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The DUNE vertical drift TPC

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The DUNE experiment is a future long-baseline neutrino oscillation experiment aiming at measuring the neutrino CP-violating phase and establishing the neutrino mass hierarchy, as well as at a rich physics programme from supernovae over low-energy physics to beyond Standard Model searches.

The baseline technology for the first far detector is a proven single-phase horizontal-drift liquid-Argon TPC based on standard wire-chamber technology.

For the second far detector, a new technology, the so-called "vertical drift" TPC is currently being developed: It aims at combining the strengths of the two technologies tested in the ProtoDUNE cryostats at the CERN neutrino platform, the proven horizontal-drift single-phase TPC and the ambitious vertical-drift dual-phase TPC, into a single design, a vertical-drift single-phase liquid-Argon TPC using a novel perforated-PCB anode design. This design maintains excellent tracking and calorimetry performance while significantly simplifying the complexity of the TPC construction.

This paper introduces the concept of the vertical drift TPC, presents first results from small-scale prototypes and a first full-scale anode module, and outlines the plans for future prototypes and the next steps towards the full second DUNE far detector.

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1. Introduction

After the discovery of neutrino oscillations, an extensive experimental programme of solar, reactor and accelerator neutrino experiments has measured many of the parameters of the neutrino-mixing matrix. However, two important puzzle pieces remain: While two squared-mass differences have been established, two mass orderings of the neutrino mass states remain possible. Additionally, a CP-violating phase is allowed in the mixing matrix, which could be part of the explanation of the baryon-asymmetry of the universe. DUNE, a next-generation long-baseline neutrino oscillation experiment, aims to measure these parameters, alongside a diverse physics programme ranging from supernova neutrinos and solar neutrinos, to beyond Standard Model measurements and nucleon decay studies[1]. The experiment uses a neutrino beam from Fermilab, which is sent to far detectors at Sanford Underground Research Facility (SURF) 1.5 km underground, for a baseline of 1300 km[2]. The DUNE collaboration consists of over 1300 scientists and engineers from 37 countries and CERN.

For its far detectors, DUNE uses liquid-Argon (LAr) TPCs[3]. LAr provides a dense, pure medium with prompt scintillation light for triggering using separate photo-detectors, allowing the construction of kt-scale detectors, while being much more abundant and affordable than Xenon. LAr TPCs offer fine-grained millimetric three-dimensional tracking and total-absorption calorimetry, which allows identifying particles via energy loss and topology.

The baseline technology for the first DUNE far detector (FD) module is a horizontal-drift single-phase LAr TPC built using wire-chamber technology[4], as used by several previous experiments. The single-phase Vertical Drift (VD) TPC was chosen as the technology for the second far detector, FD2. With 17.5 kt each, the DUNE FD modules will be the largest LAr TPCs ever built. A phased approach is foreseen, with two far detectors for Phase I, and two more FDs for Phase II, for which the technology R&D is ongoing. Upgrades to the beam, increasing the power from 1.2 to 2.4 MW, and more capable near detectors are foreseen for the second phase.

2. The Vertical Drift concept

Since 2018 the two ProtoDUNE cryostats were used to test the DUNE FD technologies. ProtoDUNE-SP successfully validated the Horizontal Drift (HD) technology of FD1, while ProtoDUNE-DP tested the more ambitious dual-phase technology including signal amplification, simpler construction and a longer drift-length. The ProtoDUNE detectors demonstrated very good LAr purity, allowing for a long 6.5 m drift distance, and resulting in excellent signal-to-noise ratio, which meant that the gain from the gaseous phase of the dual phase technology was not needed. However, some of the other advantages of ProtoDUNE-DP inspired the single-phase VD technology, which takes the best properties of both ProtoDUNE detectors for an improved *single-phase* TPC.

Based on the experience with the ProtoDUNE detectors at the CERN neutrino platform, the new "vertical drift" technology was developed for the second DUNE FD. It benefits from the advantages of the dual phase ProtoDUNE design while eliminating the complexity introduced by the liquid-gas interface.

