
Evaluating ProtoDUNE Single Phase Detector Response with a Cosmic Ray Tagger (CRT)

Richie Diurba (University of Minnesota)

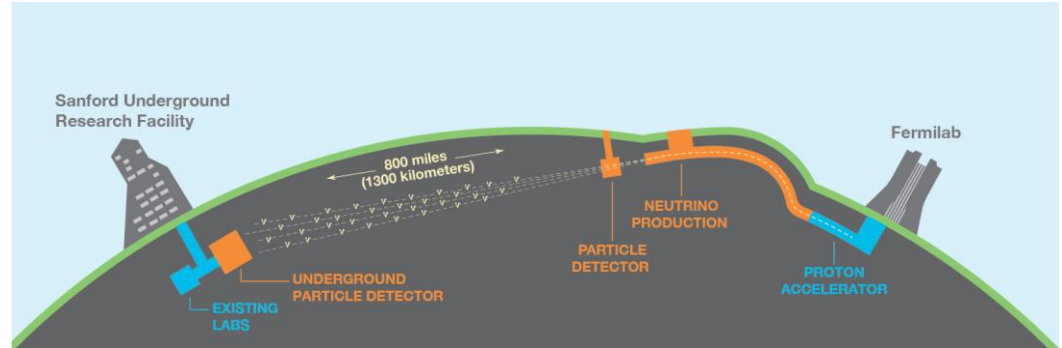
CPAD Instrumentation Frontier Workshop 2019

December 10, 2019

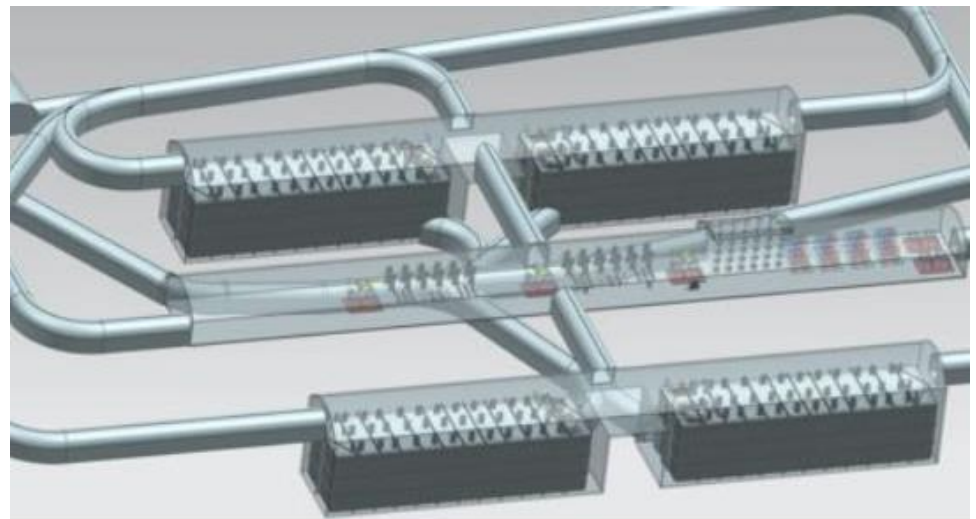


Snapshot of DUNE

- Physics Goals
 - Neutrino oscillations
 - Nucleon decay searches
 - Supernova neutrinos
- Far Detector Site
 - 1.4 km underground
 - House 4 10kT LAr detectors
- Far Detectors
 - Two Single Phase Detectors
 - One Dual Phase Detectors
 - One “Module of Opportunity”



Conceptual drawing of beamline



Conceptual drawing of far detector cavern

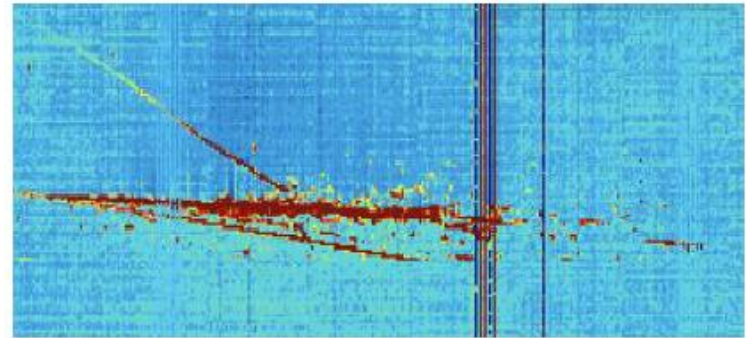
ProtoDUNE

- Research and development detectors for DUNE at the Neutrino Platform at CERN.
- One dual phase detector and one single phase detector.
- Both sit under test beams and currently measure cosmic runs.



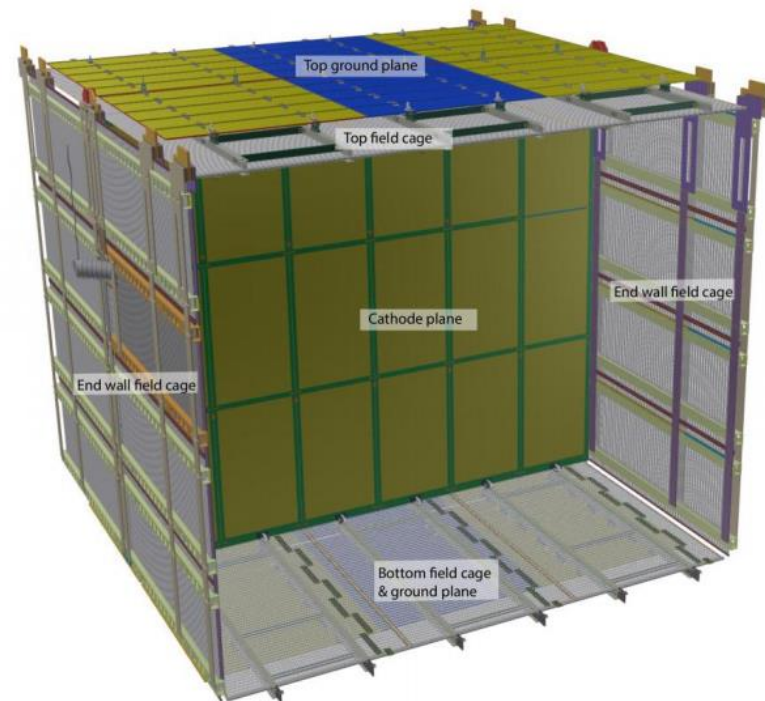
ProtoDUNE Goals

- Engineering prototype
 - DAQ testing
 - Cryostat construction and high voltage monitoring
 - Prototype photodetection system for DUNE
 - APA near identical to the ones planned for the DUNE Far Detector
- Physics test beam for LAr
 - Test beam fires pions, kaons, protons, and electrons
 - Study cross section and energy reconstruction of these particles in a Far Detector prototype.
 - Use results for model tuning.



