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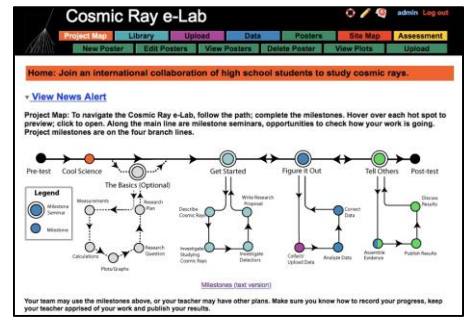
Cosmic Ray Studies II
QuarkNet Student Investigations



DAQ **Detector** **e-Lab**

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Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science | QuarkNet

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Global Cosmic Ray Effort

Outline

- QuarkNet detectors around the world
- e-Lab data analysis tools
- Examples of experiments
- Shared data format for all outreach efforts
- Proposal for global cosmic ray Measurements with and without a shared data format

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QuarkNet Data

Data Tab

Flux – Rate versus time

Shower – Correlate events from different DAQs.

Lifetime – Muon Lifetime

Time of Flight – Relative time between counters: speed of muon

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Data Analysis Flow

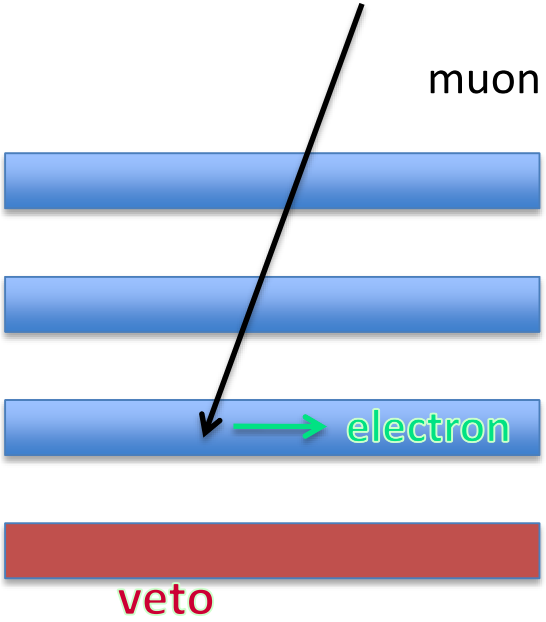
- Take data with cosmic ray detector.
- Define geometry of setup.
- Upload data.

- - - - -

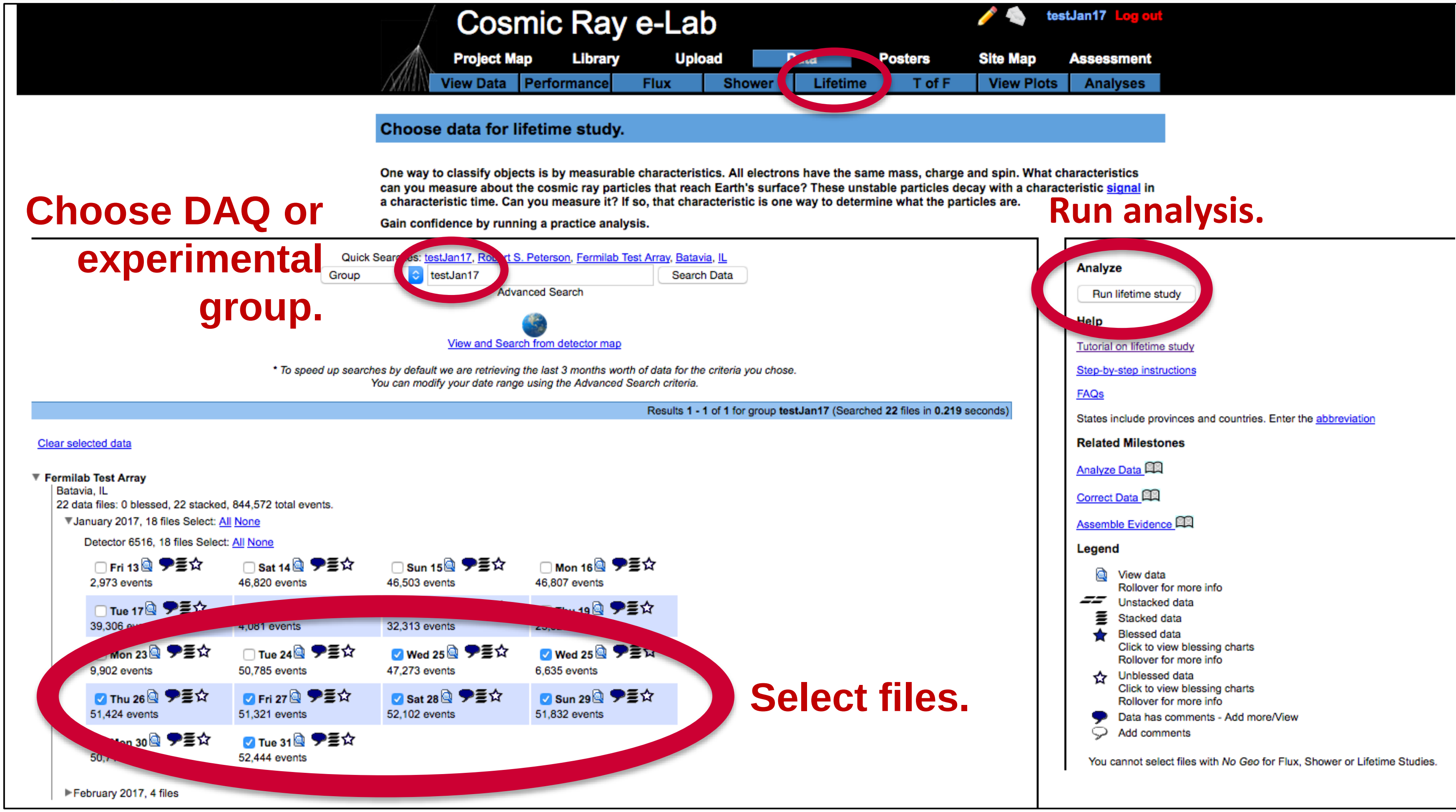
- Select data.
- Run an analysis.
- Save plots.
- Make poster.

