

Cosmic Ray Detection

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Measuring Cosmic Ray Showers

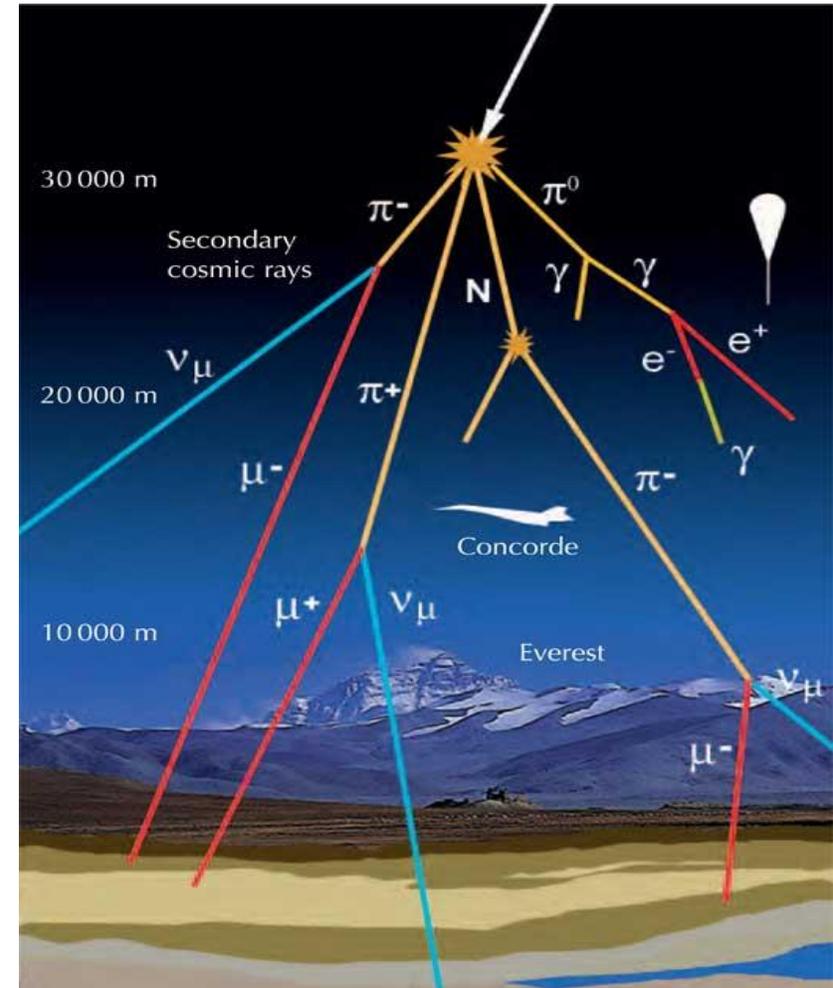
- Collect, analyze, and plot muon shower data.
- Measure muon showers with detector counters separated by 1m, 10m, 100m, and 1Km.
- Determine the shower rate for certain number of counters per DAQ
- Determine shower rate as a function of gate width and as a function of separation distance between counters.

The screenshot shows a software control panel with the following sections:

- Control Panel** (selected tab): Includes fields for log file ("Histograms of time-over-threshold.txt"), serial port ("COM24"), S/N ("7049"), and buttons for "Update", "Reset scalers(RB)", "Reset board(RE)", and "GPS(DG)".
- Help:** Includes buttons for "Page 1(H1)", "Page 2(H2)", "Barometer(HB)", "Status(HS)", "Trigger(HT)", "Setup(V1)", "Voltages(V2)", and "GPS Lock(V3)".
- GPS status:** Shows "A (valid)", "Sats used: 6", "T= 21.2 deg C", "P= 1031.0 hPa", and "DAC= 1520".
- Location:** Latitude: "40:50.904733 N", Longitude: "073:03.334196 W", Altitude: "112.914m", Time: "15/03/18 16:14:38.001".
- Scalers(DS):** Four input fields with values "109589", "0", "0", "401582", and "733".
- Control registers(DC):** Four input fields with values "19", "70", "0A", "00".
- Timing registers(DT):** Four input fields with values "00", "00", "04", "00".
- Trigger:** Includes checkboxes for "Ch. 1", "Ch. 2", "Ch. 3", and "Ch. 4" (checked), "Coincidence level: 2", "Gate width: 100 ns", and "Pipeline delay: 40 ns".
- Threshold(TL):** Four input fields with values "300.0", "300.0", "300.0", "300.0" mV.
- Status output:** A dropdown menu set to "Reset scalers(ST 3 x)" and a "time interval: 5 min" field.
- Data output:** Buttons for "Enable(CE)" and "Disable(CD)".

