Measuring ionization electron drift velocity using cathode-anode crossing cosmic muons

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Outline of the talk:

- Brief Introduction ---> Efield dependence of drift velocity
- Track selection + Methodology details
- Results using MCC11 samples
- Results for 2 ProtoDUNE data runs (run 5387—Oct 17, 2018 and run 5809—Nov 08, 2018)
- Summary

Any comment or suggestion is very welcome.

Brief Overview:

We can calculate the drift velocity at a given temperature and Electric field using the relation:

Drift_velocity=(P1*(T-T0)+1)*(P3*Efield*log(1+P4/Efield)+P5*pow(Efield,P6))+P2*(T-T0)

ICARUS parameters used as default for LArSoft in our region of interest (0.4kV/cm-0.6kV/cm)

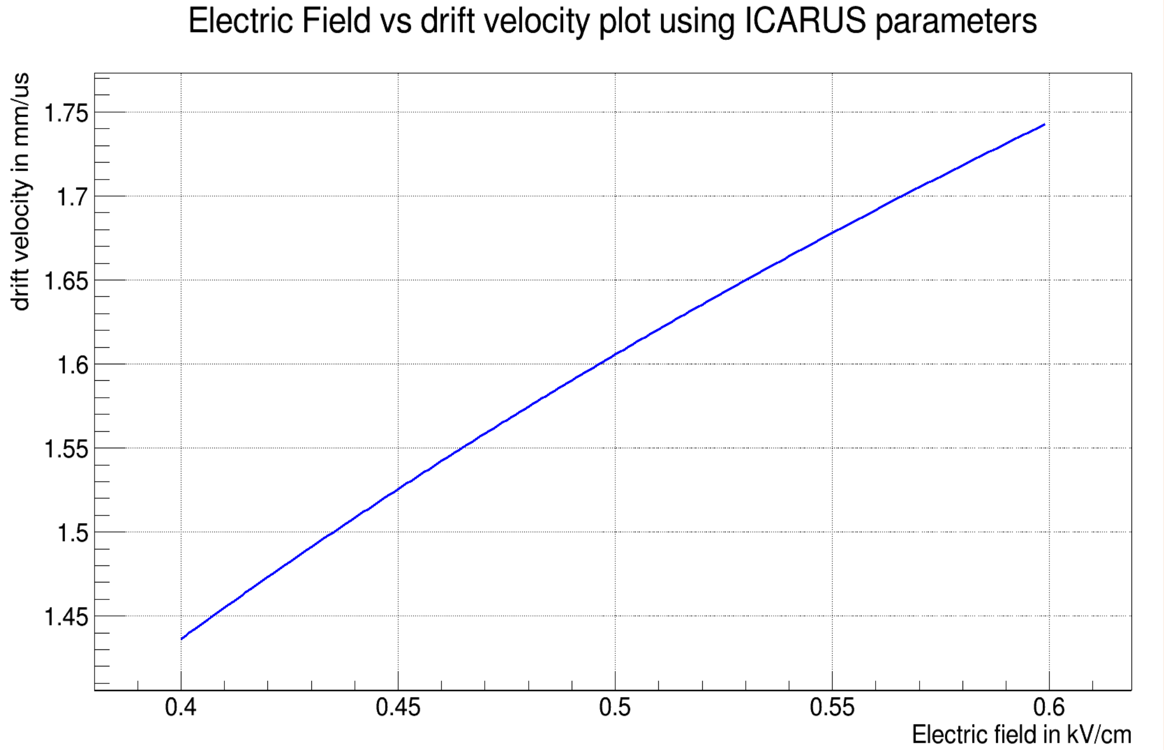
P1=-0.04640; P2 = 0.01712;

P3= 1.88125; P4 = 0.99408;

P5= 0.01172; P6 = 4.20214;

T0 = 105.749;

While at higher Efield Walkowiak Parameters are used. Details of the parametric form at different Efield and temperature can be found in link at the bottom. Which I used for conversion between Efield and velocity.



At Efield=0.5 KV/cm (input Monte Carlo Electric Field for Protodune MCC11) and Temperature, T =87K (input Monte Carlo temperature for MCC11) from the above relation:
drift velocity=1.60563 mm/us [this can also be obtained using DetectorProperties in LArSoft]

- http://nusoft.fnal.gov/larsoft/doxsvn/html/classdetinfo_1_1DetectorPropertiesStandard.html#a21a284c550d2f03bc193b1b43ab8e13e

Space-Charge Effect causes a non-uniform Efield

For a surface LArTPC like ProtoDUNE there are plenty of cosmics incident on Liquid Argon thus creating ion-electron pair throughout the TPC. While electrons are quickly collected at the anode, positive ions drift slowly towards the cathode thus introducing a non-uniform field.

Due to non-uniformity in drift field we have a non-uniform drift velocity inside the TPC. Measurement of correct Efield and drift velocity are very important for detector calibration and Energy scale measurement.

Here we are measuring the drift velocity using cathode-anode crossing cosmic muons.

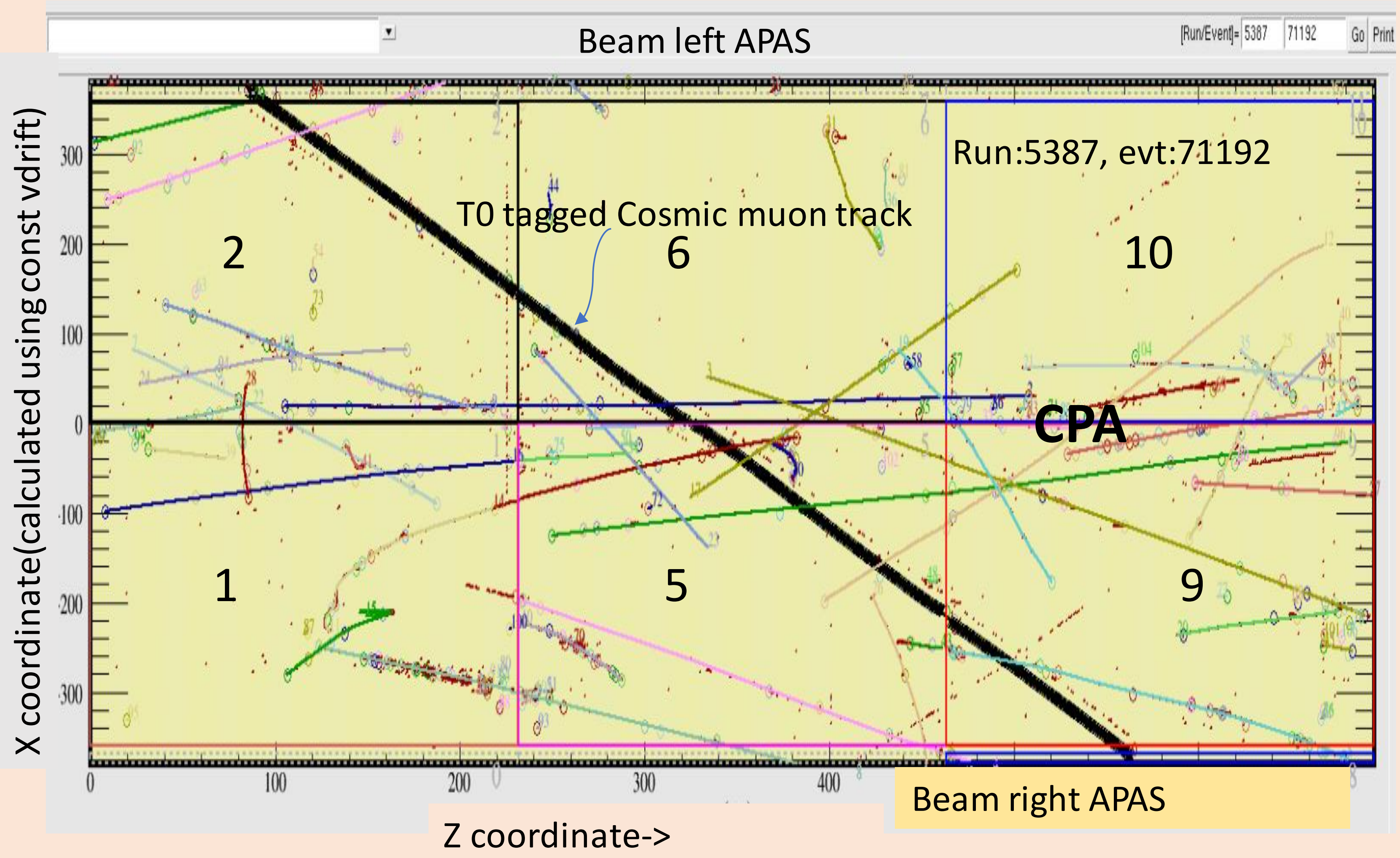
Next few slides describes our selection, Methodology and results:

Track Selection:

we use t0 associated tracks. In principle for this method to work we don't need t0 information as we are relying only on hit peak Time information and not on X-position.

We are using cosmic muon tracks which cross both CPA and APA so that the start and end X position of the track is known.

Here is an example of a track which is crossing CPA and both the APAs (But for our study crossing one APA is enough)



We are calculating velocities separately in positive and negative X direction:

For Positive X coordinate(beam left):

Make a collection of hits lying in TPC 2, 6 and 10. Find the hitpeak time and the wire number (or z coordinate) of each hit.

Find the time difference (deltaT_max) between the first and last hit on the track and belonging to TPC 2, 6 and 10.
Make a plot of deltaT for all tracks in the dataset.

For beam right: Do the same as above while using TPC numbers 1, 5 and 9.

Plots showing deltaTmax for all the t0 tagged tracks: The following is the plot of deltaTmax (time difference between the first and the last hit on a track in a drift region in ticks) vs no of tracks.

1 tick=0.5micro-sec

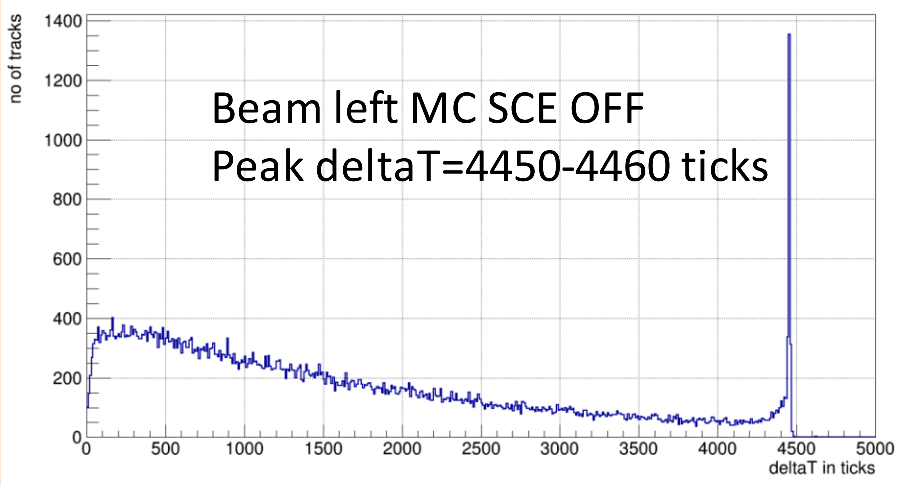
At the end of the deltaT coordinate we can see a sharp rise in number of tracks, those are CPA-APA crossing tracks. Based on the peak deltaT we select the tracks for our analysis.