Muon Lifetime

- Stack four counters.
- Program DAQ: Require three top counters to fire and veto on bottom counter.
- Record data for one week.
- Upload data file to e-Lab.
- Select data file and run "lifetime" analysis to find time between muon and next signal (electron).



Select Data



Choose DAQ or experimental group.

Run analysis.

Select files.

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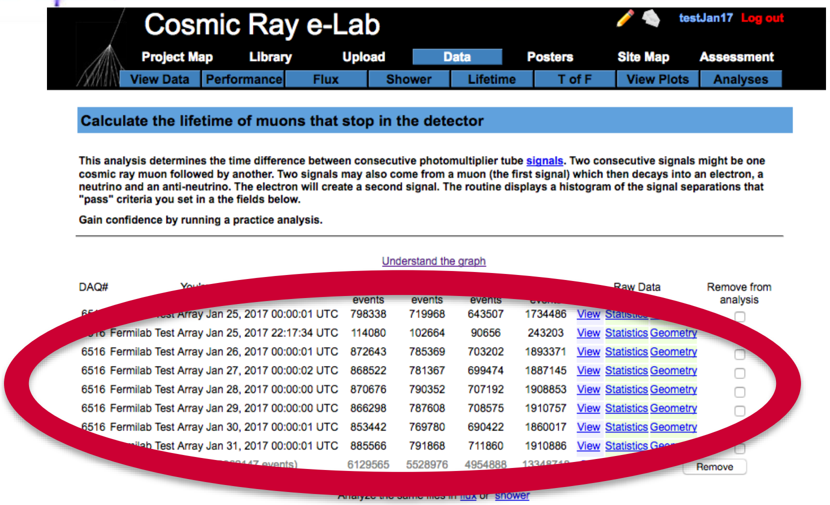
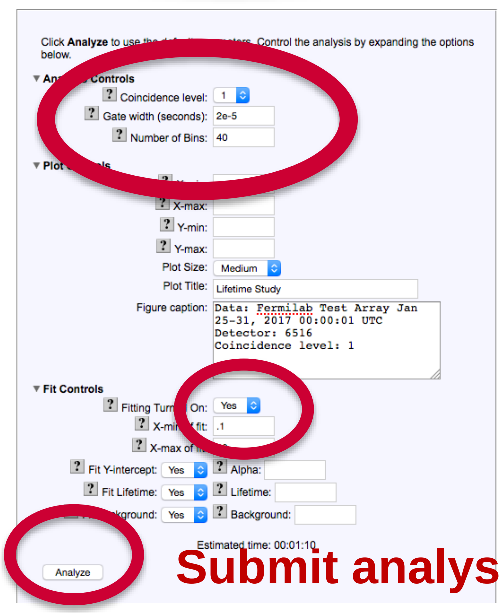
Analysis Controls



List of files selected



Controls:

Coincidence requirement for electron

Time range of plot

Number of bins

Enable fitting.

Submit analysis.

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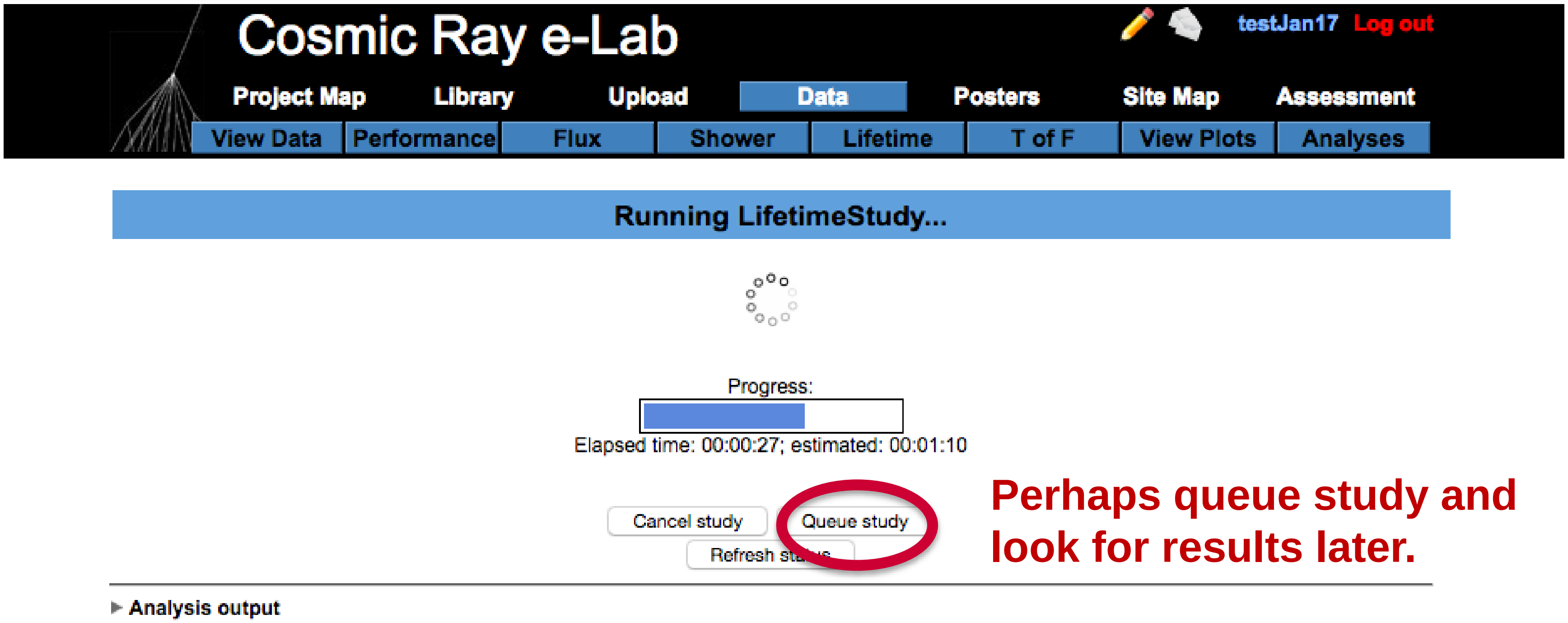
Analysis Running



Perhaps queue study and look for results later.

