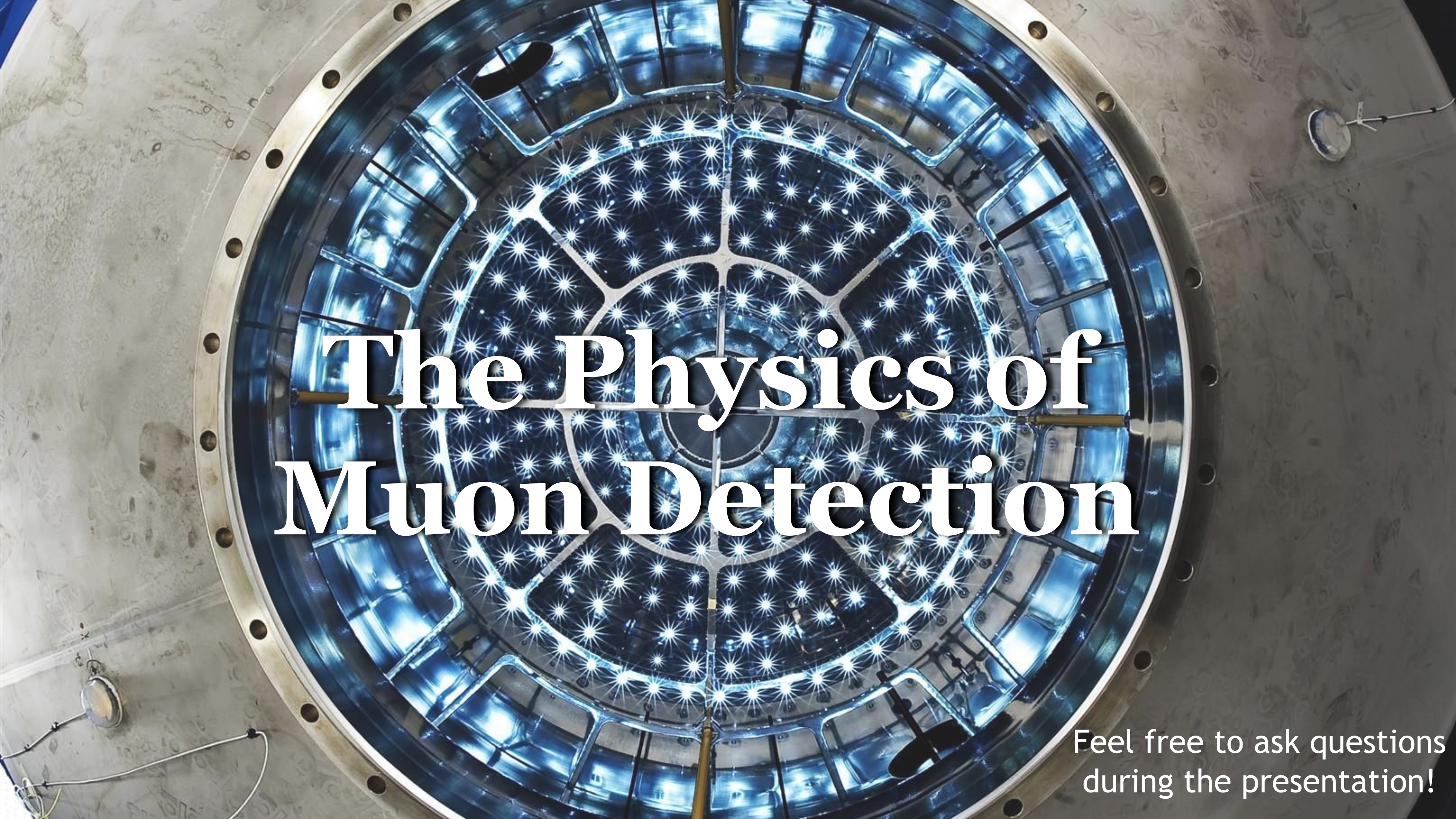


The Physics of Muon Detection

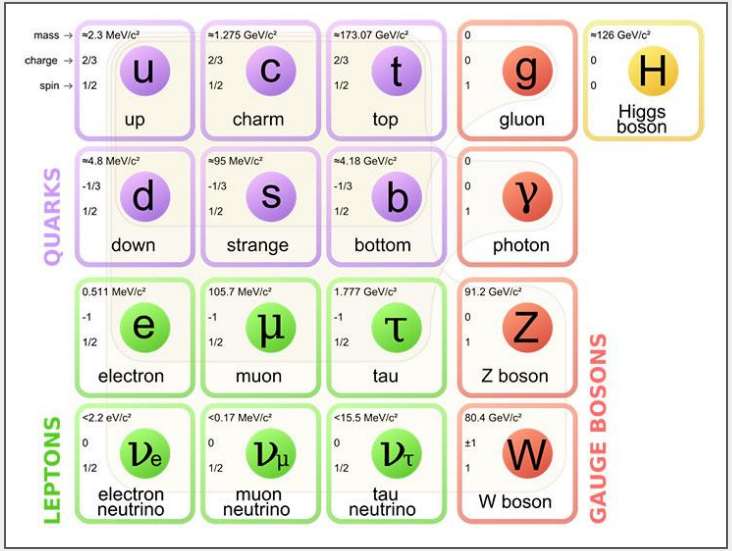
Feel free to ask questions during the presentation!

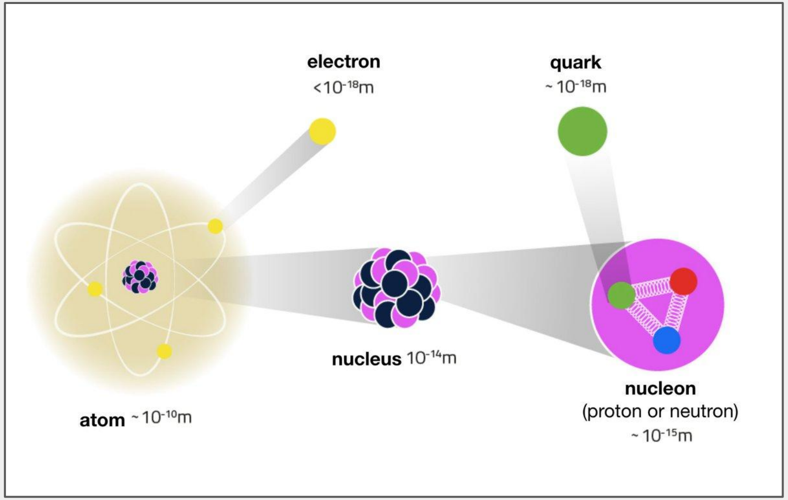
VIP project

VIP (Vertically Integrated Project) is a program in the ECE Department, but this is the first time Physics is doing a VIP, with the mentorship of Dr. Frank Geurts! Our 1 semester (so far) endeavour has included learning the basics of the standard model in particle physics, the structure of particle detectors like the one at CERN, and analyzing real cosmic rays hands-on utilizing a 3 scintillator-panel muon detector!

Standard Model

We all have a basic understanding that atoms are made of protons, neutrons, and electrons, but there is another layer to subatomic particles, and physicists use the standard model to organize them all.

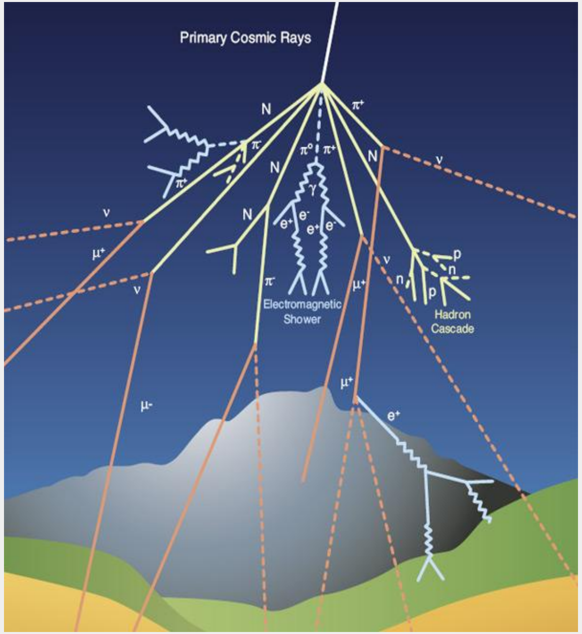




Special Relativity and Muons

$$\mu^- \rightarrow e^- \; \bar{\nu}_e \; \nu_\mu$$
$$\mu^+ \rightarrow e^+ \; \nu_e \; \bar{\nu}_\mu$$

Muons have a mean life expectancy of 2.2 microseconds, so if they are created in the upper troposphere and travel close to the speed of light (3.0 * 10^8 m/s), they should only be able to cover 660 meters before they decay into electrons and neutrinos. However, experimental data reveals that muons are still recorded at sea level.

