The Deep Underground Neutrino Experiment

Neutrinos On (Through) the Horizon

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for the DUNE Collaboration

54th Fermilab Users Meeting

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Deep Underground Neutrino Experiment

Long-Baseline Neutrino Physics with DUNE

The DUNE Near Detector

The DUNE Far Detectors

The Prototypes

Neutrino Oscillation Physics

Beyond the Beam Program

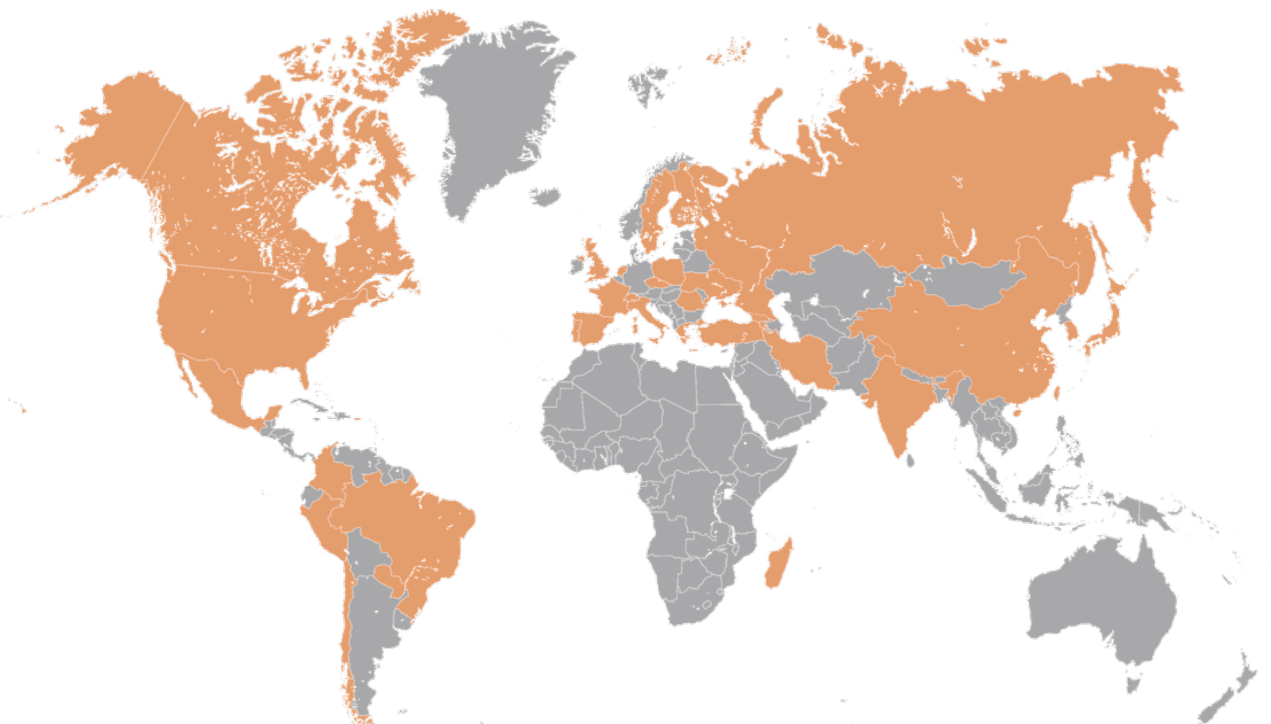
What's *up* with those neutrinos?

The DUNE Collaboration

1300+
Scientists

200+
Laboratories and universities

30+
Countries

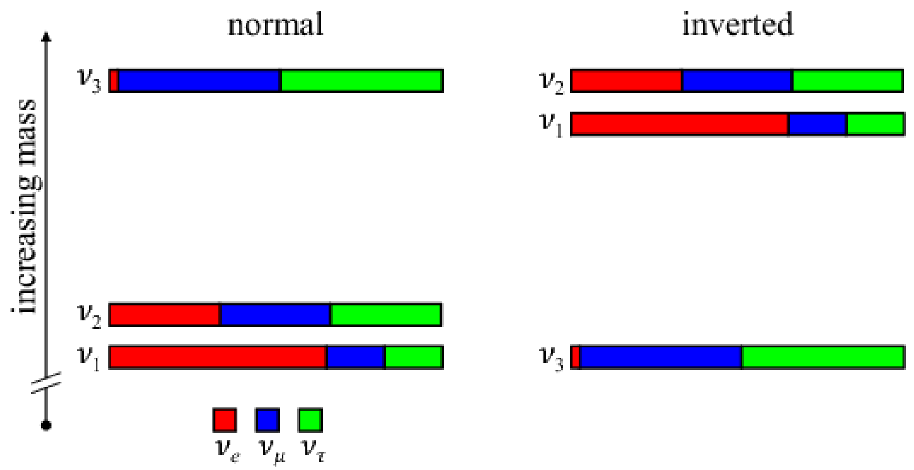


Someone's always connected on slack. ☺

Long Baseline Neutrino Physics

- Exciting physics potential through accessible long-baseline L / E
  - GeV muon neutrino and muon antineutrino beams, ~1000 km distances

- Neutrino mass ordering
  - Which mass eigenstate is the lightest?
  - Implications for 0νββ decay, cosmology, quark/lepton unification, etc.



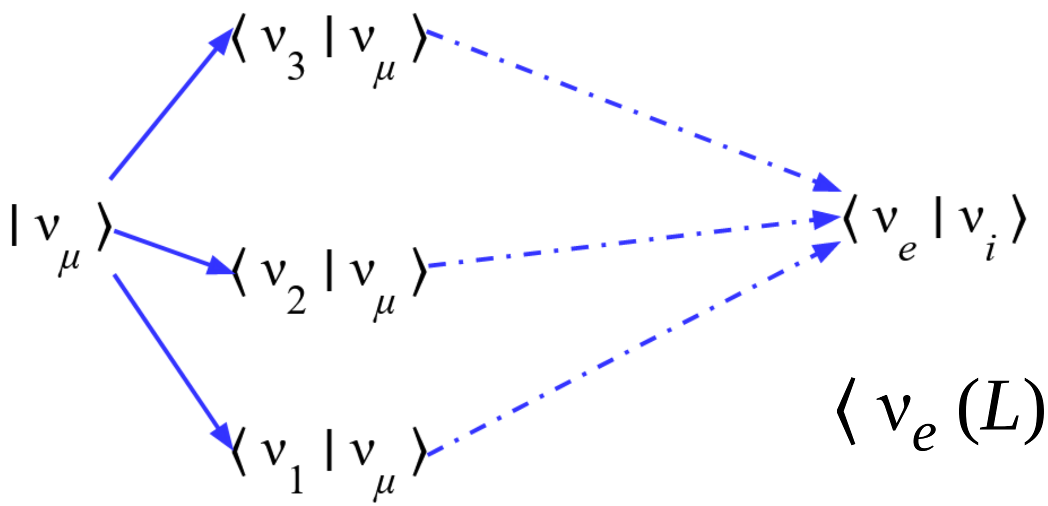
- Charge-Parity symmetry violation
  - Parameterized by phase δ_{CP}
  - Potential to address baryon asymmetry
  - Why is the universe so completely matter-dominated?

