NOvA Masterclass

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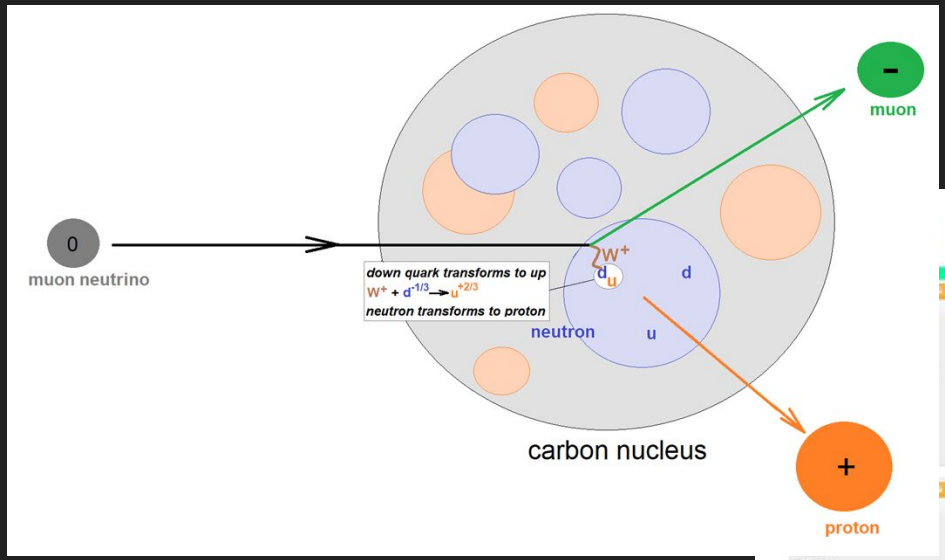
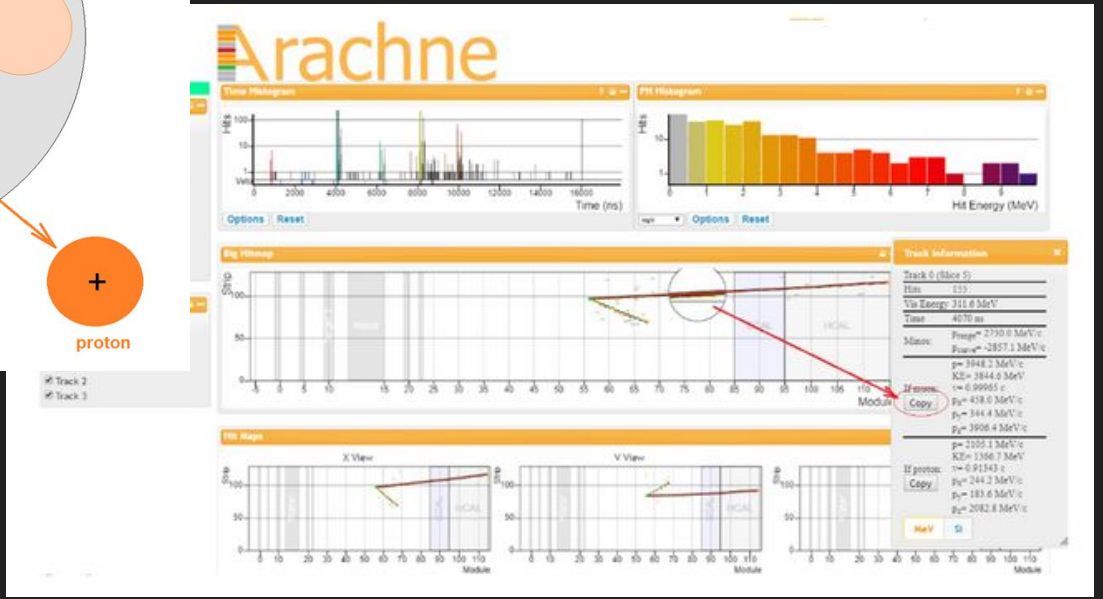
International Masterclasses

- IPPOG and QuarkNET Supported
- Modeled After Arts Masterclasses
- Students become “Particle Physicists for a Day”
  - Do a Particle Physics Data Analysis Activity
  - Do the Activity in the Presence of Physics Masters (Physicists from Local Universities)
- Data is Real, from Actual Physics Experiments
- Data Analysis Activity Mirrors Actual Physics Analysis
- Ends with a Video Conference, Connecting Students to a Particle Physics Research Lab & Physicist
  - Discuss Analysis from the Activity, Connect with a Physicist!