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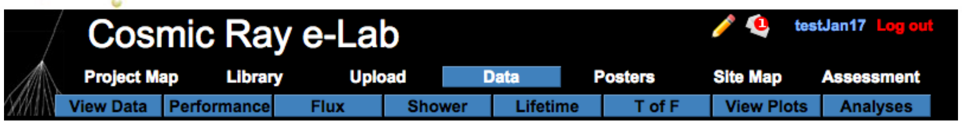
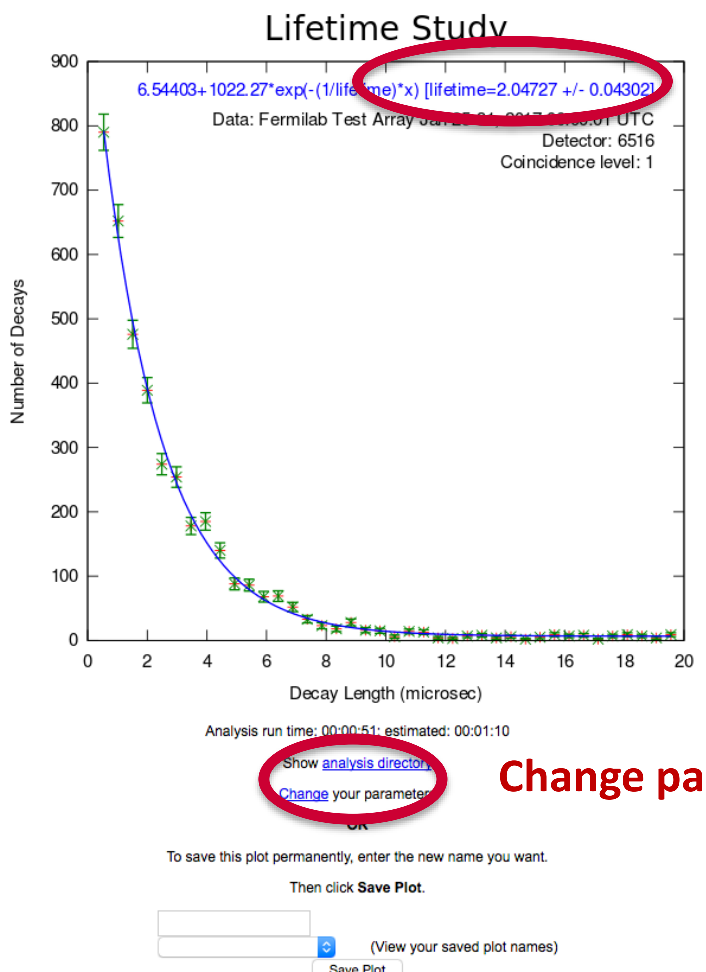
Muon Lifetime Result





3500 muon decays in 7 days

(~1 decay every 1000 muons)

Lifetime 2.05 +- 0.04 microseconds

Random background 6.5 events per 500 ns bin

Change parameters and run again.

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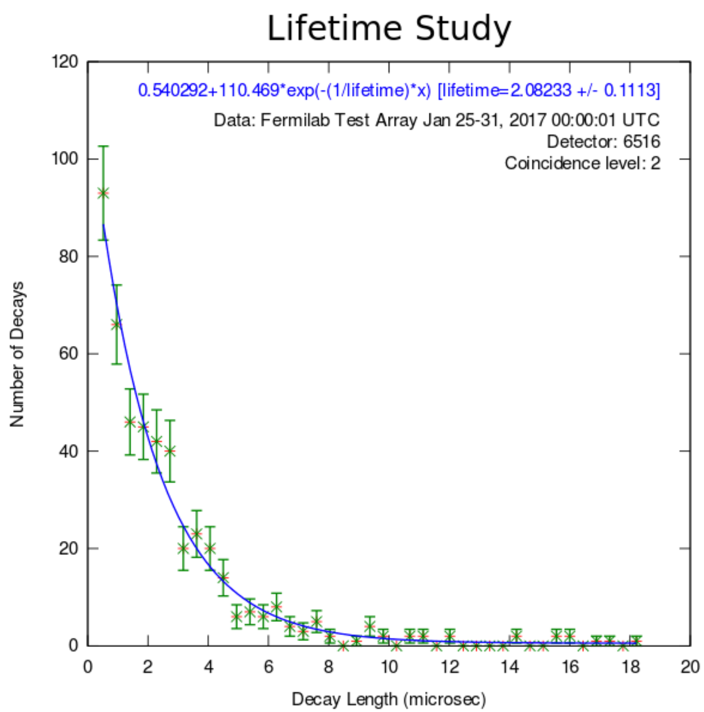
Muon Lifetime Rerun

Coincidence = 2



Analysis run time: 00:00:44; estimated: 00:01:10

Show analysis directory

Change your parameters

OR

To save this plot permanently, enter the new name you want.

Then click **Save Plot**.

(View your saved plot names)

350 muon decays in 7 days

2 hits for electron

Lifetime 2.08 +- 0.11 microseconds

Random background 0.54 events per 500 ns bin

Slightly better signal to noise

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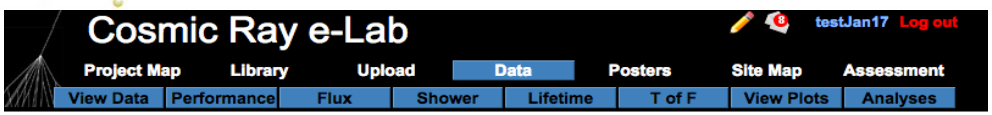
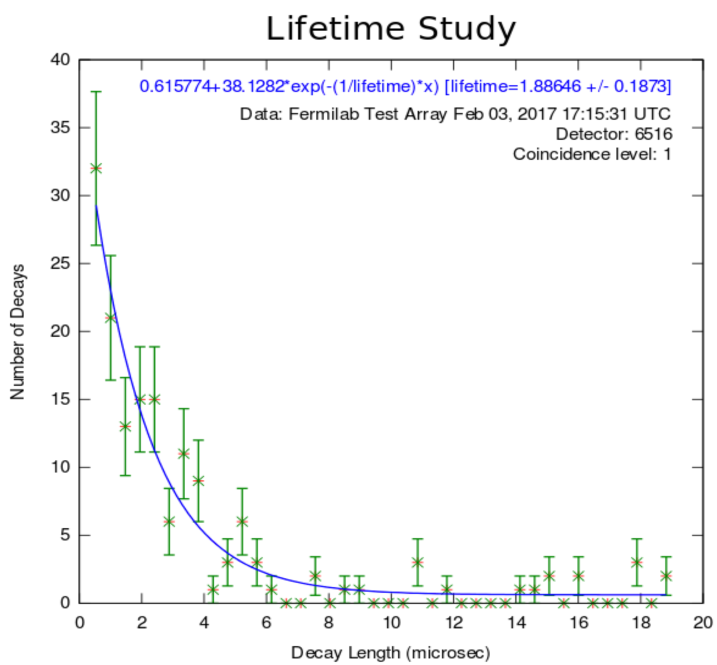
Lifetime without Veto





Short Test without Veto

140 muon decays in 2.5 hrs.

