VANDERBILT UNIVERSITY

Vanderbilt Particle Physics

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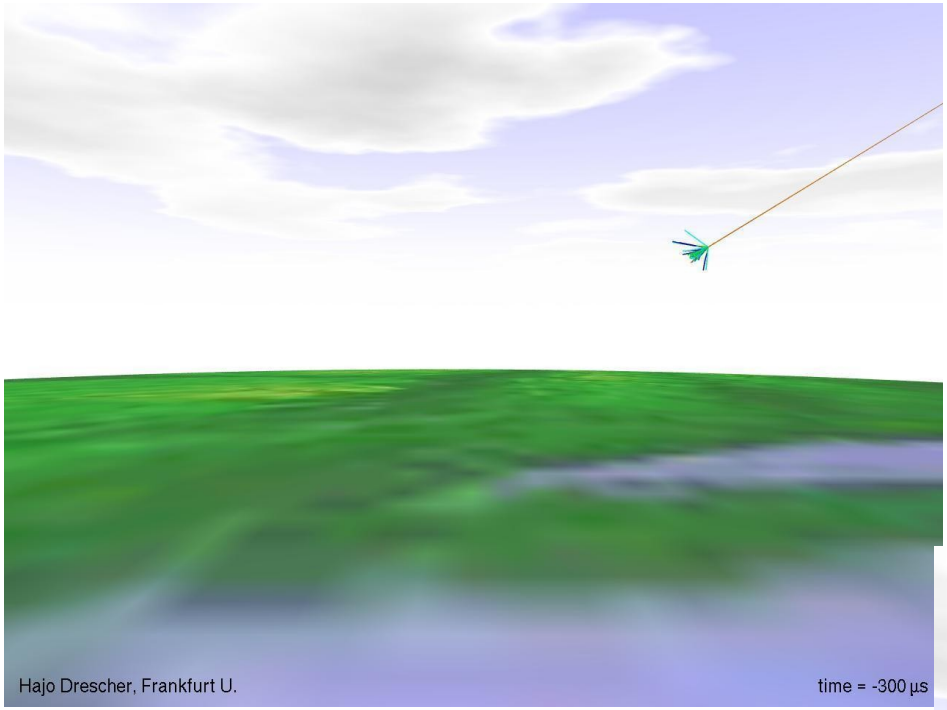
- **Global computing infrastructure** to support Particle Physics and other research making use of very large datasets (CMS at the LHC generates 0.5 Petabytes per year)

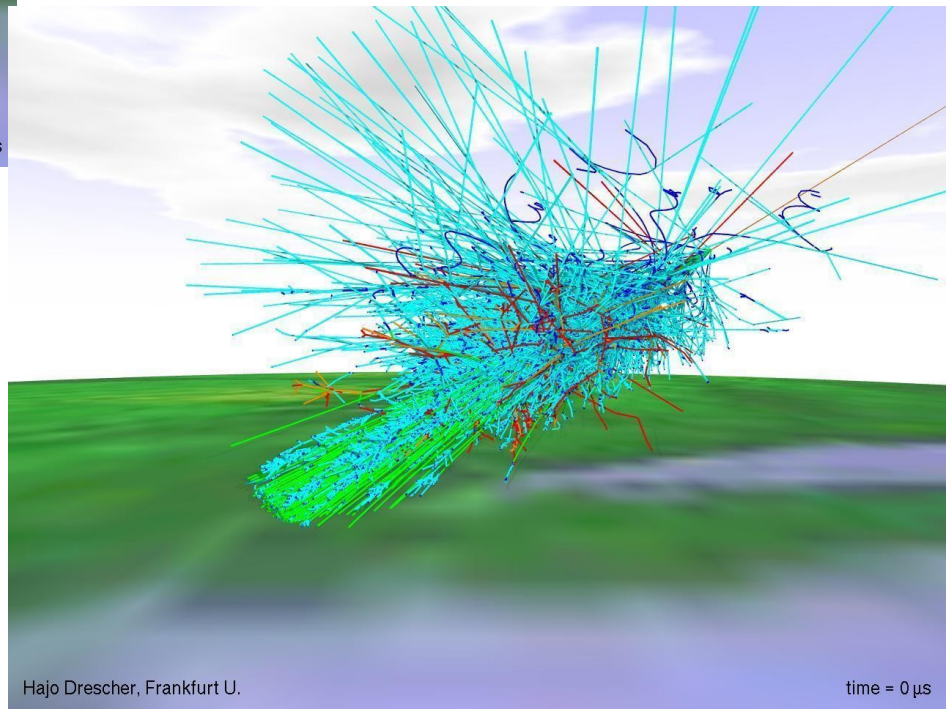
- **CMS detector** at the CERN Large Hadron Collider, general purpose detector, *discovered* the source of mass, the **Higgs** particle

