

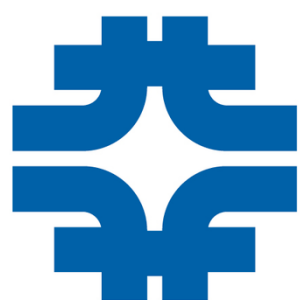
π^+ -Ar cross section measurement with 1 GeV test beam on ProtoDUNE

Yinrui Liu¹, Tingjun Yang²

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¹University of Chicago



²FNAL

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- Re-selection on Pandora-provided beam slices
- Data/MC difference in shower events

Thin slice method

Slice ID defined by the end Z position

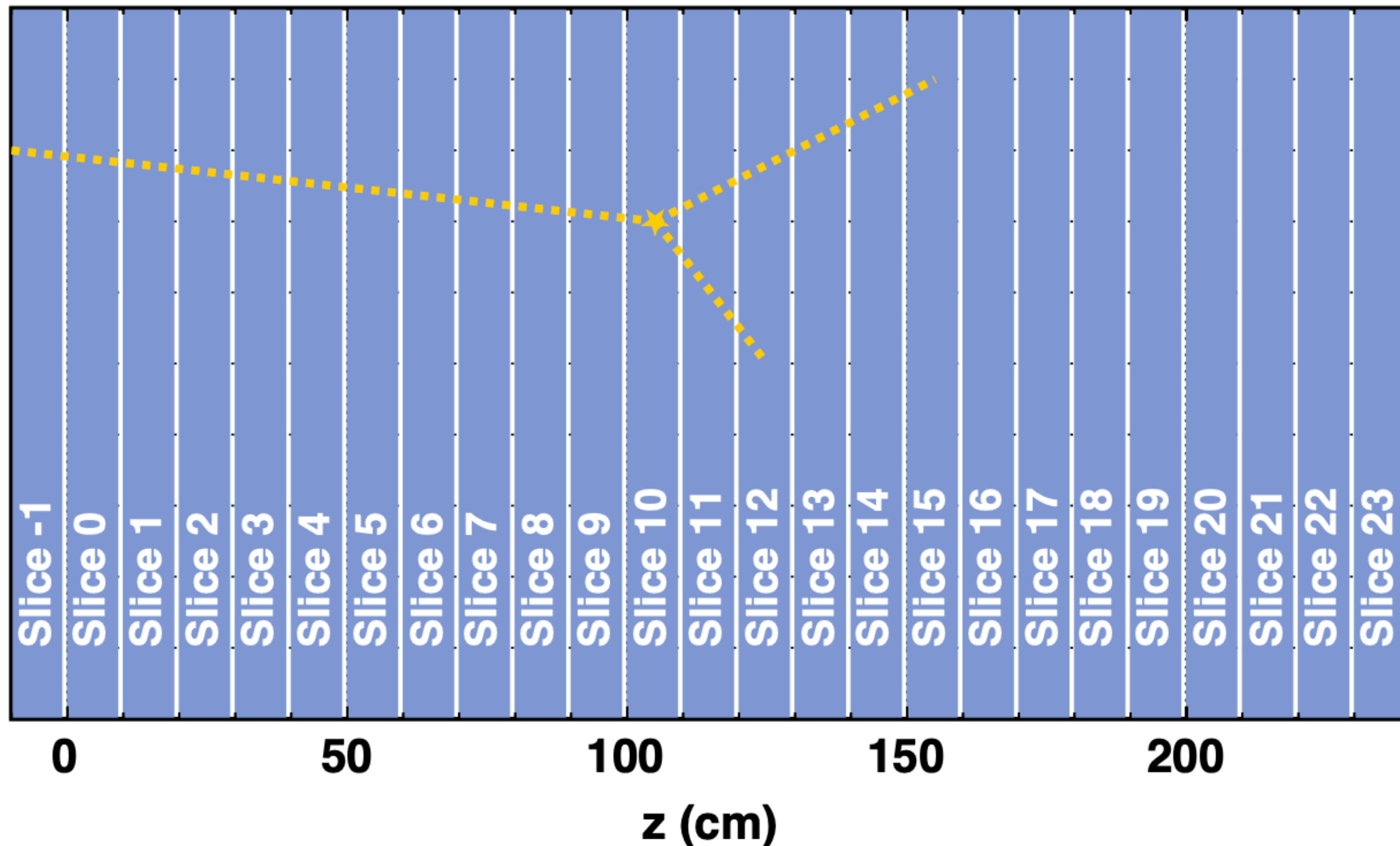


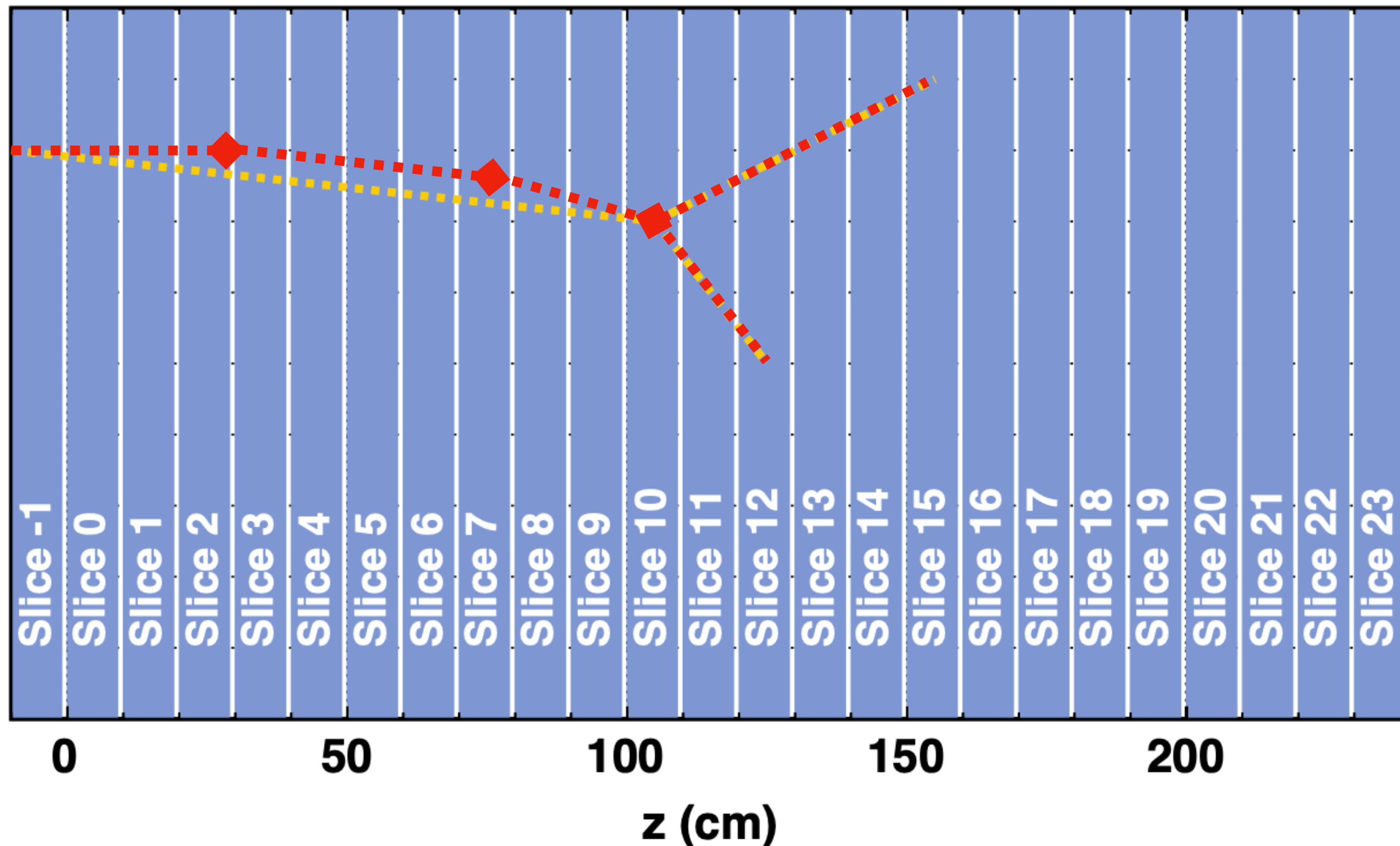
Figure credit: Jake Calcutt

$$\sigma = \frac{M_{\text{Ar}}}{\rho t N_A} \ln \left(\frac{N_{\text{inc}}}{N_{\text{inc}} - N_{\text{int}}} \right)$$

