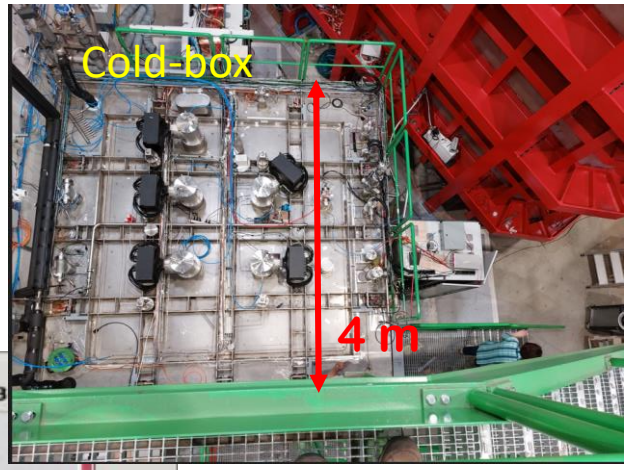
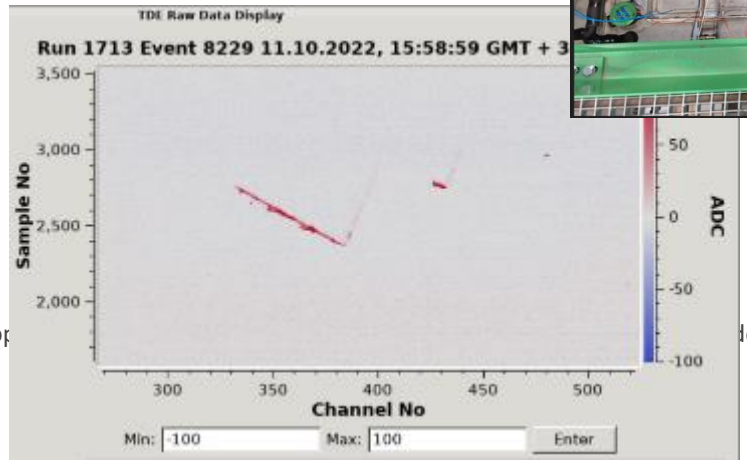
Task 9.3
Vertical Drift Charge Readout

Task partners: CNRS-IJCLab, CNRS-IP2I, CNRS-LAPP

AIDAInnova 2nd Annual meeting April 2023

D. Autiero (CNRS-IP2I Lyon)

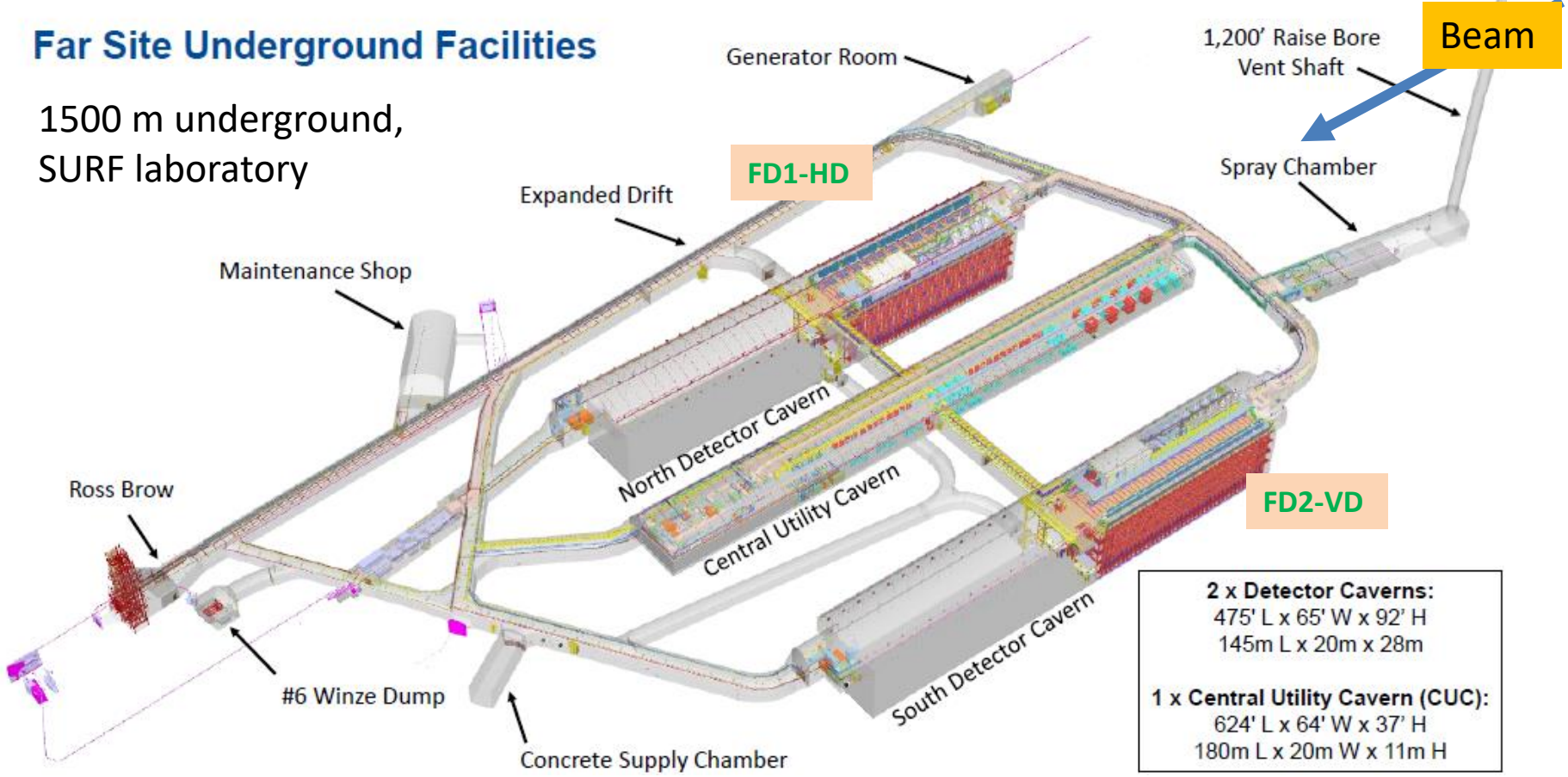




This project has received funding from the Europ ...der grant agreement No 101004761.

Far Site Underground Facilities

1500 m underground,
SURF laboratory



2 x Detector Caverns:
475' L x 65' W x 92' H
145m L x 20m x 28m

1 x Central Utility Cavern (CUC):
624' L x 64' W x 37' H
180m L x 20m W x 11m H

DUNE Phase-I :

- Beam 1.2 MW
- ND initial configuration
- **Two FD LAr TPC modules: FD1-HD, FD2-VD**

March 2023:
60% of underground infrastructure excavated

North Detector Cavern – West End

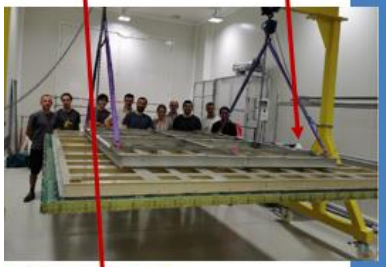
Drilling holes for blast charges for bench C (left) and removing muck (right) in North Detector Cavern (4850-33)

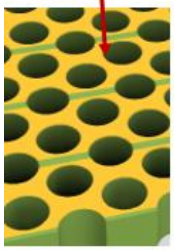
2nd DUNE Far Detector Module (**FD2-VD**) : ~15 kton of active LAr

Vertical Drift: novel and optimized LAr TPC technology, anodes based on segmented perforated PCB

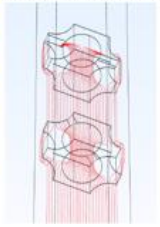
Top and bottom anode charge readout surfaces:

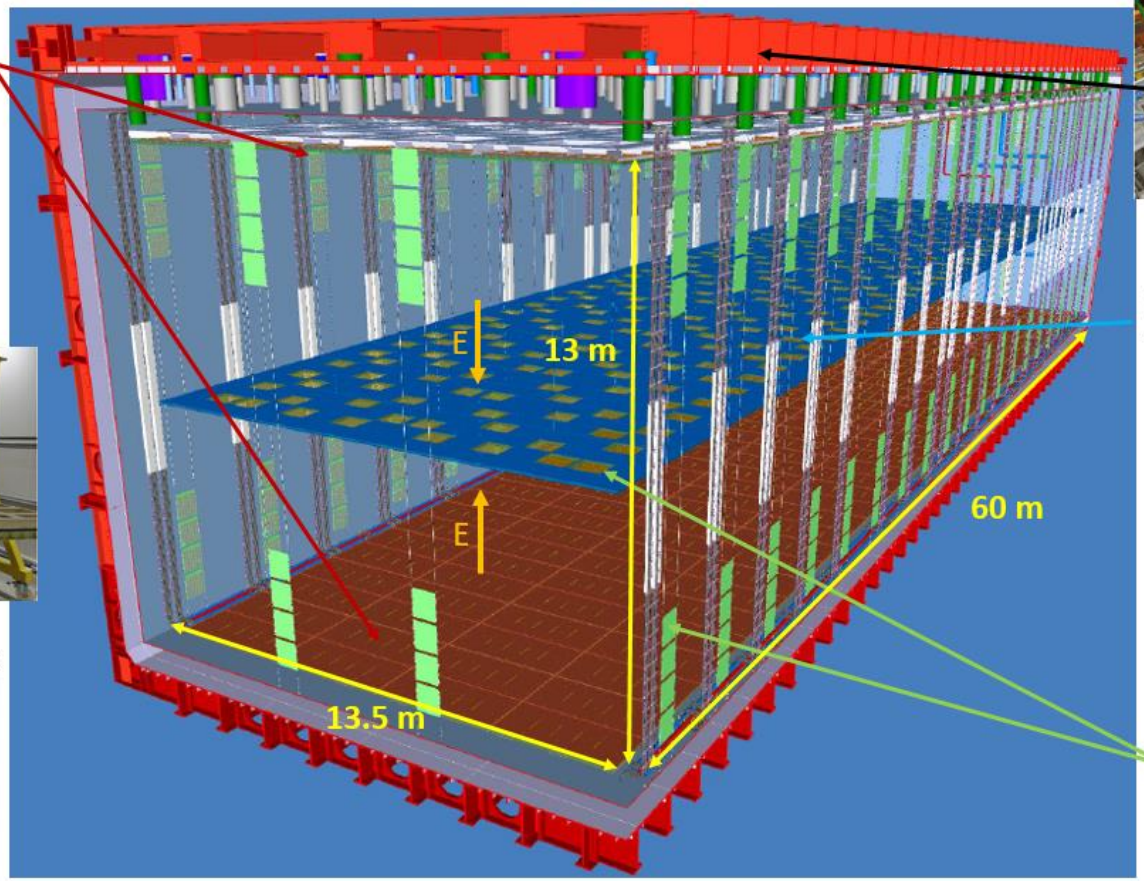
Made of 80+80 Charge Readout Plane units
3x3.375 m^2
Each unit: 2 stacked layers of segmented perforated PCBs





