Study of thin slice method

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ProtoDUNE Hadron Analysis Meeting

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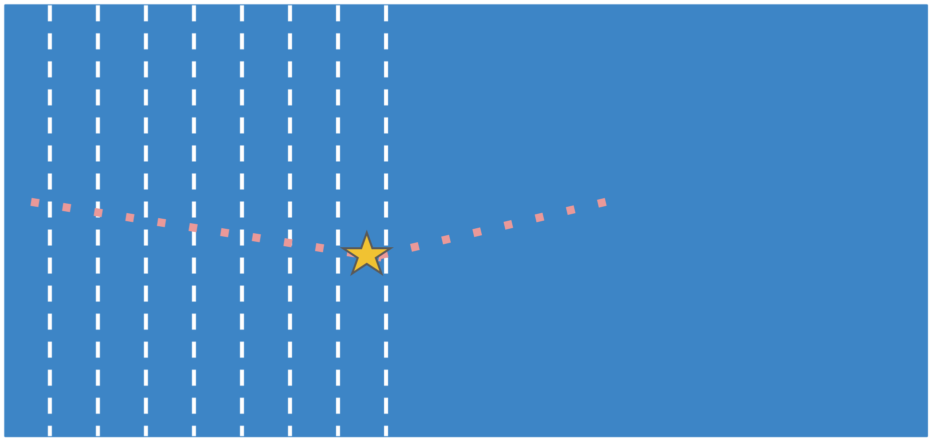
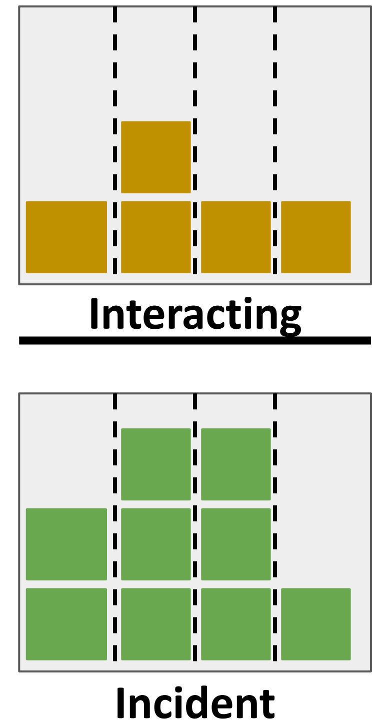
Introduction

- This talk summarizes the studies I did recently to understand the thin slice method.
- Most of the studies are done using the truth information. Reconstruction is used in obtaining some key information: thickness and pion energy of each slice.
- I would like to thank Libo Jiang, Jake Calcutt and David Rivera for helpful discussions.
  - The study was based on a ntuple Jake produced: /dune/data/users/calcuttj/pduneana_Prod4_1GeV_2_9_21.root
    - ~10% Prod4 1 GeV MC.
    - Ntuple format

