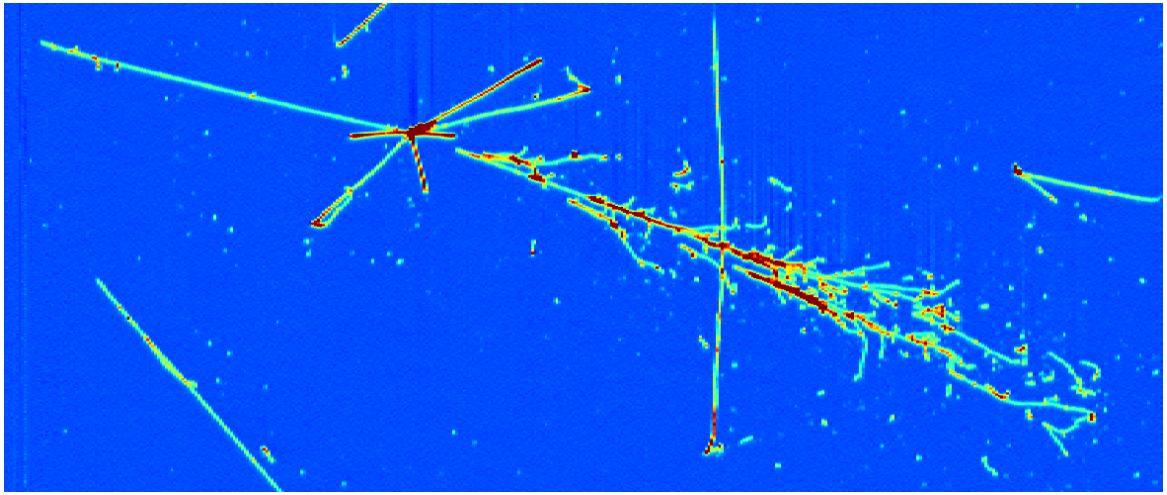


The Status of the DUNE Experiment

Tingjun Yang (Fermilab) for the DUNE Collaboration

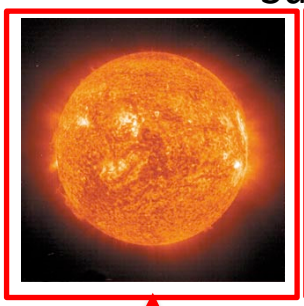
Fermilab Users Meeting

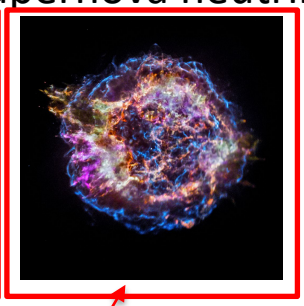
2020

Neutrinos are abundant

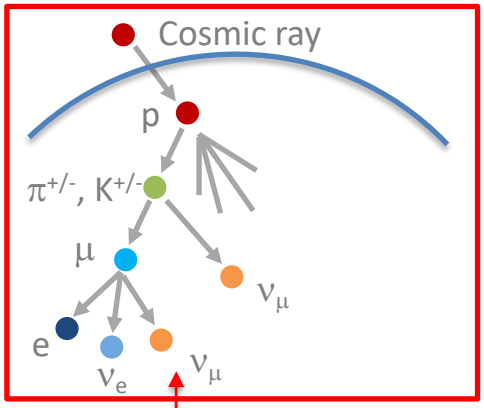
Solar neutrinos

Supernova neutrinos

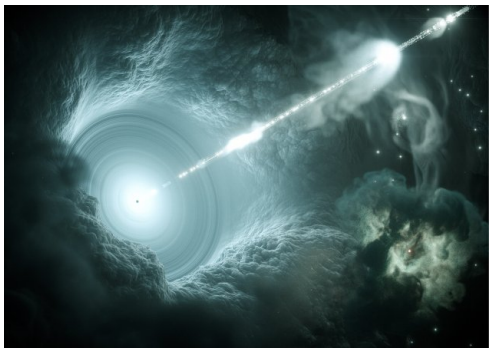




Atmospheric neutrinos



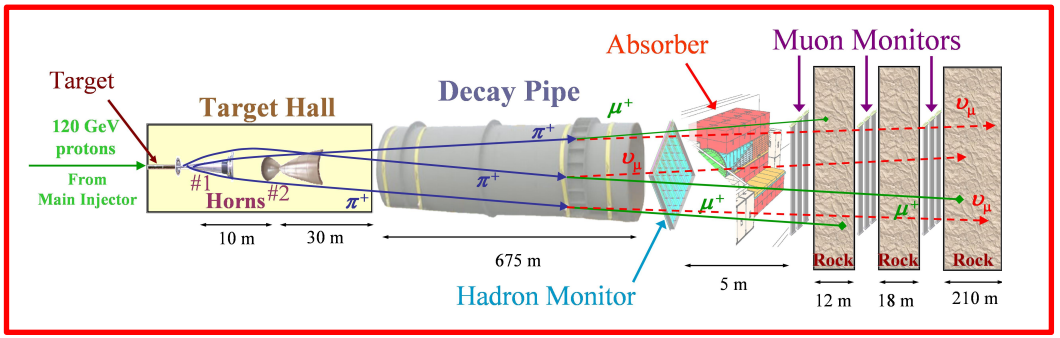
High energy neutrino astronomy



10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}

MeV GeV TeV PeV EeV Energy (eV)

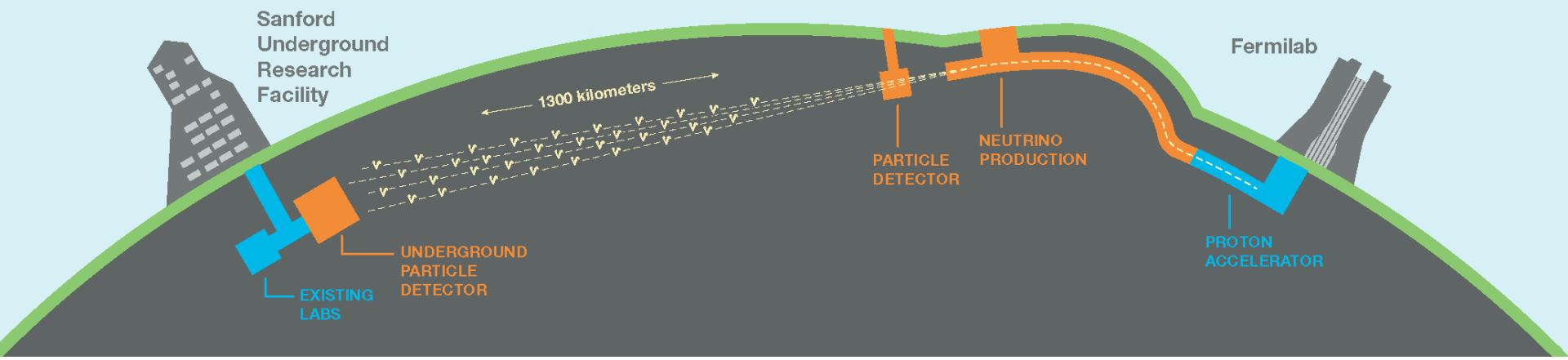
Reactor neutrinos



Accelerator neutrinos

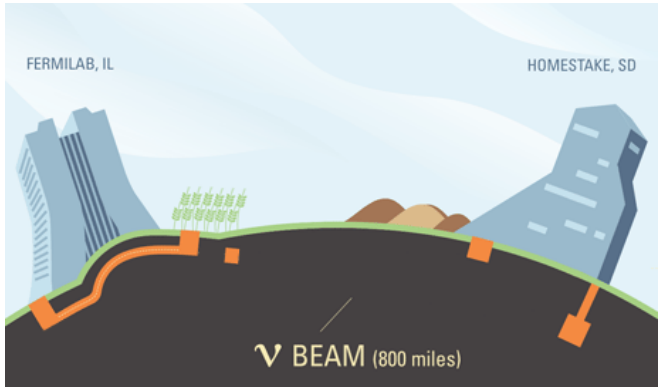
DEEP UNDERGROUND NEUTRINO EXPERIMENT

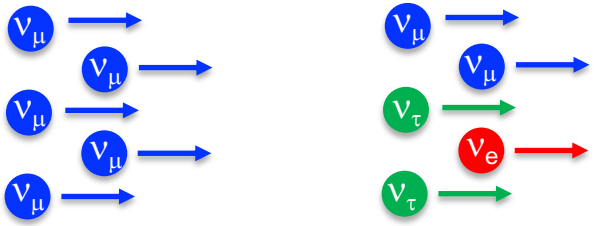
1000+ collaborators from 200+ institutions in 30+ nations



- **Neutrinos oscillations:** CP violation. Are neutrinos the reason the world is made of matter?
- **Supernova burst neutrinos:** neutron star and black hole formation
- **Beyond standard model processes:** nucleon decay, sterile neutrinos, etc.