- N_{inc} is the number of incident events in the slice
- N_{int} is the number of events which have interactions in the slice
- $t = t_0 / \cos \theta$, where t_0 is the thickness of slice (10 cm) and $\cos \theta$ is the angle-correction factor
- ρ is the density of argon
- M_{Ar} is the mass of argon atom
- N_A is the Avogadro constant

Thin slice method

Slice ID defined by the end Z position

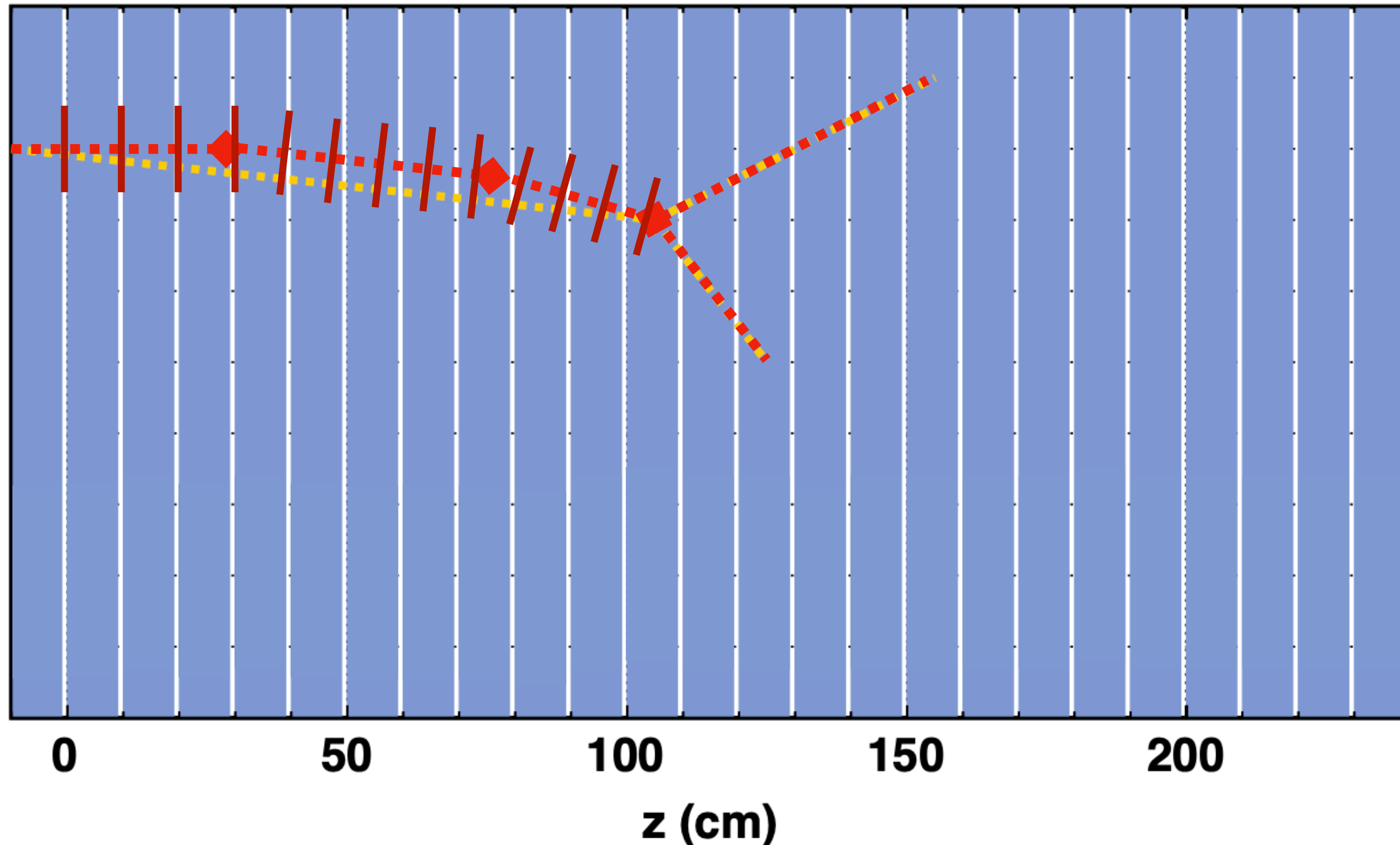


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Thin slice method

Slice ID defined by the track length

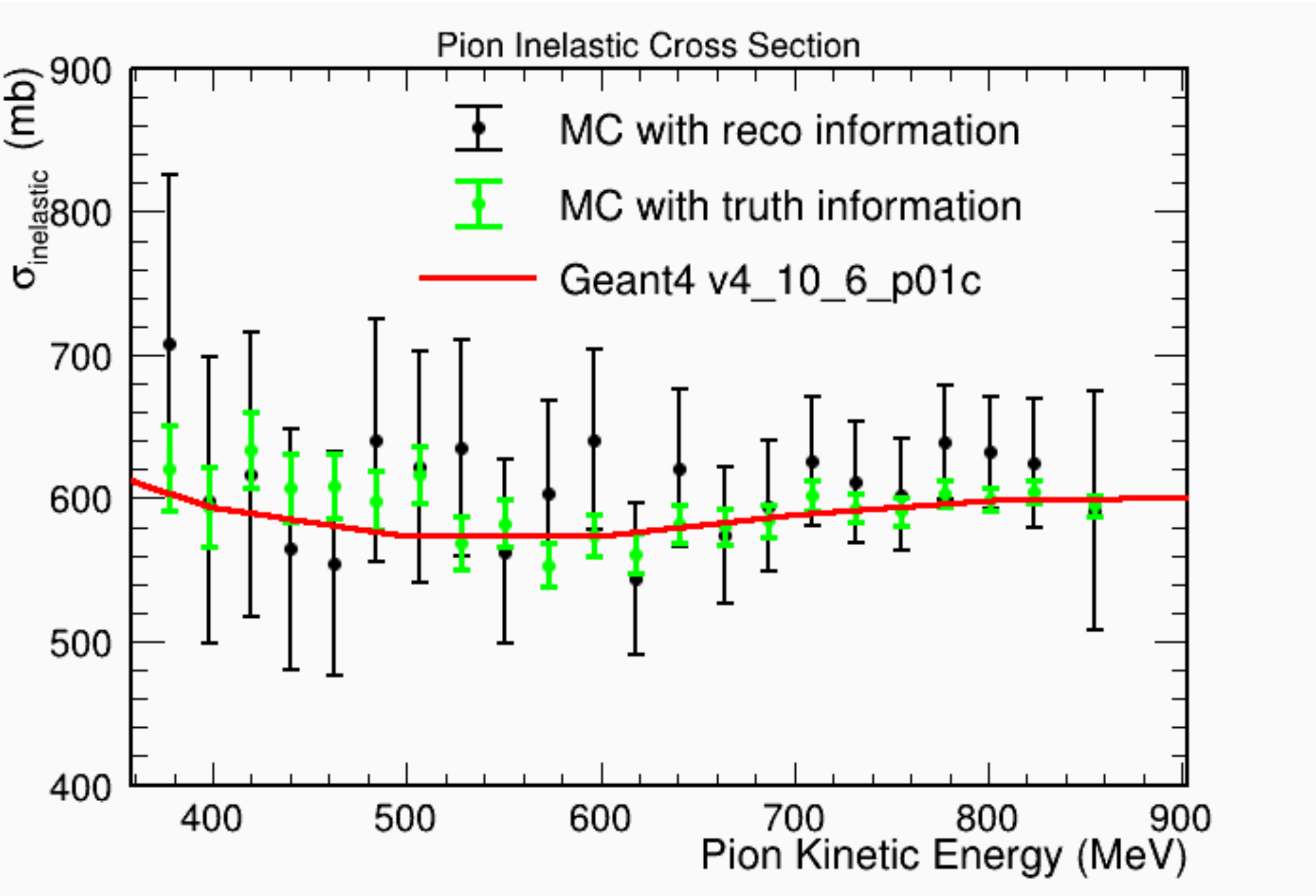


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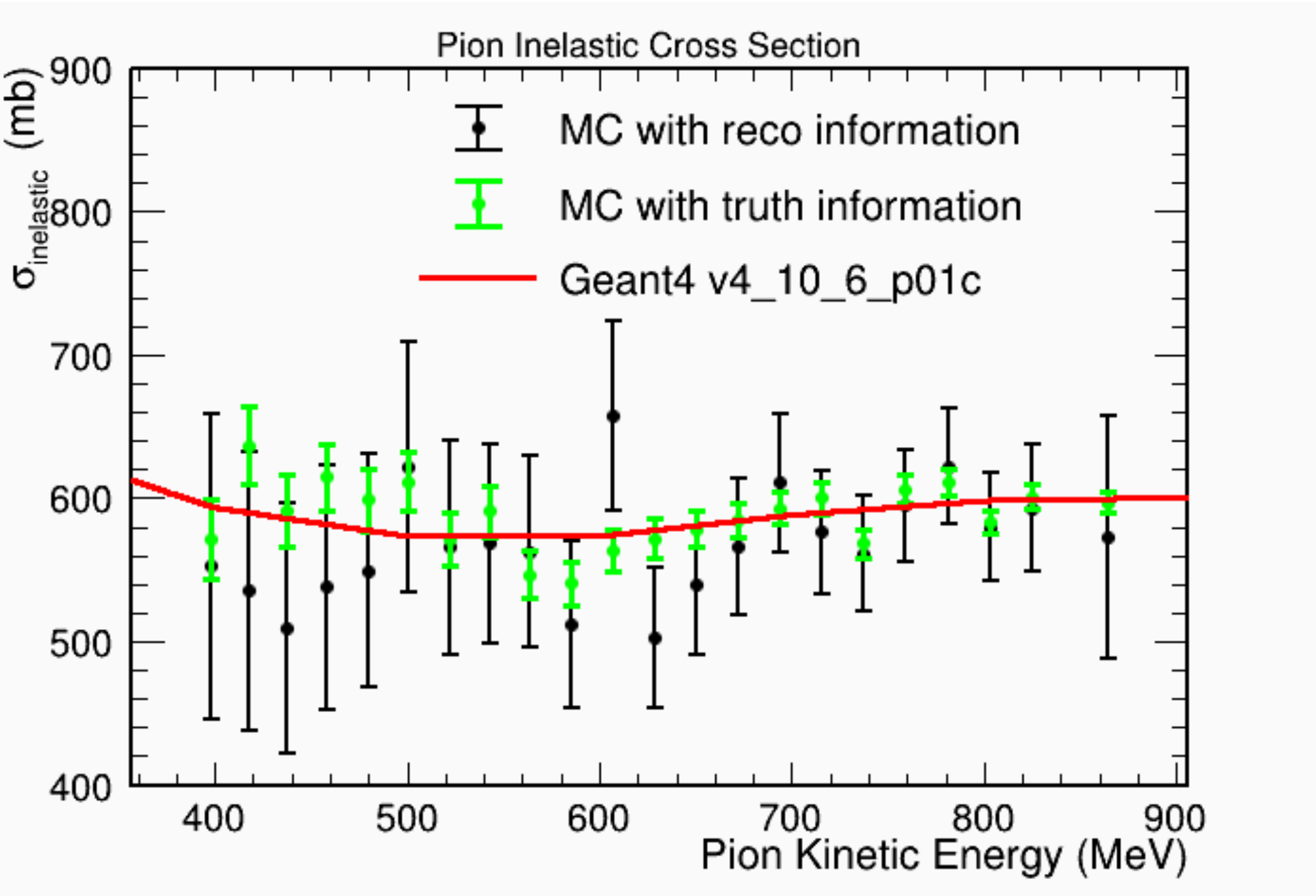
- N_{inc} is the number of incident events in the slice
- N_{int} is the number of events which have interactions in the slice
- $t = t_0$, which is the thickness of slice (10 cm)
- ρ is the density of argon
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Definition of slice ID

