THE E-SLICE METHOD – IMPROVING THE THIN SLICE METHOD FOR LAR TPC'S

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ProtoDUNE Hadron Analysis Meeting

Feb 18, 2021

Introduction

- ProtoDUNE beam particles are affected by space charge distortions
- XS calculations with the geometrical thin slice method are affected
  - *Tingjun's study of the Thin Slice Method cuts away the first 80 wires (~100MeV) due to spatial distortions*
- The E-Slice Method works in the energy phase space and thus avoids introducing the spatial distortions in the XS measurement
- Studies are based on Jakes PDSP_Analyzer ntuple
- TODAY MC true variables on full Prod4 sample
- The Method was developed at CERN by Francesco Pietropaolo, Stefania Bordoni and myself
  - *Thanks to Jake Calcutt and Kendall Mahn for fruitful discussions and help for validating the method*

Thin Slice → E-Slice Derivation

- Probability of Pion interacting within a slab
  - $P_{interaction} = \sigma n \mathrm{d}x$
- Change of N_π after going through a slab is initial number of pions multiplied by interaction Probability
  - $\mathrm{d}N_\pi = -N_\pi \sigma n \mathrm{d}x$
- **Interested in pion loss $\mathbf{d}\boldsymbol{N_\pi}$ after interaction wrt to deposited energy $\mathbf{dE}$**
  - *Using precise knowledge of dE/dx we can do the following*
  - $\frac{\mathrm{d}N_\pi}{\mathrm{d}E} = \frac{\mathrm{d}N_\pi}{\mathrm{d}x}\frac{\mathrm{d}x}{\mathrm{d}E} = -N_\pi \sigma \rho \frac{N_A}{A}\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^{-1}$
- Measurement of any XS is done as function of kinetic energy, d → Δ
  - $\frac{\Delta N_\pi}{\Delta E} = N_\pi \sigma \rho \frac{N_A}{A}\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^{-1}$
- The number of interacting pions is now in ΔN_π for the deposited energy ΔE

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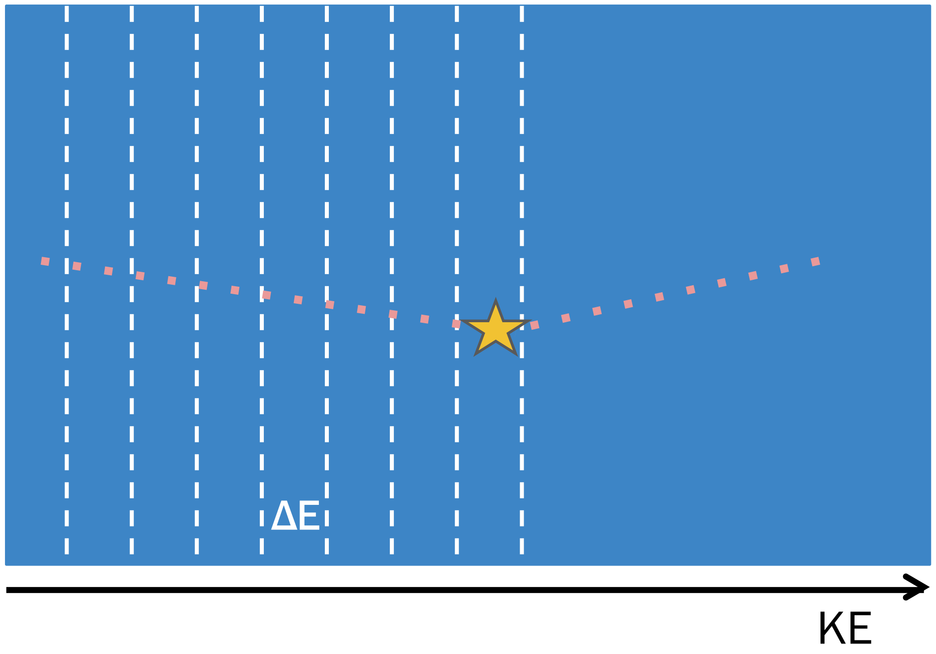
- The number of interacting pions is now in ΔN_π for the deposited energy ΔE
  - *The classic thin slice introduces the wire pitch through associating ΔE with energy deposited per slab*
  - *BUT we don't have to use the slab thickness (affected by SCE, uncertainty!) at all, we can just remain in the energy phase space*
  - $\mathbf{\Delta E}$ *is just the **energy bin** in which we measure ☺*
- **The XS is measured as**

$$\sigma(E_i) = \frac{A}{N_A \rho \Delta E} \frac{dE}{dx}(E_i) \frac{N_{\pi Interacting}(E_i)}{N_{\pi Incident}(E_i)}$$

Constant * Mean Energy Loss at Bin Energy E_i from Bethe Bloch * Ratio of Int and Inc Histogram

Thin Slice → E-Slice Derivation

Jake Calcutt



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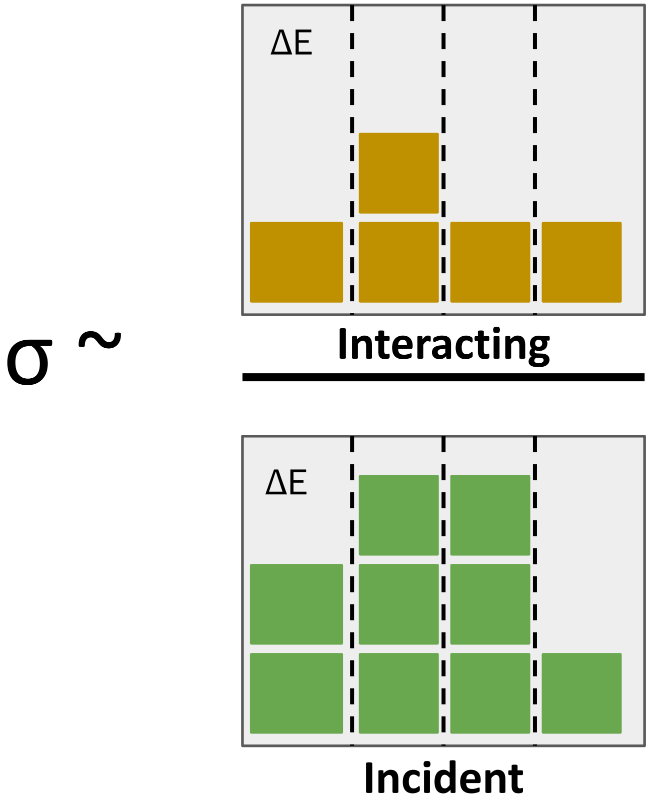


