Overview of the DUNE Experiment

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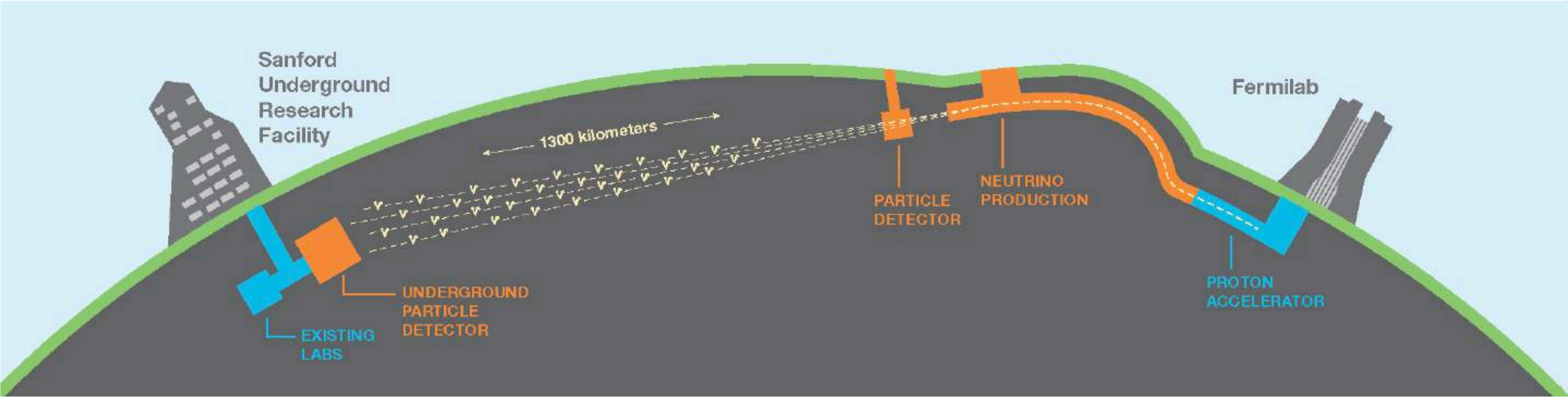
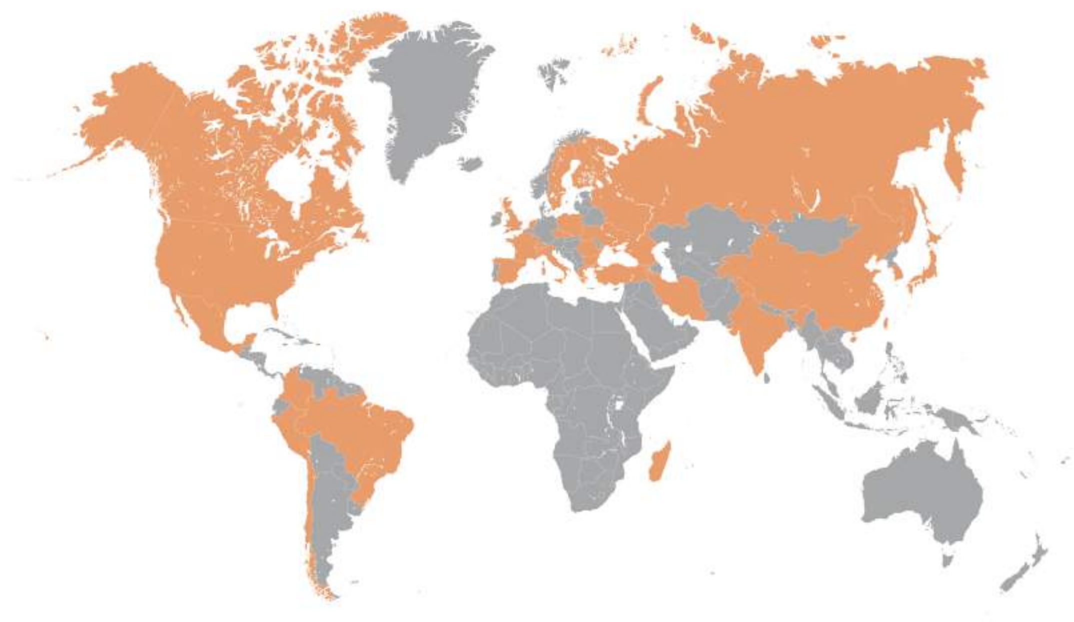
DEEP UNDERGROUND NEUTRINO EXPERIMENT



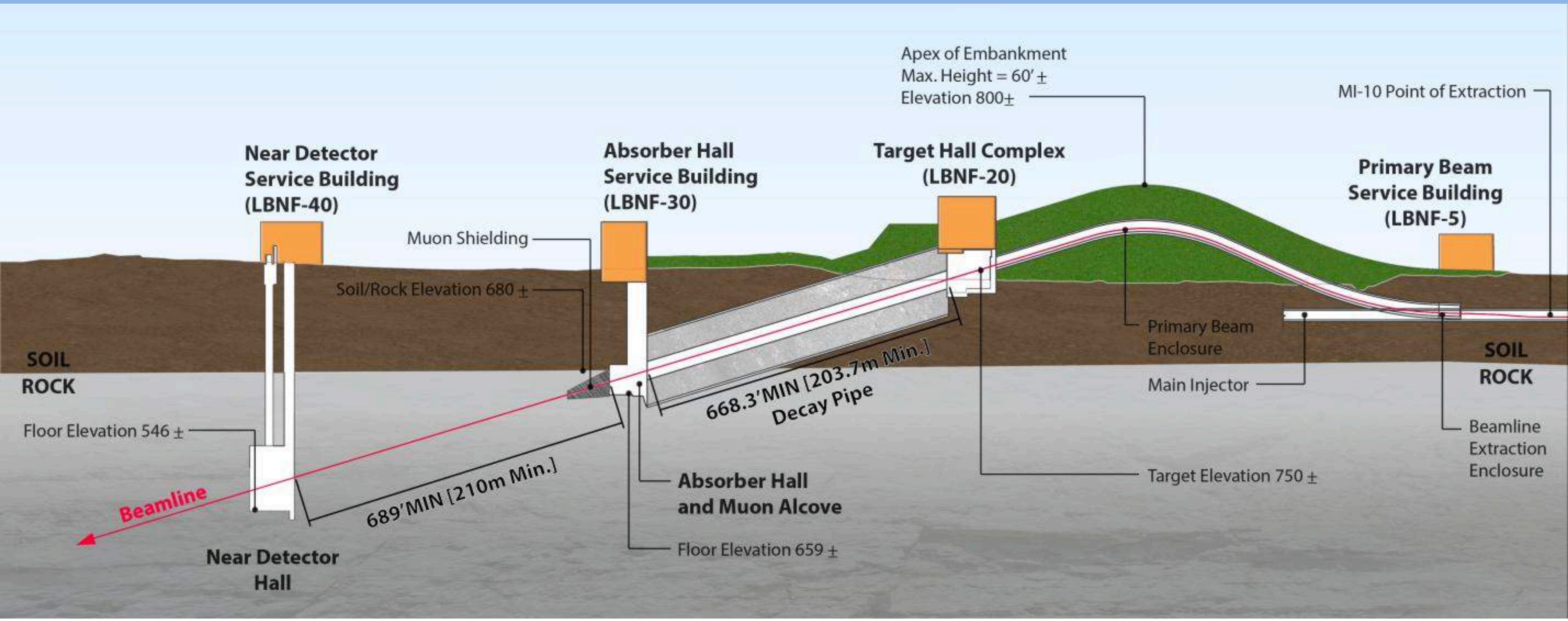
- New beam at Fermilab (1.07 MW@80 GeV protons, upgradeable to 2.14 MW), 1300 km baseline
- On-Axis 40 kton Liquid Argon Time Projection Chamber (LArTPC) Far Detector at Sanford Underground Research Facility, South Dakota, 1.5 km underground
- Highly-capable near detector at Fermilab
- ν_e appearance and ν_μ disappearance → Measure MH, CPV and mixing angles
- Large detector, deep underground → Nucleon decay, supernova burst neutrinos, atmospheric neutrinos, etc

DUNE Collaboration



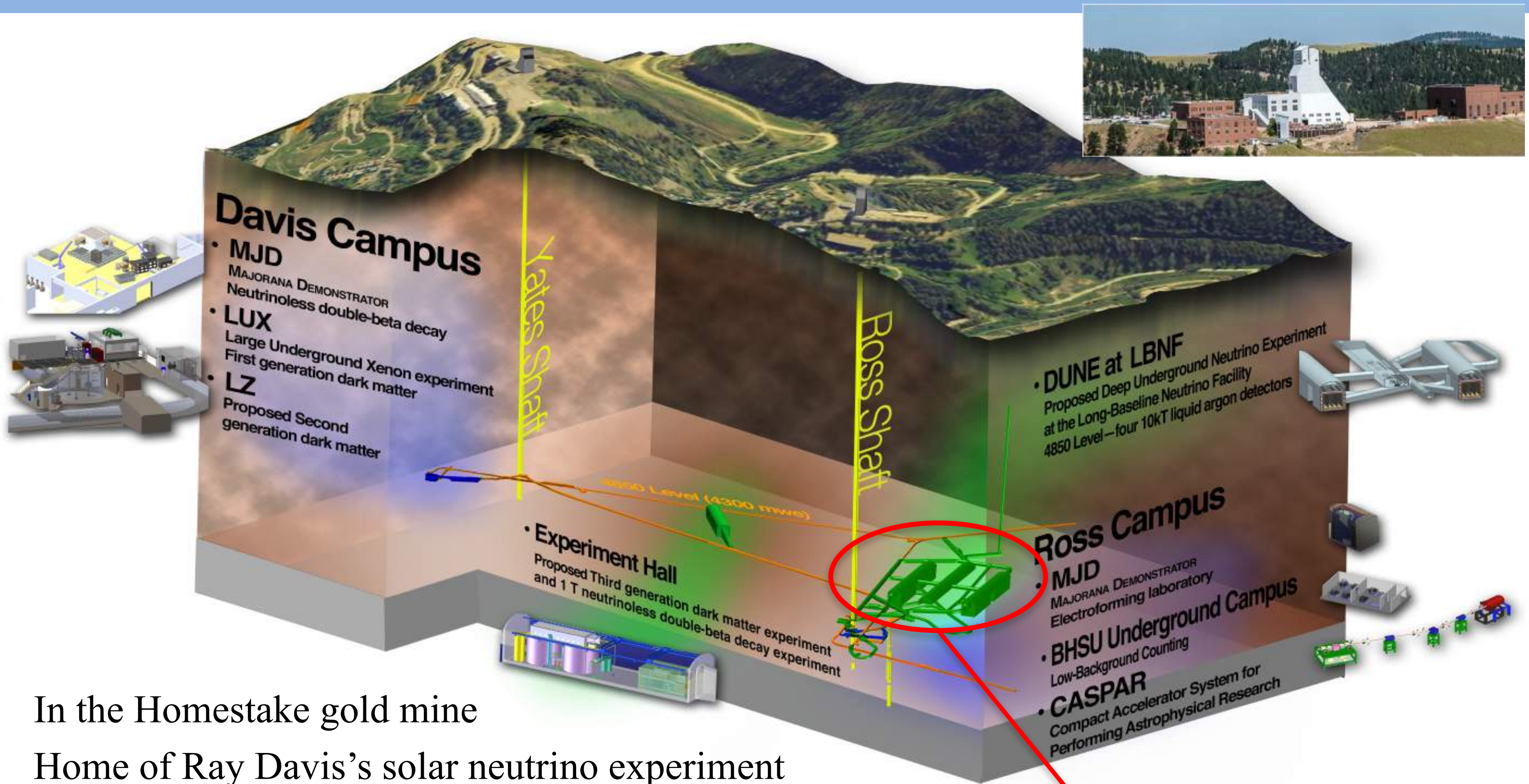
1000+ collaborators from 175 institutions in 30 nations

