FERMILAB-SLIDES-20-068-ND

Measuring electron drift-velocity in ProtoDUNE-SP using anode-anode crossing cosmic ray muon tracks

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New Perspectives 2020

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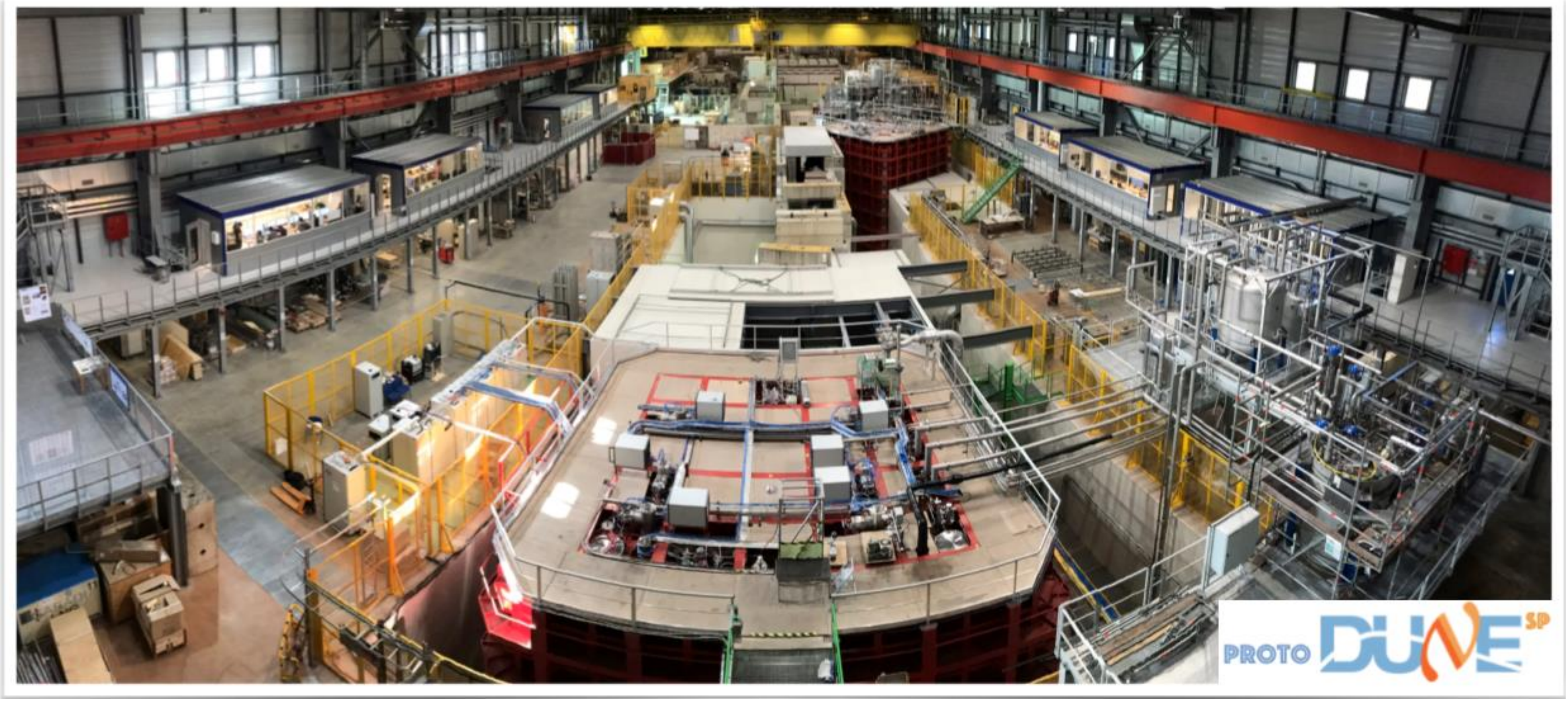
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Kansas State University

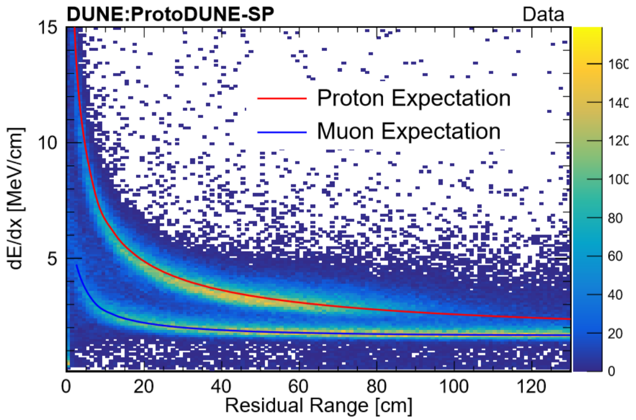


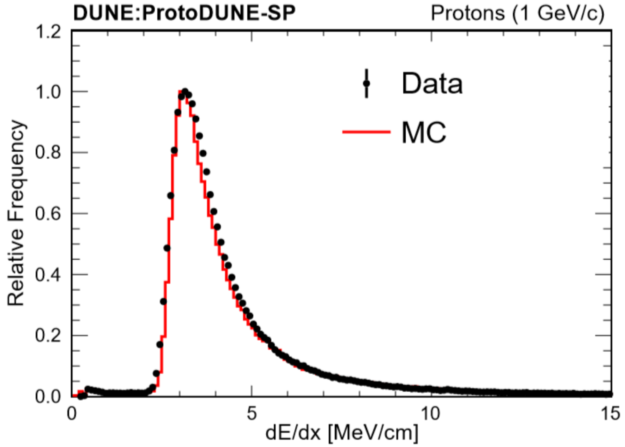
ProtoDUNE single phase (ProtoDUNE-SP) at CERN neutrino platform

Major Goals:

- Prototyping production and installation procedures for DUNE Far Detector Design
- Validating design from perspective of basic detector performance
- Accumulating test-beam data to understand/calibrate response of detector to different particle species
- Demonstrating long term operational stability of the detector