A cross-section of a single vertical drift module is shown in Fig. 1. The cryostat design is shared with the first FD module. Unlike its wire-based anode however, VD uses anodes consisting

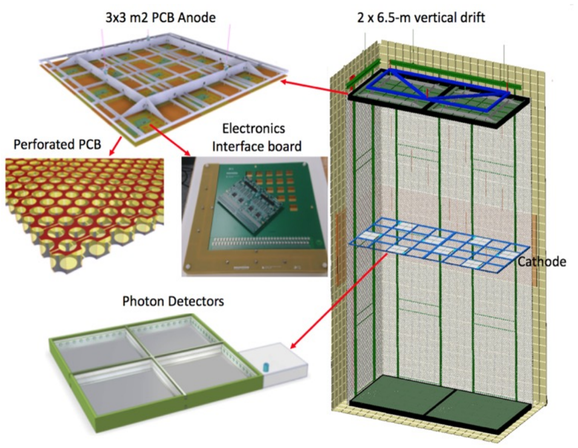


Figure 1: A cross-section of a single vertical drift module.

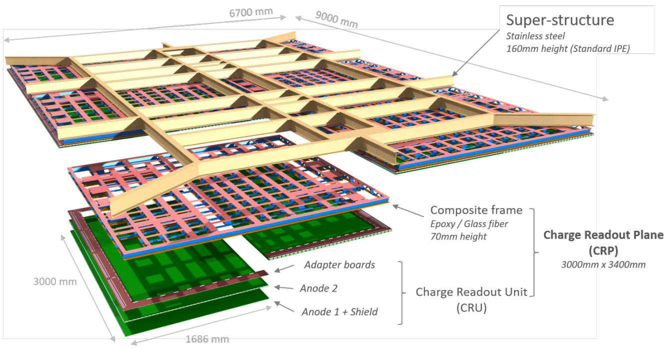
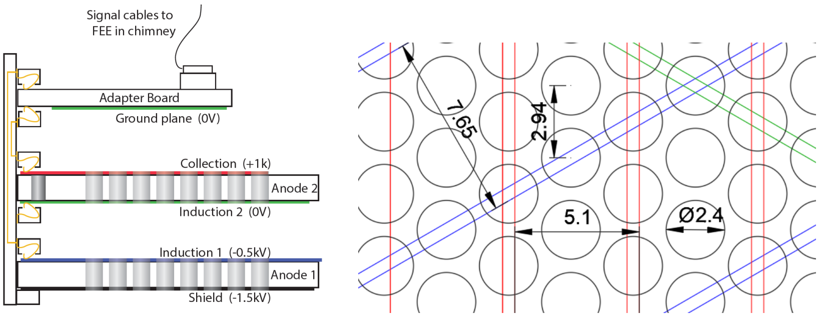


Figure 2: A schematic of a far detector CRP, attached to a mechanical support structure.

of stacked segmented and perforated printed circuit boards (PCBs) with etched electrodes, which are mechanically robust and modular for easy assembly, and mass producible. The cathode will be suspended at mid-height. Finally, photon detectors based on the X-ARAPUCA technology[5] will be embedded in the cathode and cryostat walls for timing and triggering.

A single Charge Readout Plane (CRP) is shown in Fig. 2 in an exploded view. Up to six CRPs are going to be attached to the same mechanical support structure, which is suspended from the cryostat roof by four cables, in the case of the top CRPs. Each CRP consists of two Charge Readout Units (CRUs), each consisting of two anode planes. The two CRUs are attached to a single composite frame with the same thermal expansion coefficient as the PCBs, and which is mechanically decoupled from the mechanical support frame to allow independent thermal contraction and expansion. These anode planes are connected via edge connectors to the adapter boards as shown in Fig. 3a. The individual strips are etched into the anode planes following the pattern shown in Fig. 3b.

Two different readout systems are used for the CRPs at the top and bottom of the cryostat. The top readout electronics are fully accessible from the top, which allows for simple access for maintenance and upgrade of the electronics while the detector is filled. They are connected to the adapter boards via KEL connectors. The bottom readout electronics however are near the cryostat floor, mounted directly onto the adapter boards on the underside of the CRPs, mounted directly



(a) **(b)**

Figure 3: (a) A side-on view of the PCB stack. (b) The strip pattern on the anode planes.

