Electron Drift Velocity in the μBooNE TPC

Qing He and Kirk T. McDonald
Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544
(March 20, 2009)

Abstract

This note describes a temperature-dependent fit to the electron drift velocity *vs.* electric-field strength in liquid argon. The electron drift velocity is $1.63 \pm 0.03\,\mathrm{mm}/\mu\mathrm{s}$ at $E = 500\,\mathrm{V/cm}$ and $T = 87.3\,\mathrm{K}$, and the corresponding drift time over 2.56 m is $1.57 \pm 0.03\,\mathrm{ms}$.

1 Electron Drift Velocity in Liquid Argon

As the readout time associated with a trigger of μBooNE is proportional to the drift time, it is important to know the drift velocity precisely. Likewise, the reconstruction of track position from the drift time of ionization electrons depends on knowledge of the drift velocity.

The nominal drift field in μBooNE is $E = 500\,\mathrm{V/cm}$, and the peak electric field at the surface of the collection wires is about $V_{VY}/a\ln(b/a) = 400/0.015\ \ln(0.3/0.015) \approx 9\,\mathrm{kV/cm}$.

Electron drift velocities in liquid argon for have reported in [1]-[7]. A comparison of many of these measurements was made by Walkowiak [6], as shown in fig. 1.

Kalinin *et al.*, and also Walkowiak, fit the measurements to a function that parameterizes the electron drift velocity v with respect to the electric field E and temperature T,

$$v(E,T) = [P_1(T - T_0) + 1]\left[P_3 E \ln\left(1 + \frac{P_4}{E}\right) + P_5 E^{P_6}\right] + P_2(T - T_0). \tag{1}$$

The parameters $P_1, \ldots, P_6$ obtained by Walkowiak from a global χ^2 fit are given in Table 1.

Table 1: The parameters of Walkowiak's fit [6] of form (1) to the electron drift velocity in liquid argon at $T_0 = 90.371\,\mathrm{K}$.

Parameter	Value
P_1	$-0.01481 \pm 0.00095\ \mathrm{K}^{-1}$
P_2	$-0.0075 \pm 0.0028\ \mathrm{K}^{-1}$
P_3	$0.141 \pm 0.023\ (\mathrm{kV/cm})^{-1}$
P_4	$12.4 \pm 2.7\ \mathrm{kV/cm}$
P_5	$1.627 \pm 0.078\ (\mathrm{kV/cm})^{-P_6}$
P_6	0.317 ± 0.021

The drift velocity *vs.* temperature according Eq. (1) is shown in Fig. 2 for $E = 500\,\mathrm{V/cm}$. The temperature dependence of the drift velocity in liquid argon is well approximated as linear, with relative slope [6]