Cosmic Rays,
high energy particles coming from space

The particles that hit our atmosphere:

- 90% protons (hydrogen nuclei)
- 9% alpha particles (helium nuclei)
- remainder solar wind particles and their *debris*


Hajo Drescher, Frankfurt U.
time = -300 µs


Hajo Drescher, Frankfurt U.
time = 0 µs

Earth's Surface

The particles that hit our atmosphere clobber the nuclei of the atoms and molecules:

- create a shower of x-rays, gamma rays, and light

- also make a lot of muons (like an electron but heavier), with mass 106 MeV (compare to an electron with mass 0.511 MeV).

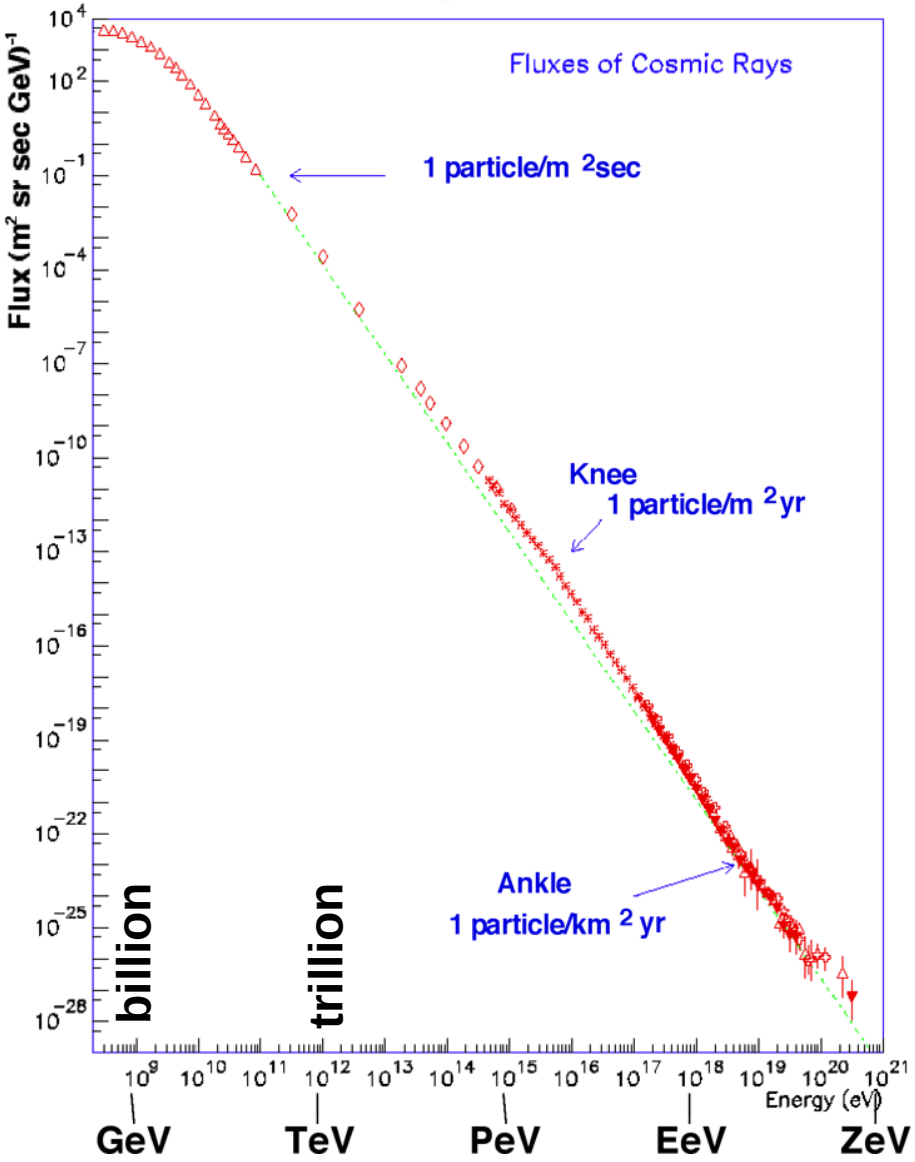
Energy and Quantity

eV is short for electron-Volt, and gives the energy of an object...or its mass!

$$E = m\,c^2$$

Energy equals **mass** times **speed of light squared** (just some constant, but a big one)

proton mass 0.924 GeV
electron mass 0.511 MeV
muon mass 106 MeV
my mass 4.3×10^{37} eV



Speed of Light

Fastest possible speed is the speed of light in vacuum.

