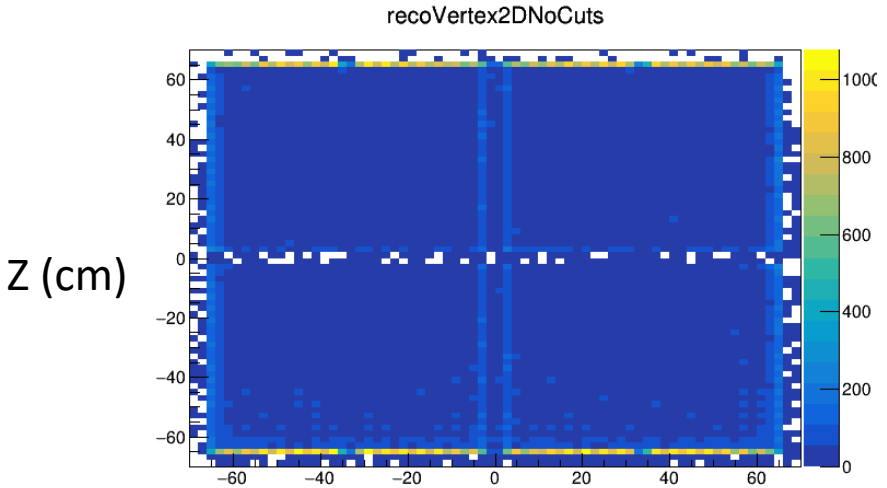
# Measuring the Charge Track Multiplicity Update

Bilal, Richie, and Zelimir for the Track Mult. Group

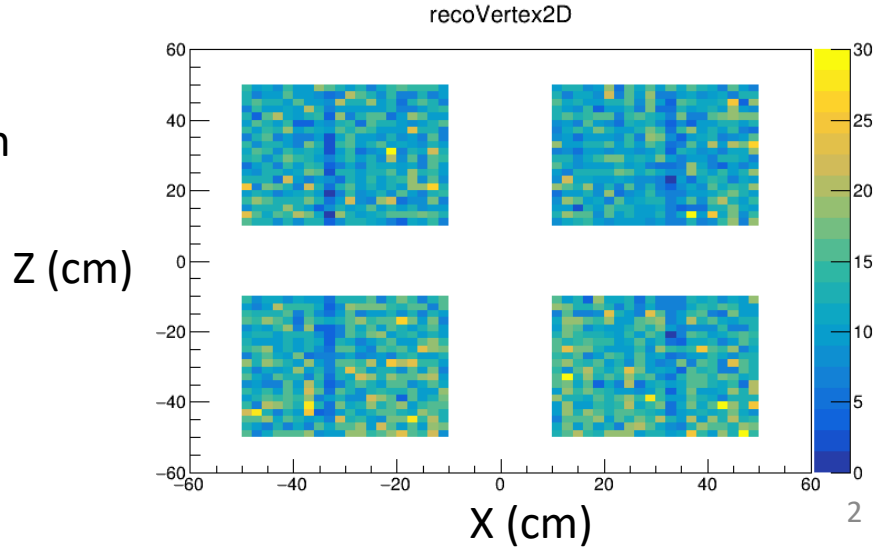
# Using CAFs without any Backtracking

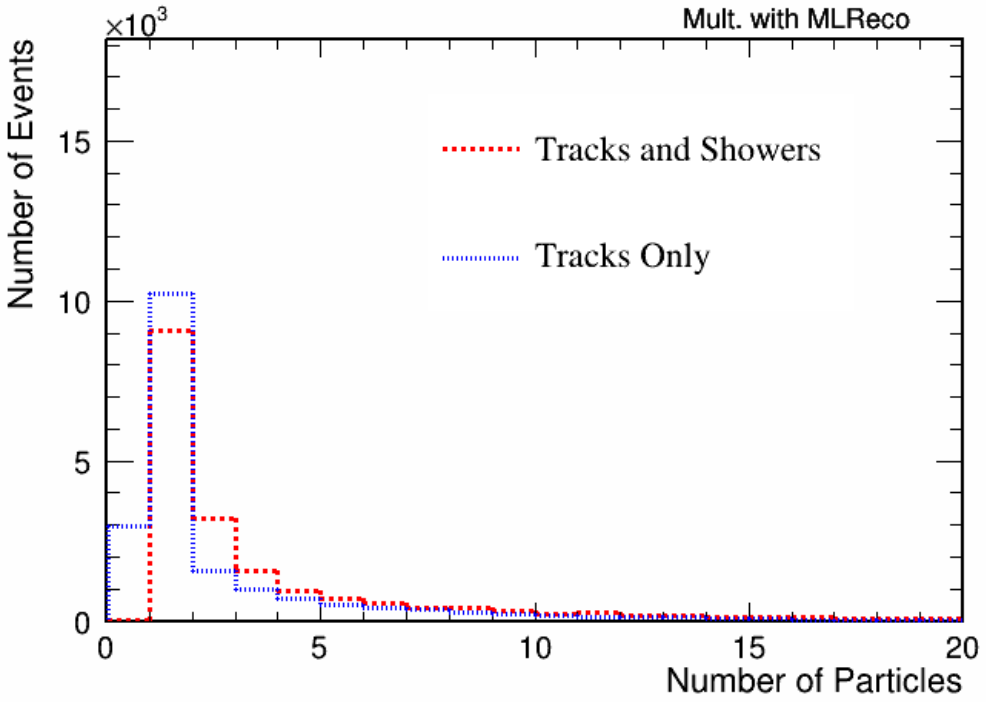
Signal Definition: All tracks, primarily consisting of charged muons, pions, protons, and kaons.
Event Selection:

1. Vertex must be at:
   - 10<|x|<50 (Offset 0)
   - |y|<50 (Offset -310)
   - 10<|z|<50 (Offset 1300)
     - Gap between the first pair and the second pair large enough to break tracks.
     - Most tracks are rock/MINERvA muons, so this cut gets rid of most of the data.
2. Vertex must have more than one shower and 0 tracks.
   - Avoid blips and detached showers being picked up as neutrino interactions.

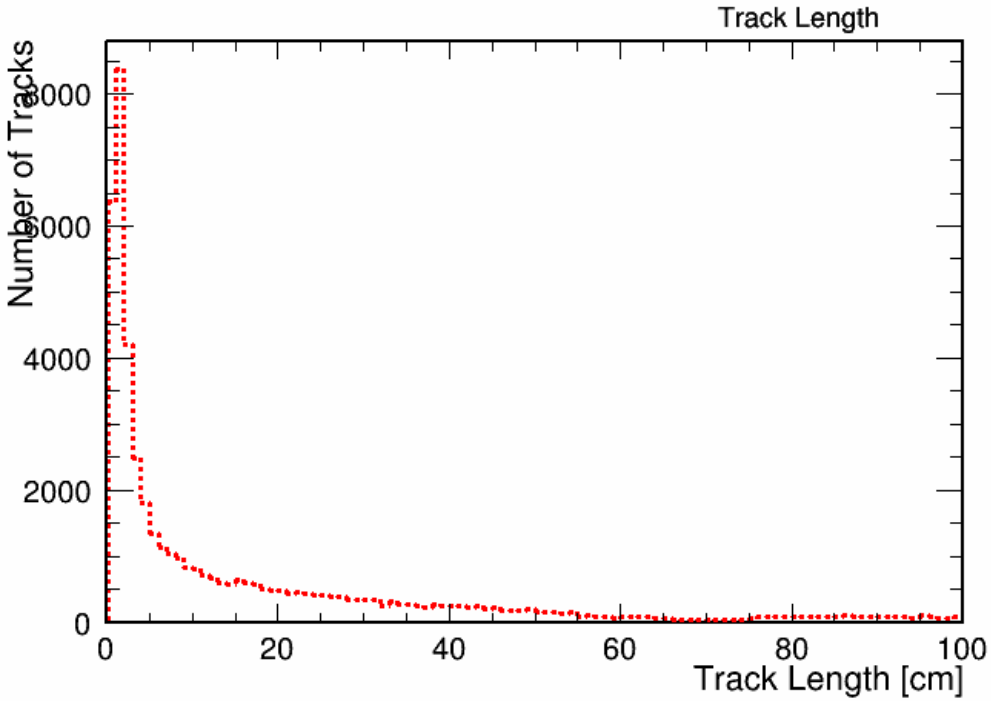



Multiplicity of all particles reconstructed from selected vertices.



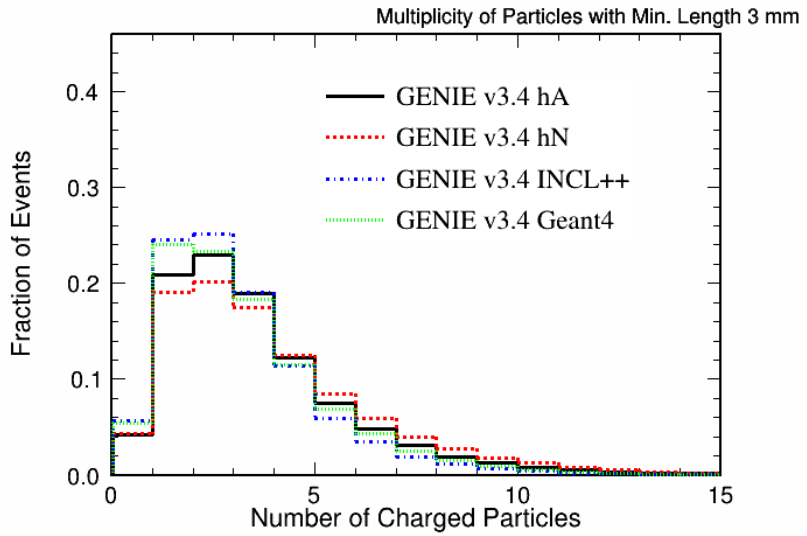



Multiplicity of all particles reconstructed from selected vertices.




Track length of all reconstructed tracks binned in 1 cm bins.

!

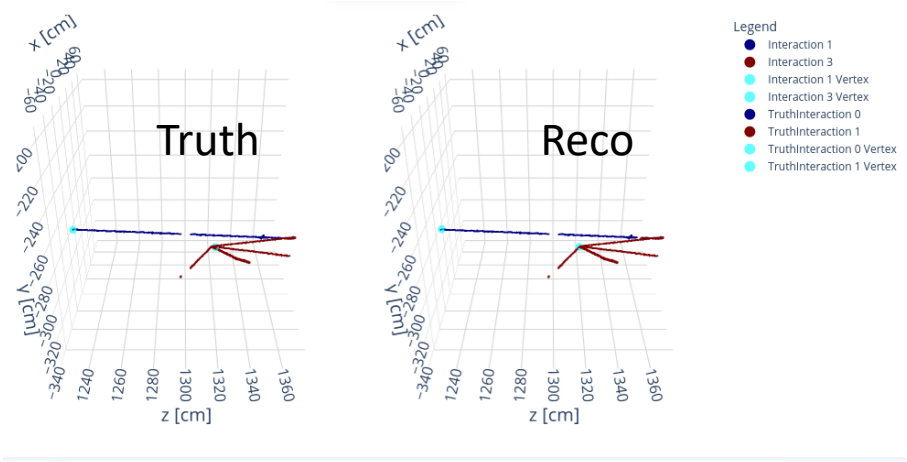


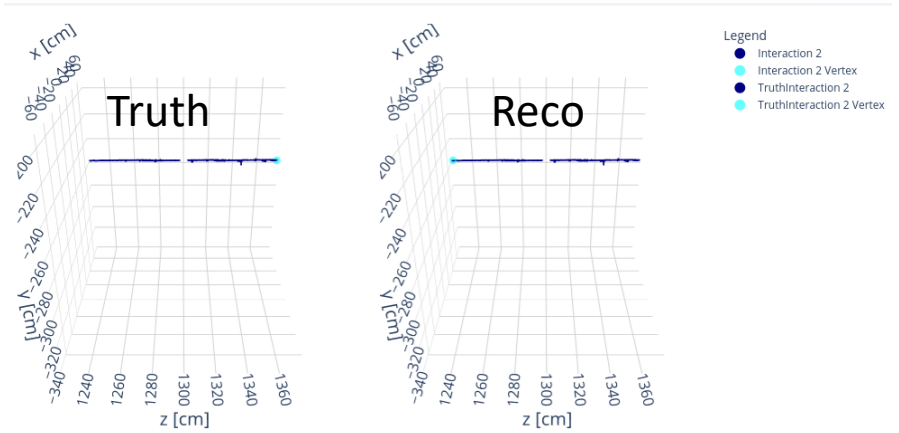

Truth-level distribution using GENIE primaries from self-made file

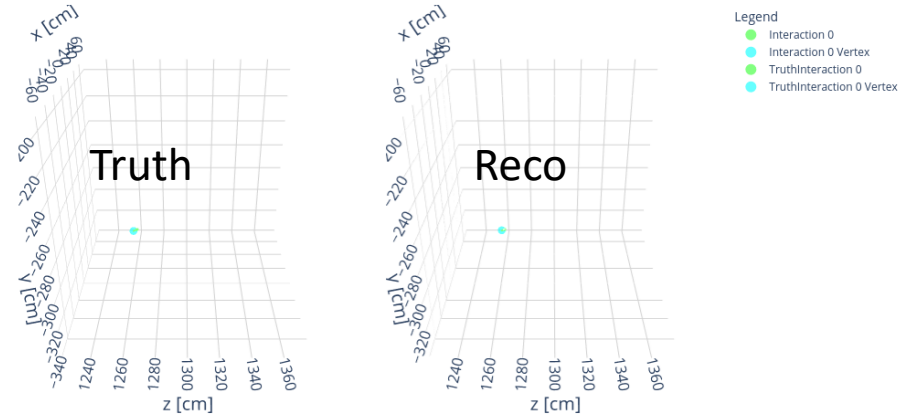
This is the same result if we combined all the raw GHEP files from MiniRun4.

