Cosmic Ray Analysis: Large Shower Array

QuarkNet e-Lab contains a large data set of cosmic ray events and analysis tools with which you can perform several types of experiments with your classes. I've recently gathered data with which you can measure the rates of muons, that come from a Large Cosmic Ray Air Shower, hitting several detectors simultaneously. One of the detectors (DAQ 6838) was moved to three locations in the Fermilab High Rise, with separations of 6m, 27m, and 66m from the other detectors. This was a calibration sample used to predict how much data it might take to observe air showers with muons that hit both the High Rise and a detector much further away (733m away at the MINOS experiment). This calibration cosmic ray sample allows for a more sophisticated project than our normal efforts (lifetime, flux, speed) and holds many challenges for the user.

I hope that you might find this useful in these remote teaching times. Please contact Mark Adams for any assistance you need.

The calibration large array study at the High Rise consisted of three detectors with three different configurations: **DAQ 6119** configured in a vertical stack; **DAQ 6148** arranged horizontally as a multi-muon large array; and **DAQ 6838** arranged in two stacked pairs of scintillators. The **6838** detector recorded data at 3 locations, approximately 6m, 27m, and 66m from the vertical stack.

Schematics of detectors (not to scale)

6119 Stack side view	6838 DoubleStack side view	6148 Large Array (multiple muons) plan (top) view

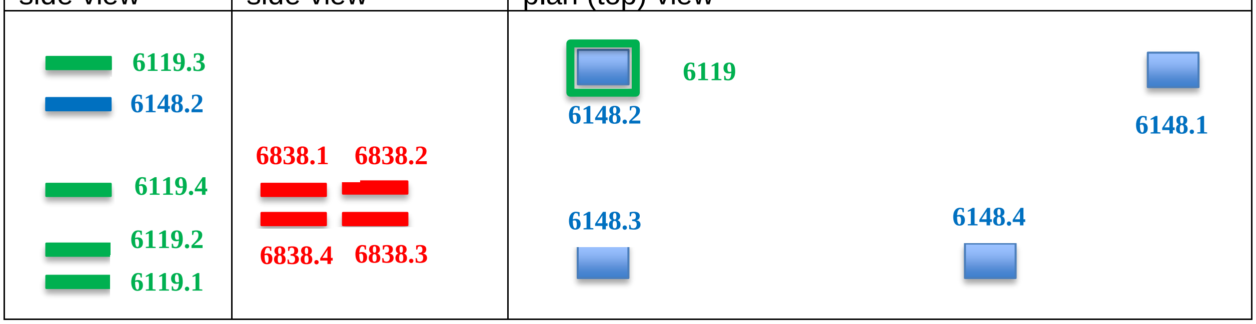

Figure 1. Schematics of detectors (not to scale).

The e-Lab Geometry files of the three detectors provide the scintillation counter configuration and relative positions. Their relative timing has not been adjusted. Almost all data collected under 2-fold trigger conditions. However, the trigger for 6119 was 3-fold during 17-22Jan19.

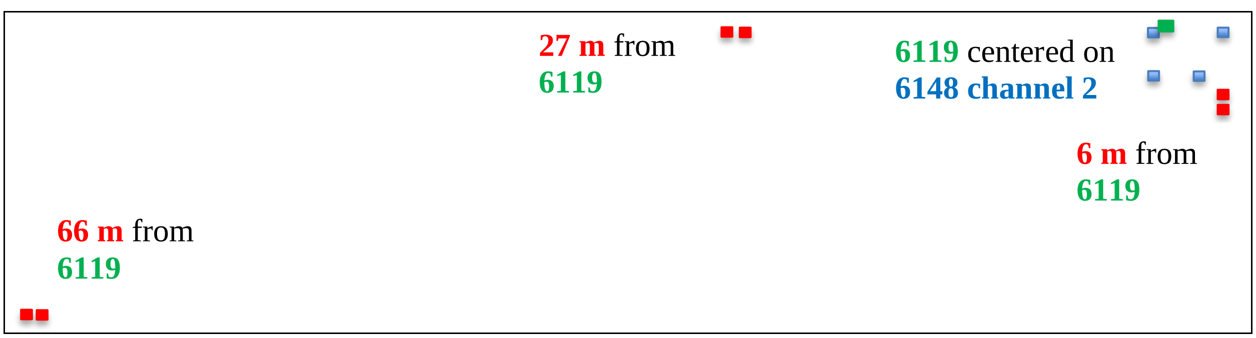

Figure 2. Plan view of the floor 15 of the High Rise.

6119 and 6148 were left at their normal positions throughout this period

6838 positions and dates:

6 m	17Jan19-22Jan19
27 m	24Jan19-1Feb19
66 m	1Feb19-6Feb19

A detailed list of files in the calibration sample is included at the end of this note; more detail from my logbook is available in a separate spreadsheet upon request. I recommend using files from the following days:
At 6 m: 4 days – Jan. 18, 19, 20, 21, 2019.
At 27 m: 5 days – Jan. 25, 26, 29, 30, 31, 2019.
At 66 m: 3 days – Feb. 2, 3, 4, 2019.