The Thin Slice Method



$\sigma \sim$



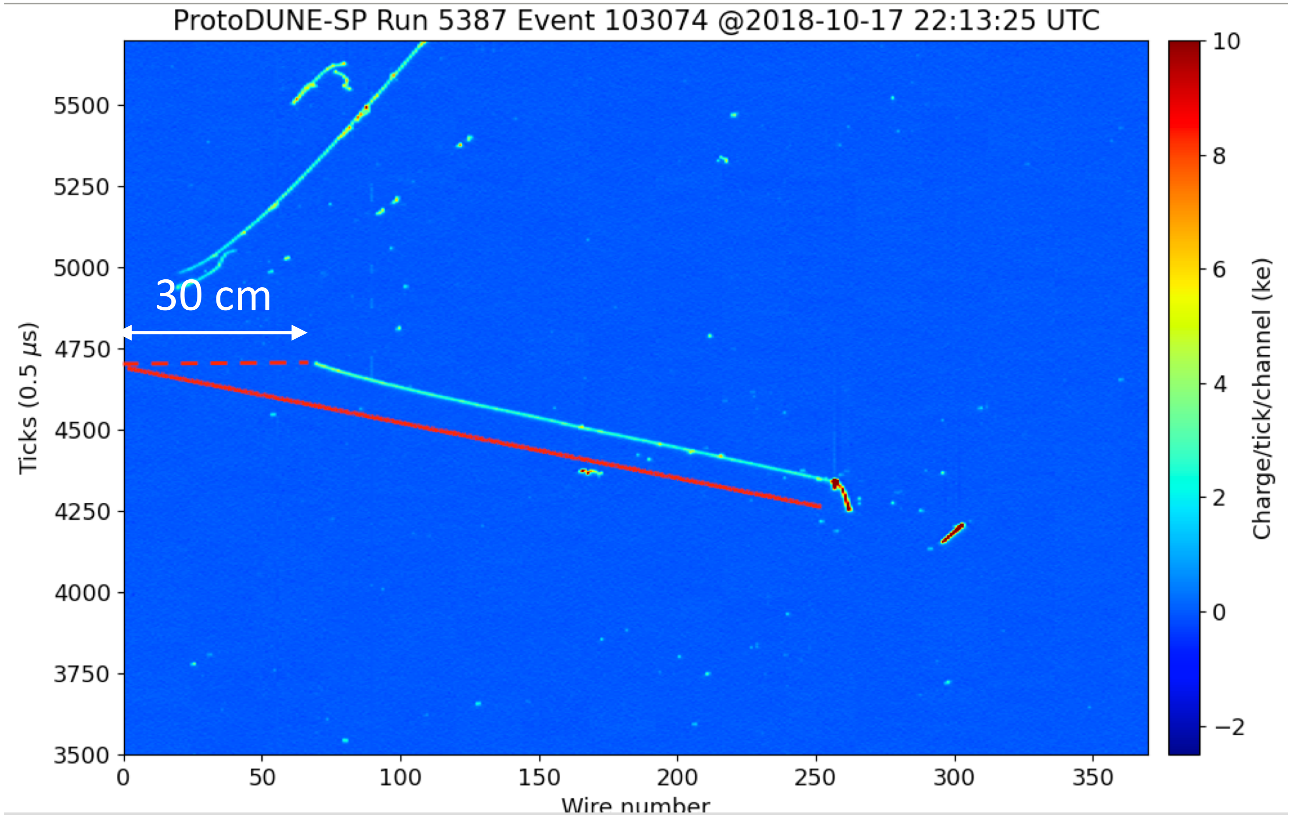
- Cross section is proportional to ratio: interacting/incident

$\sigma = (M_{Ar}/\rho t N_A) * (N_{Int}/N_{Inc})$

M_{Ar} -- Mass of Ar
t -- Thickness of slice
ρ -- Density of Ar

Credit: Jake Calcutt
Ref: LArIAT

Challenge for ProtoDUNE



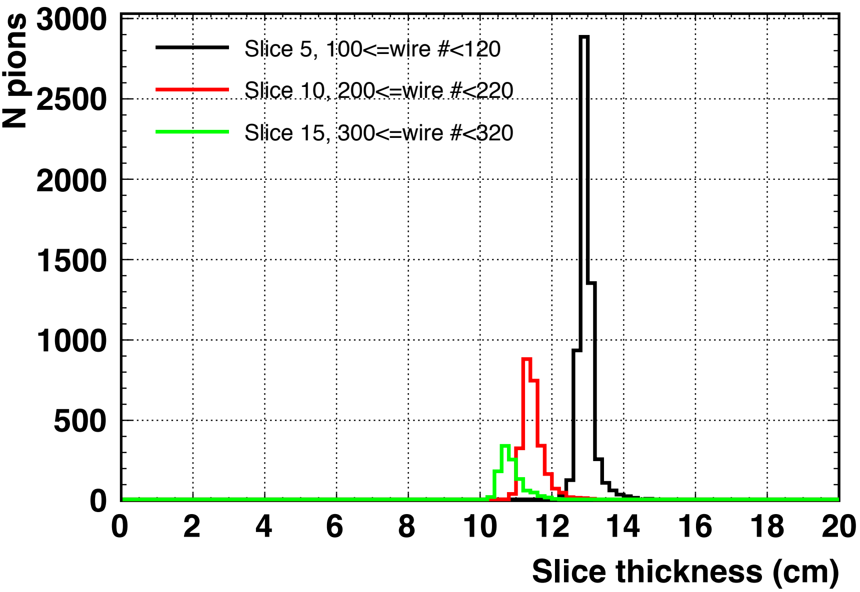
Credit: [Francesca Stocker]