ProtoDUNE Single Phase

- 700 tons of liquid argon
- Active volume of 7.2 m wide, 7 m long, 6 m high.
- Has six Anode Plane Arrays (APAs) on the side detectors.
- Drift electron field of 486 V/cm gene array in the center of the detector.
- Sept.-Oct. 2018 1st beam run
- Saved over 4 million triggers.

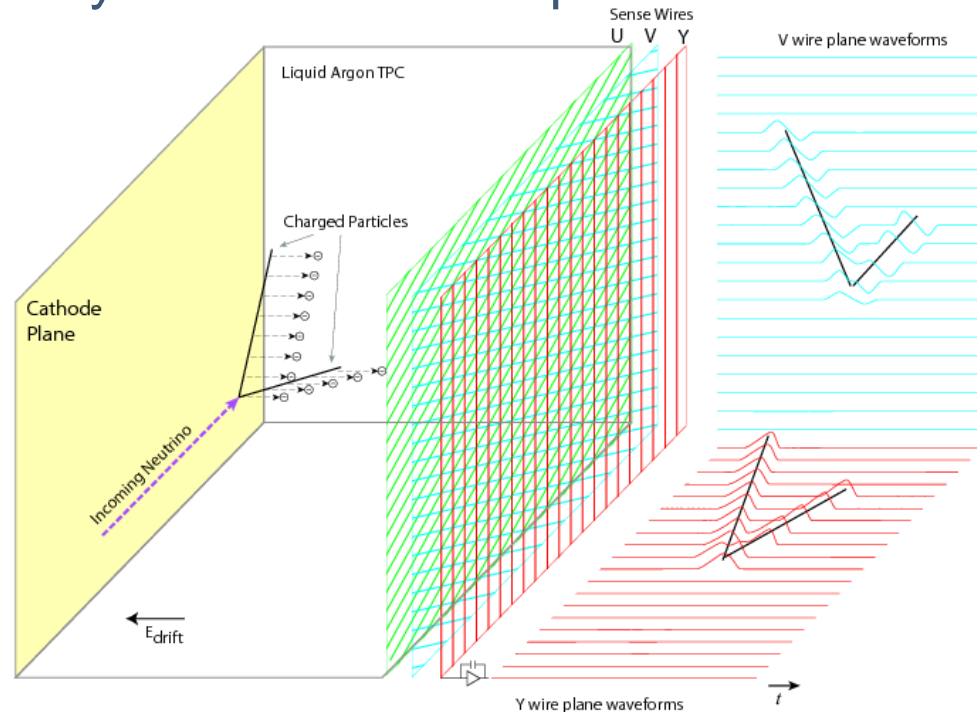


P (GeV/c)	# of Spills	# of e^+	# of K^+	# of μ^+	# of p	# of π^+	Total # of Events	Beam Time (days)
1	70K	84K	≈ 0	70K	689K	625K	1.5M	19.4 days
2	16K	19K	9K	36K	336K	572K	1.0M	4.4 days
3	13K	16K	26K	17K	181K	540K	780K	3.6 days
4	11K	13K	19K	16K	107K	510K	660K	3.1 days
5	11K	13K	29K	13K	96K	510K	660K	3.1 days
6	11K	13K	36K	12K	94K	510K	660K	3.1 days
7	11K	13K	42K	8K	87K	510K	660K	3.1 days
Total	143K	171K	161K	172K	1.6M	3.8M	5.9M	39.7 days

Run plan for 2018 beam

LAr Time Projection Chambers

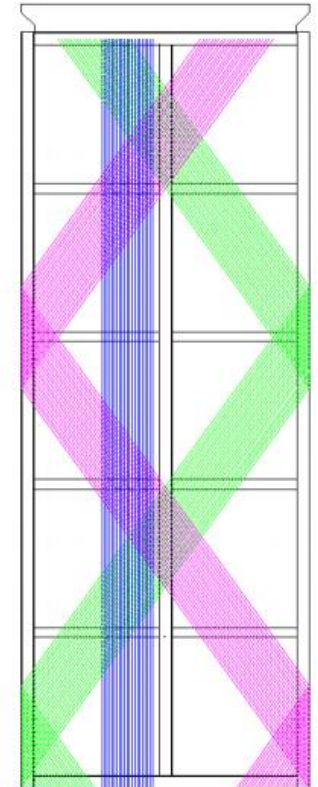
- Charged particles will ionize the LAr (MIP approx. 2.1 MeV)
- The electric field between the CPA and APA will cause the electrons to drift to the APA.
- Electrons will induce a bipolar signal on U and V planes and a unipolar signal as they collect on the Y plane.



Drawing by Bo Yu (BNL) of a neutrino interaction

LAr Time Projection Chambers

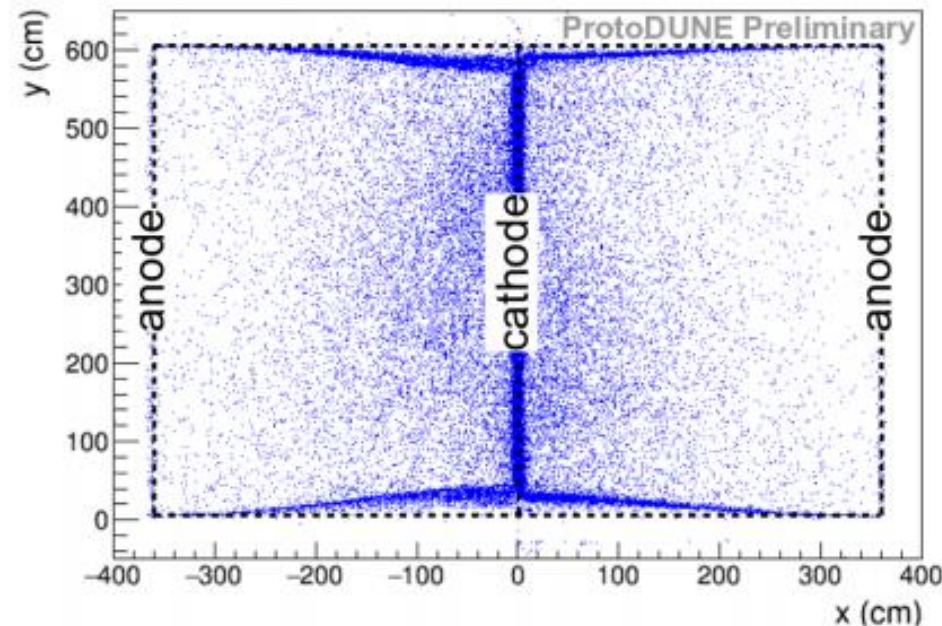
- Anode Plane Array
 - Three layers of wires (U, V, and Y plane)
 - U (red) and V (green) are angled at 60 degrees
- ProtoDUNE APA
 - Six APAs each containing 2,560 wires
 - Wire pitch of 4.8 mm between wires.
- Photon Detection System
 - A structure frame by the APA holds the PDS system
 - Uses a combination of SiPMs and a prototype ARAPUCA to detect photoelectrons from particles traveling in argon.



