The Development and Prototyping of DUNE's Vertical Drift Charge Readout Planes

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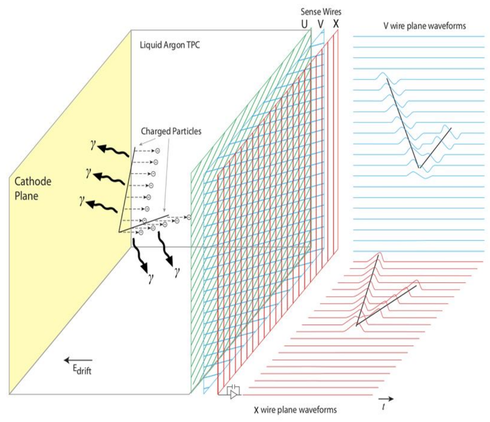
1. LAr TPCs in the DUNE Far Detector

DUNE uses LAr TPCs, offering a dense, pure medium with prompt scintillation for effective triggering.

- Ionization electrons drift to the anode in a uniform electric field (~500 V/cm)
- Detected by sense wires, creating 3D images from 2D views
- Provides high imaging resolution
- Excellent calorimetry and particle identification (dE/dx)
- Prompt scintillation light at 128 nm aids in triggering and calorimetry



The working principle of an LArTPC

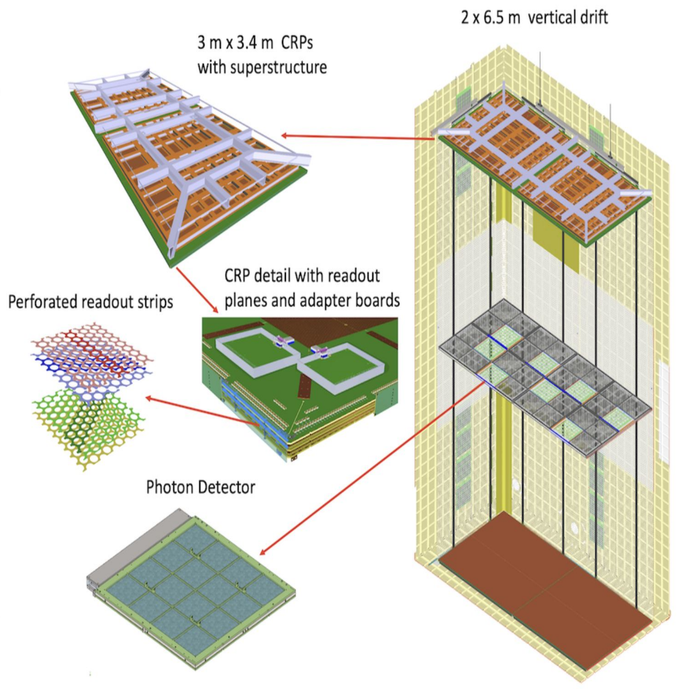
➔ The technology is similar to ICARUS and MicroBooNE. Each DUNE far detector module will be 17.5 kilotons, the largest LAr TPCs ever built.

2. Main Components of Vertical Drift Detector

The "vertical drift" technology for the second DUNE Far Detector (FD2) marks a major advancement in neutrino detection, building on the ProtoDUNE Dual Phase (DP) design and incorporating insights from earlier CERN prototypes.

- **Active Volume Maximization:** Readout units are positioned near the LAr surface and cryostat floor, with a mid-height cathode for HV stability. The system supports a 6.5 m drift, 300 kV cathode voltage, and 450 V/cm electric field.
- **Readout Units Design:** Perforated PCBs with segmented electrodes integrate electronic interfaces. Designed for planarity, lightweight, and robustness, the strips' orientation, pitch, and length are customizable.
- **Supporting Structures:** Modular superstructures support the readout planes with a cathode hanging system for stability and alignment.
- **Photon Detection:** X-ARAPUCA technology mounted into the cathode plane, using optical fibers to decouple from high voltages for safe signal and power transmission, and cryostat wall.

