DUNE Vertical Drift LArTPC Design

Laura Zambelli (LAPP)

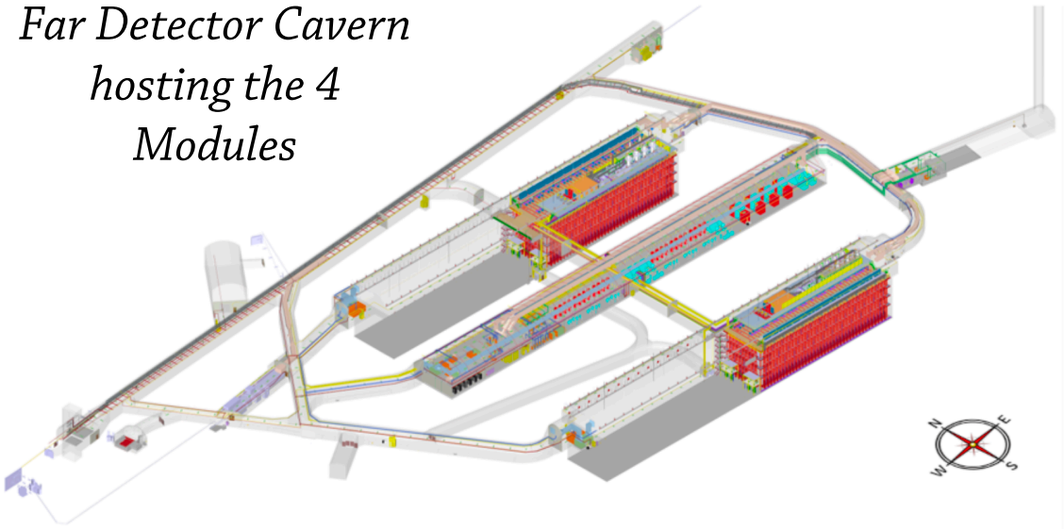
IRN Neutrino - June 2023 - Nantes

Deep Underground Neutrino Experiment

DUNE is the US-based next generation of Long Baseline Experiment

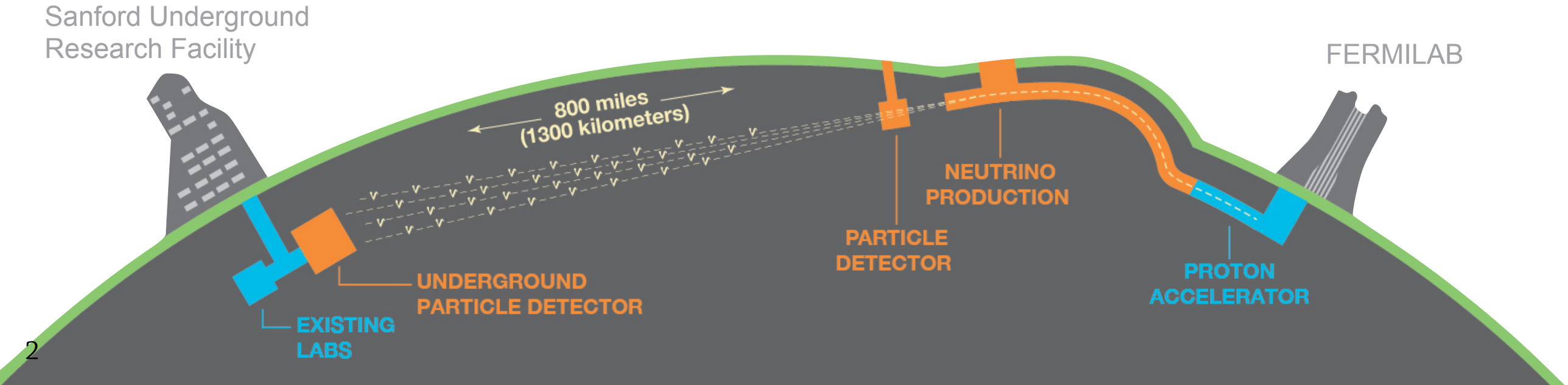
- 1300 km between FERMILAB (*beam, near detectors*) and SURF (*far detector*)

Far Detector Cavern hosting the 4 Modules



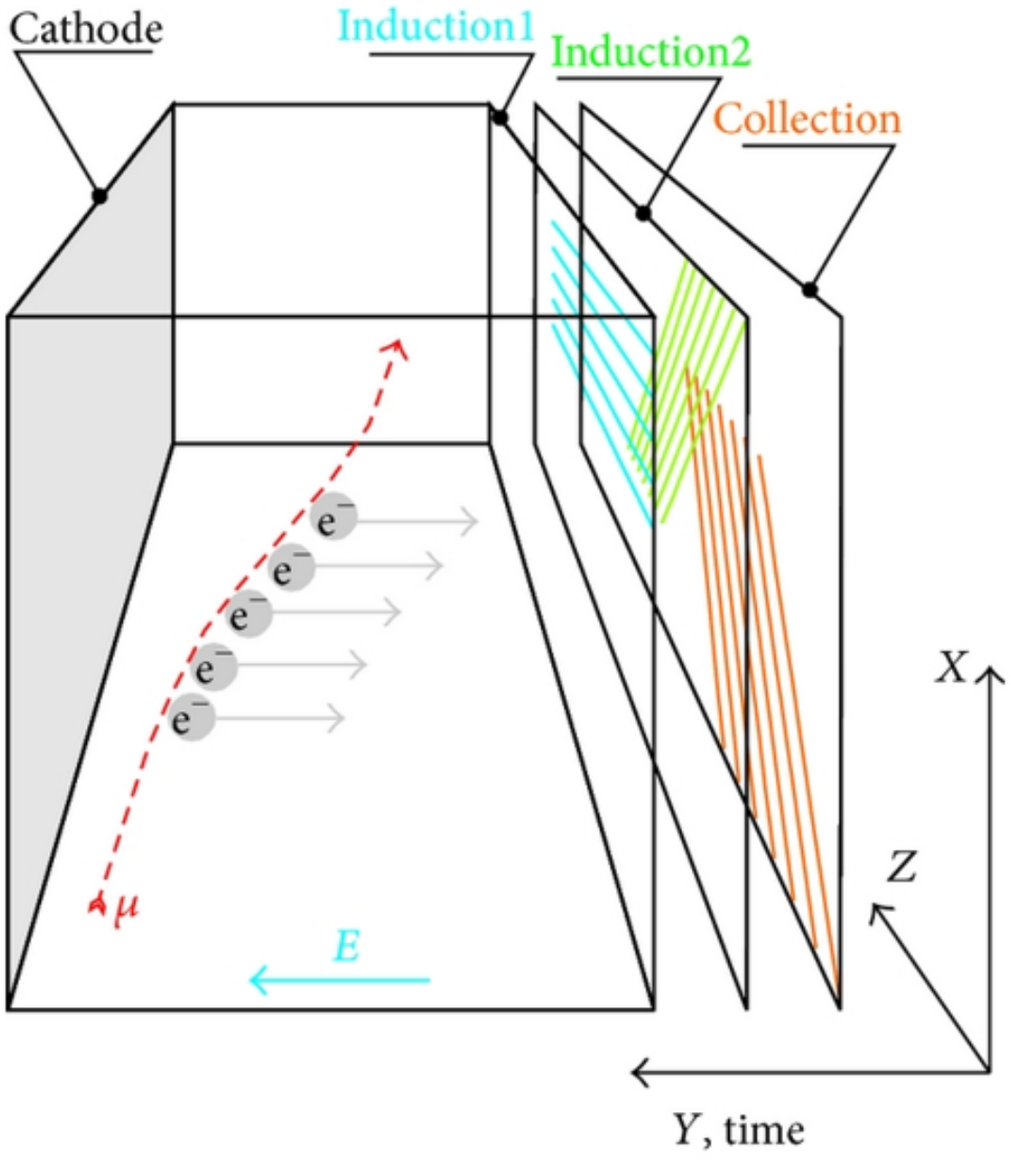
The Far Detector is made of 4 giant LArTPC modules

- Each module has~17 kt of LAr
- About 60 m × 12 m × 12 m of active volume
- FD cavern is 1.5 km underground
- Four module -> Four possible designs:
  - Module-1 : Horizontal Drift design
  - Module-2 : Vertical Drift design
  - Module 3-4 : Under discussion



Horizontal Drift LArTPC design

Formerly called the ‘Single-Phase’ LArTPC design



Charged tracks ionizes and excites the Argon

An electric field attracts the e^- to the Anode Plane

- Drift field of 500 V/cm, v ~ 1.6 mm/μs

The Anode is made of 3 wire planes or ‘views’

- Each plane has a different wire orientation
- e^- cloud induce a signal on the first 2 plane
- Last plane collects the electrons

The 3 views allows a 2D reconstruction of the event

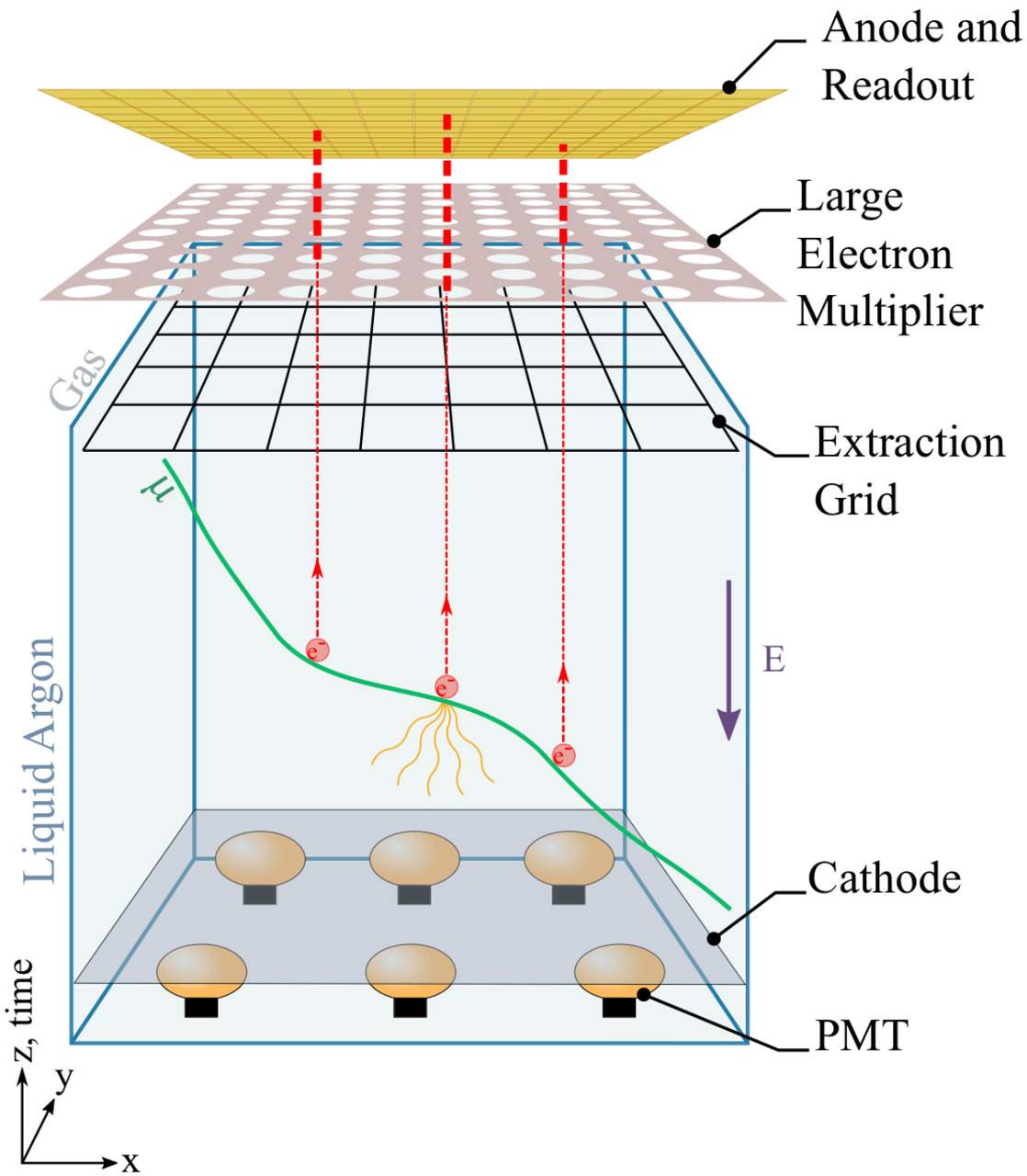
The time brings the 3rd dimension

The Horizontal Drift or Single-Phase LArTPC design has been extensively tested at large scale (ICARUS, MicroBoone, ProtoDUNE-SP, …)

Dual Phase LArTPC design

In the Dual phase design, a thin gaseous layer allows charge amplification before collection

↳ Amplification by Townsend avalanche in the LEM (drilled PCB with ~3 kV bias over 1mm)



The DP technology has been extensively tested at various scale in last decade, and was considered for Module-2

2019~2021 : Operation of ProtoDUNE-DP

↳ 300 t (6×6×6 m^3) LAr detector at CERN

Operation successes:

- Good purity of LAr achieved
- Drift field of 500 V/cm over 6m

Operation issues:

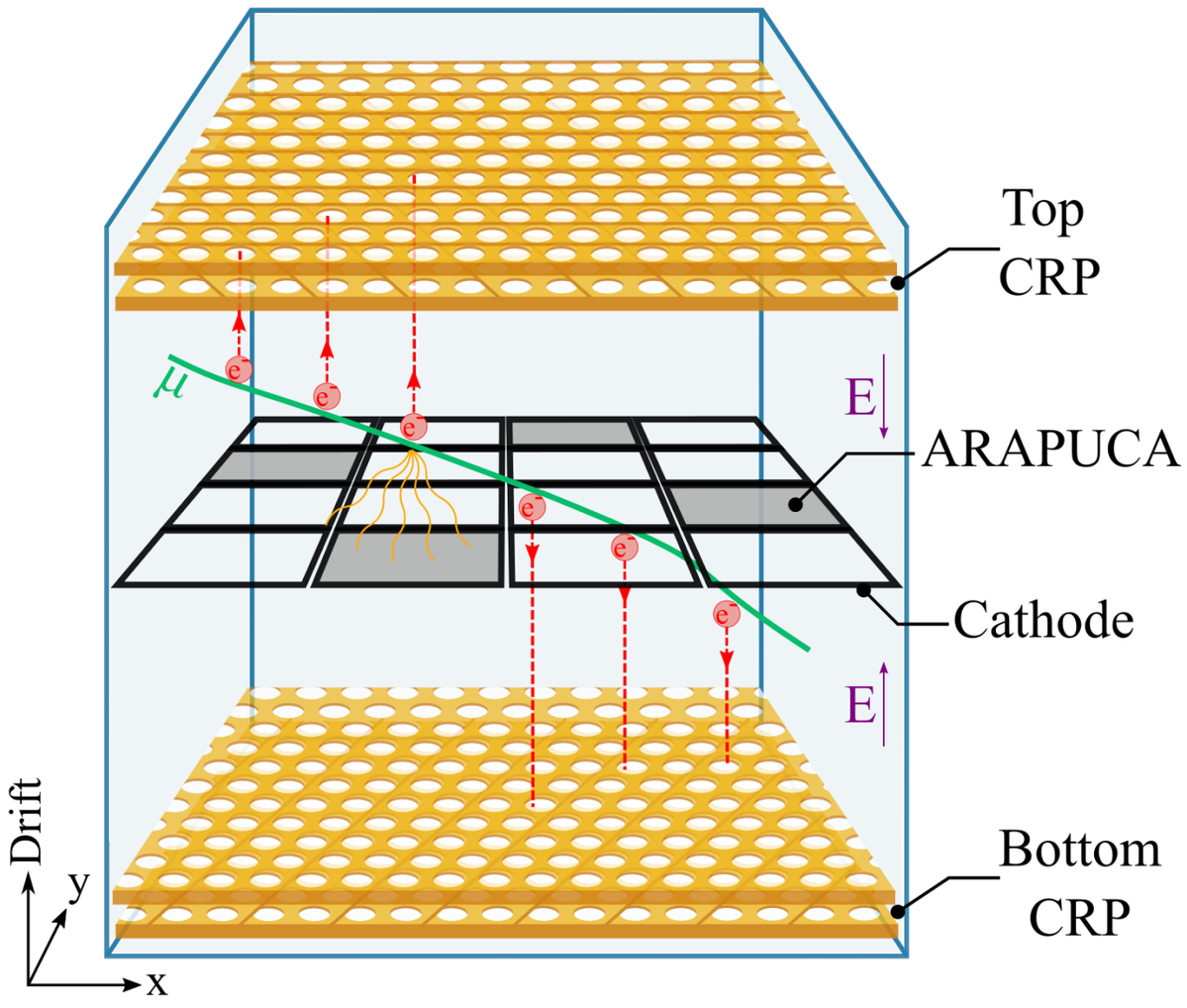
- Stability of the LAr/GAr interface
- Stability of the LEM