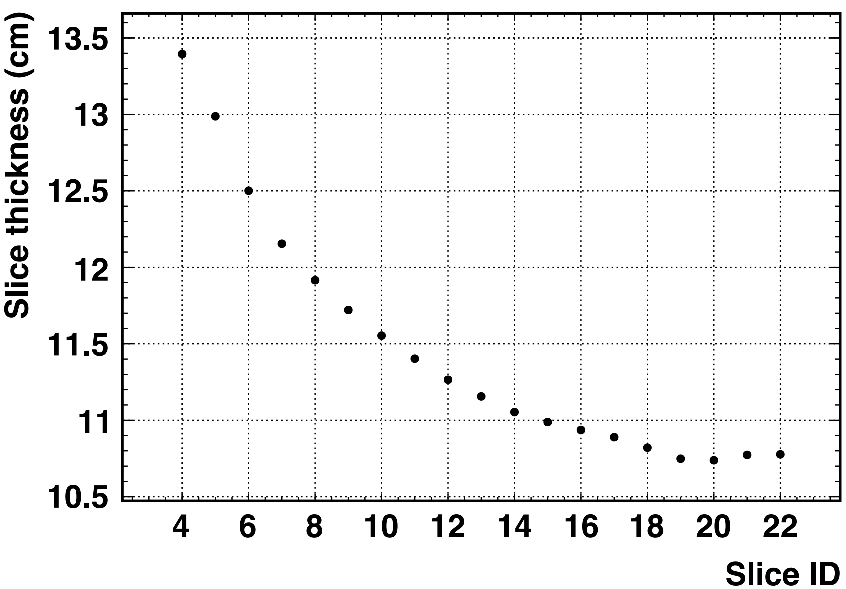
- ProtoDUNE sees a large spatial distortion due to space charge effects:
  - This complicates the calculation of slice properties

Some assumptions

- The slice thickness does not need to be a constant
  - Each slice can be considered as an independent experiment
- We define each slice to have 20 wires
  - The slice thickness is bigger near the TPC front face due to SCE
- If a pion interaction occurs at slice i, it must have gone though all the previous slices
- All pions go through roughly the same amount of LAr in each slice:
  - Beam angle is roughly a constant
- All pions have roughly the same energy when reach a particular slice:
  - Beam momentum and dE/dx are roughly constants
- Slice thickness and pion energy in each slice are slice properties and can be calculated using many pions.

