Annual Report 2021
ProtoDUNE-DP (NP02)

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CERN SPSC Meeting
13 April 2021

Report document: https://cds.cern.ch/record/2759609/files/SPSC-SR-287.pdf

Outline:

Update on the end of protoDUNE-DP first operation period and follow-up:

- HV extender repair (May-July 2020, surgery intervention on June 17th)
- Completion of operation program (August 2021 with cryostat empting on Sep 7th)
- Follow-up on cryostat inspection (February 2021)
- What learned from a year operation period of ProtoDUNE-DP and associated further R&D program

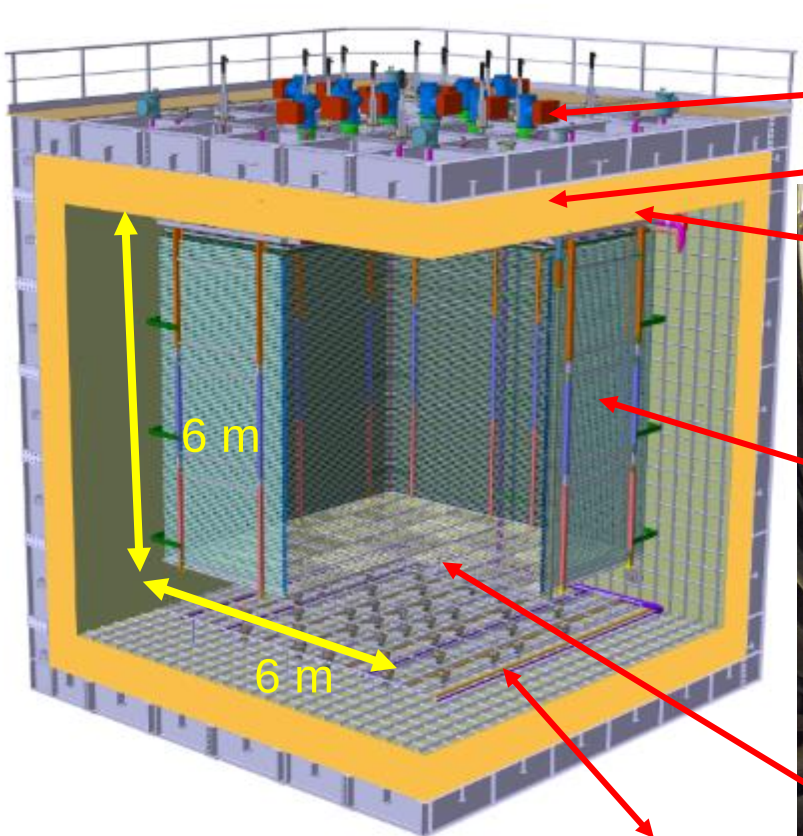
Evolution of Dual-Phase to Vertical Drift and associated experimental activities:

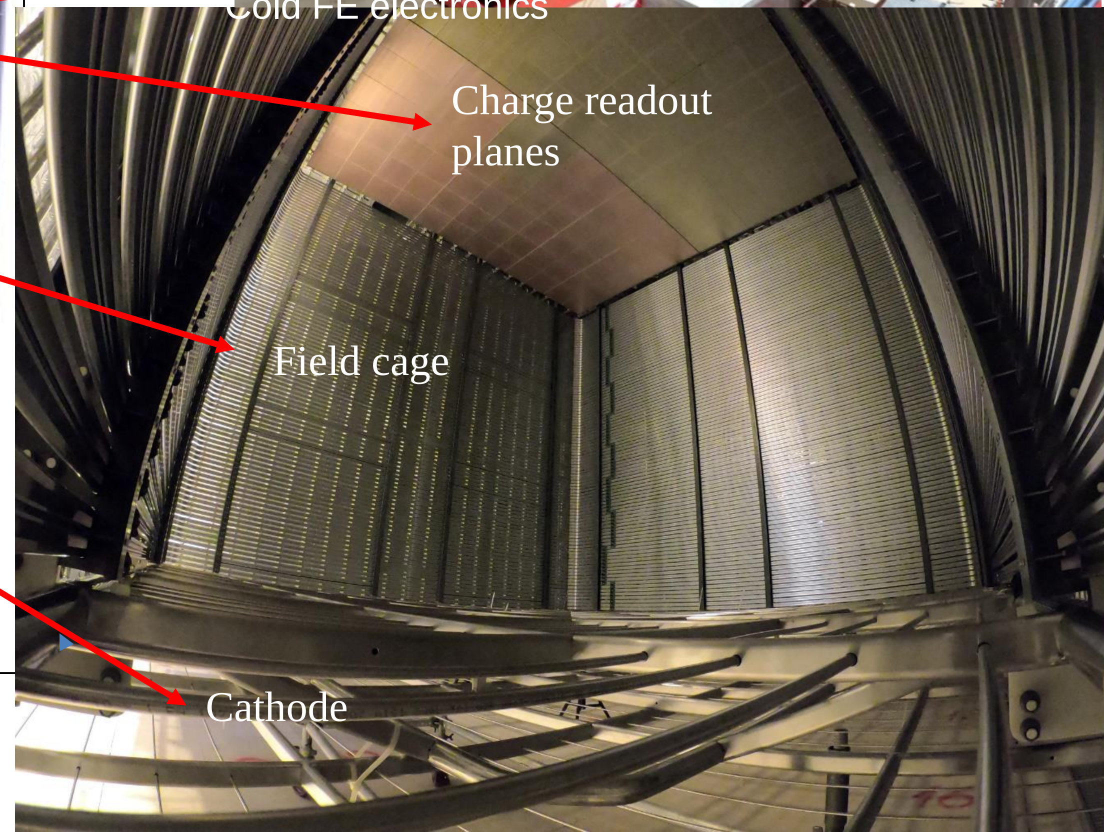
- Vertical Drift tests since summer 2020 and evolution of the dual-phase design to the new VD design
- Definition of the Vertical Drift project for the second DUNE far detector module (June 2020-February 2021)
- Vertical Drift integration tests campaigns (2021-2023)

NP02/protoDUNE dual-phase

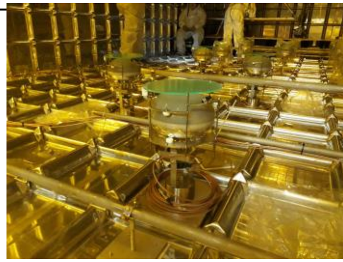
dual-phase 10 kton design based on NP02:

- 1/20 of active area of DP 10 kton
- NP02/protoDUNE DP 4 CRPs → DUNE 80 CRPs



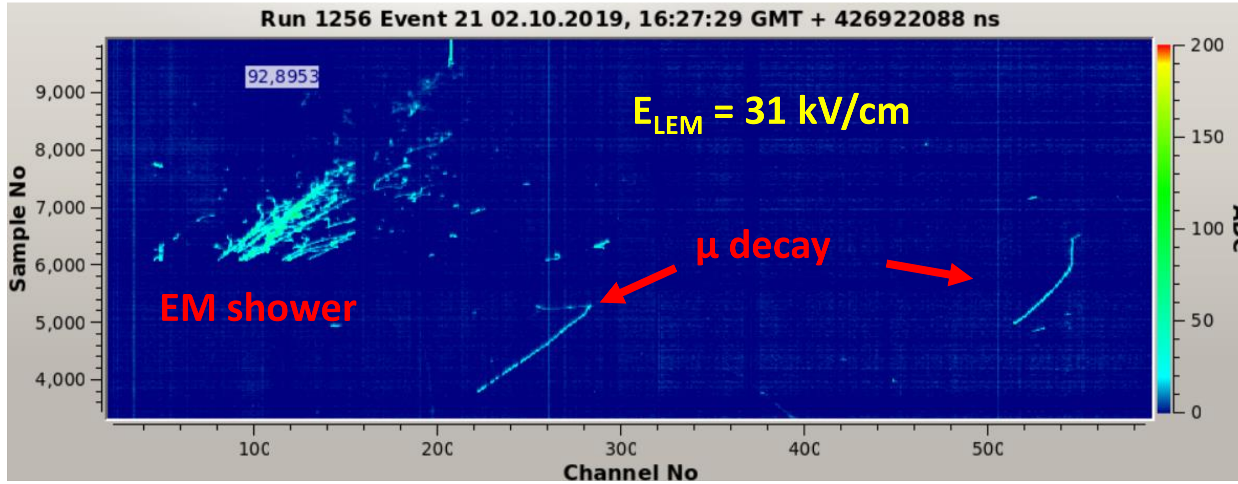


36 cryogenic photomultipliers Hamamatsu R5912-02mod with TPB coating

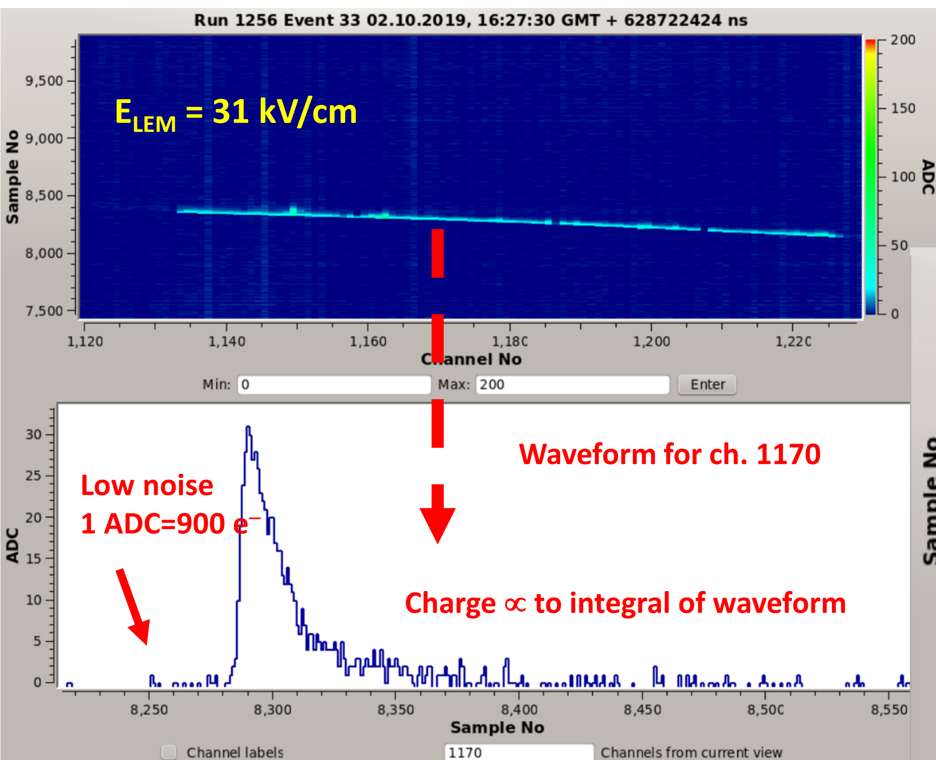


Cosmic ray events in protoDUNE dual-phase

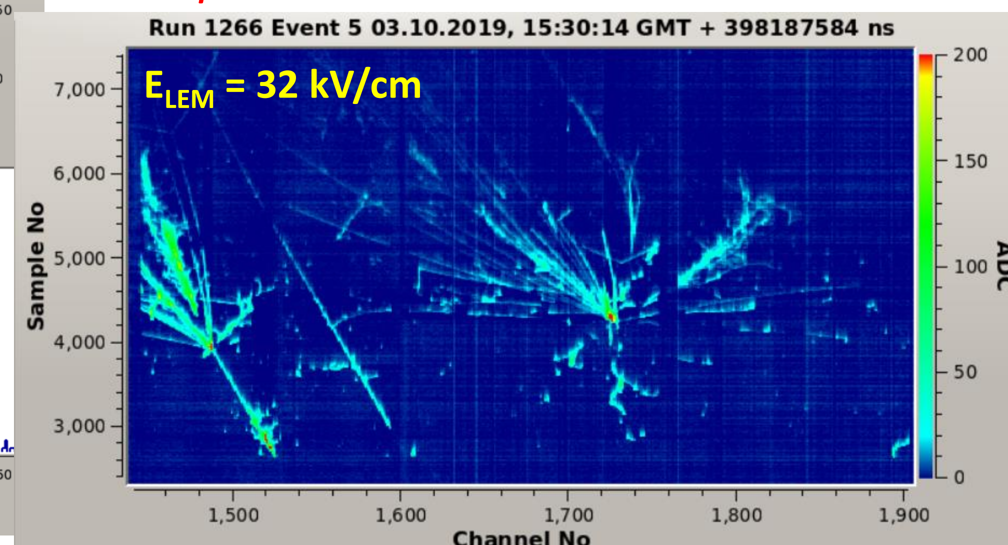
Electromagnetic shower + two muon decays

