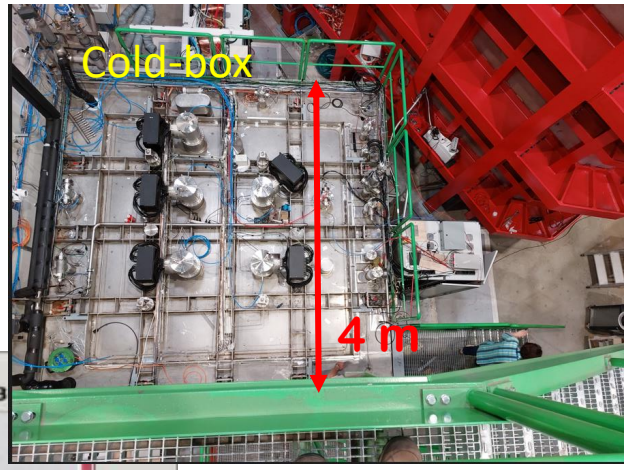
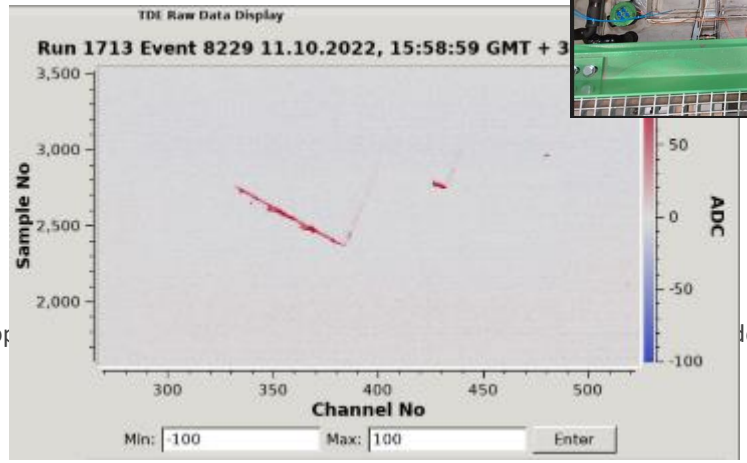
Task 9.3
Vertical Drift Charge Readout

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

AIDAInnova 3nd Annual meeting 20/3/2024

D. Autiero (CNRS-IP2I Lyon)

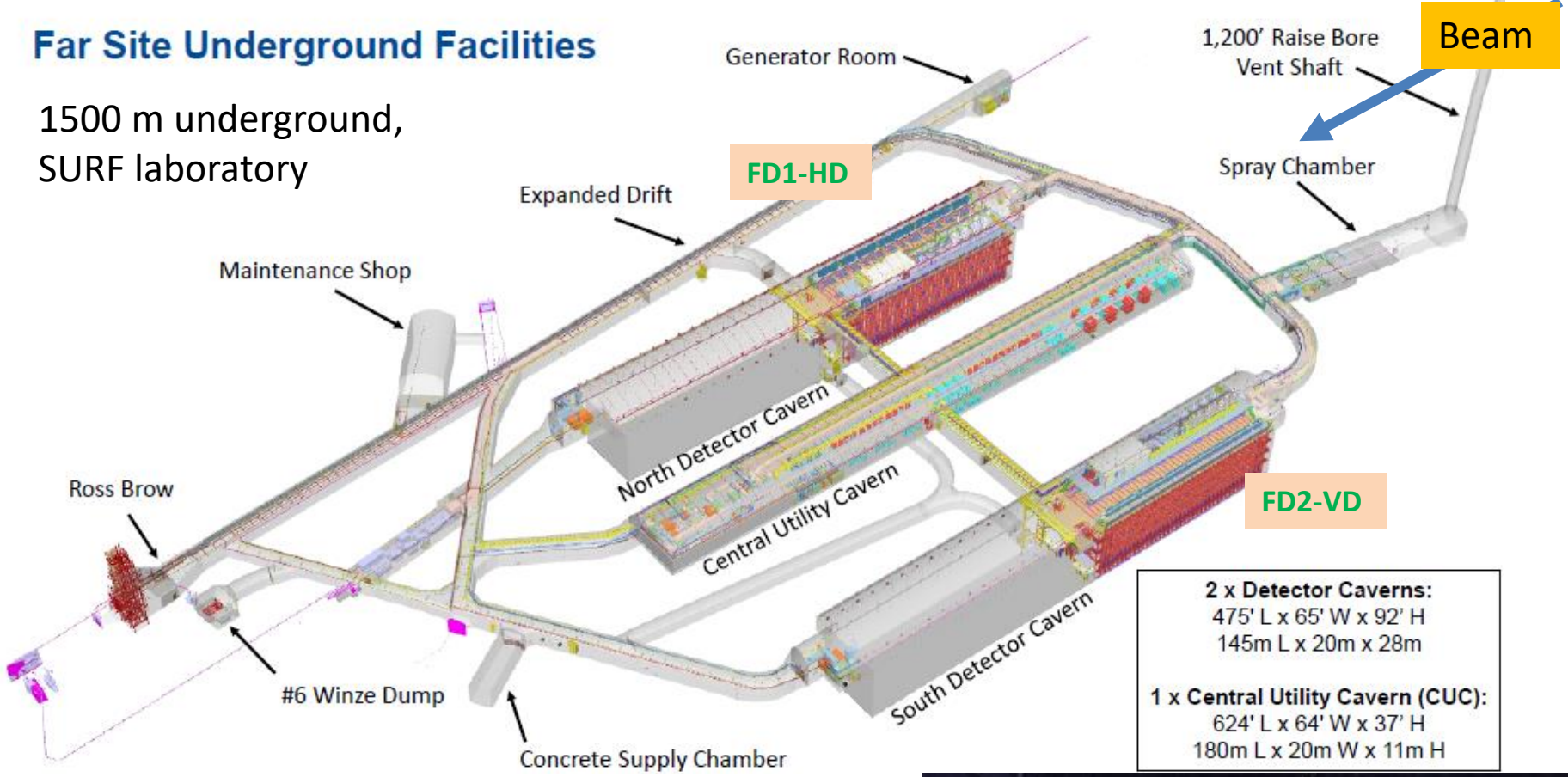




This project has received funding from the Europ ...der grant agreement No 101004761.

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**

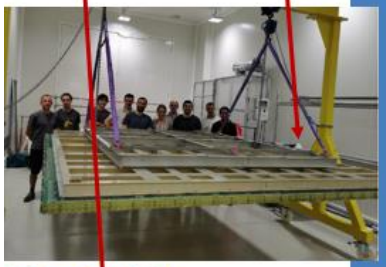
January 2024:
Excavation of underground infrastructure completed !

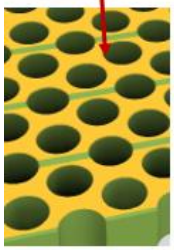
2nd DUNE Far Detector Module (**FD2-VD**) : ~15 kton of active LAr

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

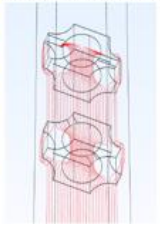
Top and bottom anode charge readout surfaces:

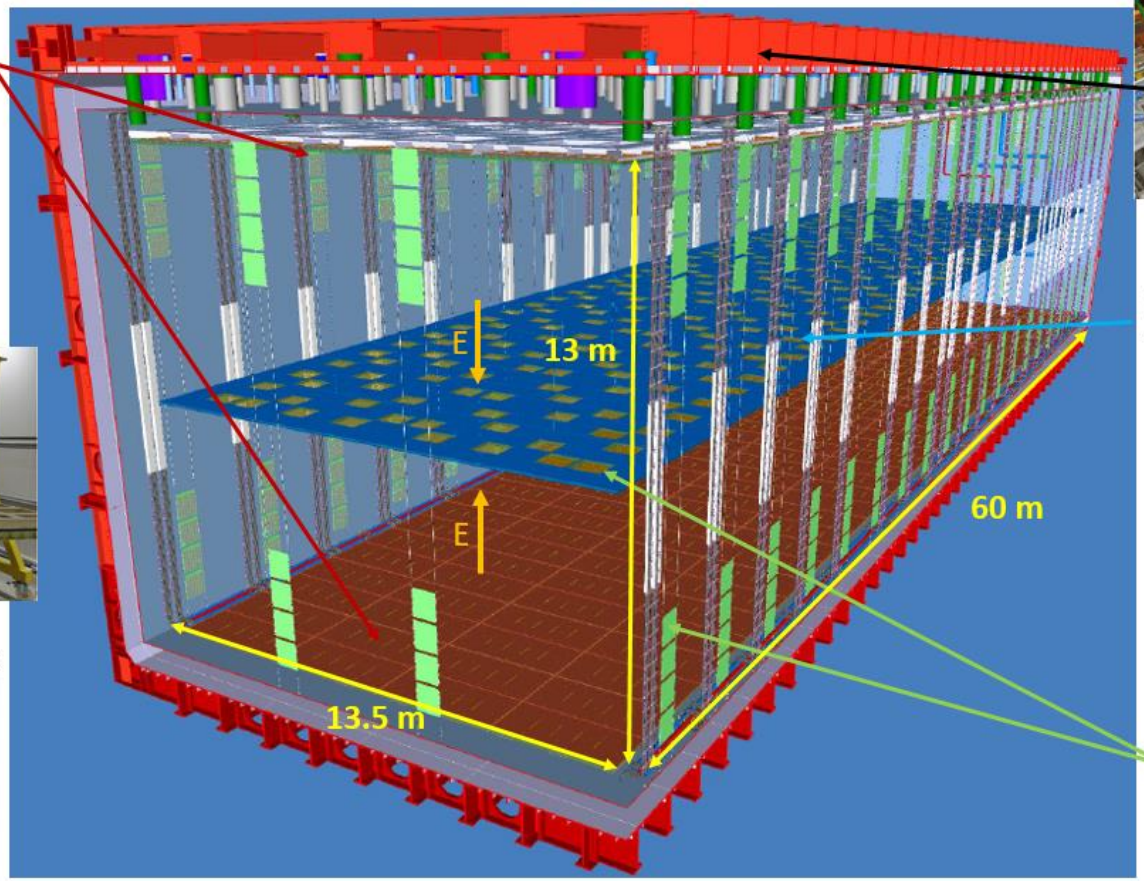
Made of 80+80 Charge Readout Plane units
3x3.375 m^2
Each unit: 2 stacked layers of segmented perforated PCBs





