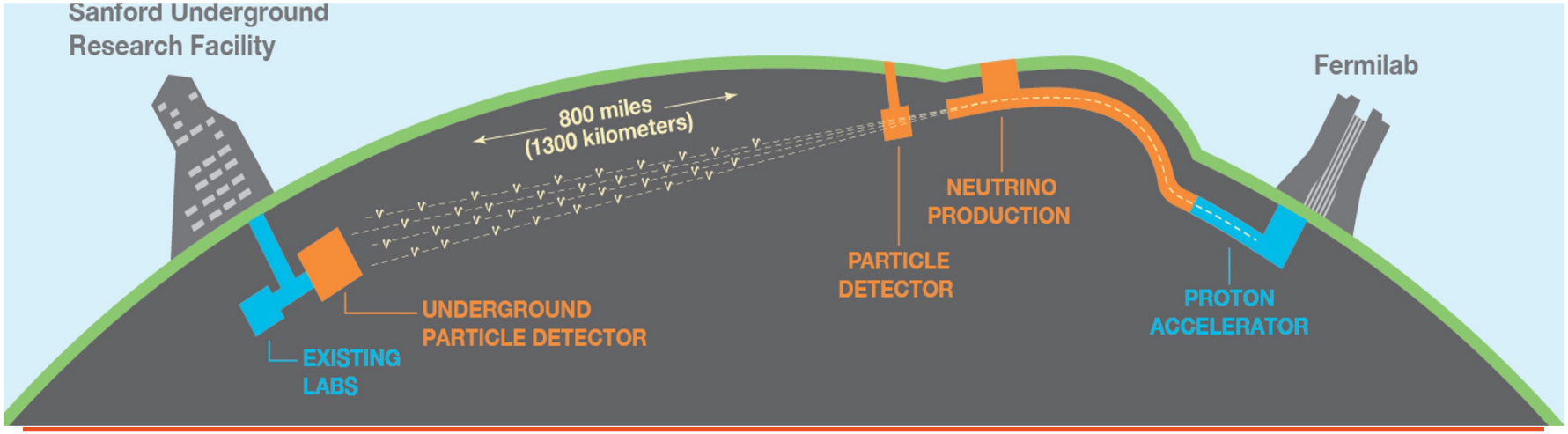
The DUNE experiment

Towards measurements of neutrino Mass Hierarchy, CP violation and more

Yoann Kermaïdic

IRN neutrino – LAPP

June 30, 2022



IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

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cnrs

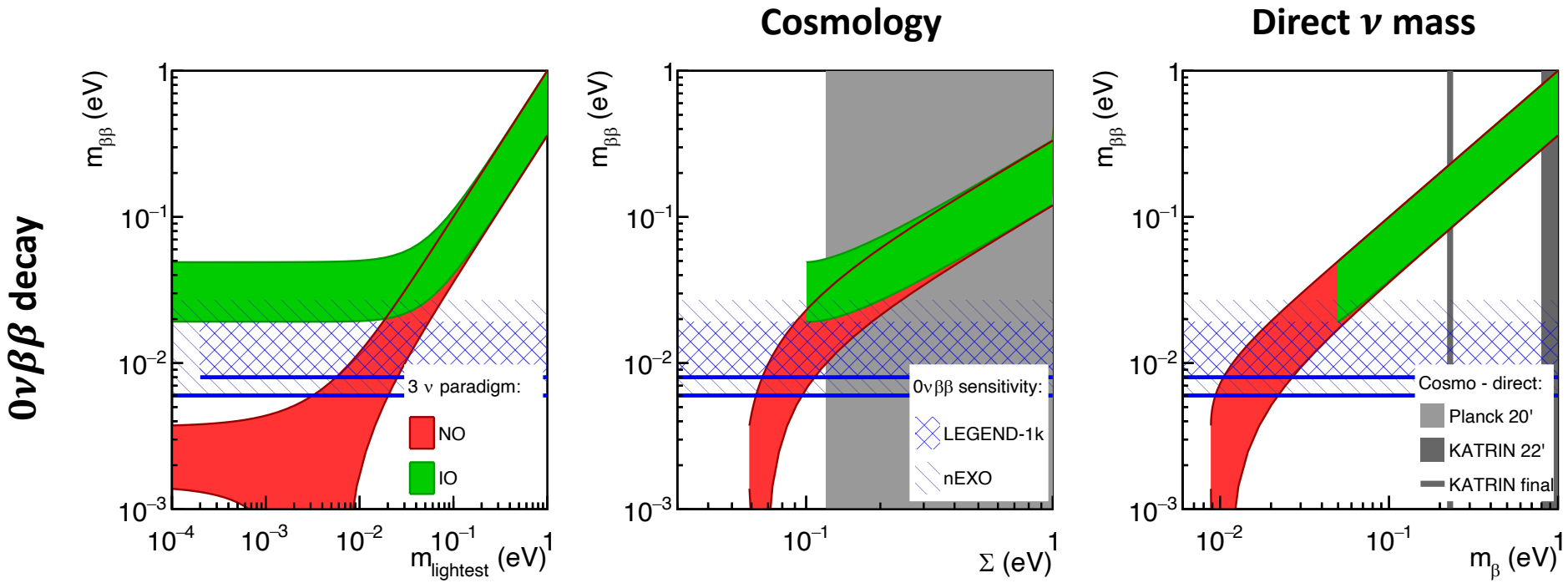
DUNE

Outline

- Physics reach
- The DUNE approach
- Status of ongoing activities

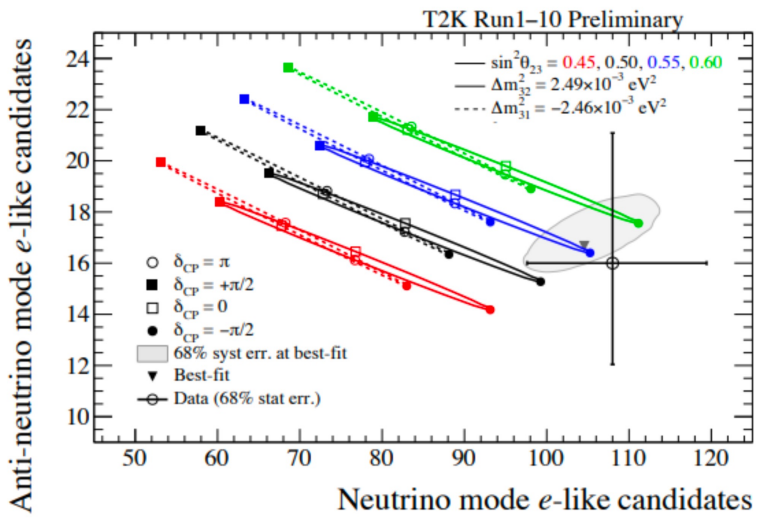
The 3ν paradigm in one slide

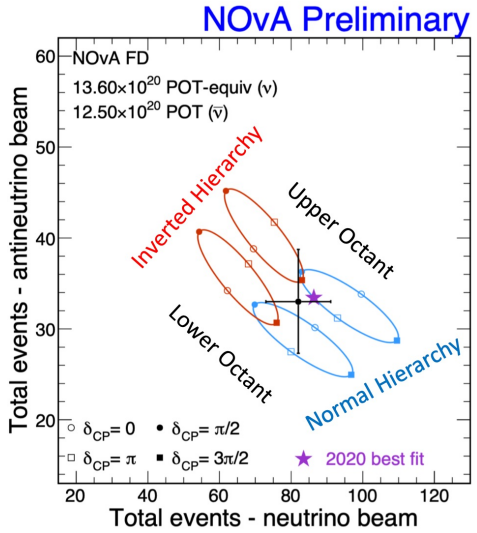
- Testing the light 3ν paradigm requires inputs from the entire neutrino community and more!
- Neutrino osc. experiments must unambiguously measure the mass ordering – a potential strong impact w.r.t. next-gen $0\nu\beta\beta$ decay exp.



Current sensitivity to MH & CP

- T2K / NOvA currently accumulating statistics
  - 0.75 MW / 0.8 MW
  - 295 km / 810 km
  - 0.6 GeV (<1 GeV) / 2 (<3 GeV) GeV neutrinos
- Weak « bi-plot » separation between IO/NO – Best fit NO @ $\sim 2\sigma$
- sensitivity to the CP violating phase : upcoming combined fit

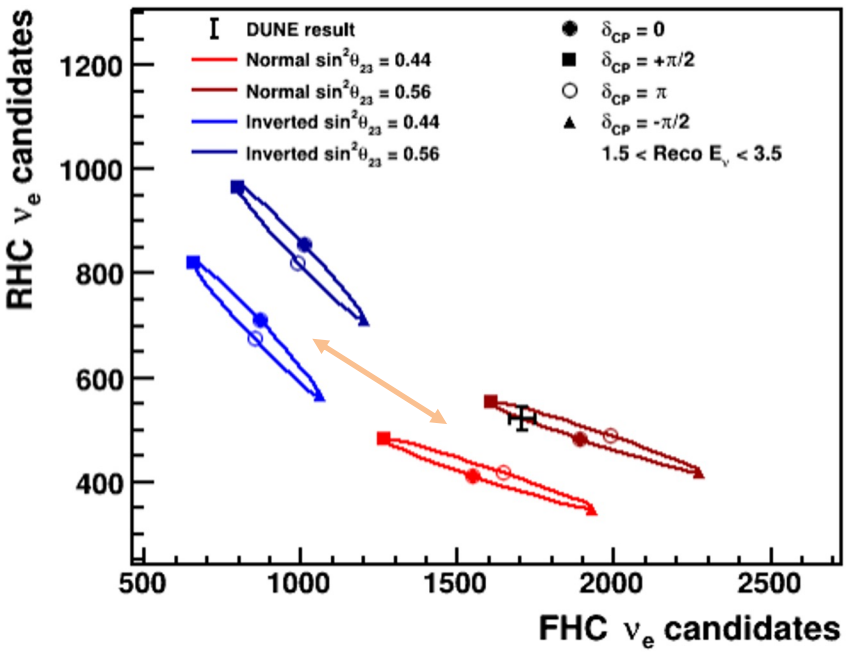




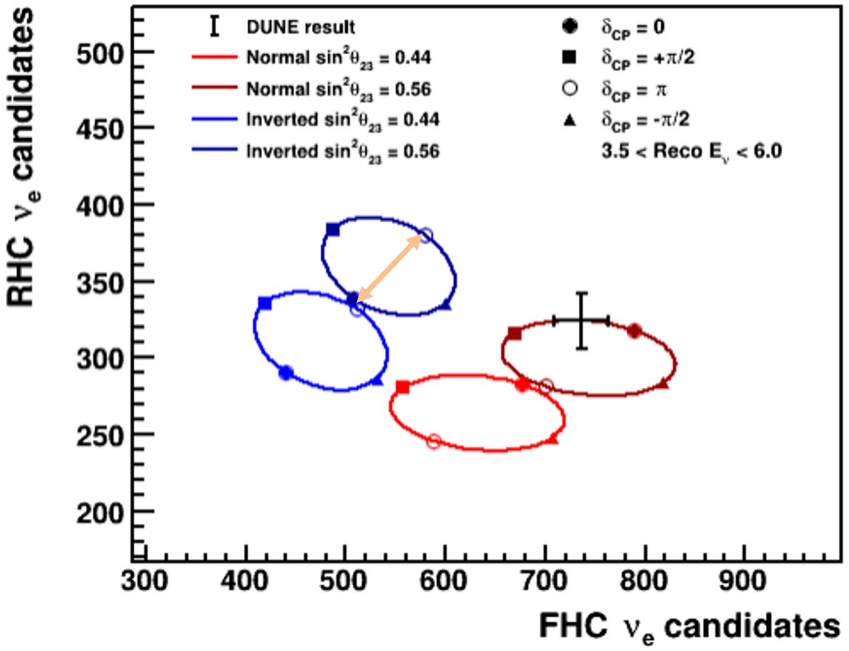
DUNE's plot

- Benefits from longer oscillation baseline (1285 km) with enhanced sensitivity coming from matter effects
- Wideband energy spectra allow to cover a full oscillation period

