fermi National Accelerator Laboratory. The detector will be used for undergraduate imbedded research and applications in engineering physics.



Artistic rendition of cosmic rays entering Earth's atmosphere. (Credit: Asimmetrie/Infn). http://cds.cern.ch/record/1345733



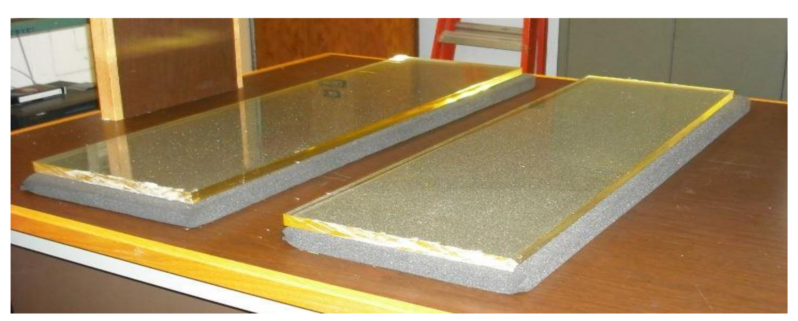
A shower of secondary particles including muons (μ) are produced as a primary cosmic ray proton collides with a nucleon in earth's atmosphere.

Figure courtesy: HAWK Observatory http://www.hawc-observatory.org/science/cosmicrays.php

Equipment

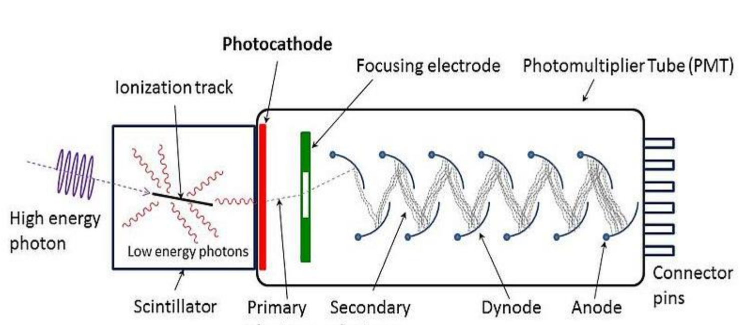
Scintillator

A scintillator "counter" consists of a plastic sheet of fluorescent scintillator material and a photomultiplier tube. A cosmic ray detector can consist of one or more scintillator counters connected to a data acquisition system. The counters used were from the MARIACHI cosmic ray project and are typically made of polyvinyltoluene plastic (PVT) with fluorescent hydrocarbon molecules. Charged muons passing through ionize PVT molecules causing them to emit faint flashes of UV light; the hydrocarbons absorb UV and re-emit longer wavelengths which pass through the plastic. The scintillators are wrapped with Tyvek construction paper containing flashes by reflecting them inward, and housed in black cases to isolate them from room lighting.

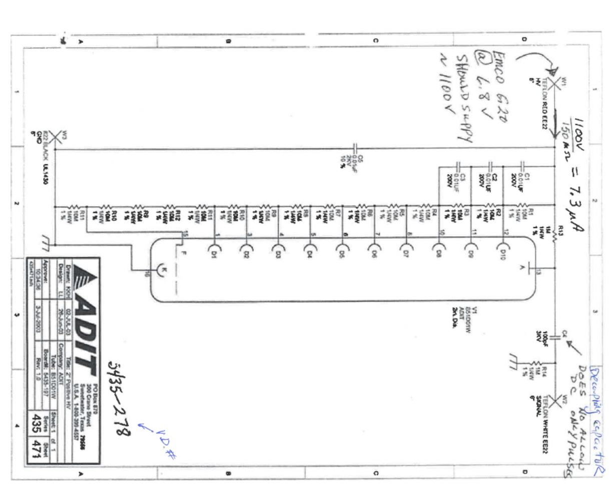


Photomultiplier tubes (PMTs)

ADIT photomultiplier tubes (model B5130B) were interfaced at one end of the scintillator to detect muon induced light flashes; each PMT has a cesium based photocathode which converts incident photons into electrons via the photoelectric effect; internal electrodes held at high voltages convert these electrons into a pulse of current which is fed into the data acquisition system.



