The Charge Readout Planes of the DUNE Vertical Drift TPC

Fatma Boran (Indiana University)
On behalf of the DUNE collaboration
EPS-HEP 2025 Marseille, France July 7-11, 2025

Content

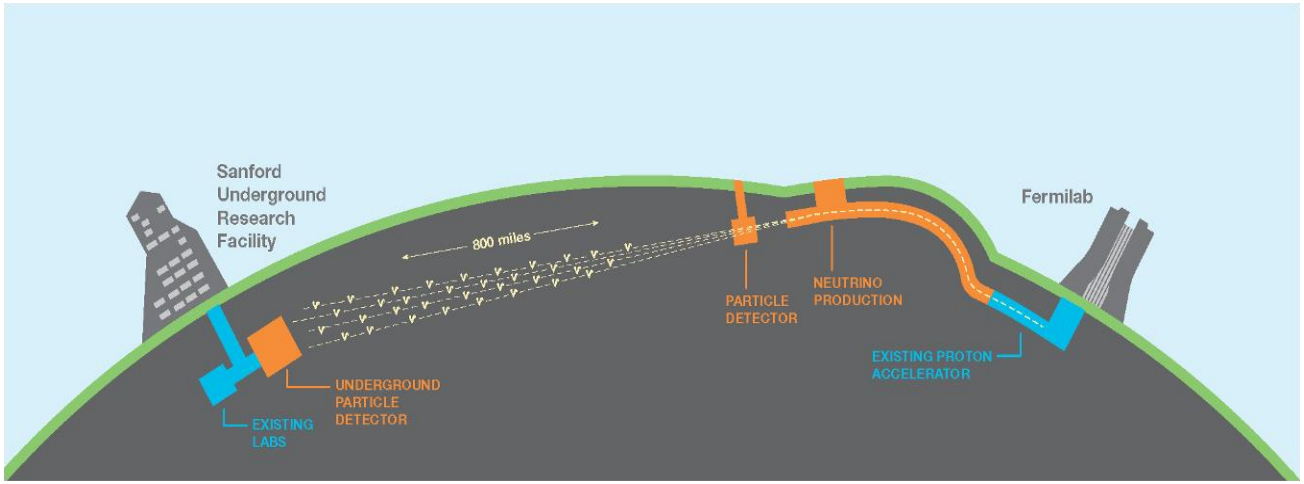
- DUNE & the Vertical Drift Concept
- Charge Detection with Perforated PCB Anodes
- Charge Readout Plane Design and Assembly Strategy
- Anode Assembly Process
- Cold-Box Testing at CERN
- ProtoDUNE-Vertical Drift Construction
- Summary

The Deep Underground Neutrino Experiment (DUNE)

DUNE is a next-generation long-baseline neutrino experiment, 1300 km from Fermilab to SURF (South Dakota)

Very intense wide band ν_μ & $\overline{\nu}_\mu$ beam (0.5 – 7 GeV), starting at 1.2 MW and upgradeable to 2.4 MW.

- Near detector located 575 m from the v source
- Two LArTPC modules as a Far Detector for phase1
  - Vertical and Horizontal Drift detectors, and 1.5 km deep underground

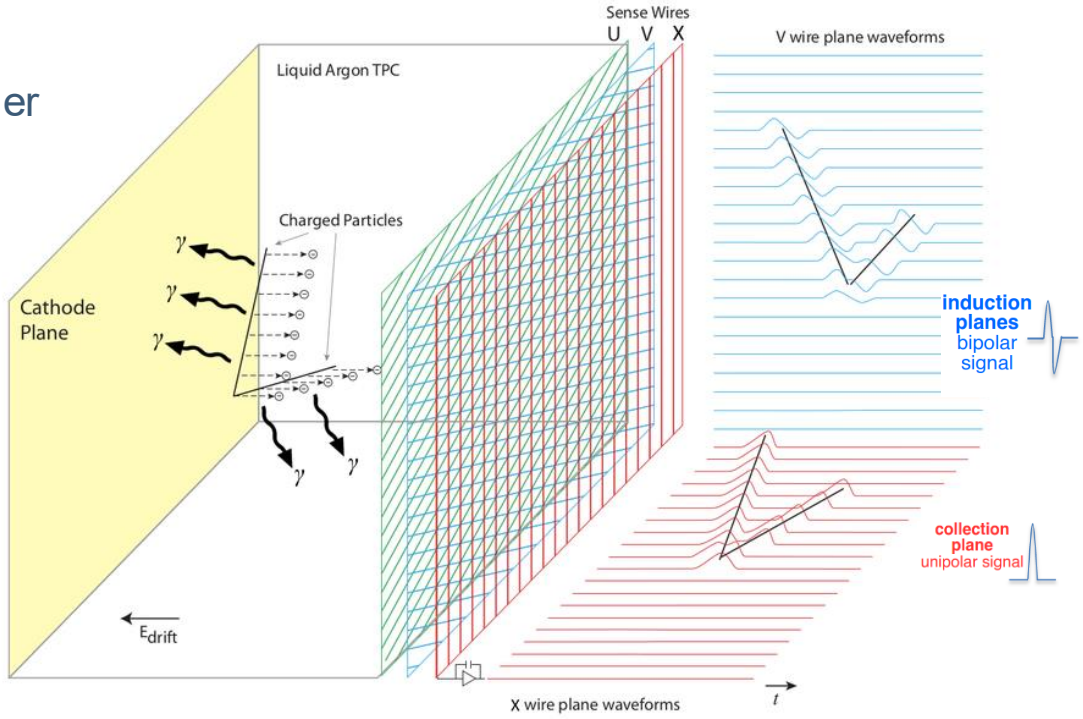


LAr TPCs in the DUNE Far Detector

DUNE uses Liquid Argon Time Projection Chambers (LArTPCs), leveraging their high density, purity, and prompt scintillation light for precise tracking and effective event triggering.

- Ionization electrons drift to the anode under a uniform electric field (~500 V/cm)
- Collected by sense wires, forming 3D images from 2D views
- Excellent calorimetry and particle identification (dE/dx)
- Prompt 128 nm scintillation light aids triggering and calorimetry

