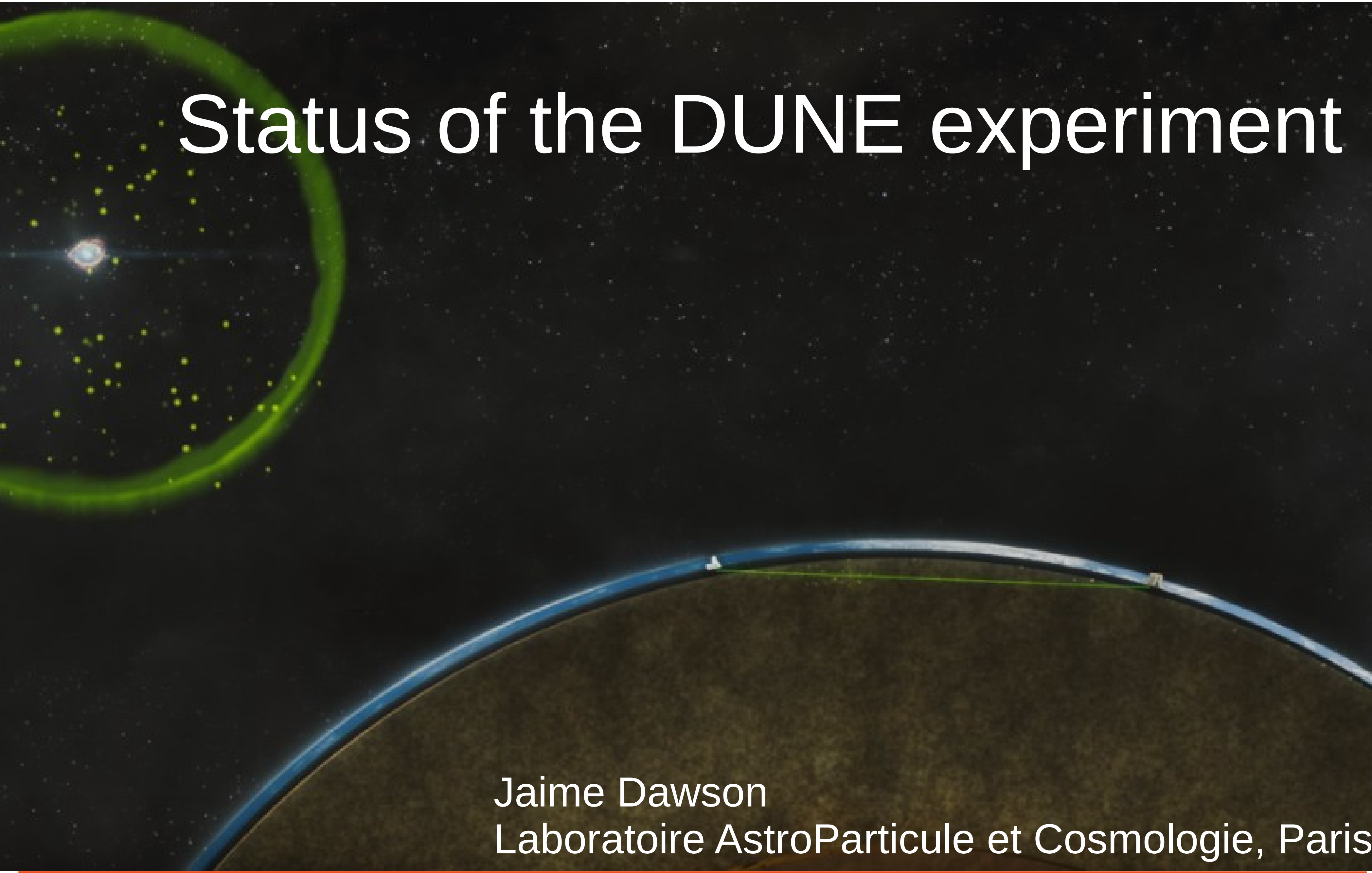
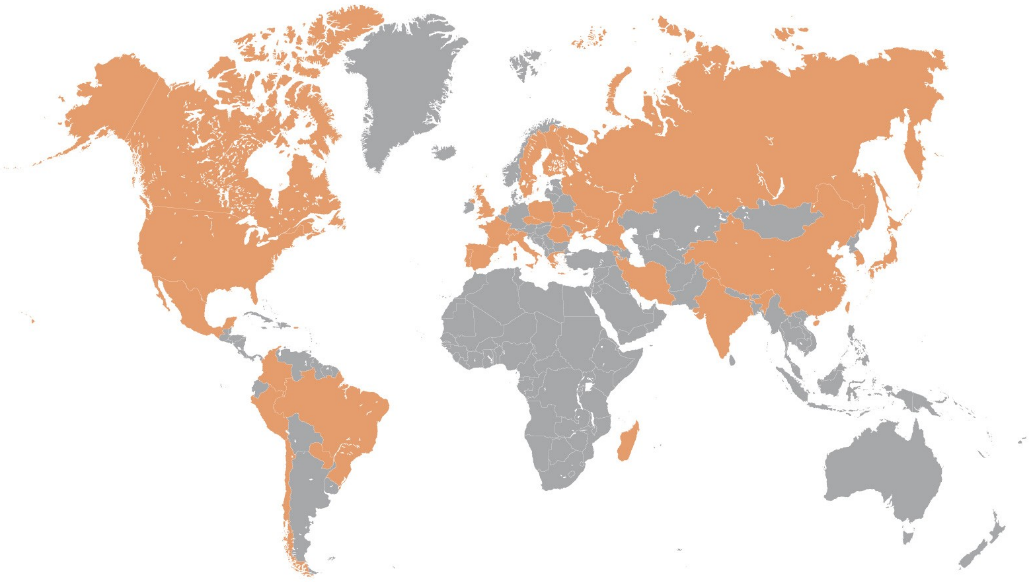
Status of the DUNE experiment



Jaime Dawson
Laboratoire AstroParticule et Cosmologie, Paris

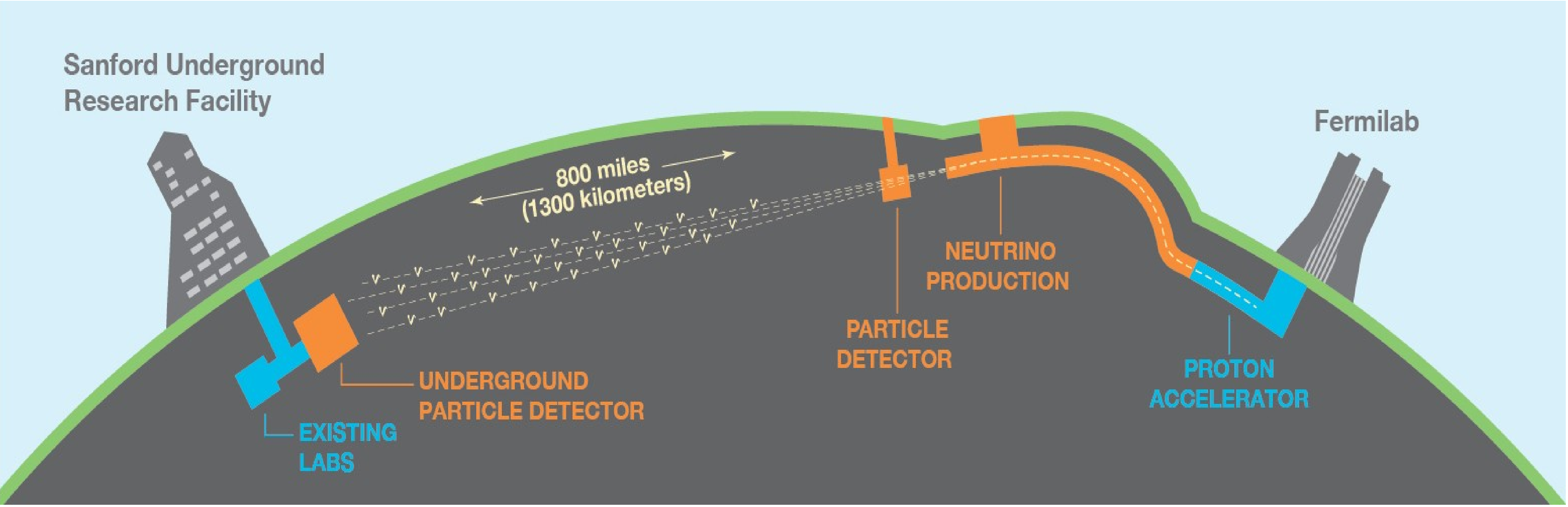
DUNE: international collaboration

- 1069 collaborators from 177 institutions in 31 countries
- 578 faculty, 184 postdocs, 109 engineers, 198 Ph.D. students



Armenia (3), Brazil (31), Canada (1), CERN (37), Chile (3), China (2), Colombia (8), Czech Republic (11), Spain (35), Finland (4), France (38), Greece (5), India (44), Iran (2), Italy (66), Japan (7), Madagascar (4), Mexico (10), The Netherlands (6), Paraguay (4), Peru (7), Poland (6), Portugal (6), Romania (7), Russia (10), South Korea (5), Sweden (1), Switzerland (30), UK (146), Ukraine (4), USA (528)

DUNE is next generation neutrino oscillation experiment



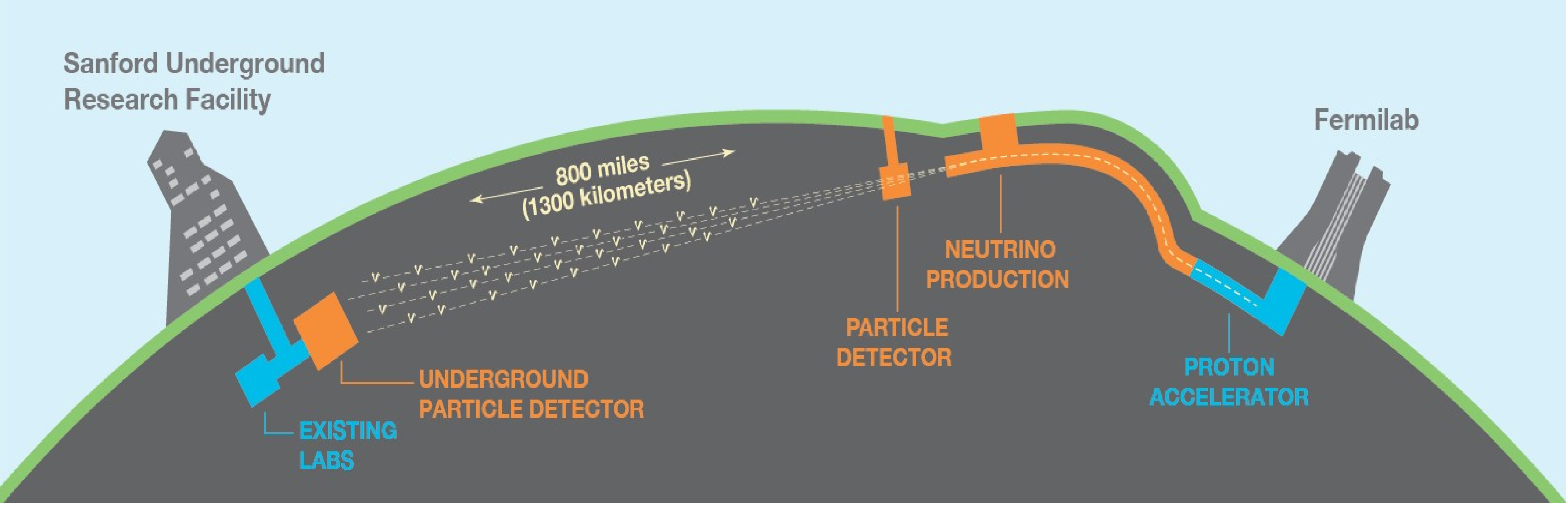
Physics goals :

Neutrino oscillations : measure ν_μ disappearance + ν_e and ν_τ appearance (both neutrino and anti-neutrino modes)

Mass Ordering, leptonic CP Violation discovery, θ_{23} octant and more in a single experiment + physics beyond the Standard Model

Large underground detectors : Nucleon Decay searches, SuperNovae core collapse etc

