DUNE Vertical Drift LArTPC Design and Prototyping

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For the DUNE Collaboration

Nufact 2023 - Seoul, Korea
August 22nd 2023

LAPP

DEEP UNDERGROUND NEUTRINO EXPERIMENT

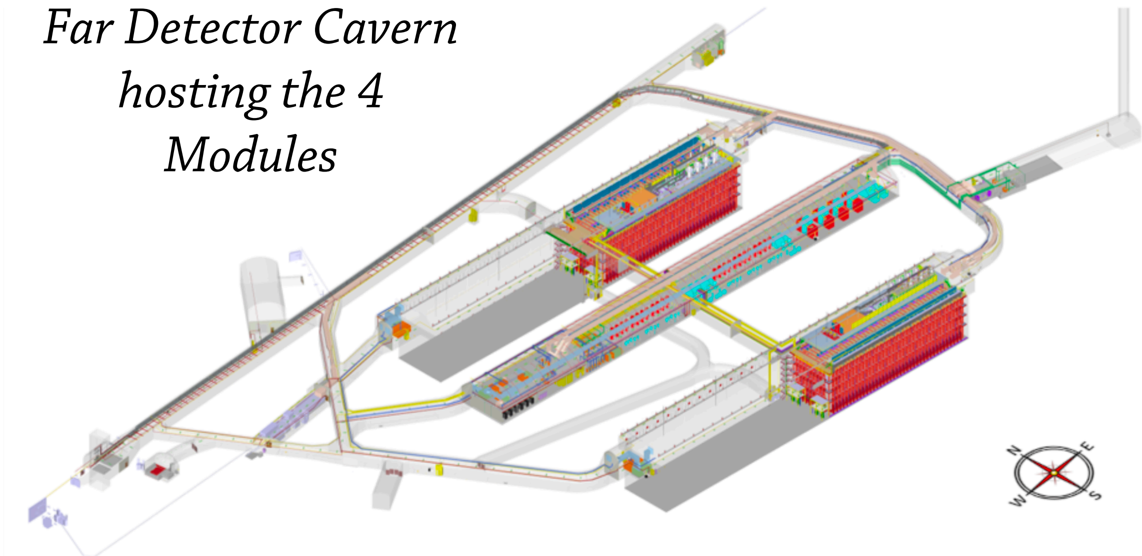
Deep Underground Neutrino Experiment

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

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

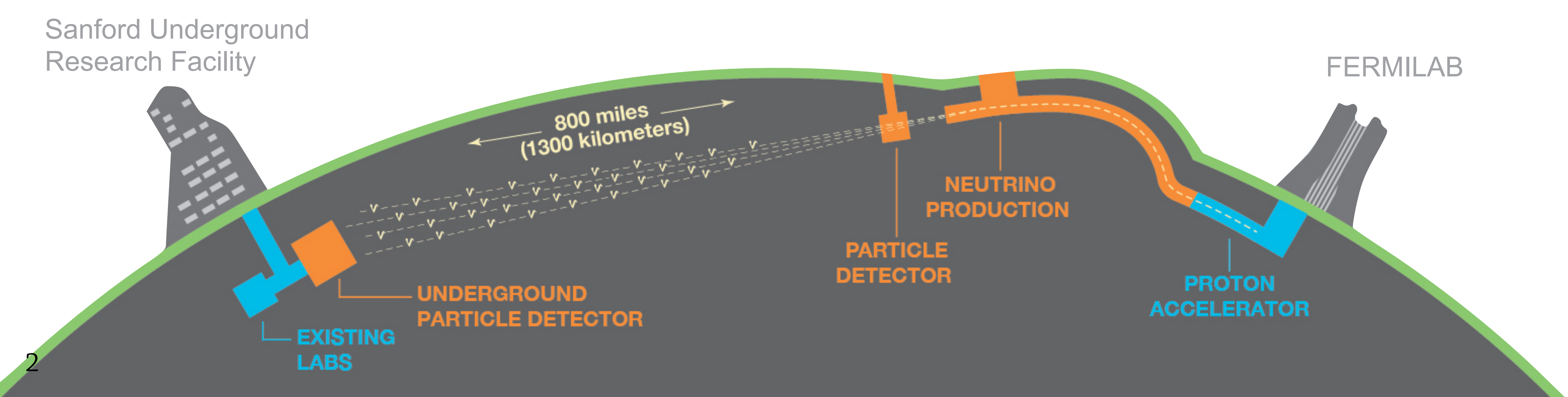
↳ *See Chris Marshall talk on Thursday about the DUNE status!*

Far Detector Cavern hosting the 4 Modules



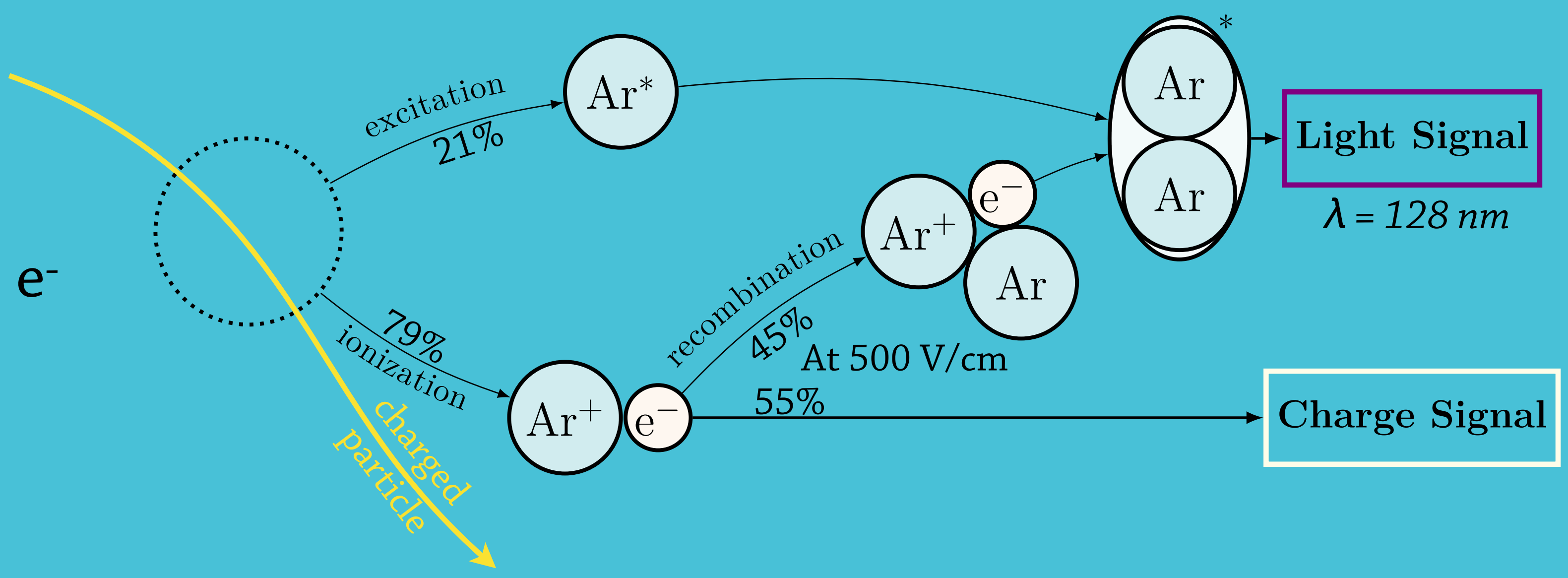
The Far Detector is made of 4 giant LArTPC modules

- 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 discussions



Liquid Argon TPC

Charge particles excite and ionize LAr
-> Produces a charge & light signal
An electric field suppresses the recombination and allow to collect the e⁻ at the anode



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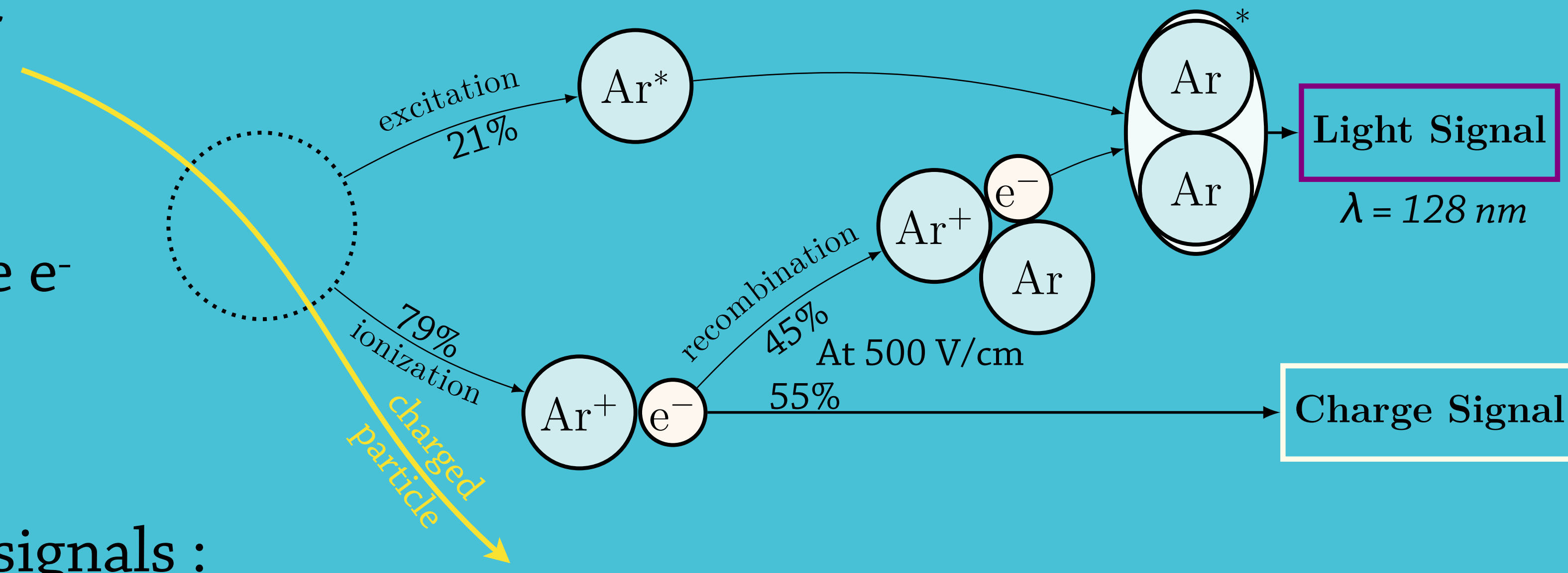
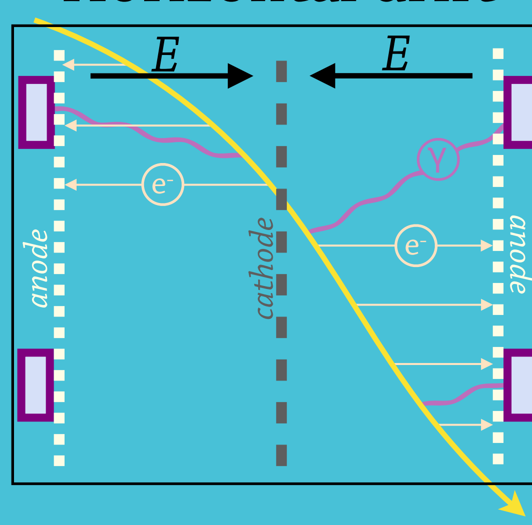


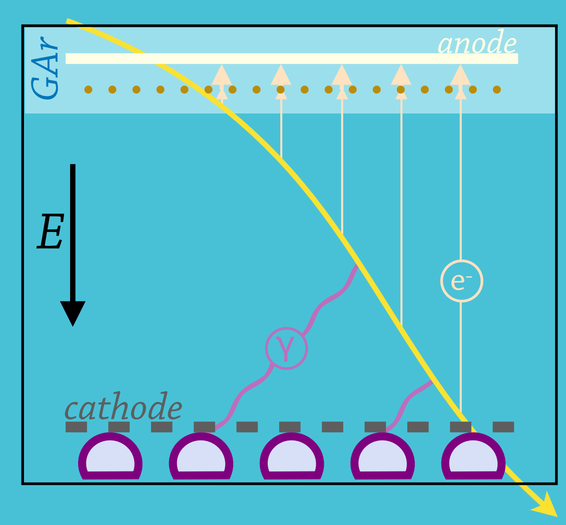
Different TPC designs to collect both signals :

Single-Phase Horizontal drift



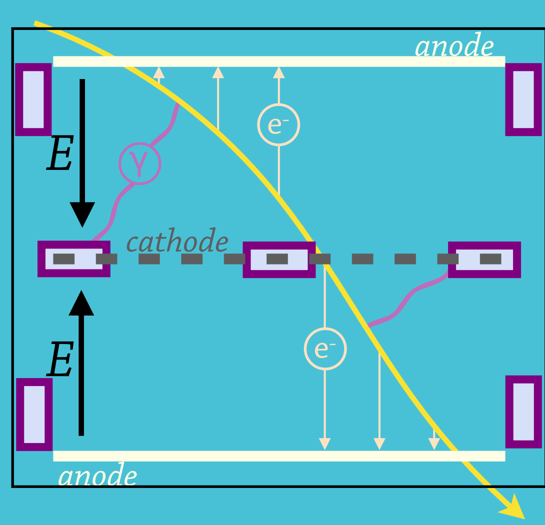
- Two drift volumes
- Anode made of wires
- Light collected with X-ARAPUCAs behind the anodes