Strips 5 mm
Holes 2.4 mm





μTCA charge readout

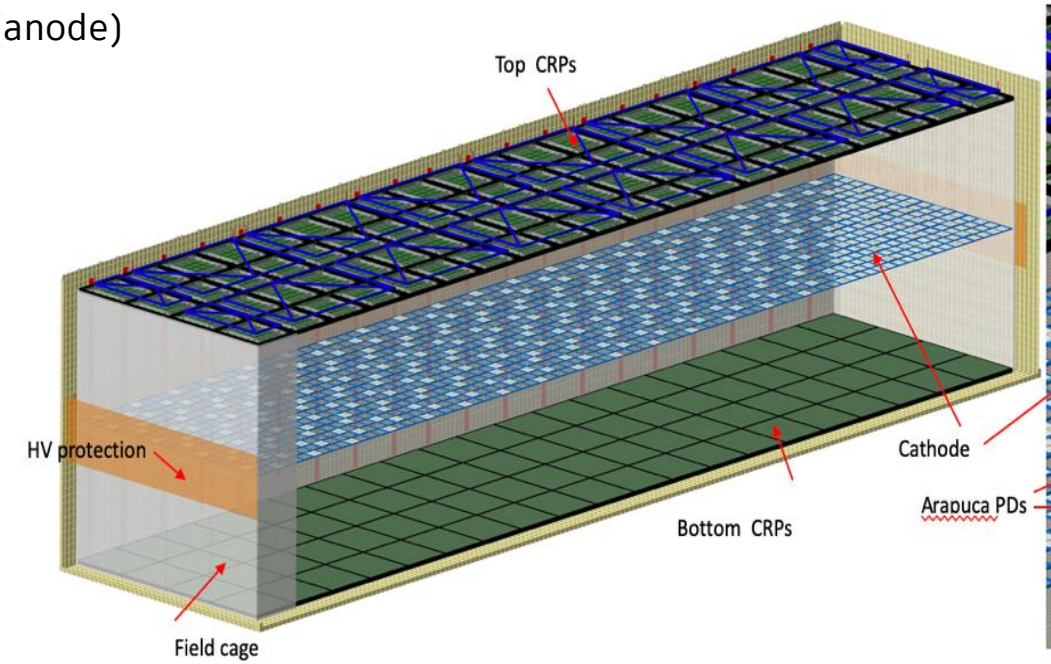
Cathode surface at -300 kV
→ E~500V/cm

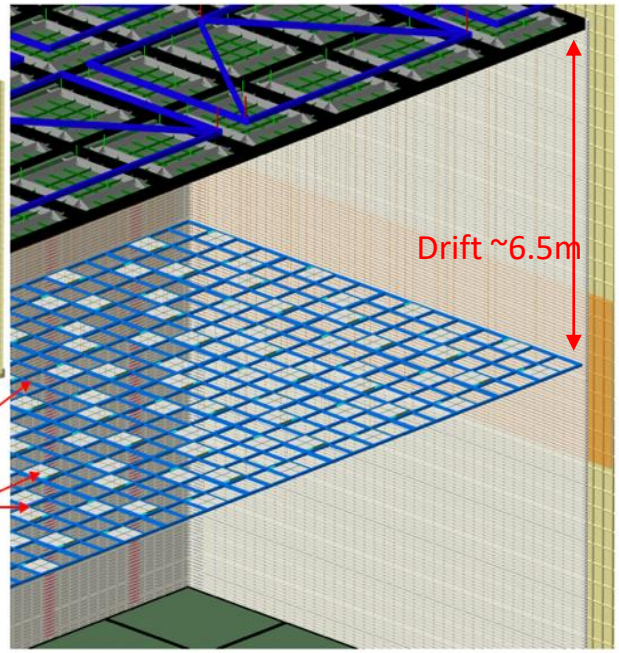
1/40
Prototype in
NP02 cryostat
Module-0

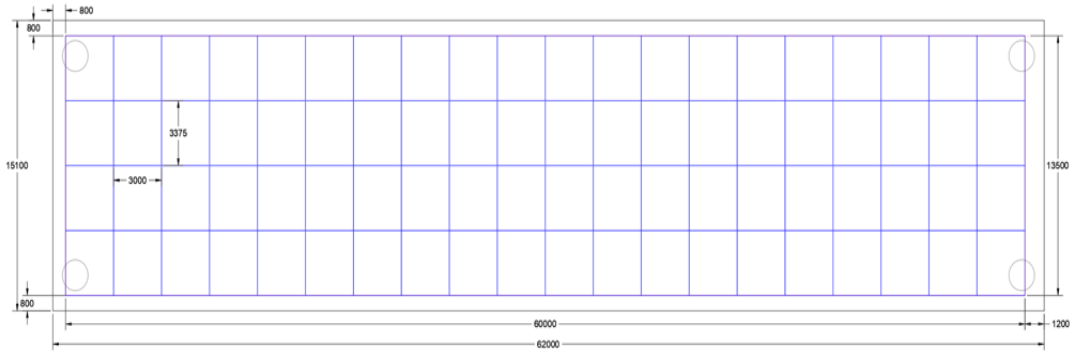
UV photon detectors on cathode and cryostat walls

Vertical Drift far detector module

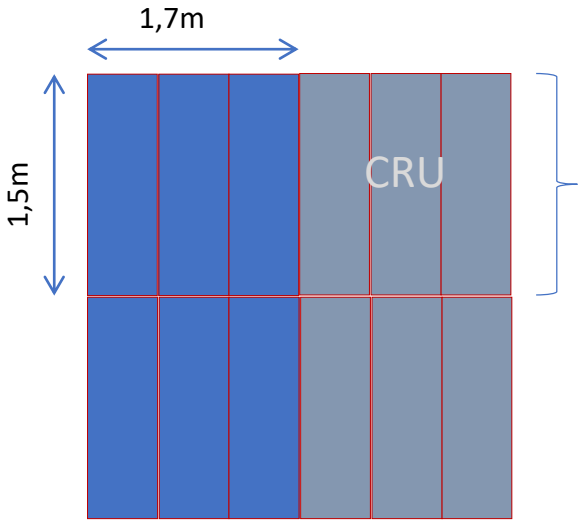
CRP= 3x3.375 m^2 readout units (anode)





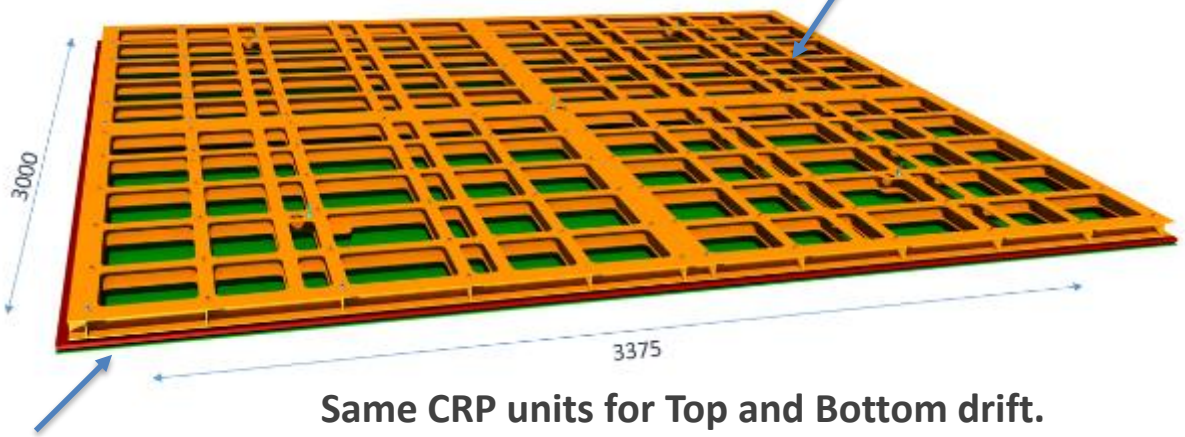


- ✓ 160 CRP units (80 on top, 80 on the bottom)
- ✓ Drift active volumes 2*5'265 m^3