Assumptions

- The E-slice thickness is chosen to be **constant**
  - *Each slice can be considered as an independent experiment*
  - *If low statistics (for lowE for example) E-slice thickness can be varied*
- We define each slice to have 20 MeV
  - *The E-slice thickness is mostly insensitive to SCE (because recombination for beam particles varies little in beam region, lucky! → See Backup!)*
- If a pion interaction occurs at slice i, it must have gone though all the previous slices
- All pions have the same energy when reaching a particular slice
  - *Smearing only from Beam momentum and uncertainty in Beam plug E loss*
- Pion energy in each E slice is a slice property and can be derived on event-by-event basis
- dEdx can be derived using the bethe bloch formula for the mean energy loss at the corresponding pion kinetic energy
  - *dEdx vs range (PID) is excellent for ProtoDUNE → Performance Paper*

Validation with MC Prod4

- Using
  - */dune/data/users/fstocker/ANALYSIS/prod4_files/pionana_Prod4_mc_1GeV_1_14_21.root*
  - *Full Prod4 MC*
- True Interactions ”pi+Inelastic”
  - *Absorption = Inelastic with no pions in the final state*
  - *Charge exchange = Inelastic with no $\pi^{\pm}$ and $1\pi^{0}$ in the final state*
  - *Total Inelastic*
- True kinetic energy
  - *Initial*
  - *At interaction*

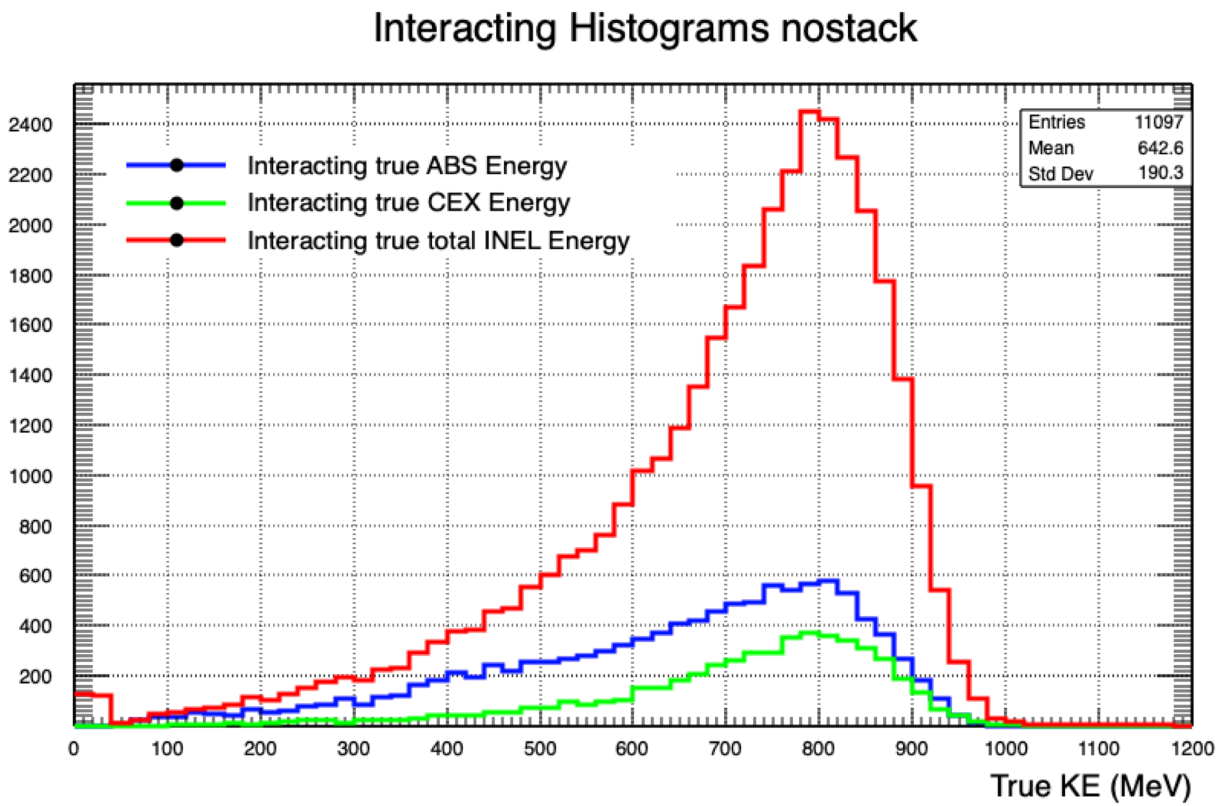
E slice – Validation in MC true Prod4

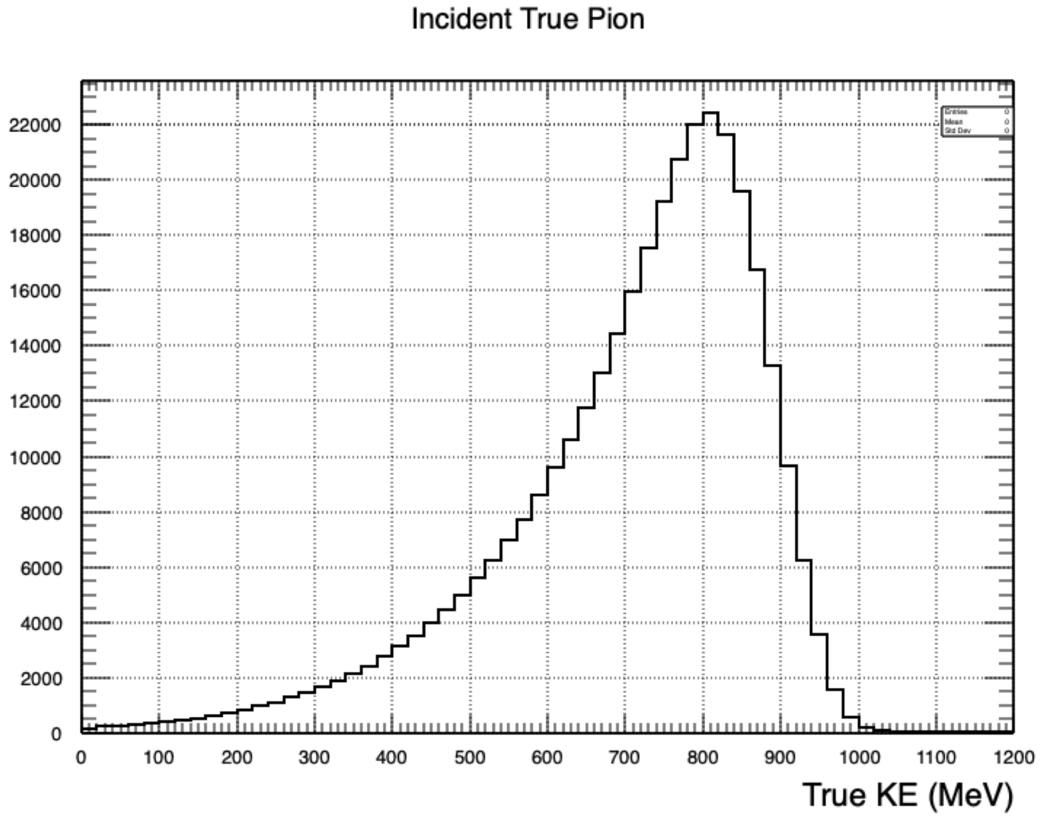
- E Slice thickness is constant
- E Slice thickness is calculated using Energy deposition information in the calorimetry data product
  - *Reminder: need to see how this is done in reco*
- Beam particles pass through a region where Efield variation from nominal is small and recombination variation negligible --> see Backup
  - *SCE corrections are not needed*

