EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SR-XXX
April 28, 2023

CERN-SPSC-2023-018 / SPSC-SR-331
28/04/2023

Yearly progress report on NP02 (2023)

April 28, 2023

The NP02 Collaboration

Abstract

In this document we report general progress on the NP02 experimental activities at CERN since the last SPSC yearly report. We report here on the successful completion of the Vertical Drift tests campaign in 2022 and on the progress in the installation of Module-0.

Contents

1 Introduction

This document describes the continuation of the NP02 activities since the last SPSC annual report of April 2022.

Large progress was achieved within the DUNE collaboration in 2022 towards the implementation of the second DUNE Far Detector (FD-2) based on the Vertical Drift (VD) technology. This process included the Preliminary Design Reviews for all components and sub-systems of FD-2 and the editing of the Technical Design Report in December 2022, which was strongly supported by the experimental tests activities at the CERN Neutrino Platform.

The Vertical Drift tests campaign at the Neutrino Platform and its successful achievements in 2021, including the performance assessment of the first VD Charge Readout Plane (CRP) shared in between the top-drift and bottom-drift configurations, were accurately described in the 2022 report.

The expected continuation of these activities in 2022 allowed, following the initial planning, for the successful the cold-box tests of the final design top-drift full Charge Readout Planes (CRP2 and CRP3). These two CRPs were then installed inside the NP02 cryostat at the end of 2022, after having freed it from the existing dual-phase detector elements. The development of the FD-2 Photon Detection System (PDS) also strongly benefited of the cold-box campaign, thanks to tests performed in combination with the top-drift CRPs or in stand-alone cold-box tests. These activities brought to the finalization of the PDS design to be implemented in *Module-0*.

The cold-box tests campaign continued in 2023 in order to test the bottom-drift Charge Readout Planes (CRP4 and CRP5). The *Module-0* program implies equipping and rerunning the NP02 cryostat with the VD CRPs and other components such as the final High Voltage system (cathode, HV feed-through and extender) and the elements of the Photon Detection System (PDS), in order to establish their integration and overall operation for the DUNE FD-2.

The Vertical Drift Installation in the NP02, including two top-drift CRPs and two bottom-drift CRPs, is presently under completion, with the goal of closing the cryostat in the Fall of 2023 and filling it with liquid argon at the beginning of 2024. This report includes the description of the current status and planning for the continuation of the *Module-0* activities.

In conclusion, since the last SPSC annual report of 2022, despite the very ambitious Vertical Drift development schedule, there was excellent progress in achieving the foreseen experimental program and in bringing the VD design to a final design level, as described in the DUNE FD-2 TDR Draft for FD-2.

Activities are well on track for their completions and in view of the run of *Module-0* with liquid argon.

2 Finalization of Charge Readout Planes design

The CRP activities in 2022 focused primarily on the optimization and validation of the design of the different components entering into the CRP assembly before finalizing the design. The anode plane design for the FD2-VD provides three-view charge readout and is constructed of two stacked, perforated PCBs with biased strip electrodes on one or both faces. The three sets of electrode strips are set at different angles relative to each other to provide charge readout from different projections. The main change in the anode design compared to the first CRP described in last year report was essentially the strip layout. The orientation of the induction-1, induction-2 and collection strips for the first CRP was at angles (+48°, 0°, 90°) respectively. The angles are given with respect to the FD2 cryostat axis. The final configuration is based on angles (+30°, -30°, 90°) and with pitches of 5.1mm for collection and 7.65mm for induction strips. The number of readout channels for each CRP amounts to 3072. The anode panels of dimension 3.4m x 1.5 m are constructed similarly as for CRP1 by joining six smaller segments with epoxy joints. Once the PCB segments are mechanically bonded to form a PCB panel, electrodes on the induction-1, induction-2, and collection views are bridged by screen-printing conductive ink patches onto them. Figure 1 shows one anode panel after gluing and a closeup view of the induction layer with the glued junction and silver printed pads to do the electrical interconnection.

Figure 1: Left: Photo of one anode panel after gluing; Right: a closeup view of the induction layer with the glued junction and silver printed pads

In the new design the vertical interconnection between the anode plane strips and the adapter boards connecting electronics are done via small PCBs called "edge cards." Small connectors on the edge cards are in contact with the strips on the PCB end and with the electrical pads on the adapter boards at the other end. Anode PCBs, adapter boards, and edge cards are connected to a composite frame that serves as the mechanical support structure. This composite structure has been redesigned at the beginning of 2022 to ease the CRP assembly and transport. It is made from imbricated glass/Epoxy U-shaped profile between two layers of glass/Epoxy skins. The composite frame is made of 2 identical parts and several configurations have been built and tested in 2022 as part of the CRP prototyping effort.

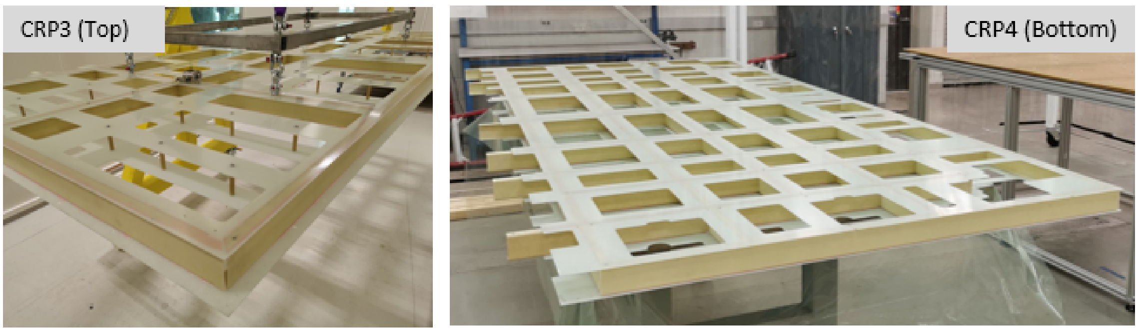


Figure 2:

Fig. 3 shows a view of a corner of one the 4 CRPs built in 2022 with the different parts mentioned above which are the edge cards, the adapter boards and the composite structure.

Four CRPs have been built (2 Top and 2 Bottom) based on this updated design and fully tested in the coldbox and characterised with the 2 types of readout electronics (Top Drift and Bottom Drift) as described in the next sections. The sequences of construction of the anodes, CRP assemblies and various tests are the following. The CRP2 and CRP3 were built in July and September respectively at CERN and the CRP4 and half of the CRP5 (both bottom CRPs) have been assembled in US and shipped to CERN beginning of 2023 for performing the coldbox tests prior to the integration in Module-0. The first top CRP (CRP2) was built in the clean room 185 at CERN from April to June

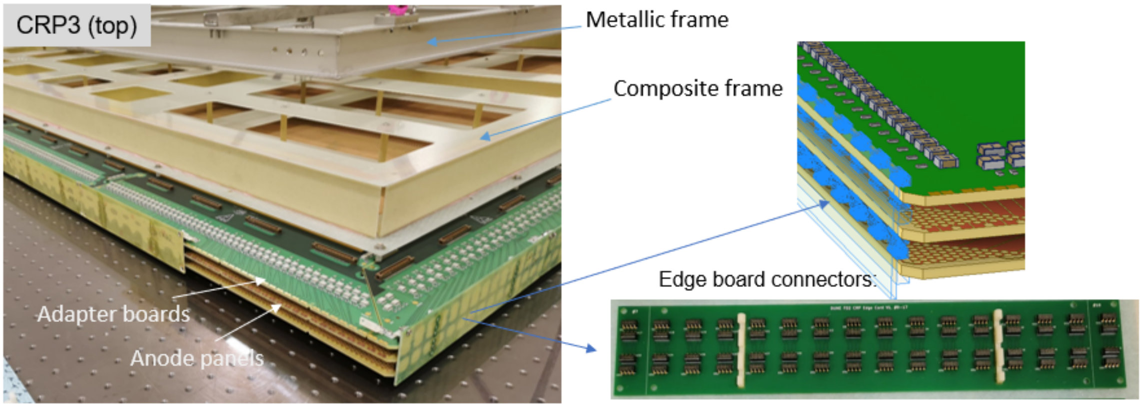


Figure 3:

2022. It was tested a first time in the coldbox in July 2022. The results showed some problematic connectivity issues on some silver printing region that were fully corrected in September and a second coldbox was successfully performed in November.