➔ A single field cage encloses the entire active volume.

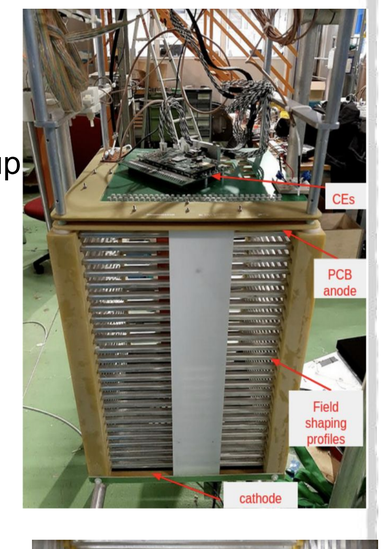


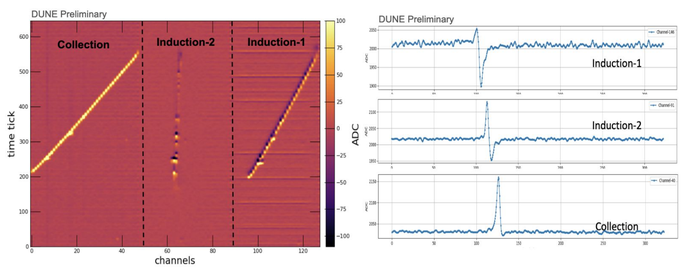
A schematic design for a vertical drift detector with a PCB-based charge readout.

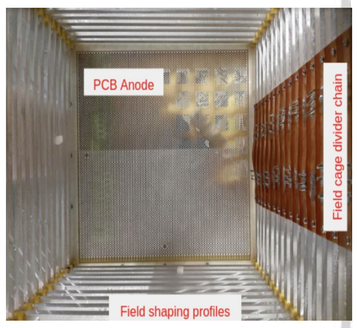
4. Small - Scale CRP demonstrator in 50L TPC

32x32 cm² two - and three view PCB anode prototypes have been developed and tested at the 50L LAr-TPC setup at CERN. The setup successfully demonstrated the first working CRP prototype.

- Tested single two-view and stacked three-view PCBs
- Validated concept and studied signal shapes
- Optimized CRP geometry and field configuration
- Provided data for optimizing larger LAr-TPCs

