Status and plans of the ProtoDUNE - Vertical Drift (NP02) Project

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on behalf of the NP02 Collaboration

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Overview

CRP developments and tests

Trigger and data acquisition of charge signals

Photon detector tests and production

HV system

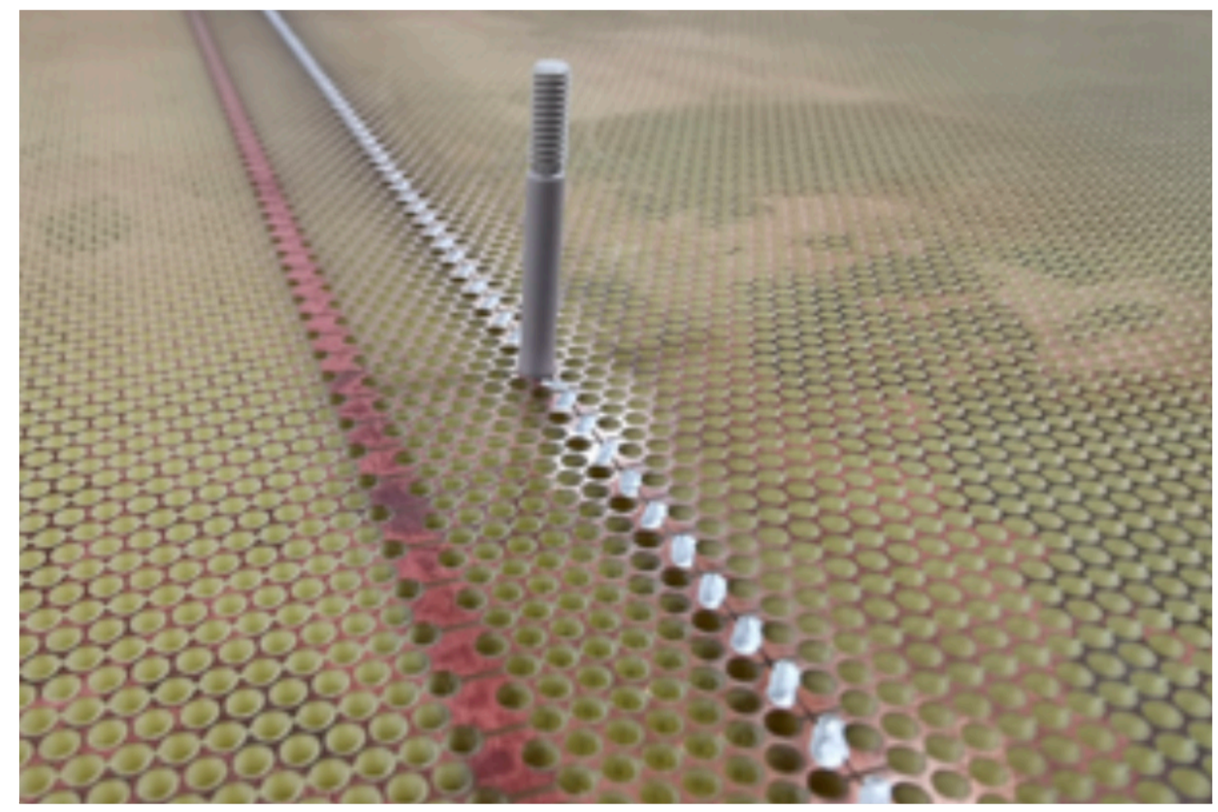
DP decommissioning

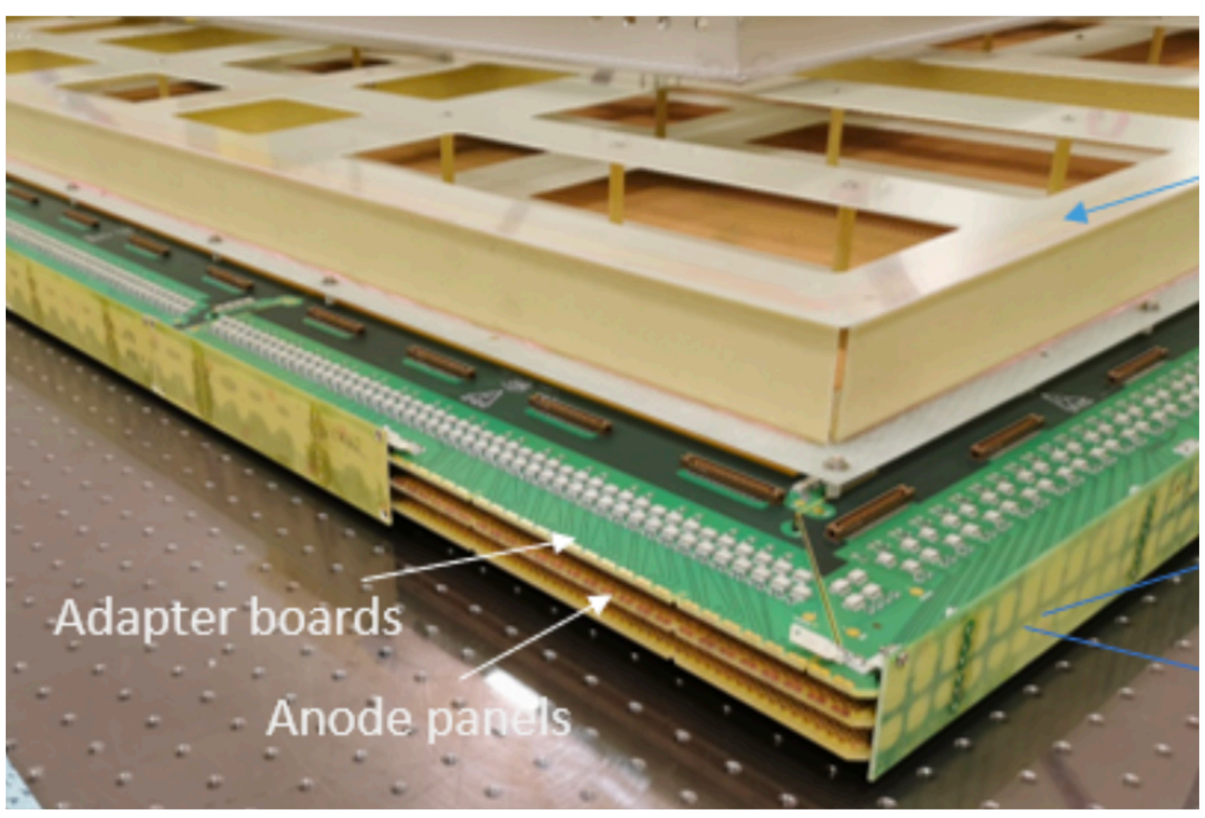
Module0 installation

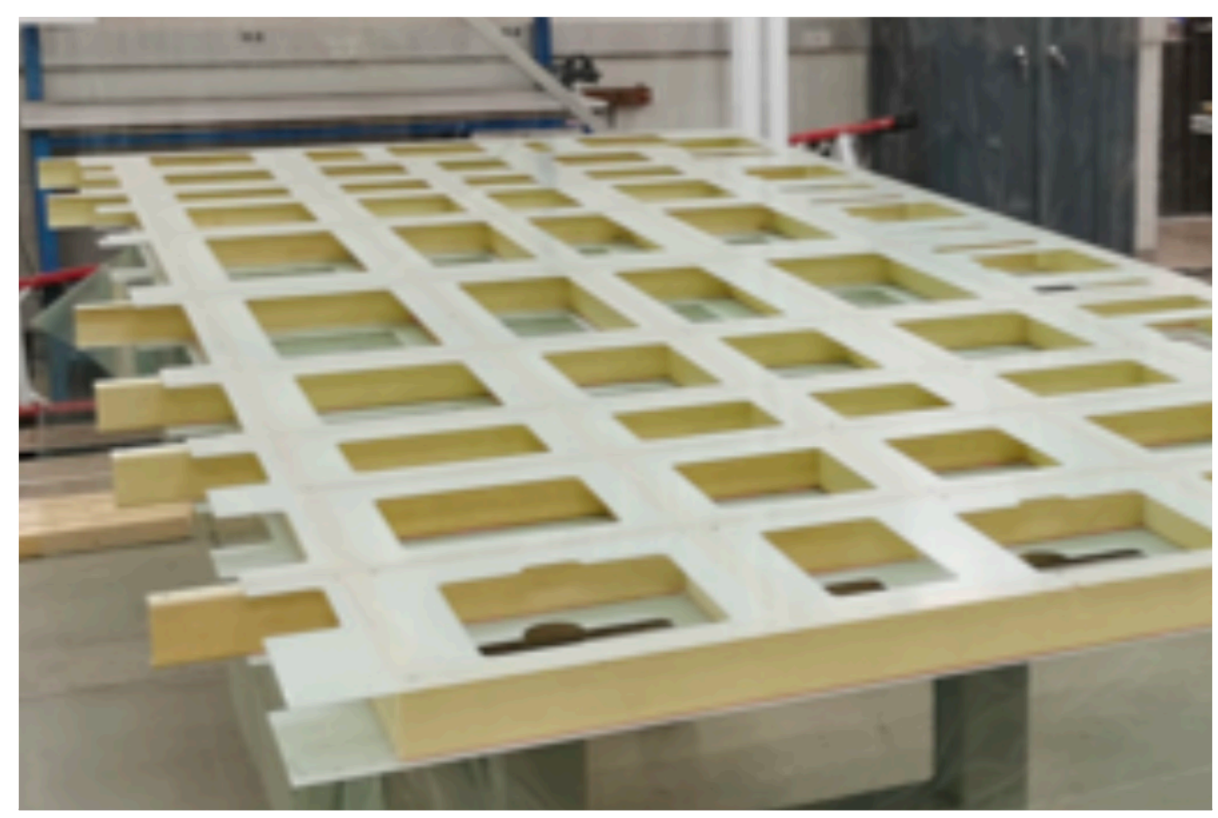
Plan and outlook

Improvements on CRP design

Charge readout plane consists of two perforated PCBs with electrode segmented into sensing strips where signal is induced by electrons while passing through the holes of the anodes.
Improvements from CRP1 and CRP1b:
- Strip orientation, width and number
90^o +/-30^o, strip width *matches* hole pitch, 3072 ch/CRP.
- Strip connection between different PCB forming the anode plates done via screen printing conductive ink.
- Vertical connection between layers done with vertically PCBs on the side of the CRP (edge cards) to reduce the dead area.
- Mechanical optimisation to ease the assembly and transport. The mechanical support consists of two identical composite frames.
- Test of different manufacturing companies and assembly sites.