Strips 5 mm
Holes 2.4 mm





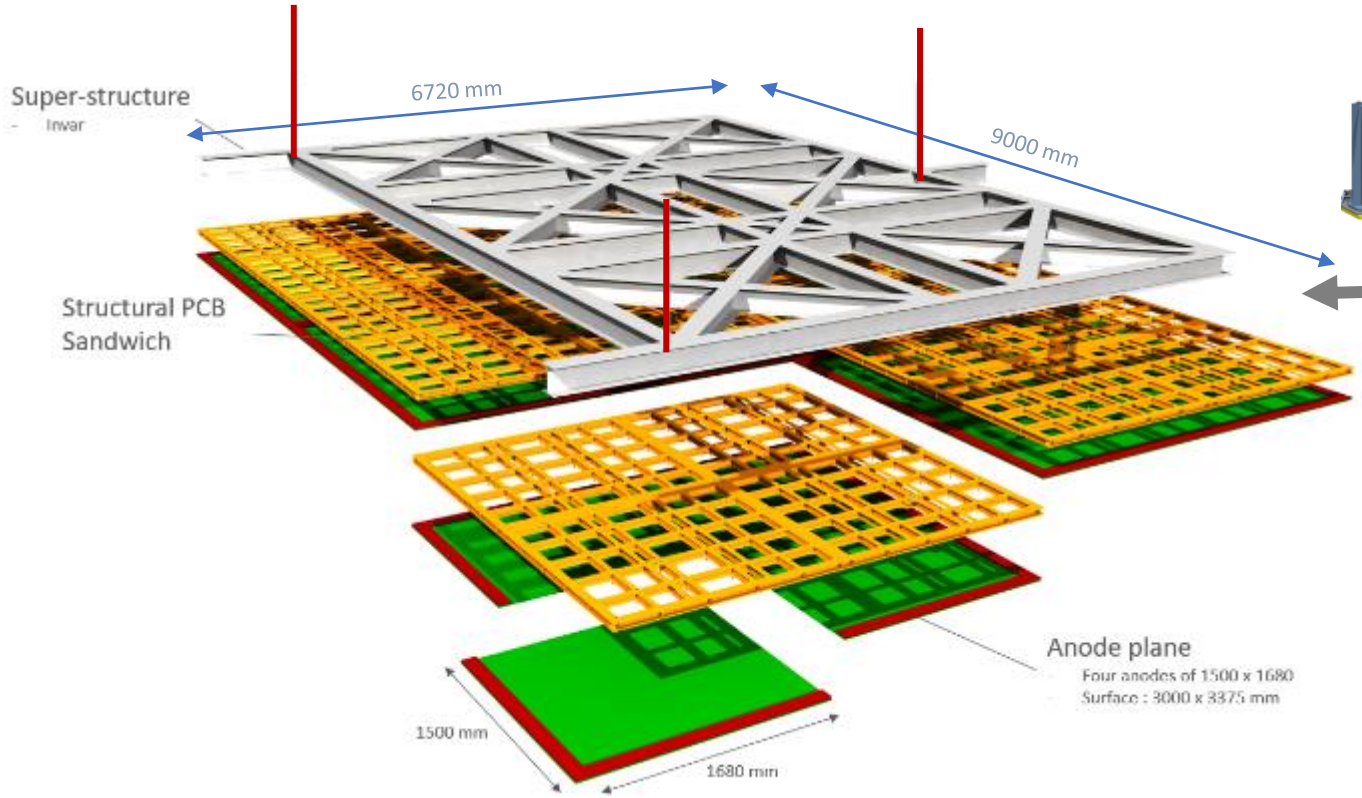
μTCA charge readout

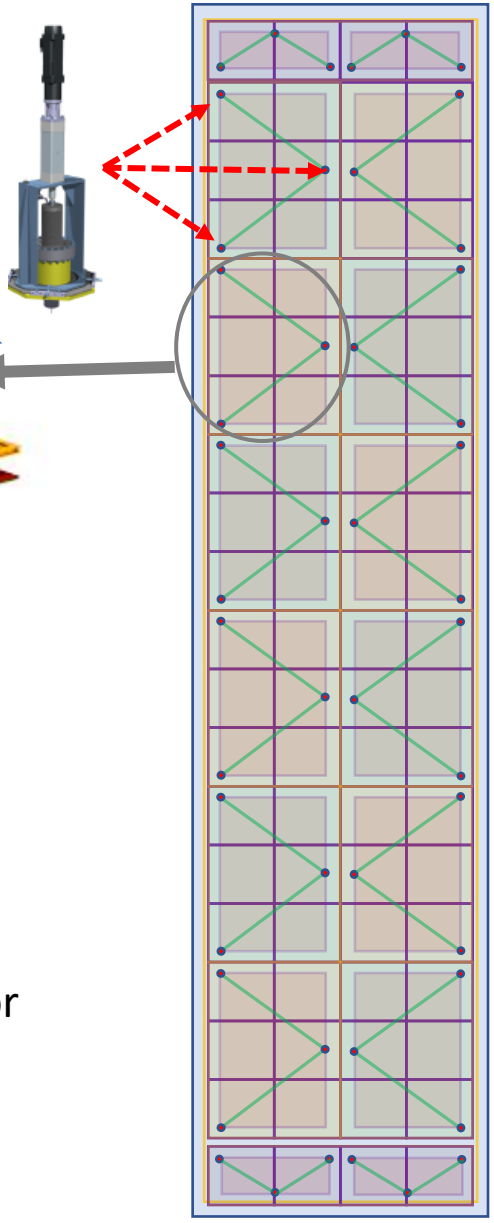
Cathode surface at -300 kV
→ E~500V/cm

1/40
Prototype in
NP02 cryostat
Module-0

UV photon detectors on cathode and cryostat walls

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

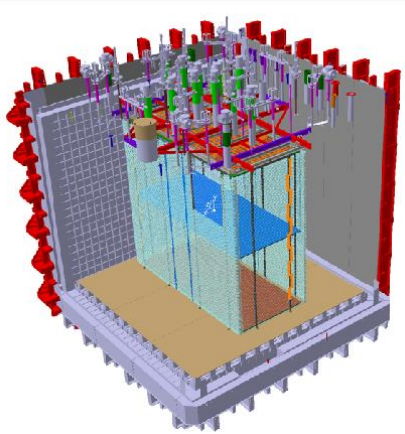
Task 9.3 focusing on top-drift readout

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 (full LAr TPC 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
- VD HV test at 300 kV in second NP02 run in 2022 with 6m long drift tracks
- Installation of top drift CRPs in NP02 cryostat (Module-0) at the end of 2022
- Completion of Module-0 integration in spring 2023
- FD2 TDR approved in 2023 (https://arxiv.org/a
- FD MOU Signed in November 2023
- Production activities set to start in 2024

→ R&D program completed 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)

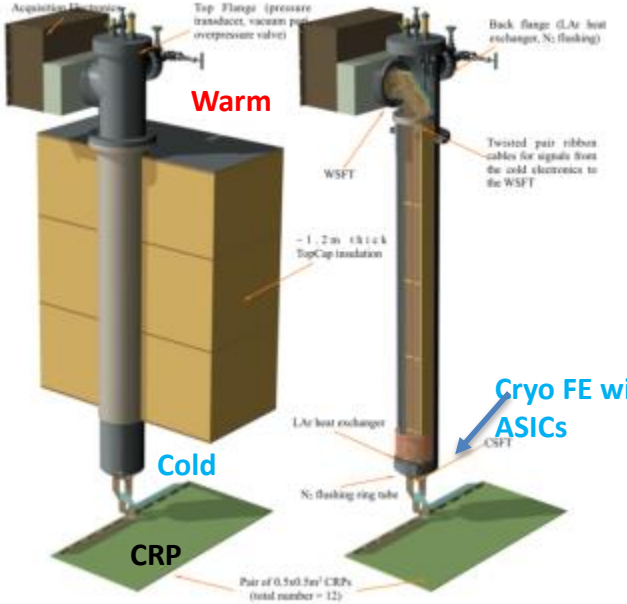
- Top drift CRPs readout based on completely accessible
- electronics:

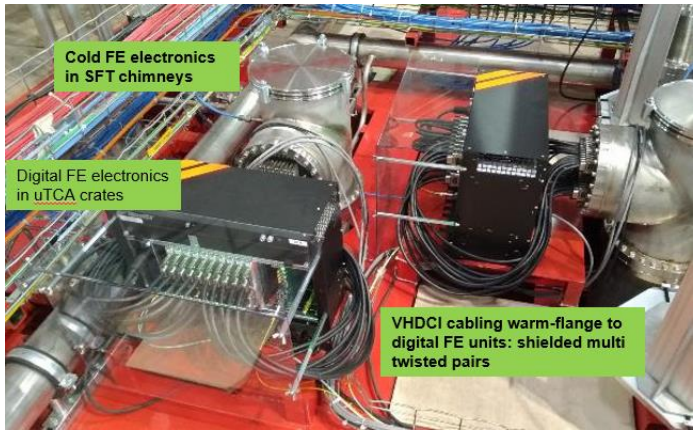
- Top Drift Electronics subsystems:

➢ **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





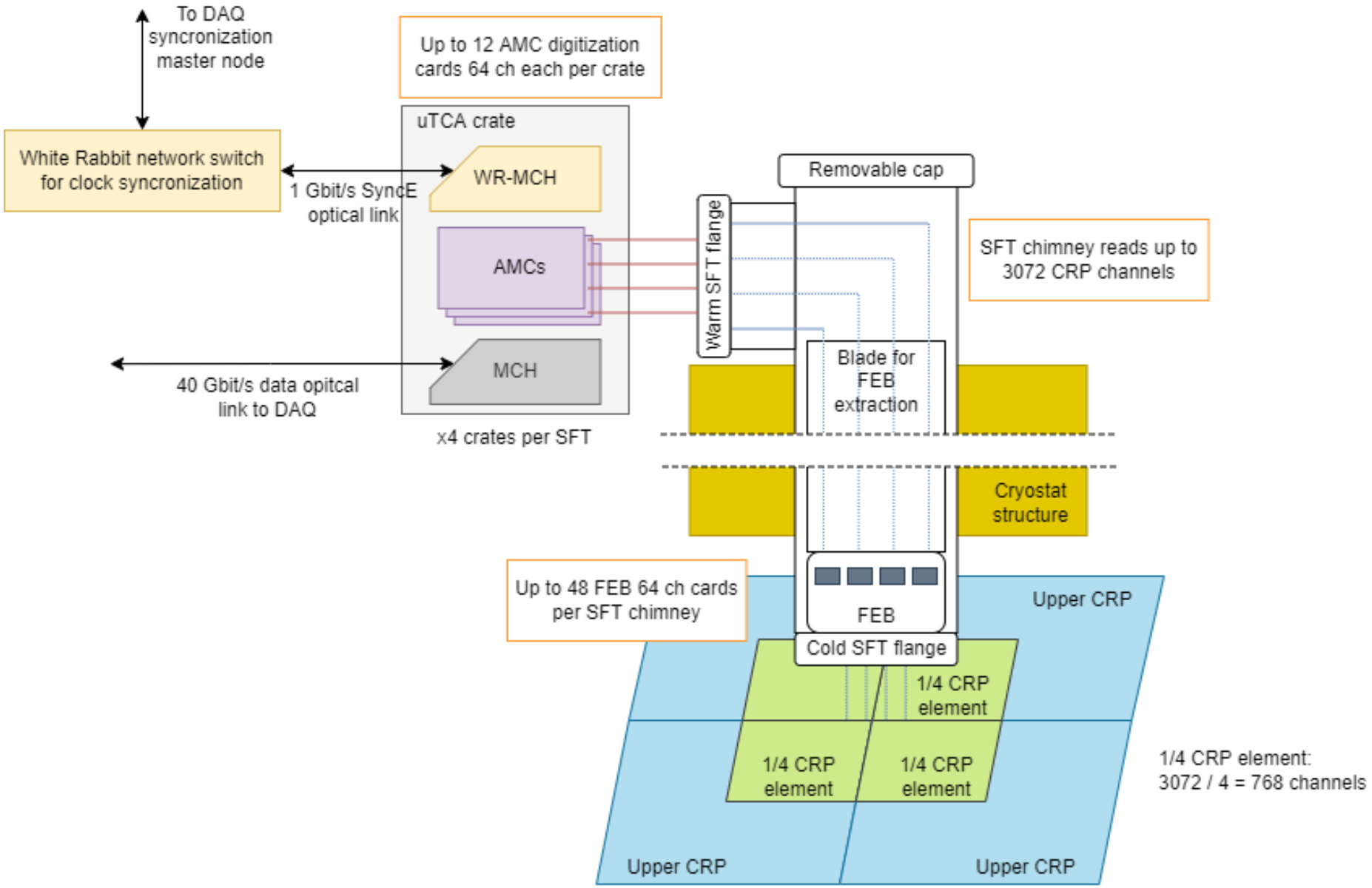
→ Adaptations and developments performed in 2021 from DP version for the Vertical Drift:

➢ 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



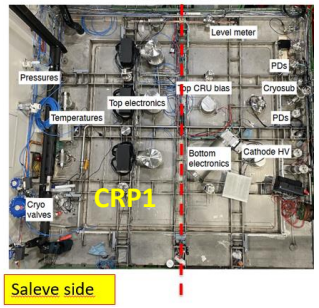
Timeline of Top-Drift/TDE activities and achieved milestones

CDR Review
Jun 21

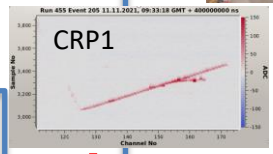
TDE components preparation
Jan-Jun 21

TDE Integration test Jul-Sep 21

Evolution from DP Design, Proposal
Sep-Dec 20

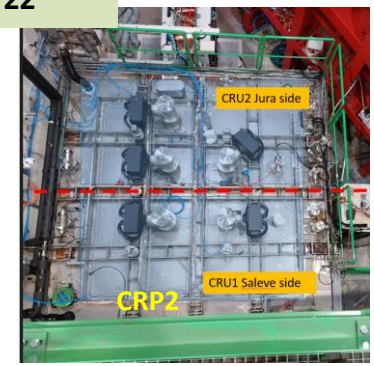


CRP1 test
Nov 21



CRP1 test
Dec 21

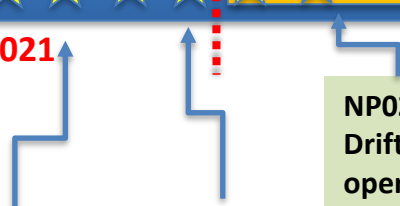
Faraday cage 1&2
Test, preparation CRP2/3
Module-0 Jan.-May 22

