TinyTPC – A test stand for photosensitive dopants

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FERMILAB-POSTER-24-0014-V

Introduction

Liquid argon time projection chamber (LArTPC) detectors have been primarily used to study accelerator neutrinos (GeV-scale).

It has been demonstrated that LArTPCs are able to reconstruct at the MeV-scale [1,2]. However, at low energies, their energy resolution is significantly degraded, since only a small fraction of scintillation photons are collected (Fig. 1).

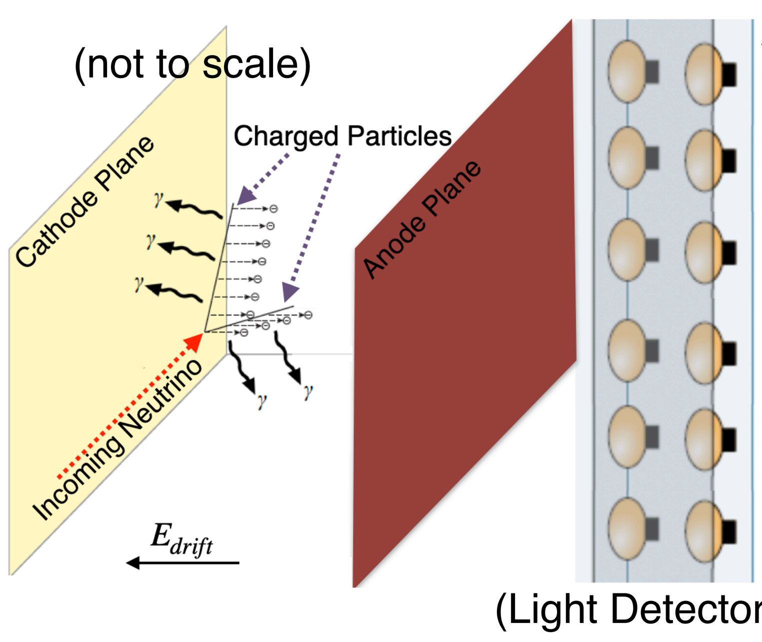

Figure 1: Illustration of the detection of an incident neutrino in LArTPCs. Figure adapted from [3].

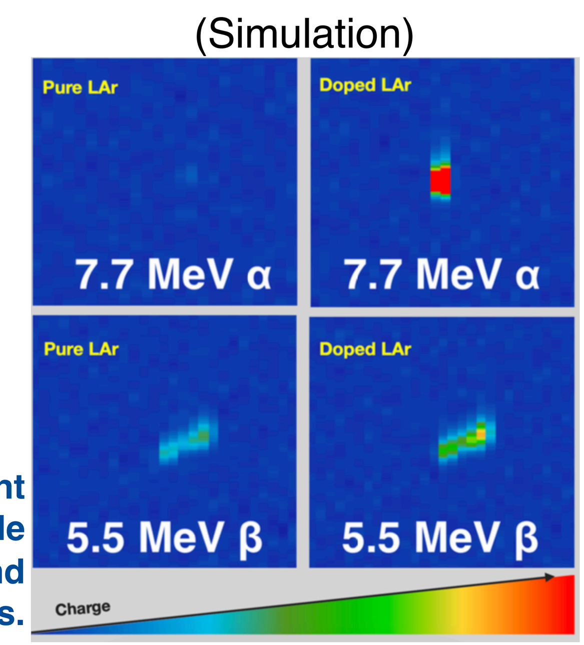

Figure 2: Simulated event displays of low energy α-particle and electron tracks with and without photosensitive dopants.

One solution is the use of a special class of hydrocarbons (photosensitive dopants), which convert light to charge (that can be collected more efficiently) (Fig. 2).

We have built a test stand (TinyTPC) to study these charge enhancements.

