A measurement of the electron Drift Velocity with the T600 data

S. Navas-Concha and A. Rubbia
Institut für Teilchenphysik, ETHZ, CH-8093 Zürich, Switzerland

Abstract

In this note we present a measurement of the drift velocity of free electrons in liquid argon using the data recorded by the ICARUS collaboration with the T600 module during the technical run, in summer 2001. As explained in the text, the method applied here is based on the analysis of events containing electrons drifting very long distances, from the cathode to the anode wire planes (\(\sim 1.5\) m), and hitting a big number of wires. To tag this kind of particular topologies, huge shower events covering a large fraction of the chamber are selected. A measurement of \(v_d\) at four values of the electric field strength in the range 75–150 kV has been obtained. The results presented in this work are in good agreement with earlier published measurements.

1 Determination of the drift velocity

The results presented in this note on the determination of the drift velocity of free electrons in liquid argon are based on the analysis of the data recorded with the T600 detector last summer, 2001 [1]. The basic idea consists on searching the starting \((T_0)\) and end \((T_{end})\) points of the event in the drift time coordinate. Their difference gives the total electron drift time, \(T_d = T_{end} - T_0\). Then, provided we know precisely the distance between the cathode and the collection wire plane \((L_d)\), the drift velocity can be computed by simple ratio of both magnitudes \((L_d/T_d)\). Therefore, only events with well defined \(T_d\) can be used to extract \(v_d\). This represents, in fact, a small fraction of the total recorded events since the largest part of them present “out-of-time” tracks that make the measurement difficult. The presence of these out-of-time tracks is expected since the total sampling time per single event during the T600 data taking period was 1638.4 \(\mu s\) (4096 drift samples \(\times 0.4\) \(\mu s\)/sample), much higher than the maximum time needed for the electrons to drift from the cathode to the anode (\(\sim 926\) \(\mu s\) for a drift velocity...
of 1.6 mm/μs). This represents a “virtual” drift distance of ~2.62 m, much bigger than the actual cathode-anode distance (~1.48 m).

Figure 1 illustrates graphically the main features of the applied method. It shows a fraction of an event with a huge activity in the T600 right-side chamber. This event was recorded during a PMT trigger (majority 7) run, with the high voltage fixed at 75 kV.

![Diagram](image)

Figure 1: Detail of one of the PMT trigger events used to compute the electron drift velocity at HV = 75 kV (Run 961, Event 7). The picture shows the event projection on the Collection view of the T600 right-side chamber (the horizontal length is 3.75 m), the vertical axis corresponding to the drift coordinate (the full drift range is shown, 4096 samples ≡ 1638.4 μs).

The picture exhibits two well defined regions:

- The first, from the top (zero time sample) to A and from B to the bottom (last time sample), appears in light grey scale. It corresponds to the “out-of-time” region and contains the baseline plus, eventually, some out-of-time tracks. This is the non-interesting region.

- The second, from drift sample A to drift sample B is the signal region, where the physical event is concentrated. This region, extending like an horizontal band from the first to the last wire, can be easily isolated “by eye” from the other region.

The key point of the analysis is to precisely bound the signal region by determining the number of time samples between points A and B (called N_s thereafter), which provides the size of the event in the time coordinate (in terms of number of time samples). The electrons generated inside the liquid argon volume and close to the anode arrive immediately after the
PMT trigger, while the most distant electrons, the ones produced near the cathode, arrive $N_s \times 0.4 \, \mu s$ later. Once $N_s$ is known, the extraction of the drift velocity is trivial:

$$v_d = \frac{L_d}{N_s \times \Delta t} = \frac{1482}{N_s \times 0.4 \, \mu s} \quad \text{[mm]}$$

where $L_d$ is the distance between the cathode and the collection wire plane in cooled detector conditions ($\textit{drift distance}$, fixed to $1482$ mm) and $\Delta t$ is the time sample size ($0.4 \, \mu s$).

2 Extraction of $N_s$

The simplest method to compute $N_s$ consists on summing up the recorded hit time distributions (4096 bins) from all wires of the selected view into a single histogram. If the event contains, for instance, a big shower this final distribution will exhibit a clear bump sitting over the baseline. The event will be useful to compute the drift velocity. On the other hand, if the event contains only random tracks, the distribution will be, in average, flat and the event will be useless.

