The DUNE Experiment and its Sensitivity to CP Violation

Jianming Bian

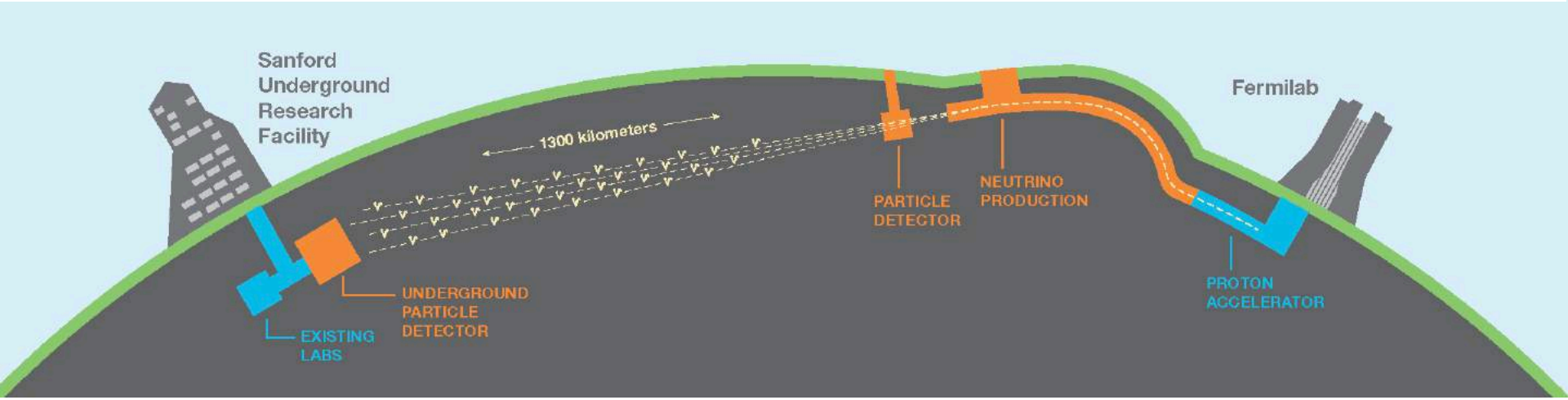
For the DUNE Collaboration

University of California, Irvine

06-20-2017

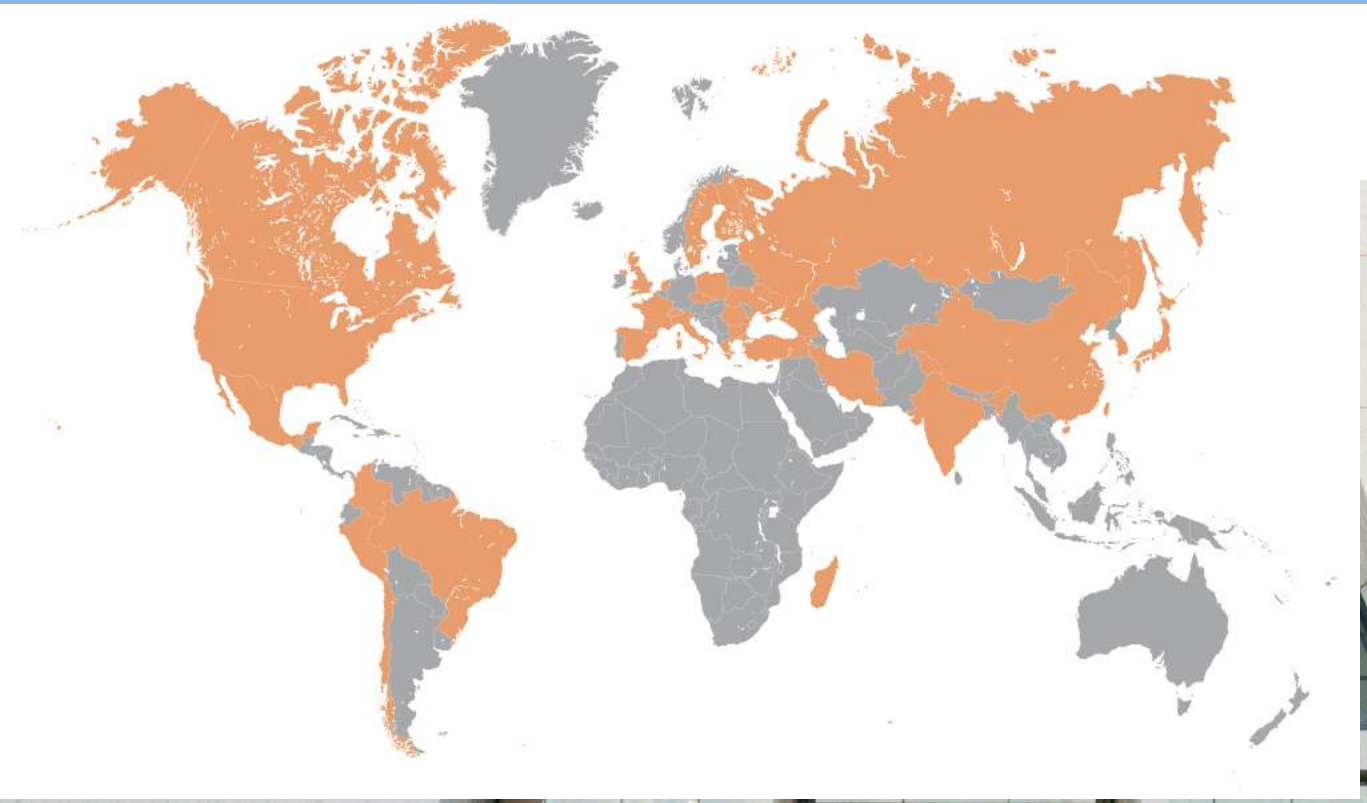
WIN2017, UCI, California

DEEP UNDERGROUND NEUTRINO EXPERIMENT



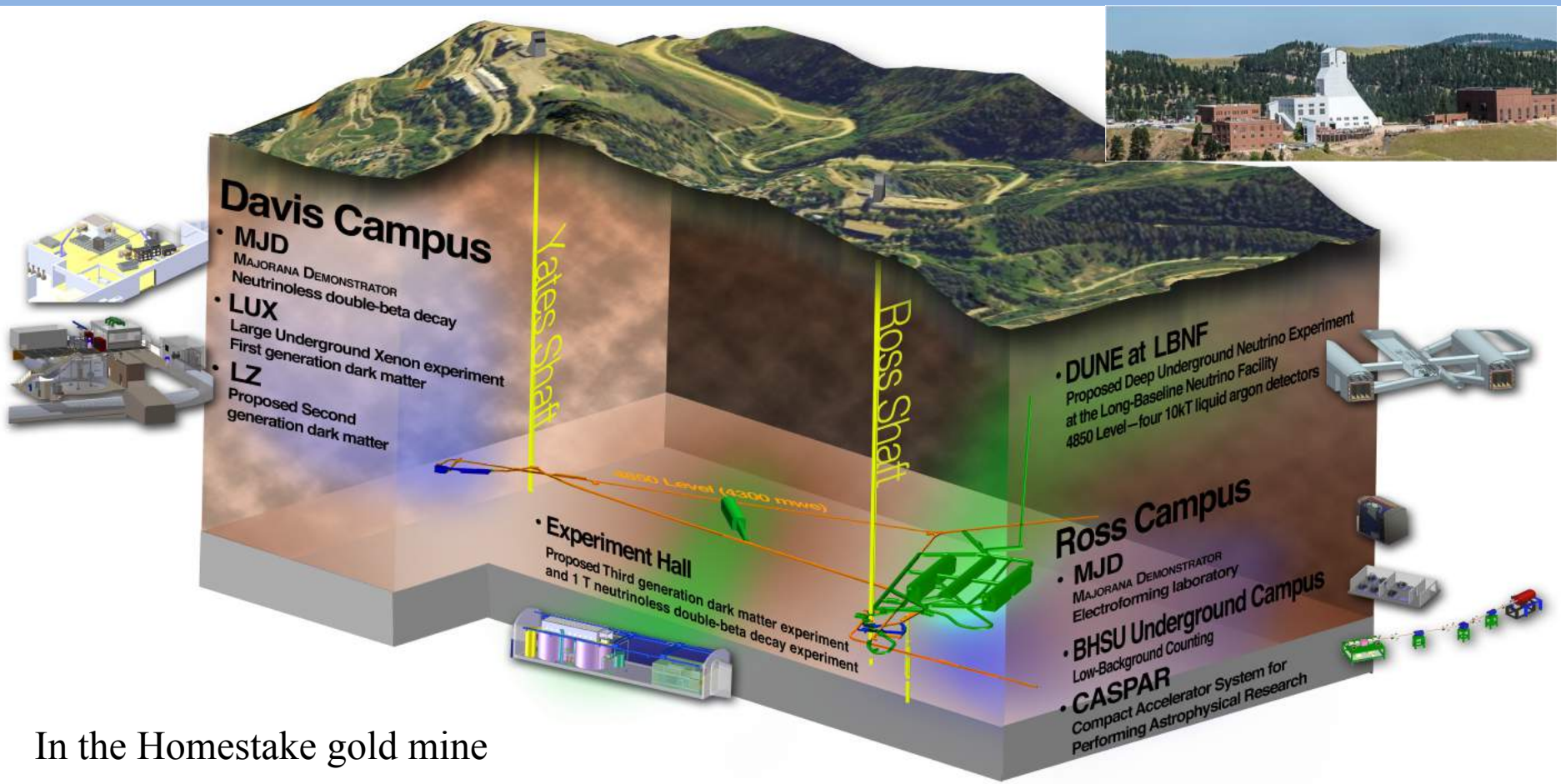
- New beam at Fermilab (1.2 MW@120 GeV protons, upgradeable to 2.4 MW), 1300 km baseline
- On-Axis 40 kton Liquid Argon Time Projection Chamber (LArTPC) Far Detector at Sanford Underground Research Facility, South Dakota, 1.5 km underground
- Highly-capable near detector at Fermilab
- ν_e appearance and ν_μ disappearance → Measure MH, CPV and mixing angles
- Large detector, deep underground → Nucleon decay, supernova burst neutrinos, atmospheric neutrinos, etc (Juergen Reichenbacher (SDSMT)'s talk, Wed.)