700 kt-MW-yrs, Flux peak

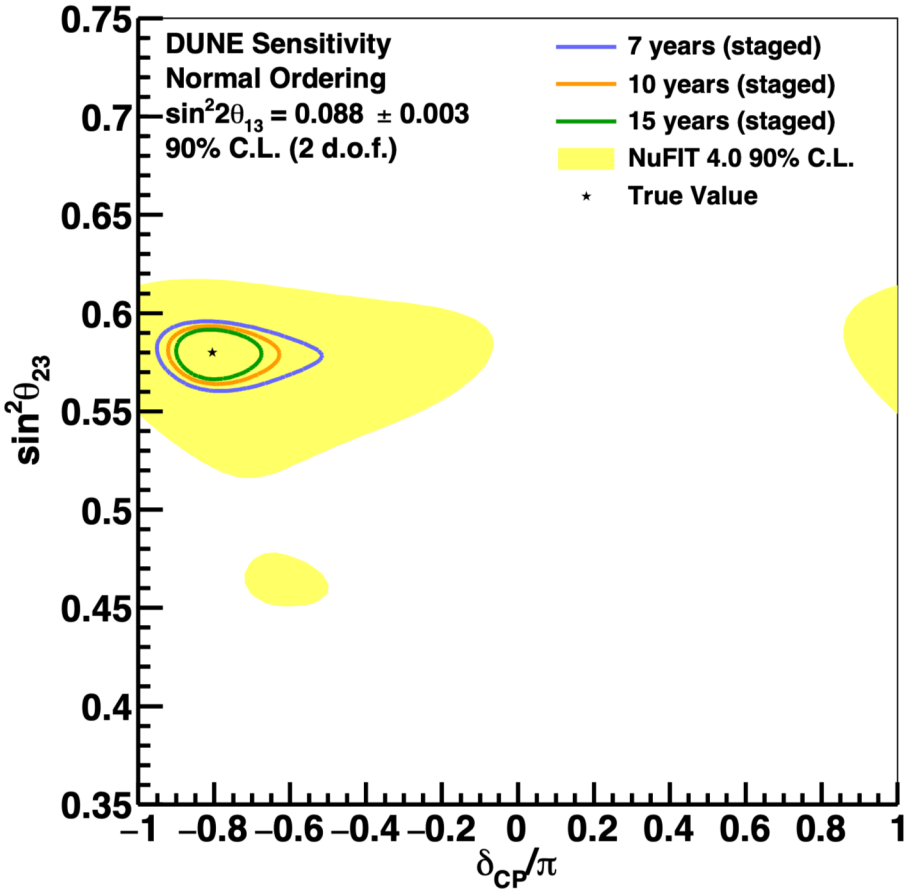


700 kt-MW-yrs, Higher energy



Improvement in sensitivity

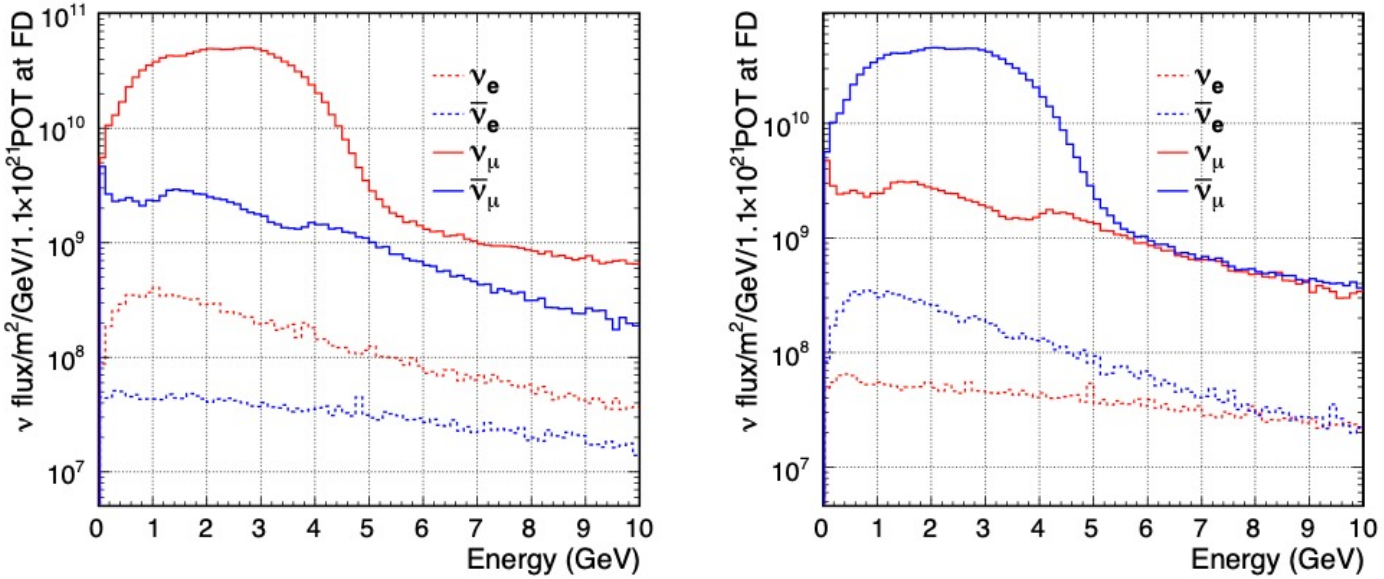
- Unique capability to sensitively probe a large fraction of the oscillation parameter space with a single experiment



See Snowmass
DUNE Physics summary
https://arxiv.org/pdf/2203.06100.pdf

LBNF Neutrino beam

- New neutrino beam to be built at Fermilab
  - 120 GeV protons interact with a carbon target
  - Initial power of 1.2 MW, upgradable to 2.4 MW
  - Wideband beam : [0-5] GeV neutrinos
  - Runs in neutrino and antineutrino modes

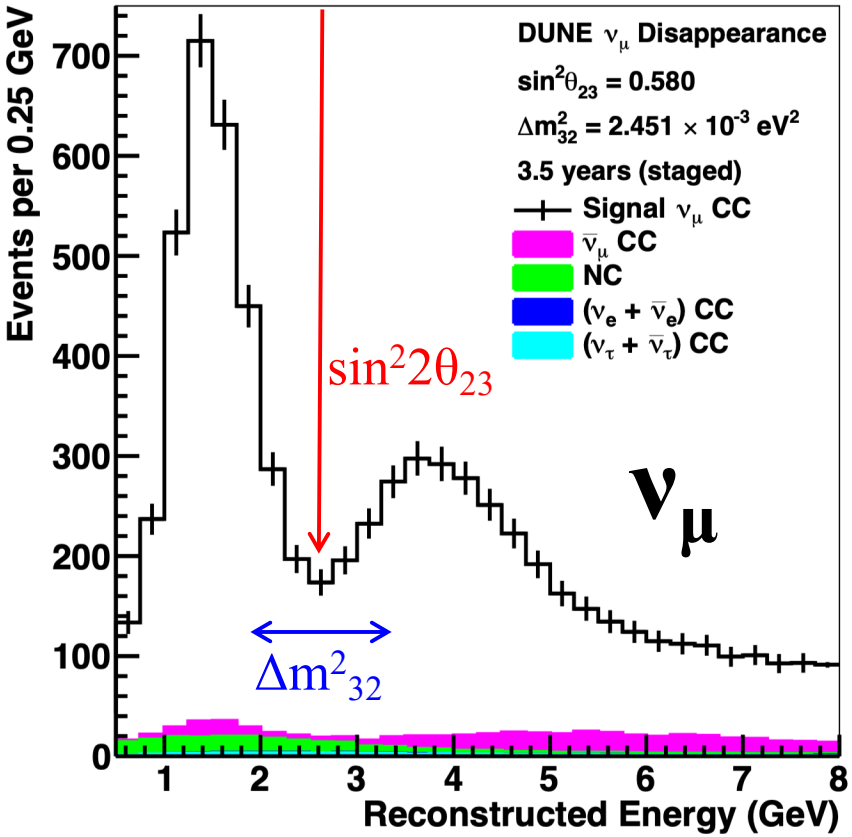


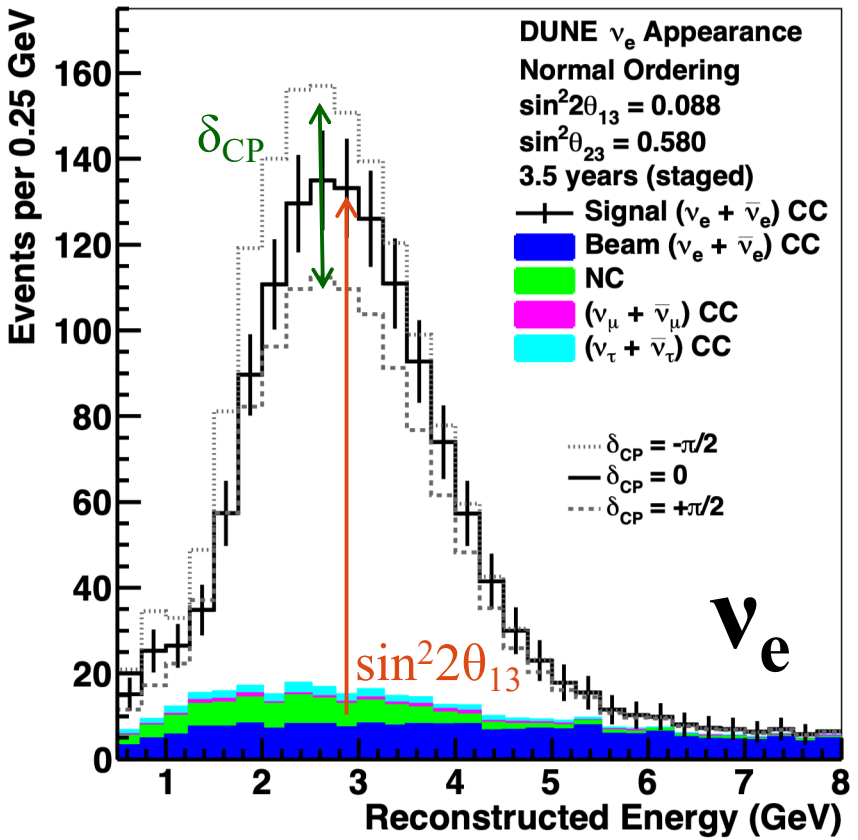
B. Abi, et al., (DUNE Collaboration), Long-baseline neutrino oscillation physics potential of the DUNE experiment Eur. Phys. J. C 80 10, 978 (2020)

DUNE is sensitive to MO, δ_{CP}, θ_{13}, θ_{23}, Δm^2_{32}

- DUNE measures ν_μ disappearance (left) and ν_e appearance (right) of neutrinos and antineutrinos (not shown) as a function of neutrino energy at the Far Detectors (FD)

Credit: C. Marshall (NUFACT21)





DUNE Plans and Installation

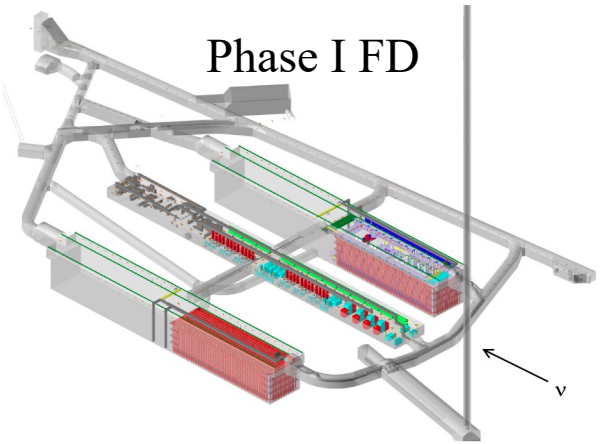
- DUNE construction is phased to provide continuous progress toward physics goals beginning this decade.

