Race & Associates, Ltd.

QuarkNet Relativity and More at ISU Workshop

July 21-24, 2025

Implementation Plans Proposed by Participating Teachers

The following pages provide examples of proposed implementation plans created by participating teachers during the workshop. Each plan is numbered to preserve the identity of the individual teacher.

August 2026

Implementation Plans

Idaho State, Thursday 24 July 2025

Teacher 1

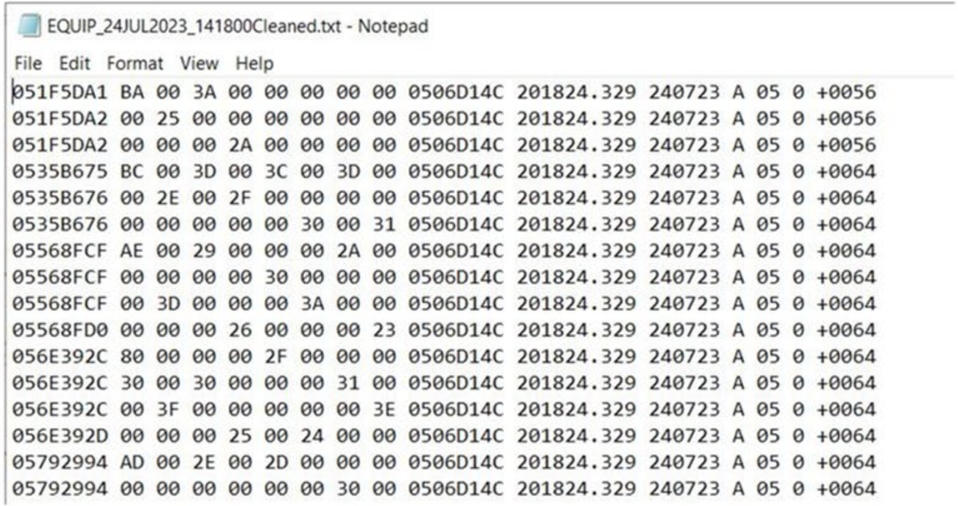
Class:IB Physics

When to present: During Relativity unit

Description: Use the MINERvA experiment to determine mean lifetime of muon. This will be done after we do Cloud Chambers and see ionization of Muons and before we do the special relativity evidence/time of flight experiment with Cosmic Ray Elab

Topics

- Creating a flux graph in R Python
- Hexadecimal Activity Implementation – Students create an Oscilloscope Graph from raw data



EQUIP_24JUL2023_141800Cleaned.txt - Notepad

File Edit Format View Help

```
051F5DA1 BA 00 3A 00 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
051F5DA2 00 25 00 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
051F5DA2 00 00 00 2A 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
0535B675 BC 00 3D 00 3C 00 3D 00 0506D14C 201824.329 240723 A 05 0 +0064
0535B676 00 2E 00 2F 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0064
0535B676 00 00 00 00 00 30 00 31 0506D14C 201824.329 240723 A 05 0 +0064
05568FCF AE 00 29 00 00 00 2A 00 0506D14C 201824.329 240723 A 05 0 +0064
05568FCF 00 00 00 00 30 00 00 00 0506D14C 201824.329 240723 A 05 0 +0064
05568FCF 00 3D 00 00 00 3A 00 00 0506D14C 201824.329 240723 A 05 0 +0064
05568FD0 00 00 00 26 00 00 00 23 0506D14C 201824.329 240723 A 05 0 +0064
056E392C 80 00 00 00 2F 00 00 00 0506D14C 201824.329 240723 A 05 0 +0064
056E392C 30 00 30 00 00 00 31 00 0506D14C 201824.329 240723 A 05 0 +0064
056E392C 00 3F 00 00 00 00 00 3E 0506D14C 201824.329 240723 A 05 0 +0064
056E392D 00 00 00 25 00 24 00 00 0506D14C 201824.329 240723 A 05 0 +0064
05792994 AD 00 2E 00 2D 00 00 00 0506D14C 201824.329 240723 A 05 0 +0064
05792994 00 00 00 00 00 00 30 00 0506D14C 201824.329 240723 A 05 0 +0064
```

Time over Threshold histograms
And Speed of Muon histogram

Creating a flux graph in R Python

- Clean the dataset manually
- Open in excel and save as txt/csv
- Read in the file into R Python

```r
#R code to import Equip data and find absolute time on events
#by Enrique Arce-Larreta
#Idaho Quarknet
#July 2023
#West High School

#load libraries
library(tidyverse)
library(cowplot)
library(patchwork)
library(readr)

# Set the number of digits to 14
options(digits = 14)

#load Equip dataset
# Load the data from the TXT file (replace "your_file_path.txt" with the ac
data <- read.delim("EQUIP_24JUL2023_141800CleanedExcel.txt")
```

EQUIP_24JUL2023_141800.txt - Notepad

File Edit Format View Help

```
H1

Quarknet Scintillator Card,  Qnet2.5  Vers 1.12  Compiled Dec 12 2011  HE=Help
Serial#=6781     uC_Volts=3.34      GPS_TempC=22.8     mBar=964.8

CE     - TMC Counter Enable.
CD     - TMC Counter Disable.
DC     - Display Control Registers, (C0-C3).
WC a d - Write   Control Registers, addr(0-6) data byte(H).
DT     - Display TMC Reg, 0-3, (1=PipeLineDelayRd, 2=PipeLineDelayWr).
WT a d - Write   TMC Reg, addr(1,2) data byte(H), if a=4 write delay word.
DG     - Display GPS Info, Date, Time, Position and Status.
DS     - Display Scalar, channel(S0-S3), trigger(S4), time(S5).
RE     - Reset complete board to power up defaults.
RB     - Reset only the TMC and Counters.
SB p d - Set Baud,password, 1=19K, 2=38K, 3=57K ,4=115K, 5=230K, 6=460K, 7=920K
SA n   - Save setup, 0=(TMC disable), 1=(TMC enable), 2=(Restore Defaults).
TH     - Thermometer data display (@ GPS), -40 to 99 degrees C.
TL c d - Threshold Level, signal ch(0-3)(4=setAll), data(0-4095mV), TL=read.
Veto   - Veto select, Off='VE 0', On='VE 1', Gate='VG c', 0-255(D) 10ns/cnt.
View   - View setup registers. Setup=V1, Voltages(V2), GPS LOCK(V3).
HELP   - HE,H1=Page1, H2=Page2, HB=Barometer, HS=Status, HT=Trigger.

043C8052 80 00 37 00 00 00 36 00 0389590C 201823.337 240723 A 05 0 +0056
D043C8052 39 00 00 00 38 00 00 00 0389590C 201823.337 240723 A 05 0 +0056
G043C8053 00 26 00 00 00 00 00 00 0389590C 201823.337 240723 A 05 0 +0056


DG
 Date+Time: 24/07/23 20:18:24.329
 Status:    A (valid)
 PosFix#:   1
 Latitude:   42:51.843532 N
 Longitude: 112:26.085701 W
```

Calculating Ksec

- Convert to seconds utc (GMT)
- Sample Calc from manual

$$Round\left(K_{sec} + \frac{P_{m\,sec}}{1000}\right) + \frac{(A - J)}{f_{clk}} = T_{abs}.$$

$$T_{abs} = Round\left(76047.727 + \frac{0096}{1000}\right) + \frac{(465042282 - 455026592)}{41666667} = 76048.240376558 \text{ sec}$$

after midnight.