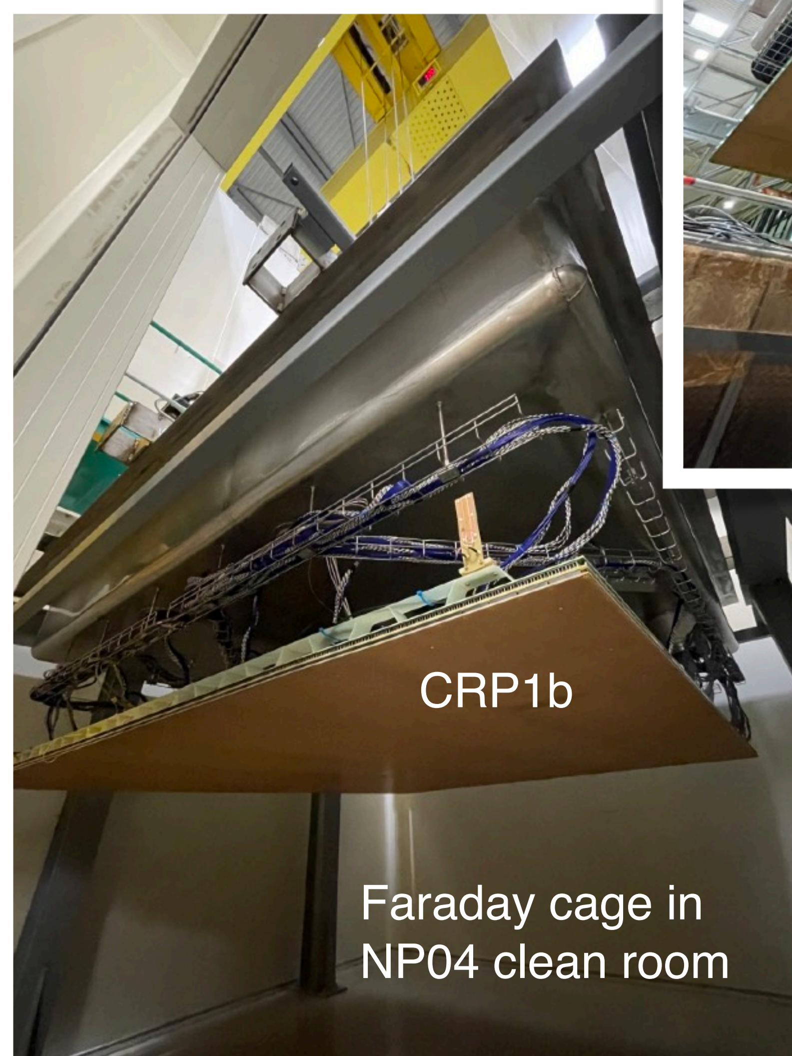
CRP tests at warm

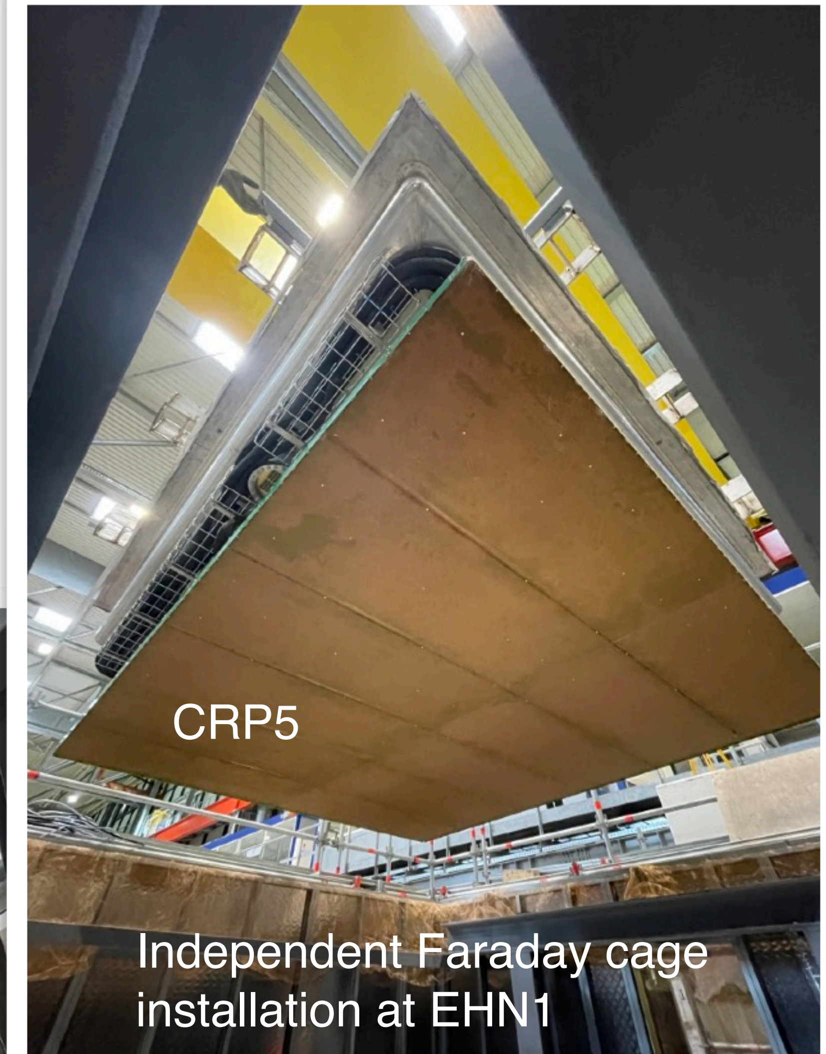
CRP1 equipped with Top Drift Electronics (TDE) and Bottom Drift Electronics (BDE) was tested twice in the cold box in fall ’21 demonstrating the Vertical Drift concept on full size components, exploiting the entire charge readout chain, and testing the functional integration of the main TPC components.

From spring ’22, noise studies were carried out at warm in a dedicated Faraday cage test stand: the access to the CRP was simplified and a number of configuration could be tested in short amount of time. Several lessons were learned, the internal grounding scheme for the bottom CRP side was improved (CRP1b). Improvements were also tested in the cold box in realistic conditions.

Cold box grounding scheme was also improved with installation of an isolation transformer to power all the equipment on the cold box, shielding of some feedthroughs, re-routing and re-grounding some cables inside the cold box, … -> significant reduction of the contribution of coherent noise.

Faraday cage test is routinely done before every cold box test.



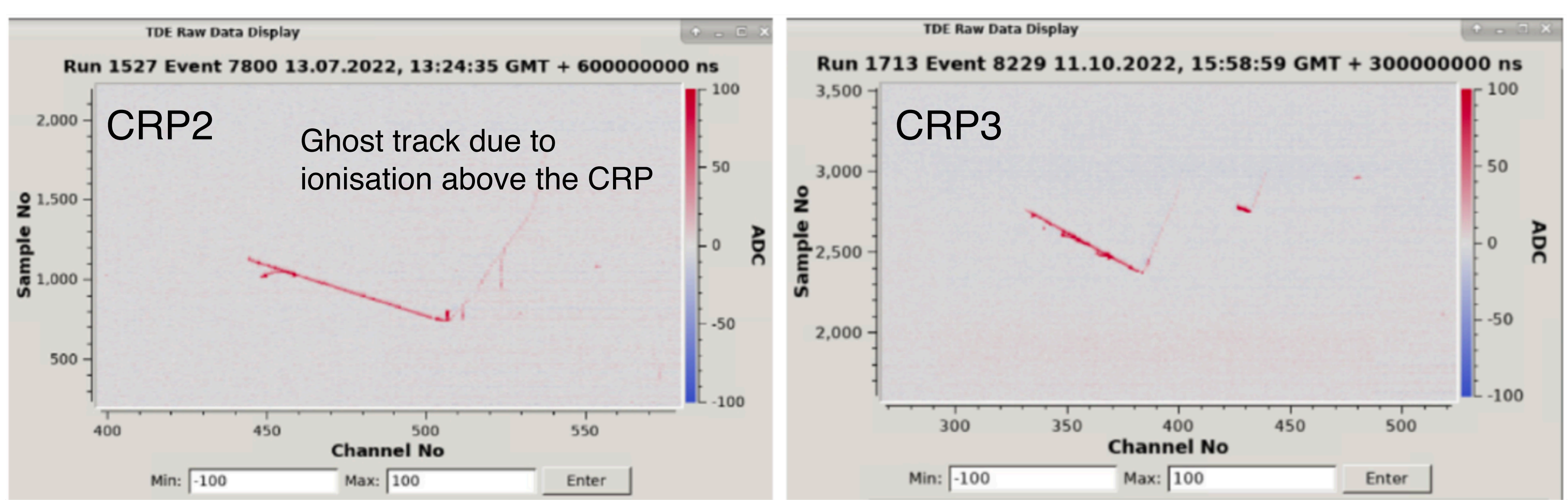


Top CRPs

Production and assembly of the two Top CRPs for the Vertical Drift module0 in NP02:
- CRP2 (first fully TDE-equipped) tested in the Faraday cage in cold box in June and July ’22.
The test showed ~1% of channel disconnecting at cold: issues of silver print connection between PCBs forming the anodes.
- CRP3 implemented the improvements on production/assembly developed after CRP2 test. CRP was successfully tested in the cold box in September and October ’23.
- After correction of the faulty connections, CRP2 was again successfully tested in November ’22.

The TDE for a full CRP consists of 48 Front End cards, in 5 chimneys, readout with 48 AMC in 5 uTCA crates.
For the tests in the Faraday cage and in the cold box, the TDE was mounted and dismounted in the chimneys about 20 times with no sign of deterioration.

Raw data



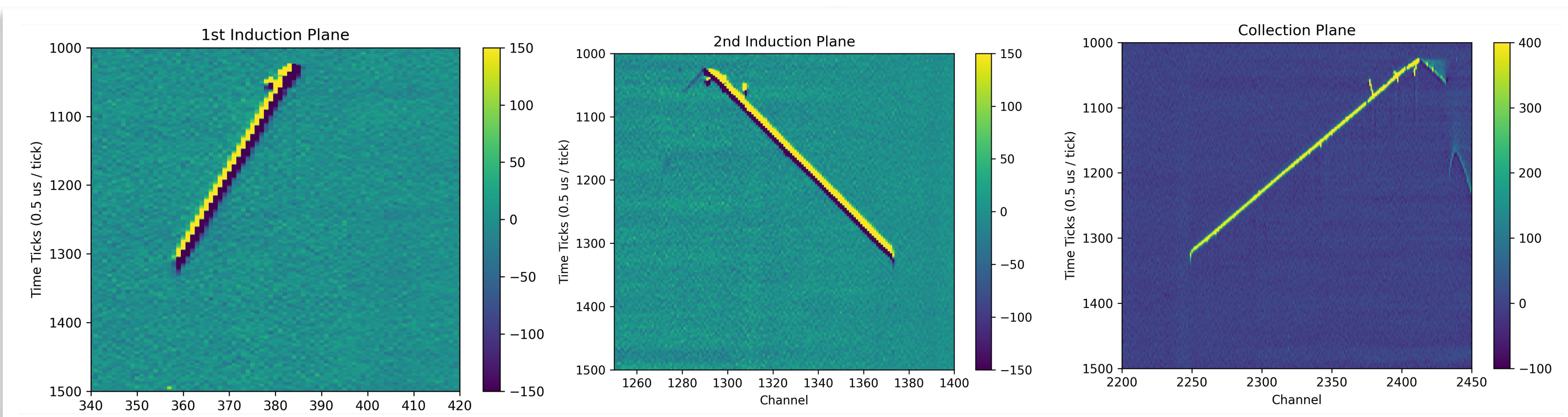
Bottom CRPs

CRP5, unlike the top CRPs that were built and assembled at CERN, was partially built in the US: 1/2 CRP was assembled, equipped with the electronics, tested at Yale and BNL, and shipped to CERN.