https://physicsmasterclasses.org

Neutrino Based Masterclasses - MINERvA



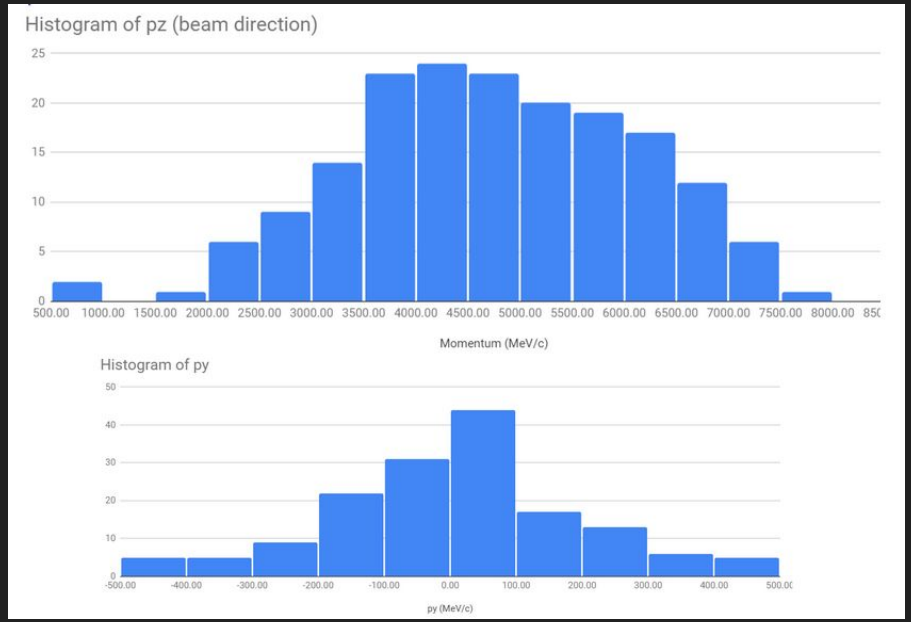


MINERvA

- Big Fan
- Momentum & Energy Data Collected, Histogramed
- Results…
  - Verified Beam Energy
  - Showcased Indirect Measurement of the Carbon Target Nucleus

However

- Not Much Learned About the Neutrino Itself



Enter NOvA Masterclass

- Masterclass Proposed and Developed by…
  - Dr. Greg Pawlowski
    - Associate Professor, University of Minnesota
    - Neutrino Physicist

- Further Developed by…
  - Shane Wood
    - QuarkNET Staff Member
    - Irondale School District, Newbrighton, MN

- Further Developed by…
  - Mike Plucinski
    - QuarkNET Neutrino Fellow
    - Physics & Engineering Teacher

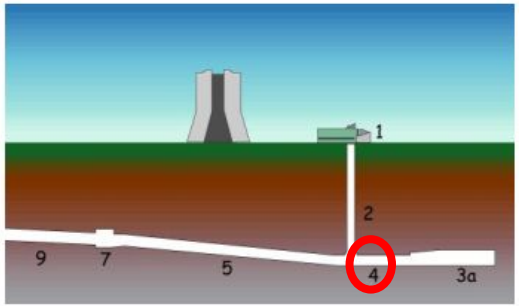
NOvA Masterclass

- Student Analysis of Neutrino Events from the NOvA Experiment
- Results to Highlight a Neutrino Property - Oscillation
- Includes Python Coding in Part 2 of the Analysis