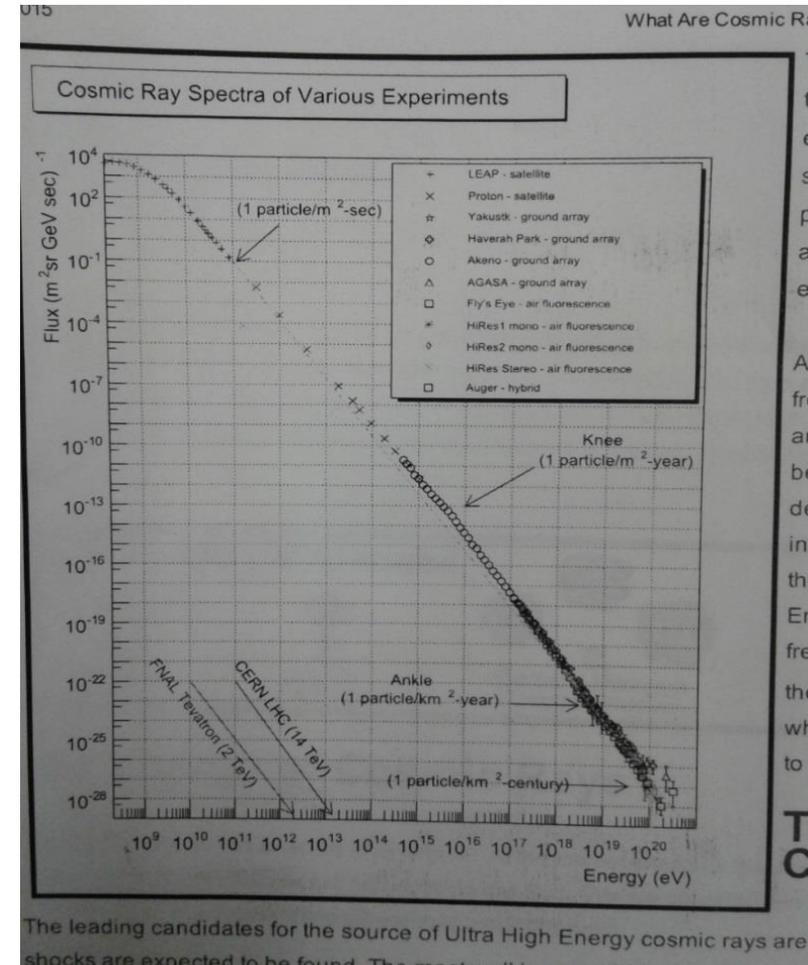
Cosmic Ray Showers

- Primary cosmic ray hits earth's atmosphere and collides with protons and other heavy elements.
- Primary ray decomposes into secondary particles such as neutrinos, pions, muons.
- Muons reach the ground due to time dilation, and are detected by plastic scintillator.



Various Experiments

- X-axis = Energy Level of Cosmic Ray Primaries (eV)
- Y-axis = Flux Rate of Cosmic Ray Primaries scaled to $(m^2 sr GeV sec)^{-1}$
- Primary flux rates of various energies.
- How many primaries enter the atmosphere of certain energy levels
- Some of these particles have an energy level of 10^{20} eV.
- What could cause these particles to accelerate with such energy?



Primaries Entering Earth's Atmosphere

- Multiply the energy of the primary cosmic ray by the rate of flux
- Divide this number by 10^9 to convert this number to eV
- In variable form, this equation looks like:
- $(\text{Energy Level})(\text{Flux})(10^{-9}) = \text{Hits} \cdot m^2 \cdot s$
- Flux depends on solar wind, earth's magnetic field, and the energy of the primary cosmic ray.
- Flux is also dependent on latitude, longitude, and azimuth angle.

Particle energy (eV)	Particle rate ($m^{-2}s^{-1}$)
1×10^9 (GeV)	1×10^4
1×10^{12} (TeV)	1
1×10^{16} (10 PeV)	1×10^{-7} (a few times a year)
1×10^{20} (100 EeV)	1×10^{-15} (once a century)

Primary Ray Flux Rate Comparison

- $(10^{14} \text{ eV}) \left(\frac{10^{-9}}{\text{GEV} \cdot \text{m}^2 \cdot \text{s}} \right) \left(\frac{1 \text{ GEV}}{10^9 \text{ eV}} \right) = 10^{-4} \cdot \text{m}^2 \cdot \text{s}$
- $(10^{18} \text{ eV}) \left(\frac{10^{-21}}{\text{GEV} \cdot \text{m}^2 \cdot \text{s}} \right) \left(\frac{1 \text{ GEV}}{10^9 \text{ eV}} \right) = 10^{-12} \cdot \text{m}^2 \cdot \text{s}$

