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

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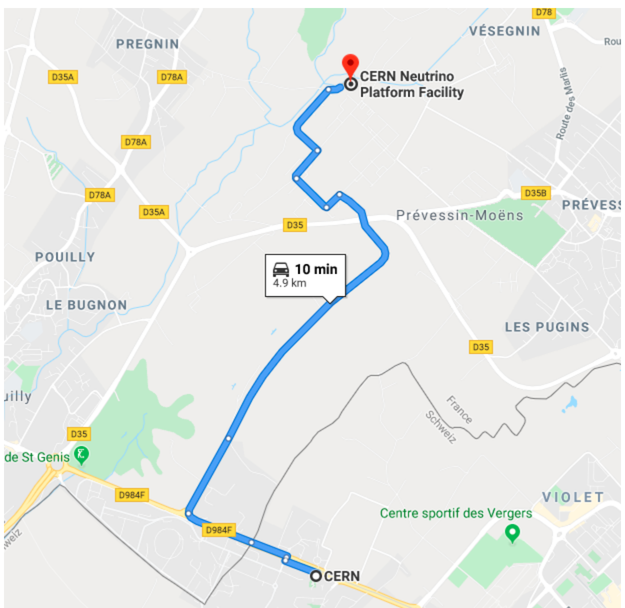
ProtoDUNE

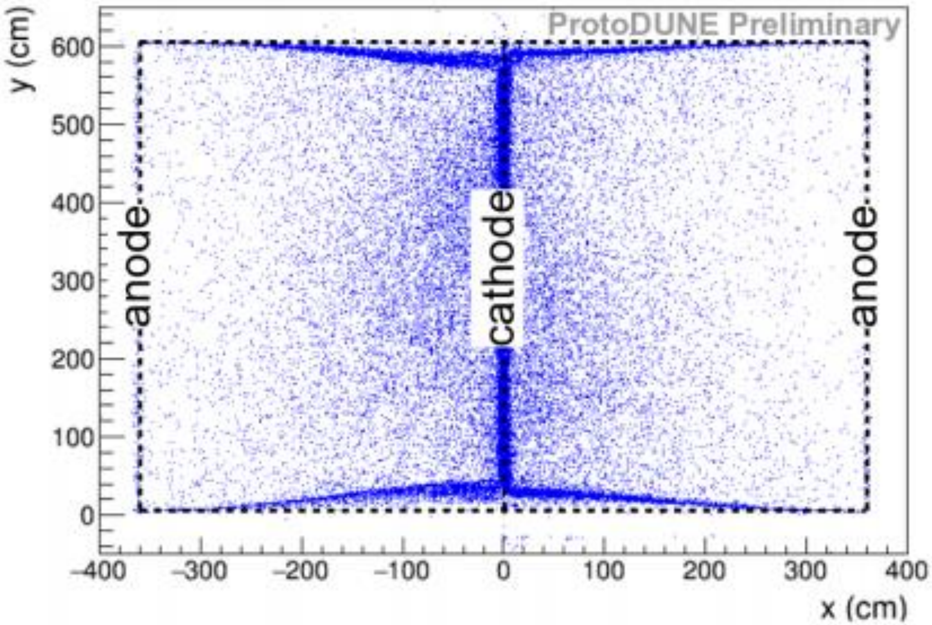
- Research and development detectors for DUNE Far Detectors at the Neutrino Platform at CERN.
- One dual phase detector and one single phase detector.
- Both have test beams and currently measure cosmic rays.



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 th[a] pass the cathode, anode, or CRT
  - Compare TPC tracking with tracking from an external system

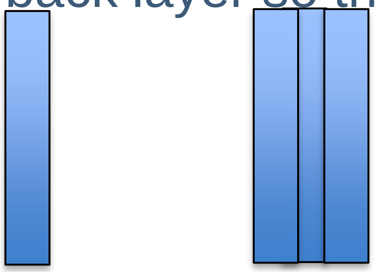
Trackpoints on the cathode and top and bottom faces for ProtoDUNE-SP



Cosmic Ray Tagger (CRT)

