DUNE status

D. Autiero

IP2I Lyon

IRN Neutrino meeting June 10-11 2021

Much more details at the DUNE TGIR kick-off meeting: https://indico.in2p3.fr/event/24119/

DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE TGIR kick-off meeting

25-26 mai 2021

Fuseau horaire Europe/Paris

- Accueil
- Ordre du jour
- Liste des contributions
- Inscription
- Liste des participants

Contacts

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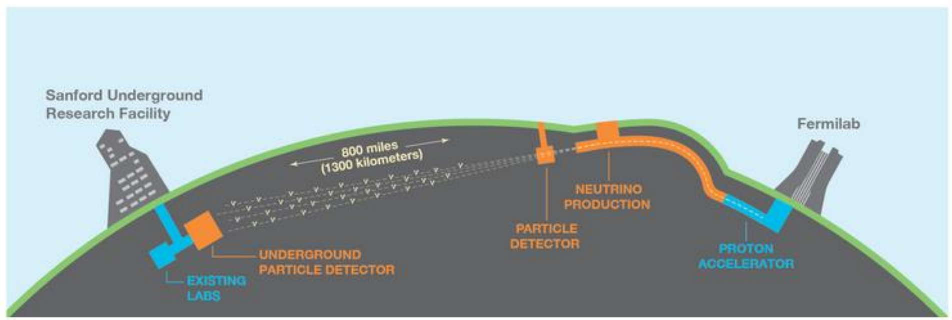


This meeting represents the official kick-off event of the IN2P3 TGIR project for the DUNE 2nd Far Detector module.

The meeting is by remote attendance only (ZOOM). Connection instructions will be distributed by e-mail to the registered participants.

The public kick-off event on May 25th afternoon (15:00-18:30), see the agenda on this page, will be followed by a discussion session on internal organization aspects, to be attended by the IN2P3 collaborators, on the morning of May 26th:

15:00 → 16:25 DUNE TGIR kick-off meeting: Session 1
Président de session: Dario Autiero (IP2I)

15:00 **Welcome** 10m
Orateur: Reynald Pain (IN2P3)

15:10 **The TGIR program for DUNE** 20m
Orateur: Laurent Vacavant (IN2P3)
Intro_DUNE_IN2P3_...

15:35 **Status of the LBNF project** 20m
Orateur: Chris Mossey (Fermilab)
Mossey - LBNF Stat...

16:00 **DUNE physics goals, organization and status** 20m
Orateur: Gina Rameika (Fermilab)
IN2P3_DUNE_V3.pdf

16:25 → 16:35 DUNE TGIR kick-off meeting: Break and group picture
Président de session: Laurent Vacavant (IN2P3)

16:35 → 18:30 DUNE TGIR kick-off meeting: Session 2
Président de session: Laurent Vacavant (IN2P3)

16:35 **The DUNE IN2P3 project and the evolution from the dual-phase to Vertical Drift** 20m
Orateur: Dario Autiero (IP2I Lyon)
TGIR_IN2P3_project...

17:00 **Vertical Drift detector overview** 20m
Orateur: Dominique Duchesneau (LAPP CNRS/IN2P3)
VD-detector-Kickoff... VD-detector-Kickoff...

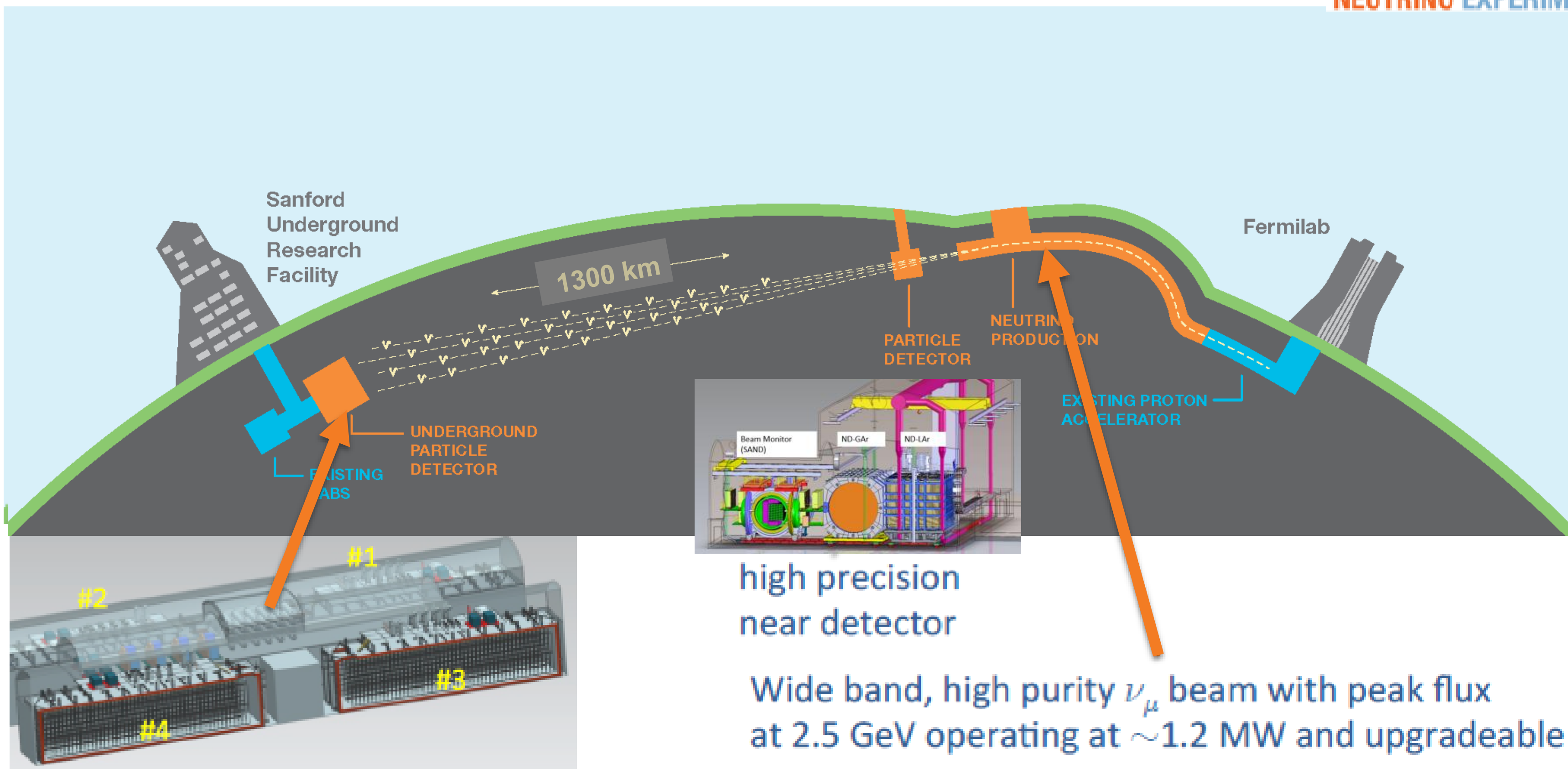
17:25 **The CERN Neutrino Platform and support to Vertical Drift test activities** 20m
Orateur: Marzio Nessi (CERN)
21-05-25-CERN-Nu-...

17:50 **The path to the Vertical Drift module: milestones and schedule** 20m
Orateur: Steve Kettel (BNL)
DUNE-TGIR_Kickoff...

18:15 **Conclusions** 5m
Orateur: Laurent Vacavant (IN2P3)

Overall Experimental Layout

DEEP UNDERGROUND NEUTRINO EXPERIMENT

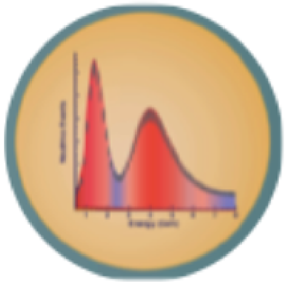


Wide band, high purity ν_μ beam with peak flux at 2.5 GeV operating at $\sim$1.2 MW and upgradeable

- four identical cryostats deep underground
- staged approach to four independent 10 kt LAr detector modules
- Single-phase and double-phase readout under consideration

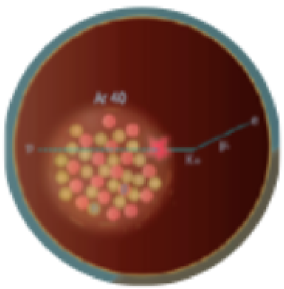
Beam 1.2 – 2.4 MW
40 kton Far Detector mass

The Primary DUNE Scientific Goals



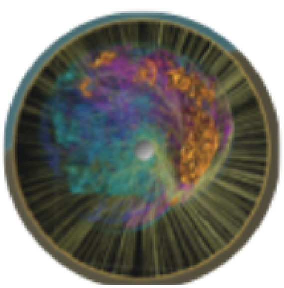
Neutrino oscillations

- CP violation in the ν sector
- Neutrino mass hierarchy
- Precision oscillation measurements
- Testing of 3ν paradigm



Proton decay

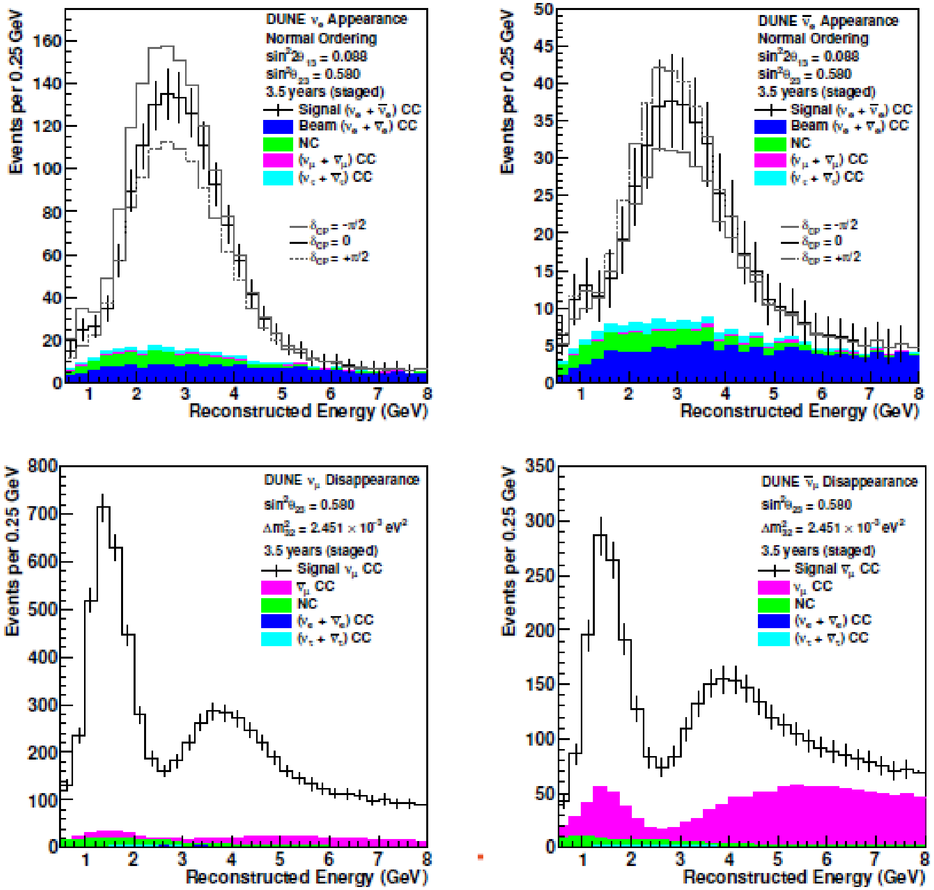
- Predicted by BSM theories, but not yet seen
- Unique sensitivity to SUSY-favored modes ($p \rightarrow \bar{\nu} K^{+}$)



Supernova neutrinos

- Neutrino burst from galactic core-collapse supernova
- Unique sensitivity to supernova ν_e's

What can we measure?

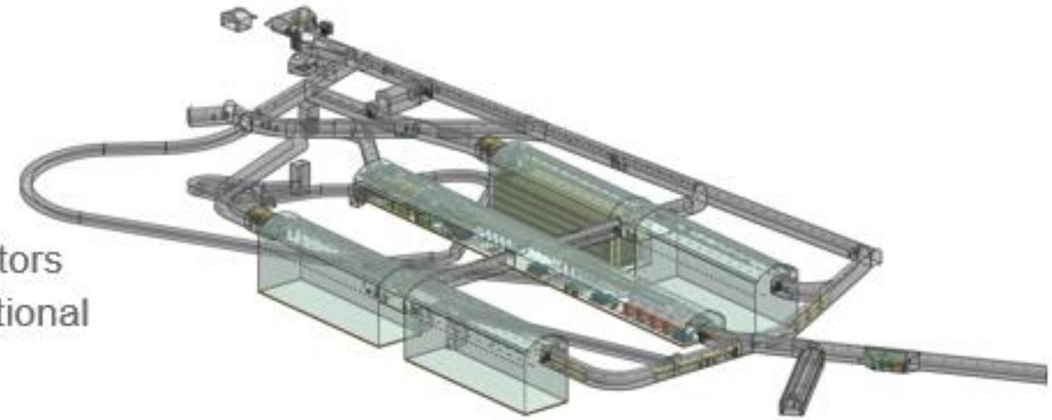


	Expected Events (3.5 years staged)
ν mode	
ν_μ Signal	6200
$\bar{\nu}_\mu$ CC background	389
NC background	200
$\nu_\tau + \bar{\nu}_\tau$ CC background	46
$\nu_e + \bar{\nu}_e$ CC background	8
$\bar{\nu}$ mode	
$\bar{\nu}_\mu$ Signal	2303
ν_μ CC background	1129
NC background	101
$\nu_\tau + \bar{\nu}_\tau$ CC background	27
$\nu_e + \bar{\nu}_e$ CC background	2

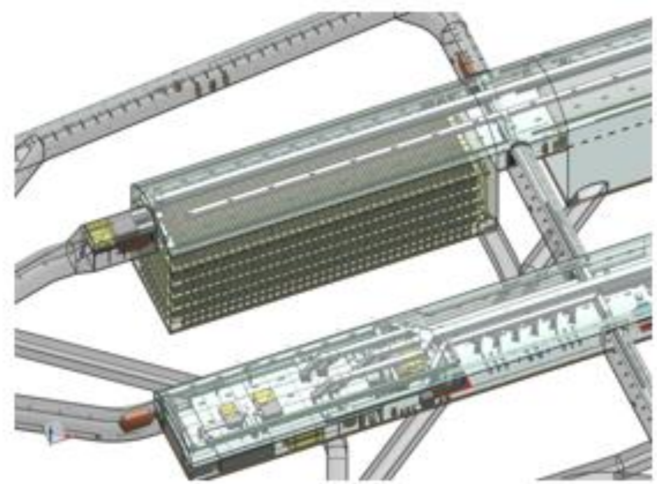
https://lbnf-dune.fnal.gov/

Overview – "Far Site" – LBNF at Sanford Lab, Lead, SD

- **Conventional Facilities:**
  - Surface and shaft Infrastructure including utilities
  - Drifts and two caverns for detectors
  - Central utility cavern for conventional and cryogenic equipment
- **Cryostats:**
  - Four membrane cryostats supported by external steel frames
- **Cryogenic Systems:**
  - LN2 refrigeration system for cooling and re-condensing gaseous Argon
  - Systems for purification and recirculation of LAr
- **Argon:**
  - 70kt LAr (~40kt "fiducial" mass)



4850L caverns and drift layout



Single cryostat and portion of central utility cavern

LBNF facilities will support DUNE experiment

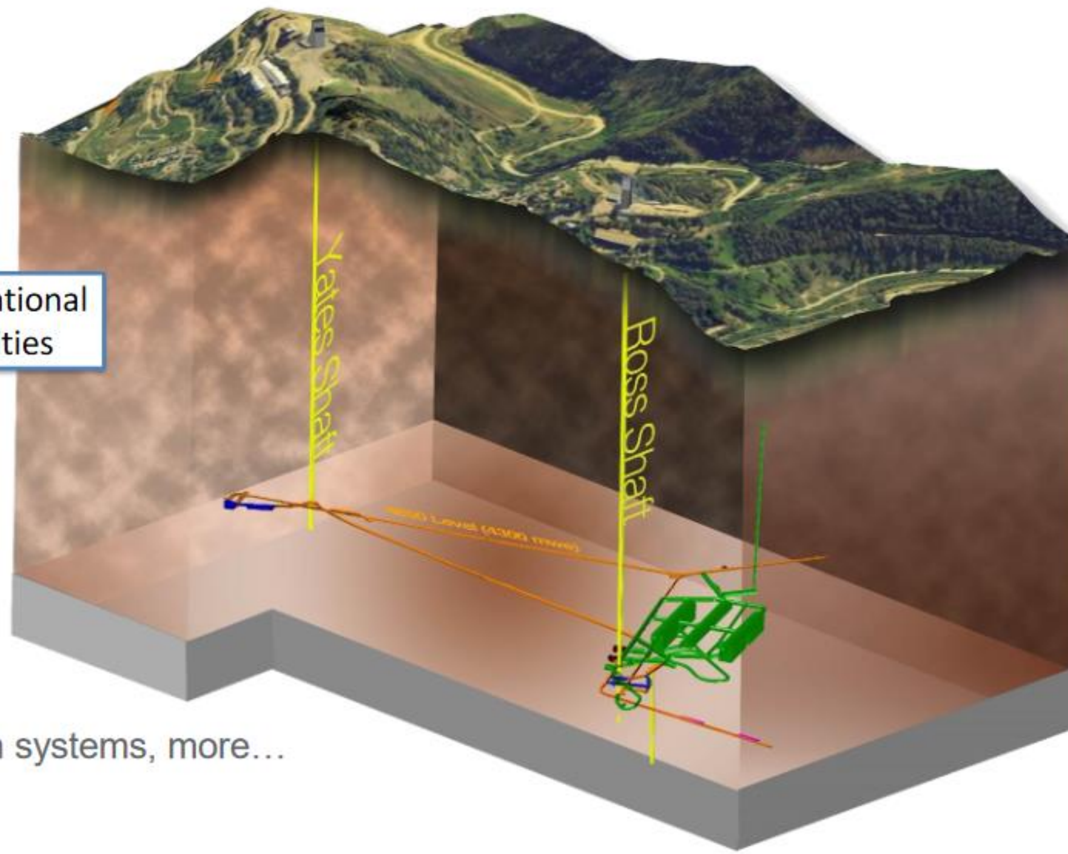
➢ **LBNF CD-3a 2016 – Approval of Initial Far Site Construction by DOE**

Far Site – LBNF Phases of Work

1. **Reliability Projects**
   - Ross shaft rehabilitation
   - Hoist motor replacement, new drives, brakes, clutches, more…
2. **Pre-Exc Construction**
   - Rock disposal systems
   - Ross headframe upgrade, sub-station upgrade, more…
3. **Exc & Surface Construction**
   - Brow enlargement, drifts, central utility and detector caverns, more…

Conventional Facilities

4. **Cryostats/Cryogenic Systems**
   - Cryostats
   - Nitrogen refrigeration and Argon purification systems, more…
5. **Detector Installation**



Far Site Conventional Facilities Status

Reliability Projects

- ✓ Refuge Chamber Capacity Increase
- ✓ Oro Hondo Fan VFD Replacement
- ✓ Ross Crusher Roof Replacement
- ✓ Ross Shaft Cage Replacement
- ✓ Ross Shaft Skips Replacement
- ✓ Ross Hoist Motor Replacement
- ✓ Ross Hoist Bearing/Bushing Refurb
- ✓ Ross Hoist Mech/Electrical Components Upgrades
- ✓ Ross Shaft Rehabilitation

Renovation of Ross Shaft in progress, with old and new structural steel sets visible.

