DUNE Experiment

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For the DUNE Collaboration

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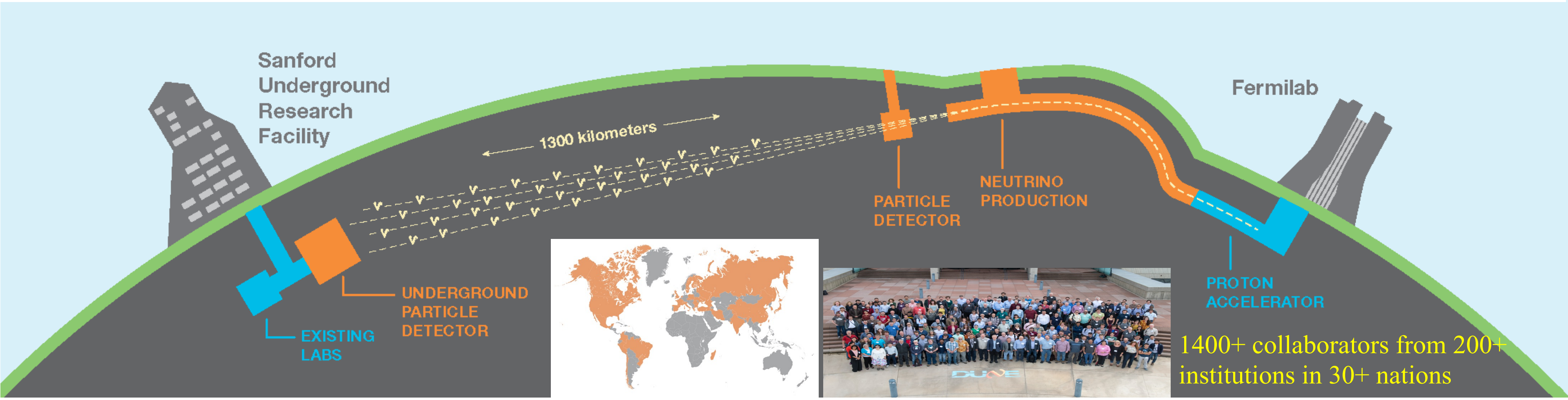
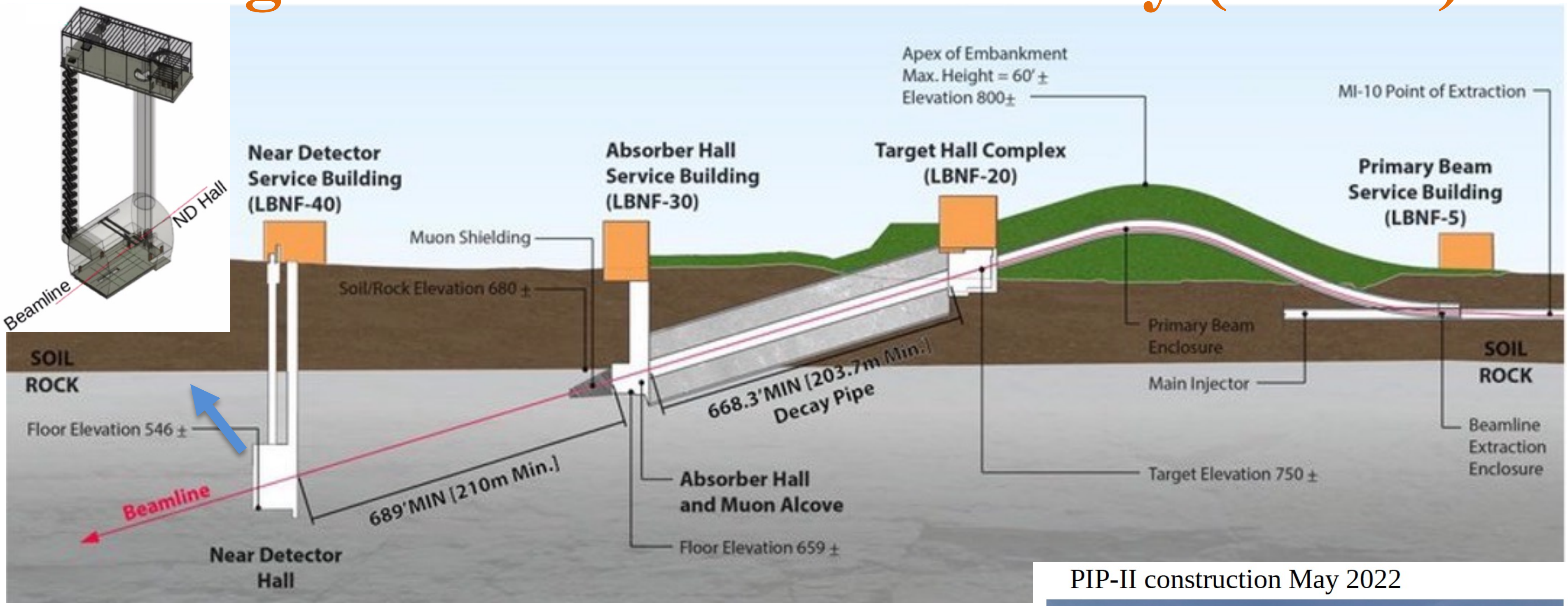
Interplay between Particle and Astroparticle physics 2022 (IPA2022), 5–9 September 2022, Vienna, Austria

DEEP UNDERGROUND NEUTRINO EXPERIMENT



- New neutrino beam at Fermilab (1.2 MW, upgradeable to 2.4 MW), 1300 km baseline
- Four 17 kton Liquid Argon Time Projection Chamber (LArTPC) Far Detector modules at Sanford Underground Research Facility, South Dakota, 1.5 km underground
- Multiple technologies for the Near Detector (ND)
- ν_e appearance and ν_μ disappearance → Neutrino mass ordering and CP violation
- Large detector, deep underground, high intensity beam → Supernova burst neutrinos, atmospheric neutrinos, sterile neutrinos, nucleon decay, other BSM, etc

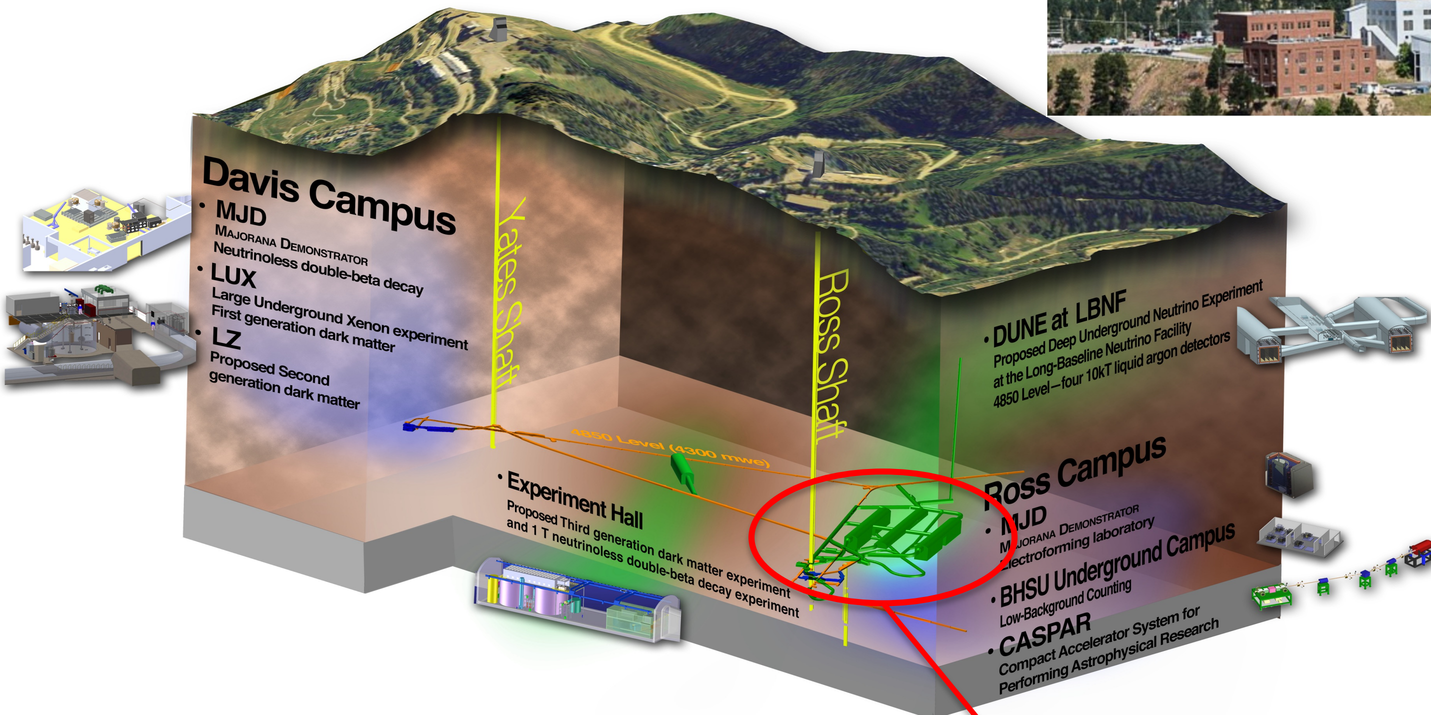
Long Baseline Neutrino Facility (LBNF)

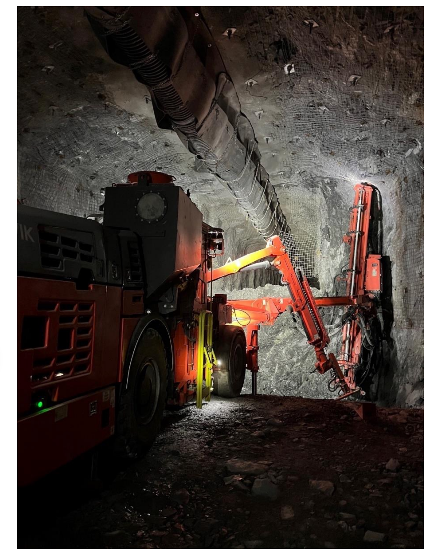


PIP-II construction May 2022

- Proton beam
  - Proton Improvement Plan-II (PIP-II)
  - 1.2 MW, upgradeable to 2.4 MW
  - 60-120 Proton GeV from FNAL accelerator complex
  - Initial upward pitch, bent down at 5.8° to reach Sanford
- Horns/beam line designed to maximize CP violation sensitivity, long baseline optimizes MH measurement
- Near Detector Hall at edge of Fermilab site

