# Status and plans of NP02

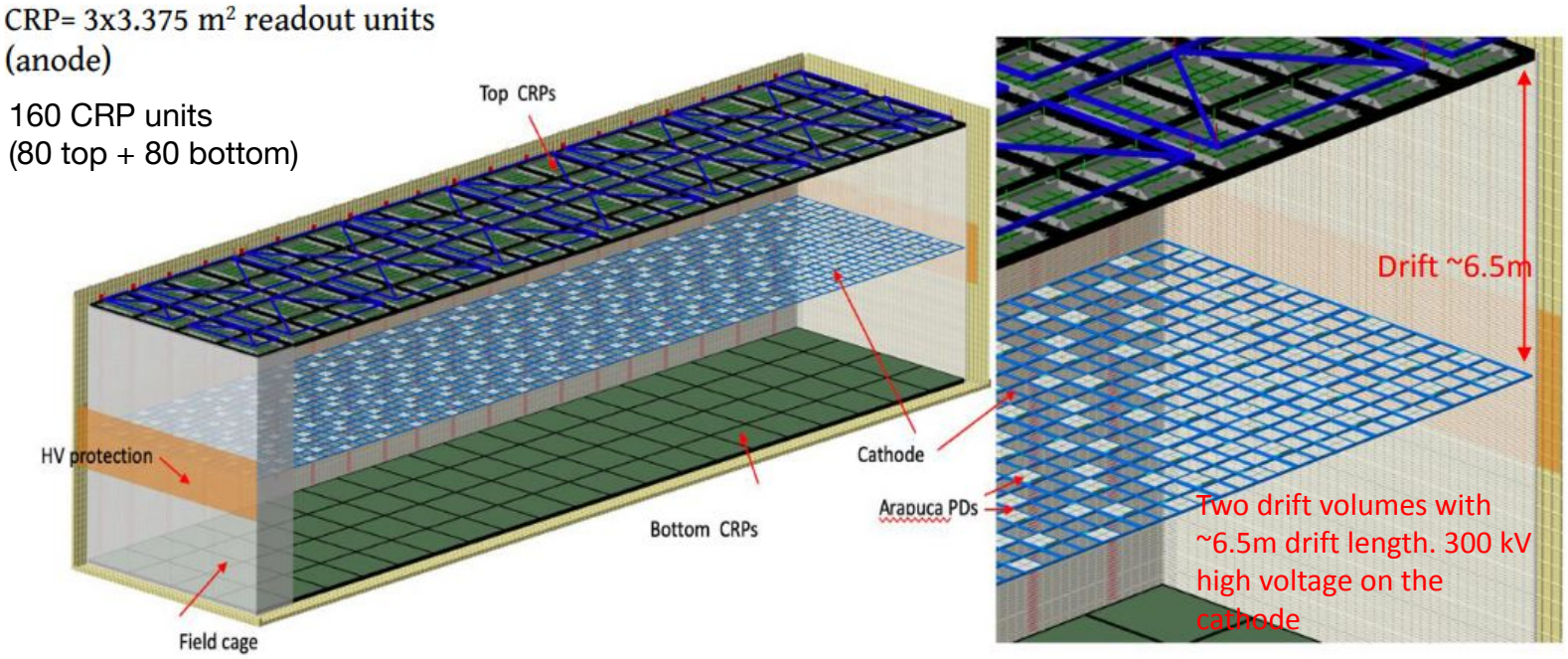
Serhan Tufanli (CERN)

145th Meeting of the SPSC

April 12, 2022

Report Document: https://cds.cern.ch/record/2805710?ln=en

# DUNE Vertical Drift far detector module

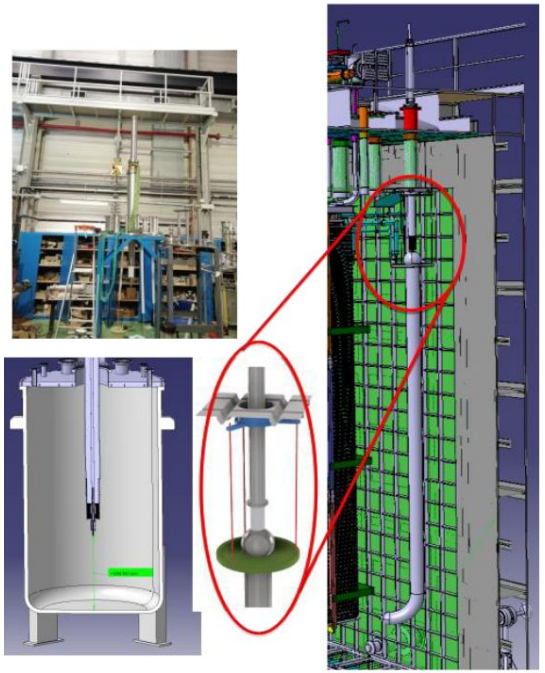


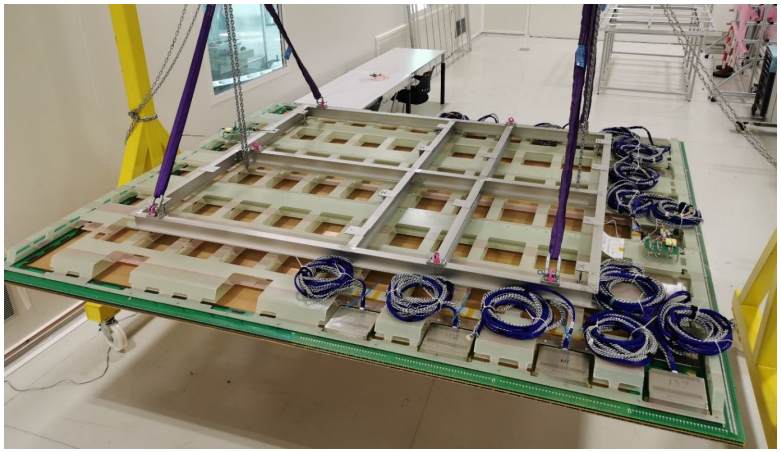

- Detector details are described in the conceptual design report
- Vertical drift detector and related tests in NP02 were introduced and described in the last year's SPSC meeting
- This talk covers the details of HV and CRP tests that were performed in 2021

# Vertical Drift HV and CRP tests in 2021

- Delivering 300 kV to the cathode, HV long term stability runs and validation of 6 m readout
  - in the 2ton cryostat at CERN for the individual HVS distribution components
  - then in the NP02 cryostat at CERN taking advantage of the existing DP TPC (also for the charge readout)

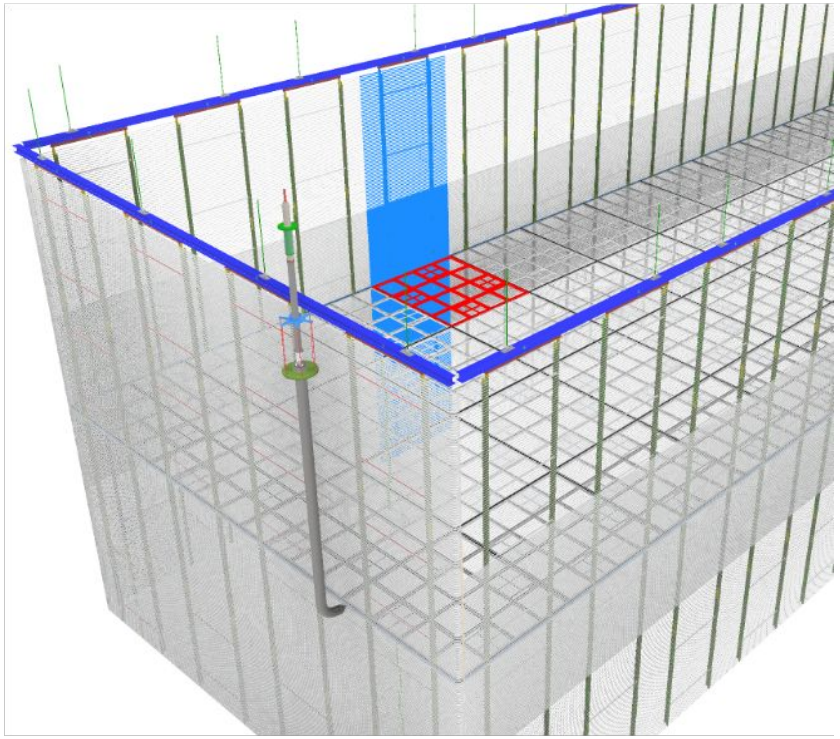
- Validation and optimisation of the new single phase charge readout with perforated PCB anodes
  - demonstrated first  with existing small scale prototype at CERN
  - finally tested in the NP02 coldbox with 1:1 scaled CRP with high LAr purity and 20 cm drift



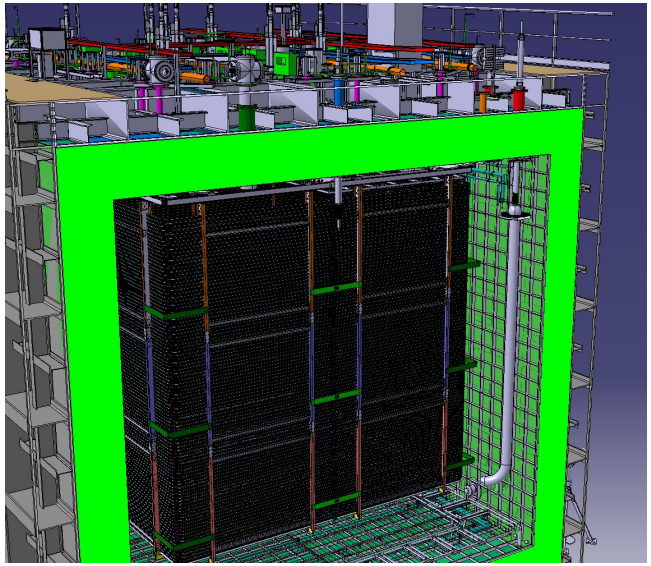


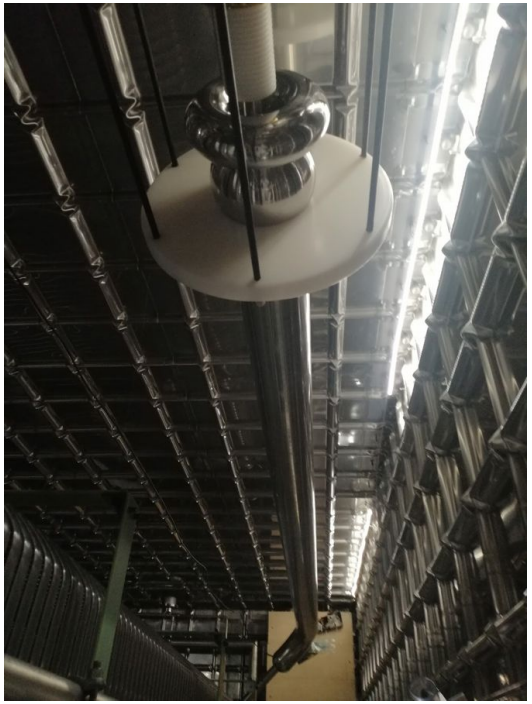
# Goal of the HVS test in NP02

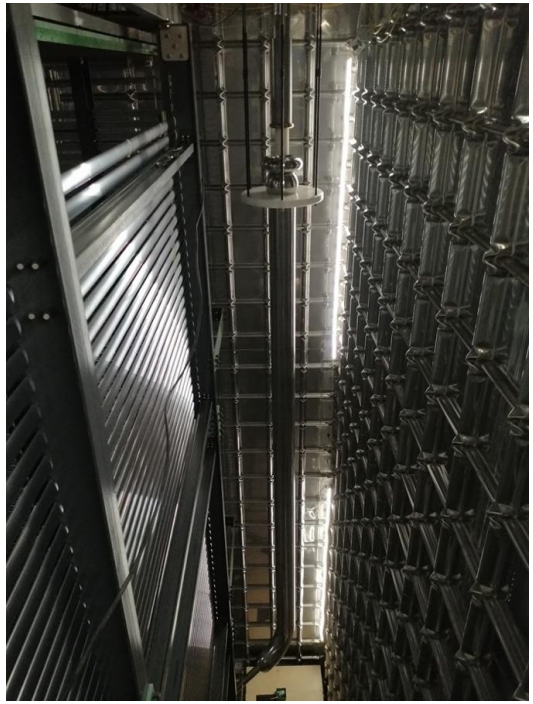
- Final validation of the critical components of the Vertical drift HV distribution chain:
  - HV extender (which is improved/simplified version of the one used in dual-phase)
  - HV Feed-through + HV cable + HV PS power supply
- Validation procedure:
  - assembly and integration of the HVS distribution systems with existing NP02 cathode and field cage
  - Long term operation at nominal electric field of 450 v/cm
  - Monitoring of HV stability and live-time
  - 6 m drift with charge and light readout (with existing DP readout)