Defined as $299792458\,\mathrm{m/s}$

$3.0 \times 10^8\,\mathrm{m/s}$

$30\,cm/ns$

$300\,m/\mu s$

$300\,\mu m/ps$

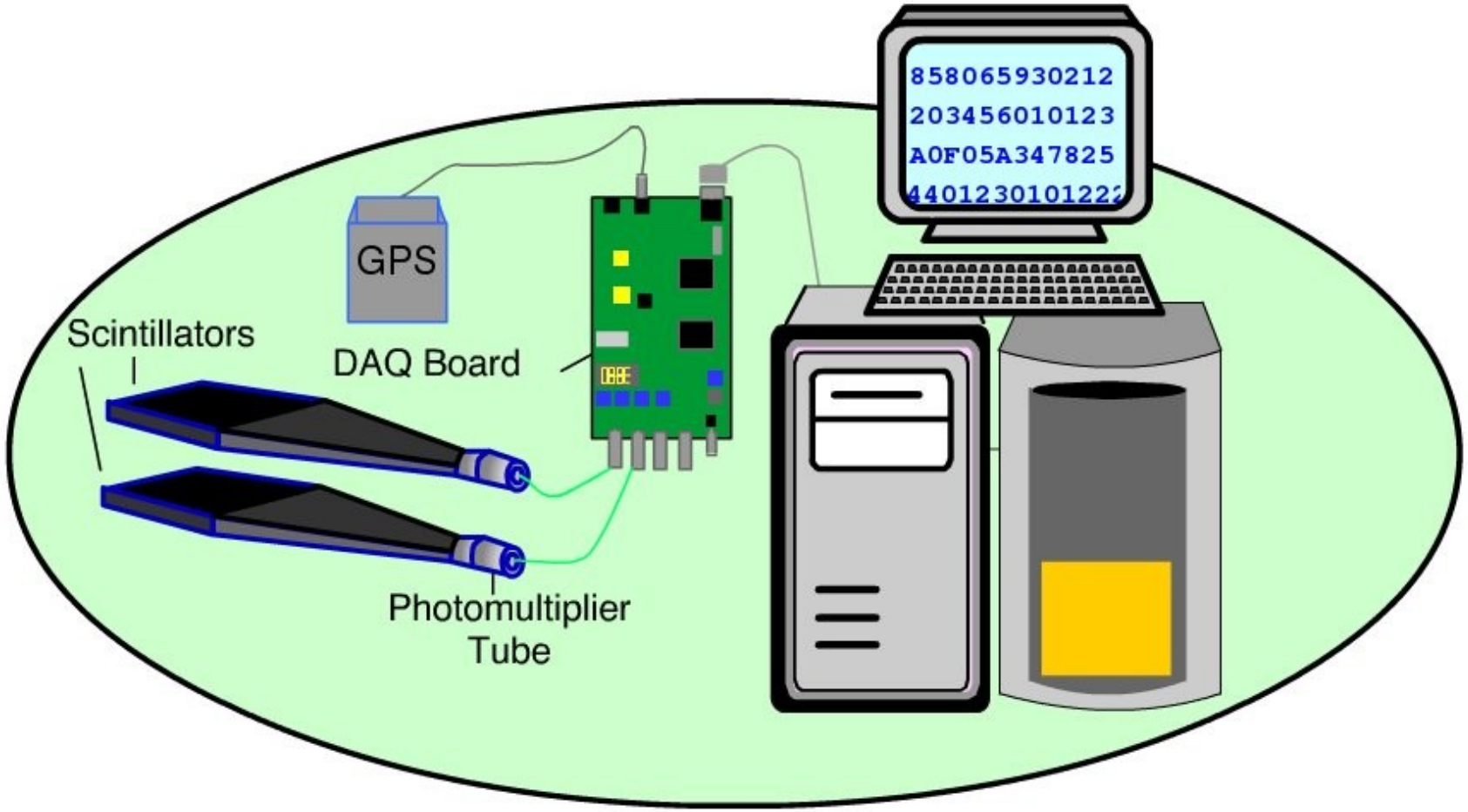
SI Prefixes

Table 5. SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

QuarkNet Detectors

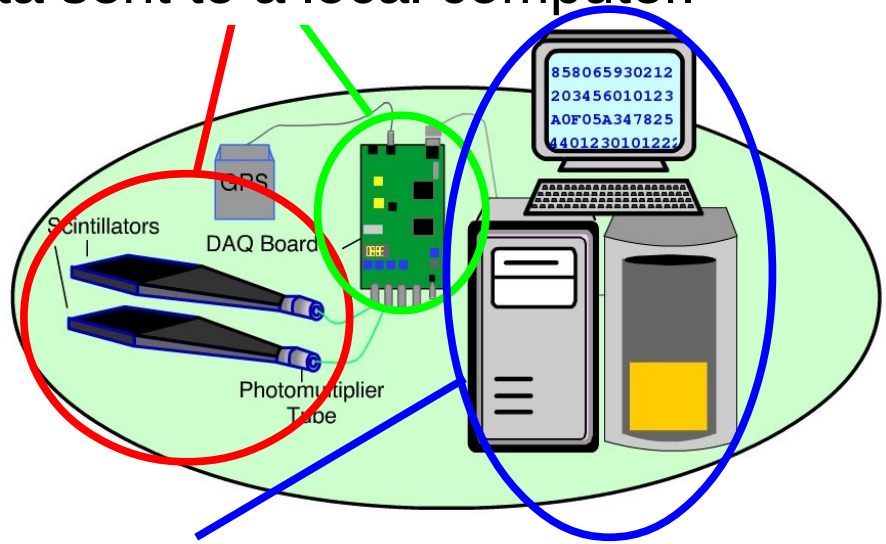
Flash description at
http://www18.i2u2.org/elab/cosmic/flash/daq_only_standalone.html .



Pieces / Parts

Scintillation Counter: Cosmic Rays create light in the scintillators. The photomultiplier converts light to an electronic pulse.