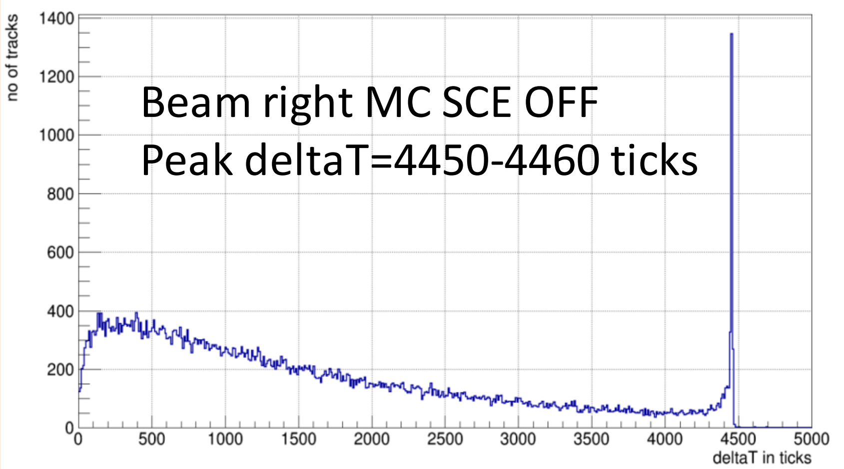
The vlaues for peak deltaT shown includes only the sharp peak region in the distribution . But there are many CPA-APA crossing tracks in regions of deltaT±10 ticks

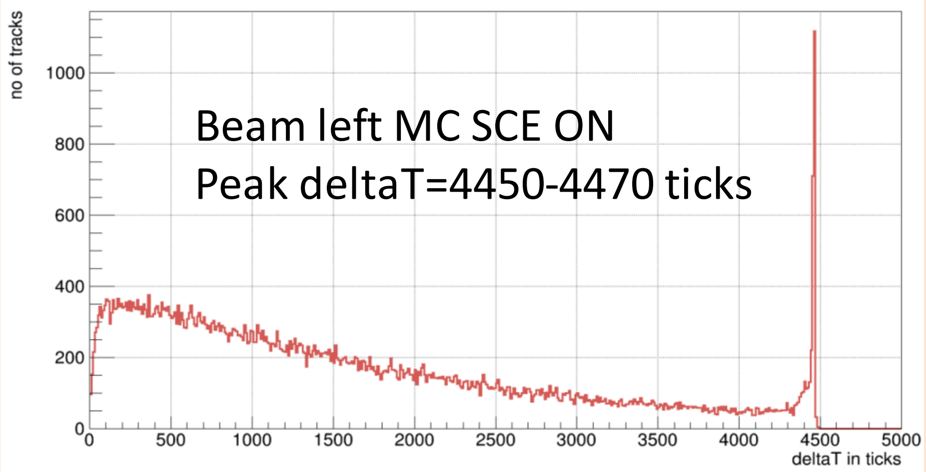
Also, for comparison, at nominial field:
Using, drift distance=3600mm
And vdrift=1.60563 mm/us
DeltaTmax=2242micro-sec
=4484 ticks

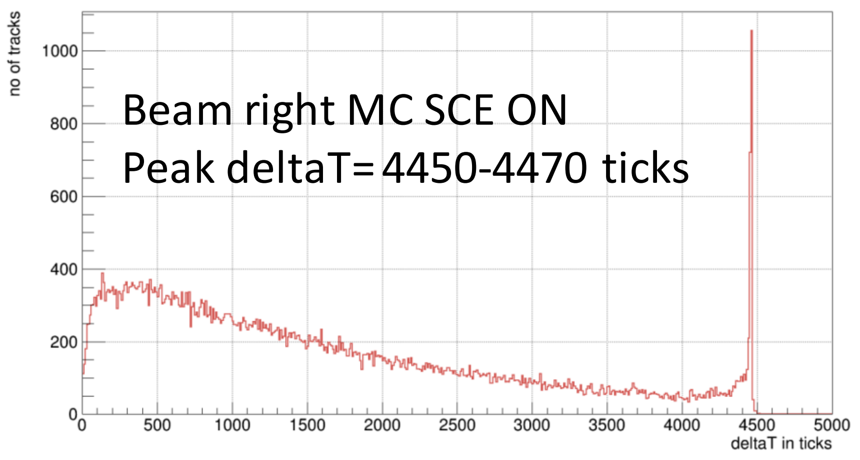
From this study I believe we are losing atleast ~15 to 25 ticks somehow
At vdrift=1.60563mm/us
Distance not accounted for=12mm-20mm

Wire pitch= 4.792 mm for collection plane which causes some uncertainty
+CPA width?
+Resonstruction issues? Or any other reason?







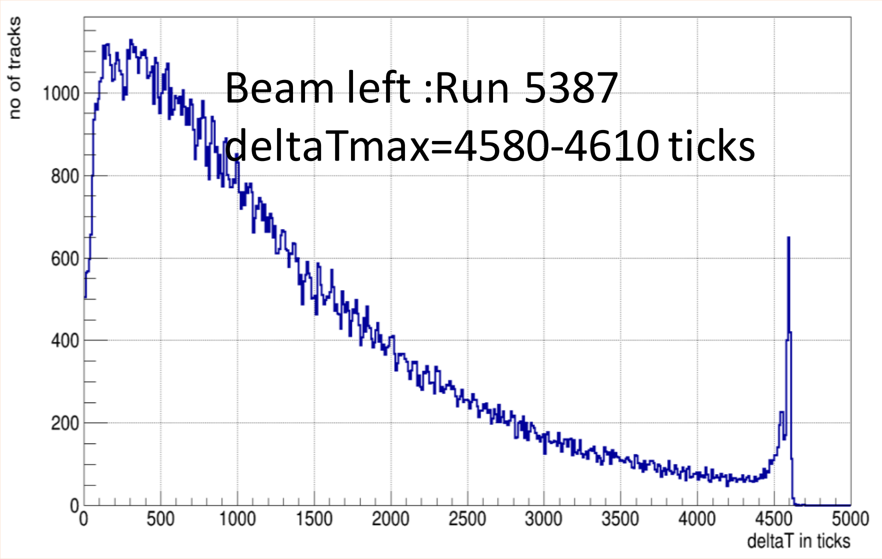


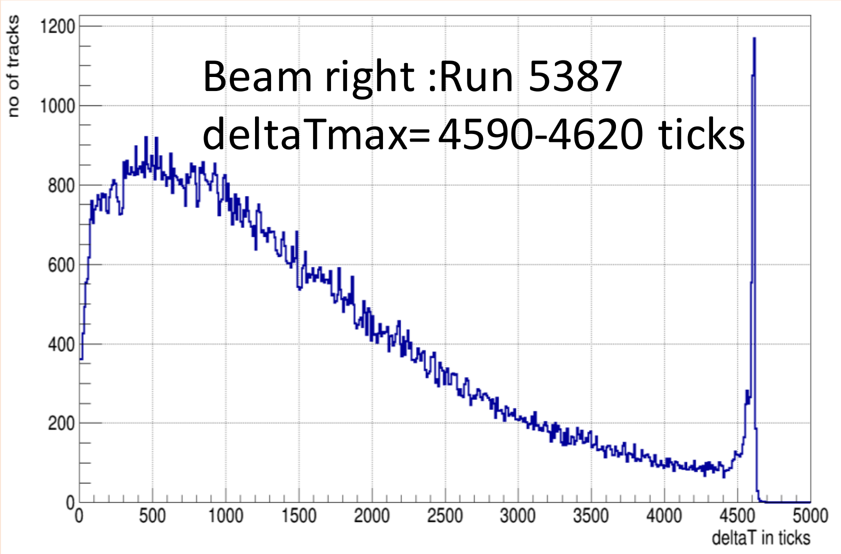
DeltaTmax vs no of tracks plots for proto-DUNE data:

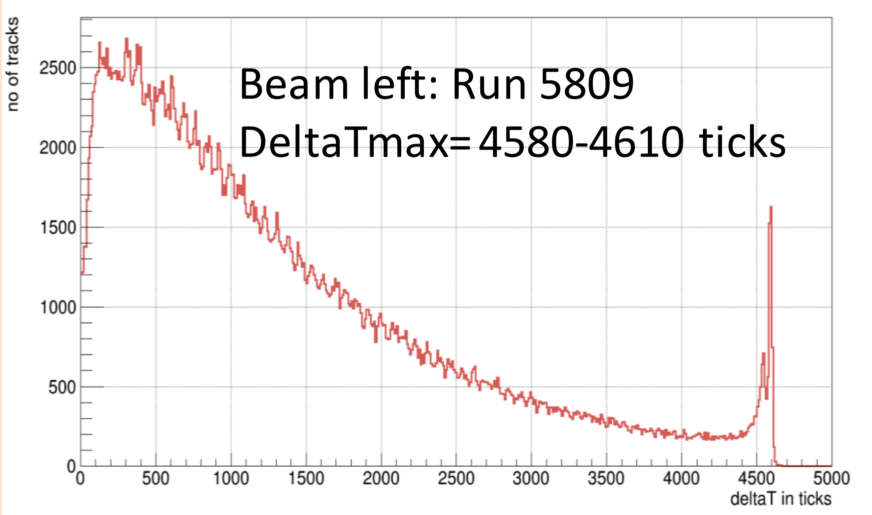
We can see that the maximum peak Time is higher for data then MC samples implying lower average drift velocity and Electric field

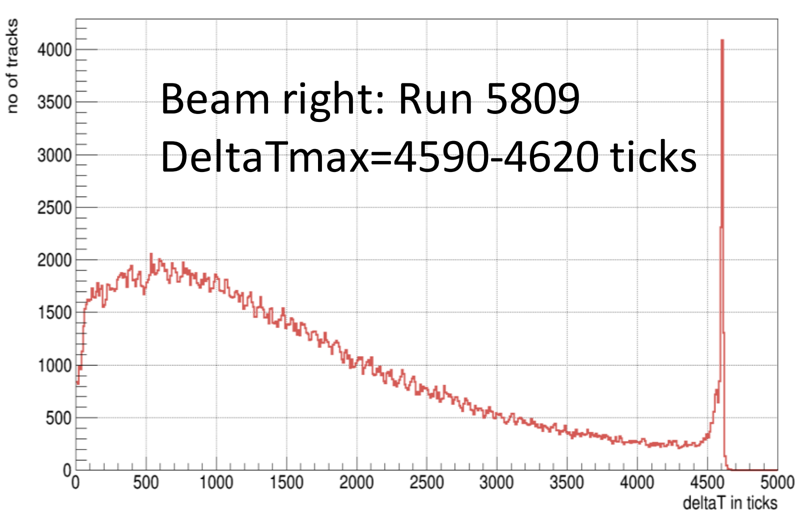
At nominial field:
In terms of distance 4600 ticks= 2300us* 1.60563mm/us ≈ 3692mm

Low number of CPA-APA crossers on the beam left could be because all the FEMBs mights not be ON in beam left, while beam right being where the beam is it was made sure all the FEMBs are turned on on that side. Need further investigation.









Now we have a collection of cathode-anode crossing tracks for each sample.

For a particluar tracks: We know the **peak Time** of each hit and also the wire number (which gives us Z position).

For drift velocity --------> need X position of the hit as well? As X position(drift position) is not directly measured in LArTPCs, we used the wire number(or equivalently Z coordinate of the hit) to get the approximate X position of the hit.