TPC working principle of LArTPC

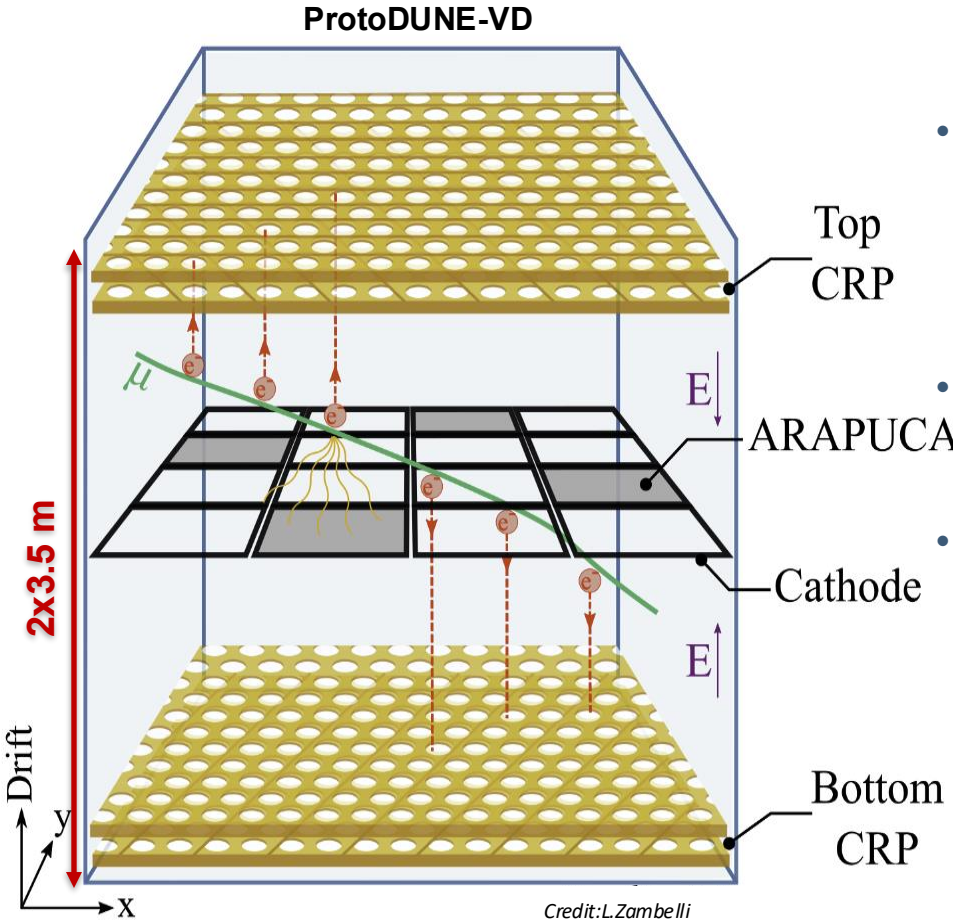


➢ The technology is similar to ICARUS and MicroBooNE. Each far detector module will hold 17.5 kilotons of liquid argon, the largest LArTPCs ever built.

Neutrino PLATFORM Indiana University DUNE

Overview of the Vertical Drift Concept

The Vertical Drift (VD) technology developed for the DUNE second Far Detector module (FD2) marks a significant advancement in neutrino detection. It builds on the ProtoDUNE Dual-Phase (DP) design and integrates critical improvements based on insights from previous CERN prototypes.

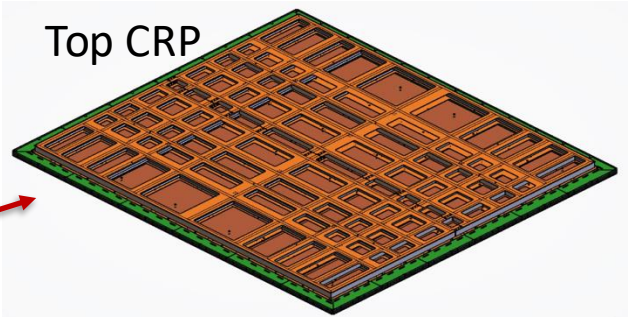


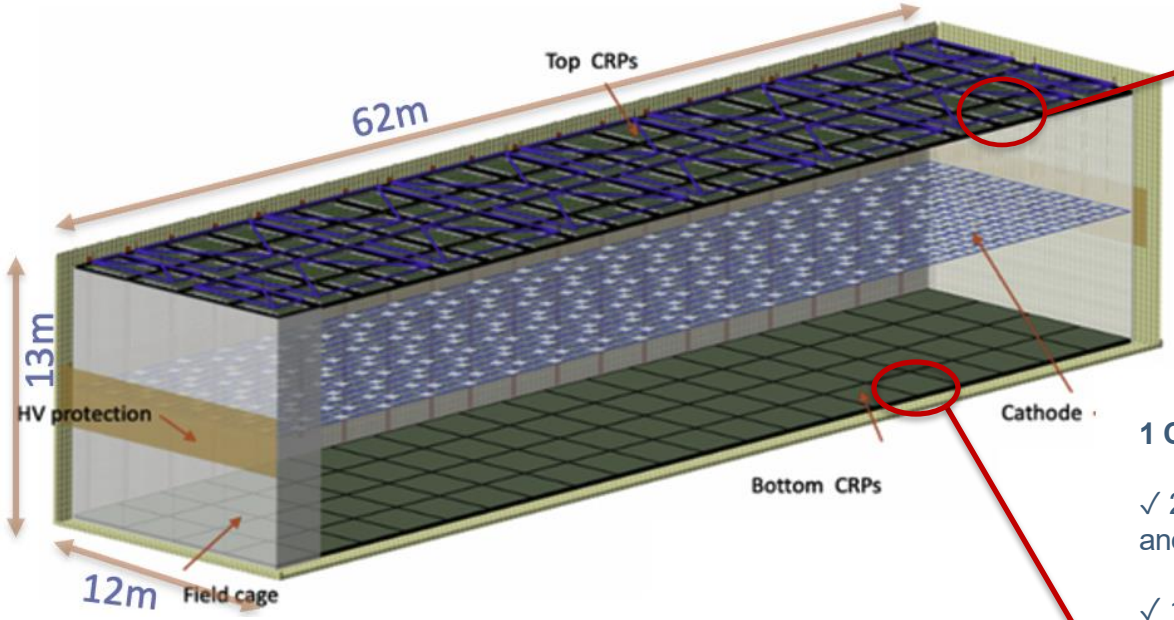
- **The anode** consists of a perforated printed circuit board (PCB) with etched strips, providing 3 independent views for effective ambiguity resolution.
- **Two separated drift volumes** with a centrally suspended cathode.
- **The photon detection system** incorporates X-ARAPUCAs, which are embedded within the cathode structure and on the cryostat wall for efficient light collection.

Neutrino PLATFORM Indiana University DUNE

FD2 Vertical Drift Layout and CRP Overview

- **160 CRP units in total:** 80 on the top, 80 on the bottom
- **Each CRP:** 3 × 3.37 m² readout unit (anode plane)

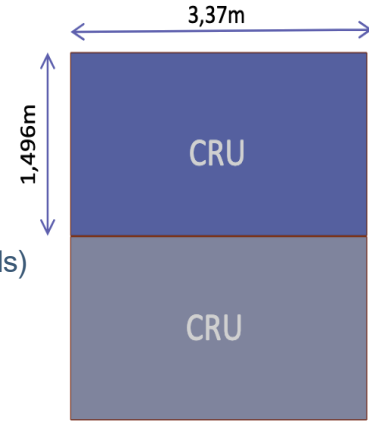


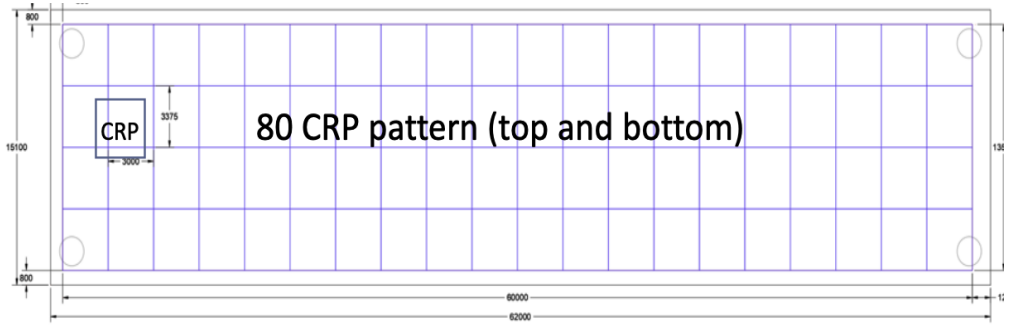


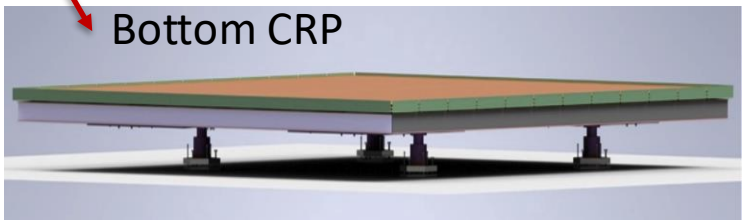
1 CRP = 2993 × 3370 mm²

✓ 2 Charge Readout Units (2 anode layers + adapter boards)