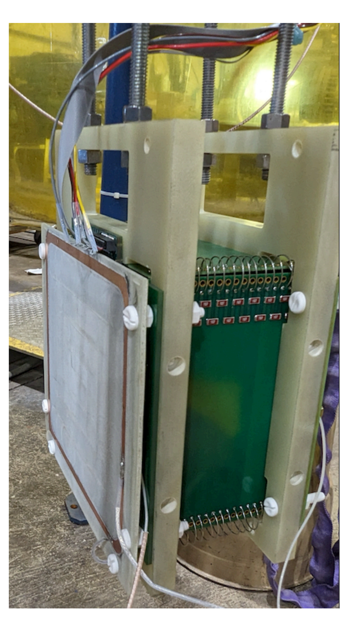

Figure 3a

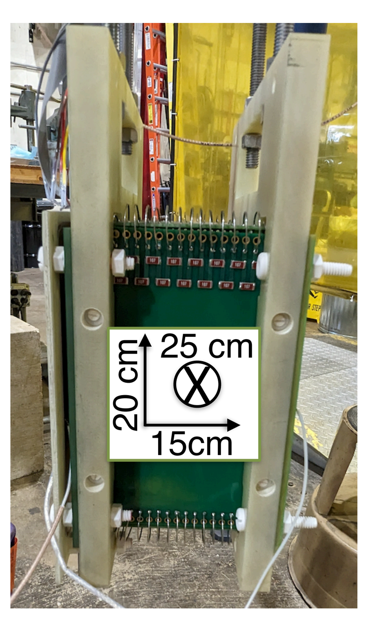

Figure 3b

Figure 3c

Figure 3 a,b,c: Different angles of the TinyTPC detector. Figure 3b also includes its dimensions.

Motivation & Prior Art

Physics opportunities at the MeV-scale [4, 5]:

- study of supernova and solar neutrinos
- test of proposed theories (for example, neutrinoless double-beta decays and millicharged particles)

Previous studies demonstrated that the mix of photosensitive dopants in LAr results in increase of ionization signal:

- of 5.5 MeV α-particles in LAr calorimeter test stands [6] (Fig. 4)
- of cosmic muons in ton-size LArTPCs [7] (Fig. 5)

Our research question: Do photosensitive dopants improve LArTPCs' energy resolution at the MeV scale?

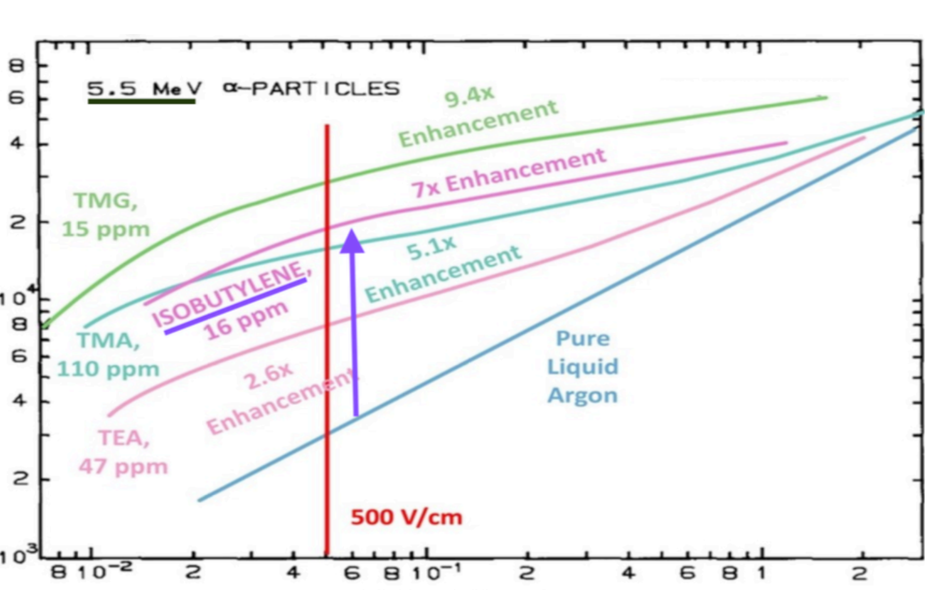

Figure 4: Amount of charge observed for different electric fields and for different photosensitive dopants. Figure adapted from [6].

