Status and plans of ProtoDUNE - Vertical Drift (NP02)

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on behalf of the NP02 Collaboration

Summary of the main NP02 activities and progresses since last report in April 2023

Report Document: http://cds.cern.ch/record/2896627

153rd SPSC meeting
May 7th , 2024

Outline:

- Introduction
- Vertical Drift Detector latest developments:
  - CRP upgrades
  - Photon Detector System
- NP02 Cold Box activities and tests
- Improvements in Module-0 and preparation to run
- Integration tests for DUNE FD2 module
- Summary and plans

Introduction

NP02 activities:

Intensive activities at the neutrino platform => leading to tests, validation and finalisation of vertical drift detector component designs for DUNE FD2 module:

- ❑ Detector assembly
- ❑ Cold box tests
- ❑ Module-0 detector integration
- ❑ Development of installation test stands for several FD2 key systems

In parallel:

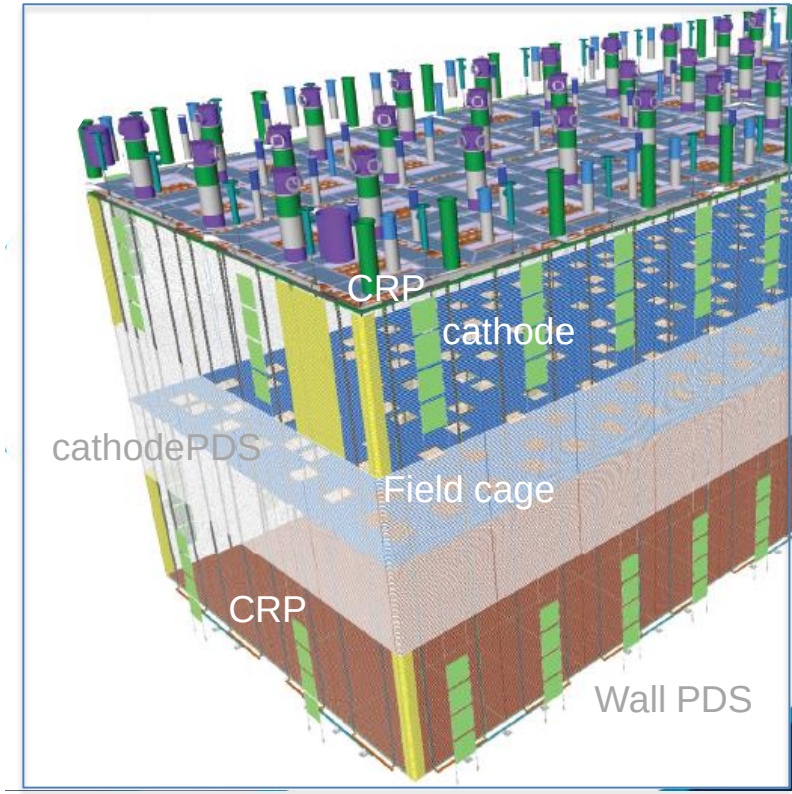
Significant progress achieved within the DUNE collaboration in 2023 towards the implementation of the second DUNE Far Detector (FD2) module based on the Vertical Drift (VD) technology.

This process included:

- the Vertical Drift TDR: https://arxiv.org/abs/2312.03130 submitted to JINST
- the Final Design Reviews for all the TPC components of FD2 in 2023:
  - ➢ CRP, PDS, TDE, BDE, HV system, DAQ

Production Readiness Reviews (PRRs) for the DUNE detector component production ongoing since this year, a few already concluded.

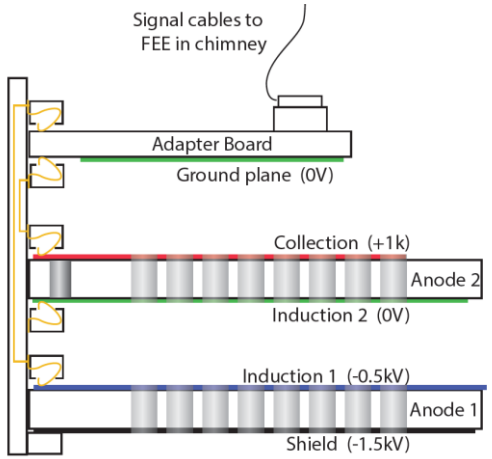
DUNE FD2 Vertical Drift detector

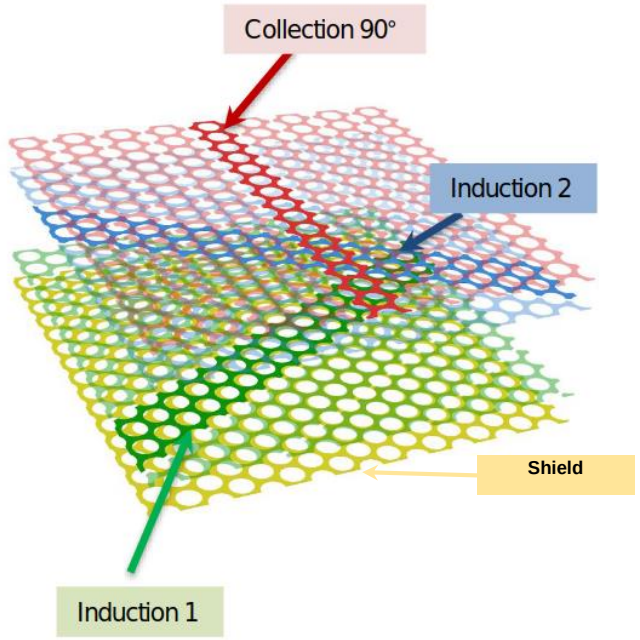


Charge Readout Plane (CRP)

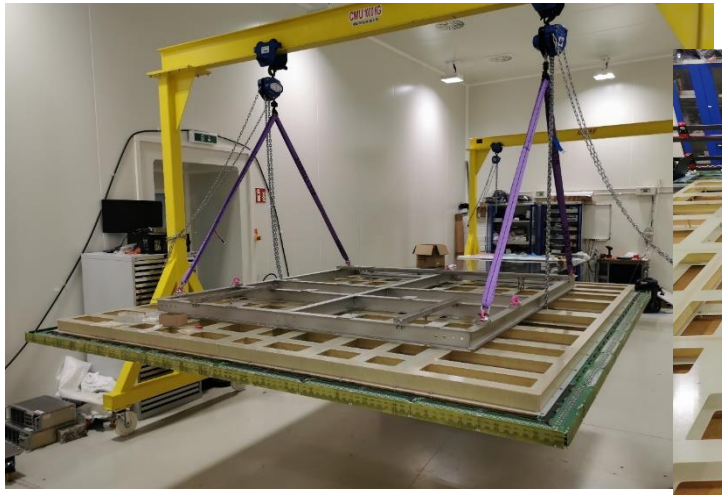
Design features: validated in 2022 in the cold-box with the 4 CRPs installed in Module-0 beg. of 2023

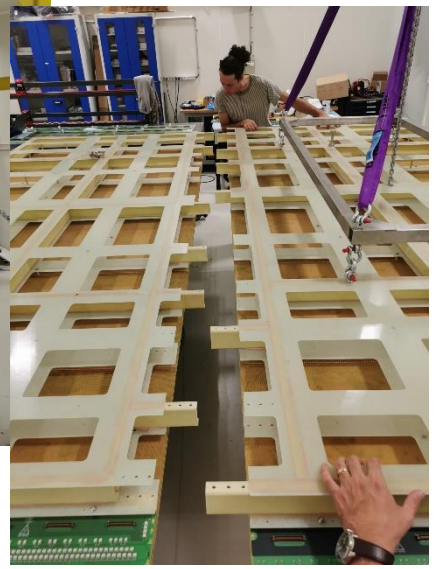
- Three view anode layout with perforated PCBs
  - +30º, -30º, 90º strip orientation with 5.1mm collection, 7.65mm induction strip pitches
  - 3072 readout channels for each CRP

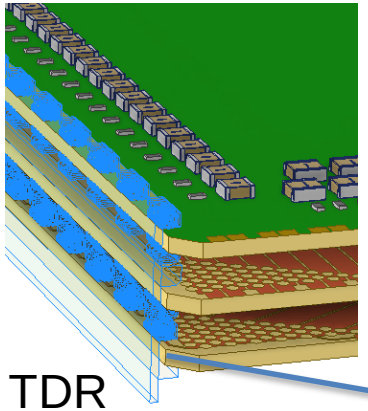




Composite frame design:







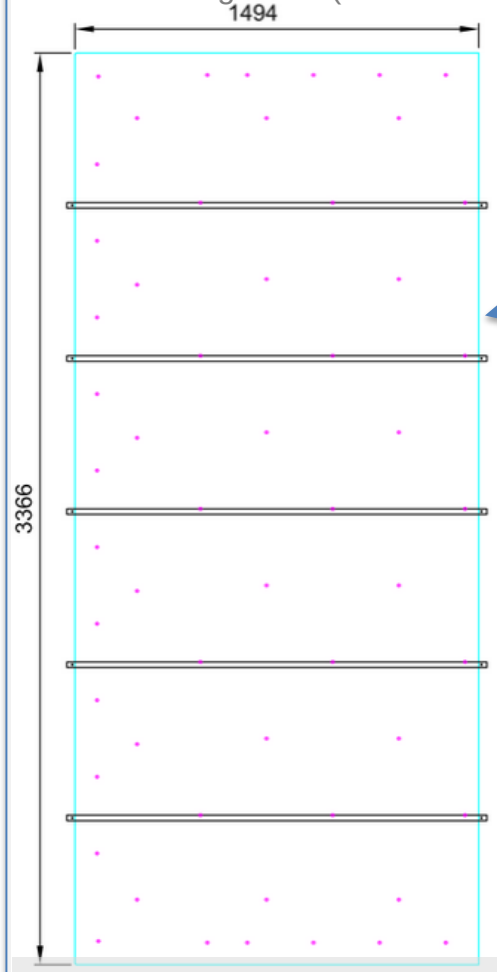
Edge cards: to allow strip connection to adapter boards for bottom and top drift electronics:

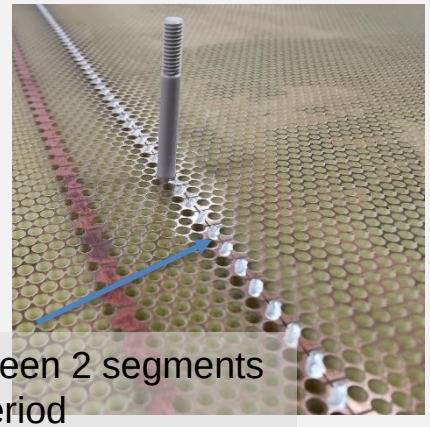
Presented in FDR in April 2023 and described in DUNE VD TDR
https://arxiv.org/abs/2312.03130

CRP value engineering:

Original anode PCB assembly process (2022)

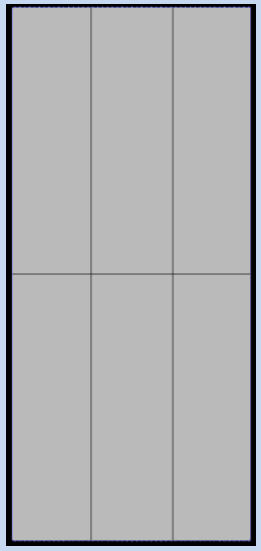
3.2mm thick PCB with copper strip pattern on both sides
All copper strips cross several panels => require electrical connection between segments (several thousands per CRP)

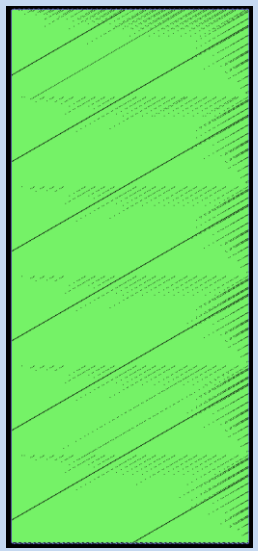


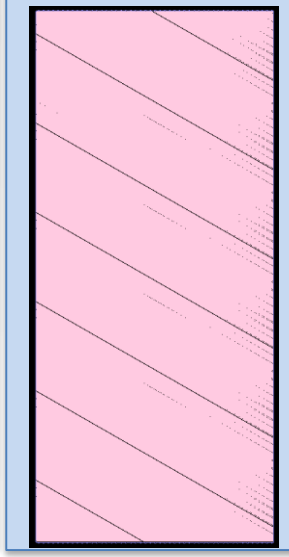


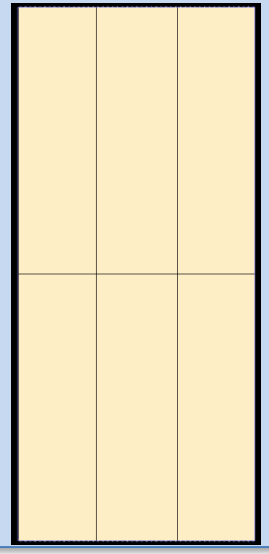
Silver printing to bridge the strips between 2 segments
=> special heat treatment for a long period

New anode PCB assembly process (since August 2023)









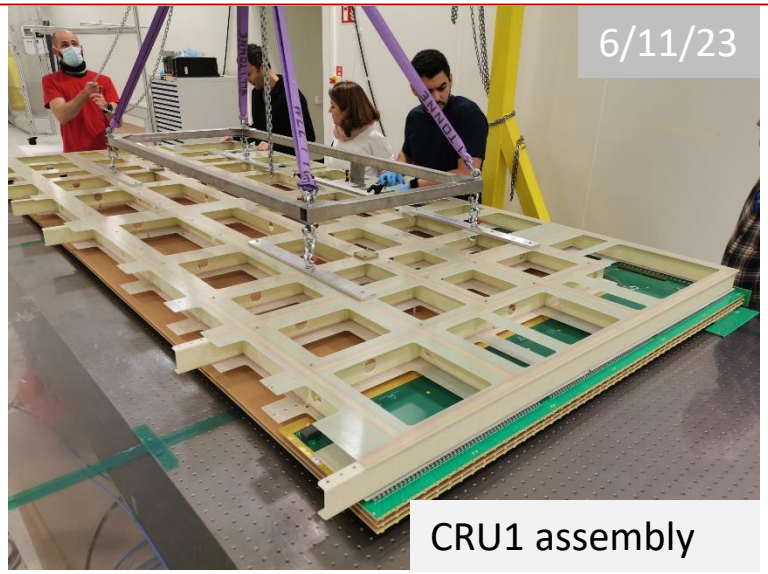
- 1.6mm thick PCB with copper pattern on one side. Copper pattern follows the strip pitch and orientation.
- The second side for the induction-1 and induction-2 has bare PCB base material while Shield and Collection segments are laminated 3M VHB adhesive tape

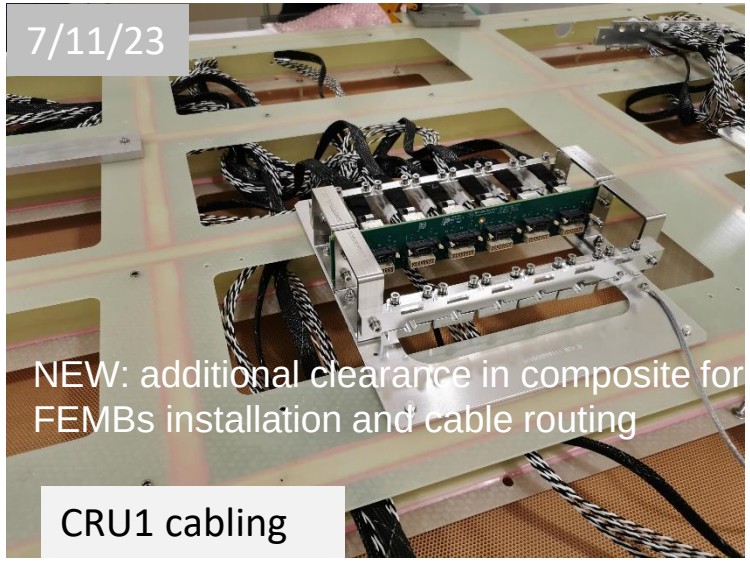
No more silver printing nor epoxy gluing => assembly time much reduced

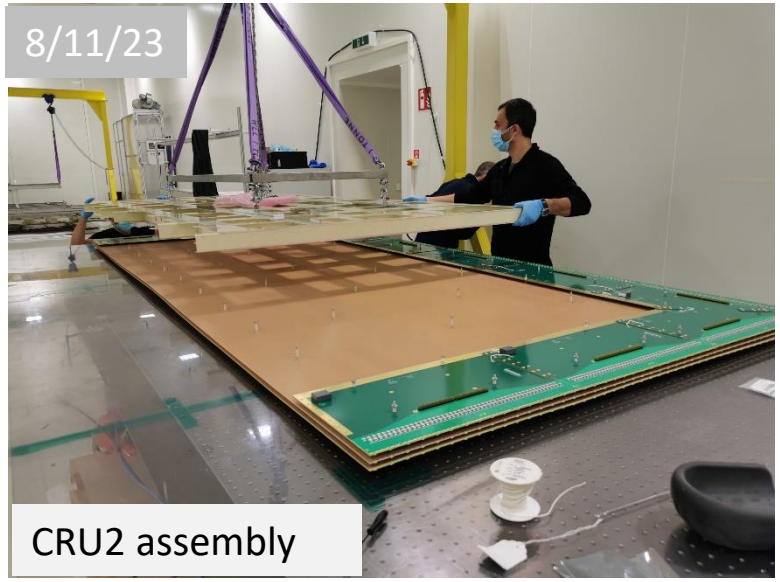
CRP new prototypes

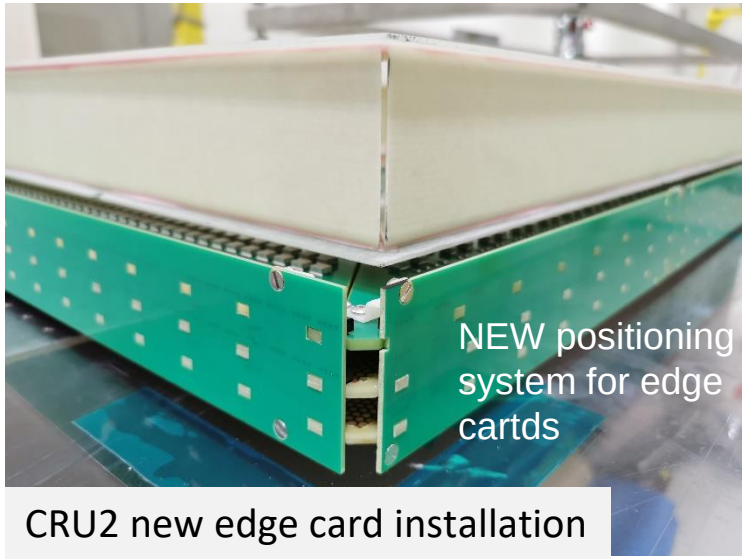
Some CRP6 construction steps

With the upgrades described, two new CRPs were built at CERN from fall 2023 to early 2024 => a Bottom (CRP-6) and a Top (CRP-7).







