Deep Underground Neutrino Experiment

Nicola McConkey on behalf of the DUNE Collaboration

NuPhys 2019: Prospects in Neutrino Physics

18th December 2019

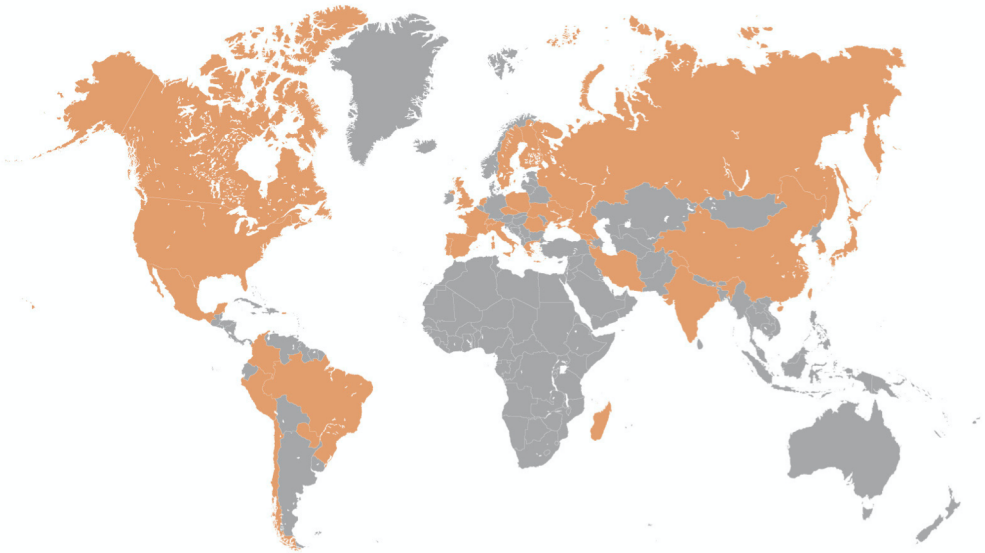
MANCHESTER 1824
The University of Manchester

DUNE

Contents

- DUNE Physics
- DUNE / LBNF beam
- DUNE Detectors
- ProtoDUNE – Detectors & Latest Results
- DUNE Timeline

