Measuring Cosmic Ray Muon Showers at Suffolk County Community College

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STEM Day Undergraduate Research Poster Presentations, Suffolk County Community College , March 7th and 14th 2018. (Poster v.2)

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, primarily helium nuclei. 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, during periods of solar activity, lightning, and influences from earth's magnetic field. At the Suffolk County Community College Ammerman Campus three MARIACHI cosmic ray detector counters each, with a 2" 400 nanometer photomultiplier tube, were retrofitted with a QuarkNet DAQ board from Fermi National Accelerator Laboratory. The detector is being developed in engineering physics projects and used in undergraduate research.

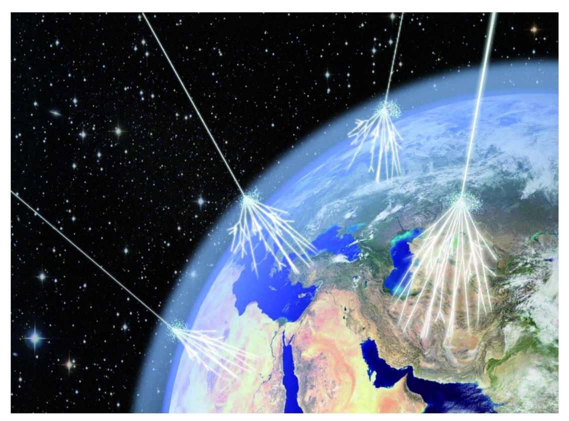


Fig. 1: Artistic rendition of cosmic rays entering Earth's atmosphere
(Credit: Asimmetrie/Infn). http://cds.cern.ch/record/1345733

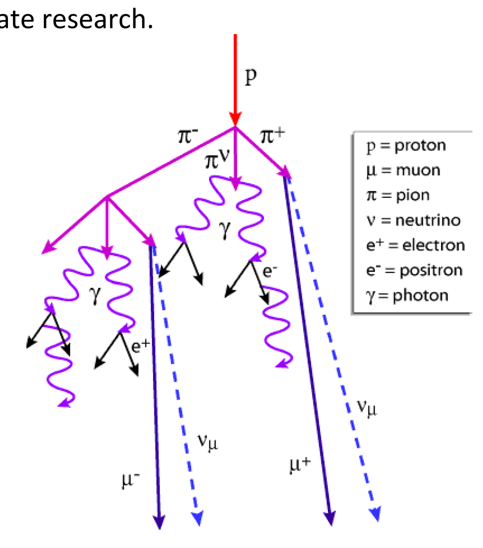


Fig. 2: A shower of secondary cosmic ray particles
The shower can be as large as 100 km across and include muons (μ), pions, electrons, and neutrinos. The shower of particles is produced when a primary cosmic ray proton collides with a nucleon in earth's atmosphere.
Figure courtesy: HAWK Observatory
http://www.hawc-observatory.org/science/cosmicrays.php

Detector Equipment

Fig. 3: A scintillator cosmic ray counter
The detector "counter" consists of a plastic sheet of fluorescent scintillator 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 project. The scintillator is made of polyvinyltoluene plastic (PVT) doped with fluorescent hydrocarbon molecules. Charged cosmic ray muons passing through ionize PVT molecules causing them to emit faint flashes of UV light; the hydrocarbons absorb the UV and re-emit longer wavelengths which the plastic is transparent to. The scintillators are wrapped with Tyvek reflective construction paper with a small hole cut at one end where the PMT lens is mated; a black case is used to isolate the detector from room lighting.

Fig. 4: Photomultiplier tube
ADIT B51B03 PMTs are used; they have a 2" lens, 10 dynode stages, and peak sensitivity at about 400 nanometers; the PMT lens is pressed flat against the scintillator and held in place with a spring.

Fig. 5: The PMT and scintillator
The PMT lens is mated against the flat face of the scintillator which is wrapped in Tyvek reflective wrap