K

hr min sec. MS

EQUIP_24JUL2023_141800Cleaned.txt - Notepad

File Edit Format View Help

```
051F5DA1 BA 00 3A 00 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
051F5DA2 00 25 00 00 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
051F5DA2 00 00 00 2A 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0056
0535B675 BC 00 3D 00 3C 00 3D 00 0506D14C 201824.329 240723 A 05 0 +0064
0535B676 00 2E 00 2F 00 00 00 00 0506D14C 201824.329 240723 A 05 0 +0064
0535B676 00 00 00 00 00 30 00 31 0506D14C 201824.329 240723 A 05 0 +0064
05568FCF AF 00 29 00 00 00 2A 00 0506D14C 201824.329 240723 A 05 0 +0064
                                          201824.329 240723 A 05 0 +0064
                                          201824.329 240723 A 05 0 +0064
                                          201824.329 240723 A 05 0 +0064
                                          201824.329 240723 A 05 0 +0064
```

Note: for "6000" series DAQ, f_{clk} = 25 MHz

for all older DAQ, f_{clk} = 41.666667 MHz

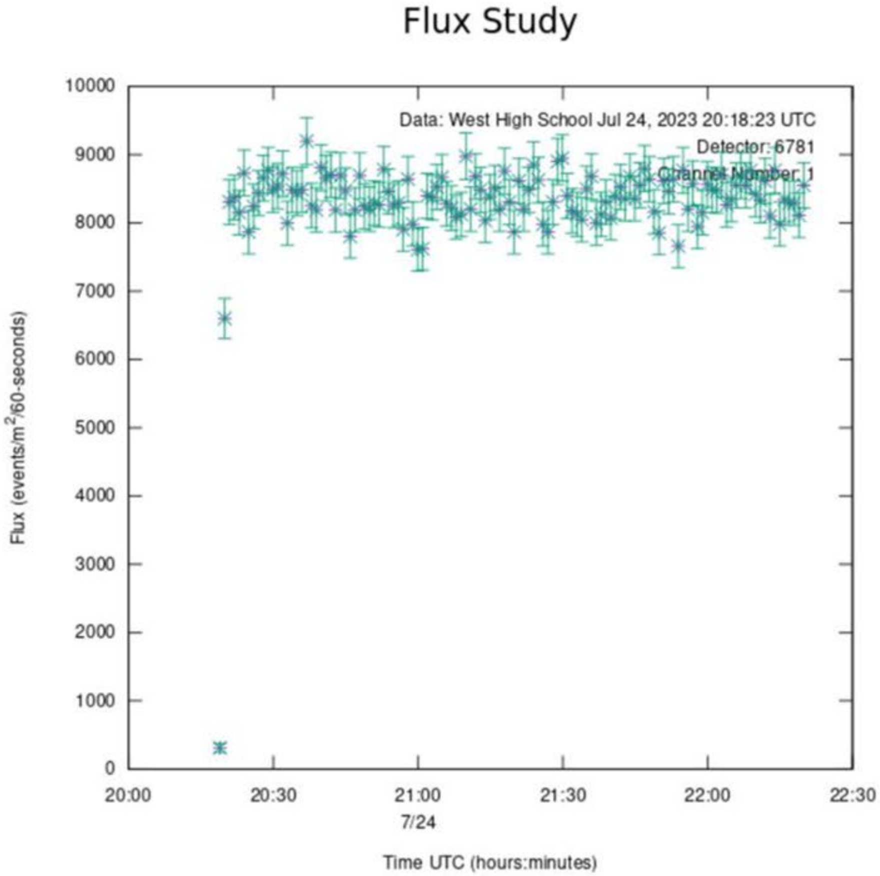
Flux Counts per minute per square meter

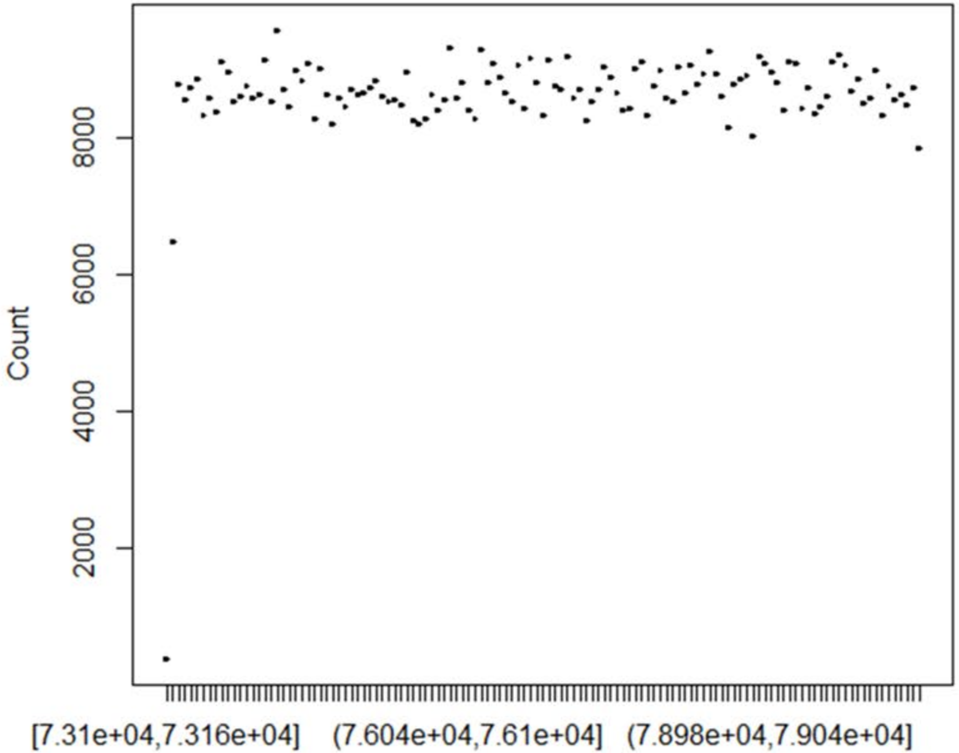
- 60 second intervals
- Then measure scintillator area and take inverse to see how many needed per square meter
- 744 cm^2 = 13.43 per m^2
- Divide by 4 to get mean channel results

```r
# Calculate the minimum and maximum values of Tabs
min_time <- min(Tabs)
max_time <- max(Tabs)

# Create intervals (bins) with 60-second width
intervals <- cut(Tabs, breaks = seq(min_time, max_time + 60, by = 60),
                 include.lowest = TRUE)

# Count occurrences within each interval
count_per_interval <- table(intervals)
```

```r
# Convert the result to a data frame for easier plotting
count_df <- as.data.frame(count_per_interval)

# Create a scatter plot
plot(count_df$intervals, 13.43/4 * count_df$Freq,
     type = "p", xlab = "Intervals", ylab = "Count", col = "blue", pch = 16)
```

Graph Comparison





https://yout

CosmicRayFluxStudy.ipynb

File Edit View Insert Runtime Tools Help

Commands + Code + Text Run all

Files

..