# Event Displays and Move to MLReco Files

- Thank you to Francois for showing us all how to use the MLReco files and their event displays.



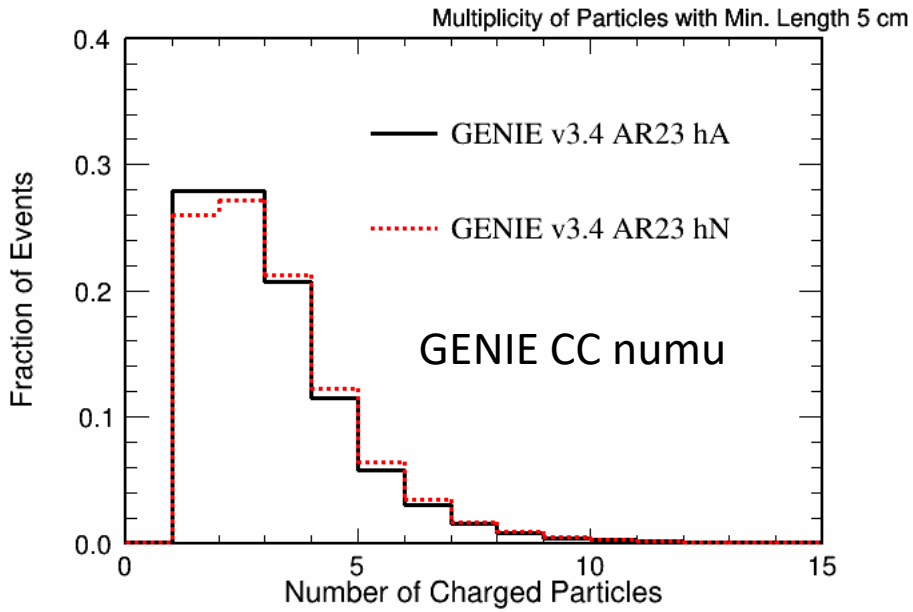



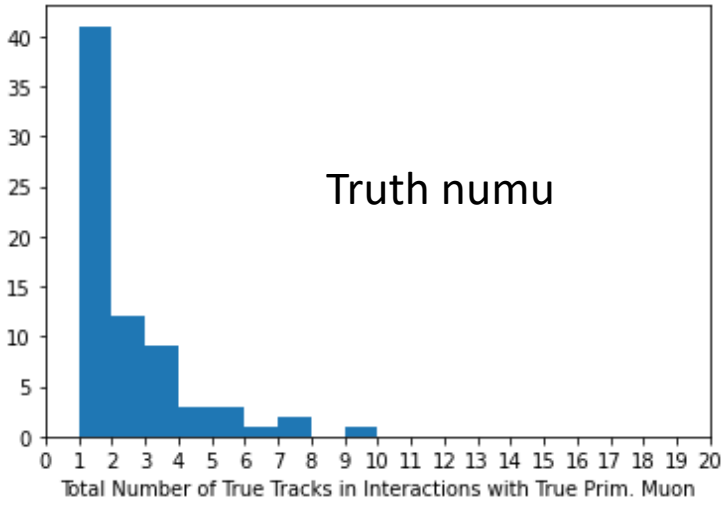
# Cheated CC Events

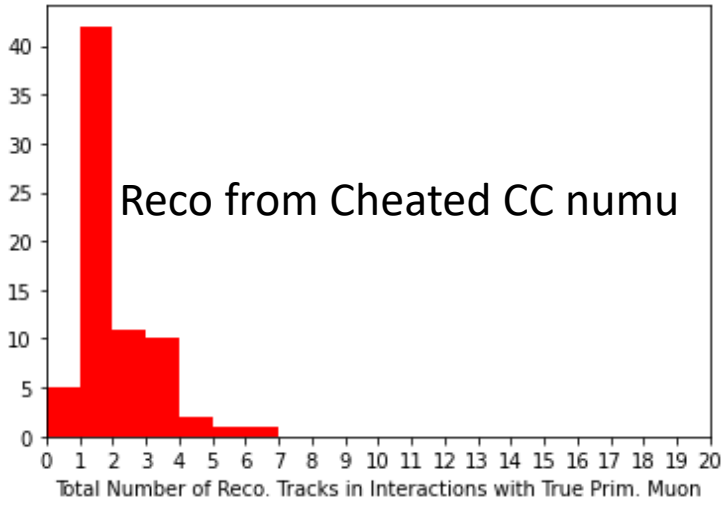
Signal Definition: All tracks, primarily consisting of charged muons, pions, protons, and kaons.

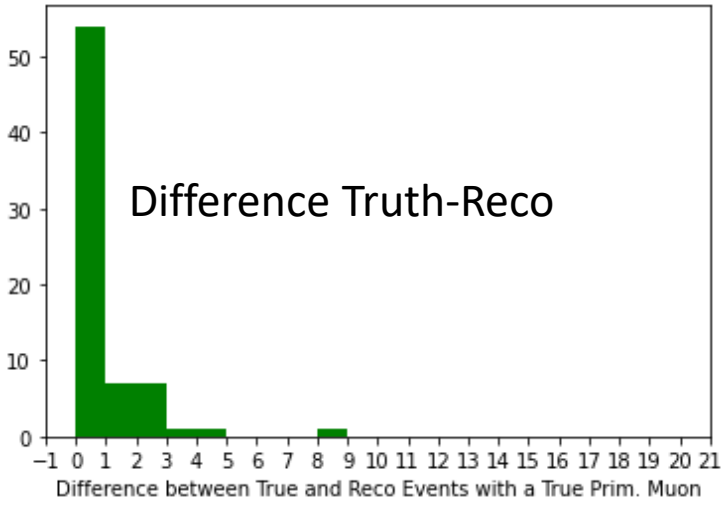
An event with a muon should be a CC event so only select events with a true primary muon.

Tracks must be 5 cm long

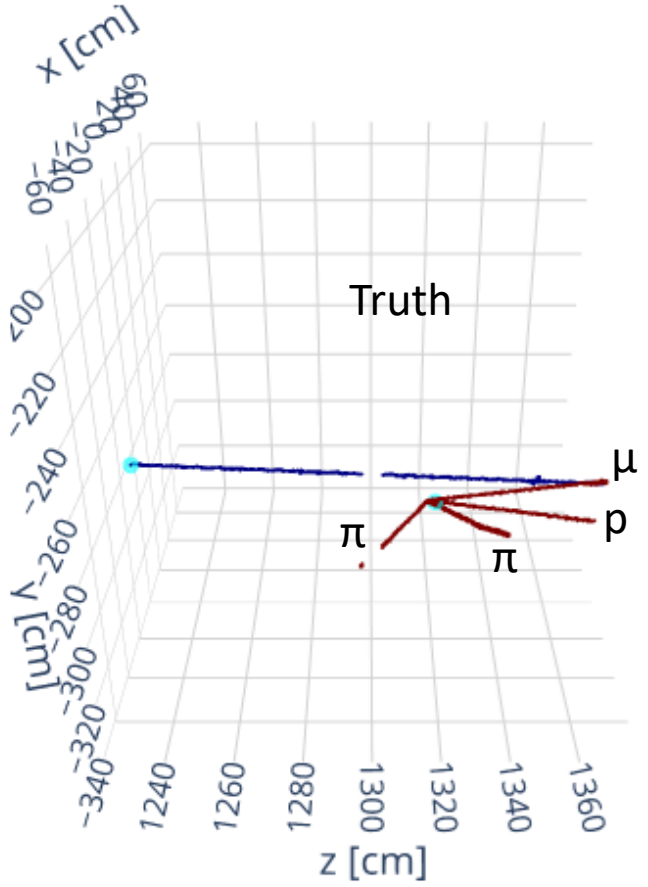


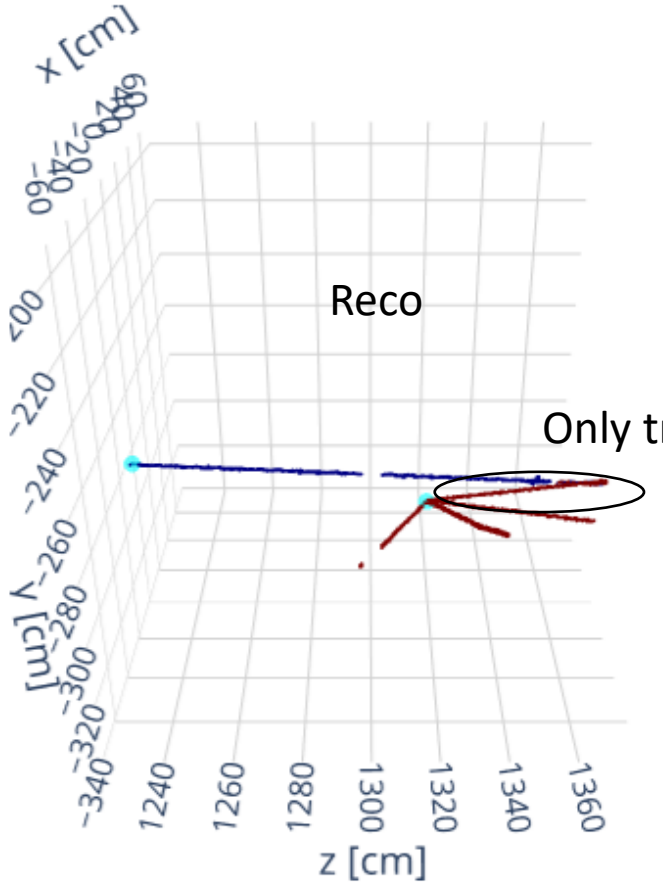



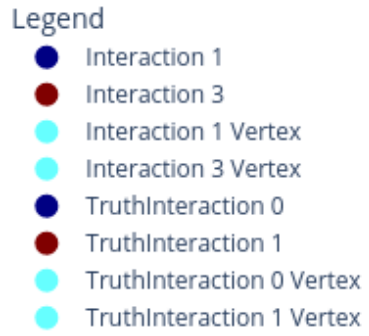



# Cheated CC Events



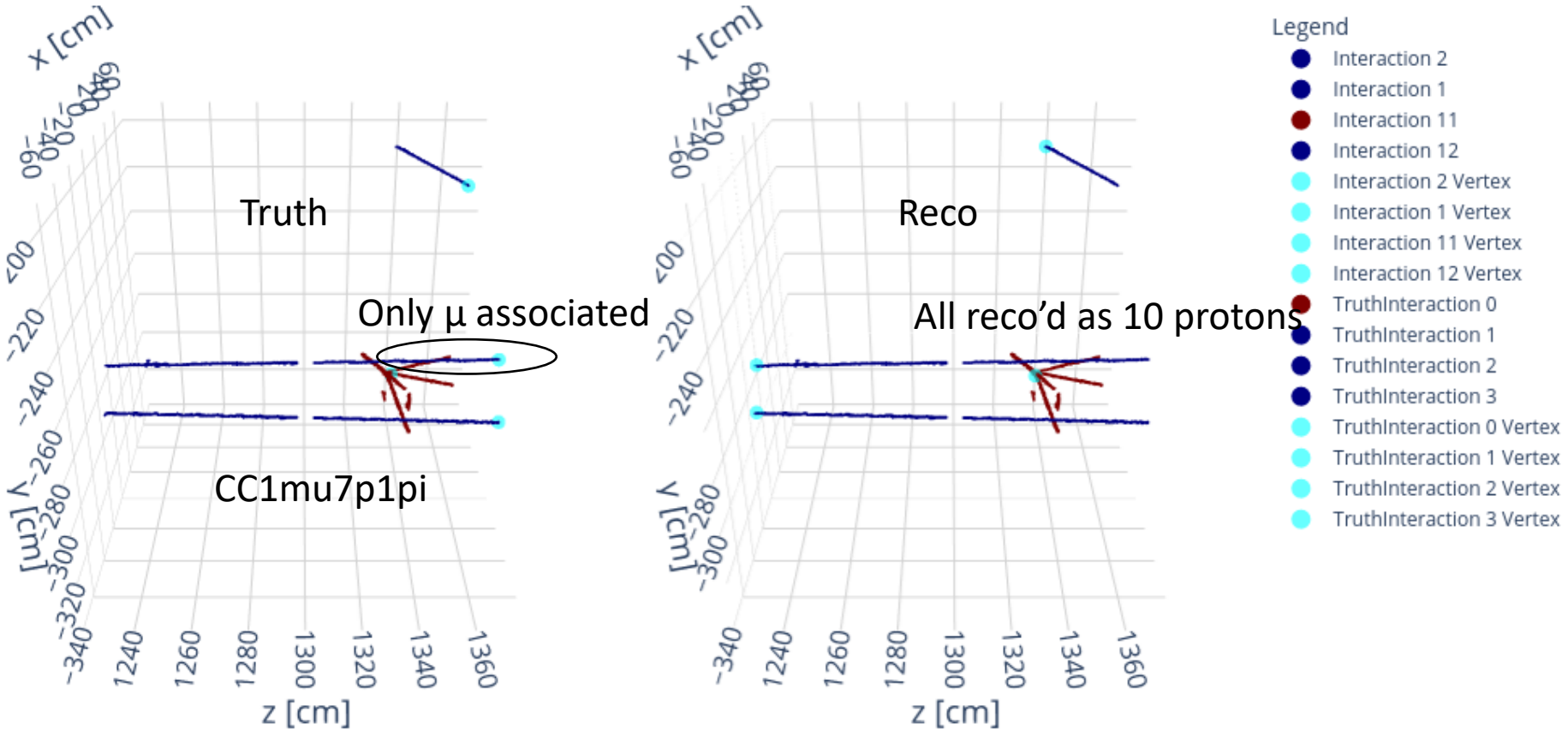




Only track in reco (μ)