Lifetime 1.9 +- 0.19 microseconds

Random background 0.6 events per 500 ns bin

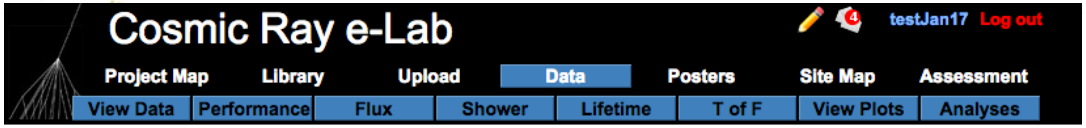
Background is larger:

Without veto – 140 decays with 12 background

With veto – 3500 decays with 130 background

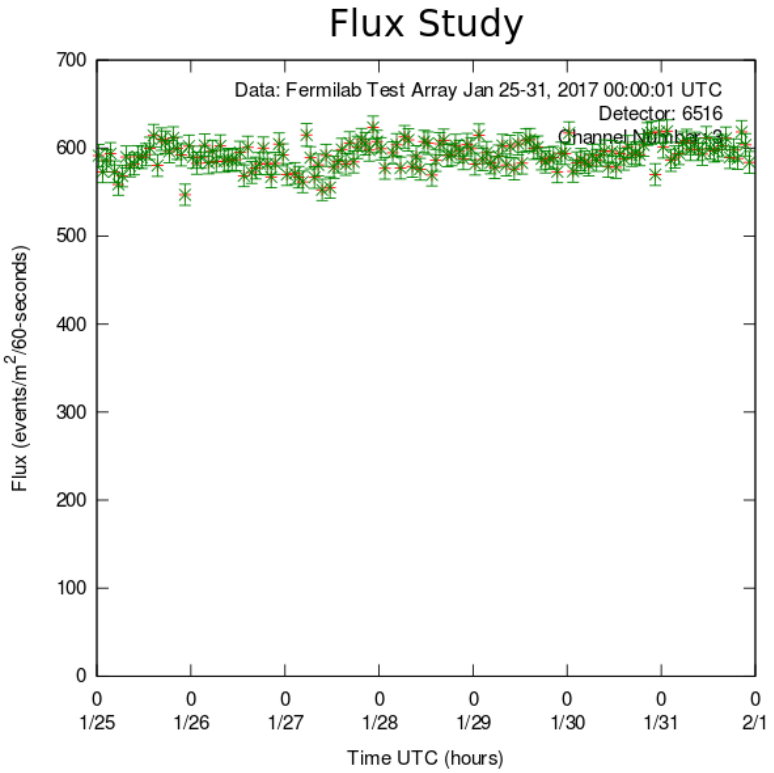
Signal/Noise: 27 (11) with (without) veto

Run Flux on Same Data



View blessing plots

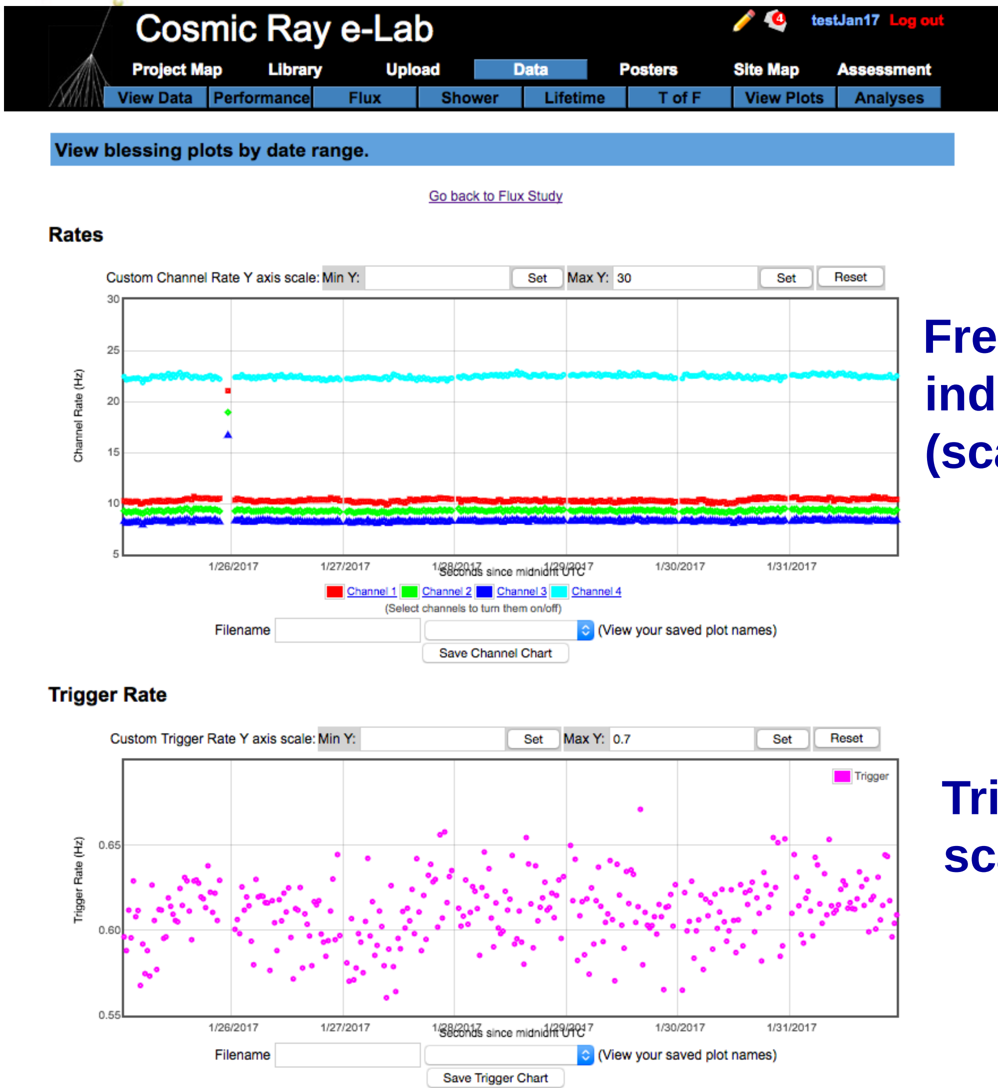
View interactive Flux plots (Beta Version)



Rate versus time over 7 days

Verify that data collection looks normal.