Reliability work started in 2012 with the start of renovation of the 1.5km deep Ross shaft

Far Site Conventional Facilities Status

Pre-Excavation Scope

- ✓ Empty & Repair Ore Pass
- ✓ Replace Skip Loading System
- ✓ Replace/Restore Rock Crushing System
- ✓ Rehabilitate the Existing Tramway
- ✓ Install New Conveyor System
- ✓ Install additional Electrical Capacity at Ross Substation
- ✓ Structural Reinforcement of Ross Headframe
- ✓ Install Shaft Utilities
- ✓ Early Ventilation Improvements

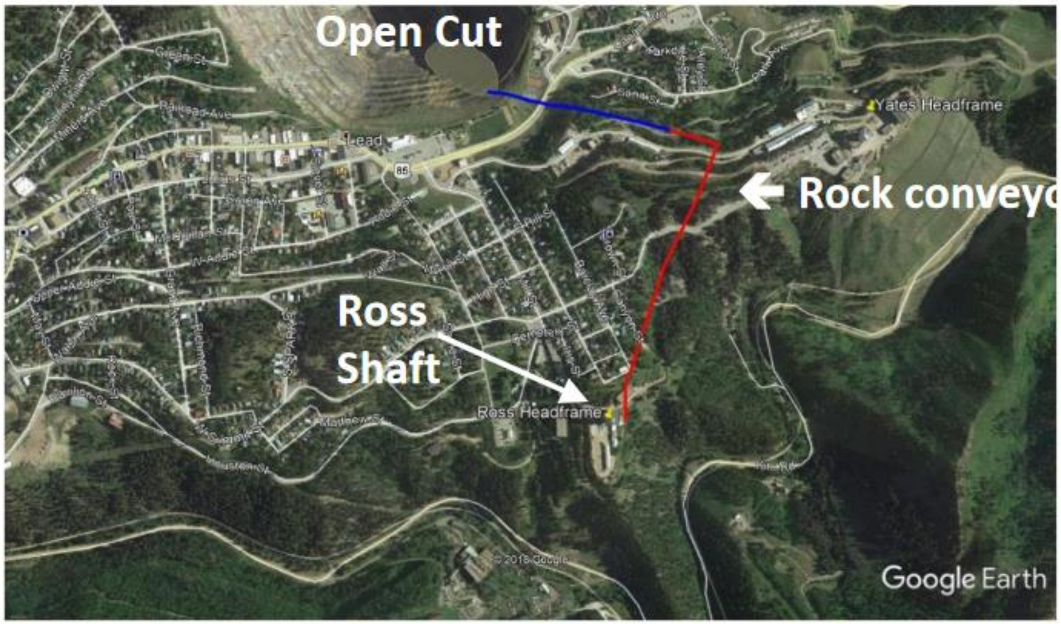
Groundbreaking for pre-excavation work was held in August 2017

LBNF Groundbreaking held at 4850L (1.5km underground) at Sanford Lab. Participants included:

- International funding agencies: CERN, INFN, and STFC
- Congressional delegation and the Governor of South Dakota
- Executive Office of the President (Michael Kratsios, OSTP) and DOE
- Fermilab and Sanford Lab

Rock Conveyor for Cavern Excavation Work

- ✓ 1280m long conveyor to move excavated rock from rock crusher at the top of Ross Shaft to the Open Cut in Lead, SD for disposal.



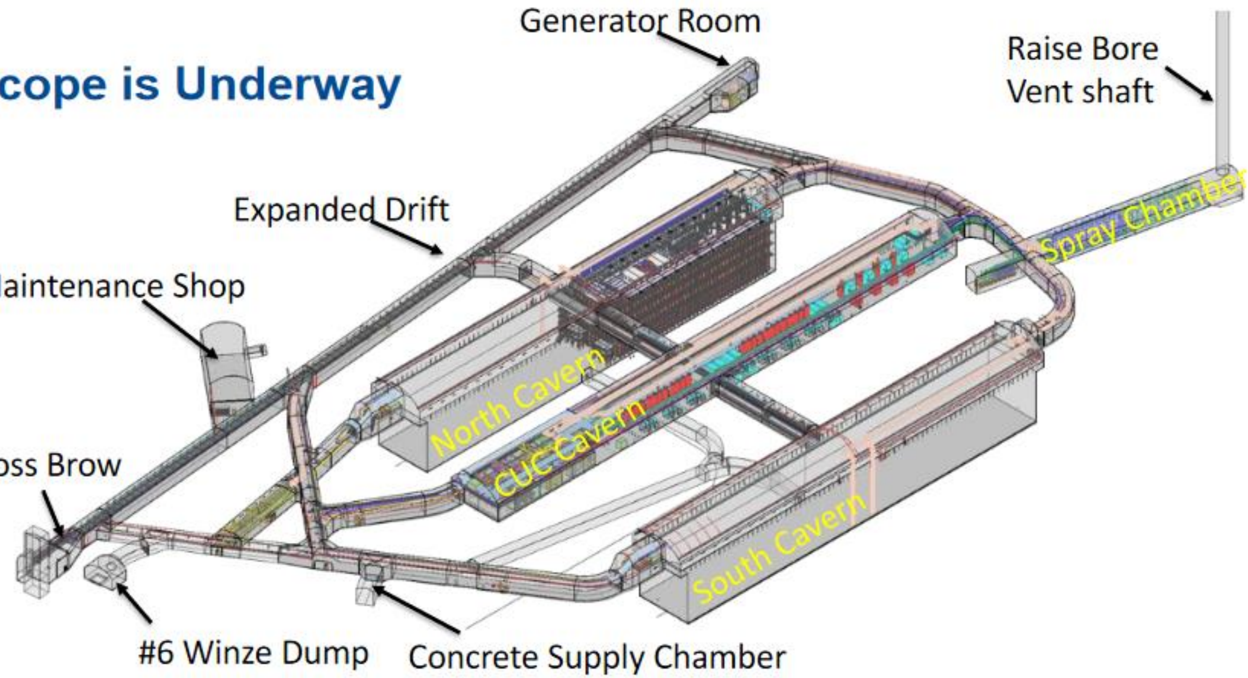
20 25 May 2021 C. J. Mossey | Status of the LBNF Project LBNF/DUNE

Commissioned in April/May with a stress test at 450 tons/h, design max 390 tons/h, Normal operation expected at <200 tons/h

Final contract for main excavation of the caverns assigned to Thyssen Mining Inc. 20/10/2020
→ Start of main excavation: April 2021. Major milestone achieved !

Main Cavern Excavation Scope is Underway

- Main excavation contract started work on 5 April; planned for 36 months
  - Approximately 800,000 tons of rock to be excavated to create 17,000 m^3 floor area
    - ~24 months for blasting and rock removal to create drifts and caverns
    - ~12 months for concrete base, cryostat foundation, cranes, hoists, etc.
- Then start to install cryostats and complete utility systems; contracts planned for award in 2023 – 2024 timeframe.

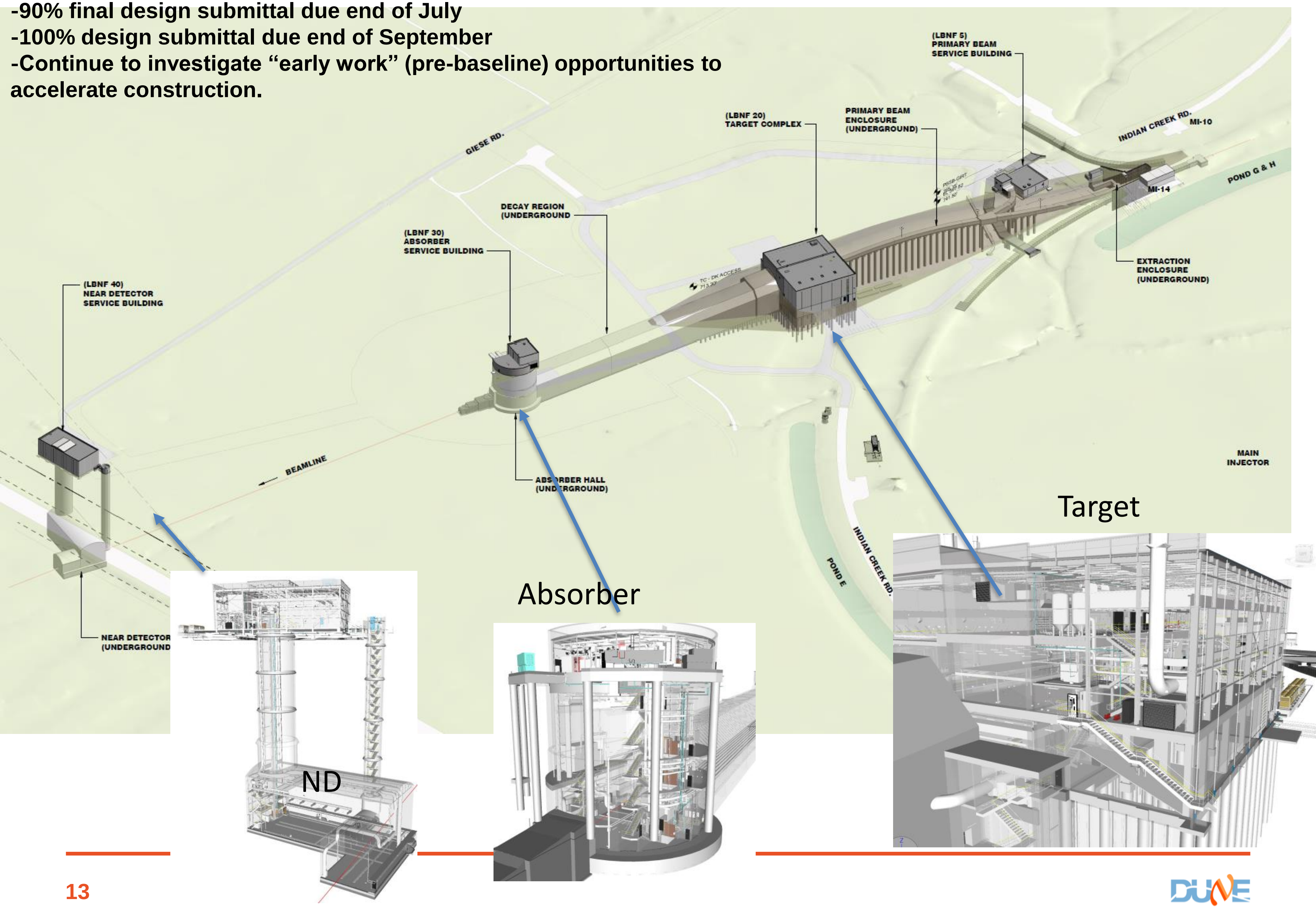


2 x Detector Caverns:
145m L x 20m W x 28m H

1 x Central Utility Cavern (CUC):
190m L x 20m W x 11m H

23 25 May 2021 C. J. Mossey | Status of the LBNF Project LBNF/DUNE

Near Site Conventional Facilities design now ~80% complete.
-90% final design submittal due end of July
-100% design submittal due end of September
-Continue to investigate "early work" (pre-baseline) opportunities to accelerate construction.



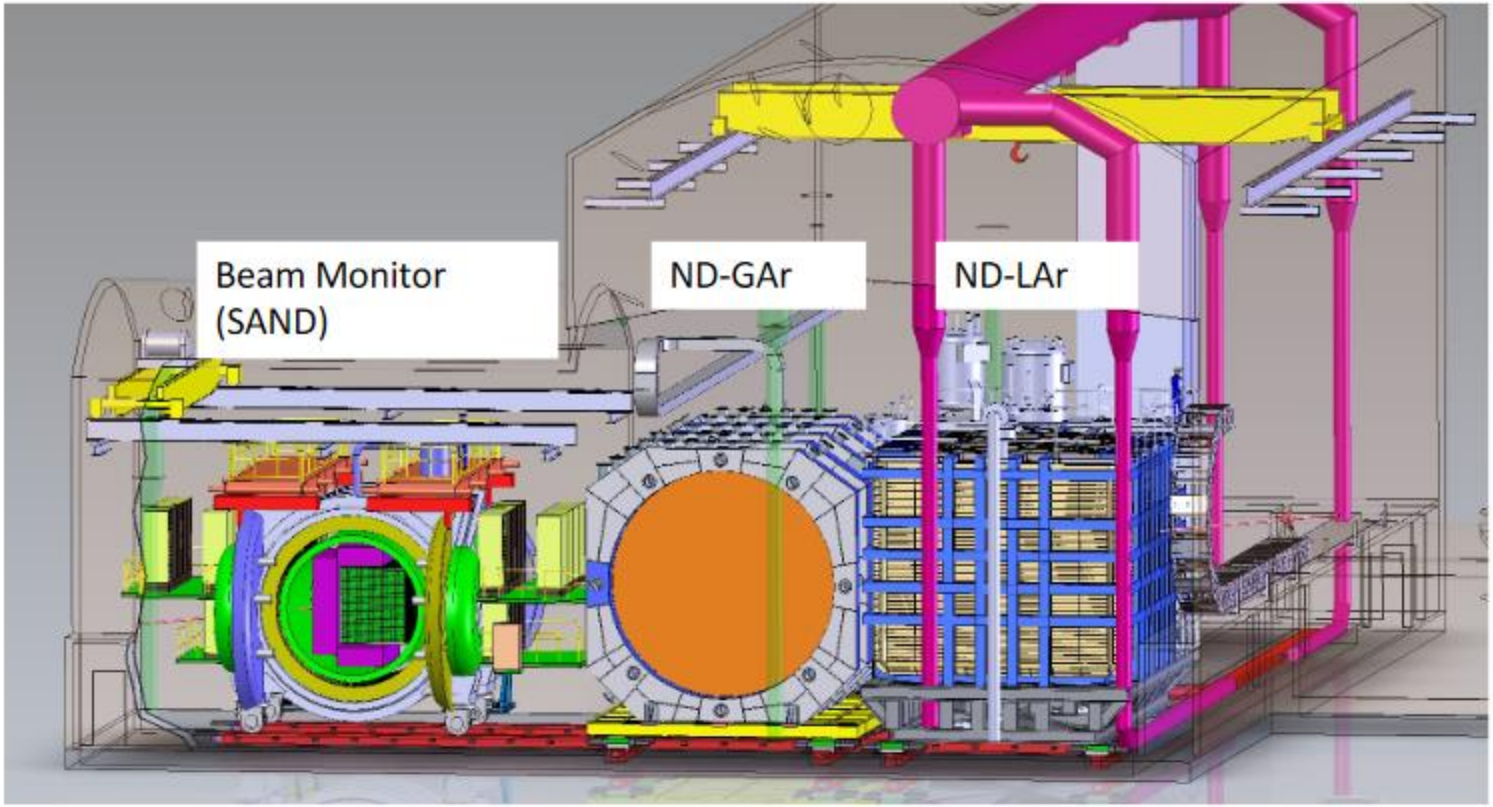
Near Site Conventional Facilities - Site Preparation Work

- Prepared site for LBNF Beamline facilities. Rerouted Indian Creek, relocated utilities, replaced Fermilab cooling pond with cooling tower.
- Completed on schedule in October 2020.

Rerouting Indian Creek with a new 140m long culvert system with fish channel

ND CDR: https://arxiv.org/abs/2103.13910 March 2021
PDR (Day 1 configuration) in 2021, complete TDR in 2022

DUNE ND CDR Reference



- Measures the neutrino beam rate and spectrum to predict un-oscillated event rates in the far detector
- Constrains systematic uncertainties for oscillation measurements

PIP-II https://pip2.fnal.gov/
FERMILAB Proton Improvement Plan-II
Another O(1G$) program on top of LBNF-DUNE

PIP-II enables the accelerator complex to reach 1.2 MW proton beam on LBNF target. Upgradable to multi-MW power

800 MeV LINAC + transfer line to Booster + Booster upgrade → Under construction

DUNE Detector Consortia : Consortia Leads/Technical Leads

Far Detector

- APA: C. Touramanis (Liverpool), TLs: B.Rebel (UW,FNAL), J. Evans (Manchester)
- Photon Detection System: E. Segreto (Campinas), TLs: D. Warner (CSU), F. Terranova (Milano Biccoca)
- TPC Electronics: D. Christian (FNAL), TL: M. Verzocchi (FNAL)
- CRP: D. Duchesneau (LAPP), TL: S. Tufanli (CERN)
- Top VD TPC Electronics: D. Autiero (IPNL), TL: T. Hasegawa (KEK)
- HV System: F. Pietropaolo (CERN), TL: Bo Yu (BNL)
- Calibration/Cryogenic Instrumentation: J. Maneira (LIP), TLs: S. Gollapinni (LANL),A. Cervera (IFC)

Near Detector

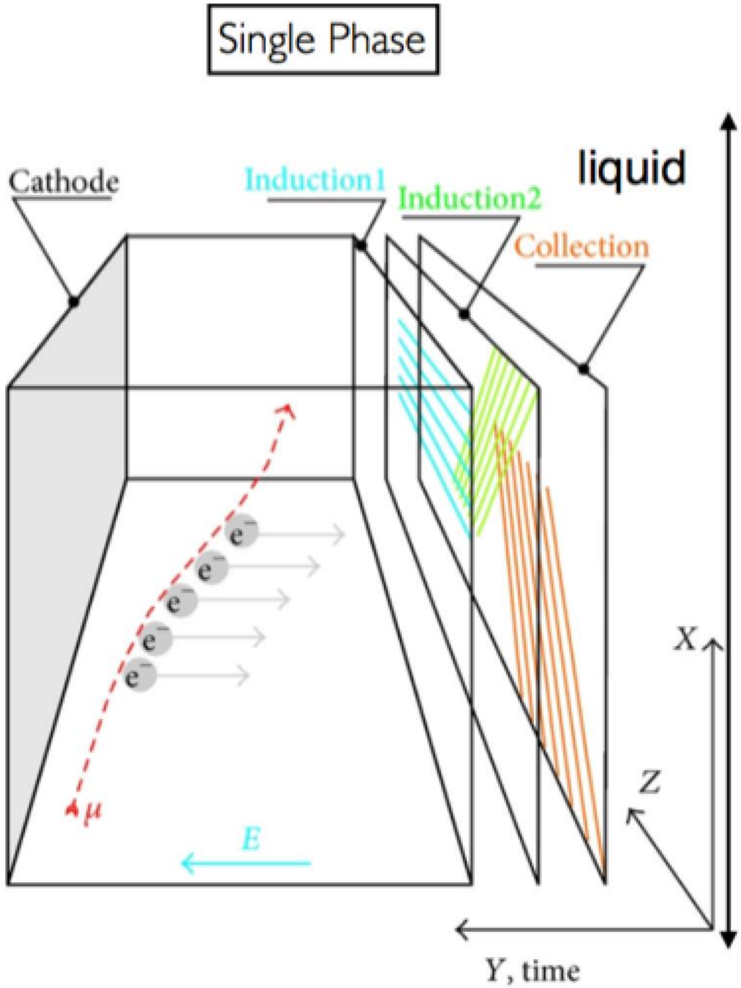
- Liquid-argon Detector (ND-LAr): M. Weber (Bern), TL: D. Dwyer (LBL)
- Beam Monitor – SAND: L. Stanco (INFN Padova), TL: C. Montanari (Pavia,FNAL)
- Argon Gas TPC (ND-GAr)* : A. Weber (STFC/Oxford), A. Bross (FNAL), TL : T. LeCompte (ANL)

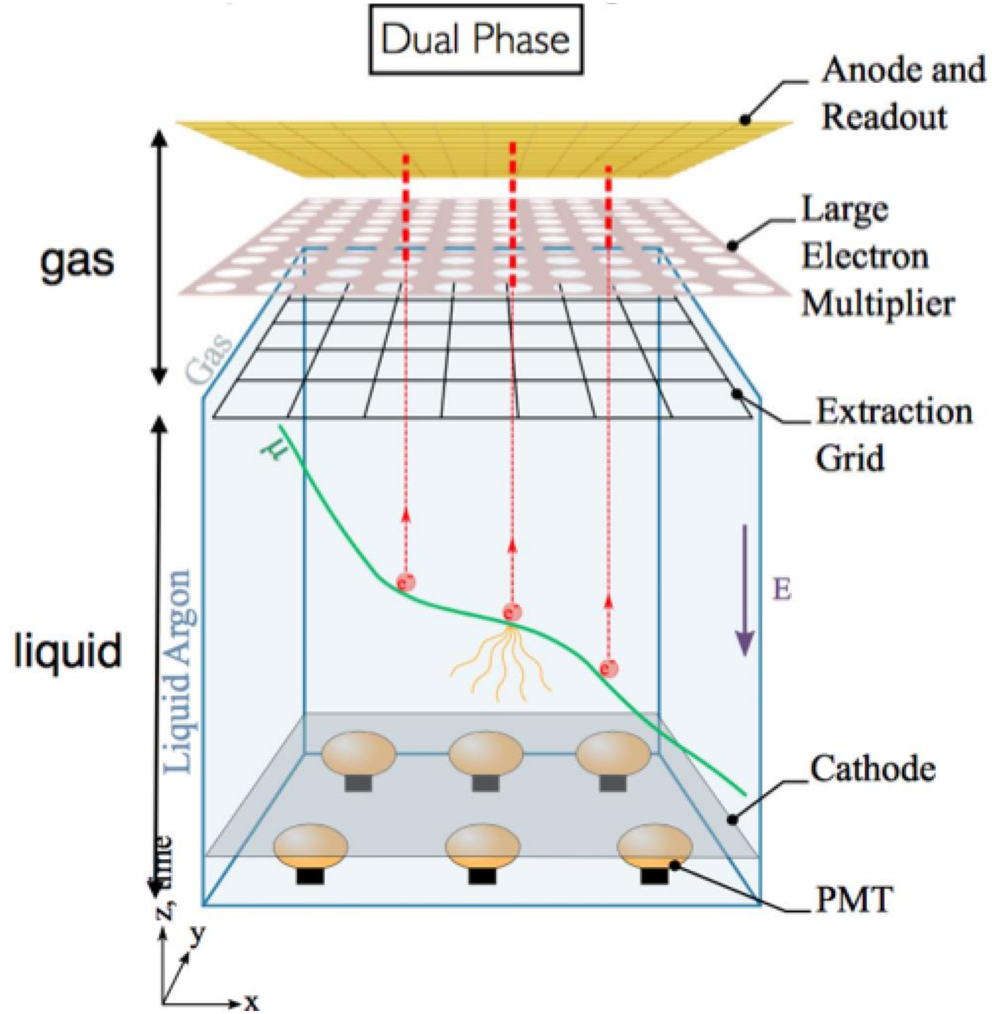
Joint Near/Far

- DAQ/Slow Controls: G. Lehmann Miotto (CERN), TLs: A. Thea (RAL), A. Kaboth (RHUL)
- Computing: H. Schellman (Oregon State), TLs: M. Kirby (FNAL), A. McNab (Manchester)

