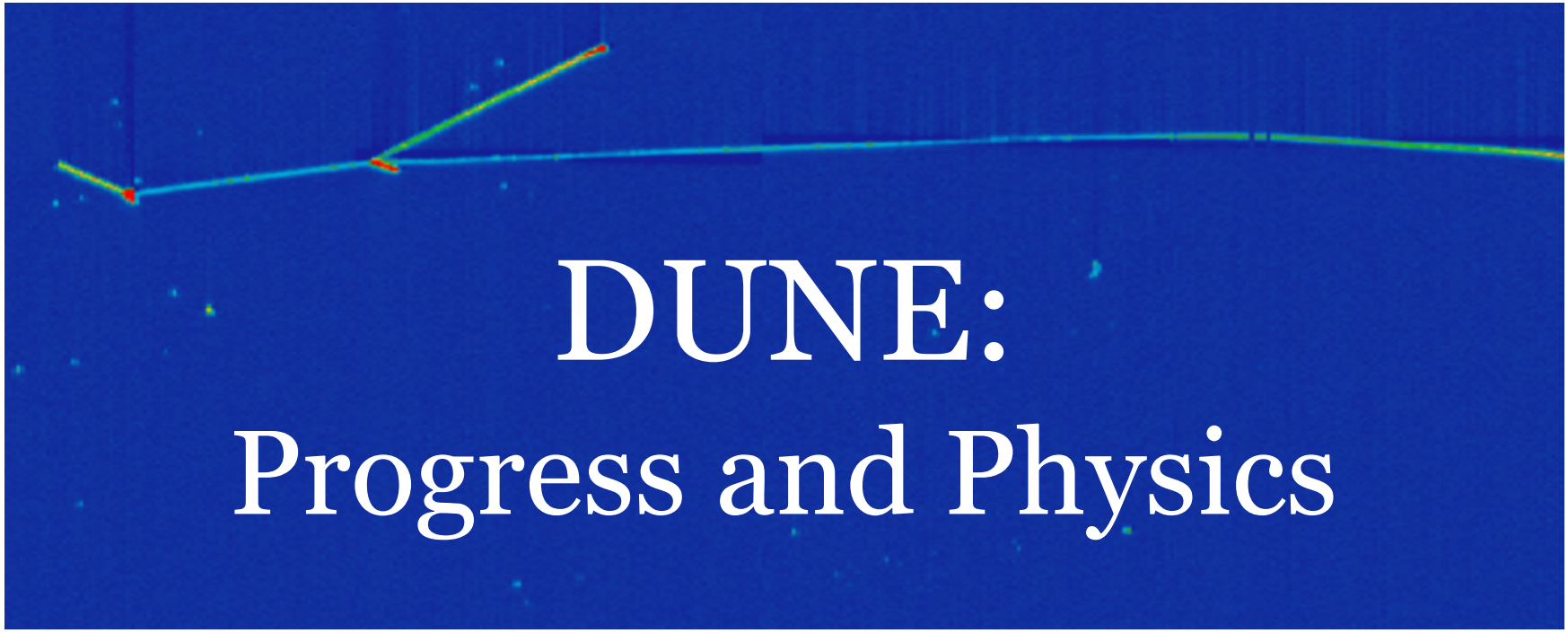


DUNE: Progress and Physics

Michael Mooney (Colorado State University)

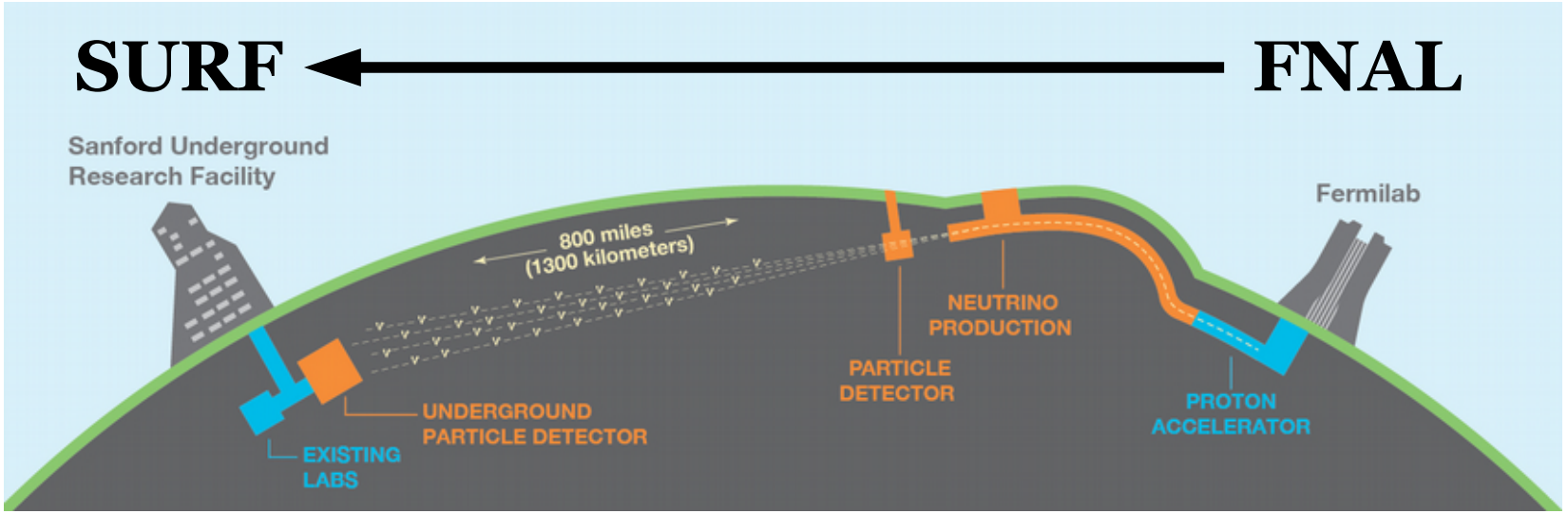
On behalf of the DUNE Collaboration

XXIX International Conference on Neutrino Physics and Astrophysics

June 29th, 2020

Introducing DUNE

- "Deep Underground Neutrino Experiment"
  - 1300 km baseline
  - Large (70 kt) LArTPC **far detector** 1.5 km underground
  - **Near detector** w/ LAr component
- Primary physics goals:
  - ν oscillations ($\nu_\mu/\bar{\nu}_\mu$ disappearance, $\nu_e/\bar{\nu}_e$ appearance)
    - $\boldsymbol{\delta_{CP}}$, θ_{23}, θ_{13}
    - **Ordering of ν masses**
  - Supernova burst neutrinos
  - BSM processes (baryon number violation, NSI, etc.)



DUNE Collaboration

- **1157 collaborators** from 197 institutions in 33 countries (w/ CERN)!

May 2019 Collaboration Meeting

DUNE Collaboration

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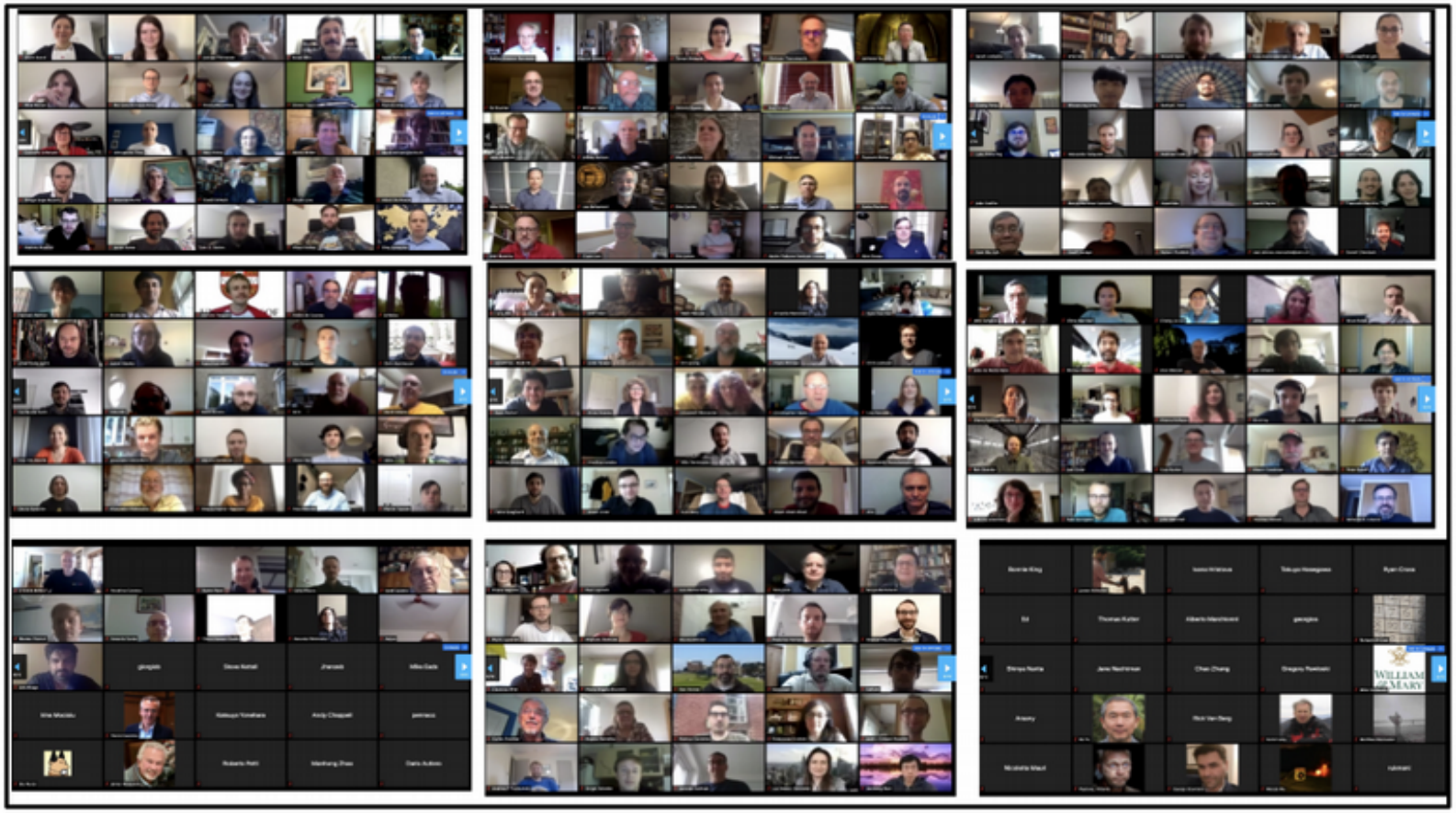