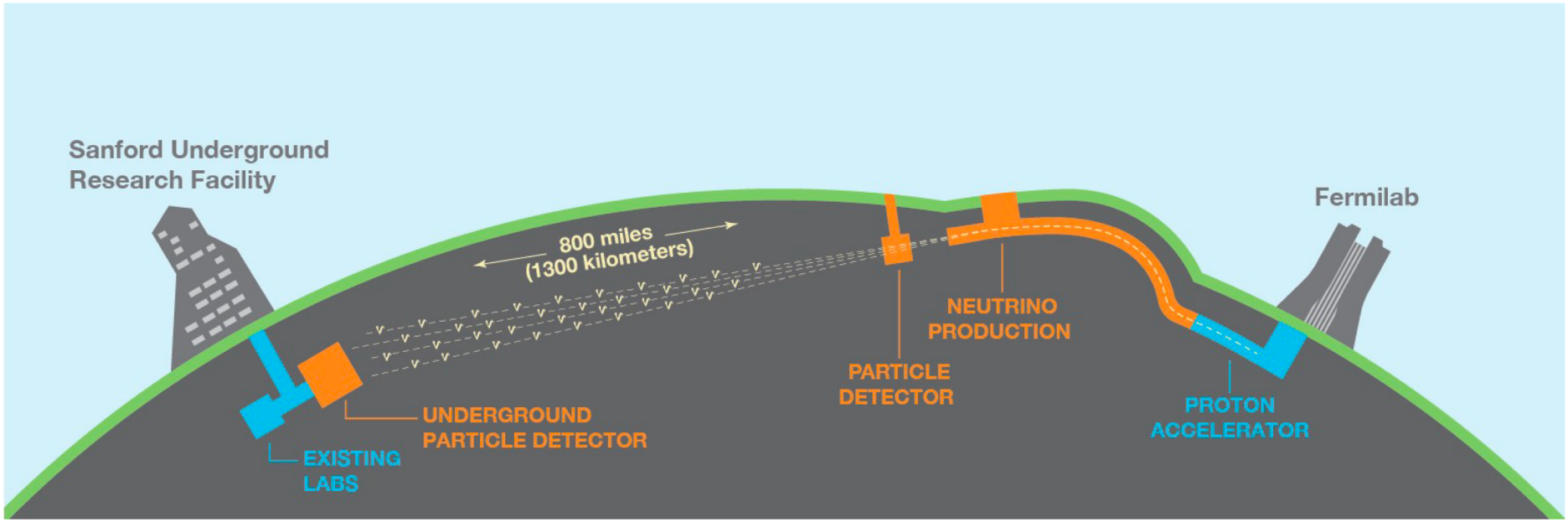
DUNE Collaboration



Global collaboration

- 34 countries
- 192 institutions
- 1104 collaborators

Deep Underground Neutrino Experiment

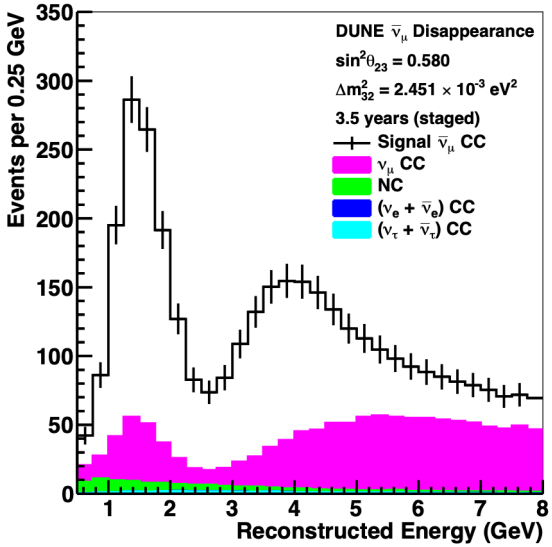


- 1.2MW neutrino beamline from Fermilab (Illinois, USA) to SURF (South Dakota, USA)
- Far Detector: Liquid argon time projection chamber (1300km downstream)
- Near Detector: composite (574m downstream)

