Cosmic Ray Muon Detector (CRMD) Program

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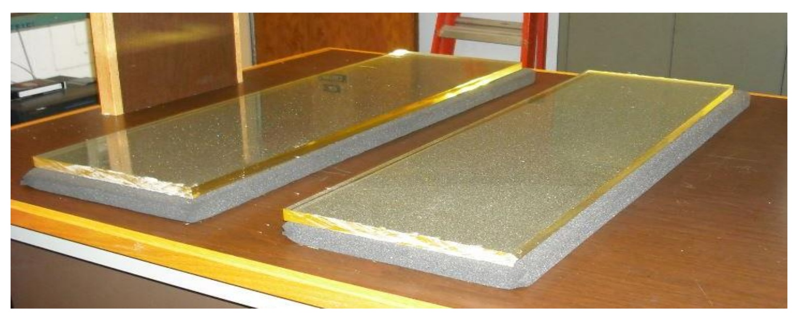
Introduction

A cosmic ray detector has been built by students for research in applied physics. Cosmic rays are high speed protons emitted from the sun, supernovae, and black hole regions and which travel great distances across the universe. When one of these protons collides with a nucleon in earth's atmosphere a shower of subatomic particles is created including charged muons which are detected by QCC cosmic ray detectors. The detectors are used in particle physics, astrophysics, atmospheric physics, and to study solar activity, lightning, and earth's magnetosphere.

Equipment

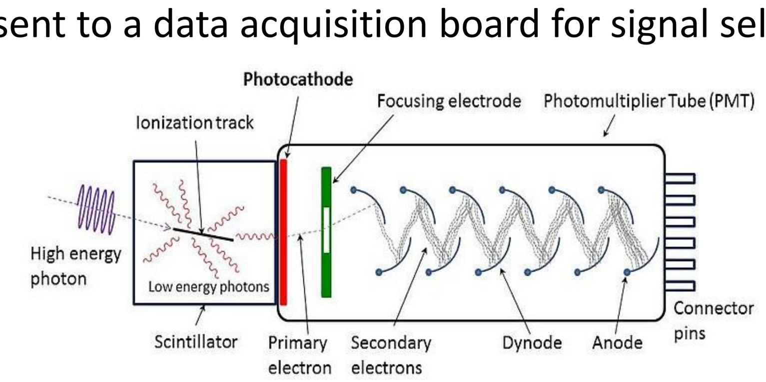
Fluorescent plastic scintillator doped with hydrocarbon molecules



Scintillator is made of PVT plastic doped with fluorescent hydrocarbon molecules. When a charged muon goes through the scintillator it ionizes plastic molecules causing them to emit photons of UV light. The hydrocarbons absorb UV and re-emit green light which is detected by a photomultiplier tube. The plastic is wrapped with foil to prevent loss of light and with black paper to prevent outside light from getting in.

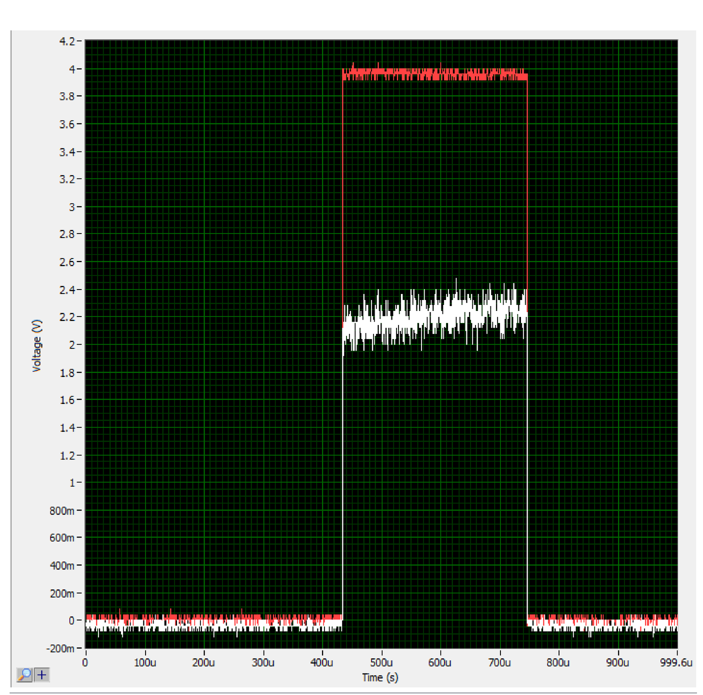
Photomultiplier Tubes (PMT)

A photomultiplier tube detects these very faint light flashes of light by transforming the light via the photoelectric effect into an electrical pulse which is sent to a data acquisition board for signal selection.