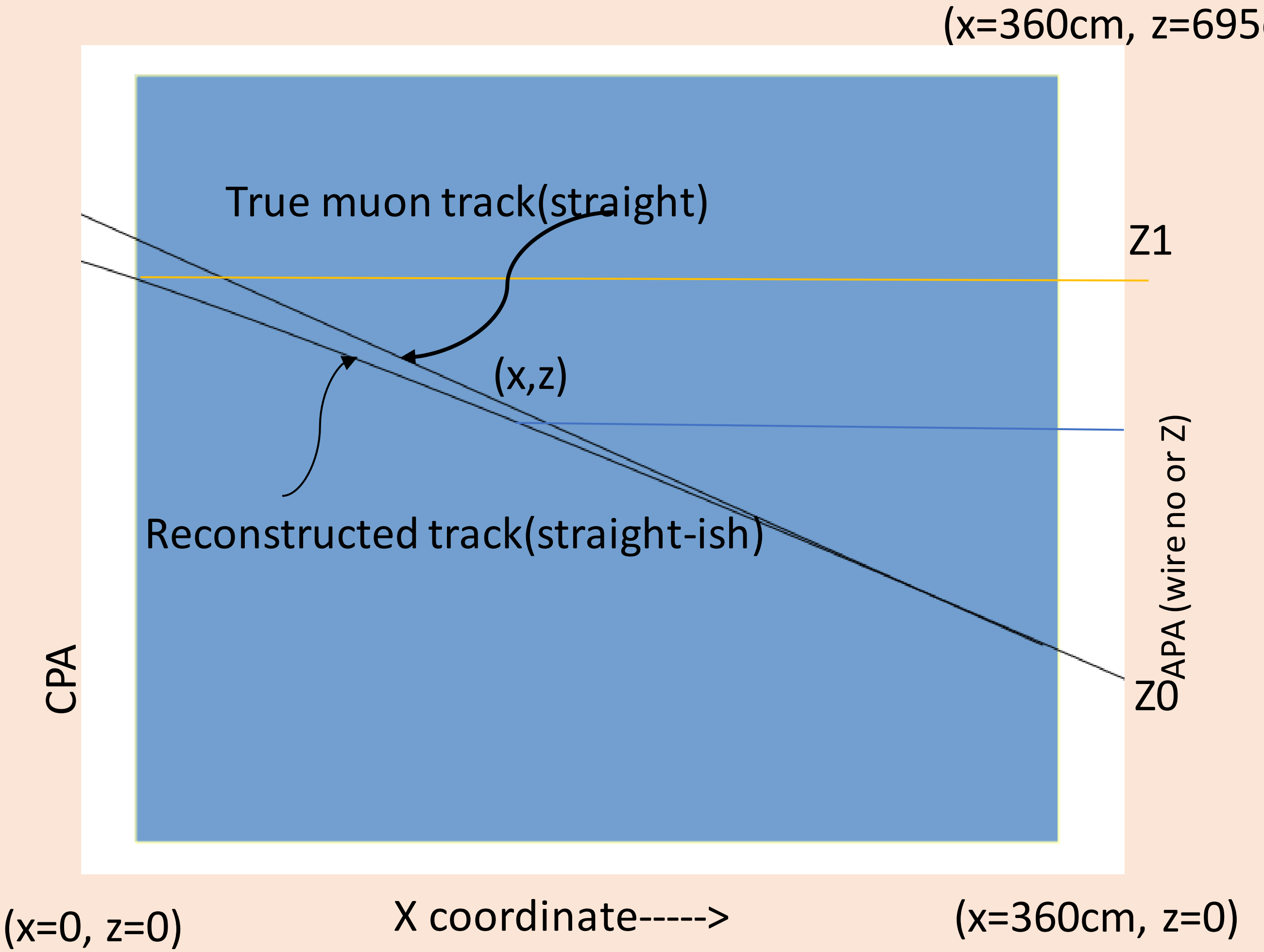


Fig aside shows the projection of a track on XZ plane.
top track : true muon track
Bottom: reconstructed track (distorted due to SCE)
Z0 = Z coordinate of the hit closest to APA
Z1=Z coordinate of the hit farthest from the APA
x and z are the x and z position of any arbitrary hit

x/360=abs((Z1-z)/(Z0-Z1))
x=360*abs((Z1-z)/(Z0-Z1))

Higher and higher Efield Z will result in more deviation from straight line and thus the above formula will result in bigger error.

If we take tracks well inside the TPC EField Z is negligible and we can get a good estimate of X position.

Calculating the drift velocity:

Now we know the time and x position for each hit on the track:

In the current analysis I made 45 equal sized time bins. For any track the X coordinate at the beginning and end of a time bin is calculated the difference of which gives deltaX and the corresponding time difference gives deltaT.

Drift velocity=deltaX/deltaT,
I am using truncated mean drift velocity for each time bin:

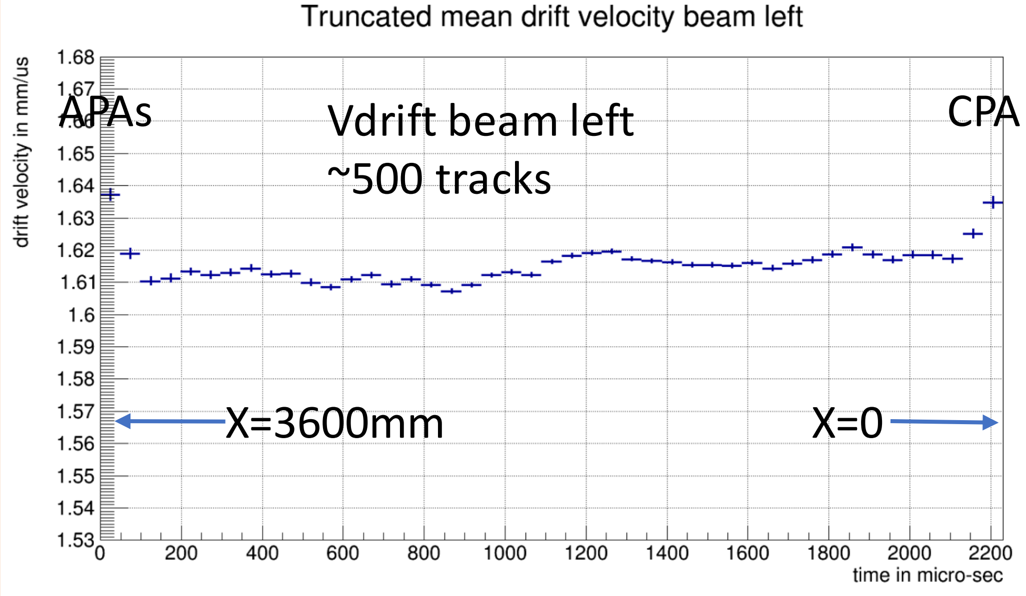
we fill each time bin with the corresponding drift velocity from all the tracks and finally a truncated mean drift velocity for each bin is calculated taking the middle 60% of distribution (ommiting lowest 20% and highest 20% drift velocity values in each bin).

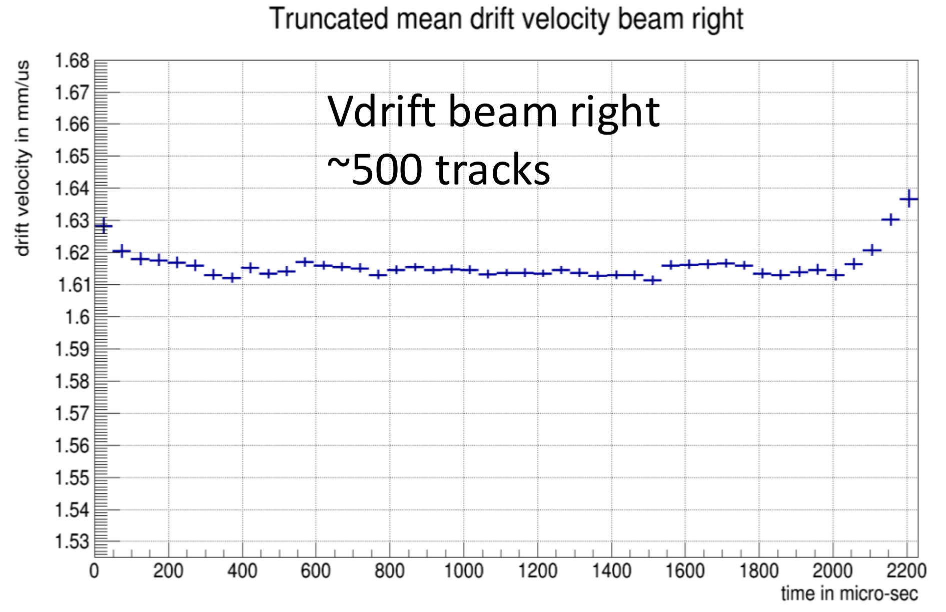
The corresponding EfieldX is calculated using TSpline3 once vdrift is known (based on the relation between vdrift and Edrift described in the link in slide 2).

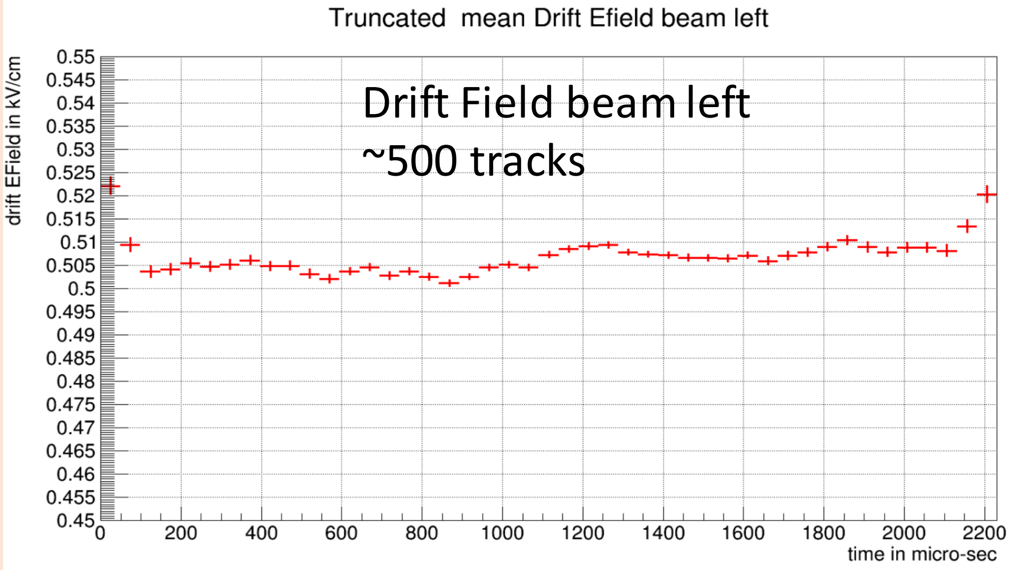
Results using **MCC11 SCE OFF sample:**

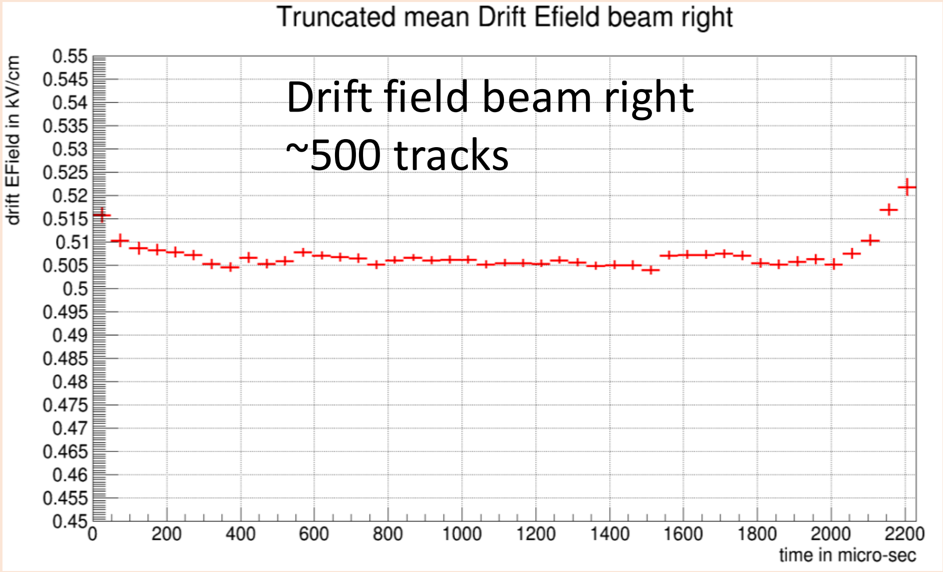
Top plots : vdrift as a function of drift time measured from APA. **Bottom Plots:** Efield calculated using measured vdrift