4 charge readout units (CRU) compose a CRP

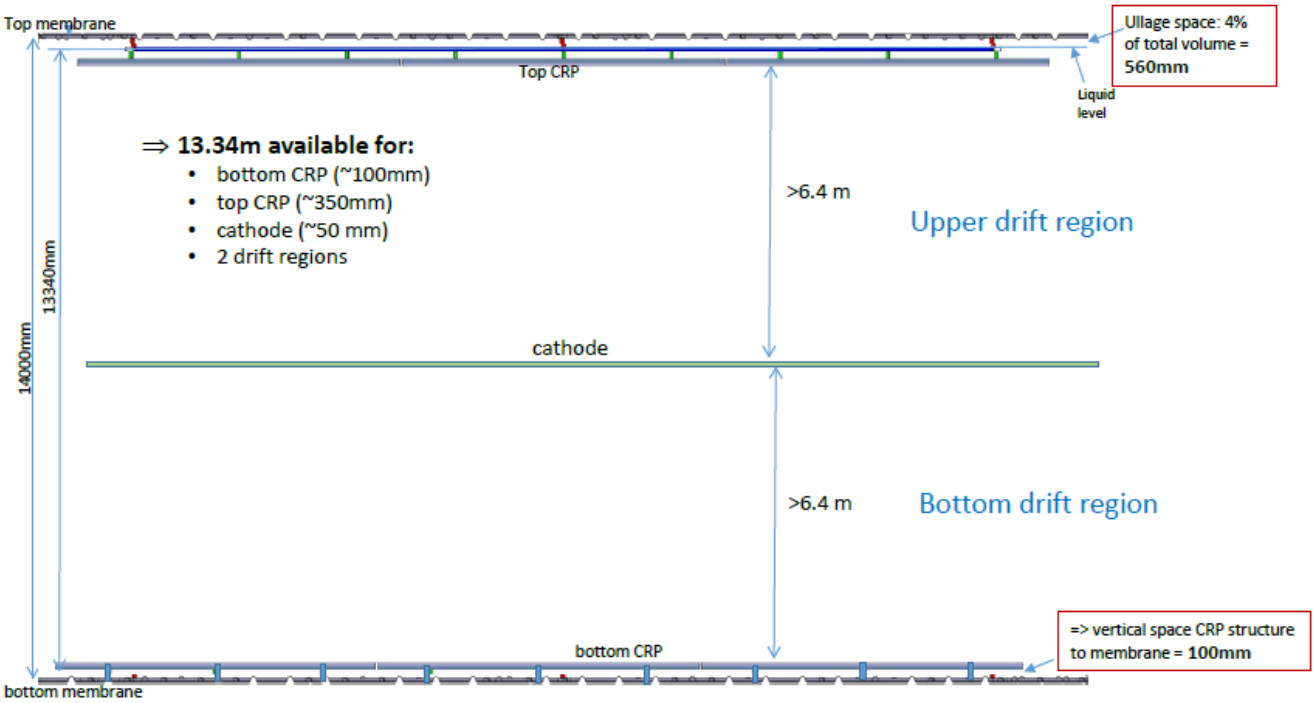
Structural PCB sandwich



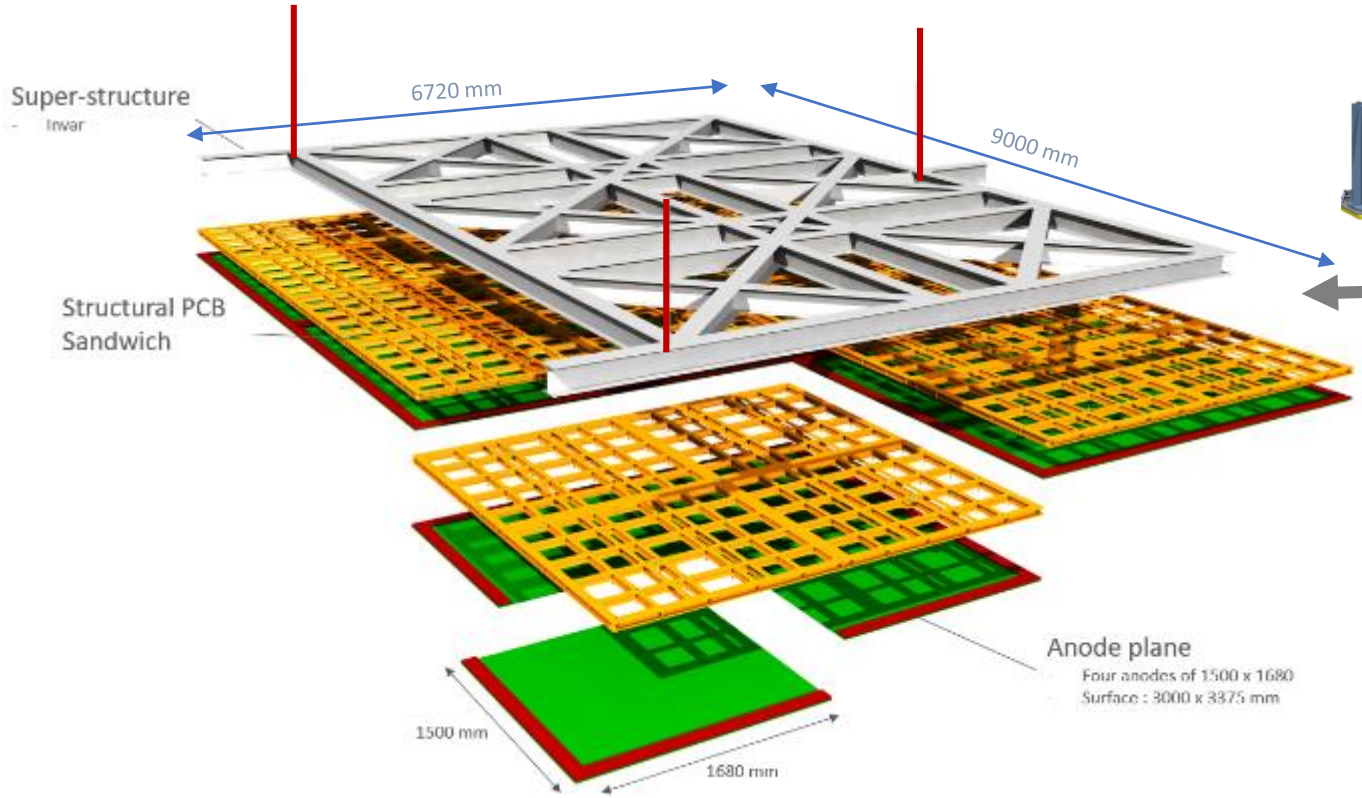
Perforated anode

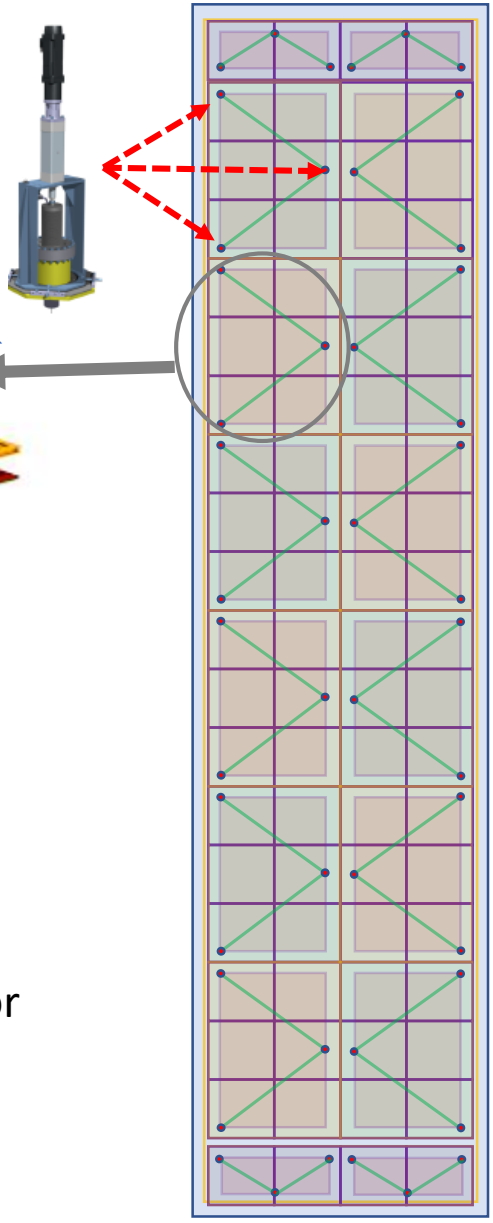
Same CRP units for Top and Bottom drift.
Each anode PCB unit (CRU) (1.5m x 1.7m) constructed by bonding 3 PCBs side by side

Vertical dimension range:



TOP drift CRPs hanging mechanical superstructures





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

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

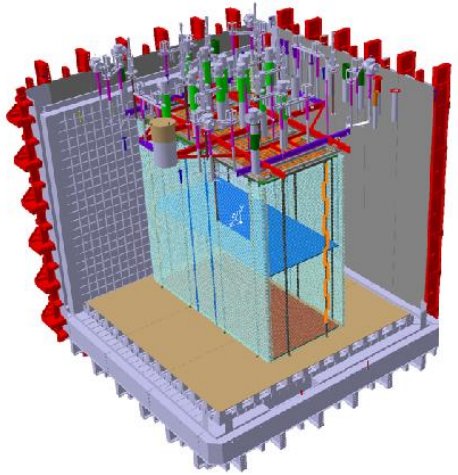
Task 9.3 focusing on top-drift readout

Tests program (strong support provided by CERN Neutrino Platform infrastructure):

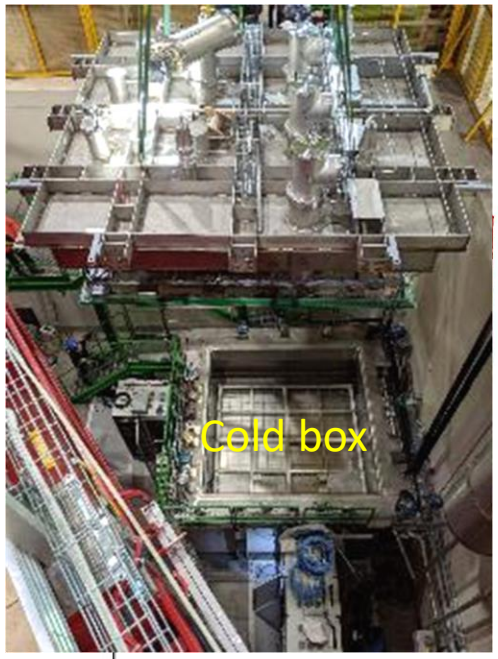
→ Development of Vertical Drift Charge Readout Planes, associated electronics and chimneys

- Development of cold-box infrastructure (sized to CRPs dimensions in 2021)
- First CRP + readout (CRP1) successfully tested in two cold box tests in Fall 2021
- Followed by tests of improved version of CRP1 (CRP1b) in spring 2022
- First final layout top-drift CRP (CRP2) tested in cold box in July 2022
- Second final layout top-drift CRP (CRP3) tested in cold box in October 2022
- Installation of top drift CRPs in NP02 cryostat (Module-0) at the end of 2022
- FD2 TDR Draft (December 2022)
- Completion of Module-0 integration in spring 2023

→ R&D program well on schedule
with expected results and excellent performance



Vertical Drift
Module-0 in NP02 cryostat



Task 9.3. Vertical Drift charge readout
- Novel Vertical Drift perforated anodes charge readout design evolving from the Dual-phase charge readout stack
- Development and tests of novel design of the Charge Readout Plane (CRP) integration surface of the Vertical Drift perforated anodes
- Developments and tests of integrated cold electronics, new feedthrough chimneys design
- Developments in associated digitisation hardware and online data treatment

→ CRP, Chimneys, Top Drift-Electronics

Top Drift Electronics (TDE)

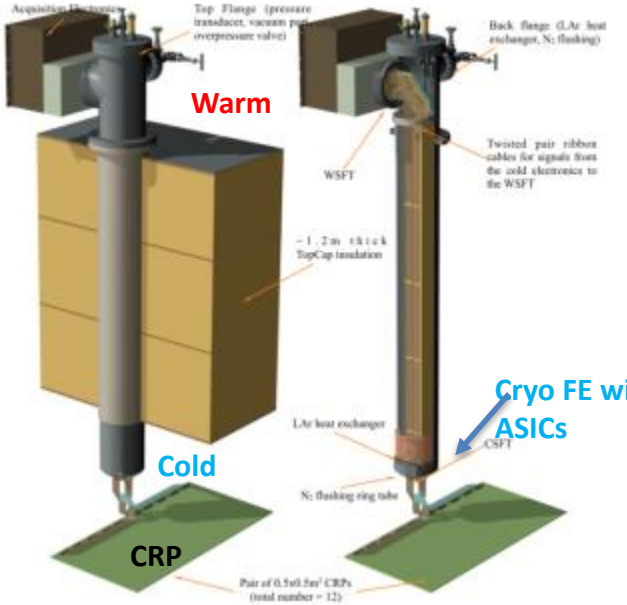
- Top drift CRPs readout based on completely accessible
- electronics:

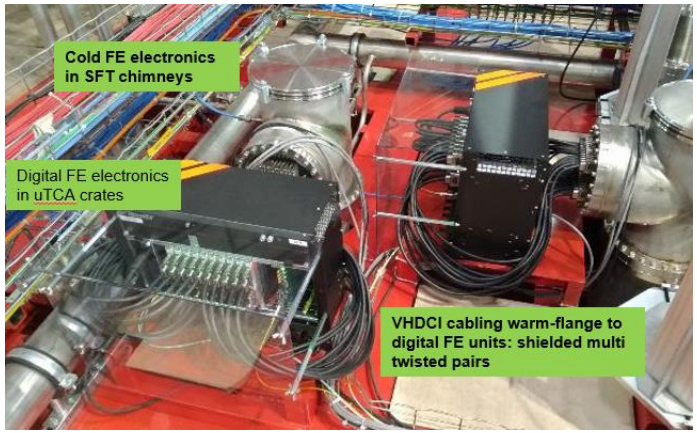
- Top Drift Electronics subsystems:

➢ **Analog FE cryogenic electronics:** Cryogenic ASICs and Front-End cards at the bottom of the chimneys (FE cards with cryogenic ASICs, Chimneys, LV distribution system)

➢ **Digital FE electronics on cryostat roof**: AMC digitization cards + uTCA systems, timing distribution system (AMC digitization boards, uTCA crates PU,CU, MCH, White-Rabbit MCH)

TDE (DP) electronics successfully operating on 3x1x1 and on NP02/protoDUNE dual-phase, R&D carried on since 2006





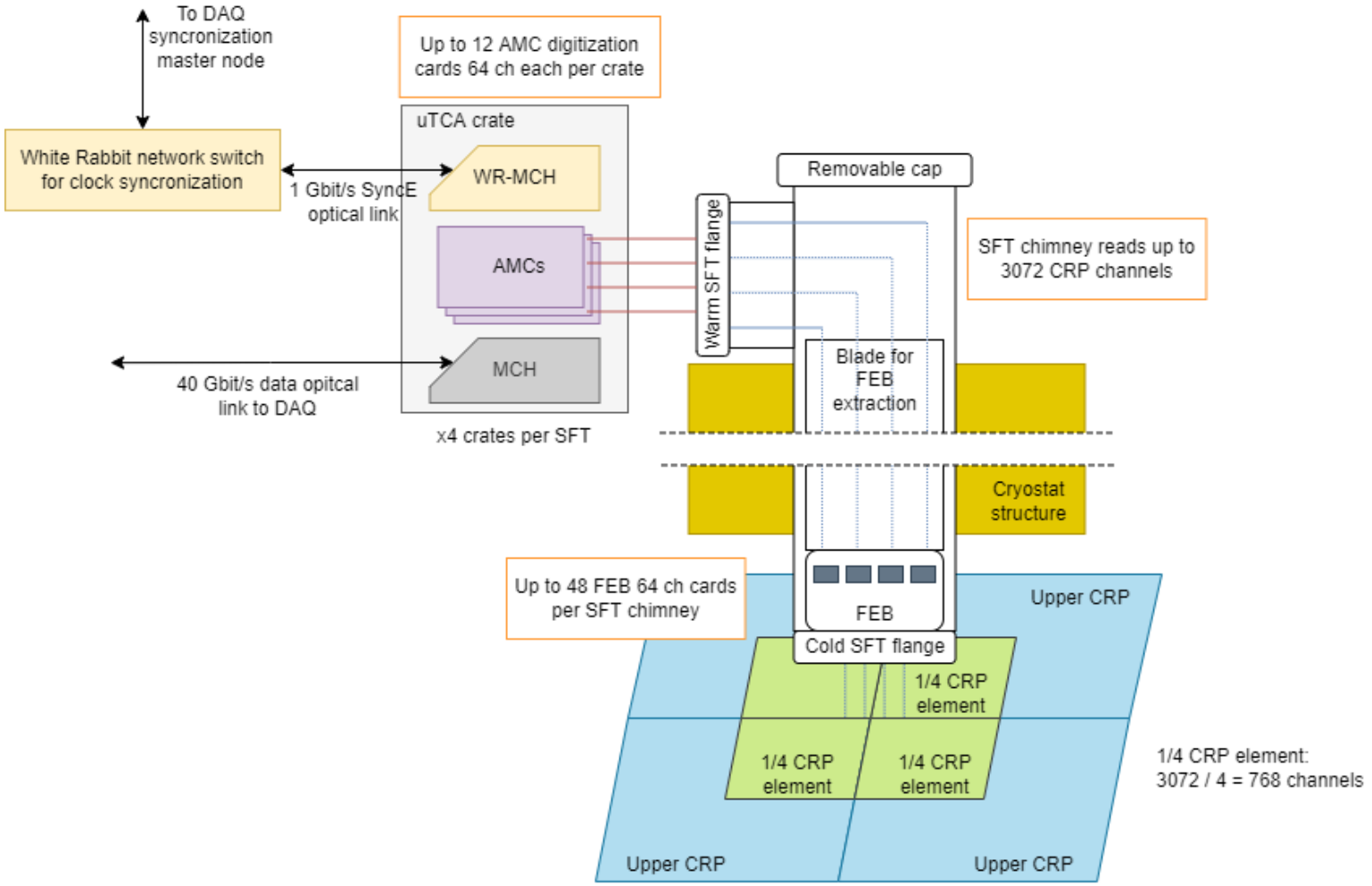
→ Adaptations and developments performed in 2021 from DP version for the Vertical Drift:

➢ New FE cards with decoupling components for Vertical Drift anodes

➢ Modification of digitization cards dynamics for bipolar signals of Vertical Drift induction views

➢ Development of 40 Gbit/s uTCA connectivity and associated DAQ.