$$\nu_\mu \to \nu_e \overset{?}{\Leftrightarrow} \bar{\nu}_\mu \to \bar{\nu}_e$$

Long Baseline Neutrino Physics

Neutrino Flavor Oscillations

- *Produced* in a flavor eigenstate
- *Propagate* in a mass eigenstate
- *Interact* in a flavor eigenstate



$$\langle \nu_e(L) | \nu_\mu(0) \rangle \neq 0$$

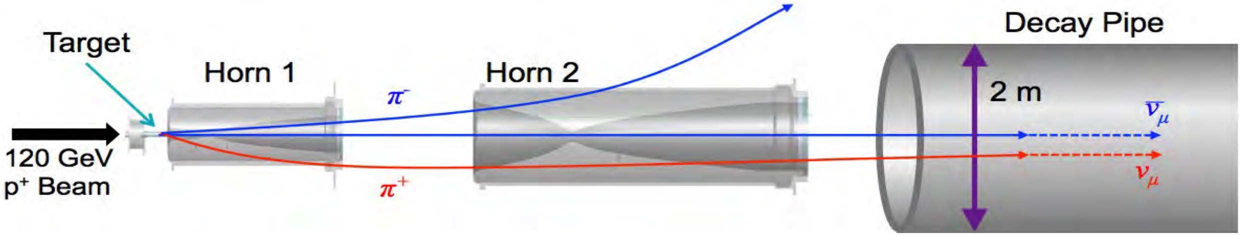
$$\begin{array}{c} \nu_\alpha \\ \nu_\beta \end{array} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$
$$\qquad\quad \nu_1 \qquad\quad \nu_2$$

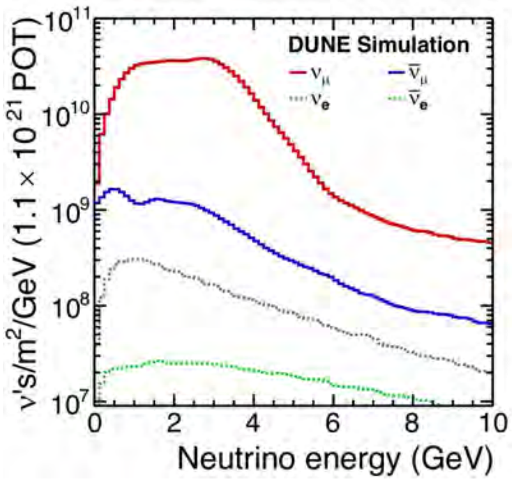
Two-Flavor Version (for simplicity)

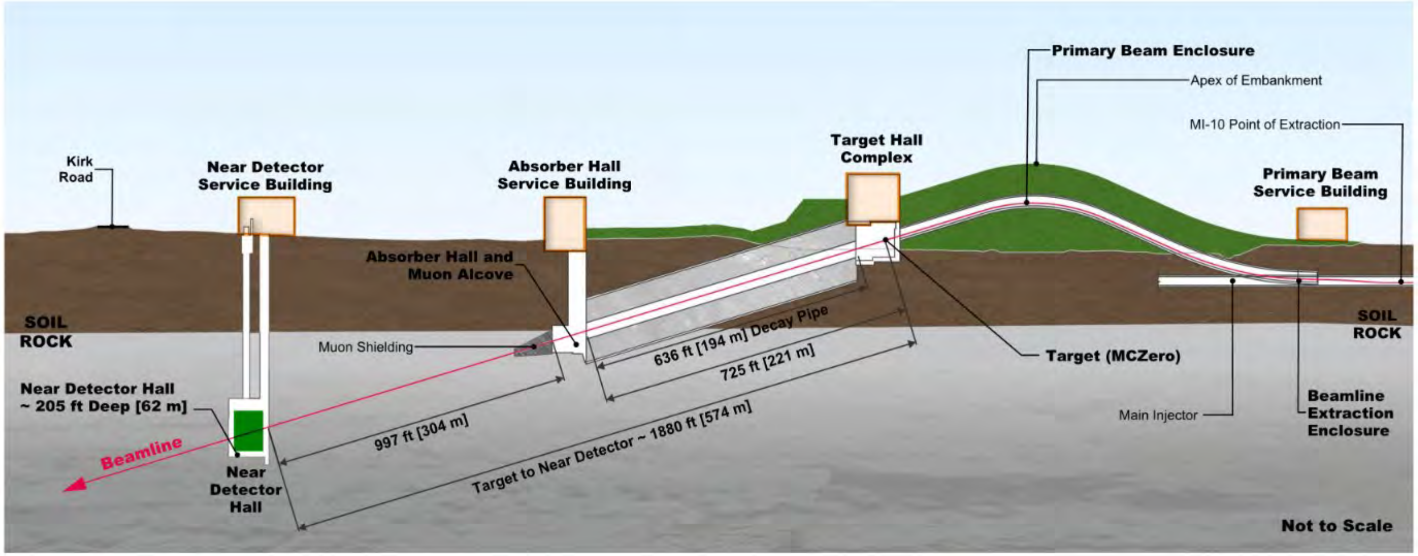
$$P_{\alpha\beta} = \sin^2(2\theta)\sin^2\left(1.27\Delta m^2\,[\mathrm{eV}^2]\frac{L\,[\mathrm{km}]}{E\,[\mathrm{GeV}]}\right)$$

Long Baseline Neutrino Facility

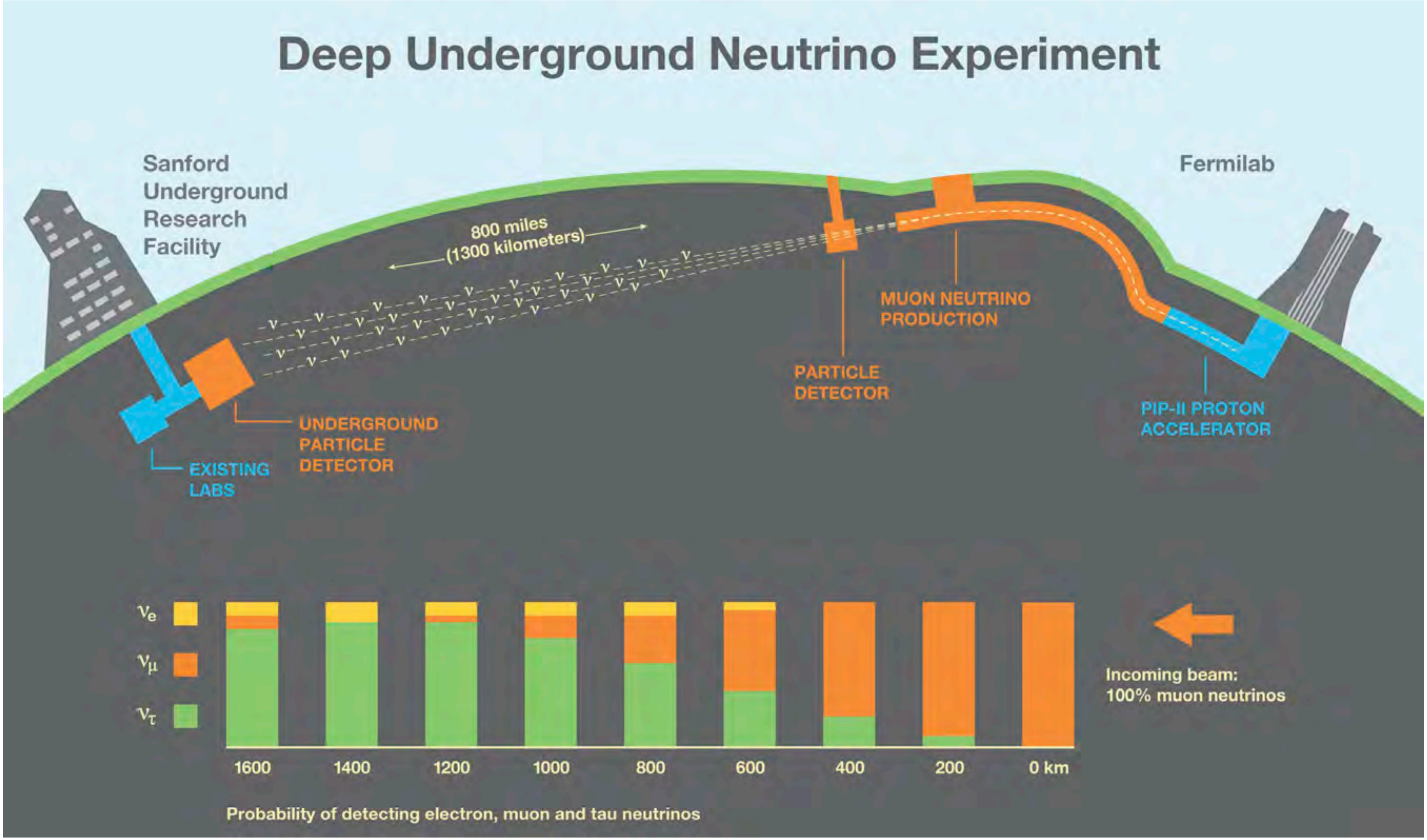
- Beam line design under way
  - 60-120 GeV proton beam
  - 1.2 MW by late 2020's, upgradable to 2.4 MW