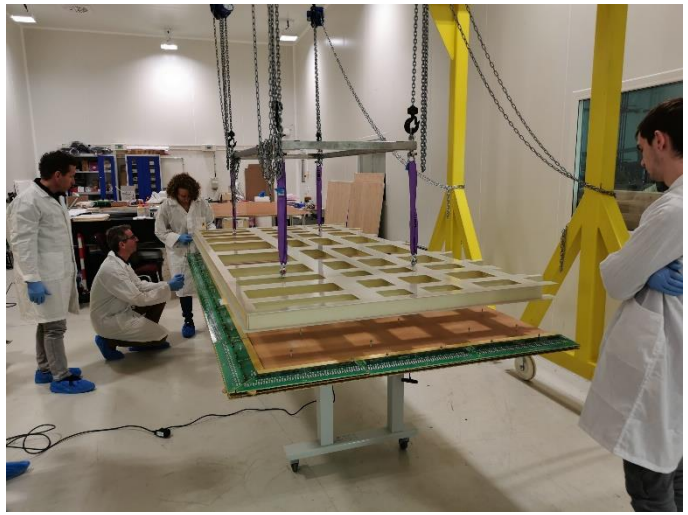


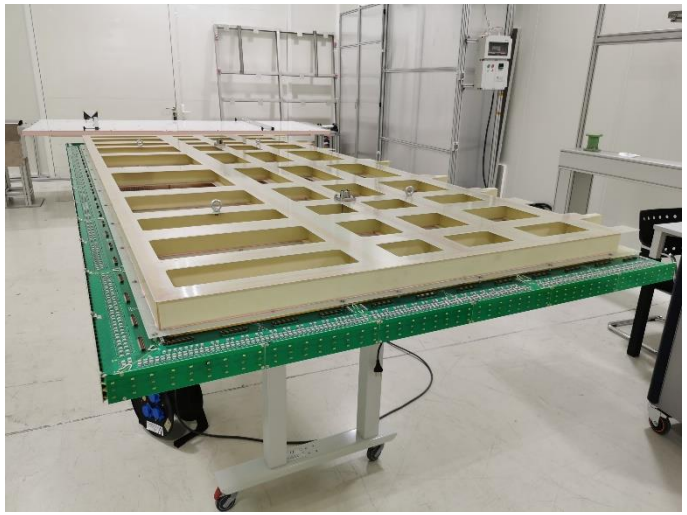
CRP assembly

For the CRP7 (Top version): the tooling developed by Grenoble for the Top CRP factories have been brought to CERN for its construction in February 2024

⇒ Very important step to optimise and validate the tooling with a full scale assembly sequence

⇒ Very useful to verify and define all the procedure steps and time evaluation





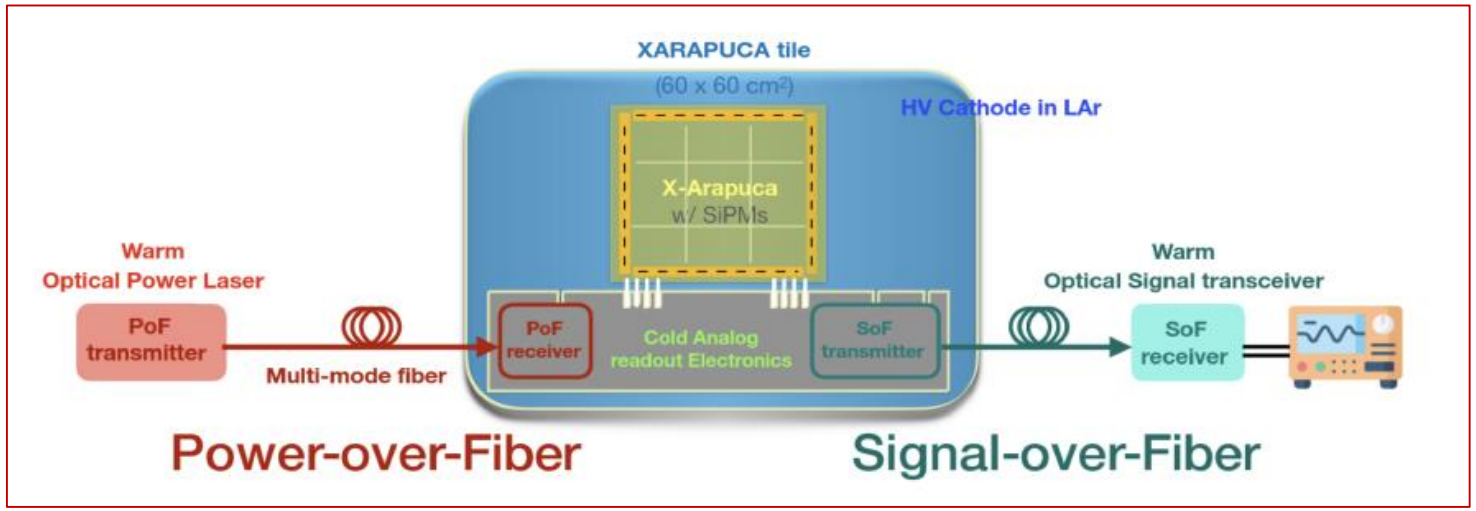
A full CRP assembly at CERN (without cold test) takes less than 2 days when the anodes are built and tested

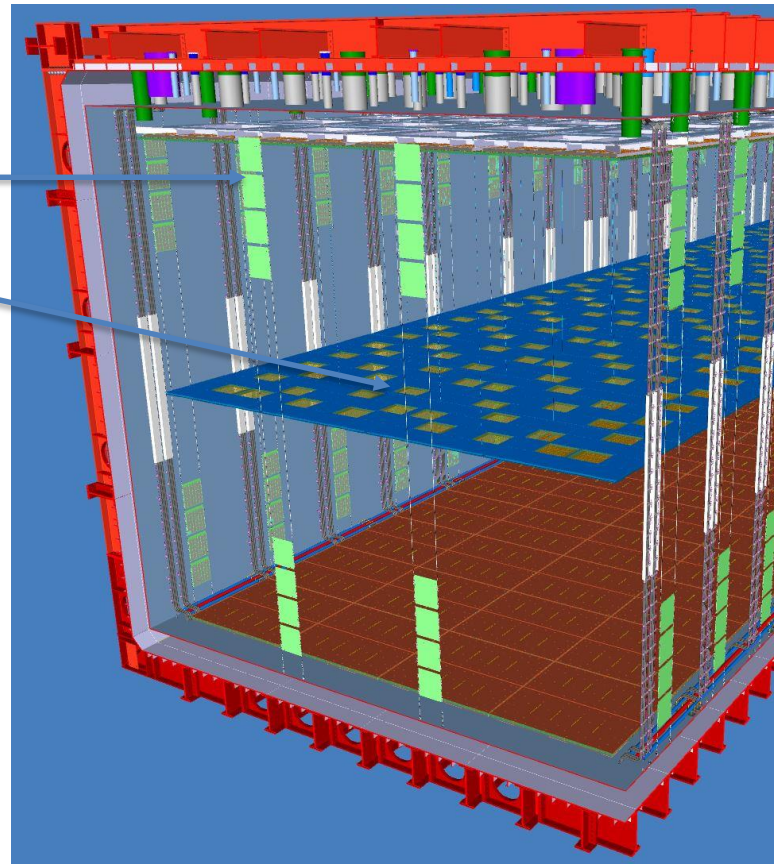
CRP factories in Europe (Top) and in US (Bottom) are being set up for full DUNE production during the year 2025

Photon Detector System (PDS)

PDS configuration in DUNE-FD2 (replicated in NP02):

- xArapuca modules on the cryostat wall behind 70% field cage transparent
- xArapuca modules on the cathode seeing top and bottom volumes
  - ❑ => to operate xArapuca modules at HV, developed Power over Fibre (PoF) and Signal over Fibre (SoF) technologies (to use electrically floating photo-sensors and read-out (r/o) electronics)





- Validation of readout solutions mostly done in 2022 and pursued in 2023
- A series of successive prototypes of double-sided cathode-modules and single-sided membrane-mount modules with dedicated CE readout boards, were produced and tested in real cryogenic and powered cathode conditions.
  - ❑ => Integration in Module-0 in 2023 of 8 cathode-mount modules with on-board PoF/SoF electronics and 8 membrane-mount modules with CE electronics via standard copper cable transmission

PDS development in 2023-2024

Following DUNE FD2 PDS reviews a program has been developed with the aim to do:

- ❑ the complete optimization of the cold r/o electronics,
- ❑ the finalization of the warm r/o stage (Signal-over-fiber output conversion and digitization),
- ❑ the integration with DAQ and other systems, and
- ❑ the preparation for mass production.

This includes:

- long-term testing of the cold electronics,
- stability and tuning of the gain of the signals,
- channel to channel variation minimization, and
- integration of the SoF conversion stage with the DAPHNE digitizer at the warm end of the FD2 PD electronics chain.

