Cosmic Ray Detector Software

Studying cosmic rays has never been easier…

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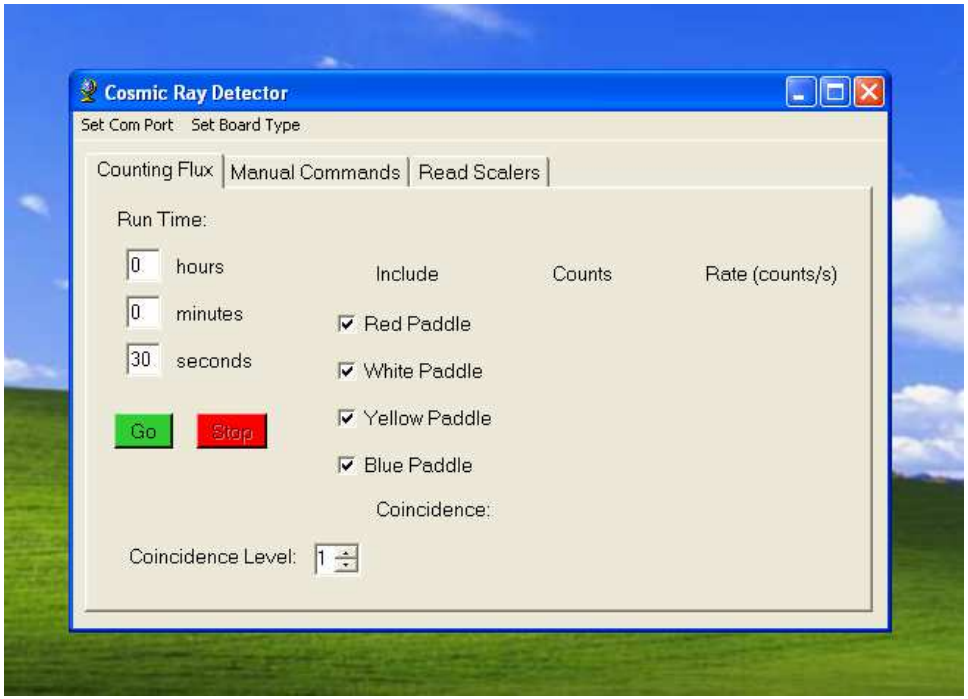
2012 QuarkNet Summer Workshop

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: RXTX 2.1
JFreeChart 1.0.14
JCommon 1.0.17
freehep-jminuit 1.0

Please report bugs/crashes to
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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…