TDE readout system synoptic



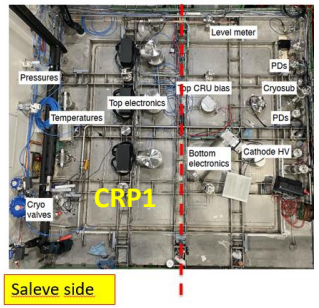
Timeline of Top-Drift/TDE activities and achieved milestones

CDR Review
Jun 21

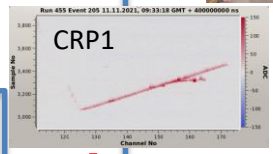
TDE components preparation
Jan-Jun 21

TDE Integration test Jul-Sep 21

Evolution from DP Design, Proposal
Sep-Dec 20

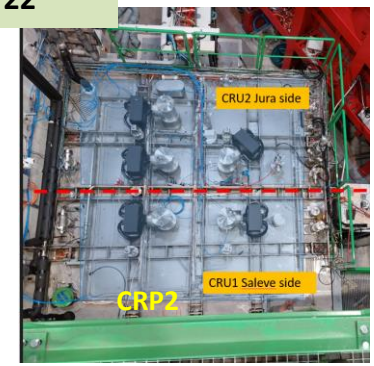


CRP1 test
Nov 21



CRP1 test
Dec 21

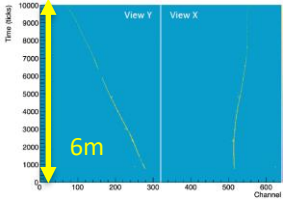
Faraday cage 1&2
Test, preparation CRP2/3
Module-0 Jan.-May 22

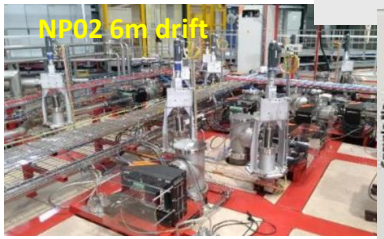


PDR Review
May 22

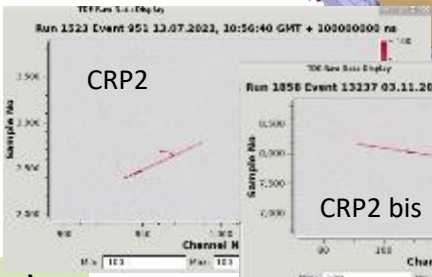
CRP1b test
May-Jun 22

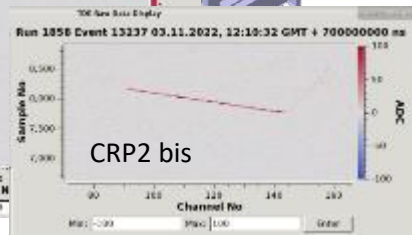
NP02 6m Drift operation
Feb 22



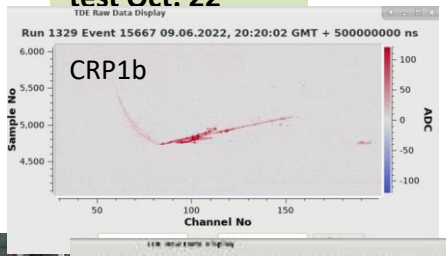


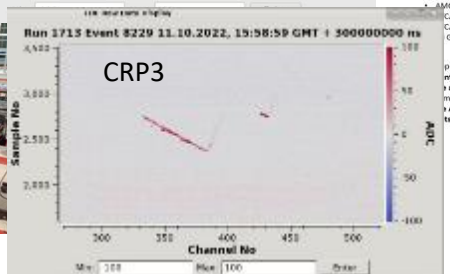
CRP2 (full-top) test Jul 22





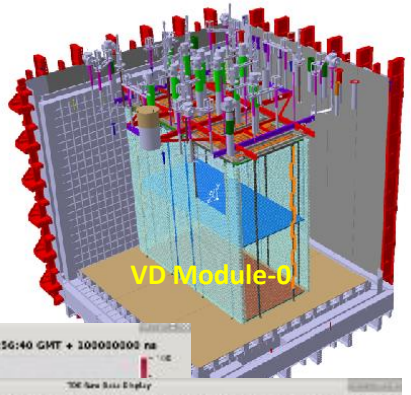
CRP3
test Oct. 22



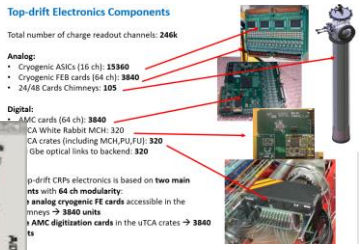


CRP2 (full-top) Re-test Nov 22

VD Module-0
Fall 22-Fall 23



TDE FD2 production
End 23-Summer 26



2021

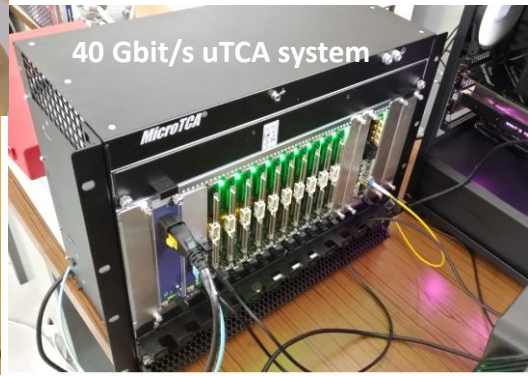
2022

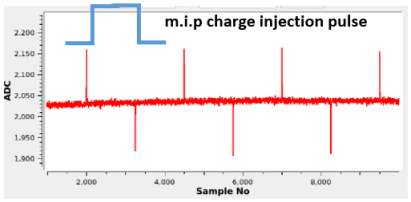
2023

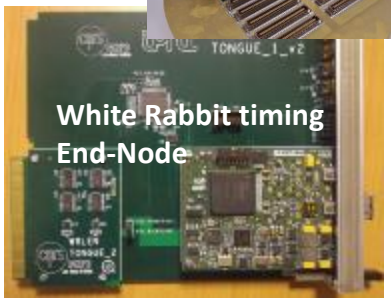
2023-…

Components for the cold-box test of top-drift procured with new productions in spring 2021 including adaptations for Vertical Drift → Large efforts for production and completion of extensive tests before bringing materials to CERN by the beginning of the summer 2021.

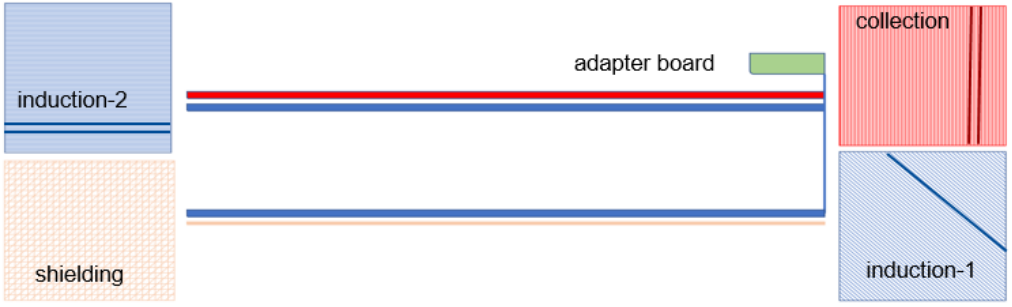
- New ASICs production
- New front-end cards production
- Modifications to digitization cards and validation
- Production of new timing cards and new timing distribution network dedicated for cold-box
- New MCHs in uTCA crates at 40 Gbit/s developed with NAT and associated infrastructure
- New low voltage generation and distribution system independent on NP02
- New calibration system also usable for FD2
- Setting up new DAQ/network system for cold-box
- Production of new cold/warm flanges and tests
- Production of VHDCI cabling + inner chimneys cabling
- Dedicated production of 5 mini-chimneys for the cold-box tests