Event 107: /dune/data/users/drielsma/minirun4/output_ana/output_27023276_11-larcv_mlreco_ana.h5

# Cheated CC Events

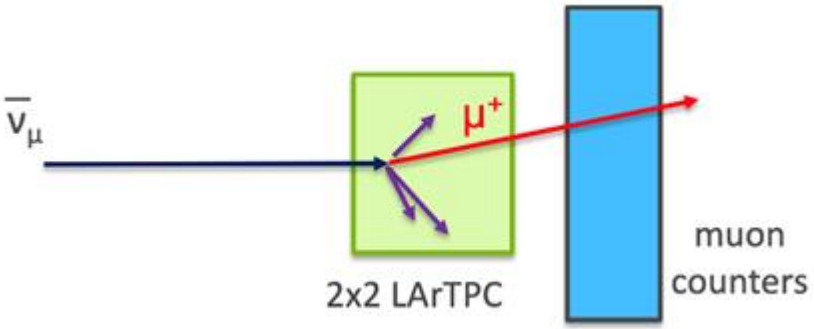


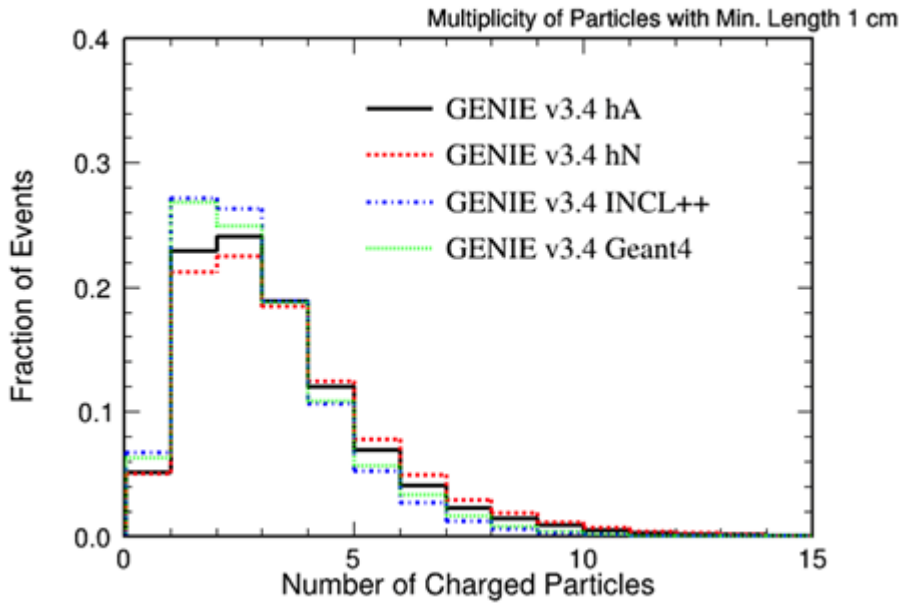

Event 94: /dune/data/users/drielsma/minirun4/output_ana/output_27023276_20-larcv_mlreco_ana.h5

# Break

# Motivation

- One of the early 2x2 goals
  - Measure the charged particle track multiplicity generated by $\nu$ interactions
- Count the final states charged particle tracks with a minimum length
- Multiplicity of final state charged particles peaking at $\sim 2$




- We started looking at ML-reco files provided by Francois et. al.

  *Thanks to the ML-reco group for the hard work!*

- "Typical" events (truth level):

nfs: 0, PDG: -13, Energy: 2.15266
nfs: 1, PDG: 2112, Energy: 1.51648
True Multiplicity: 2
Enu [GeV]: 2.74847, isCC, Interaction Mode1 (QE)

nfs: 0, PDG: -13, Energy: 3.24516
nfs: 1, PDG: 2212, Energy: 1.52932
nfs: 2, PDG: -211, Energy: 2.12432
nfs: 3, PDG: 111, Energy: 0.246221
True Multiplicity: 4
Enu [GeV]: 6.21714, isCC, Interaction Mode4 (DIS)

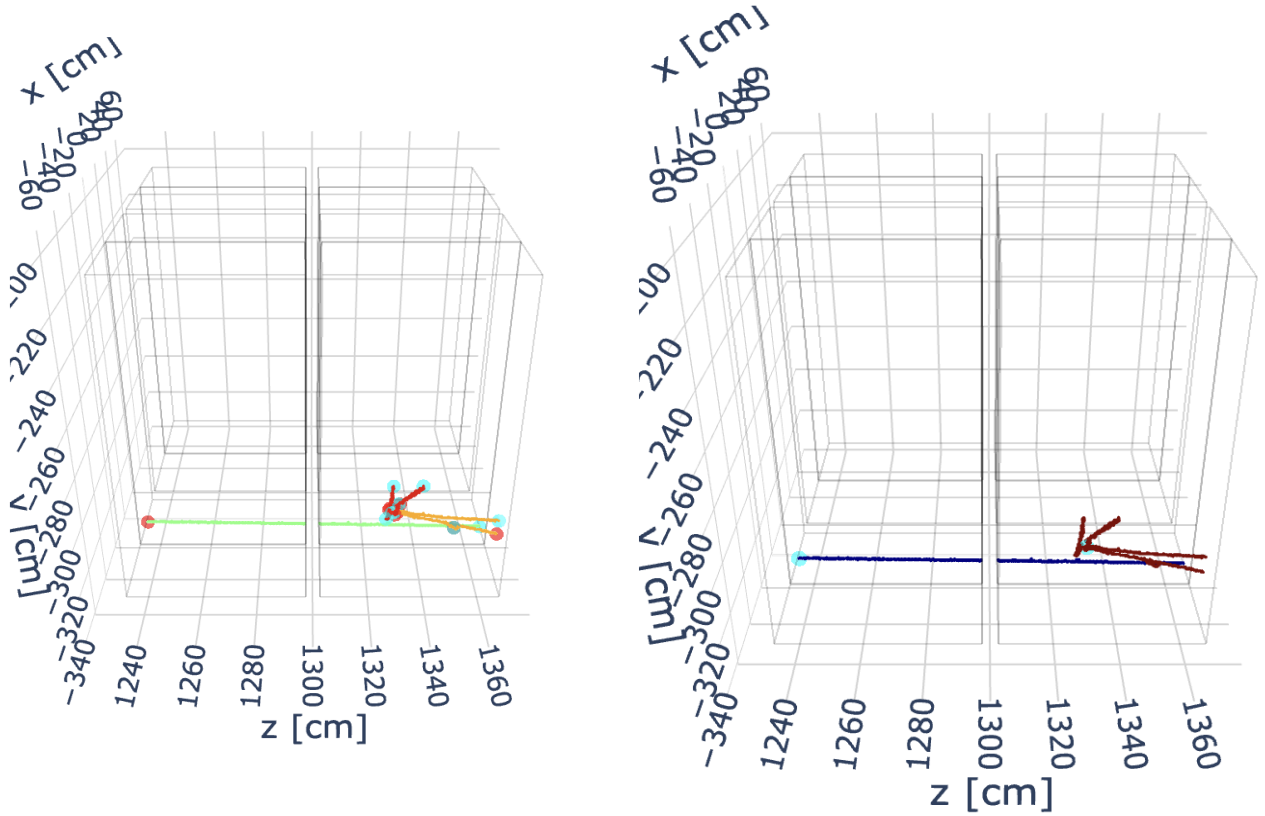
nfs: 0, PDG: -13, Energy: 4.61715
nfs: 1, PDG: 2112, Energy: 1.70563
nfs: 2, PDG: 2112, Energy: 0.98661
nfs: 3, PDG: 111, Energy: 0.153597
nfs: 4, PDG: 111, Energy: 0.353586
nfs: 5, PDG: 111, Energy: 0.438901
True Multiplicity: 6
Enu [GeV]: 6.37624, isCC: 0, Interaction Mode4 (DIS)

nfs: 0, PDG: -13, Energy: 5.99438
nfs: 1, PDG: 2112, Energy: 1.45012
nfs: 2, PDG: 2112, Energy: 1.26948
nfs: 3, PDG: 111, Energy: 0.264022
nfs: 4, PDG: 111, Energy: 0.135409
True Multiplicity: 5
Enu [GeV]: 7.24335, isCC: 0, Interaction Mode3 (RES)

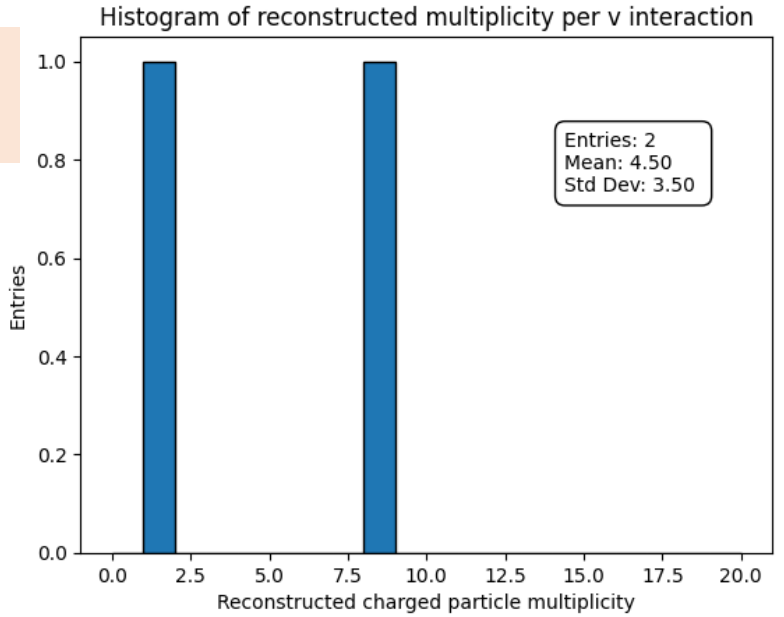
nfs: 0, PDG: -13, Energy: 6.58947
nfs: 1, PDG: 2112, Energy: 1.21353
nfs: 2, PDG: 2212, Energy: 0.962704
nfs: 3, PDG: 2112, Energy: 0.98693
True Multiplicity: 4
Enu [GeV]: 6.93975, isCC: 0, Interaction Mode2 (MEC)

# Example of an Event

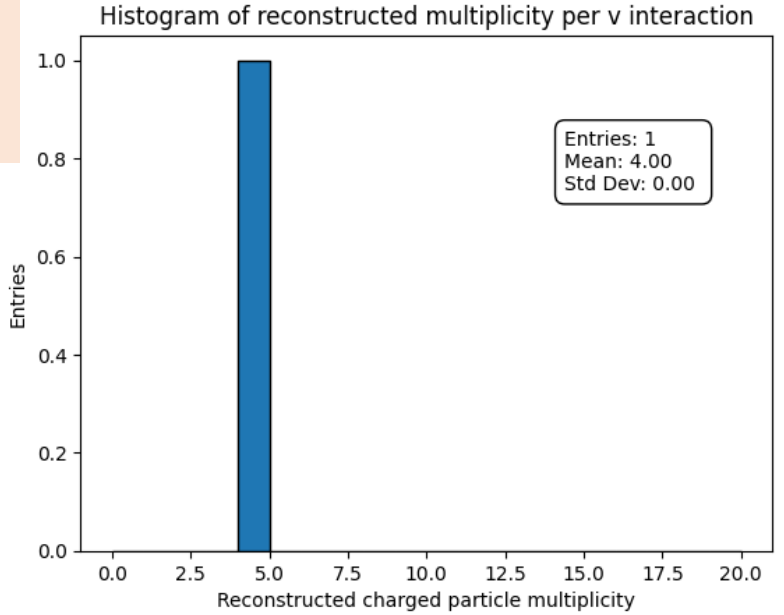
- No cut optimization. Cuts used for demonstration only
- **File:** output_27025991_10-larcv_mlreco_ana.h5
- **Event:** 44