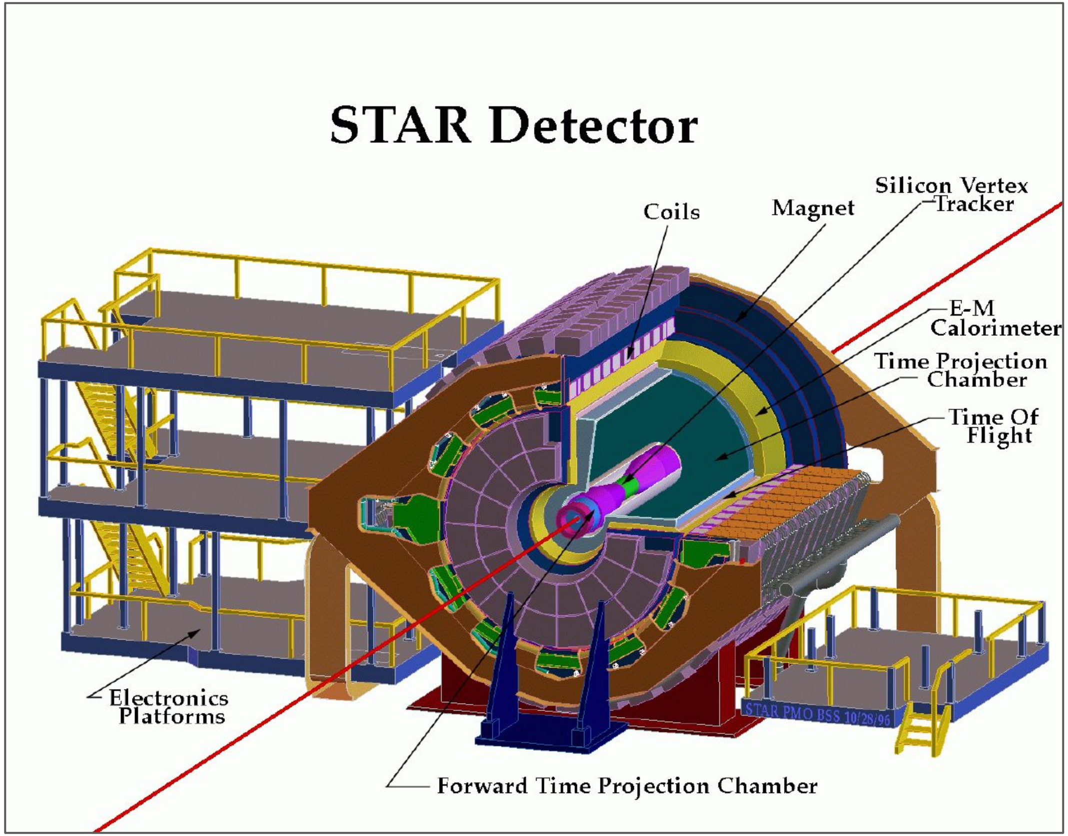


This is due to the time dilation effect from the theory of Special Relativity. Because they travel at relativistic speeds, their “clocks” run slow!

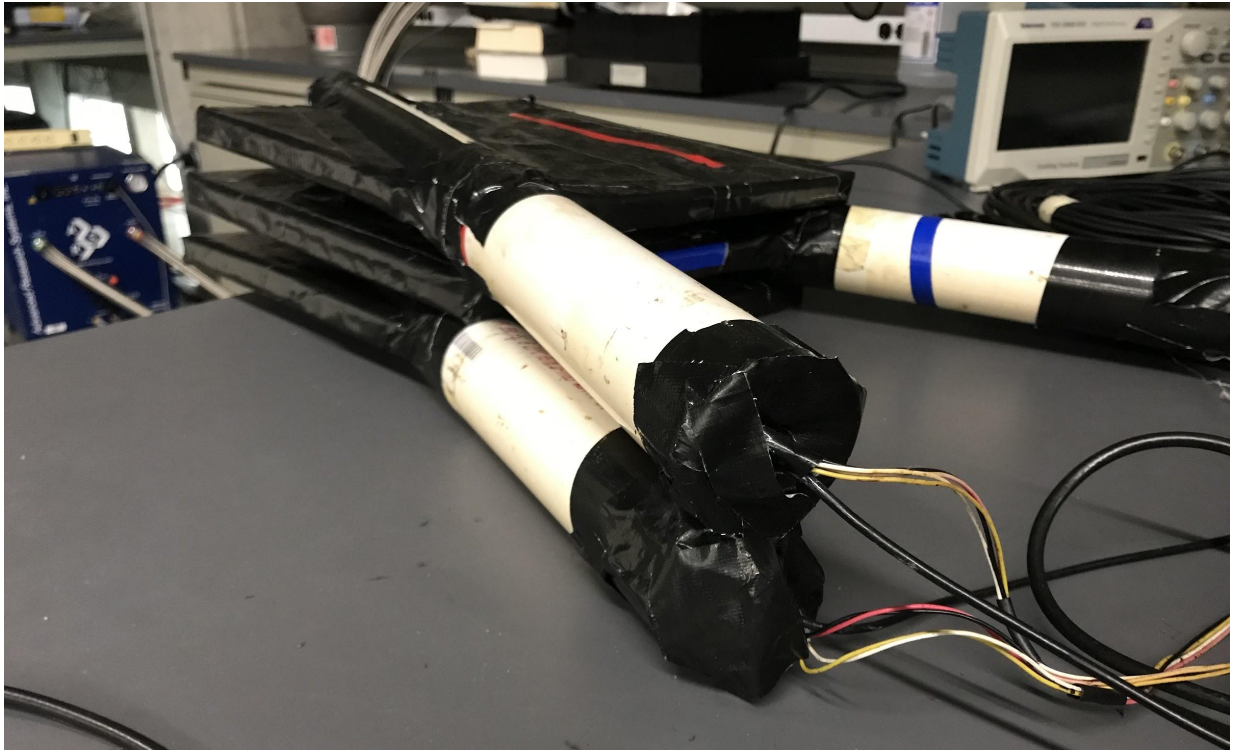
Cosmic Rays in a Cloud Chamber

https://drive.google.com/file/d/1MxhCFBdwGcN3iTKqXT7fBTFrZOg-Zdfa/view?usp=sharing

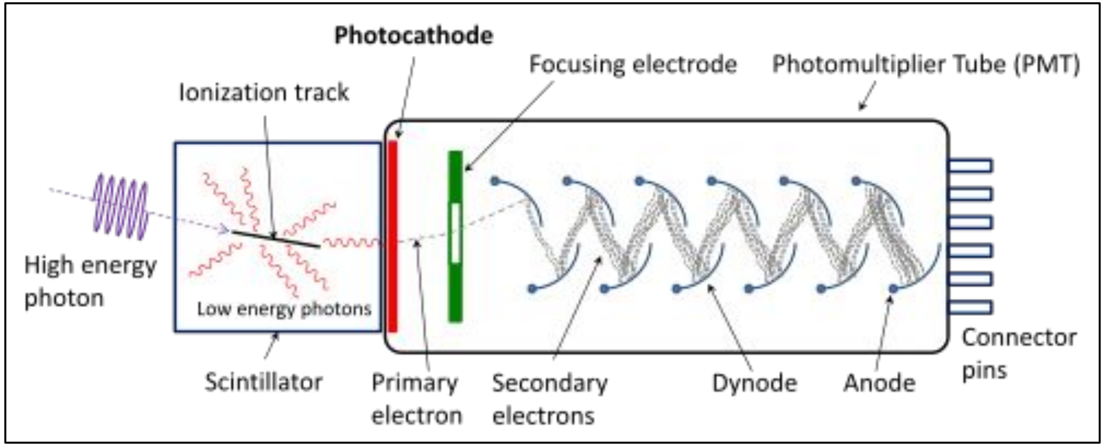
STAR experiment at Brookhaven Laboratory



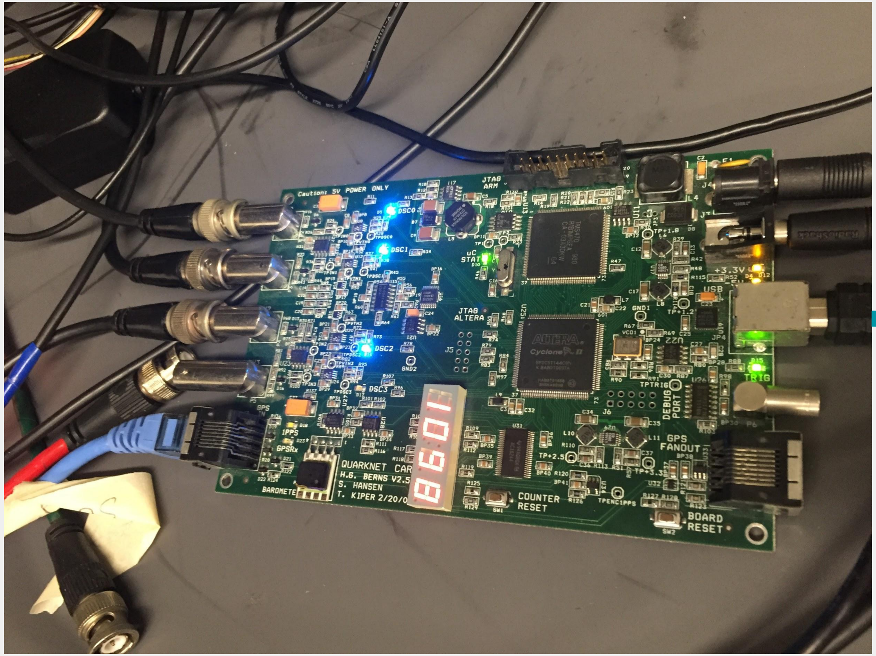
3 panel scintillators & PMT basic structure



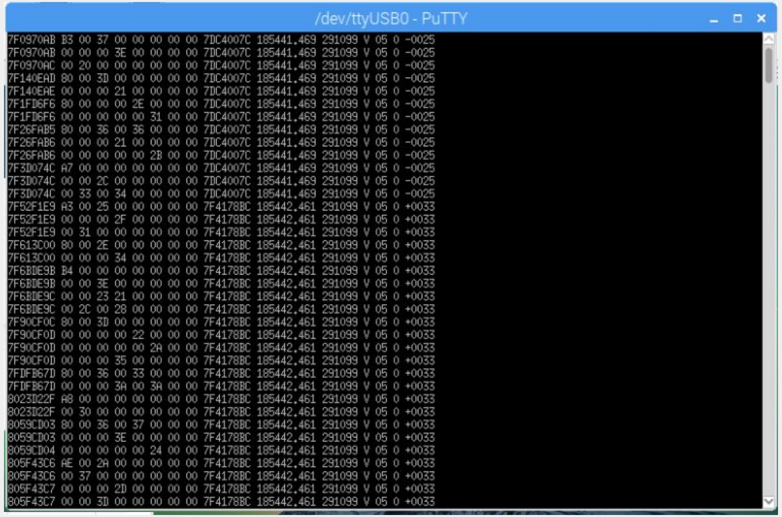
Inside the panels…



DAQ (Data Acquisition Board)



Control the DAQ using a PC:



A Few Important Commands...