$$\frac{\Delta v}{v \Delta T} = (-1.72 \pm 0.08)\%/\mathrm{K}. \tag{2}$$

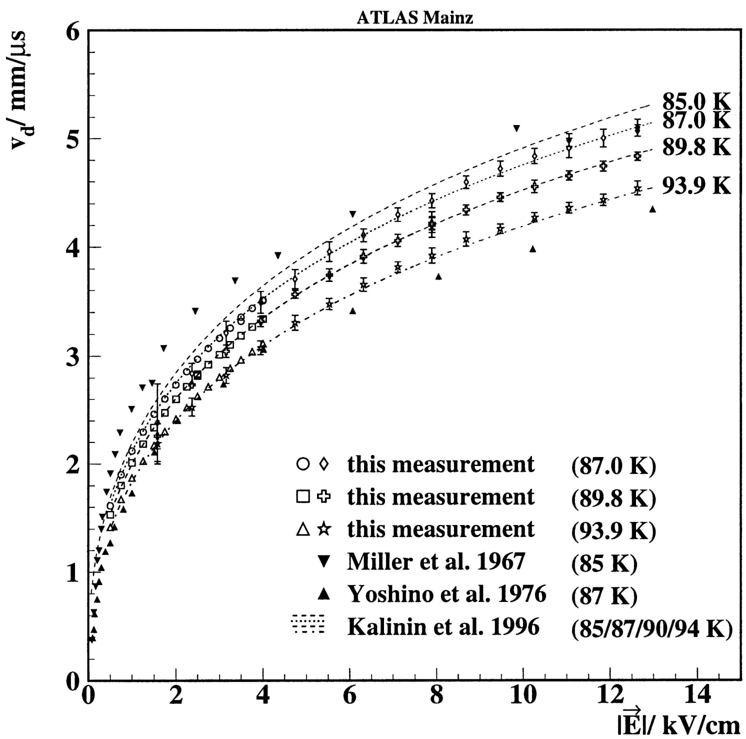

Figure 1: Drift velocities in liquid argon reported by [6] (this measurement), by Miller *et al.* [2], by Yoshino *et al.* [3], and fits to measurements by Kalinin *et al.* [5].

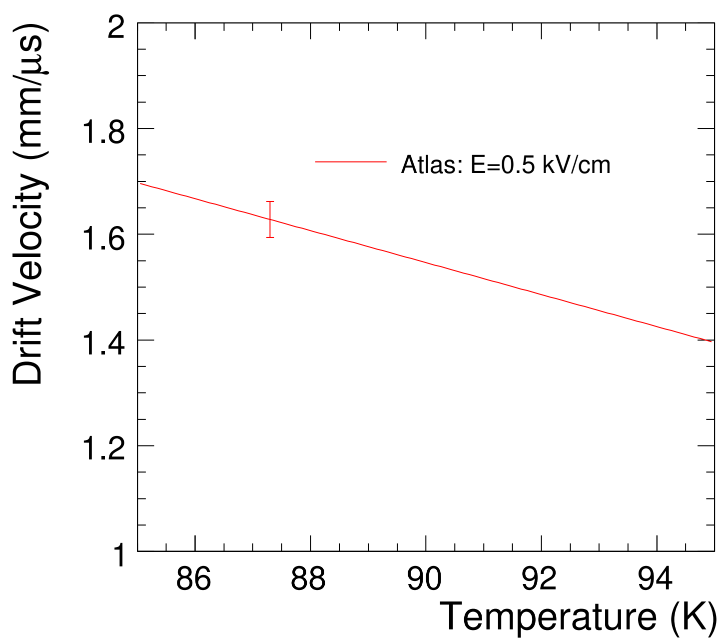

Figure 2: Electron drift velocity *vs.* temperature in liquid argon at $E = 500\,\mathrm{V/cm}$, from Eq. (1) [6]. A representative uncertainty is shown at $T = 87.3\,\mathrm{K}$ (nominal temperature of μBooNE).

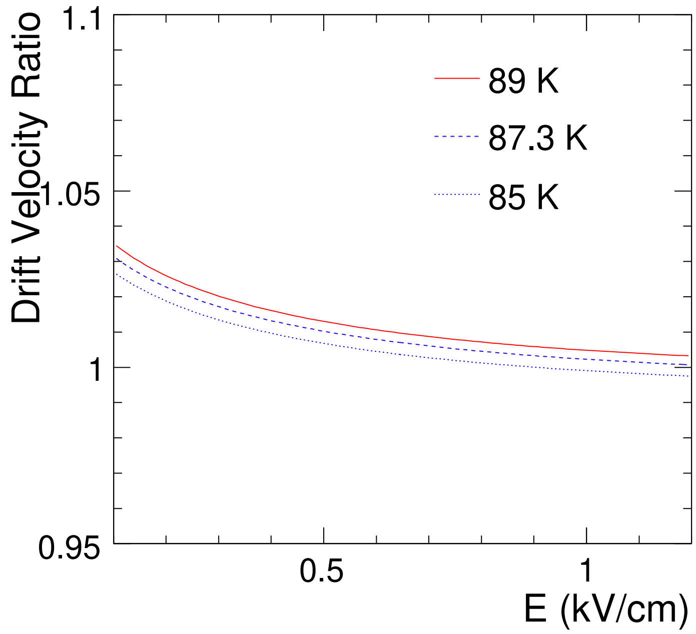

Figure 3: Ratio of the fits of form (1) to the drift velocity by Kalinin *et al.* [5] and [6] as a function of the electric field strength E.

The fits of Kalinin *et al.* and of Walkowiak have somewhat different parameters, as a result of different assumptions as to the temperature T_0. However, the fitted curves are very consistent with one another, as shown in Fig. 3.