DUNE is next generation neutrino oscillation experiment

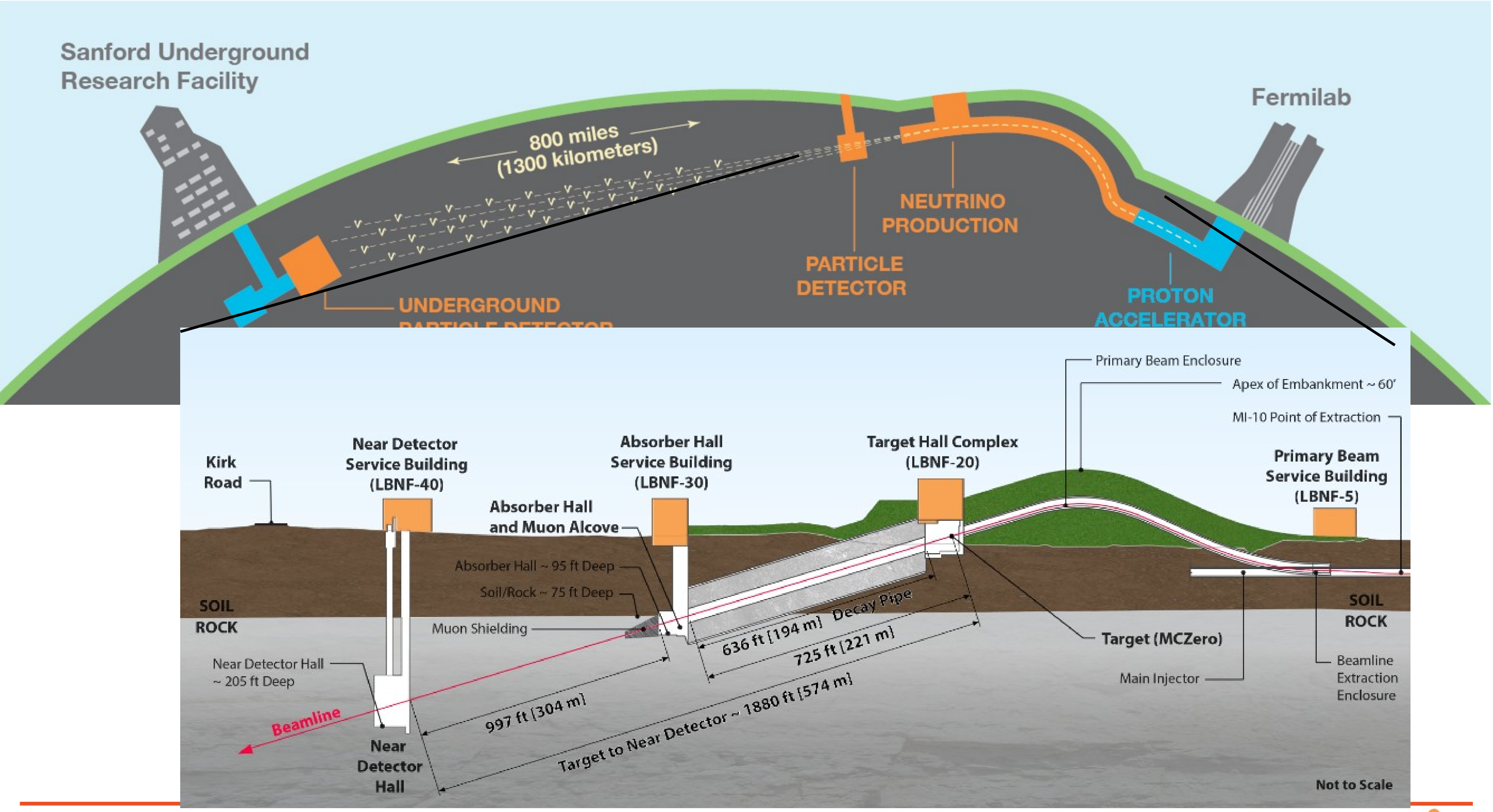


Far detectors at SURF:
4 x 10 kt (fiducial) Liquid Argon TPCs
1.5 km underground
First module to be ready by 2024

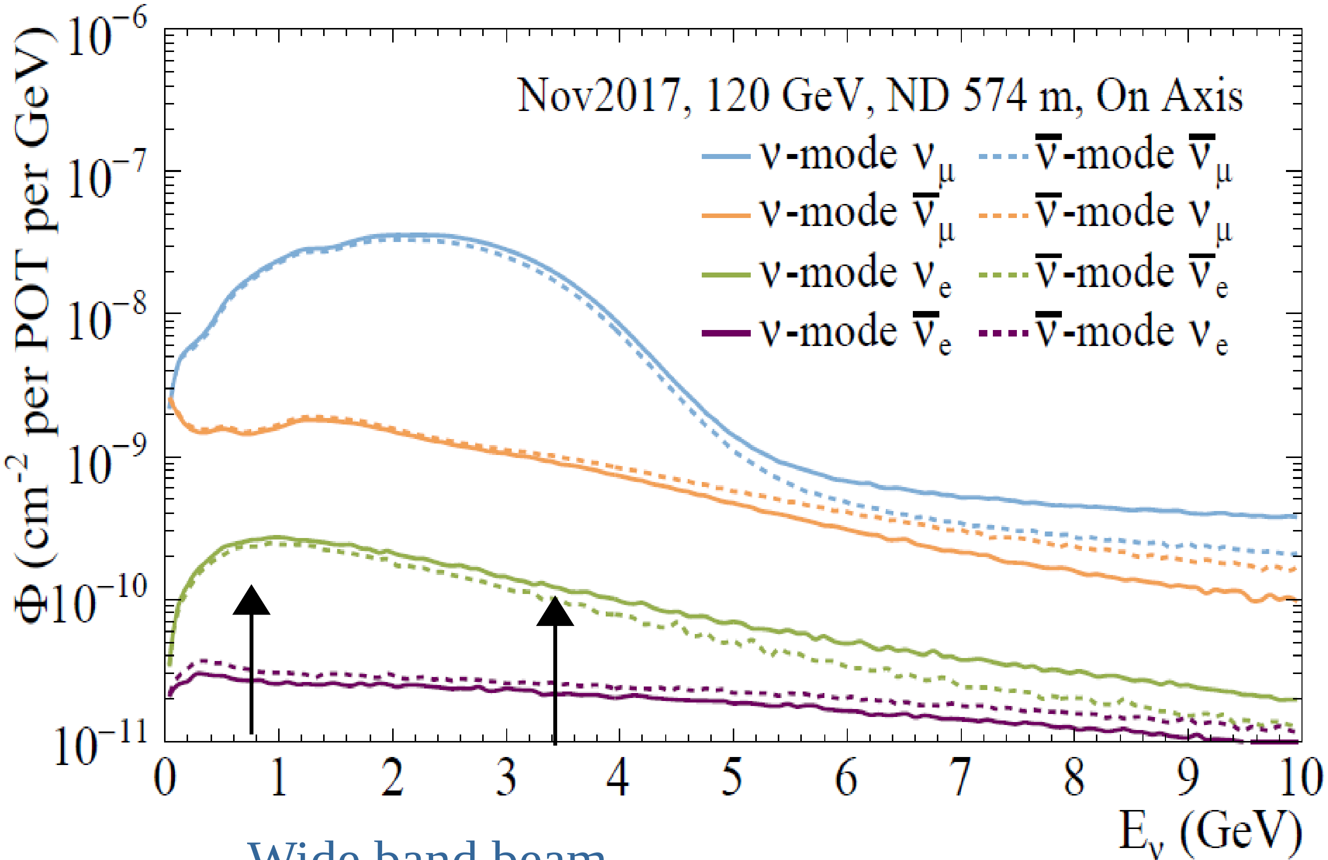
1.2 MW wide-band beam from Fermilab (upgradable to 2.4 MW)

Near Detector to measure initial composition

Long Baseline Neutrino Facility



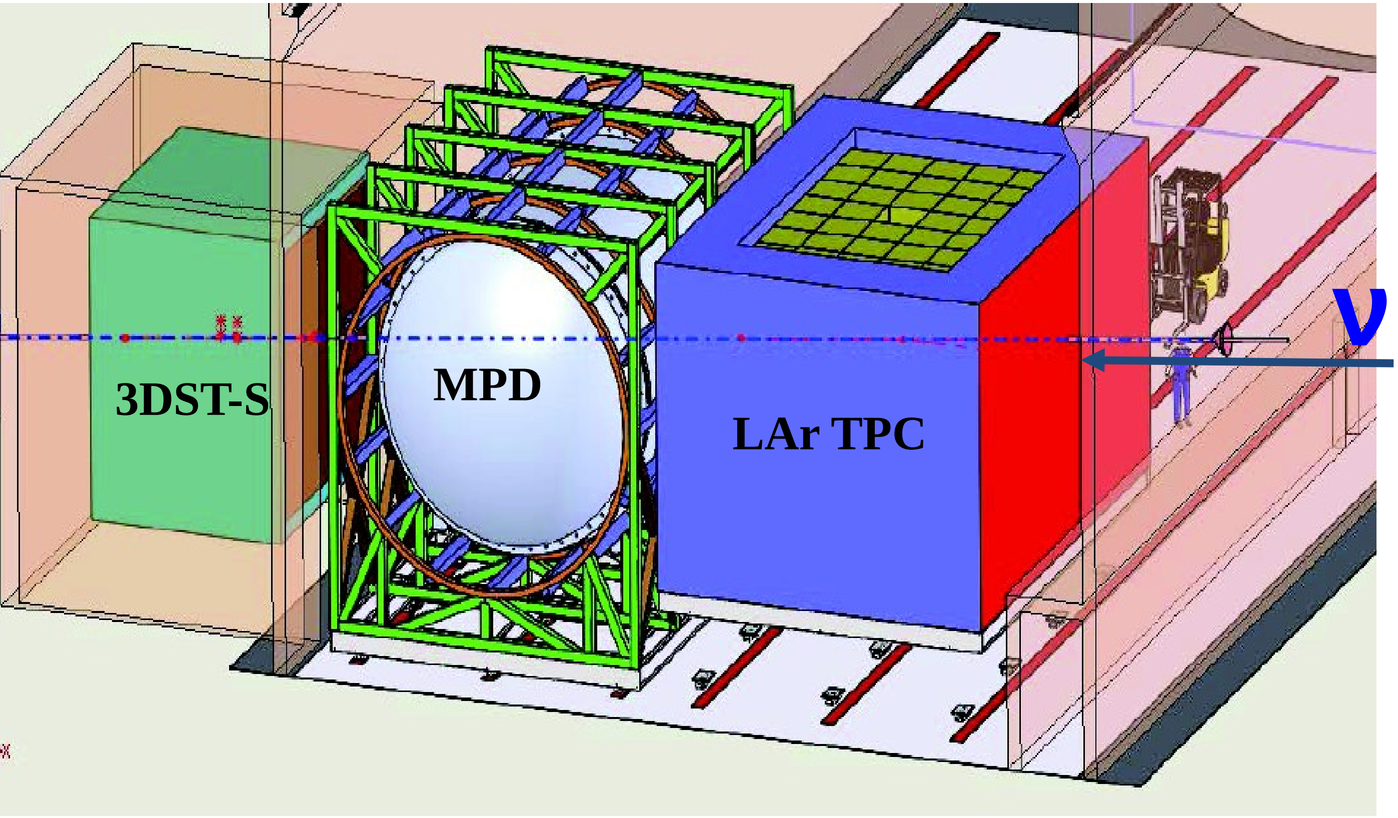
LBNF beam



Wide band beam
2 oscillation maxima

- 120 GeV Main Injector proton beam
- 1.2 MW initial beam power, upgradeable to 2.4 MW
- Beamline and focusing system optimized for CP violation sensitivity

Near detector system at Fermilab

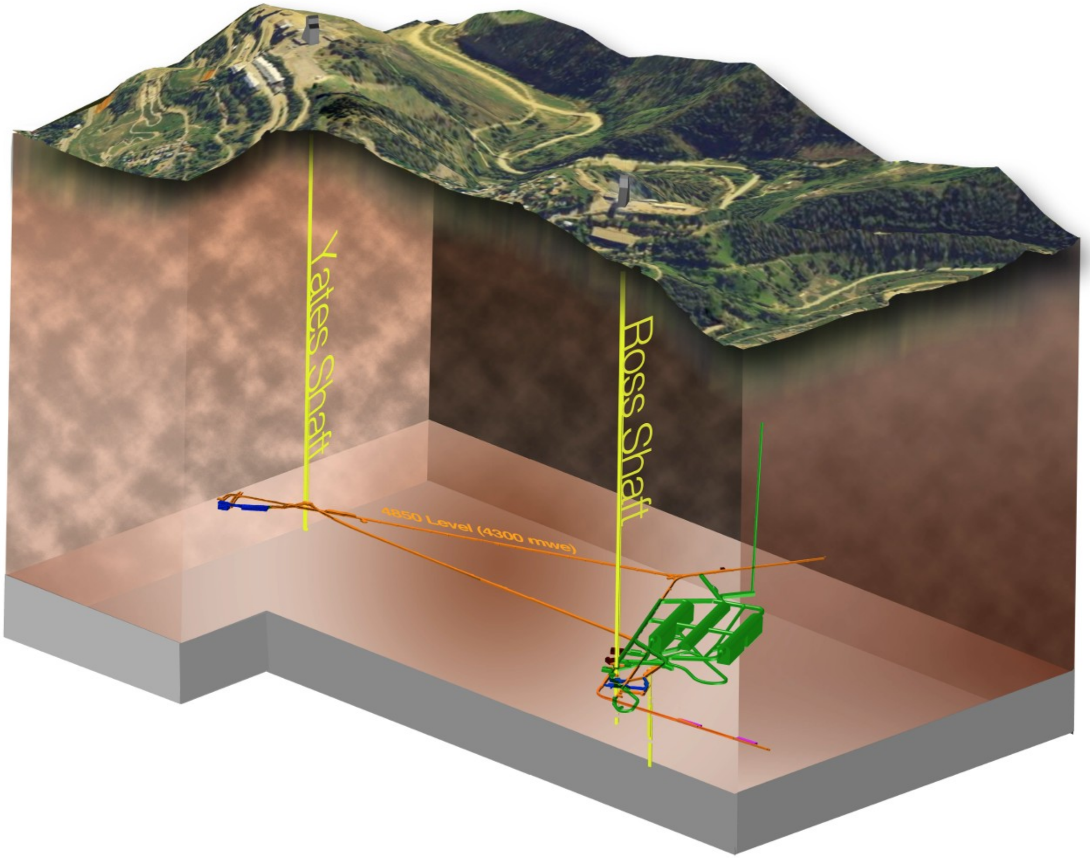


Predict the neutrino spectrum at the FD

Measure interactions on Ar
Measure neutrino energy
Constrain x-section model
Measure neutrino flux
Obtain data with different fluxes
Monitor the neutrino beam

Liquid Argon TPC
Multi-Purpose Detector - HP gaseous Argon TPC + ECAL + Magnet
3D Scintillating Tracking Spectrometer