H1, **H2** : Help Commands, shows all the commands to set/reveal different settings.

DS : Display Scalars, reveals how many signals for each panel, and total valid events counted (coincidence).

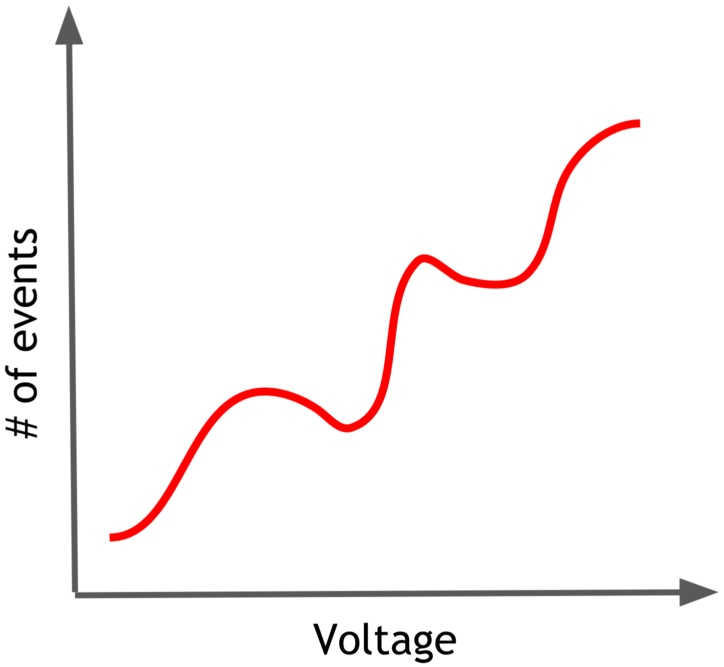
CE : Counters Enable, starts reading data out.

RB, **RE** : Reset Board, Reset Everything

Calibrating Voltages:

In order to make sure we are getting a significant amount of signals and reduce noise, we must calibrate high voltage values and threshold voltage values for each panel, respectively.

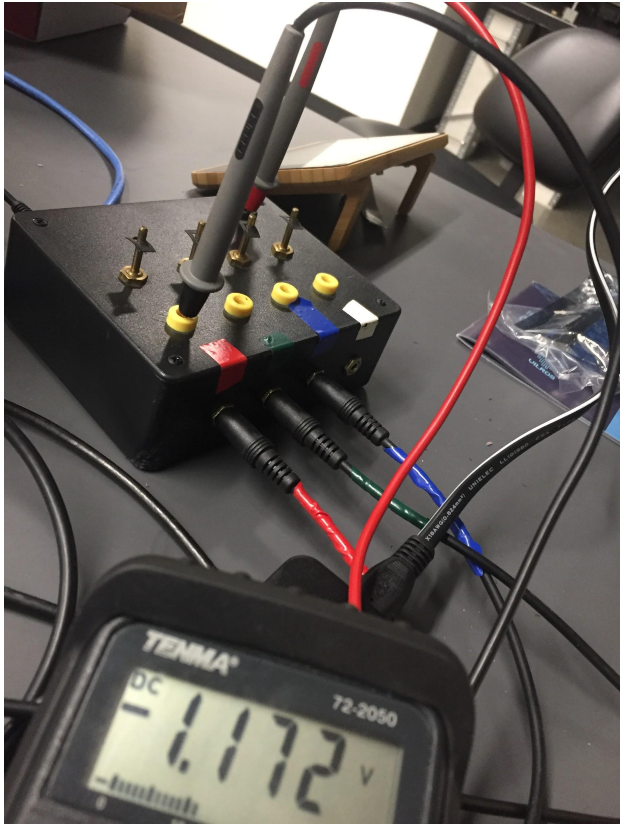
The way we can find the right value to set both is by plotting a graph...



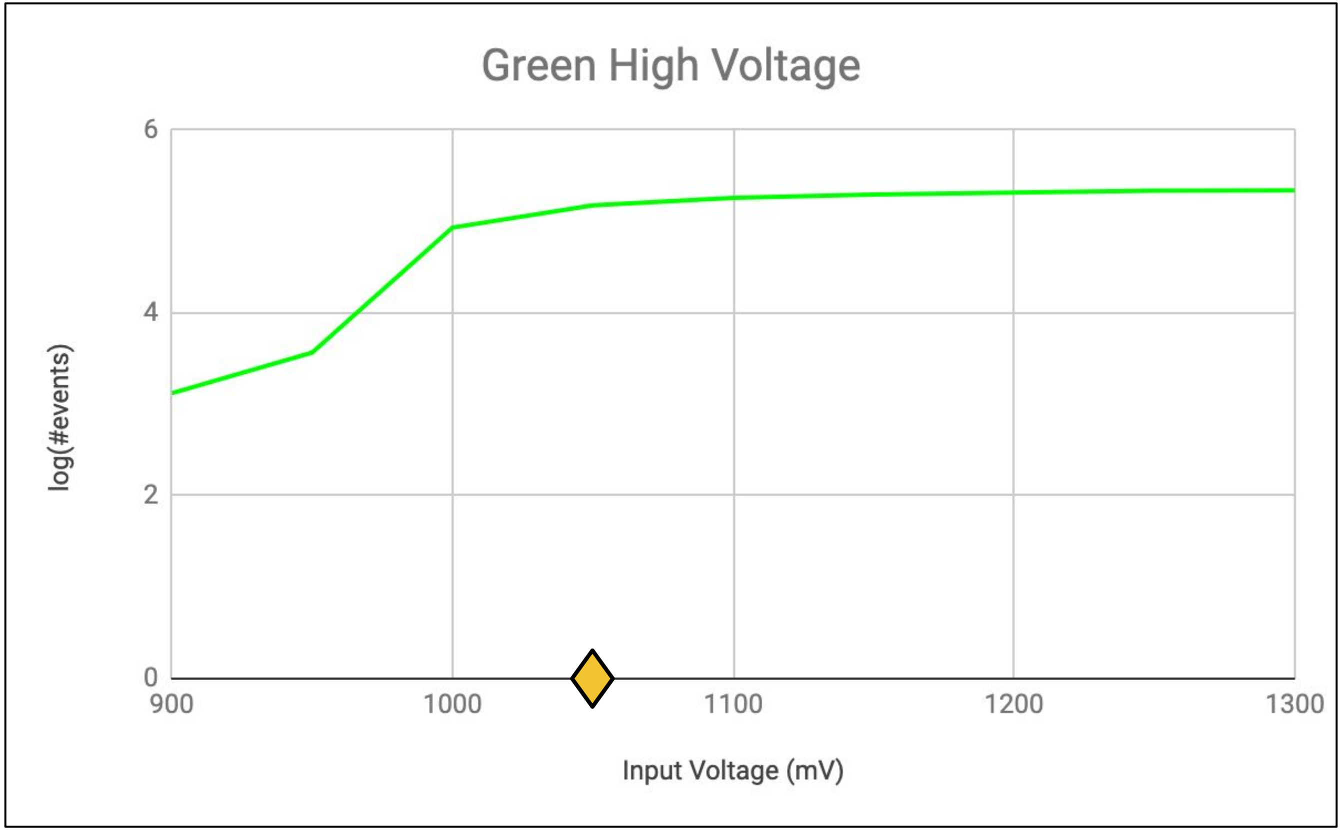
High Voltage

This is the voltage we apply to the PMT to amplify signals so we can easily detect the slightest proton creation.

You can change the voltage by turning the square knobs and check the voltage with a digital multimeter!



Finding the right high voltage for a panel:



Threshold Voltage

Because we applied a high voltage, the noise signals are also amplified, so we must use a **threshold** to set a level under which we do not accept signals.