Dataset: Run 5387, 1 GeV



Slice ID defined by end Z position



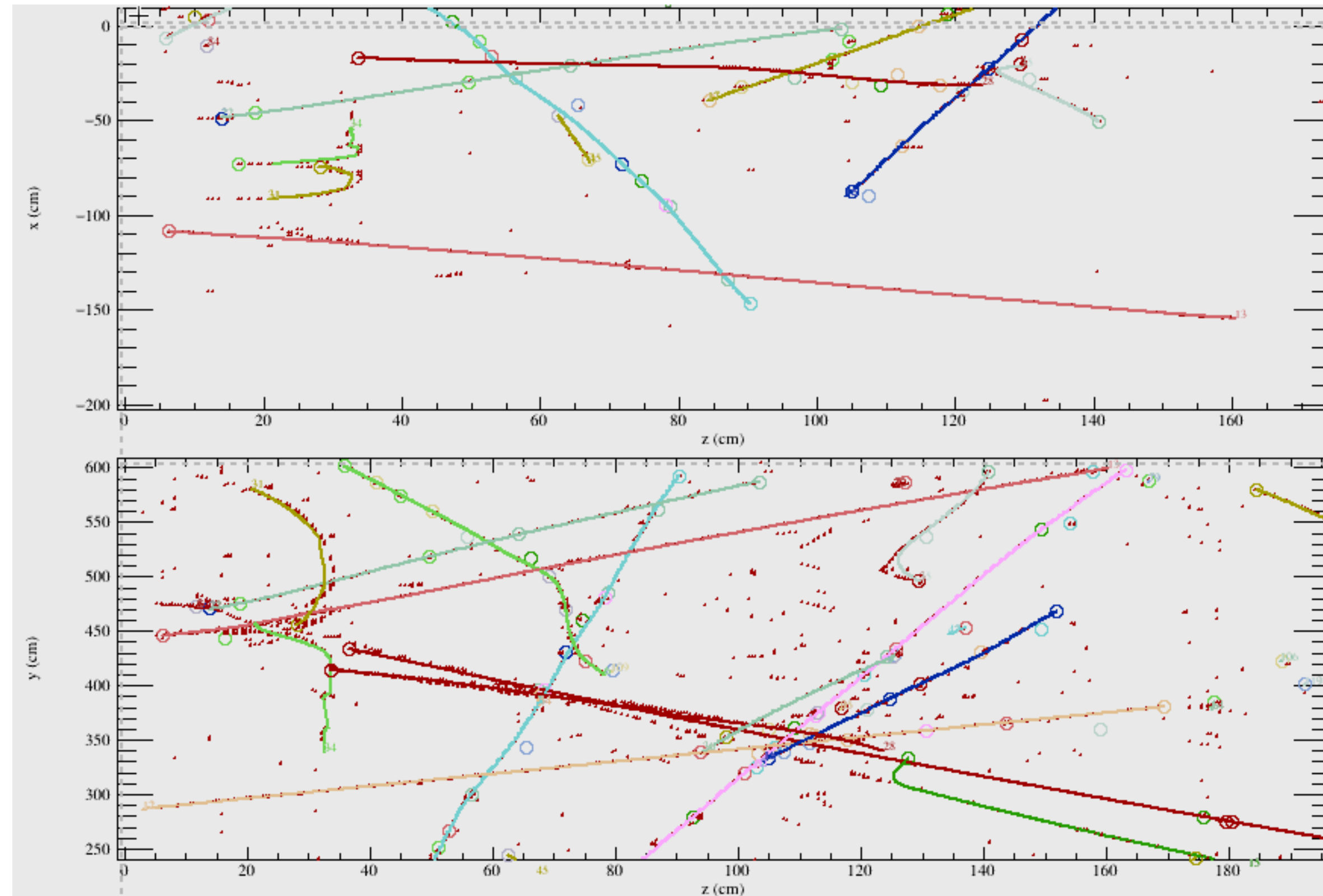
Slice ID defined by track length

Re-selection on beam slices

- In some events, the beam track given by Pandora is obviously wrong (such as the reconstructed entering position is far away from the beam plug)
- And sometimes, there is a visible real beam in such event.

A data event display

The light-red track is given by Pandora as the beam slice, while the dark-red one seems to be the real beam.