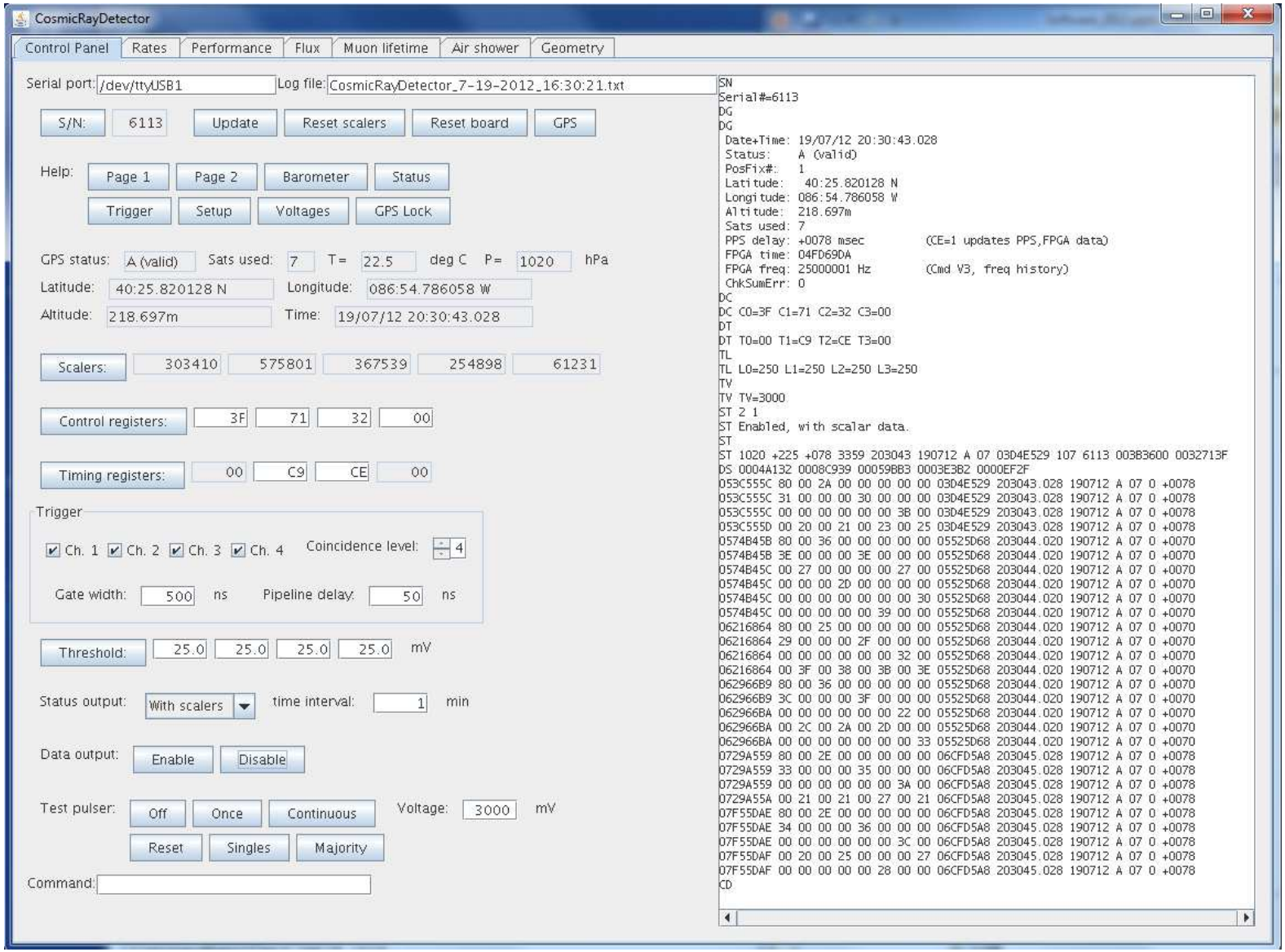
Cosmic Ray Detector Hardware

- 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

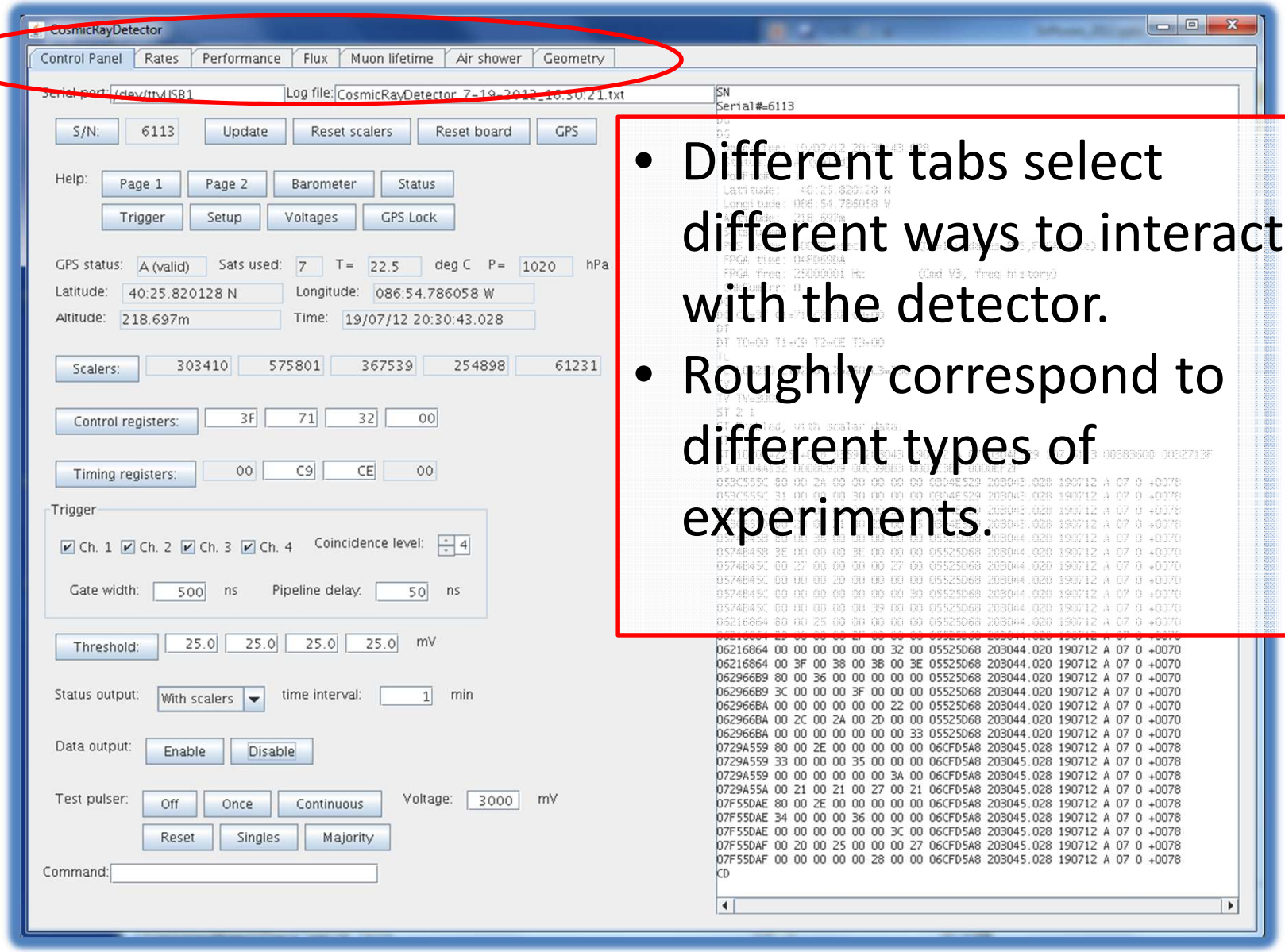
Software Design Model

- 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

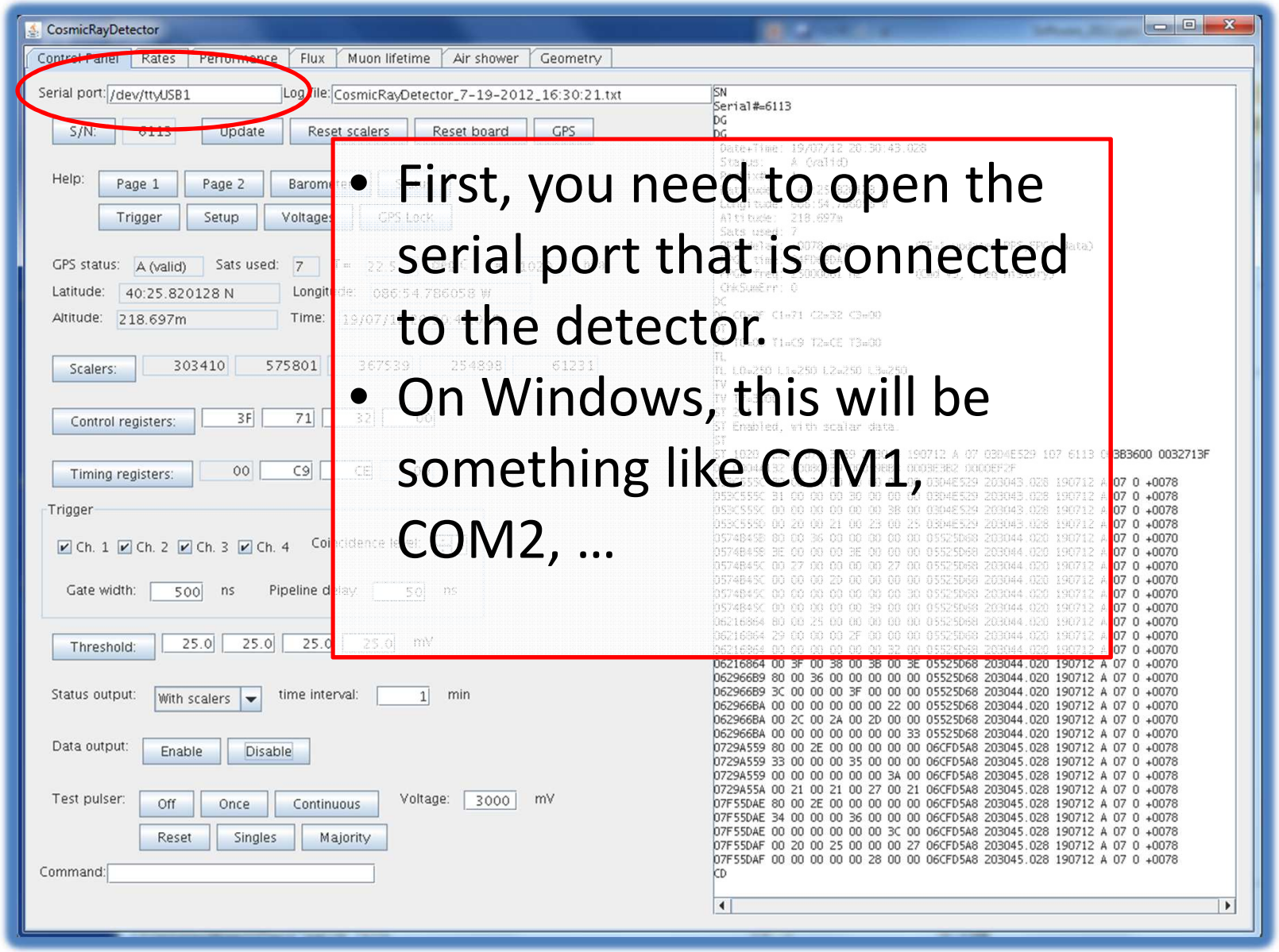


Software Overview



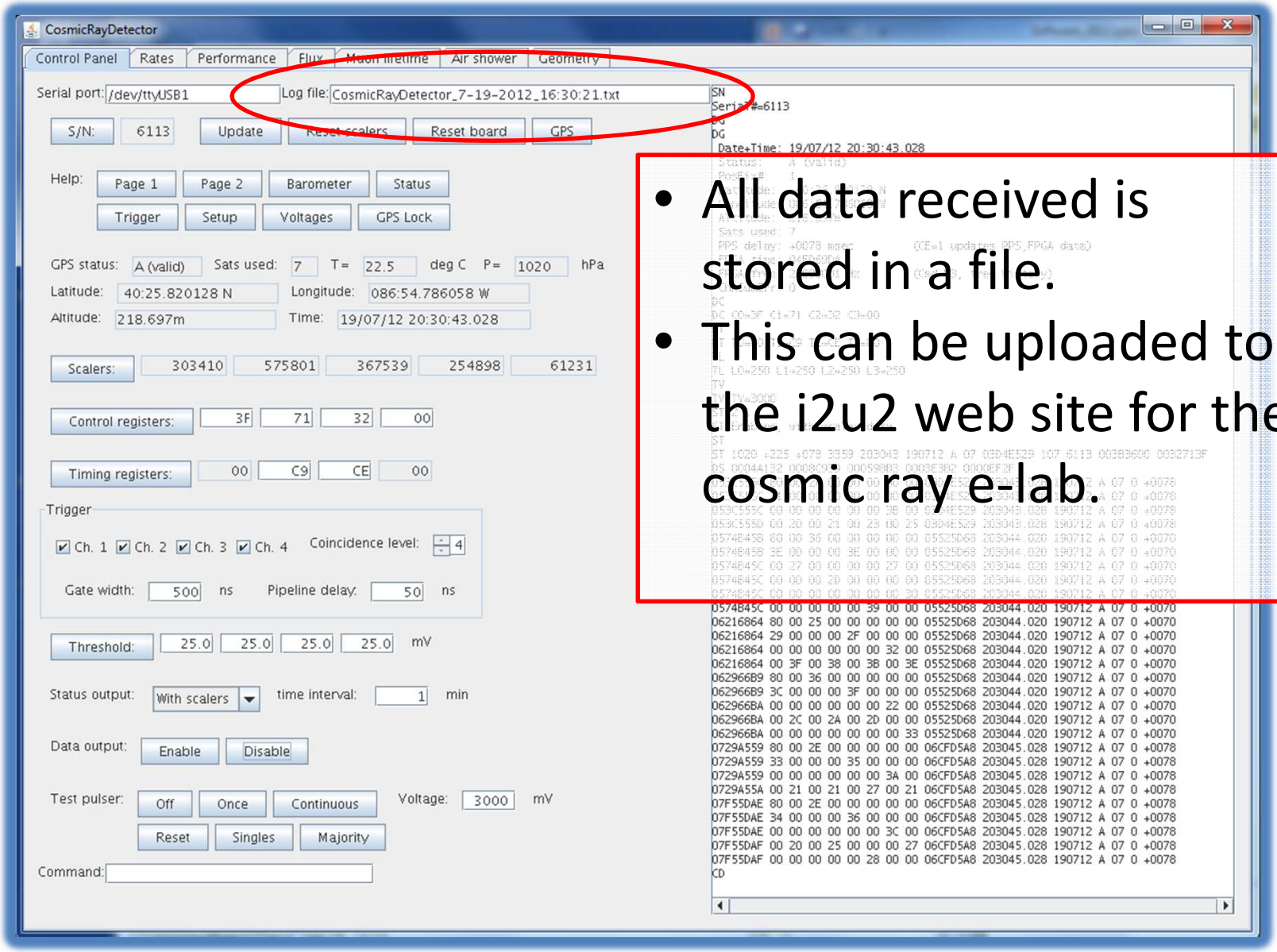
- Different tabs select different ways to interact with the detector.
- Roughly correspond to different types of experiments.

First Things First



- First, you need to open the serial port that is connected to the detector.
- On Windows, this will be something like COM1, COM2, …