✓ 1 Mechanical Frame



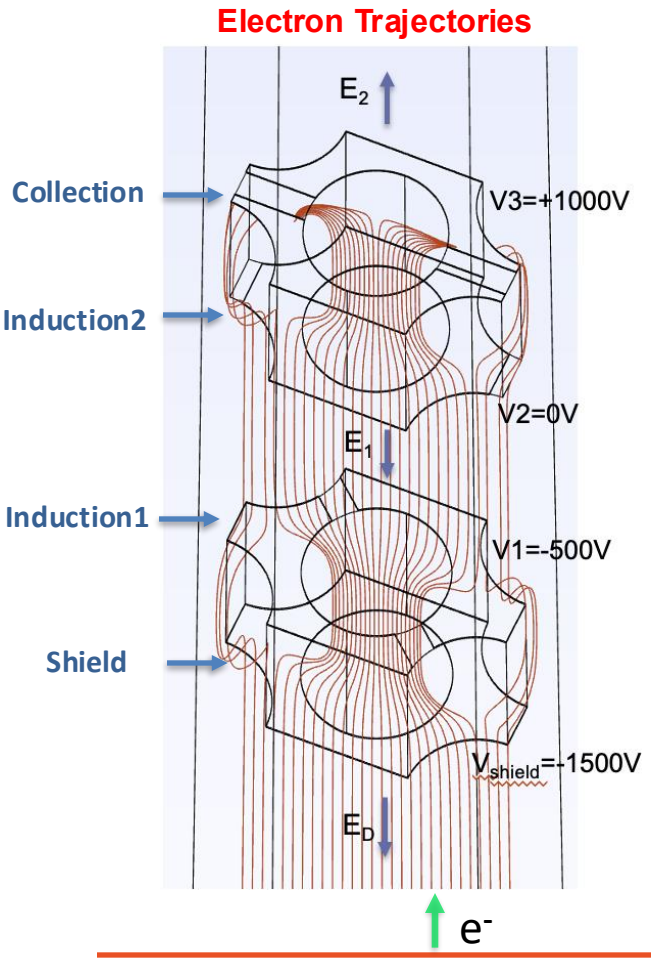


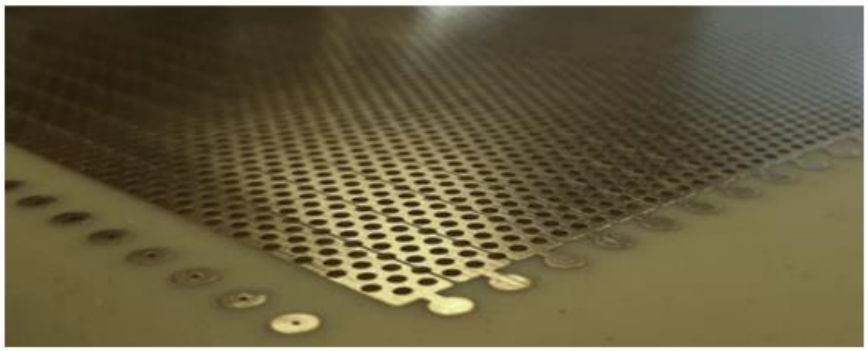


Neutrino PLATFORM Indiana University DUNE

Vertical Drift Charge Detection System

- Cold electronics are integrated on the Charge Readout Plane (CRP) for the bottom plane and are connected via cables to the cold FE electronics for the top plane.
- Each anode plane is 3.2 mm thick.
- The concept has been developed with different orientations in the 50 L setup at CERN since 2021.



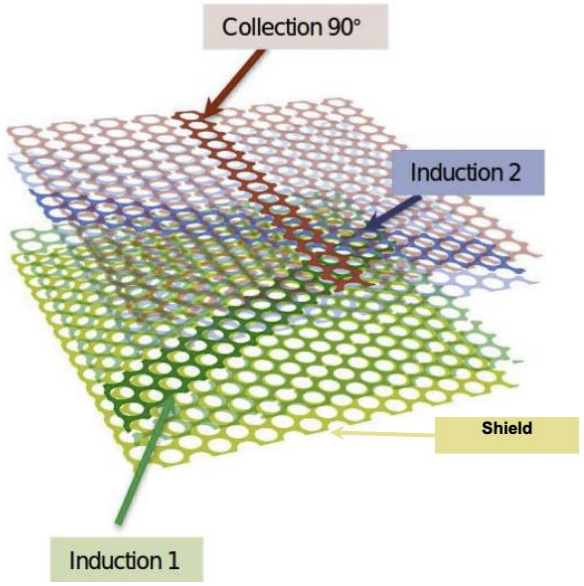


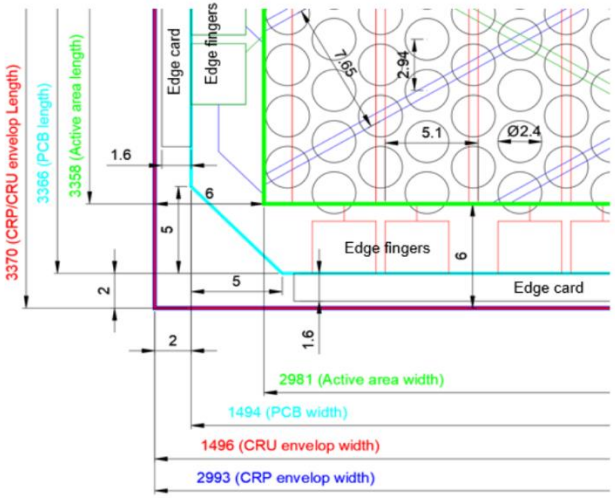
- With proper bias voltages applied to each plane, ionization electrons are pulled through the induction layers without loss and collected on the final plane, the collection plane.
- The electric field guides electron trajectories through the perforations of the cathode-facing PCB.
- The shield plane facing the drift volume is not read out; it serves to protect the readout strips from charge injection originating at the cathode.

