



# The DUNE vertical drift TPC

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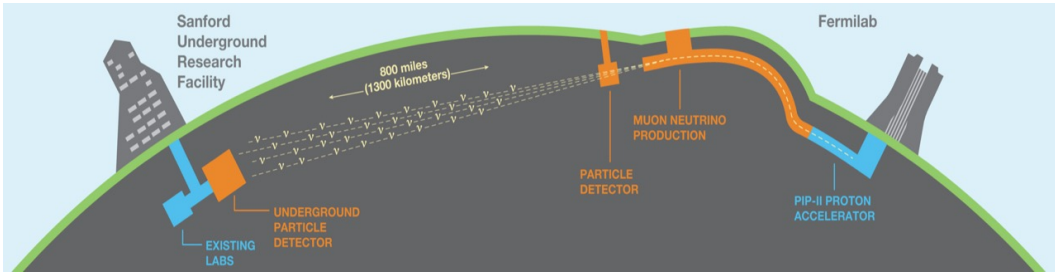
NuFACT 2022

# Deep Underground Neutrino Experiment (DUNE)

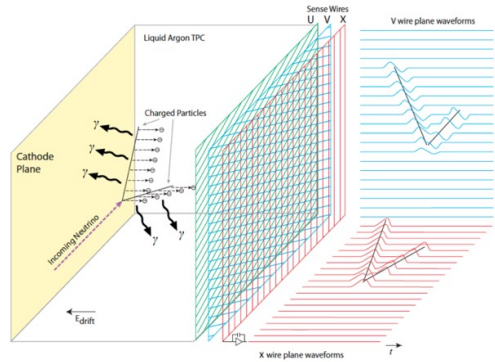
- Collaboration of over 1300 scientists and engineers from 37 countries and CERN
- 1.2 to 2.4 MW neutrino beam with a baseline of 1300 km to far detectors 1.5 km underground



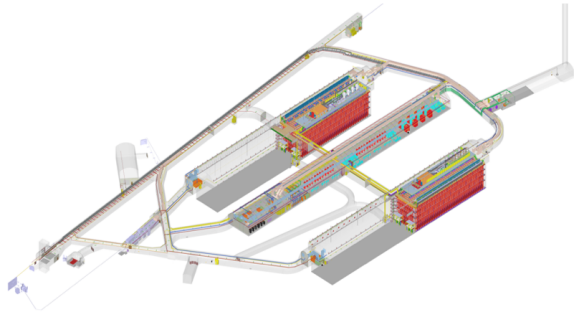

- Precision neutrino physics:
  - Measure neutrino hierarchy
  - Measure neutrino oscillation parameters including $\delta_{\mathrm{CP}}$
- But also supernova neutrinos, solar neutrinos, BSM and much more!

# Liquid Argon TPCs

- Liquid Argon (LAr) provides a dense, pure medium with prompt scintillation for triggering (using separate photo-detectors), allowing the construction of kt-scale detectors, while being much more abundant and affordable than Xenon
- LAr Time Projection Chambers (TPCs) offer fine-grained (mm) three-dimensional tracking and total absorption calorimetry, which allows identifying particles via energy loss and topology



# The DUNE far detectors



- The baseline technology for the first DUNE far detector (FD) module is a horizontal-drift single-phase LAr TPC built using wire-chamber technology, as used for ICARUS, MicroBooNE
- Single-phase Vertical Drift (VD) was chosen as the technology for FD2
- With 17.5 kt each, the DUNE FD modules will be the largest LAr TPCs ever built
- Phased approach foreseen, with FD1 and FD2 for Phase I, and two more FDs for Phase II (technology R&D ongoing)

# Evolution of ProtoDUNE detectors

- Since 2018 the two ProtoDUNE cryostats were used to test the DUNE FD technologies
  - ProtoDUNE-SP validated the horizontal drift (HD) technology of FD1
  - ProtoDUNE-DP tested ambitious dual-phase technology for improved signal amplification, simpler construction and a longer drift-length
- The ProtoDUNE detectors demonstrated very good LAr purity,
  - allowing for a long 6.5 m drift distance
  - and resulting in excellent $S/N$
    → gain in gaseous phase is not needed
- Advantages of ProtoDUNE-DP inspired single-phase VD technology

