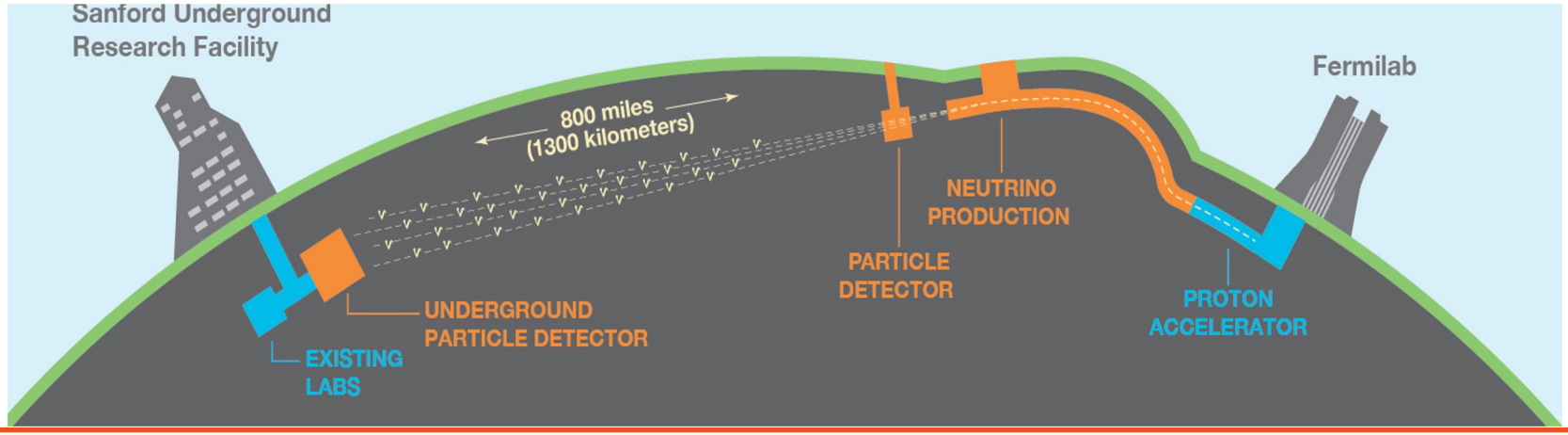
The DUNE experiment

Towards measurements of neutrino Mass Hierarchy, CP violation and more

Yoann Kermaïdic

Workshop France - Ukraine – IJClab

June 11, 2025



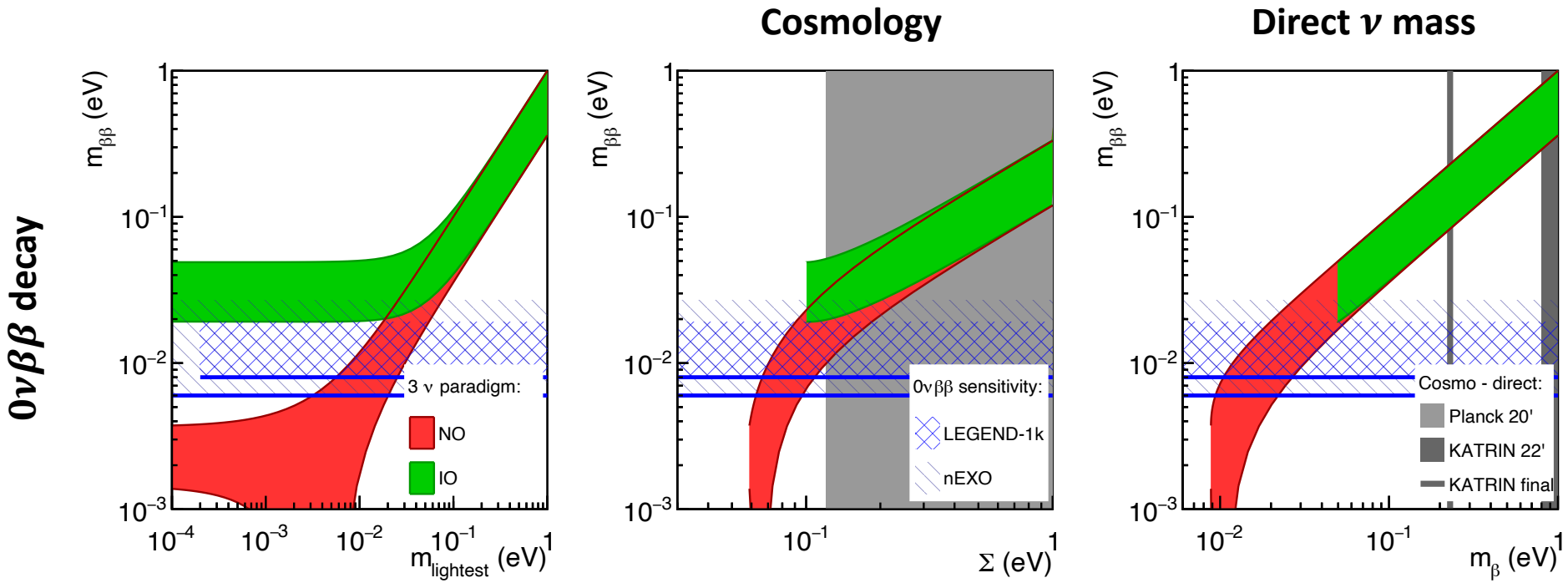
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis
université PARIS-SACLAY
cnrs
DUNE

Outline

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

The 3ν paradigm in one slide

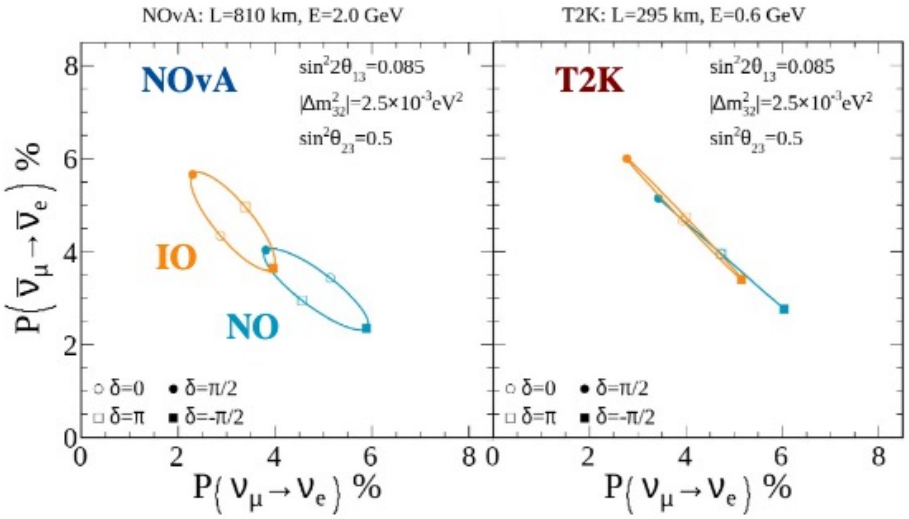
- Testing the light 3ν paradigm requires inputs from the entire neutrino community and more!
- Neutrino osc. experiments must unambiguously measure the mass ordering – a potential strong impact w.r.t. next-gen $0\nu\beta\beta$ decay exp.



Current sensitivity to MH & CP

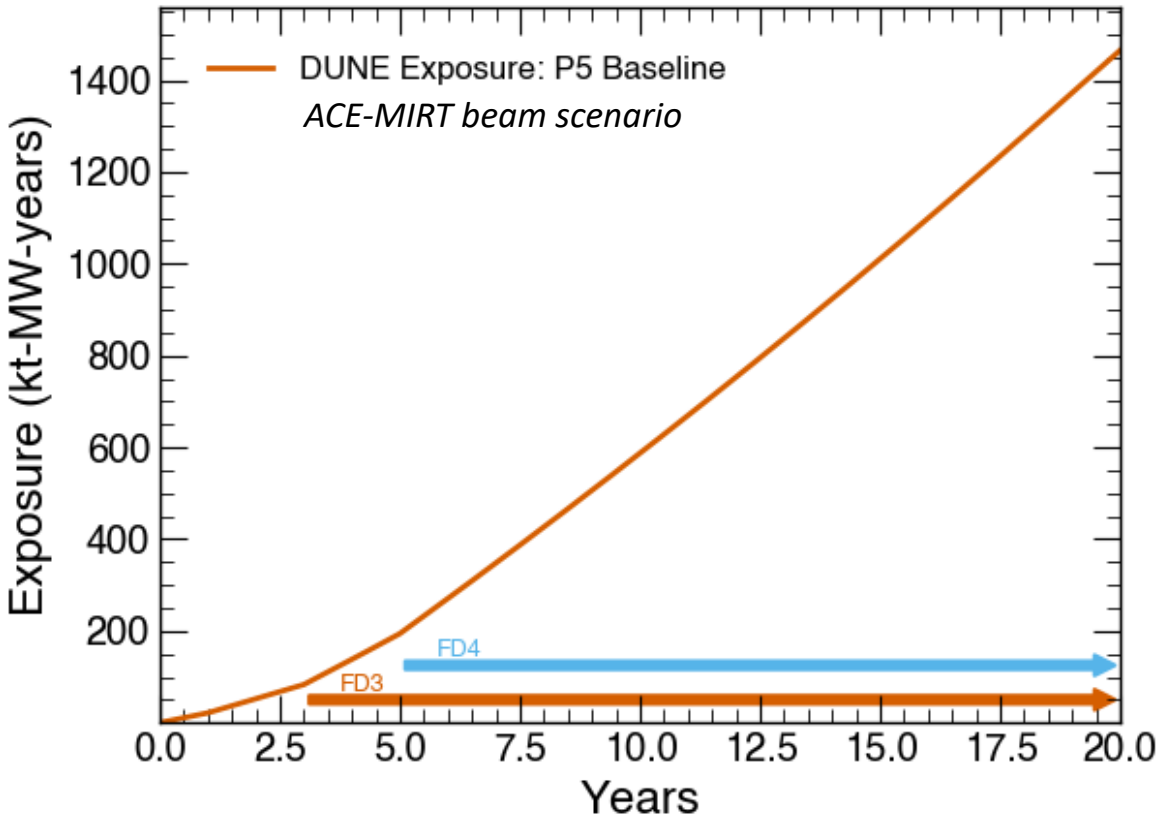
- T2K / NOvA currently accumulating statistics since 2010 / 2014 resp.
  - 0.75 MW / 0.8 MW
  - 295 km / 810 km
  - 0.6 GeV (<1 GeV) / 2 (<3 GeV) GeV neutrinos
- Weak « bi-plot » separation between IO/NO – Best fit NO @ $\sim 2\sigma$
- Sensitivity to the CP violating phase : combined fit to be published

