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First observation of 140-cm drift ionizing tracks in the ICARUS liquid-argon TPC

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Abstract

This is a short note to acknowledge the successful operation of a 140-cm drift liquid argon TPC built in the framework of the ICARUS experiment. We show few cosmic muon tracks crossing the whole drift volume from the wire planes to the cathode. Data were taken at drift fields of 450 and 500 V/cm. © 2000 Elsevier Science B.V. All rights reserved.

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1. Motivations

In the new Liquid-Argon Time Projection Chamber (LAr TPC), under construction for the first 600-ICARUS module, an electron drift distance of 140 cm is foreseen [1]. Up to now the longest drift path exploited in the R&D phase of the ICARUS experiment was only 50 cm [2,3]. It was therefore important to perform a test with the drift increased to 140 cm to enhance any unwanted effects to the long drift. Among possible drawbacks due to the long electron drift path, we can cite the following.

Distortions of the track pattern could be due to electric field non-uniformity, especially near the boundary of the TPC where the field shaping electrodes are discontinuous. The field non-uniformity can induce a local variation of the electron drift velocity, which in turn can produce a delay in the electron arrival times on the read-out wires along the border of the sensitive region.

Degradation of the signal shape could be due to electron diffusion (longitudinal and transverse) which can spread out the drifting electron cloud. Being the induced signals read in current mode, this spread turns into a decrease of pulse height and increase of pulse duration with negative effect on the recognition of single pulses and on the separation of subsequent pulses.

In parallel with that, it was important to test the possibility to apply the nominal electric field value foreseen for the ICARUS T600 module, namely ≈ 500 V/cm. This implies a HV of about -70 kV, which was never been tested in ultra-pure liquid argon. The possible weak points could be the HV feed-through which has to stand cryogenic stresses and hold ultra-high vacuum, and the power supply ripple that could induce capacitatively coherent electronic noise on the read-out electrodes through the field shaping electrodes.

2. The LAr TPC

The LAr TPC used in this test is essentially that exposed to the CERN neutrino beam in 1997 and 1998 [2]. In the original version the TPC had the shape of a parallelepiped with top and bottom faces (32.5×32.5 cm^2) acting as read-out anode and cathode respectively, while the side faces, 47 cm long, supported the field shaping electrodes.

The read-out electrodes were two stainless-steel wire planes with the wires running in orthogonal directions. The plane facing the drift volume worked in induction mode while the other was used to collect the drifting electrons. The plane separation was 4 mm, the wire pitch 2.54 mm and the wire diameter 100 μm. The total number of wires was 128 for each plane. No screen wires were present in either plane.

The wires were soldered on a vetronite frame, which supported also the voltage distributions and the de-coupling capacitors. The front-end electronics was mounted directly on the wire frame in order to reduce the input capacitance of the preamplifiers, which were designed to work immersed in liquid argon.

The electronics connected to the 128 wires of the induction plane was set to work in charge mode with a RC constant of about 100 μs. The electronics connected to the 128 wires of the collection plane was set in quasi-current mode with a RC constant of 3 μs [4].

The cathode and the field shaping electrodes were obtained by metallisation of vetronite boards. The boards were glued on honeycomb structure to ensure rigidity. The field shaping were horizontal strips, 1.27 cm wide, spaced 2.54 cm. A high-voltage divider, made by a series of 14 MΩ resistors interconnecting the strips, supplied the correct voltage to the strips. The drift high voltage (≈ -15 kV) was brought to the cathode by a commercial ceramic feed-through.

In order to perform the test described in this note, the LAr TPC required few modifications.