These tests have been fully integrated in the joint CRP-PDS cold box tests done since end of 2023

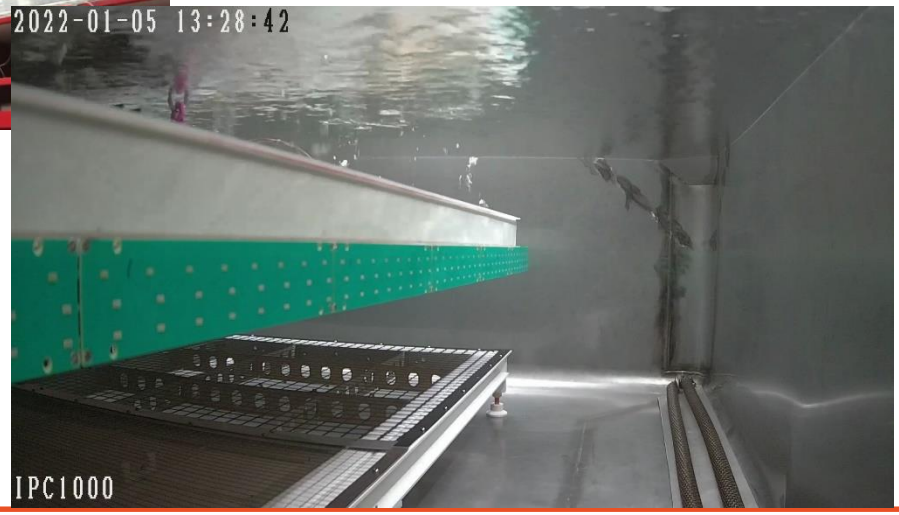
NP02 Cold box

The cold box is an instrumental tool for the development, tests, characterization and validation of CRP and PD systems since 2021 at EHN1.

Cold box size and cryogenics allow to run in TPC mode in liquid argon with full scale size FD2 VD components CRP, PDs and cathode
=> test the different electronics, the detectors and their integration

Closure of the coldbox 21/12/23

Cathode with
4 x-ARAPUCA modules



Cryo-camera view after Liquid argon filling in January 2024

Quick turnaround cycle:
=> TPC used 11 times since 2021

NP02 Cold box tests

major activity end of 2023 to April 2024

3 main coldbox tests with CRP and PDS

Used for value engineering tests on anode design, BDE grounding and to perform long term stability PDS studies together with system integration

2023 **2024**

Nov 28th | Dec 4th | Jan 11th | Feb 12th | April 4th | April 26th

First run CRP6-I

Bottom CRP6

Noise higher than Module-0 CRPs =>

- Imbedded mesh in composite not ok
- CE power cables induce noise on collection strips

Install a new ground plane identical to CRP of Module-0
Shield some specific areas where CE cables parallel to strips

run CRP6-II +PDS

Noise much improved and effectiveness of additional CE cable shield.

Charge collection non uniformity with nominal bias values observed as in Run I

Noisy channels on 2 CRP corners at cold

- Upgrade the ground plane on CRP side A to add CE cable shielding everywhere
- Study the PCBs doing details imaging processing on many samples

⇒ Found a systematic shift in hole alignment from PCB production process

⇒ A small change is made when building a new anode for 1 side of the CRP to mitigate for the 3rd test;

run CRP6-III +PDS

Noise on side A is reaching the optimal value.

Charge collection uniformity is slightly improved as expected at nominal settings;
Transparency Is fully recovered if increase of inter PCB field

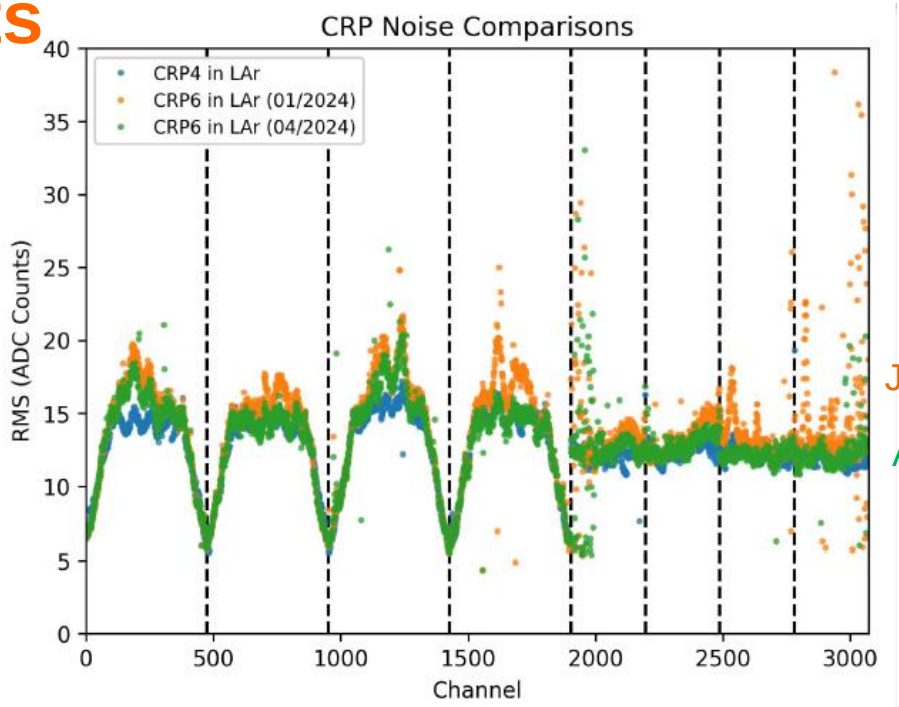
A new production of perforated anodes is expected with the shift problem solved => a new CRP should be constructed and tested in September 2024

PDS: the 2 long runs in 2024 were essential and important to study the long term stability of the electronics

Cold box tests

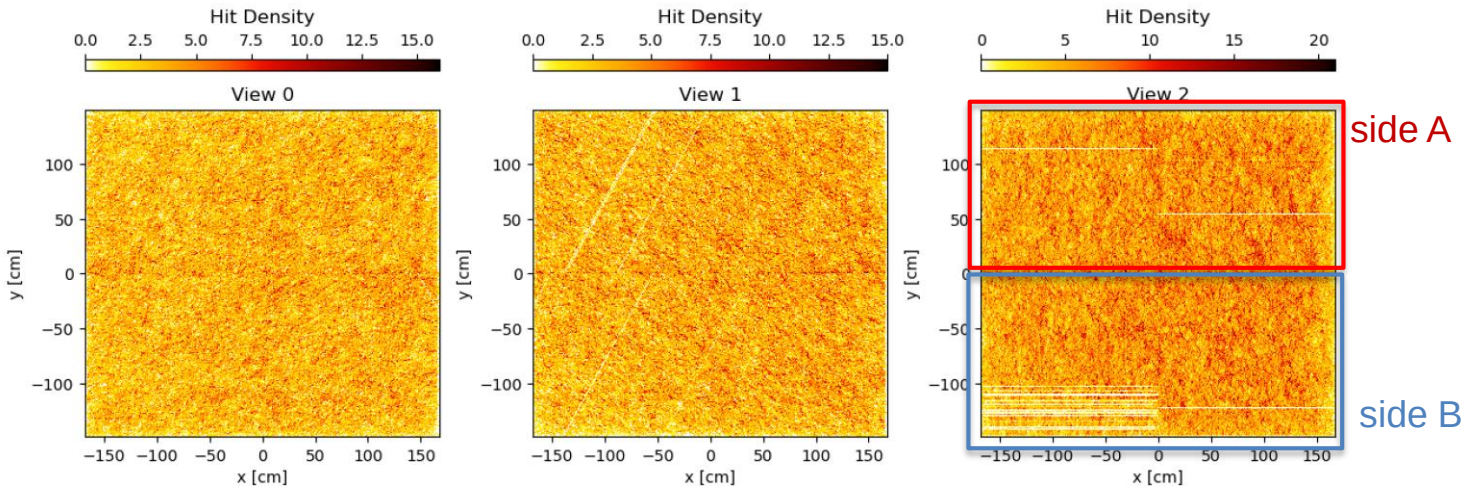
CRP6

CRP-6 noise levels at the second and third cold-box runs in comparison with the CRP-4



