Calibrating dQ/dx and dE/dx for protoDUNE data using cathode crossing cosmic muons

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We do detector calibration in 2 steps, namely **dQ/dx calibration** and **dE/dx calibration**:

dQ/dx calibration:

One of the main advantages of LArTPC technology is its ability to reconstruct both particle tracks and energies with high precision. But due to a number of effects the particle energy reconstruction can be restricted. Some of these effects are:

- Distortions in detector response due to **mis-configured or shorted TPC channels**
- Electron **attenuation** due to impurities such as H_2O and O_2
- **Space Charge Effects (SCE)**
- **diffusion**

Here we are using **cathode piercing TPC crossing cosmic muons** to make the detector response (dQ/dx – Charge deposited per unit track pitch) uniform throughout the detector and later we will get the correct particle energies for particle identification.

References:

microBooNE public note

my previous sim-reco meeting talk

Data samples and event selection:

About the data:

Run_number 5460 (Oct 24, 2018) ; Number of Events:20906 ; Stable run for 10hrs; **HV=180 kV;**

Beam momentum: **1GeV**

I am using full-reconstructed protoDUNE data (from production team) for my analysis.

I used pandoraTrack and pandoracalo for the track and calorimetry information respectively.

Total number of **T0 tagged tracks** (cathode crossing tracks two sides stitched together) : **40390 (1.932 per event)**

For preliminary analysis I set the following conditions for a track to be crossing the TPC:

(abs(start_X coordinate)>330cm or start_Y<50cm or start_Y>550cm or start_Z<50cm or start_Z>645cm)

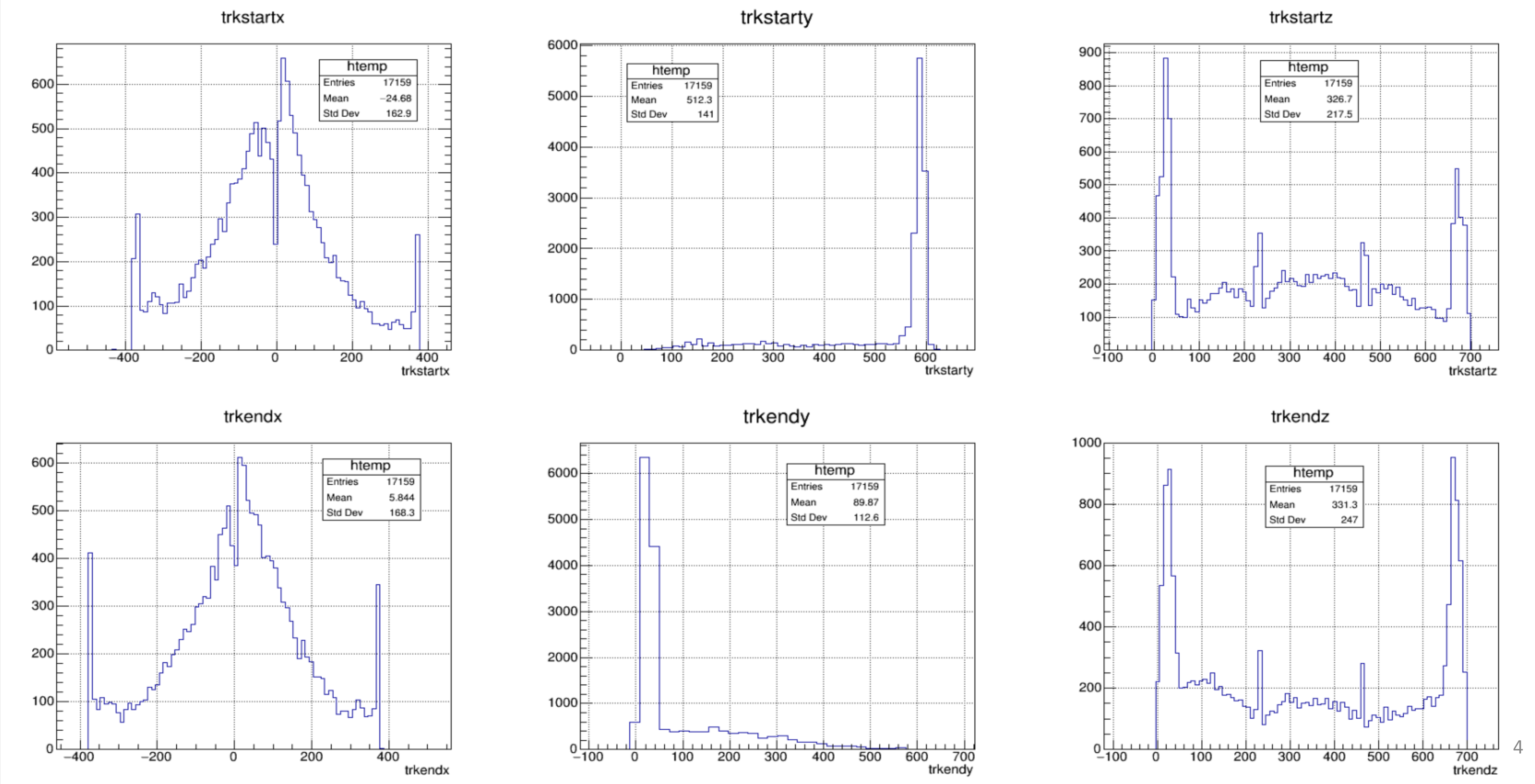
AND

(abs(end_X coordinate)>330cm or end_Y<50cm or end_Y>550cm or end_Z<50cm or end_Z>645cm)

Total number of crossing tracks passing the above criteria: **17159 (0.82 per event)**

Following plot shows the start and end X, Y and Z position of the selected tracks:

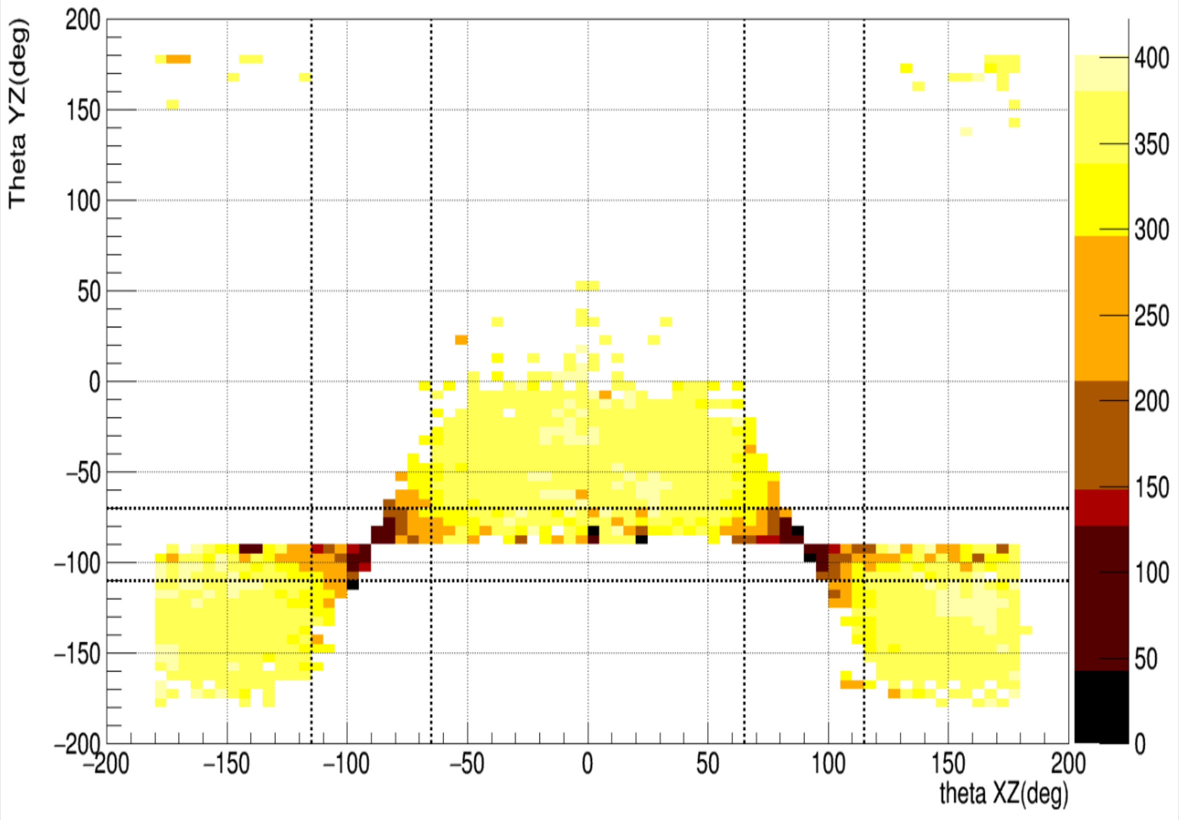
Looking at the Start and End y position we can see that majority of cosmic tracks are entering from the very top of the TPC and exiting from the very bottom