The second top CRP (CRP3) was built at CERN in June and July 2022. It has a lighter composite structure where half of the inner profiles have been replaced by G10 spacers. The mechanical behaviour was tested and proved to be withing the planarity specifications of a single CRP. It was tested in the coldbox in October 2022. Both top CRPs were inserted into the NP02 cryostat and installed in January 2023.

The anodes for the first bottom CRP (CRP5) were prepared at the same time as for CRP3. The anodes and a composite structure for one half CRP were sent to US to be assembled at Yale and cold tested after the integration of the cold electronics at BNL. The 1/2 CRP was then shipped to CERN and assembled together with the second half which was built at CERN in November. CRP5 was tested a first time in the coldbox at CERN in February. Some issues observed with the Bottom Drift Electronics were corrected in March and the CRP5 is having a second round of coldbox test at the end of April. The insertion in cryostat is foreseen in May 2023

The anodes for the second bottom CRP (named CRP4) have been built at CERN in September and October 2022. They were produced by a different company and have a silver coating. These anodes after being tested and controled have been sent to Yale together with the composite structures in December. The CRP4 was fully assembled in US, tested and shipped to CERN in February 2023. The coldbox test was performed successfully in March and CRP4 was inserted in the NP02 cryostat on March 24.

3 Cold-box tests

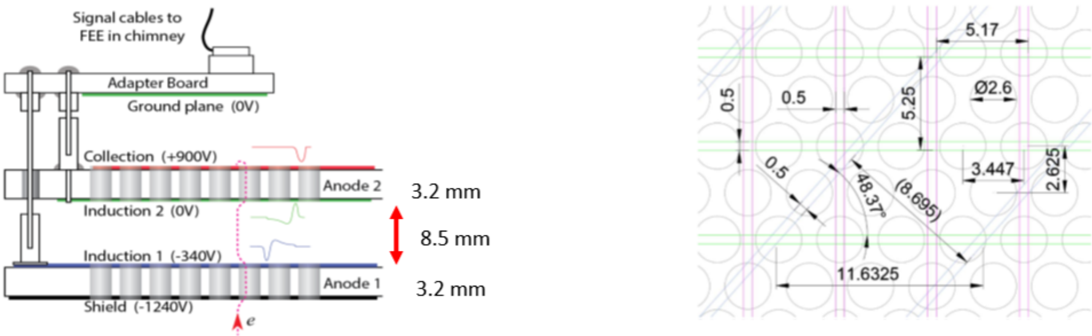
The aim of the CRP tests campaign, based on the dedicated cold-box cryostat refurbished in 2021 and installed close to NP02 to share the same cryogenic system, was to characterize and validate the design and the construction procedures of full scale Vertical Drift CRPs, for the top-drift and bottom-drift volumes, equipped with their respective electronics chains: Top-Drift Electronics (TDE), Bottom-Drift Electronics (BDE). Also for the Bottom-Drift configuration the CRPs are tested in a facing down configuration by hanging them from the cold-box roof.

The main objectives of these integration tests are:

- mechanical tests of the perforated PCB anode assembly (CRP) in cryogenic conditions
- characterization of the performance of the perforated anode and of the full electronics chain (TDE and BDE) in terms of signal to noise ratio and its stability
- mechanical test of the cathode module in cryogenic conditions

- test of the light readout system concept
- test of the integrated system and evaluation of the interplay between the powering scheme, the charge readout electronics and the light readout system

As described in the 2021 SPSC NP02 annual report, the first Vertical Drift CRP (CRP1) was successfully tested in the Fall/Winter 2021. In a single CRP it was integrated a 3 views layout including a downstream perforated anode layer with two orthogonal views (Induction-2 and Collection). A second perforated PCB placed upstream in the direction of the drift was used in order to implement a third view at 48 degrees (Induction-1) and a shield plane on its side facing the drift volume .



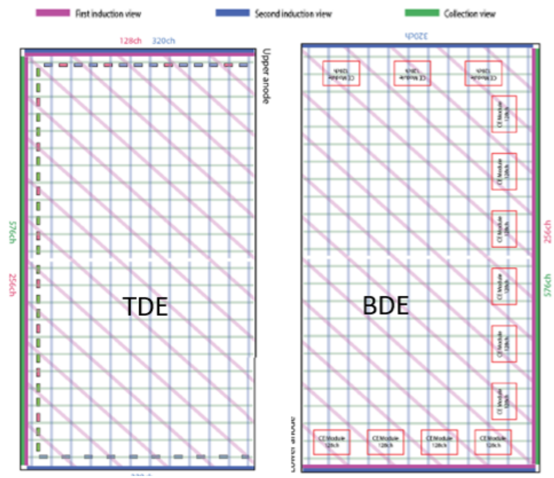


Table 3.2: Key parameters for reference anode (three-view) design

Parameter	Three-view configuration Induction 1	Induction 2	Collection
Strip length [m]	up to 2.24	1.49	1.68
Strip pitch [mm]	8.7	5.25	5.17
Strip gap [mm]	0.5	0.5	0.5
Unit capacitance [pF/m]	109	83	91
Total capacitance [pF]	up to 250	125	153
Number of strips per CRU	384	640	576
Number of readout channels per CRP	3200		
Strip angle w.r.t. beam	48°	0°	90°
Bias voltage [V]	-340	0	+900
Hole diameter [mm]	2.6	-	2.6
Inter-PCB gap within CRP (at room temp.) [mm]	1		

Figure 4: Perforated anodes and strips layout for the first Vertical Drift CRP

Given the availability of the anode PCBs to build the first CRP and the operation schedule of the cold-box, the first Vertical Drift CRP test was organized in order to exploit a single CRP divided in two halves with TDE and BDE readouts simultaneously present (see Fig. 4).

For this purpose a special CRP structure supporting the anodes was designed to be compatible with both types of electronics. Two cold-box runs were performed with CRP1 in the fall 2021. A summary of the noise performance for the 3 views for the TDE (Run-1 and Run-2) and the BDE (Run-2) before the CNR procedure is shown in Figure 5.

Then CRP1 was exploited in 2022 (January-May) for several tests at warm in two different versions of a Faraday cage explicitly built at EHN1 in order to be able to perform full tests and characterizations of the CRPs at warm. The Faraday cage was designed to host the roof of the cold-box with the CRP suspended below and be able to access and work on the CRP during the tests in a completely shielded area.

CRP1 was slightly modified in a version called CRP1b (including some grounding improvements in the CRP structure requested by the bottom drift electronics) which was first tested in the final

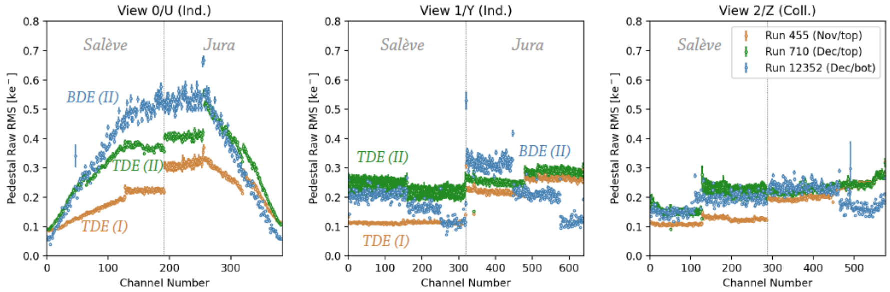


Figure 5: Noise performance for the 3 views of CRP1 before CNR

Faraday cage configuration and then in a dedicated cold box test in June 2022, which saw as well some important improvements of the grounding in the cold-box setup with the installation of an isolation transformer.