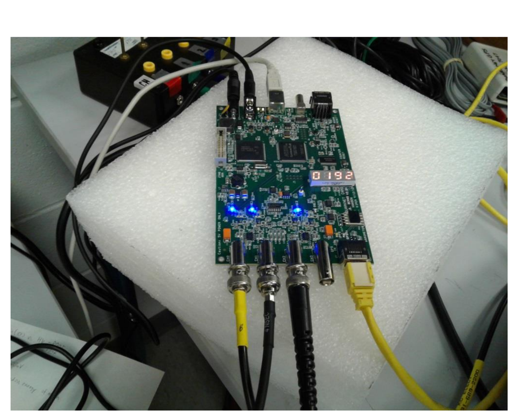
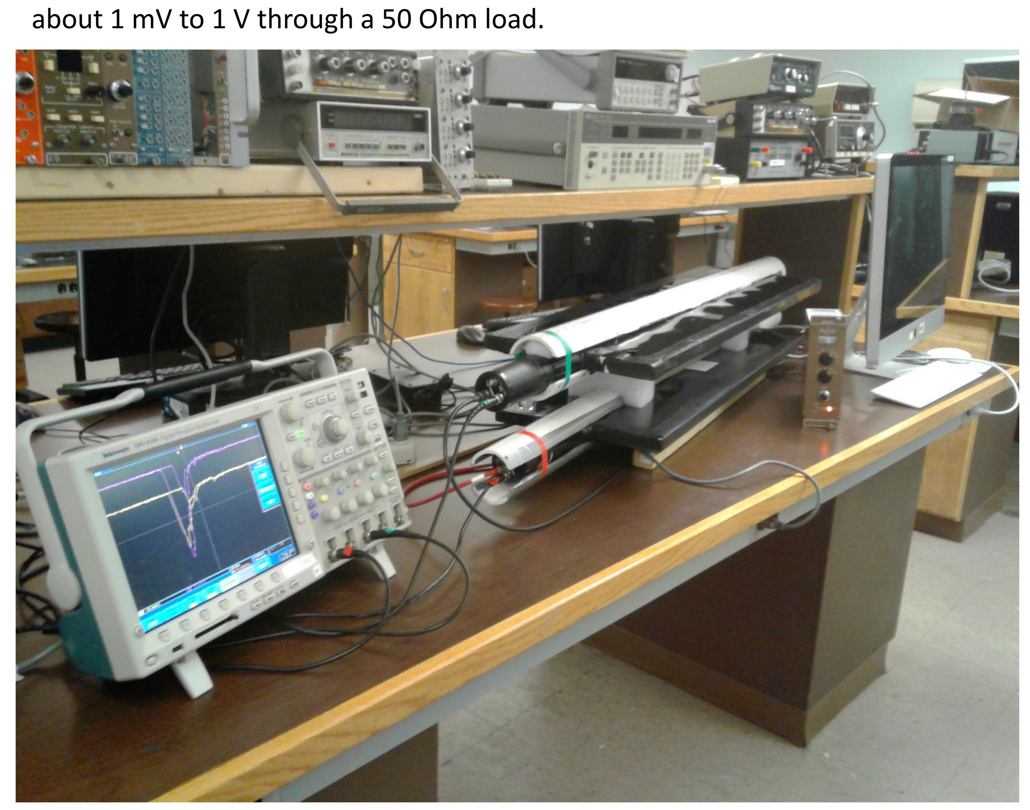


Fig. 6: Data Acquisition Board (DAQ):
The DAQ used is the QuarkNet DAQ board from Fermi National Accelerator Laboratory. It time stamps each detected cosmic ray with the UTC time, and has a 25 MHz crystal oscillator with 40 nanosecond timing resolution. The relative signal timing is further resolved with on-board electronics.

Fig. 6: Two stacked detectors shown with detected cosmic rays displayed in real time on an oscilloscope.
The signals are about 20 nanoseconds wide and range in amplitude between about 1 mV to 1 V through a 50 Ohm load.



Data Collection

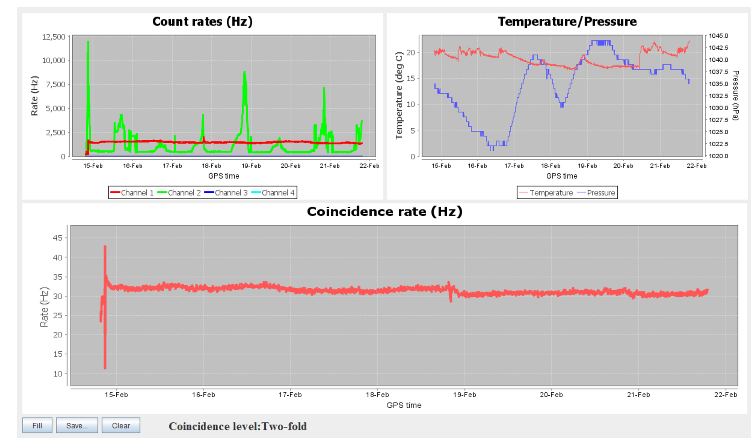


Fig. 7: Cosmic Ray Flux Measurements
One week of data taken over Feb 15-22, 2018: shown are single PMT rates, 2-fold coincidence rate, temperature and atmospheric pressure. The PMT on channel 1 is stable with a dark rate of about 1.5 kHz. The PMT on channel 2 is unstable with large spikes of noise higher than 10 kHz ; the temperature varied over 5° C and the pressure over 20 hecto Pascals. The 2 fold coincidence rate is accepted as the cosmic ray flux rate and was measured at about 32 Hz.