→ ***An extensive R&D on the LEM would be needed to meet DUNE requirements***

Vertical Drift LArTPC design

In late 2020, it has been decided to simplify the DP design towards the ‘Vertical Drift’

- No more gaseous layer nor signal amplification : single-phase type
- Detector split into two drift volumes : ‘top’ and ‘bottom’
  - Cathode suspended in the center



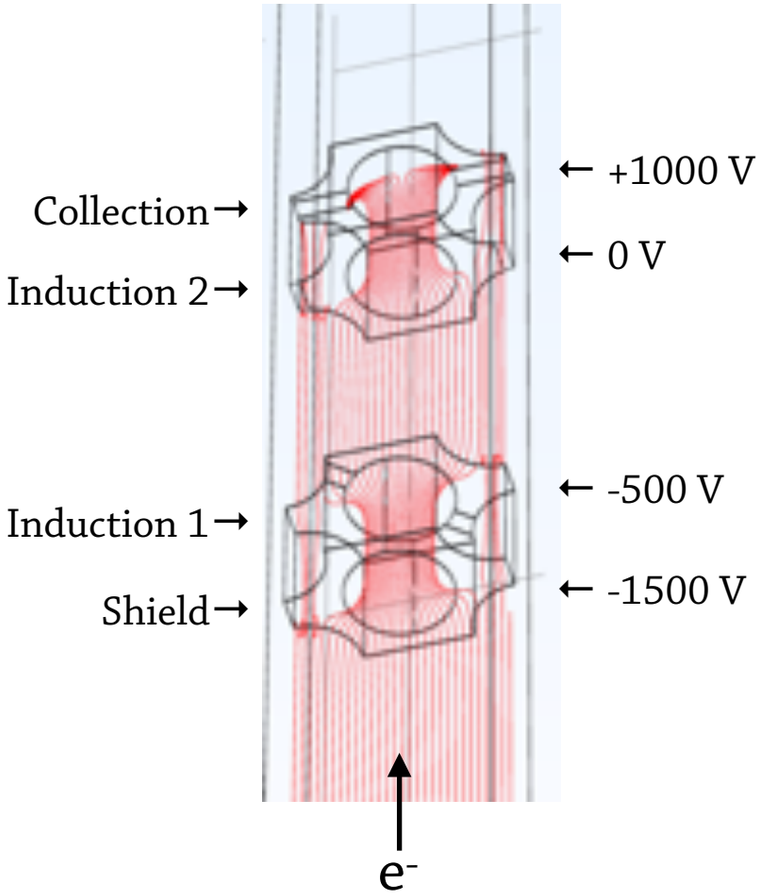
The Charge Readout Plane (CRP) reads the e- signal:

- Made of a stack of 2 drilled PCBs
- Each PCB plane has an etched copper layer
  - Electrons signal seen by induction and collection
- Top and Bottom CRP are equipped with different electronics :
  - Top: Accessible front-end, from DP design
  - Bottom: Embedded front-end, from SP/HD design

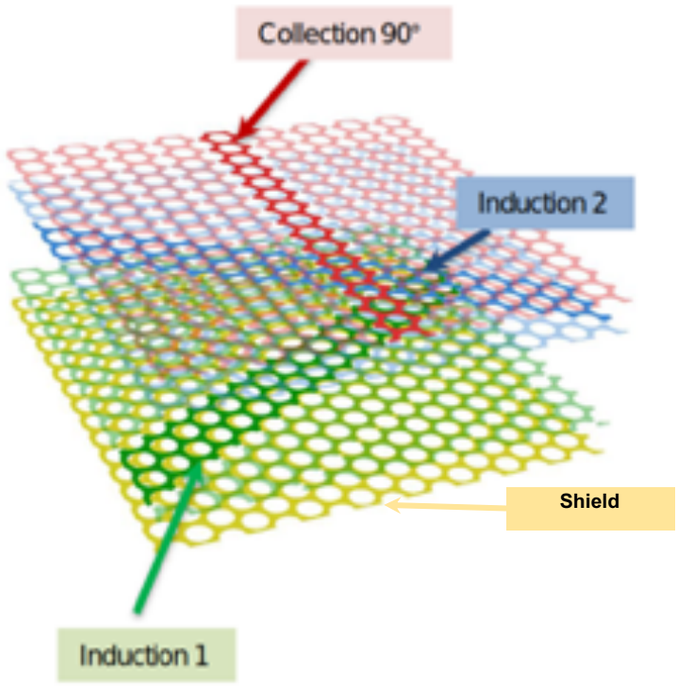
The light signal is read by the ARAPUCA:

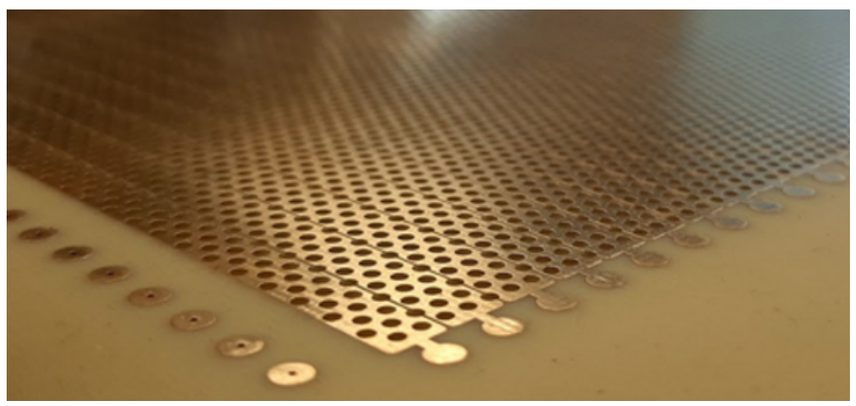
- See Henrique’s talk !

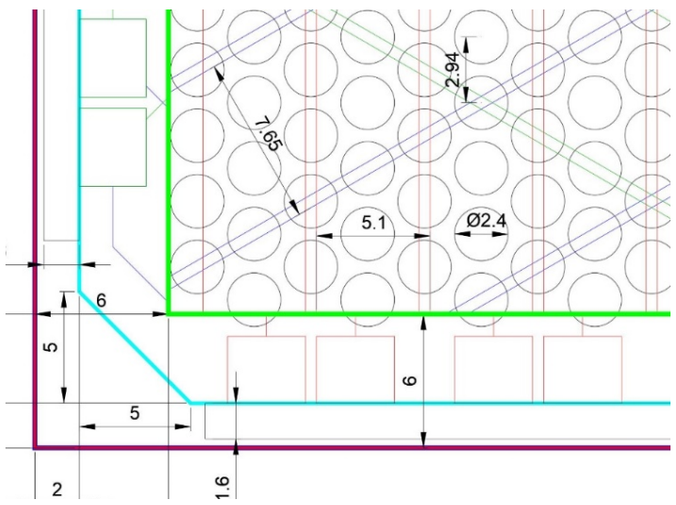
Signal Generation in VD



- Each PCB face has a bias to attract the electrons through the holes towards the upmost plane
- One shield plane facing the active volume (no etching)
- The other 3 planes, or view, have different etching, or strip, orientation
- Electrons leave an induced signal on the first two views, and are collected on the last view
- Induction views : 952 strips of 7.65 mm wide/CRP
  Collection View : 1168 strips of 5.1 mm / CRP



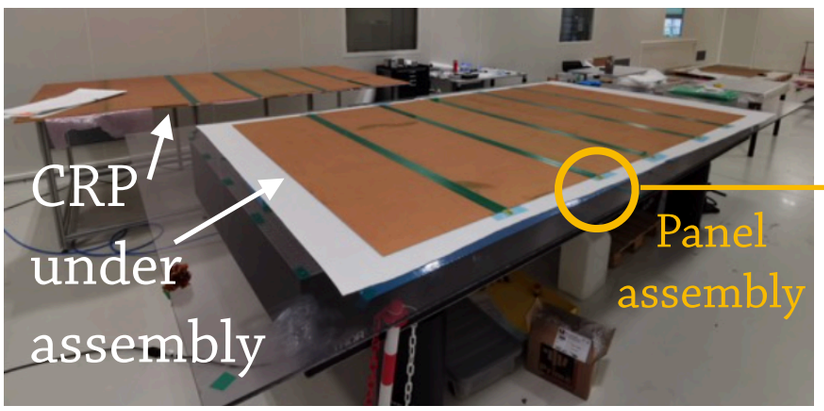


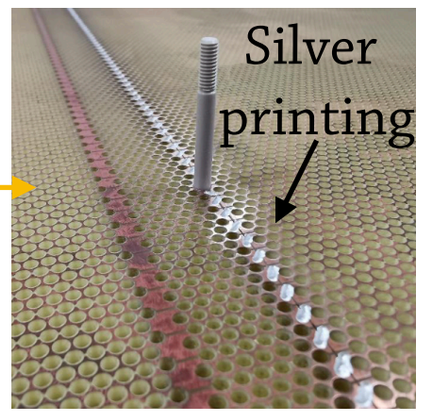


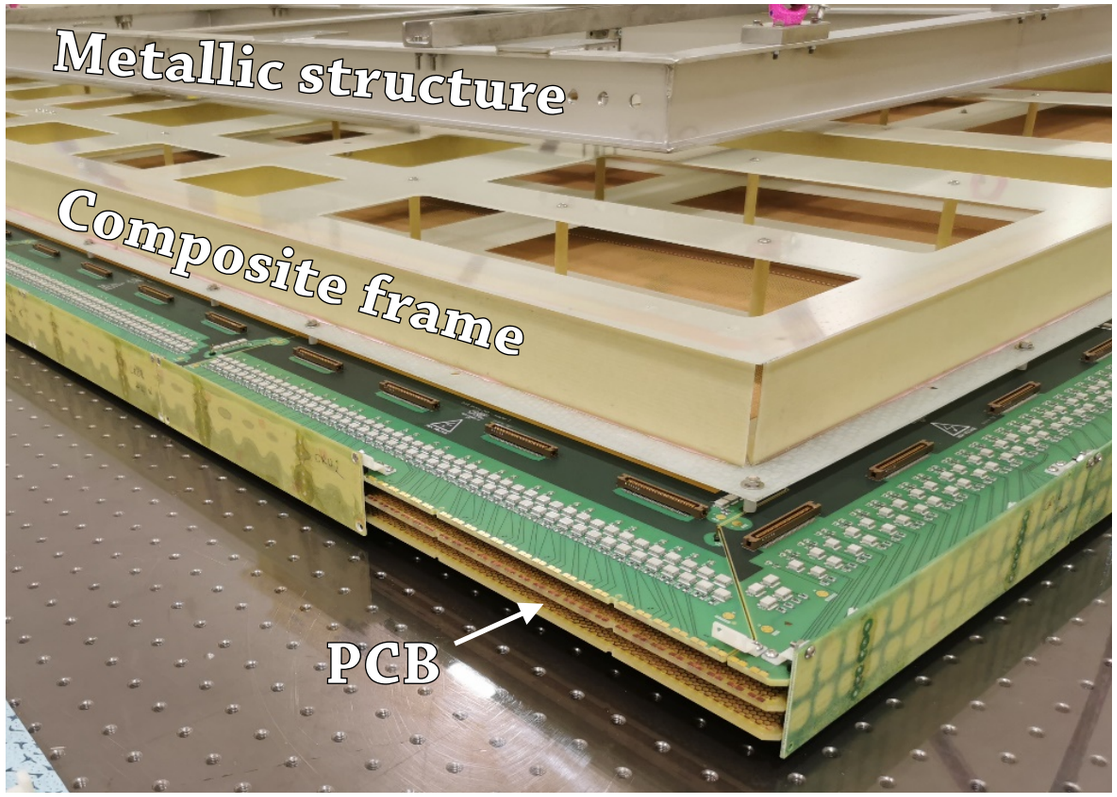
Charge Readout Plane (CRP)

CRP characteristics:

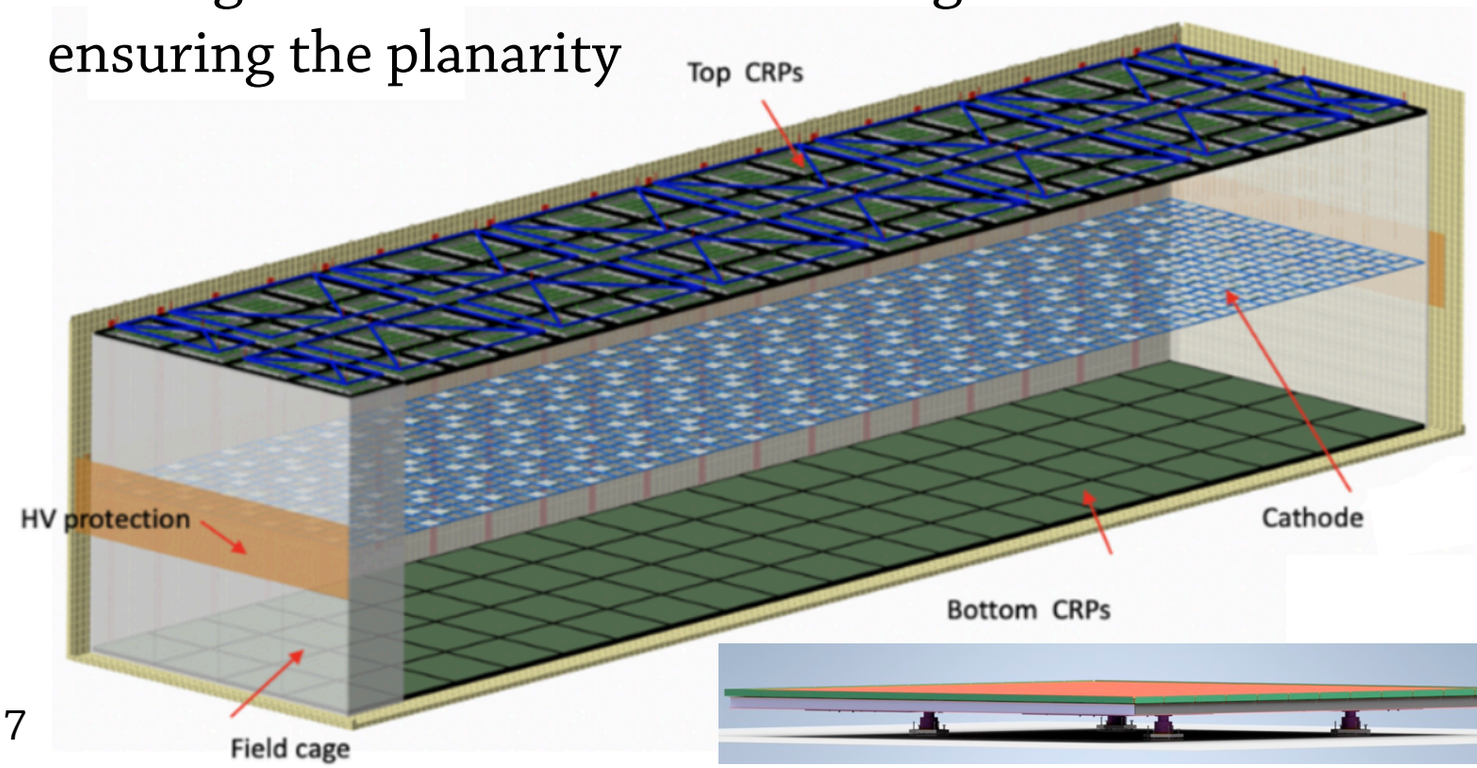
- Module of 3 × 3.4 m²
- Assembly of 2×6 panels/PCB
  - ↳Electrical strip continuity by silver printing







- The composite frame is the mechanical structure holding the PCB and electronics together while ensuring the planarity



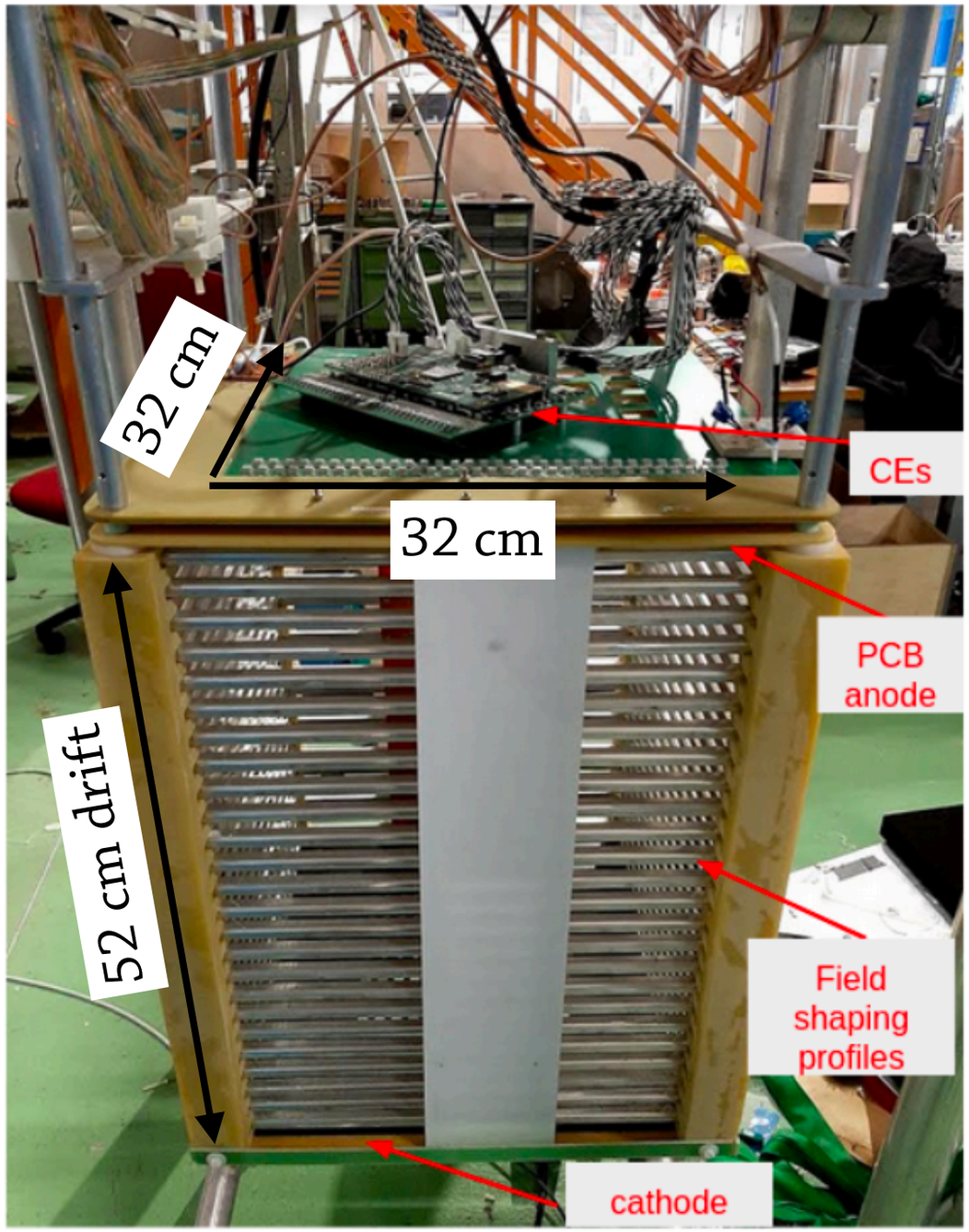
The far detector will have 160 CRPs:

- 80 suspended at the top
- 80 at the bottom, resting on the cryostat floor

And 80 cathode unit suspended from the top CRP

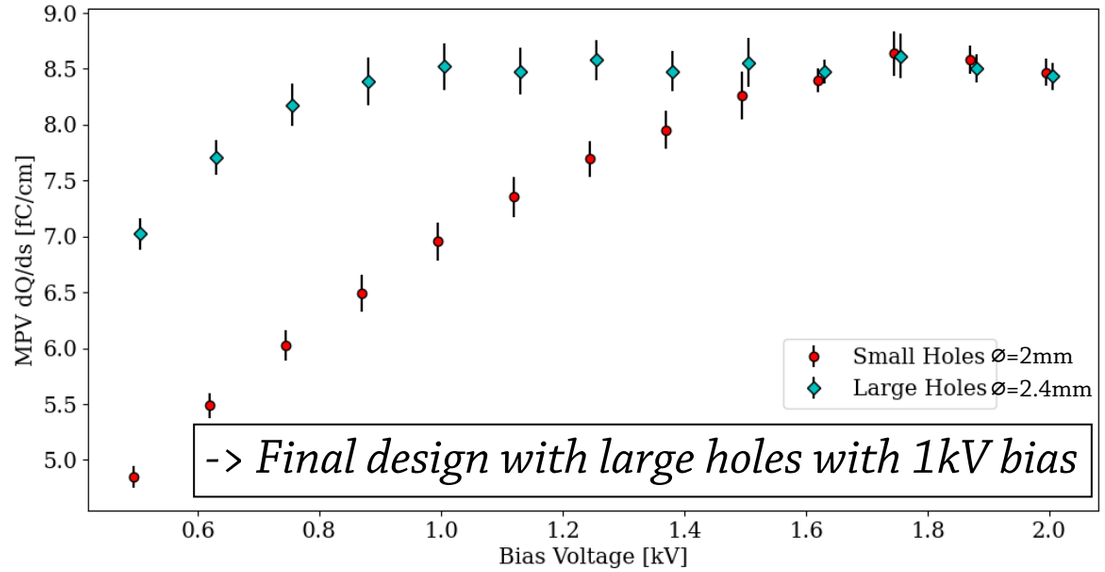
The total VD Far Detector active volume is 62 m × 15 m × 14 m

VD R&D at CERN



Small-scale tests of the Vertical Drift design has been conducted at CERN in the 50L setup
-> Cosmic and ^{207}Bi data taken for studies on the PCB design and layout

Data taking campaigns :
2020: 2 views PCB anode, Impact of PCB hole size and PCB bias on the collection efficiency:

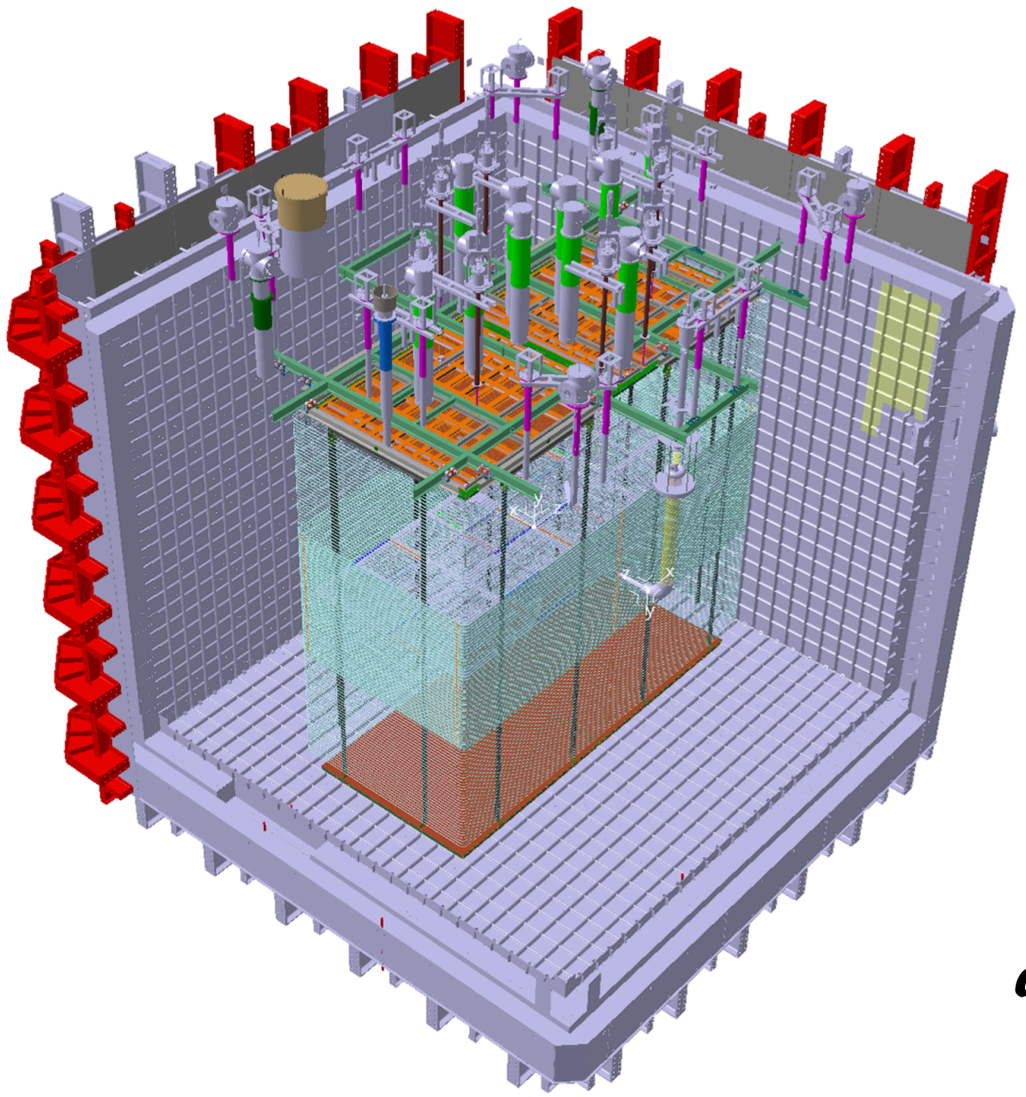


2021: 3 views PCB anode with {0°, 48°, 90°} orientations
2022: 3 views PCB anode with {±30°, 90°} orientations
2023-> Test of alternative PCB panel connection and dedicated studies of the CRP transparency (ongoing)

ProtoDUNE-VD: ‘Module-0’

Large-scale test of the Vertical Drift design in the NP02 cryostat in the Neutrino Platform at CERN

Installation is ongoing ; cosmic and test-beam data foreseen in 2024



Characteristics of ProtoDUNE-VD:

- Active volume : 3 × 6.8 × 7 m^3
- 4 CRPs : 2 top + 2 bottom
  - ↳ {±30°, 90°} strip orientation
- Cathode hanged in the center, 2×3.5 m of drift
  - ↳V_{cath} = 175 kV for the nominal drift field of 0.5 kV/cm
- Arapuca on the cathode and on the field cage

Each CRP have been individually tested in a dedicated instrumented cryostat prior to their installation in ProtoDUNE-VD

Goals of Module-0:

- Integration test with final detector elements before starting massive production
- Validate as many procedures as possible from shipping to installation
- Validate tools, personnel needs and time required for each procedure

CRP tests in the VD-ColdBox

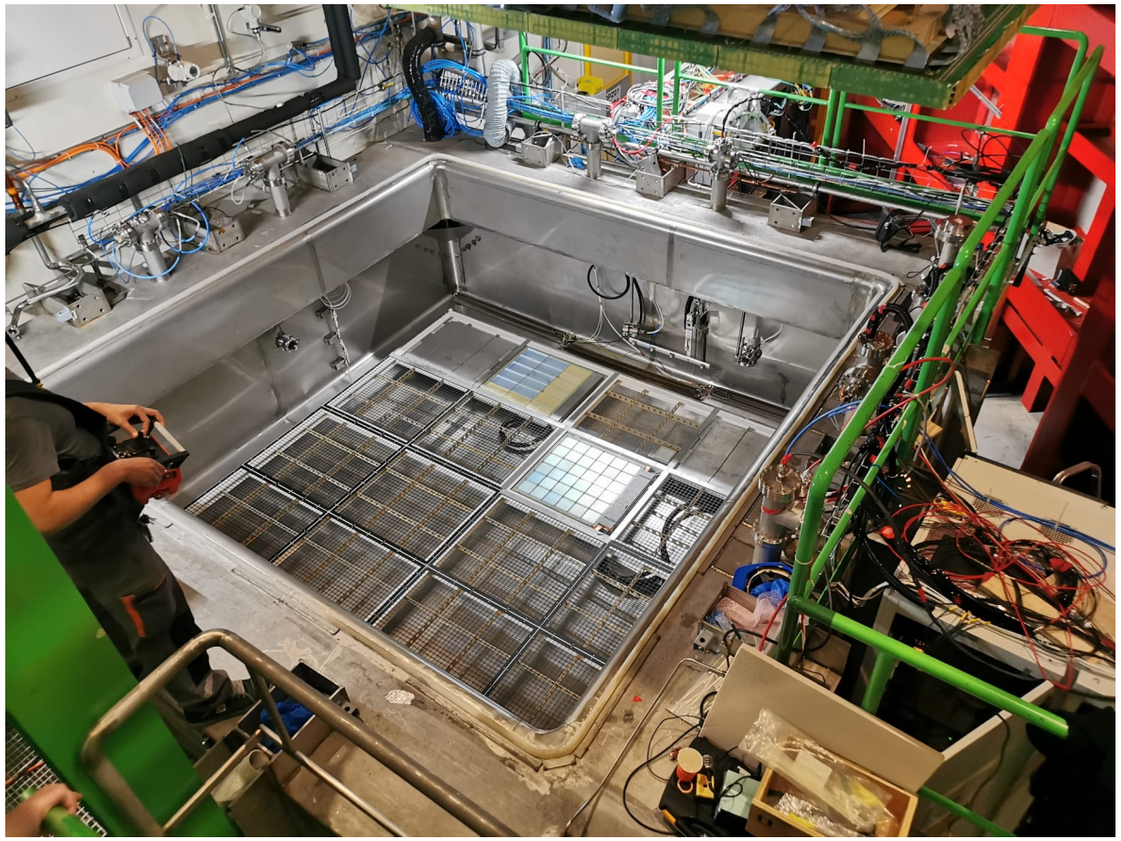
The testing cryostat is know as the Coldbox