DUNE Collaboration



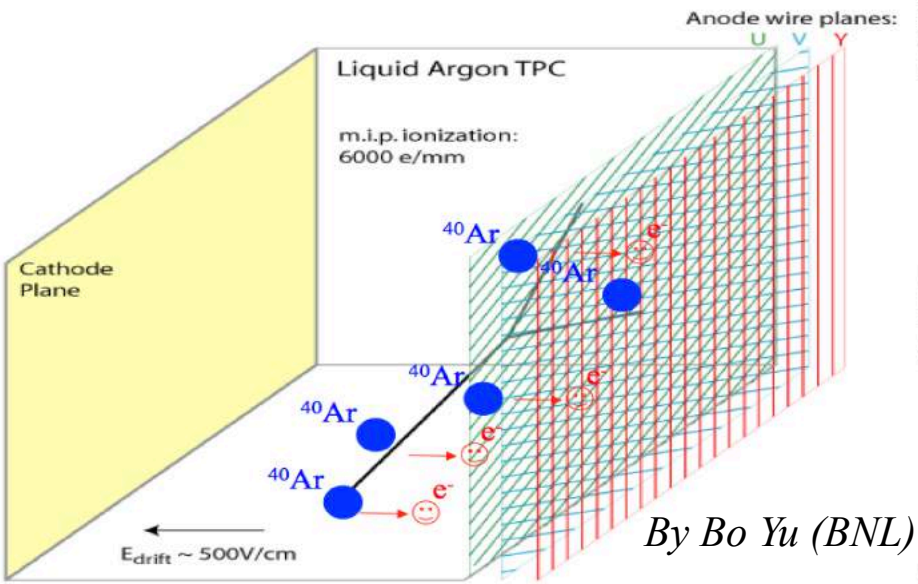
974 collaborators from 166 institutions in 30 nations

Sanford Underground Research Facility, Lead, S. Dakota

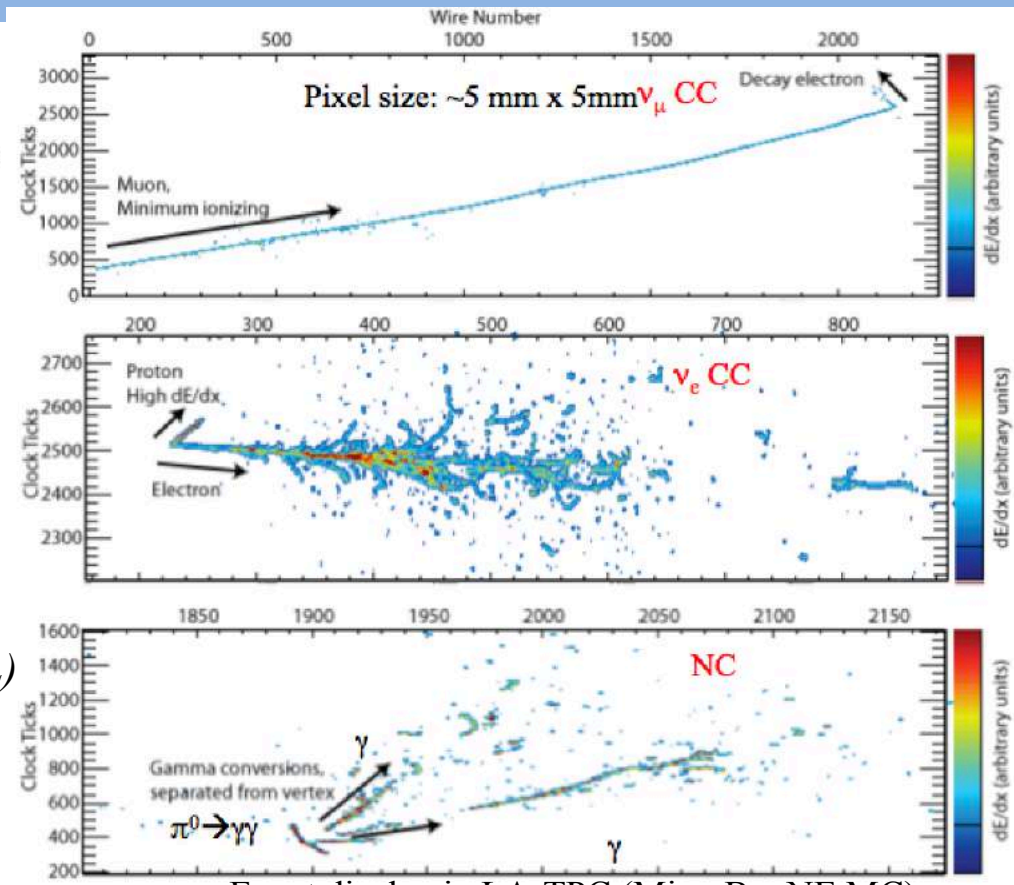


- In the Homestake gold mine
- Home of Ray Davis's solar neutrino experiment
- 4 caverns for detector and one utility hall for DUNE
- Begin excavation for the first two caverns in FY2017
- Blast vibration study has been done

Far Detectors: Liquid Argon Time Projection Chamber (LArTPC)



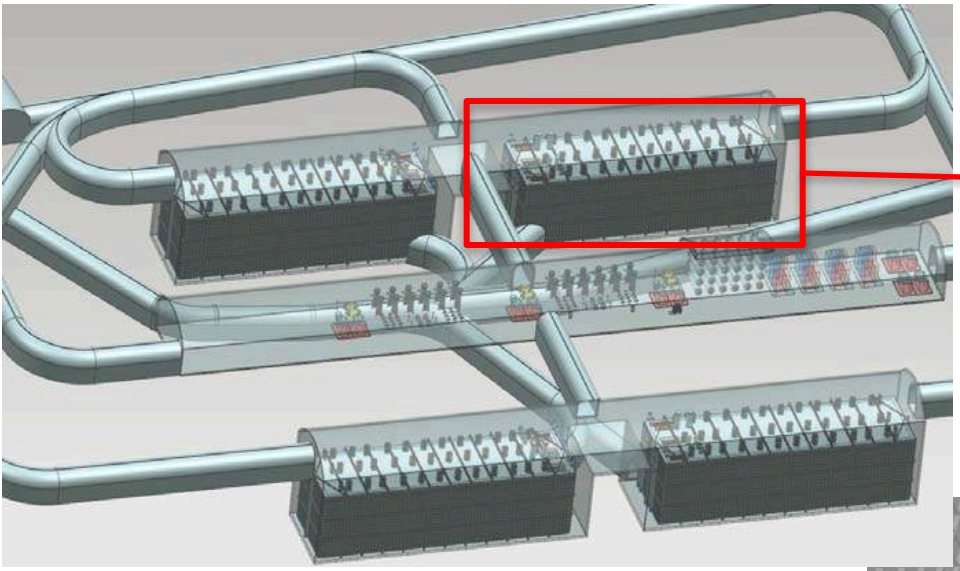
By Bo Yu (BNL)

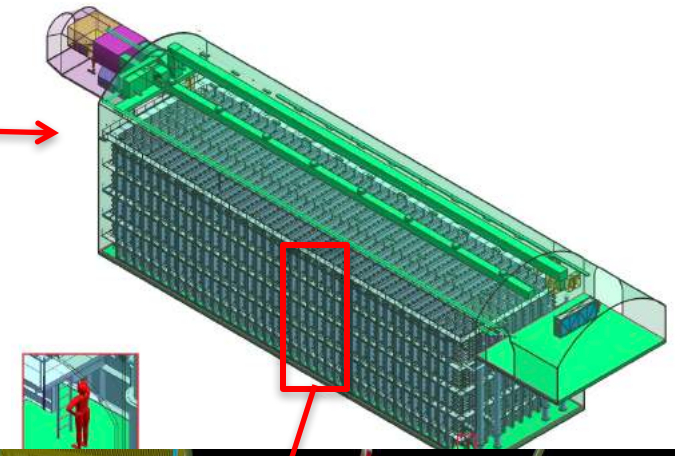


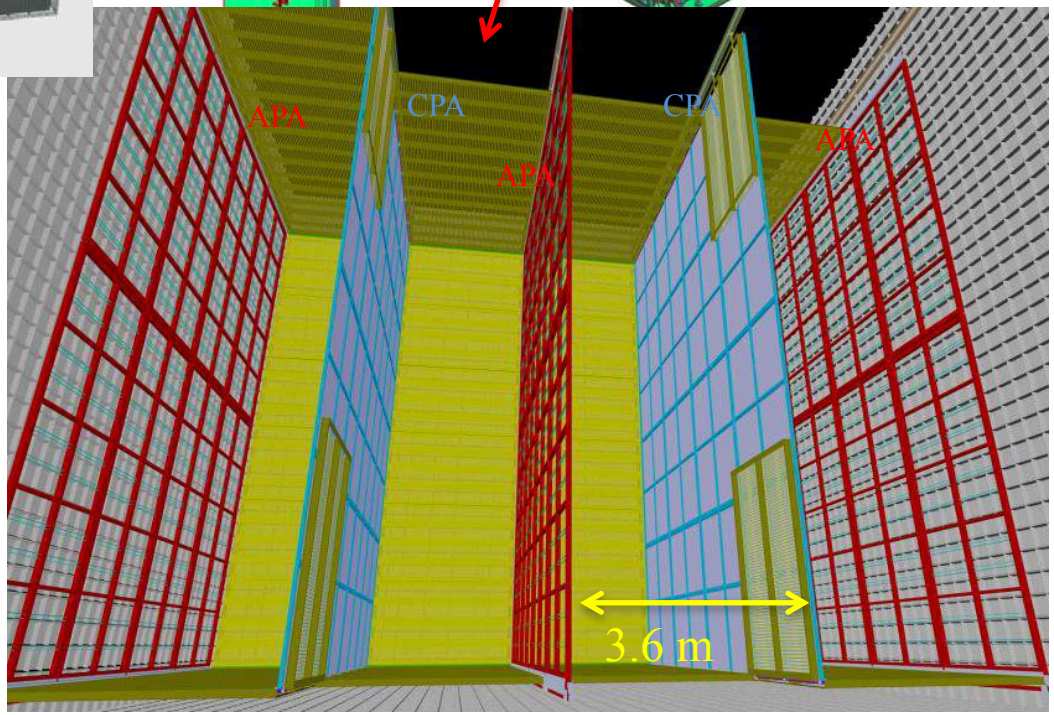
Event display in LArTPC (MicroBooNE MC)

