Measuring Free Electron Lifetimes in the ProtoDUNE-SP Single Phase Detector

Richard Diurba (University of Minnesota) on behalf of the DUNE Collaboration

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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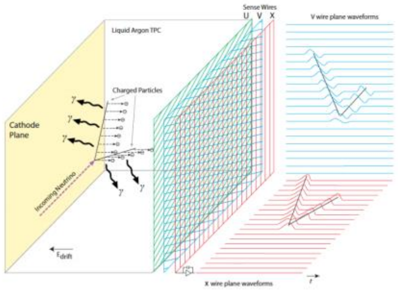
Drift Electron lifetime in Liquid Argon

- Single phase liquid argon time projection chambers (LAr TPCs) are used by neutrino experiments like ArgoNEUT, MicroBooNE, and SBND and will be used for DUNE.
- Impurities in liquid argon can capture ionized electrons as they drift, reducing the signal read on the wires.
- This effect can be quantified as hit charge (Q), which comes from the exponential decay of a constant (Q_o) as a function of a hit drift time (t) and the drift electron lifetime of the TPC (τ):

$$Q(t)=Q_o e^{-t/\tau} \qquad (1)$$



Example of final state particle tracks from a neutrino scattering being measured in a LAr TPC [1].

ProtoDUNE-SP TPC and Cosmic Ray Tagger (CRT)

- ProtoDUNE-SP is a 700 ton single phase LAr detector that is 7 m long, 7.2 m wide, and 6 m tall at the CERN Neutrino Platform.
- Contains two 3.6 m long drift volumes with a cathode at the TPC's center.
- Sits under a charged hadron beam of pions, electrons, muons, protons, and kaons.
- External to the TPC is a Cosmic Ray Tagger, a collection of scintillator strips to calibrate the TPC using cosmic muons.

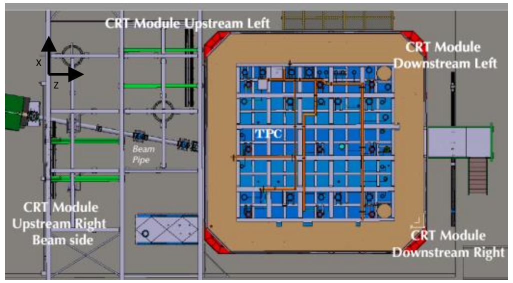
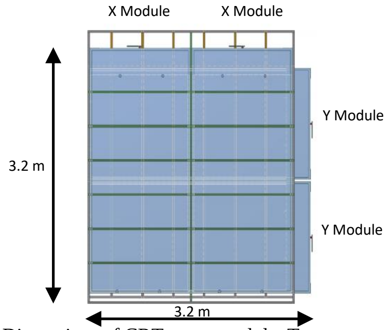


Diagram of CRT placement in relationship to the TPC. Four supermodules sit upstream and four downstream. CRT covers 6 m in y and 3.2 m in x at each location.



Dimensions of CRT super module. Two super modules are stacked to cover the TPC height.

- 32 CRTs arrays containing 64 scintillator strips that are 5 cm wide.
- Four arrays are overlaid into a super module that reconstruct a hit in 2D with 20 ns timing resolution.
- A track is reconstructed if one upstream hit and one downstream hit is measured within 80 ns of coincidence
- These CRT tracks travel in Z, parallel to the wire planes of the TPC. This significantly reduces the distortions on hit drift time from space charge effect, which are prevalent for cathode-anode crossers.

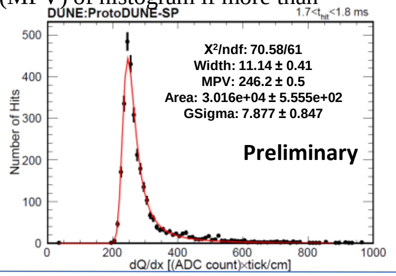
Measurement of the Drift Electron Lifetime