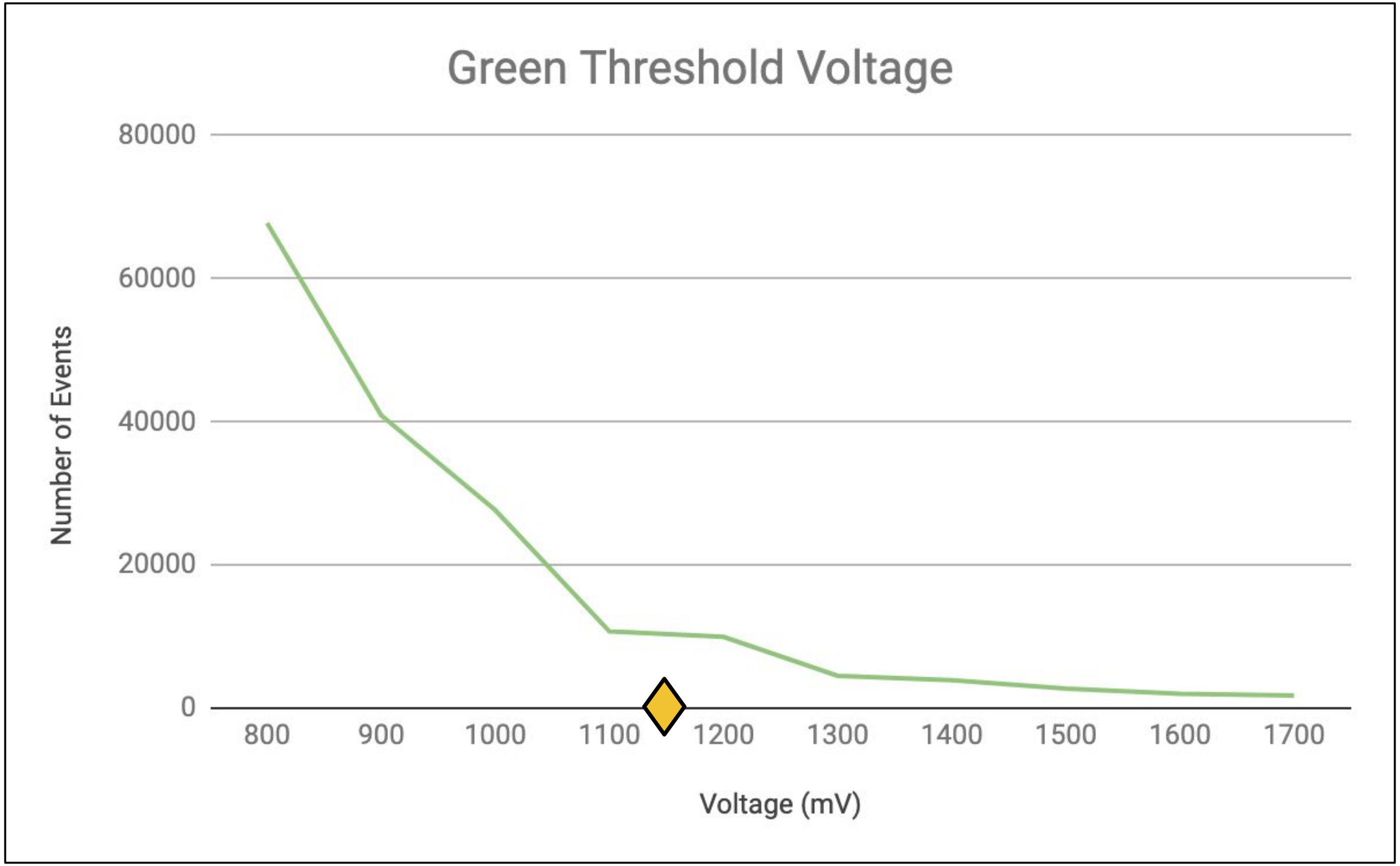
Command to change threshold:

TL #counter #milivolts

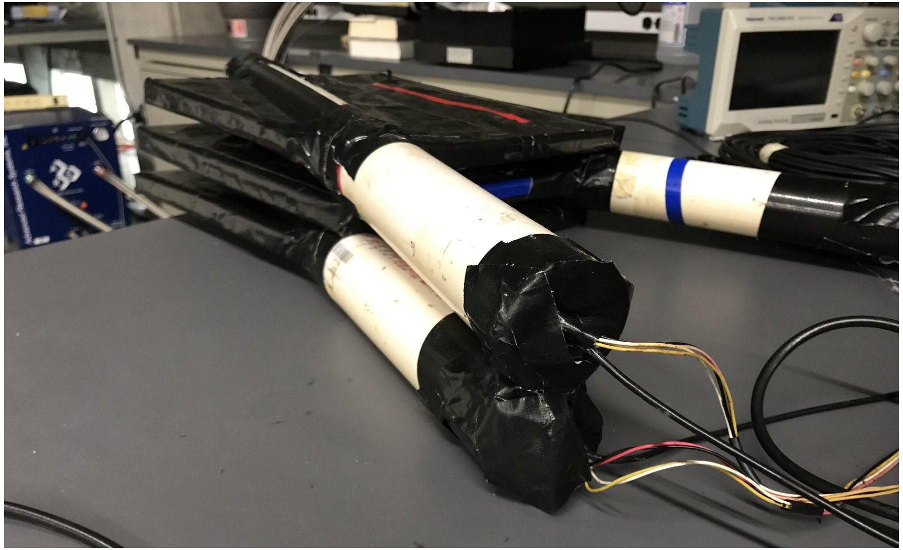
Example for setting the 1st counter to 1300 mV is:

TL 0 1300

Finding the right threshold for a panel:



Experiments with the Detectors: Flux



This setup can show if and how flux is affected by external factors (air pressure, temperature, et cetera).

Coincidences:
1-fold, 2-fold, 3-fold

For example, 2-fold meaning a muon hitting at least 2 detectors within an almost simultaneous period of time.

Commands to set coincidence levels:

WC 00 #coincidence level #which counters are enabled

For example, 2-fold coincidence with the first and third counters enabled is:

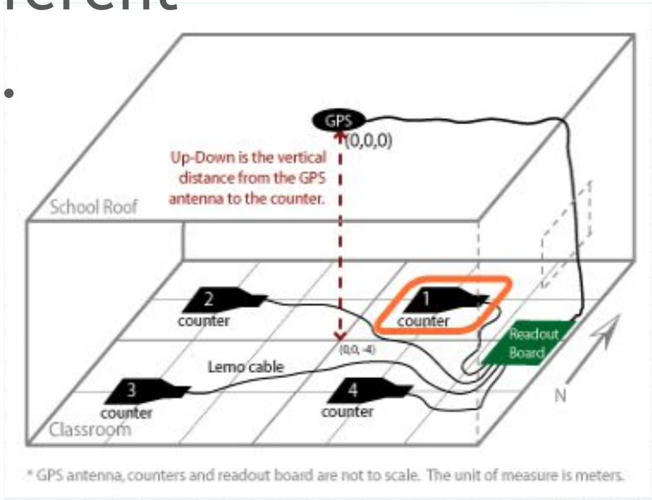
WC 00 1A

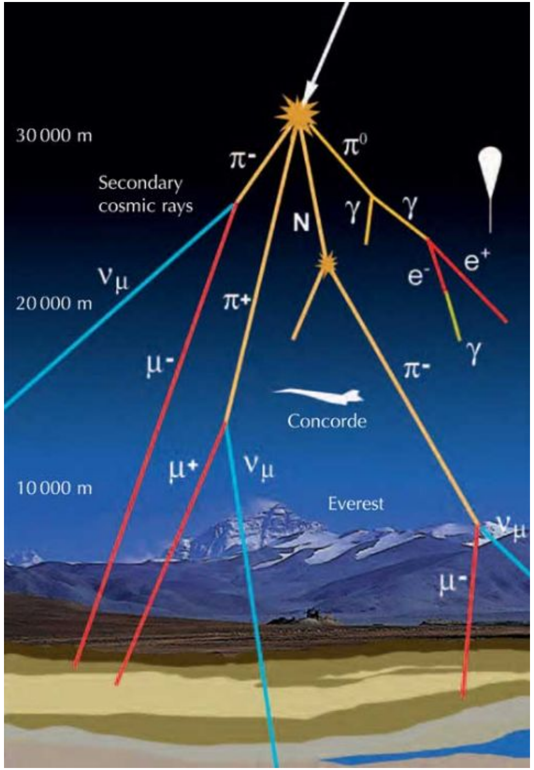
#counters enabled is in HEX, convert to Binary:

Channel:	0	1	2	3
Decimal Value:	8	4	2	1

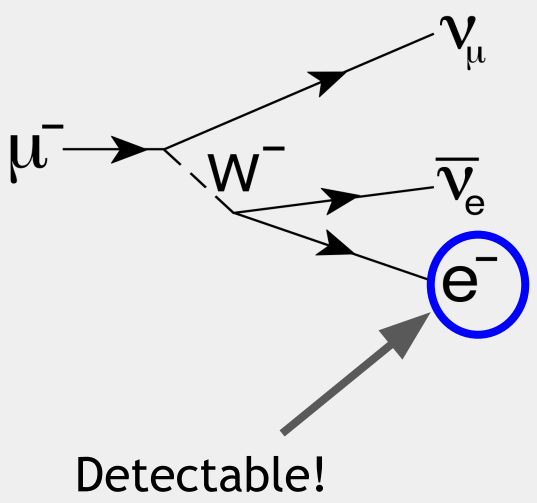
Experiments with the Detectors: Shower

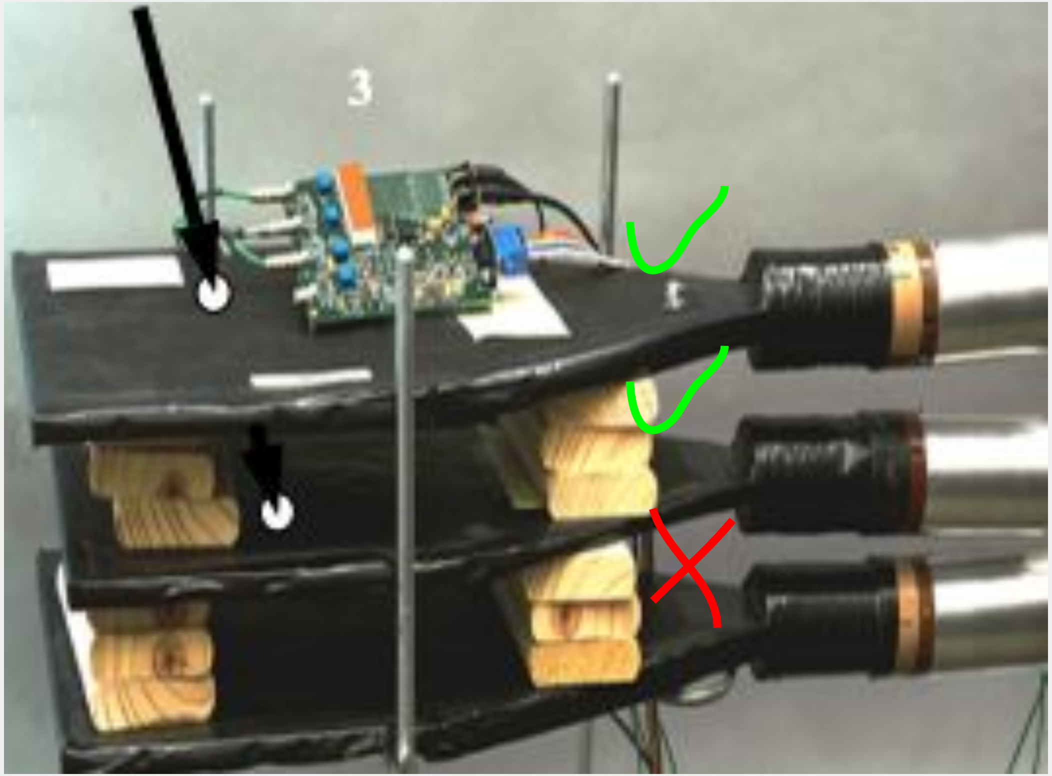
Coincidences between counters at the same altitude, but can be counters from different schools/locations.