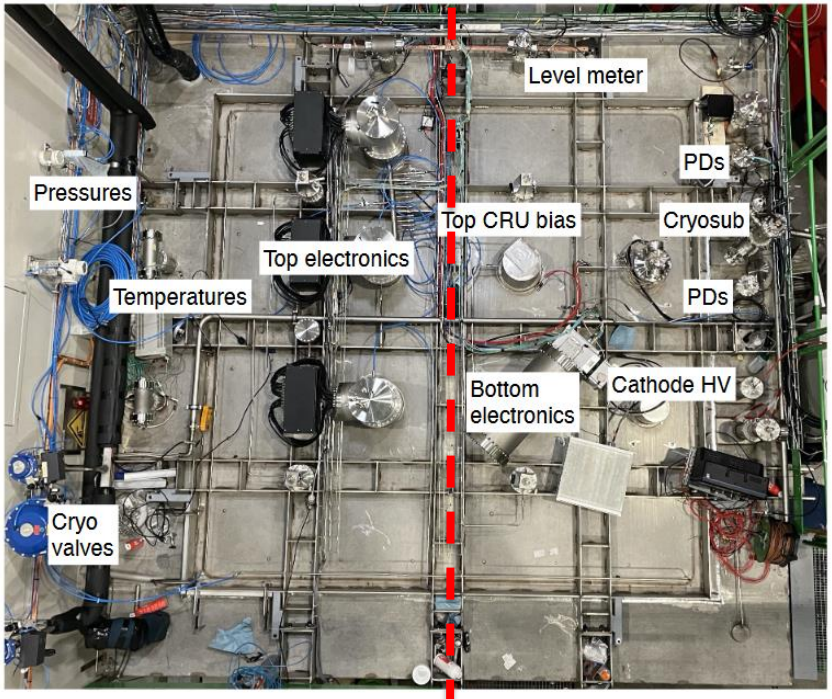


CRP1 for first cold-box test, shared by the TDE and BDE
Nov-Dec 2021

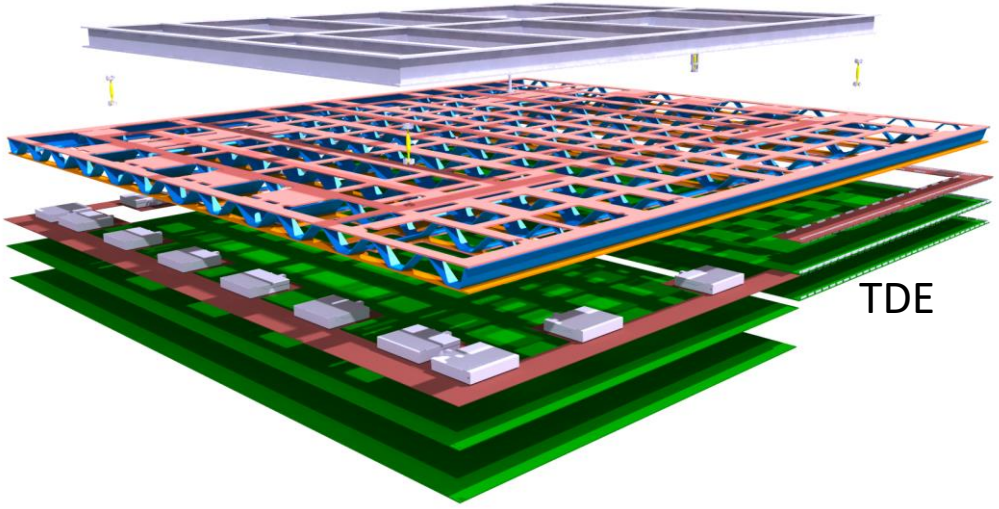


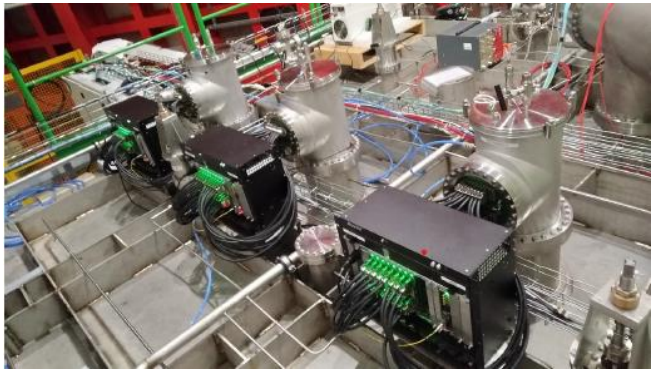
Jura side

TDE BDE



Saleve side

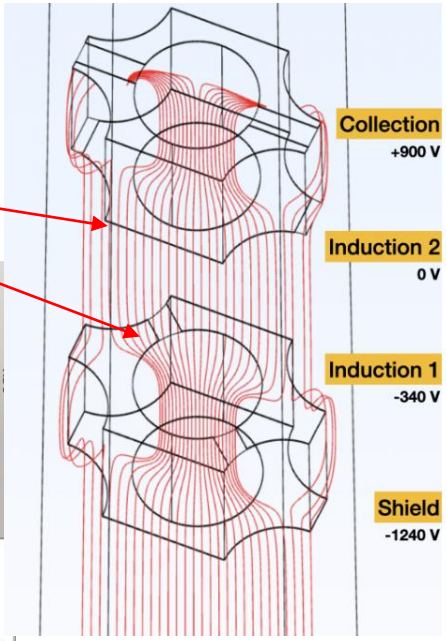


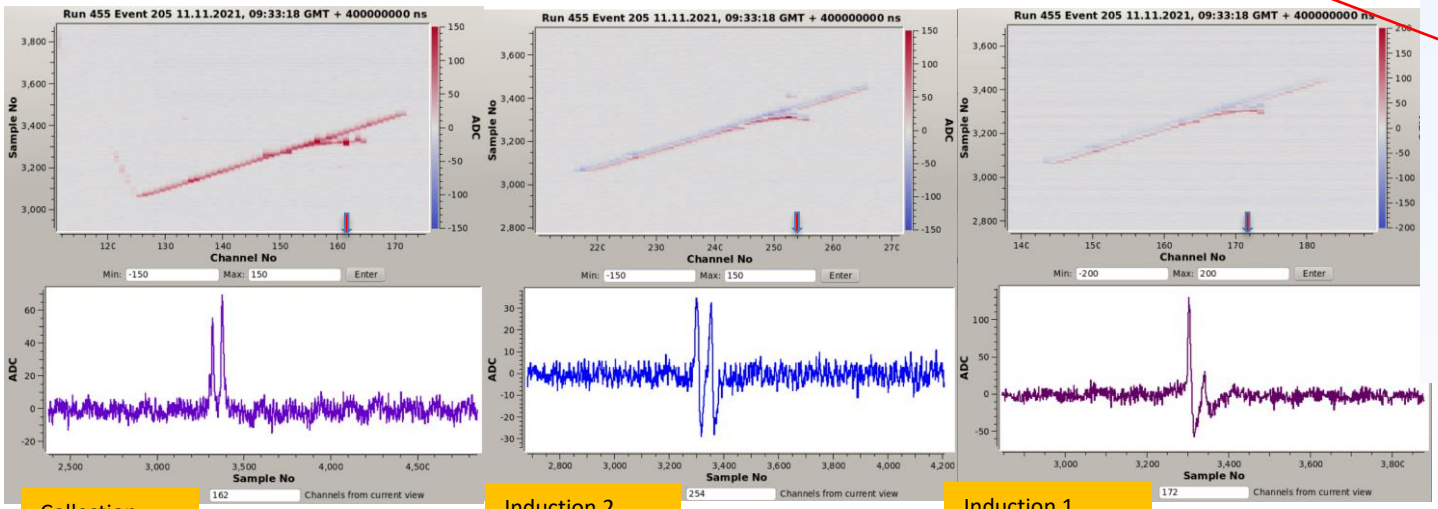


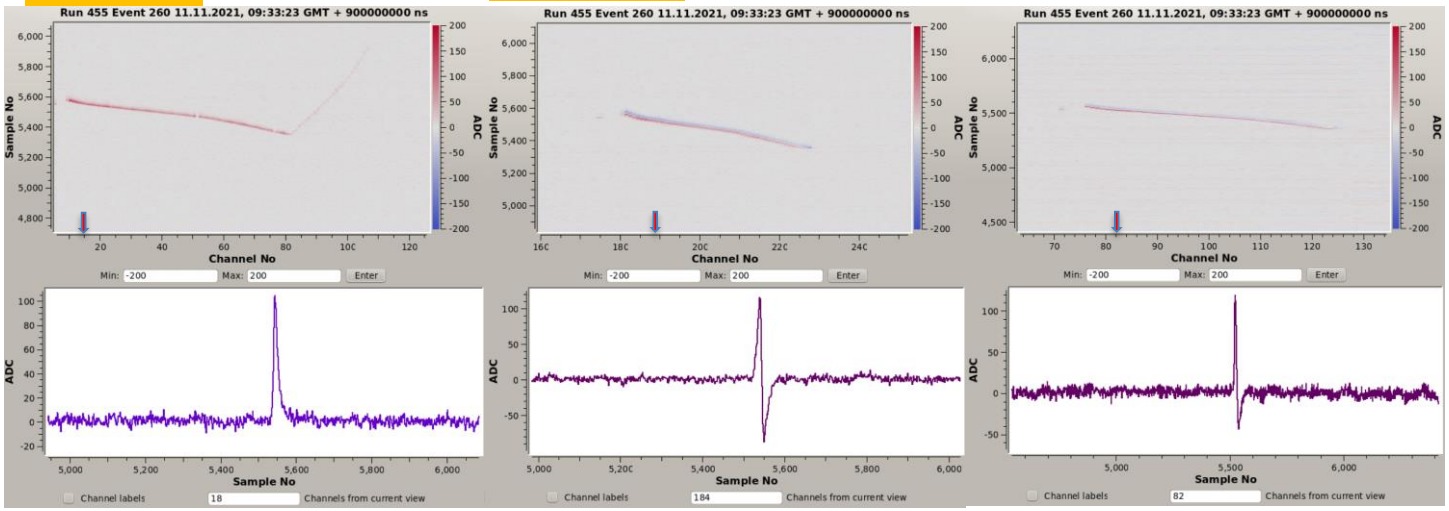
Images and channel waveforms for the 3 views

→ induction views have, as expected, bipolar signals due to the approaching and departure of the electrons

→ Last view (collection) has unipolar signals





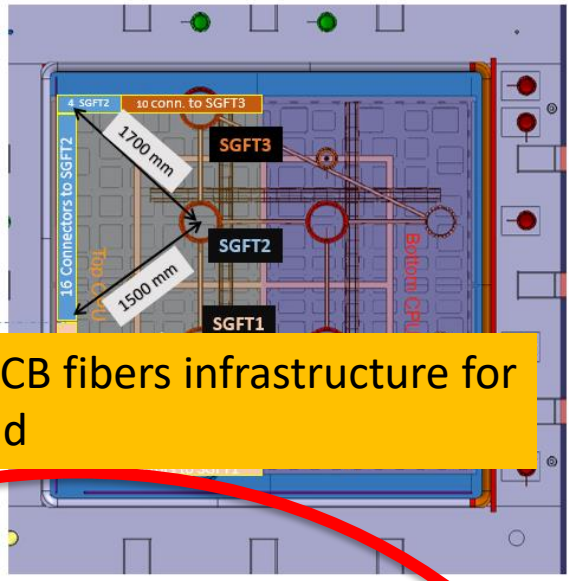


Top Drift Electronics immediately performing well since beginning of first test of CRP1 in November 2021

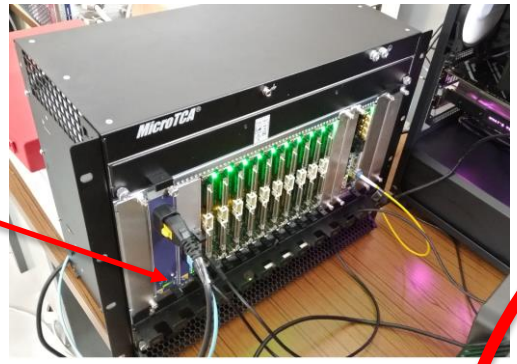
First cosmic tracks were immediately seen with TDE after detector biasing (raw data online event display, no noise removal). Large data sample collected in stable conditions

uTCA crates with MCH design with 40 Gbit connectivity

- ✓ **Joint definition of the project by the TDE team with NAT since 2018**
- ✓ **TDE first world users in April 2021 when initial units delivered**
- ✓ **Extensive tests and firmware debugging April-July 2021**

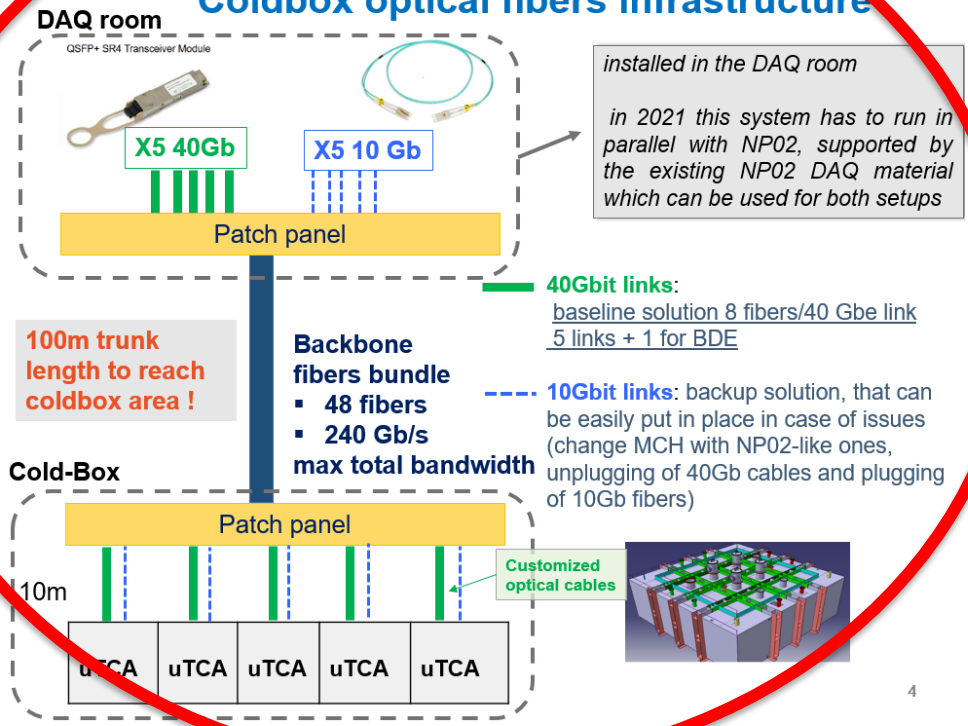


Replication of CB fibers infrastructure for NP04 test stand



- ✓ **First large scale system installed in the world for the DUNE cold-box tests (3 crates for 2021 CRP test)**
- ✓ **Dedicated fiber network infrastructure (240 Gbit/s) deployed for cold-box to support 5 crates (full top-drift CRP tests in 2022 of CRP2 and CRP3)**

Coldbox optical fibers infrastructure

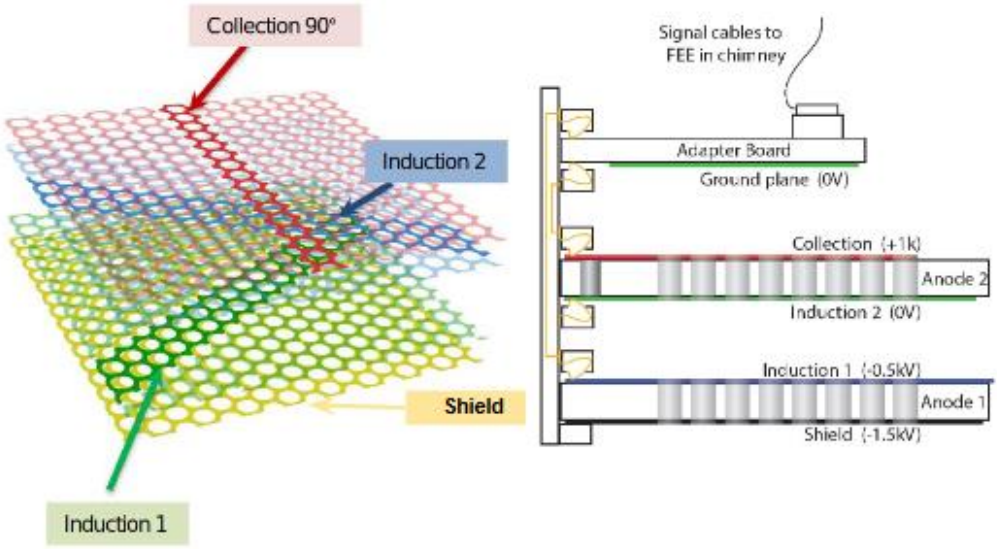


First Faraday cage version (Feb 2022)

CRP2 test in Faraday Cage June 2022

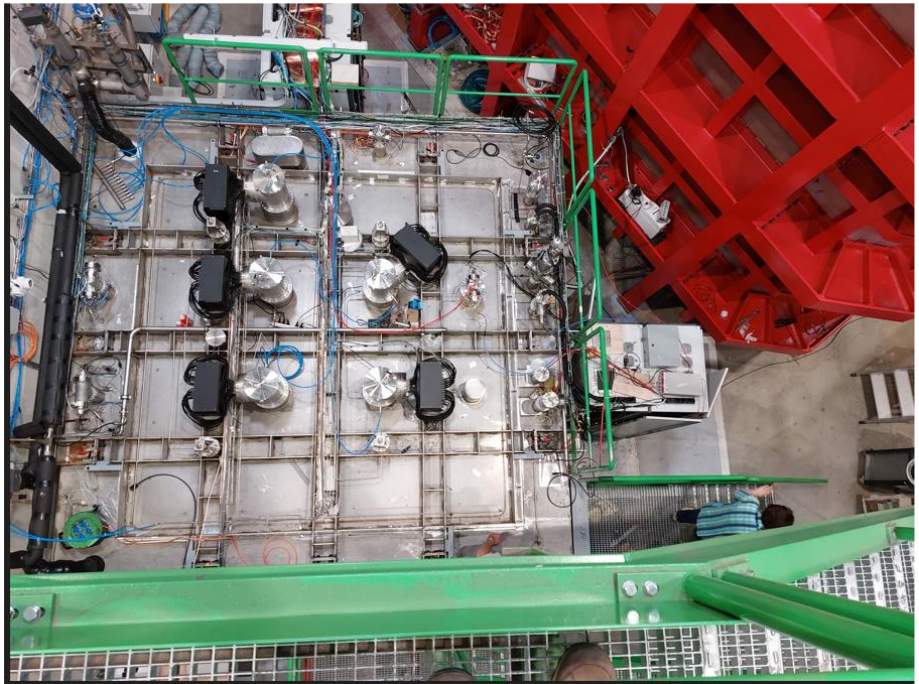
First full Vertical Drift CRP (**CRP2**) with final channels layout after optimization (3 strip layers, two induction views and one collection view at +-30° and 90°) tested in cold-box in July 2022

(→ top-drift CRP with 3072 readout channels
5 uTCA crates, 5 chimneys,
48FEBs, 48 AMCs)



Test of second top-drift CRP (**CRP3**)
Successfully completed in October!