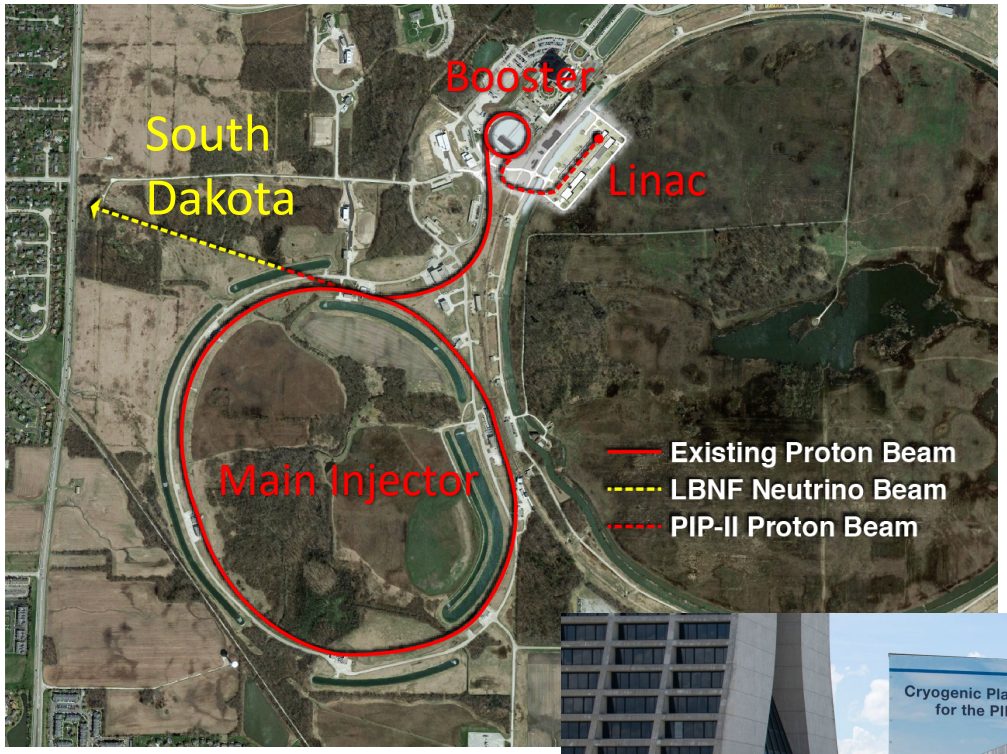
Long Baseline Neutrino Oscillations





- Primary physics goal is to measure neutrino oscillations
  - Intense Beams: Required to produce and detect ghostly neutrinos
  - Long Baseline: Matches the physics goals of oscillations
  - Liquid Argon: Capable of revealing exquisite detail of ν interactions
  - Deep underground: Reduced backgrounds for ν's and other science

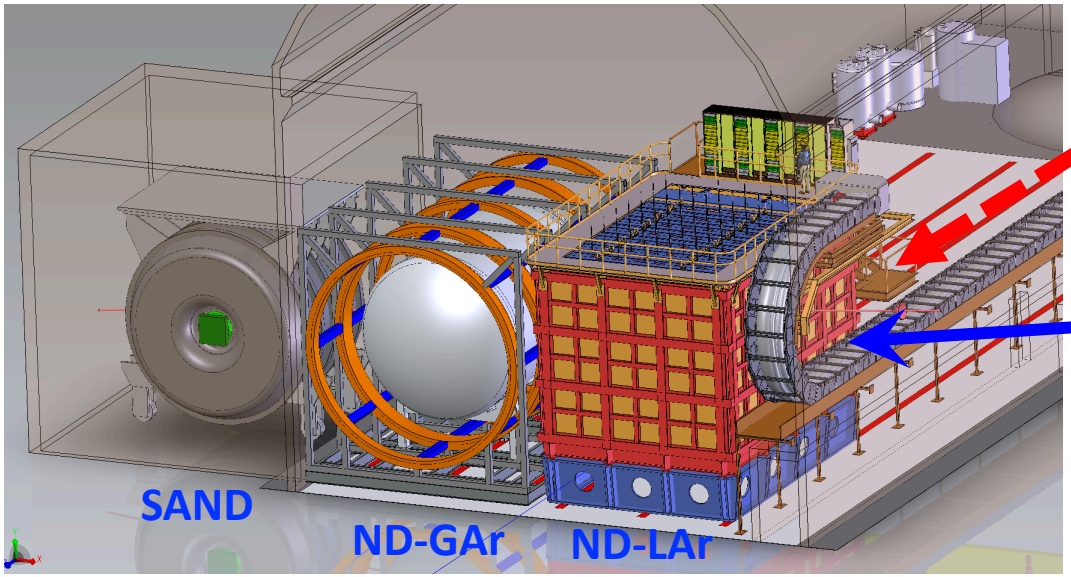
LBNF Neutrino Beam



- Proton Improvement Plan – II (PIP-II)
  - 1.2 MW beam power, upgradeable to 2.4 MW
  - beamline optimized for CP violation sensitivity

Lidija Kokoska: PIP-II

DUNE Near Detector Design



ND-LAr and ND-GAr move off-axis to receive different beam fluxes for flux and cross sections disentangling (DUNE-PRISM)

beam direction

- Measure neutrino flux, background in oscillation analysis
  - ND-LAr: Modular, pixelized liquid argon TPC
  - ND-Gar: High pressure gaseous argon TPC + ECAL + magnet
  - SAND: Scintillator trackers + ECAL + magnet

ND hall location:
- 574 m from LBNF target
- ~60 m underground

Site Preparation Work at Fermilab

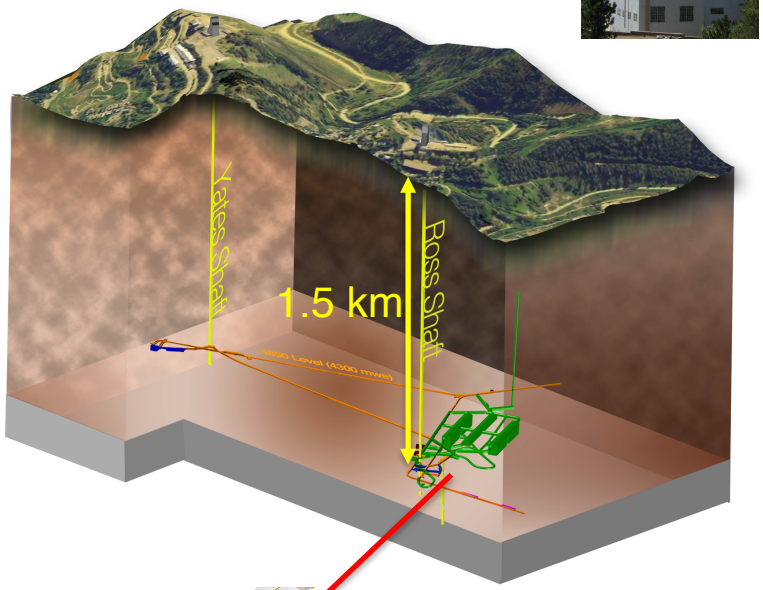
Installation of new power and communications duct bank

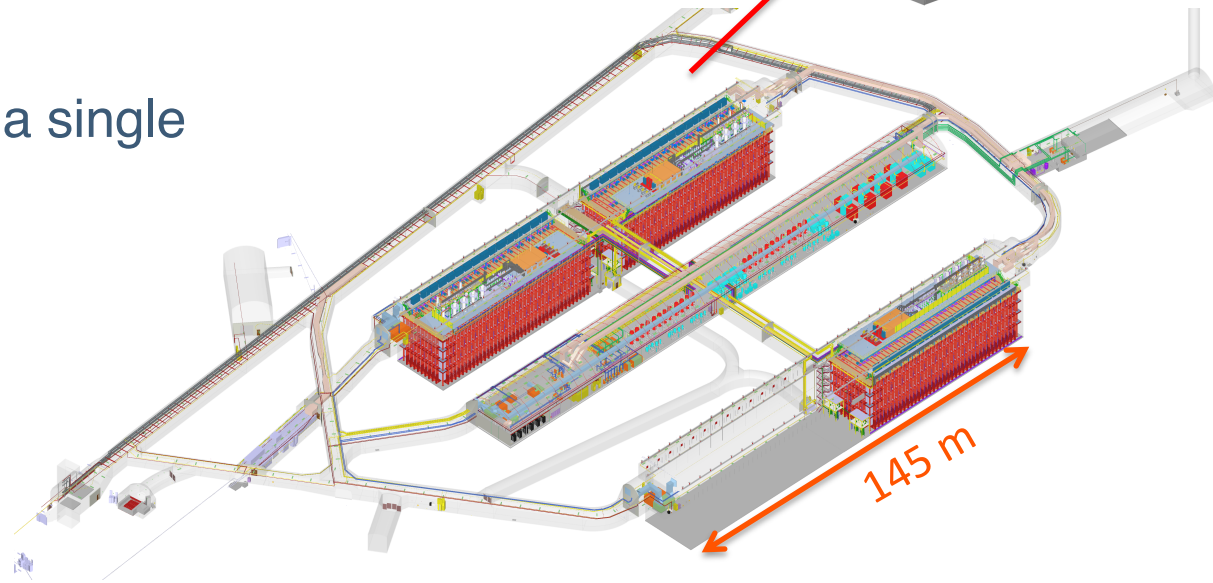
Installation of Indian Creek culvert reroute

- Site preparation at Fermilab has worked to clear the site where the future beamline facility will be installed

DUNE Far Detector

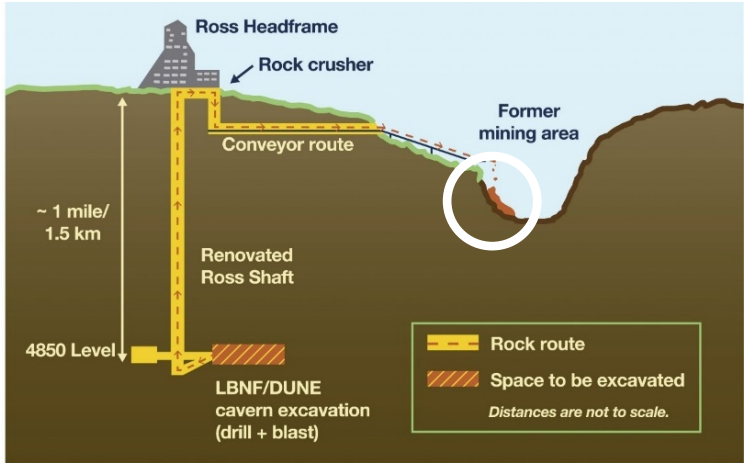
- Sanford Underground Research Facility (SURF), Lead, SD
- 1.5 km underground
- Four 17-kt modules
- Single- and dual-phase detectors being prototyped
  - First module will be a single phase LArTPC