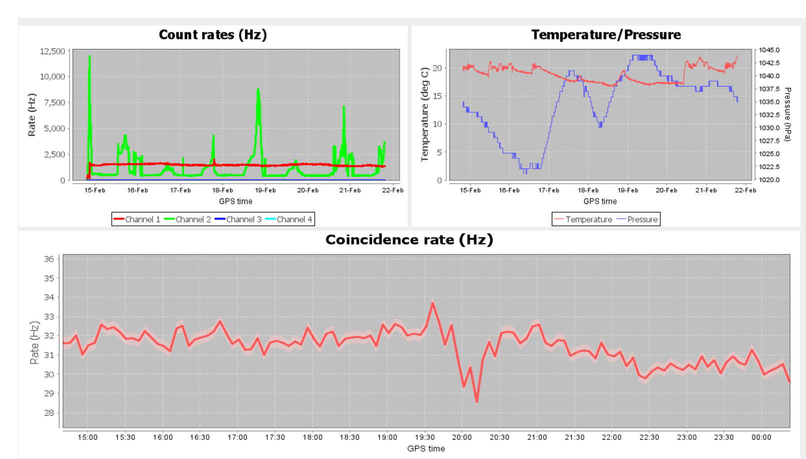


Fig 8: Cosmic Ray Flux Measurements
Here the Feb 18th coincidence data from Fig 7 is shown up-close; a drop in the 2-fold coincidence rate of a few Hertz is observed about 2000 UTC; this drop corresponds to a sharp rise in the single PMT noise rate on channel 2 and thus may be artificial. The 2 fold coincidence rate is accepted as the cosmic ray flux rate and is about 32 Hz.

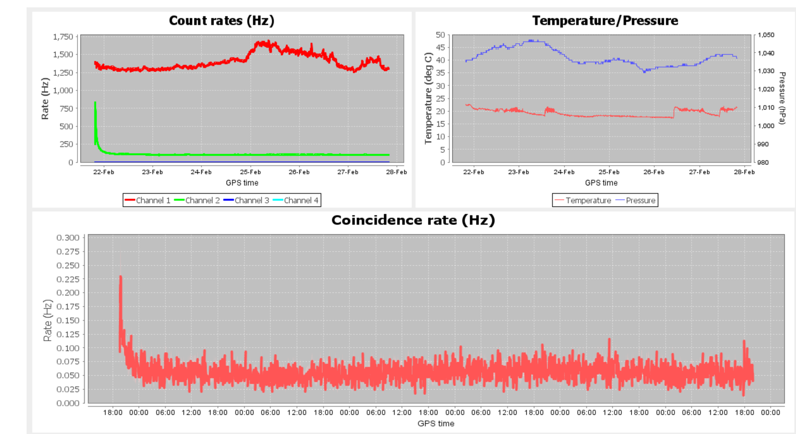


Fig. 9: Cosmic ray Shower Measurements
A second week of data was taken over Feb 21-28, 2018: shown are single PMT rates, 2-fold coincidence rate, room temperature, and atmospheric pressure. The PMT on channel 1 is somewhat unstable with a noise rate ranging over 1.25 kHz to 1.7 kHz, it varies by 36%; this was the same PMT on channel 1 in Fig. 7. The PMT on channel 2 is a different PMT than was used on Ch 2 in Fig. 7; it is stable with a rate of about 125 Hz. The temperature varied over 4° C and the pressure over 13 hecto Pascals. The 2 fold coincidence rate is accepted as the cosmic ray shower rate and was measured at about 0.06 Hz.