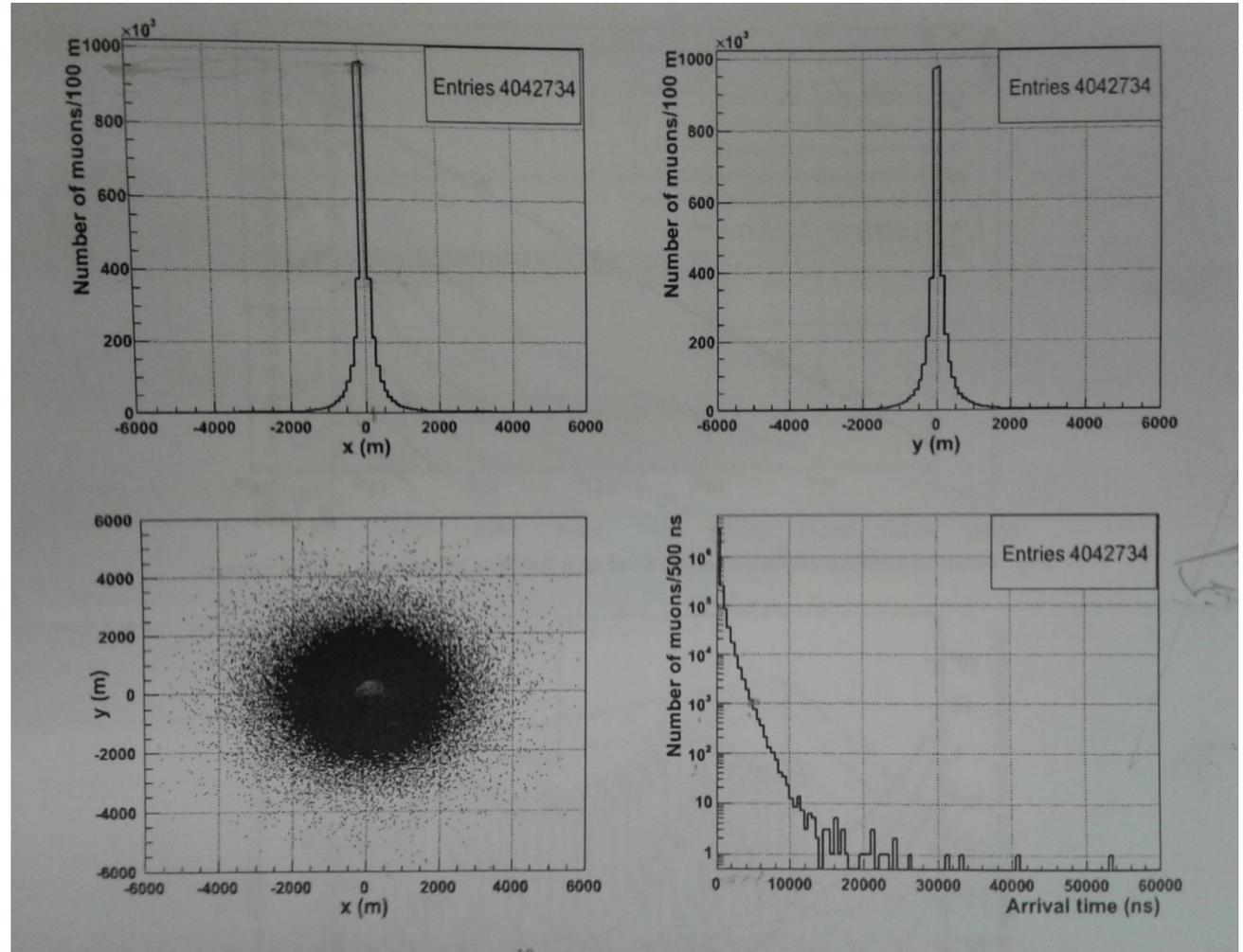
*** $(10^{-4} \text{ m}^2 \cdot \text{s}) (3.154 \times 10^7 \text{ s}) = 3154 \text{ particles/m}^2/\text{year}$**

*** $(10^{-12} \text{ m}^2 \cdot \text{s}) (3.154 \times 10^7 \text{ s})(1000 \text{ m})^2 = 31.54 \text{ particles/Km}^2/\text{Year}$**

- **This is a hundred times less particles, in an area of sky a million times bigger.**
- **Particles of energy levels of 10^{20} eV or higher are seen about once per square meter per century.**

Muon Showers at ground level

- 90% of muons hit the ground less than 2000ns after collision
- For a 10^{18} eV Primary Cosmic Ray all muons fall in a radius of 6km of the core impact
- Particles are distributed as a function of distance from the core.
- The energy level of primary cosmic rays is proportional to the diameter of the pancake of muons.