*proto-Consortium

Liquid Argon Time Projection Chamber readout

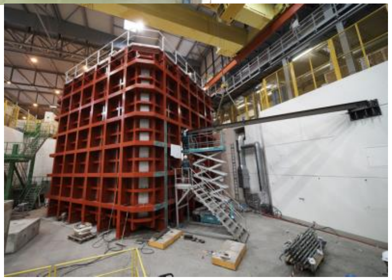




A little bit of history:

- LAr **R&D started in 2006 for the charge readout electronics**, also supported by the LABEX LIO since 2012
- French groups contributed to the **LAGUNA-LBNO program (2008-2014) and R&D** where the **dual-phase detector** technology was developed
- **Project for the dual-phase R&D program at CERN** launched **at CS IN2P3 of June 2013 for LBNO-Demo**, then becoming **NP02/protoDUNE dual-phase in 2015**
- French groups contributed in **2014** to the **fusion of the EU and US efforts** and to the birth of DUNE (**IIEB, LBNF/ELBNF EOI**)
- Since **2015 → DUNE/protoDUNE IN2P3 project**
- **2016-2017: construction and operation of the 3x1x1** detector. Provided: Charge Readout Electronics, suspension system of Charge Readout Plane

- **2017-2019: construction of NP02/protoDUNE dual-phase**. Provided: Charge Readout Electronics, Charge Readout Planes +LEMs (CEA), DAQ system



- 2017 start of discussions for **DUNE IR project**, **2018 DUNE in TGIR roadmap**
- **2018 IN2P3 CS, start of discussions for TGIR project**, based on DP module: submitted summer 2019, on the way of approval in fall 2020
- **August 2019-September 2020: operation of protoDUNE dual-phase**
- **October 2020- December 2020: definition of Vertical Drift FD module #2**
- **January 2020-… preparation activities for Vertical Drift FD module #2**

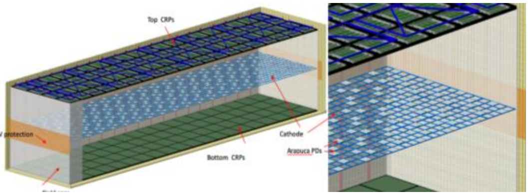
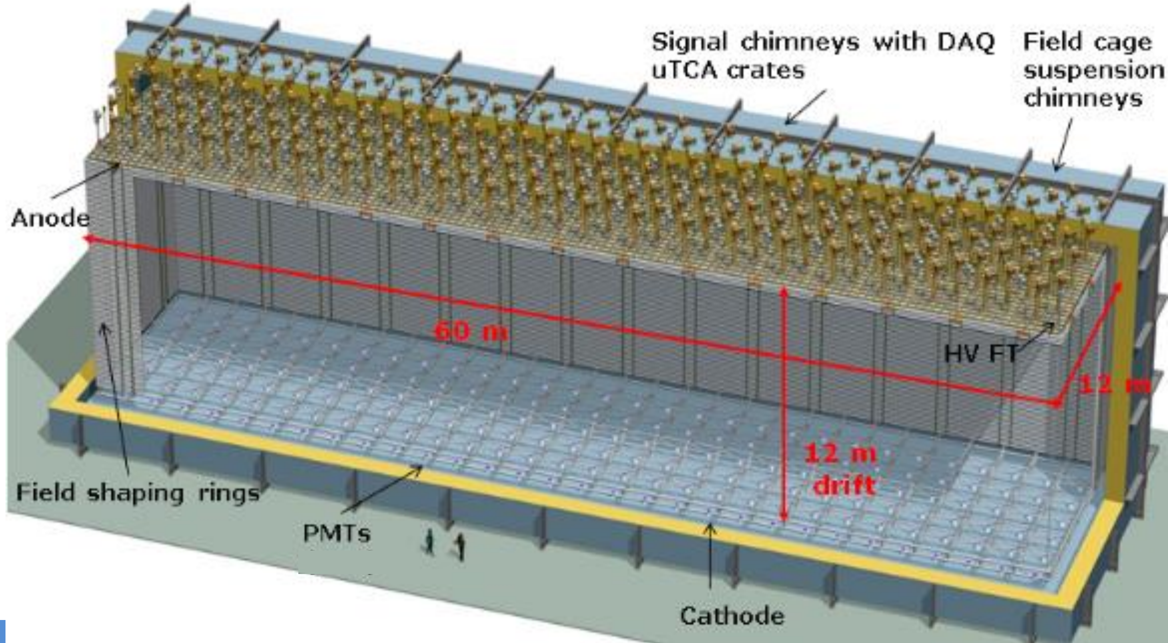


Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

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

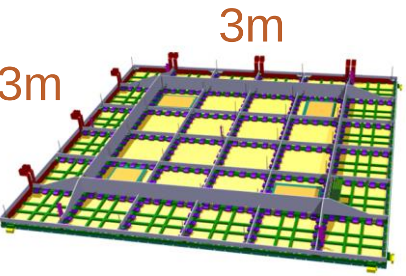
Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600



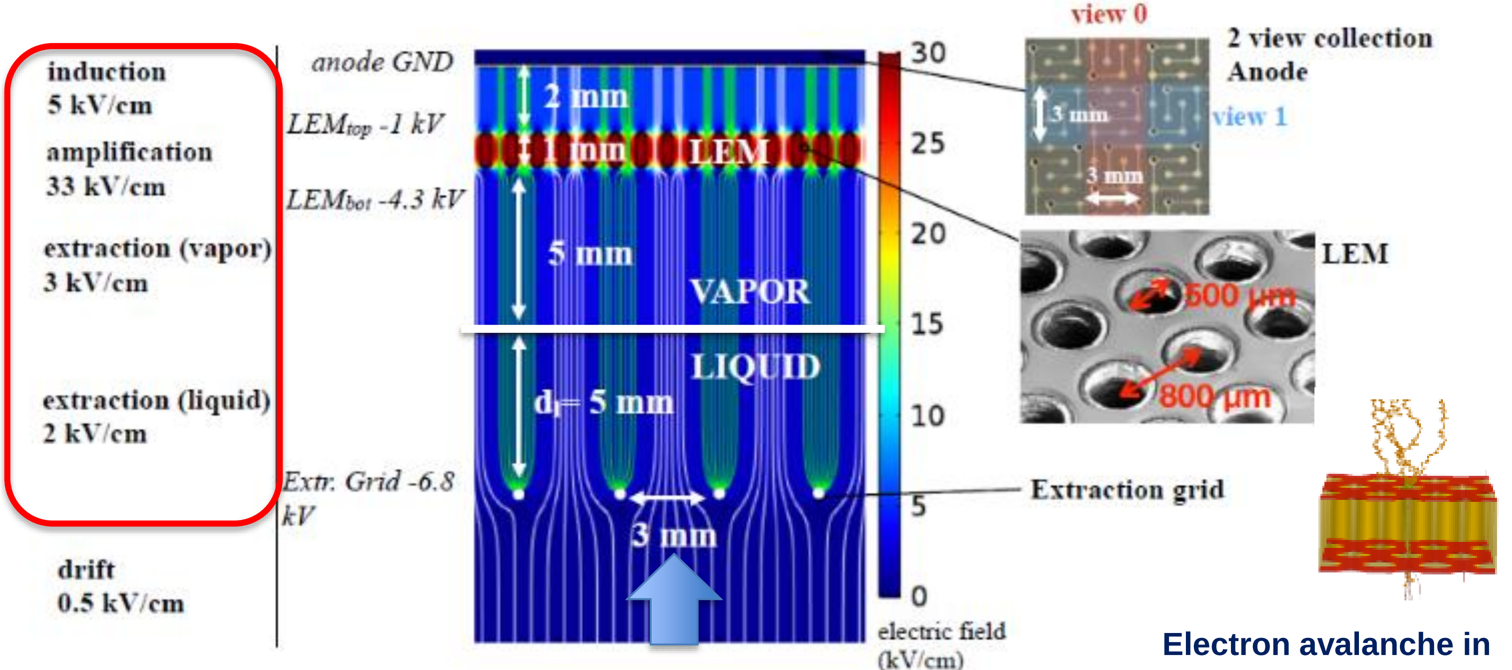
Advantages of dual-phase design:

- 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

Dual-Phase Charge Readout

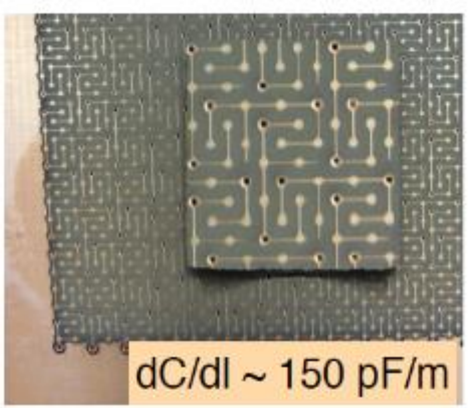


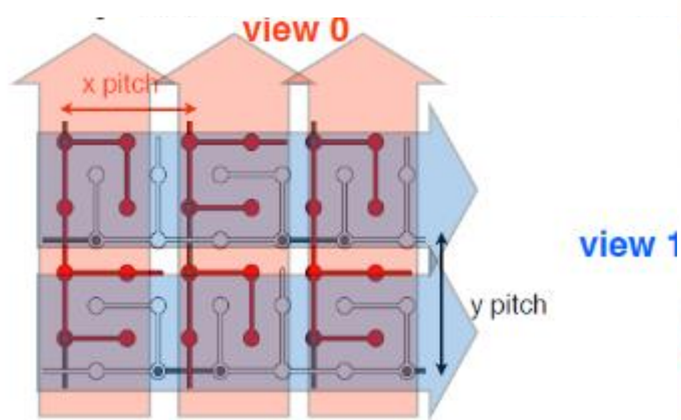
Charge Readout Plane integrating LEM-anode sandwiches



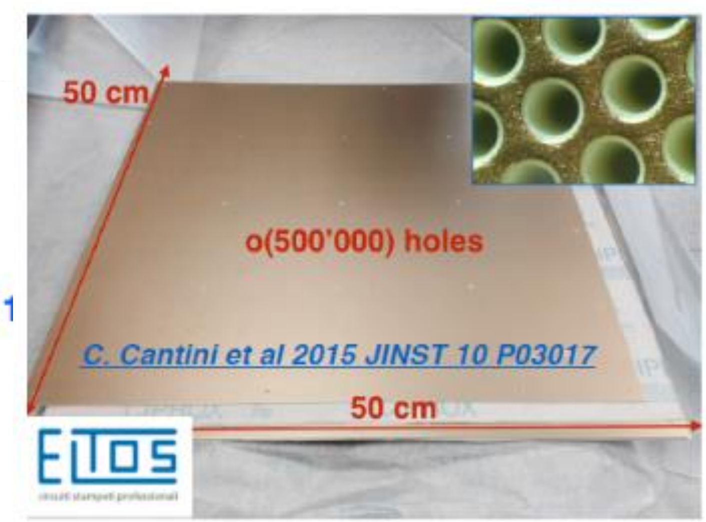
Electron avalanche in LEM hole

50x50 cm² anodes with 2 collection views





50x50 cm² LEM

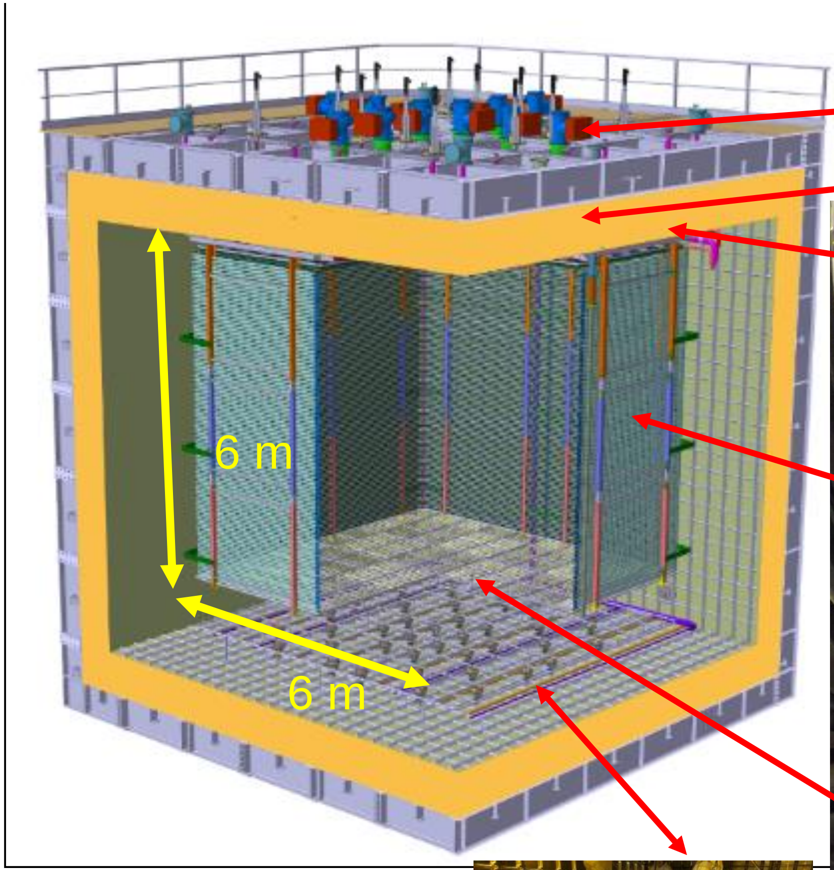


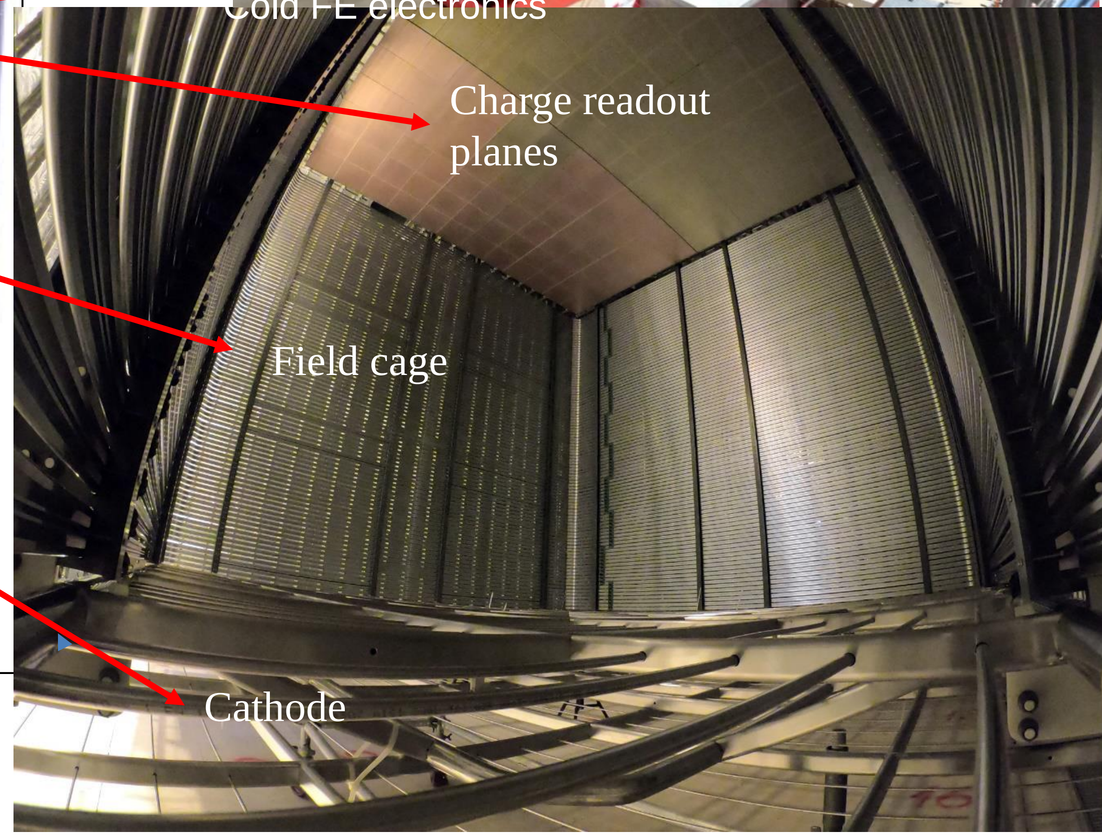
NP02/protoDUNE dual-phase

dual-phase FD design based on NP02:

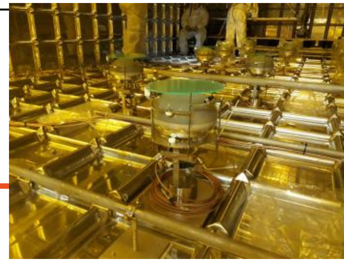
- 1/20 of active area of DP 10 kton
- NP02/protoDUNE DP 4 CRPs → DUNE 80 CRPs