NOvA Experiment

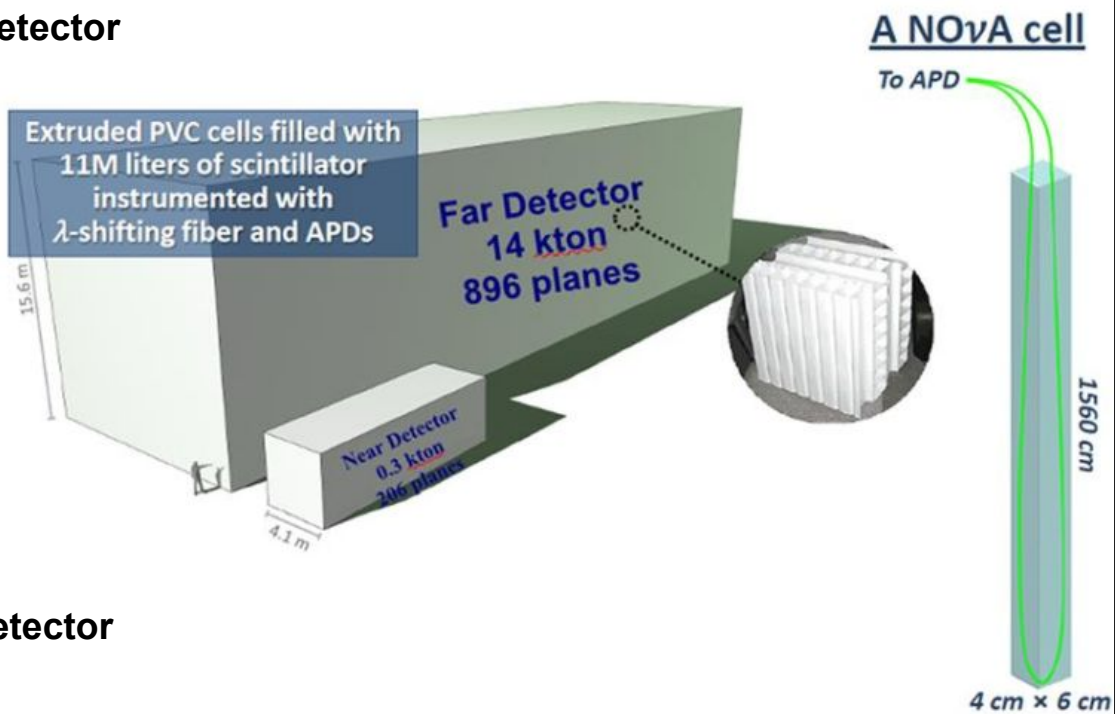
Far Detector

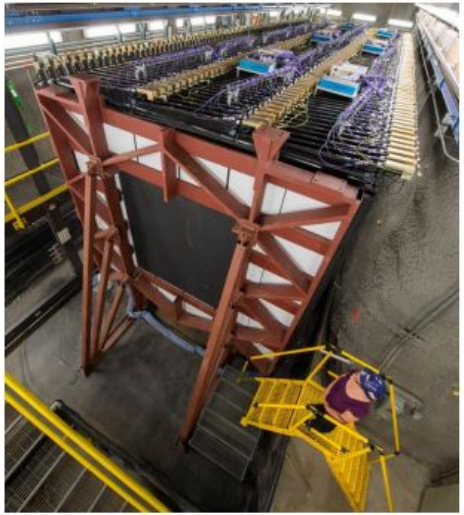
Near Detector



NOvA Detectors

Far Detector





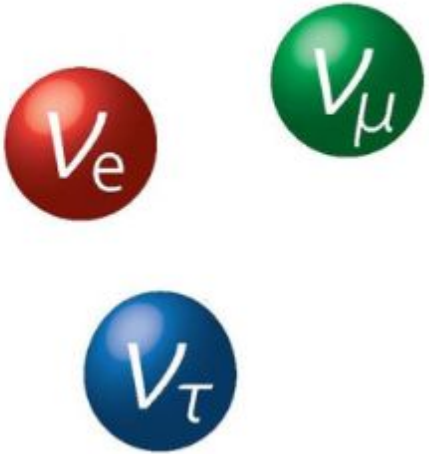
Near Detector

Neutrino Reminders

What about the neutrinos

3 Flavors of Neutrinos

- Electron
- Muon
- Tau



How they're different

No electric or color charge

No EM or strong interactions

Extremely tiny mass

At least a million times less massive than an electron

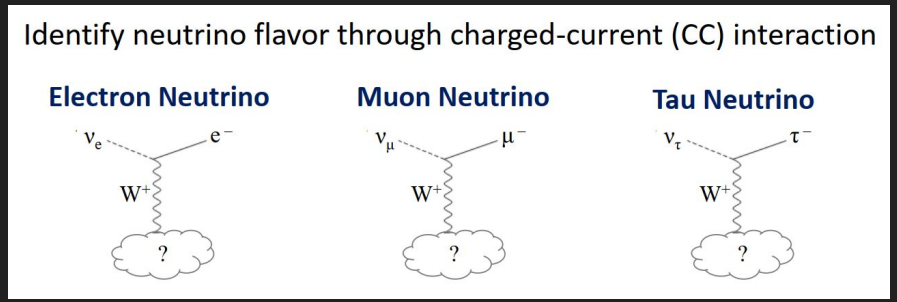
Neutrino Events - 2 Types

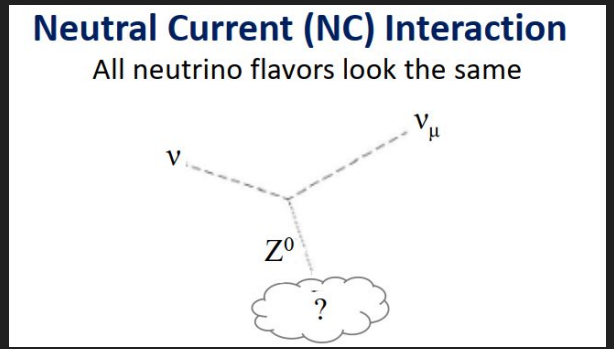
Charged Current Interaction

- W+ Boson Mediated
- Can Tell the Type (Muon)

Neutral Current Interaction

- Z Boson Mediated
- All Types Look the Same





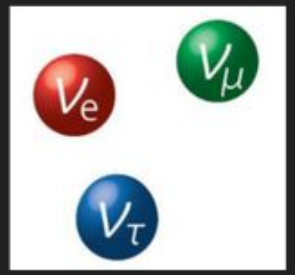
Analysis Goal: Find the Ratio of Charged Current Events to Total Events

- Is this Ratio the Same for the Far and Near Detectors?

