# Introducción al ejercicio

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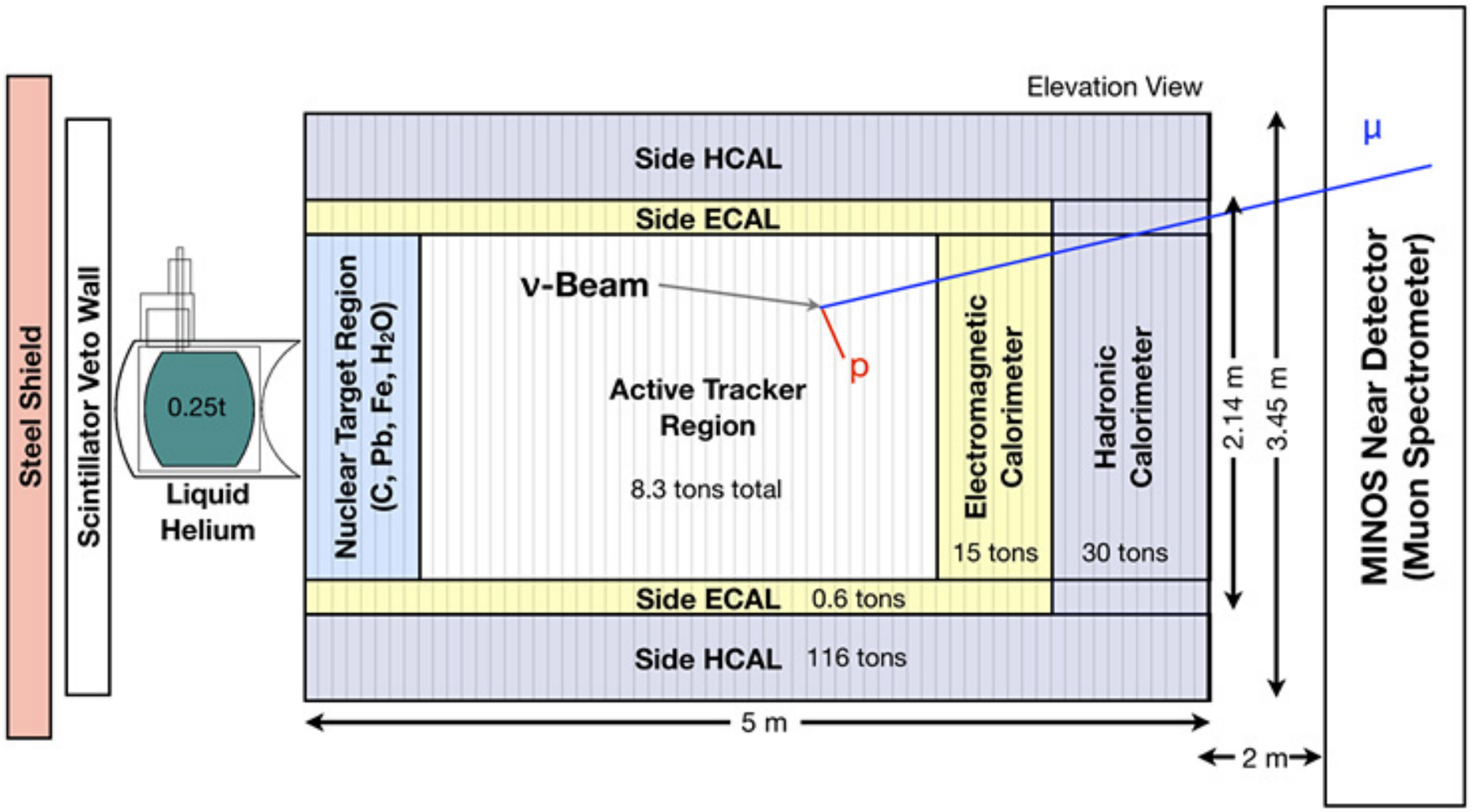
Masterclass Hands on Particle Physics: ejercicio MINERvA
Abril 2019

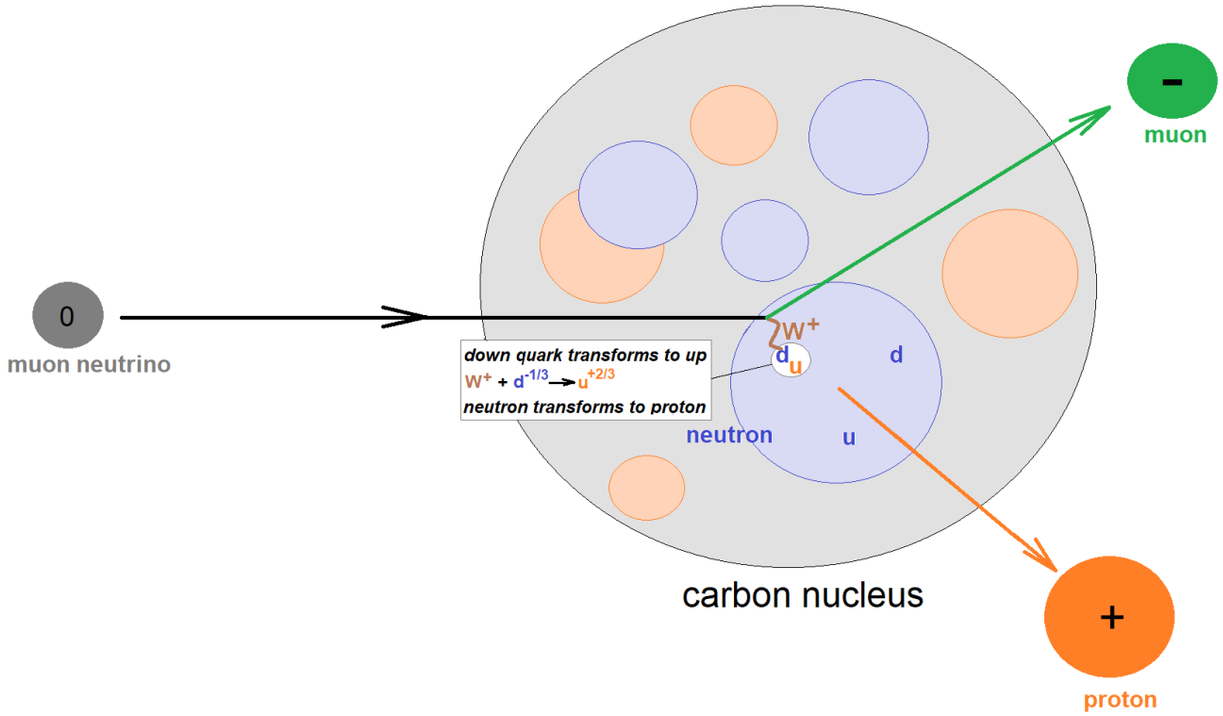
# MINERvA masterclass measurement

- The MINERvA masterclass measurement enables you to examine actual events from the MINERvA detector in the MINOS neutrino beamline at Fermilab
- It enables you to draw conclusions based on categorization of the data and the kinematics of the interactions