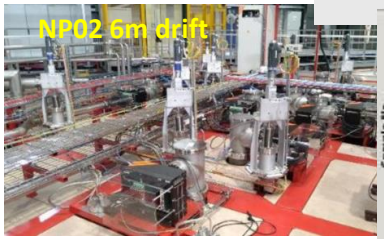


PDR Review
May 22

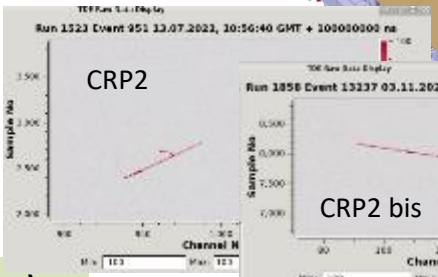
CRP1b test
May-Jun 22

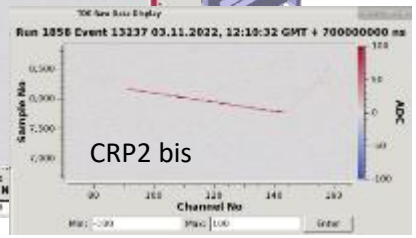
NP02 6m Drift operation
Feb 22



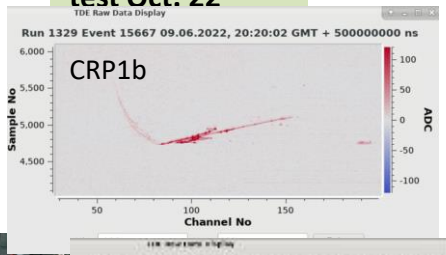


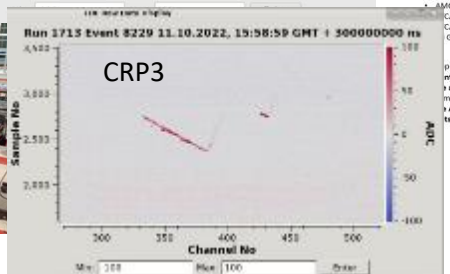
CRP2 (full-top) test Jul 22





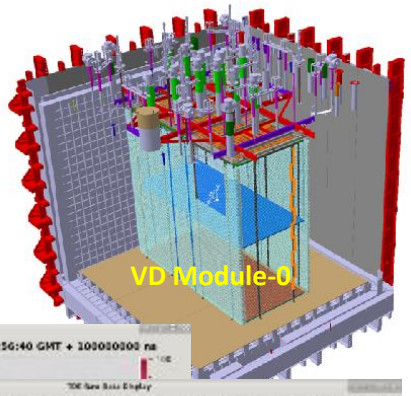
CRP3
test Oct. 22



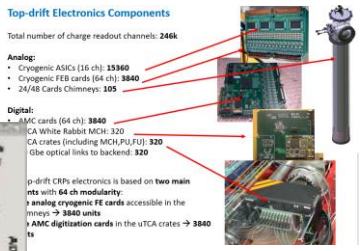


CRP2 (full-top) Re-test Nov 22

VD Module-0
Fall 22-Fall 23



TDE FD2 production
End 23-Summer 26



2021

2022

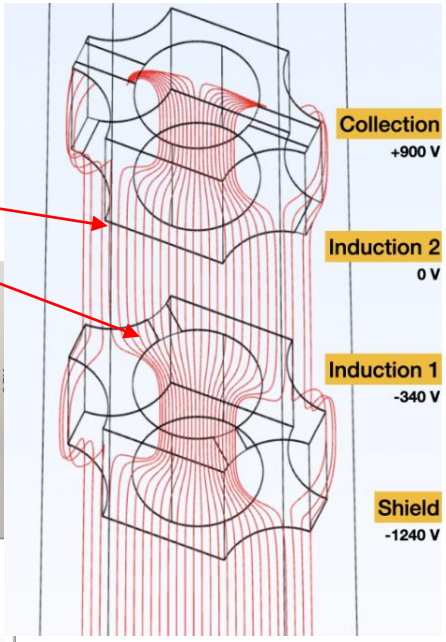
2023

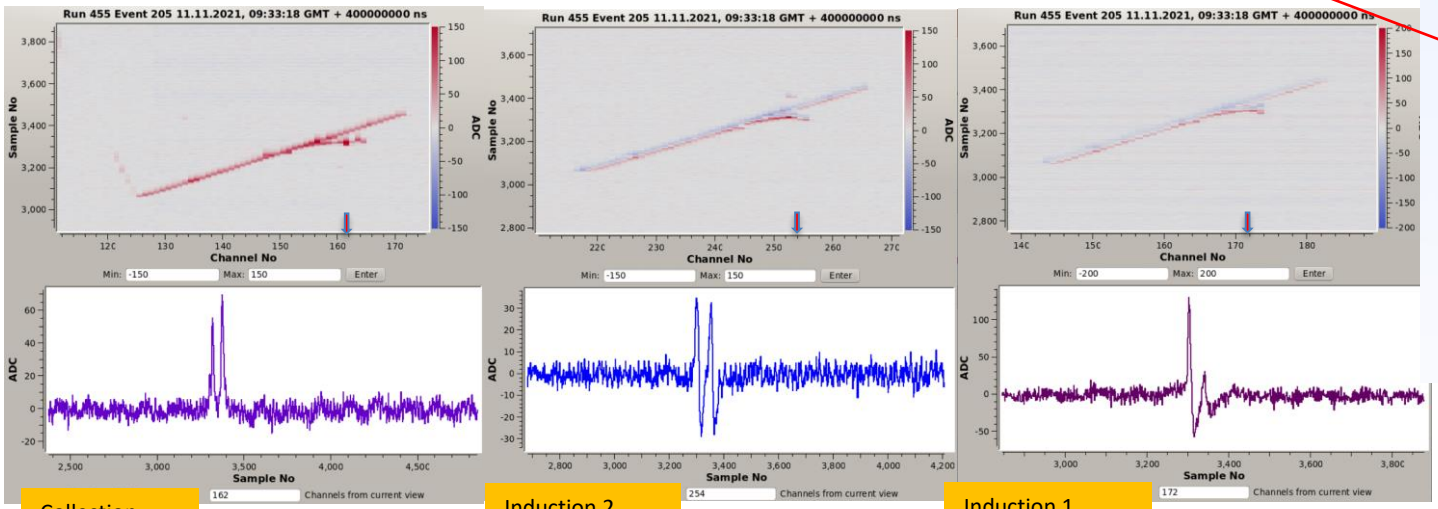
2023-…

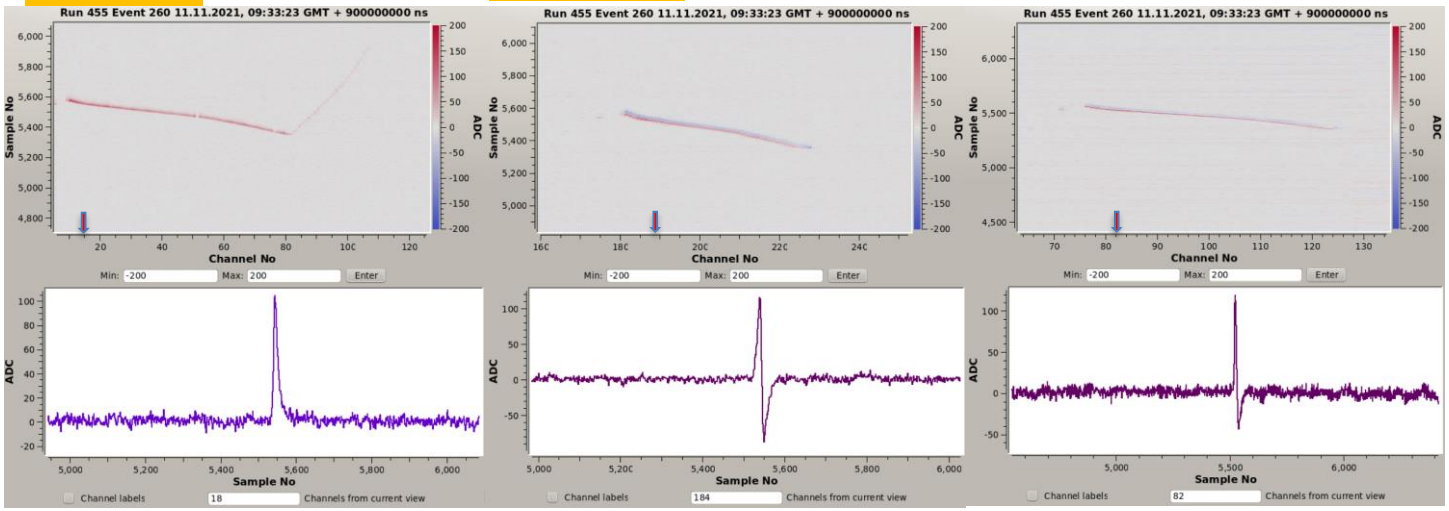
Images and channel waveforms for the 3 views

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

→ Last view (collection) has unipolar signals





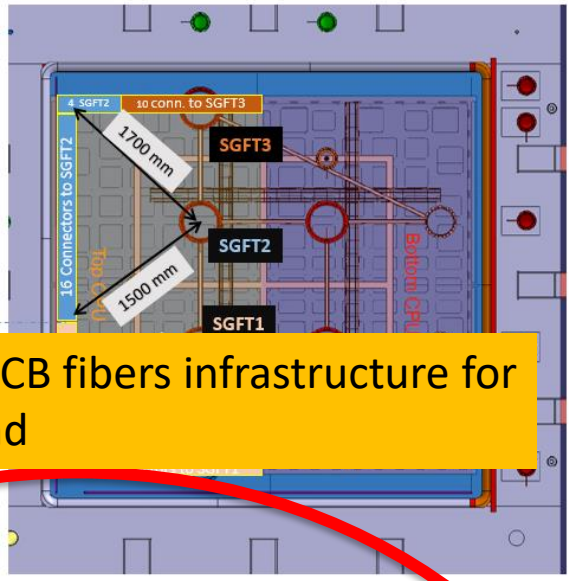


Top Drift Electronics immediately performing well since beginning of first test of CRP1 in November 2021

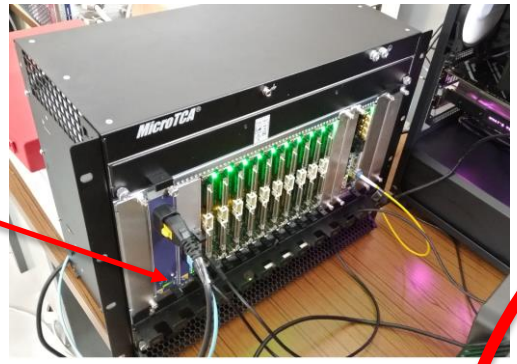
First cosmic tracks were immediately seen with TDE after detector biasing (raw data online event display, no noise removal). Large data sample collected in stable conditions

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**

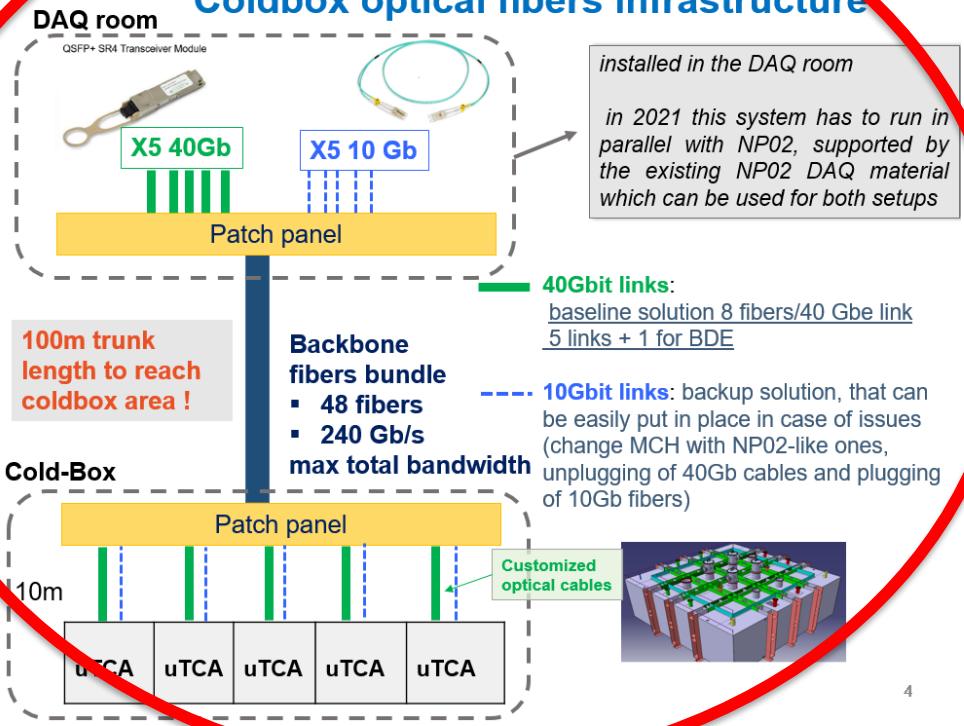


Replication of CB fibers infrastructure for NP04 test stand



- ✓ **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

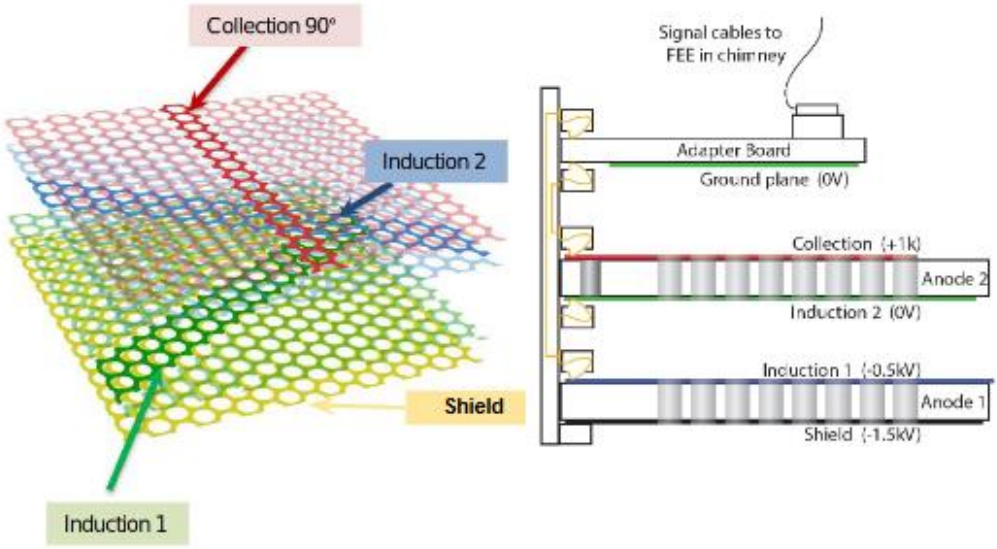


First Faraday cage version
(Feb 2022)

CRP2 test in Faraday Cage
June 2022

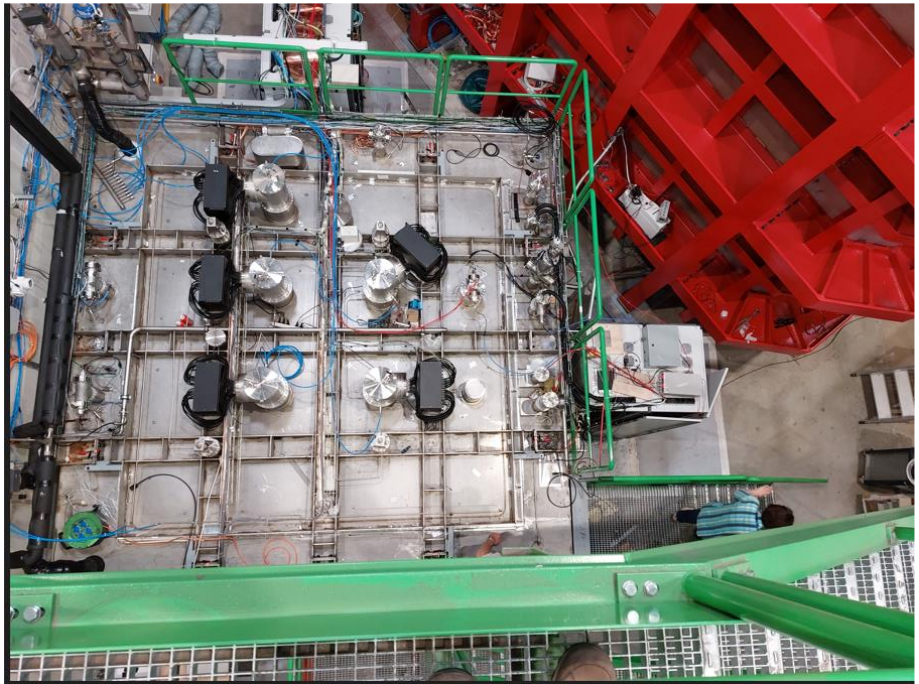
First full Vertical Drift CRP (**CRP2**) with <u>final channels layout after optimization</u> (3 strip layers, two induction views and one collection view at +-30° and 90°) tested in cold-box in July 2022