Dual-Phase



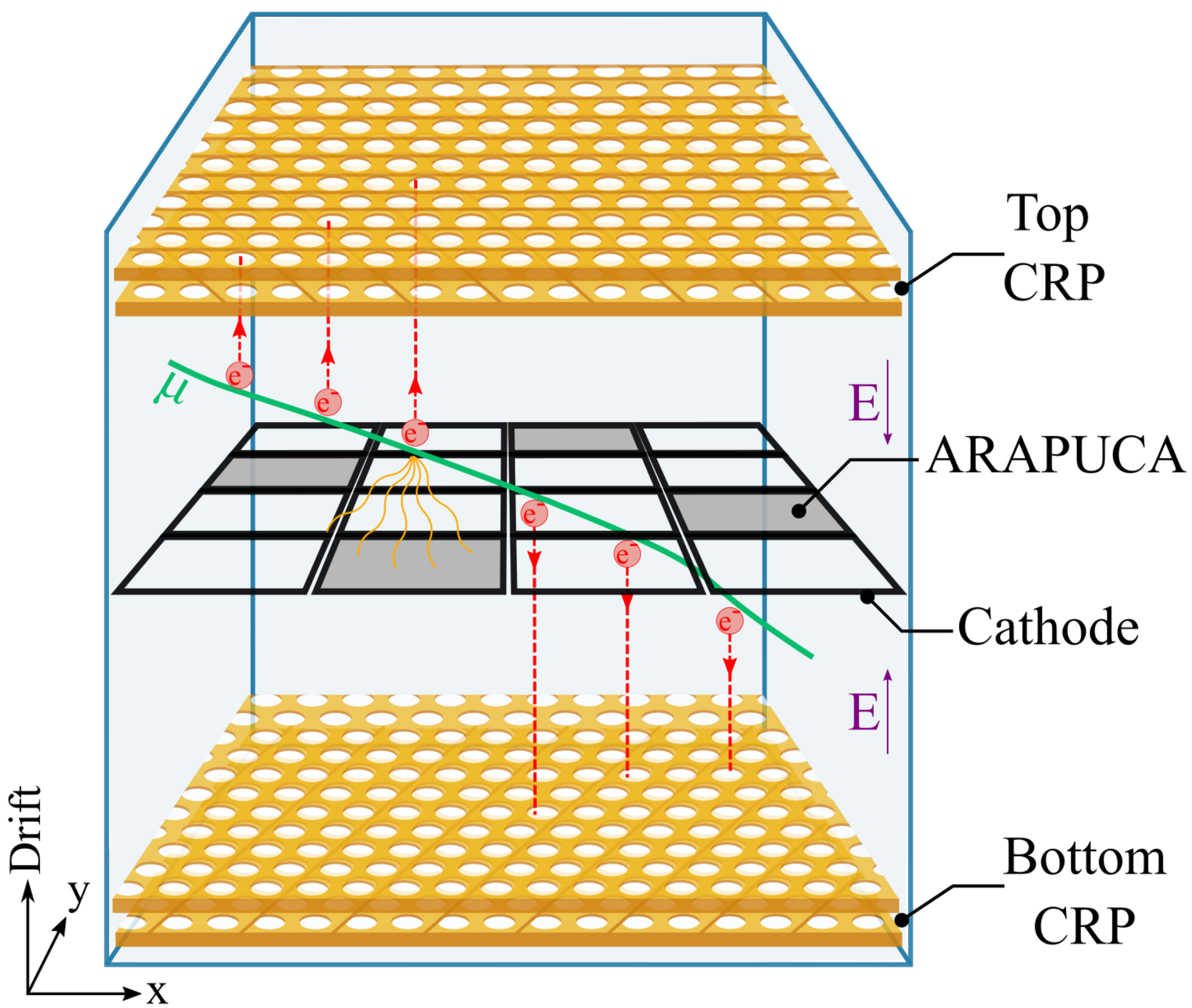
- Single drift volume
- Electron cloud amplified in gas argon layer with thick GEM
- Anode made of PCBs
- Light collected with PMTs below the cathode

Vertical drift



- Two drift volumes
- Anode made of drilled PCBs
- Light collected with X-ARAPUCAs on the cathode and behind the field cage

Vertical Drift LArTPC design



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

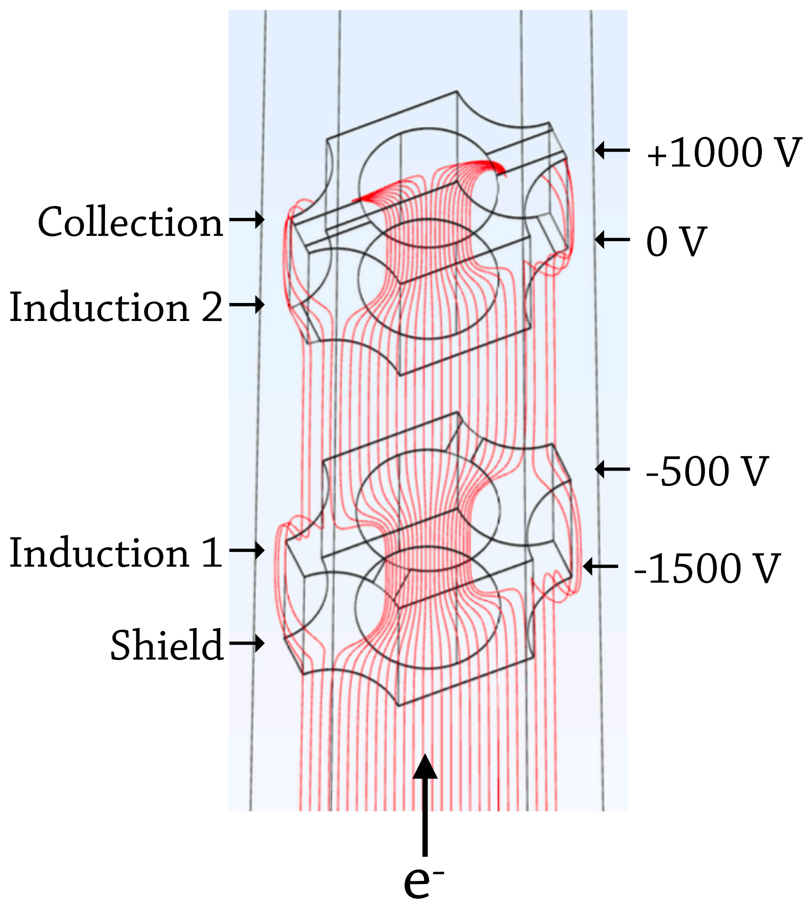
- Top and Bottom CRP are equipped with different electronics :
  - Top: Accessible front-end, from DP design
  - Bottom: Embedded front-end, from SP/HD design

The light signal is read by X-ARAPUCAs, a light trapping device, installed on the cathode and behind the field cage

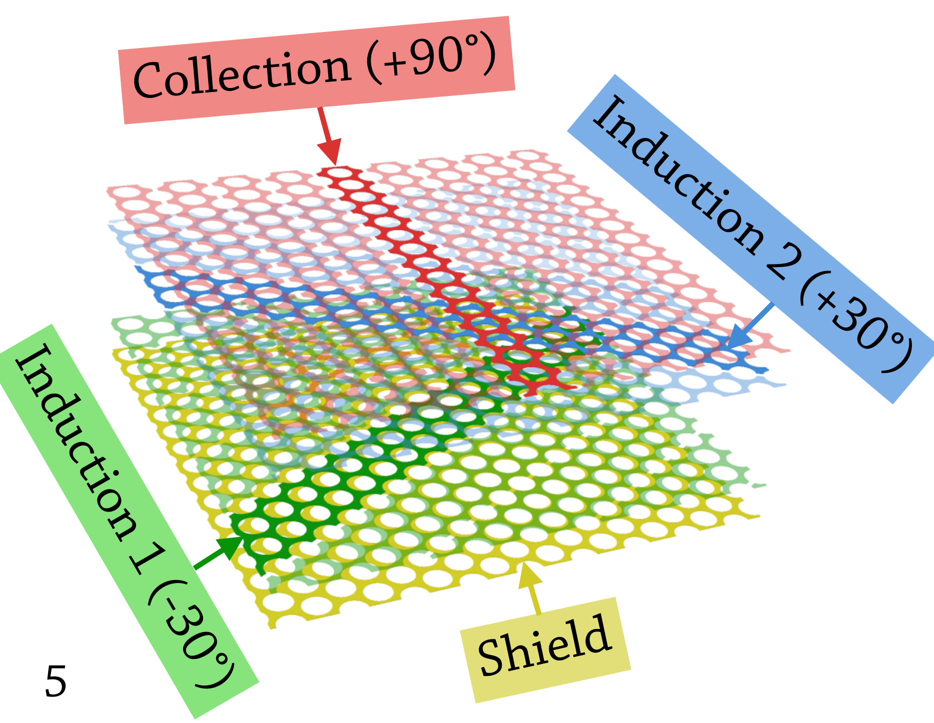
Compared to the Horizontal Drift design, the Vertical Drift LArTPC design:

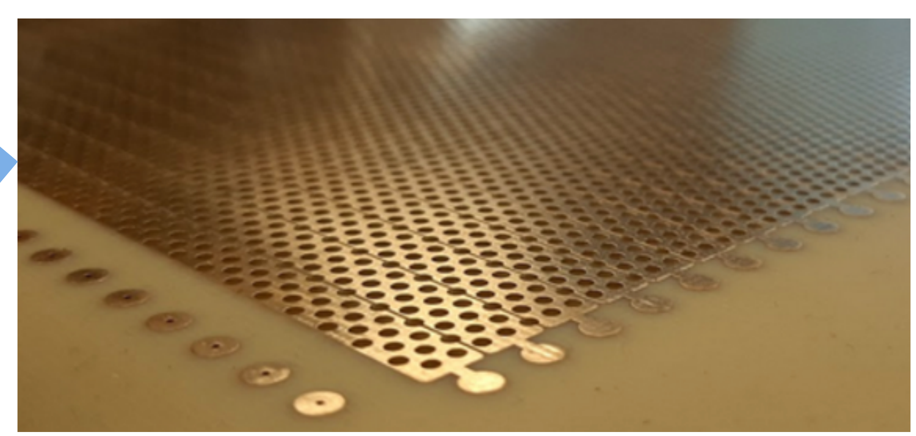
- Is less expensive and more robust (no wires)
- Has better light detection coverage
- Has similar charge reconstruction and calorimetric performances

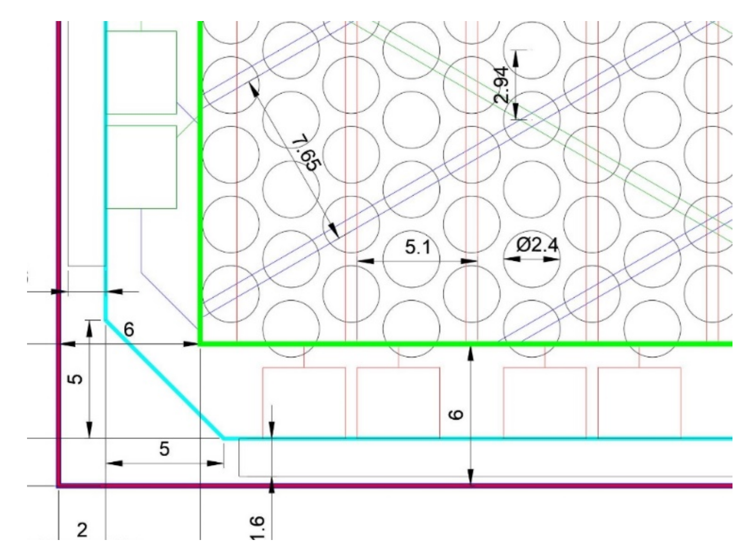
Charge signal Generation



- Each PCB face has a bias to attract the electrons through the holes towards the collection (last) plane
- One shield plane facing the active volume (no etching)
- The other 3 planes, or views, have different etching, or strip, orientation : final design is {-30°, +30°, +90°} w.r.t. the ν beam
- Electrons leave an induced signal (bipolar) on the first two views, and are collected (unipolar signal) on the last view
- Induction views : 7.65 mm wide strips, total of 952/view/CRP
  Collection view : 5.1 mm wide strips, total of 1168 strips/CRP



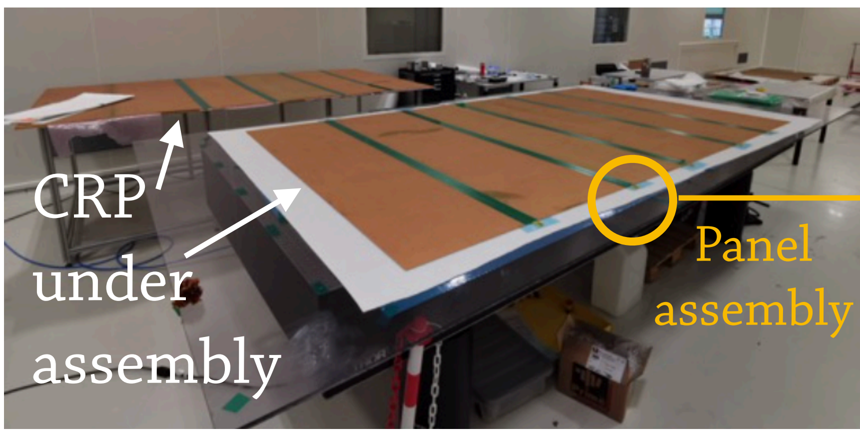


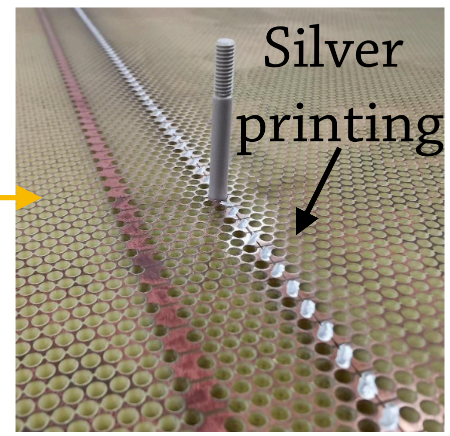


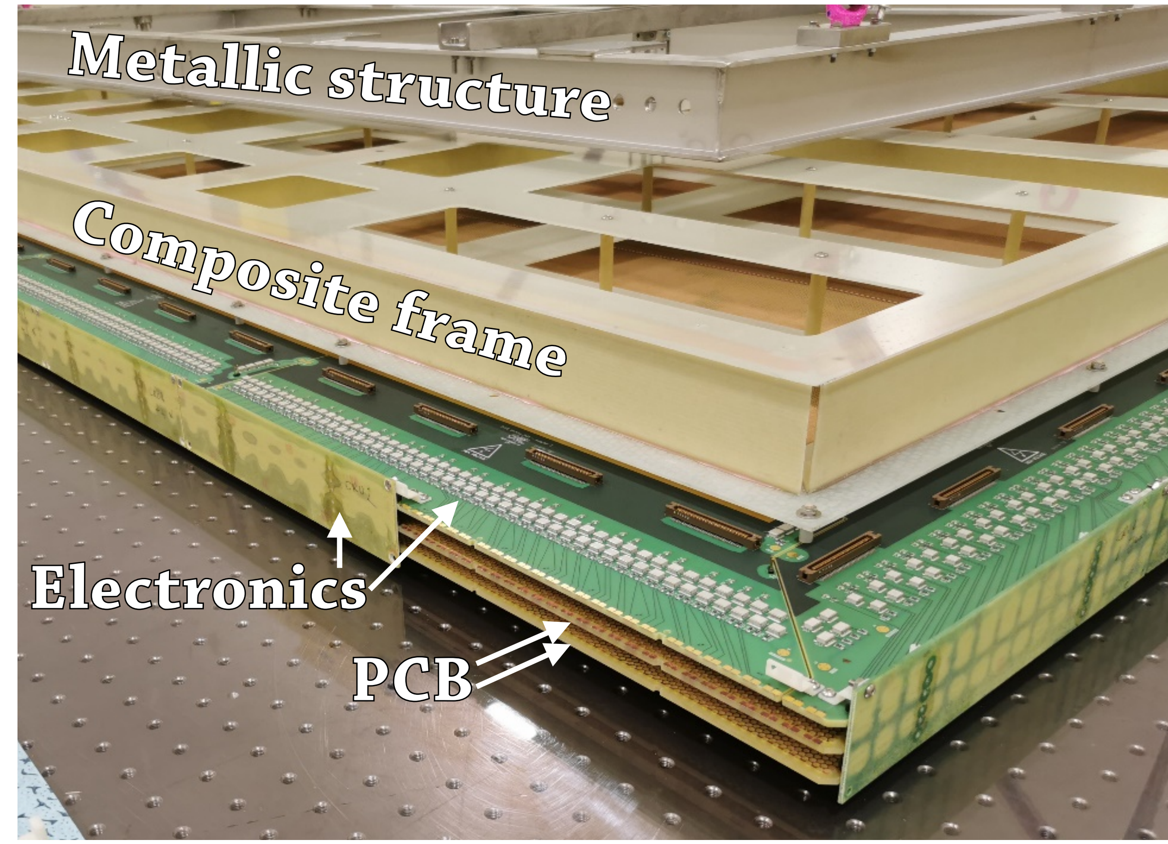
Charge Readout Plane (CRP)