CRP5 was tested at warm and in the cold box in February ’23. Noise levels were good, but a portion of the induction plane had bias problems (QC plan during assembly was updated), some data issue were observed at cold, and during CRP manipulation, five edge connectors were damaged. It was decided to test it again after CRP4.

CRP4, fully assembled and tested at Yale and BNL, was tested in the cold box in March ’23: electronic noise was nominal, with minimal contribution from coherent noise. No channels was lost at cold, and the response was stable throughout the test.

After fixing the issues of the CRP5, a second test was conducted between April and May ’23, and it was concluded last week. All the four CRPs were successfully tested and validated for the installation in NP02.



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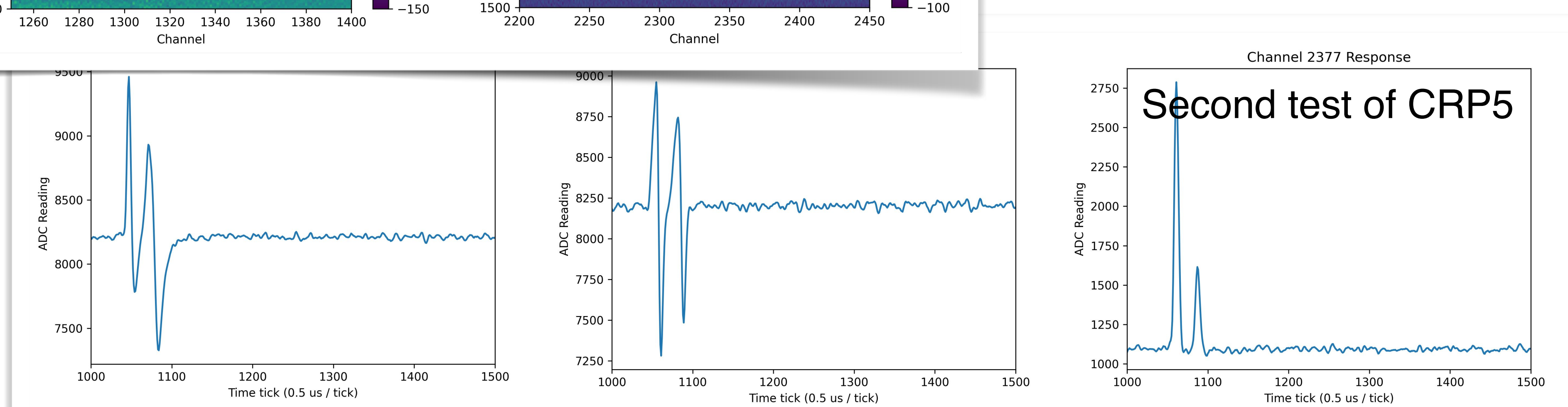
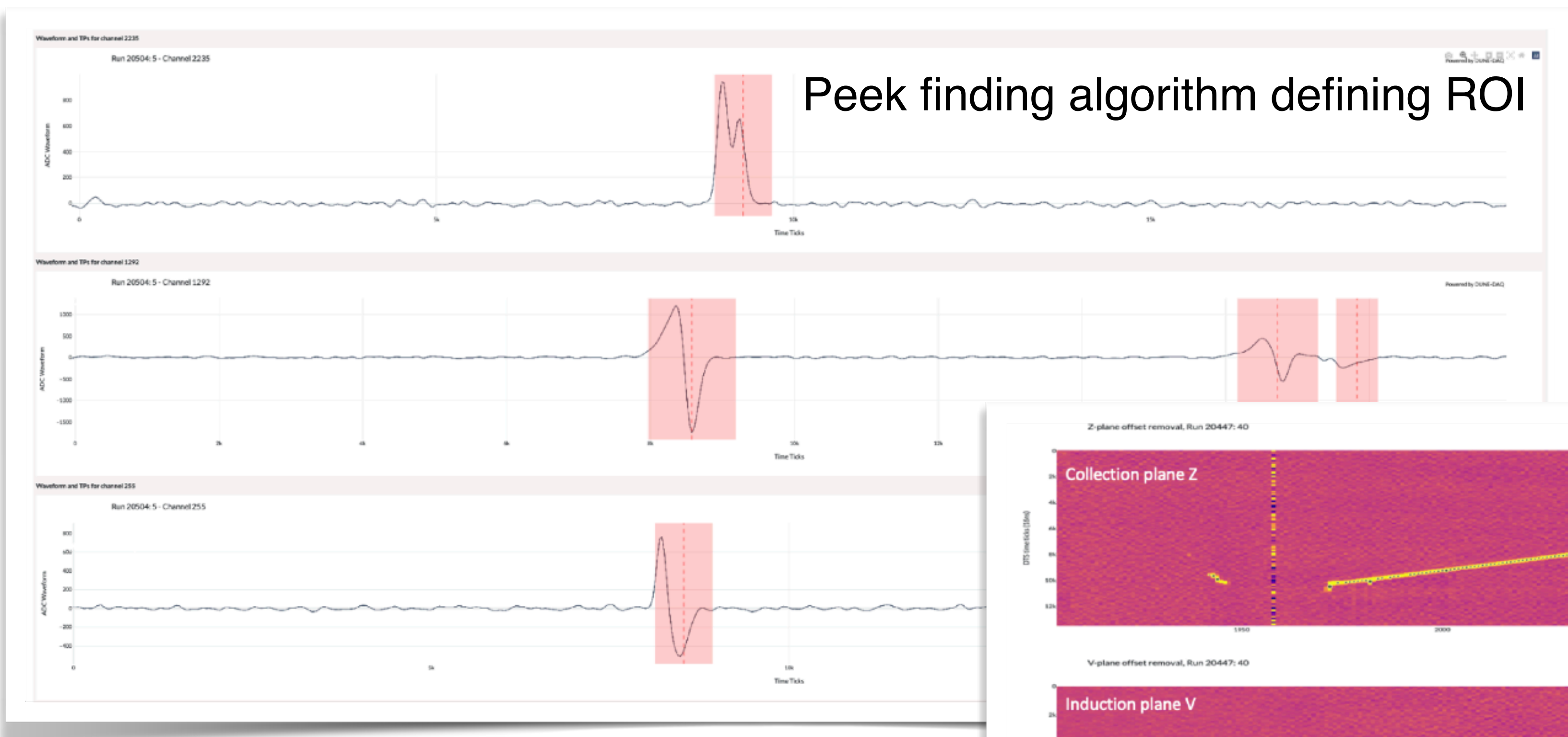


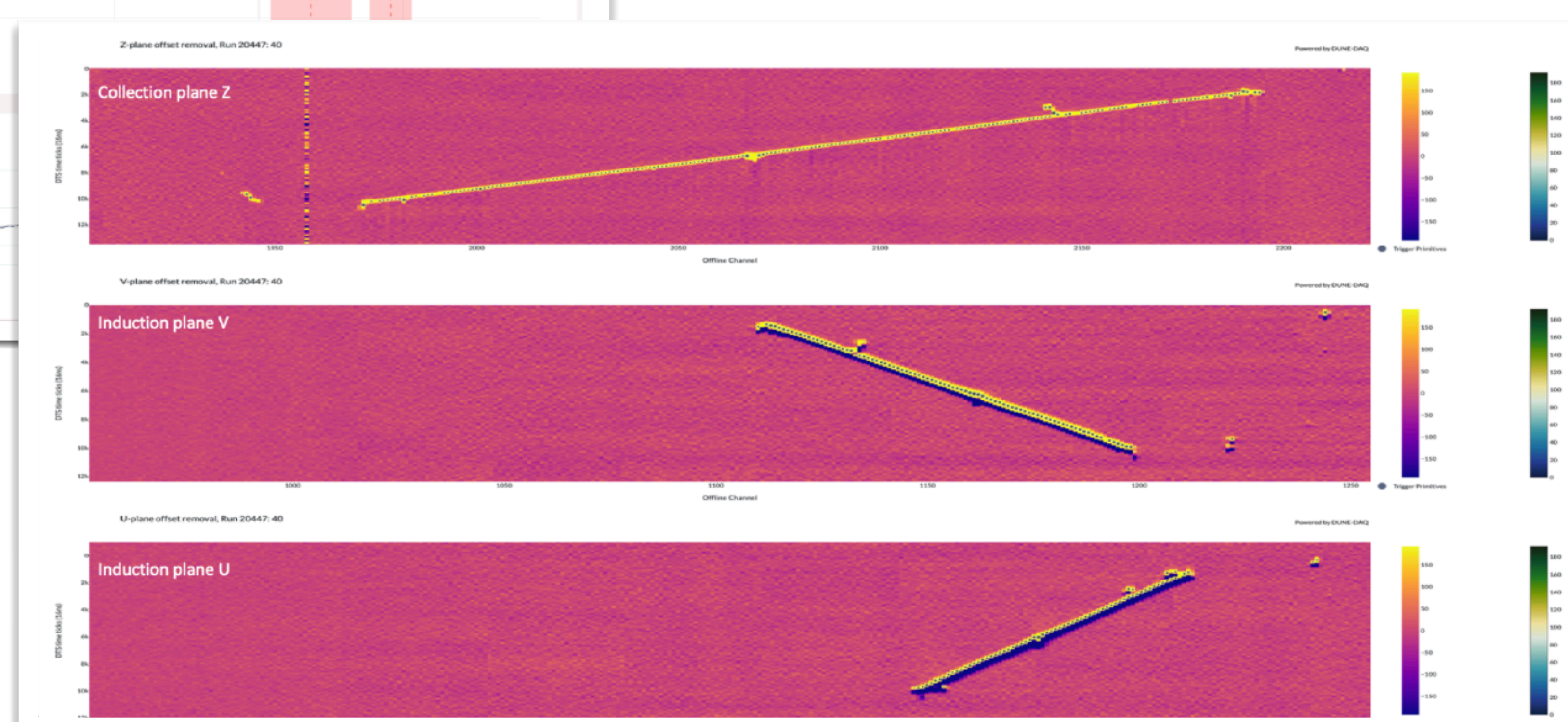
Trigger system

CRP4 and CRP5 were used to test the trigger as designed for DUNE on a live stream of data: BDE data is continuously analysed by the DAQ software (Single Instruction Multiple Data). Peak finding algorithm identify trigger primitives (TP) saving basic parameters such as time, time over threshold, amplitude, …
TP are passed to trigger software that on the base of criteria, such as multiplicity, adjacency, isolation decides which raw data from electronics to safe for offline analysis.