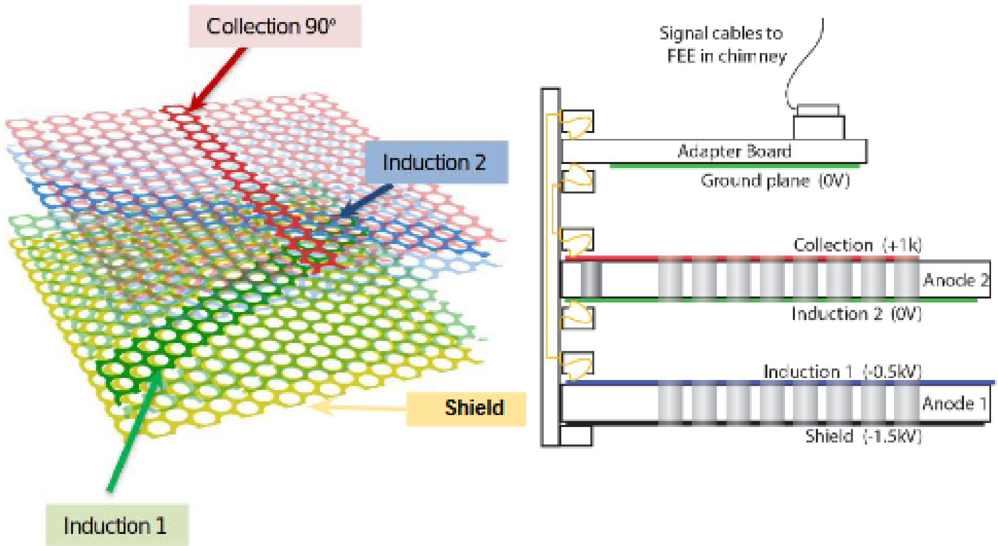


Figure 6: Final Vertical Drift CRP strips layout, the PCB stack corresponds to a top-drift CRP with the adapter boards connected to the chimneys via flat cables

After the assessment of CRP1 in a shared top/bottom drift configuration, the tests campaign focused since the summer of 2022 on the tests of two full top-drift CRPs (CRP2 and CRP3), completed by the fall 2022, followed by two full-bottom drift CRPs (CRP4 and CRP5) in spring 2023 with their final strips configuration at 90 and ±30 degrees (see Figure 6) and channels counting (3072 readout channels per CRP). These were the final detector elements foreseen to be then integrated in Module-0 since the fall of 2022.

The coherent noise in the cold-box setup greatly improved with the installation of the isolation transformer and other little improvements of the setup and better shielding of the flanges used for the slow-control services. This brought the coherent noise to then much cleaner environmental conditions measured during the tests of CRP1b, CRP2 and CRP3.

The test of CRP1b also allowed comparing at several months distance the signals stability on CRP1 (see Figure 7). The dQ/ds and dE/dx curves for the November (black) and June (red) runs are represented superimposed. The Landau distributions correspond to the nominal values/shapes and show a very good detector resolution. The curves corresponding to different periods are practically

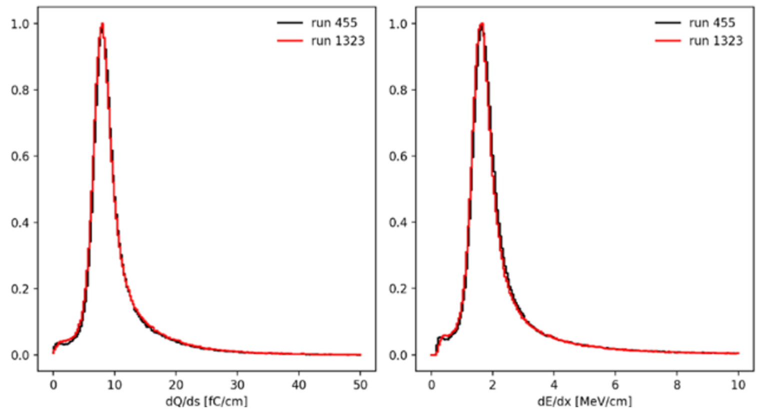


Figure 7: Calorimetric response stability for runs taken at months difference with CRP1/CRP1b

indistinguishable, demonstrating the stability of the detector and of its readout system.

The first Vertical Drift CRP with the final channels layout and strips orientation (CRP2) (see Figure 8) was built for the top drift layout and tested in the Faraday cage and in the cold-box in June-July 2022.

The second final Vertical drift CRP (CRP3) was also tested in both the Faraday cage and the cold-box in September-October 2022. Eventually, CRP2 was tested for a second time in the cold-box in October-November 2022 in order to validate some corrections to a small fraction ($\approx 1\%$) of silver-printed joints in between the perforated anode PCBs which had been shown discontinuity issues during the first test in July.

Figure 8: CRP2 suspended from the cold-box roof being moved from the Faraday cage to the cold-box location

It was then concluded in 2022 the qualification campaign of the two final CRPs which had been built to equip the top drift volume of Module-0 and of their associated TDE electronics.

Being the cold-box roof, also exploited in the Faraday cage tests, a dis-mountable system, the TDE readout chain used for this campaign has been installed and dismounted about 20 times with no deterioration. This tests campaign was a useful exercise for the installation procedures and also demonstrated the robustness of the components. A time-line of all these milestones and achievements is presented in Figure 9.