Francesco Lanni made an empirical fit to the data of Miller *et al.* [2], taken at 85 K for liquid argon, as shown in Fig. 4. His parameterization is,

$$v(E) = \frac{2a_0 E^{a_1}}{1 + \mathrm{e}^{a_2 E^{-a_3}}}\,, \tag{3}$$

where E is the electric field, $a_0 = 1.31195$, $a_1 = 1.87803\times10^{-7}$, $a_2 = 10.9707$, and $a_3 = 0.216244$. This fit has been used in some μBooNE Garfield simulations, although the measurements of Miller *et al.* do not agree well with those of Kalinin *et al.* at the same temperature. Further, because of the difference between the temperature of liquid argon of Miller *et al.* (85 K) and μBooNE (87.3 K), it is inappropriate to use Lanni's fit for μBooNE

A comparison of the parameterizations (1) and (3) is shown in Fig. 5. The blue dashed line represents Lanni's parameterization, Eq. (3), at $T = 85$ K; the red lines represent Walkowiak's parameterization, Eq. (1) [6], at $T = 89$ K (solid line), $T = 87.3$ K (dashed line), and $T = 85$ K (dotted line). Also shown is ICARUS' measurement [7] at $E = 500$ V/cm and $T = 89$ K, which agrees well with the fit of Walkowiak at that temperature.

There is a 20% difference between the blue dashed line (Lanni) and the red dotted line (Walkowiak) at $E = 500$ V/cm and $T = 85$ K. Parameterization (1) is recommended for use in future μBooNE simulations and data analysis.

At the nominal operating temperature of μBooNE, $T = 87.3$ K, Eq. (1) predicts the drift velocity to be 1.63 ± 0.03 mm/μs at $E = 500$ v/cm. Of the 2.1% uncertainty reported in [6], the

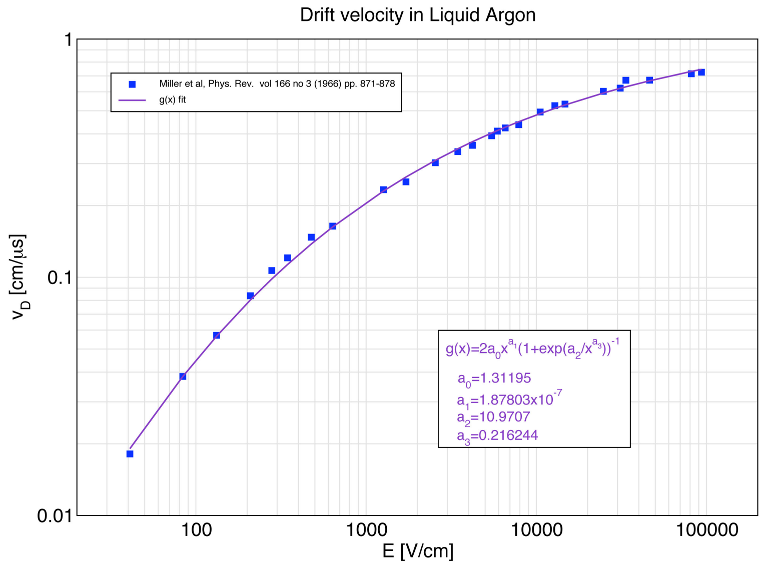

Figure 4: Drift velocities in liquid argon reported by [6] (this measurement), by Miller *et al.* [2], by Yoshino *et al.* [3], and fits to measurements by Kalinin *et al.* [5].