Construction 2018-19 Operation 2019-20

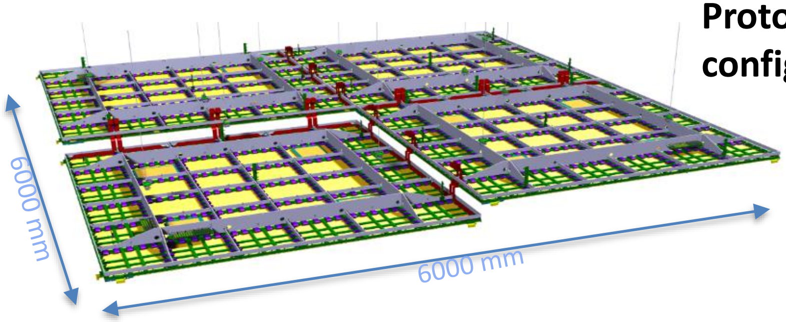




36 cryogenic photomultipliers
Hamamatsu R5912-02mod
with TPB coating

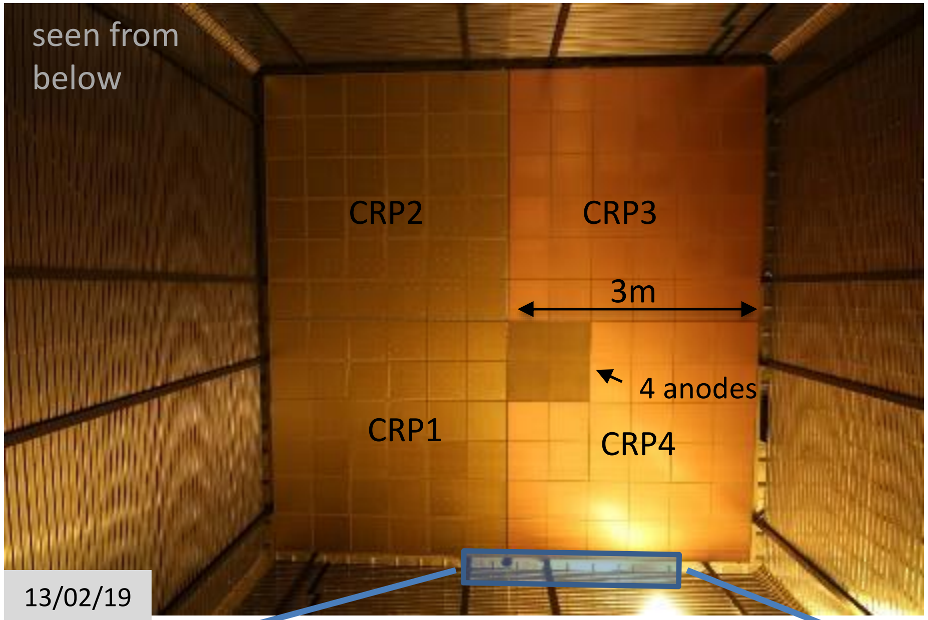


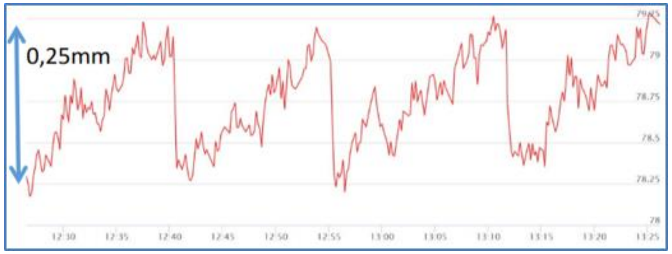
Charge Readout Planes

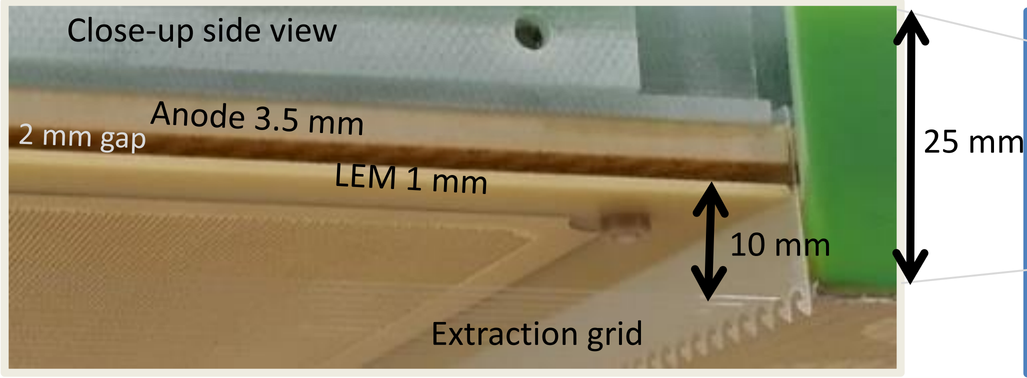


ProtoDUNE-DP configuration

4 CRPs







ProtoDUNE-DP accessible cryogenic front-end electronics and uTCA FE system

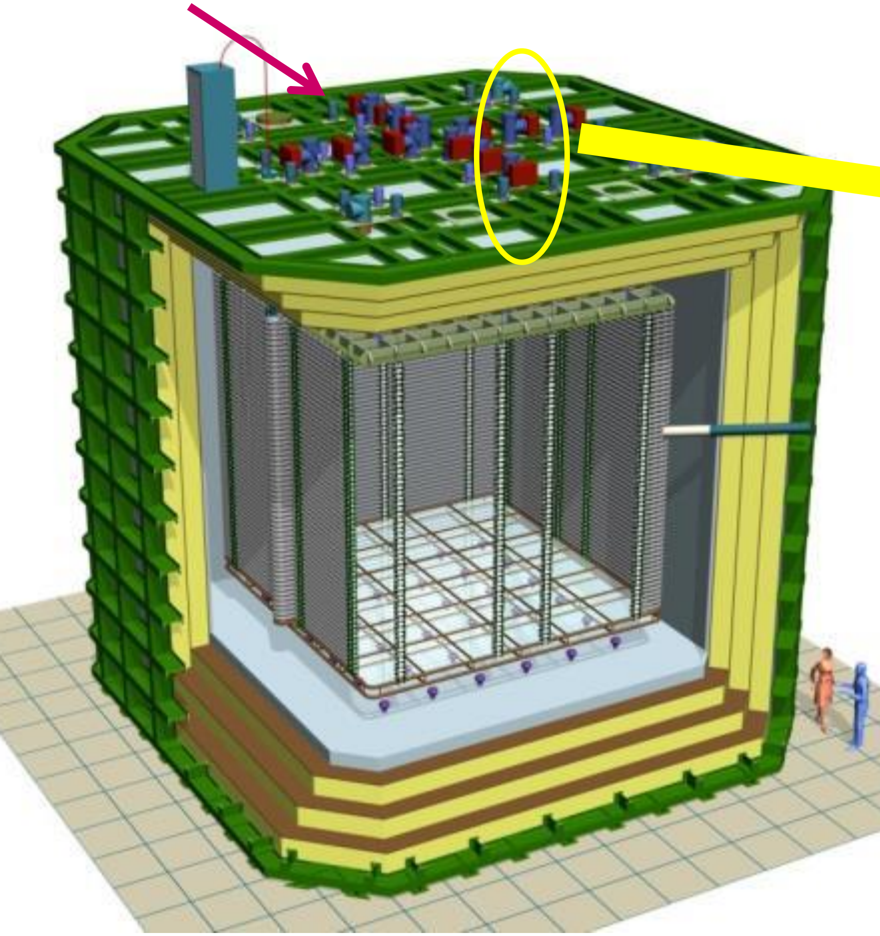
Full accessibility provided by the dual-phase charge readout at the top of the detector

➢ **Digital electronics <u>at warm</u> on the tank roof:**
- Architecture based on uTCA standard
- 1 crate/signal chimney, 640 channels/crate

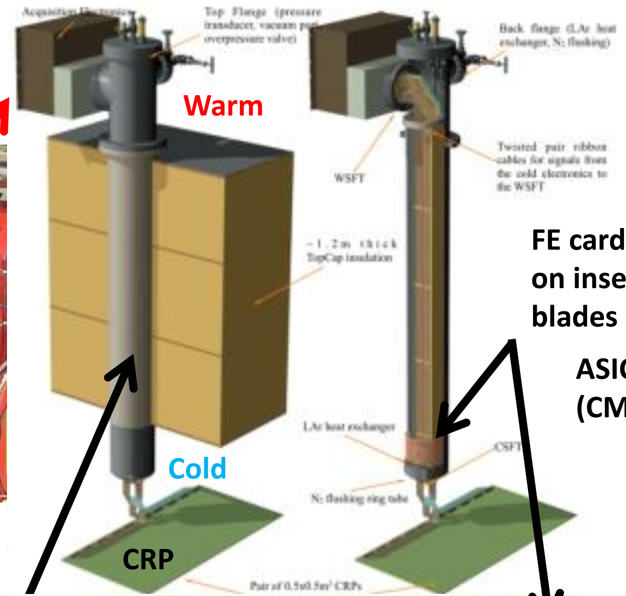
→ 12 uTCA crates, 10 AMC cards/crate, 64 ch/card

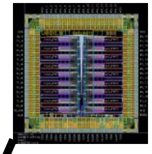
➢ **Cryogenic ASIC amplifiers (CMOS 0.35um) 16 ch <u>externally accessible:</u>**
- Operating at 110K at the bottom of the signal chimneys
- Cards fixed to a plug accessible from outside

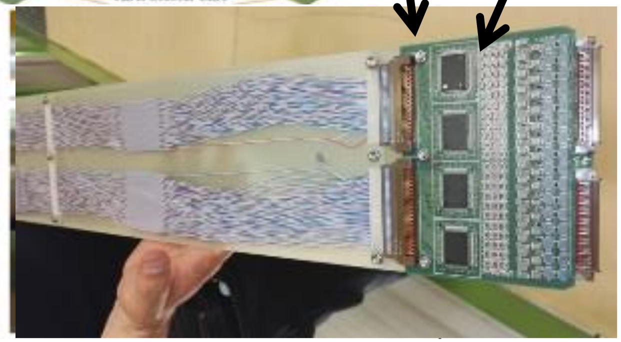
→Short cables capacitance, low noise at low T



<50 cm

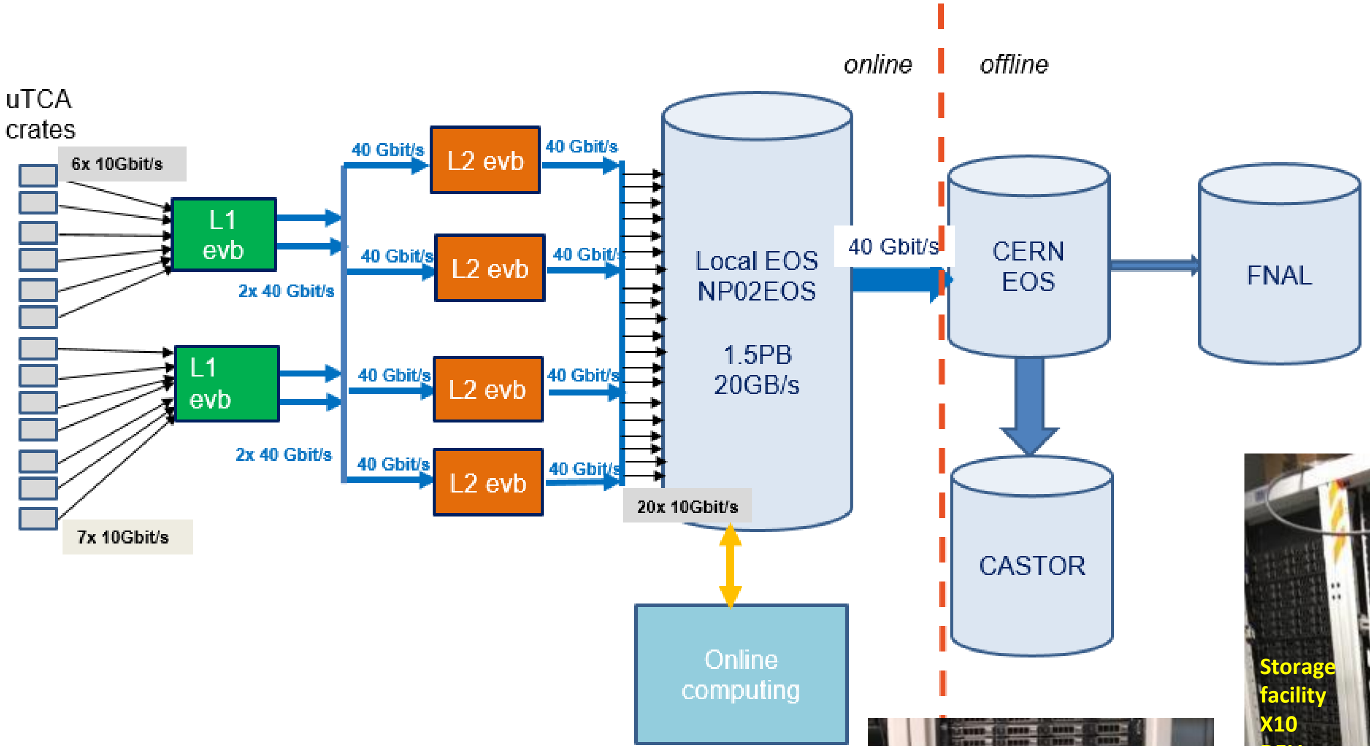


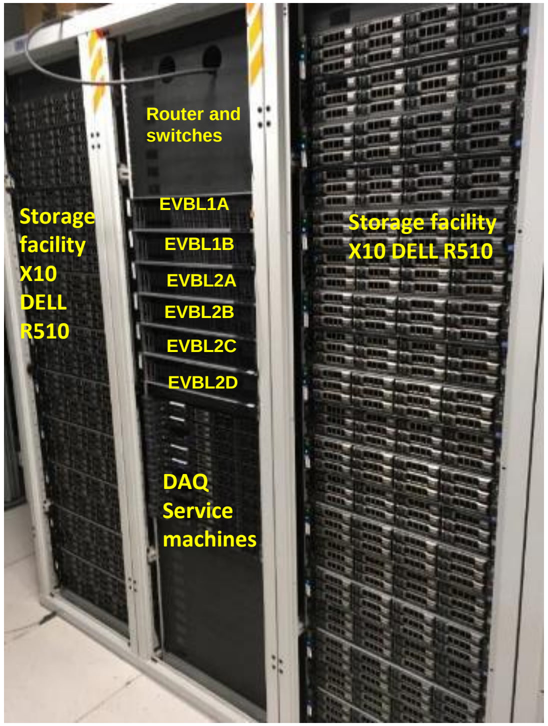




Signal chimney

NP02 DAQ/network infrastructure, 20 GB/s bandwidth

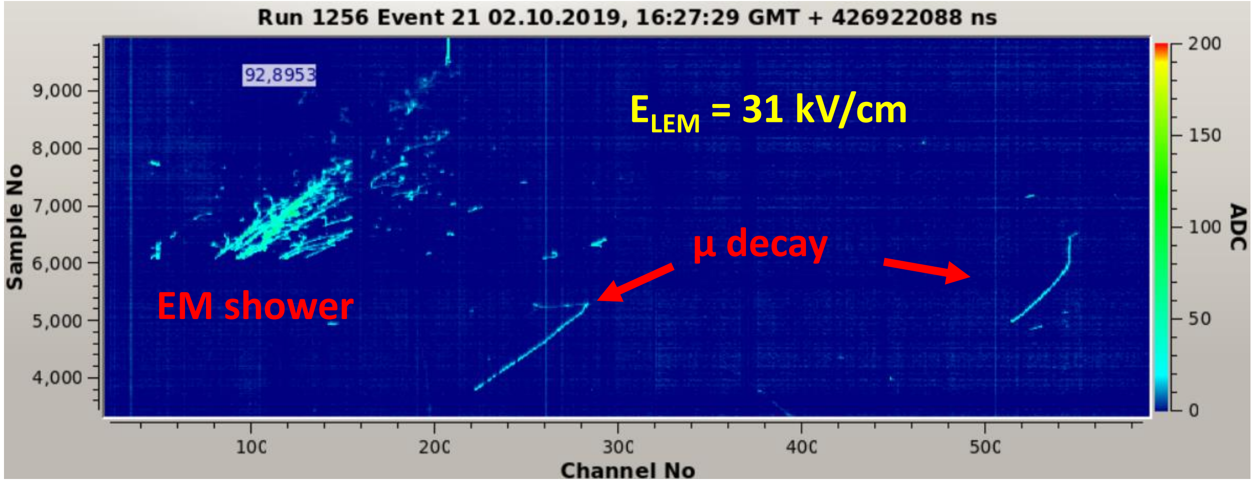




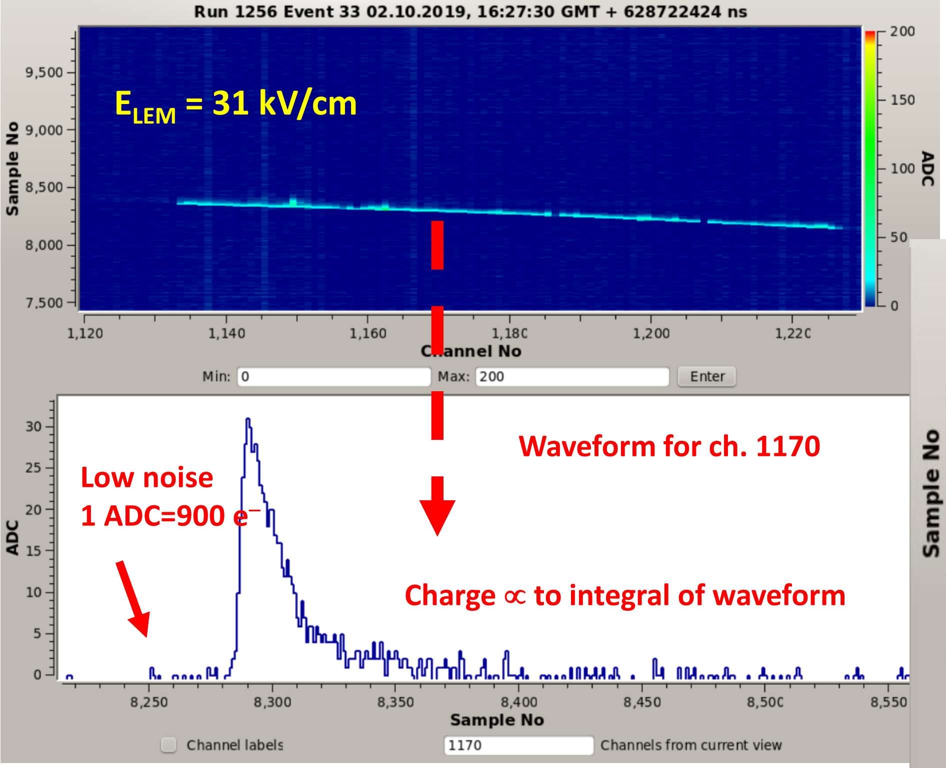
Online storage servers for distributed EOS system (1.5 PB) and online computing nodes (450 cores) provided by CCIN2P3

Cosmic ray events in protoDUNE dual-phase

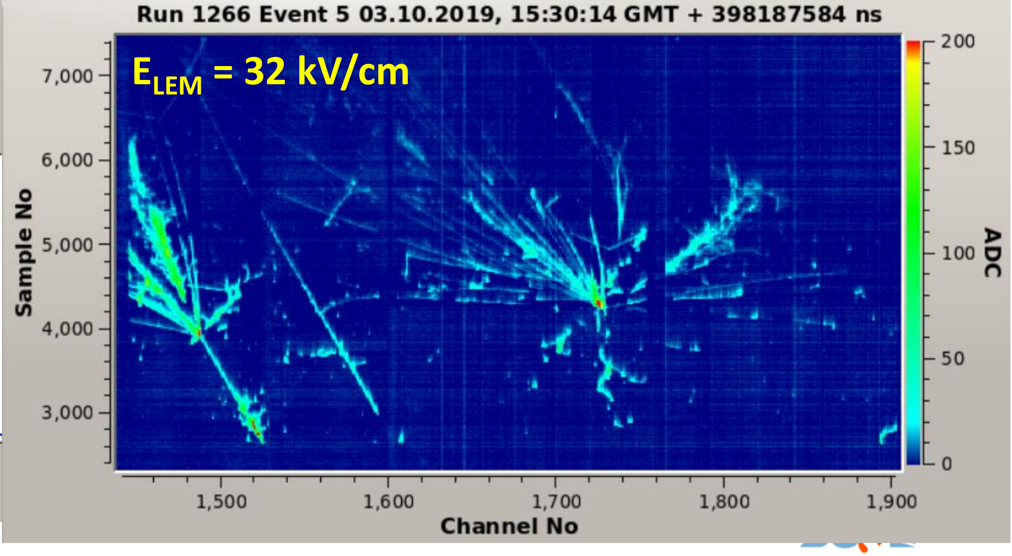
Electromagnetic shower + two muon decays



Horizontal muon track



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



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

- **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**

Main features of what learned from operation period :

- 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)**

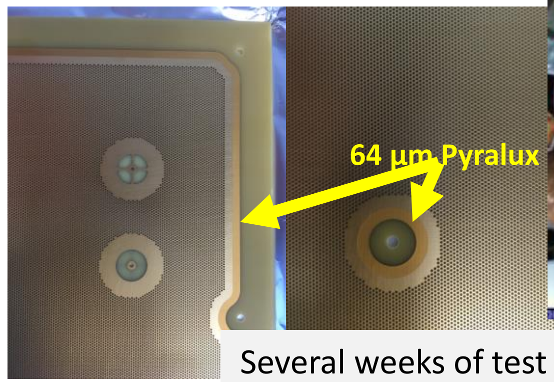
makes LEMs gain much less required to compensate for signal attenuation during drift

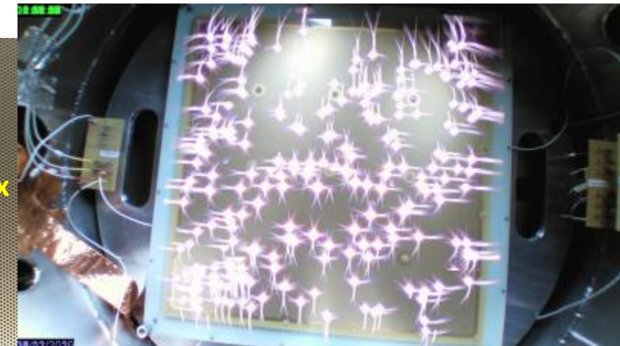
ProtoDUNE-DP R&D activities: (SPSC April 2020)

<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>

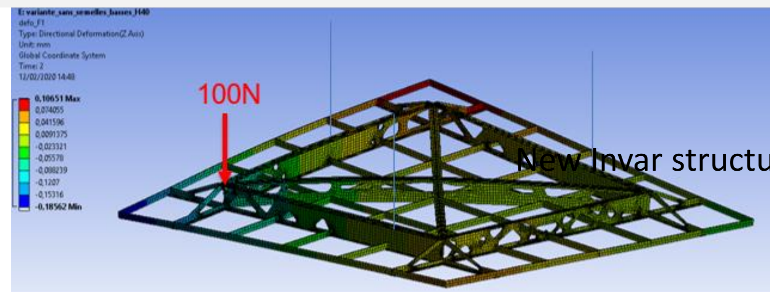
- Improving LEM design with high quality rims using a micro etching technique developed by CERN
- Adding an insulating material in the dead regions of LEM using 64 um thick Pyralux coverlay (successful tests at Saclay) very effective to eliminate sparks in those regions