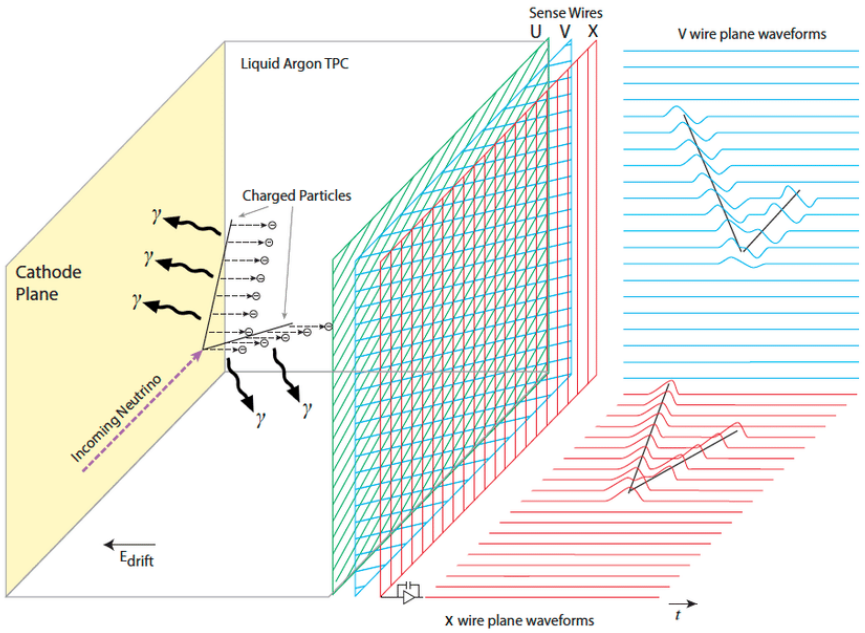
Progress at SURF

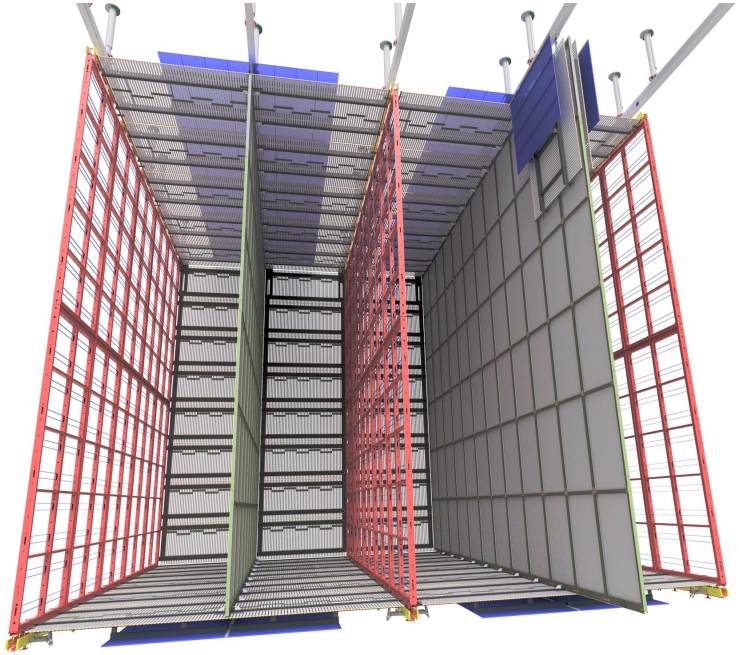
- Construction work at SURF started in November 2018, and has focused on
  - creating the pathway for rock removal and excavation from 4850L to the final disposition location (Open Cut)
  - establishing initial ventilation needed for excavation underground
  - installing power needed for LBNF and DUNE at the 4850L
  - Pre-excavation will complete in early 2021, at which time main excavation will begin.



Terminus of 4,200LF Rock Conveyor to deposit excavated rock into the Open Cut in Lead, SD

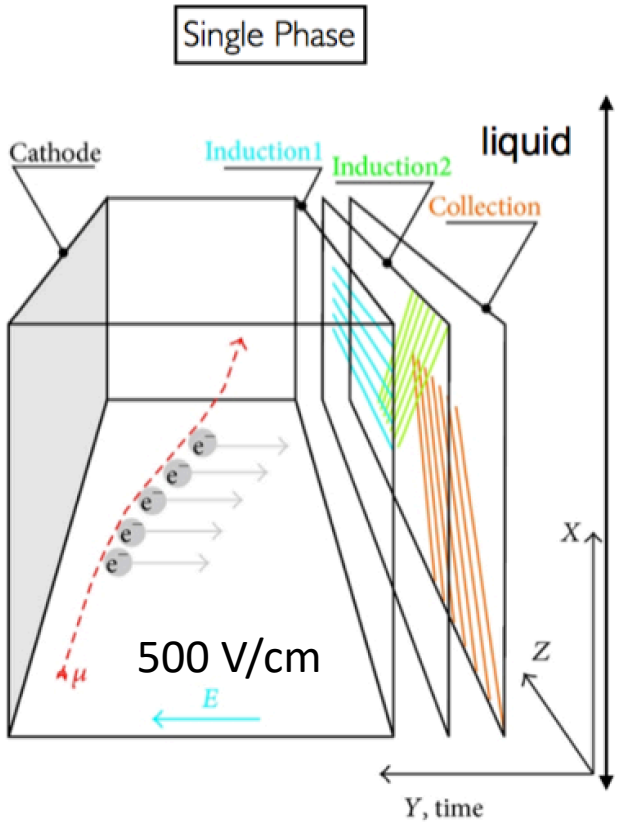
Liquid Argon Time Projection Chamber

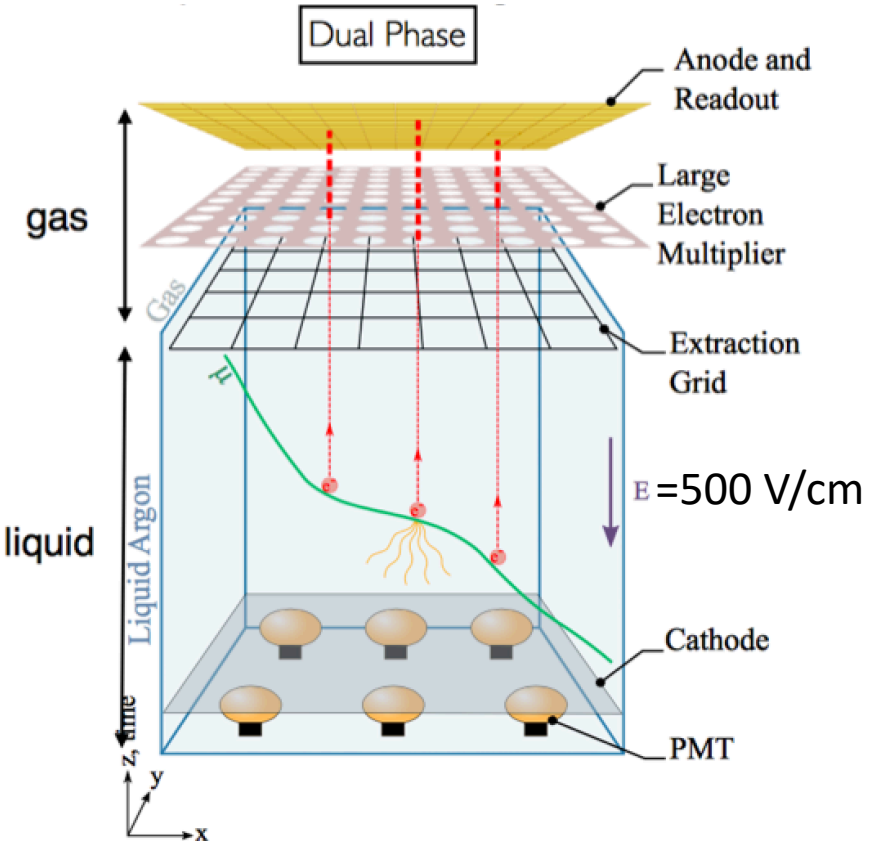




- Detector technology for DUNE.
  - Provide high resolution images.
  - Excellent spatial and calorimetric resolutions.
- Massive LArTPCs for DUNE far detector (10 kt fiducial mass).

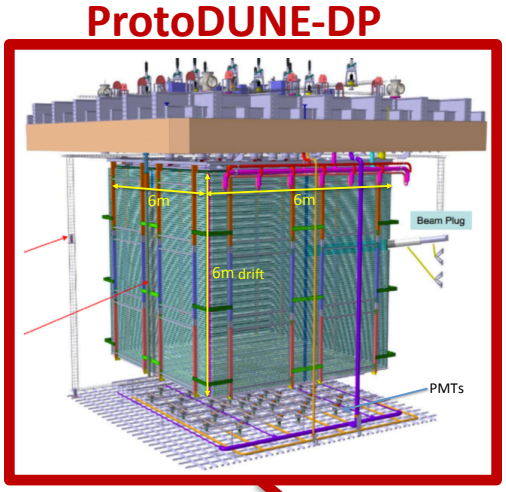
Single-Phase and Dual-Phase LArTPCs



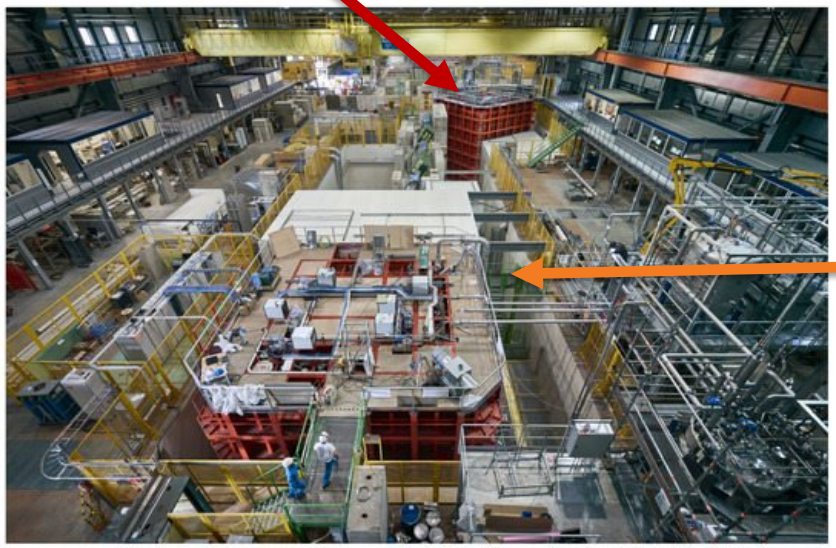


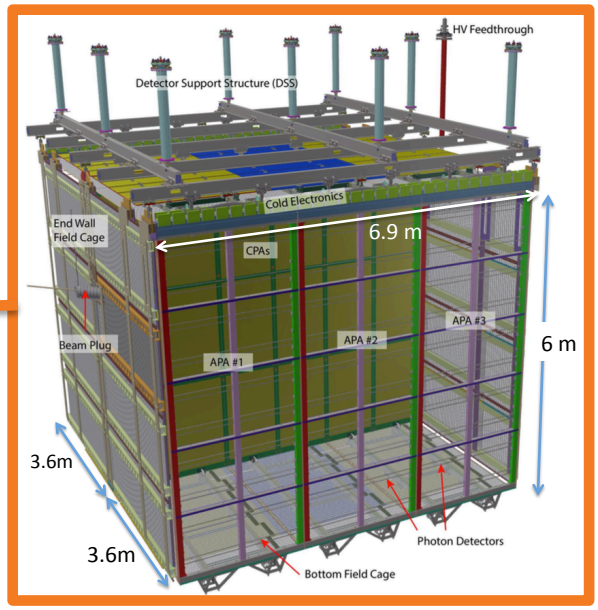
- Single phase: liquid argon
- Dual phase: liquid argon + gaseous argon
  - Amplification of signal in gas phase by LEM