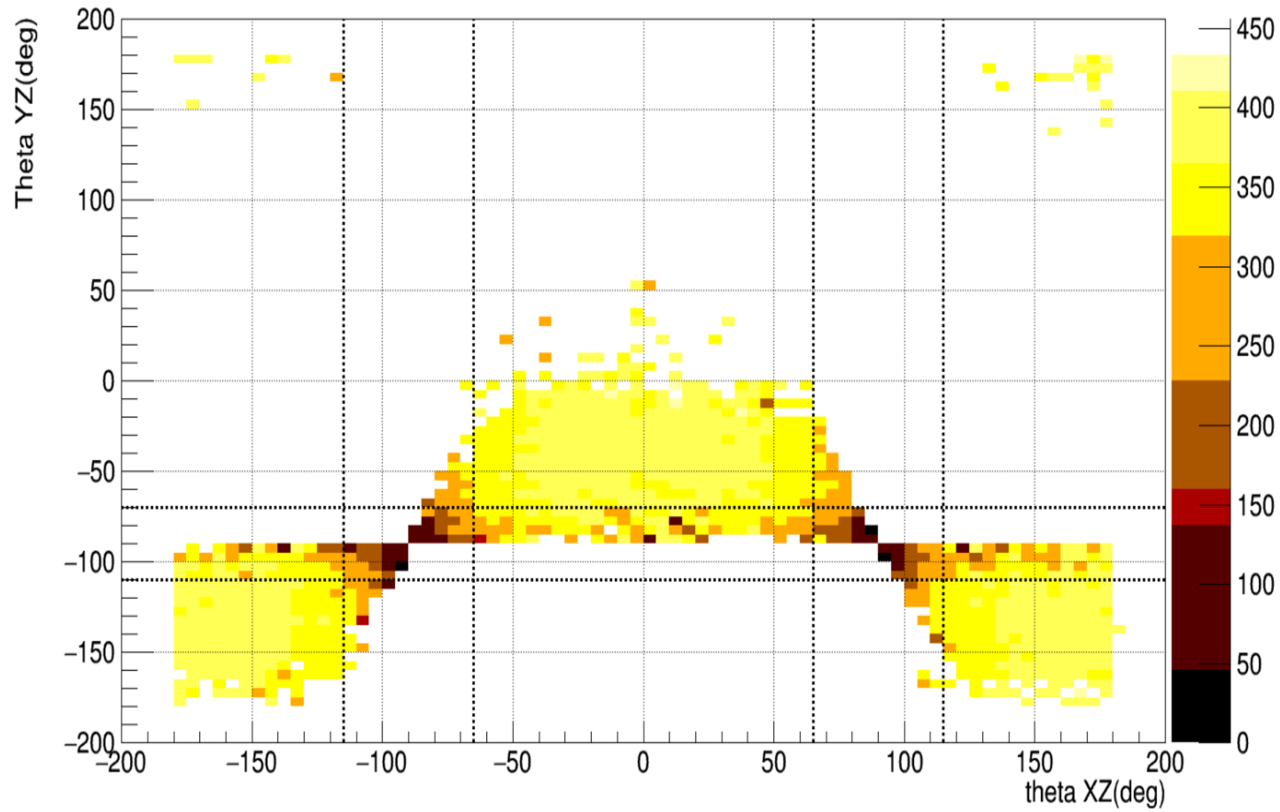
Angular cuts:

Tracks which are parallel to the wire planes or moving straight towards the wire planes are not reconstructed well, we remove those tracks based on the angle made by the projection of the track on the XZ and YZ planes with Z axis:

Left Plot: Plane 2, Xcoordinate<0(beam right)



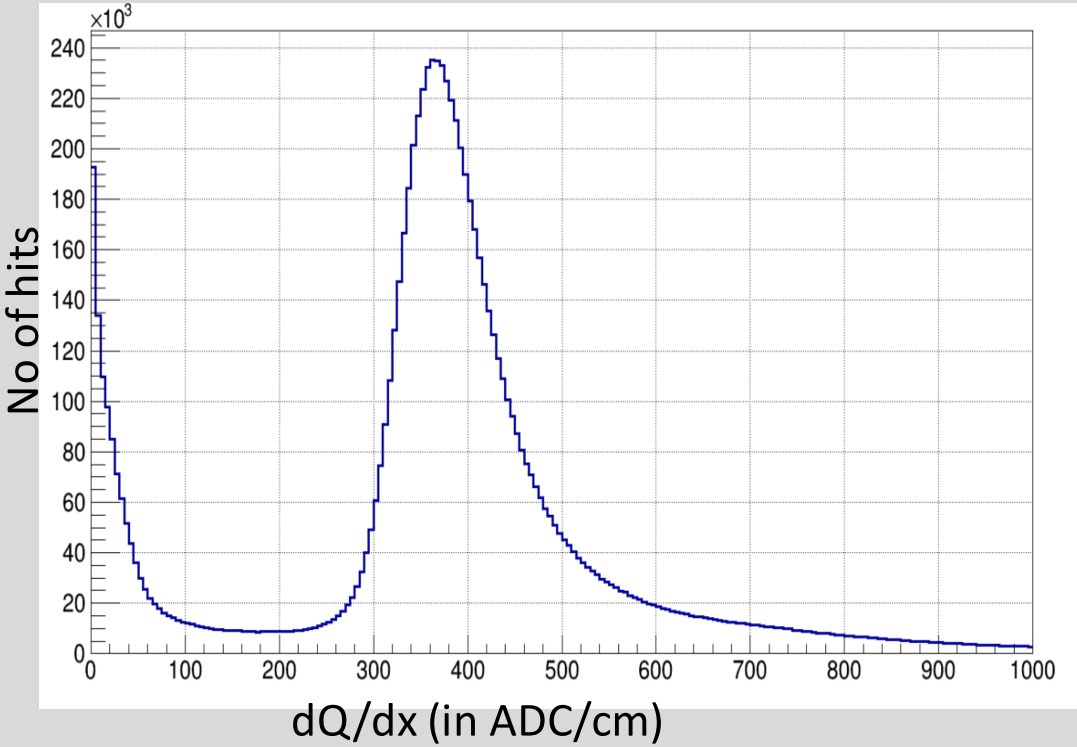
Right Plot:Plane2, Xcoordinate>0 (beam left)

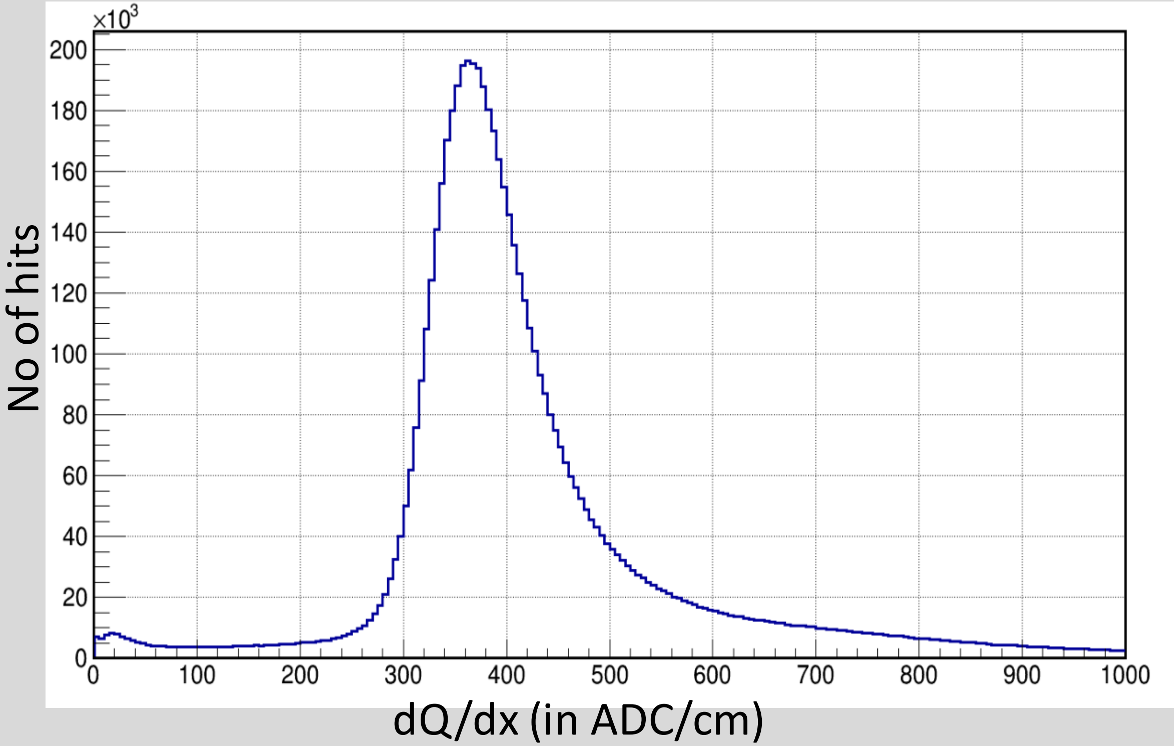


Plots shows dQ/dx distribution as a function of theta_XZ and theta_YZ, we remove the tracks incident at angles corresponding to very low dQ/dx values. For plane 2 we remove any track for which

115deg>abs(theta_XZ)>65deg and –110deg<theta_YZ<-70deg (The region inside the dashed line shows the angles excluded)

Effect of angular cuts:





Left Plot: dQ/dx distribution for crossing tracks before the angular cuts

Right Plot: dQ/dx distribution for crossing tracks after the angular cuts

No of Tracks before angular cuts = 17159 and No of tracks after the angular cuts=9451 tracks

From the above histograms we can see that most of the low dQ/dx region is removed after the angular cuts, those were from the tracks moving parallel to the wire plane or moving straight towards the wire planes which are not well reconstructed.