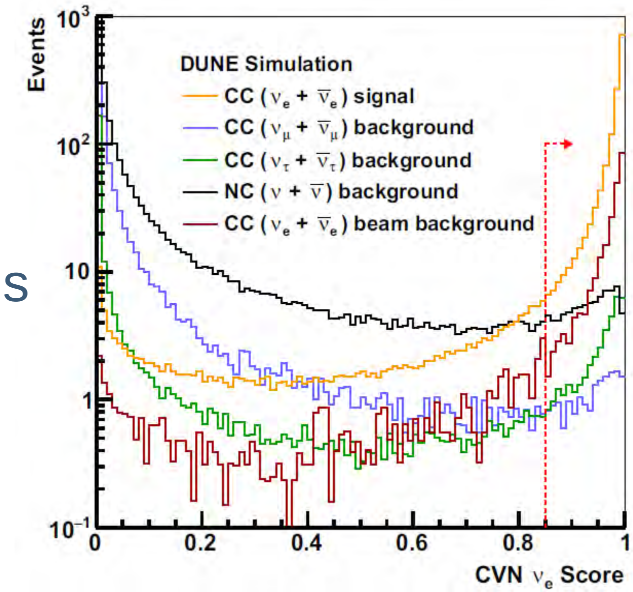
The Neutrino Experiment

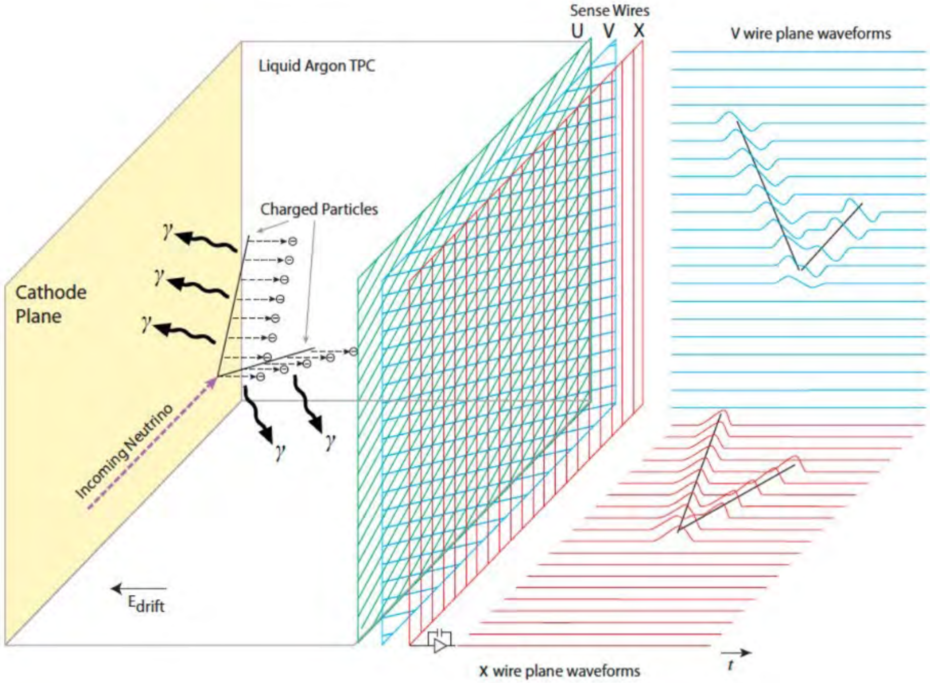


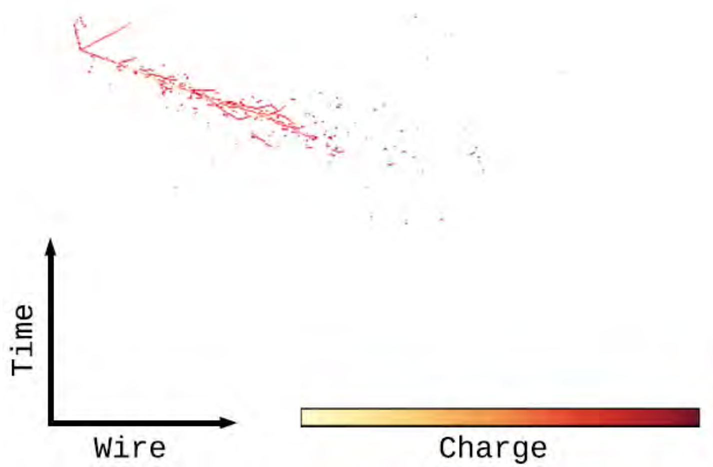
The Neutrino Experiment

Liquid Argon Time Projection Chamber

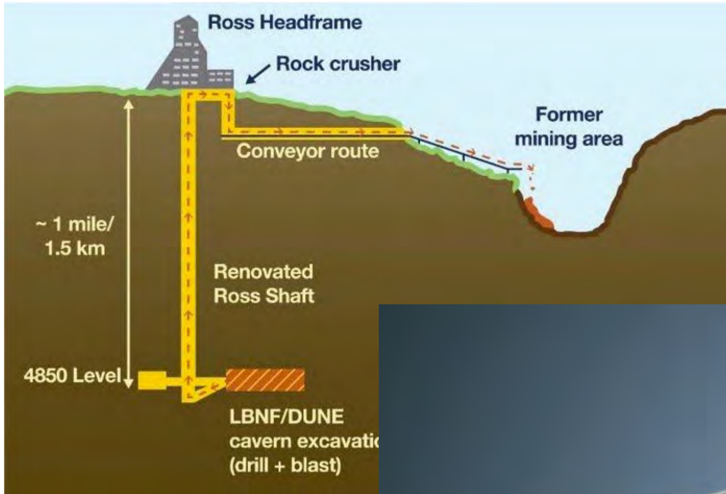
- primary detector technology
- reconstruct detailed images of events
- apply advanced machine learning algorithms for event classification and reconstruction