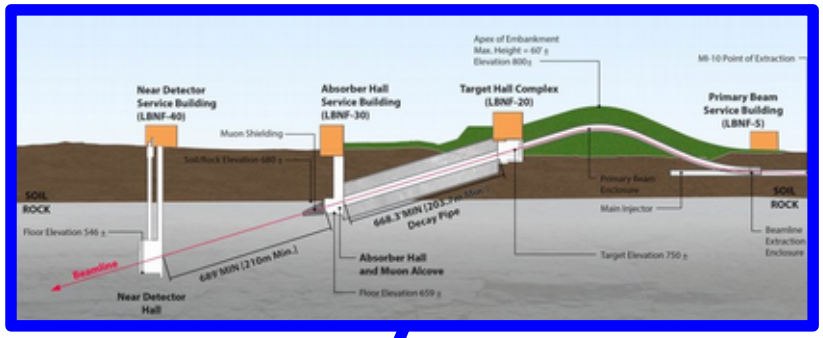
May 2020 Collaboration Photo

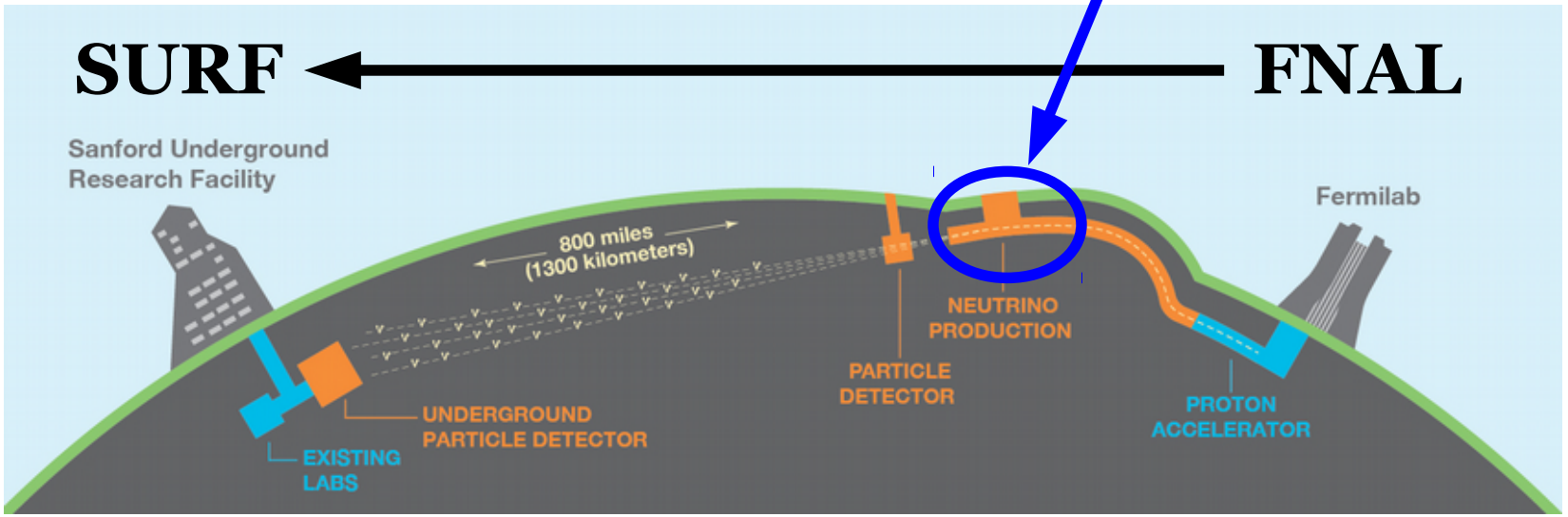
Beam and Detectors

DUNE's Neutrino Source

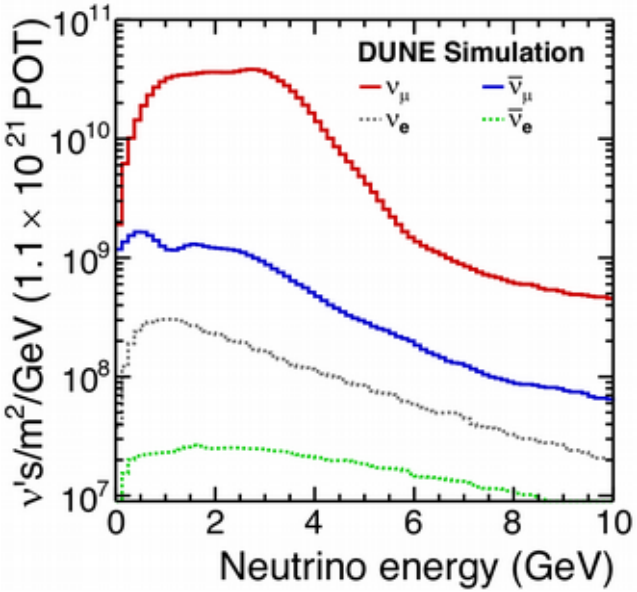
DUNE's Neutrino Source:

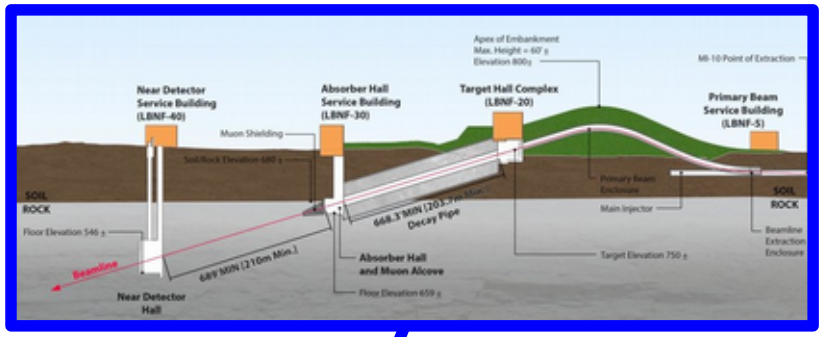
LBNF Beam

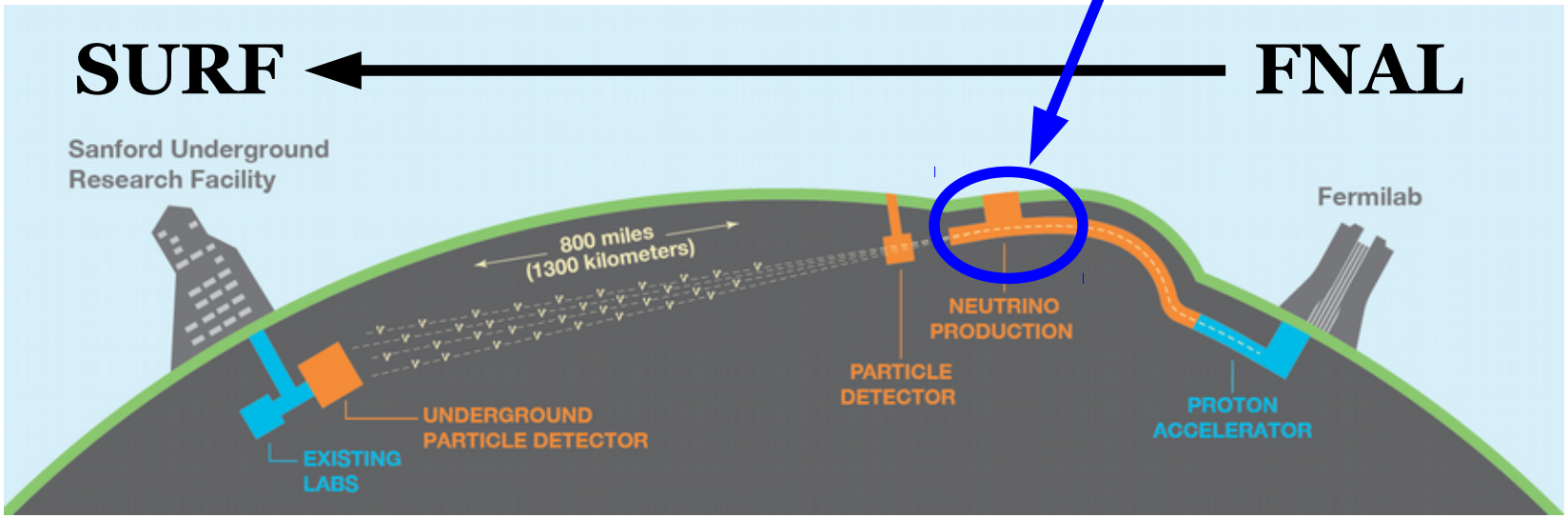




DUNE's Neutrino Source

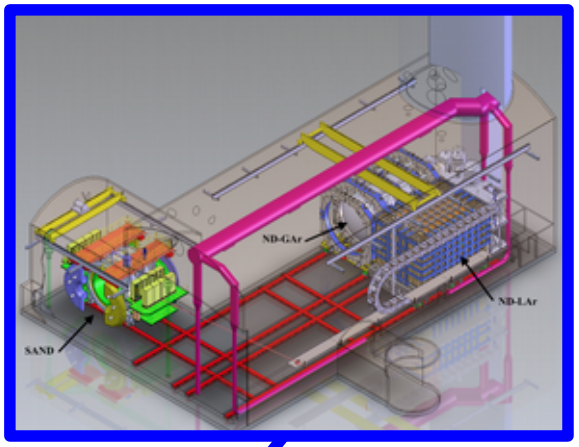


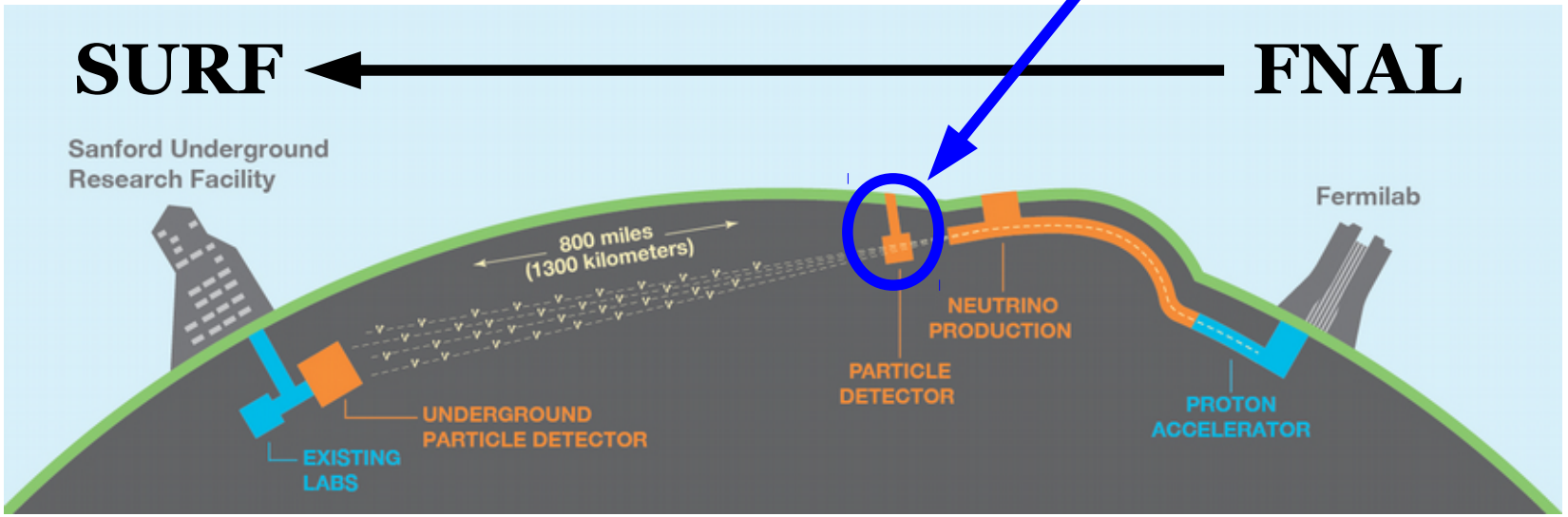




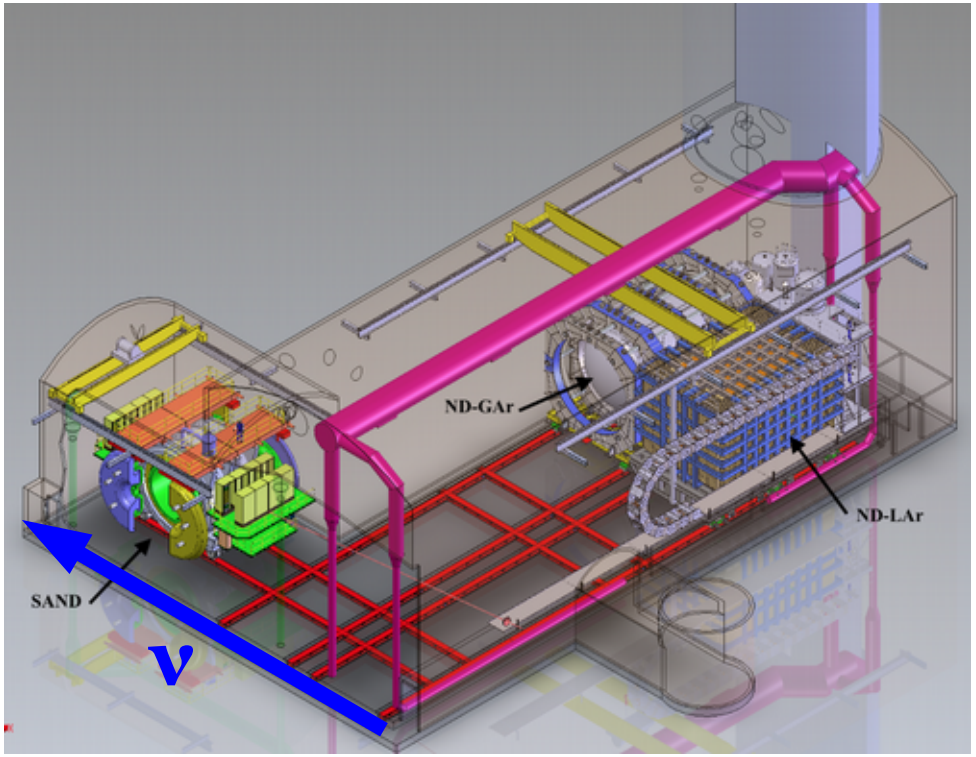
DUNE Near Detector (ND)