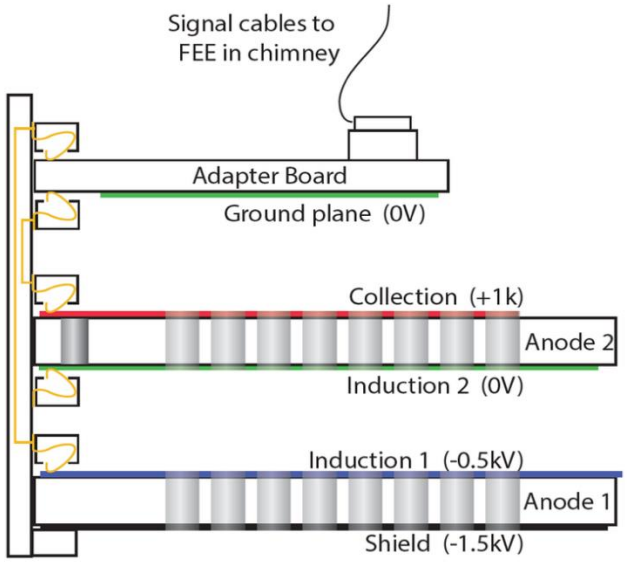
Charge Readout Plane (CRP)

Three-view anode layout (+30°, –30°, 90°):

- 2.4 mm hole diameter
- 5.1 mm collection, 7.65 mm induction strip pitches
- 3072 readout channels per CRP







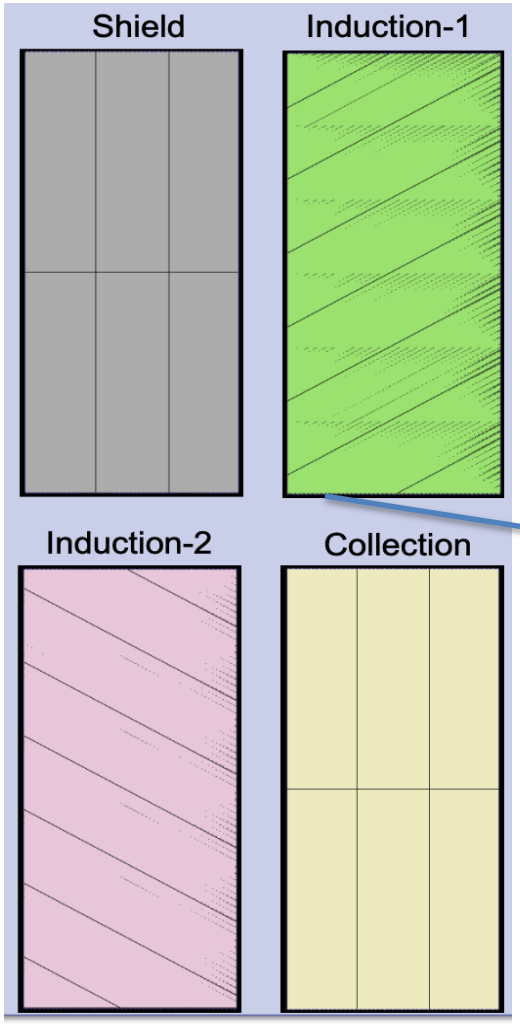
- ✓ 10 mm gap between anode layers
- ✓ Asymmetric bipolar signal (induction), unipolar (collection)

Layered anode stack with shield, induction, and collection planes. Biasing enables charge transparency and signal readout via adapter boards

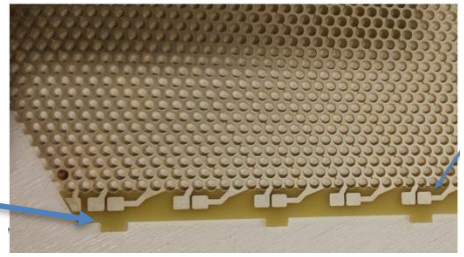
Charge Readout Module Construction

CRU Anode Assembly

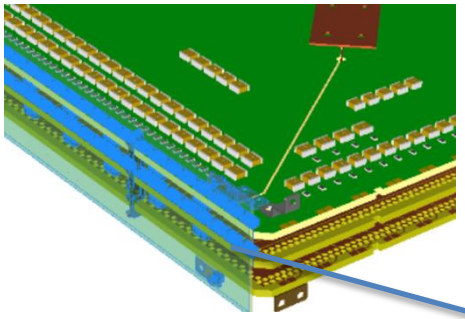
The PCB is 1.6 mm thick and features a single-sided copper pattern aligned with the strip pitch and orientation.



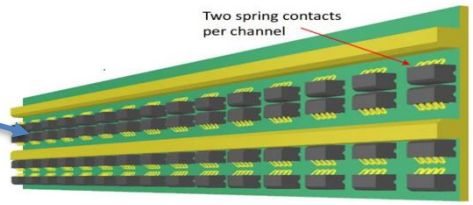
- Each CRU is made by gluing together 1.6 mm thick PCBs.
- The non-copper side of the Induction-1 and Induction-2 segments is bare FR4, while the Shield and Collection segments are laminated with 3M VHB adhesive tape.



➢ The borders are designed to support the edge cards and maintain spacing between the anode panels.



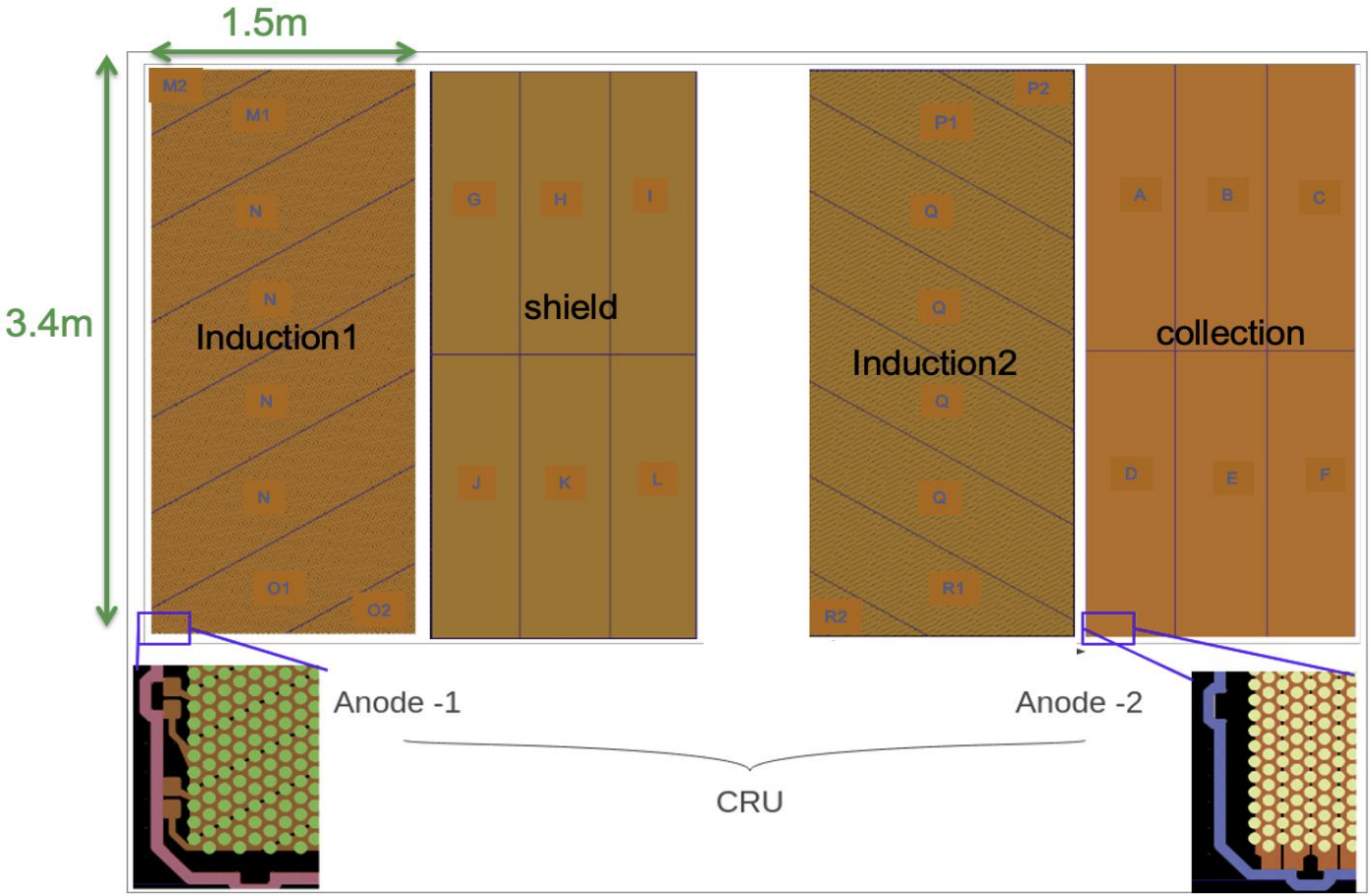
➢ Edge cards enable strip connections to adapter boards, interfacing with both bottom and top drift electronics.



