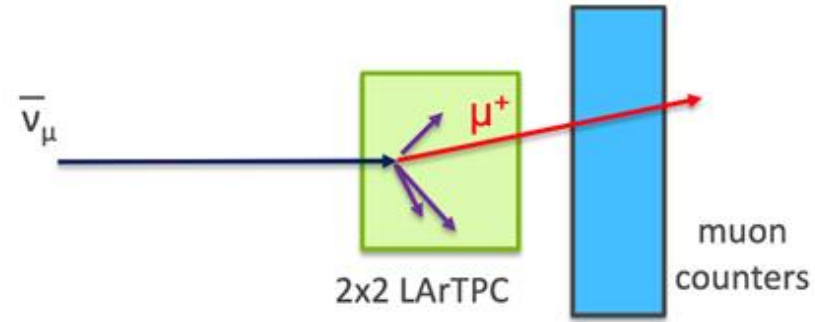# Charged Track Multiplicity Studies
(Update: March 27, 2024)

M. Bilal Azam, Z. Djurcic, et. al.

Motivation

- Study of charged particle multiplicity

- Analyzing the latest MiniRun4.5 Beta3 Flat CAFs

2x2 LArTPC   muon counters

Applied Selection Criteria

- All interactions are CC and within LArFV.

- Distance from outer walls is set to 5 cm in all directions and from inner boundaries is 10 cm along x and z.

- Minimum track length is set to 5 cm.

- Reconstructed interactions are matched with Primary GENIE interactions.

- All cuts are applied on reconstructed quantities only.

- Only those primary GENIE interactions are plotted which matches to Reco interactions.

- MINERvA-matching is implemented for both GENIE truth and Reco Truth tracks.

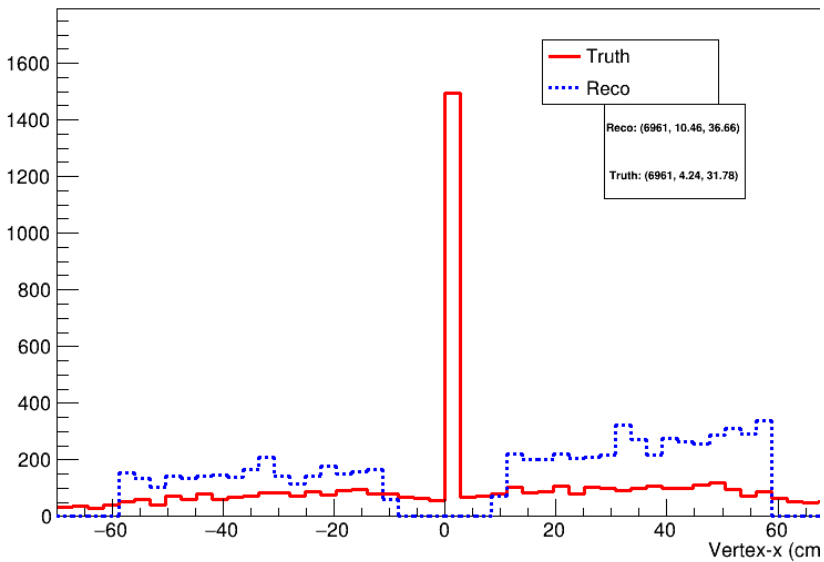- The projected distance between LAr TPC and MINERvA tracks is set to be less than 10 cm.

FV Bounds are (in cm)
$X\ (-63.931, +63.931)$
$Y\ (-62.076, +62.076)$
$Z\ (-64.538, +64.538)$

Neutrino Interaction Vertices
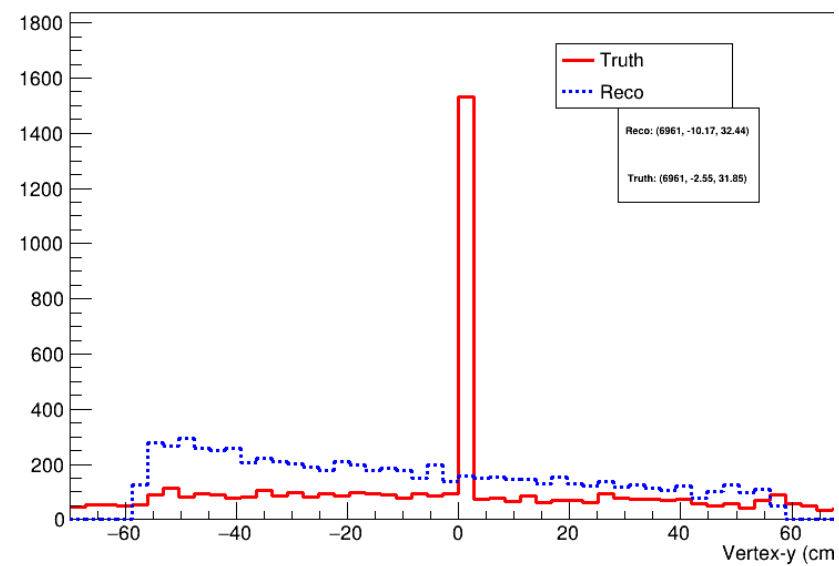
➢ Truth and Reco neutrino interaction vertices are shown.

➢ Vertex-x (cm)   ➢ Vertex-y (cm)   ➢ Vertex-z (cm)
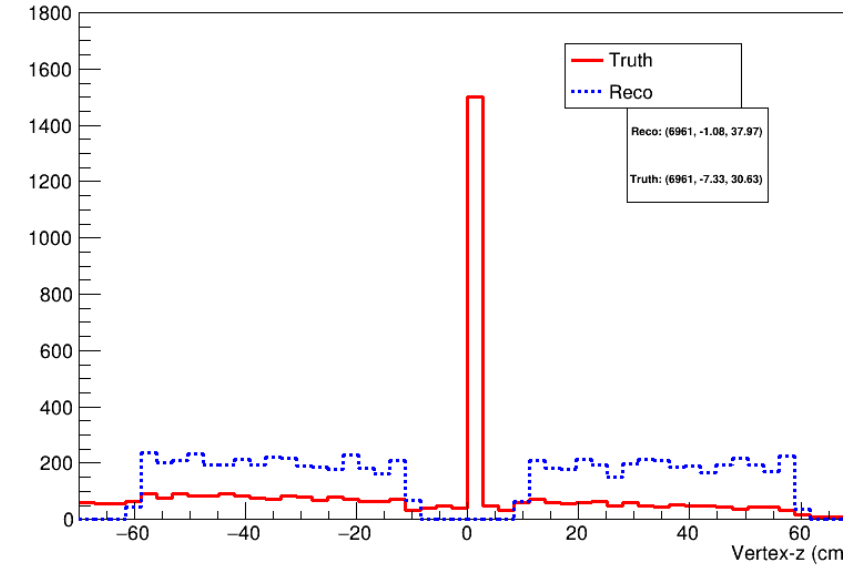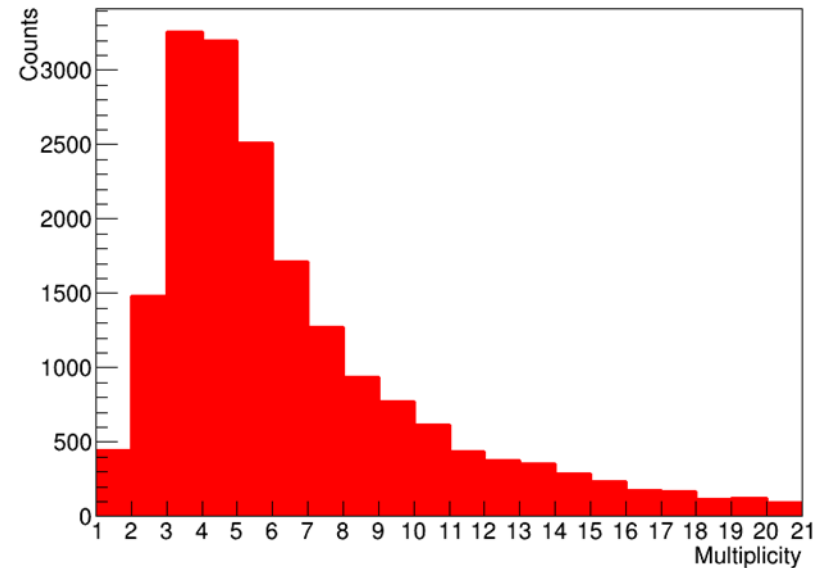
Multiplicity of GENIE Truth and Reco Charged Tracks

➢ Primary track distribution of GENIE Truth and Reco is shown.

➢ After applying length cut on charged tracks within LArFV, reco and truth shows good agreement.

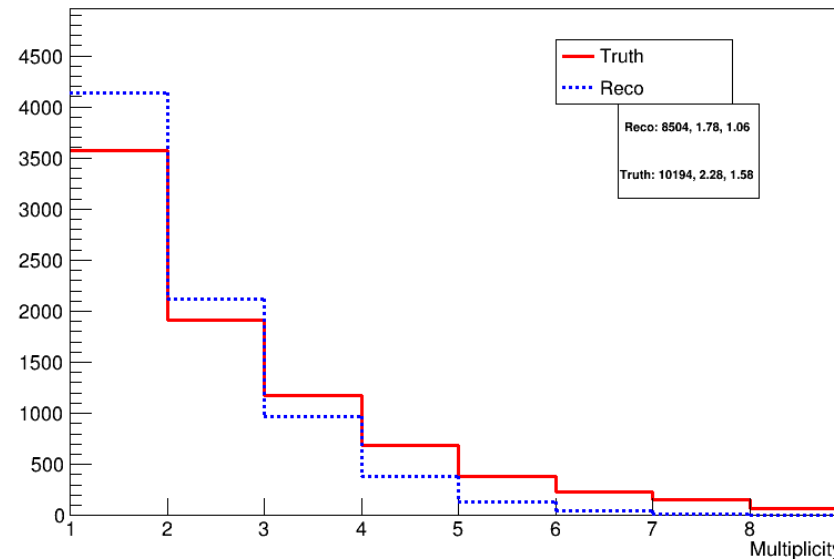➢ Here, multiplicity count includes hadrons only.

➢ All charged primary GENIE truth tracks

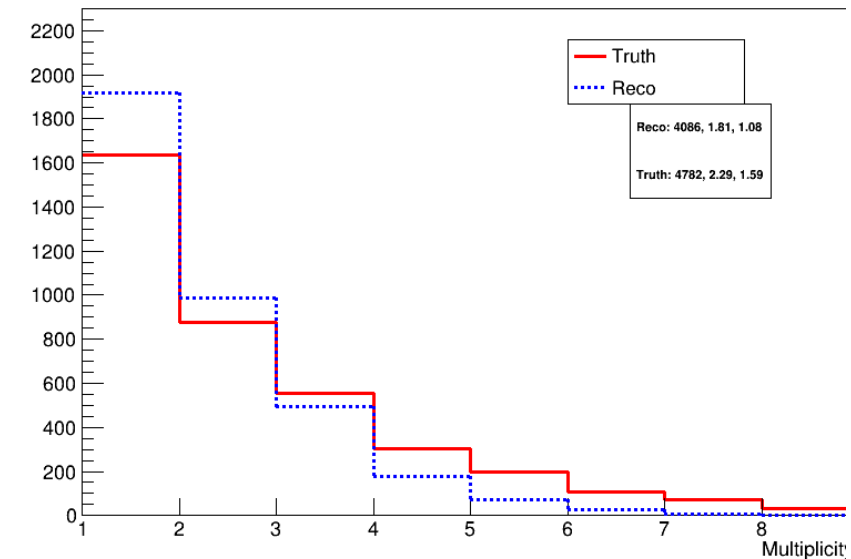➢ No MINERvA-matching (track length> 5 cm)
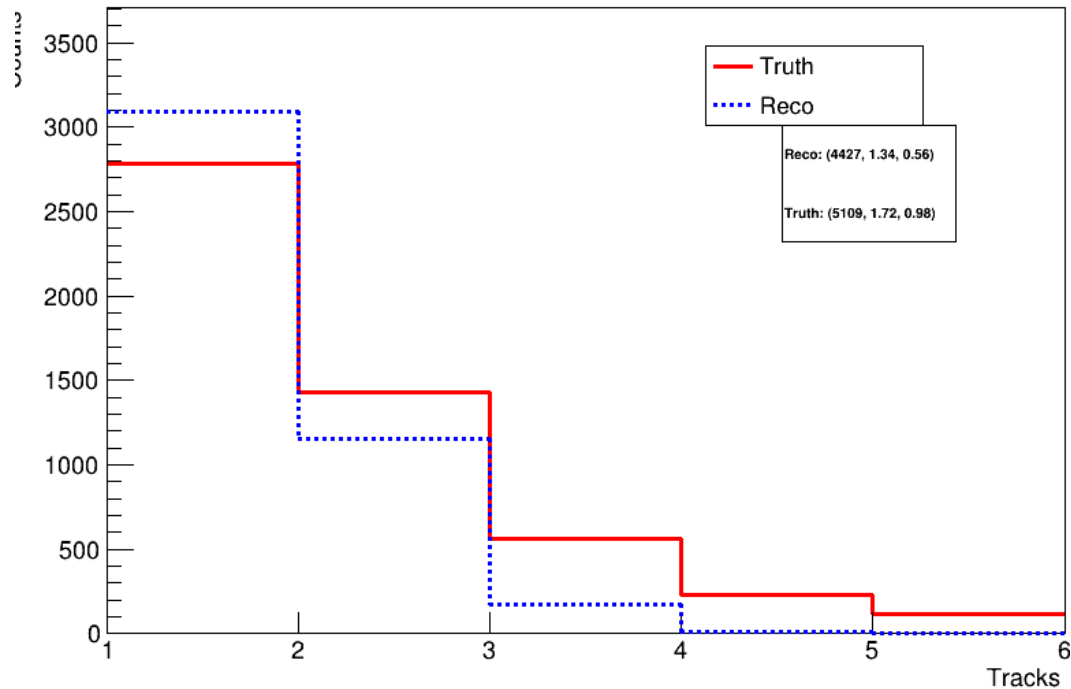
➢ MINERvA-matched (track length> 5 cm)

Number of Primary Charged Pion Tracks ($L > 5$ cm); based on interaction matching

➤ Track counts for charged pions are shown here.