ProtoDUNE's Biggest Challenge

- Bombardment of cosmic rays being on the surface
 - Creates an excess of positive argon ions, known as the space charge effect, that leads to distortions in the electric field.
 - These ions build on the cathode plane and sides without APAs.
- Ways to measure SCE
 - Look at difference between start and end of track for exiting and entering tracks
 - Done through t0-tagging tracks that pass the cathode, anode, or CRT
 - Compare TPC tracking with tracking from an external system

Trackpoints on the cathode and top and bottom faces



Cosmic Ray Tagger (CRT)

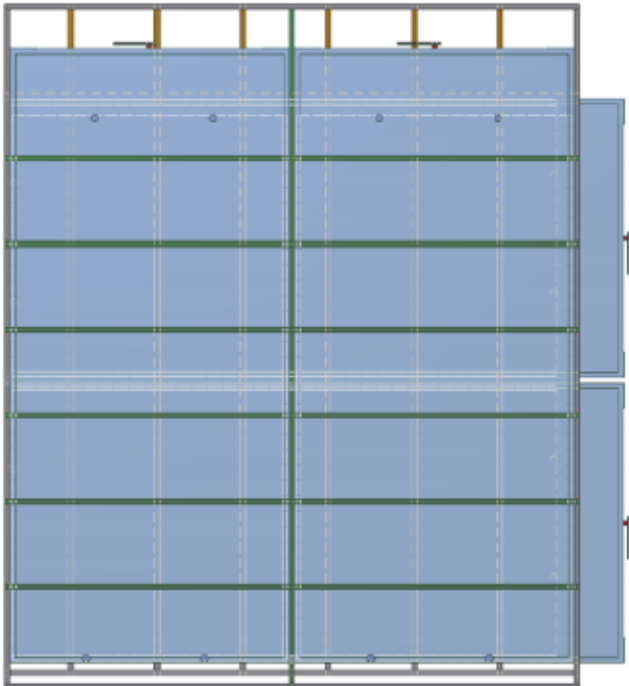
- Array of scintillator strips covering the front and back TPC faces.
- Intended to calibrate the space charge effect using cosmic rays
 - T0-tag tracks to ensure the position along the drift is measured
 - Can draw a track from front to back using the scintillator strips to compare with TPC tracking
- Repurposed from Double Chooz
 - 32 panels (1.6 m by 3.2 m) of 64 polystyrene scintillator strips (5 cm wide, 3.2 m long)
 - 32 strips in a front layer of a panel and 32 in a back layer so the strips appear to only have a 2.5 cm thickness

Single strip (left) and
three strips overlaid
(right) (Not to scale)

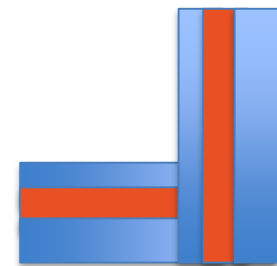


Cosmic Ray Tagger

- CRT Assembly
 - Four modules placed in 3.2 m by 3.2 m assembly
 - Strips upright measure the x-position of a track and strips laying horizontally measure the y-position



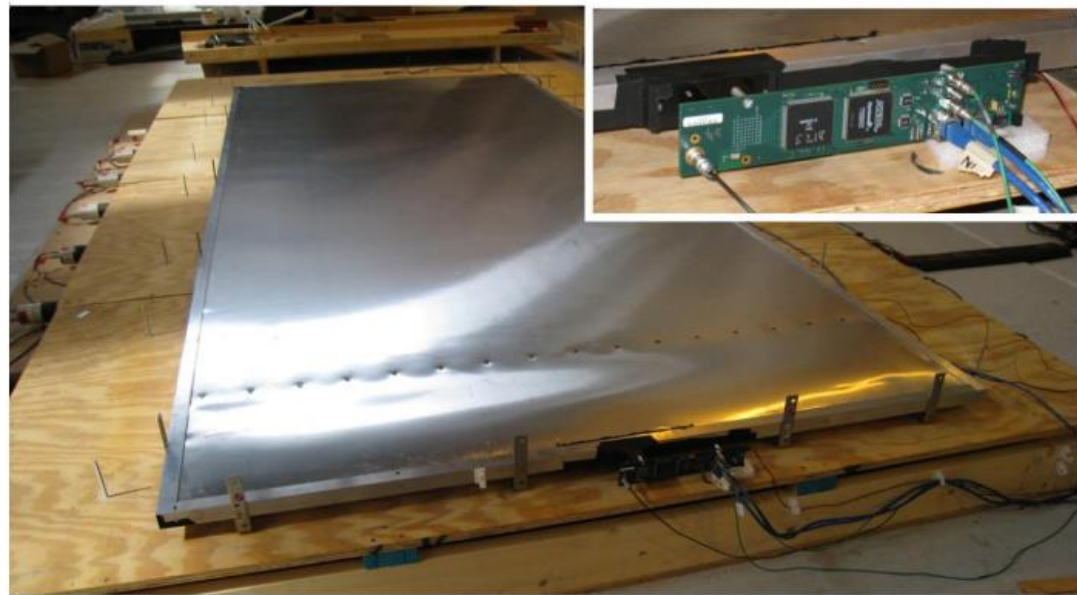
CRT assembly (left) and a section of six strips zoomed in on a part of the assembly (right).



CRT Electronics

- Each strip connected to a wavelength-shifting fiber
- Fibers connected to a Hamamatsu M64
- Read by an ADC and then sent to the DAQ