Far detector at SURF

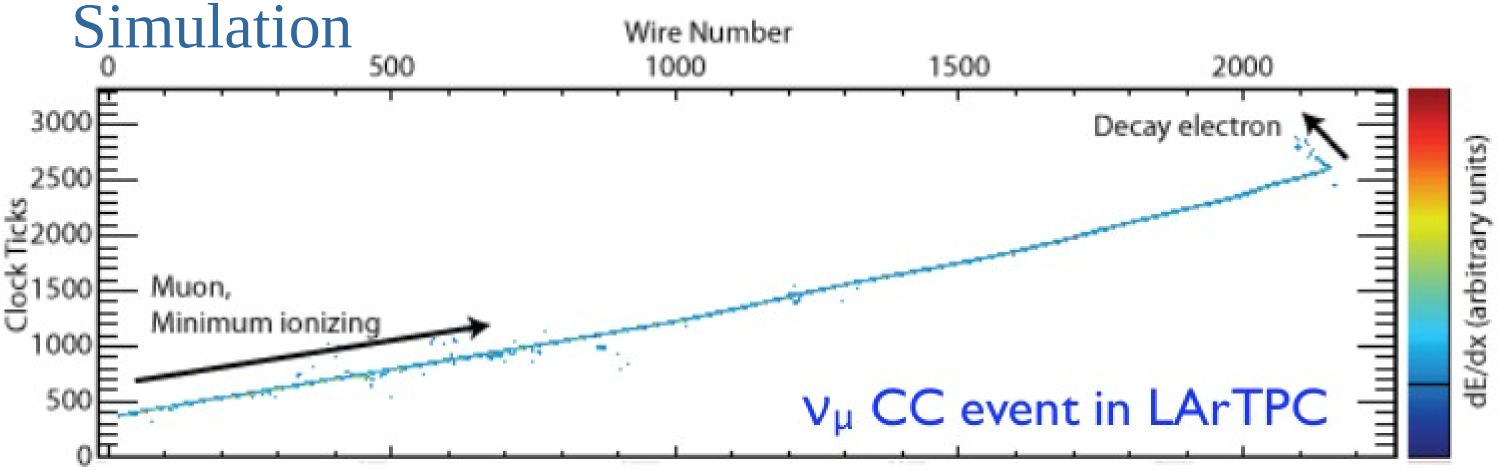


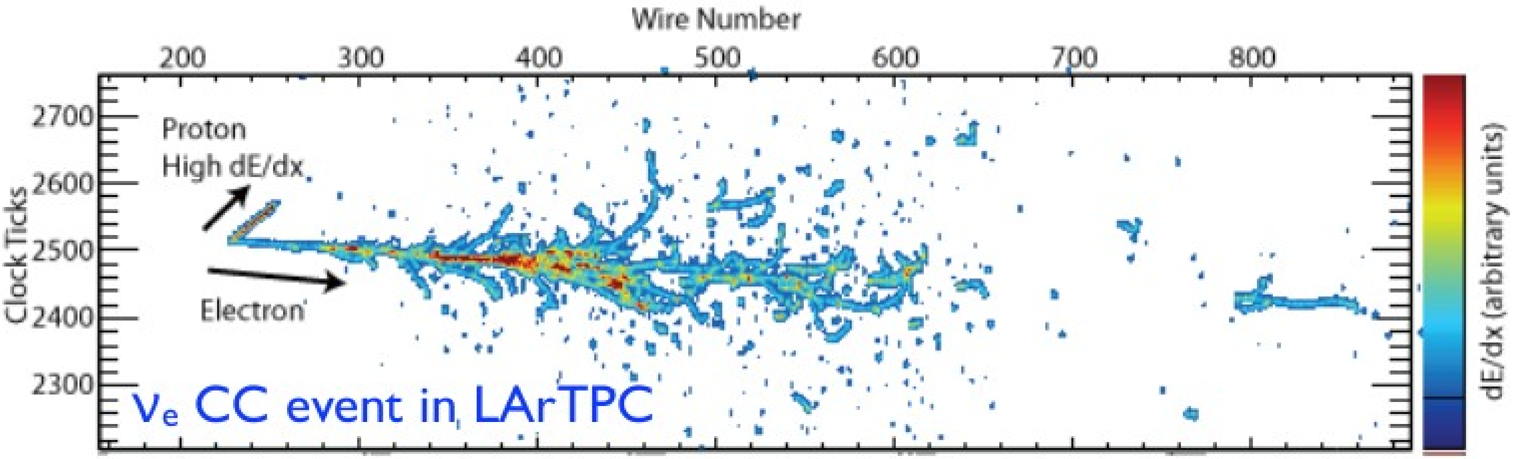
- Sanford Underground Research Facility in Lead, South Dakota
- Four 10-kt Fiducial LAr TPC modules, located 1.48 km underground
- Excavation in 2019
- first module operational in 2024
- Start of run: 2 FD modules (20 kt), 1.2 MW beam power, with ND
- +1 year: 3 FD modules (30 kt)
- +3 years: 4 FD modules (40 kt)
- +6 years: upgrade to 2.4 MW beam

LAr TPCs

- Gigantic detectors with
- Excellent calorimetric and spatial resolution

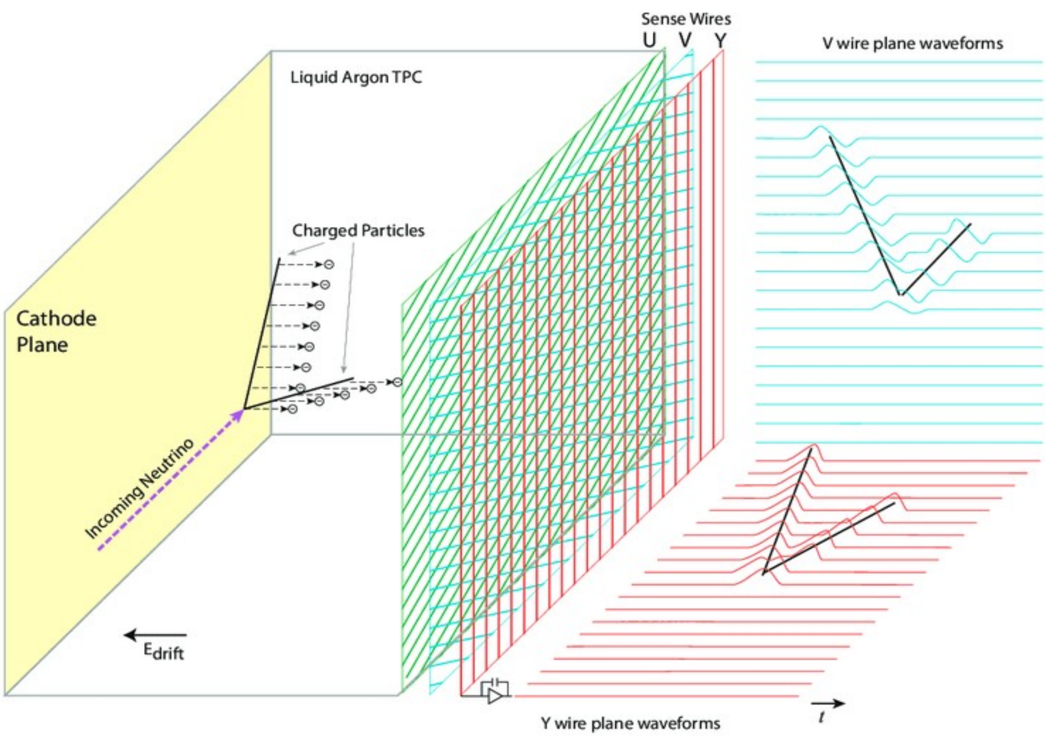
Simulation



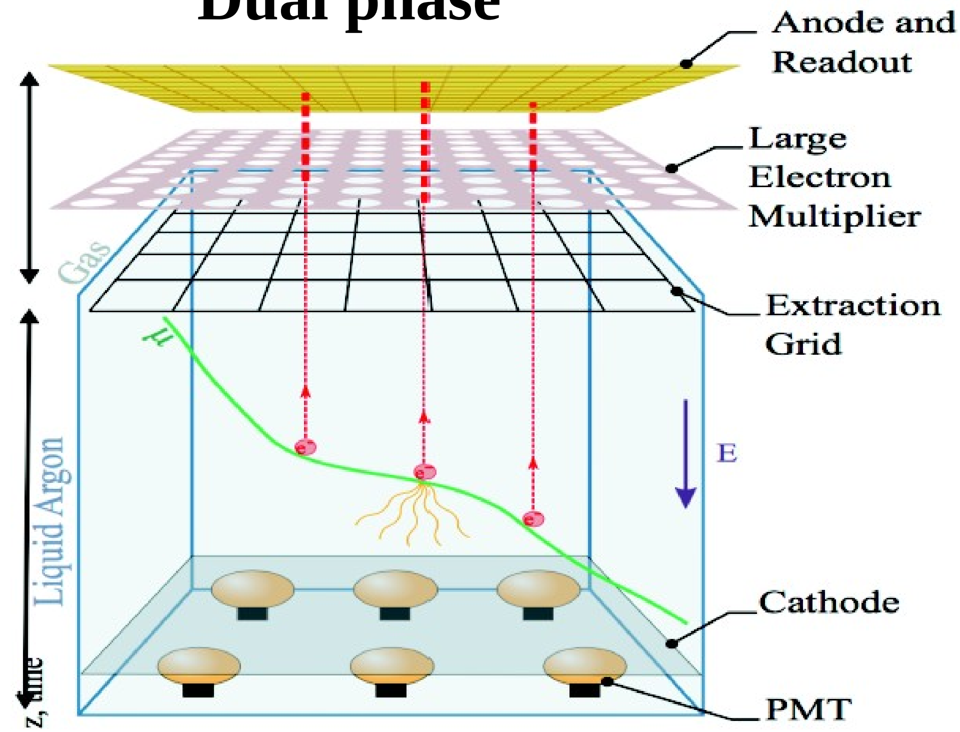


Two detector technologies

Single phase



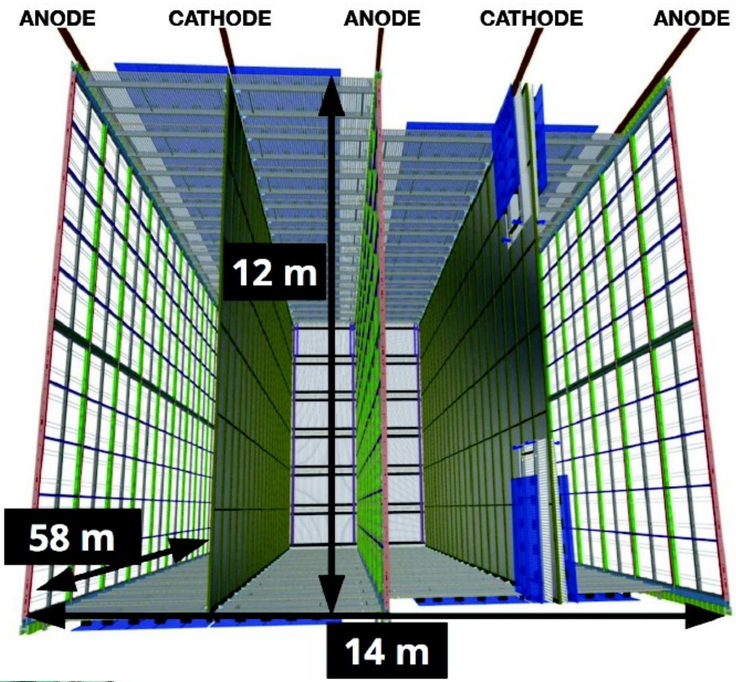
Dual phase



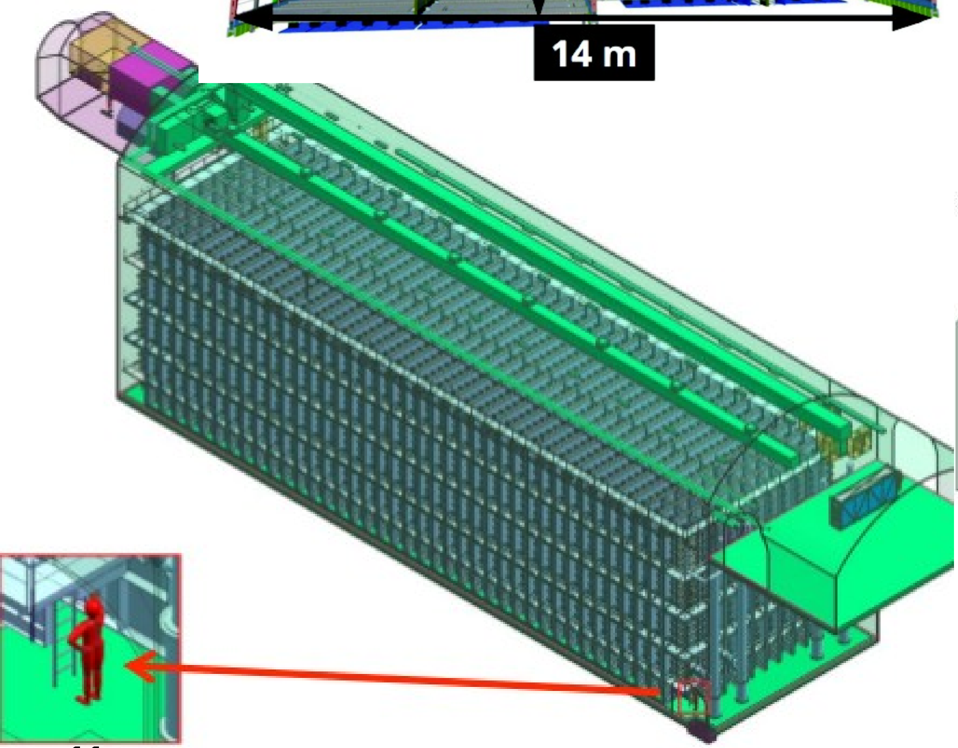
Horizontal drift, distance 3.6 m
Anode wires immersed in LAr
Vertical Anode and Cathode Plane Assemblies (APA,CPA)
1 collection, 2 induction wires at 37.7^{o}, wire pitch 5 mm
Photon detectors: light guides + SiPM,embedded in APAs