ProtoDUNEs

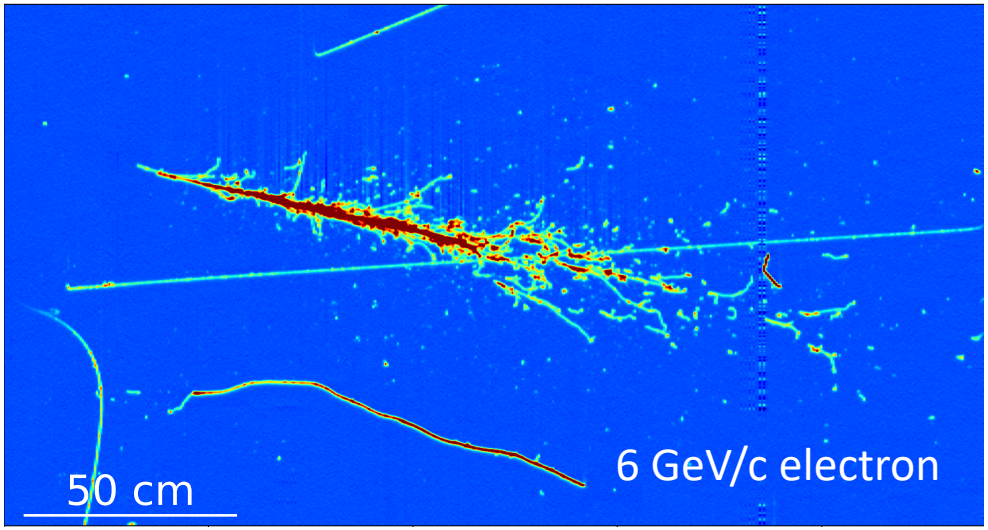


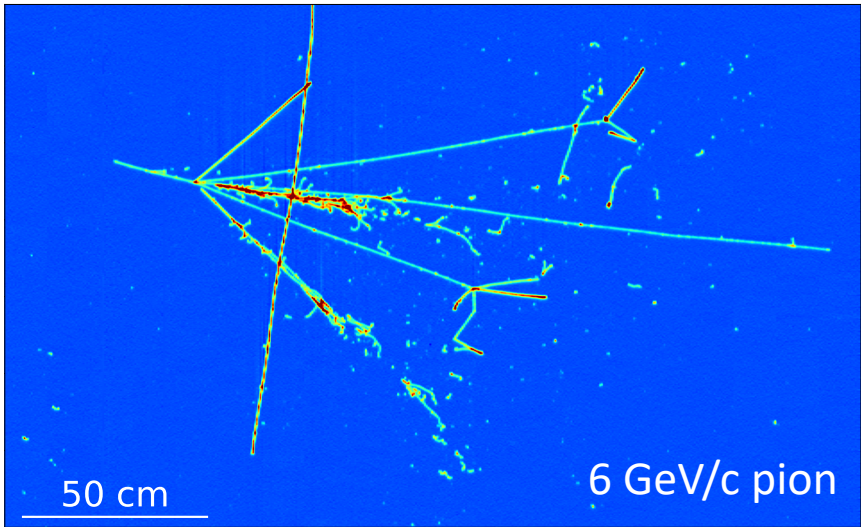
- Two ~1kt LArTPC prototypes for the DUNE far detector at CERN
- Test of component installation, commissioning, and performance
- ProtoDUNE-SP operating since 2018; ProtoDUNE-DP since 2019





ProtoDUNE-SP Events

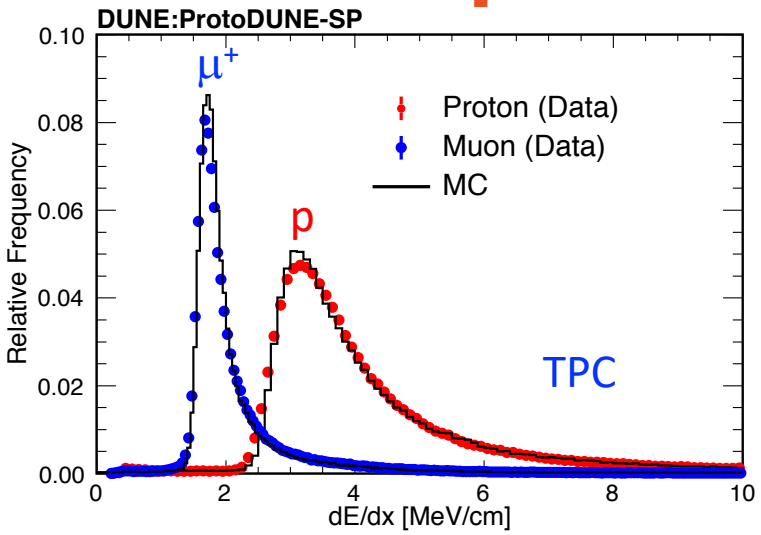


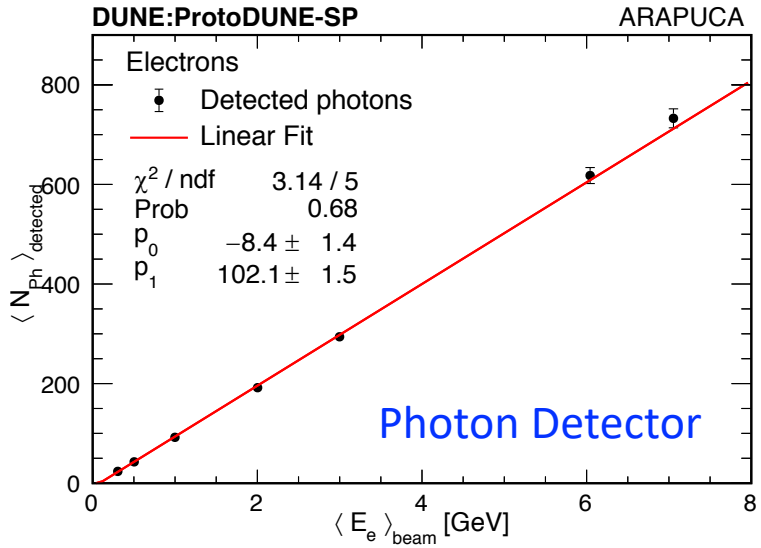


- Exposed to test beams of pions, protons, kaons and electrons between 0.3 and 7 GeV/c.
  - Study detector response and measure hadron-Ar cross sections
- Excellent signal-to-noise ratio
  - S/N ratio > 20 in all 3 wire planes (> 40 for collection plane)

ProtoDUNE-SP Performance Paper

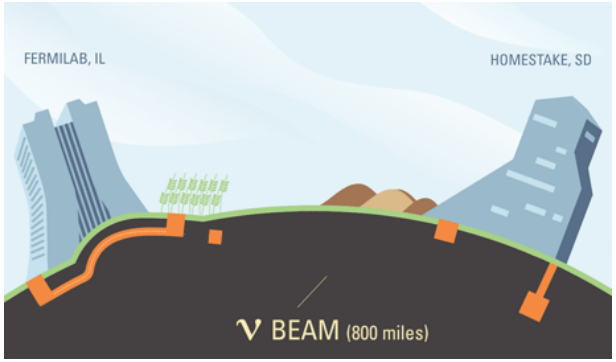
- First DUNE physics results!
- Over 600 days of stable running conditions
- Excellent TPC and photon detector responses
- ProtoDUNE-SP performance meets or largely exceeds the requirements for DUNE Far Detector.