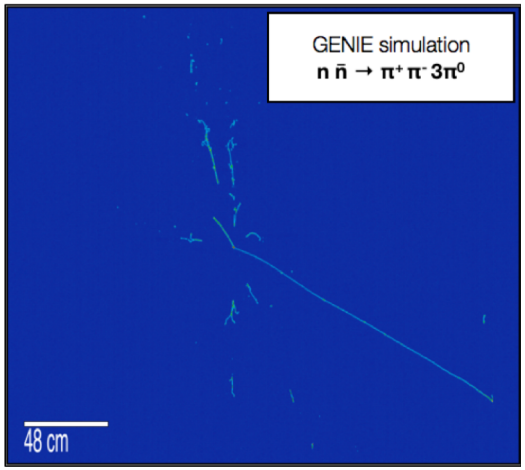
Motivation for DUNE

- Rich neutrino physics programme for DUNE

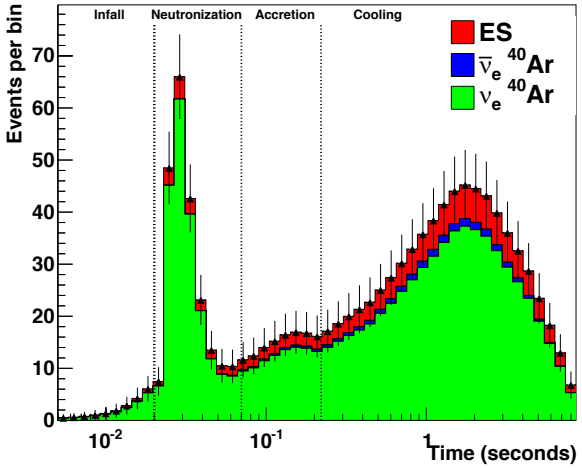
Long baseline neutrino physics



Beyond Standard Model physics



Astroparticle physics

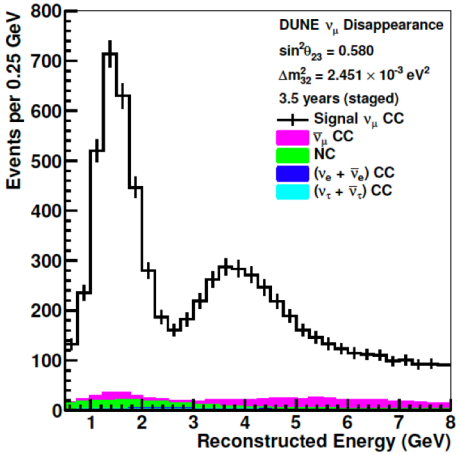


- …to name but a few! See DUNE IDR for more! *arxiv:1807.10334*

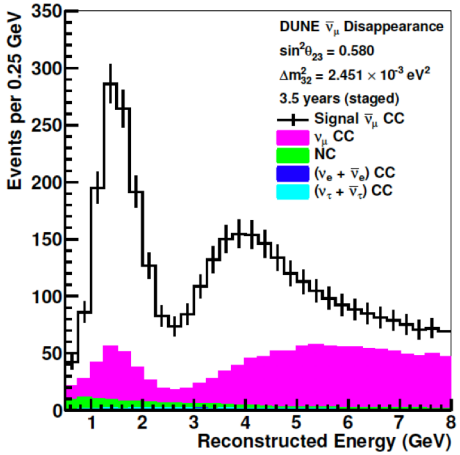
Neutrino Oscillation Physics

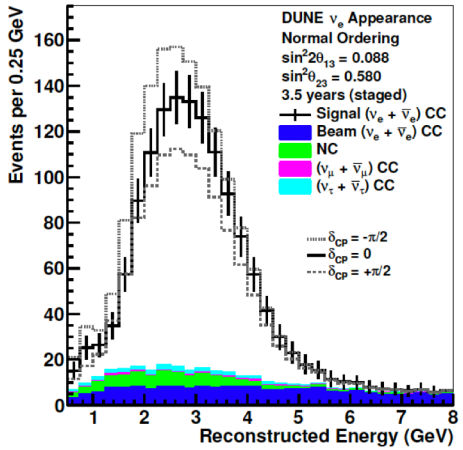
- Wide band beam, on-axis far detector
  - Sensitivity to first and second oscillation maxima
- Sensitivities from full simulation and reconstruction and event selection with CVN
- Neutrino and antineutrino running modes
- Great statistics at far detector!
  - 10,000 ν_μ ($\overline{\nu}_\mu$) disappearance events (7 years)
  - 1,000 ν_e ($\overline{\nu}_e$) appearance events (7 years)