Using the TPC crossing muon tracks we make the dQ/dx values uniform throughout the TPC:

We correct the dQ/dx values in three steps **(YZ correction, X correction, correction as a function of time)**

YZ correction factors: (here we make the dQ/dx values uniform throughout the YZ plane)

- Divide YZ plane into 5cm X 5cm bins (120x139=16680 bins) (we do it separately for X>0 and X<0)
- Median dQ/dx value for each bin is calculated ($(dQ/dx)_{\mathbf{local\_yz}}$)
- Median dQ/dx for all such bins taken together ($(dQ/dx)_{\mathbf{global\_yz}}$)

Finally, YZ correction factor

$$C(y,z)=(dQ/dx)_{global\_yz}/(dQ/dx)_{local\_yz}$$

X correction facors: (here we make the dQ/dx values uniform along drift direction)

Before deriving X correction factors we apply YZ correction factors for each hit based on Y,Z coordinate of the hit:

- Divide X-coordinate into 5cm bins (144)
- Median dQ/dx value for each bin is calculated ($(dQ/dx)_{\mathbf{local\_X}}$)
- Median dQ/dx for all such bins taken together ($(dQ/dx)_{\mathbf{global\_X}}$)

$$C(x)=(dQ/dx)_{global\_X}/(dQ/dx)_{local\_X}$$

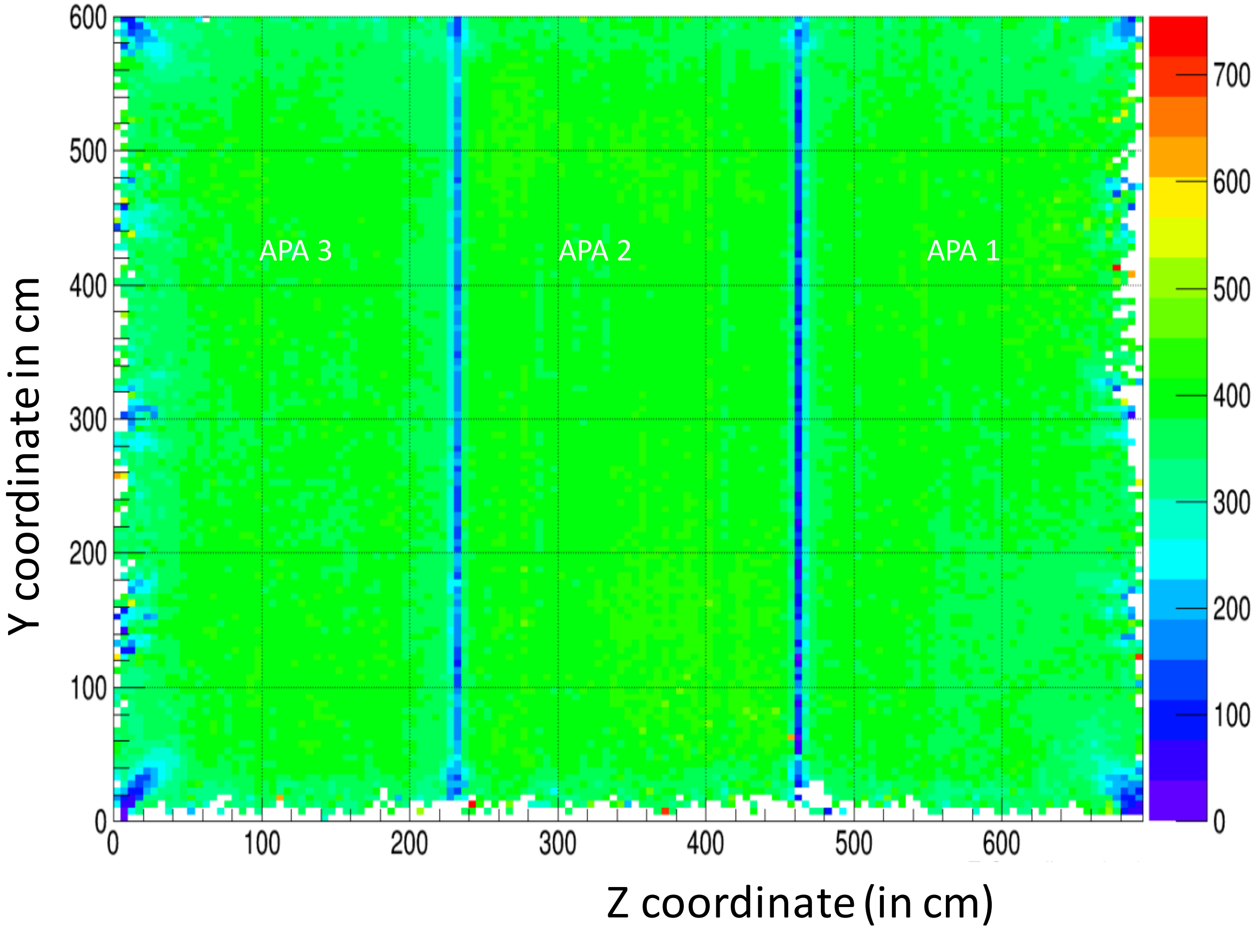
Correction in time:

To account for the change in purity with time, we apply the correction factors based on the time of data taking;
We divide the YZ and X corrected dQ/dx values into different time bins and calculate the correction factors similarly as for YZ plane and X-direction. Finally,

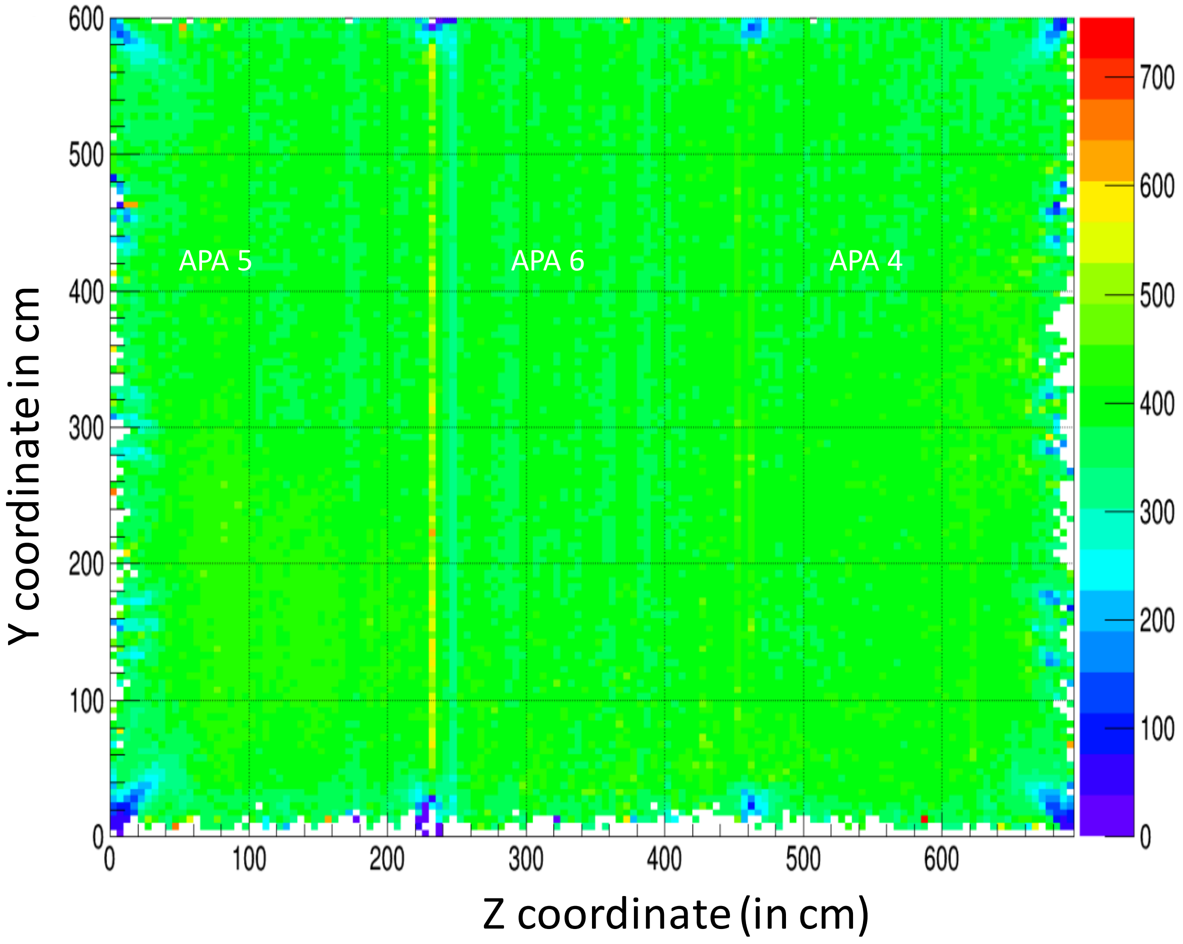
$$\mathbf{(dQ/dx)corrected=(dQ/dx)reconstructed*C(y,z)*C(x)*C(time)}$$

Results: dQ/dx distribution for YZ plane

Plane 2(Collection Plane), X coordinate<0 (beam right)