sample_data

EQUIP_22JUL2025_074711.txt

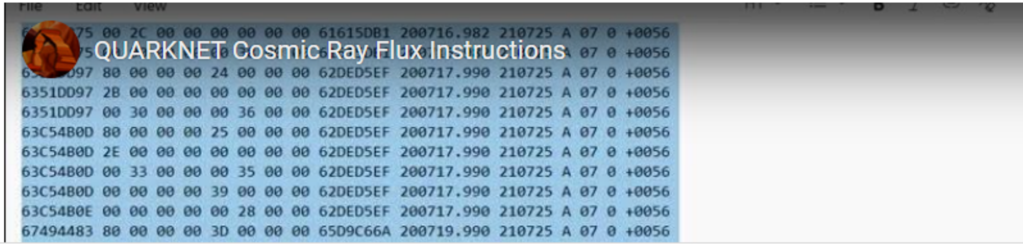
Disk 69.49 GB available

Flux Study for use with Quarknet Cosmic Ray
by Enrique Arce-Larreta
Idaho Quarknet Group
Physics Teacher
West High School
Salt Lake City, Utah

Needed: Raw data file from Equip data folder

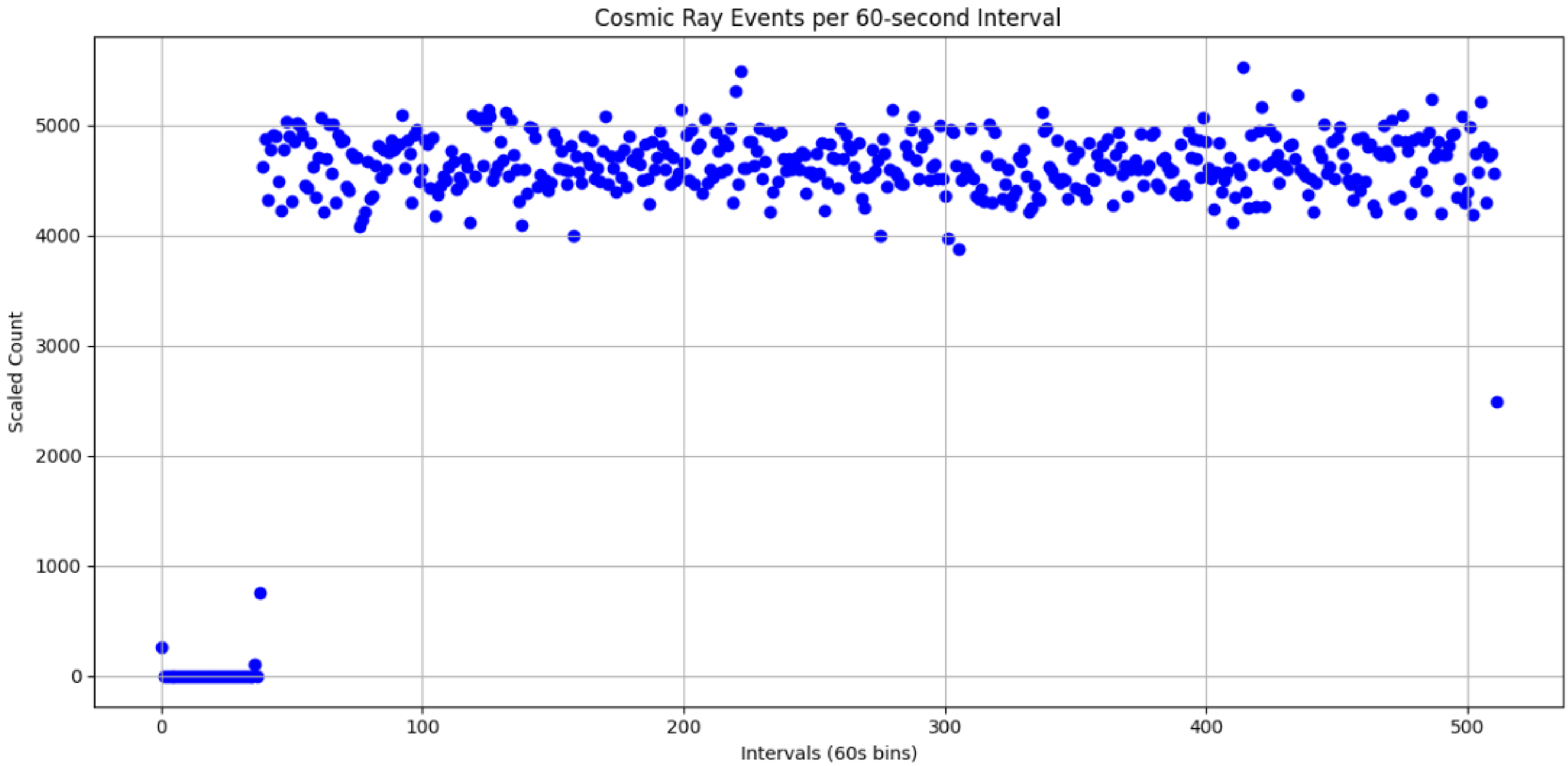
[1]
```python
# Pandas is used for data manipulation
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

[ ]
```python
# Video player
from IPython.display import YouTubeVideo