Data Acquisition (DAQ) Board: When the signal is in a certain range, the DAQ executes onboard logic and processes the signal. The result may be a string of data sent to a local computer.



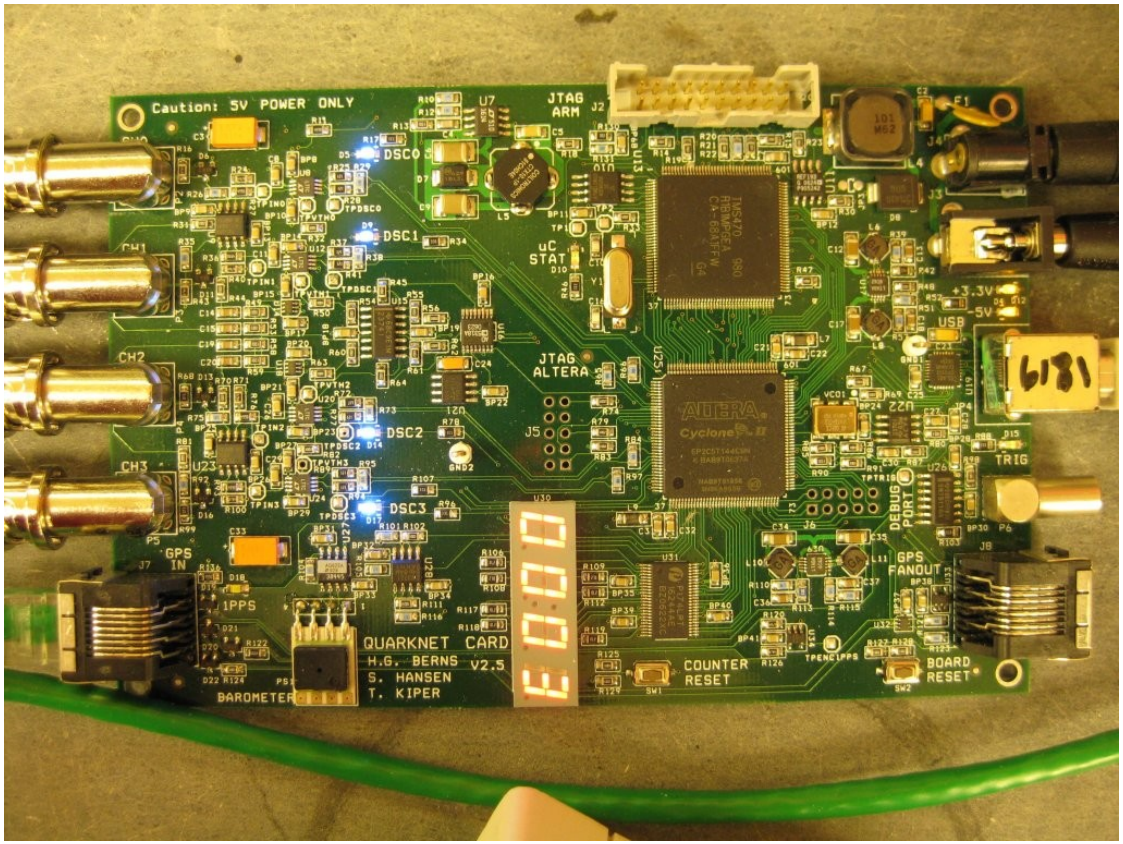
Computer: The DAQ sends data to a local computer for storage and later analysis. The hexadecimal text includes information on pulse size and GPS time for signals from each counter.