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

- For the anodes: new design to incorporate a guard ring on both faces of PCB



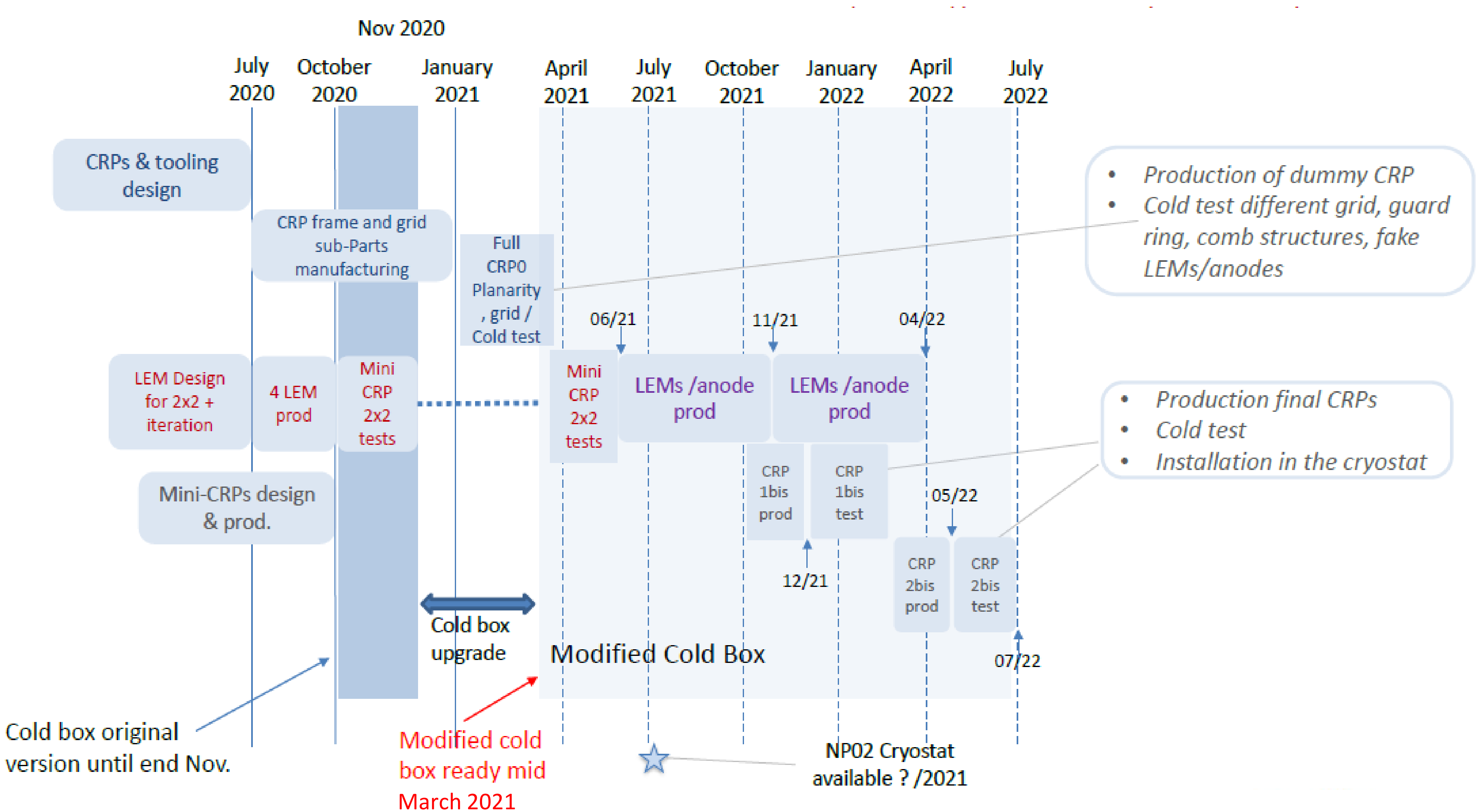
<u>For the CRP structure and extraction grid:</u>

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)

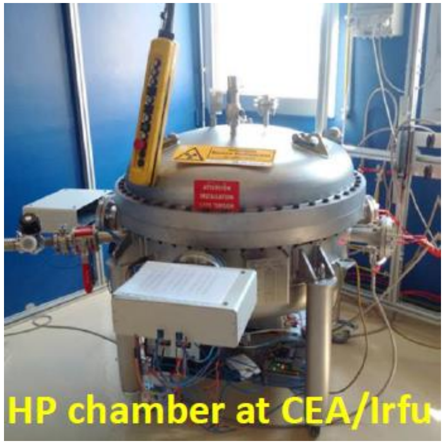


Schedule now replaced by Vertical Drift integration tests 2021-2023

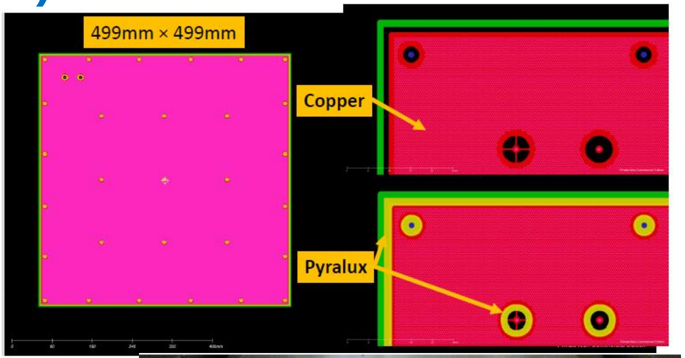
Progress on small tests R&D activities: (Summer 2020)

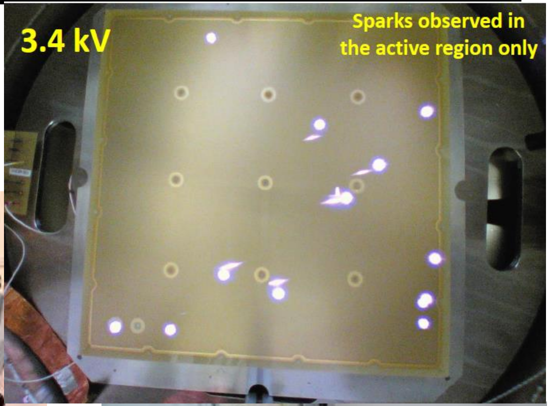
Tests of new LEMs design at CEA to reduce sparking

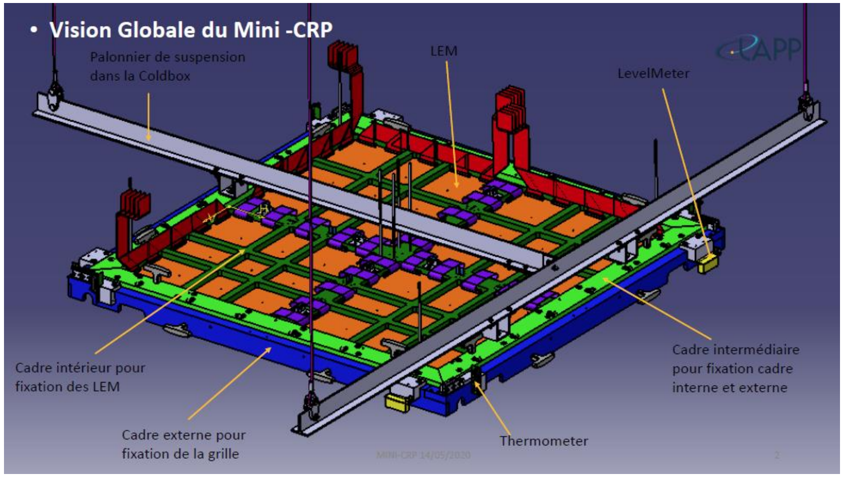
- Pyralux insulator on edges and pads
- Increased active area to 93-95%
- Studies on segmented and resistive LEMs and on RIMs optimization

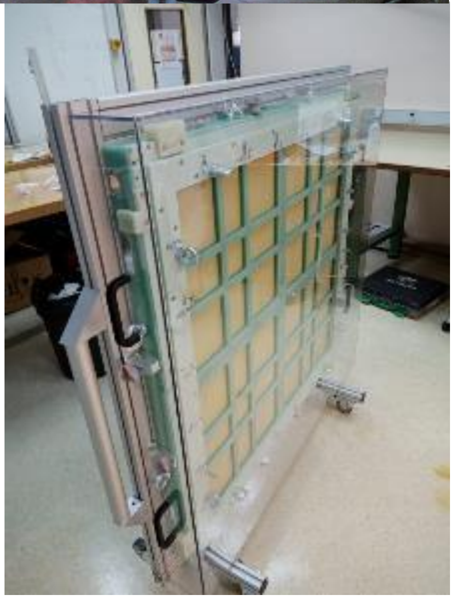


LEM design with 95% active area







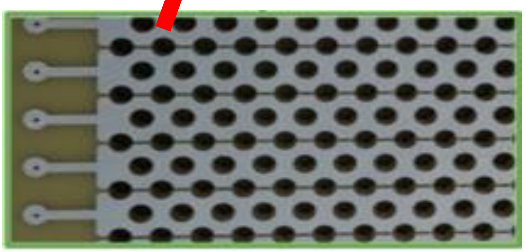


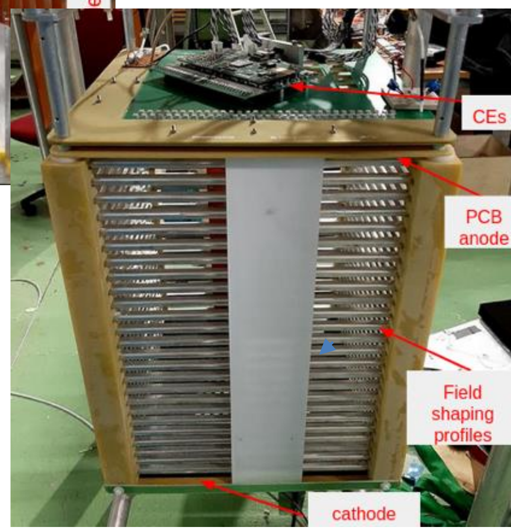
New design developed for 3x3 m^2 CRPs following the CRPs improvement program:

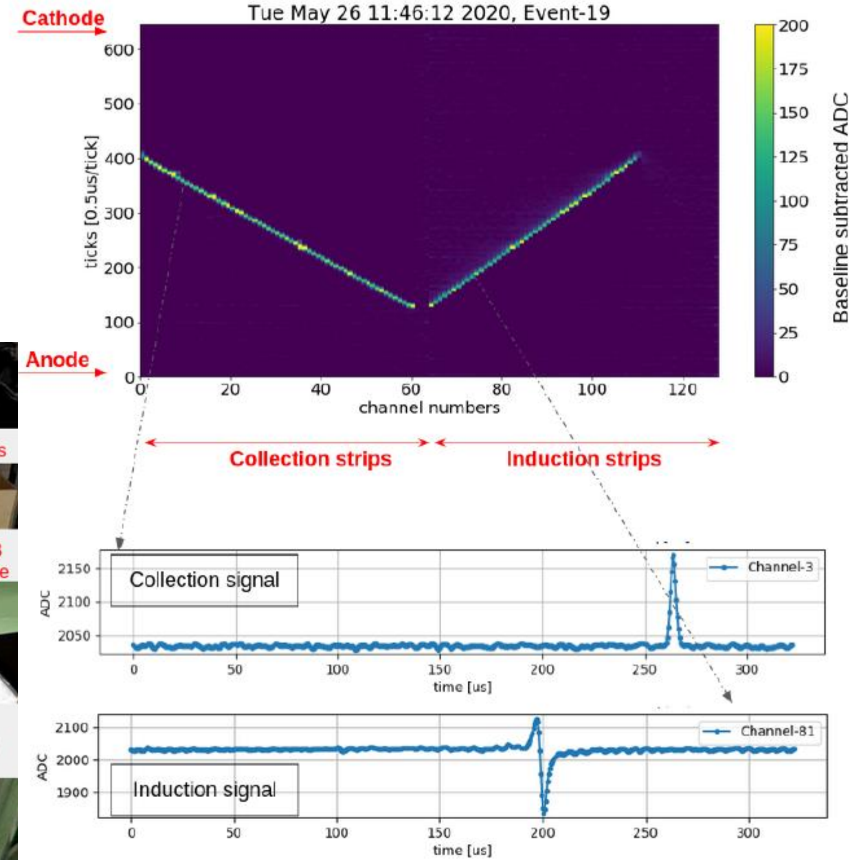
→ First design implementation on a MiniCRP structure (1x1m^2) made following the CRP improvement program to test 4 LEMs from new design

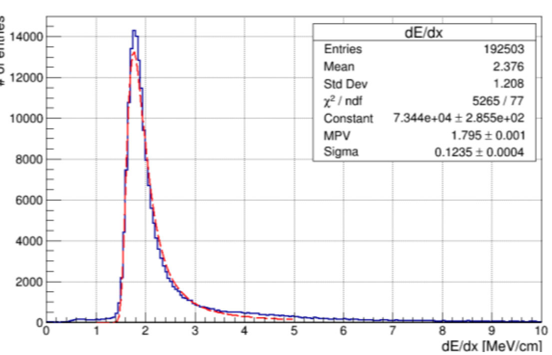
- New extraction grid + grid sparks prevention system

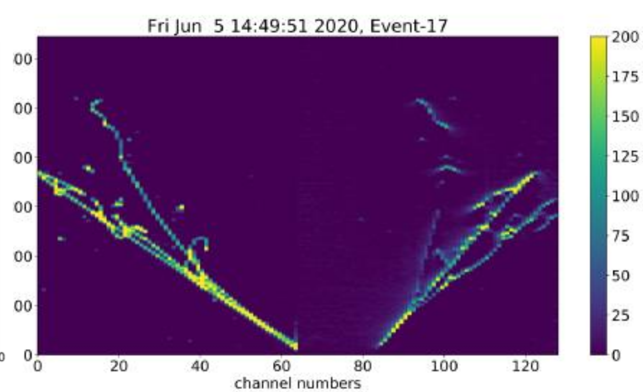
Perforated anodes tests at CERN Neutrino Platform with the 50l TPC test stand (Summer 2020)

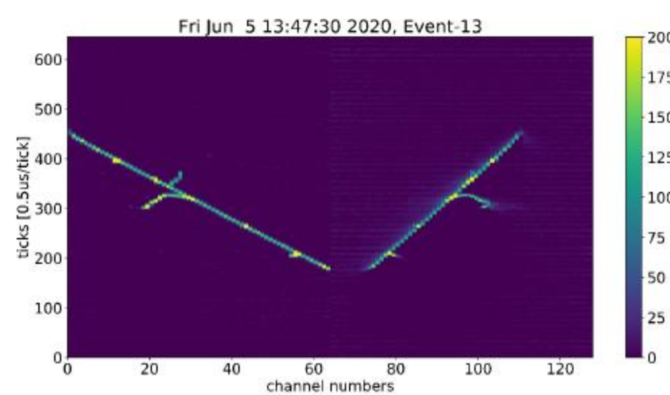












Can we think of a simplified DP detector without LEMs (w/o the extra time needed to complete LEMs/CRP developments) which could be immediately built for DUNE, quickly and at affordable costs ?

→ 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 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 also performed in April-May 2021)**

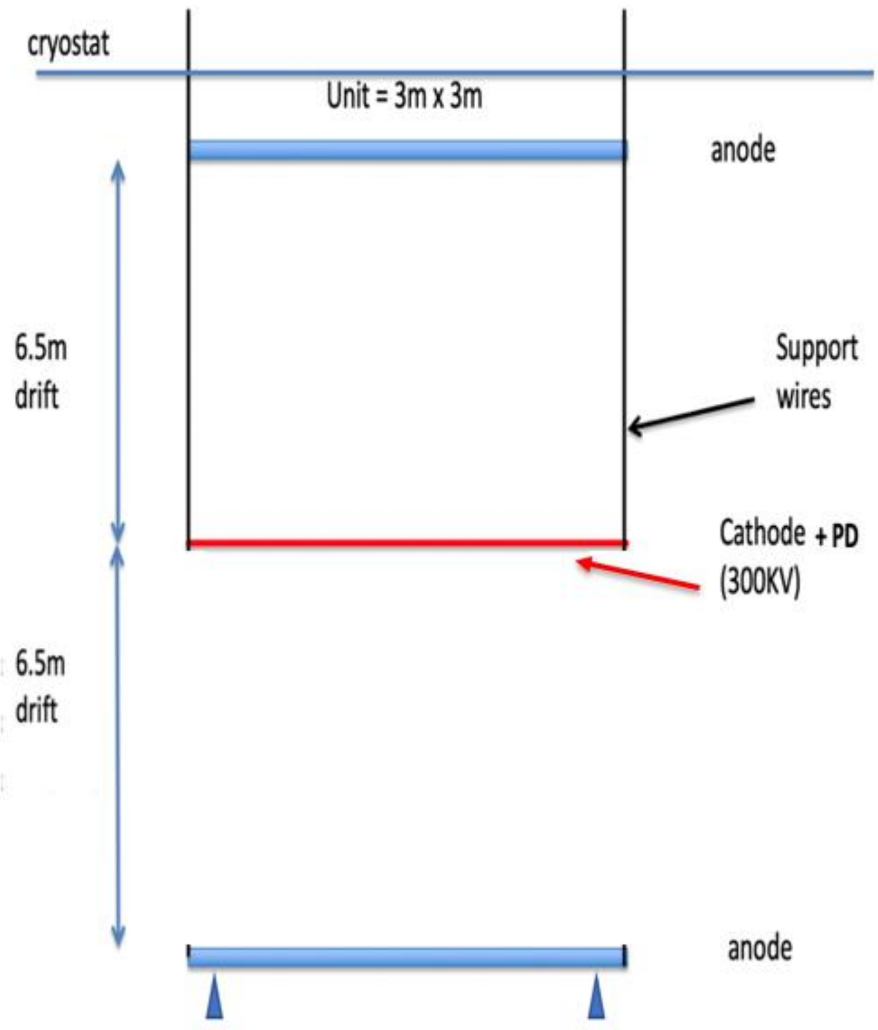
  →confirmed the idea of evolving from the LEM design

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

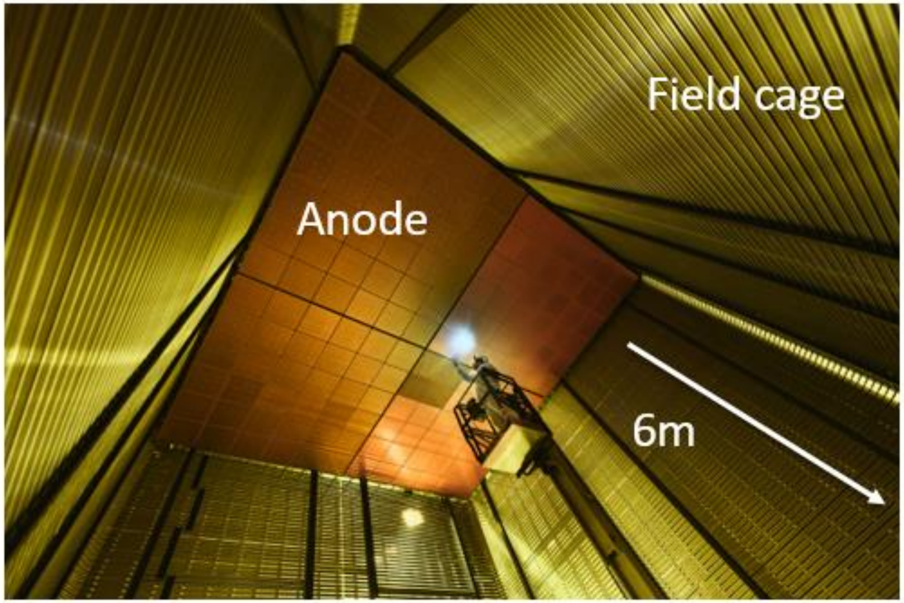
  → process completed in December 2020

- **DOE IPR concluded in January 2021** → very strong support to this evolution of DUNE far detector configuration
- **VD became preferred option by the DUNE collaboration to build the 2nd FD module**