CRP characteristics:

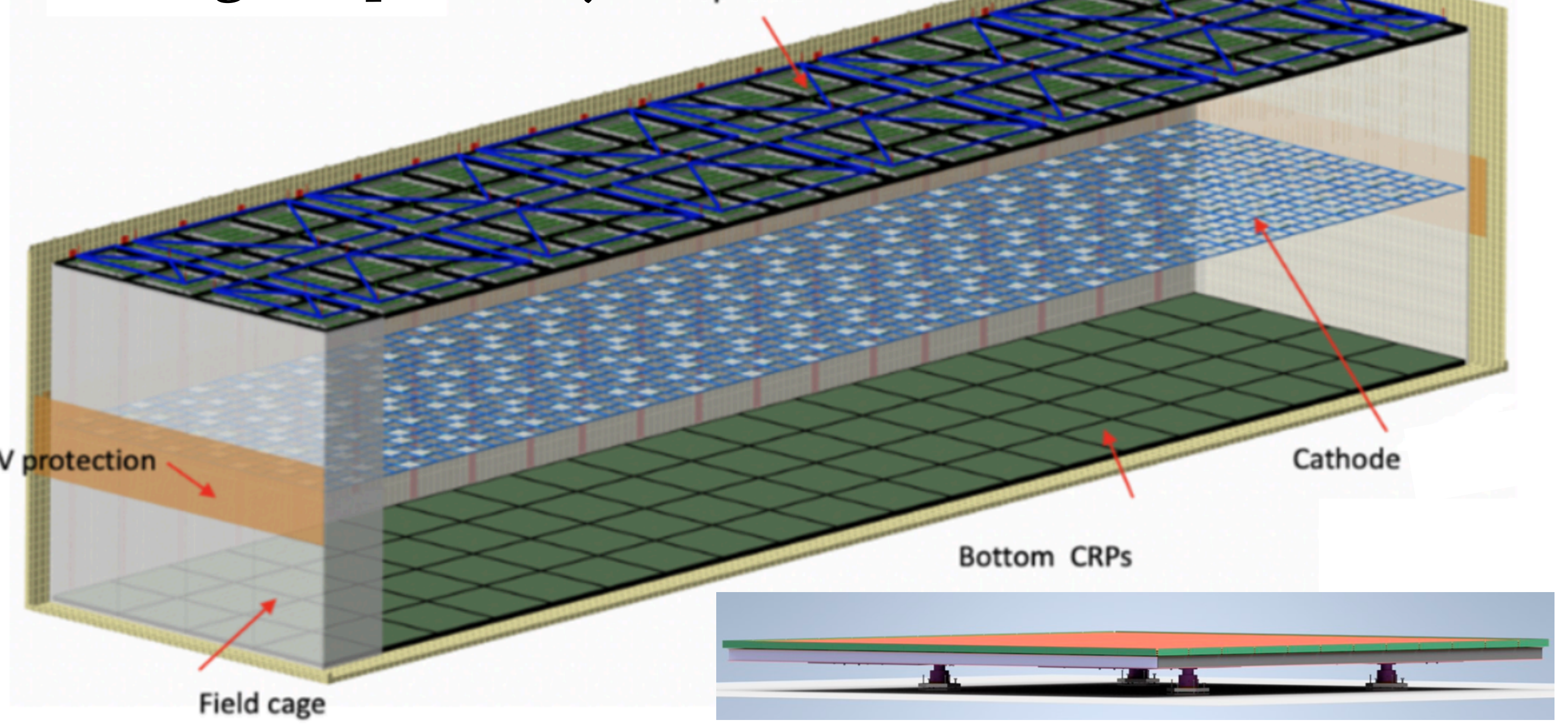
- Modules of $3 \times 3.4\ m^2$
- Assembly of 2×6 panels/PCB plane
  ↳Electrical strip continuity by silver printing







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



The far detector will have 160 CRPs:

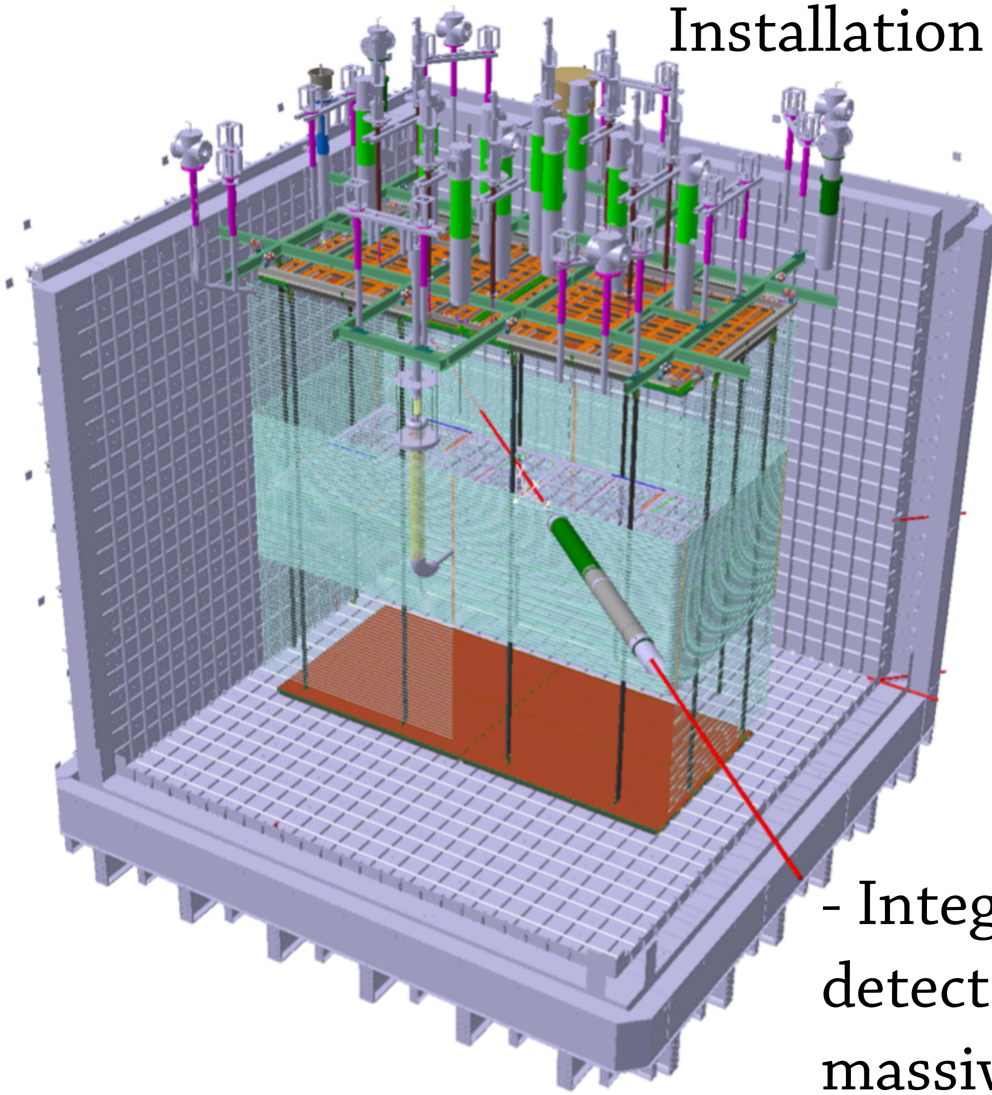
- 80 suspended at the top
- 80 at the bottom, resting on the cryostat floor

And 80 cathode unit suspended from the top CRP

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

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:

- 4 CRPs : 2 top + 2 bottom ($2\times3\times6.8$ m^2)
- Cathode hanged in the center, 2×3.5 m of drift
  ↳ V_{cath} = 175 kV for the nominal drift field of 500 V/cm
- X-ARAPUCAs on the cathode (8) and on the field cage (2×4)

Goals of Module-0:

Hardware

- 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

Physics

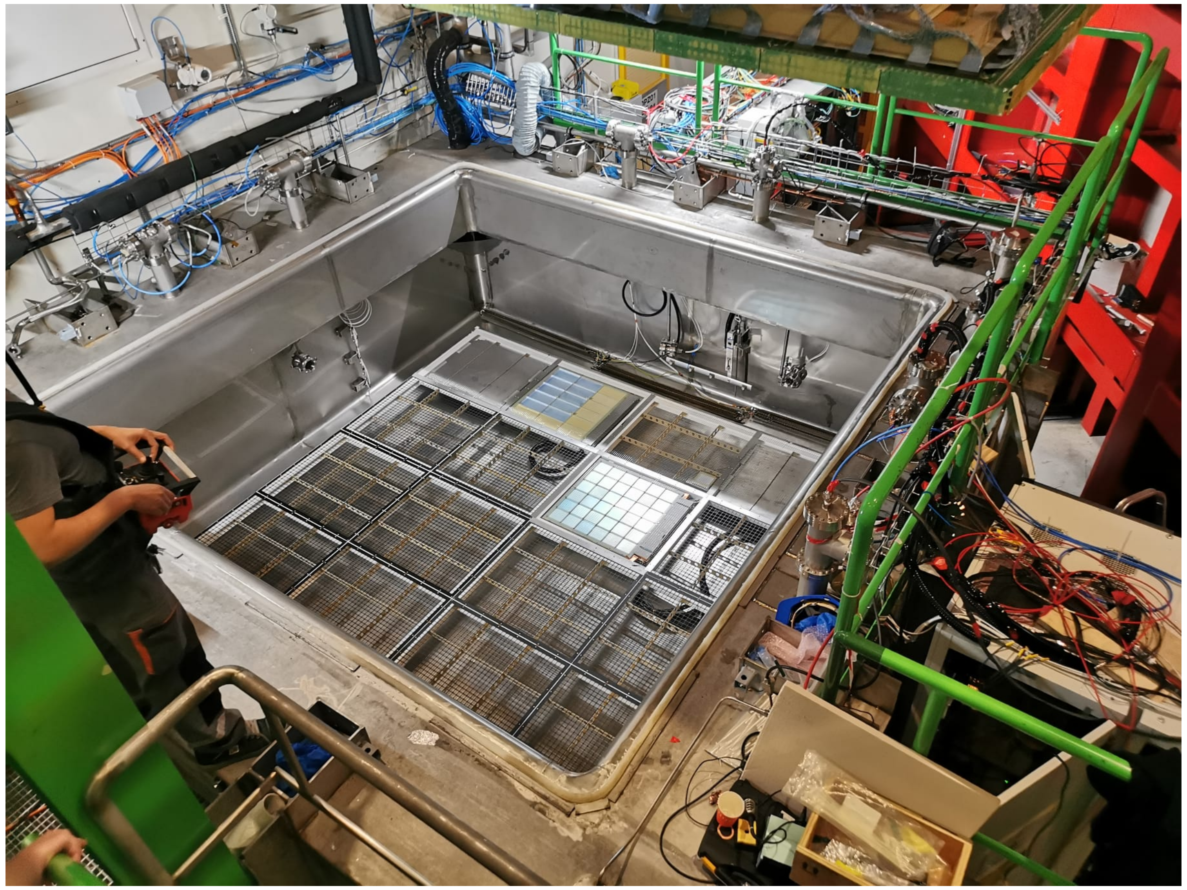
- Validation of reconstruction algorithms (3D, ID, history, calorimetry, charge+light, space-charge corrections, ...)
- Calibrations with:
  • test-beam particle at various momentum
  • Ar^{39}, michel e^-, multiple coulomb scattering, ...
- hadron-Ar cross sections

