Updates on protoDUNE detector calibration based on cathode piercing cosmic muons

Ajib Paudel[1], Tingjun Yang[2] , Glenn Horton-Smith[1]

[1]Kansas State University

[2]Fermi National Accelerator Laboratory

Brief review: dQ/dx calibration summary

dQ/dx values vary throughout the TPC due to a number of factors namely, misconfigured or shorted TPC channels, Space Charge Effect, attenuation due to impurities like H_2O and O_2 present in liquid argon, diffusion etc.

We have studied a method of correcting dQ/dx values to make the detector response uniform throughout the TPC using cathode piercing TPC-crossing cosmic muons. The method is similar to that described in MicroBooNE public note 1048 (http://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1048-PUB.pdf). In our method calibrated dQ/dx value is calculated using the relation,

$(dQ/dx)_{calibrated} = (dQ/dx)_{reconstructed}$ .C(y,z).C(x). Normalization factor

where, C(y, z) is the correction factor for the Y-Z plane

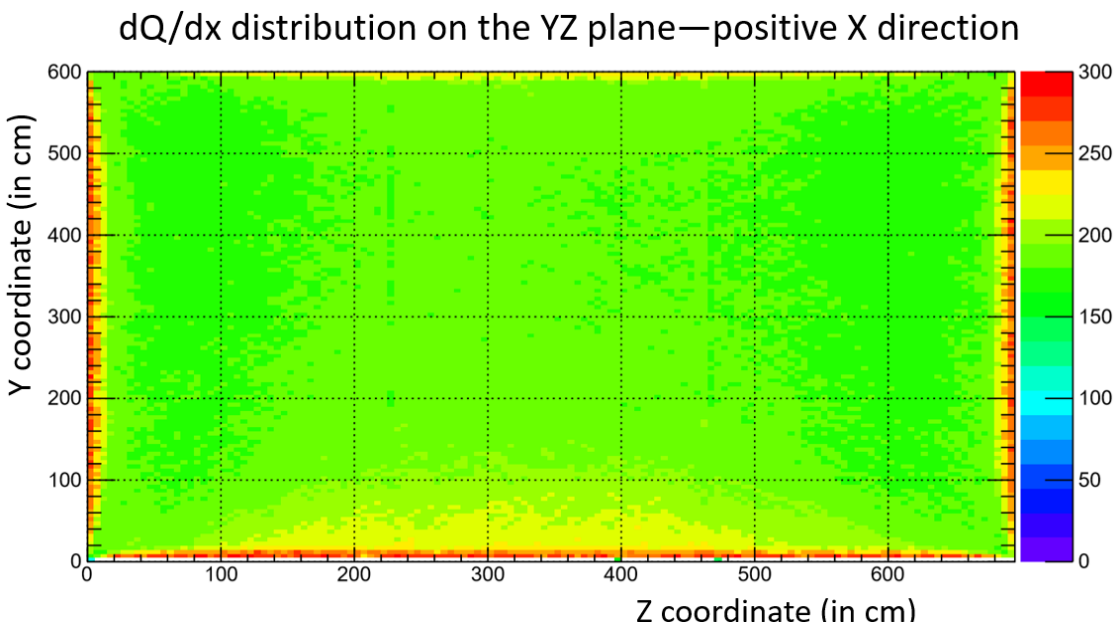
C(x) is the correction factor along drift direction

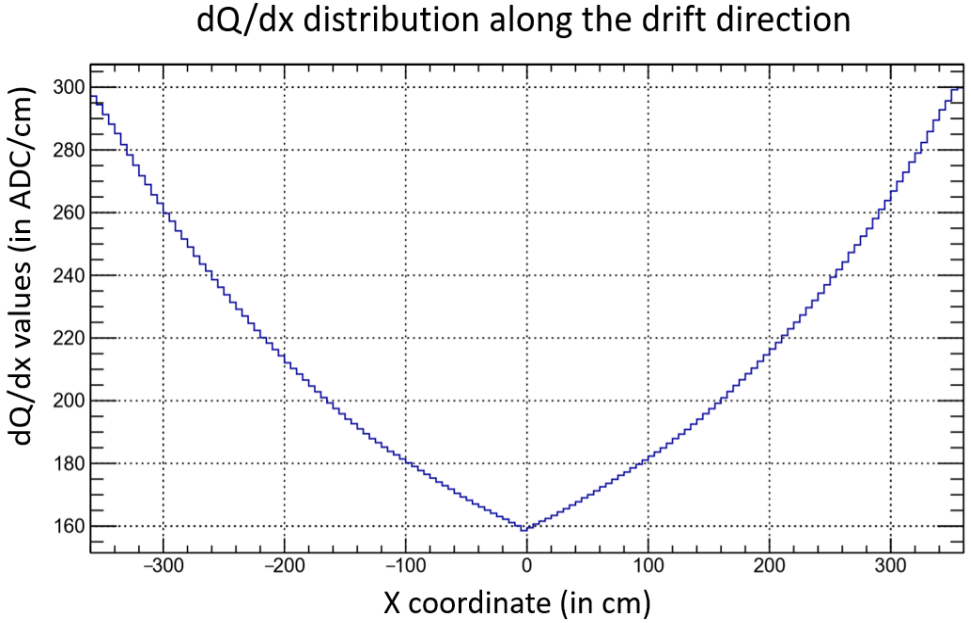
$$C(y,z) = \frac{(dQ/dx)_{global-yz}}{(dQ/dx)_{Local-yz}} \qquad C(x) = \frac{(dQ/dx)_{global-x}}{(dQ/dx)_{Local-x}}$$