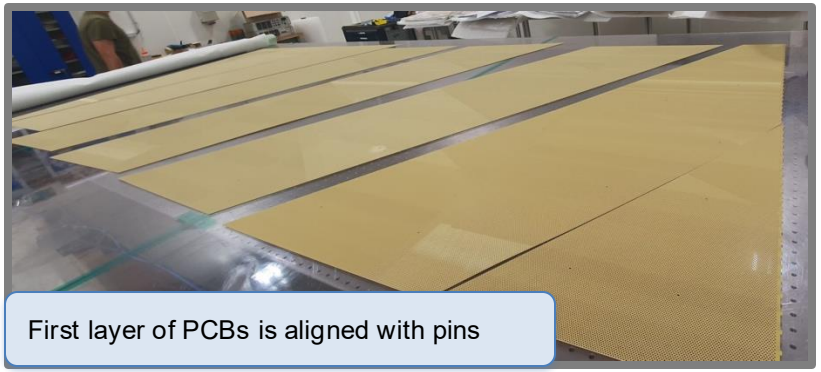
Neutrino PLATFORM Indiana University DUNE

CRU Anode Assembly

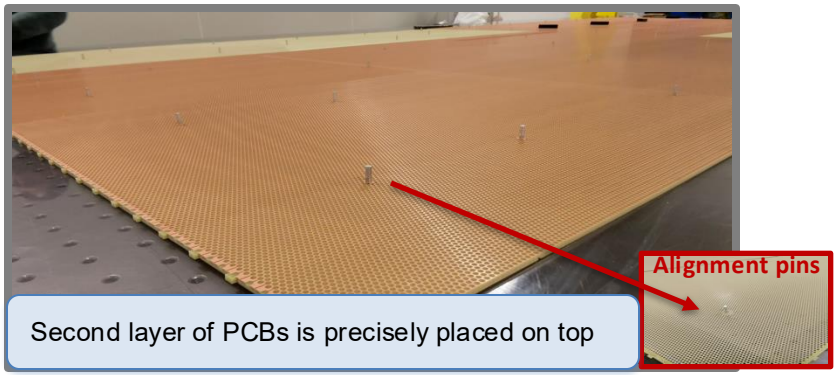
- 22 different types of PCB panels must be produced by manufacturers for one CRU
  - One full anode panel is made by gluing together 11 different PCB-type segments
  - Two full anode panels form a single CRU
  - Two CRUs are assembled for a CRP



Anode Assembly Method

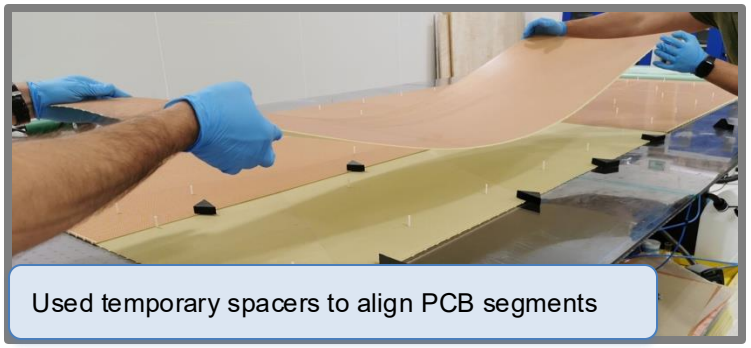


First layer of PCBs is aligned with pins



Second layer of PCBs is precisely placed on top

Adhesive tape removed before gluing



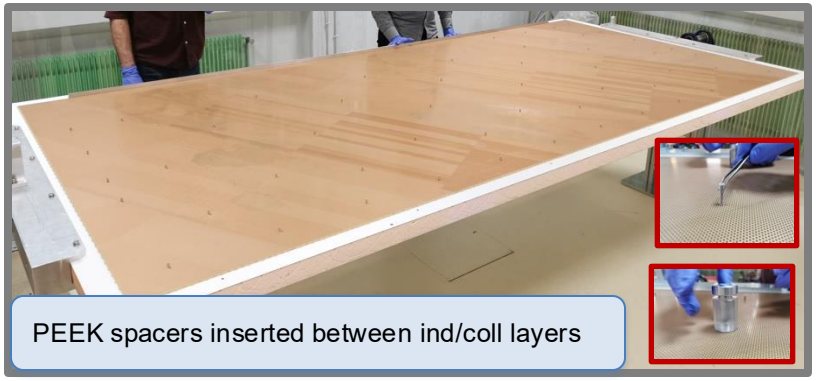
Used temporary spacers to align PCB segments

Sealing the bag, leave it under vacuum for ~1.5 hours to dry

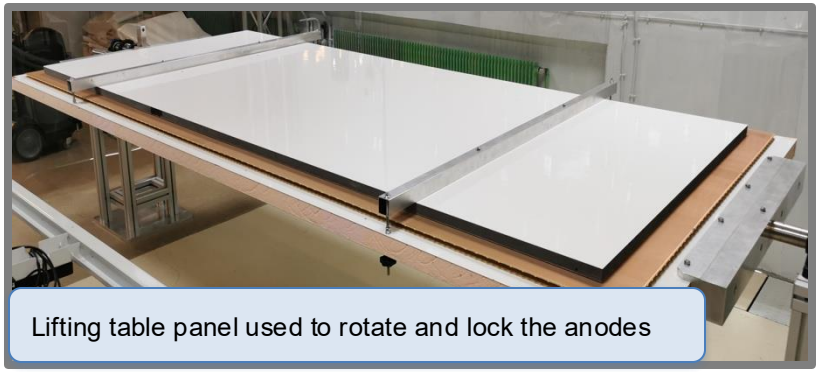
Anode panel after the vacuum process

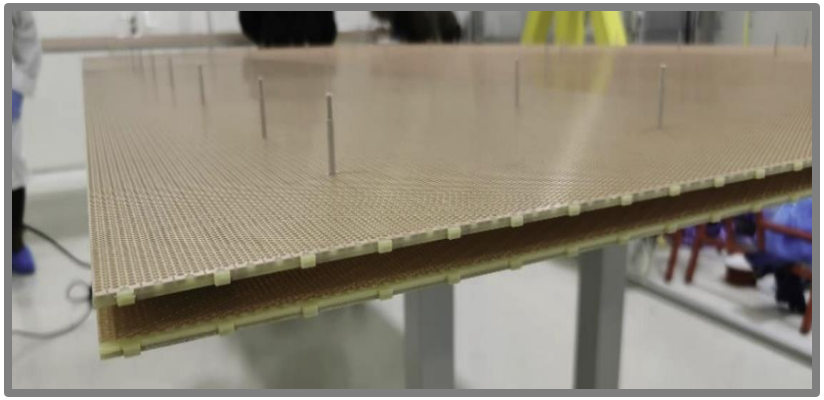
Neutrino PLATFORM Indiana University DUNE

