Presentation of the global project and scientific stakes

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Conseil Scientifique IN2P3
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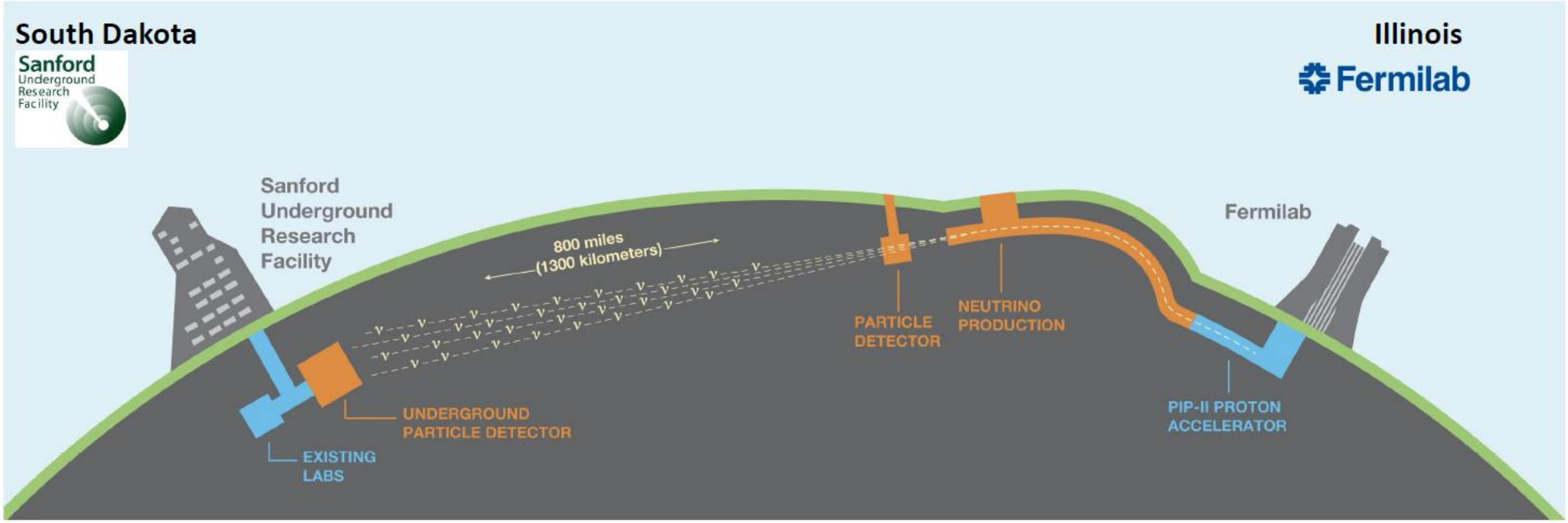
The Deep Underground Neutrino Experiment (DUNE) supported by the Long Baseline Neutrino Facility (LBNF)



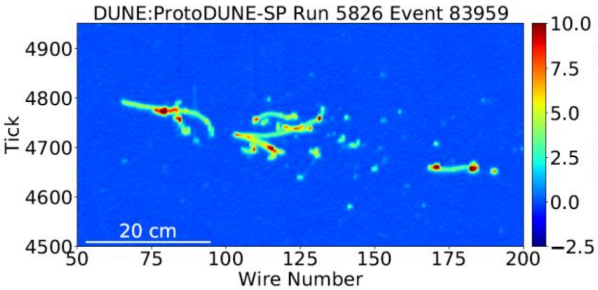
- The 1300 km baseline enables unambiguous measurement of the neutrino mass ordering
- The detector's on-axis location provides for a wide-band energy spectrum of neutrinos enabling detailed fitting of the oscillation parameters, including δ_{CP}
- The liquid argon technology for the Far Detector, at a depth of 1480 m, fully exploits the wide-band neutrino beam
- The Near Detector complex provides control of systematic uncertainties

Liquid Argon Technology

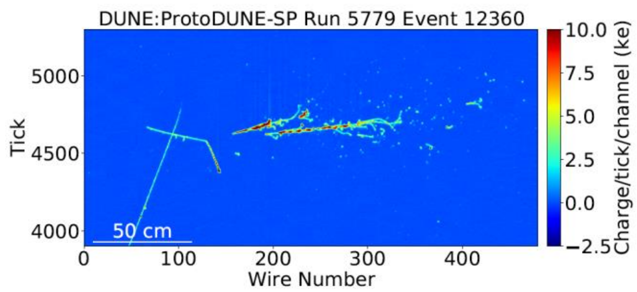
- Use of LAr for the detection of high energy particles first suggested by L.W. Alvarez (1968)
- To mitigate the unsuccessful attempts to achieve charge amplification in LAr, B.A. Dolgoshein (1970) proposed and tested the main features of dual-phase argon detectors, in which ionization electrons produced in the liquid are extracted to the argon vapor on top and are there amplified.
- LAr TPCs proposed by C. Rubbia (1977) and H.H. Chen (1978)
    - Thanks to the high mobility and low diffusion of electrons in LAr, large LAr volumes can be operated as TPCs, providing high-quality imaging and high-resolution energy measurements from the detection of the ionization charge
    - The abundant scintillation light emitted by excited argon diatomic molecules can be used to determine the absolute event time (~10 ns resolution), to provide a self-trigger with no bias on the charge detection, and for calorimetry
    - High readout granularity, can sample electromagnetic showers down to a few % of a radiation length (as Gargamelle with Freon & NOMAD)
    - LAr TPCs overcome the deficiencies of both bubble chambers (limited in size and sensitive for short times) and large-size calorimetric detectors (coarser granularity)
    - **Ideal detectors for physics in the MeV to GeV range**
    - Many LArTPC detectors operating in the last ~15 years: ICARUS, ArgoNEUT, MicroBooNE, LARiAT, CAPTAIN, protoDUNE_SP, 3x1x1 m^3, protoDUNE_DP

Events from LAr TPC detectors

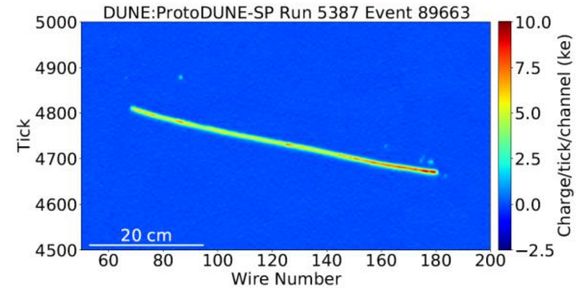
ProtoDUNE-SP, single phase



(a) A 0.5 GeV/c electron candidate.

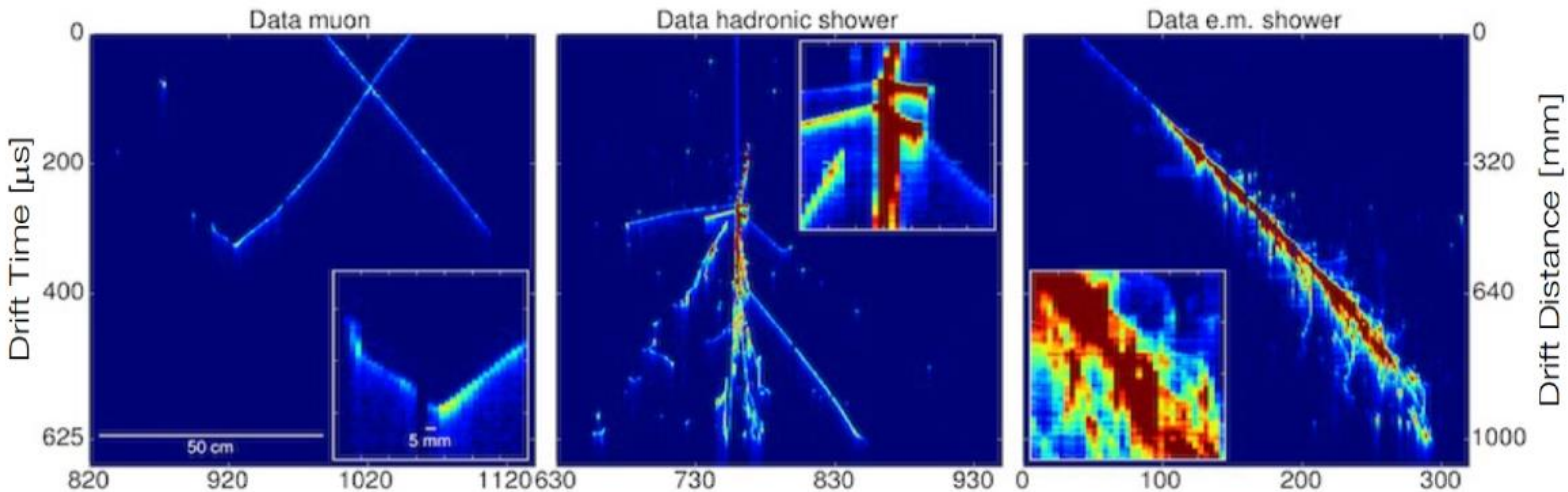


(f) A 2 GeV/c pion charge exchange candidate.

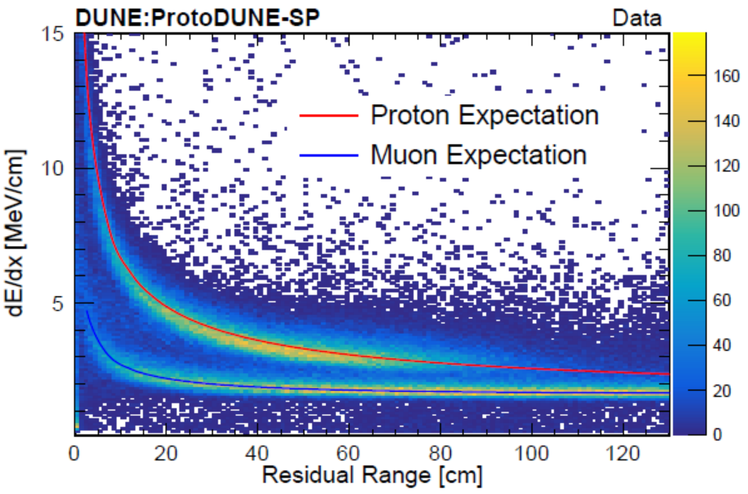


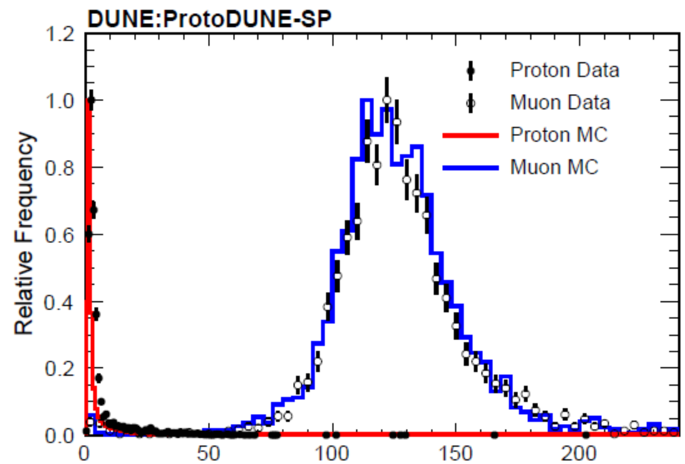
(e) A 1 GeV/c stopping proton candidate.

3x1x1 m^3, dual phase

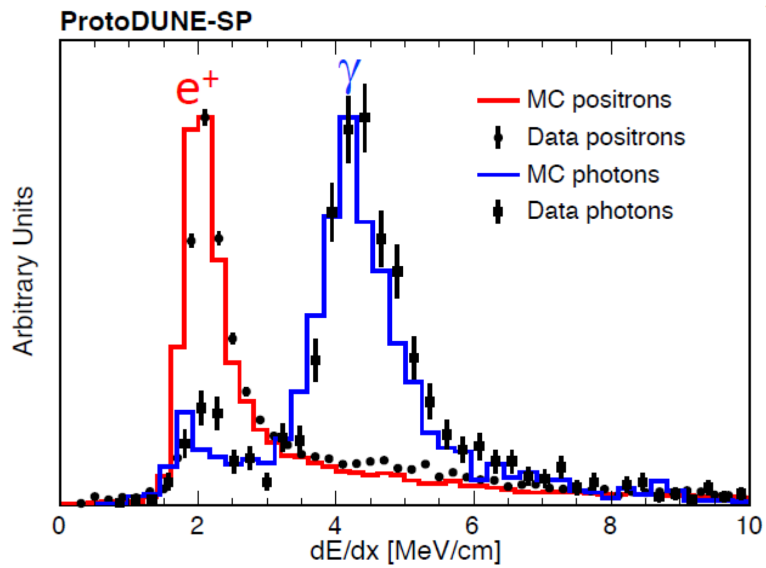


Particle Identification in protoDUNE-SP





$$\zeta = \frac{1}{n_T}\sum_j \frac{\left[\left(\frac{dE}{dx}\right)_j(\text{Data}) - \left(\frac{dE}{dx}\right)_j(\text{MC Proton})\right]^2}{\sqrt{\left[\sigma\left(\frac{dE}{dx}\right)_j(\text{Data})\right]^2 + \left[\sigma\left(\frac{dE}{dx}\right)_j(\text{MC Proton})\right]^2}}$$

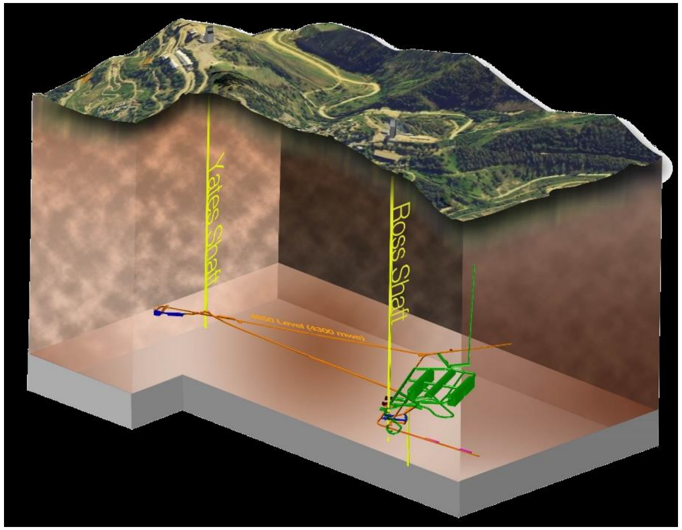


Good e/γ separation crucial for electron neutrino ID

The physics program of DUNE

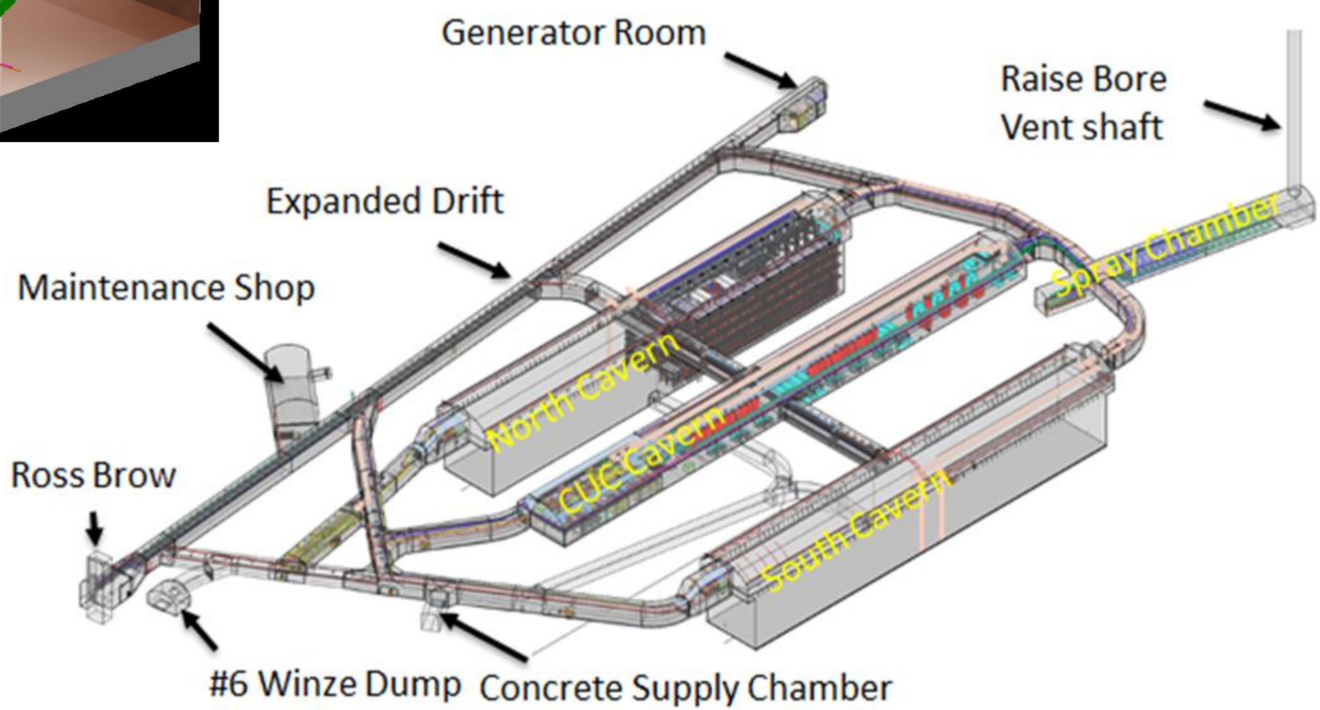
- Long-baseline wide-band neutrino beam
  - Measurement of CP violation and determination of the mass hierarchy in a single experiment with spectral information
- Deep underground location allows access to astrophysical neutrinos
  - Supernova neutrino burst detection – sensitive to ν_e component
  - Atmospheric neutrino – capability for ν_τ identification
  - Solar neutrinos – potential for detection of hep flux
- Massive detector with excellent tracking and calorimetric information
  - Search for proton decay – preferred channel $p \rightarrow \bar{\nu} K^+$
- Long baseline + higher energy neutrino beam
  - ν_τ appearance, NSI searches

The LBNF Far Site Facility



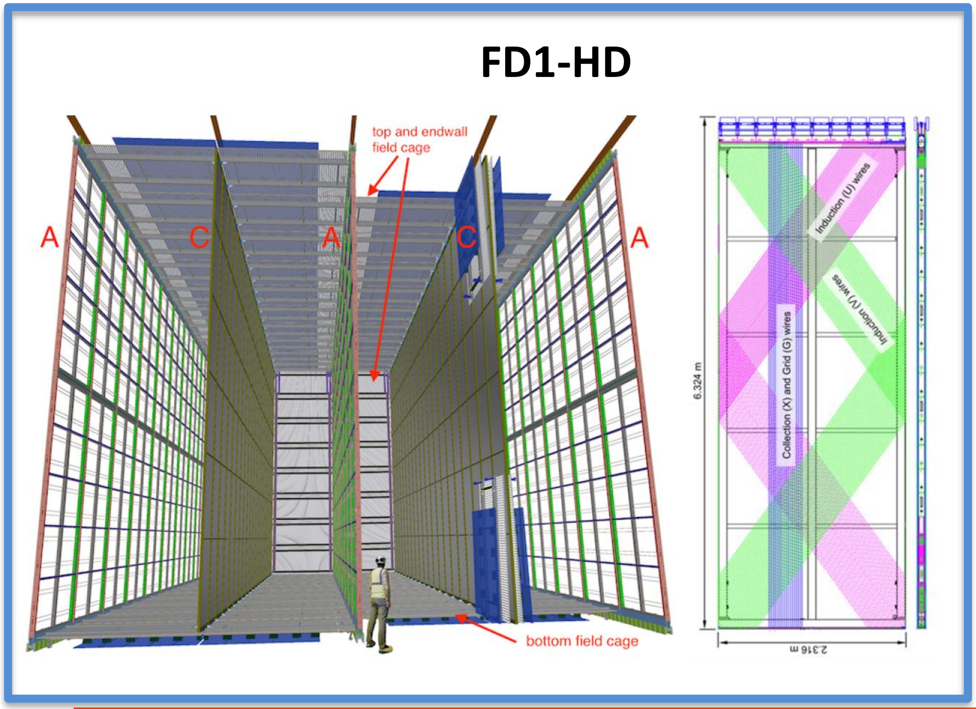
2 x Detector caverns:
145m L x 20m W x 28m H
to house four 17.5 kt total mass modules

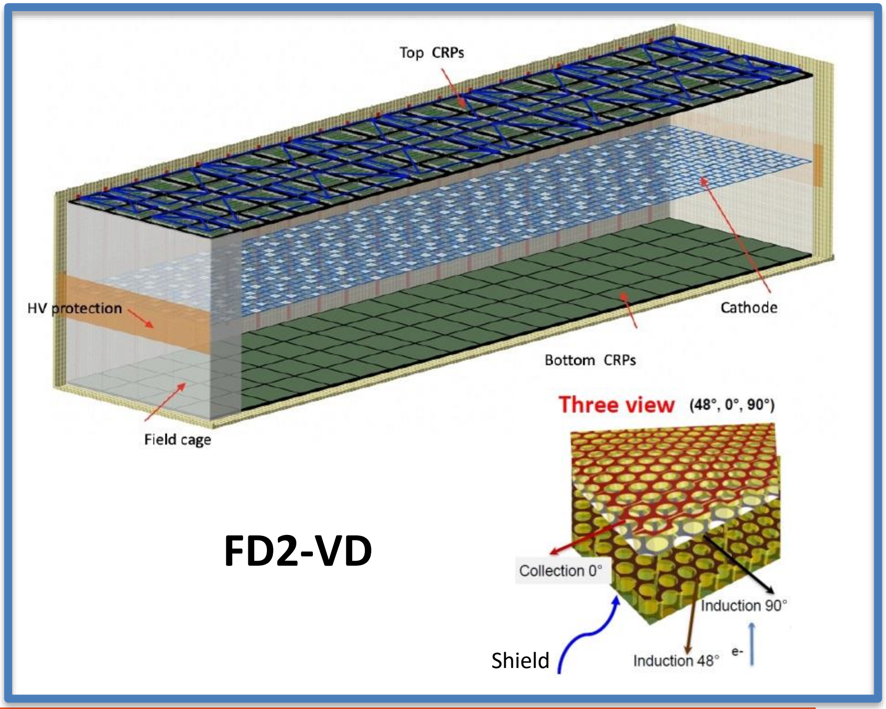
1 x Central utility cavern:
180m L x 20m W x 11m H



The DUNE Far Site Detectors

- The ultimate DUNE detector will comprise 4 Far Detector (FD) modules
- The Collaboration currently focuses on delivering 2 FD modules by 2029
  - FD1-HD: single-phase horizontal drift detector with anode wire planes (APA) readout
  - FD2-VD: single-phase vertical drift detector with perforated PCB's with segmented electrodes (strips) as Charge Readout Planes (CRP)





LBNF Far Site Status

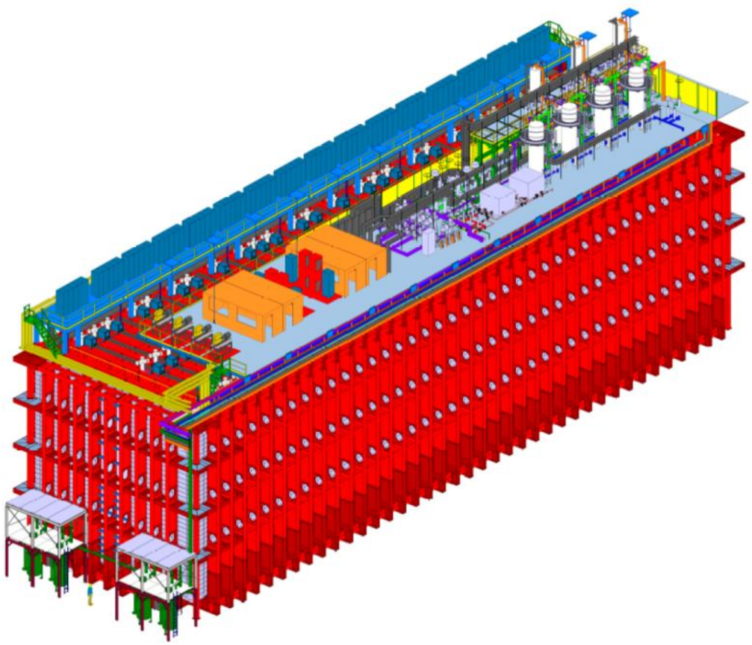
- ✓ Reliability Project upgrades completed
  - significant improvements, including new hoist system and refurbished shaft
- ✓ Pre excavation work completed
  - work to move excavated rock from one mile underground to the surface and deposit in the Open Cut
- Excavation work construction of three DUNE caverns underway
  - Work stated in April 2021; will finish April 2024

Rock conveyor in operation

Drilling charge holes

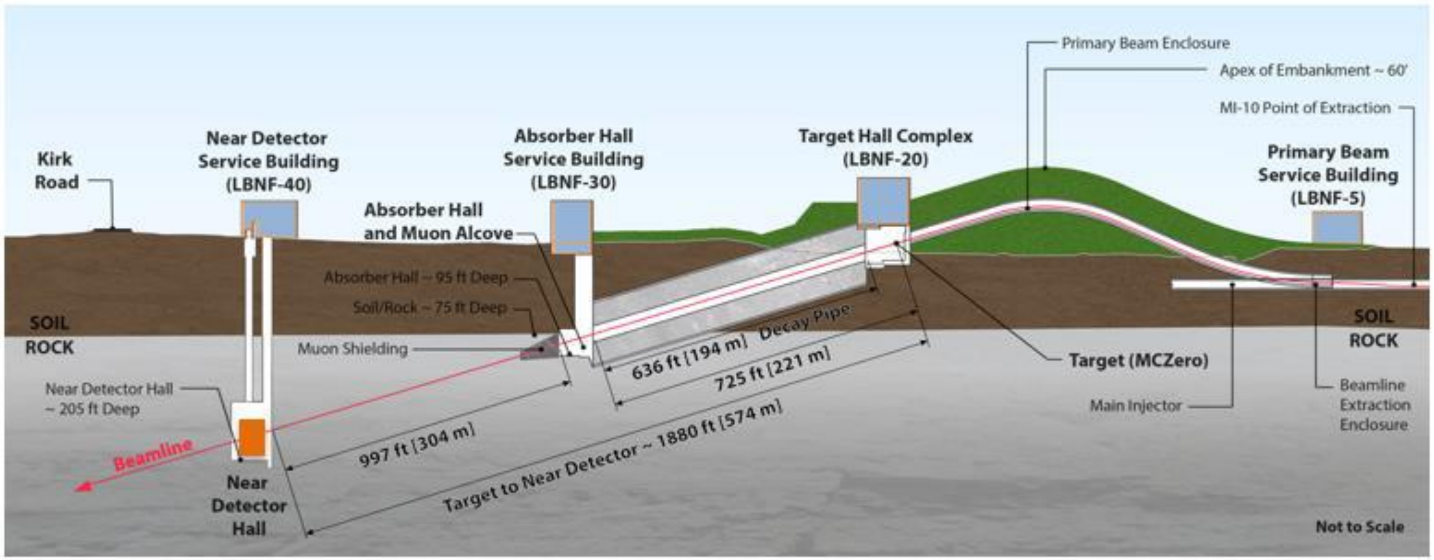
Far Site Cryogenic Infrastructure

- In addition to the 1st cryostat, CERN Council agreed to provide 2nd cryostat module at June 2021 meeting
- Nitrogen system acquired via commercial contract (in initial award process)
- Argon system (receiving facility on surface, purification, recirculation and condensing systems, internal cryo systems) with in-kind contributions from international partners



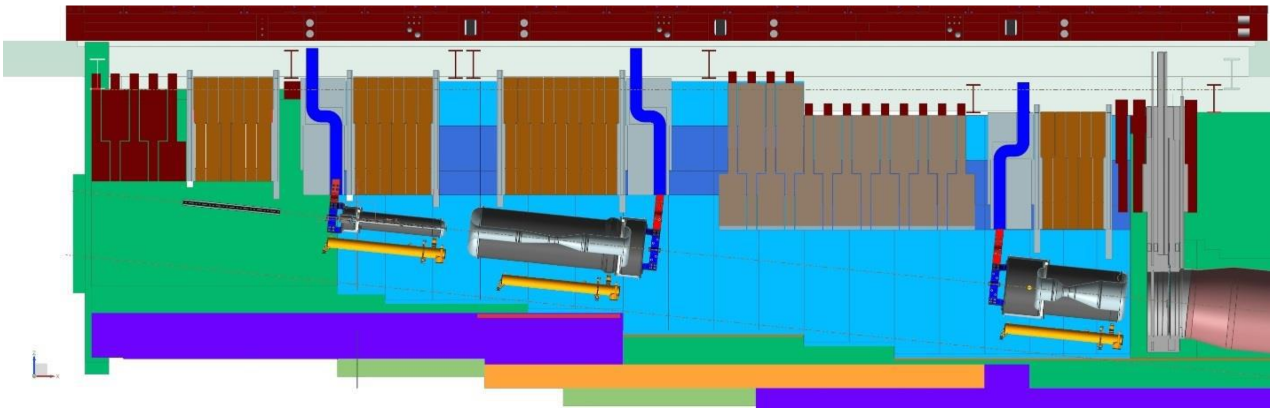
- Warm structure final design completed in Nov 2018
- Membrane design for FD1-HD completed by GTT in April 2019
- Membrane design for FD2-VD in progress

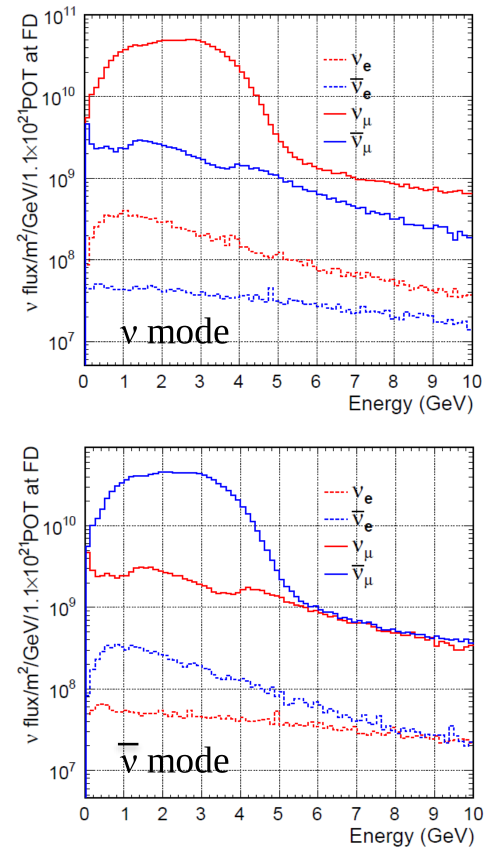
The Near Site Facility



- High intensity primary protons (60 - 120 GeV energy range) on a graphite target
- Designed for 1.2 MW initial proton beam power, upgradeable to 2.4 MW
- PIP II upgrade of the current LINAC necessary to reach 1.2 MW (with participation of IN2P3 and CEA)
- Presently achieved record beam power of 803 kW in March 2021 (no PIP II)

Neutrino Beamline

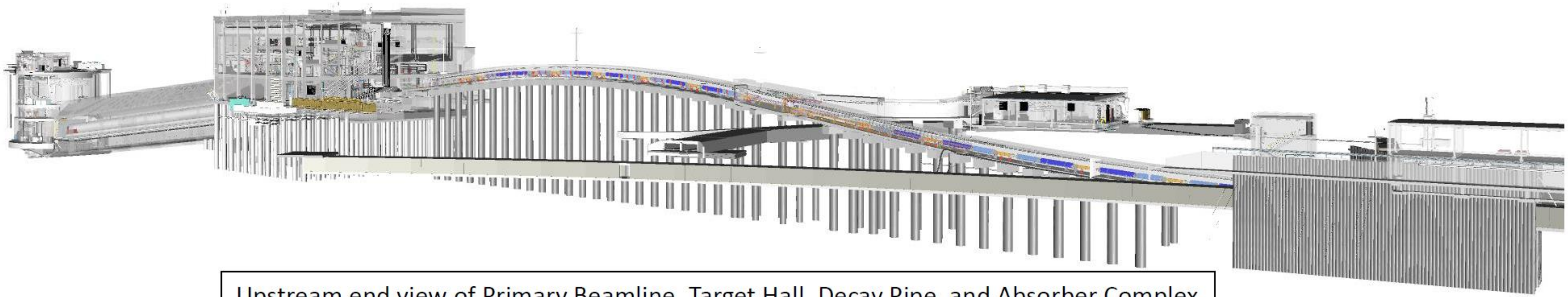




- Neutrino beamline at a slope of 5.8°
- Design optimized with a genetic algorithm using sensitivity to CP violation as input to the optimization process
- 3 horn focusing system, water cooled, peak current of 300 kA
- He cooled cylindrical graphite target, inserted in Horn 1
- N_2 filled target chase
- He filled decay pipe, 194 m long, 4 m Ø

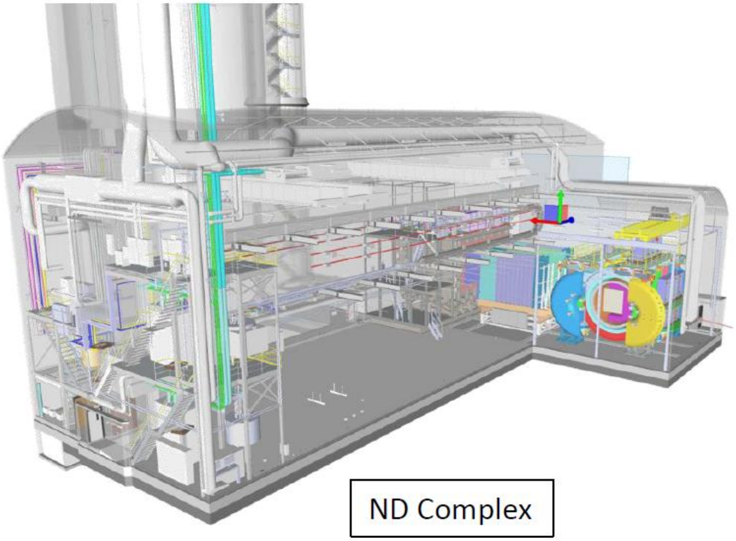
Near Site Facility Conventional Facilities Status

- Final designs completed
- Proceeding with the contracting process



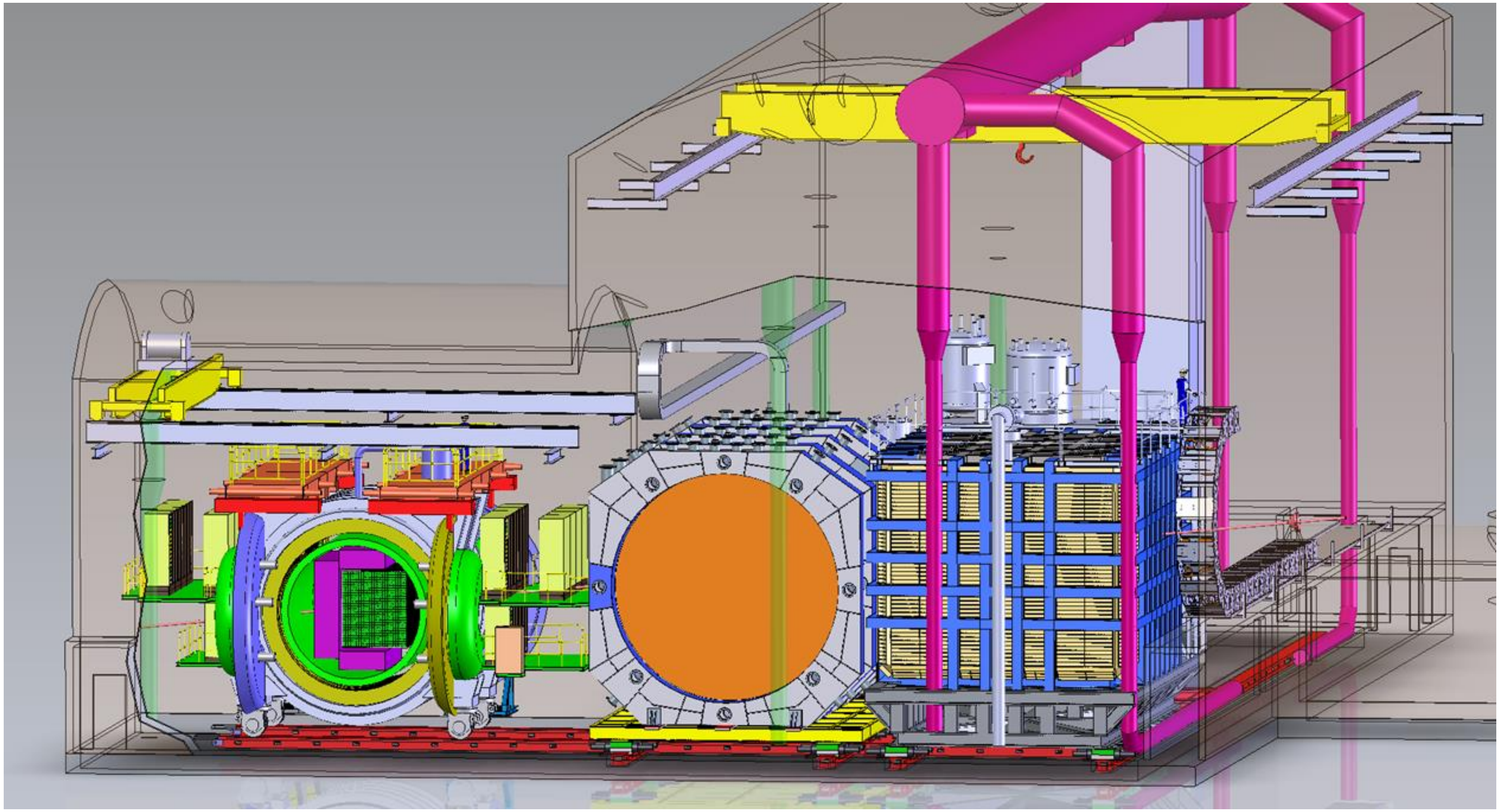
Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber Complex

Site preparation for LBNF Beamline facilities completed on schedule in October 2020.



ND Complex

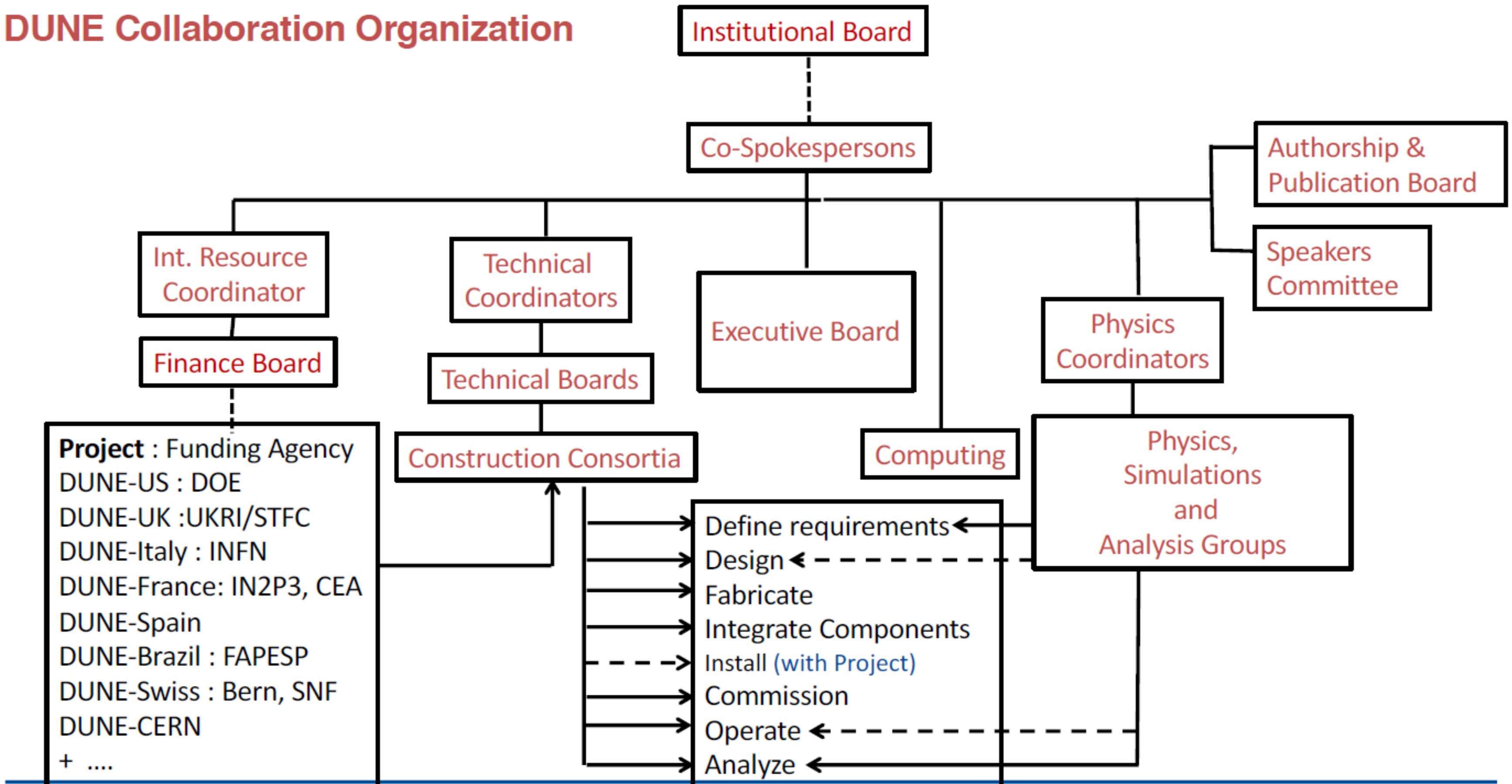
The Near Detector CDR Reference



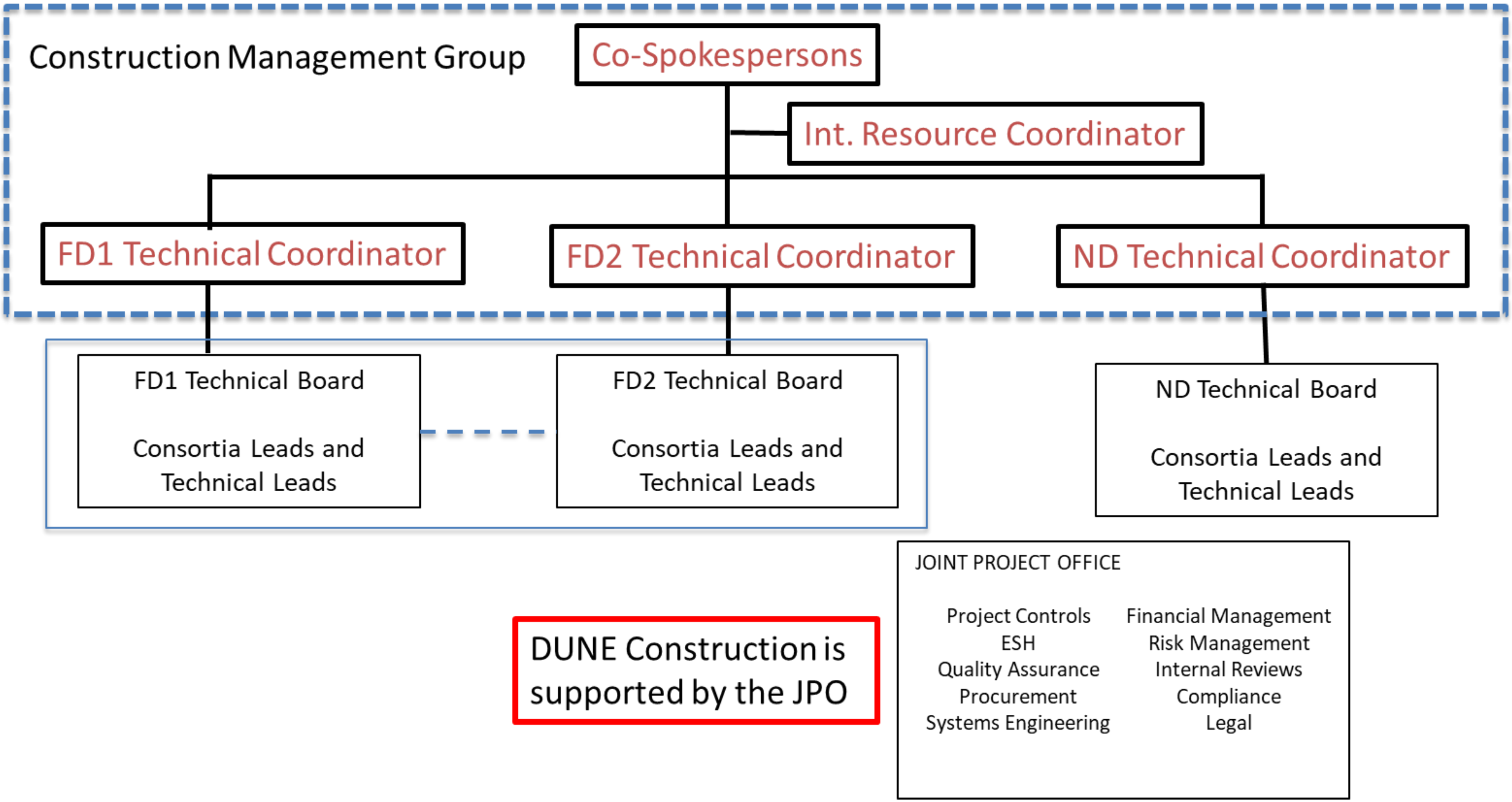
- Measures the neutrino beam rate and spectrum to predict un-oscillated event rates in the far detector
- Constrains systematic uncertainties for oscillation measurements

The DUNE Collaboration

1347 Collaborators, 204 institutions in 33 countries



DUNE Detector Consortia 1 of 2



DUNE Detector Consortia 2 of 2

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

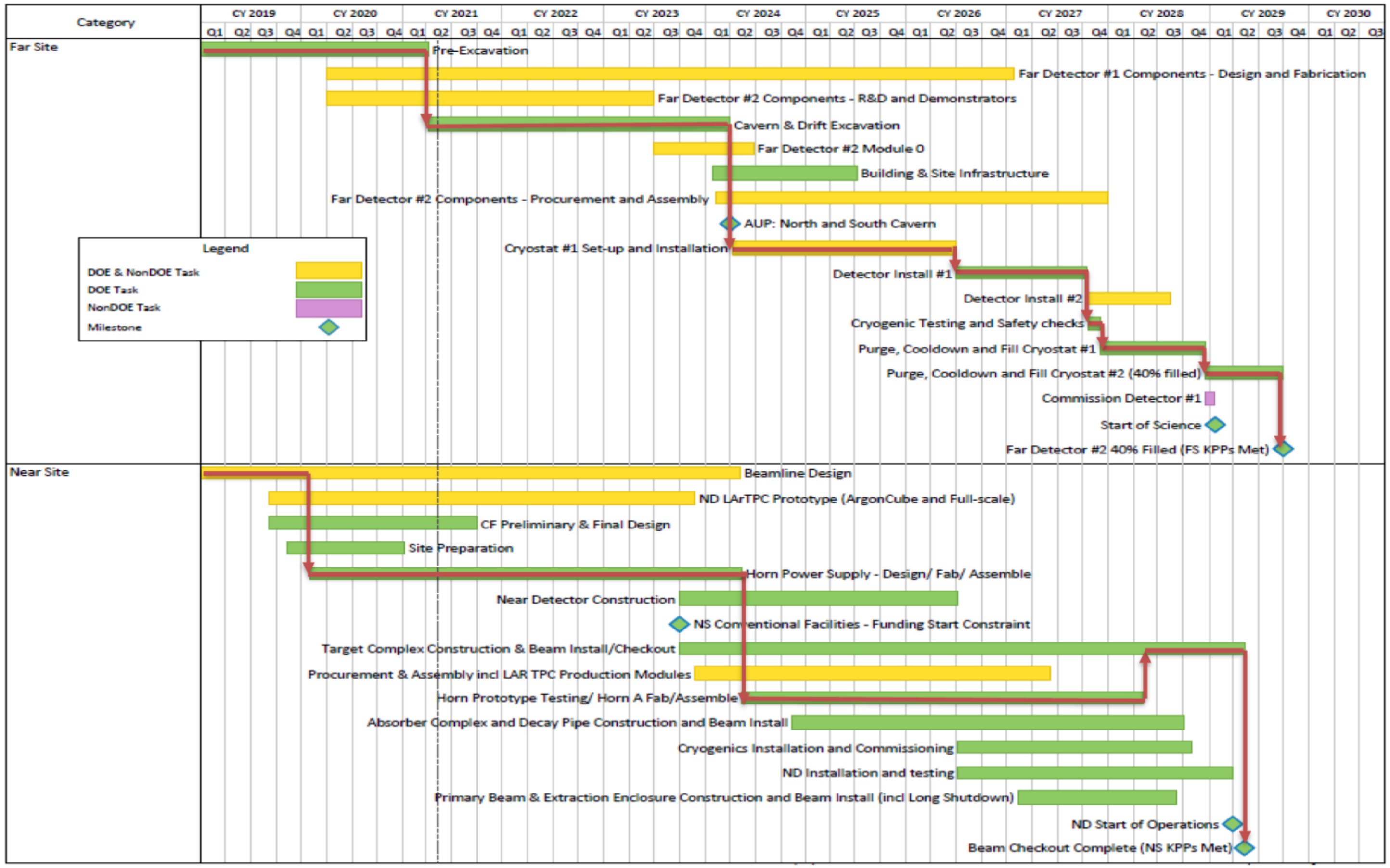
- DAQ/Slow Controls: G. Lehmann Miotto (CERN), TLs: A. Thea (RAL), A. Kaboth (RHUL)
- Computing: H. Schellman (Oregon State), TLs: M. Kirby (FNAL), A. McNab (Manchester)