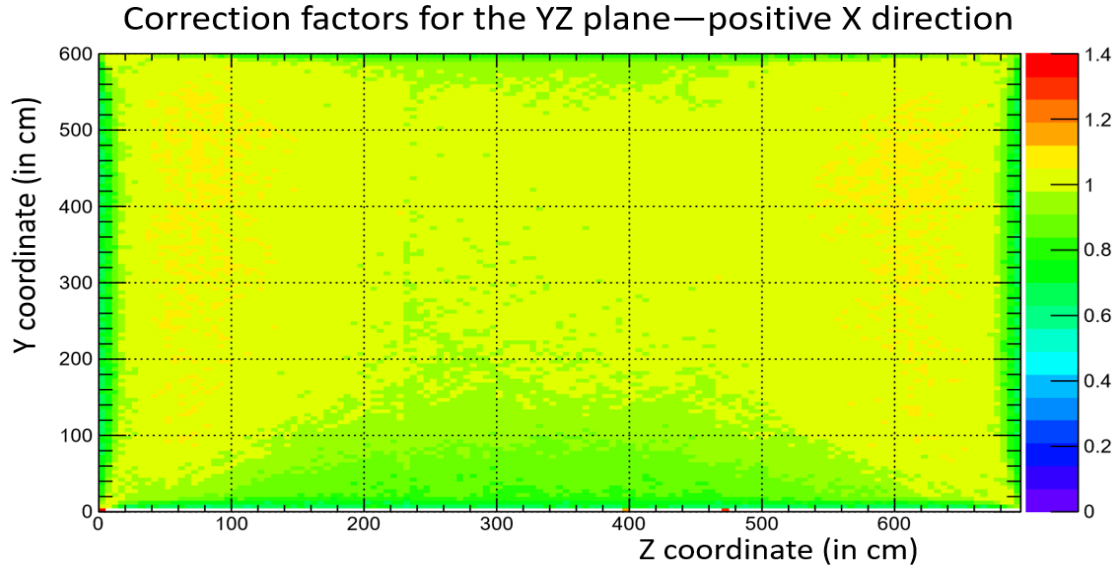
and Normalization factor=(dQ/dx at the anode)/$(dQ/dx)_{global\text{-}x}$

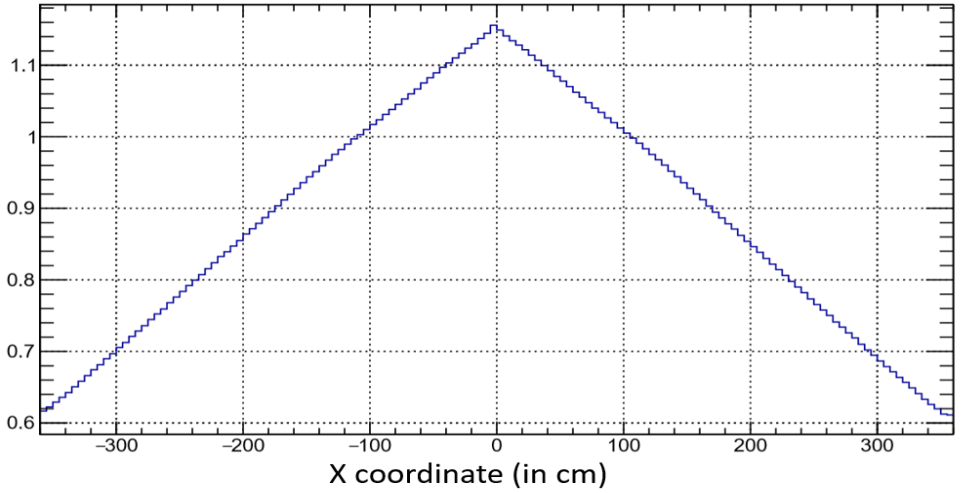
Details of which can be found in DUNE collaboration meeting talk, link for which is https://indico.fnal.gov/event/14582/session/36/contribution/125/material/slides/0.pdf

