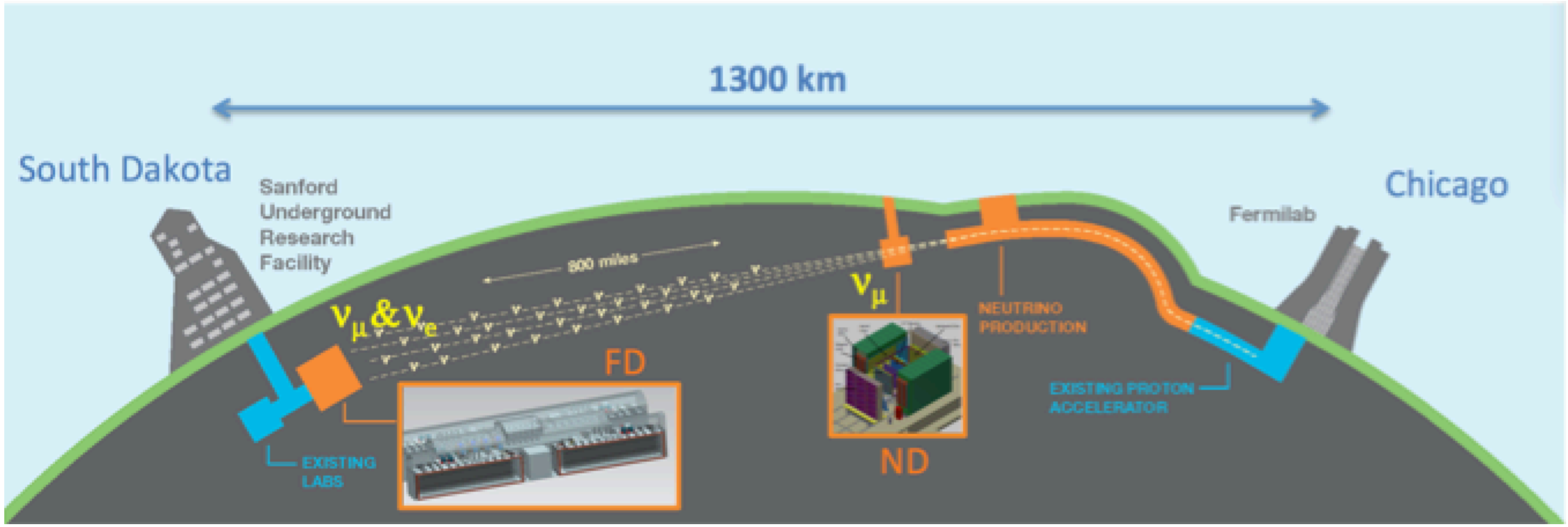
STATUS of LBNF/DUNE



Albert De Roeck / CERN 12 August 2017

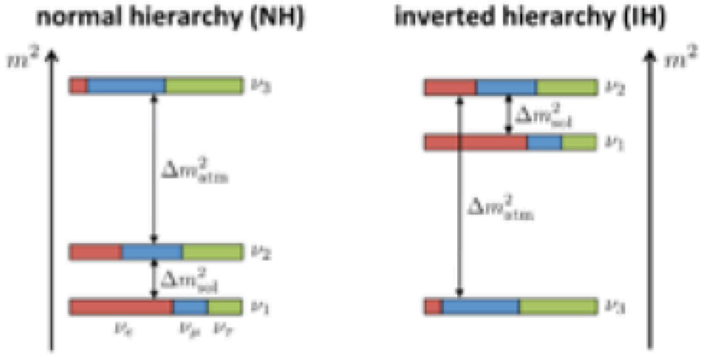
Lepton-Photon 2017, Guangzhou, China

On behave of the DUNE Collaboration

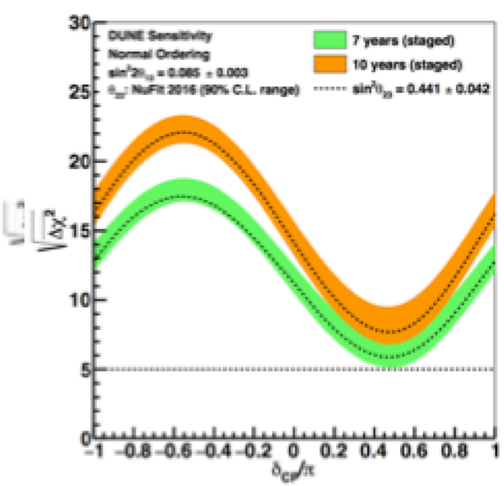
Neutrino Oscillation Physics and More…

Short- and long-baseline oscillation experiments probe several of the essential questions

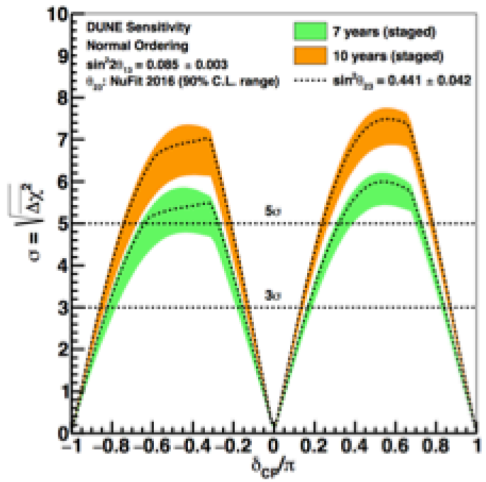
- How are the neutrinos masses ordered?
- Do neutrinos and antineutrinos oscillate differently?
- Are there additional neutrino types & interactions?



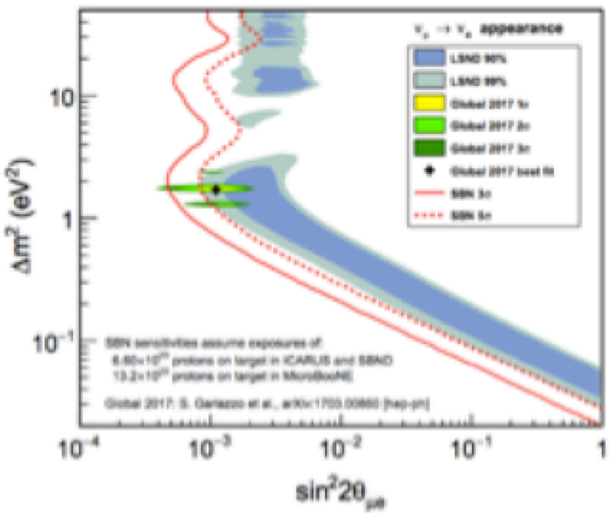
DUNE Mass Hierarchy Sensitivity



CP Violation Sensitivity

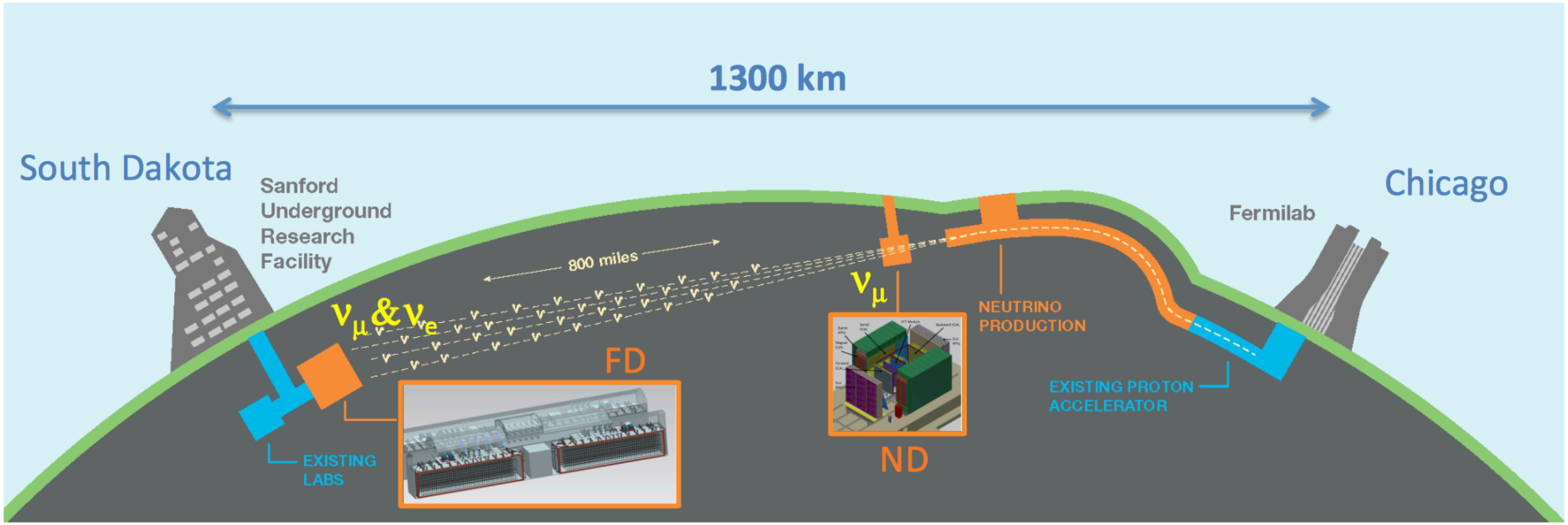


SBN Sensitivity



LBNF/ DUNE Overview

- Muon neutrinos/antineutrinos from high-power proton beam
  - **1.2 MW** from day one; upgradeable to 2.4 MW
- Massive underground Liquid Argon Time Projection Chambers
  - **4 x 17 kton** fiducial mass of > 40 kton
- Near detector to characterize the beam (100s of millions of neutrino interactions)



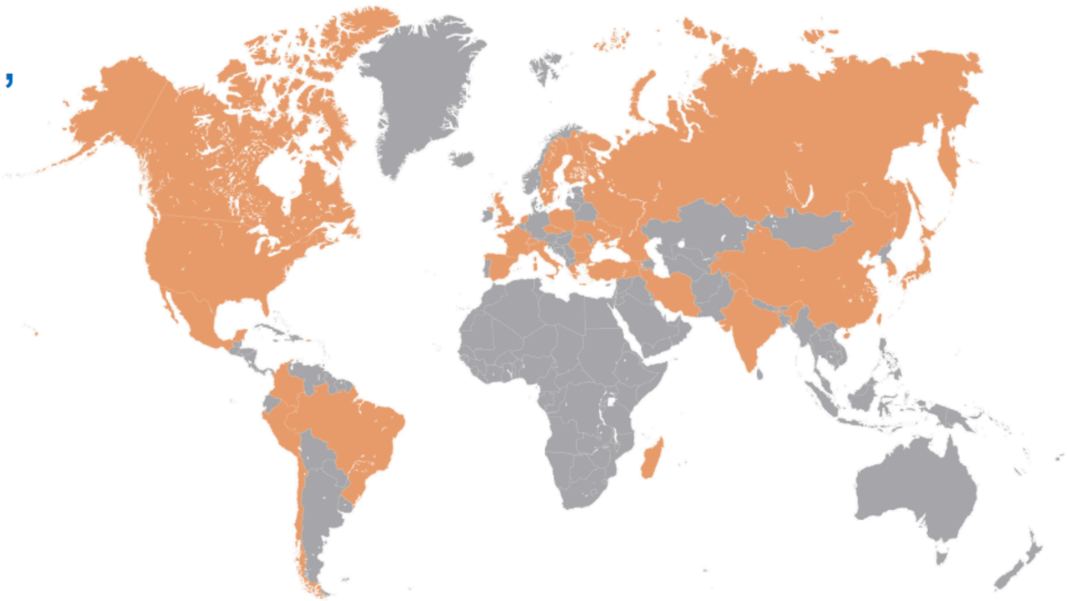
The DUNE Collaboration

As of today:

60 % non-US

999 (!) Collaborators from 164 institutions in 31 nations

Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Spain, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Peru, Poland, Romania, Russia, South Korea, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE: a fully international science collaboration
LBNF (Long Baseline Neutrino Facility): US(DOE)-hosted project with international contributions

DUNE meeting @ CERN, Geneva, Switzerland, January 2017

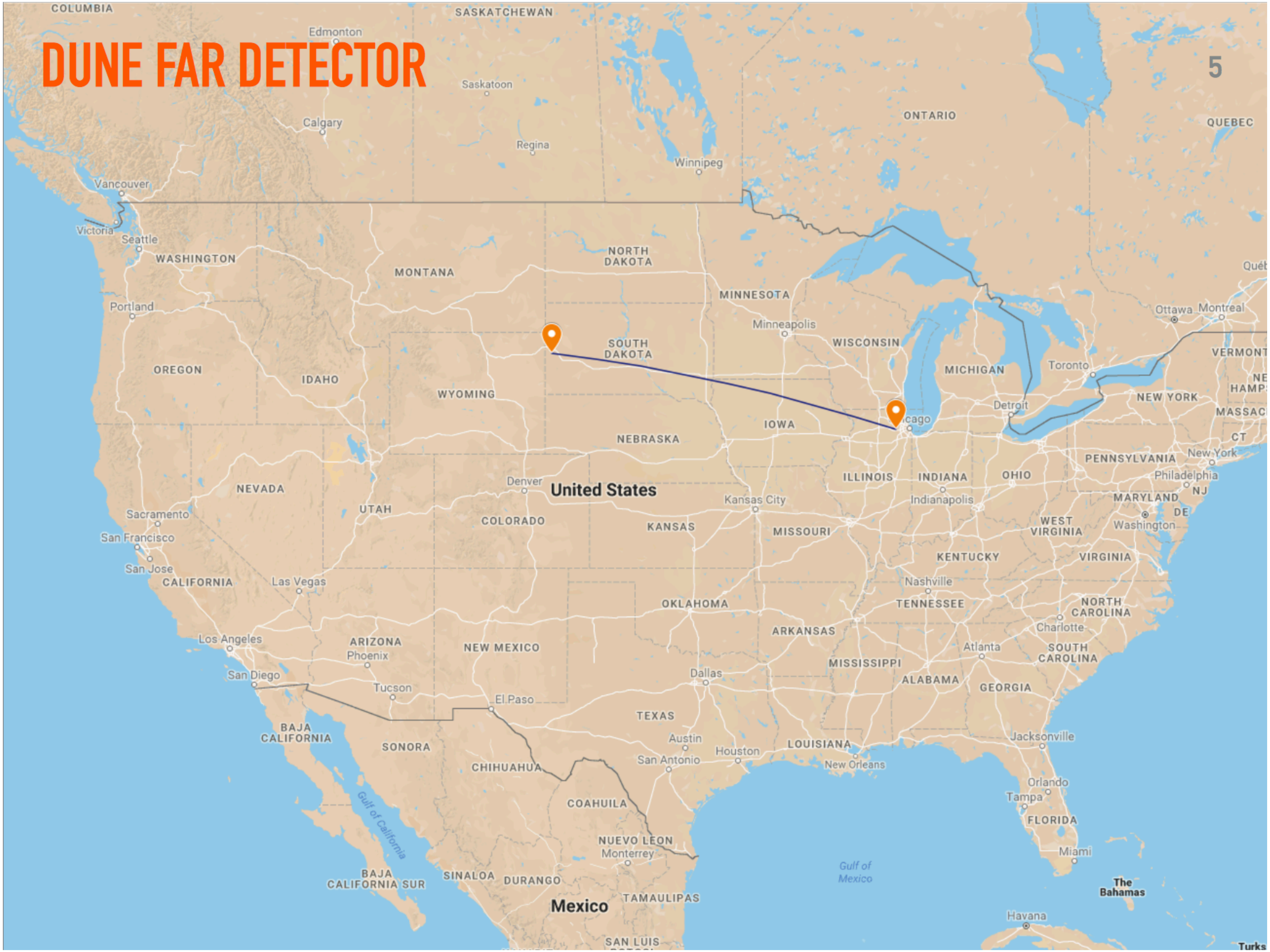
- CERN is a member of DUNE
- This is the first off-site experiment for CERN