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 1.07 MW @ 80GeV, upgradeable to 2.14 MW
- Reference design similar to NuMI, optimized to improve sensitivity to oscillation measurements

Sanford Underground Research Facility (SURF), Lead, S. Dakota



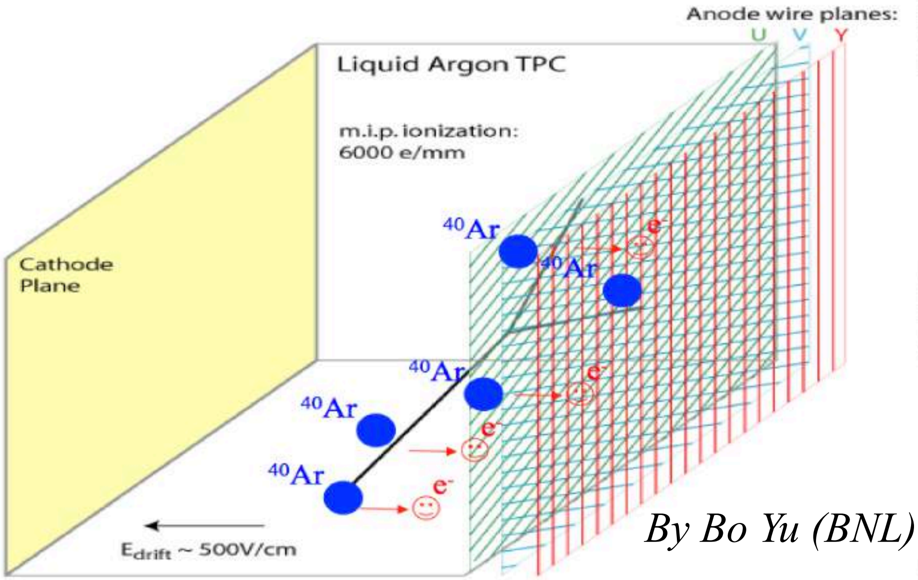
DUNE facility, 4850 ft (4300 mwe)

- 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

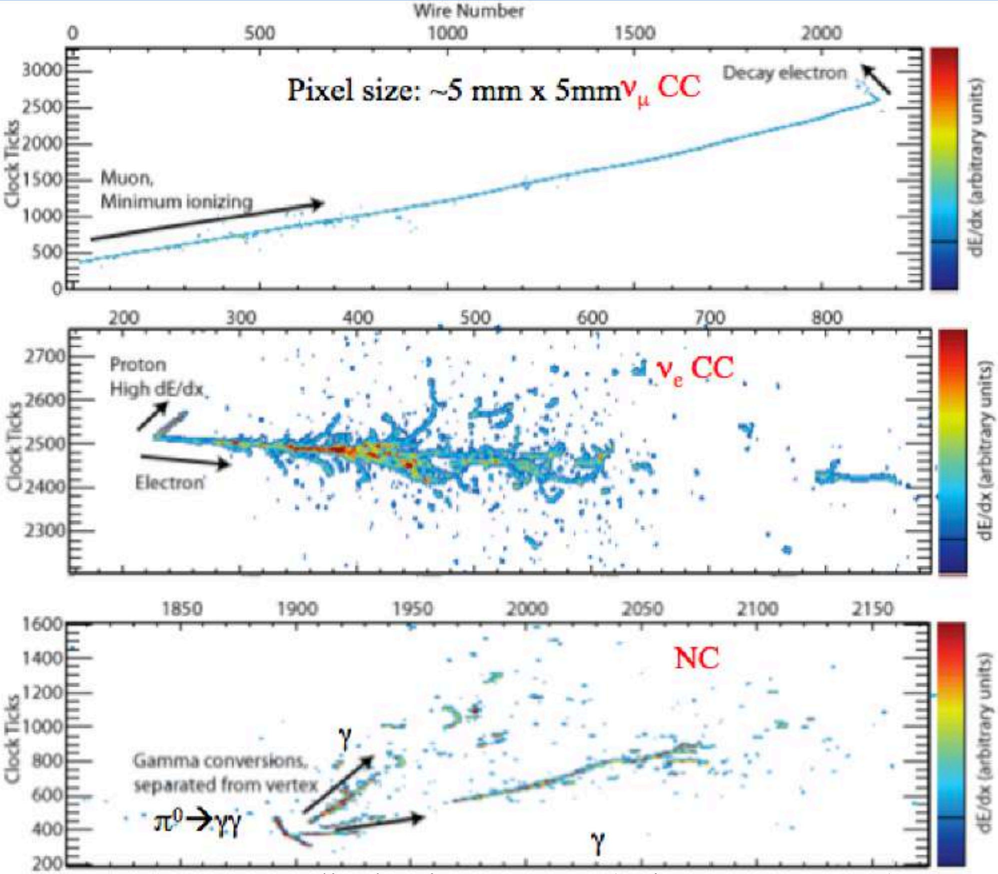
SURF groundbreaking

Ceremony held 21st July, 2017 at the 4850 ft (4300 mwe) level

Far Detectors: Liquid Argon Time Projection Chamber (LArTPC)



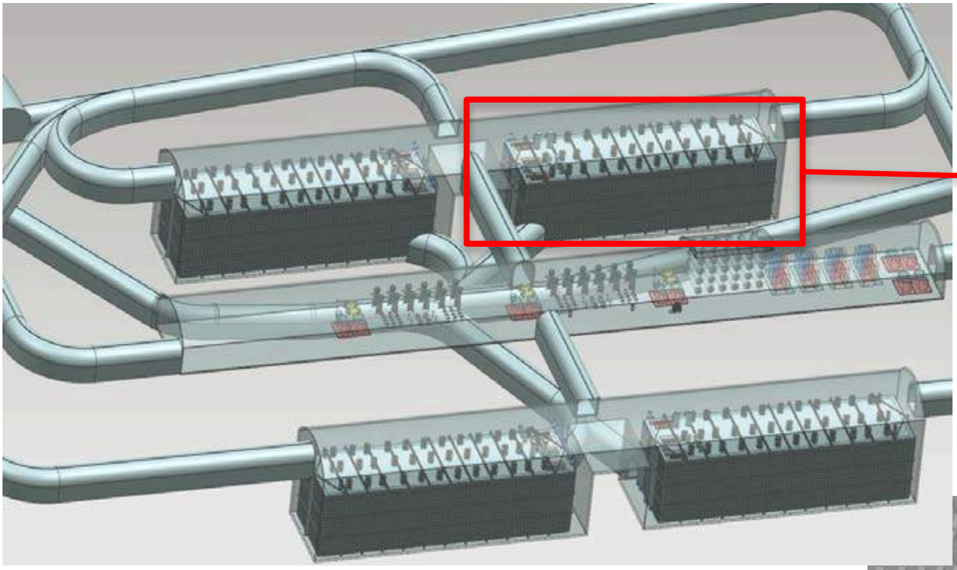
By Bo Yu (BNL)

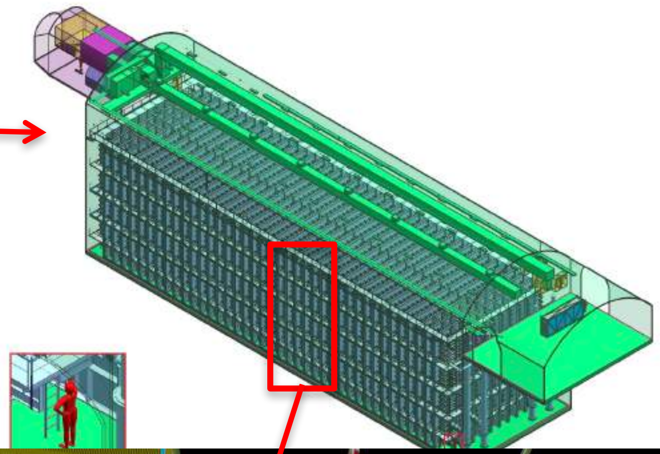


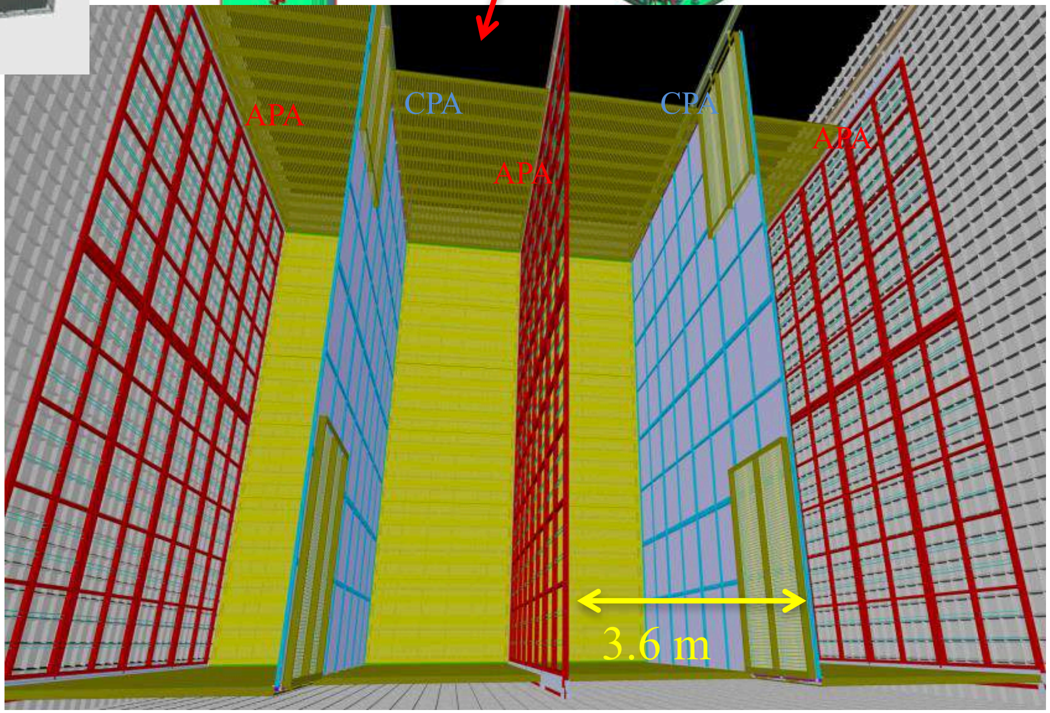
Event display in LArTPC (MicroBooNE MC)