January test

April test

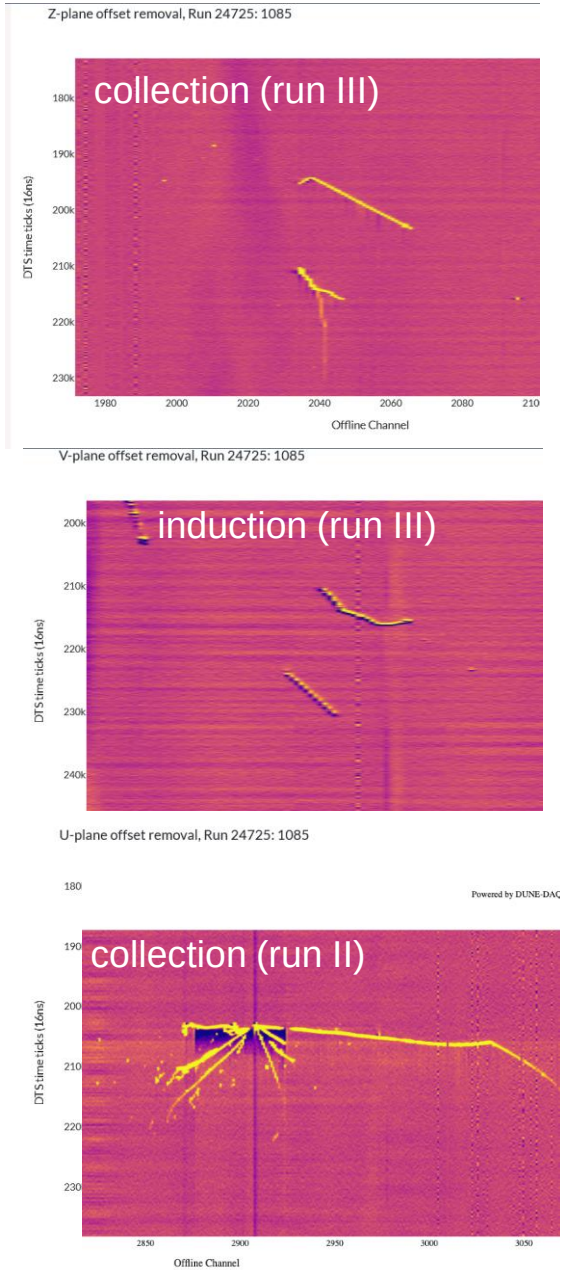


side A

side B

Hit density distribution of the CRP-6 during the third cold-box runs

Cosmic tracks seen in CRP6 during different cold box tests

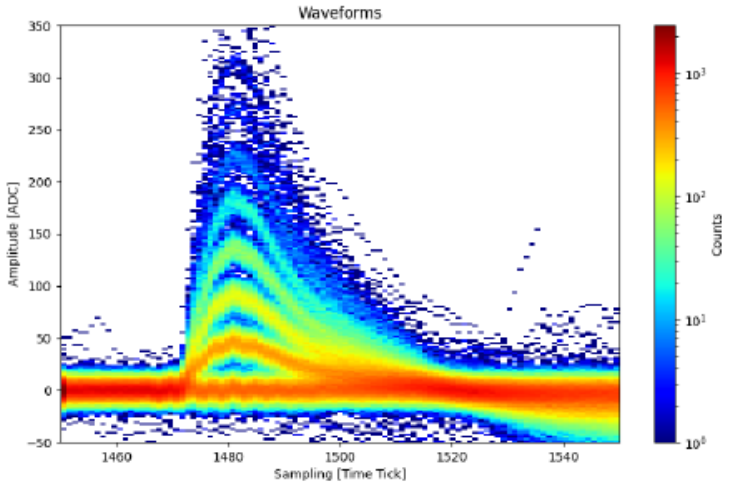


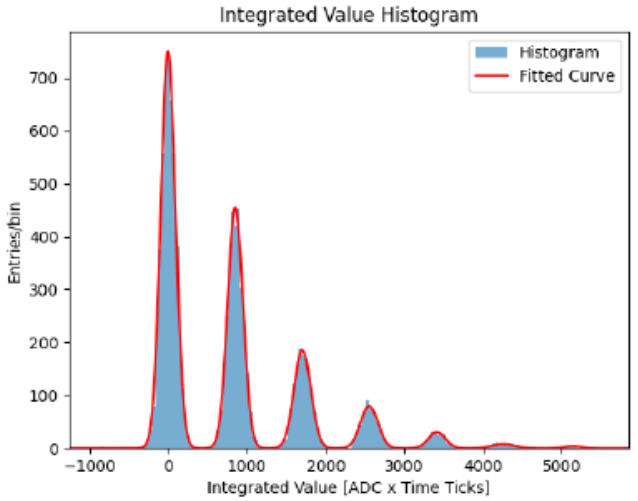
The performance of the CRP6-III reaches the expected one for the side A which incorporates all the latest grounding and shielding modifications

Cold box tests PDS

- Development and qualification of PDS
- Integration with HV and CRP
- Integration with DAQ

- Two production cycles of CE motherboards (DCEM) with optimized PoF receivers, SoF transmitters, DCDC converters and OpAmp components were tested





- Several optimisations were introduced, on X-ARAPUCA mechanical and optical design
- light-leakage protection kit to prevent disturbance from residual light from PoF receivers in the electronics box.

- Single and multiple PEs signal and amplitude distribution from LED calibration and DAPHNE read-out

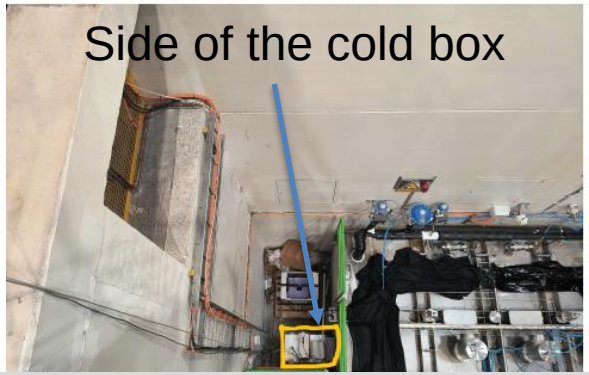
  => High signal-to-noise ratio achieved

Cold box tests

Pulsed Neutron Source (PNS) installed for a few days during the third run in April 2024

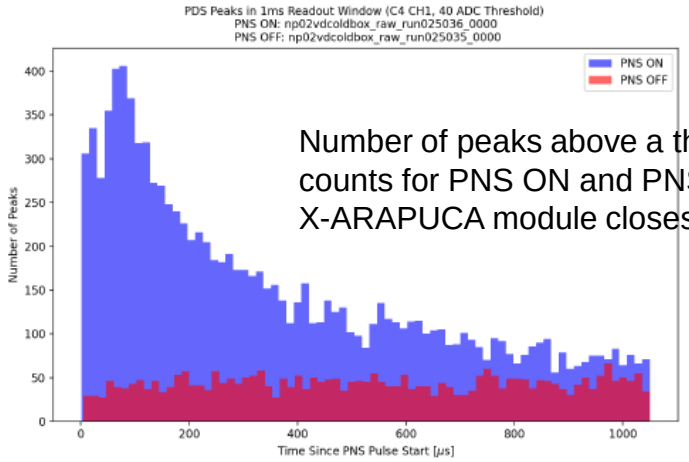
Aim: study the feasibility of using neutron capture for the absolute energy scale calibration of PDS

objective of the run:
identify neutron capture signals using PDs. In addition
opportunity to look at the low energy neutron signals simultaneously from both PD and CRP readouts



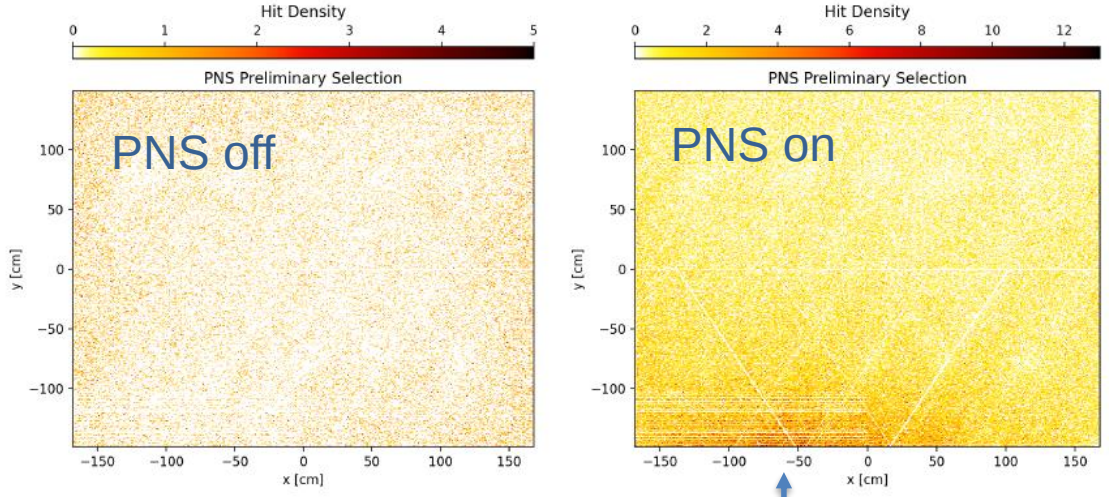
mono-energetic 2.45 MeV neutrons with a flux of up to 10^6 neutrons /s

operated in burst mode with a pulse width of 400 microseconds, and the data acquisition window was approximately 1 ms



Number of peaks above a threshold of 40 ADC counts for PNS ON and PNS OFF runs for the X-ARAPUCA module closest to the PNS (C4).

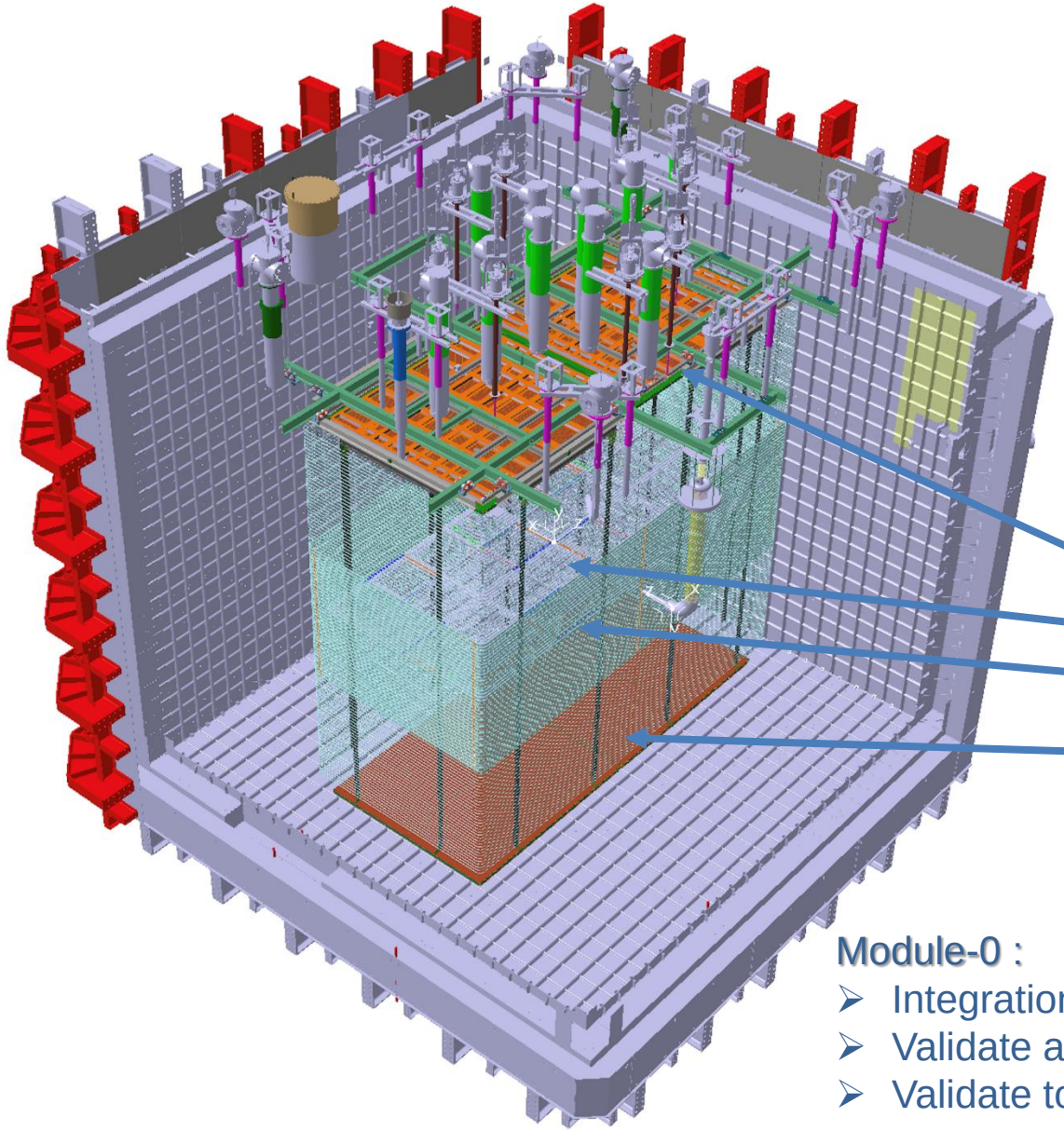
Projected charge hit density (seen from above the CRP) for 2 runs; the area corresponds to size of the CRP