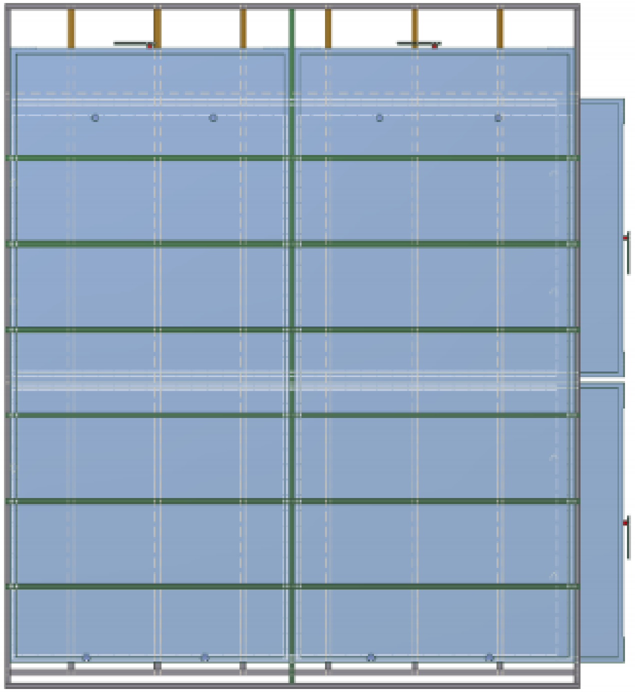
- Array of scintillator strips covering the front and back TPC faces.
- Intended to calibrate the space charge effect using cosmic rays
  - T0-tag tracks to ensure the position along the drift is measured
  - Can draw a track from front to back using the scintillator strips to compare with TPC tracking
- 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)

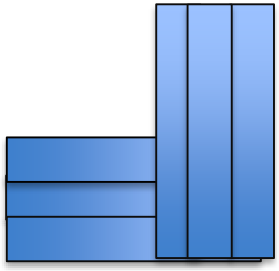


Cosmic Ray Tagger

- 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



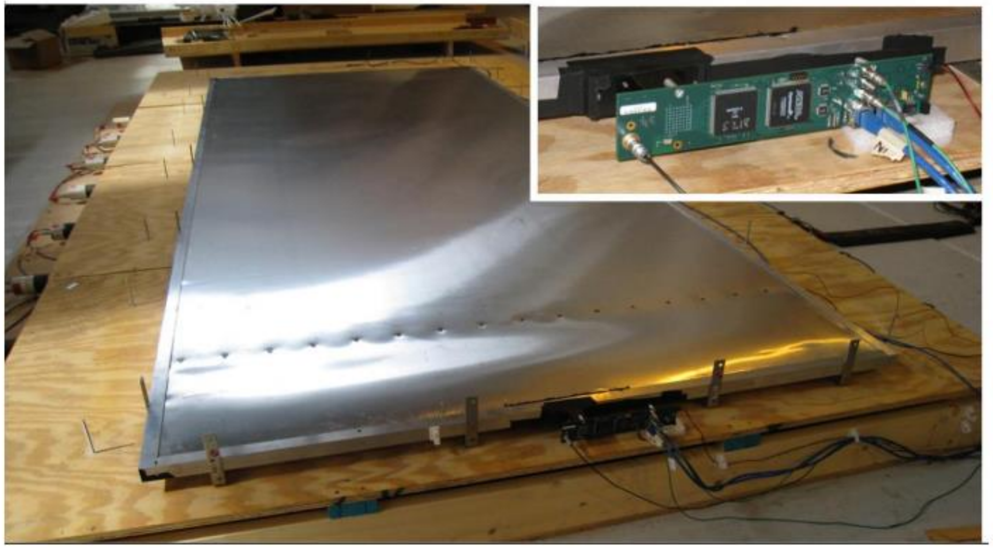
CRT assembly (left) and a section of six strips zoomed in on a part of the assembly (right).



CRT Electronics

- Each strip connected to a wavelength-shifting fiber
- Fibers connected to a Hamamatsu M64
- Read by an ADC and then data sent to be stored with the TPC data.