(→ 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



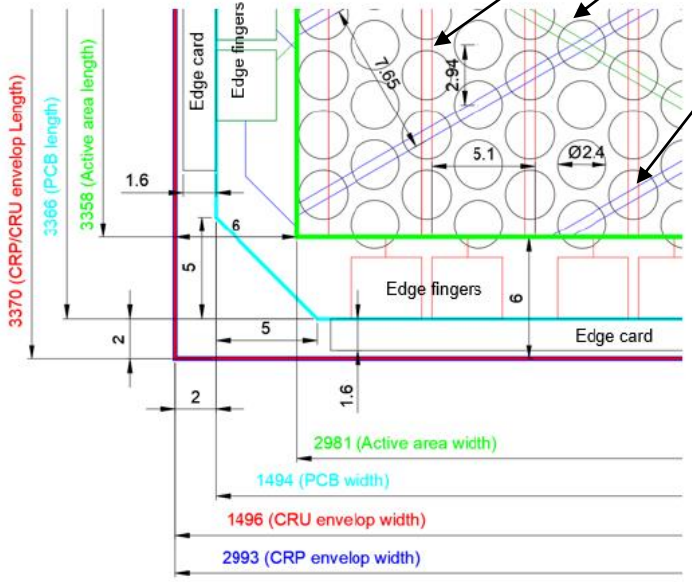
VD final CRP anodes layout

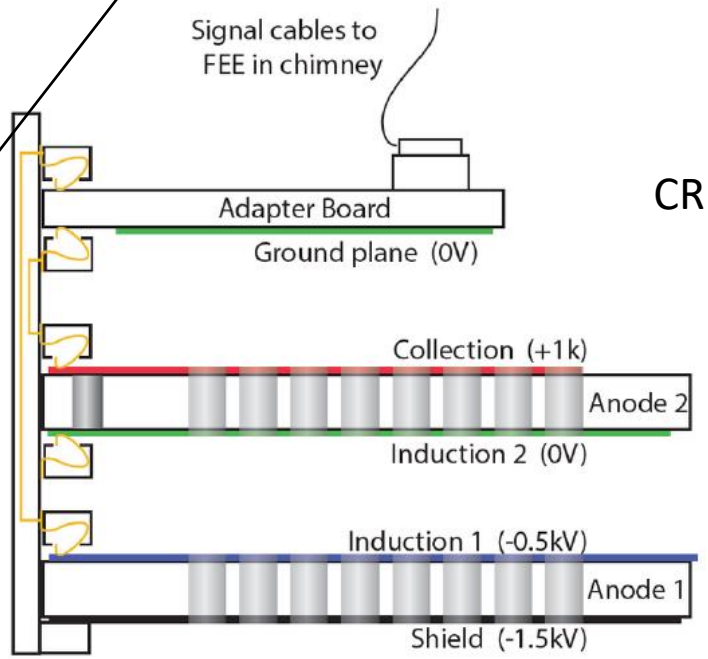
Parameter	Three-view configuration		
	Induction 1	Induction 2	Collection
Strip length [m]	up to 1.74	up to 1.74	1.68
Strip pitch [mm]	7.65	7.65	5.1
Strip gap [mm]	0.5	0.5	0.5
Unit capacitance [pF/m]	103	103	81
Total capacitance [pF]	up to 177	up to 177	135
Number of strips per CRU	476	476	584
Number 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

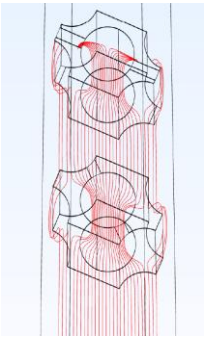
Green: Induction 2 7.65mm pitch

Blue: Induction 1 7.65mm pitch

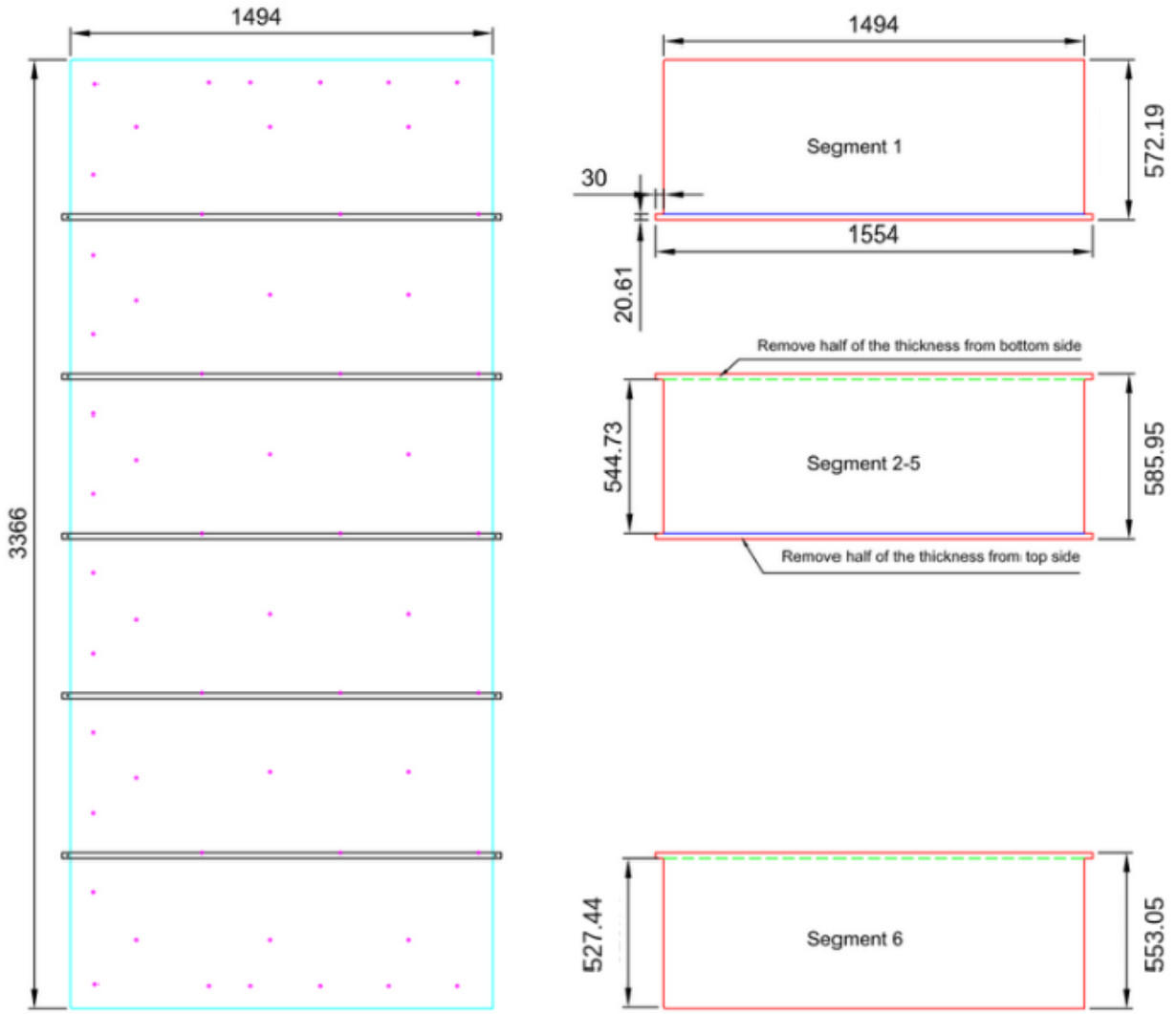


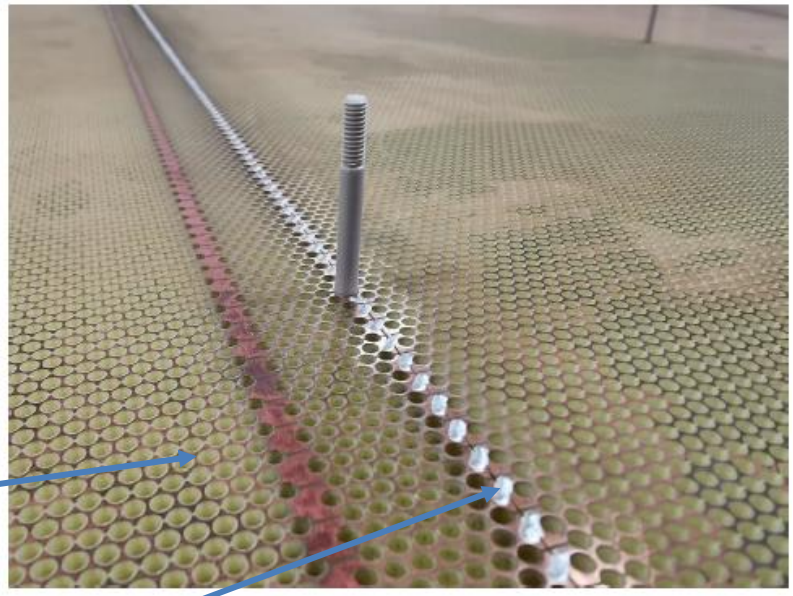


CRP Side view



Perforated PCB panel assembly

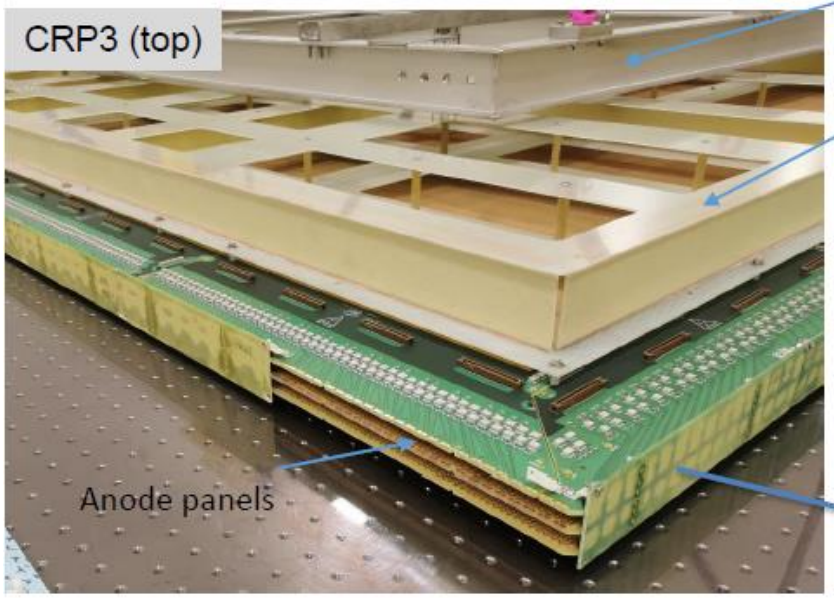




- Assembly of perforated anode PCB panels

Silver printed PCB joints

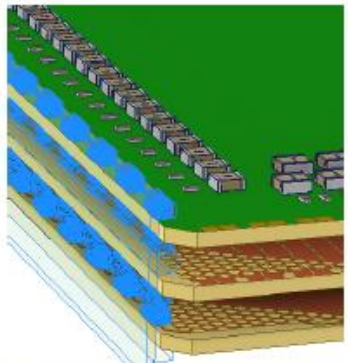
- Two perforated anodes stack integrated with composite frame in CRP structure