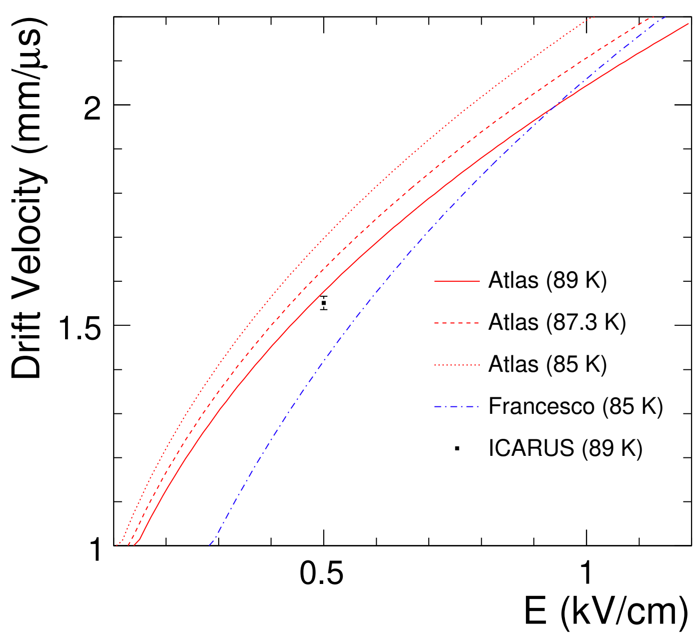

Figure 5: Electron drift velocity *vs.* electric field in liquid argon. Red lines: Atlas' fit, Eq. (1) [6], at $T = 89\,\mathrm{K}$ (solid line), $T = 87.3\,\mathrm{K}$ (dashed line), and $T = 85\,\mathrm{K}$ (dotted line). Blue dashed line: Lanni's fit, Eq. (3), at 85 K. Point with error bars: ICARUS measurement [7] at $E = 500\,\mathrm{V/cm}$ and $T = 89\,\mathrm{K}$.

systematic uncertainty dominates. For a 2.56-m drift length, the drift time is 1.57 ± 0.03 ms at $E = 500$ V/cm.

2 Effect of Diffusion

We used Garfield [8] to simulate the drift time, with and without diffusion, with the drift velocity parameterized by Eq. (1). Diffusion was parameterized by $D_{\parallel} = D_{\perp}$ where $D_{\perp} = 15.5\,\text{cm}^2/\text{s}$, as measured by [4].

Garfield uses a Monte Carlo method to simulate the diffusion. In our simulation, 200 electrons drifted from the same initial point, 2.6 m from the collection (Y) wire plane. The drift lines are shown in Fig. 6a. The drift-time distribution at the collection plane, shown in Fig. 6b, is fit by a Gaussian function with mean of 1572.4 μs, and standard deviation of 1.29 μs.