- 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 Detector: Single-Phase LArTPC



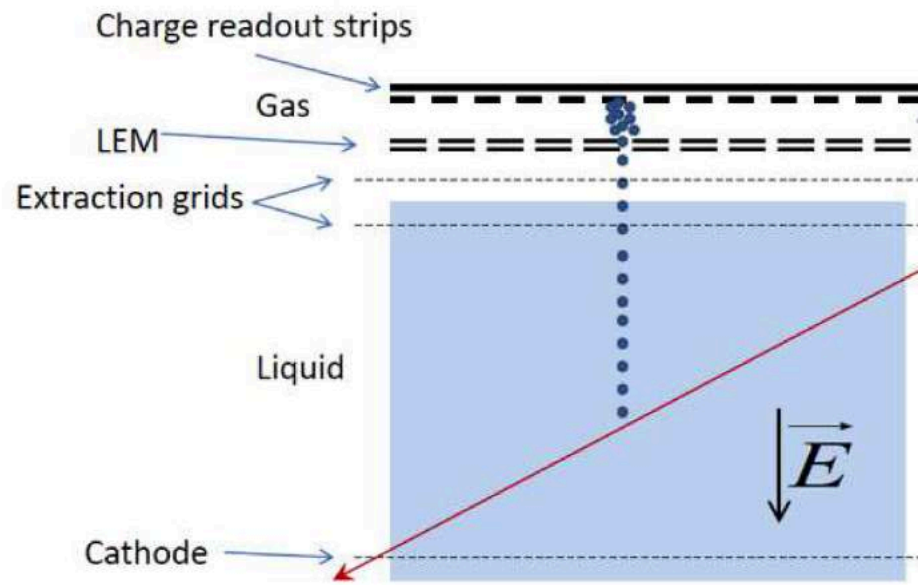




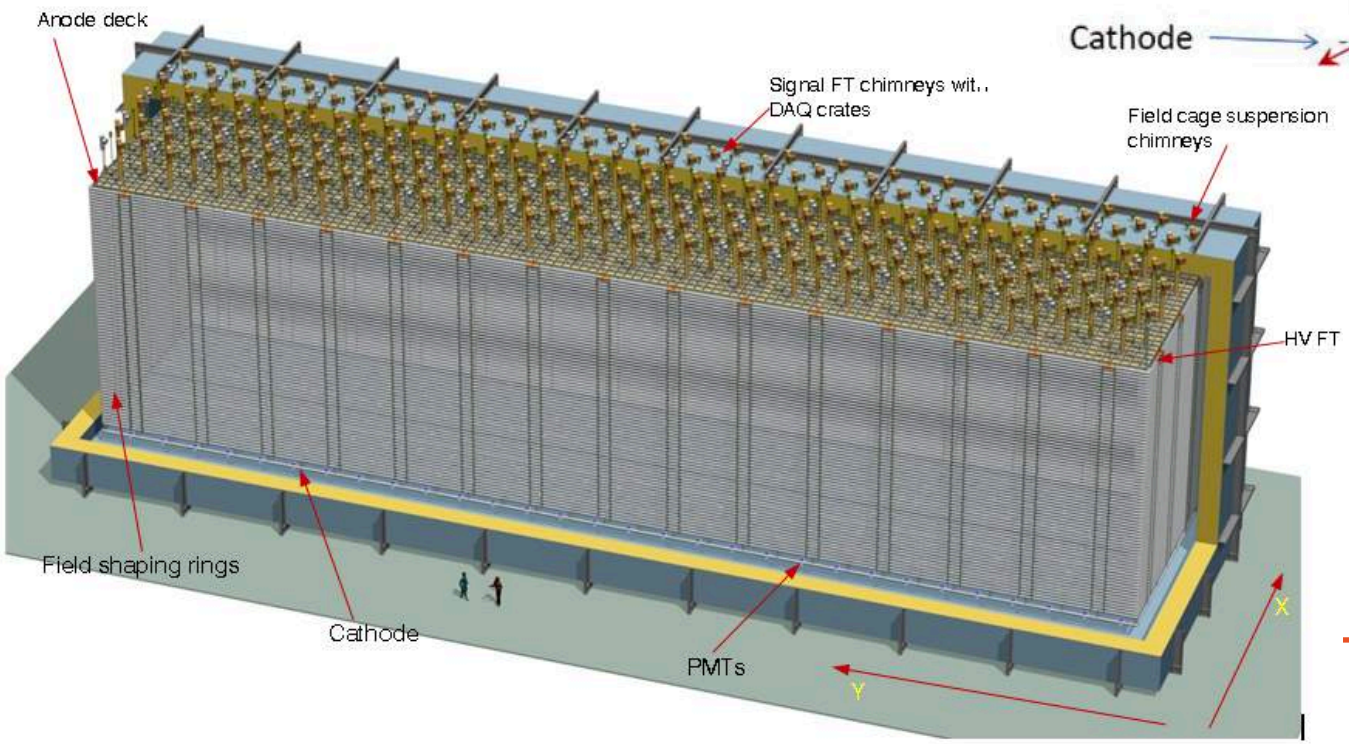
- Anode wires immersed in LAr
- Anode and Cathode Plane Assemblies (APA, CPA) suspended from ceiling
- Drift distance: 3.6 m, wire pitch: 5 mm
- Induction wires +-37.7^{o} to collection wires, wrapped around APA
- Photon detectors: light guides+SiPMs, embedded in APAs

Far Detector: Dual-Phase LArTPC

- Electrons extracted from LAr to a gaseous volume
- Signal amplified by LEM in the gas phase
- The charge is collected and recorded on a two-dimensional and segmented anode.
- Drift distance: 12 m (vertical)
- Better Signal/Noise
- Photon detectors: PMT below cathode



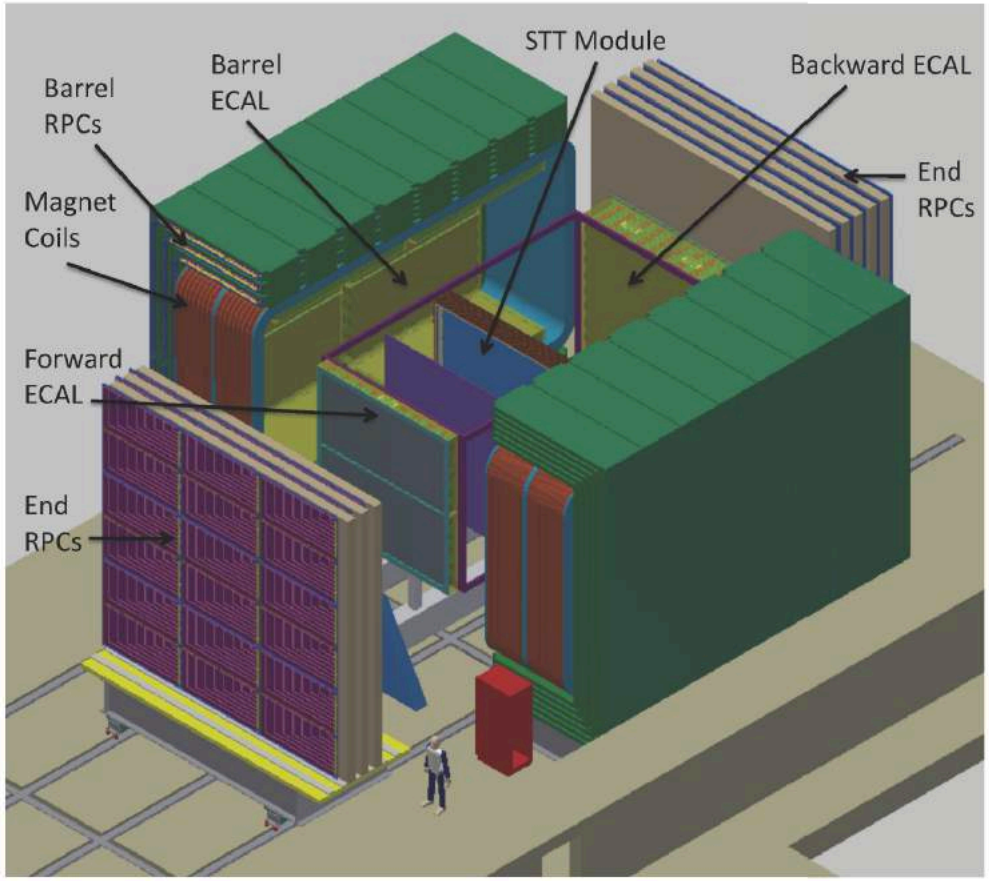
Arxiv1307.8166



UCIRVINE DUNE

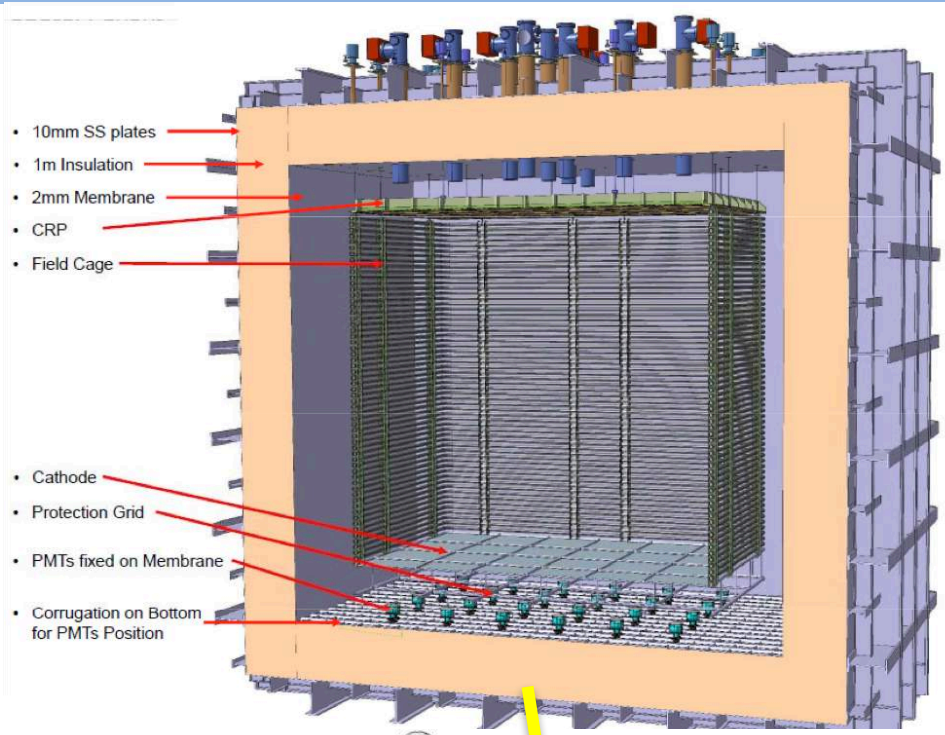
Near Detector

- Constrain systematic error for FD oscillation measurements
- High-precision cross-section/short-baseline measurements
- Reference design in CDR - fine grained tracker inspired by NOMAD
- Other designs being investigated
  - High-pressure Ar Gas TPC
  - LArTPC
  - Hybrid detector