YouTubeVideo('B3ace7eGgyU', width=1200, height=600)
```



Python link

https://colab.research.google.com/drive/1IqVaes2Z9XW8cKUsB3LspqtLiQ7WVWXb?usp=sharing


Cosmic Ray Events per 60-second Interval
Scaled Count
Intervals (60s bins)
0
1000
2000
3000
4000
5000
0
100
200
300
400
500

Create a coincidences dataframe

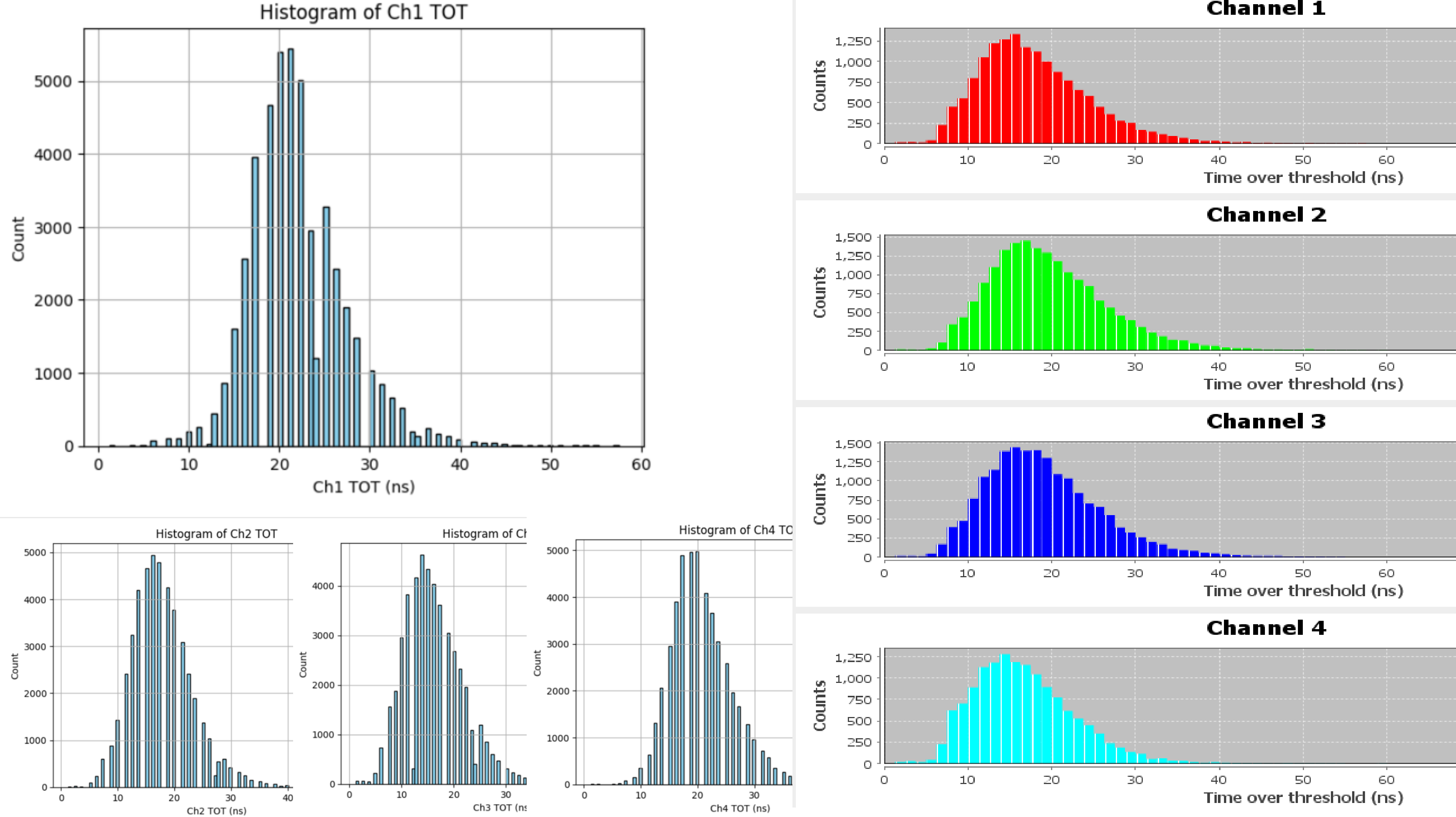
1. Looks for first nonzero time in a Channel with Tabs
2. Opens 100ns gate
3. Records channel start time
4. Looks ahead for first nonzero endtime*
5. Checks for other channels within the gate window
6. Looks for end time for other channels

```
[18] coinc_df
```

	ch1_start	ch1_end	ch2_start	ch2_end	ch3_start	ch3_end	ch4_start	ch4_end
0	49683.203936	49683.203936	49683.203936	49683.298461	NaN	NaN	NaN	NaN
1	49683.743464	49683.743464	49683.743464	49683.743464	NaN	NaN	NaN	NaN
2	49683.874735	49683.874735	49683.874735	49683.874735	NaN	NaN	NaN	NaN
3	49683.874735	49683.874735	49683.874735	49683.874735	NaN	NaN	NaN	NaN
4	49683.898742	49683.898742	49683.898742	49683.907206	NaN	NaN	NaN	NaN
...	...	...	...	...	...	...	...	...

Calc TOT, Speed then make histograms

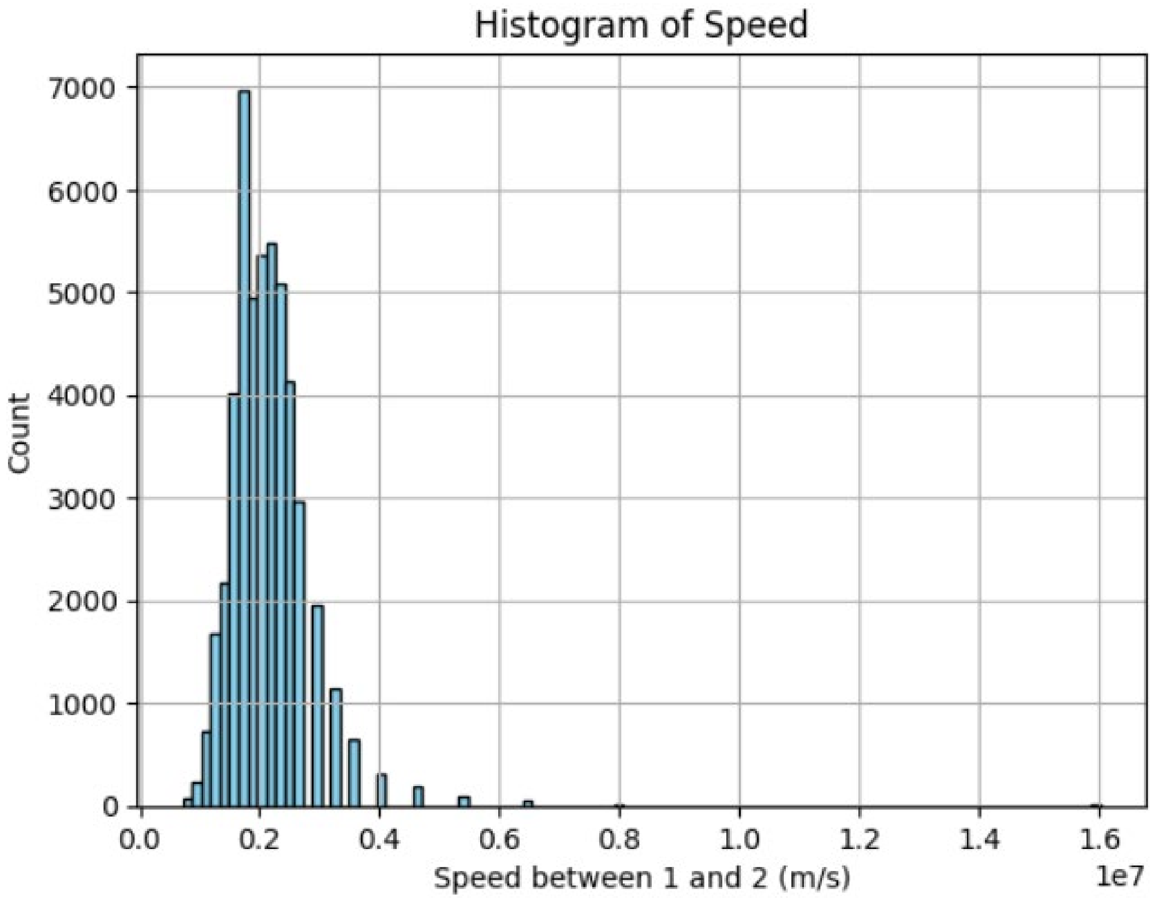
```
coincidences['Ch1_TOT'] = coincidences['ch1_end'] - coincidences['ch1_start']


# Time between detector 1 and 2
coincidences['Ch12TOF'] = coincidences['ch1_end'] - coincidences['ch2_start']
# calculate speed
LengthBetweenDetectors = 0.04 #meters
coincidences['Speed12'] = LengthBetweenDetectors / coincidences['Ch12TOF']
```


Histogram of Ch1 TOT
Count
Ch1 TOT (ns)
Histogram of Ch2 TOT
Ch2 TOT (ns)
Ch3 TOT (ns
Ch4 TOT (ns)
Channel 1
Channel 2
Channel 3
Channel 4
Counts
Time over threshold (ns)

Speed