- The drift length was increased to 140 cm simply using longer vetronite boards, supporting the field shaping electrodes, built with the same technique exploited for the shorter ones.
- To reach a drift field of 500 V/cm, a new high-voltage feed-through was mounted. This is a rigid coaxial structure, 80 cm long, where the inner conductor (HV) is a thin copper tube and the outer one (ground) is an inox cylinder

(2.54 cm in diameter). The insulator is epoxy-resin poured into the inox cylinder and the copper tube and slowly solidified under controlled conditions. The length of the metal-to-epoxy interface ensures the vacuum tightness. Cryogenic stresses are avoided because the top half of the feed-through works at room temperature. This feed-through was successfully tested in LAr for HV up to -70 kV.

The LAr TPC was housed into an ultra-high vacuum stainless-steel vessel, 65 cm in diameter and 170 cm height, for a total volume of 550 l. The active mass of LAr in the drift volume was 200 kg. In order to regulate the heat losses, the whole vessel was partially immersed in a thermal bath of commercial LAr contained in an open air Dewar.

3. Argon purification

The detector was equipped with an improved version of the ICARUS recirculation-purification system [5]. It allowed a recirculation rate of about 10 l of LAr per hour with the purification filter working in gas phase. The initial filling of the TPC, in liquid phase, took about 2 h.

The improvement consisted in connecting a small empty container in series to the detector vessel. Both containers were roughly evacuated and then cooled down at LAr temperature. At the beginning of the filling, LAr mixed with argon gas flows through the purifier into the detector vessel; the argon gas, together with most of the impurities due to degassing, is then sucked into the second vessel where it is condensed. As the detector temperature decreases, less and less argon gas and degassing impurities are produced and condensed into the second vessel until the latter is no more needed.

This simple method allowed obtaining electron lifetimes of the order of few milliseconds immediately after filling. We tested it with the 50-l LAr TPC several times. The electron lifetime reached soon after filling was always better than 1 ms and no decrease was observed during the following days with the recirculation system active.

4. Test set-up

We filled the detector with the procedure previously described. The initial value of the electron lifetime was sufficient to detect ionization charge produced more than 1 ms away from the chamber. We took cosmic ray data in the following running conditions.

- High voltage on cathode set to -63 or -70 kV; these values correspond to drift fields of 450 and 500 V/cm, respectively.
- Second wire plane (*collection*) set to virtual ground through the pre-amplifiers.
- Voltage on the first wire plane (*induction*) set to -280 V; this corresponds to a drift field in the gap between *induction* and *collection* of 700 V/cm, enough to ensure complete transparency to drifting electrons.

In order to select tracks close to the vertical axis, the trigger of the TPC was made exploiting the analog sum of two groups of collection wires (nos. 17–32 and 65–80), discriminated and converted to NIM standard. The DAQ stop was obtained by the signal from the first group of wires, delayed by 600 μs, in coincidence with the signal from the second group.

An 8-bit FADC sampling at 400 ns digitized the signal waveform from each wire. To safely contain the full drift length, a DAQ buffer of 4 k bytes per channel was used, for a total of 1 M bytes per event.

A simple RC filter was applied to the HV power supply; it was made by a discrete 20 MΩ resistor placed at the output of the power supply plus the capacitance of the 10 m long coaxial HV cable. This allowed minimizing the coherent electronic noise induced on the read-out wires by the ripple (16.6 kHz) of the HV power supply. This noise component was decreased from ≈ 5 ADC counts peak-to-peak to negligible level.

The remaining RMS noise level, calculated on a window of 256 samples, was about 0.7 ADC counts for the amplifiers working in current mode and 1.0 in charge mode.

The charge deposited by minimum ionizing particle on a single wire induces a signal with a pulse height of 10–12 ADC counts. In the case of electron collection slightly more charge is available because 100% of the electrons contribute to the signal pulse height while in induction mode only 80% of the drifting charge is useful [3]. Hence, a signal-to-noise ratio of at least 10 was always available on the wires of both planes.