CRP tests in the VD-ColdBox

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

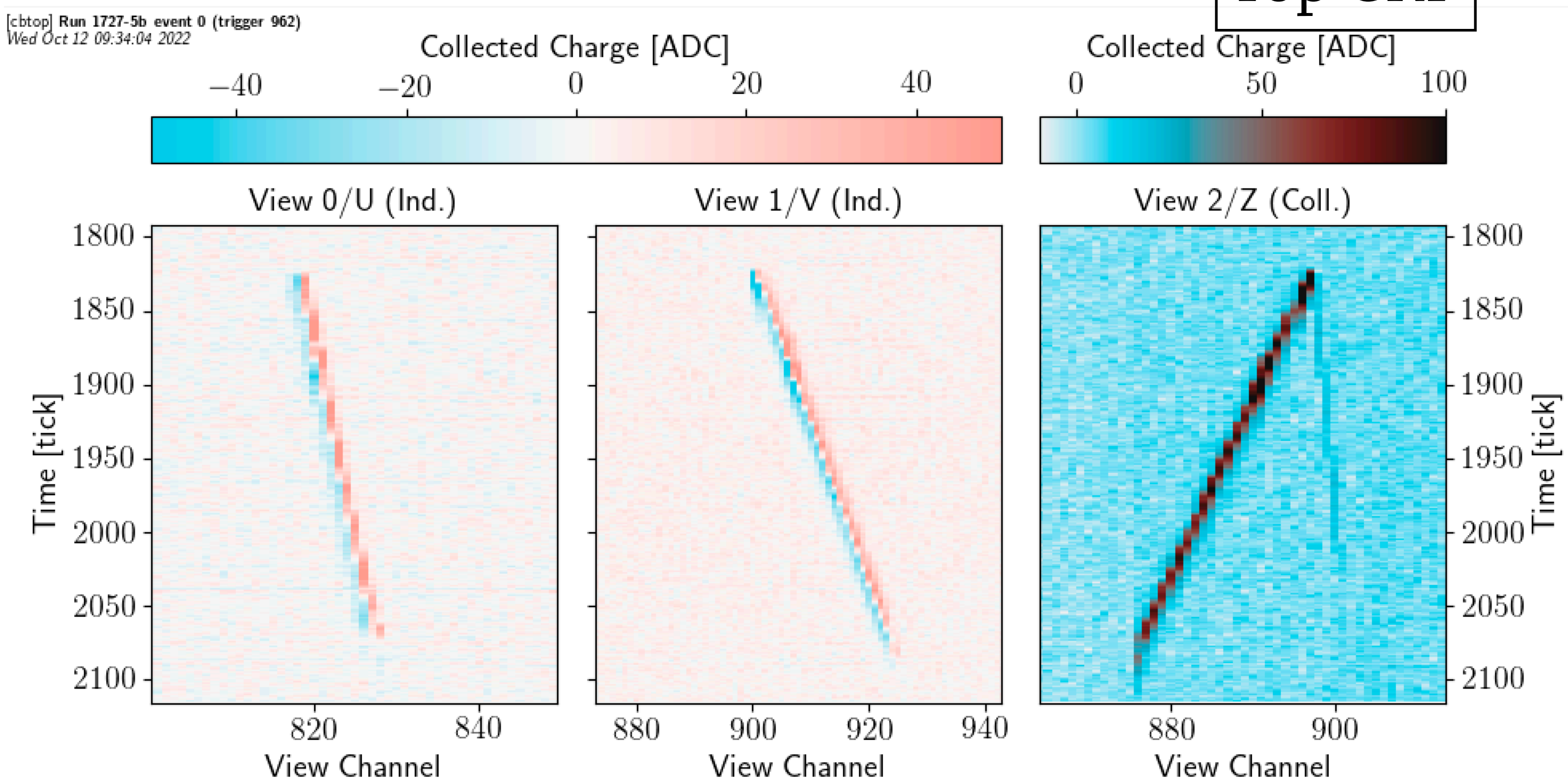
-> Equipped with cryo-camera, slow control sensors, a cathode and light detection devices
-> The CRPs are hanged on the ColdBox roof
-> Both Top or Bottom electronics CRPs was be tested

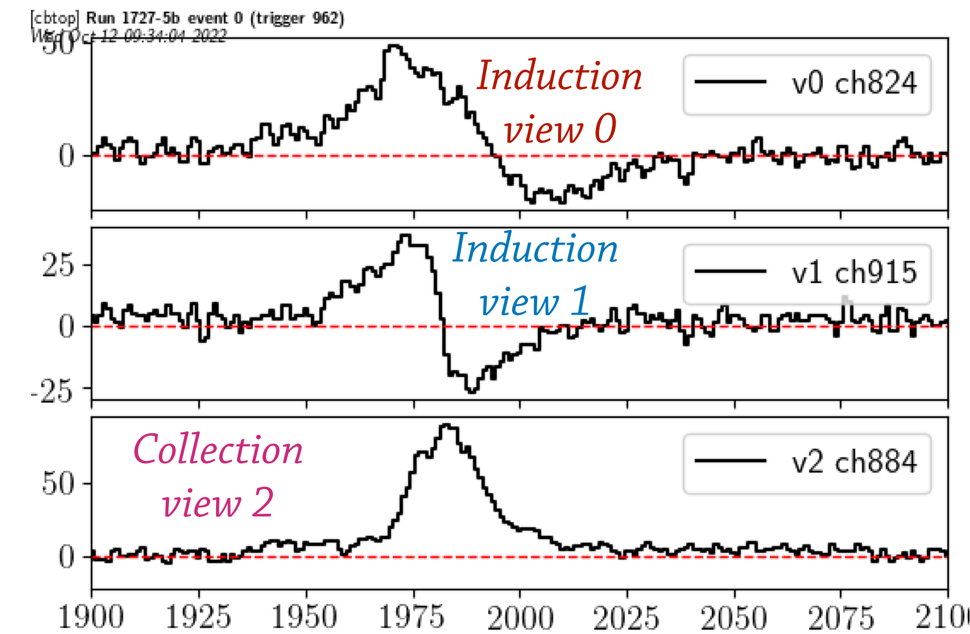
The ColdBox is a small TPC collecting cosmic data with 23 cm of drift