The DUNE Near Detector



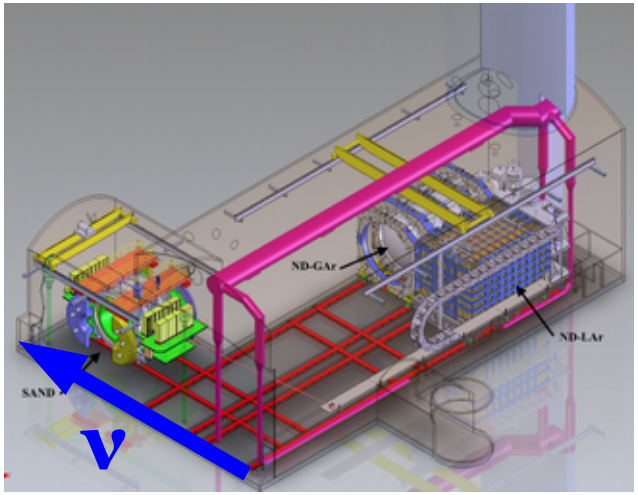


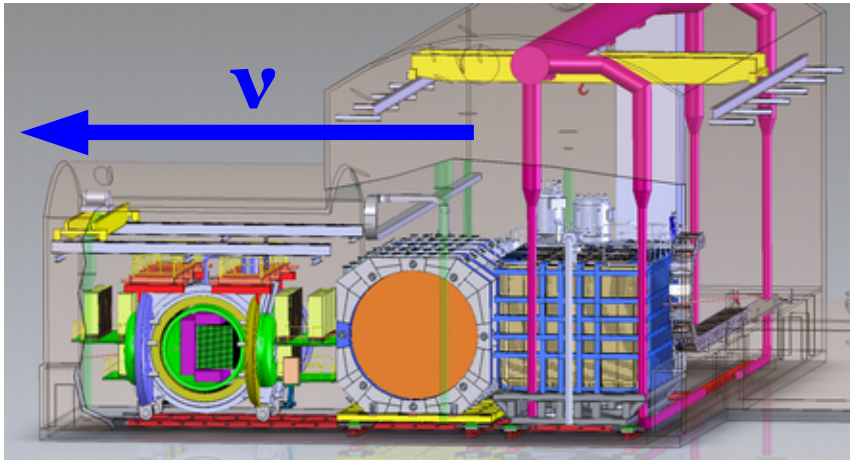
DUNE ND Overview



- DUNE ND located 574 m from neutrino beam target
- Primary purpose is to **characterize neutrino beam** and **constrain cross section uncertainties** in long-baseline neutrino oscillation analysis

DUNE ND Complex





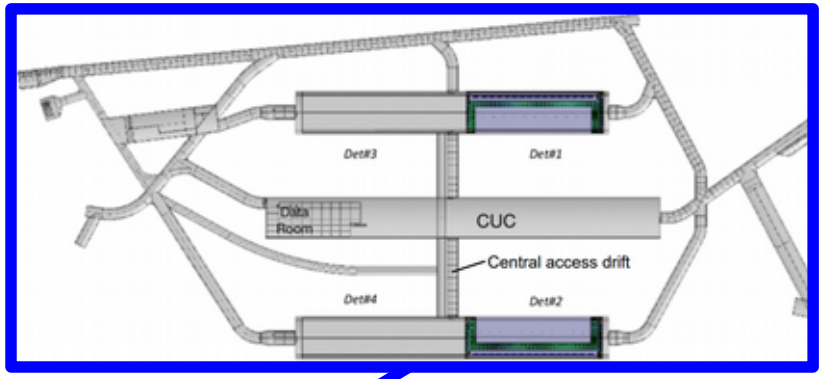
SAND ND-GAr ND-LAr

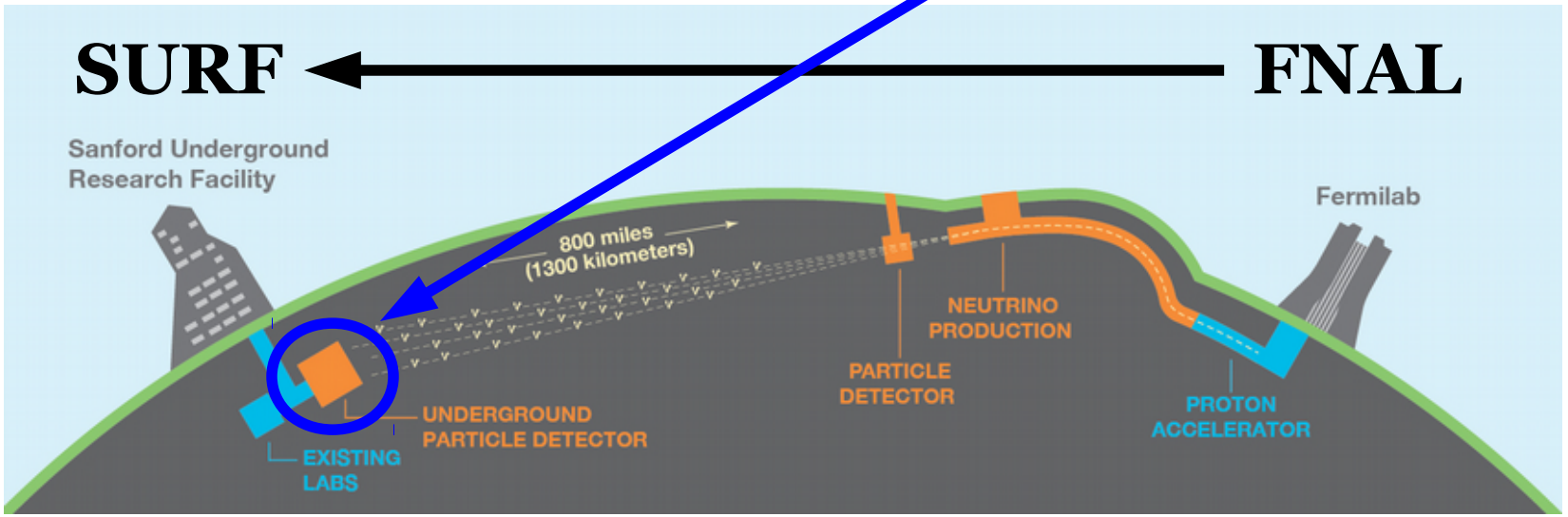
- DUNE ND complex: multiple complementary systems
  - ND-LAr: modular, pixelated LArTPC
    - Acts as primary target and is most similar to FD (both contain LAr)
  - ND-GAr: high-pressure GArTPC surrounded by ECAL and magnet
    - Constrains nuclear interaction model; muon spectrometer
  - SAND: tracker surrounded by ECAL and magnet
    - On-axis monitor of beam spectrum
- ND-LAr/ND-GAr can move off-axis (DUNE-PRISM)

DUNE Far Detector (FD)

The DUNE Far Detector:

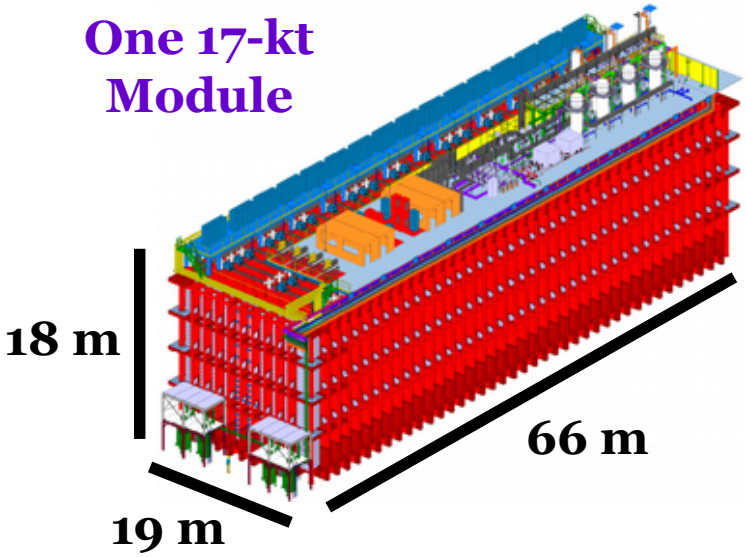
Four LArTPC Detector Modules

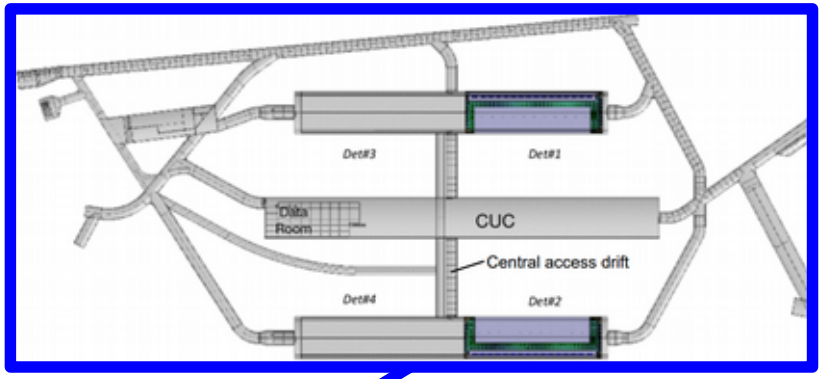


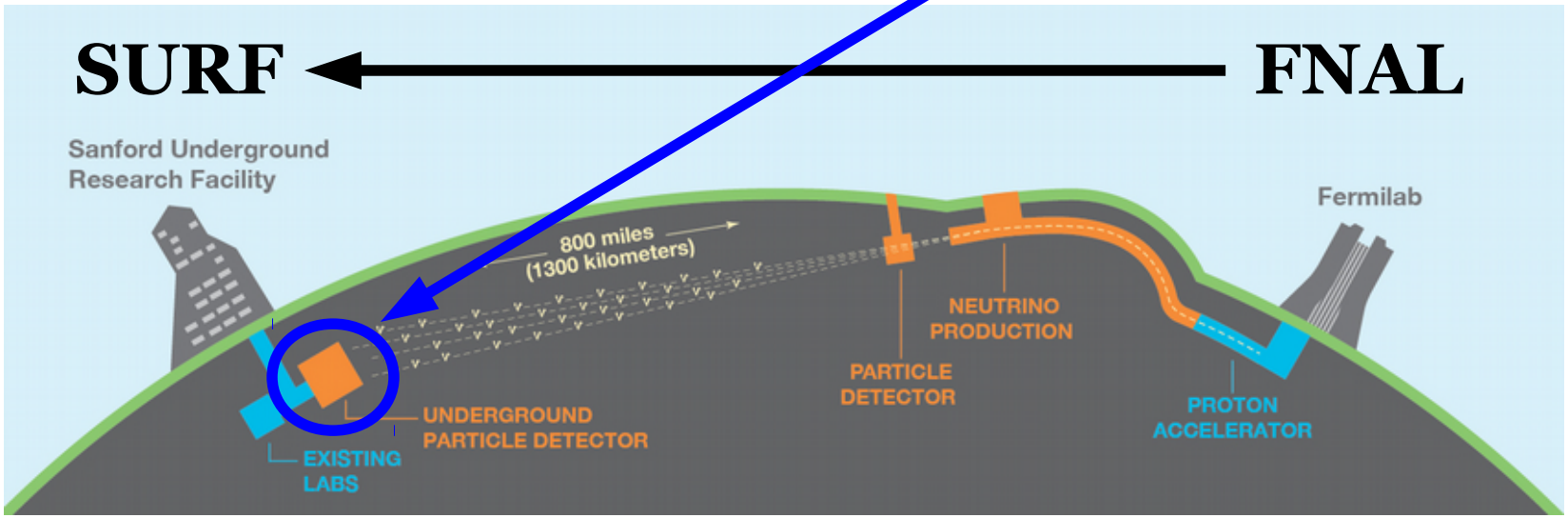


DUNE Far Detector (FD)