MAROC2 and Altera FPBA

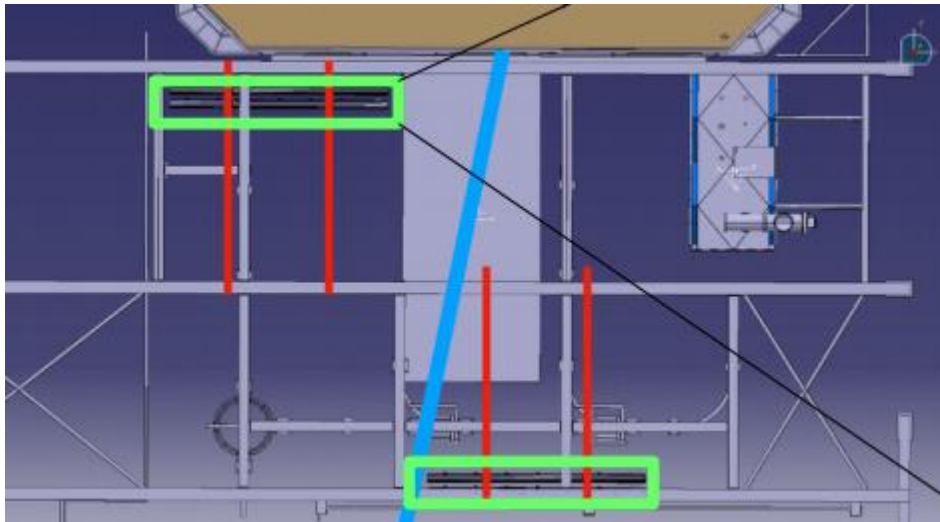
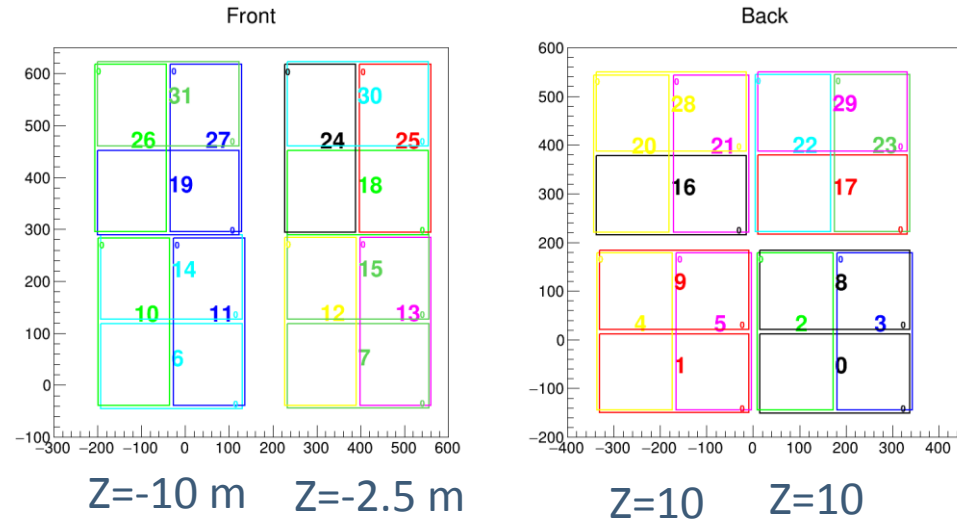


One CRT Module of 64 strips

CRT Placement

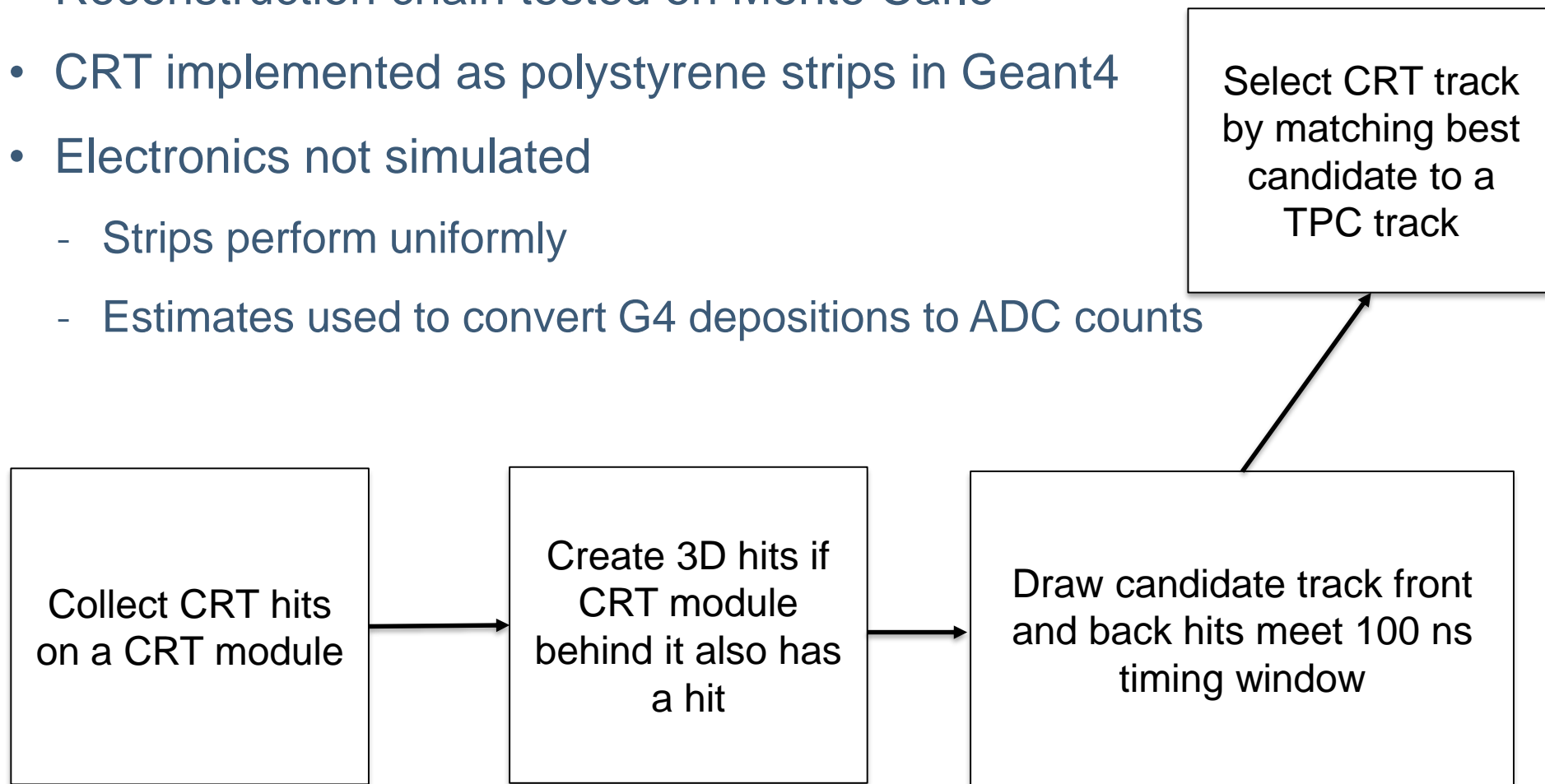
- CRT upstream offset due to beam pipe
- $Z=0$ corresponds to the front TPC face
- TOF (40-70 ns)