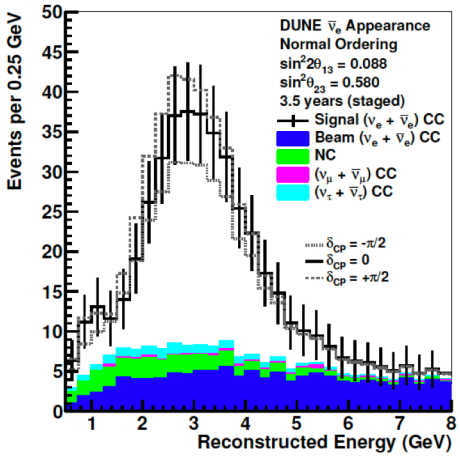
Neutrino mode



Anti-neutrino mode

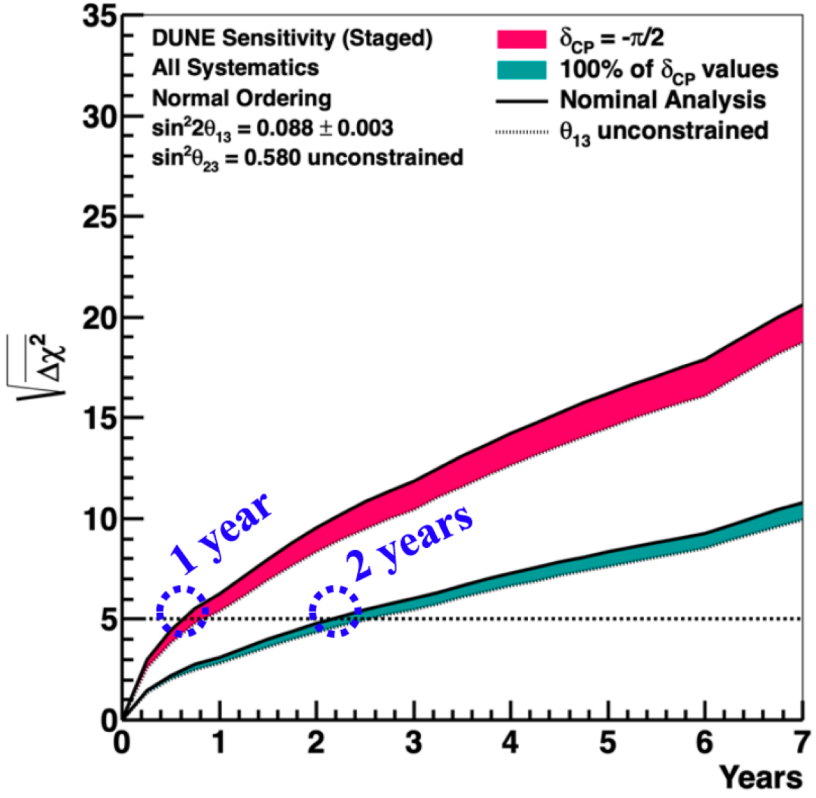




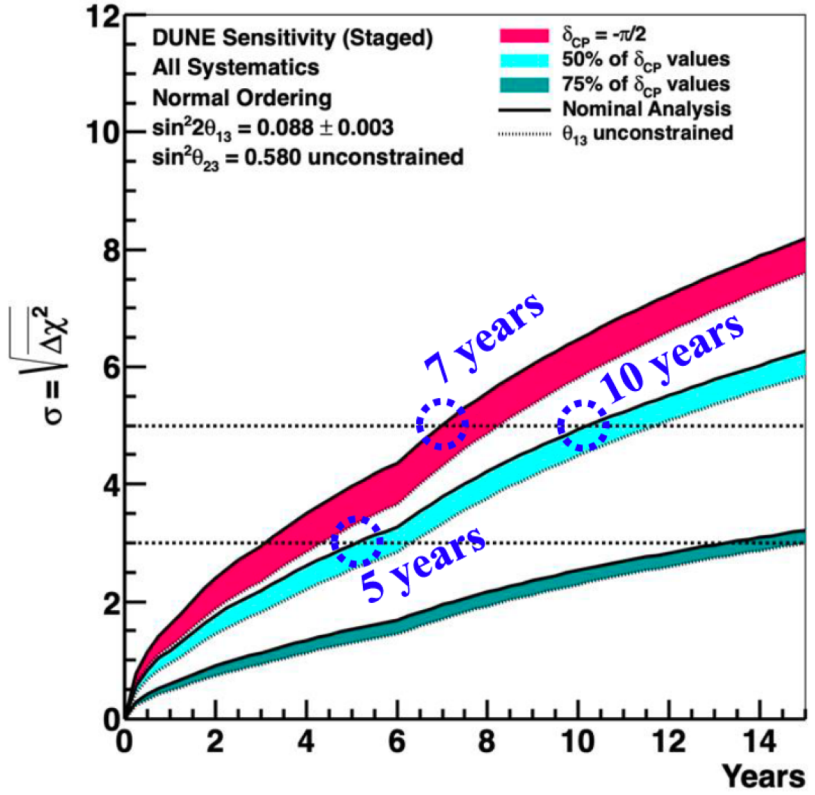


Neutrino Oscillation Physics

Mass ordering sensitivity



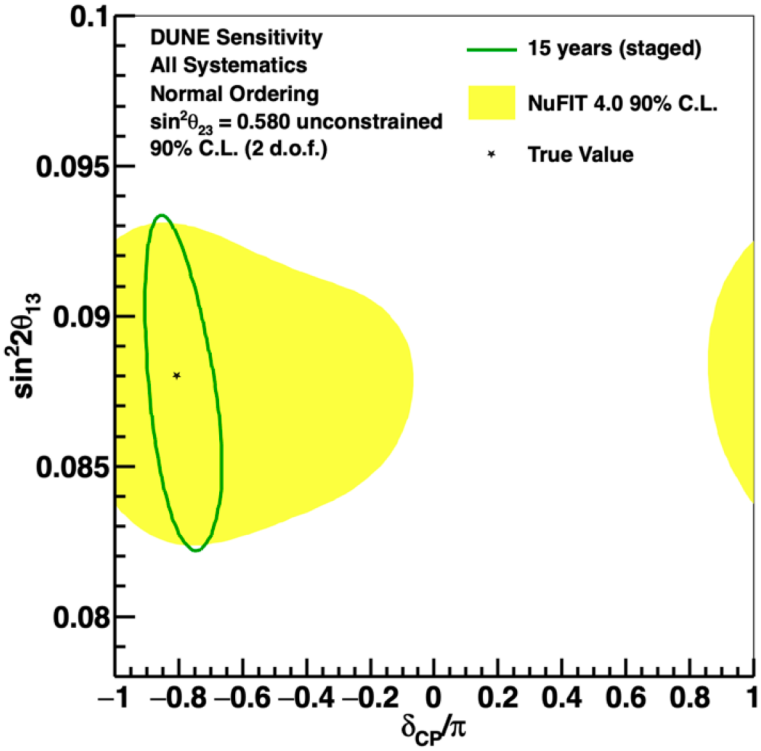
CP violation sensitivity



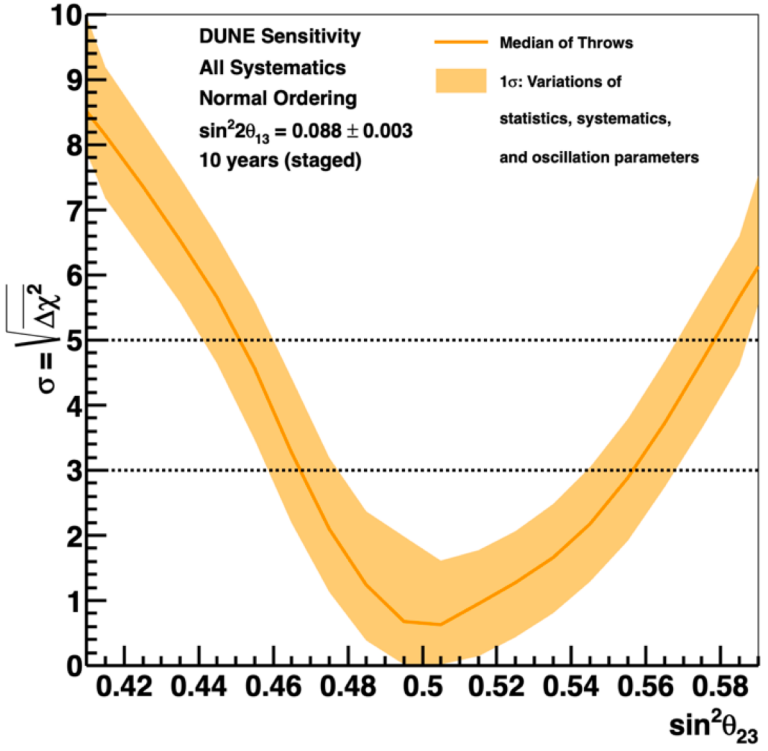
- 5σ sensitivity to mass ordering after 2 years of beam running (for any value of δ_{CP})
- 5σ sensitivity to 50% of δ_{CP} values after 10 years of beam running

Neutrino Oscillation Physics

$\sin^2 2\theta_{13}$ vs. δ_{CP} at 15 years



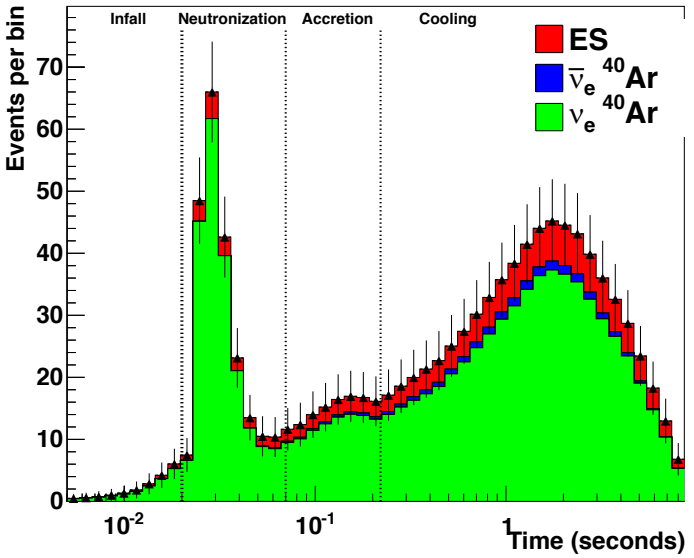