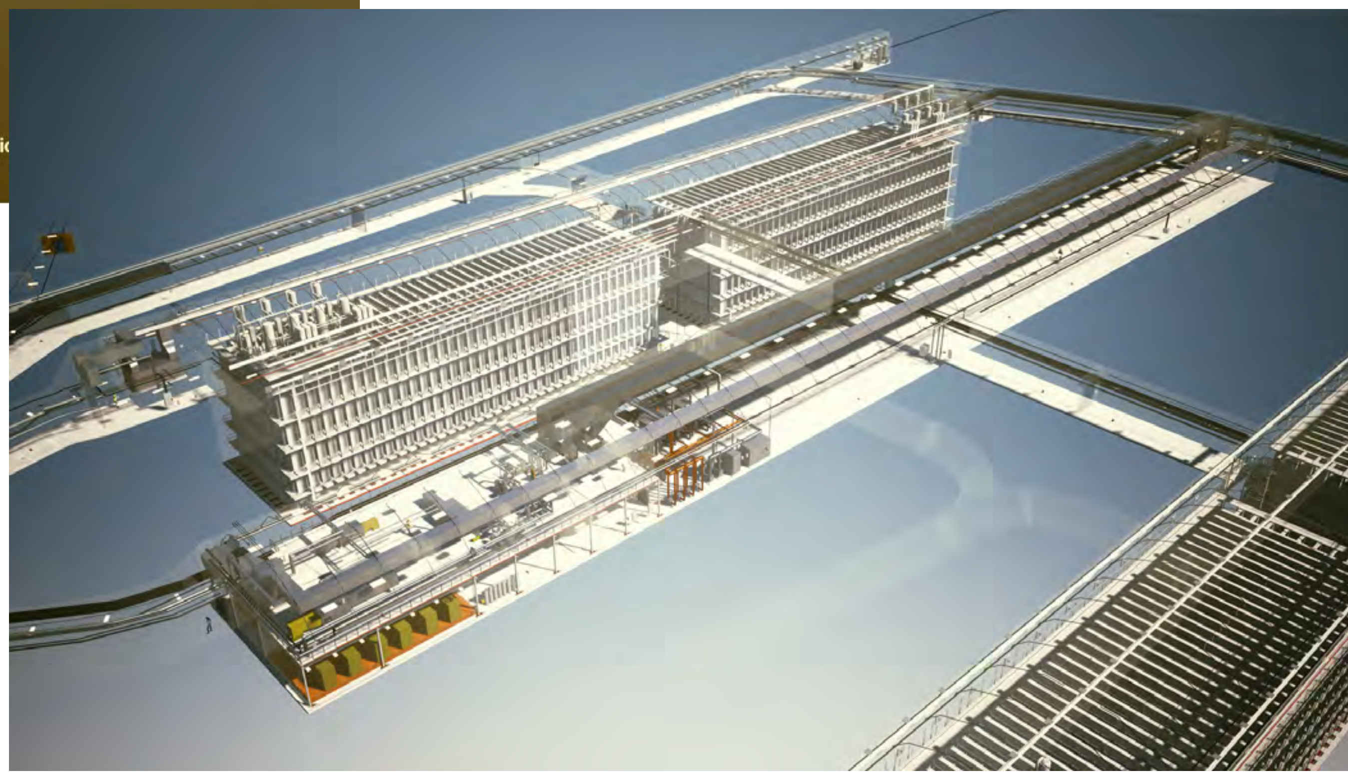


Far Detector Facility



Sanford Underground Research Facility (SURF) in Lead, SD

- Excavation at former Homestake goldmine at 4850-ft level underway



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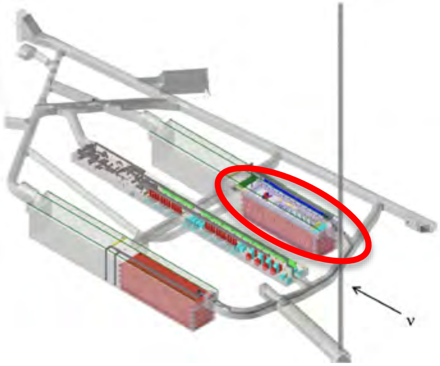
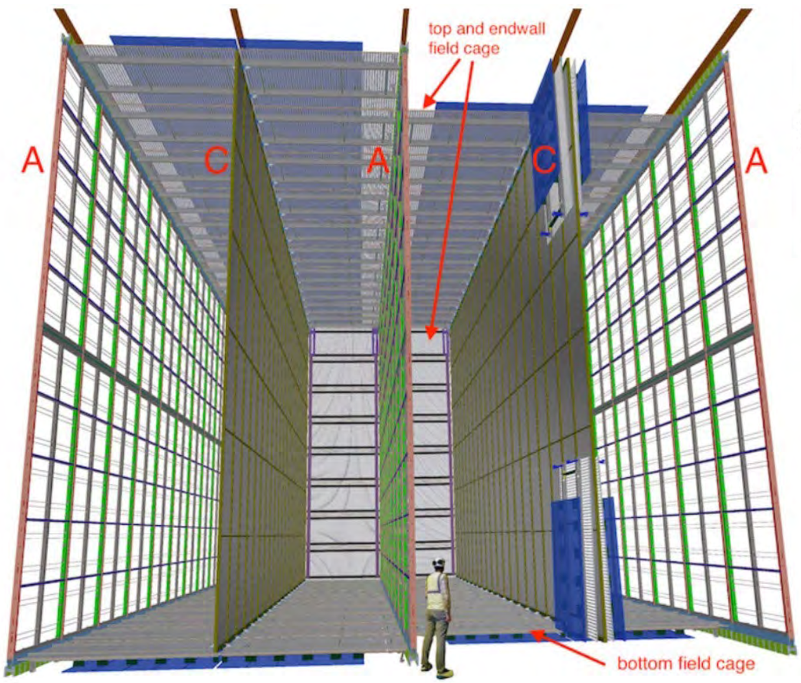
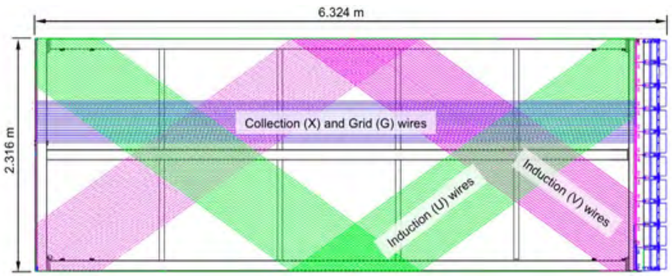
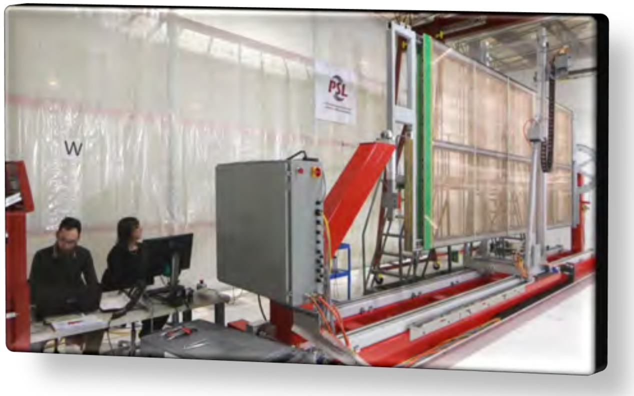


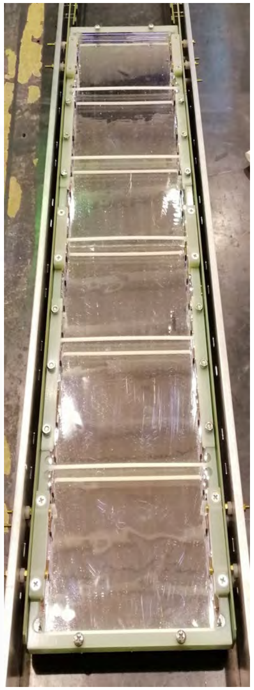
FD Module 1 – Horizontal Drift

- 4 drift volumes, 3.6 m drift w/ E = 500 V/cm (HV = -180 kV)
- 150 anode plane assemblies
  - each with 4 wire planes – grid | induction ×2 (wrapped) | collection
- X-ARAPUCA light trapping scintillation detectors (10 per APA)