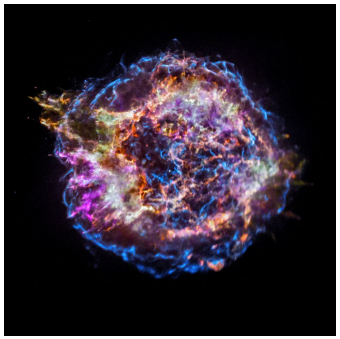


arXiv:2007.06722: First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform

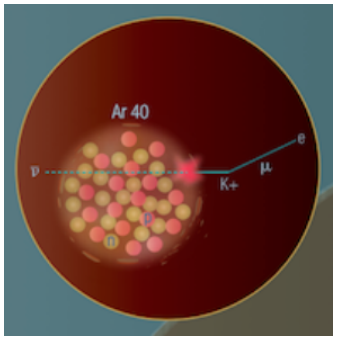
DUNE Physics Goals



Long-baseline neutrino oscillation

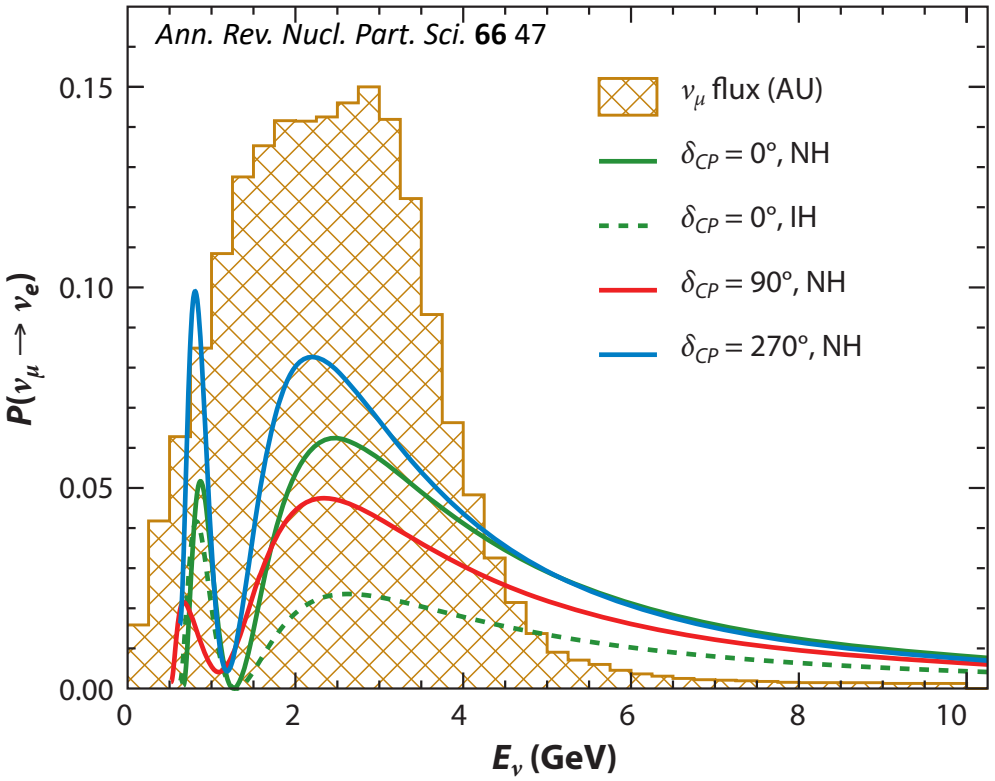


Supernova neutrinos

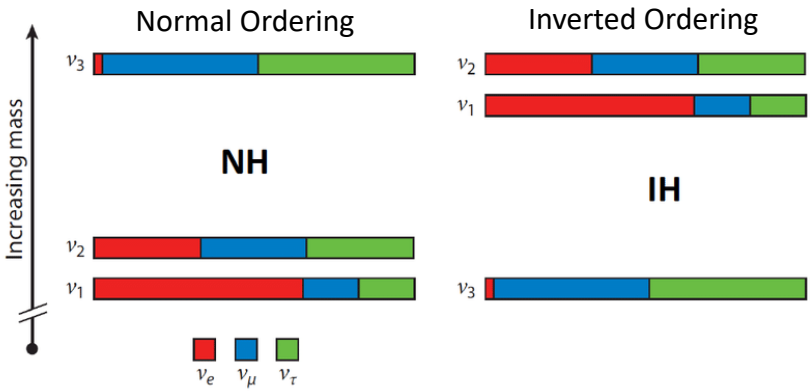


Beyond standard model processes

Neutrino Oscillations



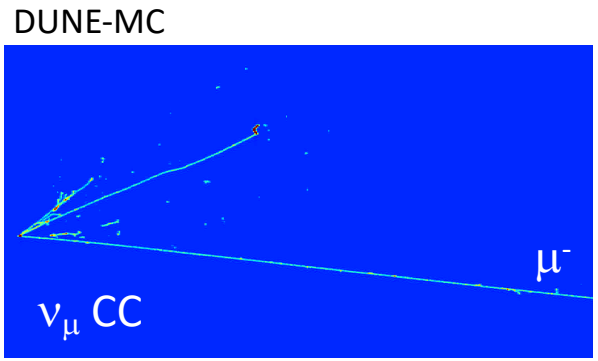
- δ_{CP}: CP violating phase in the neutrino mixing matrix.
- Neutrino mass ordering:

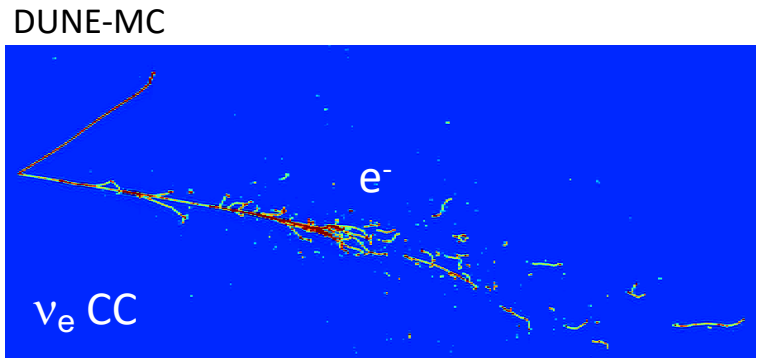


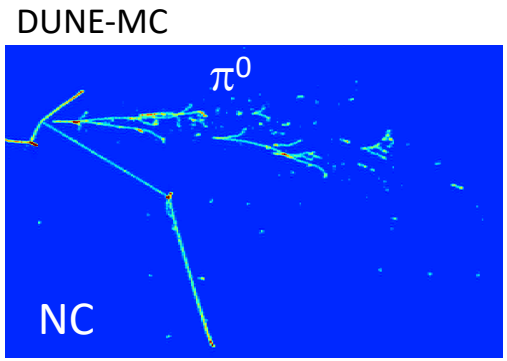
To measure δ_{CP} and neutrino mass ordering

- Select ν_μ and ν_e events in the Far Detector
- Compare energy spectra with predictions using different parameters

Event Classification







- Developed a convolutional visual network (CVN) to select ν_μ CC and ν_e CC signal and reject NC background.

	ν_e	ν_μ
Efficiency	85%	90%
Purity	91%	90%

(Assuming FHC, NH, δ_{CP}=0)

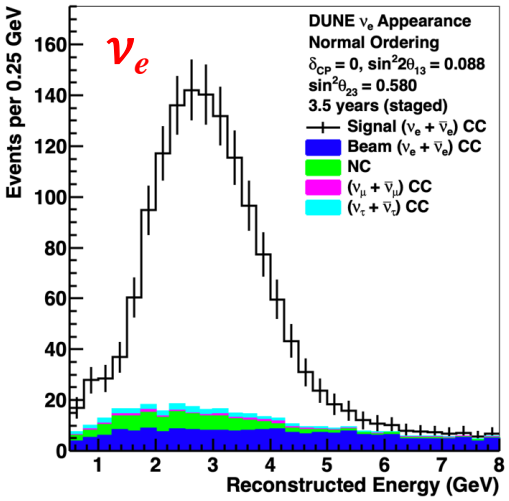
arXiv:2006.15052: Neutrino interaction classification with a convolutional neural network in the DUNE far detector