Excess on the side where the PNS sits

Evidence of neutron capture in Argon. Further analysis of the PNS data ongoing.

ProtoDUNE-VD (Module-0)



NP02 Cryostat:

- **2 top CRPs**
- 2 cathode modules in the middle **hanging from the top CRP supports**
- Field cage modules hanging independently from the DSS; 70% transparent at the level of the Photon detectors on the cryostat membrane
- **2 bottom CRPs**
- ~3.2 m long drift, 300 kV capable HV system (tested in ProtoDUNE-DP)
- x-Arapuca PD modules in the cathode and on the membrane walls
- 4.3 m long beam plug NP04 style

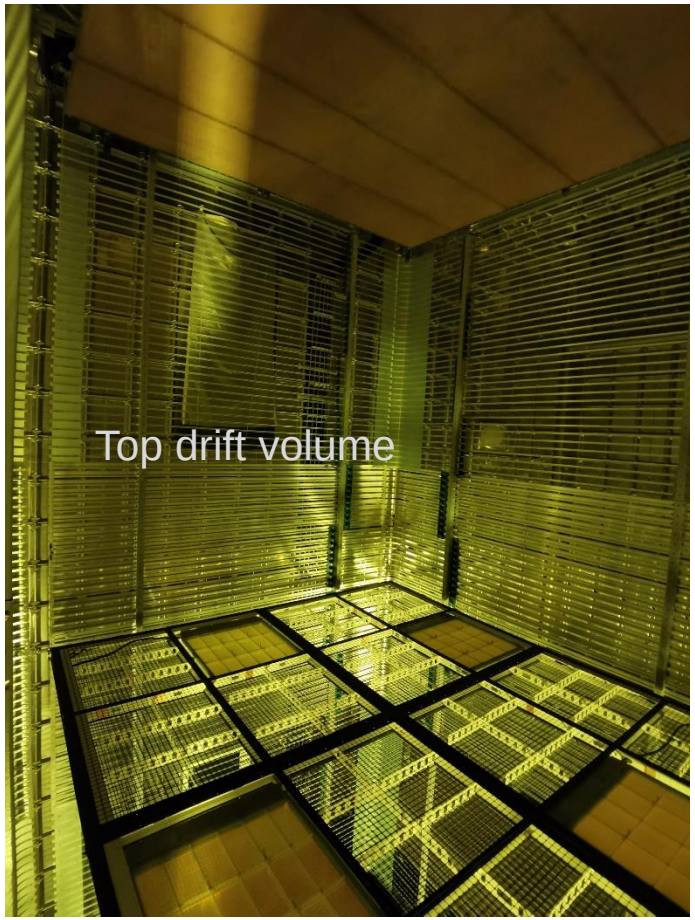
Module-0 :

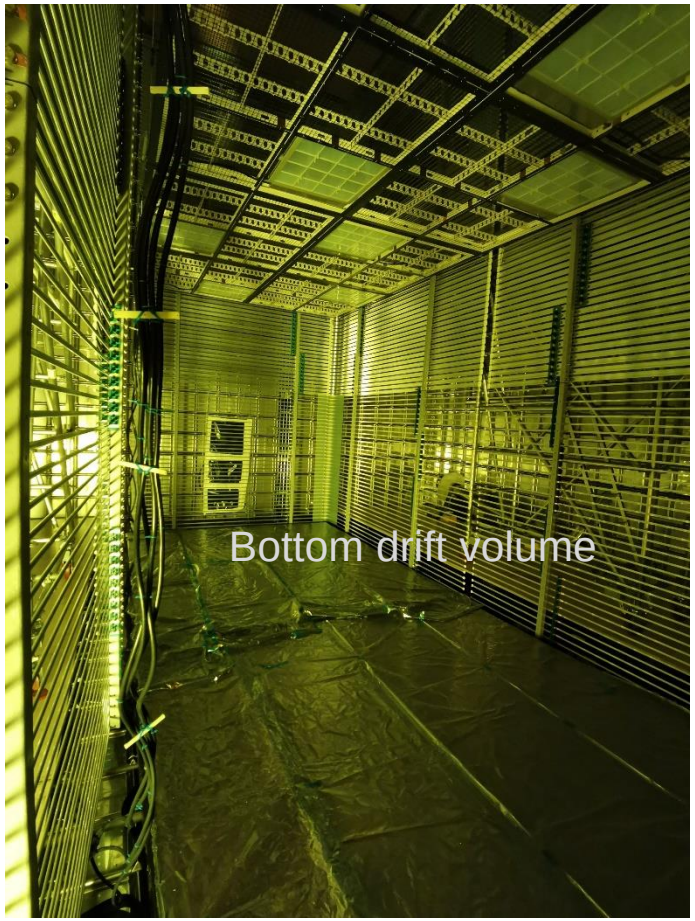
- Integration test with final detector elements before starting massive production
- Validate as many procedures as possible from shipping to installation
- Validate tools, understand personnel needs and time required for each procedure

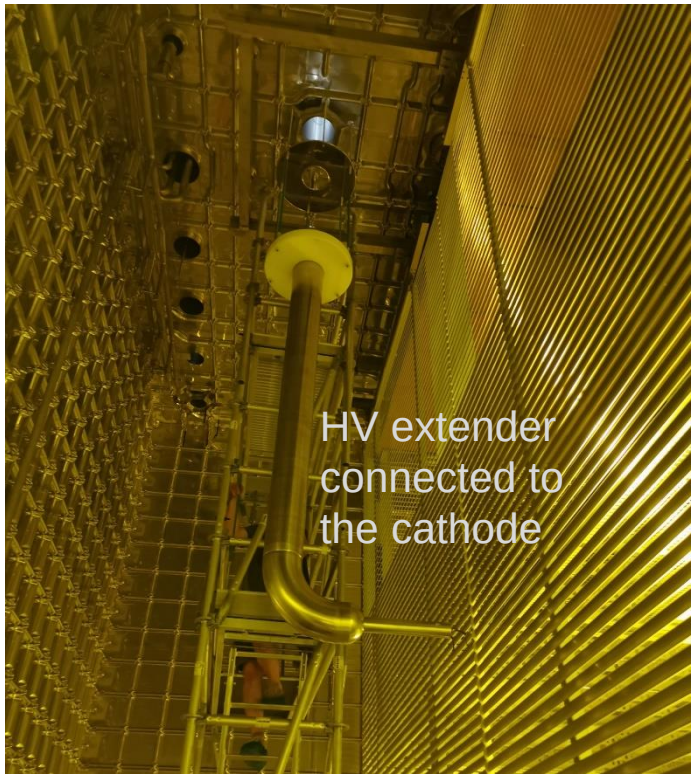
Module-0 status end of 2023

Detector components have been aligned, cabled and connected
- TDE and BDE installed, commissioned; data chain tested till DAQ barracks
- DAQ for PDs based on developments of NP04

TPC was fully completed in 2023:
- 2 top and 2 bottom CRPs,
- top and bottom drift electronics,
- field cage, HV extender, and 2 cathode modules
- 8 PD modules in cathode and 8 modules on cryostat membrane walls







Tests to monitor regularly the installation:
- Continuity test of the full HV system
- Regular electronics noise measurements by BDE and TDE for Top and Bottom CRPs
- PoF activation at warm