```
[66] print("Min:", coincidences['Speed12
     print("Max:", coincidences['Speed12
```

```
Min: 727190.230010582
Max: 16027866.294110788
```



Teacher 2 in collaboration with Teacher 1

Classes: general physics and Beamline for Schools team/club

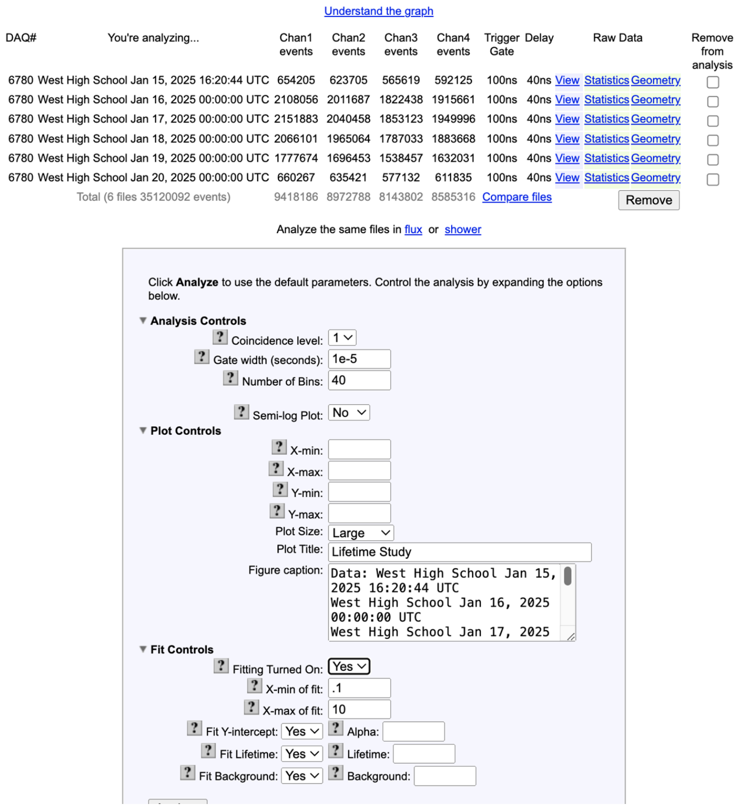
When to present: general physics - sprinkled in throughout the year. Beamline for Schools team/club - fall meetings and "particle camp" in preparation for BL4S proposal development.

Description: Muon Lifetime Studies in 3 variations

- Fundamentals/develop background knowledge: QuarkNet Data Activities Portfolio
  - Dice, Histograms, and Probability
    - Use post-it notes for generation of the histogram. Then convert post-it note histogram to either (intro to) Jupyter notebook or (intro to/review of) Excel
  - Mean Lifetime, Part 1
    - Might use the Jupyter notebook version as also intro to Python. Probably just with BL4S students
  - Possible to add in discussion of Special Relativity and time dilation/length contraction as relates to fast/CR muons' ability to reach Earth's surface even given their quick decay.
- Apply to open source **MINERvA data**, more QN Data Activity
  - Mean Lifetime, Part 3
    - Focus on experimental design, how the data gives muon lifetime.
- Apply to experimental design and analysis - **eLab with CRMD** vs. **"homemade" Python** data analysis
  - Start with Data Portfolio - Mean Lifetime, Part 2
    - how is the CRMD experiment and data analysis similar to and different from MINERvA.
  - Set up CRMD, collect and analyze "real" data
  - Analyze data using eLab, as practiced in Mean Lifetime, Part 2. This will also work as a check for data quality
  - Analyze same data using homemade Python to see more detail about how the lifetime is measured with CRMD data, how the plots are generated, more details about the statistics available from Python's histogram, etc.*

Note to self: remind Steve Shropshire to add **INL visit** and **cloud chambers** to ID Workshop next year!

Examples of the 3 versions of muon lifetime* results: eLab "Standard" Lifetime Study


Understand the graph

DAQ#	You're analyzing...	Chan1 events	Chan2 events	Chan3 events	Chan4 events	Trigger Gate	Delay	Raw Data			Remove from analysis
6780	West High School Jan 15, 2025 16:20:44 UTC	654205	623705	565619	592125	100ns	40ns	View	Statistics	Geometry	☐
6780	West High School Jan 16, 2025 00:00:00 UTC	2108056	2011687	1822438	1915661	100ns	40ns	View	Statistics	Geometry	☐
6780	West High School Jan 17, 2025 00:00:00 UTC	2151883	2040458	1853123	1949996	100ns	40ns	View	Statistics	Geometry	☐