Incident and Interacting Histograms – MC true Prod4

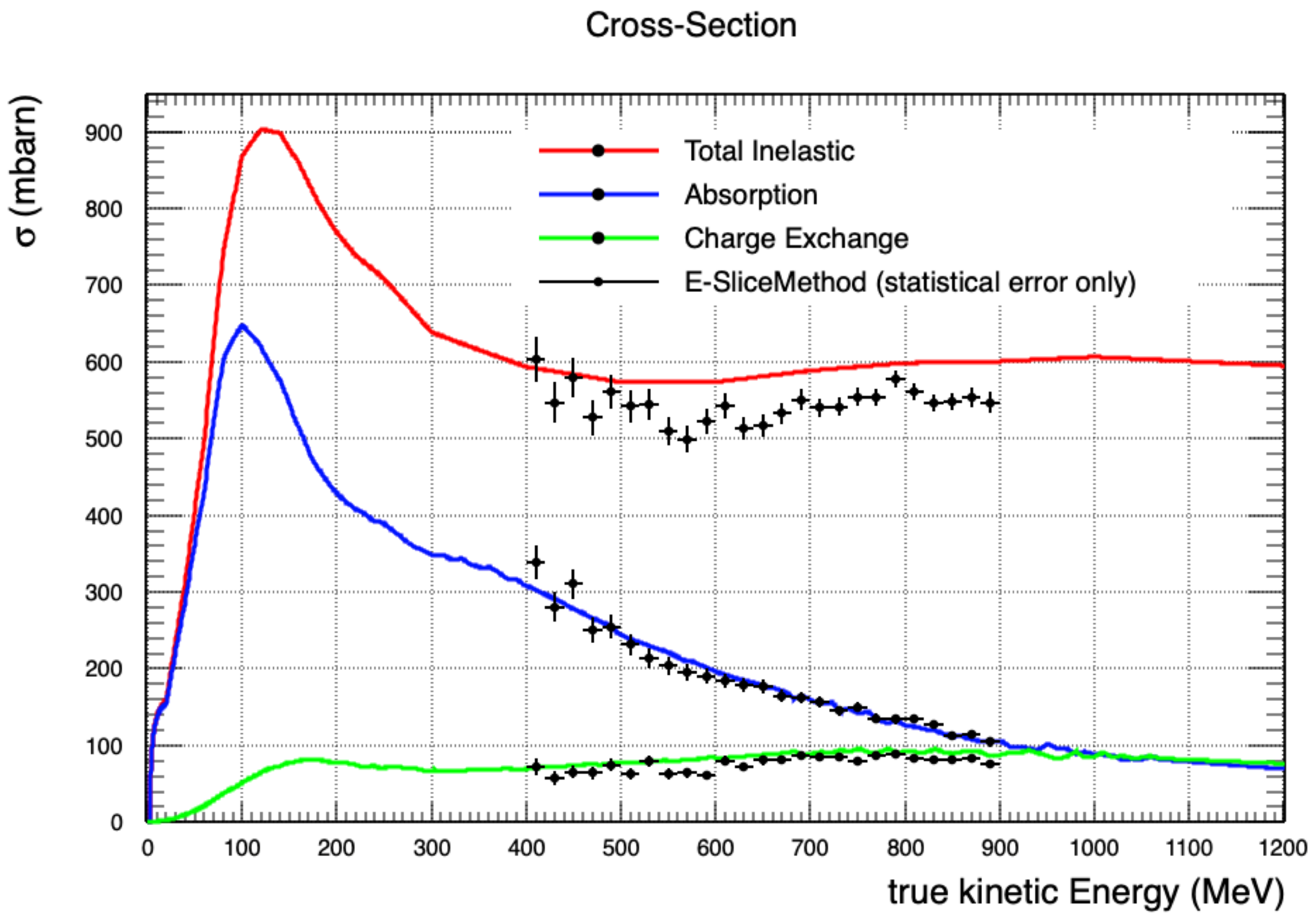
- Select true pion events
- For pions with "pi+inelastic" find true initial KE and KE at interaction point
  - *"true_beam_incidentEnergies[0]"*
    - Work in Progress, the first incident KE bin is not uniformly filled, can be easily taken care of with weights (ToDo)
  - *"true_beam_endP" → convert to KE*
    - There are some issues with true_beam_interactingEnergy (sim IDE, slicing Jake)
- Add an entry in incident histogram for each energy bin from initial KE to interacting KE, for each pion
- Interacting histogram receives an entry for the interacting KE, for each pion

