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# Preliminary measurement of ion drift velocity in T2K gas mixture

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Abstract: In recent years, the near detector of the T2K experiment underwent an important upgrade of part of its equipment, which involved the construction of a set of new detectors. As a part of the upgrade, two gaseous Time Projection Chambers (TPC), placed above and below the active target, enable the study of particles produced at large angles with respect to the beam axis by neutrino interactions. Each High Angle TPC includes a large active volume defined by rectangular cross-section field cages with lightweight composite material walls and two readout planes instrumented with eight Encapsulated Resistive Anode Micromegas (ERAM) each.

A deep knowledge of this detector is crucial to achieve good performance. This communication reports the studies that are being carried out in order to get a deeper comprehension of the T2K mixture properties that have a relevant impact on the signal formation; in particular, the focus is on the determination of the ion drift velocity, which affect the spread of the electrons in the resistive layer of the ERAM and, consequently, the signal shape.

Keywords: Charge transport and multiplication in gas; Gaseous detectors; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Time projection Chambers (TPC)

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## Contents

## 1 Introduction

In 2023 the T2K experiment started a new data taking phase with increased beam power; to cope with the challenges posed by the increase in power, the upstream part of ND280 was equipped with new detectors [1]. The core of the upgrade, in central position, is a highly granular scintillator target tracker, Super-FGD, lodged between two gaseous Time Projection Chambers (TPC) that lay above and below it and detect particles that scatter at a large angle with respect to the beam axis, hence the name High Angle TPC (HA-TPC); the whole upgrade structure is surrounded by six scintillating panels that measure the particles' time of flight (TOF).

The HA-TPCs are composed of two flanged boxes about 1 m long in the drift direction with a $0.8\times1.8\,\mathrm{m}^2$ aperture transverse to the drift; the apertures host the cathode, at the junction of the two boxes, and two readout planes at the extremities. In each readout plane eight Encapsulated Resistive Anode Micromegas (ERAM) are allocated [2]; each ERAM is $42\times34\,\mathrm{cm}^2$ in surface. The mesh is made of woven stainless steel wires with a diameter of 18 µm spaced with a pitch of 63 µm; the nominal height of the mesh above the resistive plane is 128 µm. The ERAM readout plane, segmented in a matrix of 1152 pads of about $1\,\mathrm{cm}^2$ area, is covered by a resistive layer made of an insulated 50 µm Apical polyimide foil (pressed with 150 µm glue), on which diamond-like carbon (DLC) is deposited by electron beam sputtering. The resistive layer technology is used to spread the charge over several pads and thus improve the spatial resolution; a resistive layer can protect the Front-End Electronics (FEE) against sparks. The nominal surface resistivity is 400 kΩ/□.

The same gas mixture is used both in the HA-TPCs and in the other TPCs in the experiment, namely 95% of Ar, 3% of $CF_4$ and 2% of $iC_4H_{10}$; the same mixture is present both in the drift volume and in the multiplication gap.

## 2 Study of the drift velocity of the ions

The ERAMs are powered in a way that the electrons move towards the resistive layer and the ions drift towards the mesh. In a resistive detector design, the signal collected by the FEE is induced by electric charges moving in the resistive layer while the electron ion pairs, created during the multiplication process, drift in the amplification gap. In this environment, the presence of ions drifting towards the mesh might influence the spread of the charges in the resistive layer, thus affecting the signal formation. To obtain a precise calculation of this effect, however, the drift velocity of the ions moving in the amplification gap, i.e. in an electric field of about 30 kV/cm, must be known.

The ion drift velocity can be estimated from the study of the development of the signal induced on a non resistive anode. The signal contains a fast electron contribution (~ns) and a slower ion component (~100 ns), as shown in figure 1 left; the signal develops while the charges are moving in the gap and is over when they reach an electrode. Due to the exponential nature of the charge multiplication process, the majority of the electron ion pairs are produced in the proximity of the anode, thus implying that the electrons arrive almost immediately at the anode while the ions travel across the entire amplification gap. Hence, the electron component of the signal can be regarded as the starting time of the ion movement, while the time at which the ion component is over is the end of the ion movement. From a time measurement, the drift velocity is obtained.