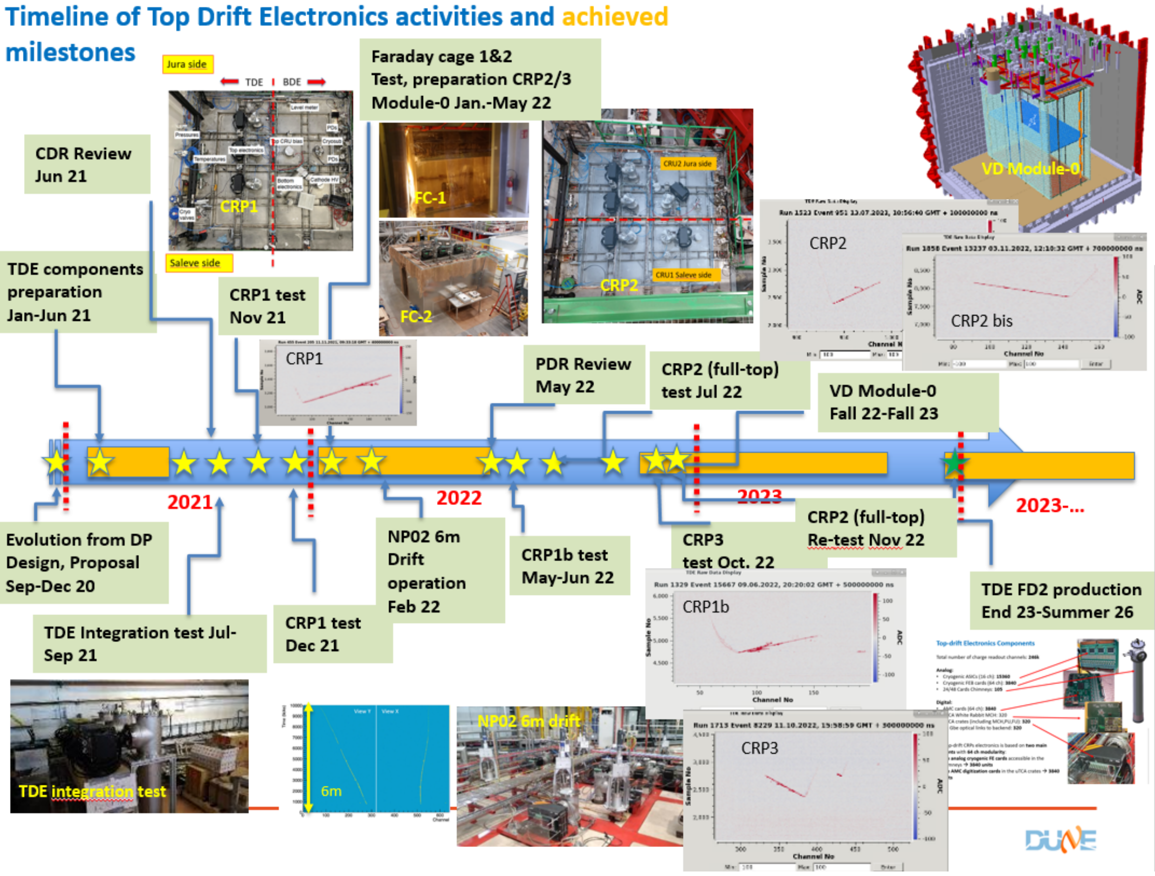


Figure 9: Time-line of the top drift electronics/CRP tests campaign in 2021-2022

Figure 10 shows the Faraday cage and cold-box installations in occasion of the tests in June-July performed on CRP2. This first full Vertical Drift CRP was involving for its readout 48 FE cards hosted by five 10-cards chimney connected to five crates with 48 AMCs.

Given the reduction since the spring 2022 of the coherent noise present in the cold-box setup, cosmic ray tracks were collected in very clean conditions. Figure 11 shows examples of cosmic ray tracks respectively acquired during the cold-box test of CRP2 in July 2022 and the one of CRP3 in October 2022. The picture shows the raw data in the collection view from the online event display with no noise treatment.

The noise levels for CRP2 an CRP3 before and after noise reduction are summarized in Figure 12. Compared to the cold-box runs of CRP1 in 2021 (Figure 5) one can notice the large reduction of the coherent noise contamination, present before applying the CNR procedure.

The good performance of the top drift electronics during the various cold-box run allowed collecting a very large statistics of cosmic-ray events in order to finely map and characterize the response of CRP2 and CRP3 which were fully validated and then installed in the Module-0 at the end of 2022.

The first bottom CRP (CRP5) was tested in the coldbox in February. The noise levels and general behaviour of the CRP were good and as expected; however it was observed some issues with the data collection. One of the issue was related to corrupted data from one FEMBs not getting the clock signal. Other issues, now resolved, were coming from some FEMBs seeing corrupted data from time to time. All those problems were understood and several changes were then made on the CRP5 after this first coldbox test. It corresponded to replacing 2 FEMBs (1 on each $\frac{1}{2}$ CRP), 1 short power cable and 1

Figure 10: Top drift readout chain installed in the Faraday Cage and cold-box setups for the tests of CRP2 in July 2022

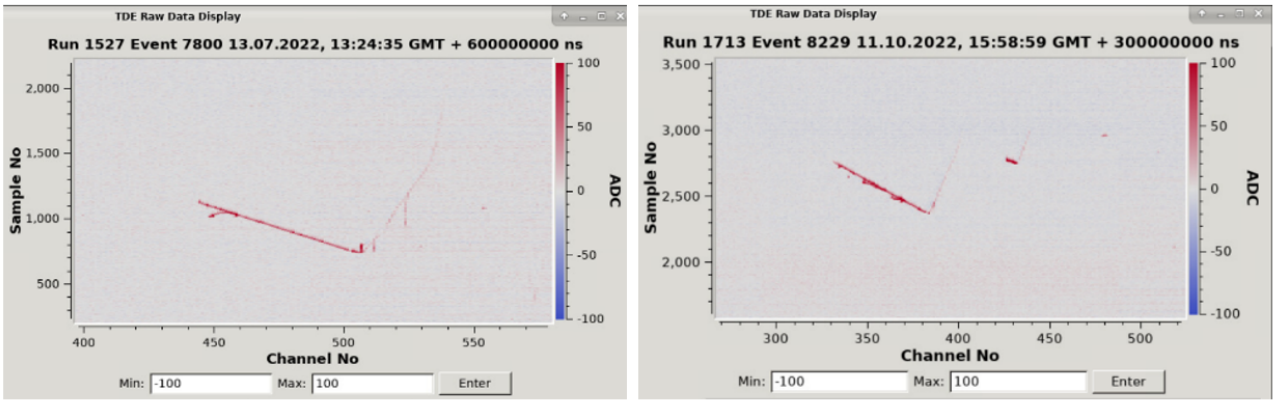


Figure 11: Examples of cosmic ray tracks collected during the cold box runs for CRP2 (left) and CRP3 (right)

patch panel. After these changes it was decided to perform a second test in the coldbox of CRP5 at the end of April to validate it before inserting it in the NP02 cryostat.

The other bottom CRP (CRP4) coldbox test took place successfully in March. The overall noise conditions were well within the expected level and all electronics channels were stably sending good data for the entire cold run test. Figure 13 shows the measured level of noise and the comparison of the CRP4 and CRP5 during the tests in the cold box.

Collected coincidence data have also been taken with PDS and demonstrated negligible effect on noise from simultaneous operation. Several cosmics runs have been taken in very stable conditions as for the other CRPs tested in the coldbox.

The cold-box runs of CRP4 and CRP5 were also used to exercise the functionality of the trigger prototype as designed for DUNE on a live system. The raw data wave forms produced by the BDE for each channel (strip) are continuously analysed in the DAQ readout software, using Single Instruction Multiple Data processing techniques, with the aim of identifying channel activity (see Figure 14) and forming trigger primitives (data structures containing information about when, by how much and for how long the waveform was above a threshold). The trigger primitives are then passed to the trigger software which selects time windows in which there are interesting groups of trigger primitives according to, e.g., high multiplicity, adjacency, isolation criteria. The data corresponding to the selected time

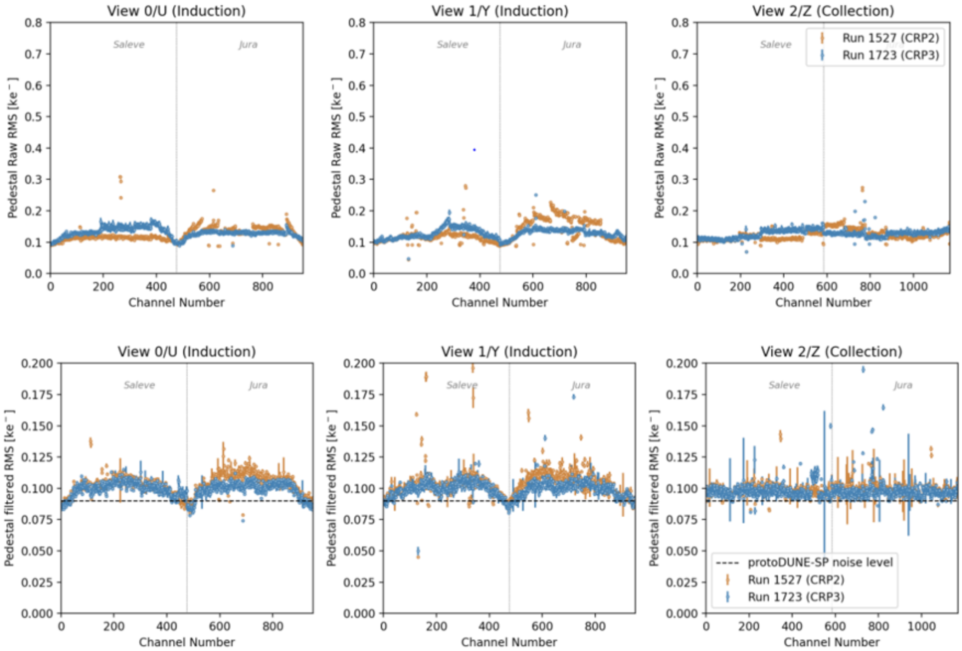


Figure 12: Noise levels before (top) and after (bottom) CNR for the operation of CRP2 and CRP3.

window are collected by the DAQ and form trigger records which are stored in files for offline analysis. An example trigger record is shown in Figure 15.