-> Equipped with cryo-camera, slow control sensors, a cathode and light detection devices

-> The CRPs are hanged on the ColdBox roof

-> Both Top or Bottom electronics CRPs can be tested

The ColdBox is a small TPC collecting cosmic data with 23 cm of drift



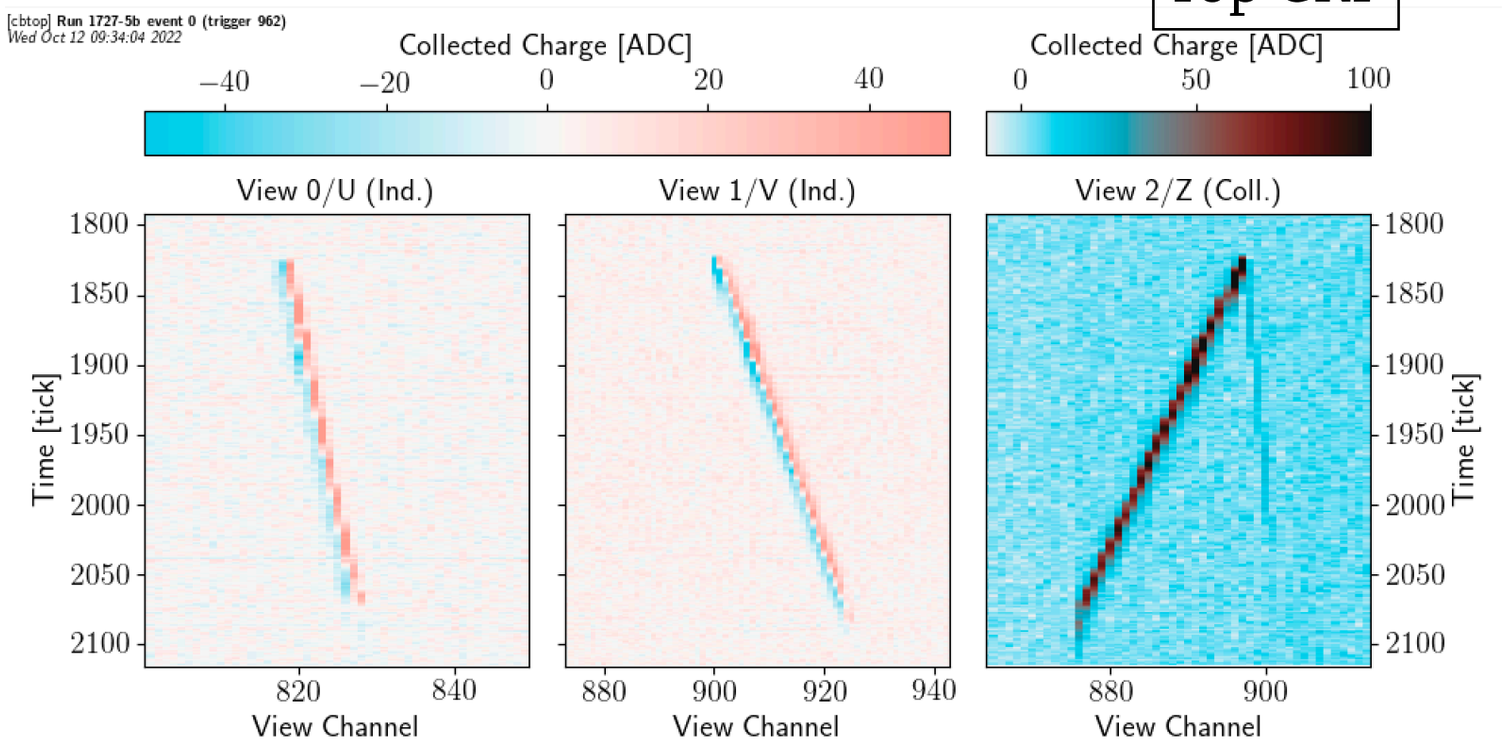
-> 5 CRPs tested from Nov'21 to May'23

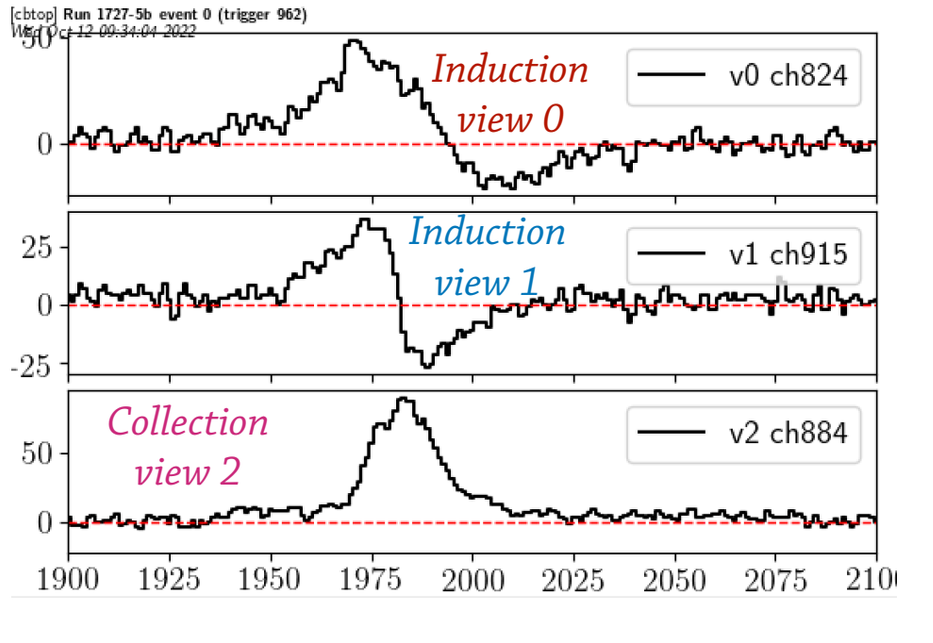
1 CRP in the {0°, 48°, 90°} strip orientation with both electronics mounted

The 4 CRPs of ProtoDUNE-VD (with {±30°, 90°} strip orientation)