The DUNE Science Program

- Neutrino Oscillation Physics
  - **Search for leptonic (neutrino) CP Violation**
  - Resolve the mass hierarchy ($m_3 > m_{1,2}$ or $m_{1,2} > m_3$)
  - Precision oscillation physics
    - Parameter measurements, θ_{23} octant
    - **Testing the current 3-neutrino model, non-standard interactions,** …
- Nucleon Decay
  - Particularly sensitive to $p \rightarrow K^+ \bar{\nu}$
- Supernova burst physics and astrophysics
  - 3000 ν_e events in 10 sec from SN at 10 kpc

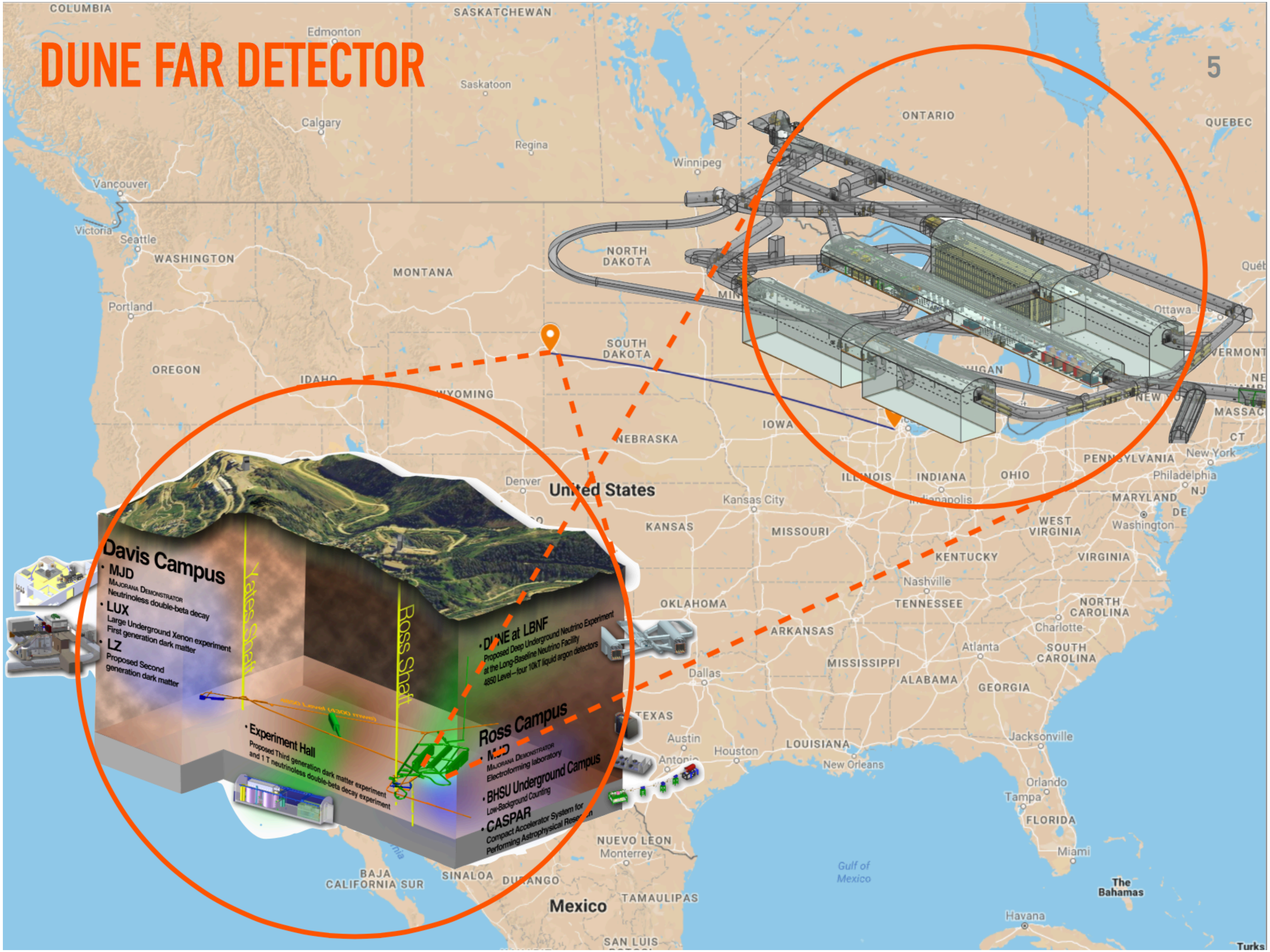
+ many other topics (ν interaction physics with near detector, atmospheric neutrinos, sterile neutrinos, WIMP searches, Lorentz invariance tests, etc.)

DUNE FAR DETECTOR

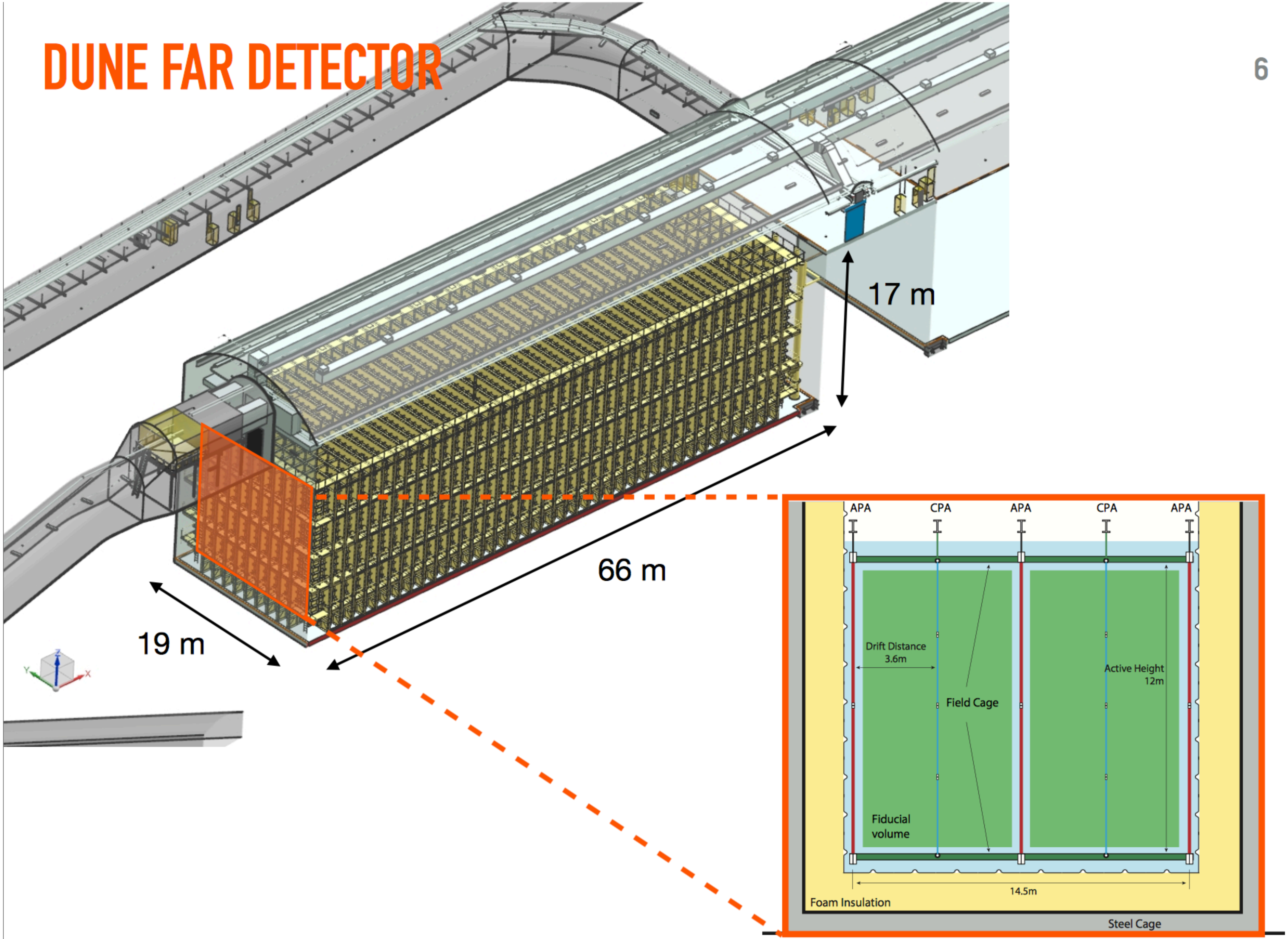


DUNE FAR DETECTOR

DUNE FAR DETECTOR



DUNE FAR DETECTOR



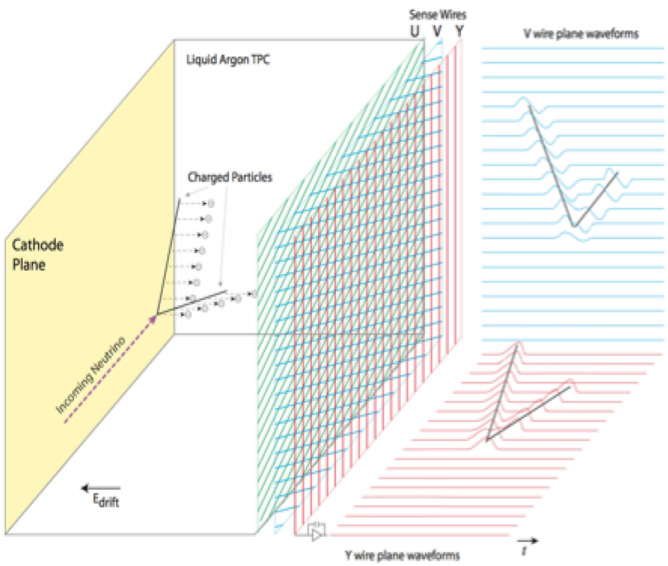
The DUNE Detector Choice: LArTPC

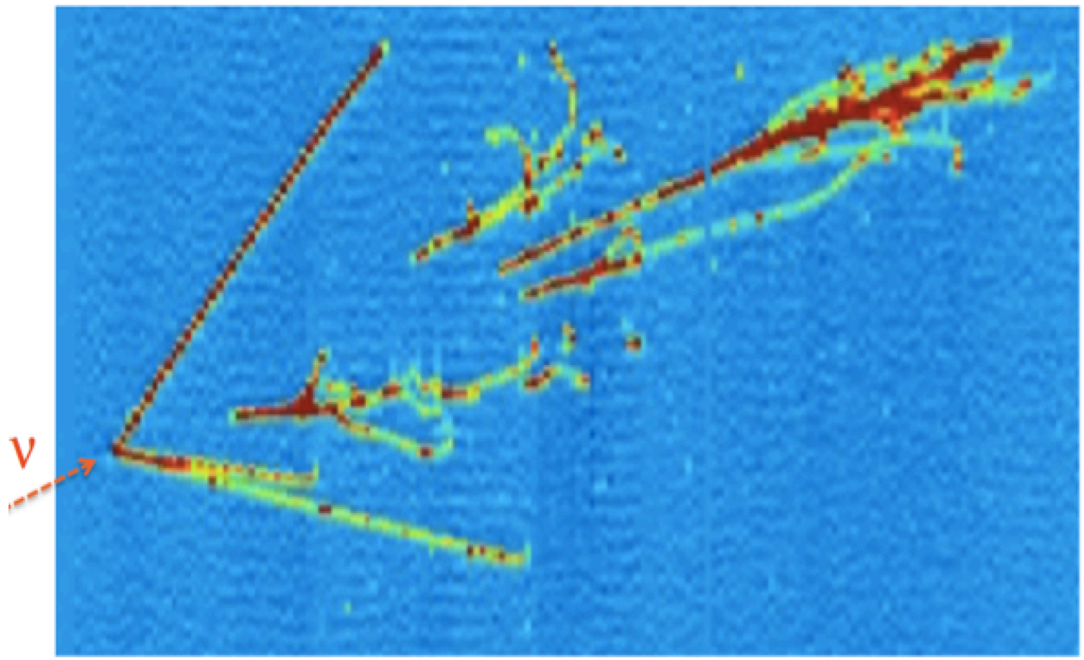
The LAr TPC technology provides:

- excellent 3D imaging capabilities
  - few mm scale over large volume detector
- excellent energy measurement capability
  - totally active calorimeter
- particle ID by dE/dx, range, event topology, .

