Cosmic Ray Detector Software

Studying cosmic rays has never been easier...

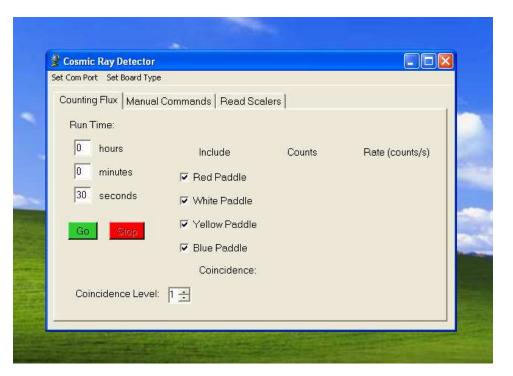
Matthew Jones *Purdue University* 2012 QuarkNet Summer Workshop

Brief History

- First cosmic ray detector built at Purdue in about 2005.
- We wanted to measure angular distribution of cosmic rays
 - Expected to follow $1+\cos^2\theta$ distribution
- The i2u2 web interface couldn't do it...
 - No way to enter the geometry (eg, independent variable, azimuthal angle)
 - No way to graph count rates as a function of angle
- We wrote a simple software interface...

Cosmic Ray Detector 3.0

• Previous versions written in Visual Basic/C



• Installed on the laptops that followed the cosmic ray detectors around Indiana.

Brief History

- Apparently quite useful:
 - You could do experiments in an hour or less
 - Fast turn-around time when graphing data
 - No need to upload data to i2u2 web site
- Still not applicable to several types of experiments:
 - Muon lifetime
 - Long term flux measurements
 - Looking for air showers
- We wanted more...
 - Frank Roetker from Jefferson High School had experience programming in Java and got the ball rolling...



Cosmic Ray Detector Java™ Interface Version 2.00

Developers: M. Jones (Purdue University) F. Roetker (Jefferson High School)

> Built using: <u>RXTX 2.1</u> <u>JFreeChart 1.0.14</u> <u>JCommon 1.0.17</u>

> > freehep-jminuit 1.0

Please report bugs/crashes to mjones@physics.purdue.edu

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Cosmic Ray Detector Java[™] Interface 2.0

- Why Java?
 - Object oriented, high level language
 - Fast to develop powerful graphical user interfaces
 - Portable to a wide variety of machines and operating systems without recompiling
- Disadvantage:
 - You first need the Java Runtime Environment
 - Easy to install if your IT people will let you...

Cosmic Ray Detector Hardware

- What does the cosmic ray detector measure?
- Two types of measurements:
 - Singles/coincidence counts (rate measurements)
 - Times of leading and trailing edges of all pulses occurring within the adjustable gate
- Main controls:
 - Selected channels + coincidence level
 - Gate width, pipeline delay
- Other controls:
 - Discriminator thresholds
 - Time interval for automatically reading out counters
 - GPS information
 - Test pulser

Software Design Model

- Send commands to the DAQ board
- Interpret data sent from the DAQ board
- A "stateless" model
 - Software does not need to remember what state the DAQ board is in
 - Don't have to worry about them getting out of sync
- The software acts as an intermediary:
 - Converts units you know and like (eg, nanoseconds or millivolts) to parameters that the DAQ board uses
 - Converts units the DAQ board uses (like hexadecimal numbers) to units you like (eg, nanoseconds, Hertz)
 - Presents the data in the form of graphs or histograms
 - Performs some of the more technical analysis of the data
- It also saves all the raw data
 - You can still upload it to i2u2 for the Cosmic Ray e-lab
 - You can export the data and read it into Excel for doing other analyses
- It helps you do experiments but it doesn't do them for you!