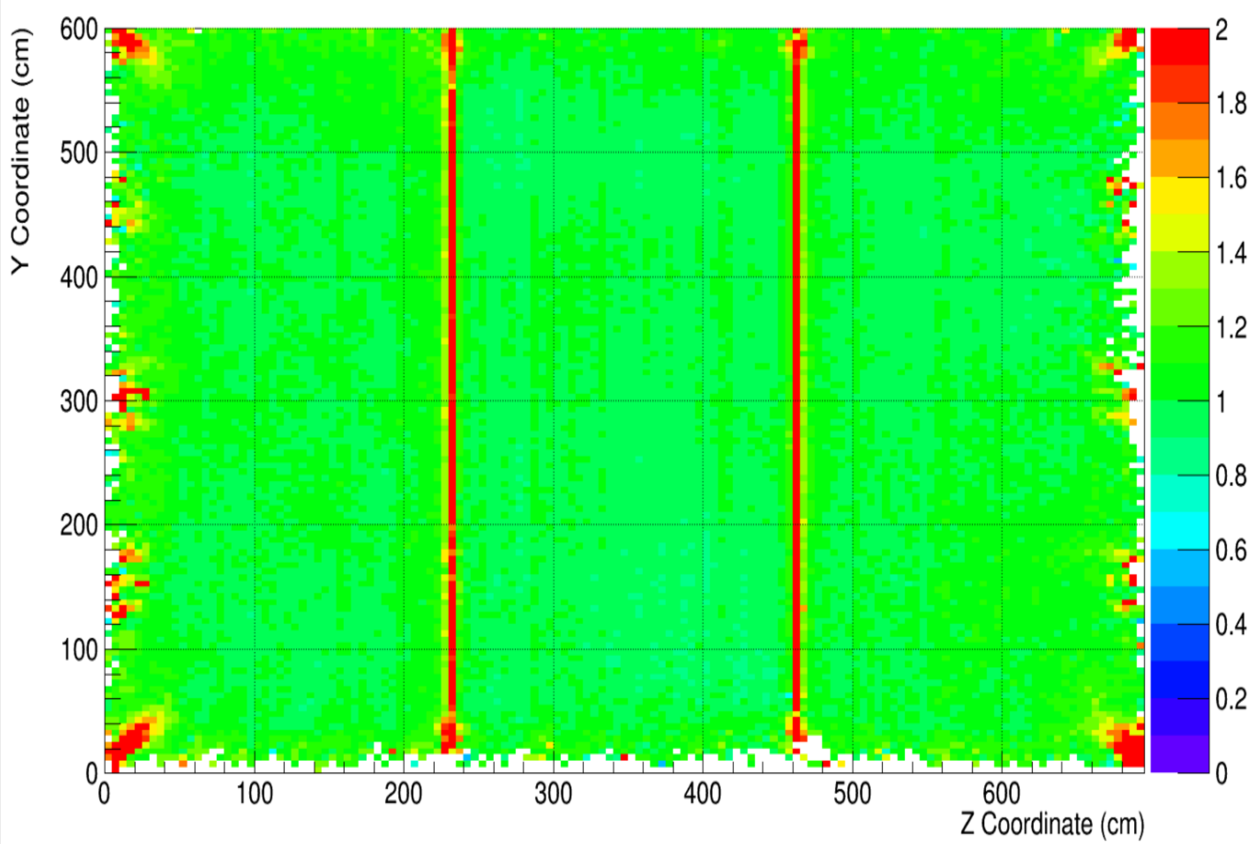
Plane 2(Collection Plane), X coordinate>0(beam left)



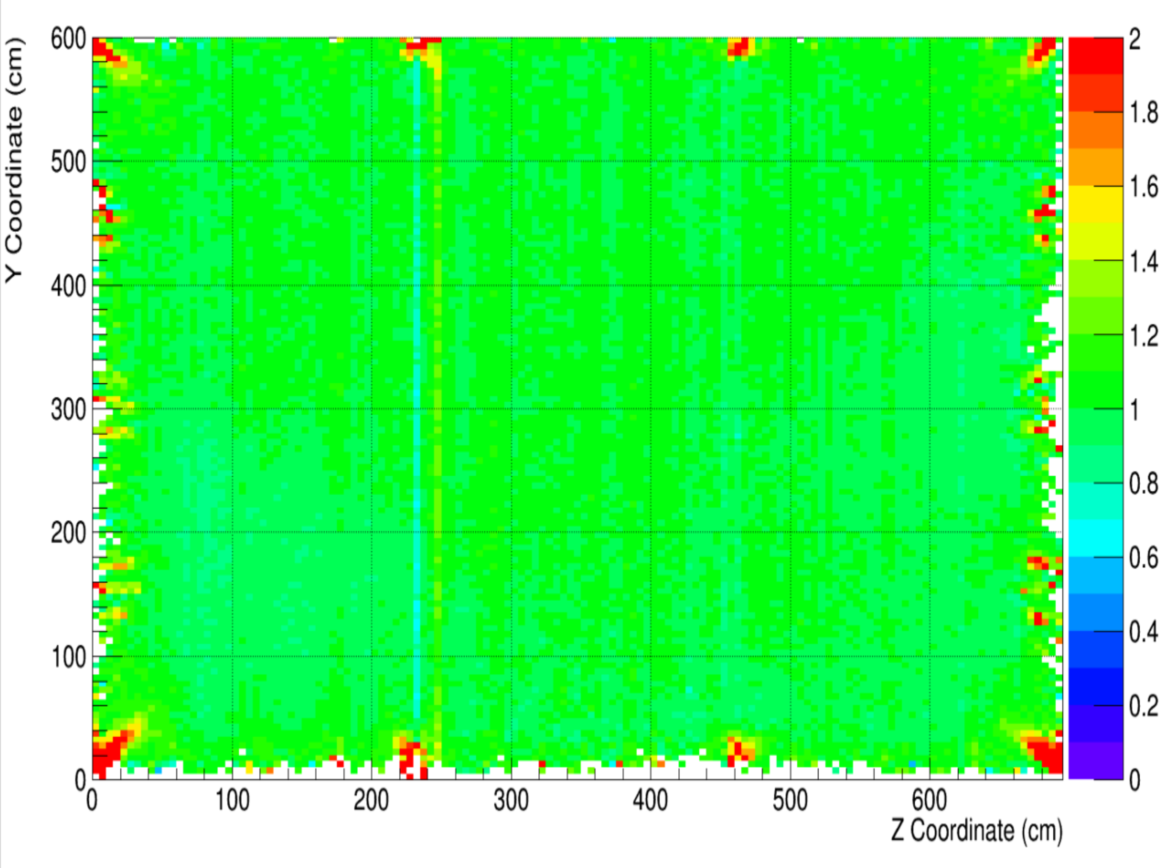
The above plots shows median dQ/dx values for each 5cm x 5cm bins for YZ plane. We can observe that for the left plot dQ/dx values around the APA boundaries are unusually low.

YZ correction factors: Plots shows correction factors as a function of Y and Z coordinate

Plane 2, Xcoordinate<0



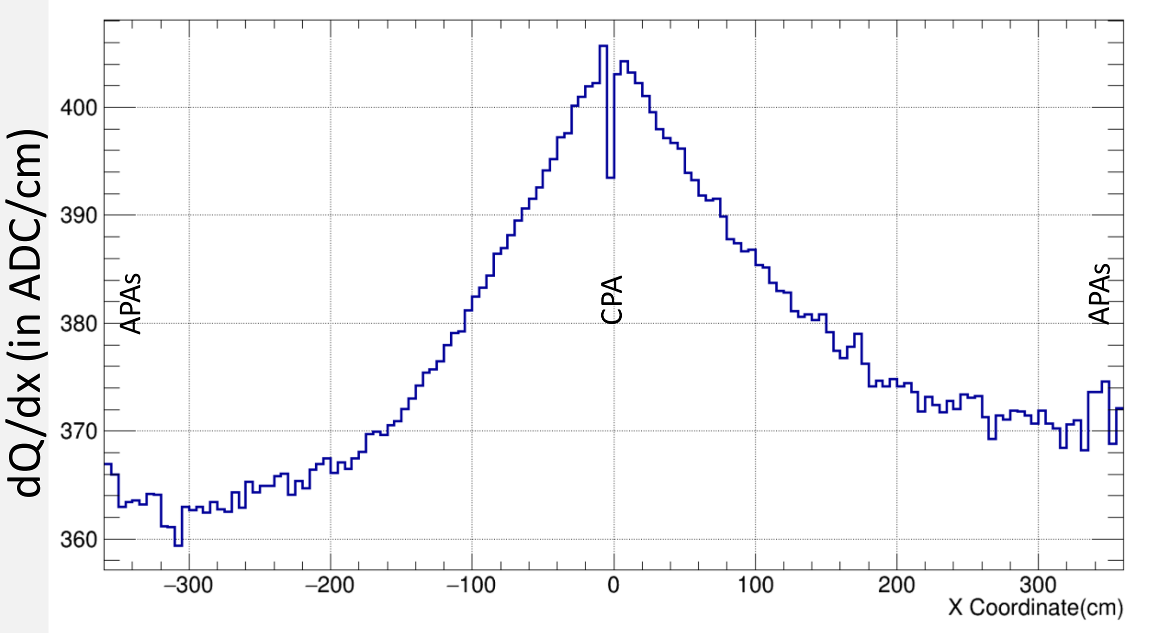
Plane 2, Xcoordinate>0



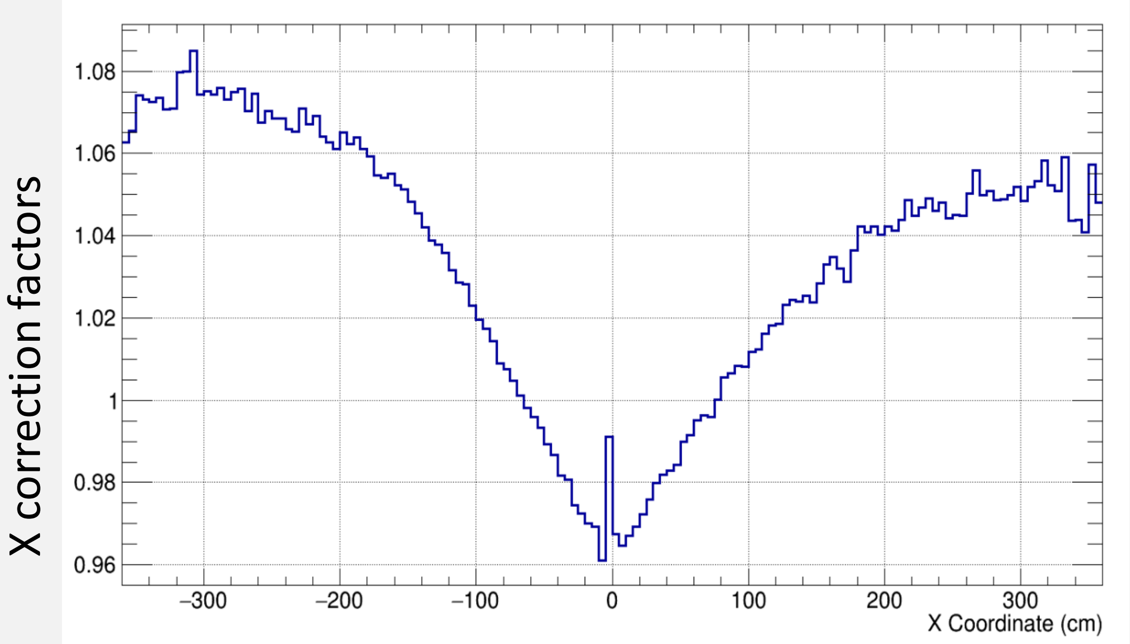
Around the APAs and in some edges of TPC correction factors are very high(exceeds the scale shown in the plot)

X correction:

Left Plot: median dQ/dx value for each 5 cm bin along the drift direction



Right Plot: X correction factors for each 5 cm bin along the drift direction



From the plot on the left we can see that dQ/dx values at the cathode is higher than at the anode, this could be attributed to Space Charge Effect.
This is very different from what we observed for 3ms_lifetime_SCE_ON_sample for MCC10. It appears at high purity effect of SCE is even higher.