*proto-Consortium

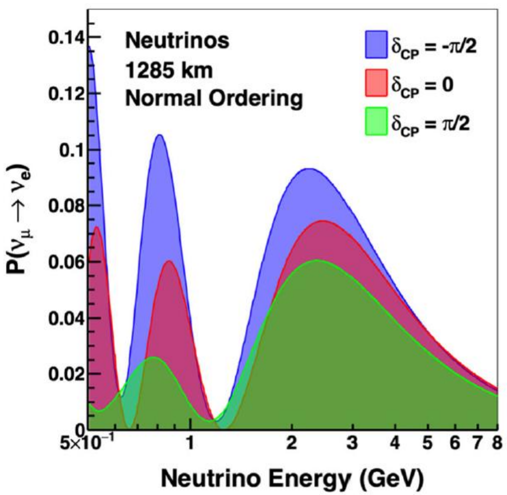
LBNF/DUNE summary schedule

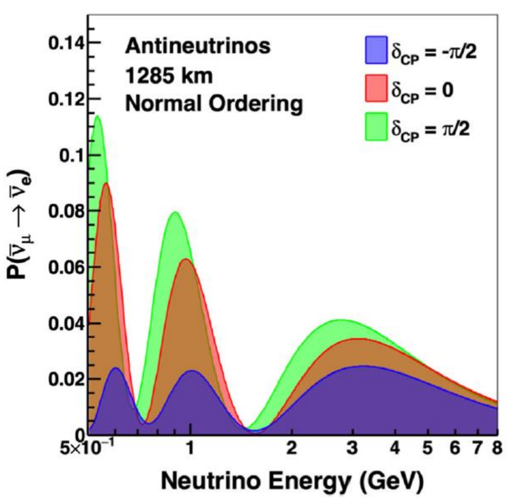
- Schedule for FD2 is estimated
- Schedule is dependent on funding profile which will not be finalized until CD-2 baseline is approved by DOE

NS/ FS Critical Paths

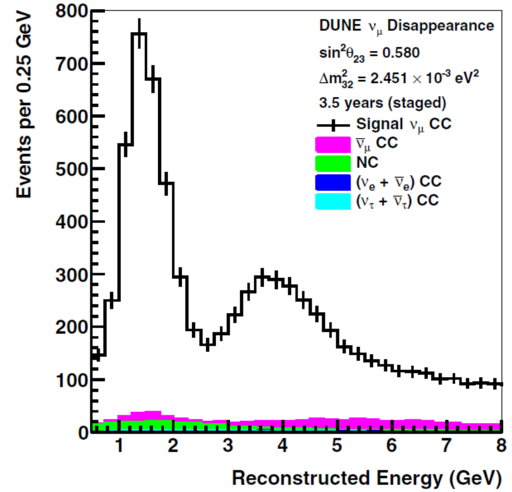


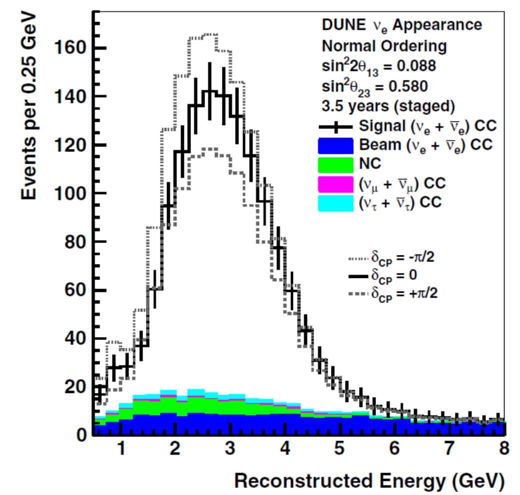
Long-baseline neutrinos: the measurements

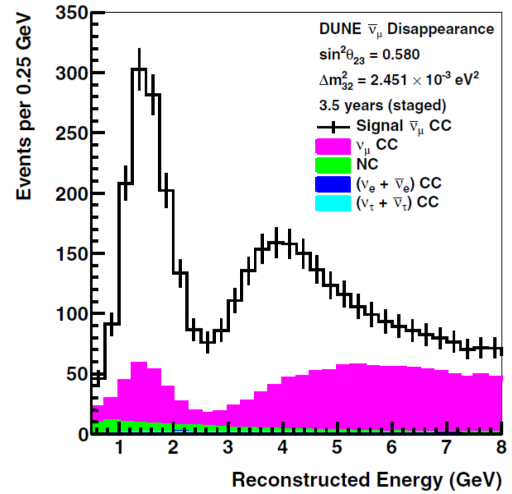


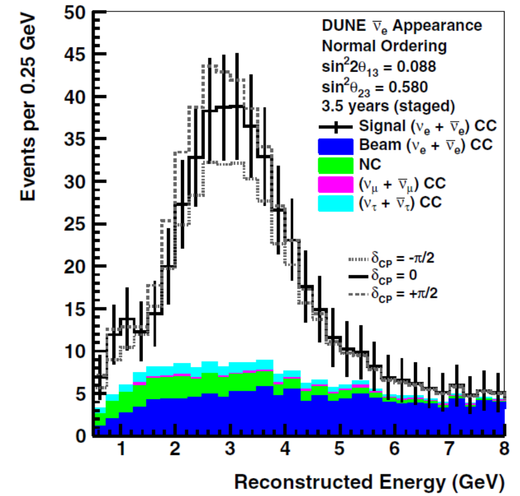


120 kt MW yr





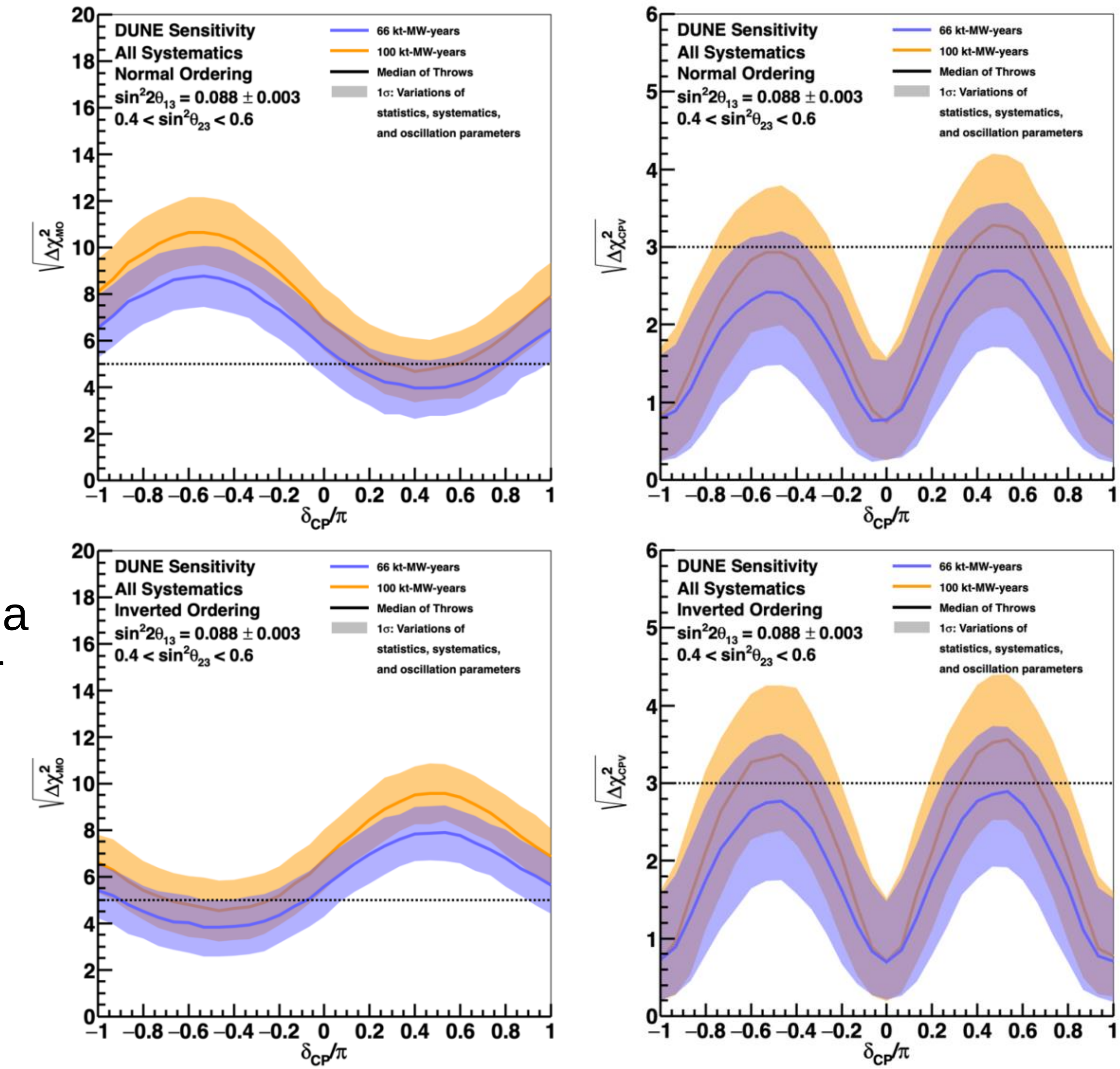




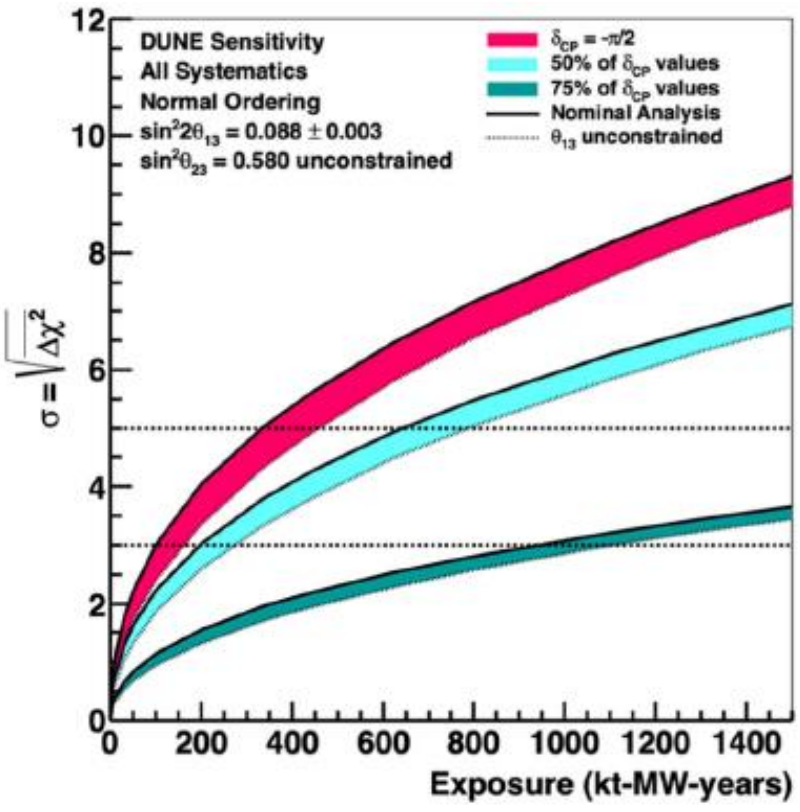
Long-baseline neutrinos: sensitivities at low exposures

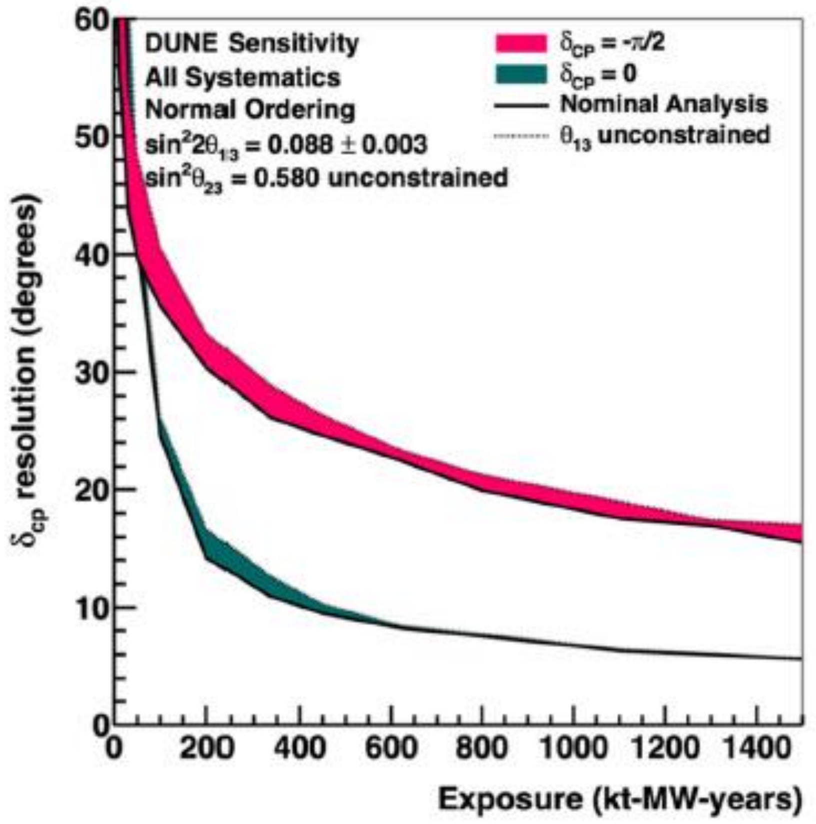
- DUNE will unambiguously resolve the neutrino mass ordering at a 3σ (5σ) level, with a 66 (100) kt-MW-yr exposure

- DUNE can measure CPV at a 3σ level with a 100 kt-MW-yr exposure for the maximally CP-violating values $\delta_{CP} = \pm\pi/2$



Long-baseline neutrinos: ultimate sensitivities





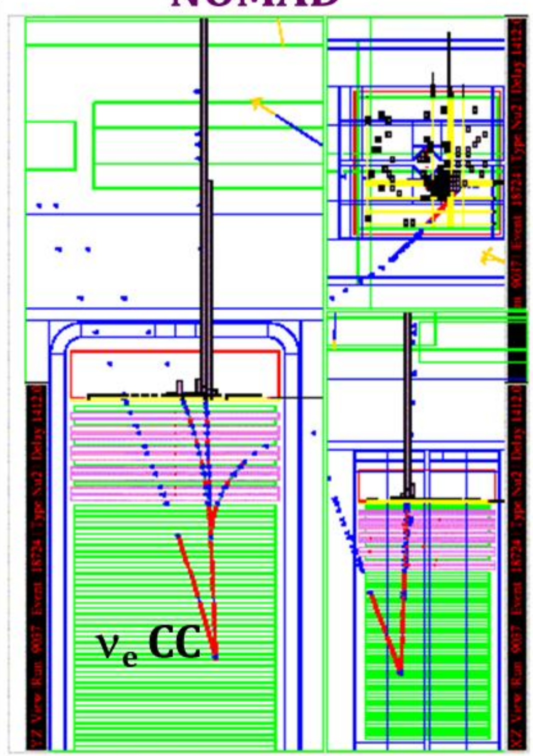
DUNE and Hyper-K

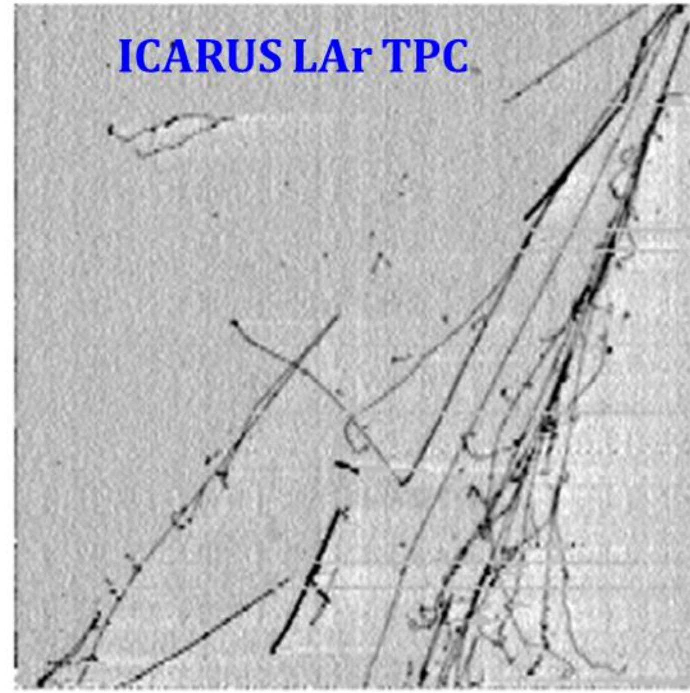
- An important similarity between DUNE and Hyper-K
  - Very large neutrino detectors are only feasible by instrumenting the surface of the detector and not the volume
  - DUNE FD2-VD is the optimized solution for single-phase LAr, derived from the main concepts of the dual-phase LAr TPC
- Hyper-K (shorter baseline, off-axis beam & Water Cerenkov detectors) and DUNE (longer baseline, wide band beam & LAr detector) are more complementary than competitive, both for neutrino physics and proton decay searches
  - Higher statistics & lower details vs Lower statistics & higher details
  - DUNE sensitivity to the shape of the oscillation spectrum and the larger matter effects allow simultaneous measurements of δ_{CP} and mass ordering
  - Systematics are very different, which is a good thing for difficult measurements like CP violation with neutrinos and proton decay searches
- Healthy competition is very welcome. “To be the first is good, but to be first and to be right is better” (S. Ting)

Conclusions

- LAr technology has seen an incredibly large growth in the last ~15 years
  - while 2 DUNE detectors are defined, the remaining 2 may still take advantage of new developments
- LBNF/DUNE well in progress
  - Excavation of the far site caverns is in progress
  - Module 0 components for FD1-HD are being constructed (1st APA delivered at CERN)
  - FD2-VD finalizing configuration with a focused test plan
- Long baseline + wide-band ν beam + LAr detector allow simultaneous measurements of δ_{CP} and mass ordering. Unique sensitivity to ν_τ appearance
- DUNE & HYPER-K: two approaches with very different systematics

NOMAD





Bubble ∅ (mm)	3
Density (g/cm^3)	1.5
X_0 (cm)	11.0
λ_T (cm)	49.5
dE/dx (MeV/cm)	2.3

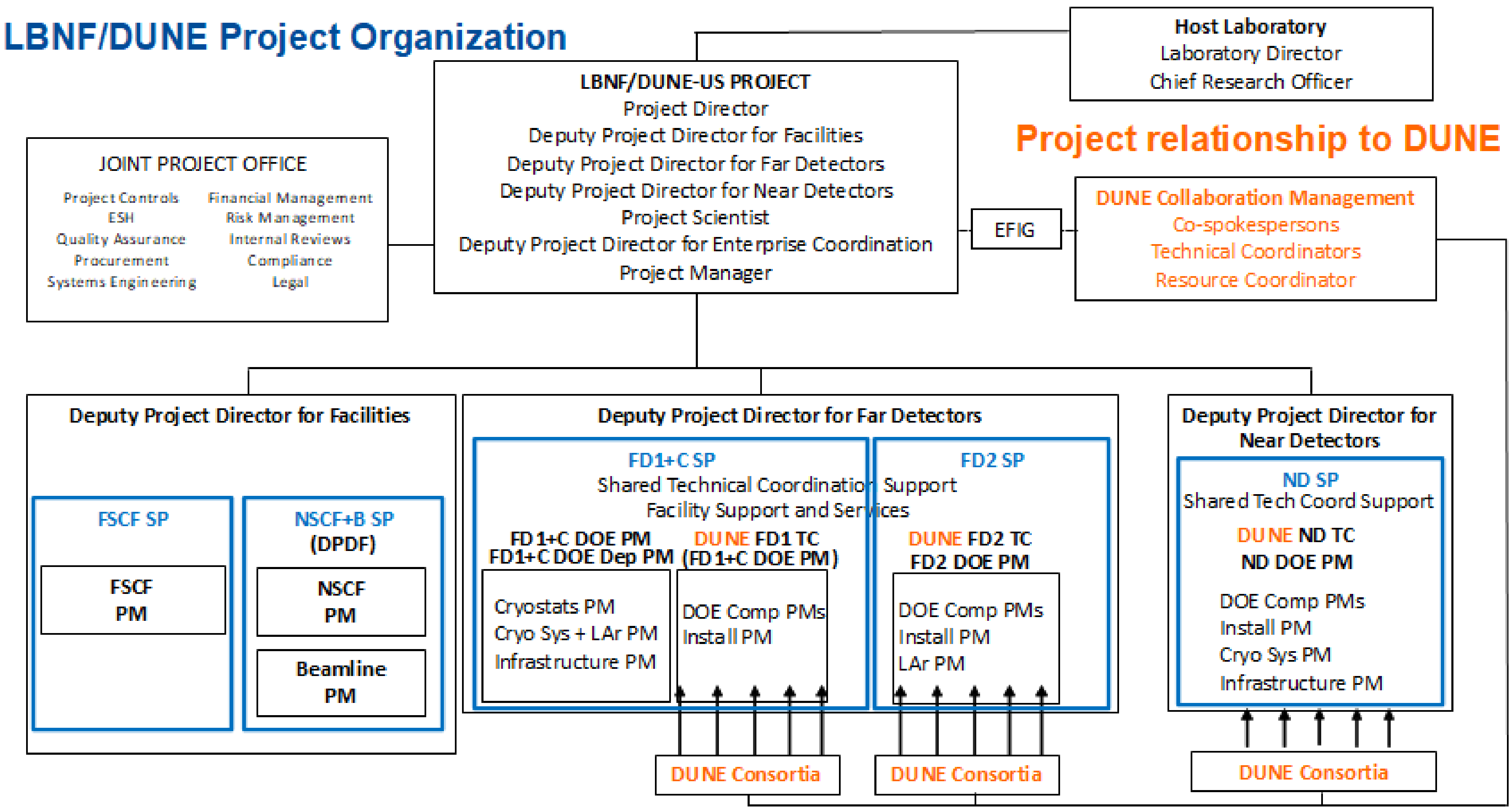
2.7 tons drift chambers target
Density (g/cm3) 0.1
2% X_0/chamber
0.4 T magnetic field

TRD detector
Lead glass calorimeter

Resolution (mm^3)	3×3×0.2
Density (g/cm^3)	1.4
X_0 (cm)	14.0
λ_T (cm)	54.8
dE/dx (MeV/cm)	2.1

C. Rubbia,
CERN Report 77-8,
May 1977

LBNF/DUNE Organization



Electron neutrino appearance rates

120 kt MW yr
integrated rate between
0.5 and 10 GeV

Sample	Expected Events $\delta_{CP} = 0$ NO	IO	$\delta_{CP} = -\frac{\pi}{2}$ NO	IO
ν mode				
Oscillated ν_e	1155	526	1395	707
Oscillated $\bar{\nu}_e$	19	33	14	28
Total oscillated	1174	559	1409	735
Beam $\nu_e + \bar{\nu}_e$ CC background	228	235	228	235
NC background	84	84	84	84
$\nu_\tau + \bar{\nu}_\tau$ CC background	36	36	35	36
$\nu_\mu + \bar{\nu}_\mu$ CC background	15	15	15	15
Total background	363	370	362	370
$\bar{\nu}$ mode				
Oscillated ν_e	81	39	95	53
Oscillated $\bar{\nu}_e$	236	492	164	396
Total oscillated	317	531	259	449
Beam $\nu_e + \bar{\nu}_e$ CC background	145	144	145	144
NC background	40	40	40	40
$\nu_\tau + \bar{\nu}_\tau$ CC background	22	22	22	22
$\nu_\mu + \bar{\nu}_\mu$ CC background	6	6	6	6
Total background	216	215	216	215

Le projet DUNE à l'IN2P3 : contributions, responsabilités et partenariat

D. Autiero

IP2I Lyon

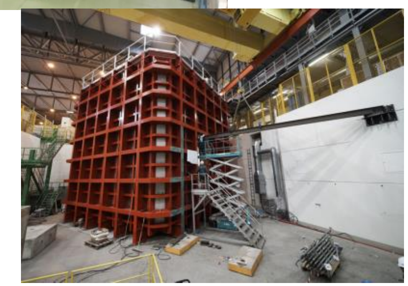
CS IN2P3
26/10/2021

A little bit of history:

- LAr **R&D started at IN2P3 in 2006 for the charge readout electronics**, also supported by the LABEX LIO since 2012
- IN2P3 groups contributed to the **LAGUNA-LBNO program (2008-2014) and R&D** where the **dual-phase detector** technology was developed

- **IN2P3 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**
- IN2P3 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 mechanics, 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 2021-… preparation activities for Vertical Drift FD module #2**

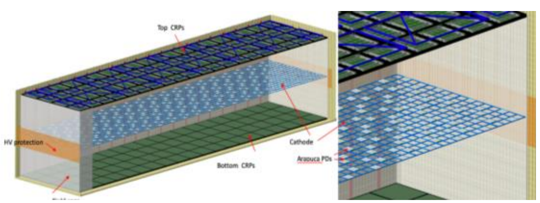
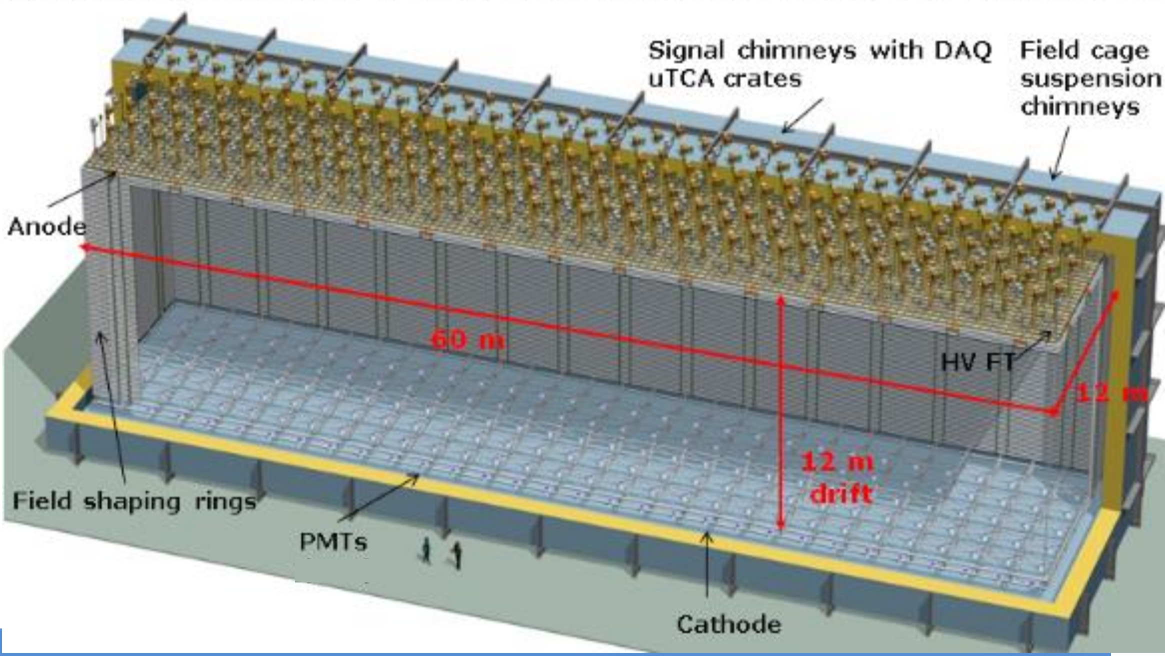


Table 1.2: Quantities of items or parameters for the 12.096 kt DP module

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 × 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

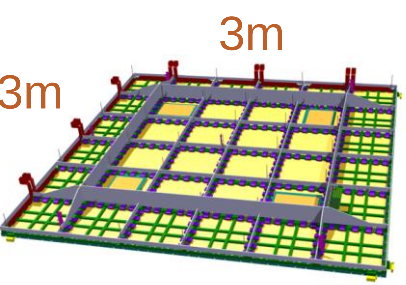
Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600



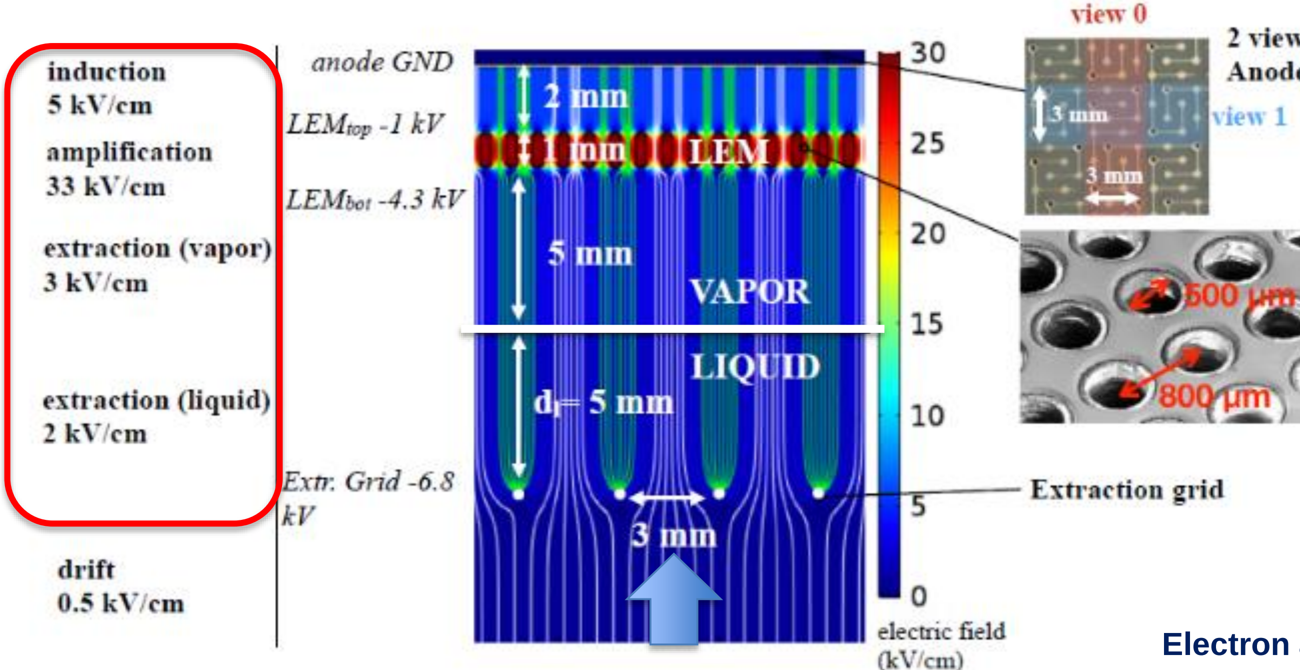
Advantages of dual-phase design:

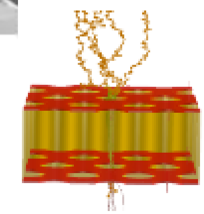
- Gain in the gas phase → compensation for charge attenuation due to long drift paths, required gain 6 for 12 m drift (TDR requirement of gain 6 computed for 12m drift, 250V/cm drift field 300kV, and 5ms electrons lifetime)
- Simplified dual-phase detector design with vertical geometry→ cheaper production 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

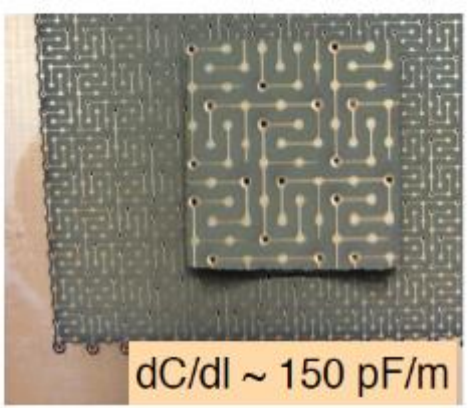


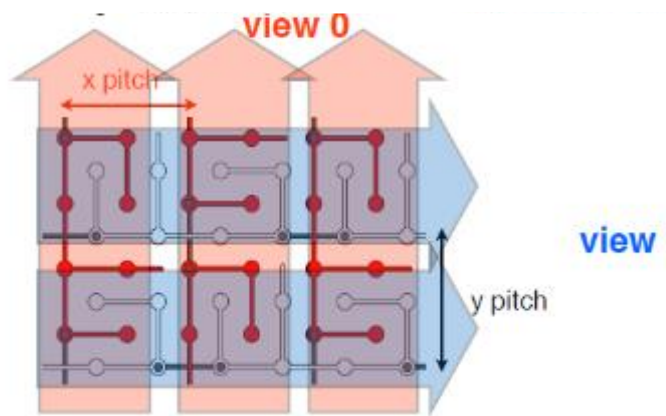


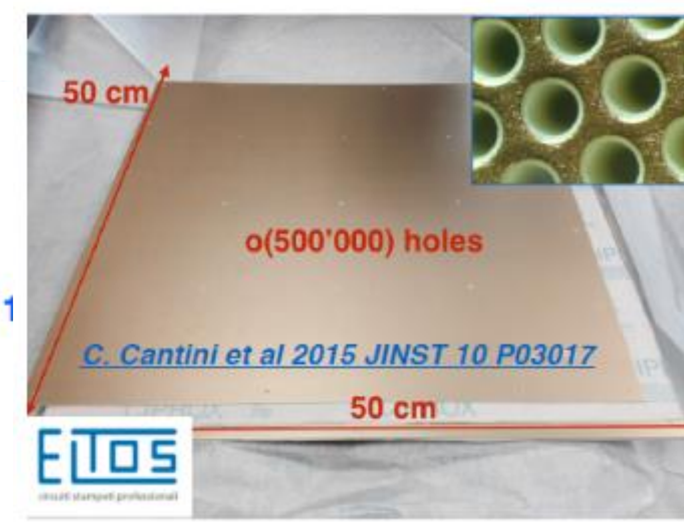
Electron avalanche in LEM hole

50x50 cm^2 LEM

50x50 cm^2 anodes with 2 collection views





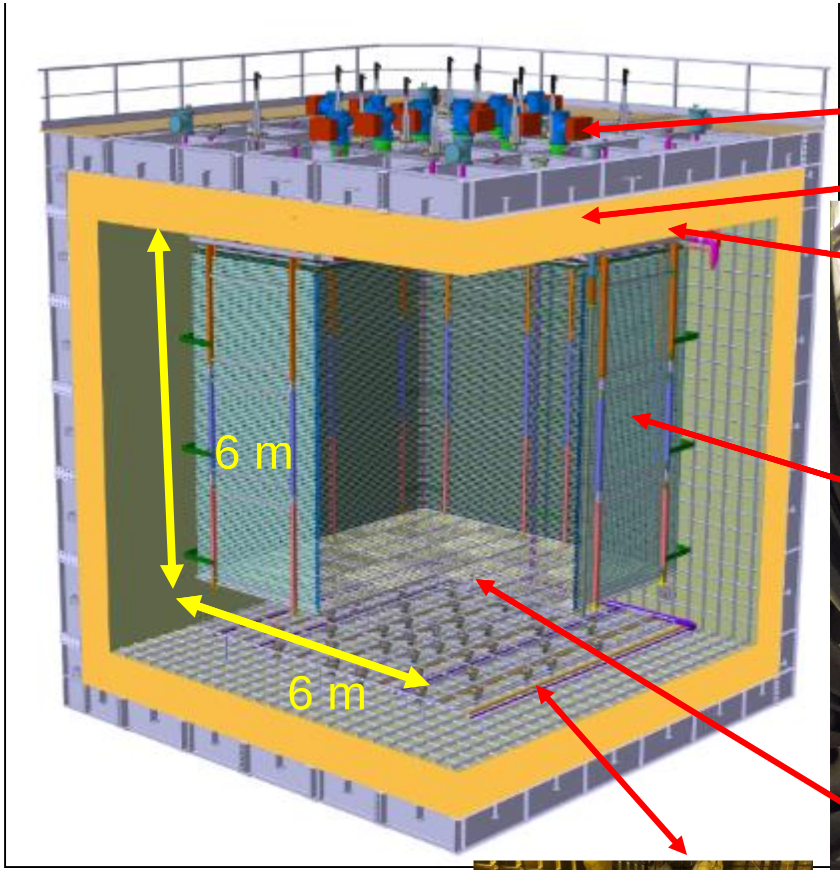


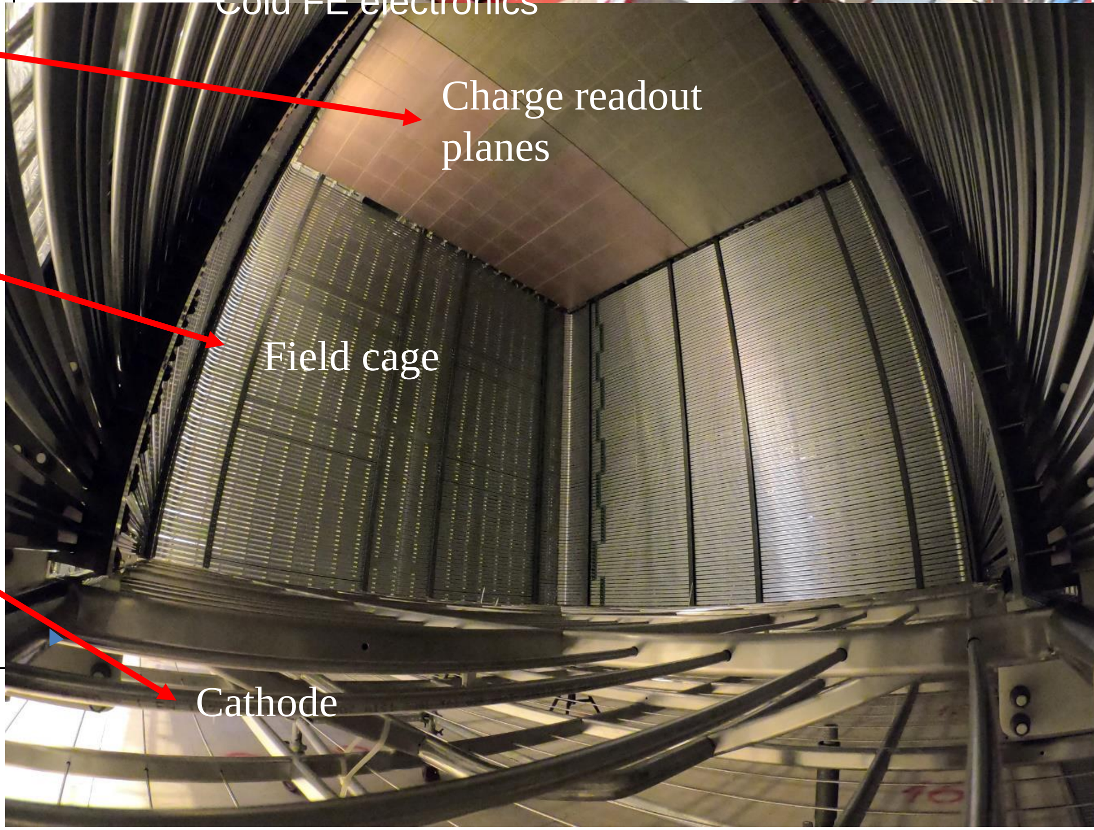
NP02/protoDUNE dual-phase

dual-phase FD design based on NP02:

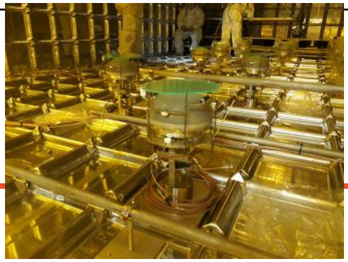
- 1/20 of active area of DP 10 kton
- NP02/protoDUNE DP 4 CRPs → DUNE 80 CRPs

Construction 2018-19 Operation 2019-20



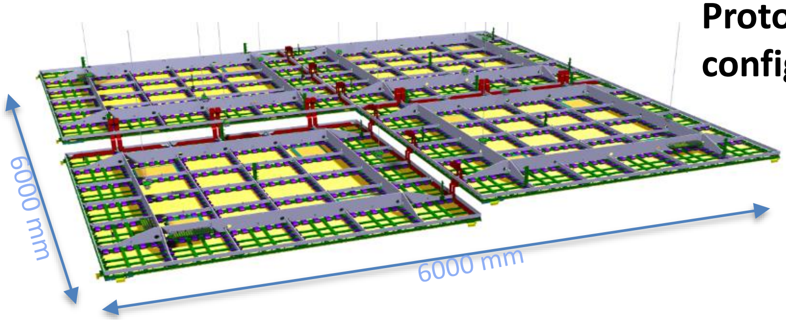


36 cryogenic photomultipliers
Hamamatsu R5912-02mod
with TPB coating

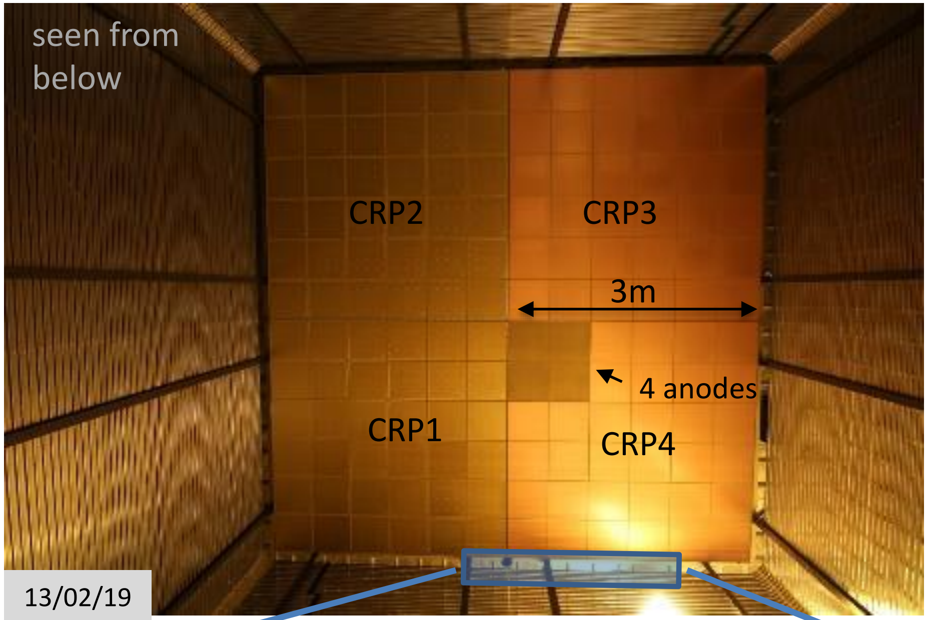


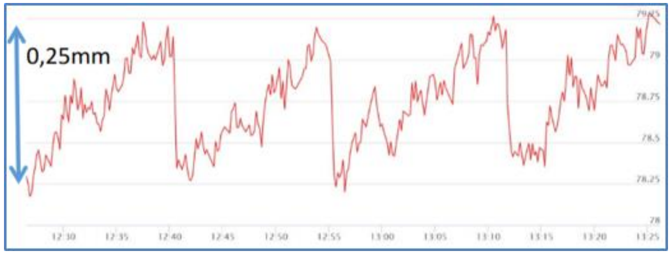
Charge Readout Planes
(LEMs CEA contribution)

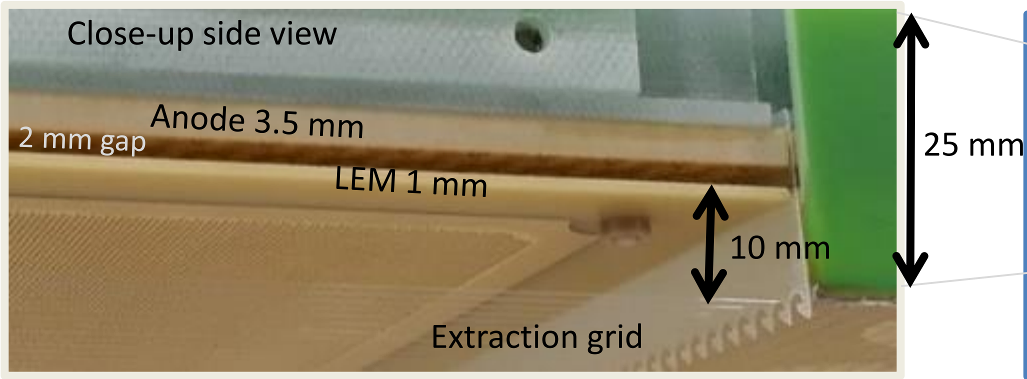
ProtoDUNE-DP configuration



4 CRPs





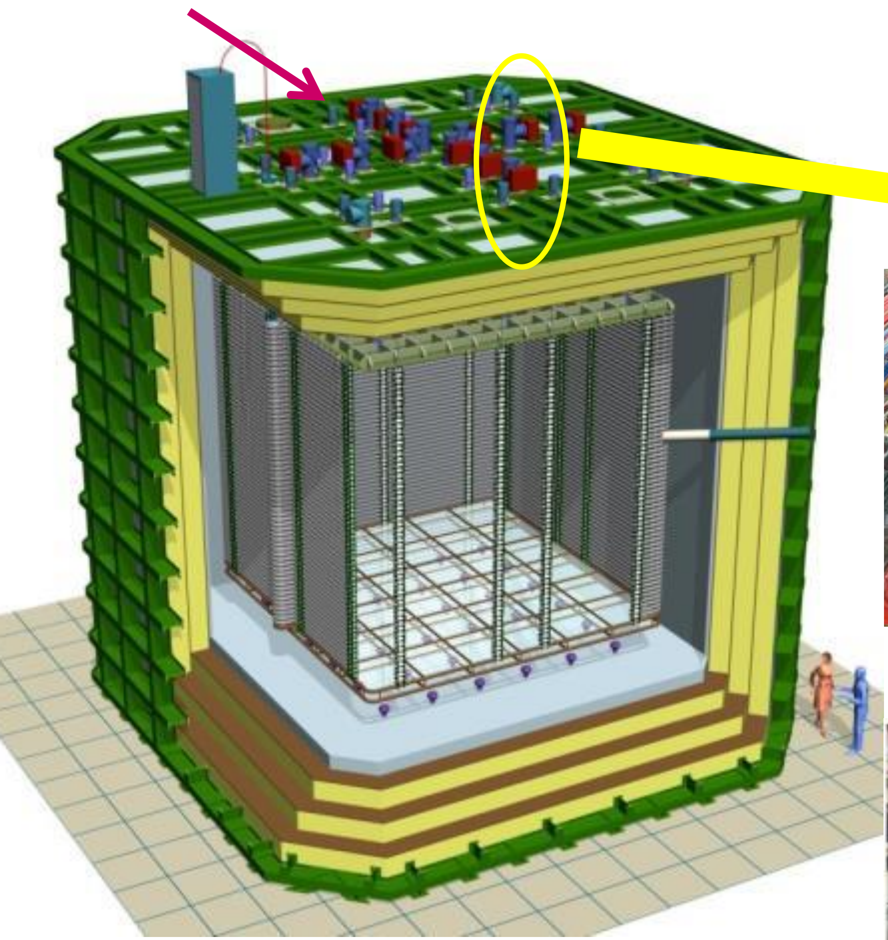


ProtoDUNE-DP accessible cryogenic front-end electronics and uTCA FE system

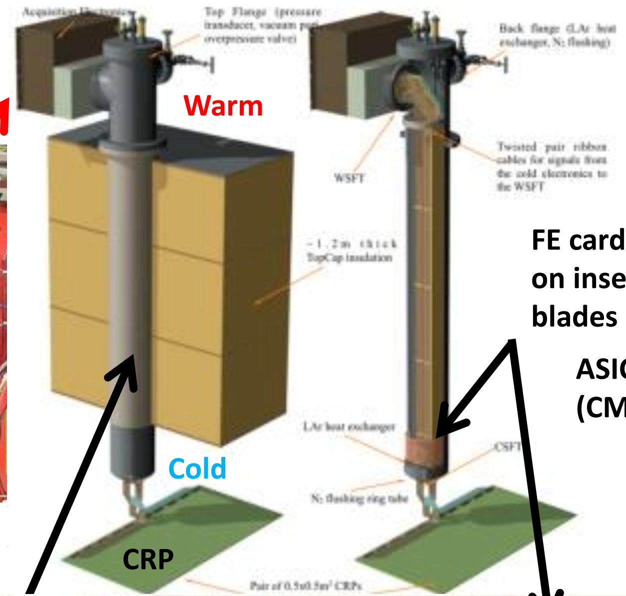
Full accessibility provided by the dual-phase charge readout at the top of the detector