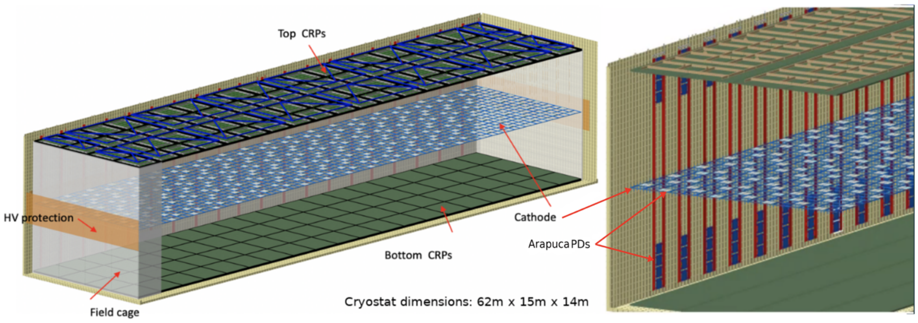


Figure 4: The layout of the Vertical Drift FD module.

onto the adapter boards, and are fully immersed in LAr. While the top electronics are based on the ProtoDUNE-DP electronics, the bottom electronics design is shared with FD-HD.

The final 17.5 kt FD2 VD will have 80 CRPs at the top and 80 CRPs at the bottom of the cryostat, each measuring 3.4 m × 3 m, as shown in Fig. 4. The FD-component mass production should start in 2024.

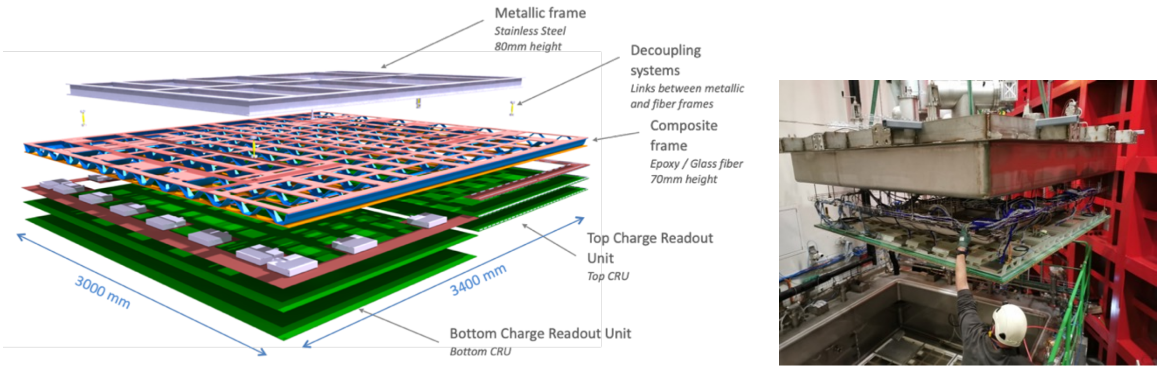
3. Prototyping the VD TPC

Since the conception of the VD technology, several milestones needed to be reached on the way to the full FD. After initial tests using a 50 litre proof-of-concept TPC, a full-CRP test in a cold-box demonstrated the concept, leading to the full Module-0, currently in preparation, to demonstrate the technology's readiness for the far detector.

3.1 The 50 litre TPC

A $32\times32\,\mathrm{cm}^2$ prototype TPC was built at CERN to test hole-sizes, strip pitch, signal shapes and energy resolution using cosmic muons and a ^{207}Bi source in several runs from 2020 to 2022.

Several different PCB configurations were tested, including a single PCB with two views, and two stacked PCBs with two induction and one readout view for three views in total, in addition to a shield layer. The prototype was also used to successfully test the edge connectors used for the Module-0 CRPs. For all these tests, the 50 l TPC was read out using bottom readout electronics.



(a) **(b)**

Figure 5: (a) A diagram of the first full CRP, instrumented with different readout systems for each half. (b) The first CRP as it is being lowered into the cold-box.

3.2 The cold-box

The $4 \times 4 \times 1\,\mathrm{m}^3$ NP02 cold-box at the CERN neutrino platform was refurbished in order to test full-scale CRP modules, the cathode and the photon detection system at cold with a drift distance of about 20 cm. Half of the first CRP, built in 2021 and shown in Fig. 5a, is instrumented half with top, half with bottom electronics to test both readout electronic systems.

Due to manufacturing constraints, each anode panel has to be assembled from 6 segments to form a 3.4 m × 1.5 m panel, which are glued together with epoxy in a half-lap configuration. Channels are bridged between segments using screen-printed silver-epoxy connections, which are then cured using heating strips.