https://pos.sissa.it/476/153



DUNE data taking time scale

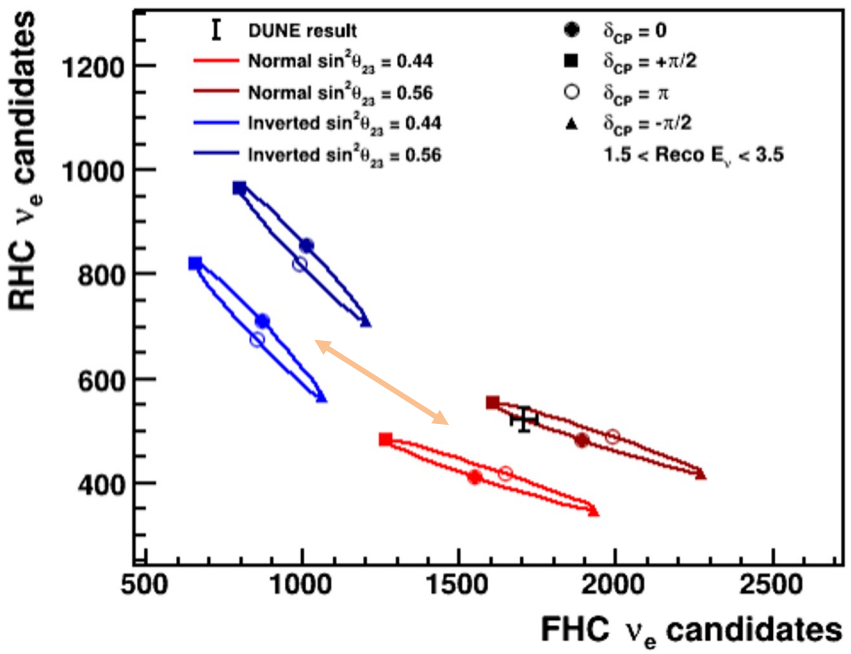
- Statistics accumulation depends on the phasing (see P5 report)
- Full project spans over 20 years, i.e. 1400 kt.MW.years