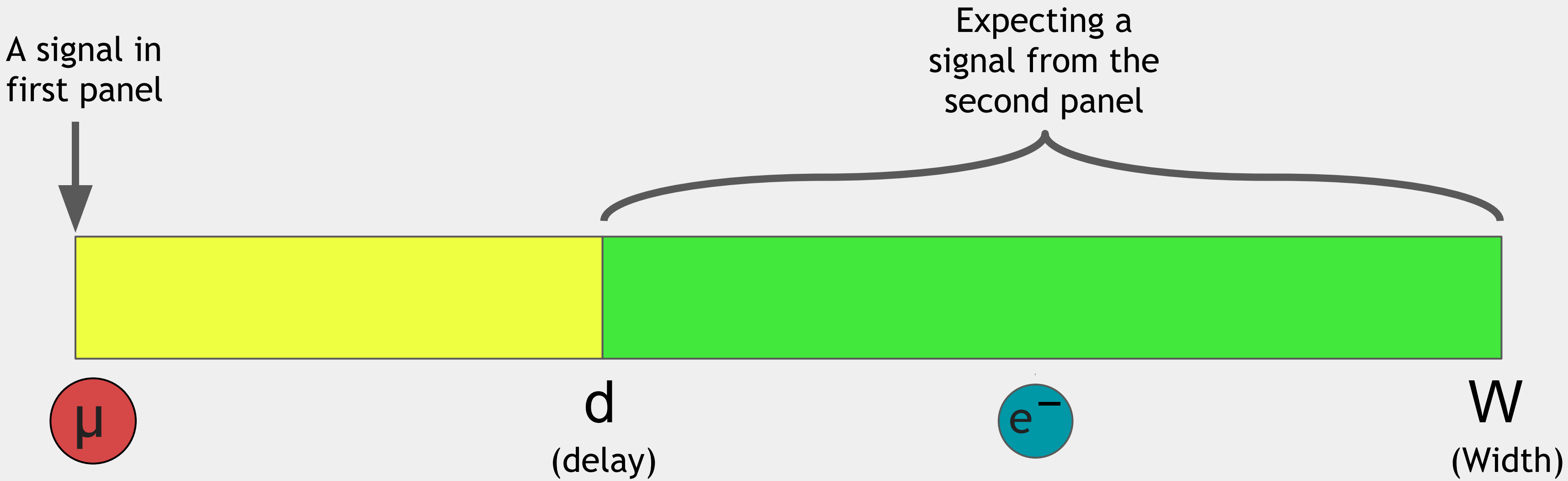
Experiments with the Detectors: Lifetime





How do we make sure it’s an electron?

By manipulating the range of time in which a signal is accepted!

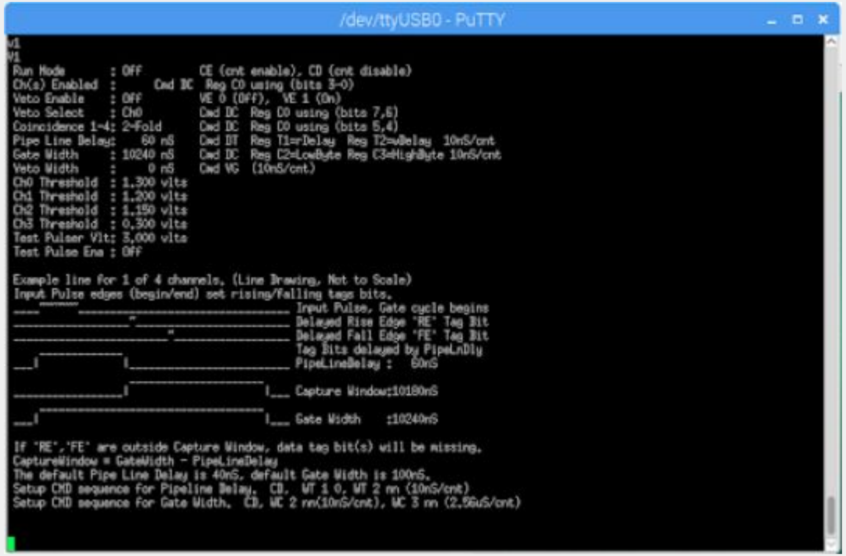


(And by choosing to cut out events that have a 3rd signal).

Changing the “d” and “W”:

The default values for d and W are 4 (40 ns) and 10 (100 ns), respectively (10 ns bins).

For lifetime measurements, the W will be much larger at 400 HEX (10240 ns).



Commands in HEX:

d	W
WT 02 04	WC 02 00
	WC 03 04

Interpreting the Raw Data Stream:

Once you decide an event is valid, you can record the time difference between the signals of the first two panels. This will be the “decay length”.

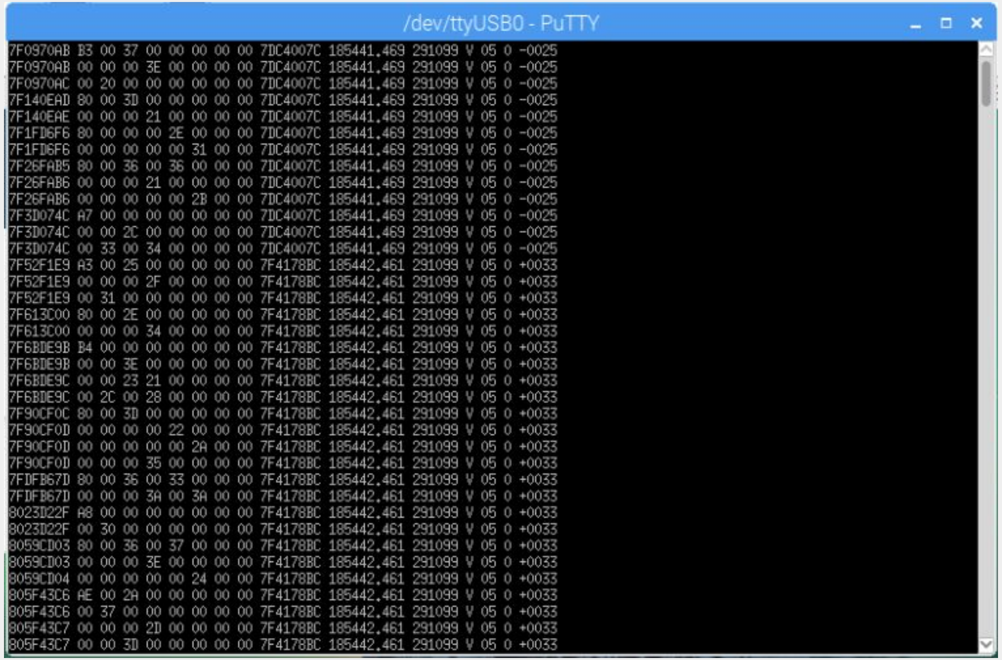
By doing this for several events, you can plot the frequency of events vs the decay length, which will show the number of decays that occur in each time “bin”.

For example, if 20 events had a decay length of 3 μs, you would plot (3, 20).

Interpreting the Raw Data Stream:

By plotting several data points (usually from 24+ hour runs), you can fit the equation for exponential decay.

$$N(t) = N_0 e^{-\frac{t}{\tau}}$$


/dev/ttyUSB0 - PuTTY

```
7F0970AB B3 00 37 00 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F0970AB 00 00 00 3E 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F0970AC 00 20 00 00 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F140EAD 80 00 3D 00 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F140EAE 00 00 00 21 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F1FD6F6 80 00 00 00 2E 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F1FD6F6 00 00 00 00 00 31 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F26FAB5 80 00 36 00 36 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F26FAB6 00 00 00 21 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F26FAB6 00 00 00 00 00 2B 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F3D074C A7 00 00 00 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F3D074C 00 00 2C 00 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F3D074C 00 33 00 34 00 00 00 00 7DC4007C 185441.469 291099 V 05 0 -0025
7F52F1E9 A3 00 25 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F52F1E9 00 00 00 2F 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F52F1E9 00 31 00 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F613C00 80 00 2E 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F613C00 00 00 00 34 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F6BDE9B B4 00 00 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F6BDE9B 00 00 3E 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F6BDE9C 00 00 23 21 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F6BDE9C 00 2C 00 28 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F90CF0C 80 00 3D 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F90CF0D 00 00 00 00 22 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F90CF0D 00 00 00 00 00 2A 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7F90CF0D 00 00 00 35 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7FDFB67D 80 00 36 00 33 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
7FDFB67D 00 00 00 3A 00 3A 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
8023D22F A8 00 00 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
8023D22F 00 30 00 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
8059CD03 80 00 36 00 37 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
8059CD03 00 00 00 3E 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
8059CD04 00 00 00 00 00 24 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
805F43C6 AE 00 2A 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
805F43C6 00 37 00 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
805F43C7 00 00 00 2D 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
805F43C7 00 00 3D 00 00 00 00 00 7F4178BC 185442.461 291099 V 05 0 +0033
```

Interpreting the Raw Data Stream:

The cosmic ray e-lab allows you to upload the raw data, and "perform a lifetime analysis", where you can choose parameters and automatically plot and fit the decays.