Check Blessing Plots



Quality of Data Measures plus temperature and pressure information

Frequency of individual counters independent of triggered events (scalers)

Trigger rate versus time from scalers

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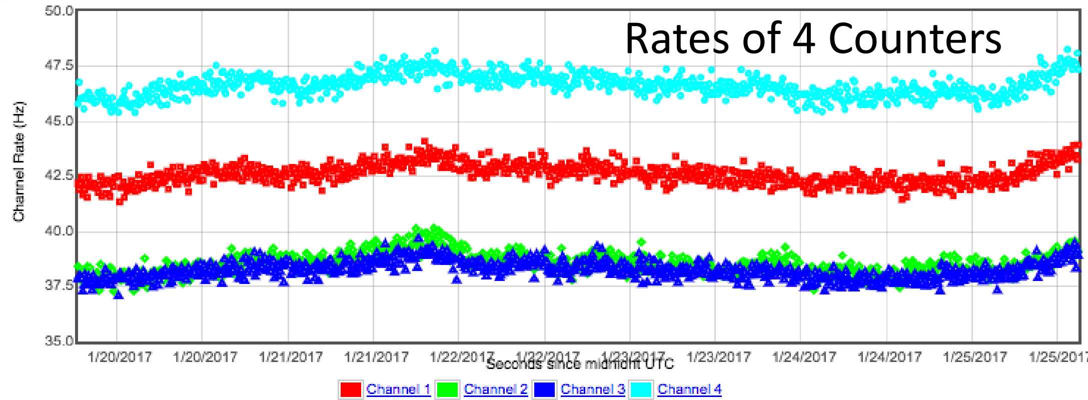
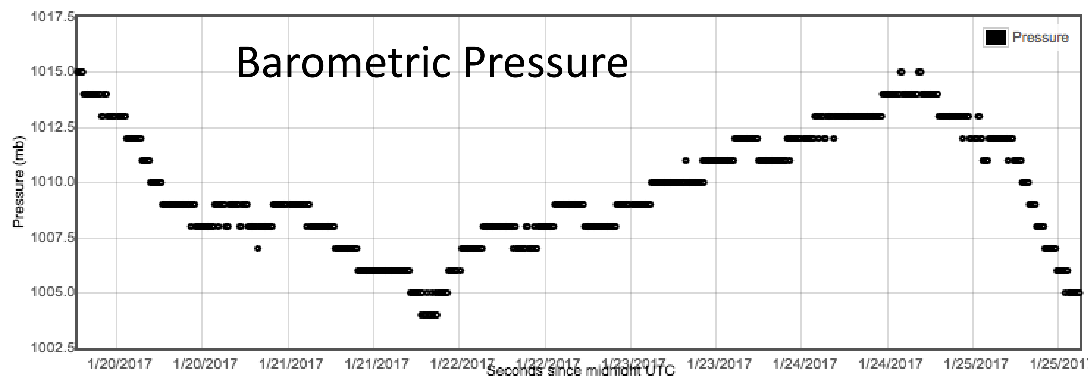
Rate vs. Pressure

Counter rates versus time inversely proportional to pressure



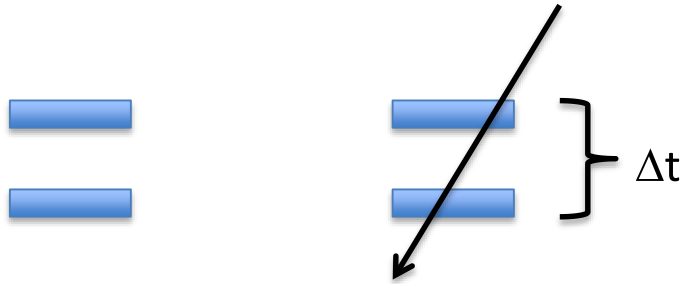
After correcting for barometric pressure, students can also study dependences on temperature, day/night—maybe latitude in future.



Time-of-Flight Analysis

Use TOF tool to get relative timing information between counters.

Vary distance between counters in two data runs to extract the average muon speed from the means of the timing distributions.