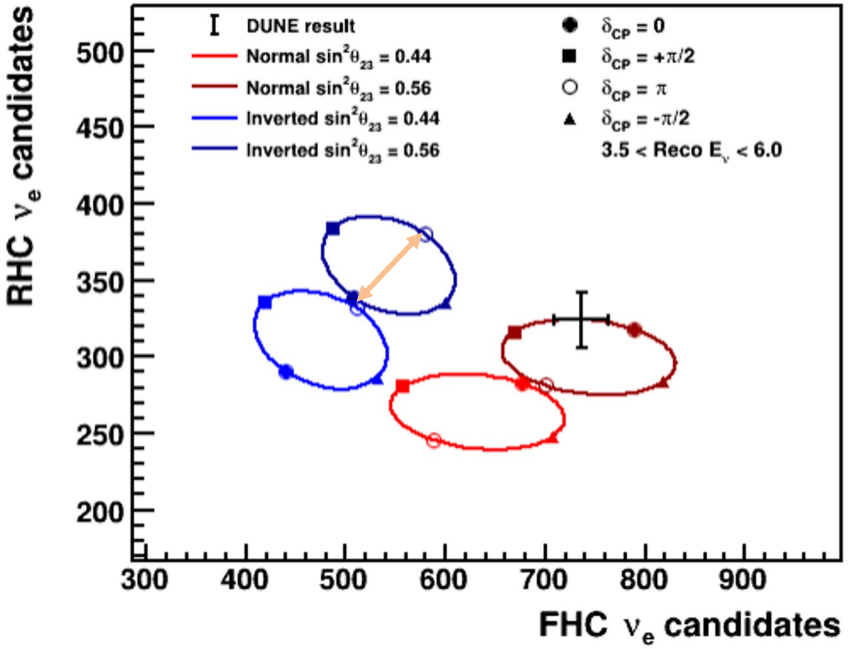
DUNE's plot

- 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

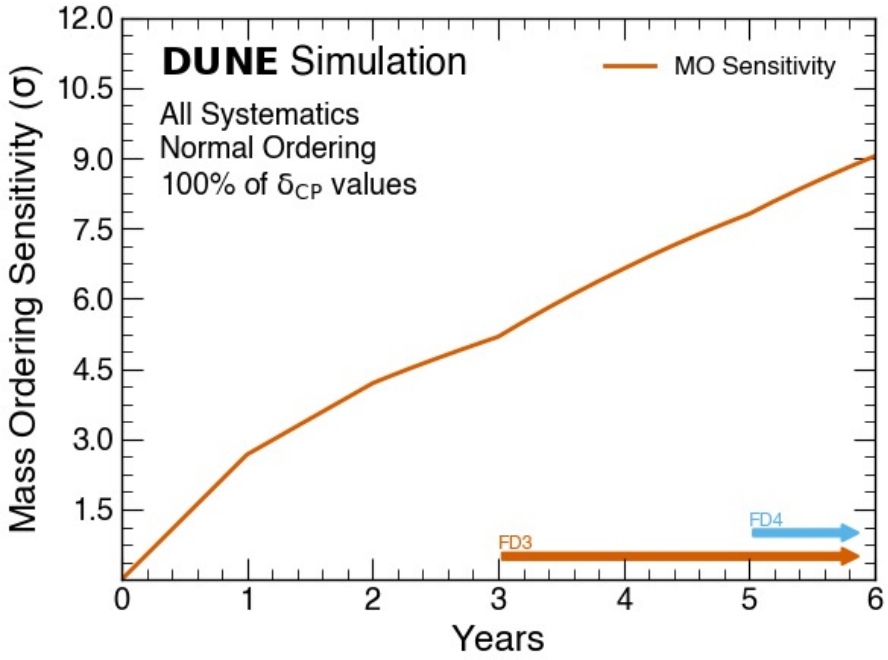


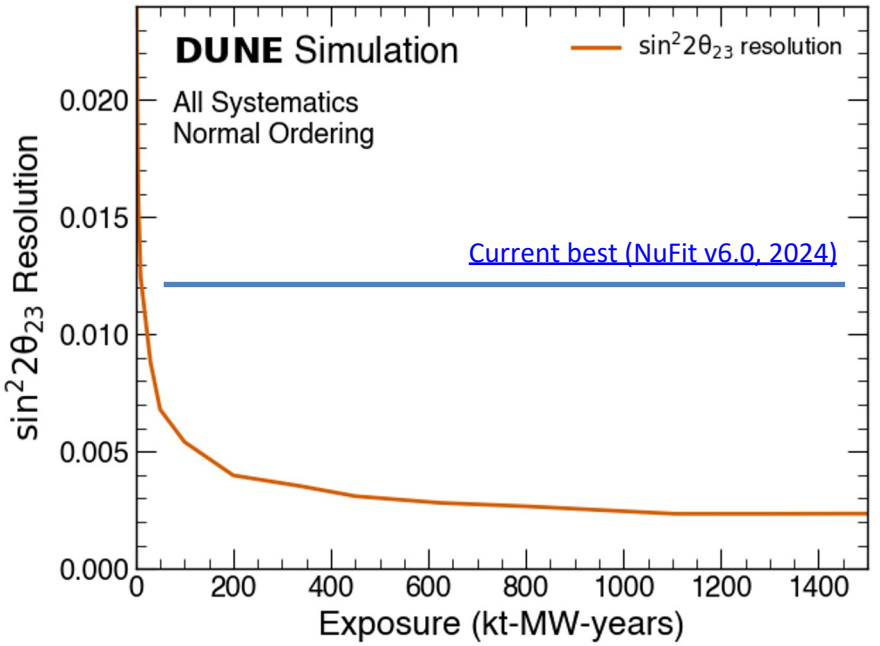
700 kt-MW-yrs, Higher energy



Improvement in sensitivity

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

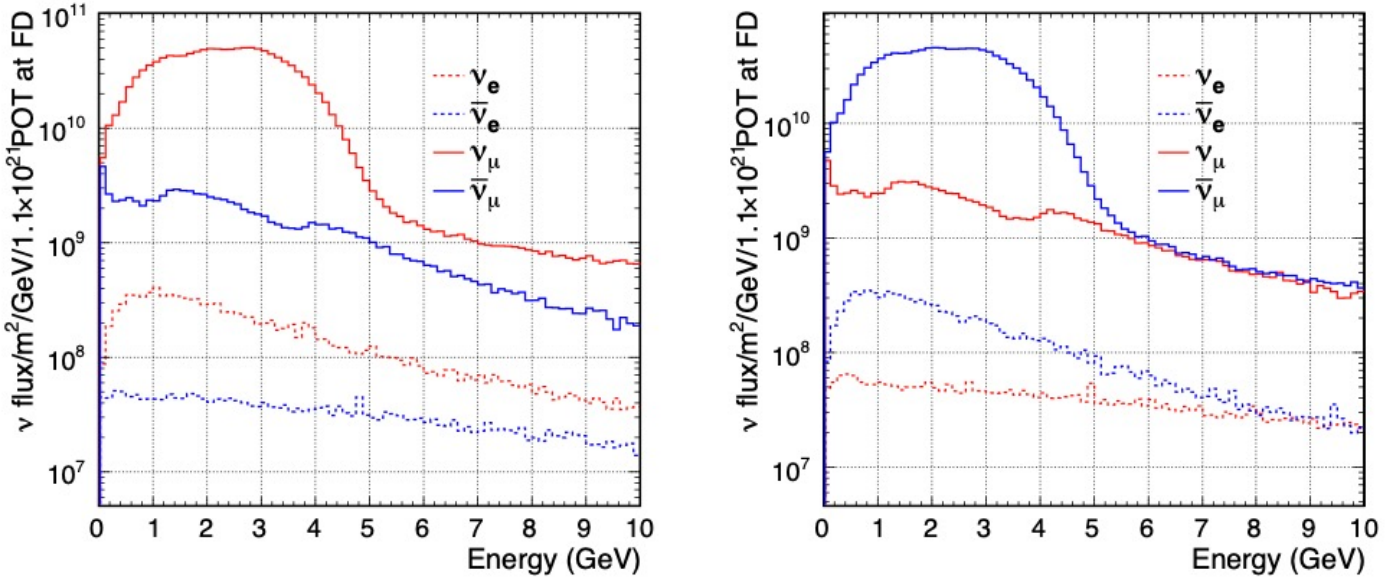




See Snowmass
DUNE Physics summary
https://arxiv.org/pdf/2203.06100.pdf

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

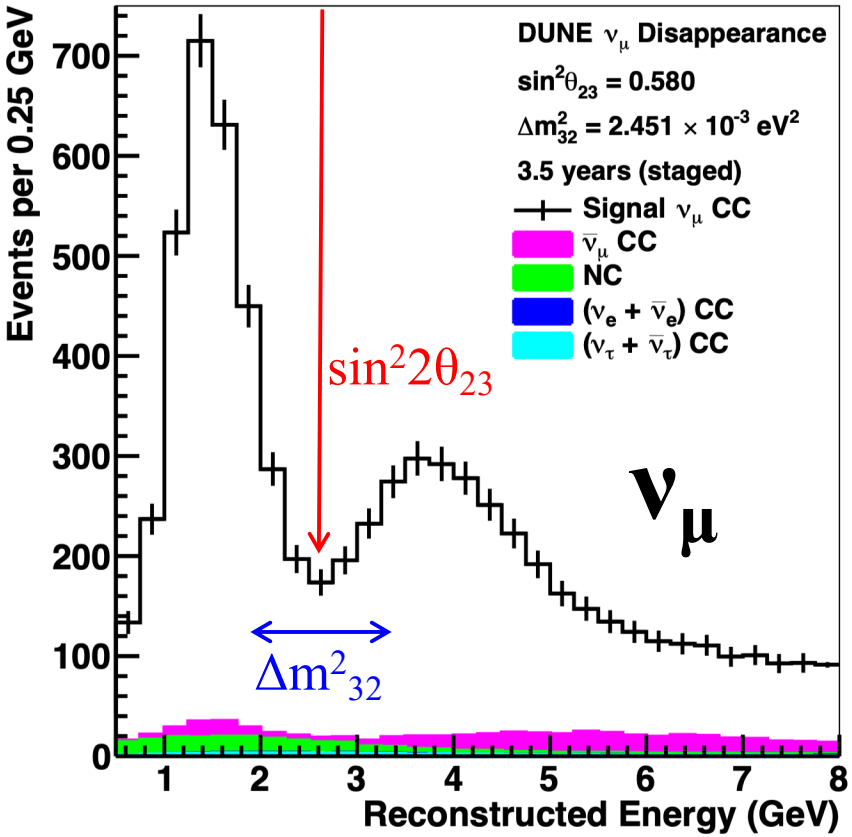


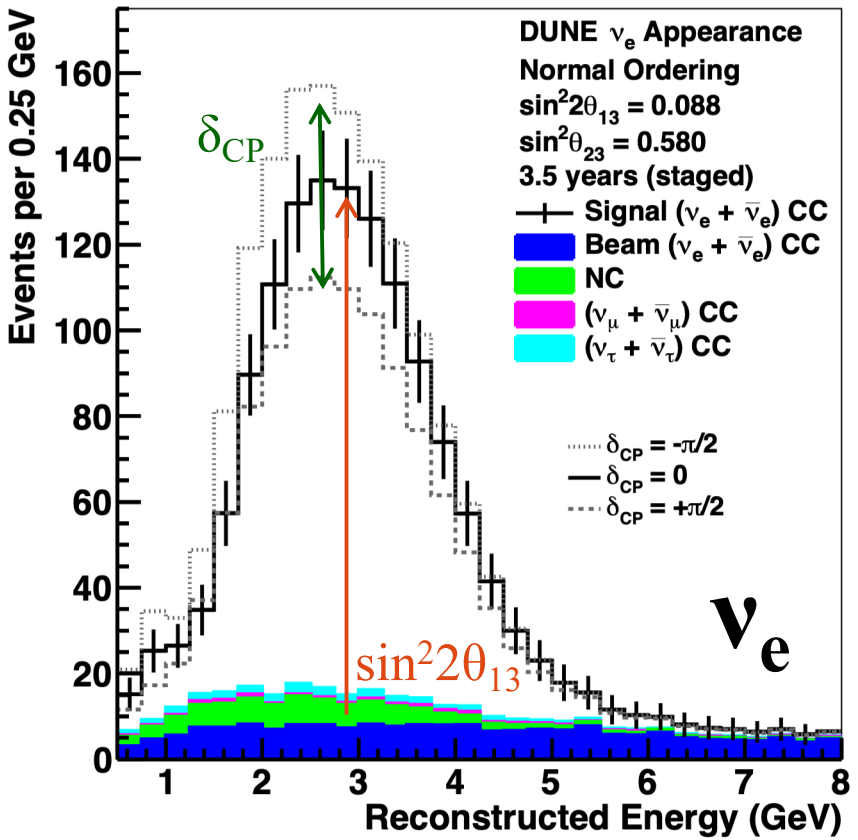
B. Abi, et al., (DUNE Collaboration), Long-baseline neutrino oscillation physics potential of the DUNE experiment Eur. Phys. J. C 80 10, 978 (2020)

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

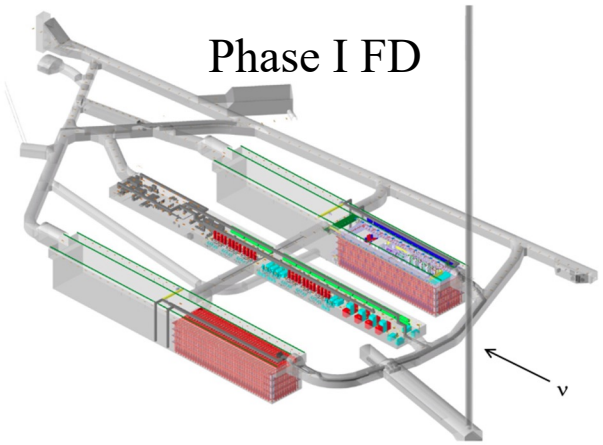
- DUNE construction is phased to provide continuous progress toward physics goals beginning this decade.

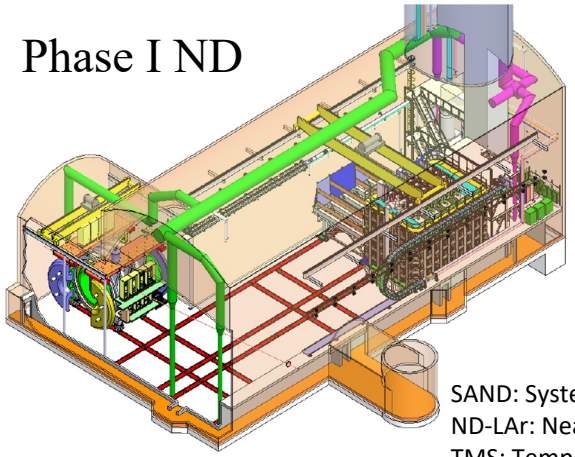
Phase I

- 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.



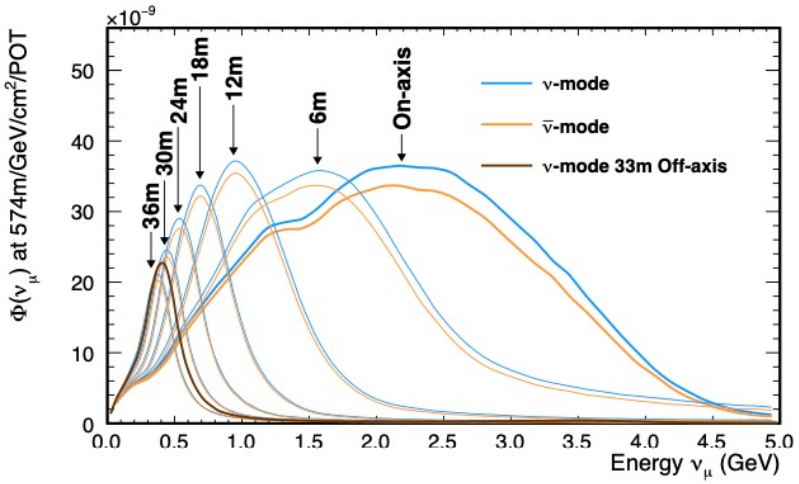


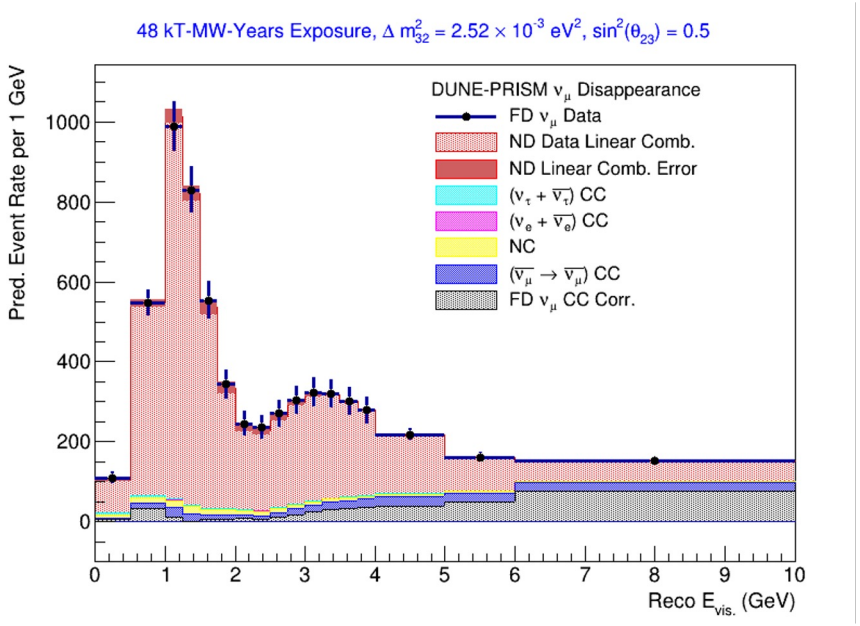
Near Detector CDR
arXiv:2103.13910

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.