# HVS in NP02

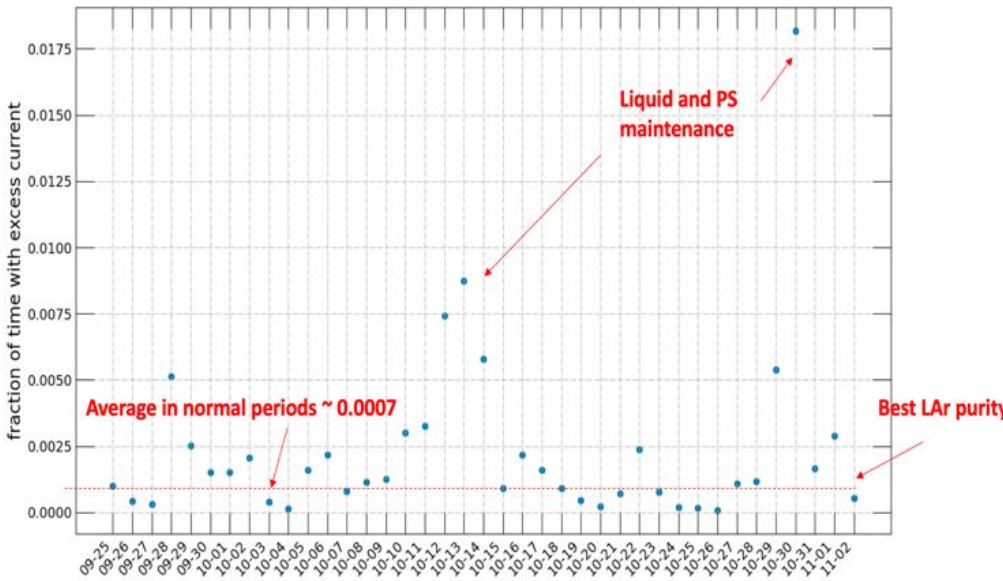






# The first stage of high voltage runs: Sept-Nov 2021

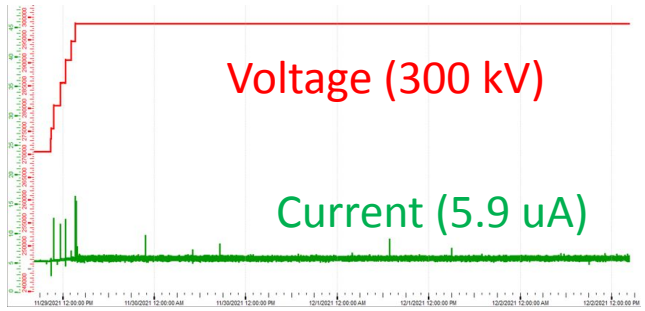
- The stainless steel extender concept has been validated to deliver 300 kV to the cathode at 6 m depth:
  - A gap of 40 cm of LAr between the extender and the corrugated membrane, as foreseen in the FD-VD layout, is enough to hold 300 kV with electron lifetime exceeding 1 ms.
  - The coupling between the extender head (donut) and the HVFT did not show any charging up instability issues.
  - The HV-FT design is effective to avoid gas pocket formation in high E-field regions




- The HVS test was temporarily interrupted after 6 weeks of continuous operation, due to a failure of the accessible HV components (cable, HVFT)
  - No damages at all in the HV components inside the cryostat
  - Rebuild the HV cable and swapped the HVFT with spare
  - Ongoing investigation (CT, Xray, EM) allows identifying the issue in defect of the insulating materials (lessons learned)

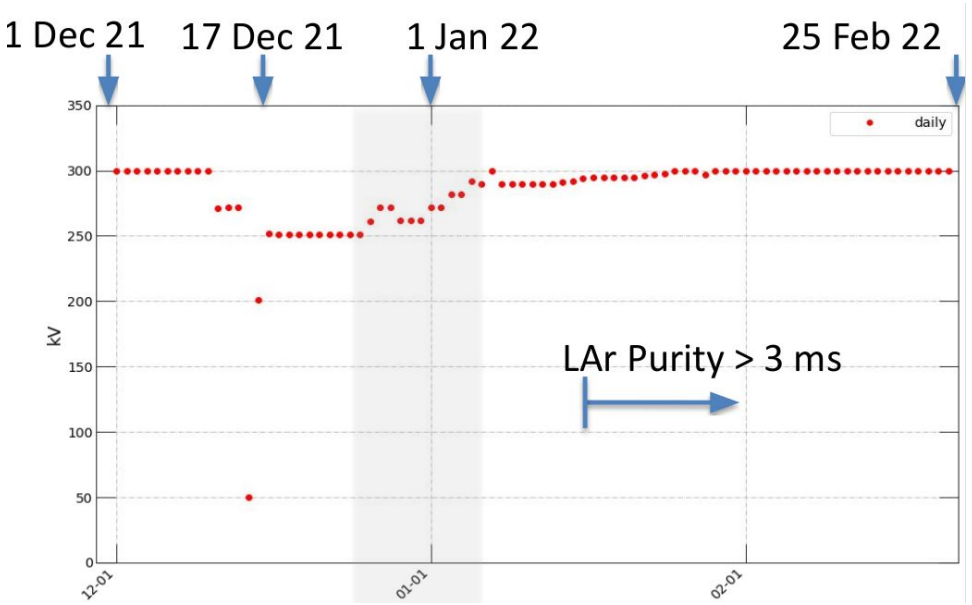
# The second stage of high voltage runs: Dec 21 - Feb 22

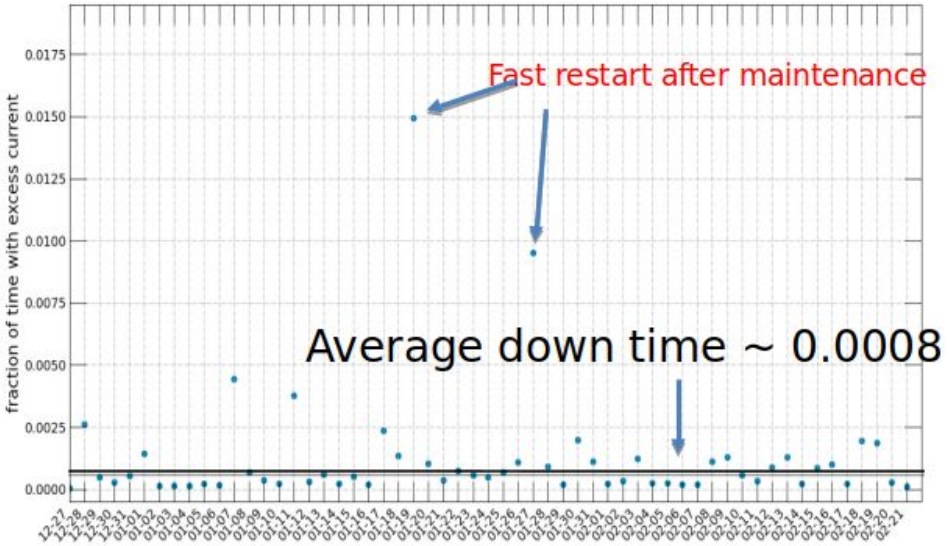
- The HV feed through was replaced when the LAr level in NP02 was lowered by up to ~30 cm (for the cold box CRP test):
- Nominal LAr level reached again on Nov 25th
  - HV ramping up started, nominal value of 300 kV reached smoothly in the morning of Nov. 29th
- Long term stability operation restarted



# The second stage of high voltage runs: Dec 21 - Feb 22

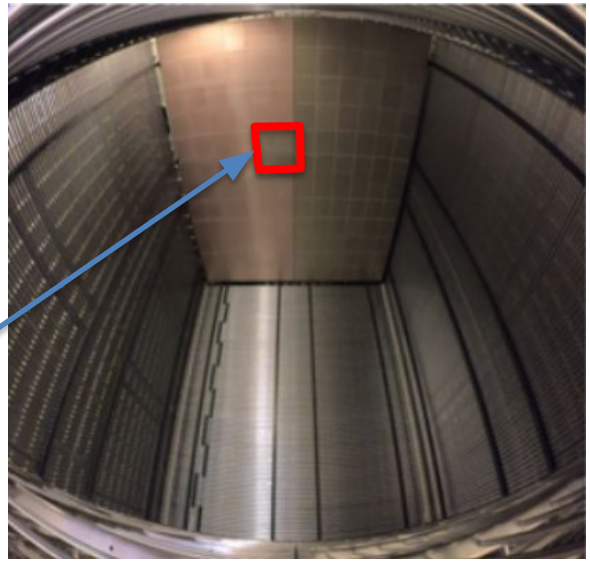
- During cold filter regeneration and cold box filling, HV kept at lower values due to LAr level reduction and pressure instabilities (bubbles)
- Reached to 300 kV during January by progressively increasing HV in small steps (5-2-1 kV) to spot out any possible criticalities in the HT-FT or in the HV cable (*none found*)
- **Successful long term operations**
  - Nominal HV at 300kV
  - High voltage uptime: ~99.9%
  - Certification of HV stability at high LAr purity
  - No sign of degradation of the HVS warm cold distribution chain
  - Full drift distance of 6 m at 500 V/cm (4 ms) recordable

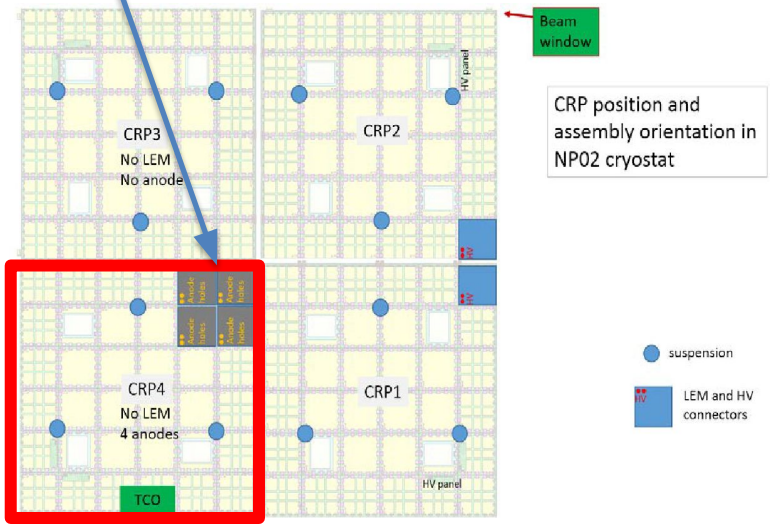


# Full 6m drift readout with 300 kV on cathode

- During Jan/Feb, efforts to activate dual-phase CRP1/CRP2 were not successful due to past damages (LEMs, stuff trapped in the grids, thermal excursions etc …).
- Focus on dual-phase CRP4:
  - Instrumented with 4 anode PCBs each of 50cm x 50cm with two orthogonal collection views, 3 mm pitch, 50% - 50% charge sharing, ~640 channels
  - Anodes operated in gas. Grid in LAr to extract electrons to the gas with high efficiency (DV = ~ 3kV over ~1.3 cm). Sensitive area = 1m$^2$.
    Given drift distance, active volume = 6m$^3$.
  - *No LEM and no dual-phase amplification.*
    Electrons simply collected by the anodes,
    as in the new Vertical Drift CRPs but signals reduced to ~1/4
  - Drift E field intensity variations due to space charge expected < 20%; thanks to central location of active CRP, E drift field direction quite uniform.