CRT channel map



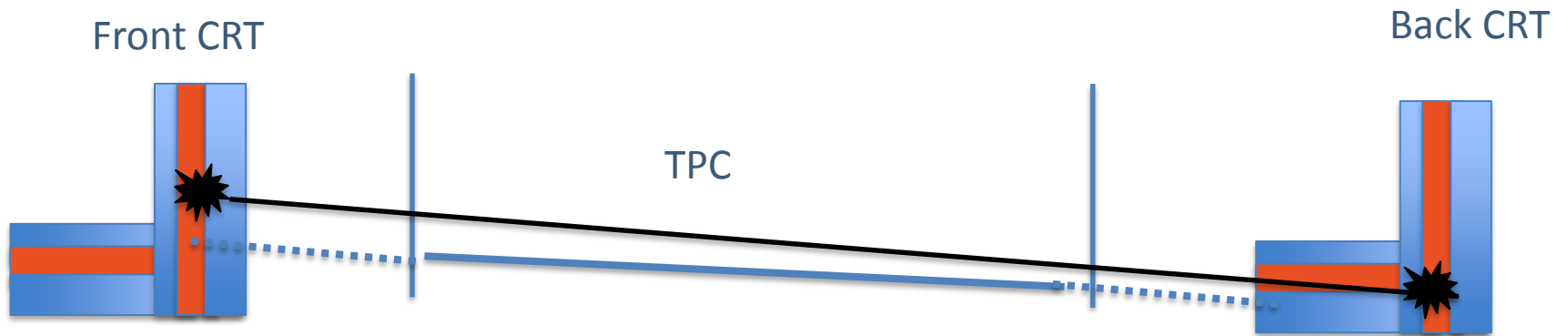
CRT Reconstruction and Simulation

- Reconstruction chain tested on Monte Carlo
- CRT implemented as polystyrene strips in Geant4
- Electronics not simulated
 - Strips perform uniformly
 - Estimates used to convert G4 depositions to ADC counts



CRT Reconstruction

- Match tracks using CRT strips to a TPC track.
 - Select strips that best match where the TPC track hits the CRT
- Two CRT Matching



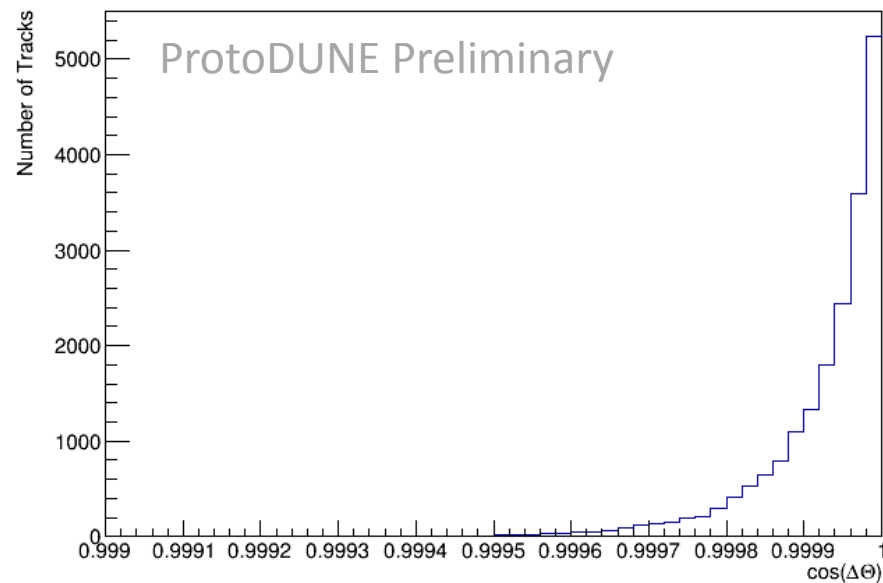
Single CRT Matching (Not currently used for SCE calibration)



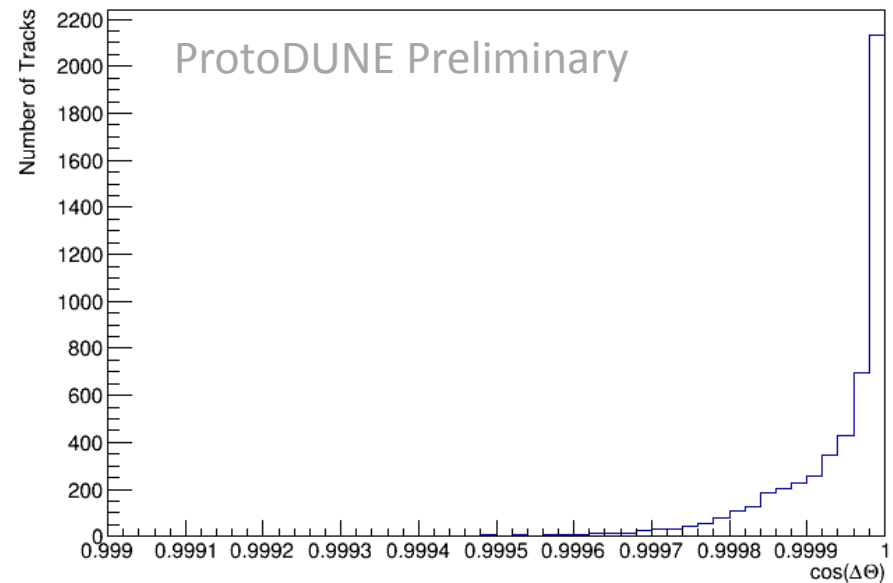
Two CRT Tracking Agreement

- Can measure by taking the dot product between the CRT direction and the TPC direction.
- Good agreement as $\cos(1.6 \text{ degrees})=0.9996$