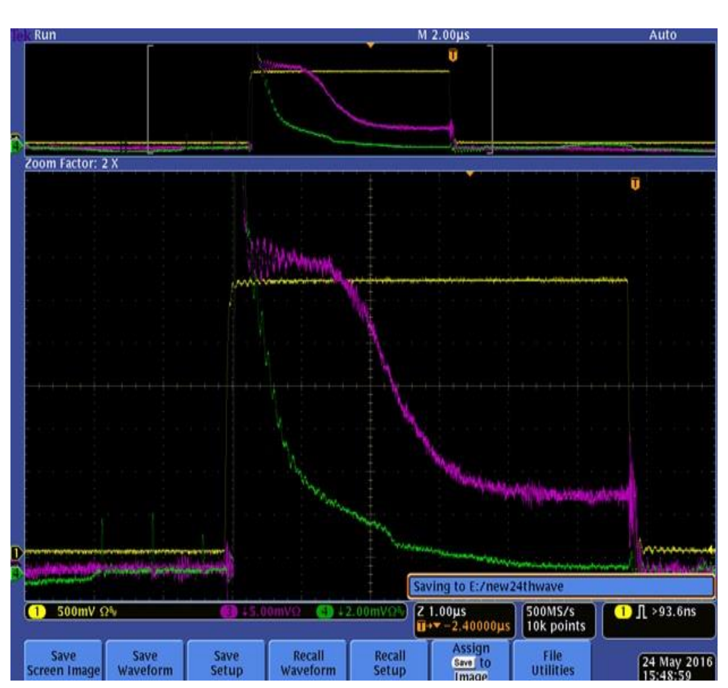


Qwerty123uiop. PhotoMultiplierTubeAndScintillator. 2013. JPEF file. https://commons.wikimedia.org/wiki/File:PhotoMultiplierTubeAndScintillator.jpg

The performance of a PMT can be checked by shining an LED light bulb in front of it and checking its response by measuring the current it puts out with an oscilloscope.

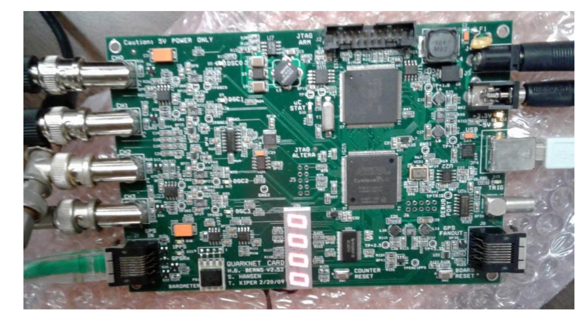


In the above oscilloscope traces the smoother red line represents the 300 micro seconds that an LED light bulb was on; the choppy white line represents the PMT response signal. Clearly the PMT detected the light for the entire time it was on. The PMT was a SensTech model used with QuarkNet cosmic ray detectors.



In the above oscilloscope traces the horizontal yellow line represents the 6 micro seconds that an LED light bulb was on. The purple line represents the response signal from one PMT and the green line the response from a different PMT. The PMTs are identicle ADIT models used in the MARIACHI array, and both have short pulse outputs; we are investigating if these PMTs are designed for pulses or if they are being saturated with too much light

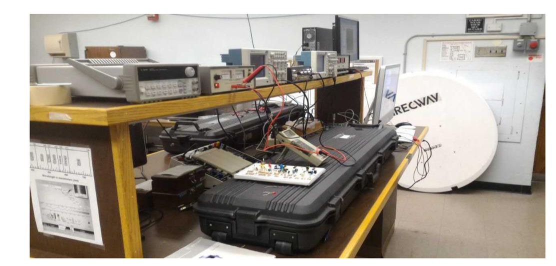
Setup



Data acquisition board (DAQ)