Sanford Underground Research Facility (SURF)



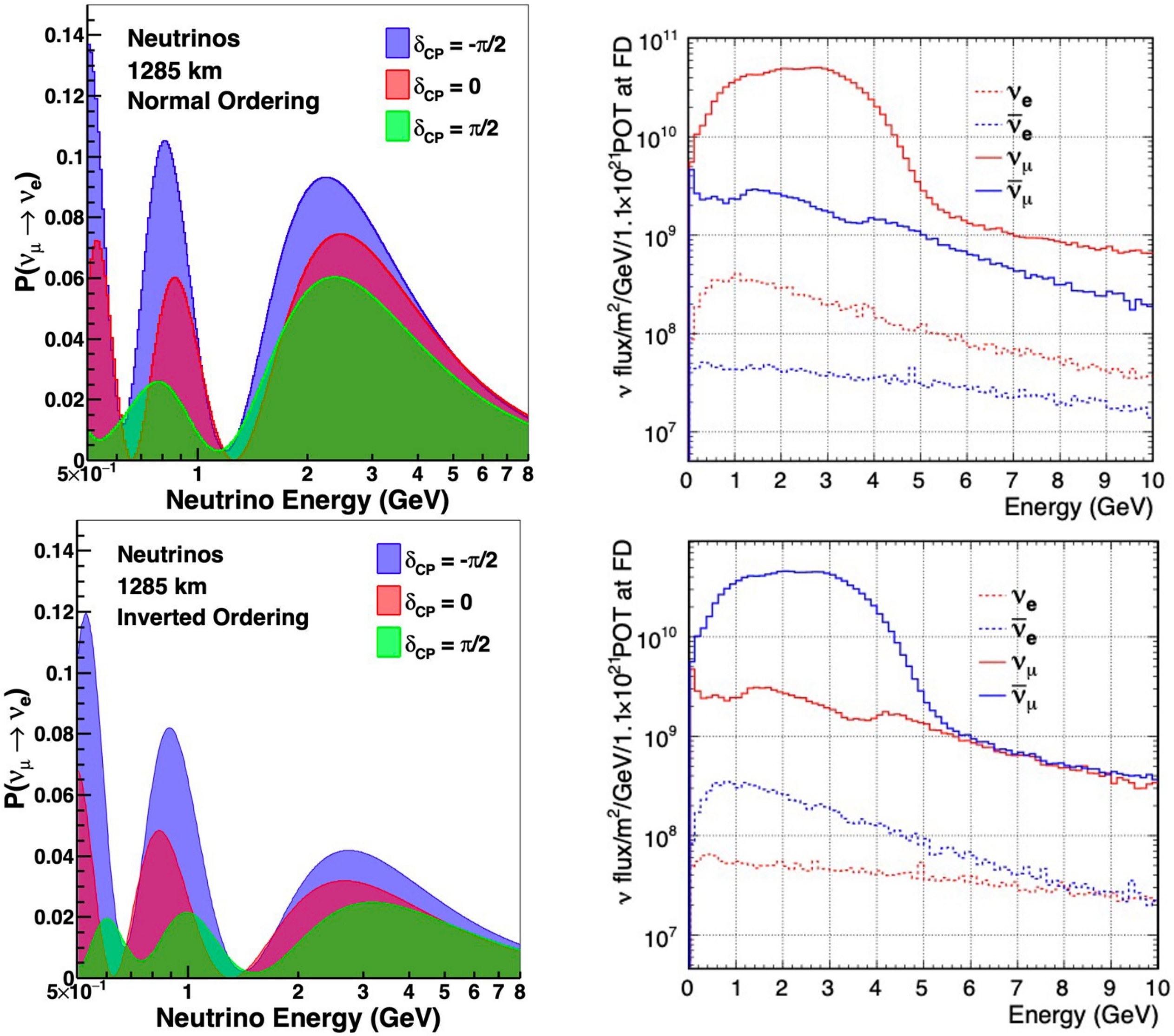


DUNE facility,
4850 ft (1.5km, 4300 mwe)

- In the Homestake gold mine, Lead, S. Dakota
- Home of Ray Davis's solar neutrino experiment
- 4 caverns for detector and 1 utility hall for DUNE
- Excavation advancing on schedule and on budget

Groundbreaking: 21st July, 2017

ν_e appearance in DUNE

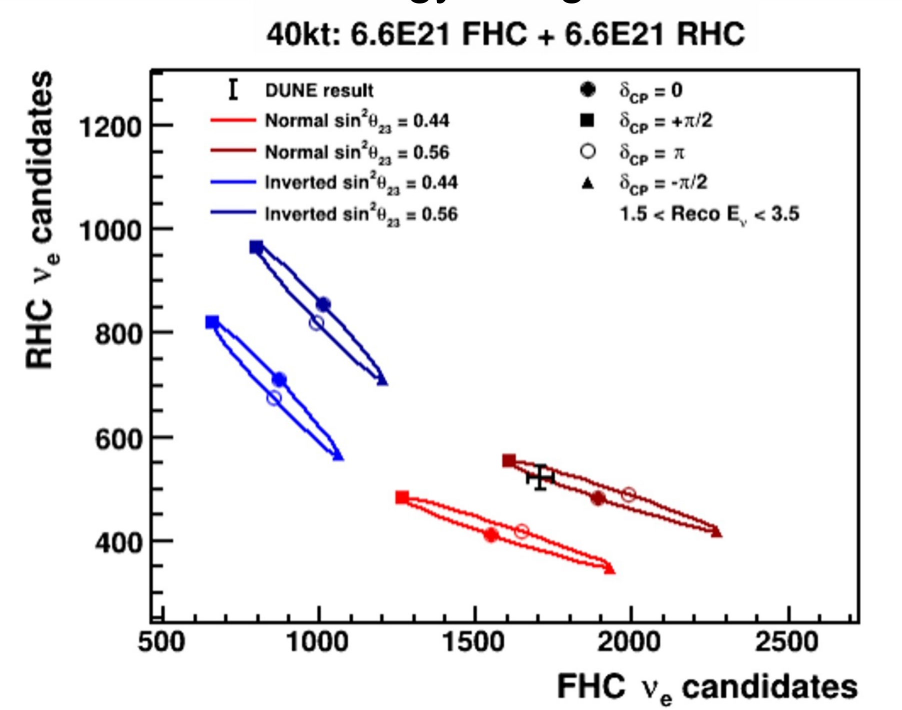


Eur. Phys. J. C 80, 978 (2020)

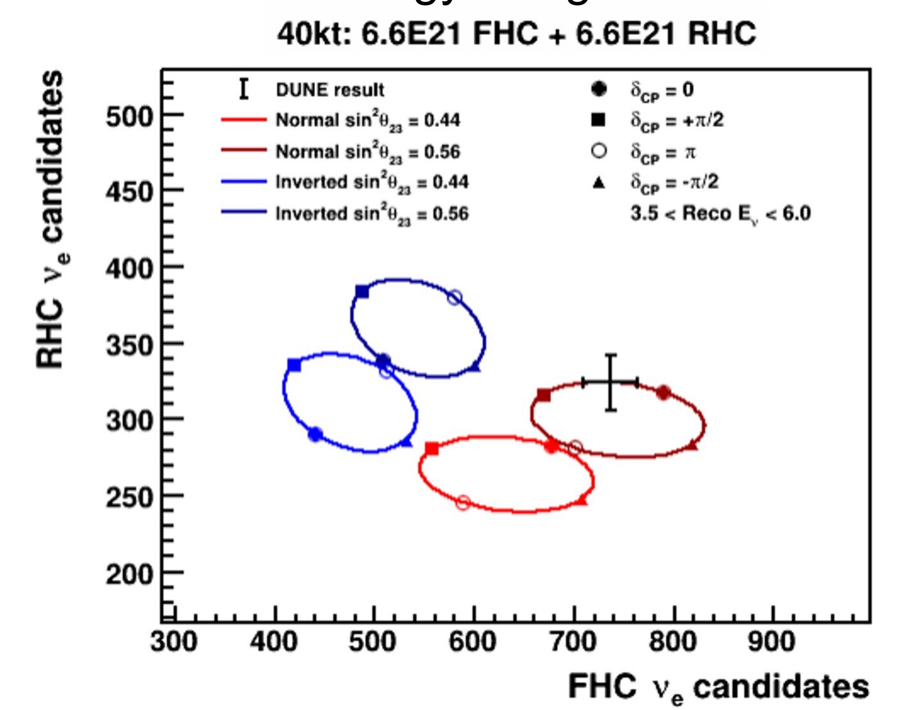
- On-axis wideband beam covering main oscillation features at 1295 km
- High performance detector to control beam backgrounds