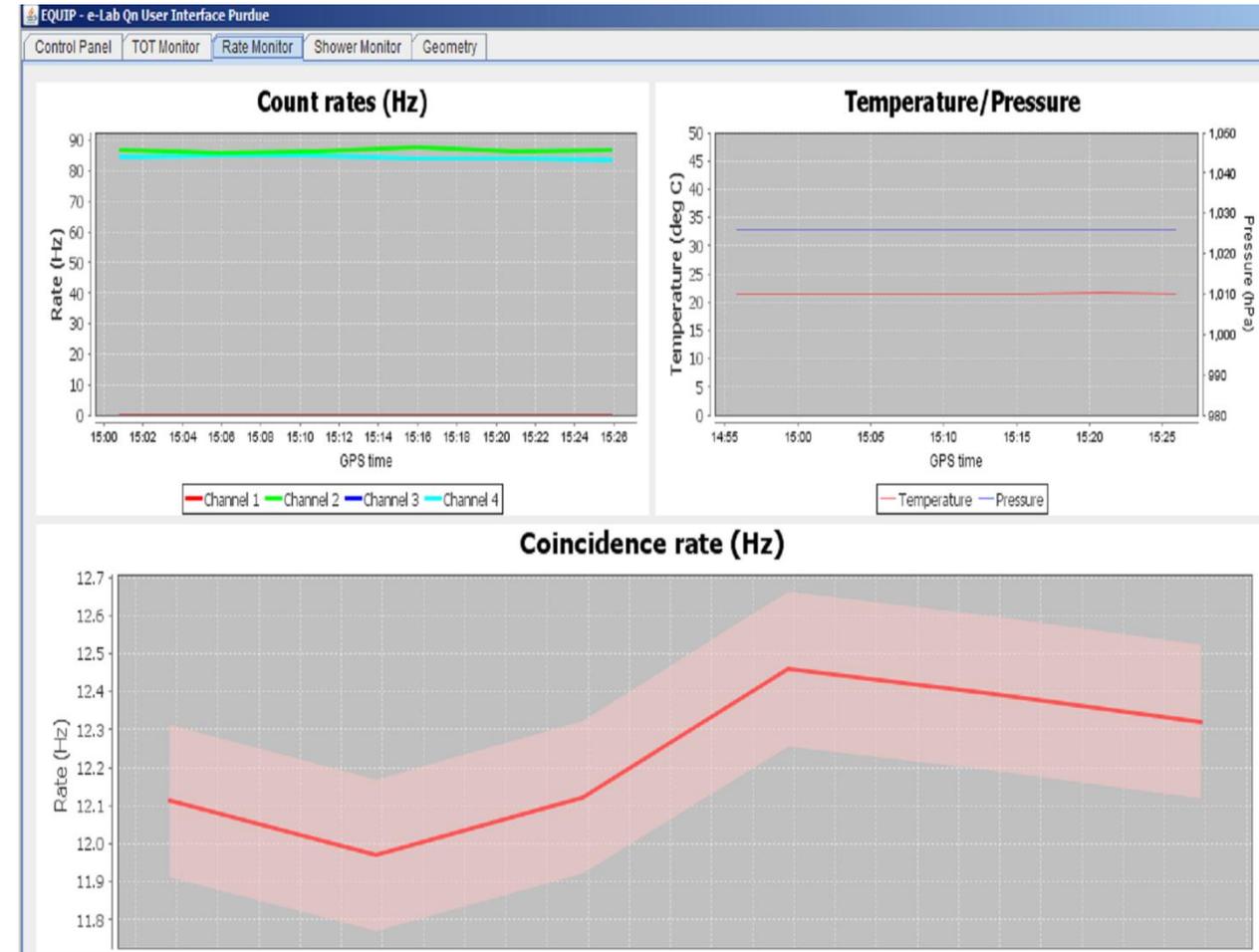
Muon Flux Rate

- Muons lose energy as they travel through earth's atmosphere.
- The accepted flux rate at sea level is 1 muon per square cm per minute.
- To calculate the flux of our counters; calculate the area of the counter and divide by 60
- This is the flux rate of the counter in hertz.