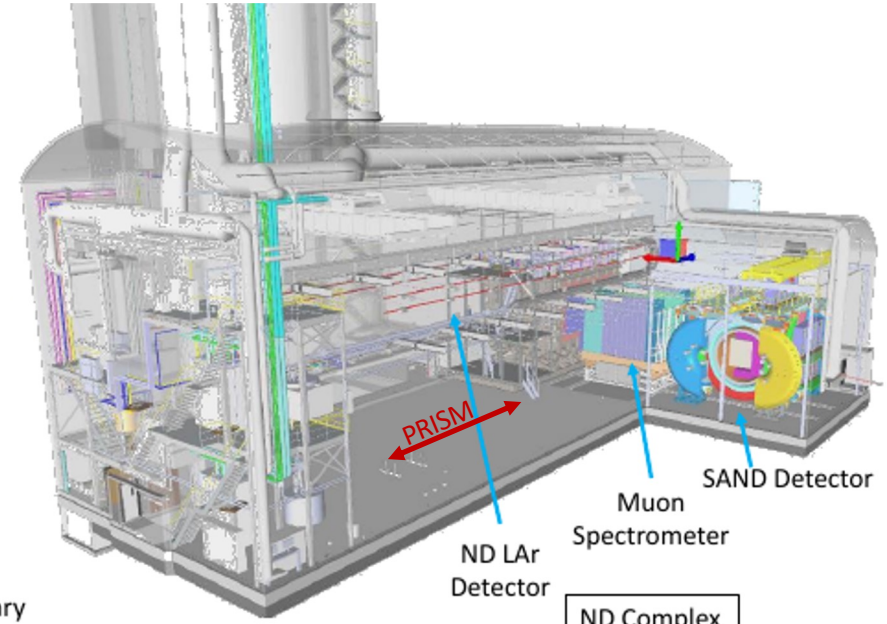


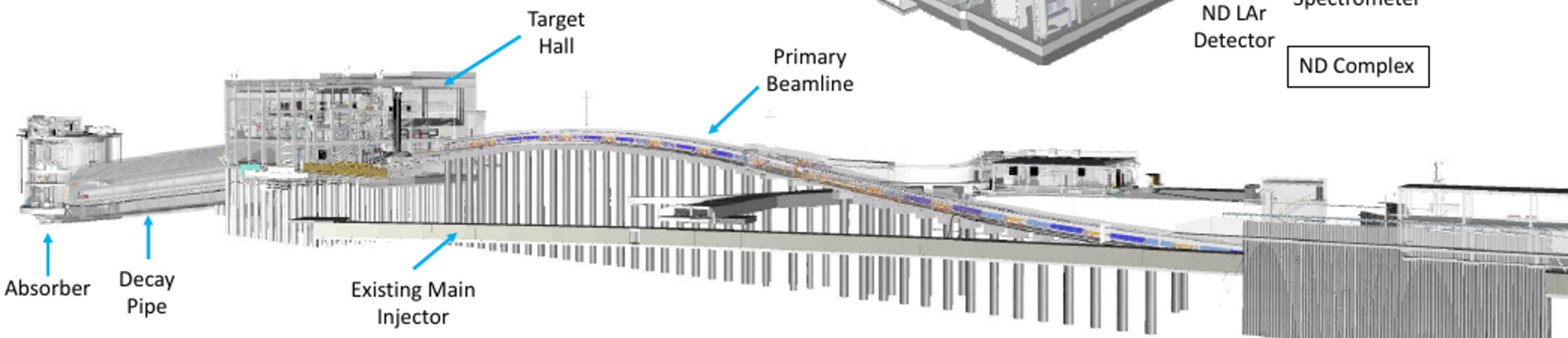


- Initially developed in the context of T2K and Hyper-K (NuPRISM)

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





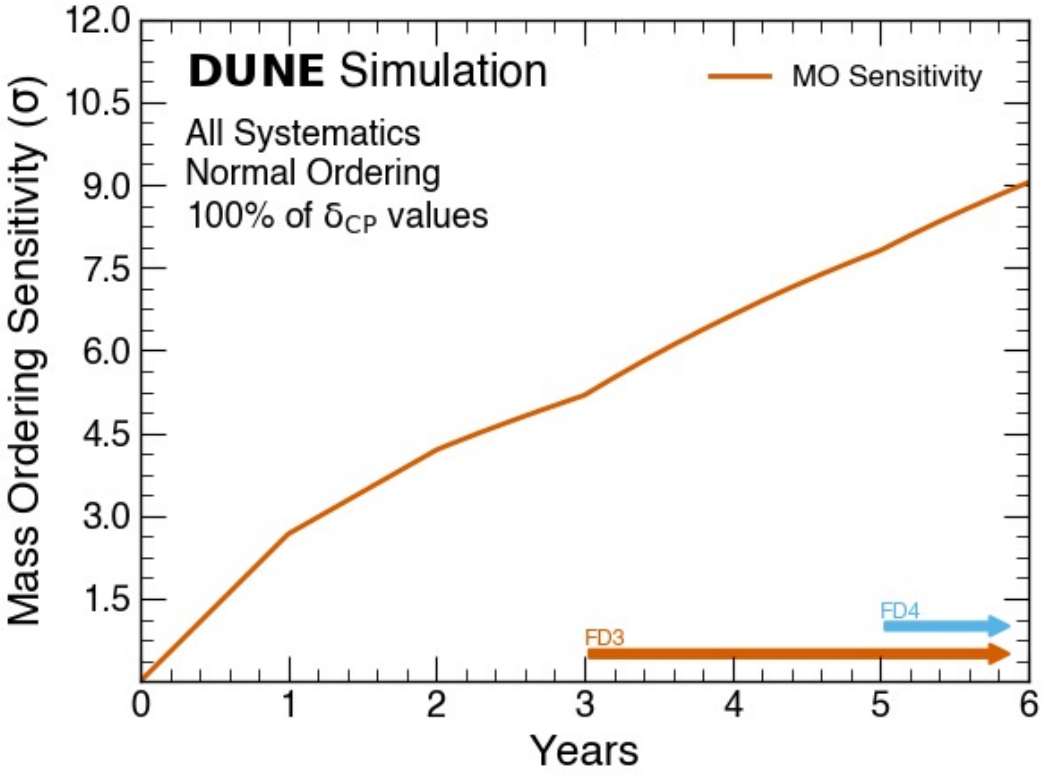
Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

Far site at SURF

- Excavation is 100% complete
- Waiting for authorization to start the assembly

Phase I main achievements

- 5 sigma sensitivity on the Neutrino Mass Ordering



- And development of the atmospherics and low energy (solar, supernova, DSNB) neutrino programs

DUNE Plans and Installation

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Phase I

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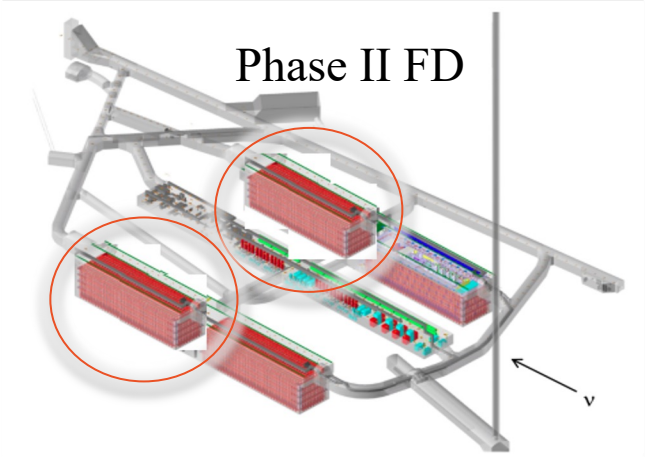
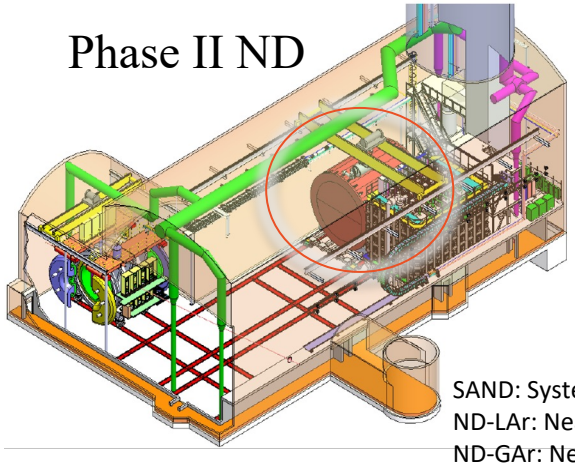