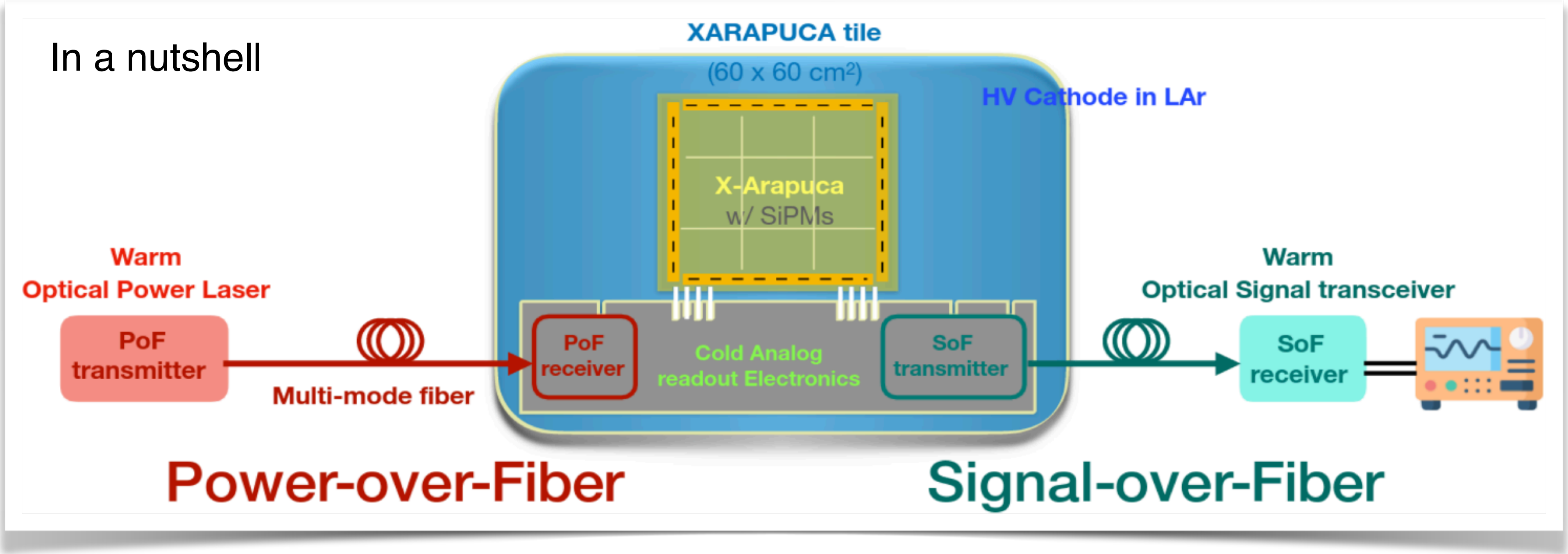


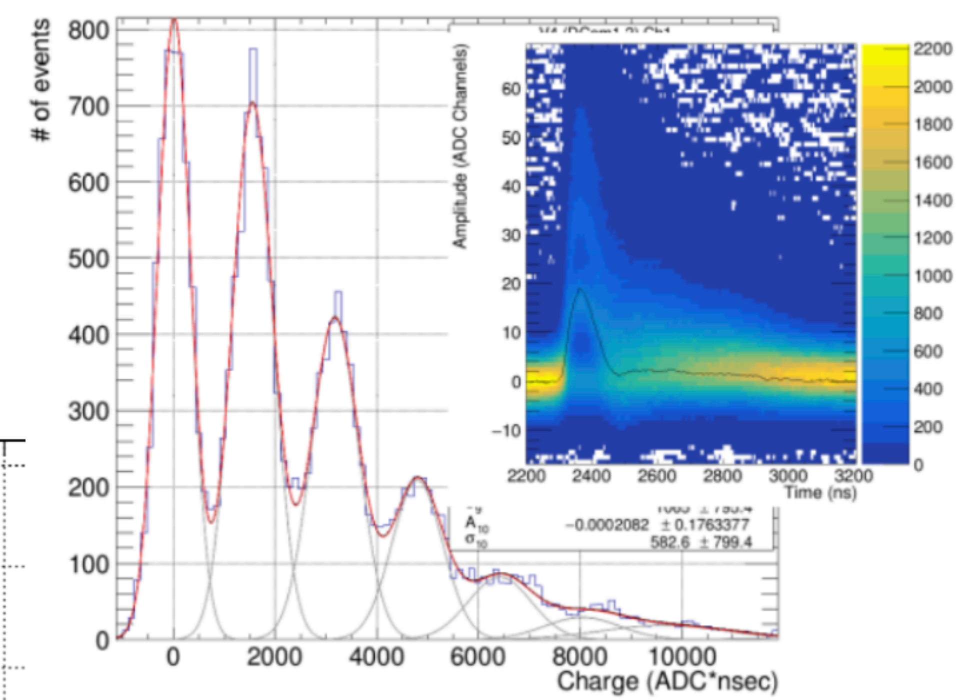
Online trigger on data from CRP5

Long track triggered on multiplicity criteria



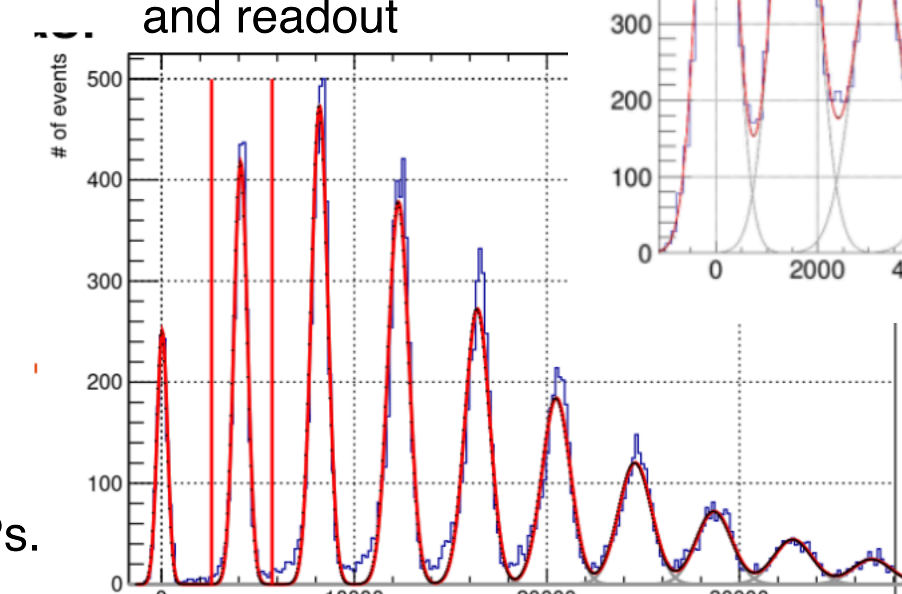
Photon detection





Baseline PD configuration in DUNE-FD2 (replicated in NP02):
- modules on the cryostat wall behind 70% field cage transparent
- modules on the cathode swing top and bottom volumes

To operate xArapuca modules at HV, developed Power over Fibre (PoF) and Signal over Fibre (SoF) technologies



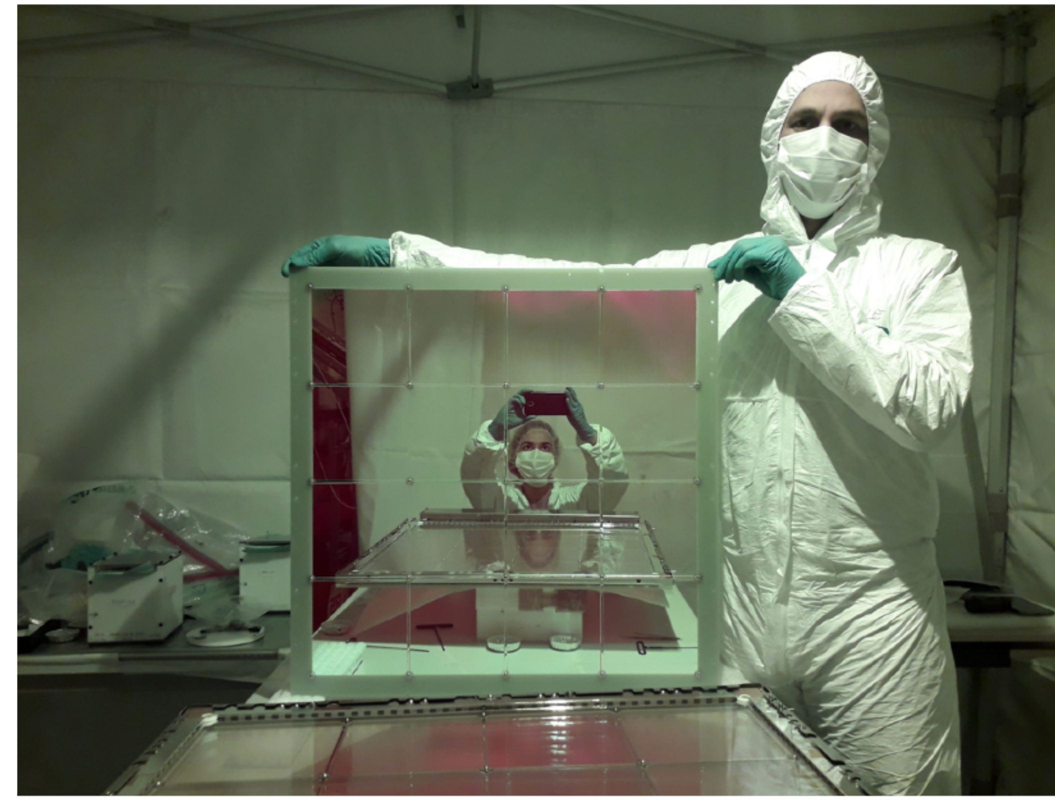
Several tests in the cold box. Optimisations introduced:
- xArapuca mechanical and optical design,
- light tightness on laser connections,
- laser wavelength and power,
- the cold electronics integration (SiPMs ganging, Cold Electronics Amplifiers, SoF and PoF integration).

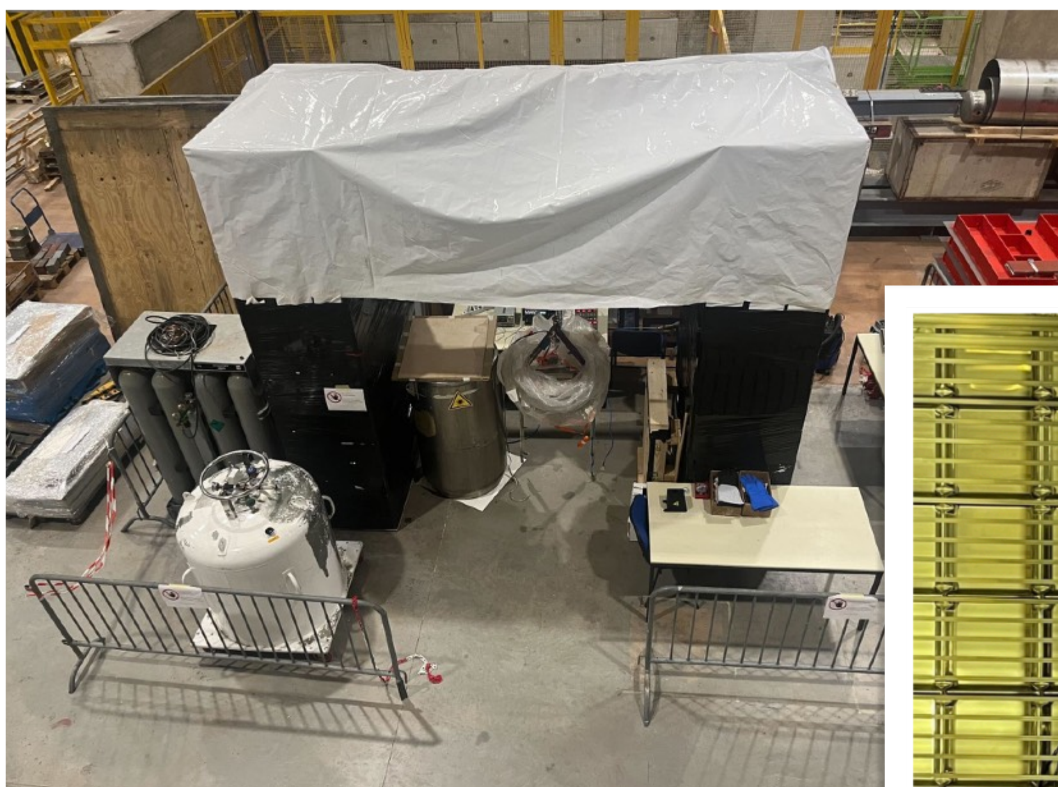
Achievements:
- demonstrated the technology at large scale,
- reliability of the entire PD chain in realistic conditions,
- integration of the PD system with top and bottom CRPs.