One 17-kt Module

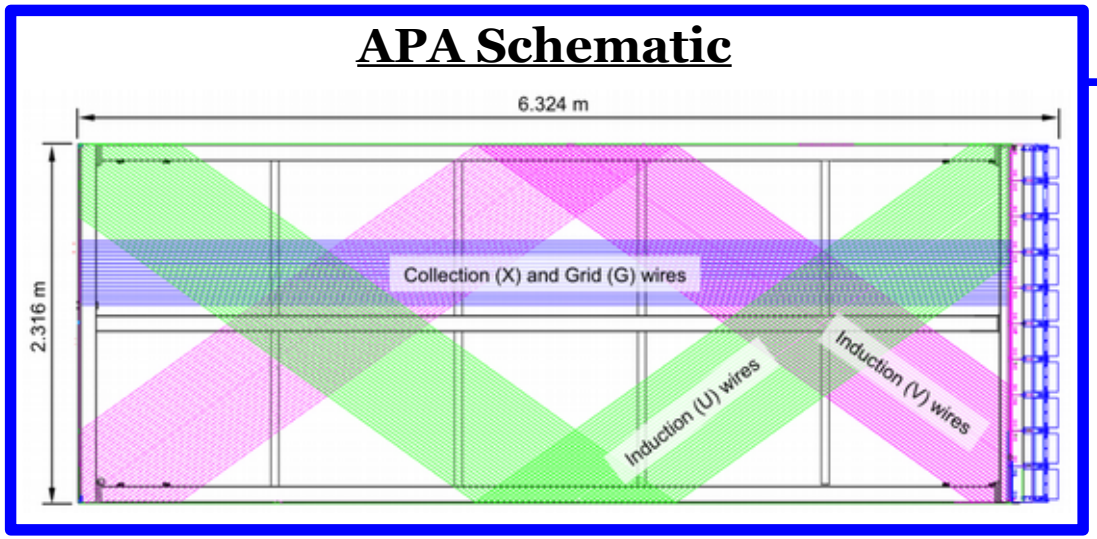


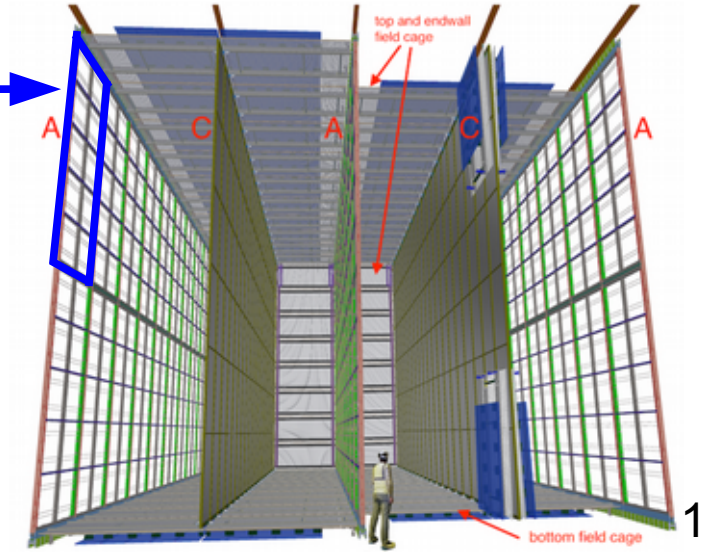




Far Detector LArTPC

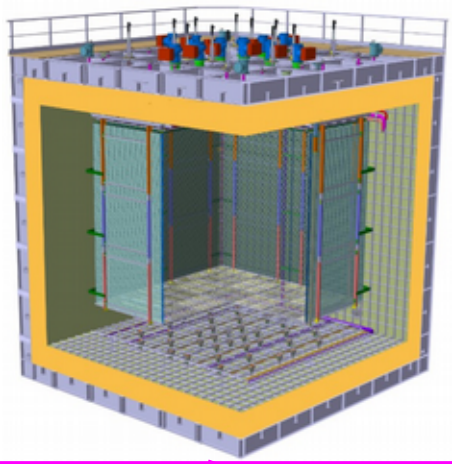
- Four 17-kt modules deployed in stages
- Two far detector designs: single phase (LAr) and dual phase (LAr+GAr) – **first module will be single phase**
- Single phase FD uses modular drift cells (scalable)
  - Suspended Anode and Cathode Plane Assemblies (APAs and CPAs)
  - **Wrapped wire** to reduce # of readout channels, cabling complexity
  - 3.6 m drift, 500 V/cm field; **photon detectors** for non-beam triggering



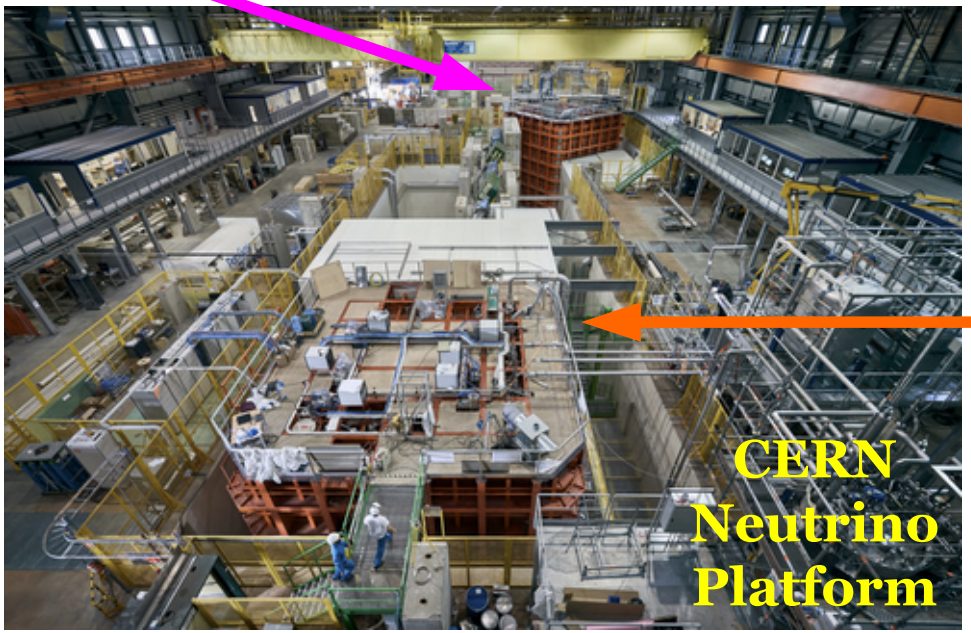


ProtoDUNEs

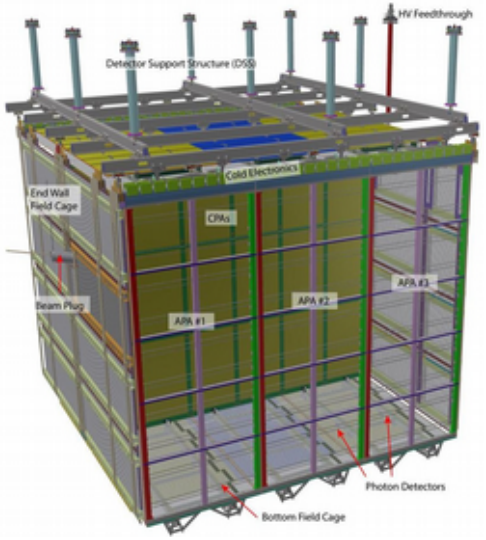
ProtoDUNE-DP



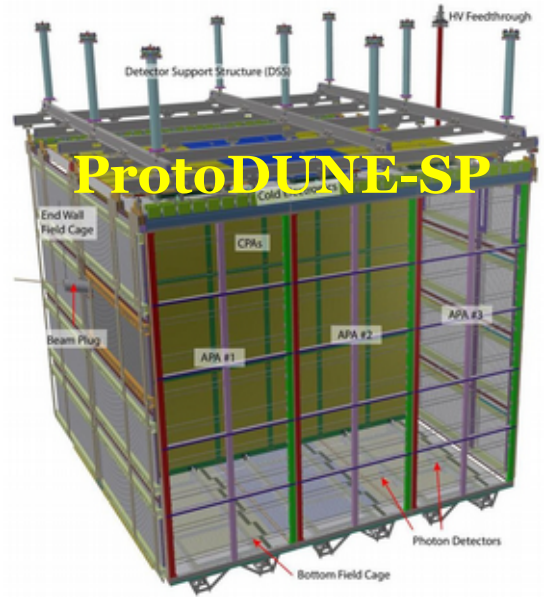
- Two 1-kt "ProtoDUNEs" in charged test beam at CERN (one per FD design)
- Test of component installation, commissioning, and performance
- ProtoDUNE-SP operating since 2018; ProtoDUNE-DP since 2019



ProtoDUNE-SP



ProtoDUNEs



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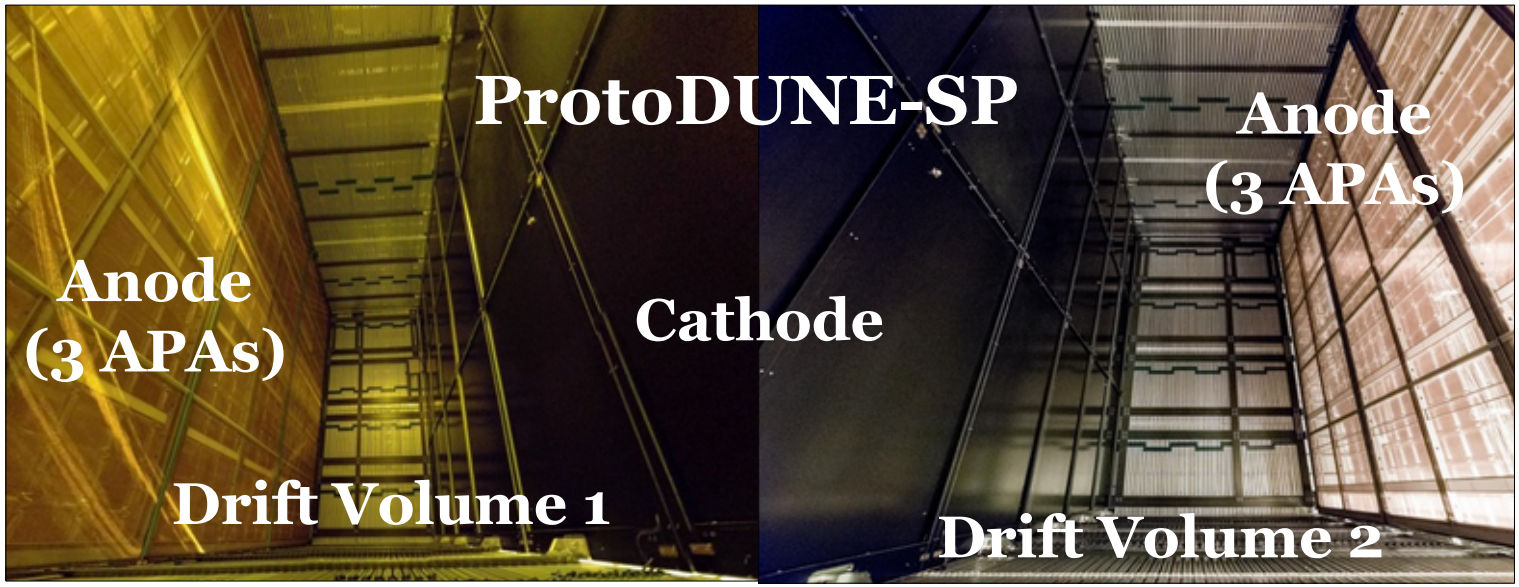
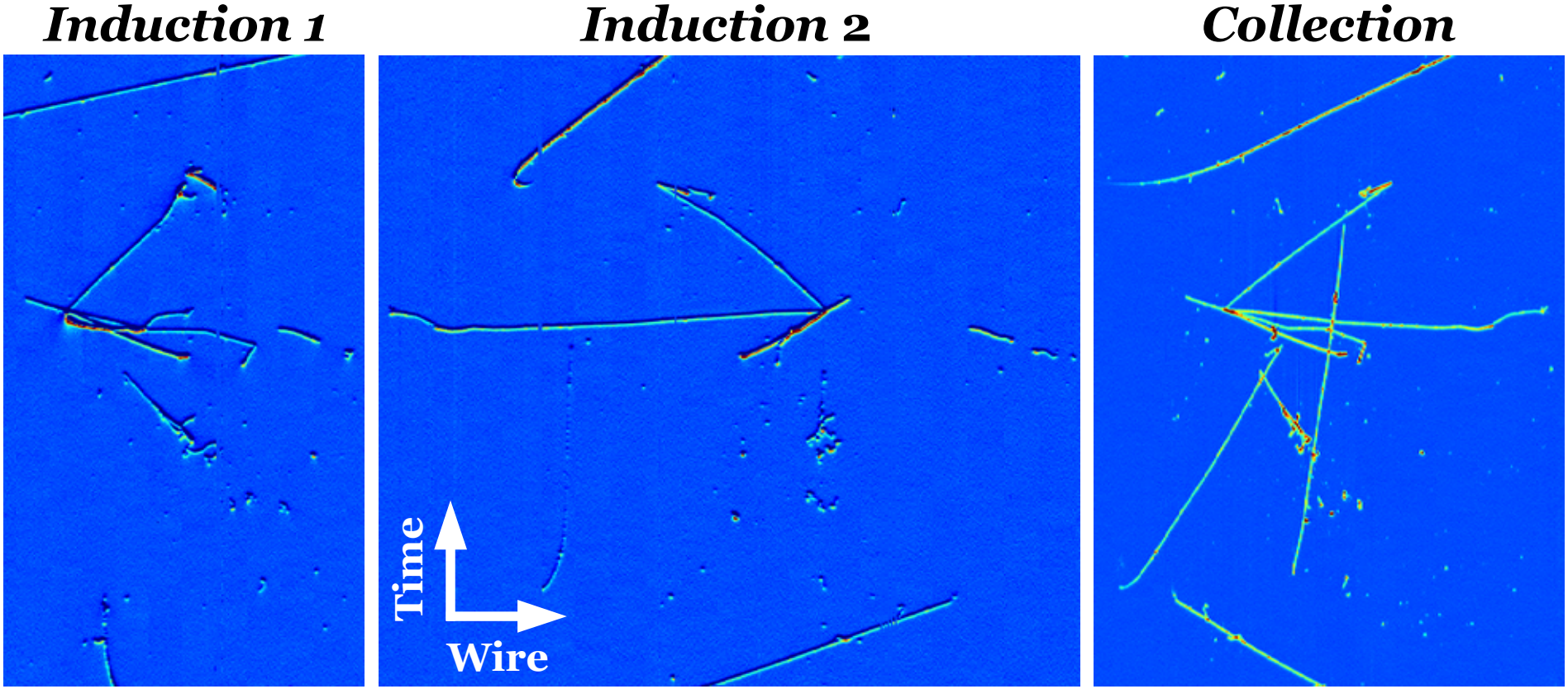
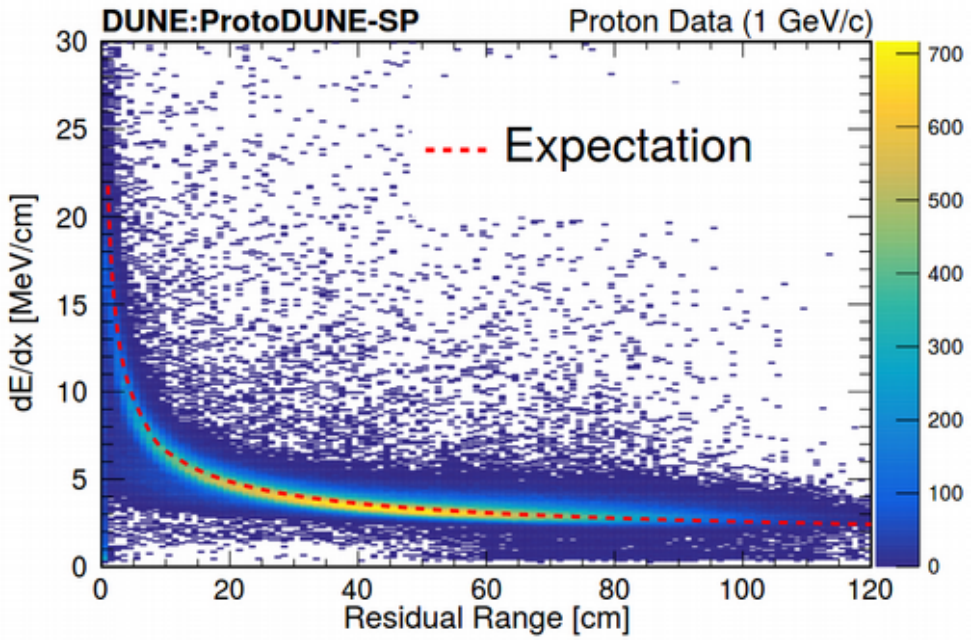