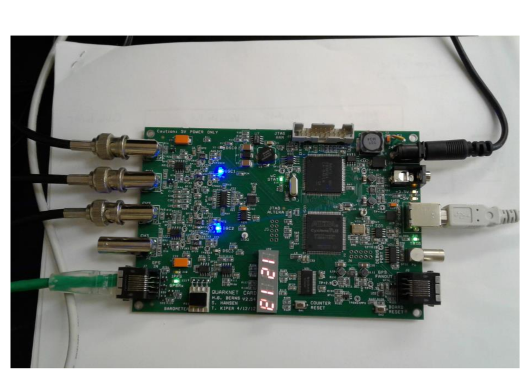
Photomultiplier Tube; Qwerty123uiop. *PhotoMultiplierTubeAndScintillator.* 2013. JPEF file. https://commons.wikimedia.org/wiki/File:PhotoMultiplierTubeAndScintillator.jpg

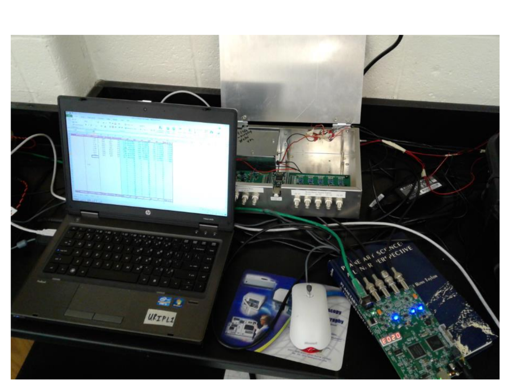


Credit: ADIT (Electron Tubes) Technical Drawing

Each PMT uses a voltage divider circuit to distribute high voltage to the electrodes. The anode has a capacitor on its output to isolate the high voltage from the signal; this limits the PMT output to pulses removing any DC component.

Data Acquisition Board (DAQ)