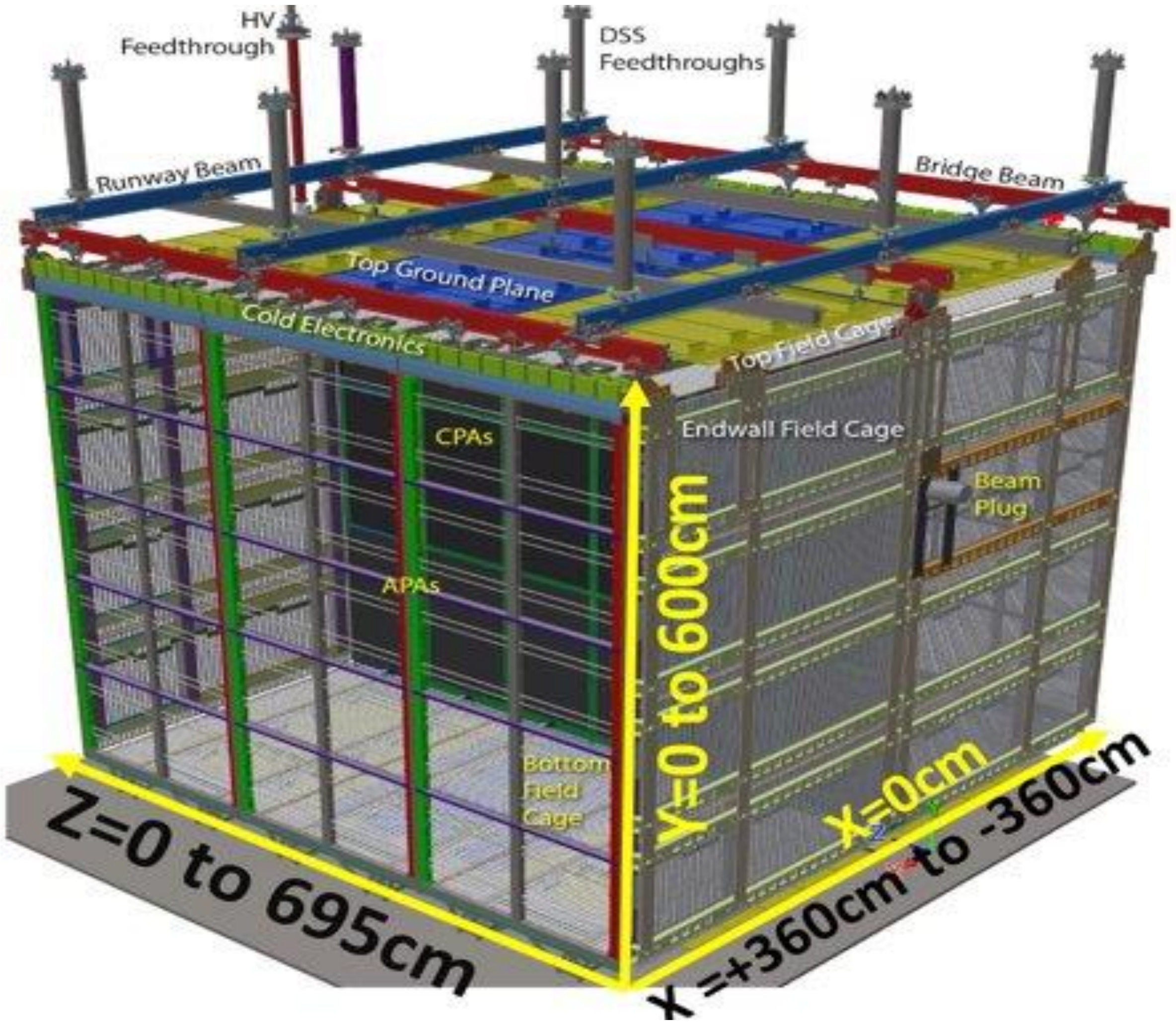
Test beam data (K^+, e^+, π^+ and p) collected between Sept 2018-Nov 2018, currently taking cosmic data.





First results on detector performance recently out in arxiv: https://arxiv.org/abs/2007.06722

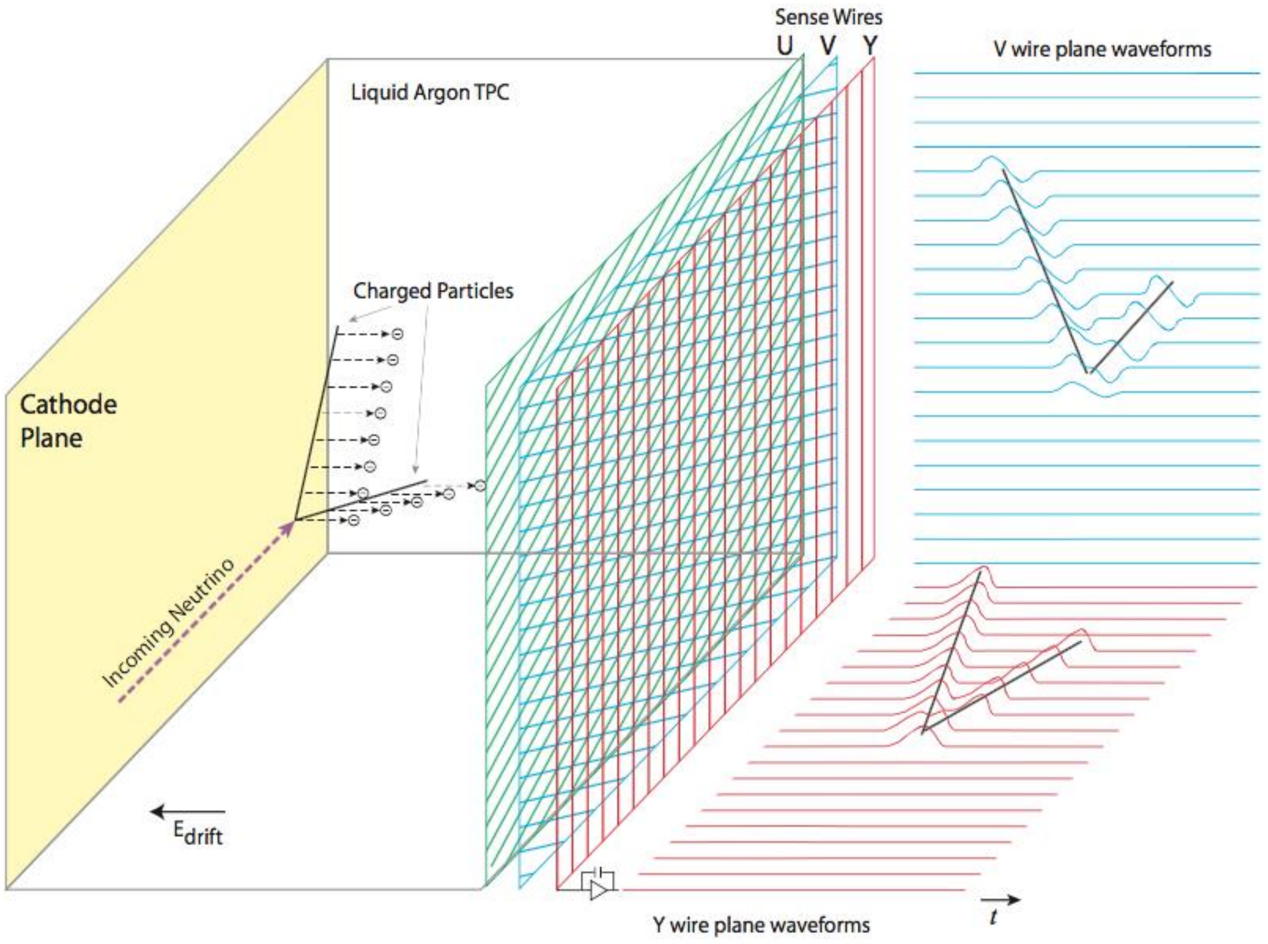
ProtoDUNE-SP (Largest LArTPC till now)