Software Overview

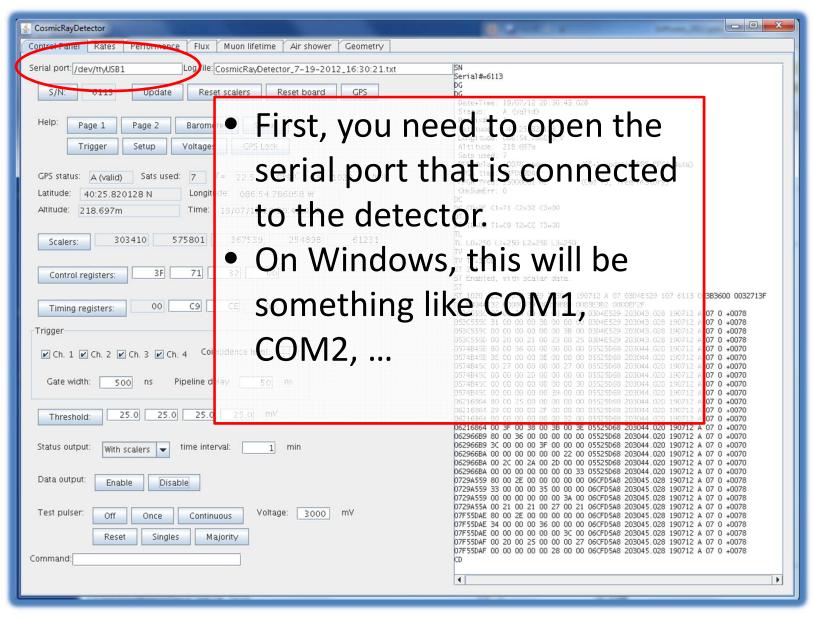
S CosmicRayDetector	
Control Panel Rates Performance Flux Muon lifetime Air shower Geometry	
Serial port: //dev/ttyUSB1 Log file: CosmicRayDetector_7-19-2012_16:30:21.txt	SN Serial#=6113
S/N: 6113 Update Reset scalers Reset board GPS	DG DG Date+Time: 19/07/12 20:30:43.028
Help:Page 1Page 2BarometerStatusTriggerSetupVoltagesGPS LockGPS status:A (valid)Sats used:7T = 22.5deg CP = 1020hPaLatitude:40:25.820128 NLongitude:086:54.786058 WAltitude:218.697mTime:19/07/12 20:30:43.028	Status: A (valid) PosFix#: 1 Latitude: 40:25.820128 N Longitude: 086:54.786058 W Altitude: 218.697m Sats used: 7 PPS delay: +0078 msec (CE=1 updates PPS,FPGA data) FPGA time: 04FD69DA FPGA time: 04FD69DA FPGA freq: 25000001 Hz (Cmd V3, freq history) ChkSumErr: 0 DC DC DC C0=3F C1=71 C2=32 C3=00 DT
Scalers: 303410 575801 367539 254898 61231	DT T0=00 T1=C9 T2=CE T3=00 TL TL L0=250 L1=250 L2=250 L3=250
Control registers: 3F 71 32 00 Timing registers: 00 C9 CE 00	TV TV TV=3000 ST 2 1 ST Enabled, with scalar data. ST ST 1020 +225 +078 3359 203043 190712 A 07 0304E529 107 6113 00383600 0032713F DS 0004A132 0008C939 00059BB3 0003E3B2 0000EF2F
Trigger Ch. 1 Ch. 2 Ch. 3 Ch. 4 Coincidence level: 4 Gate width: 500 ns Pipeline delay. 50 ns	D53C555C 80 00 2A 00 00 00 00 00 0004529 203043.028 190712 A 07 0 +0078 D53C555C 31 00 00 00 00 00 00 00 0304E529 203043.028 190712 A 07 0 +0078 D53C555C 00 00 00 00 00 00 0304E529 203043.028 190712 A 07 0 +0078 D53C555C 00 00 00 00 00 00 0304E529 203043.028 190712 A 07 0 +0078 D53C555D 00 20 00 21 00 23 00 25 0304E529 203043.028 190712 A 07 0 +0078 D5748458 3E 00 00 00 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D5748455 00 27 00 00 00 00 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 2D 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 2D 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 2D 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 00 00 00 00 00 5525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 00 00 00 00 00 5525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 00 00 00 00 00 00 5525068 203044.020 190712 A 07 0 +0070 D574845C 00 00 00 00 00 00 00 00 00 5525068 203044.020 190712 A 07 0 +0070
Threshold: 25.0 25.0 25.0 mV	06216864 80 00 25 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 06216864 29 00 00 00 2F 00 00 00 5525068 203044.020 190712 A 07 0 +0070 06216864 00 00 00 00 00 03 2 00 05525068 203044.020 190712 A 07 0 +0070 06216864 00 3F 00 38 00 38 00 3E 05525068 203044.020 190712 A 07 0 +0070
Status output: With scalers 💌 time interval: 🚺 min	D62966B9 80 00 36 00 00 00 00 00 05525D68 203044.020 190712 A 07 0 +0070 D62966B9 3C 00 00 00 3F 00 00 00 05525D68 203044.020 190712 A 07 0 +0070 D62966BA 00 00 00 00 00 22 00 05525D68 203044.020 190712 A 07 0 +0070 D62966BA 00 2C 00 2A 00 2D 00 00 05525D68 203044.020 190712 A 07 0 +0070
Data output: Enable Disable	D62966BA 00 00 00 00 00 00 03 05525068 203044.020 190712 A 07 0 40070 0729A559 80 00 2E 00 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 40078 0729A559 33 00 00 00 35 00 00 06CFD5A8 203045.028 190712 A 07 0 40078 0729A559 00 00 00 00 00 3A 00 06CFD5A8 203045.028 190712 A 07 0 40078
Test pulser: Off Once Continuous Voltage: 3000 mV Reset Singles Majority	D729A55A 00 21 00 21 00 27 00 21 06CFD5A8 203045.028 190712 A 07 0 +0078 D7F55DAE 80 00 22 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 D7F55DAE 34 00 00 36 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 D7F55DAE 00 00 00 00 00 00 00 20 06CFD5A8 203045.028 190712 A 07 0 +0078 D7F55DAF 00 20 00 25 00 00 00 27 06CFD5A8 203045.028 190712 A 07 0 +0078 D7F55DAF 00 20 00 25 00 00 00 27 06CFD5A8 203045.028 190712 A 07 0 +0078
Command:	07F55DAF 00 00 00 00 00 28 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 CD

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Software Overview

Scriel port [/dev/ttyl/SB1 Log file: CosmicRayDetector 7-19-2012_10.s0:21.txt	SN Seria]#=6113
S/N: 6113 Update Reset scalers Reset board GPS Help: Page 1 Page 2 Barometer Status Trigger Setup Voltages GPS Lock GPS status: A (valid) Sats used: 7 T = 22.5 deg C P = 1020 hPa Latitude: 40:25.820128 N Longitude: 086:54.786058 W Attitude: 218.697m Time: 19/07/12 20:30:43.028 Scalers: 303410 575801 367539 254898 61231 Control registers: 3F 71 32 00	 Different tabs select different ways to interaction with the detector. Roughly correspond to
Timing registers: 00 C9 CE 00 Trigger Ch. 1 Ch. 2 Ch. 3 Ch. 4 Coincidence level: + 4 Gate width: 500 ns Pipeline delay: 50 ns	difficercenters b 00044112 00000099 000090 000 000 000000000000
Threshold: 25.0 25.0 25.0 mV Status output: With scalers time interval: 1 min Data output: Enable Disable Test pulser: Off Once Continuous Voltage: 3000 mV Reset Singles Majority Command:	06216864 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 <