MAR0C2 and Altera FPGA

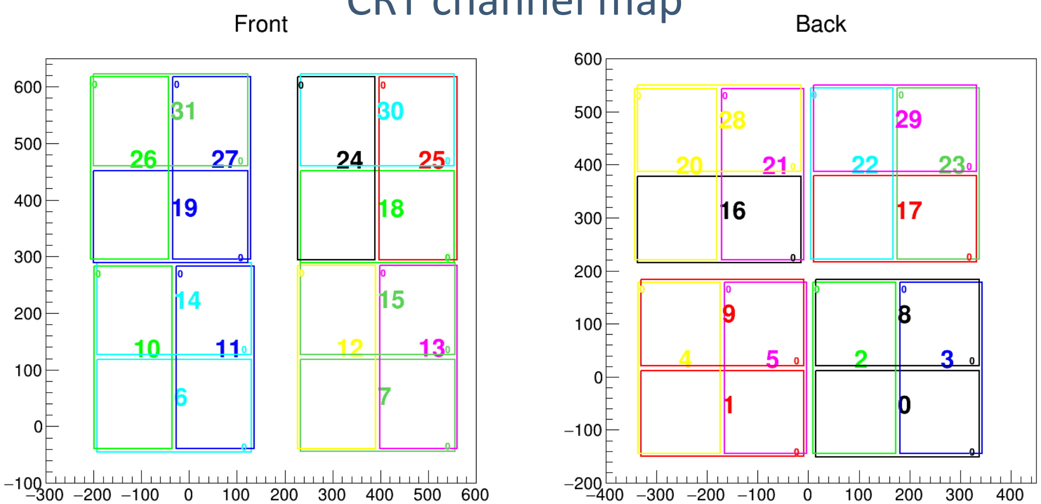


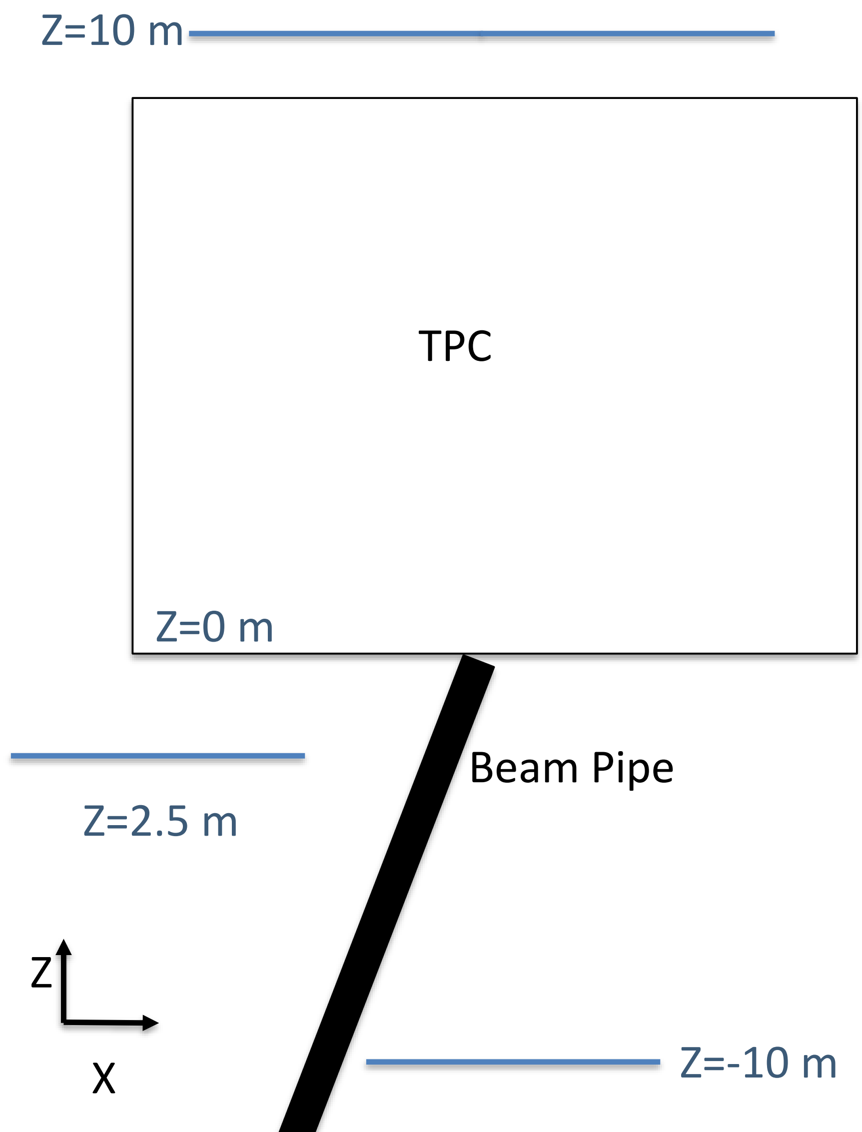
One CRT Module of 64 strips

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

Collect CRT hits on a CRT module

→ Create 3D hits if CRT module behind it also has a hit

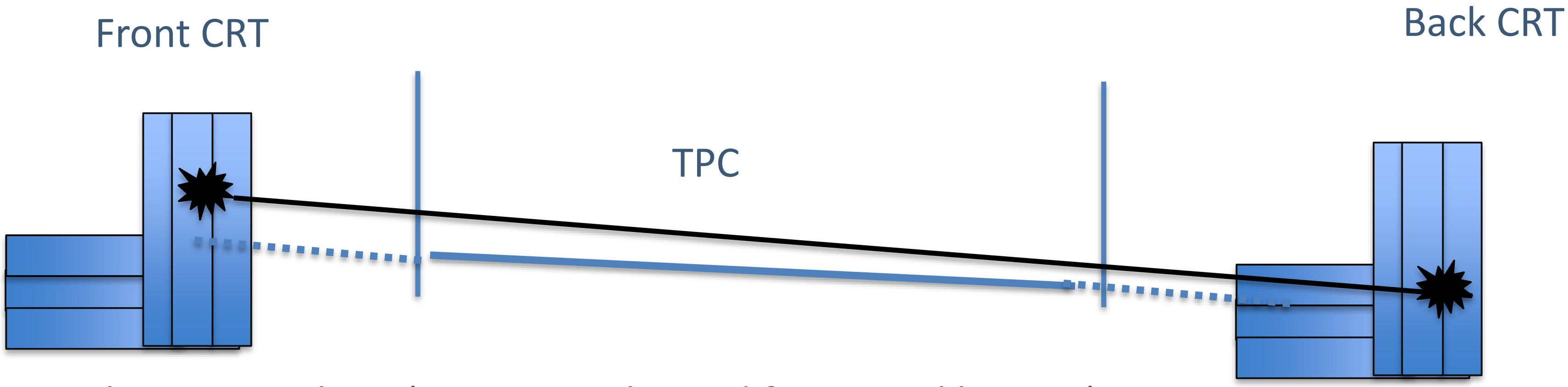
→ Draw candidate track front and back hits meet 100 ns timing window. A trigger is set up to look for these automatically.