6780	West High School Jan 18, 2025 00:00:00 UTC	2066101	1965064	1787033	1883668	100ns	40ns	View	Statistics	Geometry	☐
6780	West High School Jan 19, 2025 00:00:00 UTC	1777674	1696453	1538457	1632031	100ns	40ns	View	Statistics	Geometry	☐
6780	West High School Jan 20, 2025 00:00:00 UTC	660267	635421	577132	611835	100ns	40ns	View	Statistics	Geometry	☐
	Total (6 files 35120092 events)	9418186	8972788	8143802	8585316	Compare files				Remove	

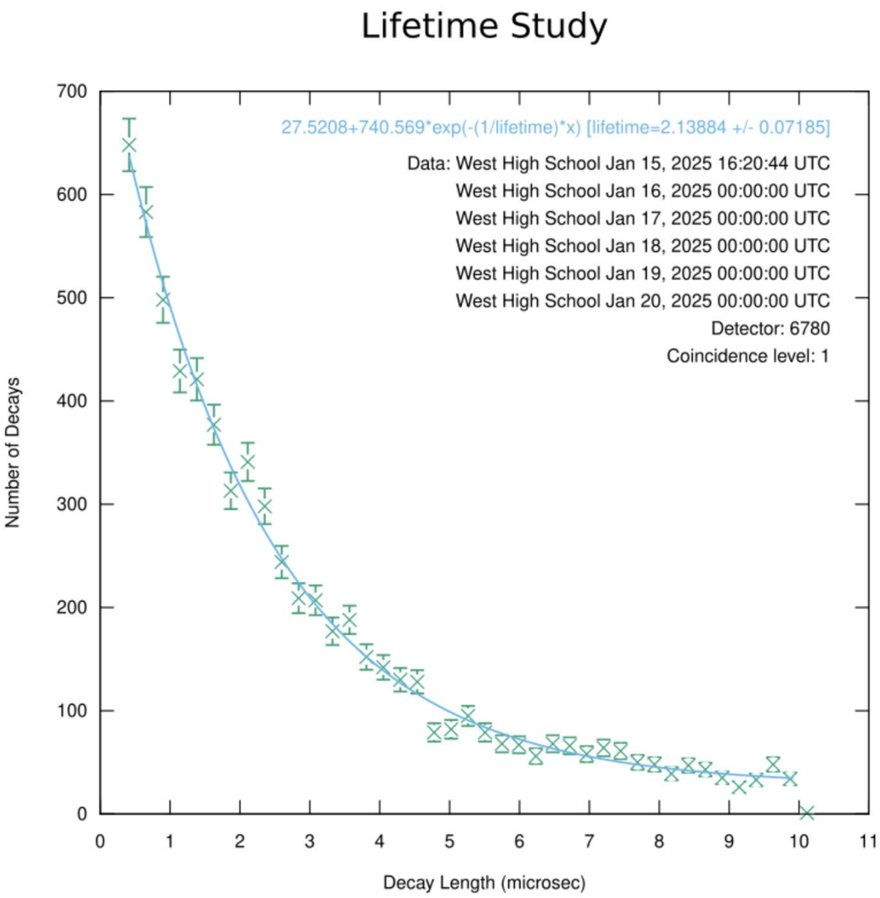
Analyze the same files in flux or shower

Click **Analyze** to use the default parameters. Control the analysis by expanding the options below.

Analysis Controls
- Coincidence level: 1
- Gate width (seconds): 1e-5
- Number of Bins: 40
- Semi-log Plot: No

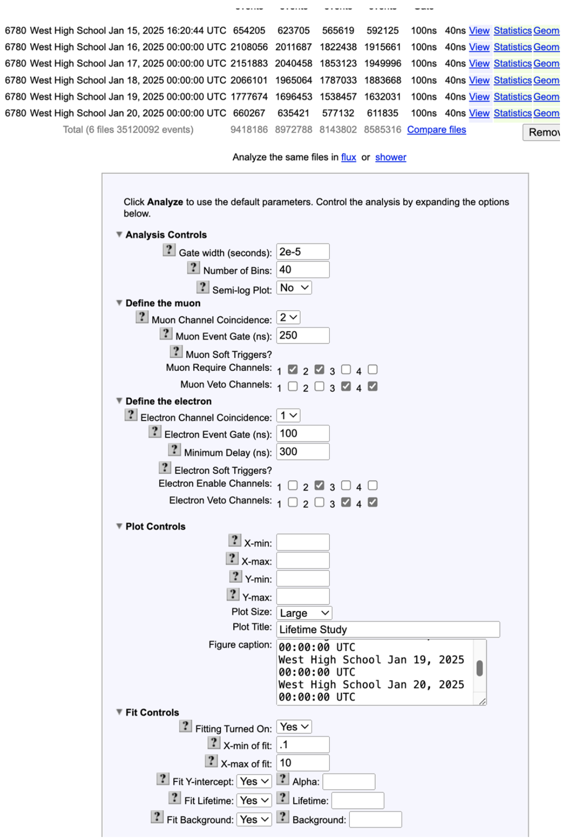
Plot Controls
- X-min:
- X-max:
- Y-min:
- Y-max:
- Plot Size: Large
- Plot Title: Lifetime Study
- Figure caption: Data: West High School Jan 15, 2025 16:20:44 UTC West High School Jan 16, 2025 00:00:00 UTC West High School Jan 17, 2025

Fit Controls
- Fitting Turned On: Yes
- X-min of fit: .1
- X-max of fit: 10
- Fit Y-intercept: Yes — Alpha:
- Fit Lifetime: Yes — Lifetime:
- Fit Background: Yes — Background:



*accepted value for muon mean lifetime: 2.2 microseconds

Examples of the 3 versions of muon lifetime* results: eLab "Advanced" Lifetime Study



6780 West High School Jan 15, 2025 16:20:44 UTC	654205	623705	565619	592125	100ns	40ns	View	Statistics	Geom
6780 West High School Jan 16, 2025 00:00:00 UTC	2108056	2011687	1822438	1915661	100ns	40ns	View	Statistics	Geom
6780 West High School Jan 17, 2025 00:00:00 UTC	2151883	2040458	1853123	1949996	100ns	40ns	View	Statistics	Geom
6780 West High School Jan 18, 2025 00:00:00 UTC	2066101	1965064	1787033	1883668	100ns	40ns	View	Statistics	Geom
6780 West High School Jan 19, 2025 00:00:00 UTC	1777674	1696453	1538457	1632031	100ns	40ns	View	Statistics	Geom
6780 West High School Jan 20, 2025 00:00:00 UTC	660267	635421	577132	611835	100ns	40ns	View	Statistics	Geom
Total (6 files 35120092 events)	9418186	8972788	8143802	8585316	Compare files				Remov

Analyze the same files in flux or shower

Click **Analyze** to use the default parameters. Control the analysis by expanding the options below.

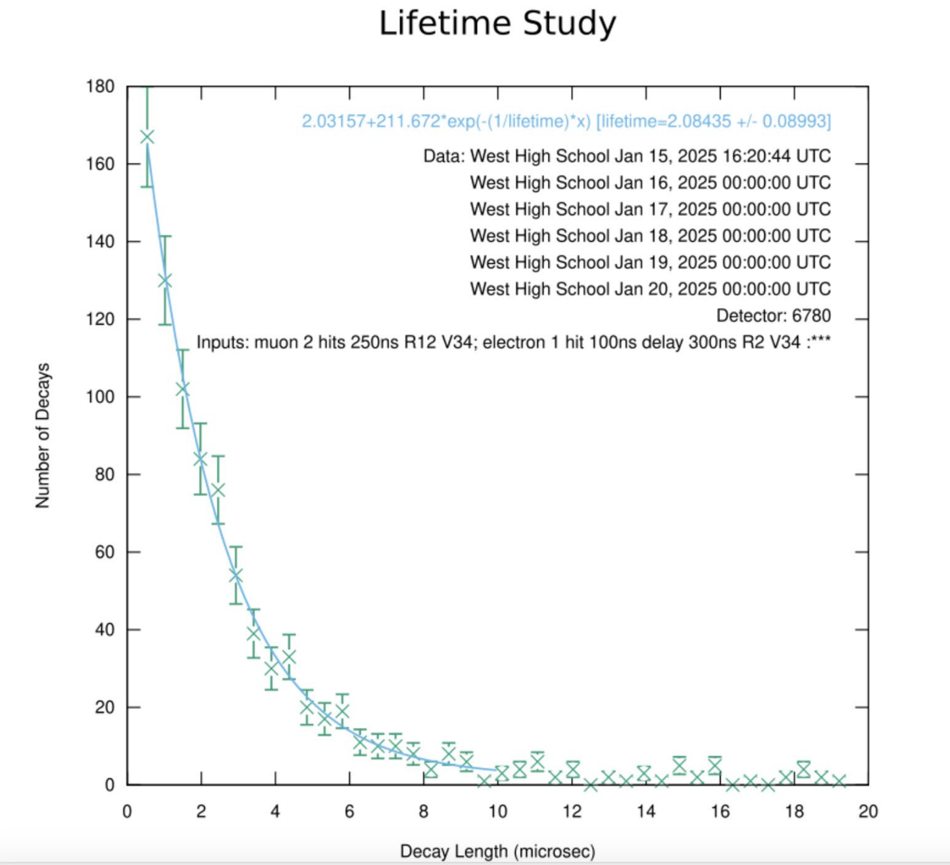
Analysis Controls
Gate width (seconds): 2e-5
Number of Bins: 40
Semi-log Plot: No

Define the muon
Muon Channel Coincidence: 2
Muon Event Gate (ns): 250
Muon Soft Triggers?
Muon Require Channels: 1 ☑ 2 ☑ 3 ☐ 4 ☐
Muon Veto Channels: 1 ☐ 2 ☐ 3 ☑ 4 ☑

Define the electron
Electron Channel Coincidence: 1