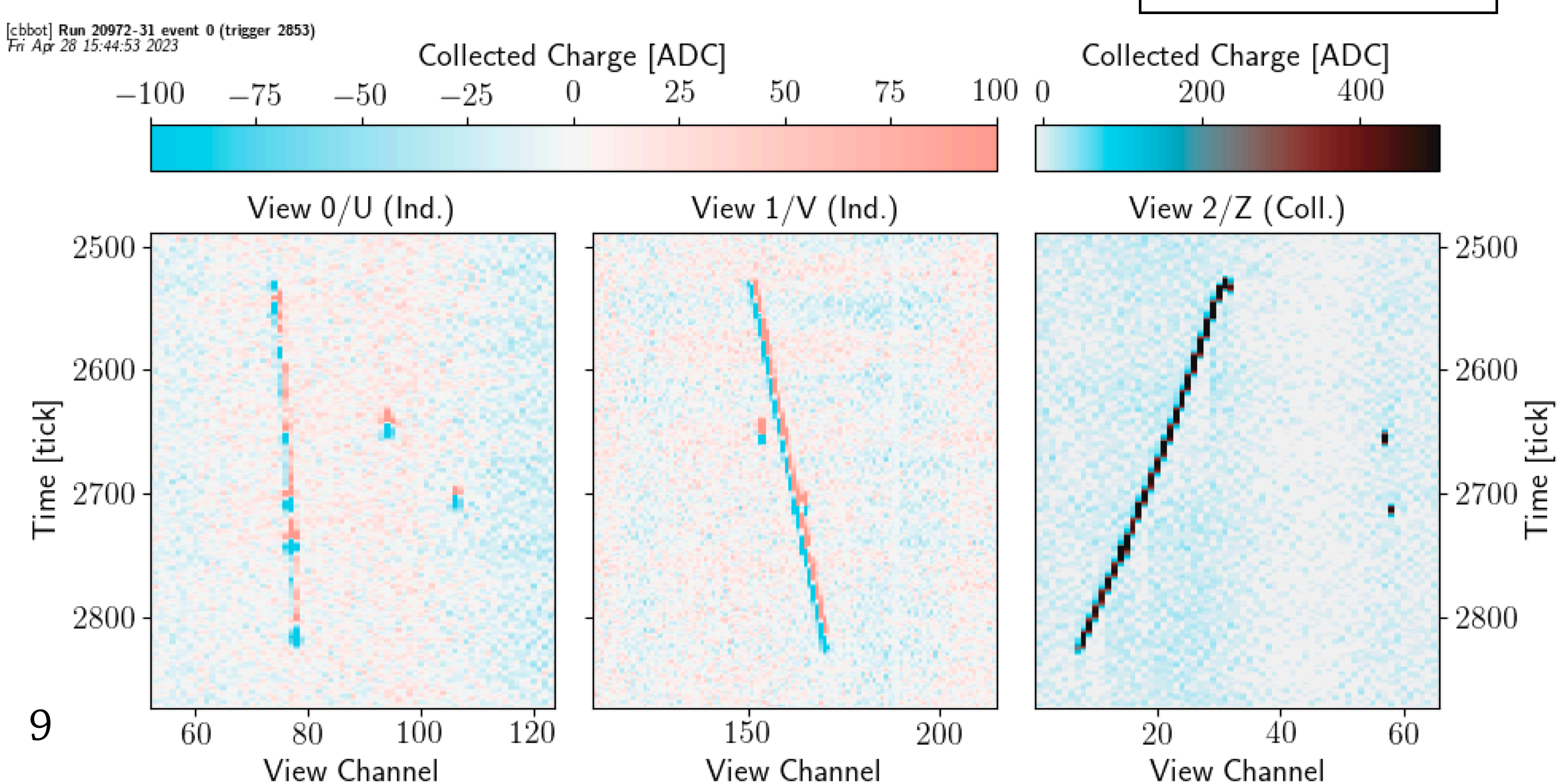
ColdBox Event Displays

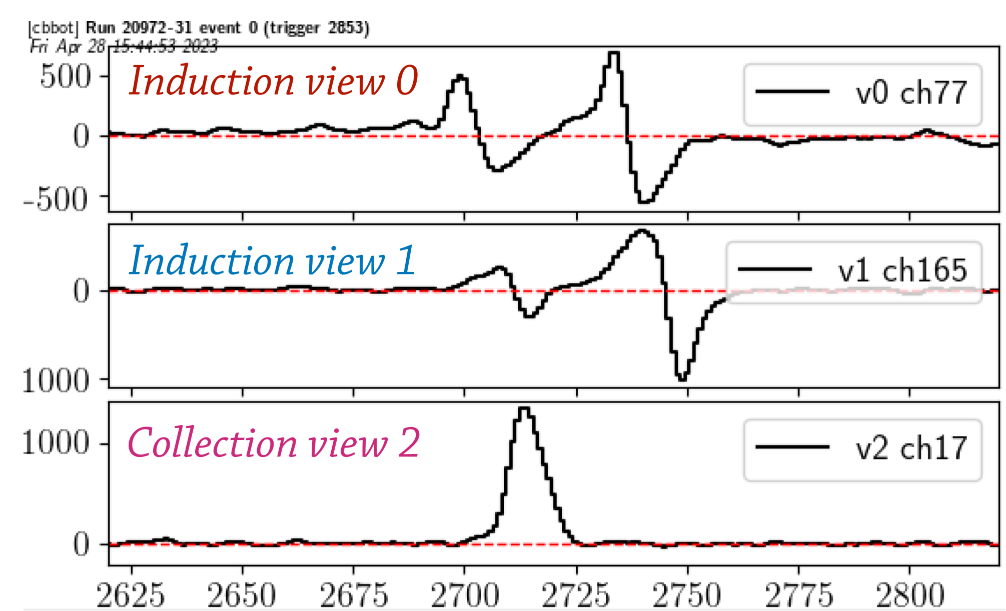
Top CRP





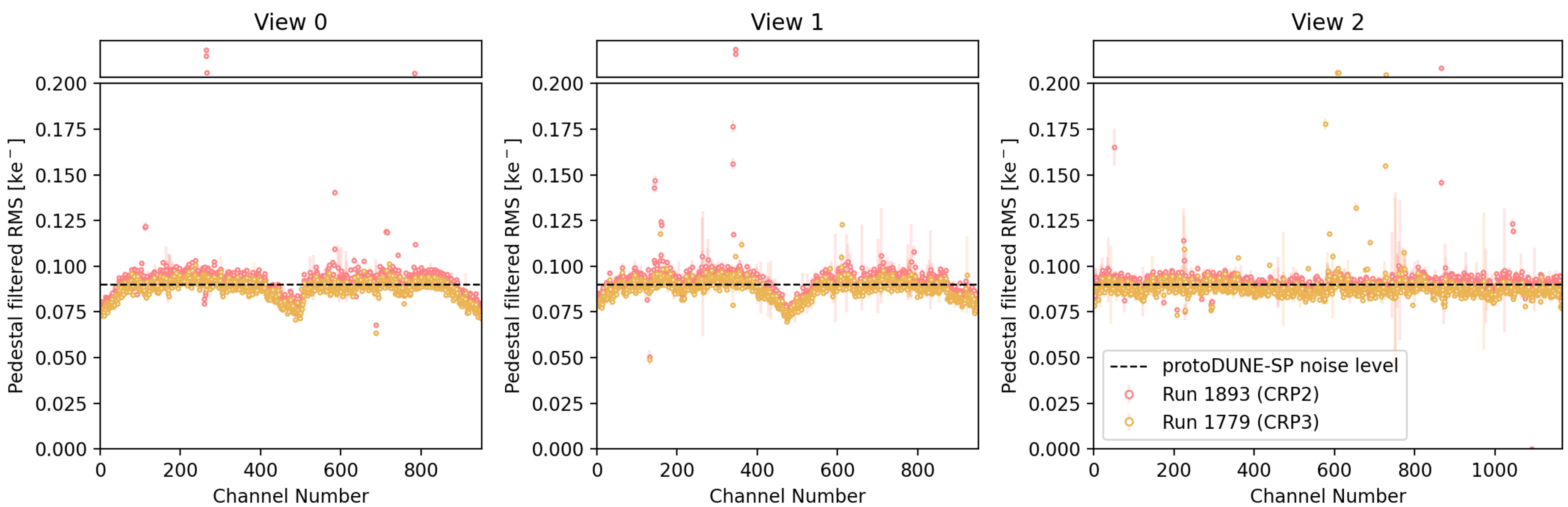
Bottom CRP



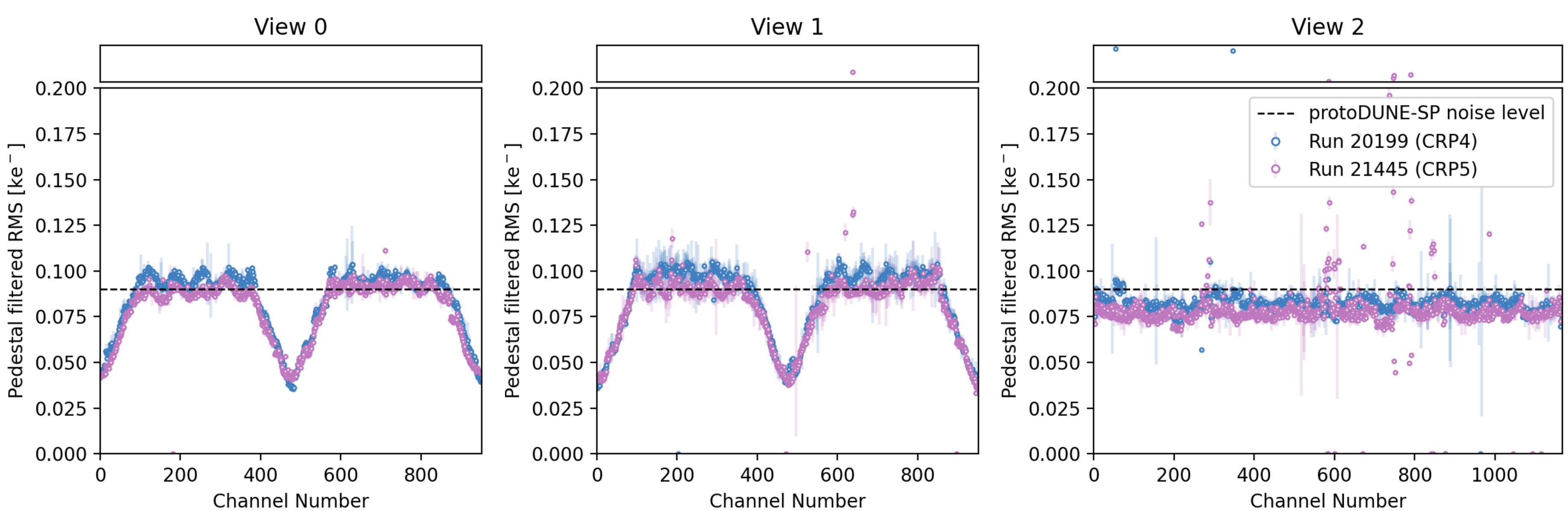


CRP Performance: Noise

Top CRP

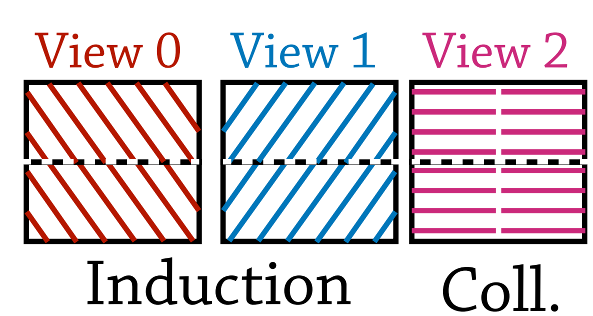


Bottom CRP

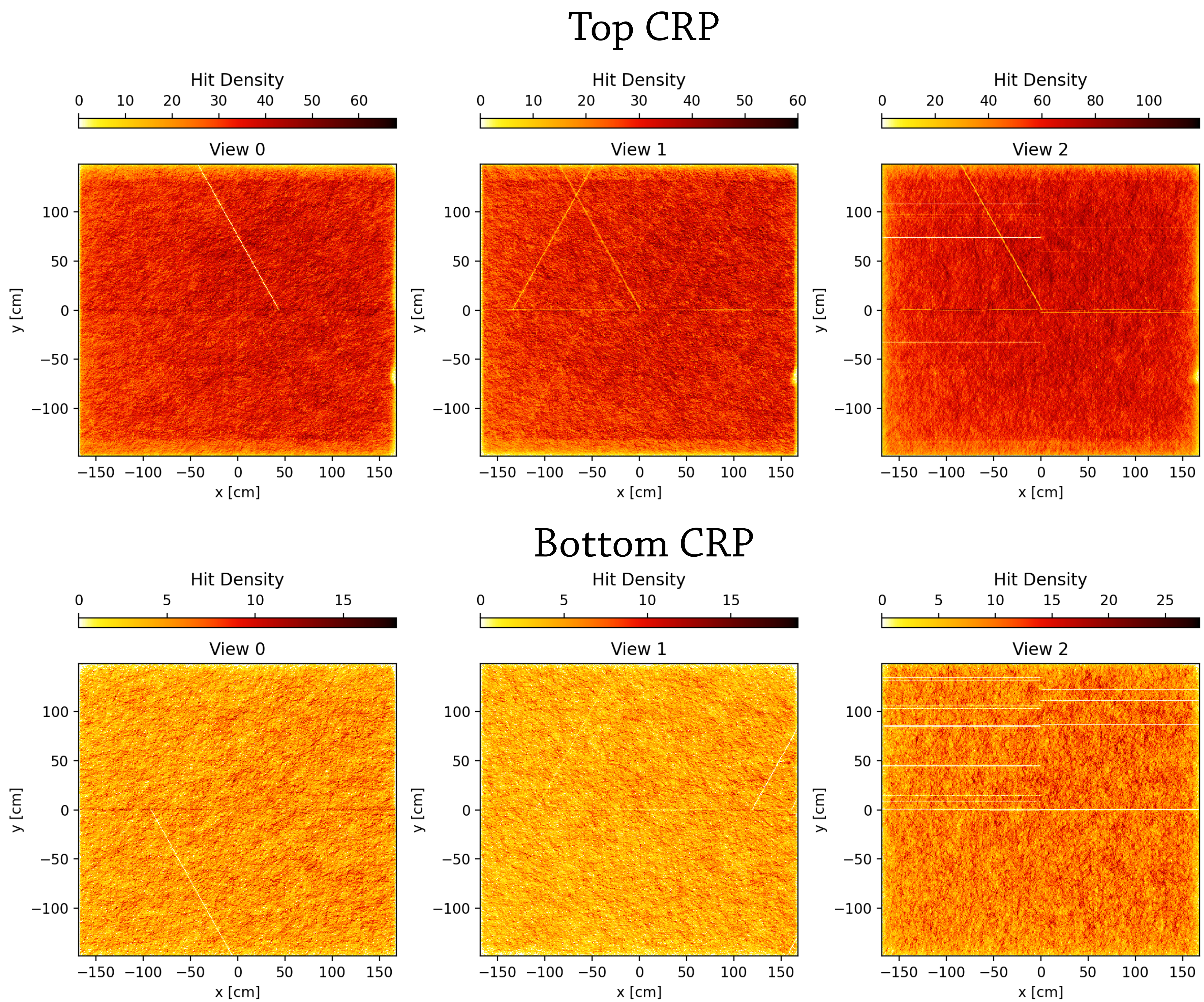


- Coherent noise filtered
- Bridge-shape due to the noise being proportional to the strip length

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

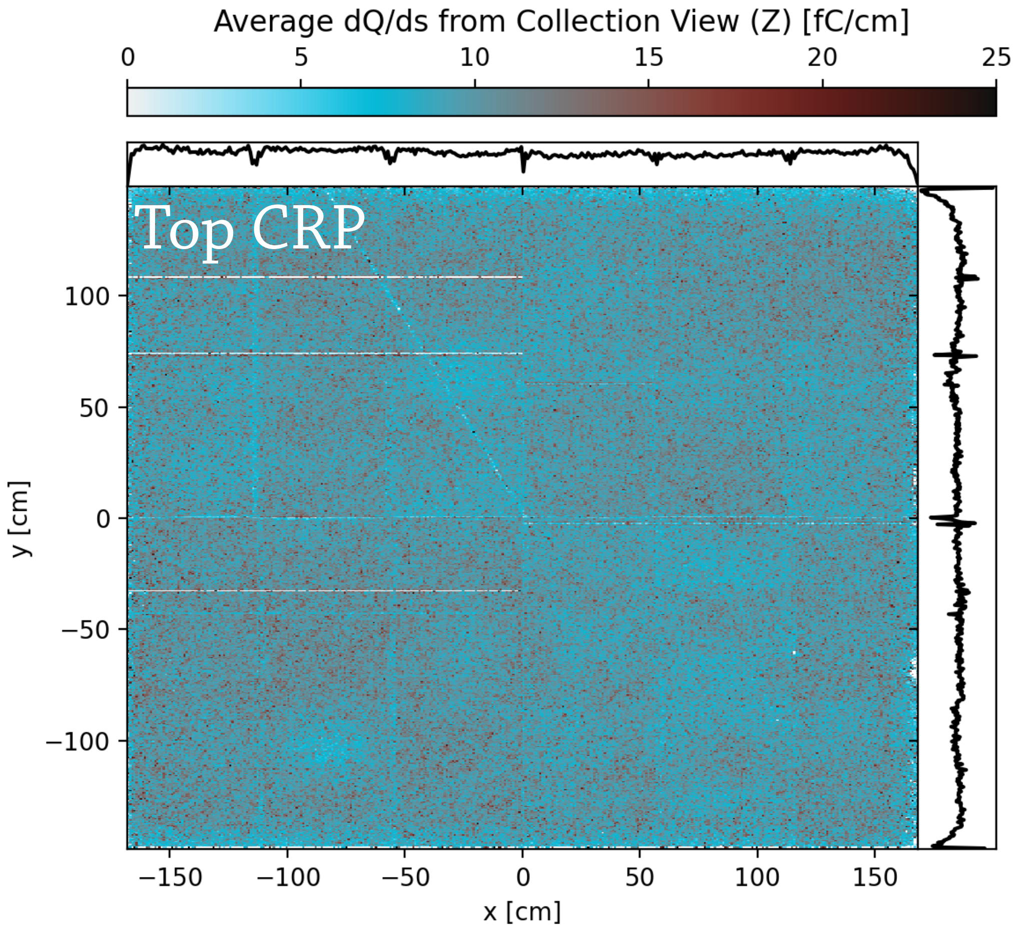


CRP Performance: Uniformity



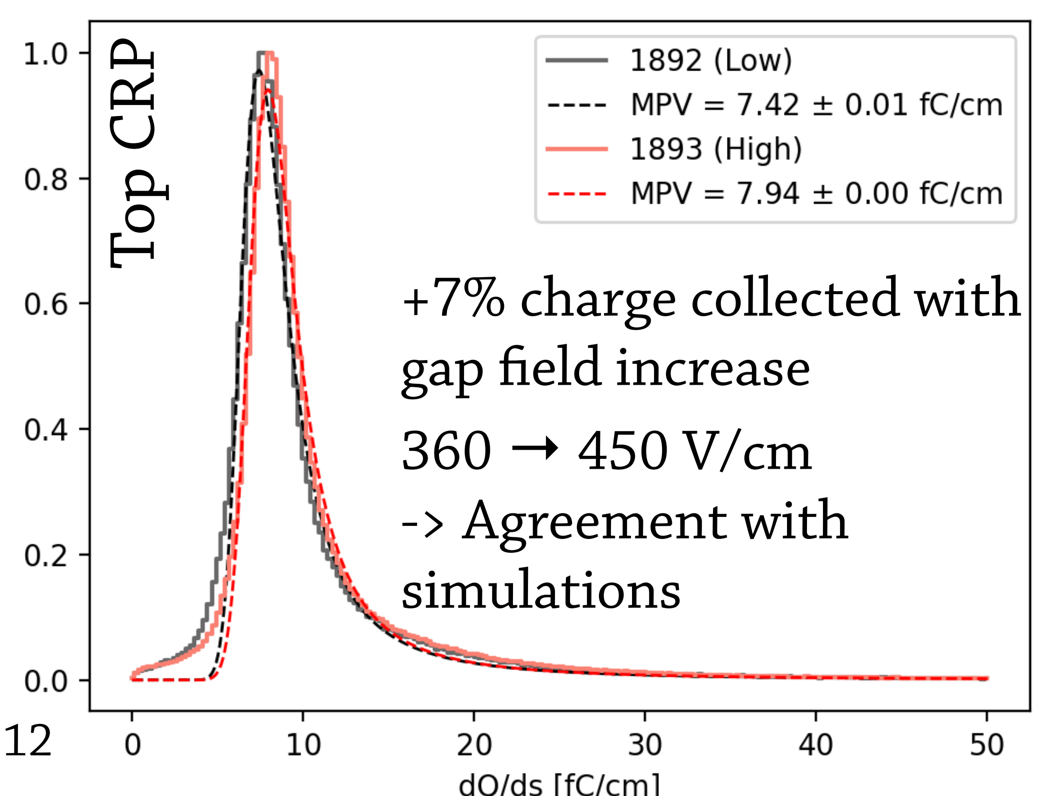
3D reconstruction of muon-like tracks allows to map the problematic channels of each view
-> Less than 1% of the channels are found problematic (out of 3072 channels/CRP)

CRP Performance: Calorimetry

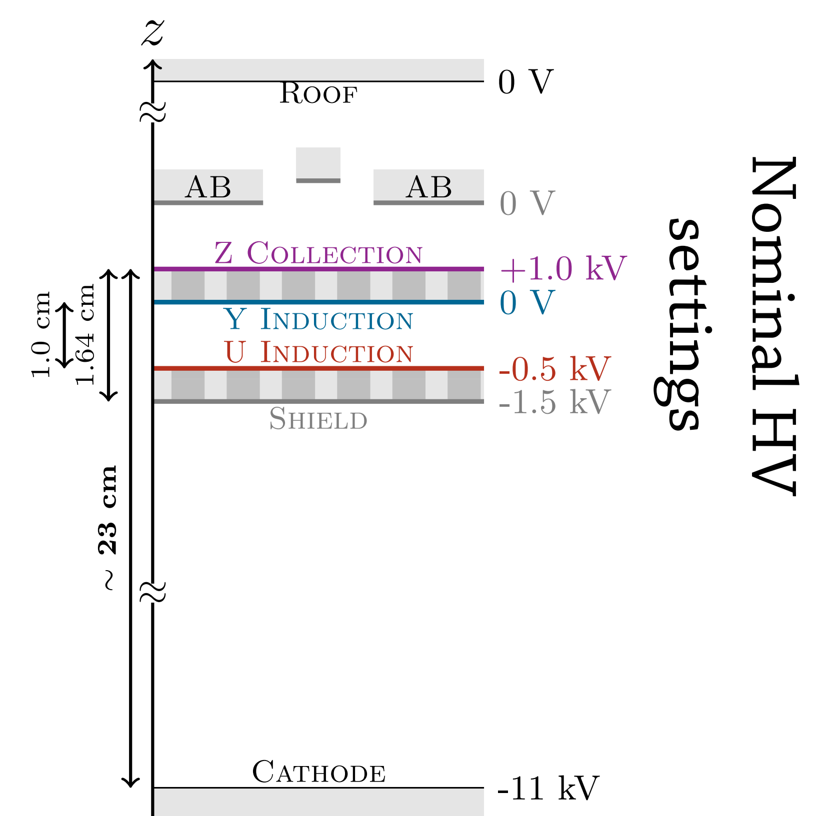


Average charge collected from muon-like tracks shows a good uniform response across the CRP surface

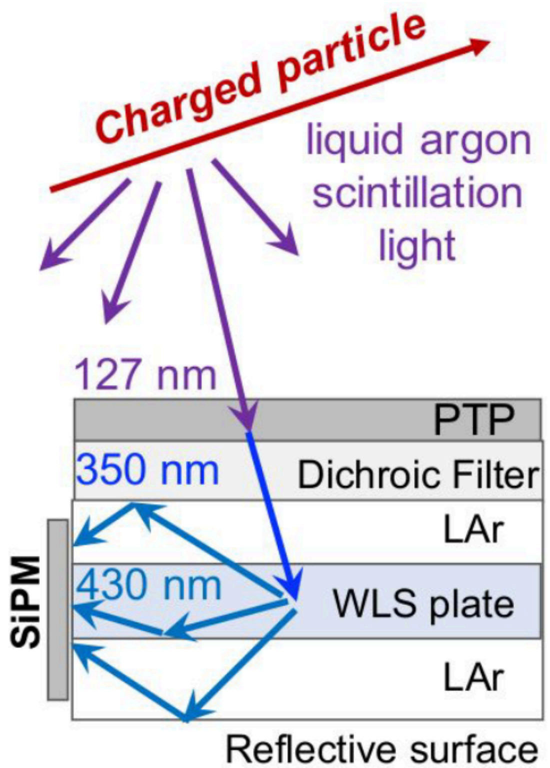
-> Vertical bands correspond to the PCB panel junctions