Octant determination at 10 years



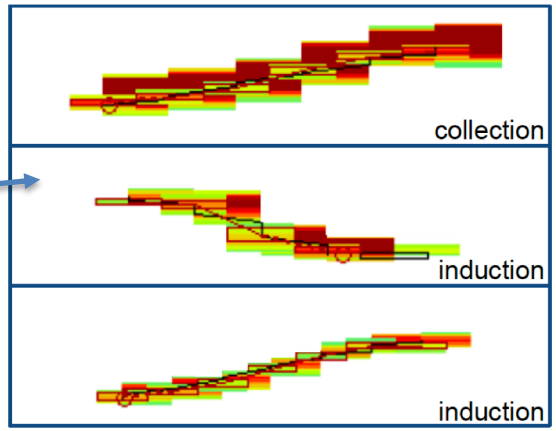
- Measurement of multiple PMNS parameters in a single experiment

Supernova Neutrinos

- 99% of energy released in a core-collapse supernova is carried away by neutrinos!
- Large mass of far detector gives sensitivity to supernova spectrum
  - 3000 ν_e over 10 seconds
- Supernova physics:
  - core-collapse mechanism, black hole formation, shock stall/revival, nucleosynthesis, cooling…
- Particle physics:
  - flavor transformations in core, collective effects, mass ordering, nuclear equation of state…
- LAr has unique sensitivity to ν_e flux