Metallic frame

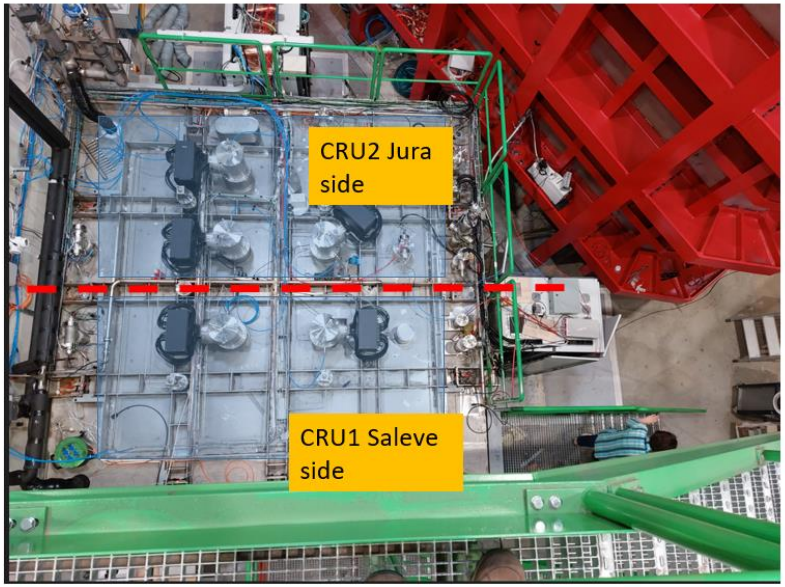
Composite frame

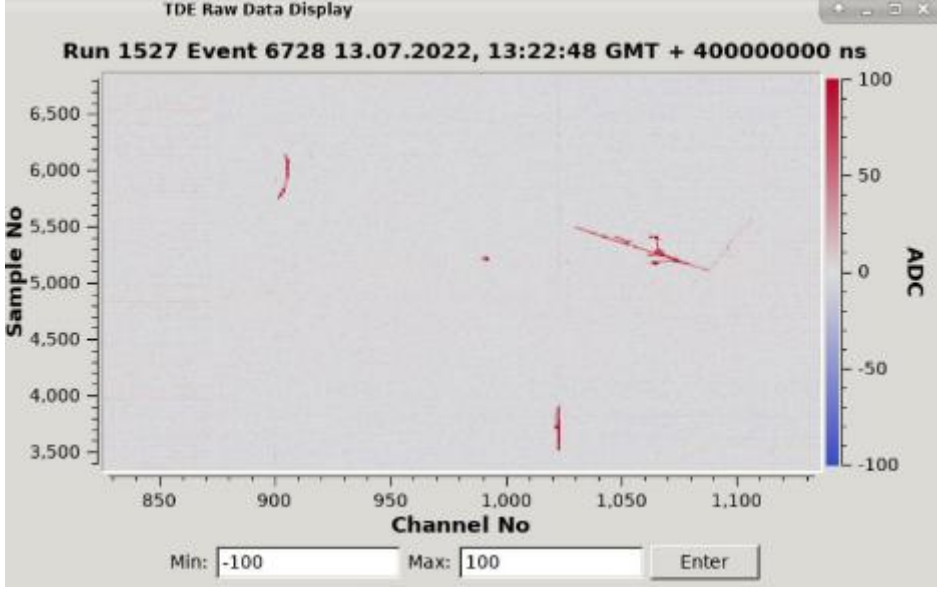
Edge board connectors:



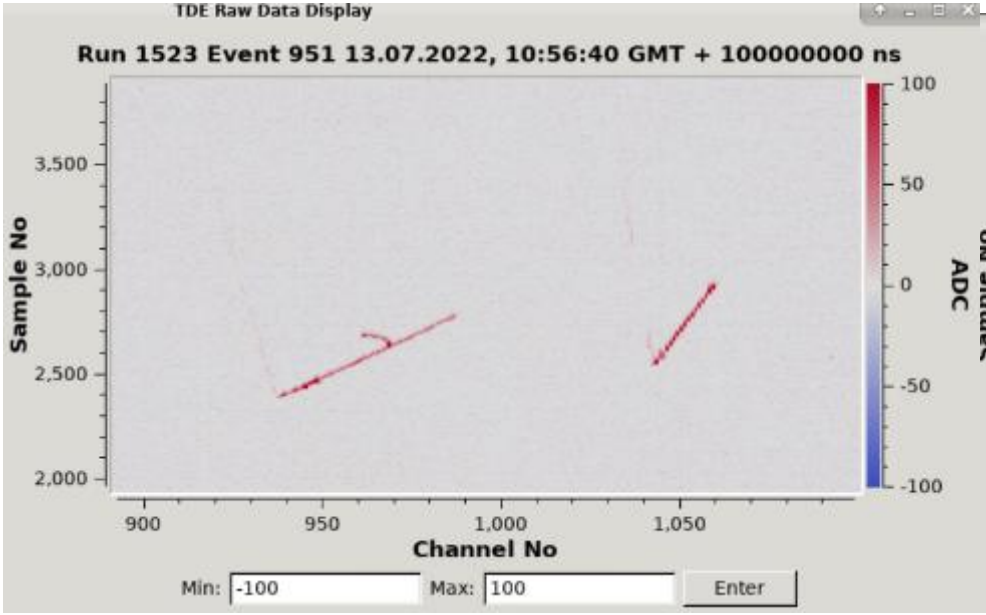
Further engineering improvements of CRP cold-box tested in 2023-2024

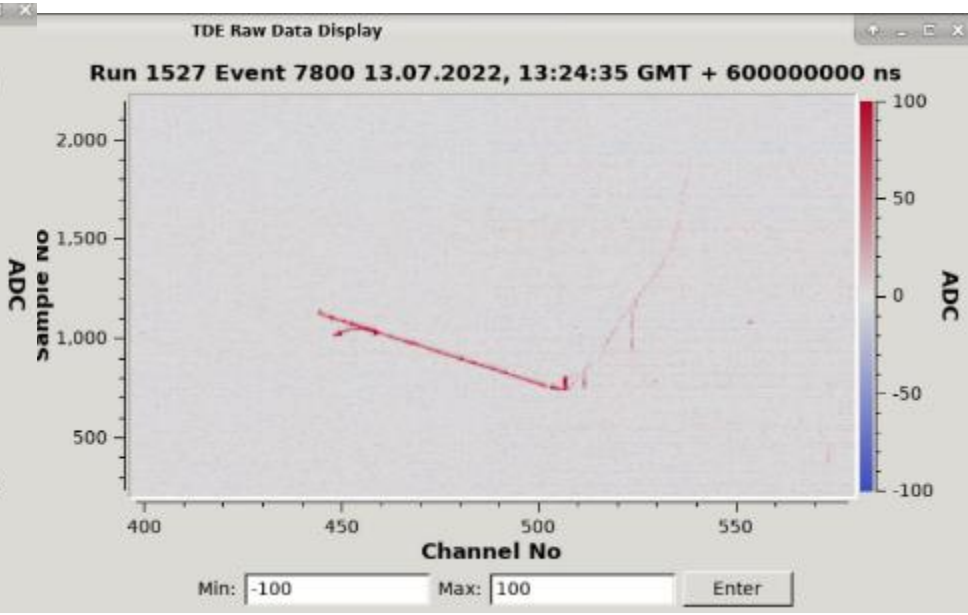
Top view of the cold box roof for CRP2 TDE readout
(5 chimneys/uTCA crates)



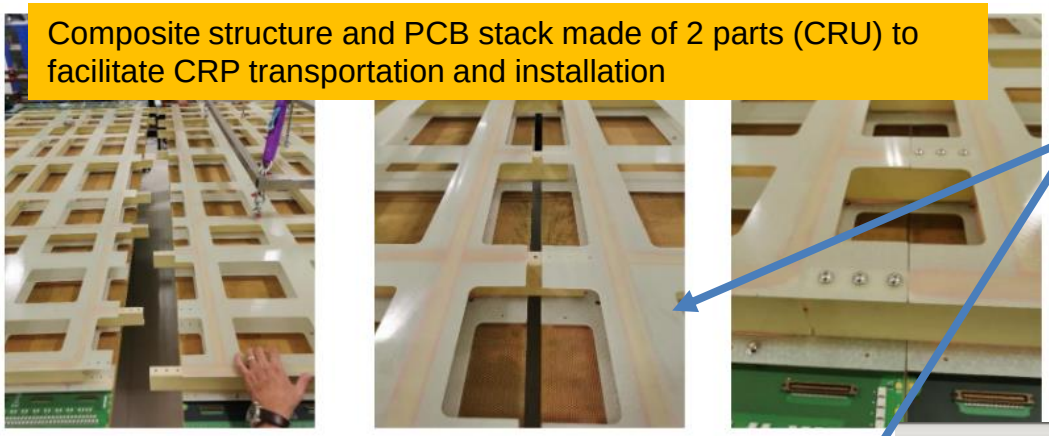


CRP2 cosmic ray events





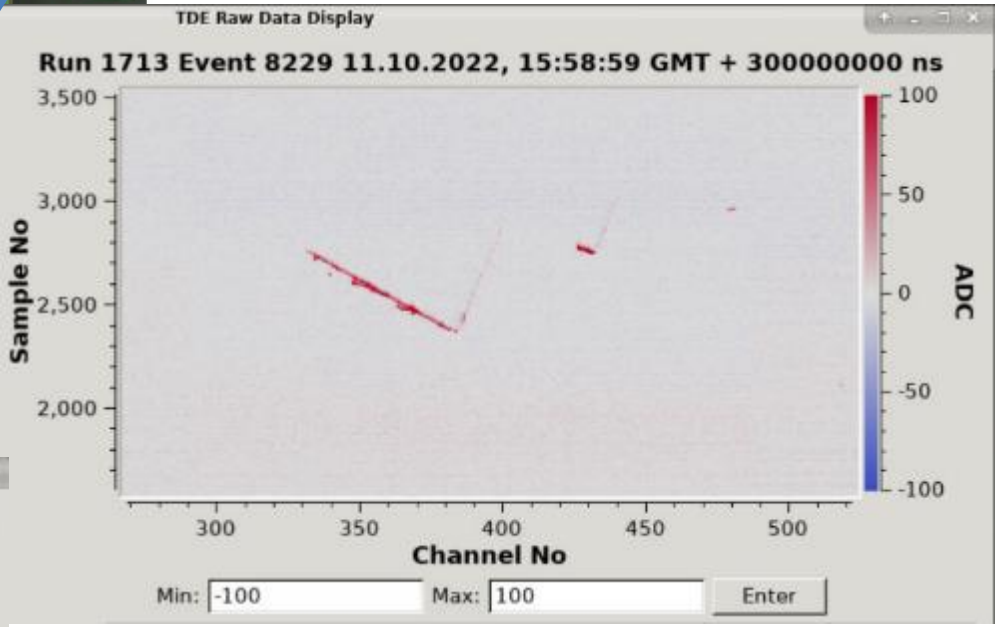
Composite structure and PCB stack made of 2 parts (CRU) to facilitate CRP transportation and installation