Interacting and Incident





Cross Section

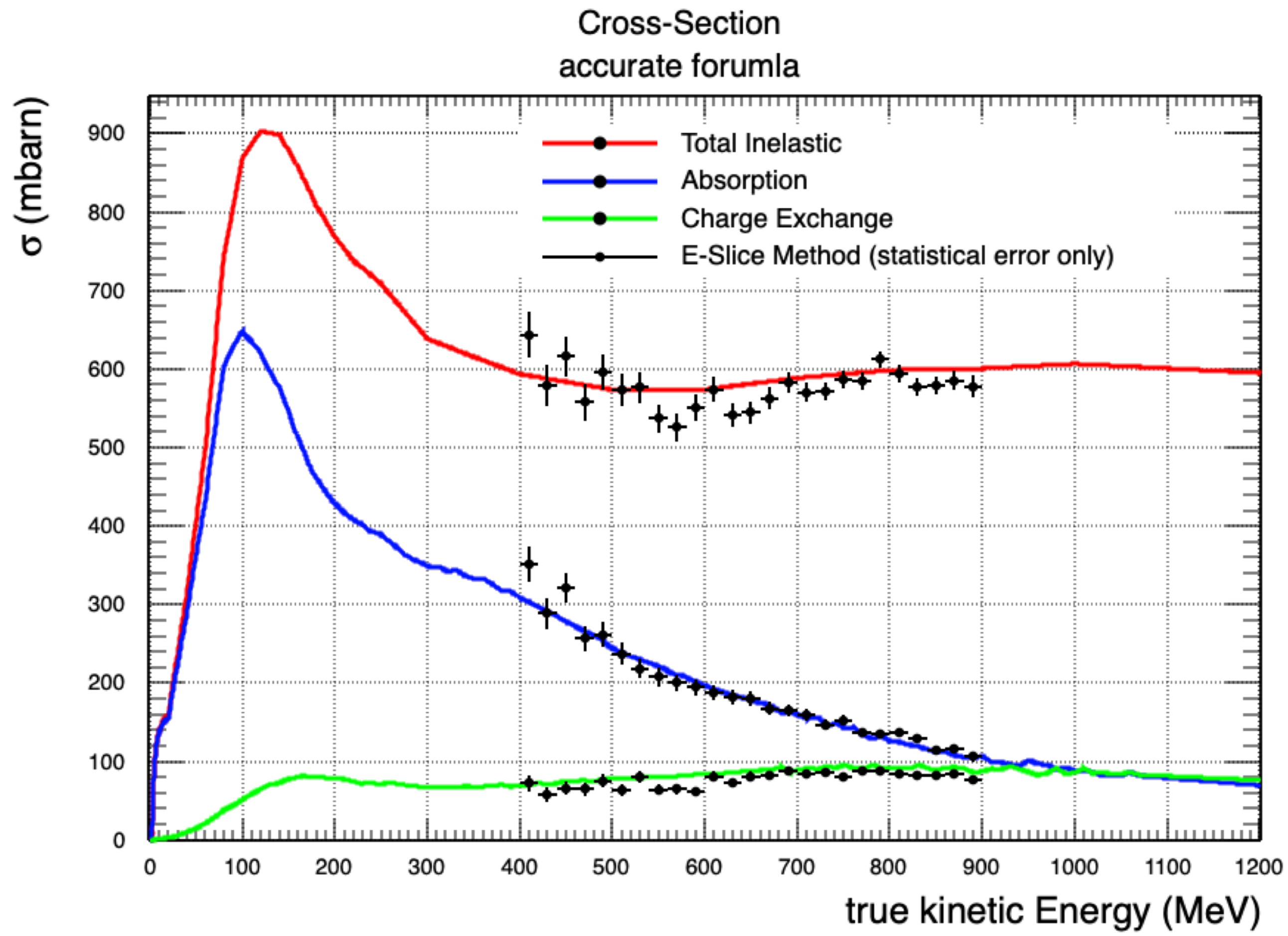


- Same discrepancy at inelastic for high KE as Tingjun saw because of Nint !<< Ninc
- Use in that case

$$\sigma(E_i) = \frac{A}{N_A \rho \Delta E} \frac{dE}{dx}(E_i) \log\left(\frac{N_{\pi Incident}(E_i)}{N_{\pi Incident}(E_i) - N_{\pi Interacting}(E_i)}\right)$$

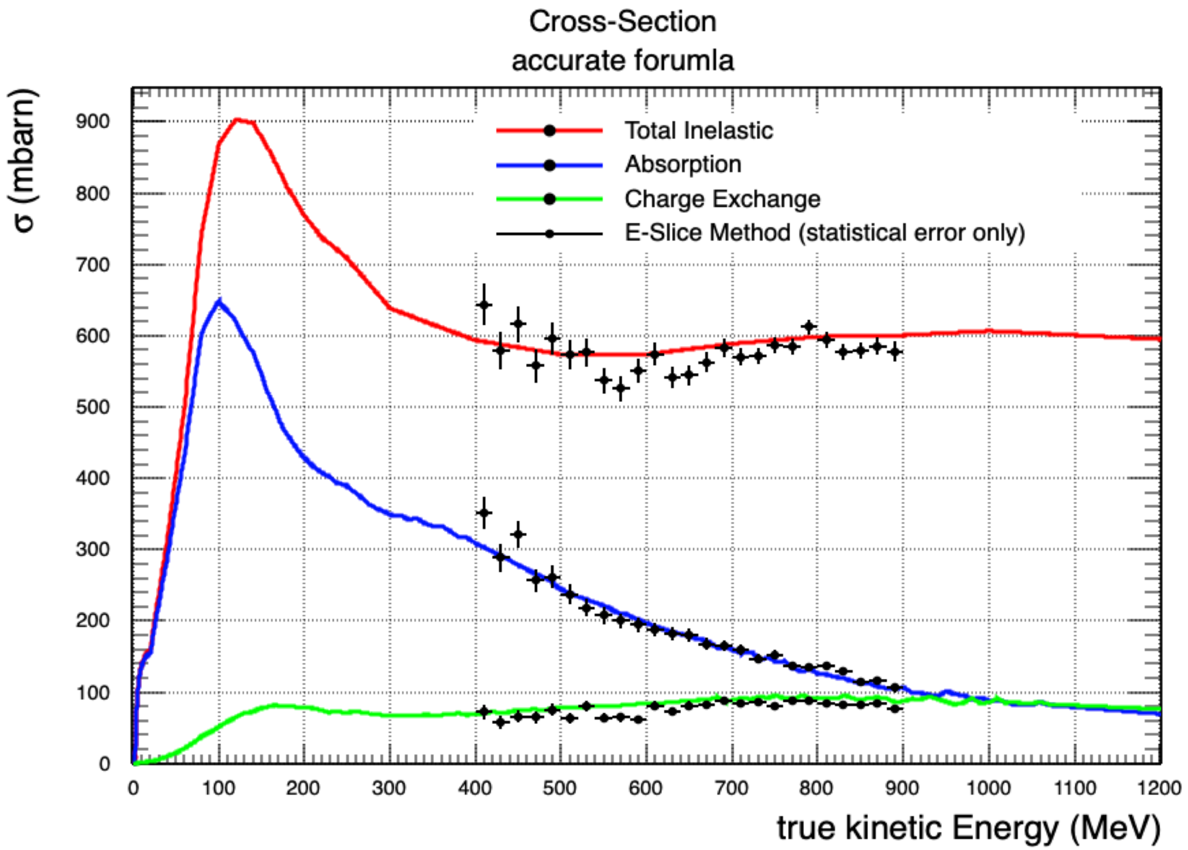
Cross Section accurate formula

$$\sigma(E_i) = \frac{A}{N_A \rho \Delta E} \frac{dE}{dx}(E_i) \log\left(\frac{N_{\pi Incident}(E_i)}{N_{\pi Incident}(E_i) - N_{\pi Interacting}(E_i)}\right)$$