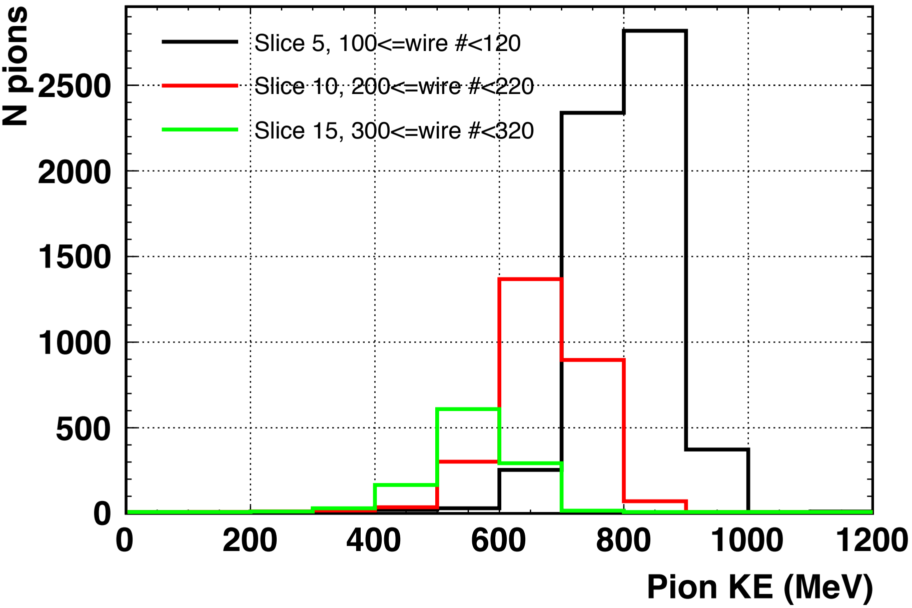
Slice thickness

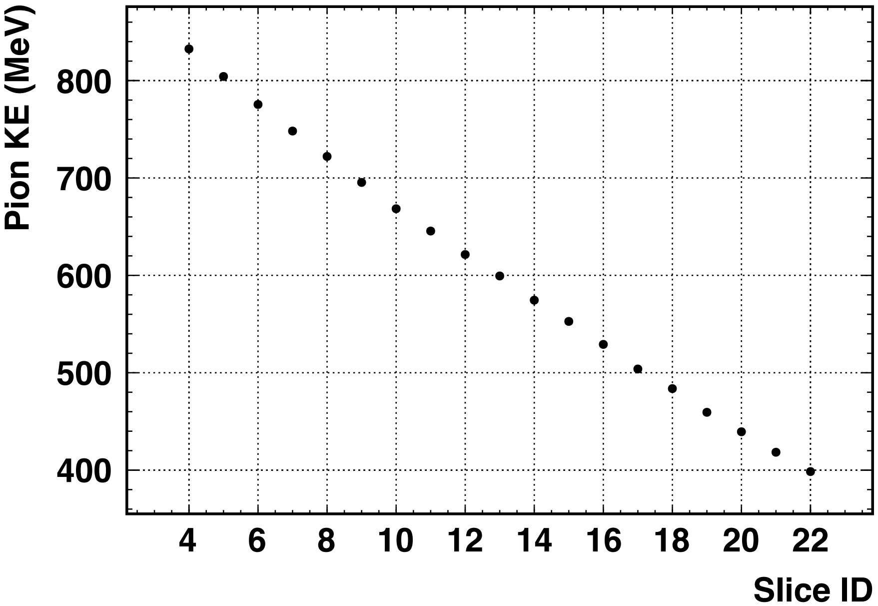




- Slice thickness is calculated using track pitch information in the calorimetry data product after SCE correction.
  - Ref: [Space Charge Corrections to Calorimetry]
- The first 4 slices (80 wires) are ignored due to the spatial distortion of the pion track.

Pion energy in each slice





- Pion kinetic energy in each slice is calculated using calorimetry information:
  - $KE = KE_0 - \sum \frac{dE}{dx} \Delta x$
  - KE_0 is the initial beam energy, dE/dx is the energy loss on each wire

Counting experiment

- Only select true pion events
- If the pion end process is “pi+Inelastic”, find the true end point, apply the SCE spatial distortion, and project the z position on the collection plane to get the wire number -> true slice ID.
- Increment the interacting count at true slice ID.
- Increment the incident count for all previous slices (including the interacting slice).
- First measure the cross-section as a function of slice ID, and then convert the slice ID to pion KE.