# Signal and background events

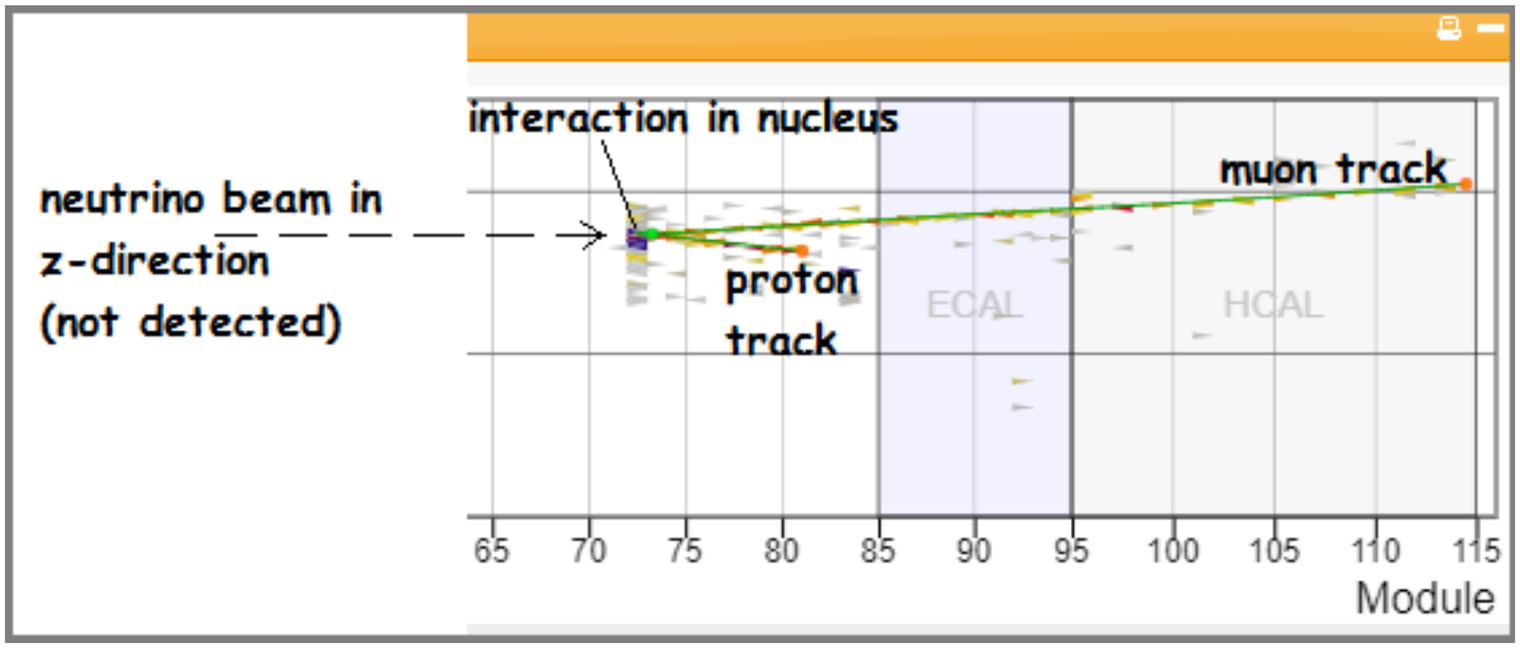
- There are both background and signal events
- In each signal event, a neutrino penetrates a nucleus in carbon target and undergoes a weak interaction with a neutron in that nucleus
    - The neutrino interacts with the neutron to become a muon, causing the neutron to become a proton!




- Background event: any other event type

# Interaction kinematics

- While MINERvA cannot directly detect the neutrino, it detects and measures the kinematics of both the muon and the proton that emerge from the interaction
- You can find this kinematic information with Arachne, the MINERvA event display that you will use to visualize the events.
- You will then put this information into a spreadsheet which applies conservation of momentum to give the momentum of the system prior to the interaction in three dimensions.



# Masterclass objectives

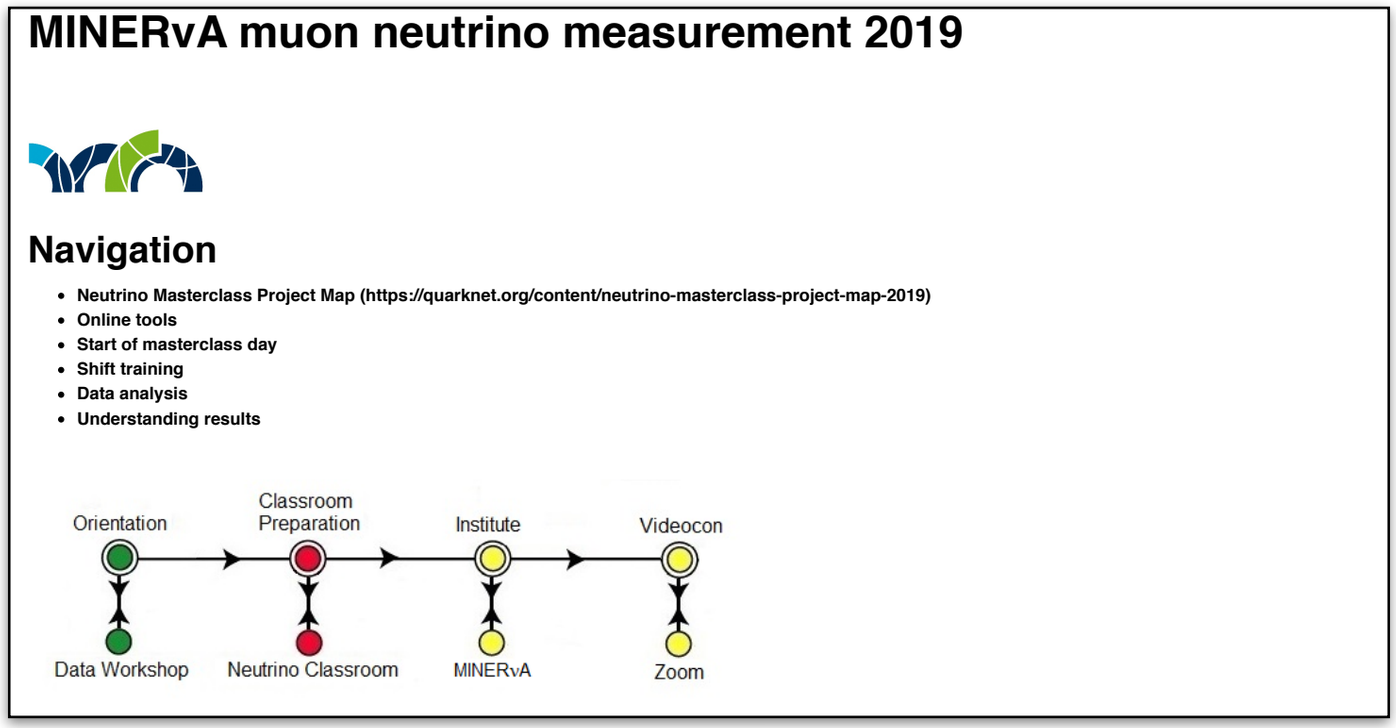
- Determine which events are **signal** events *(from which effective measurements may be made)* and which events are **background** (that cannot be used for measurements).