Time =0 ==> at APA and maximum time value==>CPA









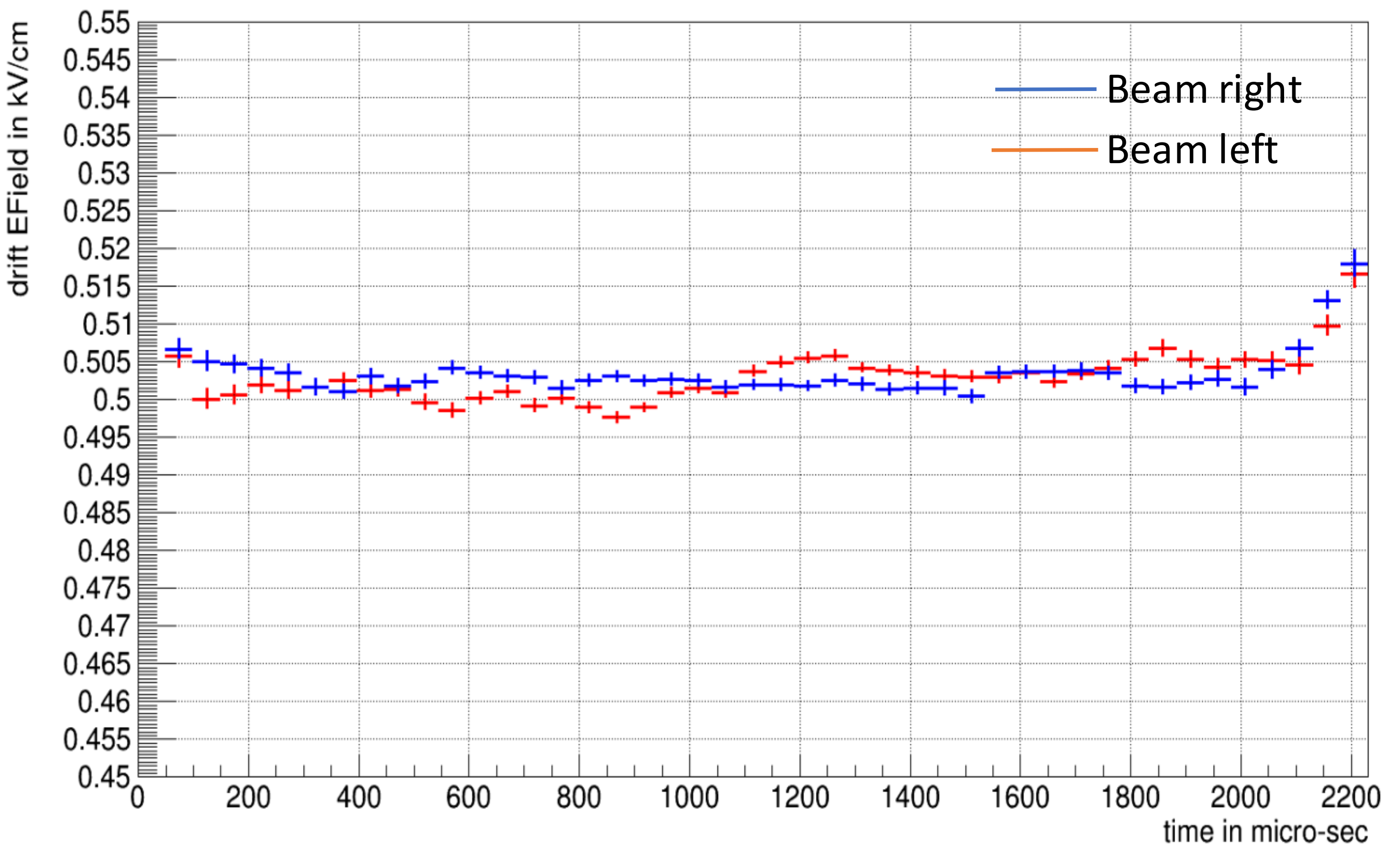
Inputs:
vdrift=1.60563mm/us
Efield=0.50kV/cm

Measured Efield looks close to input Efield with error of 1-2%

except for the bins on the edges of the distribution, which shows a rise in drift-velocity or EfieldX

The Efield values in the previous slide although close to input Efield showed a certain bias, they were always higher than nominial Efield, this could be because of some drift distance we are losing as mentioned in slide 6 .

I again made the Efield plots in previous slide using drift distance =3600-12=3588mm



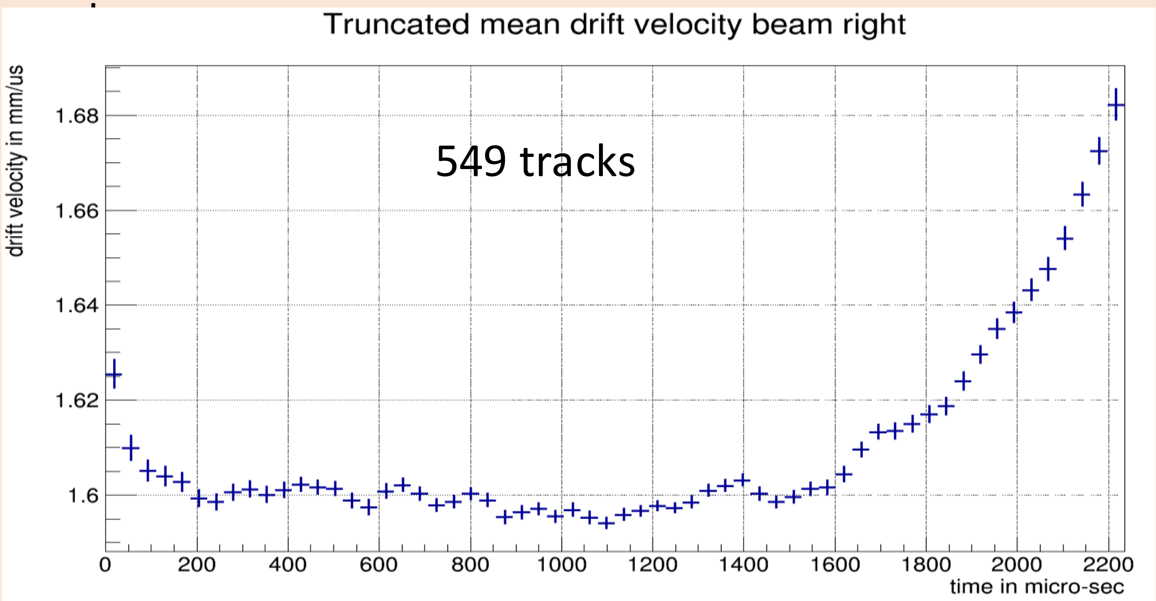
Now we can see for majority of bins measured Efield is within 1% of input Efield

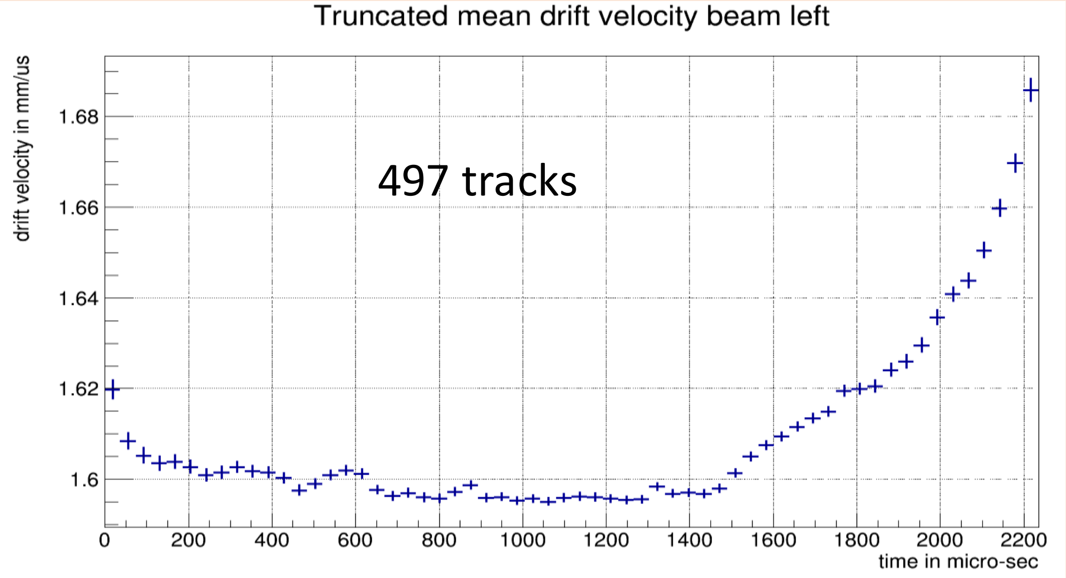
One reason for Disagreement (2-4% off) seen at the two bins could be because deltaT values for the last bin for different tracks fluctuates more than in any other bin.

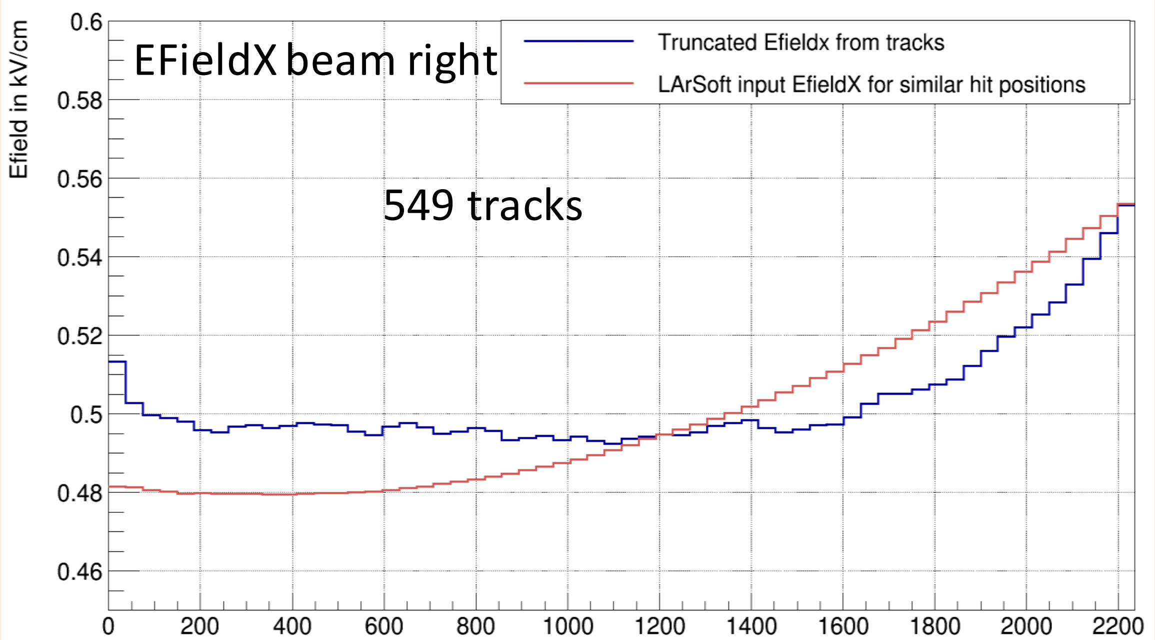
I am currently investigating on other possible reasons

Plots in the previous slide and this are a good test of the method we are using. But as SCE is turned Off in this sample is not close to reality. Next we look at the SCE ON sample which gives a more clear picture.

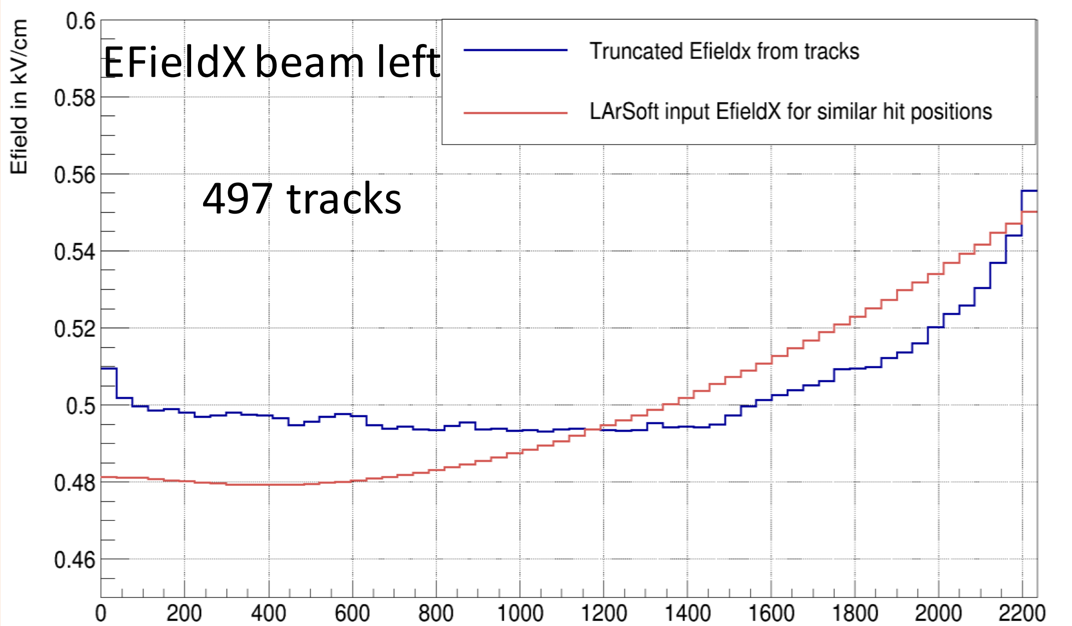
MC SCE sample results: Following plots shows vdrift and Edrift for **SCE ON** sample including all CPA-APA crossing







Time in micro-sec



Time in micro-sec

SCE ON sample continued:

The plots in the previous slide shows a difference of around 4% difference between measured and input EfieldX.
Input EFieldX is calculated using LArSoft SCE services (Thanks to Mike Mooney for the SCE services).