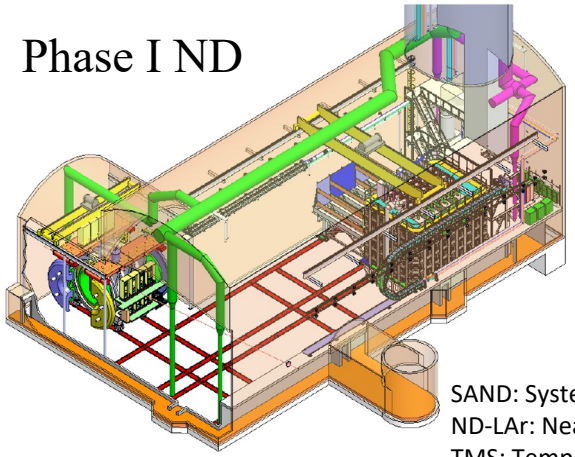
Phase I

- Ramp to 1.2 MW beam intensity
- Two 17kt (10kt+ fid.) LAr TPC FD modules. One HD on VD.
- Near detector: ND-LAr + TMS (steel/scint. range stack) + SAND
- Moveable ND to enable PRISM

Phase II upgrades

- Proton beam increase to 2.4 MW
- Four 17kt LAr TPC FD modules
- TMS Upgraded to ND-Gar to provide enhanced ND interaction physics capabilities.



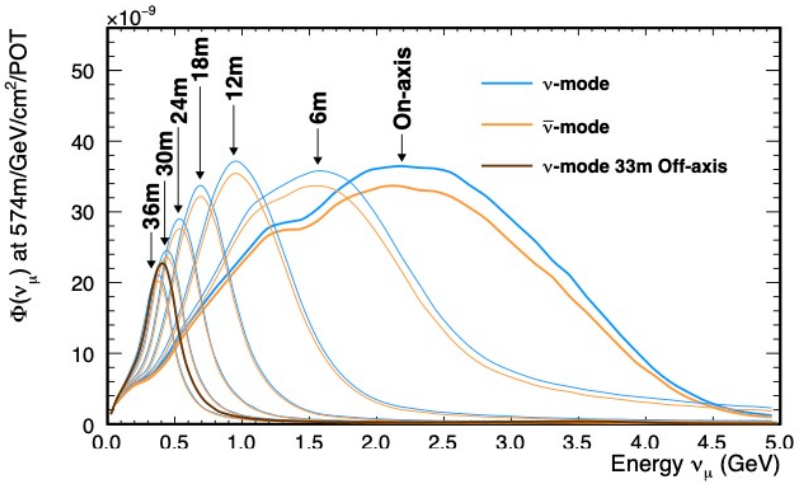


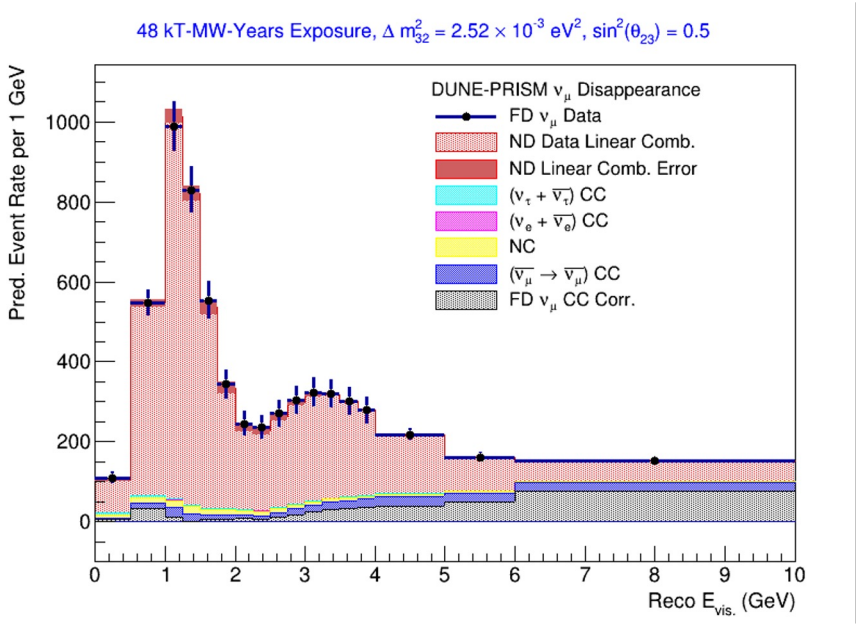
Near Detector CDR
arXiv:2103.13910

SAND: System for on-Axis Neutrino Detection
ND-LAr: Near Detector LAr TPC
TMS: Temporary Muon Spectrometer

PRISM – ν flux energy scan

- ND-LAr + Spectrometer can be moved off-axis to enhance flux at lower energies.
- These samples allow one to build a linear combination to match FD *oscillated* spectra and build analysis with minimal interaction modeling.

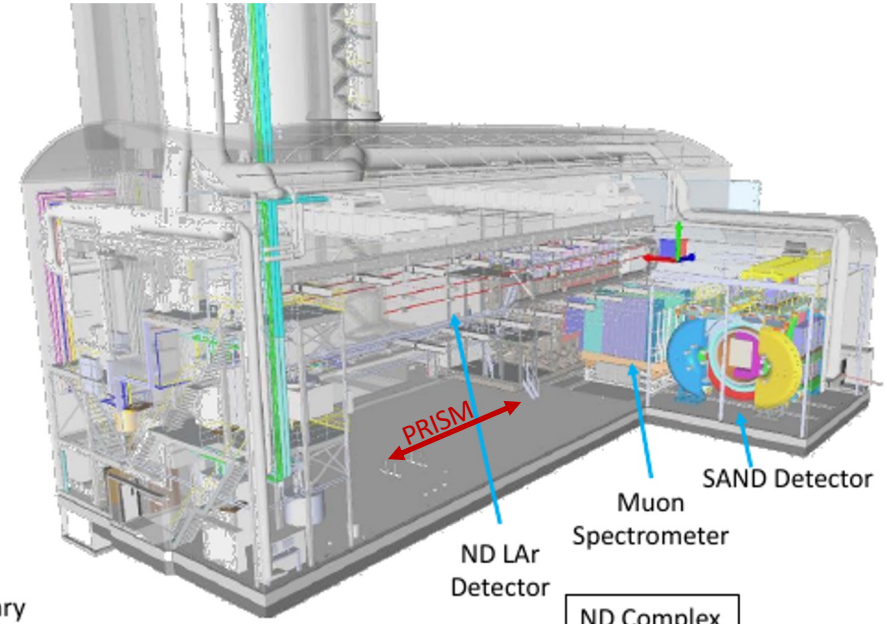


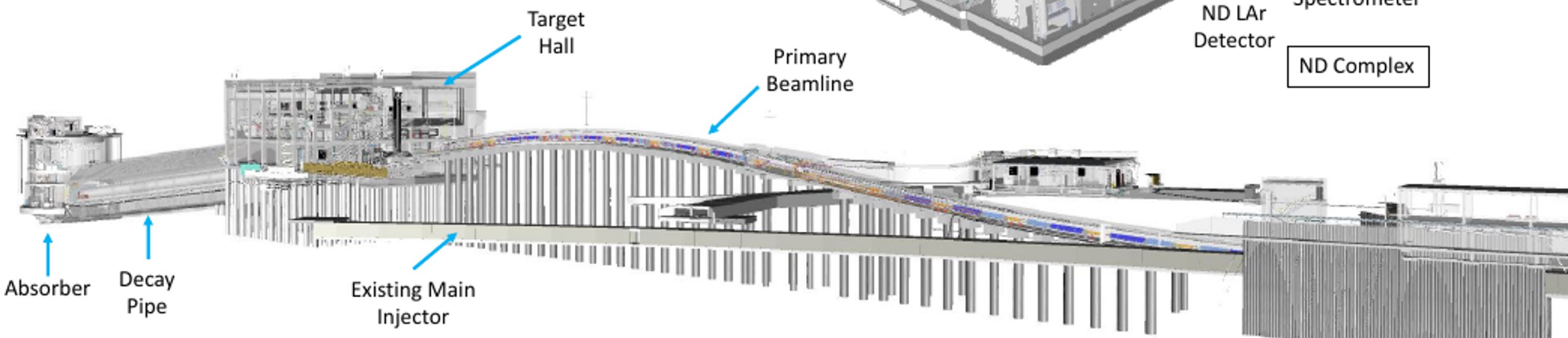


- Initially developed in the context of T2K and Hyper-K (NuPRISM)

Beamline and Near Detector site at Fermilab: design is 100% complete

- Conventional facilities for the neutrino beamline and the Near Detector underground site have completed their designs
- 0.9 MW NuMI beam already achieved for NOvA

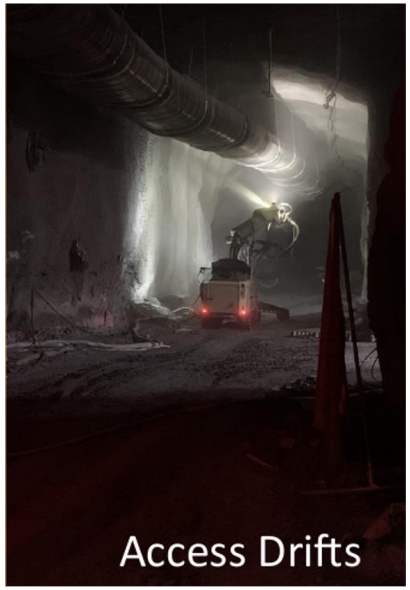


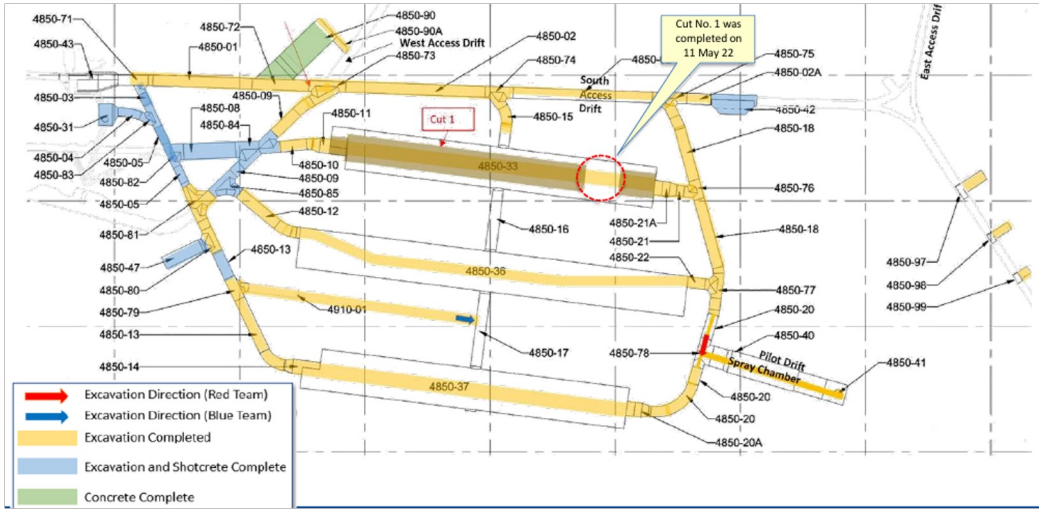


Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

Far site excavation is well underway at SURF

- Excavation is 27% complete by total rock volume
- Yellow shows complete excavation, including first cut of north detector cavern