- **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

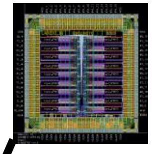


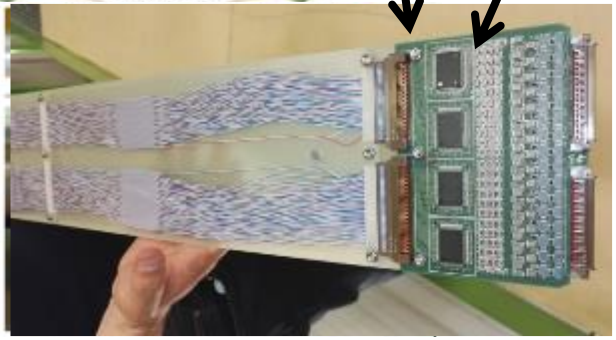
<50 cm



FE cards mounted on insertion blades

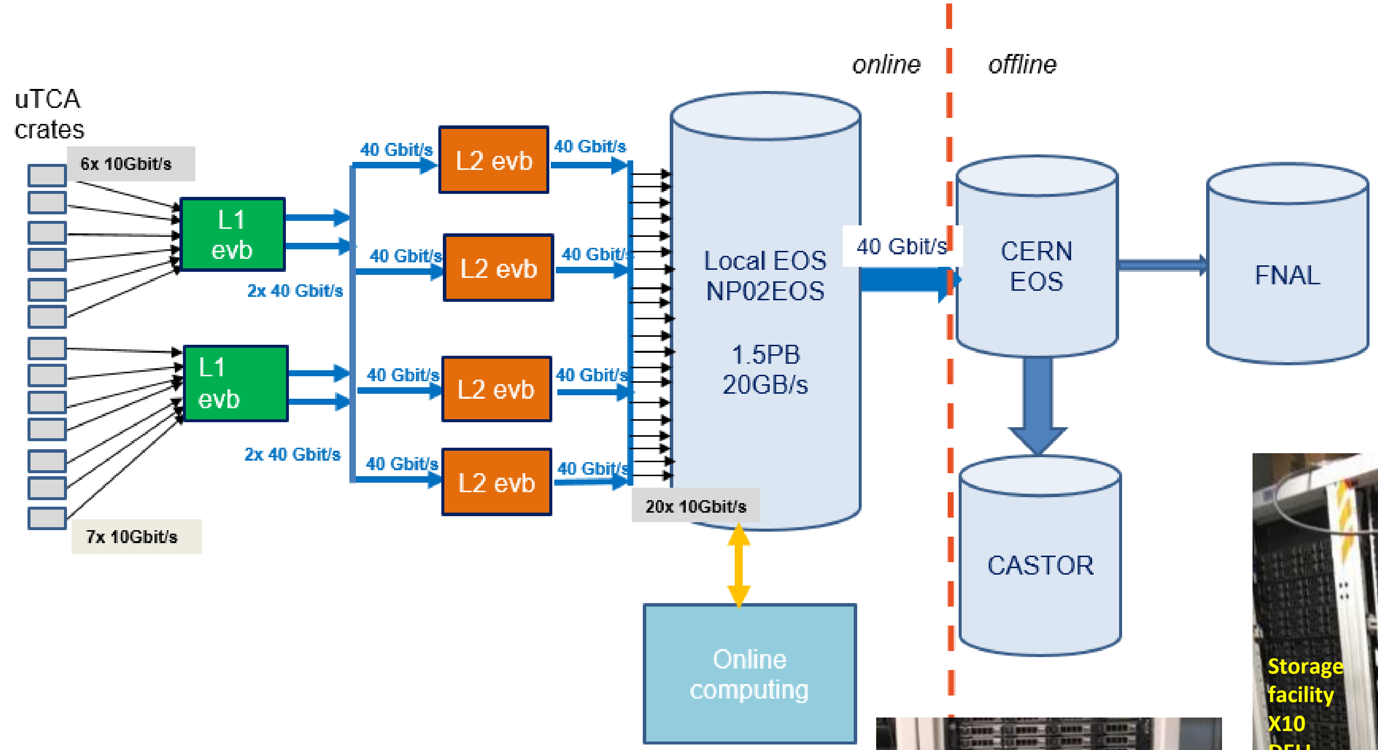
ASICs 16 ch. (CMOS 0.35 um)

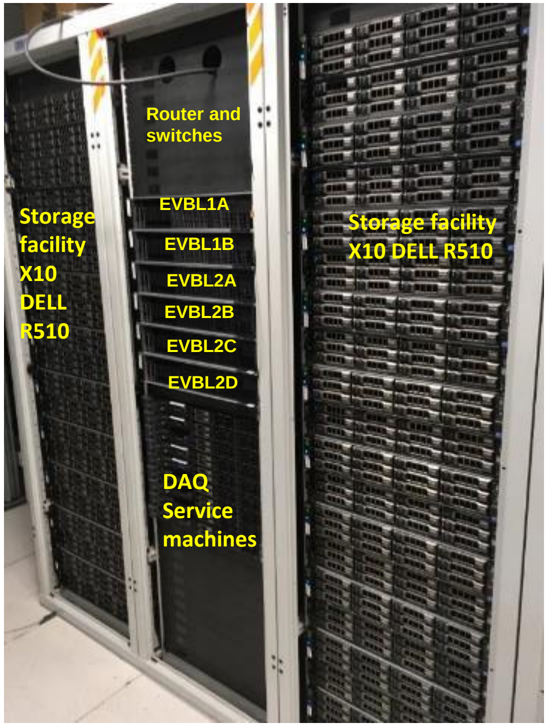




Signal chimney

NP02 DAQ/network infrastructure, 20 GB/s bandwidth

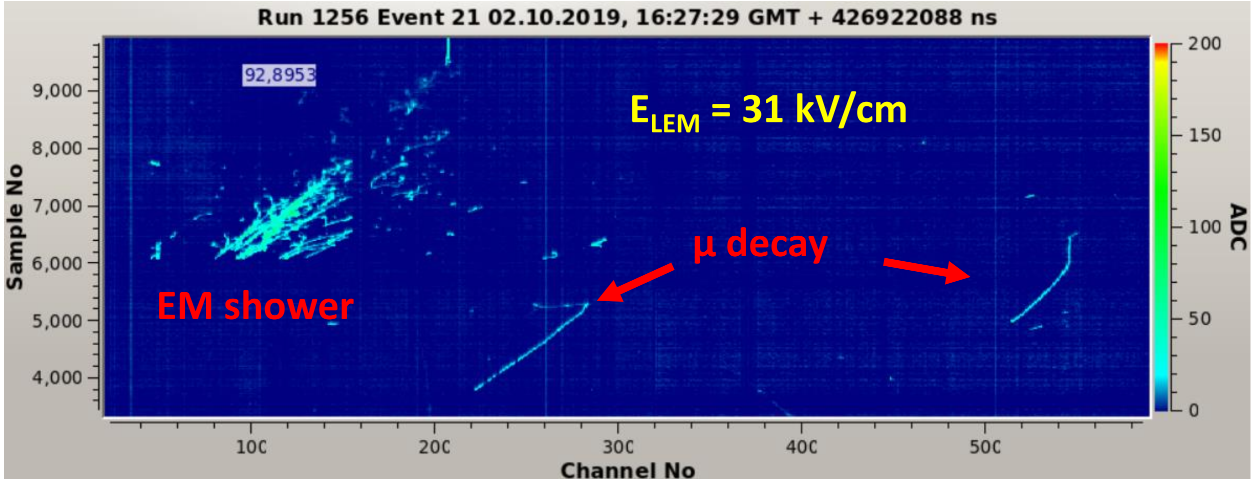




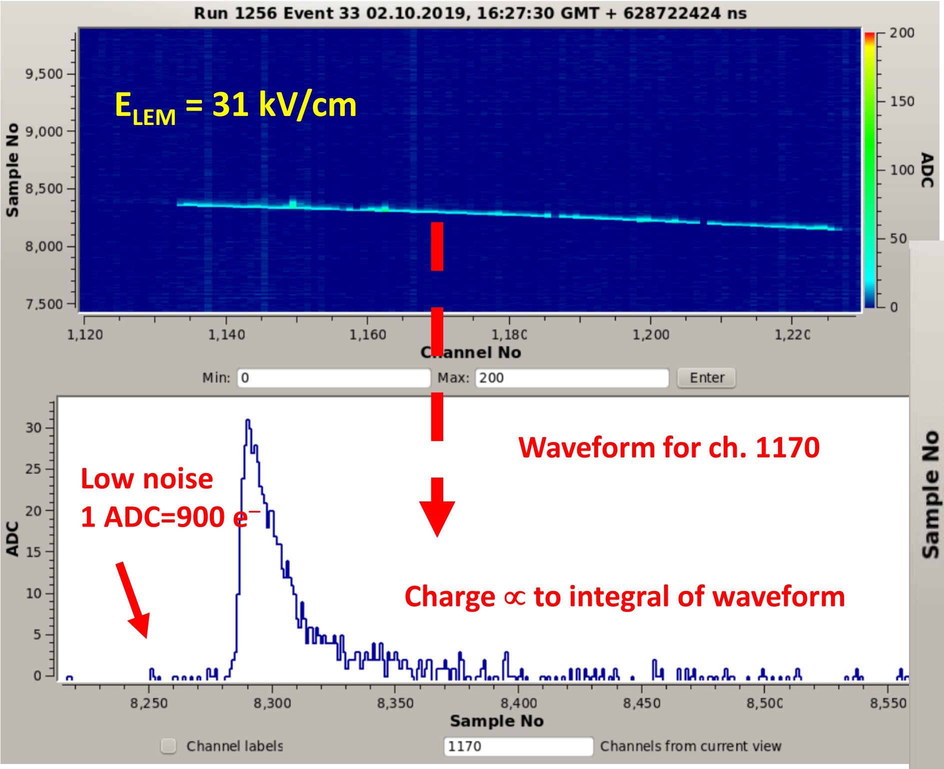
Online storage servers for distributed EOS system (1.5 PB) and online computing nodes (450 cores) provided by CCIN2P3

Cosmic ray events in protoDUNE dual-phase

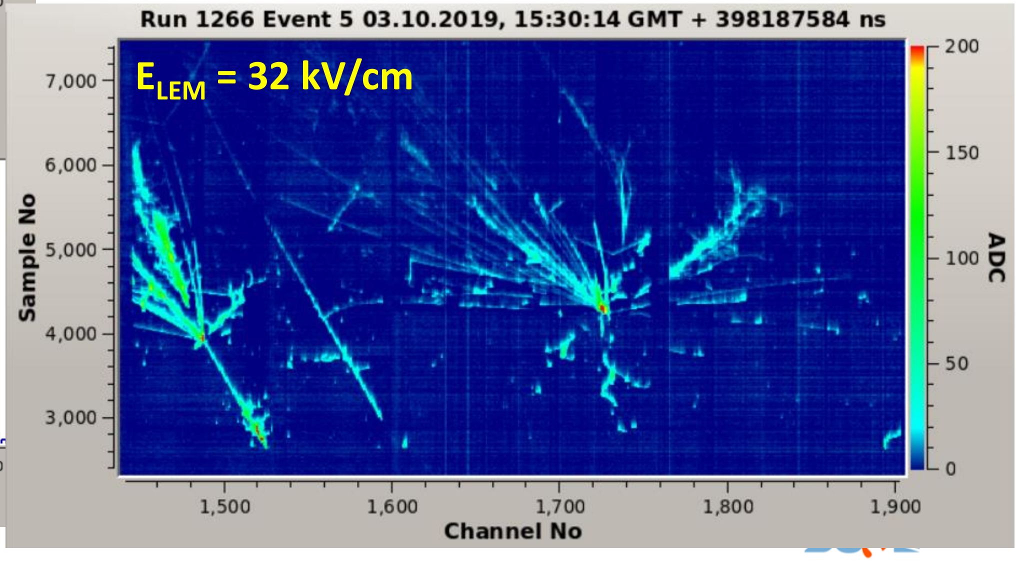
Electromagnetic shower + two muon decays



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**
- **NP02 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)**

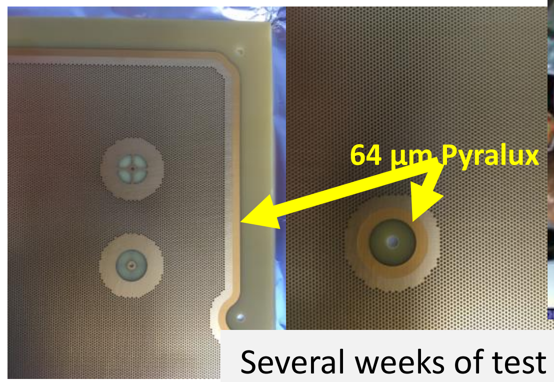
makes LEMs gain much less required to compensate for signal attenuation during drift

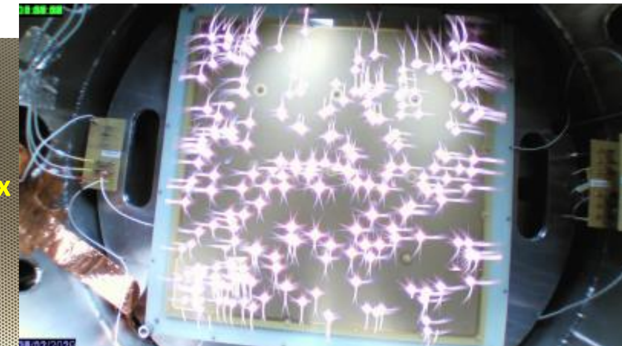
ProtoDUNE-DP R&D activities: (SPSC April 2020)

Goals: (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

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

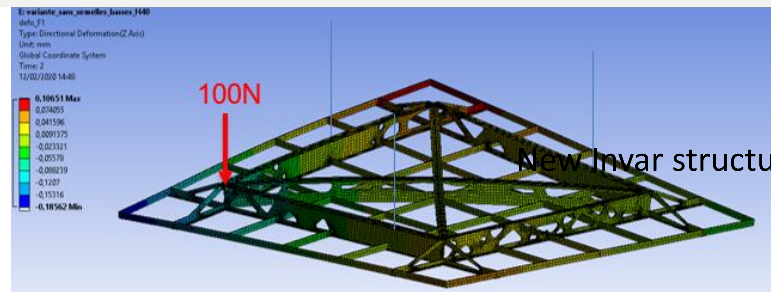
- Improving LEM design with high quality rims using a micro etching technique developed by CERN
- Adding an insulating material in the dead regions of LEM using 64 um thick Pyralux coverlay (successful tests at Saclay) very effective to eliminate sparks in those regions





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

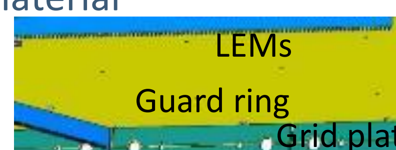
- For the anodes: new design to incorporate a guard ring on both faces of PCB

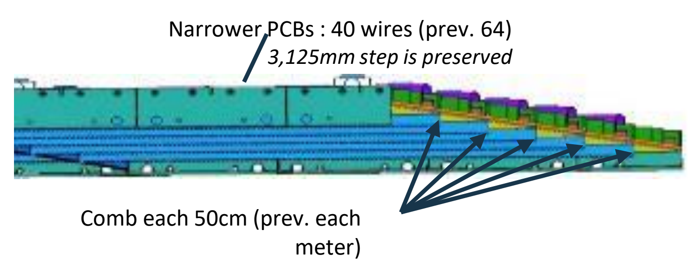


For the CRP structure and extraction grid:

Modifications of the design are being validated to incorporate:

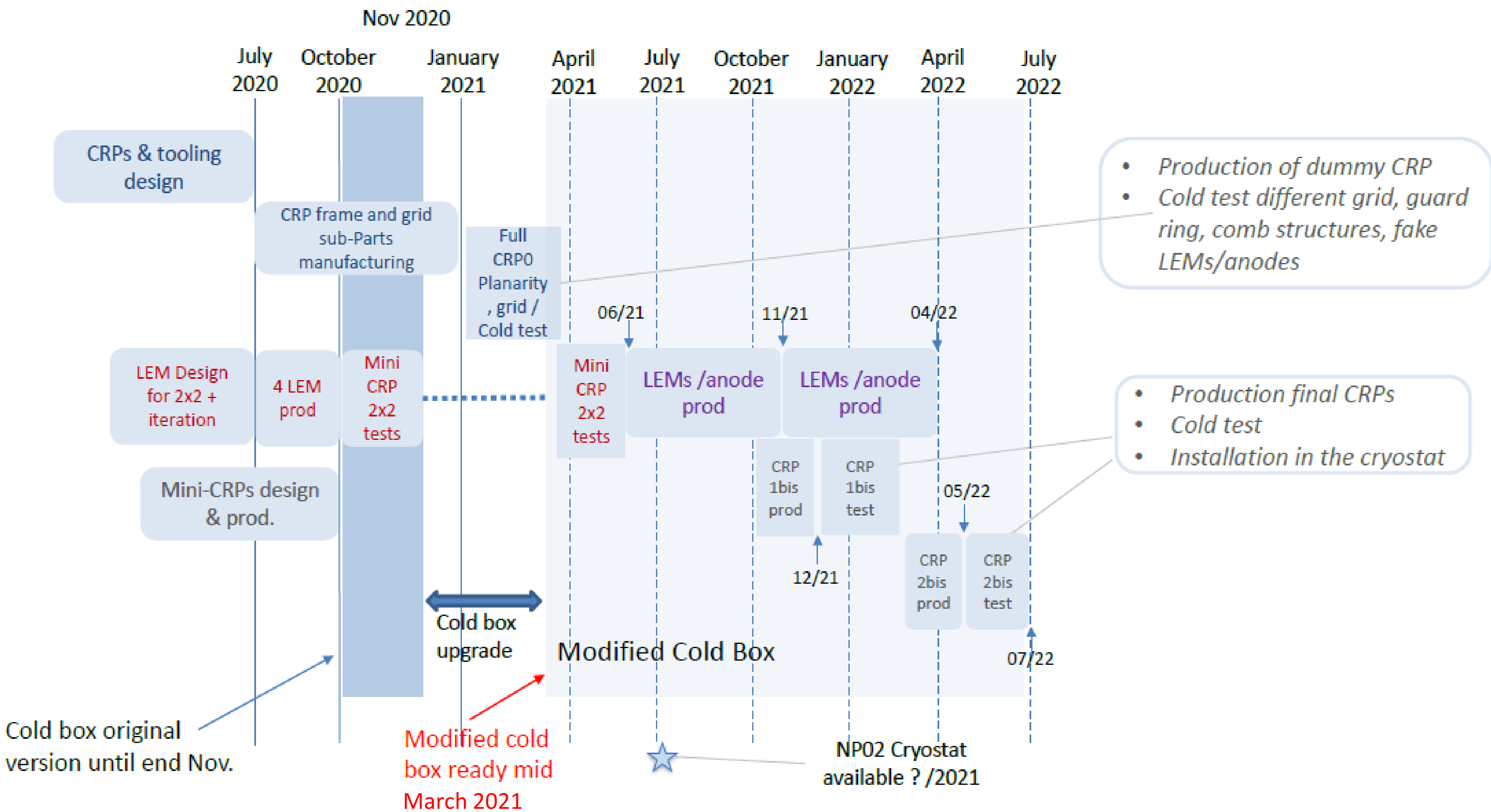
- a more stiff structure (20 times less deformations)
- A guard ring in the extraction grid support structures to guide the possible discharges
- Modifying the combs with resistive material
- Add 2mm to the grid-LEM distance





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

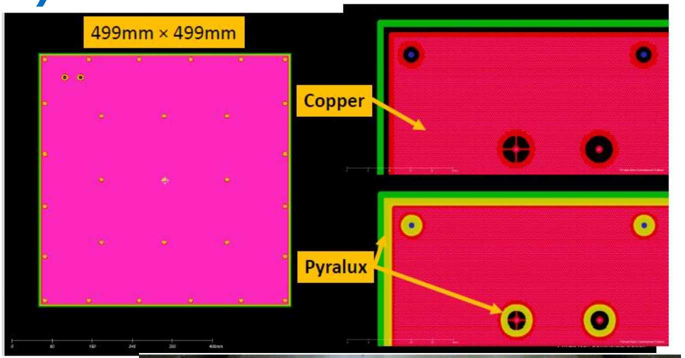
(Activities schedule presented at April 2020 SPSC meeting, updated on September 2020)



Schedule now replaced by Vertical Drift integration tests 2021-2023

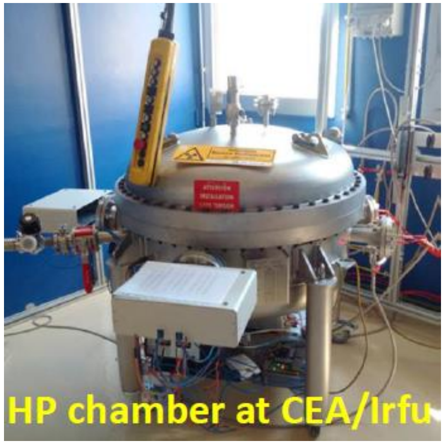
Progress on small tests R&D activities: (Summer 2020)

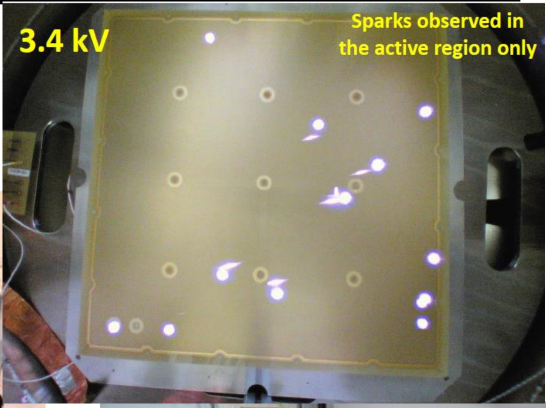
LEM design with 95% active area

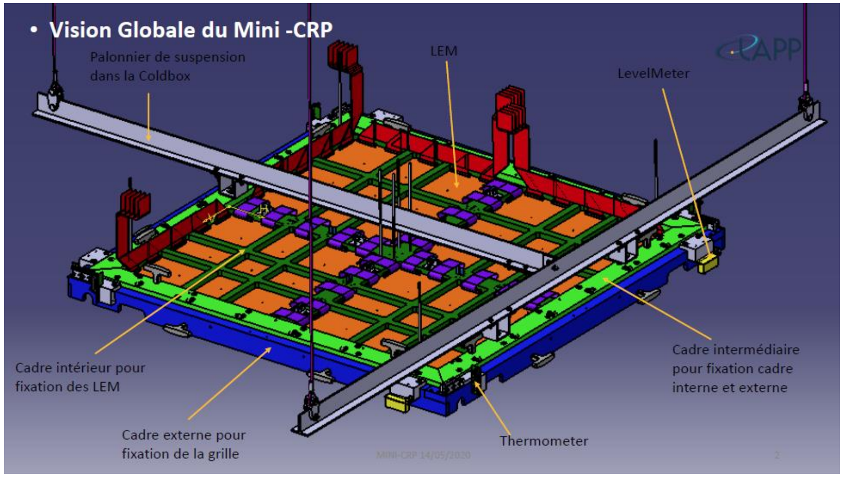


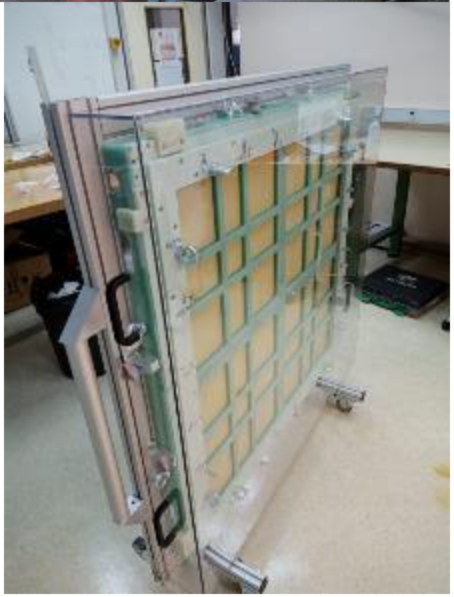
Tests of new LEMs design at CEA to reduce sparking

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







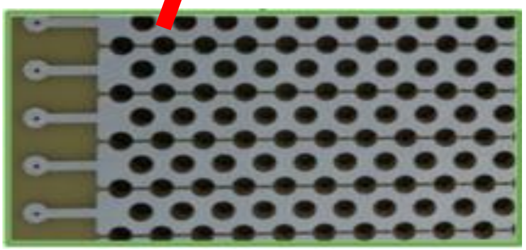


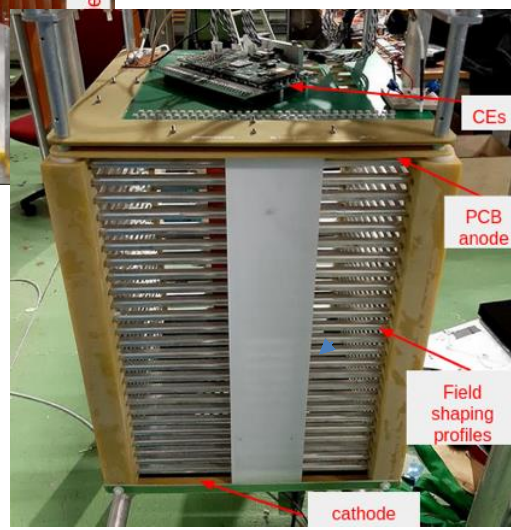
New design developed for 3x3 m^2 CRPs following the CRPs improvement program:

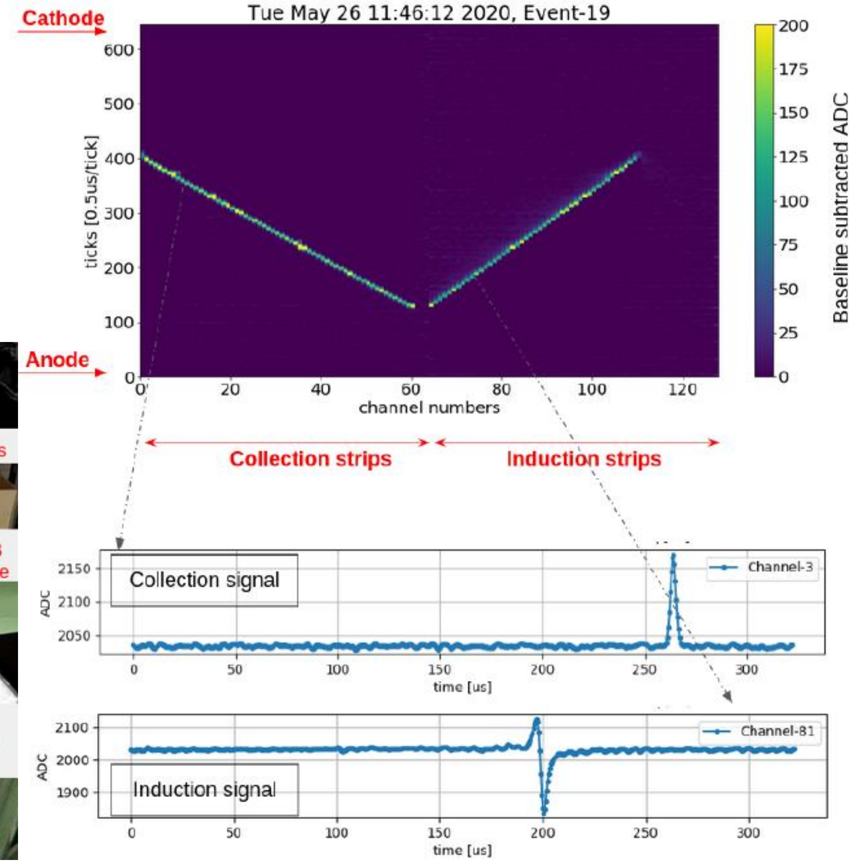
→ First design implementation on a MiniCRP structure (1x1m^2) made following the CRP improvement program to test 4 LEMs from new design

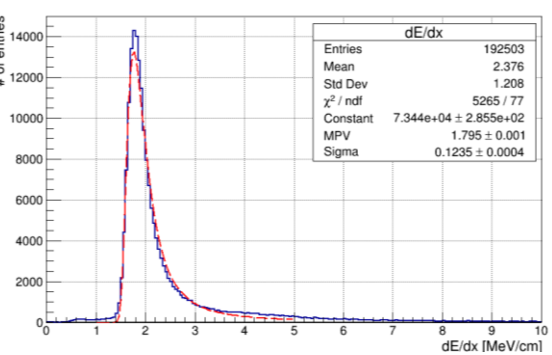
- New extraction grid + grid sparks prevention system

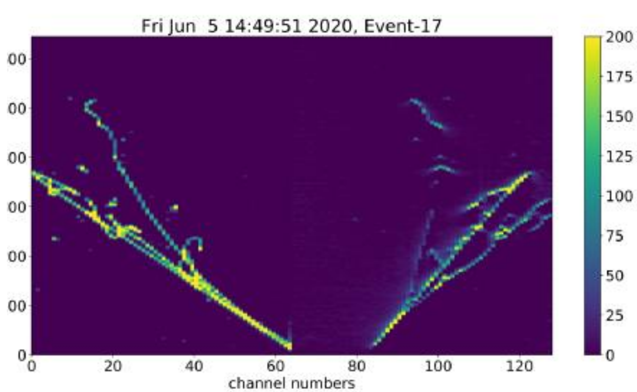
Perforated anodes tests at CERN Neutrino Platform with the 50l TPC test stand (Summer 2020)

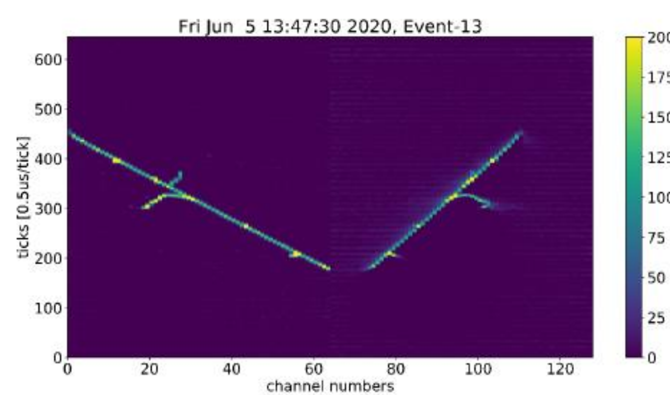












Can we think of a simplified DP detector without LEMs (w/o the extra time needed to complete LEMs/CRP developments) which could be immediately built for DUNE, quickly and at affordable costs ?

→ 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)**

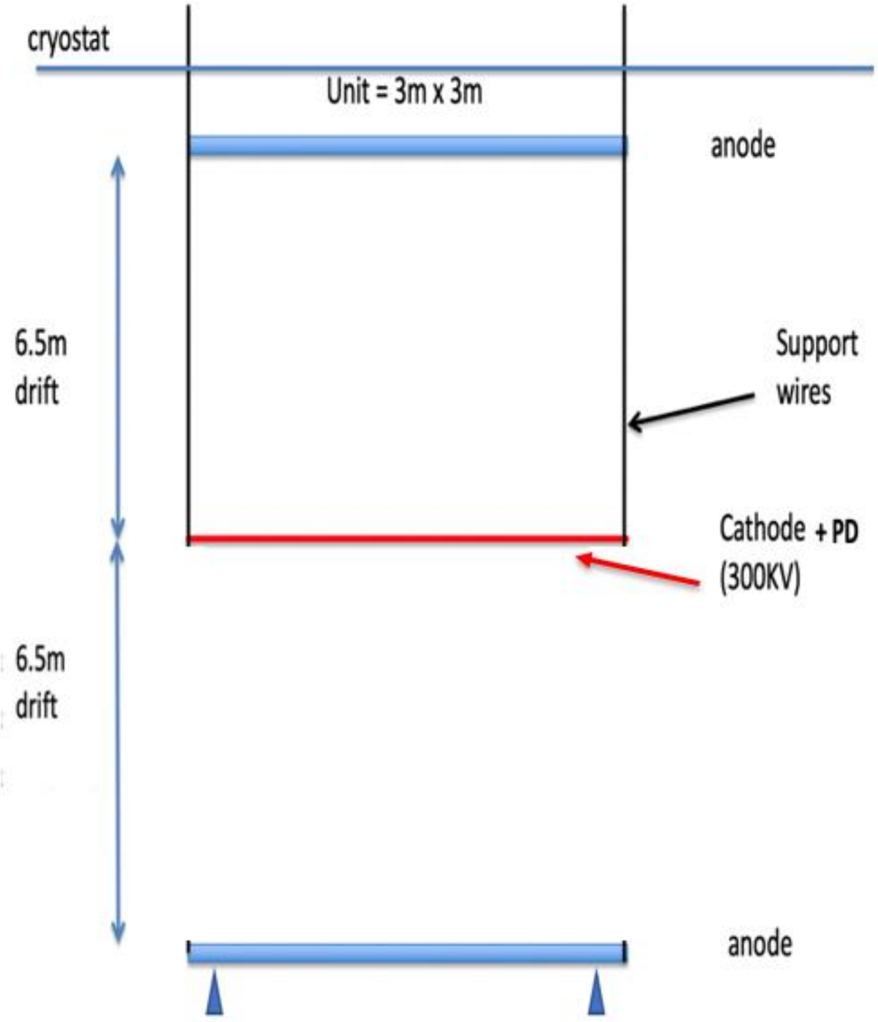
  →confirmed the idea of evolving from the LEM design

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

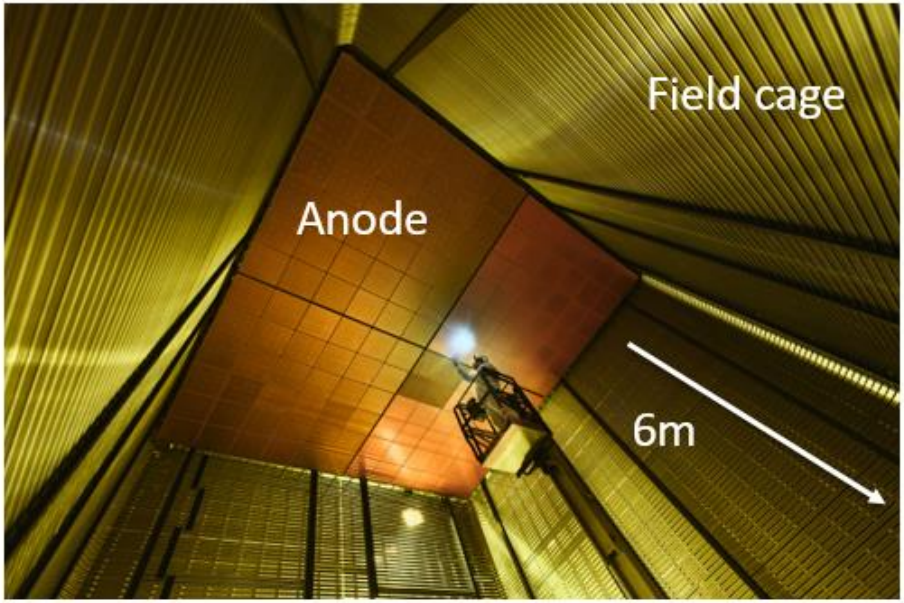
  → process completed in December 2020

- **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

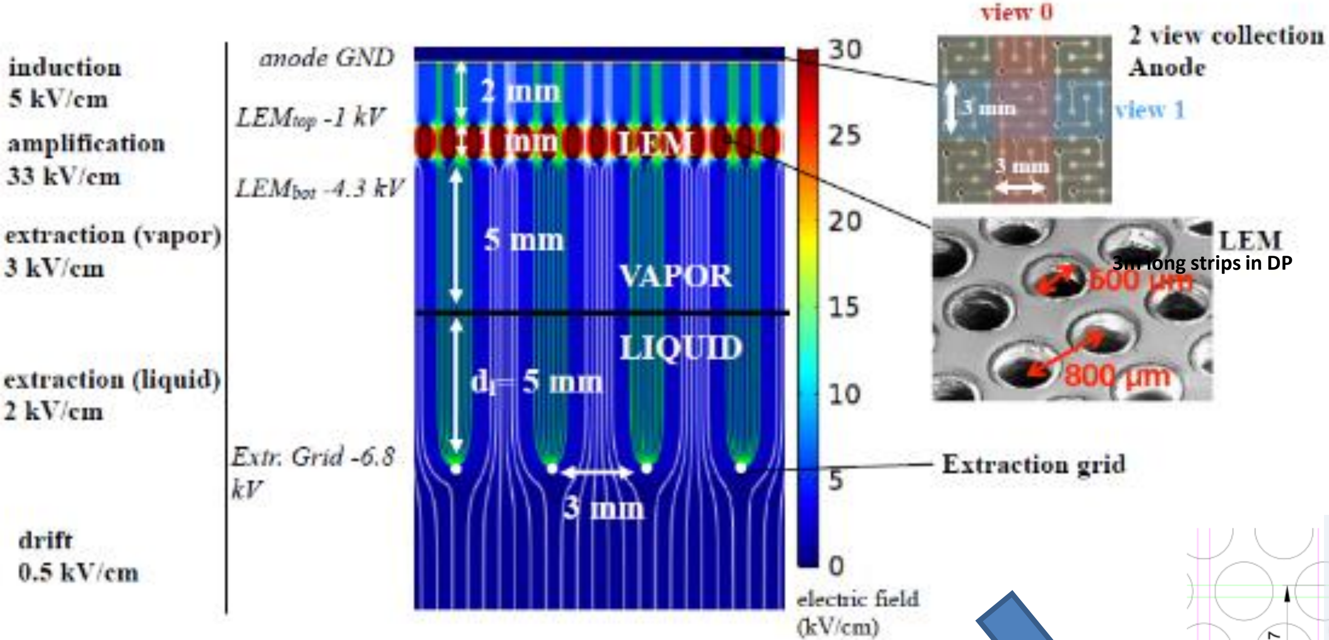


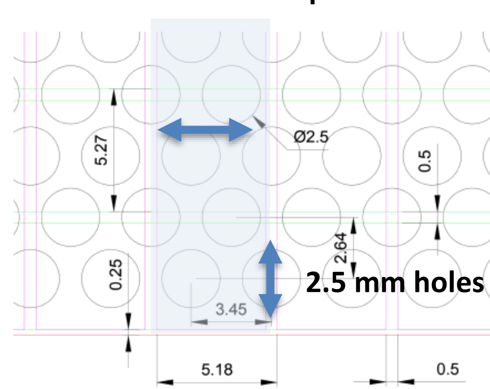
NP02 layout

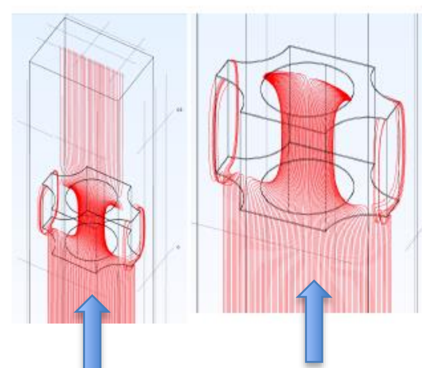


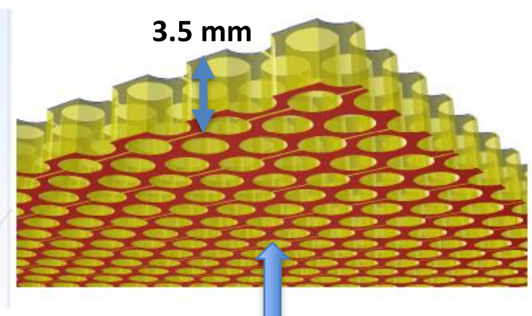
cathode

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)**

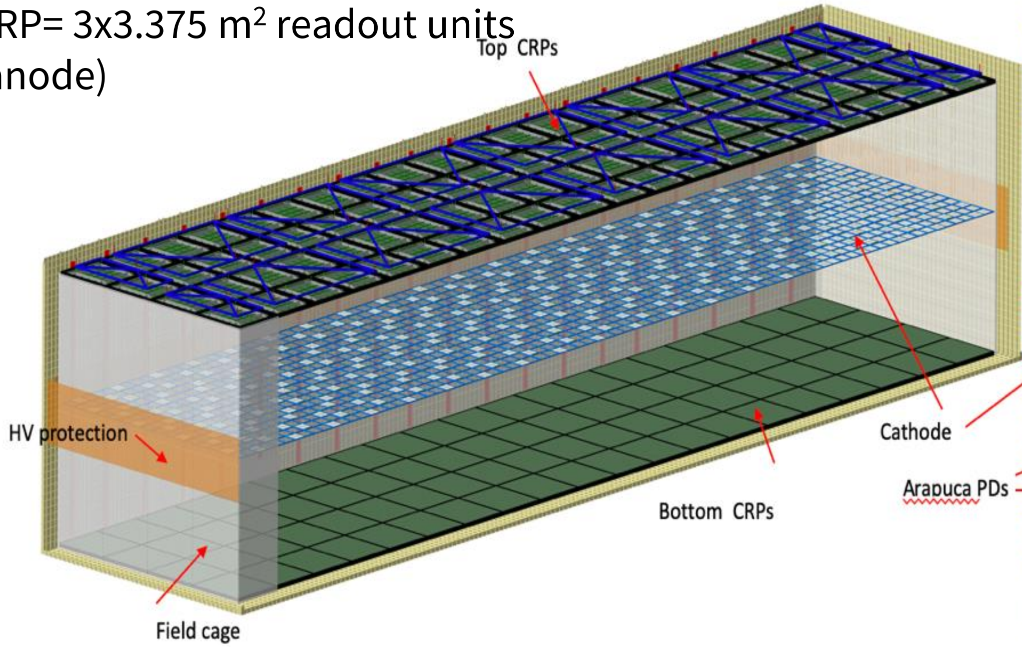
- **Strips capacitance is also lower for VD**: (<100 pF/m) over about 1.5 m length to be compared to 160pF/m x 3m length in case of DP configuration.

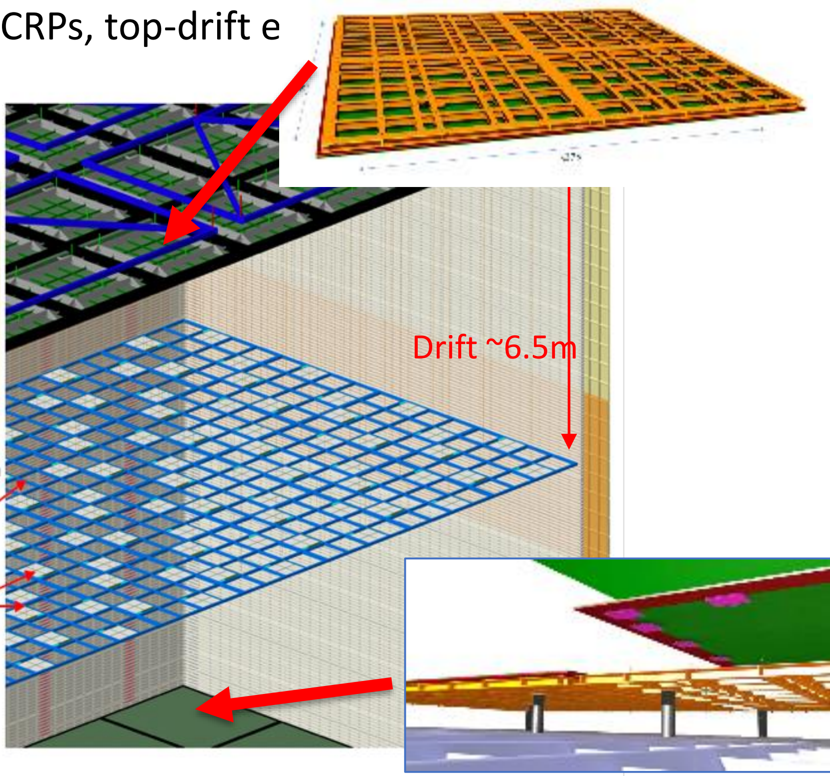
Vertical Drift far detector module

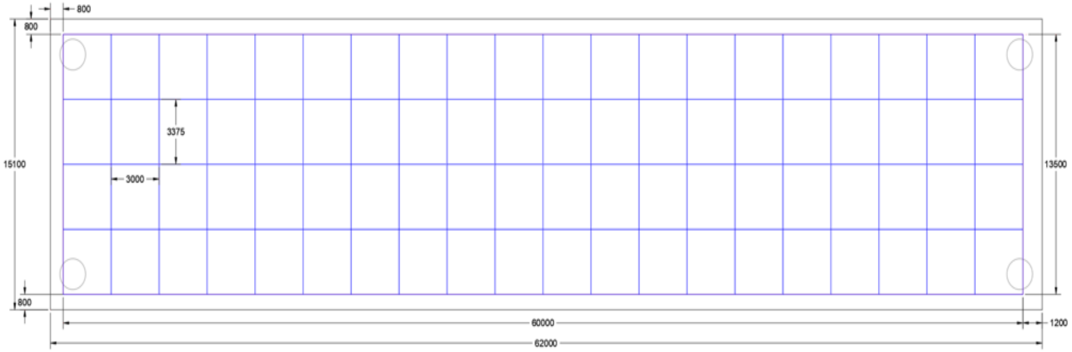
Detailed description in Vertical Drift CDR draft reviewed this summer by the LBNC and in Dominique's presentation.