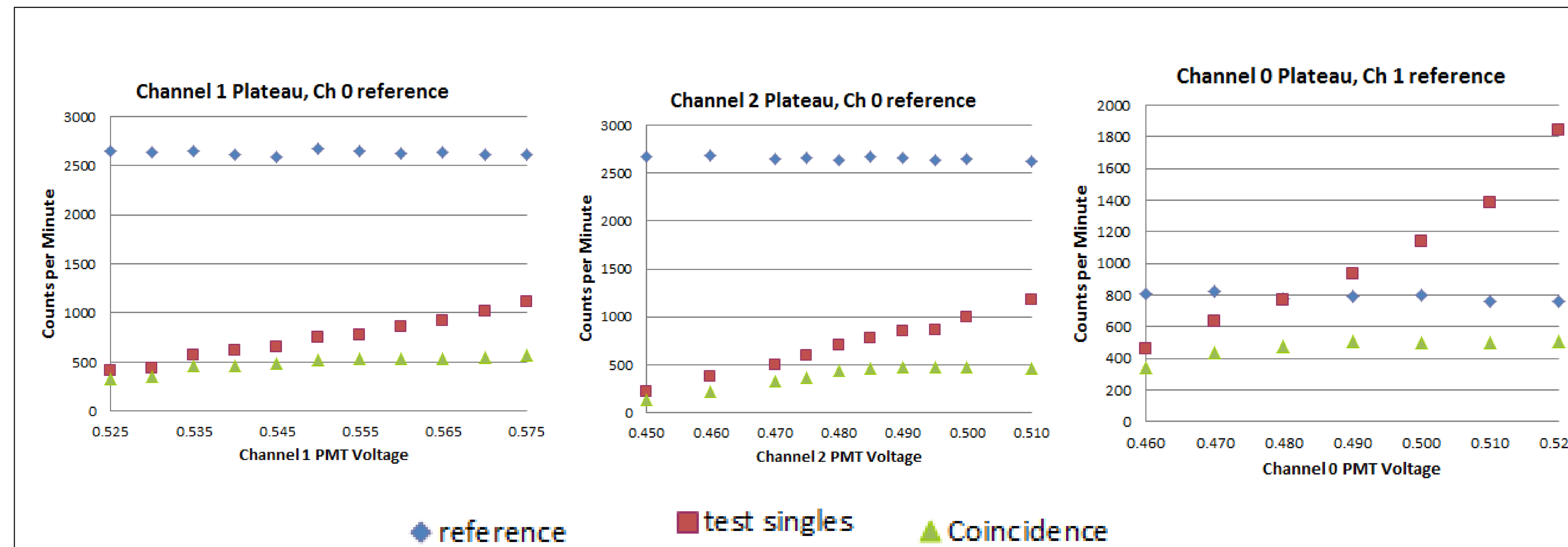
The DAQ records signals from the PMTs and determines if they satisfy criteria as cosmic rays before sending them to the computer.

Three QuarkNet scintillator detectors are shown wrapped in black, and the DAQ. The PMTs are within the white PVC tubes



The black enclosure houses a 1 meter long cosmic ray detector built by students in QCC's physics lab; the enclosure protects it from ambient light

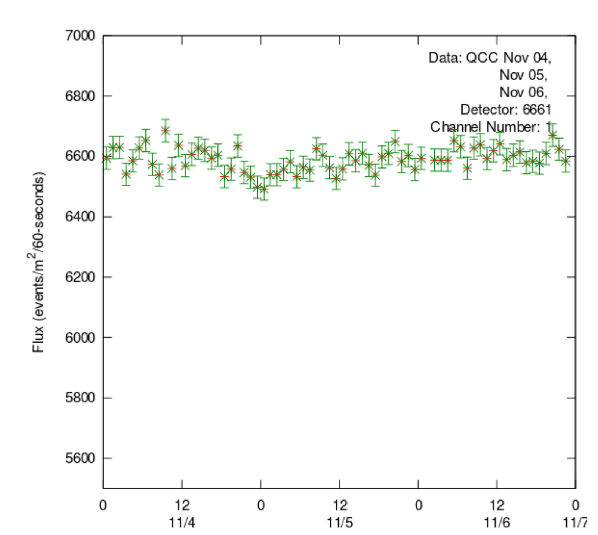
Photomultiplier tube calibrations (plateauing the PMTs)



PMTs are very sensitive and each operates at a slightly different voltage. It is critical to find their optimal operating voltages in a procedure called a "plateau calibration". In the procedure 3 scintillators detectors (each with its own PMT) were stacked one above the other such that any incident muon would go through all 3 detectors. One of the 3 PMTs was chosen as a reference and used to calibrate the other two. The goal is to find the operating voltages at which the number of muons in each detector is about the same over a given time period (shown as green triangles in the figures above)