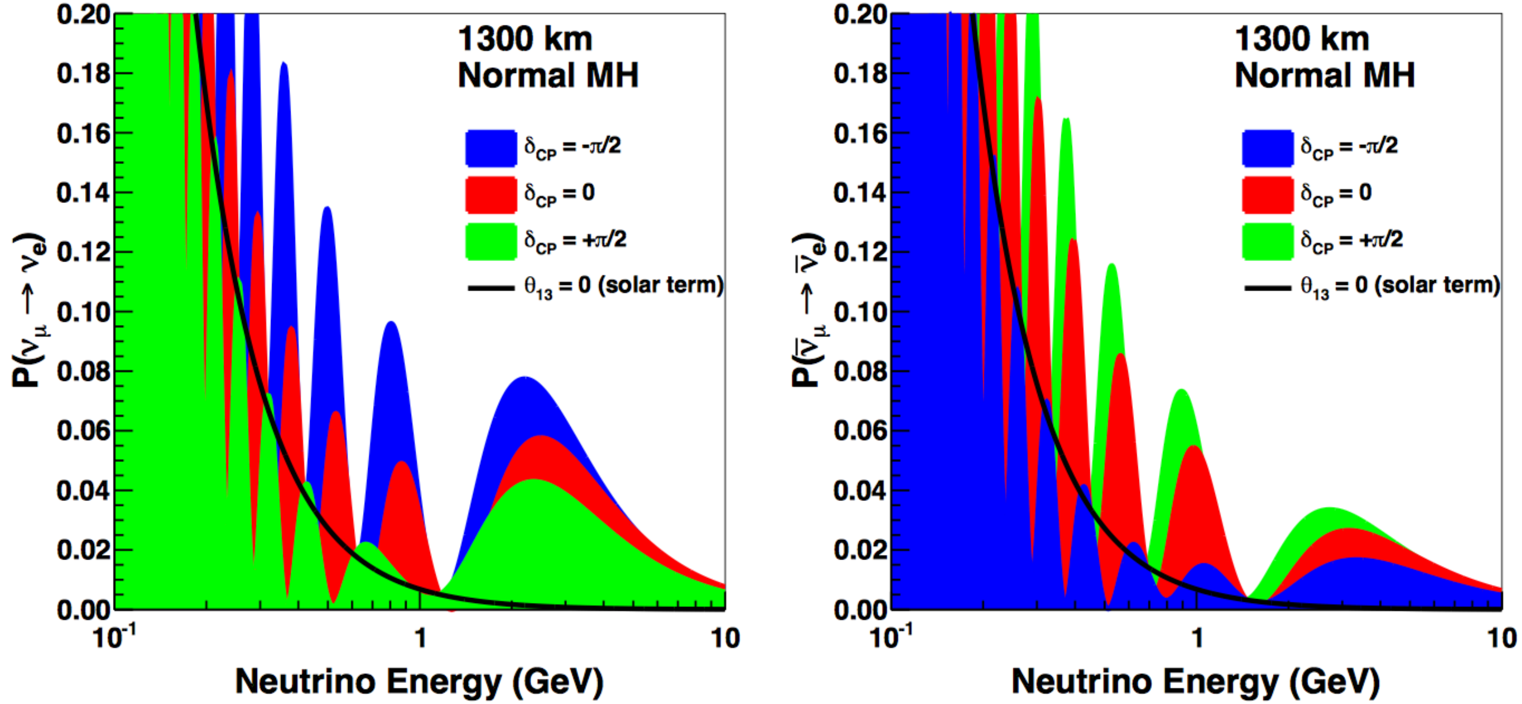
Major challenges

- Technology for very large detector volumes
- Event reconstruction and classification (eg using deep learning techniques…)



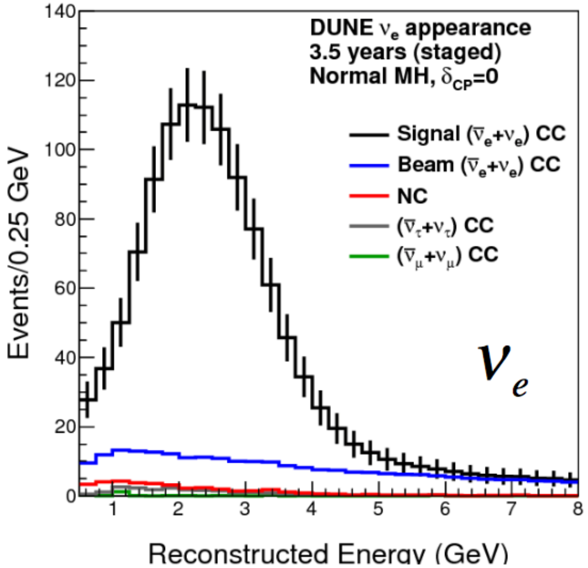


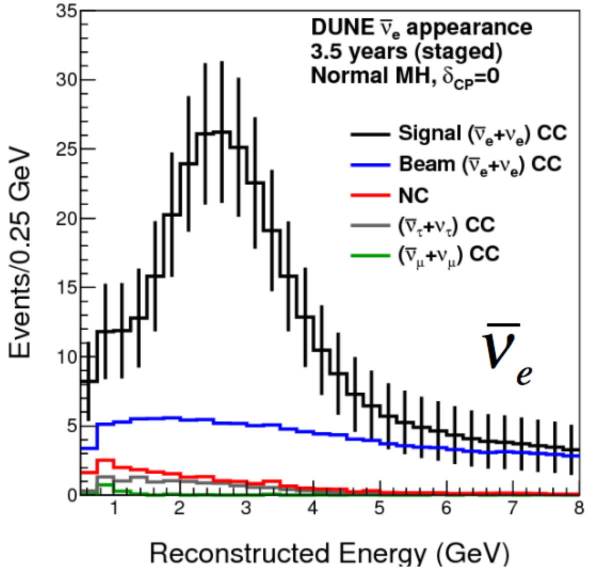
LBL Experimental Strategy

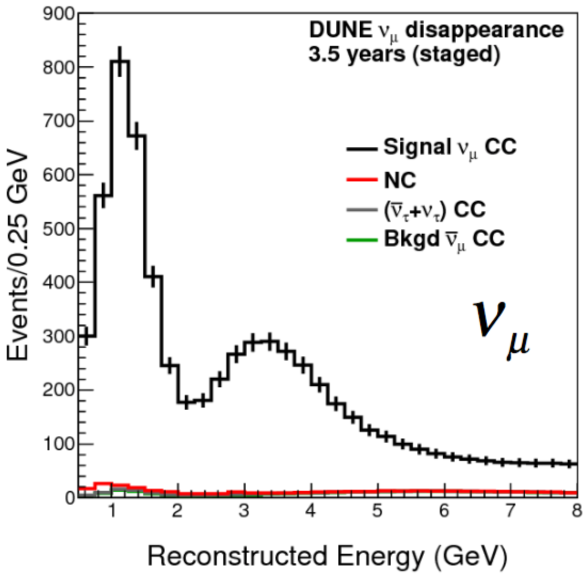


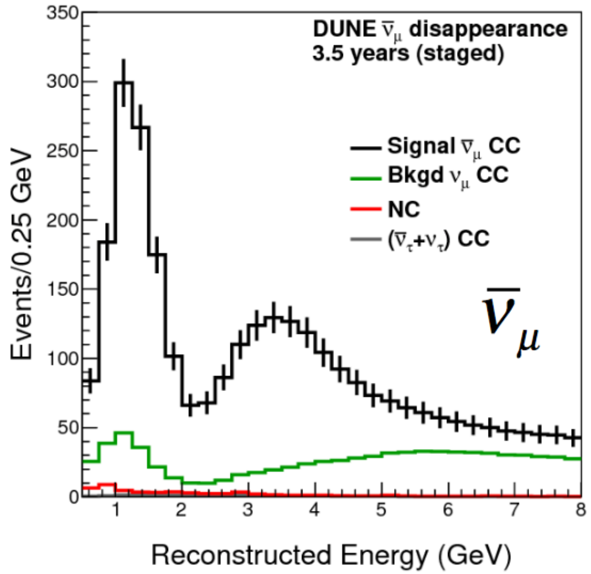
- Electron-Neutrino appearance amplitude depends on the θ_{13}, θ_{23}, δ_{CP} and matter effects. All four can be measured in a single experiment.
- Broadband and long baseline break the degeneracy between CPV and matter effects.

Appearance and Disappearance spectra







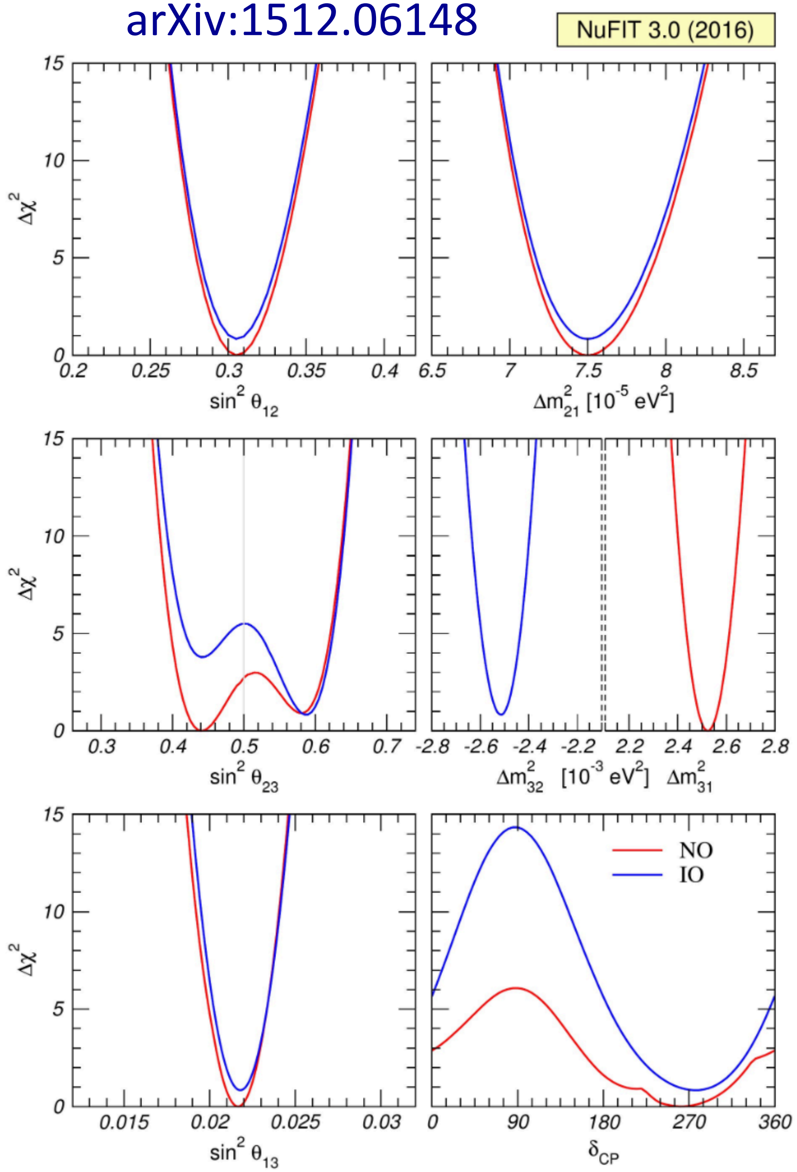


LBL Experimental Sensitivities

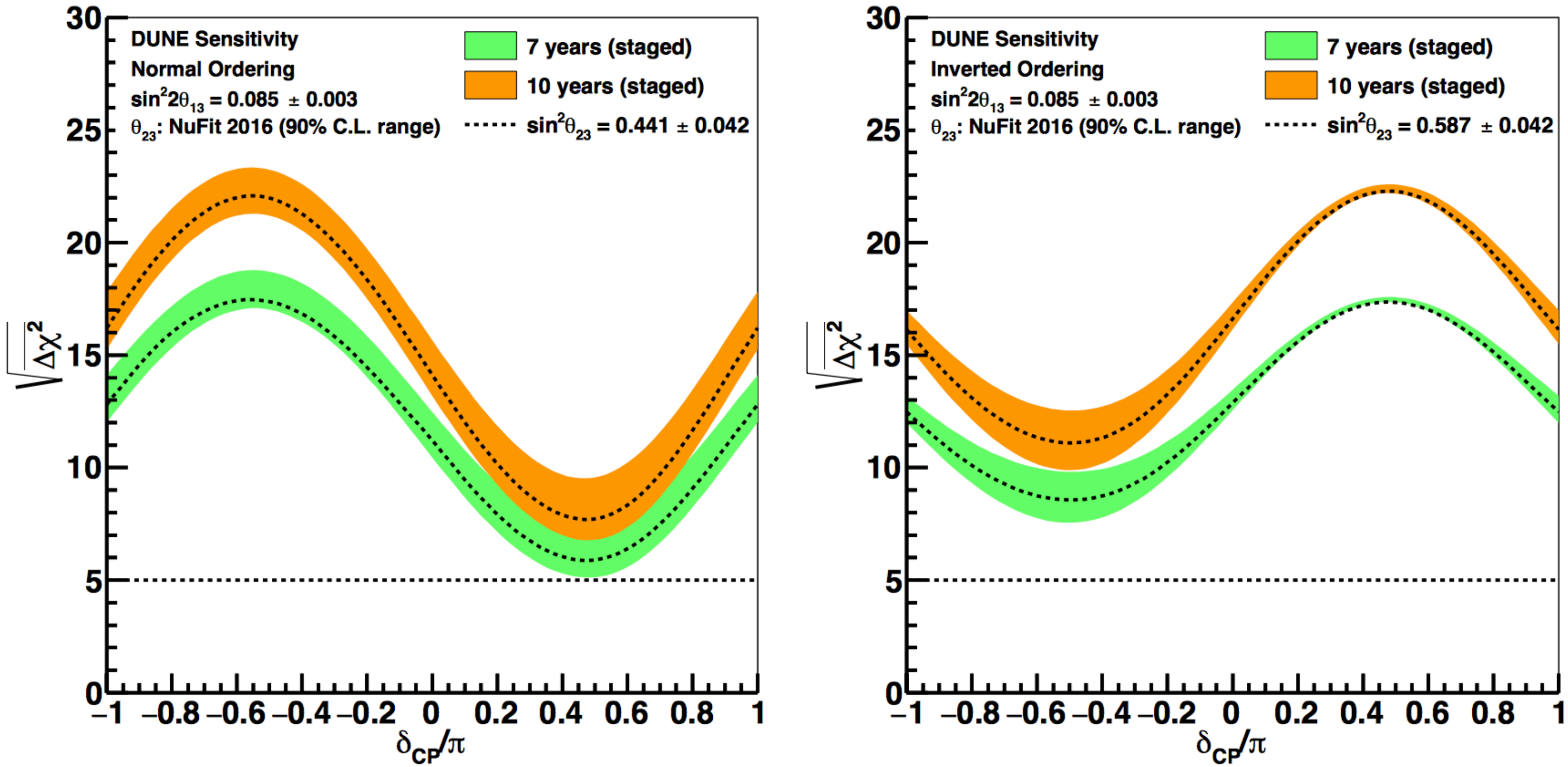
All the following sensitivity plots take the assumptions:

- Oscillation parameters from NuFit2016
- Staging scenario with equal running in the neutrino and antineutrino modes:
  - Year 1 (2026): 20-kt FD with 1.07 MW beam
  - Year 2 (2027): 30-kt FD
  - Year 4 (2029): 40-kt FD
  - Year 7 (2032): upgrade to 2.14 MW beam
- GLoBES-based fit to the FD samples with parametrized detector response

arXiv:1512.06148

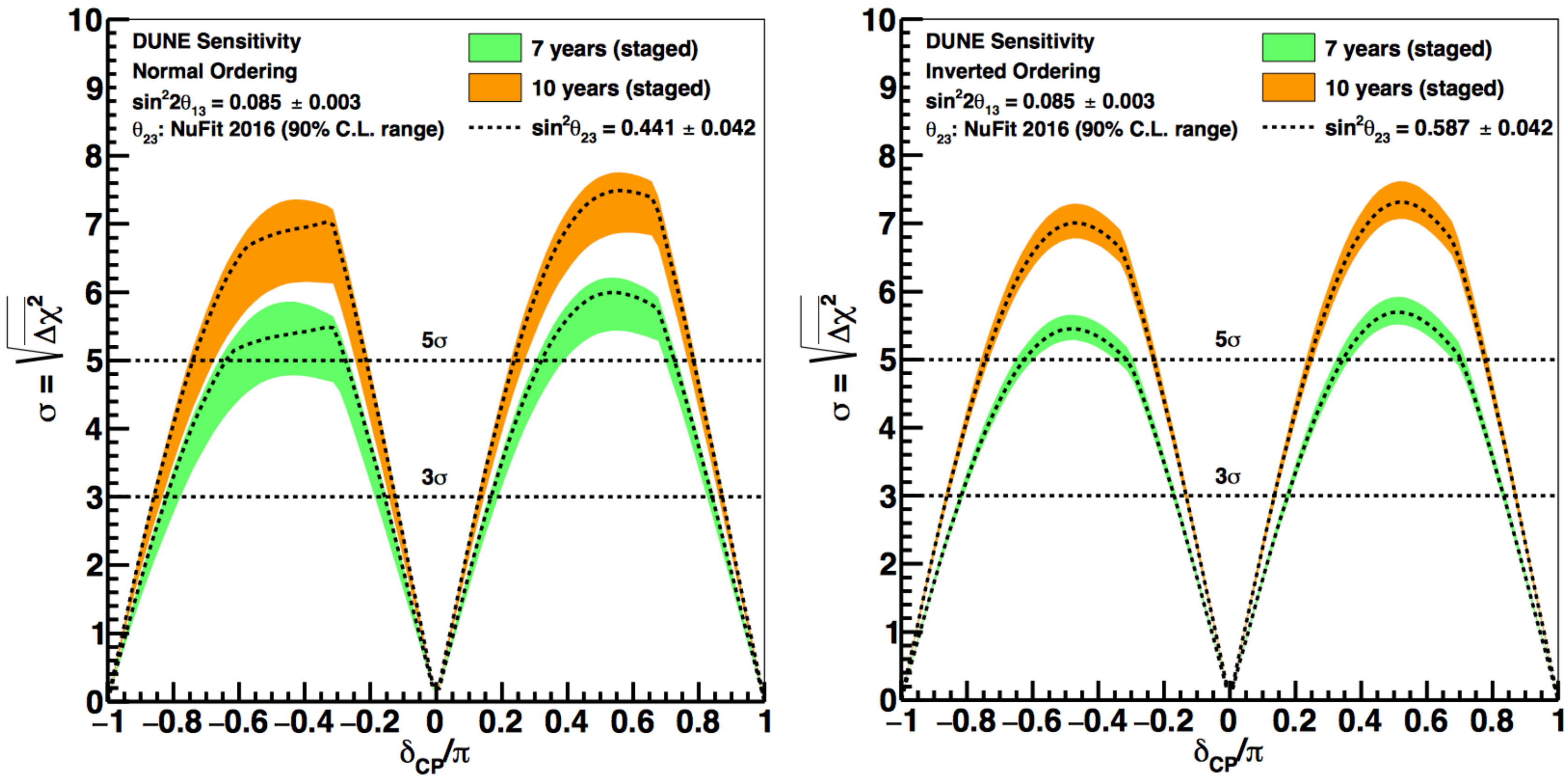


Sensitivity to Mass Hierarchy



- Width of the bands represents the range of sensitivities for the 90% CL region in the θ_{23} value range.
- Sensitivity increases with increasing θ_{23}

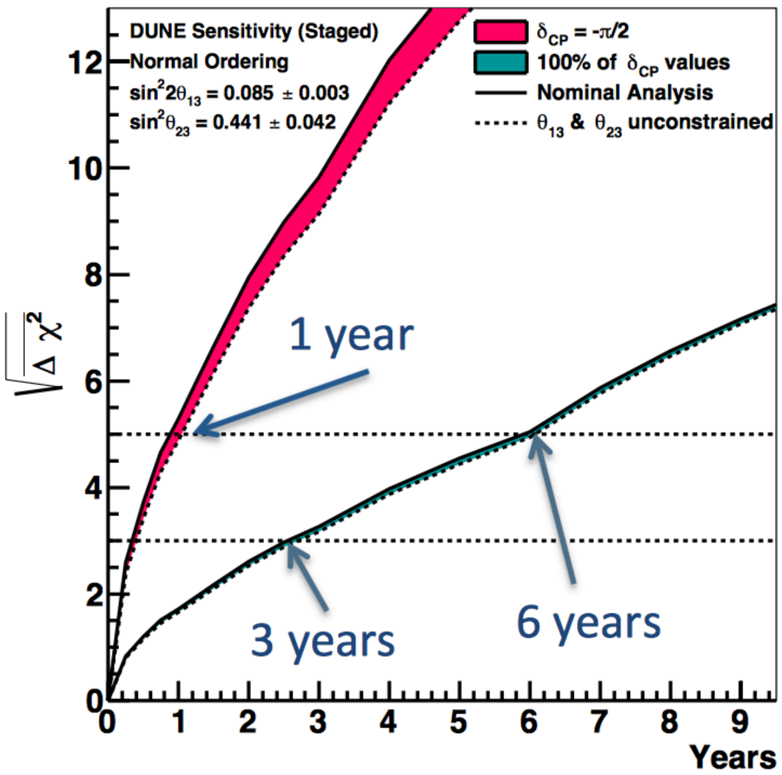
Sensitivity to CP violation



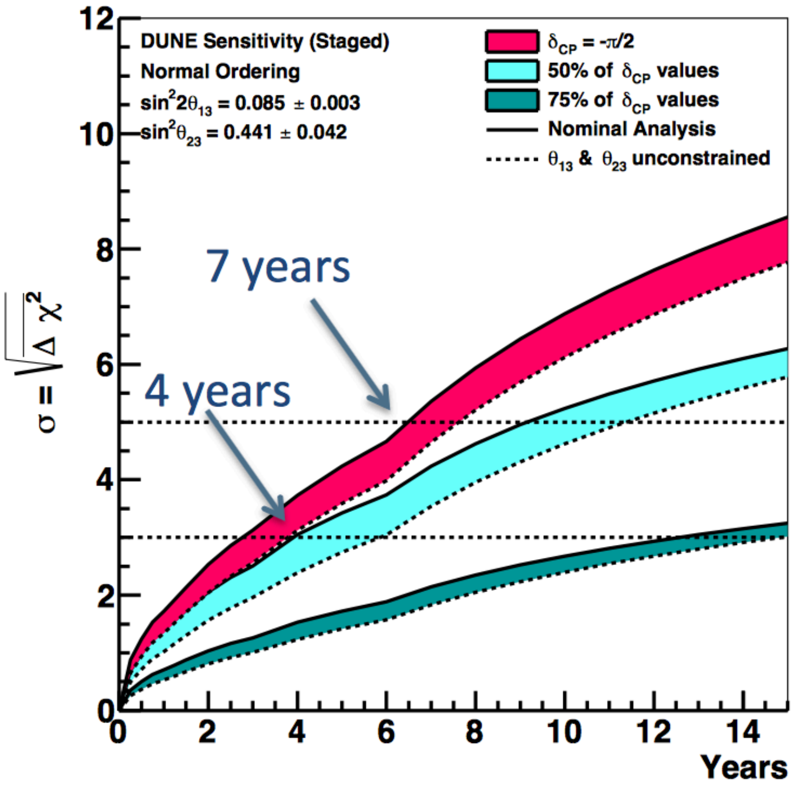
- Width of the bands represents the range of sensitivities for the 90% CL region in the θ_{23} values range.
- Sensitivity increases with increasing θ_{23}

Sensitivity versus Time

Mass Hierarchy Sensitivity



CP Violation Sensitivity



Important sensitivity milestones throughout beam physics program

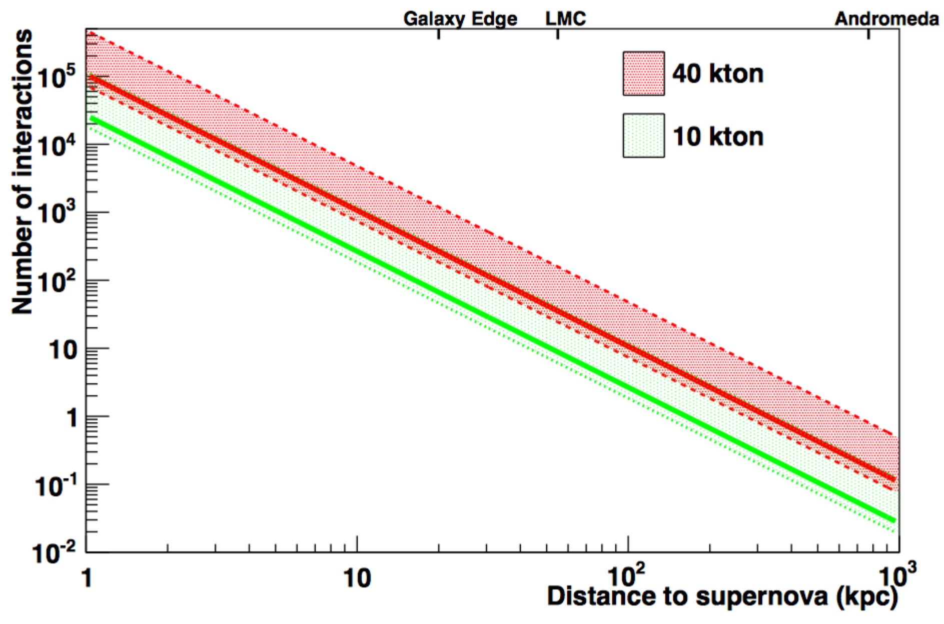
SN neutrinos in DUNE

Event rates in DUNE (40 kt LAr) for a core-collapse SN at 10 kpc

Channel	Events "Livermore" model	Events "GKVM" model
$\nu_e + ^{40}\mathrm{Ar} \rightarrow e^- + ^{40}\mathrm{K}^*$	2720	3350
$\overline{\nu}_e + ^{40}\mathrm{Ar} \rightarrow e^+ + ^{40}\mathrm{Cl}^*$	230	160
$\nu_x + e^- \rightarrow \nu_x + e^-$	350	260
Total	3300	3770
	no oscillations	*collective effects*

Electron neutrino and anti-neutrino sensitivity

- Unique sensitivity to electron neutrinos
- Width of bands represents range of models
- Solid: Garching model *PRL104 (2010) 251101*



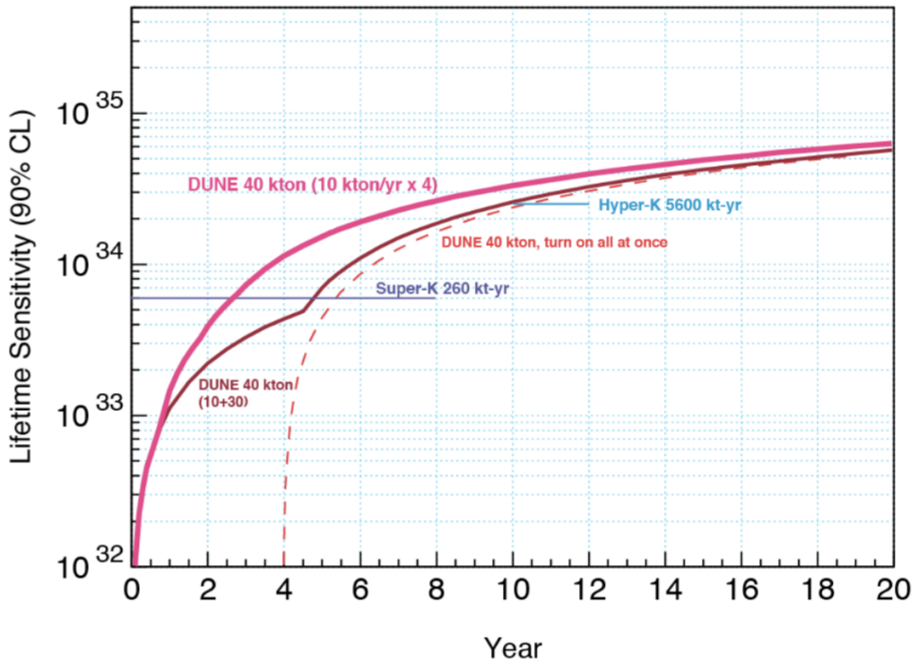
Expected DUNE Sensitivity for $p \rightarrow K^+ \bar{\nu}$

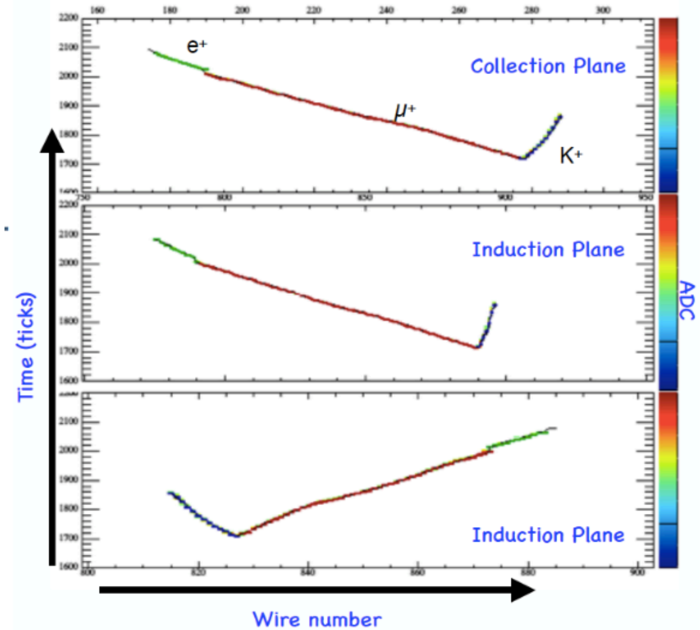
- **Low-background** mode with **high detection efficiency**
- DUNE will do well in decay modes with kaons, and modes with neutrinos or with complicated topologies