For ProtoDUNE data global median dQ/dx value ≈ 390 ADC/cm
while for MCC10 Monte Carlo sample global median dQ/dx value was ≈ 181 ADC/cm

Calibration as a function of time:

Here we plan to divide the data into 4hour intervals and derive correction factors for each time period accordingly.

I am currently working on this, there are no results to show at this time. Although for today's talk I have used a single run so the dQ/dx behaviour (lifetime) is not expected to vary significantly for this period.

dE/dx calibration: (Details of our dE/dx calibration methodology is in reference in slide 2, here I will focus on the results with protoDUNE data)

-We use cathode crossing Stopping muon sample for dE/dx calibration

-We remove the **broken tracks** in our analysis module(details in previous talks)

Boundary cuts:

Start of the track should satisfy:

start_condition=abs(X coordinate)>330cm or Y<50cm or Y>550cm or Z<50cm or Z>645cm

End of the track should satisfy:

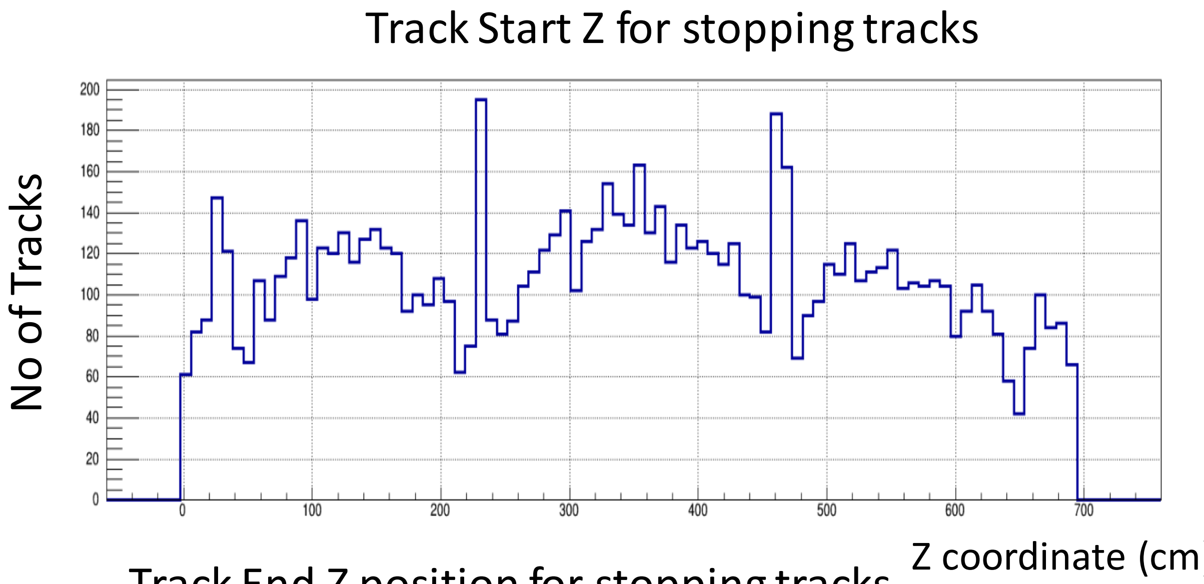
end_condition=!(start_condition)

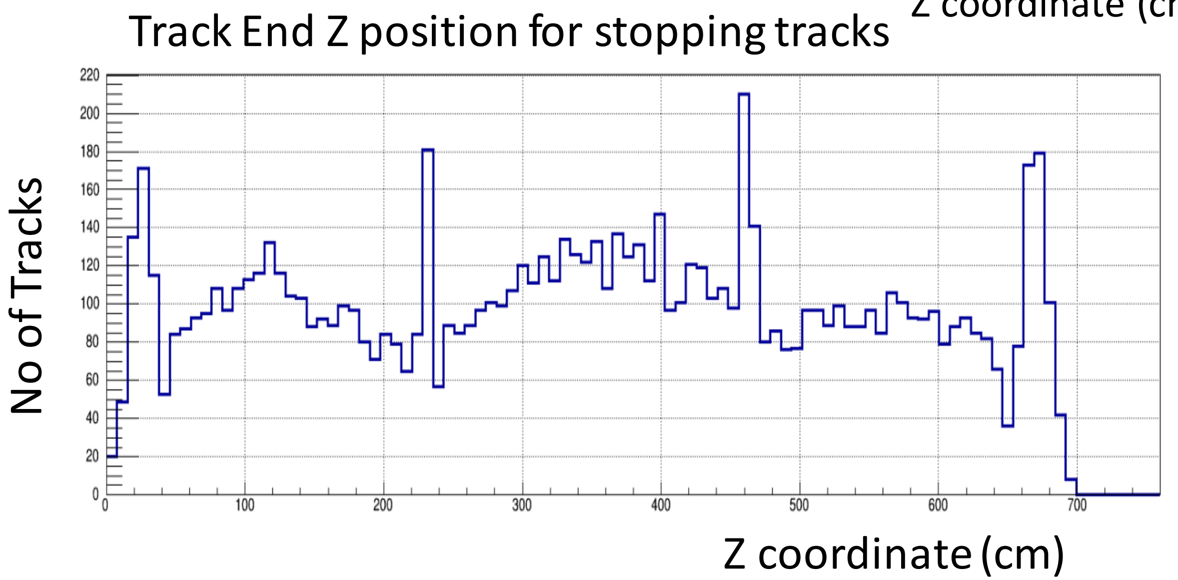
Further, from the plots aside we see that the maximum number of stopping tracks start or end around the APA boundaries, majority of those tracks are broken tracks. So we remove those tracks. To be more specific I removed the tracks with,

226cm<Z<236cm , for Z=Z_end or Z_start

Or

456cm< Z<472cm, for Z=Z_end or Z_start



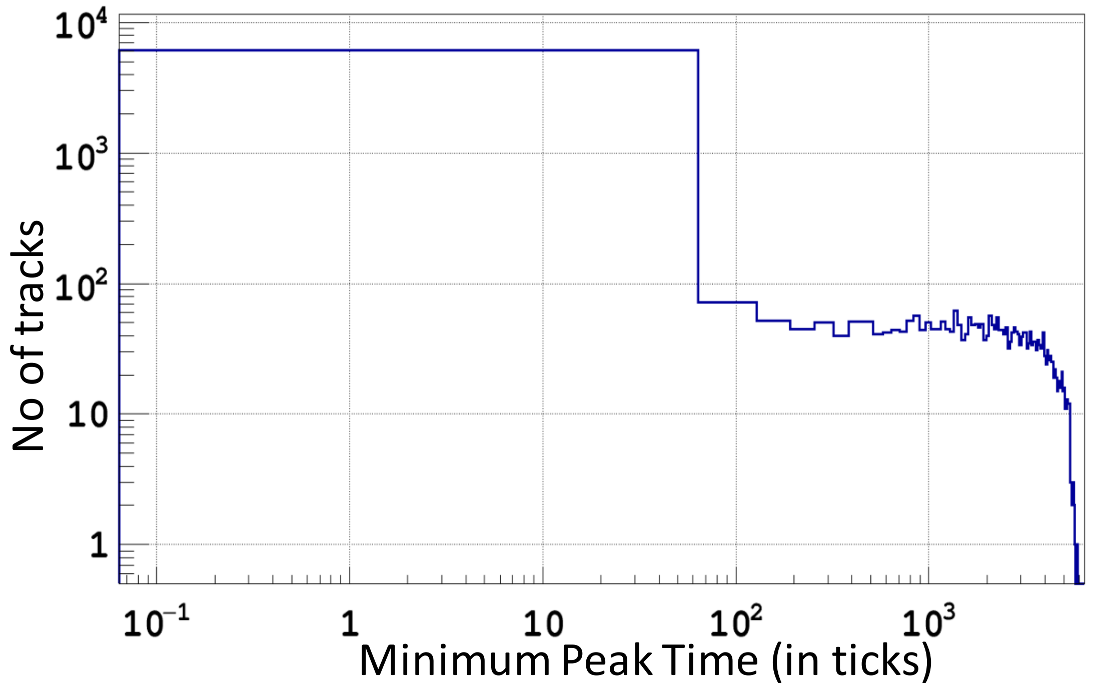


Removing Early Tracks:

Tracks present in the TPC before the beginning of the time window are removed based on the minimum value of hit peak Time for all hits in a track(Hit::PeakT(), time of the signal peak in tick unit),

From the plot aside we can see that over 6000 tracks have minimum PeakT<=50 ticks

In our analysis We are removing all tracks with minimum **peakT<100 ticks**



Data Sample for dE/dx calibration:

Run_number 5460 ; Number of Events:21852 ; Stable run for 10hrs; HV=180 kV; Beam momentum:1GeV