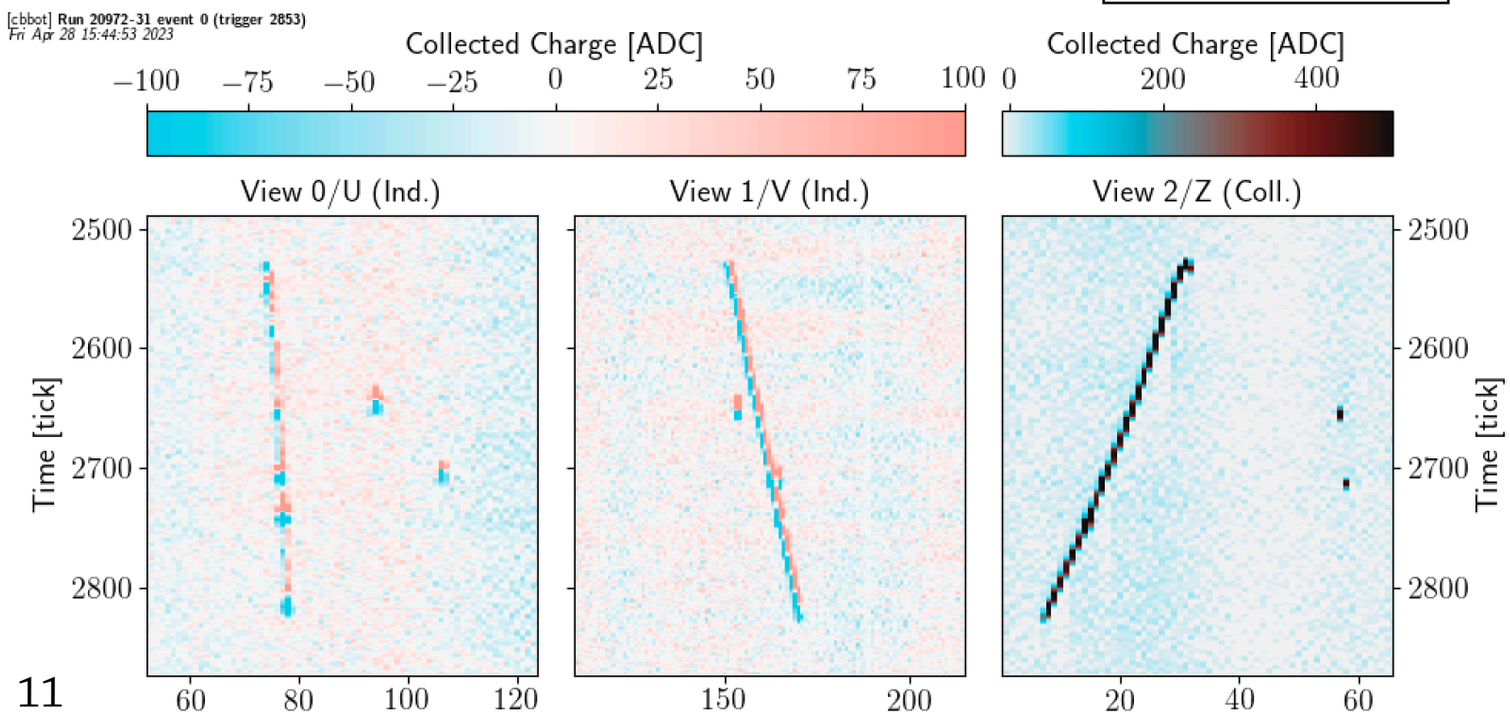
ColdBox Event Displays

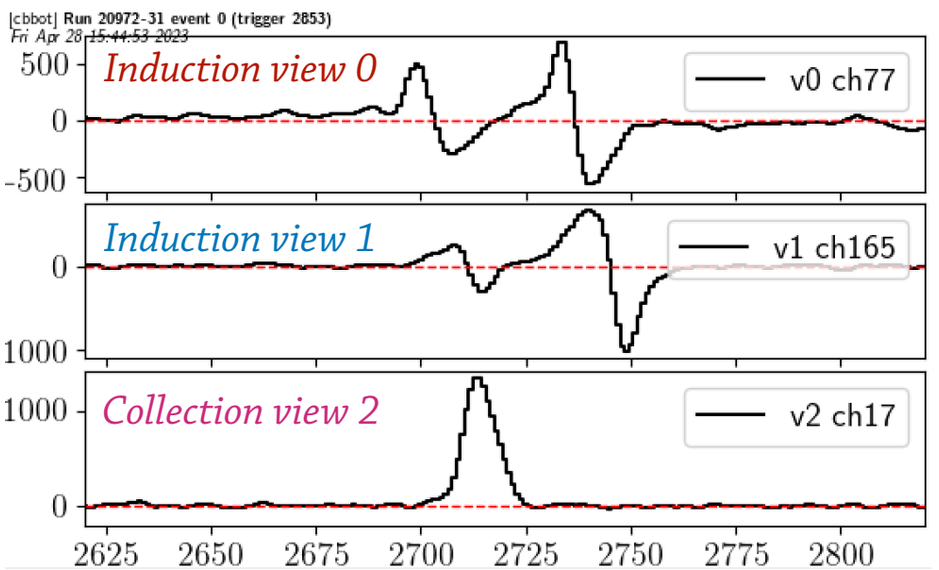
Top CRP





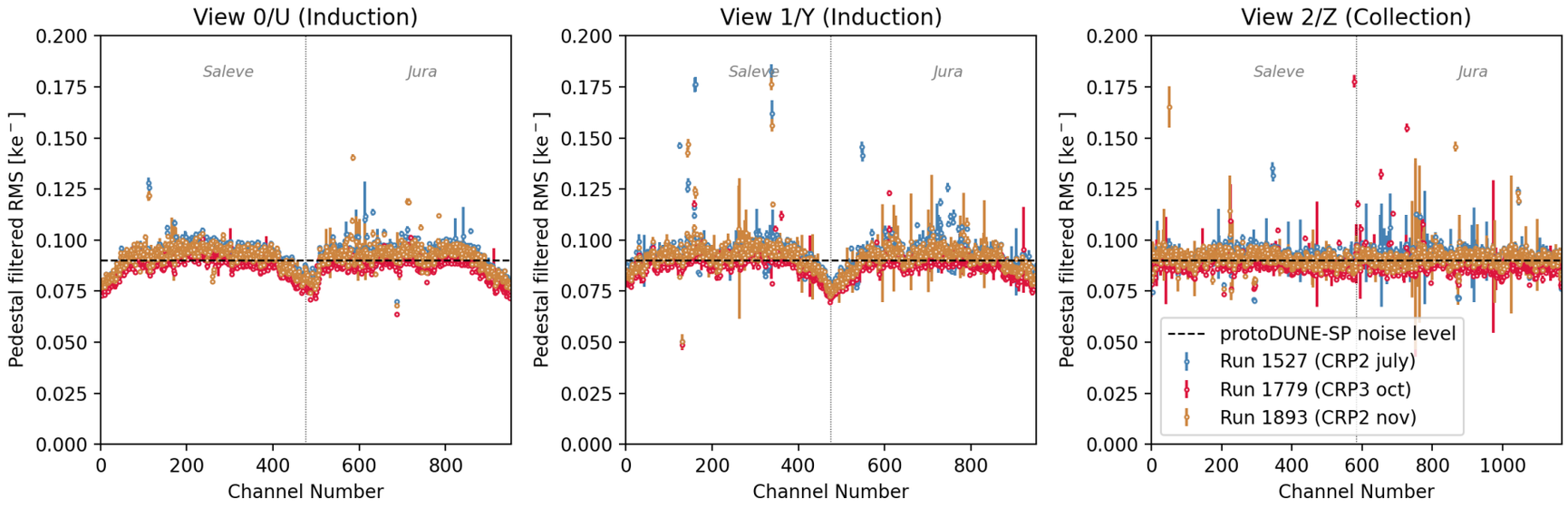
Bottom CRP



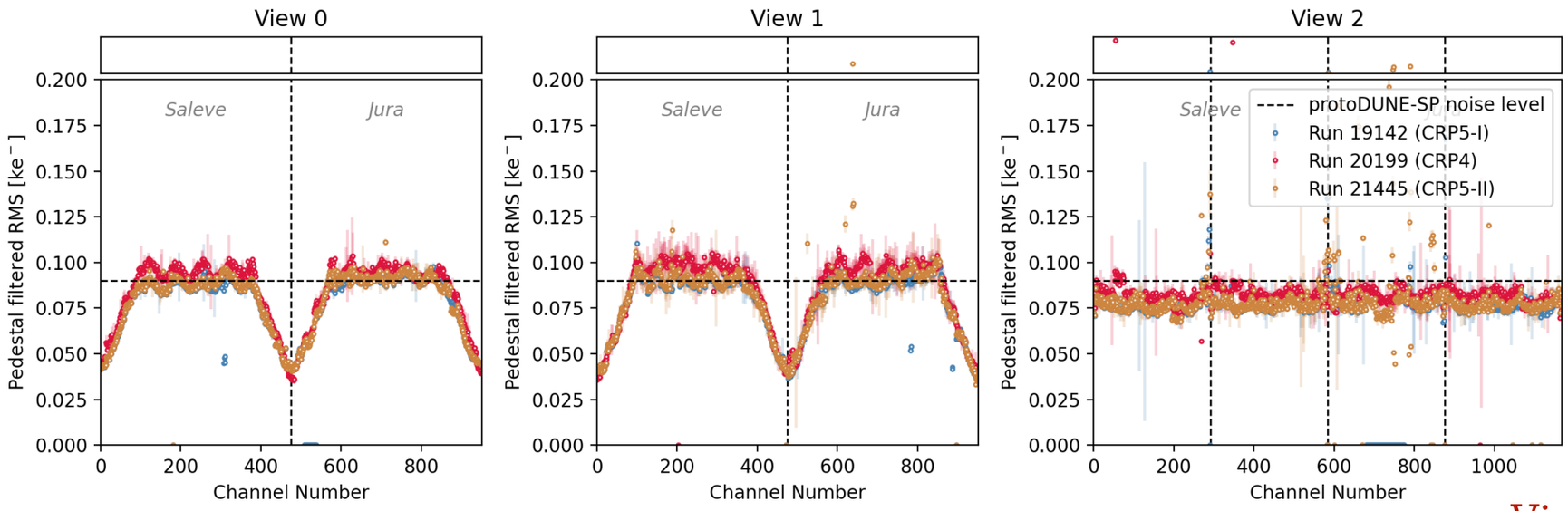


CRP Performances: Noise

Top CRP

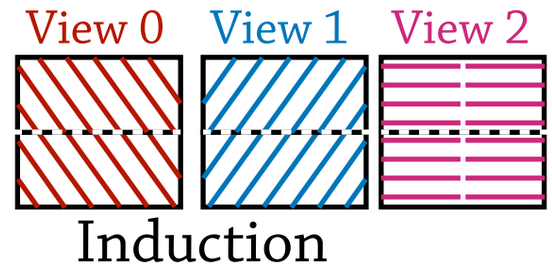


Bottom CRP



-> Bridge-shape due to the noise being proportional to the strip length

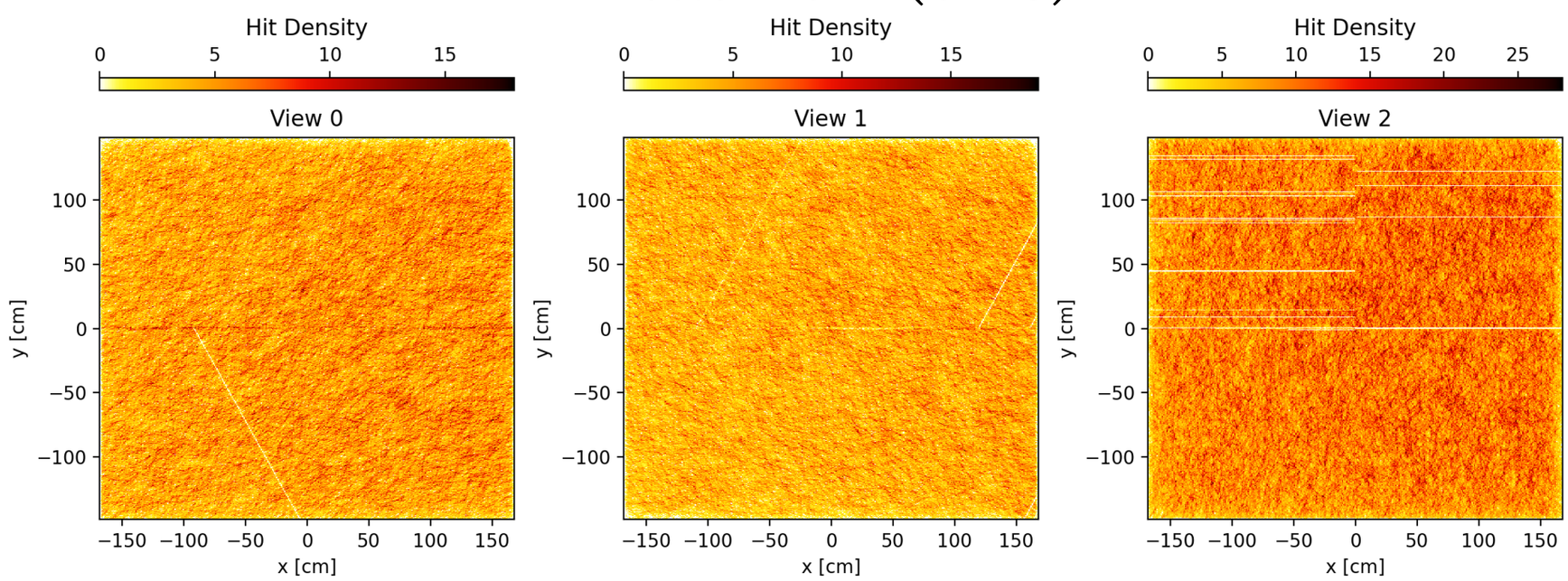
-> Equivalent amount of noise for Top and Bottom CRP, at the same level of protoDUNE-SP



CRP Performances: Uniformity

Top CRP (CRP3)

Bottom CRP (CRP5)

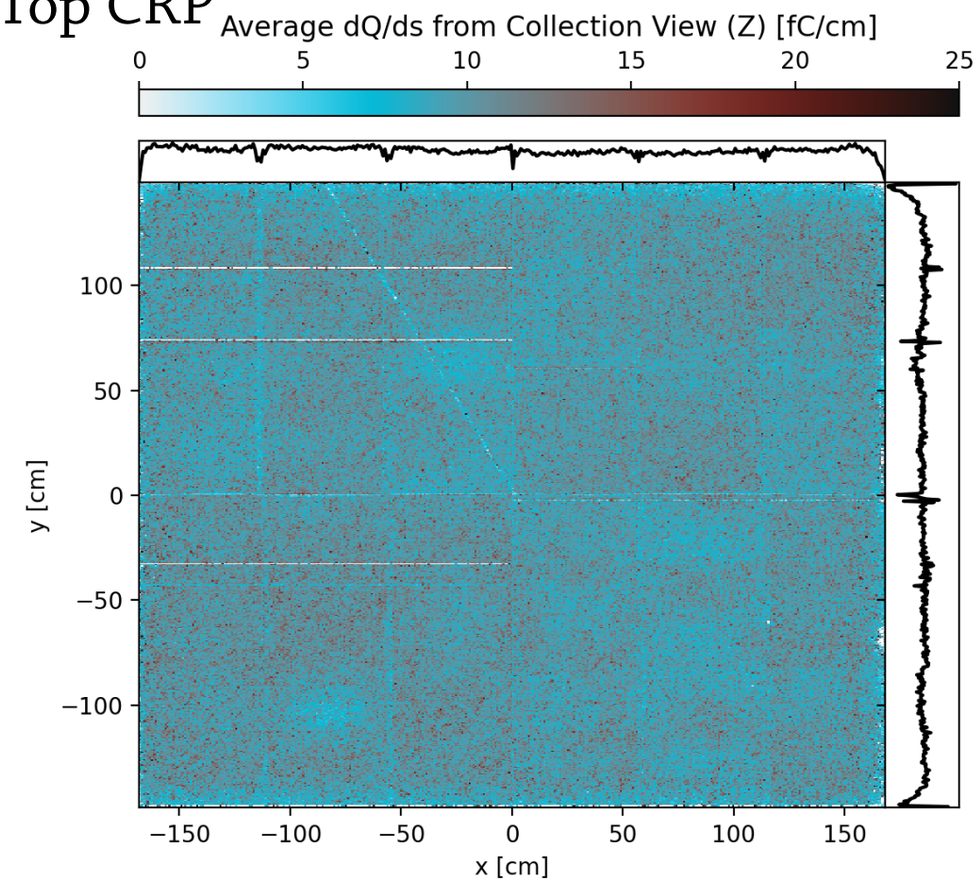


3D reconstruction of muon-like tracks allows to map the problematic channels of each view

-> Less than 1% of the channels are found problematic (out of 3072 channels/CRP)

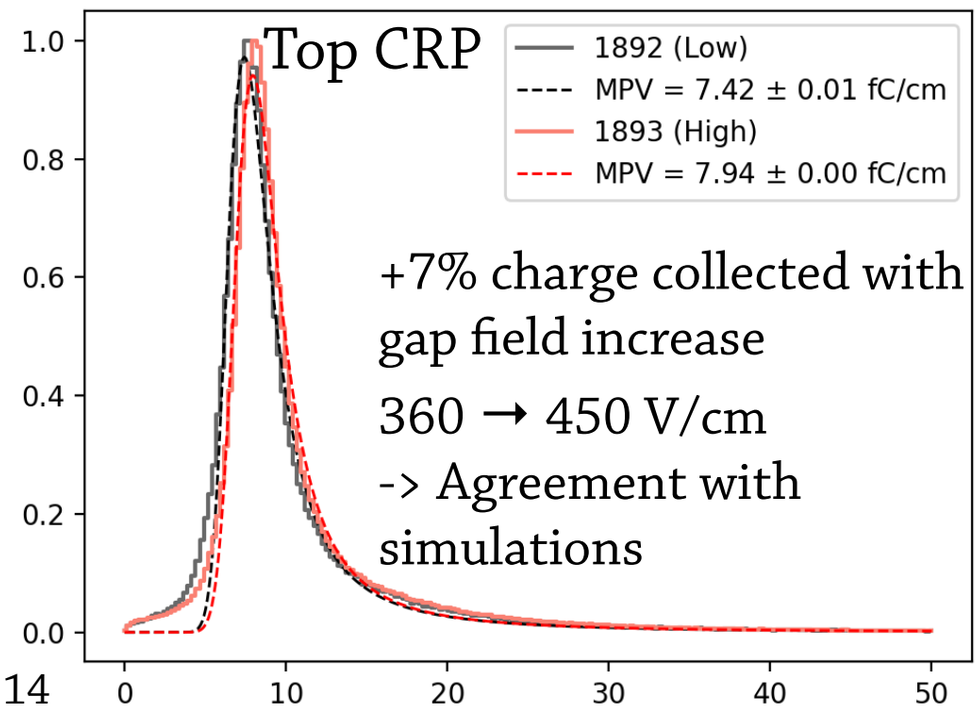
CRP Performances: Calorimetry

Top CRP



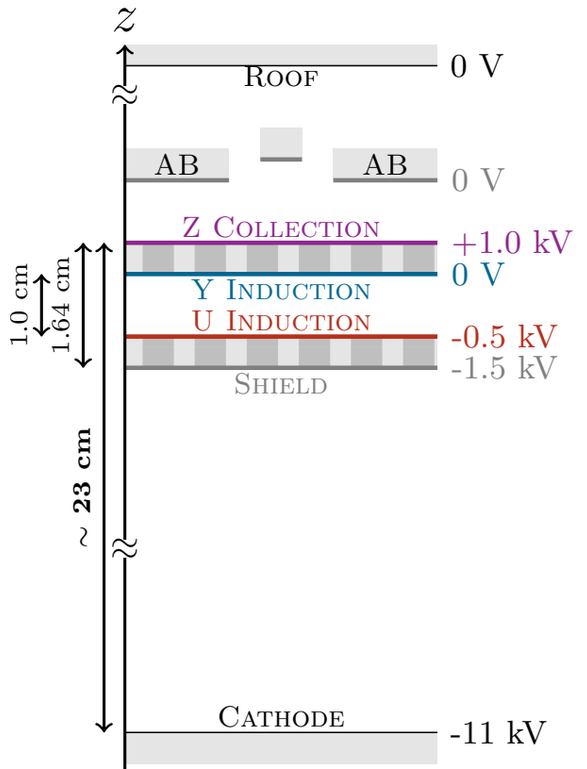
Average charge collected from muon-like tracks shows a good uniform response across the CRP surface

-> Vertical bands correspond to the PCB panels junctions



-> Understand the CRP transparency as a function of the bias and the gap field (in between the two PCB)

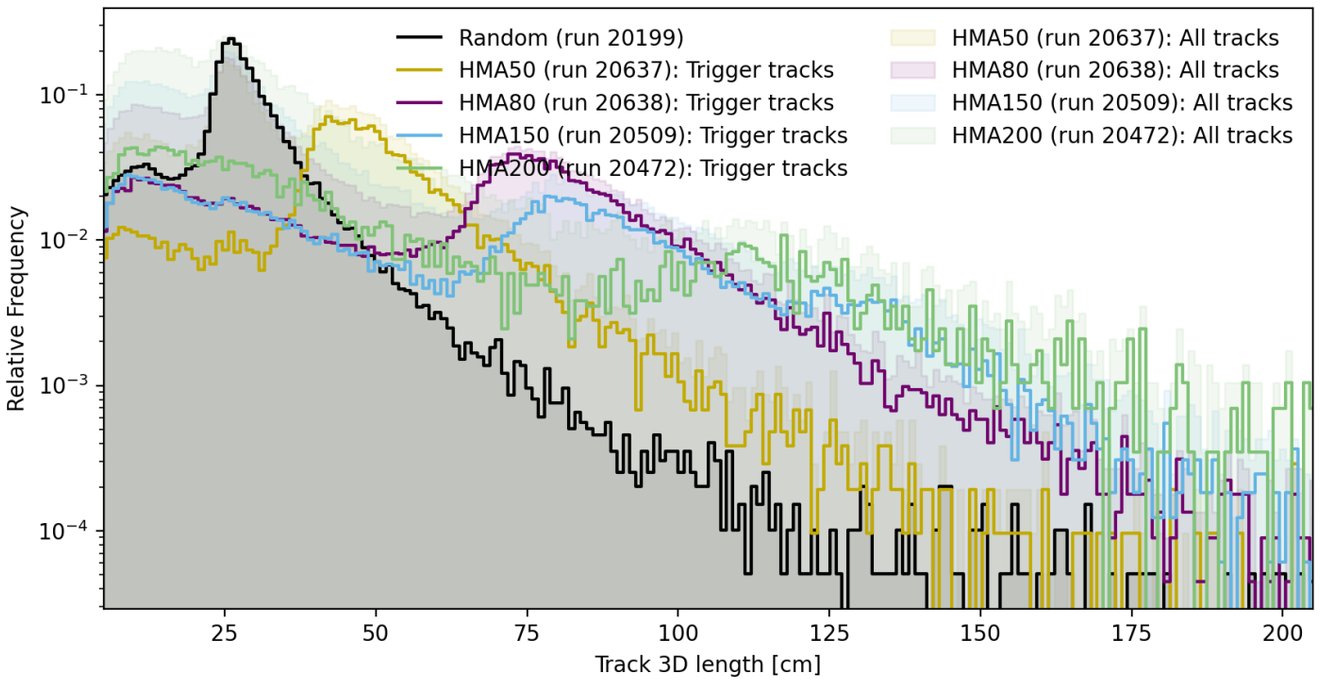
-> Further test foreseen with the ongoing 50L data taking