First Things First



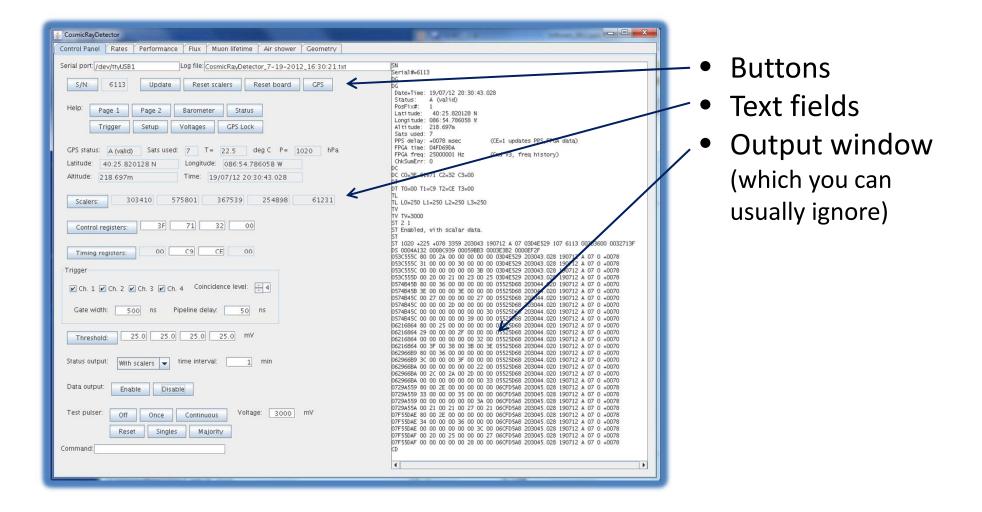
First Things First

CosmicRayDetector	
Control Panel Rates Performance Flux Haon instime Air shower Geometry	
Serial port: //dev/ttyUSB1 Log file: CosmicRayDetector_7-19-2012_16:30:21.txt	SN Seri-#=6113
S/N: 6113 Update Reset scalers Reset board GPS	DG DG Date+Time: 19/07/12 20:30:43.028
Help: Page 1 Page 2 Barometer Status	All data received is
Trigger Setup Voltages GPS Lock	Sats used: 7
GPS status: A (valid) Sats used: 7 T = 22.5 deg C P = 1020 hPa Latitude: 40:25.820128 N Longitude: 086:54.786058 W	stored in a file.
Altitude: 218.697m Time: 19/07/12 20:30:43.028	This can be uploaded to
Scalers: 303410 575801 367539 254898 61231	The second
Control registers: 3F 71 32 00	the i2u2 web site for the
Timing registers: 00 C9 CE 00	cosmic ray e-lab.
Trigger	DE3C555C C0 C0 00 C0 C0 C0 25 C0 C2/4529 202043 026 190712 A C7 0 +0078 D53C555C C0 C0 C0 C0 C0 C0 42 50 C2 6204529 202043 026 190712 A C7 0 +0078
Ch. 1 Ch. 2 Ch. 3 Ch. 4 Coincidence level: 4	05748458 60 00 36 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 05748458 3E 00 00 00 00 3E 00 00 05525068 203044.020 190712 A 07 0 +0070 15748455 00 27 0 00 00 00 00 02 70 0 05525068 203044.020 190712 A 07 0 +0070
Gate width: 500 ns Pipeline delay. 50 ns	0574845C 00 00 02 00 00 00 03 05525068 203044.020 190712 A 07 0 +0070 0574845C 00 00 03 00 00 00 03 03 05525068 203044.020 190712 A 07 0 +0070 0574845C 00 00 00 00 03 00 00 05525068 203044.020 190712 A 07 0 +0070
Threshold: 25.0 25.0 25.0 mV	b6216864 80 00 25 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 05525068 203044.020 190712 A 07 0 40070 b6216864 00 00 00 00 05525068 203044.020 190712 A 07 0 40070 b6216864 00 00 00 00 05525068 203044.020 190712 A 07 0 40070 b6216864 00 37 00 00 05525068 203044.020 190712 A 07 0 40070 b6216864 00 37 00 38 00 38 03 55255068 203044.020 190712 A 07 0 40070
Status output: With scalers 💌 time interval: 🚺 min	06296689 80 00 36 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 06296689 30 00 00 00 3F 00 00 00 05525068 203044.020 190712 A 07 0 +0070 0629668A 00 00 00 00 00 22 00 05525068 203044.020 190712 A 07 0 +0070 0629668A 00 20 00 20 00 00 5525068 203044.020 190712 A 07 0 +0070
Data output: Enable Disable	0629668A 00 00 00 00 00 00 03 305525068 203044.020 190712 A 07 0 +0070 0729A559 80 00 2E 00 00 00 00 06CF05A8 203045.028 190712 A 07 0 +0078 0729A559 33 00 00 00 35 00 00 06CF05A8 203045.028 190712 A 07 0 +0078 0729A559 00 00 00 00 03 A 00 06CF05A8 203045.028 190712 A 07 0 +0078
Test pulser: Off Once Continuous Voltage: 3000 mV	0729A55A 00 21 00 21 00 27 00 21 06CFD5A8 203045.028 190712 A 07 0 +0078 07F55DAE 80 00 2E 00 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 07F55DAE 80 00 22 00 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078
Reset Singles Majority	07F550AE 34 00 00 00 36 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 07F550AE 00 00 00 00 00 00 3C 00 06CFD5A8 203045.028 190712 A 07 0 +0078 07F550AF 00 20 00 25 00 00 00 27 06CFD5A8 203045.028 190712 A 07 0 +0078
Command:	07F55DAF 00 00 00 00 00 28 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 CD
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The Control Panel

- The Control Panel lets you control all aspects of the DAQ electronics
- Buttons send commands, text fields display the results
- This is the main way to configure it for different experiments
- Some controls you may never need to use (eg, the "Control registers")
- Some of the same controls appear on other tabs