- 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



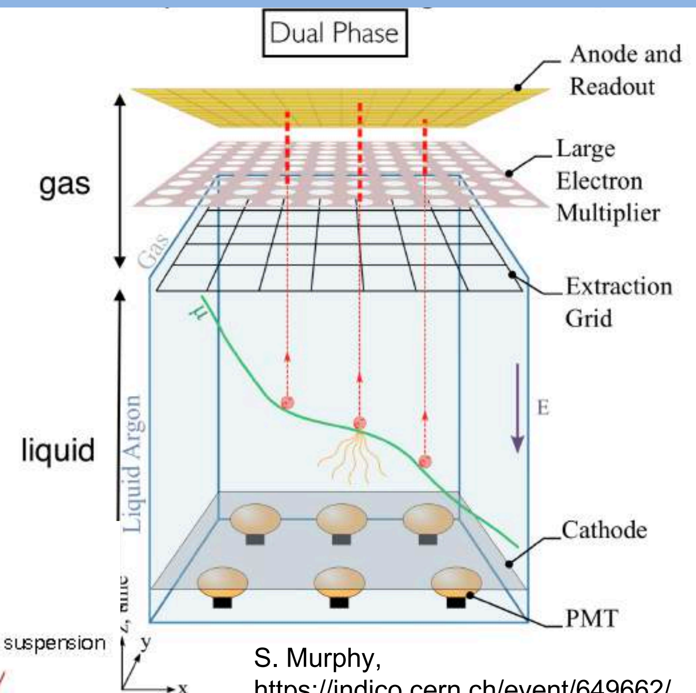




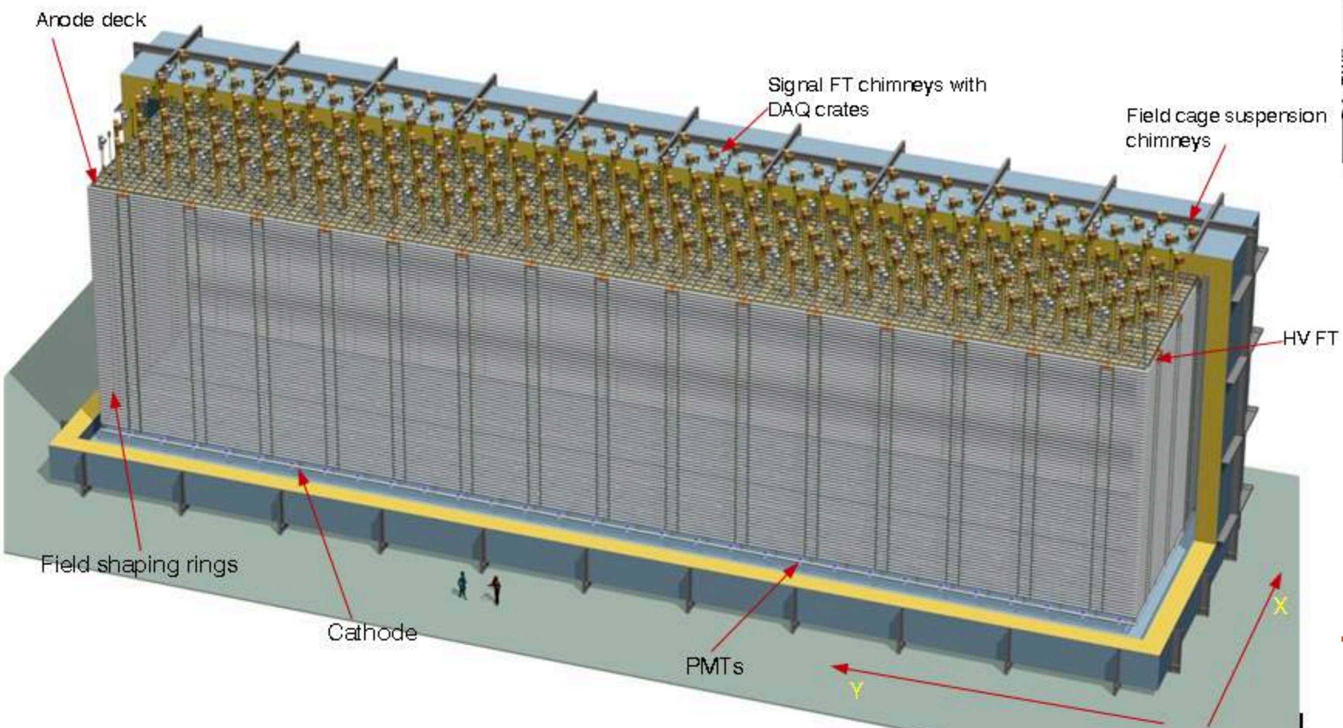
- Anode wires immersed in LAr
- Anode and Cathode Plane Assemblies (APA, CPA) suspended from ceiling
- Drift distance: 3.6 m, wire pitch: 5 mm
- Induction wires +-37.7^{o} to collection wires, wrapped around APA
- Photon detectors: light guides+SiPMs, embedded in APAs

Far Detector: Dual-Phase LArTPC

- Electrons extracted from LAr to gaseous volume
- Signal amplified by Large Electron Multiplier (LEM) in gas phase
- Charge collected and recorded on 2-D segmented anode
- Drift distance: 12 m (vertical)
- Better Signal/Noise
- Photon detectors: PMT below cathode



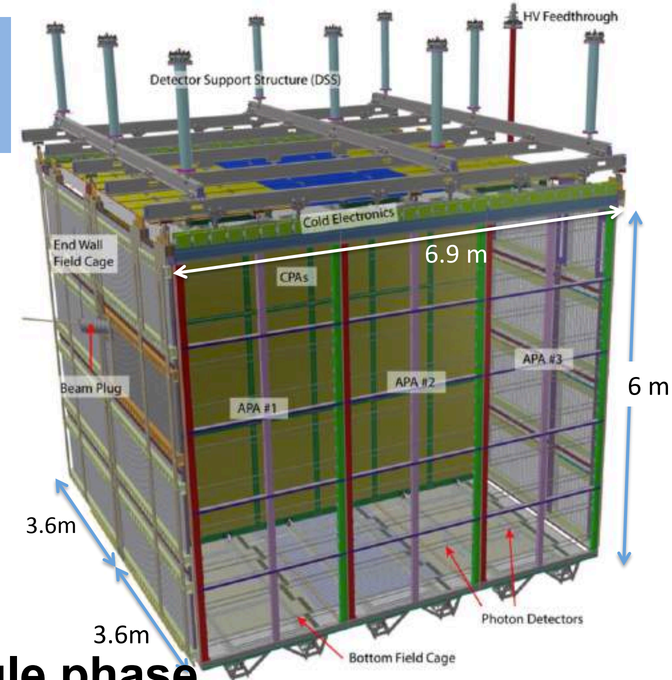
S. Murphy, https://indico.cern.ch/event/649662/



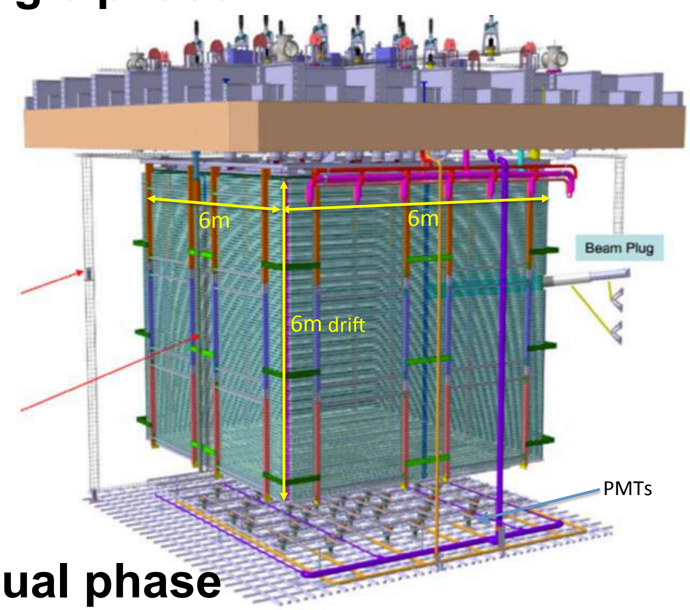
ProtoDUNE at CERN

- Two prototype TPCs under construction at CERN
  - One single phase and one dual phase
  - 770 t LAr mass each
  - Exposed to H2 (DP) and H4 (SP) testbeams at CERN

- Strategic Goals
  - Prototyping production and installation procedures
  - Validating the design from basic detector performance
  - Accumulating large test-beam data for detector response understanding/calibration
  - Demonstrating long-term operational stability