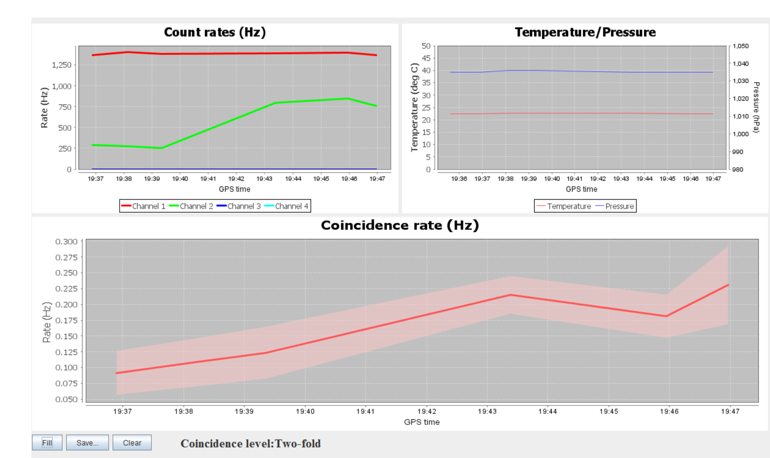


Fig. 10: Cosmic ray Shower Measurements
Here is a close-up view of Fig. 9 showing the first 10 minutes of data taken over 19:37 - 19:47 UTC on Feb 21, 2018; the PMT on channel 1 is stable with a noise rate of about 1.4 kHz; over this 10 minutes of data collection the operating voltage on channel 2 was increased and the PMT rate increased accordingly from 250 Hz to 800 Hz. The 2 fold coincidence rate is accepted as the cosmic ray shower rate and is about 0.09 Hz to 0.225 Hz.

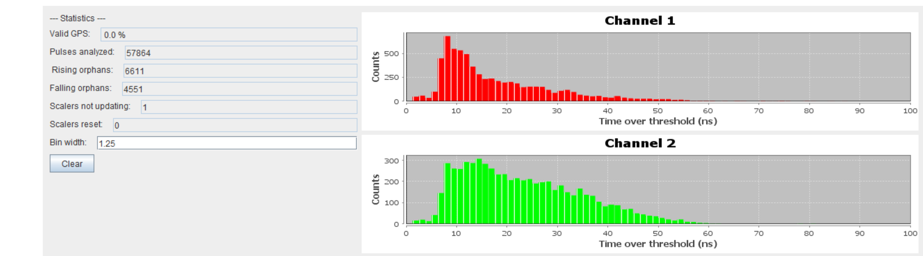


Fig 11: Time Over Threshold PMT Data
Data taken Feb 27, 2018: shown are the single PMT time over threshold data (ToT) for 57,864 recorded events from two PMT channels. The ToT is the amount of time in nanoseconds that a PMT signal is higher than the voltage discriminator threshold which is pre-set in the detector's electronics data acquisition system. The ToT histograms are a way to inspect PMT signal integrity: similar PMTs should be single peaked, Gaussian in shape, and peak at the same time.