The Control Panel

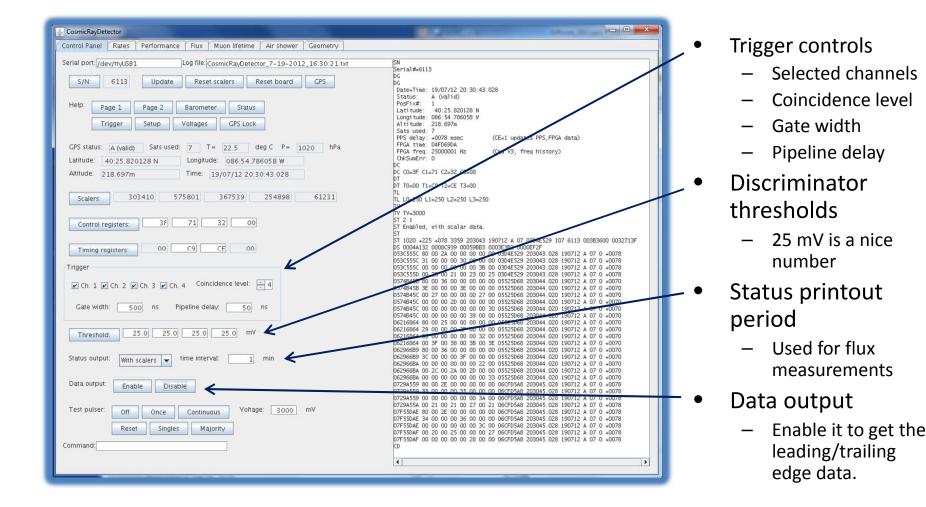


Simple Example

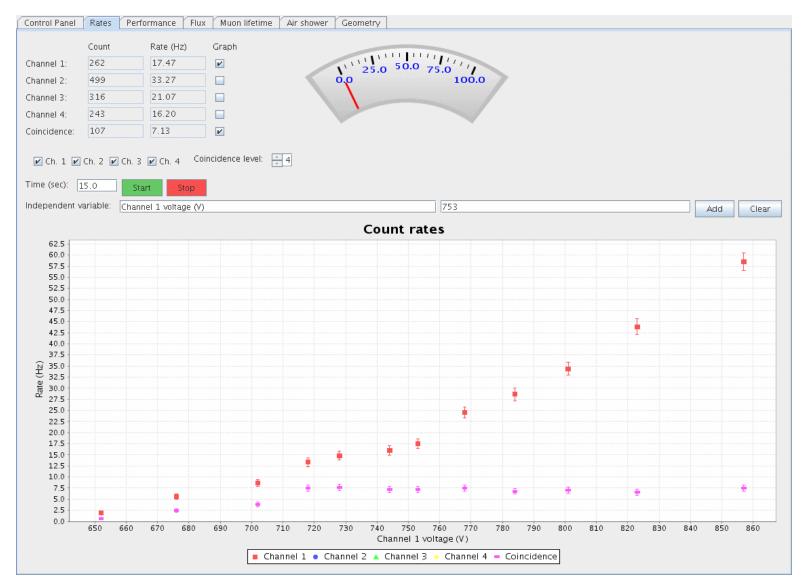
5. CosmicRayDetector	- • •
Control Panel Rates Performance Flux Muon lifetime Air shower Geometry	
	SN
Serial port: //dev/ttyUSB1 Log file: CosmicRayDetector_7-19-2012_10:30:21:th	DFT11#=6113
S/N: 6113 Update Reset scalers Reset board GPS	DG Date+Time: 19/07/12 20:30:43.028
Help: Page 1 Page 2 Parameter Status	Status: A (valid) PosFix#: 1
Help. Page 1 Page 2 Barometer Status	Latitude: 40:25.820128 N Longitude: 086:54.786058 W
Trigger Setup Voltages GPS Lock	Altitude: 218.697m Sats used: 7
GPS status: A (valid) Sats used: 7 T= 22.5 deg C P= 1020 hPa	PPS delay: +0078 msec (CE=1 updates PPS,FPGA data) FPGA time: 04FD69DA
Latitude: 40:25.820128 N Longitude: 086:54.786058 W	FPGA freq: 25000001 Hz (Cmd V3, freq history) ChkSumErr: 0
Attitude: 218.697m Time: 19/07/12 20:30:43.028	DC DC C0=3F C1=71 C2=32 C3=00
	DT T0=00 11=0-T2-CE T3=00
Scalers: 303410 575801 367539 254898 61231	TL TL L0=250 L1=250 L2=250 L3=250
	TV TV TV=3000
Control registers: 3F 71 32 00	ST 2 1 ST Enabled, with scalar data.
	ST ST 1020 +225 +078 3359 203043 190712 A 07 0304E529 107 6113 0383600 0032713F DS 00044132 0008C939 00059883 0003E382 0000EF2F
Timing registers: 00 C9 CE 00	DS3C555C 80 00 2A 00 00 00 00 00 00 00 00 00 00 00 00 00
Trigger	053C555C 00 00 00 00 00 038 00 034E529 203043.028 190712 A 07 0 4078 053C5555 00 00 00 00 02 30 02 034E529 203043.028 190712 A 07 0 4078
Ch. 1 Ch. 2 Ch. 3 Ch. 4 Coincidence level:	05748458 80 00 36 00 00 00 00 00 05525068 203044 020 190712 A 07 0 +0070 05748458 3E 00 00 03 E 00 00 00 05525068 203044 020 190712 A 07 0 +0070
	0574845C 00 27 00 00 00 00 27 00 05525068 203044 020 190712 A 07 0 +0070 0574845C 00 00 00 20 00 00 00 00 05525068 203044 020 190712 A 07 0 +0070
Gate width: 500 ns Pipeline delay: 50 ns	0574845C 00 00 00 00 00 00 00 30 05525068 203044.020 190712 A 07 0 +0070 0574845C 00 00 00 00 00 39 00 00 5525068 203044.020 190712 A 07 0 +0070
Threehold: 25.0 25.0 25.0 mV	06216864 80 00 25 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 06216864 29 00 00 02 F 00 00 05525068 203044.020 190712 A 07 0 +0070
Threshold: 25.0 25.0 25.0 mV	06216864 00 00 00 00 00 00 32 00 05525068 203044.020 190712 A 07 0 +0070 06216864 00 3F 00 38 00 38 00 3E 05525068 203044.020 190712 A 07 0 +0070
Status output: With scalers 💌 time interval: 1 min	06296689 80 00 36 00 00 00 00 00 05525068 203044.020 190712 A 07 0 +0070 06296689 3C 00 00 00 3F 00 00 00 05525068 203044.020 190712 A 07 0 +0070
With Scales V	0629668A 00 00 00 00 00 00 22 00 05525068 203044.020 190712 A 07 0 +0070 0629668A 00 2C 00 2A 00 2D 00 00 05525068 203044.020 190712 A 07 0 +0070
Data output: Enable Disable	D629668A 00 00 00 00 00 00 00 33 05525068 203044.020 190712 A 07 0 +0070 D729A559 80 00 2E 00 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078
	0729A559 33 00 00 00 35 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078 0729A559 00 00 00 00 00 00 3A 00 06CFD5A8 203045.028 190712 A 07 0 +0078
Test pulser: Off Once Continuous Voltage: 3000 mV	0729A55A 00 21 00 21 00 27 00 21 06CFD5A8 203045.028 190712 A 07 0 +0078 07F55DAE 80 00 2E 00 00 00 00 00 06CFD5A8 203045.028 190712 A 07 0 +0078
Reset Singles Majority	D7F550AE 34 00 00 00 36 00 00 00 06CF05A8 203045.028 190712 A 07 0 +0078 D7F550AE 00 00 00 00 00 00 3C 00 06CF05A8 203045.028 190712 A 07 0 +0078 D7F550AF 00 20 00 25 00 00 02 7 06CF05A8 203045.028 190712 A 07 0 +0078
Command:	07F550AF 00 20 00 25 00 00 00 27 06CF05A8 203045.028 190712 A 07 0 40078 07F550AF 00 00 00 00 28 00 00 06CF05A8 203045.028 190712 A 07 0 +0078 CD
Setting the set of the	

- Push the "GPS" button
- It sends "DG" to the DAQ board,
- Parses the output,
- 4. Displays the results