Anode Stack Assembly


PEEK spacers inserted between ind/coll layers

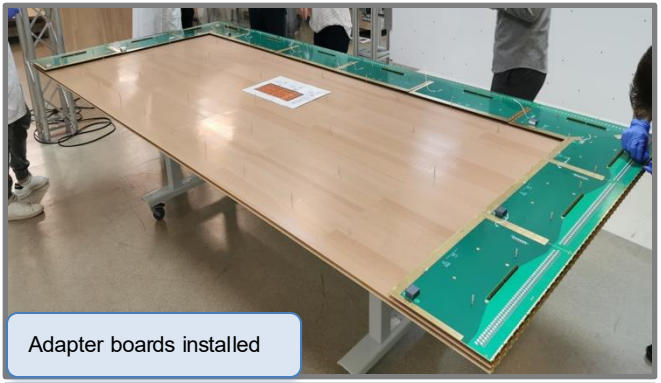

Place Shield/Ind1 anode on Coll/Ind2

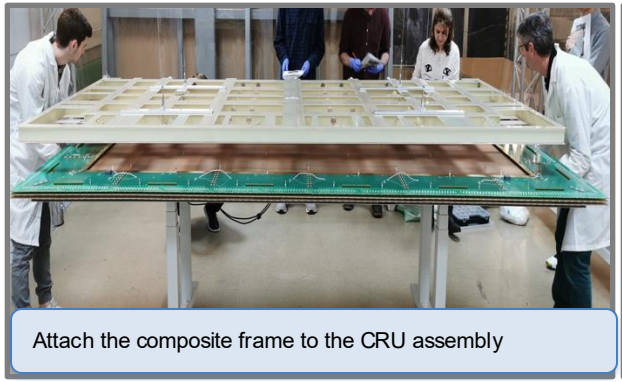

Lifting table panel used to rotate and lock the anodes

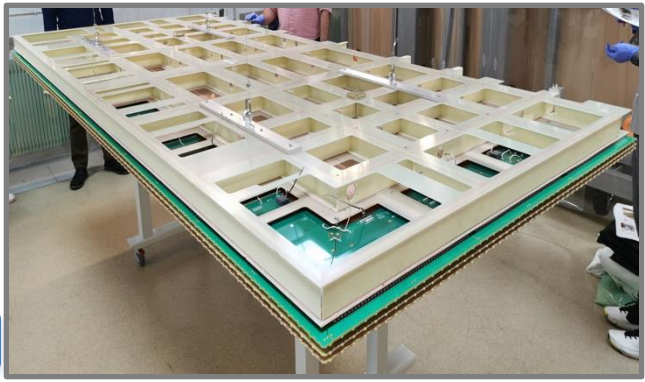


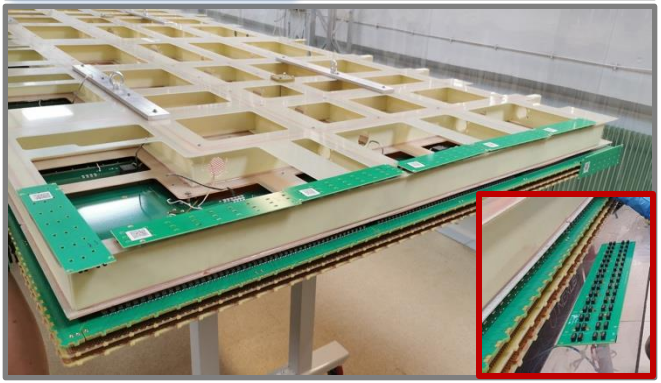
Neutrino PLATFORM Indiana University DUNE

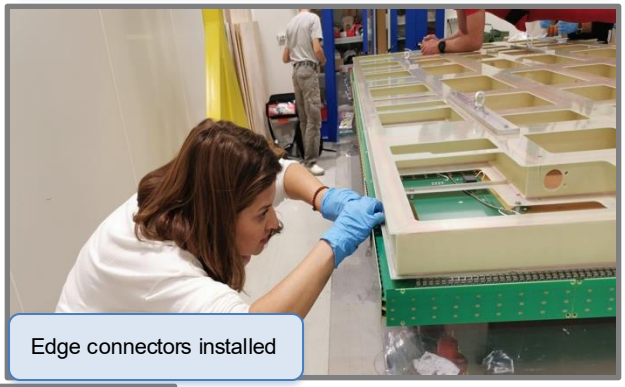
Adapter Boards / Edge Connector / Composite frame Installation


Adapter boards installed

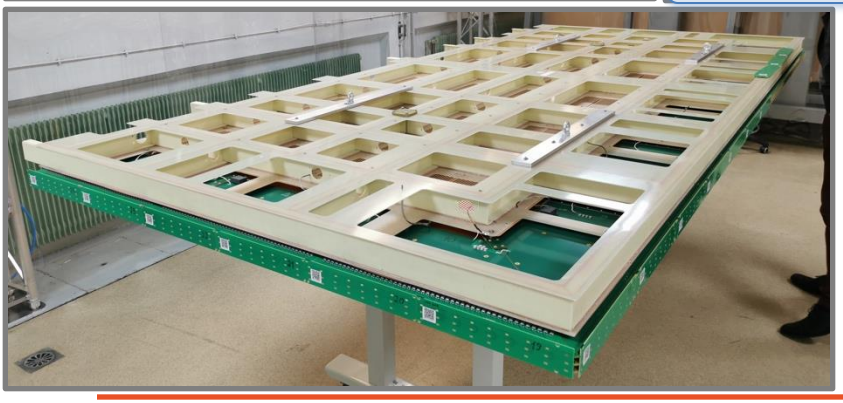

Attach the composite frame to the CRU assembly



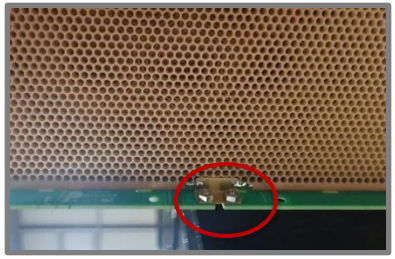



Edge connectors installed

- 7 adapter board types, 24 per CRP
- 7 edge cards type, 48 per CRP
- 2 Composite frames per CRP (Composite frame provides mechanical support for the anode flatness)