➤ There are more reco charged pions than truth. There could be some truth muons which are being reconstructed as charged pions.
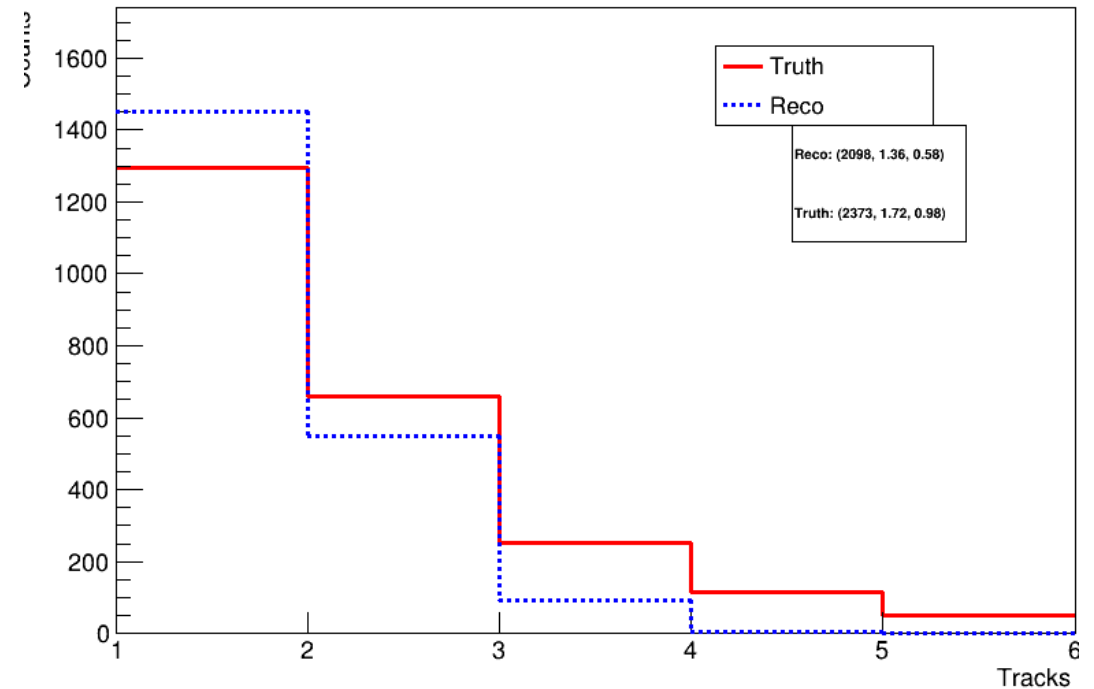
➤ No MINERvA-matching (track length> 5 cm)

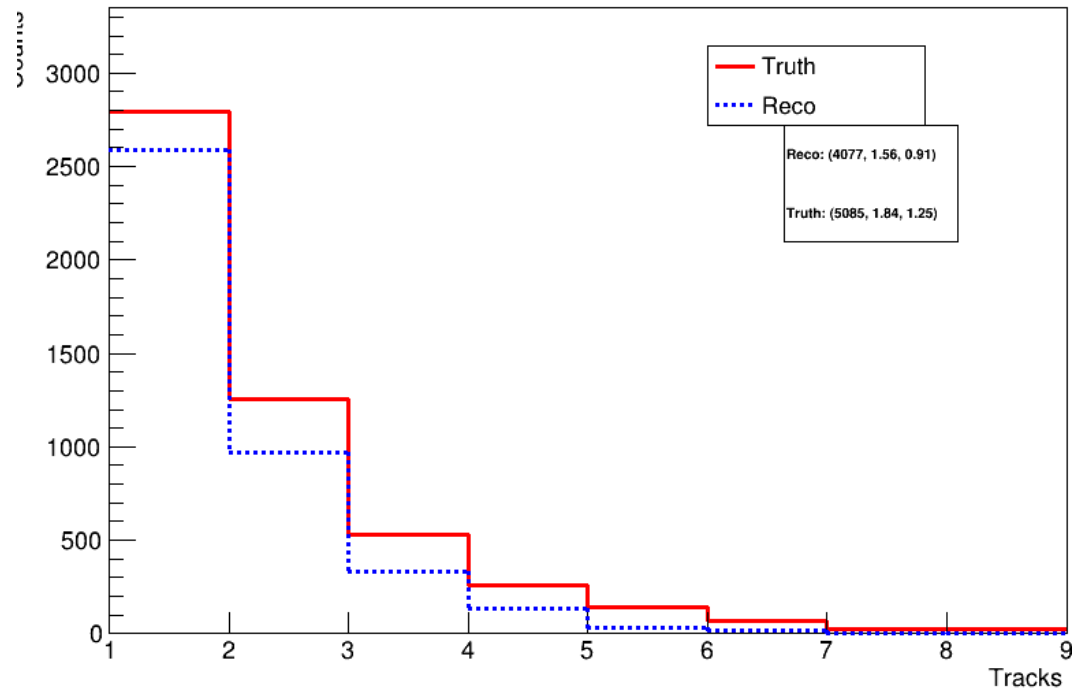➤ MINERvA-matched (track length> 5 cm)

Number of Primary Proton Tracks ($L > 5$ cm); based on interaction matching
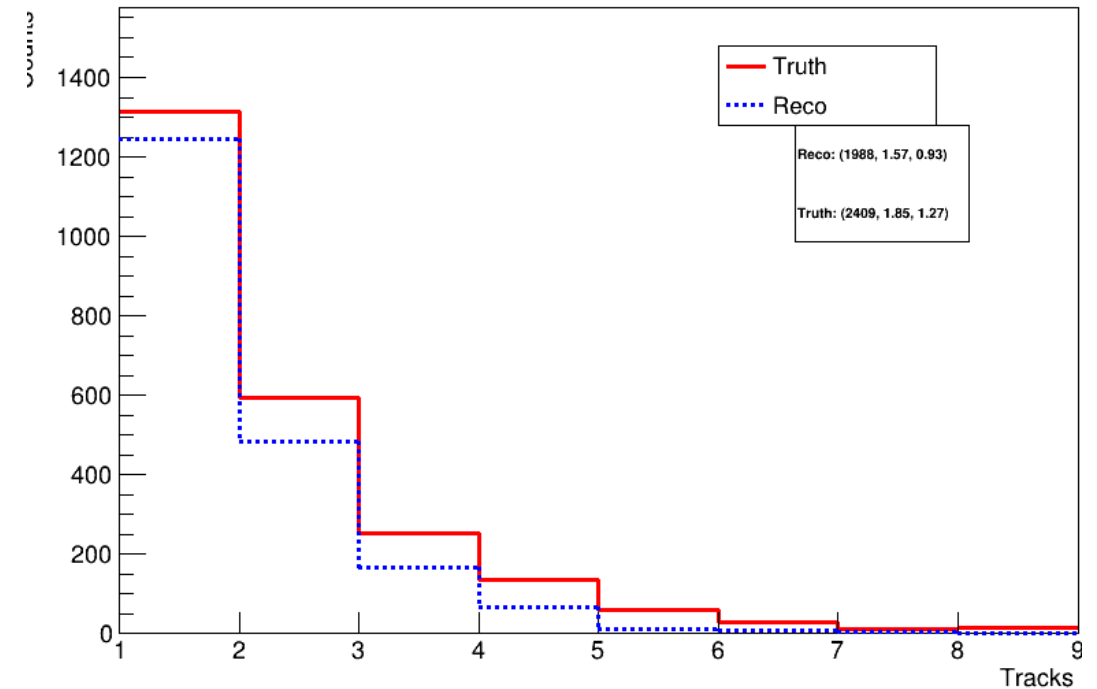
➤ Track counts for protons are shown here.

➤ No MINERvA-matching (track length> 5 cm)

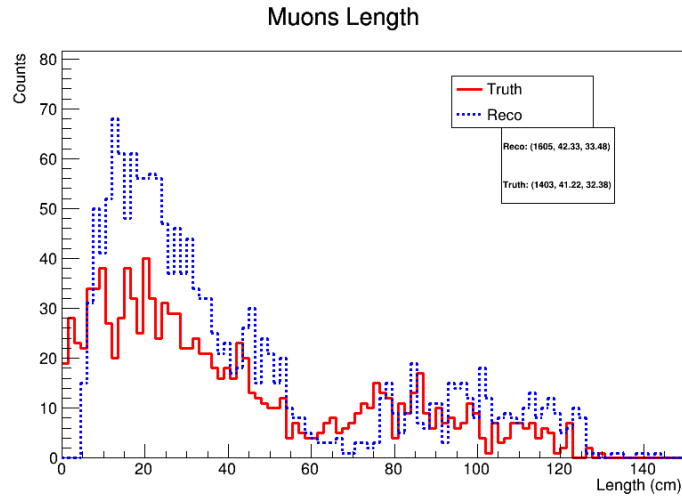➤ MINERvA-matched (track length> 5 cm)

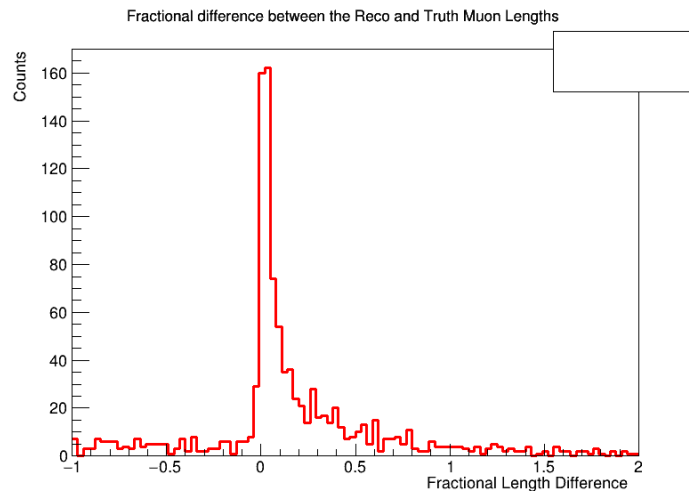# Track Lengths of Primary Muon Tracks ($L > 5$ cm)

➤ No MINERvA-matching

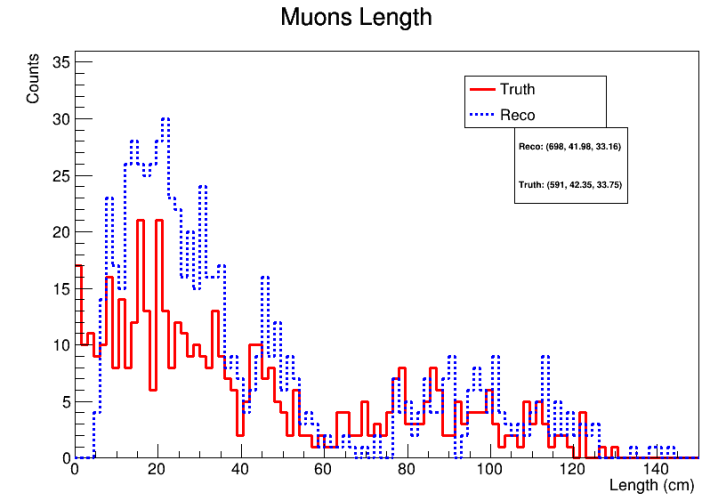➤ MINERvA-matched

Muons Length

- Upper plots show tracks after interaction matching.

- Track length distribution of primary muon tracks is shown here.

- Nearly half of reco events are MINERvA matched.

➤ Difference (No MINERvA)

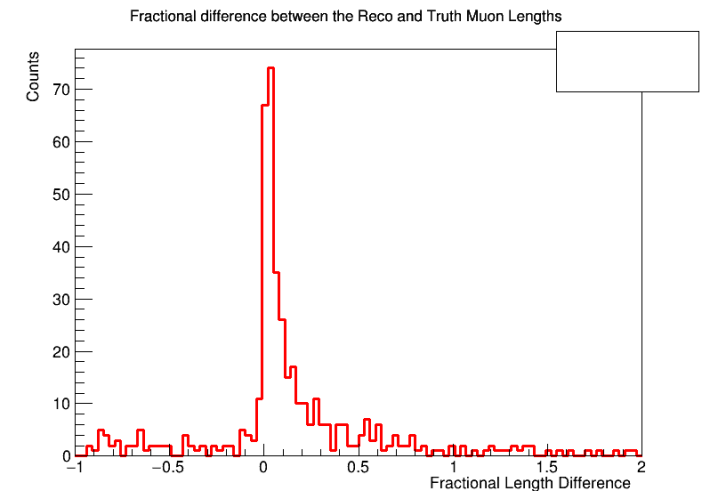➤ Difference (MINERvA-matched)

- Here we matched reco tracks to truth tracks.