Single phase

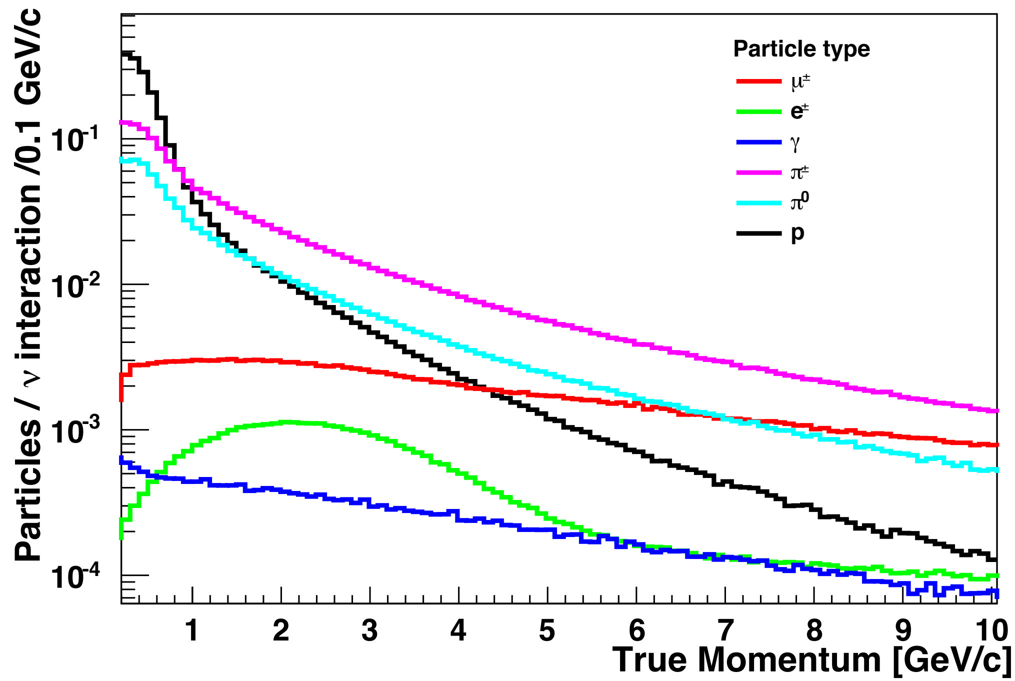


Dual phase

UCIRVINE DUNE

ProtoDUNE measurements

- Momentum-dependent beam composition contains e, $K^{\pm}$, μ, p, $\pi^{\pm}$
- $\pi^{\pm}/\,p$
  - Validate simulation, reconstruction, particle ID
  - $\pi^{+}/\,\pi^{-}$ differences
  - π^{0} production
  - Interaction cross sections
- e
  - e/γ separation
  - EM shower reconstruction
- μ
  - Michel electron reconstruction
  - dE/dx calibration and validation
  - μ^{-} capture on Ar

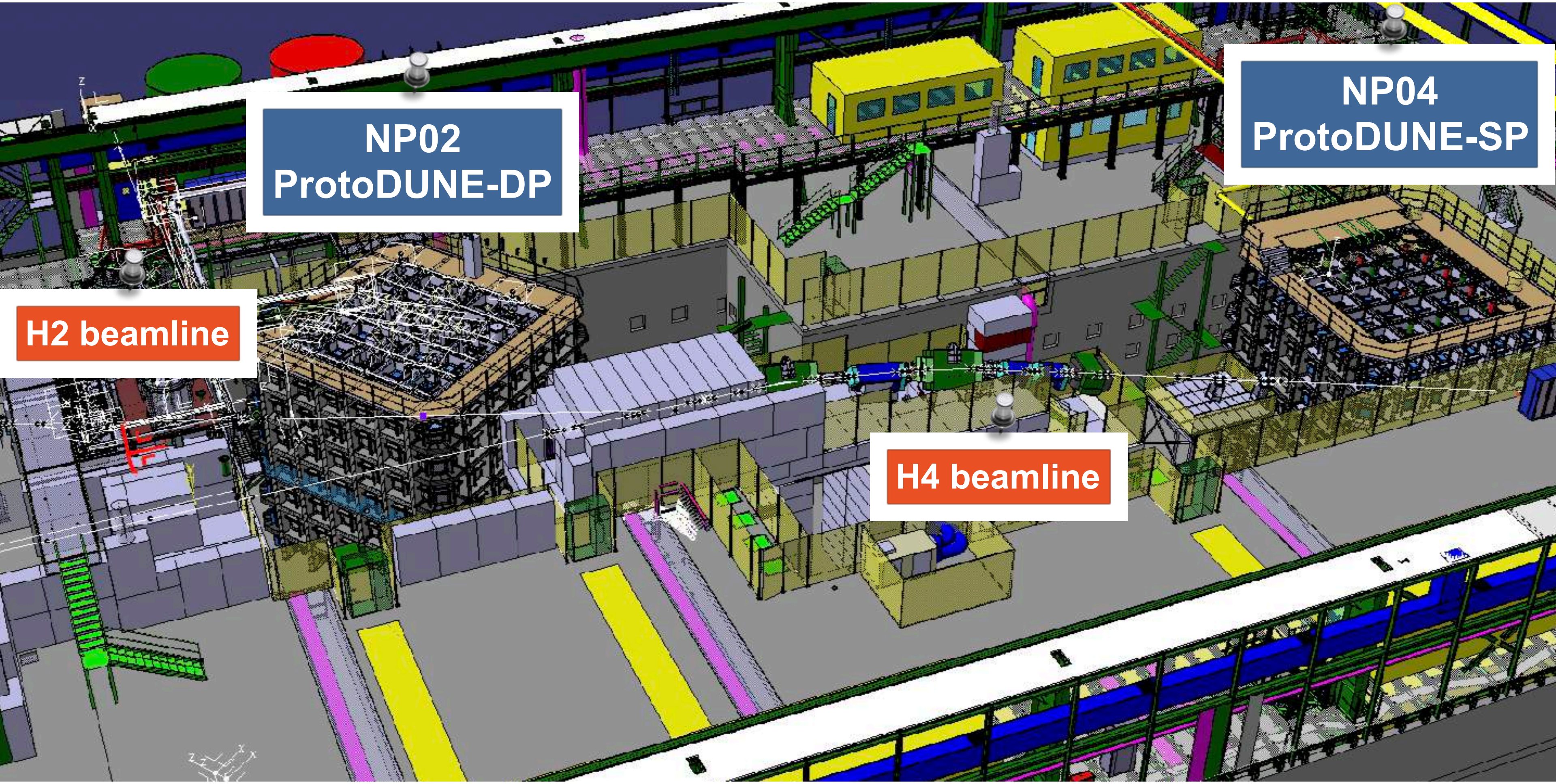


Simulation of neutrino-induced particle rates in the DUNE far detector.

ProtoDUNE design/program motivated by far detector physics.

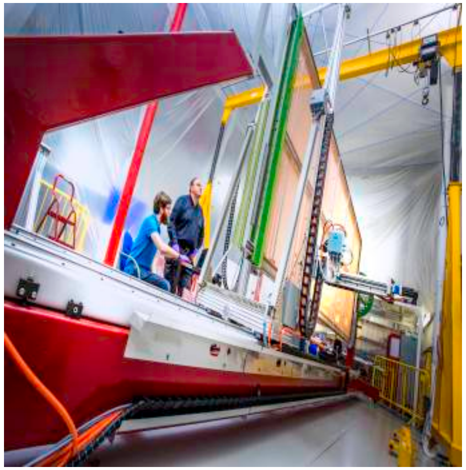
ProtoDUNE layout at EHN1 (CERN)

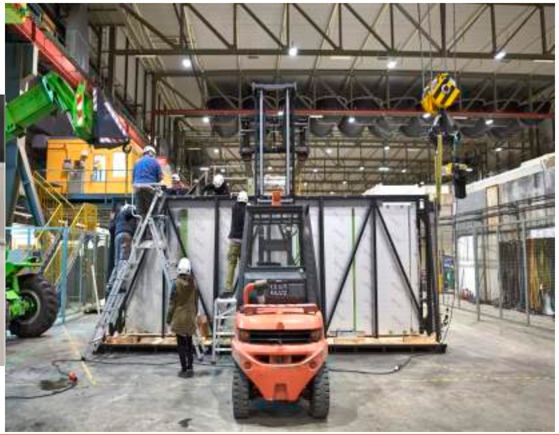
Both ProtoDUNE cryostats and their beamlines are located near to each other in the EHN1 building at CERN



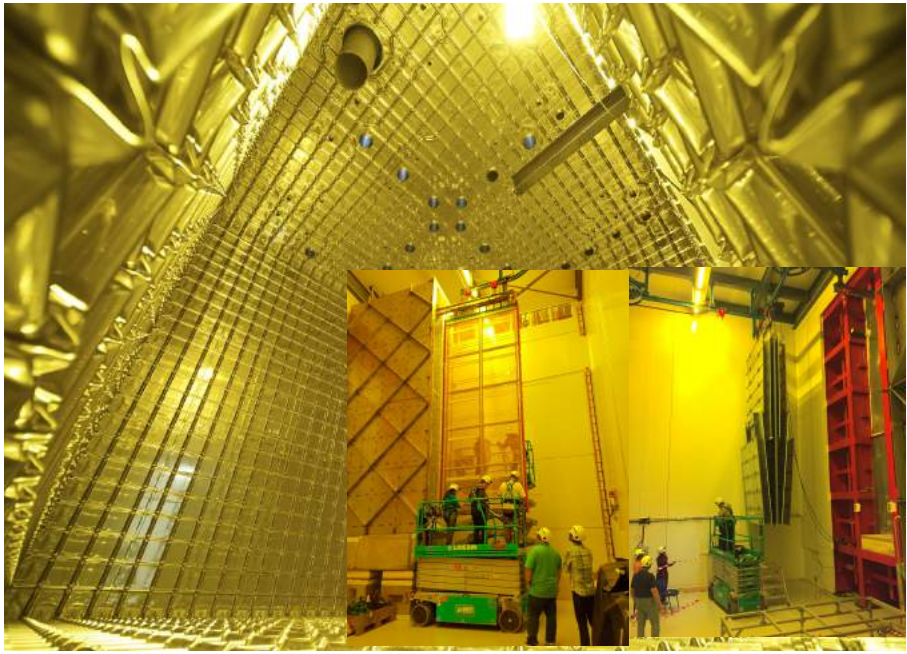
ProtoDUNE status

Components are being constructed and shipped to CERN





Construction is taking place in EHN1 at CERN



ProtoDUNE status

Detector installation under way

On track for 2018 data taking

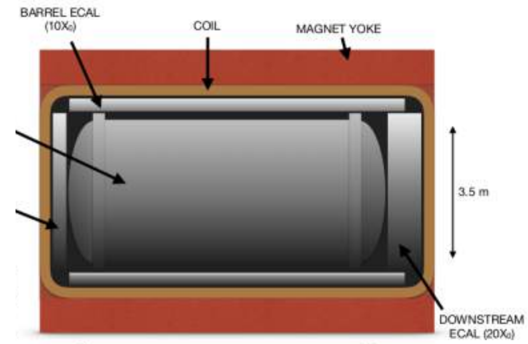
Near Detector

- Constrain systematic error for FD oscillation measurements
- High-precision cross-section/short-baseline measurements
- Hall location
  - 574 m from LBNF target
  - ~60 m underground
- Designs being investigated
  - Liquid argon TPC (LArTPC)
  - High pressure gas TPC (HPgTPC)
  - Scintillator tracker (3DST)
  - Straw tube tracker (STT)