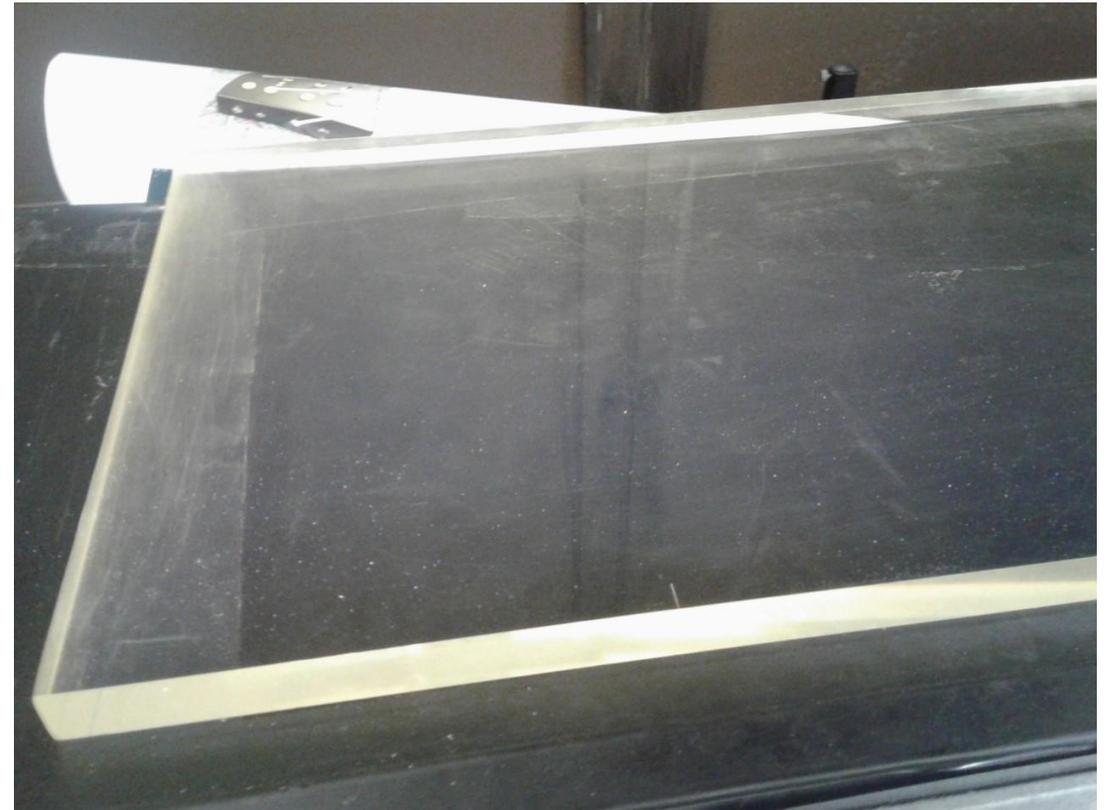
Detector Efficiency

- How do we verify our counters are running properly?
- With two counters stacked on top of each other, most noise is eliminated.
- If our counters have an area of 750 square cm what is the expected coincident rate?
- $750\text{cm}^2/60\text{s} = 12.5\text{ Hz}$