- Fractional length difference

$$\text{diff} = \frac{\text{reconstructed length} - \text{truth length}}{\text{truth length}}$$

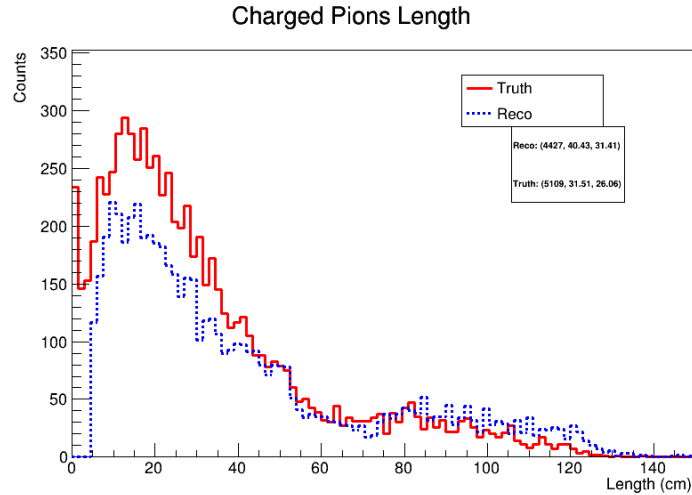- Reco lengths are somewhat 0 to 50% of truth lengths.
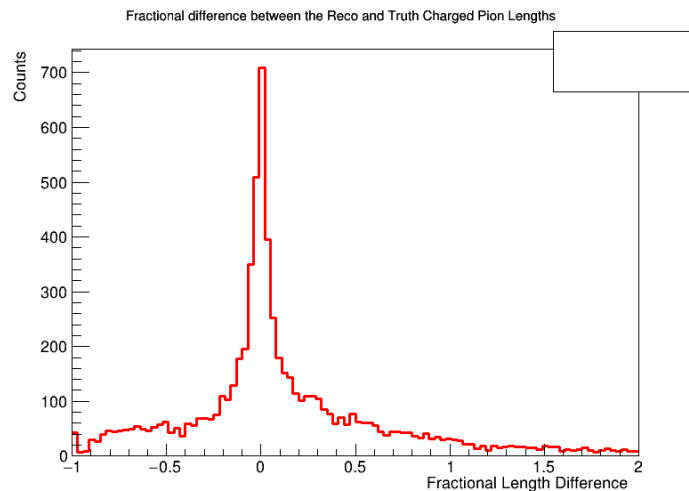
Track Lengths of Primary Charged Pion Tracks ($L > 5$ cm)

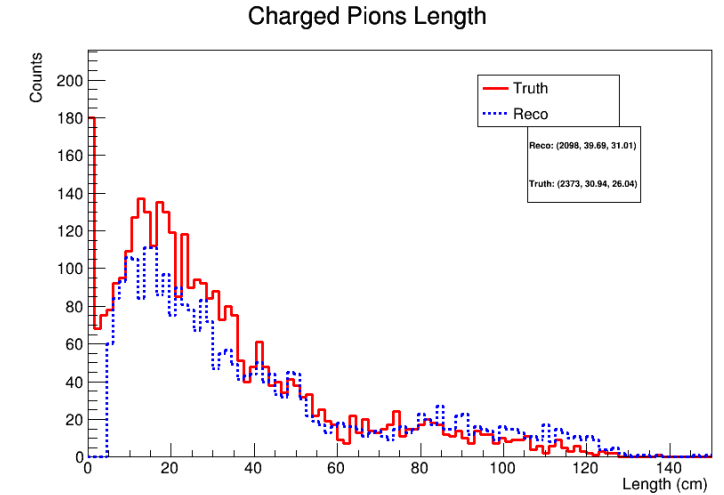➤ No MINERvA-matching

➤ MINERvA-matched

- Upper plots show charged pions track lengths after interaction matching.

- There are slightly more truth pions for track lengths $\sim < 40$ cm.

- Fractional length difference shows a nice Gaussian around zero.

- More truth events at shorter lengths and slightly more reco events for larger lengths.
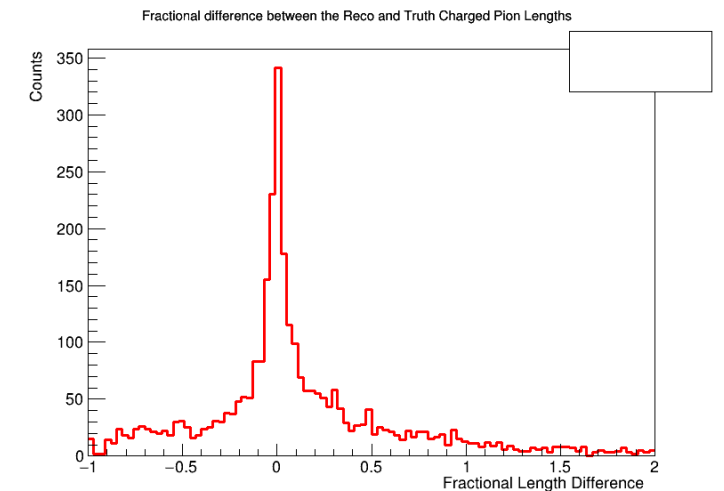
➤ Difference (No MINERvA)
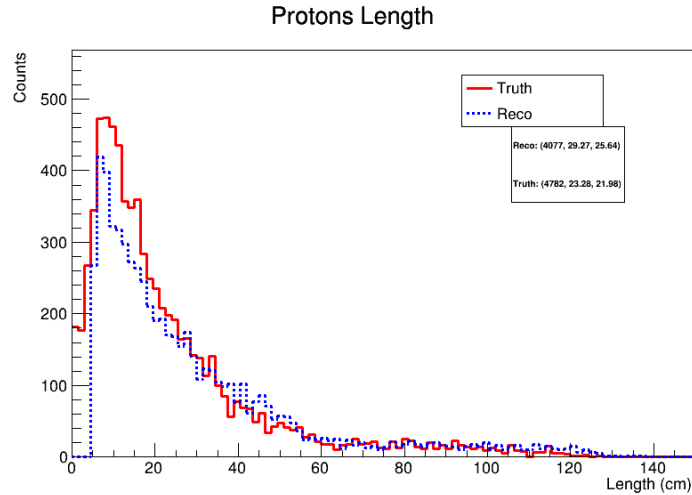

- Lower plots show track-to-track matching.

➤ Difference (MINERvA-matched)

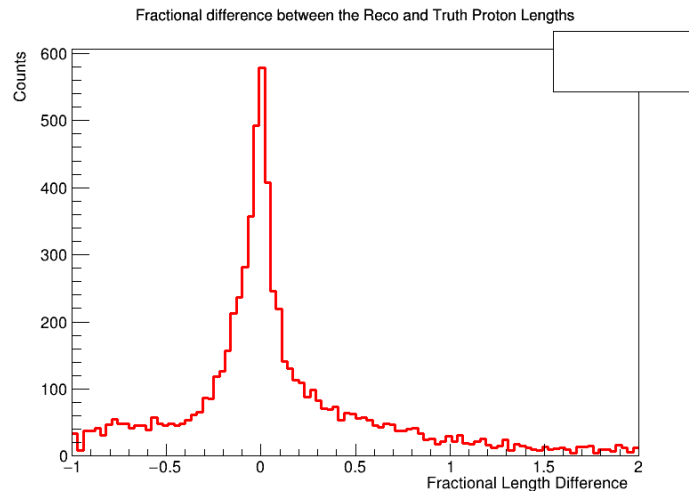# Track Lengths of Primary Proton Tracks ($L > 5$ cm)

➤ No MINERvA-matching
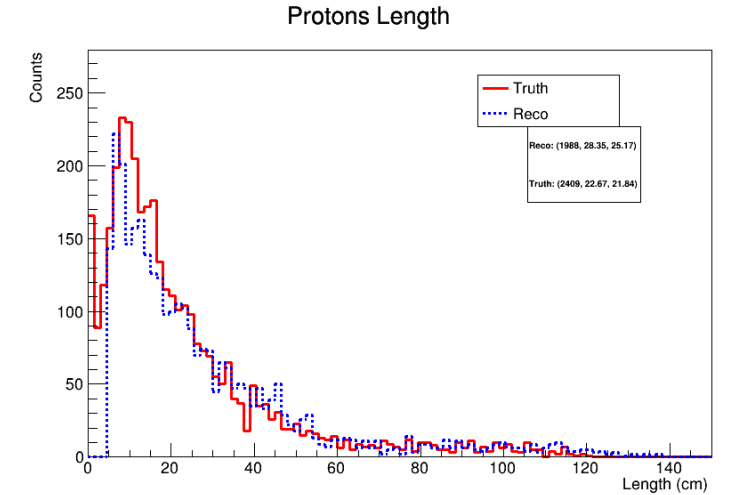

➤ MINERvA-matched

- Track length distribution for protons is shown.

- Upper plots show protons after interaction matching.

- Both Truth and Reco show similar trends here.

- There are slightly more truth pions for track lengths $\sim < 20$ cm.
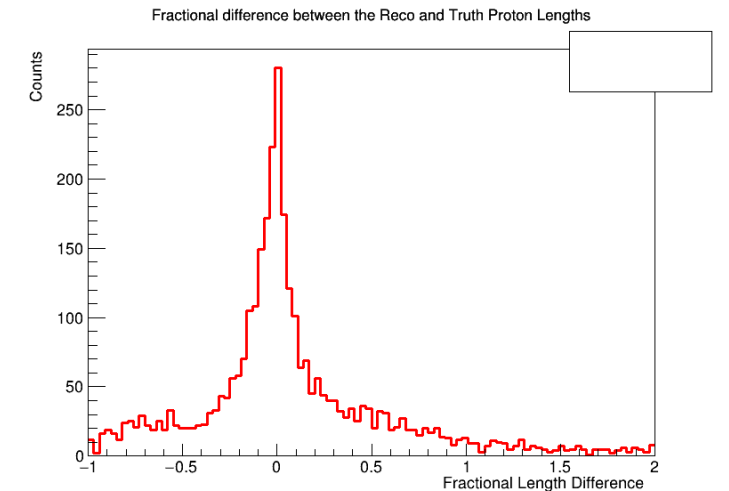
➤ Difference (No MINERvA)

➤ Difference (MINERvA-matched)

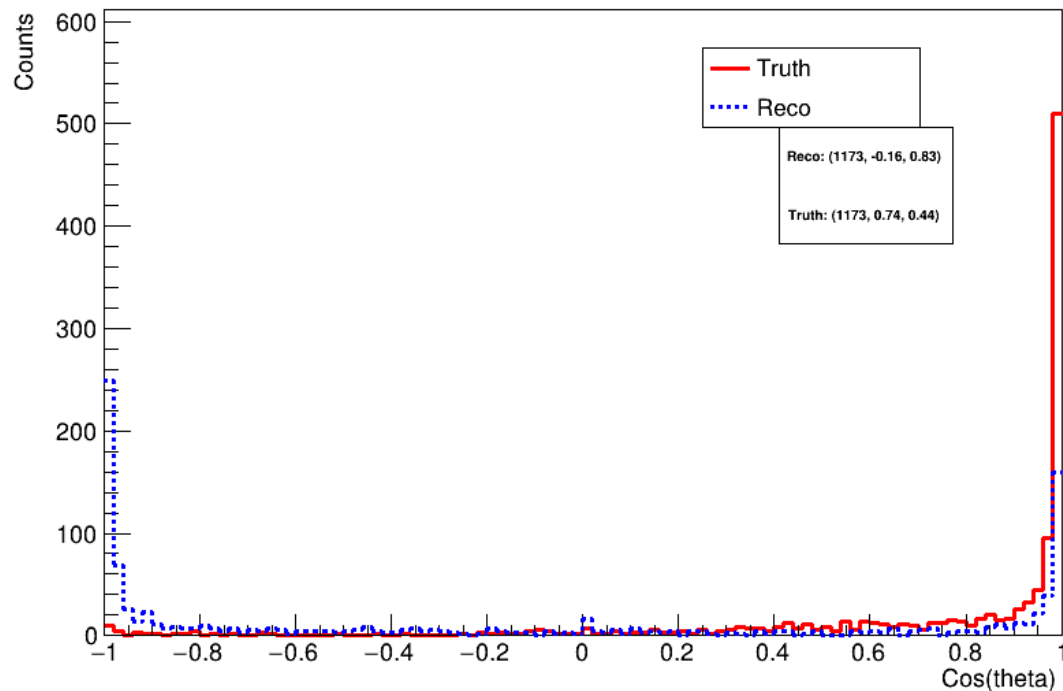- Lower plots show track-to-track matching.