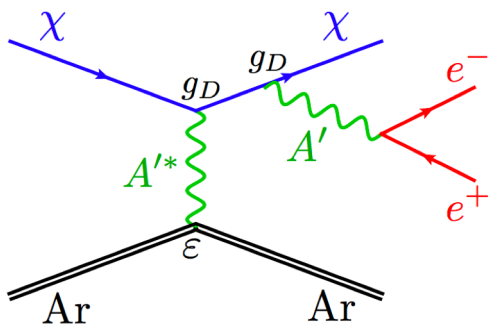


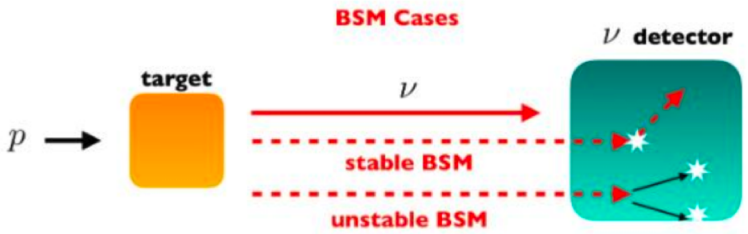
Low energy 10.25 MeV electron (simulated + reconstructed)

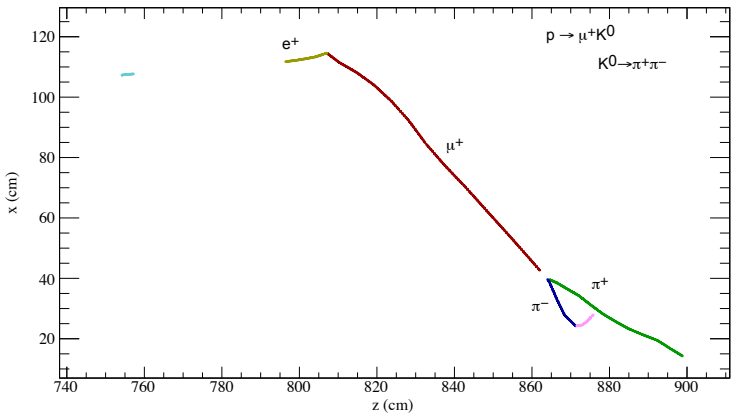


Physics Beyond the Standard Model

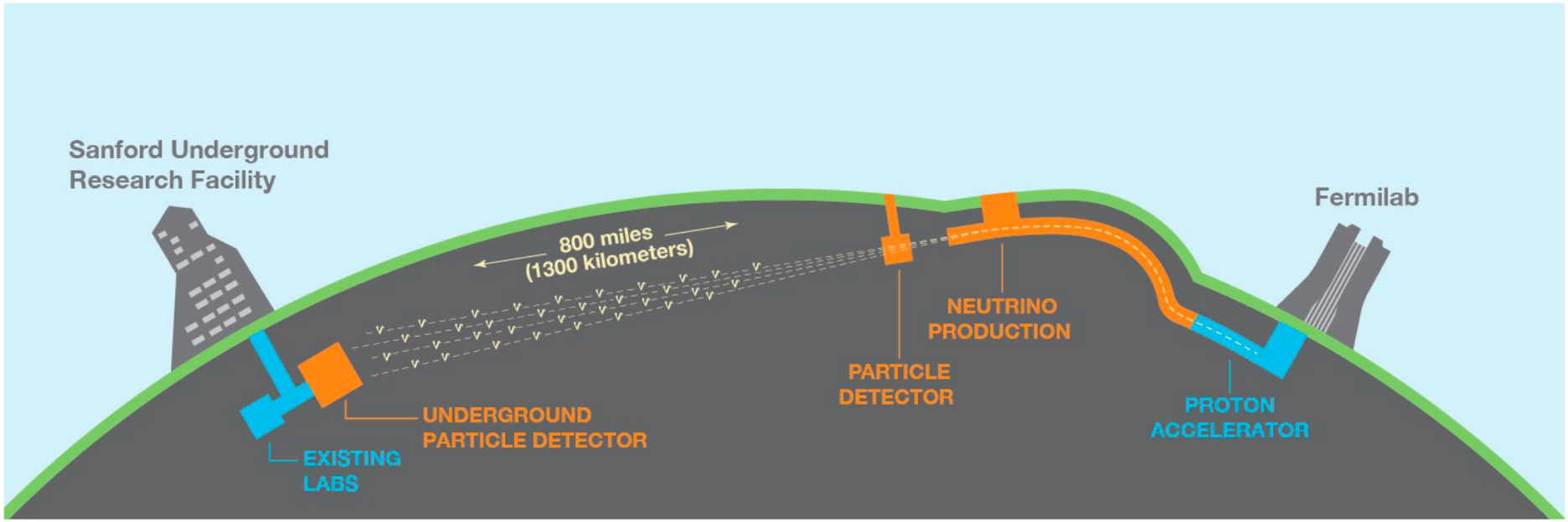
- Both near and far detectors have sensitivity to BSM physics!
- Near detector:
  - Highly granular detector in high power / high flux beam
  - Sensitivity to heavy neutral leptons
  - Sterile neutrinos
  - Neutrino tridents
  - Millicharged particles
- Far detector:
  - Large target mass
  - Proton decay searches