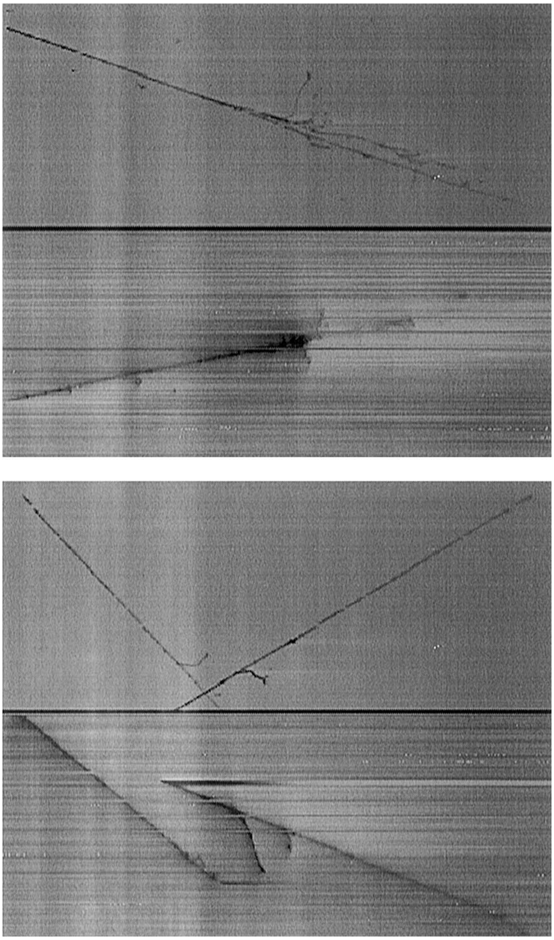

Fig. 1. Muon tracks as seen in the 140-cm LAr TPC with a drift field of 450 V/cm. The top half of the figure shows the *collection* time-projection read in current mode, the bottom half is the *induction* time-projection read in charge mode; note the different baseline behaviour. The horizontal axis is the drift time (625 samples corresponding to 1 ms), the vertical is the wire numbering (128 wires in each view corresponding to 325 mm). The track in the second event enters from the wire planes and exits from the cathode, the others either enter or exit from the lateral walls. The time gap needed to cover the wire plane to cathode distance has been measured on the first kind of events and amounts to 920 μs; the corresponding electron drift velocity is 1.52 mm/μs.

5. Results

We took cosmic ray data for few days in stable conditions of electron lifetime (≈ 1 ms). A collection of ionizing events produced in the 140-cm LAr TPC is shown here as a summary. Events in Fig. 1 were taken at 450 V/cm while those in Fig. 2 were taken at 500 V/cm. The bottom-half of each picture shows the *induction* time-projection; the top-half is the *collection* time-projection. The horizontal axis is the drift time (2500 samples corresponding to 1 ms), the vertical is the wire numbering (128 wires in each view).