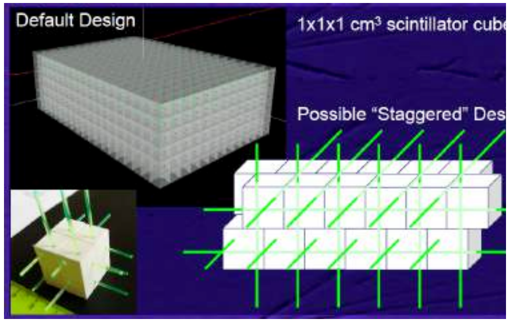
Final decision hasn't been made yet

Liquid argon TPC (LArTPC)

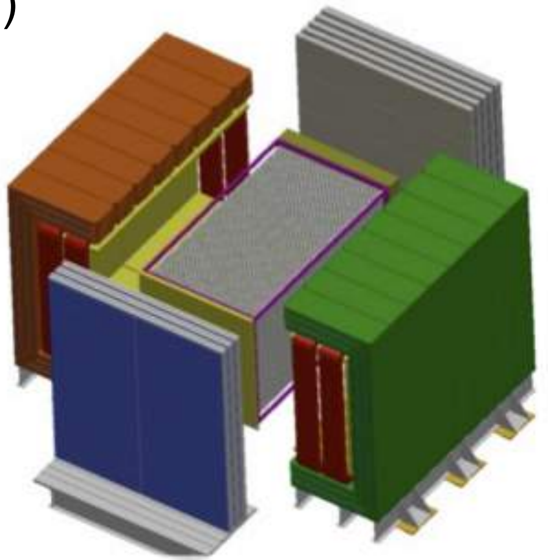
High pressure gas TPC (HPgTPC)



Scintillator tracker (3DST)



Straw tube tracker(STT)



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:
- 2019: Main Cavern Excavation
- 2020: Far Detector fabrication facilities ready
- 2022: Start to install FD modules
- 2026: Beam on with two FD modules

Neutrino Oscillation at DUNE

ν_e appearance

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

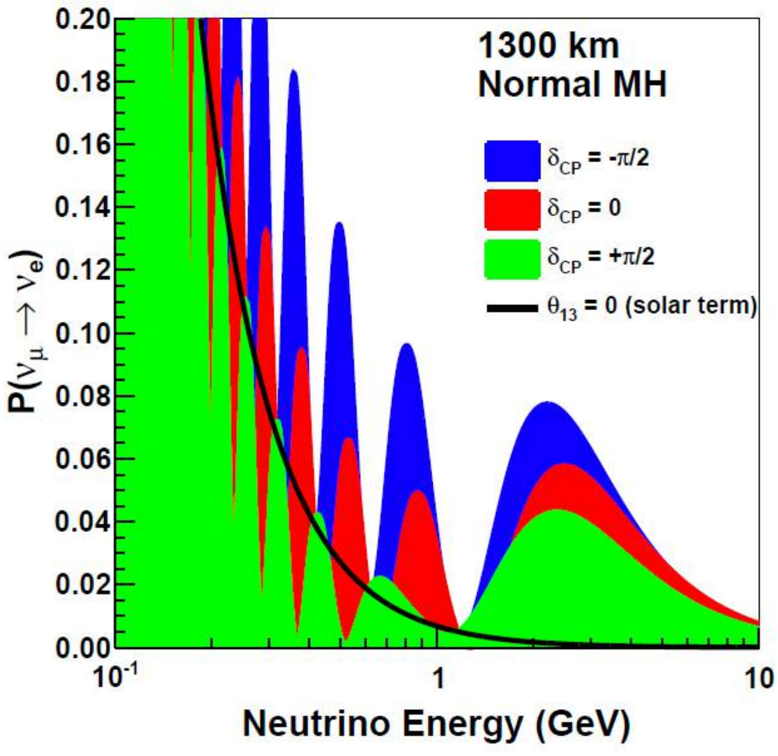
$$+ \; 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta$$

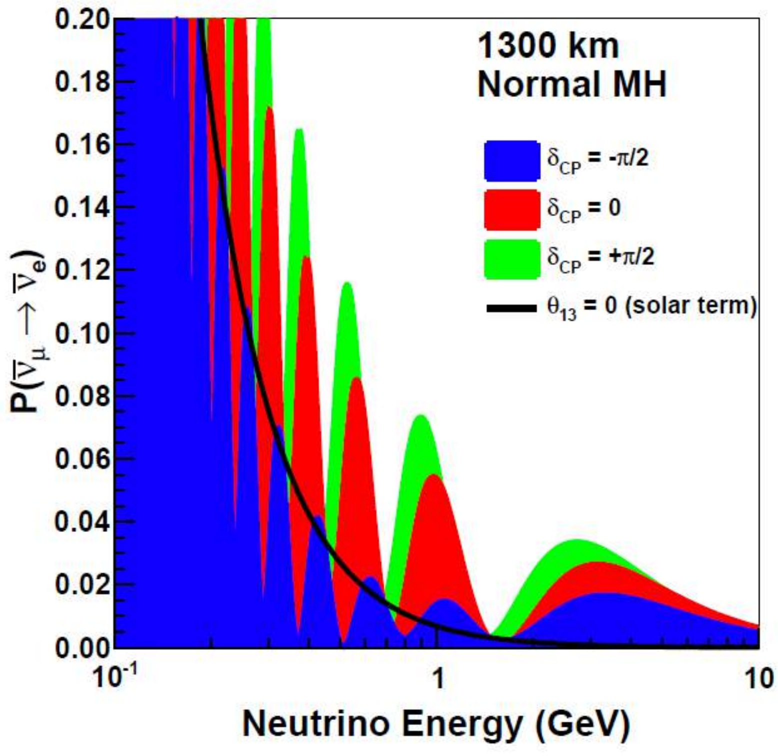
$$- \; 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta$$

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

- DUNE measures ν_e appearance probability and ν_μ disappearance probability with ν_u and anti-ν_u beam.
- ν_e appearance: mass hierarchy, δ_{CP} and octant of θ_{23}
- ν_μ disappearance: high precision $|\Delta m_{32}|$ and $\sin^2 2\theta_{23}$, constrain octant

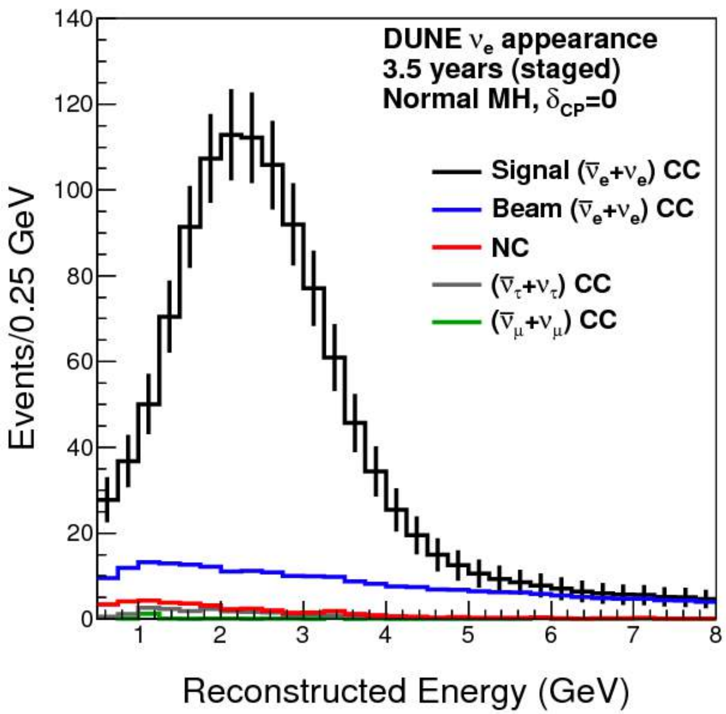
Neutrino Oscillation at DUNE

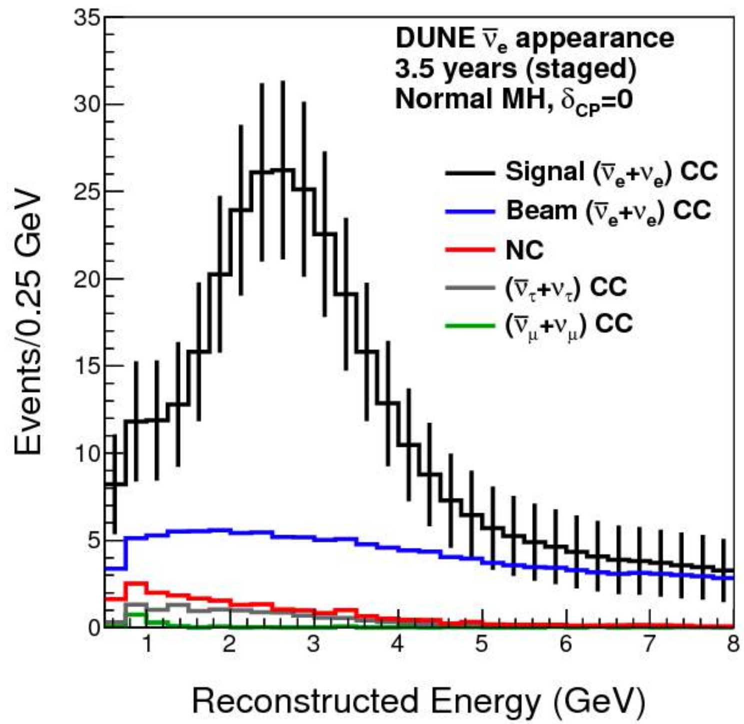




- Measure Mass Hierarchy, CP violation and mixing angles with neutrino and anti-neutrino beam
- 1300km baseline: large matter effect to solve MH
- Wide band beam covers 1st and 2nd oscillation maxima