Detectors Details 1/3

DAQ board is **Quarknet v2.5**. It has 4 coax connectors for the PMT, and ethernet for the GPS, USB to communicate with the computer, input power, and a power out to an electrical box that powers the 4 PMTs. PMT voltages are no. 1, 550V; no. 2, 735V; no. 3, 925V, and no. 4, 885V, approximately.

Coax from PMT

GPS Conn

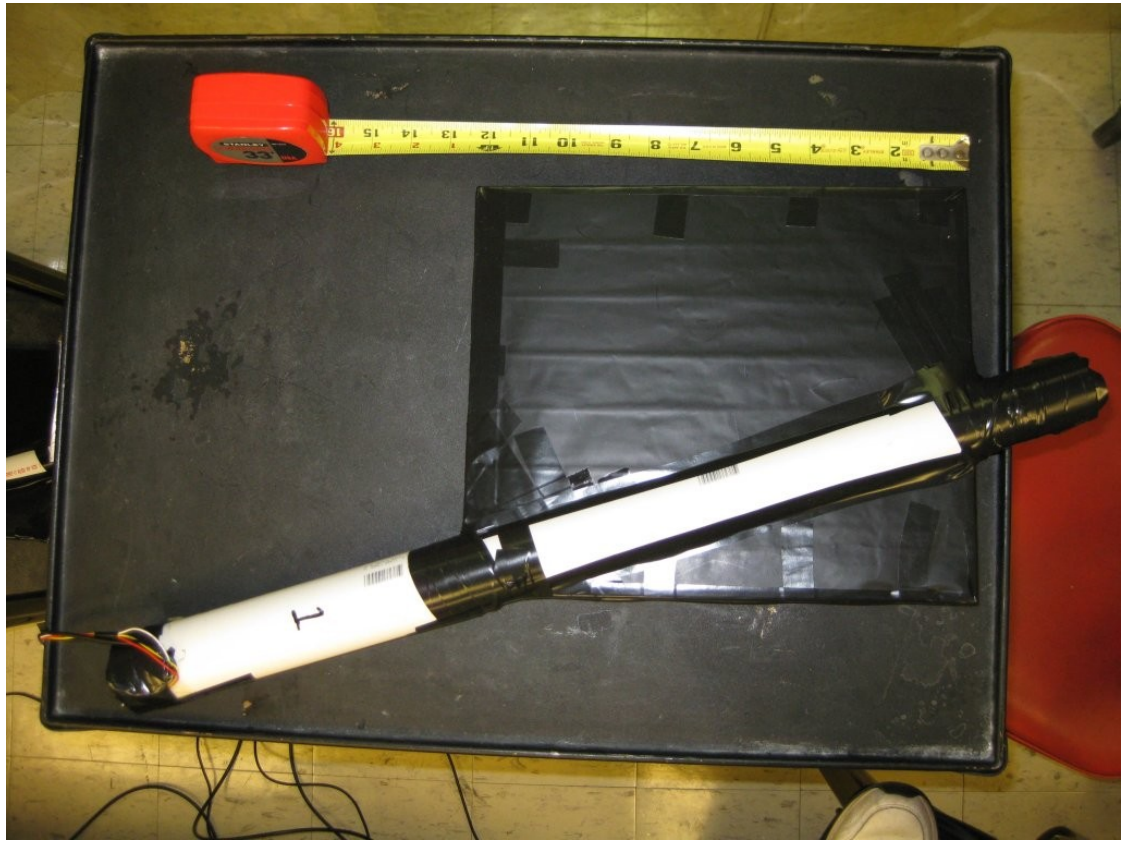


Power IN and OUT to Power Cond. for the PMTs

USB to Computer

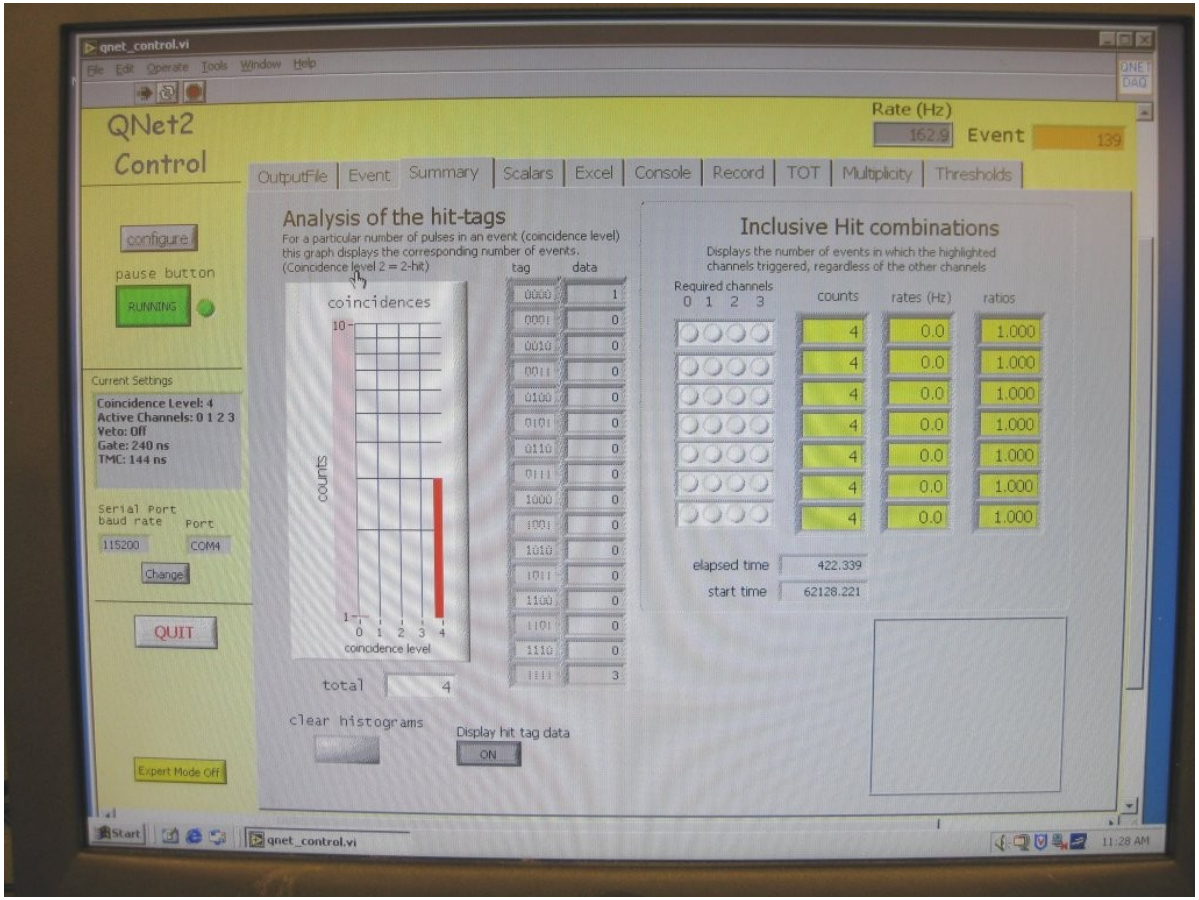
Detectors Details 2/3

Scintillator "paddle" is 12x10 inches connected to a cylindrical photomultiplier tube (PMT).