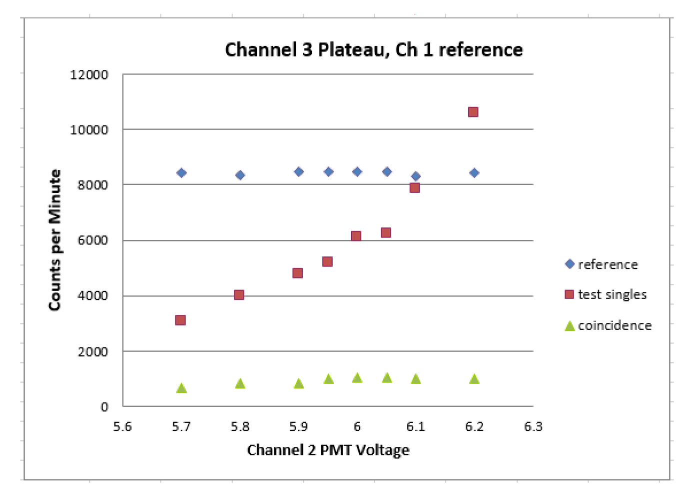


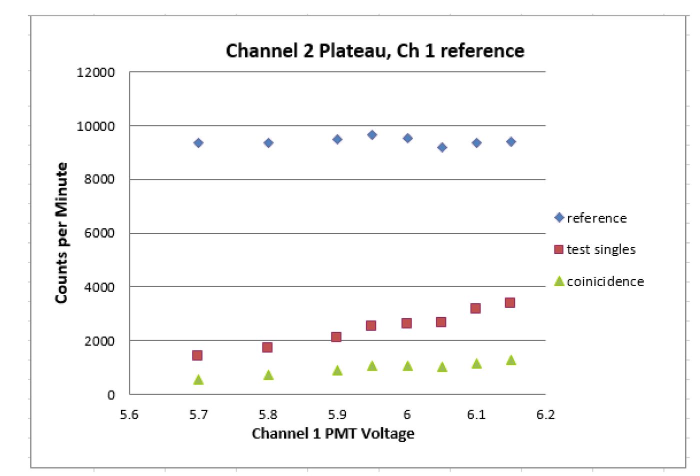


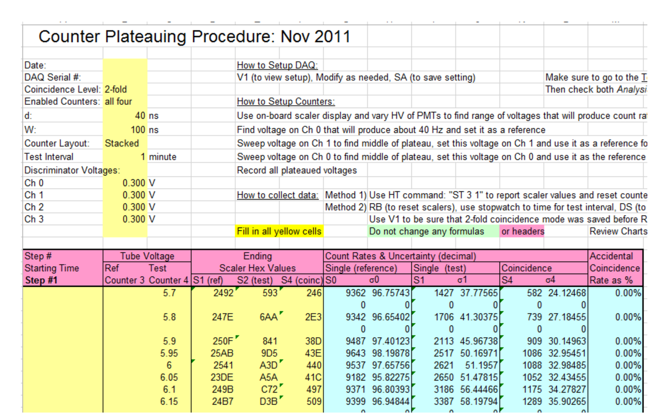
The DAQ board records pulse counts from PMTs and based on user defined criteria determines if they should be saved as cosmic ray count. The Quarknet DAQ has 1.25 nano seconds timing resolution for individual signals; the GPS satellite antenna and receiver that the DAQ relies on to time stamp cosmic ray events limits its timing accuracy to about 50 nano seconds.

Plateauing photomultiplier tubes

PMTs are very sensitive and each operates at a slightly different voltage; if the voltage is too low it doesn't detect all muons, if it's too high it pulls electrons off the cathode generating a lot of noise. It is critical to find their optimal operating voltages in a plateau calibration. In the procedure two scintillator counters, each with its own PMT, are stacked one above the other such that incident muons go through both counters within a very small window of time (a muon travelling at close to the speed of light travels about 1 foot per nanosecond); one PMT is held at a fixed voltage while the voltage to the other PMT is incremented in small steps; the goal is to find the voltage at which both PMTs put out coincident pulses within a very short time window, shown as green triangles in the plots below. The plateaued counters coincident rate was about 17Hz.



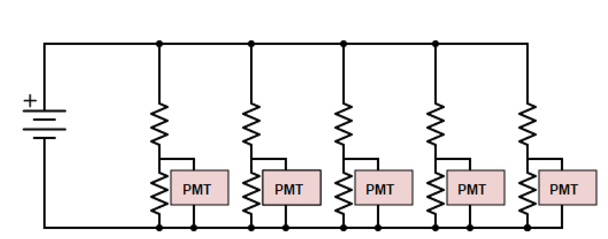




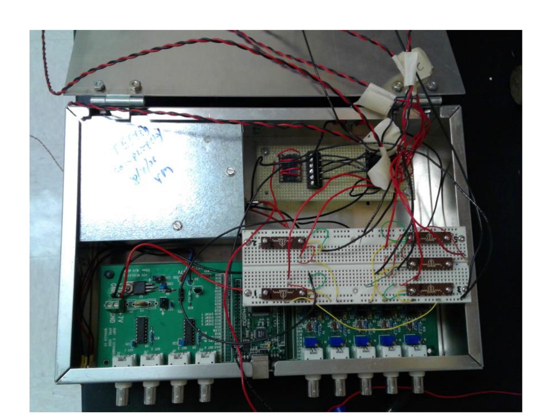
The DAQ board output is hexadecimal format which is converted to decimal format by an excel spreadsheet, then plotted