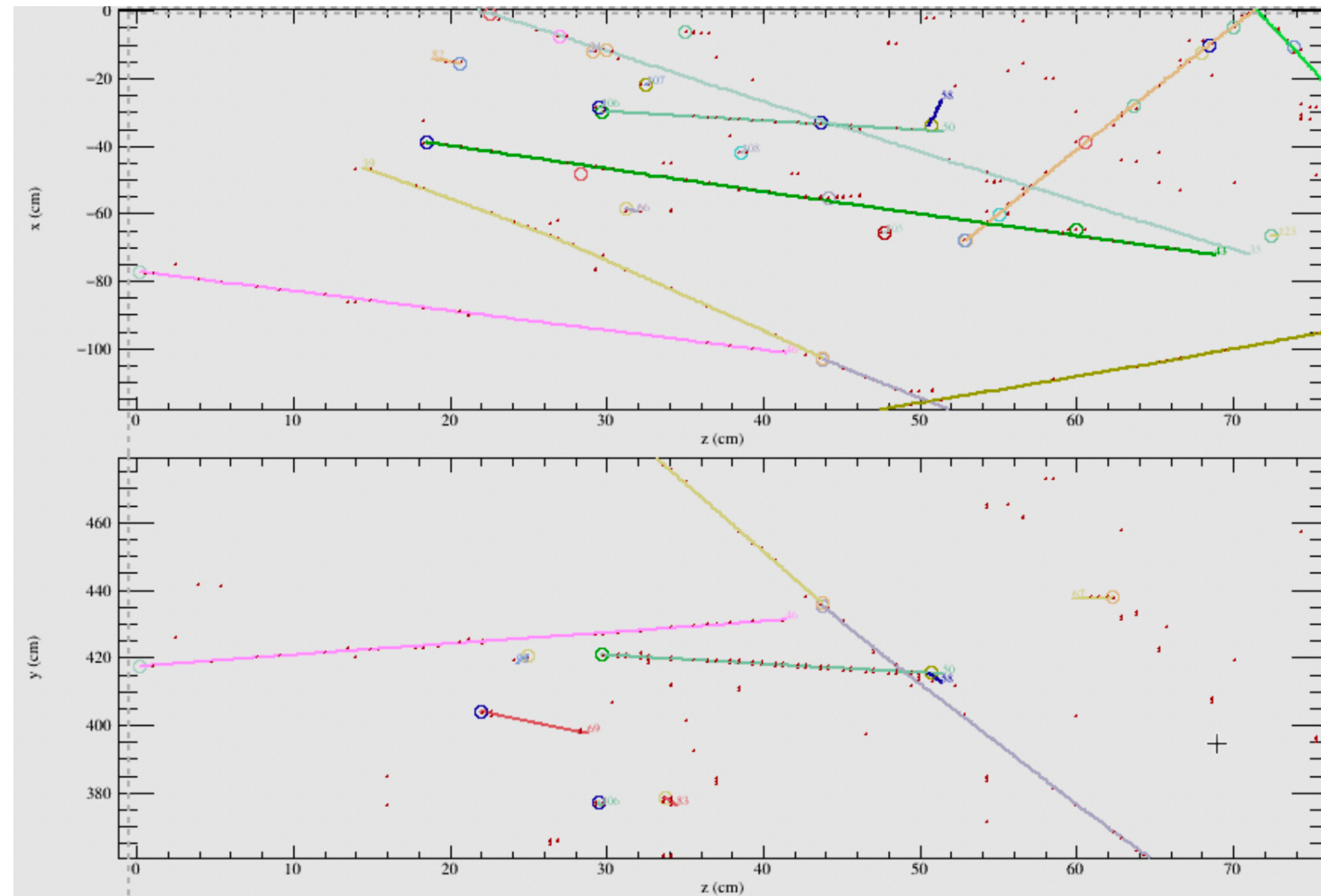


Data Run 5387 EvtNo.2852 (zoomed)

```
lar -c evd_protoDUNE_data.fcl /pnfs/dune/tape_backed/dunepro/protodune-sp/full-reconstructed/2021/detector/physics/PDSPProd4/00/00/53/87/  
np04_raw_run005387_0002_dl10_reco1_13833678_0_20201109T221815Z_reco2_21291447_0_20210619T145042Z.root
```


A MC event display

The pink track is given by Pandora as the beam slice, while the dim-green one is the real beam.