The cold box tests were exploited also for the validation of the full Photon Detection System (PDS) chain and its integration with the HV system and the CRPs.

Reflecting the baseline implementation of the Vertical Drift DUNE Far Detector Module, the PD modules will be installed along the cryostat walls, in contact with the corrugated SS membrane of the cryostat and embedded on the the cathode modules, that separate the top and the bottom drift volumes. The installation on the cathode introduce the significant challenge of operating the PD modules at HV (-300 kV nominal), and an intense R&D program was carried out to develop stable and efficient Power over Fibre (PoF) and Signal over Fibres (SoF) solutions, to connect the PD modules only via optical fibres. In a nutshell, this concept is described in figure 16.

For what concerns PDS, the first tests of 2022 served as demonstrators of PoF and SoF technologies in realistic conditions. The reliability of the solutions adopted was demonstrated in 2022, operating the PD modules on an actual cathode module operating up to 15 kV (the maximum designed voltage of the cathode in the cold box). Several PDs, electronics, PoF and SoF configurations were tested, and a number of optimisations were introduced, including the xArapuca mechanical and optical design, light tightness on laser connections, laser wavelength and power, and the cold electronics integration and optimization (SiPMs ganging, Cold Electronics Amplifiers, SoF and PoF integration). PD system was simultaneously operated together with the CRPs and the CRP electronics (both top and bottom) to ensure that full compatibility of the systems, in particular with respect to mutual induced electronic noise. As an example of the test results, the distribution of the signal amplitude from PD operated in the cold box is shown in figure 17, on the left the SiPM are powered via copper, and on the right SiPM are powered via PoF and the signal is readout via SoF.

4 Module-0

The Module-0 integration offers a large scale test with final detector elements. A 3D model view is shown in Figure 18. The design has been optimized to help validating most of the procedures foreseen

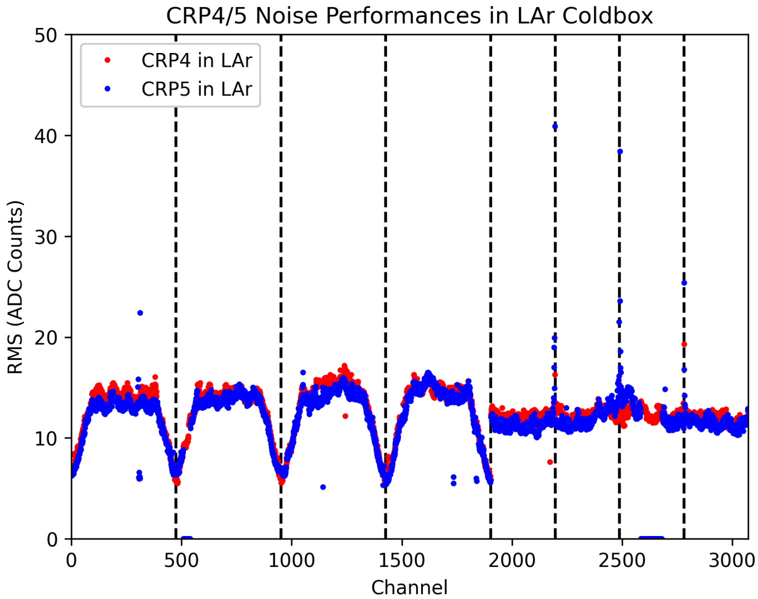


Figure 13: Comparison of the CRP5 and CRP4 noise levels during the coldbox tests done in February and March respectively.

for the DUNE Far Detector 2, from the transport of the detector components to their installation inside the cryostat.

Two CRPs are located at the top and two at the bottom. The cathode units are suspended from the top CRP supporting structures. The cathodes integrate the X-Arapucas photon detectors. Additional photon detectors are hanging along the cryostat membrane. The modular field cage surrounds the drift volume and is made 70% transparent at the level of the Photon detectors on the cryostat membrane. The HV Feed-through and Extender are located right (Jura) side of the field cage. A beam plug, similar to that of NP04 is also planned (not shown in the picture).

4.1 PDs

In the last year the developments, the production, and the QA/QC tests were aimed to install 8 xArapuca (technology developed first for the Horizontal Drift module) modules on the walls and 8 on

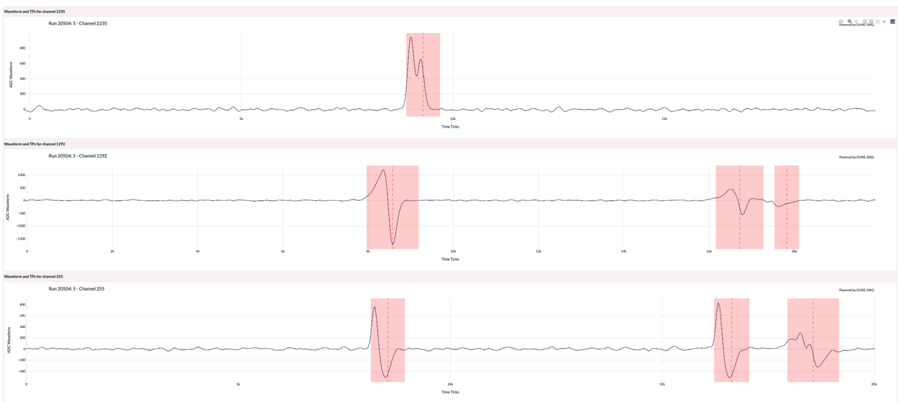


Figure 14: Identification of CRP channel activity in the DAQ, using an absolute running sum algorithm, optimised for detecting signals on both induction and collection planes.

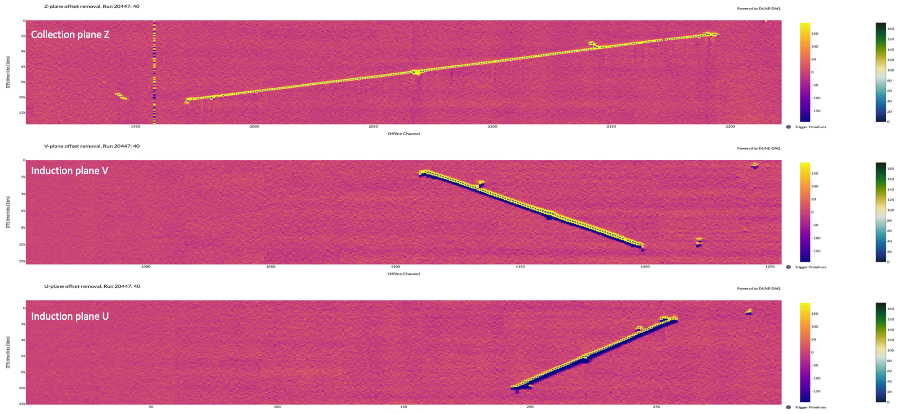


Figure 15: Example of a long track selected in CRP5 by the trigger using high multiplicity and adjacency criteria. The plot shows the evolution in time (y-axis) of the ADC values of the channels (x-axis) for the three CRP planes, superimposed with the trigger primitives information.