Cosmic Rays Detected in the QCC Science Building

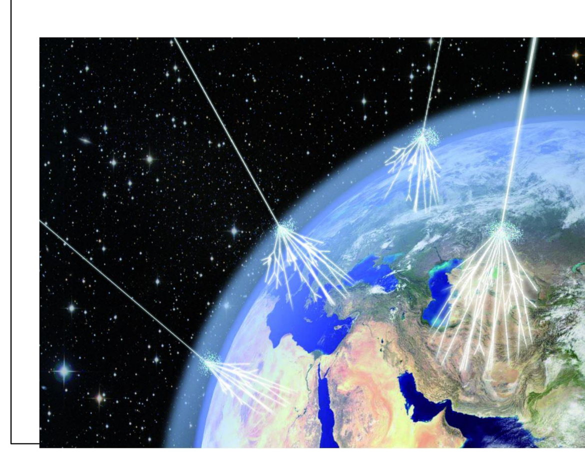
Flux study



In the figure to the left the cosmic ray flux is shown; the flux is the number of muons that hit each square meter of earth's surface per unit of time. Lots of topics can be investigated such as the relation between the flux and solar activity, angle from vertical, barometric pressure, altitude.

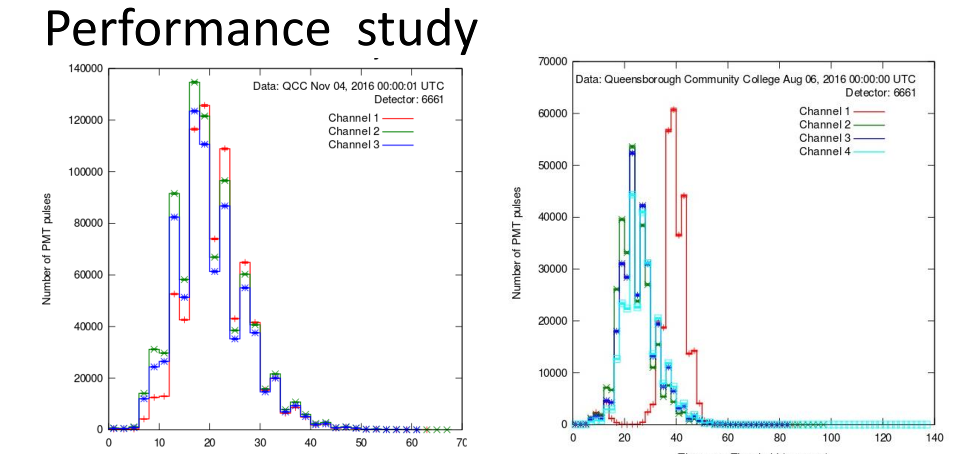
https://www.i2u2.org/elab/cosmic/teacher/

Artists rendition of a cosmic ray shower

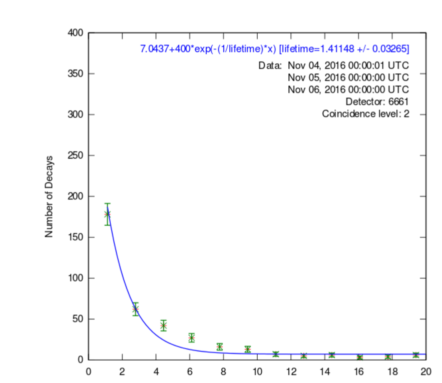


When a single proton with enormous energy hits a nucleon in the atmosphere it creates an air shower of subatomic particles. We can detect these showers with many detectors spaced apart. We are able to find out how large a shower is. With the QCC detectors collaborations have begun with other schools.

Performance study



The number of muons detected are compared across the detectors to check relative performance. If the PMTs are running properly the event counts should be similar.



Muon Life Time Study

When the cosmic ray proton collides in the upper atmosphere the muons created travel about 30,000m to earth, which takes about 100 micro seconds

$$t = \frac{d}{v} = \frac{30\times10^3 m}{3\times10^8 m/s} = 10^{-4} s = 100\mu s$$

Muons decay in 2.2 micro seconds producing an electron, neutrino, and anti-neutrino. However while traveling at high speeds towards earth the muon relativistically lives longer and as such can make it to earth's surface. In our lab the lifetime of the muon was measured at 1.4 micro seconds.

Acknowledgements

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References

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