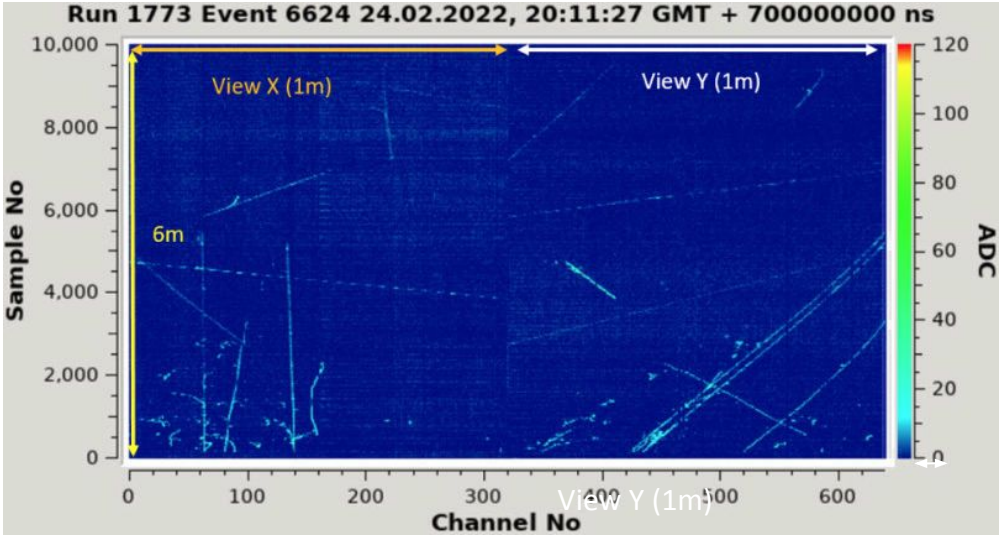




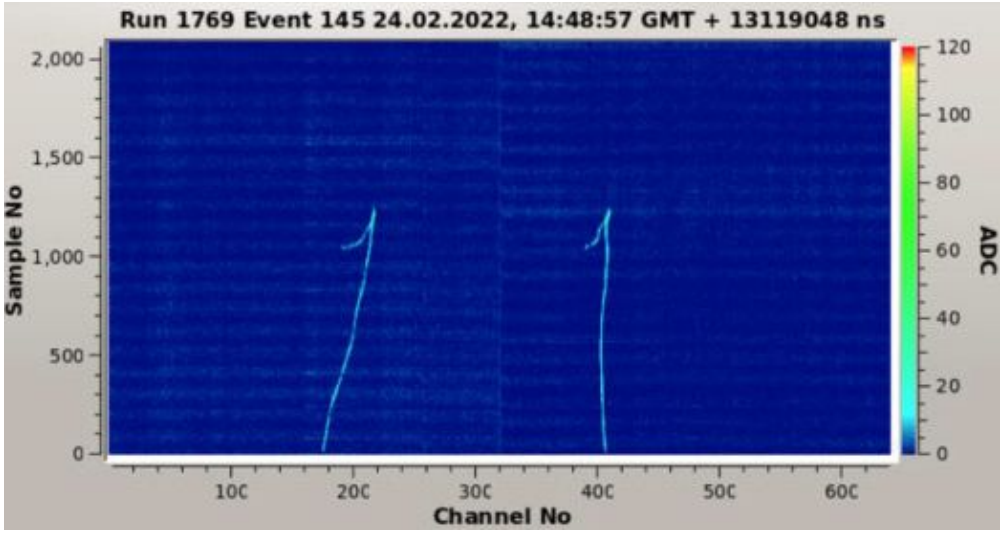
# Readout activation & data taking

- Successful activation of DP readout system (analog, digital, timing, DAQ)
- Feb 23 to 25, high rate data taking with random triggers / with an external trigger (ET, two scintillation counters located on top of the 4 anodes)
- Long tracks immediately visible
  - Tracks near the cathode are visible after 6m drift and this is with only ¼ of the charge expected in the VD case, with an additional 70% attenuation due to purity, and with a signal broadening due to diffusion
- These results demonstrate that 6m drift will be amply manageable in DUNE FD2 where more charge is expected, possibly with higher purity

Random trigger

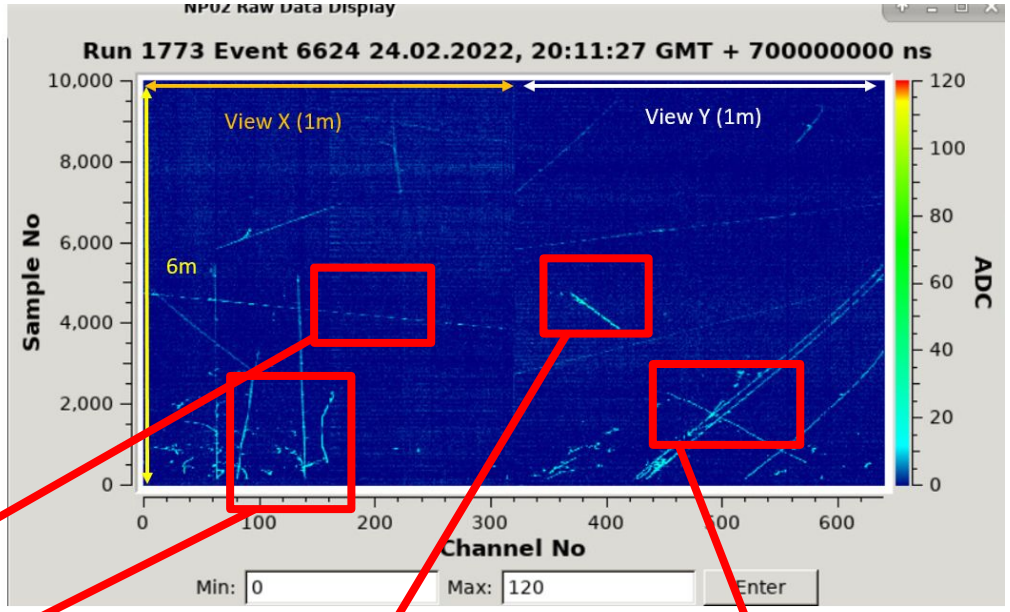


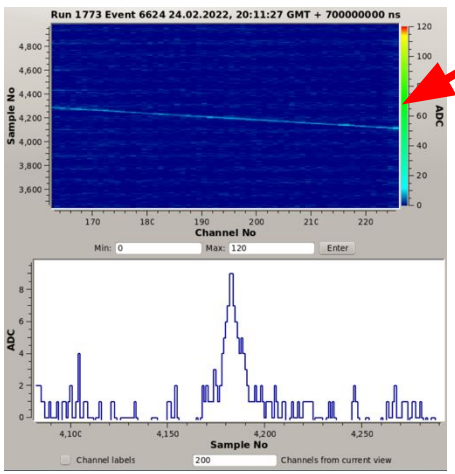

ET Muon decay candidate

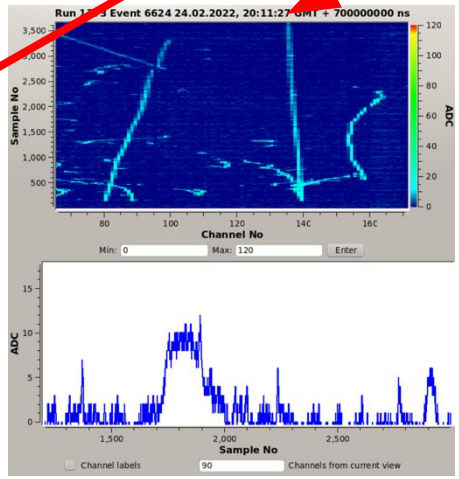


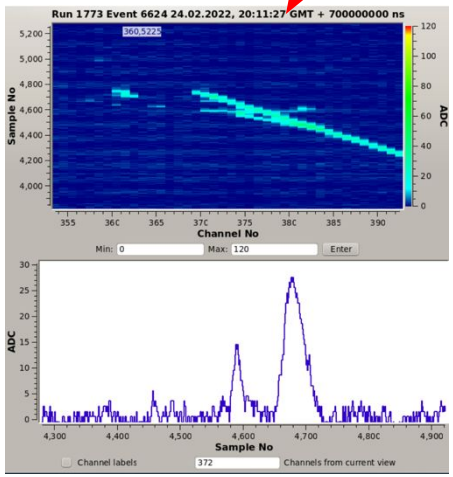
# Data overview

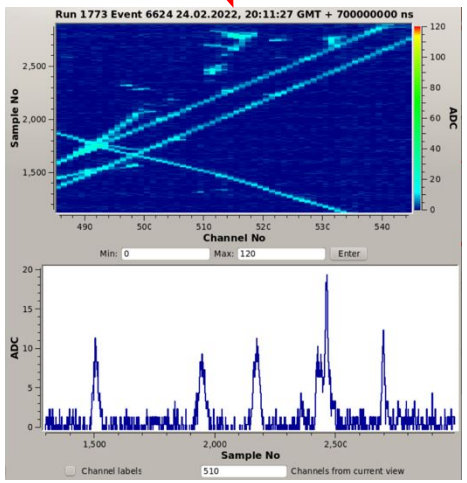
- Good performance and the low noise (~1 ADC (~600 electron noise) RMS dominated by residual coherent noise in the cryostat)
- No evidence of additional coherent noise, induced by the residual ripple of the HV system
- These results (HV stability run + 6m long tracks) is another significant milestone successfully achieved on the path toward DUNE FD2-VD



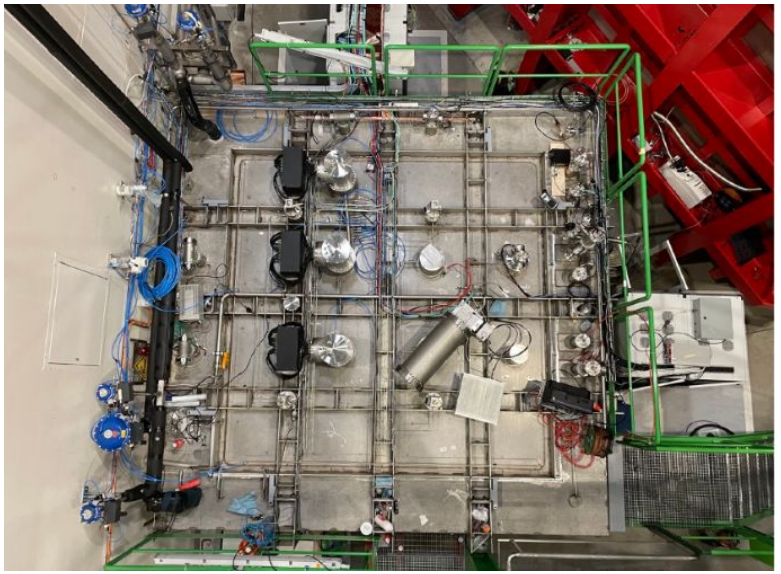



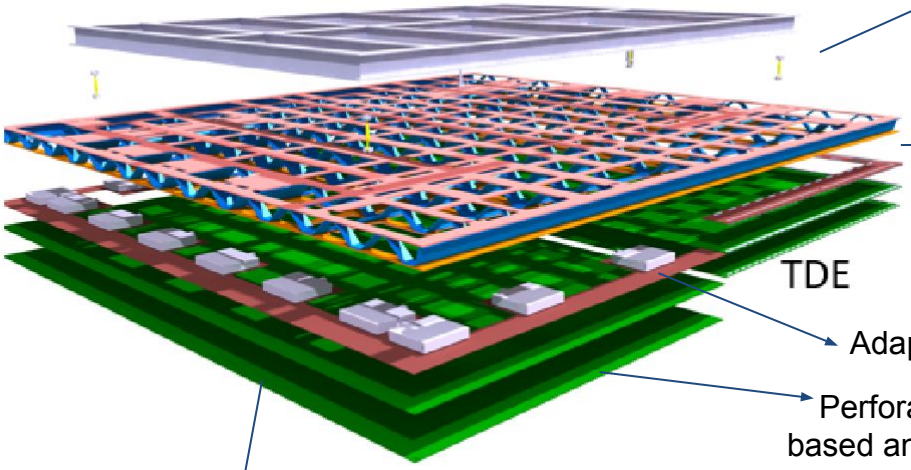



# Cold-box refurbishing

- Cold-box was first used in 2018 to test the dual-phase CRPs
- In summer 2021, it was modified for the Vertical Drift CRP tests
  - improved the leak tightness
  - changed the number and the diameter of roof penetrations
  - Reinforced the mechanical structure to cope with higher operating pressure.
- Moved to EHN1 and installed next to the NP02 cryostat to exploit safety and cryogenic infrastructure presence in place
- New cryogenics components, dedicated condenser, warm filter, cryogenic valves, transfer lines and pipes were installed
- The cold-box went through extensive leak checks and had two commissioning runs to demonstrate its capabilities



# Vertical drift first cold-box CRP design




Coupling system and support structure (Stainless Steel)

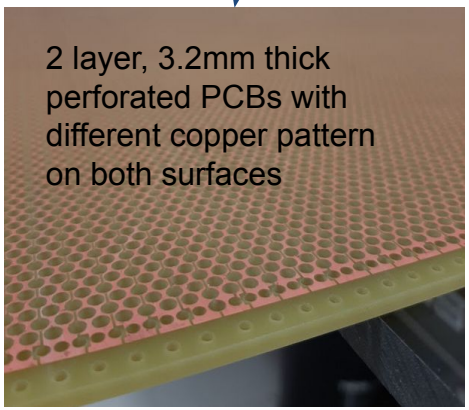
Composite frame (glass fiber/epoxy)