Main Controls



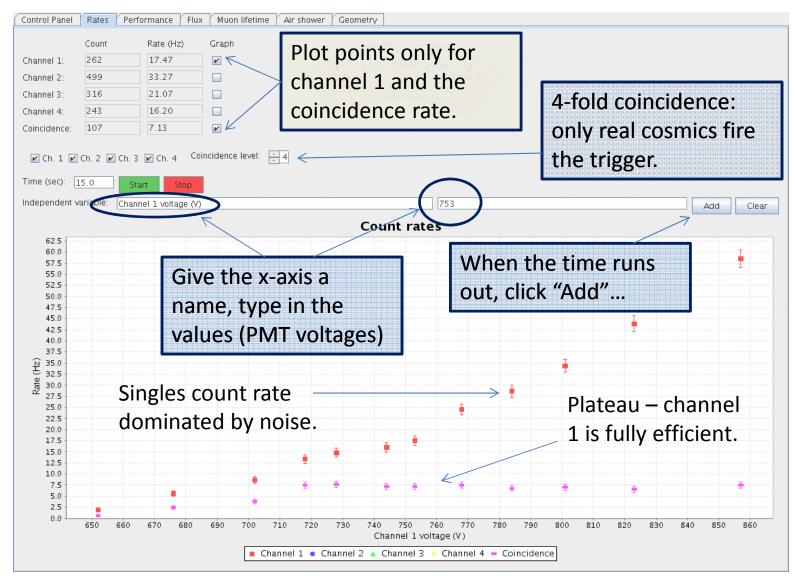
Rate Panel



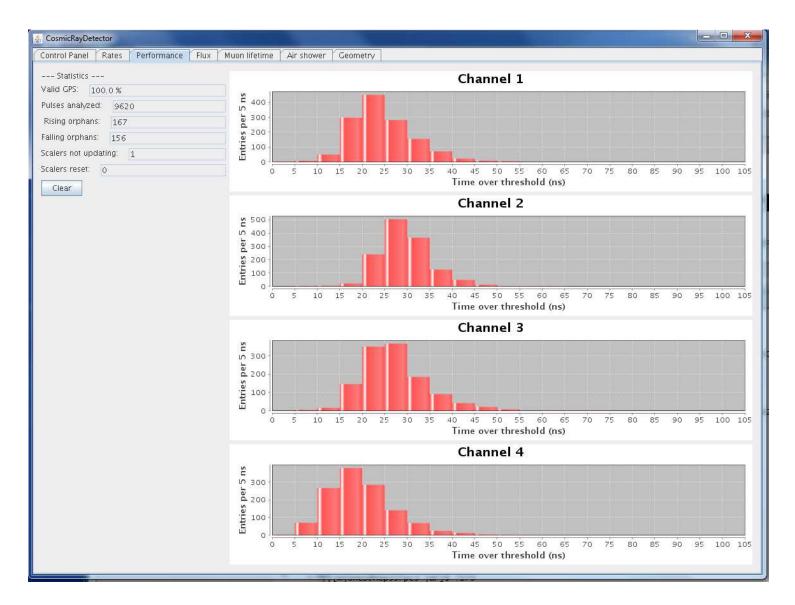
Rate Panel

- This closely resembles the old "Cosmic Ray Detector 3.0" program:
 - It measures count rates and coincidence rates in a specified time interval
- Now it can graph the results for you
- Select which channels to put on the graph
- Independent variable is not specified... you can pick anything you want!
 - PMT voltage (eg, plateauing exercise)
 - Which floor of the building you are on
 - Azimuthal angle
 - Distance between the scintillators
 - Altitude (if you can fly the detector in an airplane)
 - ???

Plateauing Example



Performance Panel

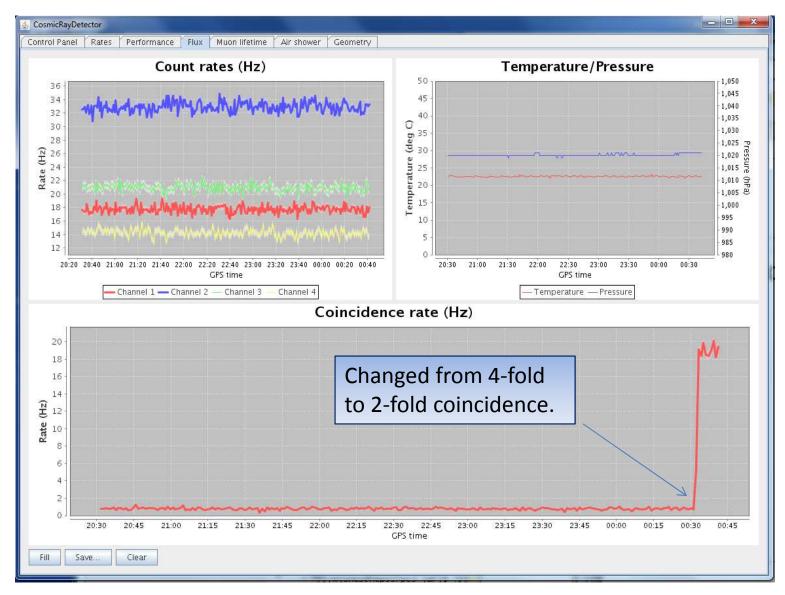


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Performance Panel

- Makes histograms of time-over-threshold
- Don't forget to enable data output!
- Checks data stream for:
 - Valid/invalid GPS data
 - Rising orphans (pulses that are cut off by the gate)
 - Falling orphans (pulses that arrived before start of the gate)
 - Number of times the counters didn't change
 - Number of times the counters were reset
- Roughly corresponds to criteria used to "bless" data sets uploaded for the cosmic ray e-lab
- Examples:
 - Compare time-over-threshold distributions as the discriminator threshold is changed...
 - Compare distributions with single and 4-fold coincidence.
 - Are noise pulses and pulses from cosmics the same or different?

Flux Panel

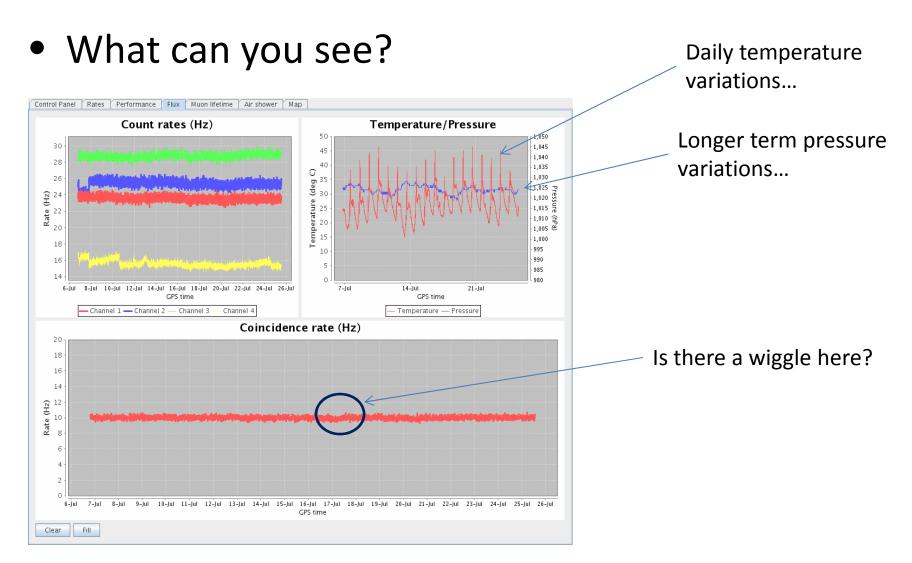


Flux Panel

- Produces long-term graphs of count rates vs time.
- Also graphs barometric pressure and temperature vs time.