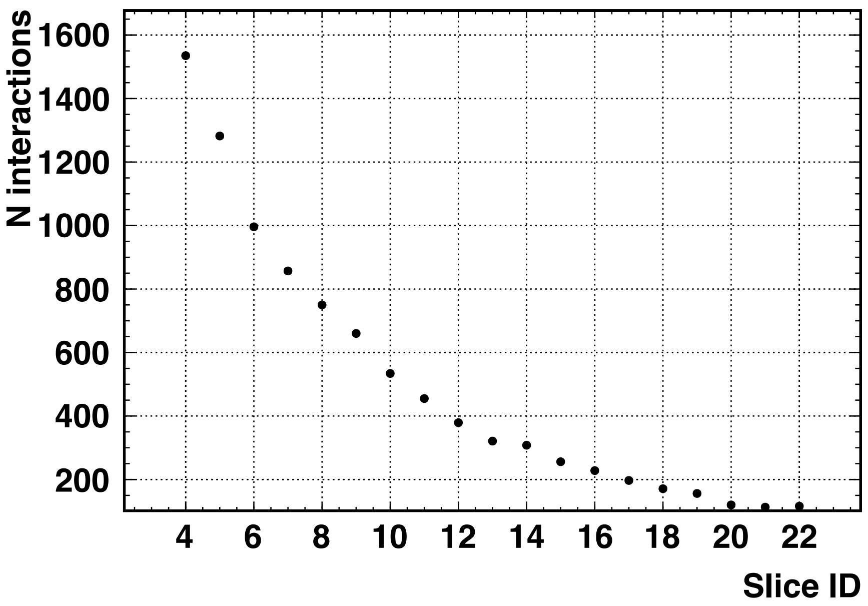
$$\sigma = (M_{Ar}/\rho t N_A) * (N_{Int}/N_{Inc})$$