Cosine Theta of Primary Muon Tracks ($L > 5$ cm); based on interaction matching

➢ Cosine theta distribution shows majority of muons are forward-going.
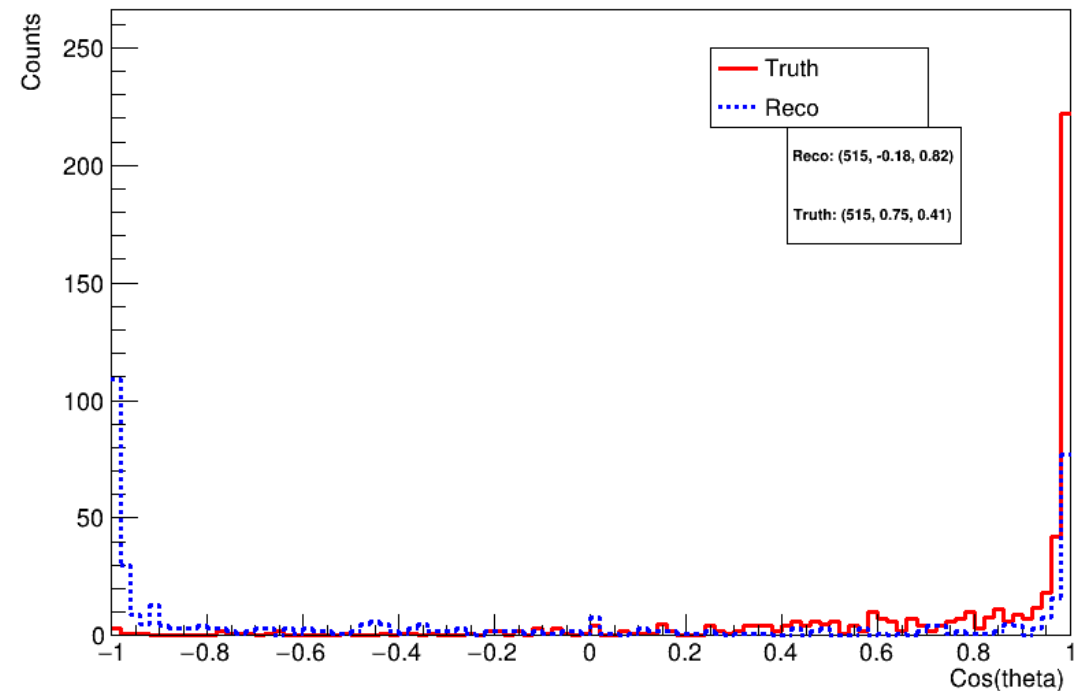
➢ These plots show tracks after interaction matching.
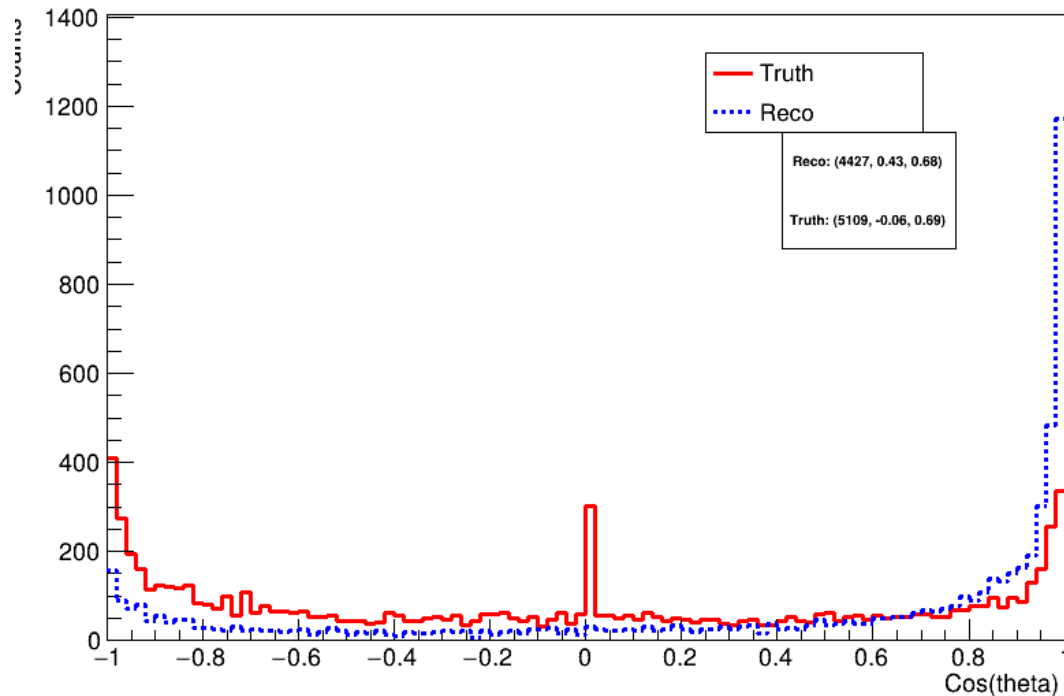
➢ No MINERvA-matching

➢ MINERvA-matched

Cosine Theta of Primary Charged Pion Tracks $(L > 5 \text{ cm})$; based on interaction matching

➢ Cosine theta distribution for positive pions is shown.

➢ We can observe a peak around 0 for truth events.

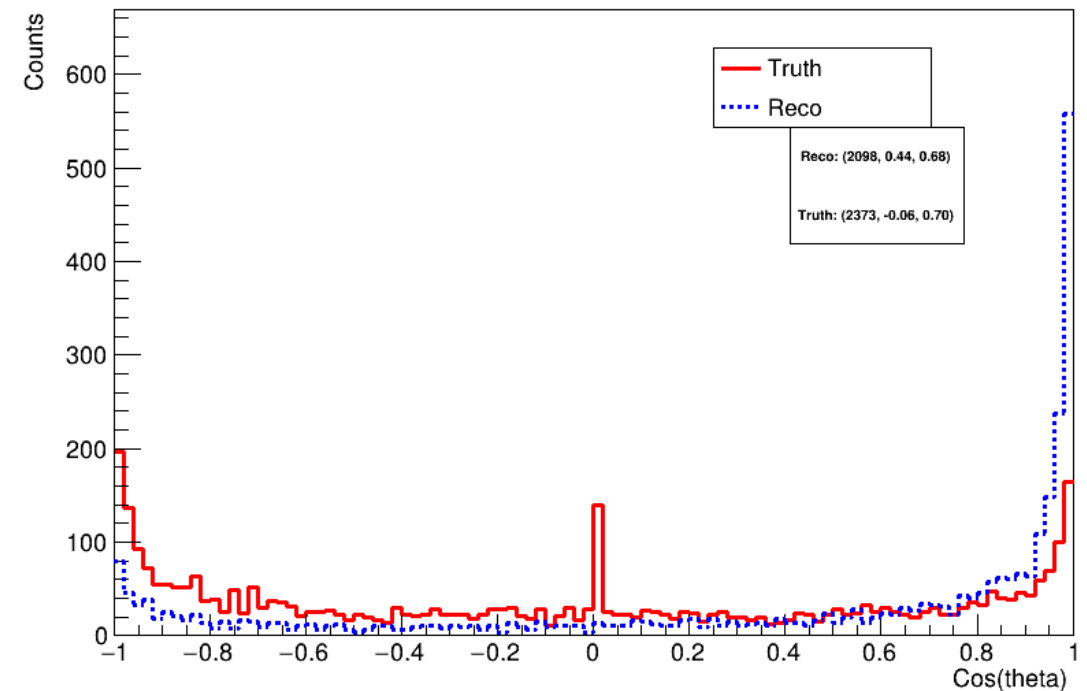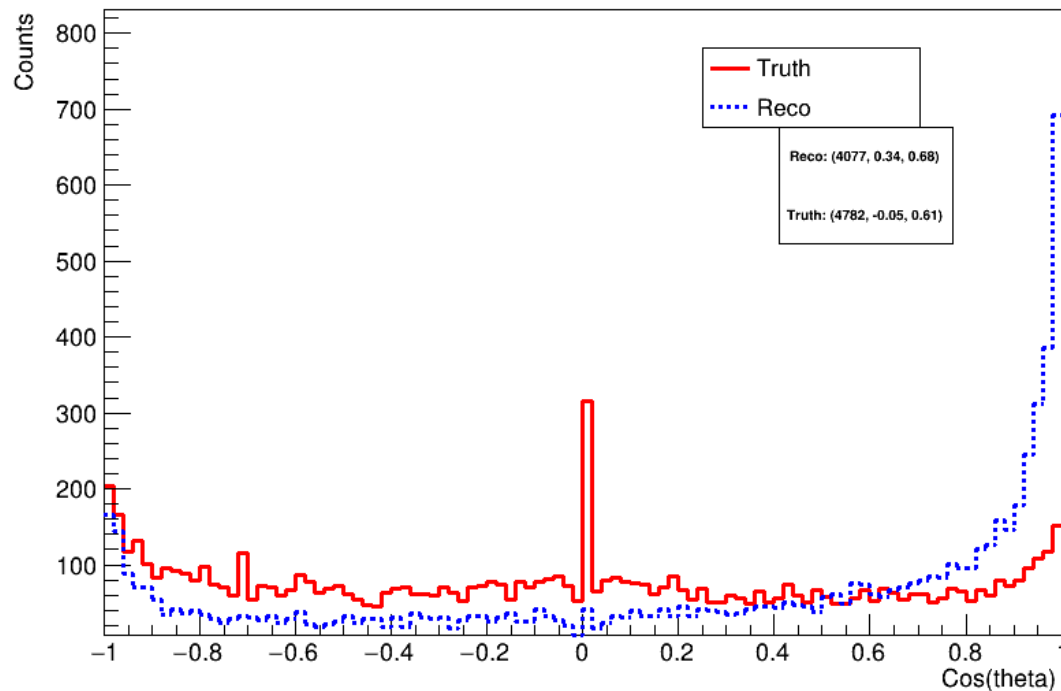➢ No MINERvA-matching

➢ MINERvA-matched

Cosine Theta of Primary Proton Tracks ($L > 5$ cm); based on interaction matching

➢ Cosine theta distribution for protons is shown.

➢ There is a reasonably good amount of truth protons around zero cosine theta but reco does not show this trend.

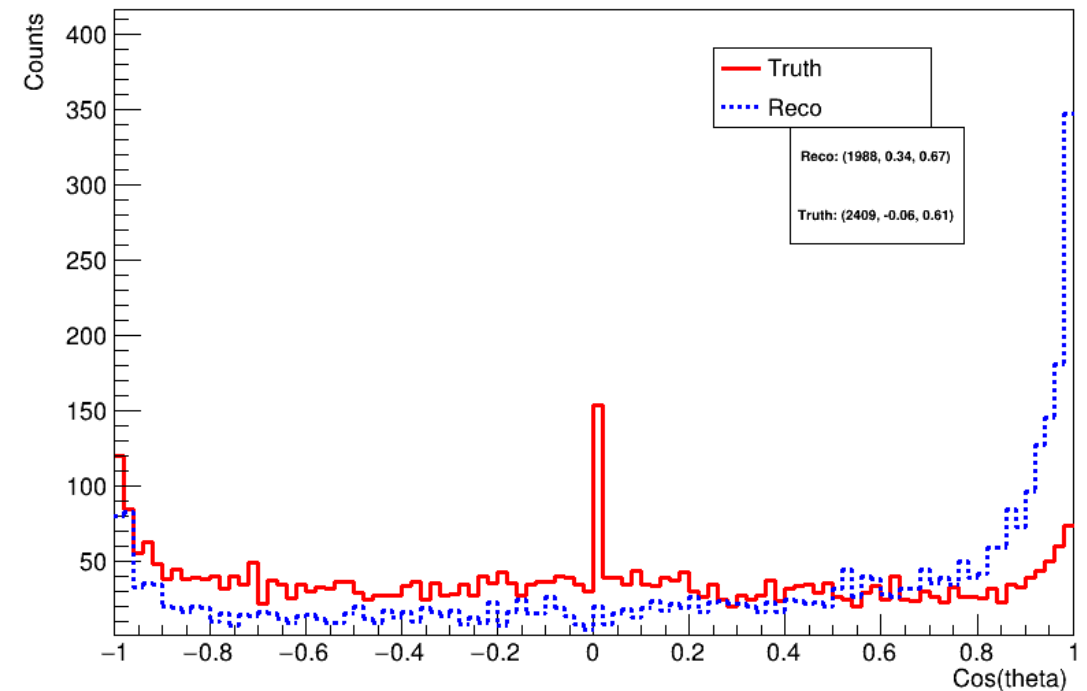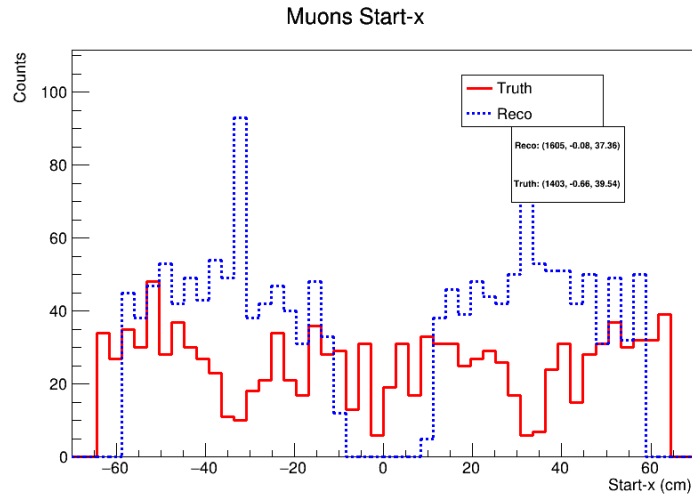➢ Reco is also constructing more protons with cosine theta > 0.5.