Vertical Drift reuses many dual-phase developments for the CRPs, top-drift e cage/cathode

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

Teams:

(people so far involved. More people are in the process of being hired and expected to add in the next months)

- **APC Paris:**

Joao Coelho, Bernard Courty, Jaime Dawson, Camelia Mironov, Dariusz Nita, Sabrina Sacerdoti, Camille Sironneau, Pierre Prat, Alessandra Tonazzo, Thomas Patzak

- **IJCLAB Orsay:**

Fabien Cavalier, Gilles Ferry, Alexandre Gallas, Thibaut Houdy, Yoann Kermaidic, Rodolphe Marie, Christopher Magueur, Philippe Rosier, Laurent Simard

- **IP2I Lyon:**

Dario Autiero, Clement Barbarin , Edouard Bechetoille, Bruno Carlus , Quentin David, Fabien Doizon, Claude Girerd, Cyrille Guerin, Slavic Galymov, Hervé Mathez, Elisabetta Pennacchio, Denis Pugnere, Konstantin Shchablo , William Tromeur
+ Electronics service of CENBG (contributing to Top drift electronics production and QC)
Frederic Druillole, Patrick Hellmuth

- **LAPP Annecy**

Benjamin Aimard, Isabelle Debonis, Guillaume Deleglise, Dominique Duchesneau, Nicolas Geffroy, Pablo Kunze, Oliver Lantwin, Alberto Marchionni, Fabrice Peltier, Laura Zambelli

- **LPSC Grenoble**

Johann Collot, Joel Dai, Thomas Kosc , Jean-Sebastien Real, Jean-Stephane Ricol, Arnaud Robert

Involvements of the IN2P3 groups:

- ➢ TGIR project focusing on construction contributions to the 2nd FD module based on the Vertical Drift. Funding accessible via TGIR program of the order ~50% M&S costs of 2nd FD module (39.5M$)
- CERN LBNF contribution to second cryostat consolidated
- CERN + UK + US groups contributing to 2nd FD

- ➢ Current IN2P3 teams: APC Paris, IJCLAB Orsay, IP2I Lyon, LAPP Annecy, LPSC Grenoble

~50 people

- ➢ Foreseen/foreseeable IN2P3 contributions:
- ✓ Top Drift CRPs and mechanical structures: LAPP + LPSC (instrumentation + contribution to construction)
- ✓ Top Drift Electronics: IP2I + E. Serv. CENBG (sharing of production and QC) + IJCLAB (Chimneys)
- ✓ Cathode: IJCLAB
- ✓ High Voltage system: LPSC
- ✓ Light readout electronics: APC (PD system design under definition)

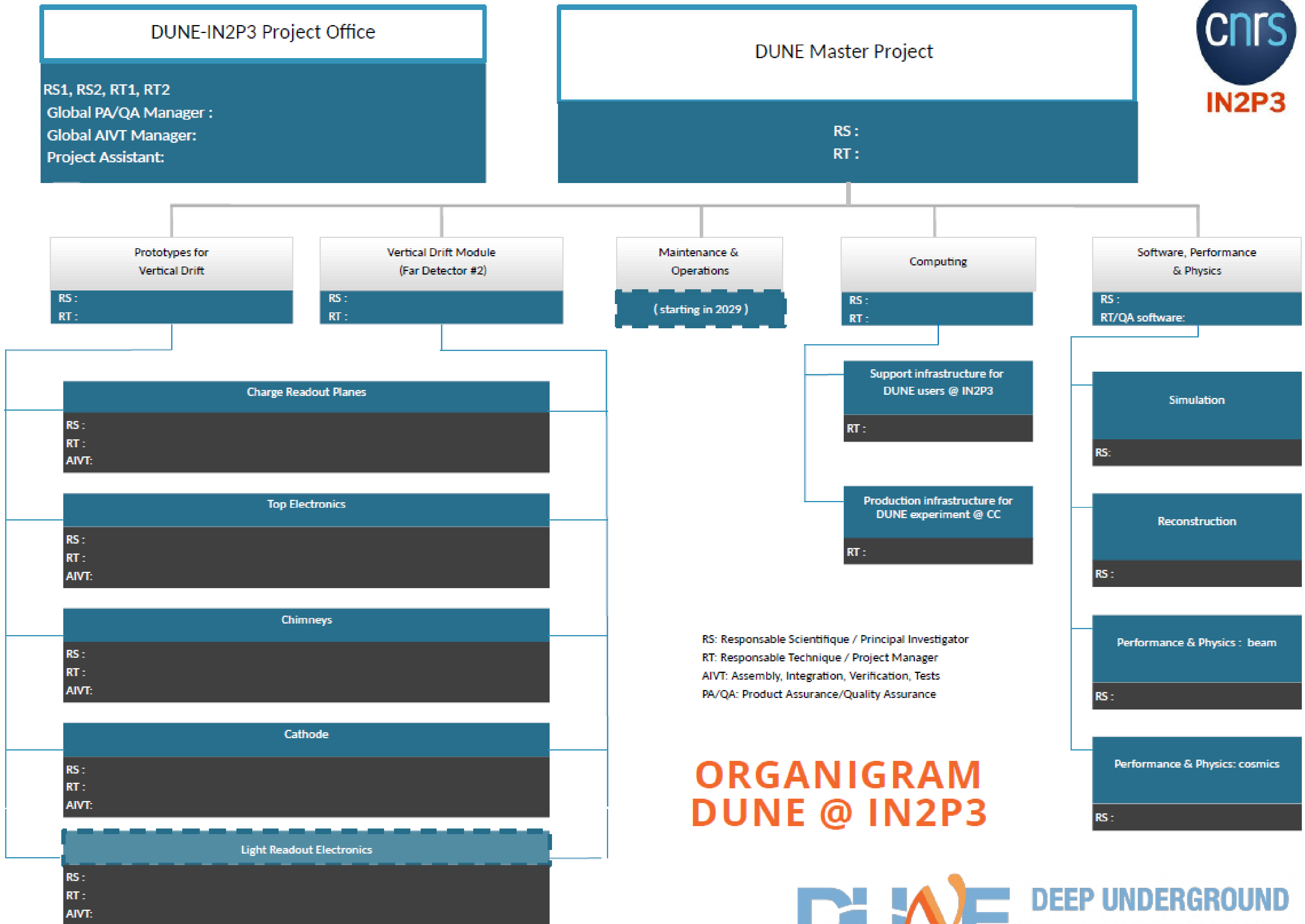
→ Involved Consortia: CRP, Top-electronics, HV, PD

IN2P3 contribution to leadership of CRP and top-electronics Consortia

- Going full steam ahead for the test campaign of VD elements (CRPs, electronics, HV, PD) at CERN (see Fabien's presentation) with cold-box, NP02, NP02 module-0: 2021-2023
- Production of detector elements: 2023-2026
- Installation at SURF: 2026-2027

→ See schedule and organization details in Alberto's presentation

- ➢ Parallel strong efforts by the groups on analysis, software developments and computing


DUNE-IN2P3 Project Office
RS1, RS2, RT1, RT2
Global PA/QA Manager :
Global AIVT Manager:
Project Assistant:
DUNE Master Project
RS :
RT :
Prototypes for Vertical Drift
RS :
RT :
Vertical Drift Module (Far Detector #2)
RS :
RT :
Maintenance & Operations
(starting in 2029)
Computing
RS :
RT :
Software, Performance & Physics
RS :
RT/QA software:
Charge Readout Planes
RS :
RT :
AIVT:
Top Electronics
RS :
RT :
AIVT:
Chimneys
RS :
RT :
AIVT:
Cathode
RS :
RT :
AIVT:
Light Readout Electronics
RS :
RT :
AIVT:
Support infrastructure for DUNE users @ IN2P3
RT :
Production infrastructure for DUNE experiment @ CC
RT :
Simulation
RS:
Reconstruction
RS :
Performance & Physics : beam
RS :
Performance & Physics: cosmics
RS :
RS: Responsable Scientifique / Principal Investigator
RT: Responsable Technique / Project Manager
AIVT: Assembly, Integration, Verification, Tests
PA/QA: Product Assurance/Quality Assurance
ORGANIGRAM
DUNE @ IN2P3

Vertical-Drift 2021 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 operation in NP02 cryostat foreseen in 2023

➢ **Cold-box tests of new CRPs**

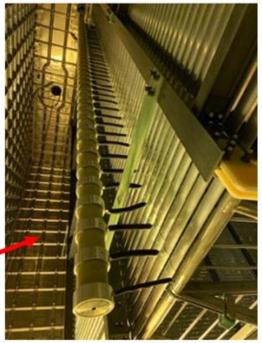
- Dual-phase cold box refurbished and installed at EHN1 side by side to NP02 by April 2021
- Since June 2021 integration at CERN of all components and commissioning
- First VD CRP installed this Monday → first cold-box cycle soon
- Tests activity continued in 2022 in preparation for Module-0

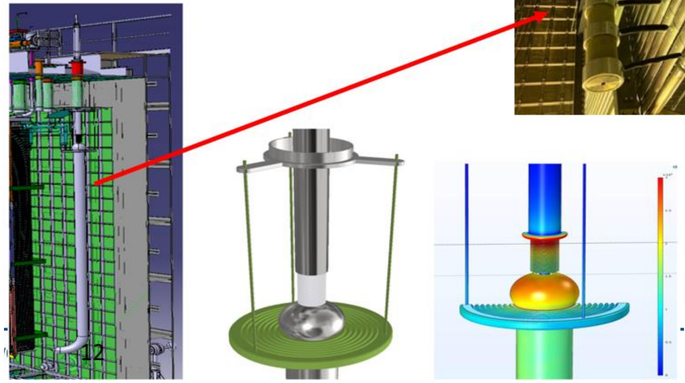
➢ **protoDUNE-DP/NP02 HV test:**

- Access to NP02 after warming up February 2021
- Removal and insertion of new HV extender March-July 2021
- Cool-down and filling of NP02 August 2021
- HV operation at 300 kV started in September 2021 for a few months

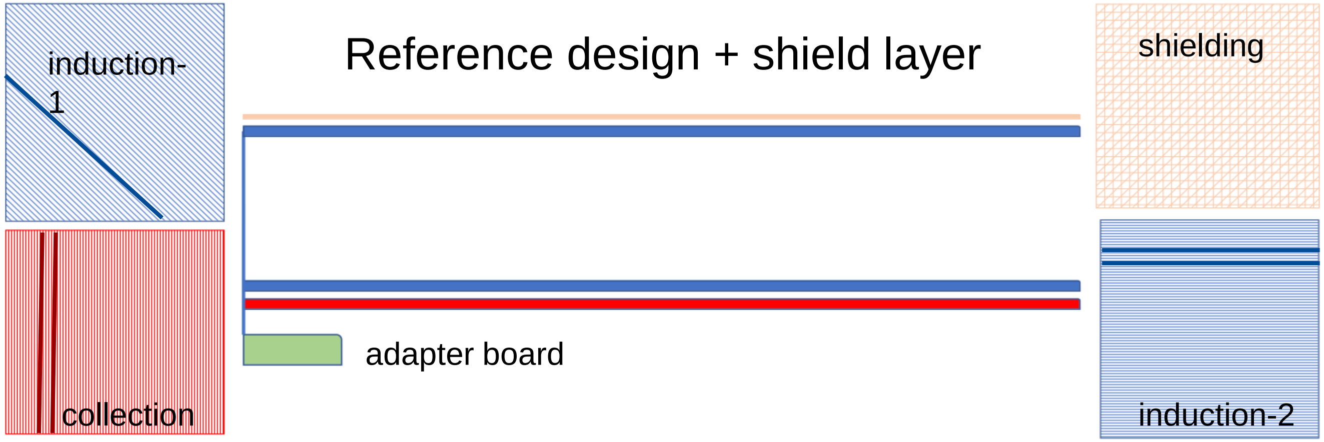
300kV test in NP02

- ✓ 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

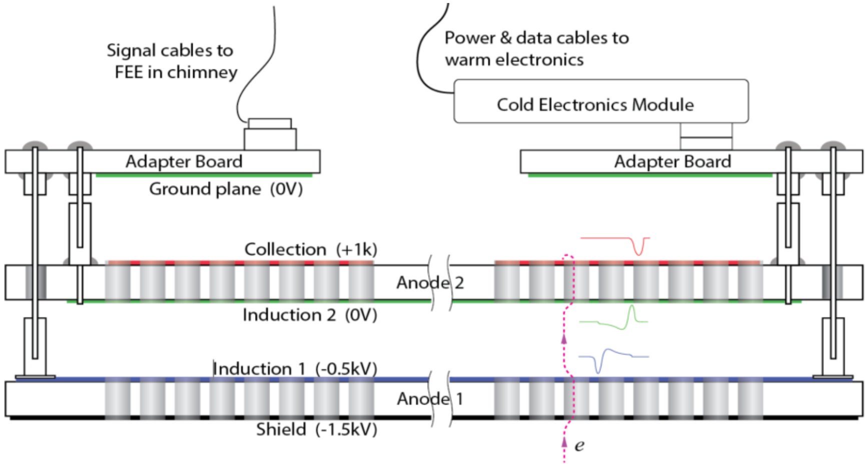


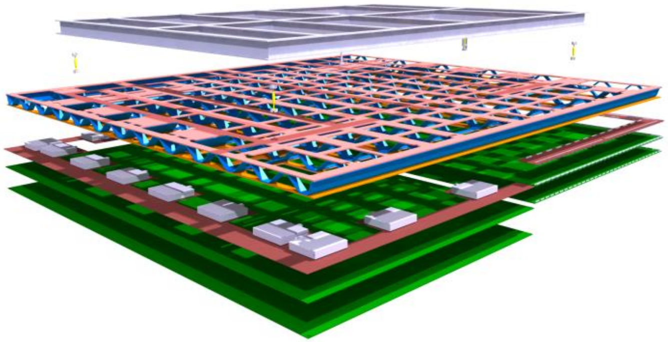


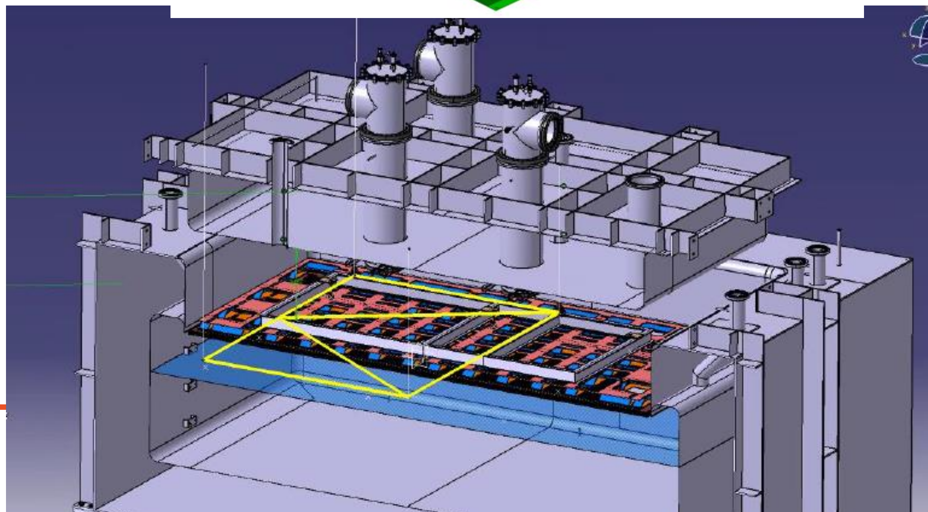
Anode PCB for the first cold-box tests in 2021



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







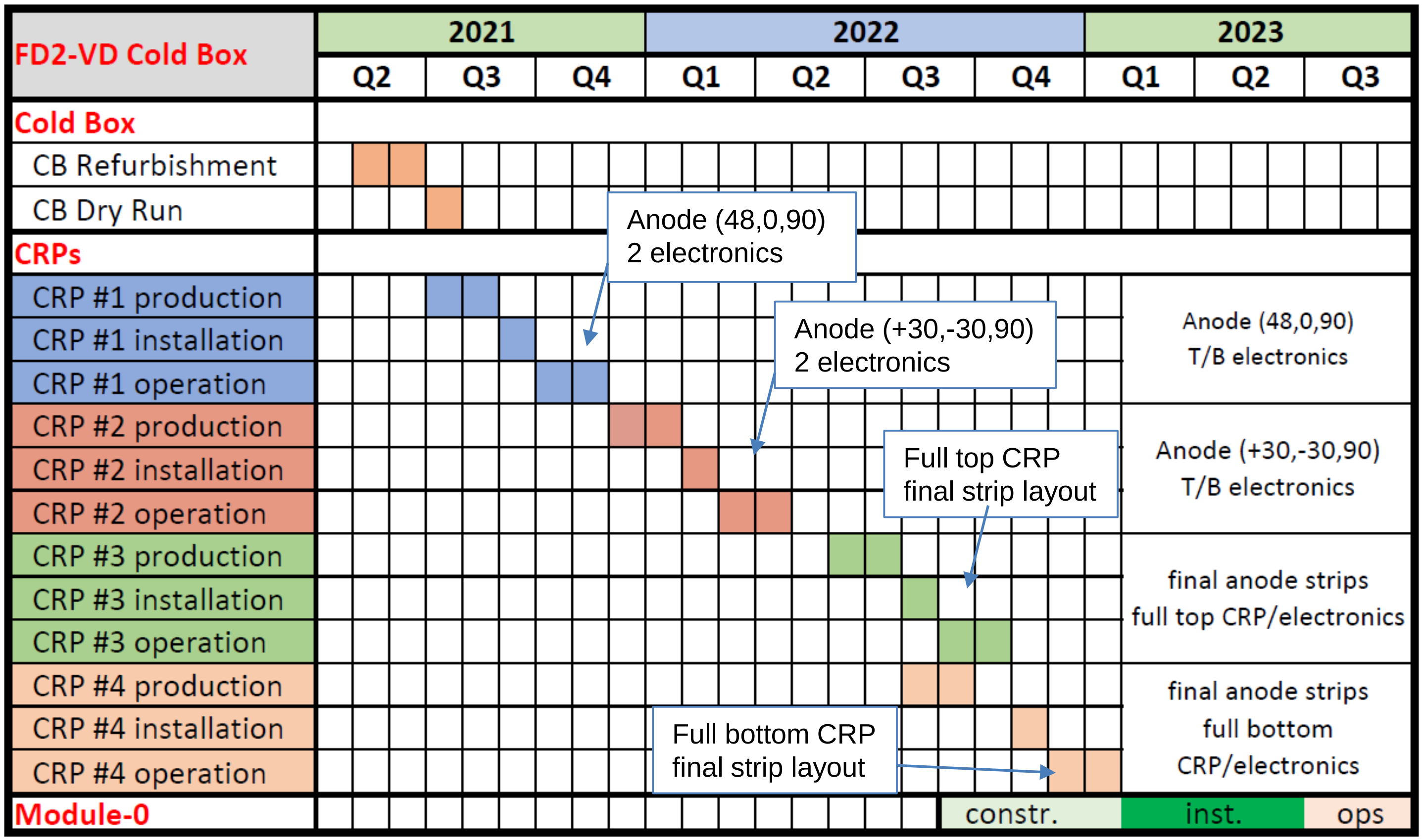
Configuration allowing assessing simultaneously the 2-views and 3-views performance in the same anodes setup to be used for the first CRP tests in 2021 → CRP shared as ½ top, ½ bottom CRPs

CRP test plan for Cold Box and Module-0

Planning from CDR

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
- ❑ 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.

Conclusions:

- **The IN2P3 project for DUNE is a long-standing project, started with the R&D phase in 2006 and prototyping activity at the CERN Neutrino Platform since 2014 (contributing to the 3x1x1 and protoDUNE dual-phase detectors). Completion of the foreseen 1 year operation program of ProtoDUNE dual-phase was achieved following expected schedule.**

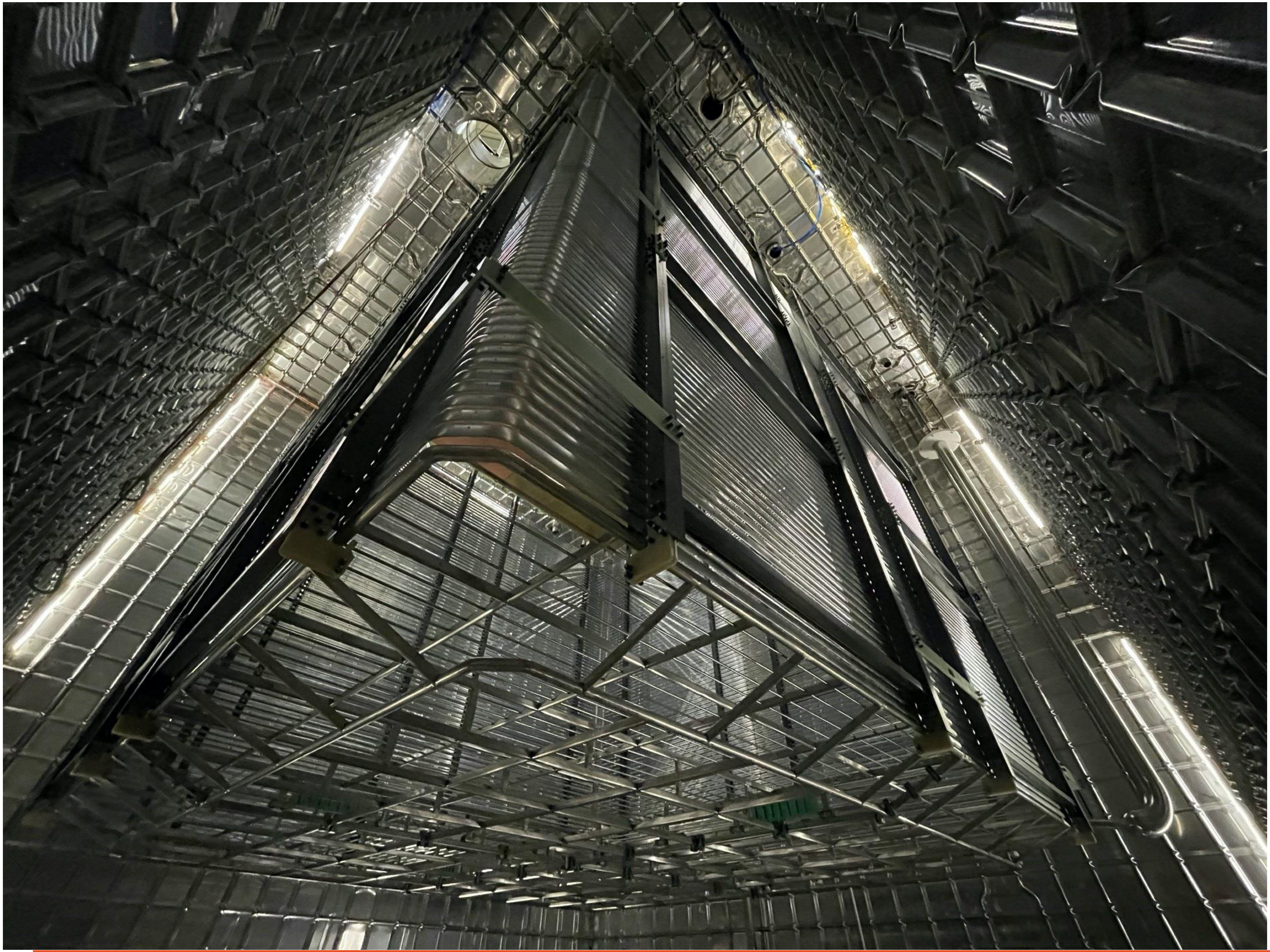
- **We have been then evolving in 2020 the dual-phase design to Vertical Drift the basis of the operation experience, lessons learned and new developments**

→ 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.

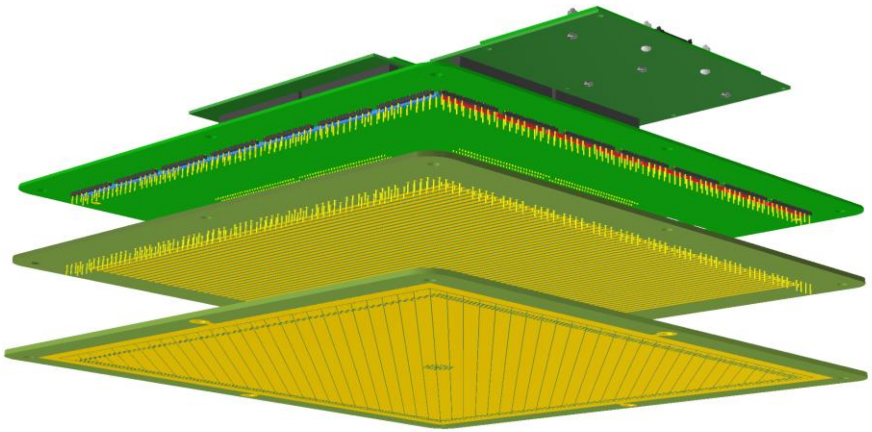
- **The DUNE IN2P3 project now benefits of the support of the TGIR (now IR*) which was prepared since 2017 and which will allow to contribute significantly and advance towards construction of the 2nd DUNE FD together with the convergence of several favorable international factors in the US and at CERN**

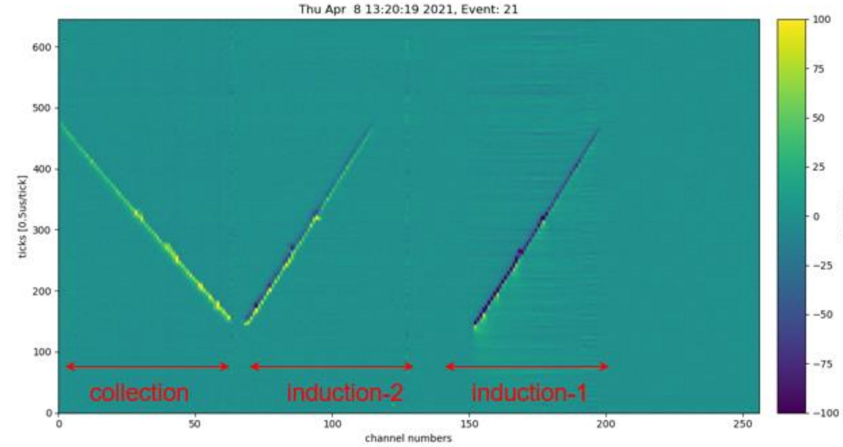
- **Detailed engineering aspects of the DUNE far detector module have been worked on the basis of the vertical drift design, which has already passed several DOE/FNAL/LBNC/SPSC reviews and a CDR review and it is now the preferred choice of the DUNE collaboration for the 2nd FD.**

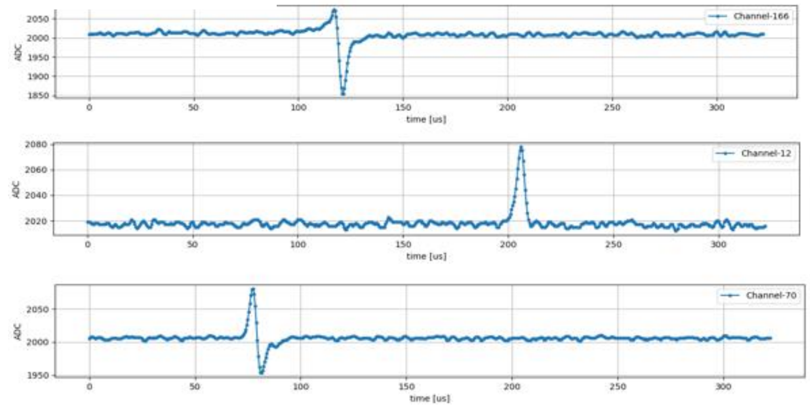
- **The experimental activities and cold-box tests program (2021-2023) have been redefined to support the integrations tests for the Vertical Drift. This effort has made large progress in 2021 with the HV test and the cold-box preparation. Production activities for FD2 expected to start at the end of 2023.**



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



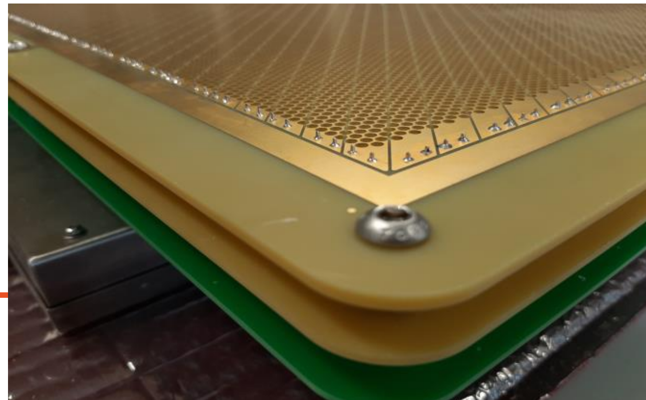




induction-1

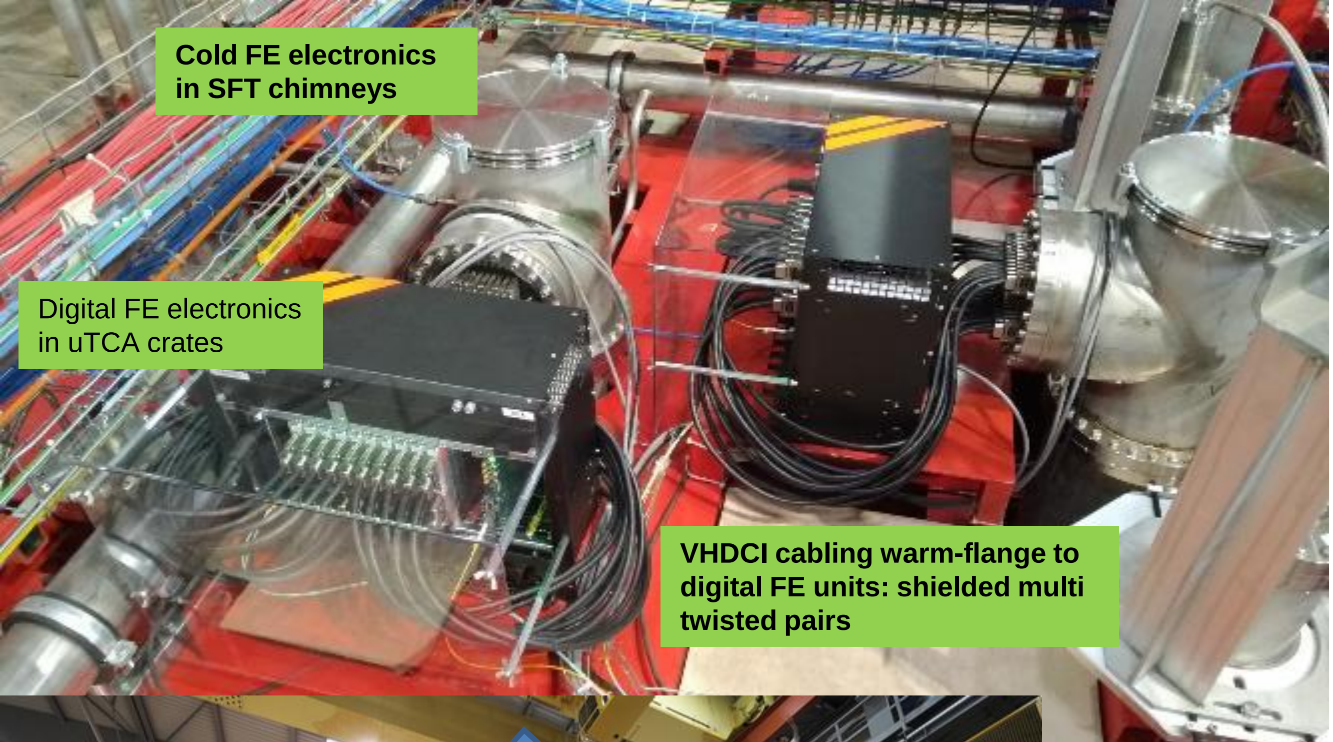
collection

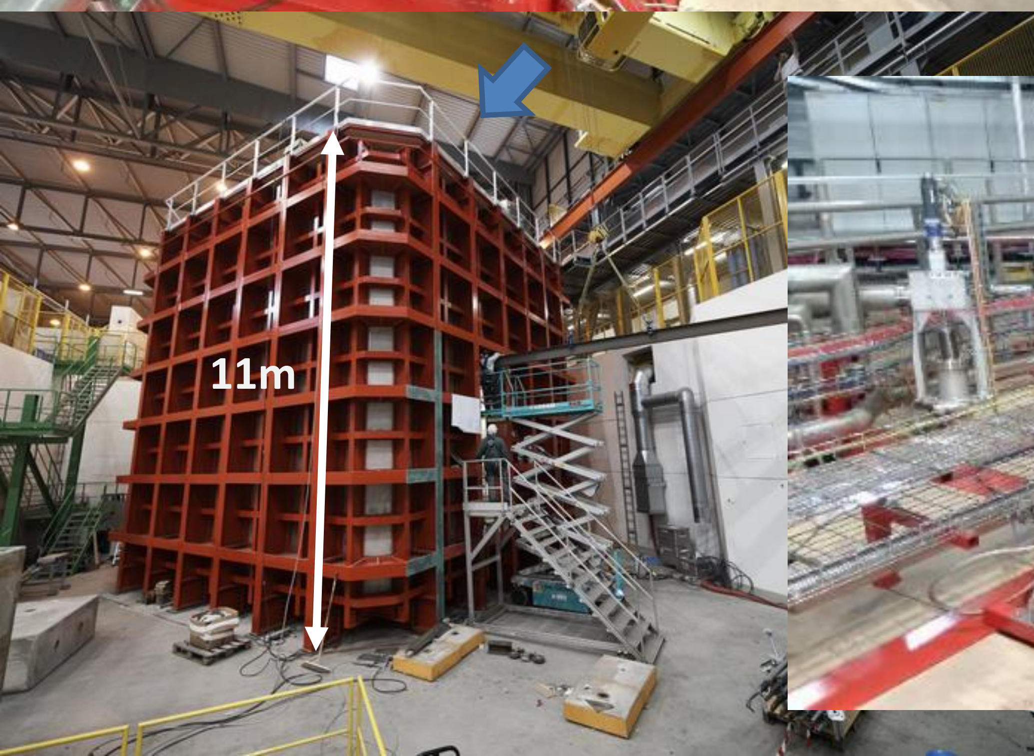
induction-2



ProtoDUNE dual-phase view of the cryostat roof with:

- **FE digitization electronics in the uTCA crates**
- **Signal feedthrough chimneys with cold electronics**

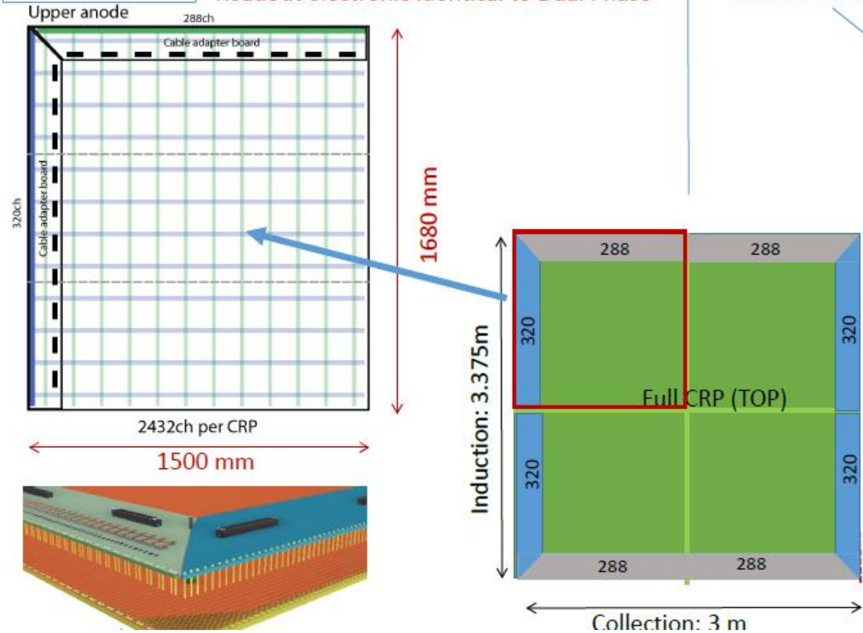




Anode electronics and Adapter Boards

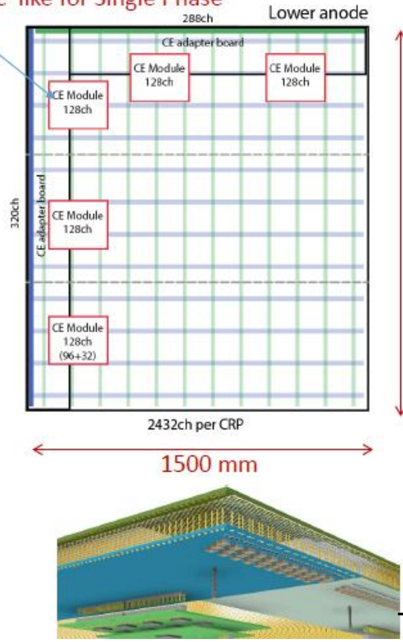
¼ of a CRP (TOP)

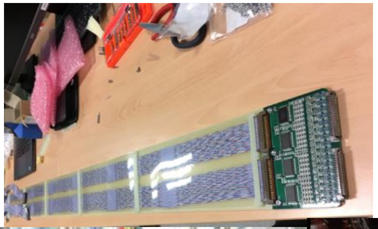
Readout electronic identical to Dual Phase



¼ of a CRP (Bottom)

Cold electronic like for Single Phase

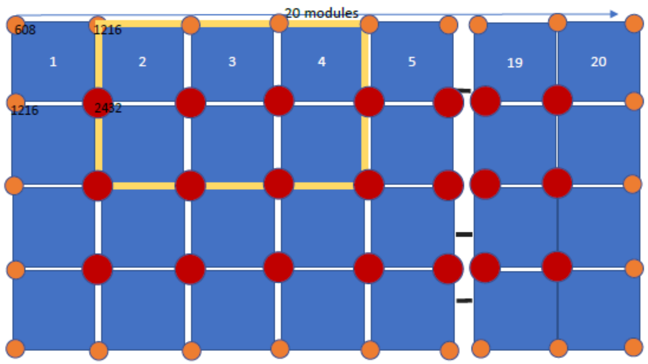




Top drift electronics from Dual-Phase design

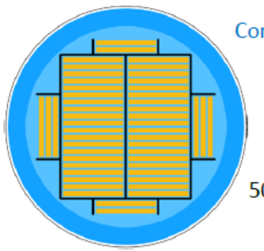
Upper Electronic Feedthroughs

Top chimney topology: connexion at each CRP corner



Total 105 feedthroughs

The peripherical one can be of smaller radius!



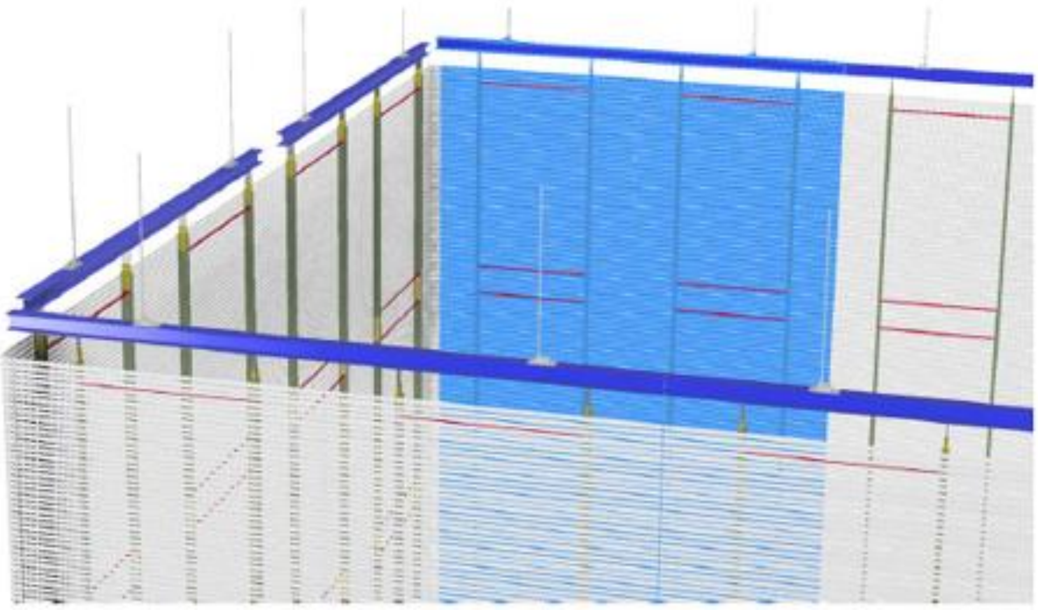
Connexion similar to DP C

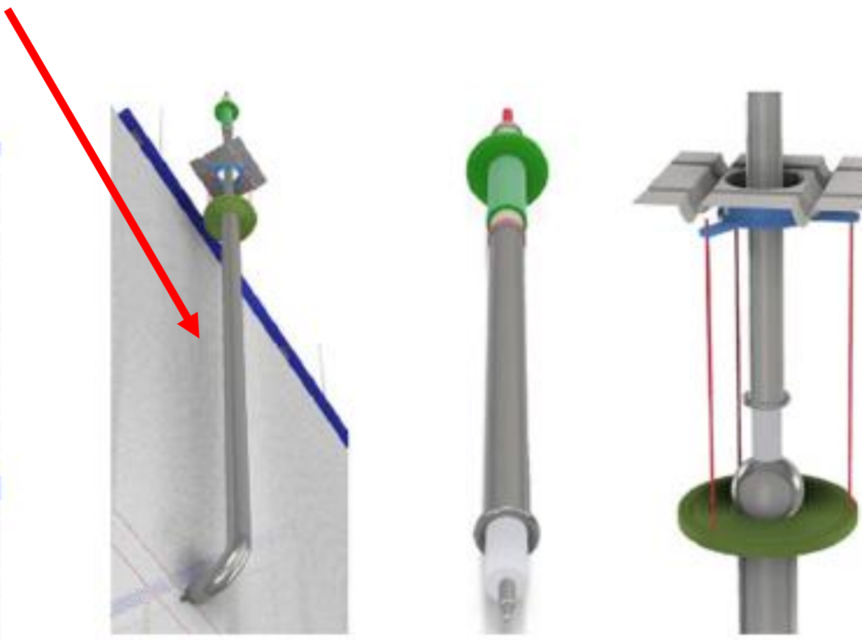
50 cards can fit inside!

Pipe internal diameter : 48 cm

Field cage and HV system

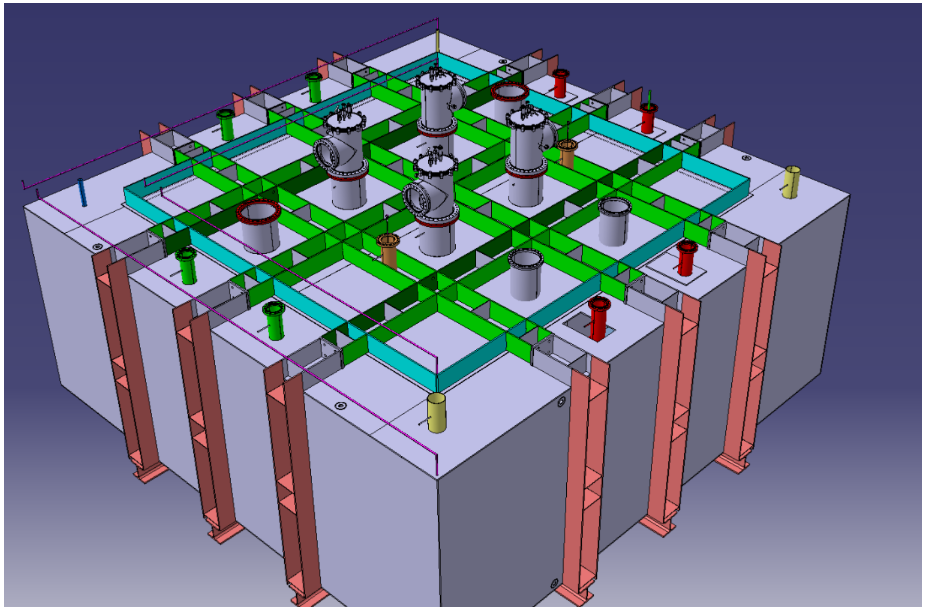
- ~300 kV applied to the cathode at the middle of the detector, max drift field ~6.5 m
- Field cage as in NP02 supported by DSS beams, using the same penetrations as bottom CRPs signals
- HV entering from the roof of the detector with a vertical penetration with the extender made with a simplified and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

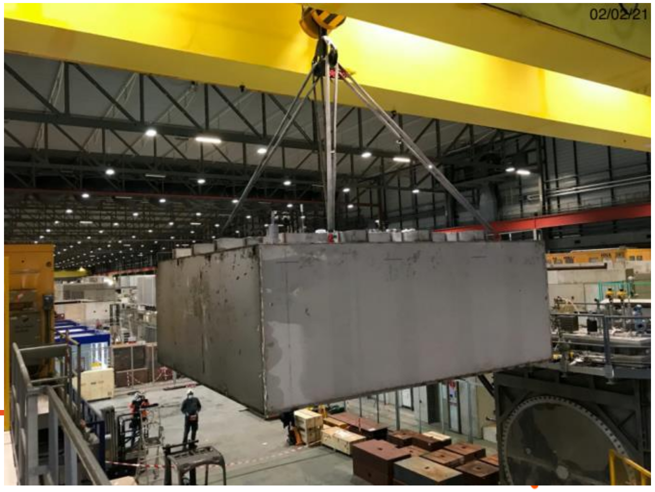




Cold-box preparation for the tests in 2021

- 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 LAr TPC design overview

D. Duchesneau
LAPP

Outline:

- General layout and dimensions
- Anodes and CRP
- Cathode, Field cage and HV
- Photon detection system
- Summary

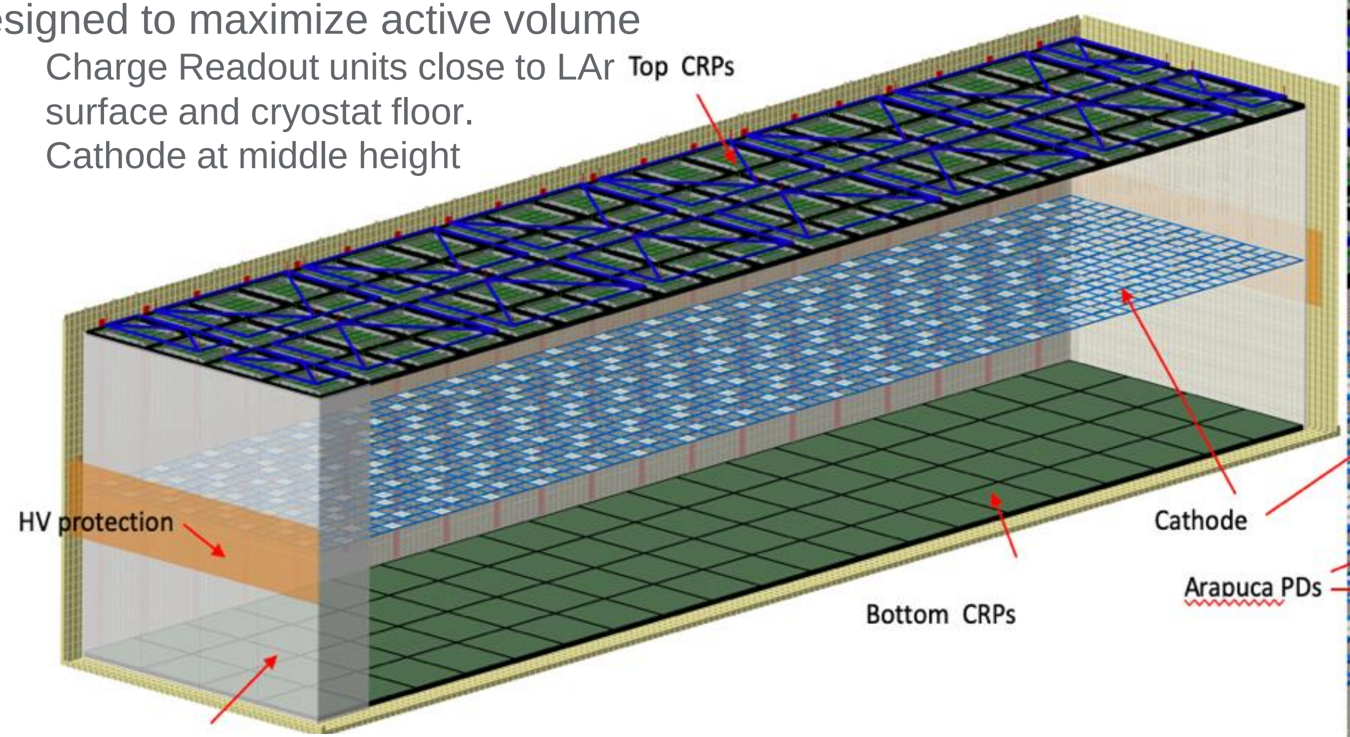
Vertical Drift Detector components

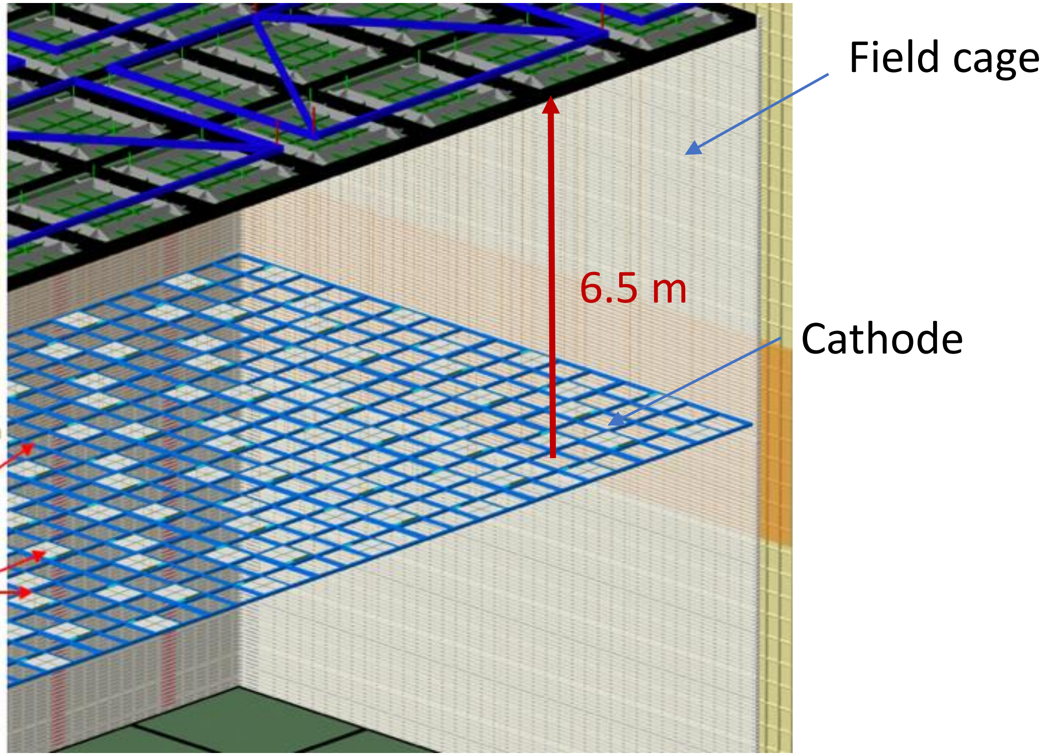
Liquid Argon TPC:

- To detect ionisation charge and scintillation light

- Single field cage surrounding entire active volume
  - derived from DUNE-DP design

- Designed to maximize active volume
  - Charge Readout units close to LAr surface and cryostat floor.
  - Cathode at middle height



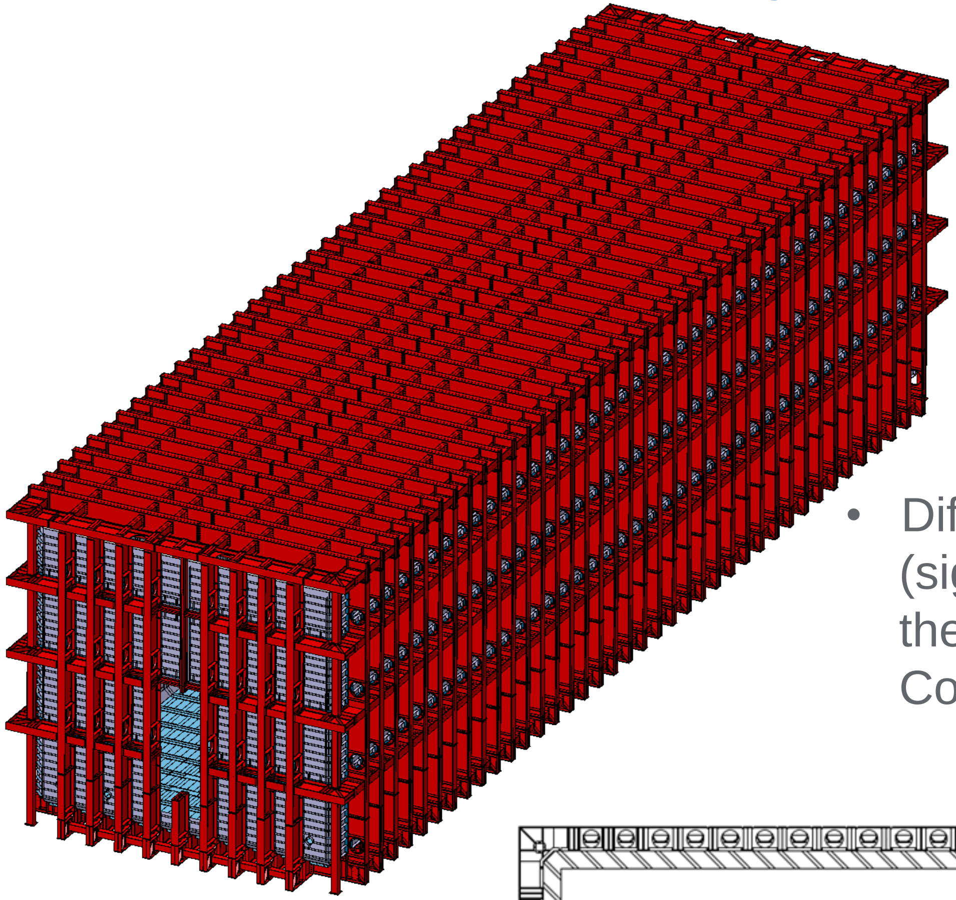


- Perforated PCB's with segmented electrodes (strips) as readout units with integrated electronic interfaces
  - 2 or 3 view using 2 perforated PCB layers
  - Optimizable strip orientation, pitch, length and PCB modularity

- Modular supporting structures for readout planes
  - Derived from CRP design of DP Incorporates cathode hanging system

- Photon detectors based on X-ARAPUCA technology (same as DUNE-HD)
  - integrated on cathode plane and on the cryostat walls.
  - decoupling from HV, achieved with optical fibers for signal and power transmission.