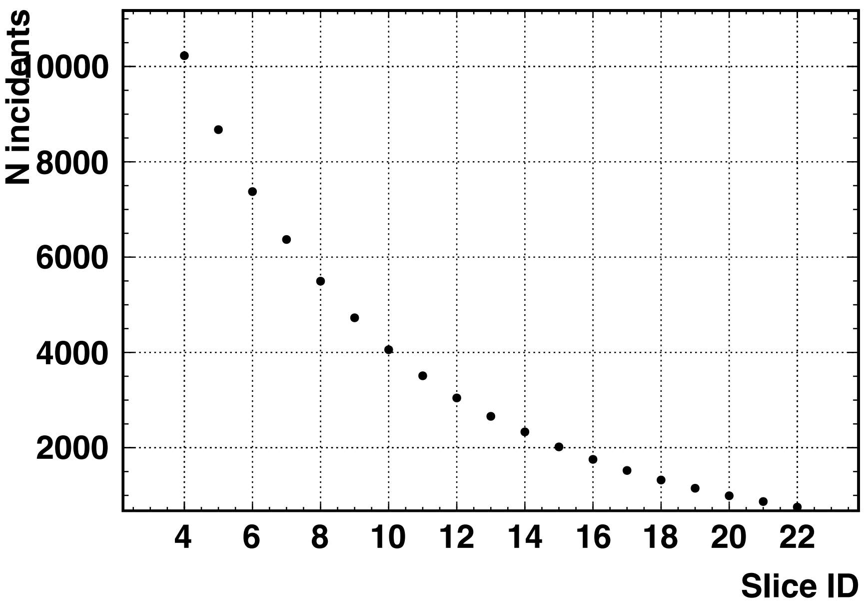
M_{Ar} -- Mass of Ar

t -- Thickness of slice

ρ -- Density of Ar

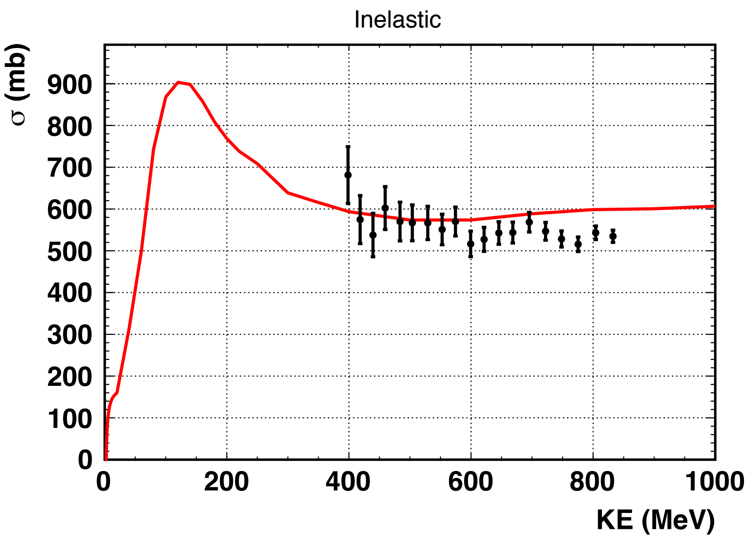
Interacting and incident counts

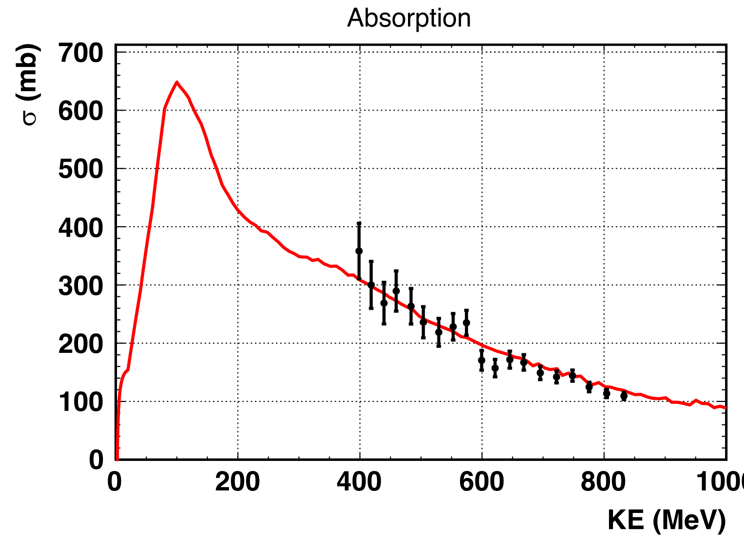


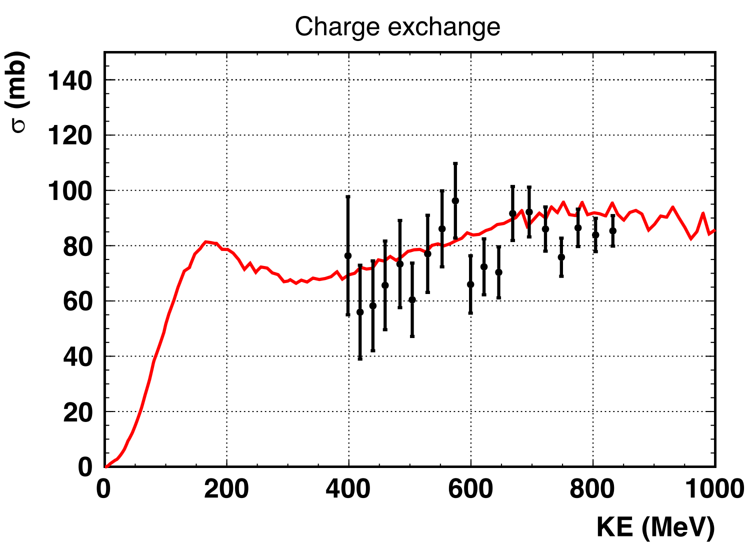


- Interaction here is defined as pion with end process "pi+Inelastic".