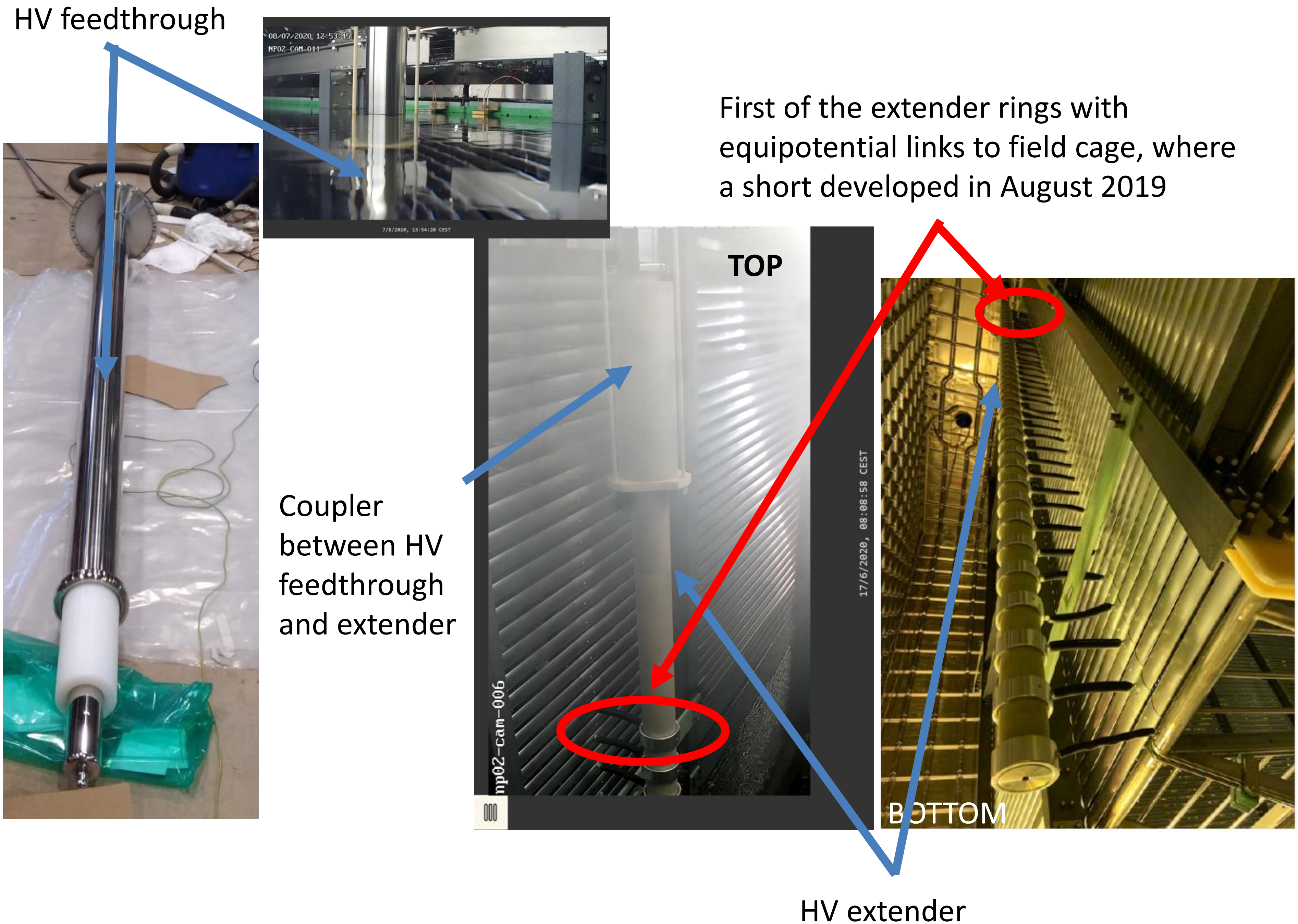


Horizontal muon track

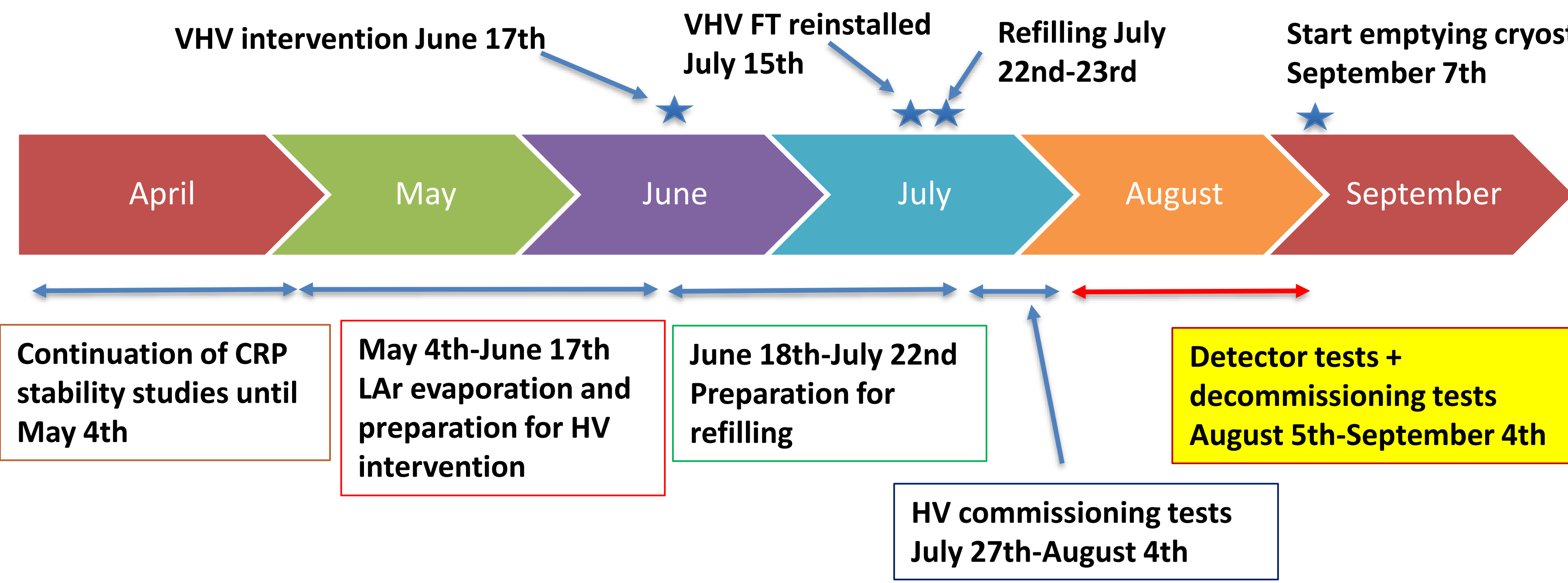


Multiple ***hadronic interactions in a shower***




HV feedthrough
First of the extender rings with equipotential links to field cage, where a short developed in August 2019
TOP
Coupler between HV feedthrough and extender
17/6/2020, 08:08:58 CEST
np02-cam-006
BOTTOM
HV extender

Last period of protoDUNE-DP operation (May-Sep 2020):



- **Preparation for VHV surgery intervention, VHV surgery intervention, VHV Commissioning**

- **Operation in August 2020 → Completion of studies on CRP stability and of several other studies:** Microphonic effects, N2 injection tests, bubbles investigations, CRPs immersion tests, scintillation light readout studies, etc…

- **R&D parallel activities and phase-II**
- **Cryostat inspection**

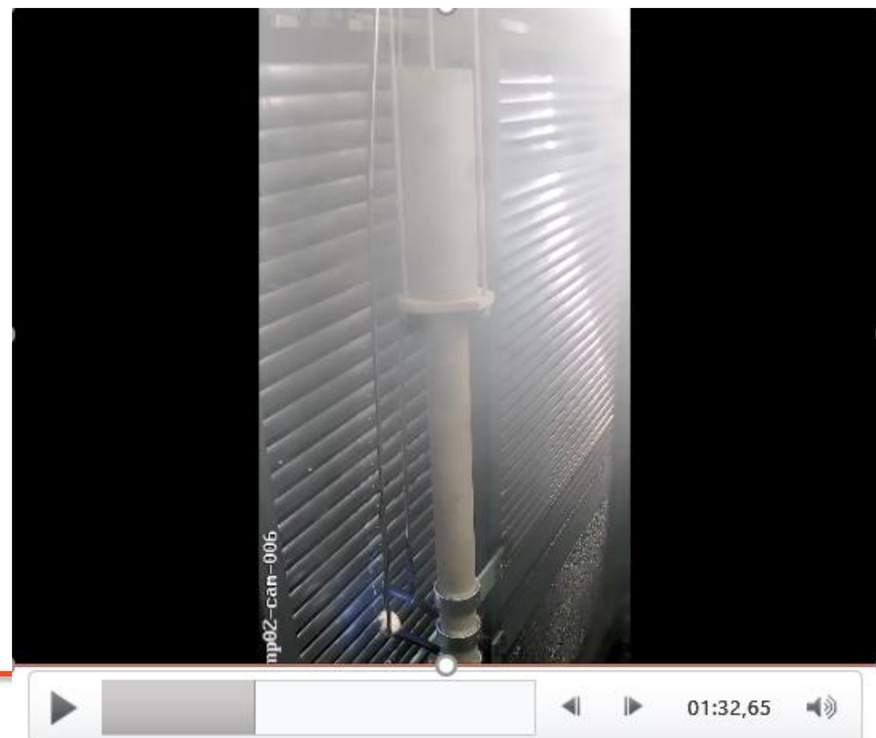
Surgery intervention on the VHV extender:

June 17th 2020: after partial emptying of cryostat, connections between the first 3 extender rings and the field cage cut and removed by accessing via the HV feedthrough penetration with dedicated tools

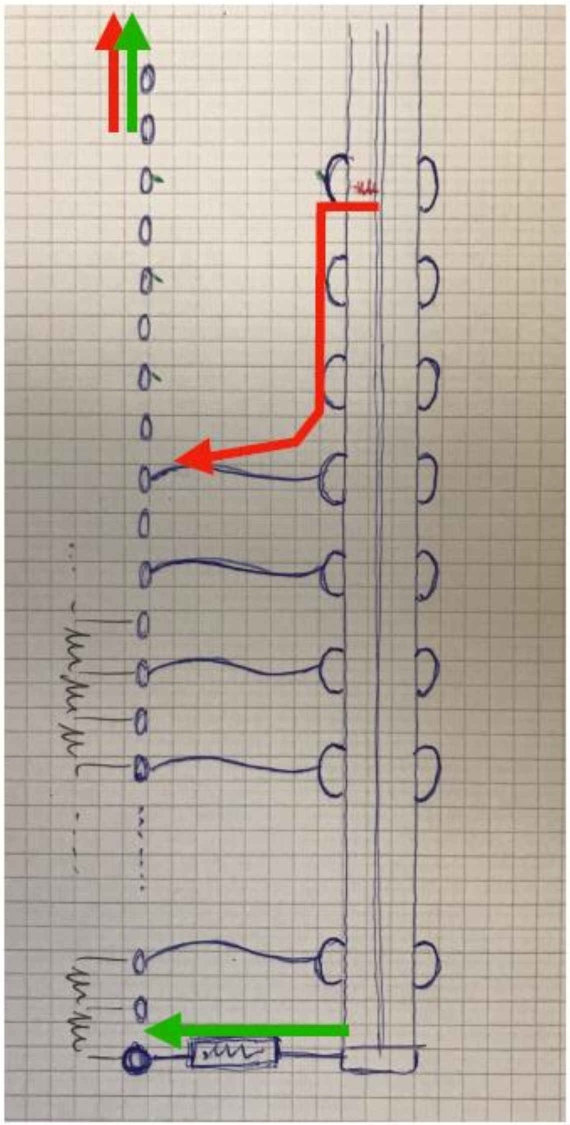
- Operation lasted about 7 h, cryostat stayed opened to air for almost 4 h.
- Morning dedicated to the tuning of the tools, afternoon to the execution of the cuts.
- Intervention technically successful with no surprises.
- HV feedthrough reinstalled on July 15th
- Tests at 10 kV → showing that short circuit which was developing in August 2019 for >7kV between the extender and the field cage looked to have been removed by the surgery intervention
- Lifetime dropped to 0.4 ms on the 18th → recovered after purification restarted on June 19th, >3.5ms achieved on July 10th

Accelerated movie (x8) of the highlights of the intervention available at:

https://cernbox.cern.ch/index.php/s/9HXtdxxw8YI2RbB

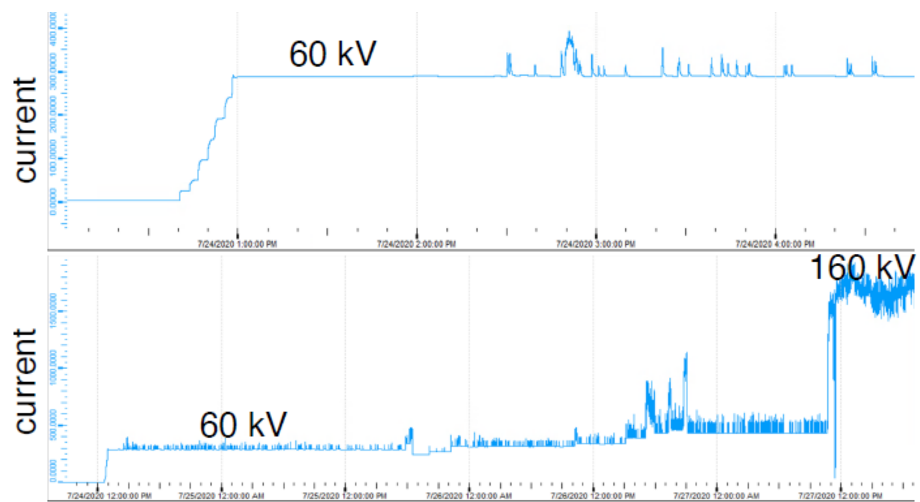


HV commissioning (week of July 27th 2020):



- During commissioning it was observed that up to -50 kV the current flowing through the field cage was nominal and stable.
- Increasing further the voltage current spikes appeared with increasing frequency as the voltage increased.

→ Development of a surface current (flashover) flowing on the extender from the first extender ring (damage in the insulation appeared in August 2019) down to the first available connection to the field cage (4th extender ring)



→ Experience with NP02 operation opened the way to an improved (simpler) HV extender design.

Experience from protoDUNE-DP 6x6x6 m^3 phase-I

(Details in 2020 SPSC Annual Report, Slides and in + 2021 SPSC Annual Report)

- **NP02 6x6x6 m^3 construction 2018-2019**
- **All 4 CRPs tested in cold-box tests program in Summer 2018**
- **Start of detector operation in August 2019 → HV extender issue**
- **LEM and CRPs stability studies August 2019-April 2020**
- **HV surgery intervention (preparation + execution+ refilling) May-July 2020**
- **Continuation of the operation after HV surgery in August 2020**
- **Completion of dual-phase NP02 Phase-I operation period September 2020**
- **Cryostat inspection in February 2021 (2021 SPSC Annual Report)**

Main features of what learned from operation described in April 2020 SPSC Report :

- Gain ~6 obtainable but LEMs performance tending to degrade over long time periods related to sparking

→ LEM design improvement program ongoing since spring 2020 at CEA,

→ Workshop with micro-pattern detectors community 6-7 April 2020: https://indico.fnal.gov/event/23774/

- Observed CRPs grid sparking instabilities
- Environmental cryostat aspects affect CRP stability: movements of LAr surface due to bubbling, presence of dust/debris
- Experience on HV system in protoDUNE-DP, short in August 2019 + result of surgery, R&D for 600 kV

→Foreseen LEMs and CRPs improvement program for Phase II running of protoDUNE-DP/NP02 (2020-22)

→Possible improvement of some environmental conditions from what learned from operation

→HV design improvements clear for 300 kV but parallel HV R&D launched for 600 kV to be completed

- **Very good LAr purity levels achieved (target 3-5 ms electrons lifetime → achieved >30 ms)**

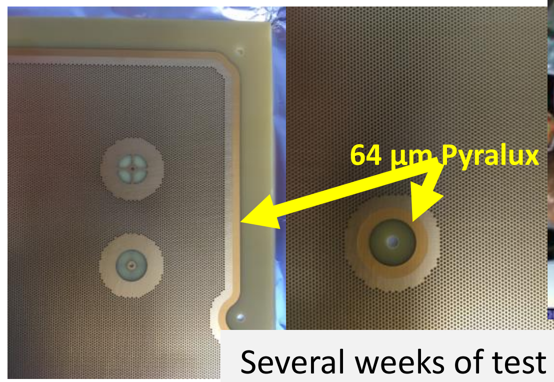
makes LEMs gain much less required to compensate for signal attenuation during drift

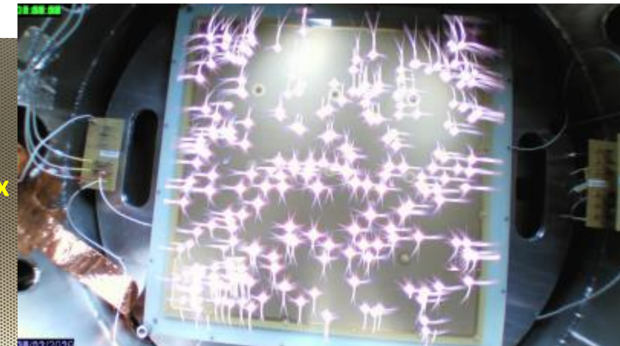
ProtoDUNE-DP R&D activities: (April 2020 SPSC)

<u>Goals</u>: (1) Improve LEM stability over time in terms of HV, spark rate and increase the active area >95%
(2) Improve CRP planarity and robustness with respect to any liquid argon surface instabilities
(3) Eliminate all risks linked to grid sparking onto the charge readout electronics

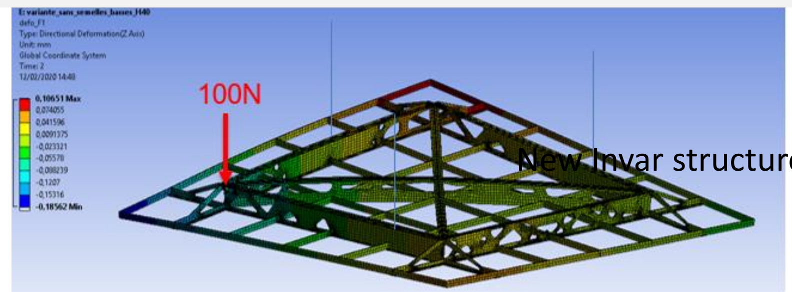
<u>LEM and anode improvement plan is in progress at CEA/Saclay:</u>

- Improving LEM design with high quality rims using a micro etching technique developed by CERN
- Adding an insulating material in the dead regions of LEM using 64 um thick Pyralux coverlay (successful tests at Saclay) very effective to eliminate sparks in those regions
- For the anodes: new design to incorporate a guard ring on both faces of PCB