Vertical Drift layout

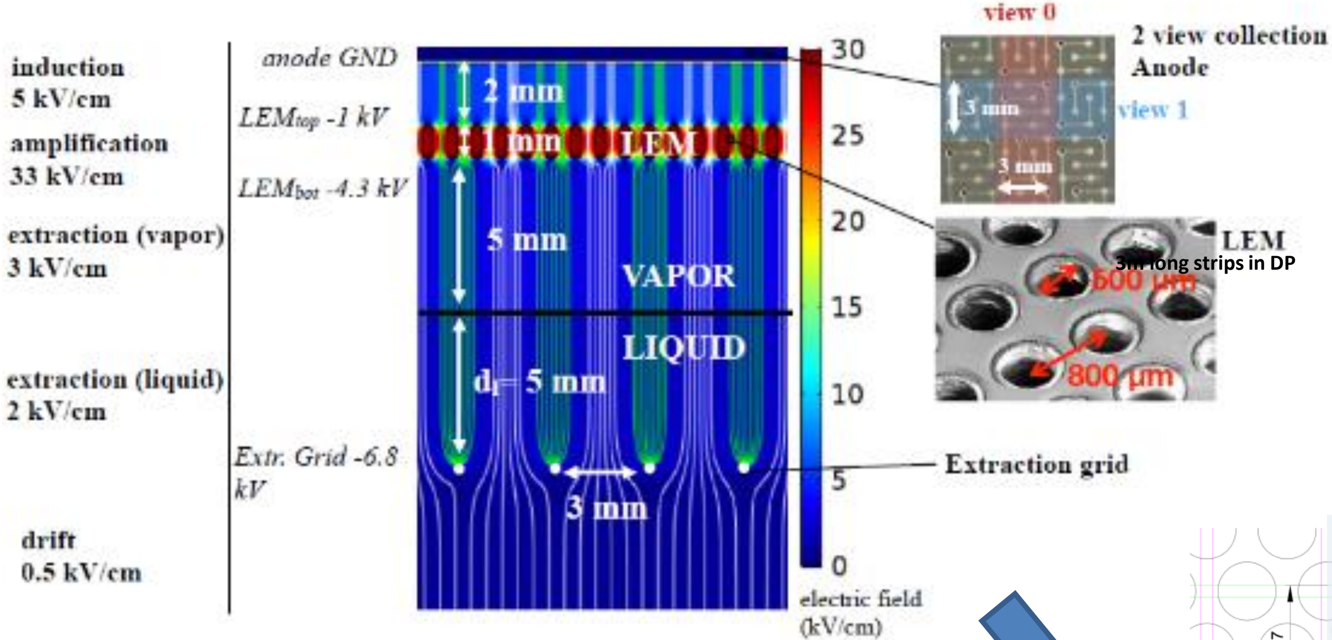


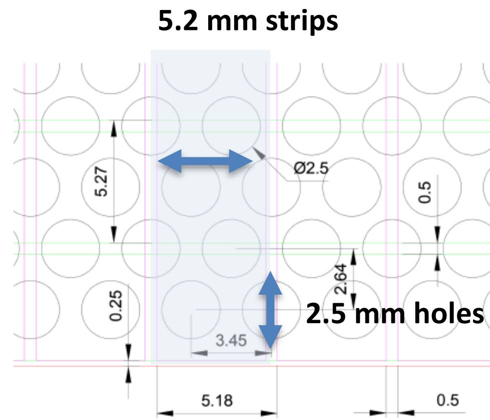
NP02 layout

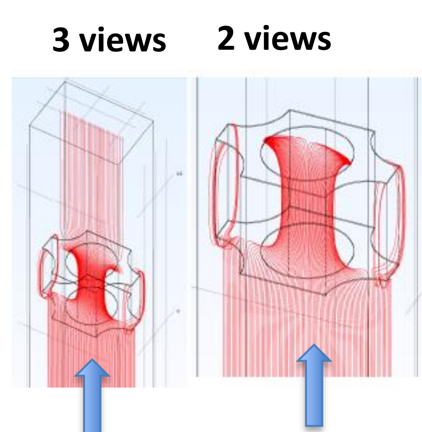


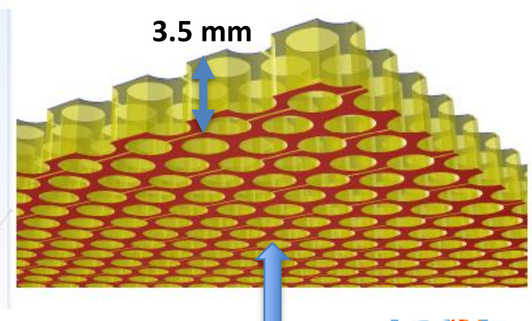
cathode

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 for DP)
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 a factor 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)

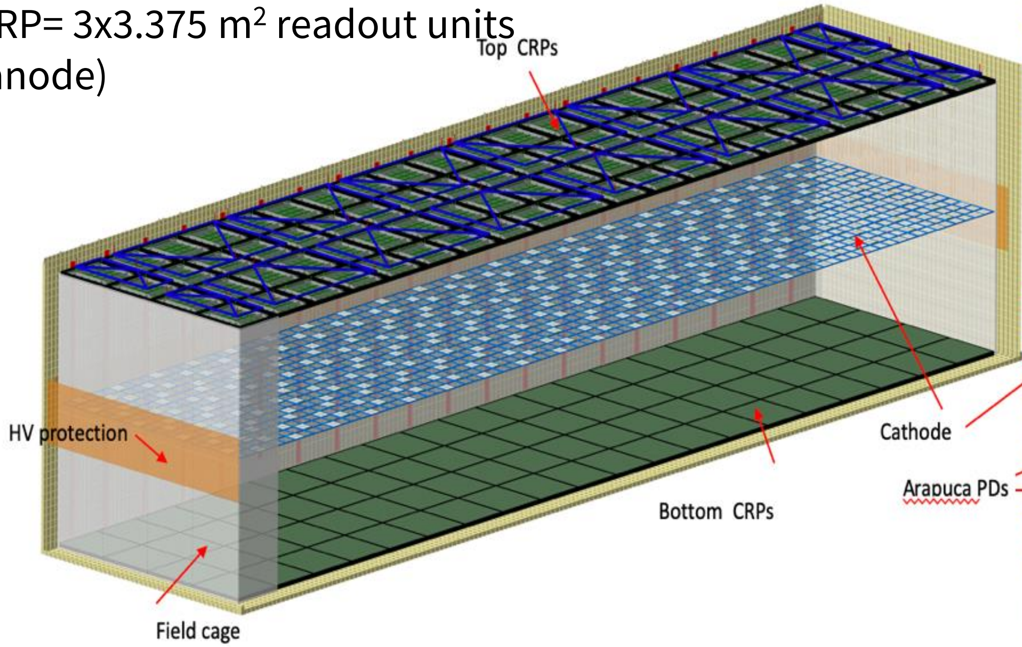
- **Signal in VD with 300 V/cm (500V/cm) is stronger than in DP requirements (gain=6) by a factor 3.5 (4.6)**

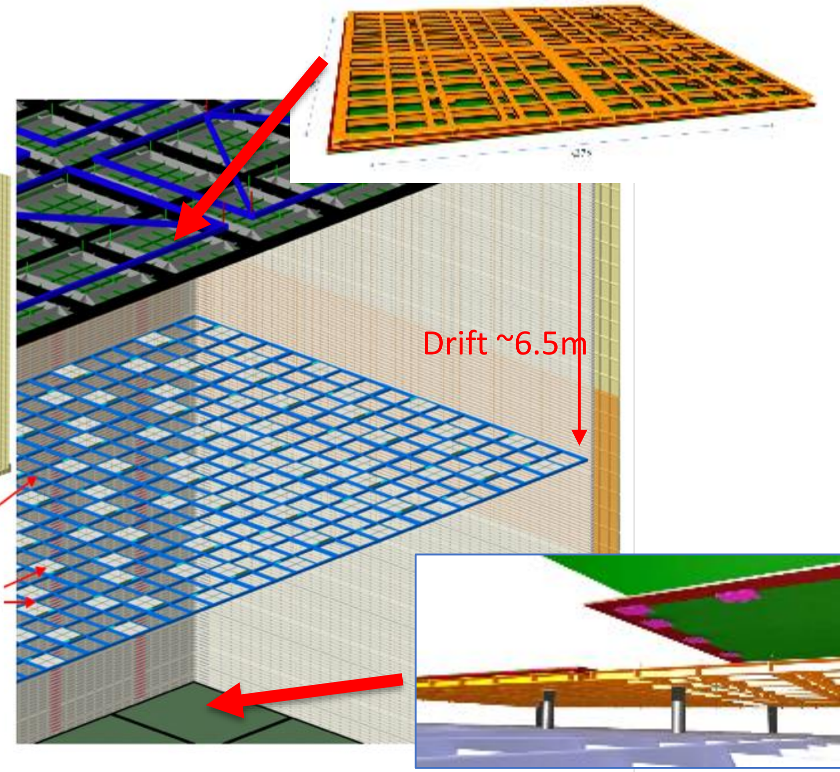
- **Strips capacitance is also lower for VD**: (<100 pF/m) over about 1.5 m length to be compared to 160pF/m x 3m length in case of DP configuration.

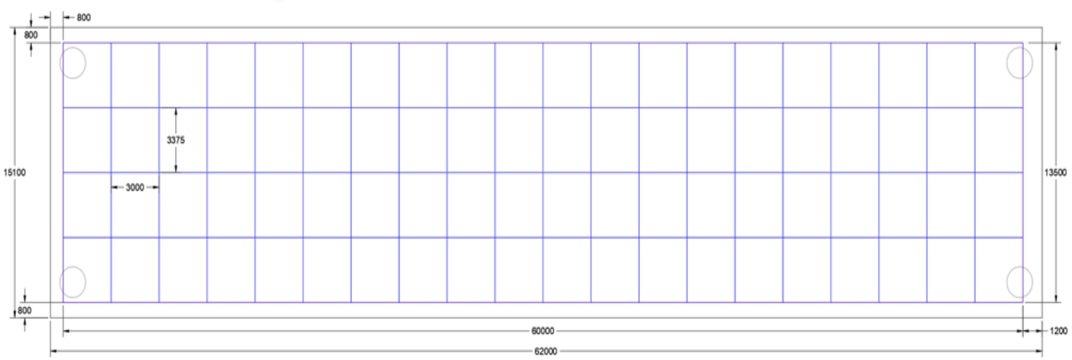
Vertical Drift far detector module (FD2)

- **Detailed description in Vertical Drift proposal document .**
- **Involved IN2P3 groups: APC, IJCLAB, IP2I, LAPP, LPSC**
- **Vertical Drift reuses many dual-phase developments for the CRPs, top-drift electronics, field cage/cathode**
- **Components production 2023-2026**
- **FD2 Installation 2026**

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





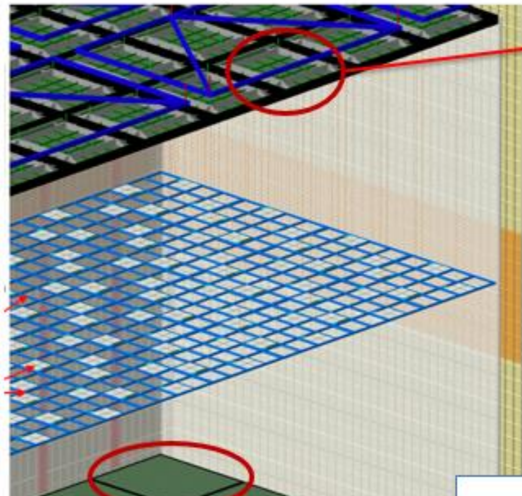


- ✓ 160 CRP units (80+80 on top/bottom, readout with DP/SP electronics)
- ✓ Drift active volumes 2*5’265 m^3 = LAr 14.74 kton

Charge Readout Plane and anode assembly

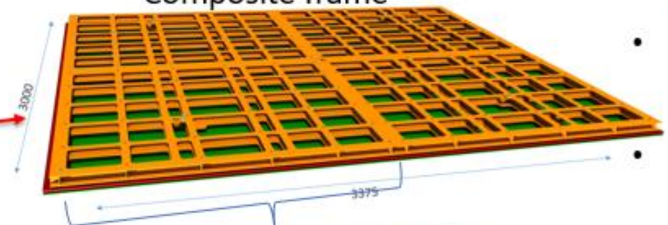
✓ 160 CRP units (80 on top, 80 on the bottom)

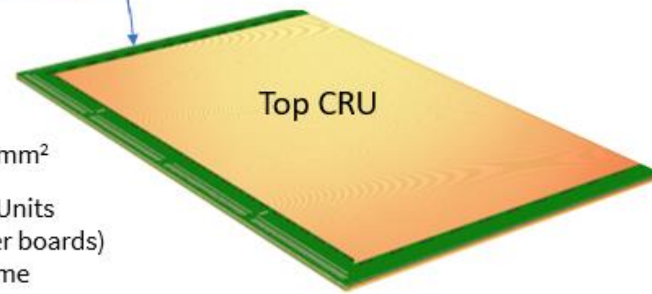
Readout by DP electronics



Readout by CE

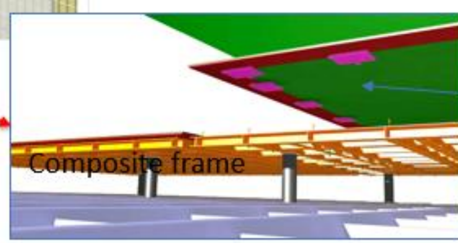
Composite frame





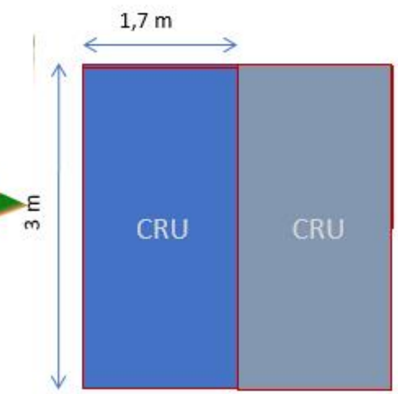
1 CRP = 3000 x 3375 mm^2

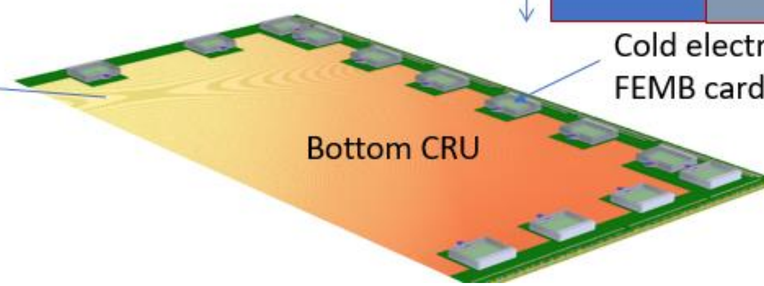
✓ Charge Readout Units (anodes + adapter boards)
✓ 1 mechanical frame



Readout geometry foreseen:
Identical for top and bottom:

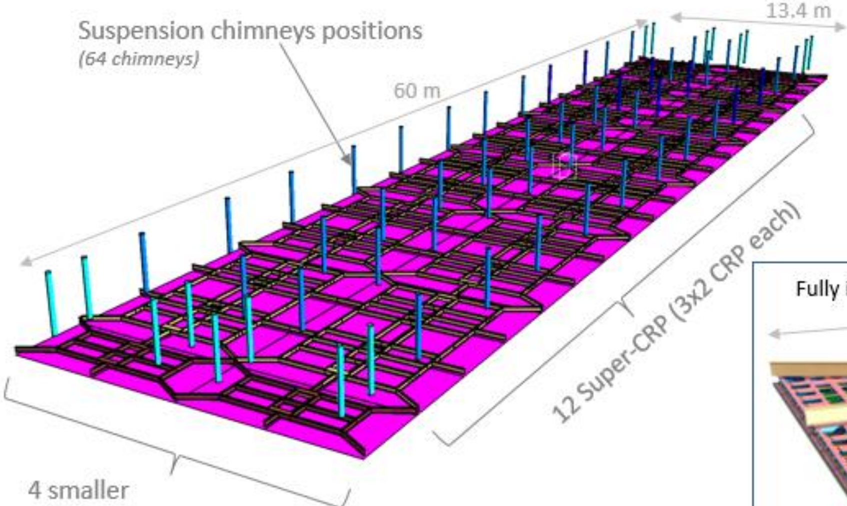
- An anode PCB unit is 3 m x 1.7m in size, constructed by bonding several PCBs side by side.
- A CRP is made of 2 CRU





Cold electronic FEMB cards

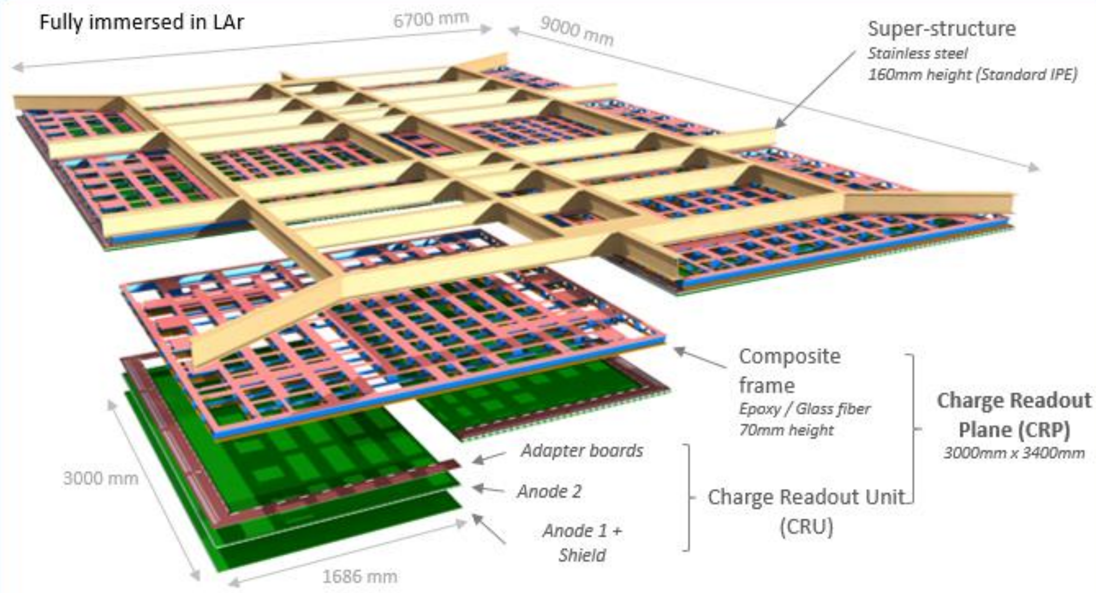
Top CRP plane layout



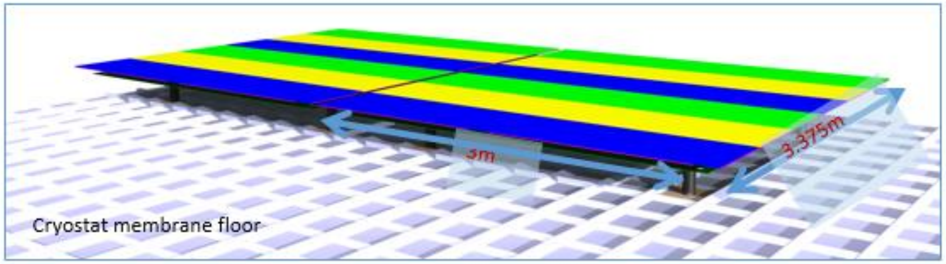
Top plane: 80 CRPs

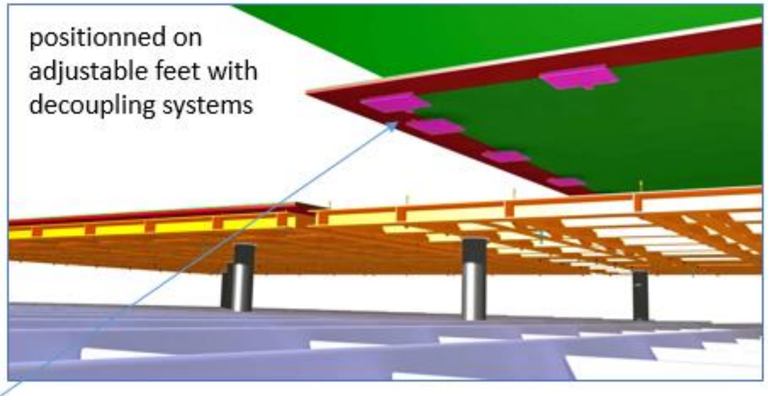
Anode planarity specification : <10 mm @ cold

Each superstructure suspended by 4 cables and position controlled from the top of the cryostat like for Dual Phase



Bottom CRP Plane Layout



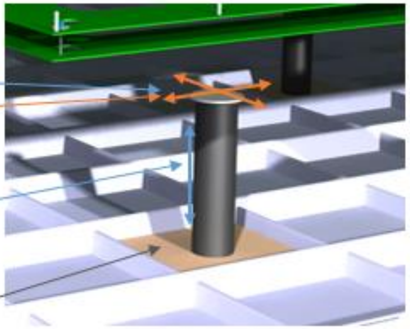


<u>Design of the bottom CRP frame</u>:
No metallic frame, only composite frame

With the bottom CE boxes attached below the anode plane +
planarity can be controlled by the supporting feet to keep each anode plane within the 5 mm deformation range

⇒ Bottom frame can be made more transparent than top frame and
⇒ Lighter thanks to the adaptable supporting feet distribution

The bottom CRPs will be positioned on adjustable feet



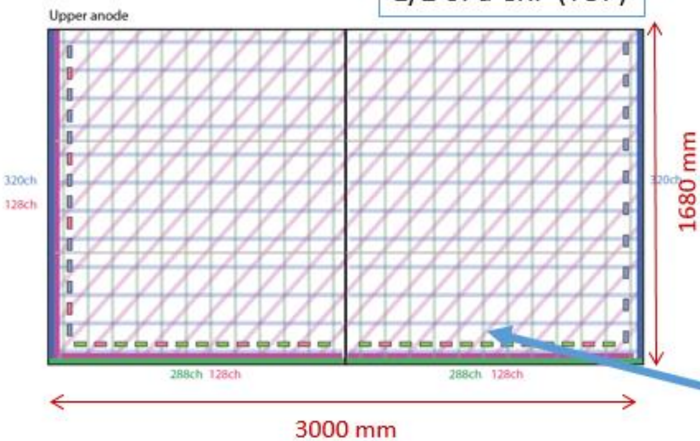
Anode electronics and Adapter Board interface

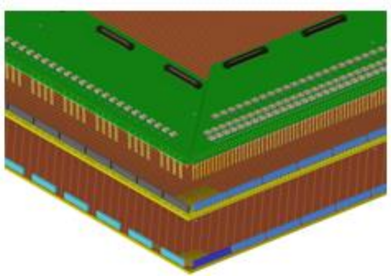
For the (48°, 0°, 90°) => 3200 channels / CRP