First Things First

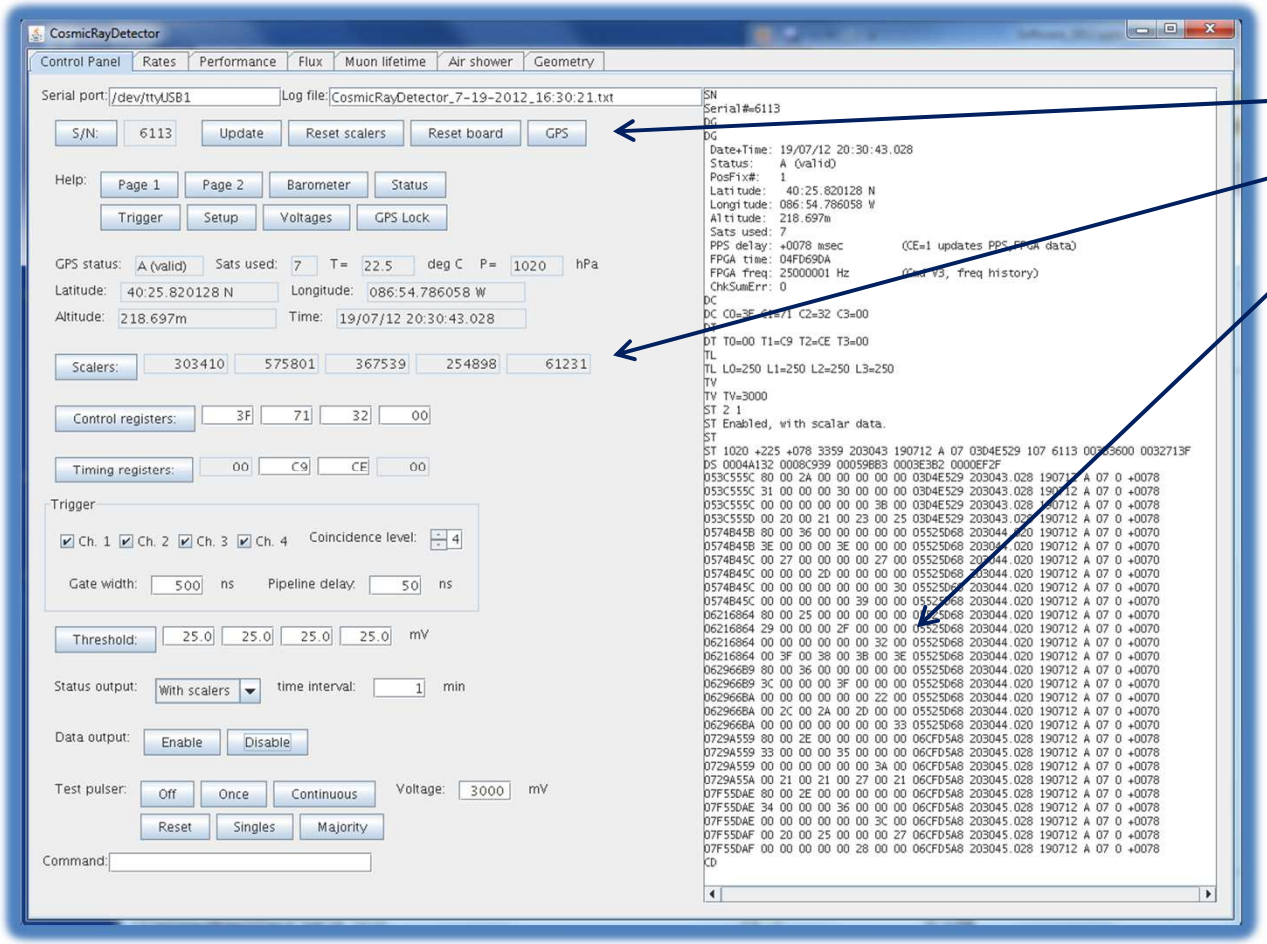


- All data received is stored in a file.
- This can be uploaded to the i2u2 web site for the cosmic ray e-lab.

The Control Panel

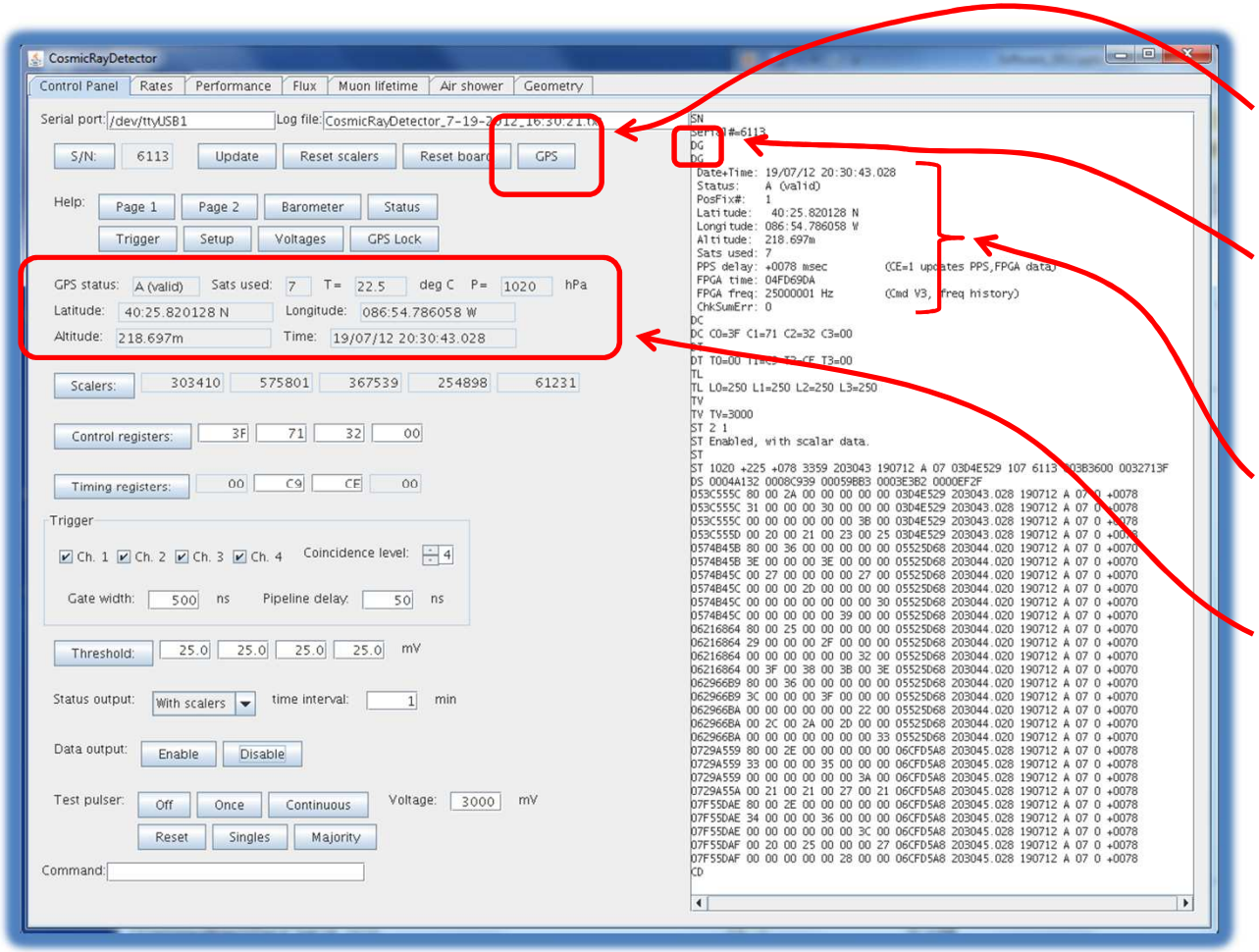
- The Control Panel lets you control all aspects of the DAQ electronics
- Buttons send commands, text fields display the results
- This is the main way to configure it for different experiments
- Some controls you may never need to use (eg, the “Control registers”)
- Some of the same controls appear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

The Control Panel



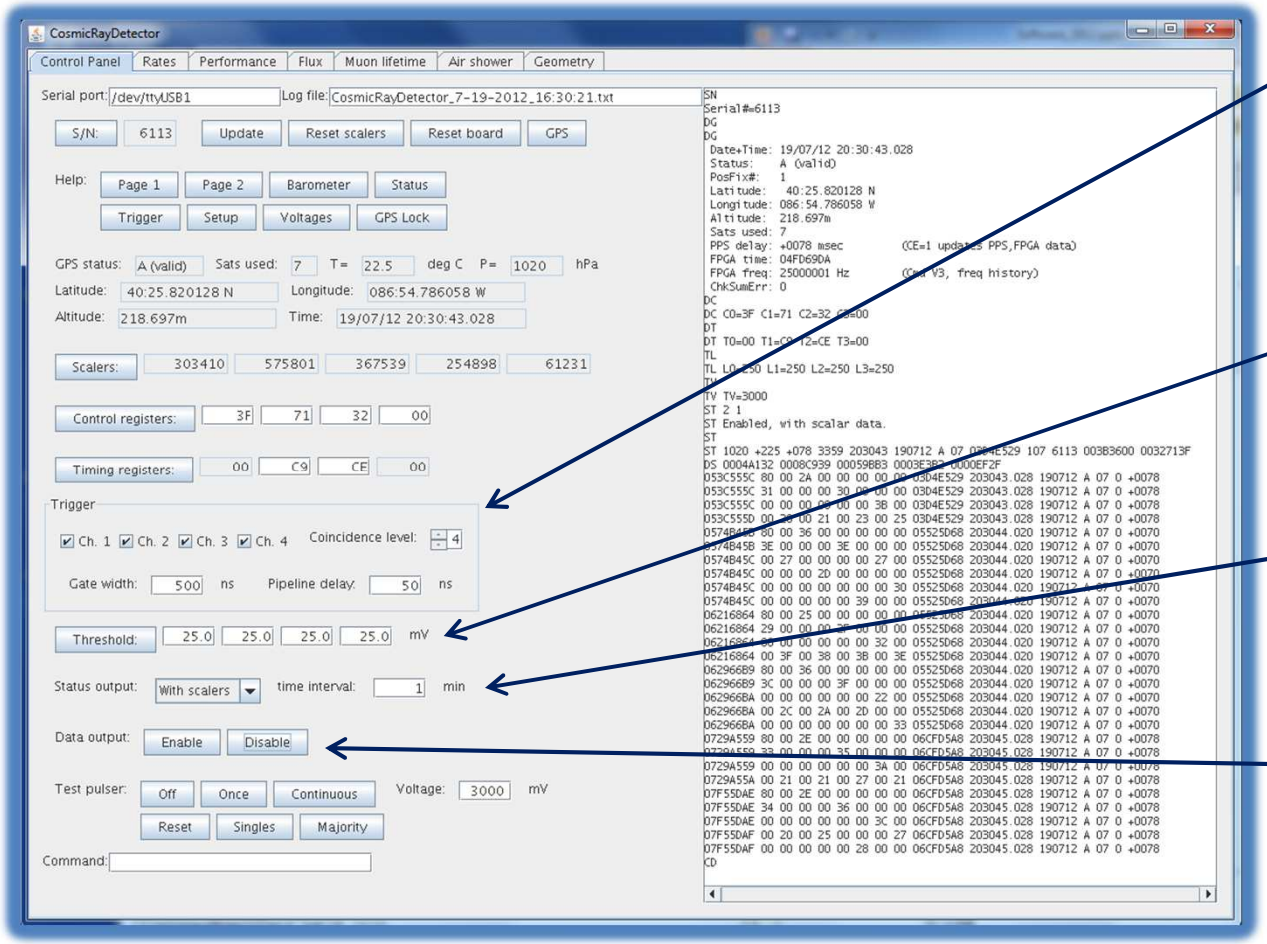
- Buttons
- Text fields
- Output window (which you can usually ignore)