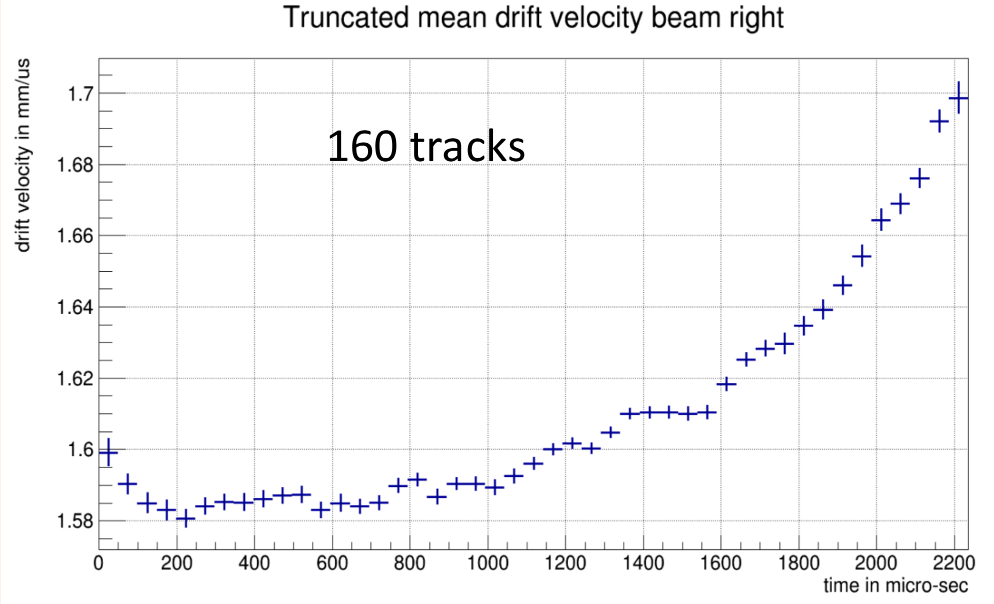
For LArSoft input EFieldX (I only did rough estimate for initial comparison): I calculated the EFieldX at a hit position based on x, y and z position of the hit and filled the corresponding time bin with the EFieldX value, later I took the mean of all the entries in a particular bin, and overlapped the distribution on the track based EFieldX. Details in **backup.**

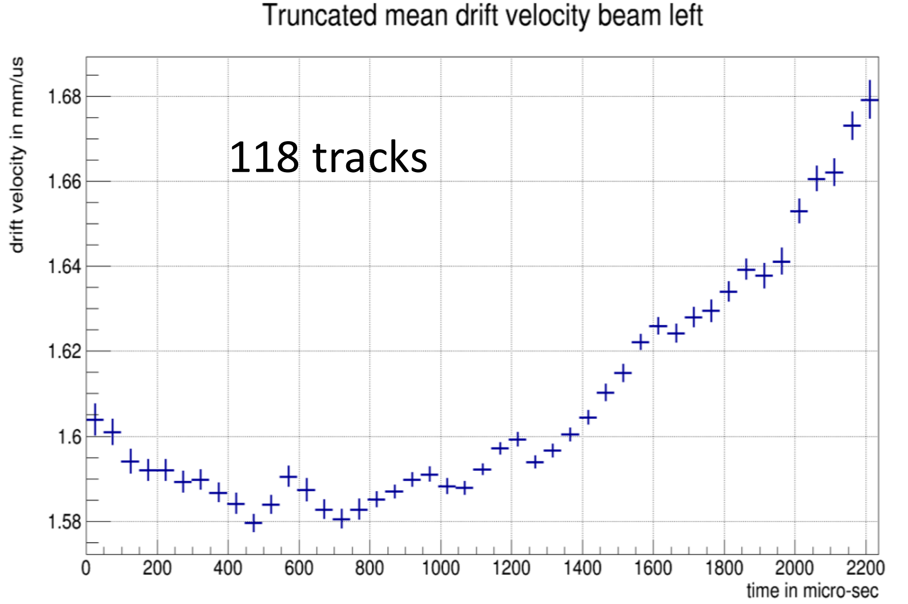
We expected some error in our track-based method, as in the presence of Space Charge Effect there will be deviation along Z direction (especially near the edges) which results in error in X-position.

But we expect this distortion in Z coordinate to be small as we move inside the TPC.

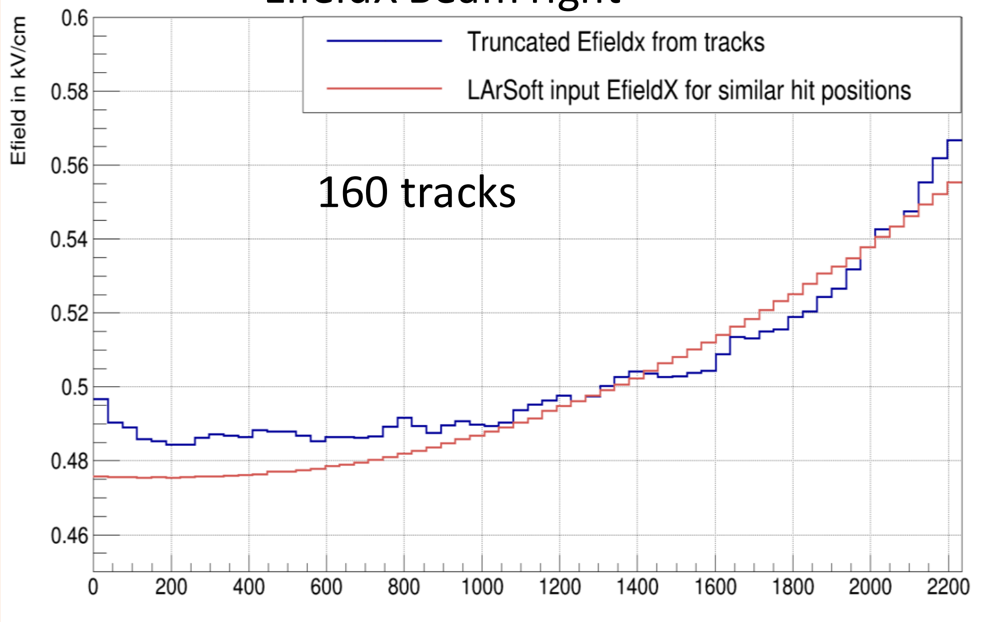
We repeated the analysis using tracks confined to Z coordinate = **250cm-440cm** (idea was to remove APA boundaries too)
and Y coordinate =50cm to 550cm

SCE ON sample with Z=250cm-440cm and Y=50-550cm Beam right-->160 tracks and Beam left-->118 tracks



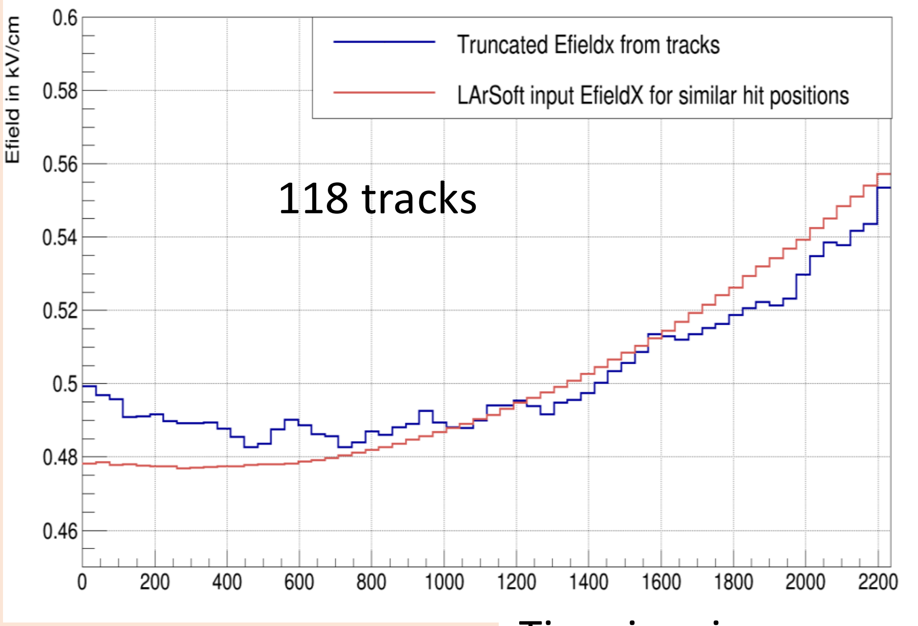


EfieldX Beam right



Time in micro-sec

EfieldX beam left



Time in micro-sec

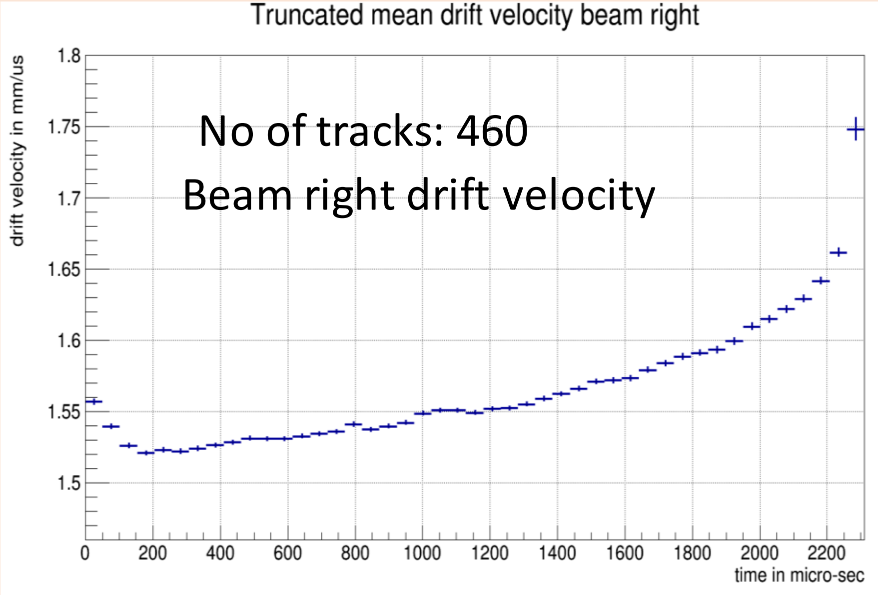
Input T=87K
With the addition of position cuts the two distribution seems to be in better agreement.
Also the statistics is greatly reduced.

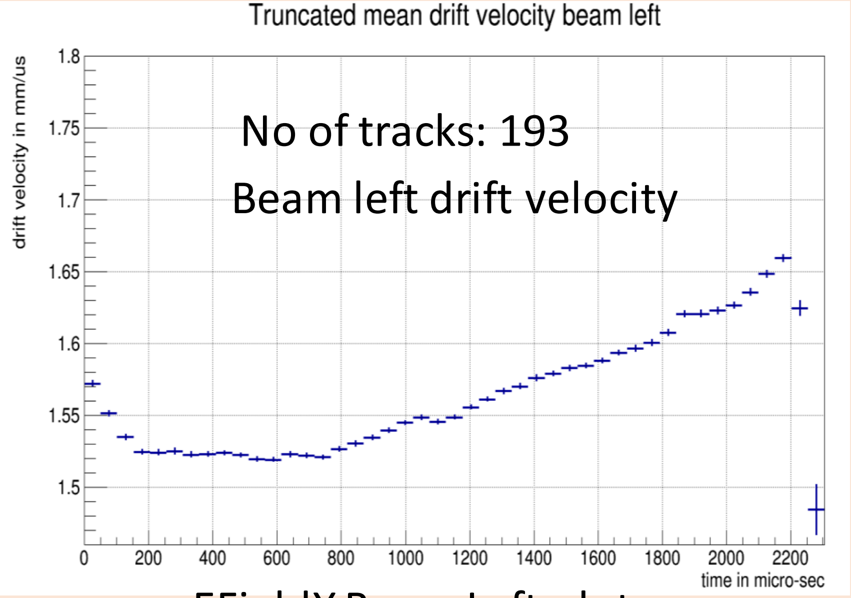
Still there is a gap between measured and expected values near APAs

Could there be any other source of Voltage contributing besides the SCE effects? there was a similar but a smaller jump on SCE OFF sample close to the APAs.