NOvA Far Detector - Event Ratio

Charged Current Interaction

- W+ Boson Mediated
- Can Tell the Type (Muon)



Neutral Current Interaction

- Z Boson Mediated
- All Types Look the Same

Charged Current Interaction

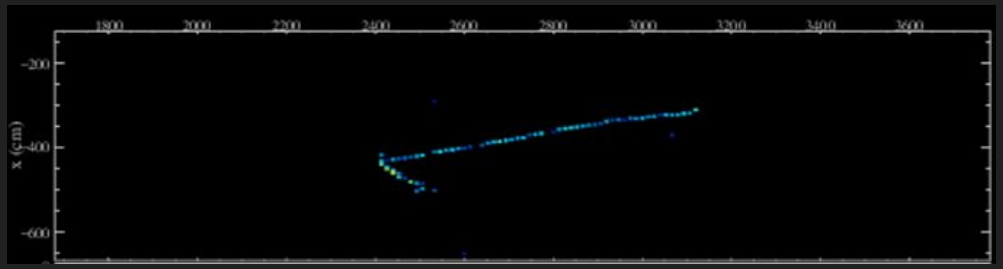
- 6 Far Detector Events

Neutral Current Interaction

- 40 Far Detector Events

Far Detector Ratio: 6 / 46 = 0.13

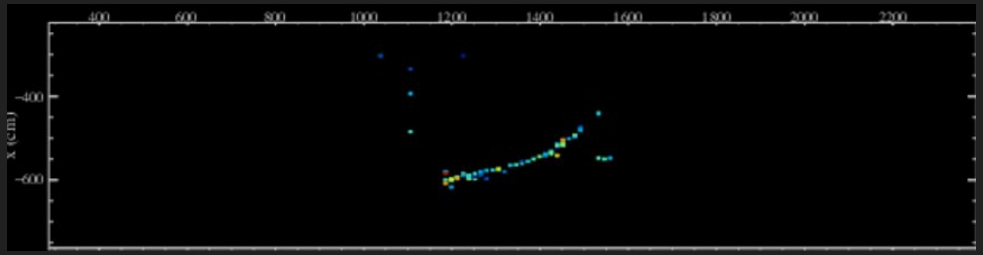
Analysis Work By the Students - Far Detector Events

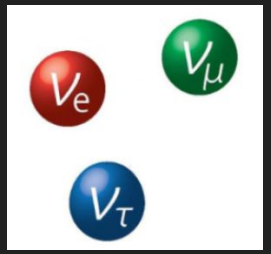


Charged Current Interaction

- W+ Boson Mediated
- Can Tell the Type (Muon)