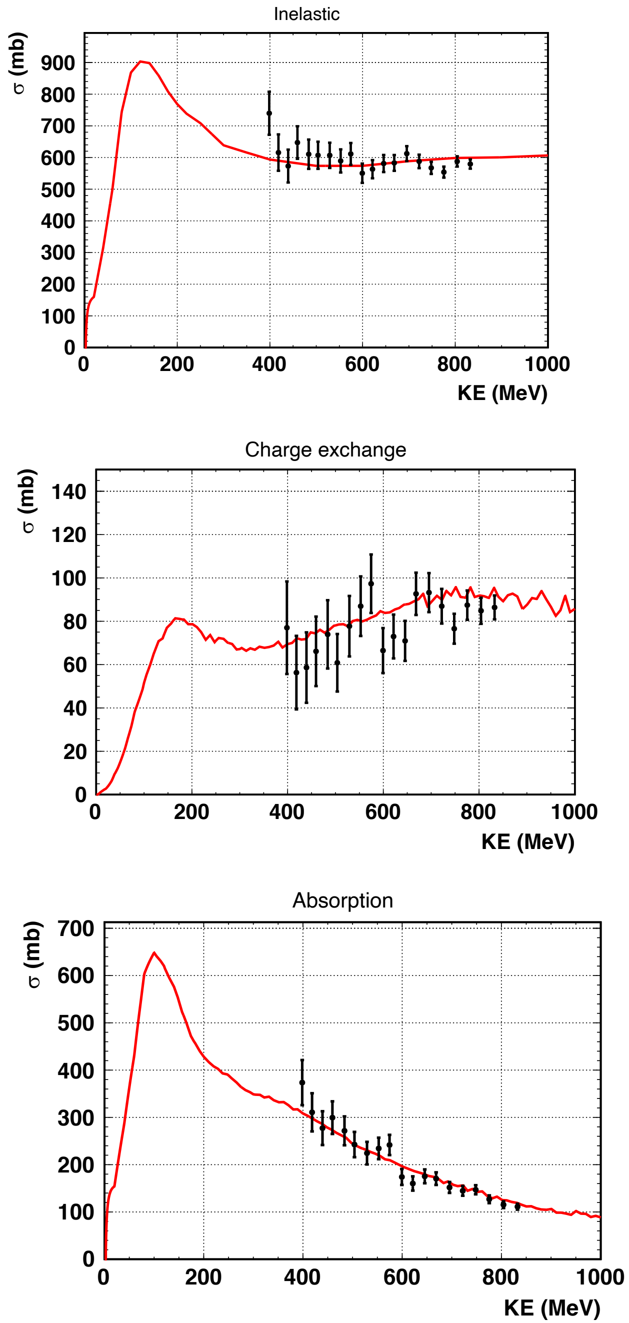


- Better agreement for inelastic XS

E-Slice vs Thin Slice



Tingjun's study of thin slice method



- The E-Slice Method shows nice agreement with the GeantXS
- Can access higher energies than the thin slice method

Conclusions & Next Steps

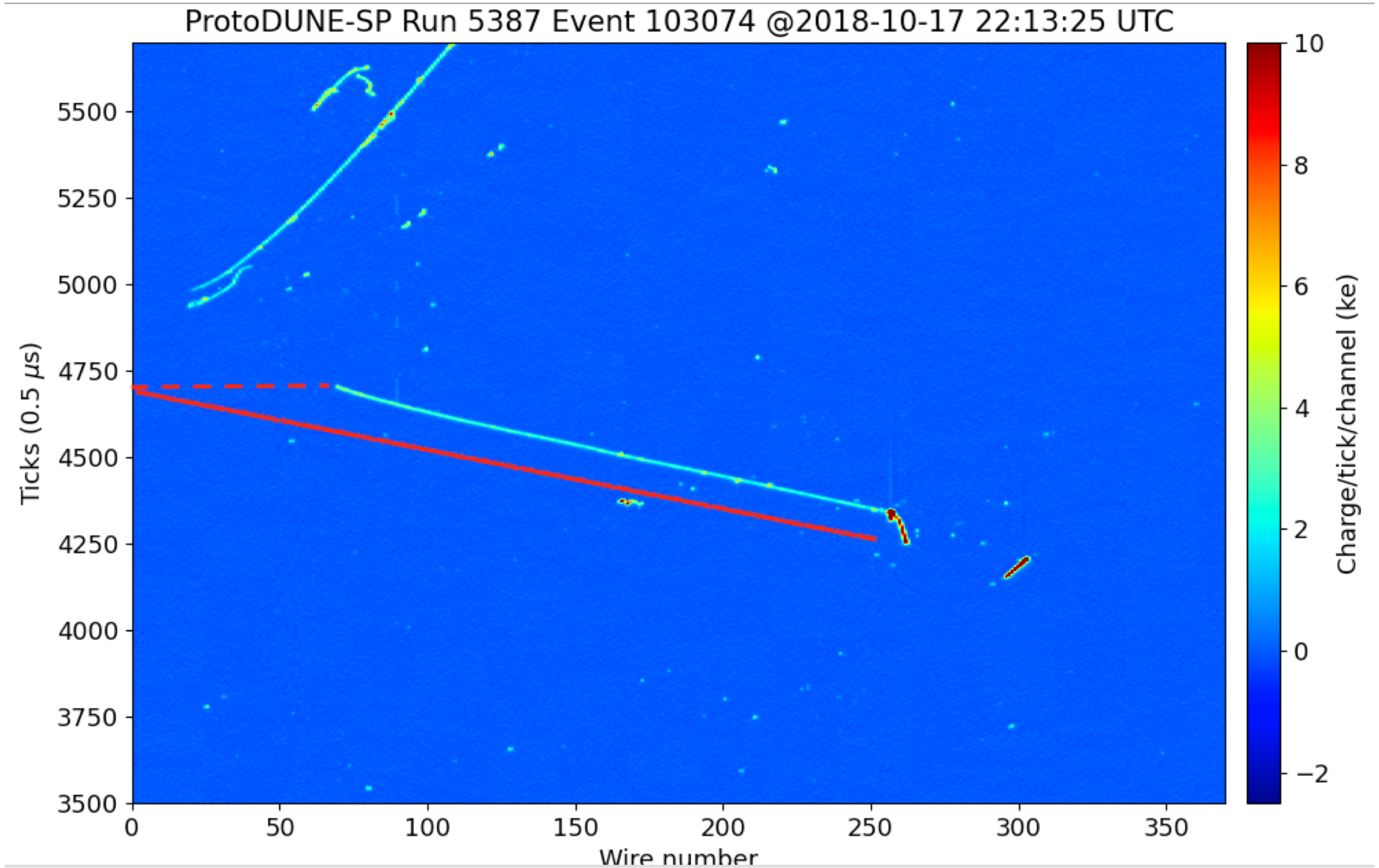
- The E-Slice method can calculate and reproduce the GeantXS for true interactions and corresponding true KE
  - *The uncertainties due to SCE can be avoided by using energy slices*
- The E-Slice method is promising than the thin slice method for ProtoDUNE beam particles

Next Steps

- Using reconstructed energy (MC and Data)
  - *Need to make sure that it is dQ → dE* ***without SCE corrections***
    - Allows to extend range to higher KE without cutting away to first 80 wires (~100MeV) for example
  - ***NOT*** *dE = dEdx*dx otherwise we might pull in SCE distortions (?)*