You can also get the frequency of counts for each time bin if you want to further analyze the data...

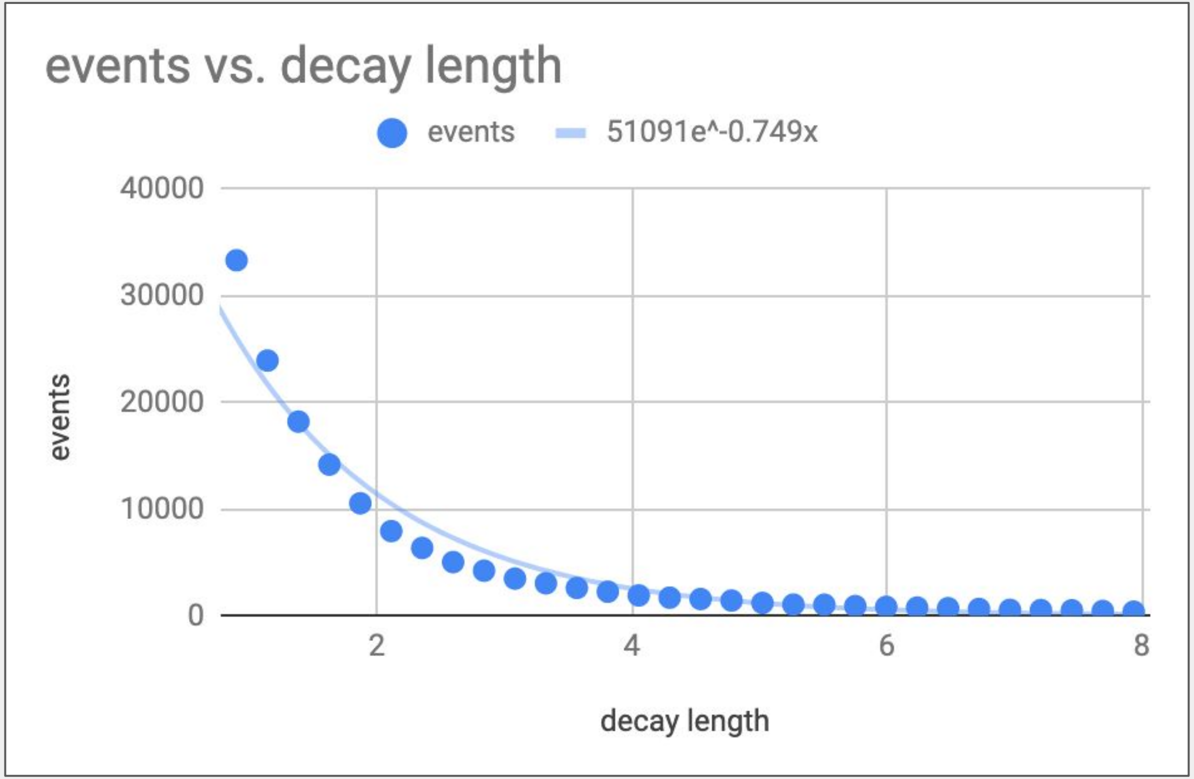
Output directory for I2U2.Cosmic::LifetimeStudy

- 6621.2019.0522.0.wd
- 6621.2019.0523.0.wd
- combineOut
- sortOut
- lifetimeOut
- frequencyOut
- extraFun_rawFile
- extraFun_out
- plot_param
- plot.svg
- plot_thm.png
- plot.png
- dv.dot

0.415041	2395	2
0.657603	1311	2
0.900166	963	2
1.142728	735	2
1.385290	609	2
1.627852	519	2
1.870415	397	2
2.112977	308	2
2.355539	236	2
2.598101	174	2
2.840664	172	2
3.083226	133	2
3.325788	112	2
3.568350	110	2
3.810913	93	2
4.053475	72	2
4.296037	70	2
4.538599	56	2
4.781162	56	2
5.023724	48	2
5.266286	47	2

Graphing and fitting the decay:

$$N(t) = N_0 e^{-\frac{t}{\tau}}$$



Manipulating the eq. to reveal a linear relationship:

$$N(t) = N_0 e^{-\frac{t}{\tau}}$$

→

$$\frac{N(t)}{N_0} = e^{-\frac{t}{\tau}}$$

→

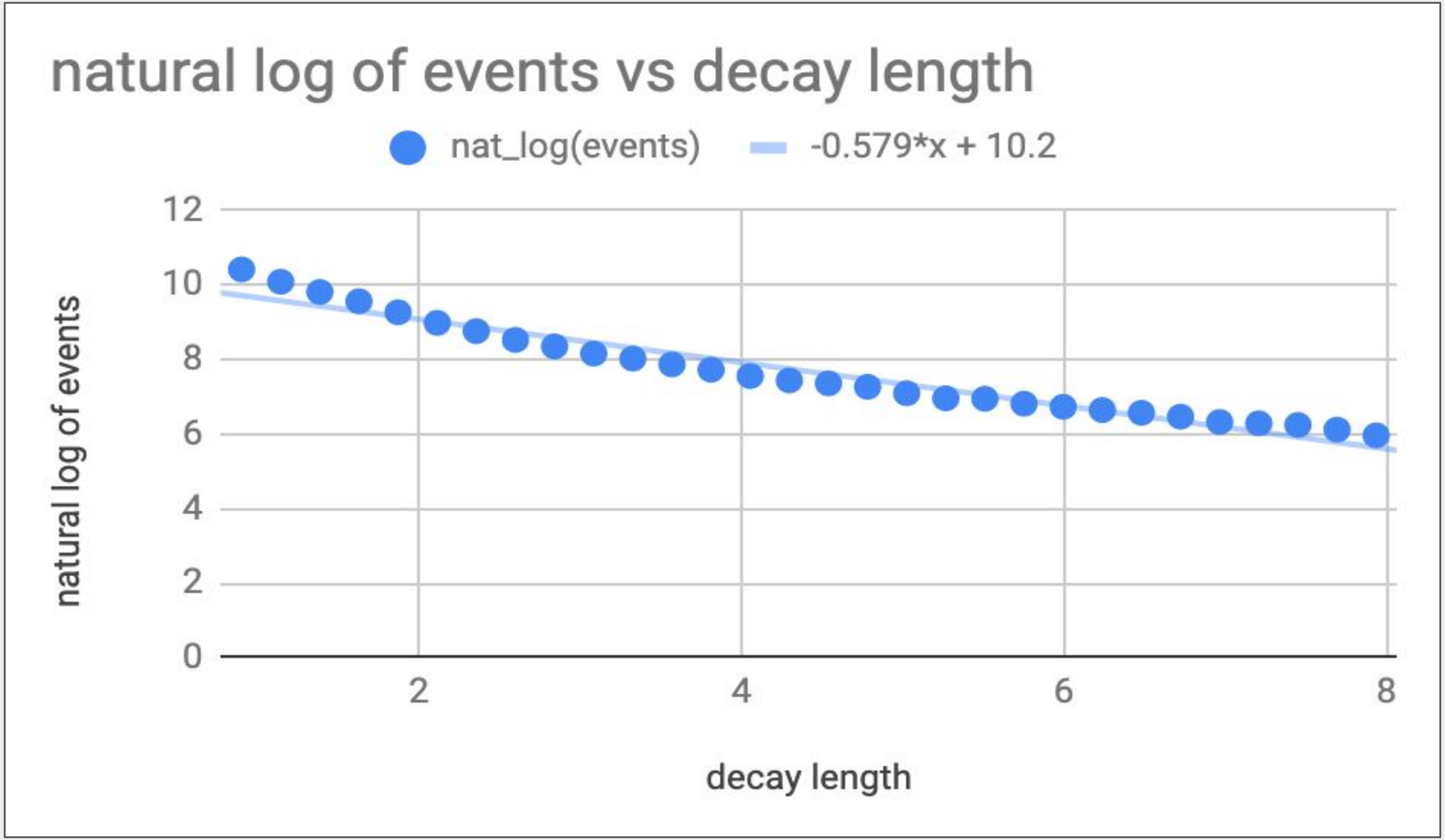
$$ln\left(\frac{N(t)}{N_0}\right) = -\frac{t}{\tau}$$