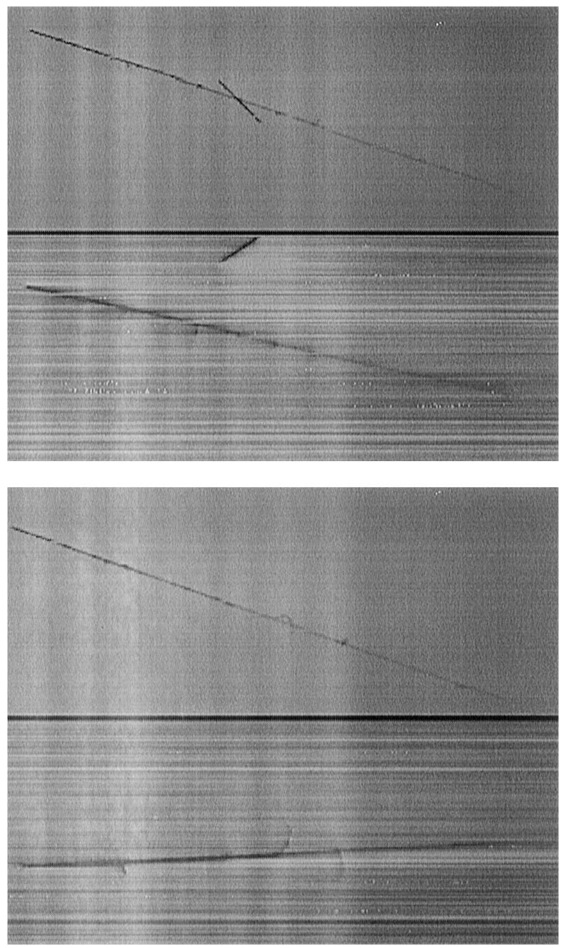

Fig. 2. Same as Fig. 1 but with a drift field of 500 V/cm. Here the time gap needed to cover the wire plane to cathode distance has been measured to be 885 μs corresponding to an electron drift velocity of 1.58 mm/μs.

The liquid-argon purity in the TPC allowed detecting signals originated close to the cathode even if with a considerable attenuation of about 40%.

Selecting only tracks entering the drift volume from the wire planes and exiting from the cathode, we estimated the electron drift time needed to cover 140 cm in LAr as a function of the electric field applied. We found 920 μs at 450 V/cm and 885 μs at 500 V/cm. These values correspond to an electron drift velocity of 1.52 mm/μs and 1.58 mm/μs, respectively, in good agreement with the measurements performed with the 3-t prototype several years ago at CERN [3].

A closer look at the signals on each wire allowed evaluating the diffusion effect both in collection (Fig. 3) and induction (Fig. 4) mode.

As expected for tracks slightly inclined with respect to the wire planes, the full-width at half-maximum of each pulse along the muon tracks (excepted those from where a delta-ray starts) was of the order of ≈ 4 μs, independently from the starting location of the free electron clouds. This is consistent with the fact that the signal spread, σ, due to electron diffusion in liquid argon, obeys the simple law $\sigma = \sqrt{2Dt}$, where the diffusion coefficient, D, is derived from the Einstein relation $D = kT/e\mu$. In liquid argon the free electrons are practically thermalized ($T \approx 87$ K) for drift fields up to 1 kV/cm and their mobility is $\mu \approx 500\ \mathrm{cm^2\ V^{-1}\ s^{-1}}$. Hence, over a distance of 140 cm the electron cloud spread should be less than 0.9 mm or 0.6 μs, negligible with respect to the typical pulse width.

A last important check was made concerning possible distortions of the track direction due to the non-uniformity of the electric field in the drift volume, especially near the boundary of the TPC.

This check consisted in fitting each muon track with a straight line and evaluating where the largest deviations from the fit occurred. The deviations were found to be uniformly distributed along the tracks and not accumulated on the pulses from the outermost wires. It follows that any distortion of the electric field in the TPC has a negligible effect