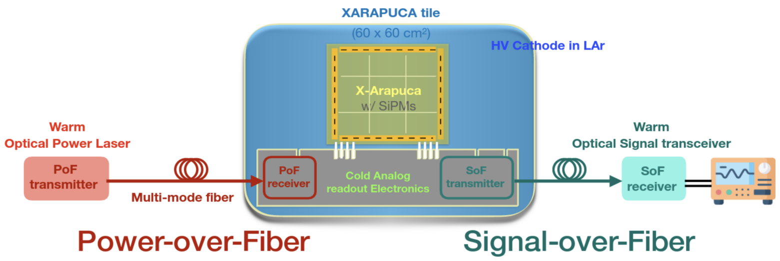


Figure 16: Cartoon of the PoF and SoF implementation for the PDs.

the cathodes of the Vertical Drift Module0 detector in NP02 cryostat. The PD modules to be installed in the Module0 were assembled at EHN1, and a test stand was setup to benchmark each one of them prior installation in NP02. In particular, PoF, SoF and signal over copper electronics were tested multiple times at room temperature and in liquid argon. The lessons learned during these QA/QC tests resulted useful also for the PD system of NP04, for what concerns the digisation of the signal over copper. 14 of the 16 xArapuca modules are installed in NP02. Cables or fibres are ready to be routed towards the dedicated penetration on the cryostat roof. 8 PD modules (4 per cathode module) are installed on the cathode. 5 modules are installed on the membrane behind field cage, and they are connected with copper cables. 1 module on the membrane is installed and uses power via copper and 2 SoF channels. This configuration is not an option for DUNE, but it is useful for debugging purposes

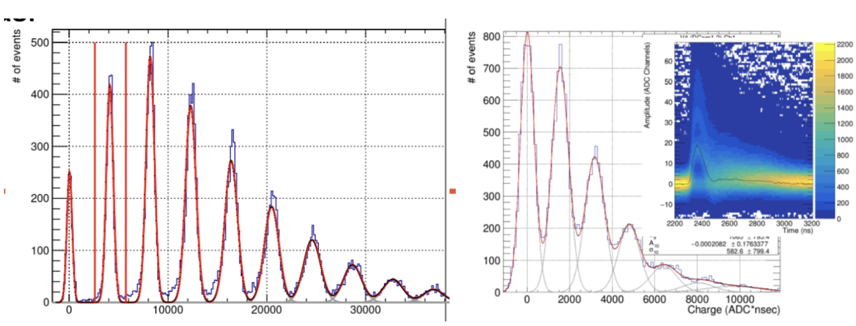


Figure 17: Photoelectron amplitude spectrum in low light levels. Left: SiPM powered via copper wires. Right: SiPM using PoF and SoF.

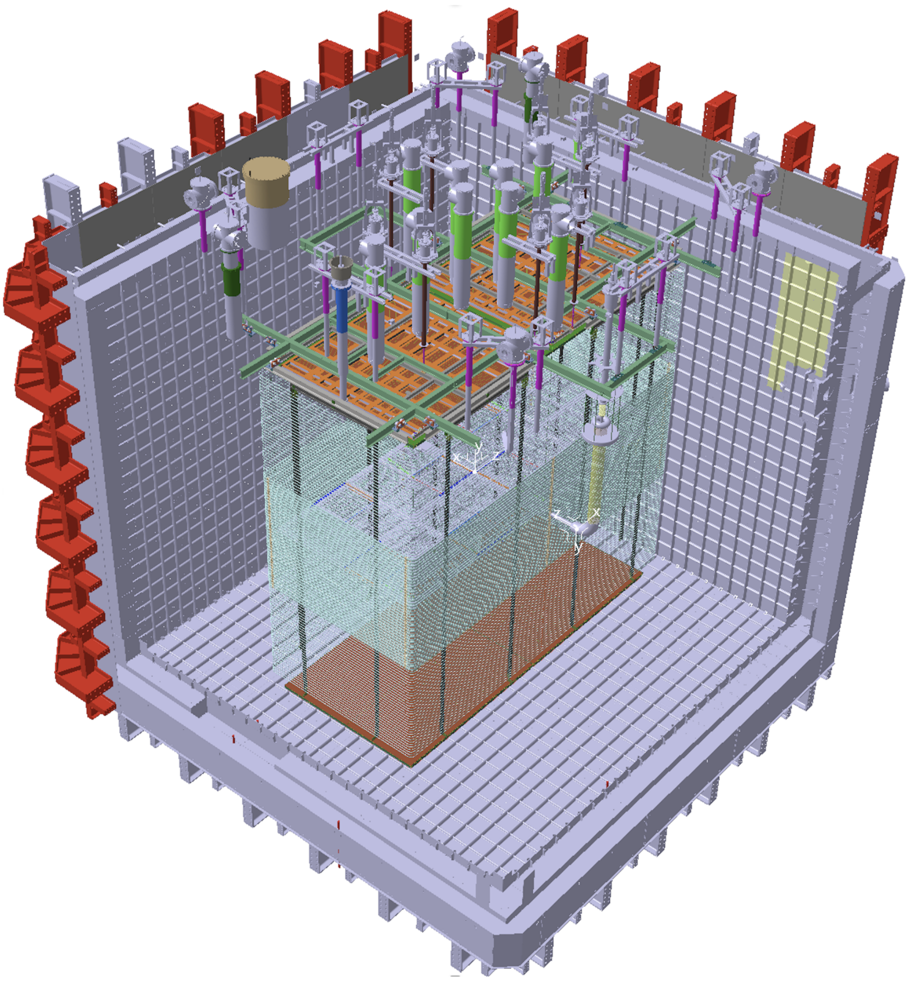


Figure 18: 3D view of the Vertical Drift Module-0 detector inside the NP02 cryostat. The TCO is located on the bottom left side.

on long term tests. The last two modules will be installed as soon as the CRP installation is complete. Figure 19 shows the moudules installed in NP02.

4.2 CRP

The two top CRPs (CRP2 and CRP3) built, tested and validated in the coldbox constitute the top plane of Module-0 while the two bottom CRPs (CRP4 and CRP5) constitute the bottom plane.

Each top CRP is suspended to the cryostat roof by mean of a metallic frame attached to four of the suspension system originally used for the Dual phase CRPs. The composite structure is linked to the metallic frame using mechanical decoupling devices made to compensate for the differential contraction between composite and stainless steel. The installation procedure of the top CRPs started with the installation of the signal cables connecting the cold flange of the TDE chimneys to the CRP connectors on the adapter boards. This procedure of pre-routing the cables before the CRPs are raised to the top structure is similar to what is foreseen for the FD2 installation. Figure 20 shows a timeline of the main installation of the top CRPs and the first bottom CRP.

The installation of the bottom CRPs started with the installation and routing along a cable tray of the 25 m long cables used to connect the signal and power cables from the patch panels sitting on the CRPs to the Bottom Drift Electronic flange. After entering the CRP inside the cryostat with the same tooling as the one used for the top CRPs, a sequence of operations is performed to get the anodes up

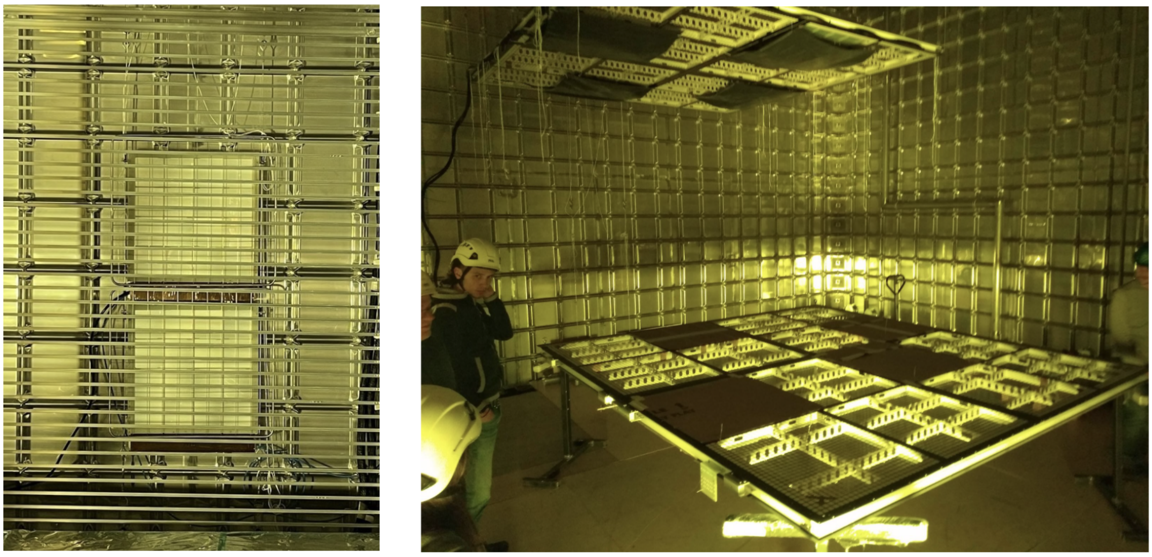


Figure 19: Photos of PDs installed in NP02 on the walls (left) seen through the field cage, and on the cathode (right).

and to get the CRP detached from the insertion tooling. In order to move the CRPs to specific place in the cryostat and to do the cabling on the patch panels a dedicated tooling called 'lifting system' developed in Wisconsin and based on a fork system picking up the CRP from below has been used. The cabling is done when the CRP is positioned on a mechanical truss at the final place. After cabling the truss is removed and the CRP lowered. The bottom CRPs are positioned with four posts attached to dedicated G10 adapter plates on the composite structure and layed on the cryostat membrane floor.