Cross sections

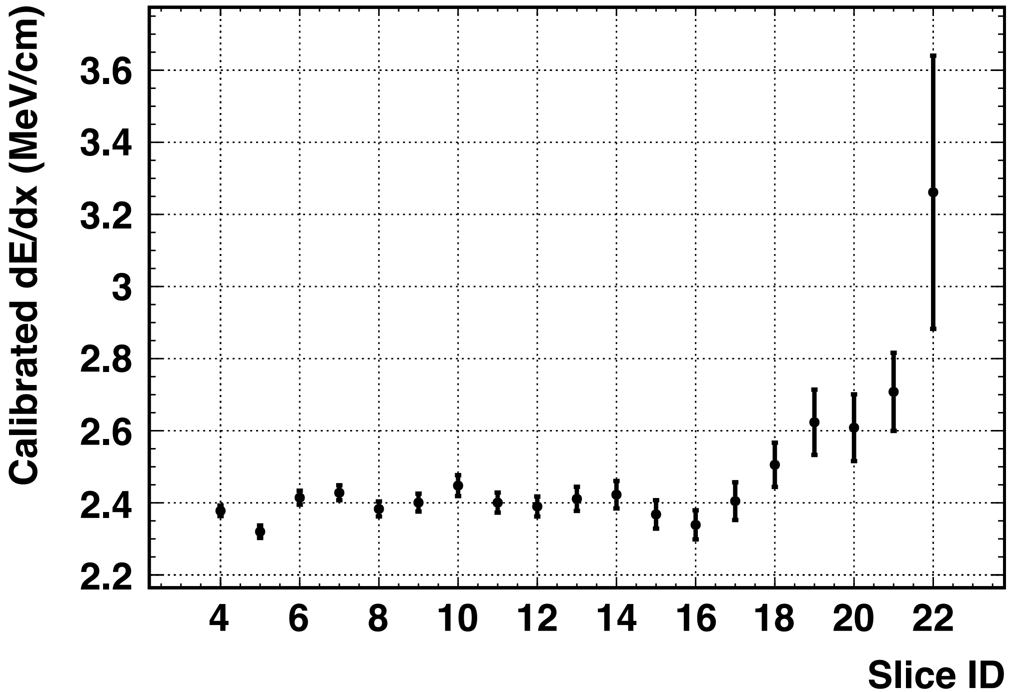






- Absorption = Inelastic with no pions in the final state
- Charge exchange = Inelastic with no $\pi^{\pm}$ and $1\pi^0$ in the final state
- Red curves: predictions provide by Jake
- **Discrepancy for inelastic at high KE**

Something wrong with slice thickness?