MCC10 cosmic sample with **3ms lifetime** and **SCE ON** (crossing cosmic muon tracks). All plots are for **Plane-2 (collection plane):**









dEdx calibration brief review:

Using the calibrated dQ/dx values (in ADC/cm), we calculated the dE/dx (in MeV/cm) values by applying the modified Box model for different calibration constants (constant to convert dQ/dx from ADC/cm to number of electrons/cm).

Compared the most probable dE/dx values for each bin with the most probable value predicted by Landau-Vavilov theory. The constant C with minimum χ^2 value is the final calibration constant. **(3 ms lifetime MCC10 sample with SCE ON-** stopping cosmic muon tracks used for the analysis).

$$\left(\frac{dE}{dx}\right)_{calibrated} = \frac{\exp\left(\frac{\left(\frac{dQ}{dx}\right)_{\text{calibrated}}}{C}\frac{\beta' W_{\text{ion}}}{\rho\mathscr{E}}\right) - \alpha}{\frac{\beta'}{\rho\mathscr{E}}}$$

where, C=Calibration constant, to be determined, which converts dQ/dx from ADC/cm to number of electrons/cm

ε=0.5kV/cm is the protoDUNE electric field

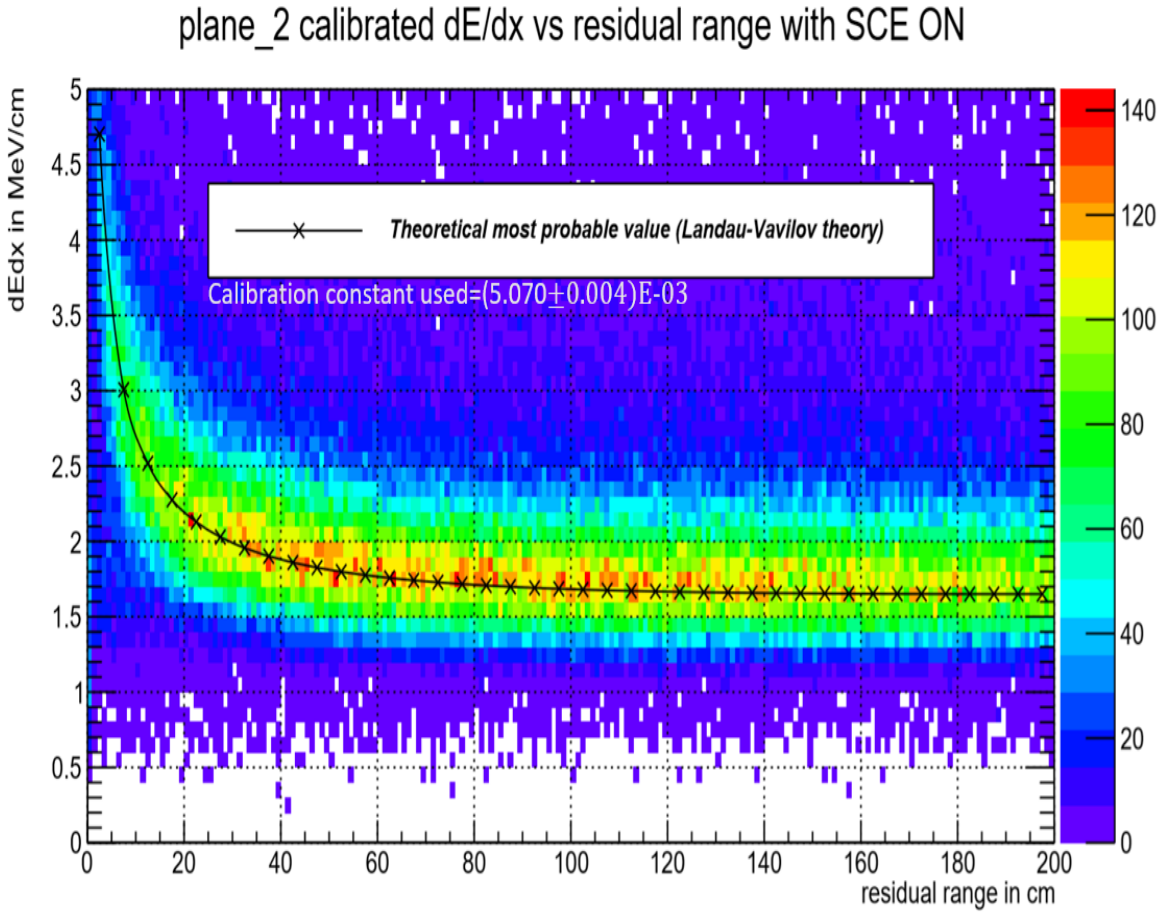
W_{ion} =23.6 x 10^{-6} MeV/electron (work function of argon)