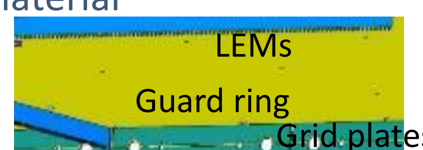
Several weeks of test at 3.4 kV, no spark on the insulated area



<u>For the CRP structure and extraction grid:</u>

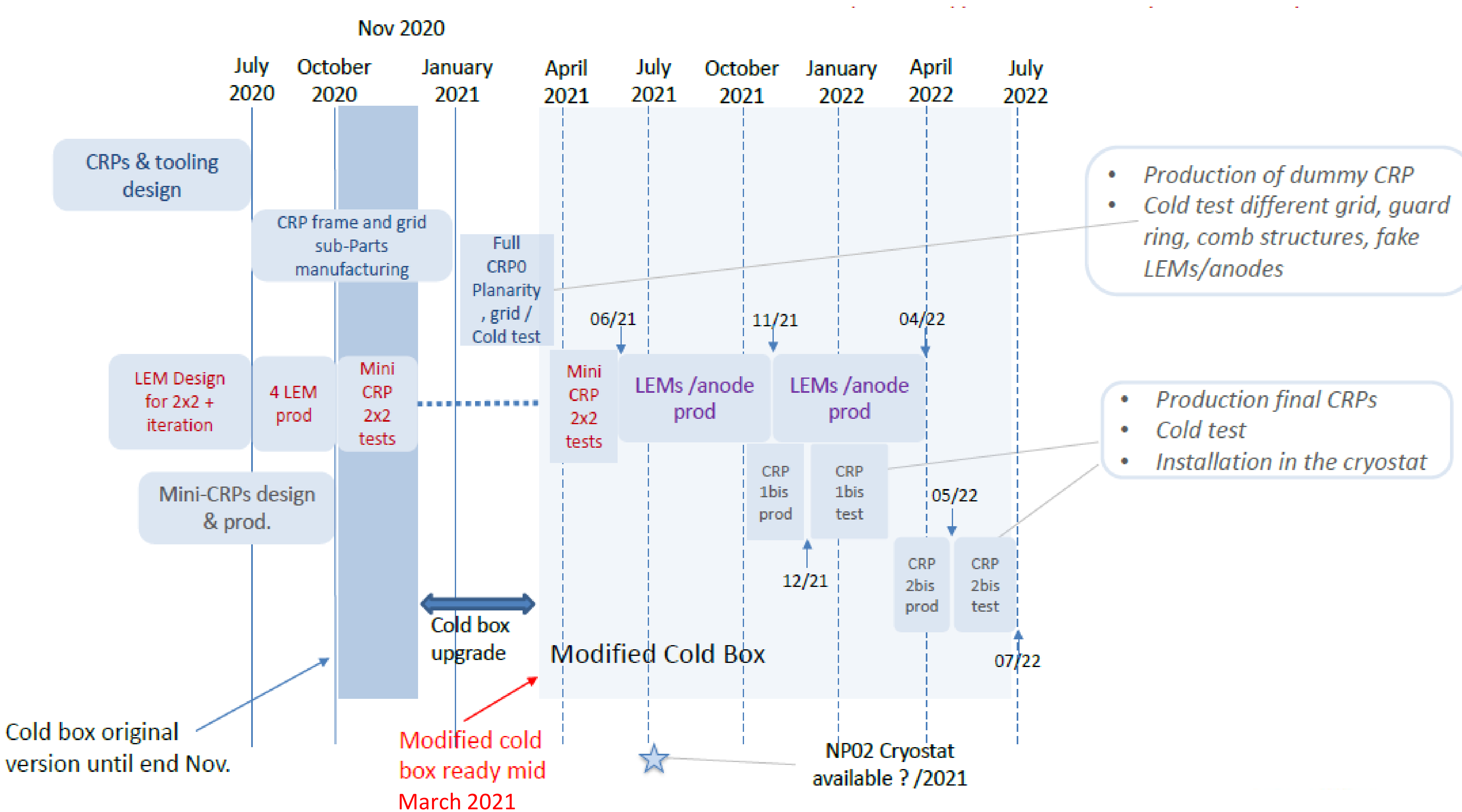
Modifications of the design are being validated to incorporate:

- a more stiff structure (20 times less deformations)
- A guard ring in the extraction grid support structures to guide the possible discharges
- Modifying the combs with resistive material
- Add 2mm to the grid-LEM distance



ProtoDUNE-DP Phase II planning (small scale tests + cold-box + Module-0):

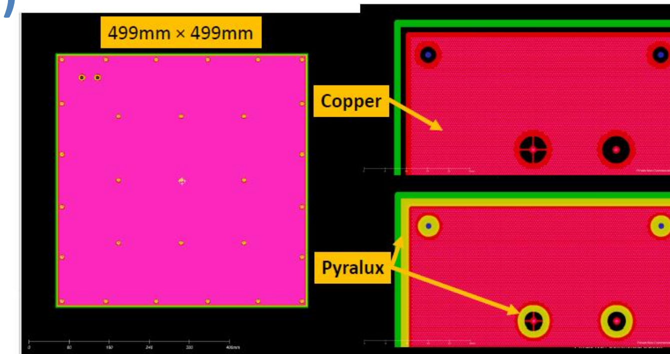
(Activities schedule presented at April 2020 SPSC meeting updated on September 2020)



Schedule now replaced by VD integration tests 2021-2022

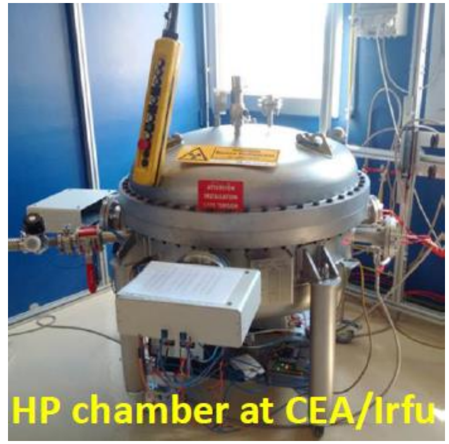
Progress on small tests R&D activities: (Summer 2020)

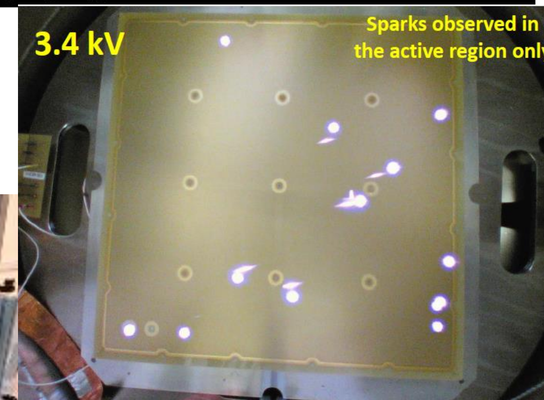
LEM design with 95% active area

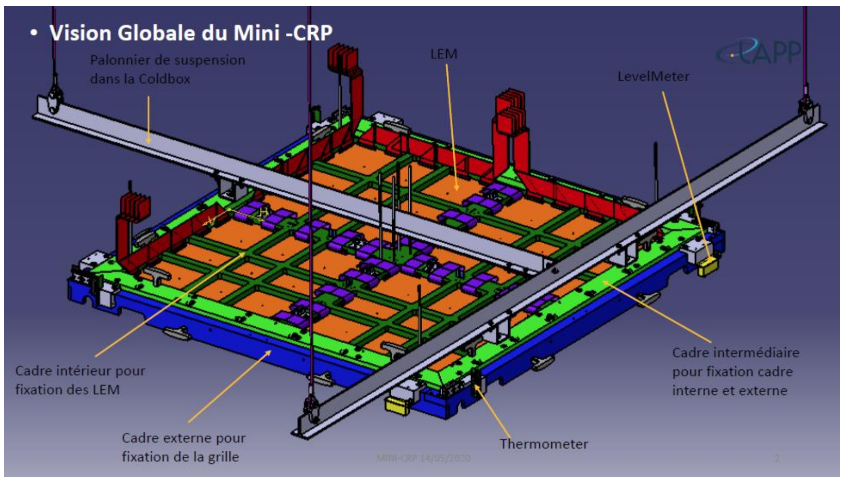


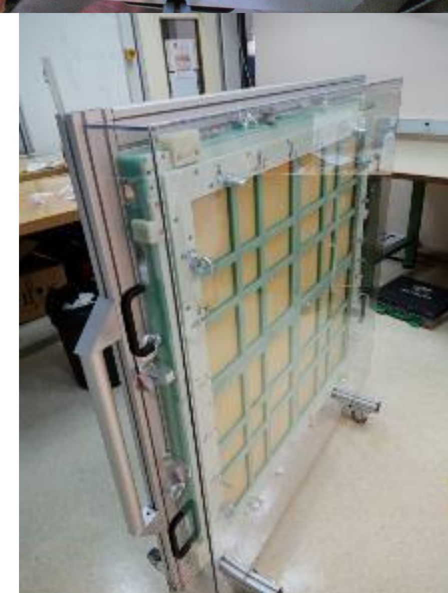
Tests of new LEMs design at CEA to reduce sparking

- Pyralux insulator on edges and pads
- Increased active area to 93-95%
- Studies on segmented and resistive LEMs and on RIMs optimization









New design developed for 3x3 m^2 CRPs following the CRPs improvement program:

→ First design implementation on a MiniCRP structure (1x1m^2) made following the CRP improvement program to test 4 LEMs from new design

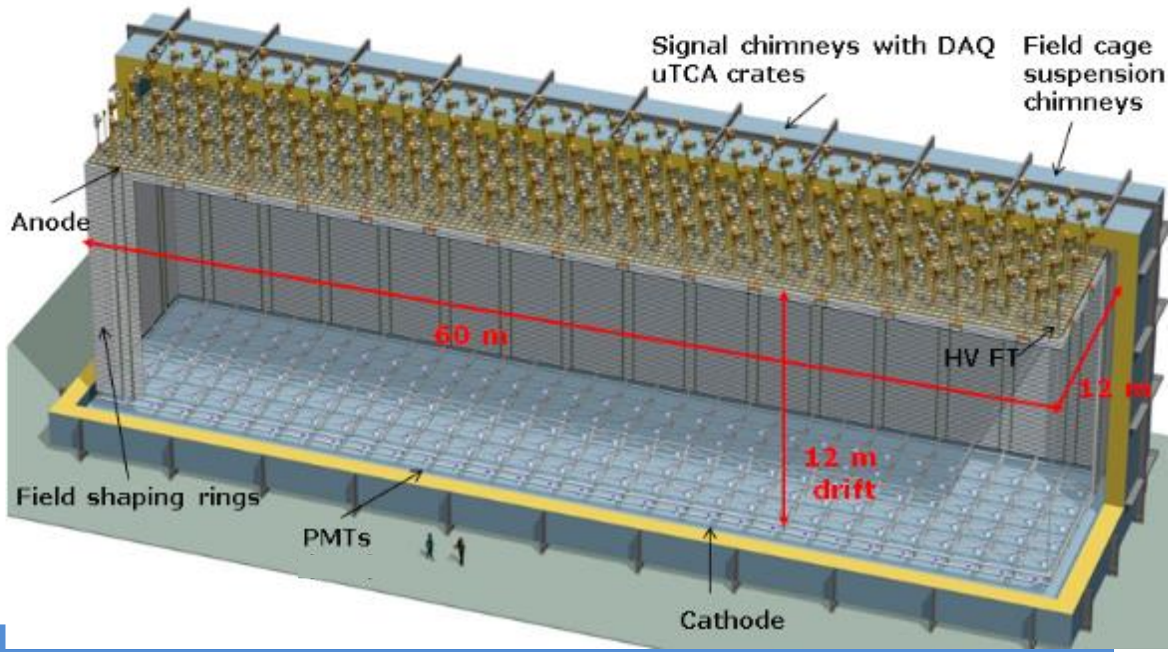
- New extraction grid + grid sparks prevention system

Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

Item	Number or Parameter
Anode plane size	W = 12 m, L = 60 m
CRP unit size	W = 3 m, L = 3 m
CRP units	$4 \times 20 = 80$
LEM-anode sandwiches per CRP unit	36
LEM-anode sandwiches (total)	2880
SFT chimney per CRP unit	3
SFT chimney (total)	240
Charge readout channels / SFT chimney	640
Charge readout channels (total)	153,600
Suspension feedthrough per CRP unit	3
Suspension feedthroughs (total)	240
Slow Control feedthrough per sub-anode	1
Slow Control feedthroughs (total)	80
HV feedthrough	1
HV for vertical drift	600 kV
Voltage degrader resistive chains	4
Cathode modules	80
Field cage rings	197
Field cage modules	288
PMTs (total)	720 (1/m^2)

Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) DUNE Conceptual Design Report, July 2015

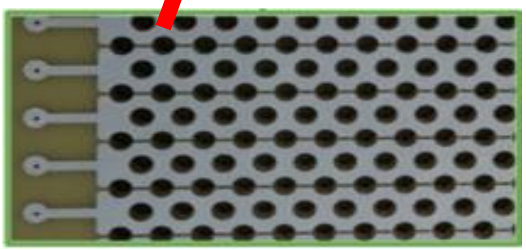
Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600

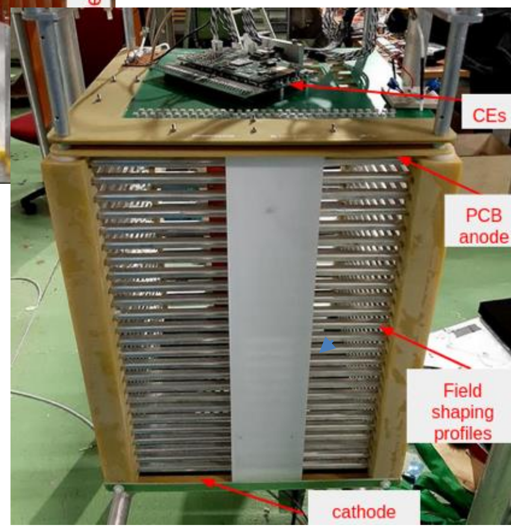


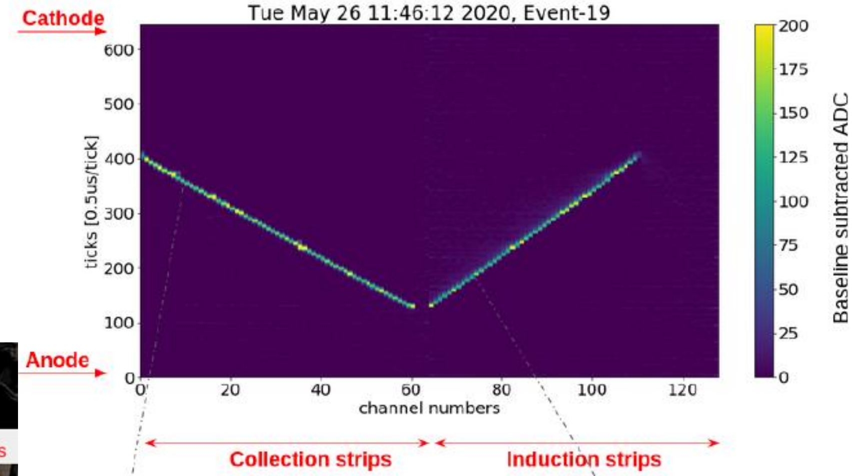
Advantages of dual-phase design:

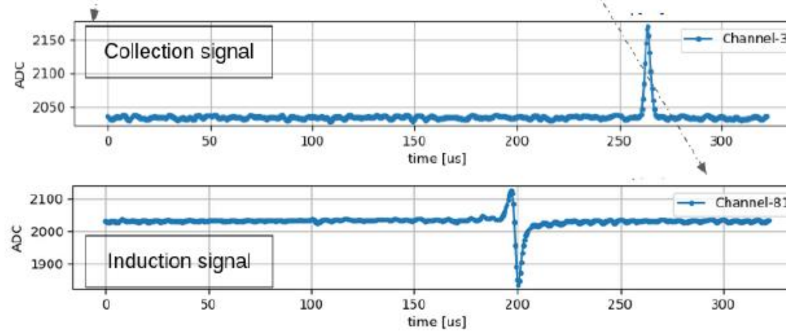
- Gain in the gas phase → compensation for charge attenuation due to long drift paths, required gain 6 for 12 m drift (TDR requirement of gain 6 computed for 12m drift, 250V/cm drift field 300kV, and 5ms electrons lifetime)
- Simplified dual-phase detector design with vertical geometry→ cheaper production and installation costs, simpler and faster installation than single phase design
- Full accessibility to electronics and possibility of replacing also cryogenic front-end (FE) electronics during detector operation

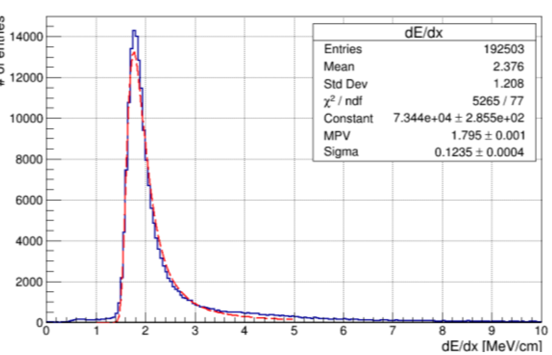
Perforated anodes tests at CERN Neutrino Platform with the 50l TPC test stand (Summer 2020)

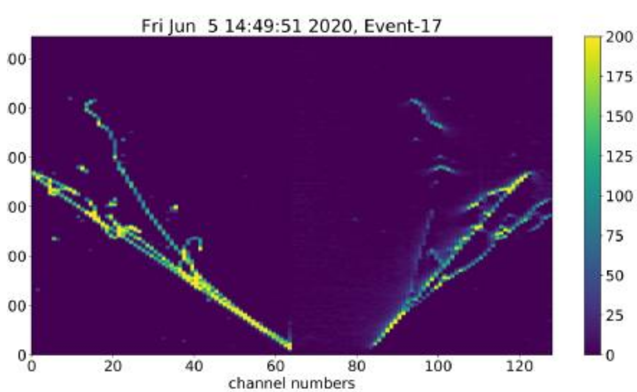


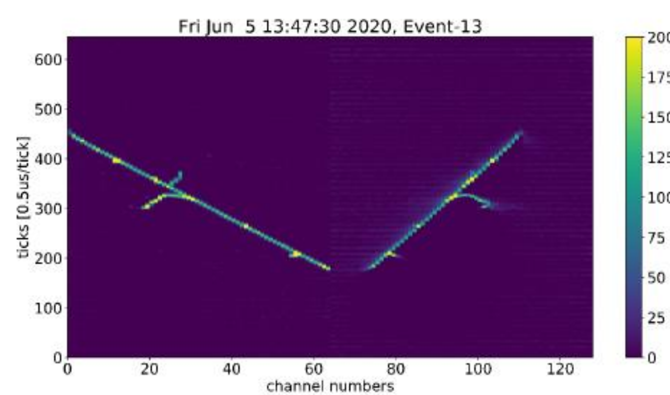












Can we think of a simplified DP detector without LEMs (w/o the extra time needed to complete LEMs/CRP developments) which could be immediately built for DUNE, quickly and at affordable costs ?

→Yes, the so called « **Vertical Drift** » :

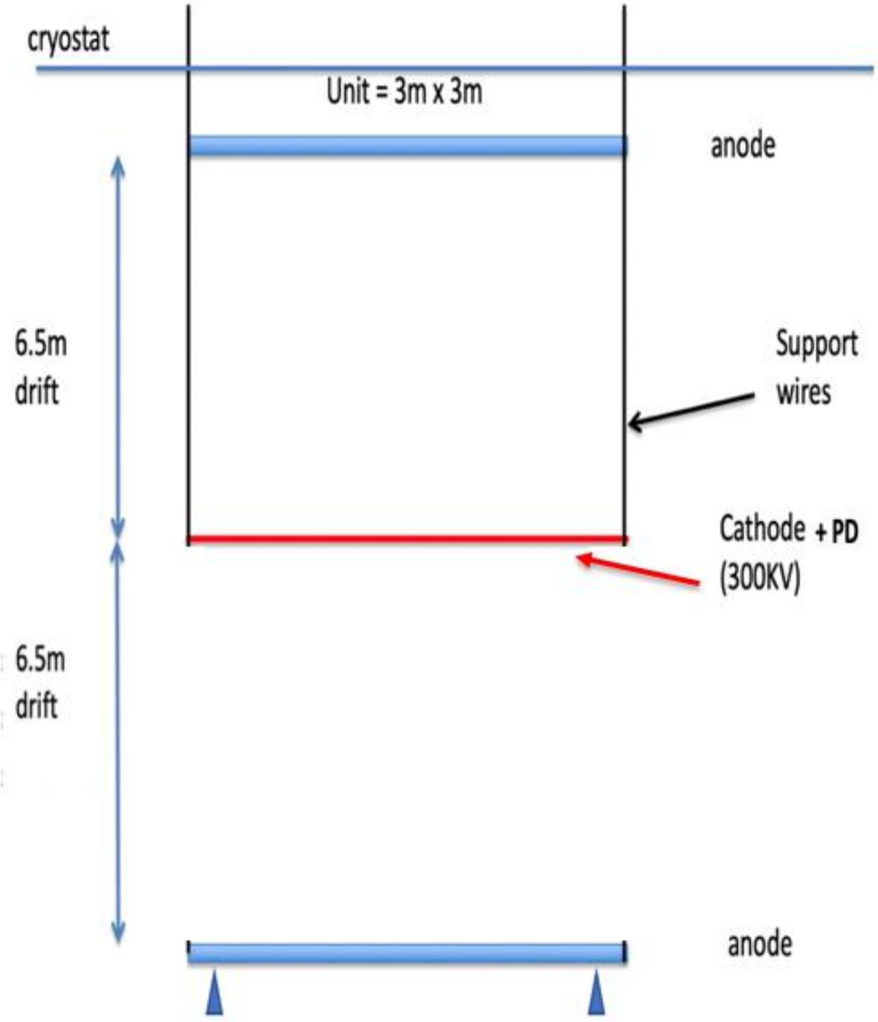
- **No LEMs → CRP evolution to perforated anodes**
- **No further changes in the cryostat needed to ensure better stability of LAr surface, can work with current performance**
- **No 600 kV → ~300 kV operation**
- **All detector components developed for dual-phase (CRPs, electronics, field cage, cathode, HV system) and associated investments maintained**
- **Geometry optimized to increase the sensitive volume, very much needed for physics → 15 kton**
- **Large cost and time reductions even with respect to DP. 20M saved also from the point of view of installation costs in South Dakota**

- **Tests at CERN on Vertical-Drift perforated anodes, since beginning of summer 2020 and continued in more complicated configurations (3 views test in progress)**
  →confirmed the idea of evolving from the LEM design

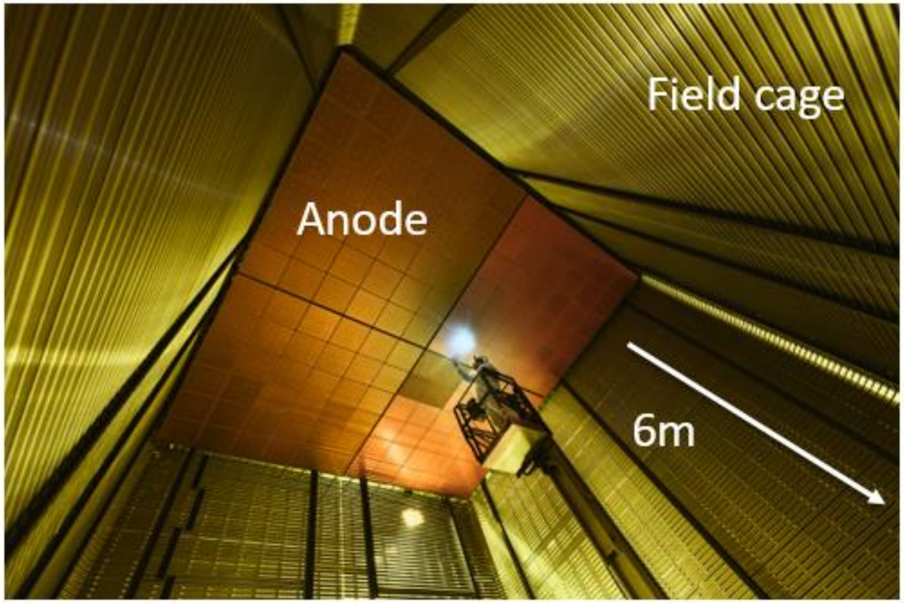
- **Developments since September 2020 to optimize the geometry and engineering of the detector and to reach a convergence with the collaboration and funding agencies**
  → process completed in December 2020

- **DOE IPR concluded in January 2021 → very strong support to this evolution of DUNE far detector configuration**

Vertical Drift layout

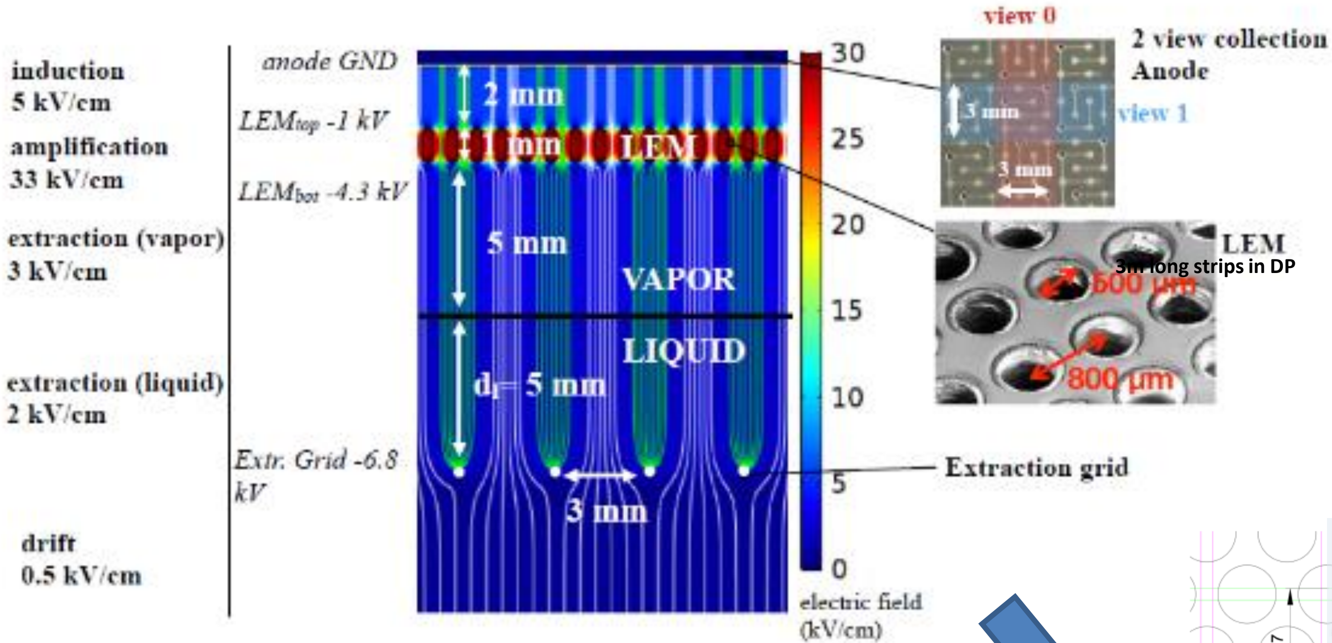


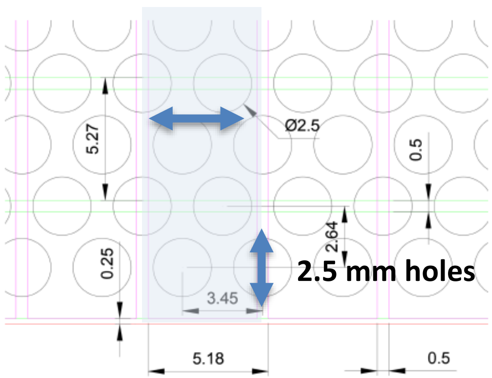
NP02 layout



cathode

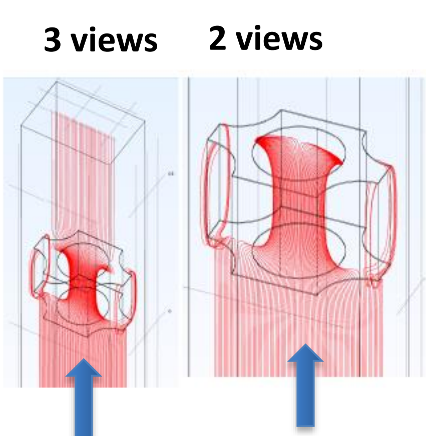
Evolution of CRP charge readout stack: Dual-Phase → Vertical Drift

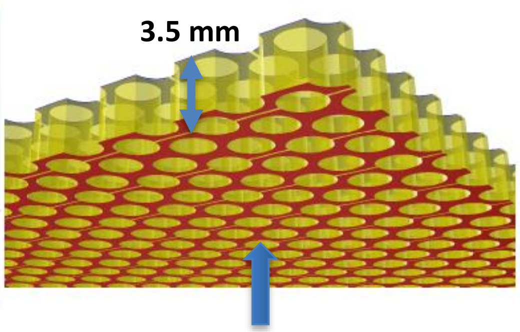




Vertical drift:

- Anode PCB (3.2 mm thick) directly immersed in LAr, 2.5 mm holes
- Perpendicular strips on the top and bottom faces of the PCB: 5.2 mm pitch, 1.5 or 1.68 m long
- Bottom strips induction signals, top strips collection, 1kV across for full transparency





Vertical Drift vs Dual-Phase

Signal reduction related to **unitary gain in VD is compensated by a few favorable differences with respect to the DP configuration:**

a) factor 2 is gained by not having to share the charge among two collection views
b) factor 1.7 is given by the strips pitch increase (5.2mm instead of 3.1 mm)
c) factor 1.6 is gained by the absence of the DP extraction/collection efficiencies (0.63)

- **VD overall signal increase factor (x5.3) similar to the DP TDR requirement (gain=6)**

- In addition **DP gain requirement was defined for a more unfavorable** drift length and drift field **configuration present in DP (250V/cm, 12m drift, 5ms lifetime)**

→ requirement relaxed by 4 (equivalent gain 1.5) for 500V/cm: 6.5m drift, 6 ms lifetime or by 5.2 (equivalent gain ~1) for 500V/cm, 6.5m drift, 6 ms lifetime (~300kV at cathode)

- **Signal in VD with 300 V/cm (500V/cm) is stronger than in DP requirements (gain=6) by a factor 3.5 (4.6)**

- **Strips capacitance is also lower for VD**: (<100 pF/m) over about 1.5 m length to be compared to 160pF/m x 3m length in case of DP configuration.