Electron Event Gate (ns): 100
Minimum Delay (ns): 300
Electron Soft Triggers?
Electron Enable Channels: 1 ☐ 2 ☑ 3 ☐ 4 ☐
Electron Veto Channels: 1 ☐ 2 ☐ 3 ☑ 4 ☑

Plot Controls
X-min:
X-max:
Y-min:
Y-max:
Plot Size: Large
Plot Title: Lifetime Study
Figure caption: 00:00:00 UTC West High School Jan 19, 2025 00:00:00 UTC West High School Jan 20, 2025 00:00:00 UTC

Fit Controls
Fitting Turned On: Yes
X-min of fit: .1
X-max of fit: 10
Fit Y-intercept: Yes Alpha:
Fit Lifetime: Yes Lifetime:
Fit Background: Yes Background:

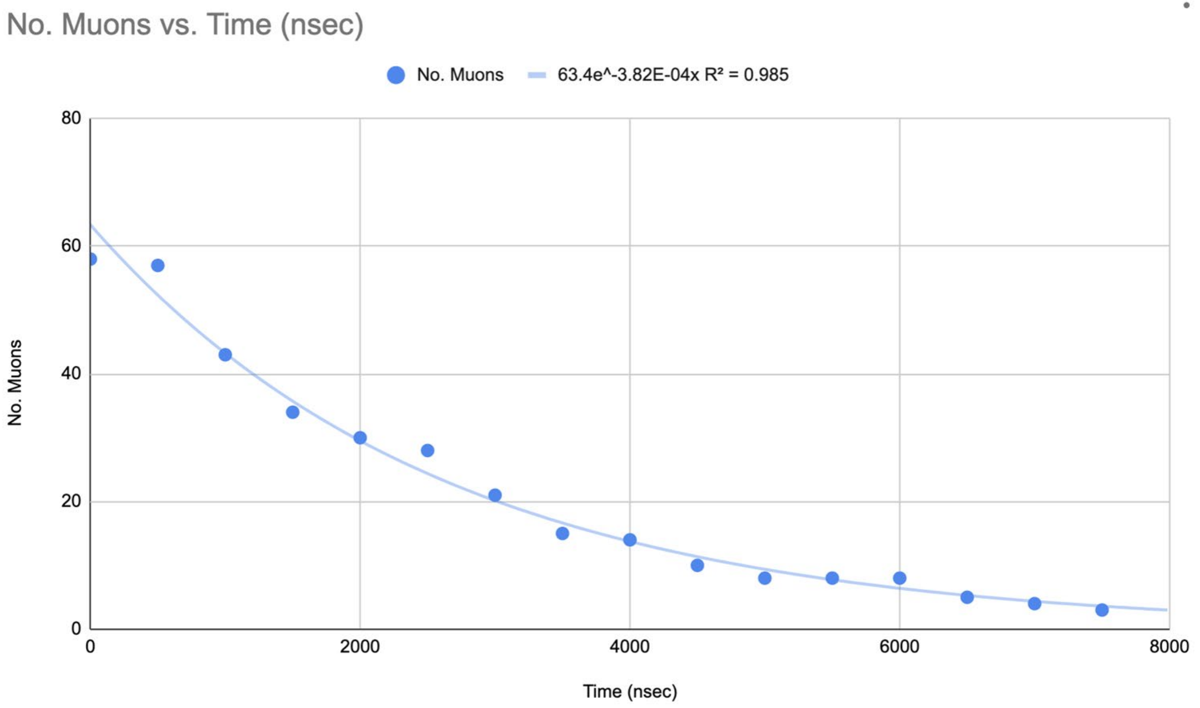


*accepted value for muon mean lifetime: 2.2 microseconds

Examples of the 3 versions of muon lifetime* results: MINERvA

[Link to activity instructions and event display]

[Example spreadsheet for data collection]



*accepted value for muon mean lifetime: 2.2 microseconds

Examples of the 3 versions of muon lifetime* results

Enrique's "homemade" Python analysis:

(this may be a work in progress for quite a while)

The aim is to give students an idea of what's going on "behind the scenes" of eLabs graphing program, more understanding of what the CRMD is actually measuring and the variety of information that can be pulled from that data, and more exposure to Python programming.

Text file version of data used in eLab: EQUIP_15JAN2025_092358.txt (in google drive, "Bulson CRMD Data")

*accepted value for muon mean lifetime: 2.2 microseconds

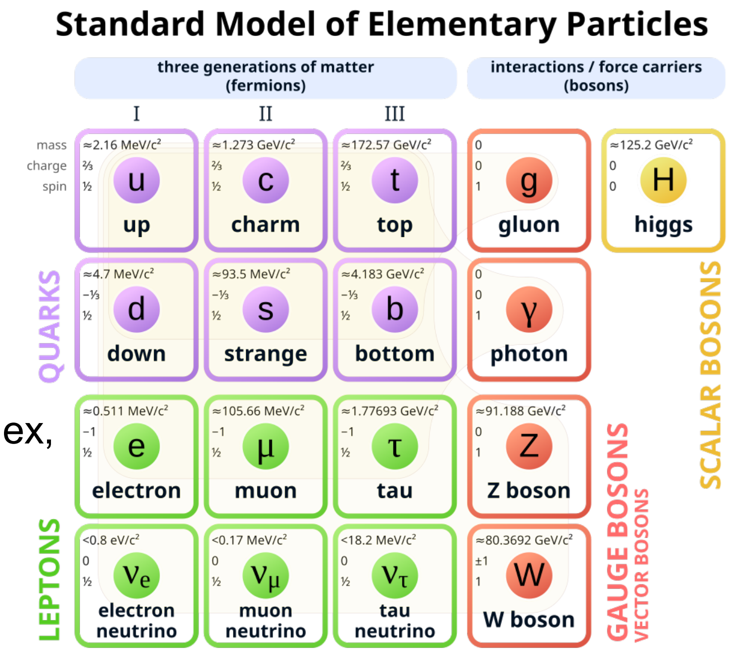
Teacher 3

Class: General Physics

When to present: Atomic Unit

Description: The Particle Zoo.

Teaching the **Particle Zoo**—the subatomic particles in the Standard Model of particle physics—can be exciting but complex, especially for students unfamiliar with quantum mechanics or high-energy physics.



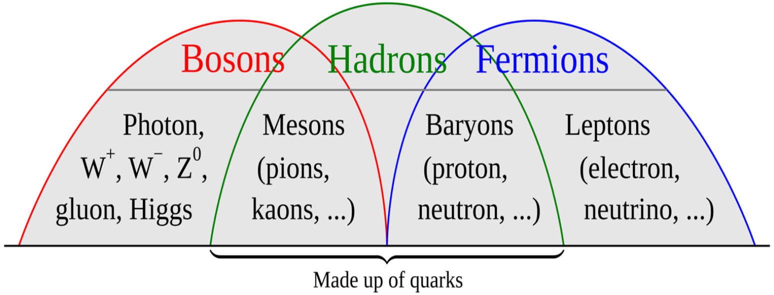
1. The Big Picture

Before diving into particles, set the context.

- **Analogy**: Having discussed atoms and nuclear reactions, discuss how even those particles can be made of other particles, (more) **fundamental particles**.
- **Goal**: Explain that all matter and forces (except gravity) can be described by the **Standard Model**.
- Use visuals or simulations to show **atoms → protons/r**

2. Introduce the Categories

Break the Particle Zoo into understandable sections (spin):



🧬 Fermions (matter particles)

- **Quarks**: up, down, charm, strange, top, bottom
- **Leptons**: electron, muon, tau + their neutrinos
- **Visuals:** particle trading cards, 3D puzzles

⚡ Bosons (force carriers)

- Photon (electromagnetism)
- Gluon (strong force)
- W/Z bosons (weak force)
- Higgs boson (mass giver)