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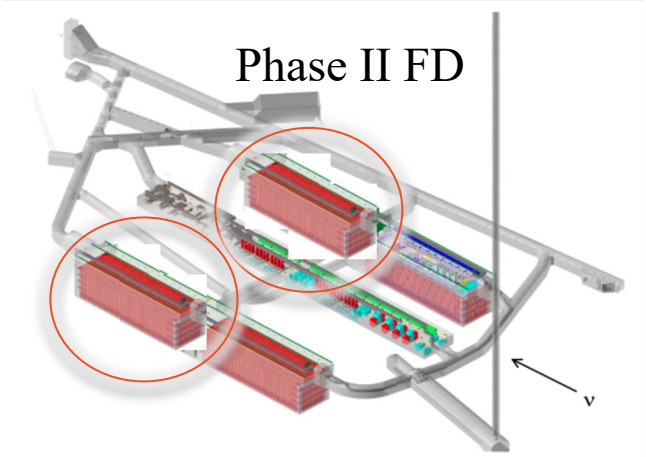
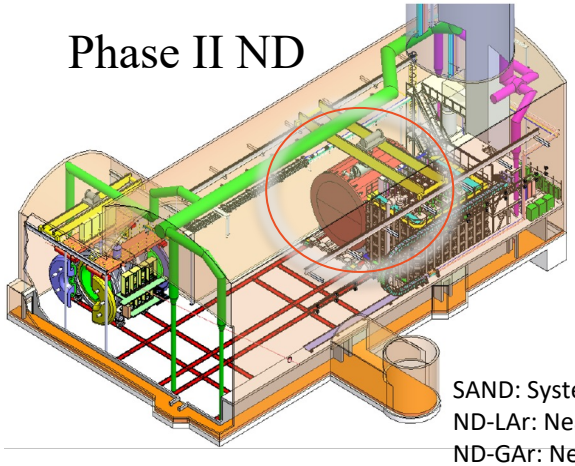


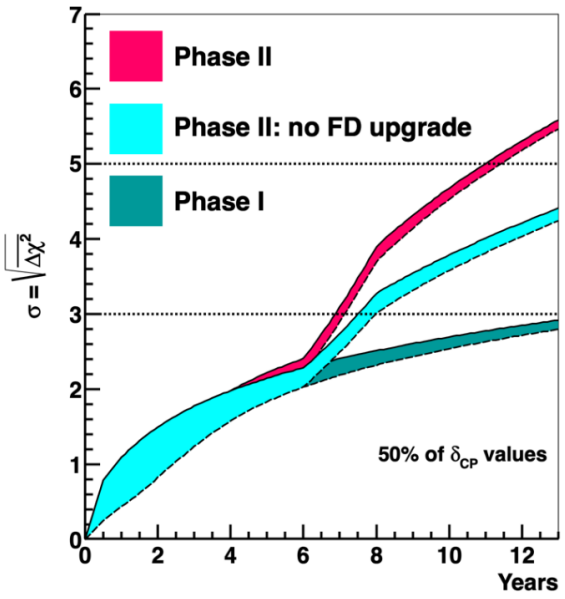


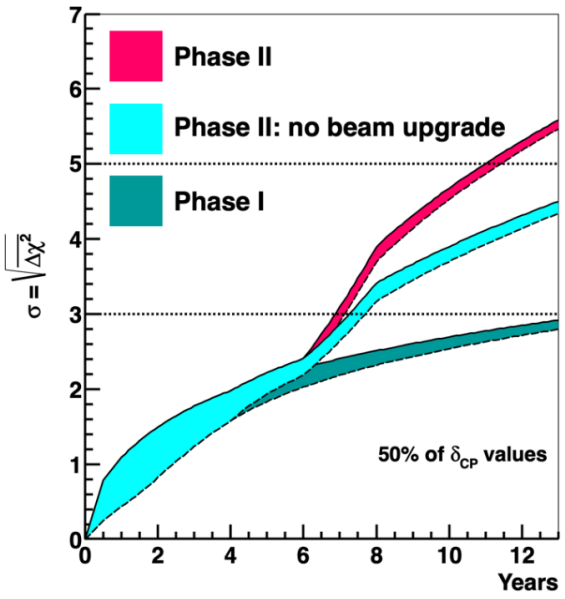
Near Detector CDR
arXiv:2103.13910

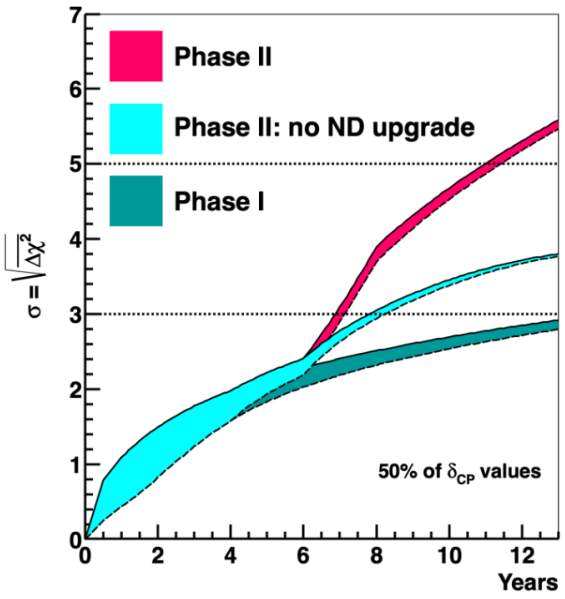
SAND: System for on-Axis Neutrino Detection
ND-LAr: Near Detector Liquid Ar TPC
ND-GAr: Near Detector Gaseous Ar TPC

Phase II upgrade impact

- All considered upgrades have significant impact on DUNE's long-term sensitivity







See Snowmass
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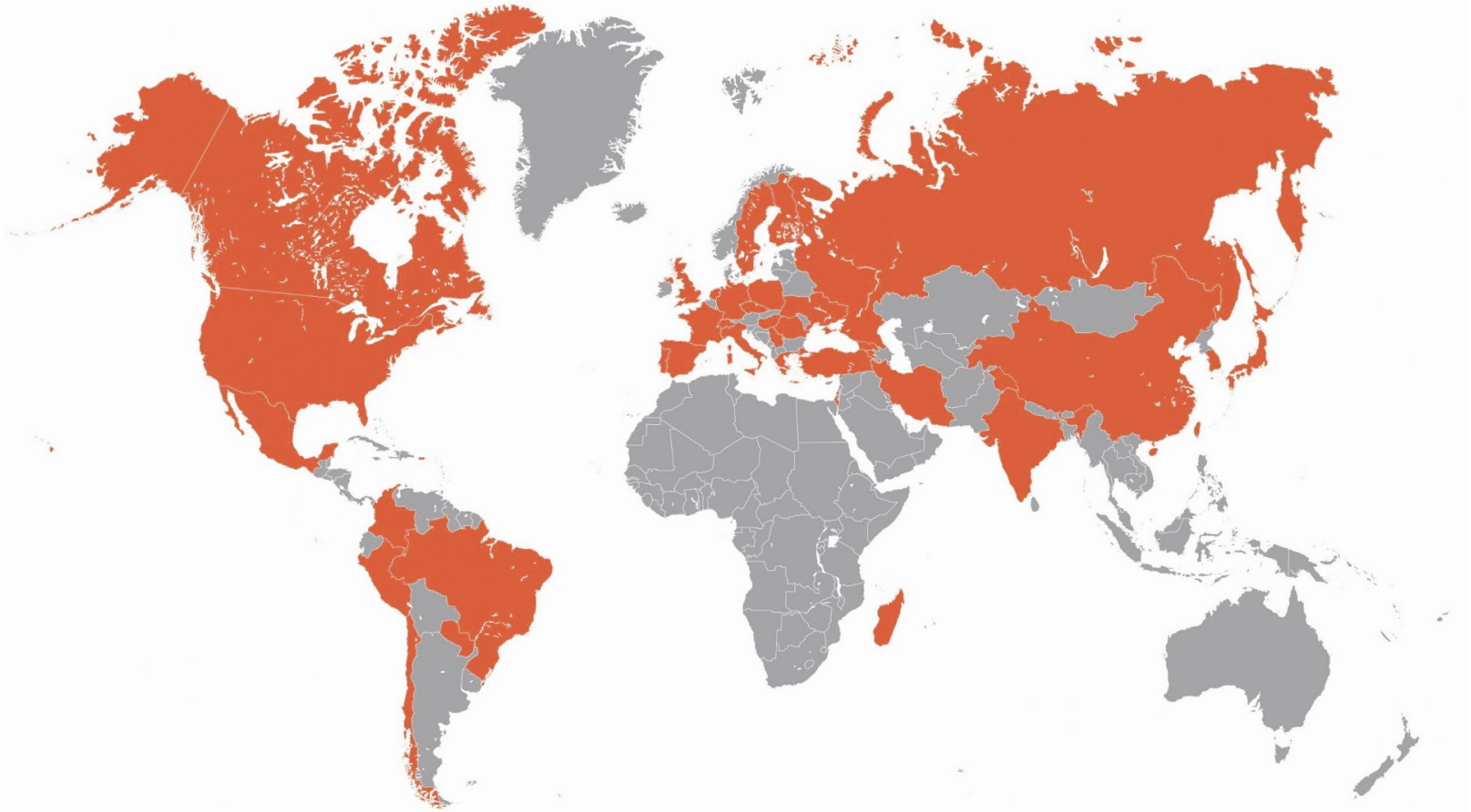
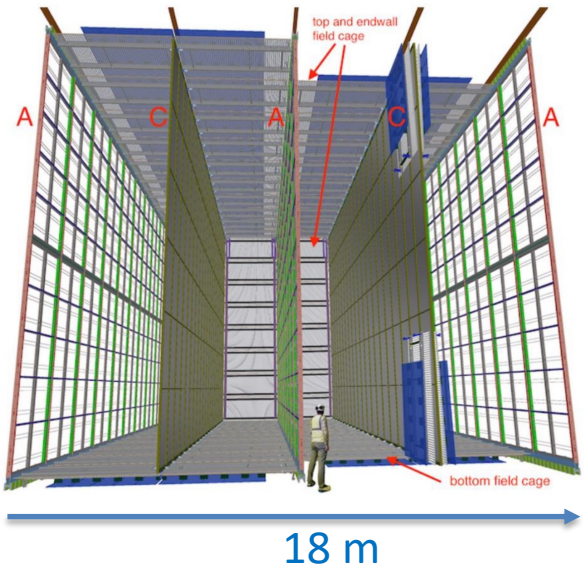
The DUNE collaboration