BACKUP

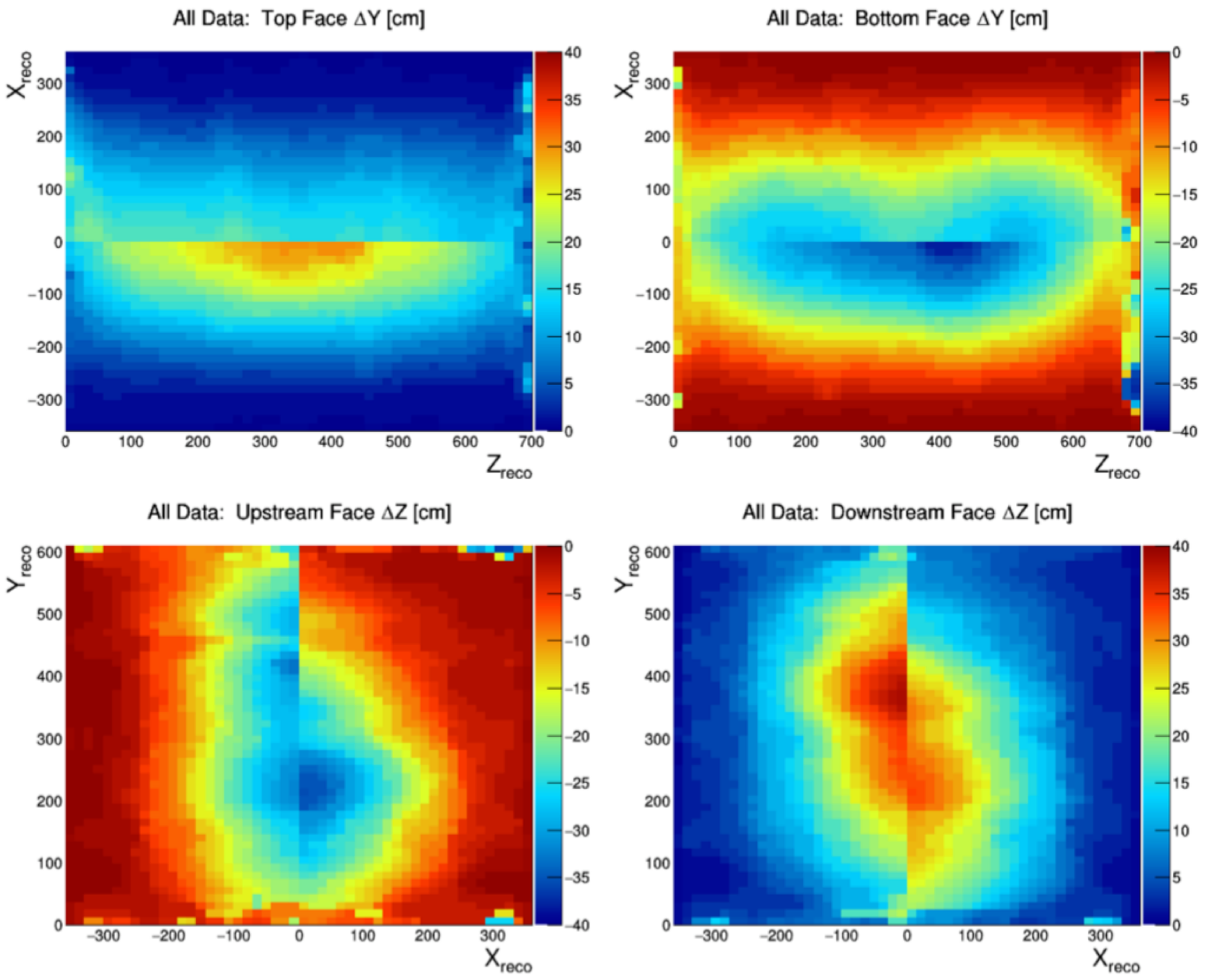
Test SCE correction with model independent approach for beam particles



- Using data a point by point correction can be found for beam particles

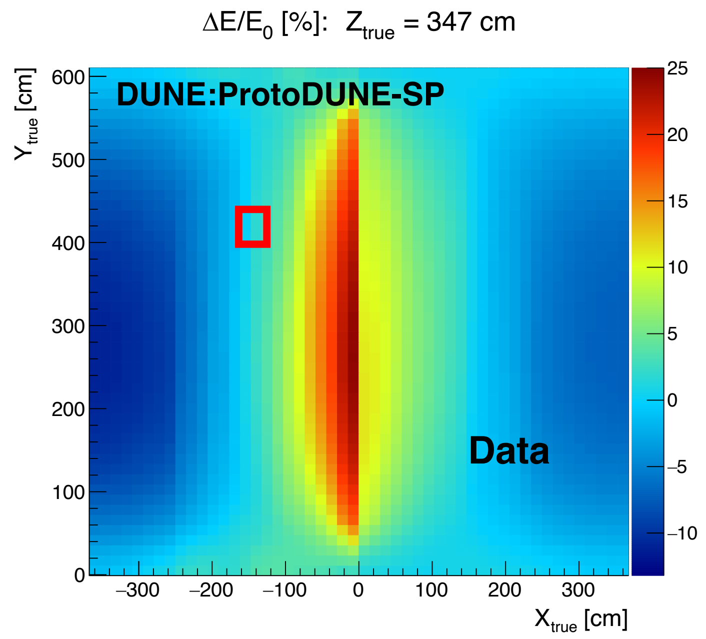
Recap SCE effect ProtoDUNE

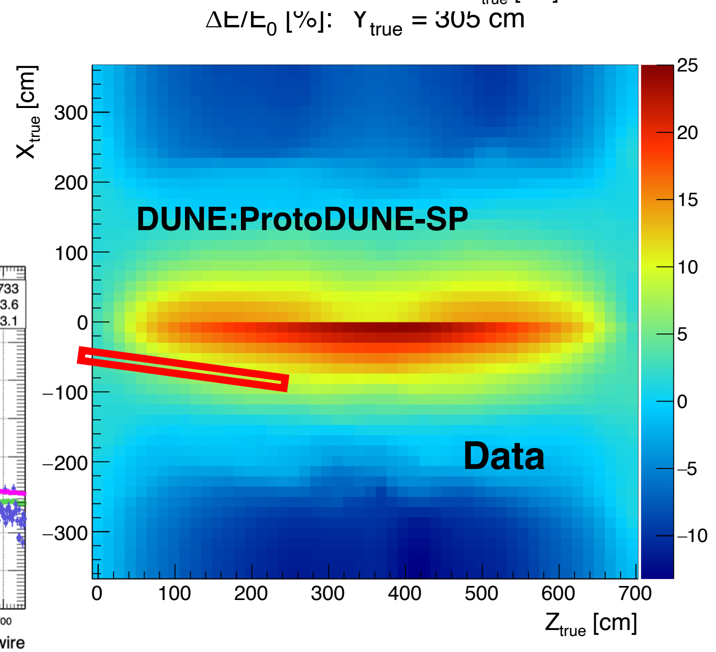
- SCE in ProtoDUNE causes displacement in X,Y,Z
- Plots show displacement in Y and Z from the detector top, bottom, front and back faces measured with cathode crossing cosmics
- The SCE effect is modeled with these plots using interpolation between the faces
- SCE corrections are based on this work so far