**Raw Multiplicity:**
No cuts




**Raw Multiplicity:**
After *preliminary* cuts



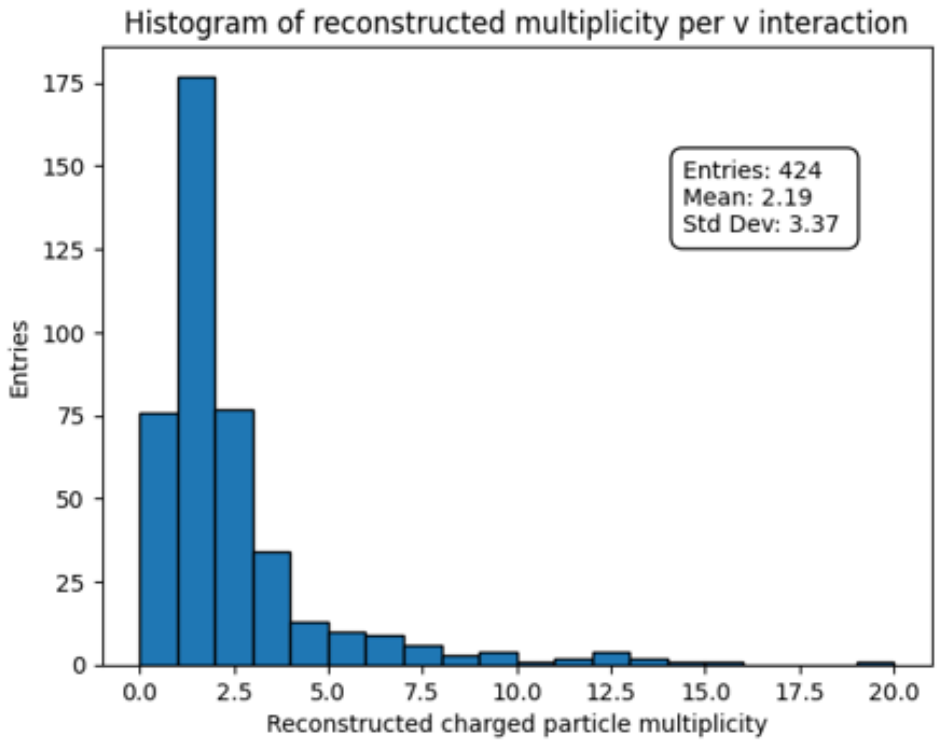

➢ **Use the following Preliminary Cuts in the study shown today:**

- Track length $>$ 5.0 cm; Distance from outer bounder: $\epsilon = 5.0$ cm
- Bounds: $-63.931 + \epsilon < x < +63.931 - \epsilon$ ; $-329.076 + \epsilon < y < -204.924 - \epsilon$ ; $+1235.462 + \epsilon < z < +1364.538 - \epsilon$

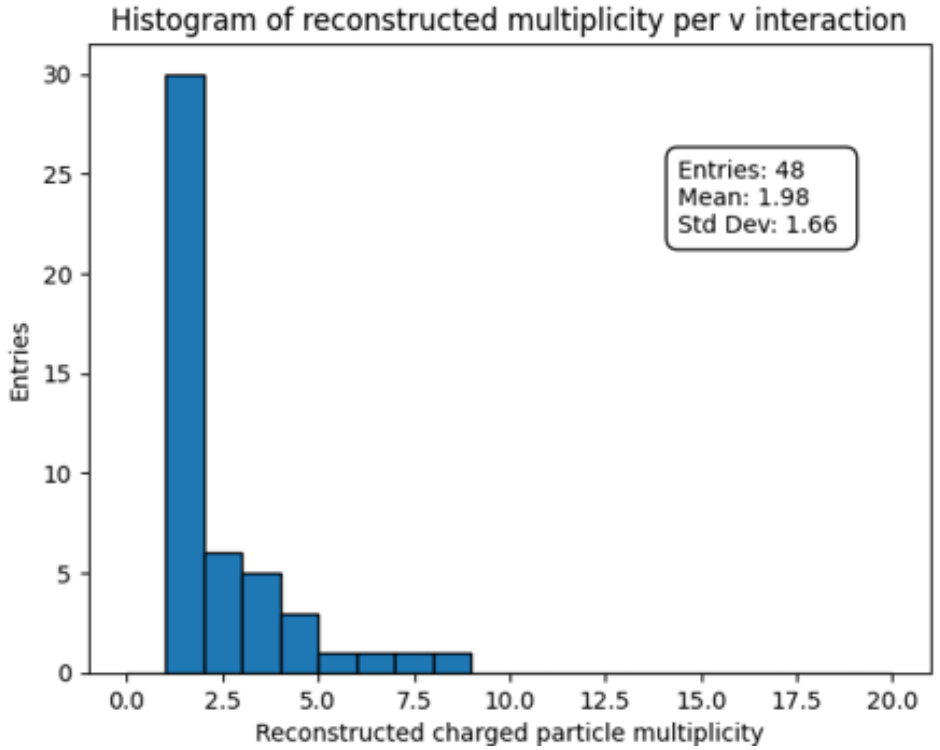
# All Events from a Single File

- **File:** output_27025991_10-larcv_mlreco_ana.h5
- Can scale-up to many/all available files *(did this for first 20 mlreco files in next slides)*

- No Cuts




- After *preliminary* Cuts




- **Use the following Preliminary Cuts in the study shown today:**
  - Track length $>$ 5.0 cm; Distance from outer bounder: $\epsilon = 5.0$ cm
  - Bounds: $-63.931 + \epsilon < x < +63.931 - \epsilon$ ; $-329.076 + \epsilon < y < -204.924 - \epsilon$ ; $+1235.462 + \epsilon < z < +1364.538 - \epsilon$

# Preliminary Cuts for this initial study, to be optimized in the future

- We looked at truth and reconstructed events from 20 `mlreco` files
- Considered only matched particle tracks
- Minimum track length is set to be greater than $5.0\ \mathrm{cm}$.
- Track starting point is set to be at $\epsilon = 5.0\ \mathrm{cm}$ distance from the outer walls (that is $> 5\ \mathrm{cm}$ from the outer walls).

$$-63.931 + \epsilon < x < +63.931 - \epsilon$$

$$-329.076 + \epsilon < y < -204.924 - \epsilon$$

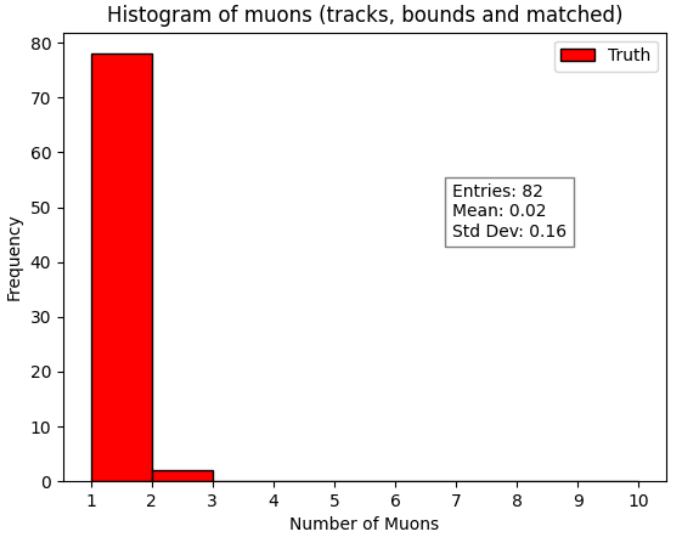
$$+1235.462 + \epsilon < z < +1364.538 - \epsilon$$

Bilal, Zelimir

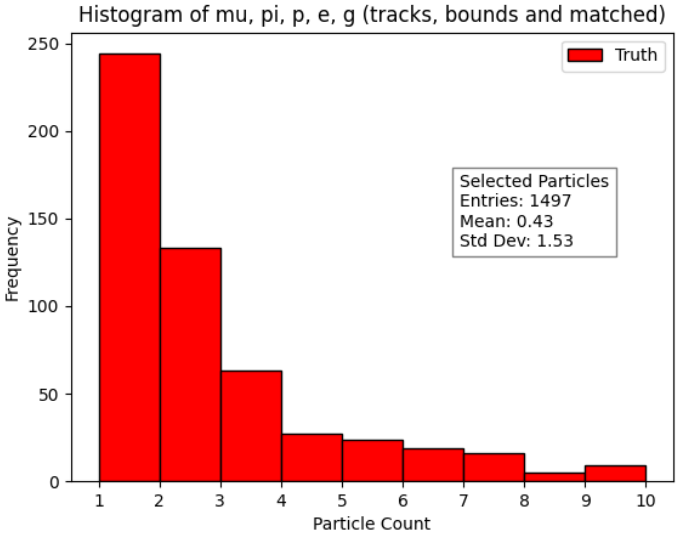
# Results with Minimal Cuts

- 5 cm from the **outer boundary (no cut at center, 50->58)**
- Track length must be greater than 5.
- Considered only matched particle tracks

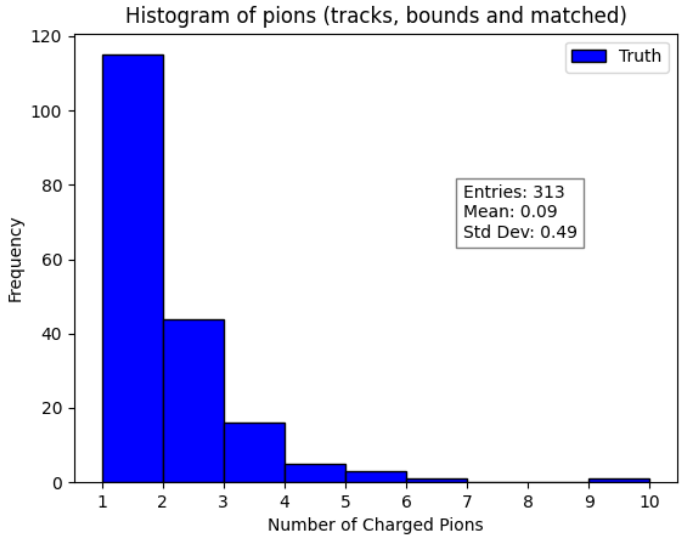
## ➢ Muons



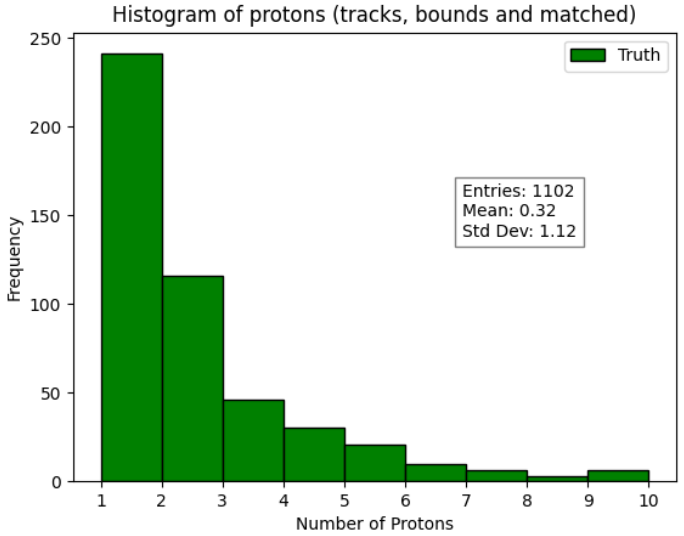

## ➢ Charged Pions




## ➢ Multiplicity




## ➢ Protons

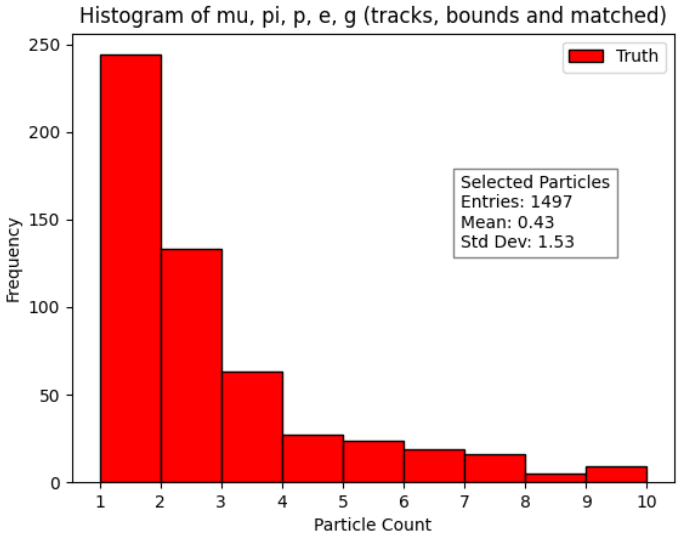


# Results with Minimal Cuts

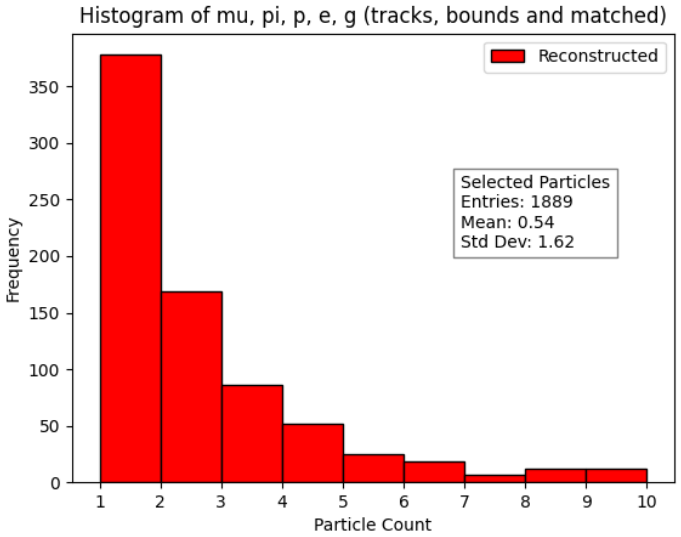
Bilal, Zelimir

- 5 cm from the outer boundary, track length must be greater than 5.