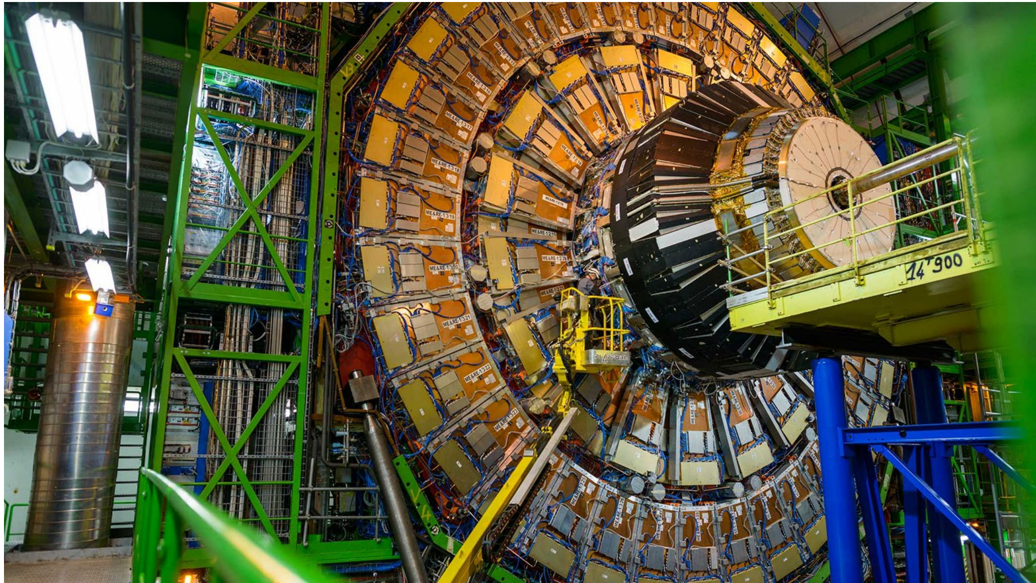
3. Use a Particle Chart

Show or draw the **Standard Model chart**. Break it down slowly.

- Emphasize which particles make up normal matter (up/down quarks, electrons, electron neutrinos).
- Show how other particles are more exotic or exist in high-energy environments.

4. Teach with Analogies

- **Quarks**: like flavors in a recipe—can't exist alone (confinement).
- **Bosons**: like messengers delivering forces between particles.
- **Neutrinos**: ghost particles—rarely interact, but abundant.



5. Bring in Experiments

- **LHC & CERN**: What happens in particle accelerators.

- **Cloud chambers** or online simulations can visually show particle interactions.

6. Hands-On Activities

- **Card games**: Make cards for each particle with properties (charge, mass, spin).

- **Build-a-particle**: Combine quarks to form protons, neutrons, mesons.

- Use LEGOs, 3D models, or interactive apps (like PhET simulations or "Quarked").

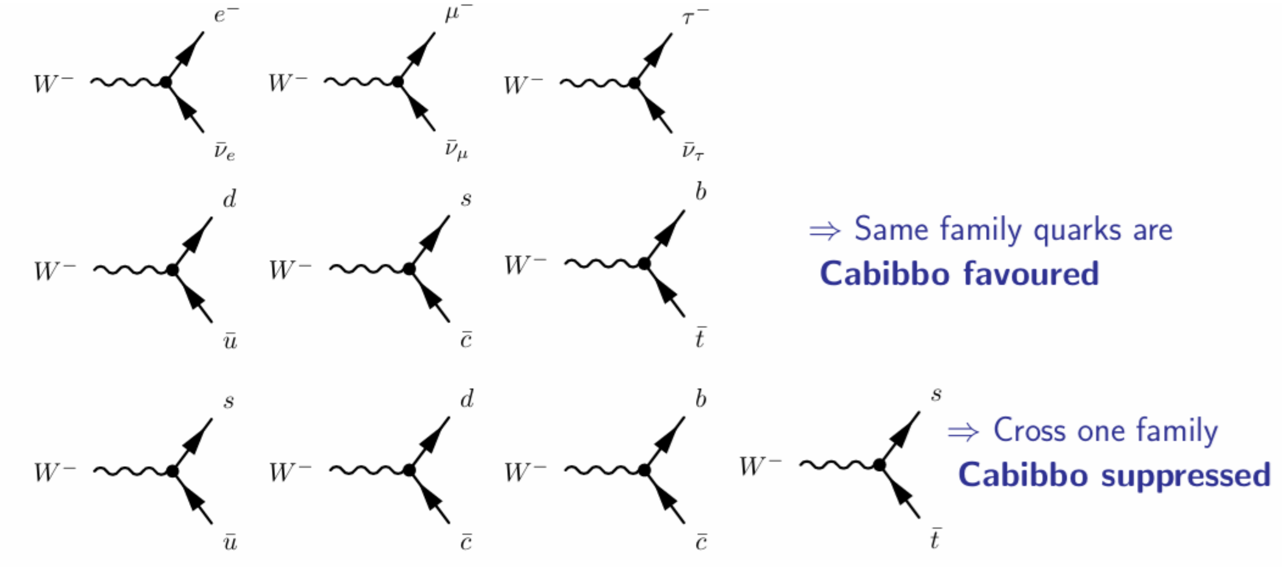
7. Address Common Misconceptions

- Particles aren’t little billiard balls.
- Antimatter doesn’t mean “evil” matter.
- The Higgs doesn’t “create” mass directly for all matter.

When you ask if Antimatter is the same as matter:

8. Use Media

- **Videos**: Kurzgesagt, MinutePhysics, or CERN explainer videos.
- **Animations** help show how particles interact or decay.



9. Optional Extensions

For advanced students:

- Introduce **Feynman diagrams**
- Discuss **quantum numbers** (charge, spin, color)
- Mention **beyond the Standard Model** ideas: supersymmetry, dark matter

10. Wrap-Up with Context

- How the particle zoo helps explain why the universe behaves the way it does.
- Current research: Higgs boson, neutrino oscillations, dark matter searches.

Teacher 4

Class:Physics

When to present: In the middle of the special relativity unit, before going over the energy-momentum connection

Description: As a lab experience for special relativity, I will try to use the Energy, Momentum and Mass data activity to have students use data to find the relation, not just telling them what the relation is.

Second semester we I will continue to have students come up with their own cosmic ray detector question to test in order to get first-hand experience doing science.

2025 CRD Project

https://i2u2.org/elab/cosmic/posters/display.jsp?name=ajl-cosmic-2025group-steven_millward-grace_high_school-grace-id-2025.0519.data

https://docs.google.com/presentation/d/1Myplq49Zju-O-Vx0N9xlzRWBMFAppXkBADAOYjaYwgo/edit?slide=id.g35a7ca3e073_0_0#slide=id.g35a7ca3e073_0_0