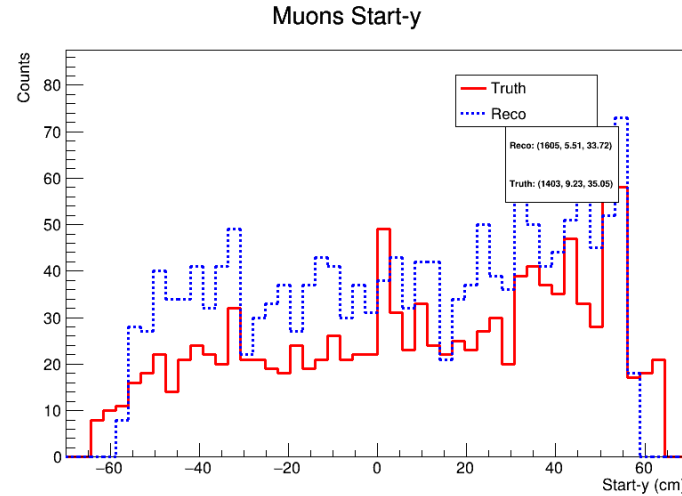➢ No MINERvA-matching

➢ MINERvA-matched

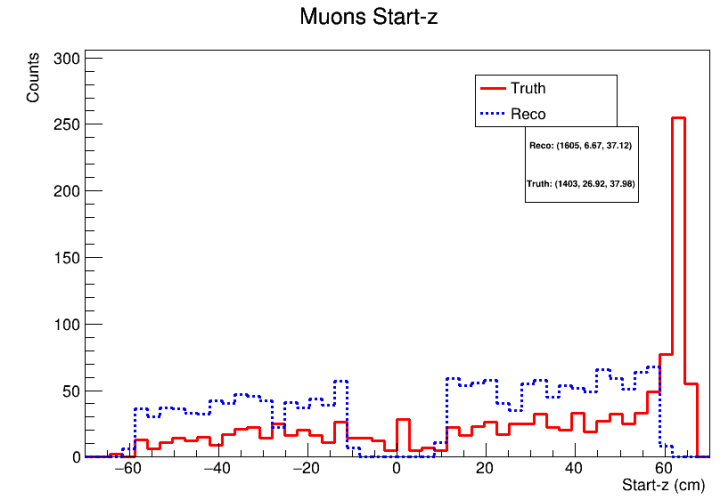# Starting Positions of Primary Muons Tracks ($L > 5$ cm); based on interaction matching
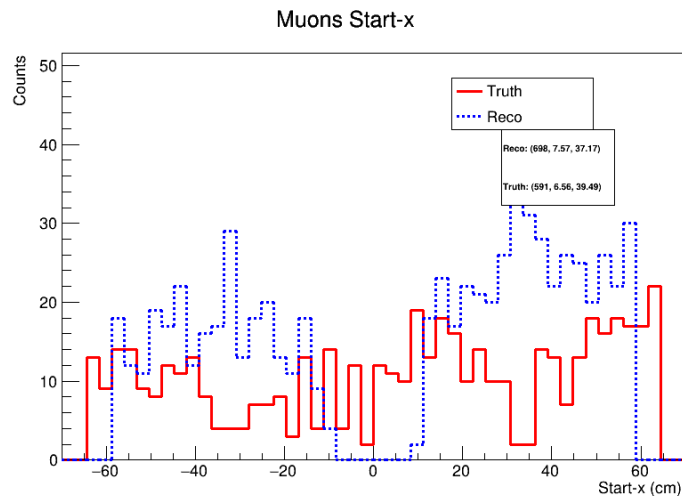
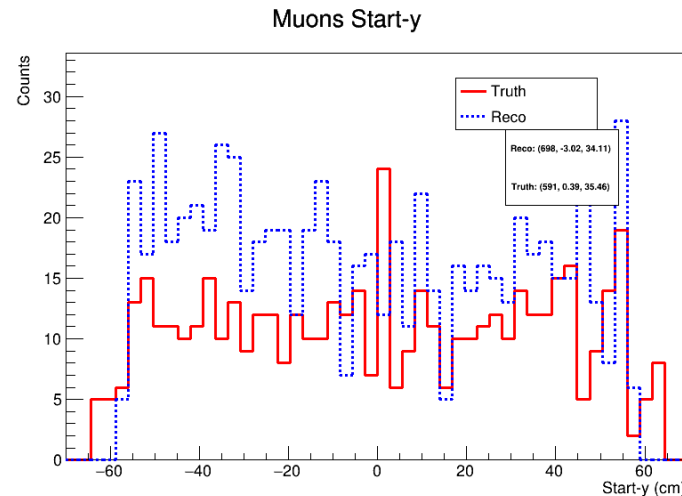➢ Start-x (not-MINERvA-matched)   ➢ Start-y (not-MINERvA-matched)   ➢ Start-z (not-MINERvA-matched)
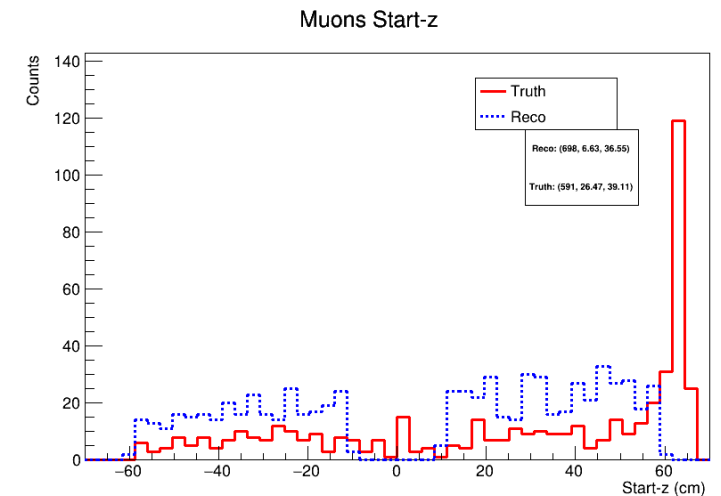

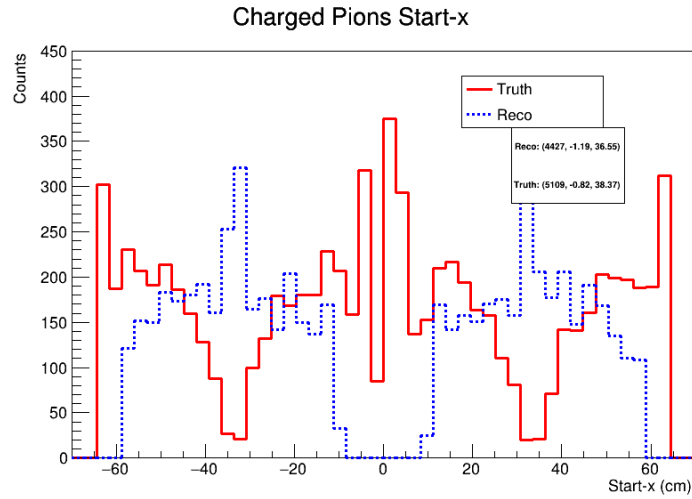➢ Start-x (MINERvA-matched)   ➢ Start-y (MINERvA-matched)   ➢ Start-z (MINERvA-matched)
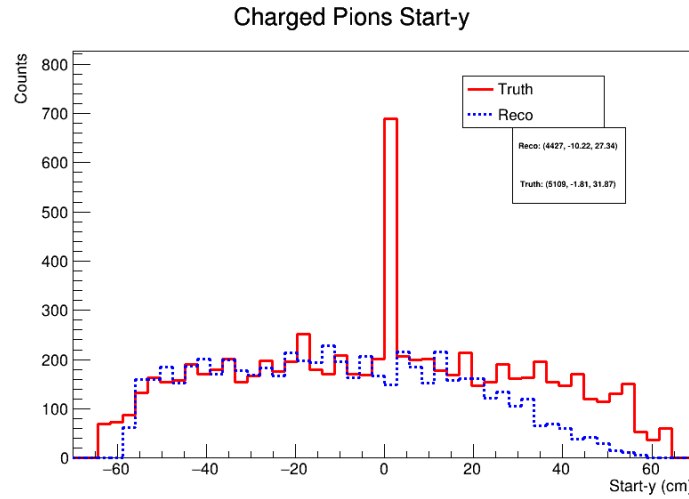
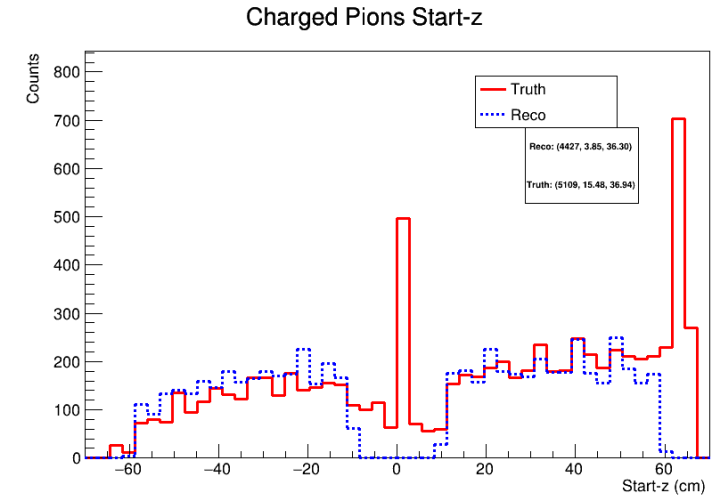# Starting Positions of Primary Charged Pions Tracks ($L > 5$ cm); based on interaction matching
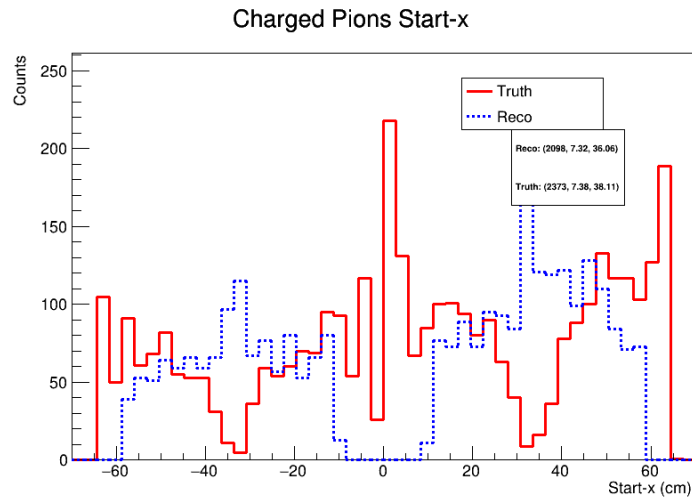
➢ Start-x (not-MINERvA-matched)
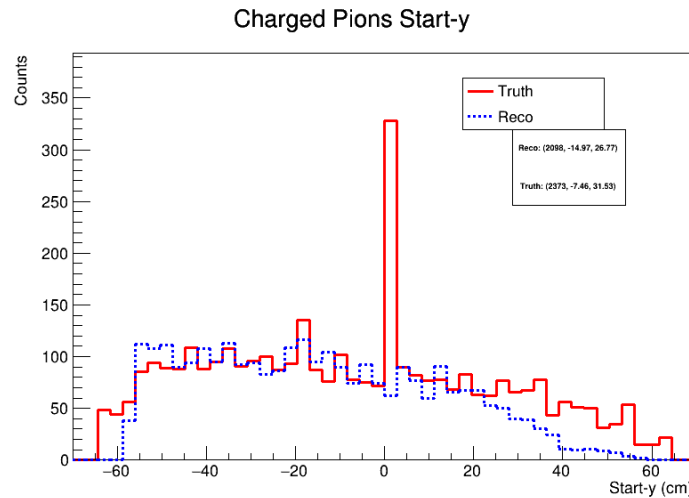
➢ Start-y (not-MINERvA-matched)

➢ Start-z (not-MINERvA-matched)
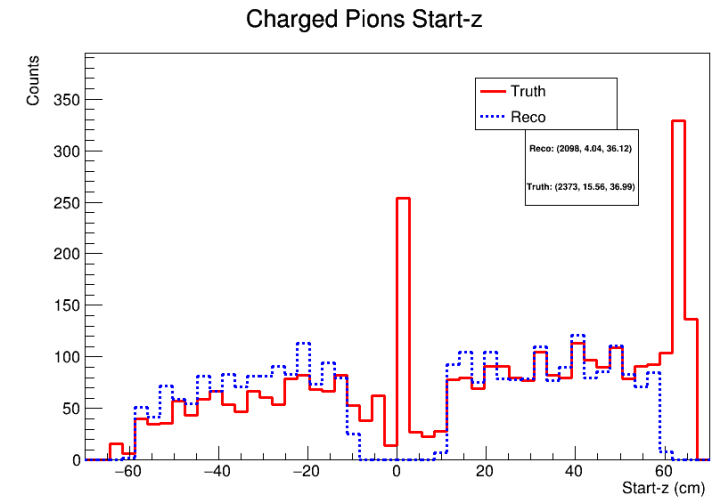

➢ Start-x (MINERvA-matched)
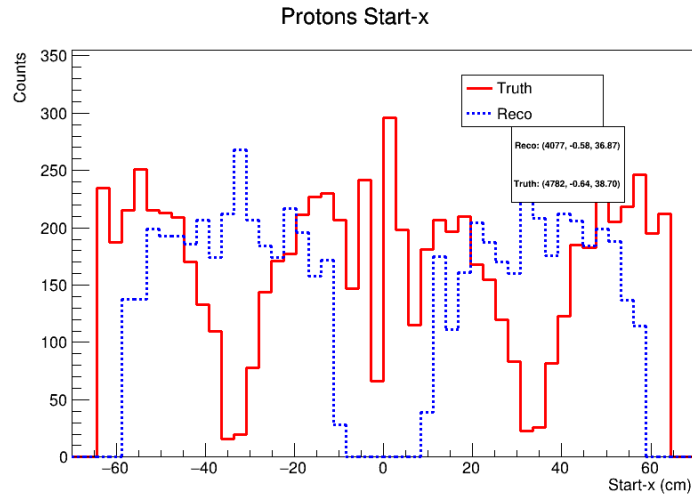
➢ Start-y (MINERvA-matched)
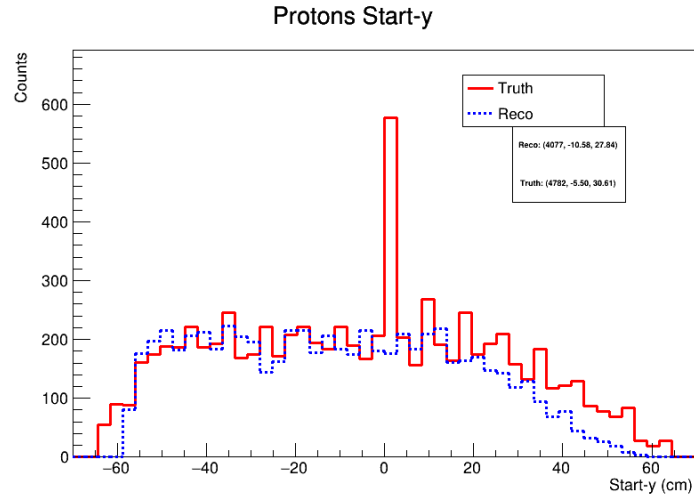
➢ Start-z (MINERvA-matched)