Simple Example



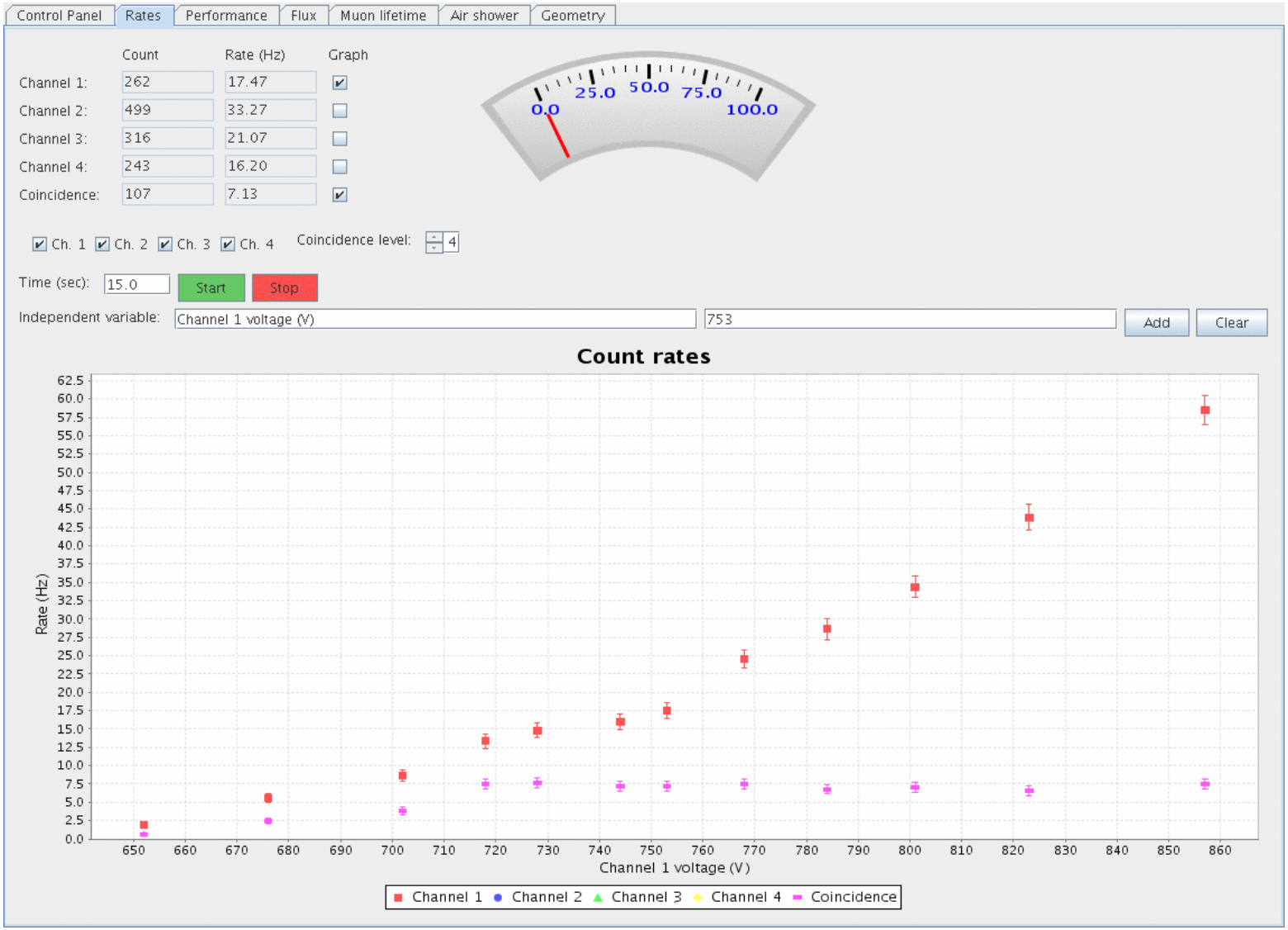
1. Push the “GPS” button
2. It sends “DG” to the DAQ board,
3. Parses the output,
4. Displays the results

Main Controls



- Trigger controls
  - Selected channels
  - Coincidence level
  - Gate width
  - Pipeline delay
- Discriminator thresholds
  - 25 mV is a nice number
- Status printout period
  - Used for flux measurements
- Data output
  - Enable it to get the leading/trailing edge data.

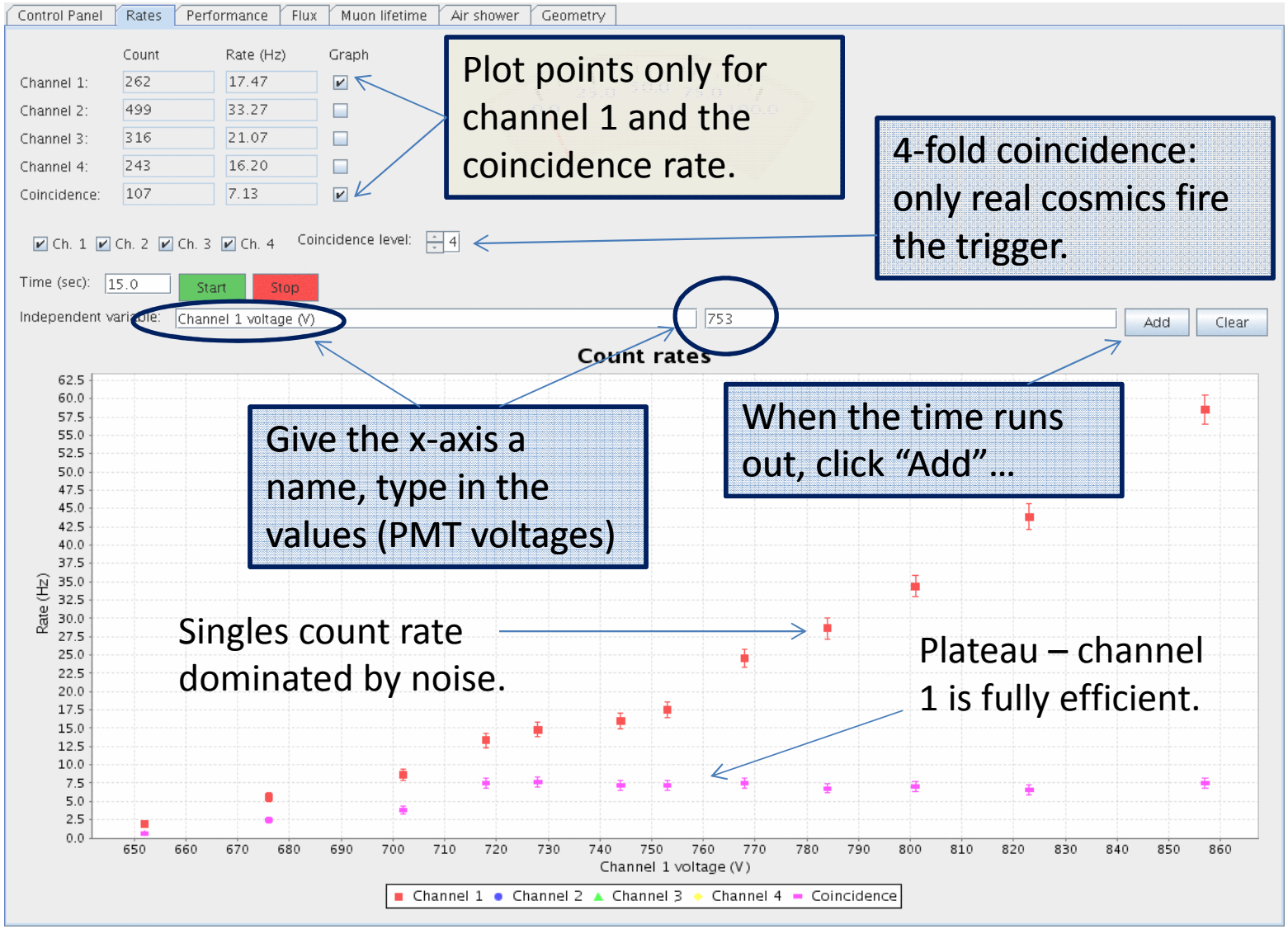
Rate Panel


Control Panel
Rates
Performance
Flux
Muon lifetime
Air shower
Geometry
Count
Rate (Hz)
Graph
Channel 1: 262 17.47
Channel 2: 499 33.27
Channel 3: 316 21.07
Channel 4: 243 16.20
Coincidence: 107 7.13
0.0
25.0
50.0
75.0
100.0
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Coincidence level: 4
Time (sec): 15.0
Start
Stop
Independent variable: Channel 1 voltage (V)
753
Add
Clear
Count rates
Rate (Hz)
Channel 1 voltage (V)
Channel 1
Channel 2
Channel 3
Channel 4
Coincidence