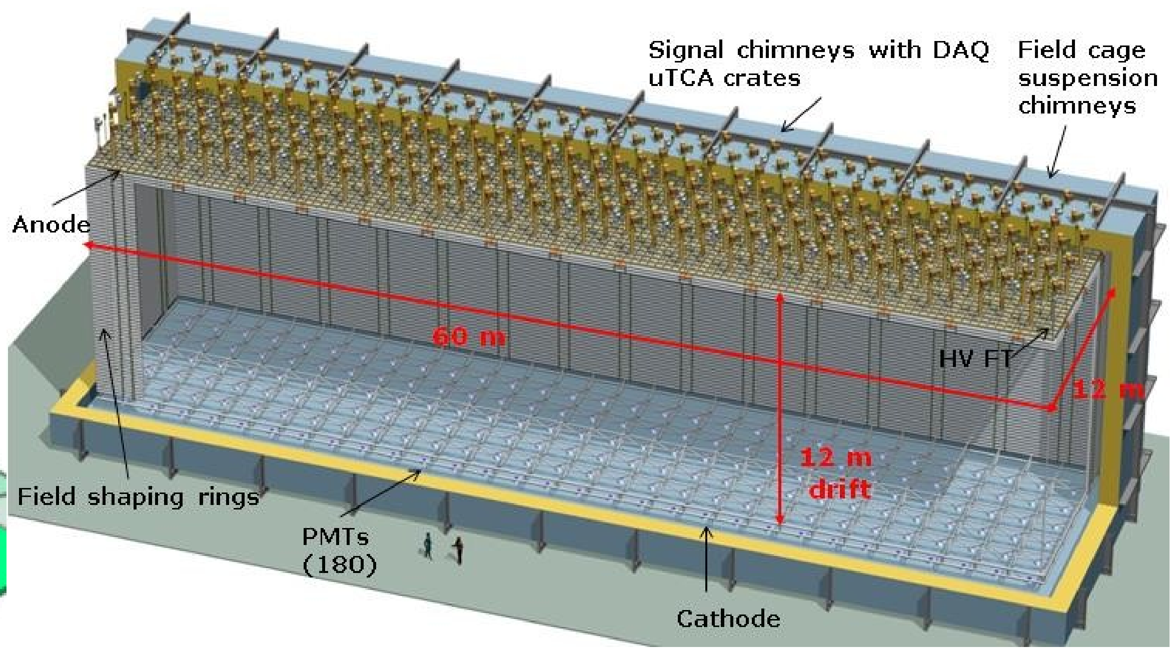
Vertical drift, distance 12 m
Ionization electrons extracted from LAr to gas
Signal amplified in GAr by Large Electron Multiplier (LEM)
Charge collected on 2 orthogonal views, 3mm pitch
Photon detectors: PMTs below the cathode

Far detector at SURF

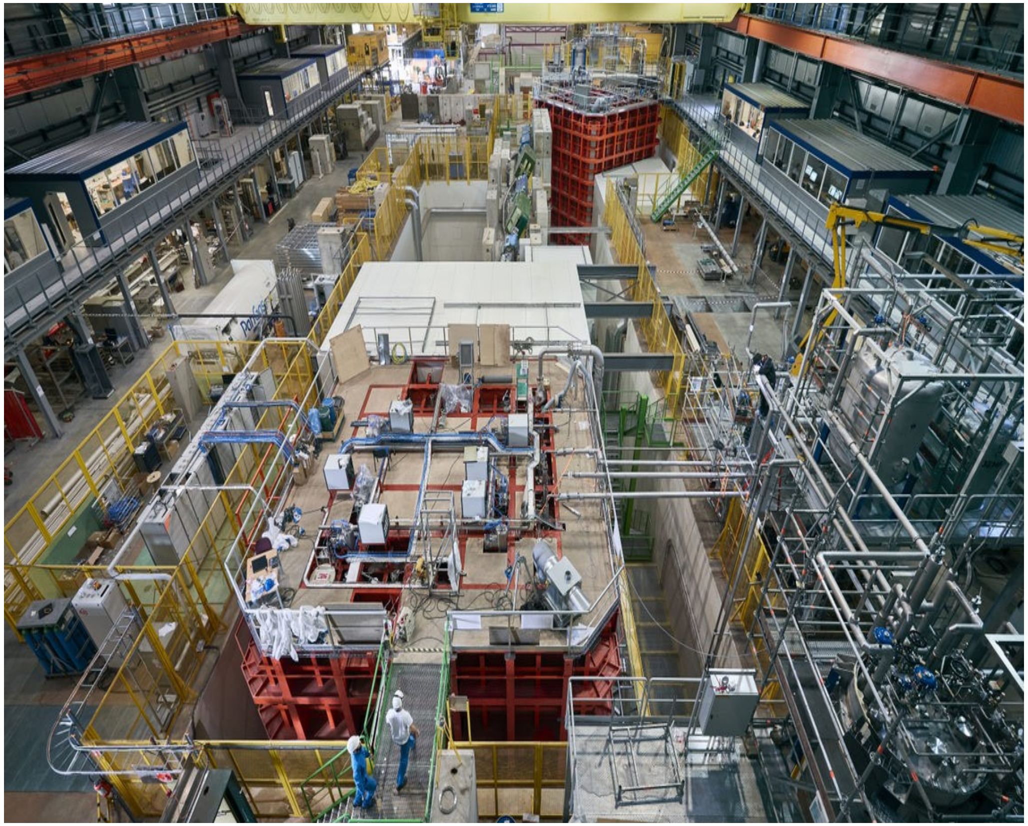


- Four 10-kt Fiducial LAr TPC modules, located 1.48 km underground
- First module is Single Phase
- DUNE Far Detector Interim Design Reports are available (arXiv:1807.10334, 1807.10327, 1807.10340)





protoDUNEs



- Necessary R&D step towards the DUNE Far Detectors
- hosted at the CERN neutrino platform
- Tests of all engineering solutions and installation procedures
- Use full-size components identical to those planned for DUNE FD
- 300t fiducial mass of LAr
- Technology demonstrators
- Demonstrate long term performance and stability
- Charged particle test beams to characterise detector response over the energy range of interest for DUNE (~0.5 GeV to 8 GeV)

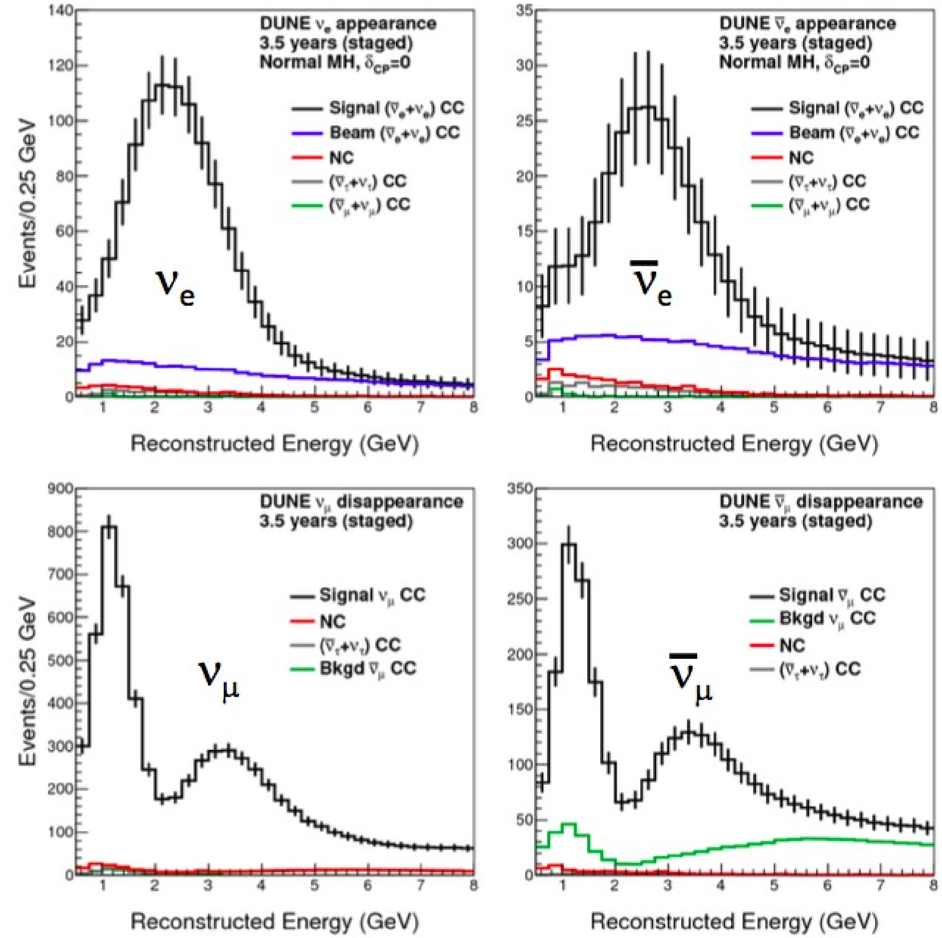
See next two talks:
Franck Filthaut – Testing the waters for the DUNE experiment
Clara Cuesta – Status of protoDUNE Dual Phase

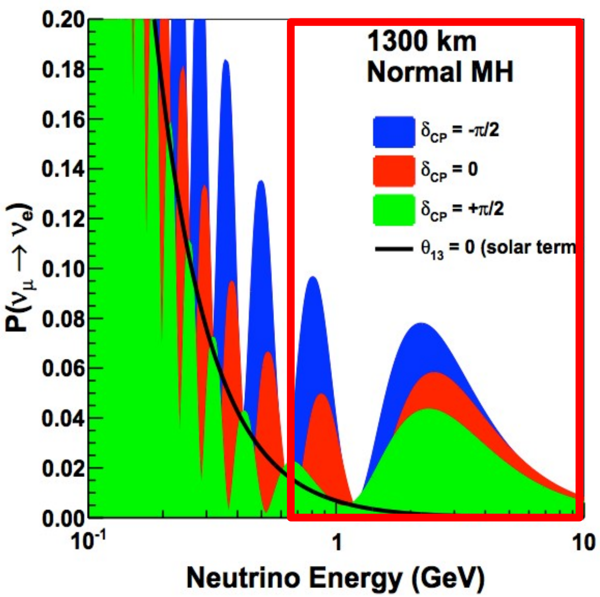
Neutrino Oscillations

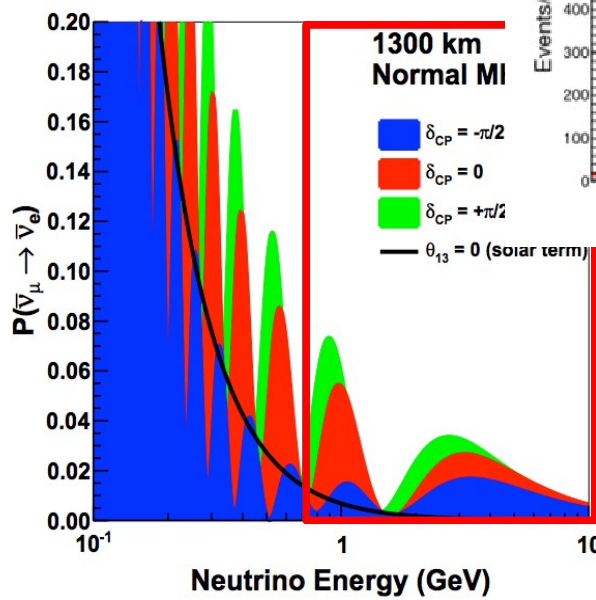
Measure appearance and disappearance for both neutrino and anti-neutrinos