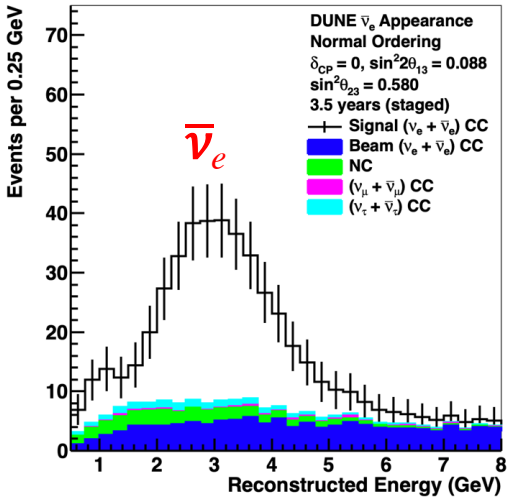
FD Selected Spectra

Neutrino Mode

Antineutrino Mode

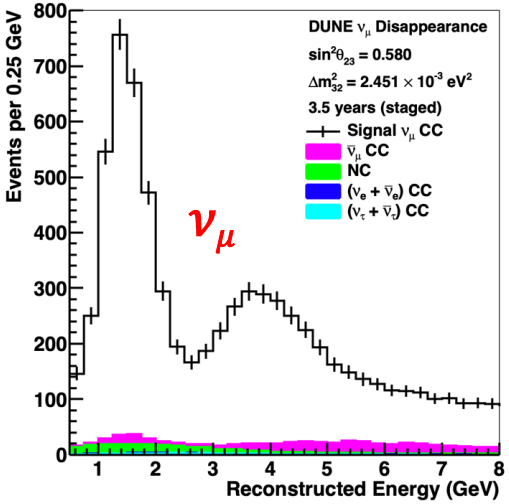
ν_e appearance

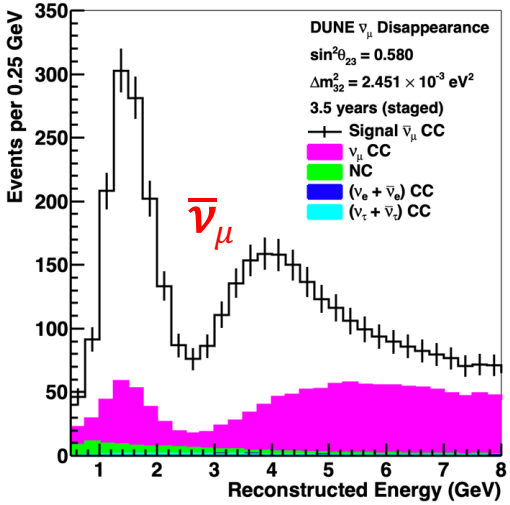




~1000 $\nu_e/\bar{\nu}_e$ events in 7 years

ν_μ Disappearance

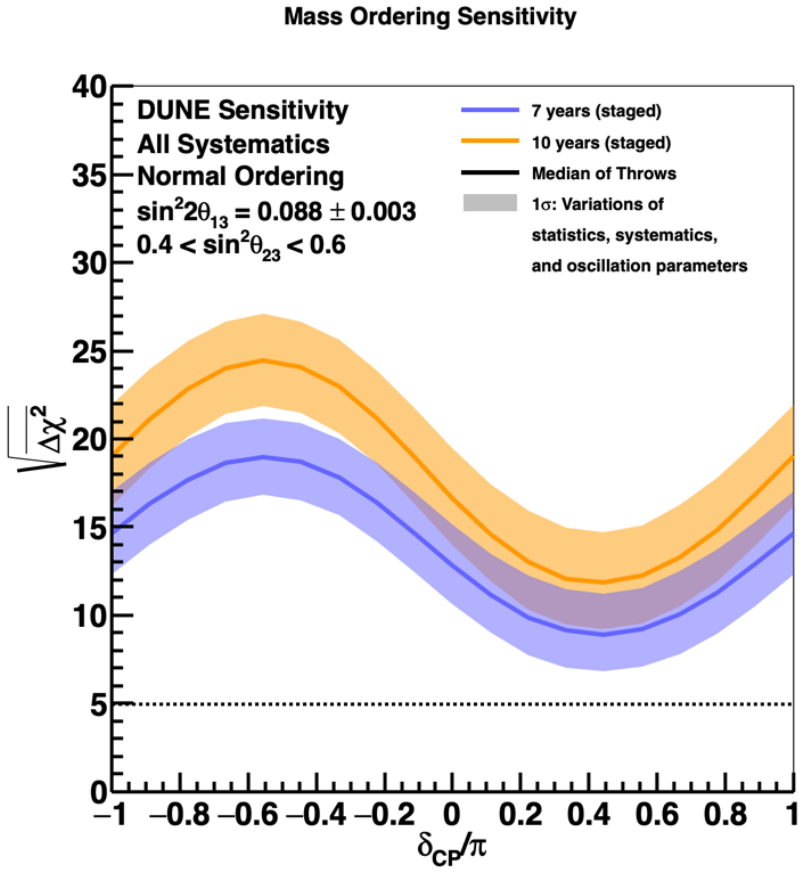


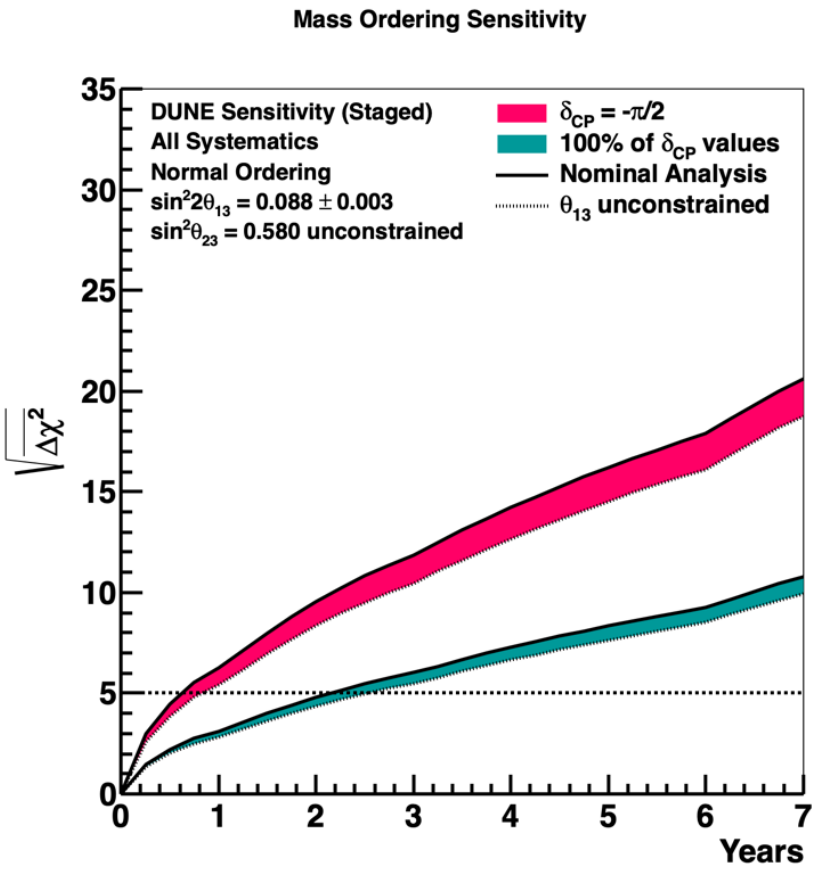


~10,000 $\nu_\mu/\bar{\nu}_\mu$ events in 7 years

NOvA: ~60 $\nu_e/\bar{\nu}_e$ ~200 $\nu_\mu/\bar{\nu}_\mu$
PRL 123 (2019) 15, 151803

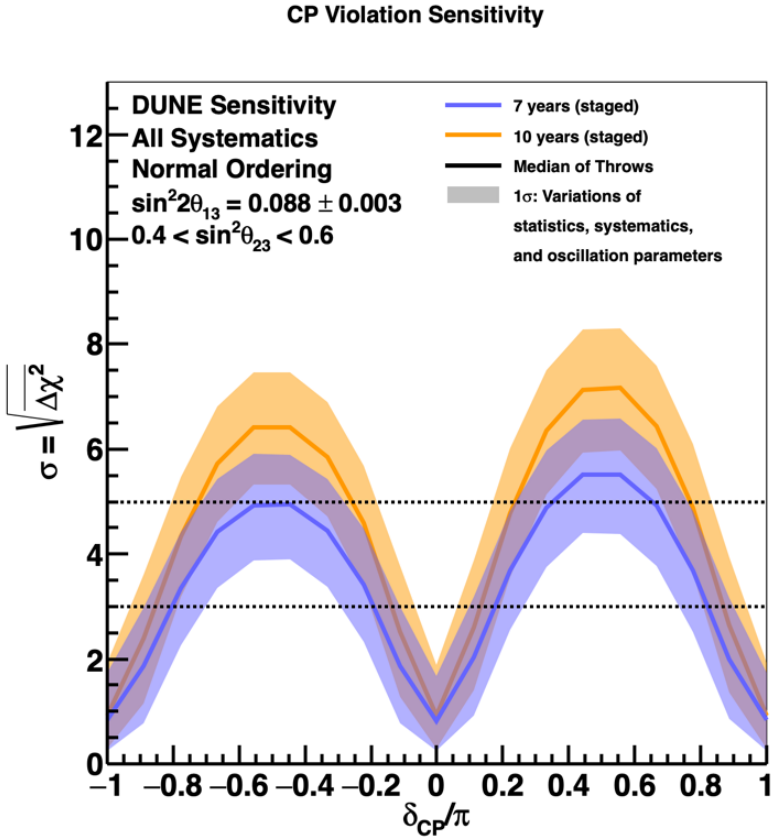
Mass Ordering Sensitivity

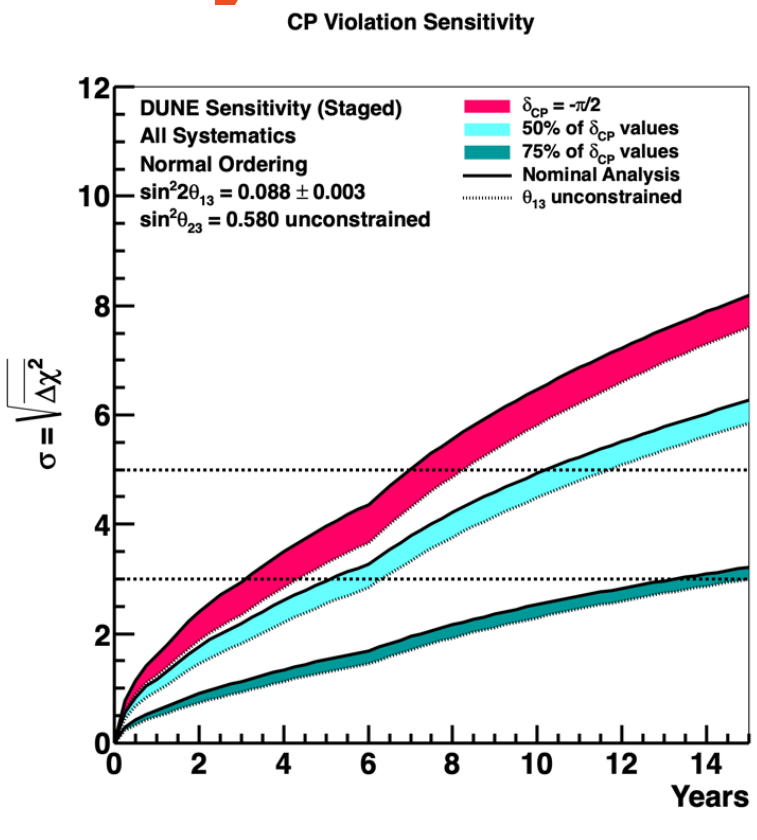




- Unambiguous determination of neutrino mass ordering within first few years.

CP Violation Sensitivity

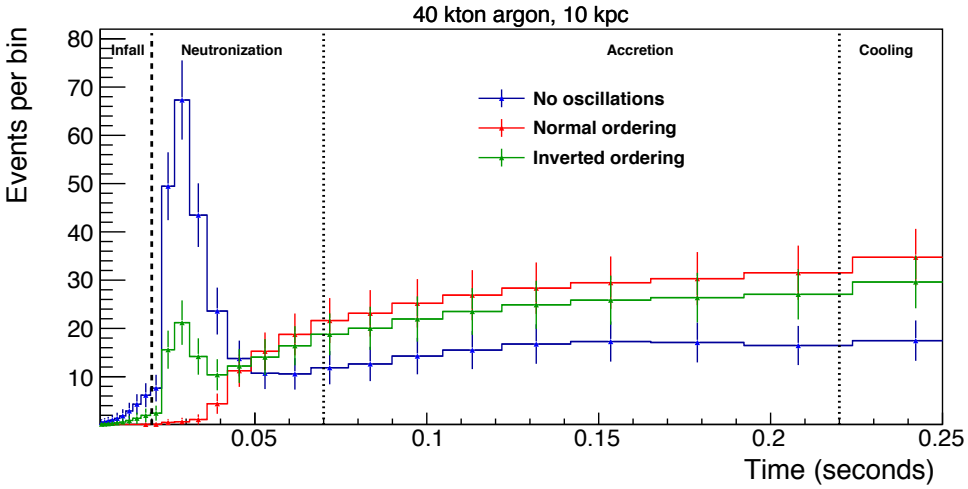


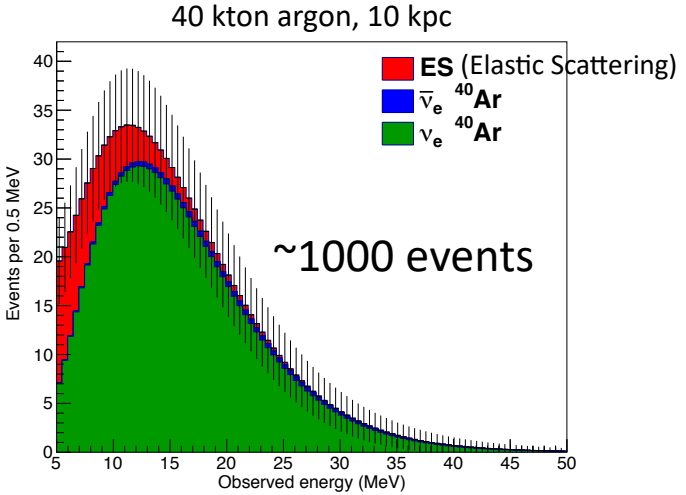


- Significant CP violation discovery potential over wide range of true δ_{CP} values in 7-10 years (staged)

arXiv:2006.16043: Long-baseline neutrino oscillation physics potential of the DUNE experiment