Neutrino Oscillation at DUNE





- Measure Mass Hierarchy, CP violation and mixing angles with neutrino and anti-neutrino beam
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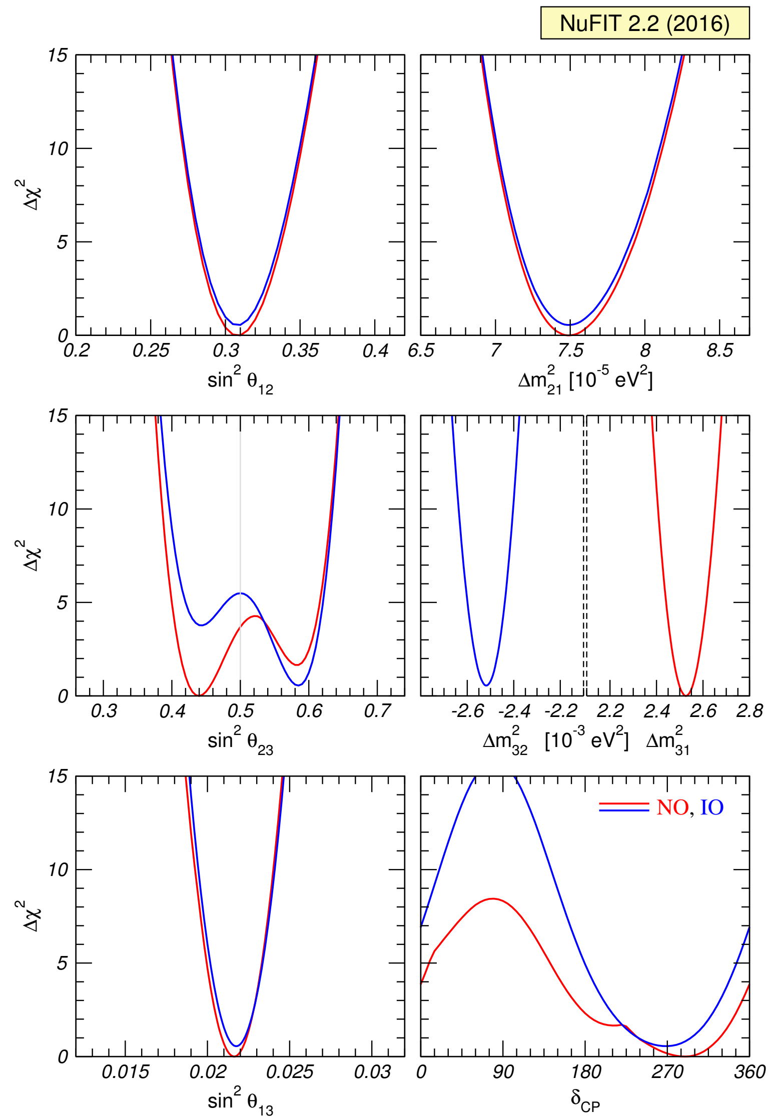
2016 Global Fit

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

DUNE/LBNF Staging Assumption

Year 1 (2026): 20-kt FD with 1.07 MW (80-GeV) beam and initial ND constraints

Year 2 (2027): 30-kt FD

Year 4 (2029): 40-kt FD and improved ND constraints

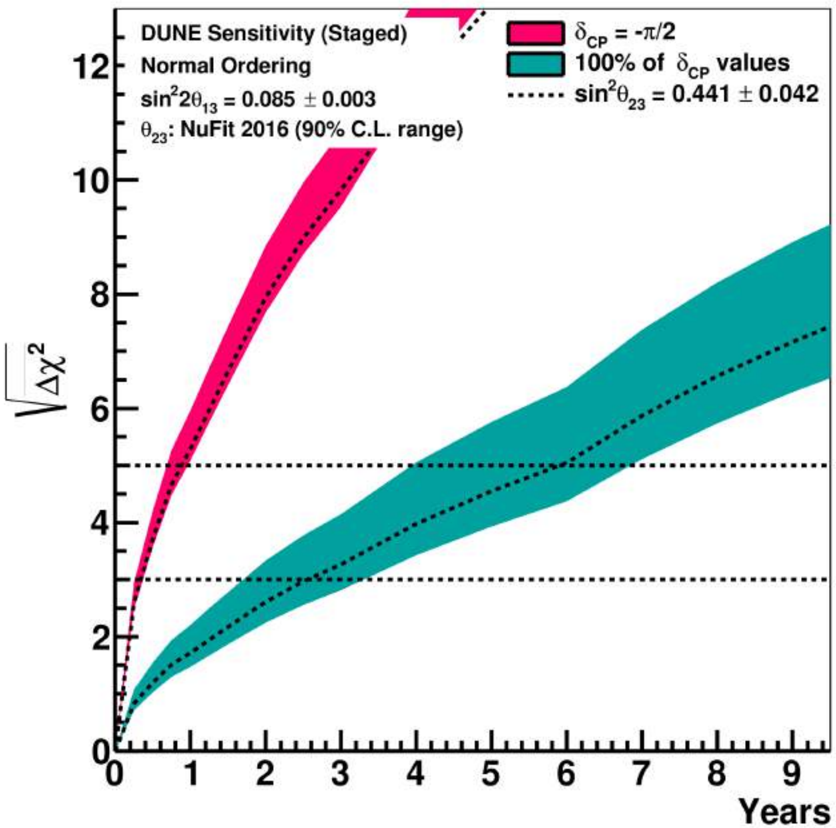
Year 7 (2032): upgrade to 2.14 MW (80-GeV) beam

Exposure Years	Number of FD modules	Total FD target mass (kt)	LBNF beam power (MW)	Exposure (kt MW yr)
1	2	20	1.07	21
2	3	30	1.07	54
4	4	40	1.07	128
7	4	40	2.14	300
10	4	40	2.14	556

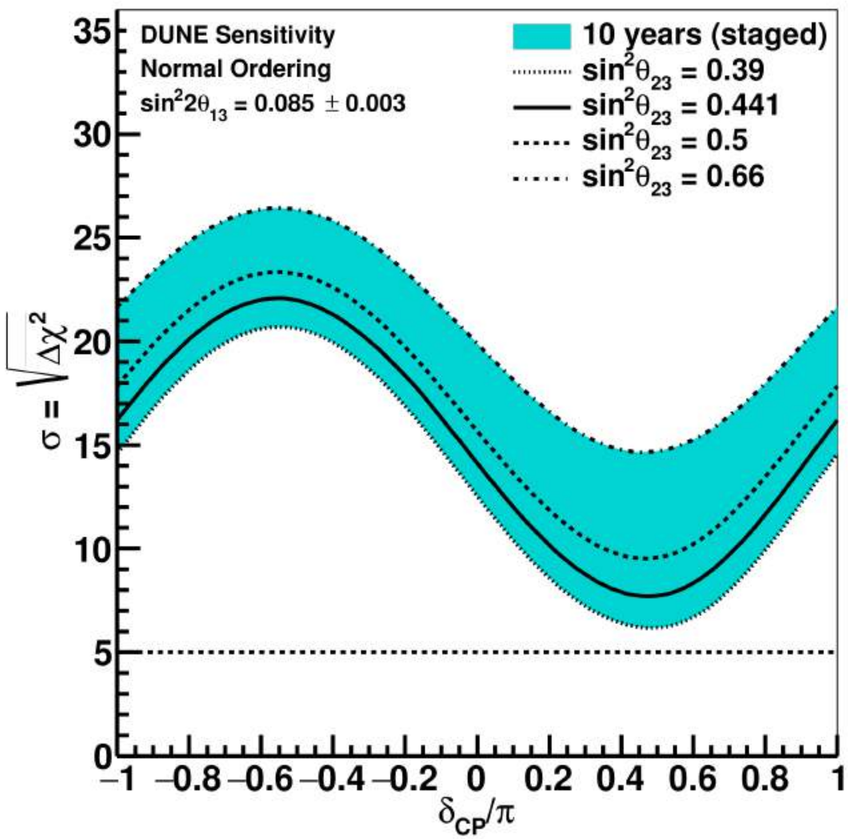
Staging scenario assumes equal ν and $\bar{\nu}$ running time