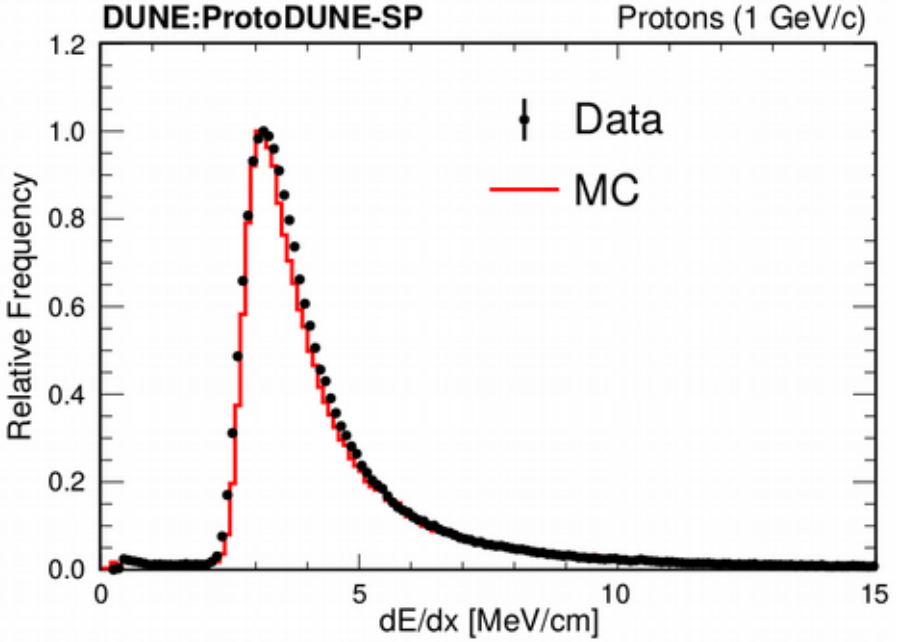
First ProtoDUNE-SP Events



- First beam data events: **noise levels low** on all three planes
- S/N ratio > 10 in all cases (> 40 for collection plane)
- **Stable running** since first operations began in 2018

First ProtoDUNE-SP Results

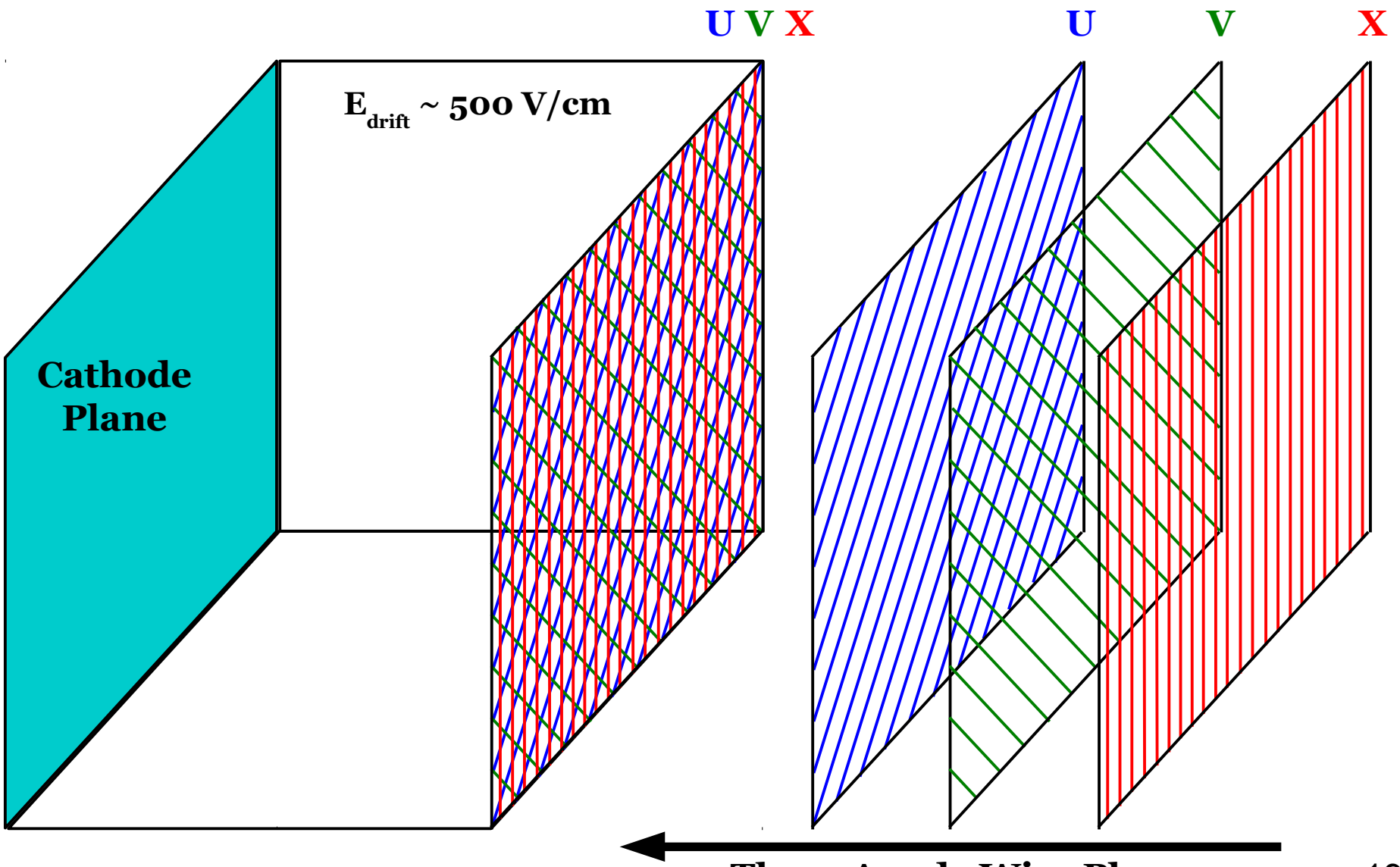




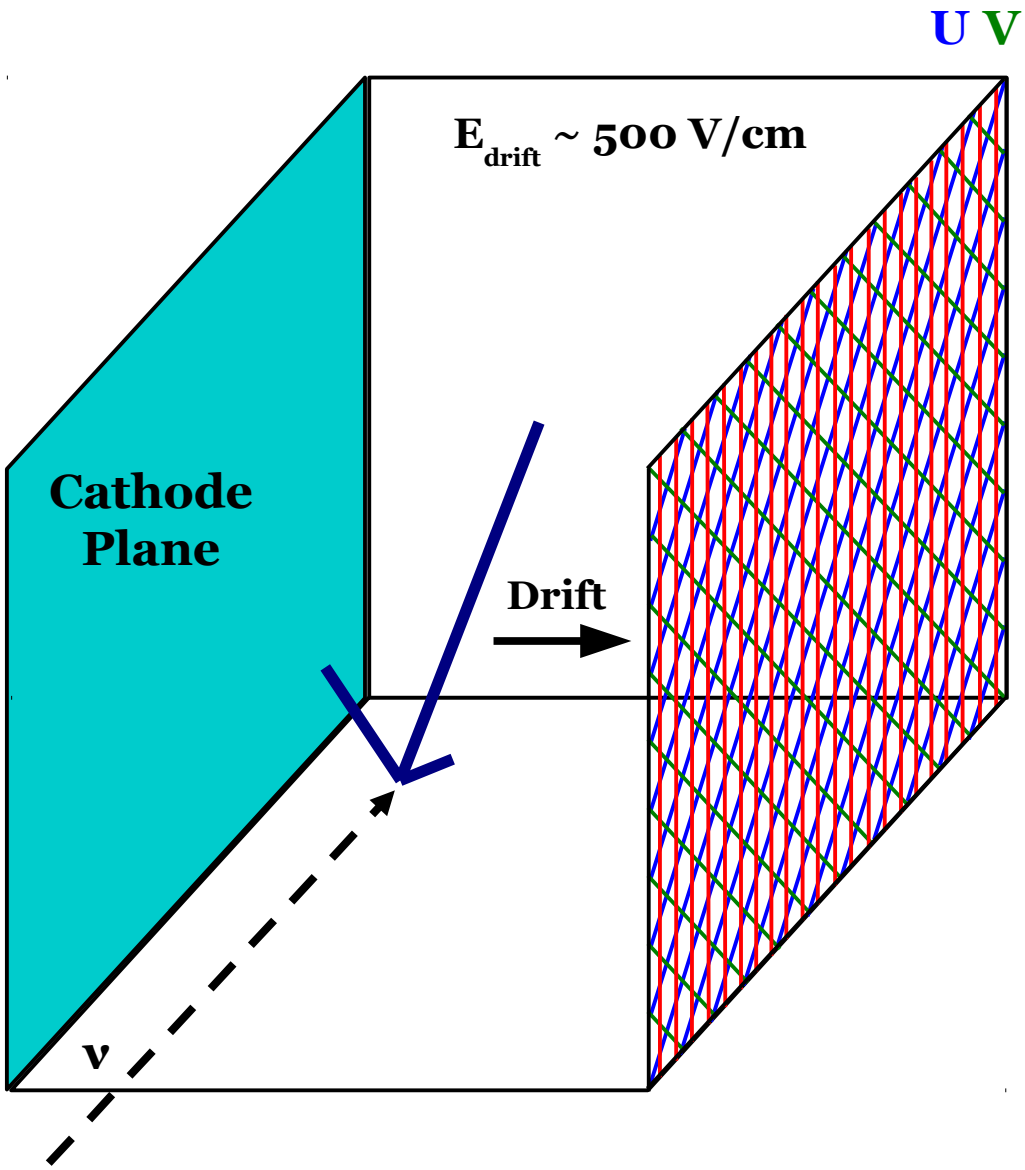
- First results from ProtoDUNE-SP informing **calibrations** and **reconstruction** for single phase DUNE FD
  - Above left: dE/dx vs. residual range for 1 GeV protons (data)
  - Above right: dE/dx distribution of 1 GeV protons (data vs. MC)
  - Upcoming paper on arXiv soon: "First results on ProtoDUNE-SP LArTPC performance from a beam test at the CERN Neutrino Platform"