$$ln(N(t)) - ln(N_0) = -\frac{t}{\tau}$$

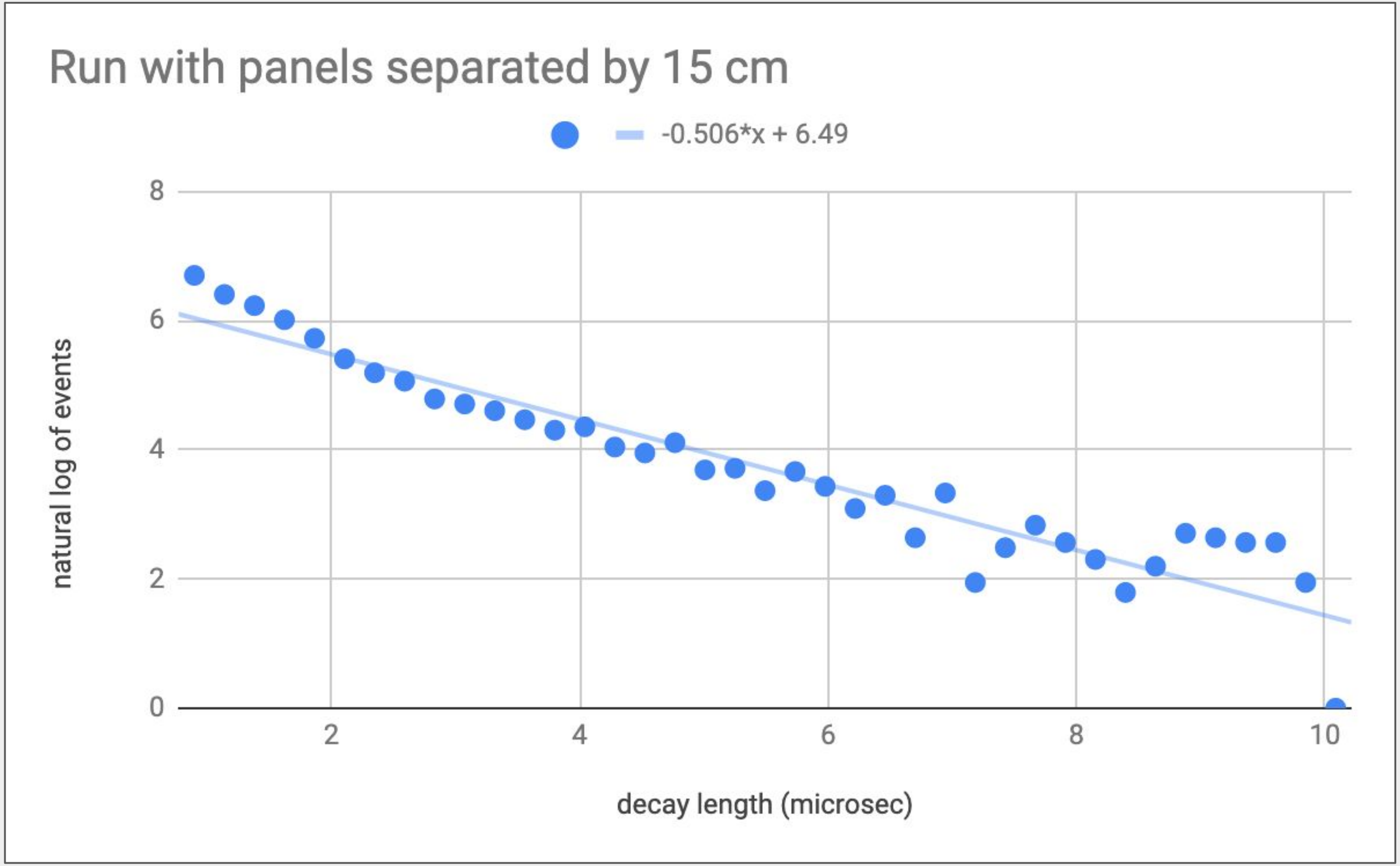
→

$$ln(N(t)) = -\frac{t}{\tau} + ln(N_0)$$

(X-coord, Y-Coord) → (X-Coord, ln(Y-Coord))



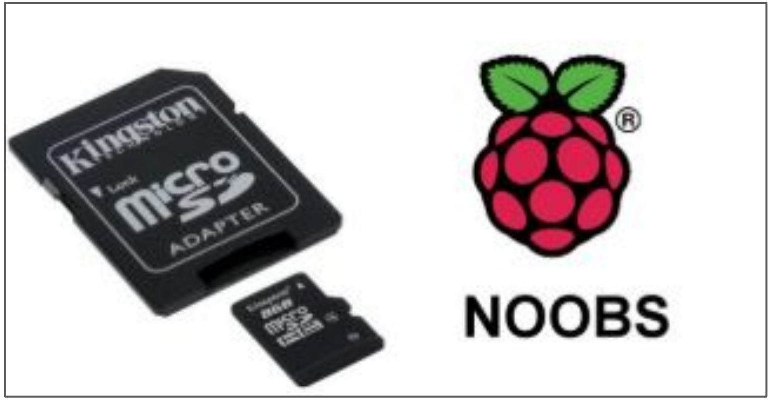
Measured Mean Lifetime: 1.727 μs



Measured Lifetime: 1.976 μs

Connecting our Detector to the Raspberry Pi

The same cables used for a PC will work with a Raspberry! So all you really need is a monitor and a mouse (and an SD card if the board doesn't come with one) to get things set up.



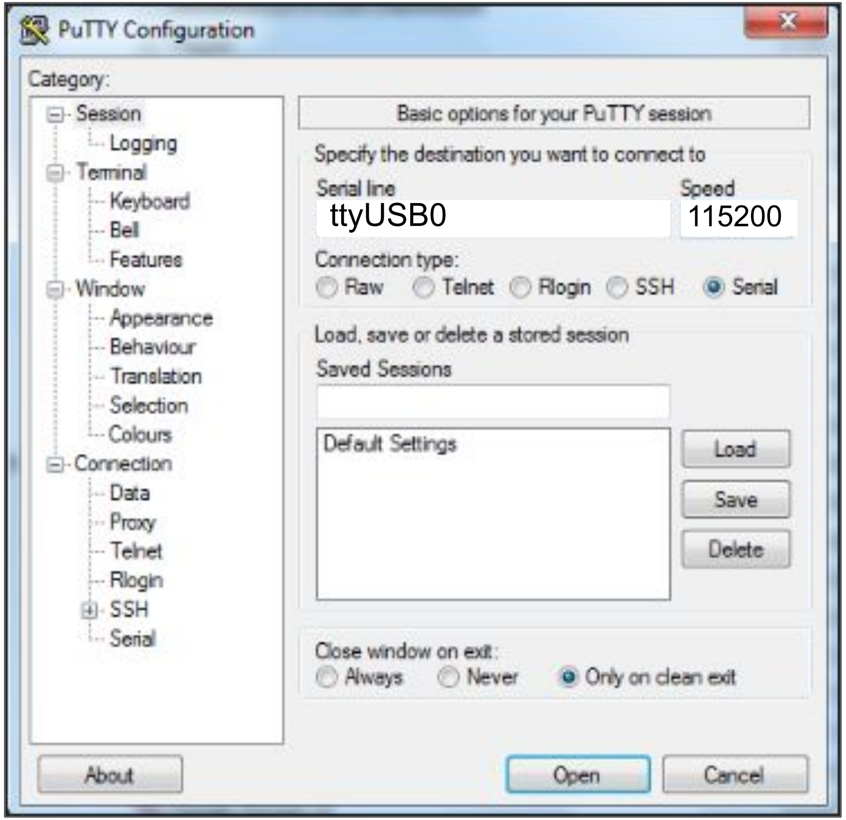
PuTTY

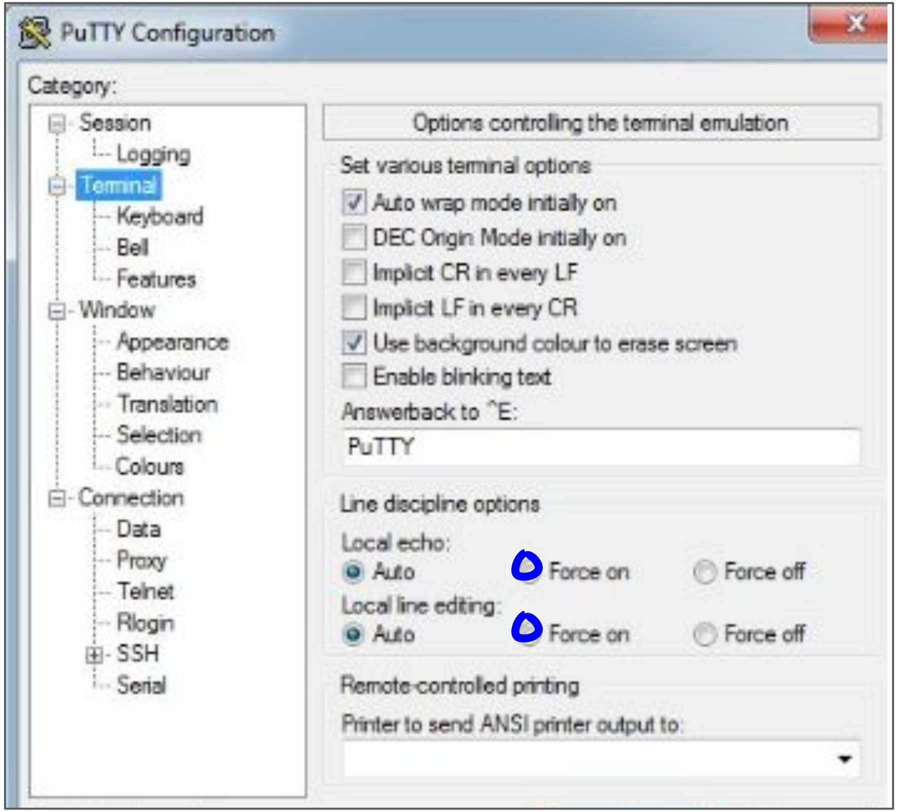
PuTTY is a free serial terminal emulator that works on the Raspberry Pi (and windows).

Once you install it from the web, you can easily launch it by typing “putty” into the terminal.

You can easily change the parameters to connect to a serial monitor, and be able to communicate with the DAQ...