ν_e appearance - ν_e vs anti-ν_e events

Neutrino energy Range: 1.5-3.5GeV

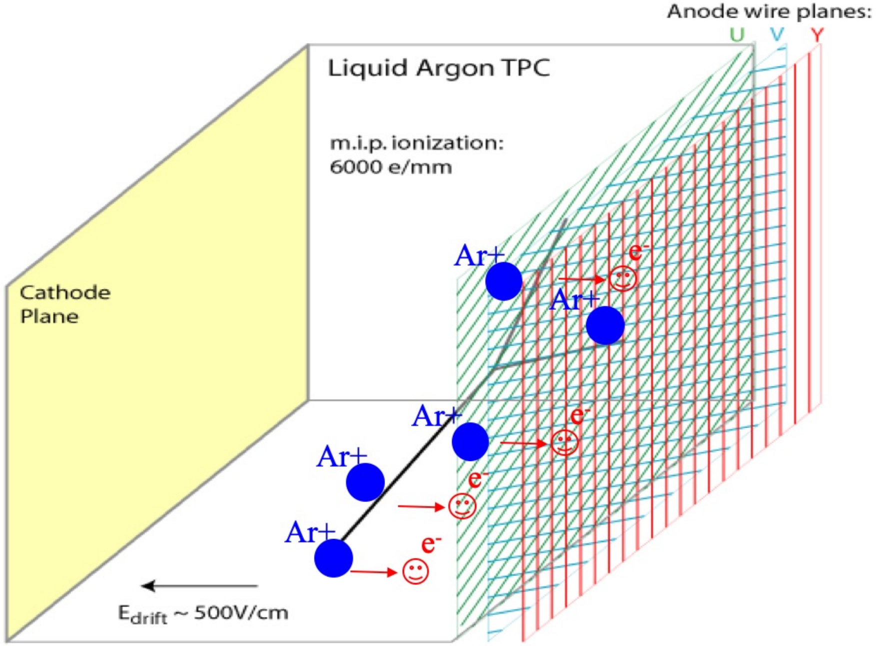


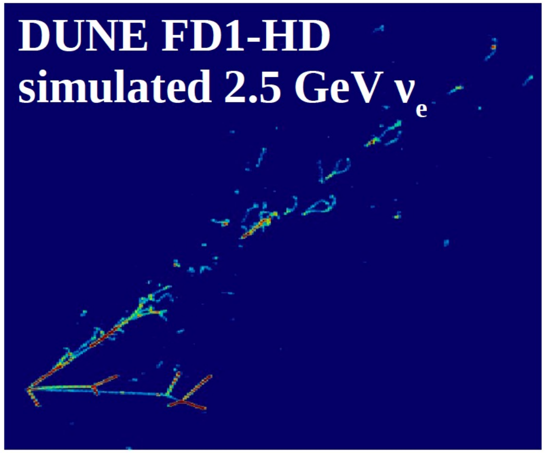
Neutrino energy Range: 3.5-6.0 GeV

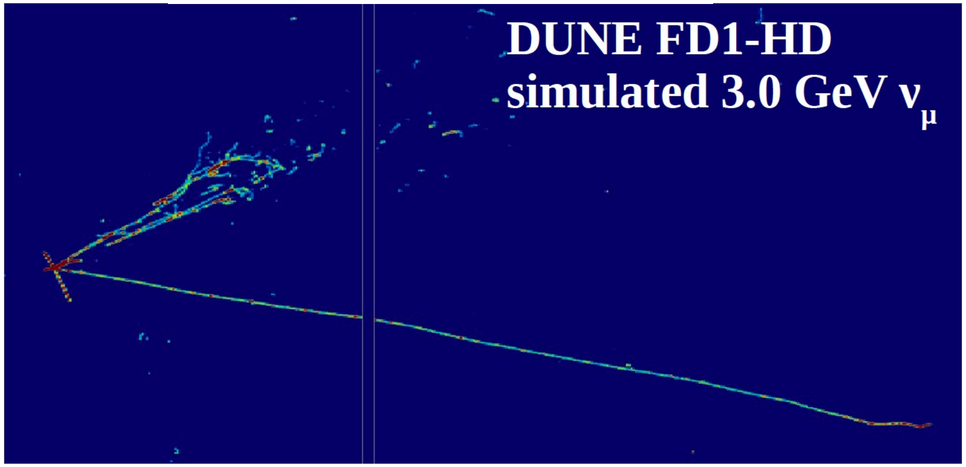


- Few percent statistical uncertainties utilizing wide band LBL
- Will make unambiguous, high-precision measurements of mass hierarch, δ_{CP} and θ_{23} octant, without relying on other oscillation parameters and experiments

Far Detectors: Liquid Argon Time Projection Chamber (LArTPC)

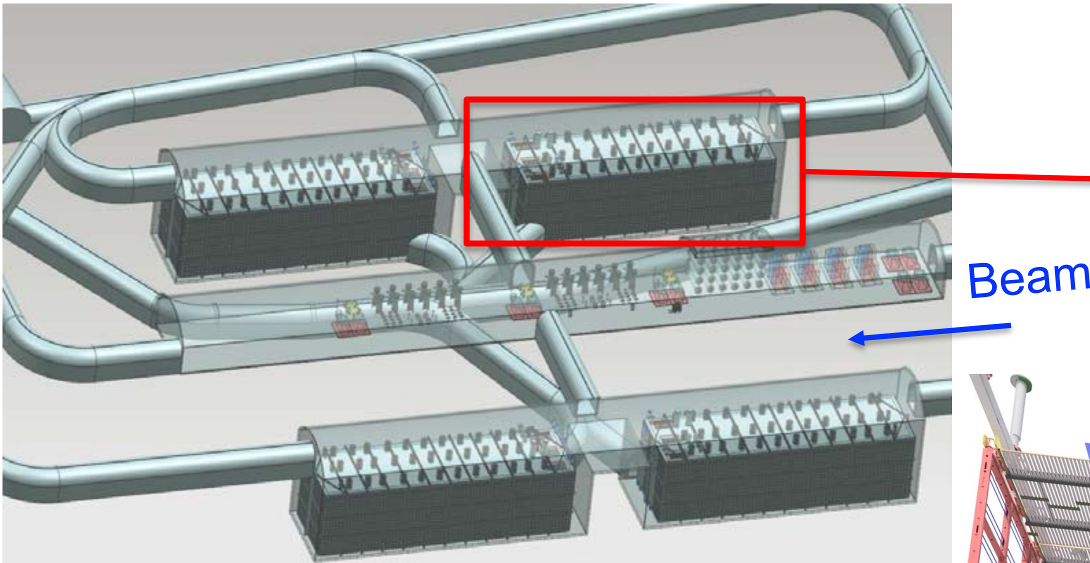


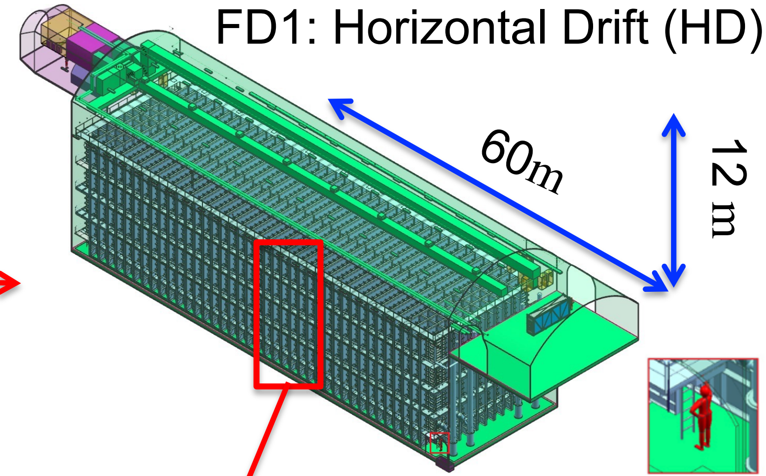




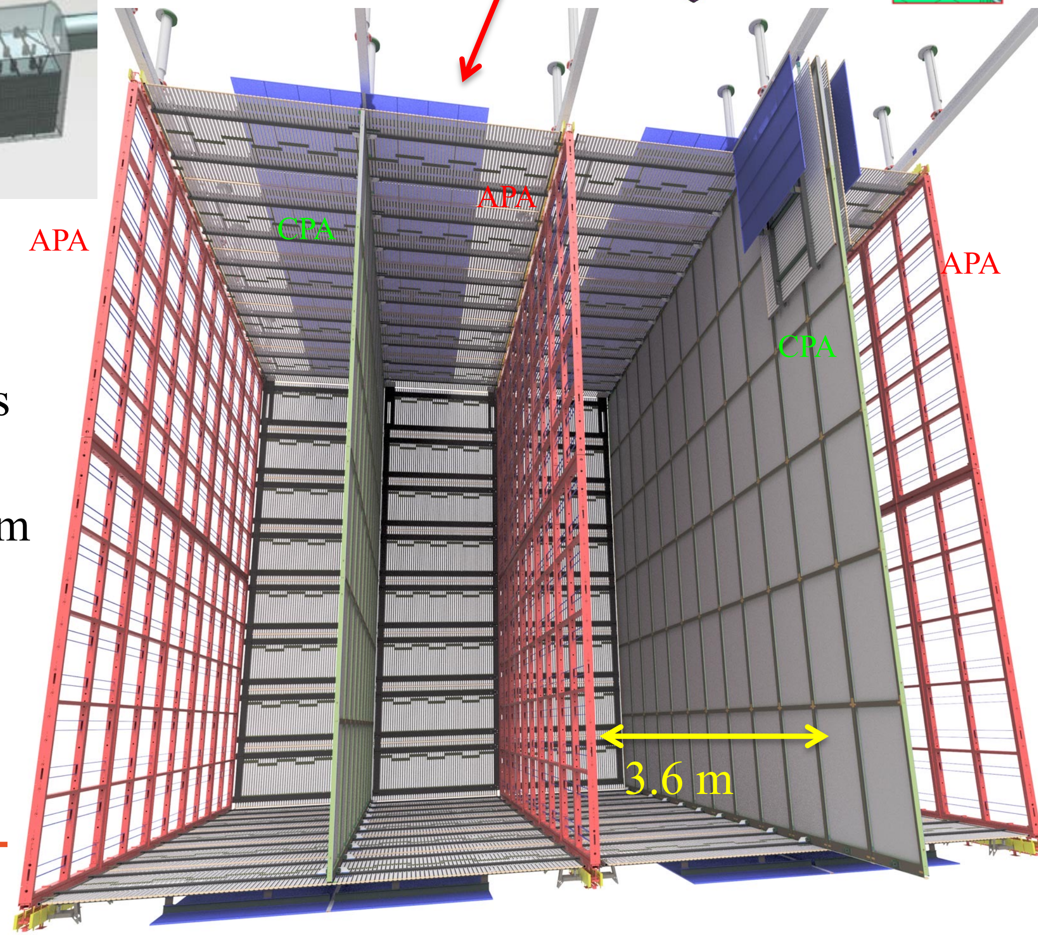
- High resolution 3D track reconstruction
  - Charged particle tracks ionize argon atoms
  - Ionized electrons drift to anode wires (~ms) for XY-coordinate
  - Electron drift time projected for Z-coordinate
- Argon scintillation light (~ns) detected by photon detectors, providing t_0