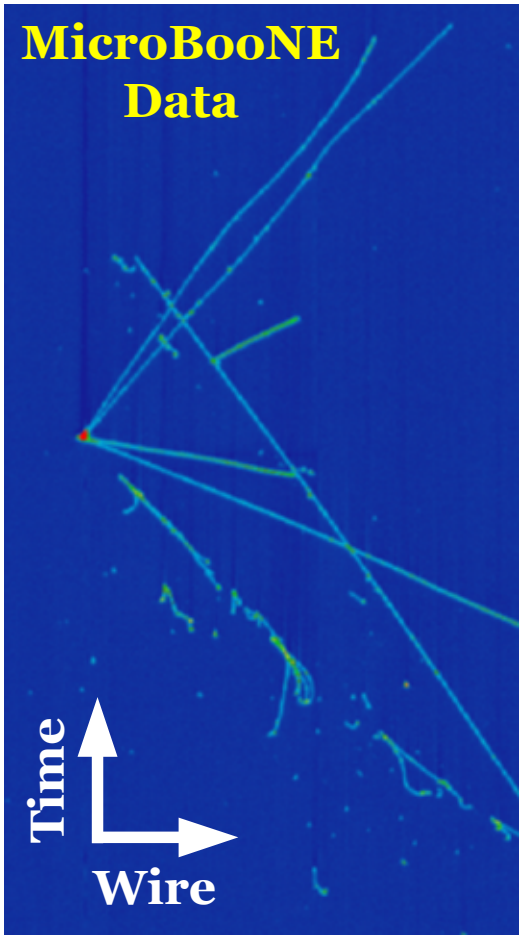
FD Neutrino Event Reconstruction/Selection

Signal Formation



Signal Formation

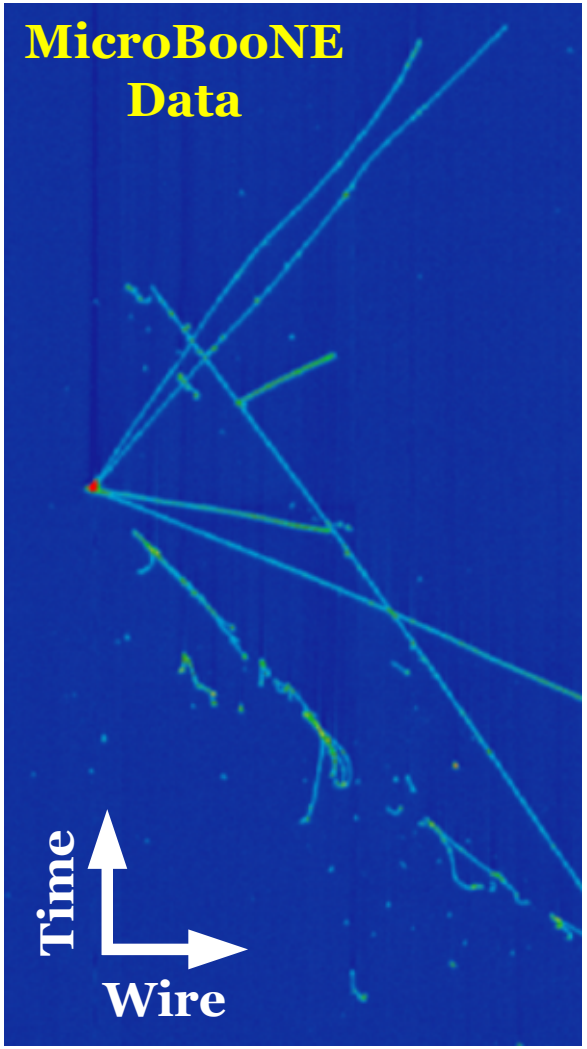




Three Images (One Per Wire Plane)

Event Reco. and Classification

- Perform pattern recognition to reconstruct neutrino event in 3D
- Use convolution neural network (CNN) to classify events (images)
- Results: 80-90% efficiency for both ν_μ and ν_e selections
- See upcoming paper (on arXiv): "Neutrino interaction classification with a convolutional neural network in the DUNE far detector"



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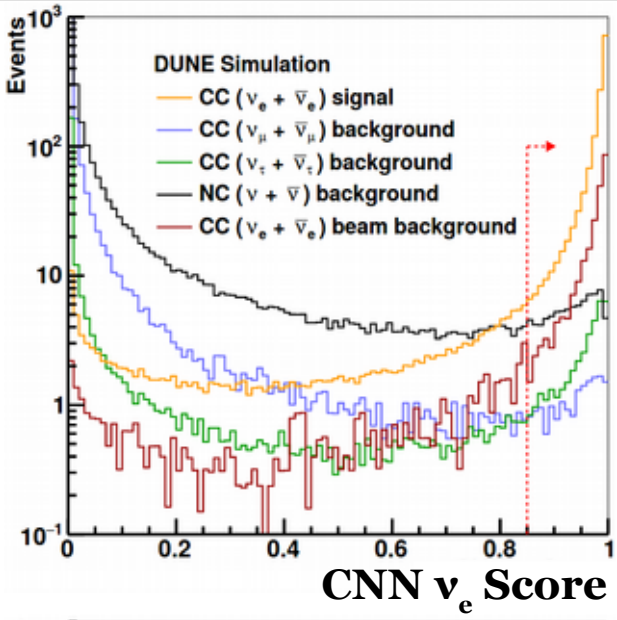
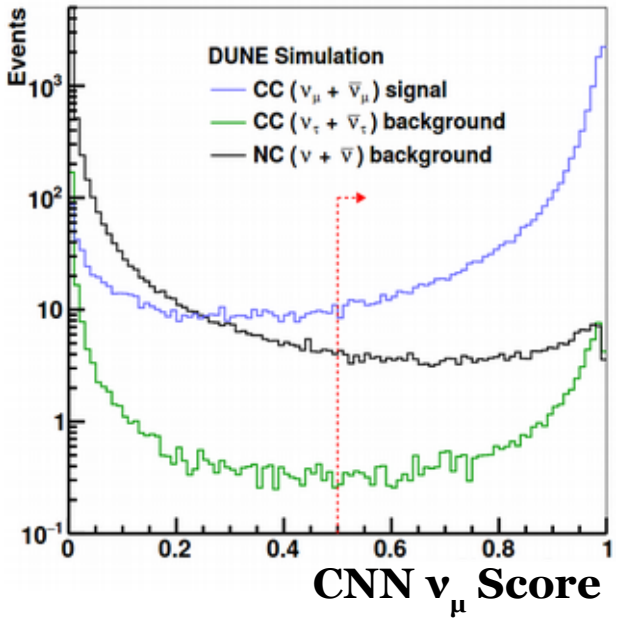
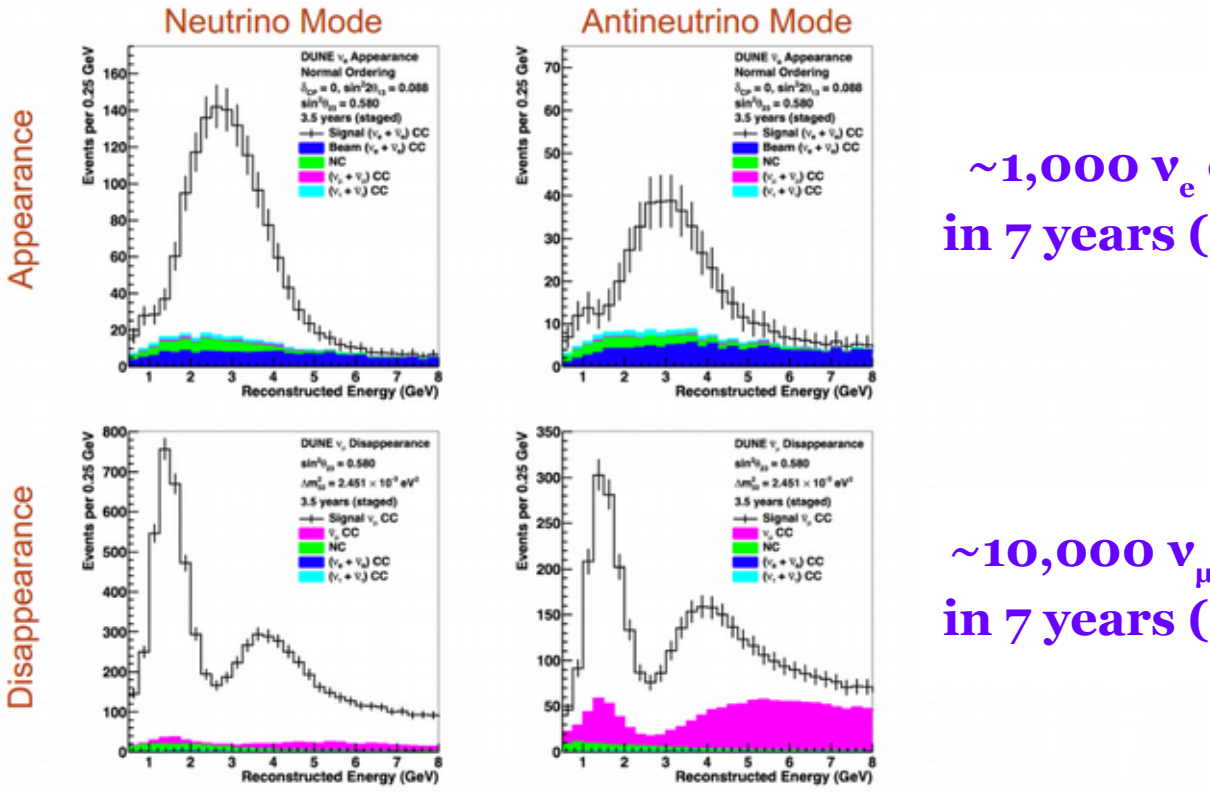




DUNE Physics Program

FD Oscillation Spectra



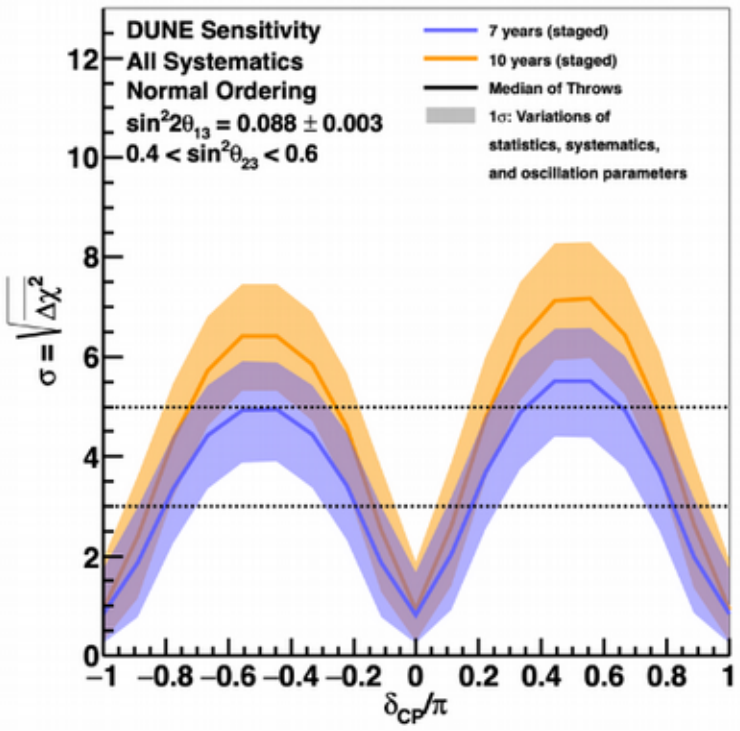
~1,000 ν_e events in 7 years (staged)

~10,000 ν_μ events in 7 years (staged)

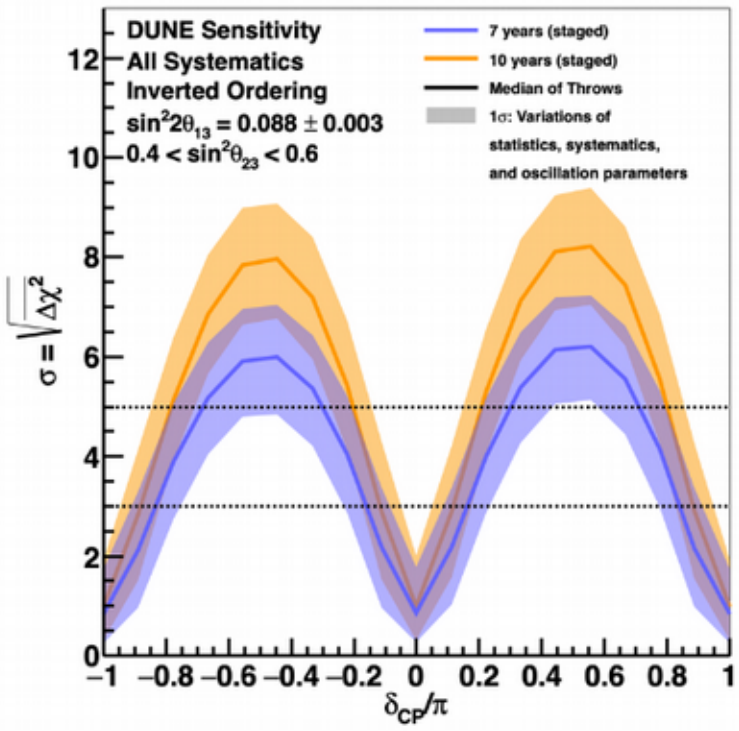
- Four-component fit of FD data w/ constraint from ND data
- New: **full systematics** (flux, cross section, detector) included
- Upcoming paper (on arXiv): "Long-baseline neutrino oscillation physics potential of the DUNE experiment"