CRP2 re-tested in cold-box in November after some improvements on a few silver-printed strips joints across PCB panels



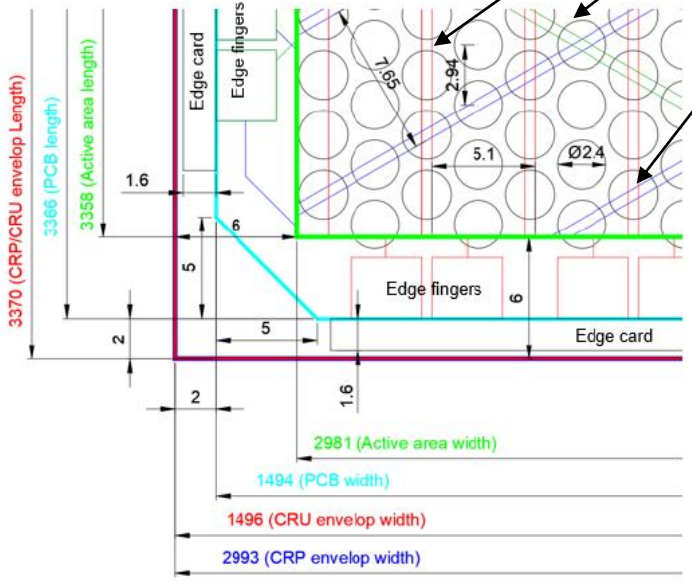
VD final CRP anodes layout

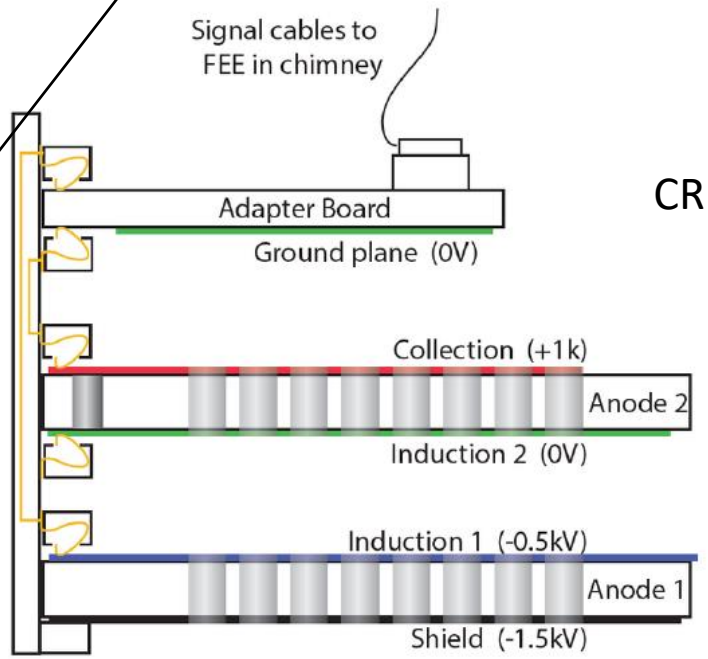
Parameter	Three-view configuration		
	Induction 1	Induction 2	Collection
Strip length [m]	up to 1.74	up to 1.74	1.68
Strip pitch [mm]	7.65	7.65	5.1
Strip gap [mm]	0.5	0.5	0.5
Unit capacitance [pF/m]	103	103	81
Total capacitance [pF]	up to 177	up to 177	135
Number of strips per CRU	476	476	584
Number of readout channels per CRP	3072		
Strip angle w.r.t. beam	30°	-30°	90°
Bias voltage [V] for a shield plane bias at -1500 V	-500	0	1000
Hole diameter [mm]	2.4	2.4	2.4
Inter-PCB gap within CRP (at room temp.) [cm]	1		

Red: Collection 5.1 mm pitch

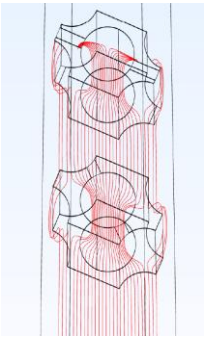
Green: Induction 2 7.65mm pitch

Blue: Induction 1 7.65mm pitch

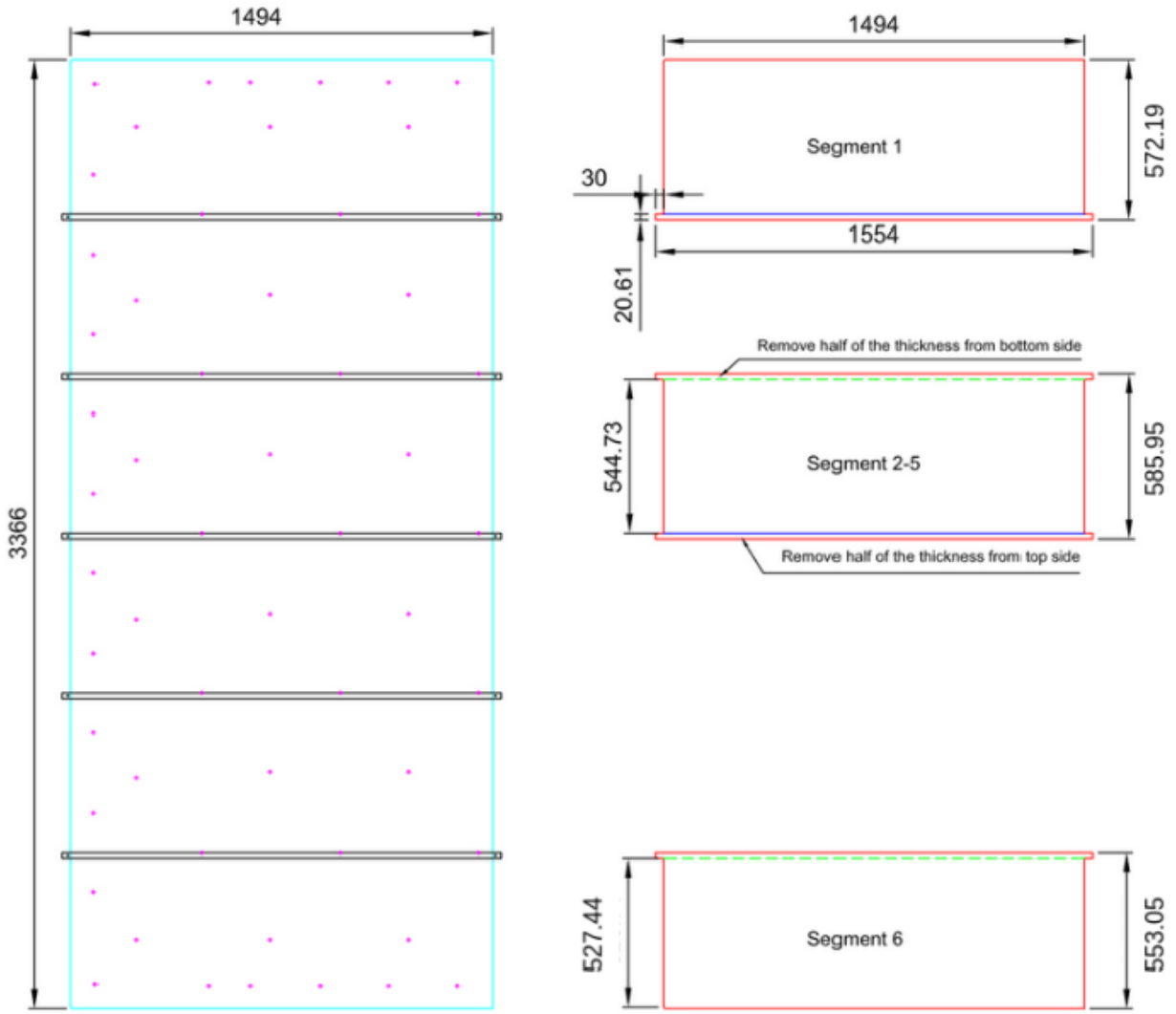


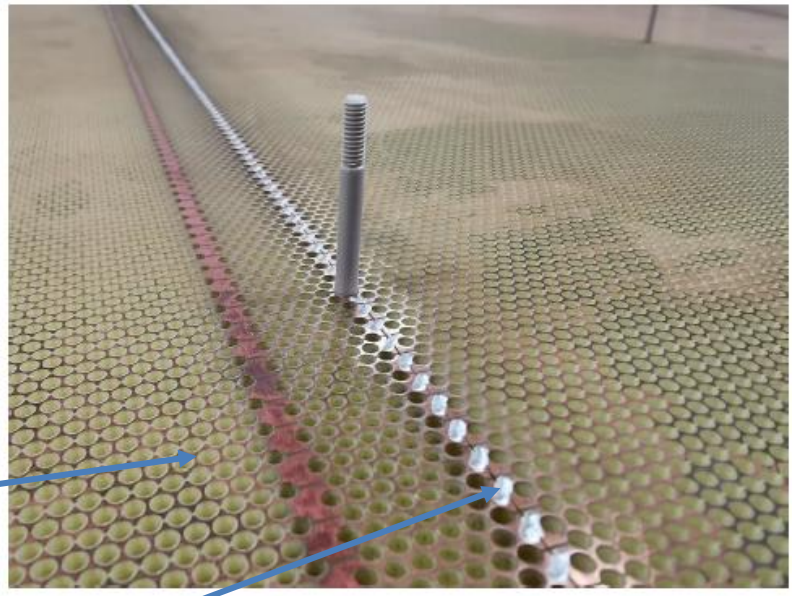


CRP Side view



Perforated PCB panel assembly

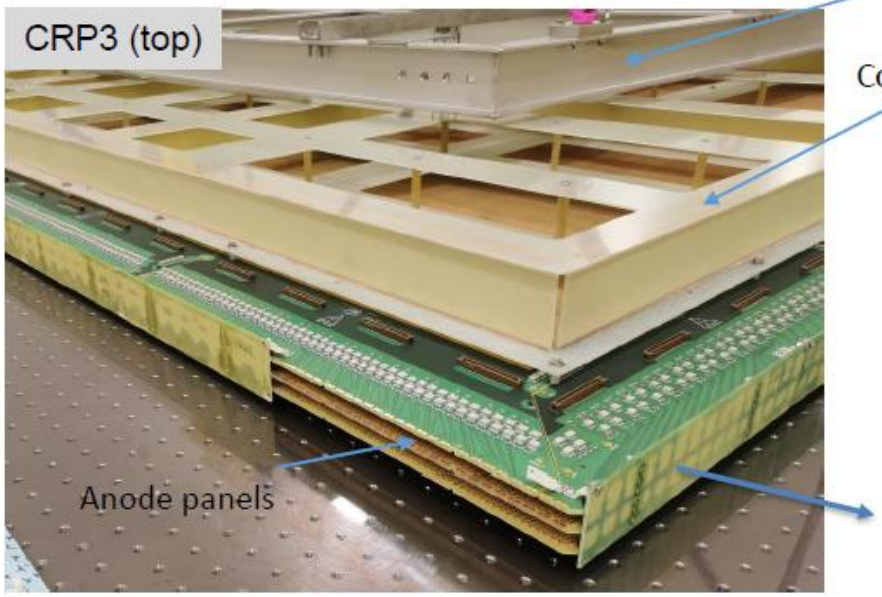




Silver printed PCB joints

- Assembly of perforated anode PCB panels

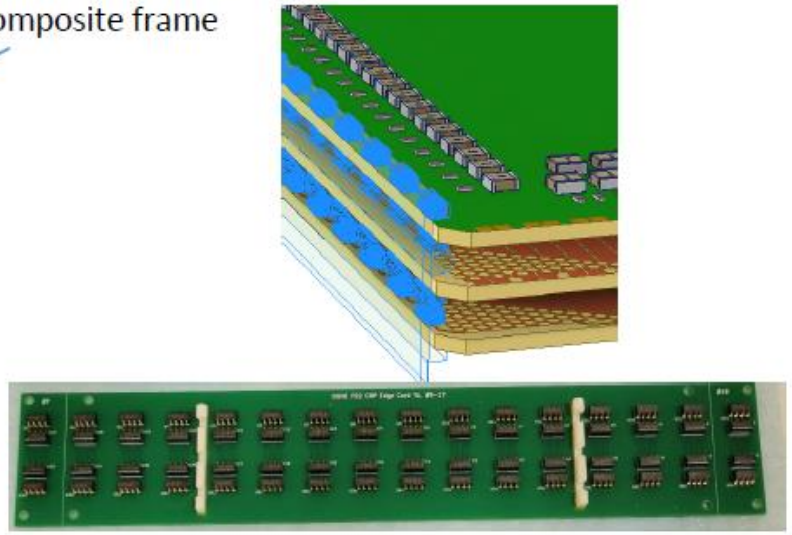
- Two perforated anodes stack integrated with composite frame in CRP structure