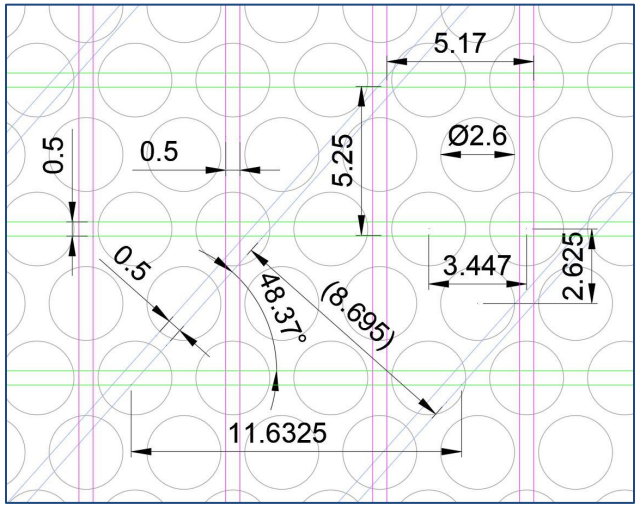
Adapter boards

Perforated PCB based anode planes

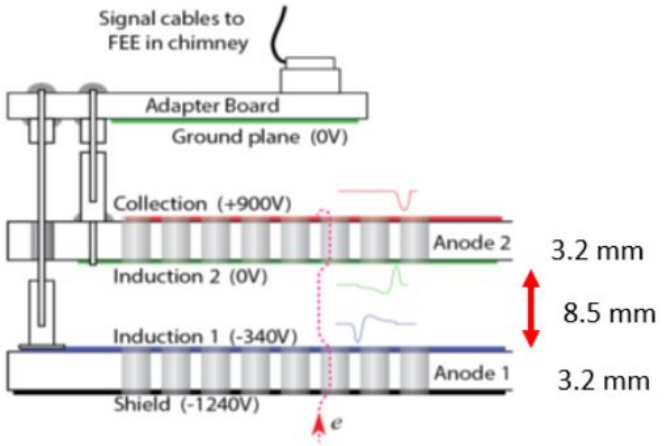
Charge Readout Unit (CRU)

Charge Readout Plane (CRP)



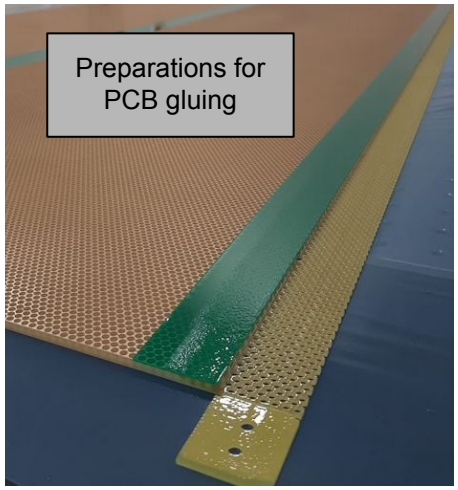

PCB pattern and various parameters

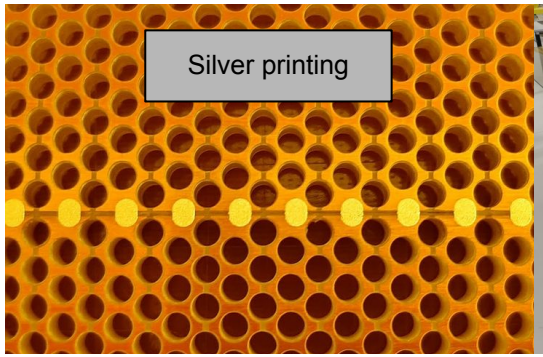


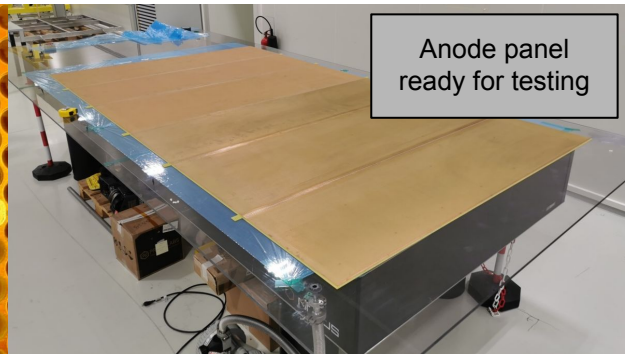

Vertical interconnection between the anode planes and adapter boards

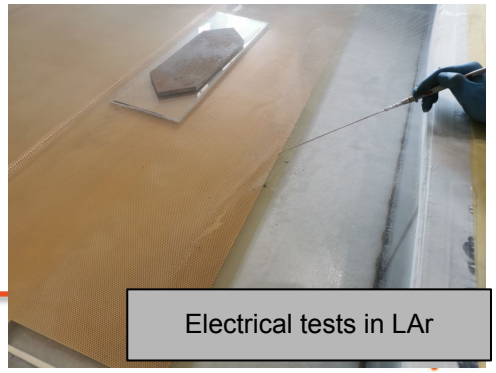
# Building the perforated PCB anode planes

- PCB gluing
  - Large panels are constructed by gluing six smaller PCB segments together
  - Drying for 1 day under vacuum
- Silver printing
  - Electrical connection between the glued segments are done by silver ink
  - Polymerization at 130-140$^{o}$C for 3 hours
- Testing
  - Continuity and isolation checks both at room and cryogenic temperatures
  - Mechanical stability check for glued PCBs under cryogenic cycles





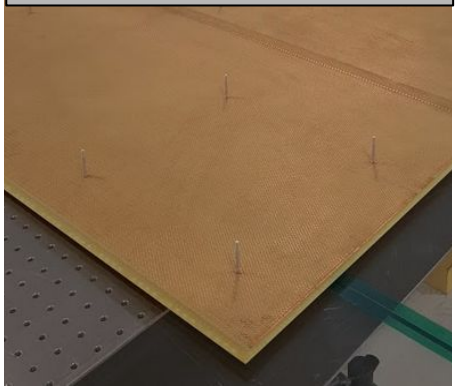



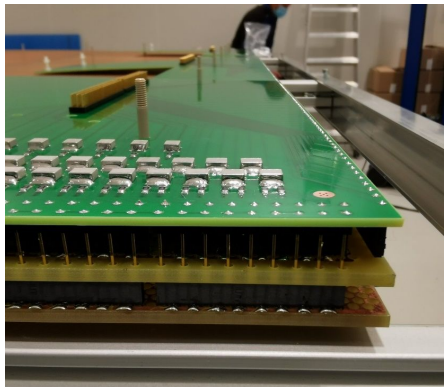


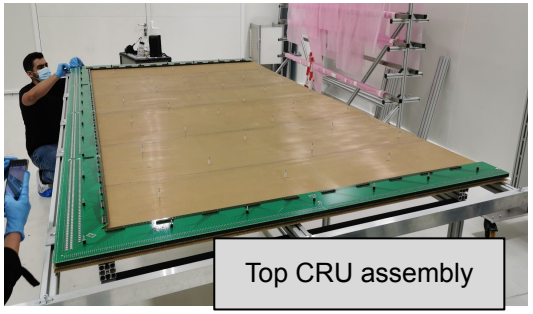
# CRP assembly

- Stack two anode layers on top of each other
- Solder interconnection pins and install adapter boards
- Finalize bias connections
- Attached two CRU units to the composite frame
- Attach CRP to the support structure and ship to EHN-1
- CRP design was finalized in April 2021 and it was built from August to mid December 2021

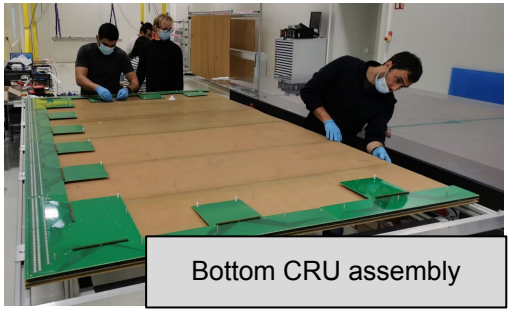
Preparations for anode stacking



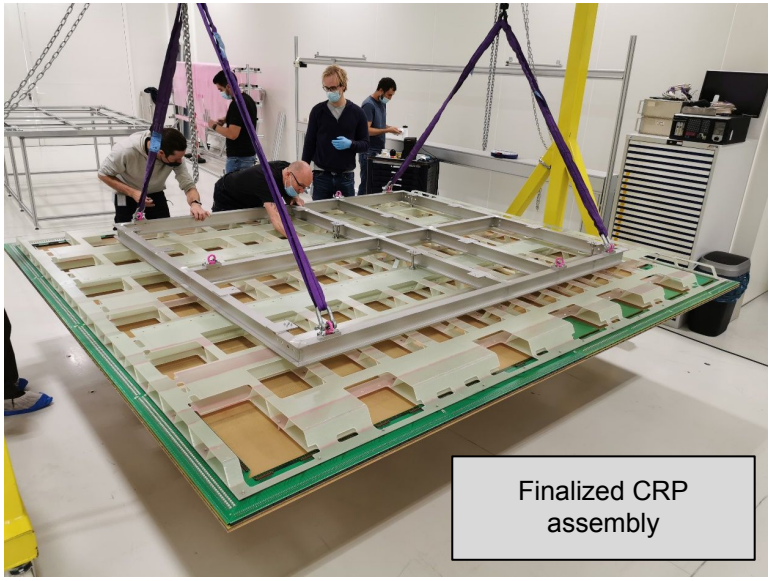




Top CRU assembly

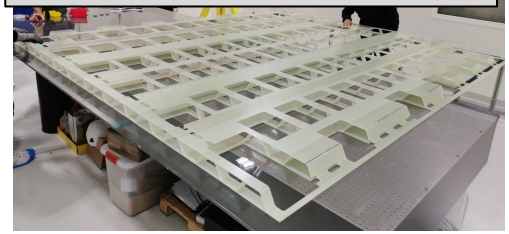


Bottom CRU assembly



Finalized CRP assembly

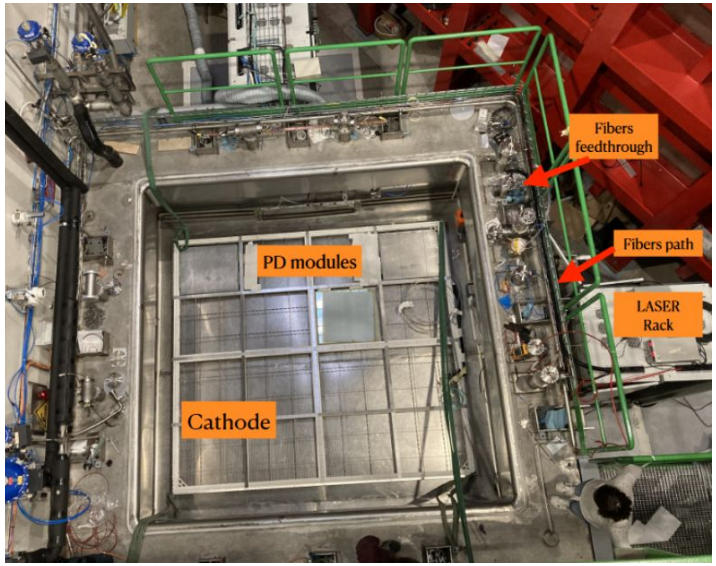
Composite frame assembly



Composite frame installation

# Cold-box setup and runs

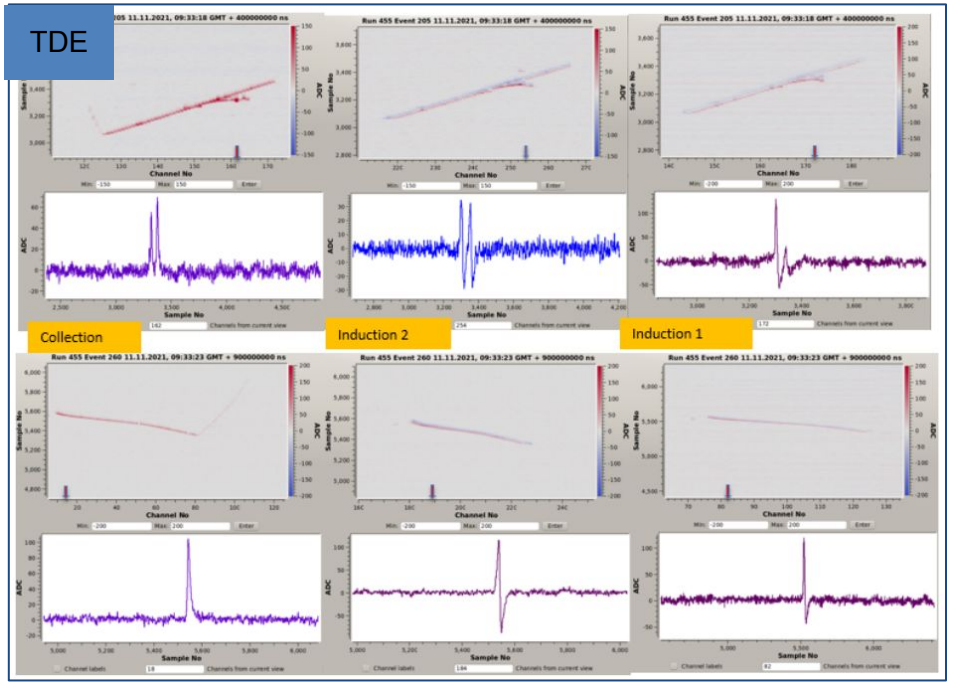
- The cold-box setup:
  - The first Vertical Drift CRP, hybrid setup with top and bottom readout systems
  - Cathode module similar to the ones foreseen for the DUNE
  - Photon detectors (X-ARAPUCA) on the cathode
    - Powered with a Power-over-Fiber system (PoF) and read out with optical analog links: Signal Over Fiber (SoF).
  - About 30 cm of drift distance