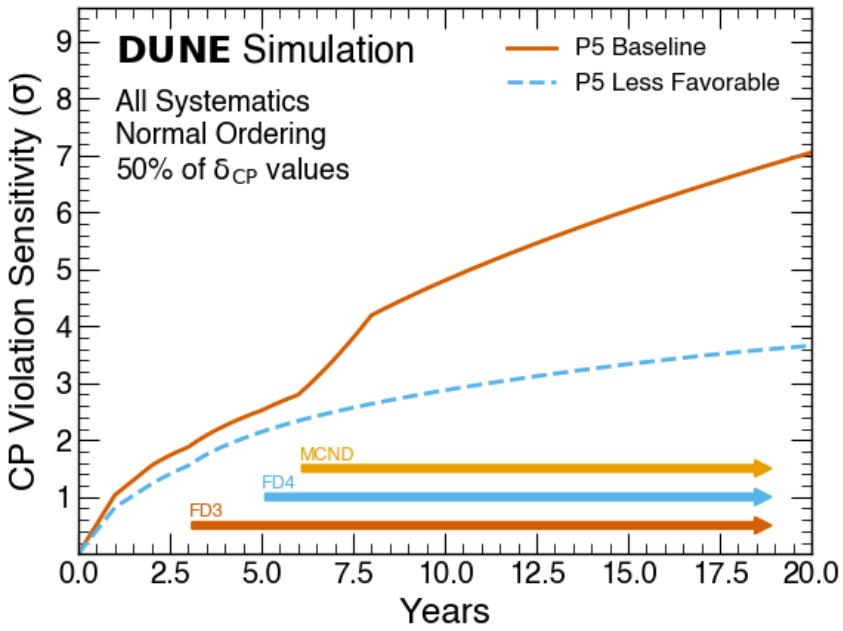


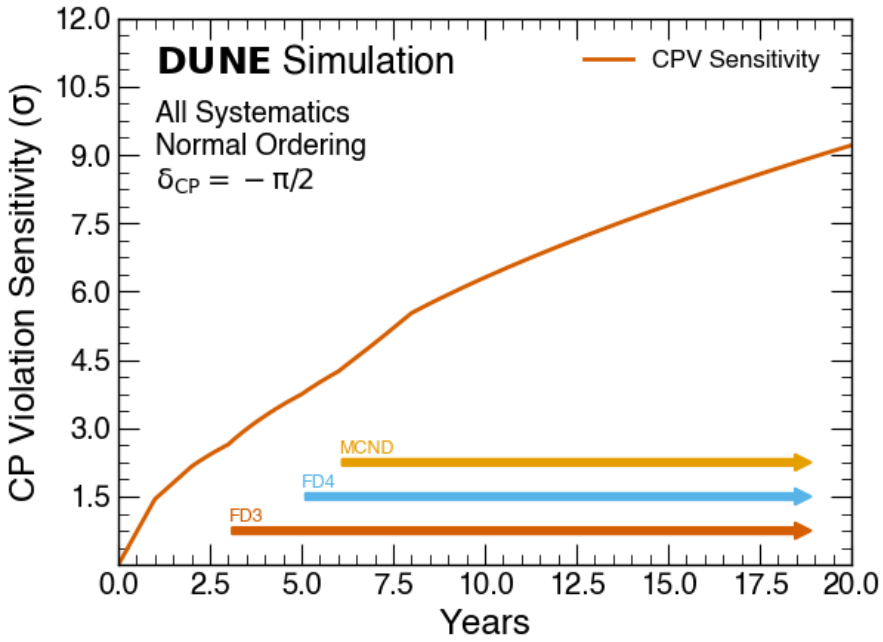
Near Detector CDR
arXiv:2103.13910

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

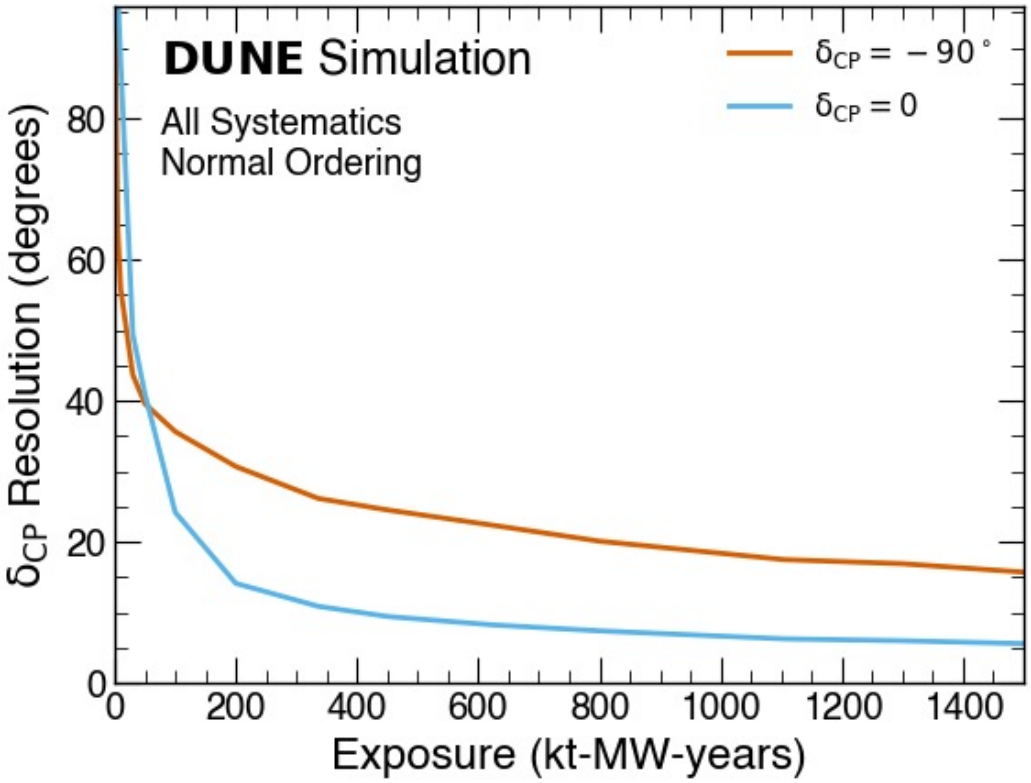




See Snowmass
DUNE Physics summary
https://arxiv.org/pdf/2203.06100.pdf

Phase II upgrade impact

- Unprecedented resolution on δ_{CP} will be achieved with the full DUNE's program



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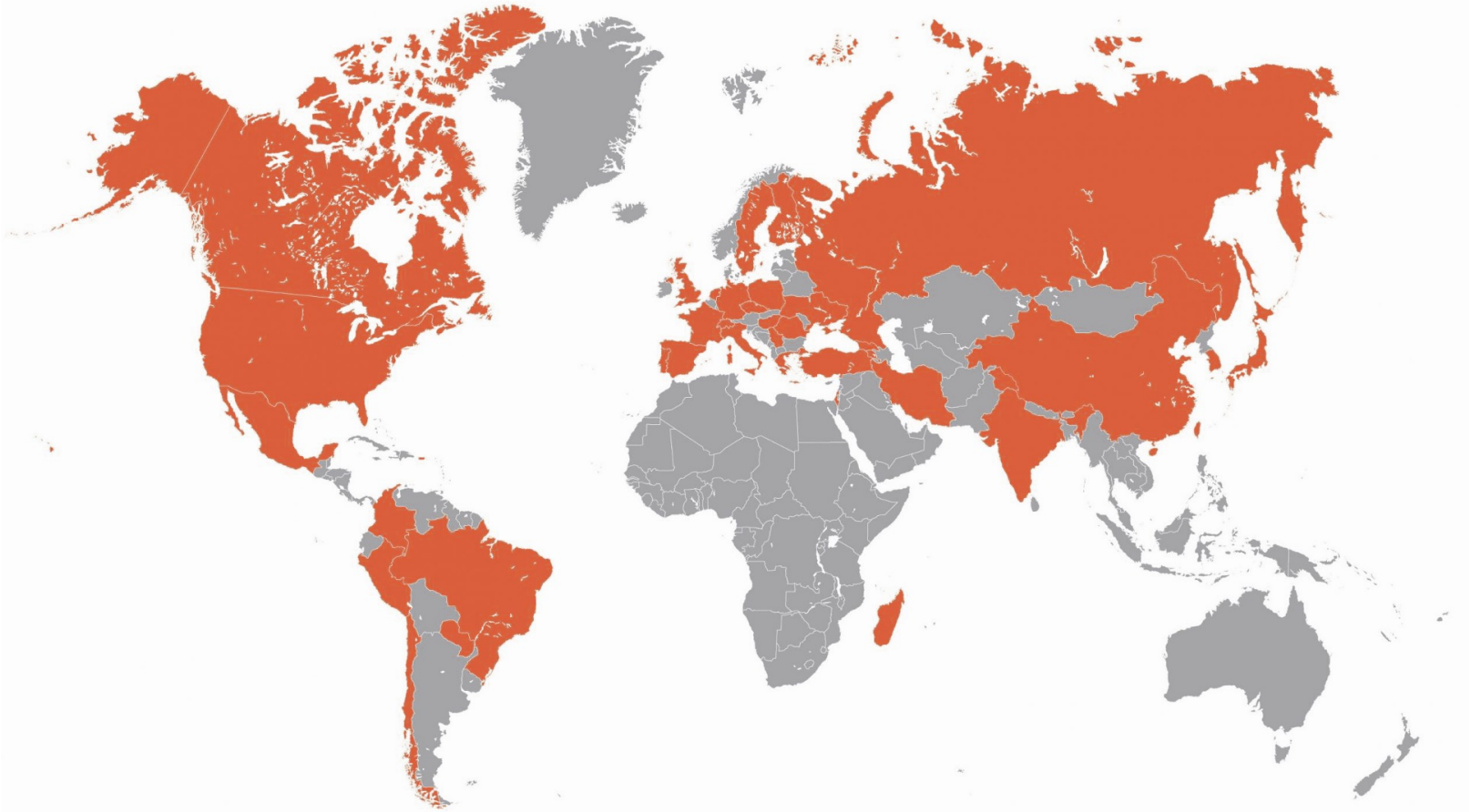
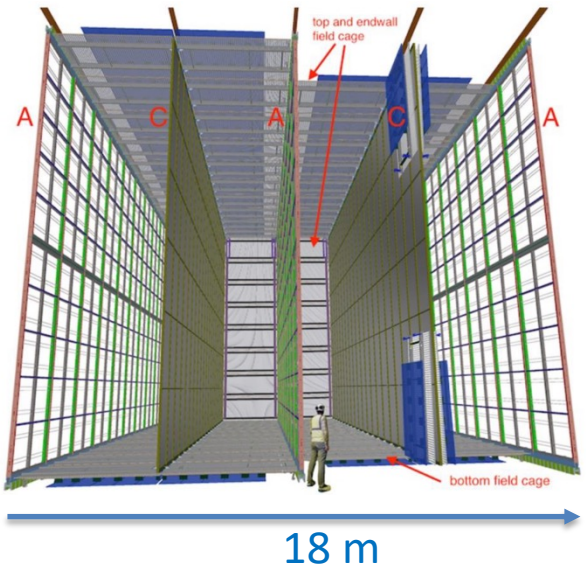
The DUNE collaboration

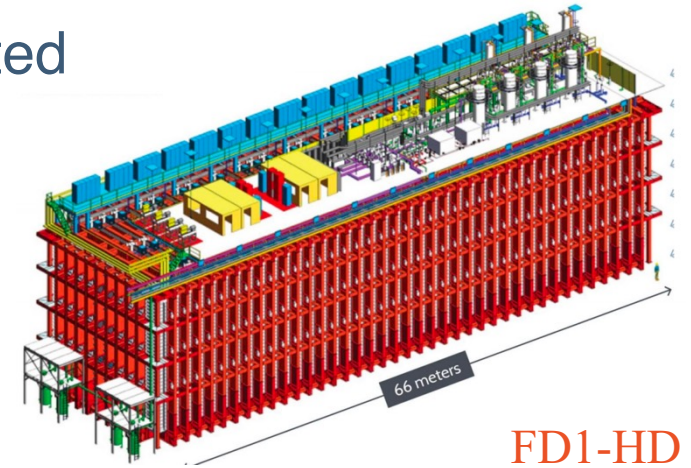
- DUNE is an international collaboration of >1300 scientists and engineers from 37 countries + CERN (and counting)