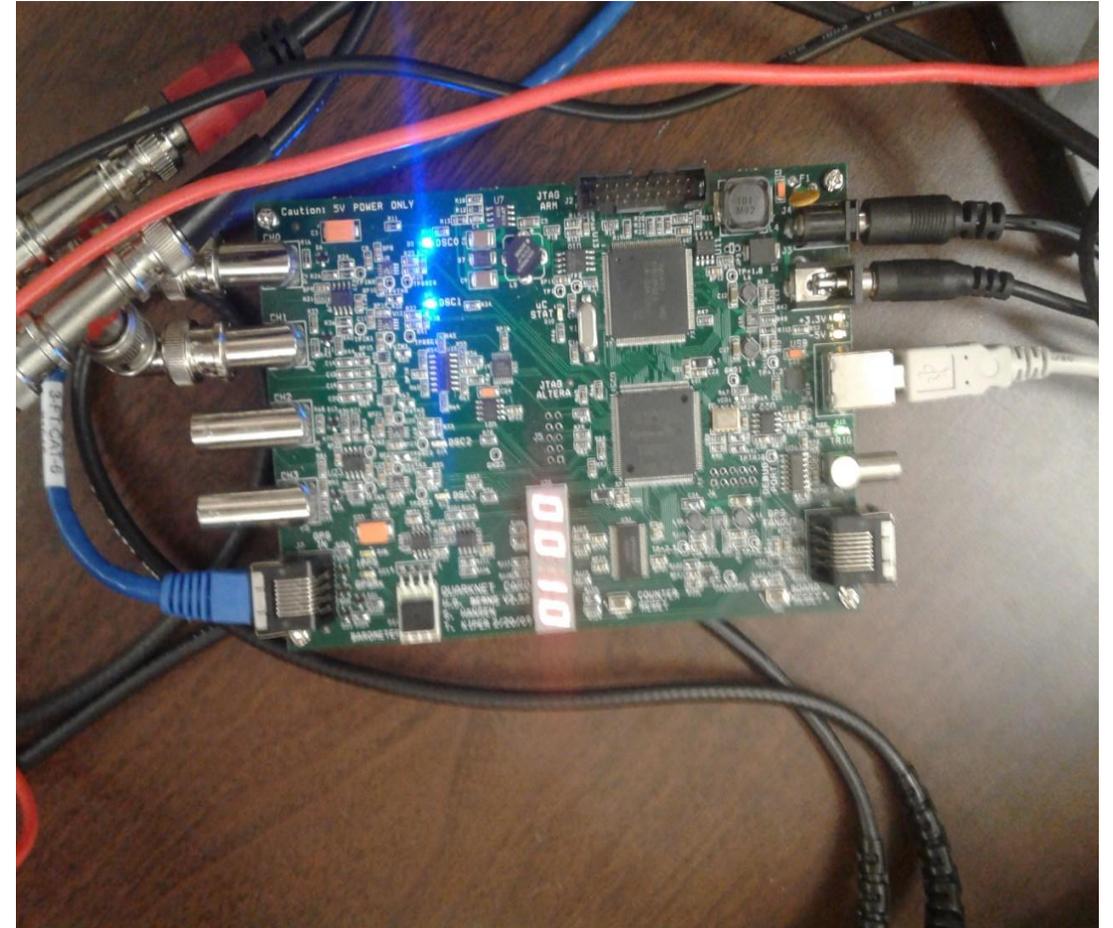
Plastic Scintillator

- Muons hit plastic scintillator which absorbs the energy and emits light.
- This light pulse is picked up and amplified by a photomultiplier tube (PMT).
- Pulse then gets sent to the DAQ board through signal cables and is binned as a function of signal duration above a user set threshold.



Data Acquisition Board (DAQ)

- If Pulse does not meet threshold it is disregarded by a discriminator.
- DAQ Board operates at a frequency of 25Mhz (25,000,000 Hz).
- Can operate with up to four separate counters.
- DAQ uses at least 5 satellites to verify data and timing information.



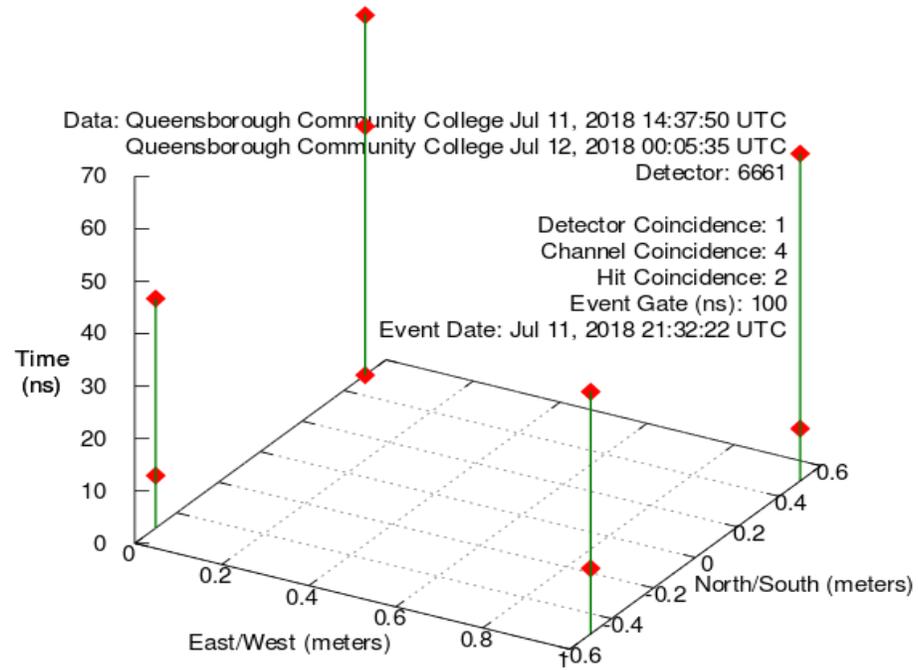
Data Analysis

- DAQ outputs data in hexadecimal format.
- Data files contain 16 “words” on each line.
- Hexadecimal data is converted to decimal and binary then interpreted.
- To calculate the absolute time an “event” occurred, the following formula is used:
- $(Ksec + Pmsec/1000) + (A-J/25Mhz) = Time$

```
EQUIP_5JUN2018_152220 - Notepad
File Edit Format View Help
66C73269 B5 00 00 00 00 00 00 00 00 655E7F6B 041921.013 060618 A 08 0 +0056
66C73269 00 00 39 00 00 00 00 00 00 655E7F6B 041921.013 060618 A 08 0 +0056
66C7326A 00 29 00 2C 00 00 00 00 00 655E7F6B 041921.013 060618 A 08 0 +0056
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66C7326A 00 38 00 00 00 00 00 00 00 655E7F6B 041921.013 060618 A 08 0 +0056
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E96DDA8E 00 00 00 2A 00 00 00 00 00 E87FD56B 042049.013 060618 A 08 0 +0056
```

First Study

Shower Study



- Shower Rate for this set up is approximately 3 per hour or ~ 0.001 Hz

Second Study

- Added a second DAQ and GPS.
- Could not find any showers.
- Timing information errors?
- GPS receiver may have to be in clear view of sky and connected to a specific number of satellites.