ρ =1.38 g/cm3 (liquid argon density at a pressure 18.0 psia)

α =0.93

β'=0.212 (kV/cm)(g/cm2)/MeV

where, the last two parameters were measured by ArgoNeuT experiment at 0.481kV/cm.

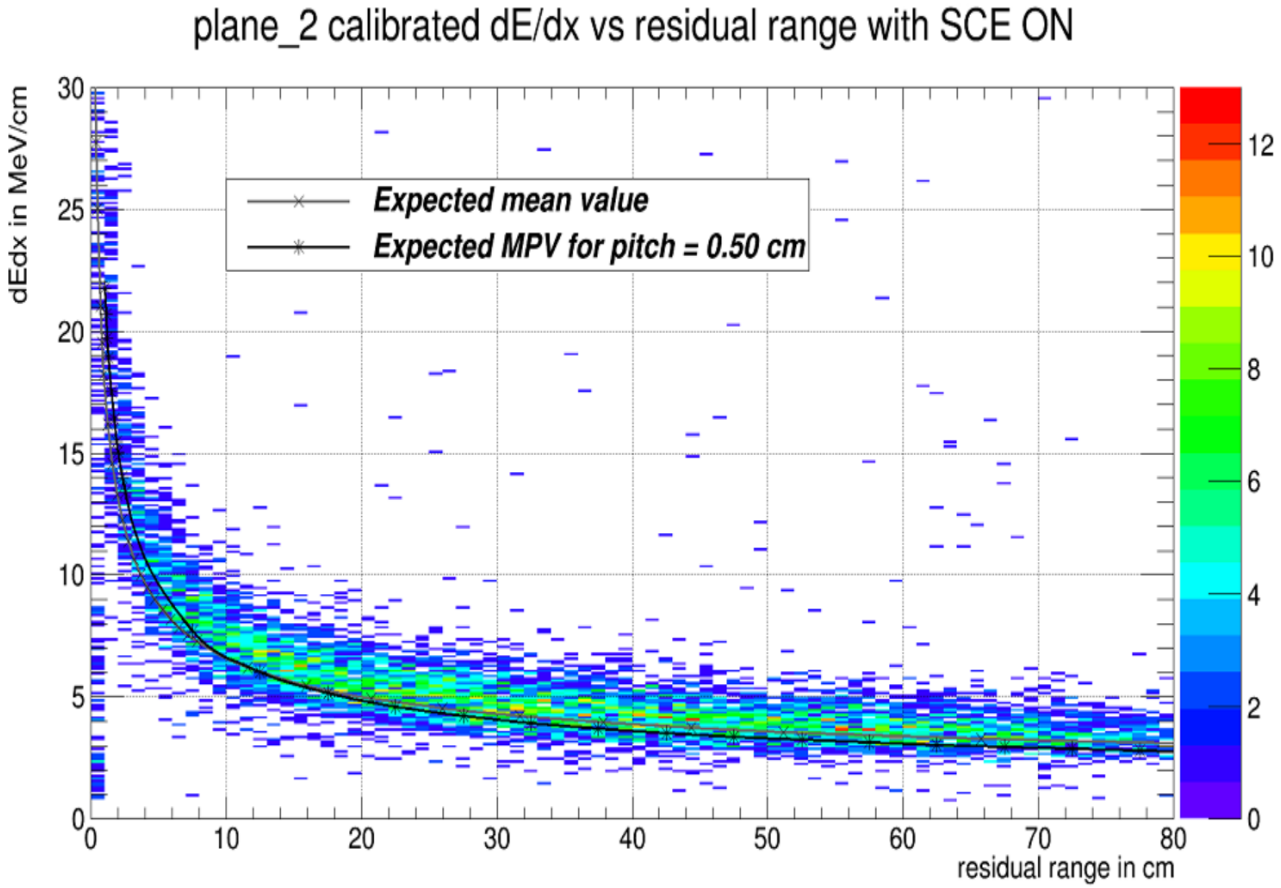


Reference for detailed analysis:

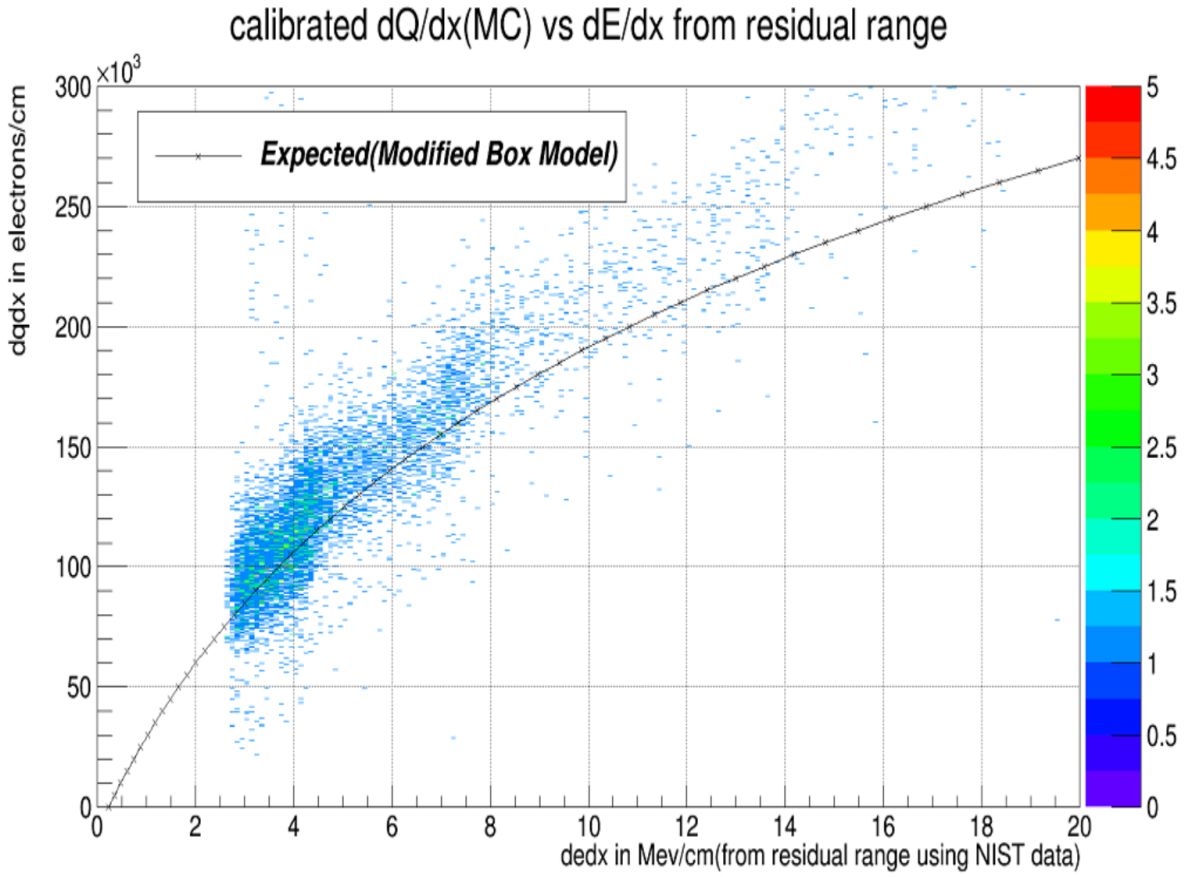
https://indico.fnal.gov/event/17467/contribution/1/material/slides/0.pdf

Validation of dQ/dx and dE/dx calibration: We applied our muon-based calibration factors to convert dQ/dx into dE/dx for stopping beam protons selected using MC truth information:

dE/dx vs residual range for stopping protons appears to be higher than expected mean and the most probable values. (74 stopping proton tracks used in the plots):