→ Select CRT track by matching best candidate to a TPC track

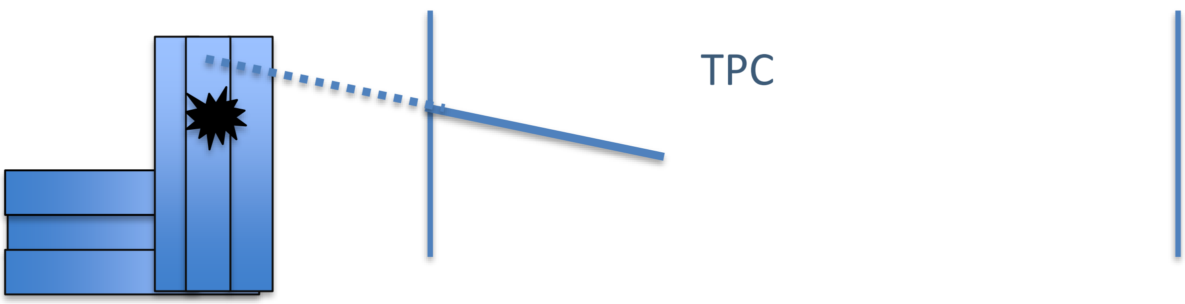
CRT Reconstruction

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

Two CRT Matching

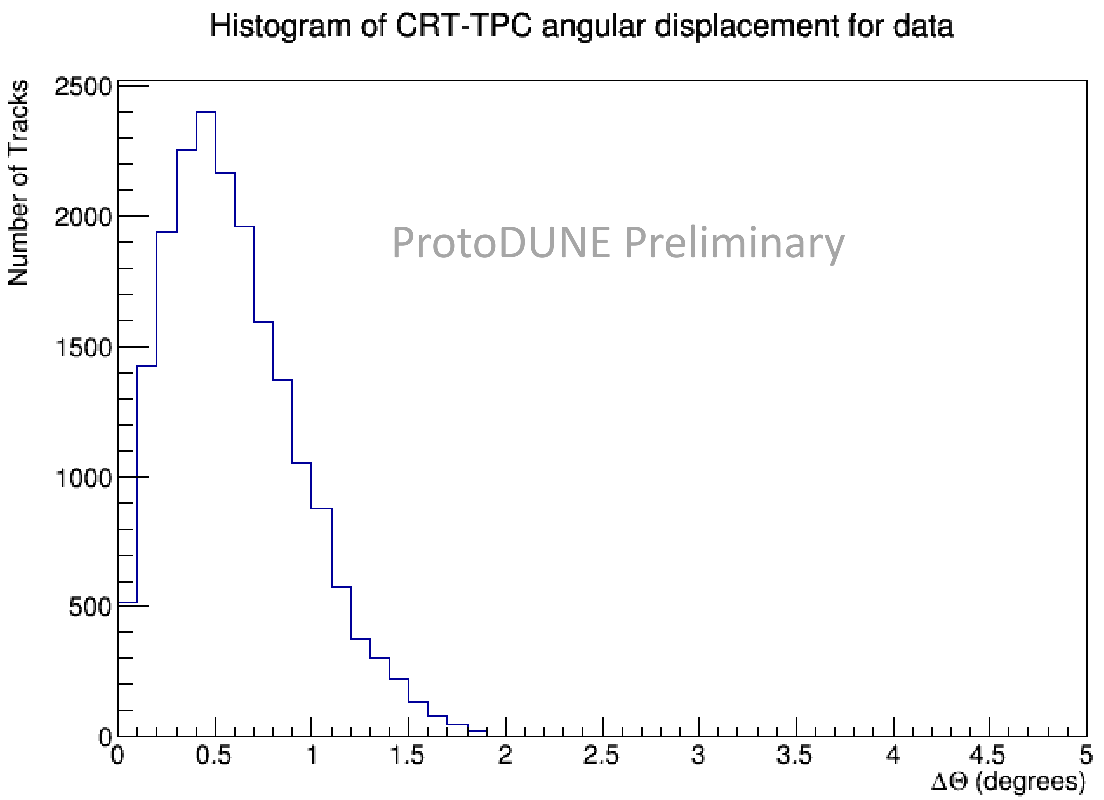


Single CRT Matching (Not currently used for SCE calibration)