The sequence has been applied successfully in March 2023 to install the first bottom CRP (CRP4) and should be repeated in May for the second bottom CRP. Figure 21 shows different steps of installation of the first bottom CRP in the cryostat. Several aspects of the installation procedure foreseen for FD2 using the lifting system have been verified, tested and demonstrated during the CRP5 integration.

4.3 HV System: Cathode, Field cage and HV delivery

The operation of the FD2 HV system at 300 kV and 6 m drift has been successfully demonstrated in the NP02-DP HV stability run in 2021-22. This achievement was extensively described in the NP02 report to the SPSC in 2022. The main additional goals with the NP02-Module-0 are:

- validation of the FD2 procedures concerning shipping, construction, assembly, installation;
- validation of tools, personnel needs and time required for each procedure;
- evaluation of the HVS performance at nominal E-drift = 450 V/cm and possibly up to 294 kV applied on the cathode (E-drift = 900 V/cm).

The active LAr volume of the NP02 Module-0 is split vertically into two drift volumes delimited by the CRPs at the top and the bottom and the suspended cathode at mid height. These volumes are surrounded by a modular field cage independently suspended from the cryostat roof. A HV delivery system composed by a HV feed-through and a HV extender connected to the Field cage electrodes at the cathode height is used to bias the cathode with the nominal HV. In details:

- the cathode is made of two units with the actual FD2 size of 3.375m x 3m; they are independently suspended to the CRP supporting structure at 3.2 m distance (one half of the nominal drift

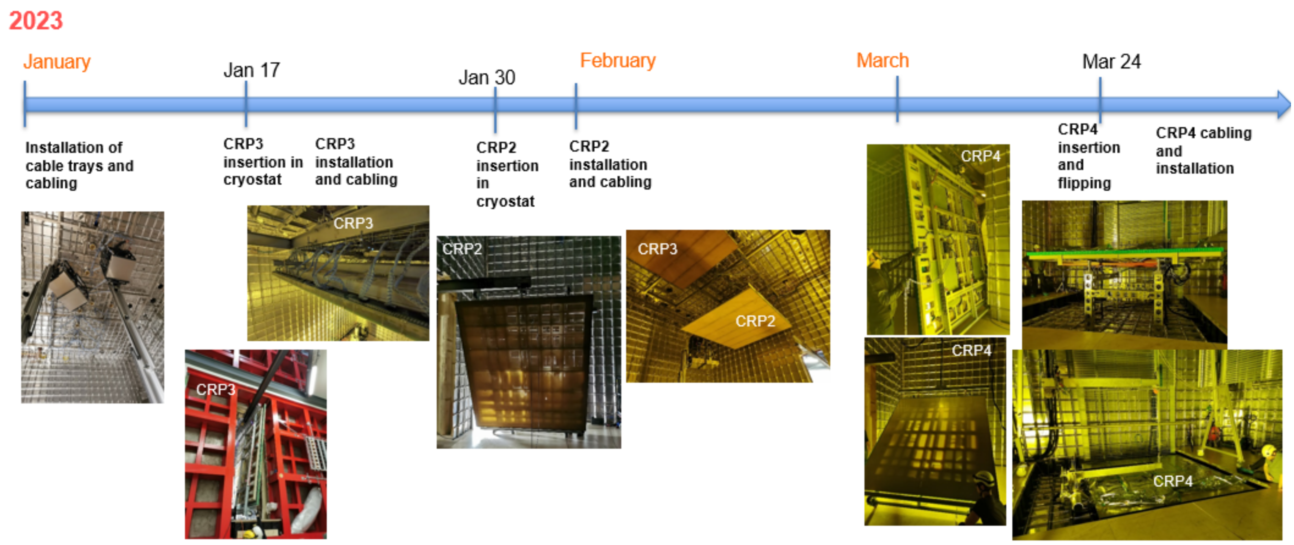


Figure 20: Timeline of the integration in the NP02 cryostat of the 2 Top CRPs and the first Bottom CRP during the first trimester of 2023

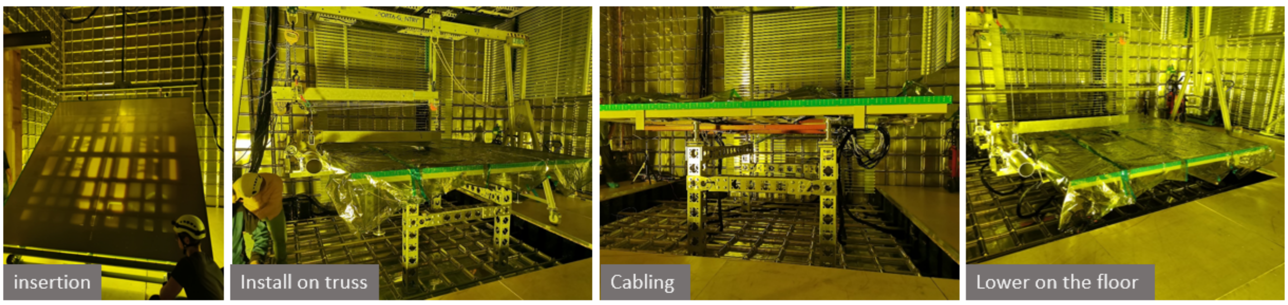


Figure 21: Illustration of the main steps performed for the installation of the first bottom CRP (CRP4) in Module-0.

distance in FD2); the cathodes units integrate the Photon detectors powered and read out with PoF and SoF respectively;

- six Field Cage columns (four with with bent profiles), 6.4 m high (one half actual FD2 height) split in three panels instead of two, due to limitations in the insertion into cryostat; the Center panel is equipped with thick profiles as in FD1/NP04; the top/bottom panels are made of thin profiles (70%) transparent) to allow the propagation of the scintillation light to the Photon Detectors suspended along the cryostat membrane; FR4 insulating sheets are applied on the bent corners to improve E-field uniformity by charging up; the FC columns are suspended from a dedicated internal DSS structure;

- the actual 75 cm FC-to-membrane distance on the short FC walls is implemented;

- the actual FD2 HV delivery system is installed except for length of the extender strait section;

- the actual assembly tools, cathode cart-wall, FC assembly station and storage carts are actually used to assemble the HVS components.

Both cathodes have been at successfully positioned in NP02 with procedures similar to FD2 (Figure 22). The cathode frames (4 halves + 2 spares) were shipped in the actual crates, with meshes, suspension systems (dyneema cables), and the assembly tools. The Cathodes were assembled in cart wall in NP04 clean room, equipped with the resistive mesh surfaces and with the integration of the Photon detection system (including electronics and PoF/SoF). After insertion in NP02 cryostat, they were attached to the supporting ropes connected to CRP Structures To complete installation, after both bottom CRP's are installed, the cathode units will be positioned at the nominal elevation, electrically interconnected and connected to field cage. The fibers of PoF/SoF will be routed along the field cage to the floor.