Top CRP: Readout electronic identical to Dual Phase completely accessible from cryostat roof

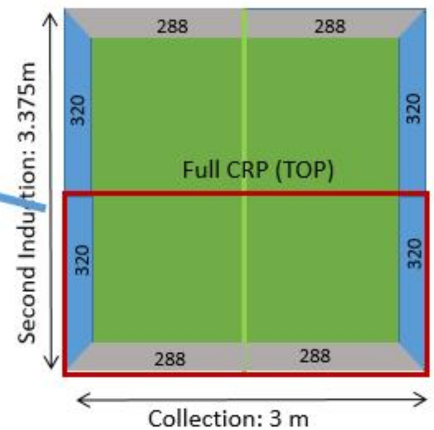
Bottom CRP: Cold electronic like for Horizontal Drift

1/2 of a CRP (TOP)

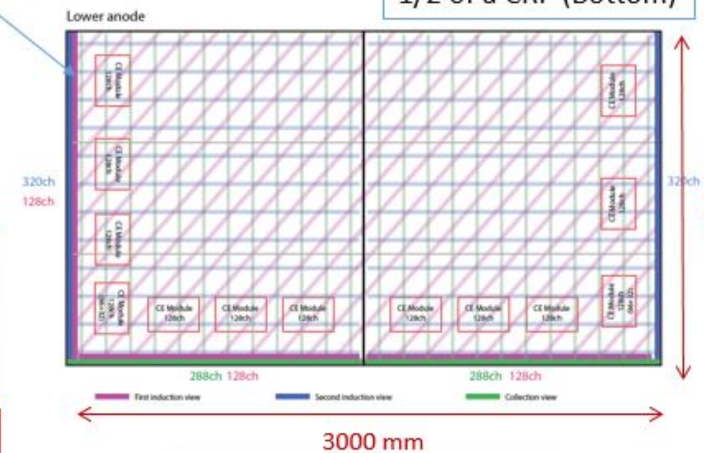


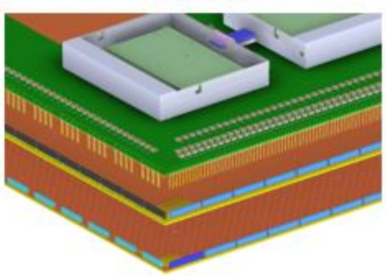


Channel count per ½ CRP
1st induction: 384
2nd induction: 640
collection: 576



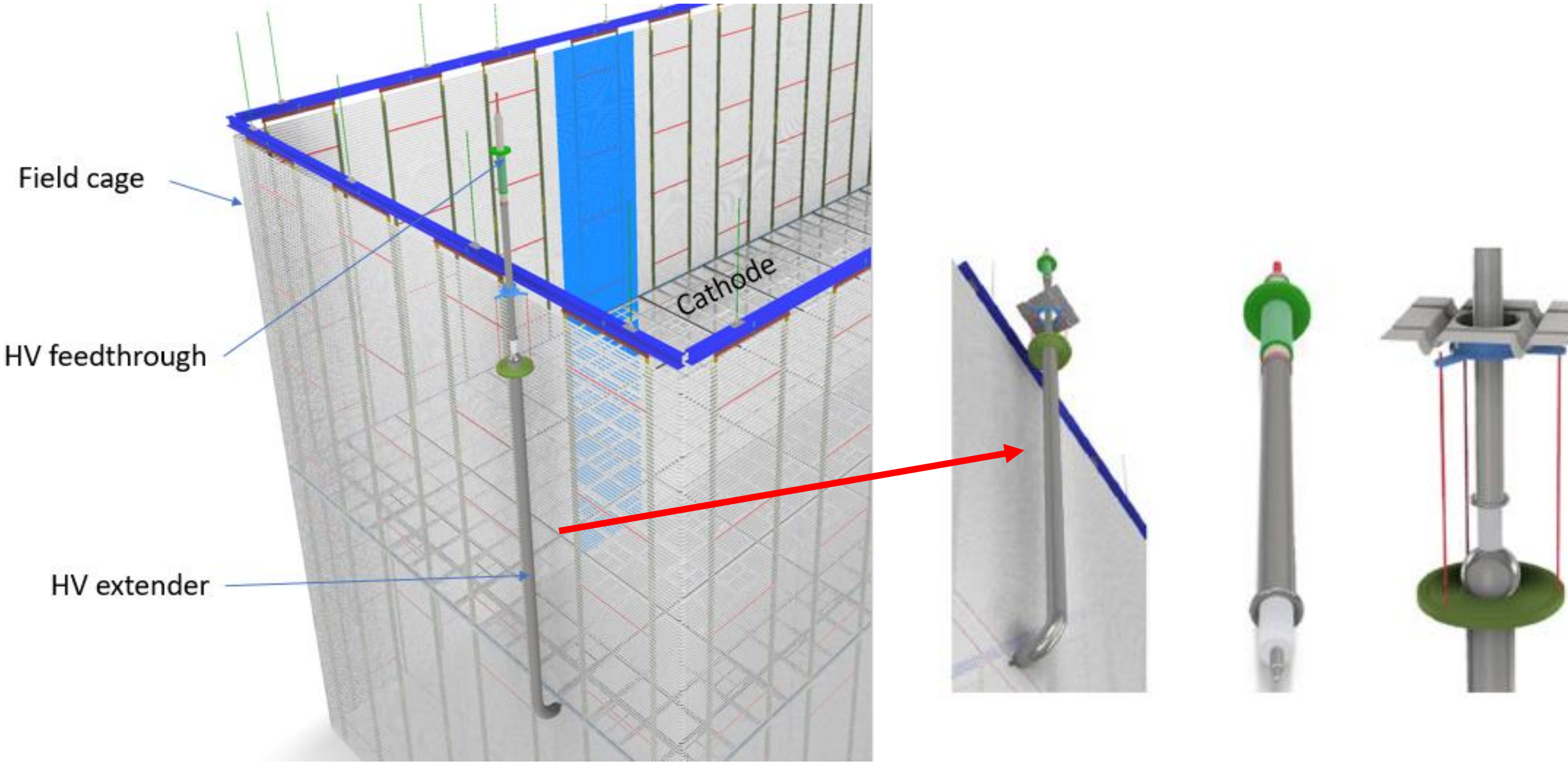
1/2 of a CRP (Bottom)





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, cathode suspended from CRPs superstructure
- 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

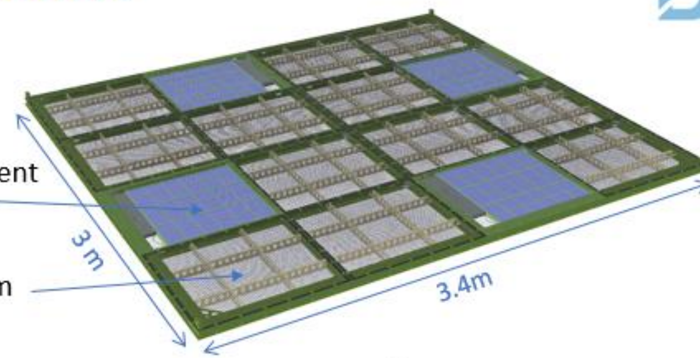


Cathode structure and interface with CRP superstructure

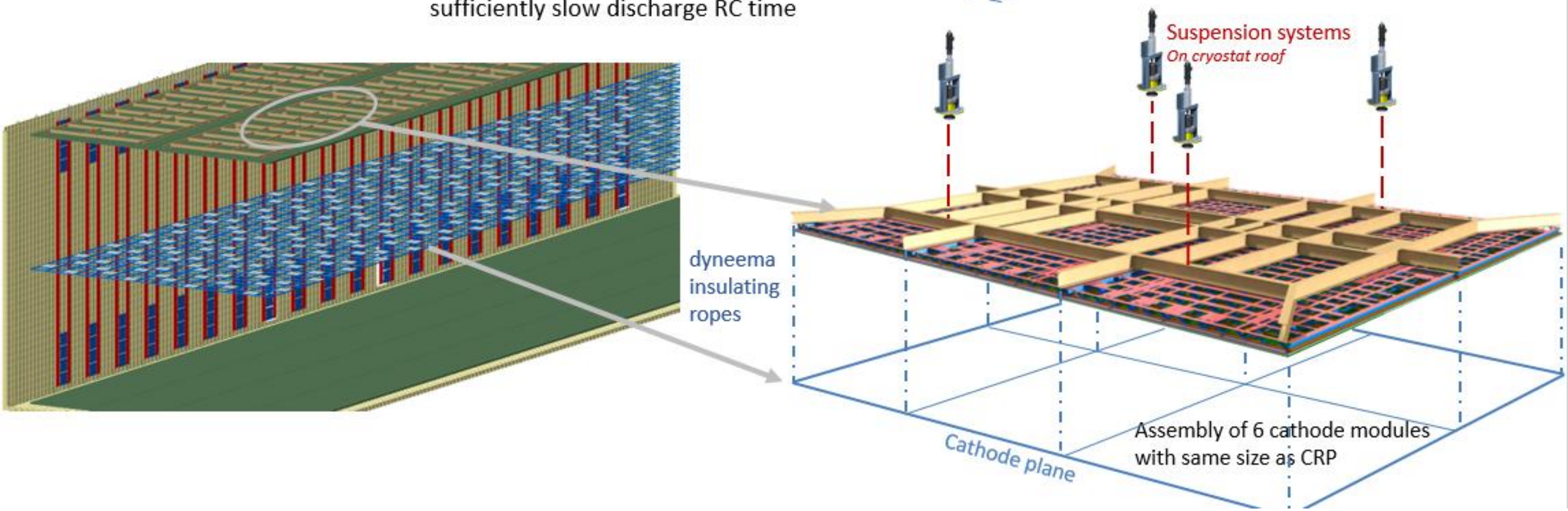
Cathode specifications:

- Planarity of the cathode plane: <20mm
- Weight: less than 10kg/m2
- Width: 50 mm
- Field distortion: < 1%

- Arapucas encased by highly transparent (~80%) metal wire mesh panels
- + perforated resistive panels to form two highly resistive surfaces with sufficiently slow discharge RC time

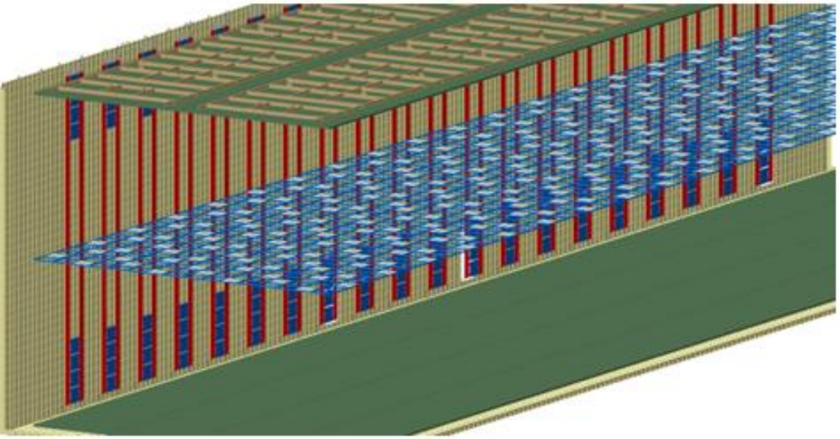


Structure: FRP beams

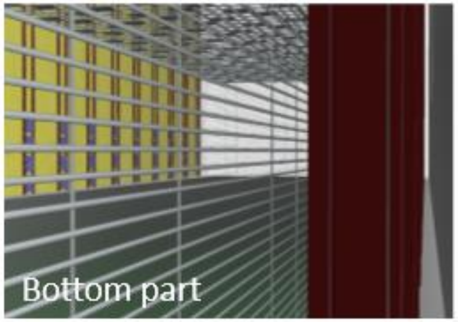


Photon detector system

Photon Detection System reference design (4π):

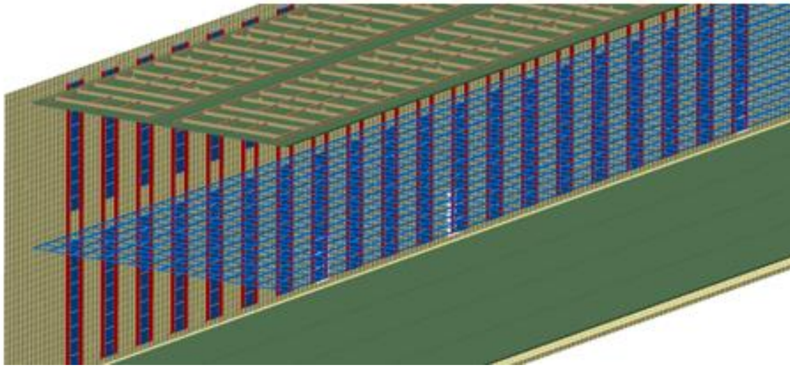


- 320 xArapuca (60x60cm^2) on cathode (2x115m^2) with analog readout
- 320 xArapuca (60x60cm^2) on cryostat membrane (115m^2) at 3m from cathode and standard FD1 readout
- 70% transparent field cage



Backup design : All arapucas on cryostat walls (no HV)

- 720 x-Arapuca (60x60cm^2) on cryostat membrane (260m^2). Standard FD1 readout with no PDS at 300kV.
- Xe doping, 70% transparent field cage



Vertical-Drift activities at the CERN Neutrino Platform in 2021-2023

- 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 (final integration tests before production for both HD and VD)

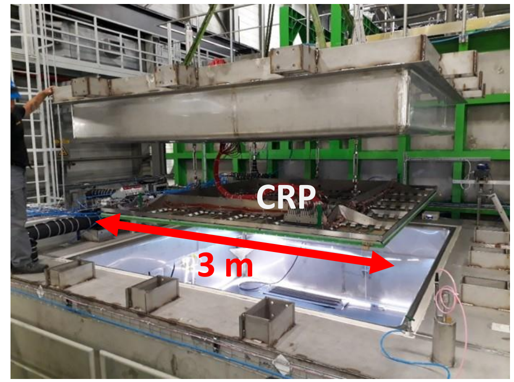
operation in NP02 cryostat foreseen in 2023

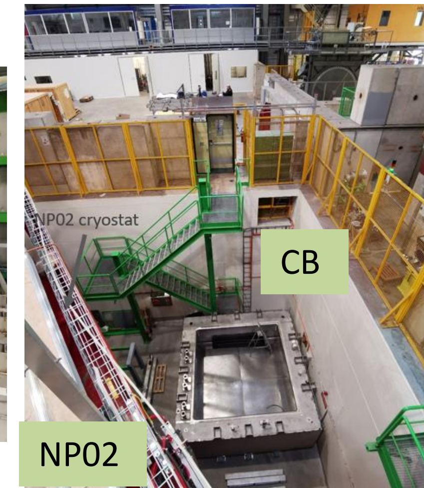
➢ **Cold-box tests of new CRPs**

- 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:**

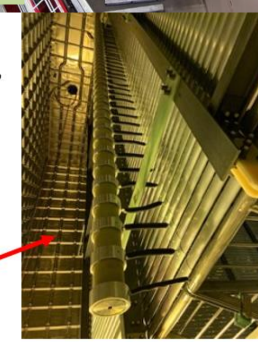
- Access to NP02 after warming up February 2021
- Removal and insertion of new HV extender March-June 2021
- Cool-down and filling of NP02 July-August 2021
- Operation and HV test September-November 2021

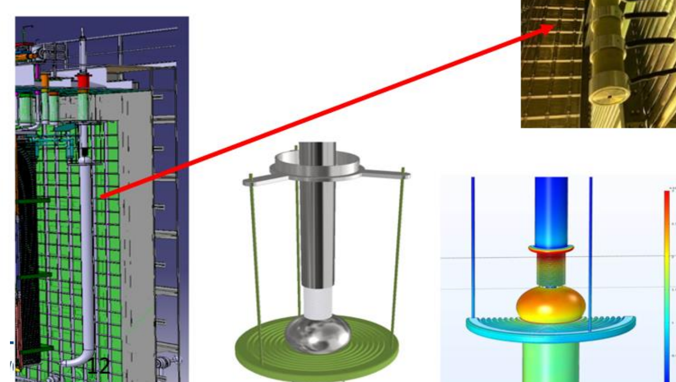




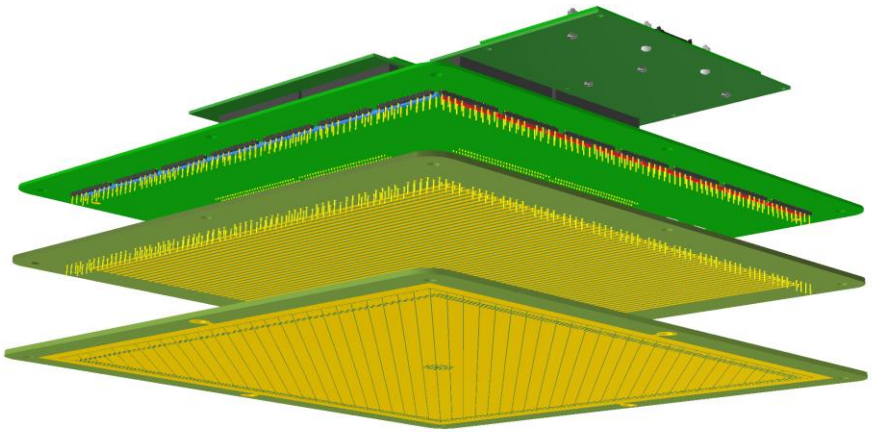
300kV test in NP02

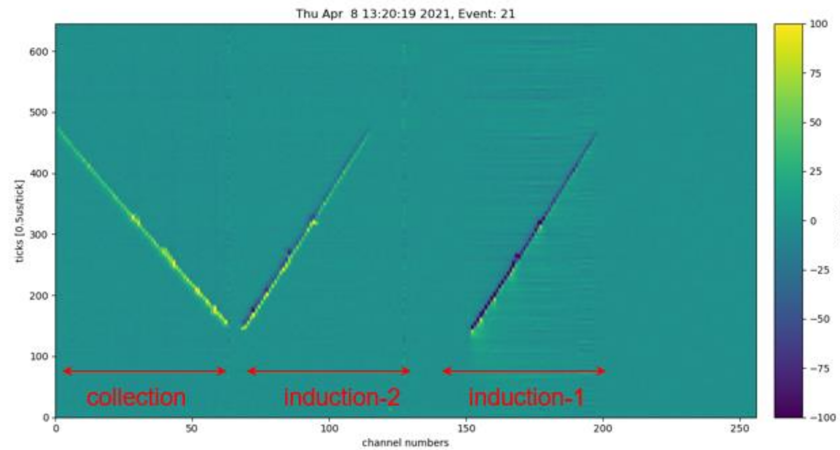
- ✓ New HV system (300KV supplier, feedthrough, extender, DAQ, ..)
- ✓ Fill NP02 and get purity
- ✓ 2-3 months operation
- ✓ No need to open the cryostat, insertion via man hole

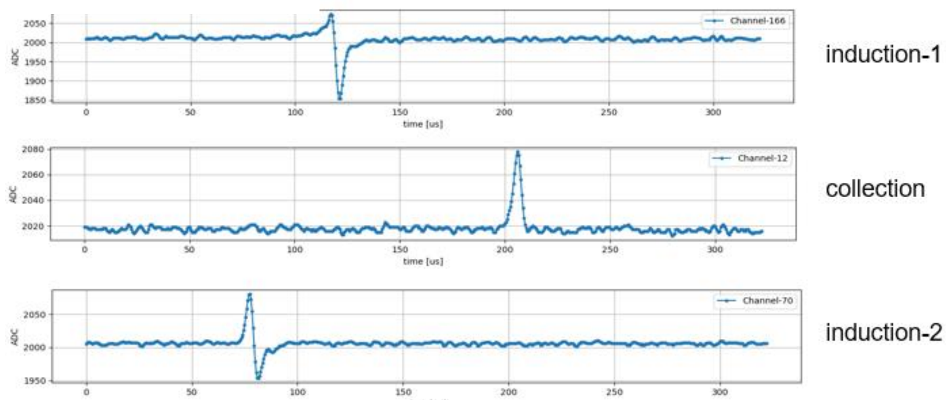


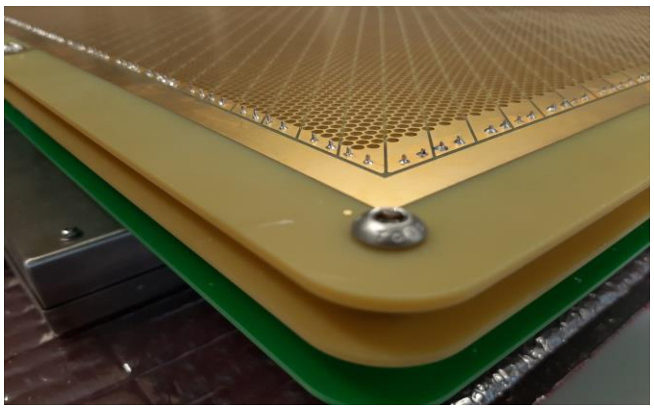


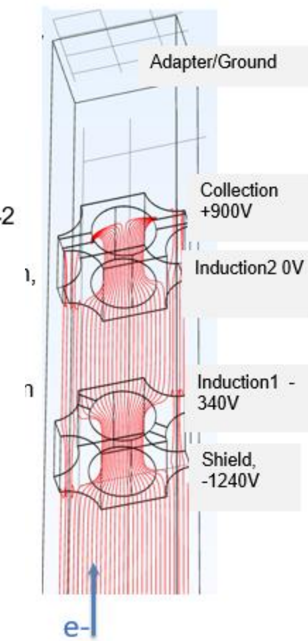
Perforated anodes tests at CERN Neutrino Platform with the 50l TPC test stand (3 views test)