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

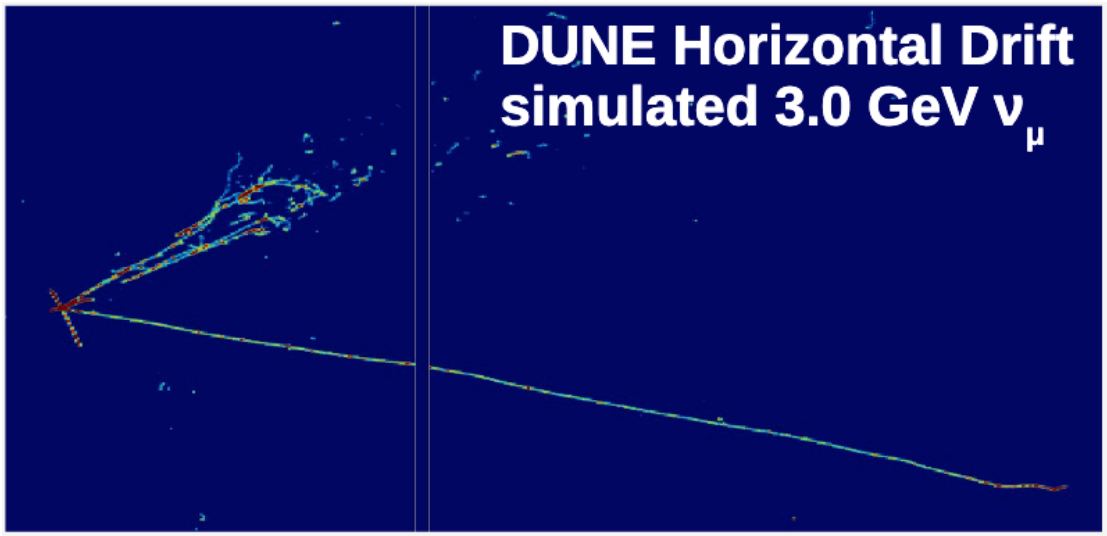


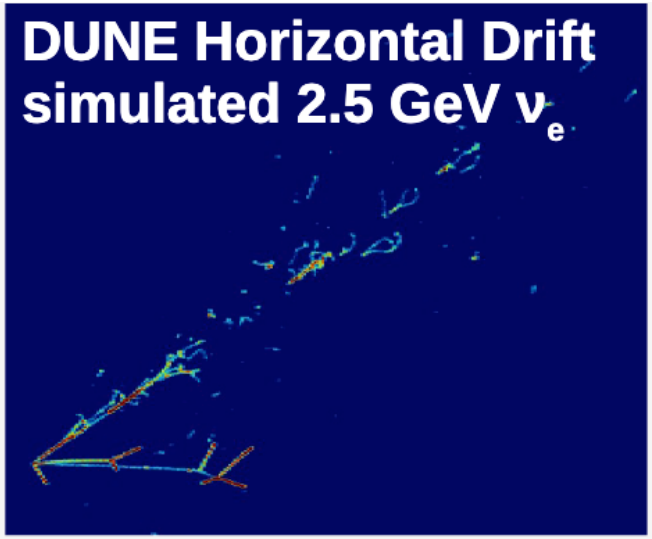


FD1-HD

High resolution imaging detector

- 60% of interactions at DUNE energy have final state pions → LArTPC enables precise hadron reconstruction
- Excellent e/μ and e/γ separation

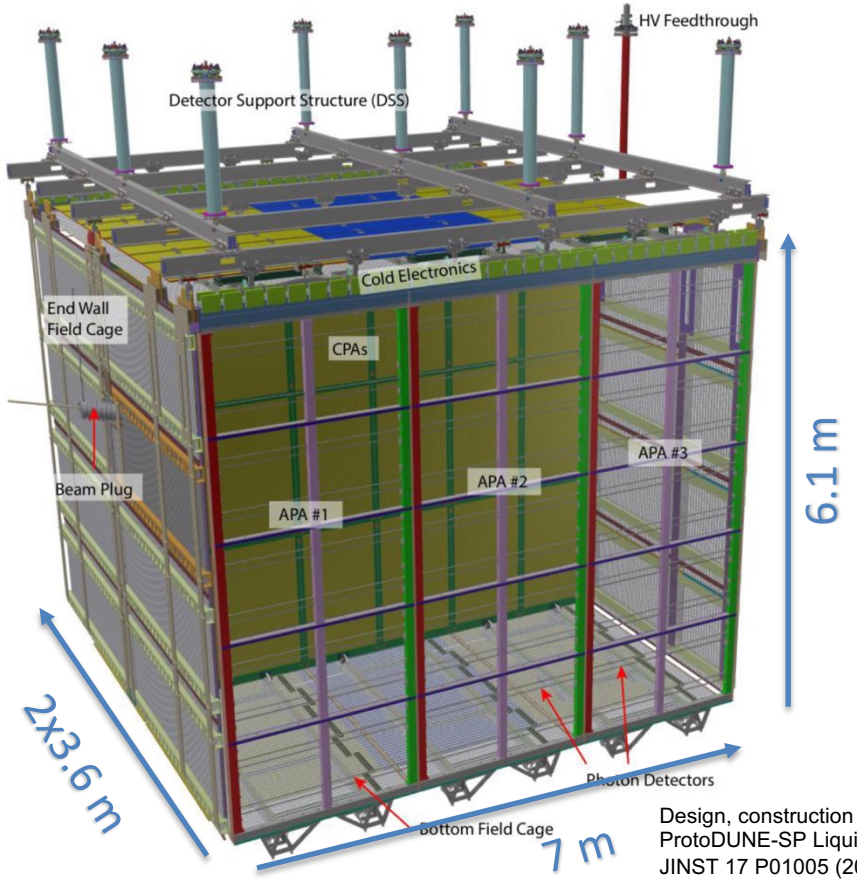


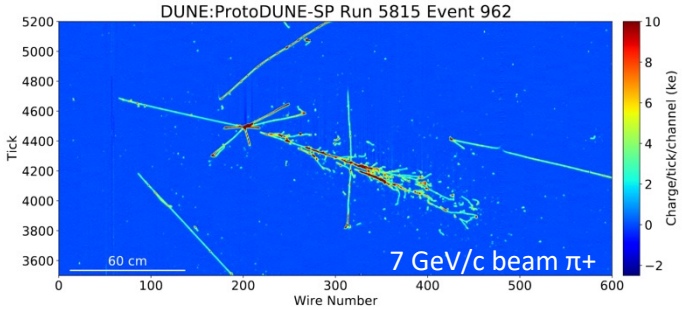


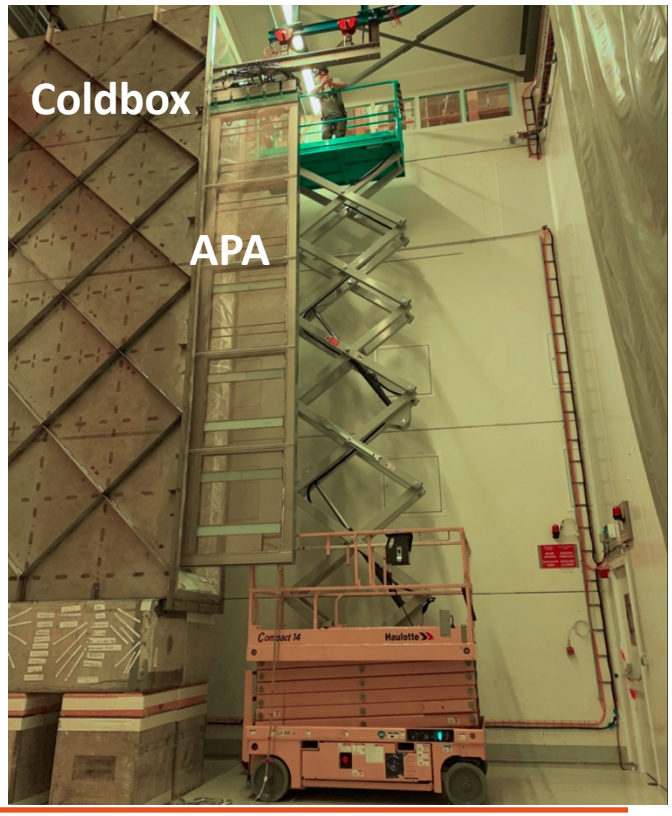
Separation of track- and shower-like energy deposits in ProtoDUNE-SP using a convolutional neural network
https://arxiv.org/pdf/2203.17053.pdf

Validation of concept at CERN

- ProtoDUNE-Single Phase (2018-2020)
- ProtoDUNE-Horizontal Drift (2024)



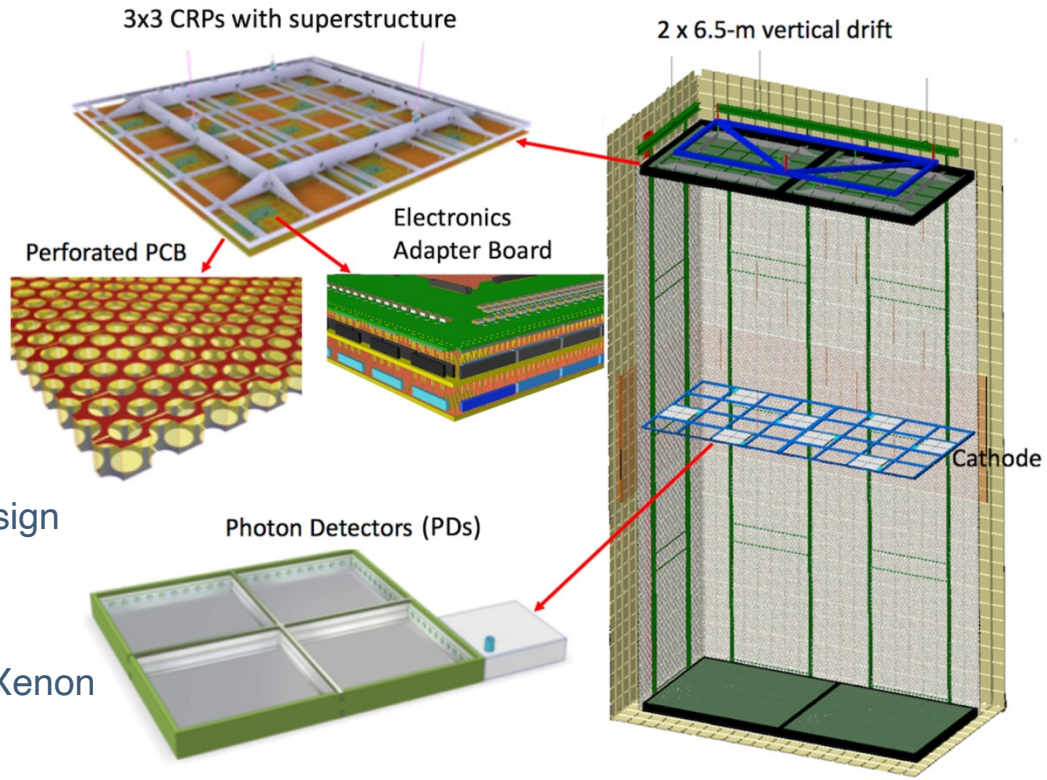




Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC
JINST 17 P01005 (2022)