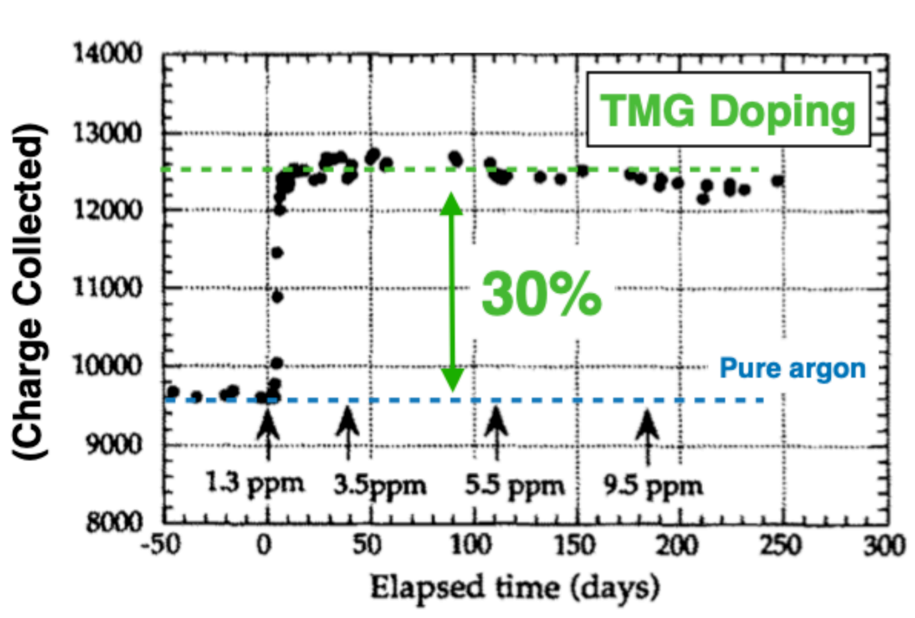

Figure 5: Amount of charge collected with and without photosensitive dopants in an electric field of 300 V/cm for 250 days. Figure adapted from [7].

Technical description of TinyTPC

It is a single-phase detector, where only charge is collected.

Its components are:

- 4 field cage boards
- a cathode (high voltage) plane
- a LArPix [8] pixelated anode plane (state-of-the-art readout system)

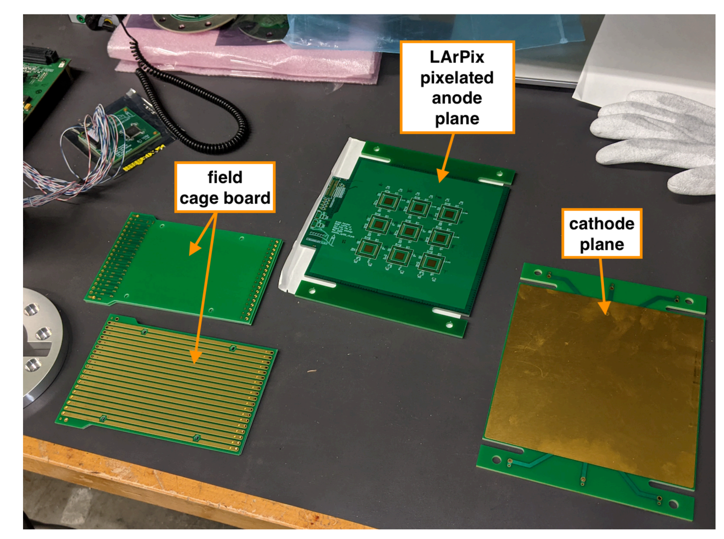

Figure 6: Components of the TinyTPC detector

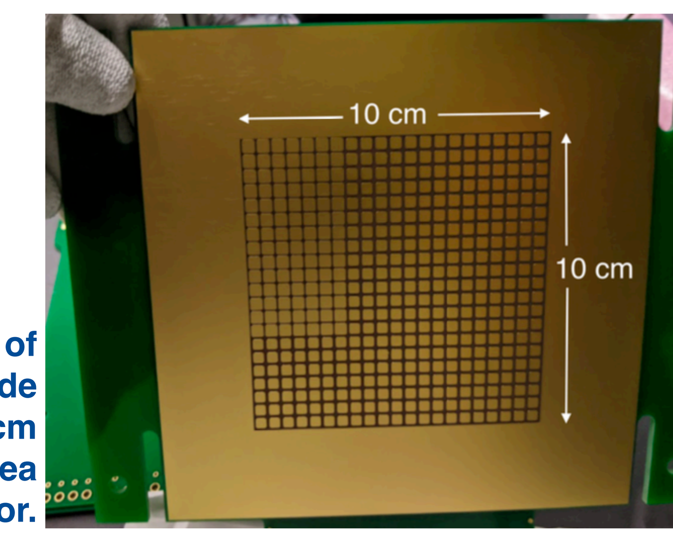

Figure 7: The other side of the LArPix pixelated anode plane. The 10 cm x 10 cm surface is the active area of the detector.

Commissioning Run

In August 2023, TinyTPC was deployed inside the BLANCHE cryostat [9], which is located at FNAL. Cosmic data were acquired over the course of 5 days at 4 kV and 4.5 kV to calculate TinyTPC's calibrations.