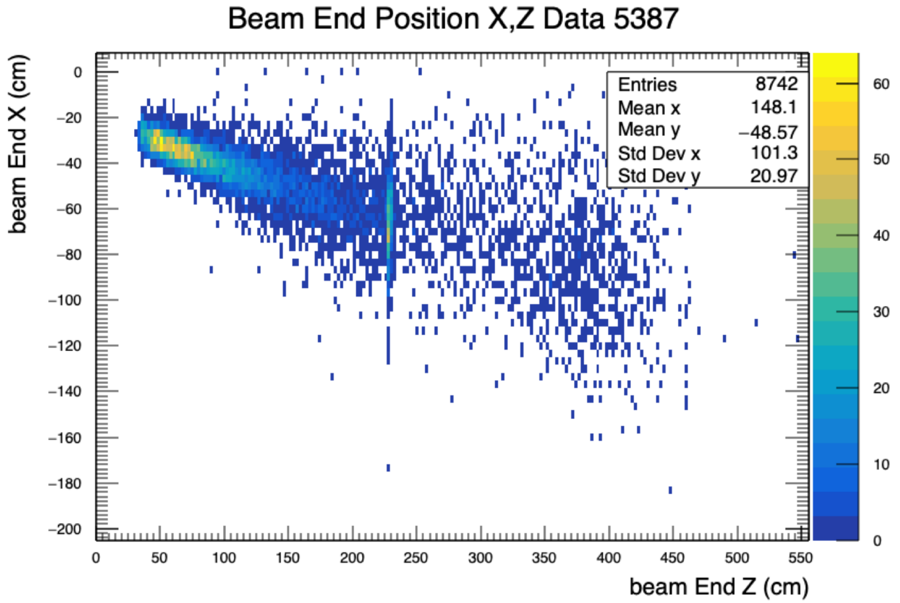


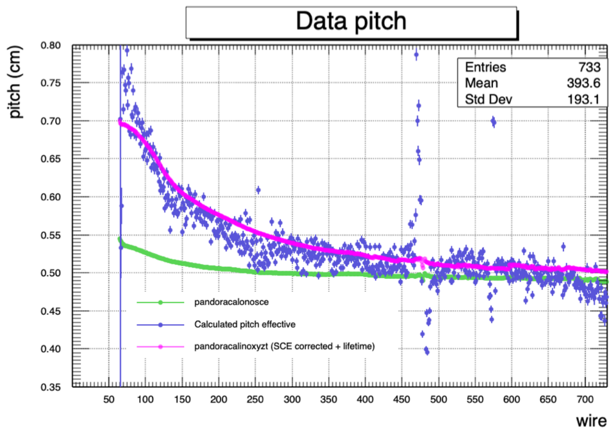
Effect of Recombination

- Efield maps in beam particle region can be trusted as SCE effect reproduces in general the data-corrected pitch
- There is no major effect to be considered from recombination on the proposed method as long as we just use beam particles