Starting Positions of Primary Protons Tracks ($L > 5$ cm); based on interaction matching
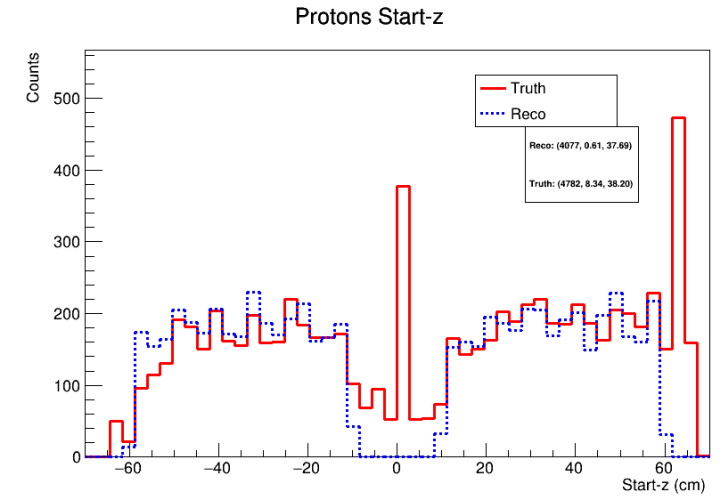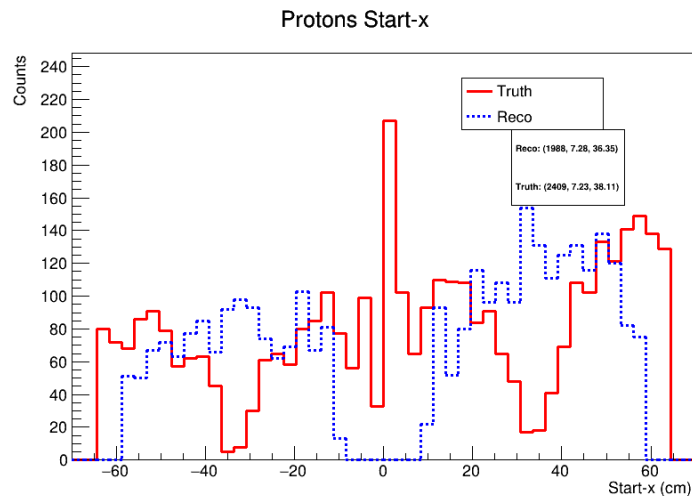
➢ Start-x (not-MINERvA-matched)   ➢ Start-y (not-MINERvA-matched)   ➢ Start-z (not-MINERvA-matched)
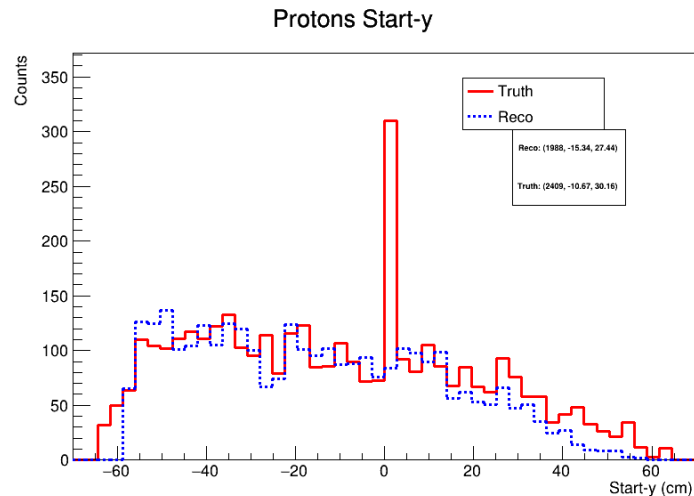
➢ Start-x (MINERvA-matched)   ➢ Start-y (MINERvA-matched)   ➢ Start-z (MINERvA-matched)
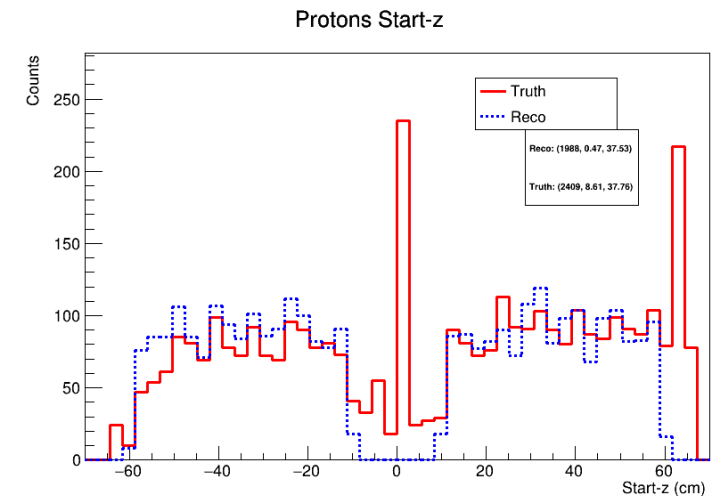
MINERvA-matched Charged Pions for Start-z > 60 cm; based on interaction matching
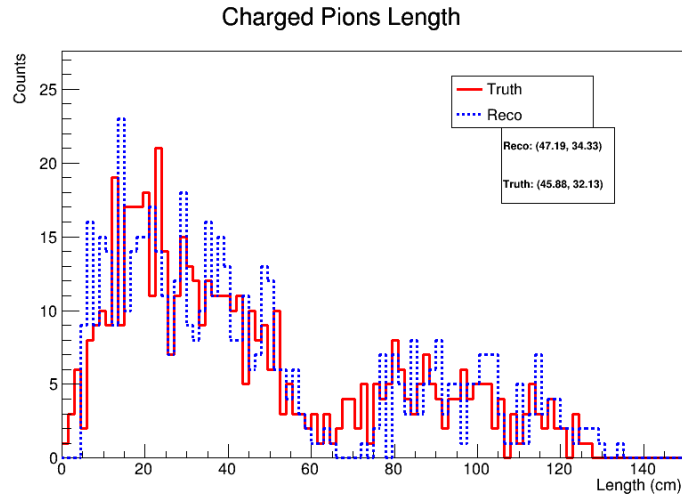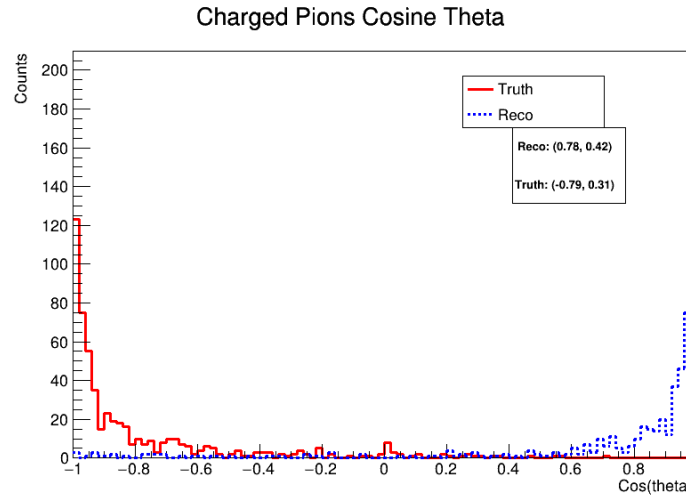
➢ Track Lengths

Charged Pions Length

➢ Cosine Theta

Charged Pions Cosine Theta

➢ All reco cuts are still kept and add an additional start-z > 60 cm cut on truth events.

➢ Also, all spikes around 0 (costheta, start-x,y,z and length) are gone.

➢ Start-x

Charged Pions Start-x

➢ Start-y

Charged Pions Start-y

➢ Start-z

Charged Pions Start-z

MINERvA-matched Protons for Start-z > 60 cm; based on interaction matching

➢ Track Lengths

Protons Length

➢ Cosine Theta

Protons Cosine Theta

➢ All reco cuts are still kept and add an additional start-z > 60 cm cut on truth events.

➢ Also, all spikes around 0 (costheta, start-x,y,z and length) are gone.

➢ We will provide this feedback to ML-Reco group.

➢ Start-x

Protons Start-x

➢ Start-y

Protons Start-y

➢ Start-z

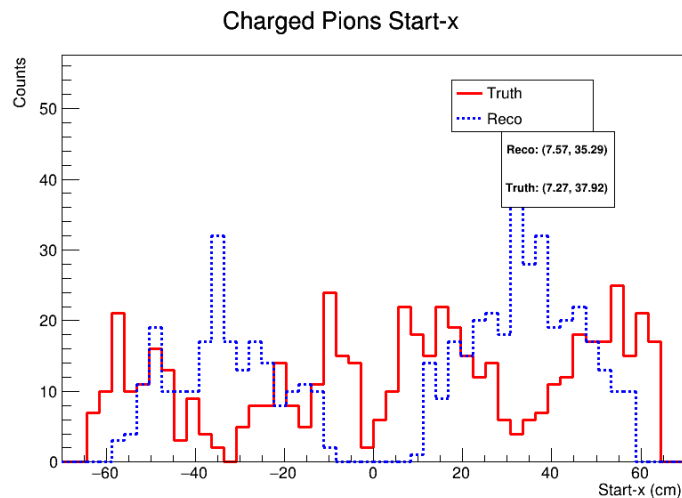Protons Start-z
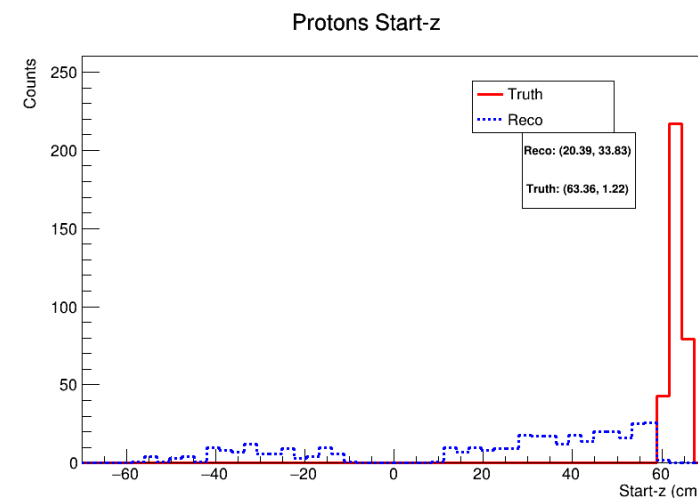
MINERvA-matched Charged Pions for $-5 <$ Start-y < 5 cm; based on interaction matching

➢ Track Lengths

Charged Pions Length

Reco: (31.24, 27.39)

Truth: (27.10, 27.56)

➢ Cosine Theta

Charged Pions Cosine Theta

Reco: (0.33, 0.67)

Truth: (-0.05, 0.67)
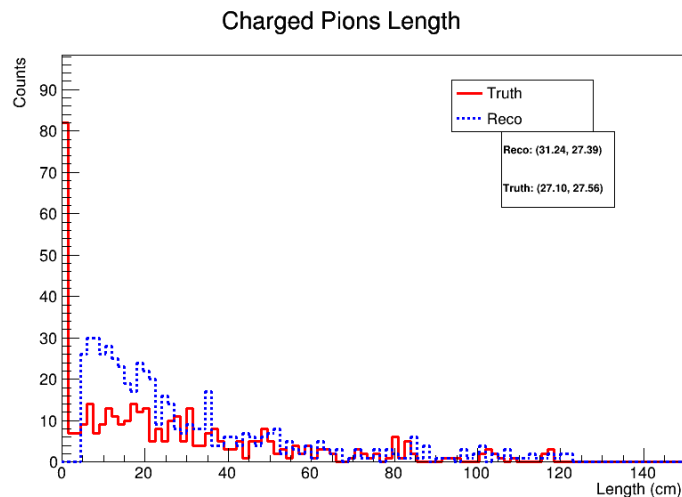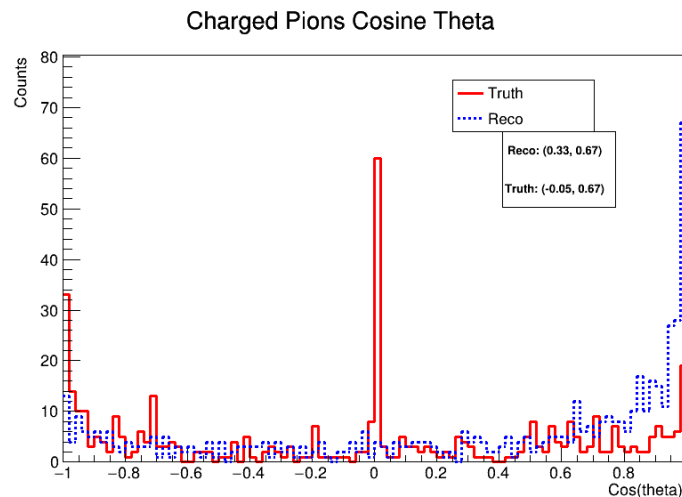
➢ Further investigated spikes around truth start-y 0.