$p \rightarrow K^+ \bar{\nu}$

$K^+ \rightarrow \mu^+ \bar{\nu}_\mu$

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$



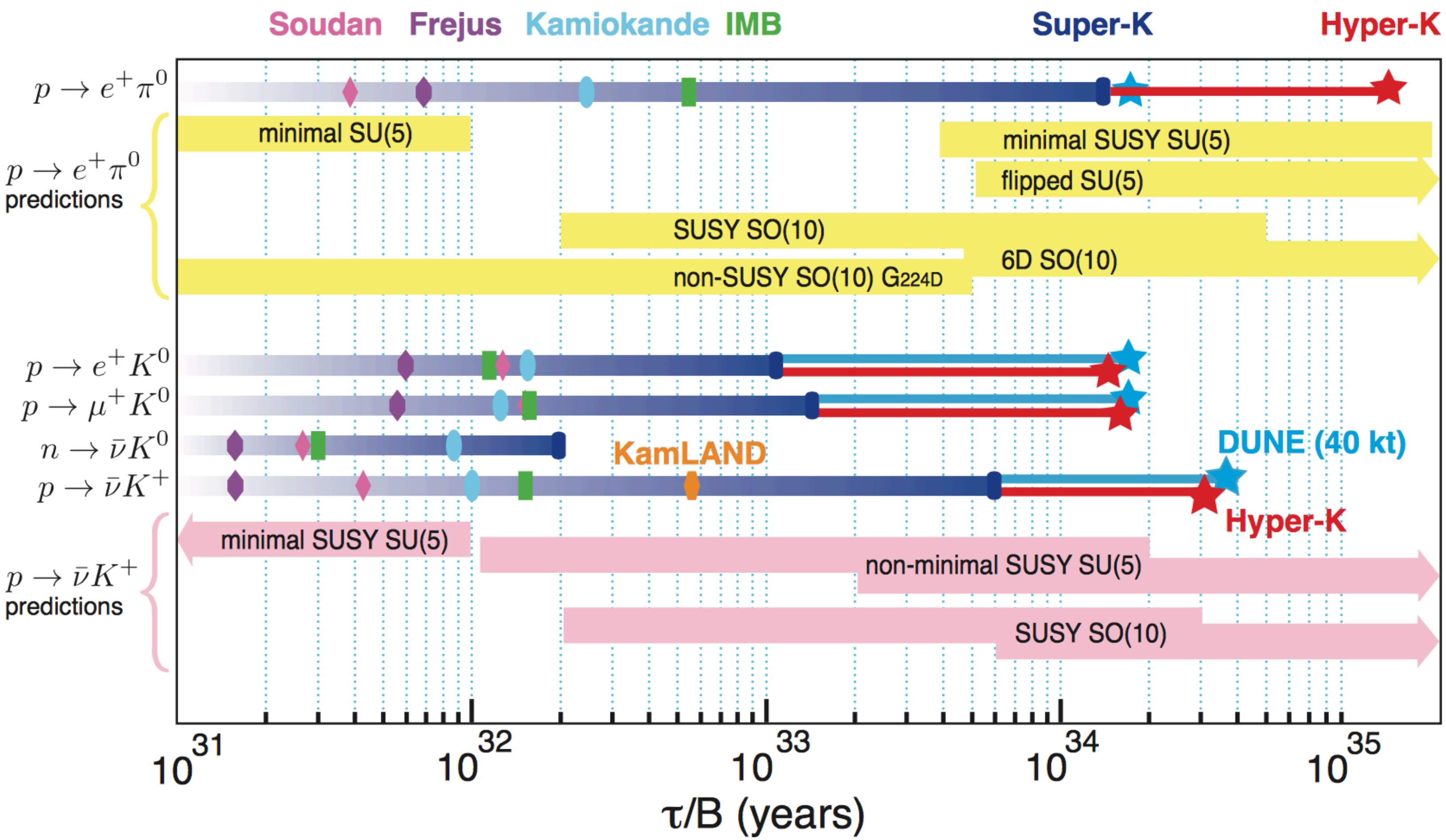


Simulation and reconstruction of proton decay at DUNE

Experimental Limits and Theoretical Predictions

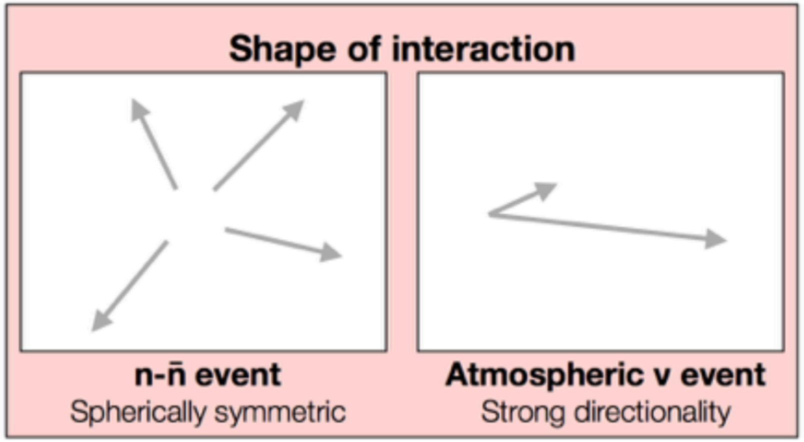
arXiv:1512.06148

Example "benchmark" decay modes, but **many others will also be searched**



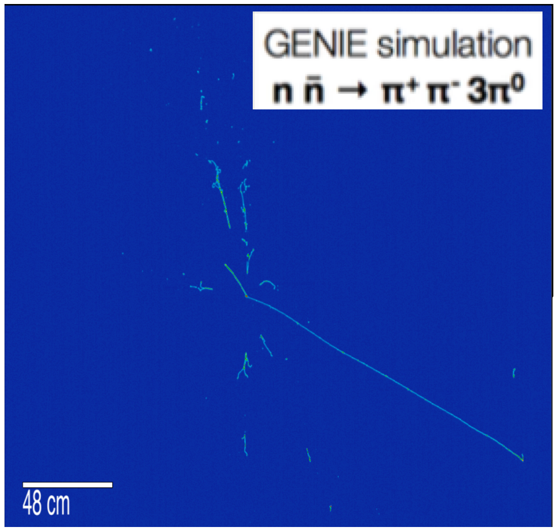
Searches for BSM Physics: Example

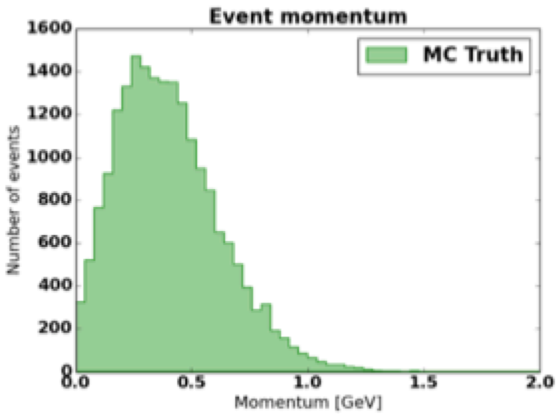
Neutron — Antineutron Oscillation



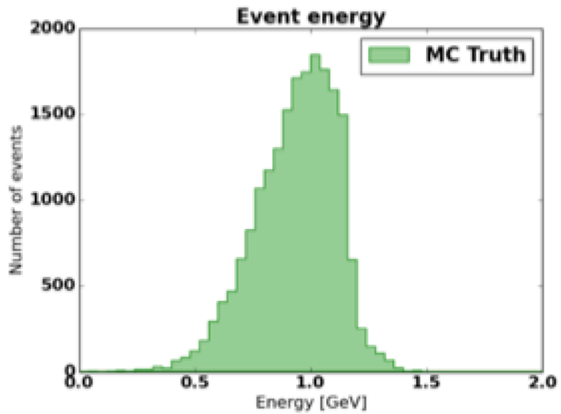
- Baryon number violation process: neutron spontaneously oscillates into an antineutron
- Search for a subsequent annihilation with a bound nucleon inside the nucleus
- Preliminary expected sensitivity:

1.7 x 10^9 s (90% CL) after 10 years running;





Event net momentum

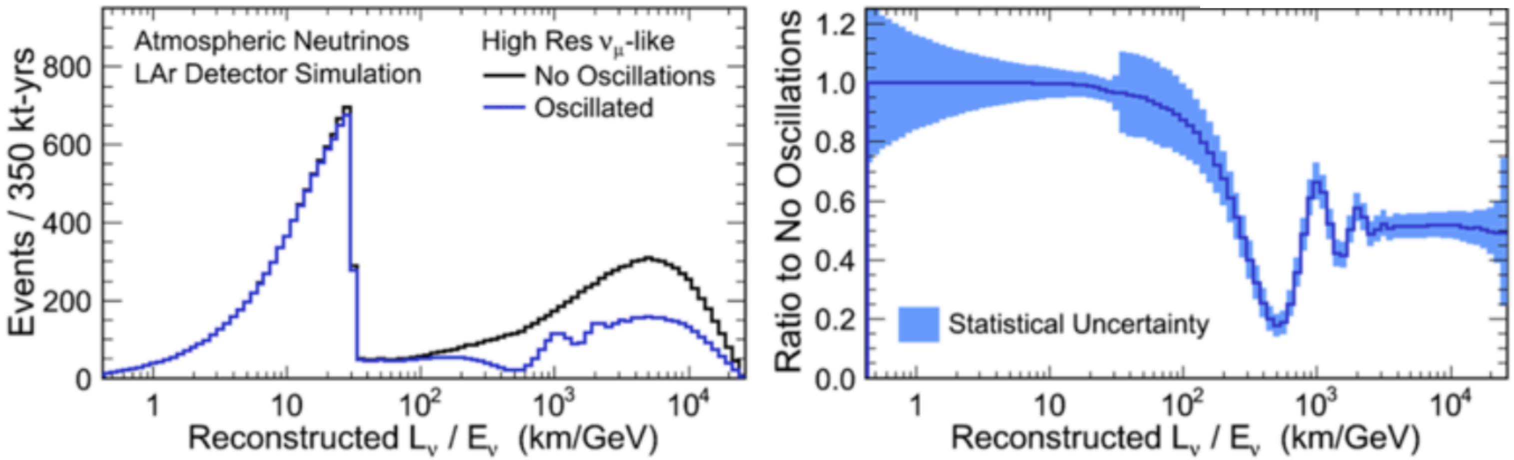


Total event visible energy

DUNE and Atmospheric Neutrinos

- Preliminary studies of the 350 kt-year exposure were performed
- Neutrino interactions on argon were simulated using the the Bartol 3 D flux model and GENIE

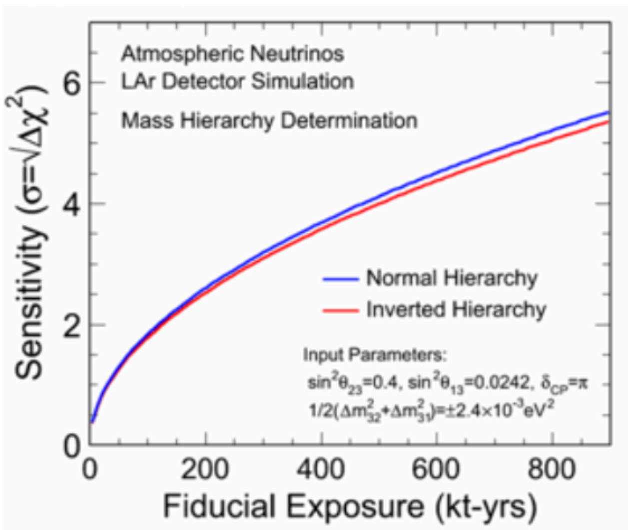
arXiv:1512.06148

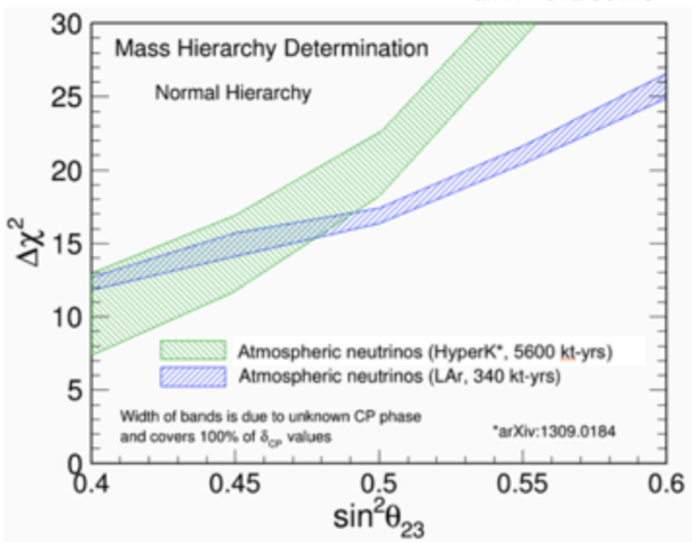


Sample	Event Rate
fully contained electron-like sample	14,053
fully contained muon-like sample	20,853
partially contained muon-like sample	6,871

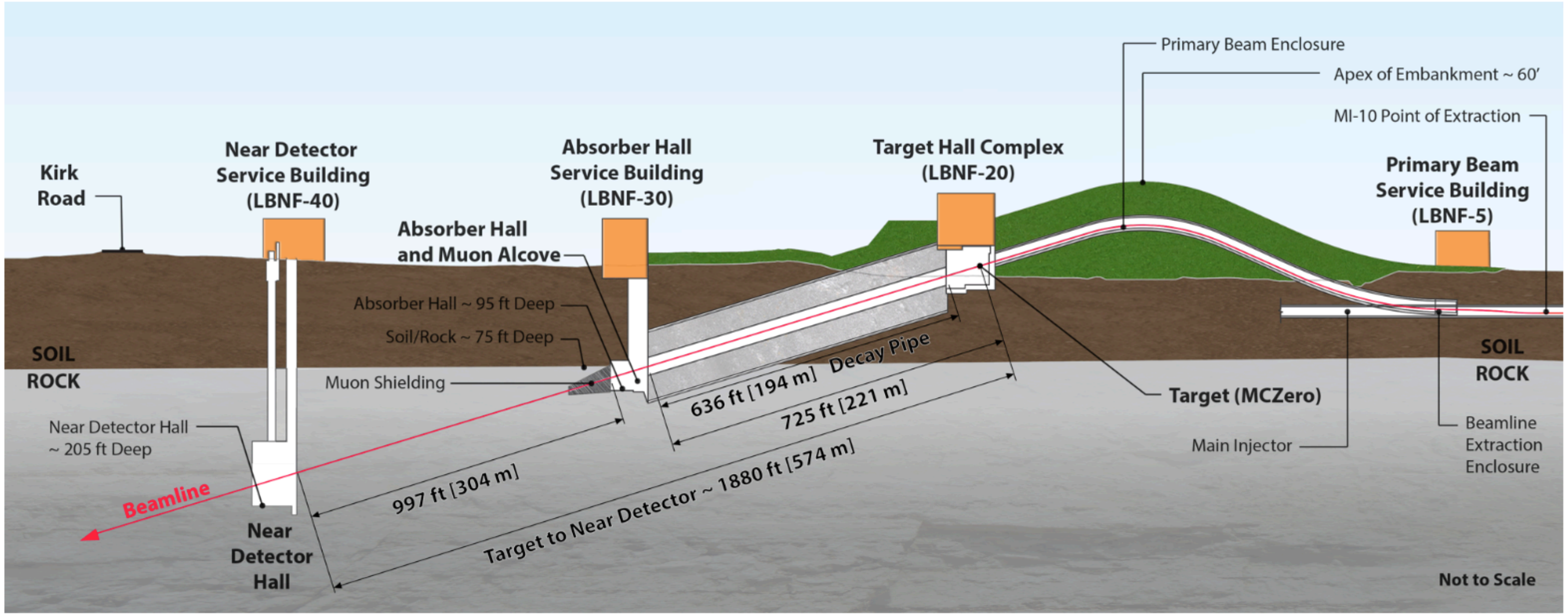
Neutrino Oscillation Sensitivities with Atmospheric Neutrinos