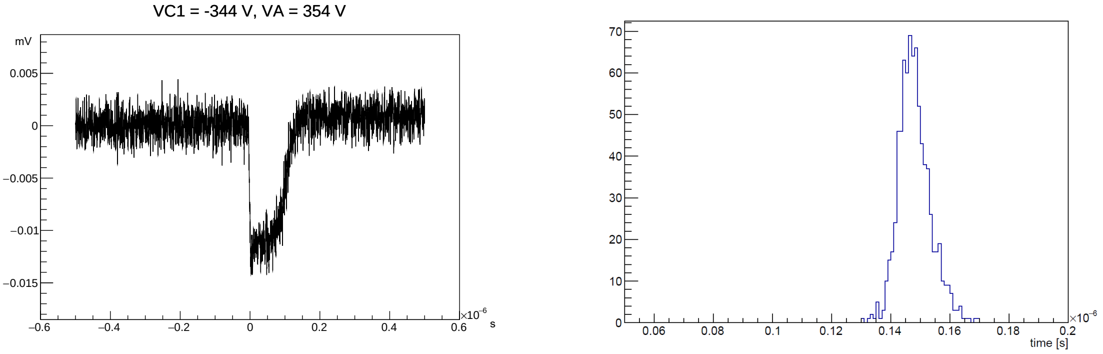

**Figure 1.** Left: typical waveform of an avalanche triggered by an $^{55}$Fe source; both rising and falling edges are clearly visible. Right: ion drift time distribution for a $\Delta V = 350\,\mathrm{V}$, nominal operating voltage in T2K ERAMs.

The measurement requires a dedicated setup: a non resistive Micromegas with a single, circular pad of area $\sim 1\,\mathrm{cm}^2$ is used. This detector has a kapton window and a 1.5 mm conversion gap which, combined, permit the use of an $^{55}$Fe source to trigger the avalanches; the mesh characteristics, as well as the amplification gap size, are the same as for the T2K ERAMs. The detector is operated with T2K gas mixture at STP. The charges collected by the anode are expected to be small so a custom design broadband amplifier is used [3]. The signal waveforms are recorded with an oscilloscope for offline analysis.

The waveforms show a steep rise (negative voltage), a plateau, and a smoother return to baseline, as shown in figure 1 left, which are interpreted, respectively, as the electron arrival time, the ion drift time and the ion collection at the cathode. The rising and falling edges are fitted with the following functions:

$$f_{\mathrm{rise}}(t) = A \cdot \frac{1}{1 + e^{-\lambda(t-t_0)}}\,, \qquad f_{\mathrm{fall}}(t) = A \cdot \left[1 - \frac{1}{1 + e^{-\lambda(t-t_0)}}\right] \tag{2.1}$$

A total of 1250 waveforms are collected for each measured voltage difference across the amplification gap. Good waveforms are selected with a basic cut on the $\chi^2$ of the fits and on the amplitude parameter to exclude noise events; around 100% of the waveforms are accepted. Figure 1 right shows the distribution of the ion drift times extracted from the waveforms for a voltage difference across the amplification gap $\Delta V = 350\,\mathrm{V}$, nominal for the T2K ERAMs. The ion drift time distribution is fitted with a Gaussian curve and the mean ion drift time is obtained. The ion drift velocity is then computed by considering the nominal distance between anode and mesh, 128 μm, as the distance traveled by the ions. Velocity itself depends on the applied electric field, thus a more general variable, the mobility μ [4], defined as

$$\mu = \frac{w^+}{E} \tag{2.2}$$

where $w^+$ is the ion velocity and $E$ the electric field, is also computed. Results are reported in table 1.

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**Table 1.** Measured ion drift time and estimated ion mobility for different voltages applied across the amplification gap.

| $\Delta V$ [V] | drift time [ns] | ion mobility [$\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}$] |
|---|---|---|
| 350 | 147.8 ± 0.2 | 2.7 ± 0.1 |
| 360 | 149.3 ± 0.2 | 2.6 ± 0.1 |
| 370 | 152.7 ± 0.2 | 2.5 ± 0.1 |
| 380 | 161.3 ± 0.3 | 2.3 ± 0.1 |

## 3 Conclusions

To achieve a complete understanding of the signal formation process in the T2K ERAMs, important gas properties need to be measured. This proceeding reports a preliminary measurement of the velocity of ions in T2K mixture, or equivalently, their mobility, at different electric fields; these measurements are a crucial input to the Monte Carlo simulations. A more detailed study, varying the gas component proportions, would unveil details on the drifting species and is under consideration for future measurements.

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