	S CosmicRayDetector	
	Control Panel Rates Performance Flux Muon lifetime Air shower Geometry	
	Serial port //dev/ttyUSB1 Log file: CosmicRayDetector_7-19-2012_16:30:21.txt S/N: 6113 Update Reset scalers Reset board CPS	461CA7A8 80 00 90 00 00 00 458524C0 003356.030 200712 A 07 +0060 461CA7A9 23 00 00 00 00 458524C0 003356.030 200712 A 07 +0060 461CA7A9 00 00 00 458524C0 003356.030 200712 A 07 +0060 461CA7A9 00 00 00 00 458524C0 00356.030 200712 A 07 +0080 462C474CE 80 02 70 00 00 458524C0 003356.032 200712 A 07 +0080 462244CEE 80 07 00 00 00 45824C0 003356.032 200712 A 07 +0080 462244CEE 85 00 00 00 45824C0 003356.032 200712 A 07 +0080
	Help: Page 1 Page 2 Barometer Status Trigger Setup Voltages GPS Lock	4c244CEF 00 00 00 2E 00 00 00 00 458524C0 003356.030 200712 A 07 0.4080 4c244CEF 00 34 00 00 00 00 00 04 58524C0 003356.030 200712 A 07 0.4080 4c66493A 80 00 00 02 2B 00 00 00 458524C0 003356.030 200712 A 07 0.4080 4c66493A 00 00 00 00 00 03 50 0 458524C0 003356.030 200712 A 07 0.4080 4c66493A 00 00 00 00 00 03 50 0 458524C0 003356.030 200712 A 07 0.4080 4c66493A 00 00 00 00 00 00 35 00 458524C0 003356.030 200712 A 07 0.4080
	GPS status: A (valid) Sats used: 7 T = 22.4 deg C P = 1021 hPa Latitude: 40:25.820128 N Longitude: 086:54.786058 W Attitude: 19/07/12 20:30:43.028	468713C0 80 00 00 33 0.37 00 45824C0 003356.03 200712.4 07 0.4080 468713C1 00 00 00 00 00 20 00 45824C0 003356.03 200712.4 07 0.4080 468713C1 00 00 00 00 00 27.42 00 35.03 200712.4 07 -0080 468713C1 00 00 00 00 27.42 00.035.03 200712.4 07 -0080 46879591 00 00 00 35.03 200712.4 07 -0080 46879591 00 00 00 35.03 200712.4 07 -0080 468047958 00 00 00 36.424C0 00336.03 200712.4 0.07 0.4080 468047958 00 37.00 00.00 00 45424C0 00336.03 200712.4 0.07 0.4080
Set status output	Scalers: 578274 1086123 692266 475908 92438	#66A9F5C 24 00 00 00 00 00 00 45824C0 003356 030 200712 A 70 +0080 #66A9F5C 00 00 00 00 00 00 200712 A 70 +0080 #66A9F5C 00 00 00 00 00 00 200712 A 70 +0080 #66L1086 00 28 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
to "with scalers"	Control registers: 1F 71 32 00	46(73047 80 00 00 00 22 00 00 00 458524(0 00356.030 200712 A 07 0 -0080 46(73047 00 00 00 00 00 00 2A 00 458524(0 00356.030 200712 A 07 0 -0080 46(73047 00 00 00 00 00 34 00 33 458524(0 003356.030 200712 A 07 0 +0080
	Timing registers: 00 C9 CE 00 Trigger Image: Ch. 1 Image: Ch. 2 Image: Ch. 3 Image: Ch. 4 Coincidence level: 1/2 1/2	L1 1021 -225 -000 359 002413 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 000855 00101F4 00A0485 000710A 0001258A 55 10026 57 0101744 0004859 000710A 0001258A 55 1021 -226 -000 3359 00354 200712 A 05 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 3359 003614 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 3359 003614 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 3359 003714 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 3359 003714 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 3359 003714 200712 A 06 0000000 107 6113 00ACA700 0032701F 55 1021 -227 -000 359 00374 200712 A 06 0000000 107 6113 00ACA700 0032701F
	Gate width: 500 ns Pipeline delay. 50 ns Mareshold: 25.0 25.0 25.0 mV	ST 1021 +226 +000 3359 003814 200712 A 08 0000000 107 6113 00ACA700 0032701F D5 0006A75 001103B0 000A5418 000716E1 00013700 ST 1021 +226 +080 3359 003914 200712 A 06 0000000 107 6113 00ACA700 0032701F D5 0000A9F 0010459E 000A5F48 000721CF 00013C39 ST 1021 +225 +080 3359 004014 200712 A 06 0000000 107 6113 00ACA700 0032701F D5 0008A9C0 00104052 000A914 200712 A 06 0000000 107 6113 00ACA700 0032701F D5 0008A9C0 00104052 000A914 20072 A 07 0000000 107 6113 00ACA700 0032701F
This just analyzes count	Status output: With scalers V time interval: 1 min	b5 00088209 0010522 00046912 00072830 0001450F 51 1021 -225 400 3359 004214 200724 A 06 00000000 107 6113 004C4700 0032701F p5 00088624 00105CE1 000460FB 0007287E 00014991 51 1021 +225 400 3359 004315 200712 A 08 00000000 107 6113 004C4700 0032701F p5 00088471 001644A 004726P 0007268E 0001463F
rates, not leading/trailing	Data output: Enable Disable Test pulser: Off Once Continuous Voltage: 3000 mV	ST 1021 +227 -080 3359 004415 200712 A 08 0000000 107 6113 004CA700 0032701F b5 0008269 00186C10 000A778 00073248 00015202 ST 1021 +227 -080 3359 004515 200712 A 10 0000000 107 6113 004CA700 0032701F b5 00062C42 001075C4 00047C6 0007577 00015767 ST 1021 +228 -080 3359 004615 200712 A 08 0000000 107 6113 004CA700 0032701F b5 00062c40 00107842 00048149 0007328 000158ED
edges, so you can disable	Reset Singles Majority	ST 1021 +226 +060 3359 004715 200712 A 06 0000000 107 6113 00ACA700 0032701F D5 0005CAC 00108315 000A6675 0007524 00016028 ST 1021 +225 +060 3359 004815 200712 A 08 0000000 107 6113 00ACA700 0032701F D5 0005CE0 00108810 000A6823 0007940 00016916 ST 1021 +224 +060 3359 004915 200712 A 07 0000000 107 6113 00ACA700 0032701F D5 00080252 001829A8 0004920 00073404 00016916
data output.		

Flux Panel



Solar Weather

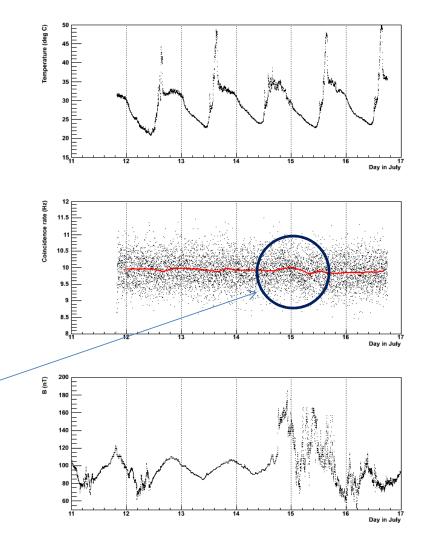
- Solar flares produce lots of protons that eventually reach earth
- They are low energy protons
 - They do not make cosmic rays
 - They do modify the Earth's magnetic field
- The Earth's magnetic field deflects high energy protons
 - Modification of the Earths' magnetic field should affect counting rates
 - But by how much?
- Can we observe solar flares?