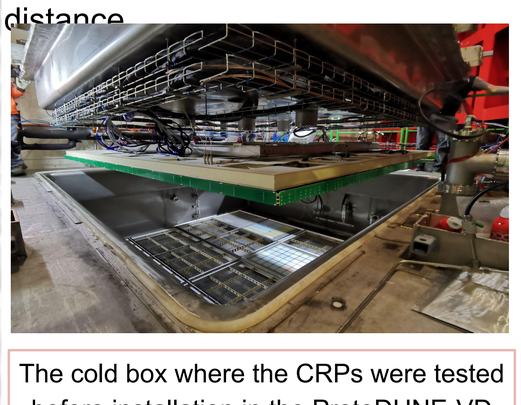




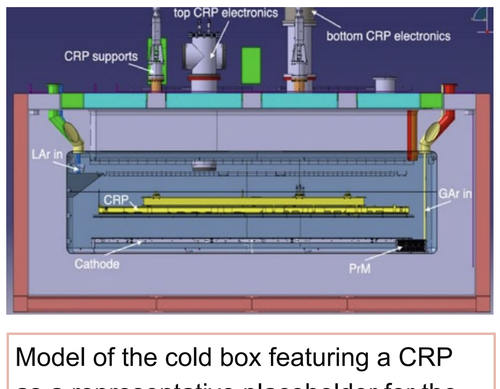


5. Full-Scale LArTPC CRP Cold-Box Testing

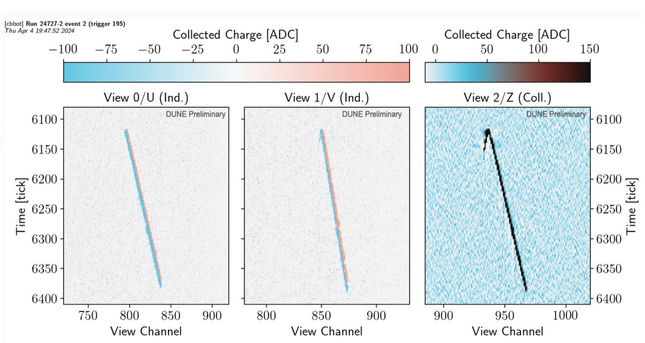
The cold box at CERN, built in 2018, has being upgraded for large-scale Vertical Drift (VD) module testing. It enables full-scale CRP, electronics chain, and photon detector characterization and validation. A cathode is placed on the floor, establishing a 25 cm drift distance.



The cold box where the CRPs were tested before installation in the ProtoDUNE-VD cryostat at CERN.



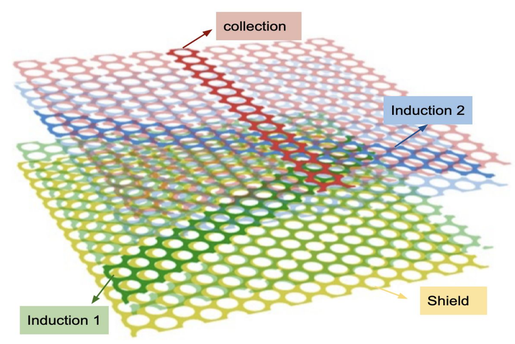
Model of the cold box featuring a CRP as a representative placeholder for the perforated anode readout structure.



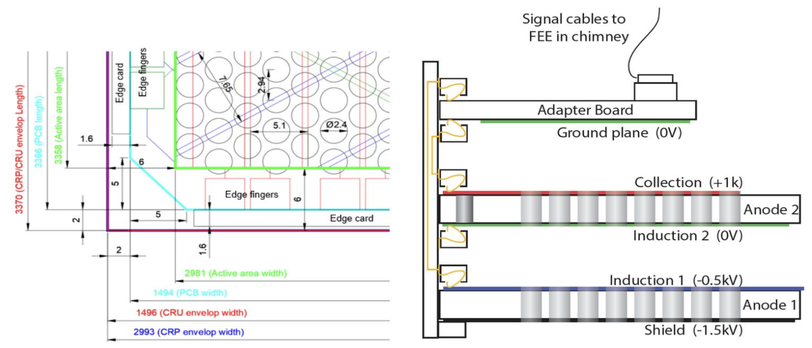
A cosmic ray track captured by CRP6 in April 2024, both induction and collection views shown.

For further details, see Laura Zambelli's poster, 'Coldbox CRP Analysis,' ID #89.

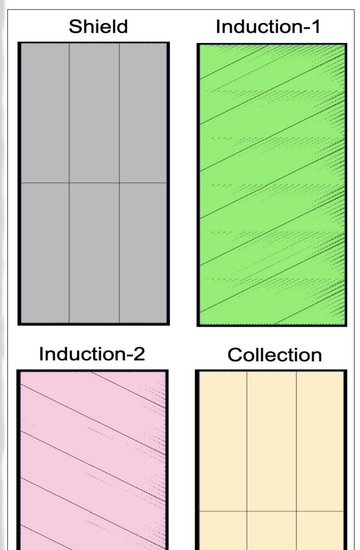
3. Charge Readout Planes (Anodes) Main Components