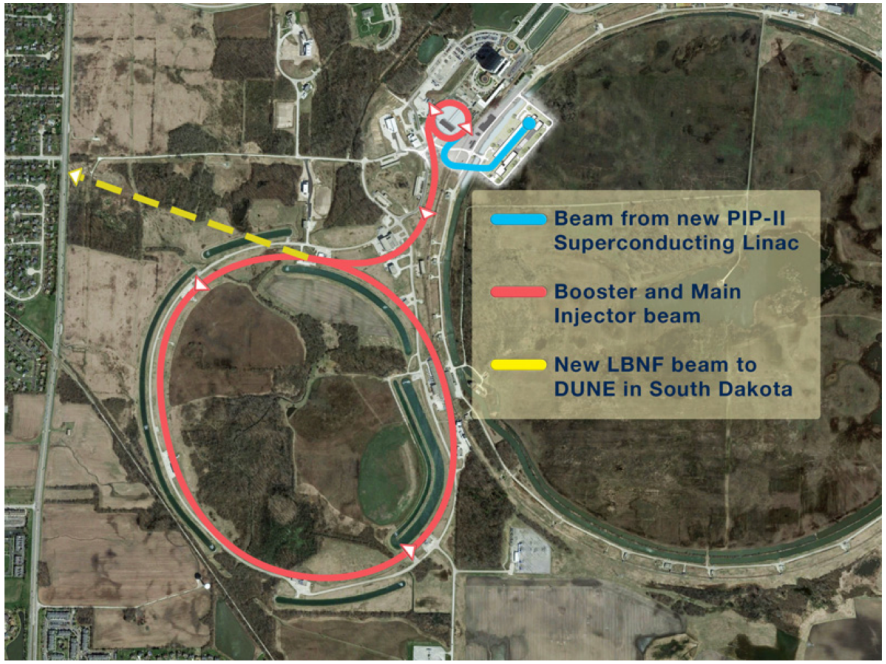
Deep Underground Neutrino Experiment



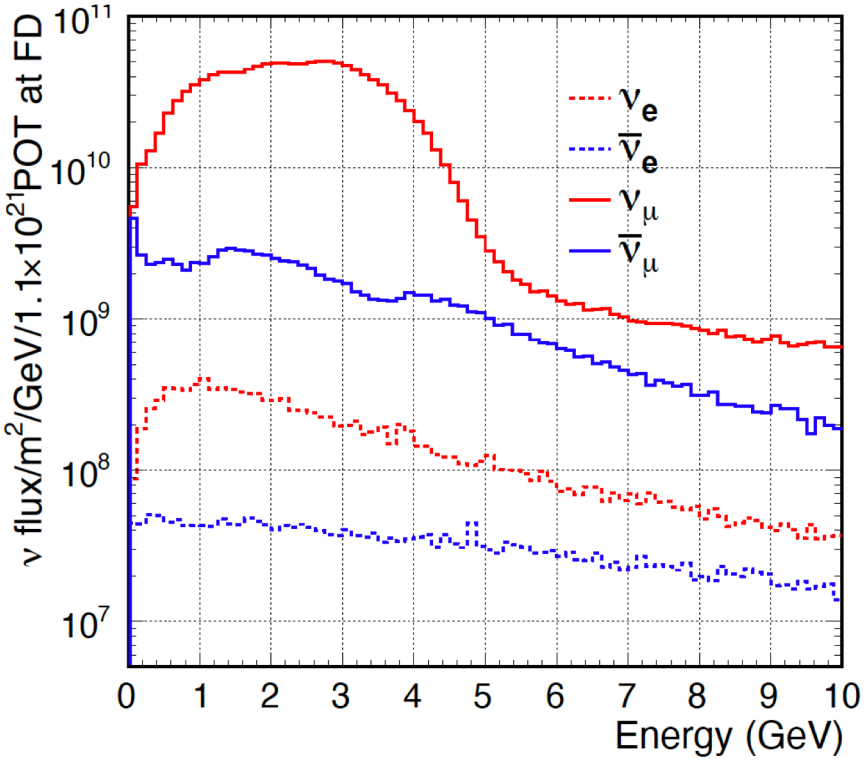
- 1.2MW Neutrino beamline from Fermilab (Illinois, USA) to SURF (South Dakota, USA)
- Liquid argon far detector (1300km downstream)
- Composite near detector (574m downstream)