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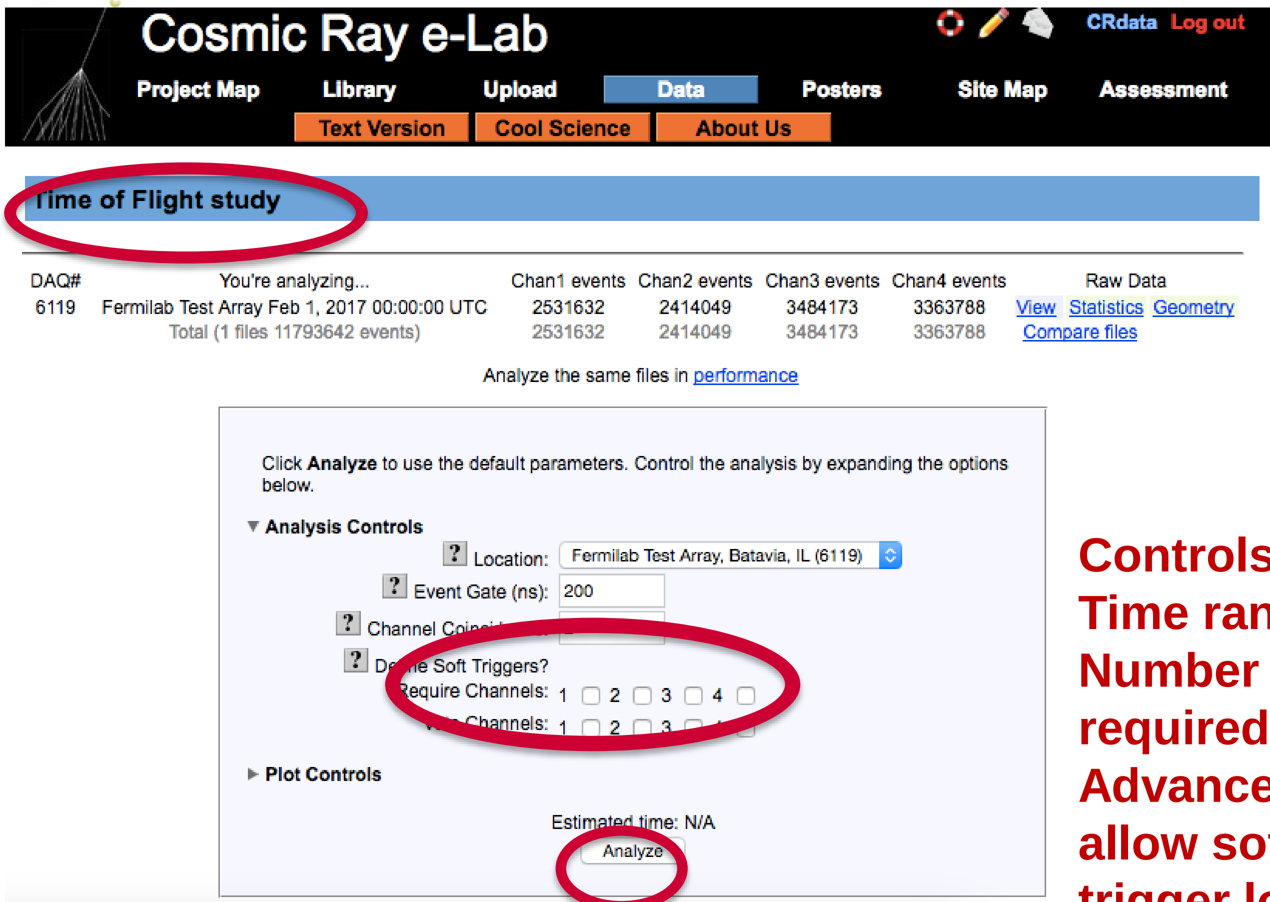
Time of Flight



Measure the average muon speed.

Get relative time between all pairs of counters.

Controls:
Time range to plot
Number of counters required
Advanced controls allow software trigger logic.

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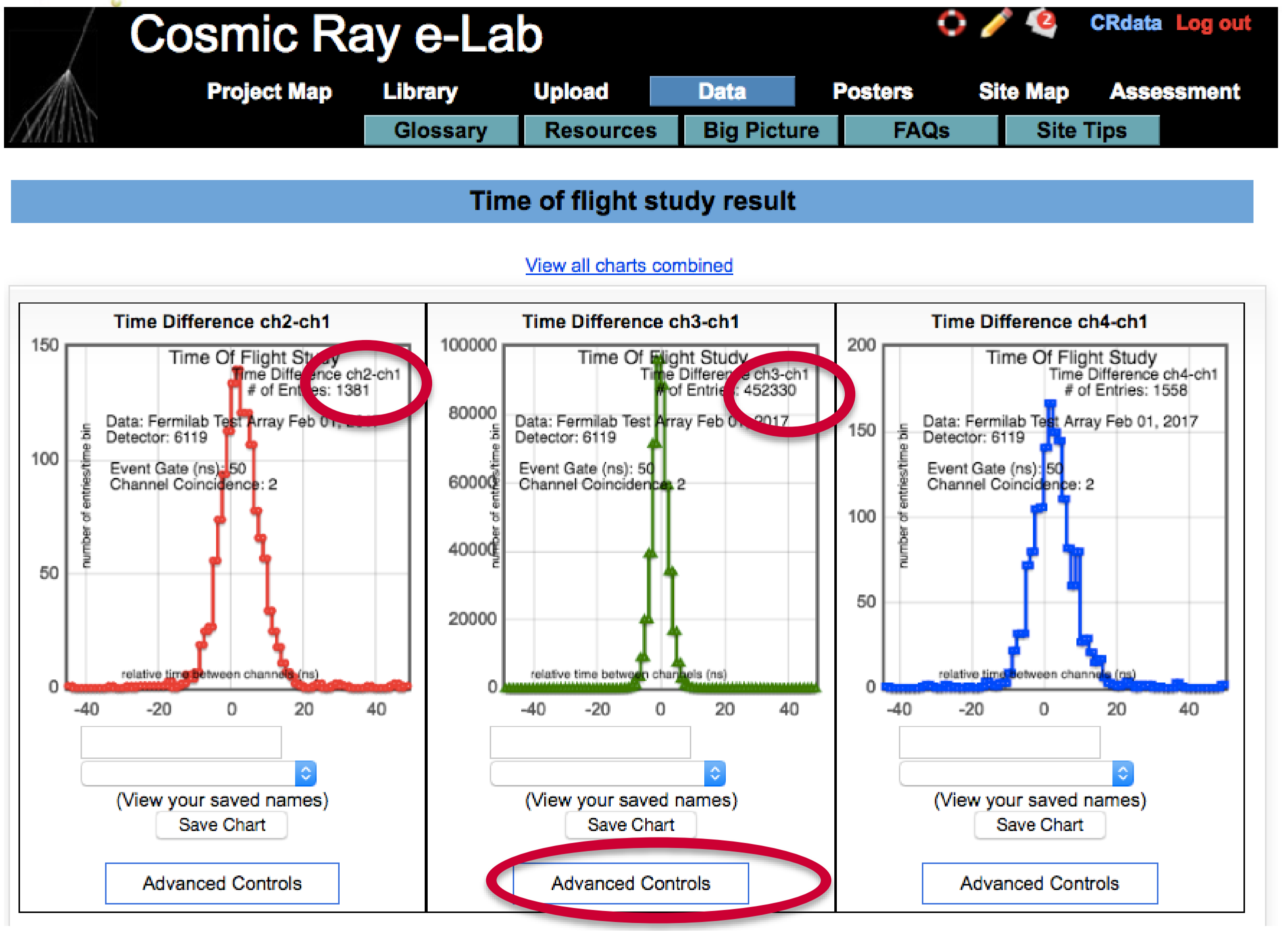
Time-of-Flight Results