Ongoing studies to understand the CRP transparency as a function of the PCB biases with simulations and data from a R&D TPC



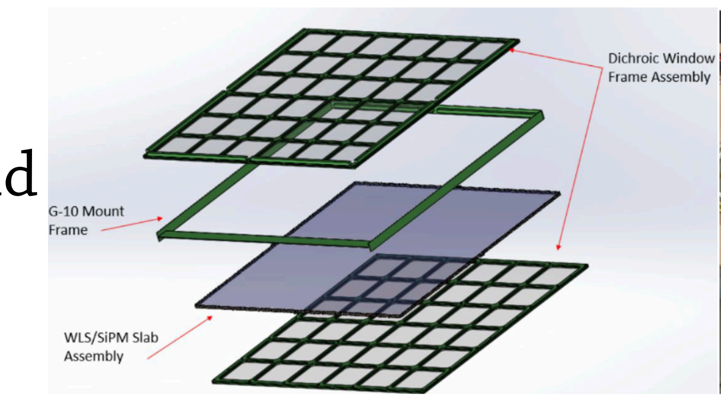
CRP Performance: Light

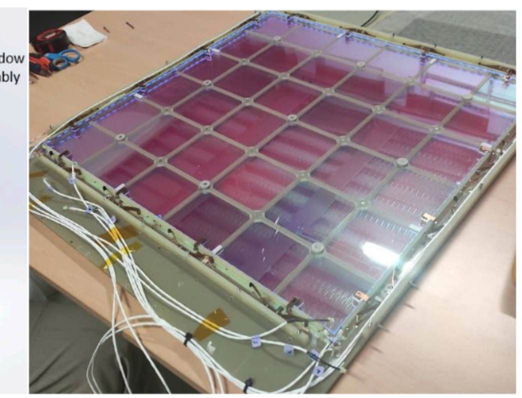


The X-ARAPUCAs acts as a light-trapping device with two wavelength shifters and a dichroic filter :

1. With PTP : 127 nm → 350 nm [dichroic is transparent]
2. With TPB : 350 nm → 430 nm [dichroic is reflective]

One module is 65×65 cm²
-> 2×36 dichroic filters and 2×80 SiPMs/module

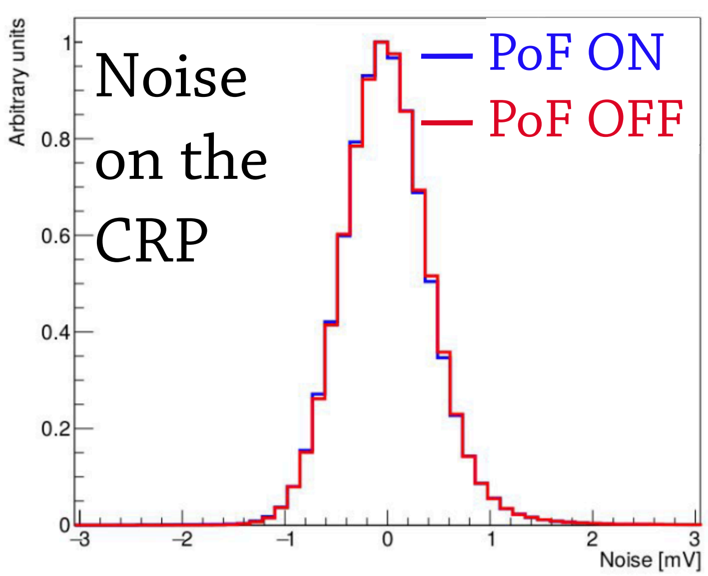




The X-ARAPUCAs are installed on the cathode powered at -300 kV

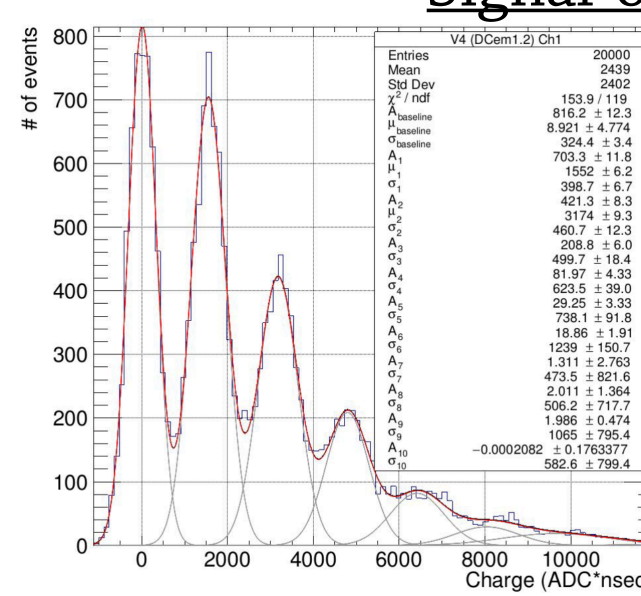
↳ Power and signal must be transmitted through non-conductive material : optical fibers

Power-over-fiber



- Stable operation in the cold box
- No impact on the CRP performance

Signal-over-fiber

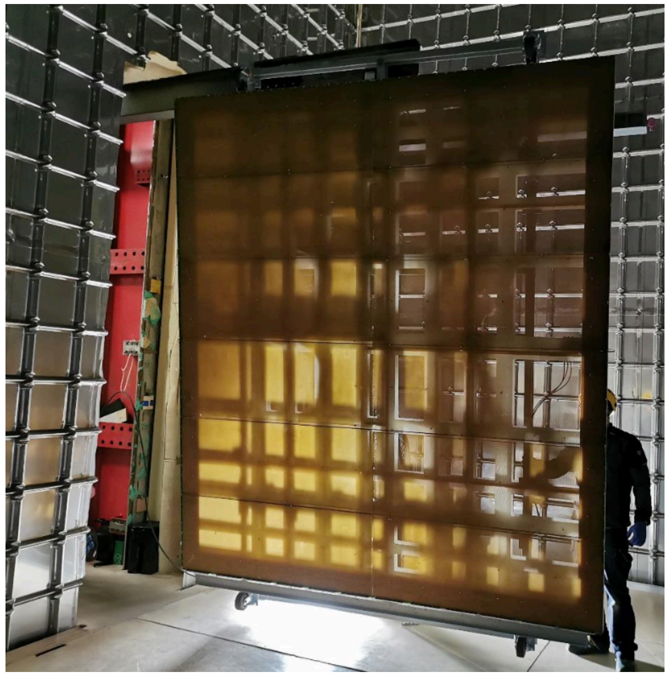


- System calibration with LED flash in the cold box
- Single PE distinguishable

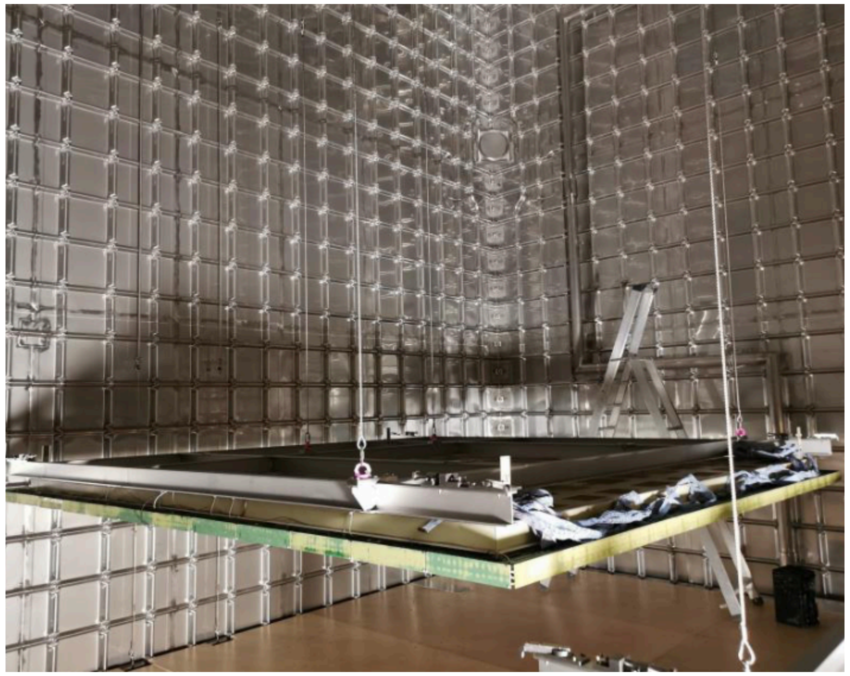
The X-ARAPUCA: an improvement of the ARAPUCA device, A.A. Machado *et al* 2018 *JINST* **13** C04026