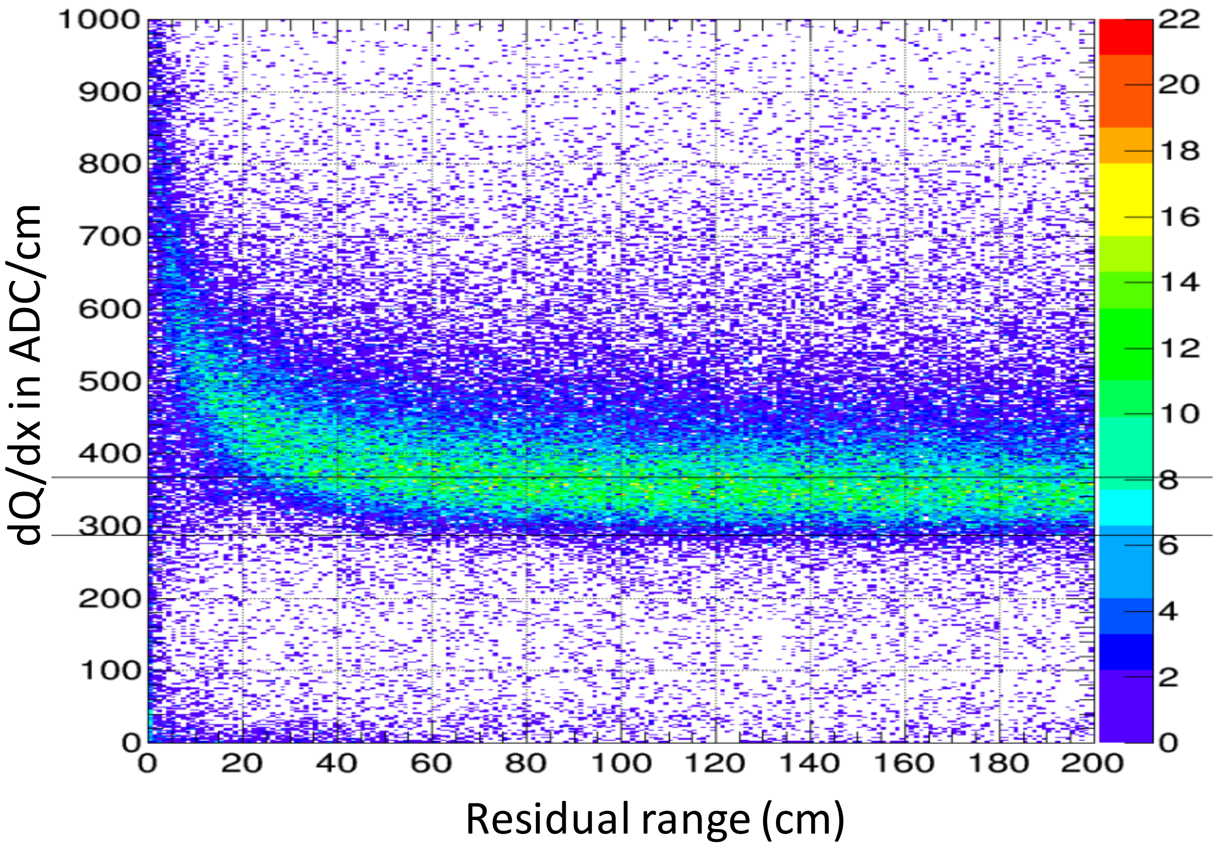
T0 tagged tracks:42261; No of total tracks with one end inside the TPC = 17492; Number of good stopping tracks (not broken) =9230; Tracks removed as early tracks ≈6100;

Number of stopping tracks finally used for the analysis after all the cuts:666

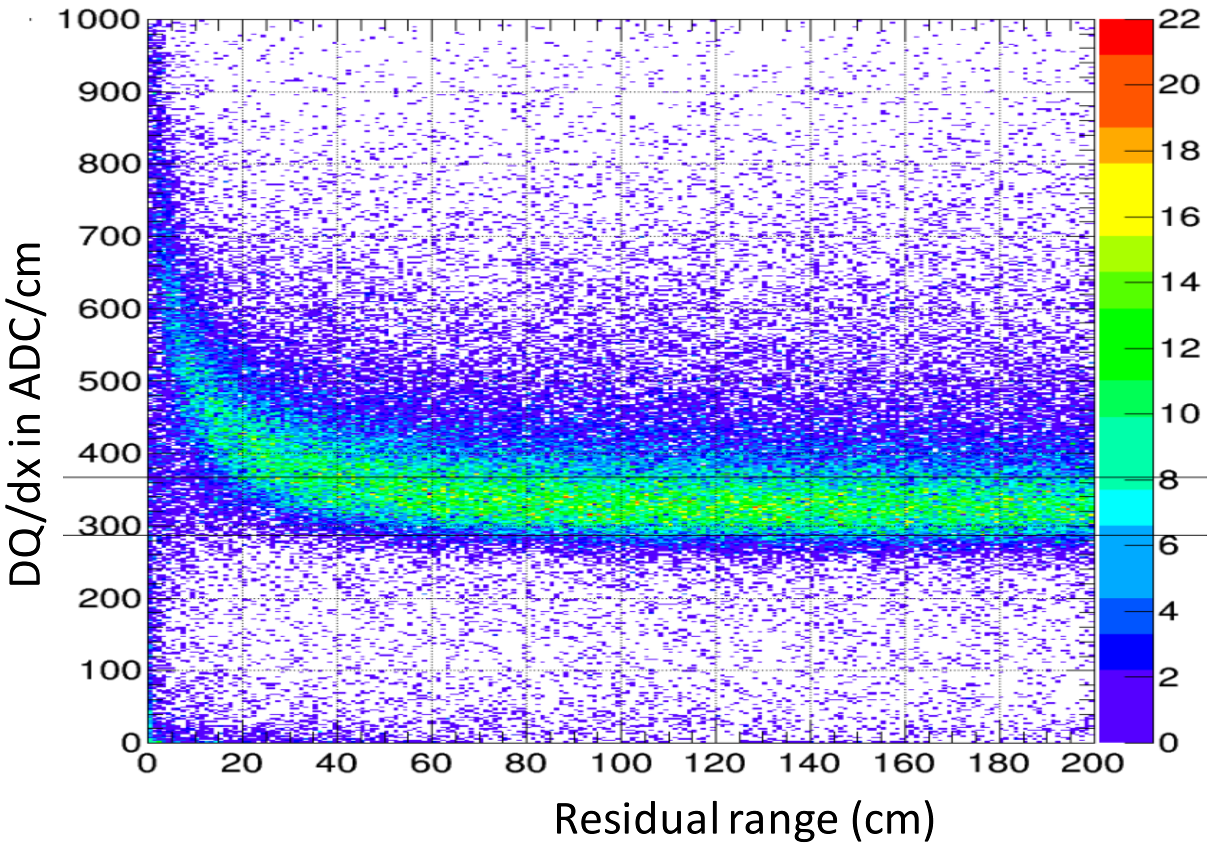
Below are the plots for dQ/dx(uncorrected and corrected) vs residual range for the stopping muon sample after all the cuts:

Plots are for Plane 2(Collection Plane), total no of tracks=666

uncorrected dQ/dx vs residual range

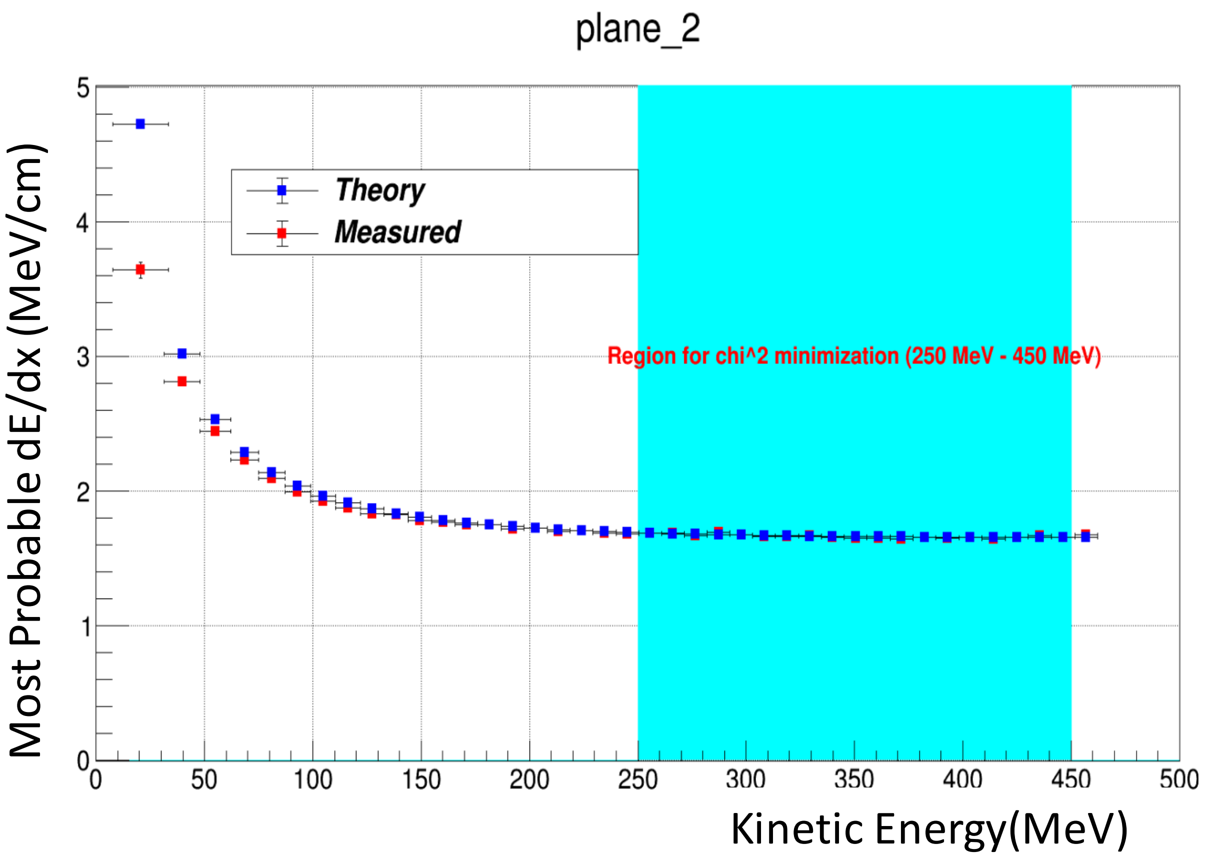


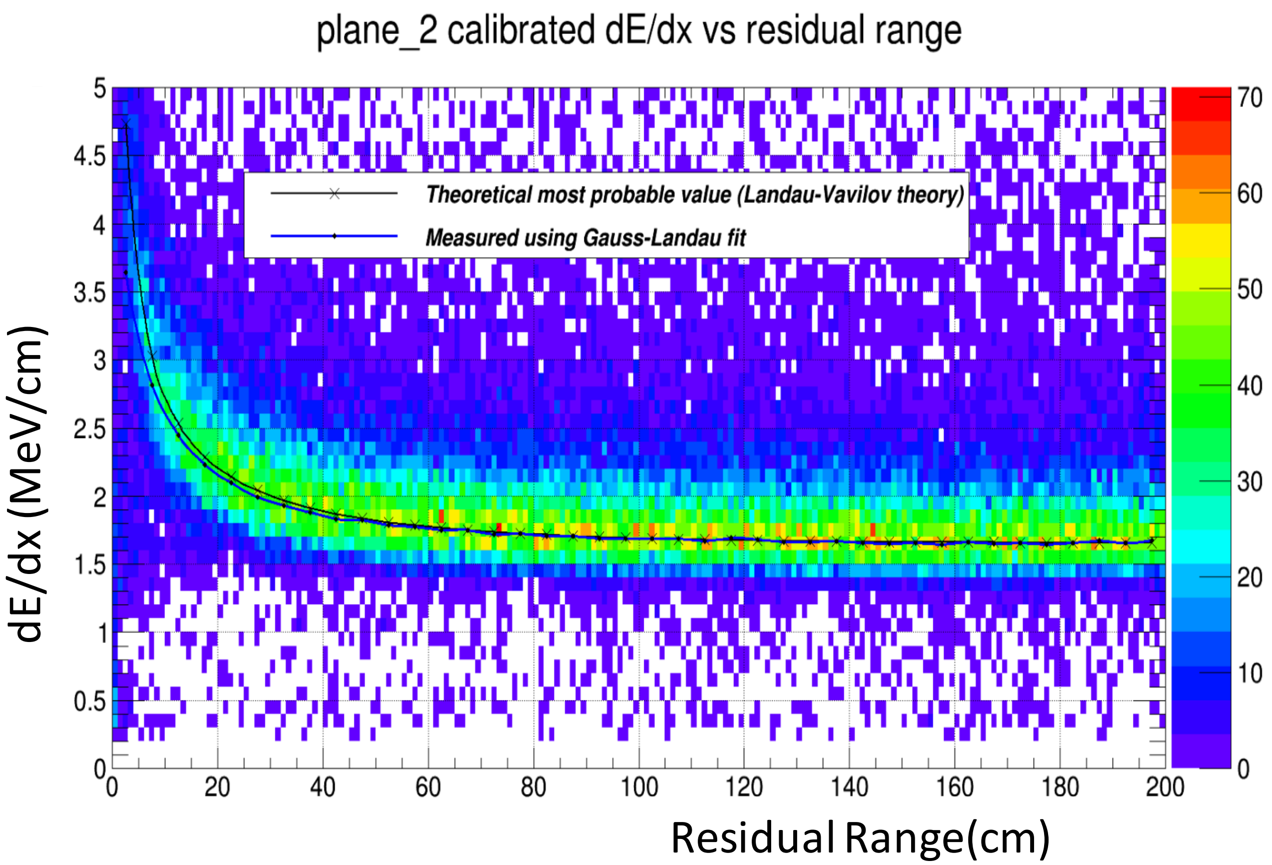
Corrected dQ/dx vs residual range



dE/dx calibration results:

We calculated the calibration constant comparing most probable dE/dx for stopping muons from data with most probable dE/dx predicted by Landau-Vavilov theory. Following plots use calibration constant=6.3e-3





At high dE/dx there is some discrepancy between observed and theoretical values, similar to what we observed for SCE ON Monte Carlo sample. We expect the results to improve further after the sample is calibrated for Space Charge Effect distortion.

Summary and Future works:

- We are able to get the stopping muon sample using similar approach (using identical cuts) as for Monte Carlo
- Next we will also include the calibration factors as a function of time (or run_numbers)
- We will repeat our analysis for larger dataset and for all the three wire planes.
- Plan is to test the muon-based calibration constant on 1GeV stopping proton sample soon

THANK YOU

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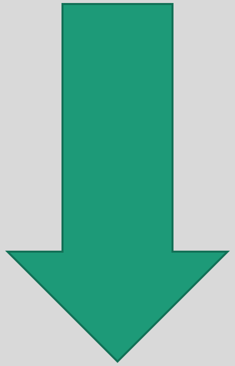
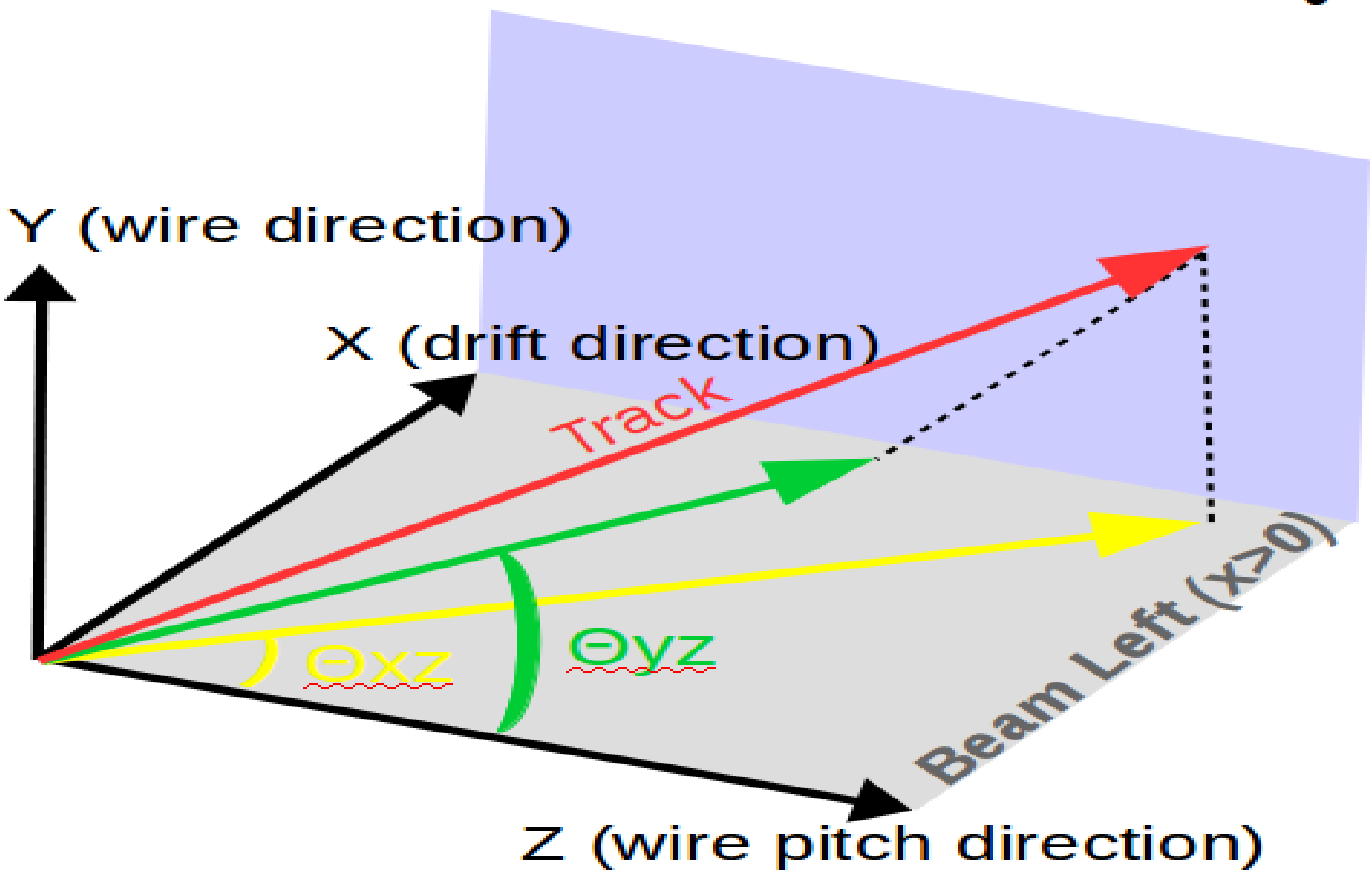
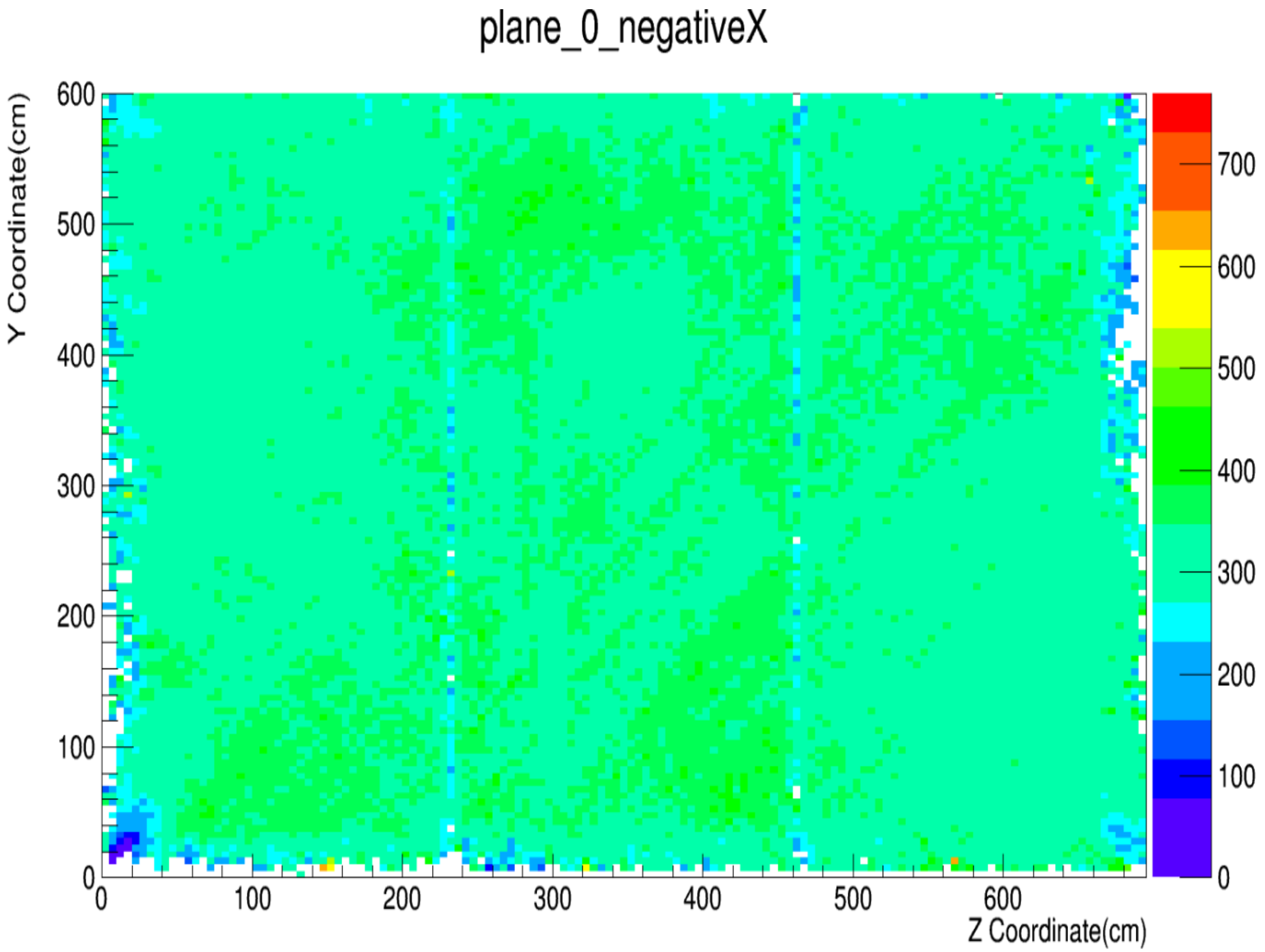
Back up Slides