- Apply conservation of momentum and energy to measure the approximate **energy of a neutrino beam** from the Fermilab accelerator complex.

- Apply conservation of momentum and energy to measure the **properties of neutrons** in nuclei of atoms in the target of a neutrino beam.

# Software

- The entire MINERvA masterclass measurement runs online in a browser
  - Please use **Google Chrome**, which should already be open at this page in your desktop, otherwise let us know!




- We will use the **Arachne** event display to visualize, select and analyse the events
- We will use **Google Sheets** to fill kinematic information, make plots and extract results

# First Step: Find events

- Please work in pairs: two students per computer. Each pair of students is assigned a **unique** mergedTuple (a 50-event dataset)
  - Aula IV uses mergedTuples 51-75
  - Aula V uses mergedTuples 76-100

| Date/time CT | Institute (Data Group) | Institute (Data Group) | Institute (Data) | Spreadsheet |
|---|---|---|---|---|
| Thu 14 Mar/11:45 | Rochester (**A**) | Syracuse (**E**) | | **FNAL-14Mar2019** |
| Fri 29 Mar 15:00 | Barranquilla (**B**) | Lead (**C**) | | **FNAL-29Mar2019** |
| Fri 29 Mar 21:00 | Qingdao (**D**) | | | **FNAL-29Mar2019** |
| Sat 06 Apr/14:00 | Fairfax (**D**) | Mayaguez (**F**, **G**) | Knoxville (**E**) | **FNAL-06Apr2019A** |
| Sat 06 Apr/16:00 | Minneapolis (**G**) | Fort Collins (**F**) | | **FNAL-06Apr2019B** |
| Thu 11 Apr/09:00 | Valencia (**C**. **D**) | | | **FNAL-11Apr2019** |
| Thu 11 Apr/15:00 | Batavia (**F**) | | | **FNAL-11Apr2019** |

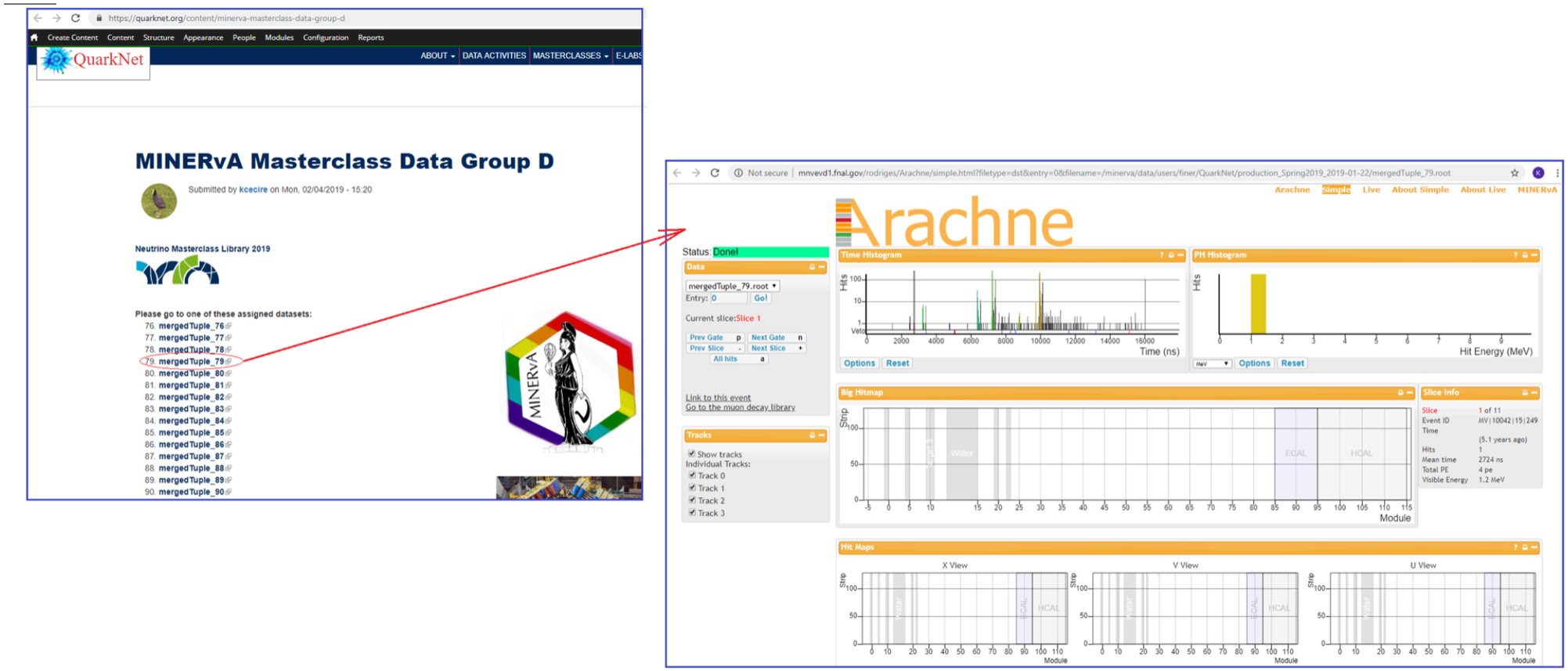
*If >50 students are expected, contact **Masterclass Coordination** for more data groups.*

All MINERvA Data for International Masterclasses:

A. **mergedTuples 1-25**
B. **mergedTuples 26-50**
C. **mergedTuples 51-75**
D. **mergedTuples 76-100**
E. **mergedTuples 101-125**
F. **mergedTuples 126-150**
G. **mergedTuples 151-175**
H. **practiceTuples** (includes teacherTuple and Archive)