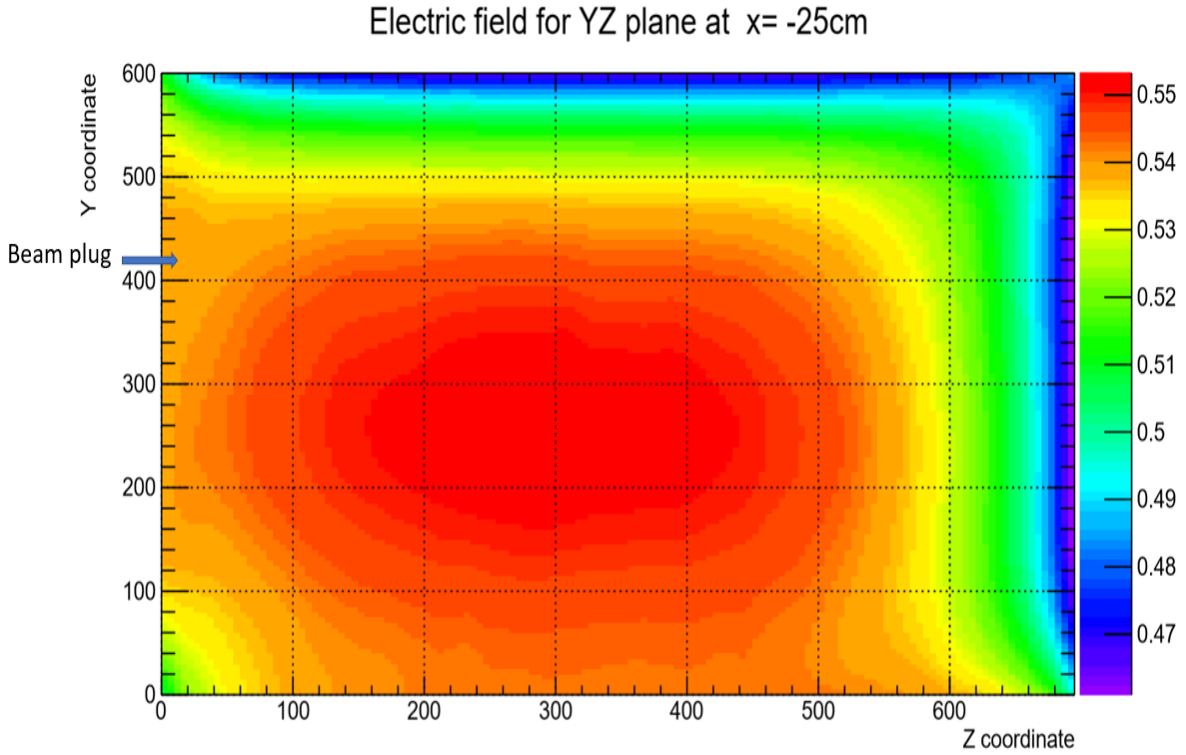
dQ/dx(from MC) vs mean dE/dx(obtained from corresponding residual range, based on NIST standard reference data base)



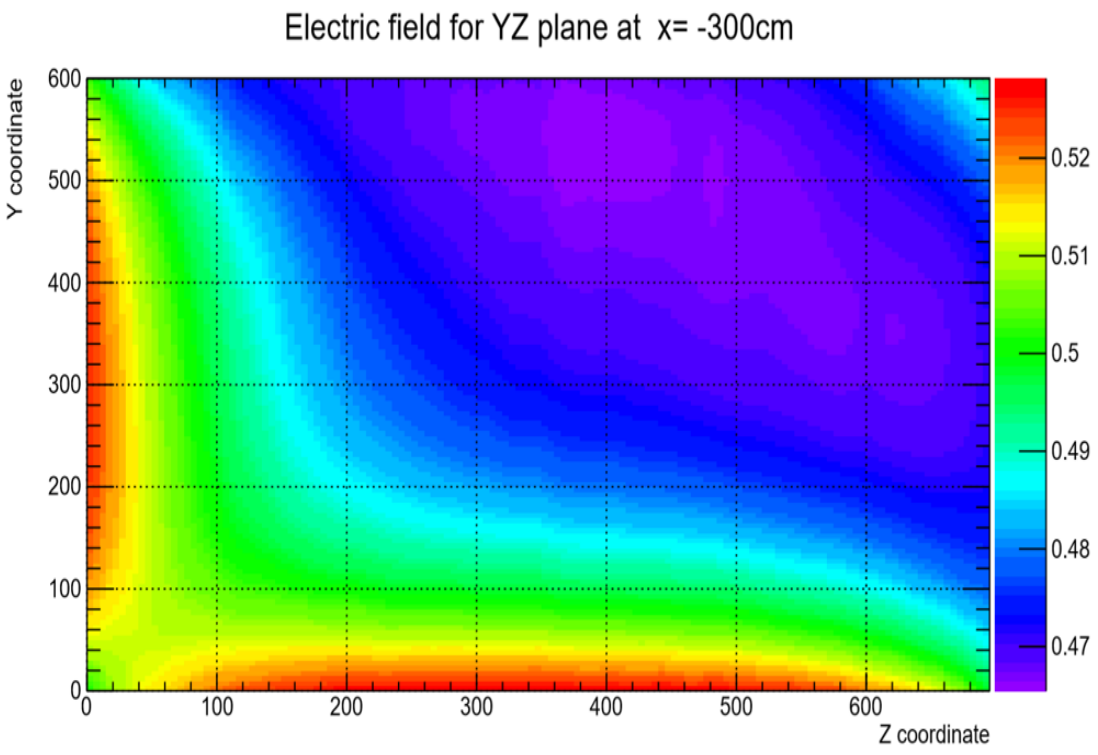
From the plots in the previous slide we could see that dE/dx values for protons are higher than expected (theory).