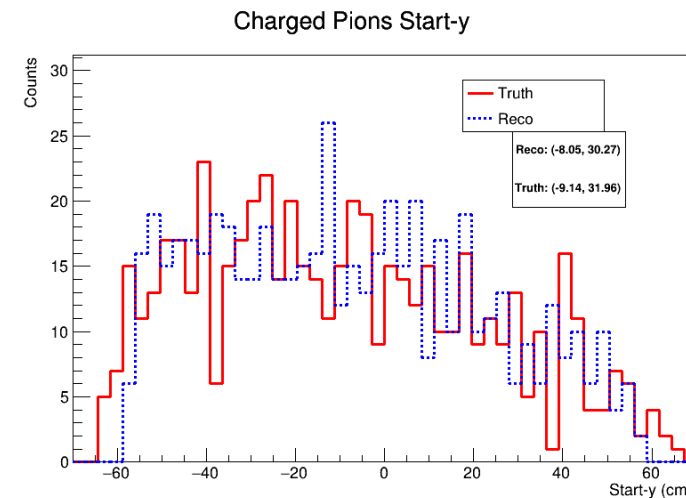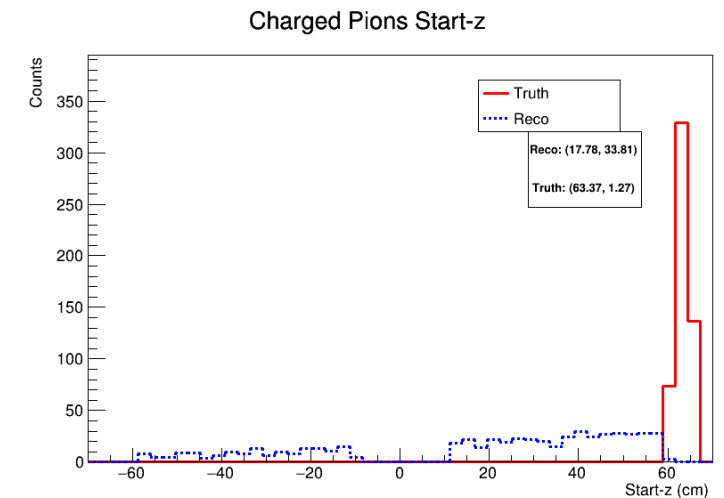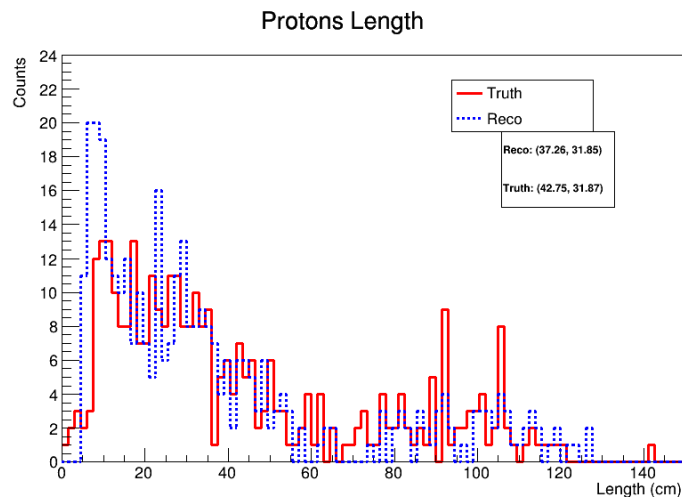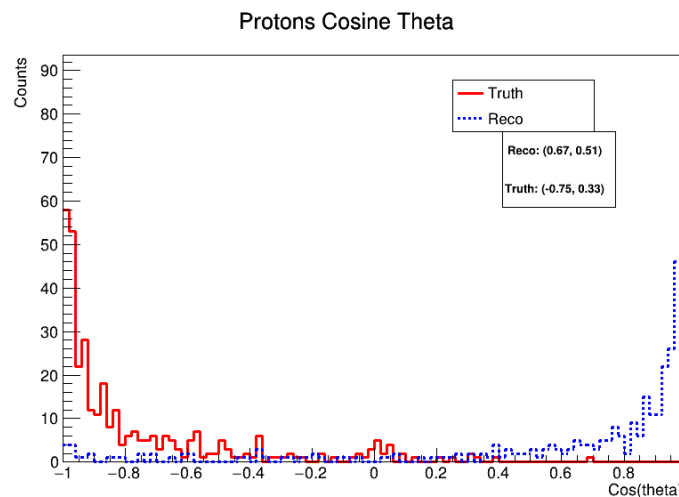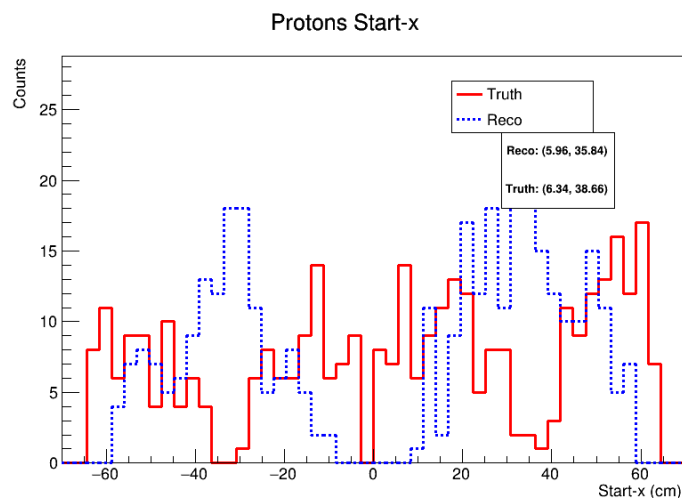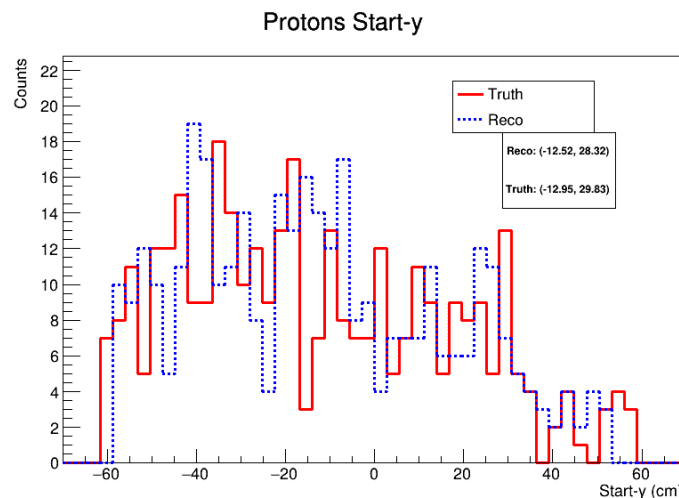➢ All reco cuts are still kept and add an additional start-y cut on truth events.

➢ Also, all spikes around 0 (costheta, start-x,y,z and length) are back.

➢ We need to understand these zero entries.

➢ Start-x

Charged Pions Start-x

Reco: (6.45, 35.86)

Truth: (5.22, 28.71)

➢ Start-y

Charged Pions Start-y

Reco: (-3.93, 23.52)

Truth: (0.15, 2.30)

➢ Start-z

Charged Pions Start-z

Reco: (10.53, 34.76)

Truth: (7.91, 29.95)

MINERvA-matched Protons for $-5 <$ Start-y < 5 cm; based on interaction matching
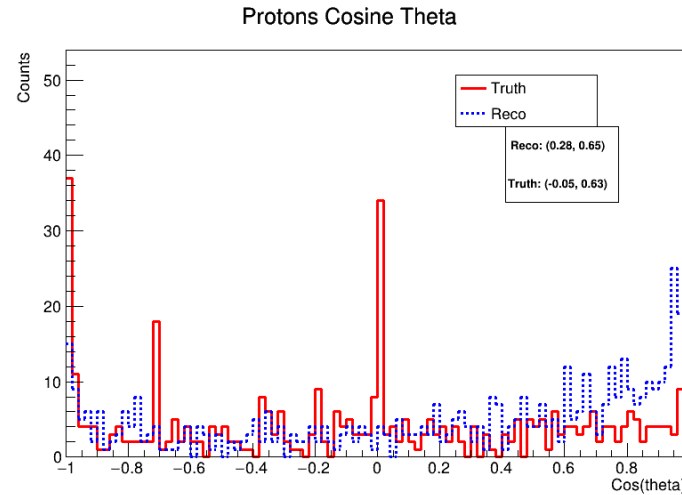
➤ Track Lengths

Protons Length

➤ Cosine Theta

Protons Cosine Theta

➤ I further investigates spikes around truth start-y 0.

➤ All reco cuts are still kept and add an additional start-y cut on truth events.

➤ Also, all spikes around 0 (costheta, start-x,y,z and length) are back.

➤ We need to explore these events further.

➤ Start-x

Protons Start-x
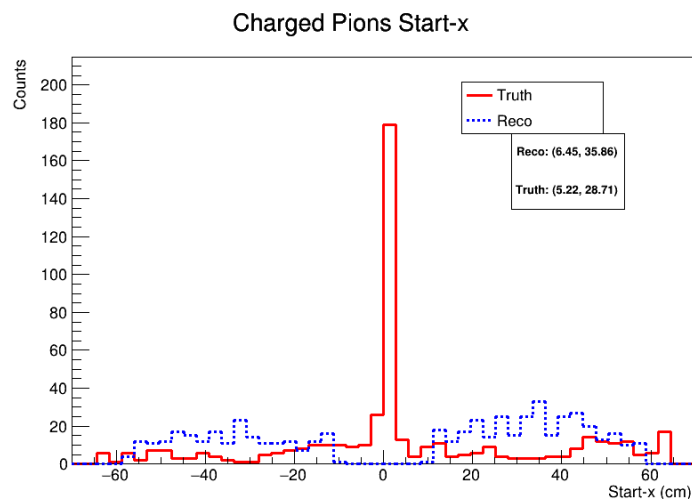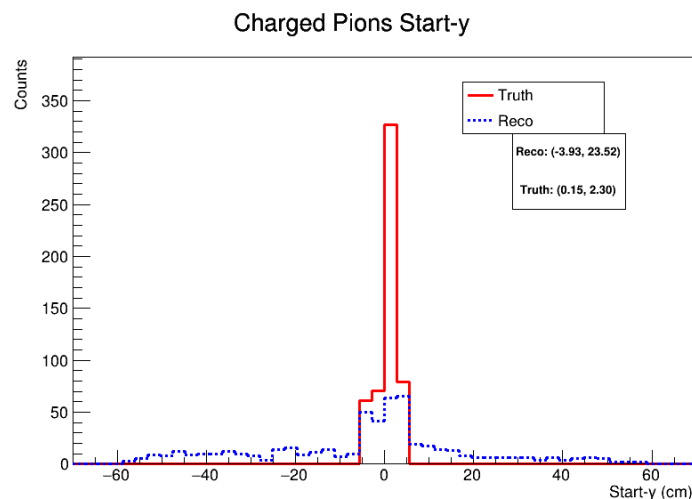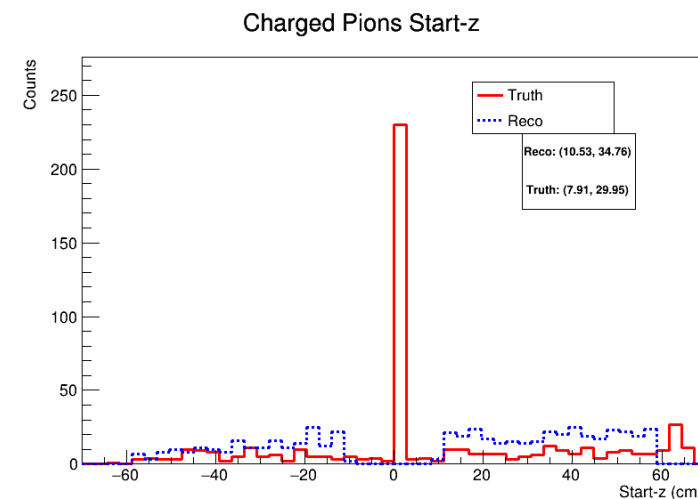
➤ Start-y

Protons Start-y

➤ Start-z

Protons Start-z
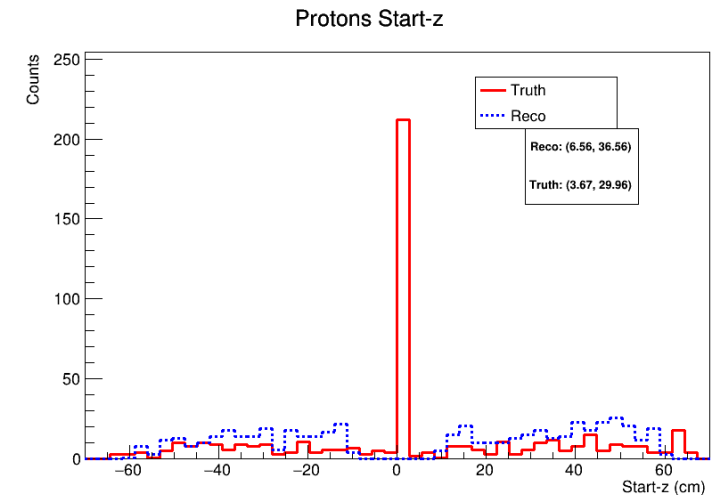
MINERvA-matched Charged Pions for $-0.05 < \cos\theta < 0.05$; based on interaction matching

- ➤ Track Lengths

Charged Pions Length

Reco: (24.00, 18.29)

Truth: (14.32, 14.53)

- ➤ Cosine Theta

Charged Pions Cosine Theta

Reco: (0.22, 0.60)

Truth: (0.00, 0.02)

- ➤ I further investigates spikes around truth costheta 0.
- ➤ All reco cuts are still kept and add an additional costheta cut on truth events.
- ➤ Also, all spikes around 0 (costheta, start-x,y,z and length) are back.
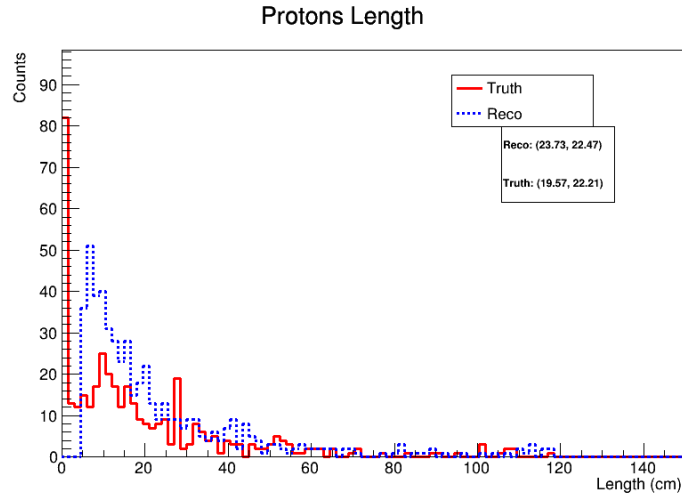- ➤ We need to explore these events further.
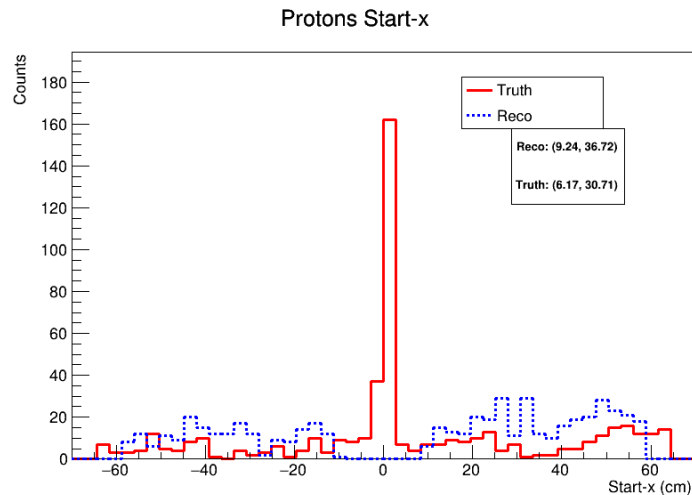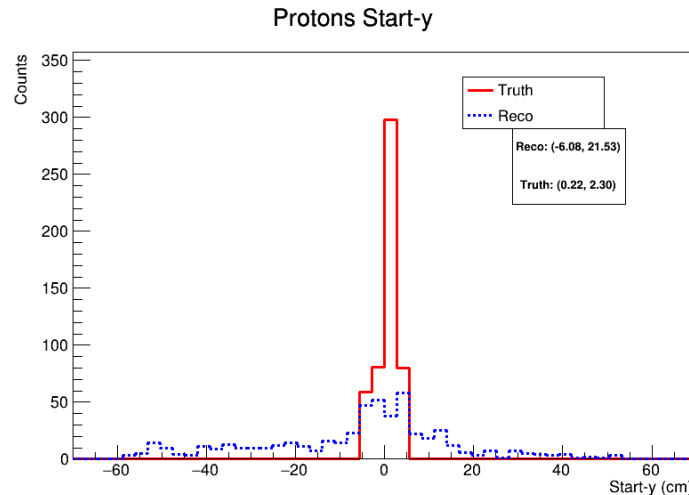
- ➤ Start-x

Charged Pions Start-x

Reco: (8.08, 36.77)

Truth: (7.80, 35.83)

- ➤ Start-y

Charged Pions Start-y

Reco: (-5.94, 30.70)

Truth: (-2.64, 28.02)

- ➤ Start-z

Charged Pions Start-z

Reco: (14.60, 34.42)

Truth: (8.35, 32.79)

MINERvA-matched Protons for $-0.05 < \cos\theta < 0.05$; based on interaction matching

➢ Track Lengths

Protons Length

➢ Cosine Theta

Protons Cosine Theta

➢ I further investigates spikes around truth costheta 0.