CP Violation Sensitivity

True Normal Ordering



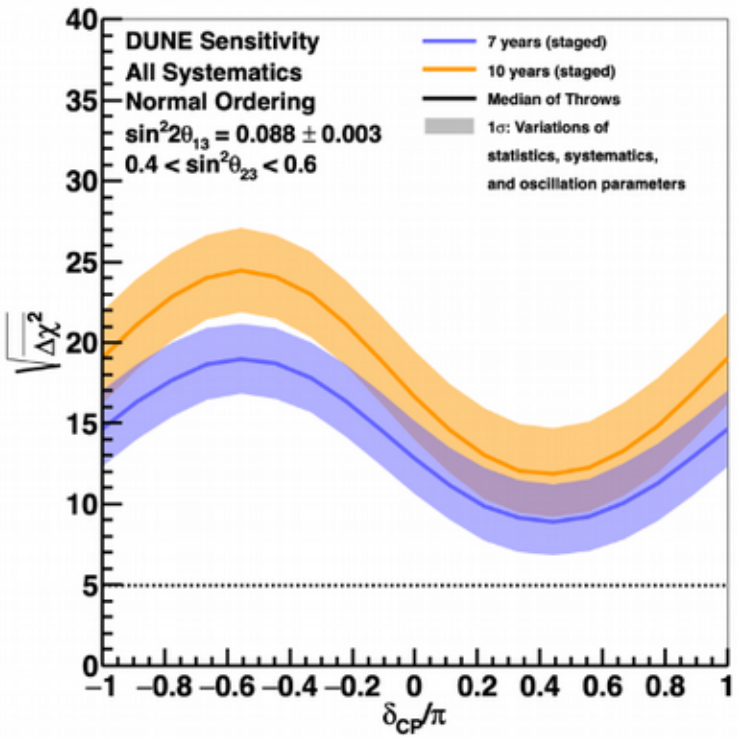
True Inverted Ordering



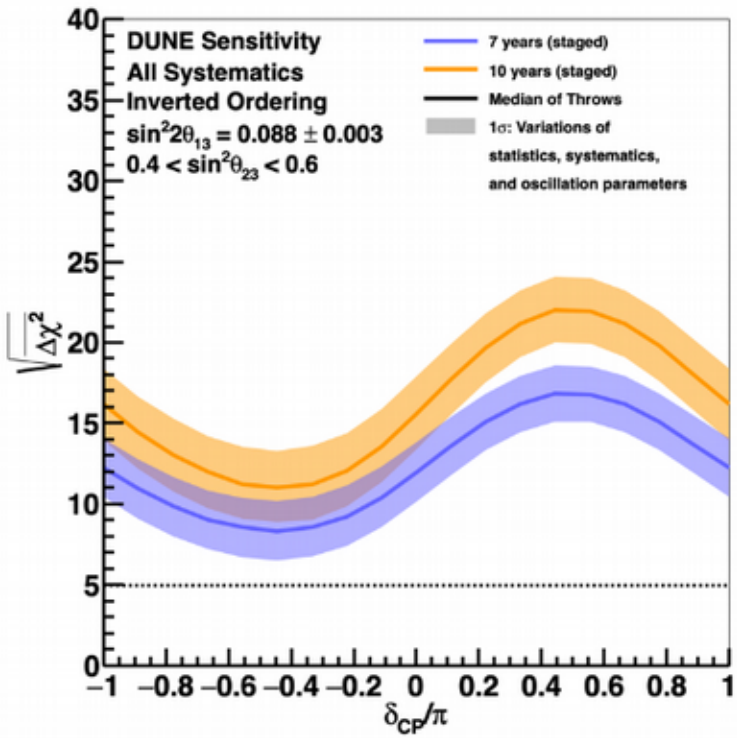
- Significant CP violation discovery potential over wide range of true δ_{CP} values in 7-10 years (staged)

Mass Ordering Sensitivity

True Normal Ordering



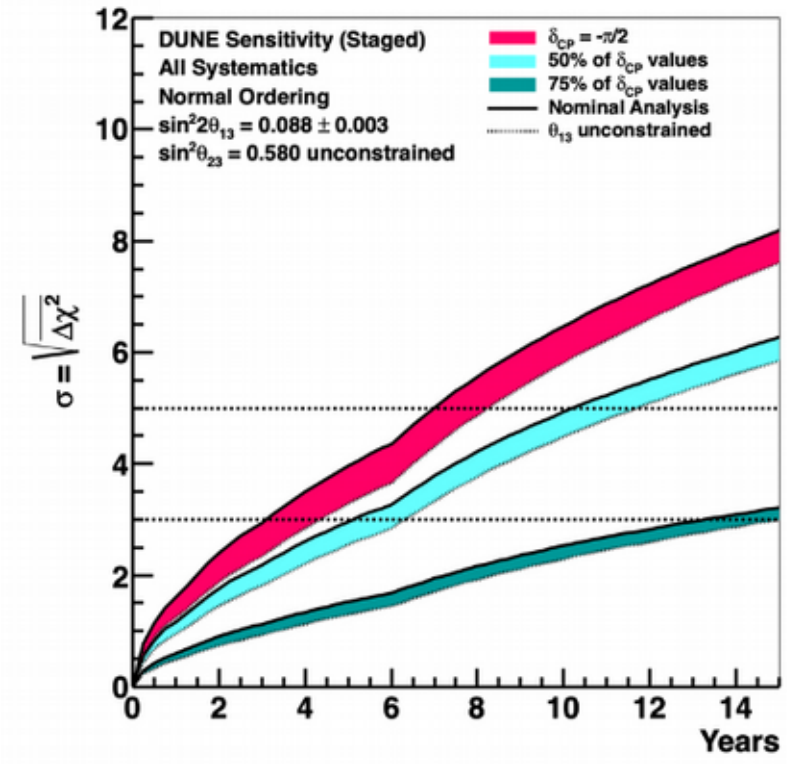
True Inverted Ordering



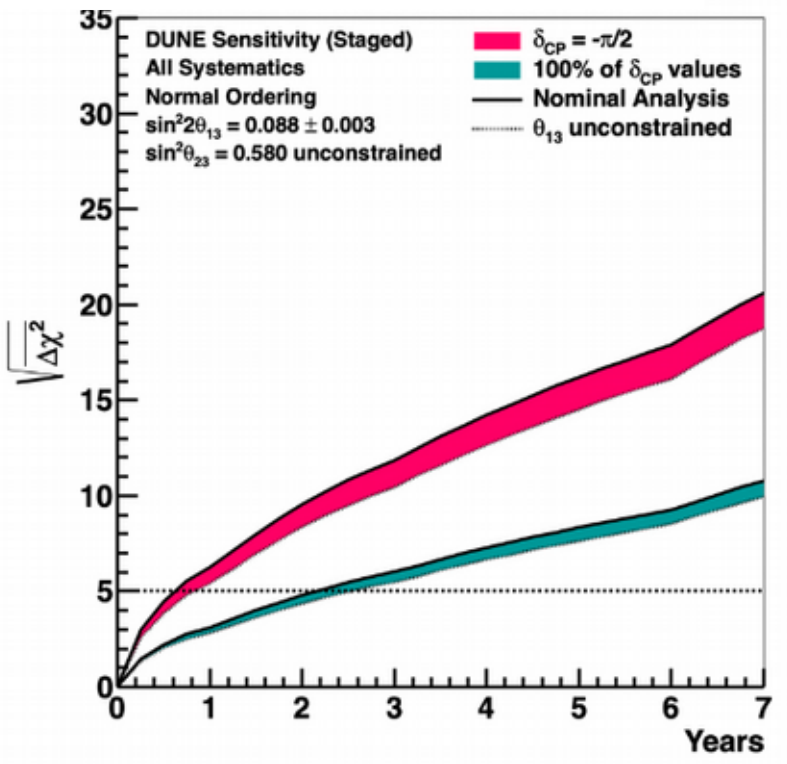
- Definitive determination of neutrino mass ordering for all possible parameters

Sensitivity Over Time

CP Violation Sensitivity



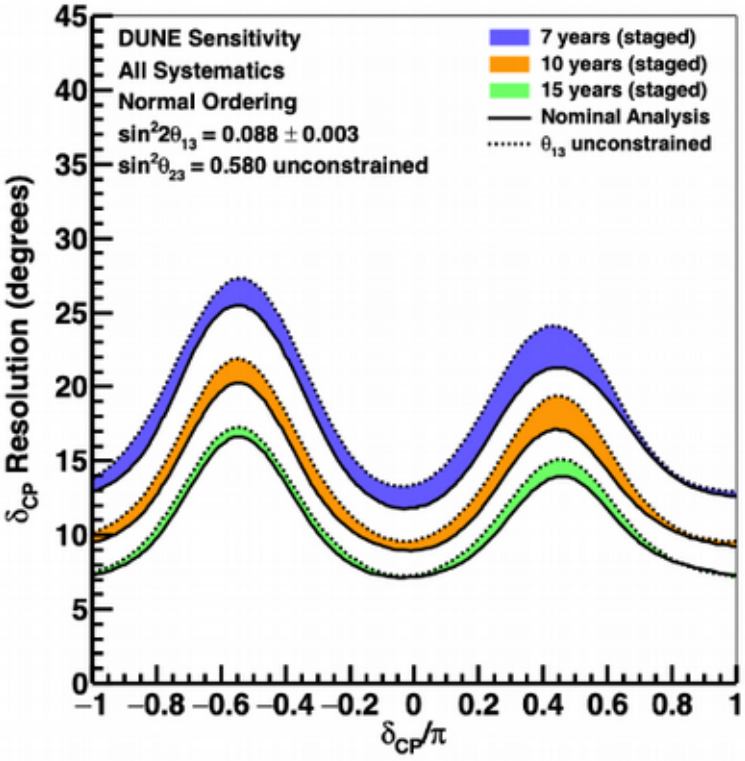
Mass Ordering Sensitivity



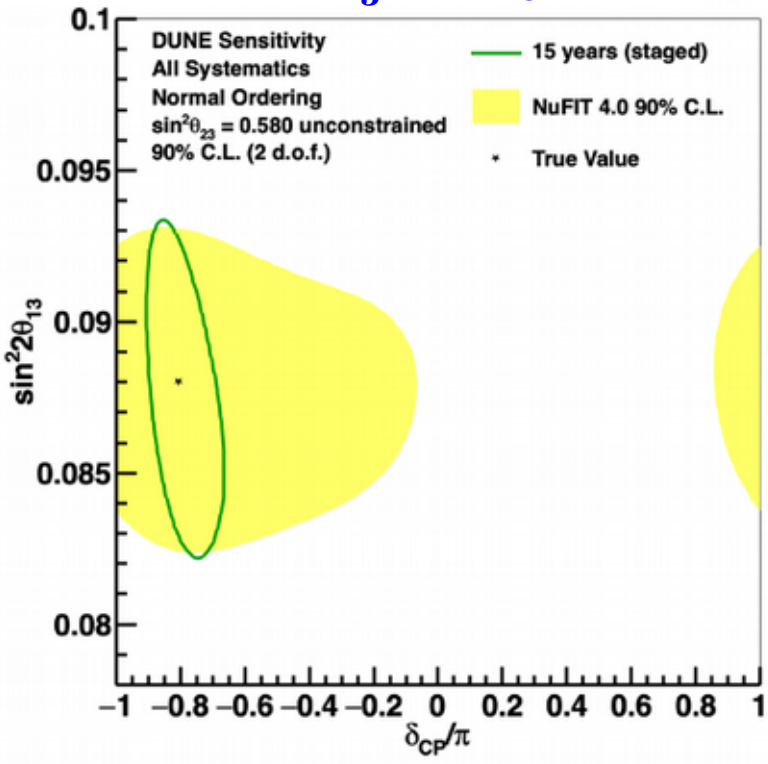
- CP violation discovery if true $\delta_{CP} = -\pi/2$ in ~7 years (staged)
- CP violation discovery for 50% of true δ_{CP} values in ~10 years
- Determination of neutrino mass ordering within first few years