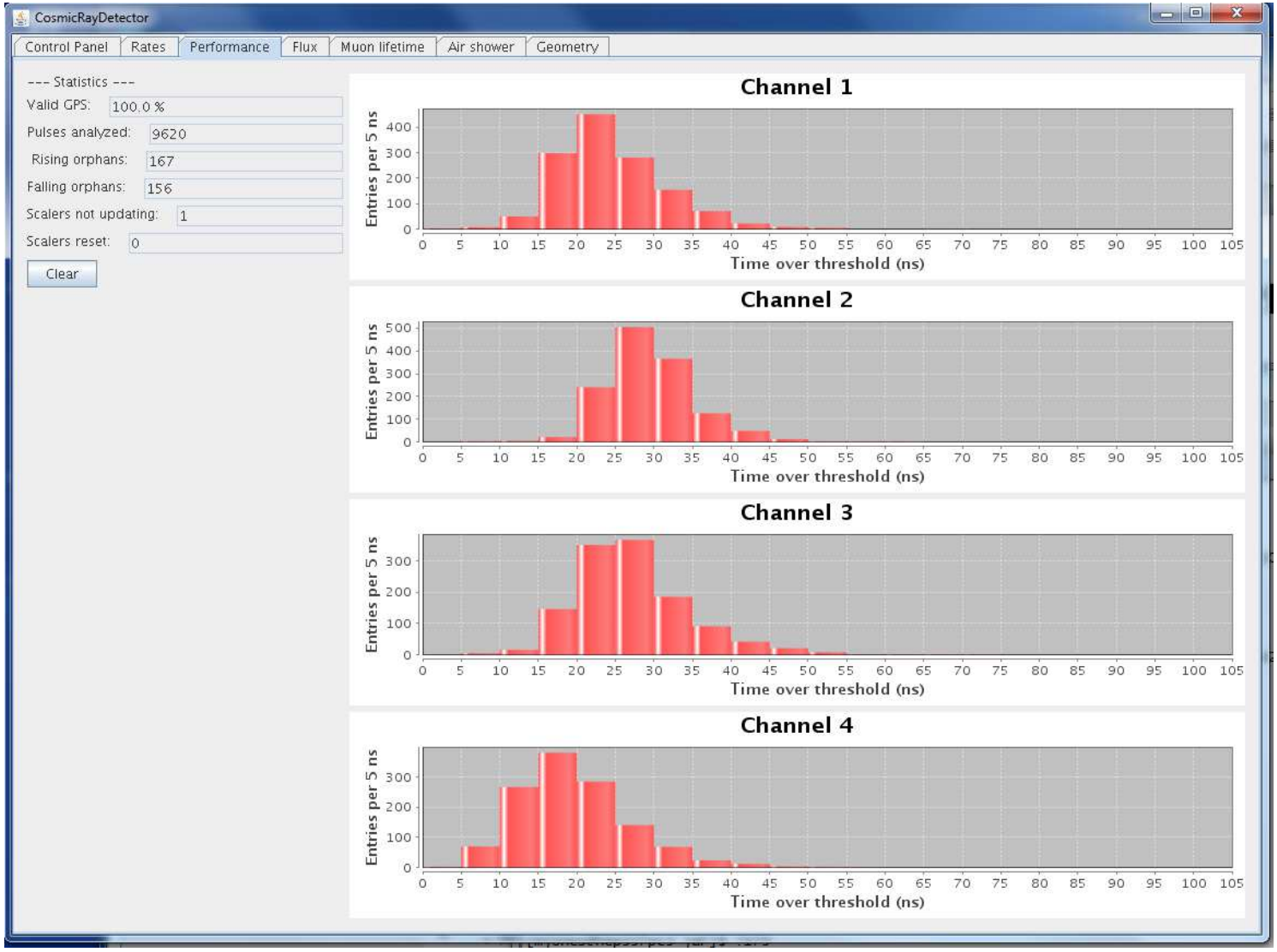
Rate Panel

- 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



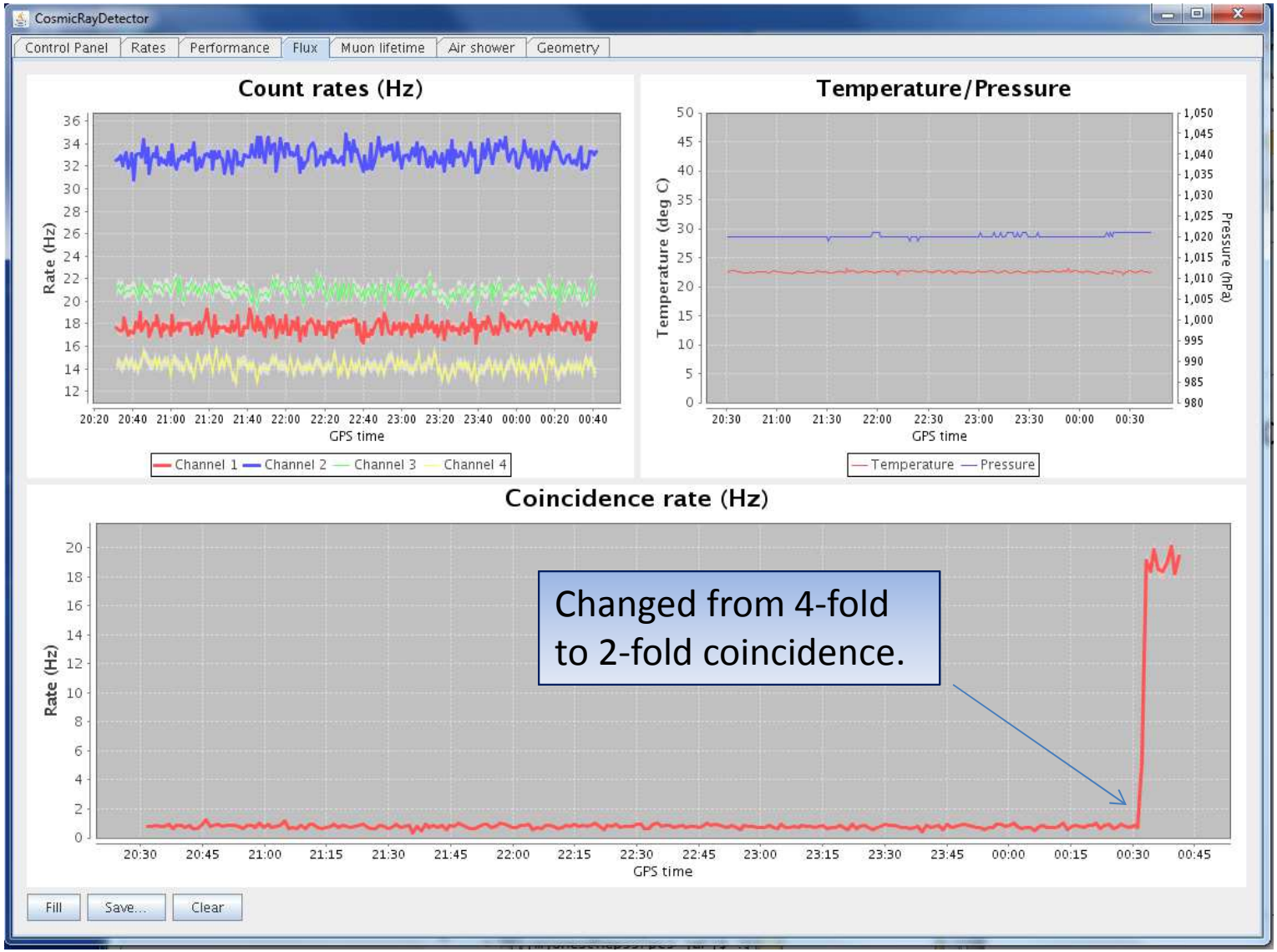
Performance Panel



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

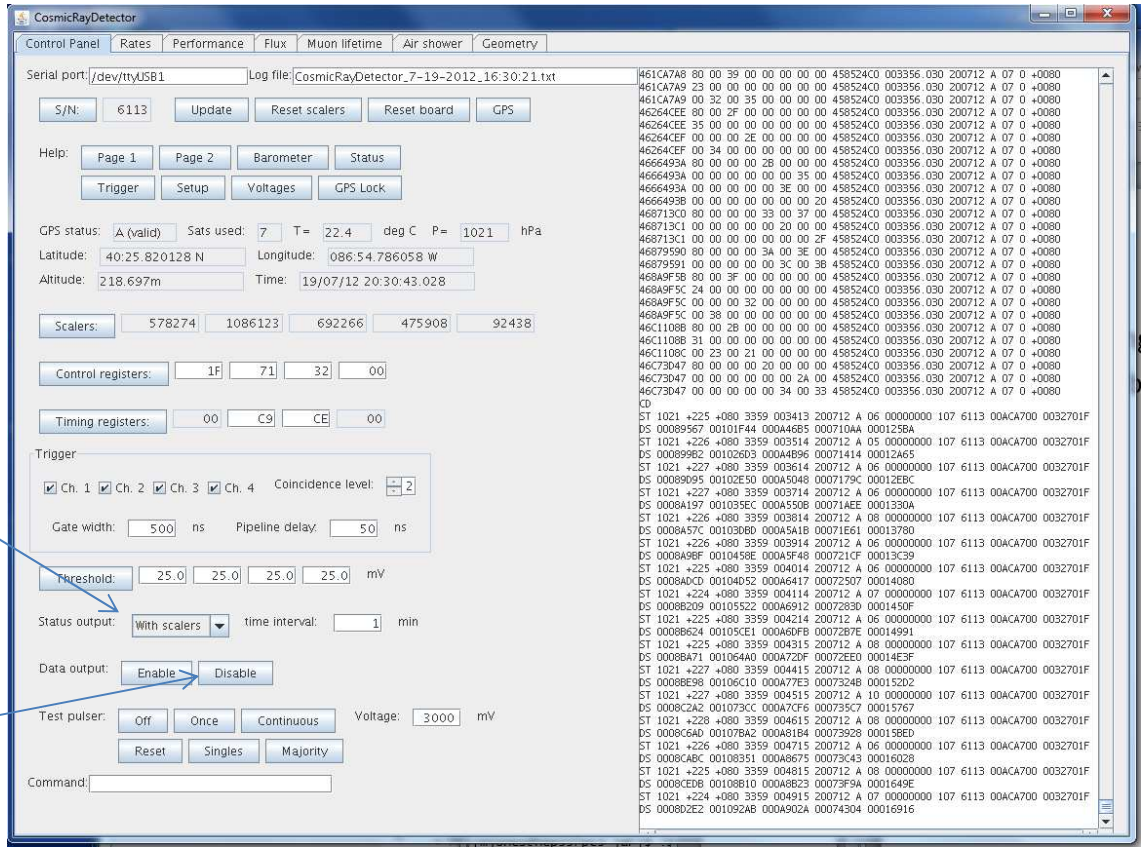

CosmicRayDetector
Control Panel
Rates
Performance
Flux
Muon lifetime
Air shower
Geometry
Count rates (Hz)
Rate (Hz)
GPS time
Channel 1
Channel 2
Channel 3
Channel 4
Temperature/Pressure
Temperature (deg C)
Pressure (hPa)
GPS time
Temperature
Pressure
Coincidence rate (Hz)
Rate (Hz)
GPS time
Changed from 4-fold to 2-fold coincidence.
Fill
Save...
Clear