Truth Multiplicity (track count)



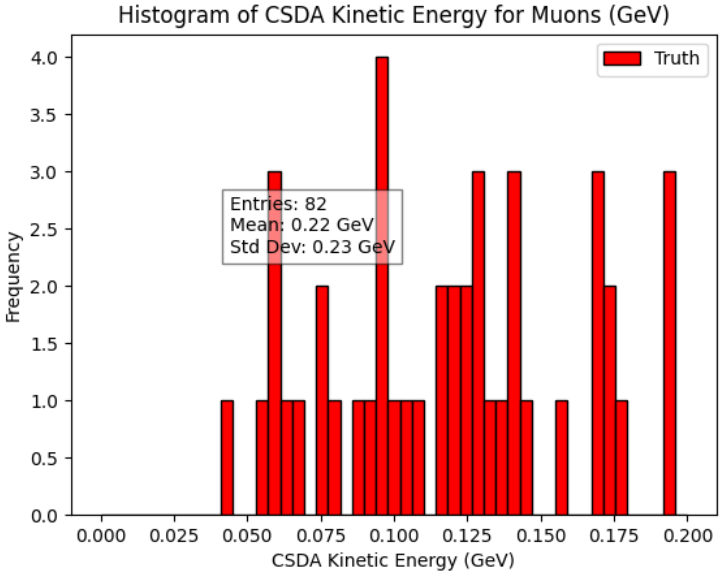

Reco Multiplicity (track count)

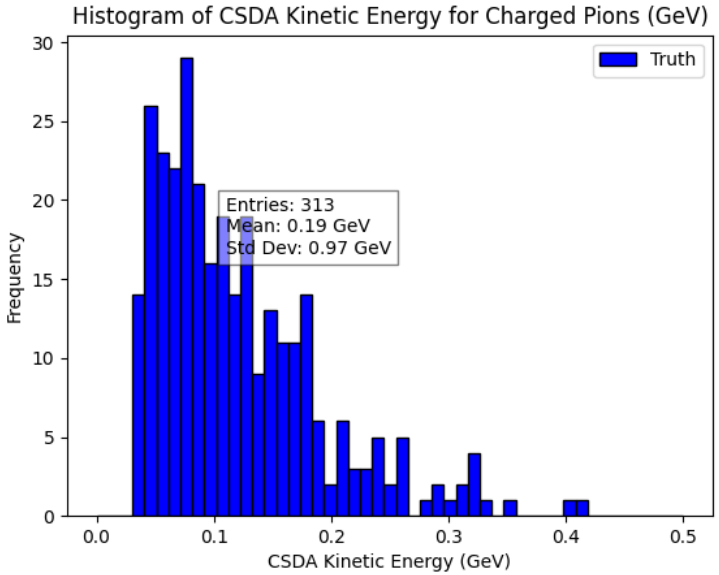


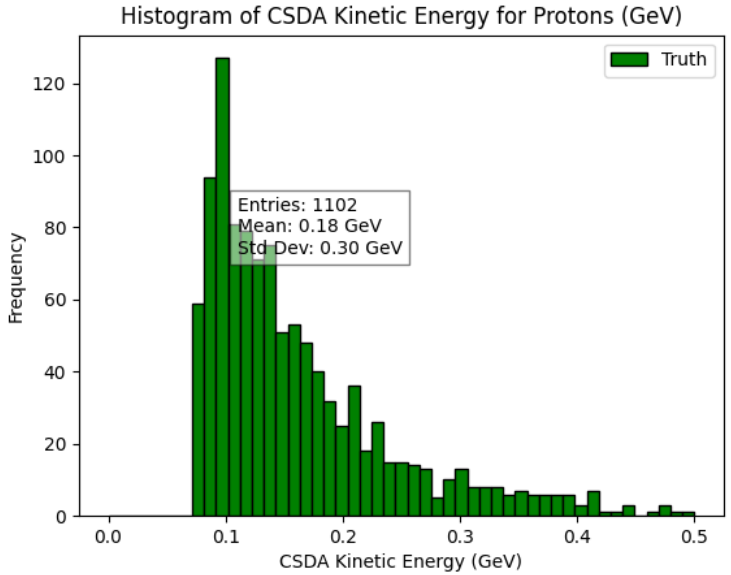
# *Truth:* Kinetic Energy of Particles

Bilal, Zelimir

- **csda_ke:** Kinetic Energy from the Continuous Slowing Down Approximation (CSDA) method
  - Calculate kinetic energy by range as particle traverses through the medium
- Muons start with the LAr FV but mostly exit the 2x2.
- Most charged pions and protons are concentrated at lower energies due to shorter tracks.



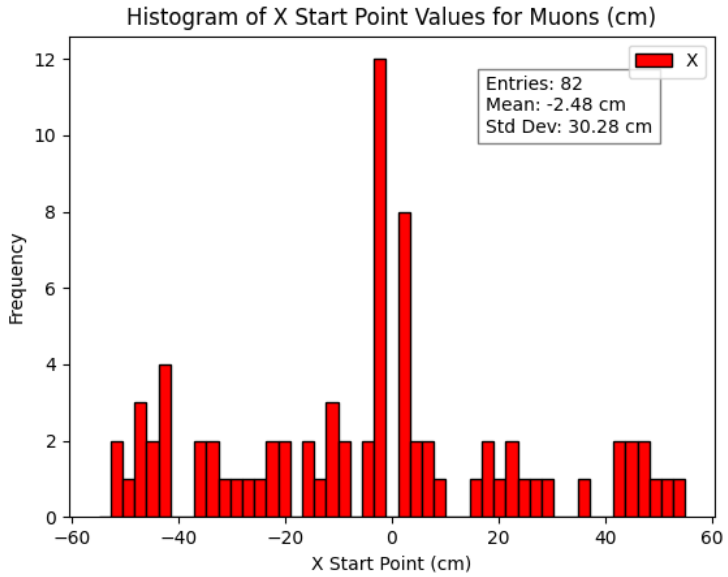



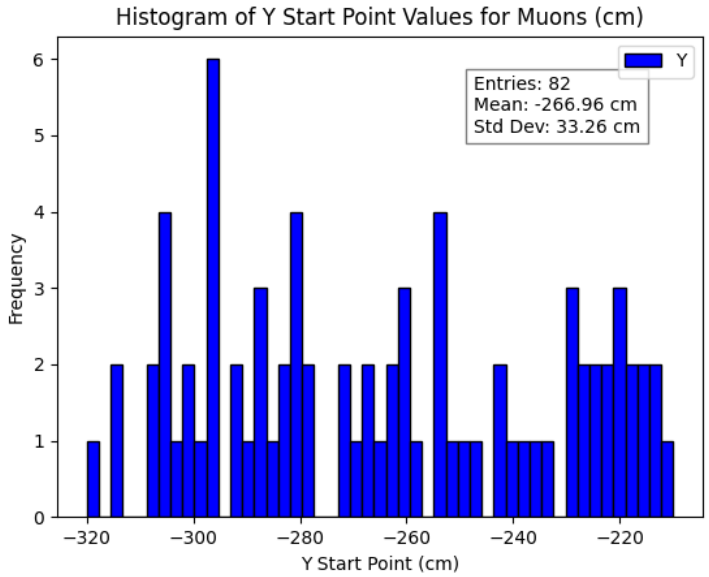



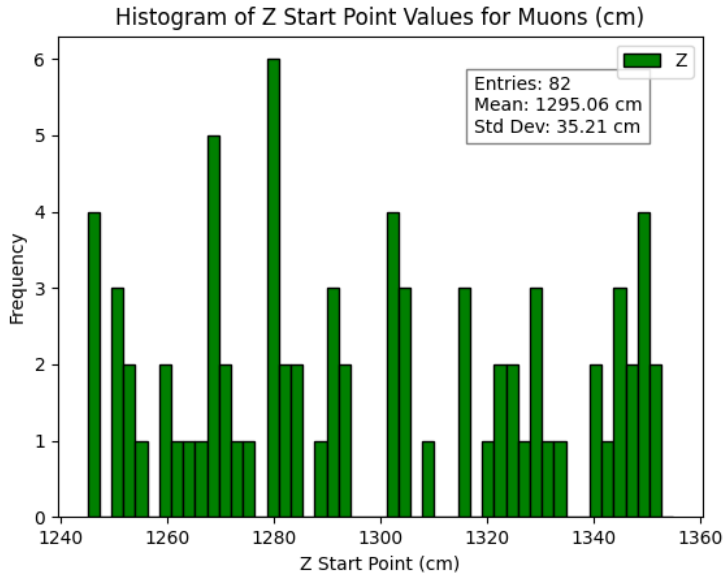
# *Truth:* Start Positions of Muons

Bilal, Zelimir

- Many muons concentrated at $x = 0$
- These may be likely passing the *preliminary* cuts that we only have set around outer boundaries