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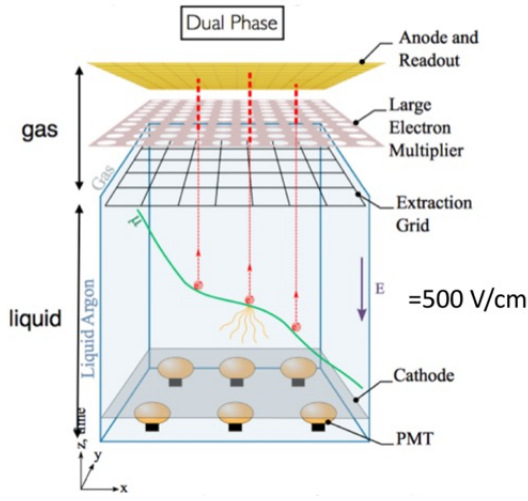
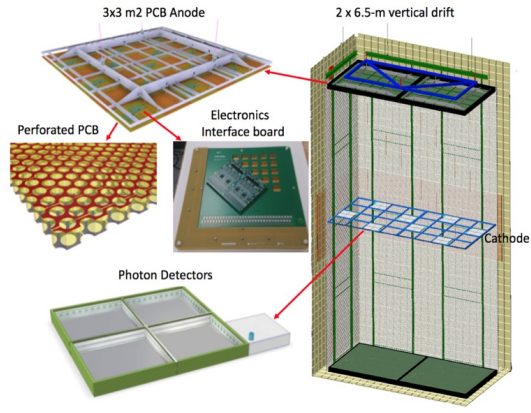
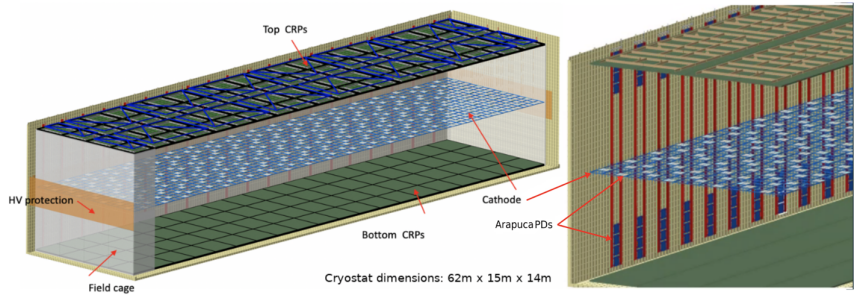


# The Vertical Drift concept

- Take best properties of both ProtoDUNE detectors for an improved *single-phase* TPC
- Shared cryostat design with first FD module
- Anode of stacked segmented and perforated printed circuit boards (PCBs) with etched electrodes
  - mechanically robust and modular for easy assembly
  - mass producible
- Cathode suspended at mid-height
- Photon detectors (X-ARAPUCA) embedded in the cathode and cryostat walls for timing and triggering



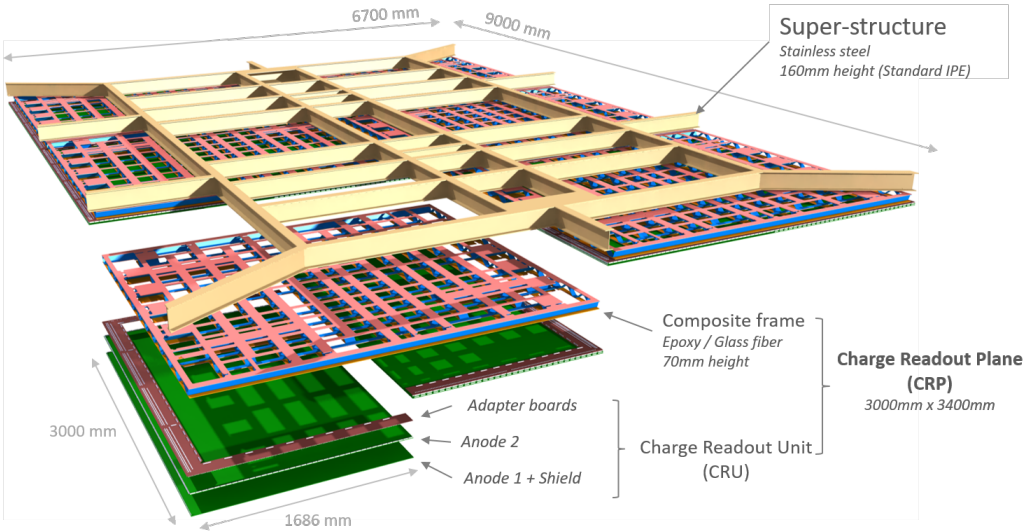
# DUNE FD2 VD




Layout of Vertical Drift FD module

- Final 17 kt FD2 VD will have $2 \times 80$ (top and bottom) Charge Readout Planes (CRPs) (with 3.4 m $\times$ 3 m each)
- FD component mass production should start in 2024