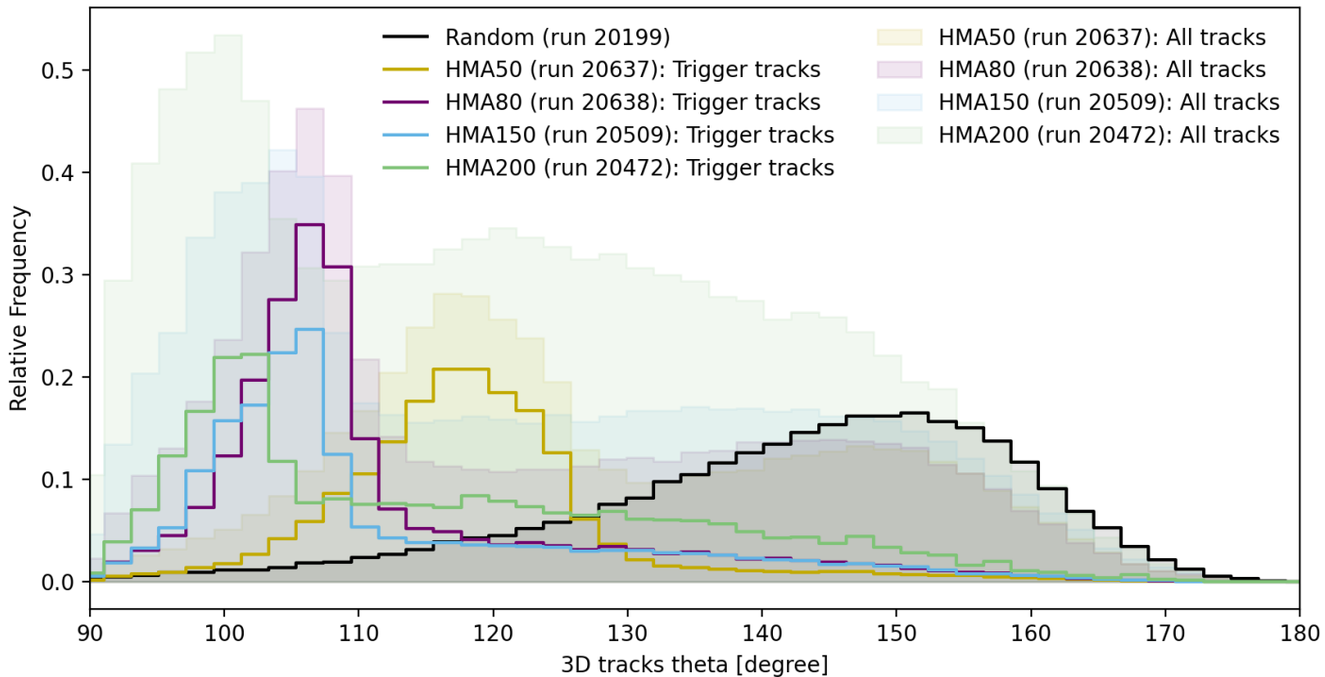


Nominal HV settings

CRP Performances: DAQ self-trigger

The DAQ system for DUNE can run in self trigger mode, where the event is continuously streamed to search for specific pattern.
In the ColdBox, the self-trigger system has been tested with the horizontal muon algorithm (HMA)





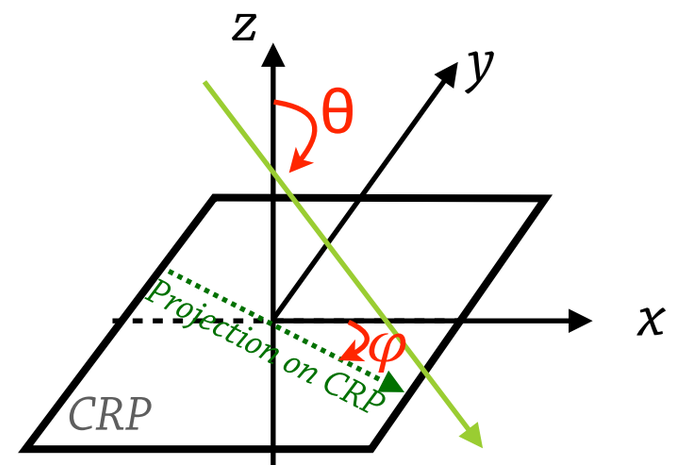
HMA××× searches for ××× adjacent hit in the collection plane

As the number of adjacent hit requirement increase, the triggered track are longer and more vertical, as expected.
The system work very well and could cope with a high trigger rate.
Other track pattern can be searched (e.g. michel electron, decay vertex, …)

<u>Angle definition :</u>

θ=90° : horizontal

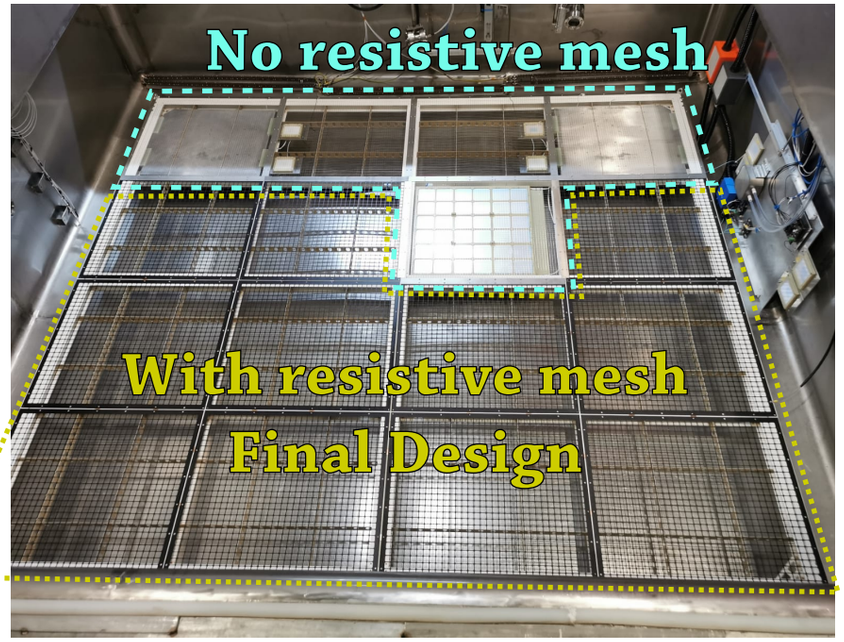
θ=180° : vertical

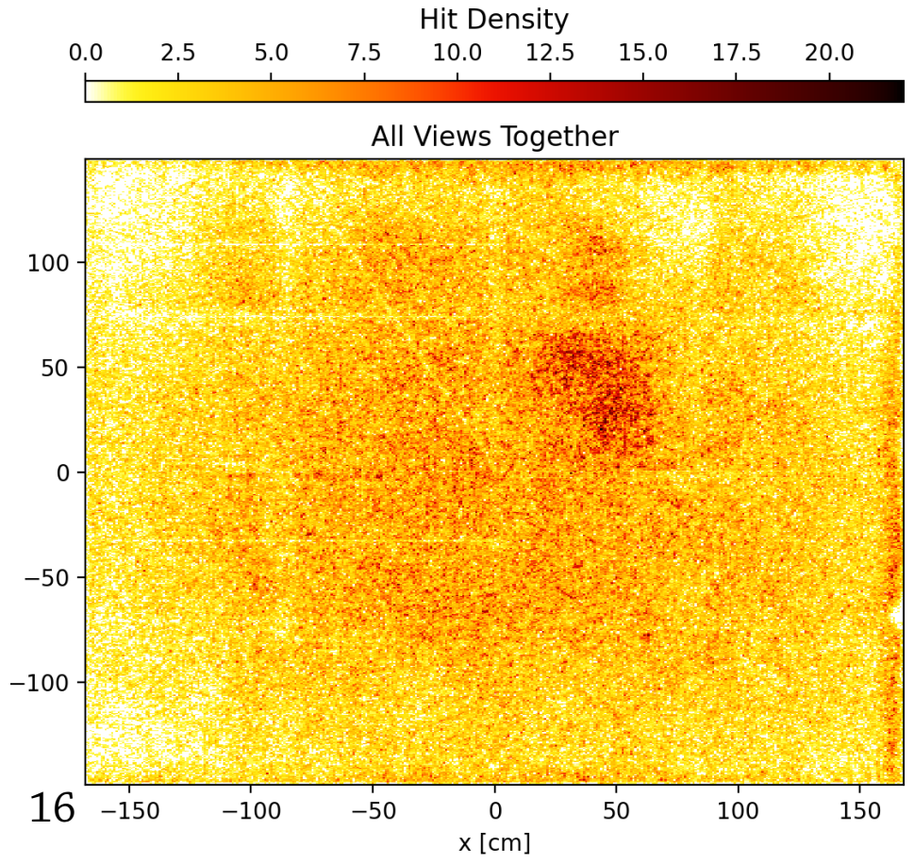


CRP Performances: Muon-scans

The cathode is made of a resistive mesh held in a FR4 structure (in stainless steel for the ColdBox)

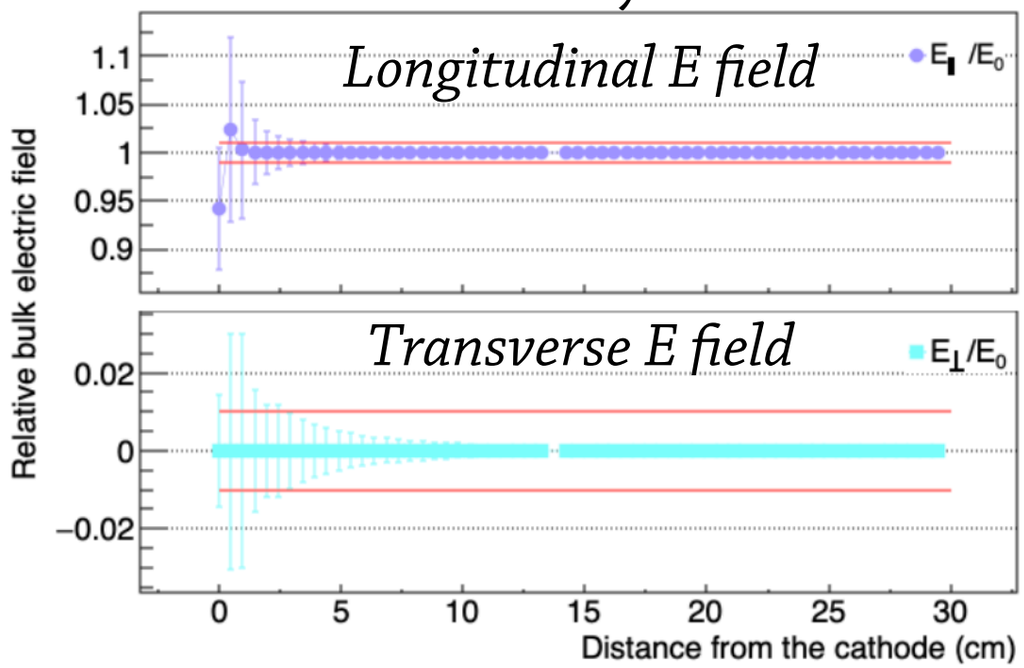
Cathode ColdBox



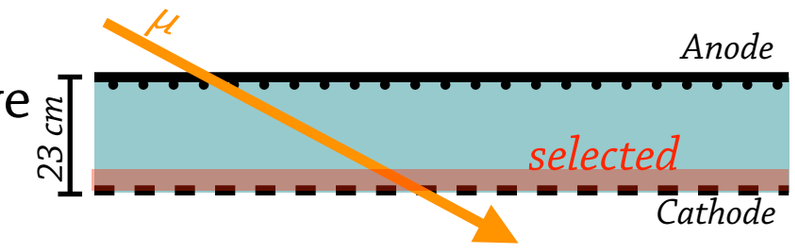


The field is distorted near the cathode bars up to ~3 cm above (simulation, within DUNE specifications):