Two CRT Tracking Agreement

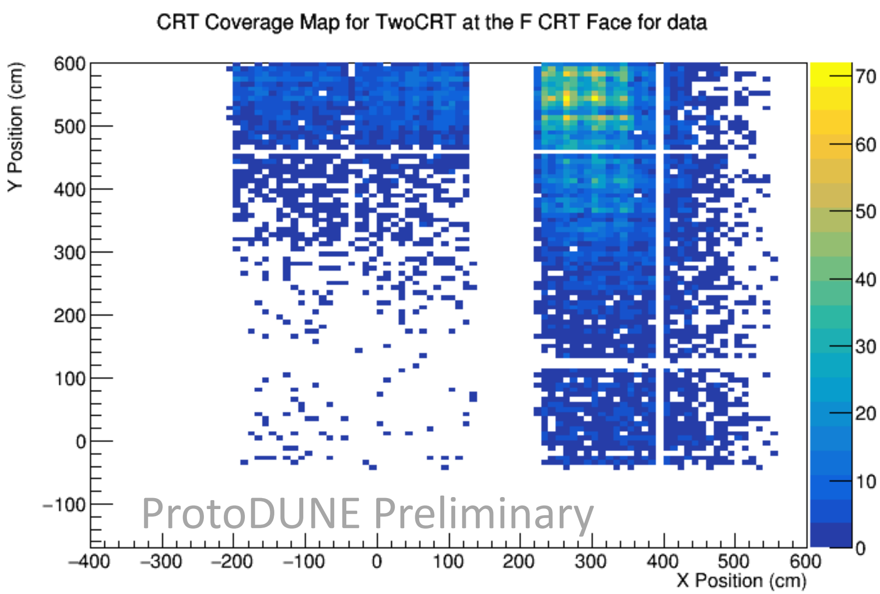
- Can measure by taking the dot product between the CRT direction and the TPC direction

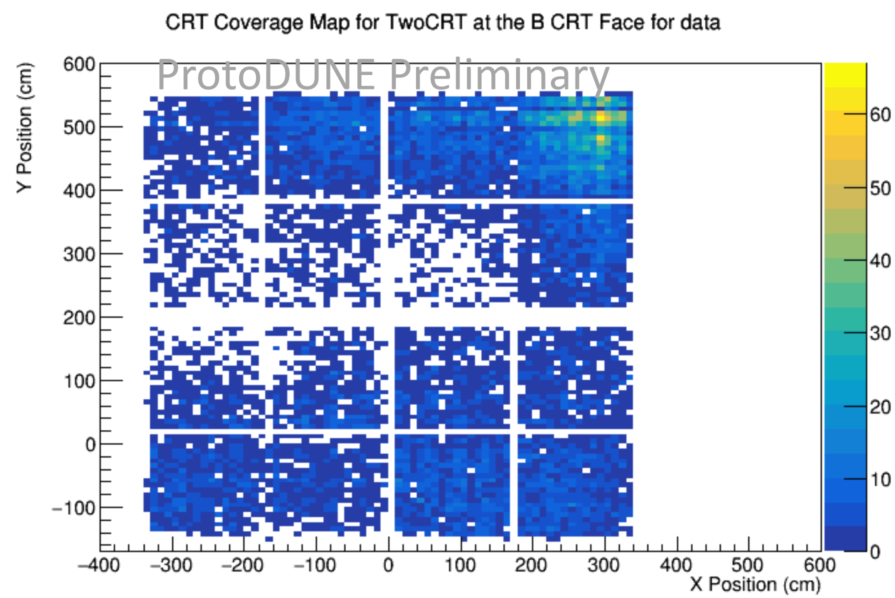


CRT Coverage

- 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.