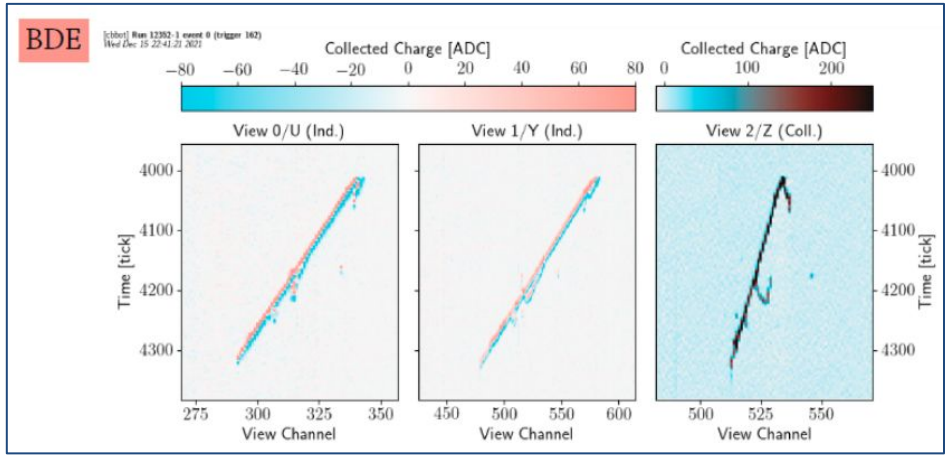



- Data taking and cold runs:
  - After an initial debugging phase (grounding and cryogenic system tests) the first filling was performed on November 11th (Run-1, covering the period 11-19 November 2021)
  - The second cold-box cycle performed in December 2021 (Run-2, covering the period 13-17 December 2021)

# Results from the CRP cold-box tests

- With the cold-box setup, it was possible to reach high purity levels immediately after LAr filling
  - Visible tracks immediately
  - Started to test the CRPs quickly
- The CRP was very stable during the operations in Run-1 and Run-2
- Similarly, stability for the cathode HV was very good as well
- Results from the cold-box Run-1 already demonstrated that the CRP was behaving well in line with expectations from the 50L TPC tests, extended at the full scale of the CRPs for the second DUNE Far Detector Module

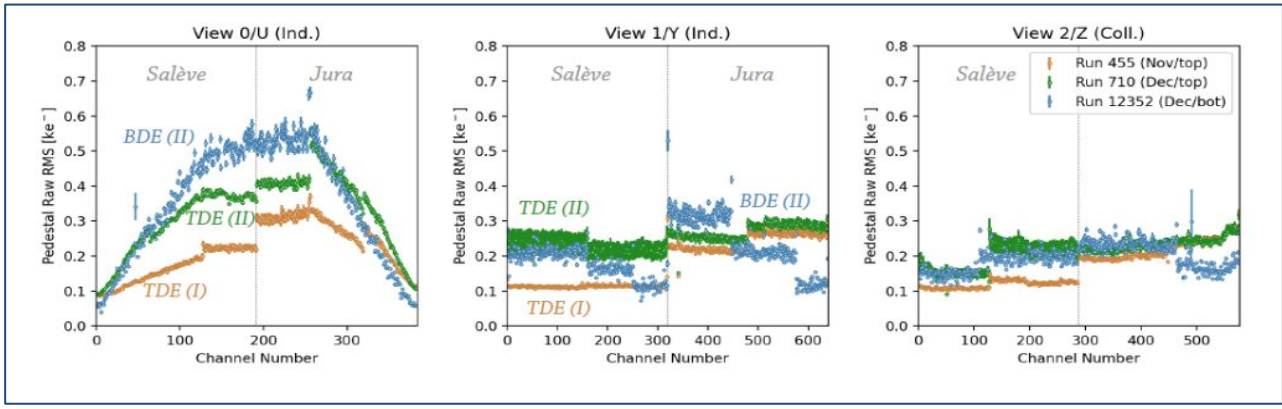


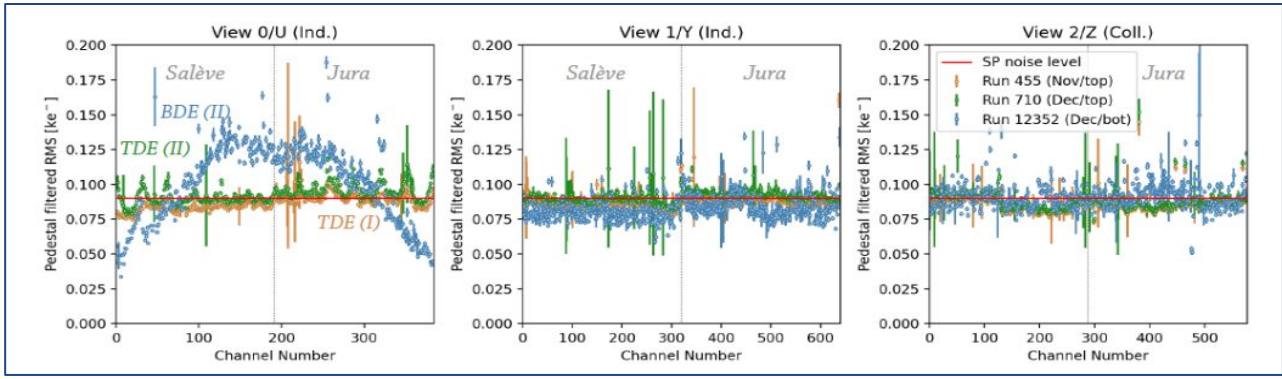
# Results from the CRP cold-box tests

- Grounding system of the cold-box during the first two runs was still perfectible
  - Presence of small coherent noise affecting both electronics
- Coherent noise could be easily removed with the standard DUNE Coherent Noise Removal (CNR) procedure
- After the CNR, the noise levels are comparable to the protoDUNE single-phase

Noise levels BEFORE the CNR




Noise levels AFTER the CNR

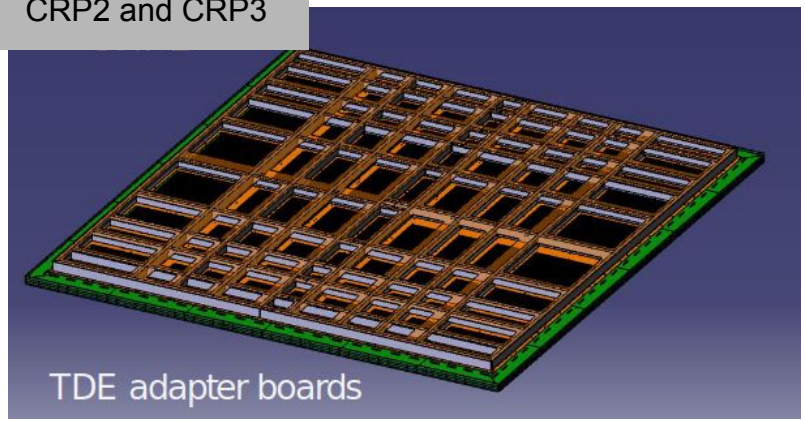


# Vertical drift CRPs in 2022

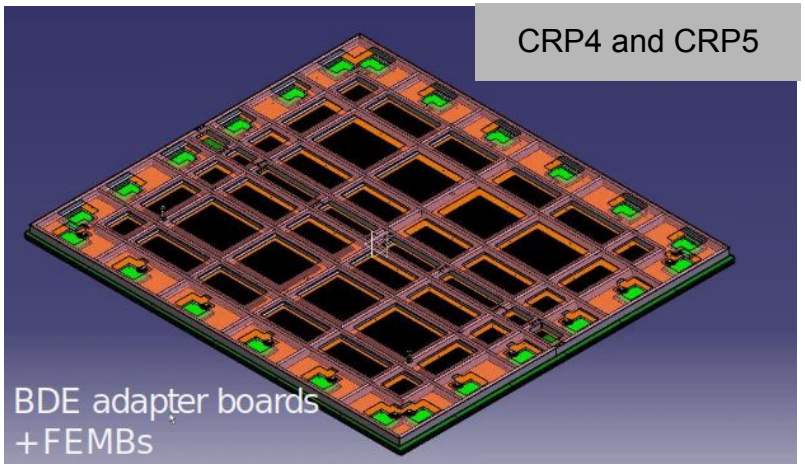
- After the successful completion of the first tests in 2021, the cold-box testing campaign for the Vertical Drift CRPs will continue in 2022

- 4 more CRPs will be built and tested in 2022
  - CRP2:
    Assembly in April-May. Test in the coldbox at the end of May
  - CRP3:
    Assembly in Aug-Sep. Test in the coldbox in Oct.
  - CRP4:
    anode and composite structure will be sent to US in September; assembly in Oct in US, ship to CERN beginning of Nov. Test in the coldbox in December
  - CRP5:
    Assembly in Nov in US, ship to CERN in Dec.

CRP2 and CRP3

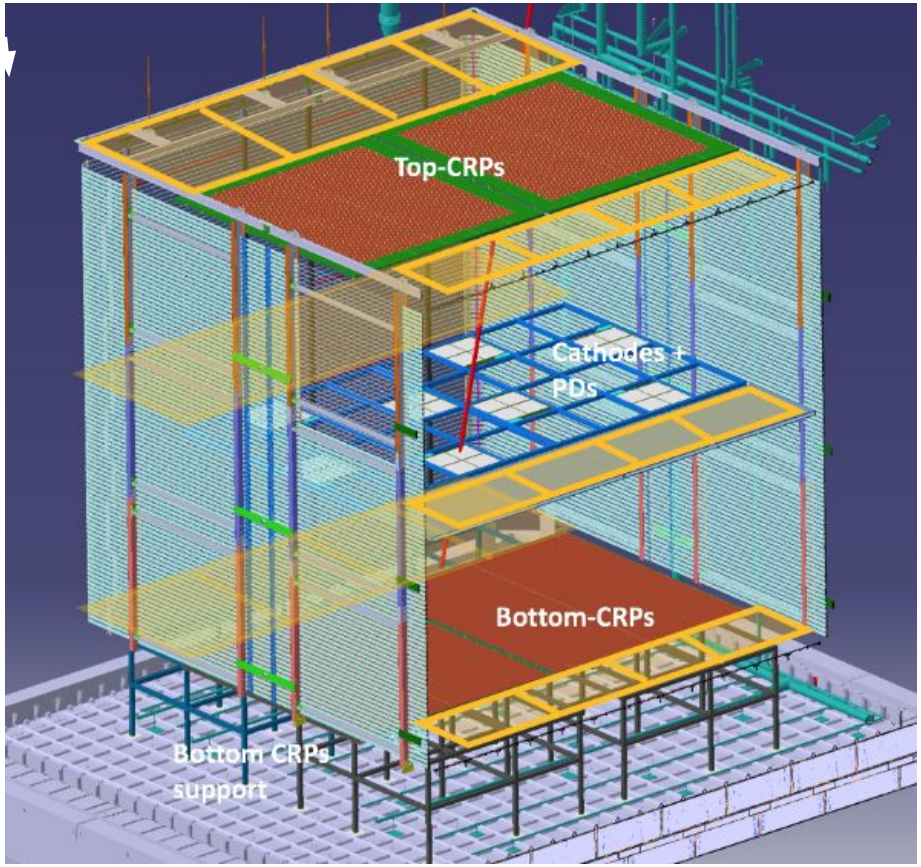



CRP4 and CRP5



# Module-0 for vertical drift

- Before entering to the production phase for the DUNE far detector, the last full integration test, so called Module-0, on the basis of the final design of the detector components will be performed in NP02 cryostat in 2023
- Detector configuration:
  - Two top and two bottom CRPs
  - Cathode in the middle at 300kV
  - Photon detectors on the crystat wall and on cathode
  - 70% transparent field cage on one side for the photon detectors
  - 3m drift on both sides of the cathode
- Schedule:
  - Currently emptying the NP02 cryostat
  - Starting September 2022, dismounting dual phase detector
  - Module-0 installation from end of 2022 to first quarter of 2023
- After filling, from July high intensity hadron beam at 100 GeV/c on the H2 beam line for up to total 4 weeks will be requested