Analysis Task: Measure & Record Length of the Longest Track from Each Event

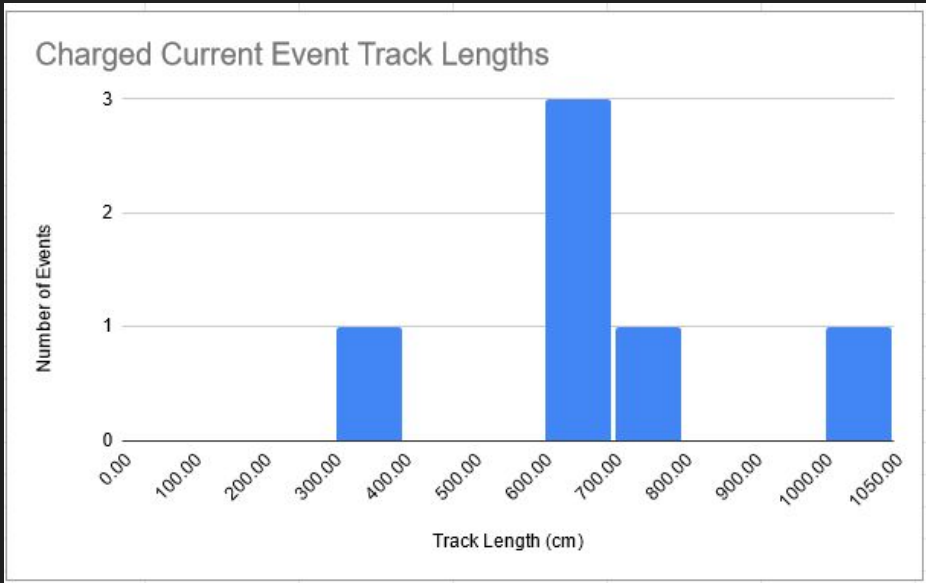


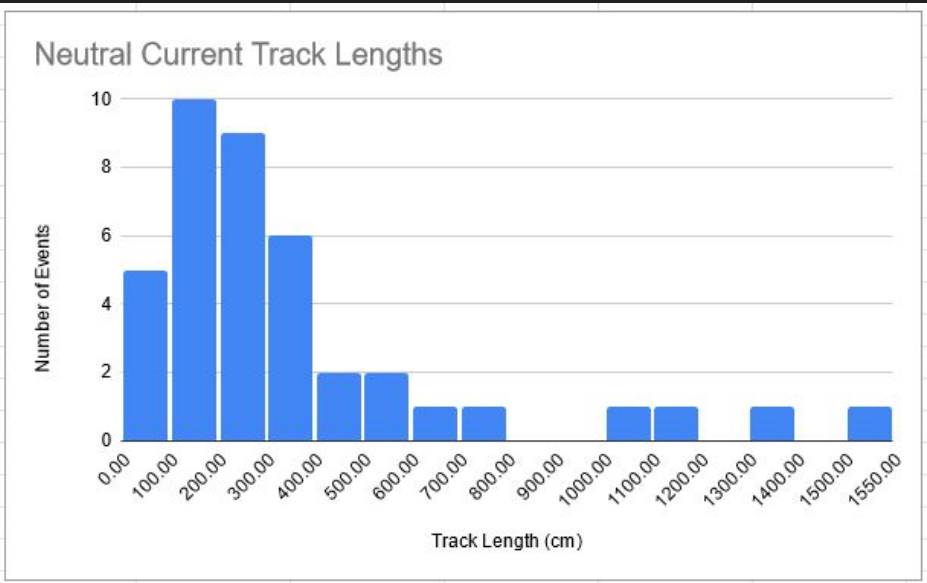


Neutral Current Interaction

- Z Boson Mediated
- All Types Look the Same

Far Detector Track Length Results



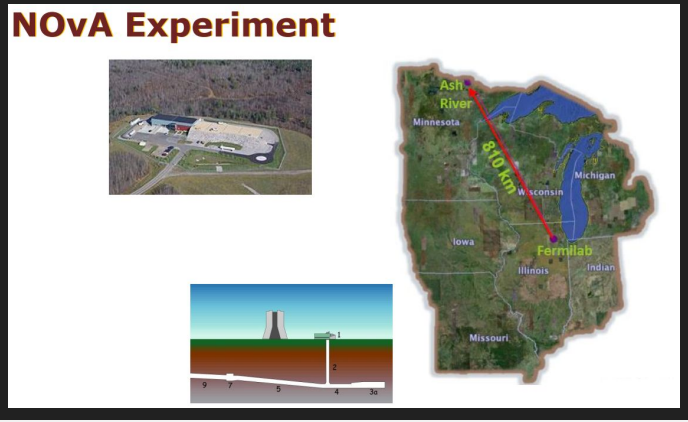


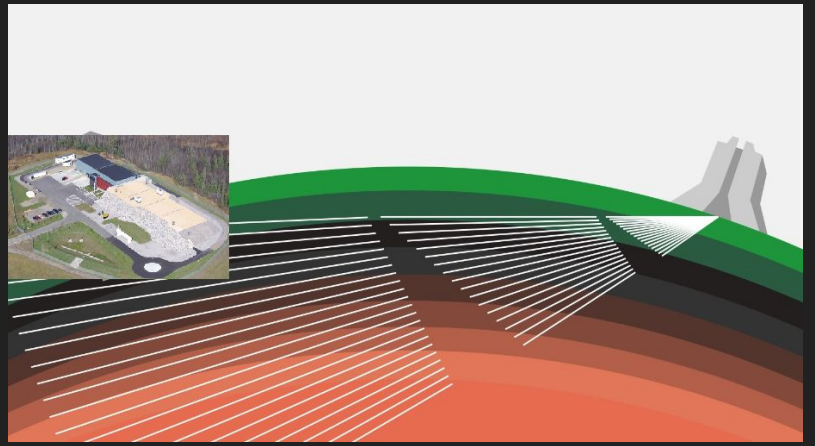
Analysis Task: Establish a “length” to Distinguish Between Charged & Neutral