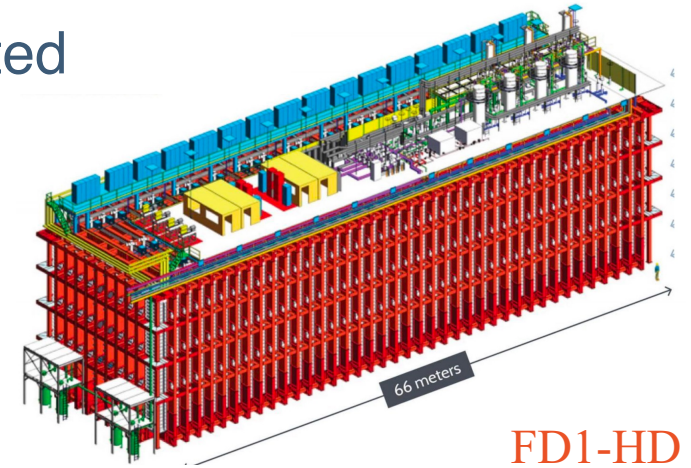
- DUNE is an international collaboration of >1300 scientists and engineers from 37 countries + CERN (and counting)



FD1-Horizontal drift detector design

- Alternate Anode and Cathode Panel Assembly (APA/CPA)
  - 4 drift volumes, 3.6 m drift
  - Electric field = 500 V/cm (HV = -180 kV)
- Anode: 150 APAs, each with 4 wire planes (Grid, 2 x Induction, Collection)
  - Wrapped induction wires
  - 2560 wires/unit -- Inter-plane distance = 4.75 mm
- FD1-HD APAs production has already started
- Photon Detectors: X-ARAPUCA light traps
  - 10 modules / APA
  - Timing
  - Cosmic / SN / BSM event triggering



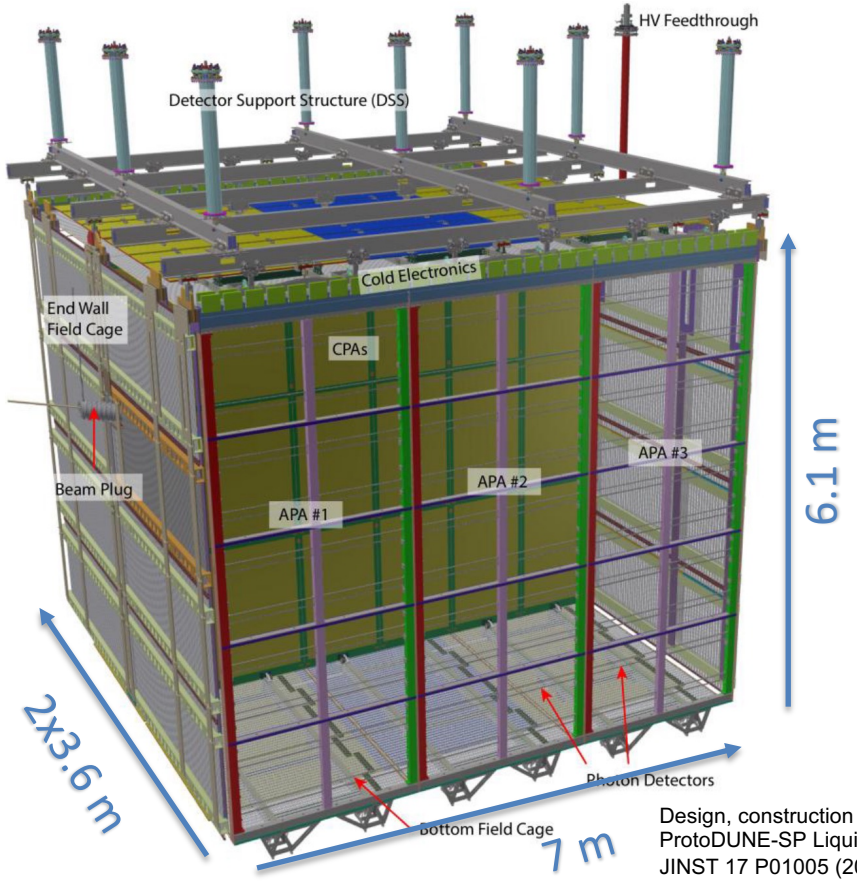


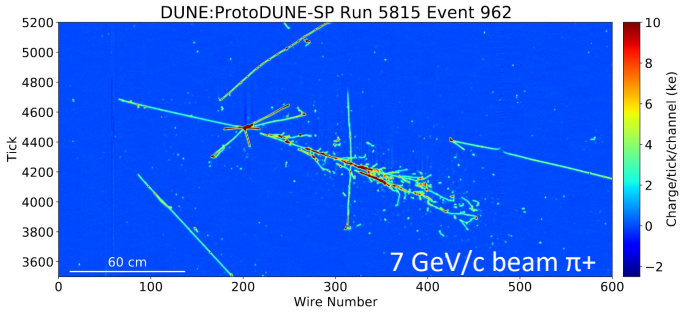
FD1-HD

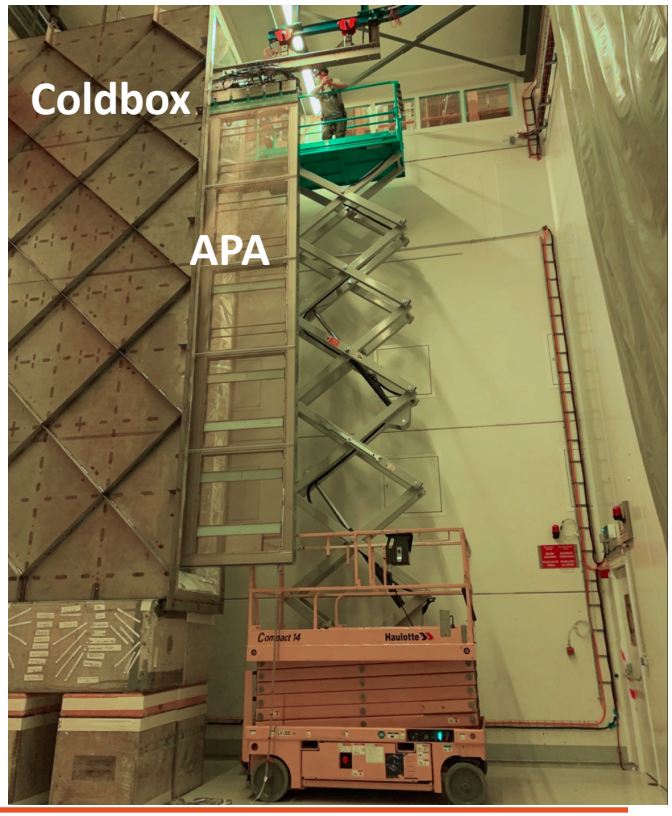
Separation of track- and shower-like energy deposits in ProtoDUNE-SP using a convolutional neural network
https://arxiv.org/pdf/2203.17053.pdf

Validation of concept at CERN

- ProtoDUNE-Single Phase (2018-2020)
- Demonstrated HQ imaging capability



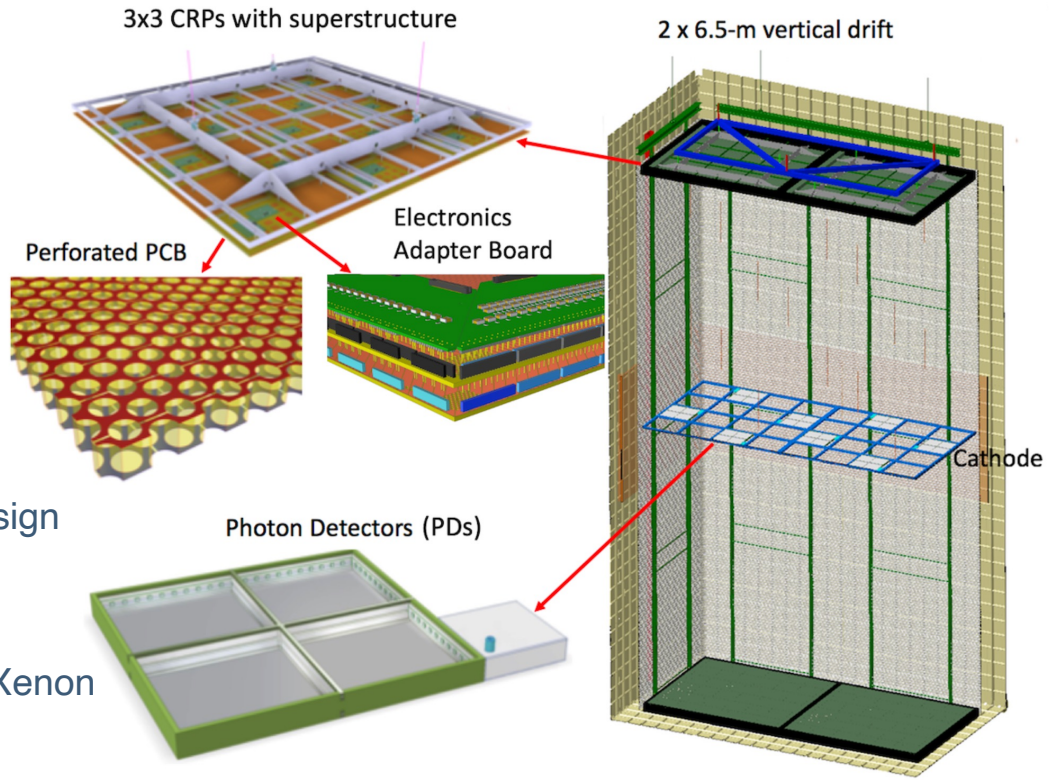




Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC
JINST 17 P01005 (2022)

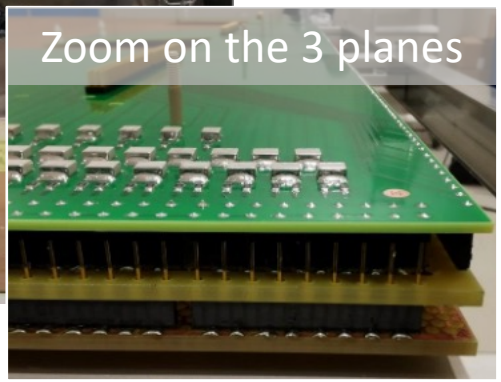
FD2-Vertical drift detector design

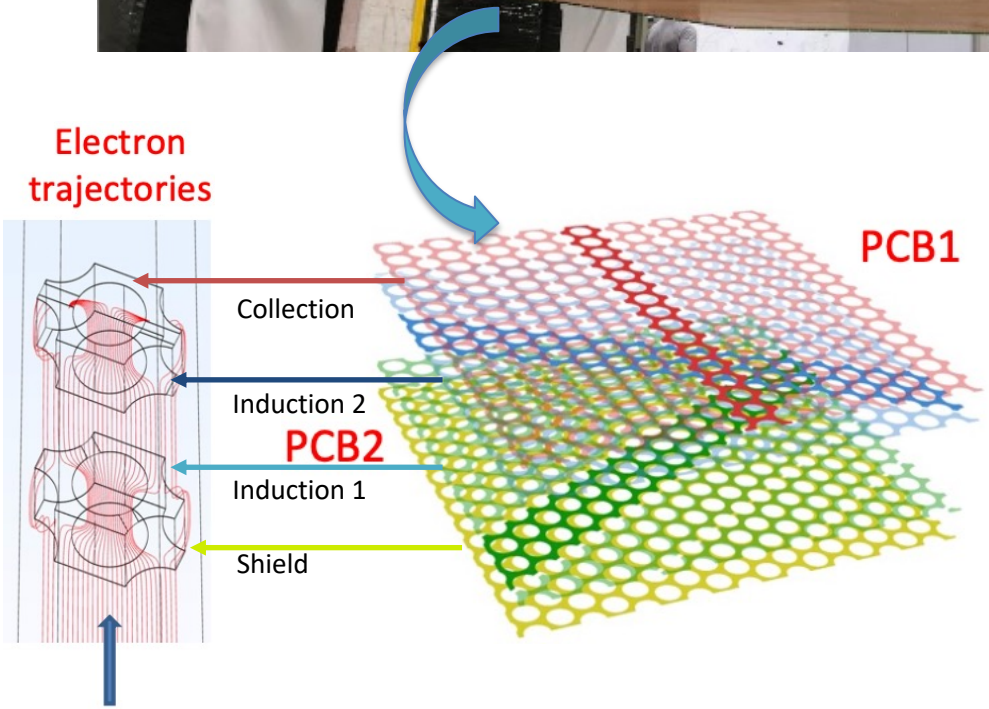
- 2 x 6.5 m vertical drift with horizontal Printed Circuit Board anode and cathode planes and photon detector
- **Charge readout:**
  - Drift along vertical direction and cathode plane in the middle
  - Readout on strips etched on PCBs
  - Two induction and one collection readout planes
  - Cathode at -300 kV, drift field of 450 V/cm
- **Photon Detection**
  - Based on X-ARAPUCA – "4π" reference design
  - SiPM and electronics partially on Cathode: @ 300 kV
  - Enhanced scintillation yield by doping with Xenon (tested in ProtoDUNE-SP)