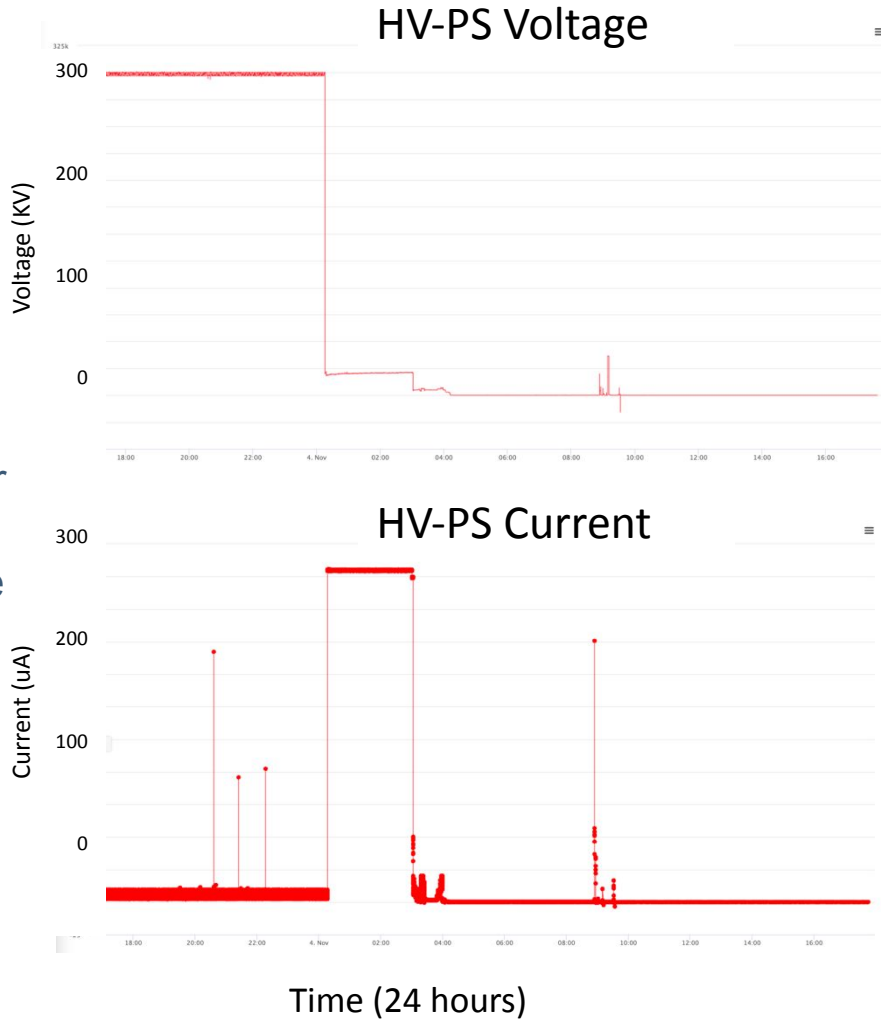
# Conclusions

- The HV campaign in NP02 successfully demonstrated the design of the new extender for Vertical Drift and its stability over several months
  - Nominal HV at 300 kV
  - LAr purity > 3 ms
  - HV uptime ~99.9%
  - No sign of degradation of the HVS warm and cold distribution chain
- Campaign was concluded with the successful TPC operation with 6m drift data taking
- Constructed and tested the first full scale Vertical Drift CRP
  - Refurbished and reutilized the cold-box for the CRP testing
  - Cold-box allows fast turnover given the good purity after filling
  - Built the first CRP and test it successful in the cold-box runs
  - Perforated PCB based charge readout performance have been validated at nominal scale
- Busy schedule for 2022 and 2023
  - 4 more CRPs will be built and test in 2022 in view of Module-0
  - Disassembling the dual-phase detector will be performed from Sept to Dec 2022
  - Finalize building Module-0 for the Vertical Drift by the first quarter of 2023
  - Module-0 runs in 2023

# Backup

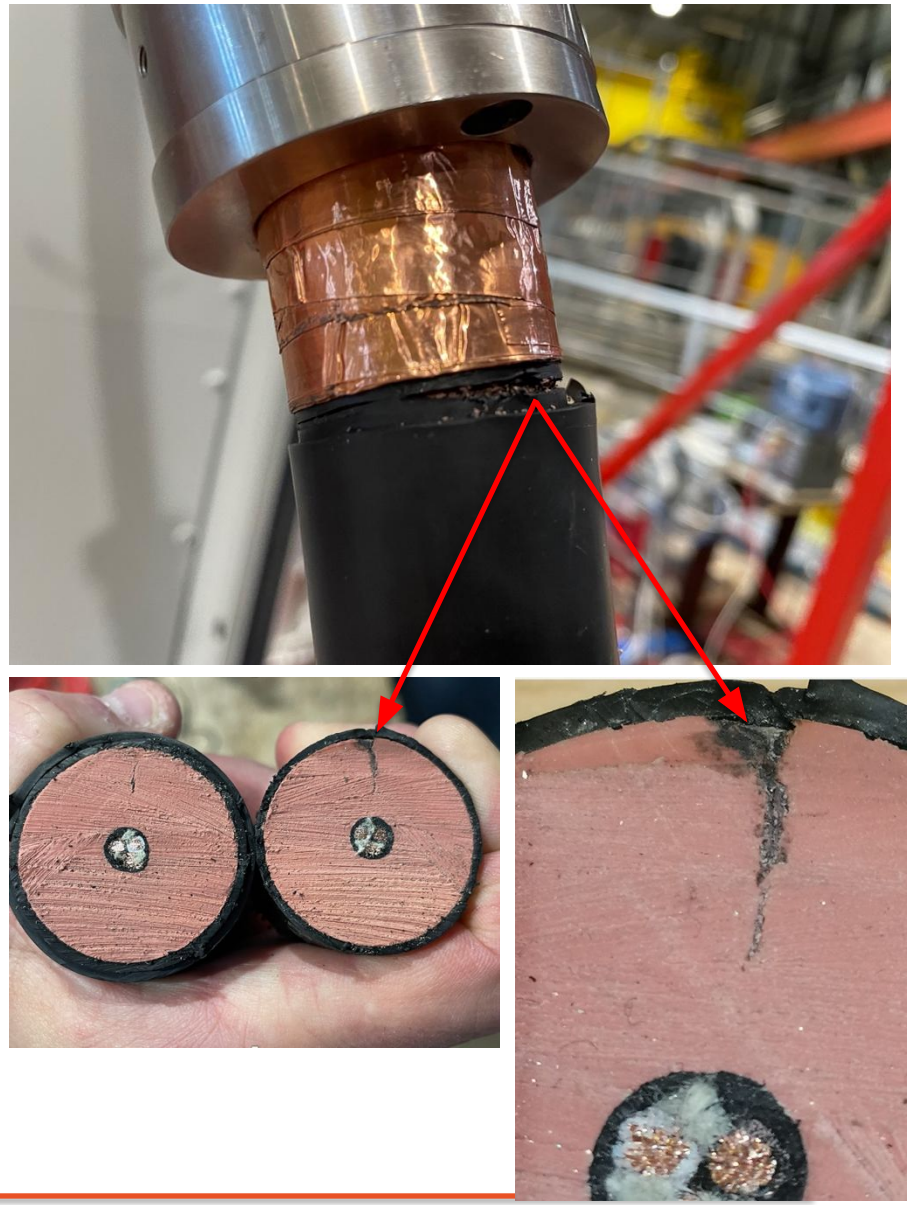
# Reminder: HVS issue on November 4th

- A sudden change in the HV impedance happened during the night
  - No specific precursors previously recorded
- After the episode, the HV-PS operated in current limited mode: 250 uA, allowing only 20 kV on cathode
  - NO sign of sparks from the cameras
  - NO sign of break-down of the TPC divider board: the voltage measured at the last FC ring always 1/200 times the HV on the cathode, as expected.
  - Visual inspection with cameras did not point to any mechanical issues in LAr
- A parallel path to ground developed
- Failure location:
  - most likely OUTSIDE of the cryostat and accessible



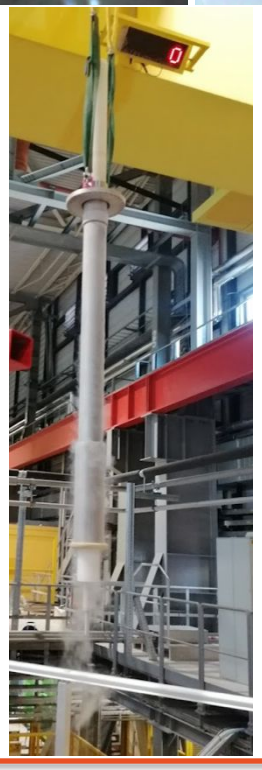
# HVS issue investigation

- HV-PS tested in stand alone mode:
  - Stable operation at 300 kV (zero current)
- HV cable disconnected from HV-FT and tested in air:
  - high current drawn similar to that measured with the TPC connected
- Visual inspection revealed a cut in the HV cable at the level of the ground shield termination, on the HV-PS side
  - Cable sliced for further inspection and the damaged part removed.
  - No other damage found at the HV-FT cable termination.
  - HV cable re-assembled and tested in air (up to 20 kV)



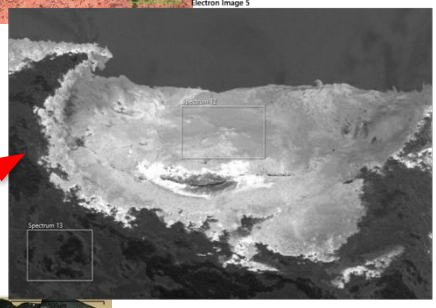
# HVS issue investigation (after LBNC rev)

- HV-cable reconnected to HV-FT
- High current drawn again
  - Visual inspection of the HV-FT cable receptacle revealed damages on inner surface of UHMW-PE insulation (3 cm thick) at the level of the cable connection to the FT inner conductor
  - Outer SS skin of HV-FT removed (warm side): through-going cracks confirmed on outer PE surface
- HV-FT extracted from cryostat to be replaced with the previous NP02 DP-HV-FT:
  - the DP-HV-FT cable receptacle flushed with high flow of dry N2 before insertion in NP02 to minimize freezing issues seen in previous runs



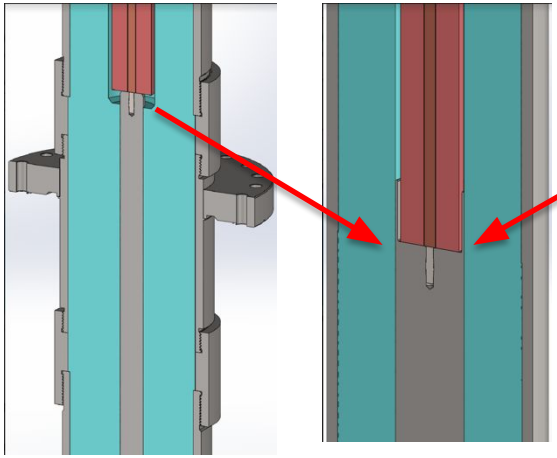
# Understanding the HVS Issue

- The accident involved only the warm side of the HVS delivery system:
  - The extender, the LAr-TPC Cathode, Field Cage and Resistive Divider chains are unaffected: resistance measurement and visual inspection
- The simultaneous failure of the cable (HV-PS side) and the damage of the HV-FT PE are most likely correlated:
  - Primary failure still to be understood
- The cable failure investigation is ongoing to understand the origin with the support of the “CERN Materials, Metrology and Non-Destructive Testing Section“:
  - Preliminary OM and SEM/Spectrospy analyses indicate that the failure proceeded as an electrical breakdown through the insulator (shape, burning..)
  - Presence of exogenous material (Zn, Al and Si) near the damaged area, indicates possible foreign particle (dust) initiating the damage (materials of all cable layers are being analyzed).
  - A mechanical weak point, due to repeated manipulations (insertion/extraction of the cable), is not excluded. Surface texture at the cut edge is being examined to better understading.