Far Detectors: LArTPC

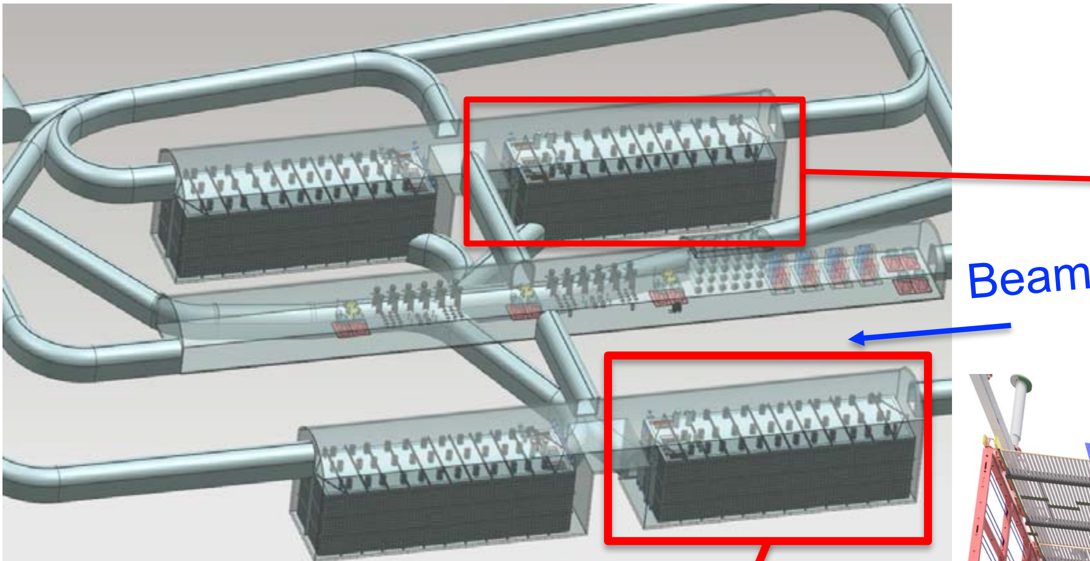




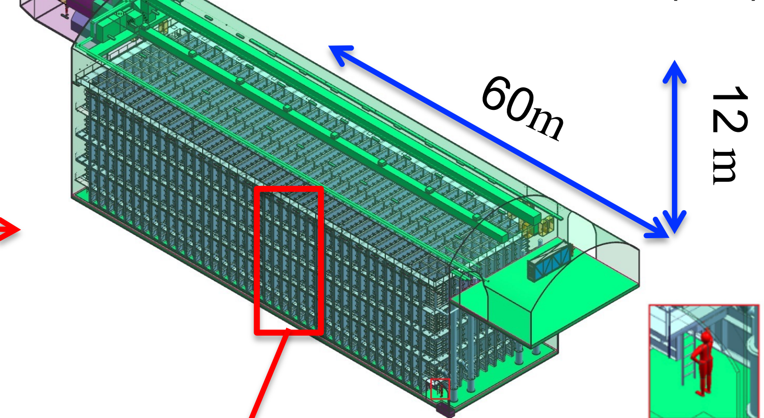
- Anode wire planes (2 induction, 1 collection) immersed in LAr
- Anode and Cathode Plane Assemblies (APA, CPA) suspended from ceiling
- Drift distance: 3.6 m, wire pitch: 5 mm
- Induction wires +-37.7^{o} to collection wires, wrapped around APA
- Photon detectors: SiPMs based, embedded in APAs

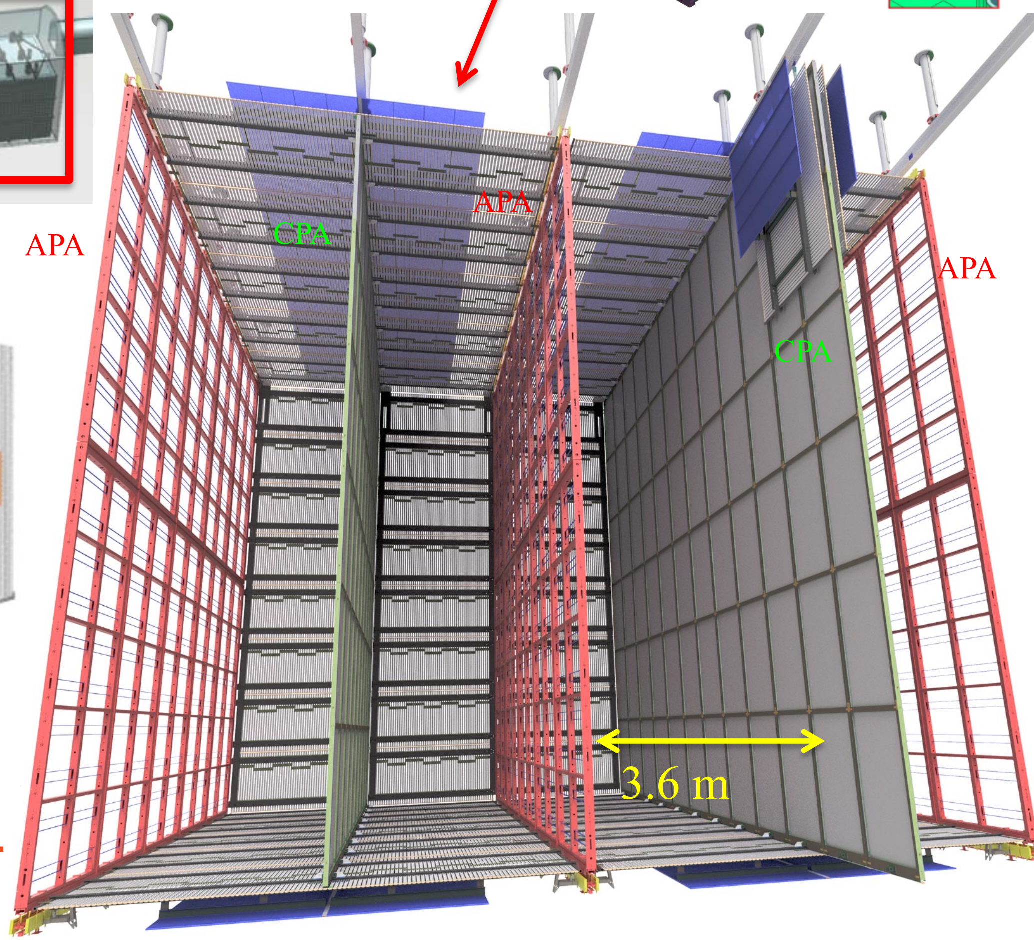


Far Detectors: LArTPC

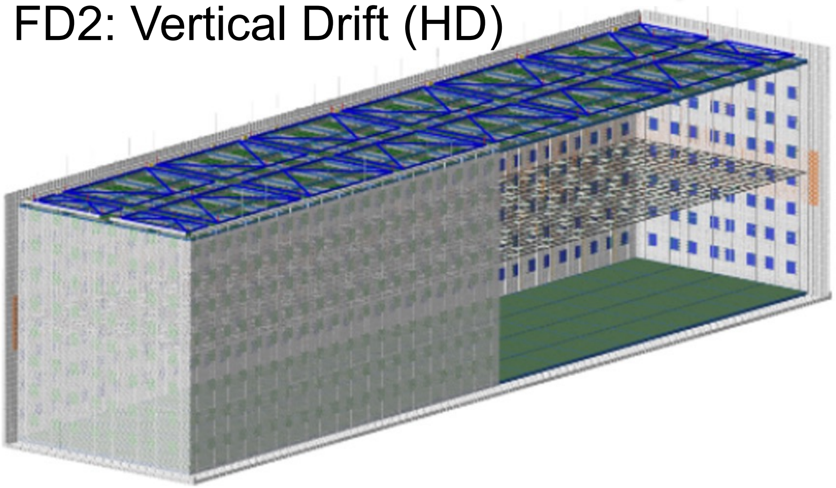


FD1: Horizontal Drift (HD)

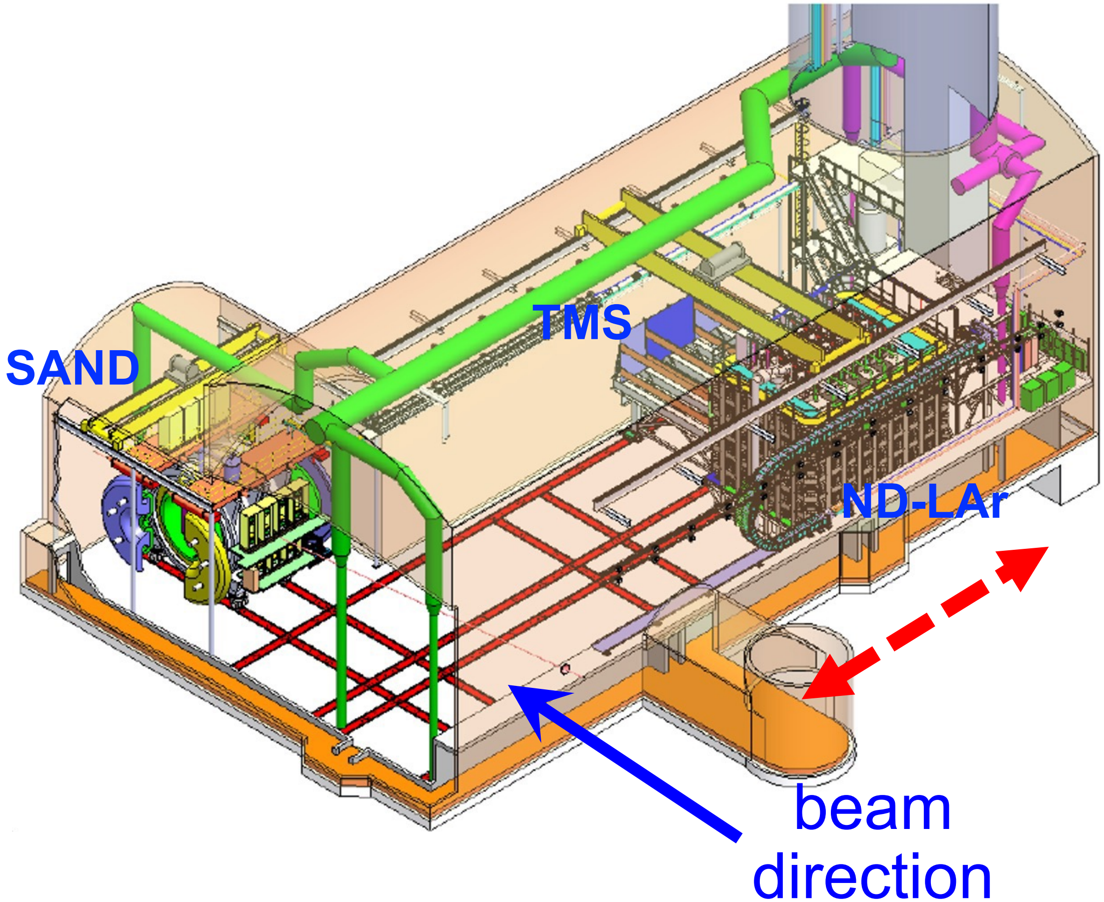




FD2: Vertical Drift (HD)