We speculated, one reason for this could be due to higher electric field close to the cathode because of Space Charge Effect (as all the protons in our analysis are coming from the beam plug which is close to the cathode):

Beam Plug is positioned around X_{mean} ≈-27cm and Y_{mean}≈421cm. From the electric field map on the LHS we can see the electric field is substantially higher around the beam plug region compared to the average electric field in the detector, and modified Box model depends on the electric field.



Close to cathode

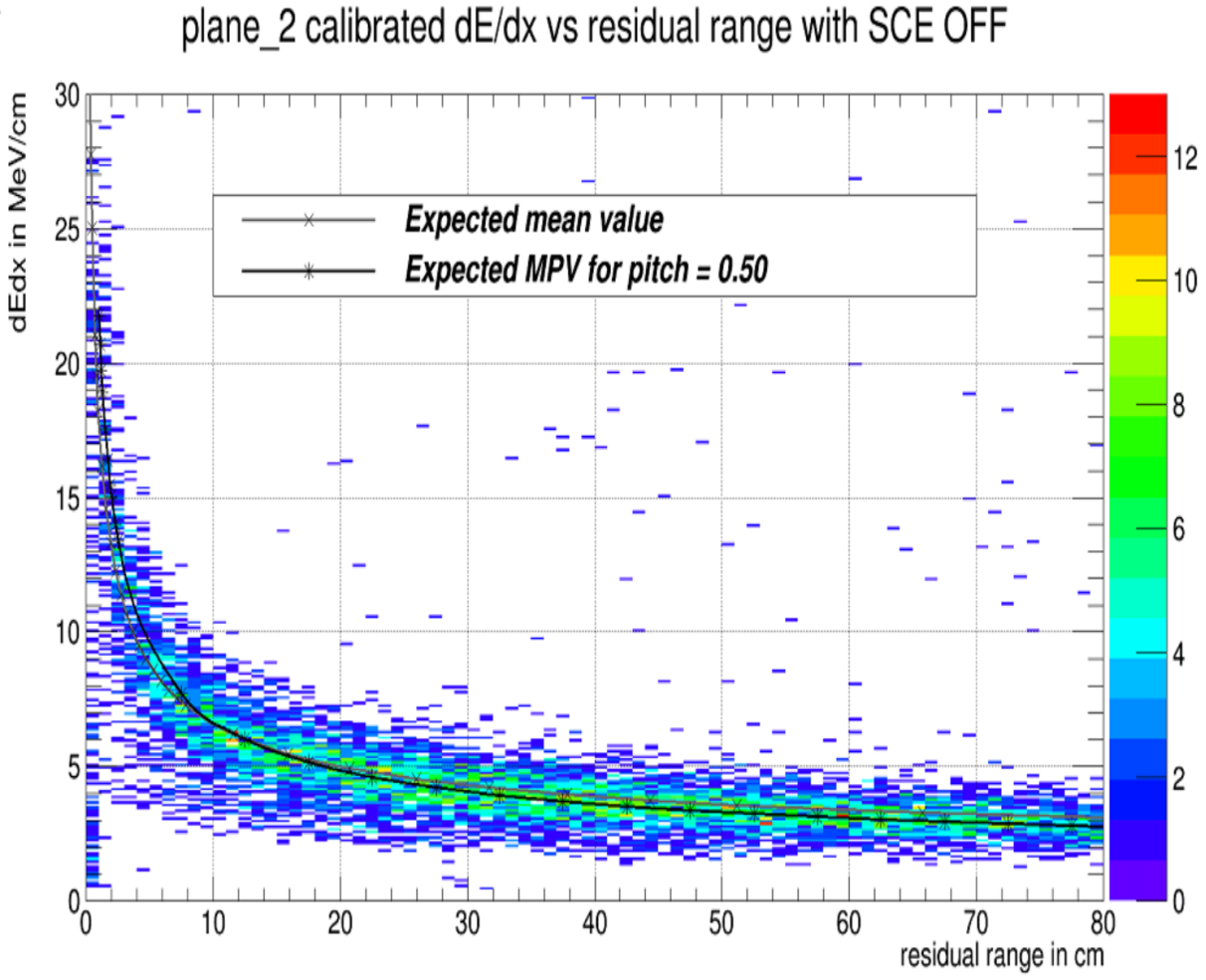


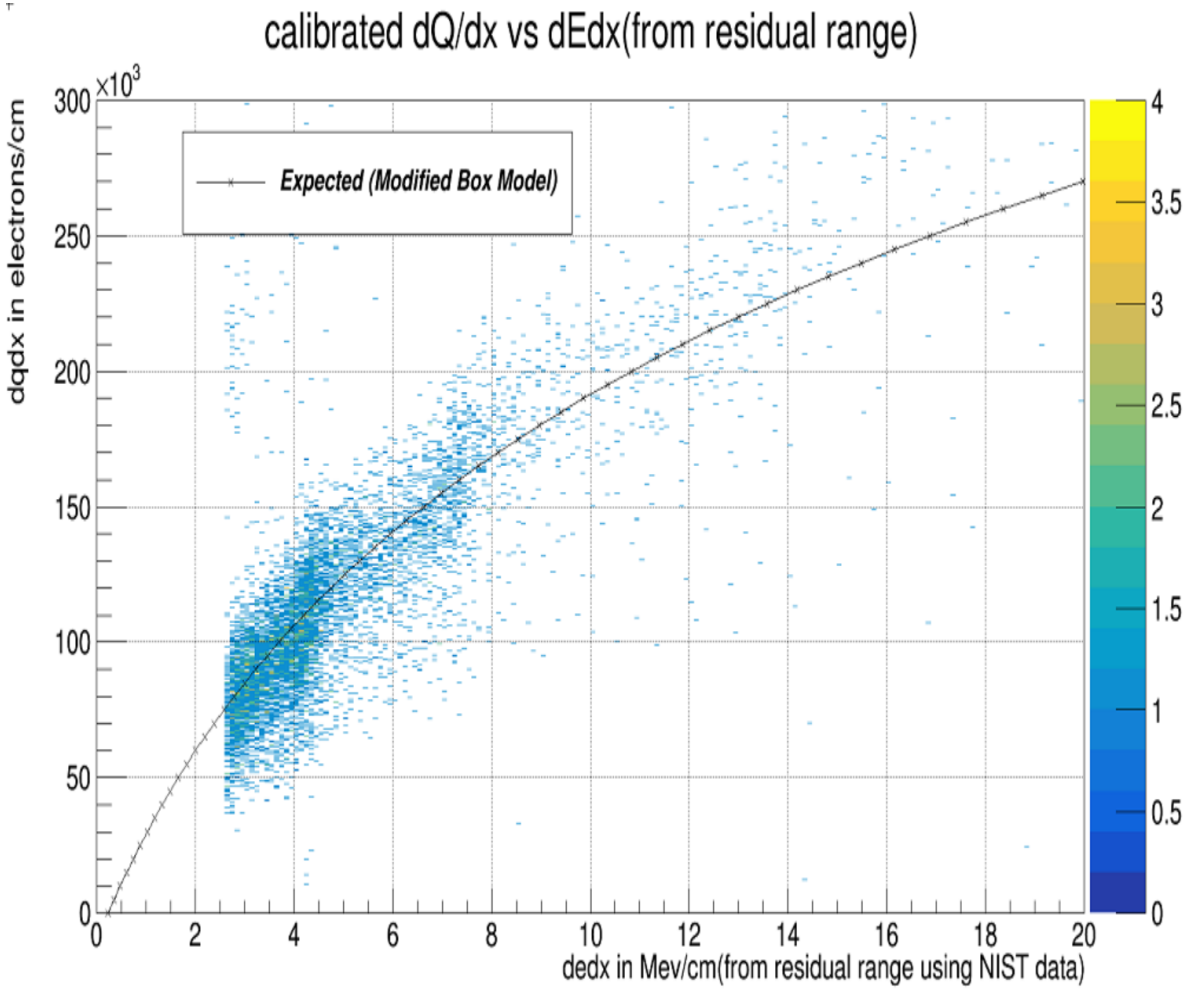
Close to anode

Calibration using **SCE off** sample:

To better understand the discrepancy observed in our proton sample we repeated the same analysis with Space Charge Effect turned off MCC sample. Again we used cosmic muons to derive a calibration constant.

Here, the Calibration constant C=(5.201±0.003)E-03, dE/dx for proton appears to agree with theory to a greater extent in the absence of SCE. (70 stopping proton tracks used in the plots)





Future works:

- Immediate plan is to validate the current analysis for MCC11 sample.
- In the current analysis we used a uniform electric field of 0.5kV/cm, we are now planning to use the SCE corrected electric field for each hit position and see the results.
- We are planning to be completely ready by the time we have access to the real data from the protoDUNE experiment.

THANK YOU