Module-0: PDS modification

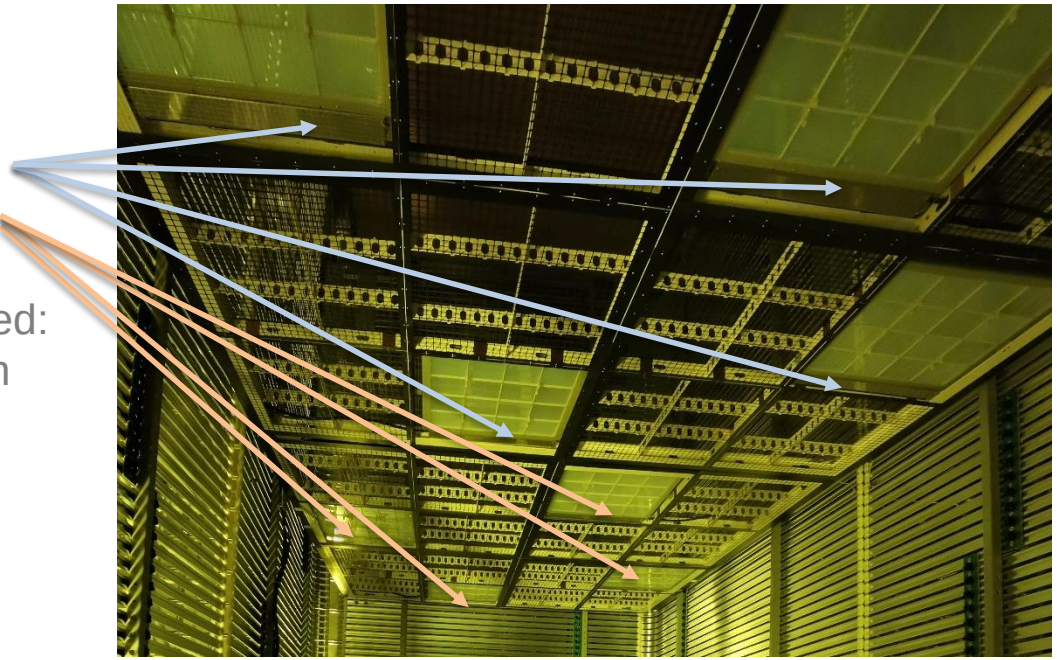
During 2023 and beginning of 2024:

- Development and tests in cold box of 6 X-ARAPUCA modules (cathode and membrane versions) with new optimised PhotoCollector optical solutions and with state-of-the-art CE readout boards - from successive generations of development/iteration and production
- **From cold box results:** Optimal performance and reliability of the readout CE (both for Cathode and Membrane modules) were demonstrated,
  - superior in all aspects of performance w.r.t. the previous generation currently implemented in 2023 in NP02 Module-0 and now baselined for production for FD2 PD.

- Decided in February 2024 to replace the Photon detector CE electronics boards of the 8 NP02 Cathode-mount PD modules with the current new production.

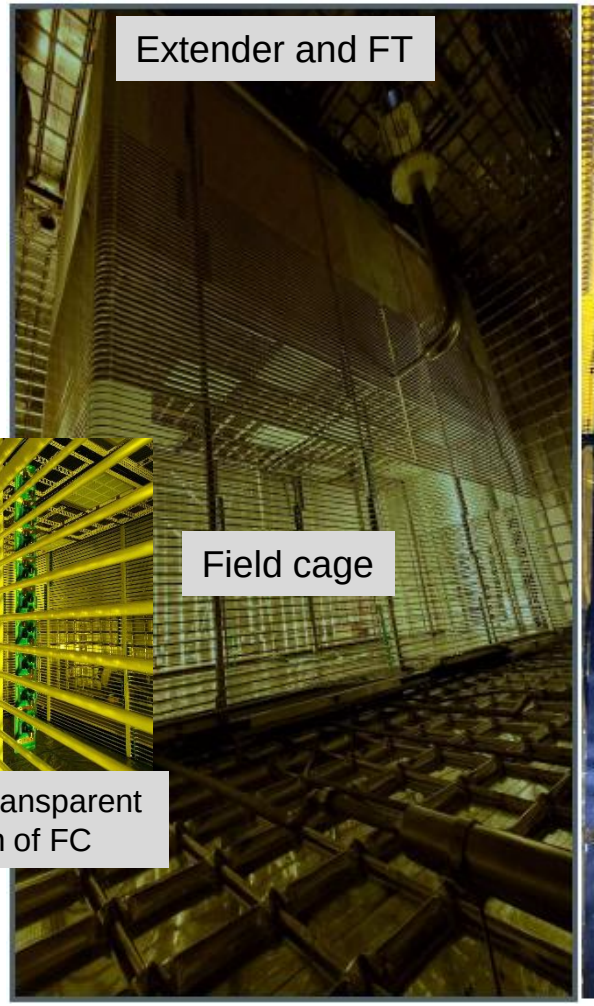
- Access to the cathode in NP02 for this replacement is being prepared:
  - Lower portion of the Field Cage modules has been removed in already March
  - special lightweight Aluminum platform/bridge to be installed above the bottom CRP plane in coming weeks

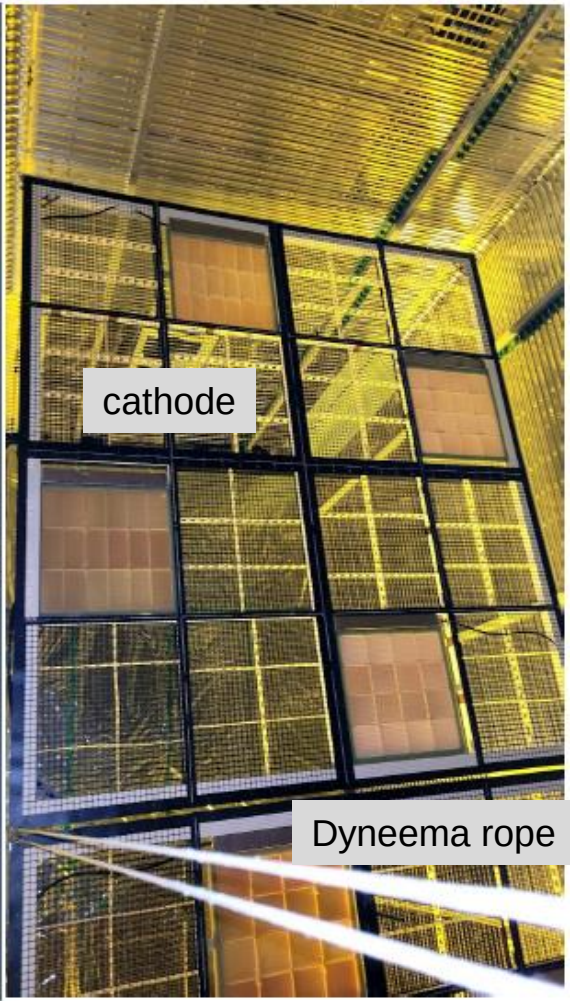
- Extraction of the PD modules from the cathode, replacement of the components and re-installation foreseen in the period May-June ’24,



Module-0: HV system

- Field cage:
  - Installation of the HV Field Cage (FC) completed after the bottom CRP's were in their final position,
  - fully cabled and validated in terms of electrical continuity and electronic noise.
  - The FC electrical connection to the Cathode HV bus and to the ground (via the termination boards with voltage and current monitoring) was also executed and validated.
- HV extender and the new HV feedthrough (HVFT)
  - installed and electrically connected to the Cathode HV bus
- HVFT: temporarily removed in fall 2023:
  - to perform long term validation tests in stand-alone mode at 300 kV : test end of 2023 successful
  - Second test to confirm the mechanical and electrical reliability of the HVFT after cryogenic thermal cycles foreseen in May 2024.





Cathode:

- Planarity survey measurement done: 2cm bowing at warm, in agreement with FEA simulation => expect 1cm in LAr
- Dyneema rope length unchanged since 1 year within 1mm precision measurement

Module-0: Beam plug

- Design of the beam plug and its supporting structure finalized and structurally validated in 2023.
- Construction started in early 2024.

Stainless steel tower

The beam plug is split into two parts of the same length (about 2.m) and coupled together with CF flanges.
A stainless steel section facing the membrane and a G10 section facing the field cage

Shape of the stainless steel tower elements supporting the beam plug:
=> optimized to take into account for the high electric field in the surrounding of the cathode,

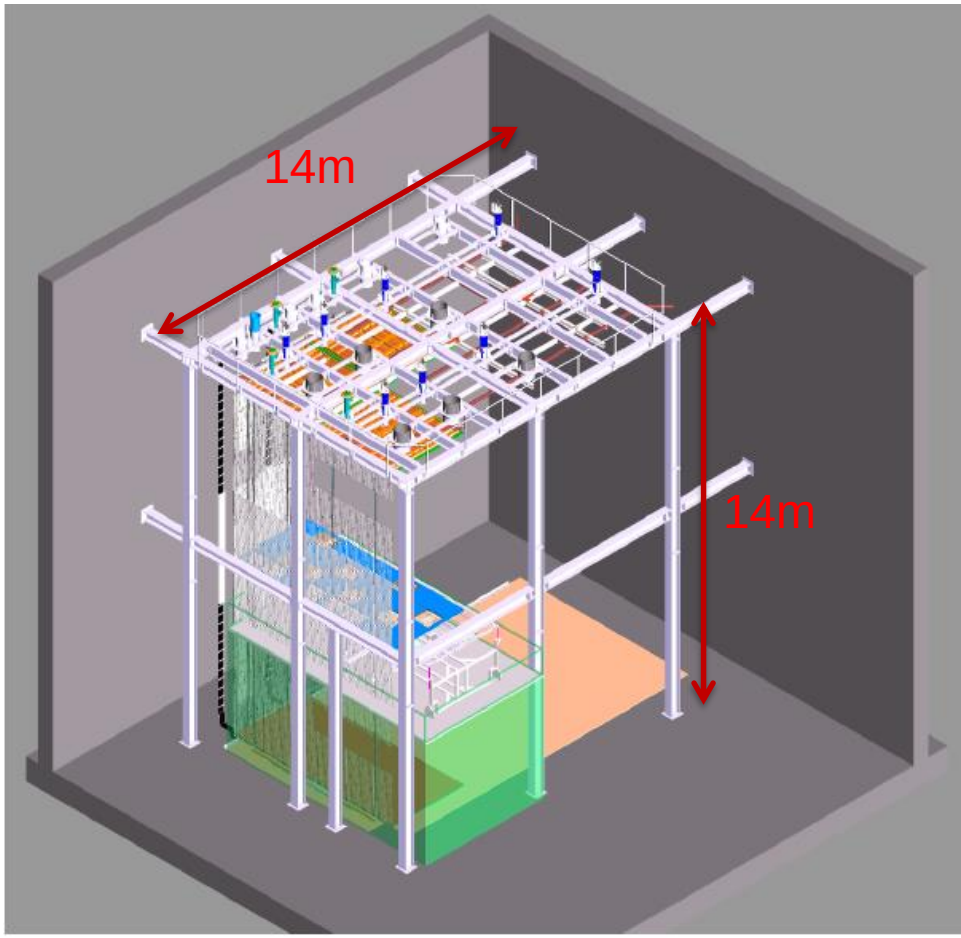
- The construction of the two parts is completed
- Testing in vacuum and in cryogenic bath is ongoing, following procedures developed for the NP04 beam plug
- The installation in 2 pieces can be done via the TCO or manhole

at Cryolab

DUNE-FD2 Integration test

A mechanical integration test stand is planned to be built at CERN in building 185 to complement all integration/installation aspects which could not be tested with Module-0 integration.