# Charge Readout Planes (CRPs) (top plane configuration)



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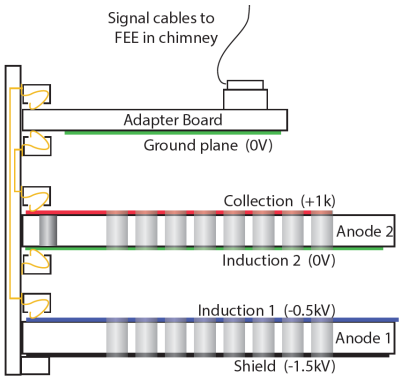
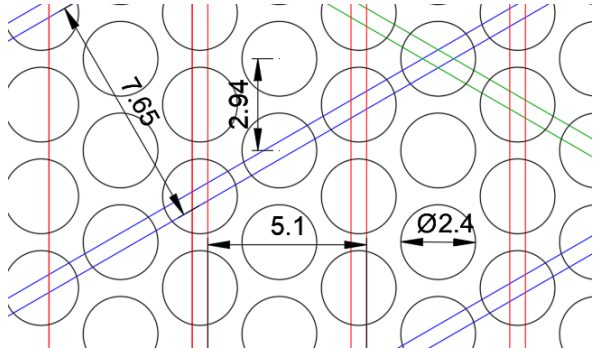
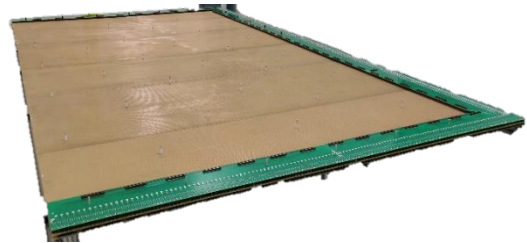


# Charge readout electronics

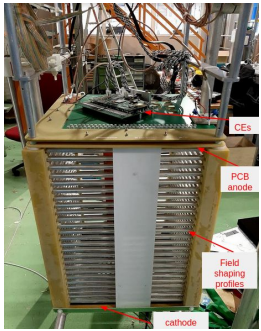
- Bottom readout electronics on cryostat floor, design shared with the FD-HD
- Attached directly to CRP



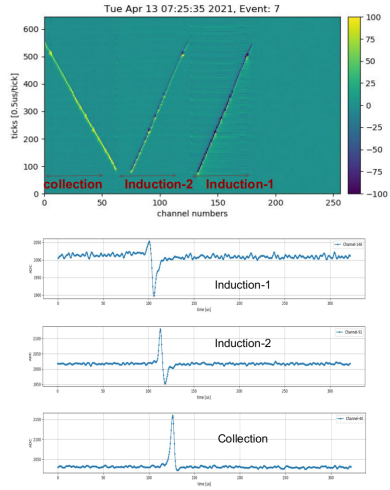
- Top readout electronics fully accessible from the top allows for maintenance/upgrade of electronics while the detector is cold
- Evolution of ProtoDUNE-DP electronics

# Successful proof of concept: The 50 l

$32 \times 32\ \mathrm{cm}^2$ prototype TPC built at CERN to test hole-sizes, strip pitch, signal shapes and energy resolution using cosmic muons and a $^{207}$Bi source in several runs from 2020 to 2022

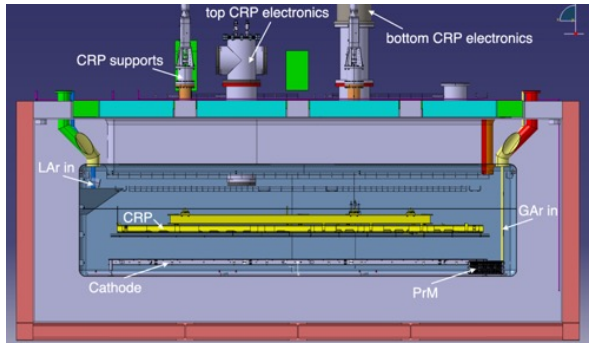



- Different PCB configurations tested:
  - Single two-view PCB
  - Two stacked PCBs (three views + shield layer)
- First test of edge connectors for the Module-0 CRPs
- Uses bottom readout electronics



# Full CRP prototype: Cold-box

- The $4 \times 4 \times 1\,\mathrm{m}^3$ NP02 cold-box at the CERN neutrino platform was refurbished in order to test full-scale CRP modules, the cathode and the photon detection system at cold with a drift distance of about 20 cm
- Half of the first CRP, built in 2021, is instrumented with top, half with bottom electronics to test both readout electronic systems