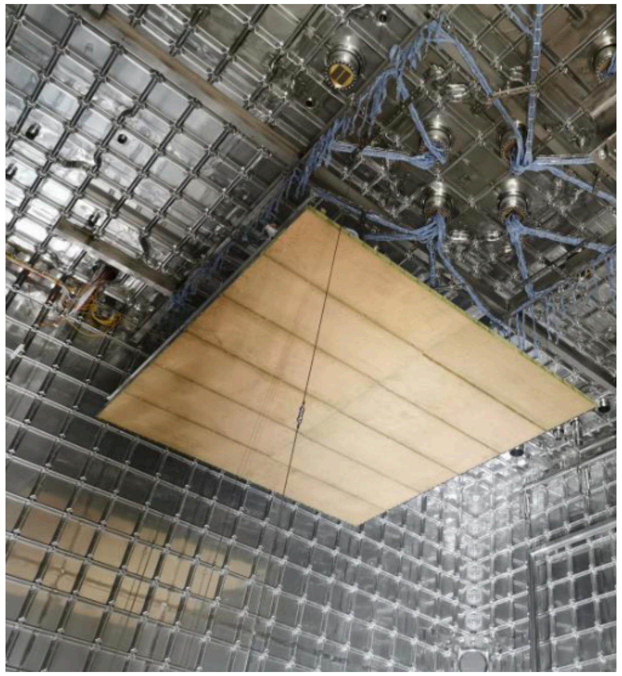
Installation of ProtoDUNE-VD: Top CRP

Insertion into the cryostat

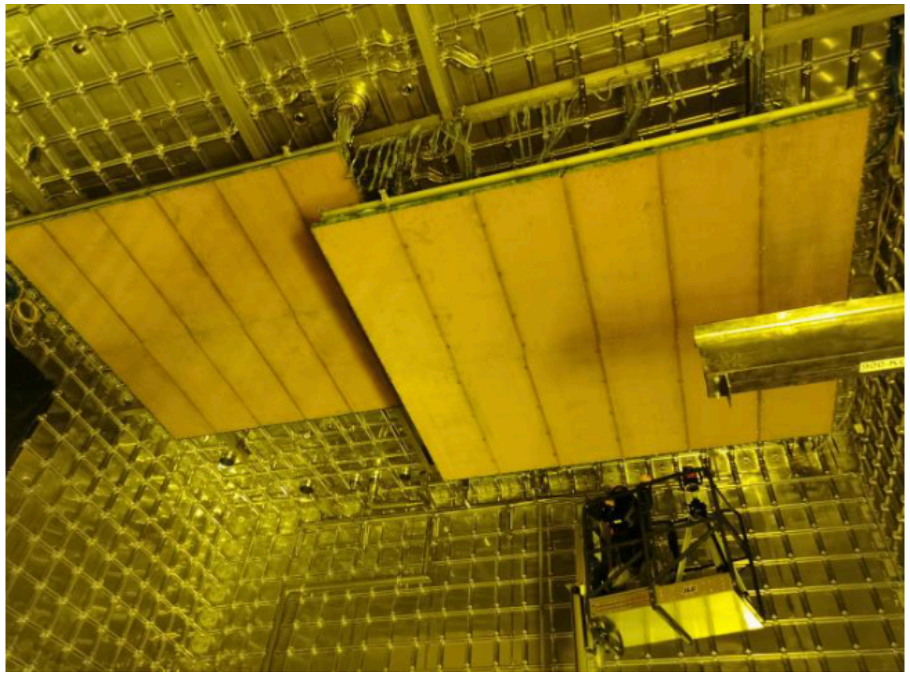


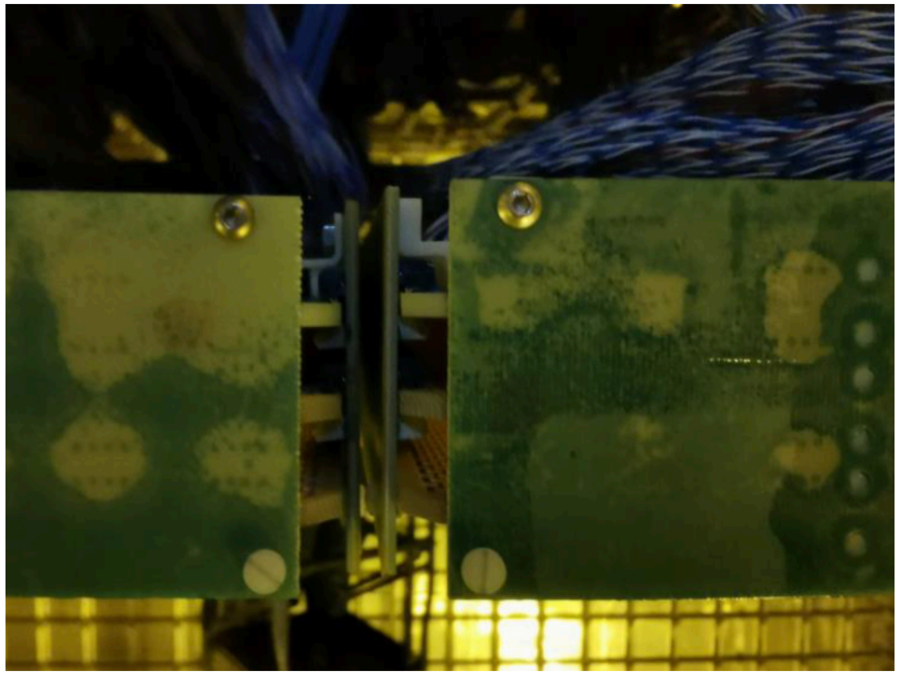
CRP lifting to the roof and cabling





Top CRP alignment

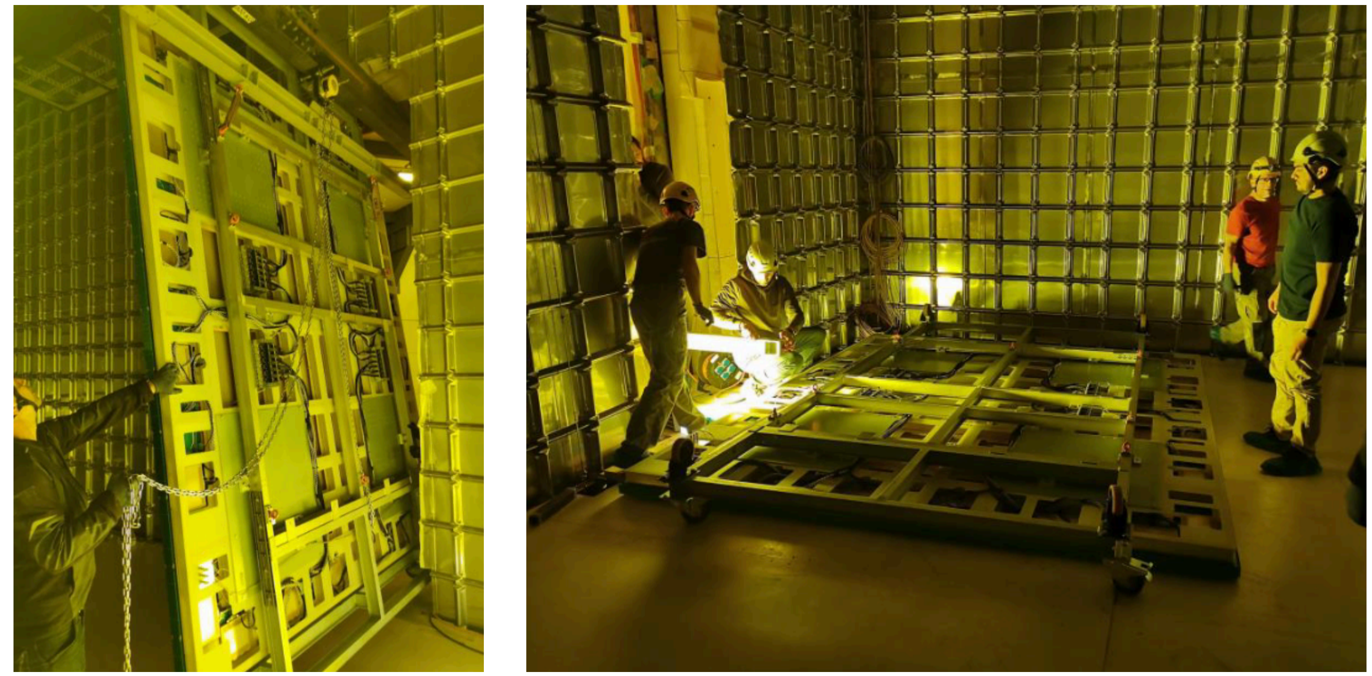




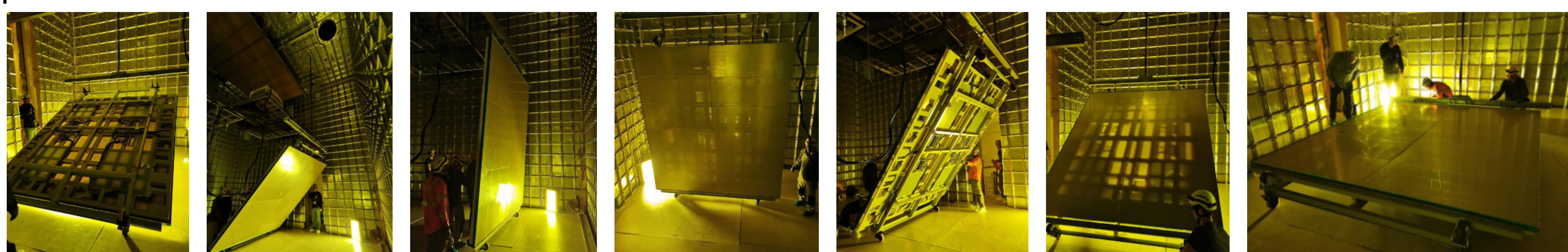
Installation of ProtoDUNE-VD: Bottom CRP

CRP transportation from ColdBox

CRP insertion into cryostat



Bottom CRP lifting, flipping, lowering procedure

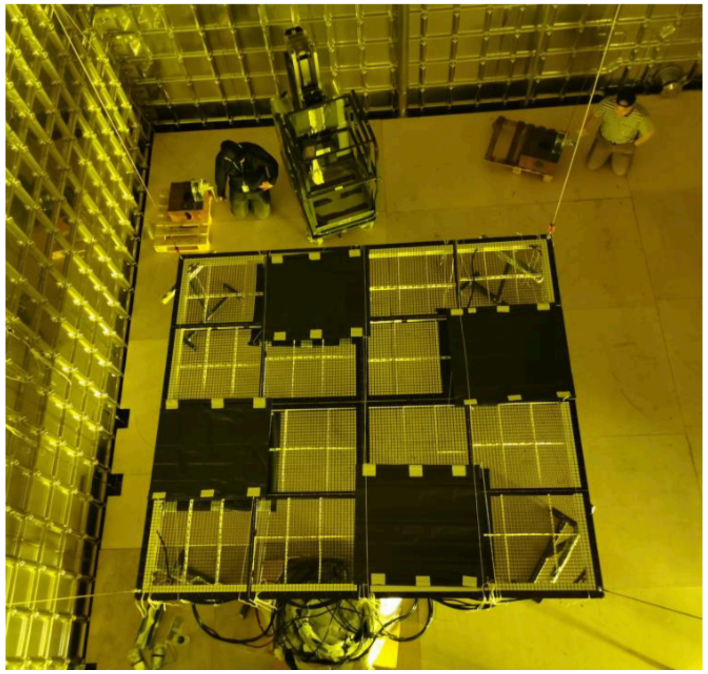


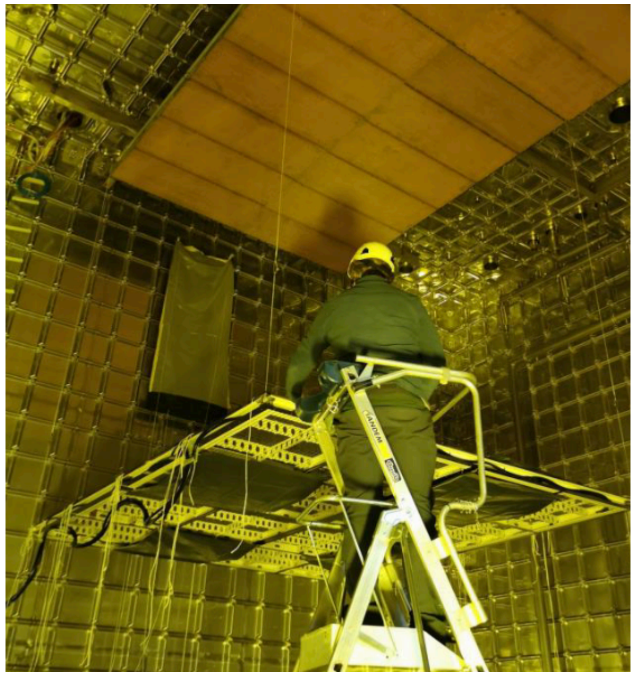
180° rotation

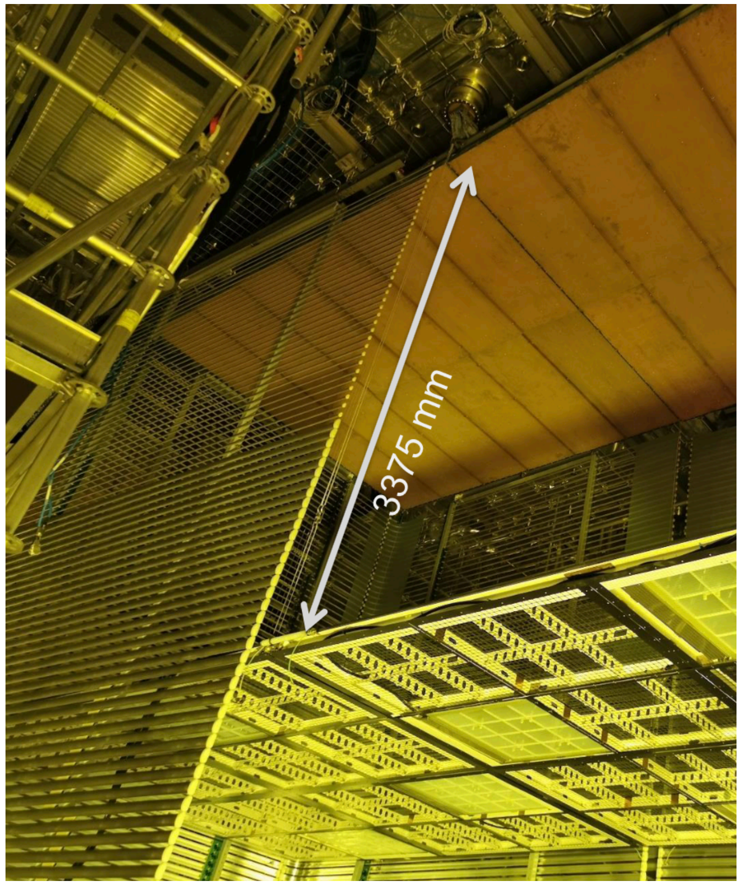
Installation of ProtoDUNE-VD: Cathode

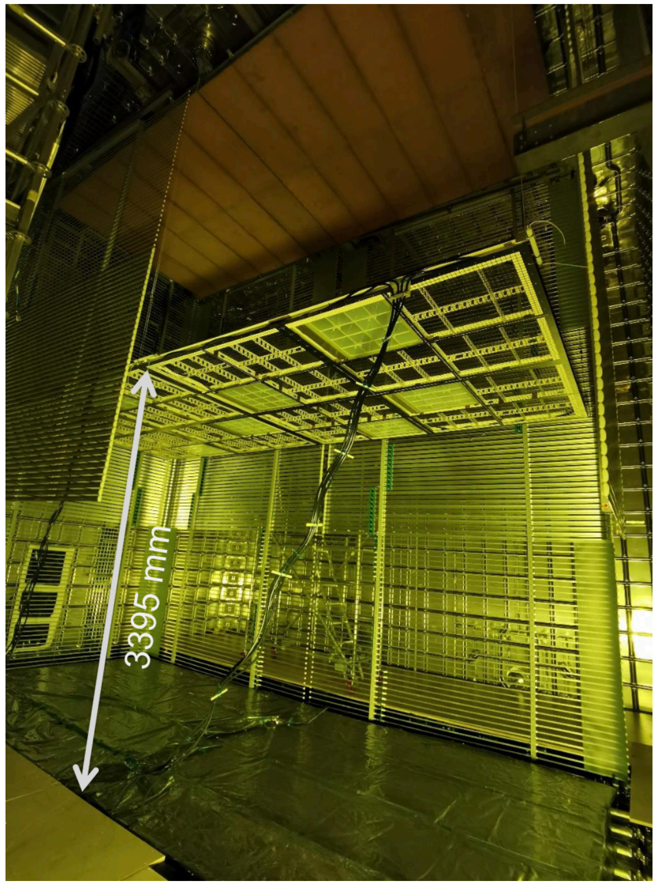
Cathode insertion in cryostat

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

Conclusions, Perspectives

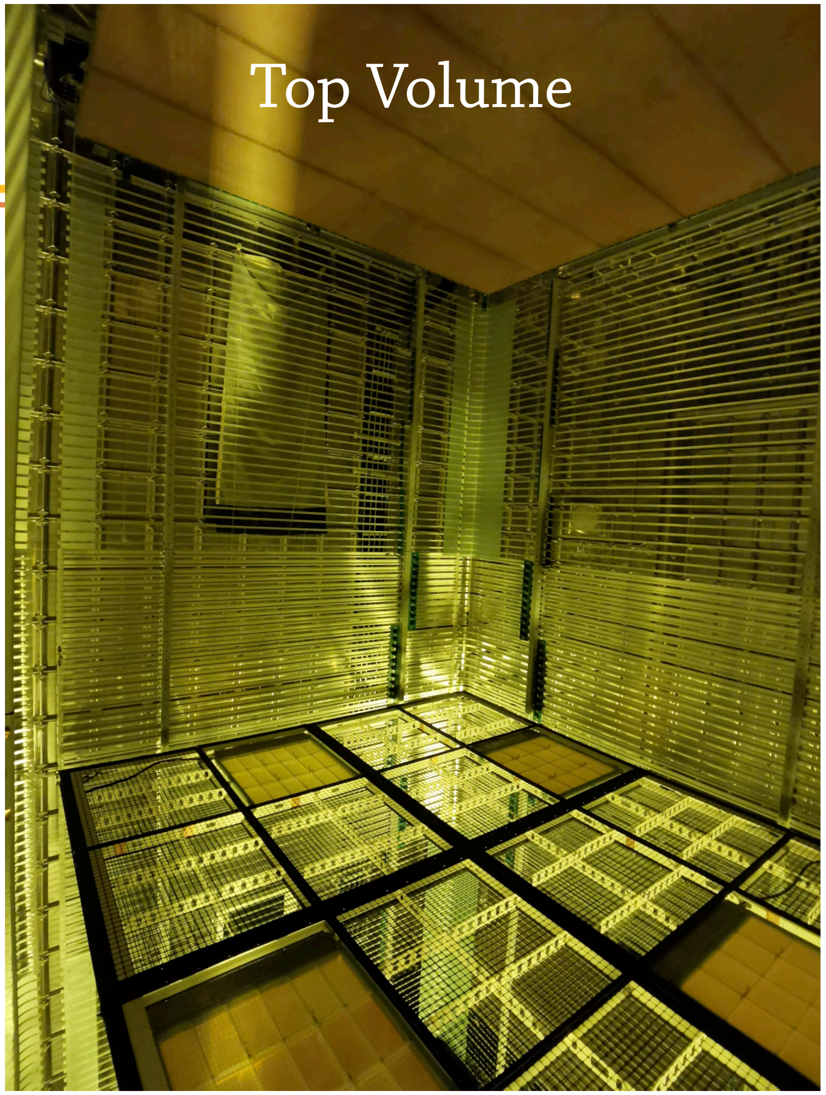
- The second far detector module of DUNE will be a Vertical Drift LArTPC design