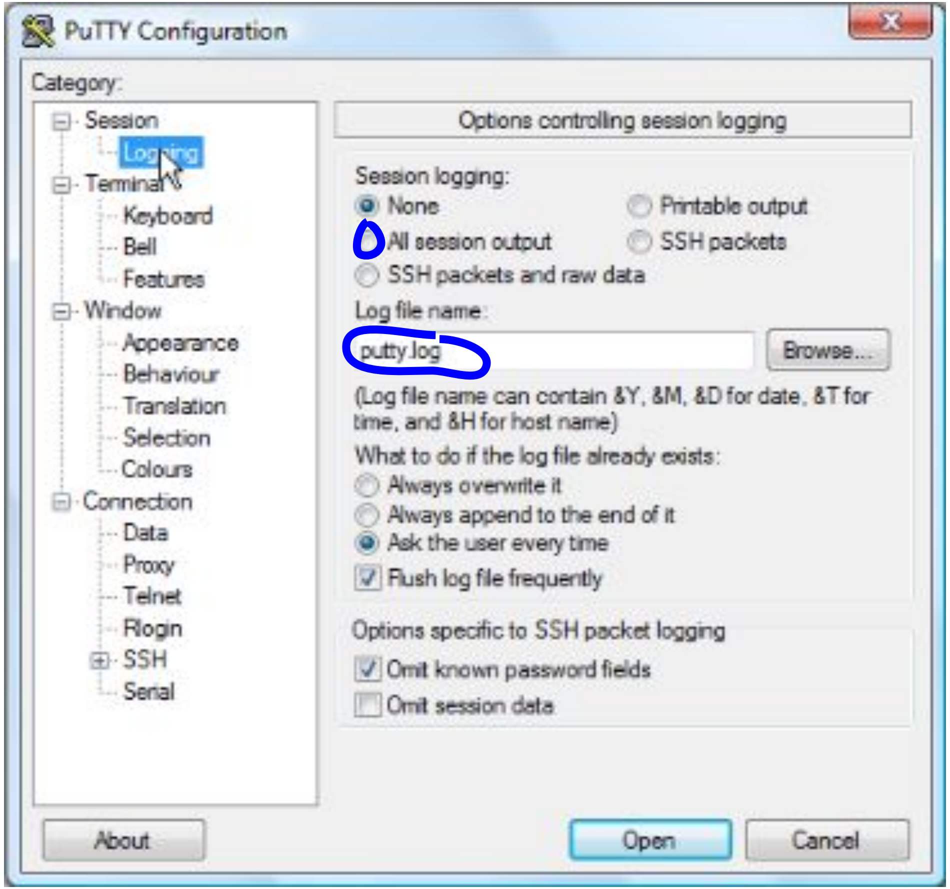
Configuring putty to read out the DAQ...



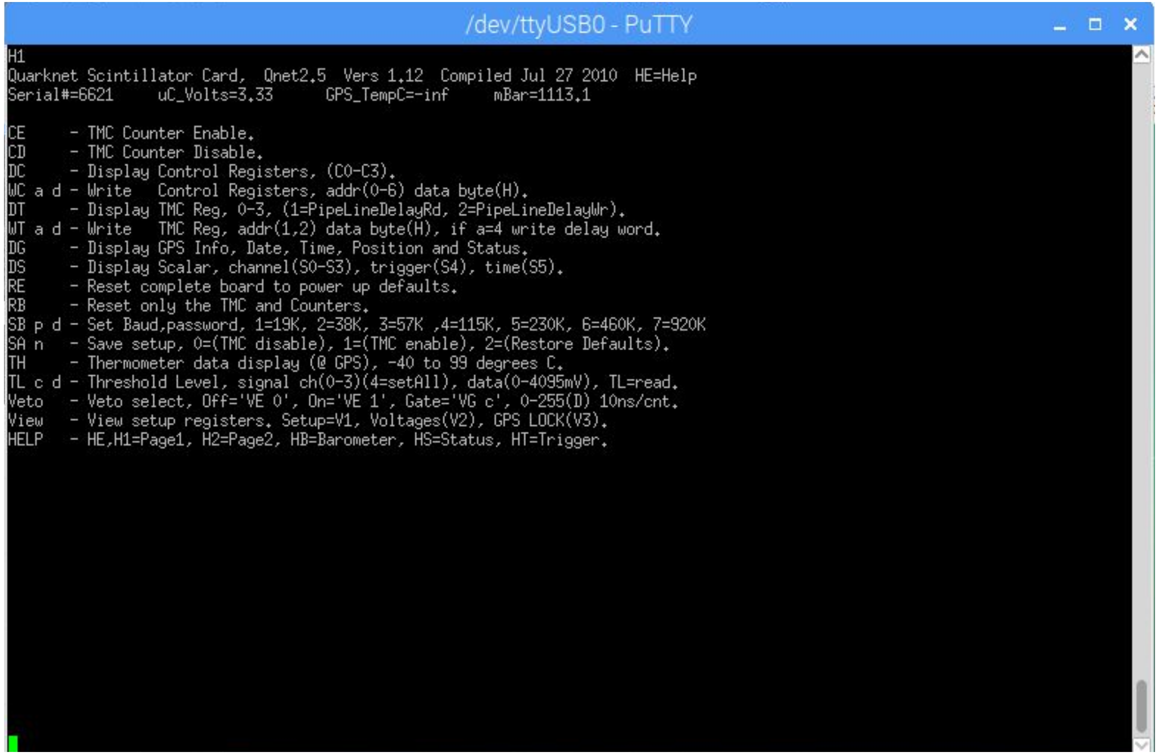


*These are screenshots of putty from Windows, but it looks the same on a Pi.

Configuring putty to read out the DAQ...

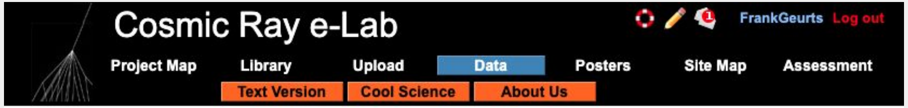


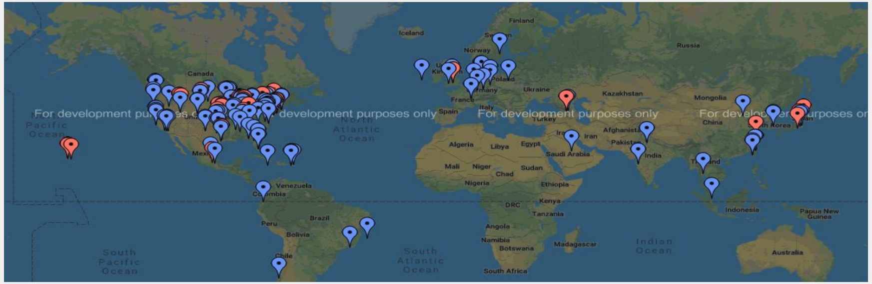
And now it works just like a PC!

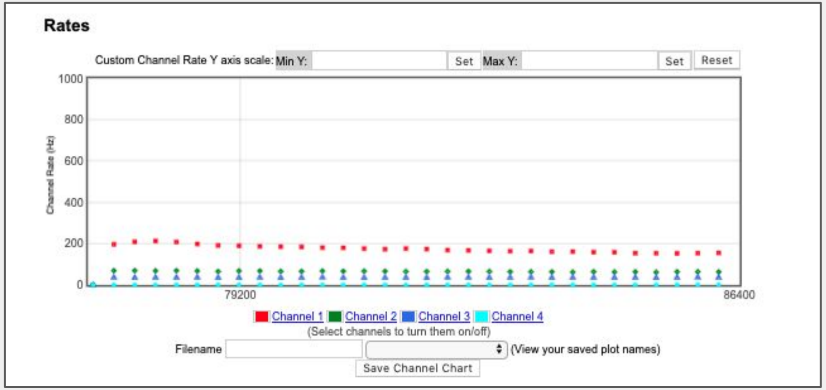


Cosmic Ray e-Lab

To make visualizing and interpreting the data much more easy, the Cosmic Ray e-Lab is a free online analysis tool where you can upload the raw data and graph plots showing muon flux, shower studies, and lifetime measurements. The best part of all is that you can see and analyze data of muon detectors from all over the world!

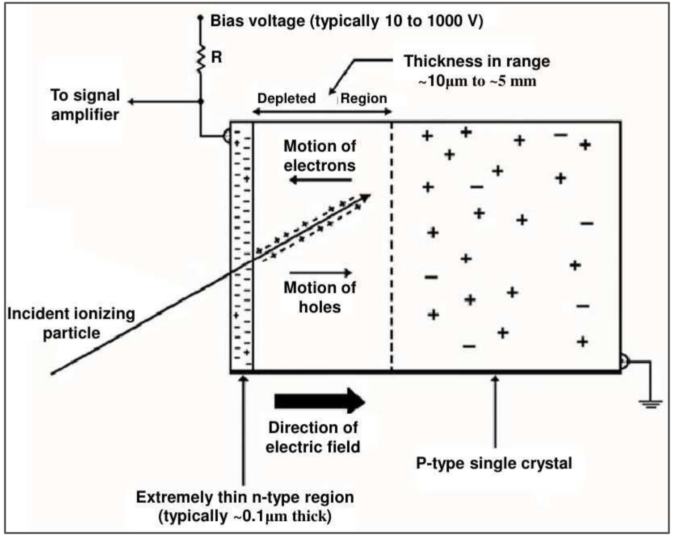






Conclusion & Related Research

Raspberry pi for large scale events cosmic showers… and to continuously track muon flux compared to air pressure, weather, and other conditions affecting muon tracks.



Thank you!

Citations: (Pictures)

https://home.cern/science/physics/cosmic-rays-particles-outer-space
https://en.m.wikipedia.org/wiki/Standard_Model
http://www.pimicrosolutions.co.uk/NOOB-Preinstalled-Micro-SD-CARD
http://scienzapertutti.infn.it
https://particlebites.com/?p=3775

https://home.cern/science/physics/cosmic-rays-particles-outer-space
http://faculty.ucr.edu/~ellison/Quarknet/6000CRMDUserManual.pdf

Questions?