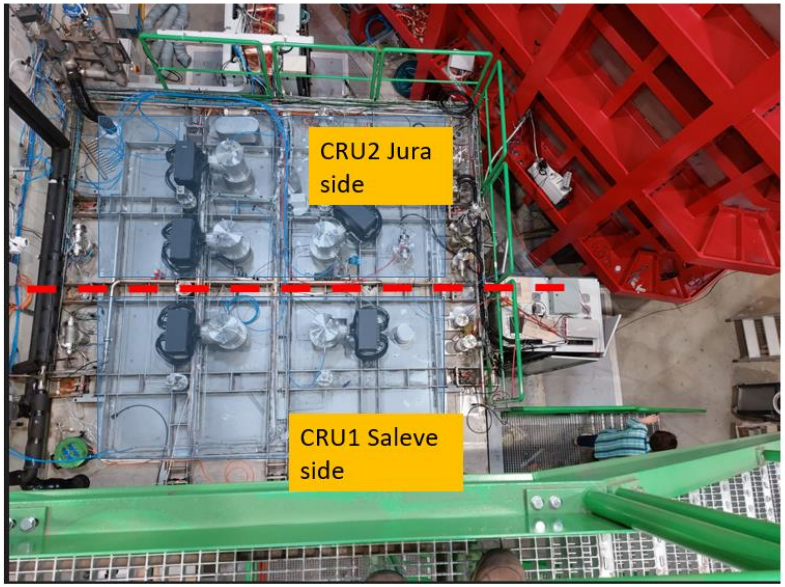
Metallic frame

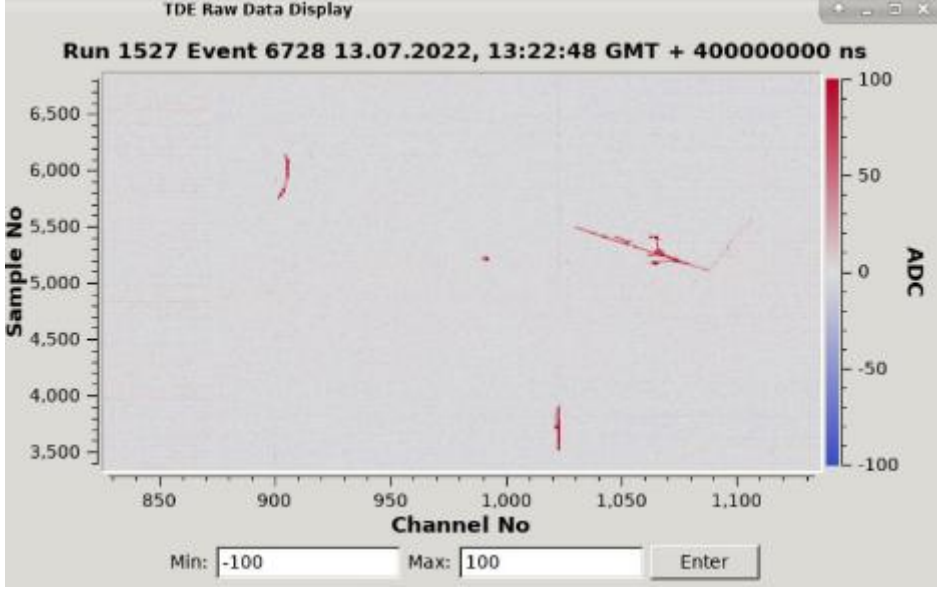
Composite frame

Edge board connectors:

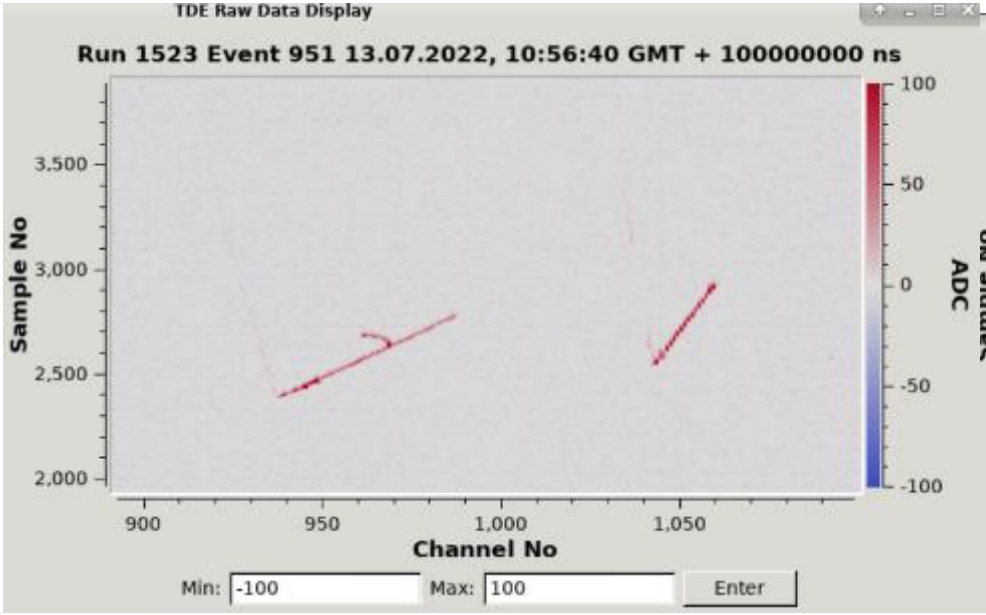


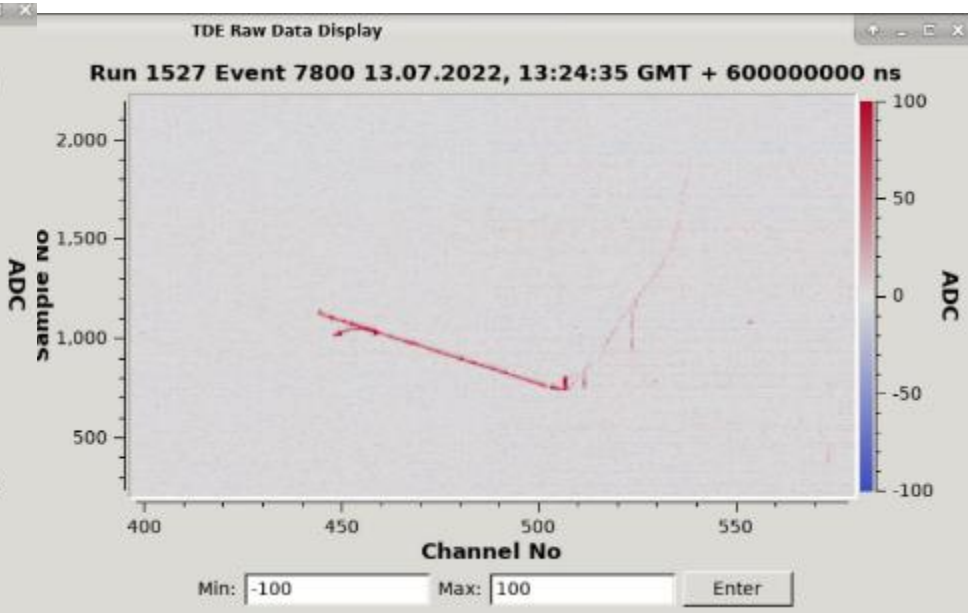
Top view of the cold box roof for CRP2 TDE readout
(5 chimneys/uTCA crates)



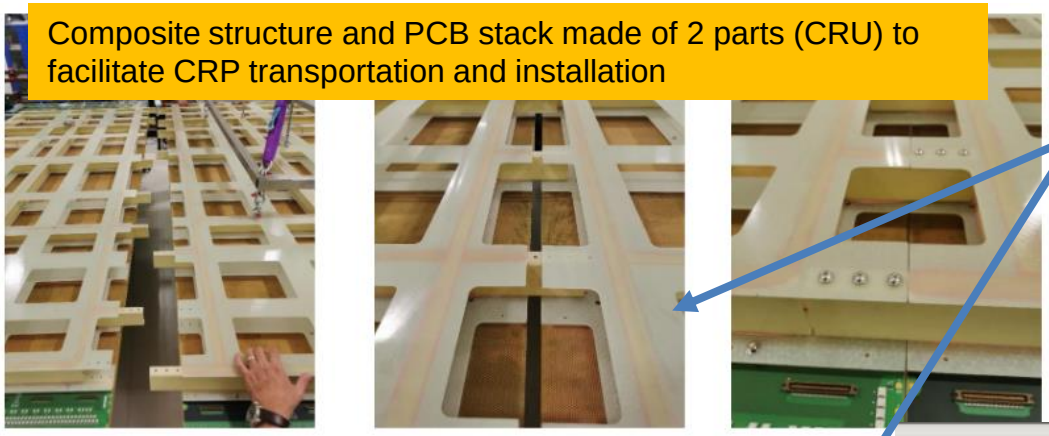


CRP2 cosmic ray events





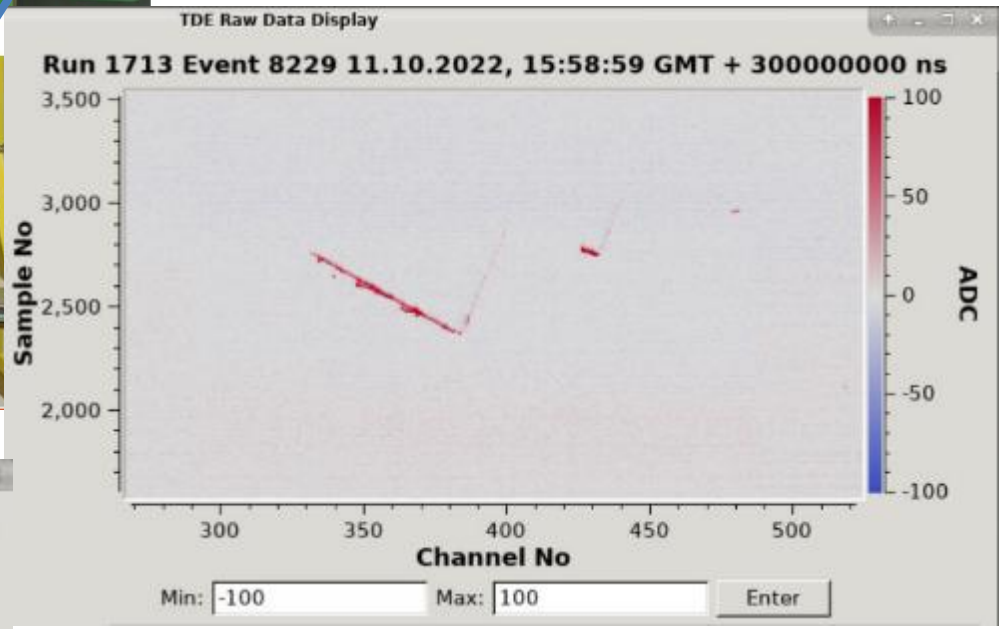
Composite structure and PCB stack made of 2 parts (CRU) to facilitate CRP transportation and installation

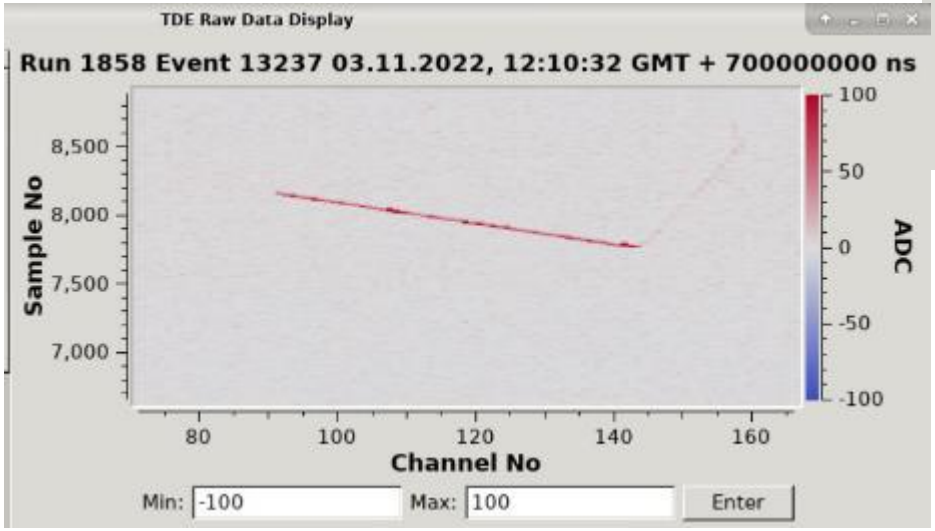


CRP3 (second DUNE full top-drift CRP) assembly of optimized lighter composite frame structure