Near Detector Concept



ND-LAr and TMS move off-axis to receive different beam fluxes for disentangling flux and cross sections and constraining systematics (PRISM)

Hall location
- 574 m from target
- ~60 m underground

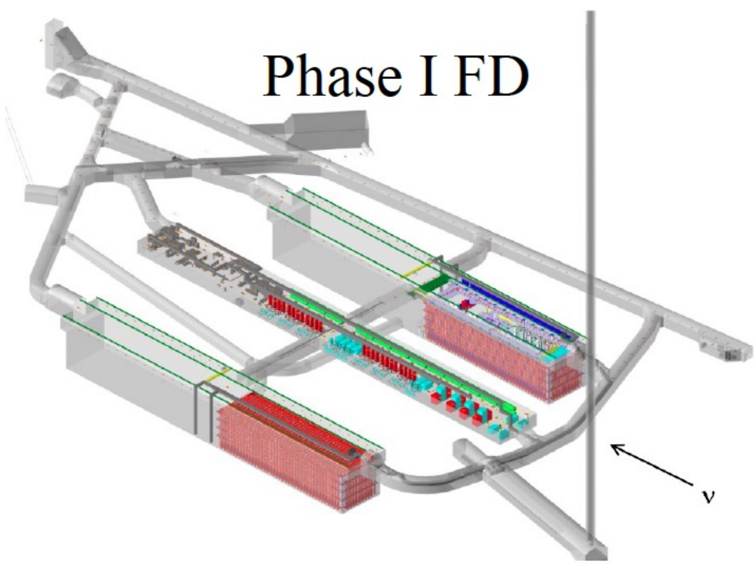
- ND-LAr: LArTPC with 3-D pixelated readout
- TMS: Muon Spectrometer built from steel and scintillator with magnetic field, will upgrade to ND-GAr
- SAND: Magnetized on-axis neutrino detector for beam monitoring

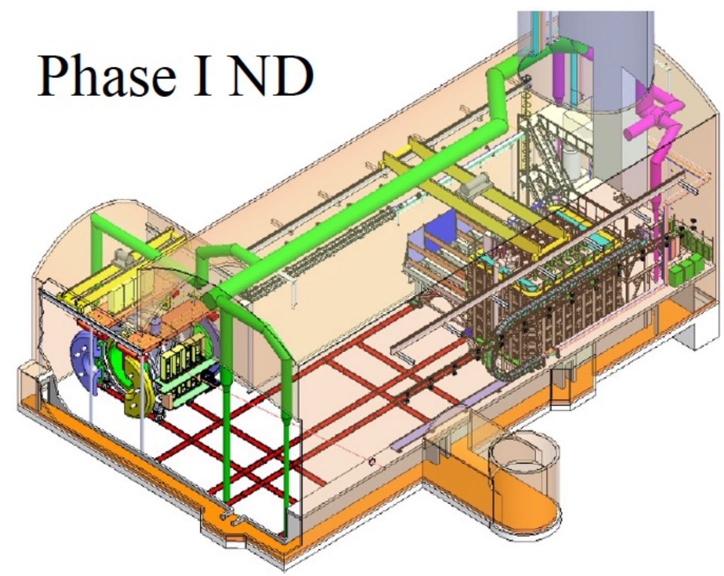
DUNE Plans and Installation

- 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.
- Near detector: ND-LAr + TMS (steel/scint. range stack) + SAND
- Moveable 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.





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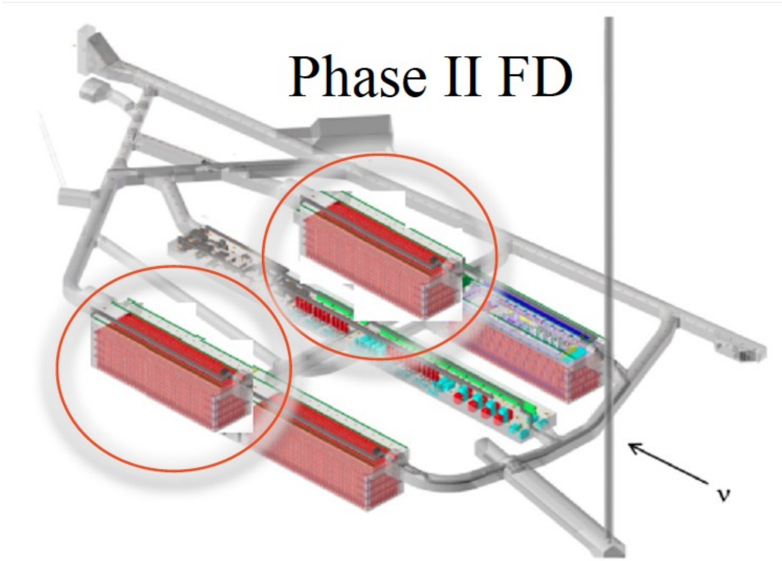
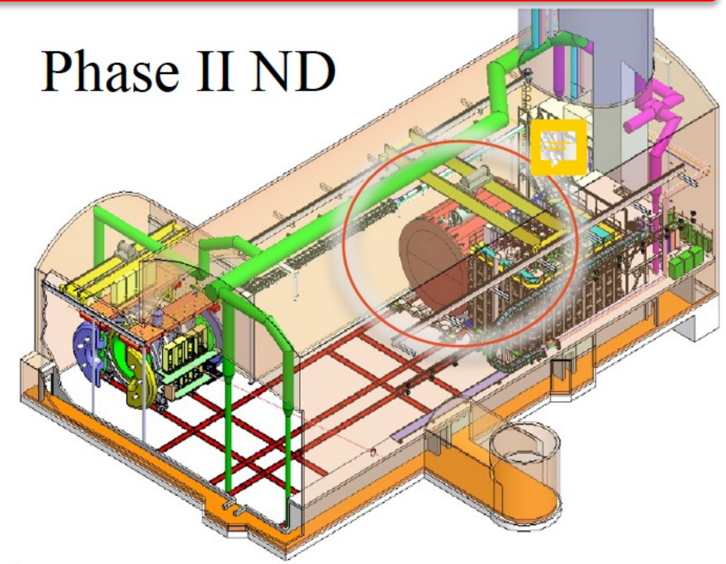
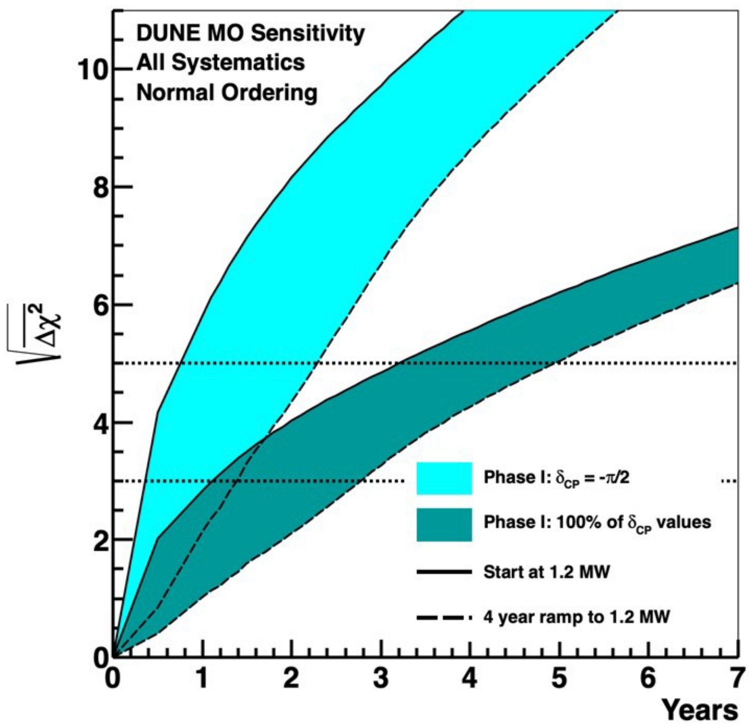
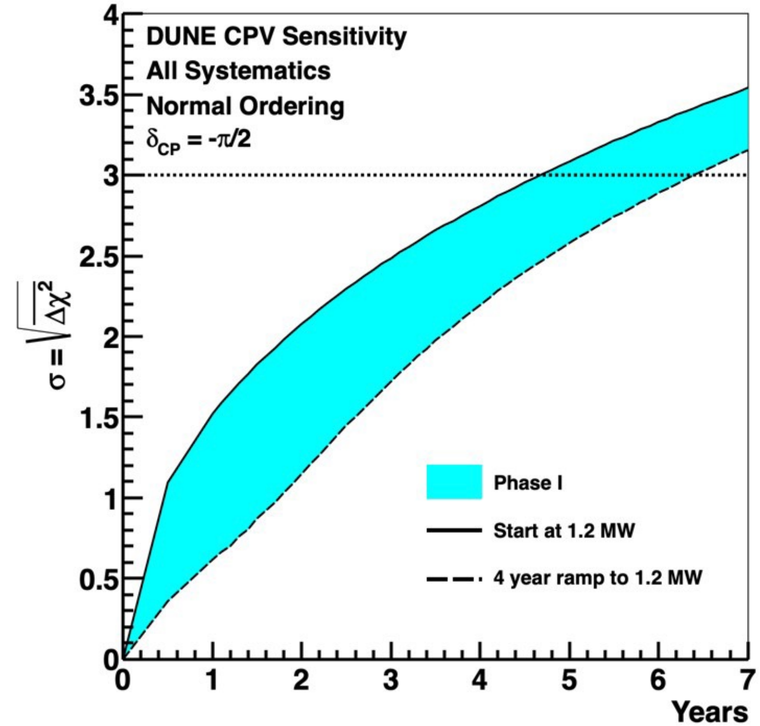