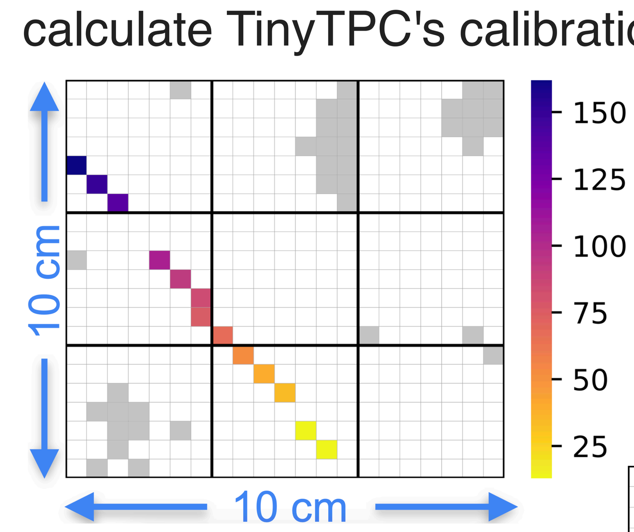

Figure 8: Event display of cosmic track from the cathode to the anode. Grey channels were masked during this run. Script was adapted from [10].

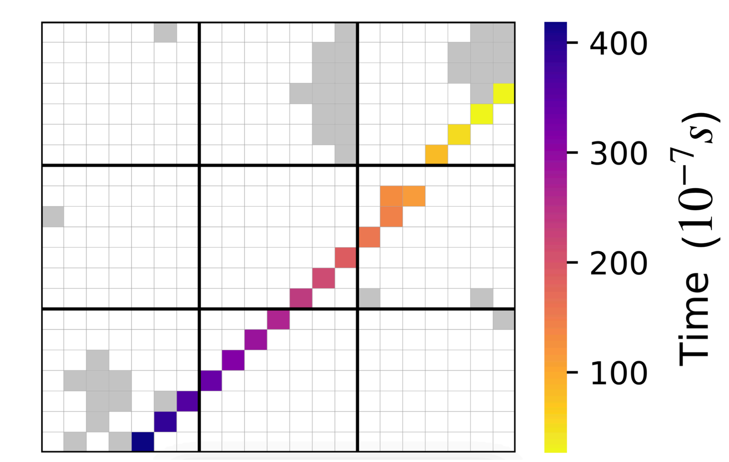

Figure 9: Event display of cosmic track from the anode to the cathode. Grey channels were masked during this run. Script was adapted from [10].

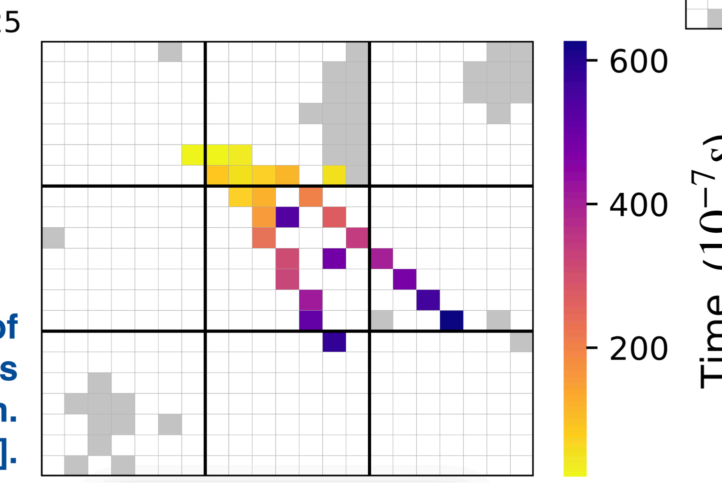

Figure 10: Event display of shower topology. Grey channels were masked during this run. Script was adapted from [10].

Next Steps

Stage 1:

Characterization of TinyTPC's energy response at the MeV-scale with radioactive sources [by comparing the sources' expected Compton edge energy with the measured ones].

Stage 2:

Introduction of photosensitive dopant (isobutylene) in LAr and repetition of Stage 1.

Stage 3:

Exploration of optimal doping strategies.

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Acknowledgments

This material is based upon work that is supported by the Visiting Scholars Award Program of the Universities Research Association and the Fermilab Neutrino Physics Center Fellowship Program.

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

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