Running Shower will enable you to find events that occur within a certain time window in multiple detectors. However, that is not enough to be able to measure the rate of correlated events, because all detectors may not have been running during the entire period. To establish the livetime periods of the experiment, Flux was run, as well as the time of the first event for each file checked. There were quite a few transitions, a power outage, and some DAQ recording problems. Using the Flux results at least three days (see above) at each location were selected during which all three detectors operated the entire day.

The e-Lab Shower Analysis searches multiple detectors (DAQs) to find events that occur within a user-controlled time period. A list of events is produced containing the time and number of counters hit from each detector. Individual event displays are also available if you click on the listing of the date. Some new features are the multiplicity of hit counters and a plot of the time between the first hits in two arrays that you choose. Studying the ΔT plots is the key to distinguishing muons arising from two random showers from muon hits from the same shower.

The Shower analysis is supported by “Tutorials” and “Step-by-Step Instructions” in the Resources page in e-Lab under the Library/Resource tabs: Shower Tutorial; Step by Step

I suggest that you start with one day of data and the stationary detectors (6119 and 6148) to discover the rates of correlated hits (showers) as a function of window size. Be brave. Use the window size to explore in-time hits (from one shower) from random hits.

What can you learn as you explore cosmic ray air showers? Measurements and Questions:

1. Measure rates of air showers hitting multiple detectors.
2. Learn how to distinguish muons that come simultaneously from 1 cosmic ray shower (intime) from the muons that come from multiple showers, and hence, are uncorrelated in time.
3. Understand rates versus separation distances.
4. Study the rates of each pair of detectors. Why are they all so different?
5. Learn how to extract the in-time signal by subtracting the random background.
6. Which pair 6119-6838 or 6148-6838 is most efficient for muon detection and which has the best in-time signal to random noise ratio?
7. What does a plot with a 100 microsecond time window teach you compared to one with a

1 microsecond window? From geometric arguments, how large must the window be if the detectors are 750m apart?

8. Why are we able to ignore the scintillators' cables and relative timing?
9. Since 6119 conditions changed on 22Jan19 in the middle of the runs, assess how much it affects your results and design a method to correct for it.
10. Study the distributions of individual counters in each detector. How are hits related to the number of muons?
11. Determine if the frequency of counter hits in a detector from one shower is the same as counter hits from showers that hit multiple detectors. Why would it not be the same?
12. In the "6 m" files, is that the correct distance to use to classify 6838's distance from the 6148 detector?
13. Make a prediction of the number of correlated showers you might see if the 6838 detector was moved to a position 200m away.
14. If you measure rates versus time, are there variations within each data set? Why? Can you find a way to verify that all detectors were functioning all the time?
15. Why are there several ΔT peaks in the 6119-6148 showers? You may have to ask Mark.

Let me know if you need assistance, or to share your creative ways to use the data. We can schedule a Zoom (or Google Hangout or Facetime) meeting at your convenience. I'm sure that there are remaining problems, particularly in the Geometry files. Let me know if you discover an inconsistency. When I get access to my logbooks again at Fermilab I'll hunt down additional problems.

Regards,
Mark

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List of files for the Fermi High Rise Large Array Study

Data Set	6119 (3-fold trigger)	6148	6838
6 m	6119.2019.0117.1 6119.2019.0118.0 6119.2019.0119.0 6119.2019.0120.0 6119.2019.0121.0 6119.2019.0122.0 6119.2019.0122.1	6148.2019.0117.1 6148.2019.0118.0 6148.2019.0119.0 6148.2019.0120.0 6148.2019.0121.0 6148.2019.0122.0 6148.2019.0122.1	6838.2019.0117.1 6838.2019.0118.0 6838.2019.0119.0 6838.2019.0120.0 6838.2019.0121.0 6838.2019.0122.0 6838.2019.0122.1

27 m	6119 (2-fold trigger) 6119.2019.0124.2 6119.2019.0125.0 6119.2019.0126.0 6119.2019.0127.0 6119.2019.0128.0 6119.2019.0129.0 6119.2019.0130.0 6119.2019.0131.0 6119.2019.0201.0	 6148.2019.0124.2 6148.2019.0125.0 6148.2019.0126.0 6148.2019.0127.0 6148.2019.0128.0 6148.2019.0129.0 6148.2019.0130.0 6148.2019.0131.0 6148.2019.0201.0	 6838.2019.0124.1 6838.2019.0125.0 6838.2019.0126.0 6838.2019.0127.0 6838.2019.0128.0 6838.2019.0128.1 6838.2019.0129.0 6838.2019.0130.0 6838.2019.0131.0 6838.2019.0201.0

66 m	6119.2019.0201.1 6119.2019.0202.0 6119.2019.0203.0 6119.2019.0204.0 6119.2019.0204.1 6119.2019.0205.0	6148.2019.0201.1 6148.2019.0202.0 6148.2019.0203.0 6148.2019.0204.0 6148.2019.0204.1 6148.2019.0205.0	6838.2019.0201.1 6838.2019.0202.0 6838.2019.0203.0 6838.2019.0204.0 6838.2019.0204.1 6838.2019.0205.0

Known problems:

a. On 22jan19 the position of 6119.4 changed from 50cm above the floor to 33cm above the floor.
b. Hardware trigger multiplicity of 6119 changed from 3-fold to 2-fold on 22Jan19.
c. Power outage on 4Feb UT forced 2 files on that date for each DAQ.