Precision δ_{CP} Measurement

δ_{CP} Resolution

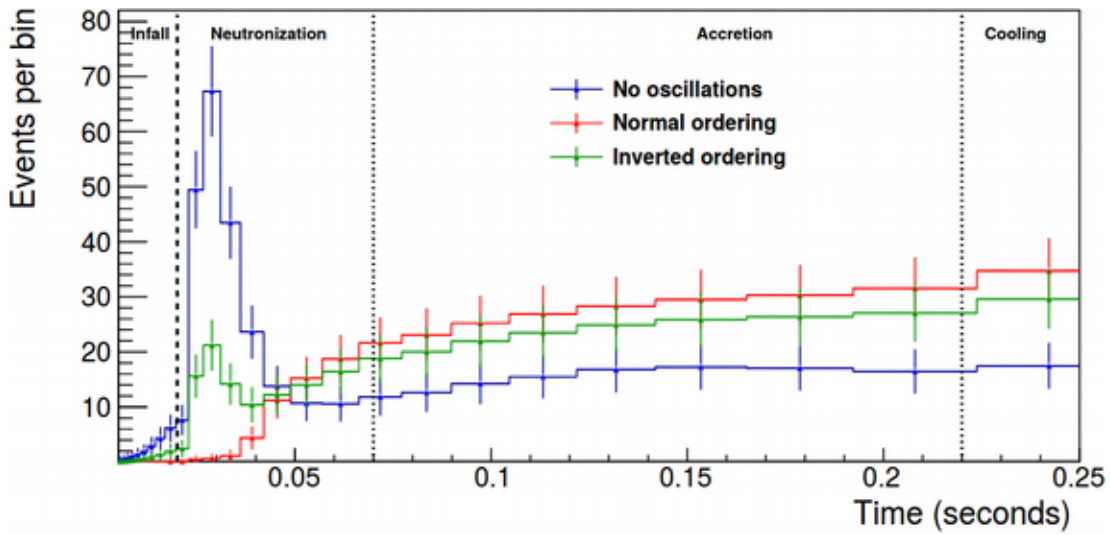


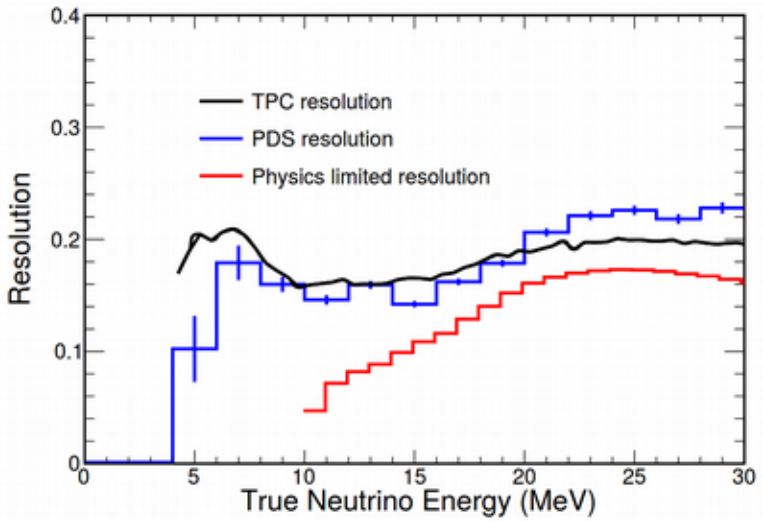
θ_{13} vs. δ_{CP}



- δ_{CP} precision of 10°-20° in ~10 years (staged)
- θ_{13} measurement comparable with reactor experiments after ~15 years (staged)

Supernova Neutrino Bursts

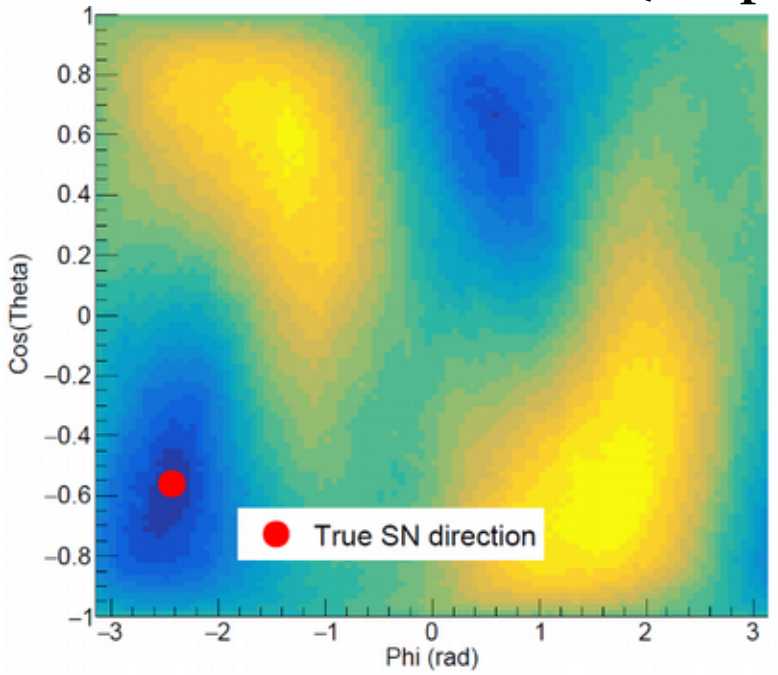




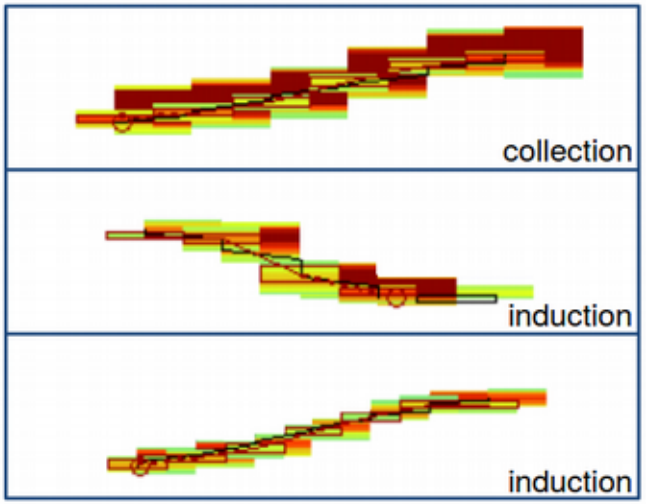
- Exciting physics aside from long-baseline physics program: **neutrino bursts** from **stellar core-collapse supernova**
- Primary interaction in argon: $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$
- Probe of interesting supernova physics (e.g. core-collapse mechanism) and particle physics (e.g. ν flavor transformations)
- Excellent energy resolution with both TPC and photodetectors

SNB Directionality

Direction Likelihood Surface (10 kpc SN)

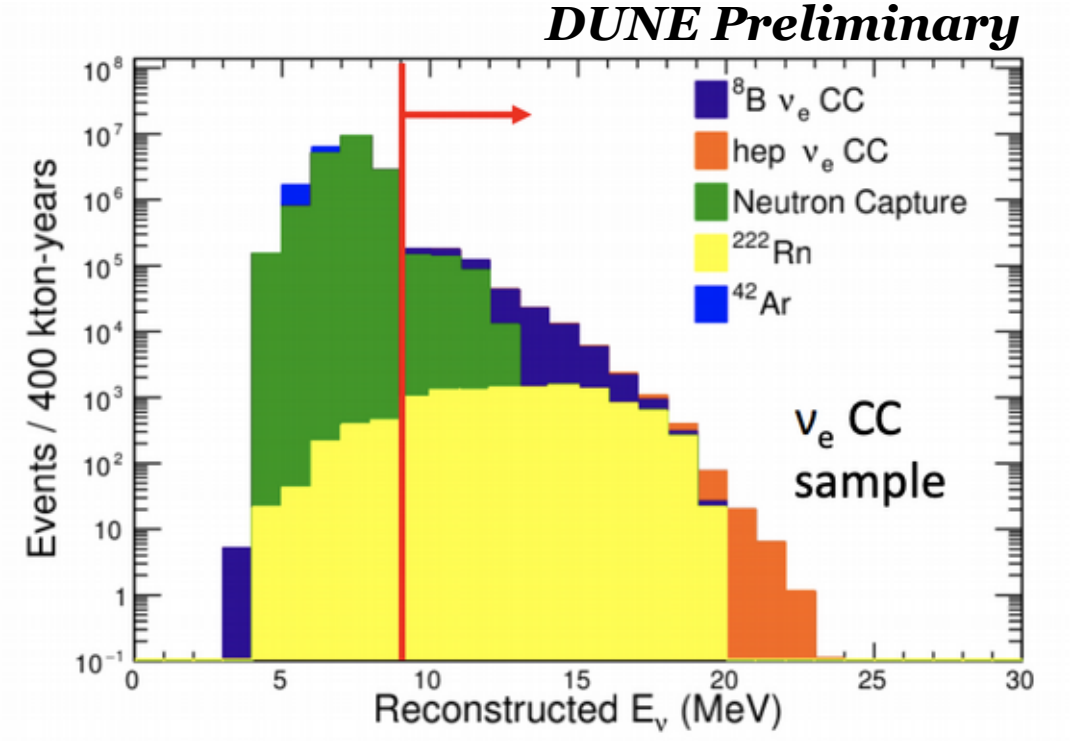


10 MeV Electron (Simulated+Reconstructed)



- Also sensitive to neutrino-electron elastic scattering, which can provide directionality of supernova neutrino burst
  - Can achieve **4.5° pointing resolution**
- Upcoming paper: "Supernova Neutrino Burst Detection with the Deep Underground Neutrino Experiment"

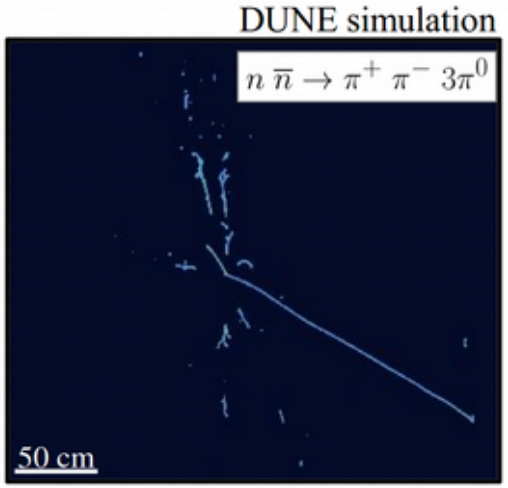
Solar Neutrinos



- Also sensitive to other low-energy neutrinos: **solar neutrinos**
  - **^{8}B solar neutrinos**
  - **hep solar neutrinos**
- Currently under investigation – difficult, but very promising!

BSM Physics Program

- **Large catalog of BSM searches at DUNE** – proton decay, NSI, large extra dimensions, sterile neutrinos, dark matter… **two recent advances shown here**

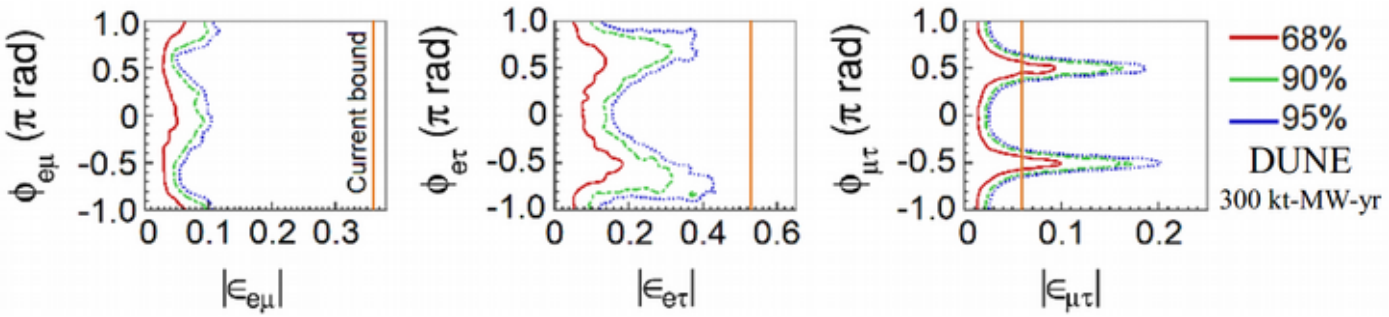


- n-$\bar{n}$ oscillations: spherical spray of hadrons with E ~ $2m_n$, net momentum < p_F ~ 300 MeV

  Free neutron-equivalent sensitivity:

  $\tau_{free,osc} > 5.5\times10^8$ s (90% C.L.)

- Non-standard interactions (NSI): modifications to standard matter effects over DUNE's long baseline



Upcoming paper: "Prospects for Beyond the Standard Model Physics Searches at the Deep Underground Neutrino Experiment"

Summary

- DUNE making good progress toward enabling high-precision neutrino measurements in next decade
  - **Exciting physics program** including CP violation measurement, neutrino mass ordering determination, supernova neutrino burst physics, solar neutrino detection, and many BSM searches
- Technical milestones:
  - Technical Design Report for DUNE FD complete: I, II, III, IV
  - ProtoDUNEs successfully operating at CERN with first results being published soon
  - Conceptual Design Report for DUNE ND under review
- Plenty of opportunities for additional **international participation**

See 26 DUNE posters for more detailed information!

Thanks!