- **The dimensions are 6 m high, 6.9 m wide and 7.2 m along the drift direction.**
- **Consists of 2 drift volumes of 3.6m drift length each.**

Major components of ProtoDUNE-SP

LArTPC signal formation



LArTPC and time vs wire readout

- **Charged particle ionizes the liquid argon producing electron-ion pairs.**
- **Electric field causes electrons to drift towards the anode planes.**
- **Electrons detected by 3 wire planes as waveforms.**
- **Particle trajectory reconstructed based on the time and position of the waveform.**

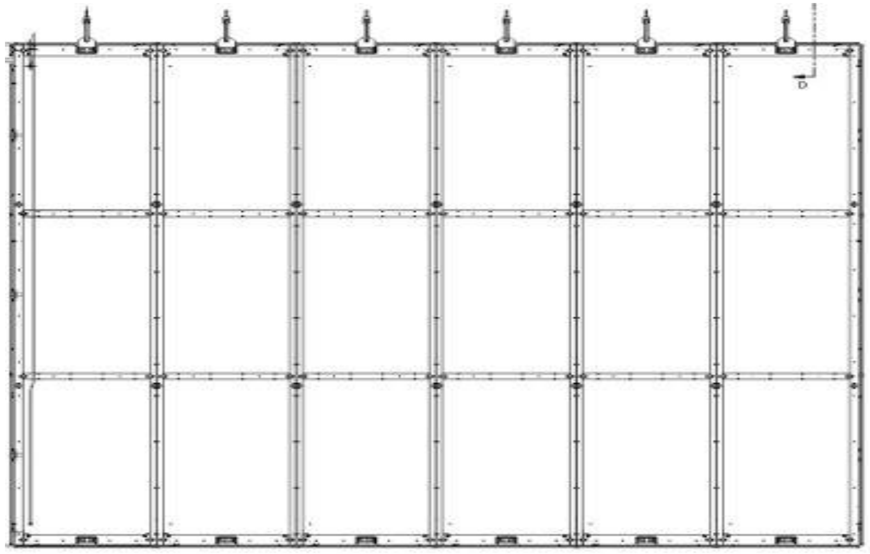
Space Charge Effect(SCE) in ProtoDUNE-SP

- ~10,000 muons/(minute.m^2) incident at the sea level.
- Cosmic ray muons ionize the liquid argon.
- Electrons swiftly move to anode-planes while positive ion drift slowly towards the cathode.
- Continuous cosmic ray flux builds up space charge, causing non-uniformity in electric field.

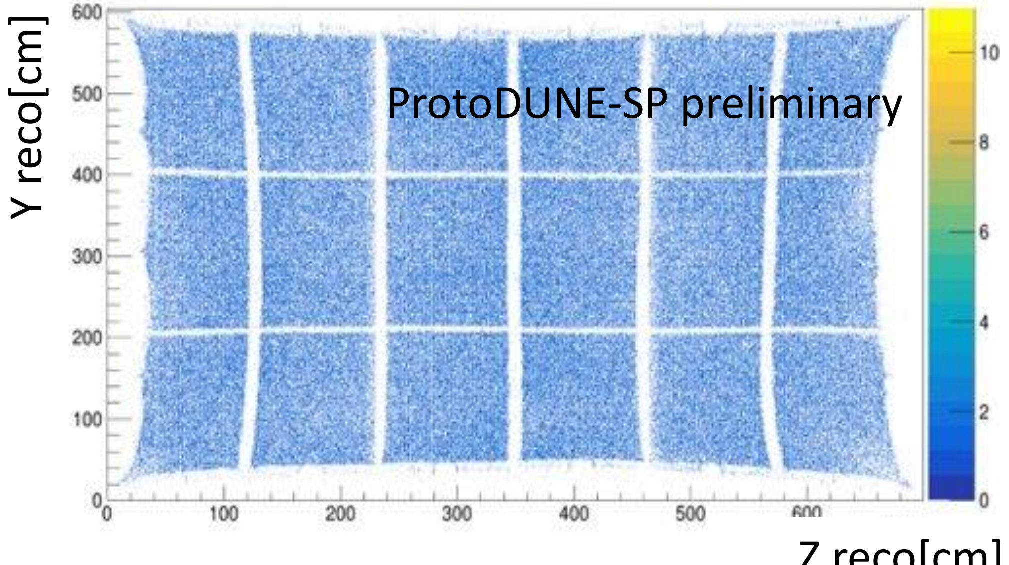
No ionization takes place in the frames which appear as gaps in bottom plot.

SCE distorts the true location of hit as shown in the bottom plot.

SCE causes non-uniformity in electron drift velocity.