Mass Hierarchy Sensitivity

MH sensitivity vs. years



MH sensitivity @ year 10

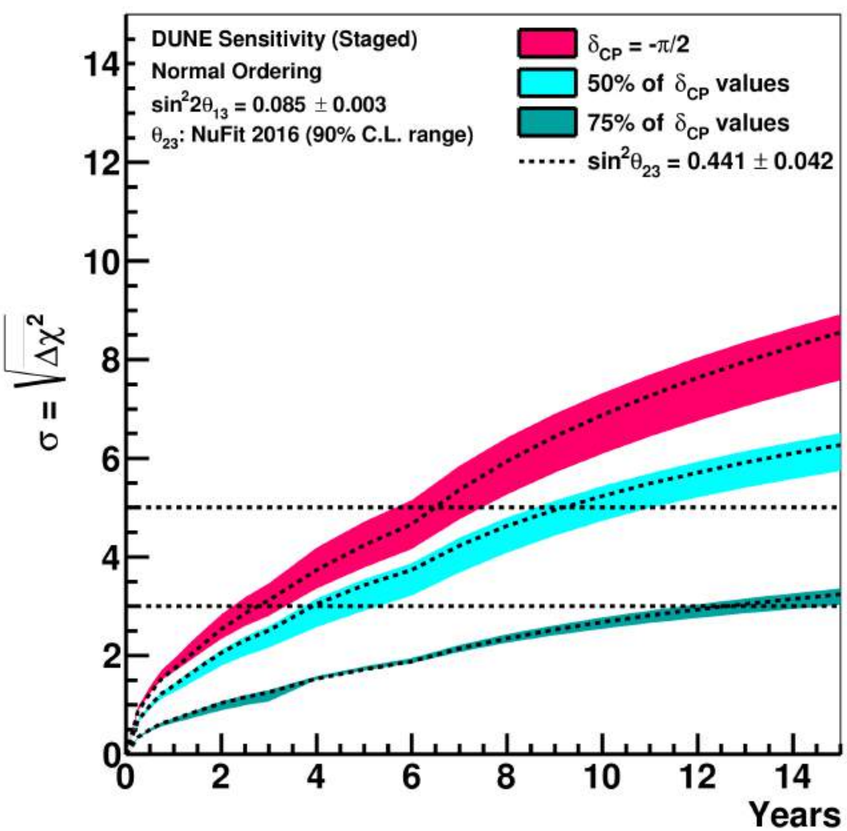


Bands corresponds to uncertainty in θ_{23}

Expect 5σ within 10 years for all δCP

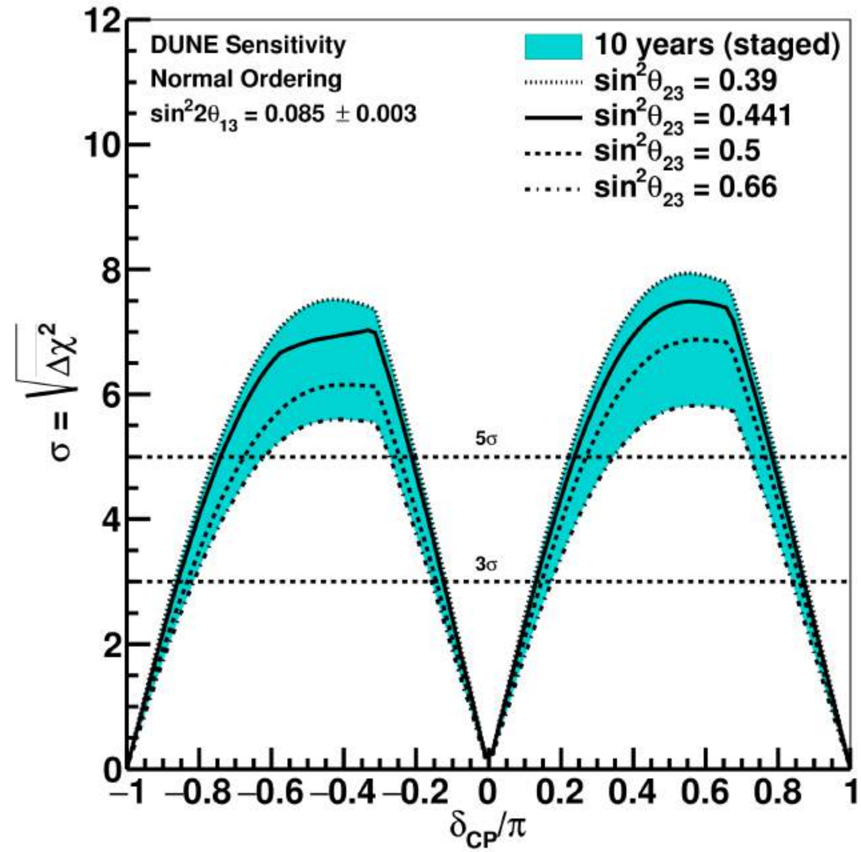
CP Sensitivity

CP violation sensitivity vs. years



Bands correspond to uncertainty in θ_{23}

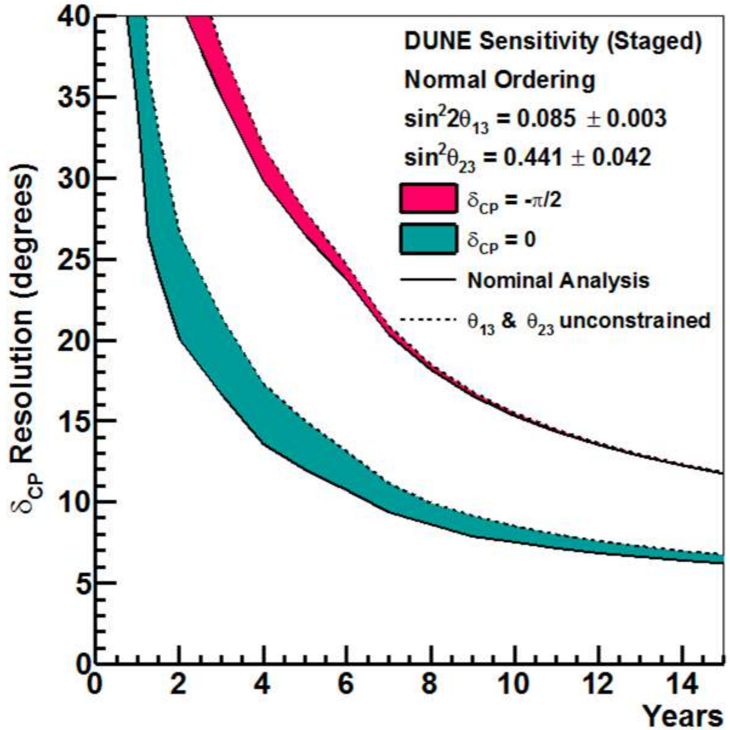
CP violation sensitivity @ year 10



CP violation defined as $\delta CP \neq 0, \pi$

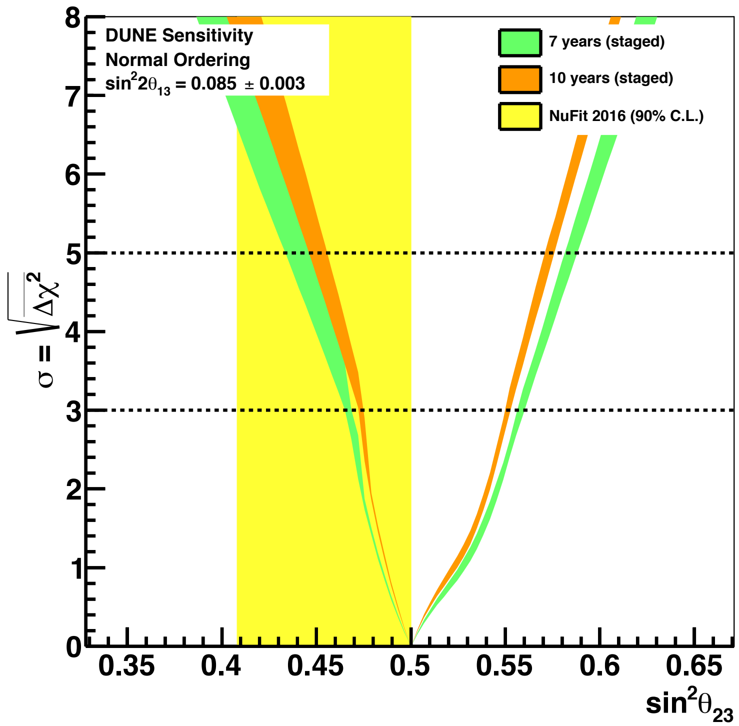
CPV & θ_{13} Resolution vs. Time

δ_{CP} resolution sensitivity vs. years



Bands correspond to uncertainty in θ_{23}

Octant sensitivity

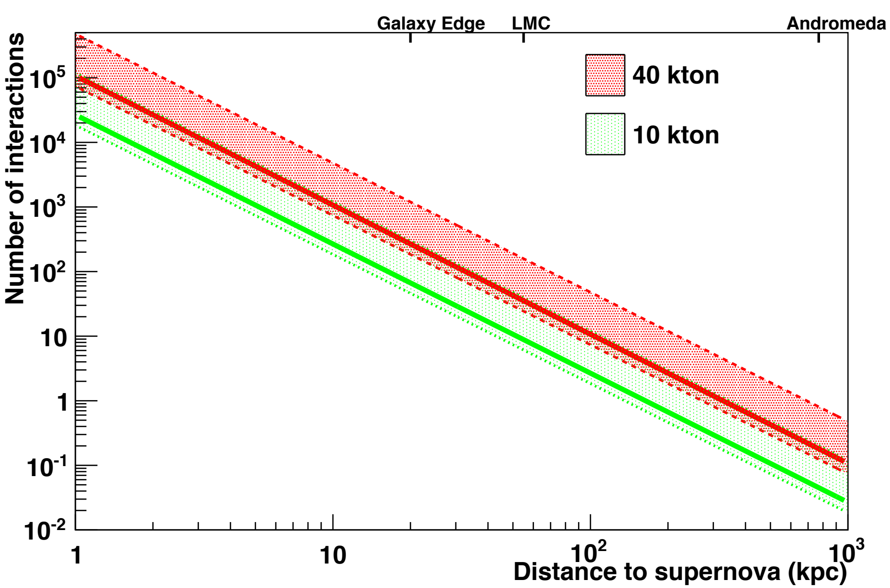


Bands correspond to uncertainty in δ_{CP}

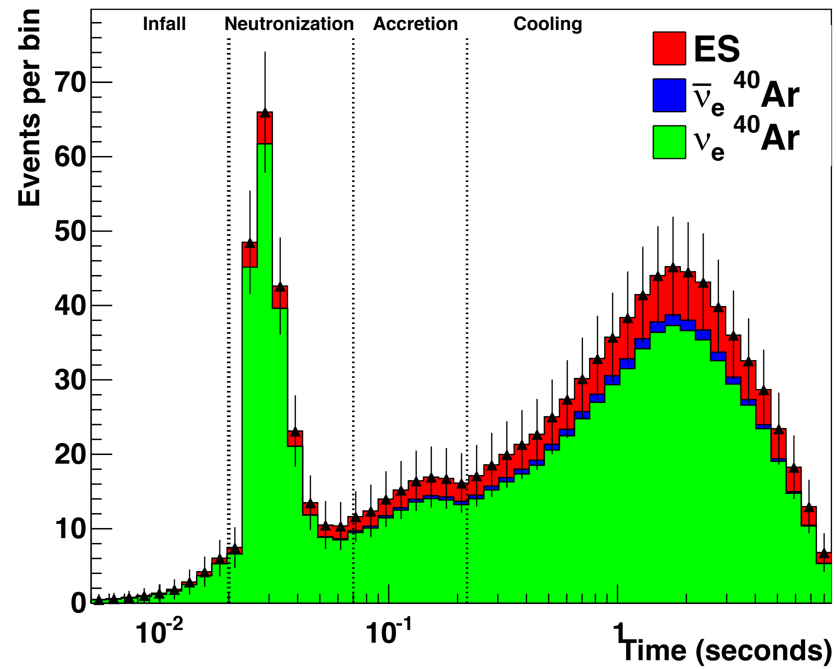
Supernova Neutrino Burst

- High-statistics observation of SNB neutrinos for astrophysics and neutrino physics
- Dominant process in LAr: $\nu_e + {}^{40}Ar \rightarrow e + {}^{40}K^*$, sensitive to neutronization
- Elastic scattering could provide directionality
- For ~10 kpc, Expect ~3,000 in 10 seconds