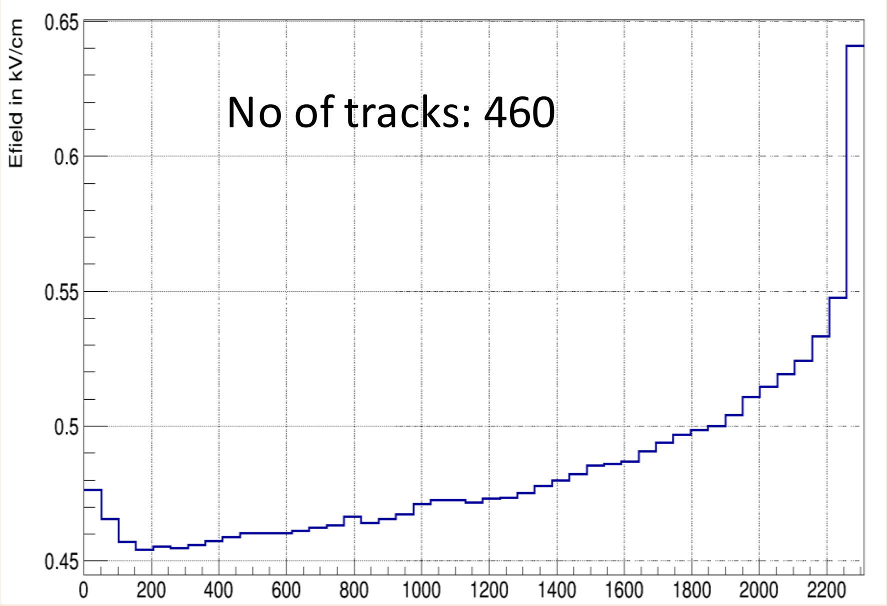
will further investigate.

Results for Run **5387**: All the plots are made using hits between Z=250cm to 440 cm and Y between 50 cm to 550 cm.



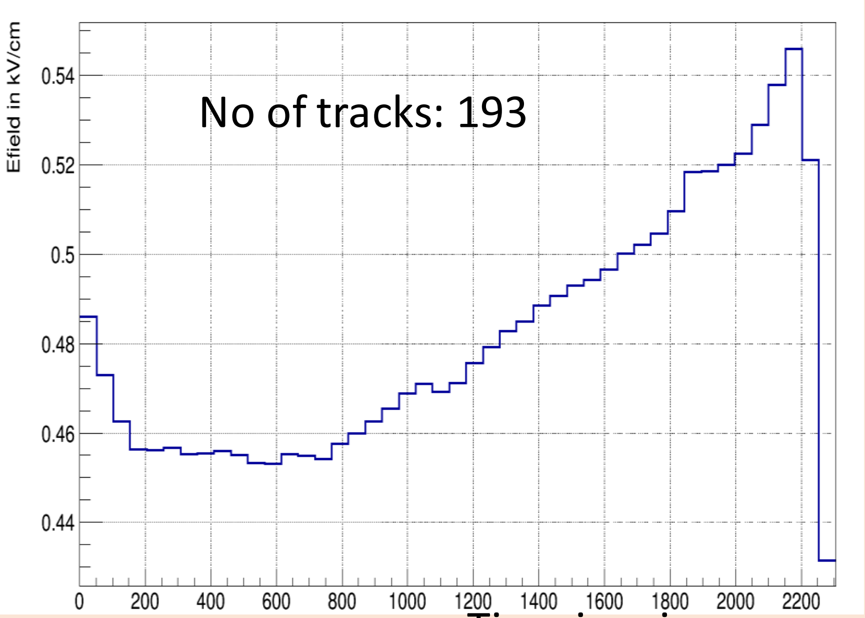


EFieldX Beam right plots



Time in micro-sec

EFieldX Beam Left plots



Time in micro-sec

For vdrift to Efield converstion:
Temperature used=87.4K

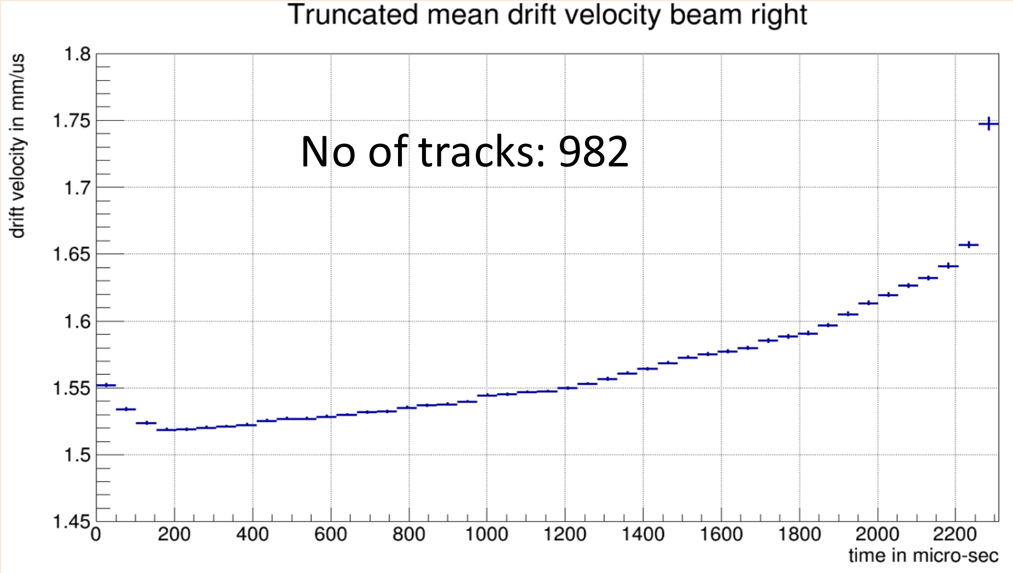
EfieldX and drift velocity appears to follow similar trend on both drift side,

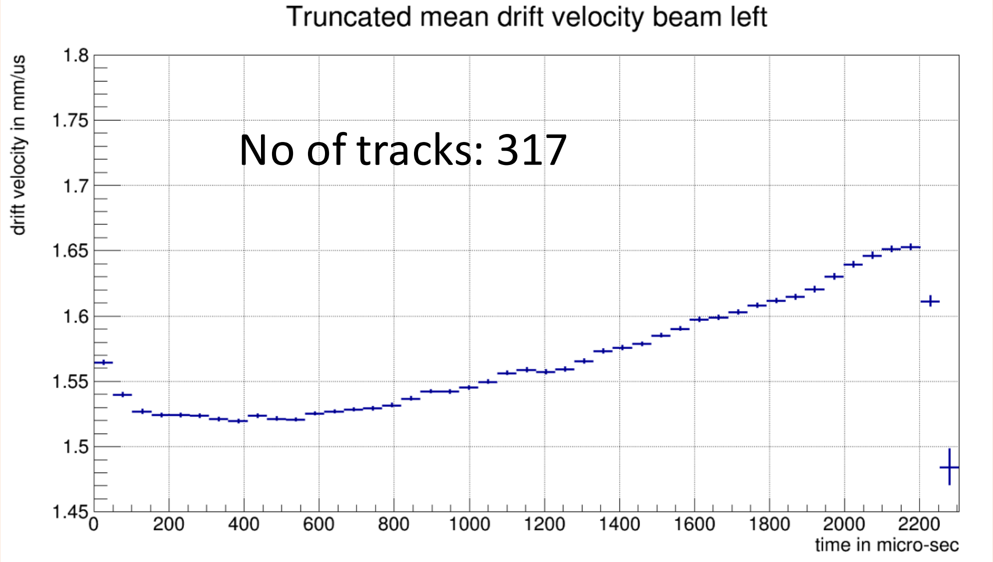
Bins close to CPA are showing big fluctuations particularly in beam left

Similar to MC samples Efield appears to jump slightly at the anode.

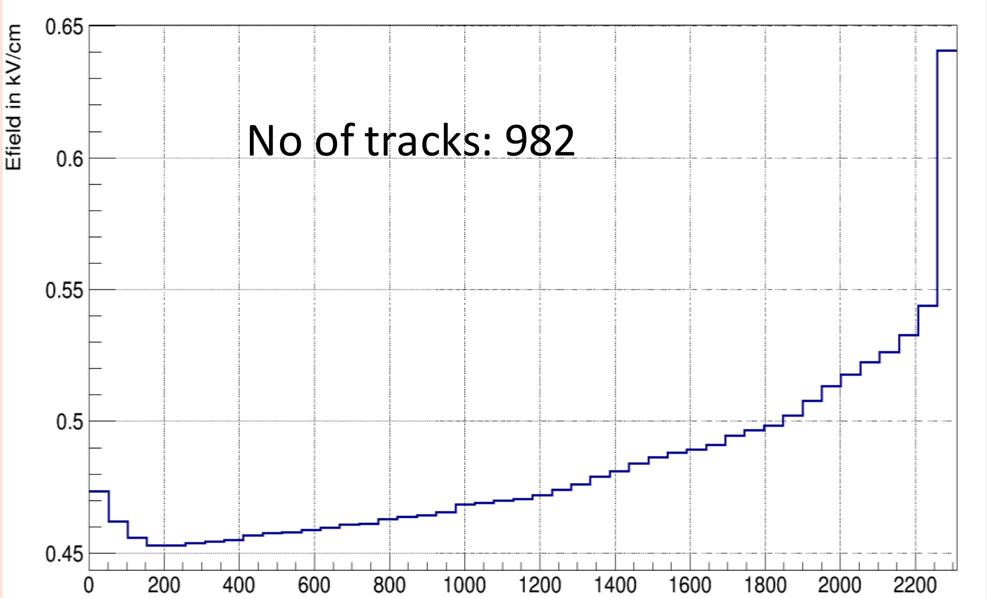
Note: Y Axis range are different for the lower 2 plots

Results for Run 5809:



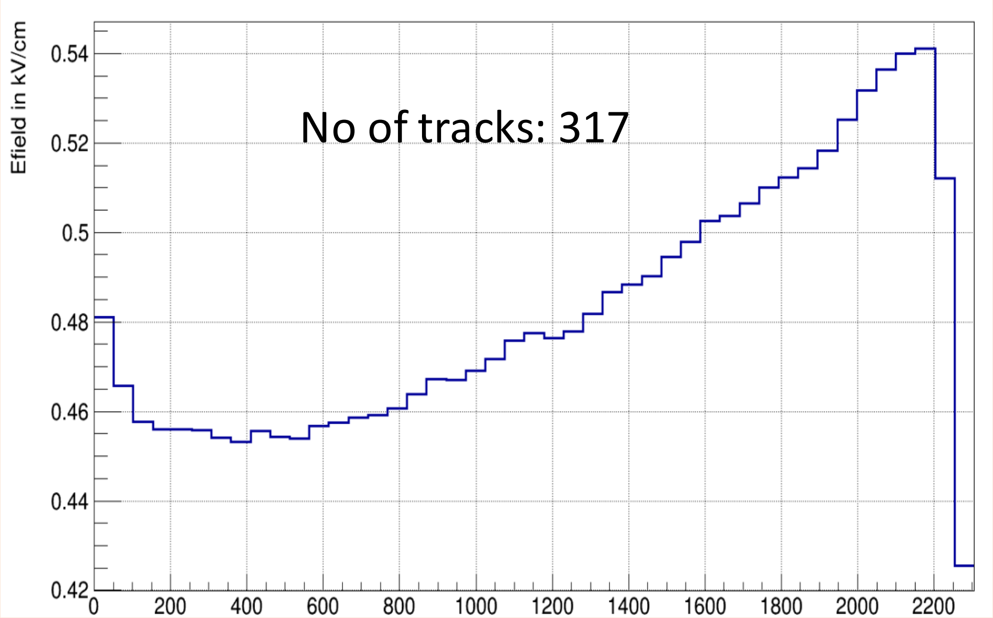


Beam right EfieldX



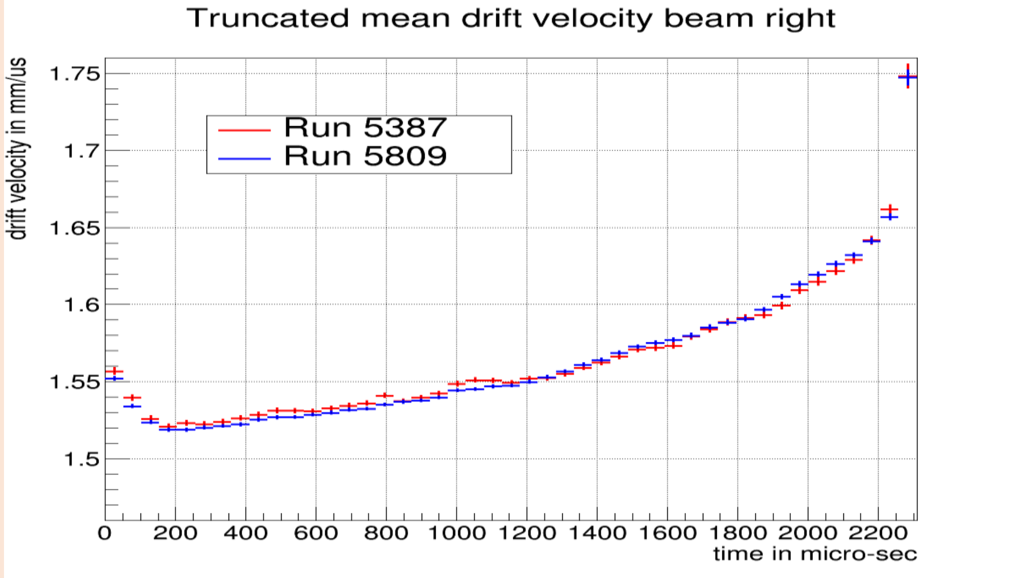
Time in micro-sec

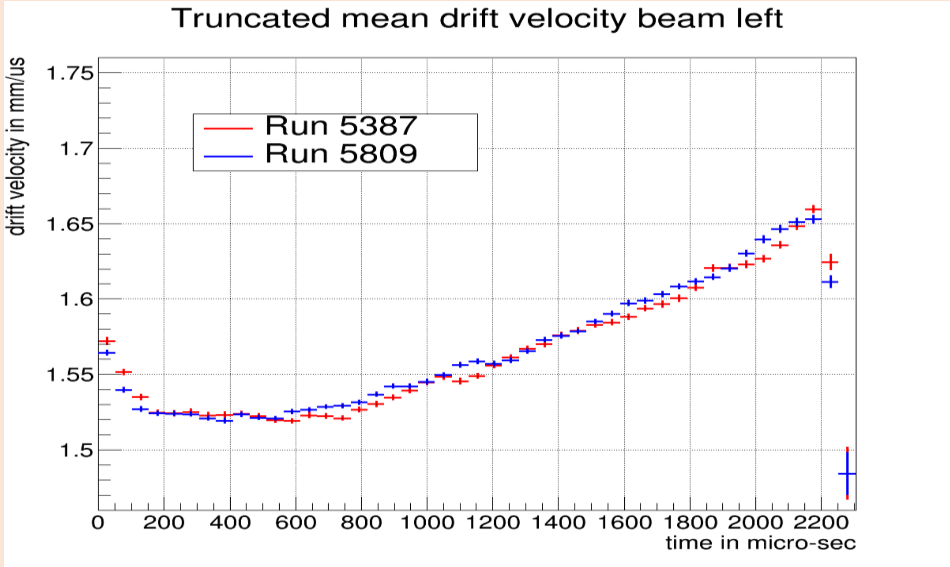
Beam left EfieldX



Time in micro-sec

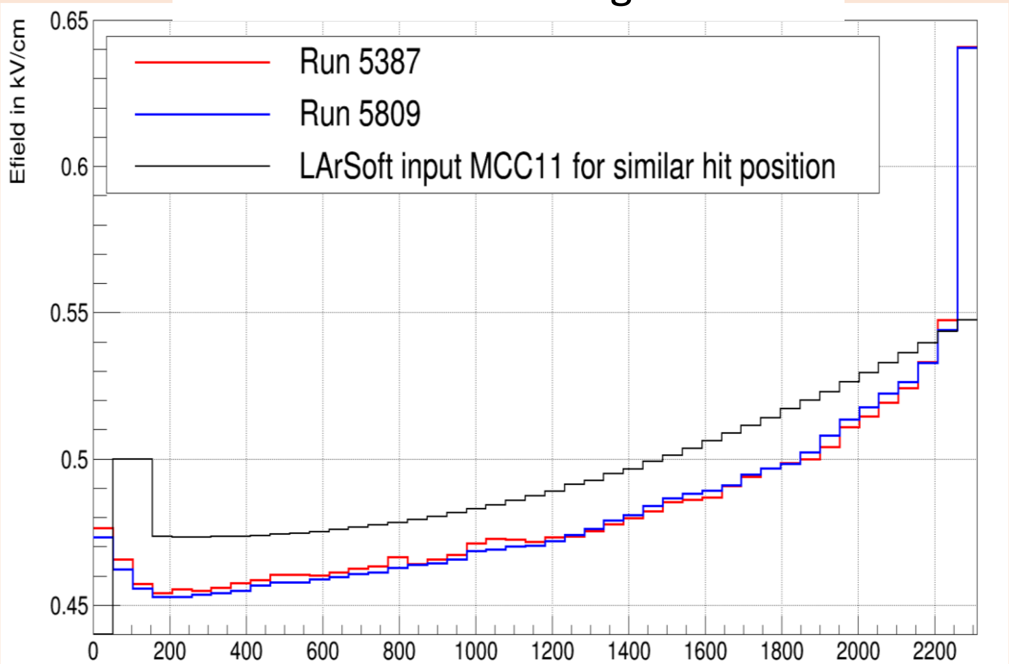
Comparing Plots for Run 5387 (top purmon value=4.21ms) and run 5809 (top purmon value=5.7ms), with MCC11 input EfieldX





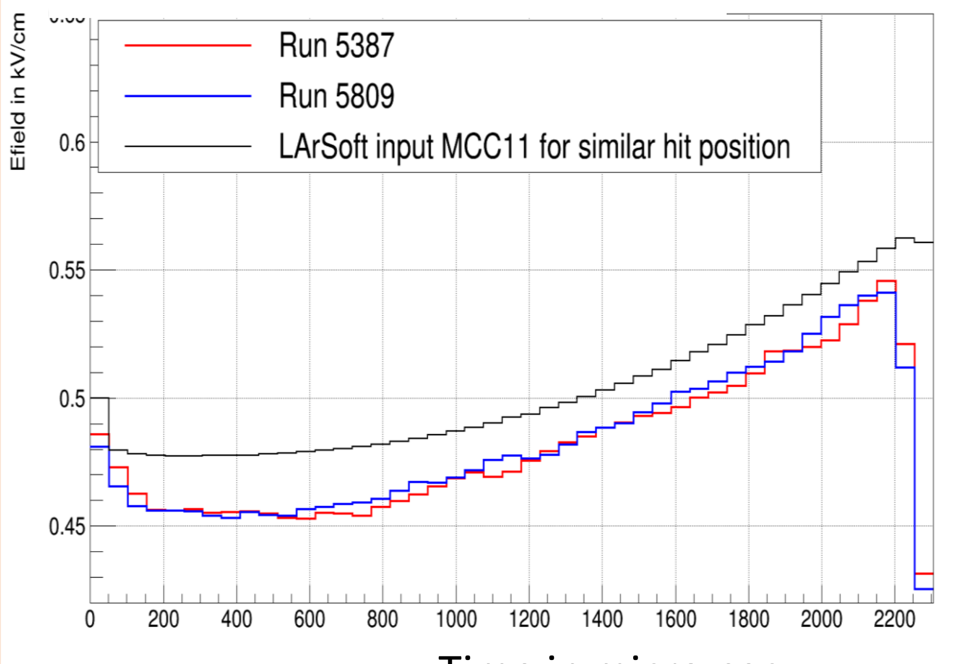
Note: I made only rough Estimate for SCE input EfieldX, I am using the input EfieldX based on hit X, Y, Z coordinate, X position being incorrect these values can only be approximate ones.

Mean EfieldX beam right



Time in micro-sec

Mean EfieldX beam left



Time in micro-sec

Also one bin close to anode has Efield=0.5kV/cm for LArSoft input, that could be default value if X>360 or X<-360?

SUMMARY:

- Average drift velocity is lower than at nominial field.
- The drift-velocity distribution for the two protoDUNE runs looks comparative although there was a gap of 3 weeks between the two runs. Purmon reading for the two runs also changes from 4.21ms to 5.7ms for the top purmon.
- Will further investigate about the big fluctuations near CPA boundaries and a jump near APA.

Thank You

Backup slides:

To calculate LArSoft input EfieldX I used the LArSoft SCE services:

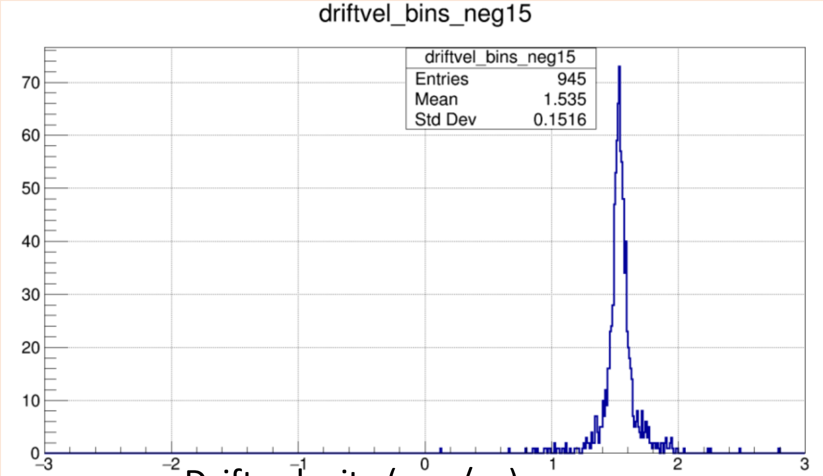
```
auto const* SCE = lar::providerFrom<spacecharge::SpaceChargeService>();
const detinfo::DetectorProperties* detprop = lar::providerFrom<detinfo::DetectorPropertiesService>();

  double efield=detprop->Efield();

 for(int i=0;i<144;i++){
      for(int j=0;j<120;j++){
    for(int k=0;k<139;k++){
      double x1=i*5.0-357.5;
      double y1=j*5.0+2.5;
      double z1=k*5.0+2.5;
      geo::Vector_t fEfieldOffsets=SCE->GetEfieldOffsets(geo::Point_t{x1,y1,z1});
      double EfX=efield+efield*fEfieldOffsets.X();
      EField3DX->SetBinContent(i+1,j+1,k+1,EfX);
    }
      }
    }
```

Thus filling a histogram EField3DX with the x component of Efield, and then based on the hit x, y, z position getting the value of EfieldX for that point and filling the correspoding time bin with that EfieldX, finally taking mean of all the EfieldX for a particular time bin.