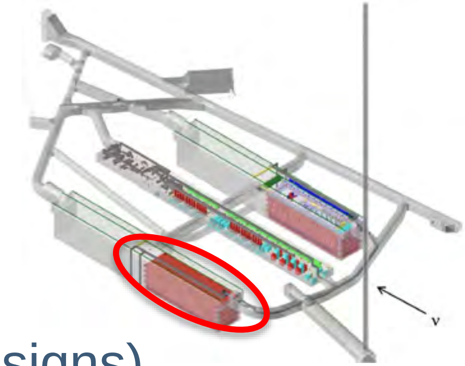






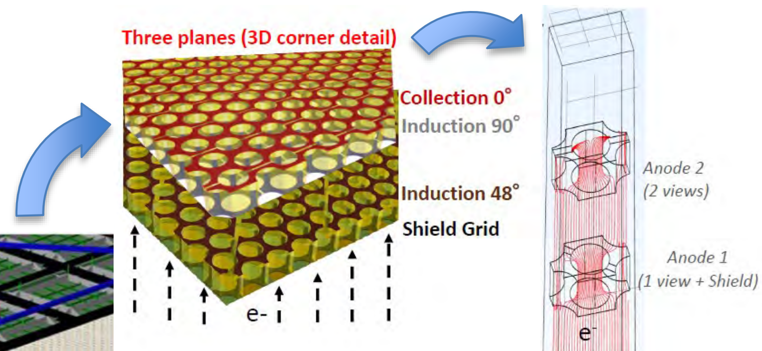


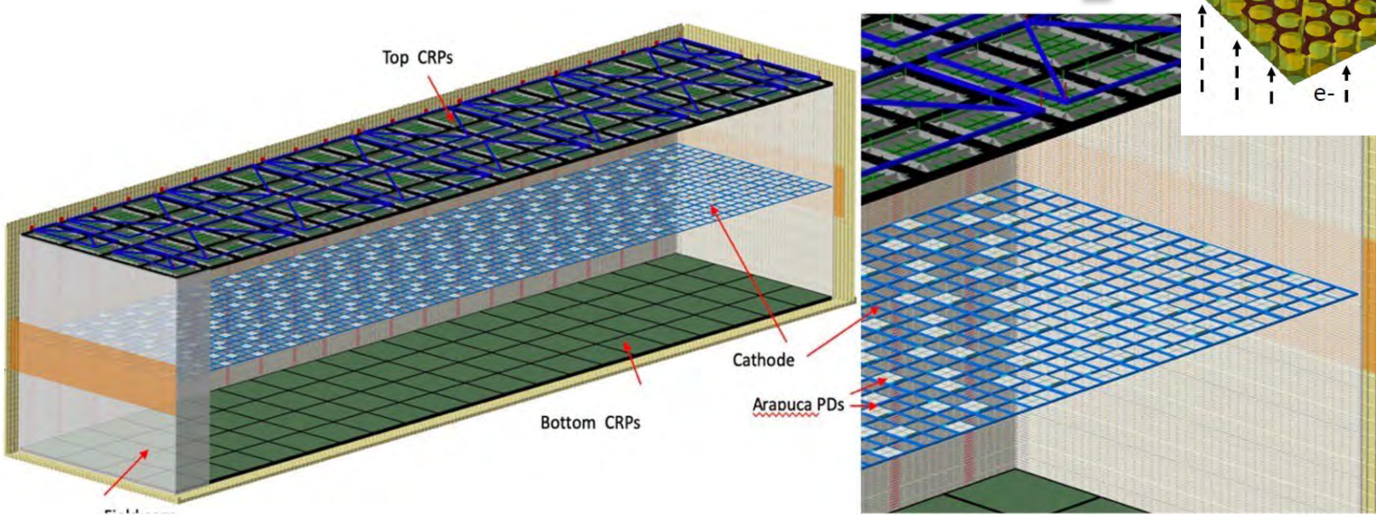
Far Detector Facility



FD Module 2 – Vertical Drift

- single-phase LArTPC (evolution from dual-phase designs)
- 6-meter drift ×2 requires 300 kV HV on (central) cathode
- greater X-ARAPUCA coverage (cryostat walls and cathode plane)
- ongoing R&D program at FNAL, CERN
  - dedicated 50 liter LAr-TPC
  - large “cold-box” at CERN by late 2021





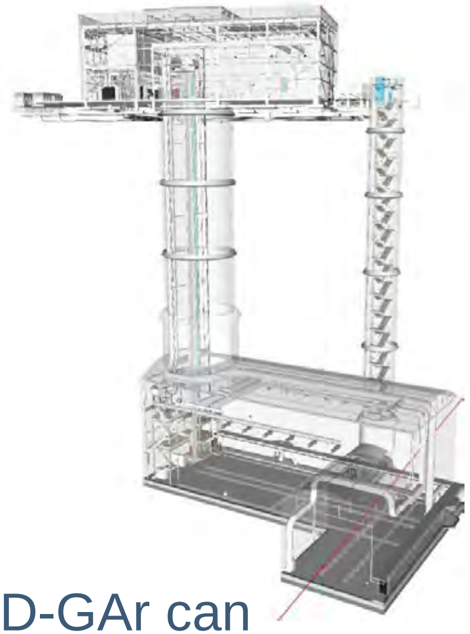
Far Detector Facility

FD Modules 3 and 4

- Third module likely to follow technology of FD Module 2
- Fourth cryostat (the "DUNE Module of Opportunity") open to ideas!
  - Check out the recent workshop at BNL to discuss range of concepts.

- Alternative single- and dual-phase charge collection schemes
- Innovations in detector design (light detectors, readout systems, etc.)
- Alternatives to liquid argon (e.g. liquid scintillator)
- Existing technologies as candidates (JUNO, COHERENT, DarkSide, etc.)

Near Detector Facility



Multiple complementary systems

ND-LAr
primary target, modular, pixelated charge read-out LAr-TPC (300 ton)

- Module 0 successfully tested at Univ. Bern

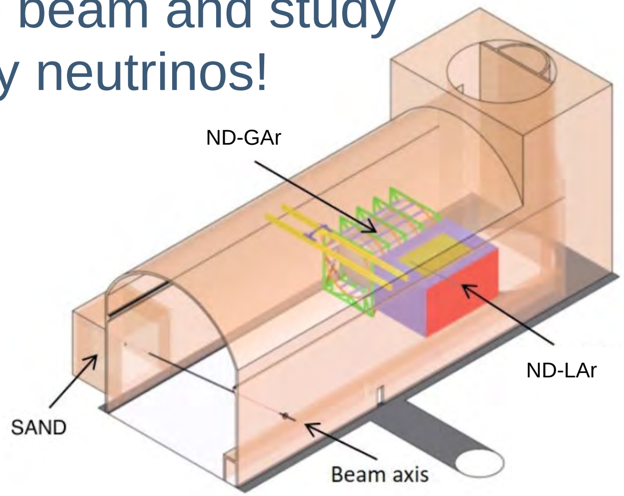
ND-GAr
high-pressure GAr-TPC, surrounded by ECAL and magnet

- muon spectrometer; nuclear interaction model constraints
- Day 1 – Temporary Muon Spectrometer (TMS)

PRISM
ND-LAr and TMS/ND-GAr can *move up to 30 m off-axis* to characterize beam and study lower-energy neutrinos!

SAND
inner tracker surrounded by 100 ton ECAL and SC magnet (0.6 T)

- on-axis beam monitor (spectrum/stability)



Prototypes

ProtoDUNE-SP and –DP

- Testing of the Far Detector technologies is well underway.
- Very Low Energy charged particle beams (~ 0.5 – 6 GeV) at CERN ENH1
- Two ~1 kton prototypes (single and dual phase detectors)