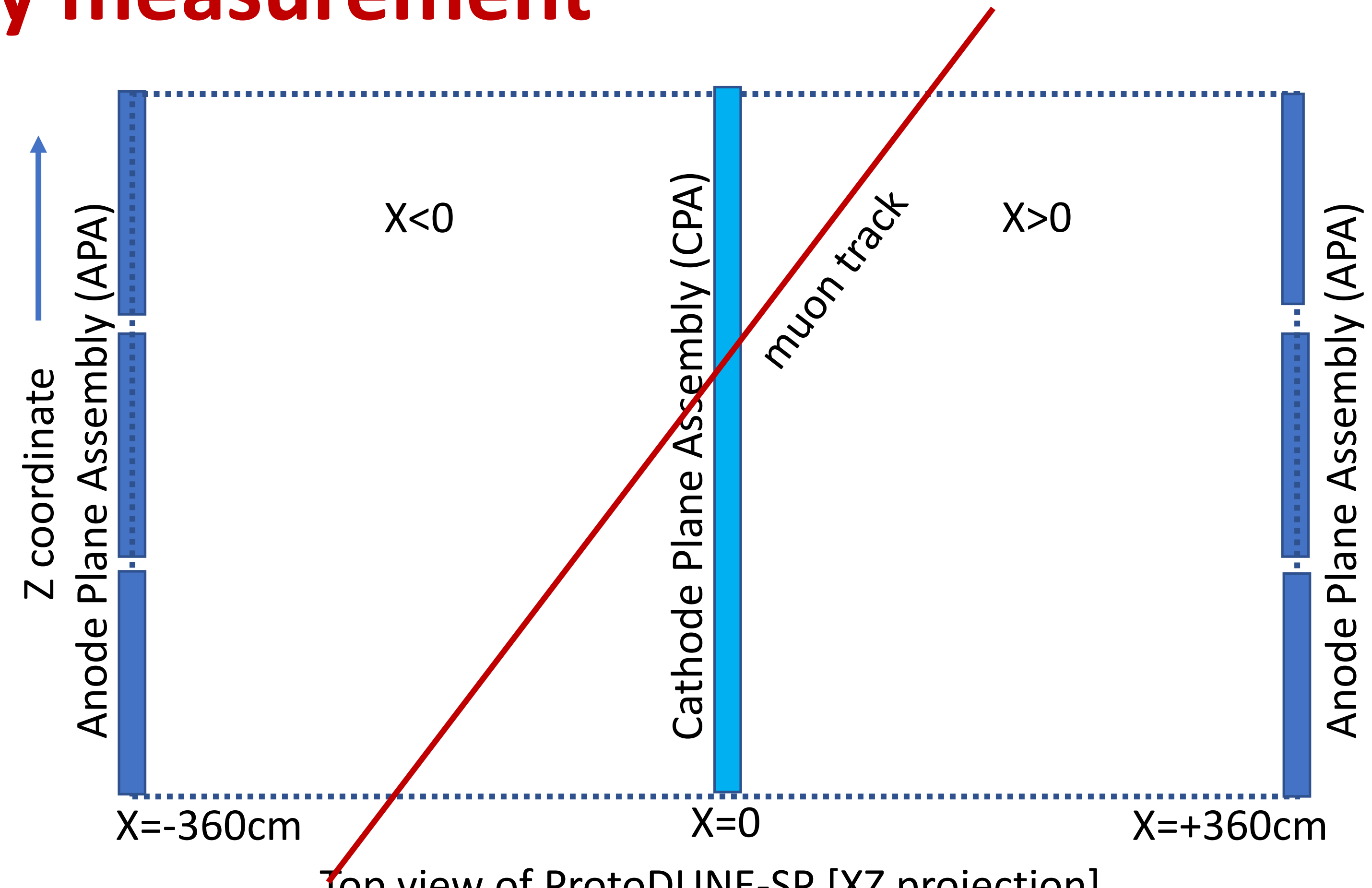
ProtoDUNE-SP cathode frame structure ~3cm thick



Reconstructed position of hits within 3cm of CPA panel

Drift velocity measurement

Anode-anode tracks selection



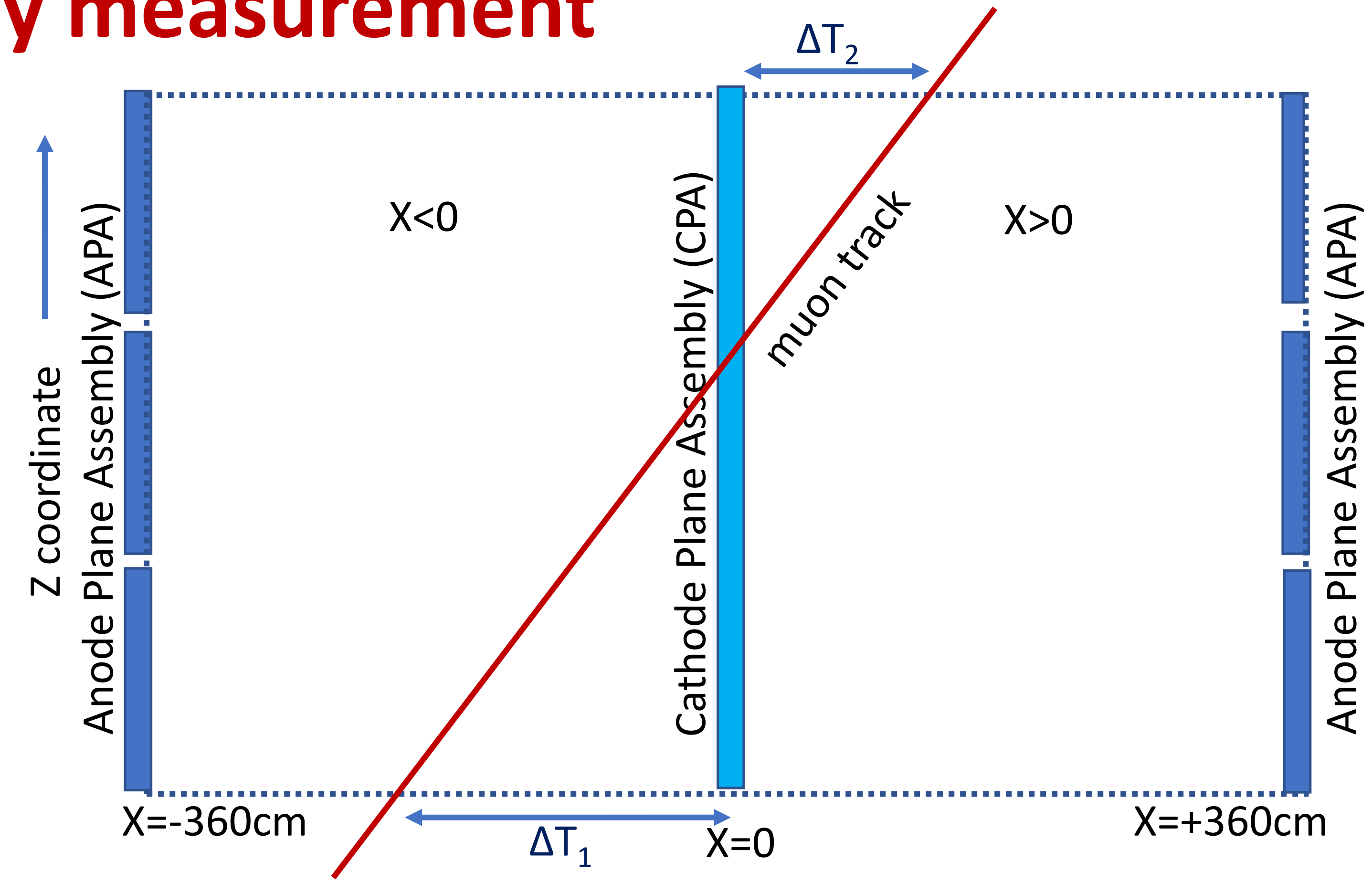
Top view of ProtoDUNE-SP [XZ projection]