- Neutrino oscillation sensitivities are calculated using a joint fit to the muon and electron neutrino sample
- MSW resonance enables determination of the mass Hierarchy
- Resonance occurs for neutrinos in case of normal hierarchy and for antineutrinos in case of inverted hierarchy





Beam and Near Detector

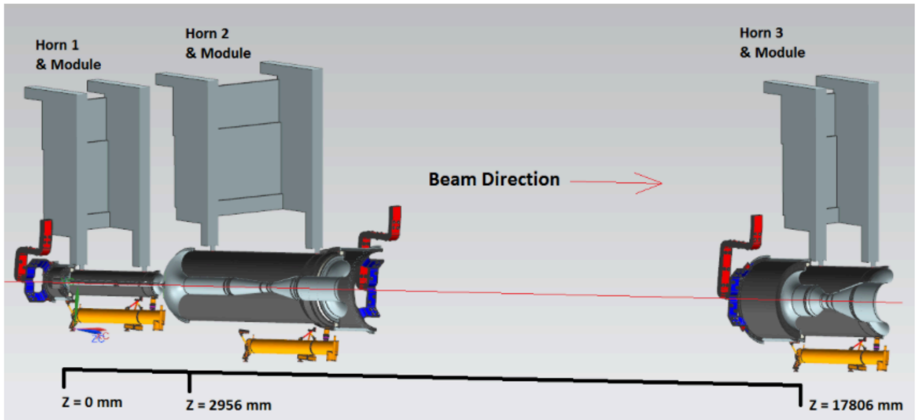


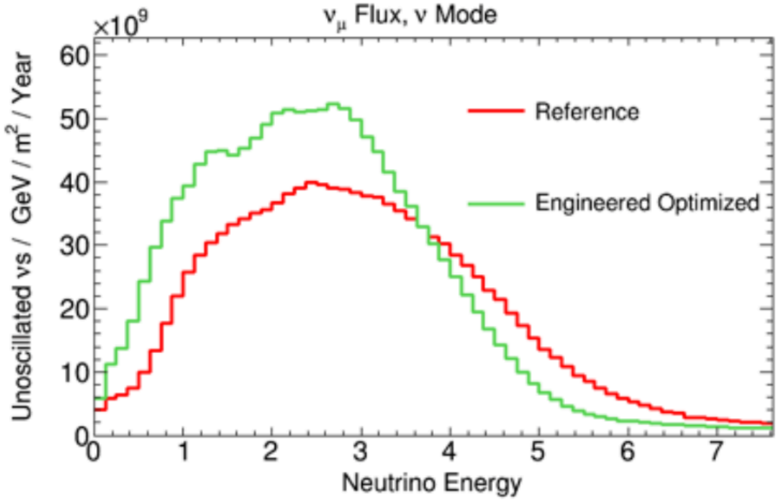
- Primary proton beam @ 60-120GeV extracted from Main Injector
- Initial 1.2 MW beam power, upgradable to 2.4 MW
- DUNE Near Detector
  - Precisely measure beam neutrino fluxes
  - Constrain systematic uncertainties for oscillation measurements
  - Multiple designs under consideration

Optimization of the neutrino beamline

- Significant effort to optimize target and horn system for better sensitivity to CP violation
- Currently, evaluating technical and cost impact of design with 4 interaction-length target and 3 horns.

->Further optimization still ongoing





DUNE Near Detector

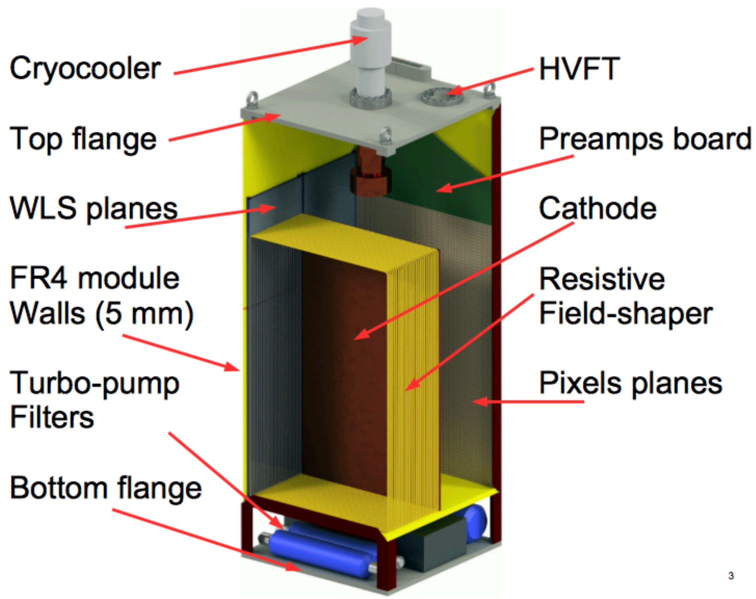
The ND has a fundamental role for LBL physics, constraining the systematic uncertainties via measurements of the neutrino flux and interaction cross sections

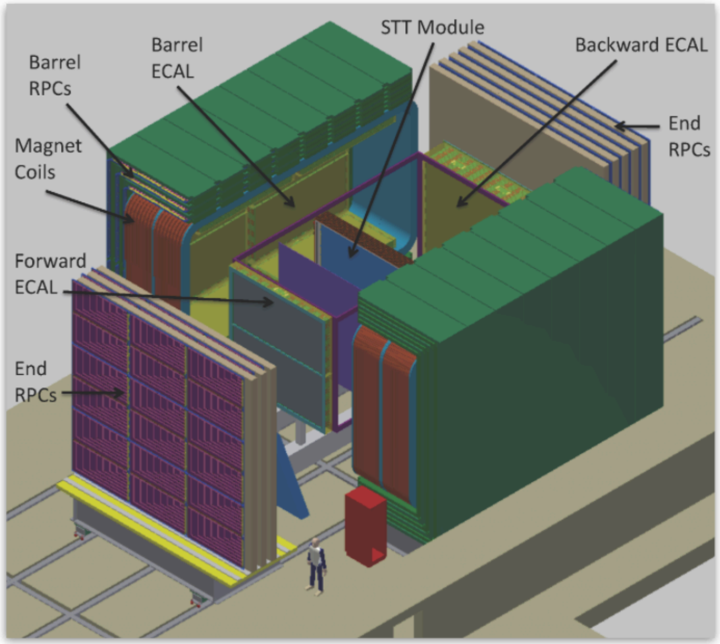
It will record the largest sample of neutrino argon interactions ever collected allowing for precision measurements (EWK, QCD)

Sensitive to new physics (eg Heavy Neutral Leptons/Sterile neutrinos, light dark matter…)

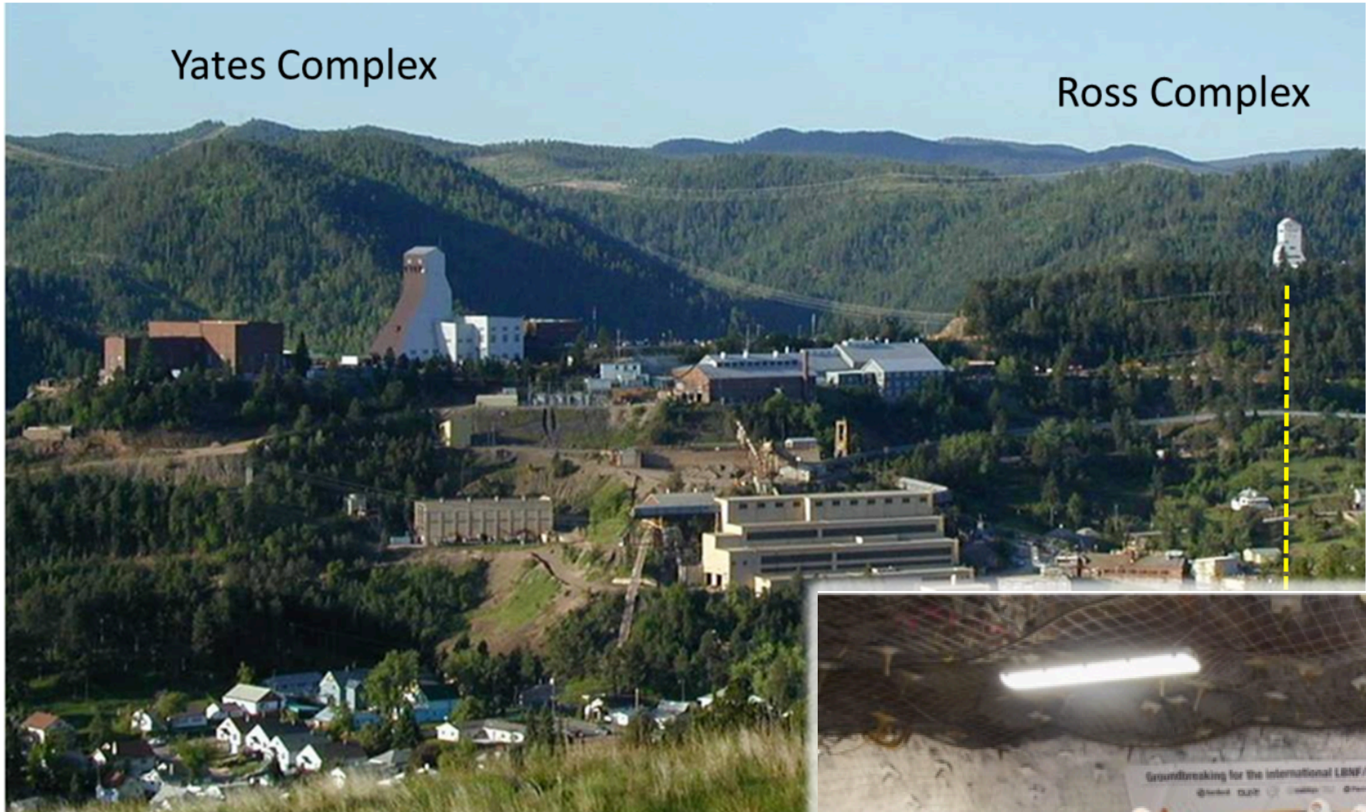
DUNE ND is currently under design. Conceptual design planned to be for 2018

It will likely include a modular liquid argon TPC and a magnetised high resolution tracker, ECAL and muon system (hybrid system)





LBNF/ DUNE Far Site

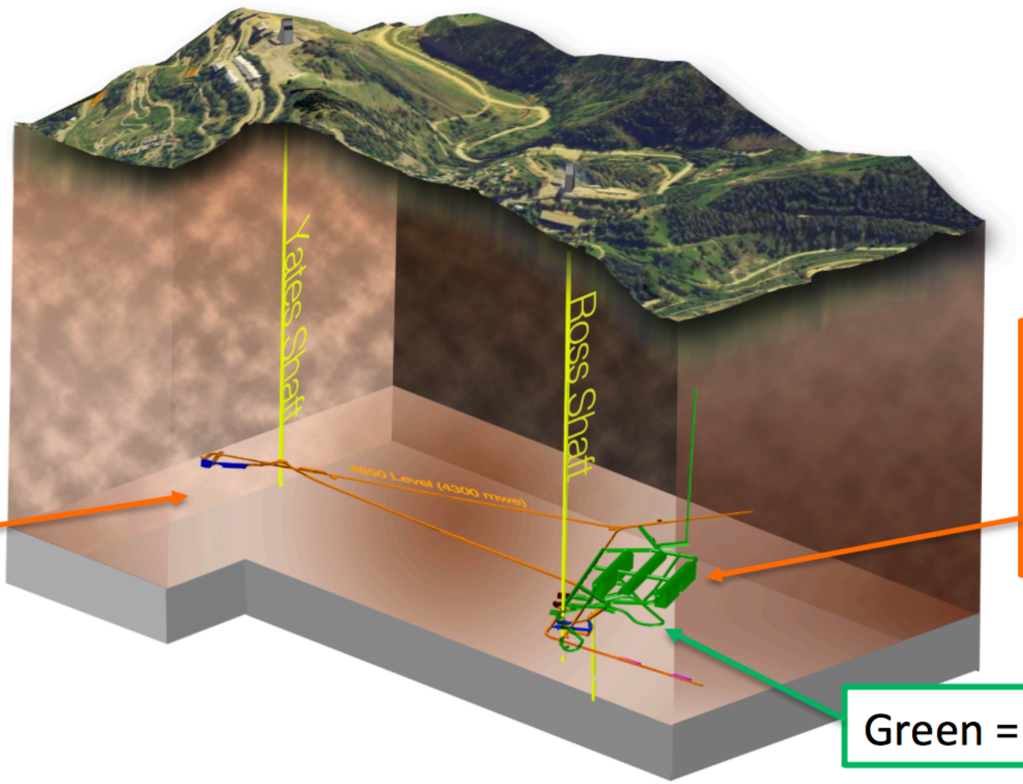


2017: start excavation at the far site (Sanford Underground Research Facility SURF)