MC Run 18804220.10 EvtNo.500 (zoomed)

lar -c evd_protoDUNE_refactored.fcl /pnfs/dune/tape_backed/dunepro/protodune-sp/full-reconstructed/2021/mc/out1/PDSPPProd4a/18/80/42/20/
PDSPPProd4a_protoDUNE_sp_reco_stage1_p1GeV_35ms_sce_datadriven_18804220_49_20210415T181816Z.root

Re-selection on beam slices

- In each event, Pandora can provide some beam track candidates (mostly only one, sometimes two or more)

reco file	total events	0 slices	1 slices	2 slices	3 slices
np04_raw_run005387_0002_dl10_reco1_13833678_0_20201109T221815Z_reco2_21291447_0_20210619T145042Z.root	136	80	55	1	0
np04_raw_run005387_0006_dl6_reco1_13832072_0_20201109T214811Z_reco2_21291345_0_20210619T145043Z.root	133	96	35	2	0
np04_raw_run005387_0008_dl4_reco1_13832576_0_20201109T215211Z_reco2_21291185_0_20210619T144846Z.root	133	71	59	2	1

- We want to resume some real beam tracks from these events with more than one candidates by adding a re-selection.
 - A possible selection: we choose the beam candidate whose start Z position (before SCE correction) is the nearest to 30 cm (smallest $\text{abs}(z-30)$)

Number of data events after each cut

Number of data events	Original	Re-selected
No cut	18556	18556
Pandora slice cut	14216	14227
Calo size cut	13847	13866
Beam quality cut	9568	9871
APA3 cut	7195	7475
Michel score cut	7030	7307
Median dE/dx cut	6648	6908

- With the re-selection, we gain $6908/6648 - 1 \approx 3.9\%$ events after full selections in Run 5387.

Ratio of truth-matched MC events

- I only looked at three MC runs.
- Matched/mis-matched is judged by *reco_beam_true_byE_matched*
<https://wiki.dunescience.org/wiki/PDSPAnalyzer>

Matched/mis-matched	Original	Re-selected	
Run 18804220	394/283	401/276	1.0% more events are matched
Run 18815590	381/268	392/257	1.7% more events are matched
Run 43491284	391/272	405/258	2.1% more events are matched

Data/MC difference in shower-track ratio

- Pandora tags an event either track-like or shower-like.
- We used to require an event to be track-like (Pandora slice cut) before adding other selections
- However, we found there are fewer shower-like events in MC than data
 - In data, shower/track = $643/14208 \approx 0.0453$
 - In MC, shower/track = $258/8485 \approx 0.0304$
- So I remove the requirement on tracks, and see how the other selections act on shower/track
 - BeamForcedTrackInfo()
 - allTrack variables

Number of events left after each cut

Num. of evt left	Data (track-only)	MC (track-only)	Data (forced-track)	MC (forced-track)
No cut	18535	18535	18535	18535
Pandora slice cut	14208	15696	14851	16208
Calo size cut	13847	15391	14407	15833
Beam quality cut	9859	11192	9932	11262
APA3 cut	7469	9110	7542	9178
Michel score cut	7301	8941	7372	9011
Median dE/dx cut	6904	8577	6947	8615

Shower/track after each cut

Shower/track	Data (forced-track)	MC (forced-track)
No cut	643/14208 \approx 0.0453	258/8485 \approx 0.0304
Pandora slice cut		
Calo size cut	560/13847 \approx 0.0404	228/8324 \approx 0.0274
Beam quality cut	73/9859 \approx 0.0074	26/6126 \approx 0.0042
APA3 cut	73/7469 \approx 0.0098	26/4993 \approx 0.0052
Michel score cut	72/7300 \approx 0.0099	26/4890 \approx 0.0053
Median dE/dx cut	44/6903 \approx 0.0064	21/4667 \approx 0.0045

Summary

- We now define slice ID based on track length.
- By adding a re-selection to Pandora-provided beam slices, we can resume ~5% beam events.
- The current selections can remove shower-like events to a low level ($<1\%$), so their impact on data/MC can be ignored.

Back-up

Selection for π^+ beams

- Pandora Slice Cut: need Pandora-tagged track rather than shower or empty
- Calo Size Cut: require at least one hit detected by wires in the collection plane
- Beam Quality Cut: cut on beam entrance location and beam angle (after SCE-correction)
- APA3 Cut: only use tracks in the first TPC (SCE-corrected end $Z < 220$ cm)
- Michel Score Cut: veto muon tracks according to Michel score at end vertex
- Median dEdx Cut: set upper limit on median dE/dx to veto proton background