Flux Panel

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

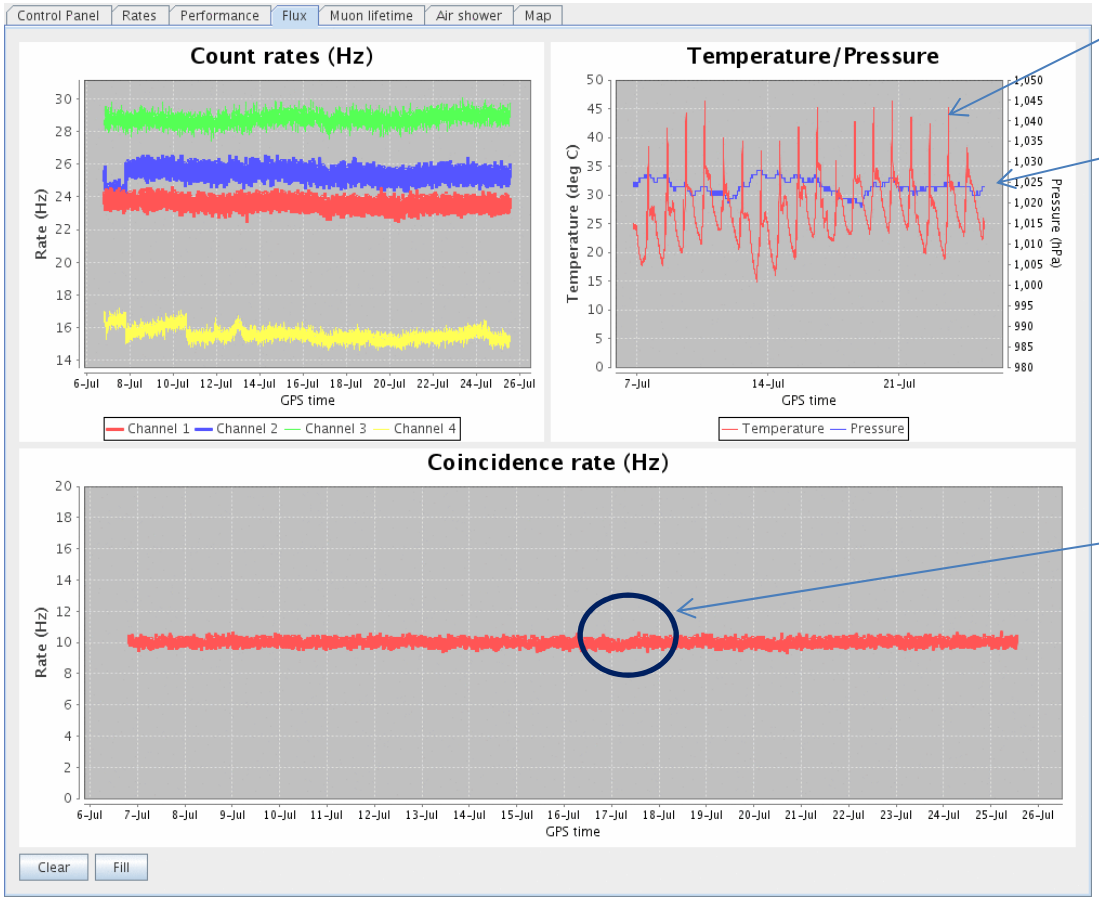
Set status output to “with scalers”

This just analyzes count rates, not leading/trailing edges, so you can disable data output.



Flux Panel

- What can you see?



Daily temperature variations…

Longer term pressure variations…

Is there a wiggle here?

Solar Weather

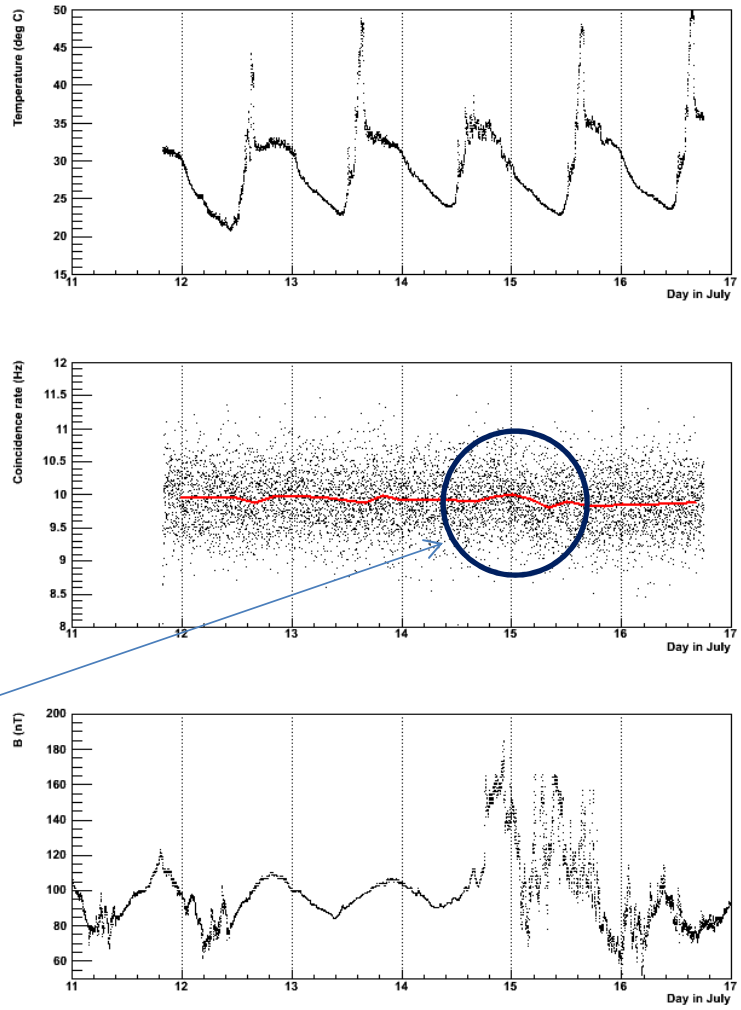
- Solar flares produce lots of protons that eventually reach earth
- They are low energy protons
  - They do not make cosmic rays
  - They do modify the Earth's magnetic field
- The Earth's magnetic field deflects high energy protons
  - Modification of the Earths' magnetic field should affect counting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

Solar Flares

- Some resources:
  - NOAA satellite data: http://www.swpc.noaa.gov/Data/index.html
  - 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)

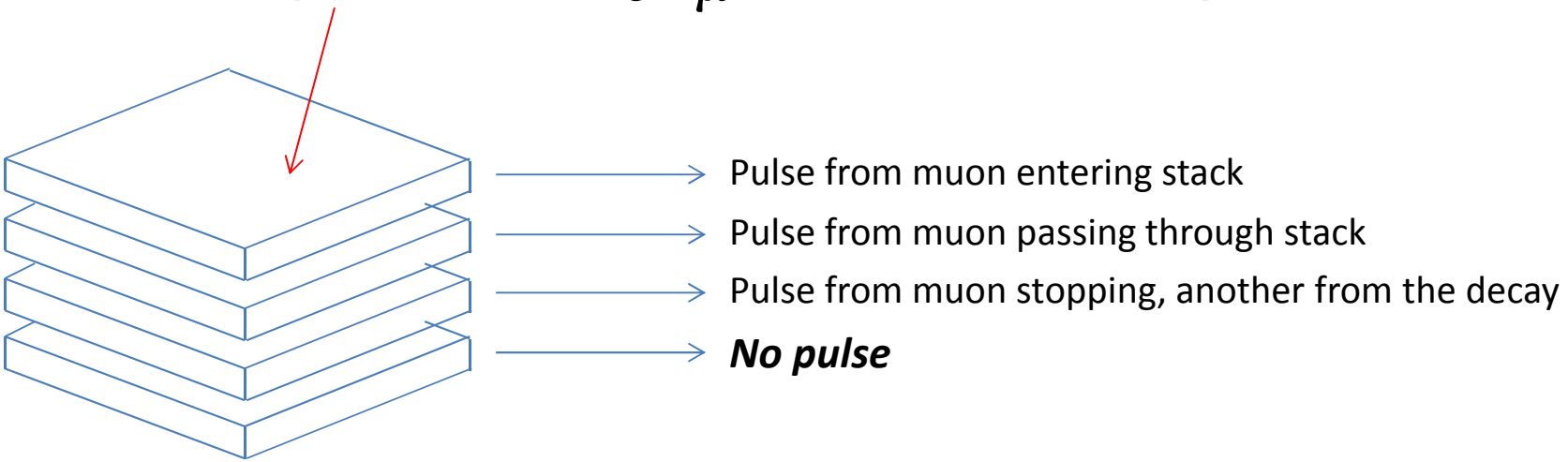
Solar Flares?

- This one was announced in the newspaper about 3 days before it arrived at earth.
- Four stacked counters with 3-fold 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 $\tau = 2.2\ \mu s$



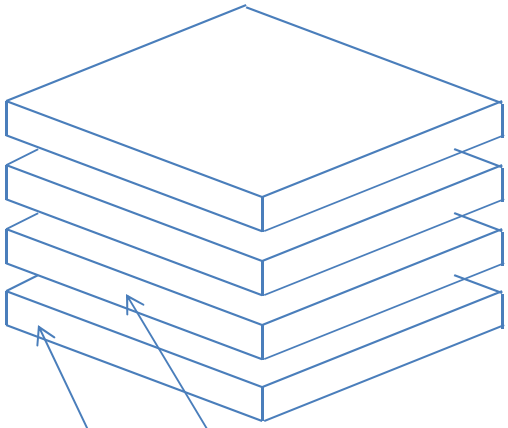
Require 3-fold coincidence
GATE WIDTH = 10,000 ns
PIPELINE DELAY = 20 ns

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.