Drift velocity measurement

Anode-anode tracks selection

ΔT_1=difference between drift times for hit closest to cathode and the hit farthest from cathode for X<0

ΔT_1=difference between drift times for hit closest to cathode and the hit farthest from cathode for X>0



Top view of ProtoDUNE-SP [XZ projection]

Drift velocity measurement

Anode-anode tracks selection

ΔT_1=difference between drift times for hit closest to cathode and the hit farthest from cathode for X<0

ΔT_2=difference between drift times for hit closest to cathode and the hit farthest from cathode for X>0

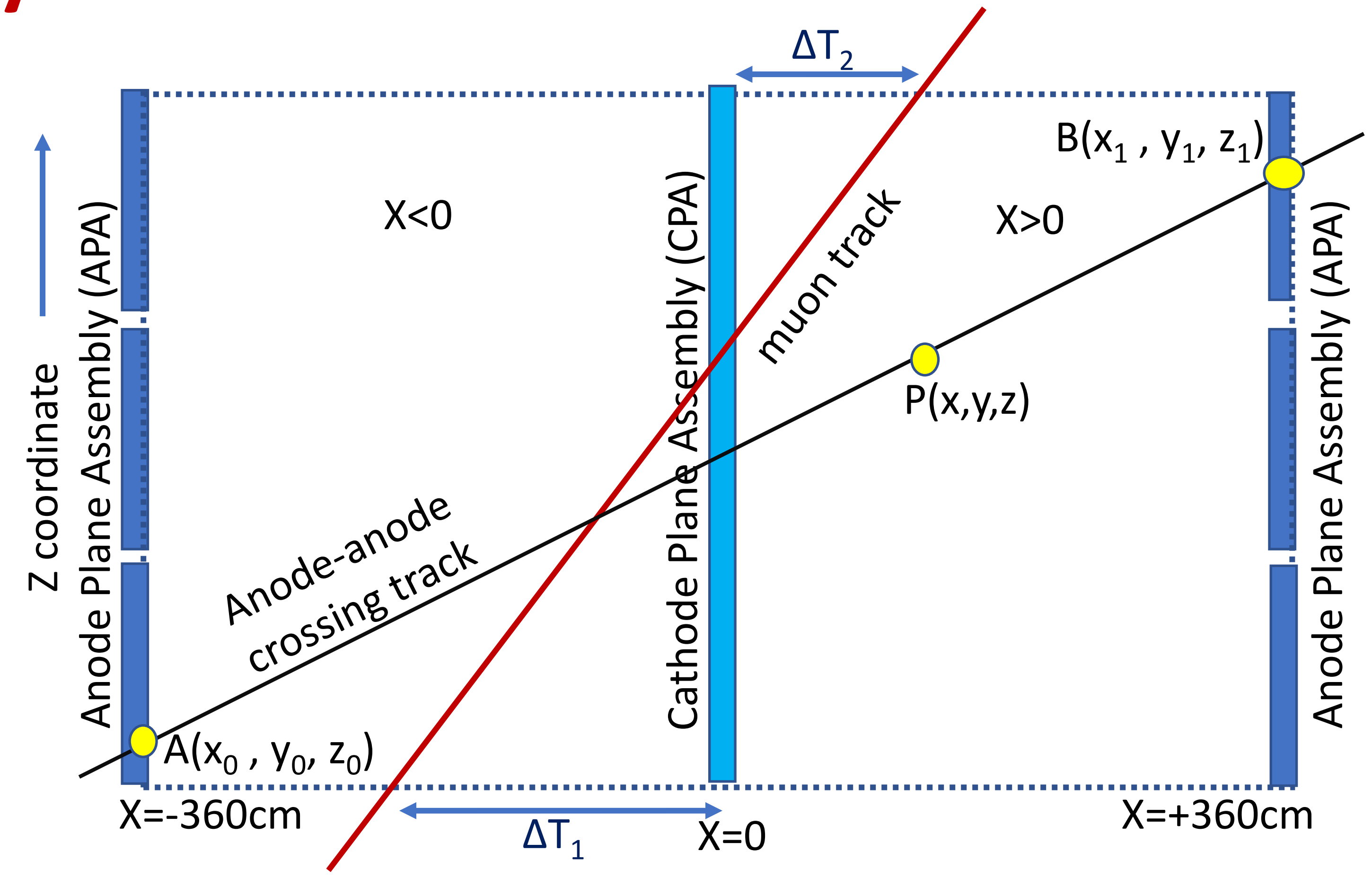
For anode-anode tracks **$\Delta T_1 + \Delta T_2$ is maximum.**

Start (A) and end point (B) are undistorted.

Knowing the start and end points, true trajectory of the particle can be determined.