disentangle Mass Ordering and CP effects

Spectral measurement - 1st and 2nd maxima



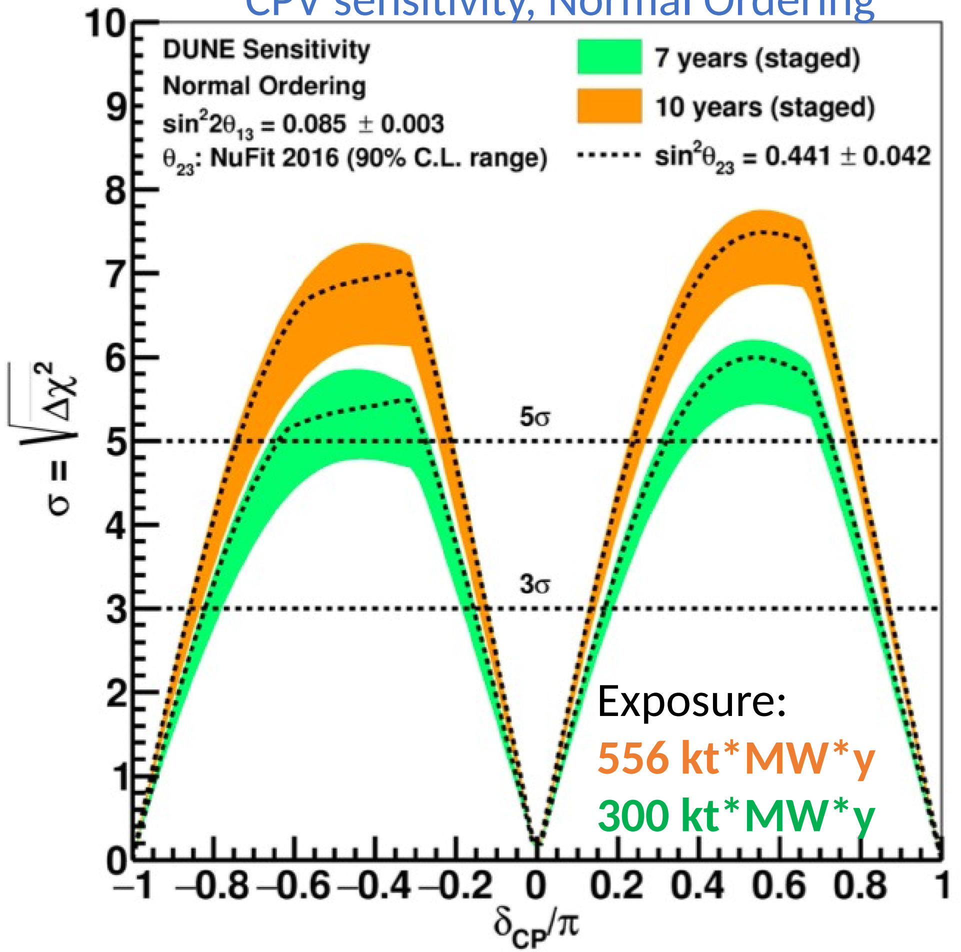




DUNE Conceptual Design Report (CDR)
arXiv:1512.06148

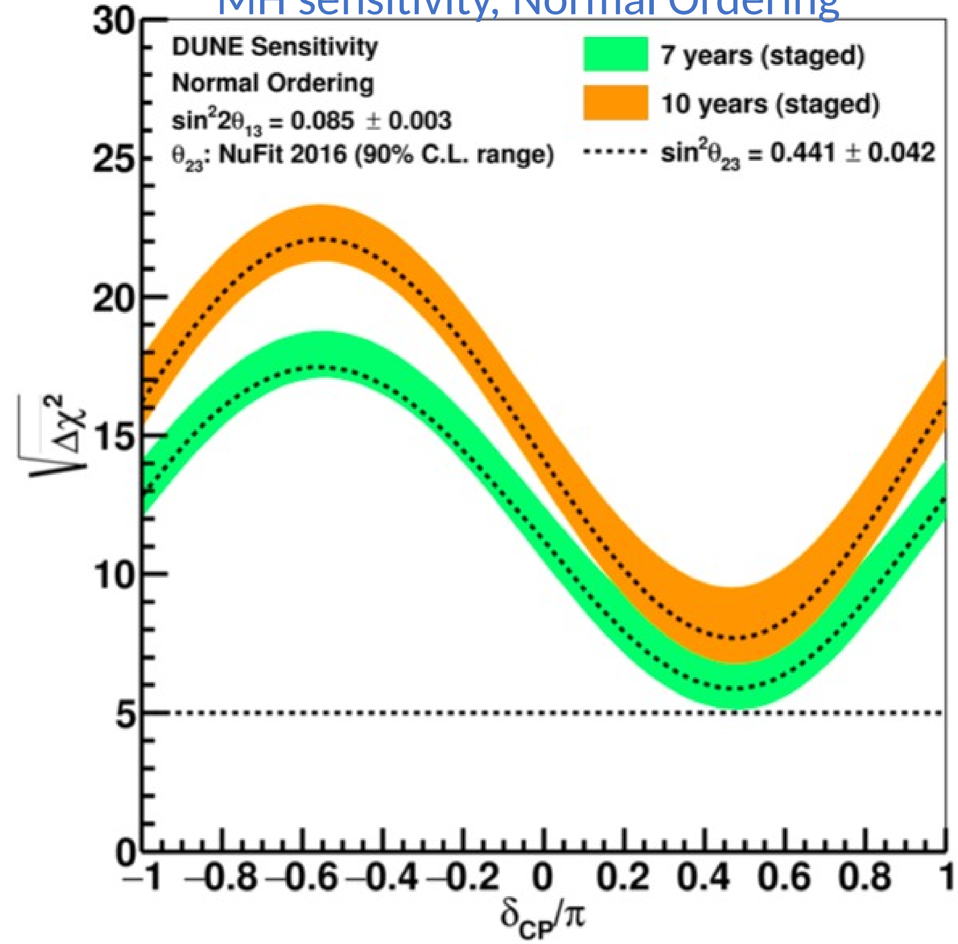
sensitivity to CPV and Mass Ordering

CPV sensitivity, Normal Ordering



DUNE Conceptual Design Report (CDR)
arXiv:1512.06148

MH sensitivity, Normal Ordering



Width of bands indicates variation in possible central values of θ_{23}

>5σ sensitivity for both orderings and the full range of δ_{CP}

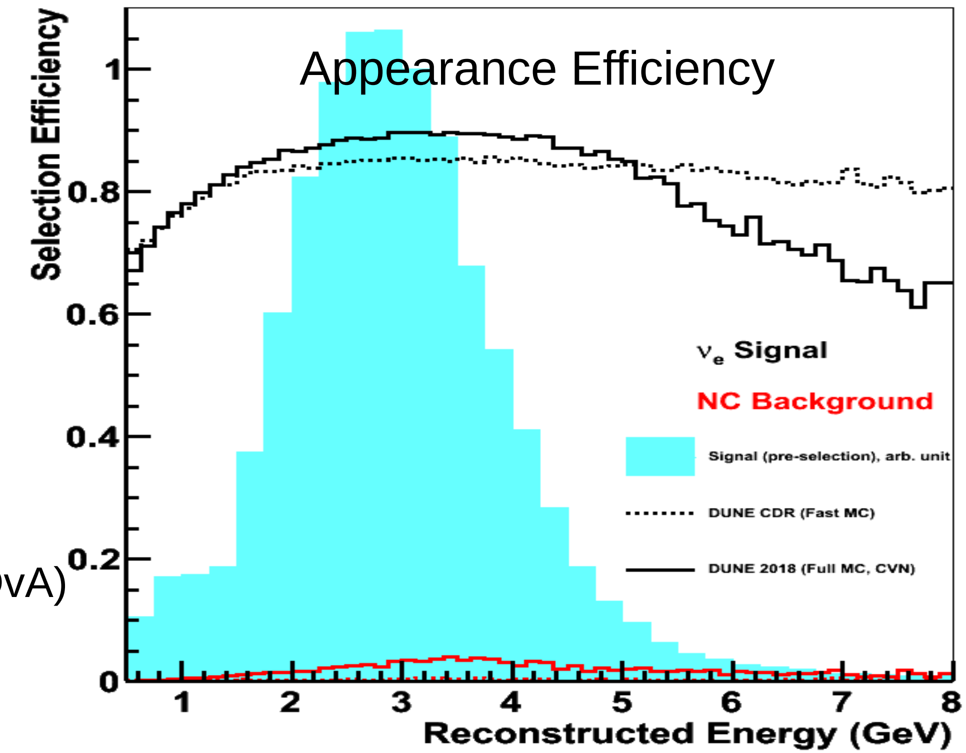
Updated analysis with full FD simulation & reconstruction, detailed systematic uncertainties, and ND, will be included in TDR (public on 2 August 2019)

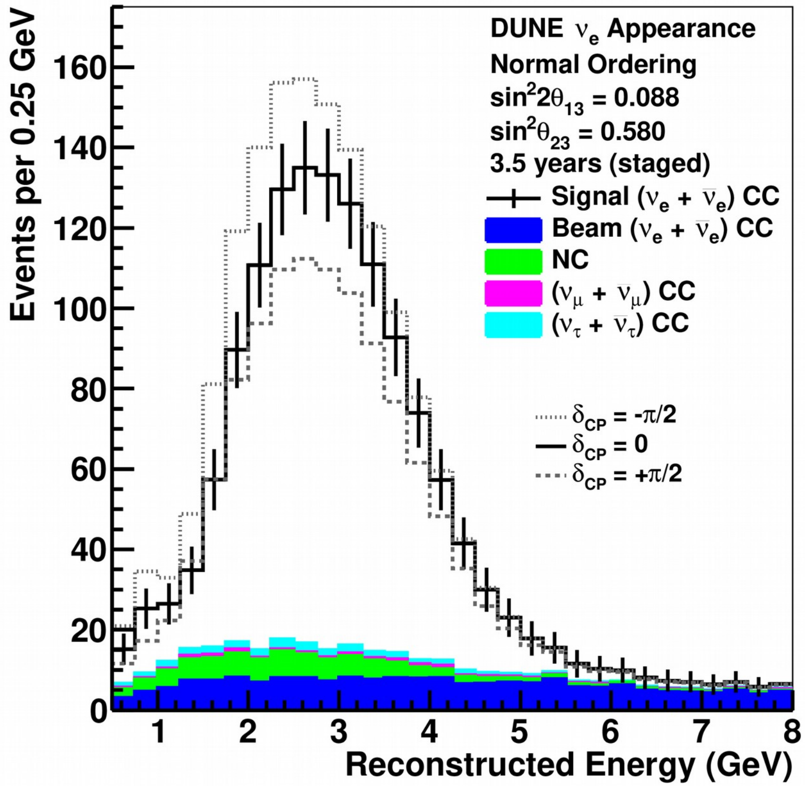
Updated Analysis - public 2 August

GEANT4 beam simulation
Full LArSoft simulation
- GENIE event generator
- GEANT4 particle propagation
- Realistic Detector ReadOut simulation

Energy Reconstruction
- Muons - either from range (contained) or
  - Multiple Coulomb Scattering method (uncontained)
- Electron and hadron energy from calorimetry

Event Selection using Convolutional Visual Network
Oscillation analysis (CAFAna - shared framework with NOvA)



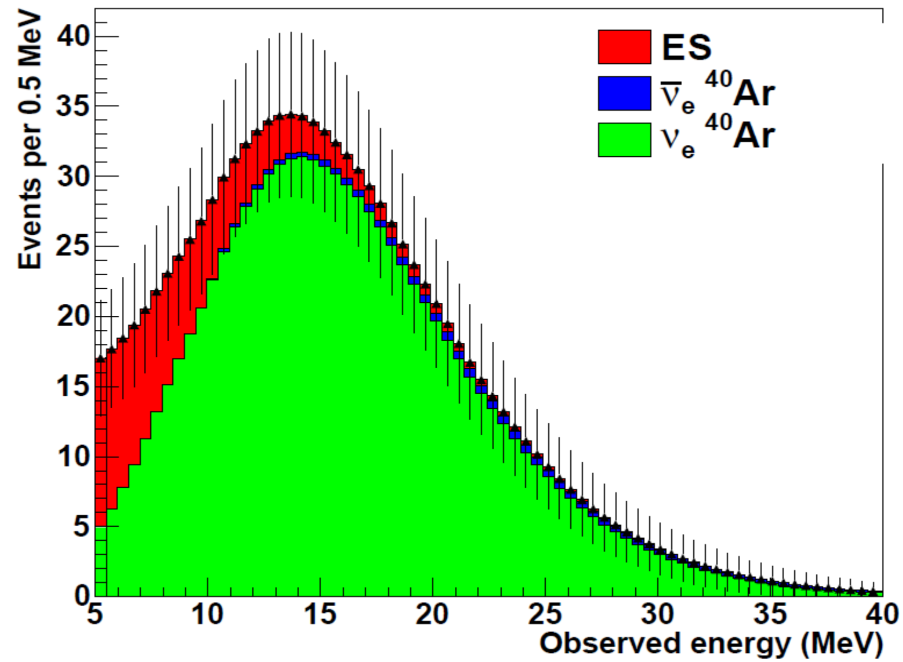


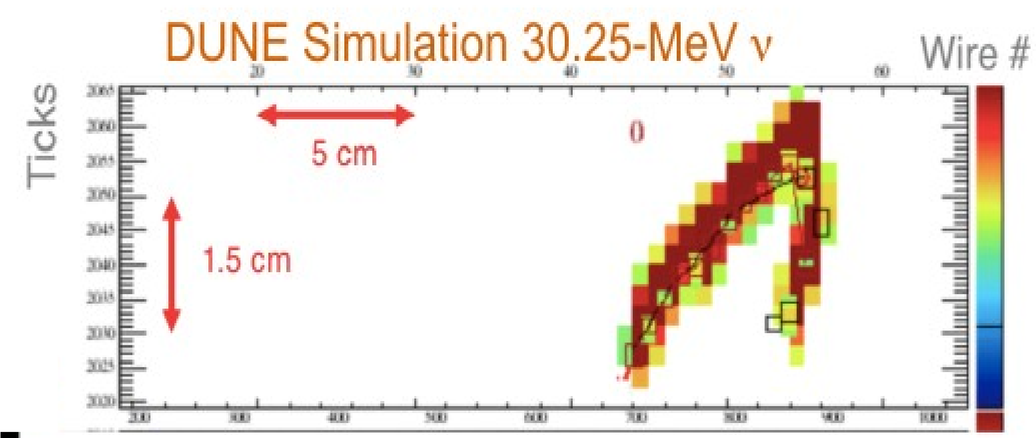
non-beam physics: SuperNova burst

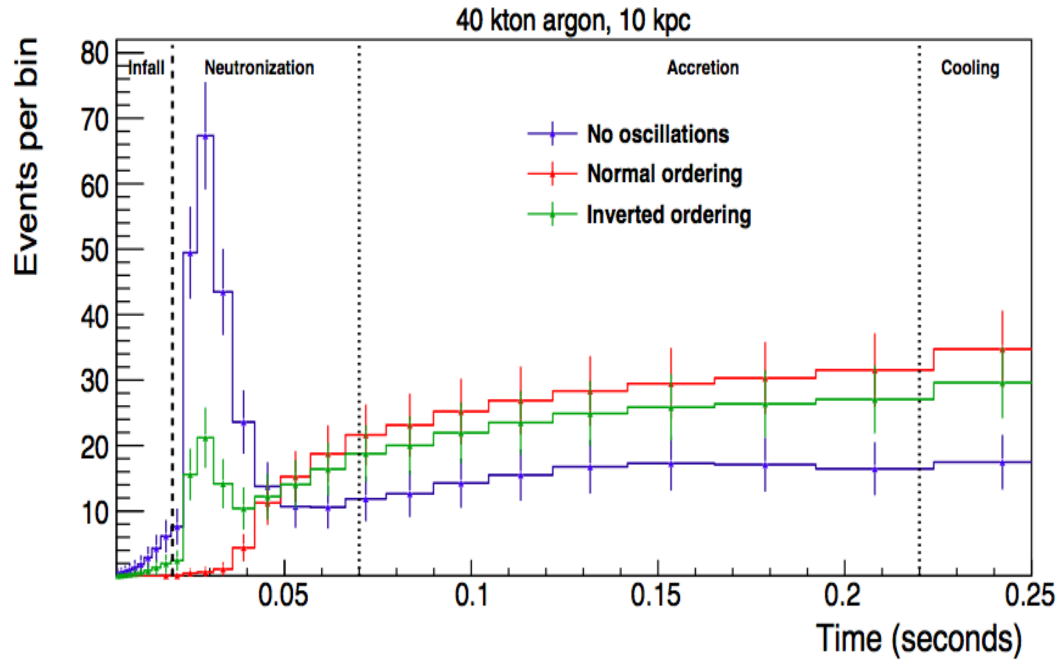
Uniquely DUNE is sensitive to ve
ve + ^{40}Ar $\rightarrow$ e^{-} + ^{40}K*