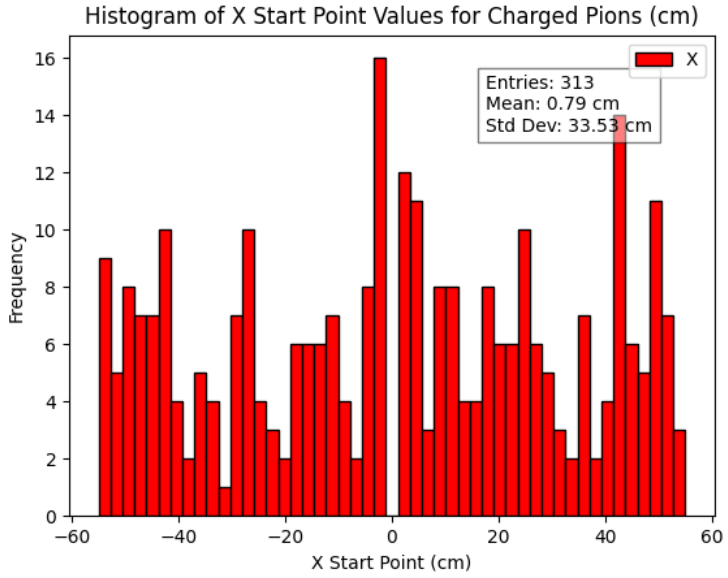


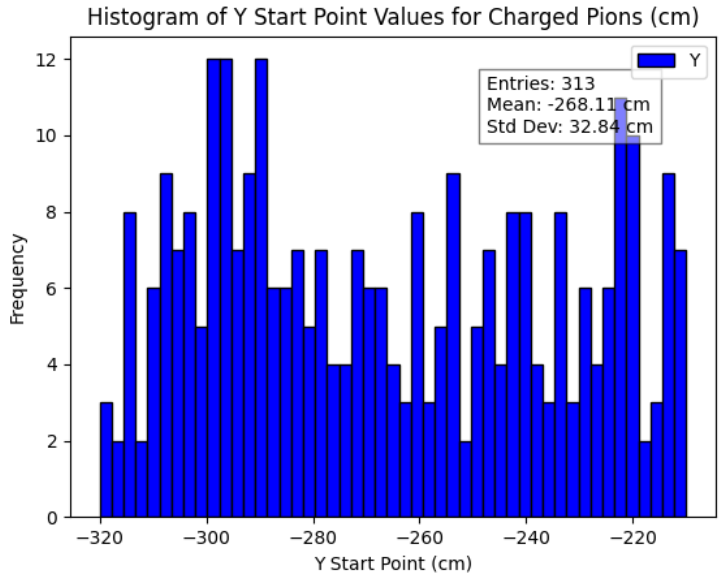



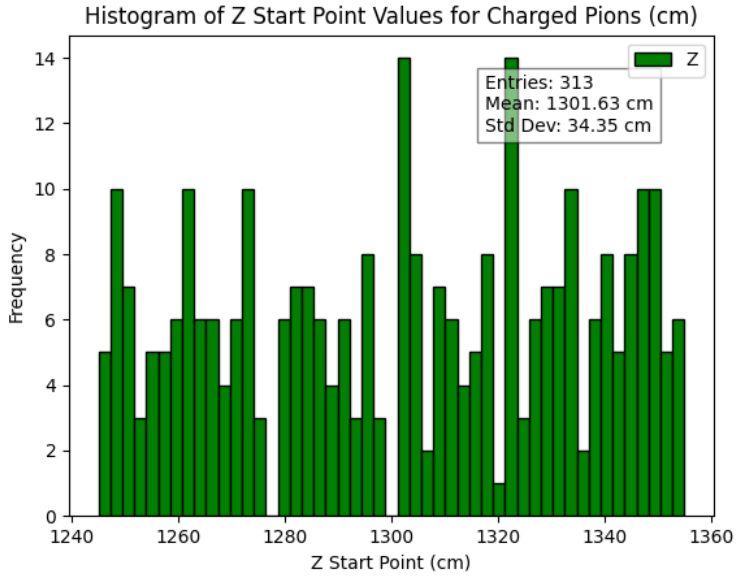



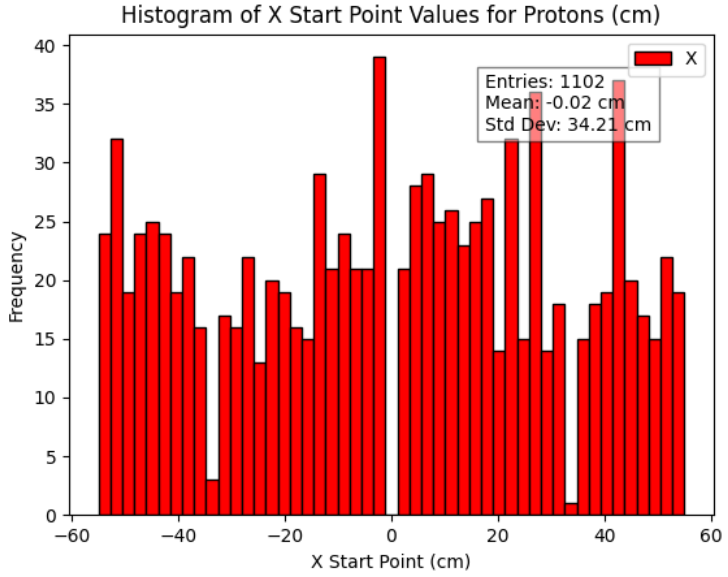
# *Truth:* Start Positions of Charged Pions and Protons

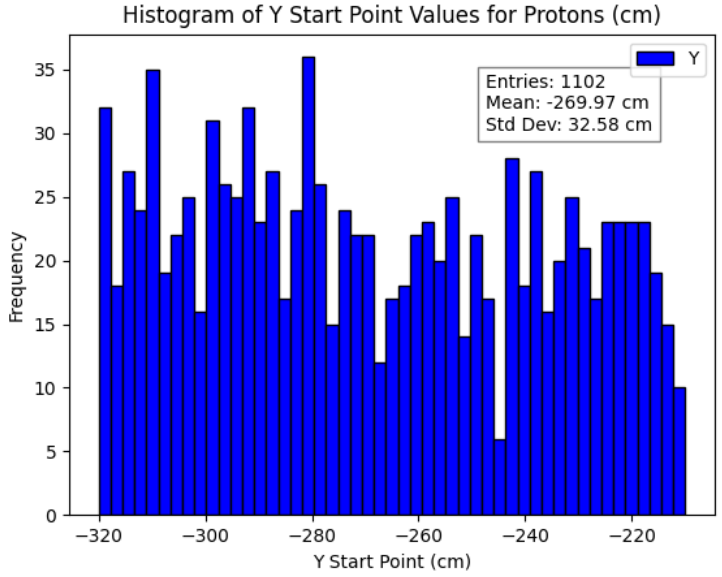
Bilal, Zelimir

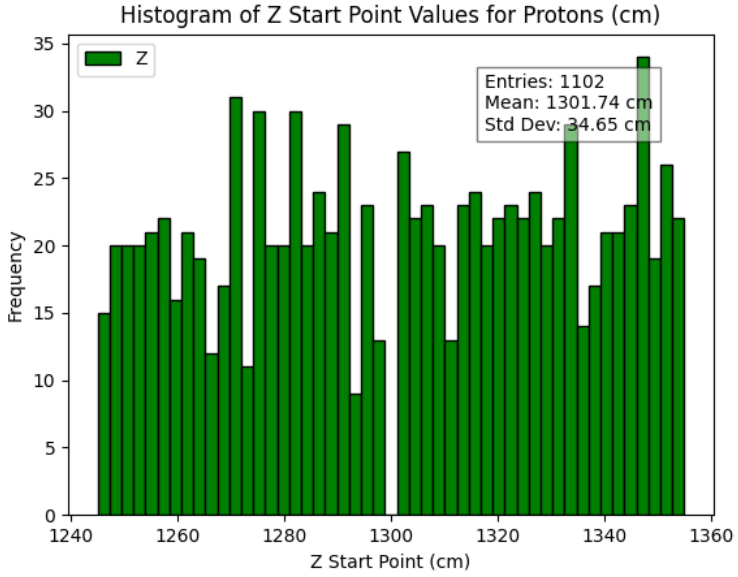


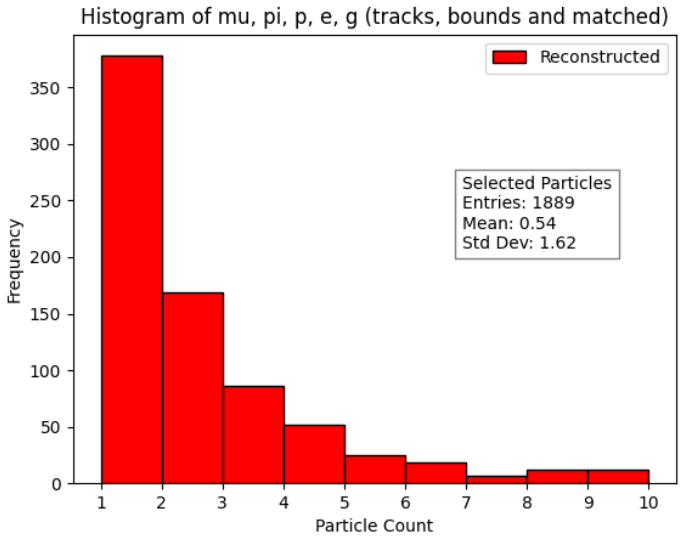



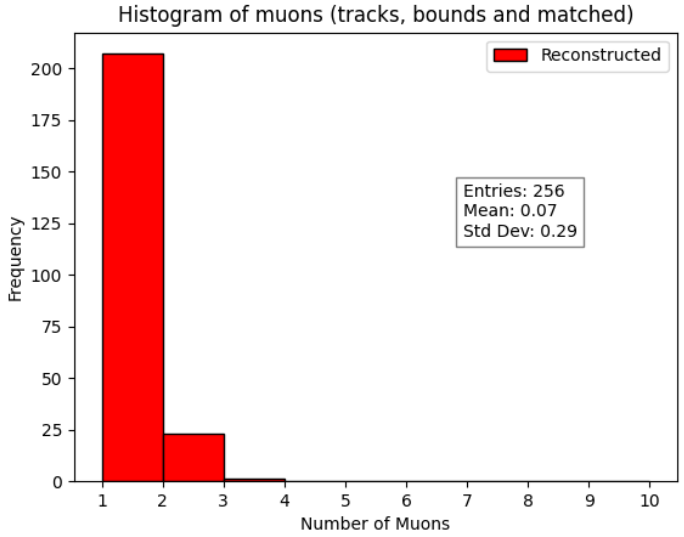
# *Reconstructed:* Multiplicity and Final State Particles