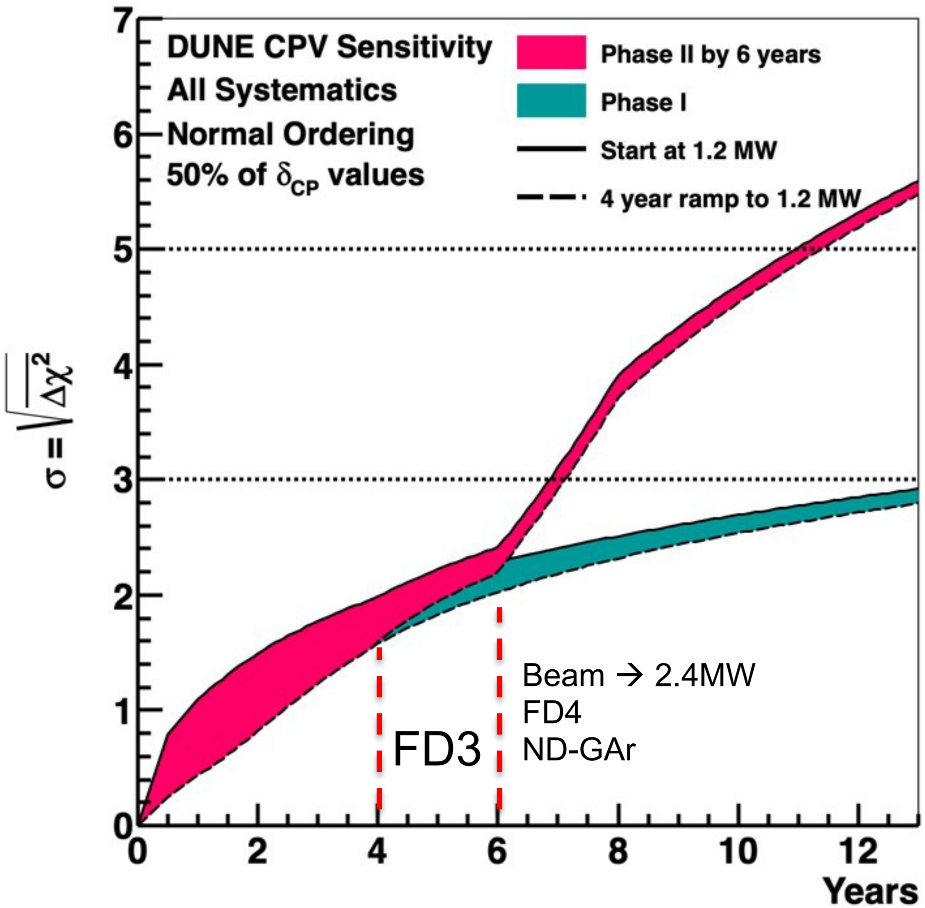
Phase I: World leading mass ordering and sensitivity to maximal CPV





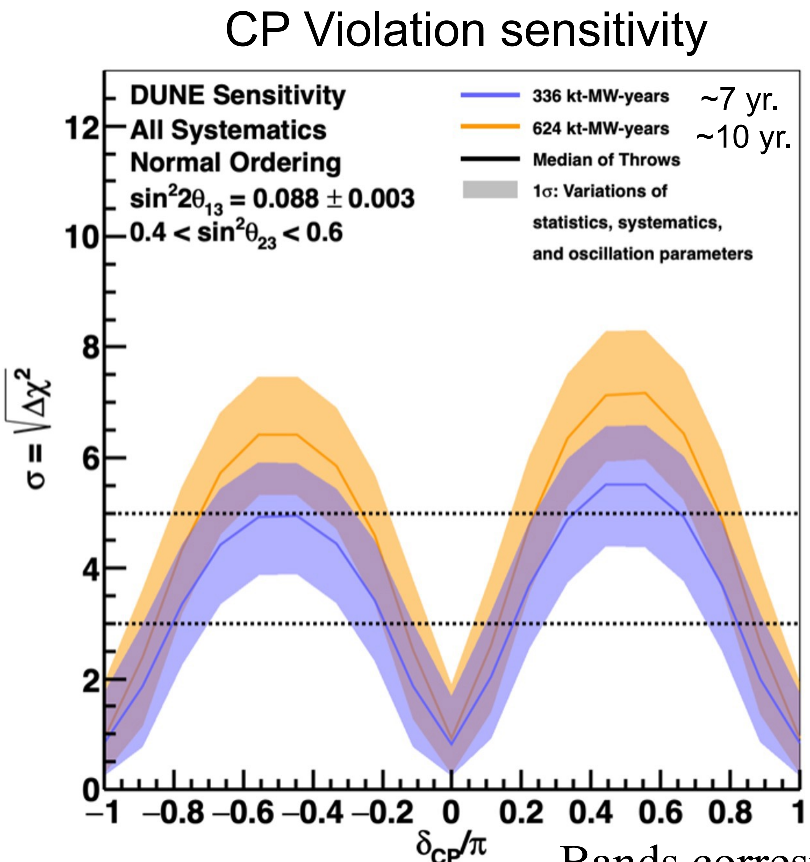
- Phase I will do world class long-baseline neutrino oscillation physics.
- Only experiment with 5σ mass ordering regardless of the true parameters.
- Discovery of CPV at 3σ if CPV is large.

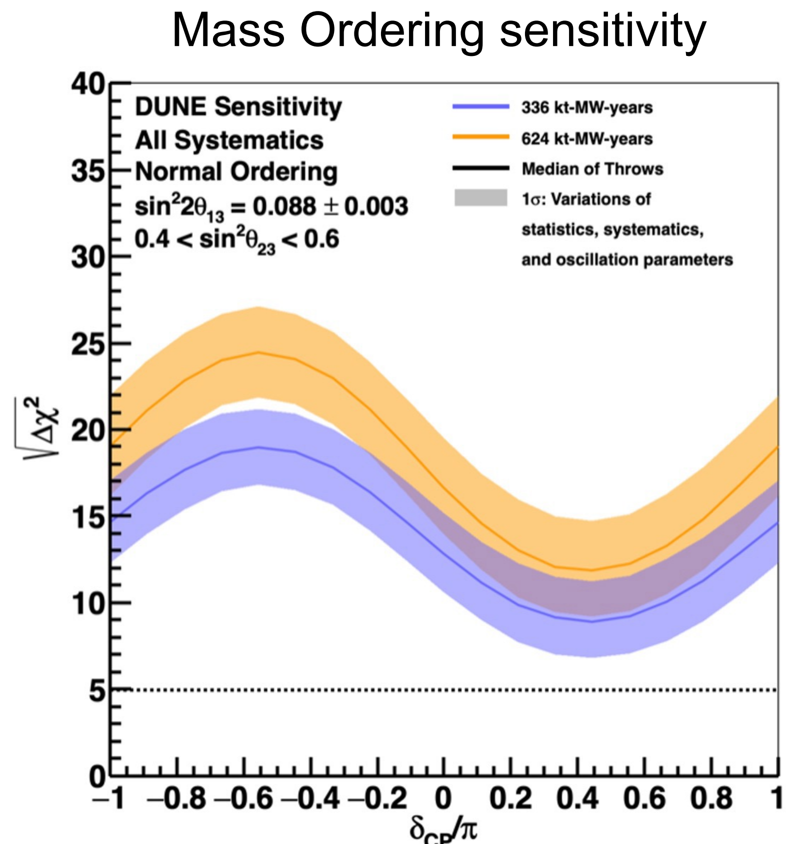
Phase-II: Full Scope to achieve physics reach



- CPV sensitivity for 50% of δ_{CP} values shown, precision measurements are similarly affected
- Timescale for precision physics is driven by achieving full scope on aggressive timescale
- Technologies for FD-3 and FD-4 are not yet established: Module(s) of opportunity

CPV and Mass Ordering Sensitivity vs δ_{CP}





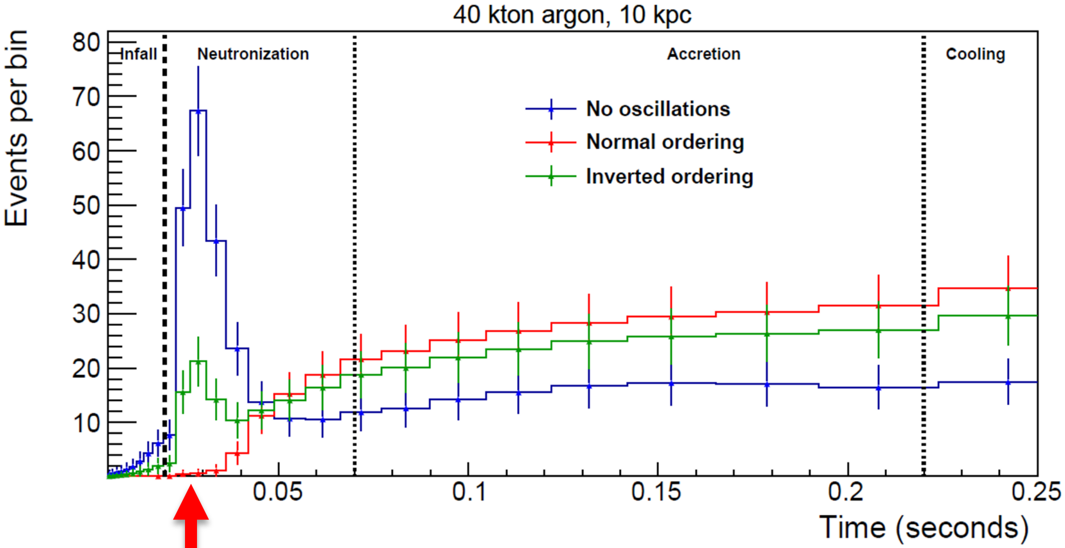
Bands correspond to uncertainty in θ_{23}