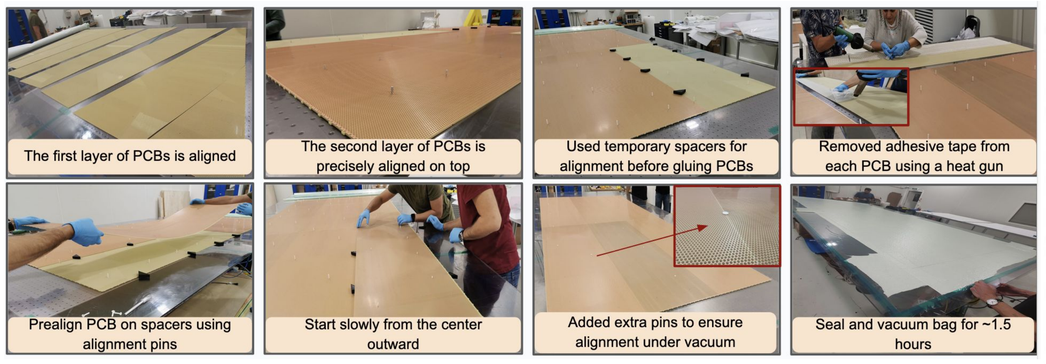
Three-view anode layout featuring perforated PCBs, +30°, -30°, and 90° strip orientation[1].

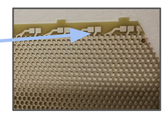


Details of the hole and strip pattern on the anode PCBs, images of the anode layers, adapter board, and edge card stack[1].



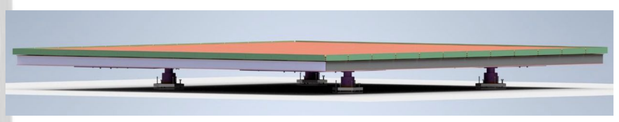
- The PCB is 1.6mm thick and features a single-sided copper pattern that matches the strip's pitch and orientation.
- Non-copper side of the PCB segments for Induction-1 and Induction-2 is bare FR4, while Shield and Collection segments are laminated with 3M VHB adhesive tape[1].



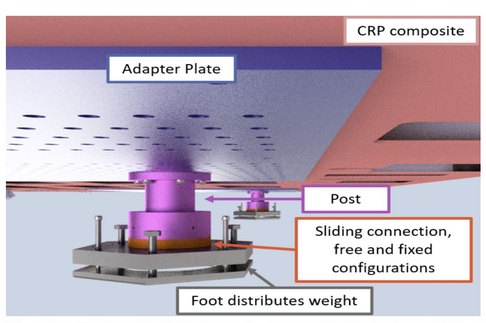


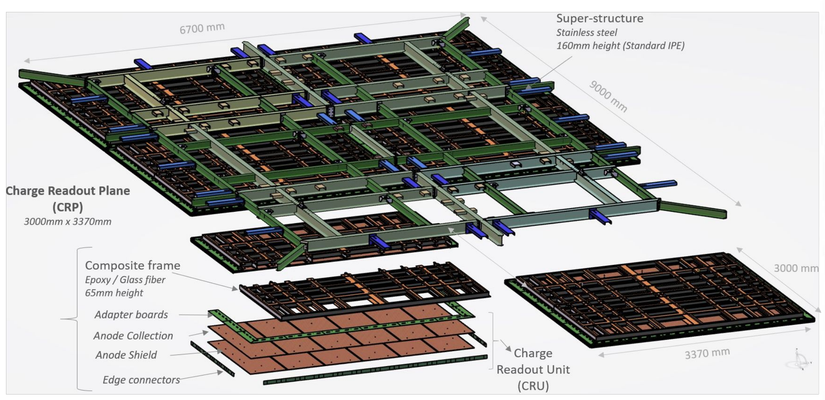
➔ The border design supports edge cards and maintains proper spacing between anode panels

The top CRPs, fully immersed in LAr, are suspended from the cryostat roof by superstructures, while the bottom CRPs are supported by posts on the cryostat floor.



Bottom CRP supported 160 mm above the flat membrane surface, supported by four posts.





A top superstructure supports a set of six CRPs, with an exploded view below illustrating the components of a single CRP[1].

[1] DUNE TDR, arXiv:2312.03130