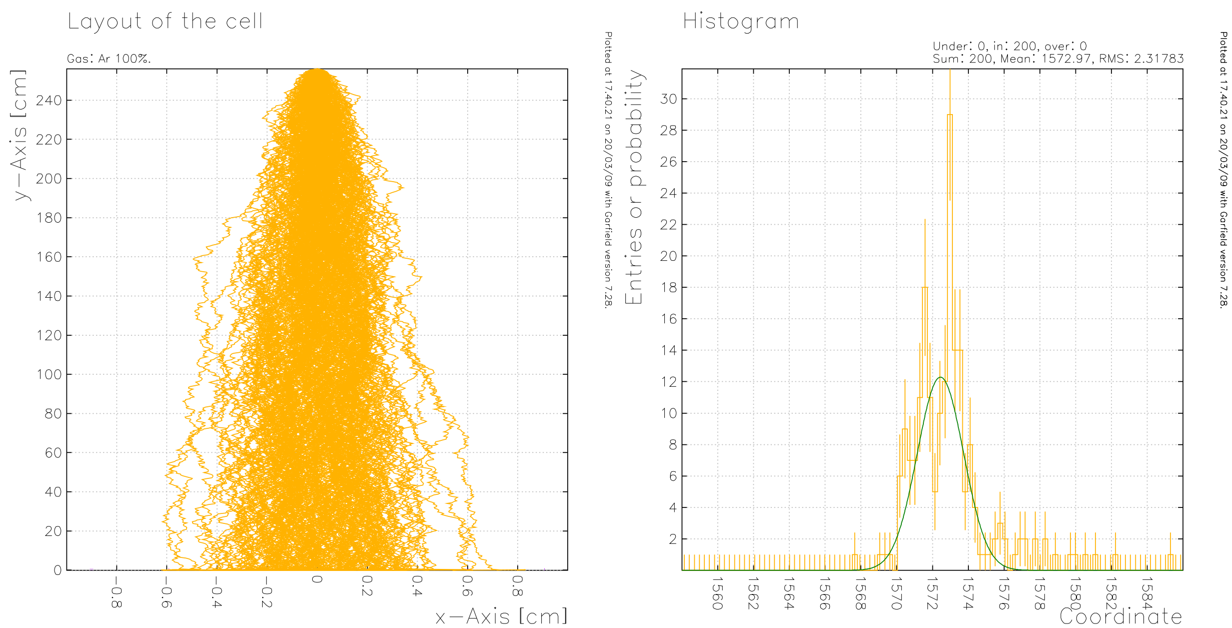

Figure 6: Left: Drift lines of 200 electrons over 2.56 m of liquid argon in a Garfield simulation with diffusion. Right: Drift-time distribution for the 200 electrons in the Garfield simulation.

These results agree well with the drift time of 1.57 ± 0.03 ms that is predicted in the absence of diffusion, and with the rms spread σ_t in drift time due to diffusion assuming a constant drift velocity v,

$$\sigma_t = \frac{\sigma_x}{v} = \frac{\sqrt{2D_{\parallel}t}}{v} = \frac{\sqrt{2 \cdot 15.5 \cdot 0.00157}}{1.63 \times 10^5} = 1.35\ \mu\text{s}. \tag{4}$$

We also used the cloud option of Garfield, which implements Eq. (4) for variable drift velocity, which method returned a drift time of 1571.8 ± 1.29 μs.

The variation of drift time caused by diffusion is much smaller than that associated with the uncertainty in the drift velocity,

3 Summary

- It is recommended to use the temperature-dependent fit (1) to drift velocity.
- The nominal drift velocity in μBooNE is $1.63 \pm 0.03\,\mathrm{mm}/\mu\mathrm{s}$ at $E = 500\,\mathrm{V/cm}$ and $T = 87.3\,\mathrm{K}$.
- The nominal drift time in μBooNE for a 2.56-m-wide TPC is $1.57 \pm 0.03\,\mathrm{ms}$. at $E = 500\,\mathrm{V/cm}$ and $T = 87.3\,\mathrm{K}$.
- The effect of diffusion on the average drift time is negligible.

References

[1] D.W. Swan, *Drift velocity of electrons in liquid argon, and the influence of molecular impurities*, Proc. Phys. Soc. **83**, 659 (1964),
http://kirkmcd.princeton.edu/examples/detectors/swan_pps_83_659_64.pdf

[2] L.S. Miller, S. Howe and W.E. Spear, *Charge Transport in Solid and Liquid Ar, Kr and Xe*, Phys. Rev. **166**, 871-877 (1968),
http://kirkmcd.princeton.edu/examples/detectors/miller_pr_166_871_68.pdf

[3] K. Yoshino, U. Sowada and W.F. Schmidt, *Effect of molecular solutes on the electron drift velocity of liquid Ar, Kr, and Xe*, Phys. Rev. A **14**, 438 (1976),
http://kirkmcd.princeton.edu/examples/detectors/yoshino_pra_14_438_76.pdf

[4] E. Shibamura *et al.*, *Ratio of diffusion coefficient to mobility for electrons in liquid argon*, Phys. Rev. A **20**, 2547, (1979),
http://kirkmcd.princeton.edu/examples/detectors/shibamura_pra_20_2547_79.pdf

[5] A.M. Kalinin *et al.*, *Temperature and Electric Field Strength Dependence of Electron Drift Velocity in Liquid Argon*, ATLAS-LARG-NO-058 (12 Dec. 1996),
http://kirkmcd.princeton.edu/examples/detectors/kalinin_larg-no-058_96.pdf

[6] W. Walkowiak, *Drift velocity of free electrons in liquid argon*, Nucl. Instr. and Meth. A **449**, 288-294 (2000),
http://kirkmcd.princeton.edu/examples/detectors/walkowiak_nim_a449_288_00.pdf

[7] S. Amoruso *et al.*, *Analysis of the liquid argon purity in the ICARUS T600 TPC*, Nucl. Instr. and Meth. A **516**, 68-79 (2004),
http://kirkmcd.princeton.edu/examples/detectors/amoruso_nim_a516_68_04.pdf

[8] R. Veenhof, *Garfield – simulation of gaseous detectors*, Version 9 (4 Jul 2008),
http://garfield.web.cern.ch/garfield/