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Electron diffusion measurements in the ICARUS T600 detector

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Abstract. In last years, the interest on LAr TPC used for neutrino physics and dark matter searches is growing; the knowledge of transport properties of Ar electrons is essential to extract faithful physical information. In particular there is a lack of experimental measurements on diffusion parameter. Dedicated runs for this measurement were carried out with the ICARUS T600 detector considering cosmic muons collected at different electric field.

1. Introduction

The diffusion of electrons drifting in an electric field is an important effect contributing to the spatial resolution of a Liquid Argon Time Projection Chamber (LAr TPC) detector.

Dedicated measurements were carried out with the ICARUS T600 detector [1] at underground condition in National Gran Sasso Laboratories (LNGS) in Italy. The T600 detector is composed by four LAr TPCs with a drift length of 1.5 m each; only the longitudinal diffusion can be measured, because the transversal one is hidden by the detector characteristics (i.e. the 3 mm wires pitch).

The T600 detector successfully operated from 2010 to 2012 at LNGS, where it took data from the CNGS (CERN Neutrino to Gran Sasso) beam to study neutrino oscillations. After the shut down of the beam, data taking is continued with cosmic rays trigger, up to June 2013, when the phase of decommissioning began. With the cosmic rays trigger, some runs were carried out with different drift electric field values: $E = [270, 360, 500, 600, 700, 978]$ V/cm.

2. Electron diffusion parameter in the ICARUS T600 detector

Diffusion process is described by Fick's law [2]: the diffusion parameter D depends on electron mobility in the medium and on its temperature. From experimental point of view, diffusion can be measured considering the width of a signal recorded with different values of electric field. It can be expressed with measurable quantity as [3]:

$$D = \frac{\sigma_t^2 \cdot v_{drift}^2}{2t} \quad (1)$$

where v_{drift} is the drift velocity, t is the drift time registered by the anode wire and σ_t is the time spread of the wire signal due to diffusion process. The data sample used to evaluate D consists of cosmic muons that completely cross the detector in any direction; each muon track



is selected by a visual scanning procedure and then it is 3D reconstructed [4]. The sample is composed by roughly 33 muons for each electric field value. Following the Eq. 1, the variables to be measured are v_{drift} , t and σ_t .

3. Drift velocity evaluation

The first step for the evaluation of diffusion parameter is the calculation of the drift velocity for each electric field value. It is possible to obtain the drift velocity value, considering muon tracks that pass both wire and cathode planes, because for these events, ionization electrons cover a fixed drift length of 1482 mm, due to the mechanical structure of the detector. Averaging the values found in every selected track, it is possible to calculate $\langle v_{drift} \rangle$ for each electric field E , as depicted in Fig 2: the drift velocity follows the square root function of the electric field [5].

4. Evaluation of longitudinal diffusion parameter

After the calculation of the drift velocity, each muon sample is processed with the hit finding procedure. A hit is defined as the segment of track whose charge is read by a given wire and it contains the spatial and energy information of the track segment (see Fig. 1) [4].

Once a hit is found, in order to retrieve the signal width information, it is convenient to compute numerically the integral of the associated wire signal. The integrated signal is then fitted by the sigmoid function:

$$f(t) = B + A \left(1 - \frac{1}{1 + e^{(t-t_0)/w}} \right), \quad (2)$$

where B is the baseline of the signal, A is its amplitude and t_0 is the peak position, while w is the width of the signal.

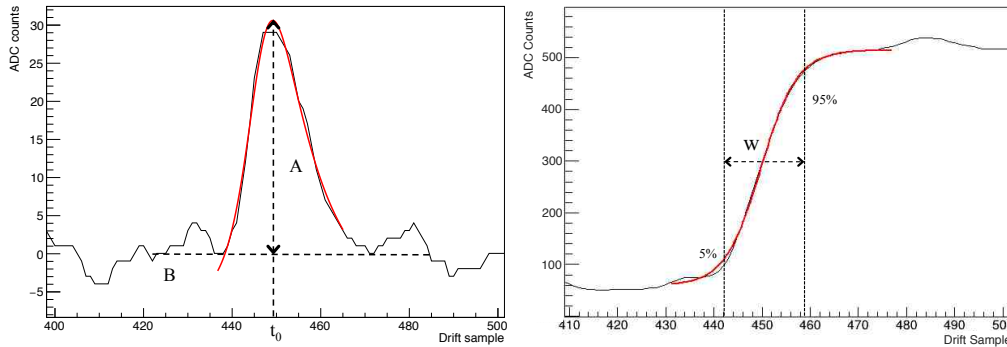


Figure 1. Example of hit signal (left) and its integral (right). The parameters used in Eq. 2 are reported.