5-20 MeV signals: efficient triggering + continuous data collection

Monte Carlo studies ongoing with Marley generator and full simulation

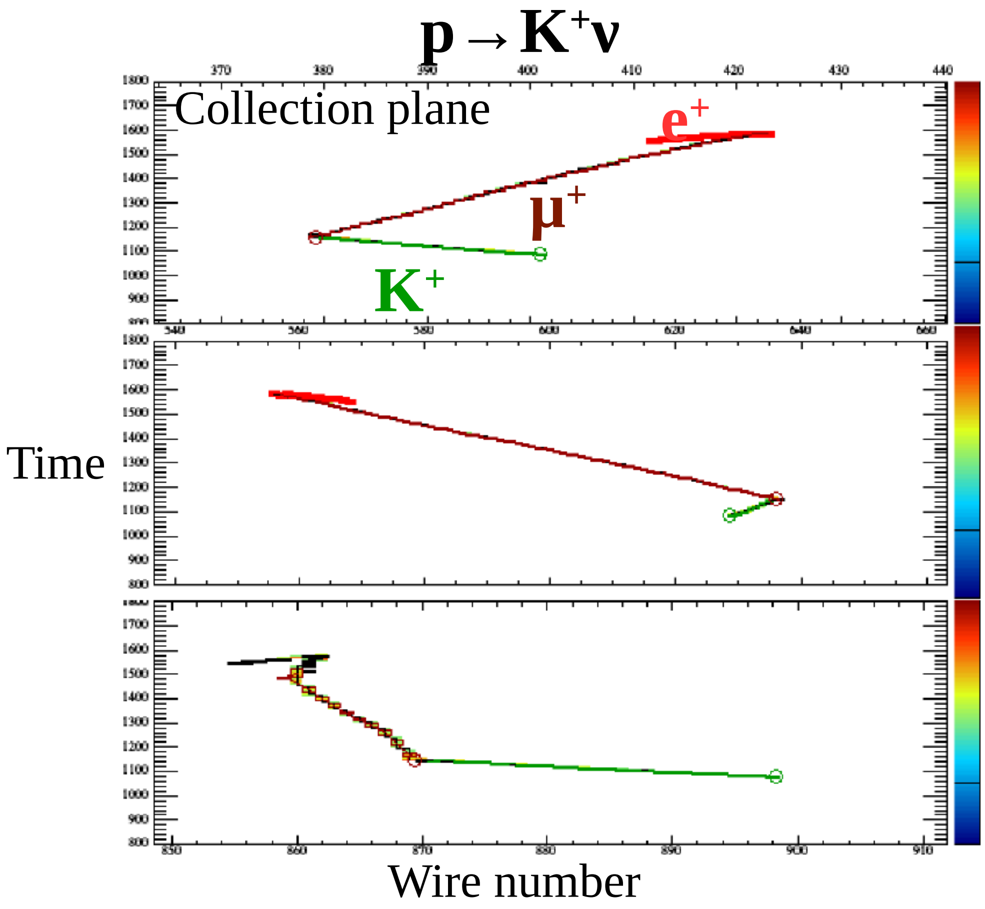






Nucleon decay

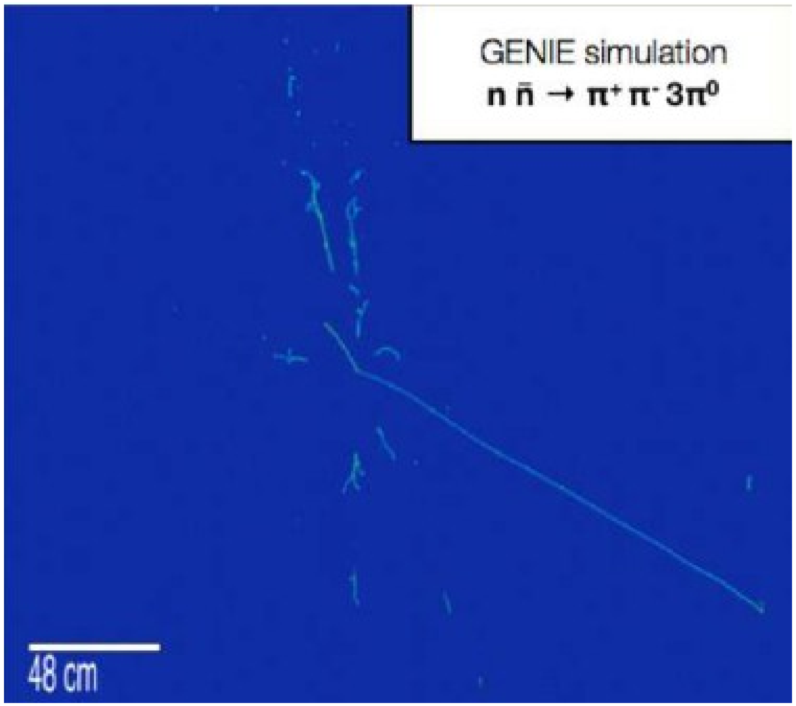
- DUNE sensitive to:
  - $p \rightarrow K^{+} \nu$
- and other channels:
  - $n \rightarrow K^{+} e^{-}$
  - $p \rightarrow l^{+} K^{0}$
  - $p \rightarrow \pi^{0} e^{+}$

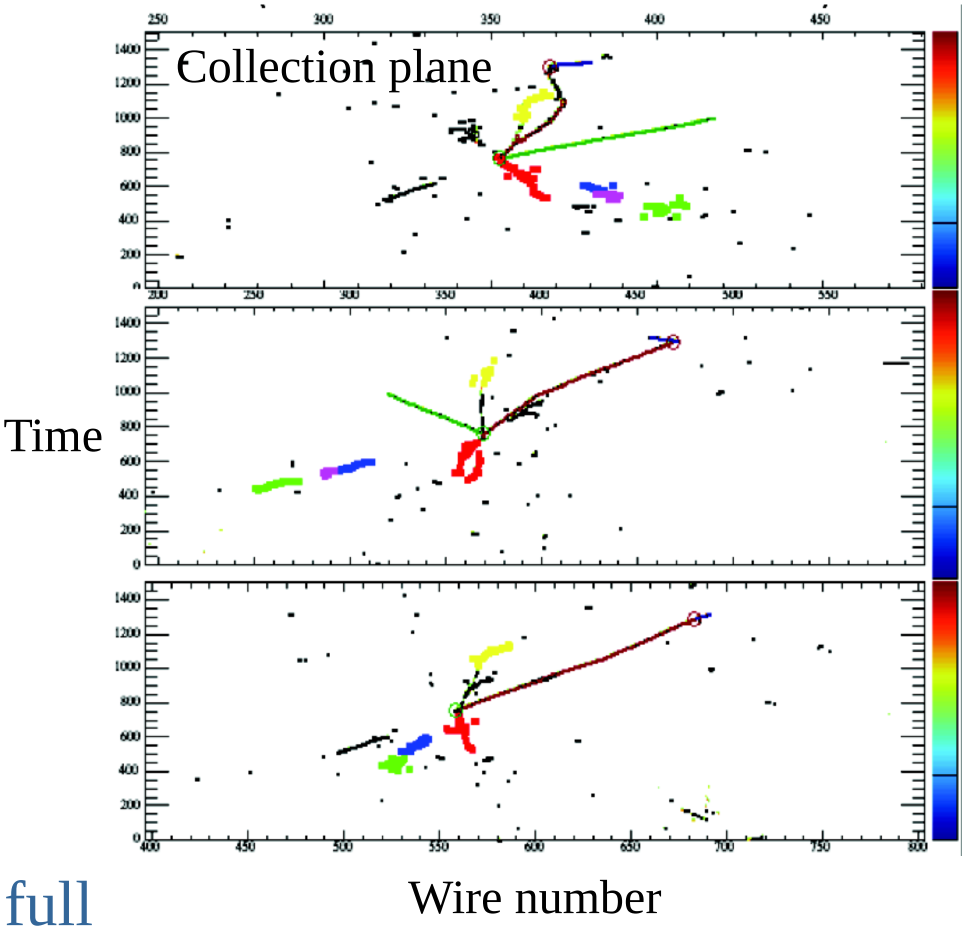


upcoming TDR contains analyses with full simulation & reconstruction

neutron-antineutron oscillations

Baryon number violating BSM process
Signature is a ‘star’ of charged and neutral pions





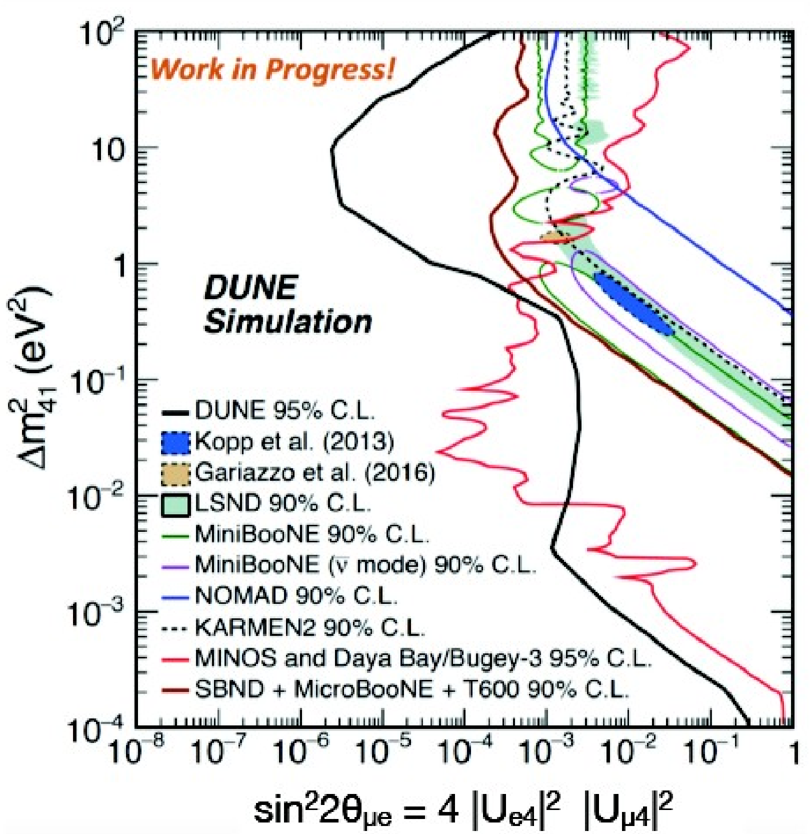
upcoming TDR contains analyses with full simulation & reconstruction

and other BSM physics

New particles:
- light dark matter, boosted dark matter, heavy neutral leptons

Deviations from PNMS ν mixing paradigm:
- non-standard ν interactions,
- non-unitarity, CPT or Lorentz violation,
- large extra dimensions,
- ν-trident production

Sterile neutrino searches
(ν_e appearance at ND)



Summary

- DUNE will measure neutrino and anti-neutrino oscillations over a 1300 km baseline with gigantic (4x10kt fiducial) LAr TPCs
- Large underground detectors will provide other interesting physics (Nucleon decay, neutron-antineutron oscillations, SN etc)
- Large-scale detector prototypes, ProtoDUNE, are being tested at CERN
- DUNE TDR will be public August 2nd 2019
- First detector ready in 2024, physics with beam from 2026