Recent evolution for the DUNE project for the 2nd Far Detector module

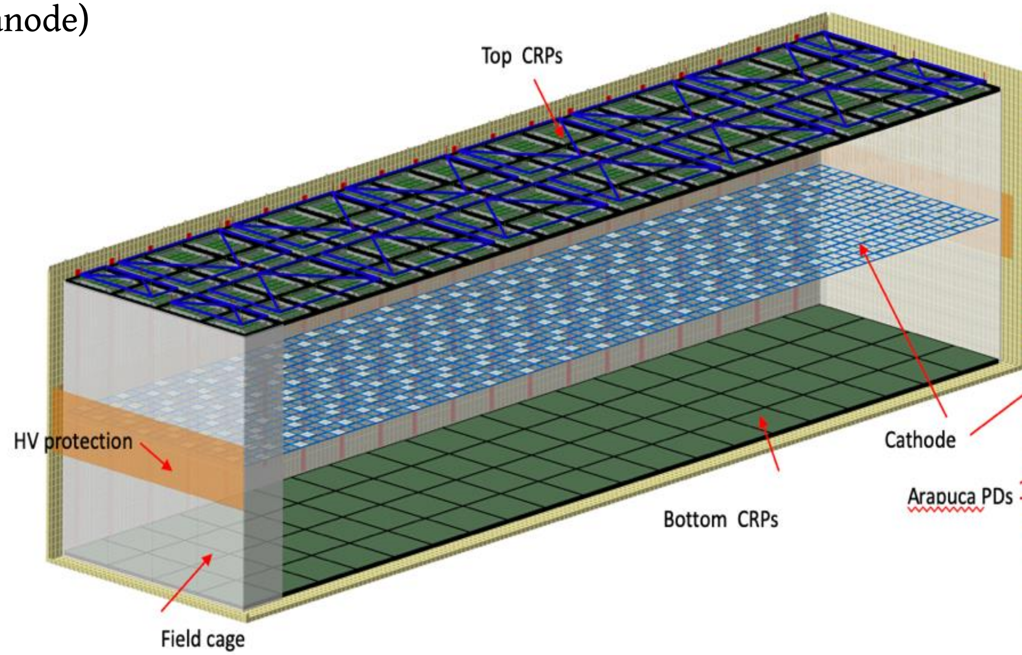
Convergence of several favorable factors during the last months:

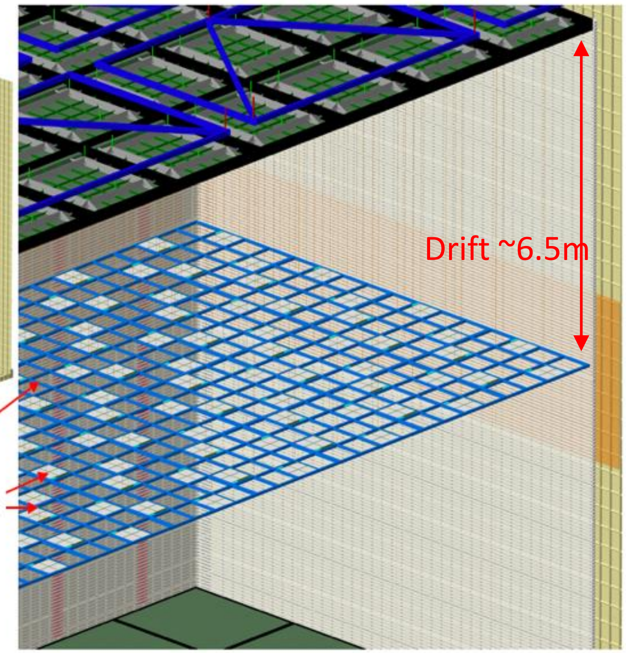
- **Need to achieve quickly far detector mass for DUNE physics sensibility**, restated in the DOE reviews in 2020 the necessity to baseline immediately two FD modules
- **Completion of experience from protoDUNE-DP running in September 2020. New tests on perforated anodes successfully performed**
- **Approval of French TGIR project for DUNE** (end of August 2020)
- **Interest of US and European groups and funding agencies** for a second FD module based on a simple, **fast and cheap Vertical Drift design, based on the DP experience with some simplifications** in order to make its implementation faster and have an **aggressive schedule for 2nd detector module construction**
  → **Vertical Drift** proposal document
- **Very strong support by DOE, CERN, major US laboratories** like FERMILAB and Brookhaven and by the DUNE collaboration to building a second DUNE far detector module based on this evolution of the DP design → VD becomes the **DUNE preferred configuration for the 2nd far detector module**
- Organization of 3 US reviews based on this concept since December. **Independent DOE Review (IPR) concluded in January → very strong support from IPR** to this FD evolution in DUNE
- Dec 2020 announcement at CERN of **funding of second cryostat needed for the construction of this 2nd FD module**)

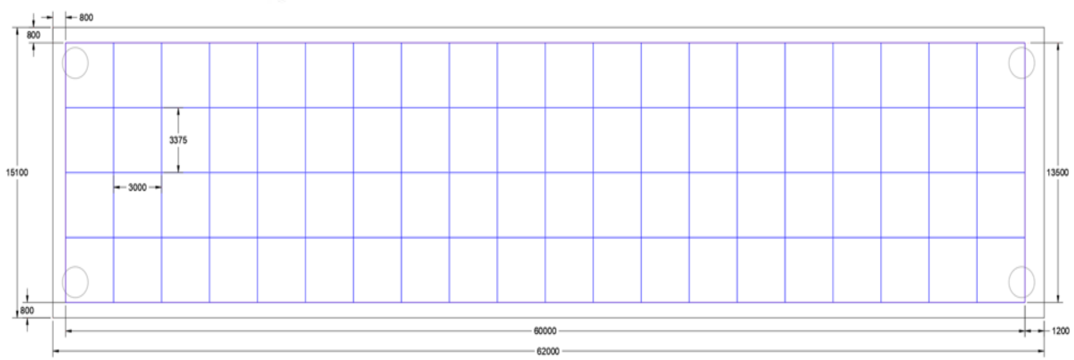
Vertical Drift far detector module

Detailed description in Vertical Drift proposal [document]

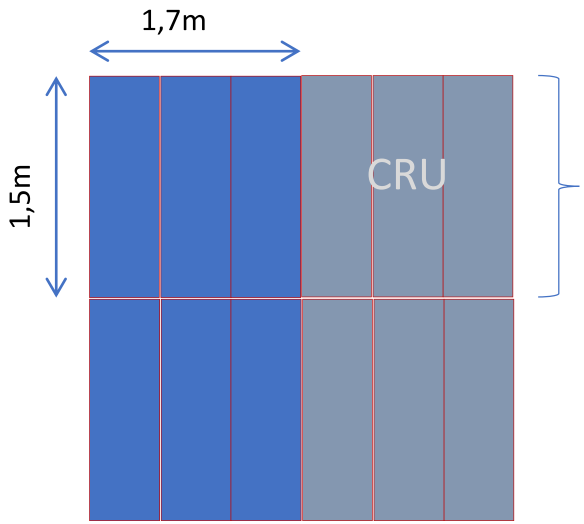
CRP= 3x3.375 m^2 readout units (anode)





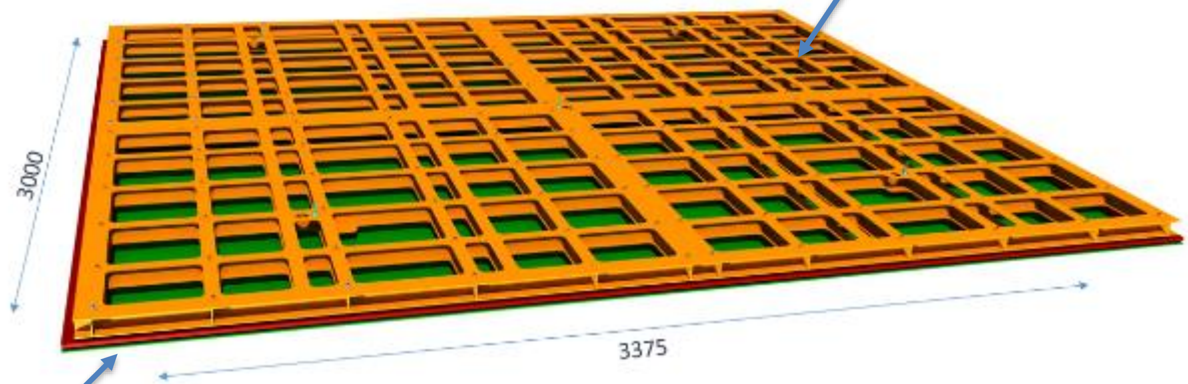


- ✓ 160 CRP units (80 on top, 80 on the bottom)
- ✓ Drift active volumes 2*5’265 m^3 = LAr 14.74 Ktons



4 charge readout units (CRU) compose a CRP

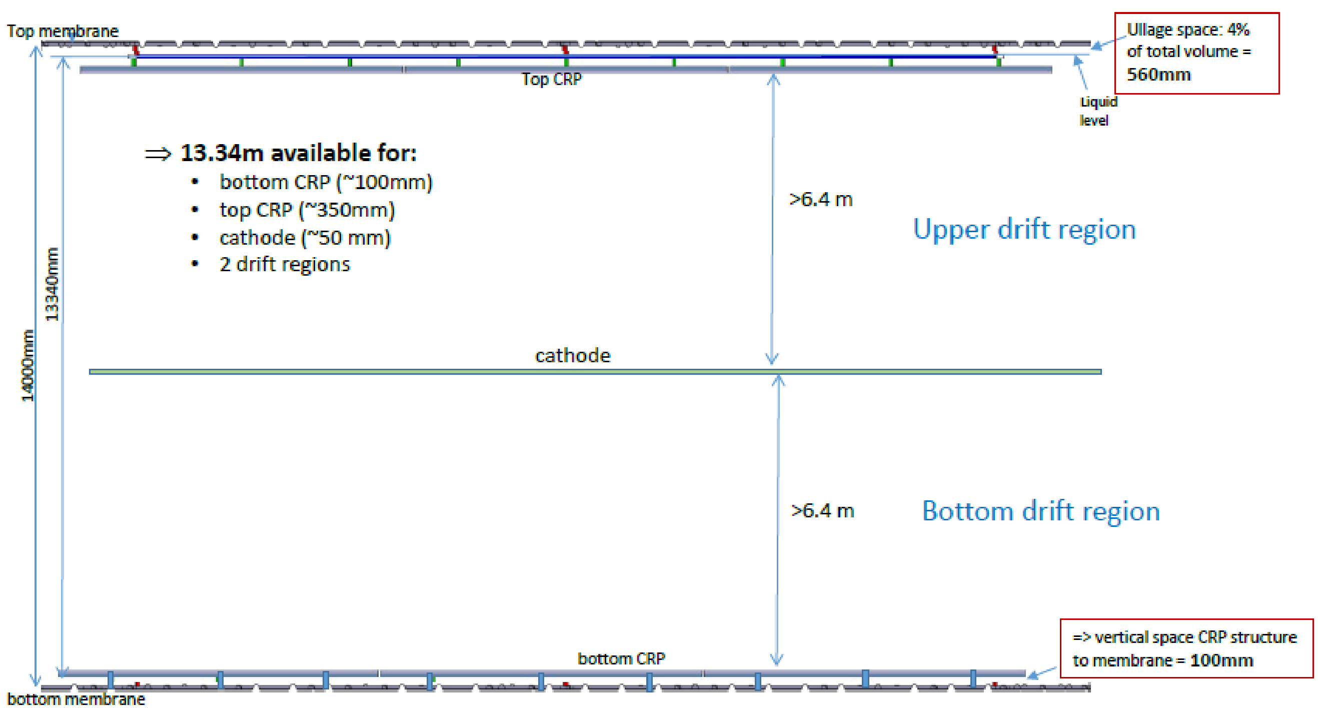
Structural PCB sandwich



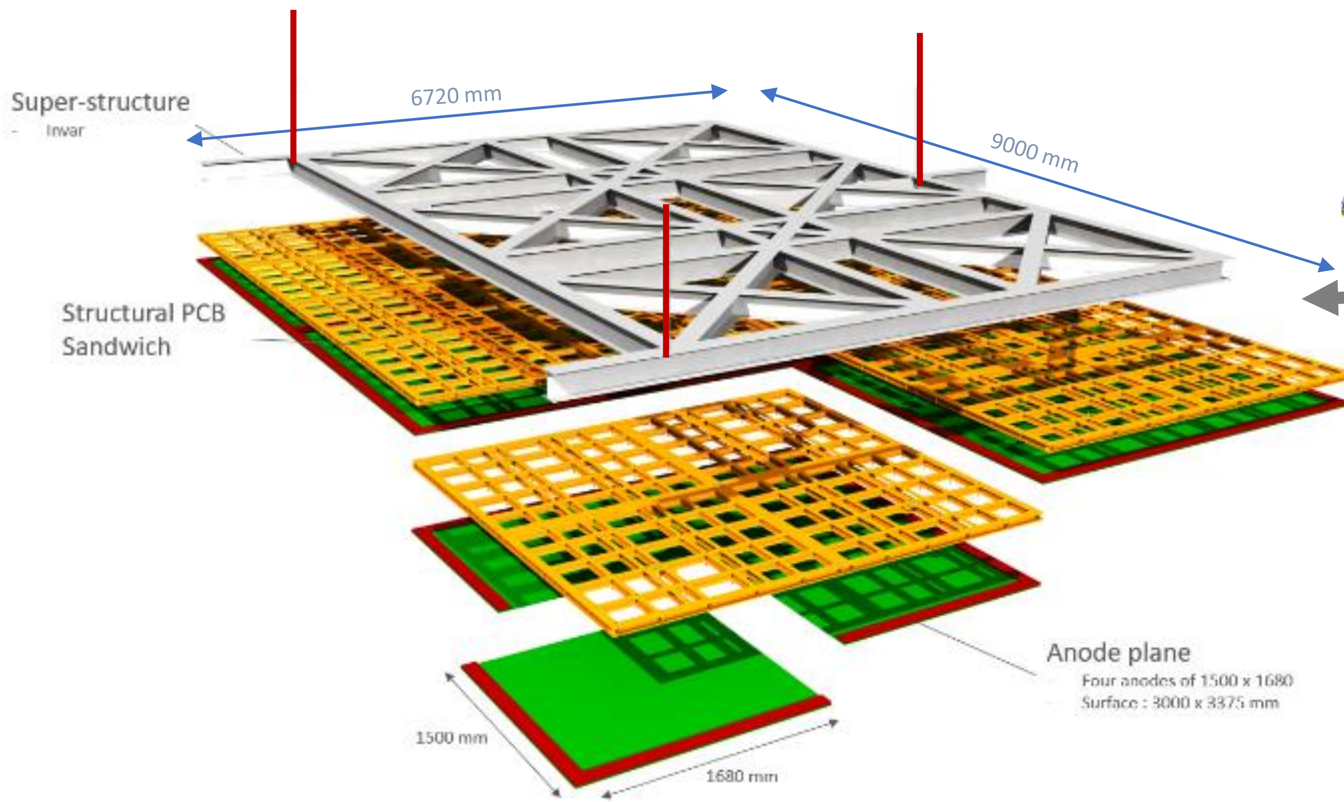
Perforated anode

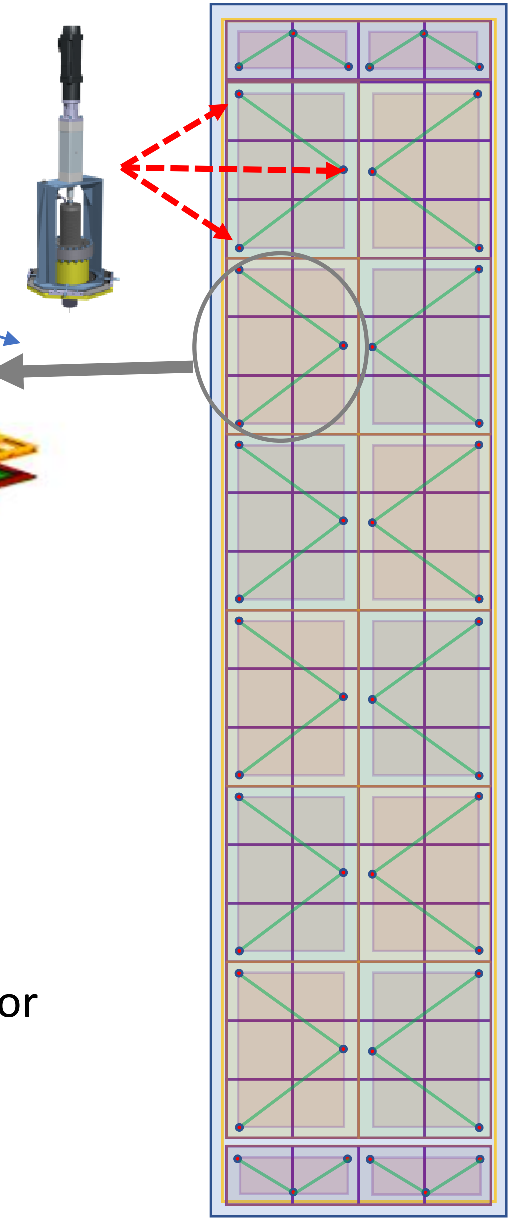
Same CRP units for Top and Bottom drift.
Each anode PCB unit (CRU) (1.5m x 1.7m) constructed by bonding 3 PCBs side by side