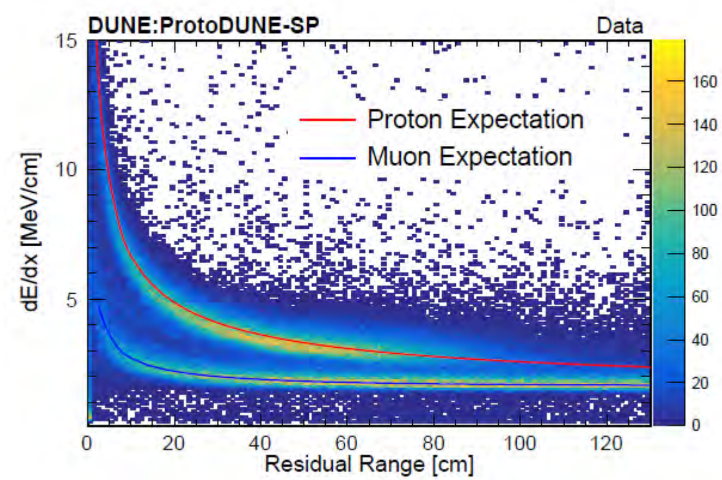
Prototypes

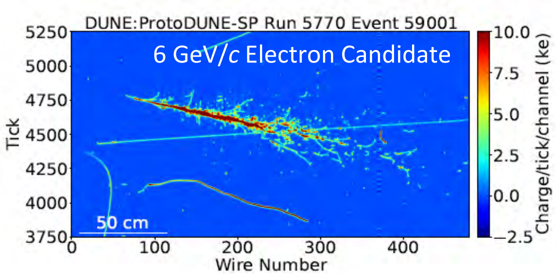
ProtoDUNE-SP and –DP

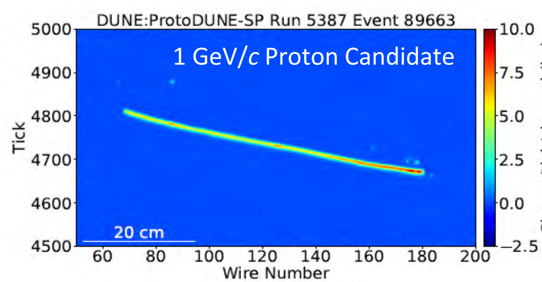
- Testing of the Far Detector technologies is well underway.
- Very Low Energy charged particle beams (~ 0.5 – 6 GeV) at CERN ENH1
- Two ~1 kton prototypes (single and dual phase detectors)

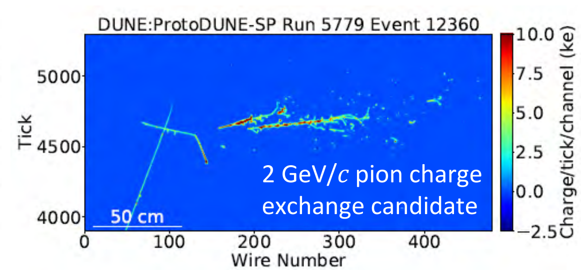
  - Single-Phase (ProtoDUNE-SP)
    - Event reconstruction/identification training
    - R&D site: low-energy calibration (neutron gun), xenon doping, Higher Voltage tests, …

  - Dual-Phase (ProtoDUNE-DP)
    - Development of CRP technology
    - Very High Voltage / large drift studies
    - Evolved into Vertical Drift



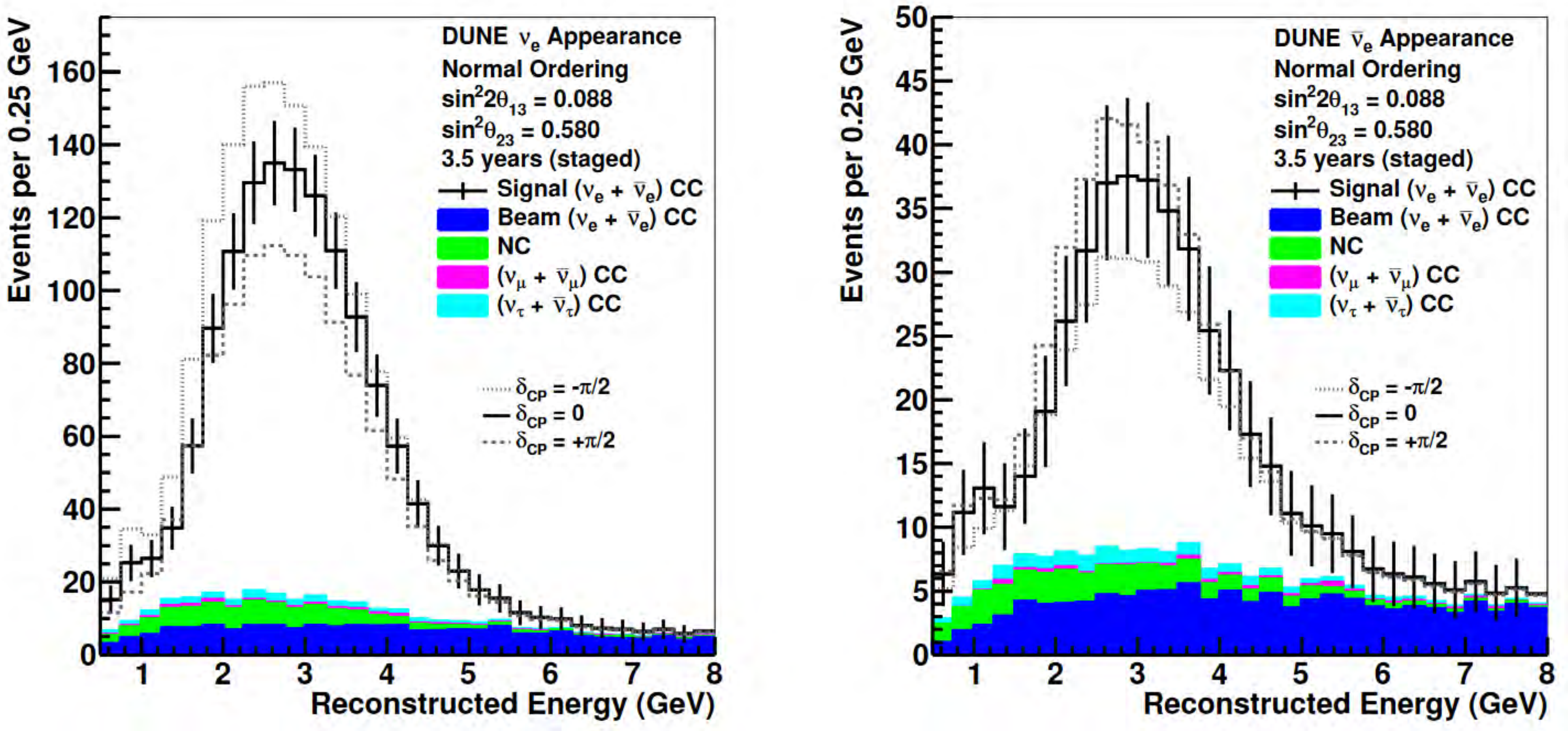






DUNE Physics Program

3-flavor Model Sensitivity (3.5 y ν-beam mode + 3.5 y $\bar{\nu}$-beam mode)