Histogram of CRT-TPC dot product for data



Histogram of CRT-TPC dot product for MCC

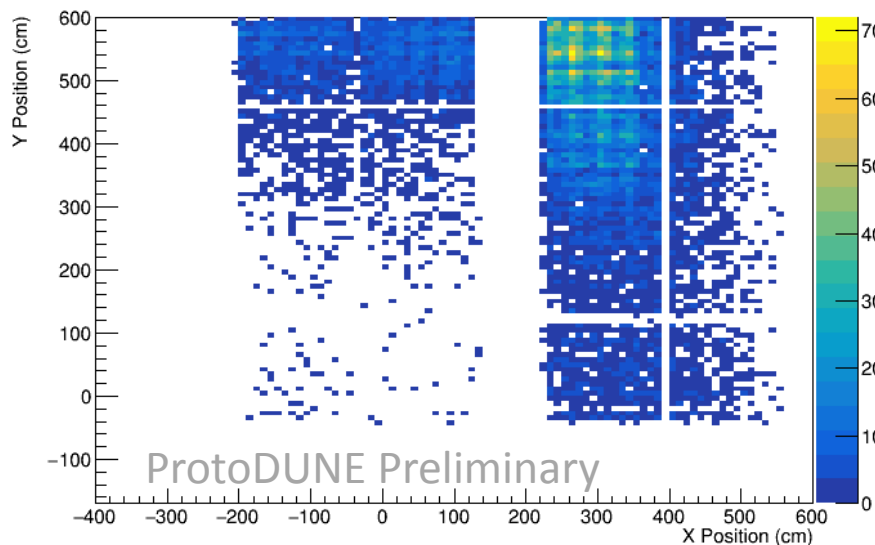


CRT Coverage

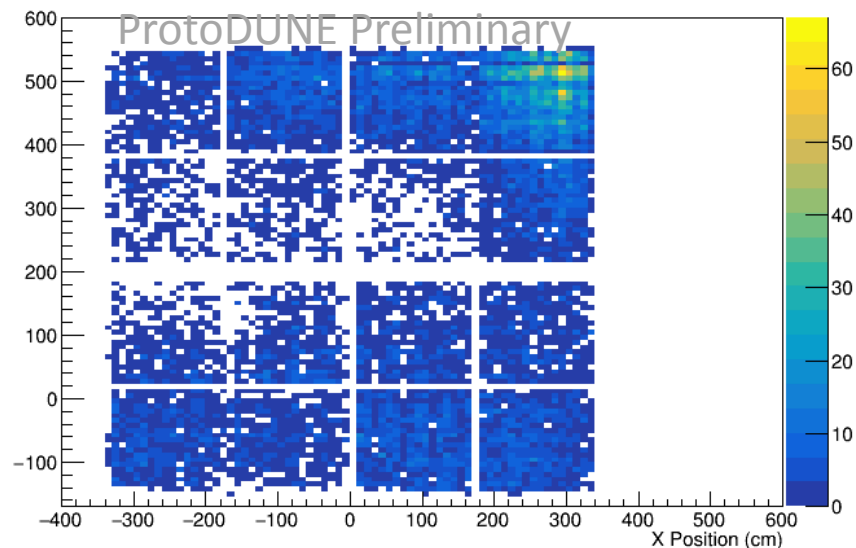
- CRT coverage map heavily dictated by the geometry.
- For a collection of four good beam runs with CRT, we see a majority of CRT modules see hits.

Upstream (left) and downstream (right) of the beam. Remember that the left side upstream is offset by an additional eight meters.

CRT Coverage Map for TwoCRT at the F CRT Face for data



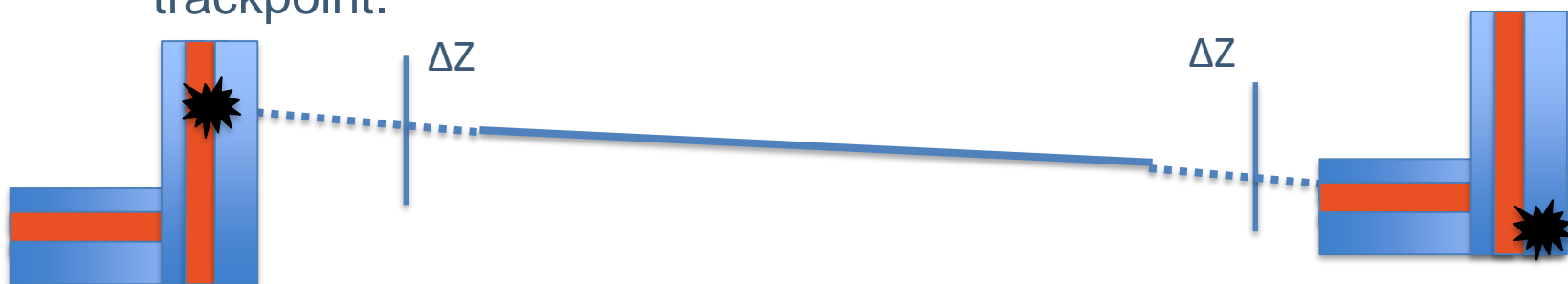
CRT Coverage Map for TwoCRT at the B CRT Face for data



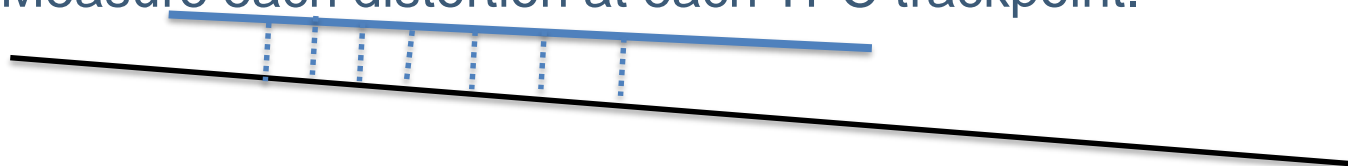
Measuring Space Charge Effect

Use Two Methods

- Start and end trackpoints for through-going muons
 - Use the timing of the CRT to the right position in X and then measure the difference between the cryostat wall and first observed trackpoint.



- Tracking distortions between the CRT and the TPC
 - Measure each distortion at each TPC trackpoint.