Vertical dimension range:



TOP drift CRPs hanging mechanical superstructures





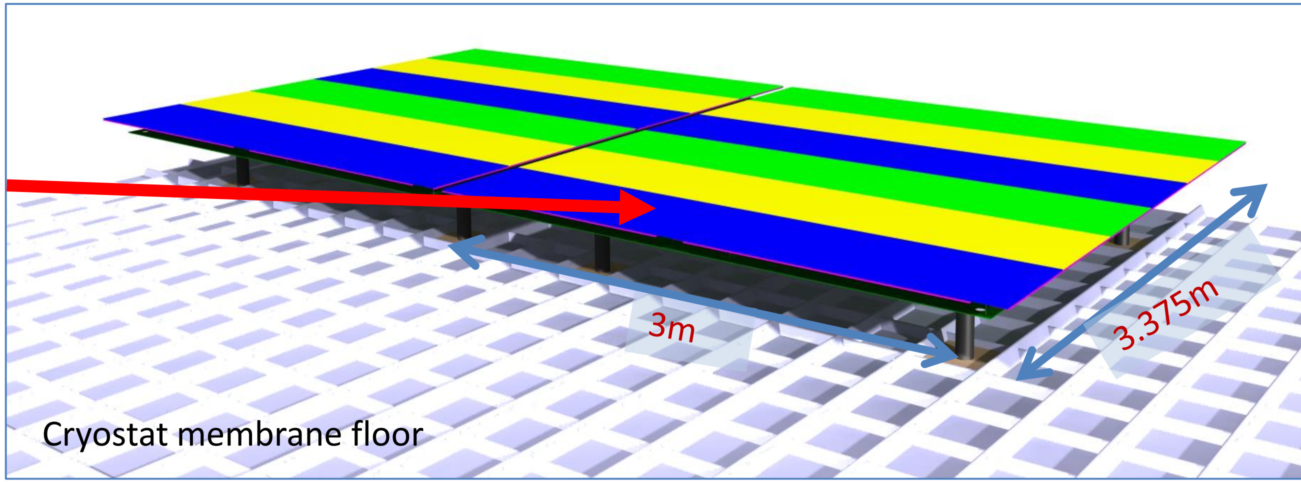
- Groups of 6 CRPs arranged in superstructures suspended from cryostat roof by 3 cables controlled with motors controlled like for dual-phase

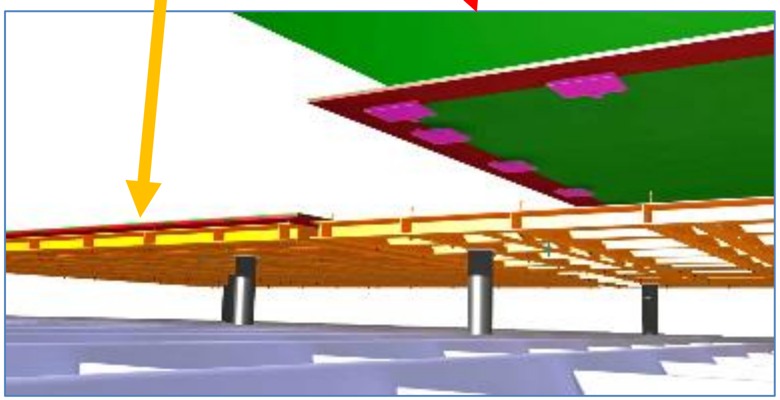
Anode planarity specification : +/-2,5mm @ cold

BOTTOM drift CRPs (simpler mechanical structures on cryostat floor)

Individual CRP structure identical to TOP drift

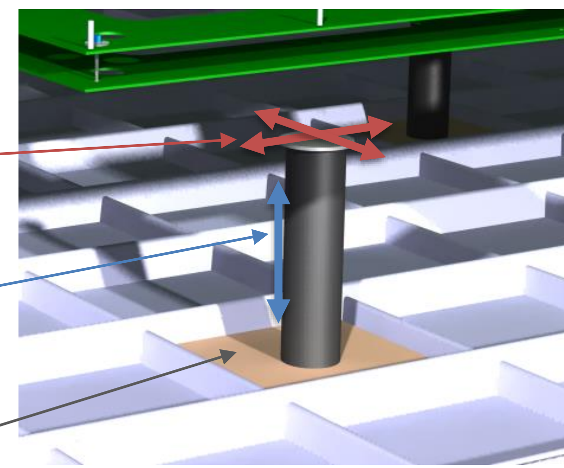
- **CRPs of 3000 x 3375 mm**
- **Consisting of 4 CRU anode planes**
- **Supporting PCB sandwich frame**





No metallic superstructure

Bottom CRPs positioning on adjustable feet



Lateral decoupling
(PTFE, bearing, …)

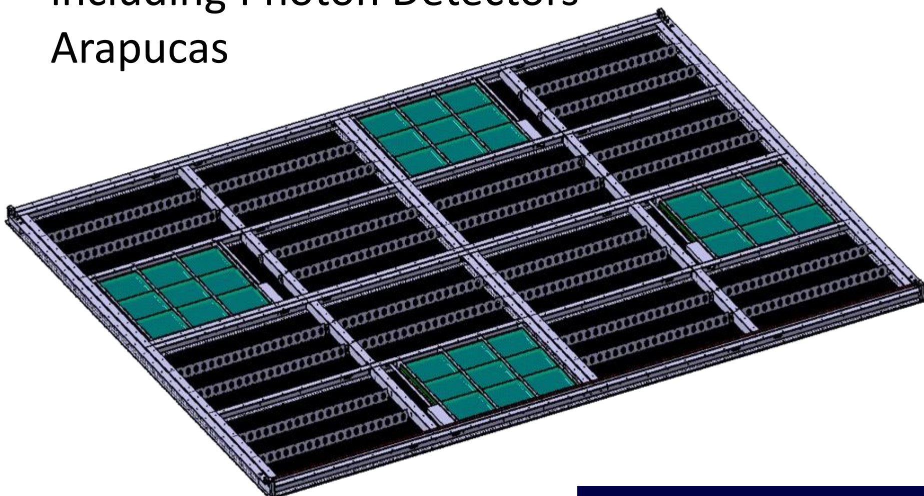
Vertical adjustment

Only laid on the membrane
No fixation, no sliding on the membrane

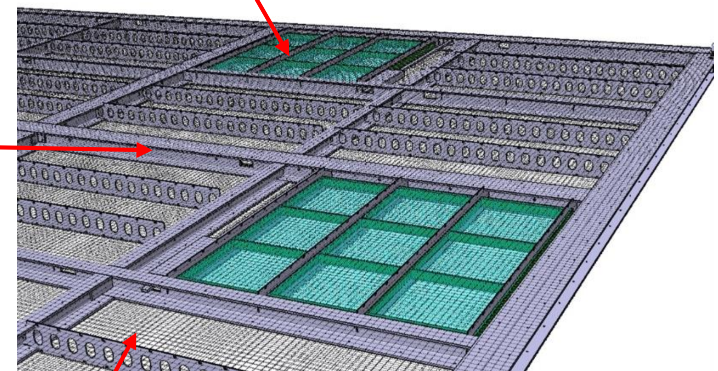
Cathode plane

Arapuca photon detector (as in SP)

Frame 3m x 3.375m, 58mm thick.
~110kg when fully equipped including Photon Detectors Arapucas



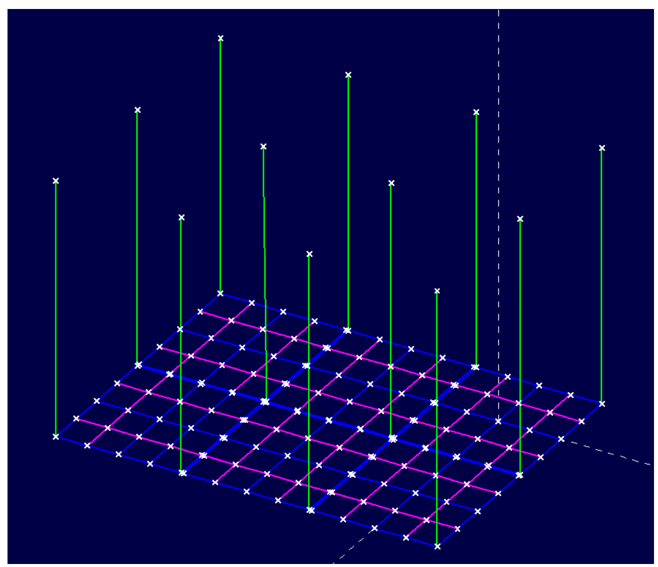
Polyester glass fiber 50mm height U/I profile



Few MOhm/square resistive coating/resistive bulk material replacing metallic mesh. Commercially available.

Super cathode (6 units) assembly suspended to SuperCRP by 16 points with 3mm dyneema (Kevlar) wires

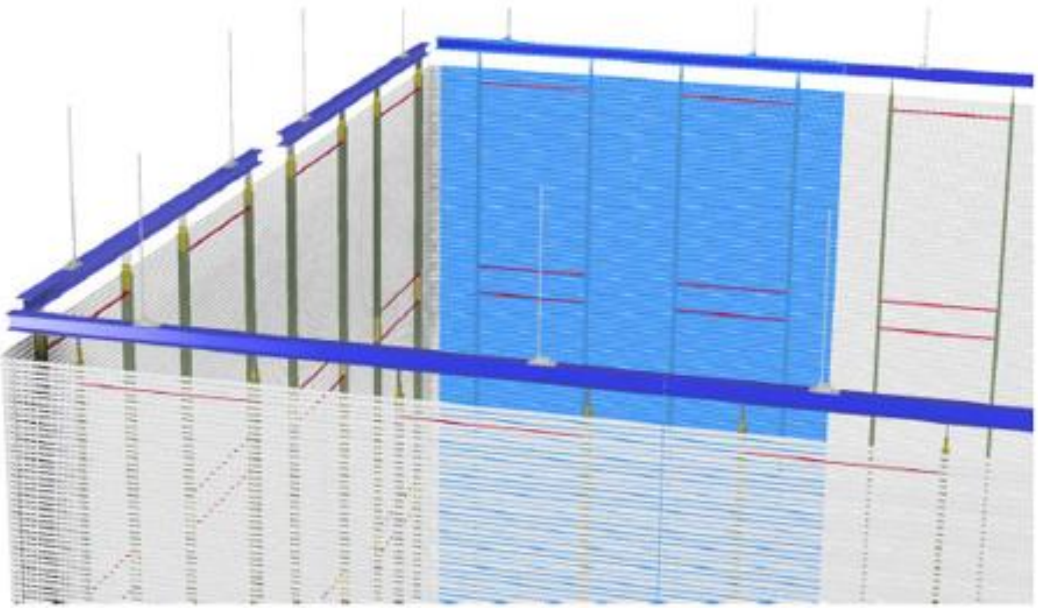
Planarity tolerance under load: 26mm max in air, <10mm max in LAr

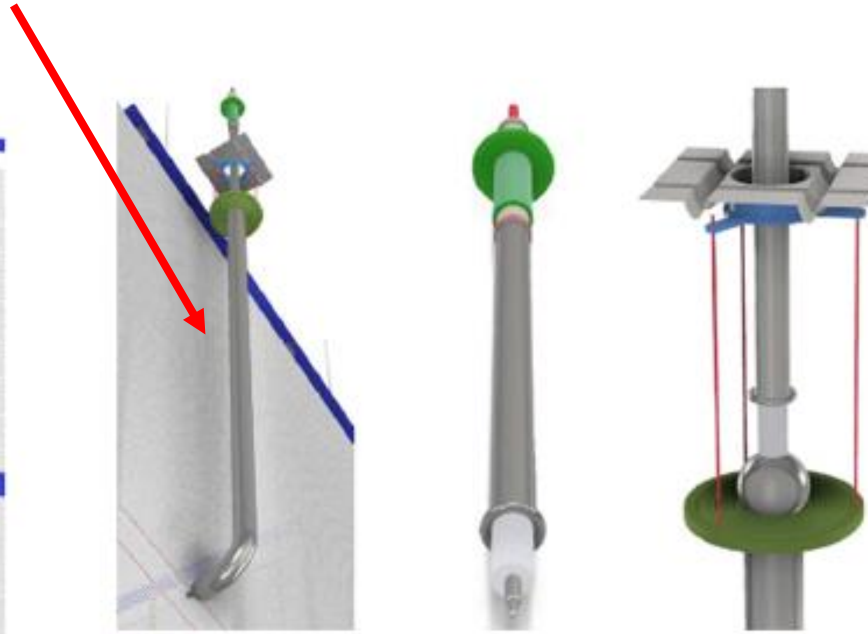


Total surface: 810m^2
Overall transparency to the LAr flow >50%
Full scale prototypes for test in preparation

Field cage and HV system

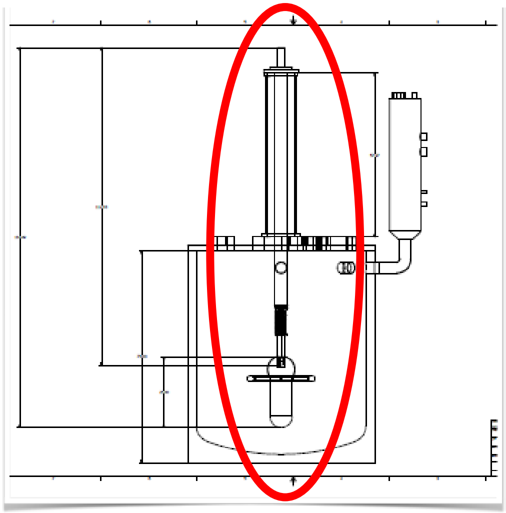
- ~300 kV applied to the cathode at the middle of the detector, max drift field ~6.5 m
- Field cage as in NP02 supported by DSS beams, using the same penetrations as bottom CRPs signals
- HV entering from the roof of the detector with a vertical penetration with the extender made with a simplified and more robust design compared to NP02: a simple round pipe of 20 cm diameter using LAr itself as insulator