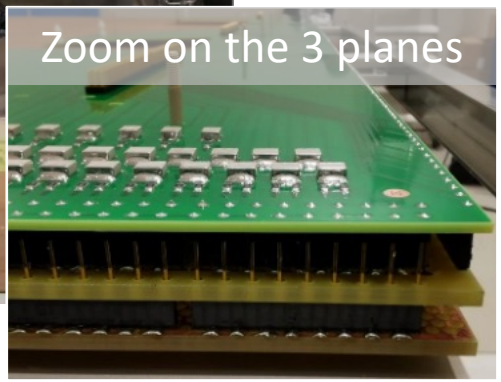
FD2-Vertical drift detector design

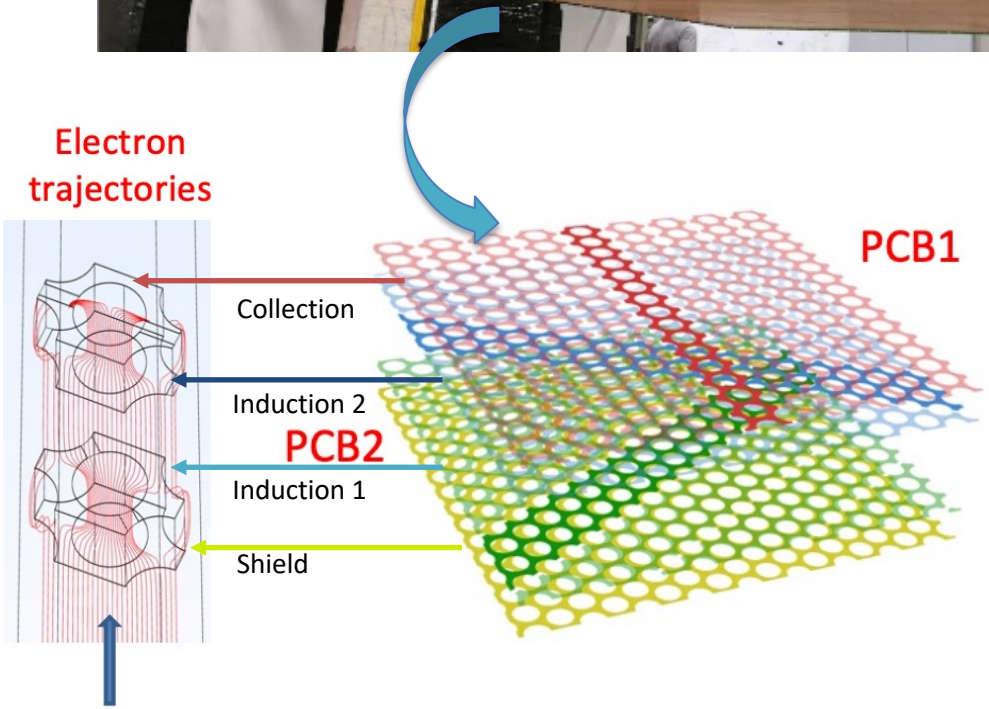
- 2 x 6.5 m vertical drift with horizontal Printed Circuit Board anode and cathode planes and photon detector
- **Charge readout:**
  - Drift along vertical direction and cathode plane in the middle
  - Readout on strips etched on PCBs
  - Two induction and one collection readout planes
  - Cathode at -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)

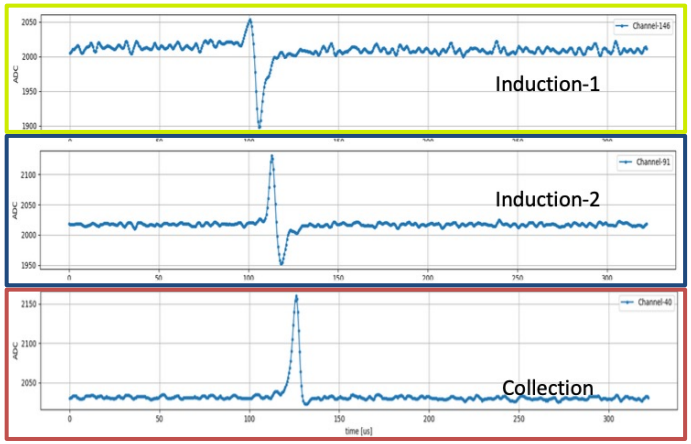


- **Full Monte-Carlo + sensitivity studies ongoing**
  - So far, FD1-HD design considered

FD2-VD detector charge readout





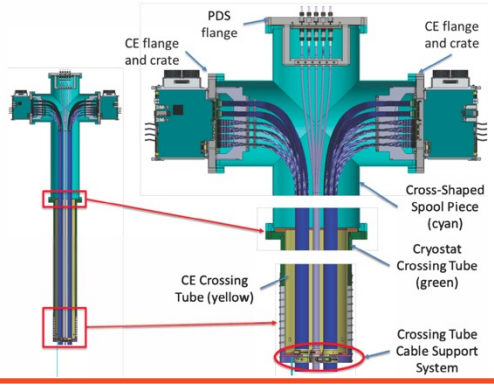


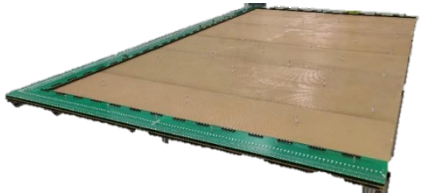
See Francesco Pietropaolo seminar at CERN on VD far detector
https://indico.cern.ch/event/1103484/

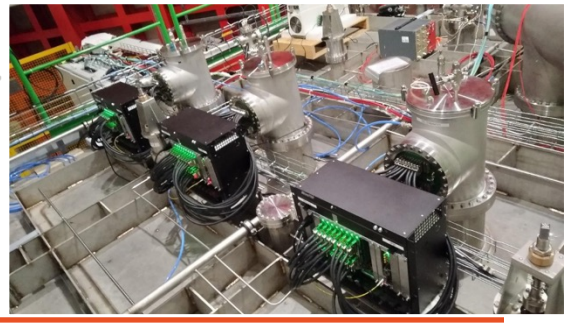
FD2-VD detector charge readout

- **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

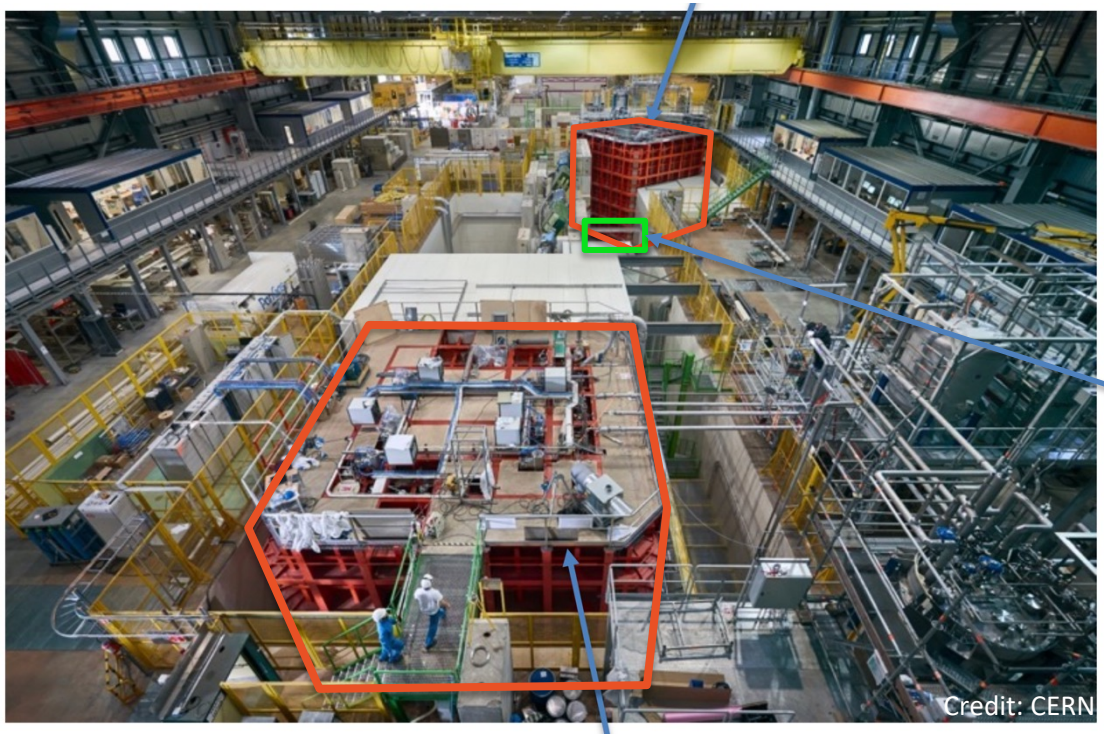






Prototypes development at CERN Neutrino Platform

ProtoDUNE VD (Filled with LAr)