2018 protoDUNE SP at CERN

2019 TDR

2019 protoDUNE DP at CERN

2019 Main Cavern Excavation

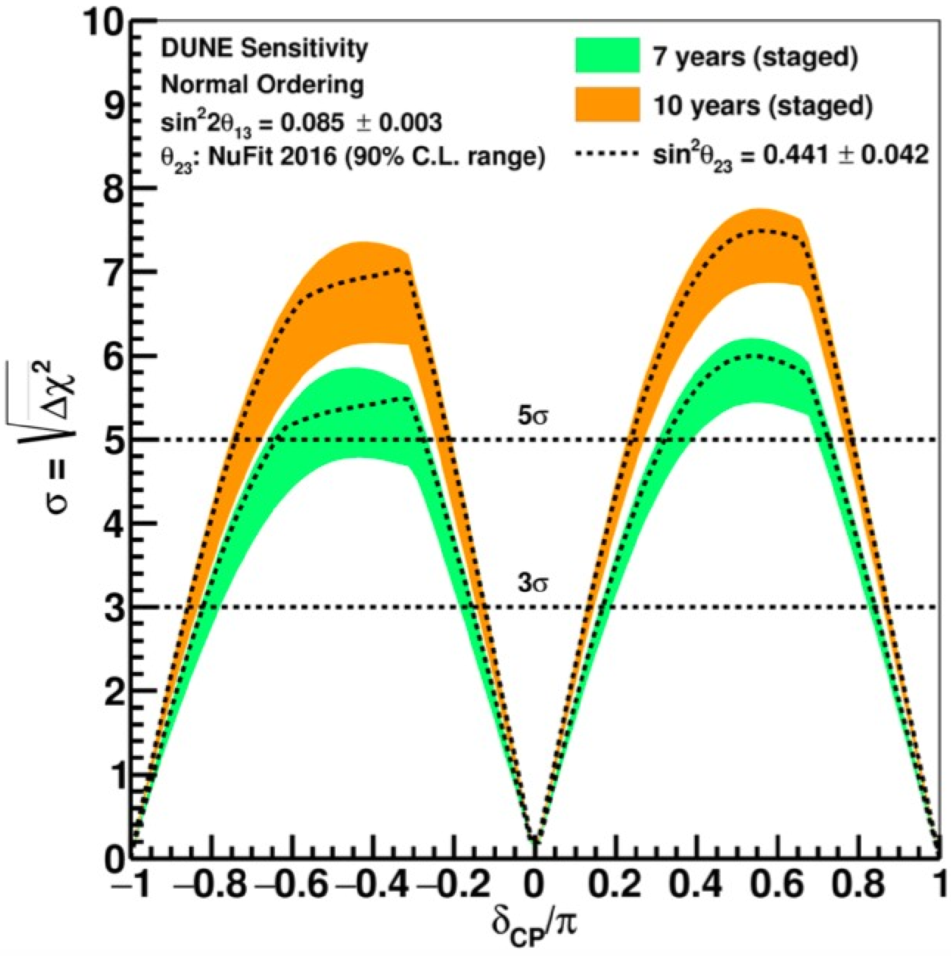
2022 Start FD Construction

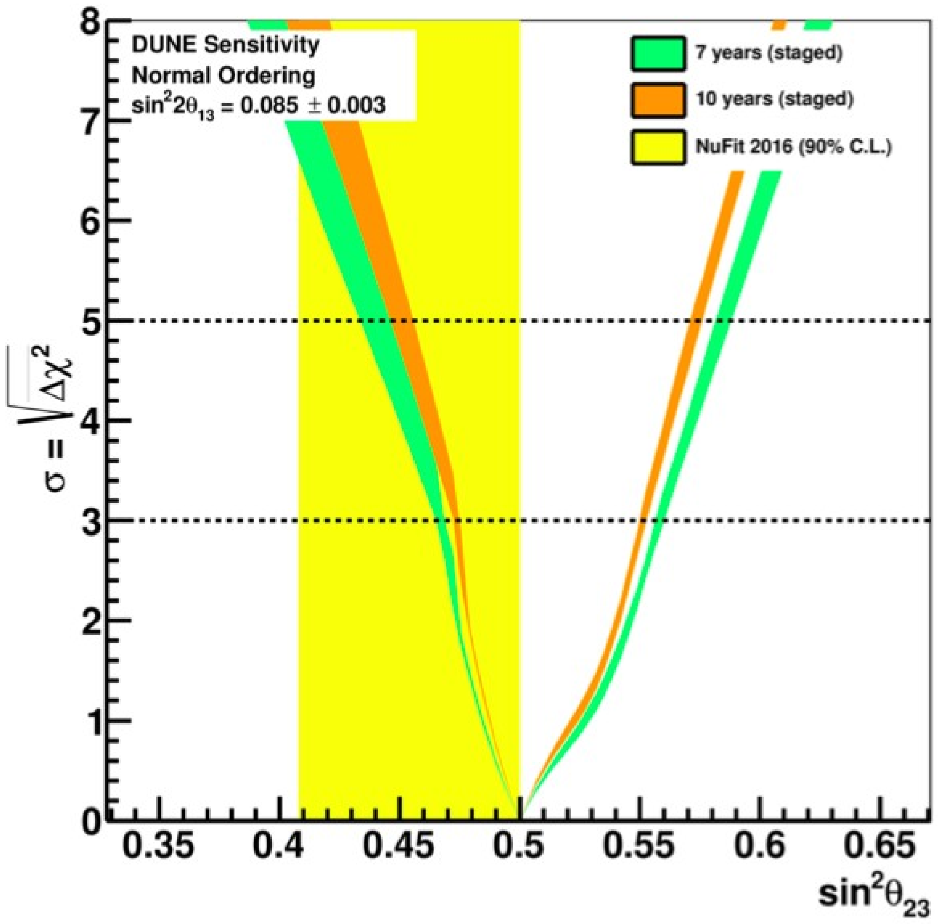
2024 1st FD Operational

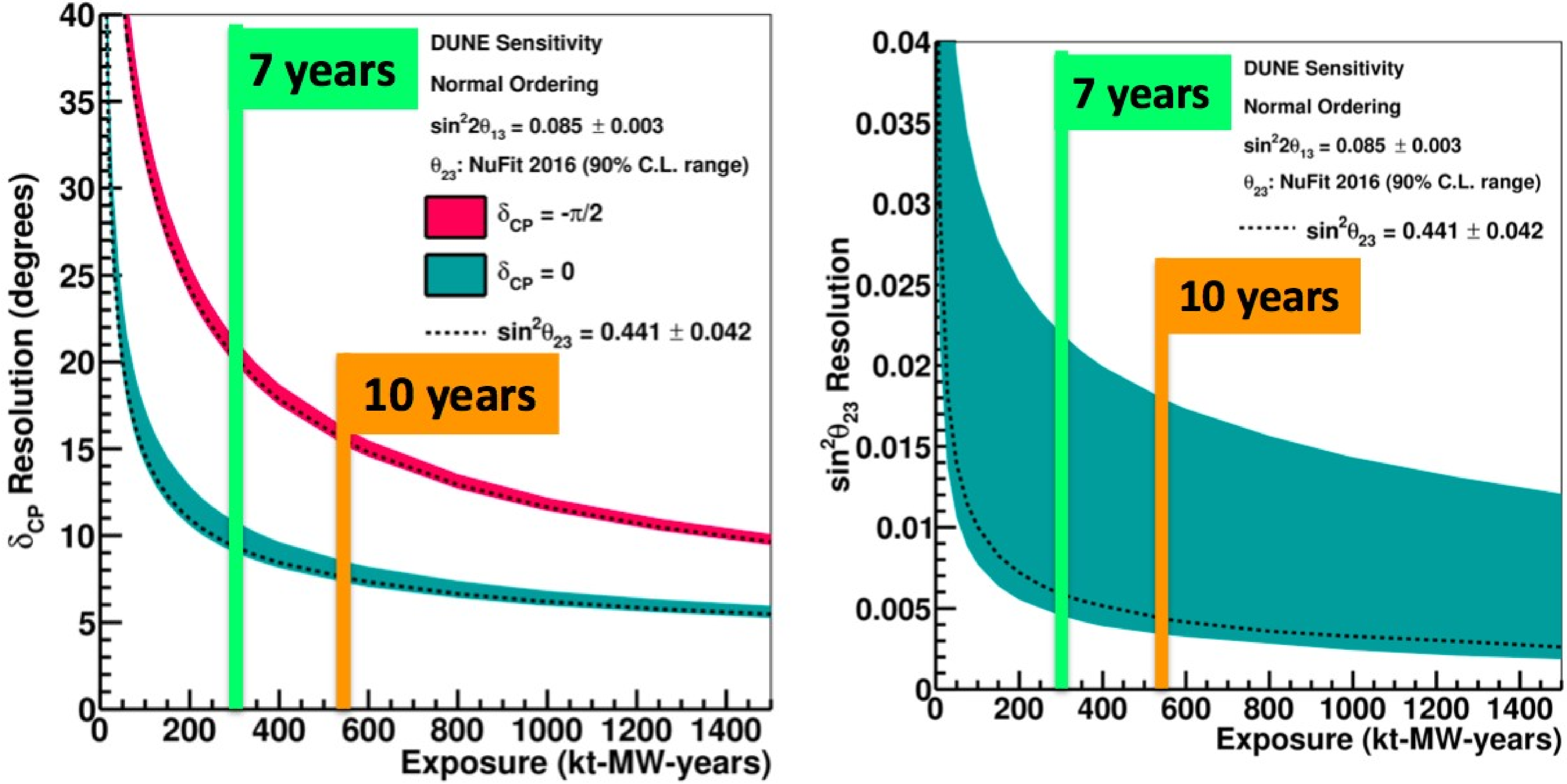
2026 Beam Arrives

Backups

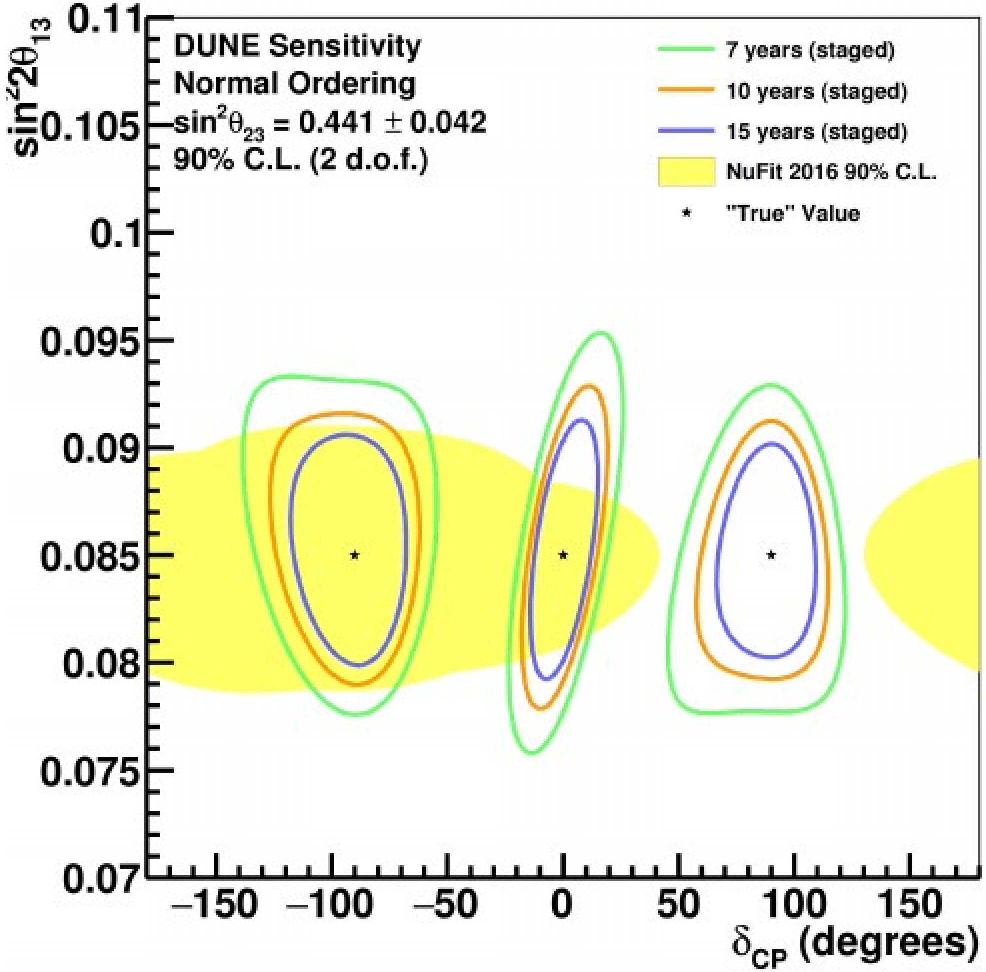
CP violation and theta_23

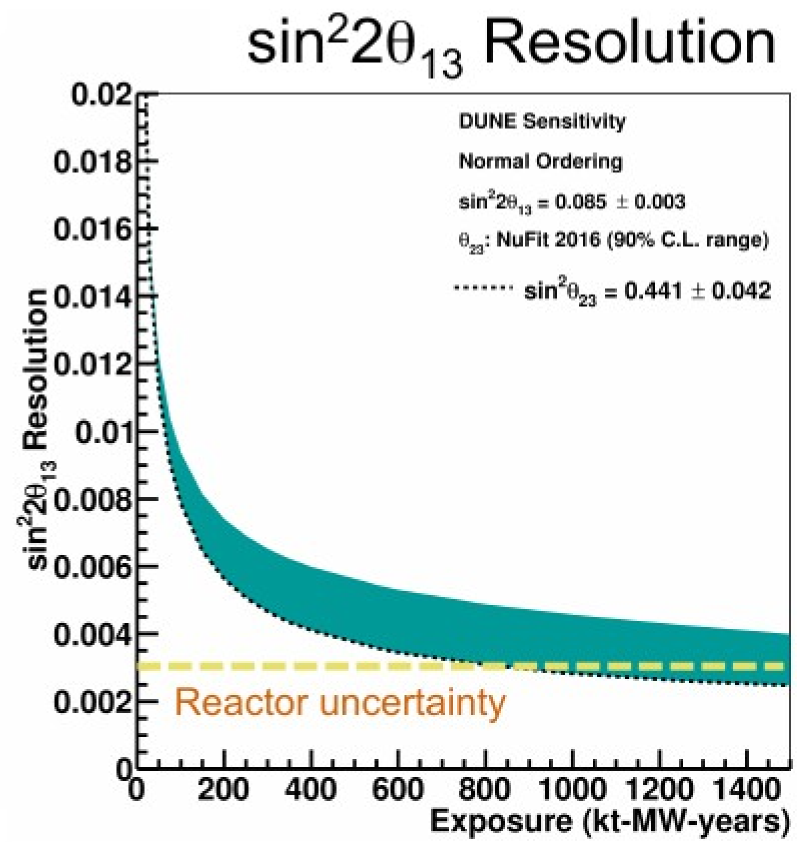






DUNE Sensitivity
Normal Ordering
$\sin^2 2\theta_{13} = 0.085 \pm 0.003$
θ_{23}: NuFit 2016 (90% C.L. range)
$\delta_{CP} = -\pi/2$
$\delta_{CP} = 0$
$\sin^2\theta_{23} = 0.441 \pm 0.042$
7 years
10 years
δ_{CP} Resolution (degrees)
Exposure (kt-MW-years)
DUNE Sensitivity
Normal Ordering
$\sin^2 2\theta_{13} = 0.085 \pm 0.003$
θ_{23}: NuFit 2016 (90% C.L. range)
$\sin^2\theta_{23} = 0.441 \pm 0.042$
7 years
10 years
$\sin^2\theta_{23}$ Resolution
Exposure (kt-MW-years)