LBNF/ DUNE Far Site

Ross Campus of 4850 ft level of Sanford Underground Research Facility

Davis Campus:
- LUX
- Majorana demo.
- …
- LZ

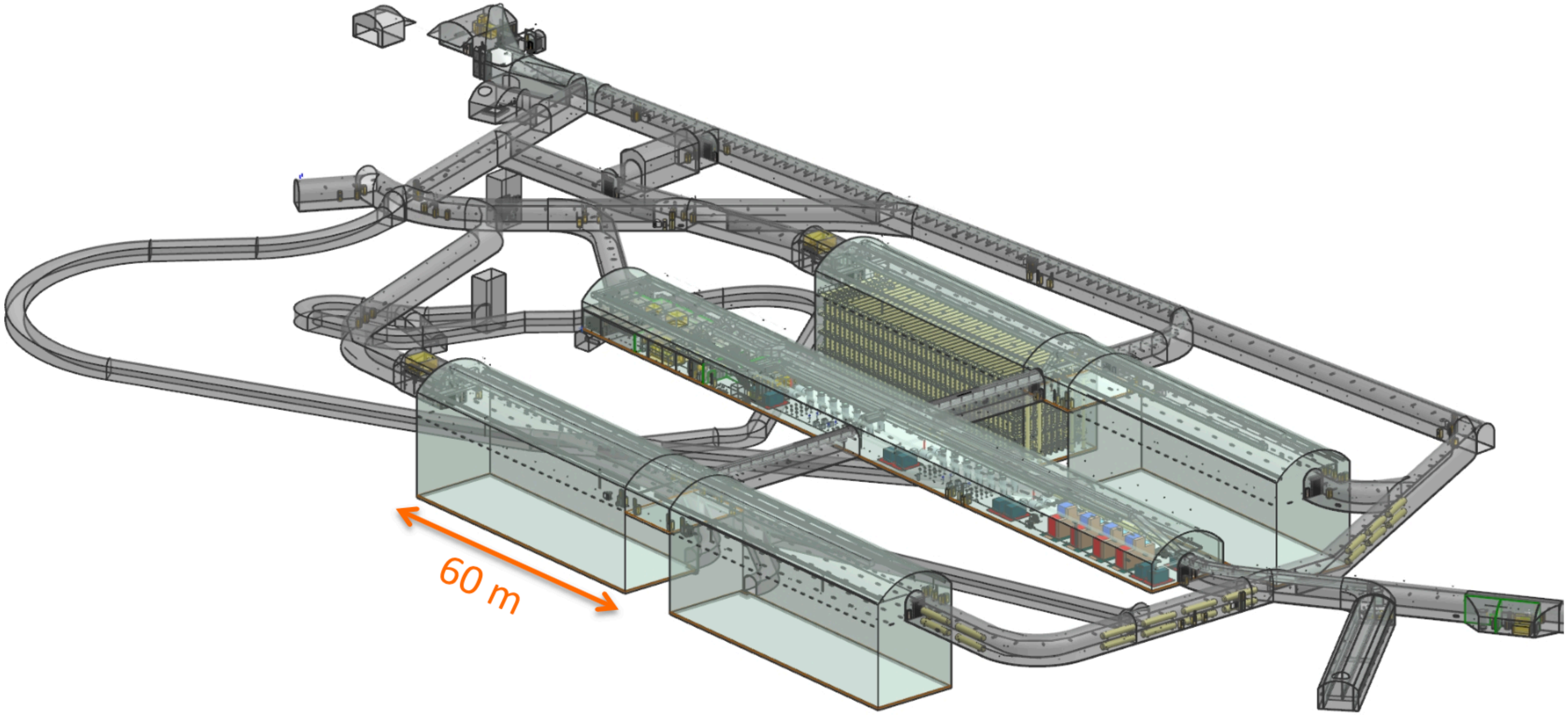


Ross Campus:
- CASPAR
- …
- DUNE

Green = new construction

DUNE Far Detector

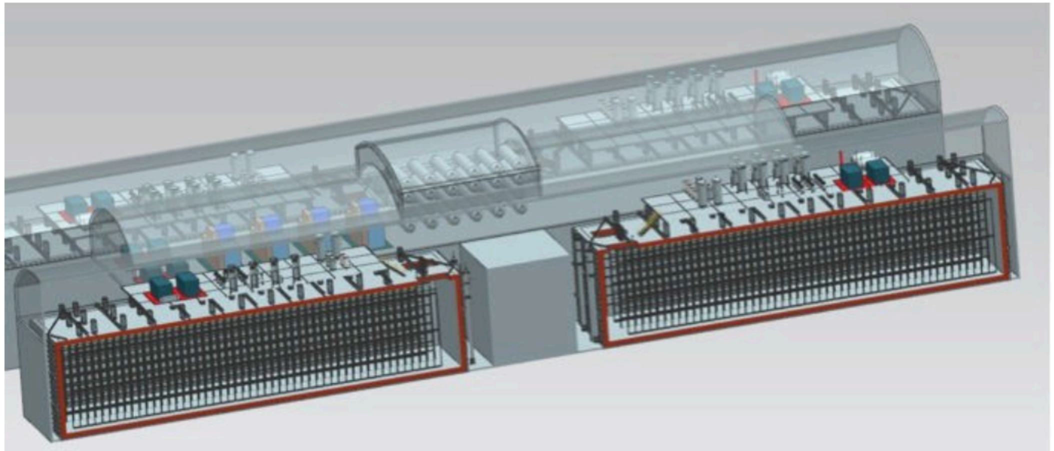
- 70-kt LAr-TPC = 4 x 17 kt (4 x 10 kt fiducial) detectors

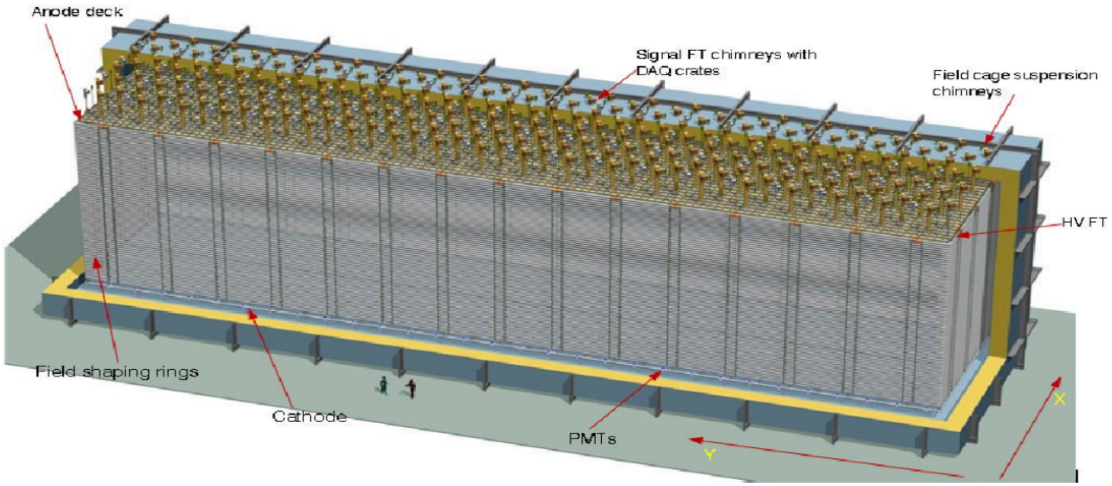


- 4 chambers, each hosting a 10 kt fiducial module
- Modules will be similar, but likely not identical

DUNE Far Detector Technologies

Collaboration is considering (and prototyping) two liquid argon readout technologies:





Single Phase

- drift electrons detected in the liquid
- Readout technology of ICARUS, ArgoNeuT, MicroBooNE, SBND
- 3.5 m max drift

Dual Phase

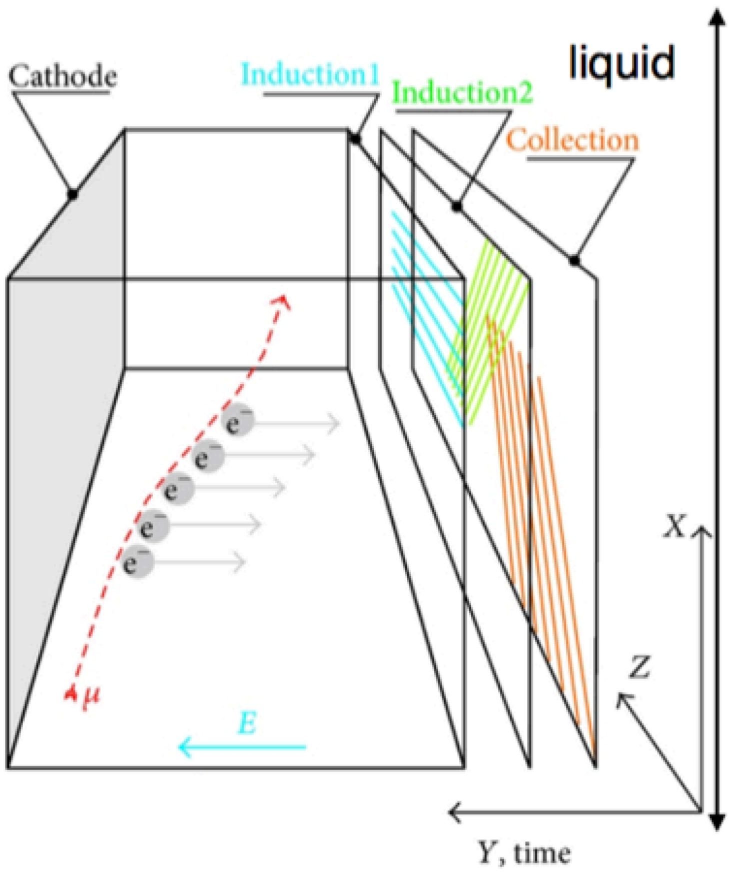
- amplification of electron signal in gas phase
- Pioneered at large scale by WA105.
- 12 m max drift

Liquid argon TPC: Single and dual phase

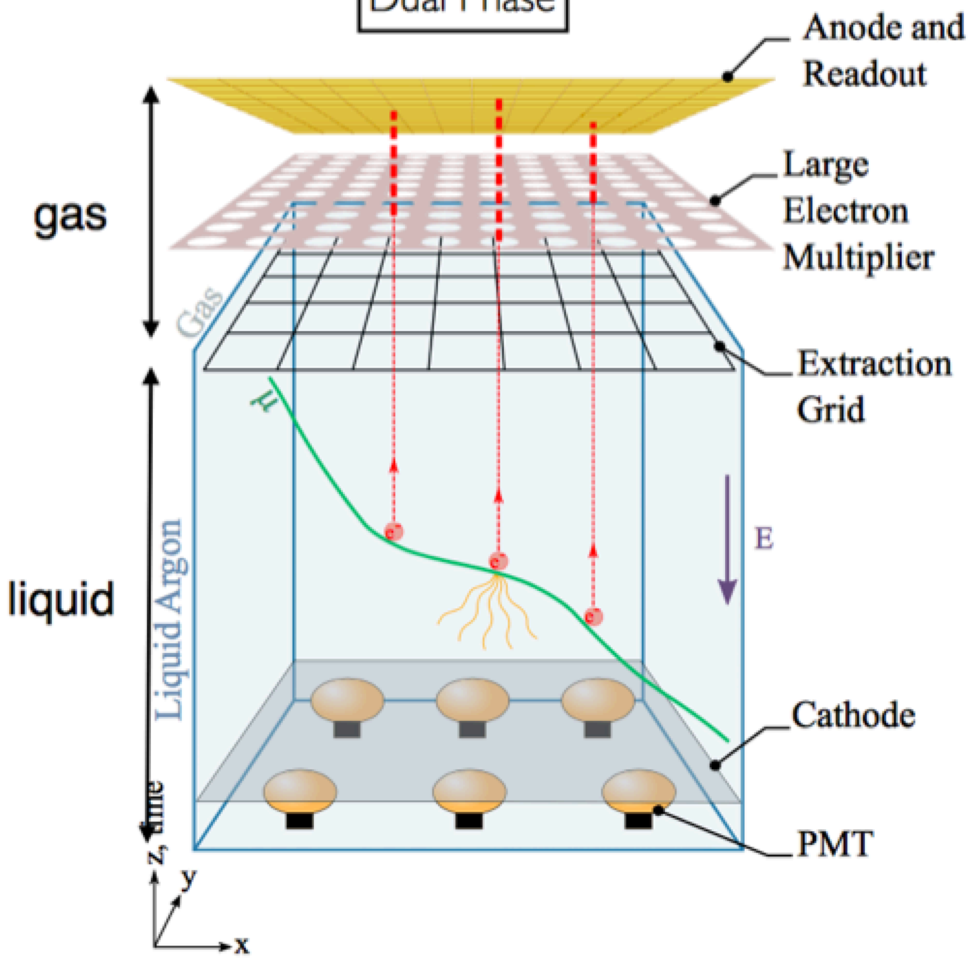
- ionisation charges are drifted horizontally and readout by wires.
- No amplification of the signal.

- ionisation charges are drifted vertical and readout by PCB anodes.
- amplification of the signal in LEMs