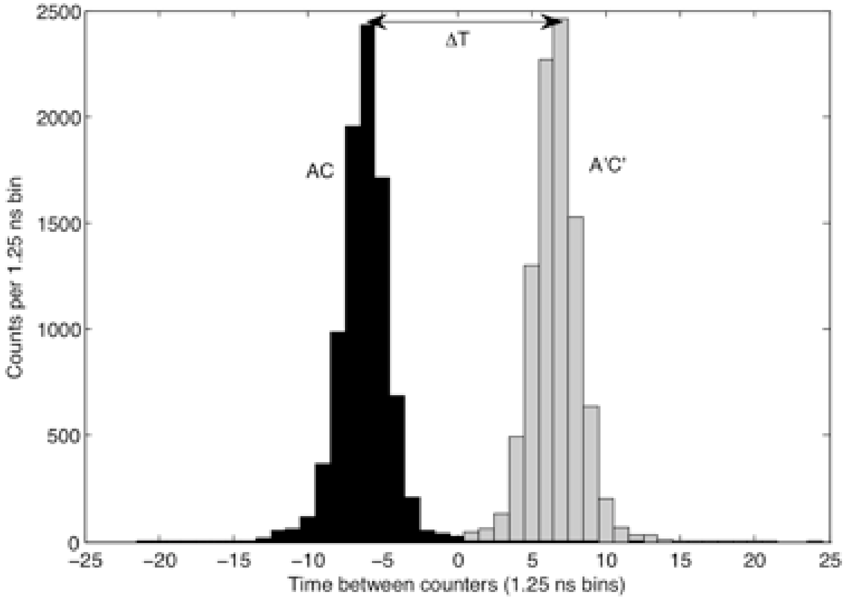
6 plots of time between counters i and j

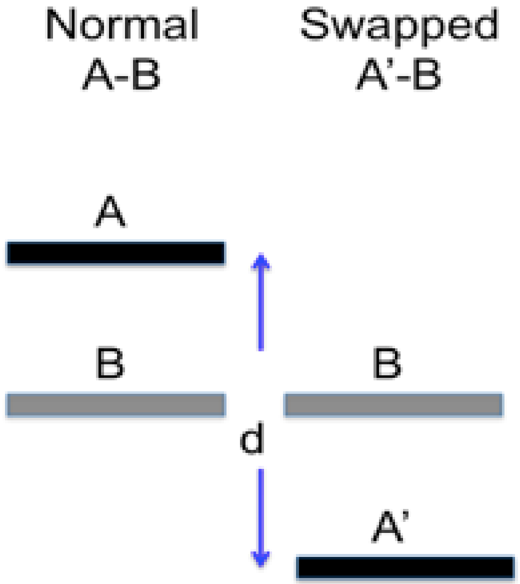
Note number of events:
Two stacks
1 over 3 and
2 over 4

Advanced controls provide fit results.

Speed

Glenbrook South High School students published a 1% measurement of the muons' average speed = d/ΔT from two configurations.





Shower e-Lab Tool

Shower enables user to search for coincidences in time in different DAQ readouts.

This can find very large showers in detectors separated by large distances or measure muon multiplicity of a large number of counters and DAQs located in a smaller space.

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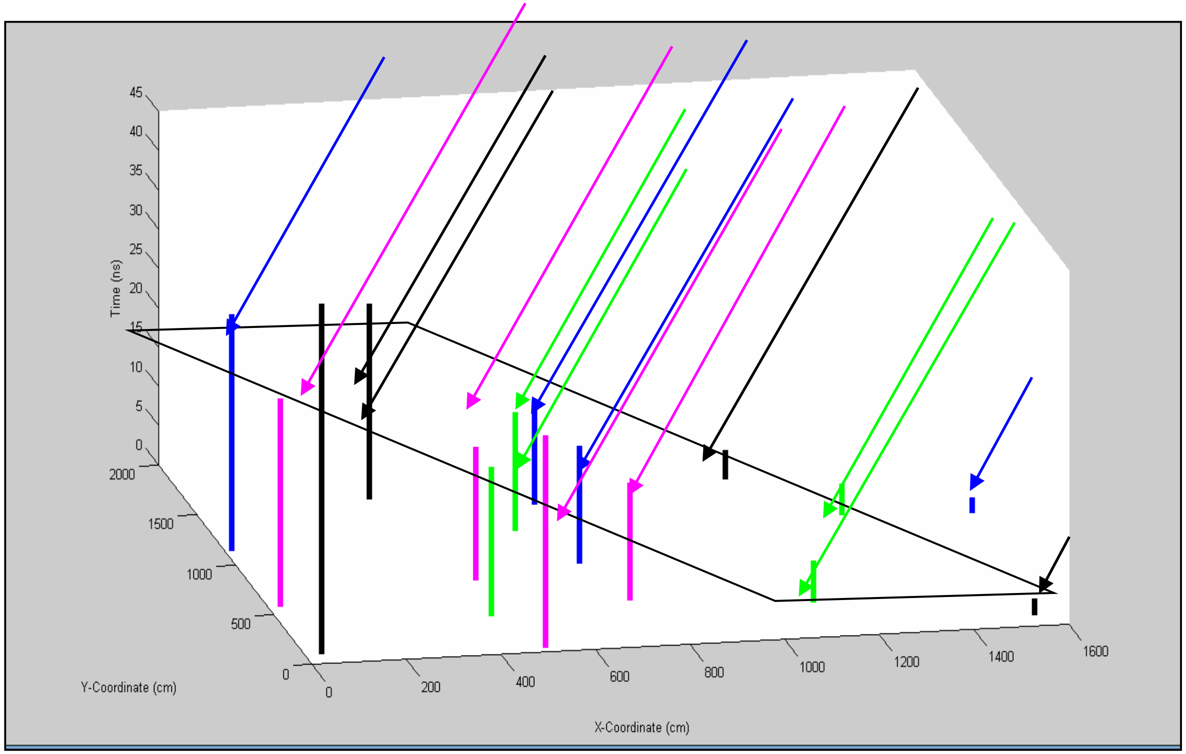
Cosmic Ray Shower

16 counters observing 16 muons in one shower using 5 separate DAQs

The educational journey required lots of collaboration and calibration effort.