# Second Step: Open and use Arachne

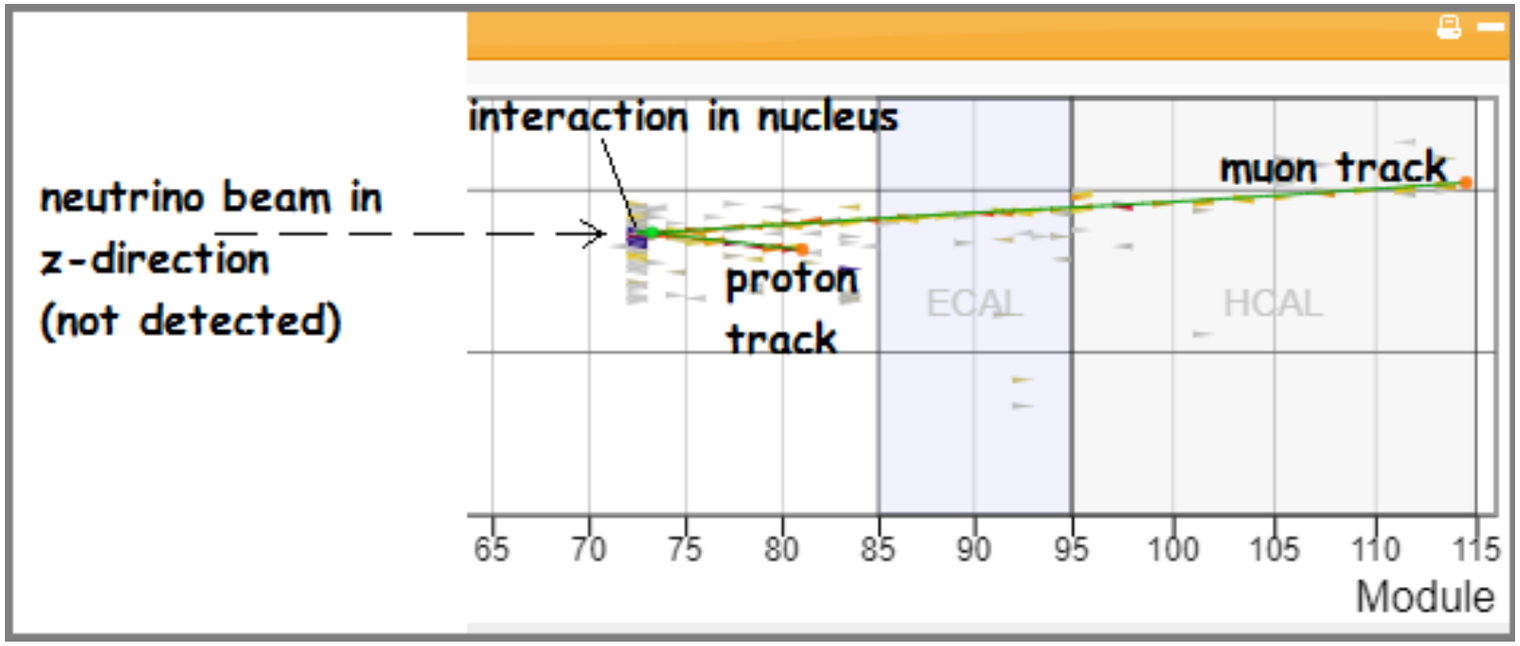
- When you click on your assigned mergedTuple, Arachne will open in a new tab




- Arachne will open at the initial time **Slice** in the first **Gate** (or event, shown as **Entry** 0; the next Gate will be Entry 1, etc.).
- In most cases, it will not initially show the event you are looking for. You must find it, if it is there, by advancing from Slice to Slice within the Gate.

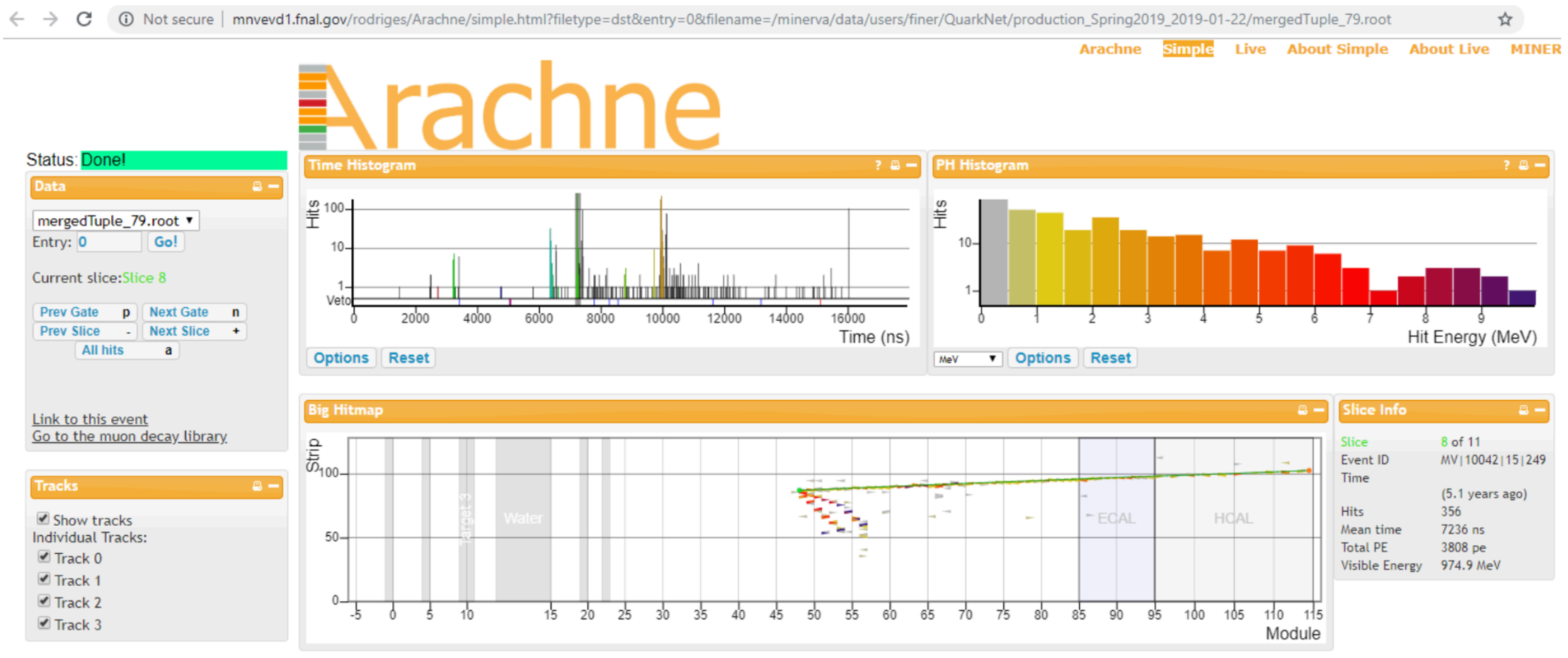
# Second Step: Open and use Arachne

- You choose Next Slice, which moves to a slightly later time in the Gate with each click. The progress can be seen in the Time Histogram in Arachne.
- You advance the Slice until you find an instance of one long track and one short track coming from a common vertex. This is the actual event you seek:



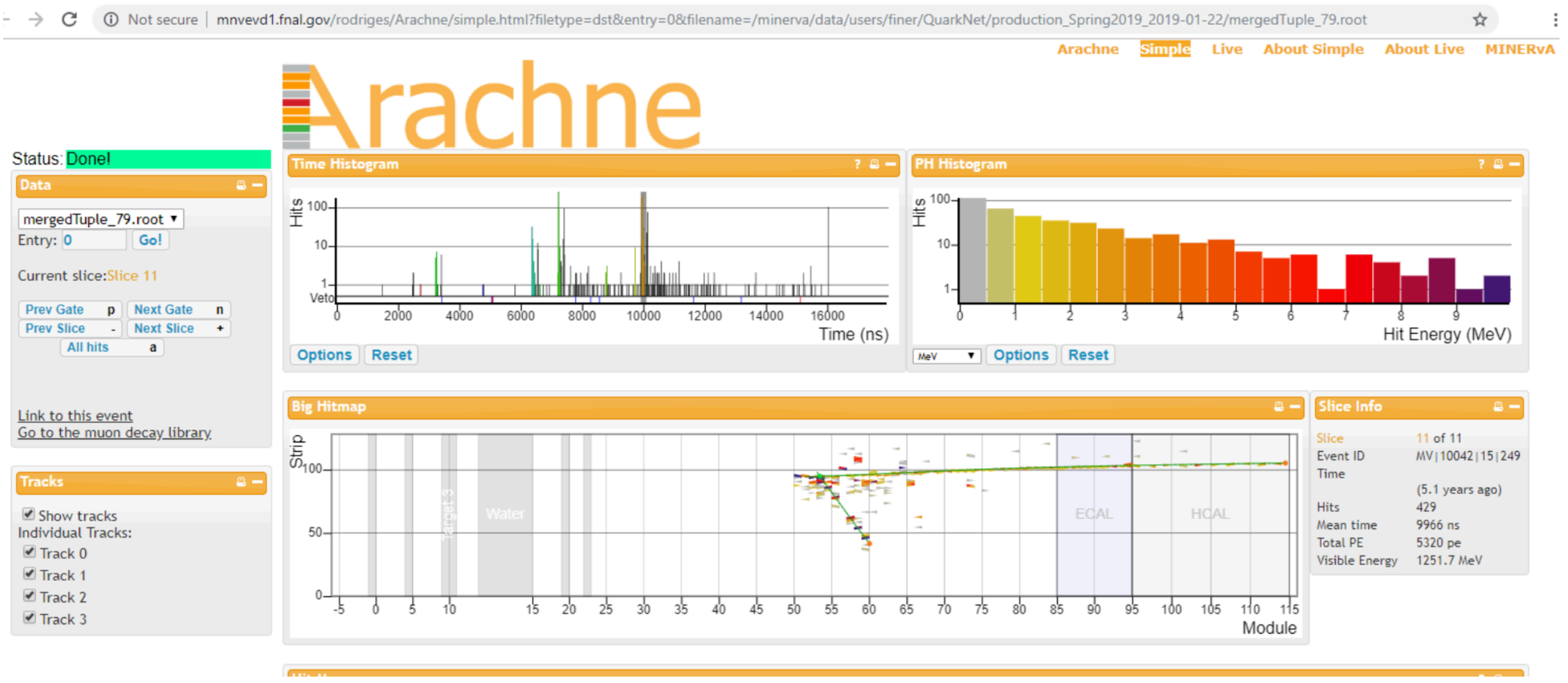
# Second Step: Open and use Arachne

- In this particular Gate, we find two possible events but both are background.
- The first one, in Slice 8 of 11, has two short tracks rather than one:



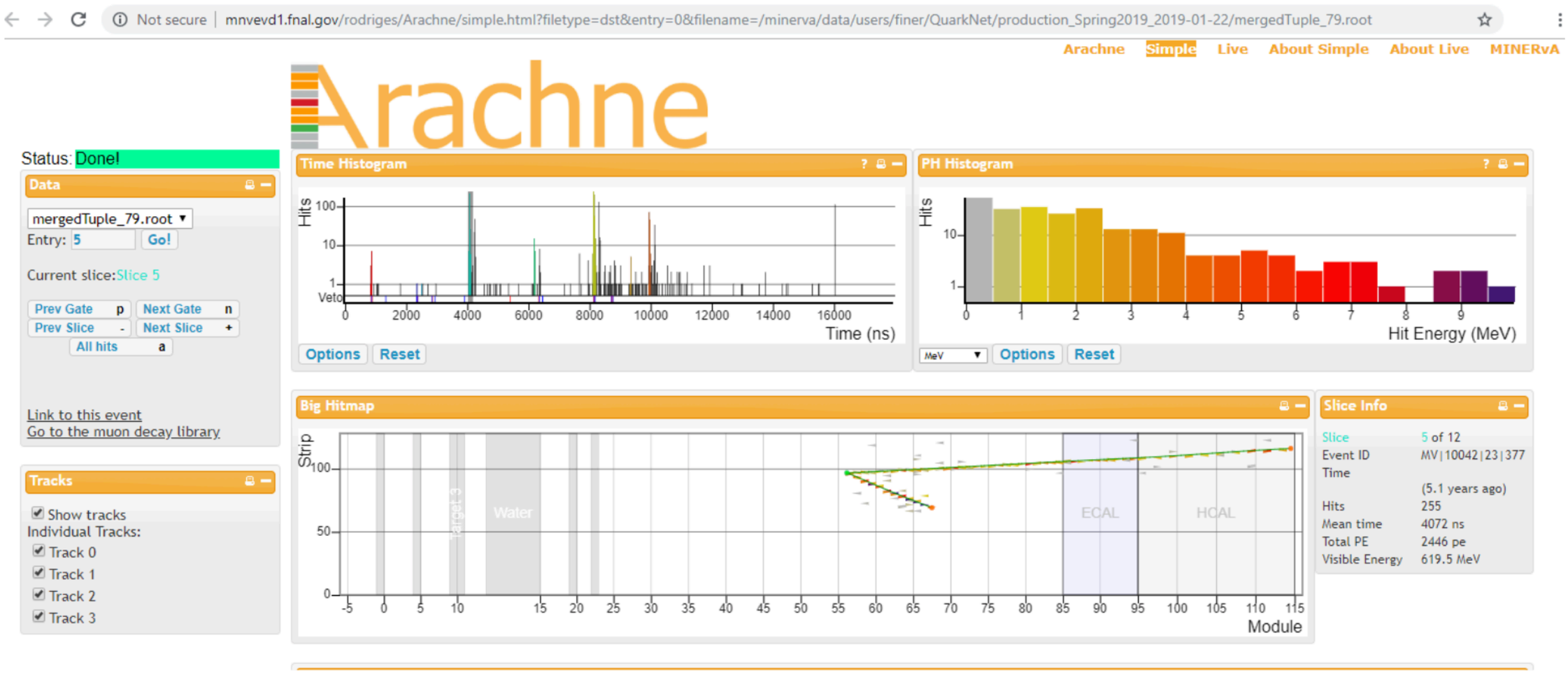
# Second Step: Open and use Arachne

- In this particular Gate, we find two possible events but both are background.
- The second one, in Slice 11 of 11, has a an extra track which appears to go backwards (negative z direction) from the vertex, plus several lines of red and orange dots also coming from the same place.