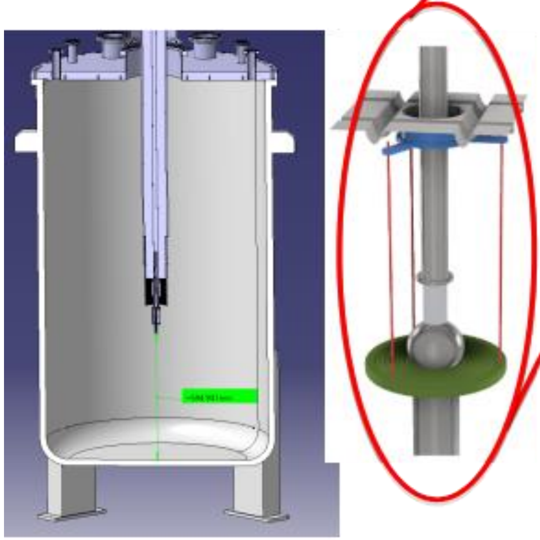


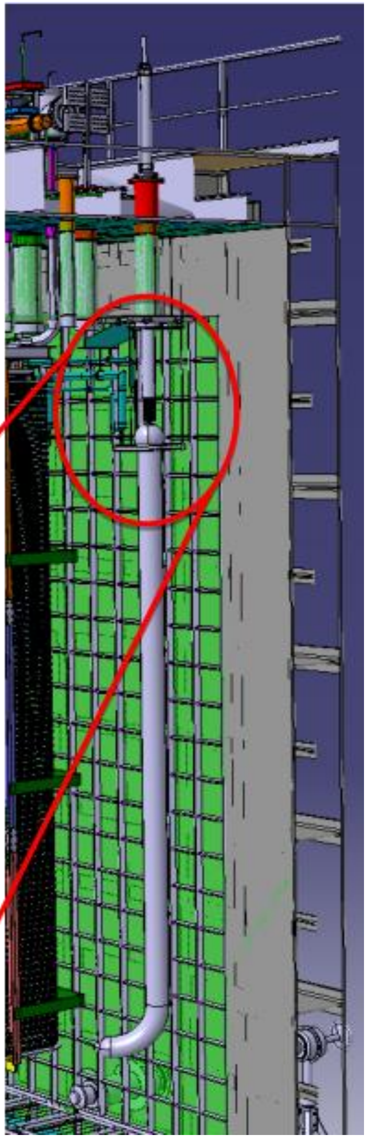


Staged validation activities of the improved design of the HV system for ~300 kV

- Dedicated tests of the improved High Voltage feedthrough design at CERN started in January 2021
- Full test of the upper section of the HV extender (the most critical part with the coupler to feedthough) organized at Fermilab (Iceberg cryostat). Completion by April 2021





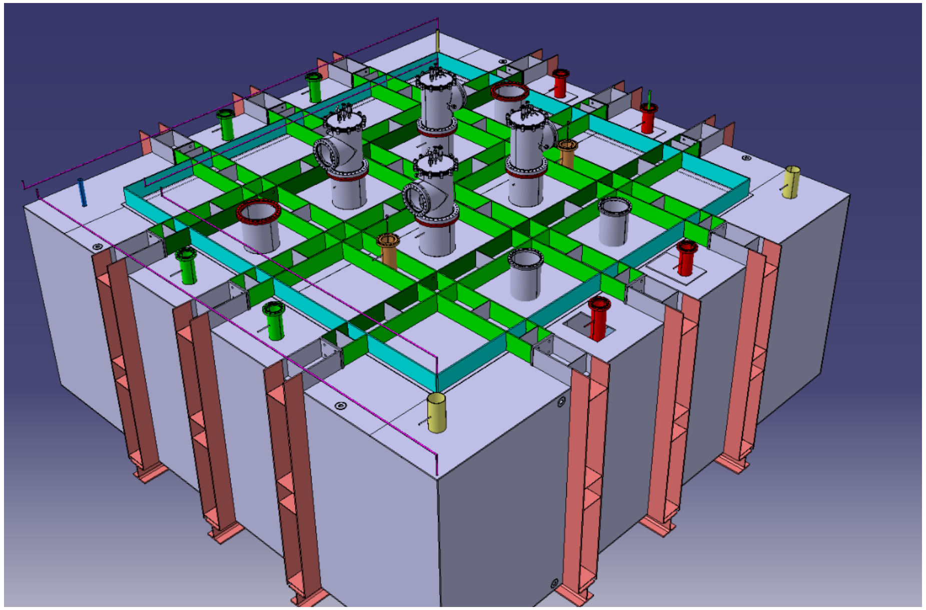


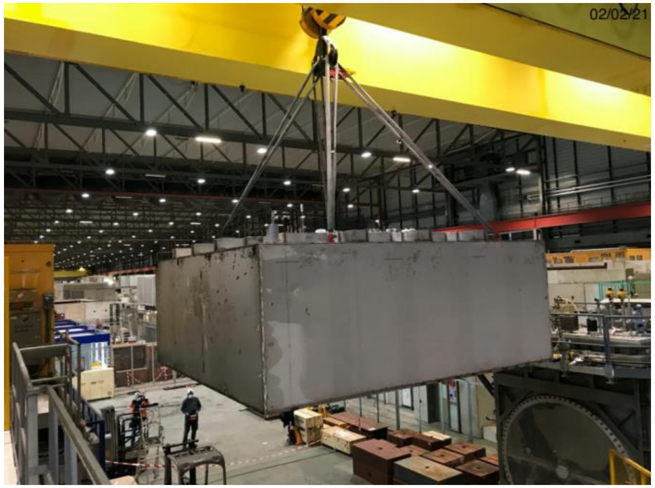
- Full scale HV integration test in NP02 (with Proto-DUNE-DP field cage/cathode) Fall 2021

→ complete test of the HV system, LAr to be moved from NP02 to NP04 in 2022

Cold-box preparation for the tests in 2021

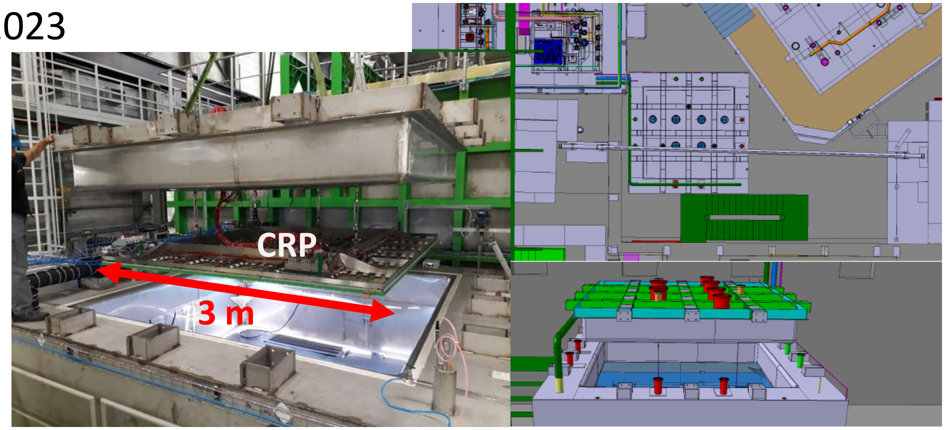
- Cold-box used in 2018 for DP CRPs tests moved from Bld-182 to EHN-1
- Mechanical reinforcements, top-cap modifications has started (additional feedthroughs for electronics and HV)
- Cold box modifications will be completed in May
- Cryogenic modifications to achieve necessary purity (~0.5 ppb, ~600 us) will be completed by July





Vertical-Drift 2021 activities at the CERN Neutrino Platform in 2021

- Substituting the already planned DP Phase II tests activities foreseen with the cold-box built in 2018 for individual CRP tests. → Cold-box modified and upgraded from the DP configuration and moved to EHN1.
- Parallel tests of new simplified HV extender design in ProtoDUNE dual-phase/NP02.
- Continuation of the cold-box tests campaign in 2022 to define final CRPs for module-0
- Module-0 operation in NP02 cryostat foreseen in 2023



➢ **Cold-box tests of new CRPs**

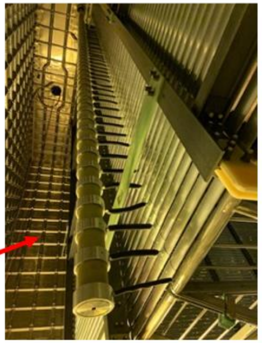
- Dual-phase cold box refurbished and installed at EHN1 side by side to NP02 by April 2021
- Since June 2021 integration at CERN of all components and commissioning
- First cold-box cycle of a CRP since the end of September 2021
- Tests activity continued in 2022 in preparation for Module-0

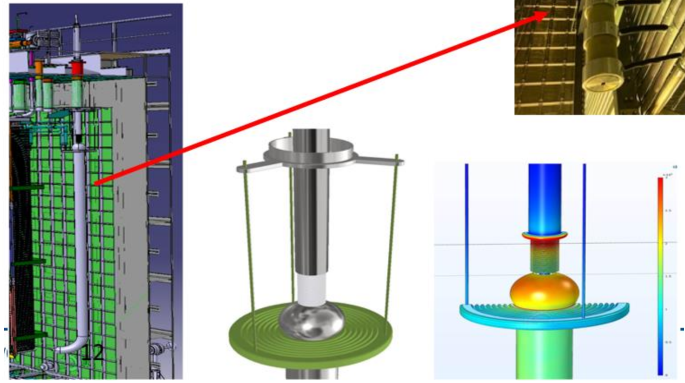
➢ **protoDUNE-DP/NP02 HV test:**

- Access to NP02 after warming up February 2021
- Removal and insertion of new HV extender March-June 2021
- Cool-down and filling of NP02 July-August 2021
- Operation and HV test September-November 2021

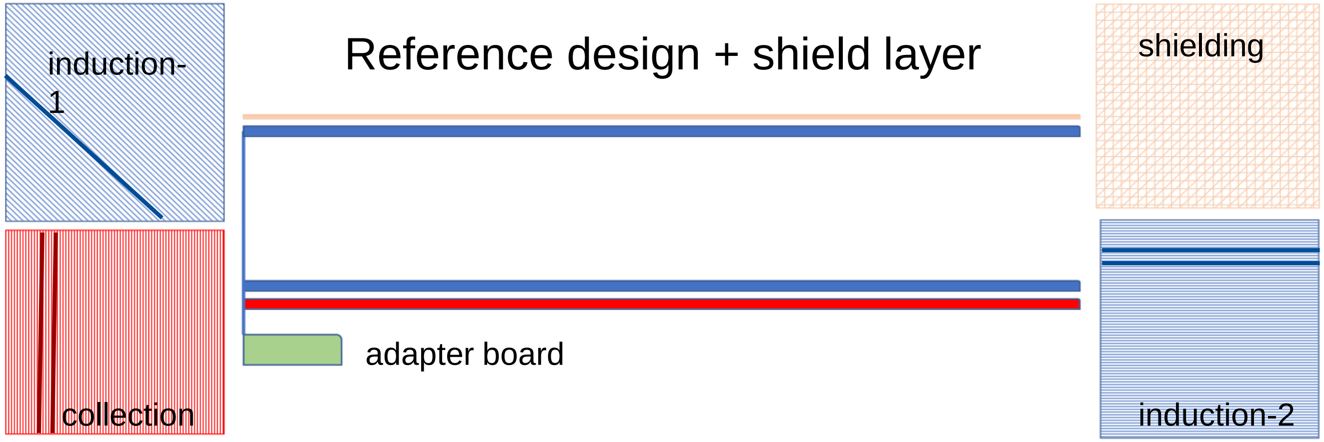
300kV test in NP02

✓ New HV system (300KV supplier, feedthrough, extender, DAQ, ..)
✓ Fill NP02 and get purity
✓ 2-3 months operation
✓ No need to open the cryostat, insertion via man hole