PMT power circuit

Low voltage DC to high voltage DC converters, which operate at 5 to 7 volts, are used to provide high voltage to PMTs; thus three low voltage variable regulated DC power supplies were used to power up the three PMTs. Shown below is a voltage divider circuit that was built to be used for future cosmic ray measurements; the circuit distributes five manually adjustable voltages, each with 0.05V resolution, to five PMTs from a single power supply. Each PMT produces a load on the circuit thus low resistance potentiometers of 100Ω were used to minimize variation in V_{out}.



$$V_{out} \approx V_{in}\left[\frac{R_2}{R_1 + R_2}\right]$$



References

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2. Student Projects in Cosmic Ray Detection by W. Brouwe et. al. http://scitation.aip.org/content/aapt/journal/tpt/47/8/10.1119/1.3246465

3. Educational Cosmic Ray Arrays, R. A. Soluk, Multiparticle Dynamics CP828, American Institute of Physics (2008), http://extras.springer.com/2006/978-0-7354-0320-8/cdr_pdfs/indexed/stage4_copyr/271_1.pdf

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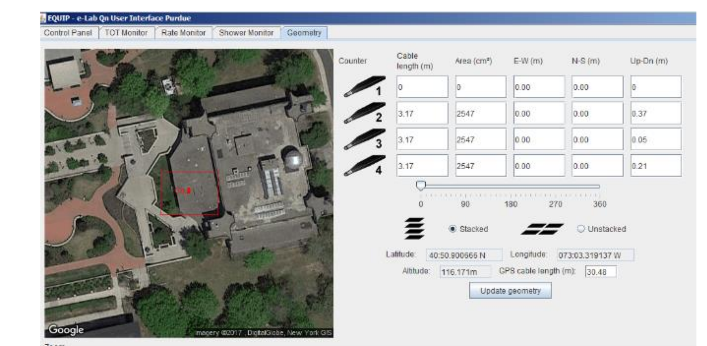
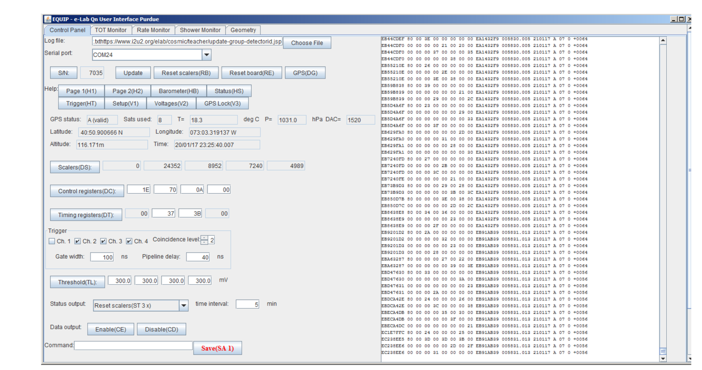
We would like to thank Professors Warasila, Breeden, and DeNicolo of the physical sciences department at the Suffolk County Community College, professor David Lieberman from Queensborough Community College, Mr. Dave Hoppert, Ken Cecire, and Dr. Mark Adams from Quarknet.

Cosmic Rays Detected in the SCCC Science Building

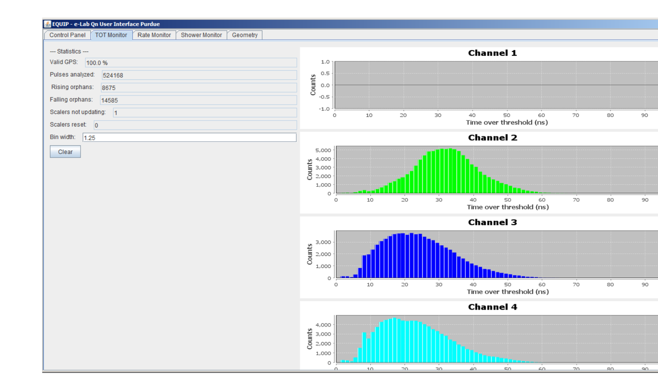
Each black plastic case contains a cosmic ray scintillator and photomultiplier tube collecting data.