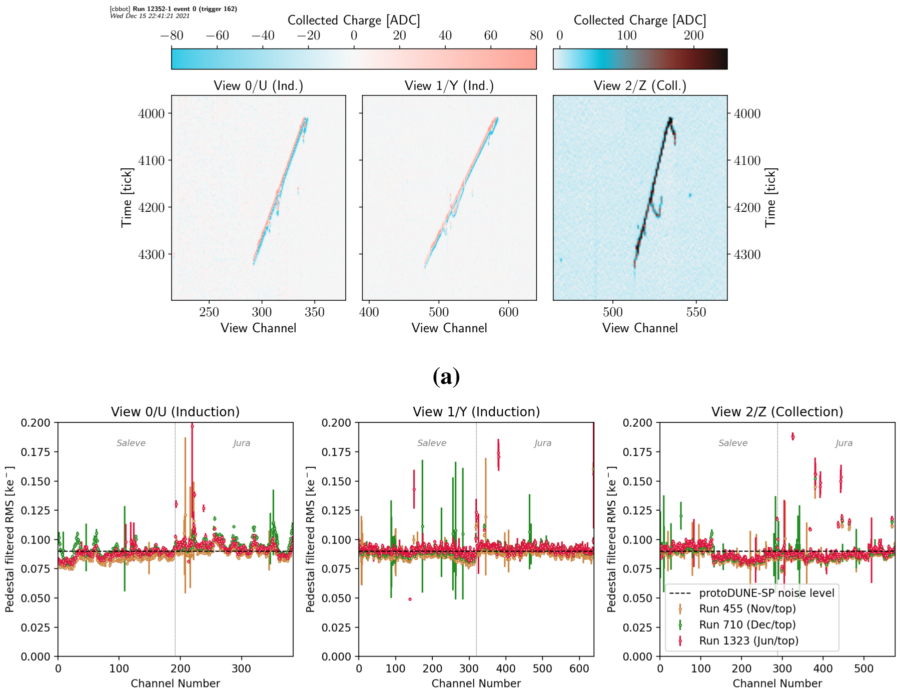
The CRP design was successfully validated at cold and both the gluing and the interconnection of segments was demonstrated. Fig. 5b shows the CRP being lowered into the cold-box. Two runs with large samples of $O(10^6)$ triggers each were taken in November and December 2021, with full analysis in progress. Good tracks were seen in both readout systems, as shown in Fig. 6a. An excellent signal-to-noise ratio was also demonstrated, matching that of the HD technology, as shown in Fig. 6b.

3.3 ProtoDUNE-VD

The NP02 ProtoDUNE cryostat will be re-instrumented as Module-0 of the FD-VD for 2023, with dedicated test beams and cosmic runs in 2023 and 2024. It will contain two full modules with two top and bottom CRP each, and suspended cathodes in between, resulting in a drift distance of about 3 m, due to the limited size of the cryostat. Several more cold-box runs are being performed this year to test the final strip orientation of ±30° and 90°, the edge connectors and homogeneous top/bottom modules, and to test the CRPs before integration into the Module-0.

4. Conclusion

The Vertical Drift technology aims to unite the best features of both ProtoDUNE technologies for the second DUNE far detector. It maintains the high performance and signal-to-noise ratio of



(a)

(b)

Figure 6: (a) A reconstructed track from a cosmic ray event in the cold-box. (b) The noise levels achieved, compared to the reference noise level of the Horizontal Drift TPC.

the Horizontal Drift technology, while being more mechanically robust and simple to assemble. The prototyping is progressing well and the first parts of the Module-0 are assembled and being tested. The completion of Module-0 is foreseen for early 2023, on track for DUNE Phase I.

References

[1] DUNE collaboration, *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics*, `2002.03005`.

[2] DUNE collaboration, *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE*, *JINST* **15** (2020) T08008 [`2002.02967`].

[3] C. Rubbia, *The Liquid Argon Time Projection Chamber: A New Concept for Neutrino Detectors*, Tech. Rep. CERN-EP-INT-77-08, CERN-EP-77-08, CERN, Geneva (5, 1977).

[4] DUNE collaboration, *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology*, *JINST* **15** (2020) T08010 [`2002.03010`].

[5] A.A. Machado, E. Segreto, D. Warner, A. Fauth, B. Gelli, R. Maximo et al., *The X-ARAPUCA: An improvement of the ARAPUCA device*, 4, 2018, DOI [`1804.01407`].