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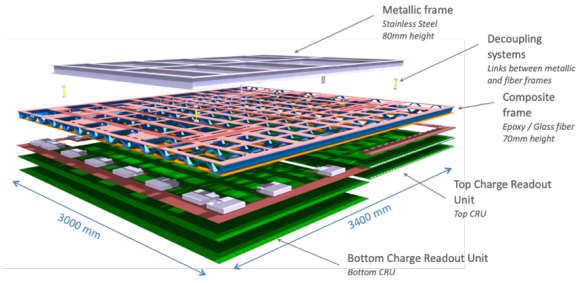
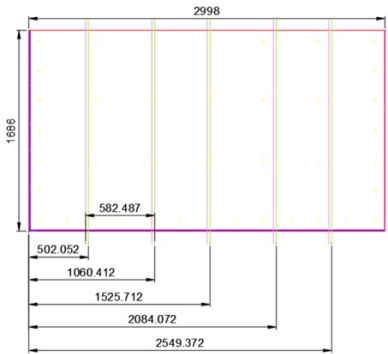


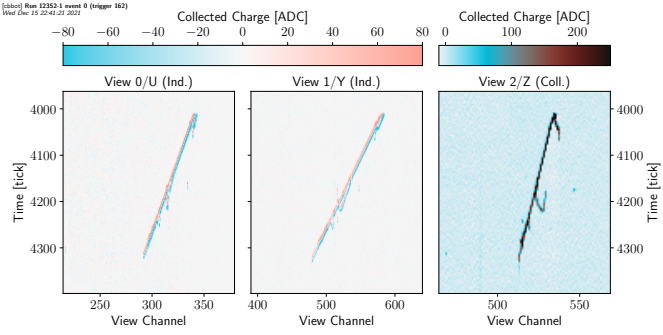

# Aside: PCB glueing and silver-printing




- Due to manufacturing constraints, each anode panel has to be assembled from 6 segments, which are glued together with epoxy in a half-lap configuration
- Channels are bridged between segments using screen-printed conductive-ink connections

# Cold-box Results

- CRP design validated at cold and gluing/interconnection of segments demonstrated.
- Two runs with large samples of $\mathcal{O}(10^6)$ triggers each were taken in Nov and Dec 2021, with full analysis in progress, with good tracks seen in both readout systems
- Excellent signal-to-noise ratio



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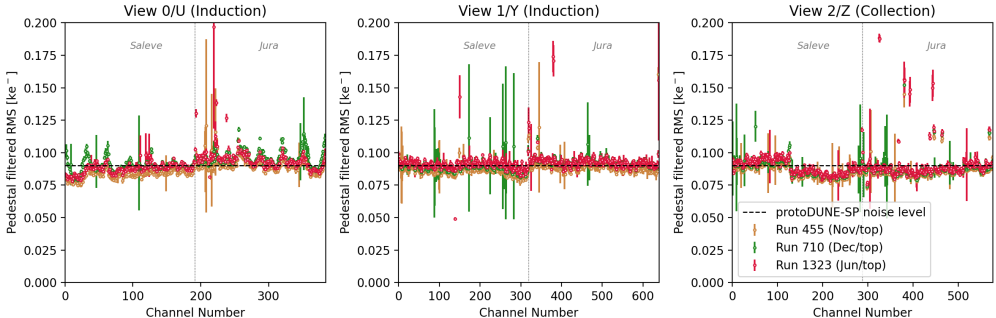
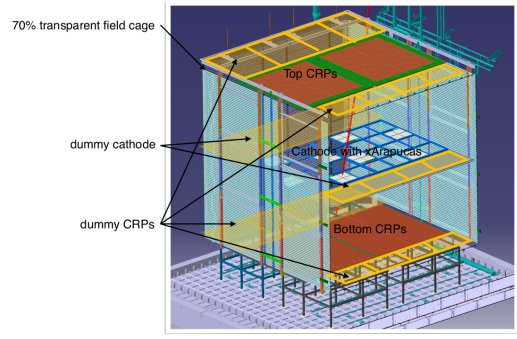


# ProtoDUNE-VD

- NP02 ProtoDUNE cryostat will be re-instrumented as Module-0 of the FD-VD for early 2023, with dedicated test beams and cosmic runs in 2023 and 2024
- Several more cold-box runs foreseen this year to test:
  - the final strip orientation ($\pm 30°$, $90°$),
  - edge connectors and homogeneous top/bottom modules,
  - and for testing the CRPs before integration into the Module-0
- First CRP for the Module-0 was just tested in the cold box two weeks ago



# Conclusion

- The Vertical Drift technology aims to unite the best features of both ProtoDUNE technologies for the second DUNE far detector.
  - High performance and signal to noise
  - Mechanically robust and simple to assemble
- The prototyping is progressing well and the first parts of the Module-0 are assembled and being tested
- Full Module-0 foreseen for early 2023, on track for DUNE Phase I