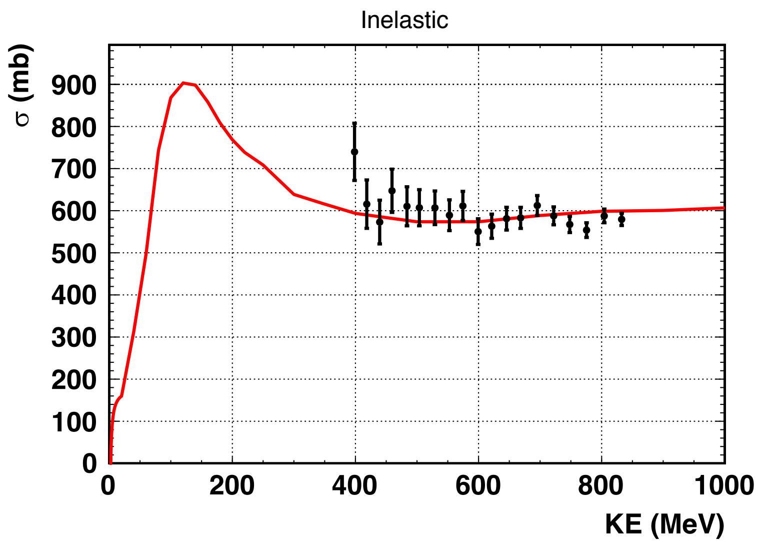


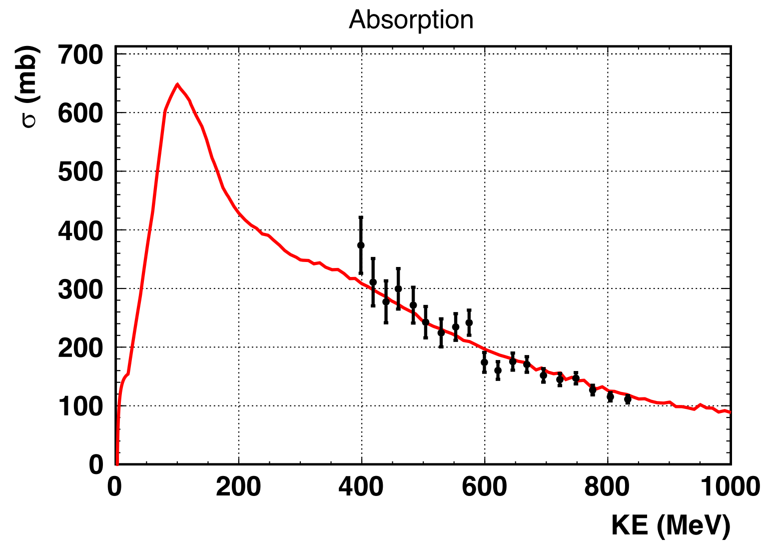
- Motivated by Francesca's study, I looked at dE/dx vs slice ID after SCE correction.
  - It looks flat up to slice 17.
  - This indicates the pitch/thickness is correctly calculated.

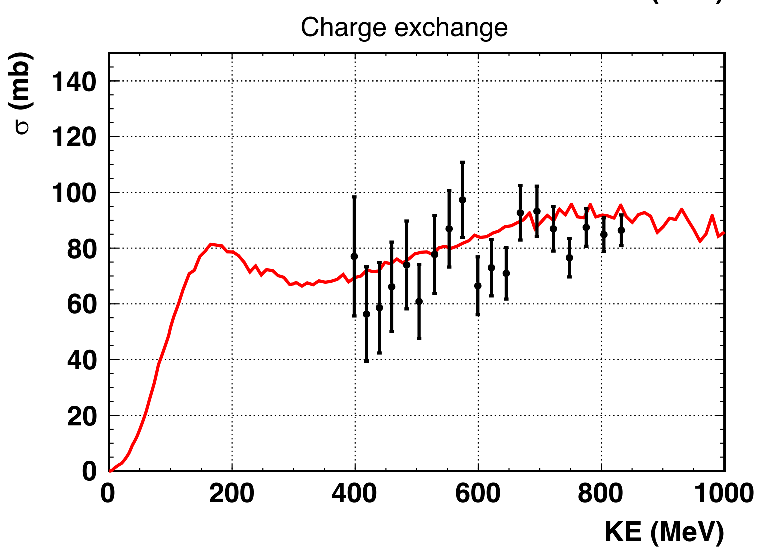
Approximation in thin-slice method

- Generally the survival probability of a pion traveling through a thin slab of argon is given by:
  - $P_{survival} = e^{-\sigma n t}$
  - where $n = \rho N_A / M_{Ar}$, $P_{survival} = \frac{N_{inc} - N_{int}}{N_{inc}}$
- This gives a more accurate calculation of the cross section
  - $\sigma = \frac{M_{Ar}}{\rho t N_A} log\left(\frac{N_{inc}}{N_{inc} - N_{int}}\right)$
- If $N_{int} \ll N_{inc}$, this gives the approximation
  - $\sigma = \frac{M_{Ar}}{\rho t N_A}\left(\frac{N_{int}}{N_{inc}}\right)$

Cross sections







- Using the more accurate formula improves the agreement with theory.
- The changes are smaller for small cross sections (abs, cex).

Conclusions

- We can calculate cross sections using the thin slice method
  - Slice thickness and pion energy using reconstructed information
  - Interacting point using the true pion end point
- For a real measurement, we need to apply corrections using MC
  - Efficiency
    - Reconstruction (Pandora beam tagging, track reco etc.)
    - Interaction selection
  - Background
    - Mis-reconstruction
    - Mis-selection
    - Muons
- This method also provide a way to measure differential cross section at each slice (for a given pion KE).
- With information in the first TPC, we can approach pion at 400 MeV. If we can use information in the second TPC, we can measure lower KE.