Bilal, Zelimir

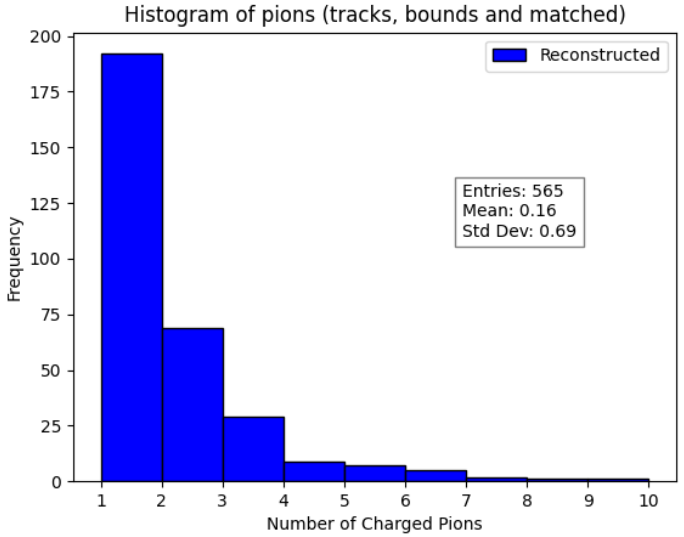
## ➢ Multiplicity



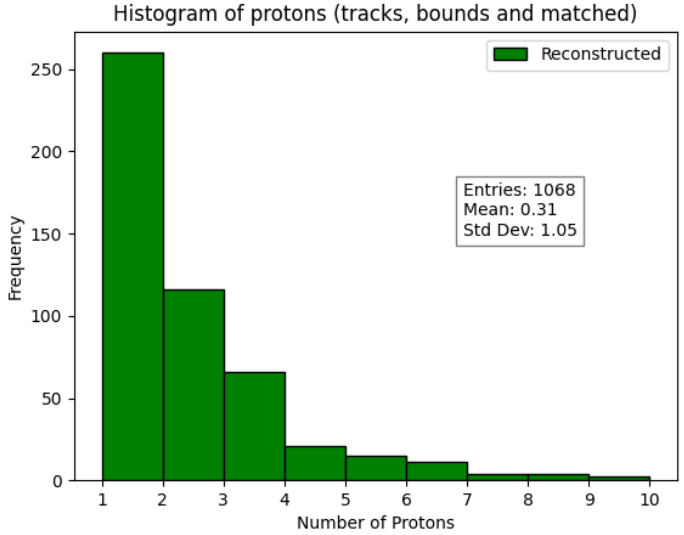

## ➢ Muons




## ➢ Charged Pions

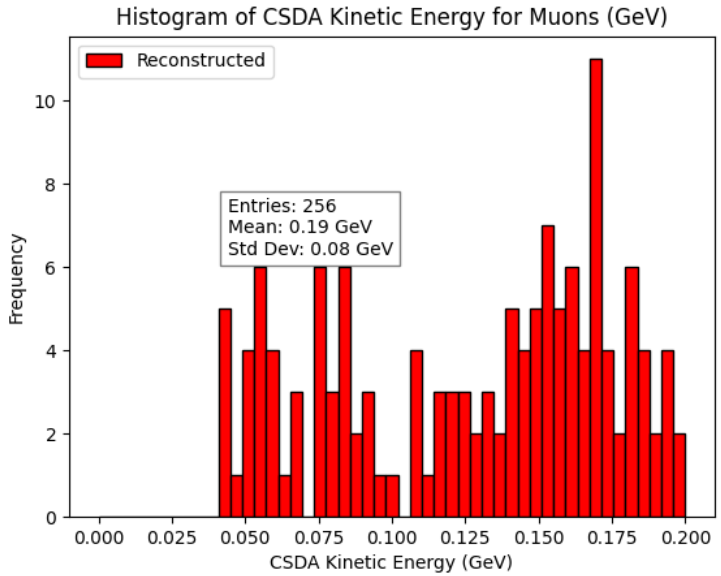


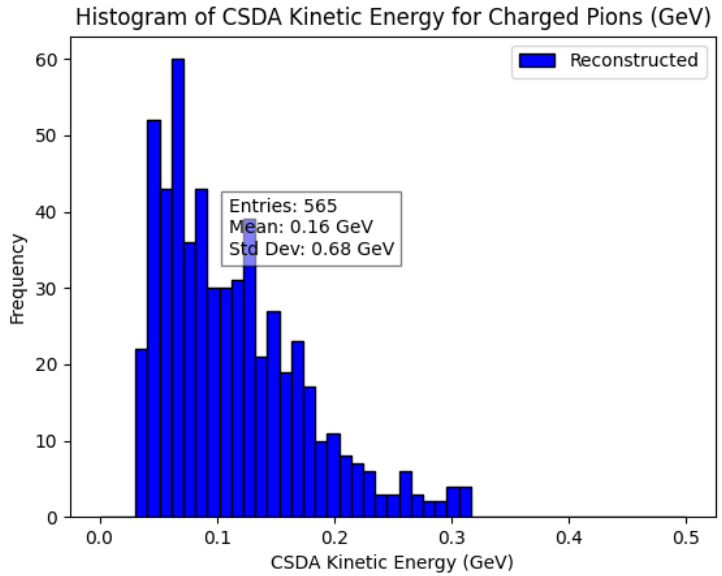

## ➢ Protons

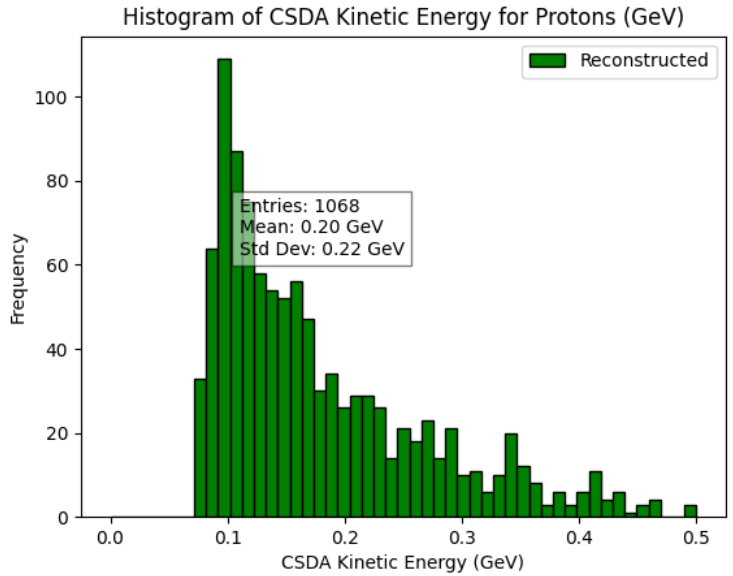


# *Reconstructed:* Kinetic Energy of Particles

- **csda_ke:** Kinetic Energy calculated using range as particle passes through the liquid argon
- Muons start greatly exit the 2x2.
- Charged pions and protons: low energies and short tracks



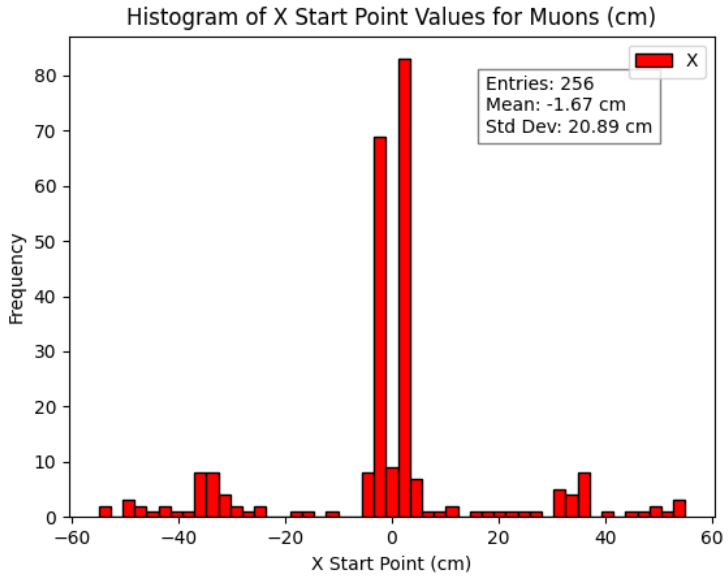



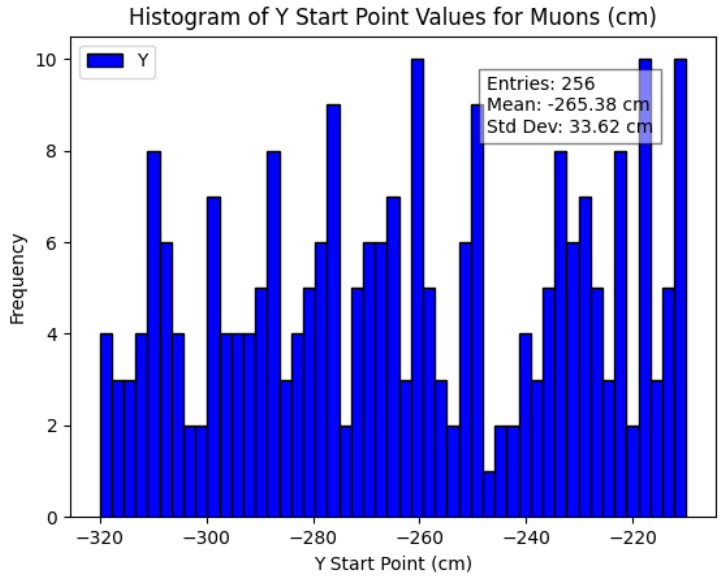



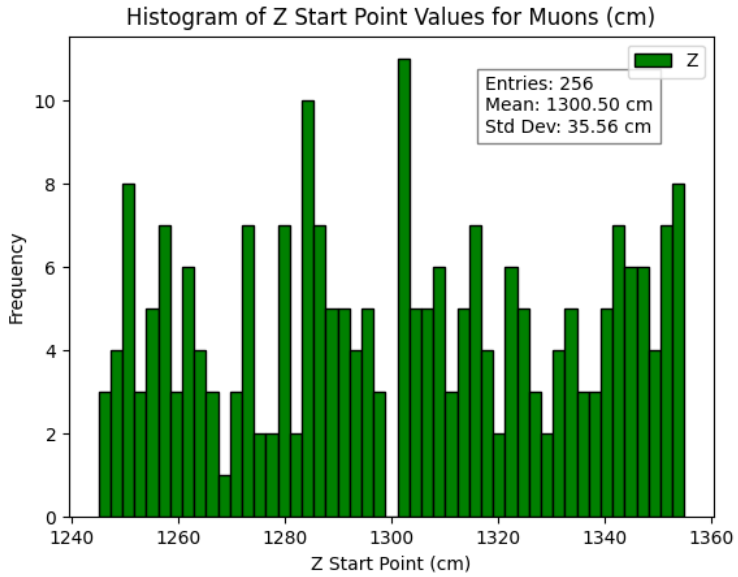
# *Reconstructed:* Start Positions of Muons

Bilal, Zelimir

- Many muons are reconstructed at $x = 0$
- Muons are likely passing the *preliminary* cuts that we only have set around outer boundaries.

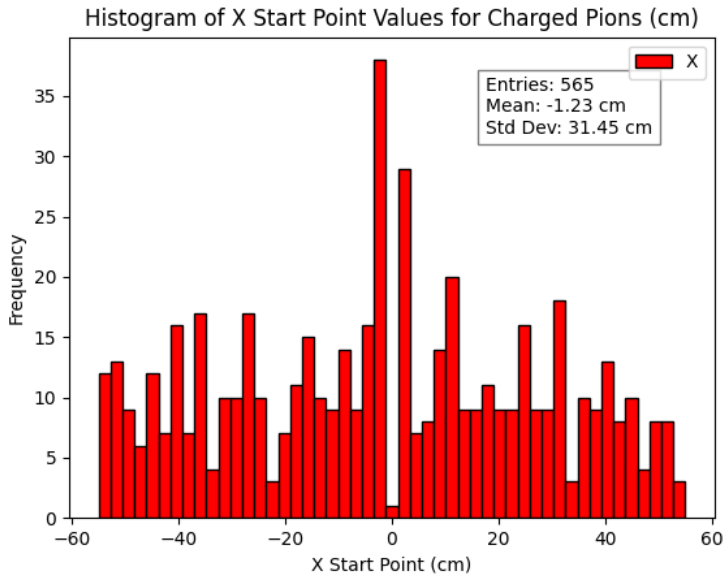


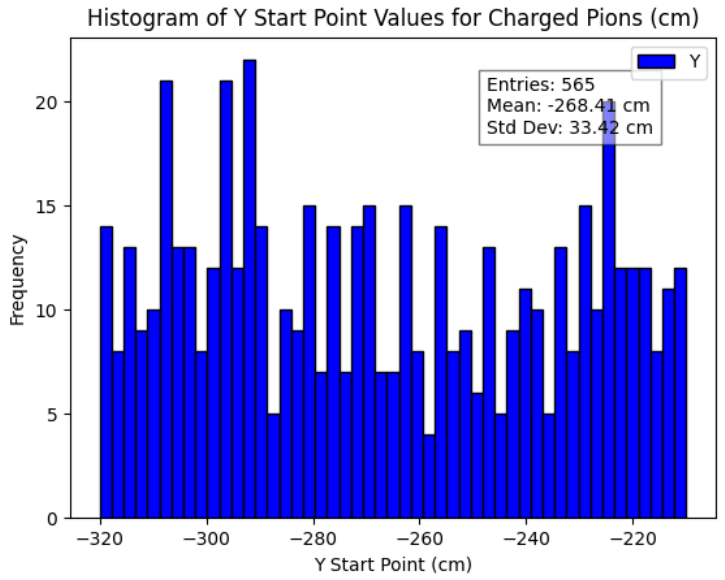



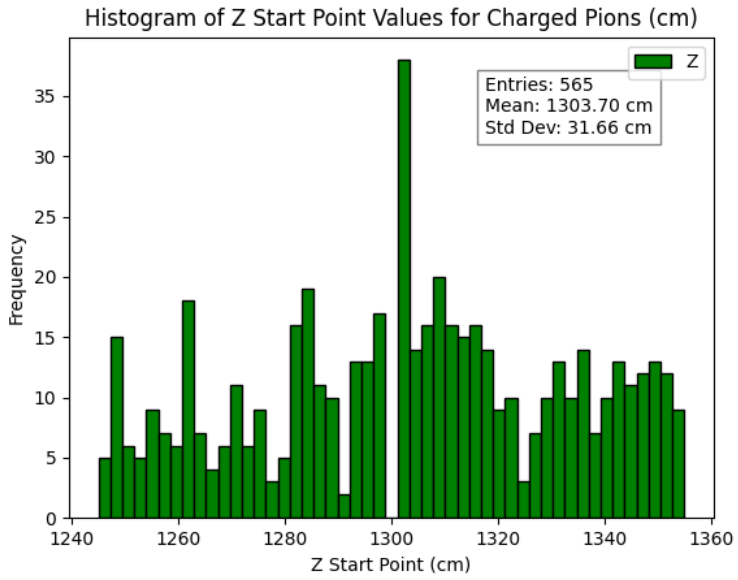



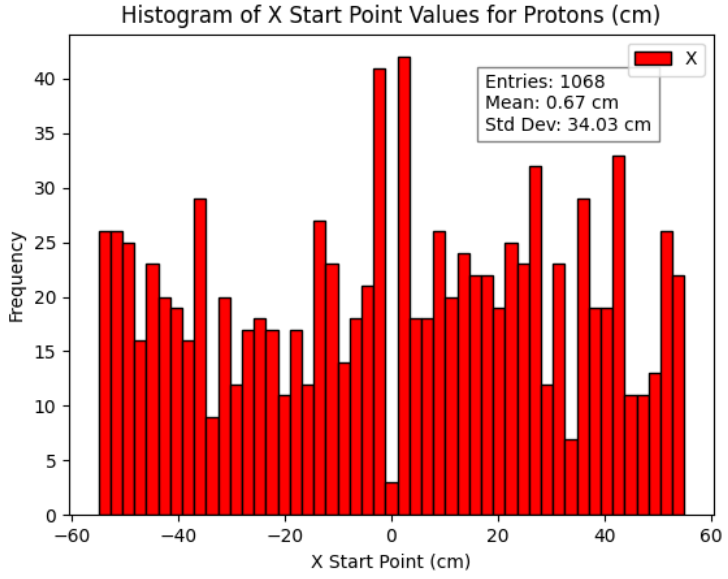
# *Reconstructed:* Start Positions of Charged Pions and Protons