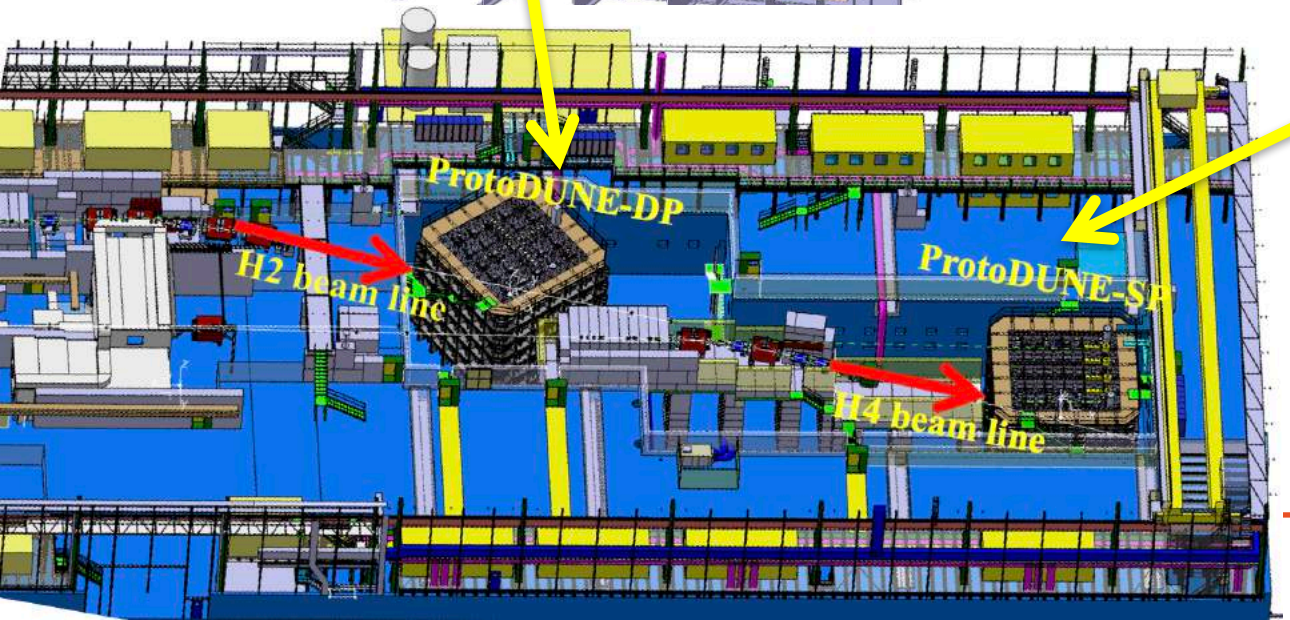


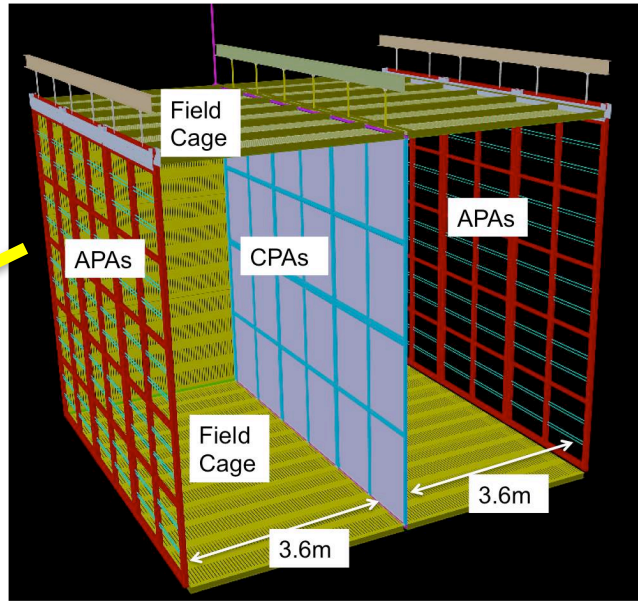
Reference design in Concept Design Report (CDR)

ProtoDUNEs at the CERN Neutrino Platform



- Single-phase ProtoDUNE: Full-sized APA-CPA, full drift distances (3.6m)
- Dual-phase ProtoDUNEs: Full-sized readout planes, half of final drift distance (6m)
- CERN Neutrino Platform in construction
- Test-Beam operations in 2018: 0.4-12GeV, e,μ,π,K,p





UCIrvine DUNE

DUNE Plan and Strategy

- 2017: Far Site construction begins
- 2018: Start to operate full-scale ProtoDUNE-SP/DP at CERN
- 2019: DUNE Technical Design Report (TDR) ready for funding agencies:
- 2020: Far Detector fabrication facilities ready
- 2021: Start to install FD module
- 2024: 20kt Far Detector operational, increasing to 40kt
- 2026: Deliver neutrino beam

ν_e Appearience

$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2 (A-1)\Delta}{(A-1)^2}$$

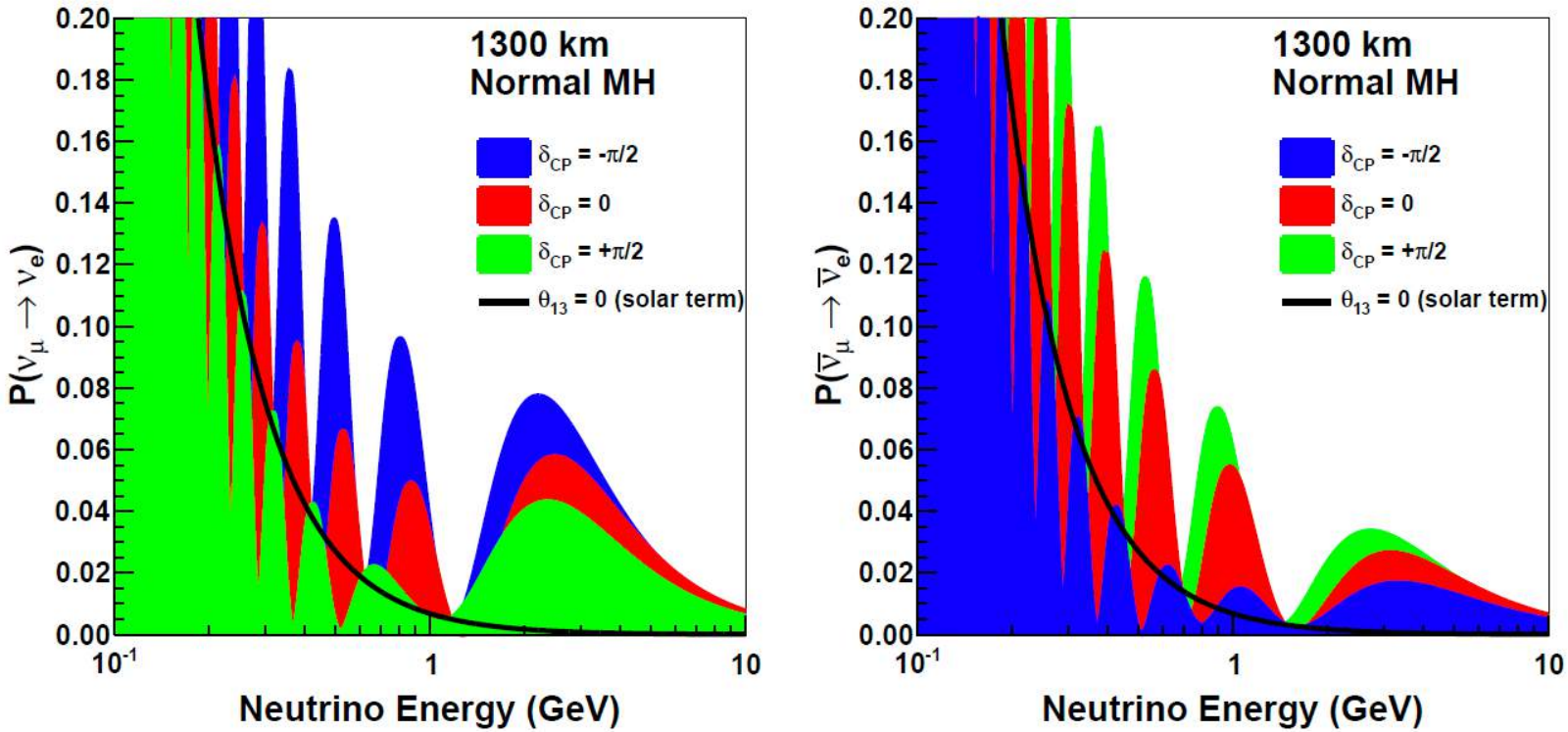
$$+ \; 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$

$$- \; 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$

$$\alpha = \frac{\Delta m_{21}^2}{\Delta m_{31}^2} \qquad \Delta = \frac{\Delta m_{31}^2 L}{4E} \qquad A = +G_f N_e \frac{L}{\sqrt{2}\Delta}$$