- a simplified 1:1 scale version of a portion of the DUNE FD2 cryostat. Large enough to test the largest structural components
- to develop and validate the installation procedures for the DUNE-FD2 components in realistic conditions,
- planned to start the struture installation in summer 2024.



Major project involving all DUNE FD2 detector related consortia

The goals of the tests are:

- Test the cable tray installation and cabling of the top CRP,
- Prototype the construction of the CRP Support Structures and associated assembly tooling,
- Test the hoisting system for the CRP support structures,
- Test the installation of the CRP using the lift table,
- Investigate alternate fiber routing concepts for the cathode PDS modules,
- Prototype the cathode installation including the PDS fiber integration.
- Test the FC lifting and support system,
- Test the installation of the last FC end wall lower panels,
- Test the bottom CRP installation process,
- Test install the last Bottom CRP modules,
- Refine the BDE cable tray design and prototype the installation process,
- Test the access possibilities for the TCO closure

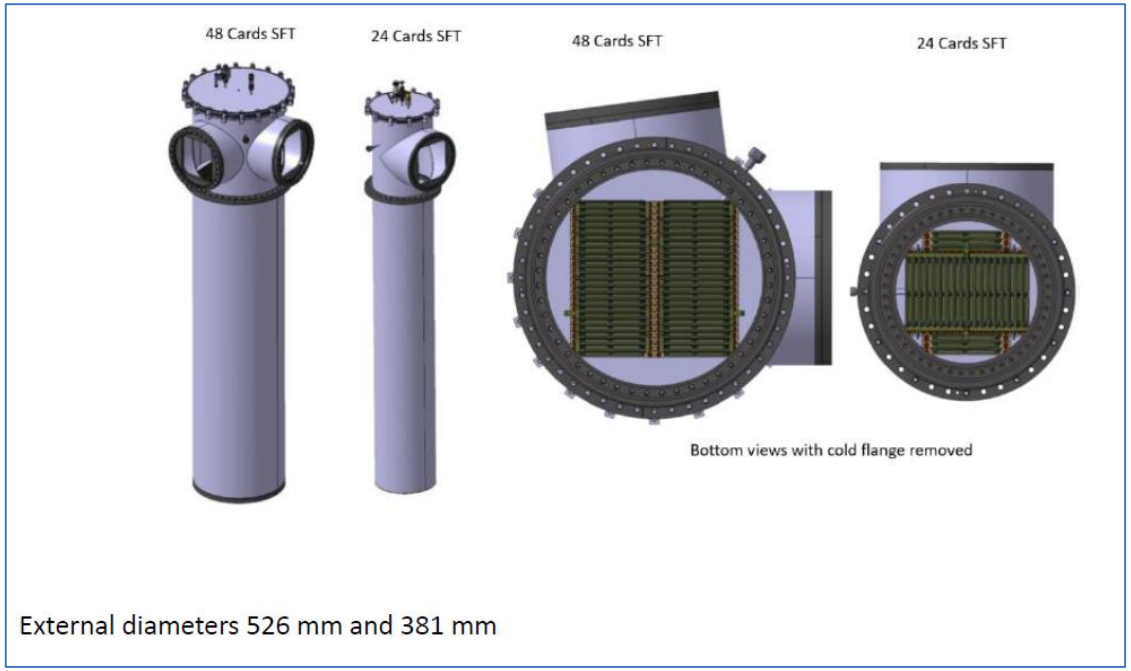
DUNE-FD2 Integration test

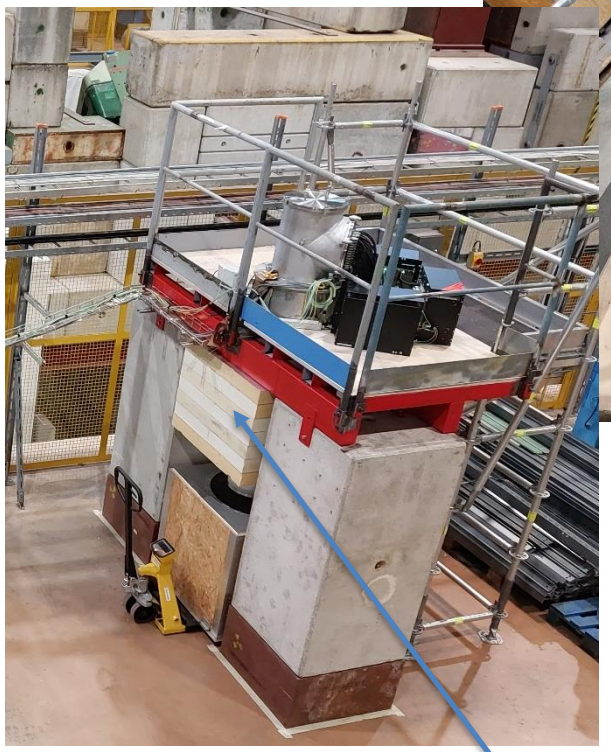
In building 887 (Neutrino Platform)

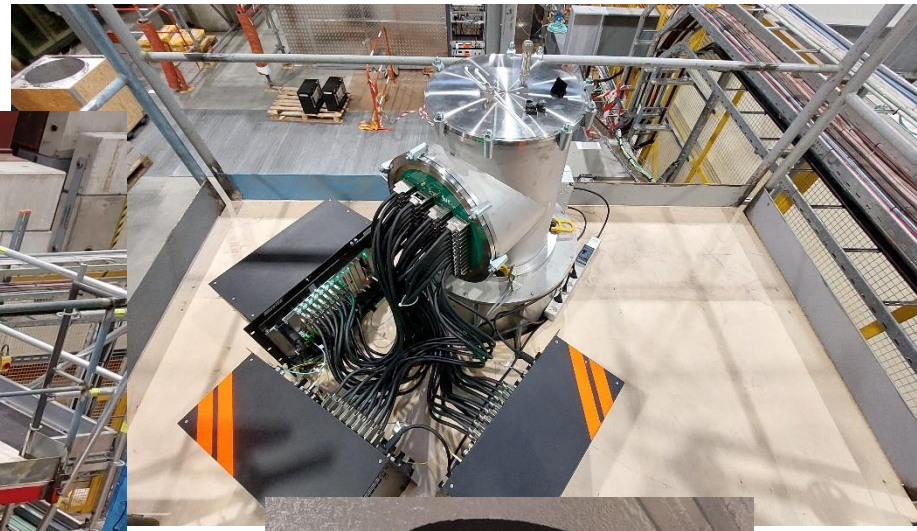
TDE Large Chimney integration test at CERN

- 10 cards chimneys fully exploited and validated in NP02 and cold-box tests

- **New test goals**: validate design extension to 24 and 48 FE boards chimneys (not implementable in Module-0) in real cold conditions, operating FE boards and readout:
  - Check temperature profiles and noise
  - Validate blade insertion/extraction, continuity, blade guiding system and its impact on gas circulation and FE card cooling







- Test mimicking FD2 cryostat structure started in April

- To be pursued in May-June with liquid argon for both chimney sizes

24 FE boards chimney

Summary and plans

- Three additional Cold Box tests were performed between Nov. 2023 and April 2024. They led to improvement of the CRP design and validation of PD onboard electronics,
- NP02 detector status:
  - The four CRPs are installed and functional since 1 year and are regularly checked with electronics readout
  - Complete HV system installed and tested
  - First version of PDS system installed in 2023;
  - Exchange of the electronics of the PD module on the cathode to be completed in June.
  - Reinstallation of the complete Field cage after PDS intervention
  - Beam plug is constructed and being tested at warm and cold; should be ready to be installed beginning of the summer
- The cryogenic instrumentation, (purity monitors, calibration systems, lights and cameras) will be installed after the Temporary Construction Opening (TCO) is closed
- TCO closure: contract awarded, date not yet defined, expected not later than Fall 2024; the material is at CERN
- Liquid argon filling: after completion of the NP04 technical and scientific programme since most of the liquid is being transferred from NP04 to NP02
- Neutrino Platform strongly supporting FD2 construction with several activities in addition to NP02 integration to optimize, develop and validate the installation procedures for the DUNE-FD2 components in realistic conditions:
  - cold-box tests,
  - large TDE chimneys integration tests,
  - FD2 VD mechanical integration test stand in building 185, planned to start in Summer 2024