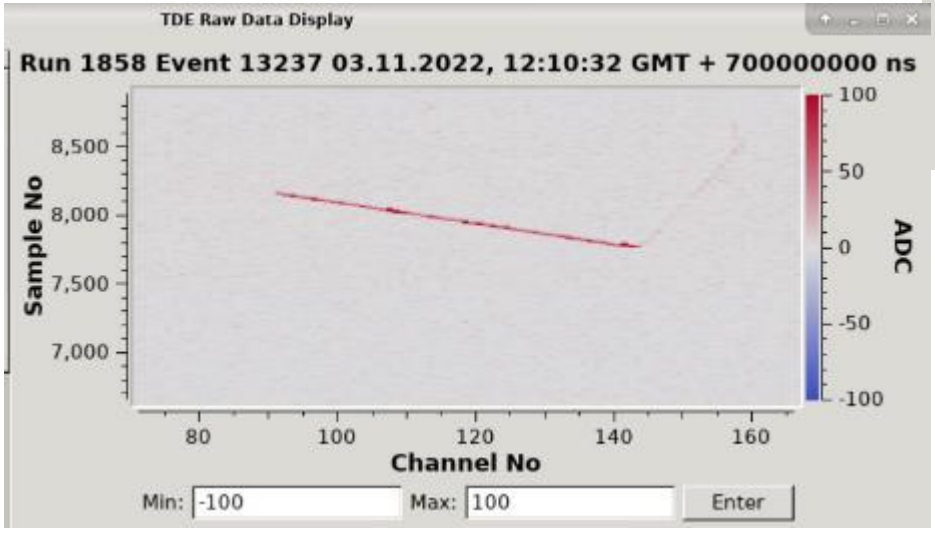


CRP3 (second DUNE full top-drift CRP) assembly of optimized lighter composite frame structure

CRP3 cosmic ray tracks, October 2022

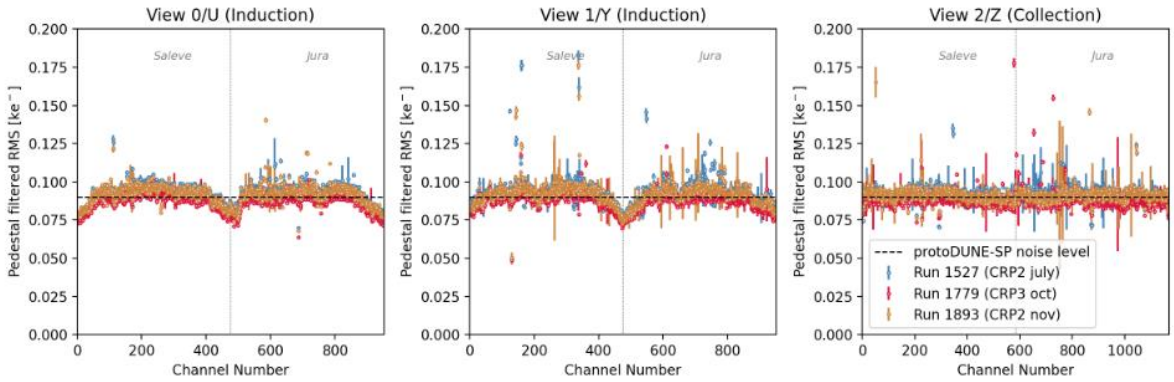
Fully assembled CRP3





CRP2 second test (November 2022)

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



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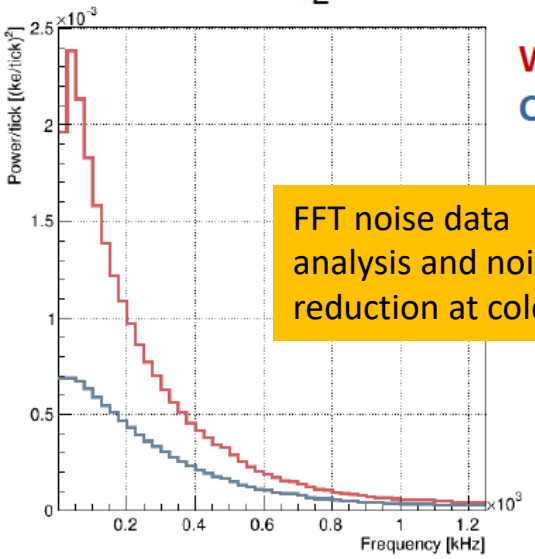
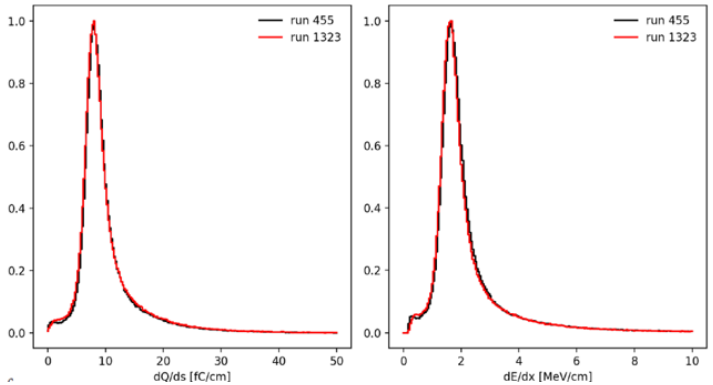


FFT noise data analysis and noise reduction at cold

Calorimetry through time

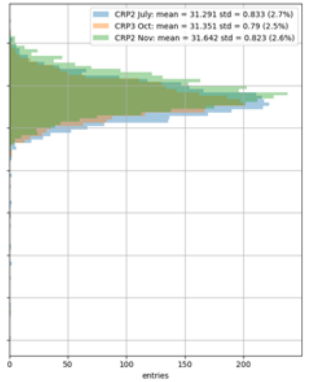
- dQ/ds corrected from impurity losses
- E_{drift} June estimated at ~450 V/cm

-> 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



Readout System for the top-drift volume of FD2-VD
80 CRP, 3072 channels/CRP, 246k total channels

Elements needed to be installed on FD2-VD (production 2024-2026):

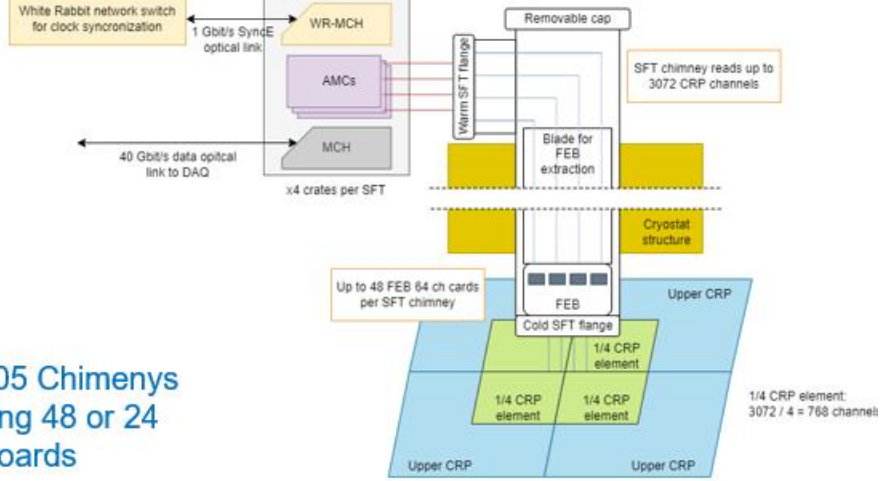
- 3840 cryogenic FE boards (64 channe with 15360 ASIC 16 channels amplifiers

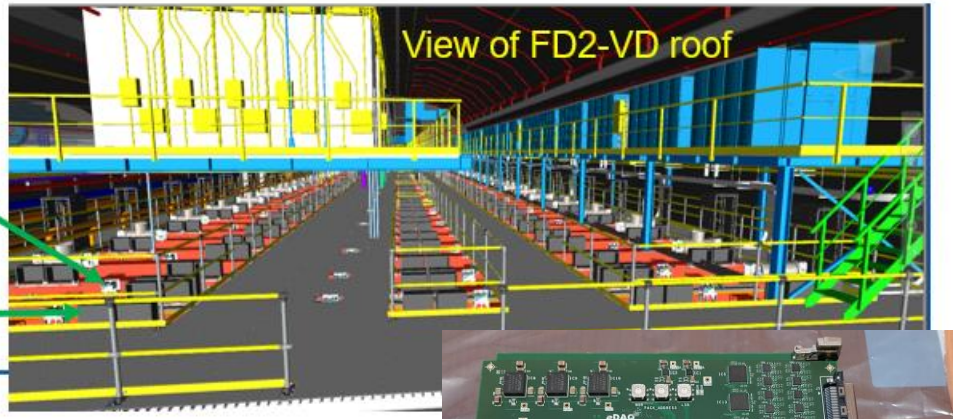
- 3840 AMC (64 channels)

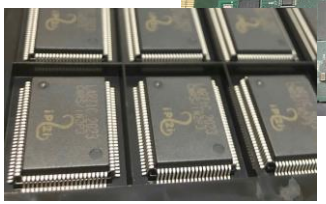
- 105 Chimenys hosting 48 or 24 FE boards

- 320 WR-MCH

- 320 µTCA systems with 40 Gbit/s MCH





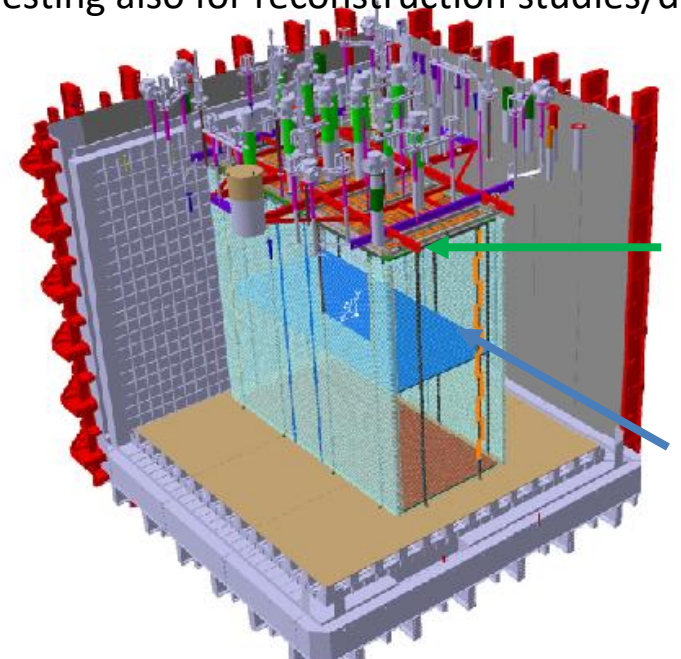


Setting up for production activities for FD2 (going to regime in 2024)