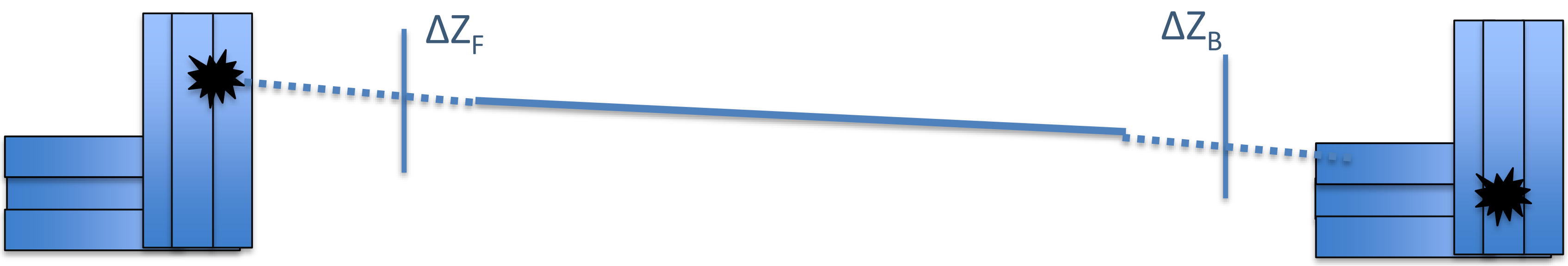




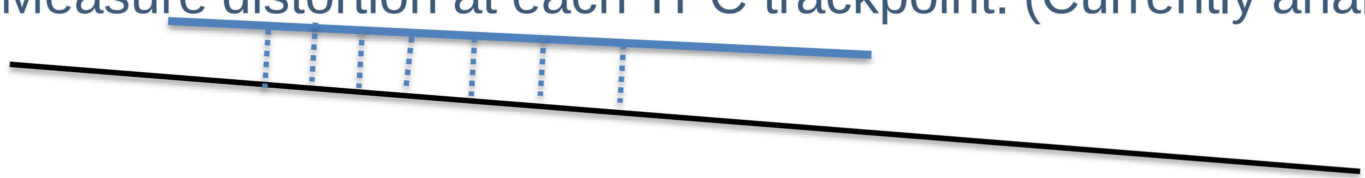
Measuring Space Charge Effect

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.



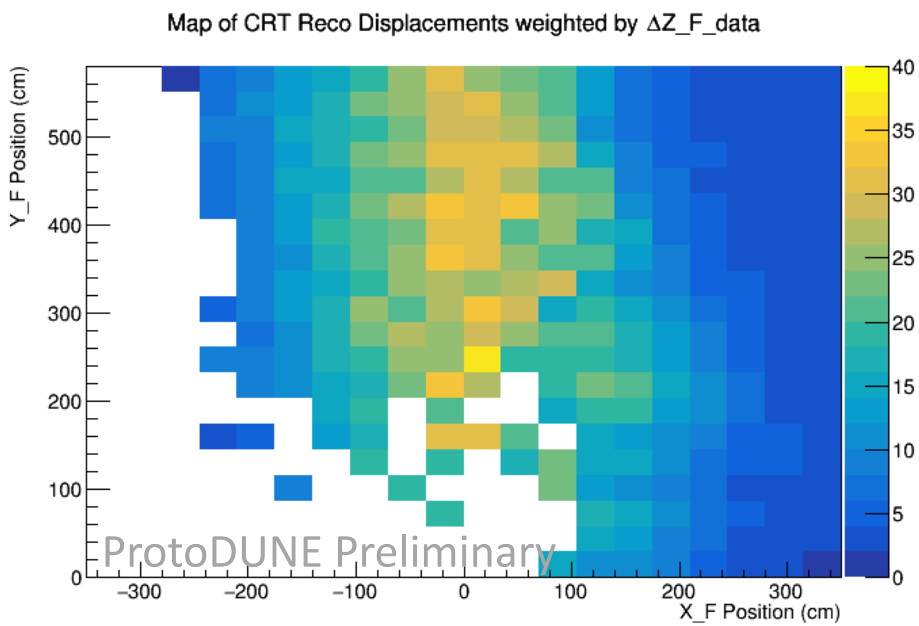
- Tracking distortions between the CRT and the TPC
  - Measure distortion at each TPC trackpoint. (Currently analyzing)