➢ Secured the connection between the edge card and the adapter board

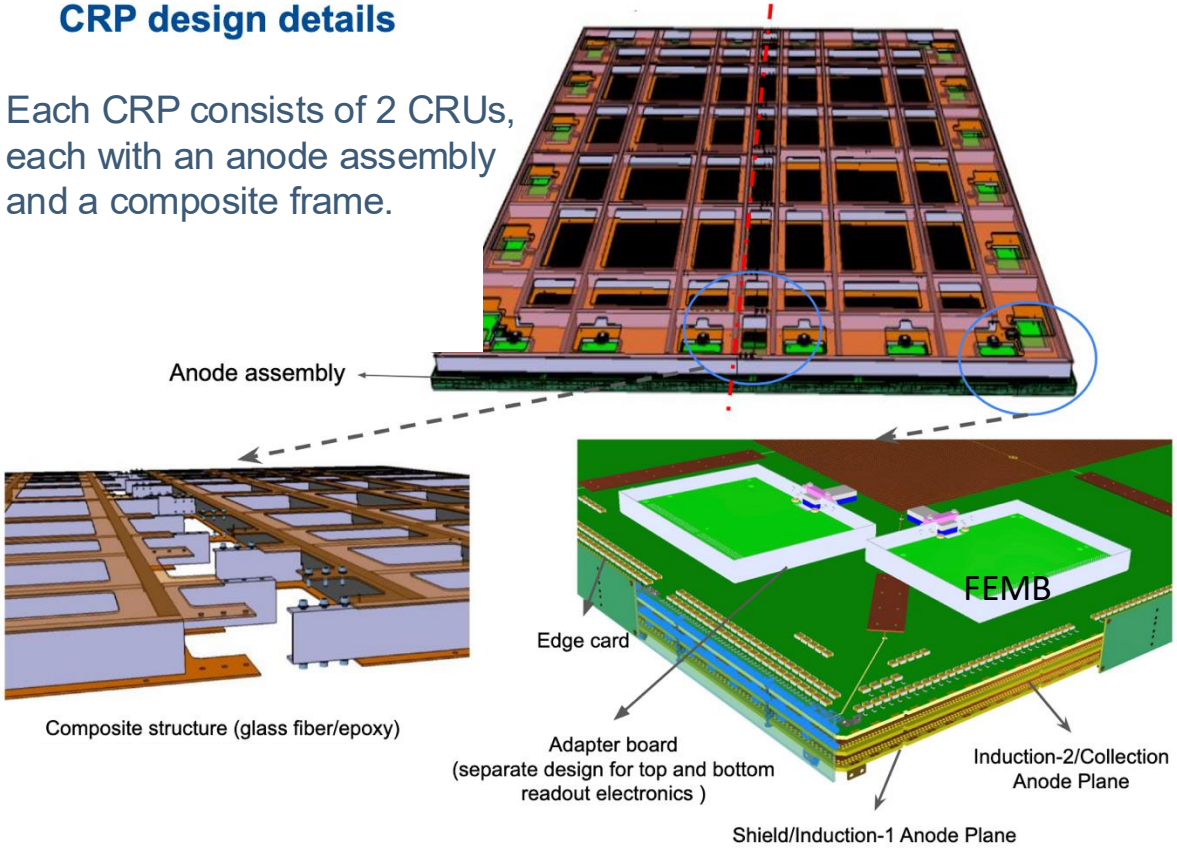


Neutrino PLATFORM Indiana University DUNE

Full CRP Assembly

CRP design details

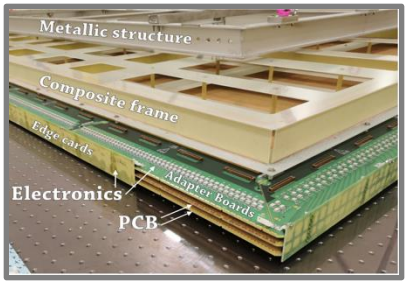
Each CRP consists of 2 CRUs, each with an anode assembly and a composite frame.



The 12 FEMBs are installed after mounting the composite structure.

Assembly of the full CRP

Composite structure (glass fiber/epoxy) made of two parts to ease transport and installation.
A separate design for the top and bottom CRPs is used to meet different needs.

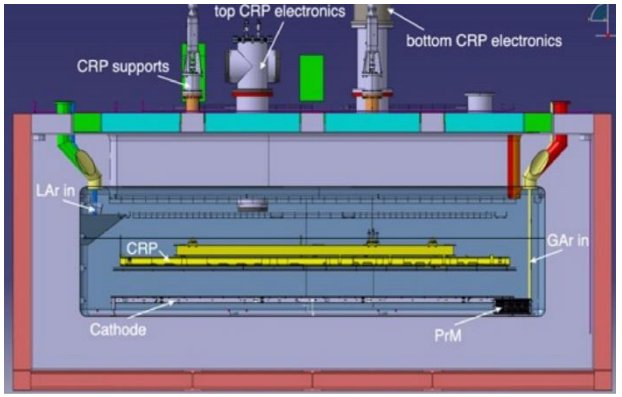


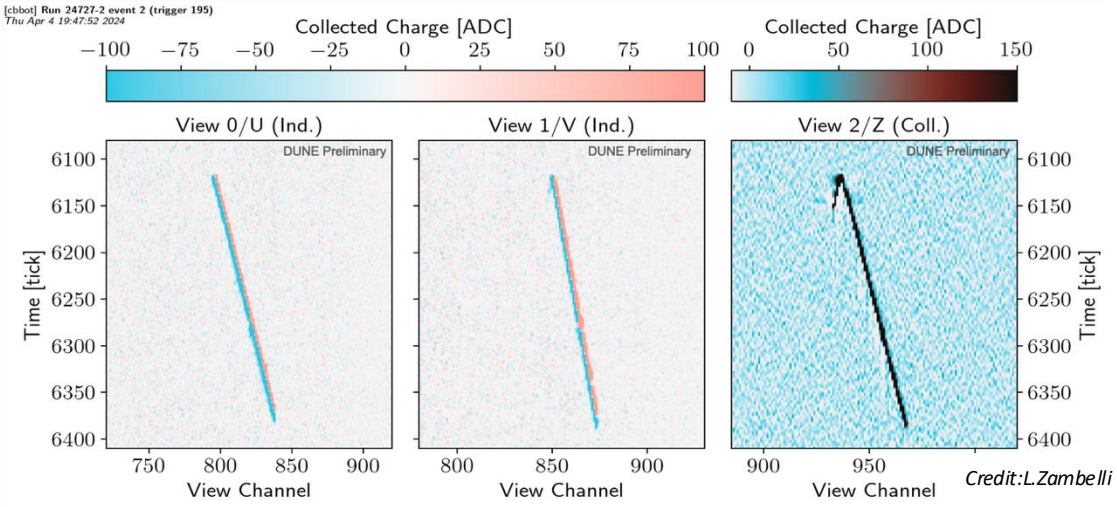
A fully assembled CRP module

Neutrino PLATFORM Indiana University DUNE

Full-Scale LarTPC CRP Cold-Box Testing

Since 2021, the cold box at CERN has been an essential tool for the development, testing, characterization, and validation of CRP and photon detector systems(PDs). A cathode placed on the floor provides a 23 cm drift distance.