Last Example: Time Dilation

- **Package of three counters measures muon rates at ground and on top of Sears Tower in Chicago.**
- **Muon lifetime implies few that reach roof should survive long enough to also reach ground.**
- **Result is that almost all muons reach ground.**
- **Demonstrates Einstein's time dilation (time run slower for moving objects—the muons)**

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QuarkNet Data Format

Interpolate between CPU ticks.

Date: ddmmyy

Number of satellites

5A49E0F4	A6	00	00	00	27	00	00	00	59289115	000002.023	010217	A	07	0	+0081
5A49E0F4	00	3D	00	00	00	3C	00	00	59289115	000002.023	010217	A	07	0	+0081
5A8F5C5C	80	00	32	00	00	00	32	00	59289115	000002.023	010217	A	07	0	+0081
5A8F5C5D	00	00	00	00	00	00	00	27	59289115	000002.023	010217	A	07	0	+0081
5A8F5C5D	00	00	00	28	00	00	00	00	59289115	000002.023	010217	A	07	0	+0081
5AA6CF4C	80	00	30	00	00	00	31	00	5AA60955	000003.031	010217	A	07	0	+0081
5AA6CF4D	00	00	00	00	00	00	00	27	5AA60955	000003.031	010217	A	07	0	+0081
5AA6CF4D	00	00	00	29	00	00	00	00	5AA60955	000003.031	010217	A	07	0	+0081

1 2 3

Ch 1 Ch 3 Ch 4

40 ns CPU counter at trigger time

Channel 2 LE; TE 1.25 ns least counts

GPS 1 PPS latches CPU counter.

Universal Time: hhmmss

Absolute time accuracy of 100 ns
Relative time of counters in 1 DAQ to 1.25 ns least count

3 triggered events! Each line represents hit information in a 10 ns time slice.

QuarkNet Data Format2

Counter hits from triggered events stored in fraction of Julian Day: leading edge; trailing edge; width

Contains corrections for counter lengths; hardware errors; counter overflows; and correct 1 PPS

```
#USING WIREDELAYS: ID.CHANNEL, Julian Day, RISING EDGE(sec), FALLING EDGE(sec), TIME OVER THRESHOLD
(nanosec)
6119.1  2457785 0.5000122652727026      0.5000122652729485      21.25
6119.3  2457785 0.5000122652726736      0.5000122652729919      27.50
6119.2  2457785 0.5000126299322889      0.5000126299325782      25.00
6119.4  2457785 0.5000126299322454      0.5000126299326216      32.51
6119.1  2457785 0.5000126831204167      0.5000126831207495      28.76
6119.3  2457785 0.5000126831204167      0.5000126831208073      33.75
6119.2  2457785 0.5000143909095892      0.5000143909099219      28.75
6119.4  2457785 0.5000143909096181      0.5000143909100521      37.50
```

This level of data is useful to experimenters outside of QuarkNet.

A common data format requires counter ID, time, size, position, and orientation to neighboring counters.

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Global Proposal

- Form a collaboration of high schools.
- High schools take cosmic ray data and share with other sites around the world.
- High schools analyze data and share results with others around the world.
- Learn about what other groups are doing. Advertise their own experimental results.

Does it make sense to develop a globally dispersed detector? Yes: 1. single muon rates; 2. large array correlated air showers

What could we do? Let's try!

Events That Change Muon Rates World-Wide

Without or before a common data format – SINGLE MUONS

Coordinate detector configurations and share results!

Take standard data over a long period of time: Establish baseline; perhaps correct for pressure dependence.

1. **Search for change in nominal rate, e.g., due to a coronal mass**

Ejection on the Sun that changes the Earth's magnetic field

When an abnormal rate is observed, send an e-mail request to detectors world-wide to capture rate histograms for a day surrounding the target time and share via a website that we can use as a logbook.

Tailored for rates from single muon setups

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Events That Change Muon Rates World-Wide

Without or before a common data format – SINGLE MUONS

Coordinate detector configurations and share results!

Take standard data over a long period of time: Establish baseline; perhaps correct for pressure dependence.

2. Study rates versus pressure; altitude; latitude.

Website info: detector owner; rate every 20 minutes; time; latitude; longitude; stack or large array configuration; zenith angle; normal rate; comments

Tailored for rates from single muon setups

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Correlated Events World-Wide

Without or before a common data format – Large Array Data

3. Rare Events Study

Search for events world-wide correlated in time or for clusters of showers anywhere.

If found in any set of detectors (A) e.g., QuarkNet or HISPARC, ask groups world-wide to search for similar cluster within ~1 millisecond of the target time.

Data to share on website: detector owner; individual event times; latitude; longitude; array configuration; zenith angle; normal rate of occurrence at site B, time between A and B events

Rare Events – continued

Key is the battle against random overlaps.

Time window of search depends on rate of Rare Event A (e.g., 3 x year) and rate of second group's correlated type of event (B).

Group B might search for similar rare event over seconds, or define a less rare event and search over 10 ms.

QuarkNet example: Rare Event – 2 large arrays located outside typical air shower area (5 km apart). Rate DAQ1 and DAQ2 = 0.05 Hz leads to 0.2 random events within 10 microseconds in 3 months (0.05 Hz x 0.05 Hz x 10^{-6} s x $8x10^{5}$ s).

User B would search at a specific time. If B rate is 0.1 Hz, 1 random event overlap would occur within 10 s search window.

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With Common Format

With a common format, studies of any user with any other user's data would become much easier. A better shared logbook would need to be implemented.

Imagine a world-wide network of detectors that high school students can:

1. Monitor for rare events.
2. Mine for rate variation around the world.
3. Explore effects of latitude or pressure versus altitude.
4. Monitor the entire celestial sphere for cosmic ray variation.

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Summary

- Students all over the world thrive doing research with QuarkNet cosmic ray detectors in their schools.
- It is inquiry-based learning at its best.
- Global cosmic ray experiments are well underway.
- Students understand technology and the process of science in a big collaboration.

Let's try a project! Next steps:

- **Build a closer global collaboration!**
- **Explore what global cosmic ray coverage can accomplish.**