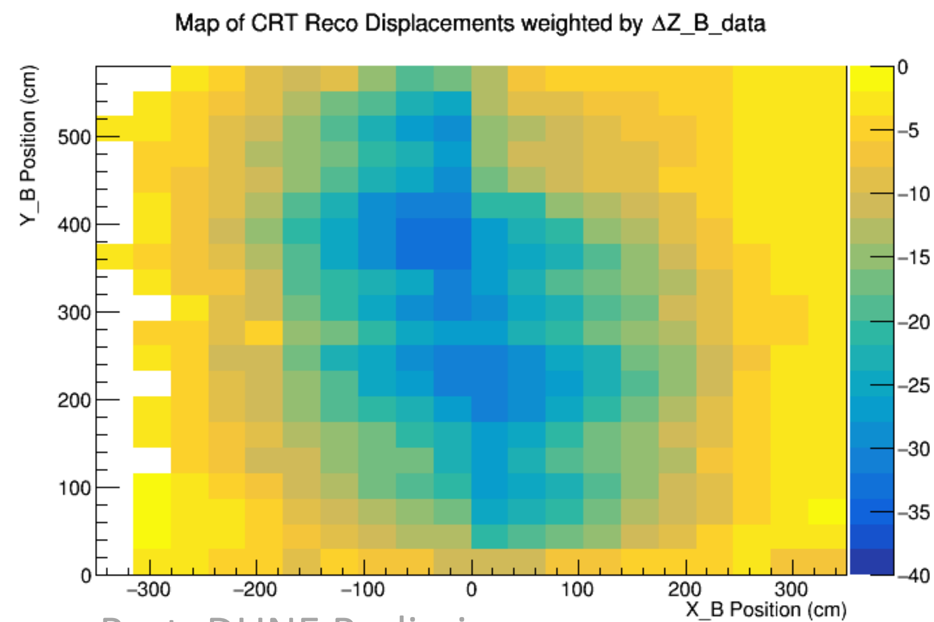


CRT SCE Measurements of ΔZ

- 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.





ProtoDUNE Preliminary

Electron Lifetime Studies

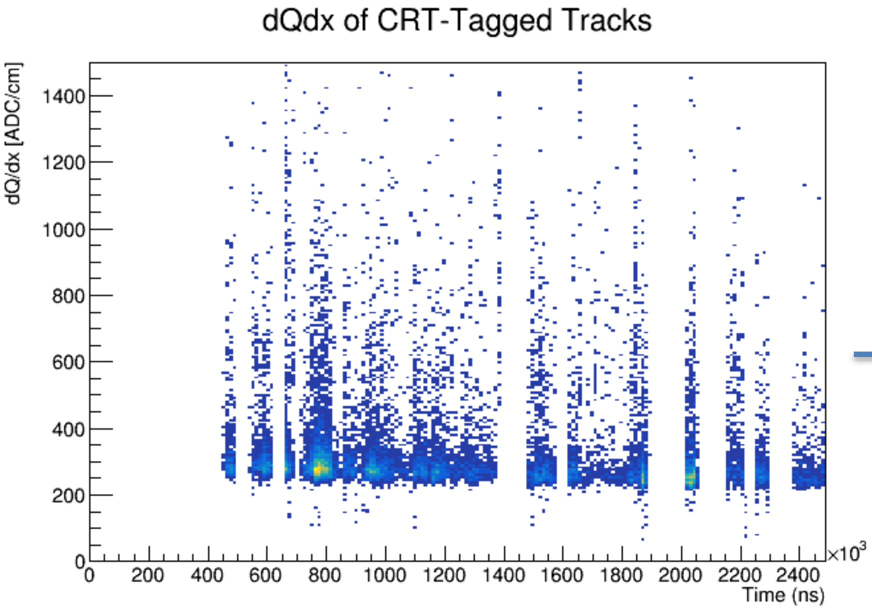
- Impurities in the liquid argon like oxygen, water, and nitrogen can capture electrons.
  - This leads to less charge on the wires and a reduced dQ/dx and dE/dx.
  - The electron lifetime (τ) corresponds to the amount of free electrons drifting as a function of drift time (t).

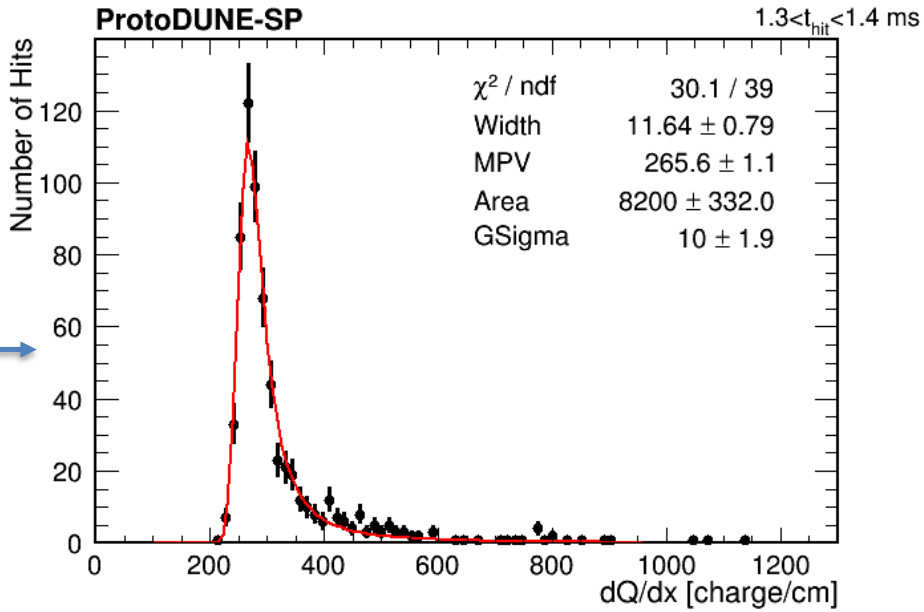
$Q(t)=Q_o*exp(-t/\tau)$

- Use the CRT to t0 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/dx 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 convolved with a Gaussian.