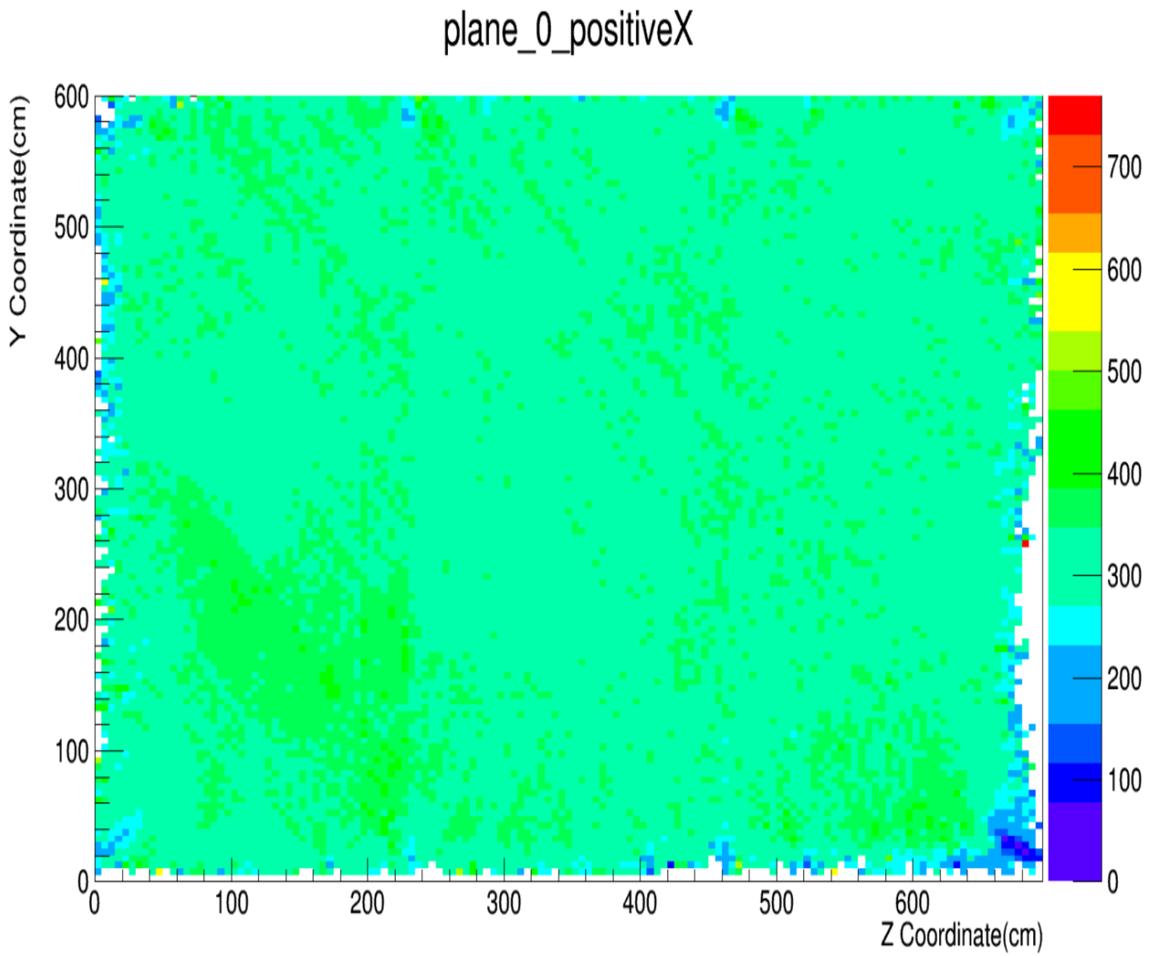


Definition of Theta_XZ and Theta_YZ



Plane 0, Plot shows dQ/dx distribution for YZ plane

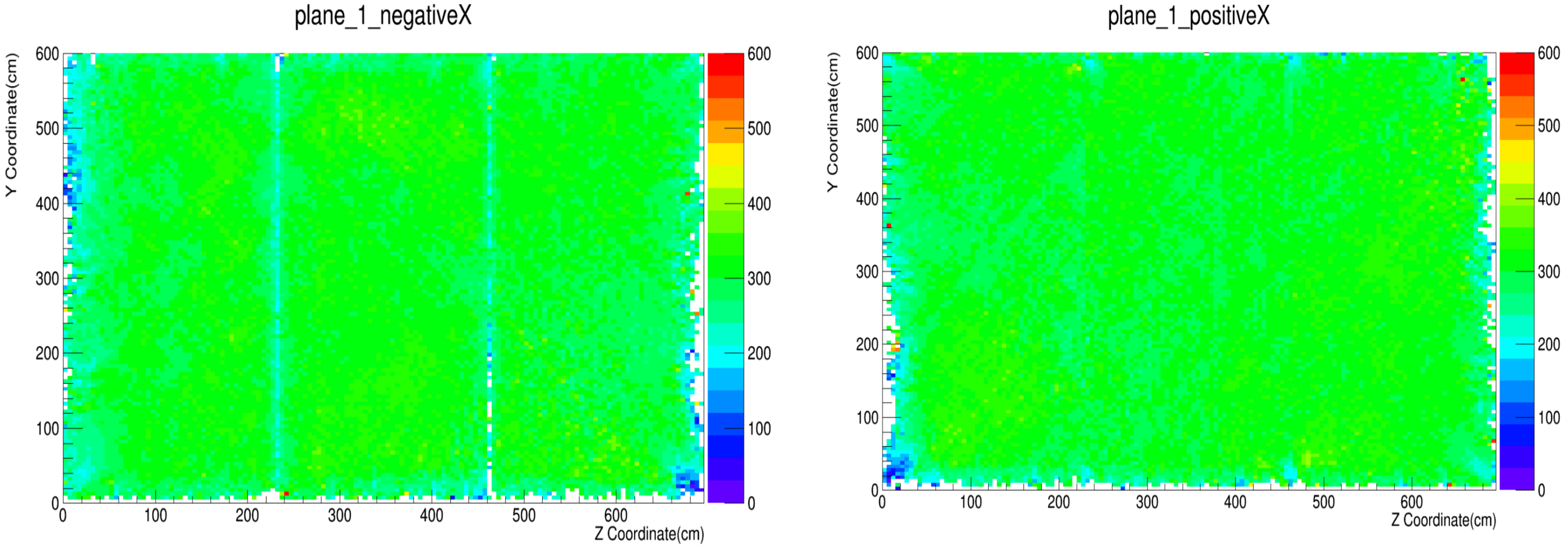




Number of events=20906

On the beam right a few bins with no signal can be seen along the APA boundary

Plane 1, Plot shows dQ/dx distribution for YZ plane



Number of events=20906

On the beam right a few bins with no signal can be seen along the APA boundary

Note: I have used different scale for plane 0 and plane 1 plots.