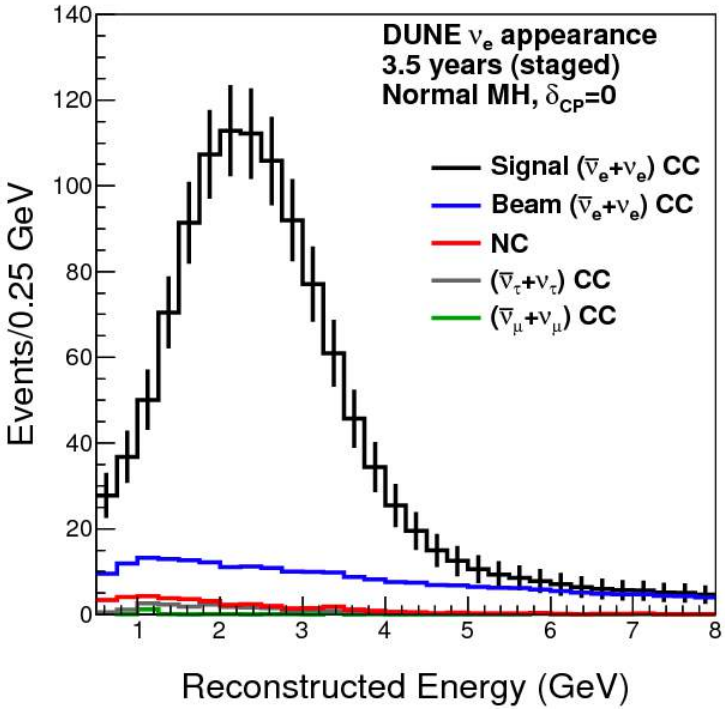
- DUNE measures ν_e appearance probability and ν_μ disappearance probability with ν_u and anti-ν_u beam.
- Measuring mass hierarchy, δ_{CP} and octant of θ_{23} with ν_e appearance

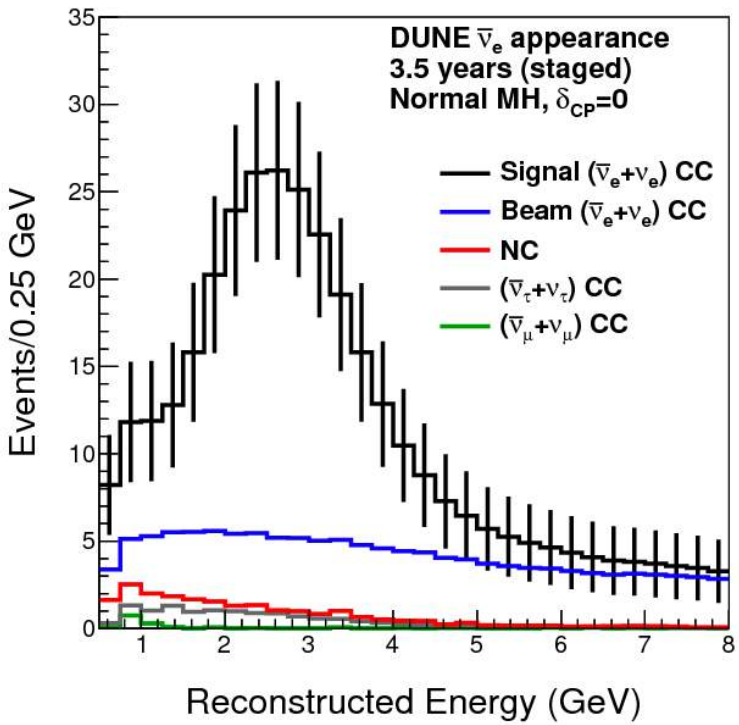
Neutrino Oscillation at DUNE



- Measure Mass Hierarchy, CP violation and mixing angles with neutrino and anti-neutrino beam
- 1300km baseline: large matter effect to solve MH
- Wide band beam covers 1st and 2nd oscillation maxima

Neutrino Oscillation at DUNE





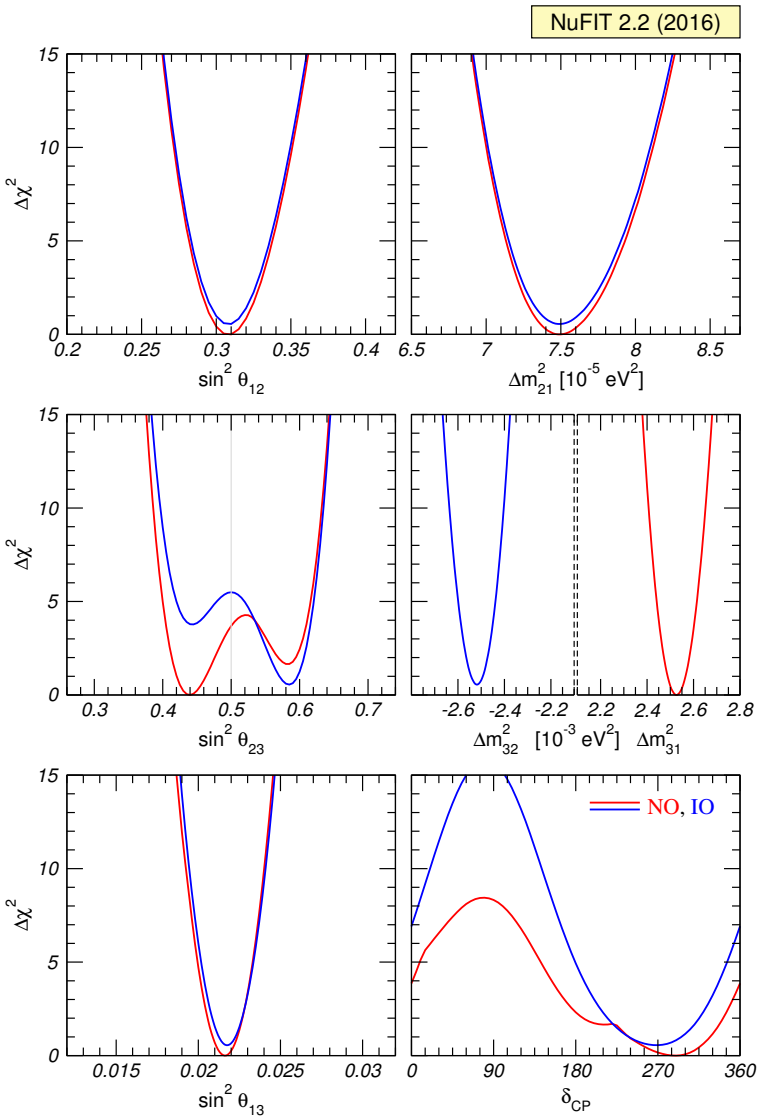
- Measure Mass Hierarchy, CP violation and mixing angles with neutrino and anti-neutrino beam
- 1300km baseline: large matter effect to solve MH
- Wide band beam covers 1st and 2nd oscillation maxima

2016 Global Fit

From previous neutrino experiments:

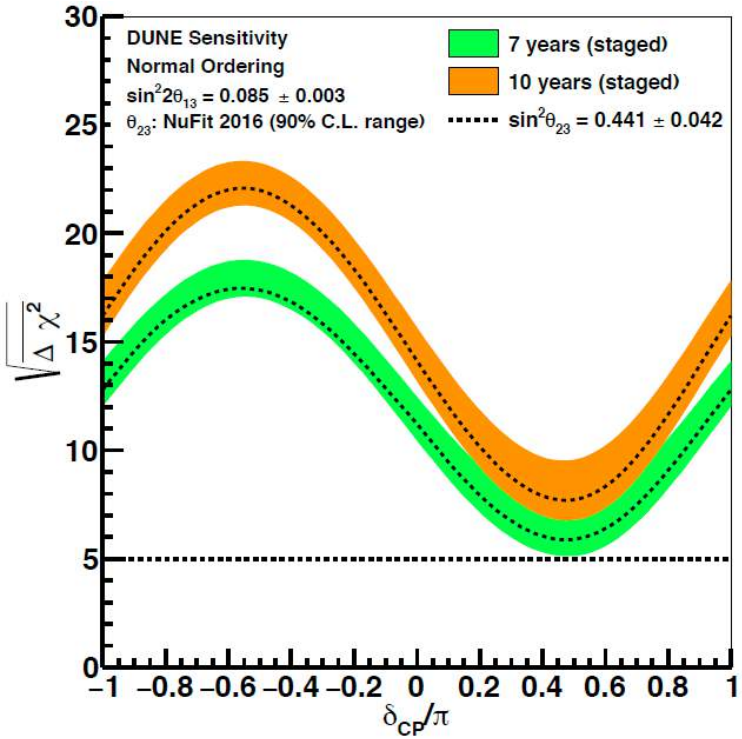
- $\sin^2 2\theta_{12}$, $\sin^2 2\theta_{13}$ and $\sin^2 2\theta_{23}$ have been measured
- Δm^2_{21} and $|\Delta m^2_{32}|$ have been measured
- Best fit for δ_{CP} close to $3\pi/2$ and can exclude some regions

Octant of θ_{23} is unclear, affects mass-hierarchy determination and δ_{CP} sensitivity