Core-Collapse Supernovae



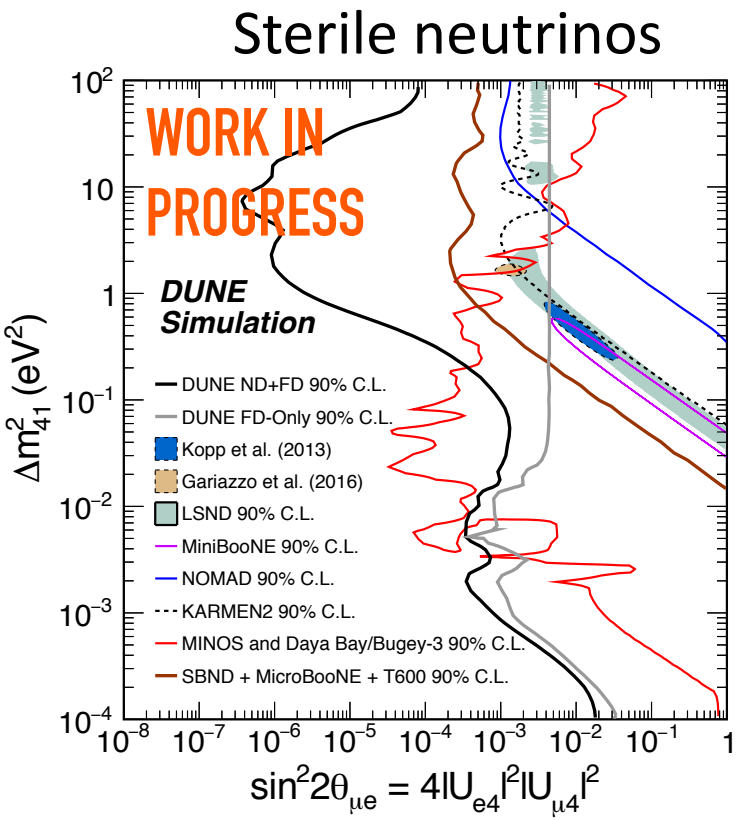


- Supernova neutrinos shed light on the astrophysics of core collapse as well as the properties of neutrinos.
- Unique opportunities for DUNE
  - Low threshold to detect MeV neutrinos
  - Most sensitive to ν_e: complementary to water Cherenkov detectors (e.g. Hyper-K, IceCube), which are most sensitive to $\bar{\nu}_e$

In preparation: Supernova Neutrino Burst Detection with the Deep Underground Neutrino Experiment

BSM Physics and Prospects in DUNE

- **Non-standard short-baseline and long-baseline oscillation phenomena:** mixing with sterile neutrinos, non-standard neutrino interactions, non-unitarity of the mixing matrix, CPT violation.
- **Searches for new phenomena at the FD benefitting from its large mass and resolution:** boosted dark matter, nucleon decay.
- **Searches for new phenomena/particles at the ND related to the beam and its interactions with the detector:** trident interactions, heavy neutral leptons, low- mass dark matter.

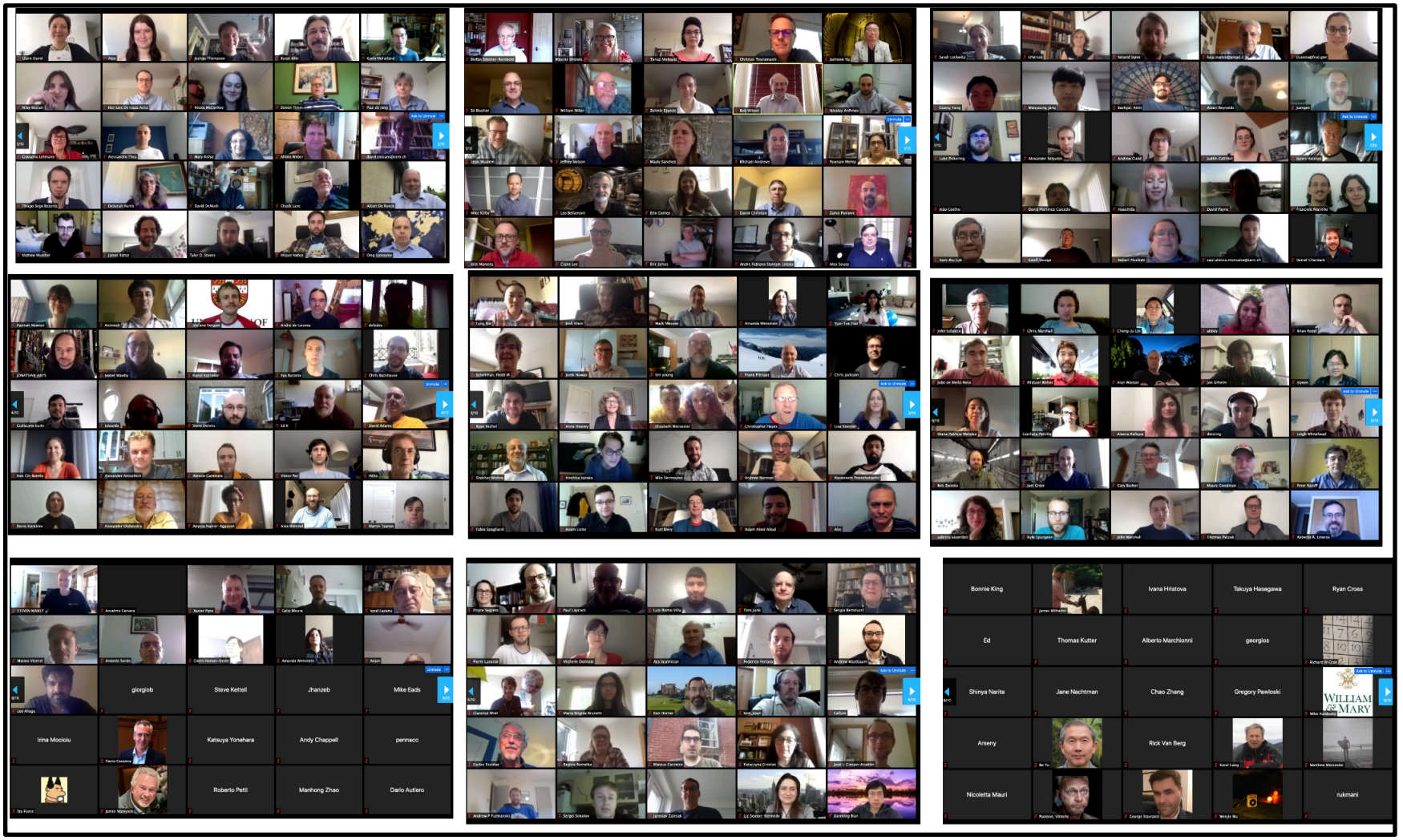


In preparation: Prospects for Beyond the Standard Model Physics Searches at the Deep Underground Neutrino Experiment

Summary

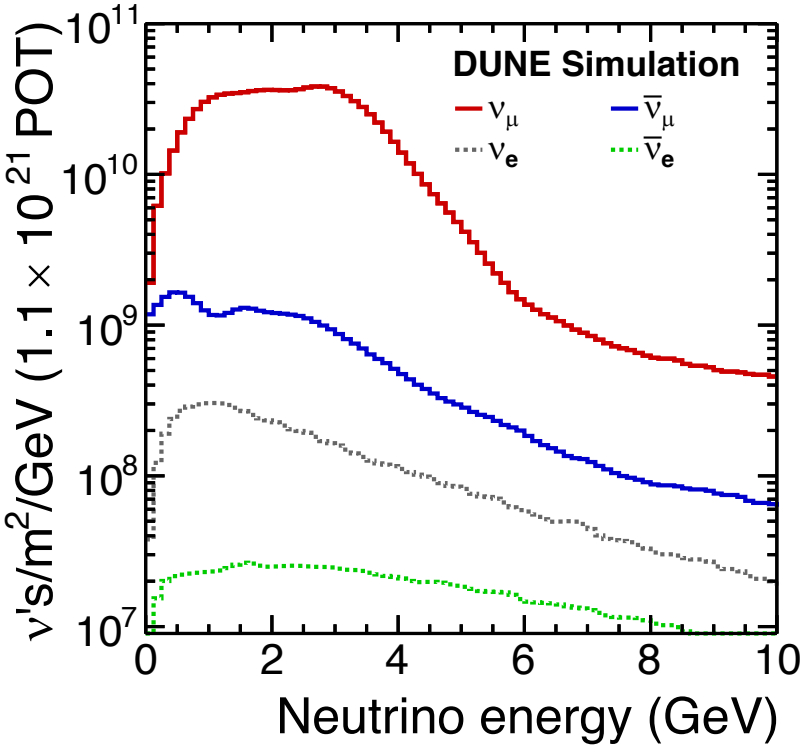
- DUNE making good progress toward enabling high-precision neutrino measurements in next decade
  - **Exciting physics program** including neutrino oscillations, detection of MeV neutrinos, and many BSM searches
- Technical milestones:
  - Technical Design Report for DUNE FD complete
    - arXiv:2002.02967, arXiv:2002.03005, arXiv:2002.03008, arXiv:2002.03010
  - ProtoDUNEs successfully operating at CERN with first results
    - arXiv:2007.06722
  - Conceptual Design Report for DUNE ND under review
- Start of exciting physics in the second half of the decade

Thank you!