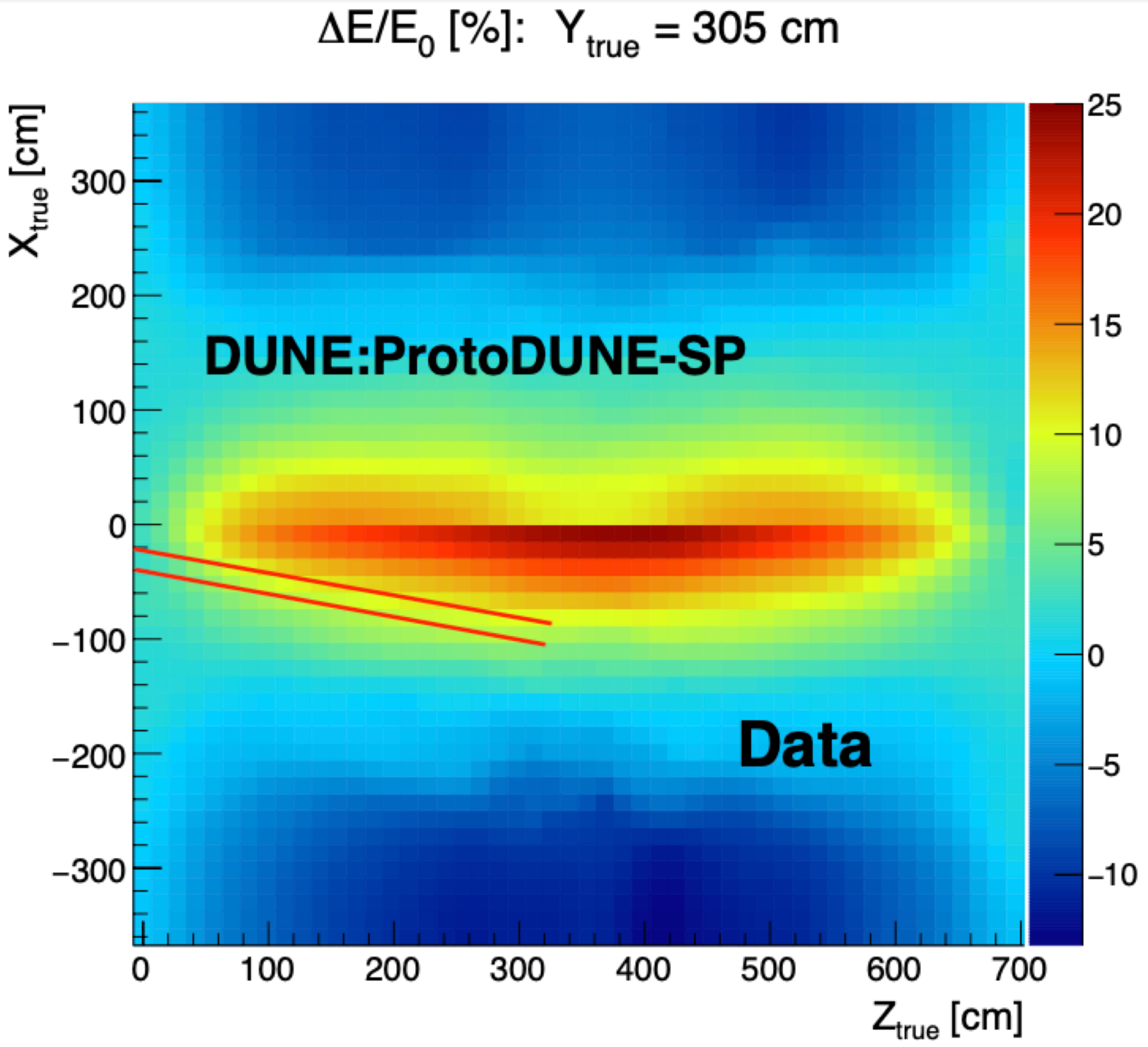




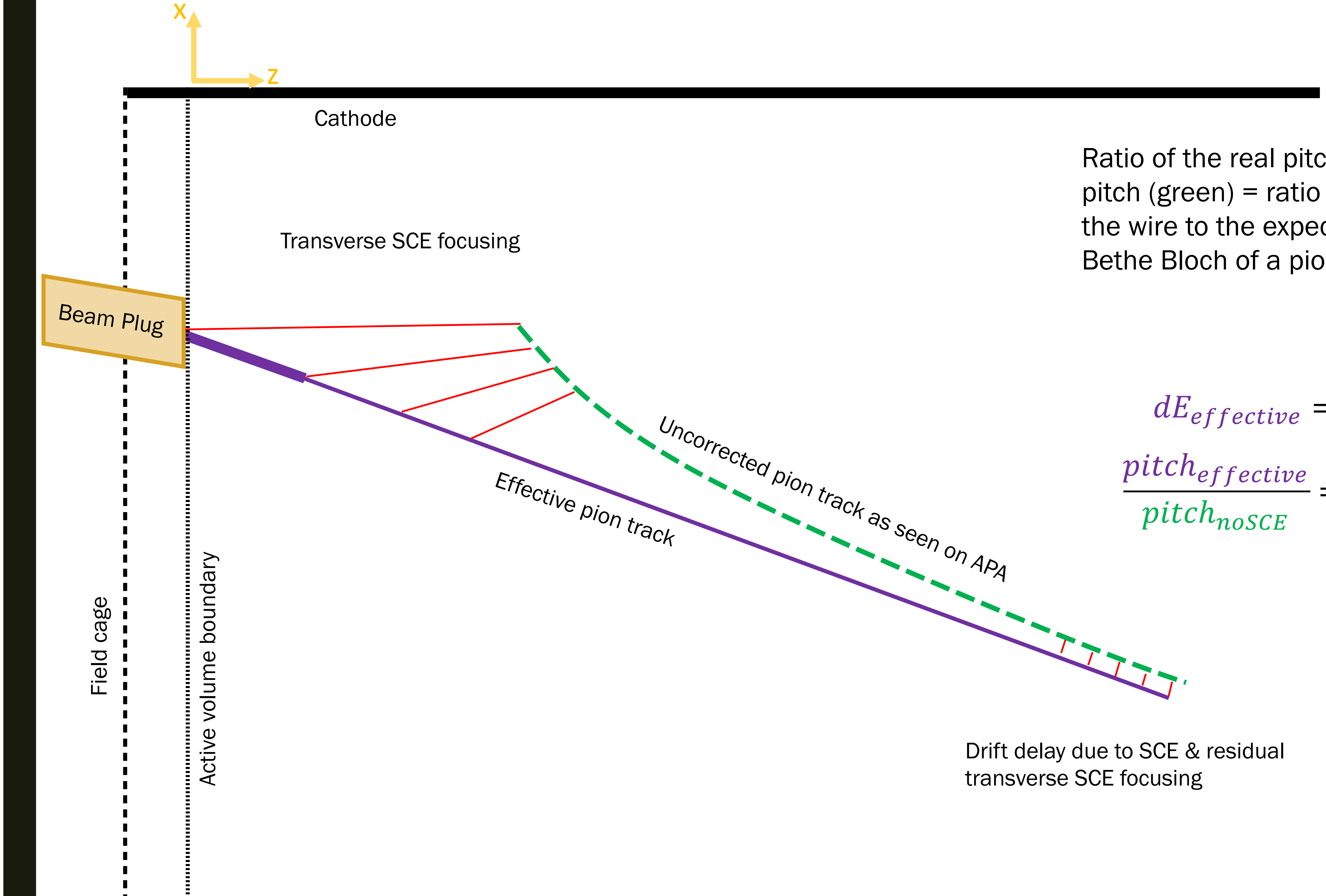


Effect of Recombination

- Efield changes maximally 10% → 550kv/cm
- Recombination at 500kV/cm = 0.698
- Recombination at 550kV/cm = 0.706
- Change of 1.2% (maximal)
- Uncertainties due to recombination are much smaller than 1%



Idea of the method

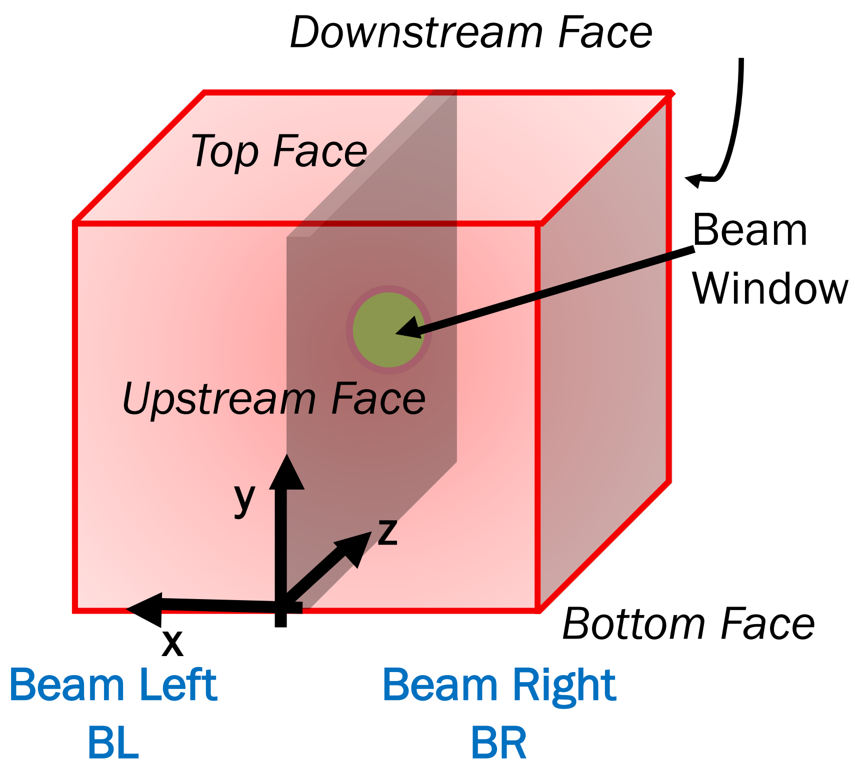


Ratio of the real pitch (purple) to the apparent pitch (green) = ratio of dEdx (MPV) recorded on the wire to the expected dEdx (MPV) from Bethe Bloch of a pion at given kinetic energy

$$dE_{effective} = dE_{noSCE+lifetime}$$

$$\frac{pitch_{effective}}{pitch_{noSCE}} = \frac{dEdx_{noSCE+lifetime}}{dEdx_{expected}}$$

ProtoDUNE



Downstream Face
Top Face
Beam
Window
Upstream Face
y
z
x
Bottom Face
Beam Left
BL
Beam Right
BR