For a point P(x, y, z) on the track

$$x = x_1 + (x_1 - x_0)(z - z_1)/(z_1 - z_0)$$

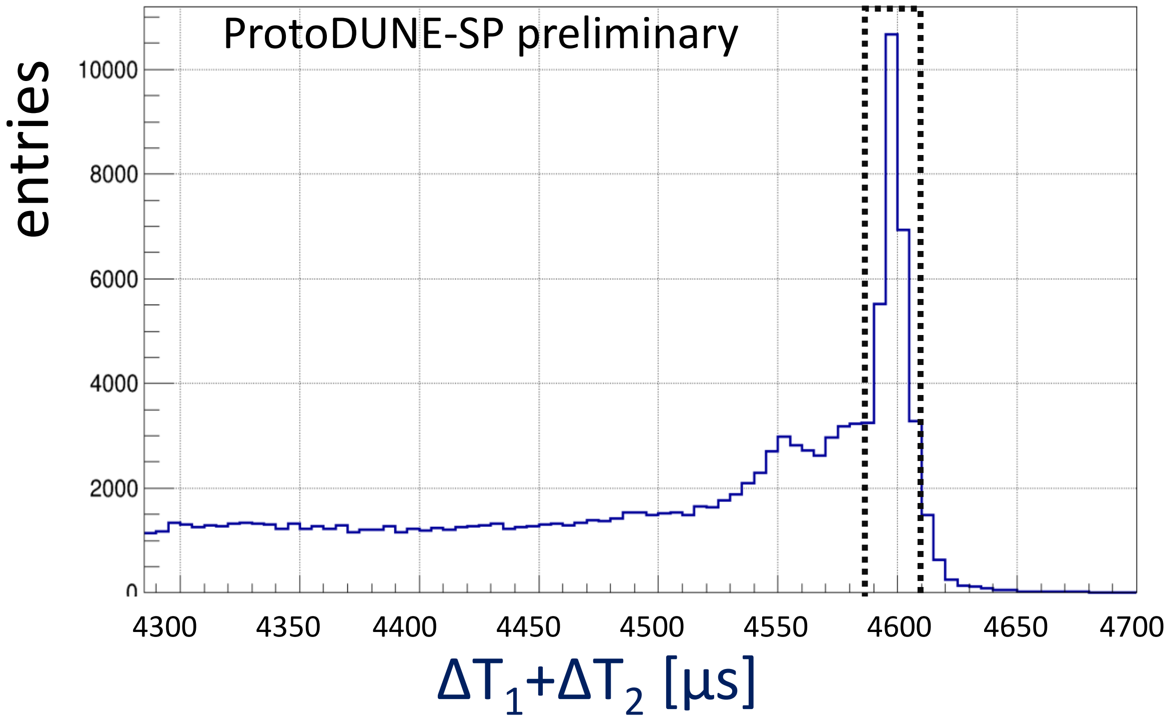


Top view of ProtoDUNE-SP [XZ projection]

Event Selection

ΔT_1 (ΔT_2)=difference in drift times for hit closest to cathode and the hit farthest from it for X<0 (X>0) (described in previous slides)

Plot shows $\Delta T_1 + \Delta T_2$ for cosmic ray muons in ProtoDUNE-SP data.



For anode-anode crossing tracks the sum $\Delta T_1 + \Delta T_2$ should maximum.

Tracks with $\Delta T_1 + \Delta T_2$ lying in the dotted region are selected.

For protoDUNE-SP at nominal running condition, for anode-anode tracks:

$$\Delta T_1 + \Delta T_2 = 4590\text{-}4610\ \mu s$$

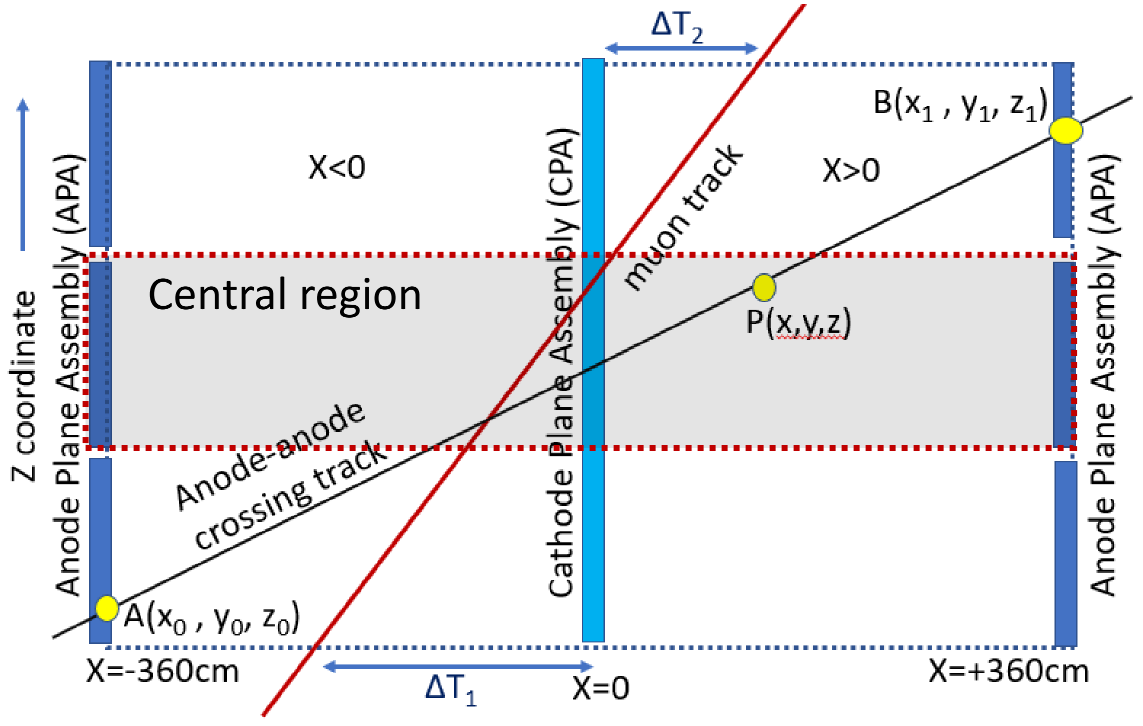
which is sum of the maximum drift times in the two drift volumes.

Drift velocity measurement: Methodology

- No direct measurement of x coordinate.
- Signal arrival times(t) measured directly
- For straight anode-anode tracks we can determine x based on z(which is known from waveform position on wires)

$$x=x_1 + (x_1 - x_0)(z - z_1)/(z_1 - z_0)$$

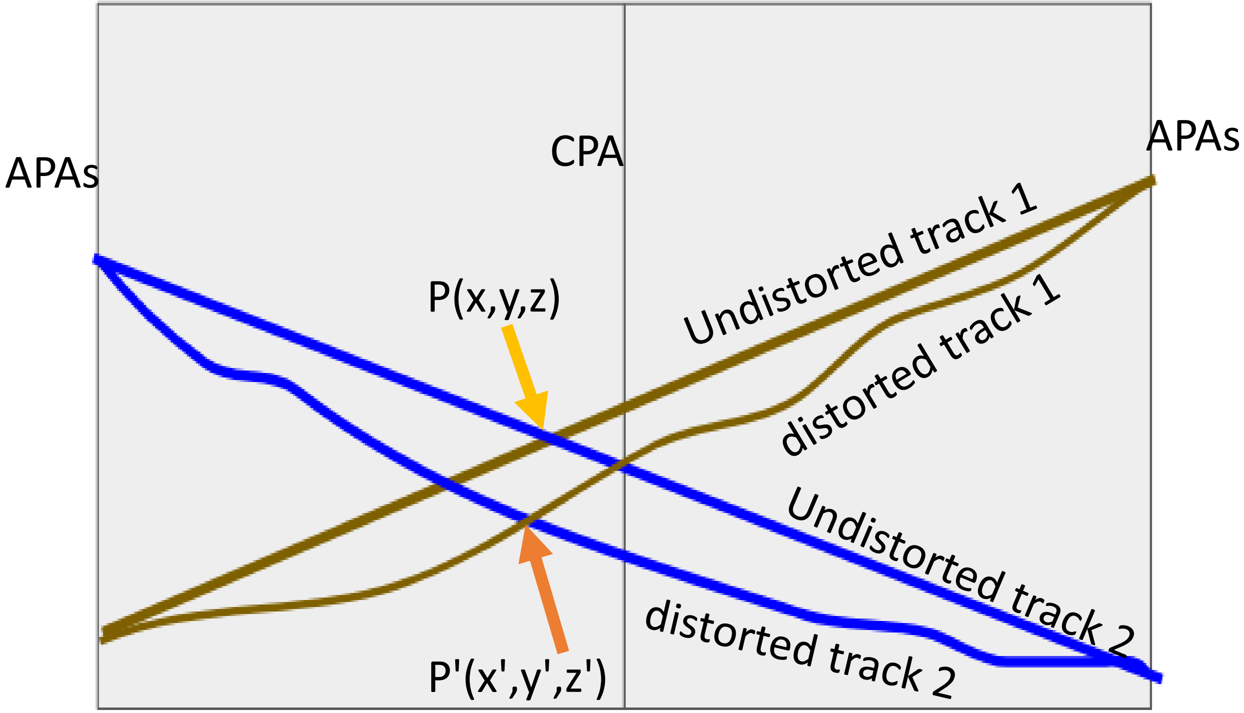
- For the portion of the track confined to the central region of the TPC (shaded region), transverse distortion in trajectory is small.
- Also, we can remove any remaining transverse distortion using crossing-track method described in next slide.