Move from Far Detector to Near Detector

Near Detector

- Many Events
  - From 46 to Over 6000
- Events are Mixed
  - Far: Given C vs N
  - Near: Mix of C and N
- Cannot Manually Analyze
  - Bring in Coding
  - Use the Length Value from Far Analysis to Differentiate C vs N





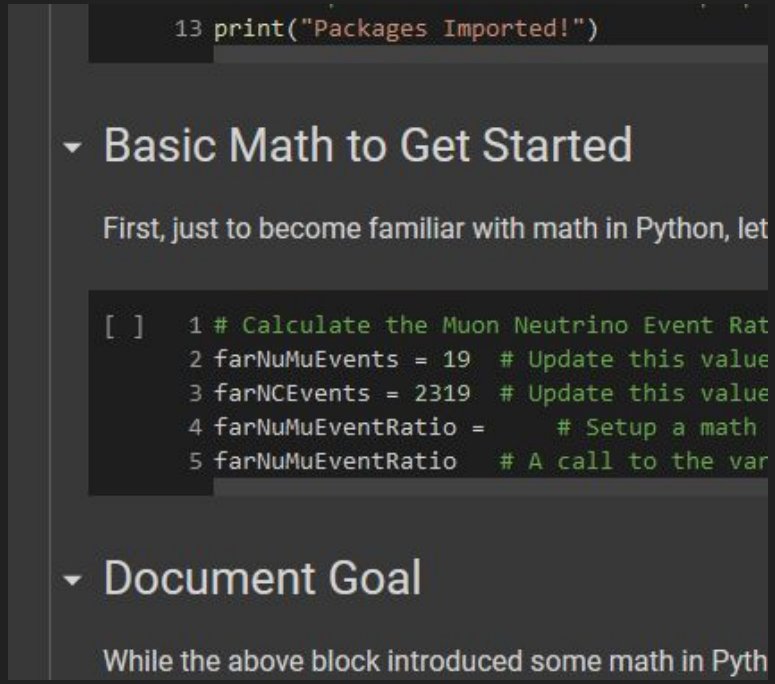
Google Colaboratory

- Jupyter Notebook
- Cloud Based
- Google Drive Extension
  - Google Apps Access
  - Sharing, Collaborative Editing (at Least in Separate Blocks)
  - Organized Within Google Drive
- No Local Install - Runs in Any Web Browser...Device Independent
  - Phone/Tablet Not Recommended if Editing

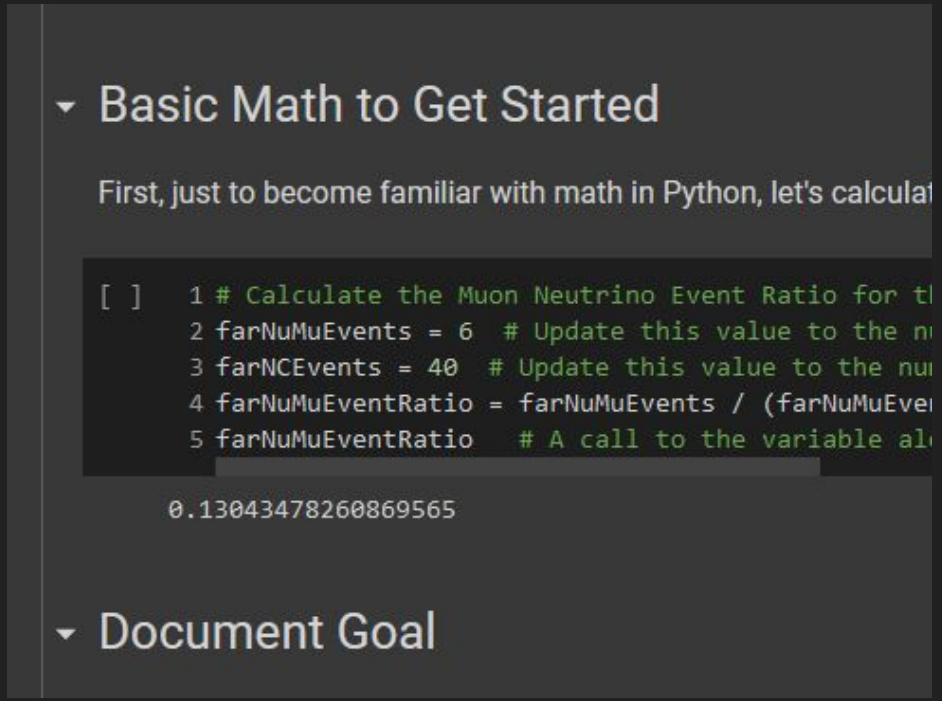
- Code Snippets, Not Mastery
  - Early - Setup Blocks & Force In-Line Editing
  - Later - Separate “Sample Blocks” Document for Reference...May Setup Empty Cells with a Comment for Guidance
- Playground Mode
  - Work/Play in a Document, Without Changing the Original