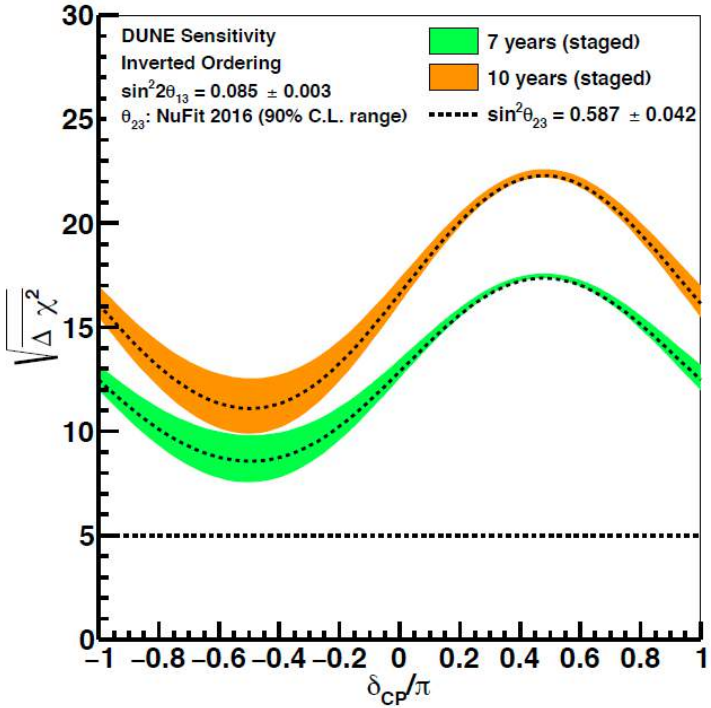


Mass Hierarchy Sensitivity

Normal Hierarchy, Lower octant



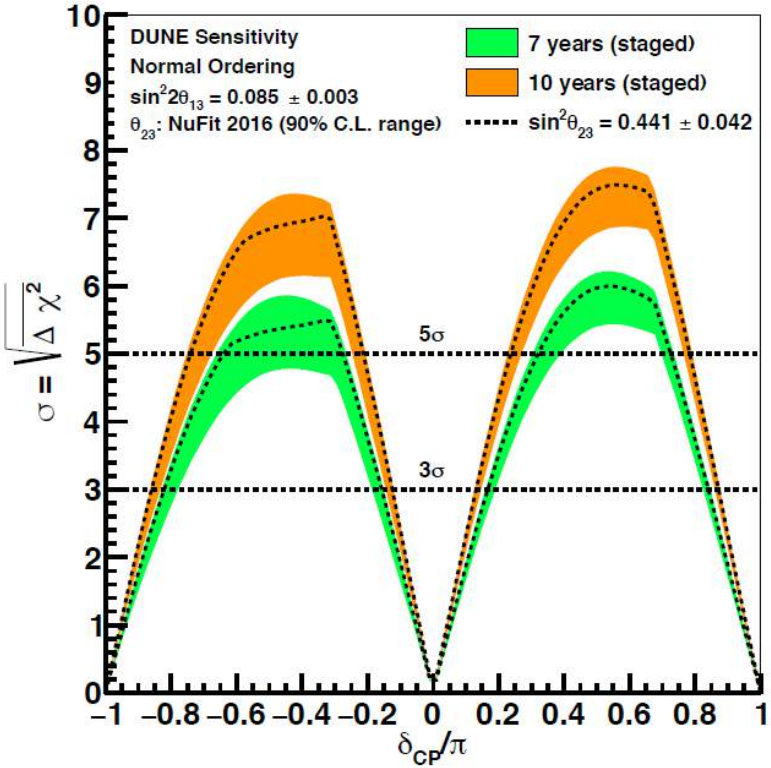
Inverted Hierarch, Upper Octant



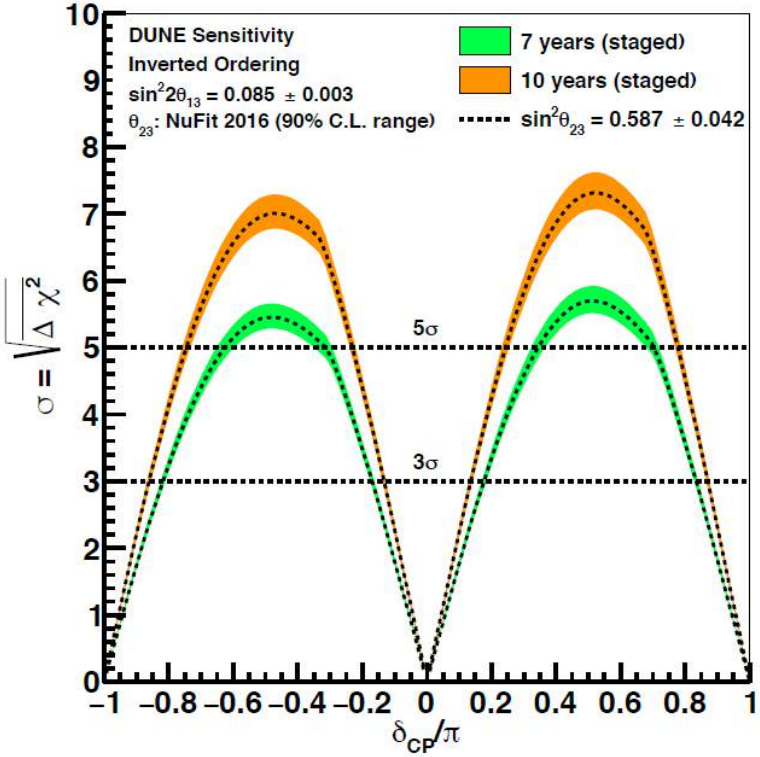
300 kt-MW-yrs
40kt @ 1.07 MW, 80GeV protons
Equal neutrino and anti-neutrino running

CP Sensitivity

Normal Hierarchy, Lower octant



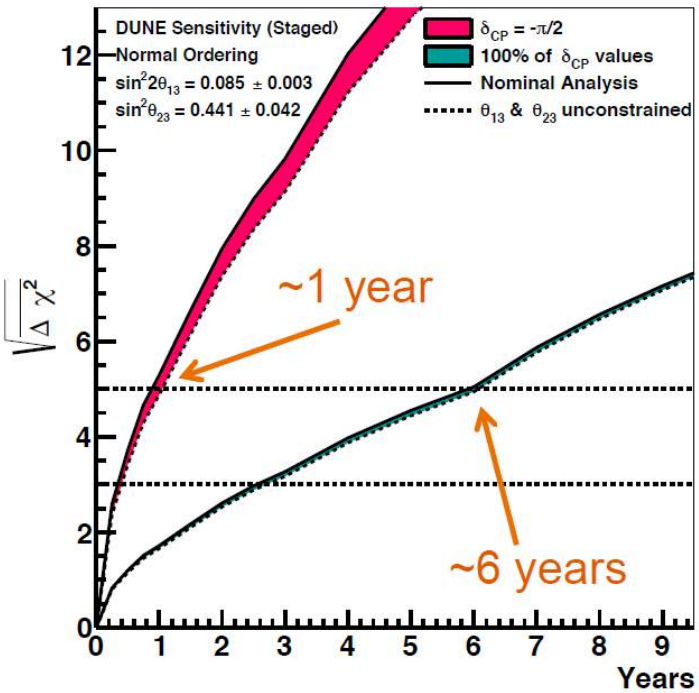
Inverted Hierarch, Upper Octant



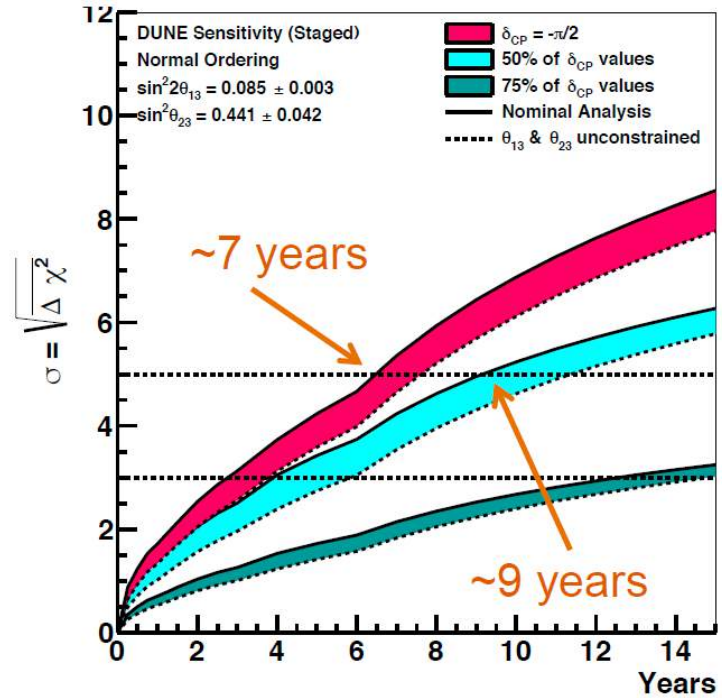
300 kt-MW-yrs
40kt @ 1.07 MW, 80GeV protons
Equal neutrino and anti-neutrino running