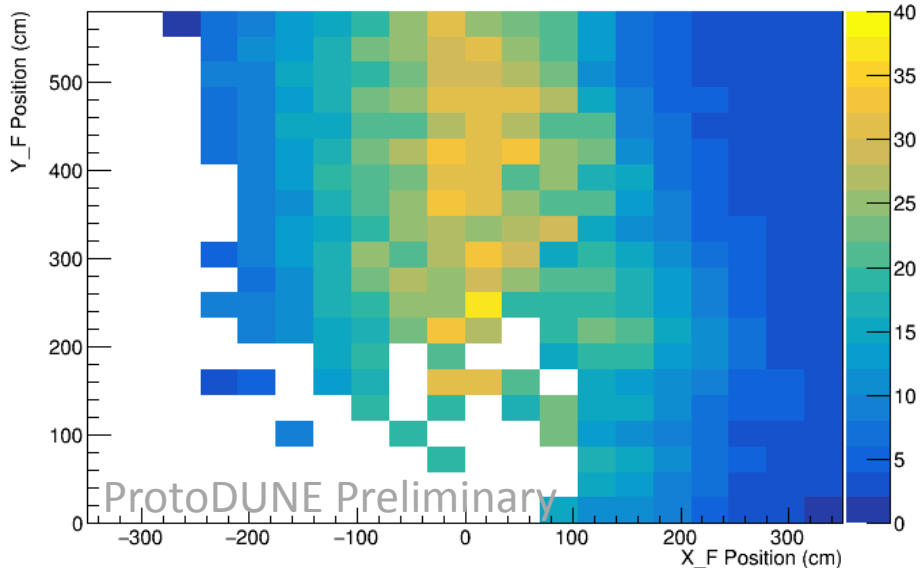


CRT SCE Measurements of ΔZ

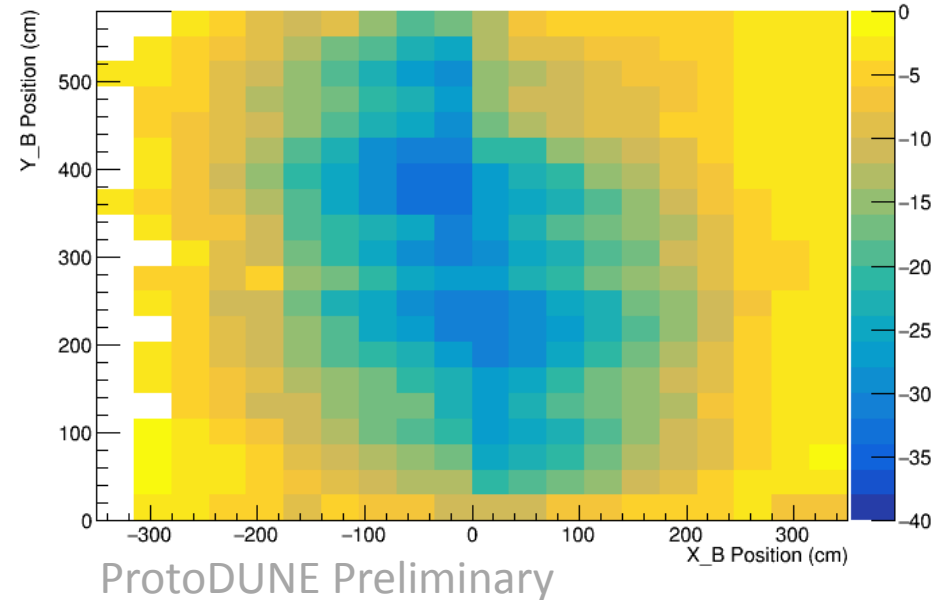
- Over good beam data runs with CRT, we see significant displacement in Z up to 40 cm on the TPC face.

Upstream (left) and downstream (right) of the beam.

Map of CRT Reco Displacements weighted by ΔZ_{F_data}

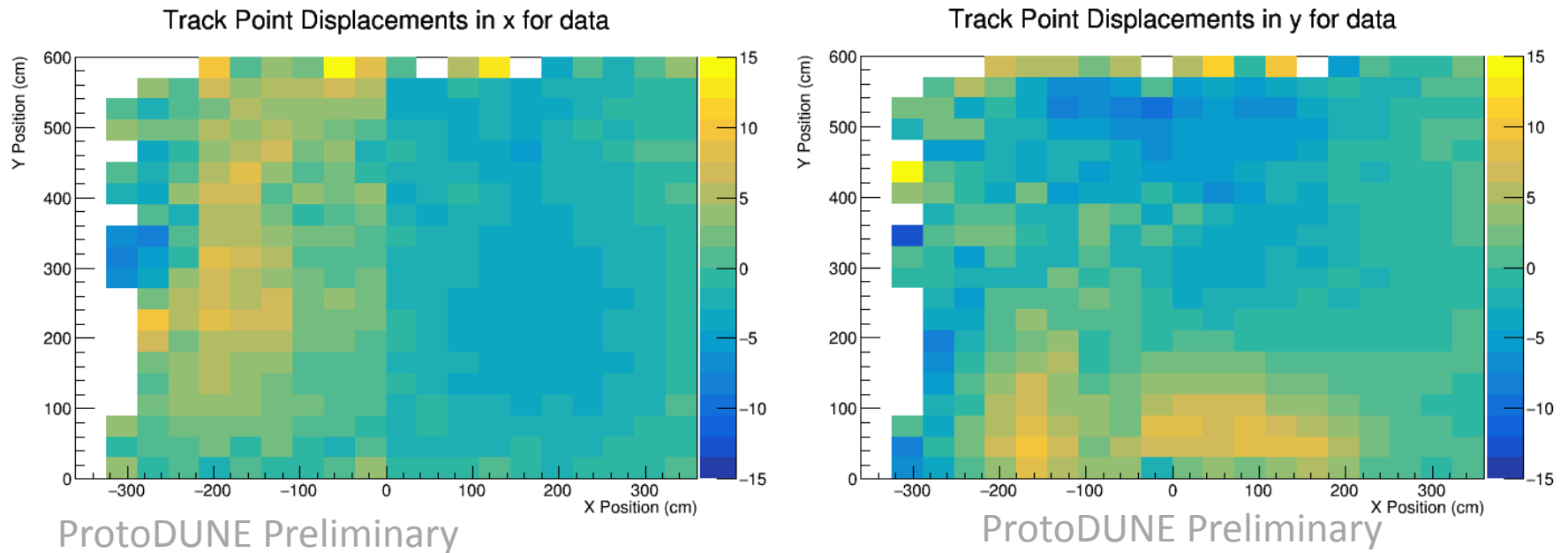


Map of CRT Reco Displacements weighted by ΔZ_{B_data}



CRT Tracking Distortions

- Displacements at most 10 cm in x and y.



Upstream (left) and downstream (right) of the beam.

Electron Lifetime Issues

- Impurities in the liquid argon can capture electrons.
 - This leads to less charge on the wires and a reduced dQ/ds and dE/ds .
 - The electron lifetime (τ) corresponds to the amount of free electrons drifting as a function of drift time (t).

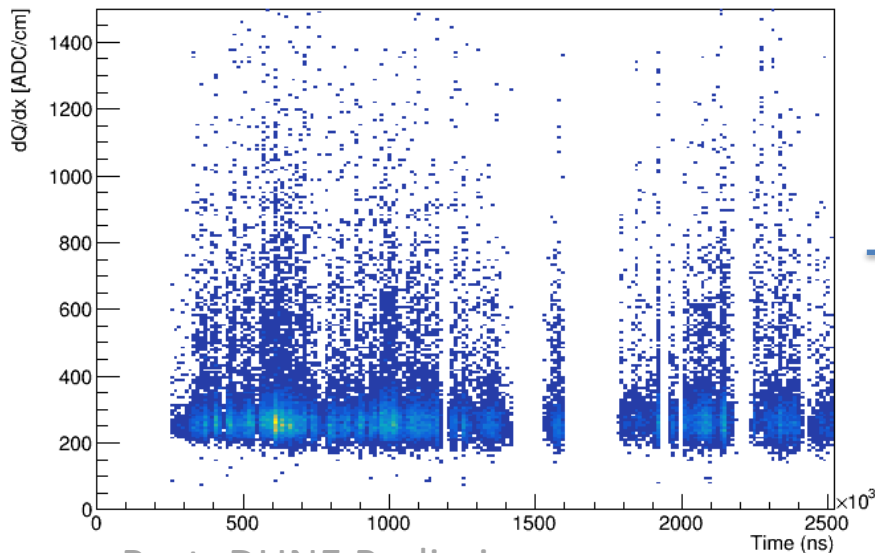
$$Q(t) = Q \exp(-t/\tau)$$

- Use the CRT to t_0 tag tracks to precisely know the drift time and use the CRT tracks to do SCE calibrations to correct for electric field deviations.
 - Collect dQ/ds on the collection plane and correct for the time that the CRT measured and electric field deviations.
 - Electric field map made from already made SCE map from tracks tagged that cross the cathode.
 - Find the most probable value (MPV) for a slice of time.
 - Plot the MPVs and timing bins and fit to an exponential.