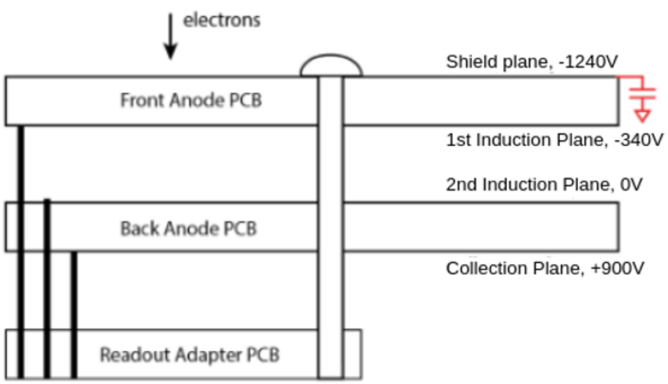


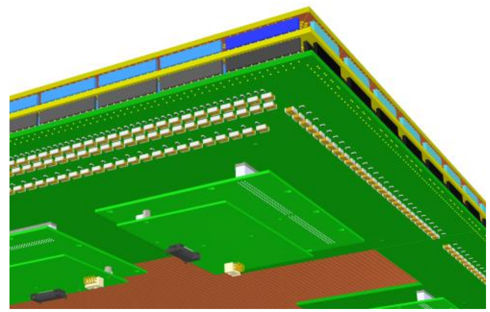


Anode PCB for the first cold-box tests in 2021

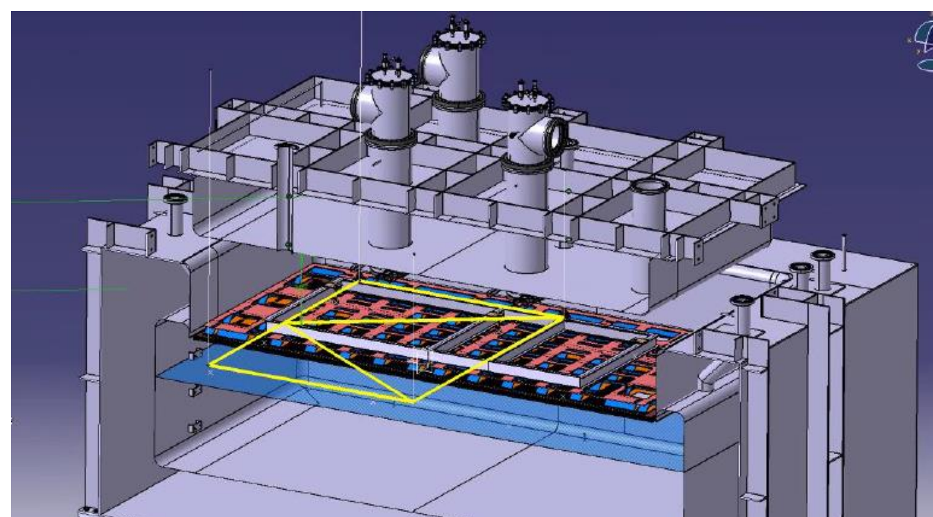


Induction-1: -48 degrees
Induction-2: 0
Collection : 90 degrees

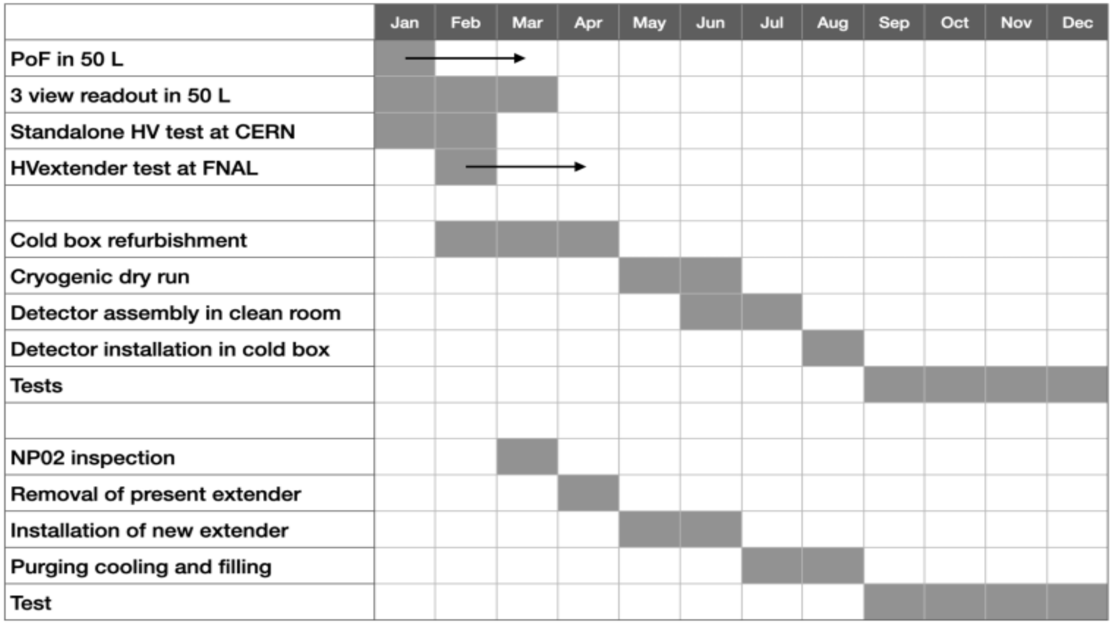




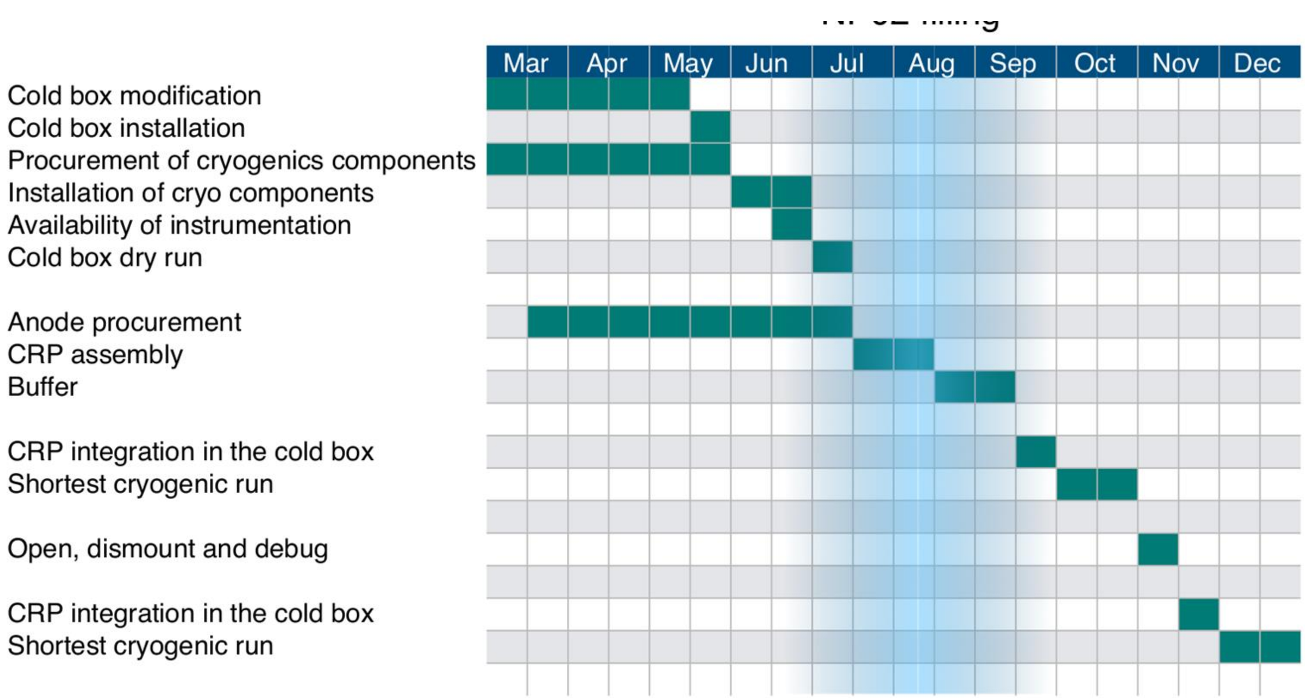
Configuration allowing assessing simultaneously the 2views and 3views performance in the same anodes setup to be used for the first CRP tests in 2021



Overall schedule in 2021:



Cold-box schedule in 2021:



Conclusions:

Since the SPSC annual report of April 2020, despite the sanitary situation due to the Covid-19 outbreak, we had a very intensive working period with rapid progress in:

- ✓ Completing the foreseen operation program of ProtoDUNE dual-phase, following expected schedule.
- ✓ Advancing on stand-alone tests and validations on small prototypes for dual-phase, VD perforated anodes and HV components.
- ✓ Evolving the dual-phase design to Vertical Drift the basis of the operation experience, lessons learned and new developments → This turns into a simplified and more robust CRP design based on the perforated anodes and included an improved design of the HV extender, based on the acquired experience.
- ✓ Defining detailed engineering aspects of the DUNE far detector module on the basis of the vertical drift design, which has already passed several reviews and it is now the preferred choice of the DUNE collaboration for the second far detector module
- ✓ Redefining the NP02 phase-II experimental activities and cold-box tests program (2021-2023) to support the integrations tests for the Vertical Drift with a staged program which is now a crucial step of the path to the second DUNE Far Detector module.

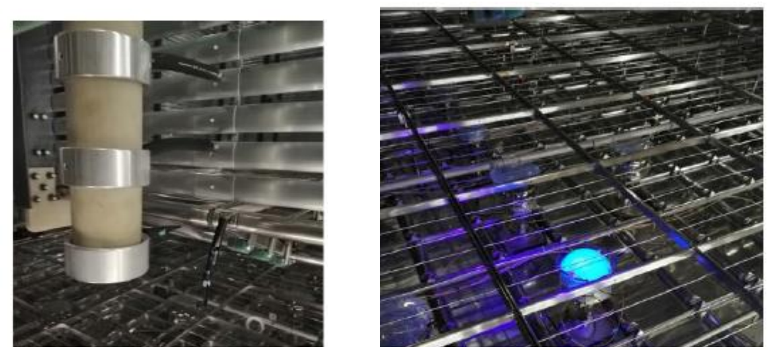
NP02 Cryostat inspection via man-hole: (February 2021)

List of verifications defined in September 2020:

- Collection of samples of contamination (dust/filaments) inside the cryostat particular (care in accessing without shuffling the dust material around)
- Presence of material in the recirculation filter
- Status of TPB coating on coated PMTs
- Status of the resistors connecting the extender to the cathode
- Status of the extender surface in the region where sparking occurred
- Presence on material trapped in the CRP grids
- Presence of spark traces connected to grids sparking
- Presence of spark traces connected to LEMs sparking and other signs of LEMs deterioration (carbonization spots)
- Status of the tension of the grid wires and status of the CRP structure

→ Observations and collections of samples, high resolution pictures of the CRPs taken from the floor of the cryostat

FIG. 1: Photos of different type of dust observed and collected on the NP02 cryostat floor.



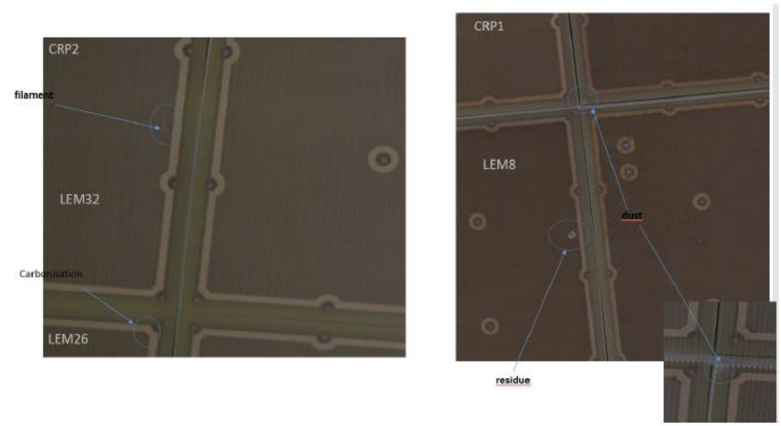
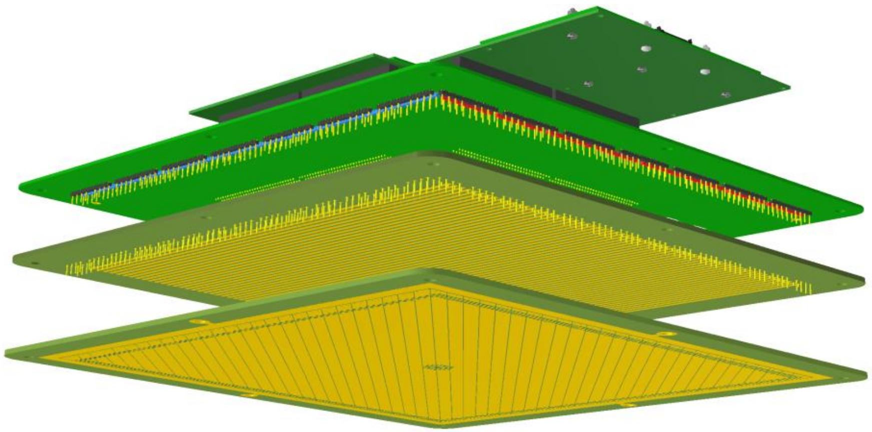
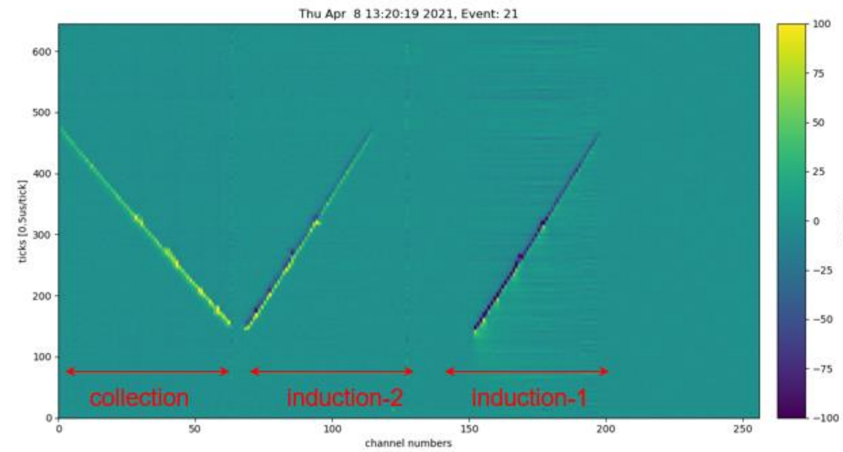
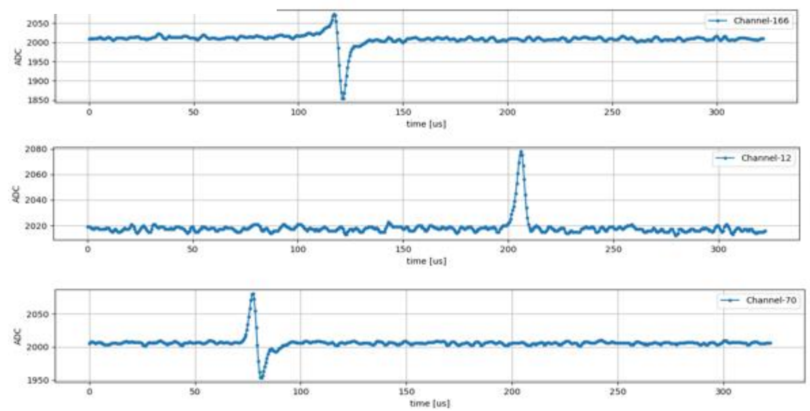


FIG. 4: Photos of LEMs and grids of both CRPs having elements between the extraction grid and the LEM surface as well as some evidence of carbonisation spot.

Perforated anodes tests at CERN Neutrino Platform with the 50l TPC test stand (recent 3 views test)



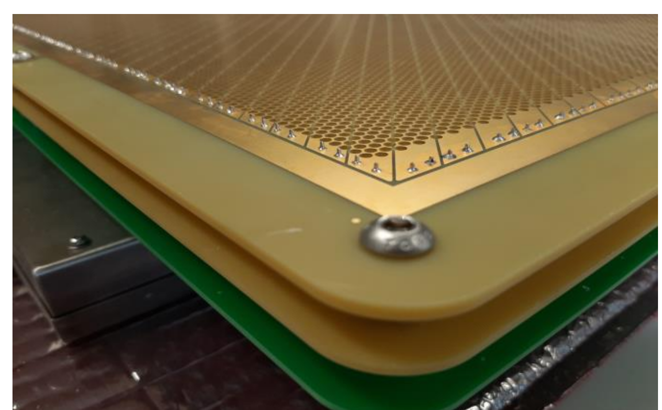




induction-1

collection

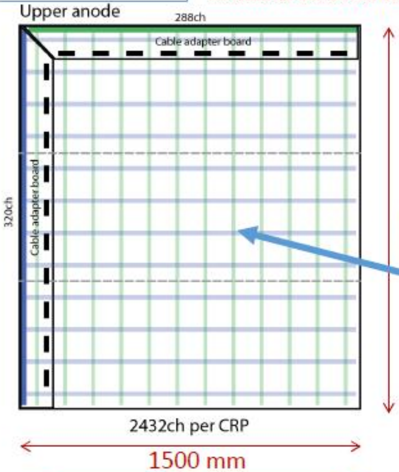
induction-2

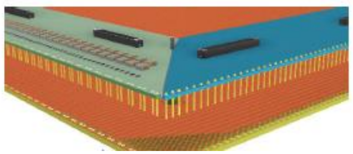


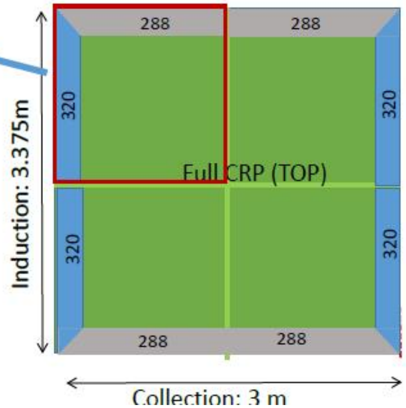
Anode electronics and Adapter Boards

¼ of a CRP (TOP)

Readout electronic identical to Dual Phase

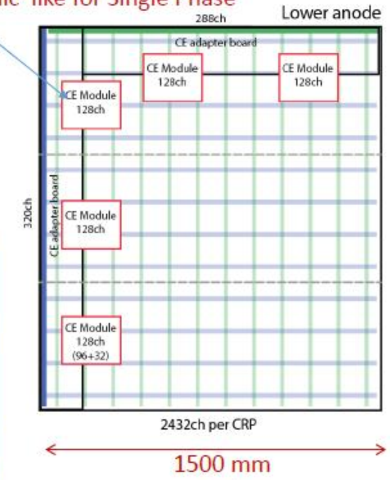


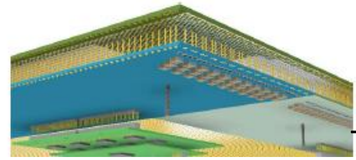




¼ of a CRP (Bottom)

Cold electronic like for Single Phase

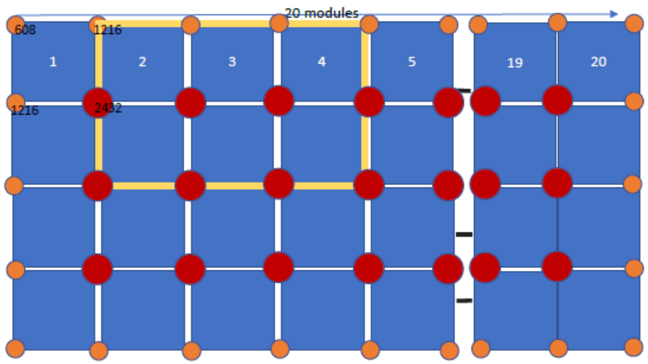




Top drift electronics from Dual-Phase design

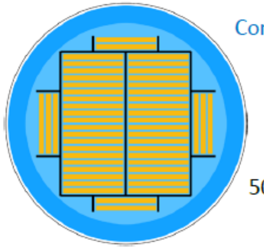
Upper Electronic Feedthroughs

Top chimney topology: connexion at each CRP corner



Total 105 feedthroughs

The peripherical one can be of smaller radius!



Connexion similar to DP C

50 cards can fit inside!

Pipe internal diameter : 48 cm