As an example, the result for the event shown in Figure 1 is given in Figure 2. The full drift time range is shown in the top plot, while the two bottom plots are zooms on the event start and end regions. The activity on this event is so huge that there is no doubt about the bounds of the signal region. The $T_0$ and $T_{end}$ values (points A and B) are obtained by subtraction of the baseline, $N_s$ being just the difference $T_{end} - T_0$. The bigger the difference between the baseline and the signal region, the better the determination of $N_s$.

In order to increase the statistics, this procedure can be applied not to single events, but to full runs (which are supposed to be taken under the same detector conditions of voltage and temperature). Figure 3 shows the result obtained when running over 10 events of a PM trigger run (Events 25 to 34 of Run 807). In this case, the high voltage applied between the cathode and the anode was 150 kV (twice the previous one). It is clear from Figure 3 that this kind of events can be used for the measurement of the drift velocity, since the signal region can be precisely determined.

Figure 4 compares the hit time distributions shown in Figures 2 and 3. Since the starting point of both distributions is approximately the same (at bin ~215), only the end of the spectra is shown. As expected, the end point moves to the left (by $\Delta N_s$, drift sample units) when increasing the high voltage from 75 kV to 150 kV, increasing the drift velocity.

The largest part of the T600 data was collected at 75 kV of nominal voltage, with small dedicated runs at different HV values from 150 kV to 0 kV, in steps of 15 kV. All these runs have been analysed searching for huge events that make possible to compute $v_d$ as a function of the electric field. Table 1 summarizes the result of this scanning. Interesting events were found at four voltages: 75, 90, 105 and 150 kV. For the rest, flat distributions appear, making very difficult the determination of $T_{end}$ (see example in Figure 5).
<table>
<thead>
<tr>
<th>HV</th>
<th>Scanned Runs</th>
<th>Scanning result</th>
</tr>
</thead>
<tbody>
<tr>
<td>30, 45, 60 kV</td>
<td>Runs 821, 820 and 819</td>
<td>No useful events</td>
</tr>
<tr>
<td>75 kV</td>
<td>&quot;PMT&quot; and &quot;Big shower&quot; triggers</td>
<td>Many useful events</td>
</tr>
<tr>
<td>90 kV</td>
<td>Run 817</td>
<td>Two useful events (no.2 and 17)</td>
</tr>
<tr>
<td>105 kV</td>
<td>Run 816</td>
<td>One useful event (no.7)</td>
</tr>
<tr>
<td>120, 135 kV</td>
<td>Runs 815 and 814</td>
<td>No useful events</td>
</tr>
<tr>
<td>150 kV</td>
<td>Runs 806–809, &quot;PMT&quot; triggers</td>
<td>Many useful events</td>
</tr>
</tbody>
</table>

Table 1: List of scanned runs and events used to determine the drift velocity as a function of the electric field.

3 Results and Comparison with previous measurements

Table 2 summarizes the final values obtained for the drift velocity and the corresponding value of the electric field. These points are also plotted in Figure 6, as a function of |E|. The error in the determination of \( v_d \) (from baseline subtraction, possible cathode uniformities, etc.) can be roughly estimated to be of the order of 2%.

| \( \Delta V \) (kV) | |E| (kV/cm) | |\( v_d \) (mm/\( \mu \)s) |
|---------------------|------------|-----------|-------------------|
| 75                  | 5.06 \( \times \) 10^{-1} | 1.55 \( \pm \) 0.03 |
| 90                  | 6.07 \( \times \) 10^{-1} | 1.68 \( \pm \) 0.03 |
| 105                 | 7.08 \( \times \) 10^{-1} | 1.78 \( \pm \) 0.04 |
| 150                 | 1.01 \( \times \) 10^{-1} | 2.03 \( \pm \) 0.04 |

Table 2: Measured values of the drift velocity \( (v_d) \), the electric fields \(|E|\) and cathode–anode high voltage differences \( (\Delta V) \). The distance between the cathode and the collection wire plane is assumed to be 1482 mm.