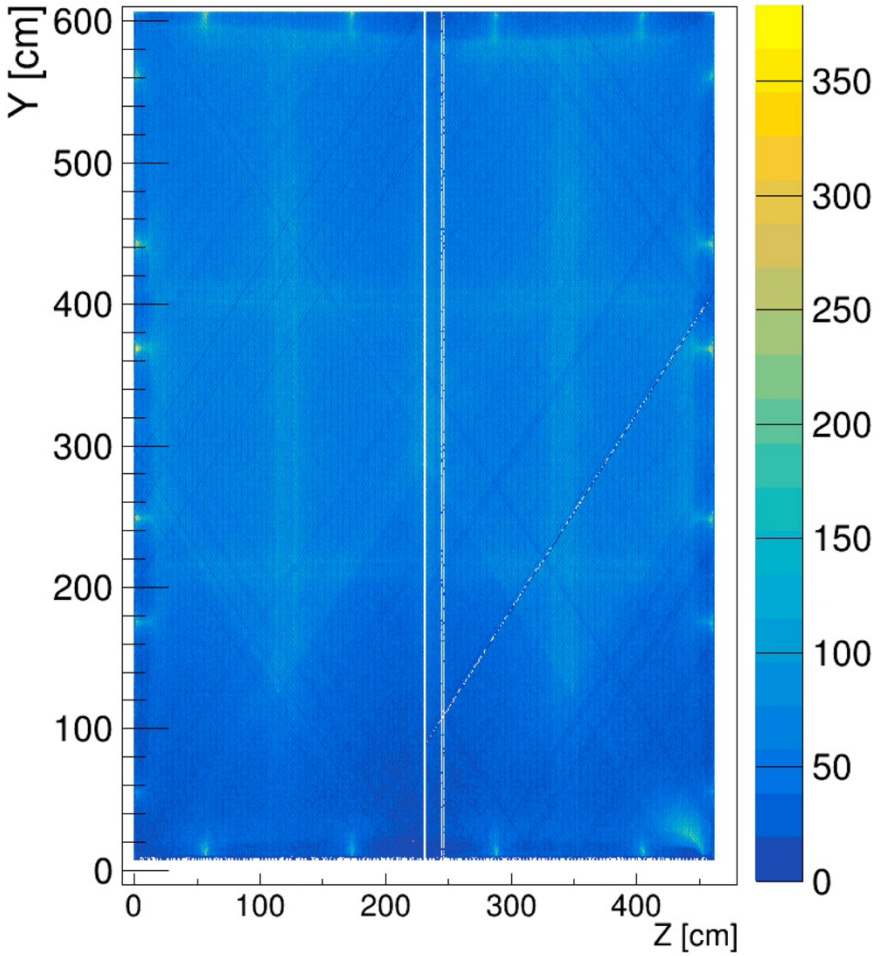


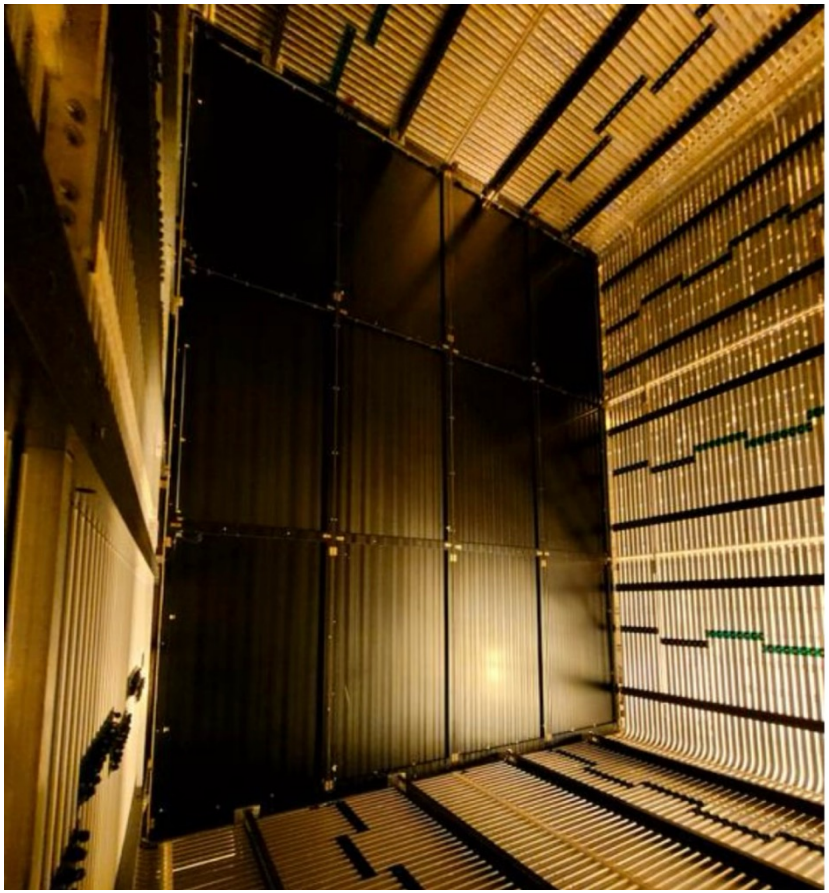
Coldbox VD (3x3x1 m)

ProtoDUNE HD (empty and at room temperature)

ProtoDUNE-HD low energy studies

- Example of low energy event reconstruction at IJClab (E. Lavaut)





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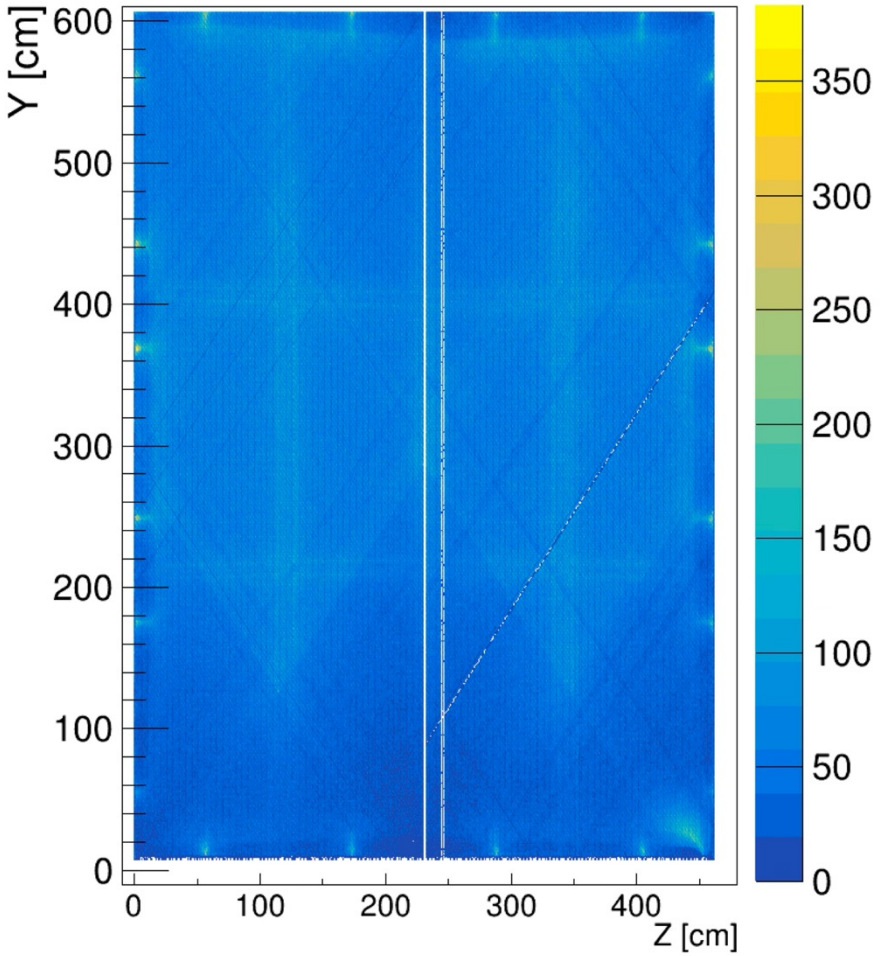
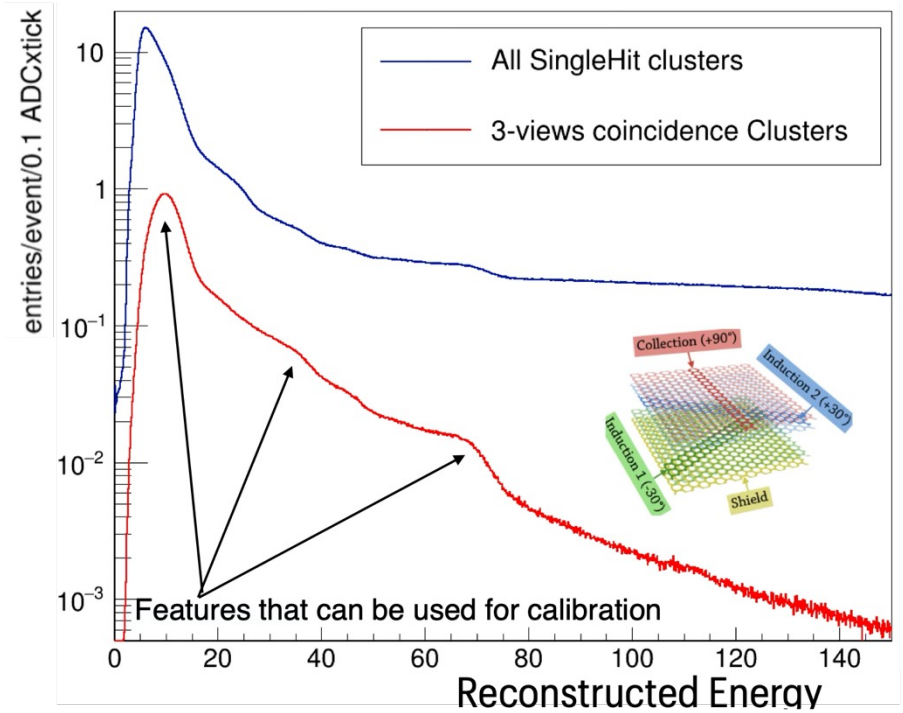
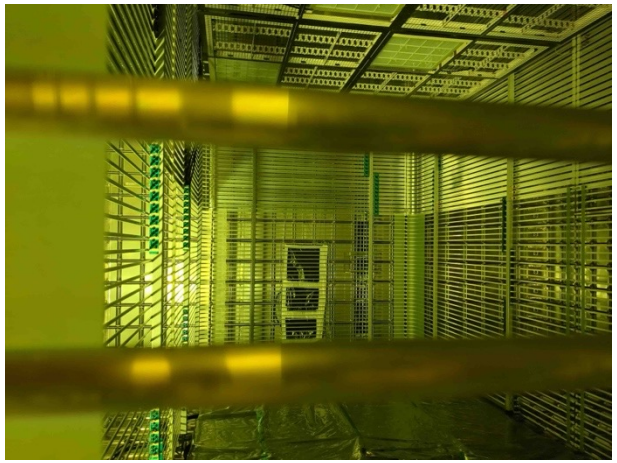




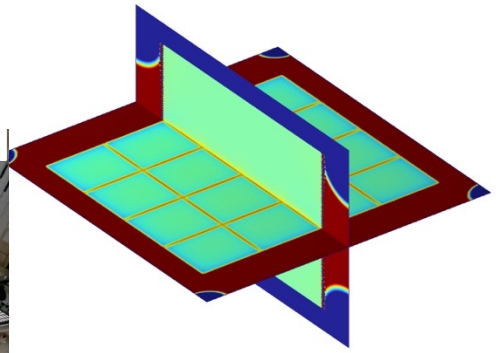
Useful to inform the low-energy physics program of DUNE

ProtoDUNE-VD prototyping development

- 300 kV HV stability demonstrated within NP02 / 6 m drift over few months period
- **Charge Readout Planes** + **Photon Detection System** in a 3x3x1 m^3 coldbox
  - TDE and BDE electronics successfully tested
  - 3-view strips arrangement similar to PDHD wires ($-30°, 30°, 90°$) and validated
- **2 x 2 CRPs (6x3x6 m^3) have been installed in the PDVD Module-0 in 2023**
  - Commissioning starting in the next weeks + requested charged particle beam from SPS



Cathode before installation in the coldbox – 2022



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**