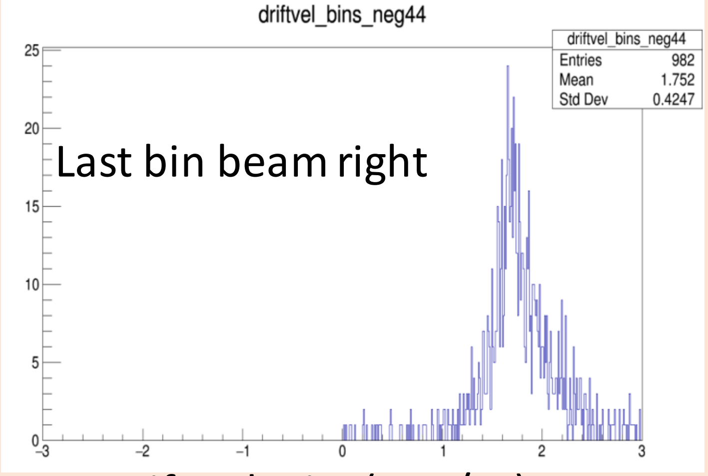
Velocity distribution for some randomly selected time bin for **run 5809 .** I sort the values in a bin and discard the lowest and highest 20% of values and take the mean of remaining distribution.

Note: Some distribution, specially near the last bin has a more scattered values which makes it necessary to truncate the distribution and take the mean.

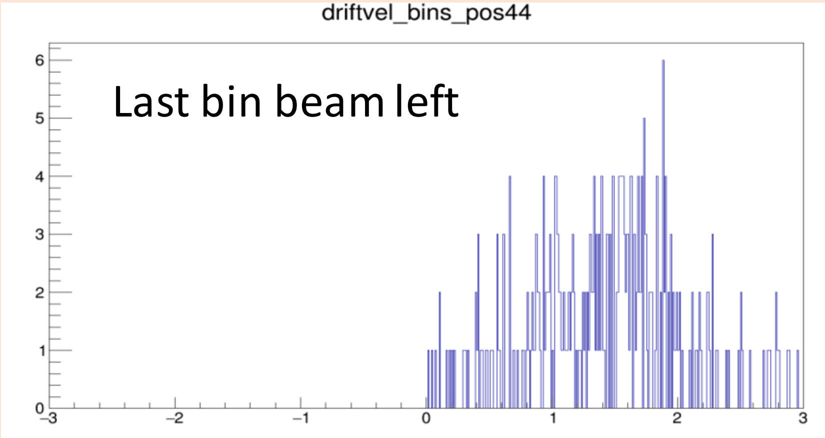
No of entries



Drift velocity (mm/us)



Drift velocity (mm/us)



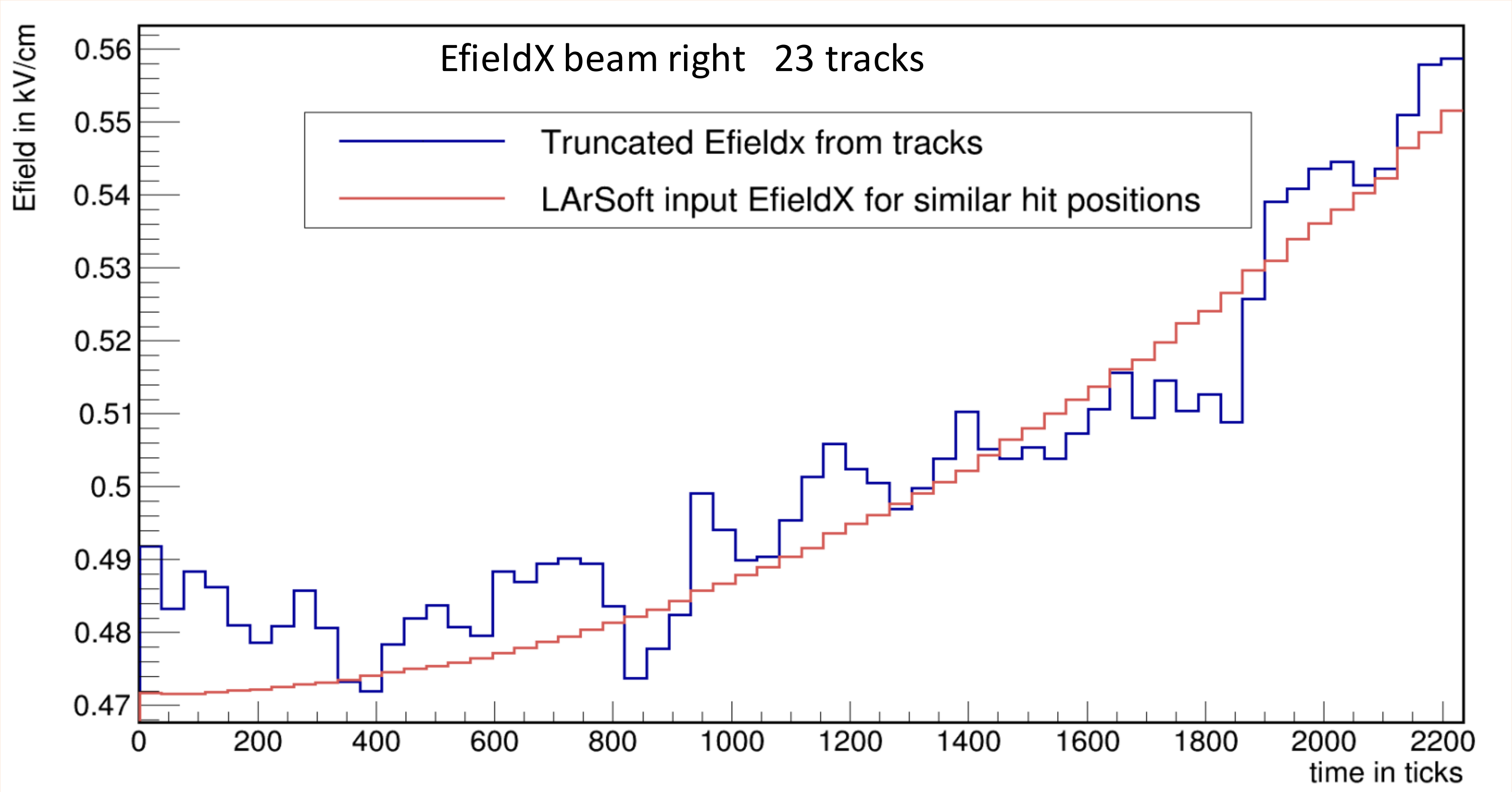
Drift velocity (mm/us)

We can see that there is a wide spread in drift velocity in the beam left side, so the value for last bin for beam left seems less reliable.

Need to do more investigation on this.

MCC11 SCE ON

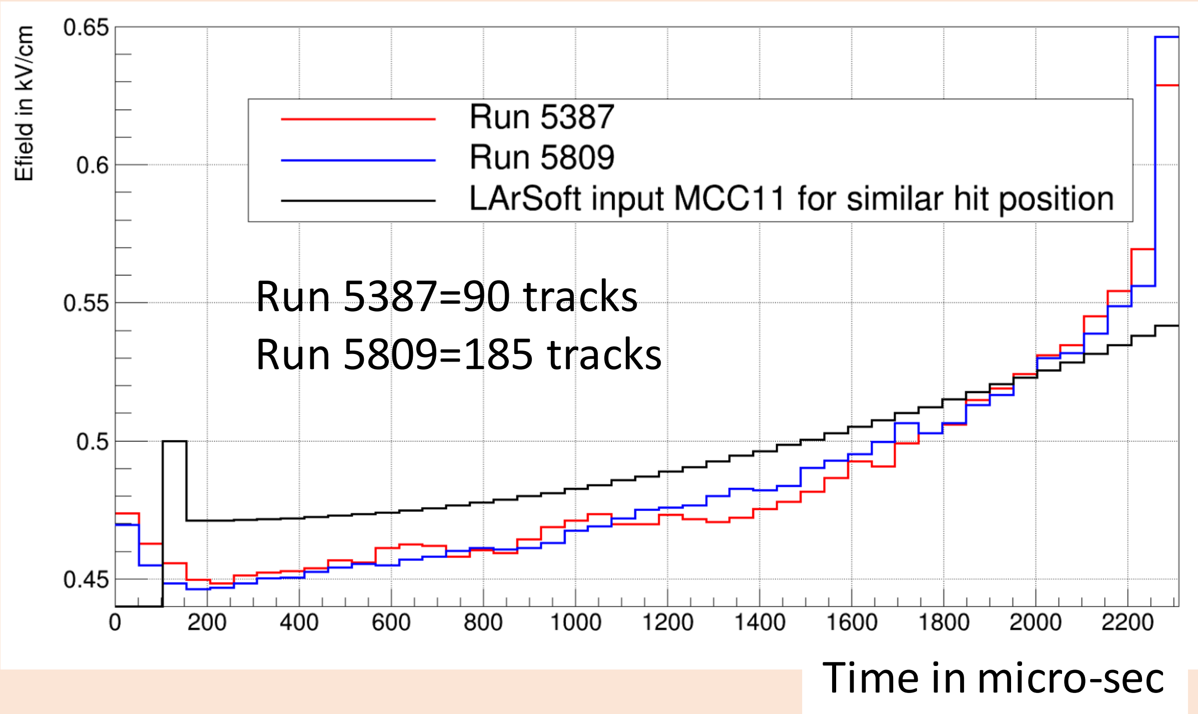
Using tracks with Z=300-400cm and Y=200-400 cm



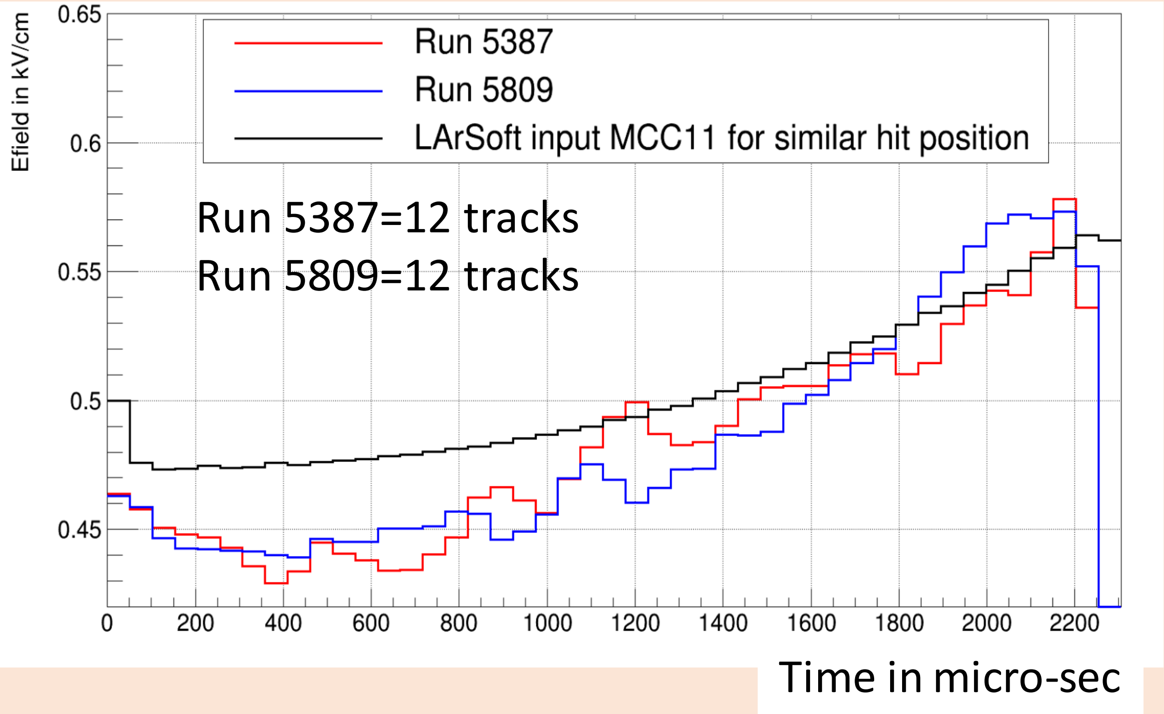
Only 3 tracks from beam left passed the position cuts, plot not shown

Efield distribution for ProtoDUNE data, with Z=300cm-400cm and Y=200cm-400cm

EfieldX Beam right



EfieldX Beam Left



With these strict position cuts applied, there should be minimum error in EfieldX estimation.
One issue with this strict position cut is big drop in statistics, a way out will be merging files within a short interval of time, few days to a week.