Electron Diffusion in the ProtoDUNE-SP LArTPC

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Introduction

- **Liquid Argon Time Projection Chamber (LArTPC) technology** is often used by experiments to study neutrinos, astrophysical phenomena, proton decay, and BSM physics
- Signals in LArTPCs are collected from ionization electron clouds, which drift away from interaction events through an electric field
- **Diffusion of the electron clouds in the longitudinal and/or transverse directions may distort the collected signal**
- Longitudinal diffusion has been measured in experiments such as ICARUS, DarkSide-50, and MicroBooNE, but **the scale of detectors to be used for the Deep Underground Neutrino Experiment (DUNE) indicate the importance of continuing to study this effect** [2, 3, 4, 5]
- Presented here is the most recent longitudinal diffusion measurement using data from ProtoDUNE-SP, a 1 kt-scale LArTPC prototype for the DUNE far detectors

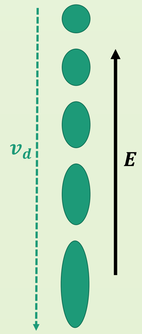

Figure 1 Cartoon modelling the effect of longitudinal diffusion on the evolution of an electron cloud moving in liquid argon at drift velocity $\boldsymbol{v_d}$ under an electric field $\boldsymbol{E}$. The image is not to scale and emphasizes **smearing of the electron cloud in the drift direction caused by longitudinal diffusion**. Transverse diffusion, which causes smearing orthogonal to the drift direction, is ignored [5].

Mathematical Background

- Longitudinal electron diffusion in liquid argon can be approximated by [5]:

$$\sigma_t^2 = \left(\frac{2D_L}{v_d^3}\right)x + \sigma_0^2 \qquad (1)$$

- $\boldsymbol{\sigma_t}$ = standard deviation of the charge deposit distribution in time for a given range of drift distances
- $\boldsymbol{\sigma_0}$ = same value for 0 drift distance
- $\boldsymbol{x}$ = drift distance of electron cloud
- $\boldsymbol{v_d}$ = electron drift velocity
- $\boldsymbol{D_L}$ = longitudinal diffusion constant

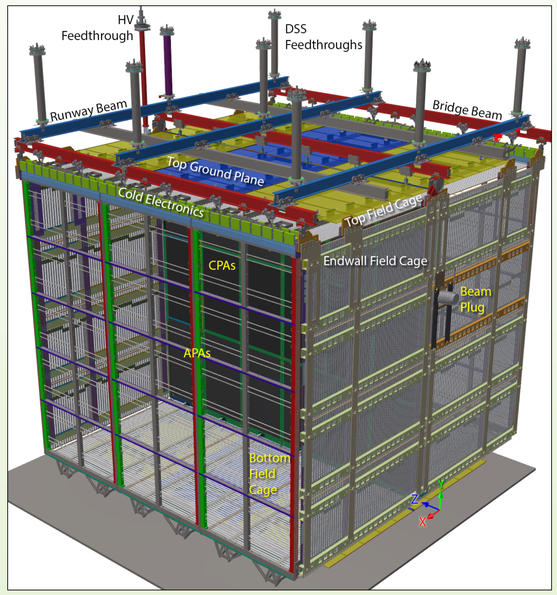

Figure 2 Drawing of the ProtoDUNE-SP detector [1].

Methods

Data used to compute D_L were collected in 2018. On the given dataset, we perform five main steps to find D_L:

- **Select** charge deposition events, or hits, from cosmic ray muon tracks which run mostly parallel to the detection planes (see Figure 3)
- **Bin** hits by drift time from ionization point to detection plane
- **Fit** the distribution of σ_t^2 in each drift time bin to a Gaussian and extract the mean value
- **Plot** mean σ_t^2 for each drift time bin against drift time
- **Calculate** D_L using Equation (1) and the slope extracted from a linear fit to the drift time vs. mean σ_t^2 plot, using v_d to compute between x and drift time

General methods and specific event selections cuts were **tested on Monte Carlo (MC) simulated event samples** with a programmed D_L of 4.0 cm^2/s.

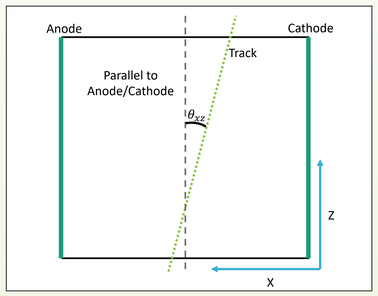

Figure 3 Schematic of the drift volume looking down on the detector from above. The value labelled θ_{xz} is one of the parameters used to make selection cuts on the dataset. **Tracks with low $\boldsymbol{\theta_{xz}}$ are ideal for this analysis** since hits on such tracks can be more accurately matched to drift times/distances.

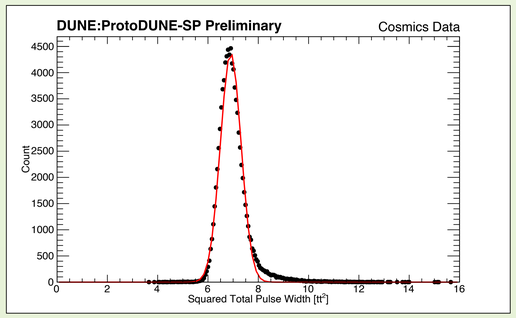

Figure 4 Example of a **histogram showing σ_t^2, or squared total time width of pulse, for all hits within a specific drift time bin.** The hits shown here have drift times between 1024 tt and 1281 tt. Units labelled "tt" are time ticks, equivalent to 0.5 μs [1]. The distribution is fitted to a Gaussian, shown here in red. The Gaussian mean is used to produce a plot of the type shown in Figure 4.

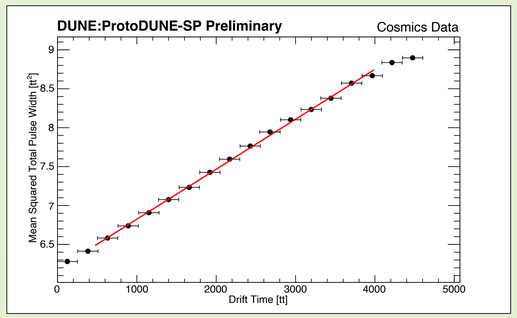

Figure 5 Plot of **mean σ_t^2, or mean squared total time width of pulse, by drift time bin**, including the linear fit used to extract D_L. Units labelled "tt" are time ticks, equivalent to 0.5 μs [1]. As seen here, the linear fit was performed between 500 tt and 4000 tt.

Results

The latest measurement on ProtoDUNE-SP data gives a $\boldsymbol{D_L}$ **of $\boldsymbol{3.91 \pm 0.13}$ cm²/s in an LArTPC with a stable temperature of $\boldsymbol{87.68}$ K and an electric field strength of $\boldsymbol{500}$ V/cm.** Uncertainty in this measurement is entirely statistical in nature, stemming from the event count of our dataset and error on the parameters extracted from Gaussian and linear fits such as those shown at left.

Conclusions/Future Steps

- We **successfully measured** the longitudinal diffusion constant for an electron in an LArTPC on the scale of the planned DUNE far detectors.
- Future work will involve further studies into **improvements of event selection criteria and characterization of systematic uncertainties** related to this measurement.

References

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Acknowledgments

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