Solar Flares

- Some resources:
 - NOAA satellite data: <u>http://www.swpc.noaa.gov/Data/index.html</u>
 - Spaceweather.com:
 http://www.spaceweather.com
- NASA satellites measure the strength of the magnetic field every minute.
 - You can download the data for free
 - You can graph it in Excel (or whatever)

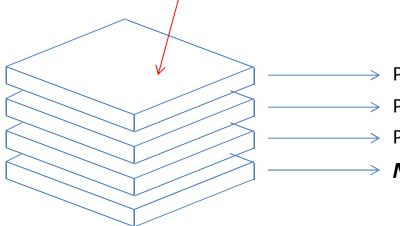
Solar Flares?

- This one was announced in the newspaper about 3 days before it arrived at earth.
- Four stacked counters with 3fold coincidence
- Counts read out every minute (lots of scatter)
- Averaged over 4 hour intervals.
- Maybe the blip is correlated with the magnetic field
- This was a relatively small flare...



Muon Decay Trigger

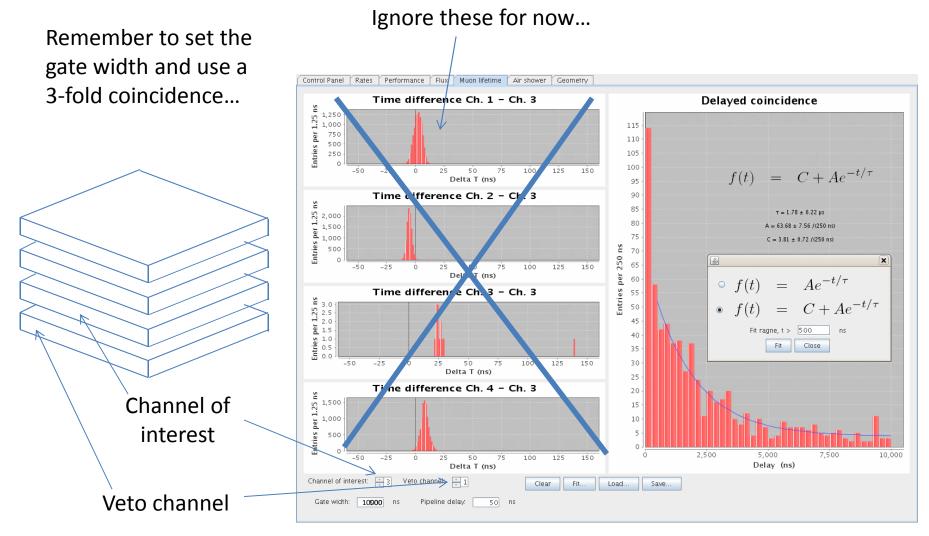
• We want to identify events where a muon stops in one of the scintillators and then decays... $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ with $\tau = 2.2 \ \mu s$



Pulse from muon entering stack
 Pulse from muon passing through stack
 Pulse from muon stopping, another from the decay
 No pulse

Require 3-fold coincidence GATE WIDTH = 10,000 ns PIPELINE DELAY = 20 ns This isn't *exactly* what we want because it triggers on any 3 channels, but the trigger rate is low enough that we can examine each event to see if it is just the top three channels with pulses. 28

Muon Lifetime (delayed coincidence)



Muon Lifetime

- In about an hour you should get 5-10 muon decay events.
 - Leave it running over night or over the weekend for better statistics
- The fit panel lets you chose whether to consider the possibility of a background component distributed uniformly in time.
- You can skip the early data since these might come from air showers.
 - How does the fitted lifetime depend on these assumptions?
 - How much data would you need to measure the muon lifetime with a precision of 10%?
 - How about 1%?

Measuring the Speed of Cosmic Rays

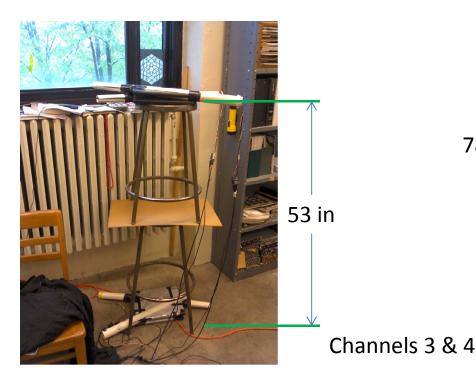
- The "Muon Lifetime" panel also measures the time between pulses on each channel and the "channel of interest"
- It calculates the mean (with uncertainty) of the time difference distributions.
- The time between pulses depends on the distance between the scintillators.
- Remember, the speed of light is 1 ft/ns...

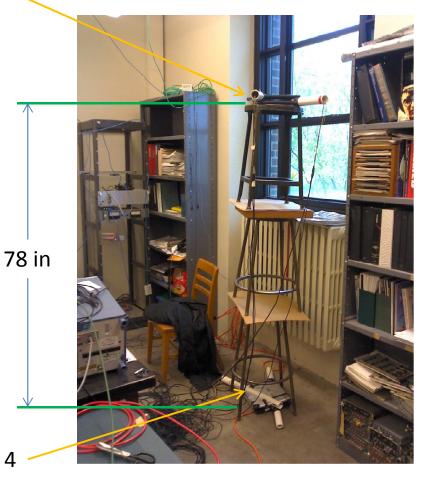
Measuring Speed of Cosmic Rays

Use a 4-fold coincidence trigger.

Channels 1 & 2

Channel 3 was the "channel of interest". Pulse in channel 1 should arrive earlier when it is up higher.





Speed of Cosmic Rays

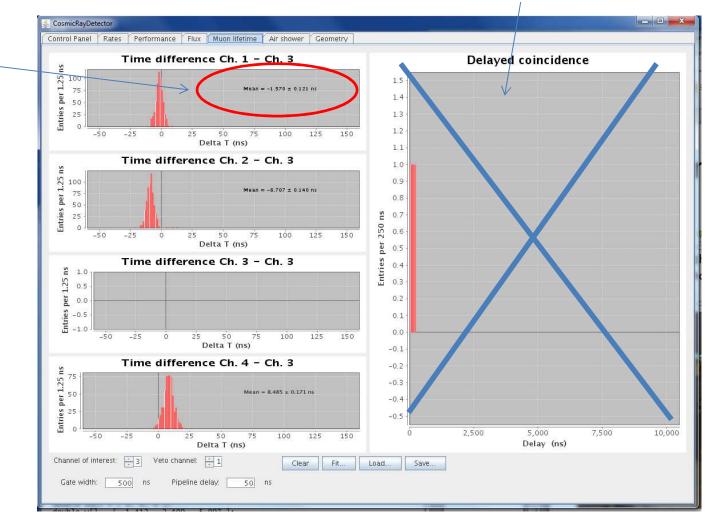
Ignore this for now...