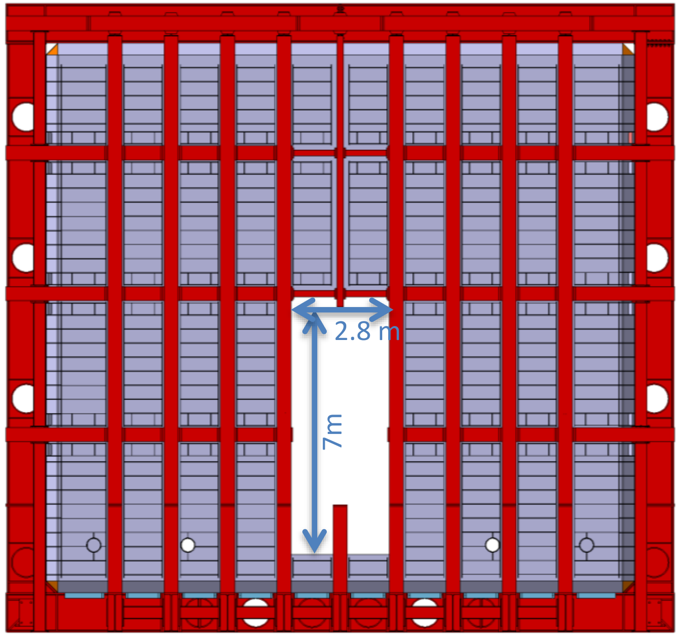
General dimensions and cryostat for the Vertical Drift detector

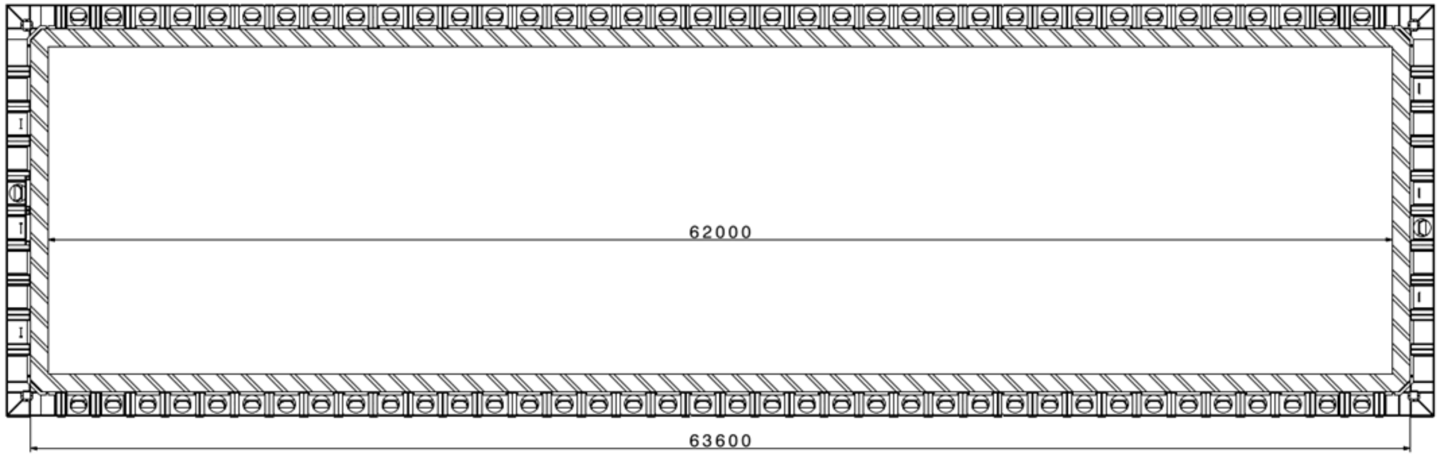


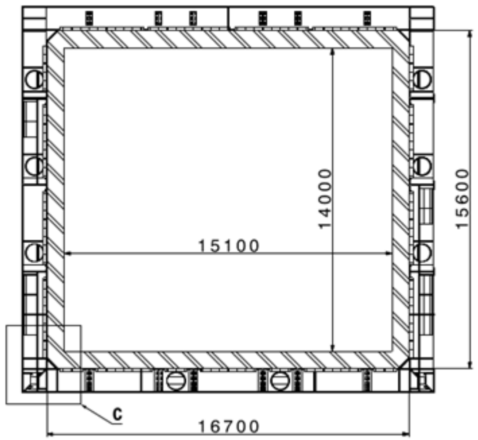
- The Cryostat layout will mostly remain the same as the one foreseen for the horizontal drift DUNE detector with internal dimension: 62m x 15m x 14m

- Differences: the roof penetrations (signal and detector support) and the size of the TCO (Temporary Construction Opening)

Cryostat - TCO

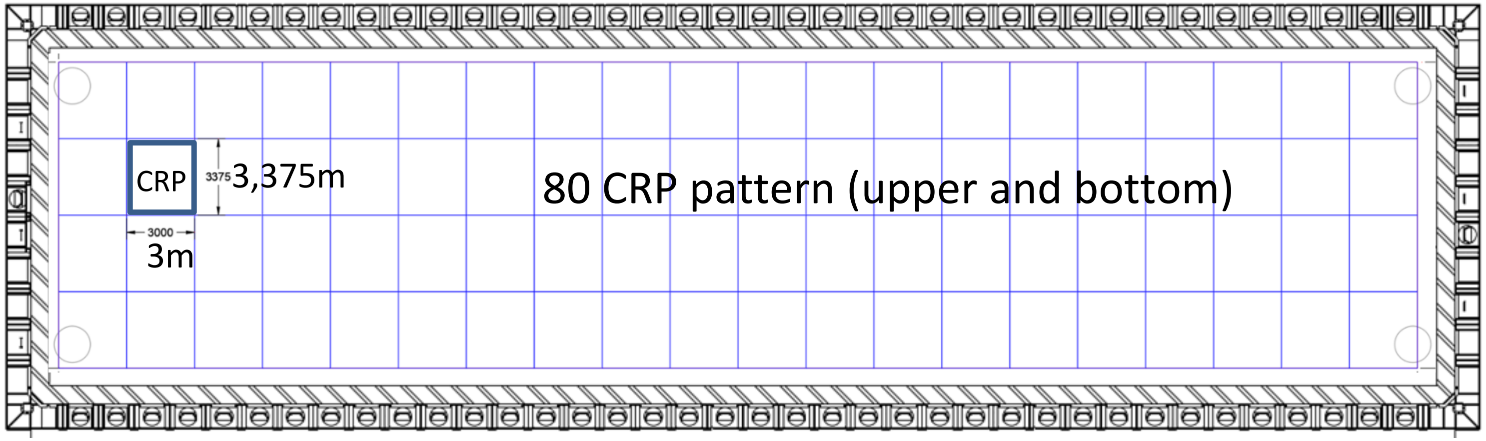




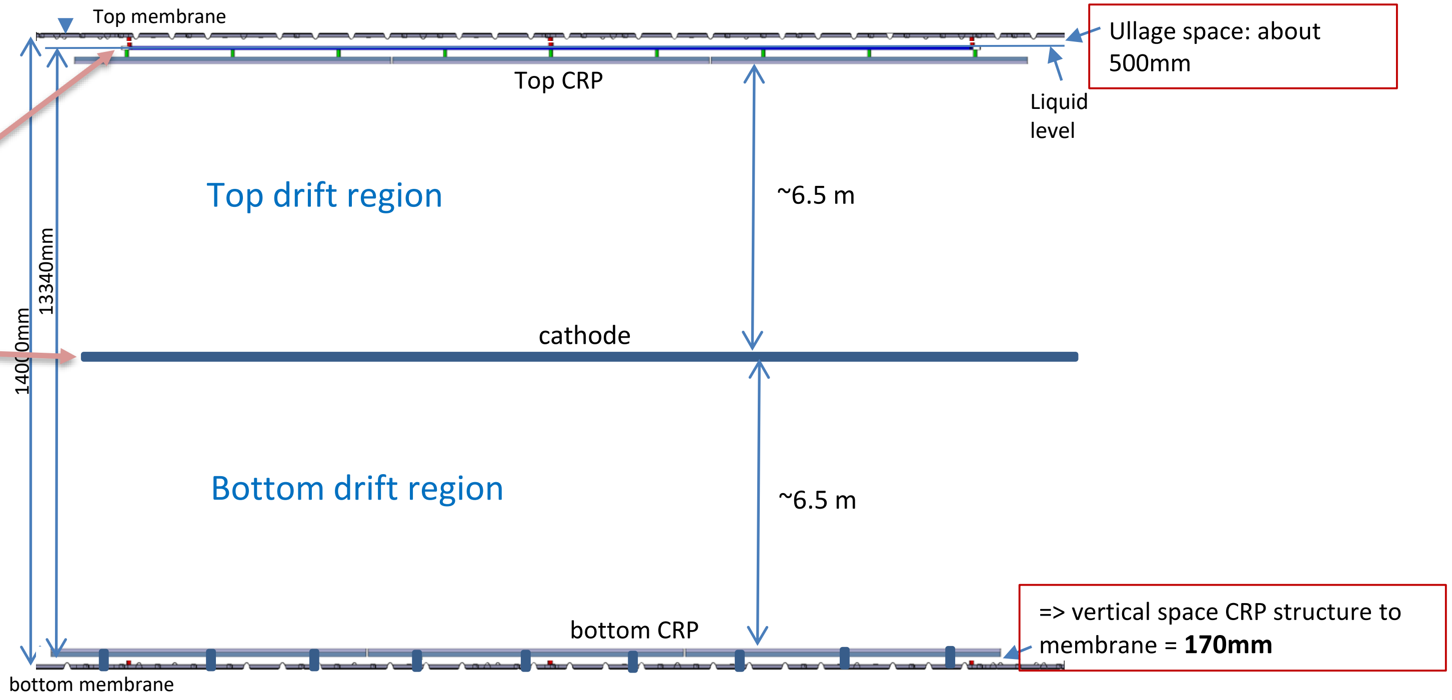


General detector geometry arrangement

Top view:



Side view :



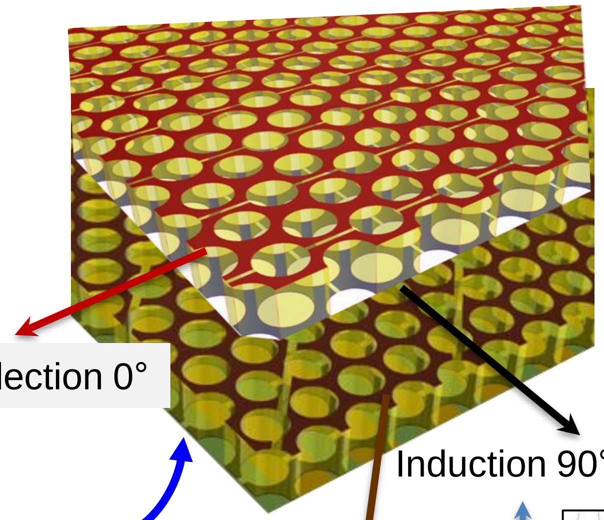
Cathode is suspended to the general CRP top support structures

6 cathode units suspended to SuperCRP by 12 points with dyneema (Kevlar) wires

Perforated PCB Anode :

Principles: Strips on perforated PCB 3.2mm thick

Three view (48°, 0°, 90°)



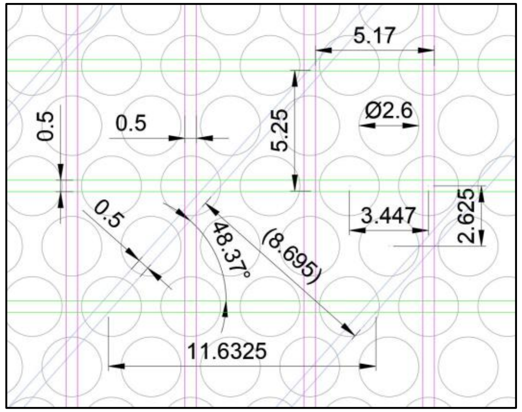
- ✓ 2.5 mm holes
- ✓ Collection strips in the transverse direction, 5.2mm width
- ✓ Induction2 strips along beam, 5.2mm width

- ✓ Adding 3rd view at ~48°
- ✓ Induction1 strip pitch: 8.7mm

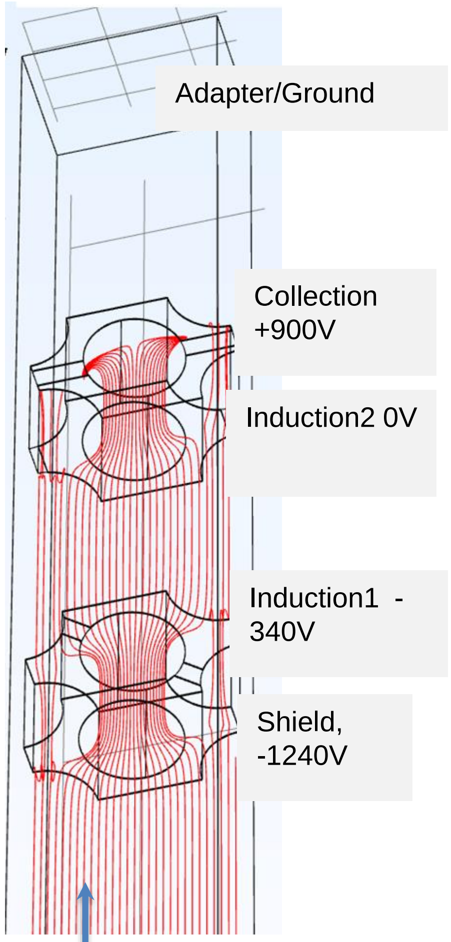
- ✓ 8.5 mm PCB spacing

adding a 'shield' layer facing the cathode to reduce the risk of charge injection to the FEE

e-

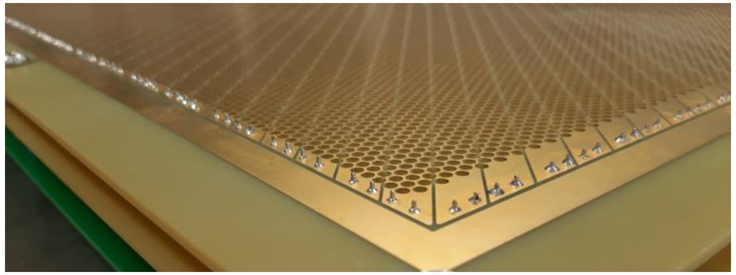


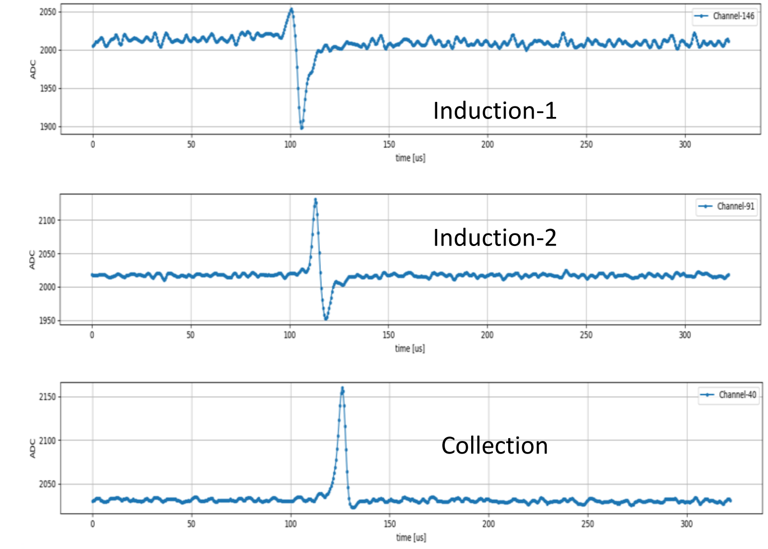
Design for the 1st CRP and cold box test in 2021

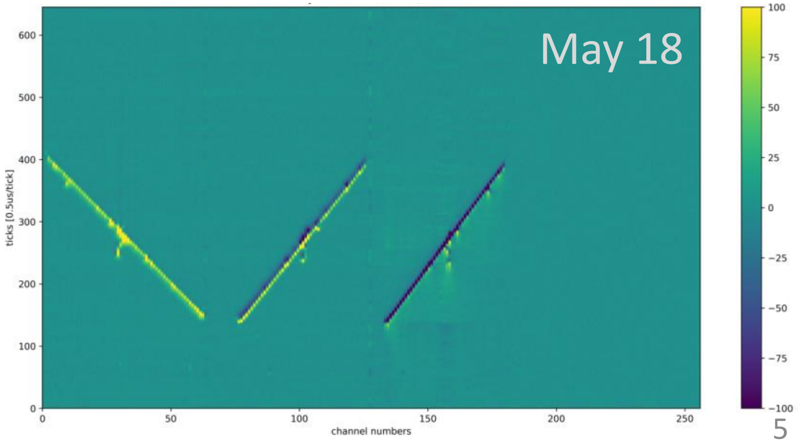


All drift electrons are passing through the holes in the 2 layers before being collected

3 View anode setup tested at CERN in 50L cryostat



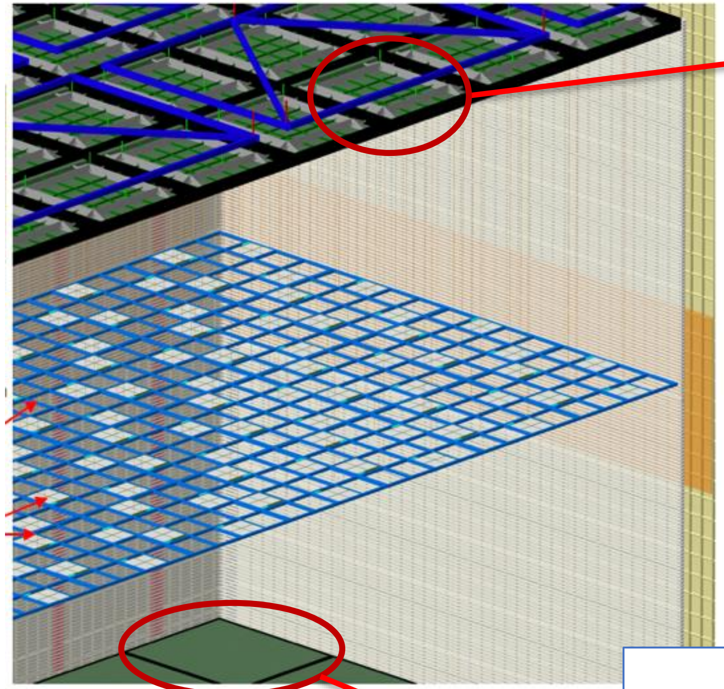




Charge Readout Plane and anode assembly

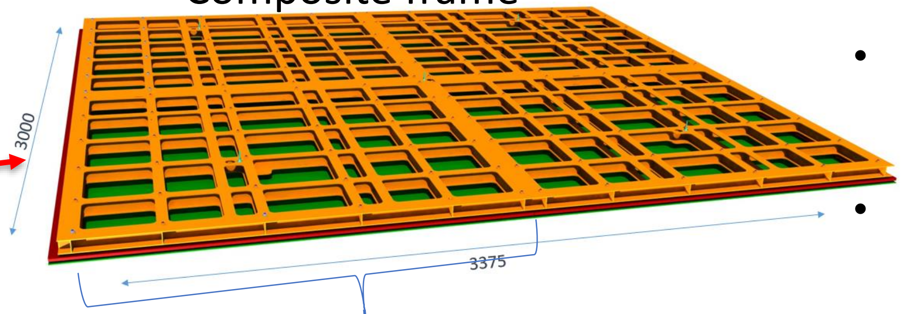
✓ 160 CRP units (80 on top, 80 on the bottom)

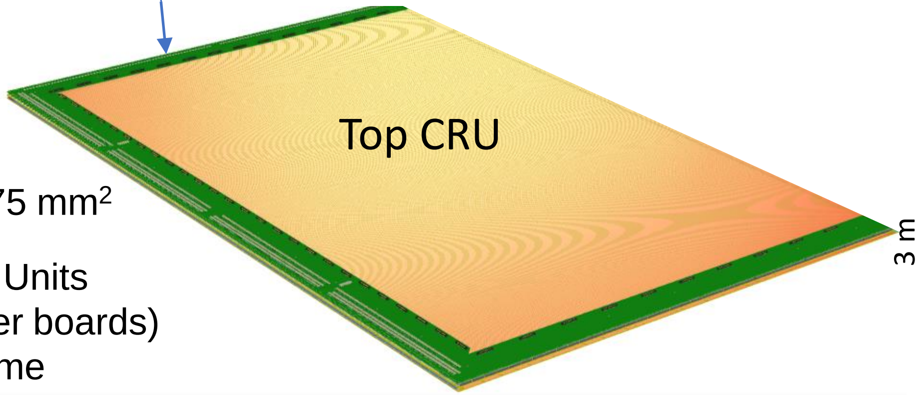
Readout by DP electronics



Readout by CE

Composite frame

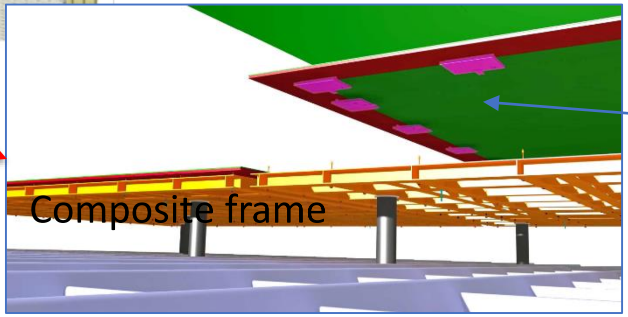


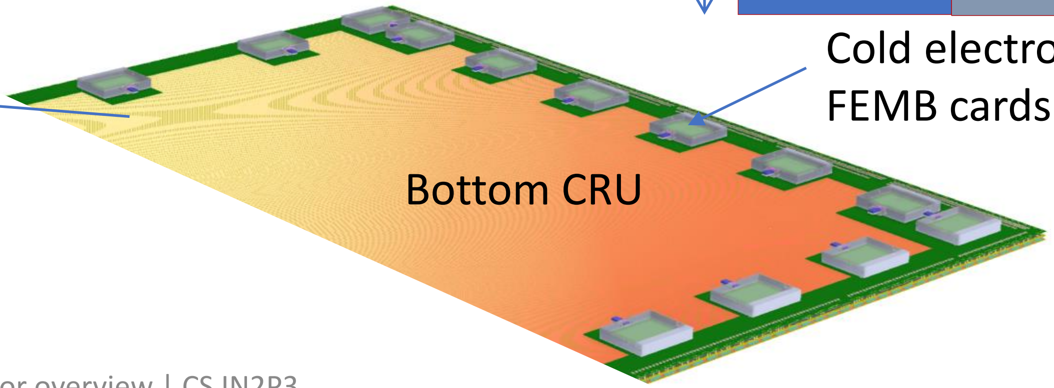


1 CRP = 3000 x 3375 mm^2

✓ Charge Readout Units (anodes + adapter boards)

✓ 1 mechanical frame

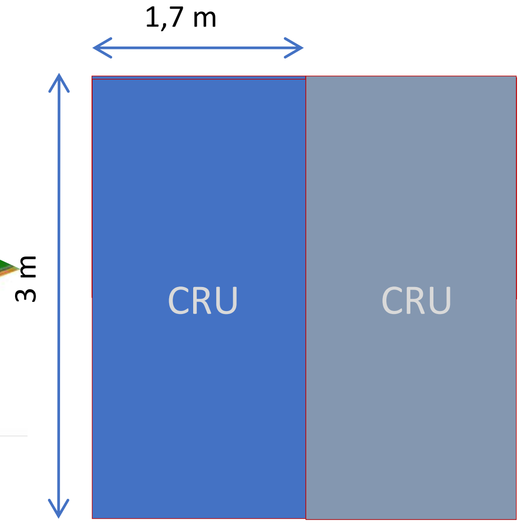




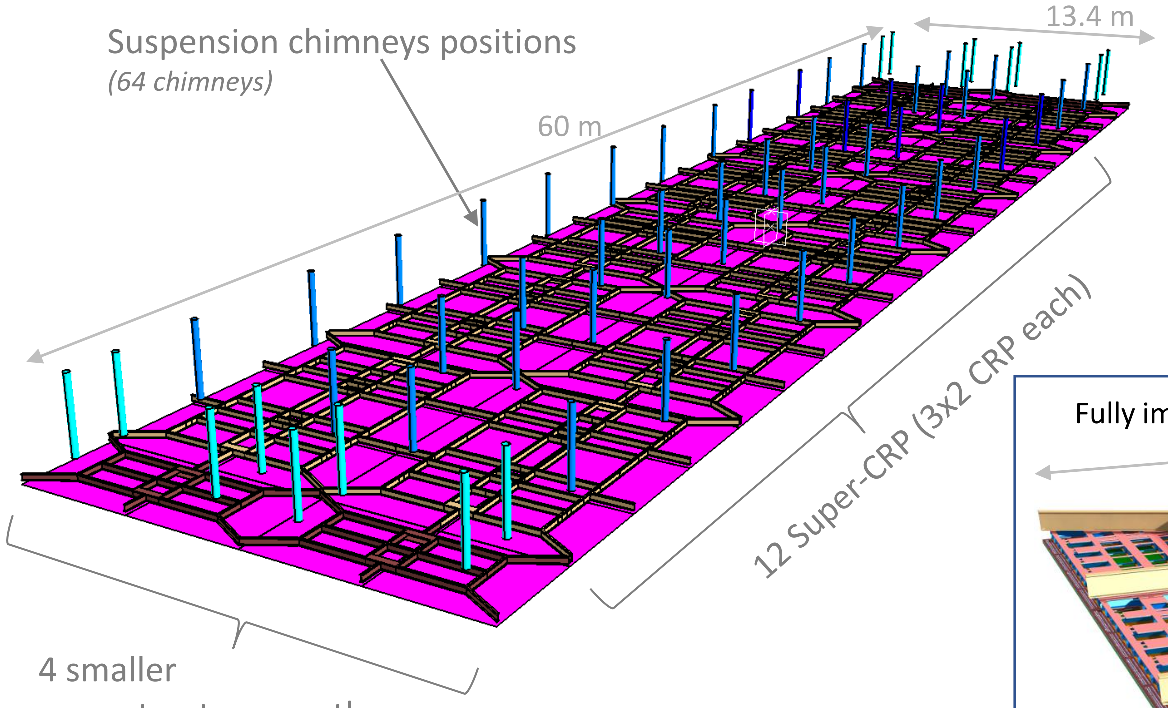
Cold electronic FEMB cards

Readout geometry foreseen: Identical for top and bottom:

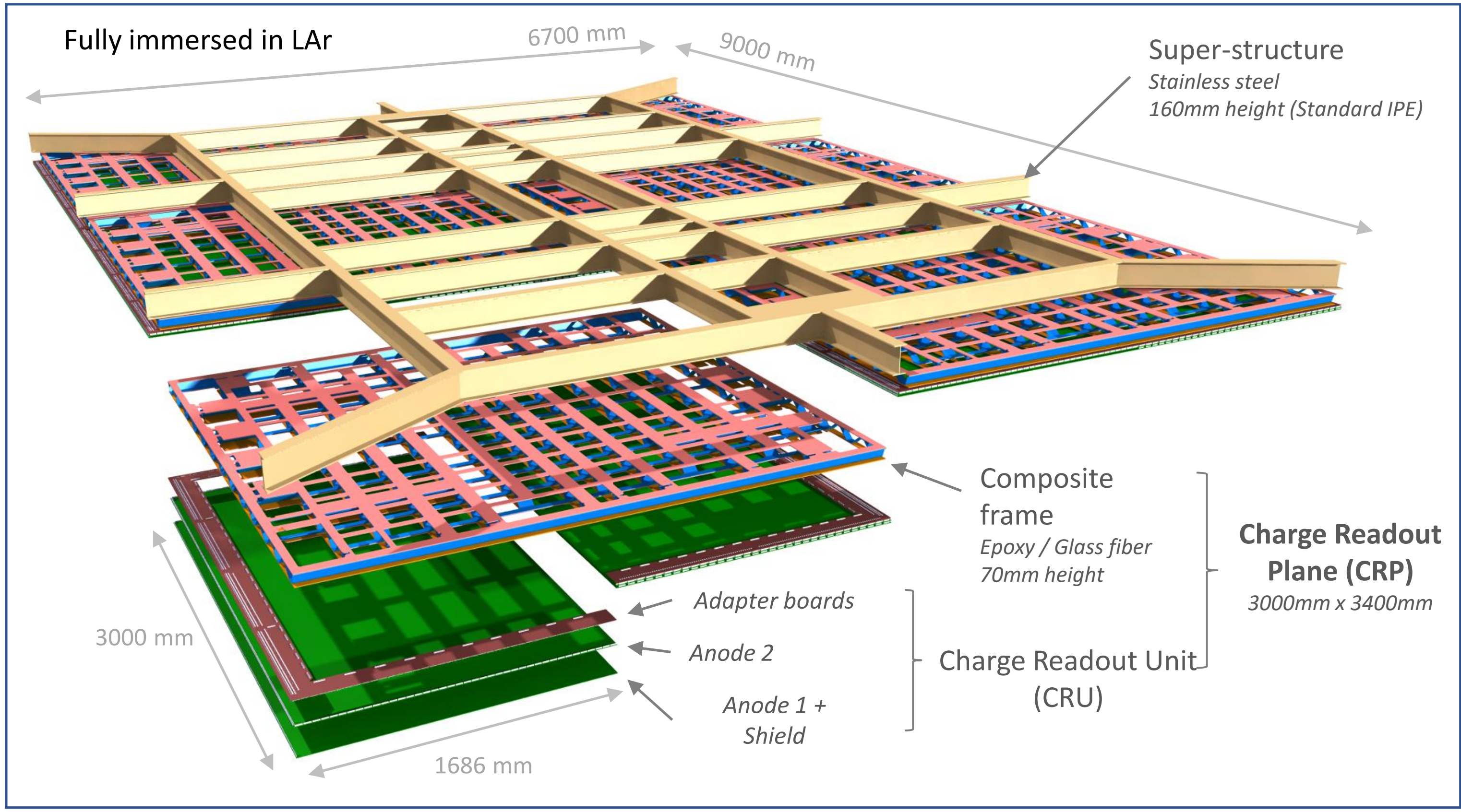
- An anode PCB unit is 3 m x 1.7m in size, constructed by bonding several PCBs side by side.
- A CRP is made of 2 CRU



Top CRP plane layout



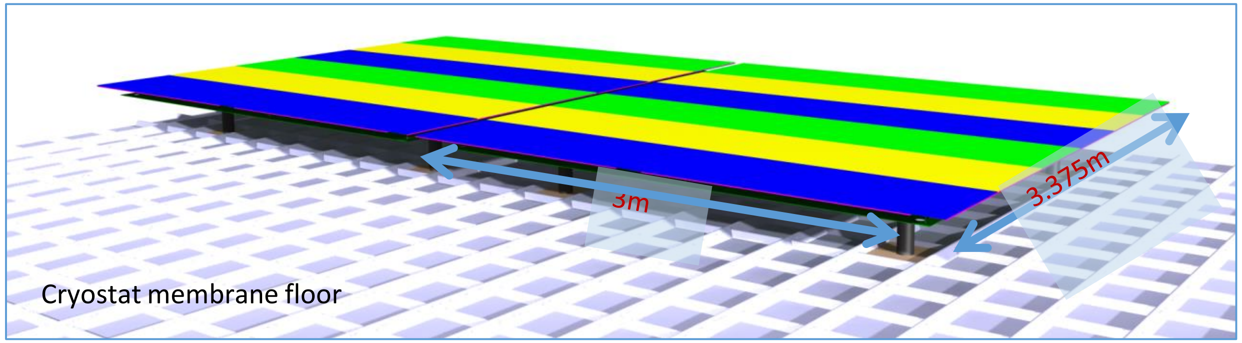
Each superstructure is suspended by 4 cables and position controlled from the top of the cryostat like for Dual Phase

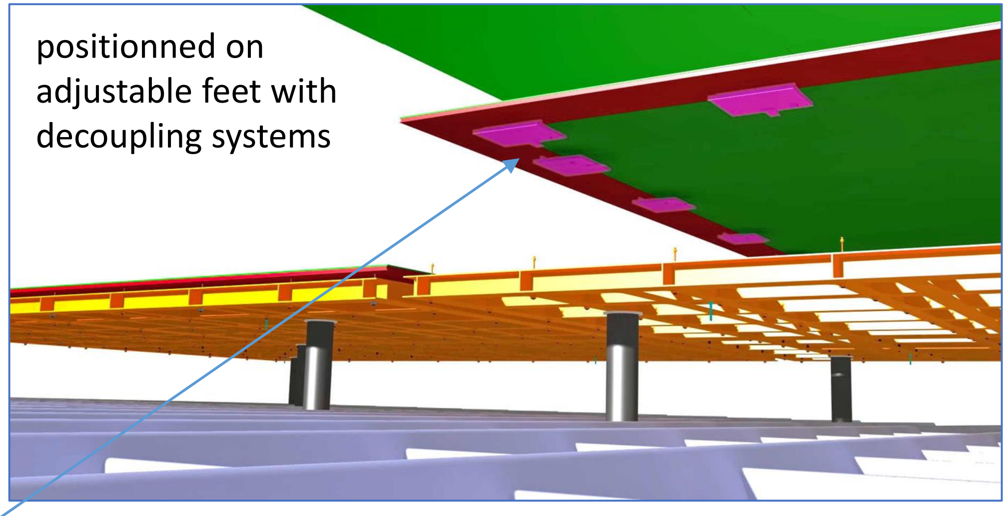


Top plane: 80 CRPs

Anode planarity specification : <10 mm @ cold

Bottom CRP Plane Layout



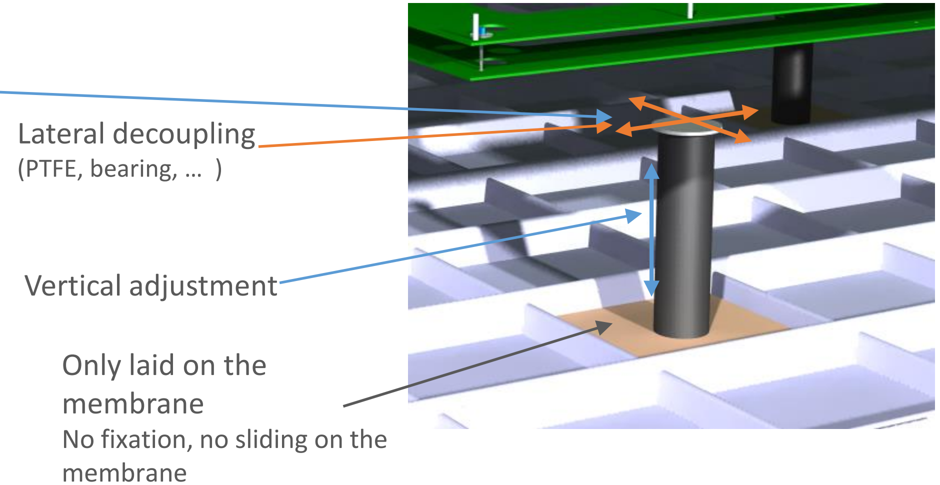


Design of the bottom CRP frame:
No metallic frame, only composite frame

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

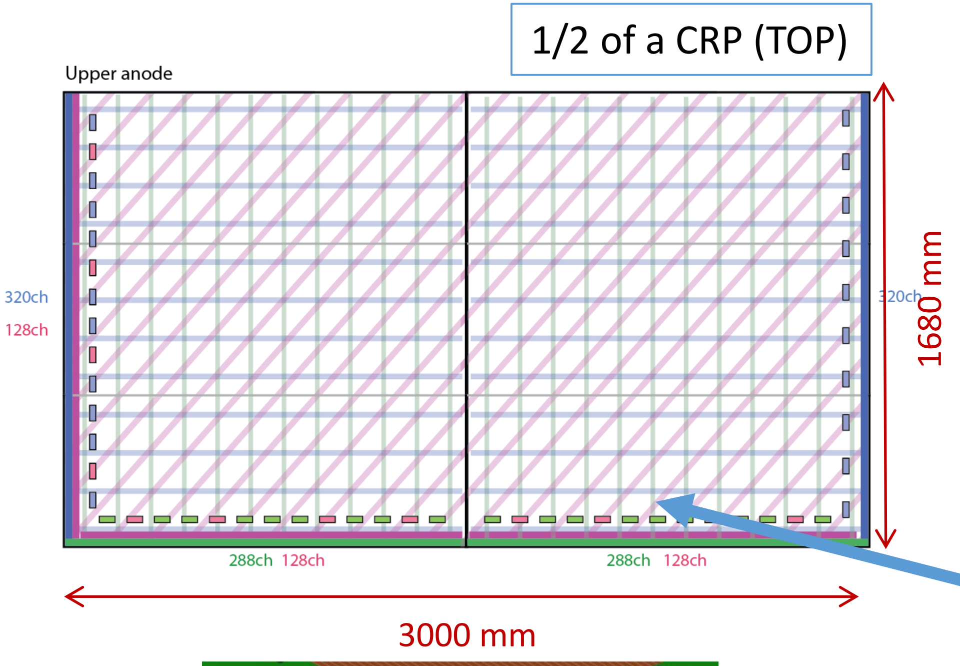


Charge readout electronics and Adapter Board interface

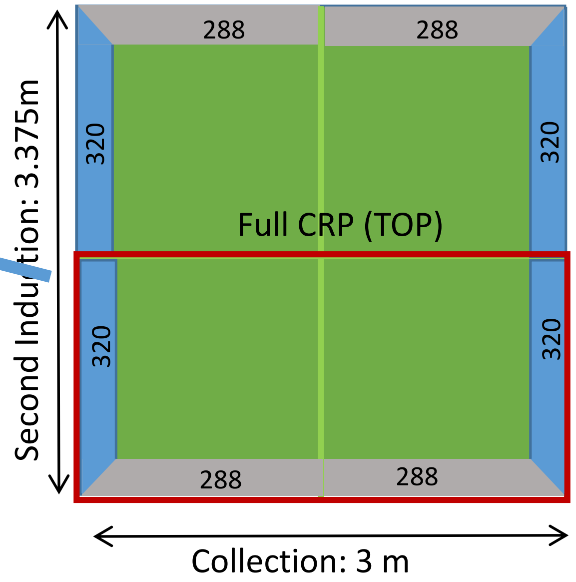
For the (48°, 0°, 90°) => 3200 channels / CRP

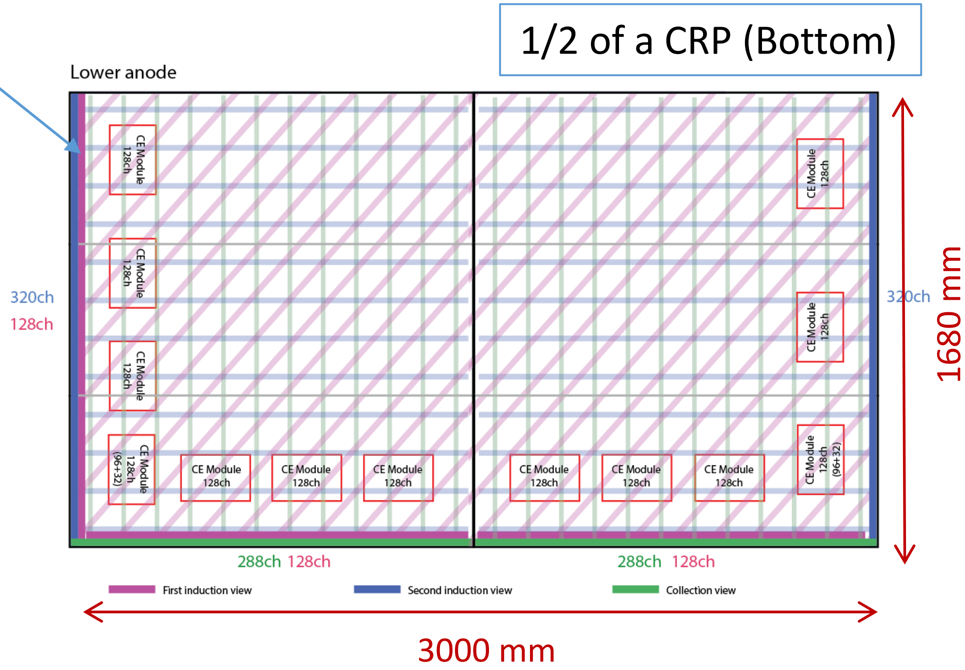
Top CRP: Readout electronic identical to Dual Phase completely accessible from cryostat roof

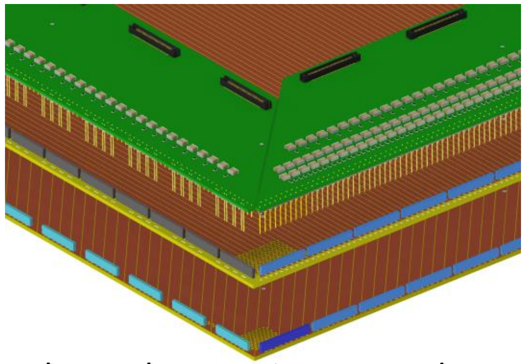
Bottom CRP: Cold electronic like for Horizontal Drift



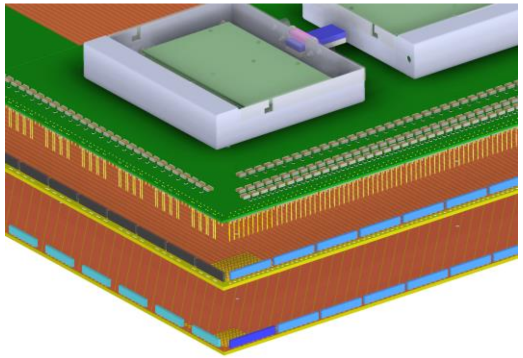
Channel count per ½ CRP
1st induction: 384
2nd induction: 640
collection: 576







Each CRU has 8 unique FEE adapter boards, carrying 50 cable connectors to the FEE inside the roof chimneys.



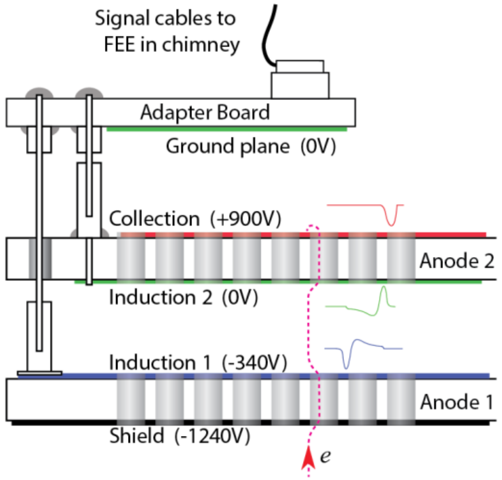
8 unique CE adapter boards carries 13 CE modules, in addition to the high voltage coupling capacitors and current limiting resistors.

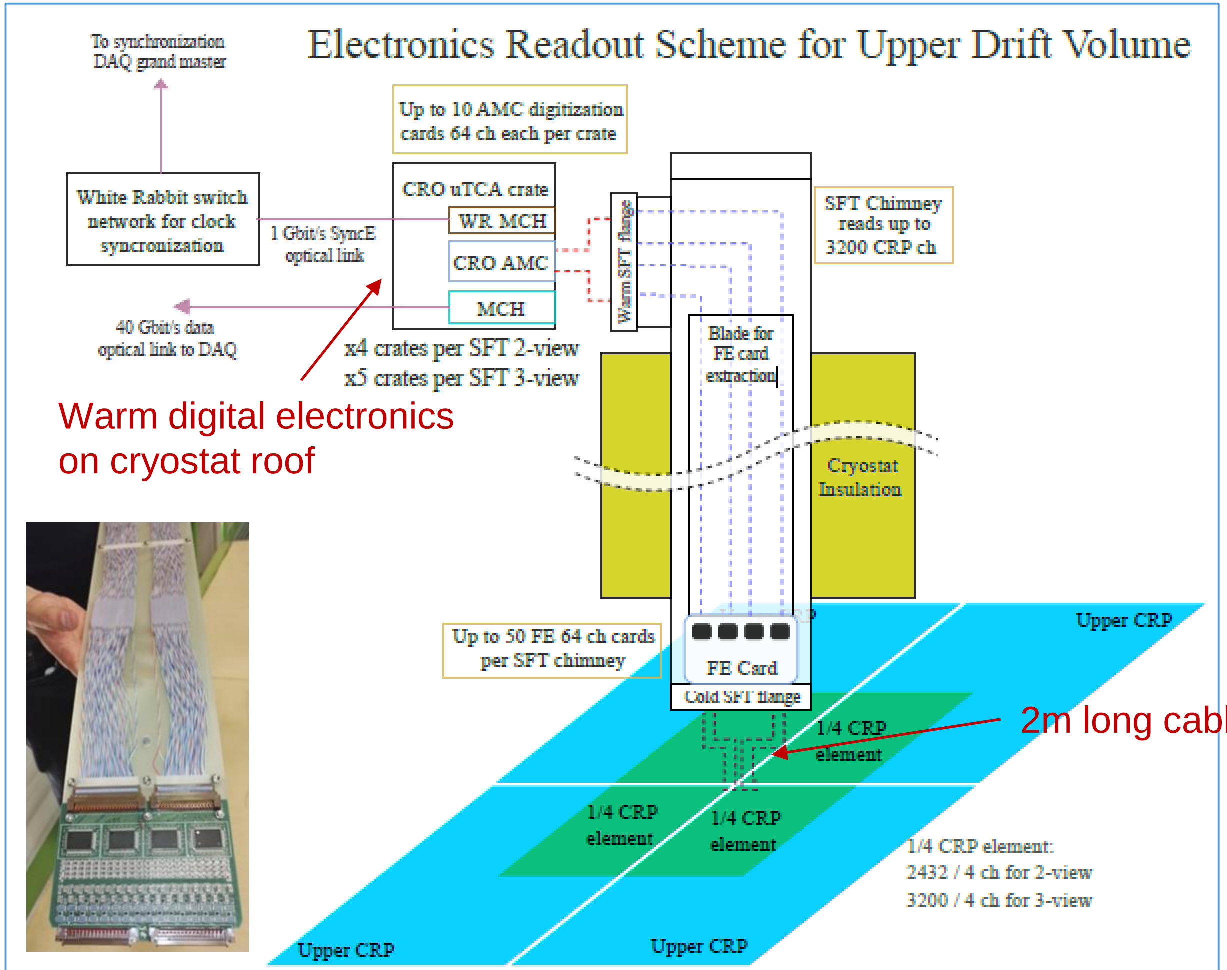
Charge readout electronics

- ❑ Requirements for the top and bottom drift electronics are the same as commonly defined in the DUNE design reports for the FD1-HD and ProtoDUNE-DP electronics.
- ❑ Top and bottom drift volumes implement different CRO electronics in order to take maximal advantage of the different configurations of the two drift volumes.