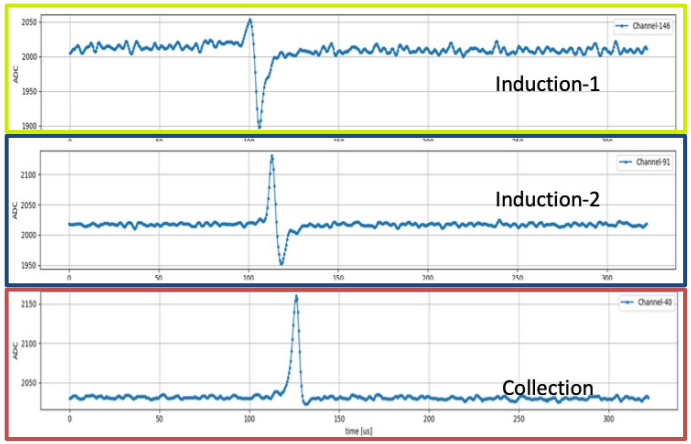


- **Full Monte-Carlo + sensitivity studies ongoing**
  - So far, FD1-HD design considered

FD2-VD detector charge readout





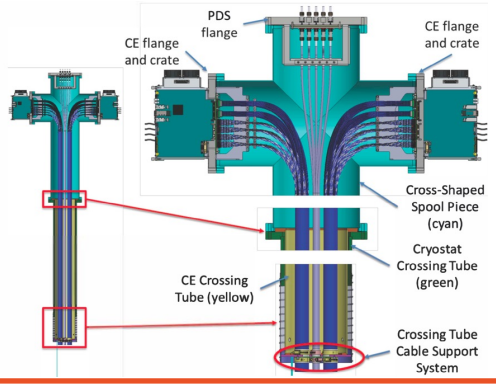


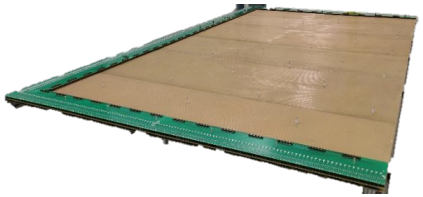
See Francesco Pietropaolo seminar at CERN on VD far detector
https://indico.cern.ch/event/1103484/

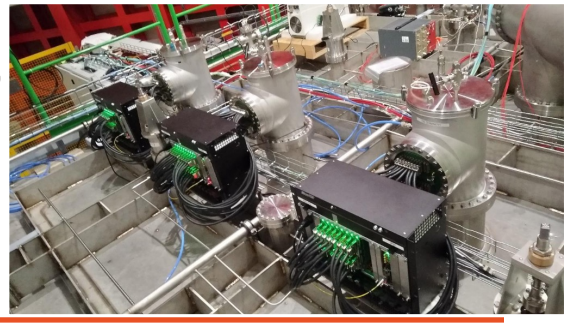
FD2-VD detector charge readout

- **Bottom Drift Electronics (BDE)**
  - Same concept as ProtoDUNE-SP
  - Front-End Mother Boards immersed in the LAr near the electrode
  - FE LArASIC charge amplifier and shaping

- **Top Drift Electronics (TDE)**
  - Evolution from Dual Phase
  - Accessible cryogenic analog front-end via the chimneys
  - uTCA digitization units with 40 Gbit/s connectivity located on the cryostat roof

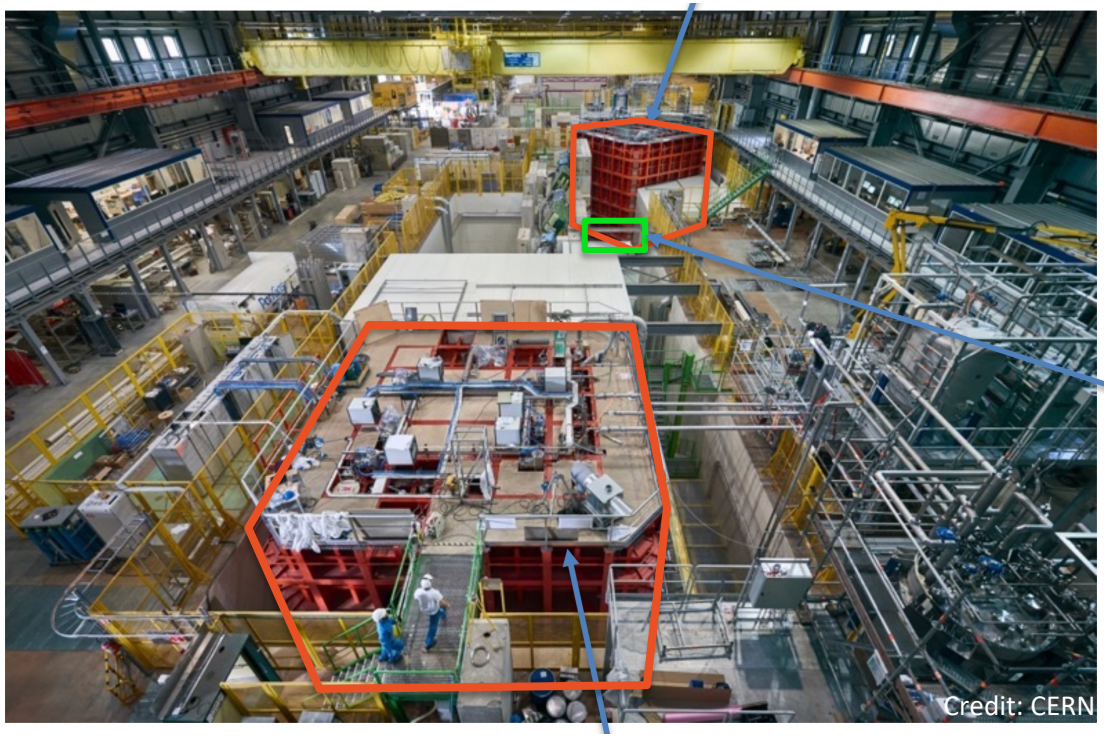






Prototypes development at CERN Neutrino Platform

ProtoDUNE VD (DP under decommissioning)

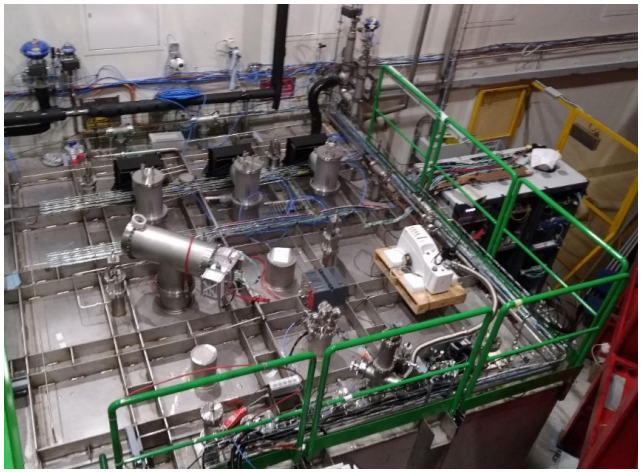


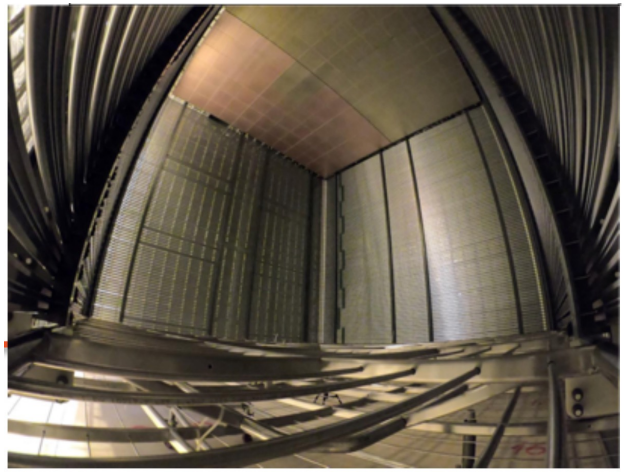
Coldbox VD (3x3x1 m)

ProtoDUNE HD (under upgrade)

Prototypes development at CERN Neutrino Platform

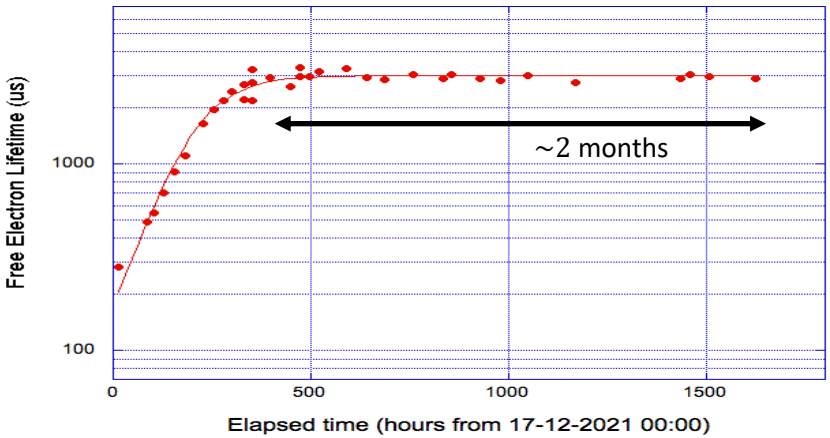
- 300 kV HV stability demonstrated within NP02 / 6 m drift over few months period
- Vertical drift test program started with a 50 L TPC (quick test of concept)
- Now testing full 3-views **Charge Readout Planes** + **Photon Detection System** in a 3x3x1 m^3 coldbox – few days time scale for installation – 23 cm long tracks
  - TDE and BDE electronics successfully tested with CRP1
  - Two strips configuration: $(48°, 0°, 90°)$ vs $(-30°, 30°, 90°$ – **CRP2 very soon in CB**)
- 2 x 2 CRPs (6x3x6 m^3) will be installed in Module-0 – data taking next year
  - Will allow to collect ~3 m long tracks in VD mode