Simultaneous measurement of neutrino mixing angles and δ_{CP}

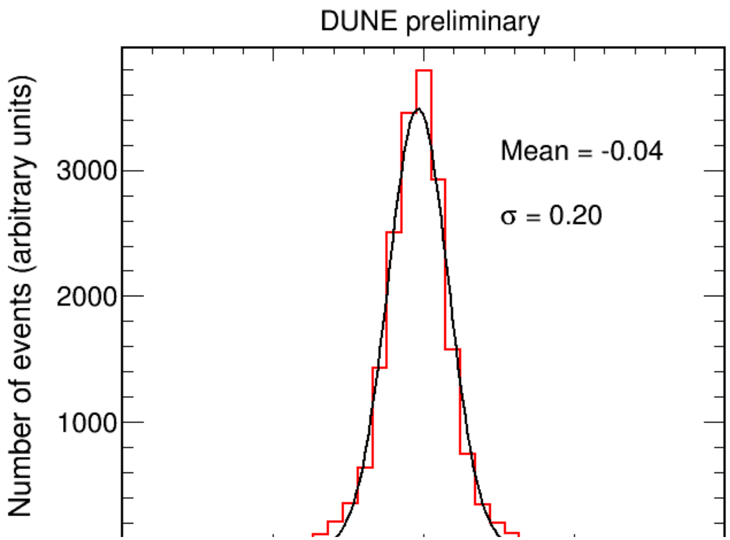
Systematic Uncertainties (CDR/IDR)

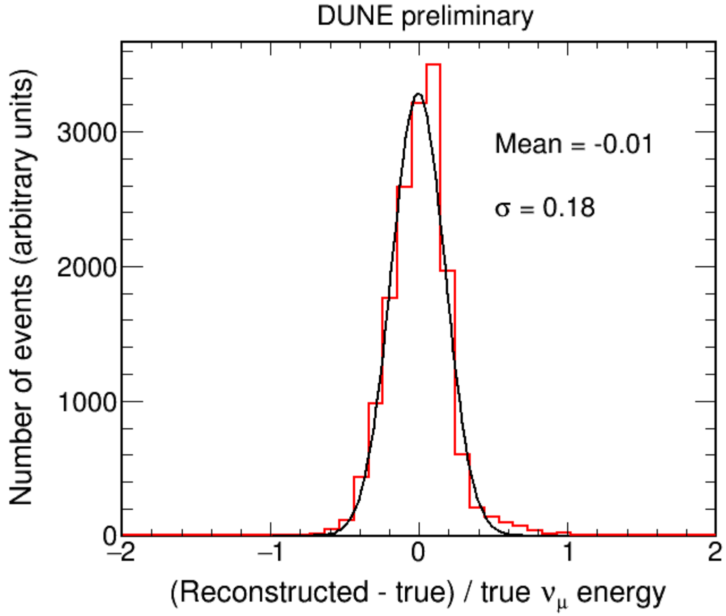
Source of Uncertainty	MINOS ν_e	T2K ν_e	DUNE ν_e
Beam Flux after N/F extrapolation	0.3%	3.2%	2%
Interaction Model	2.7%	5.3%	$\sim 2\%$
Energy scale (ν_μ)	3.5%	included above	(2%)
Energy scale (ν_e)	2.7%	2.5% includes all FD effects	2%
Fiducial volume	2.4%	1%	1%
Total	5.7%	6.8%	3.6 %
Used in DUNE Sensitivity Calculations			$5\% \oplus 2\%$

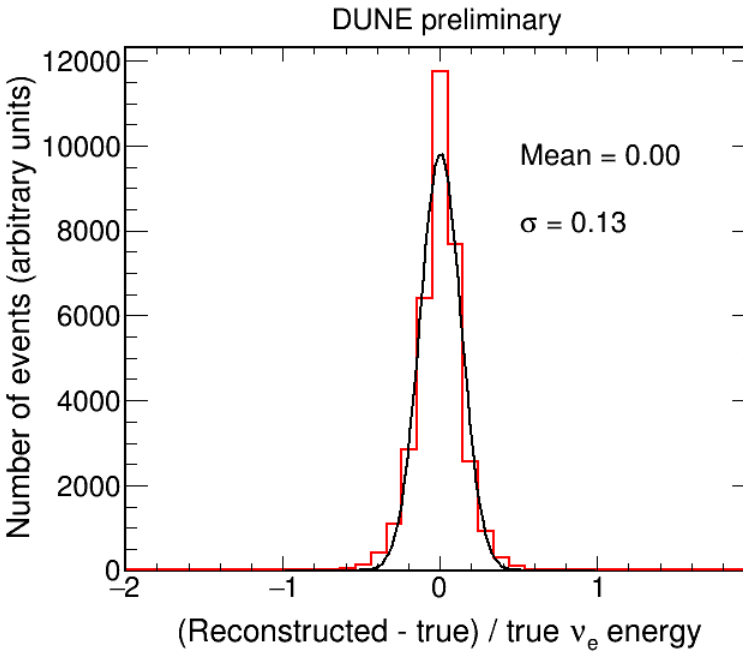
DUNE Conceptual Design Report (CDR)
arXiv:1512.06148

DUNE Conceptual Design Report (CDR) arXiv:1512.06148, the DUNE signal normalization uncertainty is taken to Be 5% ⊕ 2% in both neutrino and antineutrino mode, where 5% is the normalization uncertainty on the FD ν_μ sample and 2% is the effective uncorrelated uncertainty on the FD ν_e sample after fits to both near and far detector data and all external constraints

Neutrino energy resolution

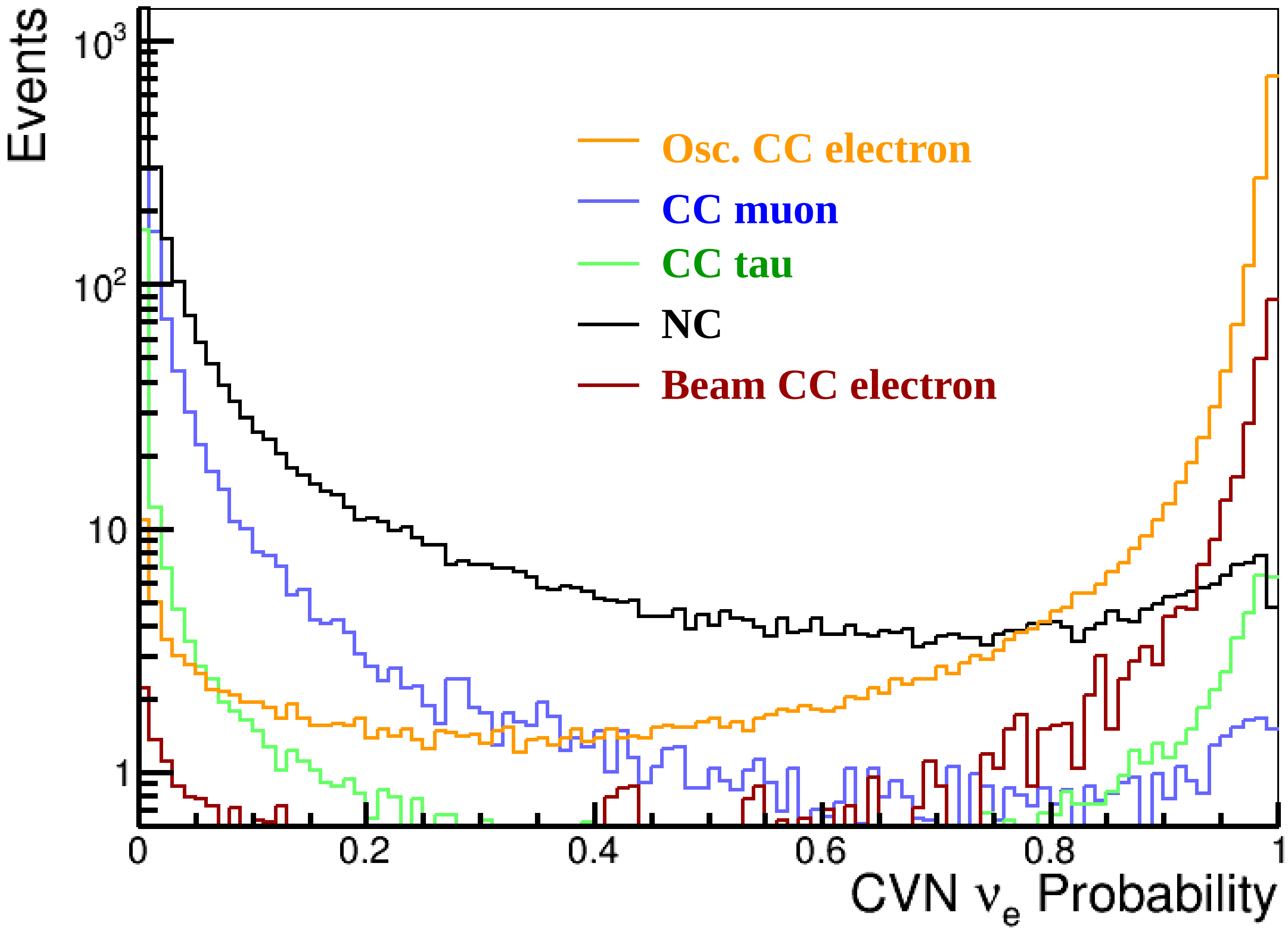






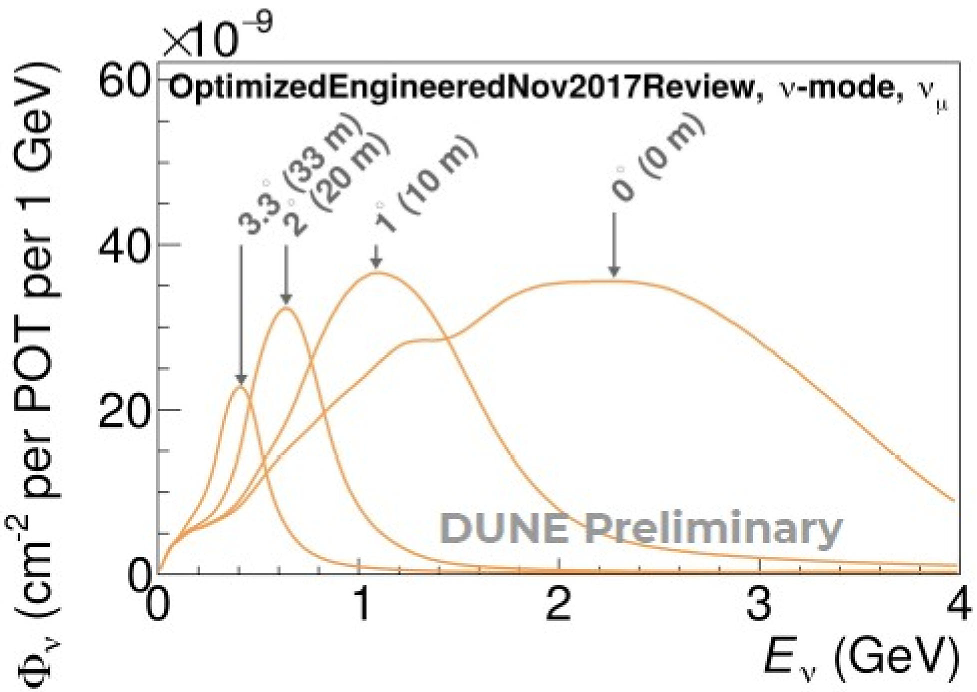
- Muons ~ 18% for contained tracks, 20% for exiting
- Electrons ~ 13%

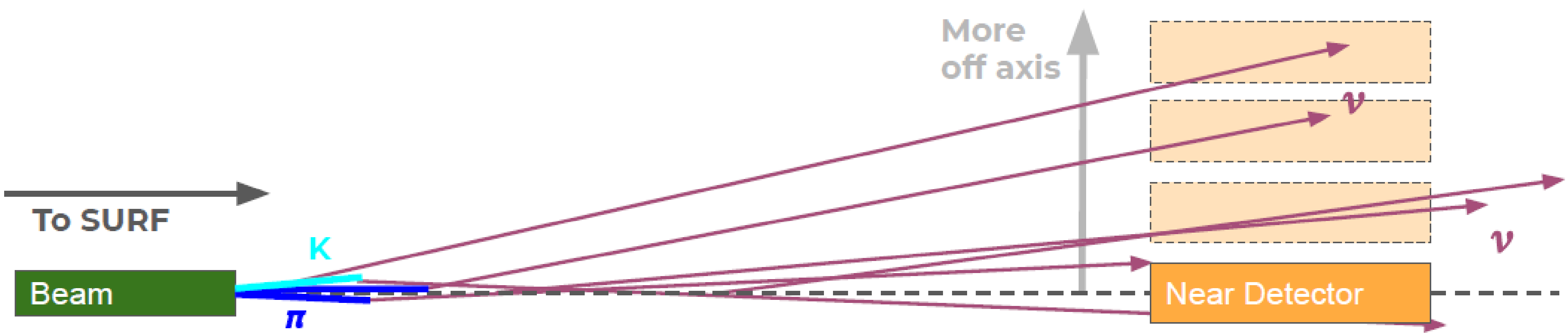
ν_e charged-current selection



- Selects both oscillated and intrinsic ν_e
- Backgrounds include $\pi^0 \rightarrow \gamma\gamma$, $\tau \rightarrow e$

DUNE-PRISM: off-axis ND





Far detector spectra, with cross section predictions vs. energy