Top view of ProtoDUNE-SP [XZ projection]

Crossing anode-anode tracks to measure the spatial distortion in trajectory*

P(x,y,z) is the true intersecting point.
P'(x,y,z) is the reconstructed intersecting points.



Two anode-anode tracks which intersect each other

all pairs of intersecting tracks selected

↓

True intersection point determined P(x,y,z)

↓

Reconstructed intersection point determined P'(x',y',z')

↓

X, Y, Z distortion at P' are true-reco coordinates i.e., x-x', y-y', z-z'

$\text{corrected}_z = \text{reco}_z + \text{Z distortion}$

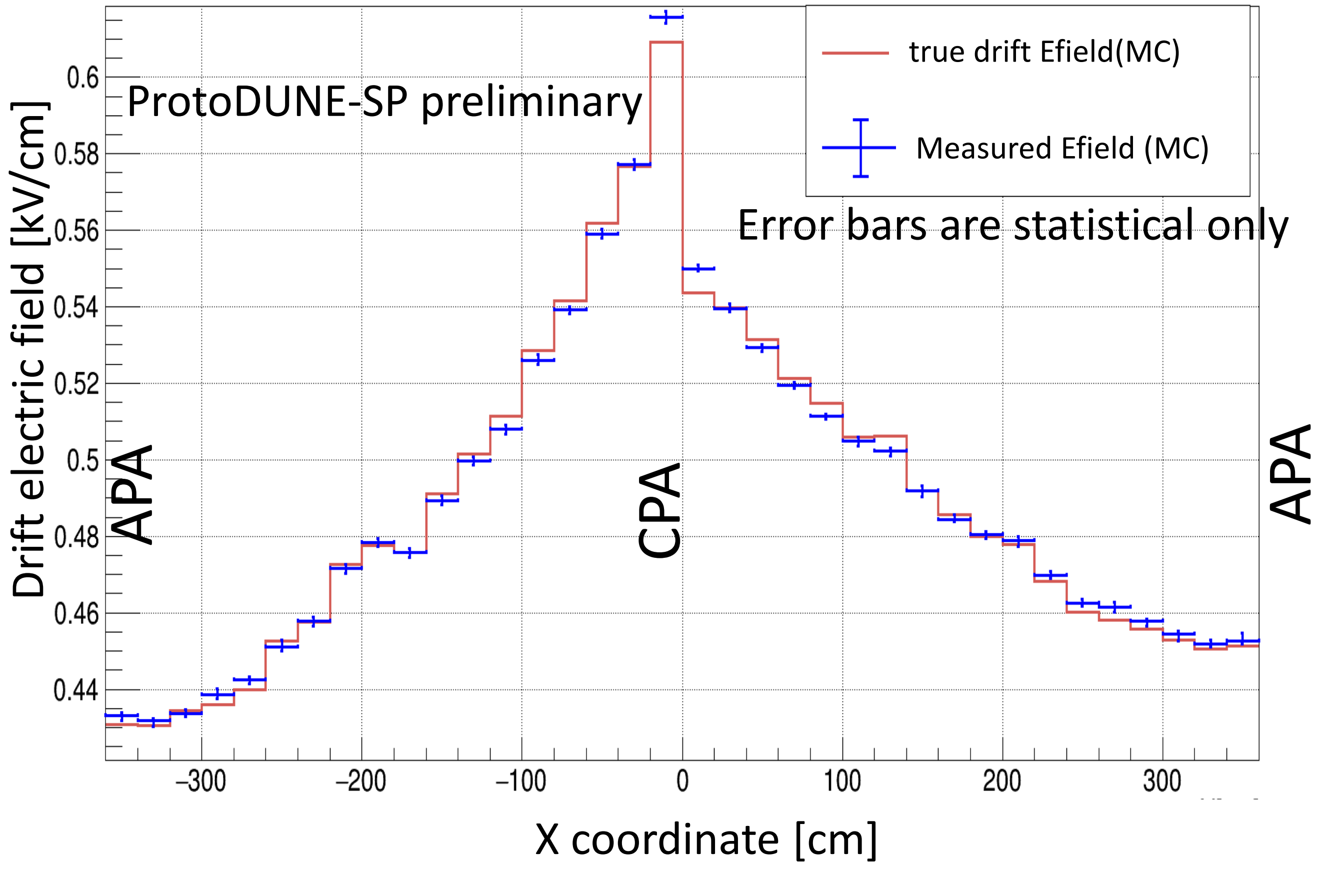
true X position is then,

$x = x_1 + (x_1 - x_0)(\text{corrected}_z - z_1)/(z_1 - z_0)$

Drift velocity is then measured by linearly fitting x vs drift times for different regions in X.

*A MicroBooNE paper is in progress on the crossing track method.