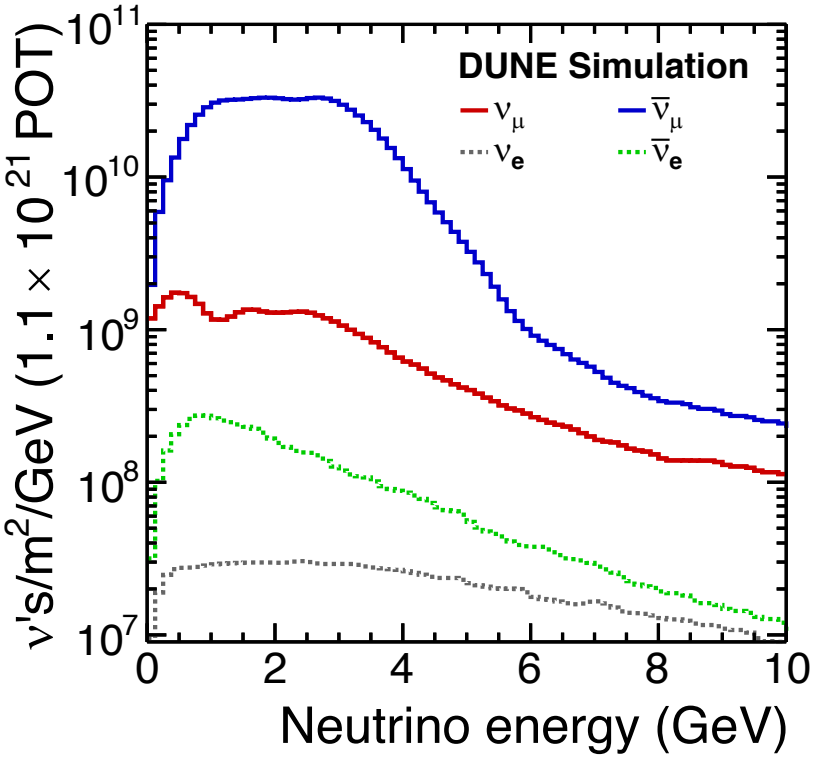

giorgiob
Steve Kettell
Jhanzeb
Mike Eads
Irina Mocioiu
Katsuya Yonehara
Andy Chappell
pennacc
Roberto Petti
Manhong Zhao
Dario Autiero
Bonnie King
Ivana Hristova
Takuya Hasegawa
Ryan Cross
Ed
Thomas Kutter
Alberto Marchionni
georgios
Shinya Narita
Jane Nachtman
Chao Zhang
Gregory Pawloski
Arseny
Rick Van Berg
Nicoletta Mauri
rukmani

Neutrino Flux

Neutrino Mode:



Antineutrino Mode:



- The beam is wideband and dominated by ν_μ flux.
- Neutrino beam line design optimized for CP violation sensitivity

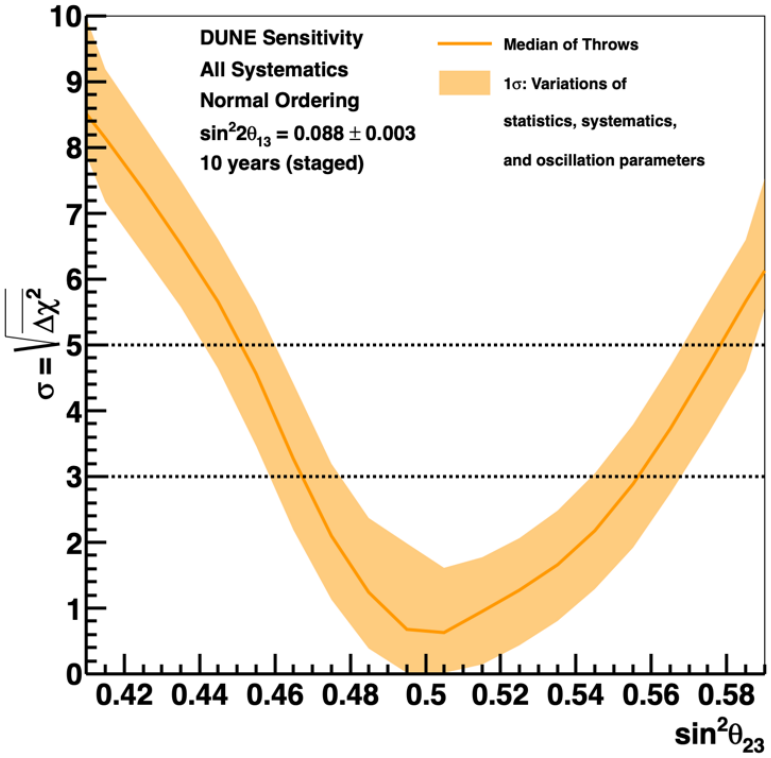
Excellent Detector Performance

Detector parameter	ProtoDUNE-SP performance	DUNE specification
Average drift electric field	500 V/cm	250 V/cm (min) 500 V/cm (nominal)
LAr e-lifetime	> 20 ms	> 3 ms
TPC+CE Noise Signal-to-noise ⟨SNR⟩	 (C) 550 e, (I) 650 e ENC (raw) (C) 48.7, (I) 21.2 (w/CNR)	 < 1000 e ENC
CE dead channels	0.2%	< 1%
PDS light yield	1.9 photons/MeV (@ 3.3 m distance)	> 0.5 photons/MeV (@ cathode distance - 3.6 m)
PDS time resolution	14 ns	< 100 ns

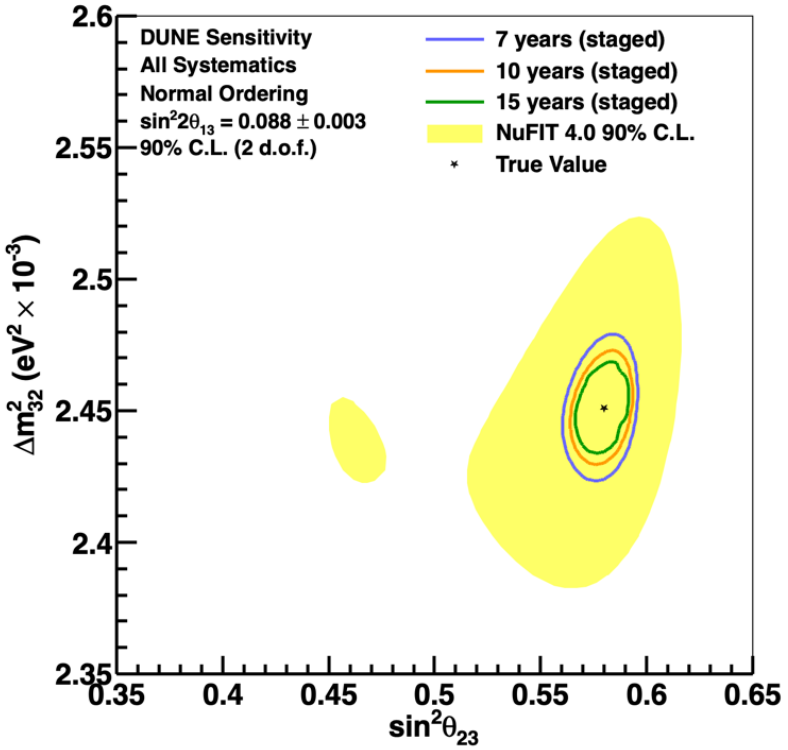
- ProtoDUNE-SP performance meets or largely exceeds the requirements for DUNE Far Detector.
- ProtoDUNE II is scheduled to start data-taking in 2022
  - Full characterization of “Module 0” for DUNE Far Detector

Other Parameters

Octant determination



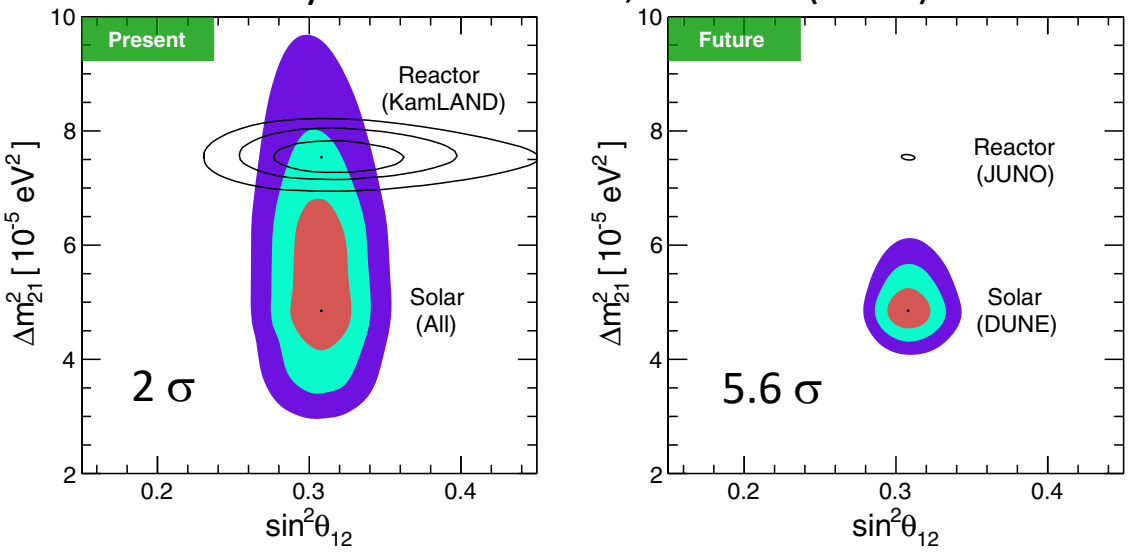
Δm^2_{32} vs $\sin^2\theta_{23}$

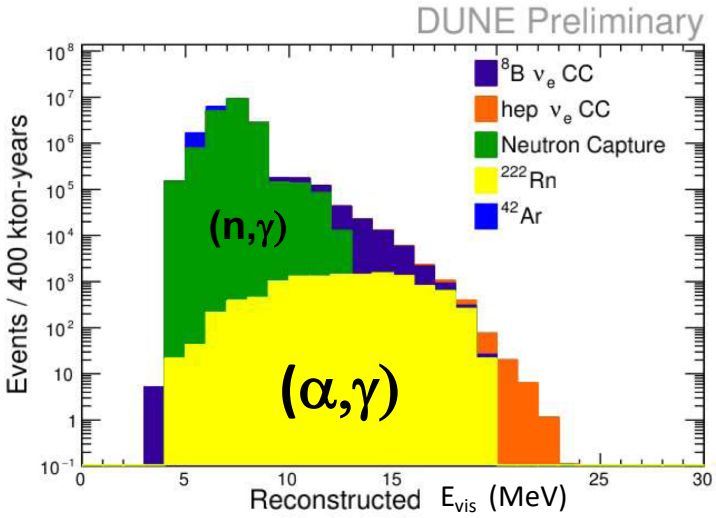


- Significant improvement in precision measurement of atmospheric mixing parameters
- arXiv:2006.16043: Long-baseline neutrino oscillation physics potential of the DUNE experiment

Solar Neutrinos

Phys. Rev. Lett. 123, 131803 (2019)





- Tension between Solar neutrino and reactor neutrino measurements.
- DUNE is considering the potential sensitivity to solar neutrinos. This depends on the ability to trigger on very small energy depositions, and rejection of backgrounds due to neutrons and α.