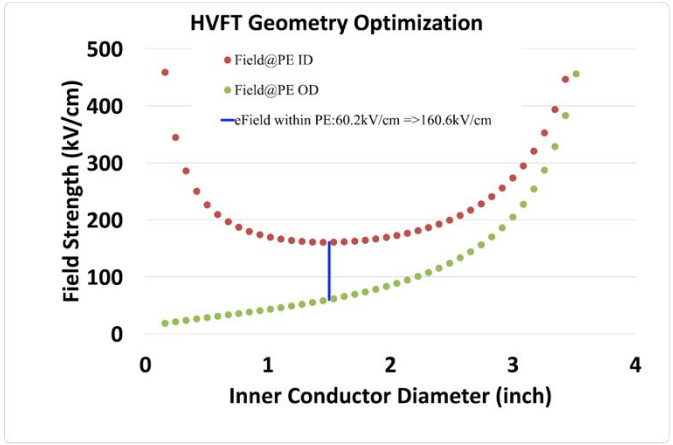


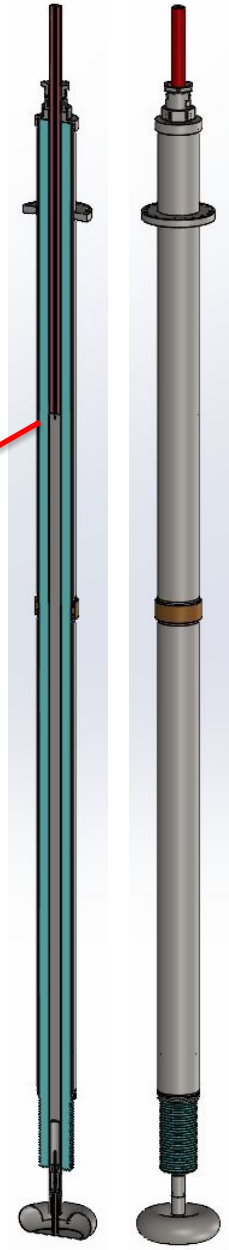
# Understanding the HVS issue

- HV-FT investigation is also starting:
  - It requires the disassembly and the slicing of the PE insulating cylinder to understand the material damage.
- Design is being re-examined, focusing on the connection between the HV cable and the HV-FT inner conductor to avoid possible weak points and local extreme high electric field.
  - DP-FT has a solution, where the FT receptacle shields electrically the connection point of the cable. This could be transposed into the UCLA design.
  - UCLA team actively involved as consultant
  - Producers of the HV-FT components already contacted.



Present design Upgraded design



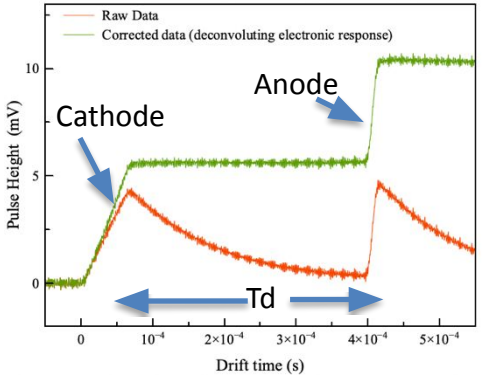



# Chronological summary since last LBNC

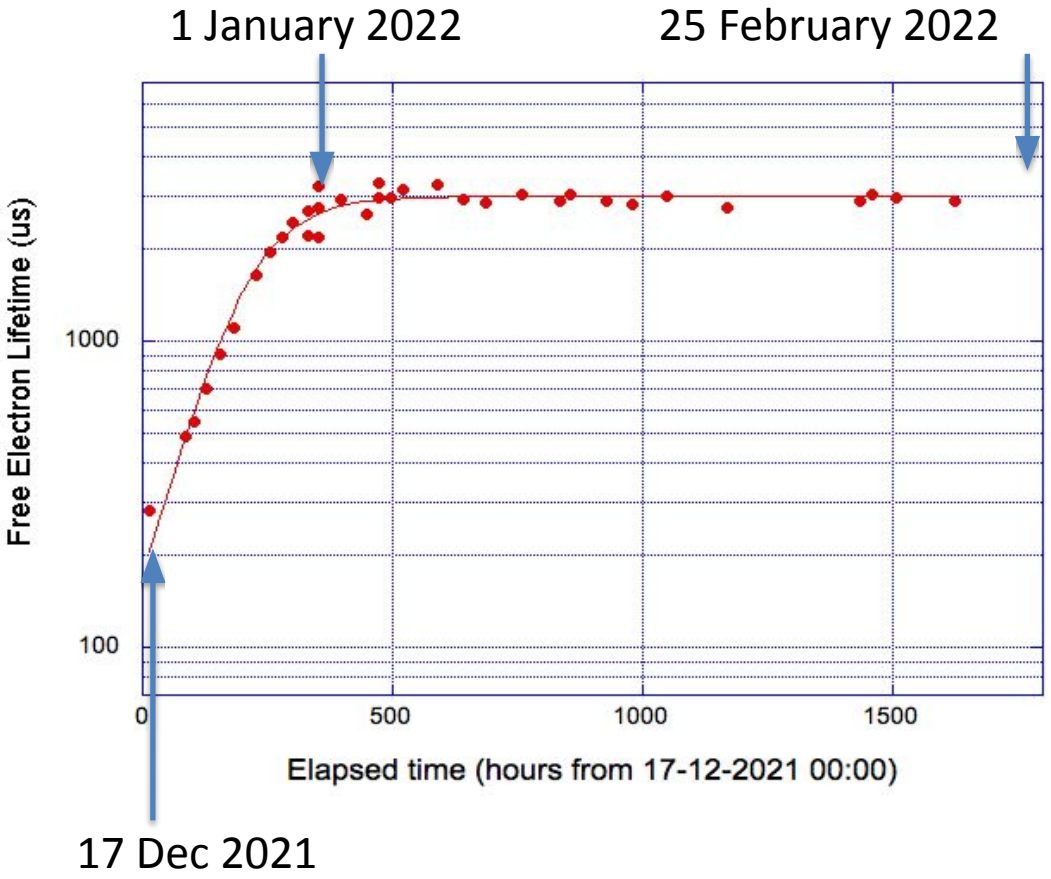
- *Nov 21:* DP HV-FT installed after previous FT failure
- *Nov 29:* 300 kV reached and kept stably until Dec 4 (but very low purity: < 30 us) due to FT insertion)
- *Dec 4:* recirculation stopped for cold filters re-generation; level reduced. HV reduced to 250 kV for precaution
- *Dec 10 to 13:* Cold filters back in operation but LAr level decrease (up to 10 cm), due to purge and filling of cold box.
- *Dec 14 to 22:* LAr level slowly recovered by GAr recondensation (also from coldbox evaporation). HV progressively increased. Purity steadily improving
- *Dec 23 to Jan 4:* HV progressive increased up to 290 kV. LAr purity >3ms at beginning of Jan.
- *Jan 7:* CRP grids lowered into Liquid. Steady state current from drifting electrons/ions measured: 7-8 nA on each 3x3m2 area at ~ 300 kV on cathode.
- *Jan 17:* start biasing CRP's Grids and LEMs in view of forthcoming CRP charge readout
- Regular data taking with PMT's and daily purity monitor runs also ongoing
- *Feb 22:* ARAPUCA data taking to study light collection efficiency through 70% transparent FC
- *Feb 23 to Feb 25:* activation of CRP 4 DP charge readout and full 6 m drift data taking for three days
- *Feb 28:* HVS OFF, cryogenic tests still on going for few days.
- *Mar 4:* Start LAr venting (~3.5 cm/day): some used for Cold Box tests, recovered by LAr provider

# LAr Purity evolution in NP02

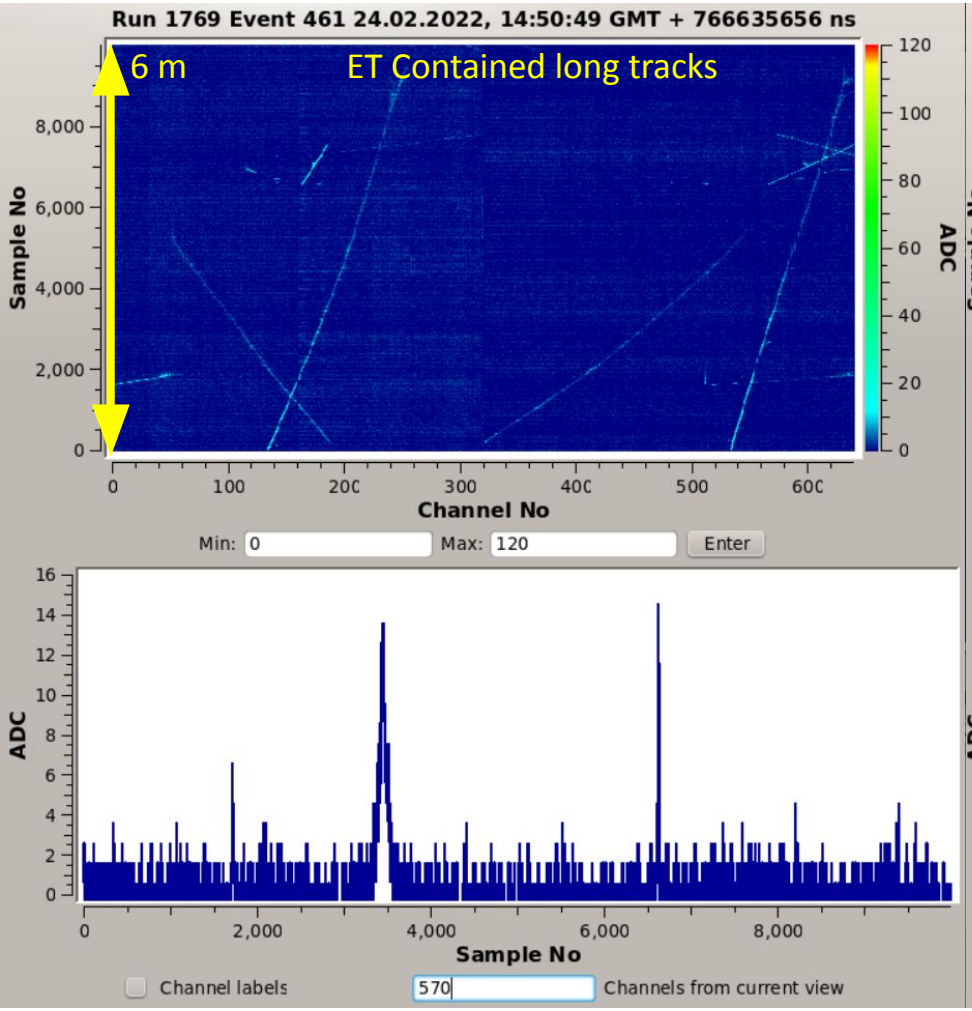
- Measured with two available purity monitors at the bottom of the cryostat
- Electron lifetime ~ 3 ms reached at beginning of 2022 however:
  - large error: (+1, -0.5ms) due to PM sensitivity
  - More accurate calibration of anode/cathode signals and grid transparency required to improve sensitivity
- Certification of HV stability at high purity reached
- Full drift distance of 6 m at 500 V/cm (4 ms) recordable
  - max attenuation: ~ 70% (space charge not accounted)