Muon Lifetime (delayed coincidence)

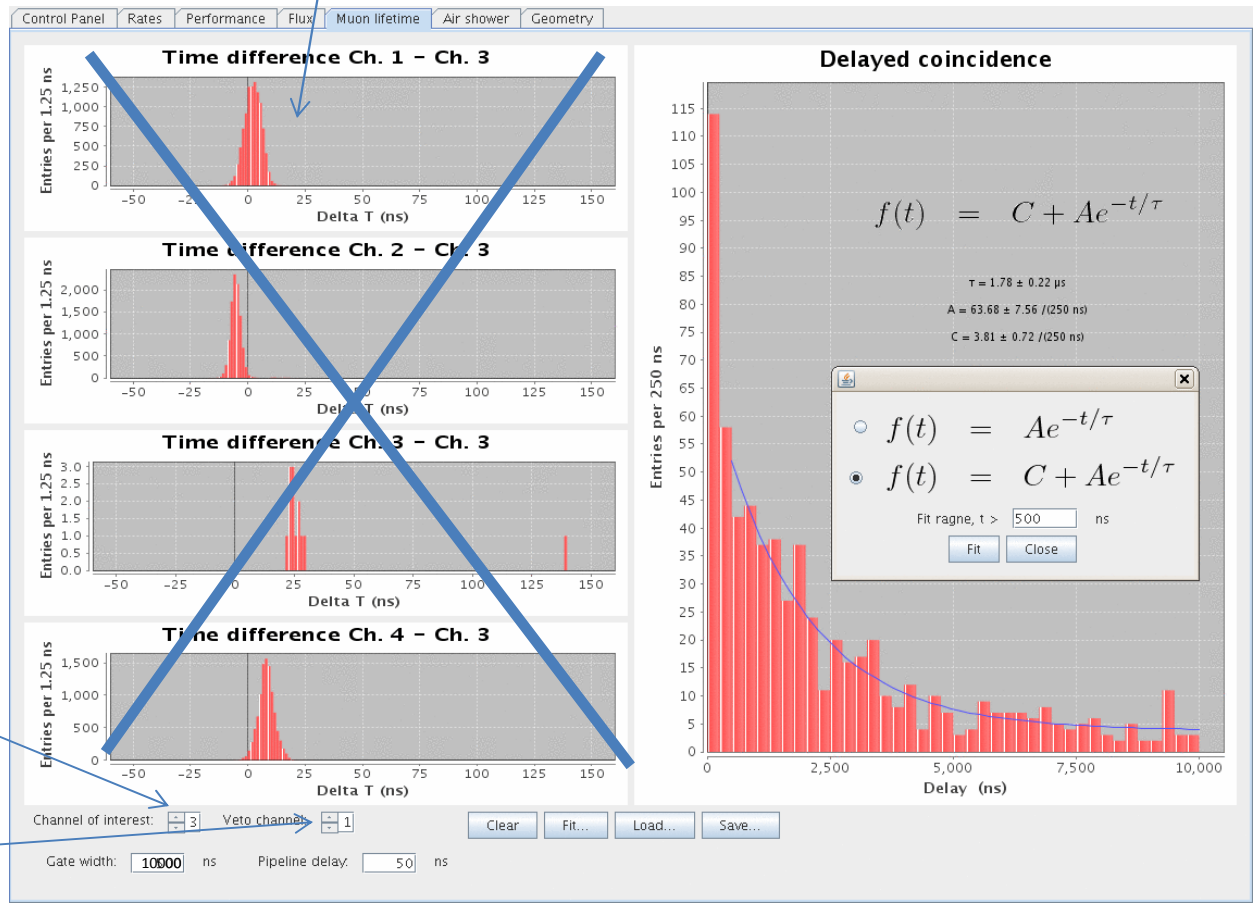
Remember to set the gate width and use a 3-fold coincidence…

Ignore these for now…



Channel of interest

Veto channel



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

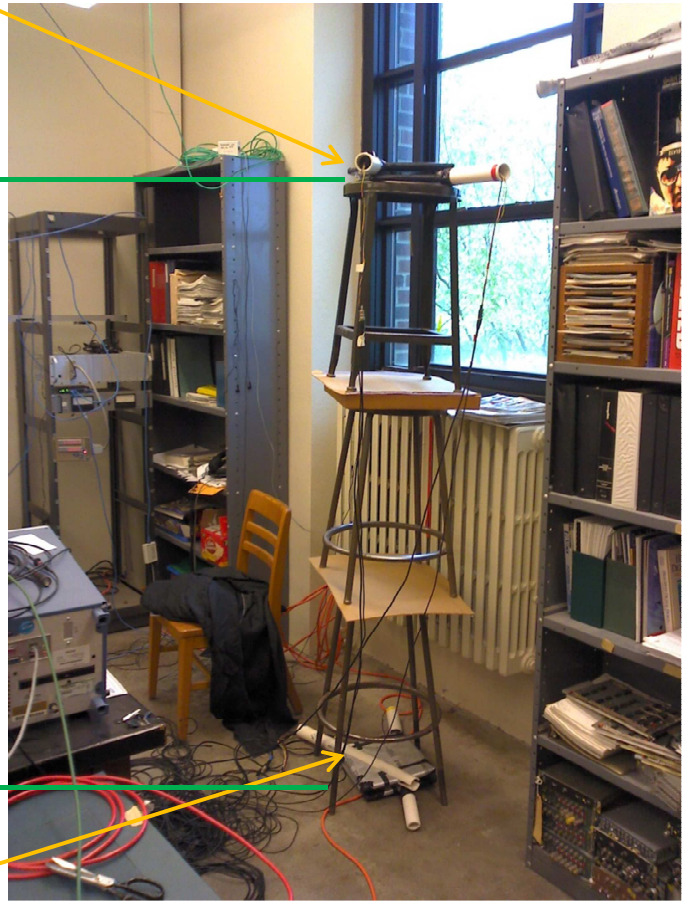
Use a 4-fold coincidence trigger.