To measure the drift lifetime, we use the following equation:

$$dQ(t)/dx=dQ_o/dx\, e^{-t/\tau} \qquad (2)$$

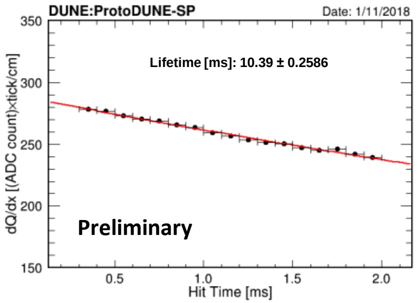
And do the following:

1. Match a CRT track to a TPC track based on their position and direction.
2. Select hits in the middle of the detector where the space charge effect is minimal. Calibrate TPC hits for timing offsets using the CRT timestamps.
3. Measure dQ/dx using the CRT to calibrate hit position and step size.
4. Calibrate dQ/dx for recombination due to the space charge effect using an electric field calibration map.
5. Bin in 0.1 ms time slices for the 2.3 ms drift of the TPC. Fit Most Probable Value (MPV) of histogram if more than 1000 hits in a slice.

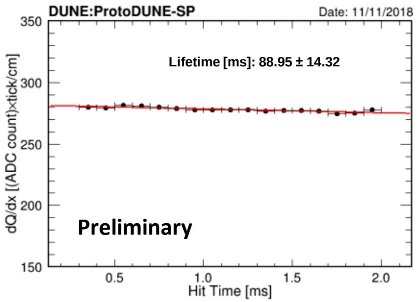


Binned TPC hit dQ/dx from TPC-CRT matched tracks from a run taking on November 1st, 2018.

6. Fit to Equation 2 to measure the drift electron lifetime.



Free electron lifetime measured on November 1st, 2018. This was the first day of CRT data-taking and occurred during LAr purity recovery. Statistical errors only.



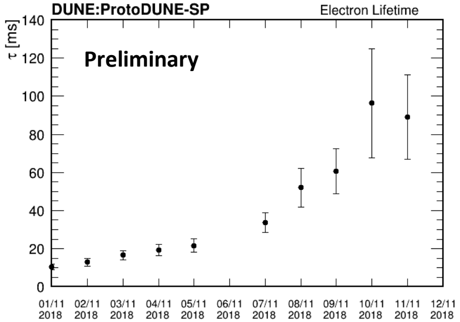
Binned TPC hit dQ/dx from TPC-CRT matched tracks from a run taking on November 11th, 2018. Statistical errors only.

Measured Lifetimes during 2018 Beam Data-Taking

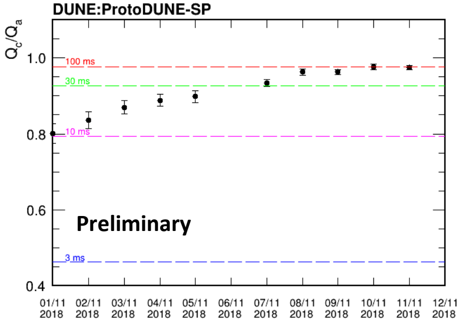
- Due to issues with recirculation pumps, the LAr purity started low when the CRT started taking data from November 1st to the end of beam data-taking on November 11th of 2018.
- Drift electron lifetime measured as high as 96.4±28.6 ms and was measured on the final day of beam data-taking as 89.0±22.1 ms.
- As the drift electron lifetime is used to calibrate hit charge, it is common then to quantify the maximum attenuation from the cathode to the anode due to impurities or:

$$Q_c/Q_a=Q(2.3\text{ ms})/Q(0)=e^{-2.3/\tau} \qquad (3)$$

- After purity was recovered, the TPC was measured to have at most Q_c/Q_a=0.976±0.007. This surpasses the DUNE Far Detector technical requirement of 0.464 (τ=3 ms) and technical goal of 0.795 (τ=10 ms).



Electron lifetime during November 2018 after the CRT started taking data. There was not enough data to make measurements on November 6th.



Q_c/Q_a for the days of data-taking with CRT data available to measure the electron lifetime using CRT-TPC matched tracks.

References

[1] B. Abi, et. al., "Deep Underground Neutrino Experiment (DUNE) Far Detector Technical Detector Report Volume 1" *arXiv:2002.02967*, 2020.