# Second Step: Open and use Arachne

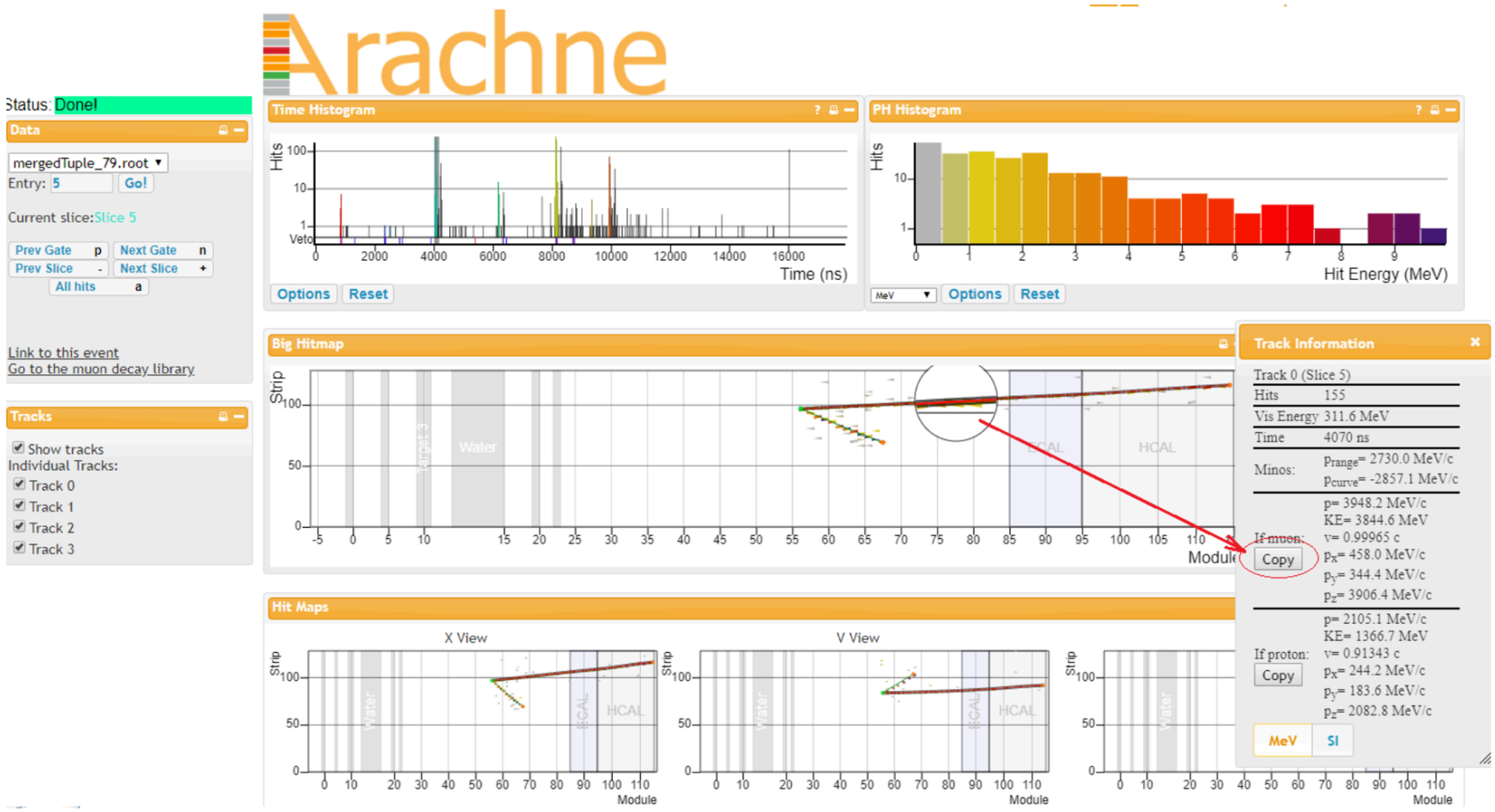
- Here is an example of a good signal event:




- Note we are in a different Gate!
- This is close to a "classic" event: one clear long track for the muon and one clear short track for the proton.

# Second Step: Open and use Arachne

- Now you must find the kinematics from each track. Here we pick the long muon track:




- When you choose a track, the Track Information box pops up. Because this is a muon, you choose the Copy button for a muon.
- This copies the kinematic data for the muon to the computer clipboard.

# Third Step: Enter data into the spreadsheet

- Track information is then pasted at the appropriate place in the Valencia Google sheet, in this case in the row for mergedTuple 79, Entry 5 and in the column under Muon KE (MeV):