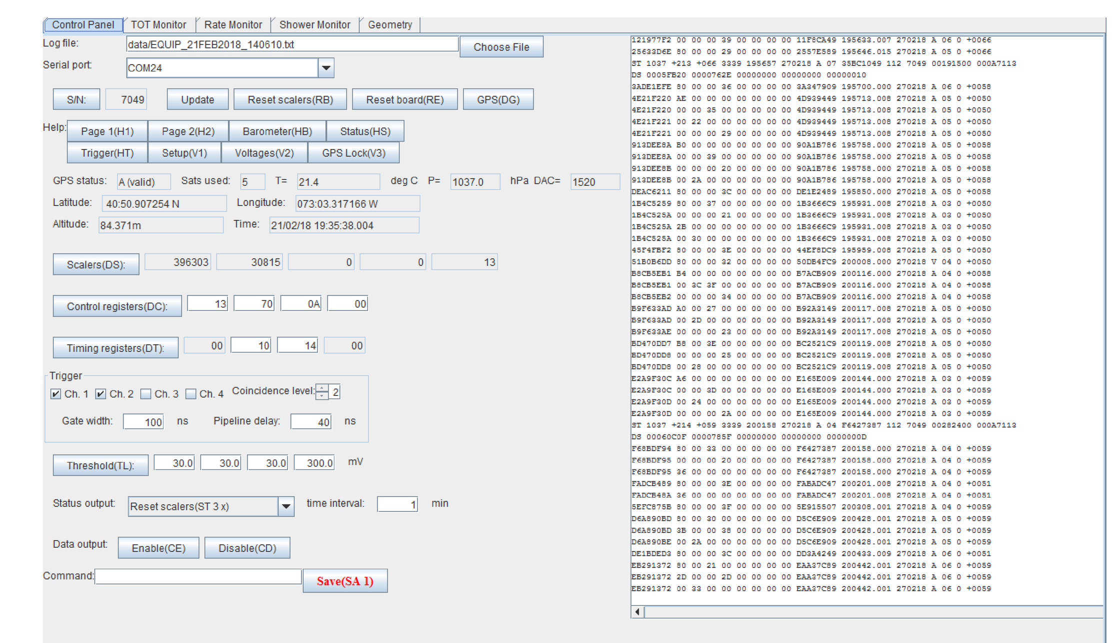


Fig. 12: QuarkNet "EQUIP" Data Acquisition Computer Interface
The detector data acquisition board (DAQ) is controlled from this graphics interface; the collected data is transferred to the computer and displayed here on the right. The data is listed in 16 columns providing information on the number of events each detector records, time per event, temperature and pressure information, and the number of GPS satellites picked up the GPS receiver. The controls on the left include information on which detector channels were used (here channels 1 and 2 were used), number of coincidences that were required to keep events (2 channel), time gate within which both detectors were required to make a detection (100 ns), and the signal amplitude threshold setting (30 mV).

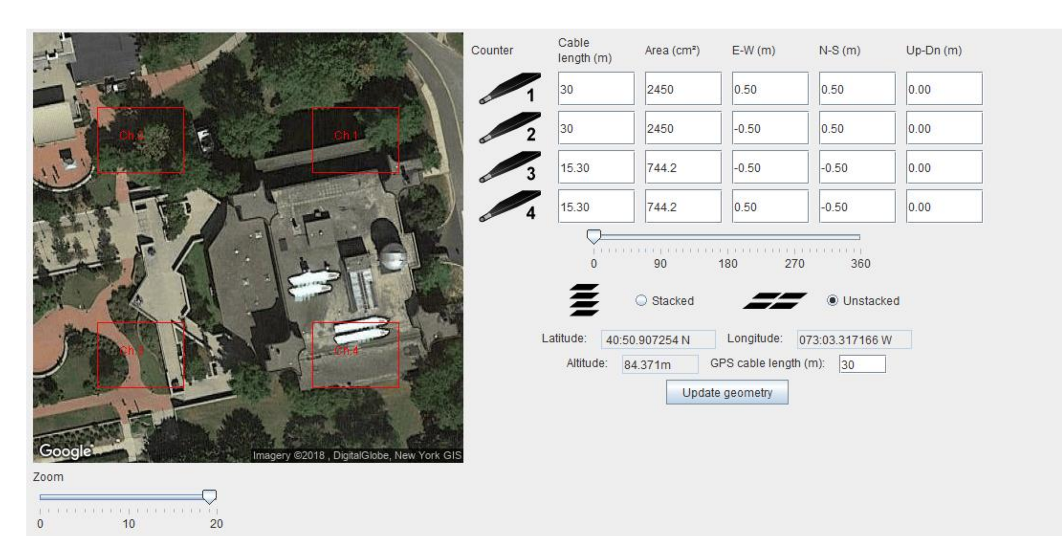


Fig. 13: EQUIP Data Acquisition Computer Interface
The detector data acquisition system is connected to a GPS antenna receiver system which pinpoints the location of the detector; shown here is the Suffolk County Community College, Ammerman campus, Physical Sciences building where the detector was located during data collection.

Results and Conclusions

The Quark Net data acquisition board was connected to MARIACHI cosmic ray detectors in the physical sciences department at the Ammerman campus of Suffolk County Community College. Three detectors were calibrated and coincidence measurements were made over the course of two weeks in February 2018.

The coincidence rate measured with the detectors is defined as the number of times per second both detectors output a signal within a small window of time, here 100 nano seconds was used as the time window. The coincidence rate is accepted as the rate of incident cosmic rays. The following two measurements were made:

1. Cosmic ray flux measured with two stacked detectors:
The coincidence rate was measured at 32 Hz; the actual rate is expected to be about 1 muon per cm^2 per minute. The scintillator panels used are 2,511 cm^2 thus the flux normalized to 1 cm^2 per minute is:

Flux = 32 Hz x (60 seconds/minute) / (2511 cm^2 per detector) = 0.8 muons per cm^2 per minute

2. Cosmic ray showers measured with the two detectors separated by about 3 meters:
The coincidence rate was measured at 0.06 Hz; this rate will be compared to the expected 3m shower rate in a future analysis.

References
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Acknowledgements
We would like to thank Professors Warasila, Breeden, and Schnal of the physical sciences department at the Suffolk County Community College; and Mr. Dave Hoppert, Ken Cecire, and Dr. Mark Adams from the QuarkNet program.