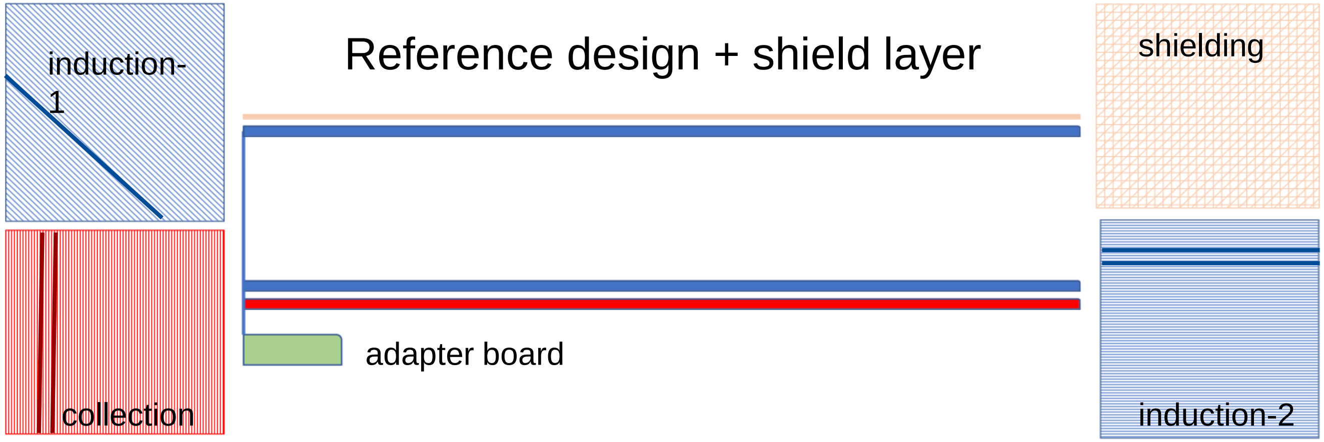




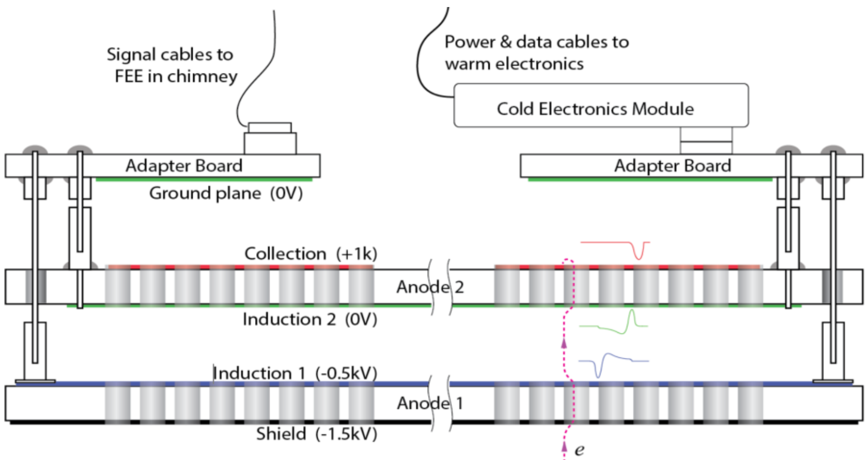


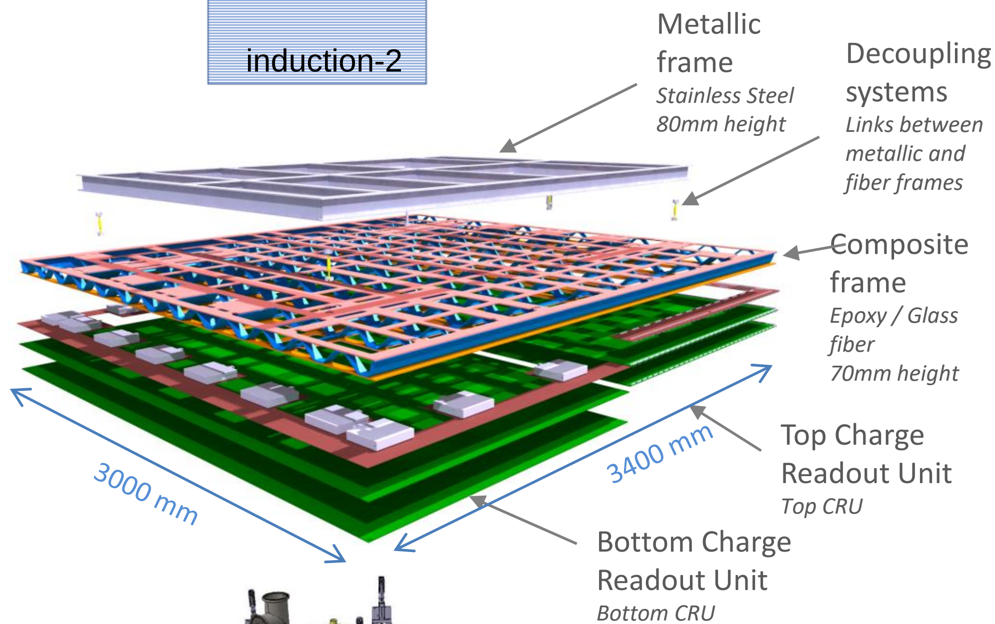


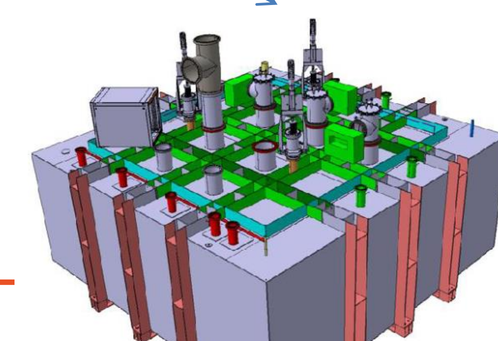
Anode PCB for the first cold-box tests in 2021



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







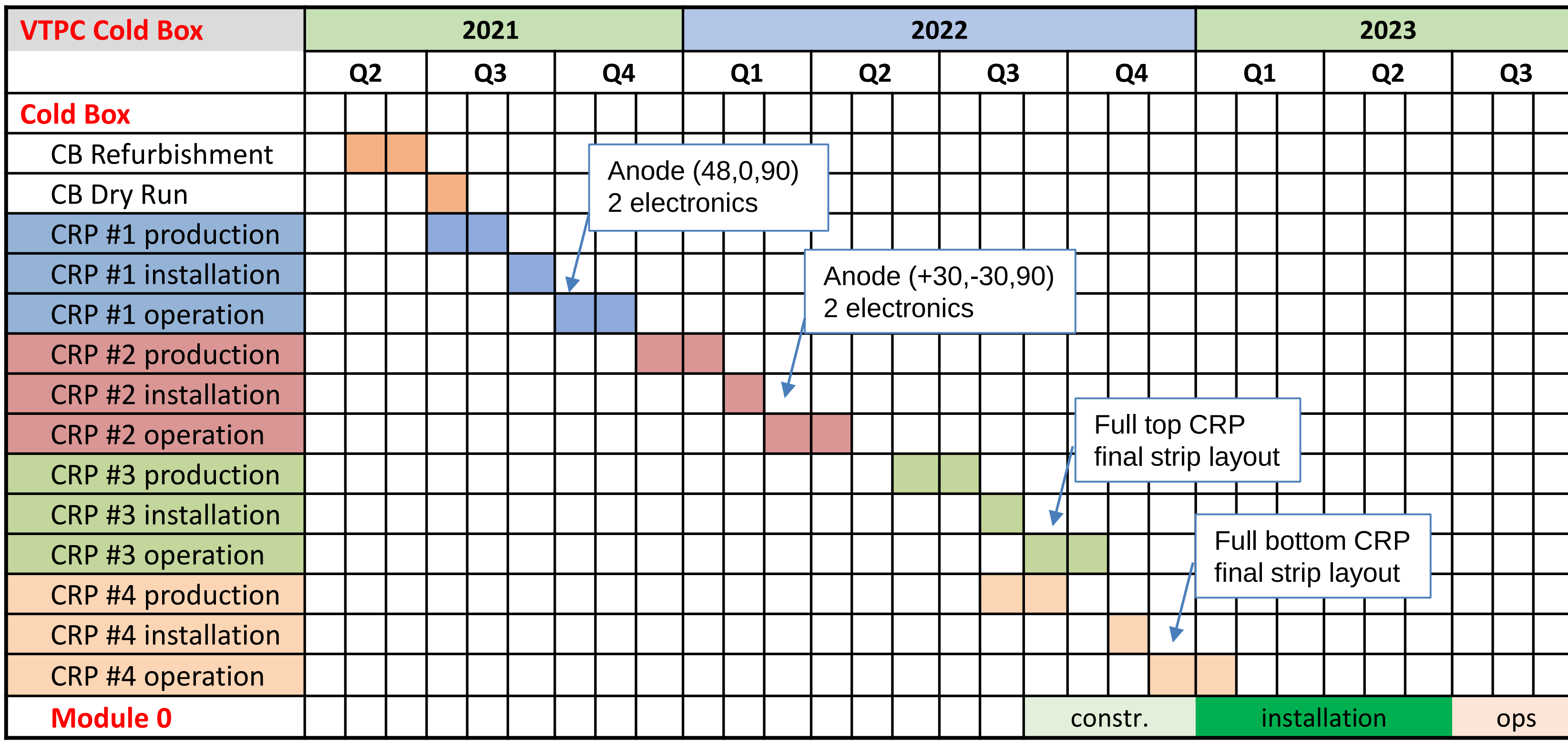
Configuration allowing assessing simultaneously the 2-views and 3-views performance in the same anodes setup to be used for the first CRP tests in 2021 → CRP shared as ½ top, ½ bottom CRPs

DUNE

CRP test plan for Cold Box and Module 0

The CRP plan for 2022 includes:

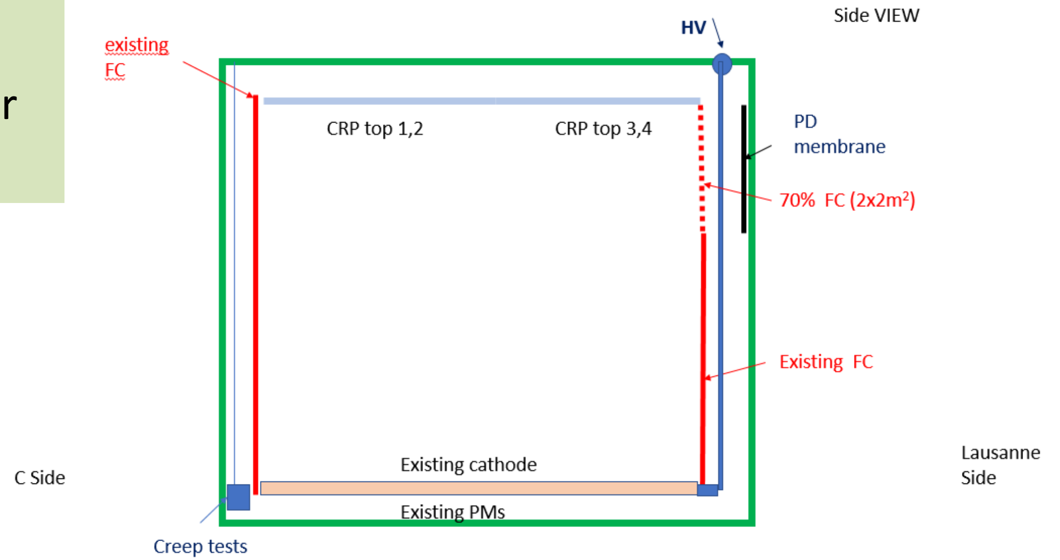
- Construction and installation of a second CRP to test different strip orientation in March 2022
- Followed by a third final top CRP after decision on strip orientation in May 2022.
- A fourth (final bottom CRP) is expected possibly from US by fall 2022.



These tests will allow a complete definition and fully instrument module-0.

NP02/protoDUNE-DP cryostat

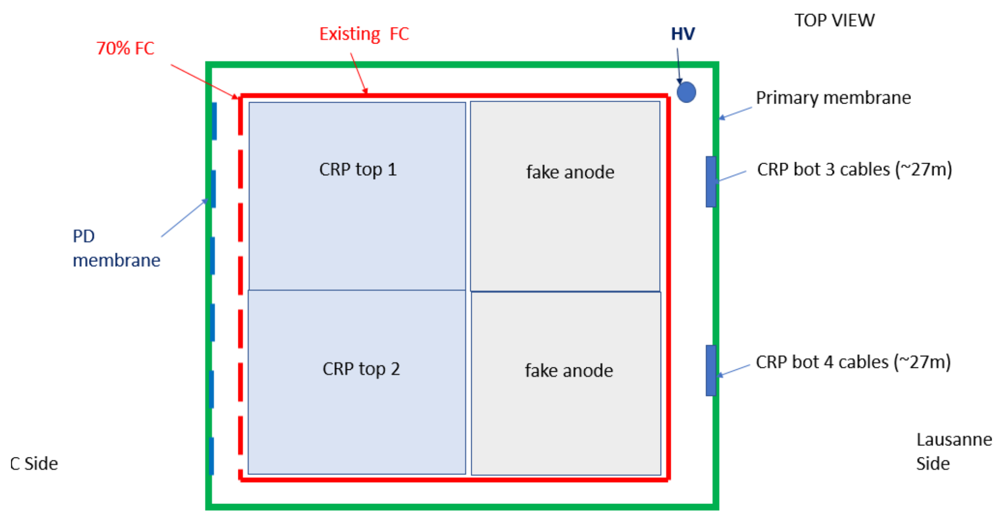
2021 Configuration For new HV extender test

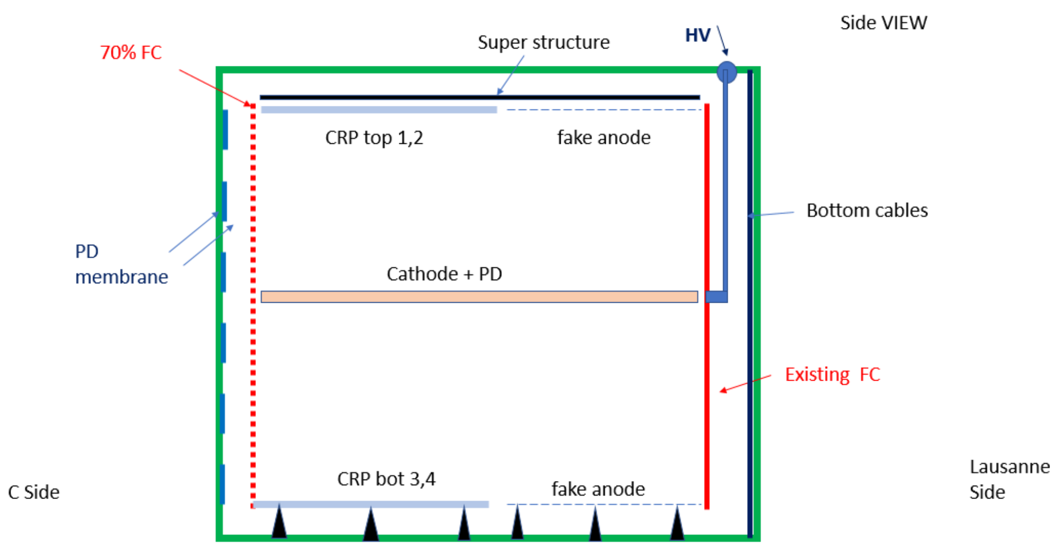


- 70% field cage on one wall for 2x2 m^2 in vertical
- Behind PDs (NP04 Arapucas+existing PDs)
- 6m drift
- HV = 300 KV
- Existing DP readout
- Existing Cathode
- New extender and feedthrough
- Existing PMs on the bottom
- Creep tests

NP02 Cryostat

Vertical Drift Module-0 Configuration 2023





Conclusions:

- LBNF infrastructure construction activities well advanced, main caverns excavation started !

- Long-standing activity for DUNE in France, started with the R&D phase in 2006 and prototyping activity at the CERN Neutrino Platform since 2014 (3x1x1 and protoDUNE dual-phase detectors). Completion of the foreseen 1 year operation program of ProtoDUNE dual-phase in August 2020

- Evolution in 2020 from 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.

- Now benefiting of the extraordinary support of the TGIR (prepared since 2017) to advance quickly towards construction of the 2nd DUNE FD together with the convergence of several favorable international factors in the US and at CERN

- Detailed engineering aspects of the DUNE far detector module have been worked 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 2nd FD. Cryostat contribution from CERN.

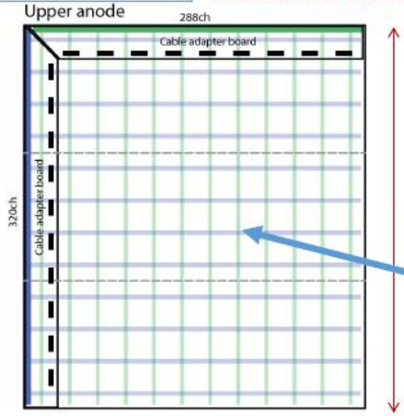
- The experimental activities and cold-box tests program (2021-2023) have been redefined to support the integrations tests for the Vertical Drift. Production activities for FD2 expected to start in 2023.

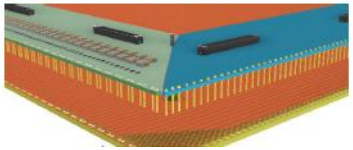
- An exciting period in front of us !

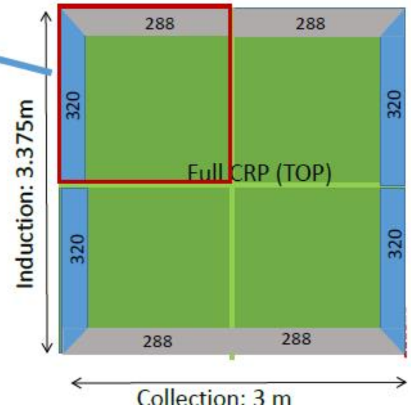
Anode electronics and Adapter Boards

¼ of a CRP (TOP)

Readout electronic identical to Dual Phase

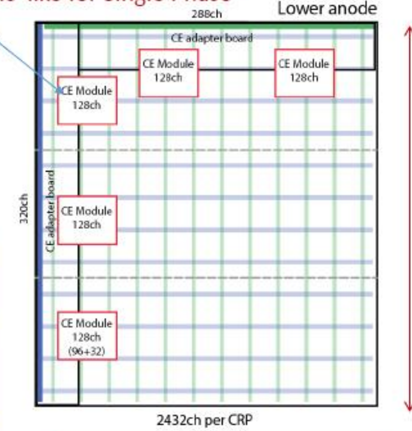


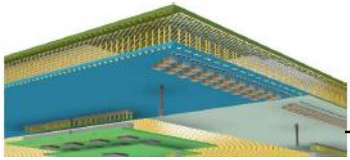


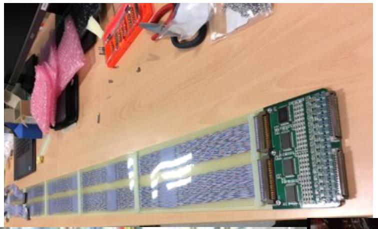


¼ of a CRP (Bottom)

Cold electronic like for Single Phase



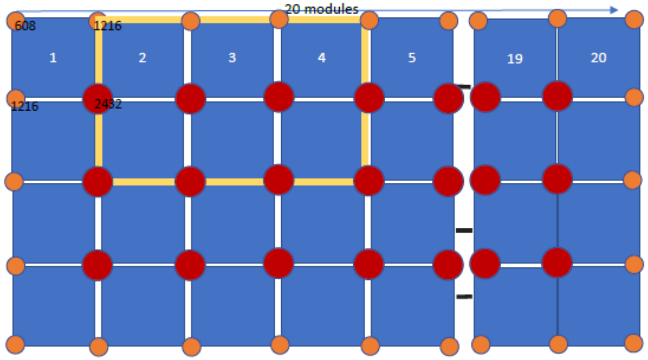




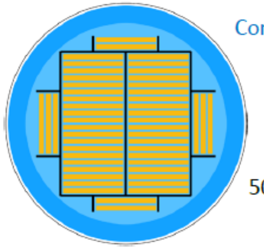
Top drift electronics from Dual-Phase design

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

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