Field uniformity simulation

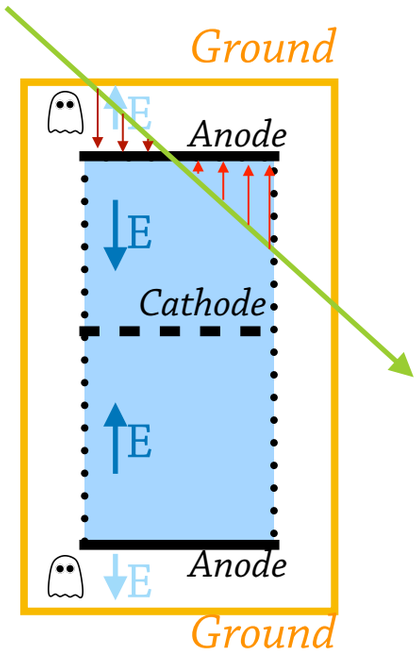


<- only hit up to 1.5 cm above the cathode selected

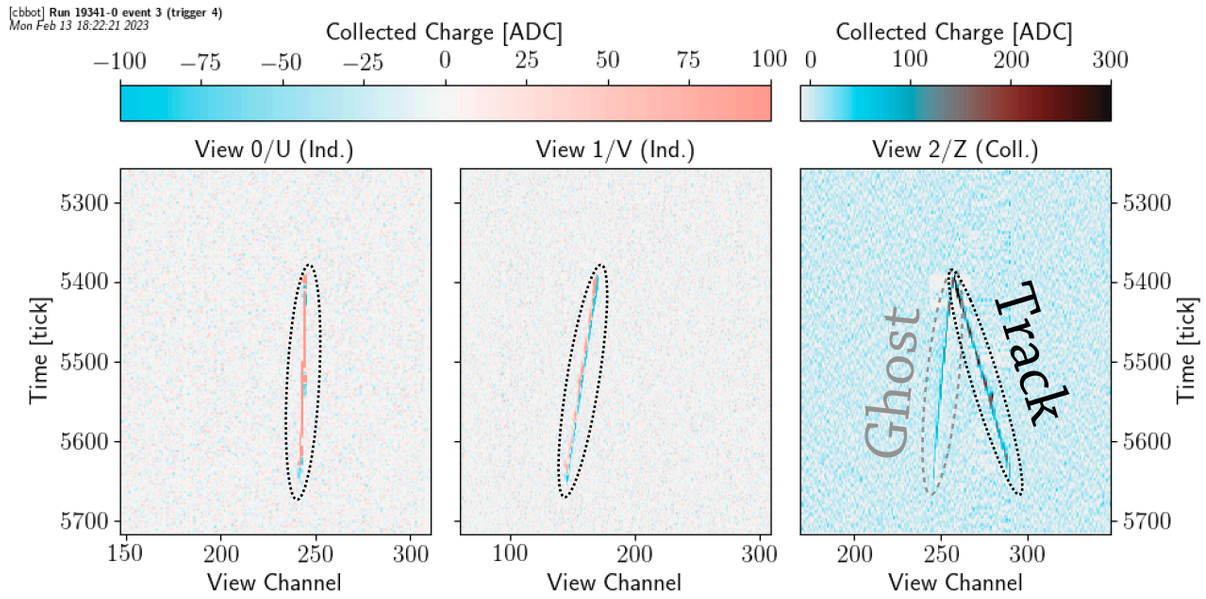


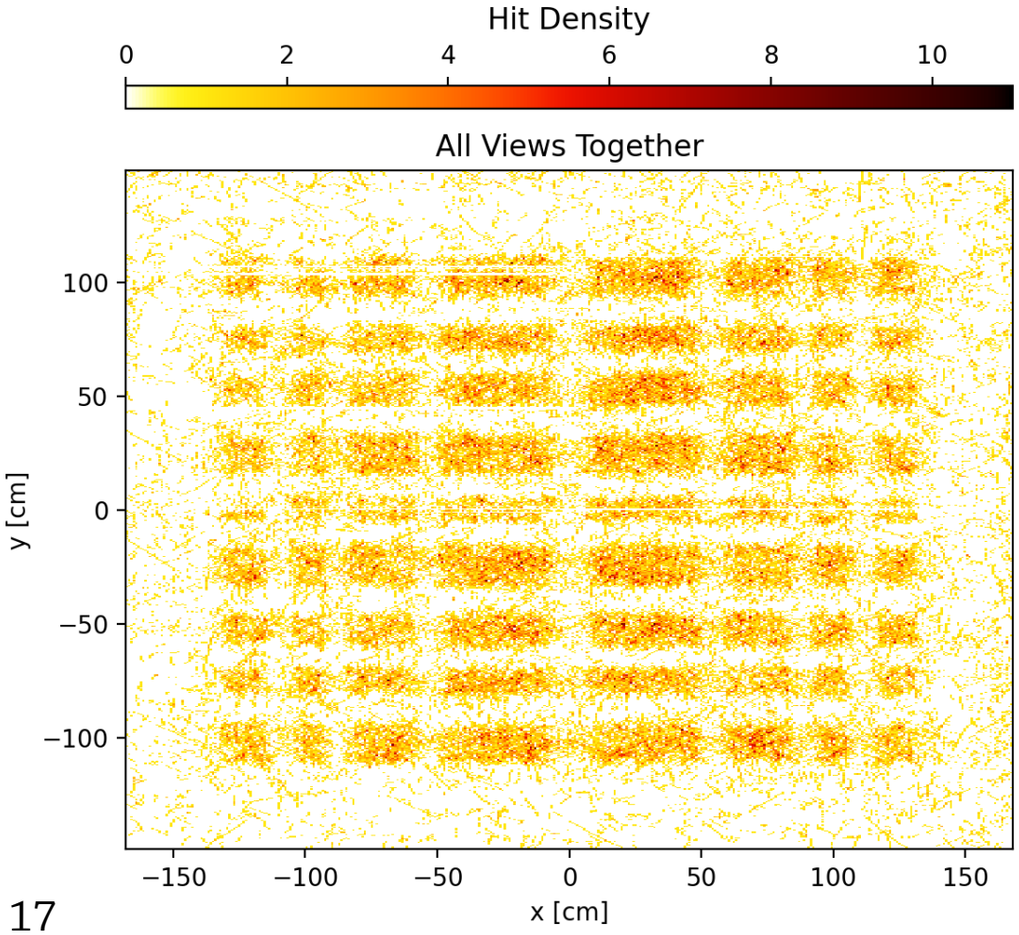
In the ColdBox data, no visible field distortion could be seen above the cathode with resistive mesh.
Small distortion (E field higher than nominal) above the bar without resistive mesh seen up to 1.5 cm above the cathode

CRP Performances: Muon-scans

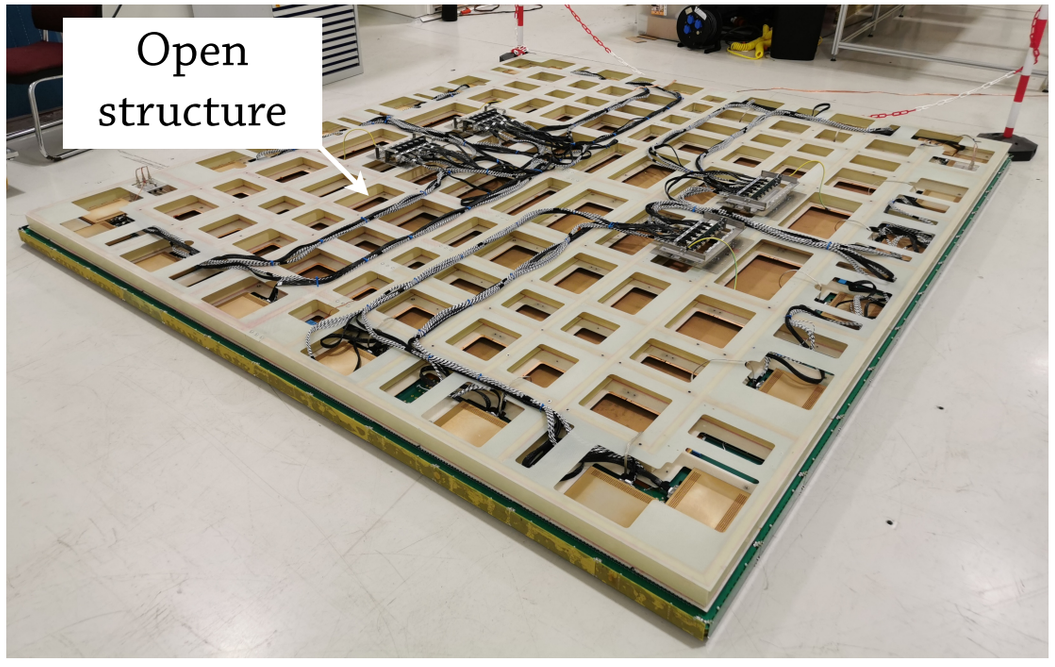


In VD design, the anode plane is powered at +1kV
-> There is a ‘dummy’ drift field region between the anode (View 2) and its closest ground



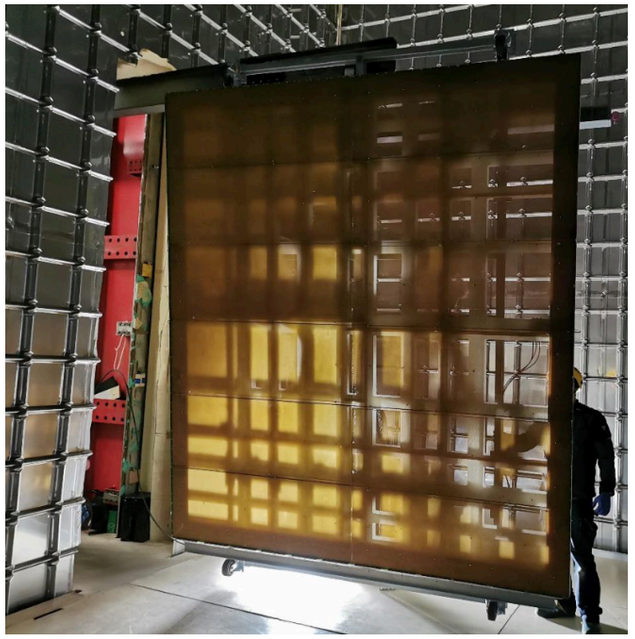


-> A 3D-reconstruction of the ghost tracks allows to muon-scan the structure of the composite frame above the PCB anode !