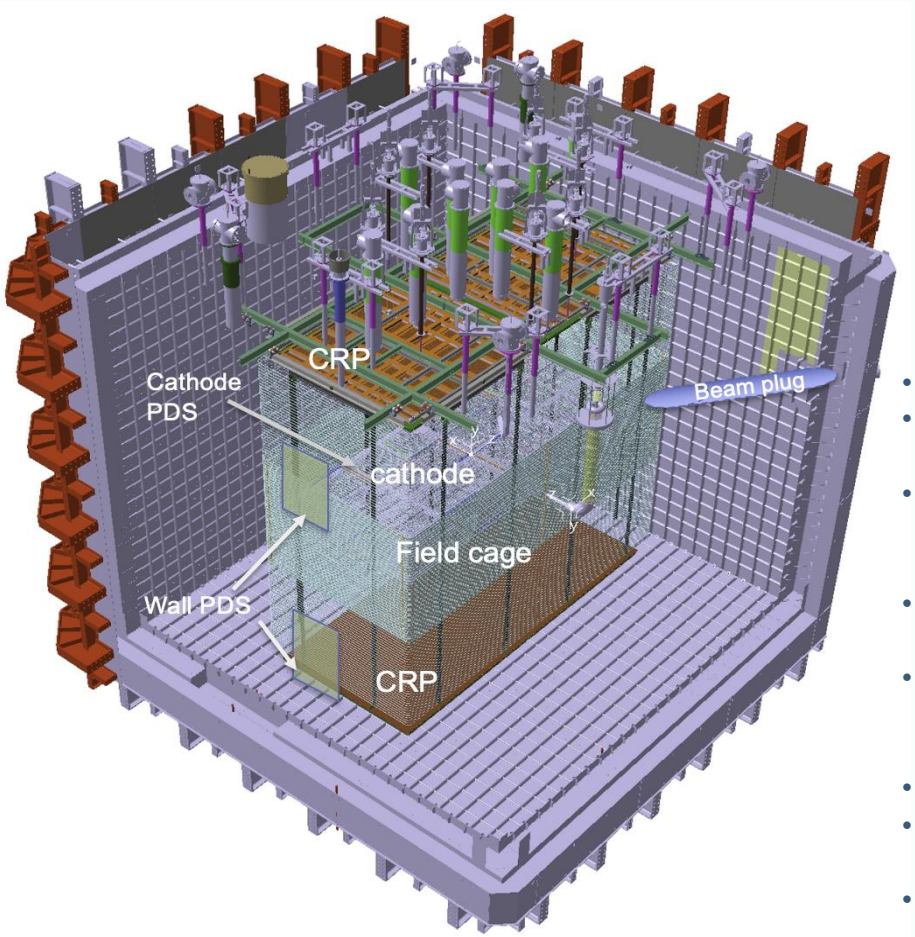


=> The cold box size and cryogenic system allow TPC-mode operation in liquid argon with full-scale VD components, including the CRP, PDs, and cathode.

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

Neutrino PLATFORM Indiana University DUNE

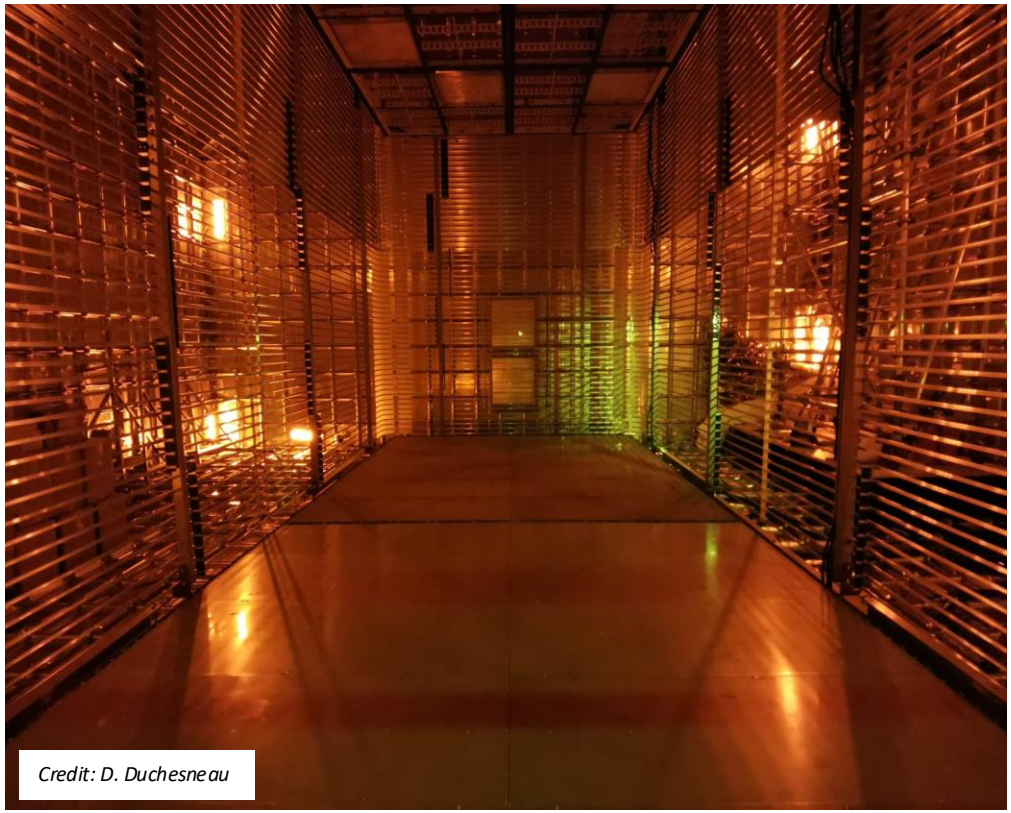
ProtoDUNE-VD: Vertical Drift Prototype at CERN

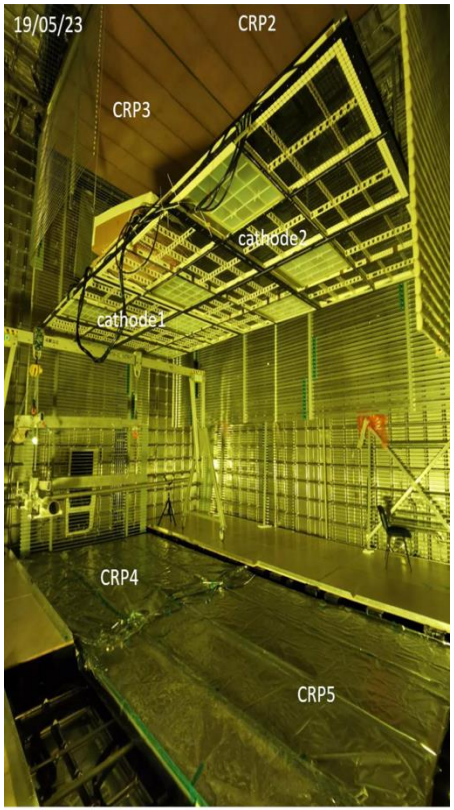


NP02 cryostat at CERN

- **2 Top CRPs**
- 2 cathode modules in the middle **hanging from the top CRP supports**
- Field cage (FC) modules hanging independently from the DSS; 70% transparent at the level of the Photon detectors on the cryostat membrane
- **2 bottom CRPs**
- ~3.4 m long drift, 300 kV capable HV system (tested in ProtoDUNE-DP)
- 8 PD modules on the Cathode (double-sided)
- 8 PD modules on the cryostat wall (single-sided)
- Beam plug -4.3m long
- PMTs on the cryostat floor
- Instrumentation: PrM, IoL, T sens, CRTs, level meters, cameras, lights

ProtoDUNE-VD: Vertical Drift Prototype at CERN





Credit: CERN

- ✓ The Top and Bottom CRPs were successfully installed in 2023.
- ✓ The detector construction opening (TCO) was closed at the end of 2024.
- ✓ The cryostat was filled with liquid argon (LAr) in early 2025.
- ✓ Commissioning is currently ongoing.
- ✓ Beam operation will start soon.

Neutrino PLATFORM Indiana University DUNE

Summary

- The **VD CRP** concept has been successfully developed, validated, and scaled since 2021.
- Full anode assemblies were produced using **PCB segments**, precision alignment, and robust mechanical structures.
- The **ProtoDUNE-VD detector** has been fully assembled, the cryostat was filled with LAr, and commissioning is ongoing.
- ProtoDUNE VD detector operation should start soon, marking a significant milestone toward DUNE FD-VD.
- The CRP system is ready for complete implementation in the DUNE experiment.

Thank you for your attention!