Coding

To-Be Completed



Completed



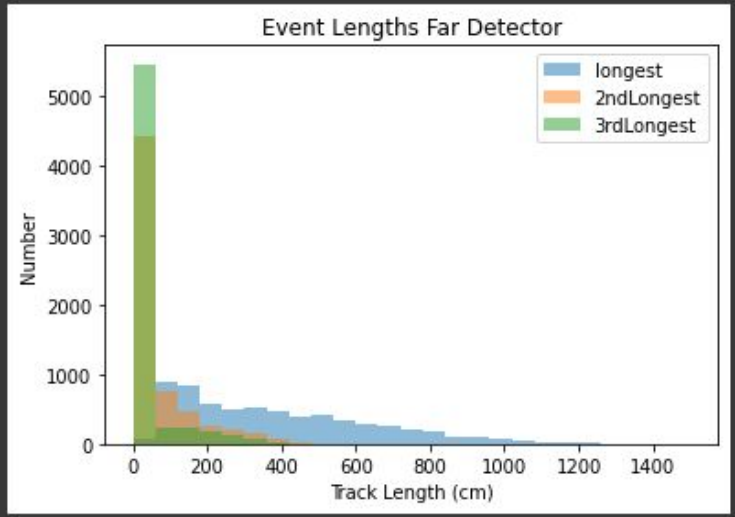
Coding Process

- Import Data from GitHub
- Visualize the Dataset
  - How many, basic stats (range, mean…)
  - Lots of Events of a Similar Nature
    - Make a Histogram!

```
1 # A call to the "describe" function can help give
2 # It can be used for all columns, as seen below, (
3 data.describe()
```

	longest	2ndLongest	3rdLongest
count	6350.000000	6350.000000	6350.000000
mean	387.910839	53.786865	26.792548
std	260.671507	95.012958	73.275730

```
14
15 # Feel free to play with the above.  Some strategic
```



Coding - Count Based on Length

```
3 # To help determine an event was a NuMu event (and not an NC
4
5 nuMuEventTrackLength = 400  # This number should be updated
6 print("NuMu Event Length Value: ", nuMuEventTrackLength)
```

```
NuMu Event Length Value:  400
```

```
3 # When used with a logical expression, the number of events that evaluate
4
5 nearNuMuEventCount = np.sum(data['longest'] > nuMuEventTrackLength)  #Upda
6 print("Near NuMu Event Count: ", nearNuMuEventCount)
7
```

```
Near NuMu Event Count:  2655
```

```
2 # Update the below line as needed to probably create the end ratio
3 nearDetectorRatio = nearNuMuEventCount / len(data['longest'])
4 print("Near Detector NuMu Event Ratio: ", nearDetectorRatio)
```

```
Near Detector NuMu Event Ratio:  0.41811023622047244
```

Coding Extension - Number Comparison

```
6
7 eventPercentDiff = (np.abs(nearDetectorRatio - farNuMuE
8 print("Event Percent Difference: ", eventPercentDiff)
```

```
Event Percent Difference:  220.55118110236225
```

```
 6 minNearNuMuEventsCount = np.sum(data['longest'] > 600)
 7 maxNearNuMuEventsCount = np.sum(data['longest'] > 300)
 8
 9 minRatioNear = minNearNuMuEventsCount / len(data['longest'])
10 maxRatioNear = maxNearNuMuEventsCount / len(data['longest'])
11
12 print("Low Ratio Near NuMu Events: ", minRatioNear, " High Ratio Near NuMu Events: ", maxRatioNear)
13 print("Far NuMu Event Ratio: ", farNuMuEventRatio)
```

```
Low Ratio Near NuMu Events:  0.21118110236220472  High Ratio Near NuMu Events:  0.5478740157480315
Far NuMu Event Ratio:  0.13043478260869565
```

Goal: Ratio Comparison

Far Detector

- Manual Image Analysis, Type of Interaction (Charged, Neutral) Given
  - Ratio: 6 / 46 = 0.13

Near Detector

- Lots of Events…Use Coding to Differentiate Between Interaction Type
  - Ratio: 2655 / 6350 = 0.42