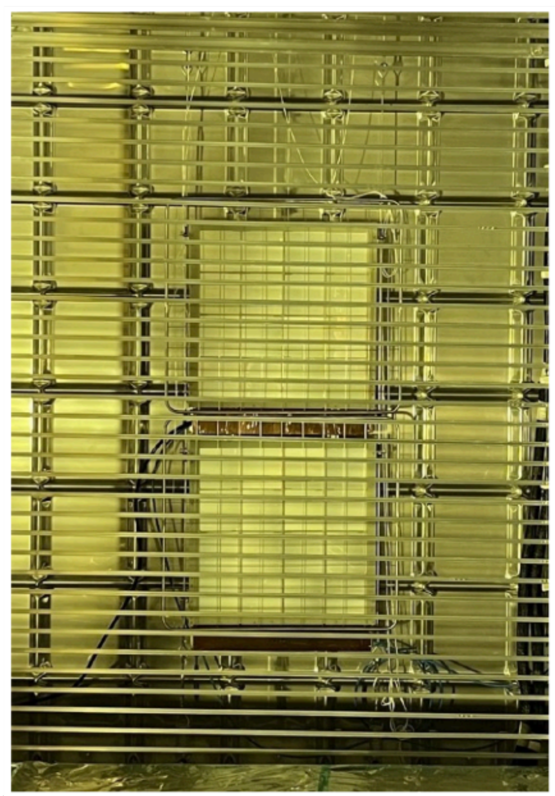
Photon detection

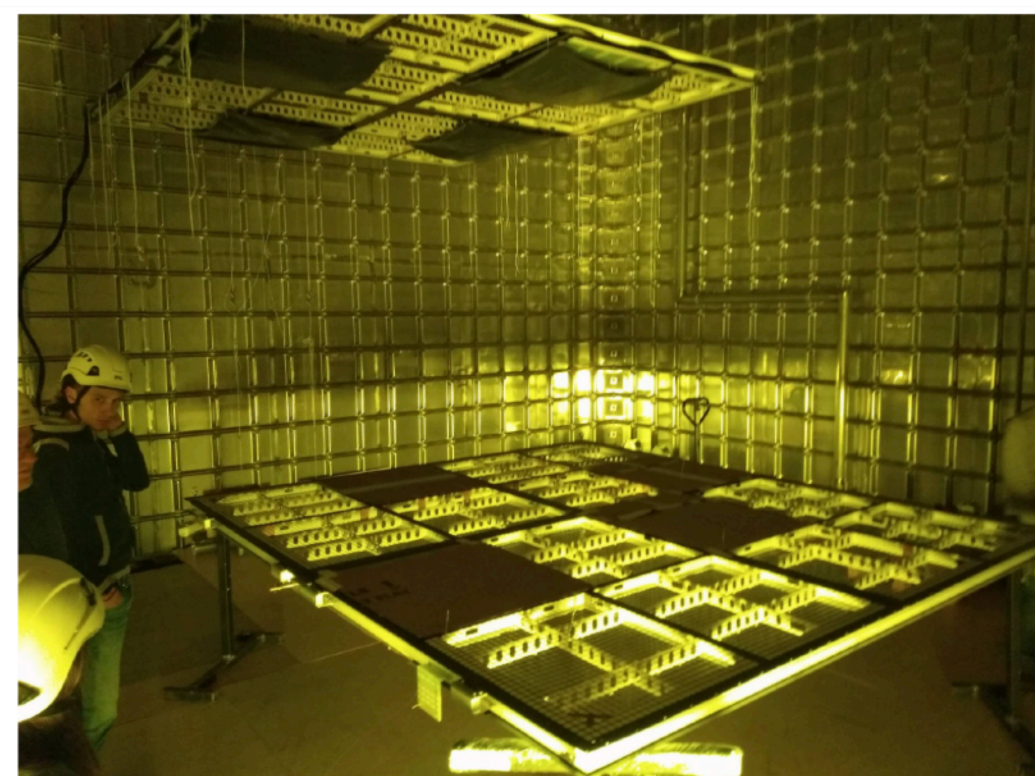
Assembly of the modules for Module0 was done at EHN1 in a clean area.
Completion of the test (full chain from power to readout in liquid argon) of the production modules in a dedicated test stand.
All module for NP02 have been produced and tested.

Installation of the modules in NP02 almost completed:
- 8/8 modules on the cathode cables and tested
- 6/8 modules on the cryostat walls installed





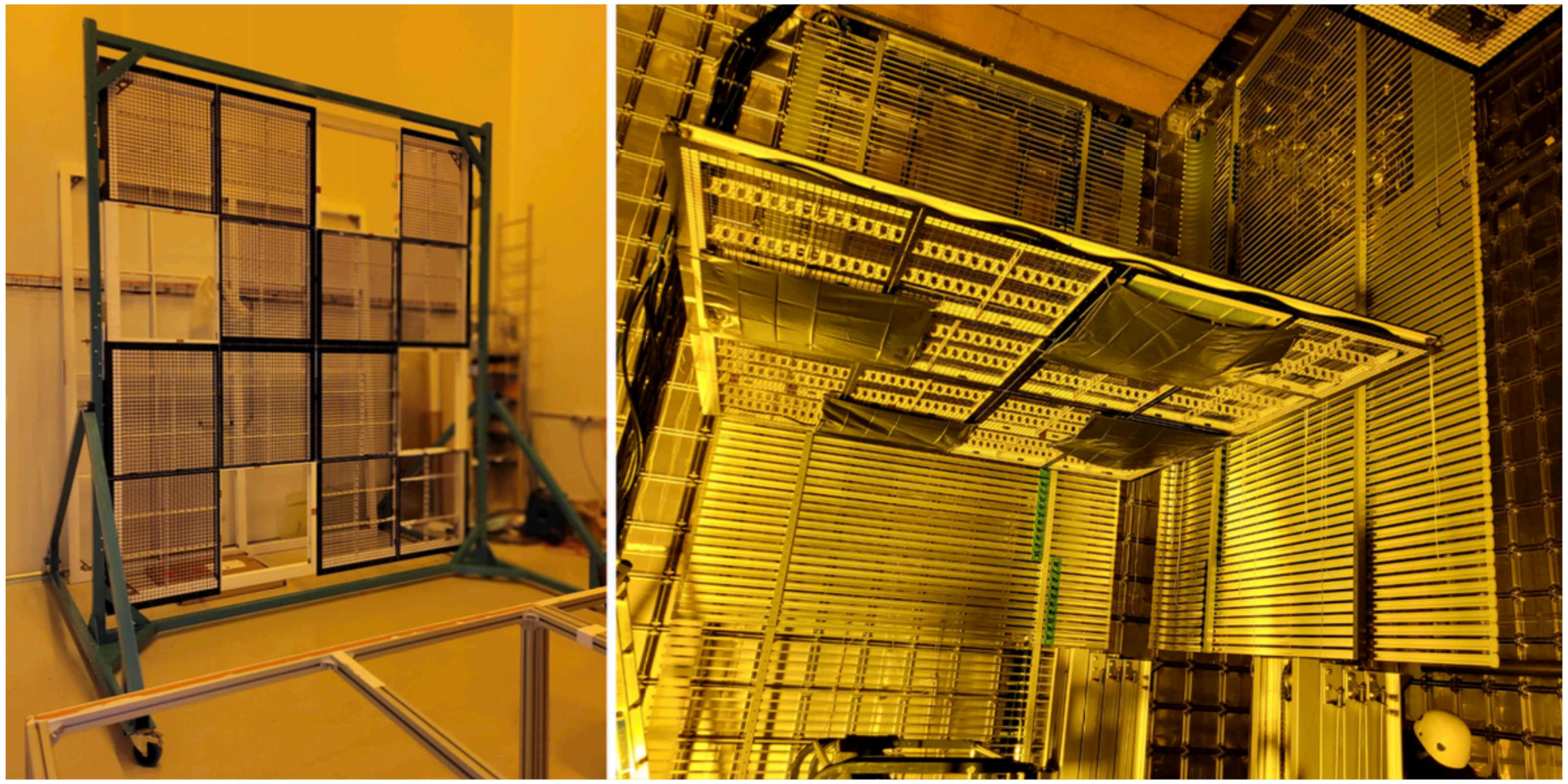




HV system

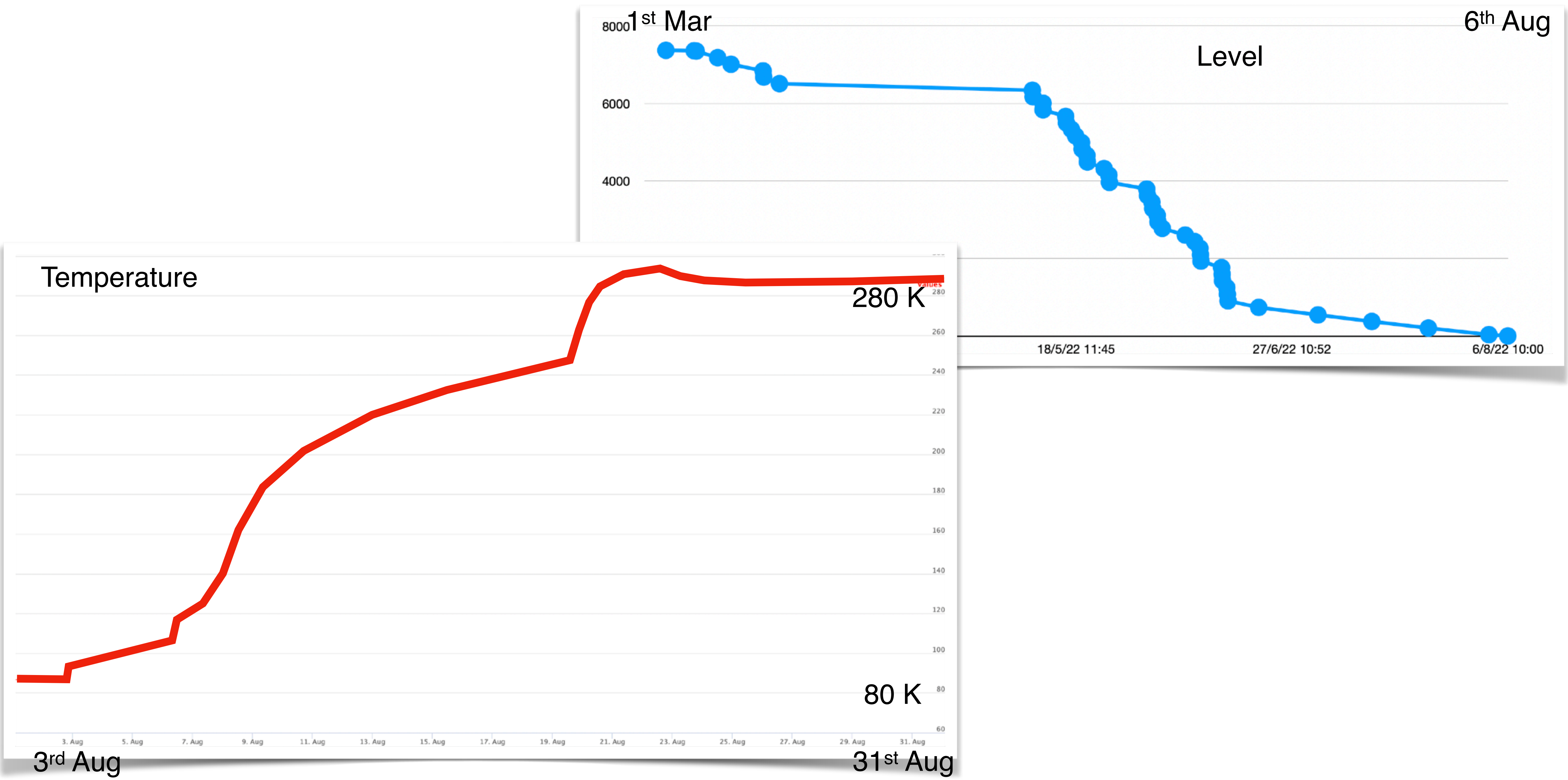
Validation of the HV extender and field cage at 300 kV and 6 m of drift achieved with DP HV system in 2021/22.
Goals of the Module 0:
- validation of the FD2 procedures concerning shipping, construction, assembly, installation,
- validation of tools, personnel needs and time required for each step,
- evaluation of the performance at nominal field (450 V/cm) and up to 294 kV applied on the cathode (900 V/cm).