Recent Study

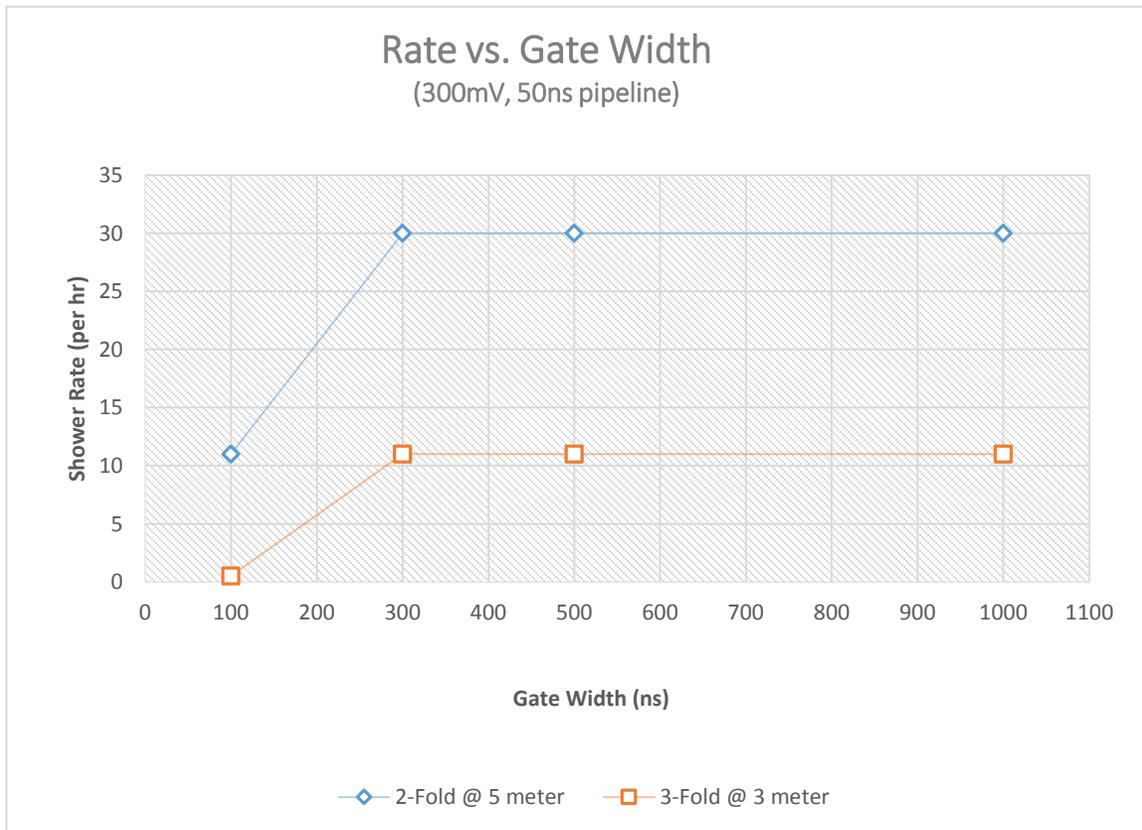
Three-Fold ~20 per hour

Four-Fold ~4-13 per hour

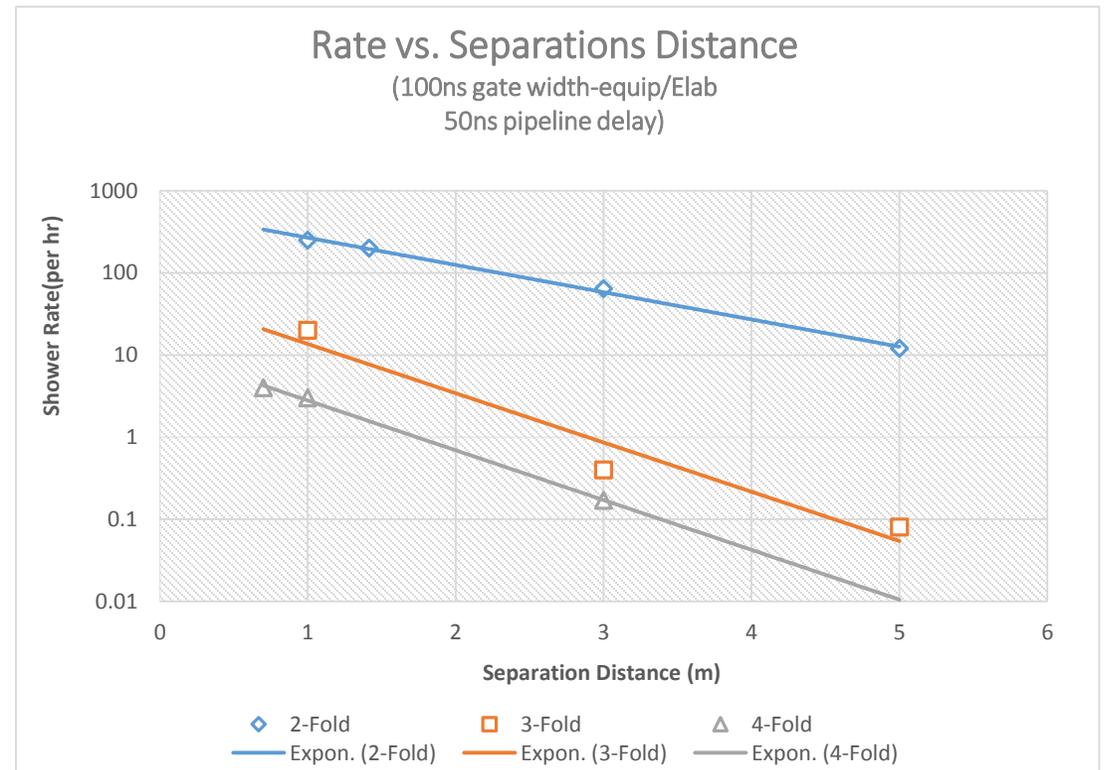


Results

Rate vs. Gate Width

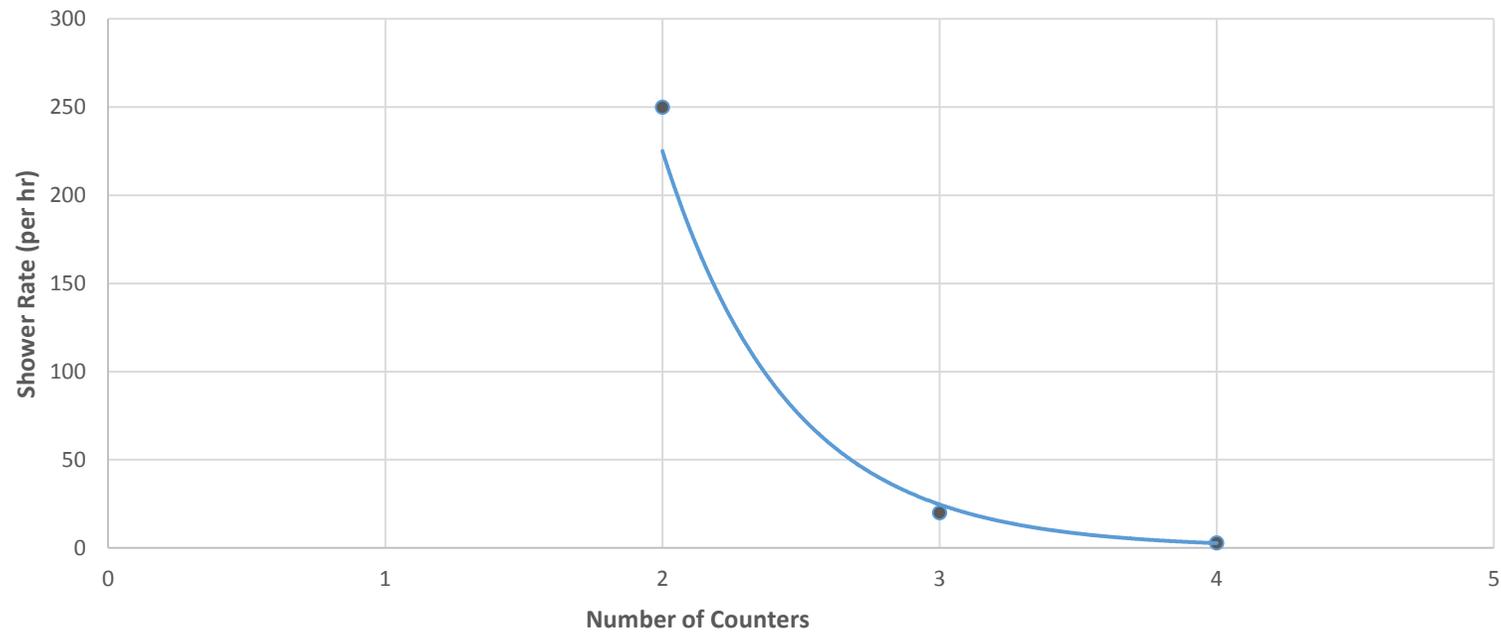


Rate vs. Separation



Results Cont.

Rate vs. Number of Counters (1DAQ @ 1meter)
(100ns gate, 50ns pipeline, 300mV)



Acknowledgements

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- The REU program and all the professors at QCC that contributed to this project.