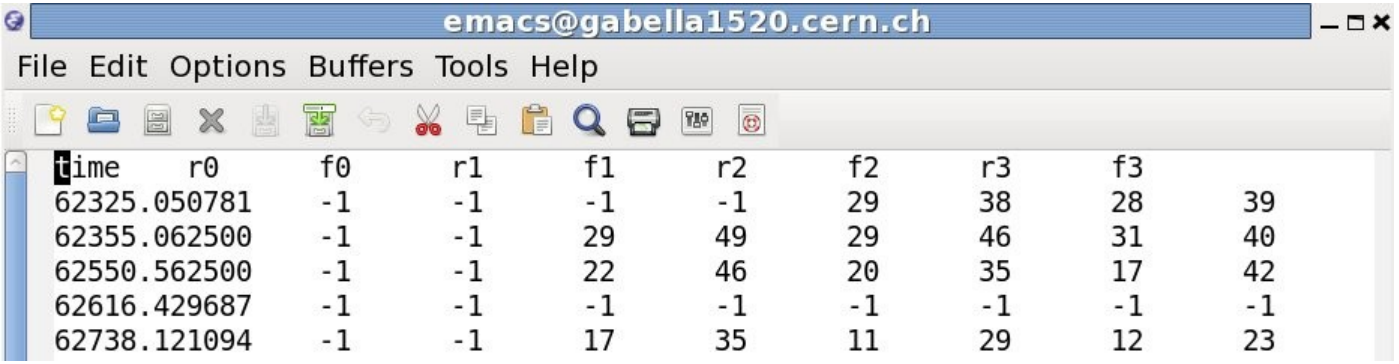
Detectors Details 3/3

On the computer a program written in LabView configures the DAQ card, receives the data, and writes to the computer files.



Data Handling - Spreadsheet 1/4

You must take data in the **Excel tab**, presumable a file with a CSV extension. The file is actually "tab separated." In an editor...



time	r0	f0	r1	f1	r2	f2	r3	f3
62325.050781	-1	-1	-1	-1	29	38	28	39
62355.062500	-1	-1	29	49	29	46	31	40
62550.562500	-1	-1	22	46	20	35	17	42
62616.429687	-1	-1	-1	-1	-1	-1	-1	-1
62738.121094	-1	-1	17	35	11	29	12	23

time - the time stamp in units of seconds
r0, r1, r2, r3 - the time at the rising edge of the corresponding PMT pulse
f0, f1, f2, f3 - the time at the falling edge of the corresponding PMT pulse
rN and **fN** time is in “ticks,” **40/32 ns = 1 tick**. Older boards use 24/32 ns = 1 tick. The two boards use two different internal clocks, new at 25.0 and older at 41.666 MHz.

Google Drive folder, http://drive.google.com

Data Handling - Spreadsheet 2/4

- Copy the file, xxxx.csv into your Google Docs/Drive area.
- Rename it xxxx.tsv (for tab separated values).
- Right Click and open the file the Google Sheets.
- Extend out the columns for our calculations: click on column “I” (the last one) and extend the column 1 right. You can use the down arrow that shows in the column. Add about 6 columns.
- Leave one blank column between the left table of numbers and the set we will calculate.
- In the next column over, “K”, put a title like “r3-r1” (that is the difference in the risetime for paddle no. 4 and no. 2).
- Under that column create a math formula for the difference, sometime like “=h2-d2” and then Copy and Paste for the whole column. Check a couple of the numbers by eye/hand. Make sure it is working.
- If there were no other delays in the signals to the computer, that column would give the speed of the particles through the paddles.