Record the mean time difference at each height...

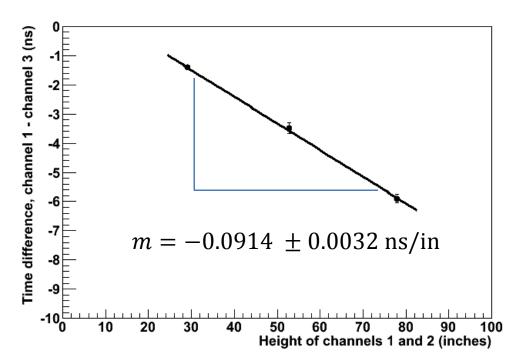
You may want to record this for all channels (except the channel of interest).

The mean is estimated more precisely the more data you collect.

Counting rates are less than 1 Hz but greater than 0.1 Hz.



Speed of Cosmic Rays



We graph it this way because the height is the *independent variable*.

The slope is 1/v. It is negative because we measured height up, but cosmic rays are going down.

Fitted speed: $v = 10.95 \pm 0.39$ in/ns Accepted speed of light: c = 11.80 in/ns

Conclusion: On average, the cosmic rays we detect might not travel at exactly the speed of light, but they are still moving pretty fast!

Connection with Special Relativity

– If the muon lifetime is 2.2 μs and they travel 200,000 inches (5 km) at 11 in/ns, what fraction will **not** have decayed?

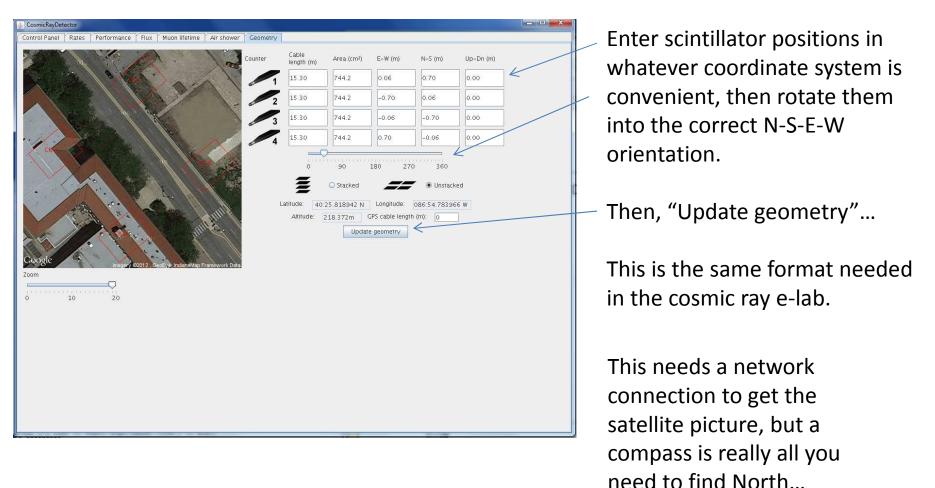
$$t = \frac{d}{v} = \frac{200,000 \text{ in}}{11 \text{ in/ns}} = 18,000 \text{ ns}$$
$$P = e^{-t/\tau} = exp\left(-\frac{18,000 \text{ ns}}{2,200 \text{ ns}}\right) = 0.03\%$$

 This is not correct... because of special relativity, the muon's "clock" runs slow by a factor of

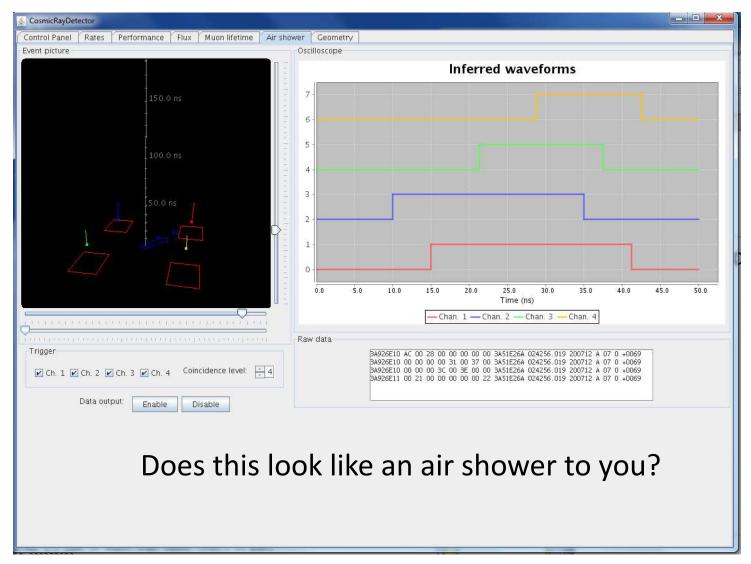
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = 2.8$$
$$P = e^{-t/\gamma\tau} = 5.3\%$$

Air Showers

• First check out the geometry tab:



Air Showers



- Count rates:
 - Plateauing exercise
 - Coincidence rates with detector oriented N-S or E-W or as a function of angle
 - Count rates on different floors of the building
 - Does anyone have a pilot's license? Could we fly the cosmic ray detector in an airplane and measure count rates as a function of altitude?
 - Measure count rates for different discriminator thresholds
 - Measure actual thresholds using the test pulser

- Performance plots
 - Compare time-over-threshold distributions for single and 3-fold coincidence
 - How does time-over-threshold distribution change with PMT voltage?
 - How does time-over-threshold distribution change with discriminator threshold?
 - Play with the test pulser...

- Flux measurements:
 - Does the 3-fold coincidence rate depend on barometric pressure? Temperature? Weather?
 - Can you see evidence for solar flares? Correlate wiggles in count rate with NASA satellite data...
 - Are count rates at different locations correlated?

- Muon lifetime/delayed coincidence
 - How much data do you need to collect to achieve a certain precision on the fitted lifetime?
 - How does the fitted lifetime depend on the assumptions used in the fit? How robust is it?
 - Speed of cosmic rays... fit data using linear regression in Excel. Can you estimate the uncertainty on the speed?
 - Add extra cable... check that the time differences change the way you expect.

Summary

- We hope that the new software interface makes the cosmic ray detector very easy to use.
- There are lots of experiments you can do to investigate the properties of cosmic rays.
- Most can be done or at least set up in less than an hour.
- Have fun!