Cathodes modules (with integrated PD modules) have the same size as the CRPs and hang from the CRP support structure.
Field Cage (FC) is made from independent modules hanging from the cryostat roof.
Two types of FC (made with Al extruded profiles and FRP beams):
- thick profiles across the cathodes to minimise the electric field,
- and thin profiles near the CRPs and the PDs on cryostat walls to increase the transparency.
FC-to-cryostat distance mimic the one of DUNE along the short walls.

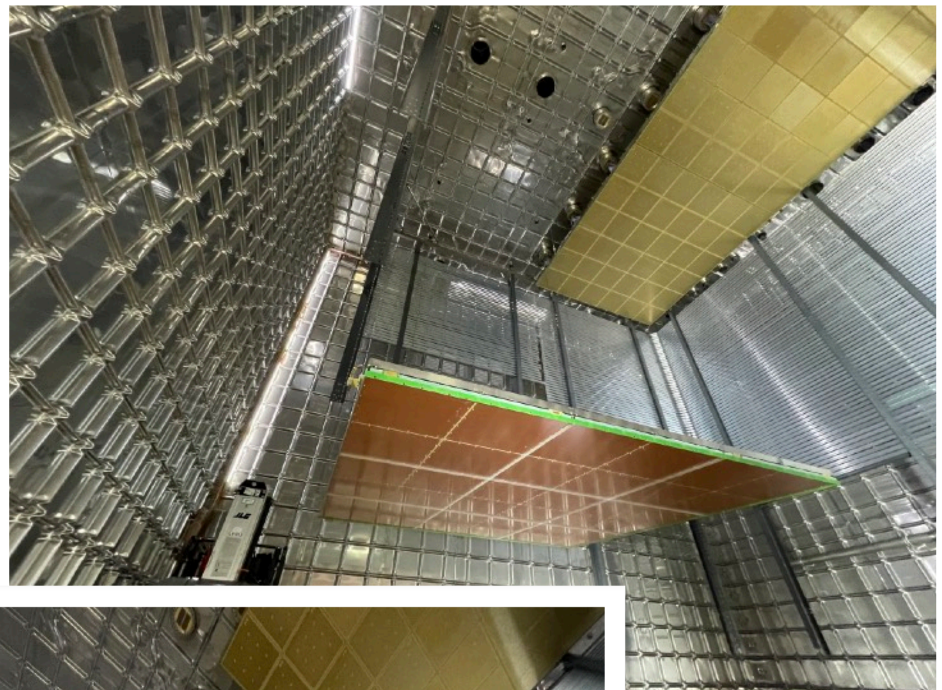


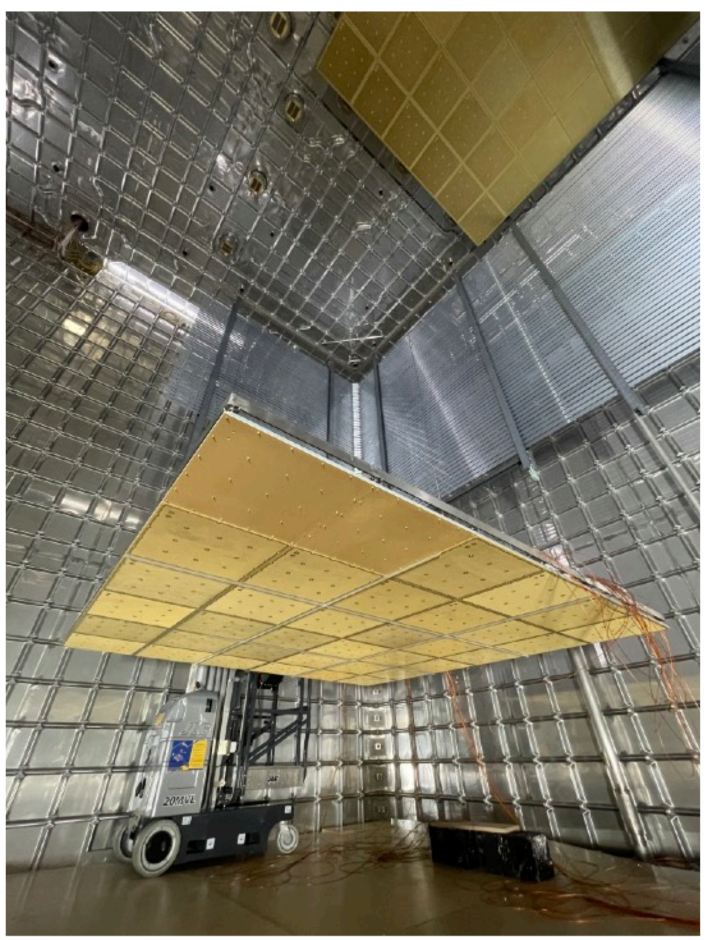
ProtoDUNE-DP emptying

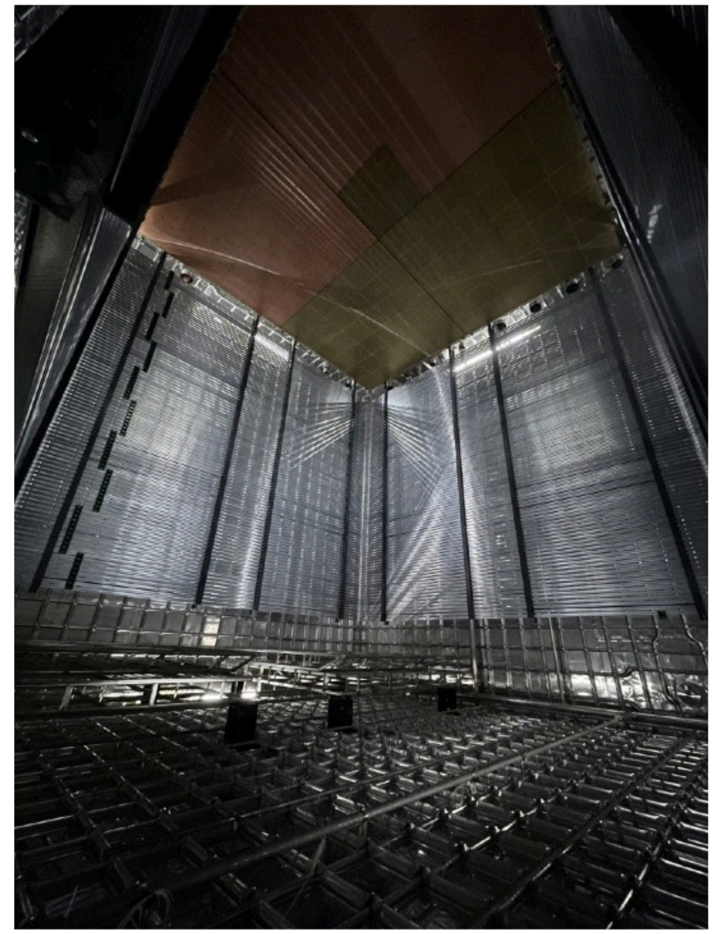
- After the 300 kV test in NP02, the cryostat was emptied and the liquid argon sold.
- At the beginning of August '22, all the argon was extracted (the last part was evaporated)
- At the beginning of September NP02 was warm, and purged with air started.
- Access via the man-hole to inspect the DP detector.