- Cryogenic ASICs produced with AMS
- AMC boards and microTCA crates (June 2024)
- Frond End boards (September 2024)
- Chimneys (September 2024)
- CRP structures (September 2024)

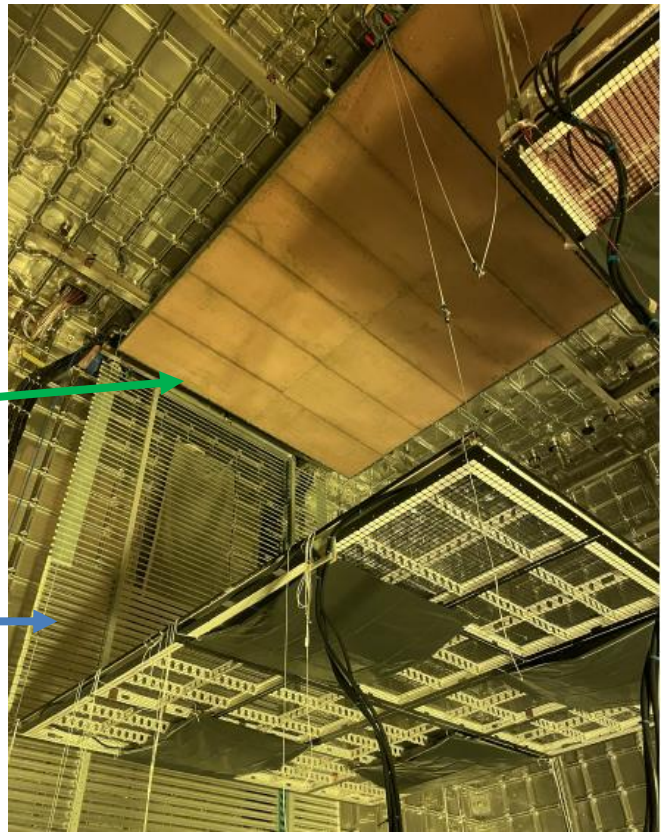
Module-0 VD assembly test in NP02 (2023)

- 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 integration successfully completed in June 2023**
- Foreseen to fill and exploit the detector with cosmics and beam (filling delayed to fall 2024 due to lack of LAr) Interesting also for reconstruction studies/developments

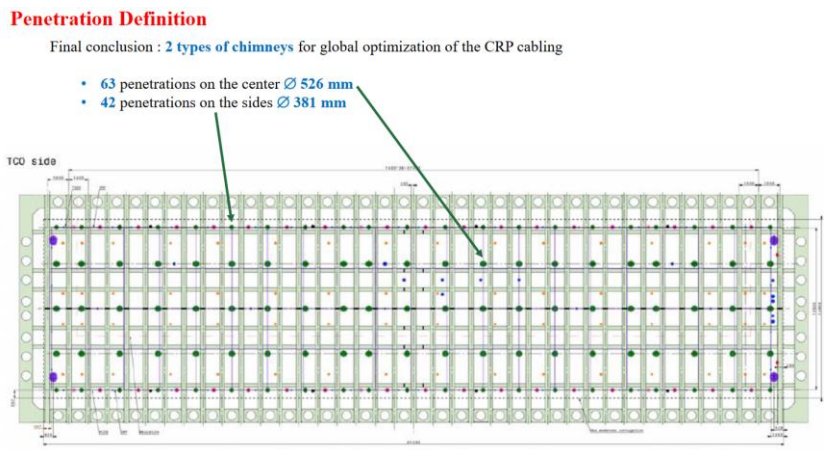


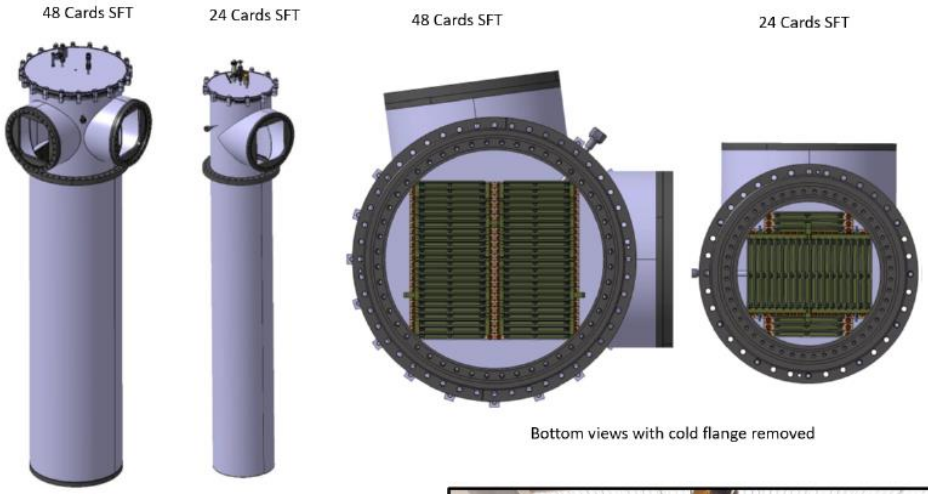
Top-drift

Cathode



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





- Large progress in 2023 on completing design and prototyping activities for 24 and 48 cards SFT and associated flanges

- Testing program of 24/48 chimneys prototypes in parallel to Module-0 at NP since April 2024 (NP02 cryostat roof has previous 10 cards smaller chimneys)

→ Implies dismounting and remounting half of the top-drift readout system installed on NP02 Module-0 (see next slide)

Overview of FD2 detector activities at CERN NP:

Vertical Drift was brought very quickly to maturity since 2021 thanks a full set of dedicated validation tools:

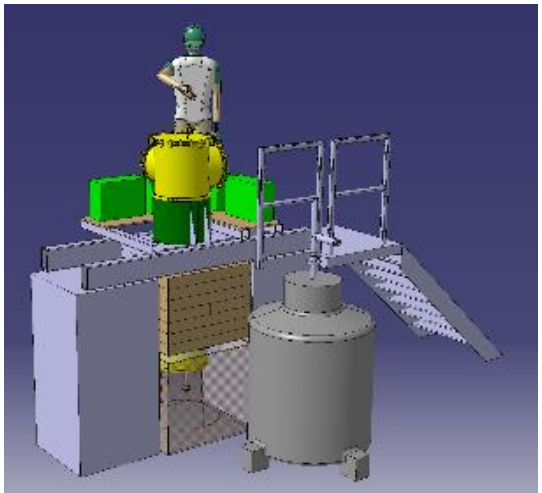
- **Cold-box (full LAr TPC not existing for FD1 elements)** to completely validate the CRPs and their readout electronics as well as the Photon Detector modules (2021-2023)
- **Second run of NP02 in 2022 to fully validate the HV system at 300kV and tracks on 6m drift**
- **Integration test in NP02 VD module-0** (two CRP top and two CRP bottom, cathodes and PDs, interface aspects) completed in June 2023

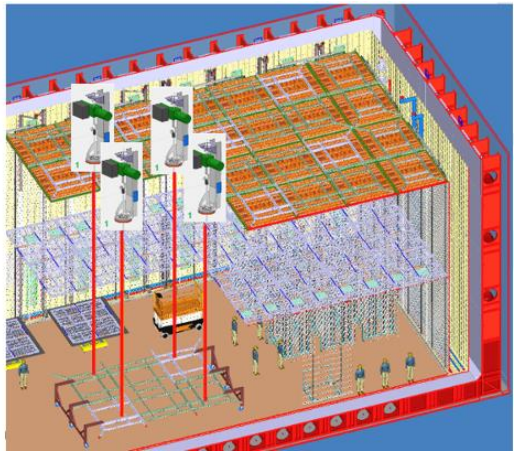
NP02 cryostat has several limitations/differences w.r.t. FD2 (3m drift, small chimneys, different detector structures and installation procedures/tools)

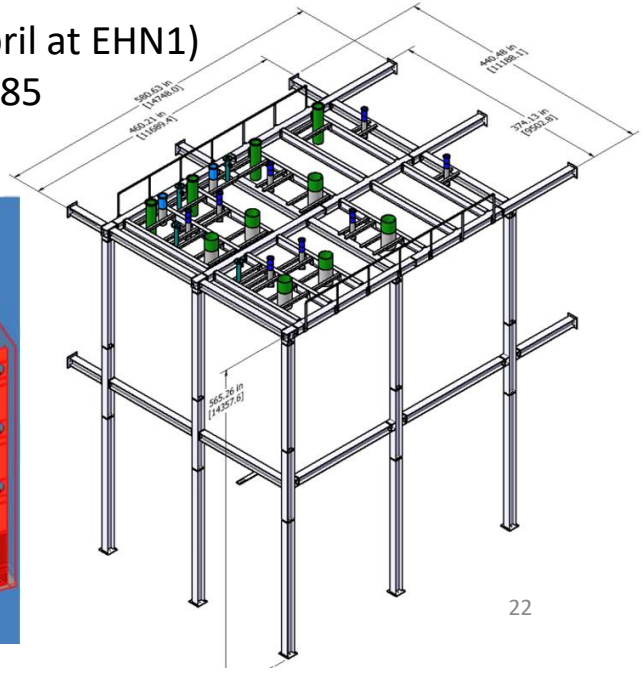
→ **Additional dedicated detector activities in 2024 at CERN NP**

- Continuation of dedicated cold-box tests (CRPs value engineering construction simplification, PDs system → further improvements)
- Dedicated large chimneys integration tests with electronics (since April at EHN1)
- FD2 full height installation test with FD2 superstructures in building 185

→ (installation of CRPs, cathode, cabling , …)







Conclusions:

- Development program on Vertical Drift top-drift readout associated to Task 9.3 succesfully accomplished well on schedule with the CRP+TDE cold-box tests campaign performed at the CERN Neutrino platform in 2022-2023

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

- Large chimneys design completed, dedicated integration test with electronics being set up to demonstrate equivalent operation to well known smaller chimenys used so far

- DUNE entered in 2024 in the construction phase and this is already involving several detector elements of Task 9.3

- Bringing the VD design to construction maturity has been possible thanks to a set of smart dedicated tools tests and infrastructures set up at the CERN NP in the period 2021-2024 with some specific activities also ongoing this year

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

Thanks