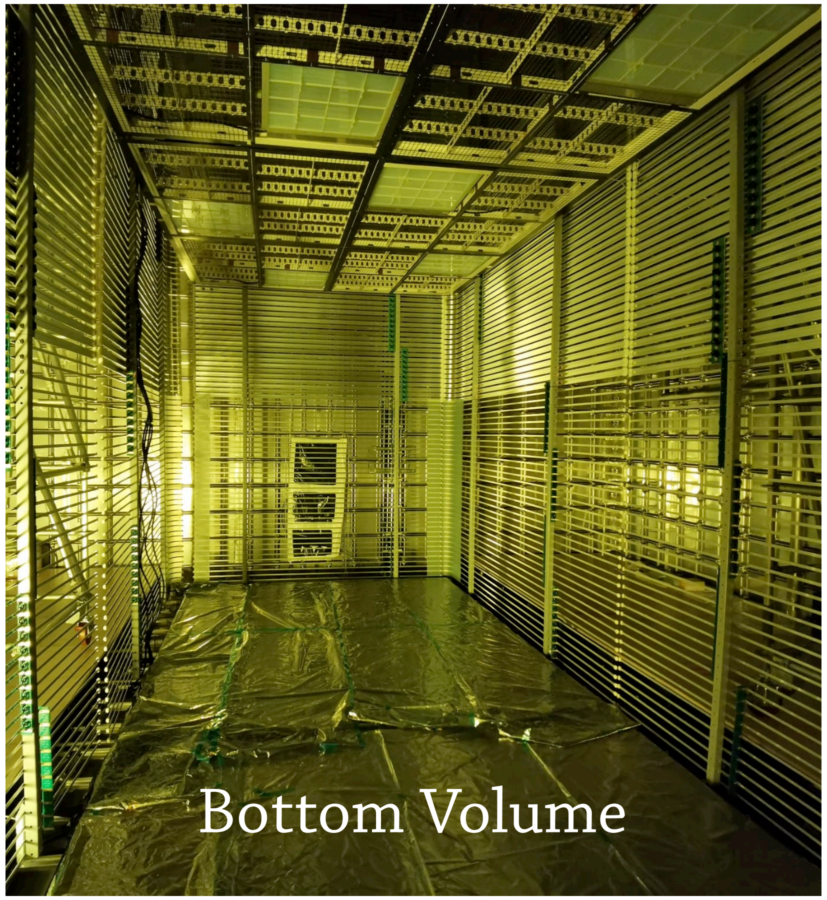
- VD concept will be tested at large scale in ProtoDUNE-VD with cosmics and beam data:
  ↳ e/p/π/K/μ beam for calibration & physics analysis

- All main elements of ProtoDUNE-VD have now been installed and previously tested in the ColdBox:
  ↳ CRPs, Cathode, Field Cage, Light Detection System

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

- ***Cryostat closure foreseen in October 2023, LAr filling should start by the end of the year***



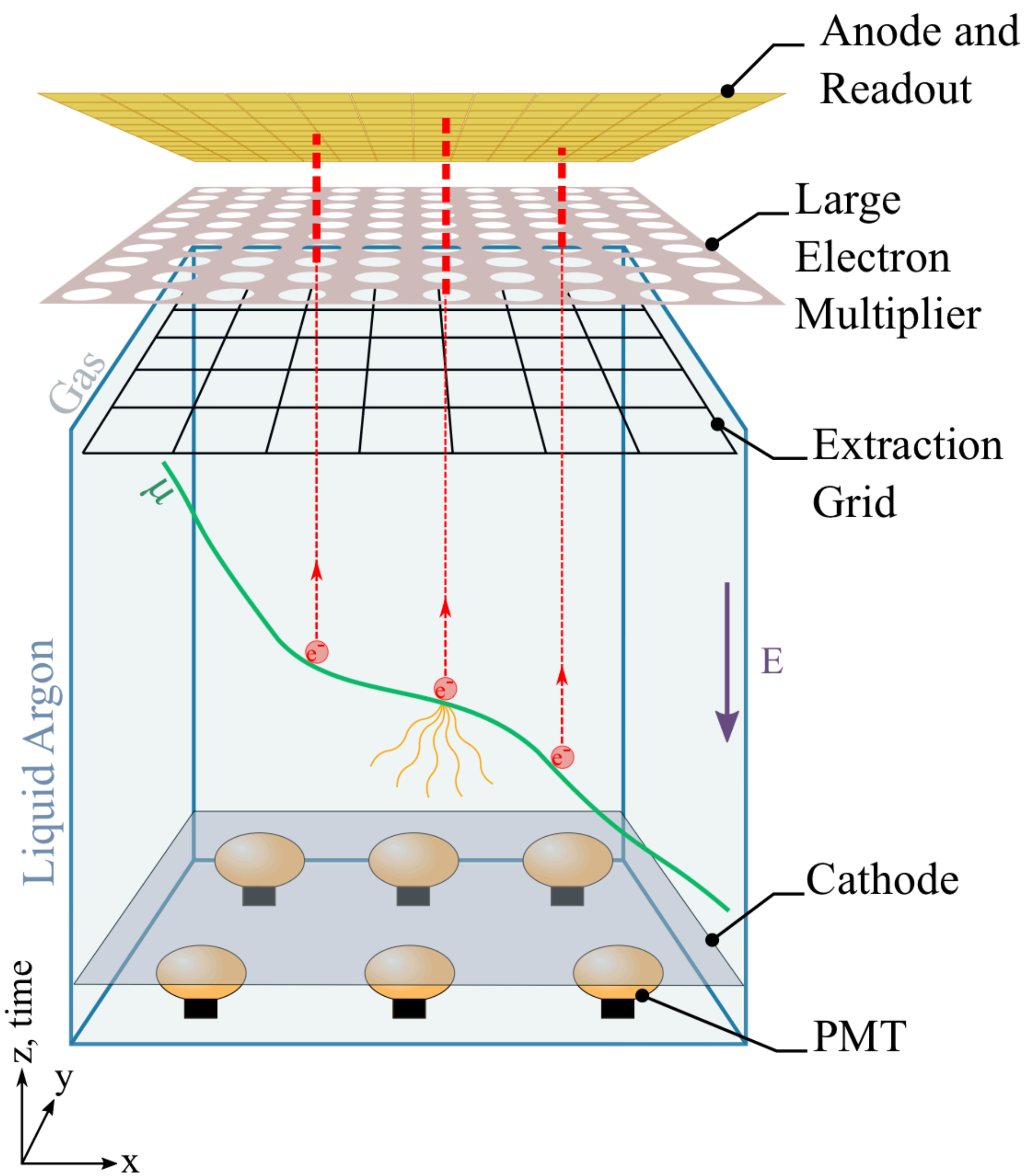


BACKUPS

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 up to 2020.

2019~2021 : Operation of ProtoDUNE-DP

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

Operation successes:

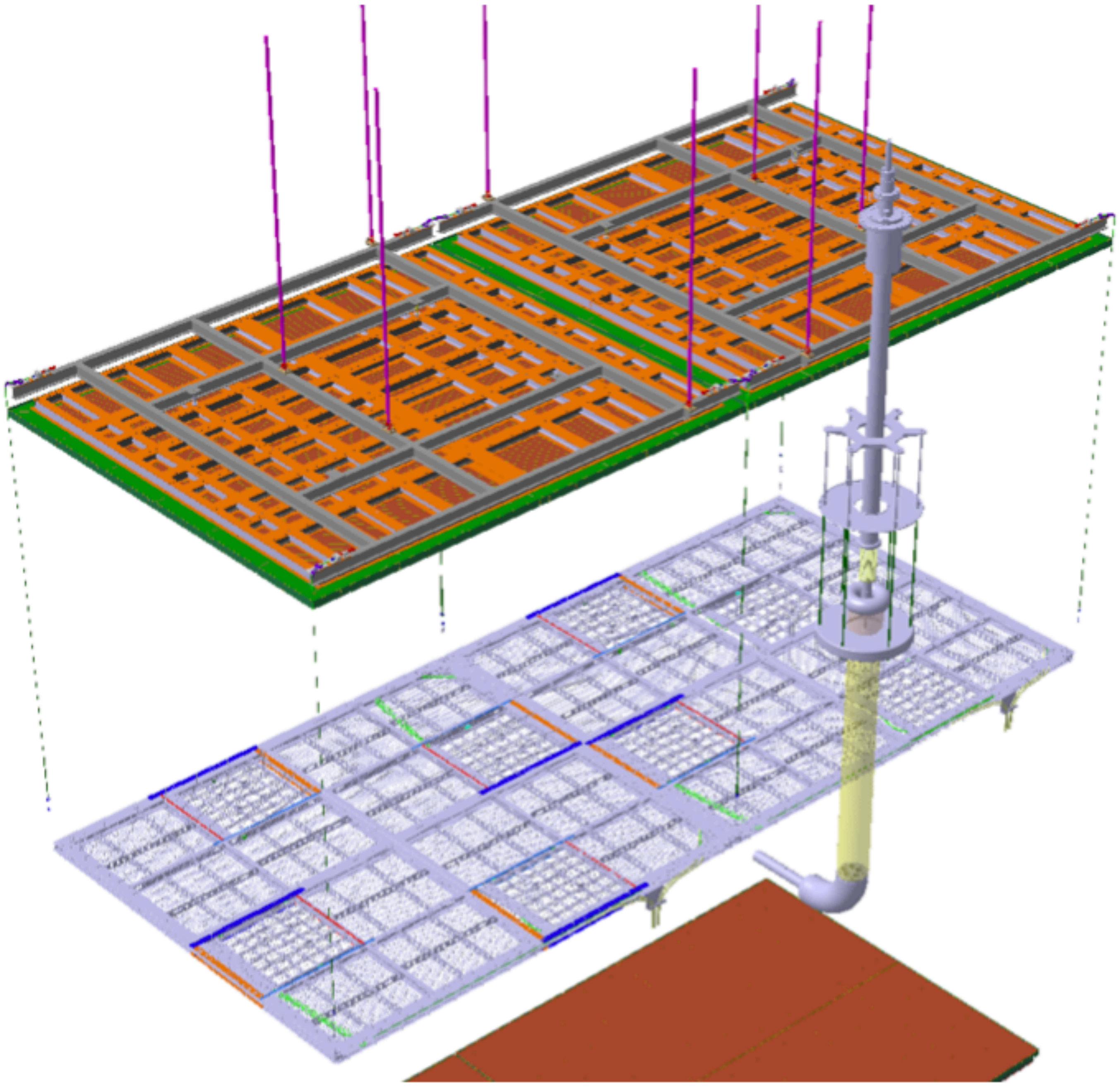
- Good purity of LAr achieved
- Drift field of 500 V/cm over 6m

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***

High Voltage to the cathode



FD-2 schedule

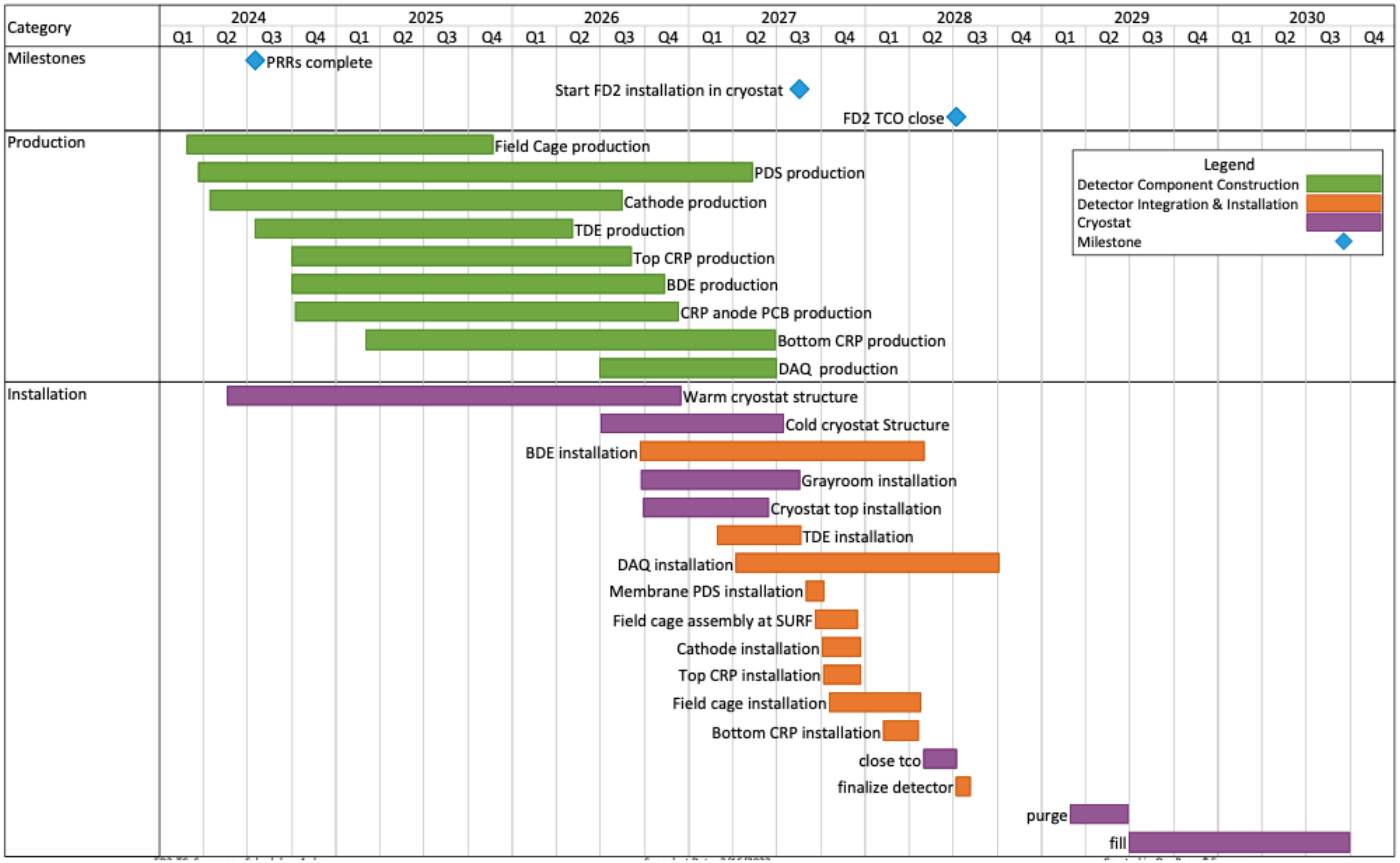


Figure 10.6: Vertical drift production and installation schedule, based on FD2-VD production estimates. Gap between TCO closing and purge/filling results from cooling power needs for FD1 filling. (Data from [55])