Data Handling - Spreadsheet 3/4

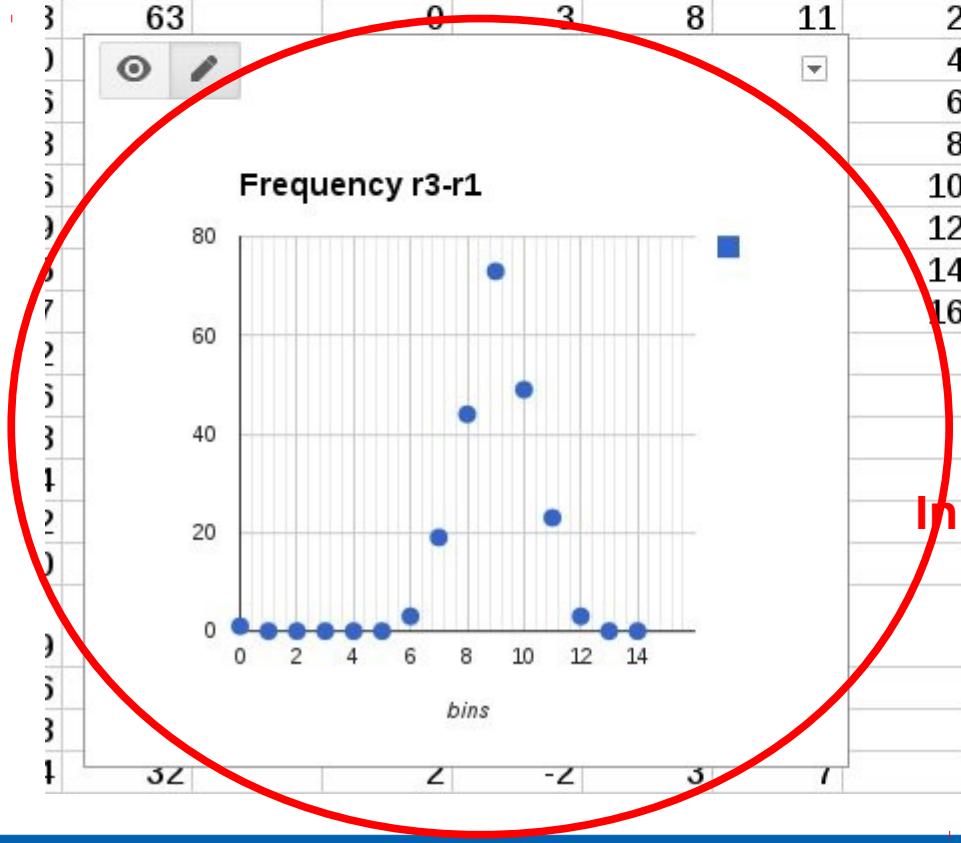
- Start looking at the differences of the risetimes.
- The units on the rise and falltimes is 40/32 ns = 1.25 ns.
- Remember the speed of light in useful units is 30 cm/ns.
- For the list of measurements of interest, do some simple statistics in the spreadsheet:
- Count the number, “= count(k2:k30)”, find the average or mean, “=average(k2:k30)”, and the standard deviation or spread in the measurements (not the *error in the mean*), “=stdev(k2:k30)”.

Data Handling - Spreadsheet 4/4

• Particle Physicists love to plot "histograms" or frequency plots. In Spreadsheets you use the “frequency” function to make a column of frequency data and then you plot it as a Scatter plot.
• It looks something like “=frequency(k2:k30; n2:n21)”. The data is k2:k30 and the set of numbers to use as bins are n2:n21.

Create bins anyway you can

	I	J	K	L	M	N	O	P	Q	R	S	T
	f3		r3-r2	r1-r0	r2-r0	r3-r1						
7	33		4	-4	4	12	14	max				
4	35		3	-3	2	8	-10	min				
5	25		5	0	2	7	from min to max	frequen	bins	frequen		
9	69		0	-3	5	8	-10	1	0	1		
2	35		6	-1	1	8	-8	0	1	0		
3	43		0	11	19	8	-6	0	2	0		
5	28		5	0	4	9	-4	0	3	0		
5	45		-3	-5	4	6	-2	0	4	0		
5	52		3	-8	0	11	0	0	5	0		
3	63		0	3	8	11	2	3	6	3		
							4	19	7	19		
5							6	44	8	44		
3							8	73	9	73		
5							10	49	10	49		
9							12	23	11	23		
5							14	3	12	3		
7							16	0	13	0		
2								0	14	0		
5									15			
3												
4												
2												
0												
										peak		
9										at	9	ticks
5										ns/tick	0.75	ns/tick
3										times	6.75	ns
4	32		2	-2	3	7						



In top cell, =frequency(N2:N216,O5:O18)

Data Handling - Results

- Look for changes in time that are all about the same.
- Toss out any obviously bad data
- Remember average speed is "change in distance / change in time"

$$V_{avg} = \frac{\Delta D}{\Delta t}$$

Websites:

Vanderbilt Particle Physics, http://www.hep.vanderbilt.edu/~focuser/index.php

Particle Adventure, http://www.particleadventure.org

Interactions (news), http://www.interactions.org/cms

Compact Muon Solenoid at the CERN LHC, http://cms.cern.ch

Cosmic Rays (wikipedia), http://en.wikipedia.org/wiki/Cosmic_ray

QuarkNet, http://quarknet.fnal.gov

Cosmic Ray e-Lab, http://www18.i2u2.org/elab/cosmic/home/

Detector Description, http://www18.i2u2.org/elab/cosmic/flash/daq_only_standalone.html

New Manual for DAQ Card