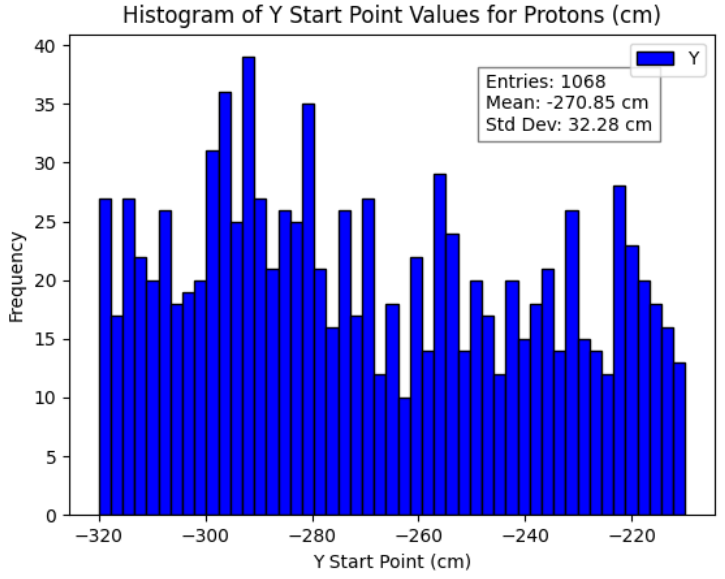
Bilal, Zelimir

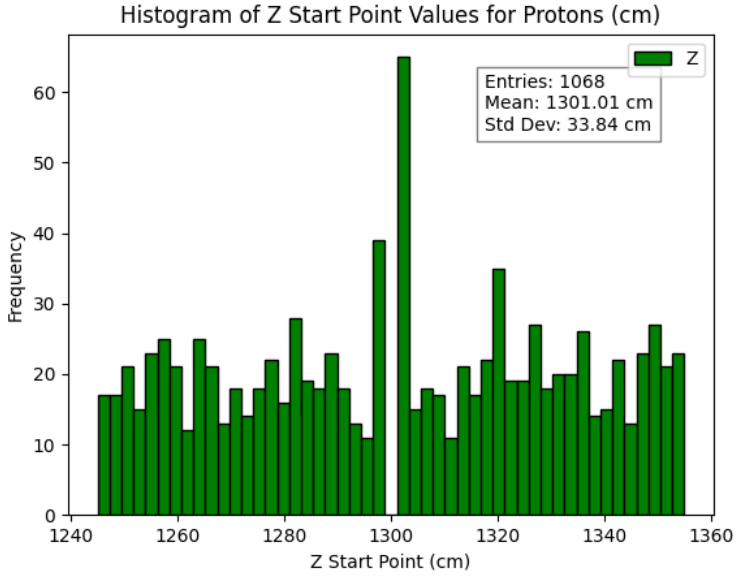


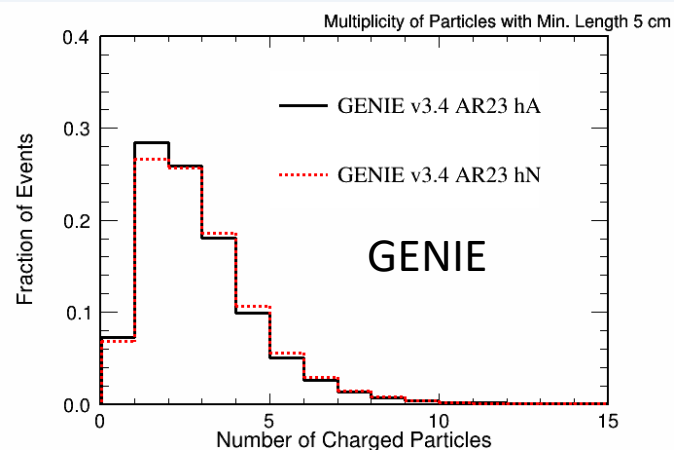



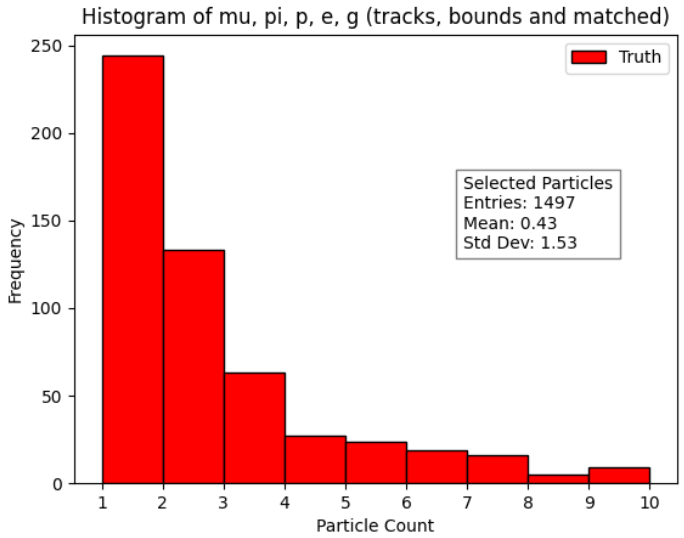



# Summary

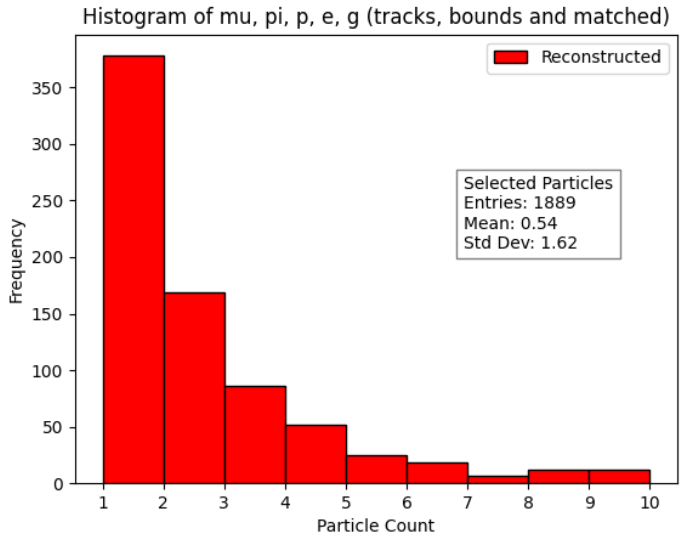
- Started to look at ML-reco in the 2x2 charge multiplicity analysis.
  - Considered only matched particle tracks, with the preliminary selection
- Initial plots presented but will continue to add statistics and perform reco-vs-true comparisons:
  - Eventually will quantify reconstruction efficiency and other metrics of interest.
- Important component of this effort is a feedback to ML-reco group as we started to work with them.
- Eventually use both ML-reco and PANDORA reconstruction in multiplicity search and other 2x2 analysis efforts.




Truth Multiplicity (track count)




Reco Multiplicity (track count)



# Backup Slides

# ML-reco file datasets

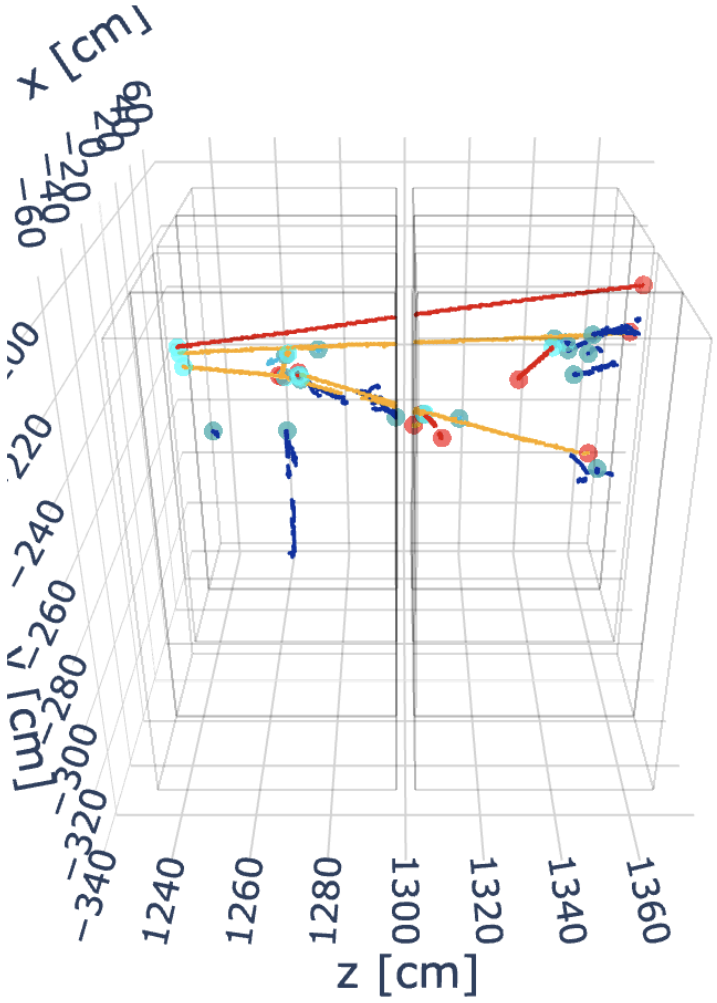
**Dataset_1:** /result/***interactions***
**Dataset_2:** /result/***truth_interactions***

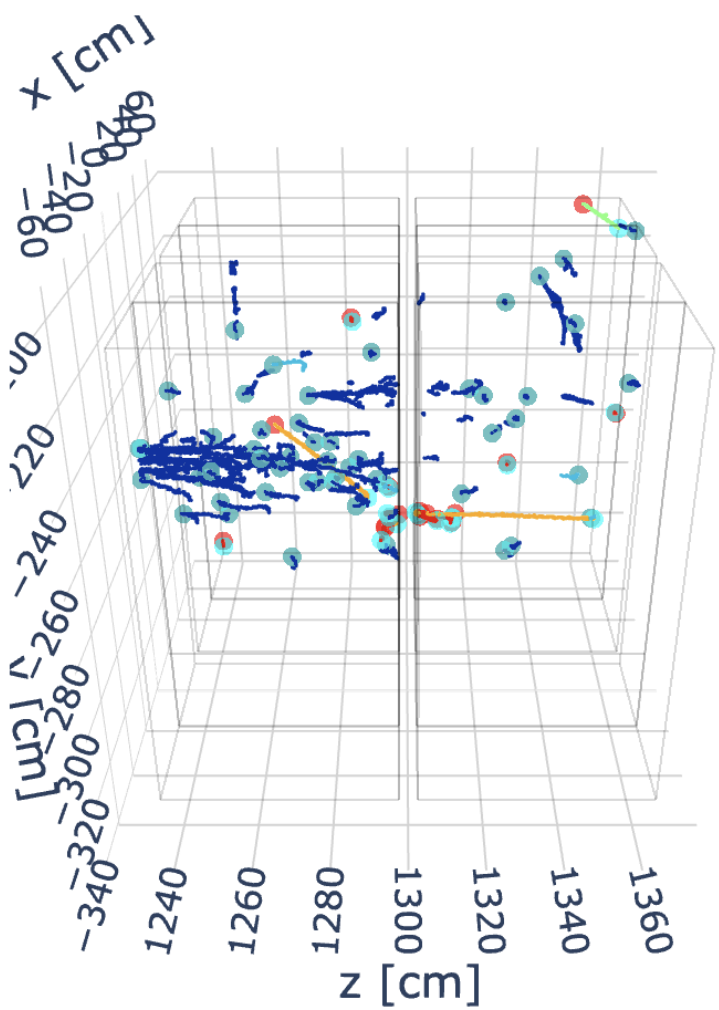
| Names | Formats | Offsets |
|---|---|---|
| crthit_id | int64 | 0 |
| crthit_matched | uint8 | 8 |
| crthit_matched_particle_id | int64 | 9 |
| flash_hypothesis | int64 | 17 |
| flash_id | int64 | 25 |
| flash_time | float64 | 33 |
| flash_total_pE | int64 | 41 |
| fmatched | uint8 | 49 |
| id | int64 | 50 |
| image_id | int64 | 58 |
| is_contained | uint8 | 66 |
| is_fiducial | uint8 | 67 |
| is_neutrino | uint8 | 68 |
| is_principal_match | uint8 | 69 |
| match | object | 70 |
| match_overlap | object | 86 |
| matched | uint8 | 102 |
| nu_id | int64 | 103 |
| num_particles | int64 | 111 |
| num_primaries | int64 | 119 |

**Dataset_1:** /result/***particles***
**Dataset_2:** /result/***truth_particles***

| Names | Formats | Offsets |
|---|---|---|
| calo_ke | float64 | 0 |
| csda_ke | float64 | 8 |
| depositions_sum | float64 | 16 |
| end_dir | ('<f4', (3,)) | 24 |
| end_point | ('<f4', (3,)) | 36 |
| fragment_ids | object | 48 |
| id | int64 | 64 |
| image_id | int64 | 72 |
| index | object | 80 |
| interaction_id | int64 | 96 |
| is_contained | uint8 | 104 |
| is_primary | uint8 | 105 |
| is_principal_match | uint8 | 106 |
| length | float64 | 107 |
| match | object | 115 |
| match_overlap | object | 131 |
| matched | uint8 | 147 |
| mcs_ke | float64 | 148 |
| momentum | ('<f4', (3,)) | 156 |
| nu_id | int64 | 168 |
| num_fragments | int64 | 176 |

# More Complicated Event Examples



# More Complicated Event Examples