CRP3 cosmic ray tracks, October 2022

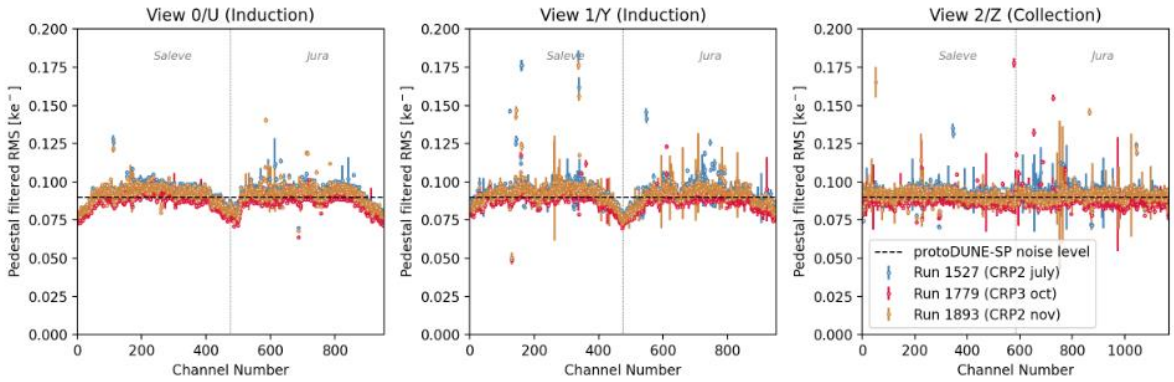
Fully assembled CRP3



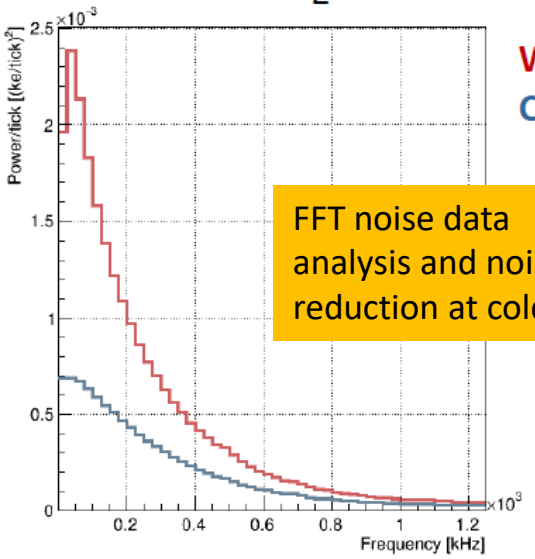


CRP2 second test (November 2022)

Reliable and stable operation during the full CRP Cold-Box runs with good noise performance



Z

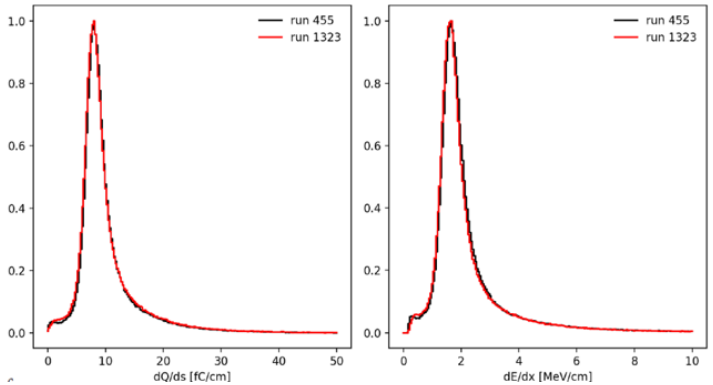


FFT noise data analysis and noise reduction at cold

Calorimetry through time

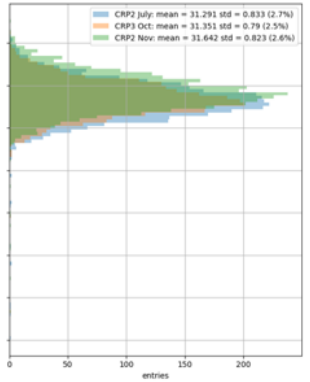
- dQ/ds corrected from impurity losses
- E_{drift} June estimated at ~450 V/cm

-> No changes with to November runs



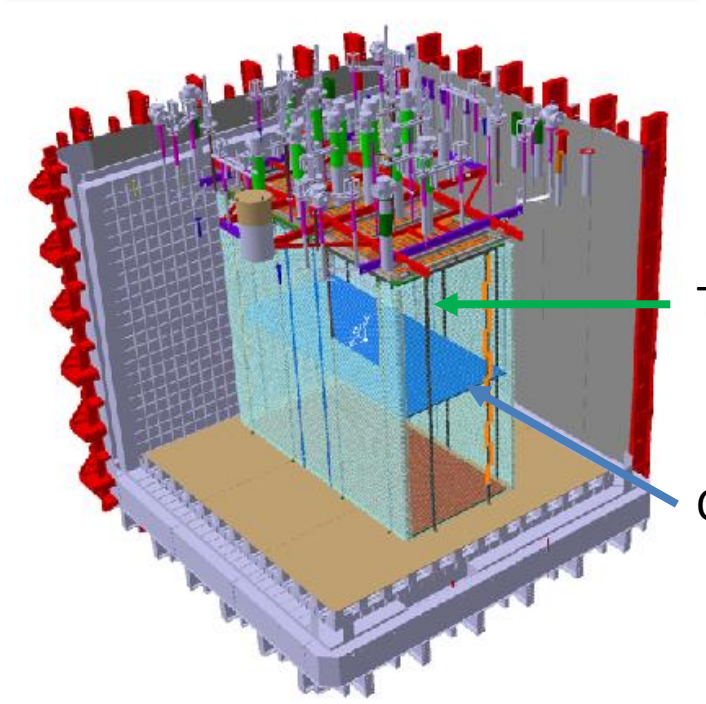
Stability of dE/dx response studied on **CRP1** October2021-June 2022

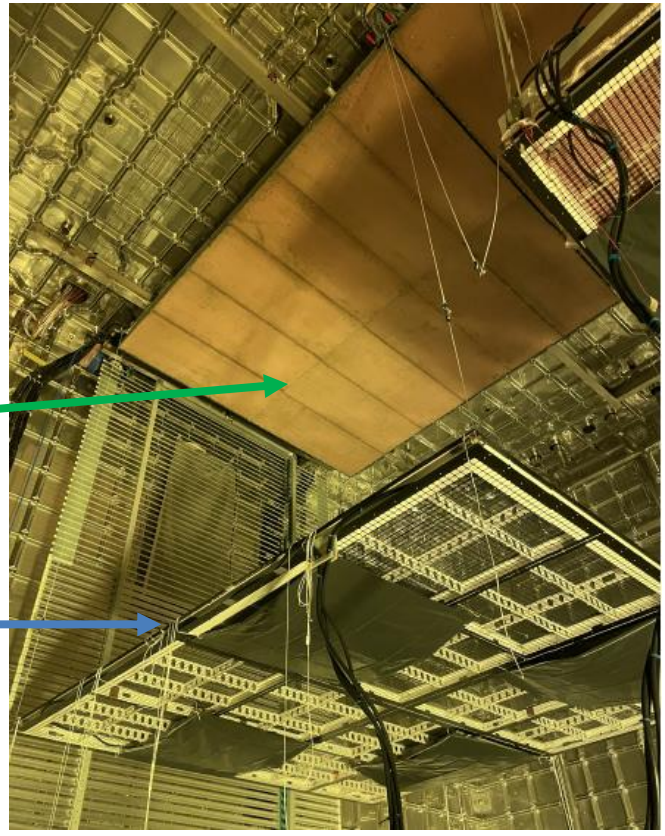
- Large cosmic data samples (~M events per test) collected in stable operation. Systematic investigation of external coherent noise sources (PD, instrumentation)
- Remarkable reproducibility of calibration data taken for CRP2/3/2 (1%) with 2.5% response spread among different channels
- Signals reproducibility confirmed in physical response to cosmic tracks (dQ/dx) from offline analysis of CRP data



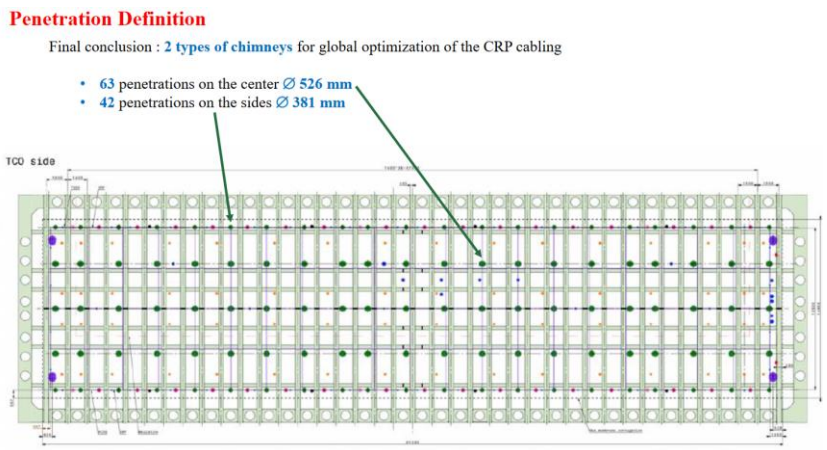
Module-0

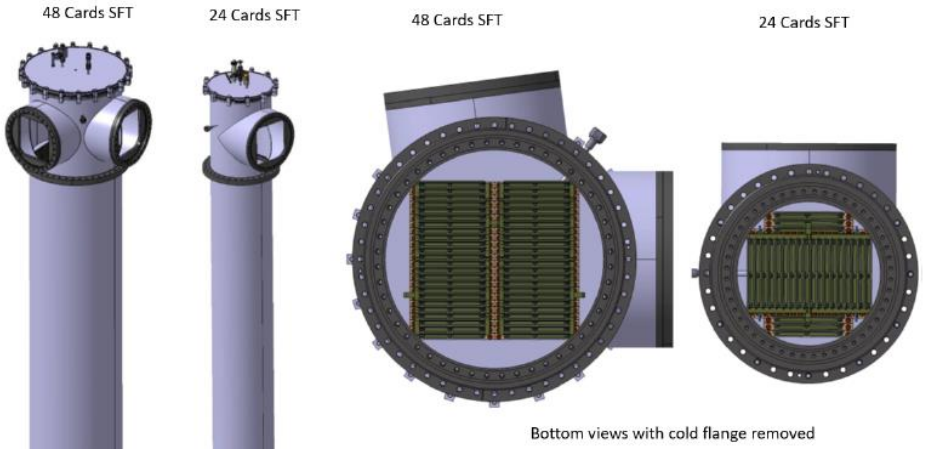
- Two final top-drift CRPs (CRP2 and CRP3) + TDE readout testing completed by October in Cold-Box
- 6144 readout channels (96 front-end and AMC boards)
- Use of existing NP02 10 cards chimneys (10 cards) → 10 uTCA crates with 10 cards each
- Very high bandwidth readout system 400 Gbit/s network infrastructure
- Module-0 integration of top-drift CRPs completed at the beginning of 2023
- Overall Module-0 integration under completion by May

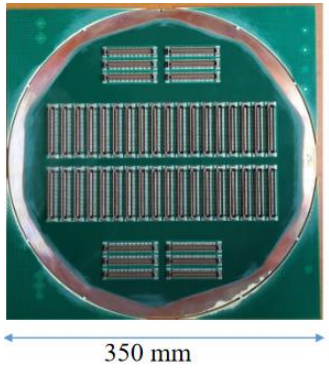




Large Chimneys for FD2 (parralel testing path to cold-box and Module-0)







- Large progress on prototyping activities for 24 cards SFT and flanges
- Progress on thermal simulations and design optimization
- Testing program of 24 chimneys prototype in parallel to Module-0 in 2023 (NP02 cryostat roof has already 10 cards chimneys)
- Production and test of 48 cards prototype foreseen as well in 2023

Conclusions:

- Development program on Vertical Drift top-drift readout associated to Task 9.3 maintained well on schedule with the CRP+TDE cold-box tests campaign performed at the CERN Neutrino platform in 2022.

- CRPs integration successfully achieved in Module-0 in the NP02 (formely used for the dual-phase configuration) cryostat.

- Excellent results achieved on all aspects involved in the Task 9.3 program.

Thanks