MH & CPV Sensitivity vs. Time

Mass Hierarchy Sensitivity

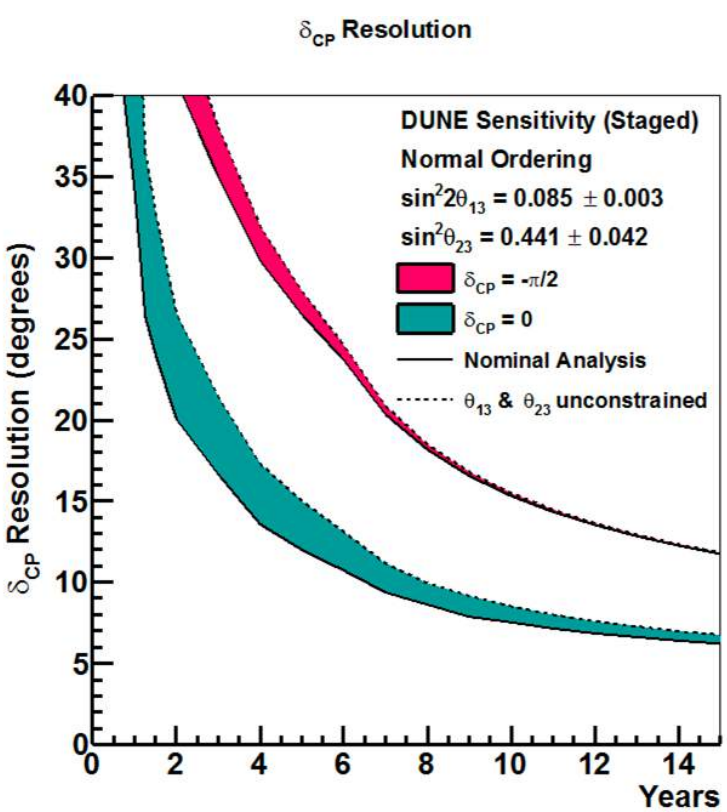


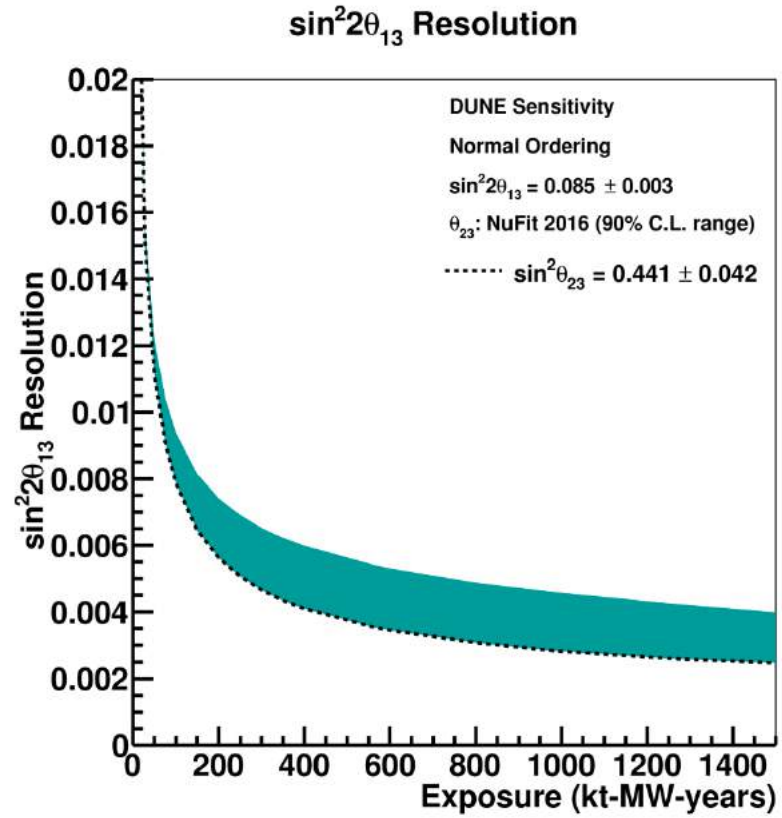
CP Violation Sensitivity



300 kt-MW-yrs
40kt @ 1.07 MW, 80GeV protons
Equal neutrino and anti-neutrino running

MH & CPV Resolution vs. Time





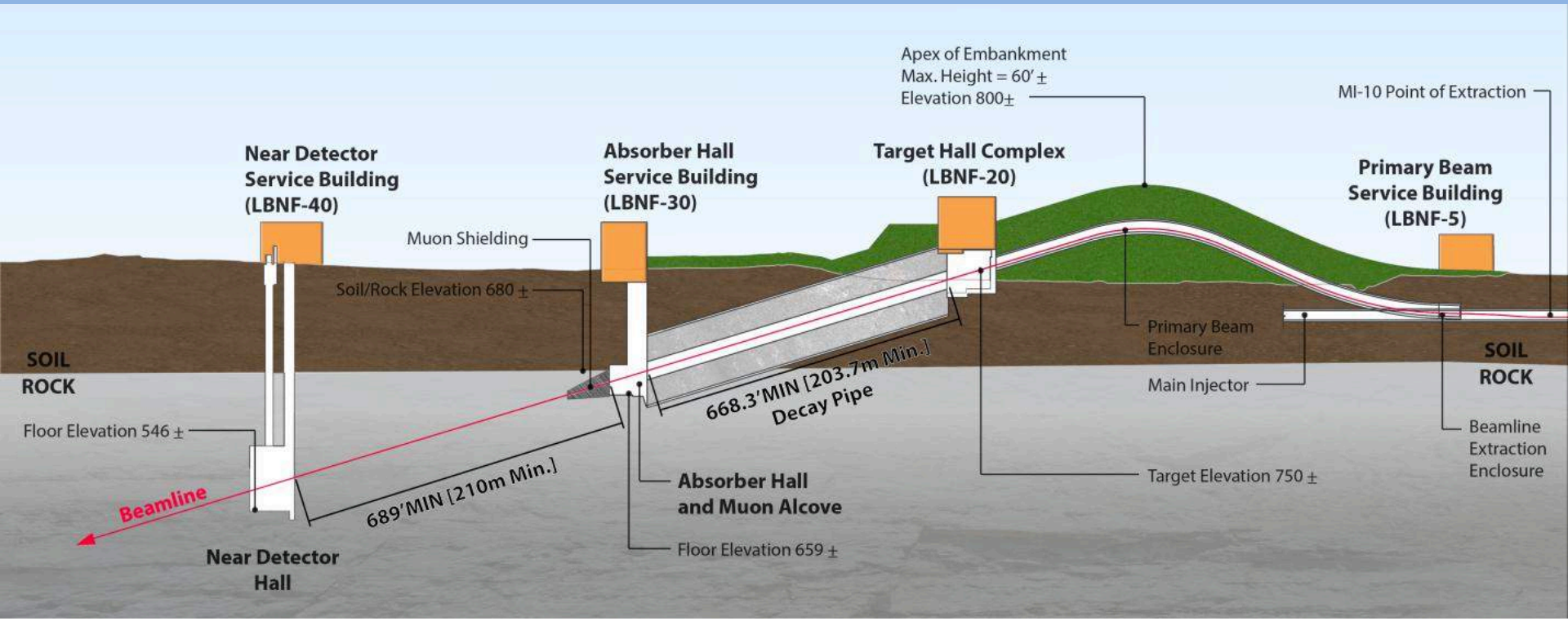
300 kt-MW-yrs
40kt @ 1.07 MW, 80GeV protons
Equal neutrino and anti-neutrino running

Summary

- DUNE Collaboration has been established as an international scientific priority
- DUNE/LBNF project: detailed plan for the 40 kt LArTPC FD and the 1.2 MW@120 GeV beam, ND design under development
- Far site construction and prototypes are underway this year
- Will make decisive measurements to CP violation, Mass Hierarchy and Octant of θ_{23}

Backup

Long Baseline Neutrino Facility (LBNF)

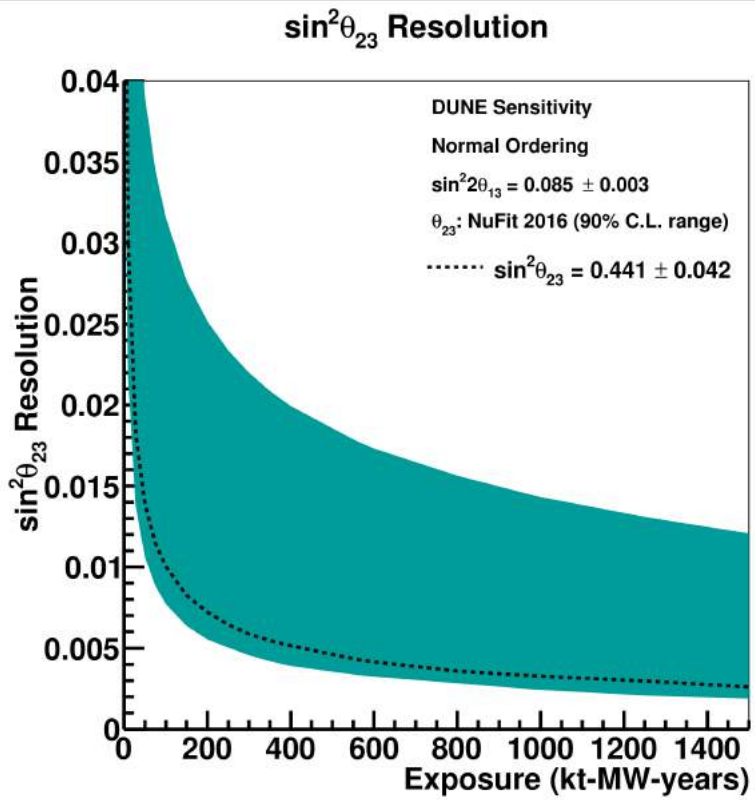


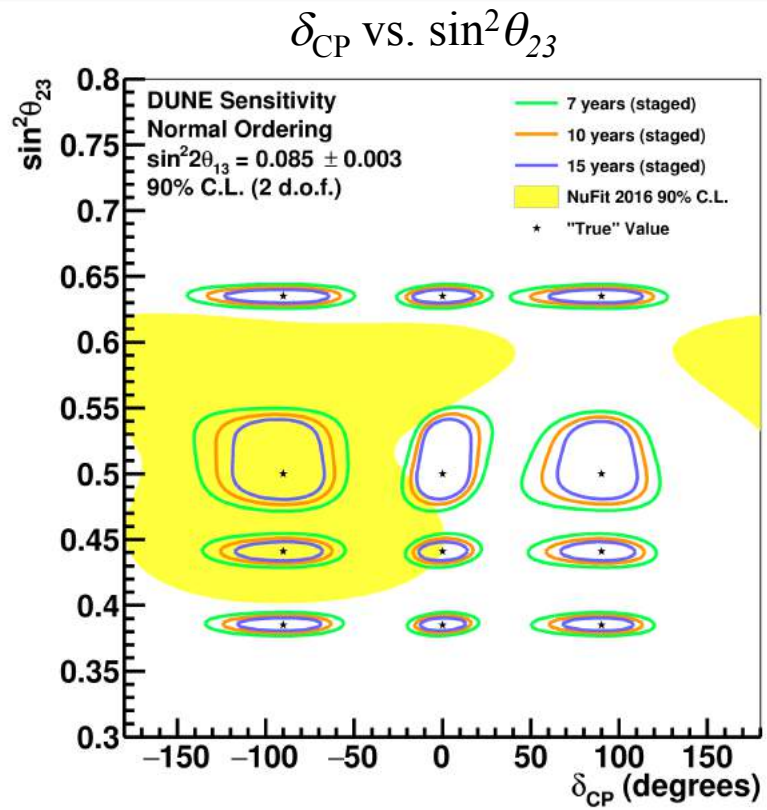
- 60-120 GeV protons from Fermilab Main Injector
- Wide energy spectrum covers the 1st and 2nd oscillation maxima
- Initial upward pitch, 101 mrad pitch to get to S. Dakota
- Near Detector Hall at edge of Fermilab site
- Initially 1.2 MW, upgradeable to 2.4 MW
- Reference design similar to NuMI, optimized to improve sensitivity to oscillation measurements

The LBNF/DUNE Project

- High-level recommendations
  - US "Snowmass" community study (2012-13) & Particle Physics Project Prioritization Panel (P5) Report (2014)
  - European Strategy for Particle Physics Update (2013)
- Neutrino Protocol signed between DOE and CERN
- Highest priority in Fermilab
- Follows the CERN LHC management model: Collaboration (DUNE) and Facility (LBNF) managed separately
  - LBNF(Long-Baseline Neutrino Facility): Neutrino beamline, Far/Near detector halls and facilities
  - DUNE(Deep Underground Neutrino Experiment): Far/Near detectors, Scientific program

CP Sensitivity vs. $\sin^2\theta_{23}$





300 kt-MW-yrs
40kt @ 1.07 MW, 80GeV protons
Equal neutrino and anti-neutrino running

CERN Neutrino Platform

CERN Accelerating science Sign in Directory

Camera NP02

*Images updated every 30 minutes.