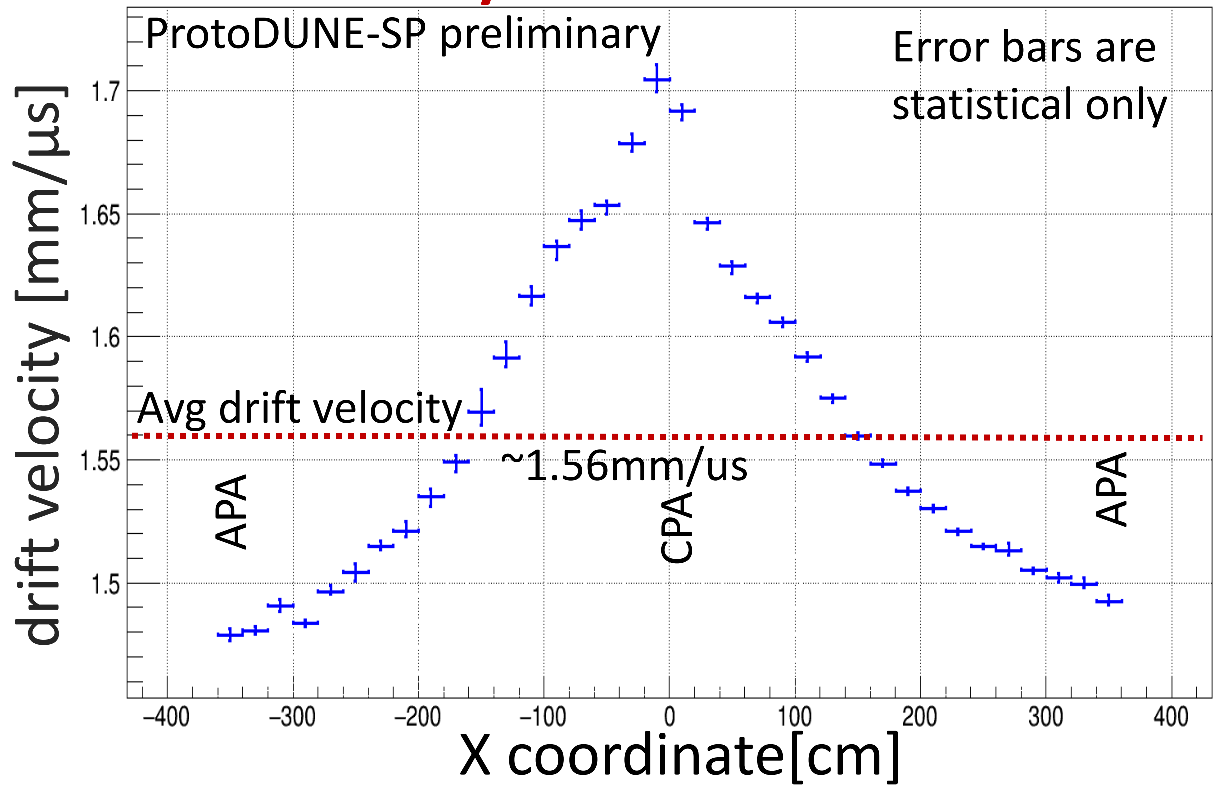
Validation of the method using Monte-Carlo simulation



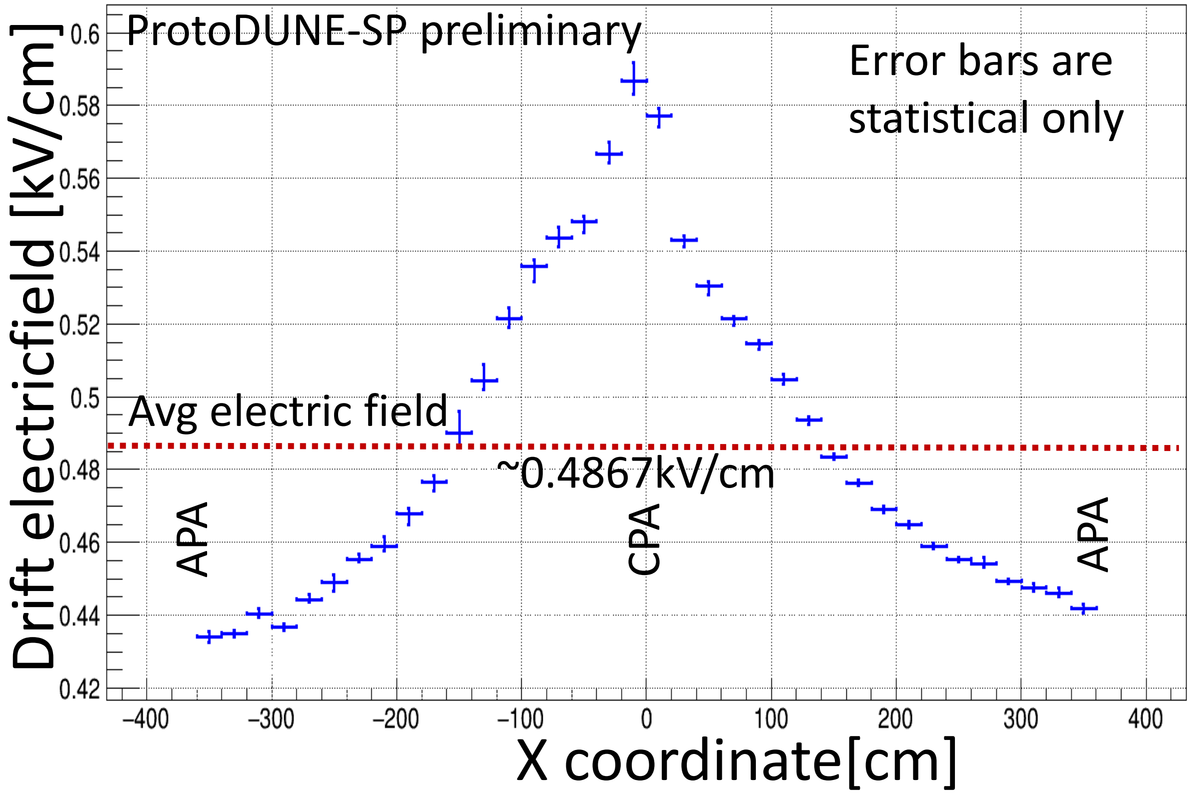
- A Monte-Carlo sample was generated with known electric field based on a data-driven Space Charge Effect model.
- Calculated the drift velocity using the method described in previous slides and converted into electric field.
- The plot on the left shows a good agreement between input drift electric field and the measured drift electric field.

RESULTS [ProtoDUNE-SP data drift velocity and Efield]

Drift velocity



Drift electric field



During beam run, average electric field used was 0.4867kV/cm, and average temperature=87.68K.

SCE causes the electric field to be about 11% lower than nominal value at the anode and about 20% higher than nominal value at the cathode.

SUMMARY

- We measured the electron drift velocity in ProtoDUNE-SP using anode-anode crossing cosmic ray muon tracks.

- Drift electric field at the cathode is about 20% higher and at the anode is about 11% lower than the nominal value.

Thank You