Top drift electronics: use same design as for Dual Phase

- ❑ Analog cryogenic FE cards accessible in the chimneys
- ❑ AMC digitization cards in uTCA crates



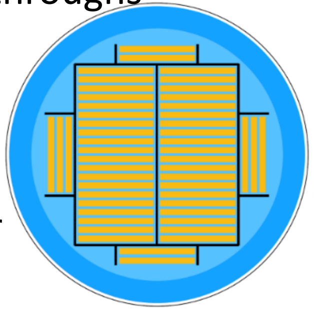


2m long cables

Blade insertion/extraction from the cryostat roof

Total 105 feedthroughs

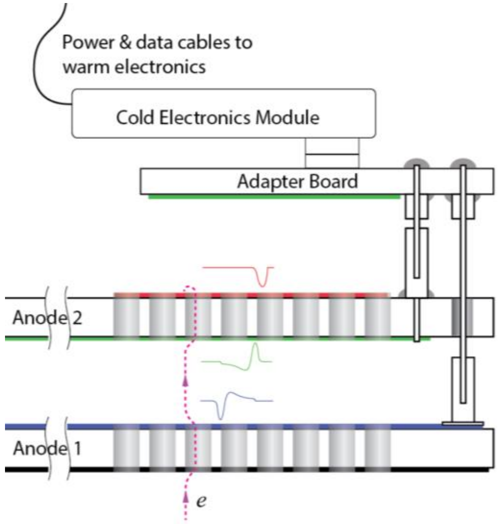
1 chimney near each CRP corner

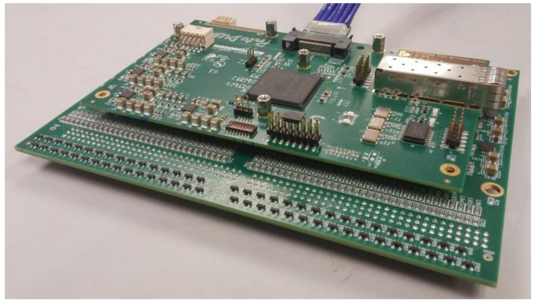


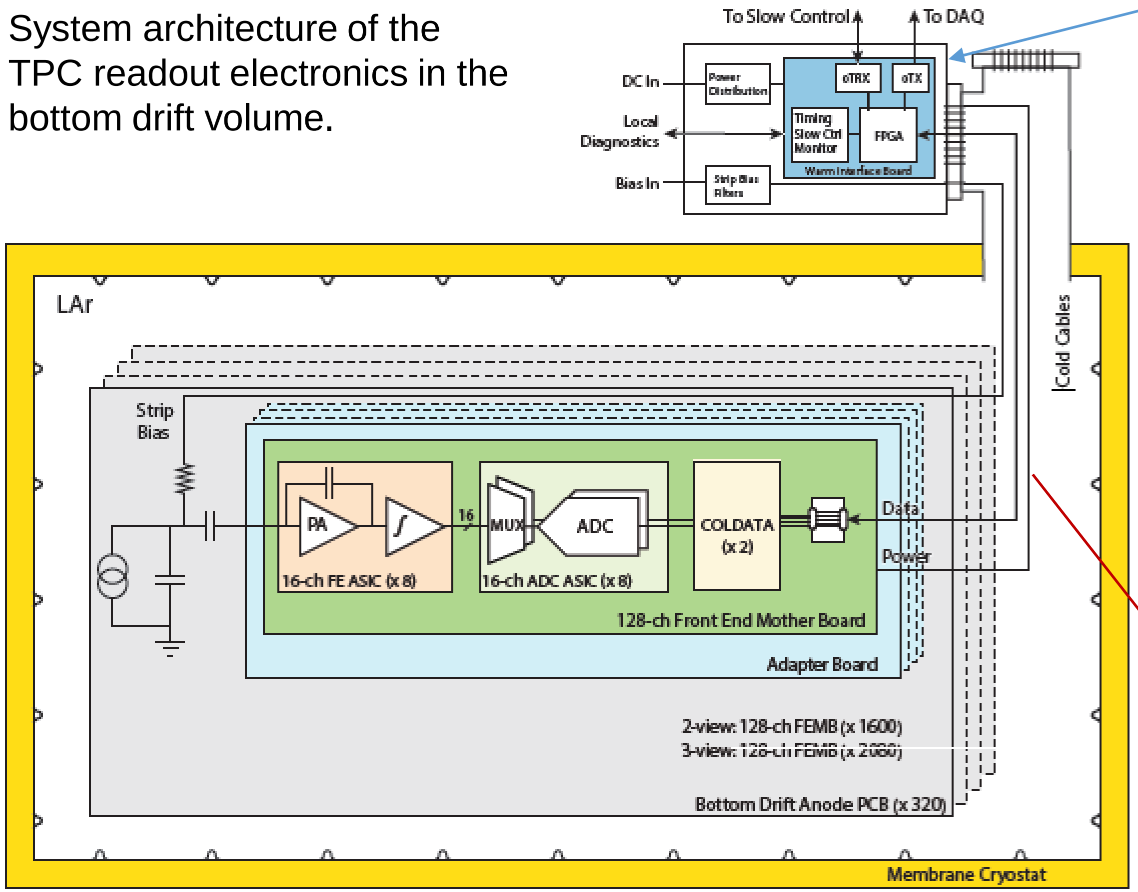
Pipe internal diameter : 48 cm
Accommodate: up to 50 FE cards

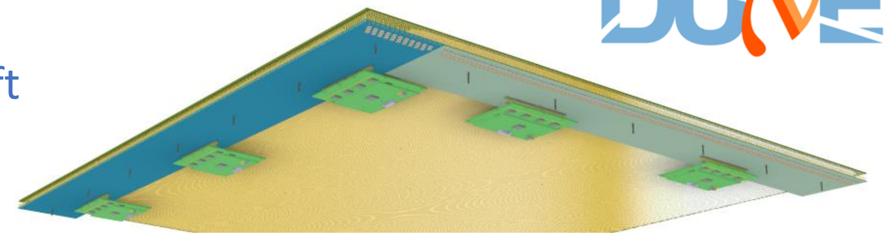
Bottom drift electronics:

Use same FEMB cards and Warm Interface Board design than the Horizontal Drift detector

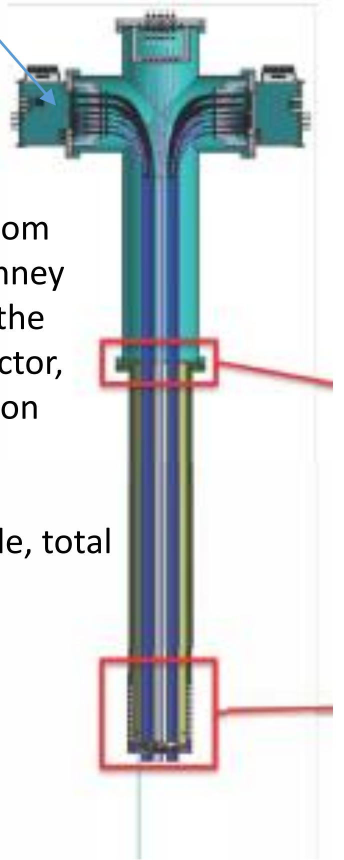








Warm Interface Board



- ✓ 1 chimney for 2 bottom CRPs = 5120 ch/chimney
- ✓ Chimney runs along the long side of the detector,
- ✓ Cables run vertically on trays attached to the primary membrane
- ✓ 20 cable trays per side, total 40 chimneys

- ❑ FEMB in LAr for amplification, pulse-shaping and digitization

25m long cables

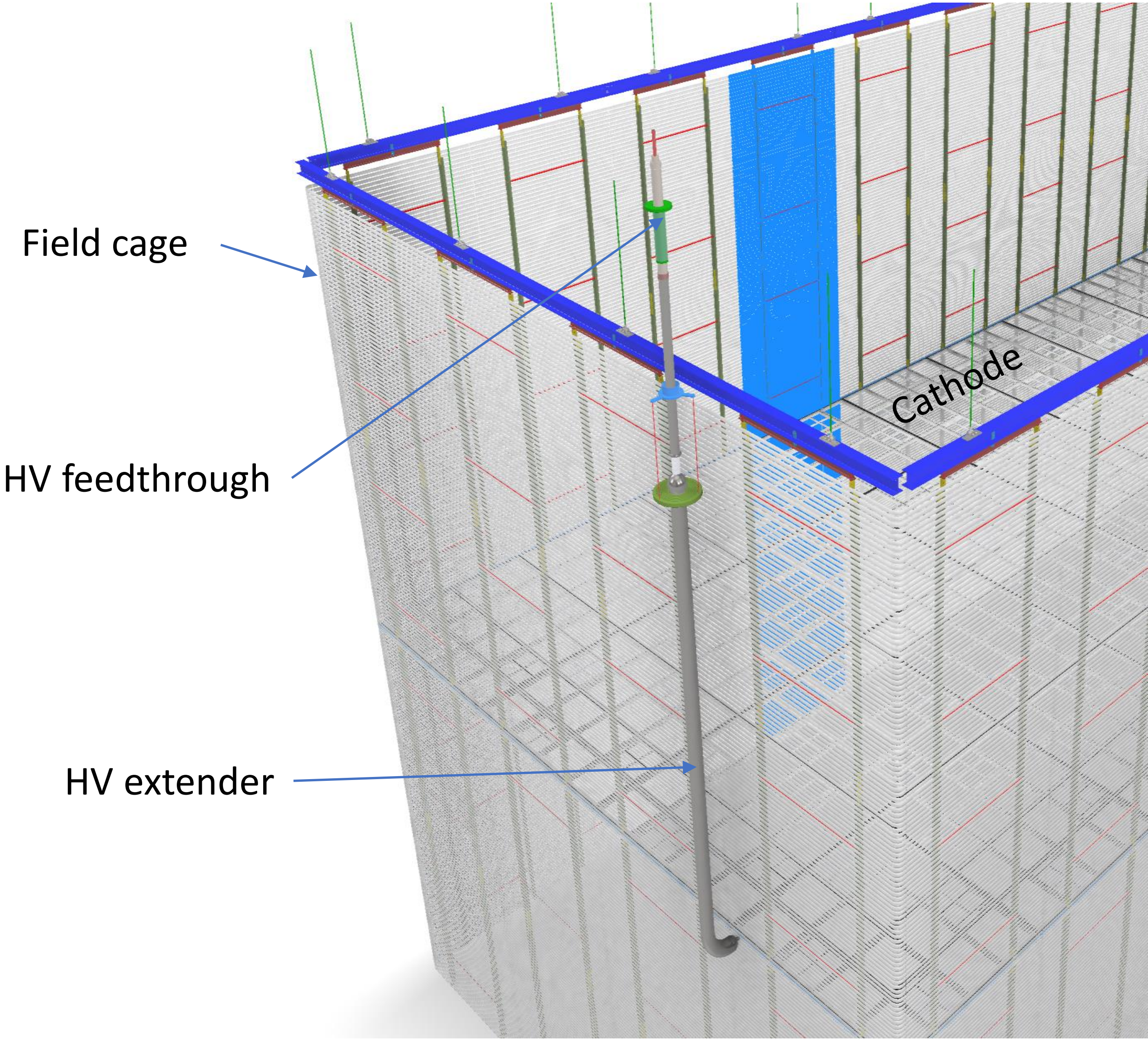
Field cage and HV distribution

The HV system consists of:

- ❑ The HV delivery system
  - HV power supply (>300 kV)
  - PS monitoring system, HV cable, ripple filters,
  - HV Feedthrough, and
  - HV extender

- ❑ The field cage
  - 192 field cage modules, with FC aluminium profiles

- ❑ The cathode

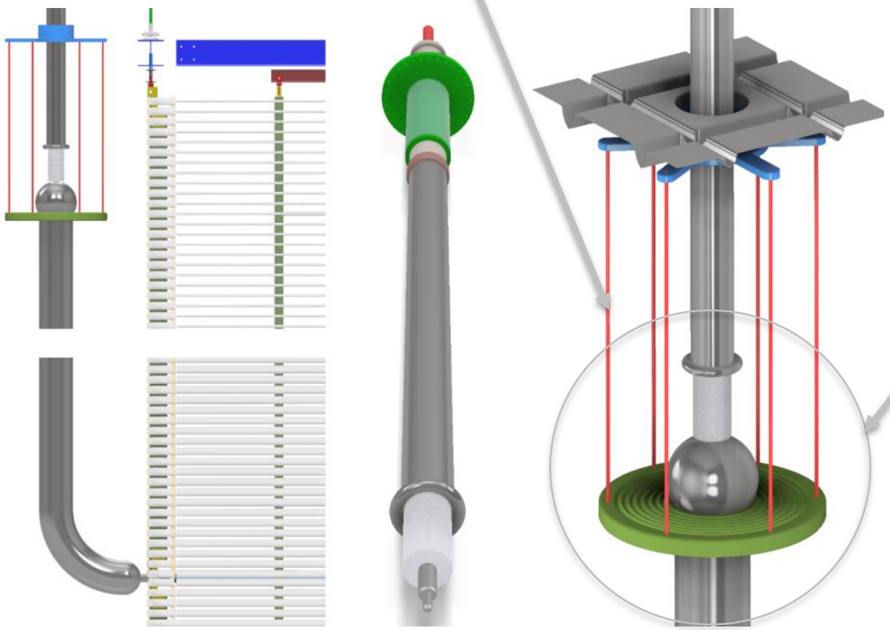


HV Feedthrough and extender

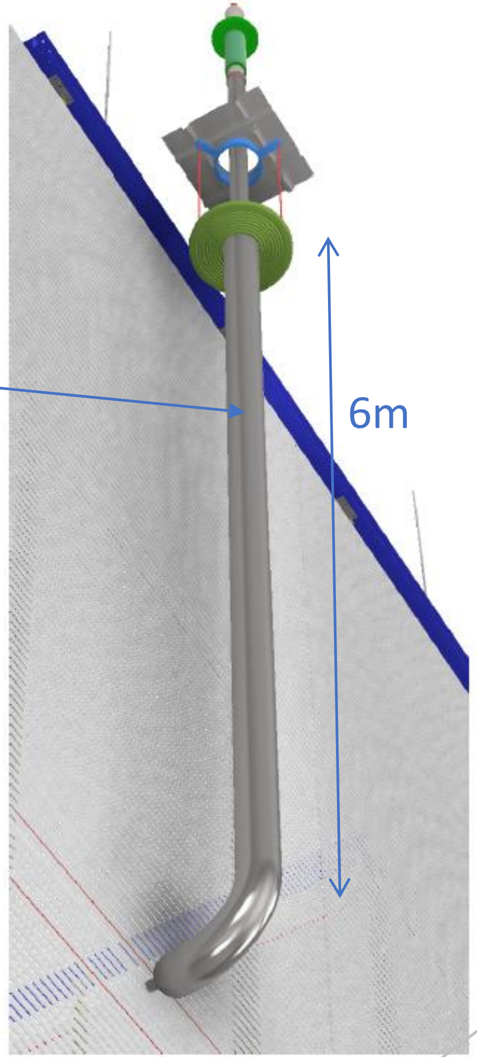
The HVS distribution system largely derived from the DP layout with upgraded design

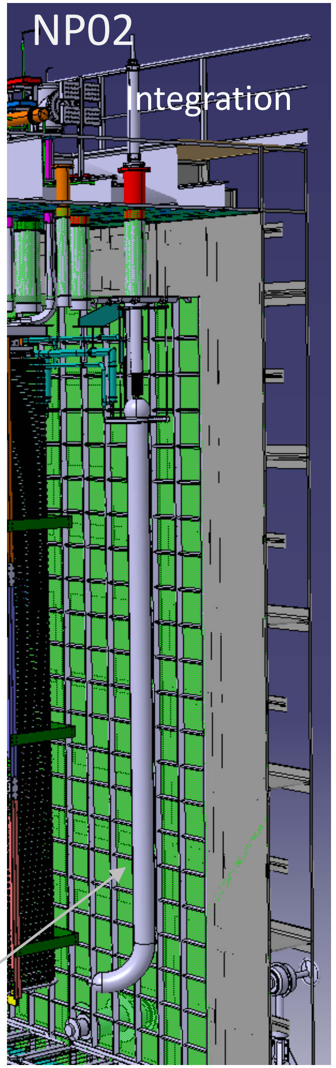
- ❑ HV of ~300 kV entering with a vertical penetration at one extremity of the cryostat in the region where FC and the cryostat wall distance is larger than a meter
- ❑ Max drift field over 6.5m ~500V/cm
- ❑ Extender has a simplified technology compared to NP02: based on a highly electropolished metallic pipe of 20 cm in diameter.

- ❑ LAr used as insulator from FC and membrane (40 to 50 cm distance)
- ❑ Spherical extender coupling to HV-FT
- ❑ Insulating extender suspension disk and rods



Critical interface region

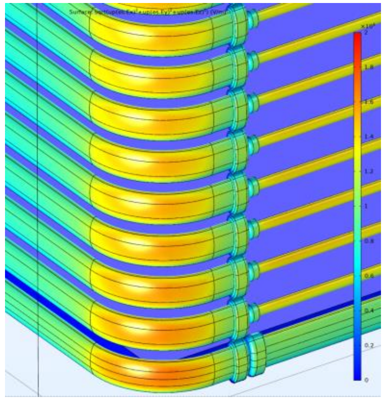




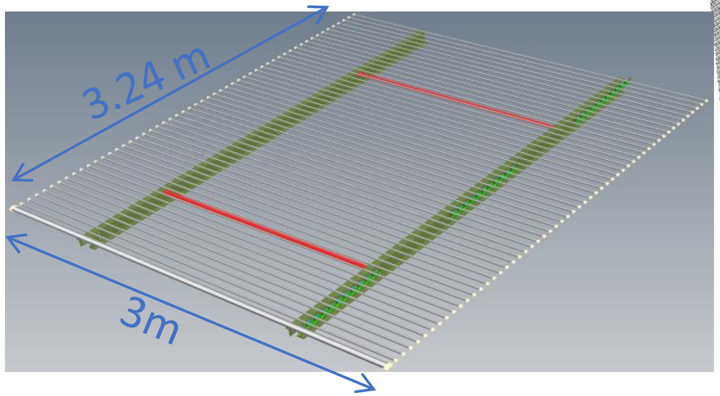
→ The whole HV distribution chain is integrated and tested at full scale in the NP02 cryostat this year

Field cage

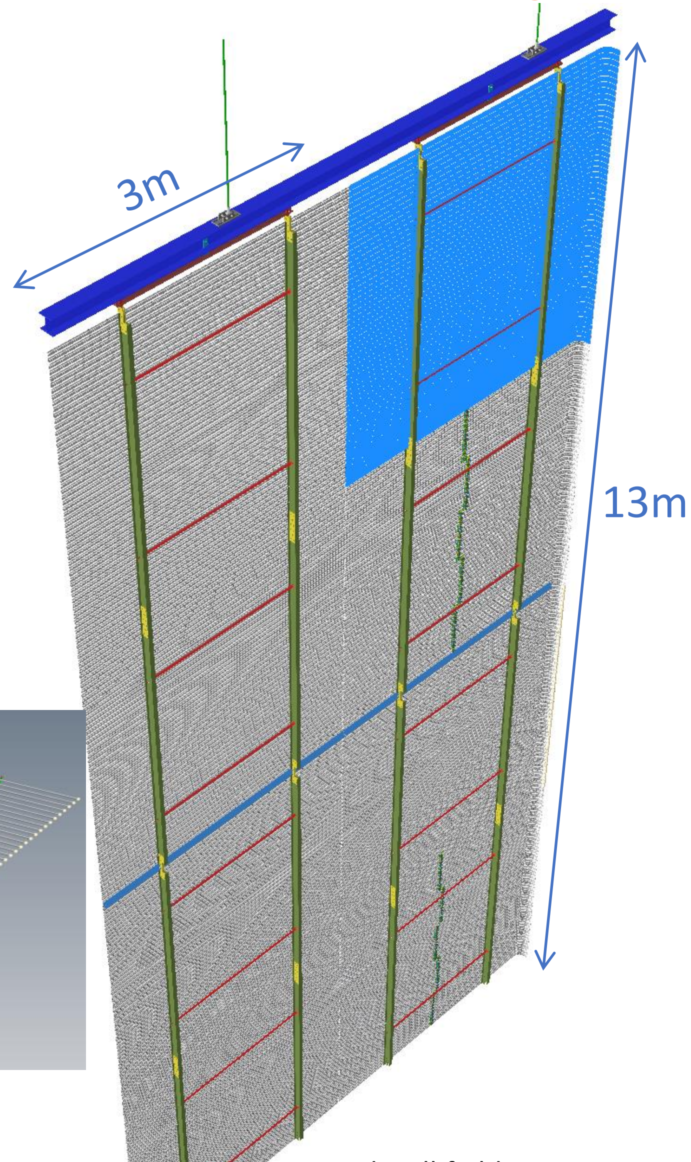
- Field cage surrounds the two active volumes (60mx13mx6.5m each) and provides a uniform electric field to LAr for ionization electrons to drift
- Modular construction with two 5cm wide, 10cm tall, 3.25m long FRP I-beam frames and 55 extruded aluminum profiles in 6cm pitch
  - FC along the long wall : 3.0m (W) x 3.24m (H)
  - FC along the end wall : 3.38m (W) x 3.24m (H)
  - Profiles mounted on outside toward the cryostat wall, minimizing charge-up in insulator
- Along the 4 vertical edges of the field cage, the profiles are bent at 90° to provide smooth conductive surfaces to reduce field enhancement



A study on improving the optical transparency of the FC modules is being conducted, providing more flexible placement for the arapucas on the cryostat walls



- The vertical installation scheme established and validated at NP02 PDDP
  - Further optimization ongoing



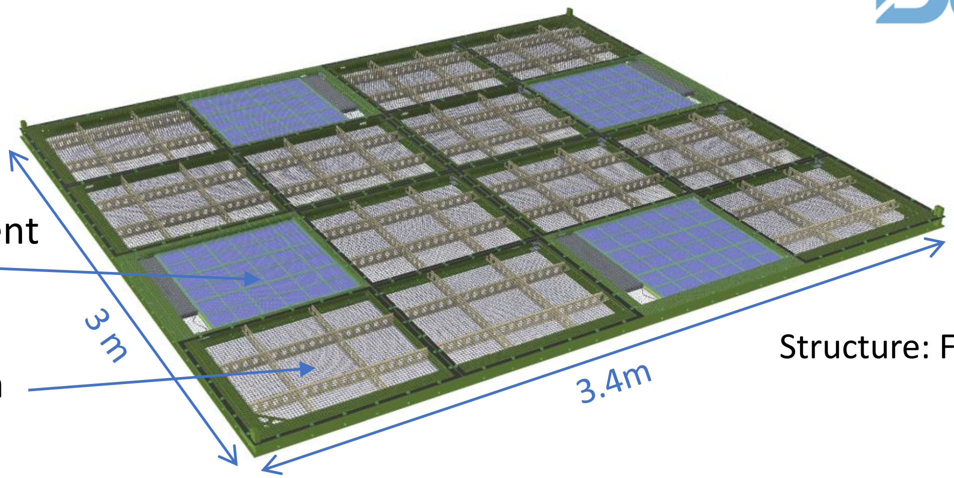
An end wall field cage supper module built with a 2x4 array of FC modules

Cathode structure and interface with CRP superstructure

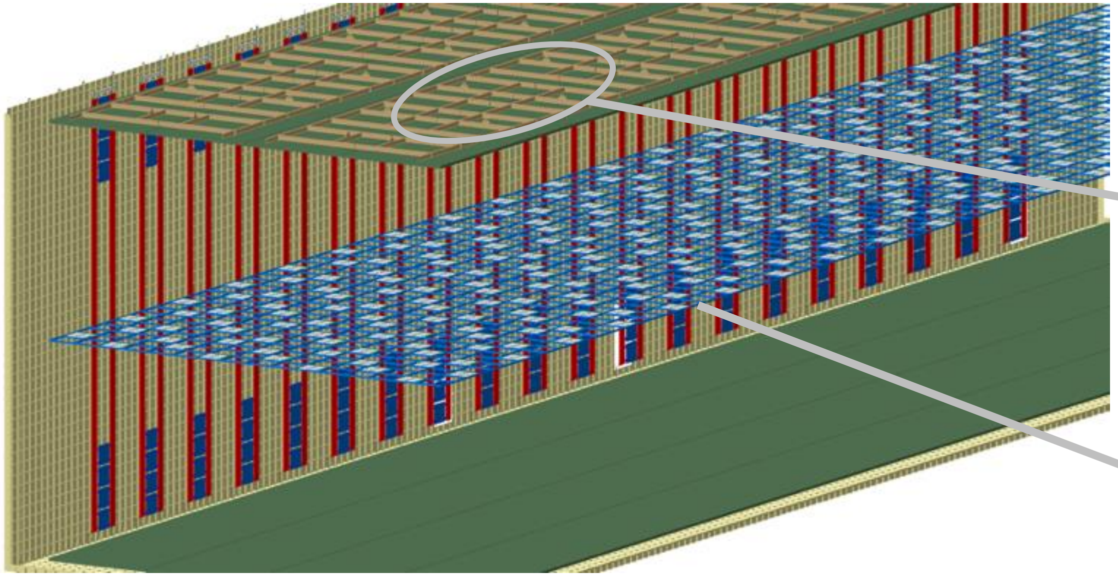
Cathode specifications:

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

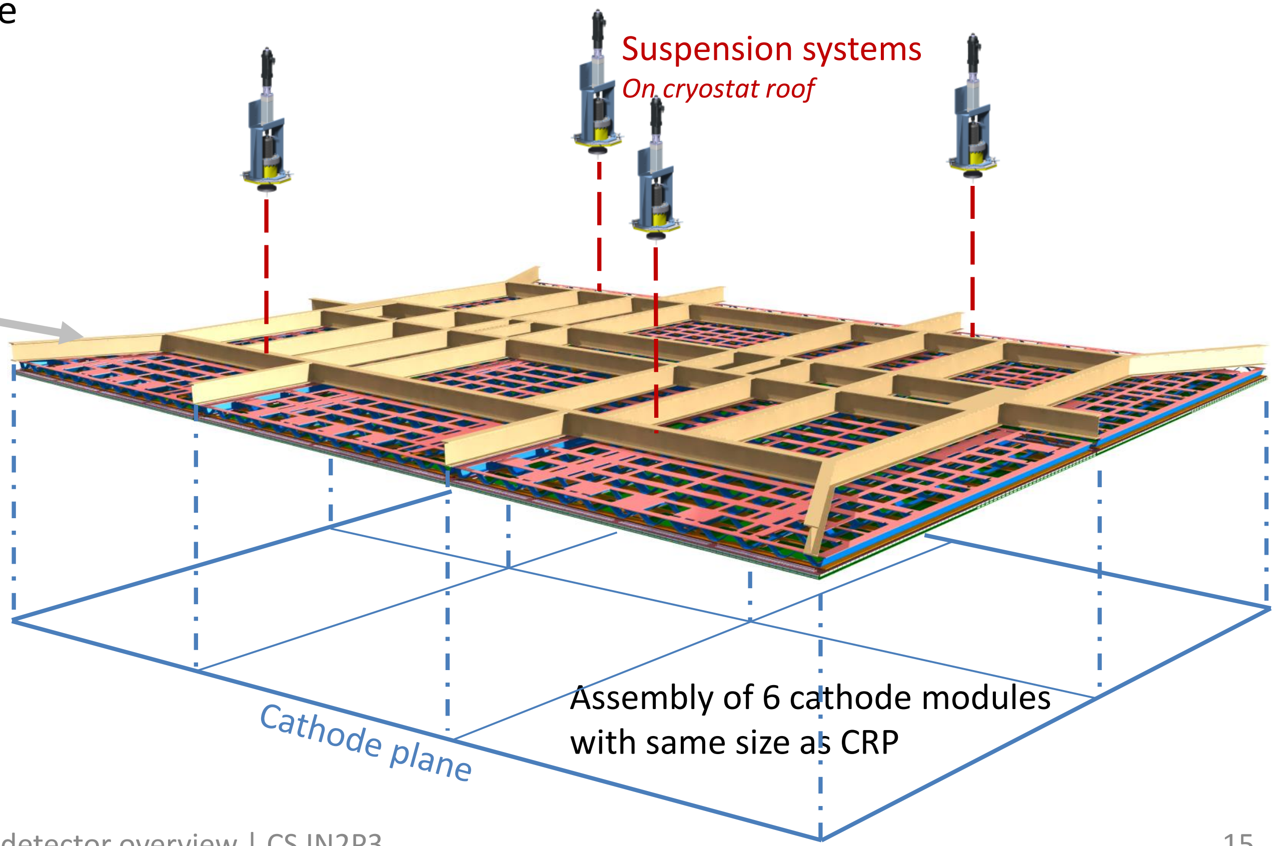
- Arapucas encased by highly transparent (~80%) metal wire mesh panels
- + perforated resistive panels to form two highly resistive surfaces with sufficiently slow discharge RC time



Structure: FRP beams



dyneema insulating ropes

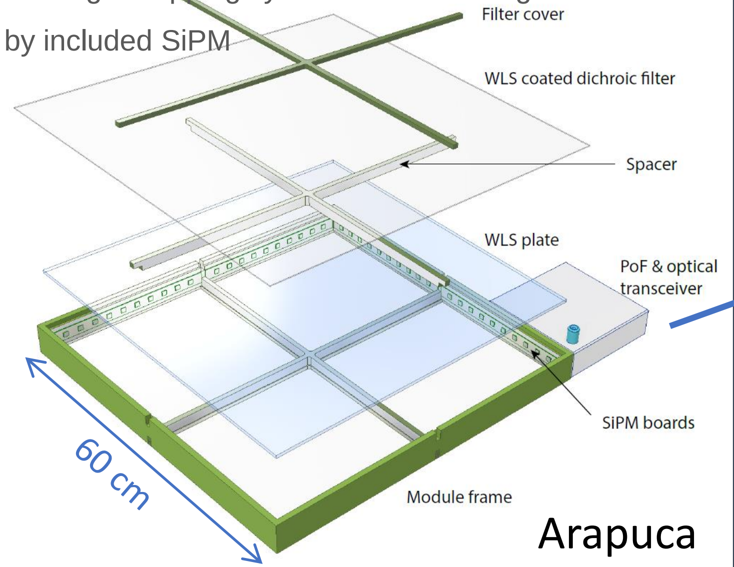


Photon detector system

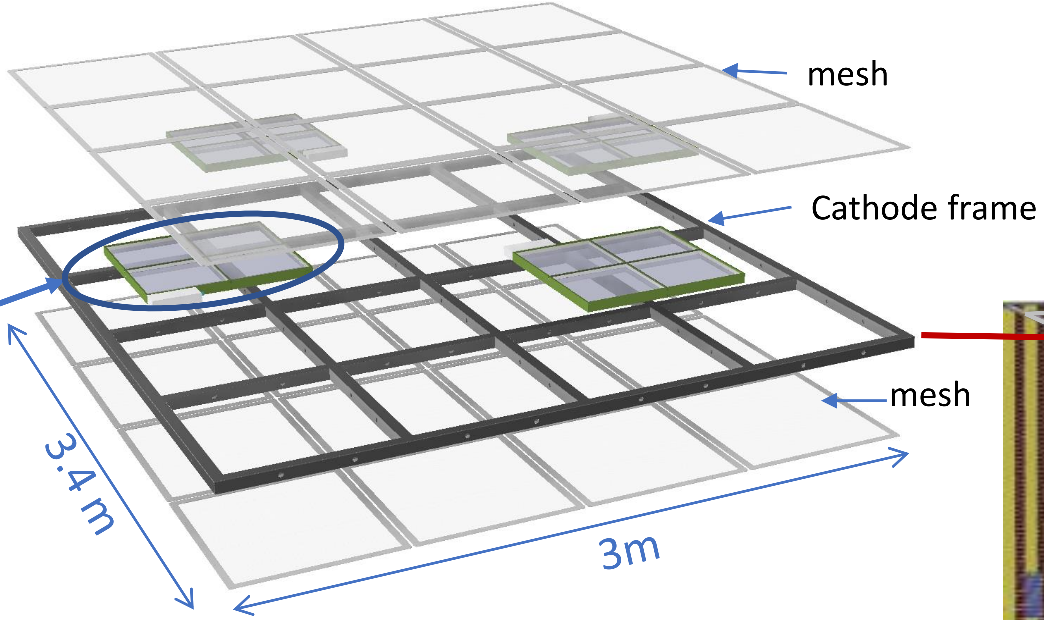
- Based on X-Arapuca tiles (like in Horizontal Single Phase detector)
- Arapucas are embedded in the cathode frame at -300 kV (4*80= 320 double sided tiles. Total surface 230 m^2)
- Challenging situation => power distribution over fiber for the SiPM boards and fiber readout; R&D in progress to demonstrate connectivity in presence of HV
- Reflector on the anode surface (material to be identified)
- X-Arapuca optimized for 10 ppm of Xenon

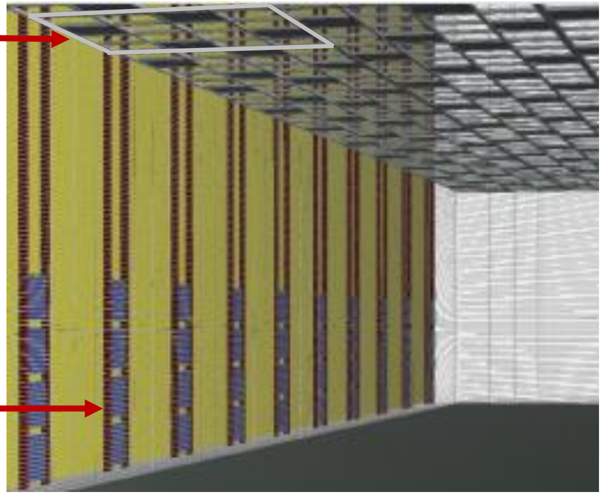
Requirements:
- Average Light yield > 20pe/MeV
- Minimum LY > 0.5 > pe/MeV
- Time resol < 1us

VUV light trapping system to enhance light collection by included SiPM



Arapuca



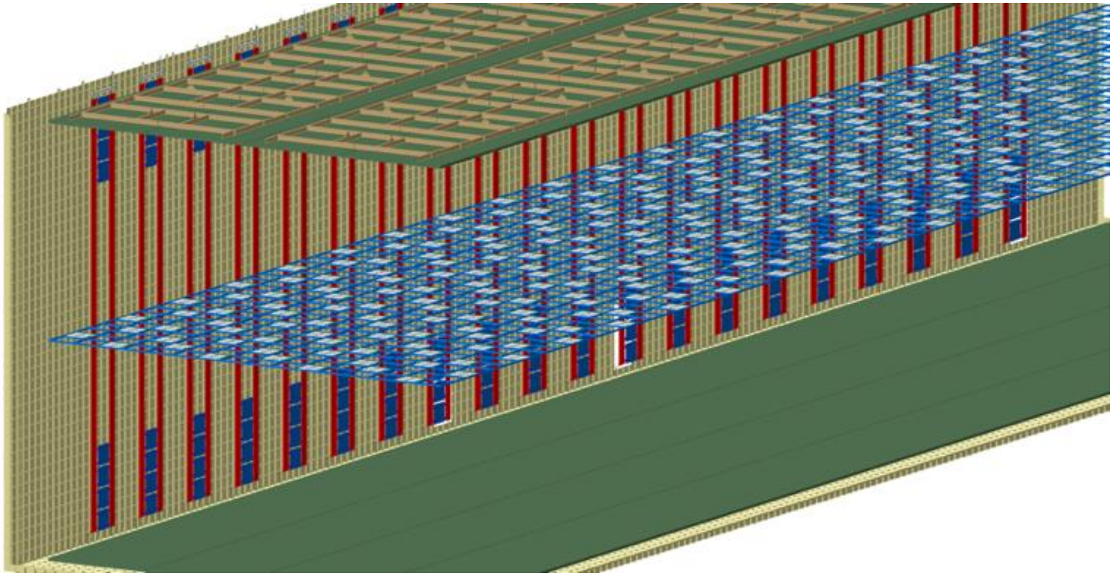


The reference design: to equip also the top and bottom cryostat walls with Arapucas

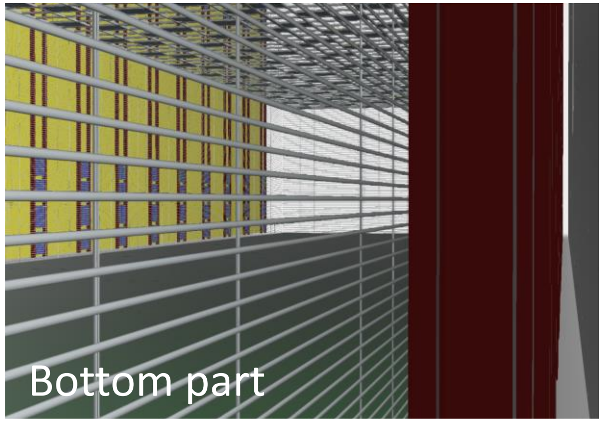
Readout: SiPM signal is transmitted over fiber (both analog and digital transmission is under evaluation)

Photon detector system

Photon Detection System reference design (4π):



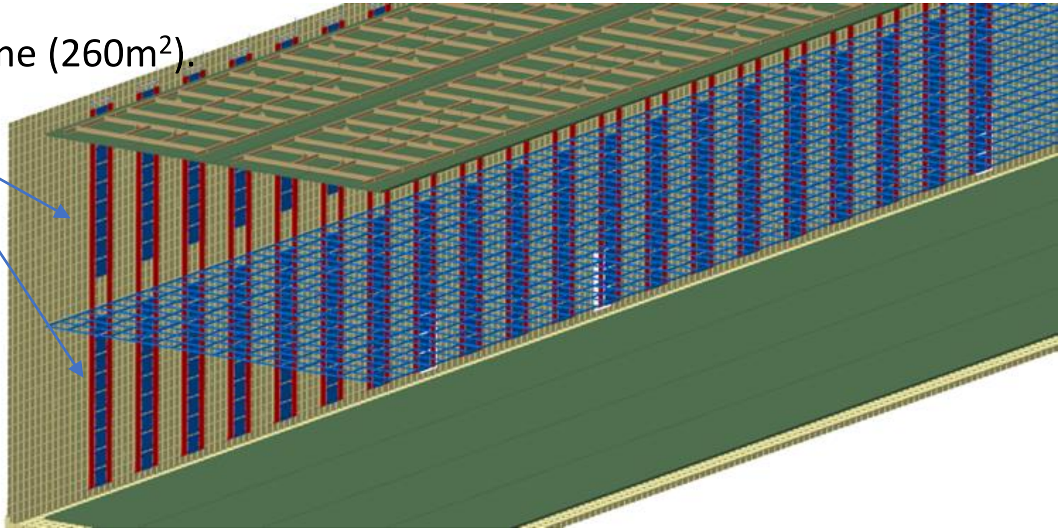
- 320 xArapuca ($60x60cm^2$) on cathode ($2x115m^2$) with analog readout
- 320 xArapuca ($60x60cm^2$) on cryostat membrane ($115m^2$) at 3m from cathode and standard FD1 readout
- 70% transparent field cage



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



- 70% transparent field cage design concept is being demonstrated in the NP02 cryostat in parallel to the 300kV test now.
- An high E field test in a small setup is planned early next year to validate if the full height transparent field cage is safe to operate

Summary:

Vertical Drift detector advantages:

- Extended drift distance, profiting from excellent LAr purity, allows to maximize the fiducial mass by reducing dead material in the active volume
- Highly modular concept of each detector component
- Simplified installation and QA/QC procedures, not requiring large in situ infrastructures
- Simplified anode structure based on standard industrial techniques
- Field cage structure completely independent from the other detector components
- R&D on photon detection system at high voltage in progress
- Possibility for a Photon detection system with improved light detection coverage and trigger efficiency wrt Horizontal Drift; equivalent to HD if only cryostat wall instrumented

The END

Activities on the Neutrino Platform at CERN

- **Vertical Drift HV system test in NP02 cryostat**

- **Cold-box tests**

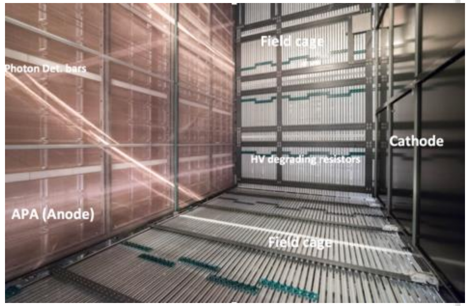
- **Vertical Drift Module-0 in NP02 cryostat**

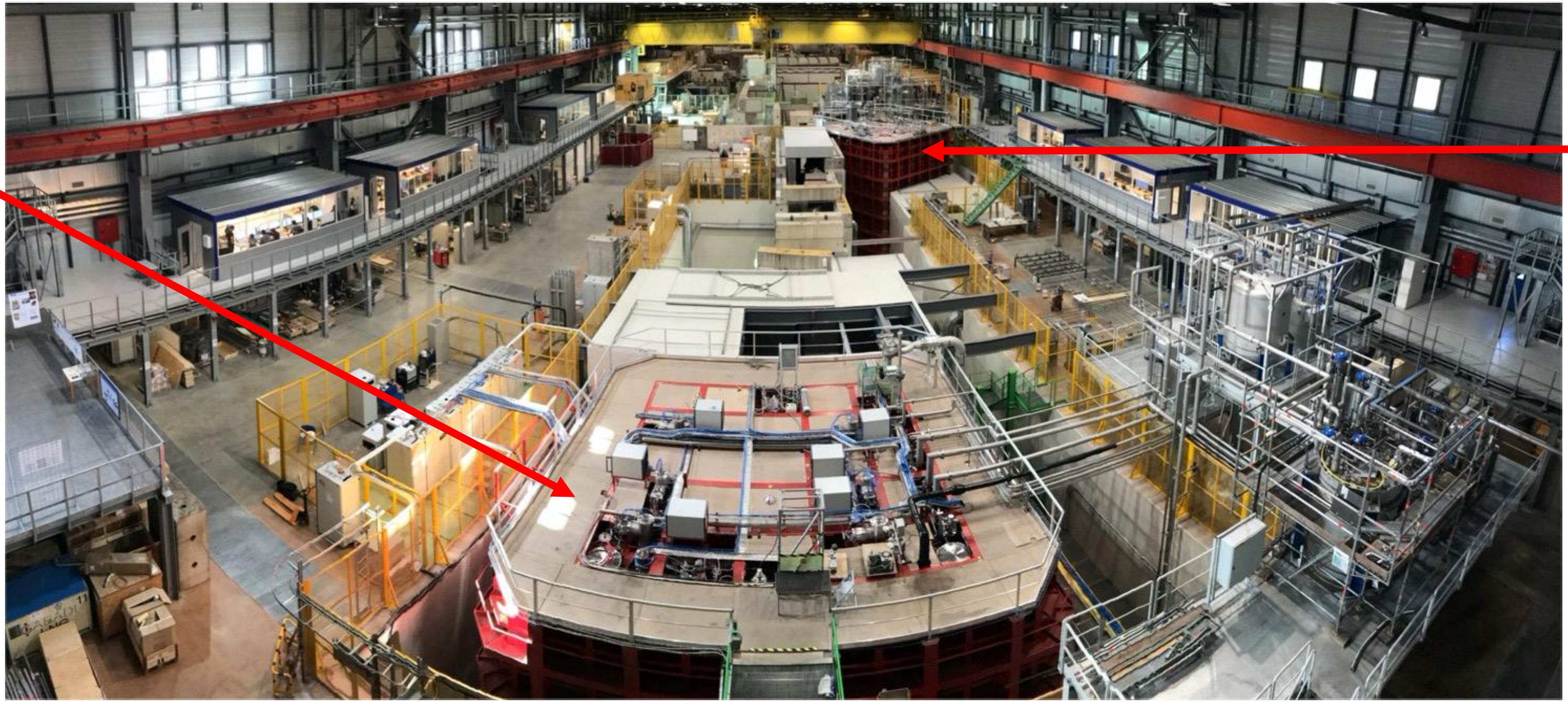
Fabien Cavalier
IJCLab
26/10/2021

Neutrino Platform @ CERN

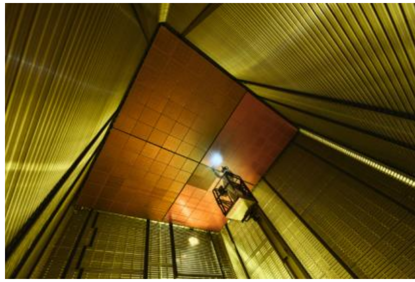
- **Provide** to the ν community a **test beam infrastructure** (charged particles)
- Bring **R&D** at the level of **technology demonstrators** in view of major technical decisions
- **Support** the short & long baseline **activities** (infrastructure & detectors)

NP04 :
Single Phase
Horizontal Drift





NP02 :
Double Phase
→ Single Phase
Vertical Drift



TPC Prototypes at the scale 1:20, with **modules at the DUNE scale**
Two technologies originally investigated **(LAr single phase (NP04), LAr double phase (NP02))**

Main Goals of tests @CERN

- **Demonstrate the continuous operation of a 300 kV distribution system**
- Test of the 70% Transparency Field Cage

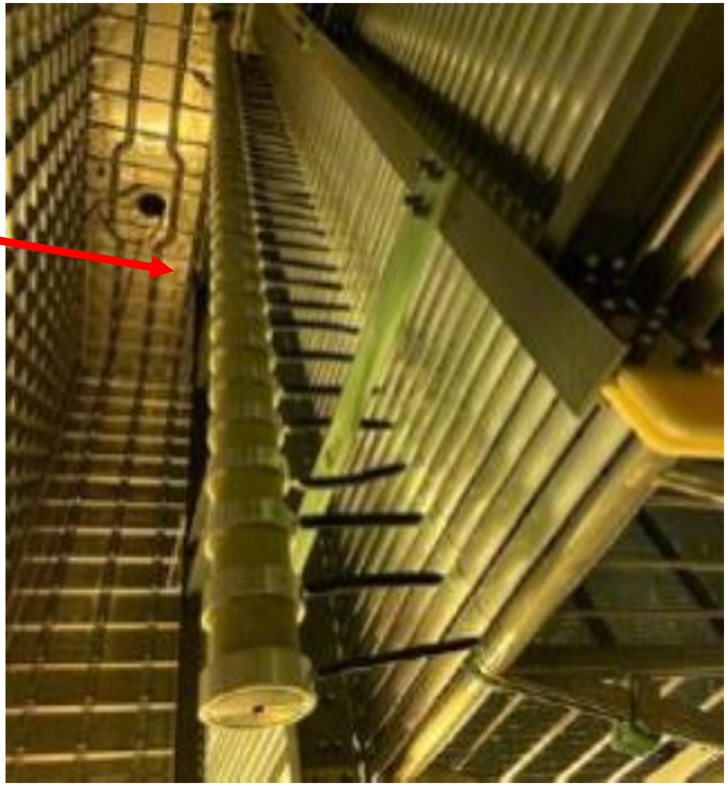
NP02

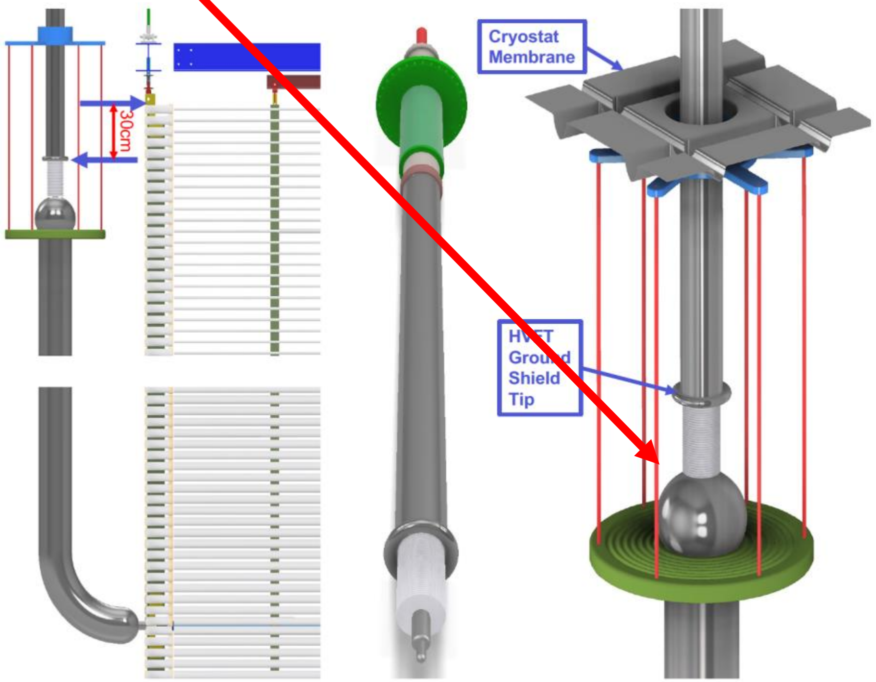
- **Characterize and validate the design and the construction procedures of:**
  - **mechanical tests of the perforated PCB anode assembly (CRP) in cryogenic conditions**
  - **characterization of the performance of the perforated anode and of the full electronics chain (top and bottom) in terms of signal to noise ratio and its stability**
  - **mechanical test of the cathode module in cryogenic conditions**
  - **test the light readout system concept running in an HV environment**
  - **test the integrated system as a whole and evaluate the interplay between the powering scheme, the charge readout electronics and the light readout system**