ES: ν-e Elastic Scattering



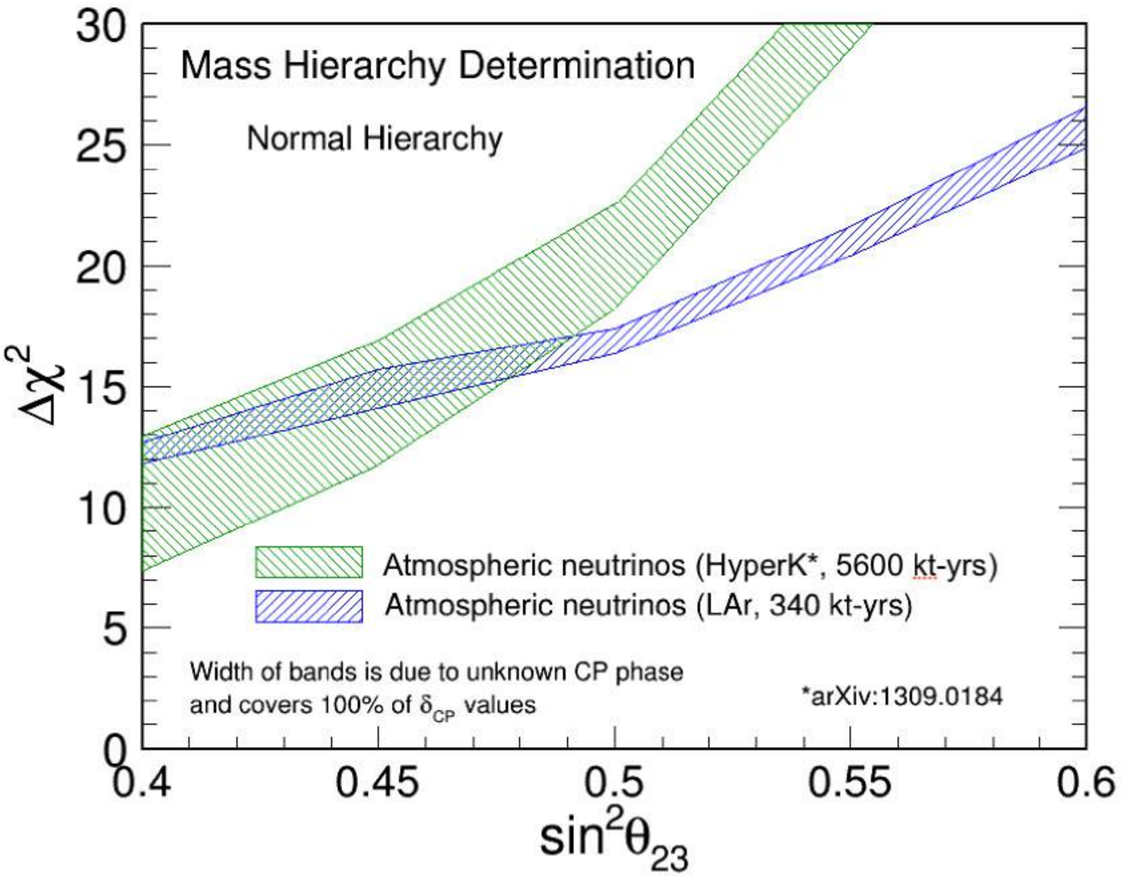
Expected number of SN neutrino interactions vs distance



number of SN neutrinos vs. time

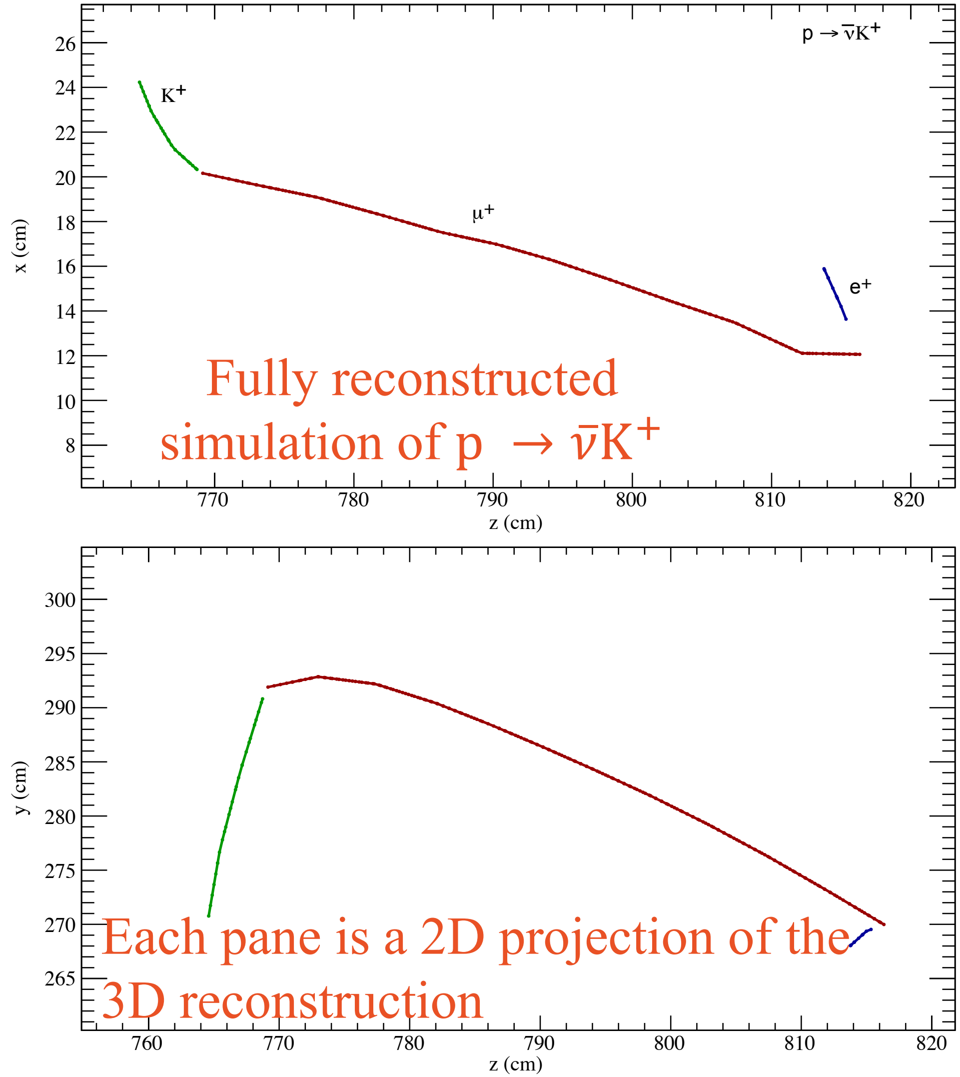
Atmospheric neutrinos

- 14,000 ν_e and 20,000 ν_μ events expected in 350 kt yrs
- Atmospheric neutrinos provide their own sensitivity to neutrino oscillation physics

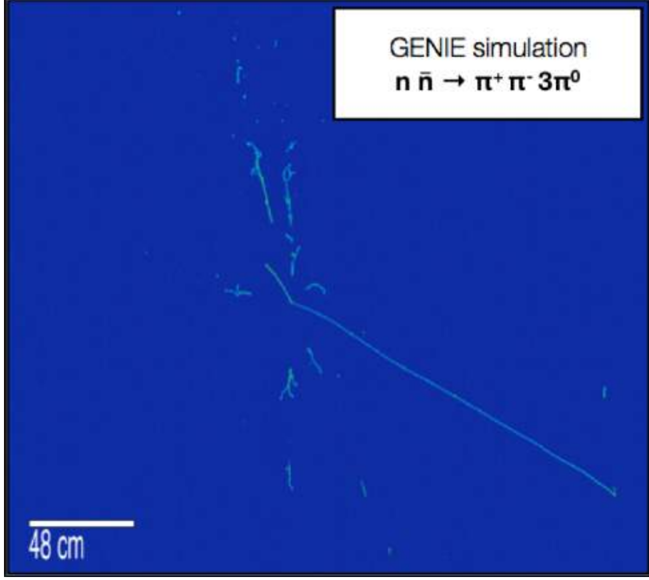


Proton decay

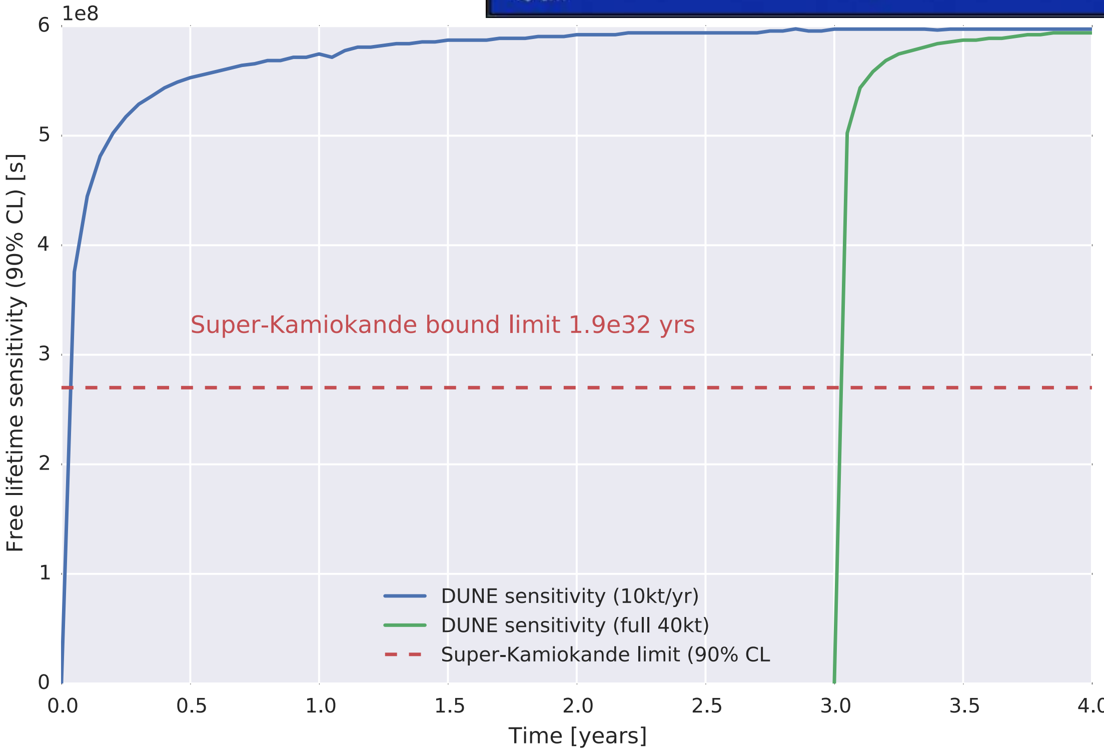
- Measurements of proton decay can test baryon number conservation
- GUTs predict proton decay modes and rates
- DUNE FD for proton decay: Large volume, deep underground, superior K reconstruction, sensitive to p→νK
- Complementary to Hyper-K and JUNO



$n - \bar{n}$ oscillation



- BSM process that violates baryon number
- 'Star' event topology consists of charged and neutral pions
- Convolutional Neural networks being investigated to identify $n - \bar{n}$ oscillation over dominant atmospheric ν background



Summary

- DUNE Collaboration has been established as an international scientific priority
- DUNE/LBNF project: detailed plan for the LArTPC FD and the neutrino beam, ND design under development
- Far site groundbreaking 7/21/2017, construction underway
- ProtoDUNEs at CERN start to take data this year
- Decisive measurements to CP violation, Mass Hierarchy and Octant of θ_{23}
- Also Nucleon decay, Astroparticle physics, BSM ...