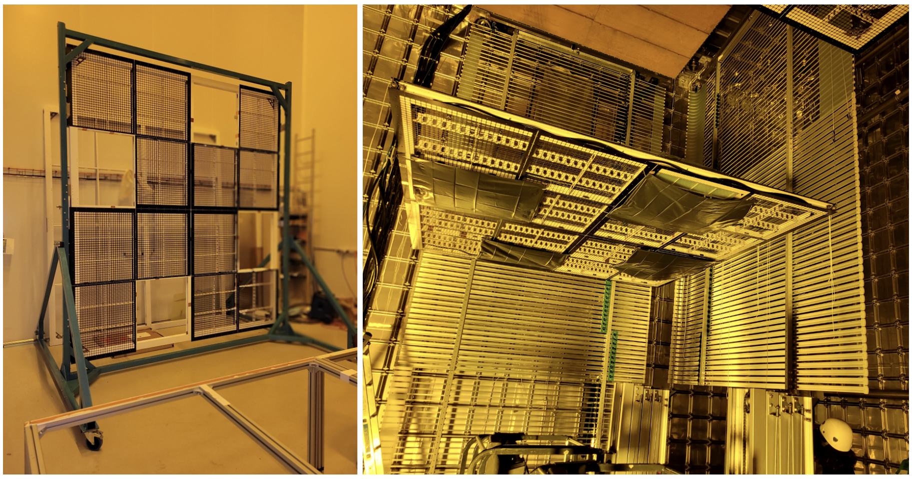


Figure 22: One cathode unit on the assembly cart wall (left) and installed in NP02 (right).

FC columns are also being successfully installed with procedures very similar to FD2 (Figure 23). Thin and thick profiles for the FC panels were shipped in actual crates and packaging from vendor Bending of profiles was performed at CERN. Box beams, aluminum yokes were machined in house. Voltage Divider boards (with resistors and varistors as in NP04 and NP02-DP) were shipped from US with the final QC performed at CERN (in LAr). The FC assembly station, the storage cart and transport tool were built at CERN according to the FD2 model. Assembly and QC were performed in NP04 clean room and storage in NP02 clean room. Installation is performed using winches mounted on DSS beams; the FC column formation and electrical connections is as in FD2. One column is deployed and several other panels are hanging from the DS. The rest of FC will be installed when bottom CRP's are in position (according to NP02 install procedure). This will be completed with the electrical connection to the HV and to the current monitoring system at ground.

The HV delivery system, composed by a newly produced 4m long HVFT and a new HV extender coupler, is being validated at the maximum 300 kV HV, in the 2-ton cryostat with a procedure similar to that of the previous HVFT used in the 2021 NP02-DP run (Figure 24). The 2-ton cryostat is equipped with Ar recirculation, purity monitors, cameras, leakage current & HV PS monitoring. Same HVPS, cable and ripple filter will be used as in 2021. No resistive load is foreseen inside the 2-ton cryostat, hence no HVPS current is expected. The validation plan consists in certifying that the uptime is >95% at nominal conditions. The procedure: (1) vacuum testing with He leak check sensitivity down to 10^{-9} mbar l /s; (2) LAr filling and system thermalisation, (3) ramping up to 300 kV as planned for FD2/NP02; (4) monitoring the system at the nominal conditions (HV = 300 kV) and high purity (>1ms) for at least a week with continuous recording of any instability occurrence (if any). The HV delivery will be installed in NP02 as a last component after the full LAr-TPC has been completed and verified.

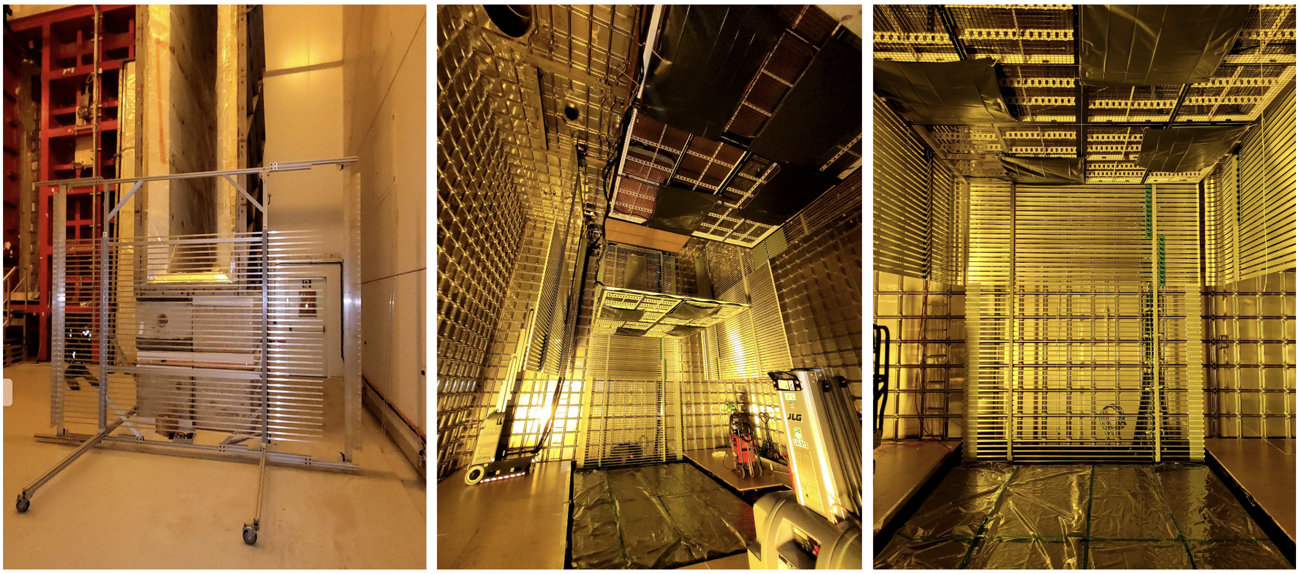


Figure 23: Field cage panels on the assembly station (left) and installed in the NP02 cryostat (center and right).

5 Plans

In the last year the tests in the cold box went from the developments of the CRP1 and CRP1b both equipped with top and bottom electronics, to the benchmark of the performance of the 4 CRPs for the Module 0. The two top CRPs, one bottom CRP, the two cathode modules, 14 of the 16 PD modules and a fraction of the field cage modules have been successfully installed in NP02. The CRP5, the second bottom CRP and the last one to be installed in NP02, is being tested in the cold box as this report is being written. The aim is to complete the installation of the main components of the TPC by the beginning of June: The cold box tests of the last CRP will be completed by the 8th of May, it will be cabled and in position inside NP02 by the 22nd of May. The completion of the installation of the field cage, the HV delivery system (extender and feedthrough) will follow. In the mean time, installation of the equipment on the cryostat roof continues. The cryogenic instrumentation (like the purity monitors), the calibration systems (like the ionisation laser), tools like cryogenics lights and cameras, and the beam plug can be installed after the closure of the Temporary Construction Opening (TCO). Extensive tests and characterisation of CRPs, electronics, PDs and HV system will happen at room temperature between the completion of the installation and the TCO closure. The design of components for the TCO closure is complete. The tender process is ready to start. We aim to close the cryostat in October '23. The filling is subjected to the availability of liquid argon, which is unfortunately still very uncertain, and it impacts the operation of NP02 as well as NP04. It is still under discussion within the DUNE Collaboration, which one of the two ProtoDUNEs should be filled first. In case NP02 is the first, the purge, the cool-down and the filling will last about 8 weeks, allowing to potentially have the cryostat full at the beginning of '24. If NP04 is filled first, about 650 ton of liquid argon can be transferred from NP04 to NP02 in about a week (already experienced), the rest will need to be topped up from standard truck delivery. Commissioning of the TPC with cosmic rays and purifying the argon to the nominal level to allow long electron drifts will be done in the first month after the filling is complete. Beam time will be requested for 2024.

Figure 24: Testing station (left and center) for the newly built HV feed-through (right).