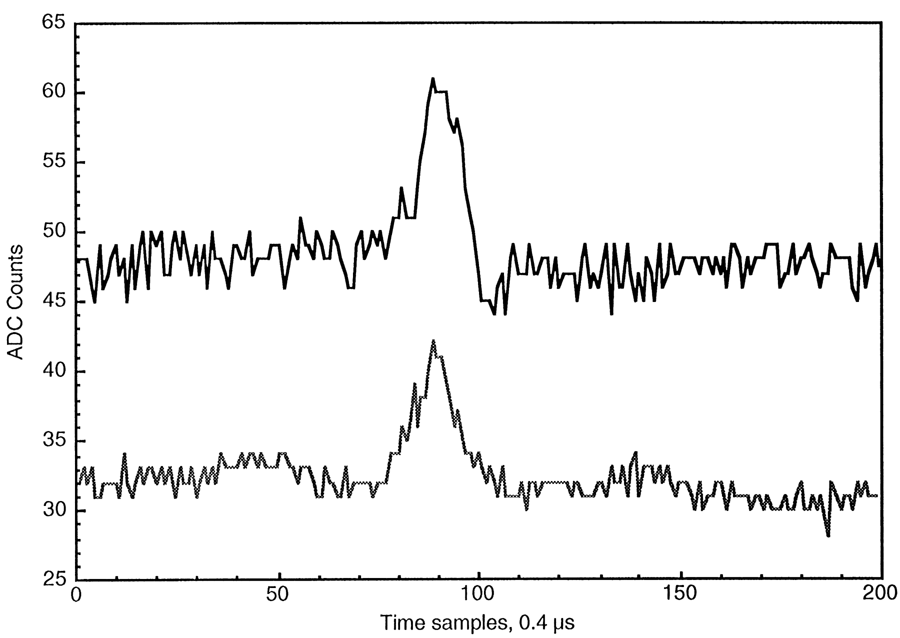

Fig. 3. Typical single wire signal on the *collection* plane read in current mode; the top one was generated near the wire chamber (short drift path), the bottom one near the cathode (long drift path). In both cases the pulse FWHM is of the order of 4 μs as expected for tracks slightly inclined with respect to the wire planes. The electron diffusion should contribute to the electron cloud spread for at most 0.6 μs, hence with a negligible effect.

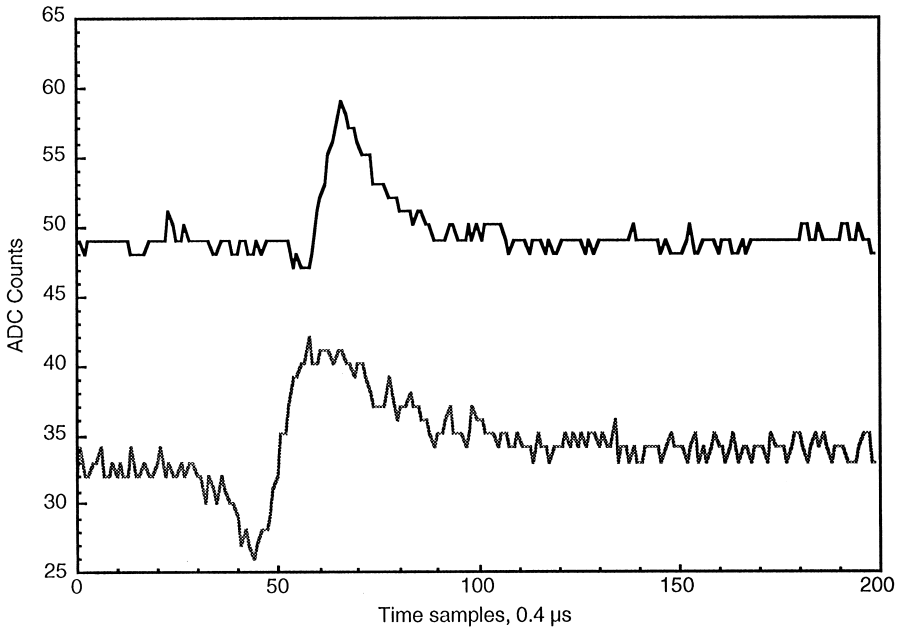

Fig. 4. Same as Fig. 3 but for the *induction* plane. Again the signal FWHM is of the order of 4 μs, hence the electron diffusion does not play a role in the signal shape.

on the electron arrival time compared with that due to multiple scattering.

6. Conclusion

We have demonstrated that it is possible to drift free electrons in a liquid argon TPC over a distance as long as 140 cm with no appreciable degradation of the basic characteristics (pulse height and width) of the signals induced on the read-out electrodes. We also succeeded in applying a uniform electric field in the drift volume as high as 500 V/cm with no negative effects on the electronic noise and the direction of ionizing tracks. We believe that these results allow to us proceed in the construction of the first 600 ton ICARUS module with increased confidence in the success of the enterprise.

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