DP decommissioning





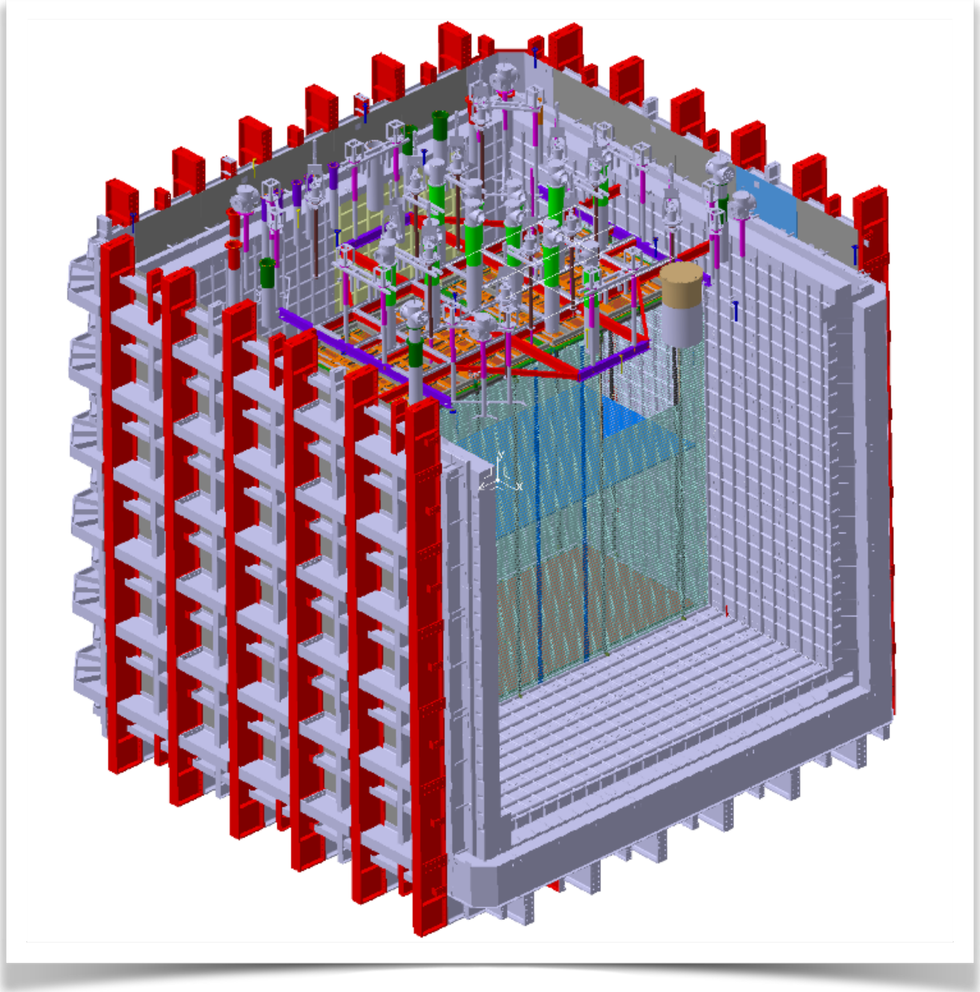


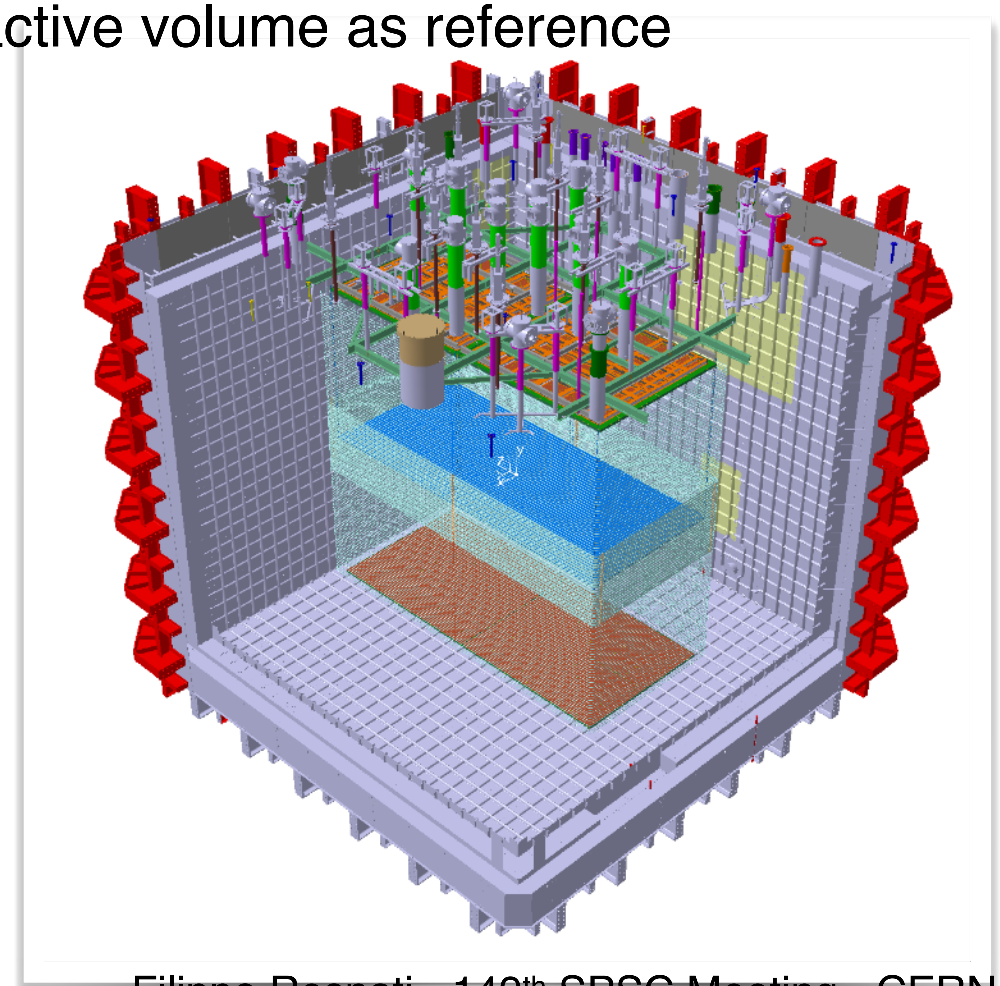
- Dismount of the Temporary Construction Opening (TCO) began at the beginning of October ’22.
- Gained access through the TCO on 24th of October.
- Start dismounting the DP detector from bottom up: PMTs, ground grid, cathode, up to the CRPs.
- NP02 cryostat was free on the 23rd of November.

Module0

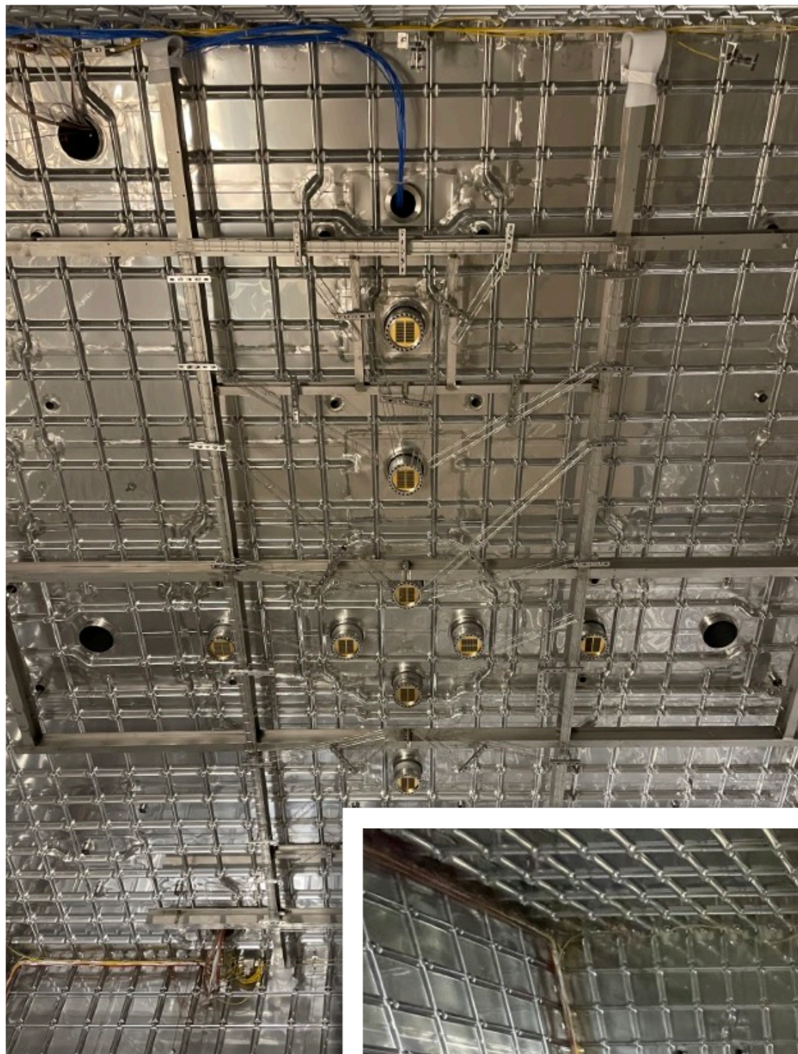
Module0 integration in NP02:

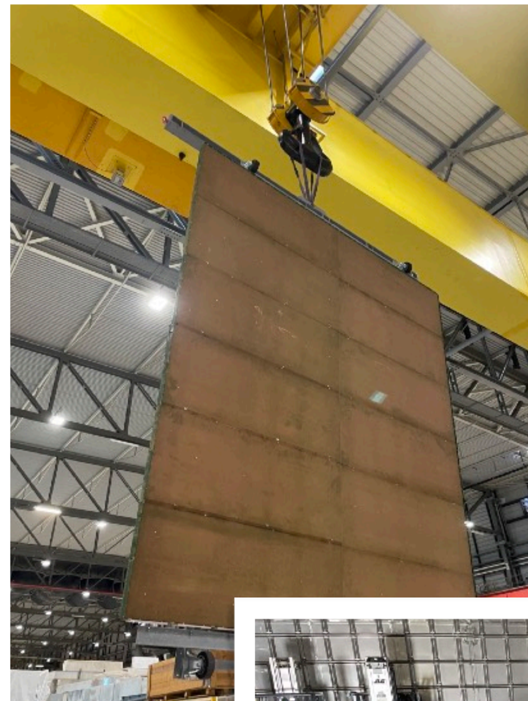
- 2 top CRPs + 2 bottom CRPs
- 2 cathode modules in the middle hanging from the top CRPs support
- Field cages (70% transparent @ top and bottom) hanging independently from the new DSS
- HV extender equivalent (shorter) to the one of DP
- ~3.2 m long drift, 300 kV capable HV system
- 8 xArapucas modules on the cathodes with PoF and SoF
- 8 xArapucas on the wall
- ~4.3 m long beam plug (NP04 style)
- Instrumentation (3 PrM, T-sensors, cryo cameras and lights)
- Ionisation laser from manhole
- PMTs outside the active volume as reference