ColdBox

Vertical Drift HV system test in the NP02 cryostat in 2021

- HV extender for Double Phase developed an issue (short path connection to the field cage)
- New Simplified Design
  - 6m long, 20cm diameter, 2mm thick polished SS tube main-body HV extender w/ a 90º elbow
  - Uses LAr as the insulator instead of of completely confining the electric field in the extender itself
  - Placed in the middle of 1m gap between Field Cage and the cryostat wall
  - Spherical HV FeedThrough receptor of 25cm diameter

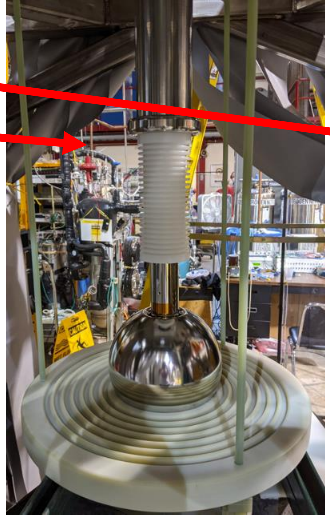


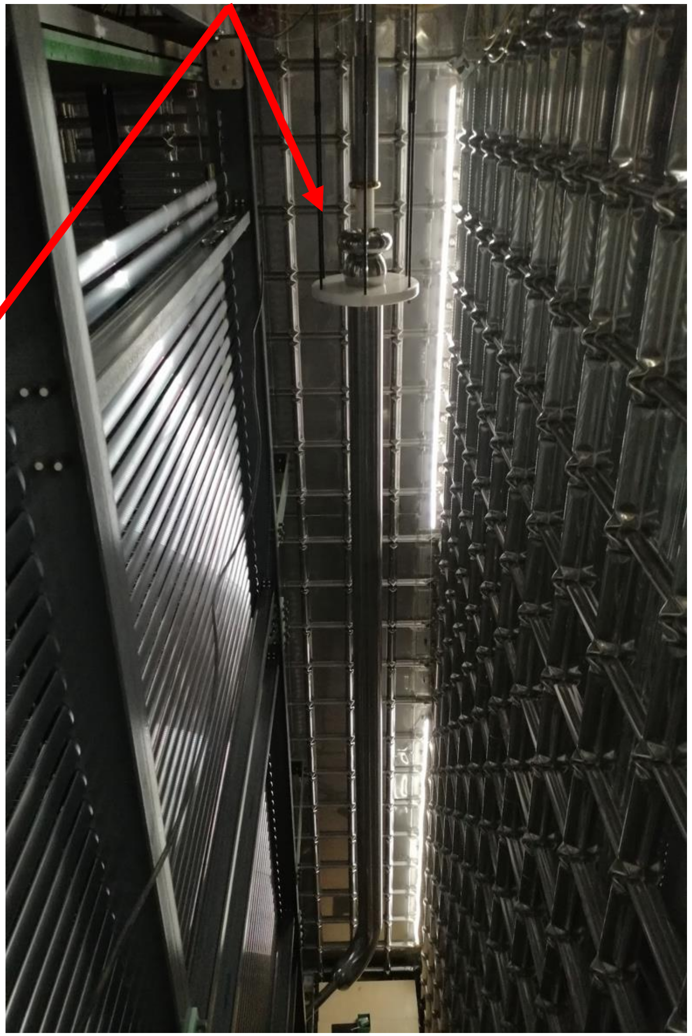


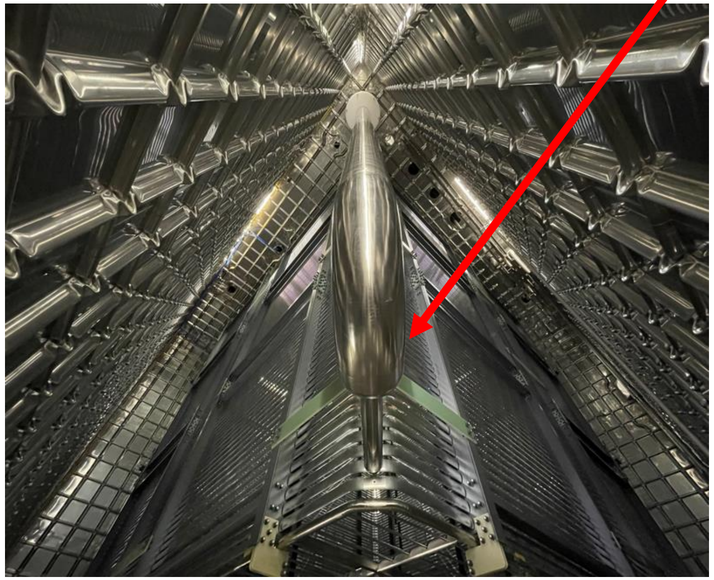
- **Tests and validations at FNAL and CERN (May-July)**

- **Modification of the HV-FT and extender coupling mechanism until successful operation at 300kV in standalone test setup**

- **New series of tests at CERN in July before NP02 installation**

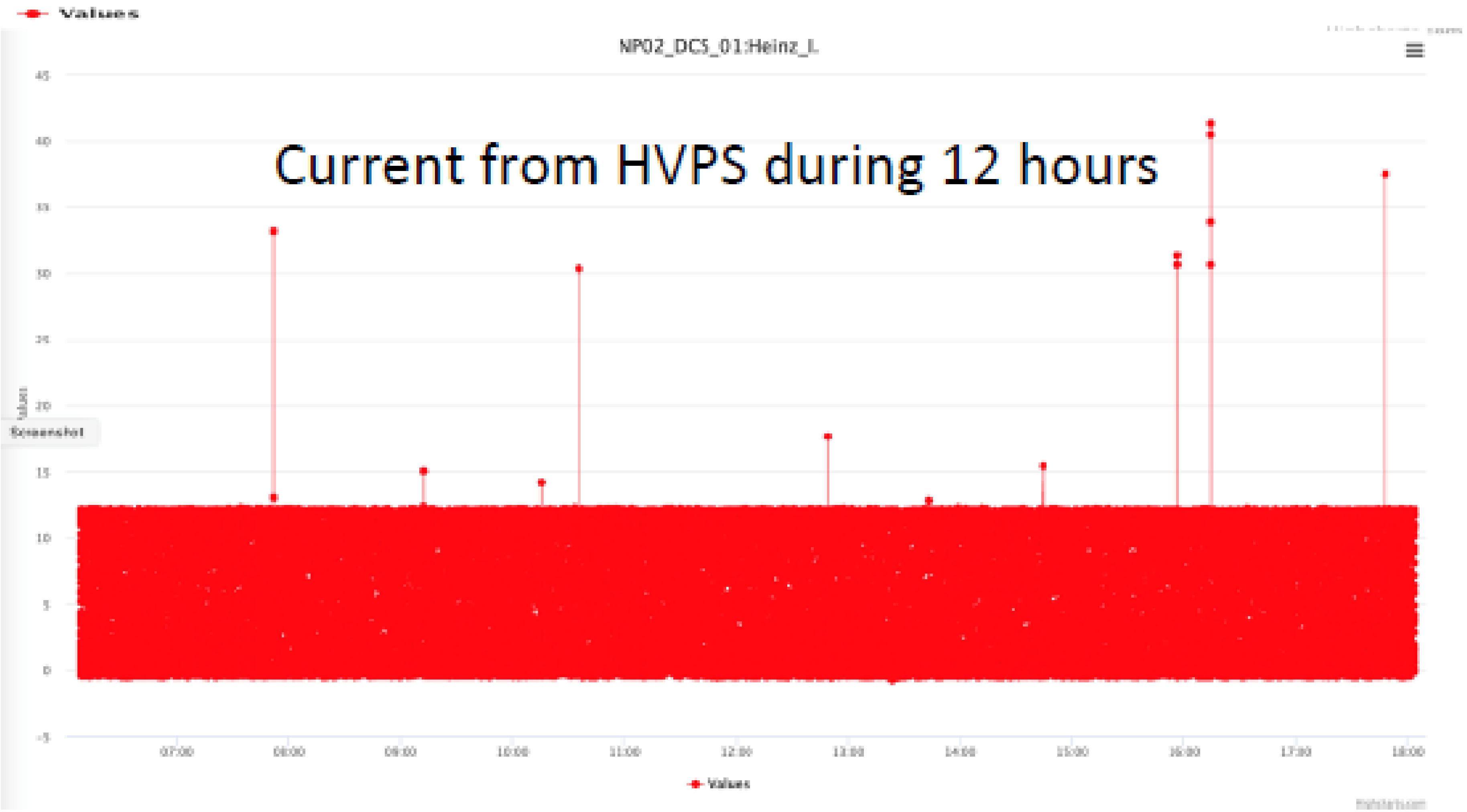






Current Status

- **HV running at 300 kV till mid-September in NP02**
- **Stable Voltage but current blips (duration < 1s) with rate of one event per 1 to 2 hours => origin under investigation**



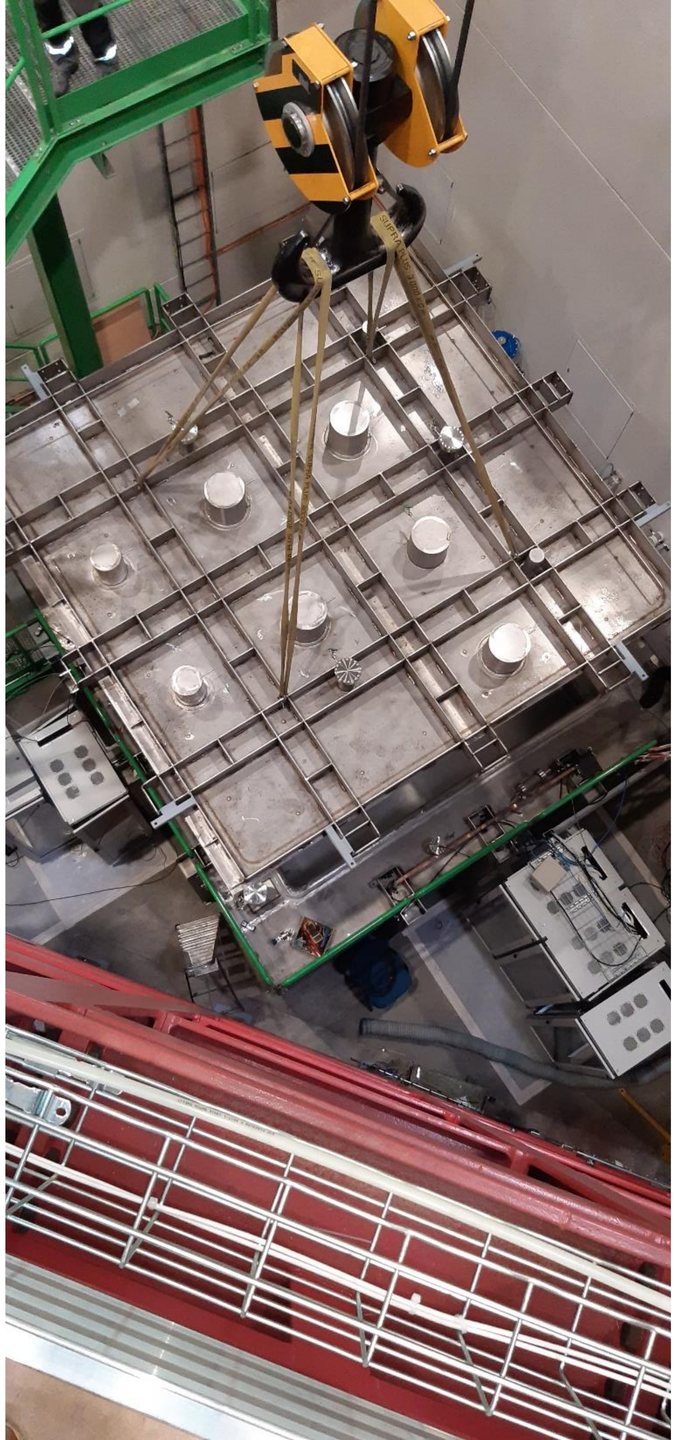
Current Conclusions

- The stainless steel extender body is very stable over the full 6 m length and the elbow termination
- 40 cm distance from corrugated membrane is enough to hold 300 kV even with LAr purity exceeding 1 ms
- The new HV Feedthrough seems perfectly adequate for operation at 300 kV
- The cable termination, including the 50 Mohm filtering resistance, is also working properly
- Any optimization of the HV distribution design should involve only the extender head and can be tested in smaller cryostat.
- Understanding in progress of the geometry and the origin of the sparks from the extender head to the polyethylen plate
- External telescope to study coincidence with large cosmic ray showers
- Data taking foreseen with Double Phase detector

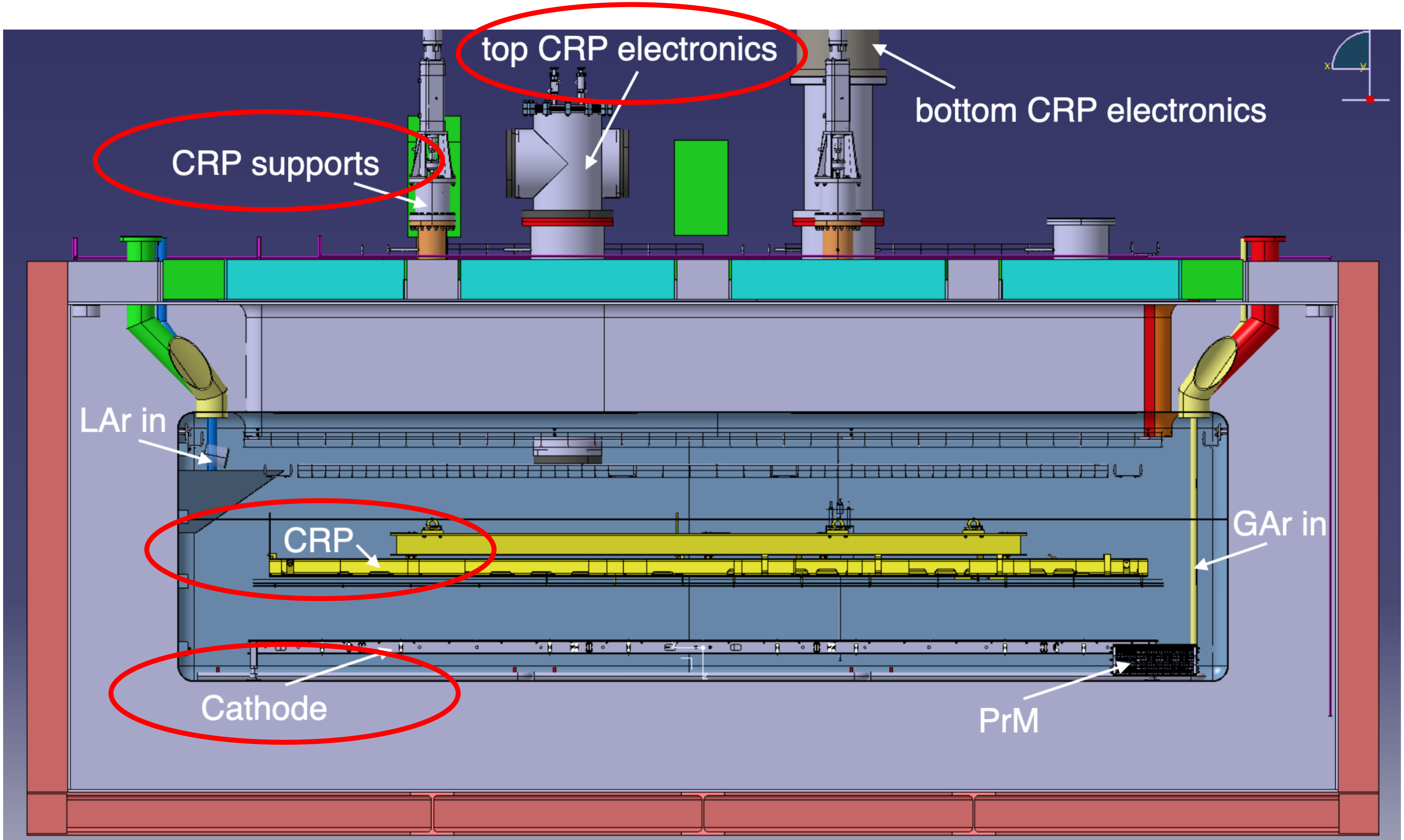
=> IN2P3 effort for DAQ (duplication with ColdBox) and running the detector (CRP, readout status …)

ColdBox Tests

- Cryostat able to host cathode and CRP of dimension 3 × 3,375 m^2
- Refurbished version of previous ColdBox for Double Phase
- LAr level stability maintained within +/- 5 mm
- Liquid argon purity compatible with electron drift over 20 cm
- Absolute vapor pressure stabilized to a few mbar around the nominal value
- Drift distance of at least 20 cm with a drift field of 500 V/cm => Cathode at –10 kV

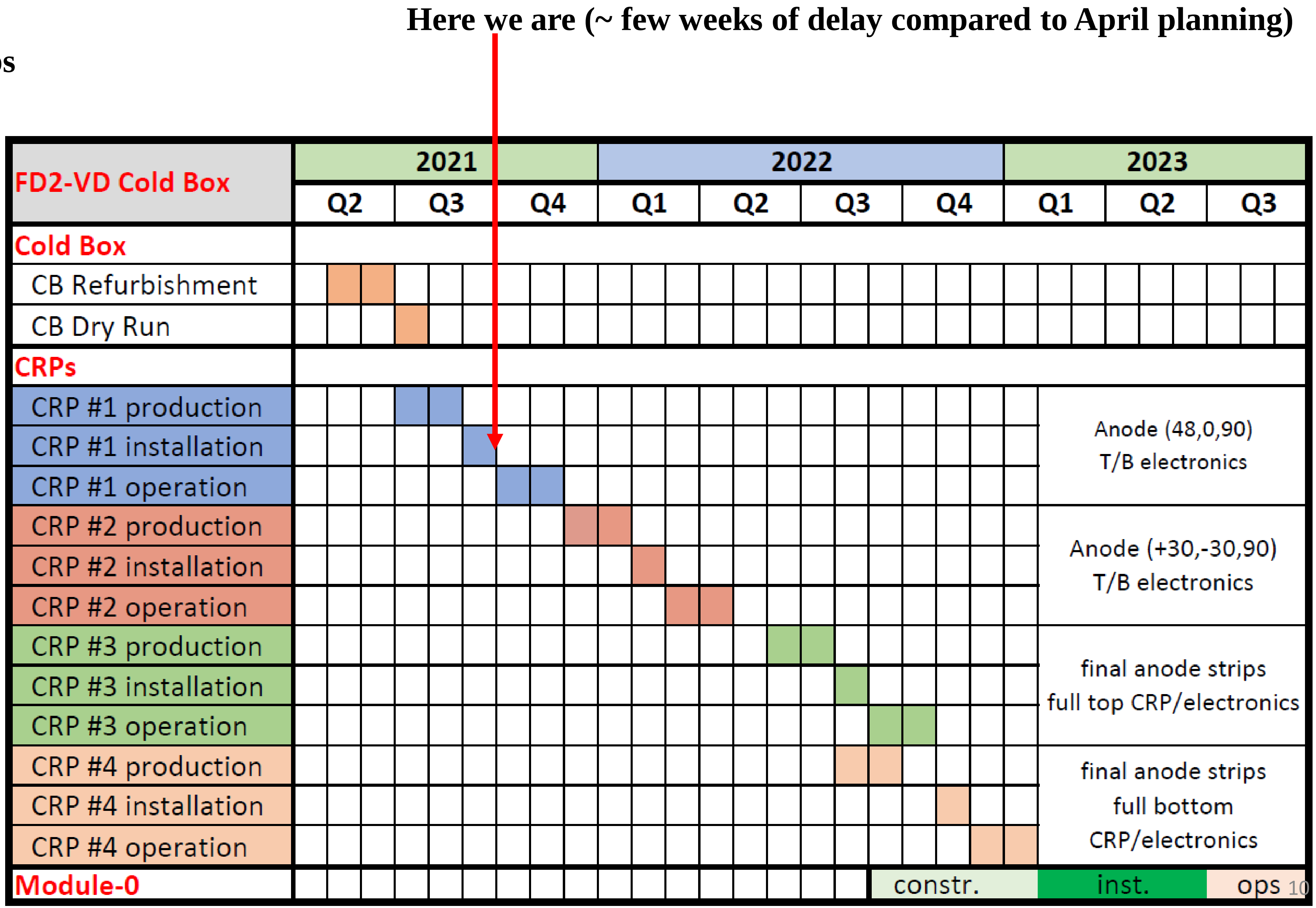


The ColdBox content (Photodetector not shown)



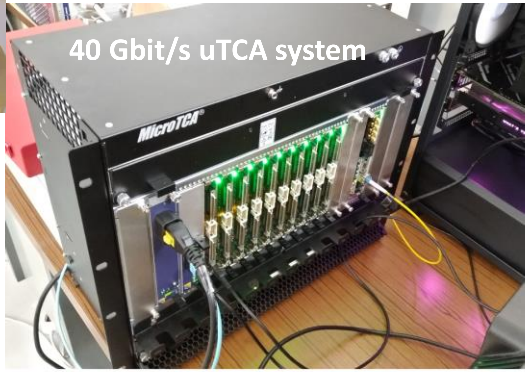
ColdBox Planning

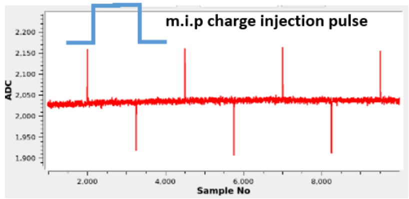
- **Huge effort of IN2P3 groups for design, production and installation**
- **Dry run : sufficient purity achieved for >20 cm drift (lifetime about 200-300 μs)**

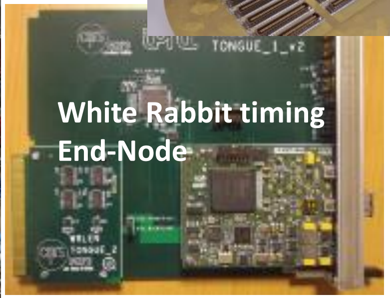


Top electronics readout and DAQ

- **Top CRP readout** based on the completely accessible electronics (cryogenic ASICs and Front-End cards, uTCA digitization cards, timing system and DAQ) successfully operating on **NP02/protoDUNE dual-phase**
- **Adaptations** and **developments** for the Vertical Drift: new FE cards with decoupling components for VD anodes, change of digitization cards dynamics for bipolar signals of VD induction views, development of 40 Gbit/s uTCA connectivity/DAQ
- Need to preserve integrity and operation of NP02/protoDUNE-DP for HV test → readout electronics, DAQ and ancillary systems. Sharing of NP02 DAQ back-end/storage. **new system independent on NP02**
- Components for the ColdBox test for a full top-drift CRP (3200 channels) procured with **new productions in spring 2021** (ASICs, front-end cards, digitization cards, timing cards and distribution, uTCA crates, low voltage system, calibration system and DAQ system) and **extensively tested** by the beginning of the **summer 2021**
- **Dedicated production** of 5 mini-chimneys for the cold-box tests.





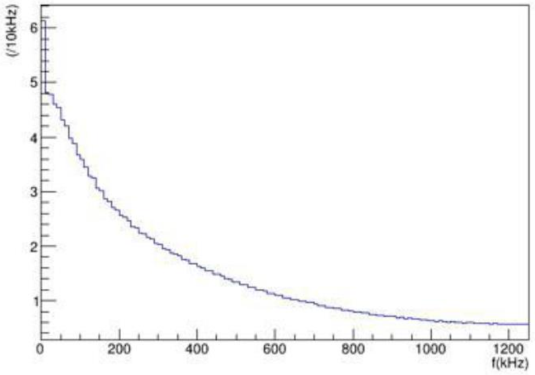


Chimneys integration with Top electronics and DAQ

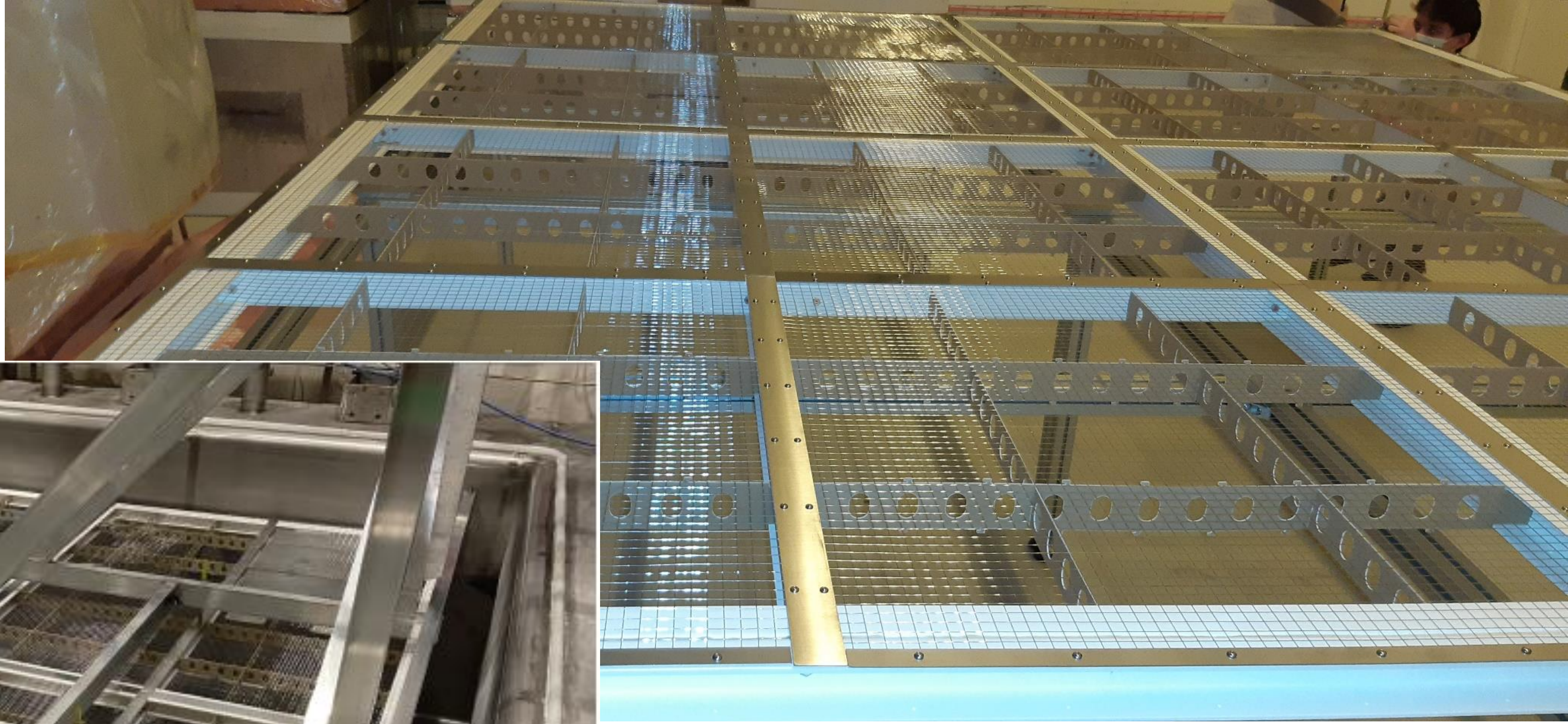
- **Full integration test performed in July** in a dedicated area at EHN1 for one chimney, including all elements produced for the cold-box (chimneys, low-voltage system, timing system, pulsing system, uTCA crates, DAQ, data fibers infrastructure) → **validation of all readout chain elements and noise in agreement with expectations**
- Three chimneys fully tested with DAQ in the integration setup: September-October
- Integration setup dismounted and **needed material moved to ColdBox area last week**
- **Chimneys** installed on ColdBox roof **last week**
- **CRP cabling** to chimneys performed **last week**

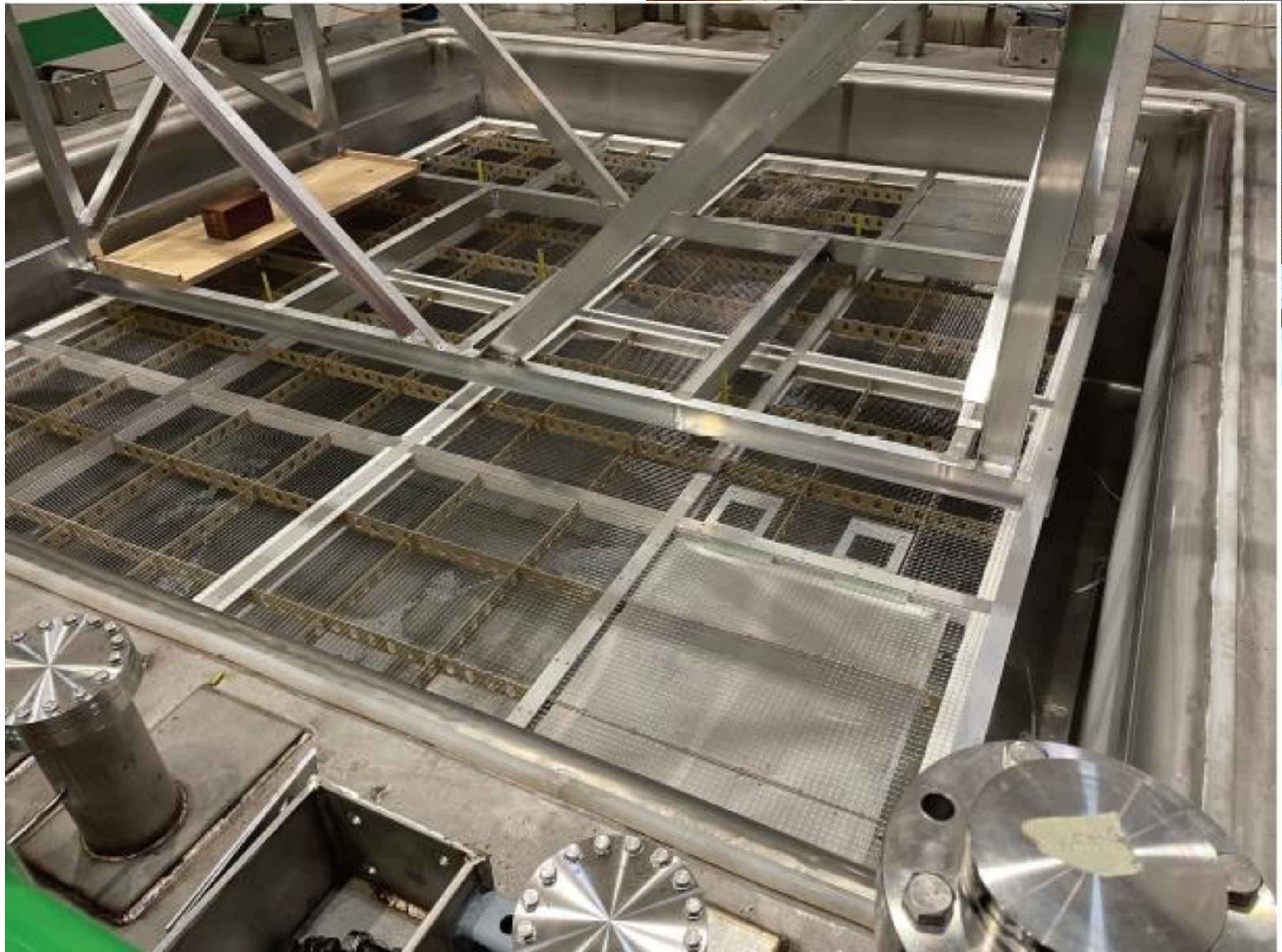
FFT noise spectrum:

- Good noise conditions despite temporary setup not connected to cryostat ground but to EHN1 building ground
- Very little coherent noise contamination present



Cathode



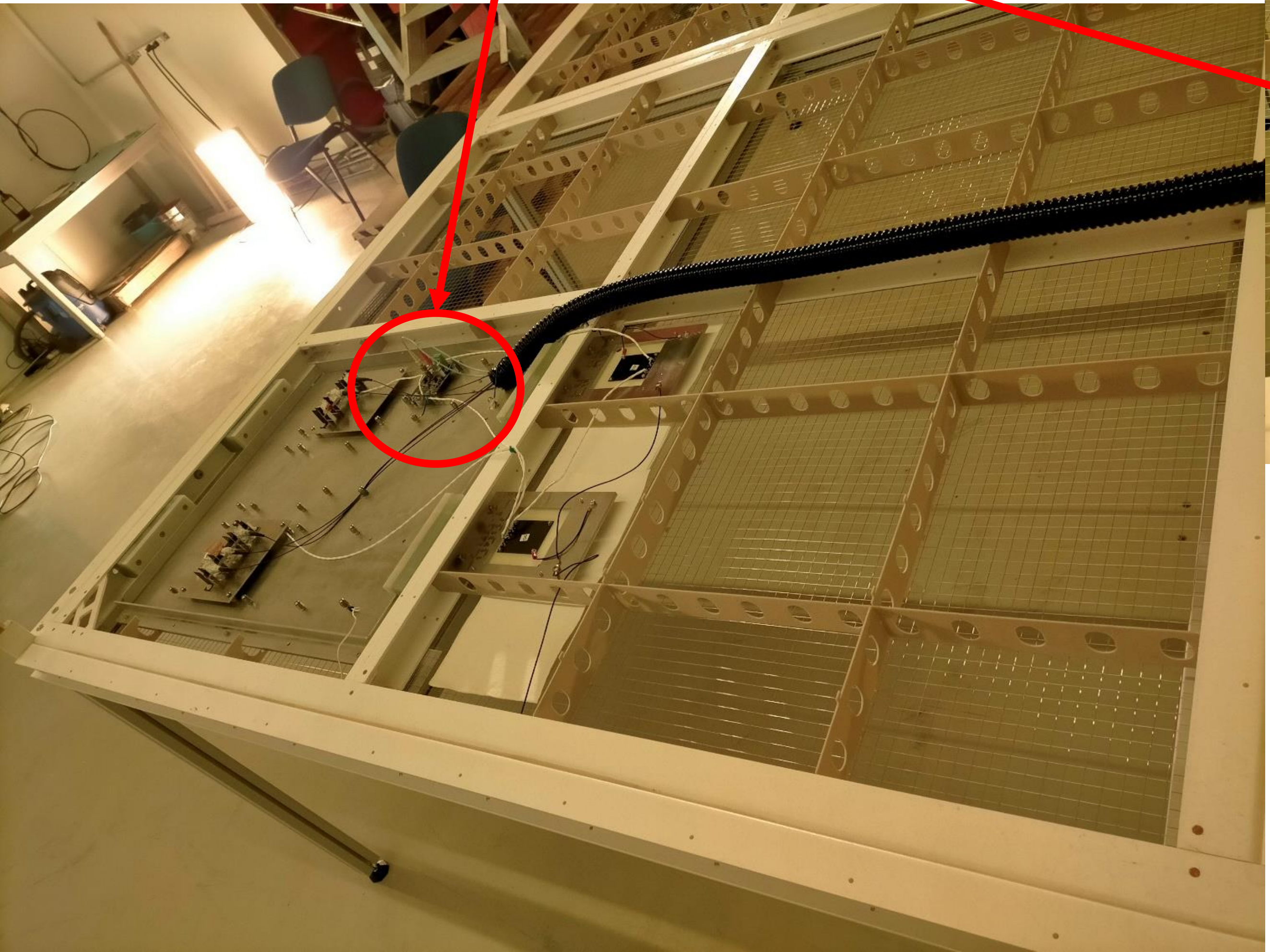


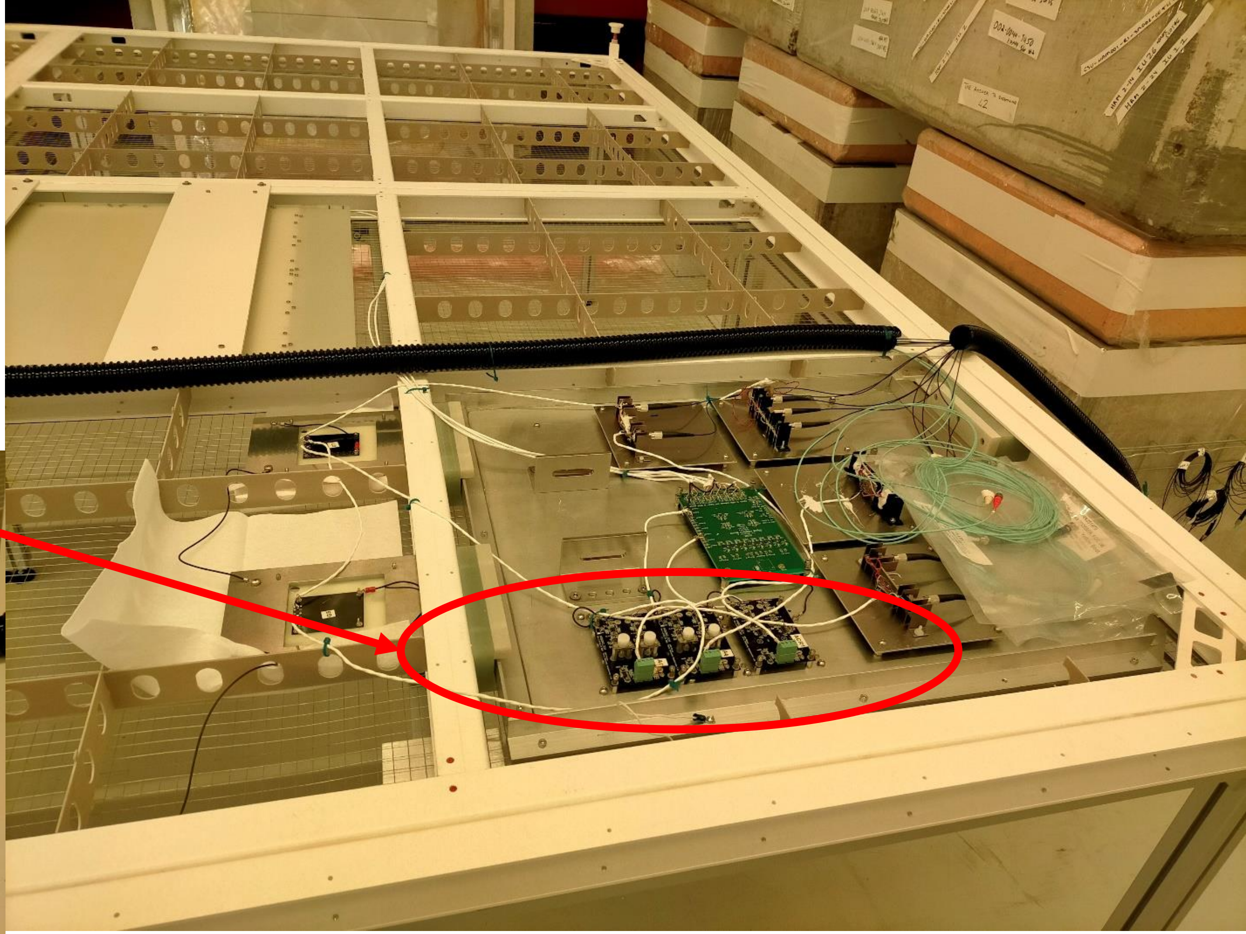
- **Designed in April**
- **Produced in the industry in June-July**
- **Assembled at CERN in September**
- **LAr tests end of September**
- **Bending about 15 mm within the requirements**

- **Photon Detector fully integrated last week**

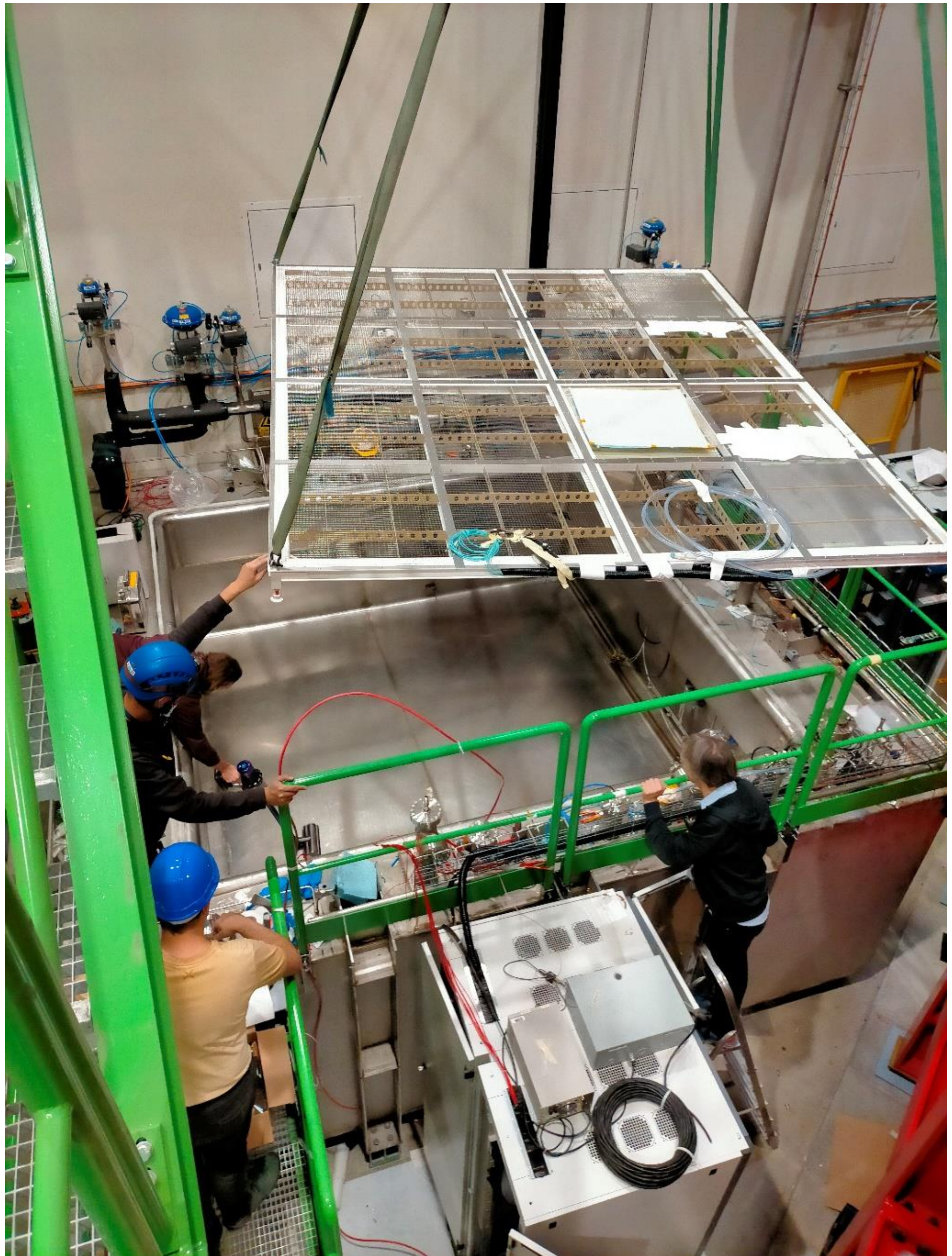
- **Several possible solutions for the electronics have been installed**

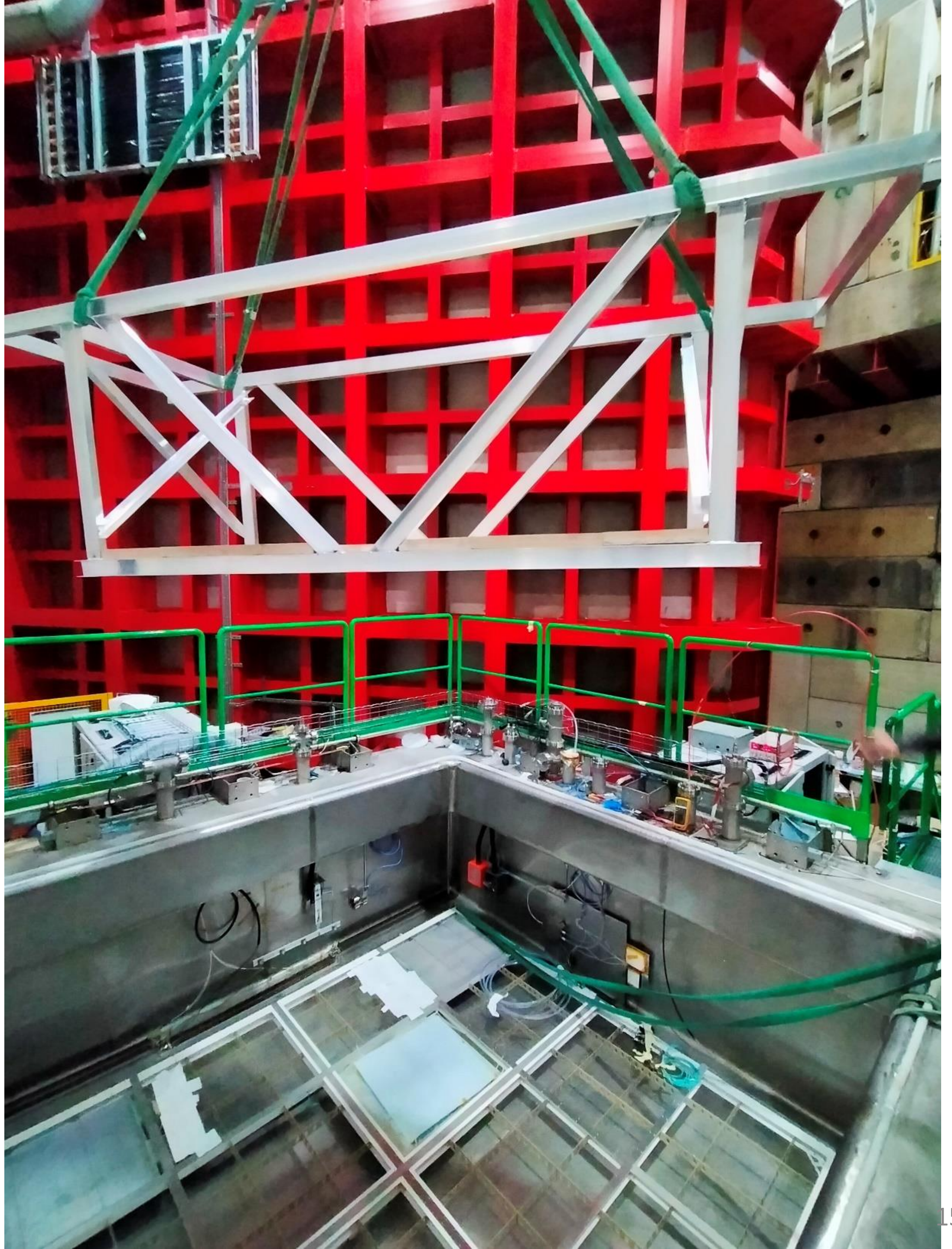
- **One solution provided by IN2P3**





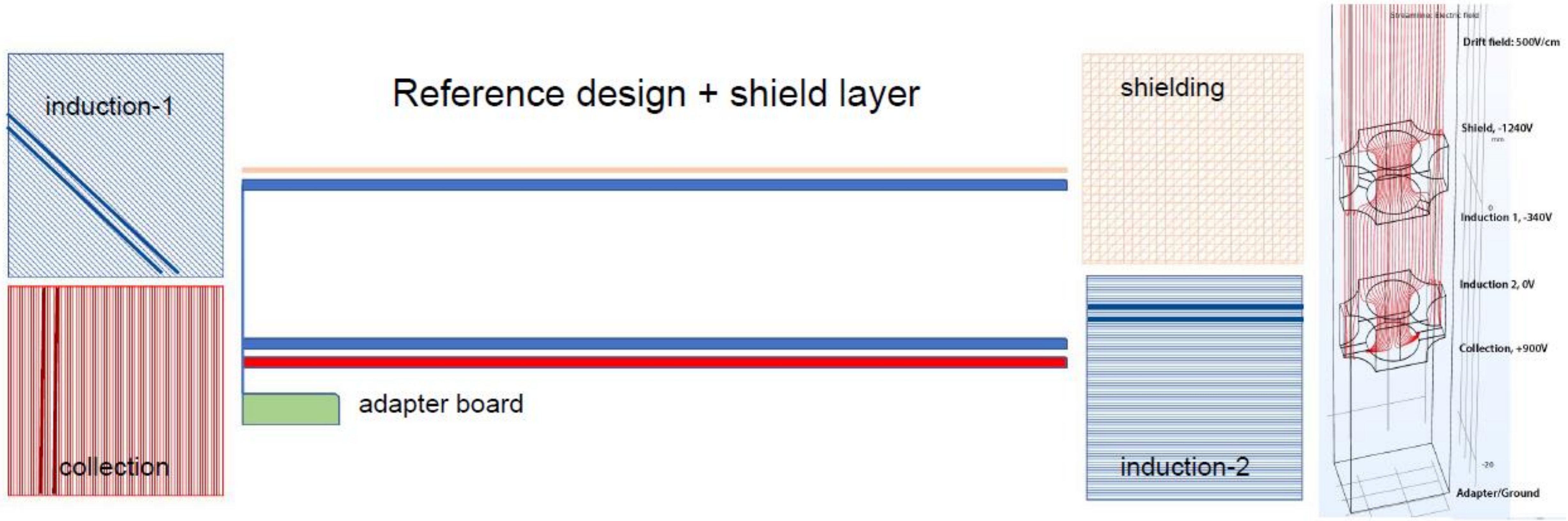
Cathode installed in ColdBox last Thursday