Each muon track is first cleaned from delta rays using a geometrical cut, otherwise the signal width can be overestimated. After that, it is possible to measure the signal width, defined as the temporal interval between 5% and 95% of the sigmoid maximum value, as depicted in Fig. 1.

The term w is the quadratic sum of two contributions, one given by the diffusion process, σ_t^2 , and the other due to the electronics response, w_{el}^2 : $w^2 = w_{el}^2 + \sigma_t^2$. While σ_t depends on electric field value, w_{el} is a constant given by the electronics read-out.

From Eq. 1, it is possible to fit linearly σ_t^2 as a function of drift time t and retrieving D as its slope. The use of w^2 instead of σ_t^2 adds only a constant term, being w_{el}^2 independent by drift time and electric field; the slope, and so D , remains unaffected. The fitting function is

$f(t) = p_0 + p_1 \cdot t$, where $f(t) = w^2 \cdot v_{drift}^2$, $p_1 = 2D$ and p_0 accounts for the constant term. The drift path is divided in time bins of $50 \mu\text{s}$; considering all w coming from the sigmoid fit, the mean w in each bin, is calculated. Then the linear fit of $w^2 \cdot v_{drift}^2$ as a function of the drift time t is evaluated for each electric field values E .

Considering each p_1 given by the fit, it is possible to calculate the diffusion parameter D , that is shown for each E in the plot in Fig. 3.

These values can be linearly fitted: the fit gives a constant diffusion parameter of $D = 4.74 \pm 1.01 \text{ cm}^2/\text{s}$, independent from the electric field value, as expected [3]. The errors are large, probably due to small samples analysed and to the presence of muons coming from all the directions.

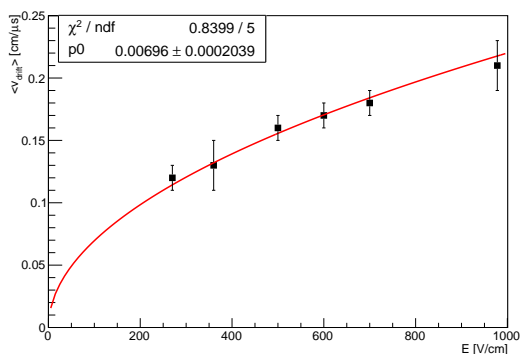


Figure 2. Electron drift velocity $\langle v_{drift} \rangle$ as a function of the electric field value E . The red line is the fit function $f(E) = p_0 \sqrt{E}$.

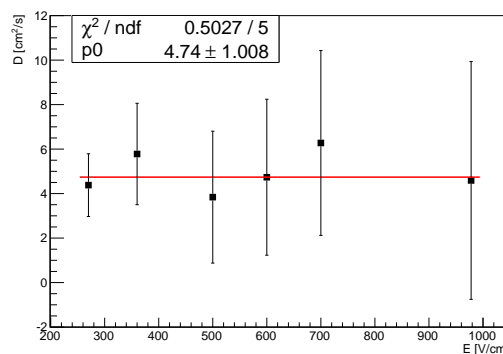


Figure 3. Diffusion parameter D as a function of electric field value E . The red line is the fit function $f(E) = p_0 E$.

5. Conclusions

Longitudinal diffusion D is an important parameter contributing to the spatial resolution of LAr TPC detectors. Dedicated measurements were carried out in underground conditions with the ICARUS T600 detector.

Experimentally, D can be calculated by measuring the width of the signal recorded by the TPC. For each electric field the value found is compatible with a constant parameter $D = 4.74 \pm 1.01 \text{ cm}^2/\text{s}$: this is a preliminary results, because the errors are large due to the small statistic analysed.

This result is similar to that already found by the ICARUS Collaboration with a 3 ton LAr TPC prototype [6]; however a comparison between the two values is not possible due to different temperature and pressure conditions.

References

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