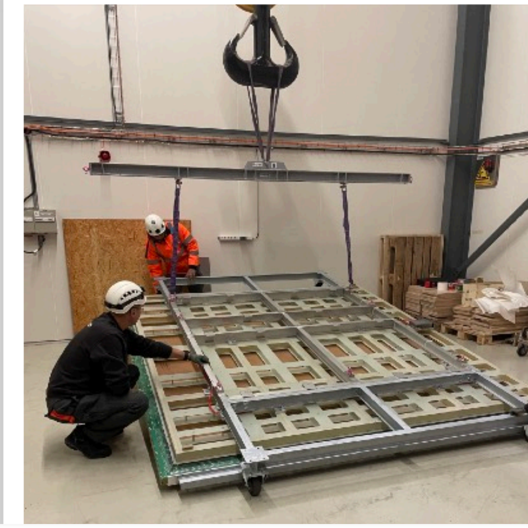


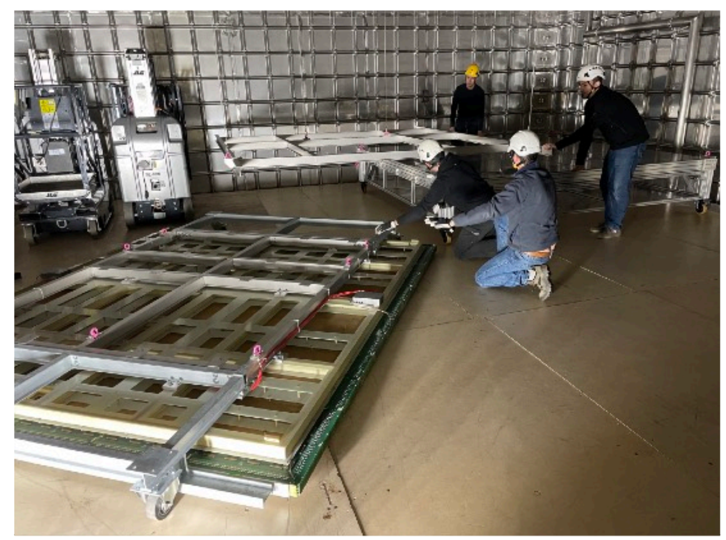


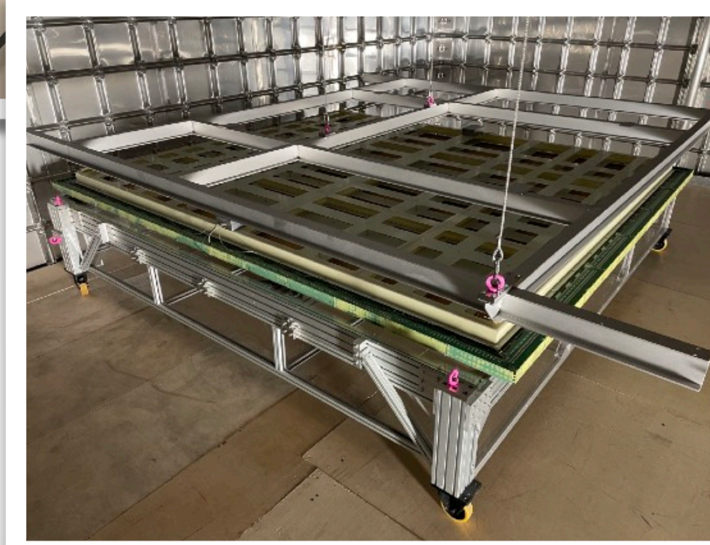
Installation highlights









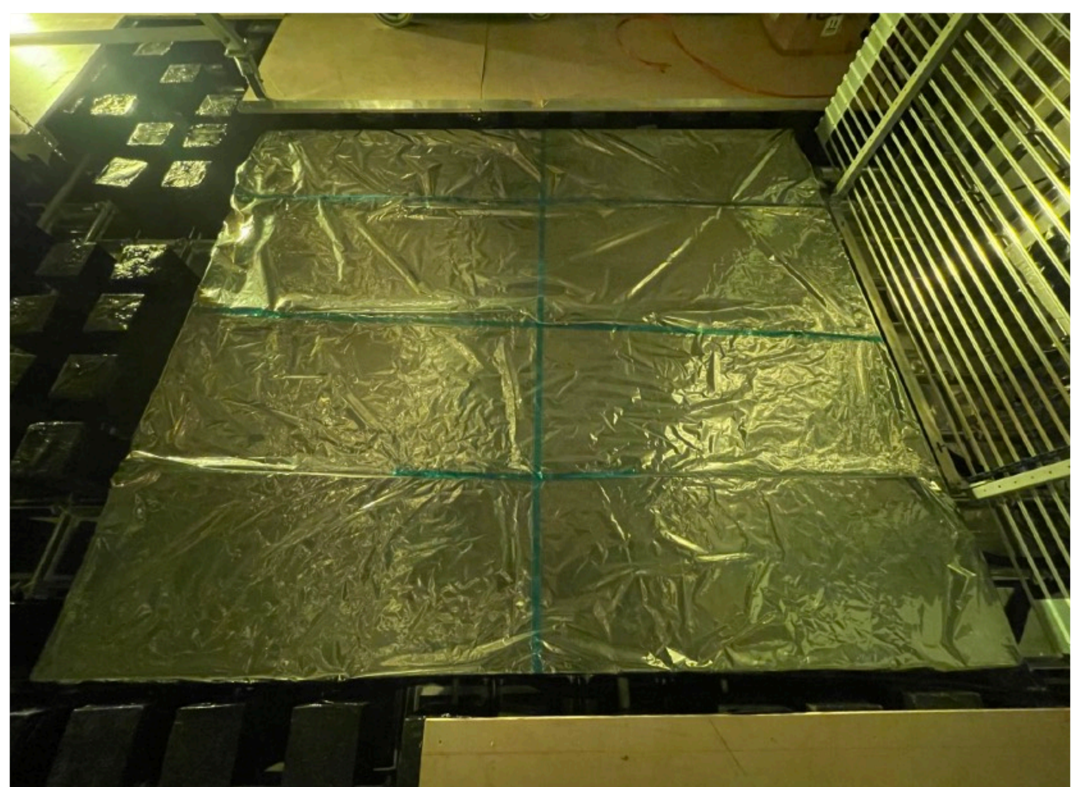


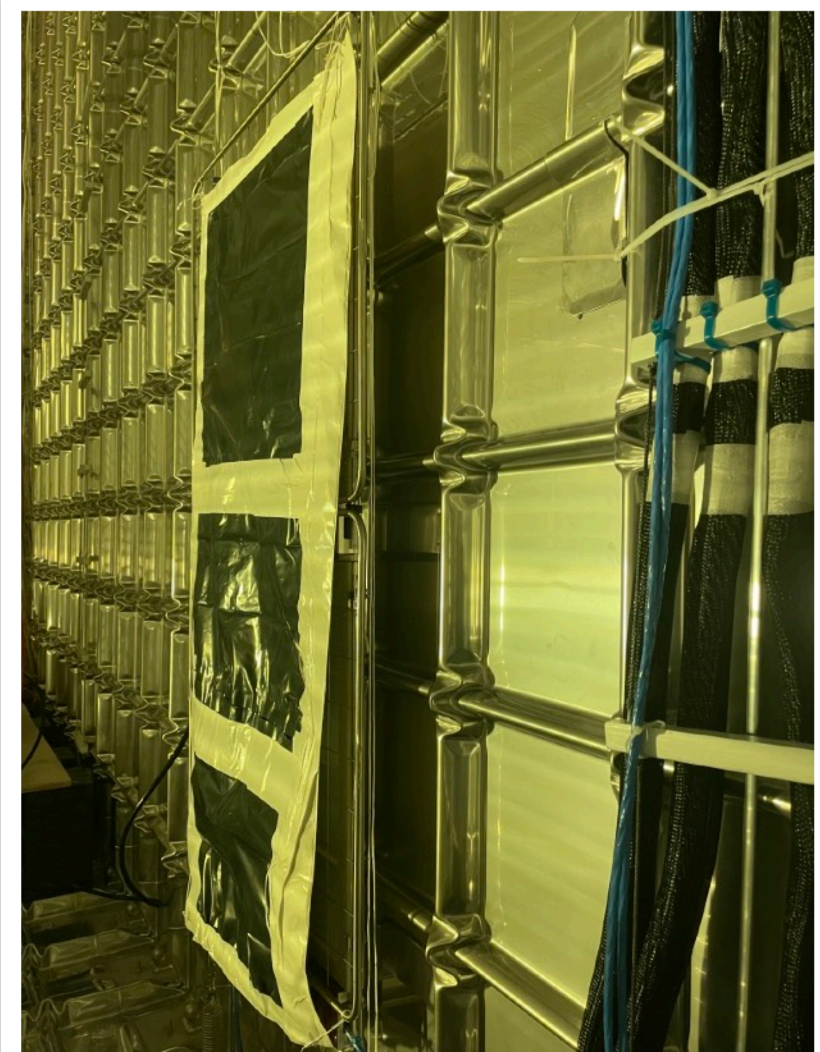
Installation highlights

Installation status

Main TPC components installed in NP02:
- 2x top CRPs installed and cabled
- 1x bottom CRP installed and cabled
- 2x cathode modules installed
- 8x PD modules on cathode
- 6x PD modules on cryostat walls
- FC production completed, 7 modules installed

Goal to complete the TPC installation by end of May.





TCO closure & filling

- Developed with GTT for ProtoDUNE-HD a procedure to close the TCO that impacts minimally the installed detector.
  - Most of the activities are carried out almost completely in the TCO opening.
  - The design of the insulation and membrane for the TCO closure is complete.
  - The documents from GTT are available and under study.

- No good news from liquid argon procurement.
  - Argon availability is less of a concern (from informal exchanges, two providers are capable of producing the quantity needed).
  - The price estimates from this informal contacts are prohibitive.
  - Delivery approximately 4 months after the awarding of the contract.

- Within the DUNE Collaboration, under discussion the filling order (NP02/NP04)
  - Purge, cooldown and filling take ~8 weeks (2x 20 ton truck/day, 5 day/week)
  - ~600 ton can be transferred from one cryostat to the other in about 1 week. Top up about 250 ton via truck in less then 2 weeks.

Next steps

Week of April 24: (start cold box test)
April 25th: Move the CRP5 into the cold box, close the cold box and start the purge
April 27th: Cooldown and fill
April 27th: Install bottom membrane PD modules (non TCO).

Week of May 1: (complete cold box)
April 28th - May 3rd: CRP5 cold box test
May 3rd: start emptying in the afternoon

Week of May 8: (bring the CRP in NP02)
May 8th: Remove existing tines from under CRP4
May 8th: Open cold box and put the roof with the CRP on the concrete blocks
May 9th: Lower CRP, un-cable it and put it in the transport box
May 9th - May 10th: Remove the CE cables from cold box and bring them in NP02
May 10th: Bring the CRP5 in clean room 185; install the adapter plates and the insertion metal frame and put in transport box
May 11th: Transport the CRP5 back to EHN1
May 11th: Disassemble needed FC.
May 11th: Assemble tine system and hook up to Gantry inside NP02
May 12th: Install extensions, insert CRP5 and flip in NP02 cryostat

Week of May 15: (install and cable the CRP5)
May 15th: Dismount the insertion tool and lift the CRP5 to move it above CRP4 to free the area in front of the TCO
May 15th: Use the 2 man lift to lower the second cathode at the same height as cathode one (slightly above nominal), remove the clamps between top CRPs, and adjust their position.
May 16th: Extract the man lifts
May 16th: Install the truss and put the CRP5 on the truss
May 17th: Cable CRP5 (not on cable tray) start CE testing
May 19th: Finish CE testing and Lower CRP into final position

Week of May 22: (continue the installation of FC)
- Install a temporary protection floor above the CRP5 and dismount the lifting system and the gantry
- Install scaffolding
- Lower the cathode PDS cables to floor
- Install cable tray on long side and route BDE and PDS cable through penetration
- Put the cathodes in the final nominal position
- Continue installing FC modules

Week of May 29: (complete the installation of HV system)
- Install remaining FC and connect to cathode
- Install the HV extender
- Ready to remove the scaffold and false floor, if needed

Beam time needs

Beam time will be requested for 2024, tentatively 2-3 weeks:
- at the beginning of the beam schedule, if NP02 is filled first, and LAr is available,
- at the end of the year if NP04 is filled first.

More detailed infos will be provided in the next months.
Relevant information will be given to the Committee as soon available.

Studies of with cosmic rays is invaluable for benchmarking the detector performance, and in general long term stability (electronics reliability, charge and light collection, cryogenic conditions, purity, HV, …)

Instead, studies that can be achieve only using beam are:
- independent calorimetric studies of light readout,
- calorimetric studies of the charge readout,
- online trigger on complex events,
- benchmark reconstruction algorithms and analysis with real data,
- measure low energy argon-hadron cross-sections to reduce systematic uncertainty of DUNE.

Summary

Intense year of developments, production, testing, and installation:
- CRP design improvements with the CRP1 and CRP1b
- 4 CRPs for Module0 produced and successfully tested in the cold box demonstrating the functional integration of the various TCP components
- Demonstration of excellent (close to ideal) noise levels of the TDE and BDE in realistic conditions during the cold box tests
- Proof of concept of triggering capability on live streaming charge signals
- Extensive development of PD system. Production and test in cryogenic conditions of the actual Module0 modules and power and readout chain
- Completion of the production of the main components of the HV system
- Decommissioning of the DP detectors, and free the NP02 cryostat
- Design and integrate the Module0 in the NP02 cryostat
- Installation of Module0 in an advance state. Completion foreseen by end of May
- Looking forward to the delivery of teh liquid argon in 2023