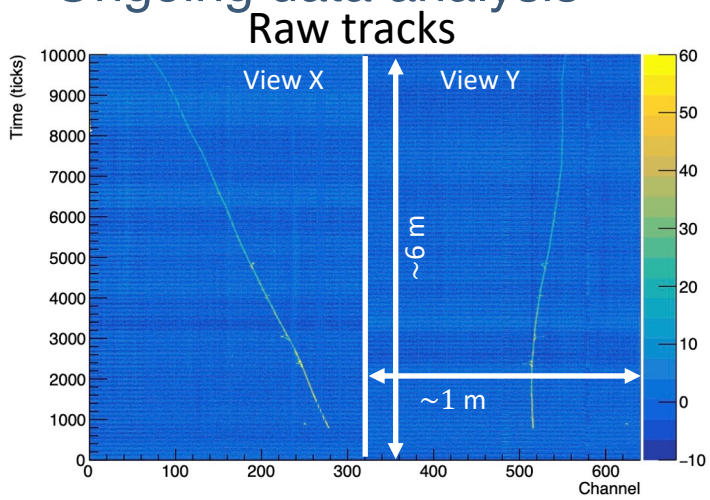


Closing studies on ProtoDUNE-DP

- **HV stability – Dec. 21 – Mar. 22**
  - New HV delivery system design validated
  - Very stable operation at **290-300 kV** with high LAr purity until end of run (Jan-Mar 2022)
  - ~500 V/cm homogeneous electric field delivered

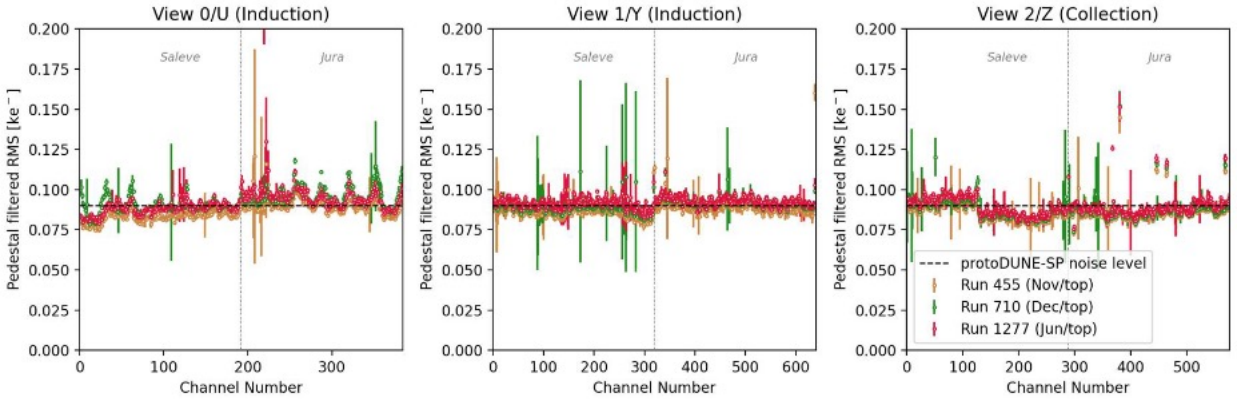


- **6 m long tracks – Feb. 2022**
  - -300 kV at the cathode
  - Up to 6 m drift x 1 m^2 active area
    longest tracks ever recorded in LArTPC!
  - No gas phase amplification ("à la vertical drift")
  - 2-3 ms electron lifetime
  - Ongoing data analysis



ColdBox tests

- **Allows to test at full scale the first VD CRPs based on perforated anode with TDE/BDE** → achieve ProtoDUNE-SP like noise level



Credit: L. Zambelli

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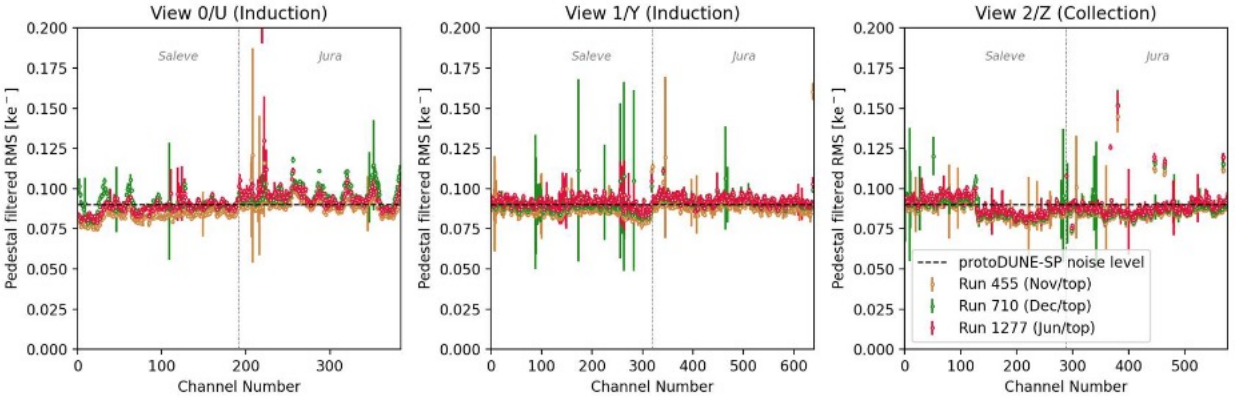
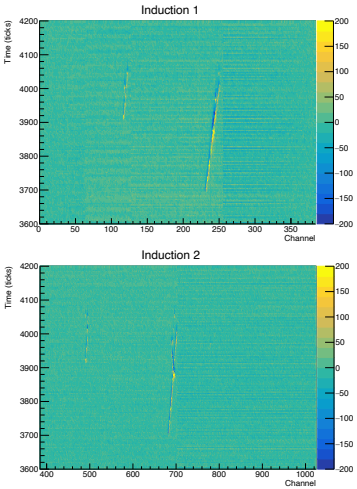
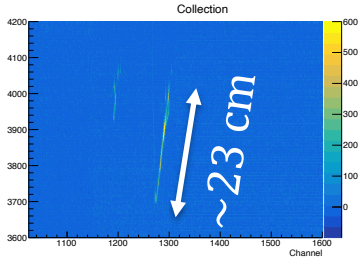


Credit: L. Zambelli

- **Understand signal formation in 3-view PCB holes based CRP**

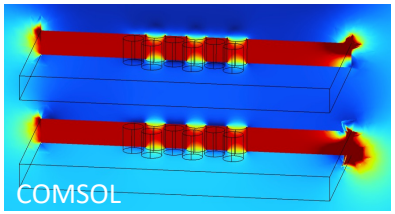


Data tracks

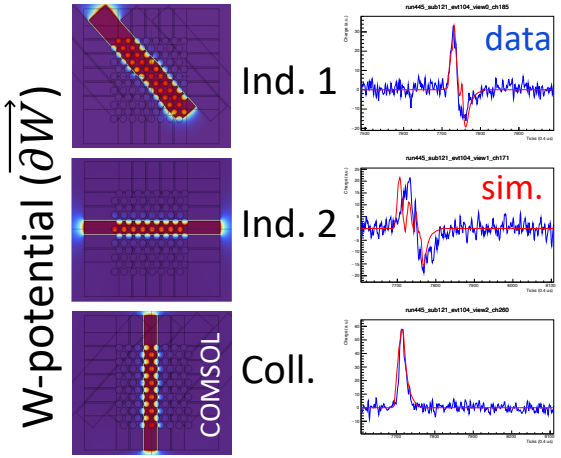


$$\boldsymbol{I = q\,\overrightarrow{\partial W}.\vec{v}}$$

E-field sim. ($\vec{v}$)

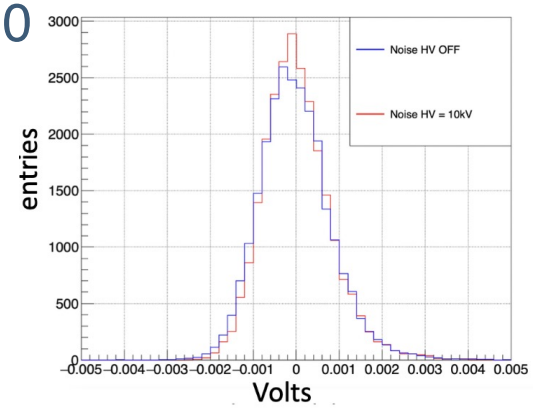


I	induced current
q	electron/ion charge
$\overrightarrow{\partial W}$	weighting field
$\vec{v}$	electron/ion speed ($f(\vec{E})$)

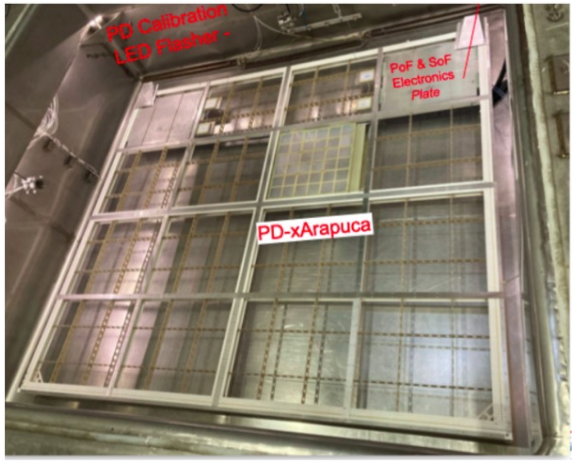


ColdBox tests

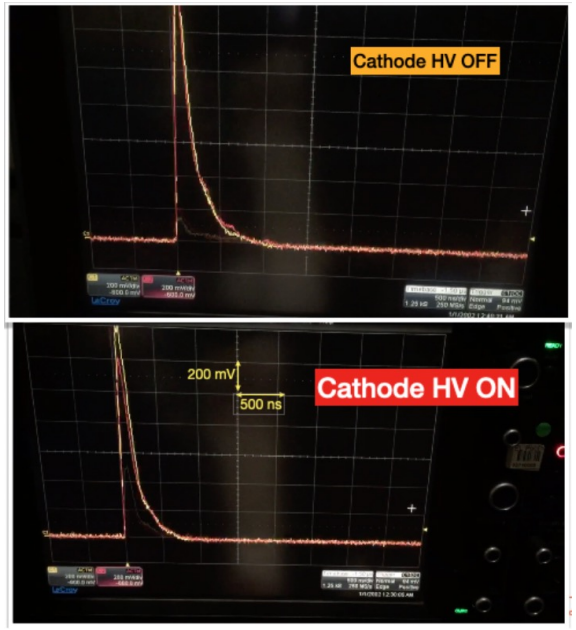
- **FD2-VD Photon Detector System**
  - Challenge: cathode PDS at -300 kV → no conductive wires
  - Power/Signal over Fiber concept validated in ColdBox
  - Both signal and noise level seen unaffected when HV ON
  - More validation/stability test to come in ColdBox and Module-0