Recent published studies (see Ref.[2]) have measured the electron drift velocity in argon, for similar conditions of field and temperature than the ones present during the T600 technical run. In this publication, the authors give a global parametrization of \( v_d \) as a function of \(|E|\) from a fit to the data. This empirical formula depends on four parameters for a given temperature in the following way:

\[
v_d \simeq P_3 |E| \ln(1 + \frac{P_4}{|E|}) + P_5 |E|^{p6}
\]

where \( v_d \) is the electron drift velocity at a given electric field \( E \), and:

\[
P_3 = 0.141 \ \ \frac{(kV)}{(cm)}^{-1}
\]

\[
P_4 = 12.4 \ \ \frac{(kV)}{(cm)}
\]
\[ P_3 = 1.627 \, (\frac{kV}{cm})^{-P_6} \]
\[ P_6 = 0.317 \]

The values of these parameters \( P_{3,4,5,6} \) were obtained from a global fit to all data at the reference temperature of 90.3 K. In order to extrapolate to different temperatures, a small temperature gradient correction has to be applied \( (\Delta v_d \approx -1.7 \% \Delta T) \). As explained in Ref.[2], to obtain the expression above the electric field and the temperature were varied, in steps, in the range \( 0.5 \, kV/cm \leq E \leq 4.0 \, kV/cm \) and \( 87 \, K \leq T \leq 94 \, K \), respectively. At each point, the recorded data was fitted individually. Therefore, the parametrization give before (Eq.2) fully covers the range of values present during the T600 run, typically \( 0.5 \, kV/cm \leq E \leq 1.1 \, kV/cm \) and \( T \approx 89 \, K \).

Figure 6 shows the comparison between our measured values (points) and the empirical function (2) for \( T = 89 \, K \). A good agreement between both sets of independent measurements.

4 Conclusions

In this note we provide an experimental estimation of the dependence of the electron drift velocity on the electric field, based on the analysis of the data taken during the technical run of the T600 module, in summer 2001.

We have concluded that, in order to do a precise measurement of \( v_d \) using the presented method, events with a huge activity on at least one of the liquid argon chambers are needed. These events were selected very efficiently during the technical run by imposing a “PMT trigger” with a high majority (at least 7 PMTs in coincidence). In addition, runs at different high voltages with the previous trigger are needed to study the dependence of the drift velocity with the electric field.

In order to reduce as much as possible the systematic errors in the \( v_d \) measurement, a precise knowledge of the distance between the cathode and the collection wire plane for the cooled detector is needed.

Finally, we have shown that the values obtained for \( v_d \) are in good agreement with earlier published measurements taken in similar detector conditions of voltage and temperature.

References


Figure 2: Time distributions of the hits recorded in a typical PMT trigger event used to compute the electron drift velocity at HV = 75 kV (Run 961, Event 7). The data corresponds to the hits recorded in the Collection wire plane of the T600 right-side chamber (see also Figure 1). The full spectrum is presented in the top plot (from 0 to 4096 time samples), while the lower plots are zooms to indicate the position of the applied cuts to select the event starting (A) and end (B) points.
Figure 3: Time distributions of the hits recorded in 10 PMT trigger events used to compute the electron drift velocity at HV = 150 kV (Run 807, Evt 25-34). The data corresponds to the hits recorded in the Collection wire plane of the T600 right-side chamber. The full spectrum is presented in the top plot (from 0 to 4096 time samples), while the lower plots are zooms to indicate the position of the applied cuts to select the event starting (A) and end (B) points.
Figure 4: Comparison between the hit time distributions obtained at two nominal voltages: 75 kV (top line) and 150 kV (bottom line). The starting point of both spectra being the same, only the last part of the distributions are shown.

Figure 5: Example of a hit time distribution useless to compute the electron drift velocity. The histogram compiles the spectra from 8 events (Run 820, Events 1 to 8) taken during a run at 120 kV.
Figure 6: The electron drift velocity as a function of the electric field strength. The four points are the data measurements obtained in this work, including a 2% error. The numbers close to the points indicate the cathode–anode high voltage difference. The superimposed curve corresponds to the result of the global parametrization given in Ref.[2] (see equation 2). The distance between the cathode and the collection wire plane is assumed to be 1482 mm and the temperature 89 K.