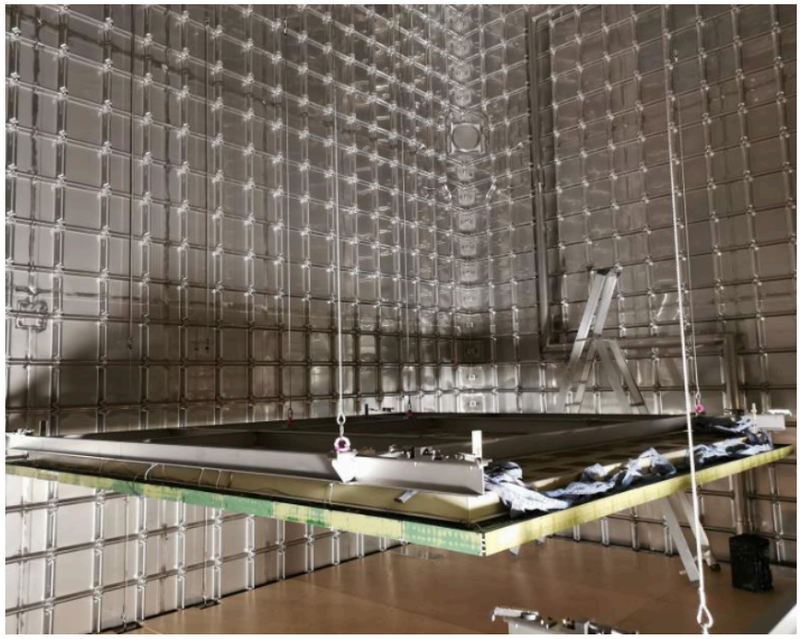


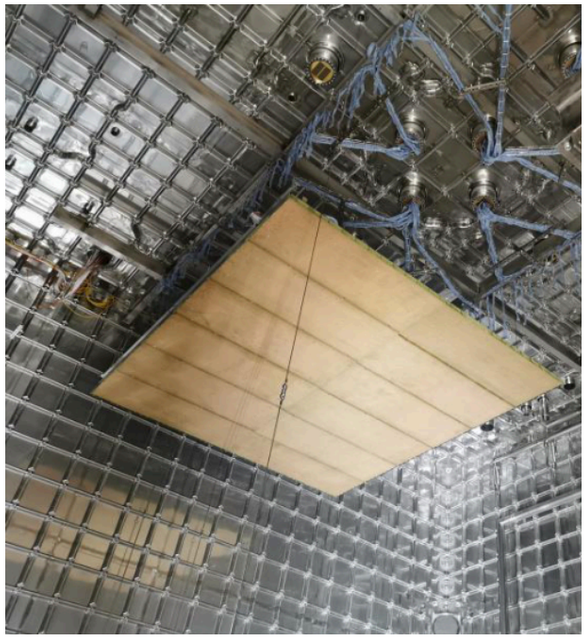
Installation of ProtoDUNE-VD: Top CRP

Insertion into the cryostat

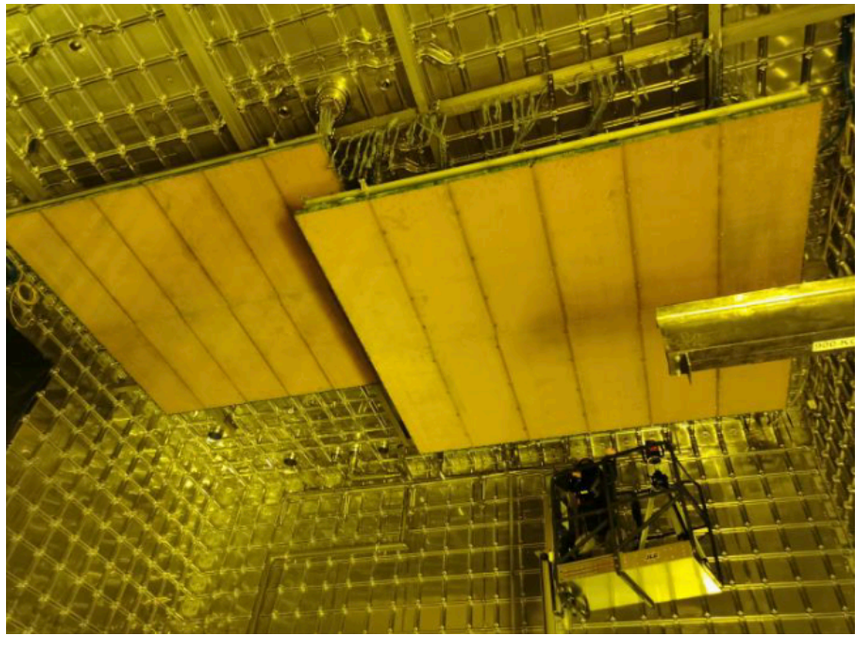


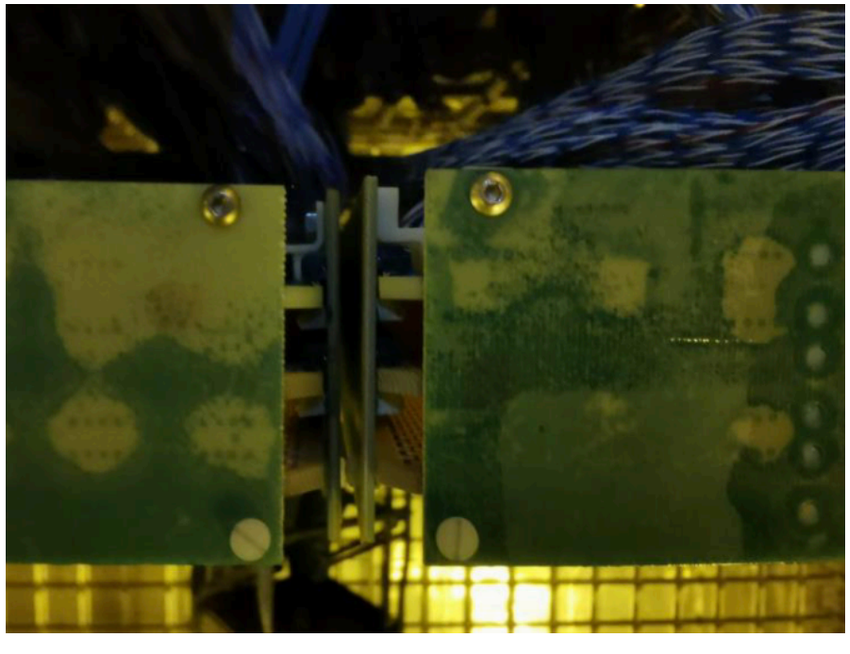
CRP lifting to the roof and cabling





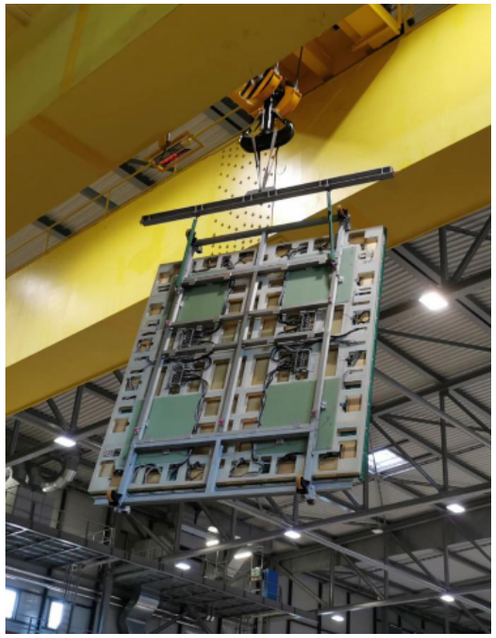
Top CRP alignment

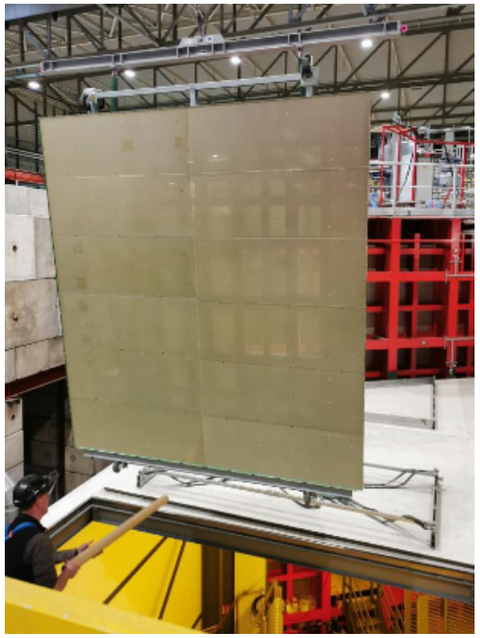




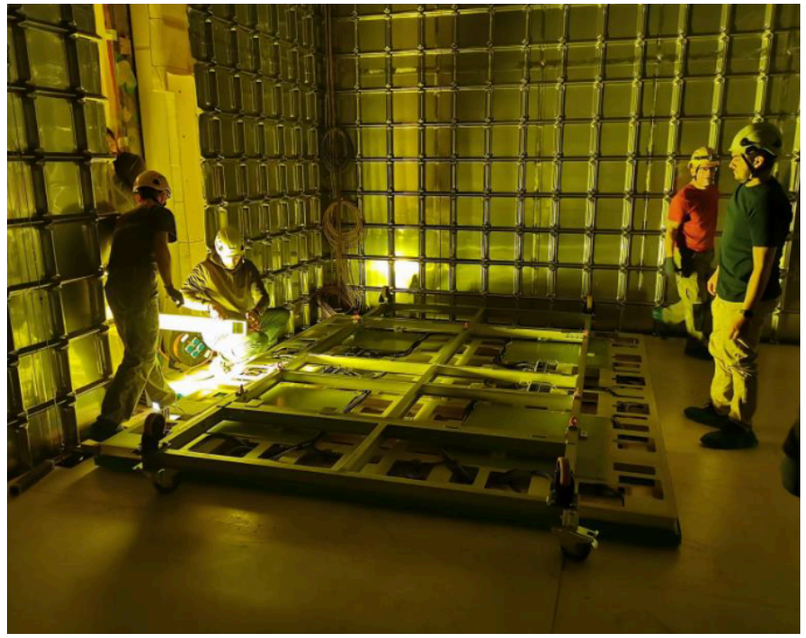
Installation of ProtoDUNE-VD: Bottom CRP

CRP transportation from ColdBox

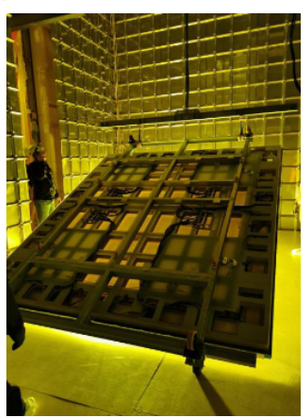


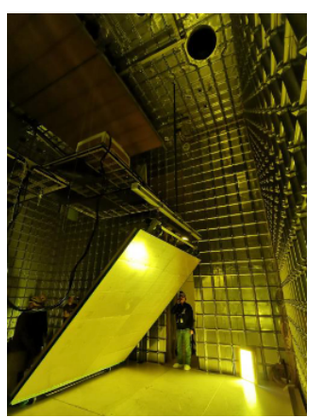


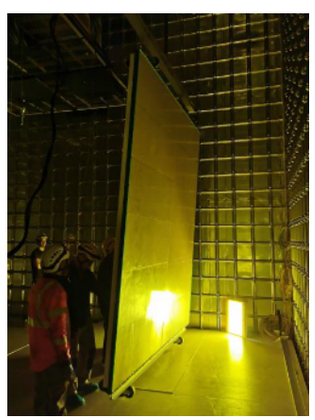
CRP insertion into cryostat

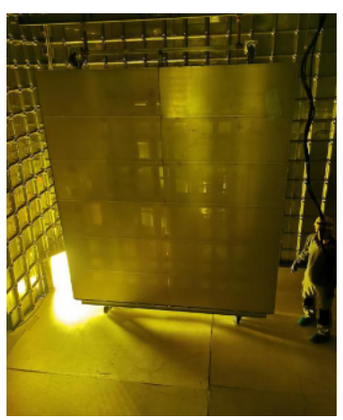


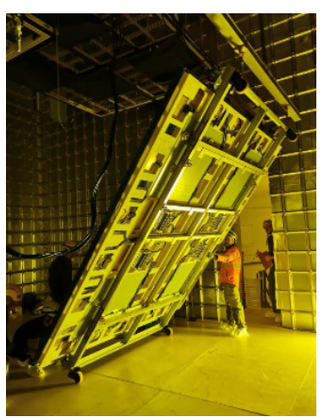
Bottom CRP lifting, flipping, lowering procedure

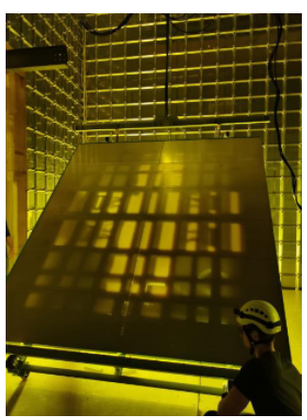


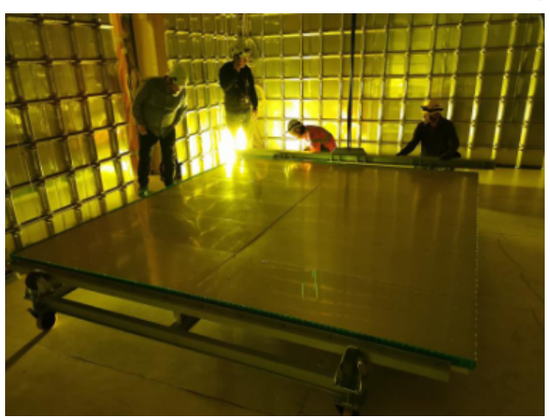








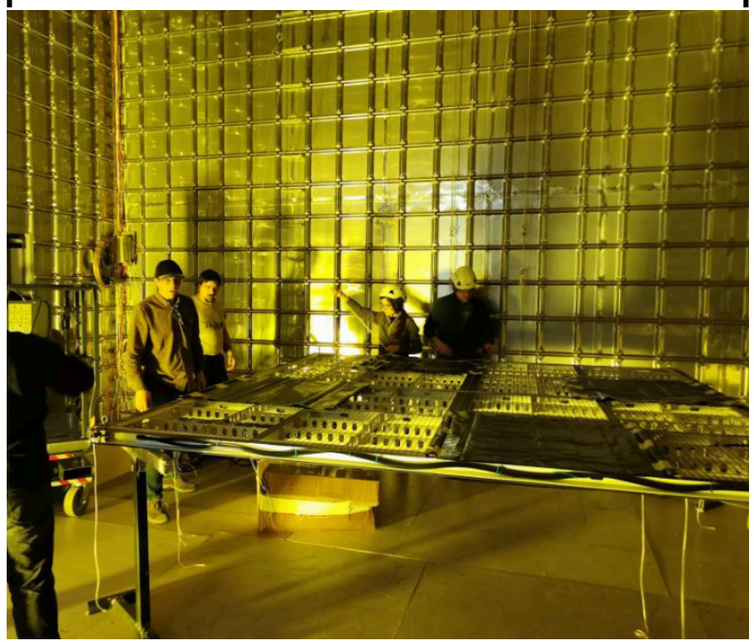




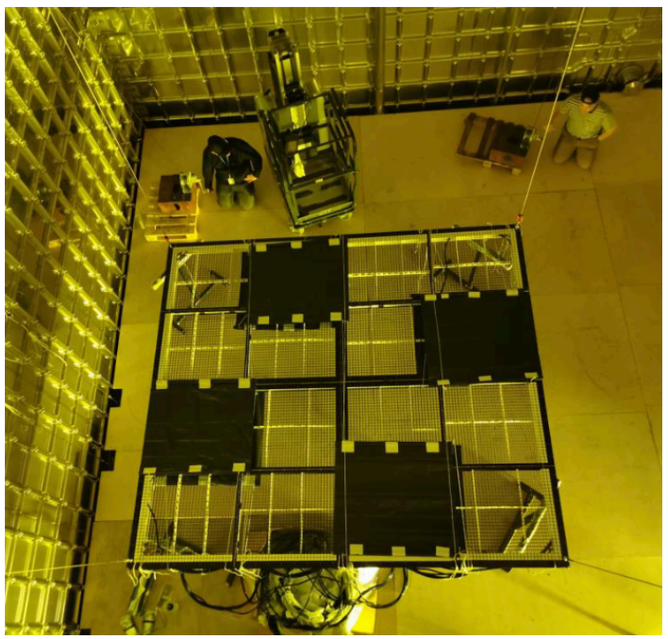
180° rotation

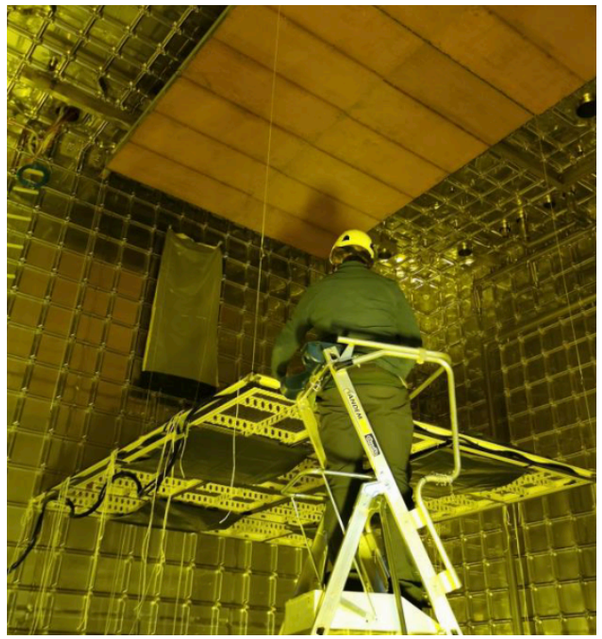
Installation of ProtoDUNE-VD: Cathode

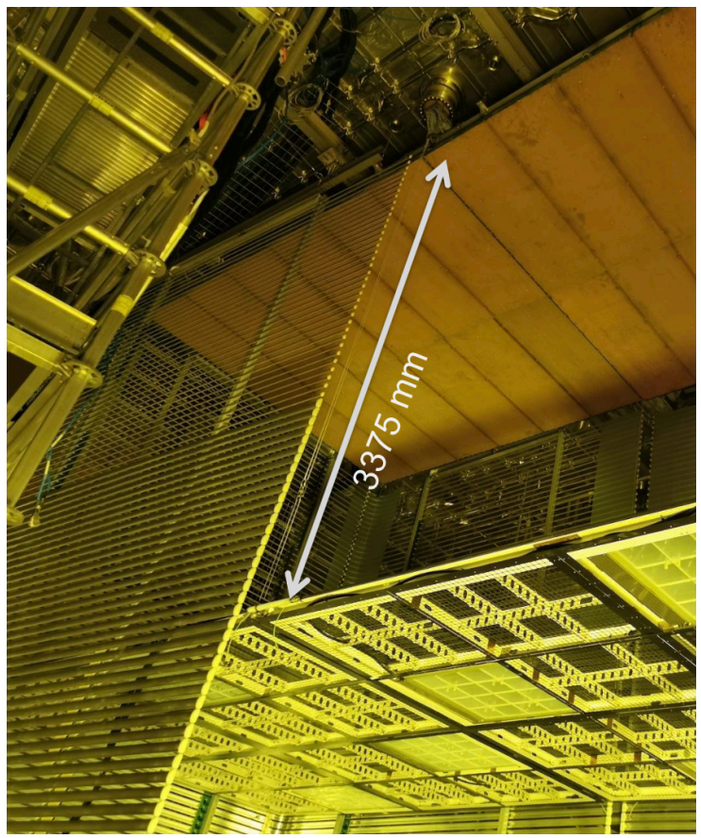
Cathode insertion in cryostat

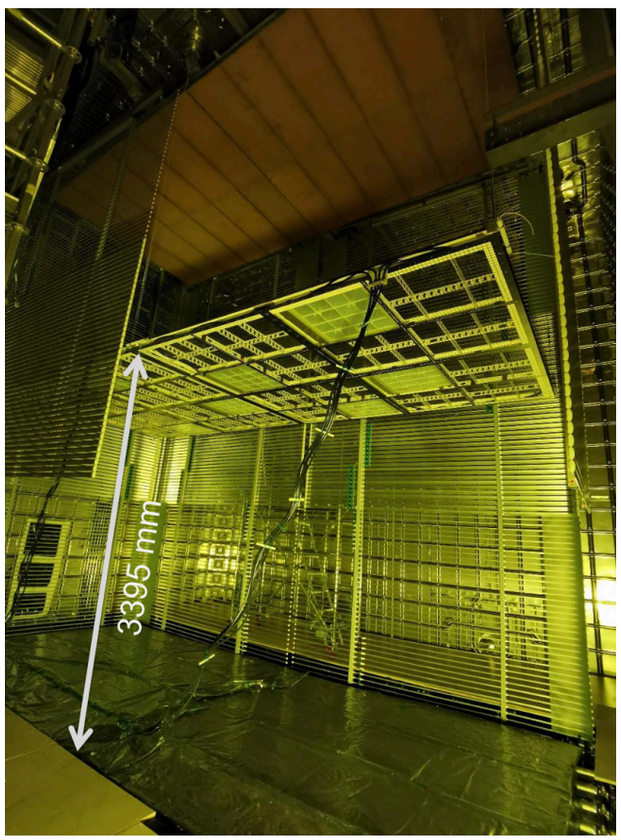


Cathode suspension below the top CRP









Adjust the cathode position with respect to top/bottom CRP at warm such that at cold the drift distance will be the same

↳Account for cathode buoyancy and cable elongation

Installation of ProtoDUNE-VD

Picture taken last week

Top volume

Bottom volume

Conclusions, Perspectives

- The Vertical Drift LArTPC design will be tested at large scale in ProtoDUNE-VD with cosmics and beam data

- Excellent performances of the CRPs when tested in the ColdBox

- All main elements of ProtoDUNE-VD have now been installed
  ↳ CRPs, Cathode, Field Cage, Light Detection System

- Elements to be installed in the cryostat:
  - Cryogenic instrumentation
    ↳ Temperature probes, purity monitor
  - Cryo-camera
  - Beam pipe

- ***Cryostat closure foreseen in October 2023***

- Liquid Argon filling could happen by the end of the year: still under discussion