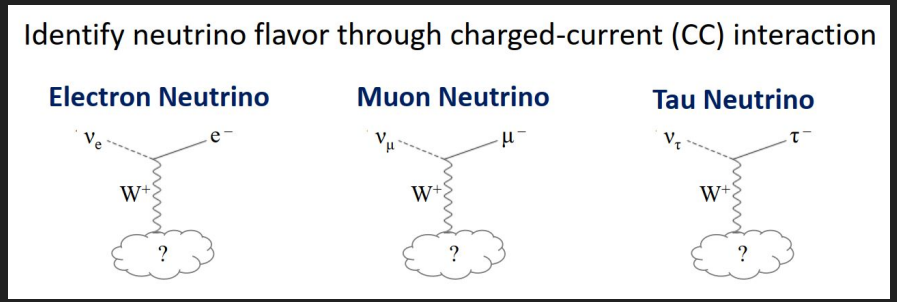
What Does the Ratio Mean?

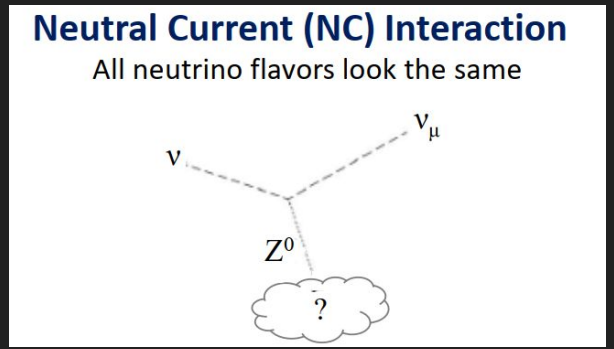
Charged Current Interaction

- W+ Boson Mediated
- Can Tell the Type (Muon)

Neutral Current Interaction

- Z Boson Mediated
- All Types Look the Same



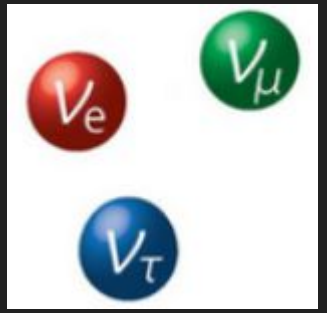


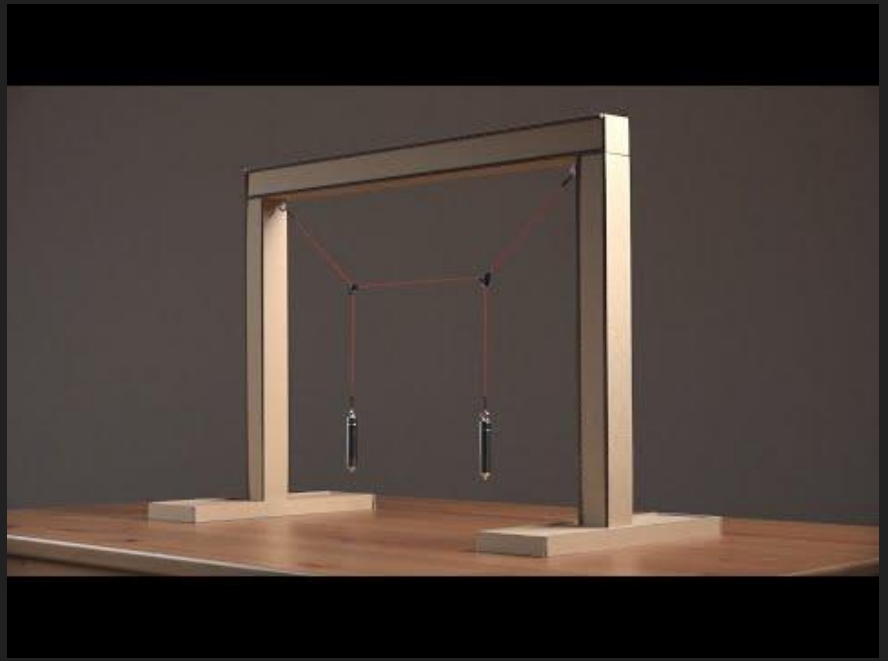
Far Detector: 13% of Total Events were Muon Type

Near Detector: 42% of Total Events were Muon Type

Neutrino Oscillation!

Even Bananas: [How Neutrino Oscillations Work]





Masterclass Next Steps

Where We've Been…

- QuarkNET Teacher Workshops Last Summer
  - Houston, Minnesota, Virginia Tech, William & Mary
- AAPT Winter Meeting
  - Workshop Session in Portland
- Piloted with Students
  - UofM Last Year, UofM early March, UC Irvine late March

Future Thoughts…

- Continue to Collect Feedback…Iterates Every Time
- Working with Dr. Pawlowski to Generate More Data Sets
- Preparation of Masterclass Documentation
- Continue to Spread the Word

Thank You!

Questions? Thoughts?