- $>5\sigma$ CPV discovery over a wide range of δ_{CP}
- $>5\sigma$ Mass Ordering determination for all δ_{CP} values

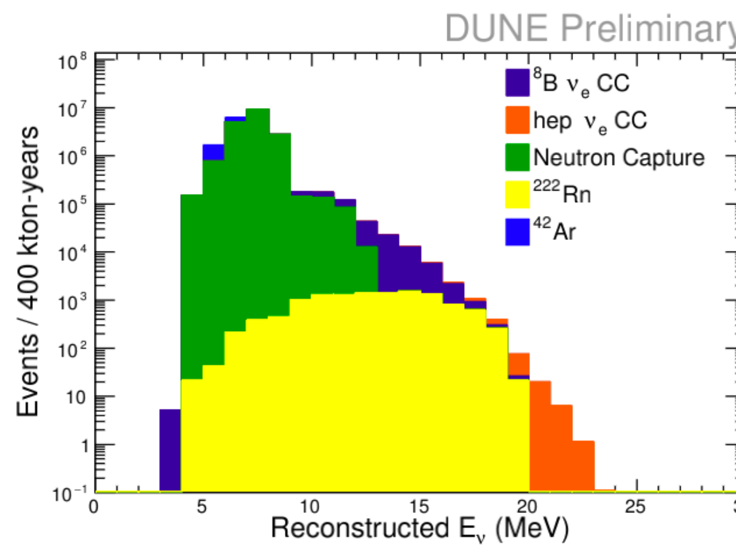
Supernova Neutrino Burst and Solar Neutrinos

- Supernova Neutrino Burst (SNB)
  - Sensitive to neutronization (ν_e) in core collapse supernova → solve neutrino mass ordering
  - ν-e elastic scattering could provide directionality, prompt pointing to supernova
  - Large statistics: for ~10 kpc, Expect ~3,000 ν_e in 10 seconds
- Also sensitive to solar neutrinos: ^{8}B solar neutrinos and hep solar neutrinos

Number of supernova neutrinos vs. time



Solar Neutrinos

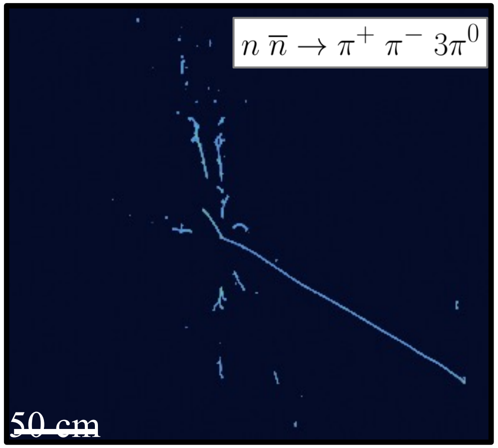


Neutronization: the initial neutrino burst in core collapse supernova, mostly ν_e

DUNE FD TDR: DUNE Physics: arxiv 2002.0300

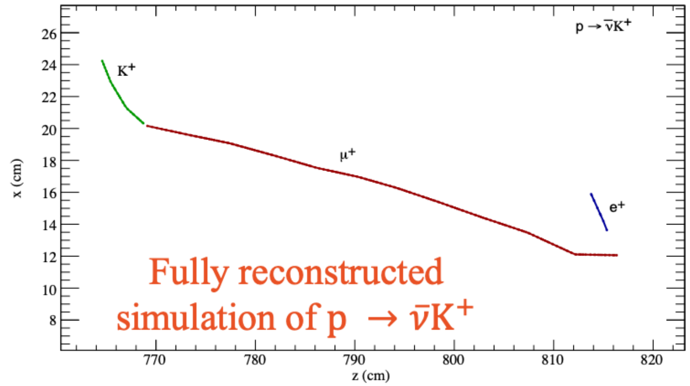
Beyond Standard Mode (BSM) Physics

FD: $n-\bar{n}$ oscillation



Free-neutron-equivalent sensitivity: $\tau_{\text{free,osc}} > 5.5\times10^8$ s (90% C.L.)

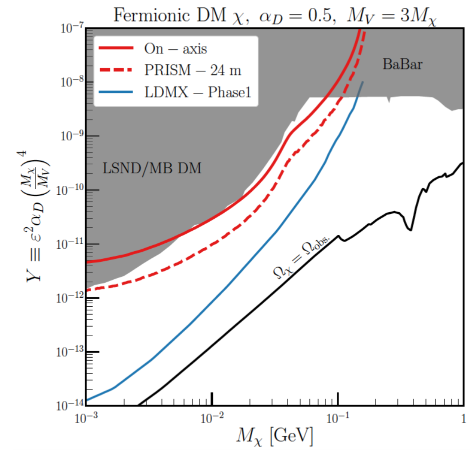
FD: Proton Decays



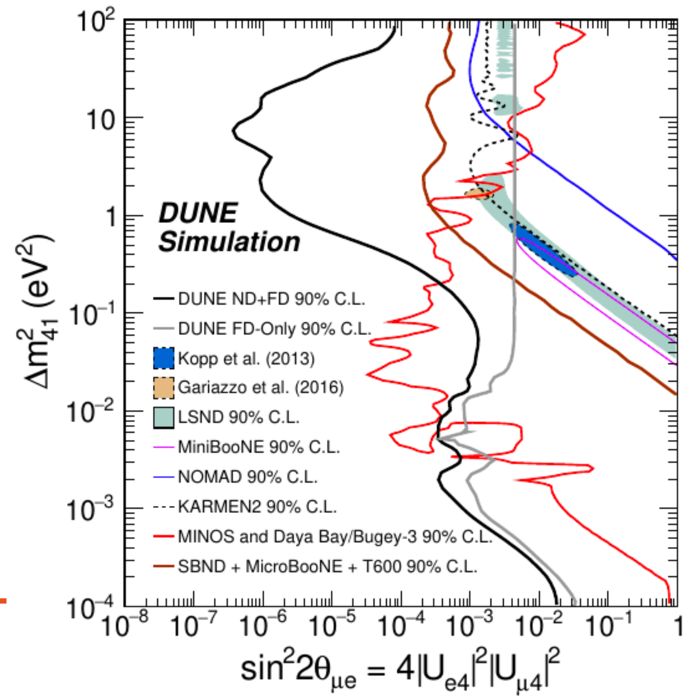
0.5 bkg events for 400 kt-yr, 30% signal efficiency

Sensitivity (no signal): $\tau/B >$ 1.3×10^{34} yr (90% C.L.)

ND: Low-Mass Dark Matter



ND: Sterile Neutrinos



- FD : Large volume, deep underground, superior K/π reconstruction
- ND: High beam power, highly capable detectors
- Proton Decay, $n-\bar{n}$ oscillation, NSI, Dark Matter, Sterile Neutrinos, Non-Unitarity, CPT Violation, etc

DUNE FD TDR: DUNE Physics: arxiv 2002.0300

ProtoDUNEs at CERN

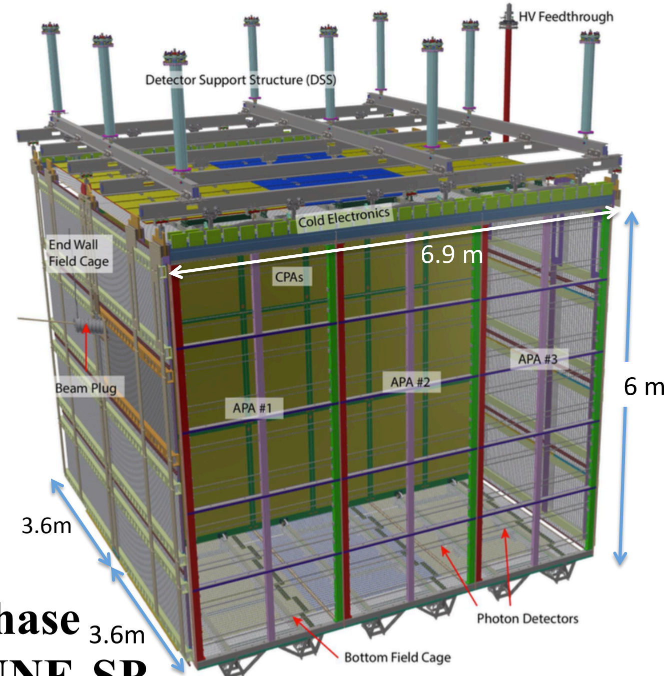
- Two major DUNE prototype LArTPCs at CERN
  - One single phase and one dual phase
  - 770 t LAr mass each
  - Exposed to H2 (DP) and H4 (SP) testbeams at CERN, momentum-dependent beam composition contains e, $K^{\pm}$, μ, p, $\pi^{\pm}$
- Strategic Goals
  - Prototyping production and installation procedures
  - Validating the design from basic detector performance
  - Accumulating large test-beam data for detector response understanding, calibration, dE/dx, PID etc.
  - Demonstrating long-term operational stability

Status:

ProtoDUNE-SP: Took test beam data in 2018

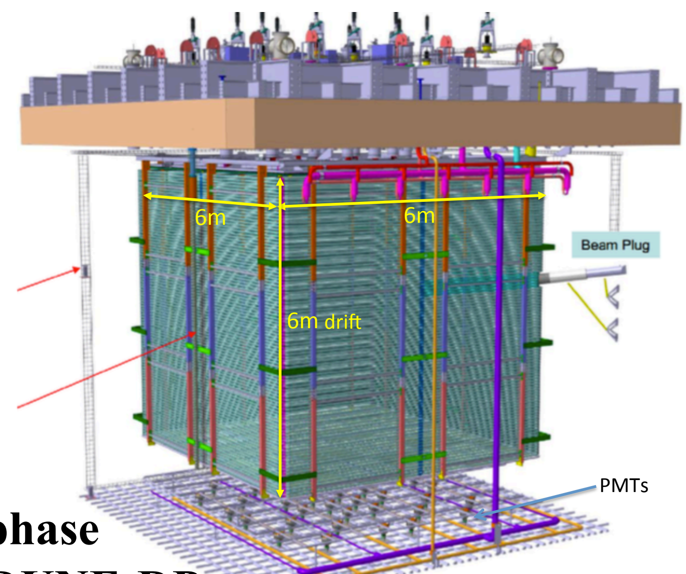
ProtoDUNE-DP: Took data in 2020

Upgrading to SP ProtoDUNE-II HD and VD in 2021-2023



JINST **17**, no.01, P01005 (2022)
JINST **15**, no.12, P12004 (2020)

Single phase ProtoDUNE-SP

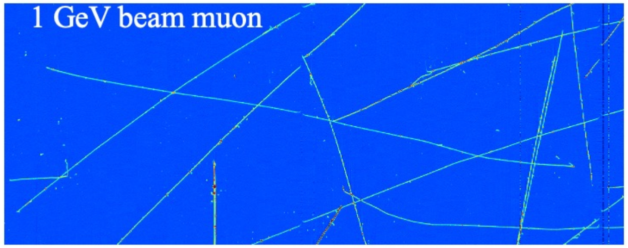


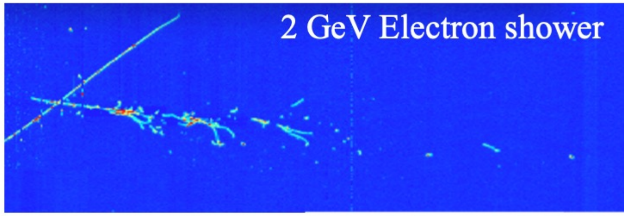
Dual phase ProtoDUNE-DP

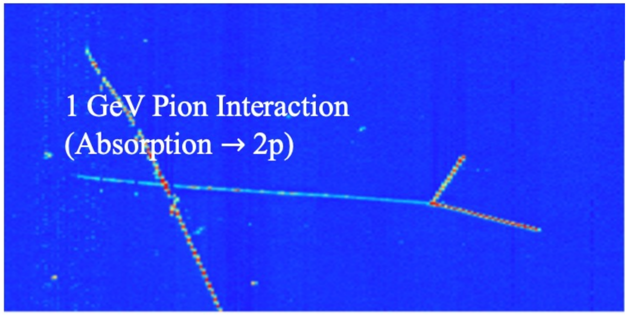
Eur. Phys. J. C **82**, no.7, 618 (2022)

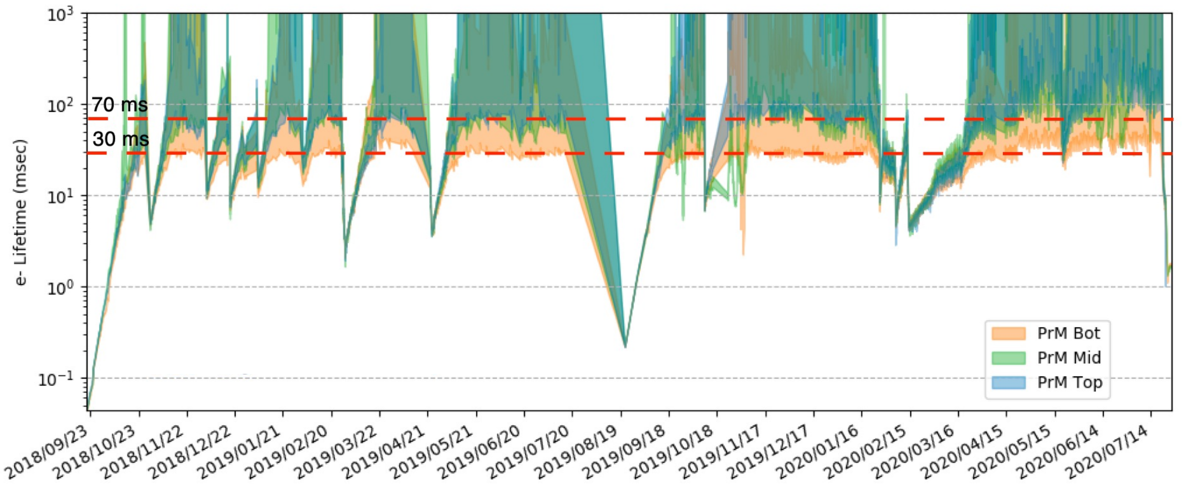
Initial ProtoDUNE-SP Results

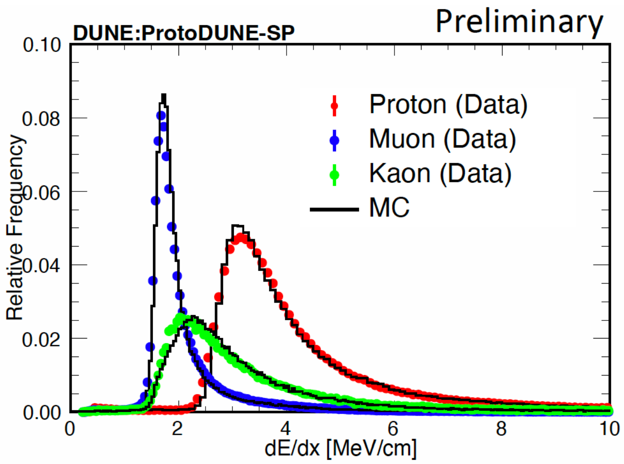
- High LAr purity reached
- Electronic noise under control
- Resolution and data quality excellent
- Calibration, Reconstruction and PID tested

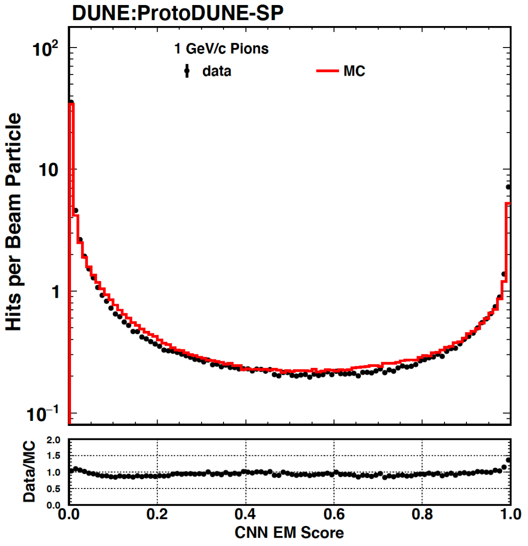




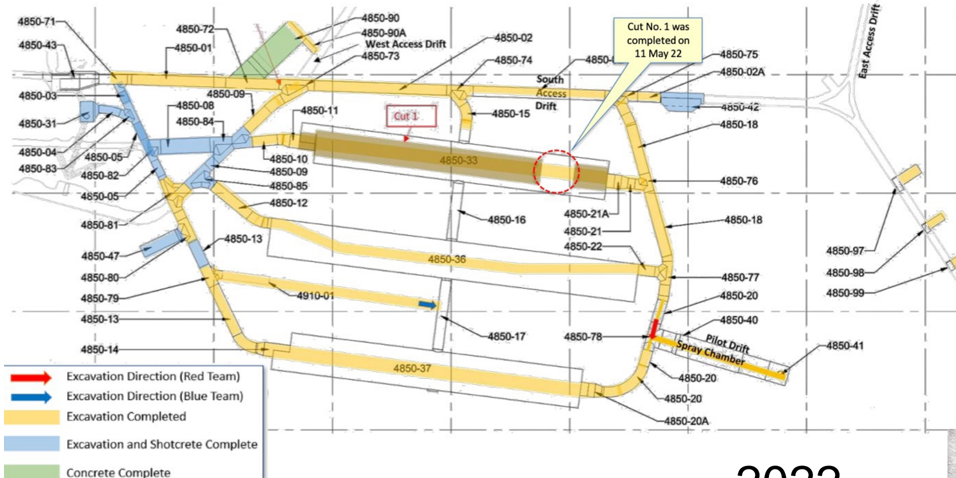






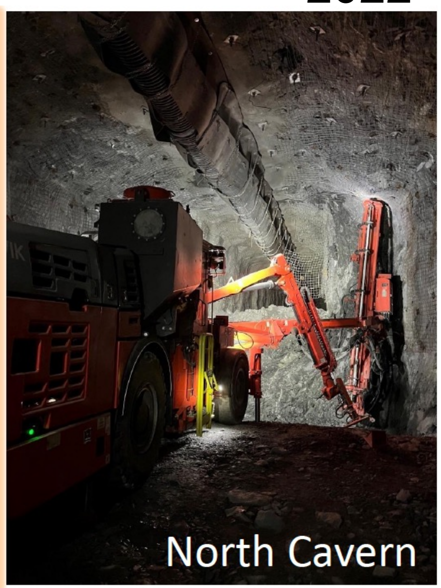


Construction at the Far Site



- Excavation work is in progress and advancing on schedule and budget
- >27% complete by total rock volume

2022



Summary

- DUNE will make decisive measurements for neutrino oscillations, including mass ordering and CP violation
- DUNE will also lead a broad physics program to explore non-beam neutrino sources, BSM, etc
- On track to deliver Phase I: ProtoDUNEs were successful, Far site civil construction is on schedule, near site and beamline are fully designed
- Will need the full Phase II program to achieve full physics reach
- Physics should begin late 2020s and the collaboration is active in planning upgrades to achieve full scope in 2030s.

Thank you!

Backup