Channels 1 & 2

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

53 in

78 in



Channels 3 & 4

Speed of Cosmic Rays

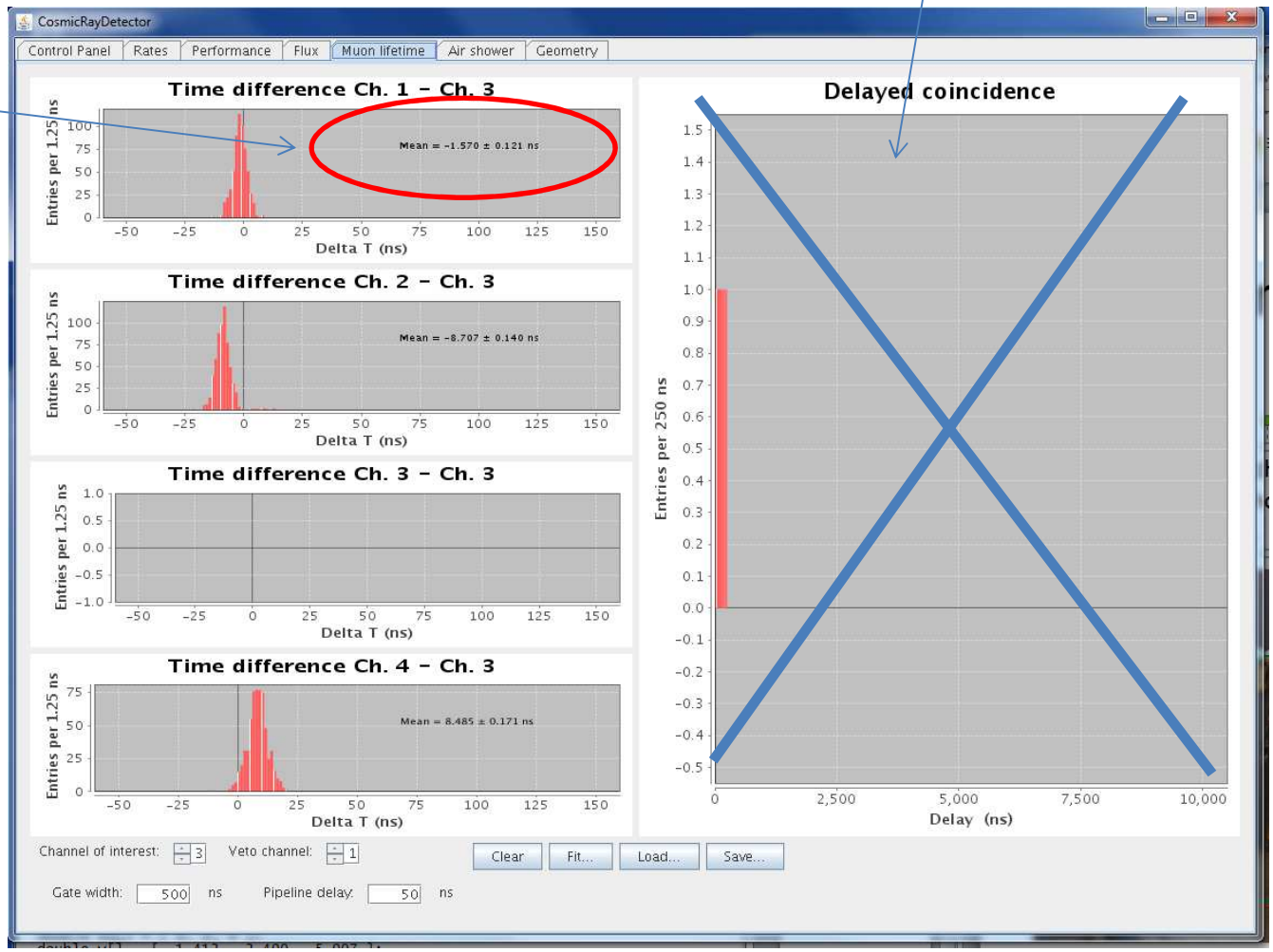
Ignore this for now…

Record the mean time difference at each height…

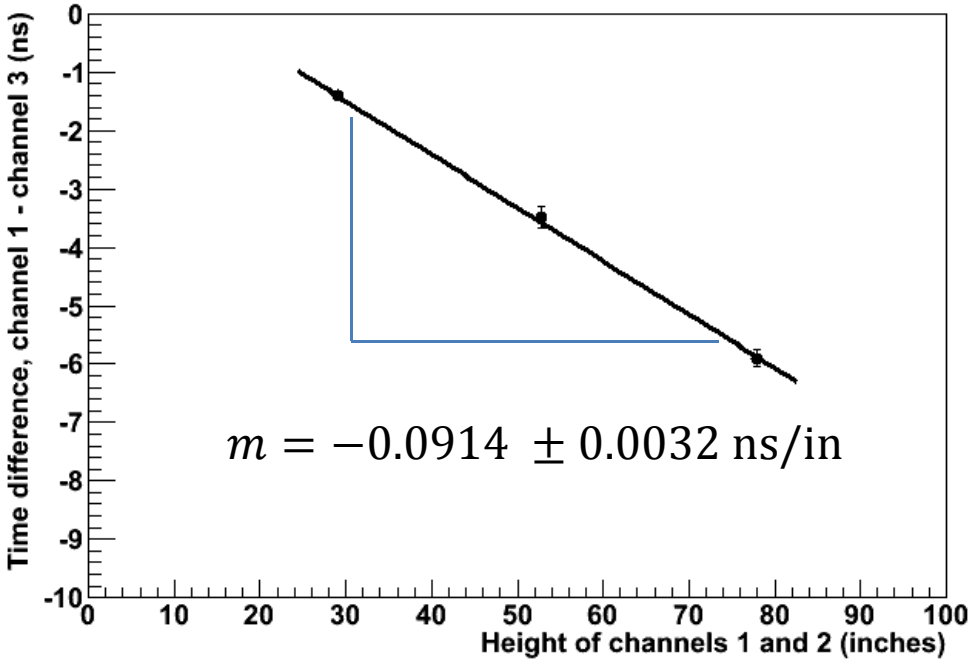
You may want to record this for all channels (except the channel of interest).

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 $2.2\ \mu s$ and they travel 200,000 inches (5 km) at 11 in/ns, what fraction will ***not*** have decayed?

$$t = \frac{d}{v} = \frac{200{,}000\ in}{11\ in/ns} = 18{,}000\ ns$$

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

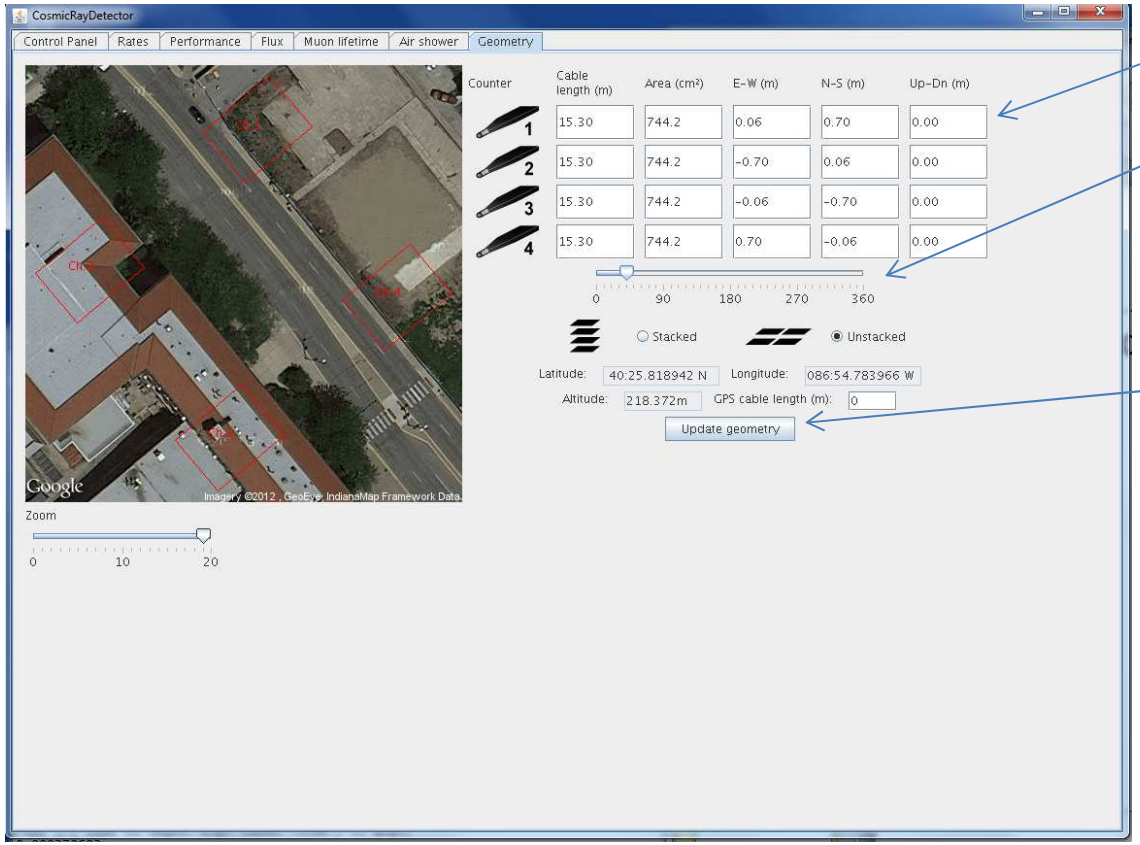
- This is not correct… because of special relativity, the muon's "clock" runs slow by a factor of

$$\gamma = \frac{1}{\sqrt{1-{v^2}/{c^2}}} = 2.8$$

$$P = e^{-t/\gamma\tau} = 5.3\%$$

Air Showers

- First check out the geometry tab:



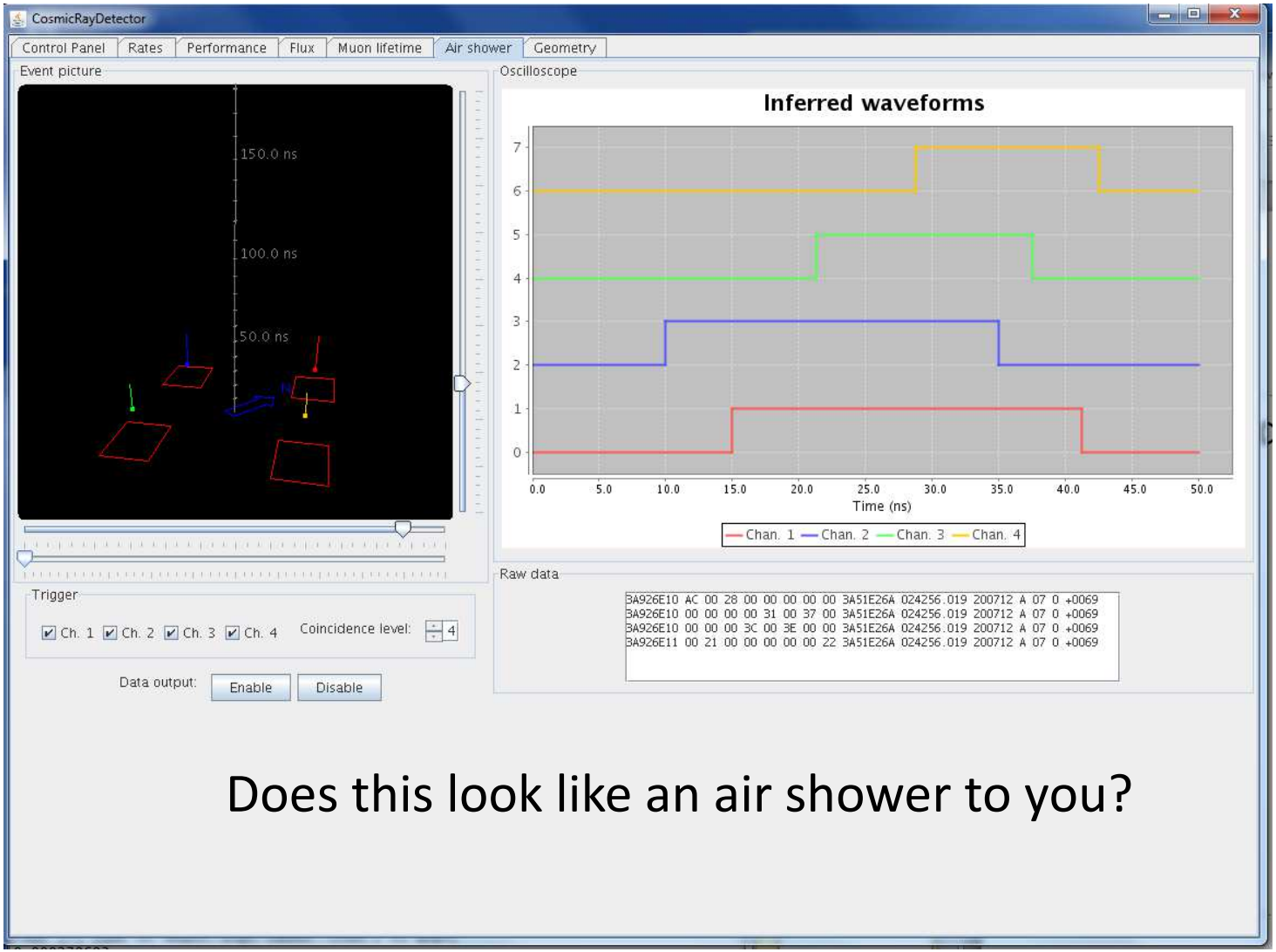
Enter scintillator positions in whatever coordinate system is convenient, then rotate them into the correct N-S-E-W orientation.

Then, “Update geometry”…

This is the same format needed in the cosmic ray e-lab.

This needs a network connection to get the satellite picture, but a compass is really all you need to find North…

Air Showers



Does this look like an air shower to you?

Suggestions for Experiments

- 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

Suggestions for Experiments

- 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…

Suggestions for Experiments

- 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?

Suggestions for Experiments

- 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!