ColdBox PDS

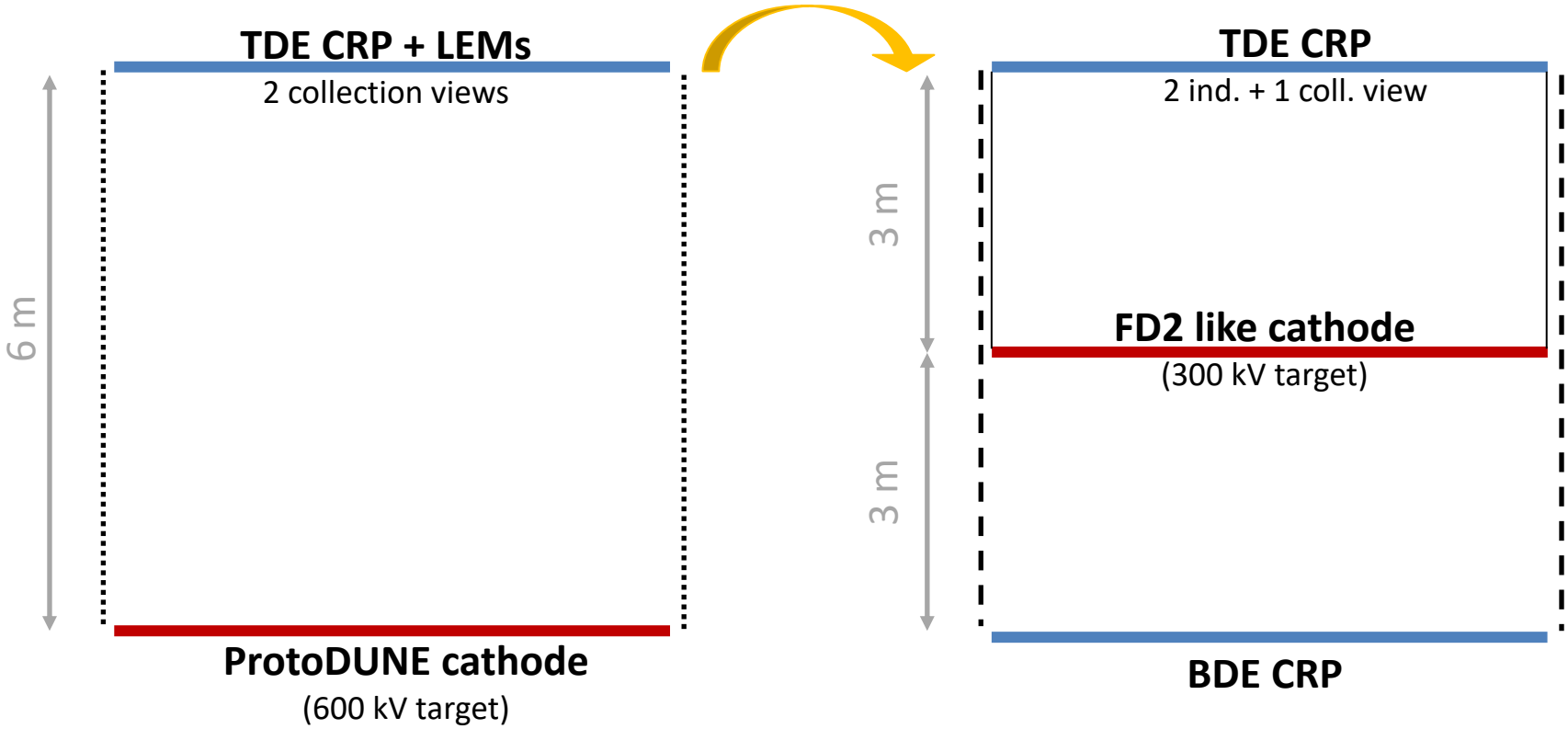


Signal over fiber readout for muon crossing

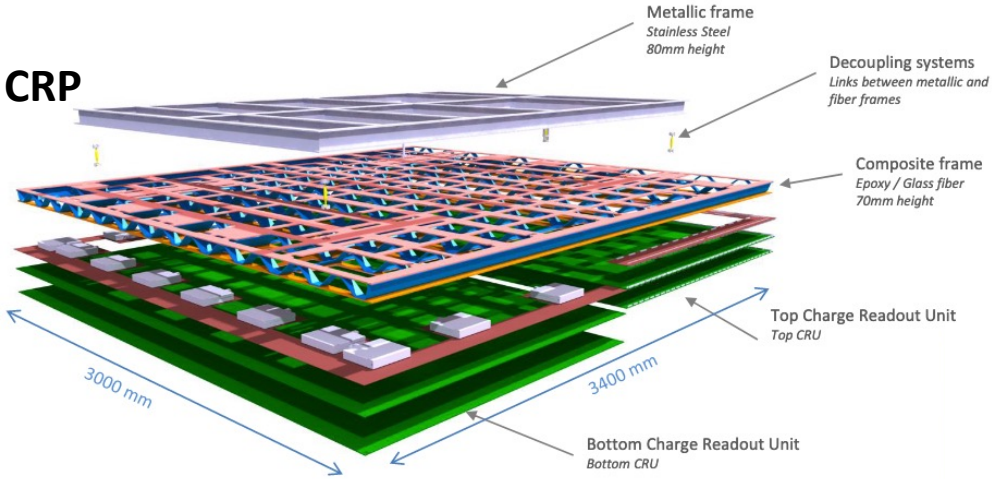


Vertical Drift Module-0 in NP02

- **ProtoDUNE-Dual Phase**
  - Needed to provide stable 600 kV
  - Liquid/gas interface ext. grid
- **ProtoDUNE-Vertical Drift**
  - Test of FD suspended cathode design + field cage profiles
  - Test of TDE/BDE + CRP + PDS



Vertical Drift Module-0 in NP02

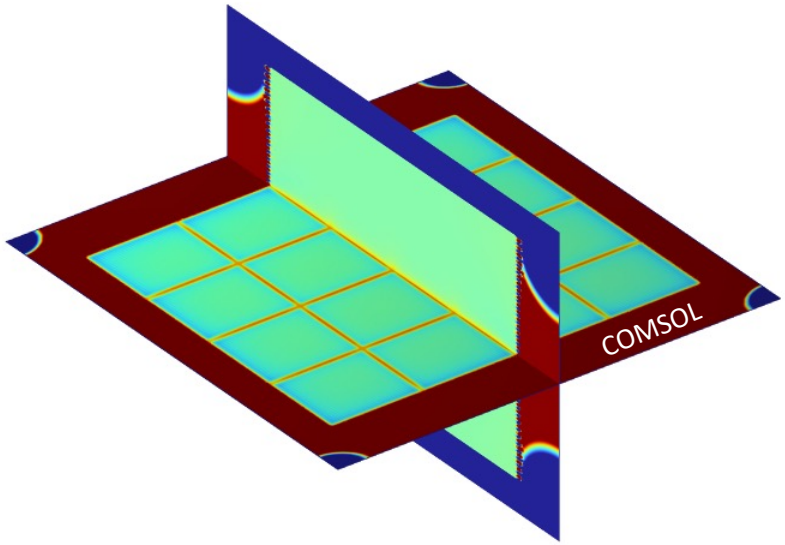


X-ARAPUCA PD electronics

Cathode before installation in the coldbox – 2022

ProtoDUNE-Vertical Drift

- Test of FD suspended cathode design + field cage profiles
- Test of TDE/BDE + CRP + PDS



- Field calculation to check for E-field homogeneity ($\Delta E \leq 1\%$)

Summary

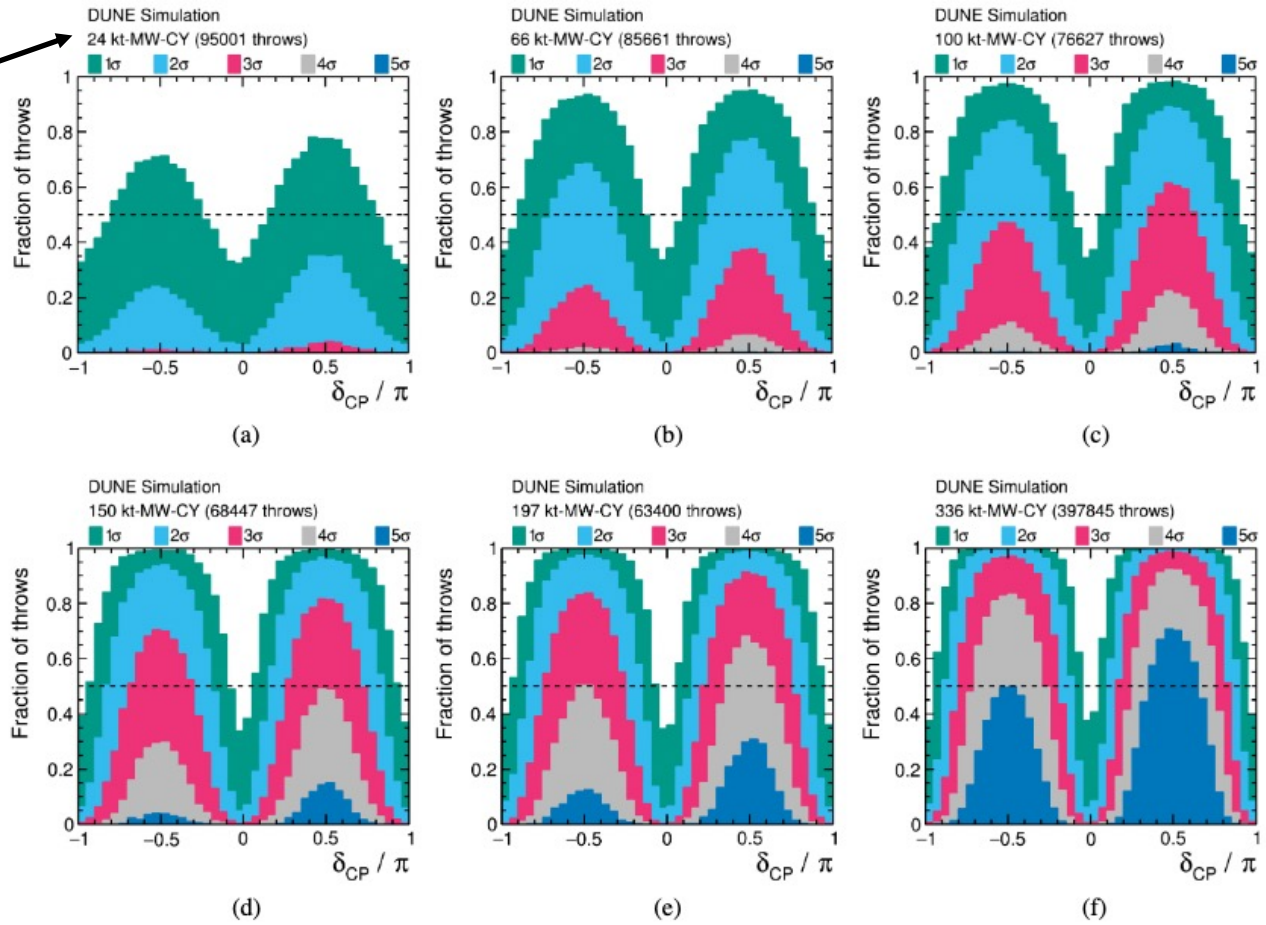
- **DUNE is committed to deliver high precision neutrino oscillation measurements, in particular MO, CPV and θ_{23}**
  - much more available given FD scale (nucleon decay, SNB, …)

- **A phased approach is foreseen**
  - starting with a 1.2 MW beam, ND and 2 FD
  - upgradable to 2.4 MW beam, highly capable ND and 4 FD modules

- **The Vertical Drift FD design is well advanced with many validation tests achieved and underway at CERN**

Low exposure δ_{CP} sensitivity

~1 year at
10(FD1)+14(FD2) kt
& 1 MW



See Low exposure long-baseline neutrino oscillation sensitivity of the DUNE experiment
Phys.Rev.D 105 (2022)