Single Phase



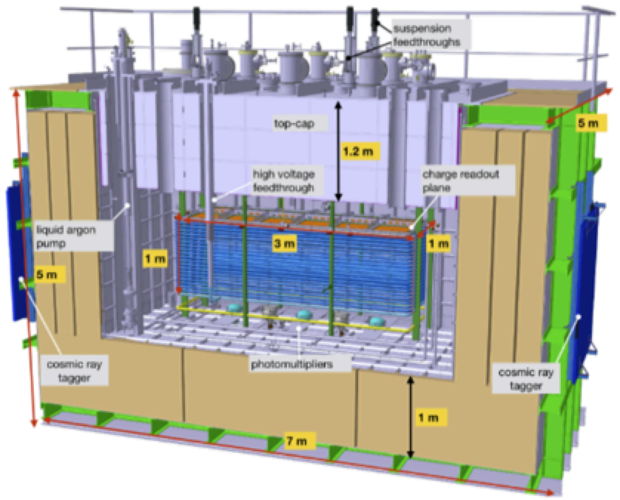
Dual Phase

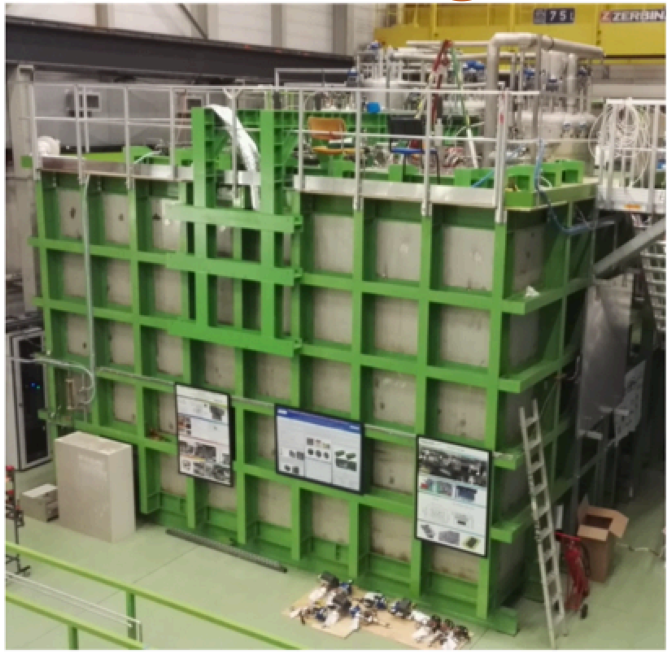


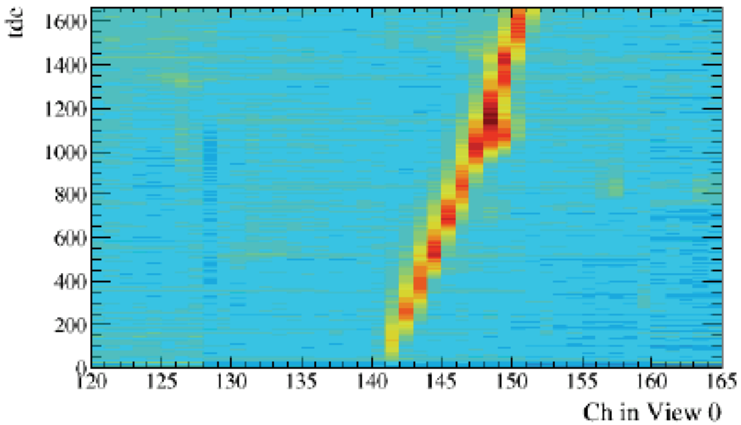
Pre-ProtoDUNE Dual Phase 1x1x3m

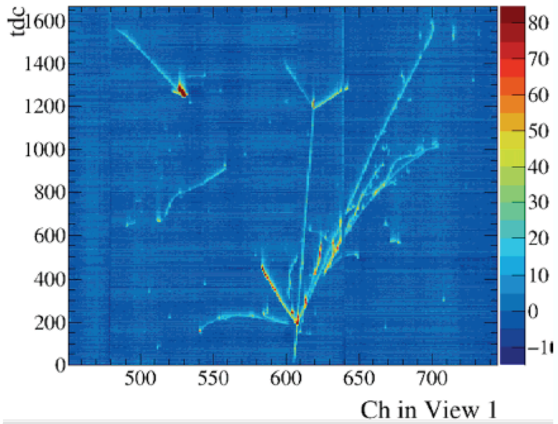
WA105 @ CERN

- Installation completed end 2016





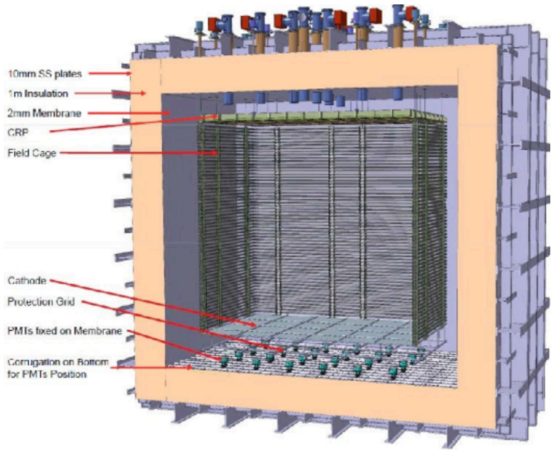




Now being taking cosmics data

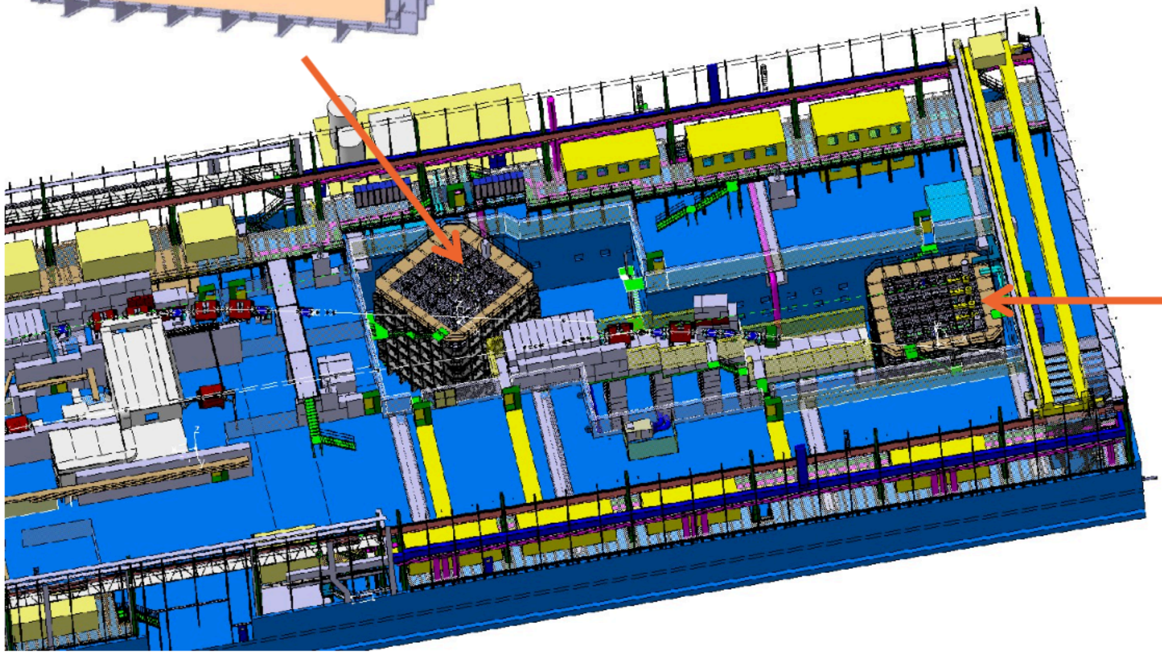
Prototypes at CERN Neutrino Platform

ProtoDUNE Dual Phase

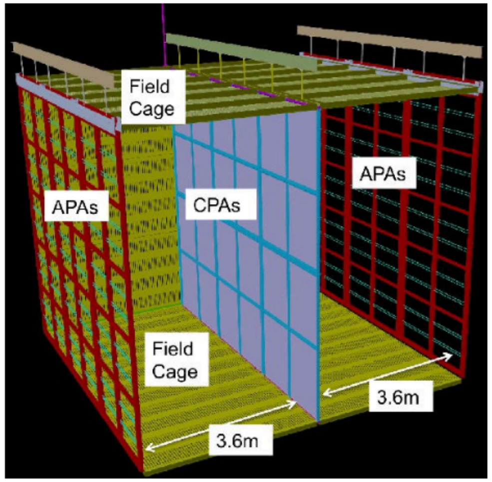


Major CERN investment to support DUNE

- EHN1 extension in the North area
- Two tertiary charged-particle beam lines
- Two 8m×8m×8m cryostats & cryogenic systems



ProtoDUNE Single Phase

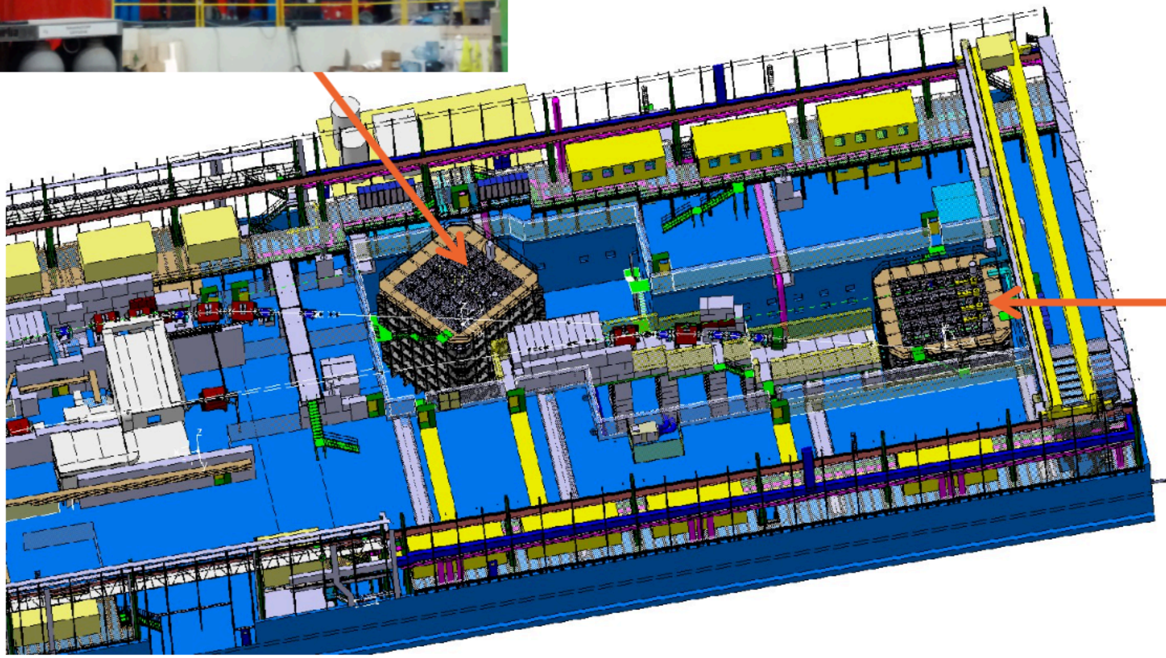


Prototypes at CERN Neutrino Platform

ProtoDUNE Dual Phase

Both ProtoDUNEs aim to begin data taking in mid 2018.

EHN1 Webcams:
http://cenf-ehn1-np.web.cern.ch/images/np04-webcam-neutrino-platform-hall-ehn1

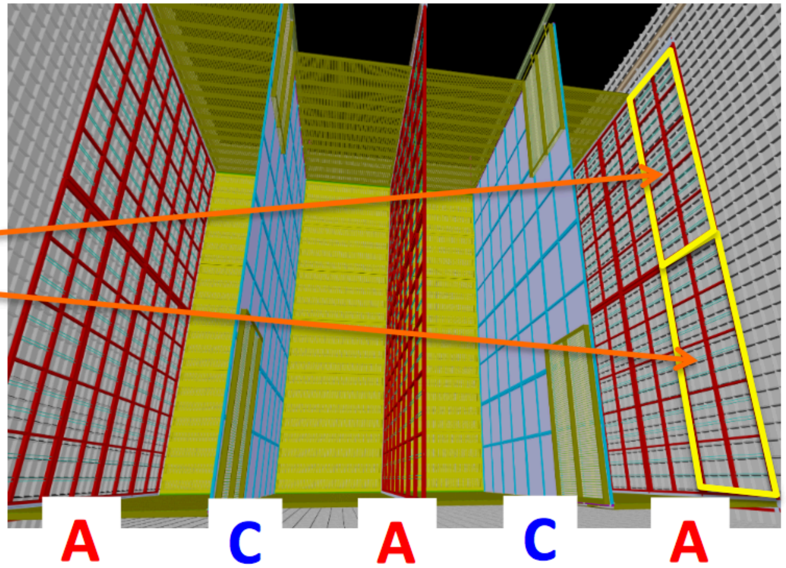


ProtoDUNE Single Phase

DUNE → ProtoDUNE-SP

DUNE Far Detector

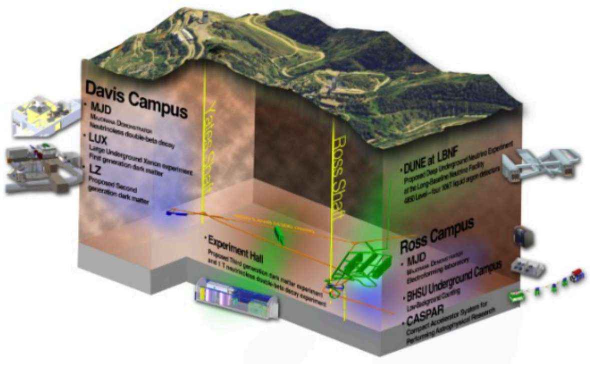
- Active volume: **12m x 14m x 58m**
- 150 Anode Plane Assemblies
  - 6m high x 2.3m wide
- 200 Cathode Plane Assemblies
  - Cathode @ -180 kV for 3.5m drift

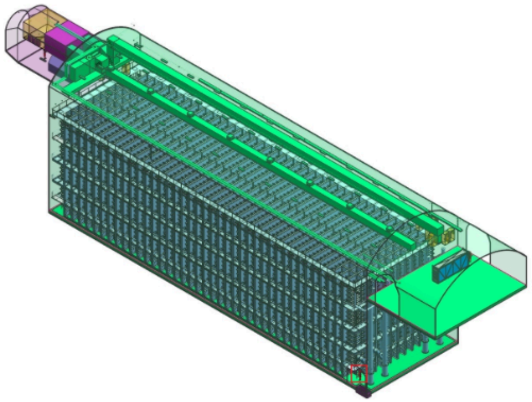


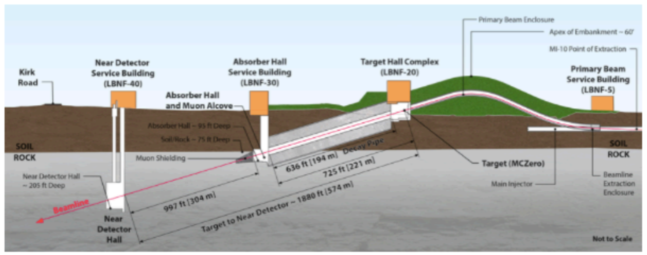
ProtoDUNE-SP

- 1/25 of full DUNE far detector
- 6 full-sized drift cells (150 in far detector)

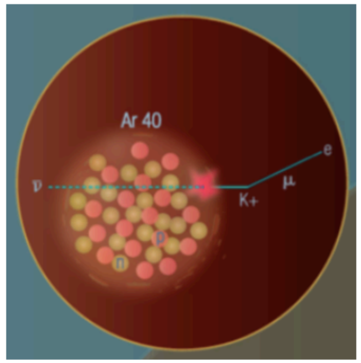
DUNE Timeline







- 2017: Far Site Construction Begins
- 2018: protoDUNEs at CERN
- 2021: Far Detector Installation Begins
- 2024: Physics Data Begins
- 2026: Neutrino Beam Available



40 kton + 2 MW beam to follow in subsequent years

Summary

- DUNE will use a broadband beam and a long baseline (1300 km) to make a precise, simultaneous measurement of the mass ordering, the CP-violation phase and the neutrino mixing angles
- The mass and high granularity and deep underground location of the DUNE far detector provide good sensitivity to baryon non-conservation and supernova burst neutrinos
- Ground-breaking ceremony at far site took place on 21st of July!
- On track to operate the ProtoDUNE-SP and ProtoDUNE-DP at CERN in summer 2018
- We look forward to start operation of the first far detector module in 2024 and first data with beam, near detector and first two far detector modules in 2026.