➢ All reco cuts are still kept and add an additional costheta cut on truth events.

➢ Also, all spikes around 0 (costheta, start-x,y,z and length) are back.

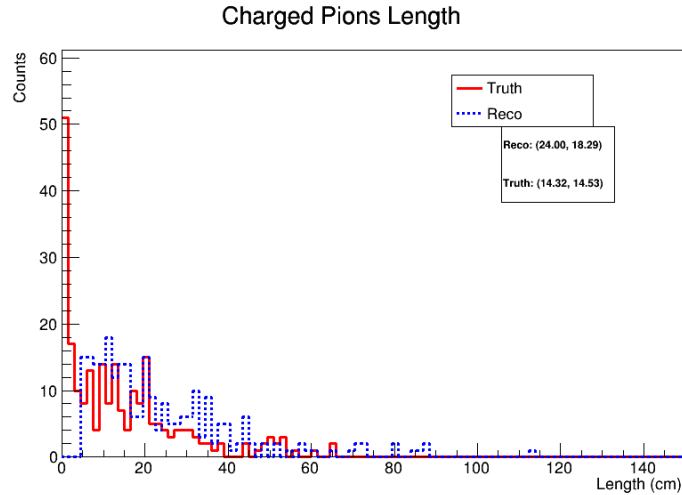➢ We need to explore these events further.
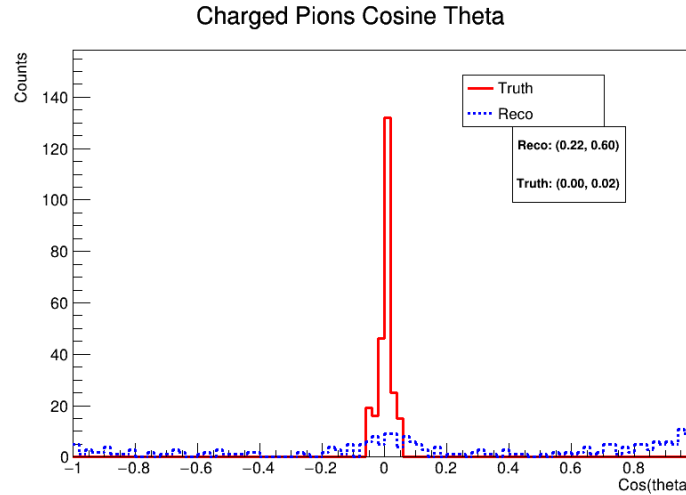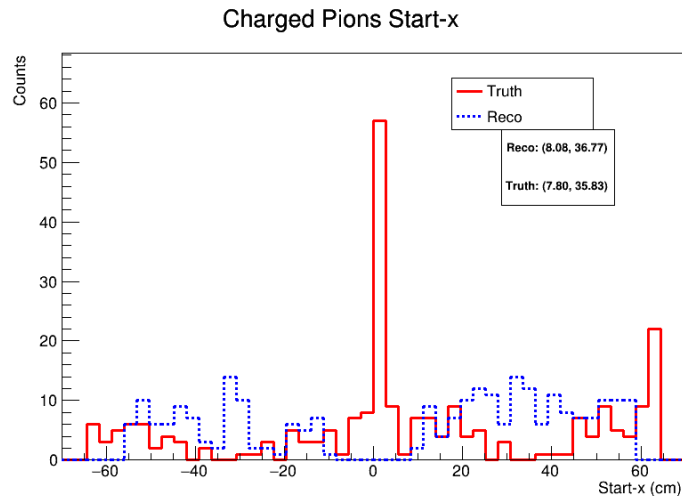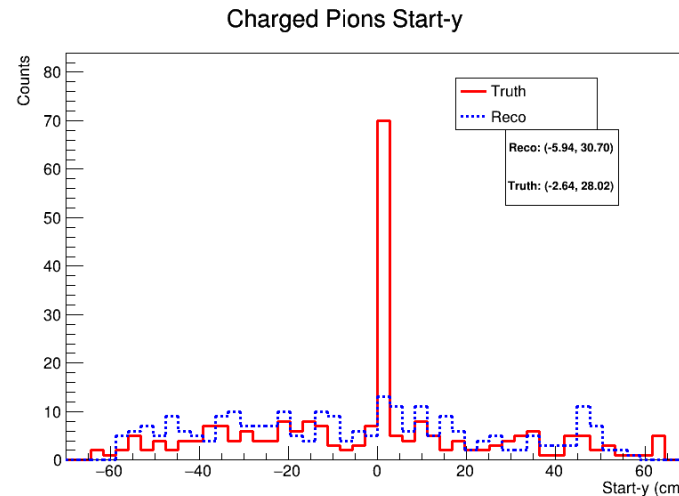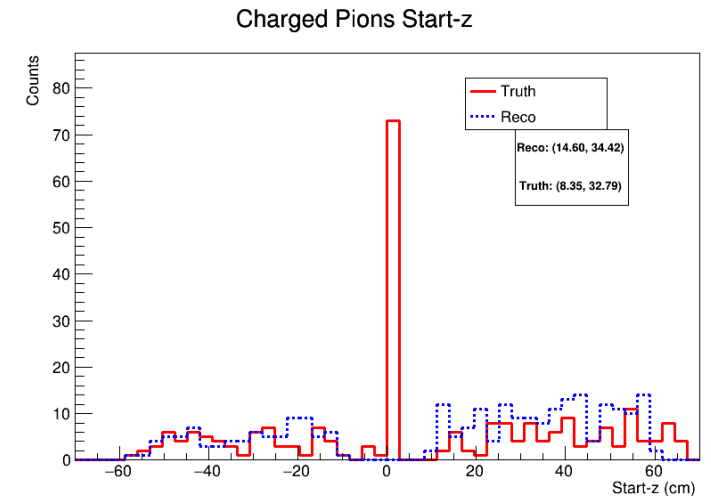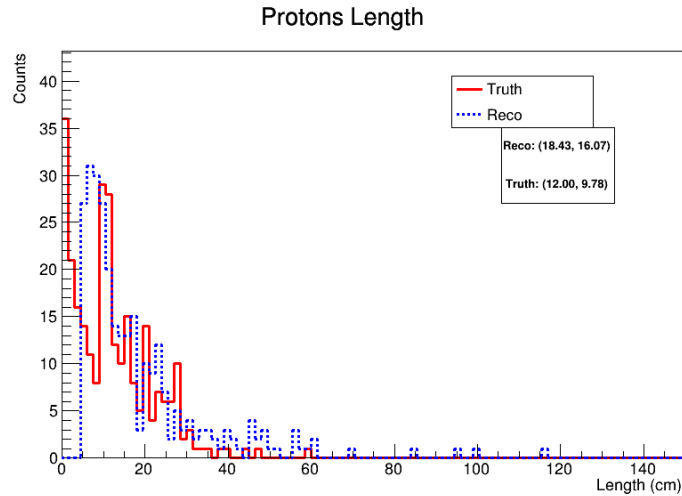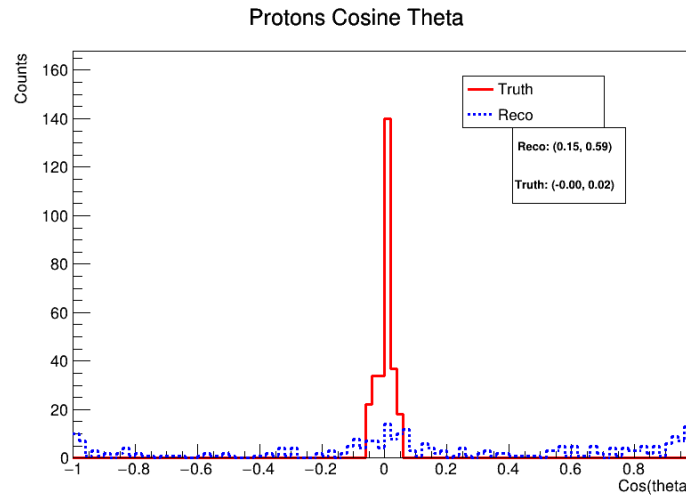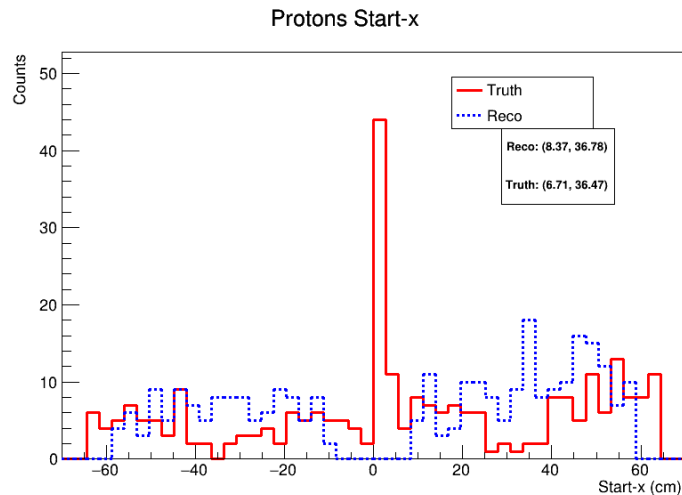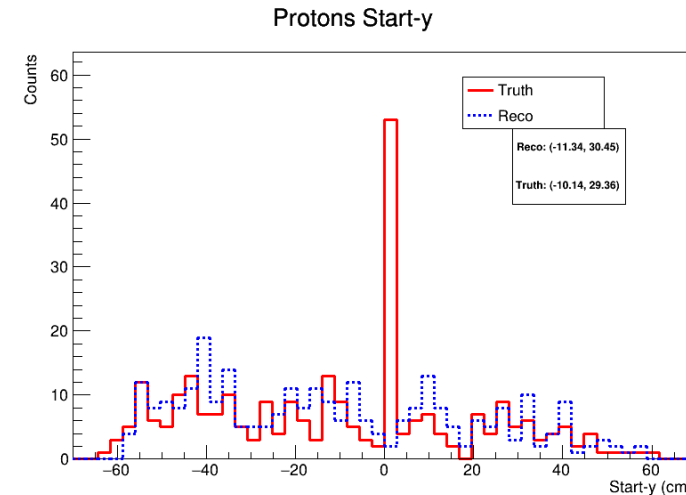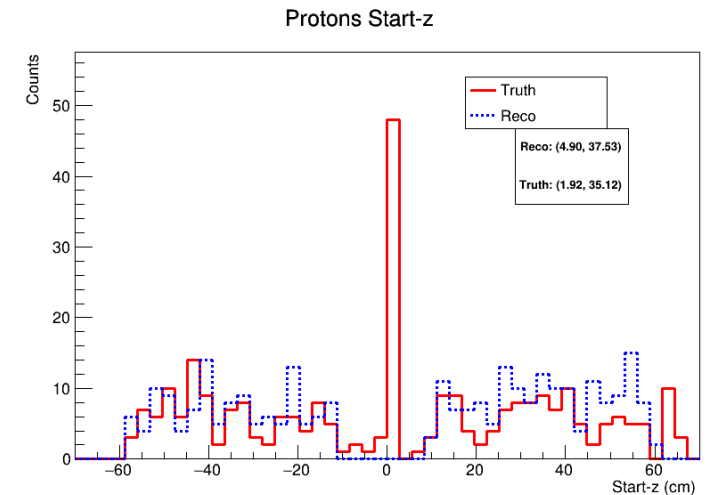
➢ Start-x

Protons Start-x

➢ Start-y

Protons Start-y

➢ Start-z

Protons Start-z

Summary

➢ We studied the 2x2 multiplicity selection with MiniRun4.5 Beta3 Flat CAFs

➢ For CC interactions within LArFV, distance from outer walls is set to 5 cm in all directions and distance from inner boundaries is 10 cm along x and z.

➢ Both GENIE and ML-reco are matched to MINERvA as well.

➢ Nearly half of the events are found to be MINERvA-matched.

➢ Good agreement between Genie truth and ML-reco multiplicities.

➢ We further looked at individual distributions of muons, positive pions and protons under the same selection criteria and we find a good agreement between true and reco multiplicities within applied cuts (including track length > 5 cm).

➢ We further looked at some specific regions ($z > 60$ cm, $-5 < y < 5$ cm, and $\cos\theta \approx 0$) to better understand the features around peaks and for a better characterize the selection effect on these variables.

➢ There are zero truth entries to be understood.

➢ We will also provide feedback to ML-Reco group.

Backup Slides