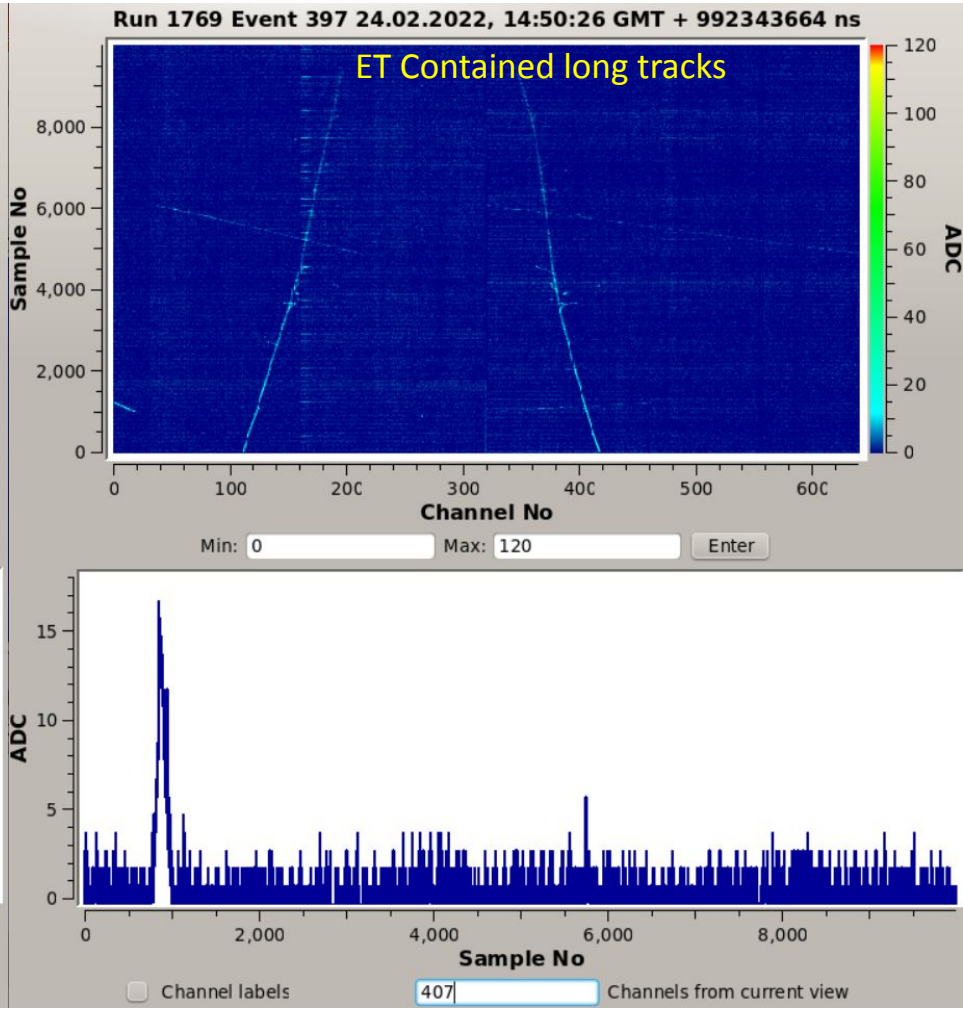



*Anode/Cathode = exp(-Td/Tau)*

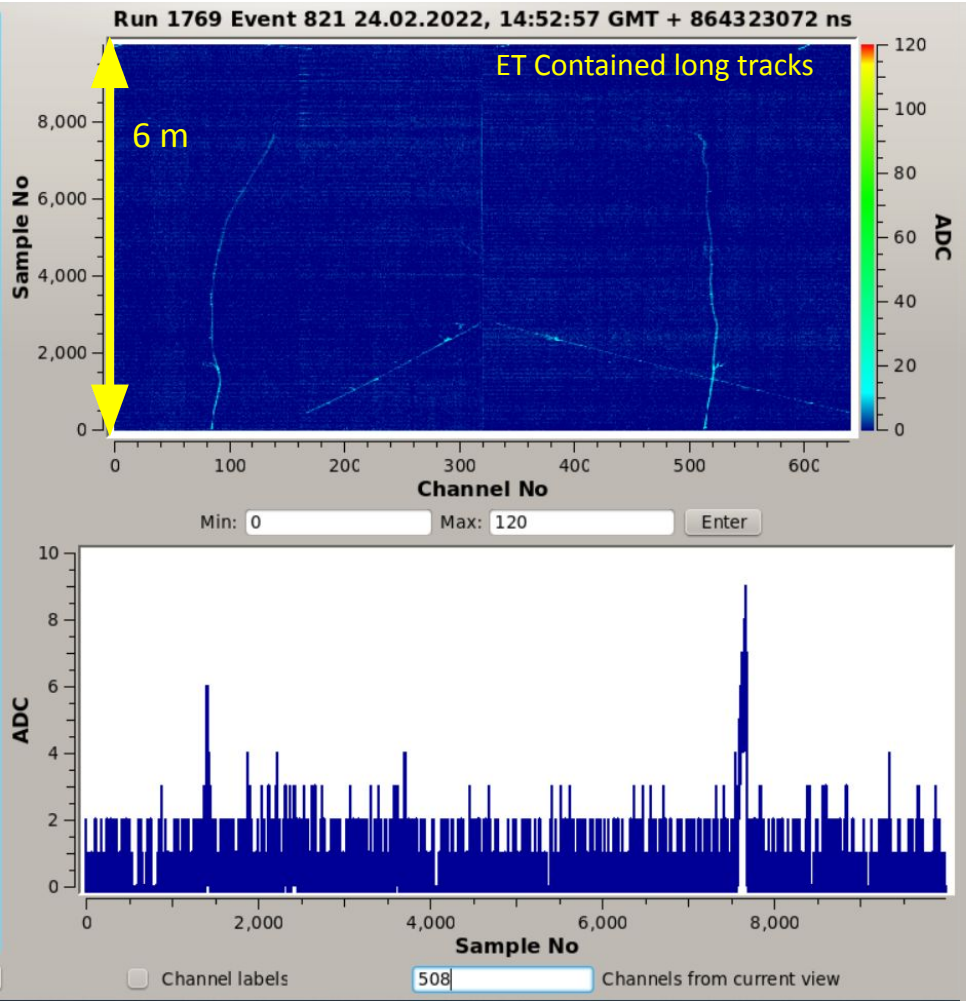


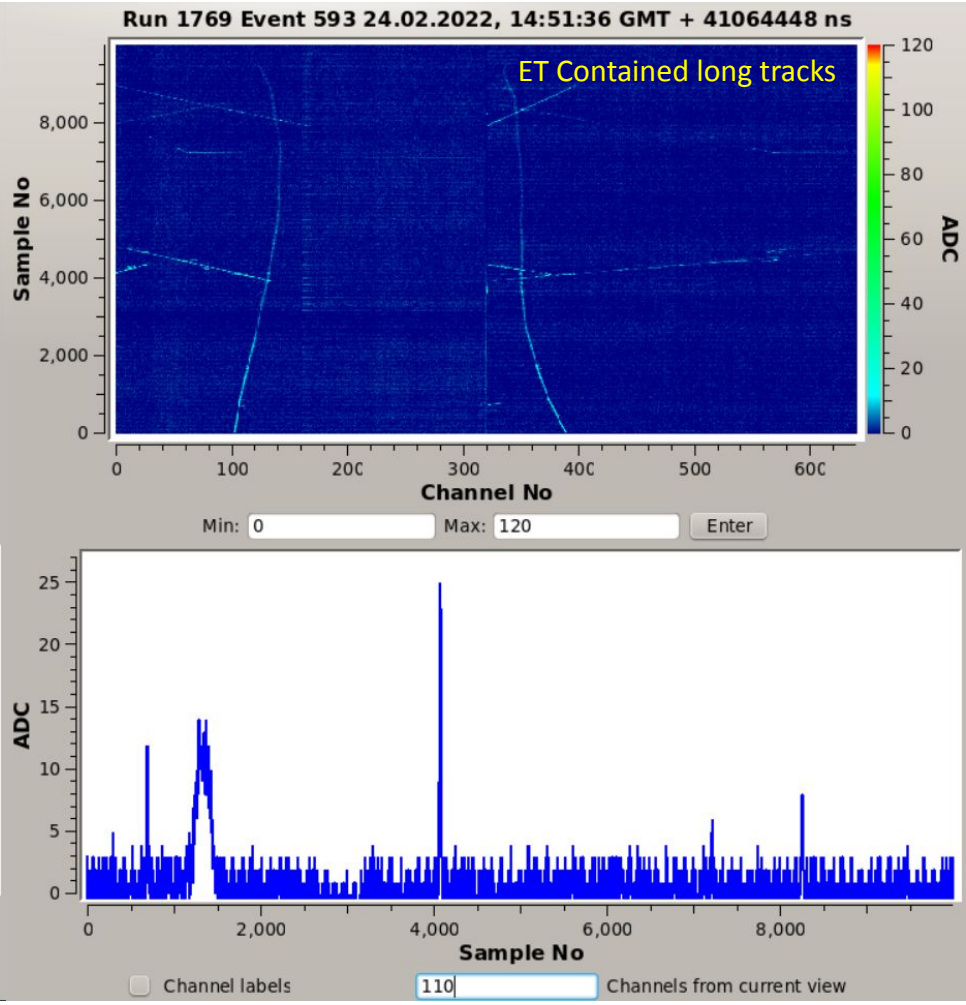
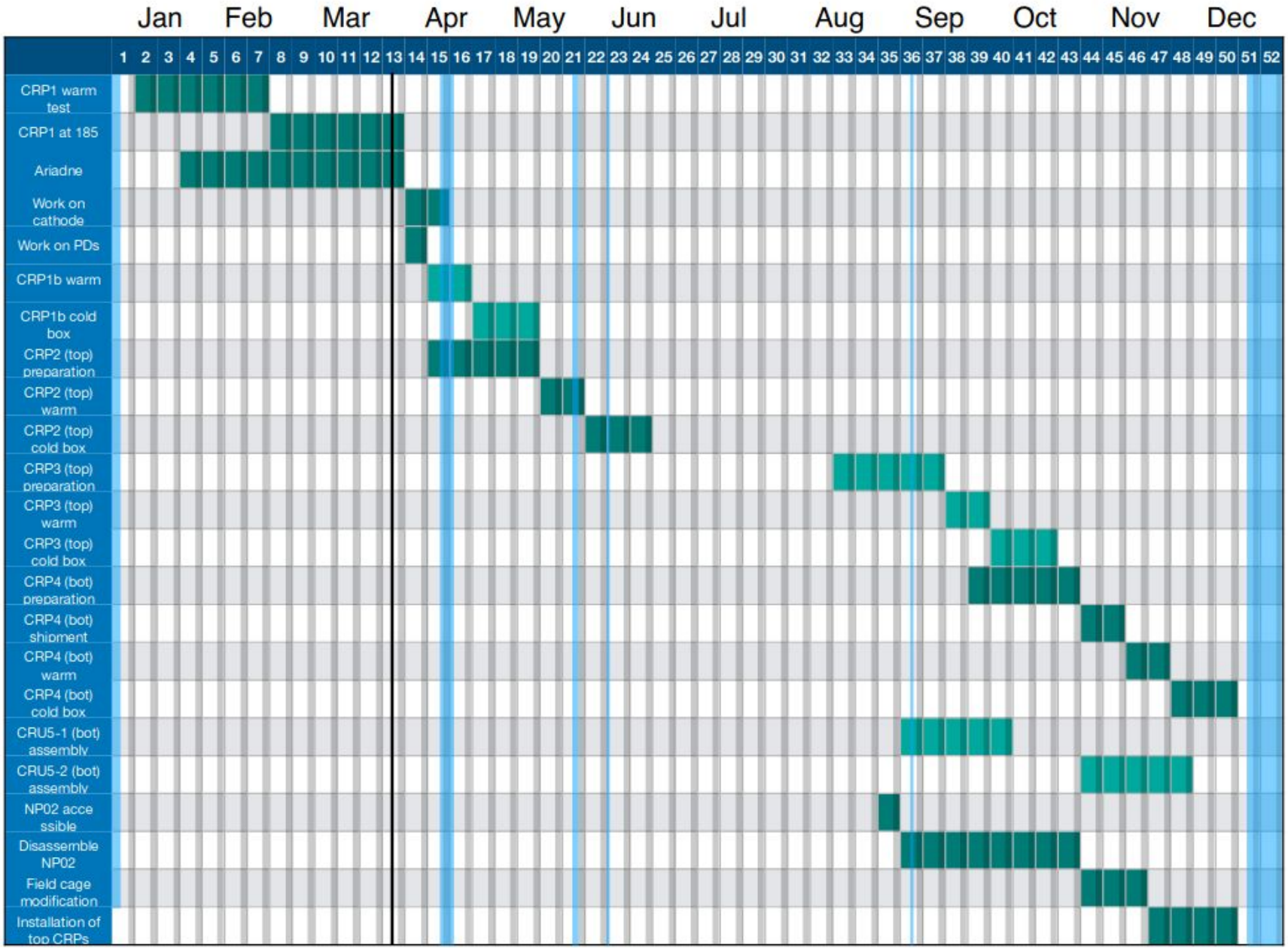
# Events gallery



# Events gallery (II)






# Vertical drift CRPs in 2022