Camera NP04

*Images updated every 30 minutes.

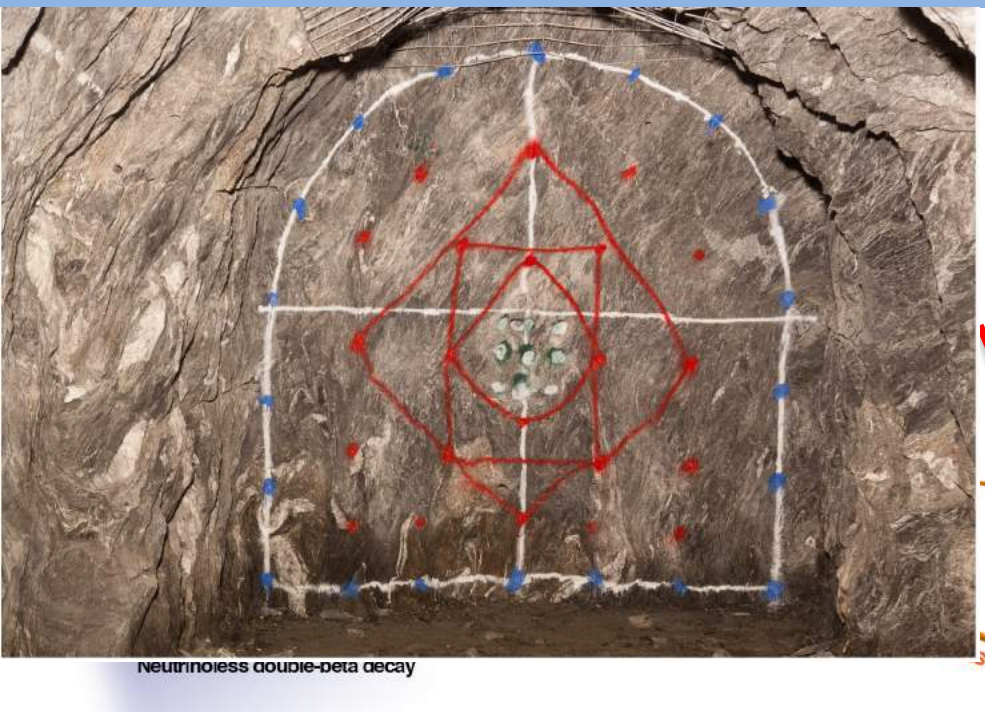
External structures of the cryostats in place!

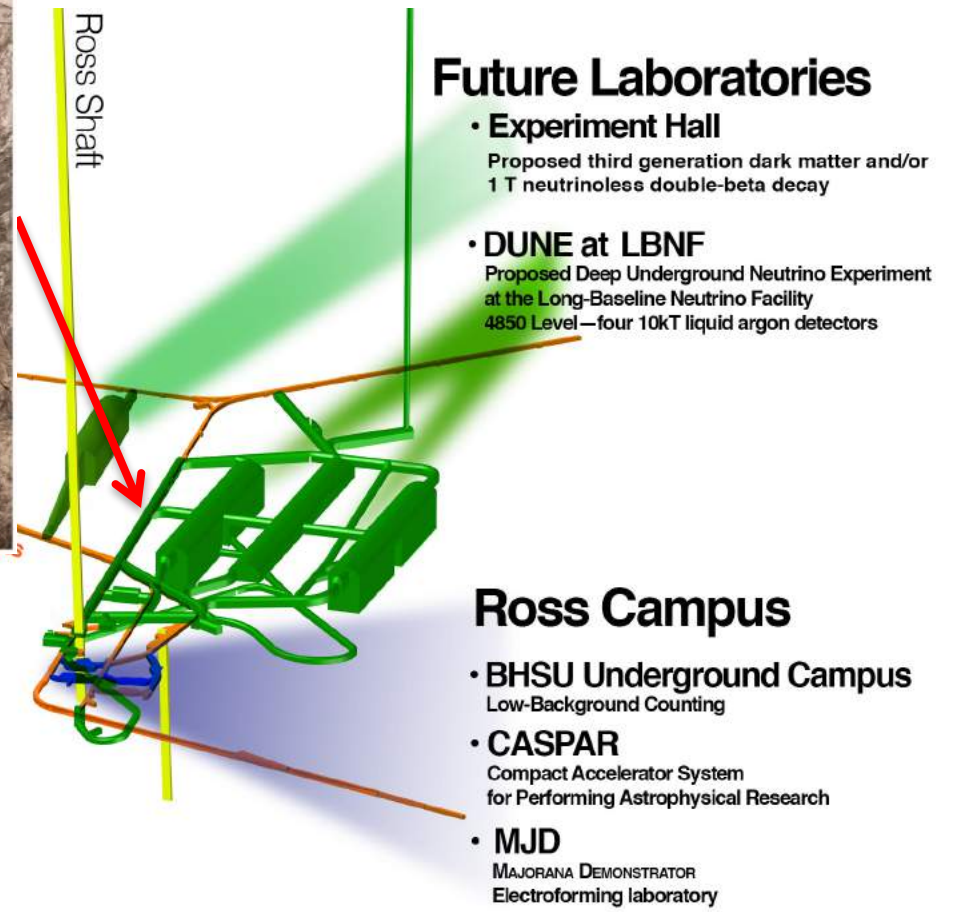
Welcome to EHN1-Neutrino Platform Facility

CENF-Homepage | Project Description | Multimedia | Useful Links | Contact Us

The 5th of September 2016 the new EHN1 extension dedicated to the Neutrino Platform has been handed over from Civil Engineering (SMB) to the final users, in order to start the installation of the detectors and the related infrastructures.

Blast Vibration Study, March 2016

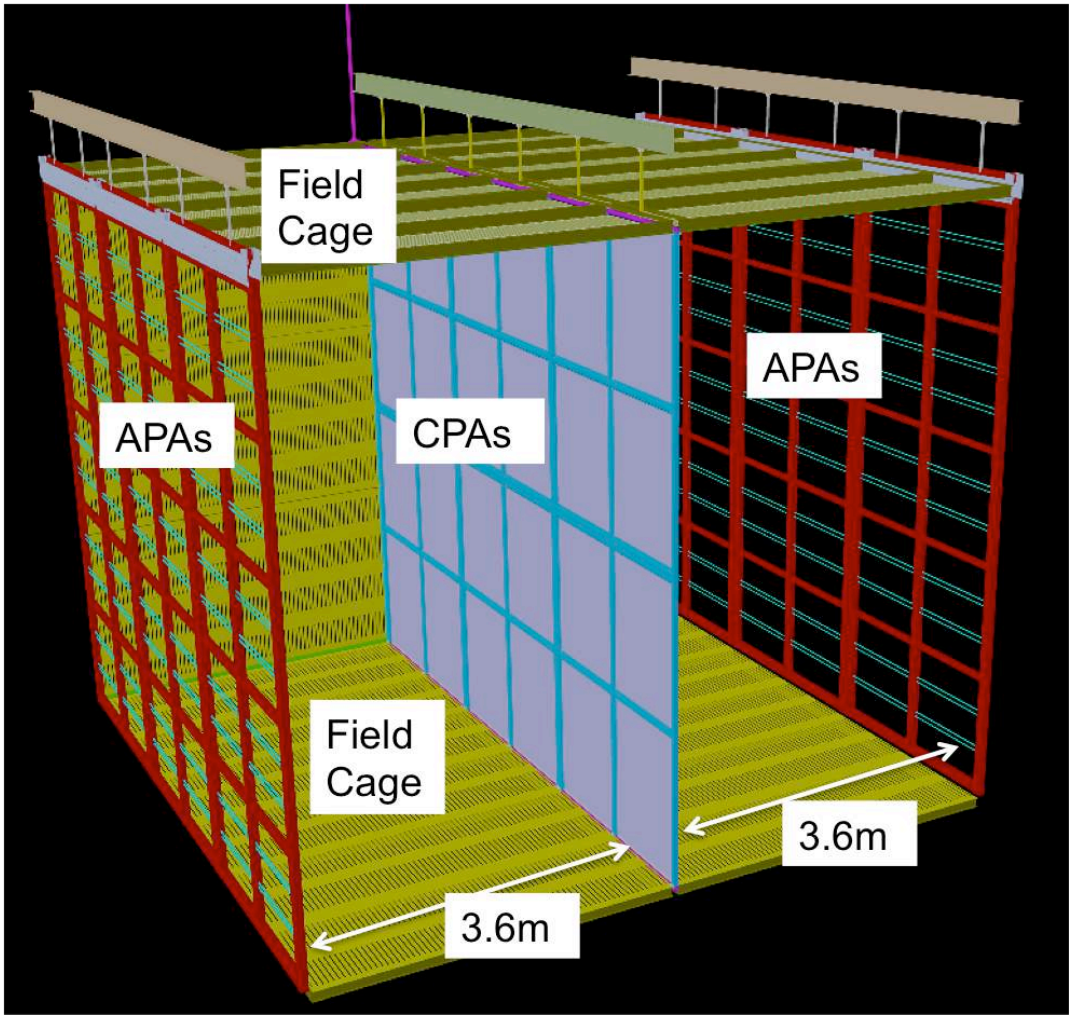




- The excavation needs to remove hundreds of kt rock
- Conducted blast vibration study to understand the impacts on existing experiments
- Studied the blast energy moves through the rock and the air in existing spaces

ProtoDUNE-SP

- Single-phase LArTPC prototype
- Full-sized APA-CPA
- Full drift distances (3.6m)
- Comparing 2 photon detector designs
- Plan for operation in 2018
- Test components, construction/installation/commissioning
- Use H4 beamline to test LAr response to charged particles



ProtoDUNE-DP

- Dual-phase LArTPC prototype
- Size: 6 m x 6m x 6m
- Full-sized readout planes, cathodes, and light collection
- Half of final drift distance (6m)
- Reuse elements and infrastructure from the 3x1x1 prototype
- Use H2 beamline