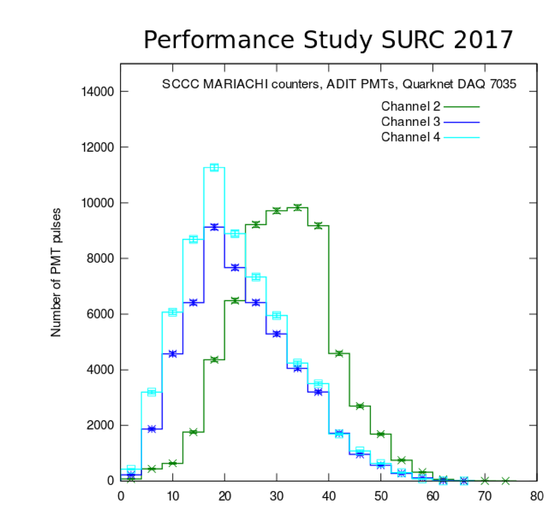
A GPS antenna locates the detector and a software program displays its latitude, longitude, and elevation in the Ammerman Campus Smithtown Science Building.



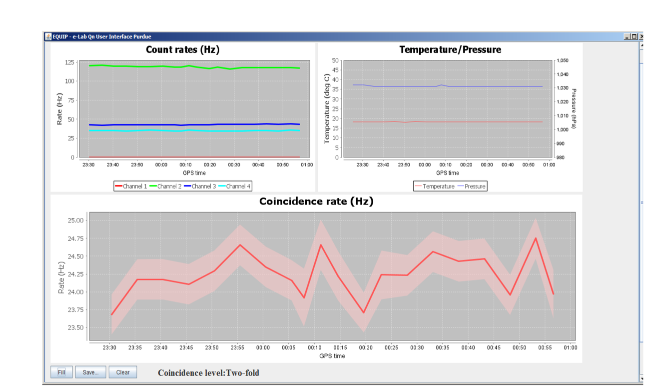
EQUIP is the Quarknet JAVA based GUI used to control the DAQ developed by Purdue University. It displays data in hexadecimal format.



The number of pulse counts detected by each scintillator counter is binned as a function of signal duration above a user defined threshold (in nanoseconds). The shapes of the histograms illustrate relative counter performance.



The numbers of pulse counts detected by the three scintillator counters are plotted as a function of signal duration and overlayed on top of one another.



1.5 hours of coincidence data was recorded which resulted in 129,600 potential cosmic rays detected:

$$\frac{24}{sec}\ x\ \frac{60sec}{min}\ x\ \frac{60min}{hour}\ x\ 1.5hours =$$

129,600 potential cosmic rays detected

If 17Hz is accepted as the expected rate than 91,800 would be the expected number of cosmic rays, thus:
[(129,600-91,800)/91,800] x 100 = 41% error

Conclusion:
The cosmic ray rate and flux will be measured again at SCCC and QCC for improved accuracy and results compared.

Results and Conclusion

Figure to the left: the scintillator **Count rate** on channel 2 was 125Hz, much higher than the other two counters as this PMT was noisier. Also recorded are detector temperature and atmospheric pressure; on high pressure days more cosmic rays are absorbed in the atmosphere resulting in lower signal rates.

The **Coincidence rate** is the number of times per second two counters fire together within a small window of time and therefore a measure of the cosmic ray frequency. The measured rate was 24Hz. Two approaches are taken to estimate an error:

1) The coincident rate obtained while plateauing the PMTs was 17Hz, thus:
difference = [(24-17)/17] x 100 = 41%

2) The SCCC MARIACHI scintillator panels were measured to be 2,511 cm^2; the Quarknet scintillator panels at QCC measure 827 cm^2 and have a typical coincidence rate of 5Hz, thus:
expect = 5 x (2511/827) = 15Hz coincident rate,
difference = [(24-15)/15] x 100 = 60%