ProtoDUNE Preliminary

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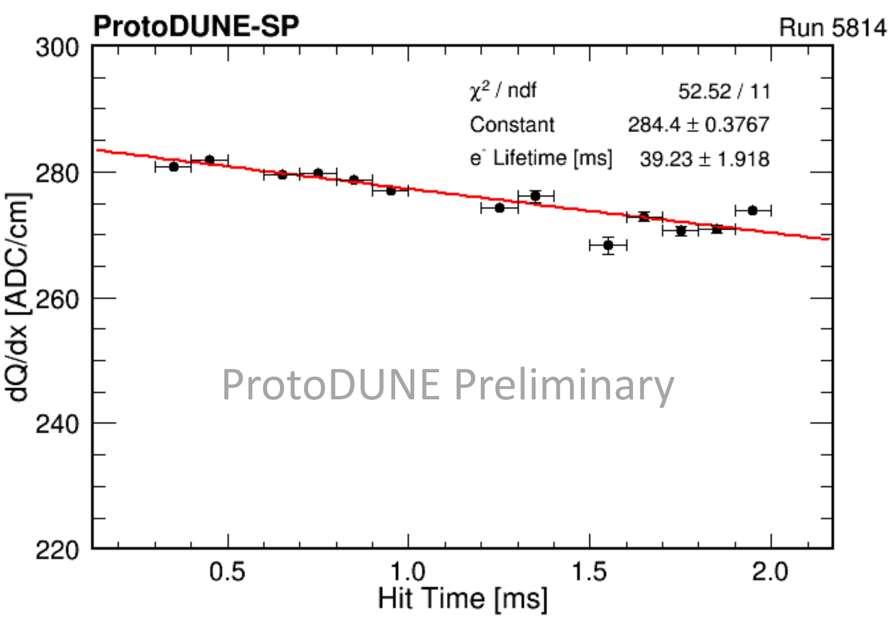
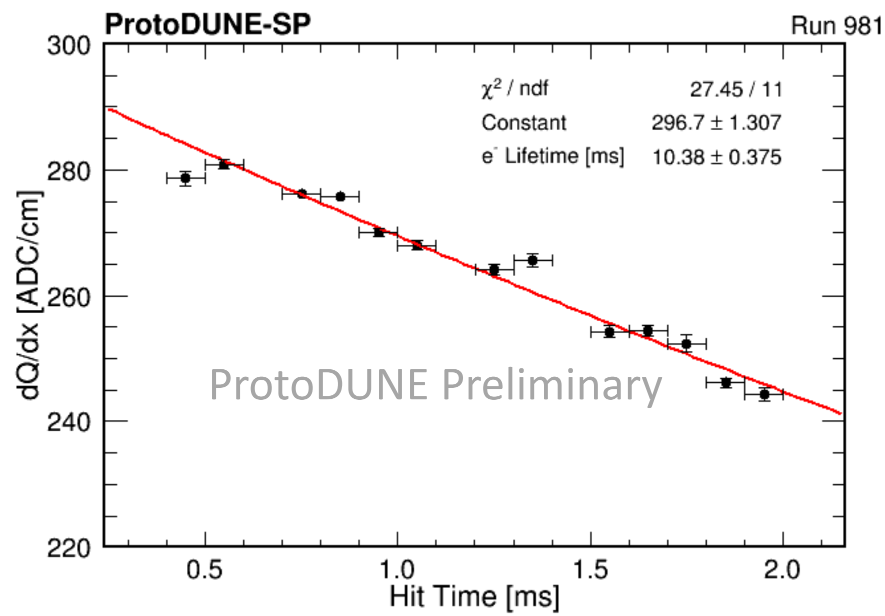
Electron Lifetime Measurements

- 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-SP is a test beam experiment intended to prototype reconstruction and engineering for the DUNE Single Phase Far Detectors.
- The space charge effect comes from large cosmic flux that can change tracking sometimes up to 40 cm.
- The Cosmic Ray Tagger can quantify the space charge effect using tracking distortions either between a side wall and track endpoint 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!