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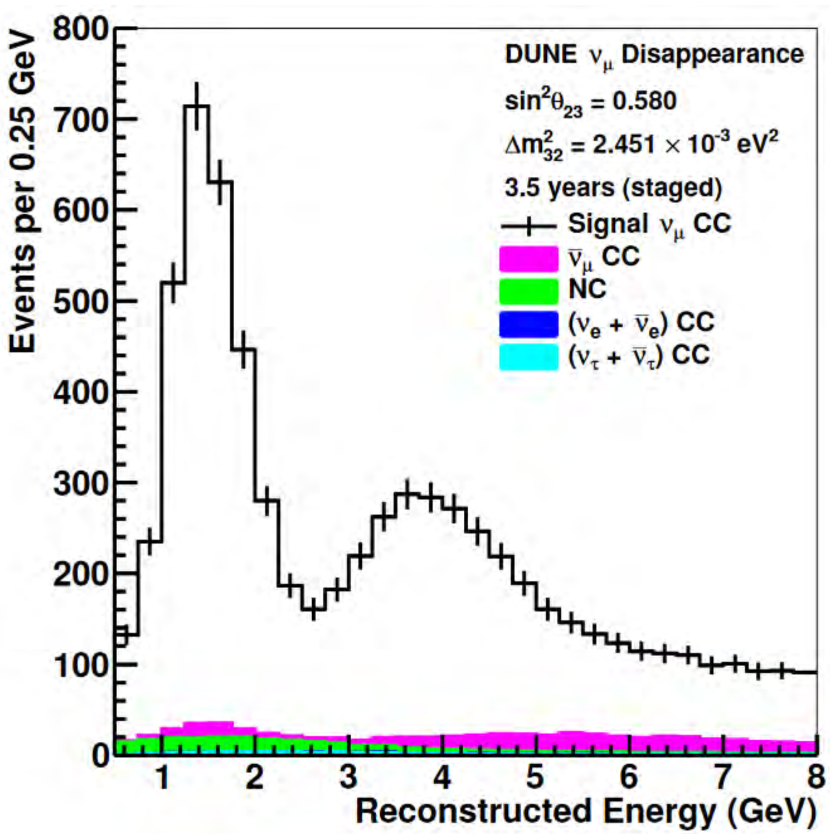
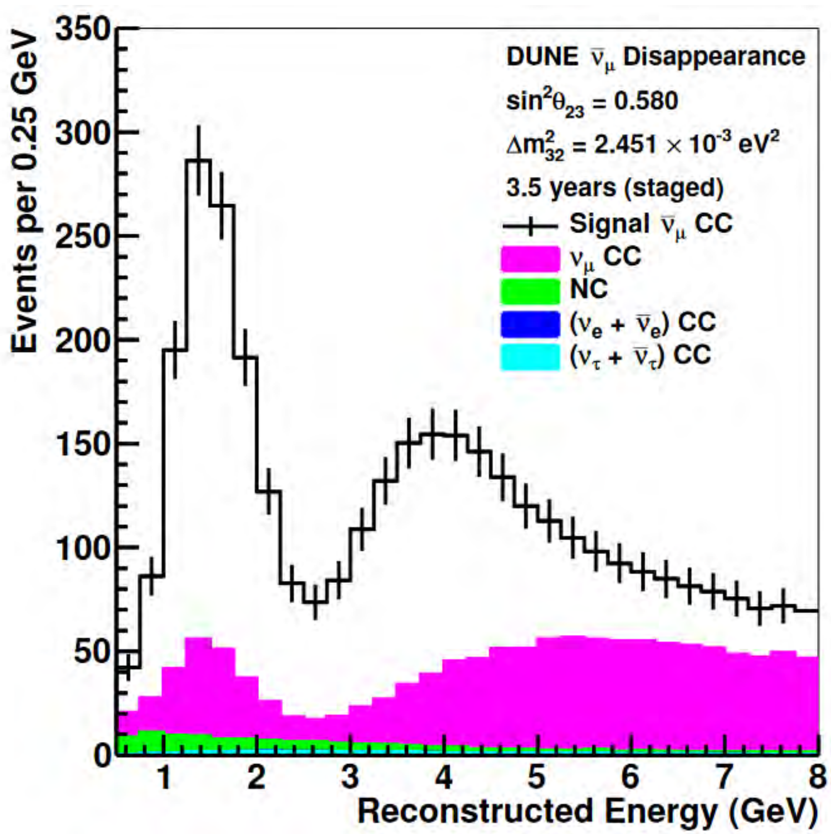
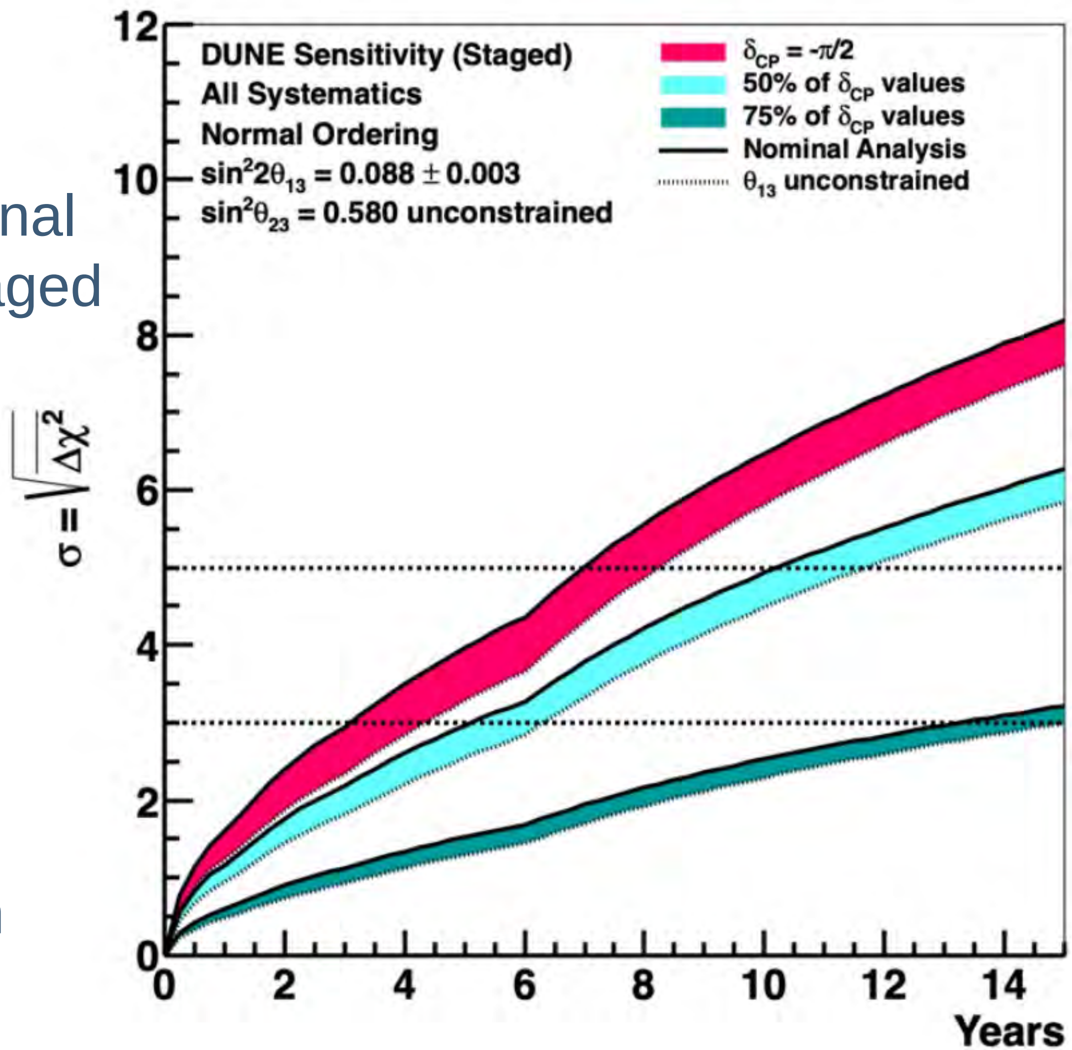




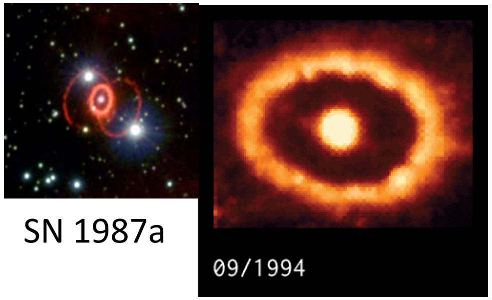
DUNE Physics Program

3-flavor Model Sensitivity

- 5σ sensitivity to δ for maximal CP-violation signal after about 7 years of staged installation/operation.
- 5σ sensitivity to about half of δ values after 10 years (staged).
- Ultimately cover about 75% of possible δ values (in the case of a minimal CP-violation signal, e.g. $\delta \approx 0$ or π)