Charge Readout Plane

- 2 PCB
- 3 views with different angles

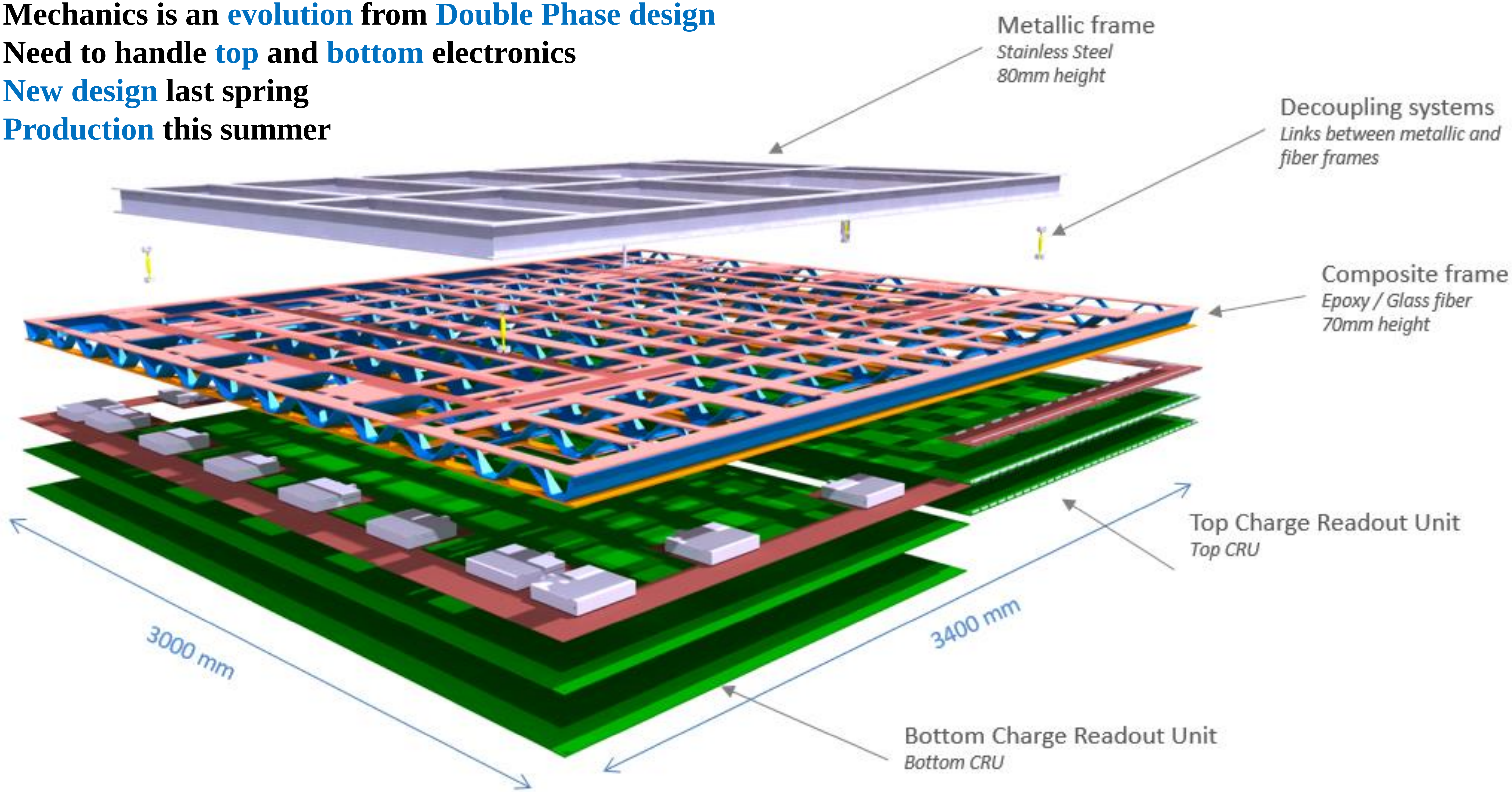


Induction-1: -48 degrees
Induction-2: 0
Collection : 90 degrees

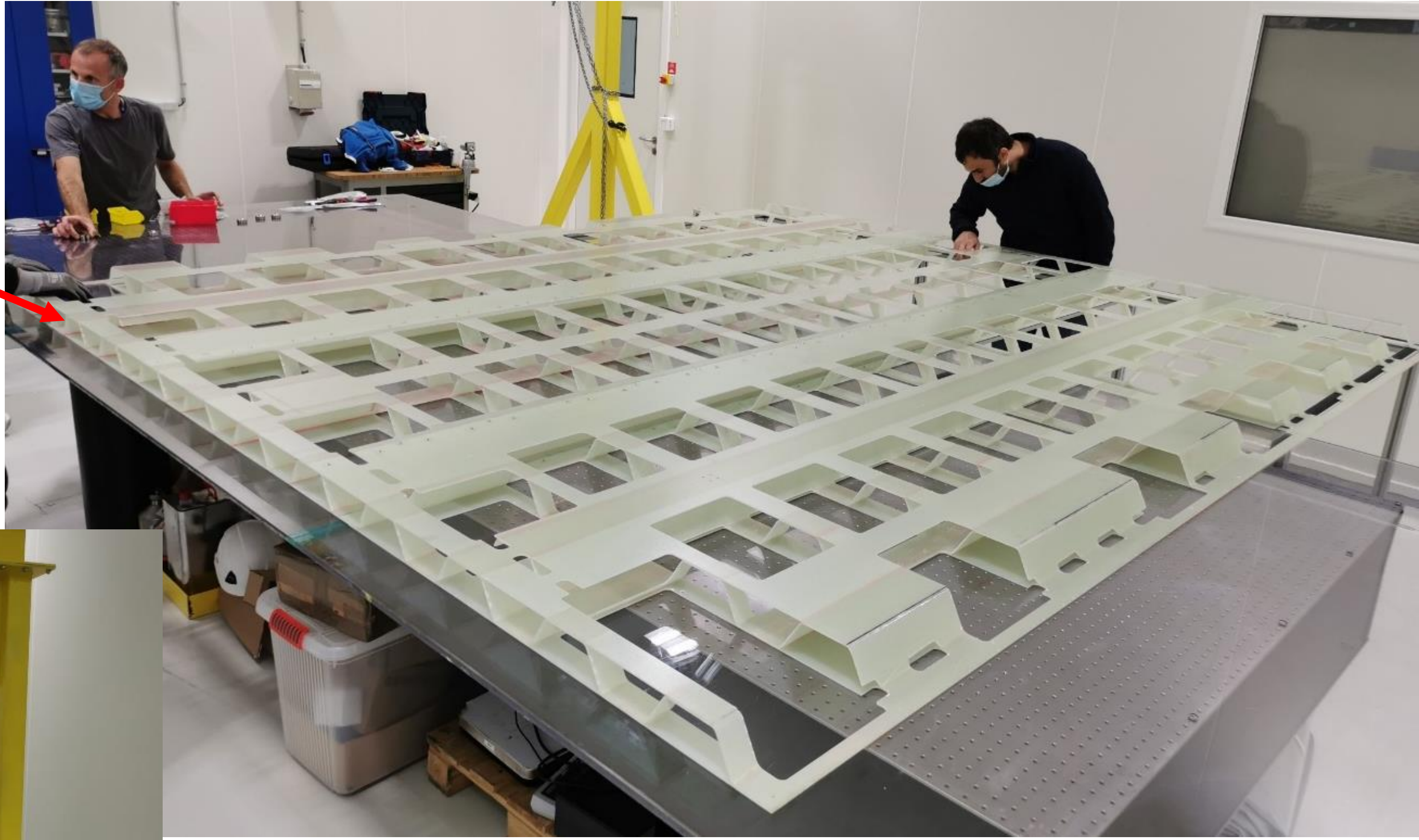
Hole alignment between PCB's allows to minimize biasing voltage on four electrode layers

Charge Readout Plane

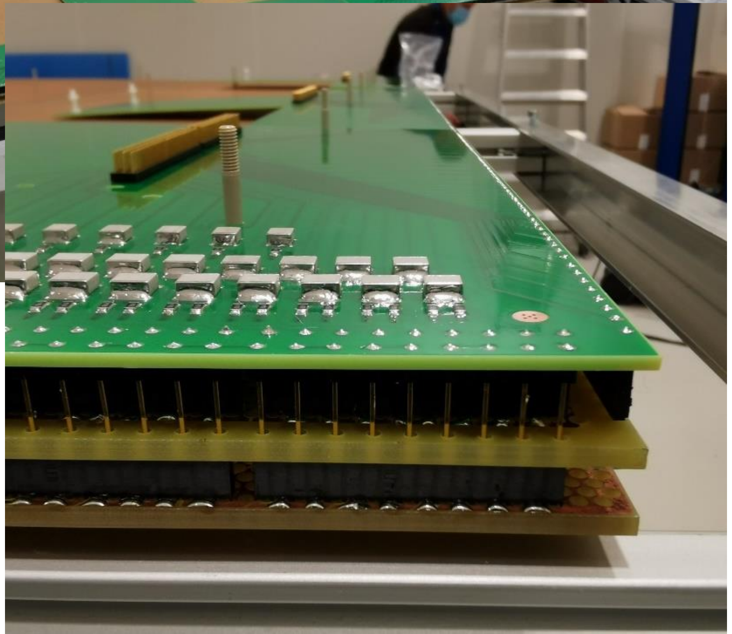
- Mechanics is an evolution from Double Phase design
- Need to handle top and bottom electronics
- New design last spring
- Production this summer

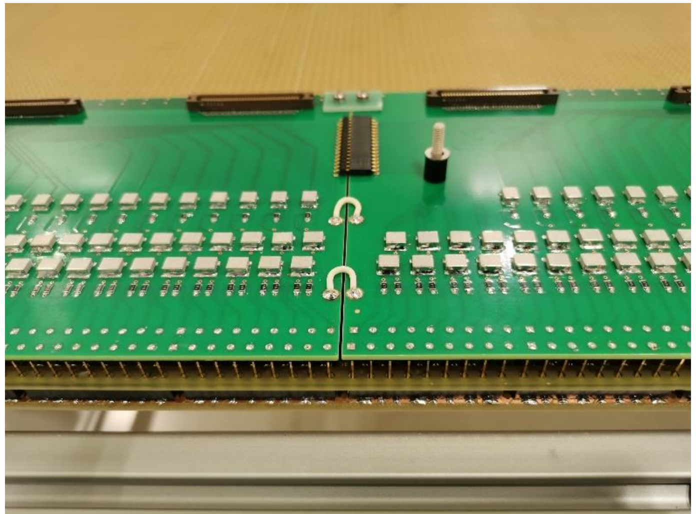


- **Composite Frame assembly**
- **Link to metallic structure**

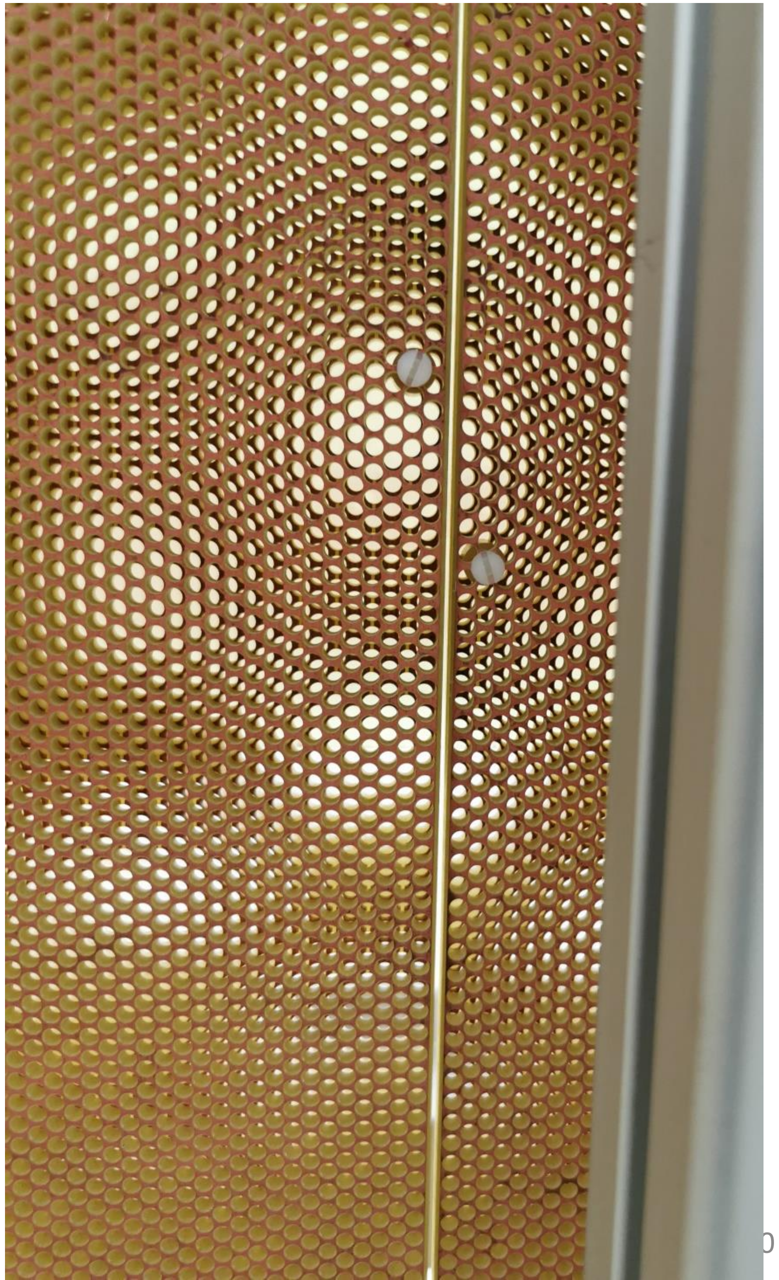


Bottom and Top Charge Readout Unit assembly

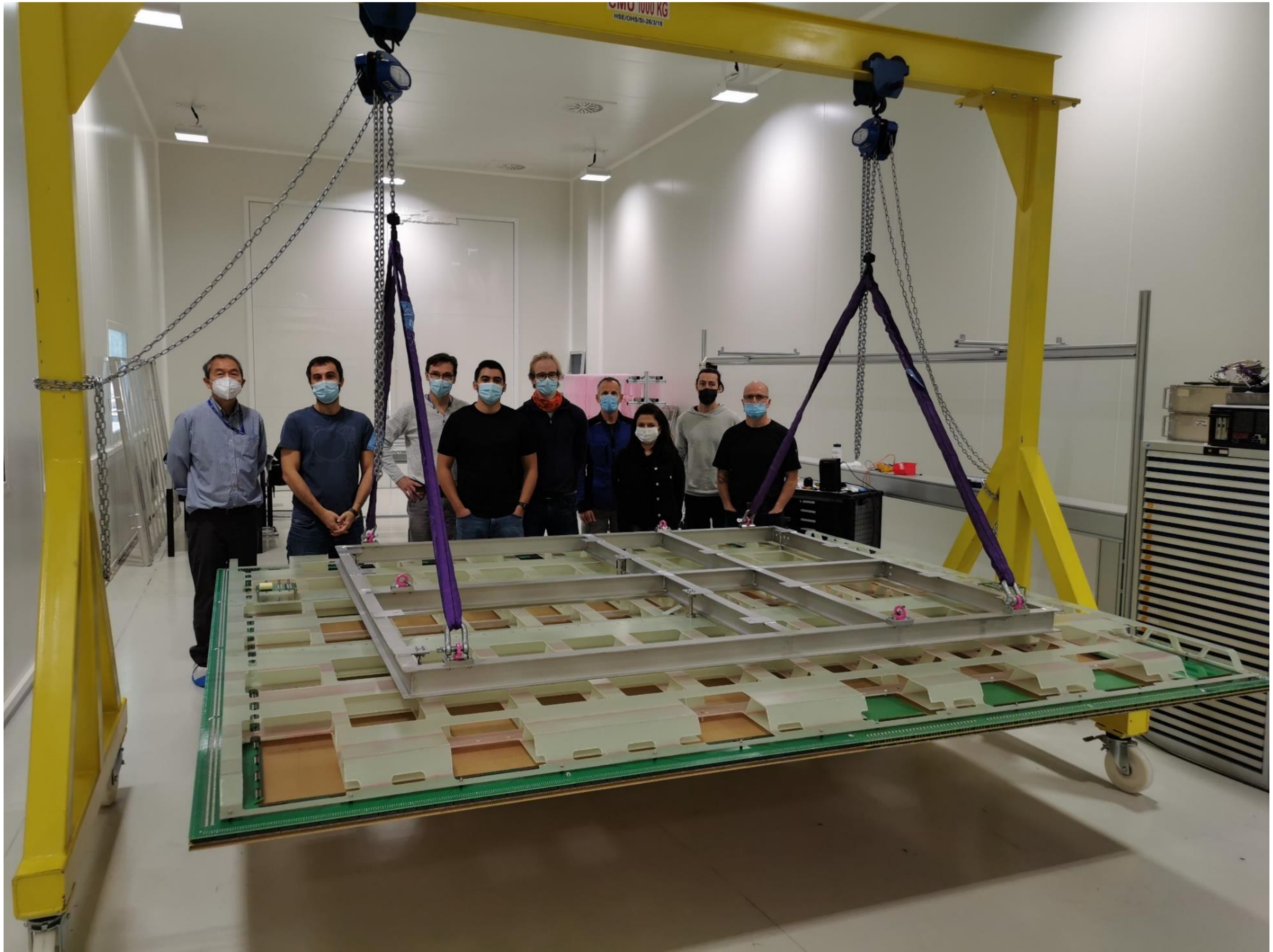




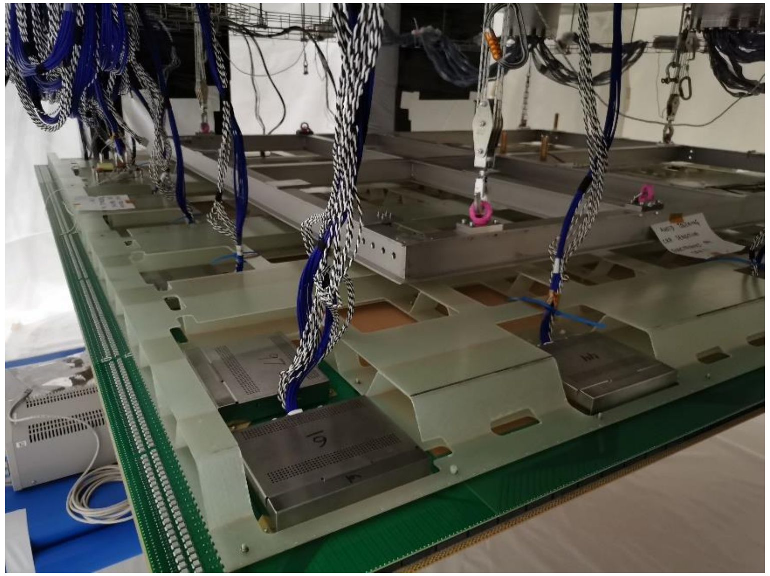
Fully assembled CRP seen from below



Fully assembled CRP seen from above



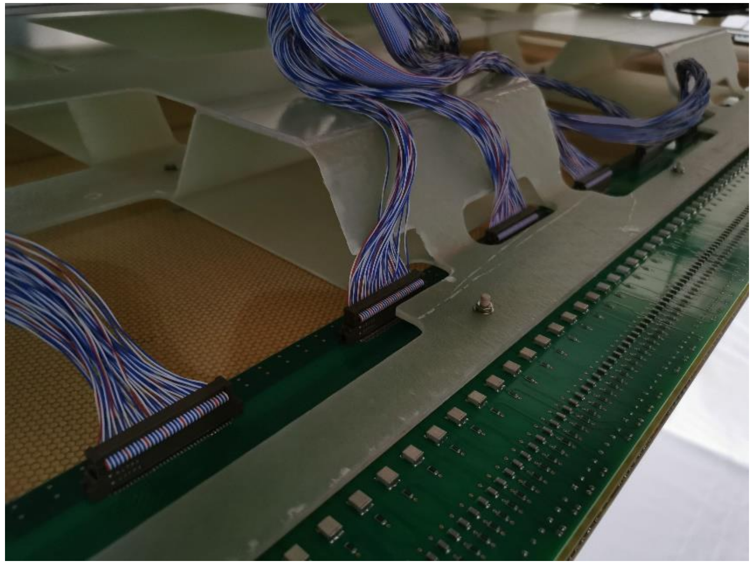
CRP Integration last week



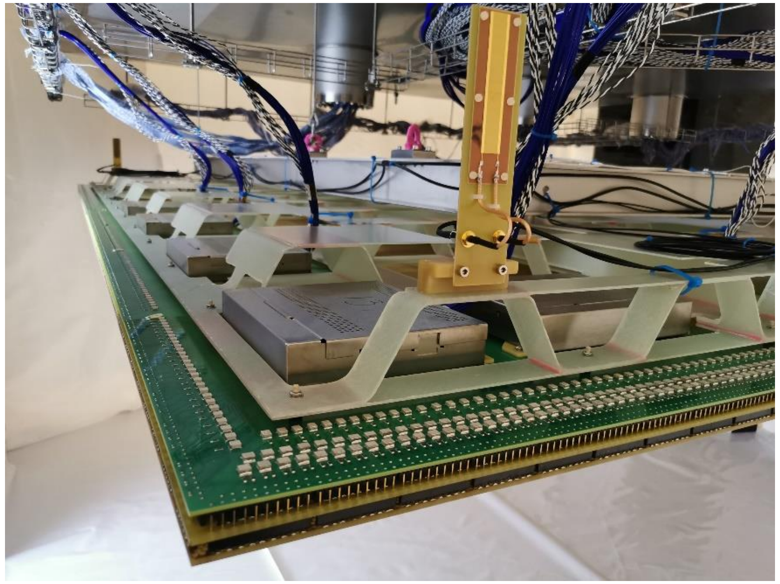
CE cable routing and connection through the flange

Attachment to the cold box roof

Top electronic routing and connection to the chimneys and on the CRP

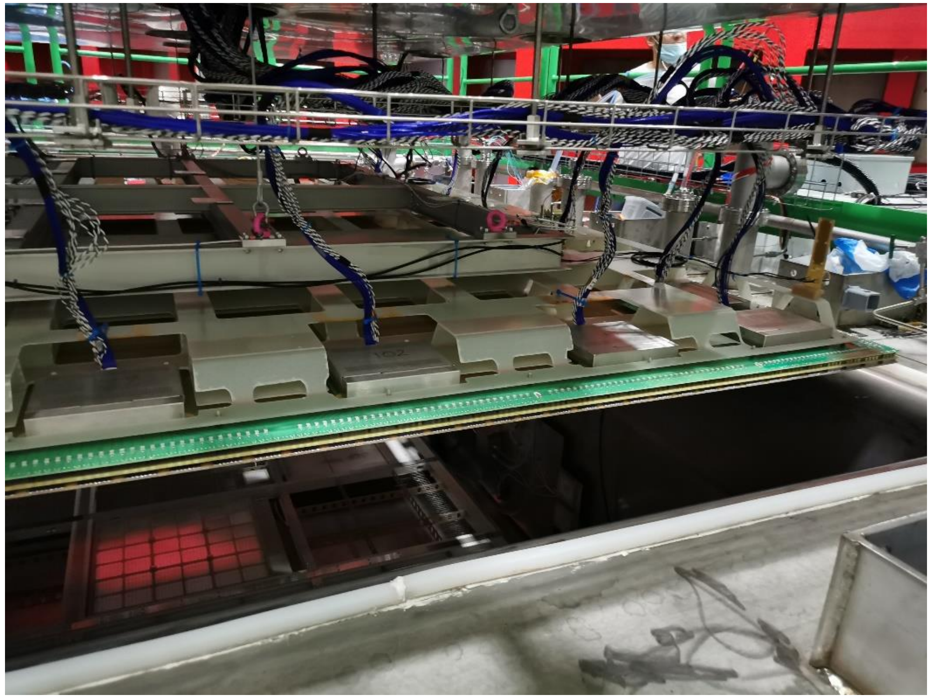


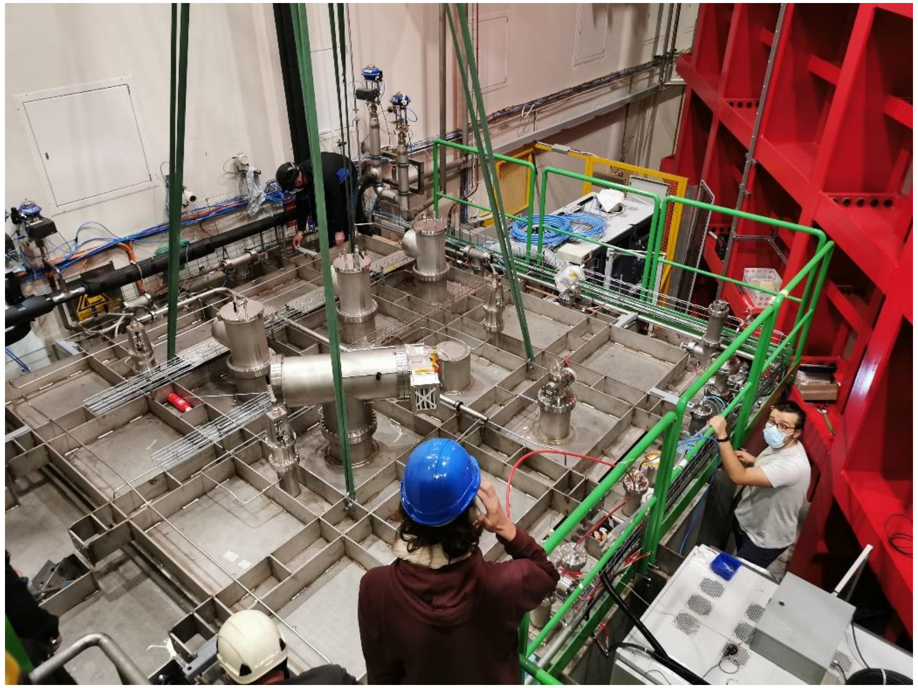
Instrumentation installation (level meters, temperature probes



- **CRP Insertion in the ColdBox yesterday**

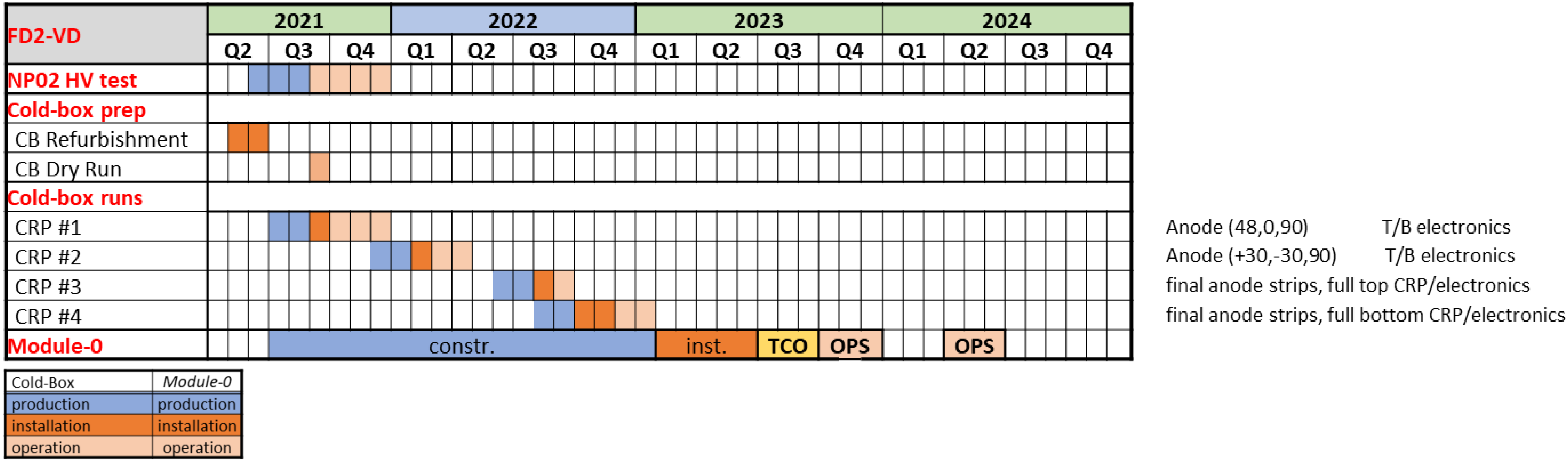
- **Start of commissioning this week in gas phase before LAr filling**



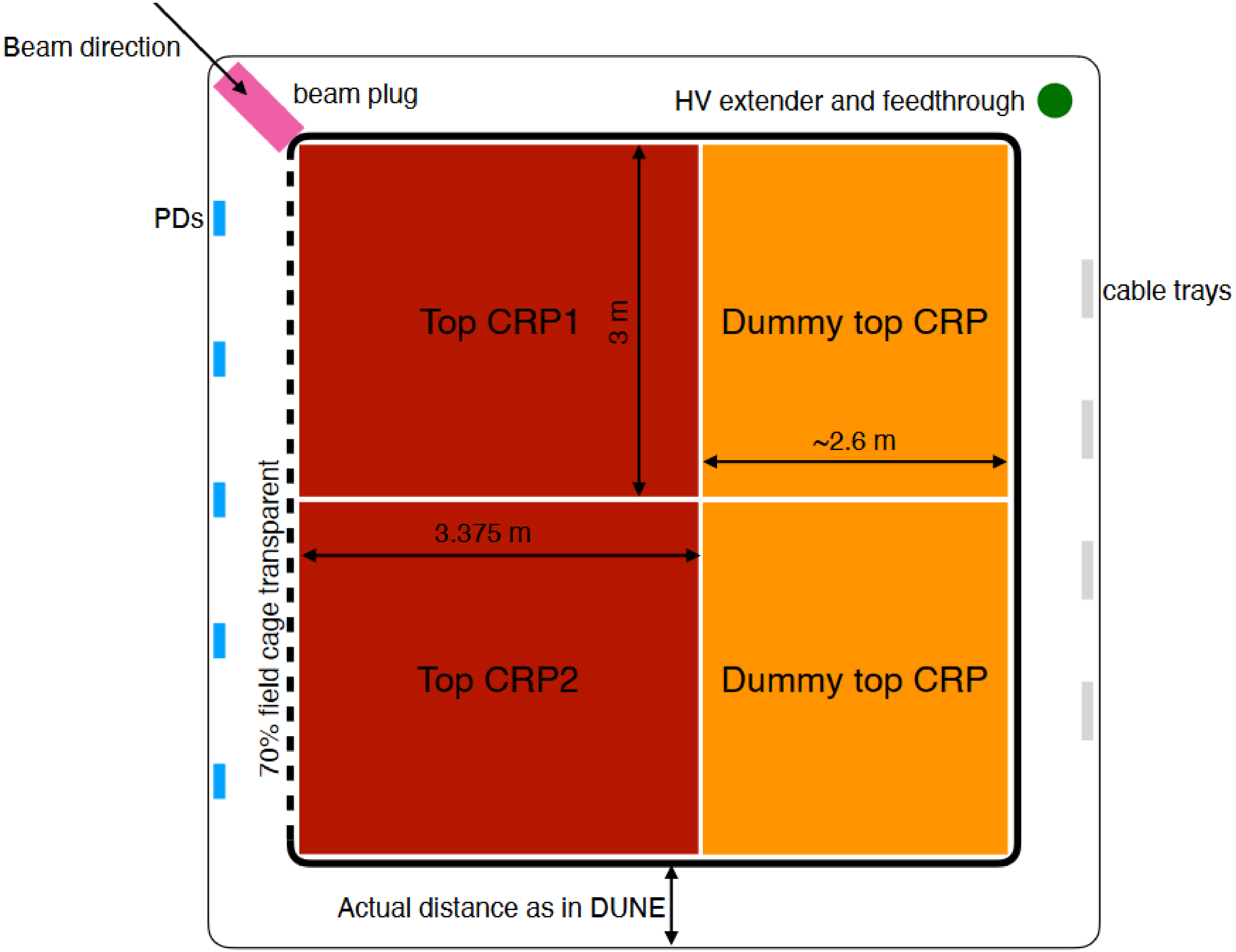


Vertical Drift Module-0 in NP02

- Almost a scale 1:1 test
- Mandatory step to validate integration of all elements before mass production
- Production Readiness Review foreseen at the end of 2023
- Same activity for HD in NP04

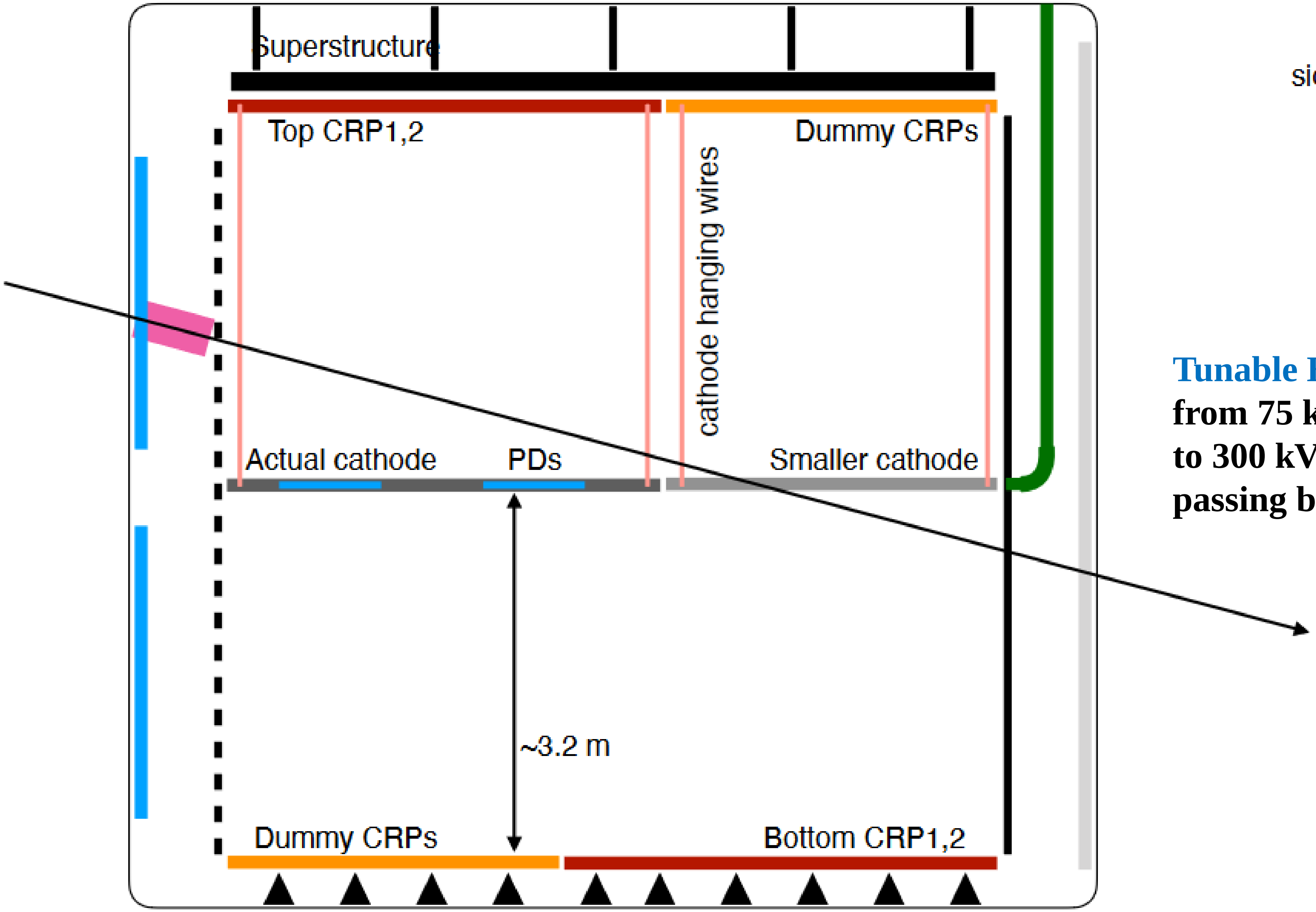


Module-0 in NP02



top view

Module-0 in NP02



side view

Tunable HV
from 75 kV (same drift time)
to 300 kV (same max HV)
passing by 150 kV (same drift field)

Conclusion

- **Intense program of tests (2021-2023) at the CERN neutrino platform in view of launching the mass production for the second VD FD module at the end of 2023**

=> IN2P3 teams deeply involved with strong responsibilities and visibility

- **New, simpler, extender design holding 300 kV => valid design for the VD HV layout**

- **Commissioning and tests for ColdBox will start in the coming days**

=> very strong effort performed in 2021 to keep the planning. Exciting period with tests results of the first fullscale VD CRPs in front of us

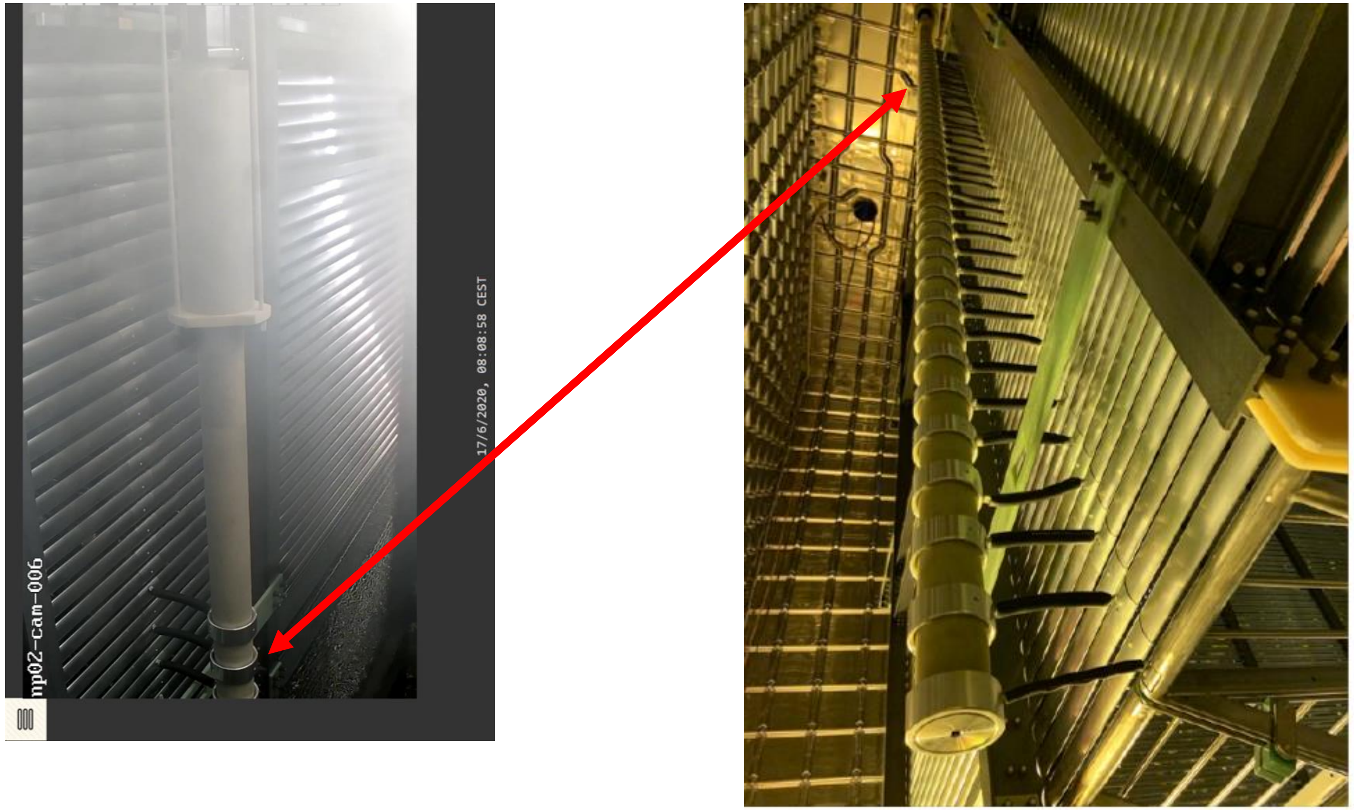
- **ColdBox runs will allow if needed in several iterations perfecting final design in view of production**

- **VD Module-0 will arrive soon almost in parallel to HD Module-0 => Sufficient scientific and technical staff needed to insure the success**

From the closeout report of the **LBNC September 2021 meeting** reviewing CDR and activities at the CERN Neutrino Platform:

"A year ago the Vertical Drift concept was a glint in a few peoples eyes. We have observed an ambitious R&D program which is enjoying amazing success. We have reviewed the technical aspects in the Spring of the year and recently reviewed a complete Conceptual Design Report. DUNE has our comments, and we have discussed their path to what we anticipate will be a recommendation for approval of the CDR by the end of the year"

BACKUP



- Original extender had very complicated design using a G10 cylinder to insulate the central conductor bring the HV to cathode. The G10 cylinder was surrounded by equipotential rings connected to the field cage in order to contain locally the electric field (very strong in the first rings)

- A short between second equipotential ring (connected to field cage) and extender conductor developed in August 2019 during commissioning at 250 kV due to a crack developed in G10

- In situ repair attempt in June 2020 (cut with external surgery first 3 connection links of equipotential rings to field cage) → short path deported to 4th connection due to surface current developing on G10

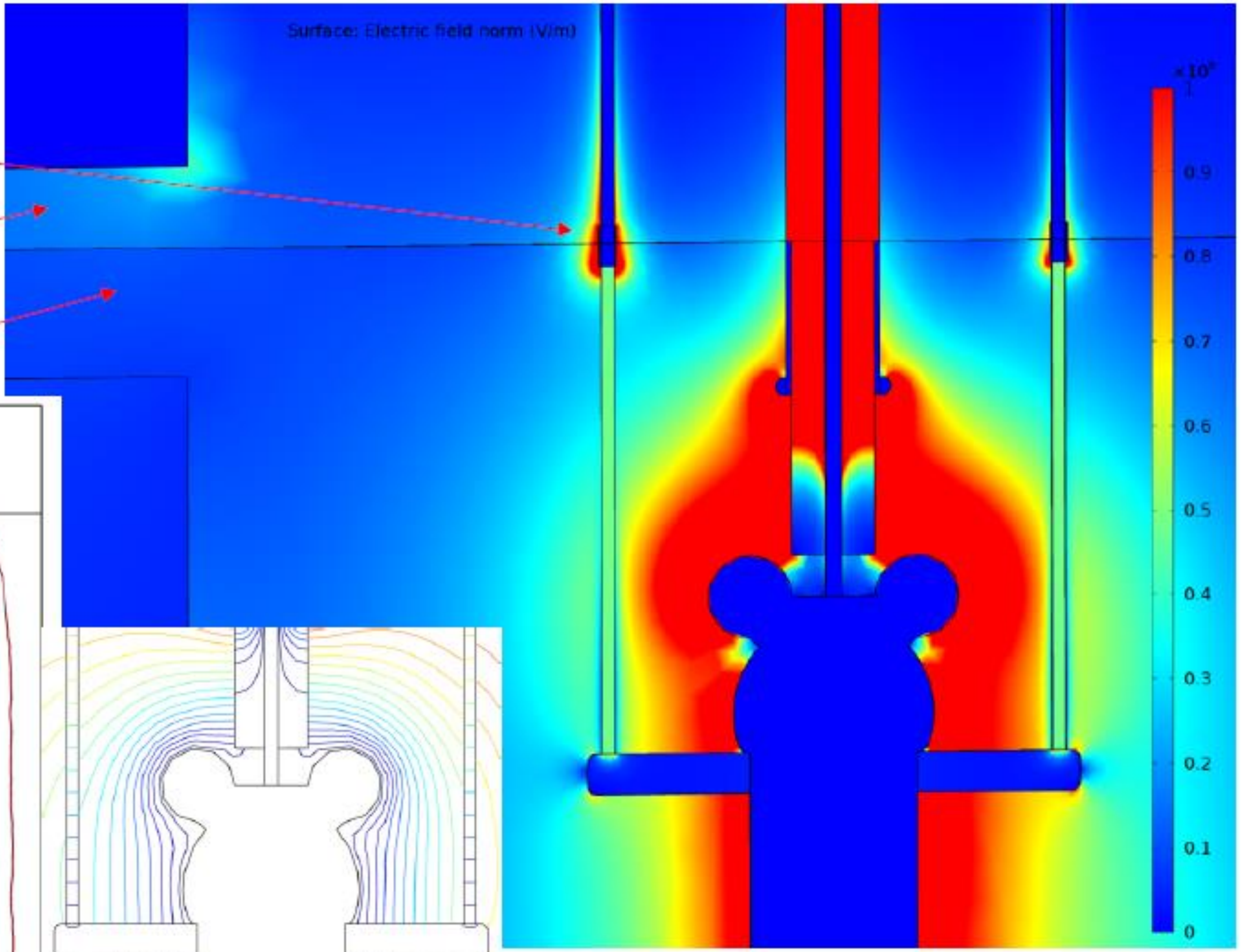
- Extender removal May 2021 → localization of the short in a fault in G10 material below the second ring

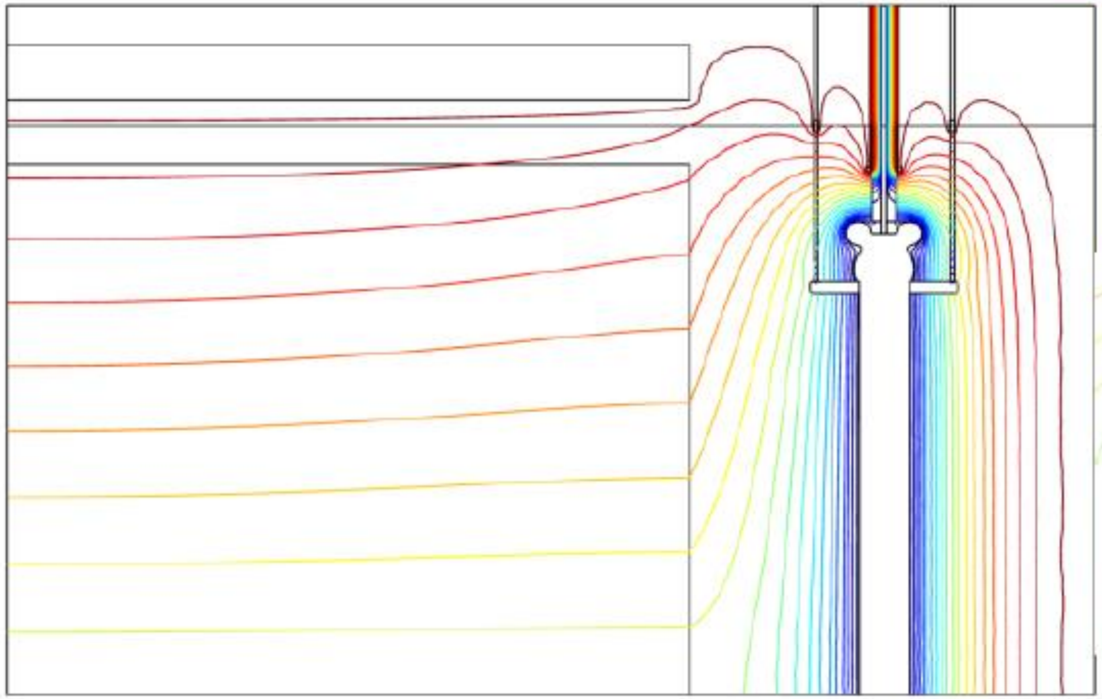
E field simulation

E field on the surface of the left nut (conductor): 12kV/cm in gas.

E field under the CRP extraction grid: 900V/cm

E field in the liquid under the surface: 600V/cm





Charge accumulation at the surface (-1μC/m^2)

E field on the surface of the left nut (conductor): 17kV/cm in gas.

E field under the CRP extraction grid: 2kV/cm

E field in the liquid under the surface: 540V/cm