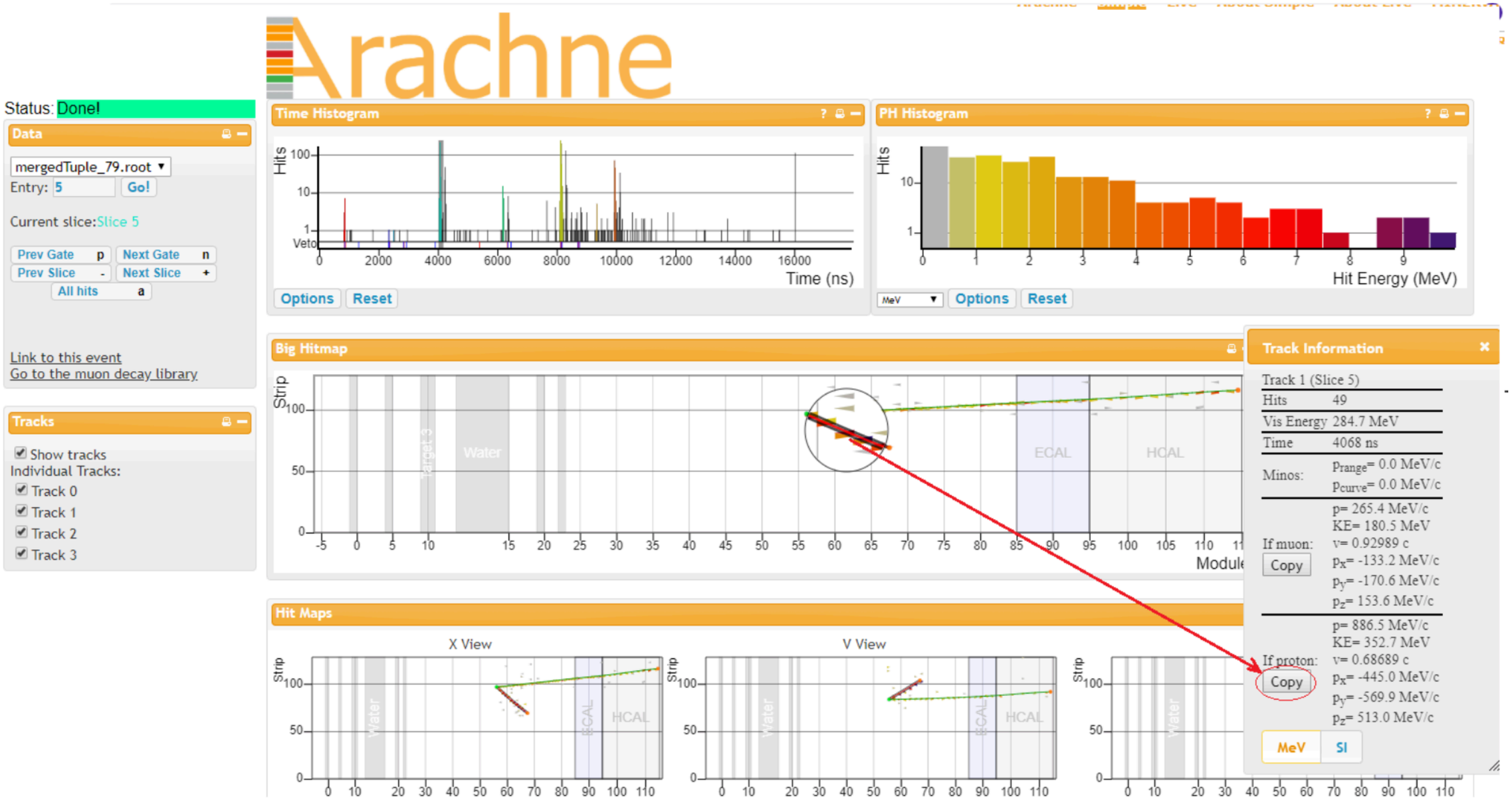
| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | | | | | | | | | | | | | | | | |
| 4 | merged | | Background | Zoo | Muon | | | | | Proton | | | | | Net | |
| 5 | Tuple | Entry | (enter a 1) | (enter a 1) | KE (MeV) | v/c | px (MeV/c) | py (MeV/c) | pz (MeV/c) | KE (MeV) | v/c | px (MeV/c) | py (MeV/c) | pz (MeV/c) | px (Me | |
| 154 | 78 | 38 | | | 2,468.00 | 0.99917 | 127.87 | -451.51 | 2,527.66 | 250.63 | 0.61 | 282.26 | 73.04 | 669.32 | | |
| 155 | 78 | 39 | | | 4,180.98 | 0.9997 | -290.25 | 322.75 | 4,262.65 | 4,180.98 | 1 | -290.25 | 322.75 | 4,262.65 | | |
| 156 | 78 | 40 | | | 2,783.10 | 0.99934 | -181.33 | -468.2 | 2,842.18 | 299.54 | 0.65 | 40.96 | 609.33 | 527.92 | | |
| 157 | 78 | 41 | | | | | | | | | | | | | | |
| 158 | 78 | 42 | | | 3,467.68 | 0.99957 | 311.9 | -624.25 | 3,502.30 | 1,219.51 | 0.9 | 169.69 | -339.63 | 1,905.48 | | |
| 159 | 78 | 43 | | | 6,862.50 | 0.99989 | 579.99 | -95.45 | 6,941.86 | 330.54 | 0.67 | -61.04 | 308.27 | 794.1 | | |
| 160 | 78 | 44 | | | 70.27 | 0.80069 | 56.54 | -31.5 | 124.52 | 158.34 | 0.52 | 228.67 | -127.41 | 503.58 | | |
| 161 | 78 | 45 | | | 4,687.34 | 0.99976 | -602.76 | -335.44 | 4,741.27 | 158.34 | 0.52 | 228.67 | -127.41 | 503.58 | | |
| 162 | 78 | 46 | | | 2,879.91 | 0.99938 | -369.07 | -127.86 | 2,957.39 | 1,286.94 | 0.91 | -249.61 | -86.47 | 2,000.18 | | |
| 163 | 78 | 47 | | | 3,890.06 | 0.99965 | -295.93 | 433.85 | 3,959.00 | 1,397.32 | 0.92 | -158.47 | 232.33 | 2,120.09 | | |
| 164 | 78 | 48 | | | 5,784.31 | 0.99984 | 370.25 | -586.18 | 5,847.42 | 169.58 | 0.53 | -246.29 | 271.65 | 460.9 | | |
| 165 | 78 | 49 | | | 3,074.27 | 0.99945 | -228.59 | -303.83 | 3,154.71 | 1,432.36 | 0.92 | -156.6 | -208.15 | 2,161.23 | | |
| 166 | 78 | 50 | | | 5,756.19 | 0.99984 | 326.56 | -411.38 | 5,836.67 | 5,784.31 | 1 | 370.25 | -586.18 | 5,847.42 | | |
| 167 | | | | | | | | | | | | | | | | |
| 168 | | | | | | | | | | | | | | | | |
| 169 | | | | | | | | | | | | | | | | |
| 170 | | | | | | | | | | | | | | | | |
| 171 | 79 | 0 | | | | | | | | | | | | | | |
| 172 | 79 | 1 | | | 125.64 | 0.89036 | 111.97 | -12.75 | 171.66 | 260.46 | 0.62 | 406.75 | -46.31 | 623.59 | | |
| 173 | 79 | 2 | | | | | | | | | | | | | | |
| 174 | 79 | 3 | | | 2,745.79 | 0.99932 | -396.07 | -157.98 | 2,816.76 | 1,493.81 | 0.92 | -311.93 | -124.42 | 2,218.35 | | |
| 175 | 79 | 4 | | | 235.04 | 0.60049 | 337.93 | -438.13 | 435.93 | 235.04 | 0.6 | 337.93 | -438.13 | 435.93 | | |
| 176 | 79 | 5 | | | 3,844.64 | 0.999646564 | 457.9591639 | 344.430018 | 3,906.44 | | | | | | | |
| 177 | 79 | 6 | | | | | | | | | | | | | | |
| 178 | 79 | 7 | | | | | | | | | | | | | | |
| 179 | 79 | 8 | | | | | | | | | | | | | | |
| 180 | 79 | 9 | | | | | | | | | | | | | | |
| 181 | 79 | 10 | | | | | | | | | | | | | | |
| 182 | 79 | 11 | | | | | | | | | | | | | | |
| 183 | 79 | 12 | | | | | | | | | | | | | | |
| 184 | 79 | 13 | | | | | | | | | | | | | | |

mergedTuples1to25 | mergedTuples26to50 | Copy of mergedTuples51to100 | videocon plots

The students next choose and copy for the proton:

# Third Step: Enter data into the spreadsheet

- For the same signal event, you then choose and copy proton track information:



# Third Step: Enter data into the spreadsheet

- Then paste the proton kinematics in the next cell to the right of the muon numbers:

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | merged | | Muon | | | | | Proton | | | | | Net | Net | nu-beam |
| 5 | Tuple | Entry | KE (MeV) | v/c | px (MeV/c) | py (MeV/c) | pz (MeV/c) | KE (MeV) | v/c | px (MeV/c) | py (MeV/c) | pz (MeV/c) | px (MeV/c) | py (MeV/c) | pz (MeV/c) |
| 154 | 78 | 38 | 2,468.00 | 0.99917 | 127.87 | -451.51 | 2,527.66 | 250.63 | 0.61 | 282.26 | 73.04 | 669.32 | 410.13 | -378.47 | 3,196.98 |
| 155 | 78 | 39 | 4,180.98 | 0.9997 | -290.25 | 322.75 | 4,262.65 | 4,180.98 | 1 | -290.25 | 322.75 | 4,262.65 | -580.50 | 645.50 | 8,525.30 |
| 156 | 78 | 40 | 2,783.10 | 0.99934 | -181.33 | -468.2 | 2,842.18 | 299.54 | 0.65 | 40.96 | 609.33 | 527.92 | -140.37 | 141.13 | 3,370.10 |
| 157 | 78 | 41 | | | | | | | | | | | | | |
| 158 | 78 | 42 | 3,467.68 | 0.99957 | 311.9 | -624.25 | 3,502.30 | 1,219.51 | 0.9 | 169.69 | -339.63 | 1,905.48 | 481.59 | -963.88 | 5,407.78 |
| 159 | 78 | 43 | 6,862.50 | 0.99989 | 579.99 | -95.45 | 6,941.86 | 330.54 | 0.67 | -61.04 | 308.27 | 794.1 | 518.95 | 212.82 | 7,735.96 |
| 160 | 78 | 44 | 70.27 | 0.80069 | 56.54 | -31.5 | 124.52 | 158.34 | 0.52 | 228.67 | -127.41 | 503.58 | 285.21 | -158.91 | 628.10 |
| 161 | 78 | 45 | 4,687.34 | 0.99976 | -602.76 | -335.44 | 4,741.27 | 158.34 | 0.52 | 228.67 | -127.41 | 503.58 | -374.09 | -462.85 | 5,244.85 |
| 162 | 78 | 46 | 2,879.91 | 0.99938 | -369.07 | -127.86 | 2,957.39 | 1,286.94 | 0.91 | -249.61 | -86.47 | 2,000.18 | -618.68 | -214.33 | 4,957.57 |
| 163 | 78 | 47 | 3,890.06 | 0.99965 | -295.93 | 433.85 | 3,959.00 | 1,397.32 | 0.92 | -158.47 | 232.33 | 2,120.09 | -454.40 | 666.18 | 6,079.09 |
| 164 | 78 | 48 | 5,784.31 | 0.99984 | 370.25 | -586.18 | 5,847.42 | 169.58 | 0.53 | -246.29 | 271.65 | 460.9 | 123.96 | -314.53 | 6,308.32 |
| 165 | 78 | 49 | 3,074.27 | 0.99945 | -228.59 | -303.83 | 3,154.71 | 1,432.36 | 0.92 | -156.6 | -208.15 | 2,161.23 | -385.19 | -511.98 | 5,315.94 |
| 166 | 78 | 50 | 5,756.19 | 0.99984 | 326.56 | -411.38 | 5,836.67 | 5,784.31 | 1 | 370.25 | -586.18 | 5,847.42 | 696.81 | -997.56 | 11,684.09 |
| 167 | | | | | | | | | | | | | | | |
| 168 | | | | | | | | | | | | | | | |
| 169 | | | | | | | | | | | | | | | |
| 170 | | | | | | | | | | | | | | | |
| 171 | 79 | 0 | | | | | | | | | | | | | |
| 172 | 79 | 1 | 125.64 | 0.89036 | 111.97 | -12.75 | 171.66 | 260.46 | 0.62 | 406.75 | -46.31 | 623.59 | 518.72 | -59.06 | 795.25 |
| 173 | 79 | 2 | | | | | | | | | | | | | |
| 174 | 79 | 3 | 2,745.79 | 0.99932 | -396.07 | -157.98 | 2,816.76 | 1,493.81 | 0.92 | -311.93 | -124.42 | 2,218.35 | -708.00 | -282.40 | 5,035.11 |
| 175 | 79 | 4 | 235.04 | 0.60049 | 337.93 | -438.13 | 435.93 | 235.04 | 0.6 | 337.93 | -438.13 | 435.93 | 675.86 | -876.26 | 871.86 |
| 176 | 79 | 5 | 3,844.64 | 0.999646564 | 457.9591639 | 344.430018 | 3,906.44 | 352.6635494 | 0.686893643 | -445.034096 | -569.8872402 | 512.9732787 | 12.93 | -225.46 | 4,419.41 |
| 177 | 79 | 6 | | | | | | | | | | | | | |
| 178 | 79 | 7 | | | | | | | | | | | | | |
| 179 | 79 | 8 | | | | | | | | | | | | | |
| 180 | 79 | 9 | | | | | | | | | | | | | |
| 181 | 79 | 10 | | | | | | | | | | | | | |
| 182 | 79 | 11 | | | | | | | | | | | | | |
| 183 | 79 | 12 | | | | | | | | | | | | | |
| 184 | 79 | 13 | | | | | | | | | | | | | |

mergedTuples1to25 | mergedTuples26to50 | Copy of mergedTuples51to100 | videocon plots | Sum: -148.5976145

- Note that the spreadsheet automatically calculates Net px, Net py, nu-beam pz

# Third Step: Enter data into the spreadsheet

- Repeat this for all 50 entries (or gates)
- Put a “Background = 1” for entries with no signal events in any time slice, leaving empty muon and proton cells

FNAL-11Apr2019

File Edit View Insert Format Data Tools Add-ons Help Last edit was made 5 hours ago by anonymous

Share

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | |
| 2 | | | *Numbers initially seen in Rows 6-12, Columns C-N are placeholders only. Please overwrite them as you enter actual data.* | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | |
| 4 | **merged** | | **Background** | **Signal Event** | **Muon** | | | | | **Proton** | | | | |
| 5 | **Tuple** | **Entry** | **(enter a 1)** | **Slice No.** | **KE (MeV)** | **v/c** | **px (MeV/c)** | **py (MeV/c)** | **pz (MeV/c)** | **KE (MeV)** | **v/c** | **px (MeV/c)** | **py (MeV/c)** | **pz (MeV/c)** |
| 6 | 51 | 0 | | 1 | 4,000.00 | 1.00000 | 300.00 | 100.00 | | 100.00 | 1.00 | -400.00 | 500.00 | 100.00 |
| 7 | 51 | 1 | | 4 | 4,000.00 | 1.00000 | 300.00 | 100.00 | | 100.00 | 1.00 | -400.00 | 500.00 | 100.00 |
| 8 | 51 | 2 | 1 | | | | | | | | | | | |
| 9 | 51 | 3 | 1 | | | | | | | | | | | |
| 10 | 51 | 4 | | 7 | 4,000.00 | 1.00000 | 300.00 | 100.00 | | 100.00 | 1.00 | -400.00 | 500.00 | 100.00 |
| 11 | 51 | 5 | | 7 | 4,000.00 | 1.00000 | 300.00 | 100.00 | | 100.00 | 1.00 | -400.00 | 500.00 | 100.00 |
| 12 | 51 | 6 | | | | | | | | | | | | |

- **DONE! This afternoon we will present our findings!**