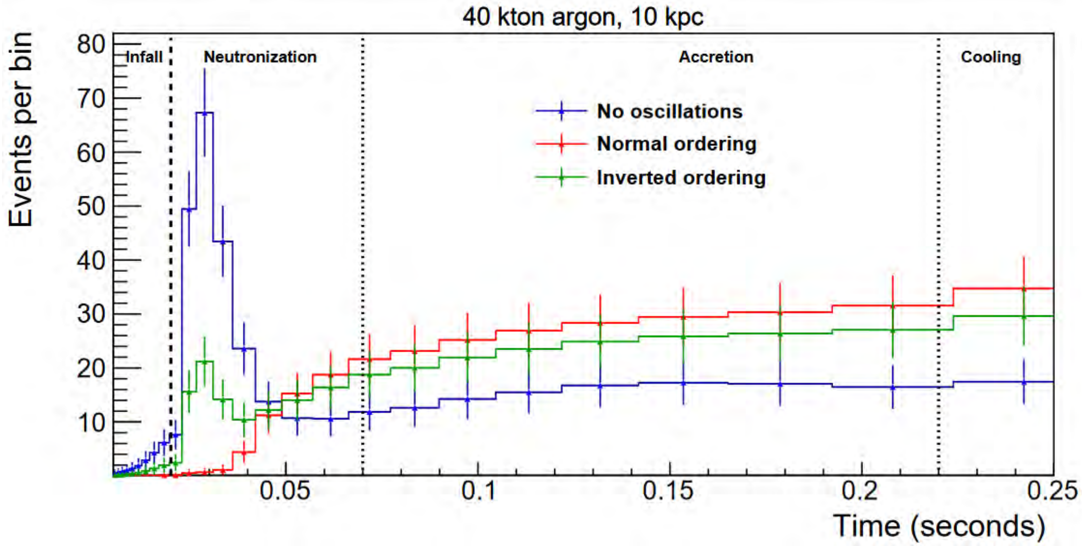


DUNE Physics Program

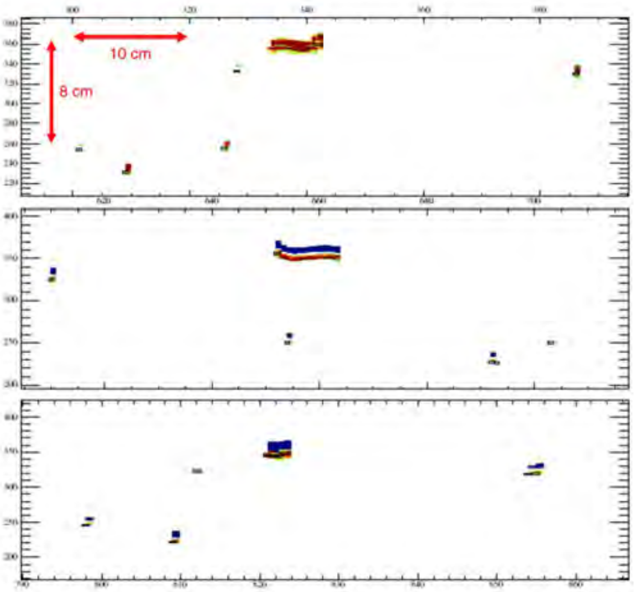

SN 1987a

Supernova Neutrino Burst

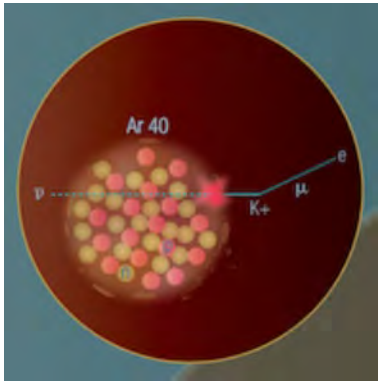
- Formation of a neutron star in a core-collapse supernova
  - Neutronization releases copious neutrino flux
  - About 10% of the star's rest mass converted to neutrinos
- Expected to occur a few times per century (most-likely distance of around 10 to 15 kpc)
- Rich variety of phenomena to look for!
  - neutronization burst and neutron star formation
  - shock wave and turbulence effects
  - formation of a black hole



challenging little signals to reconstruct!

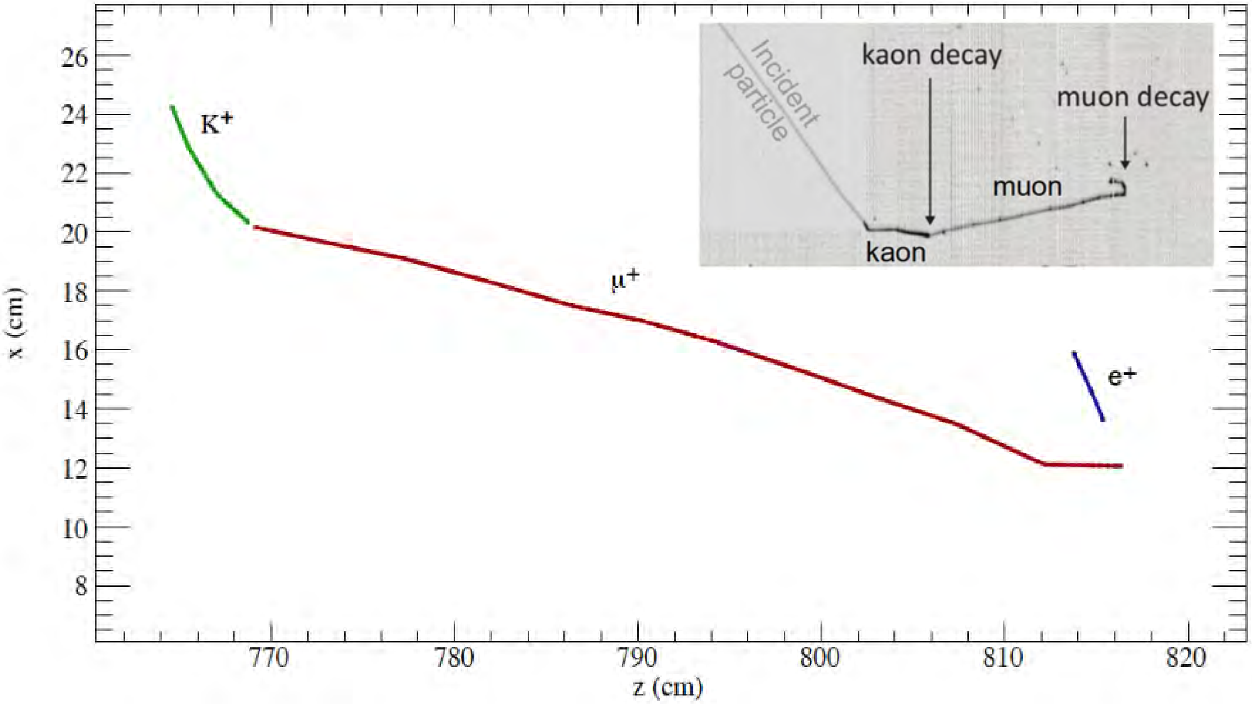


DUNE Physics Program



BSM Physics

- Sterile ν-mixing
- Non-standard ν interactions
- Baryon number violation
- **Nucleon decay**
- Low-mass Dark Matter (@ ND)
- (in-)elastic Boosted Dark Matter - BDM (@ FD)
- *and more …*



DUNE Physics Program

Recent Publication Highlights

- *Long-baseline neutrino oscillation physics potential of the DUNE experiment*
  Eur. Phys. J. C (2020) 80:978
- *Prospects for beyond the Standard Model physics searches at DUNE*
  Eur. Phys. J. C (2021) 81:322
- *Supernova neutrino burst detection with DUNE*
  Eur. Phys. J. C (2021) 81:423
- *First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform*
  2020 JINST 15 P12004
- *Experiment Simulation Configurations Approximating DUNE TDR*
  arXiv:2103.04797
- *…and more in progress*

Thanks!

New members & new ideas *always welcome!*