Electron Lifetime Measurements

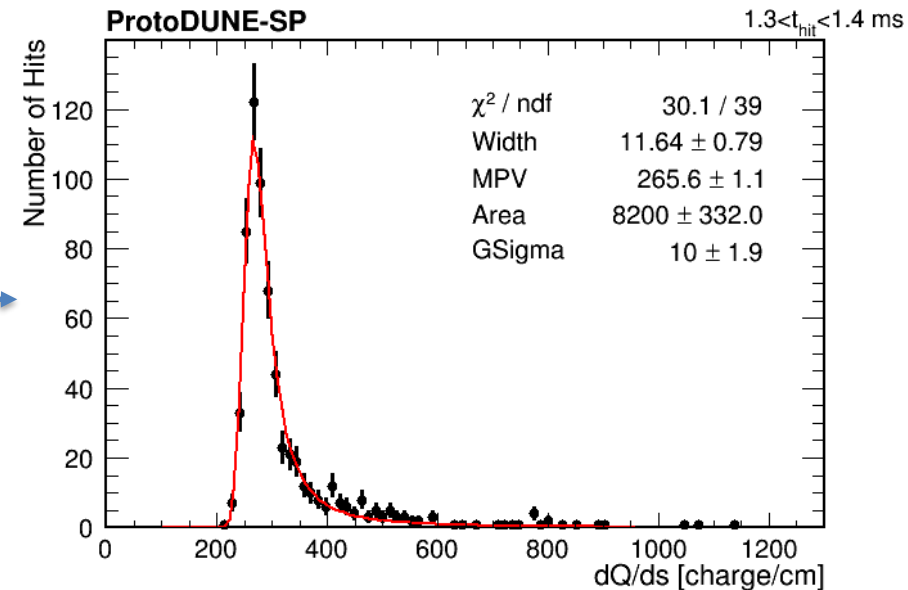
- We need to get the MPV due to the distribution of dQ/ds at a specific slice in drift time.
- Find MPV through a Landau-Gauss fit.

dQ/dx of CRT-Tagged Tracks



ProtoDUNE Preliminary

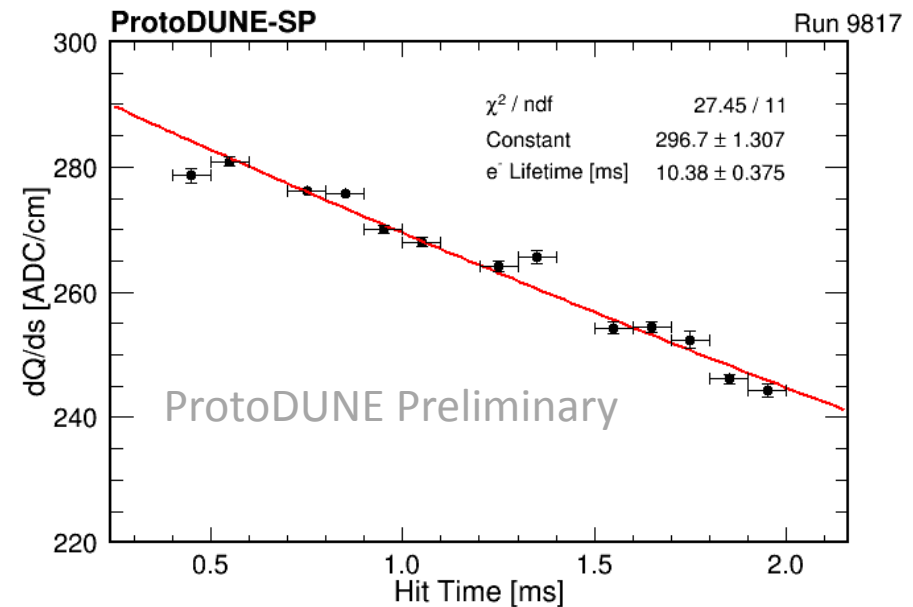
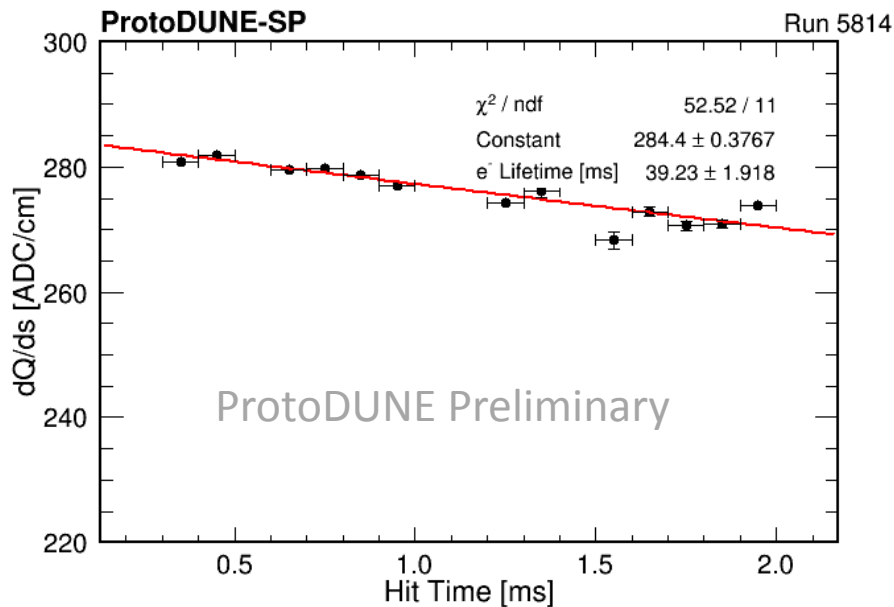
ProtoDUNE-SP



ProtoDUNE Preliminary

Electron Lifetime Measurements

- Plan to go back and quantify electron lifetime for each run
- Loss 5.5% of charge between the cathode and anode for a 39.23 ms lifetime and 21% for a 10.38 ms lifetime.



High purity run (left) and low purity run (right)

Conclusion

- ProtoDUNE is a test beam experiment intended to prototype reconstruction and engineering for DUNE
- The space charge effect comes from large cosmic flux that can change tracking sometimes up to 50 cm.
- The Cosmic Ray Tagger can quantify the space charge effect using tracking distortions either between a side wall and track endpoints or comparing directly to the CRT track.
- The electron lifetime can be measured using the CRT with good precision thanks to its tracking calibration.
- Future analyses for ProtoDUNE will use the CRT's measurements. Stay Tuned!