The LBNF beam

- A new (anti)neutrino beam from Fermilab to SURF
  - 1.2 MW proton beam
    - 10^{21} POT/year
- Wide band neutrino beam

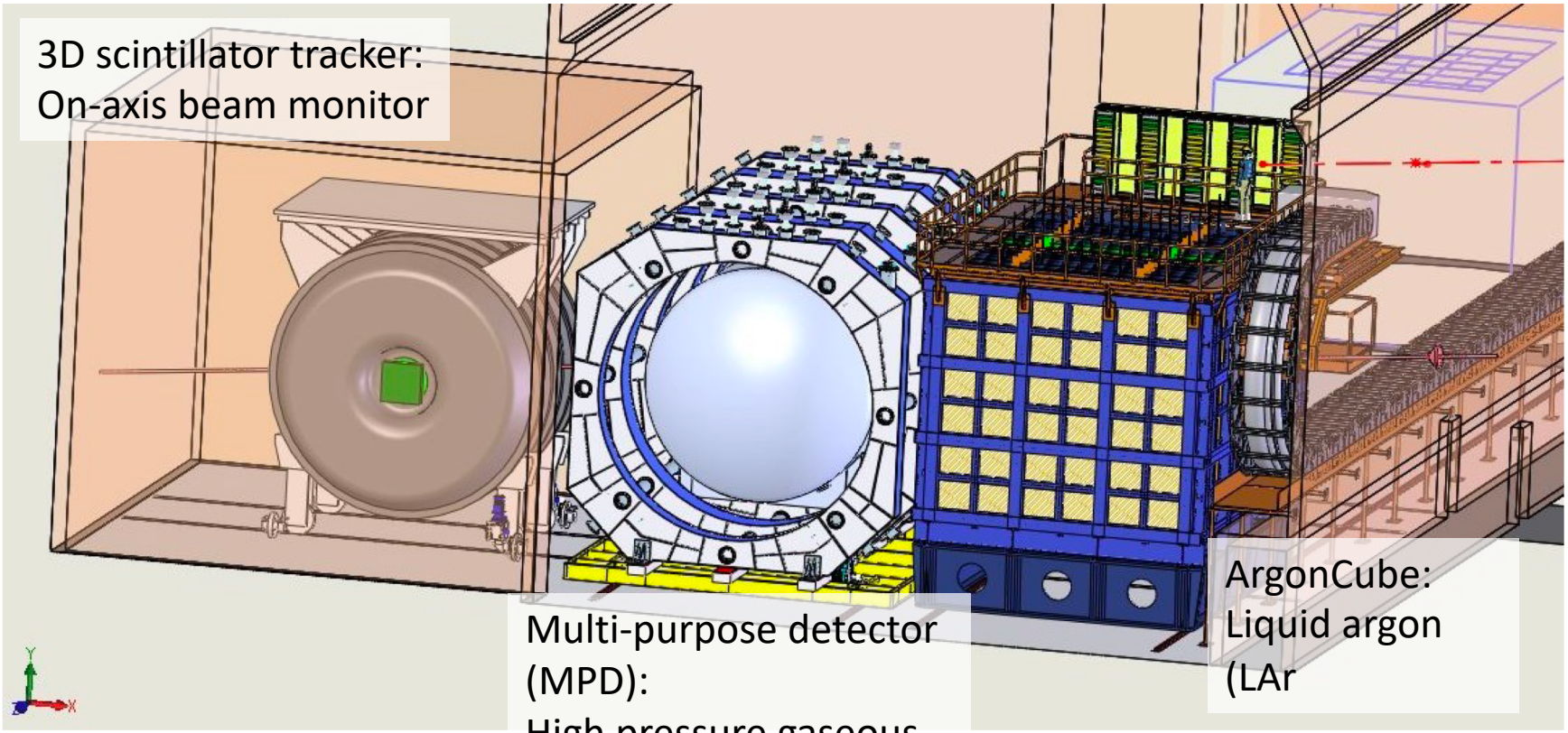


Neutrino energy for unoscillated flux at FD (neutrino mode)



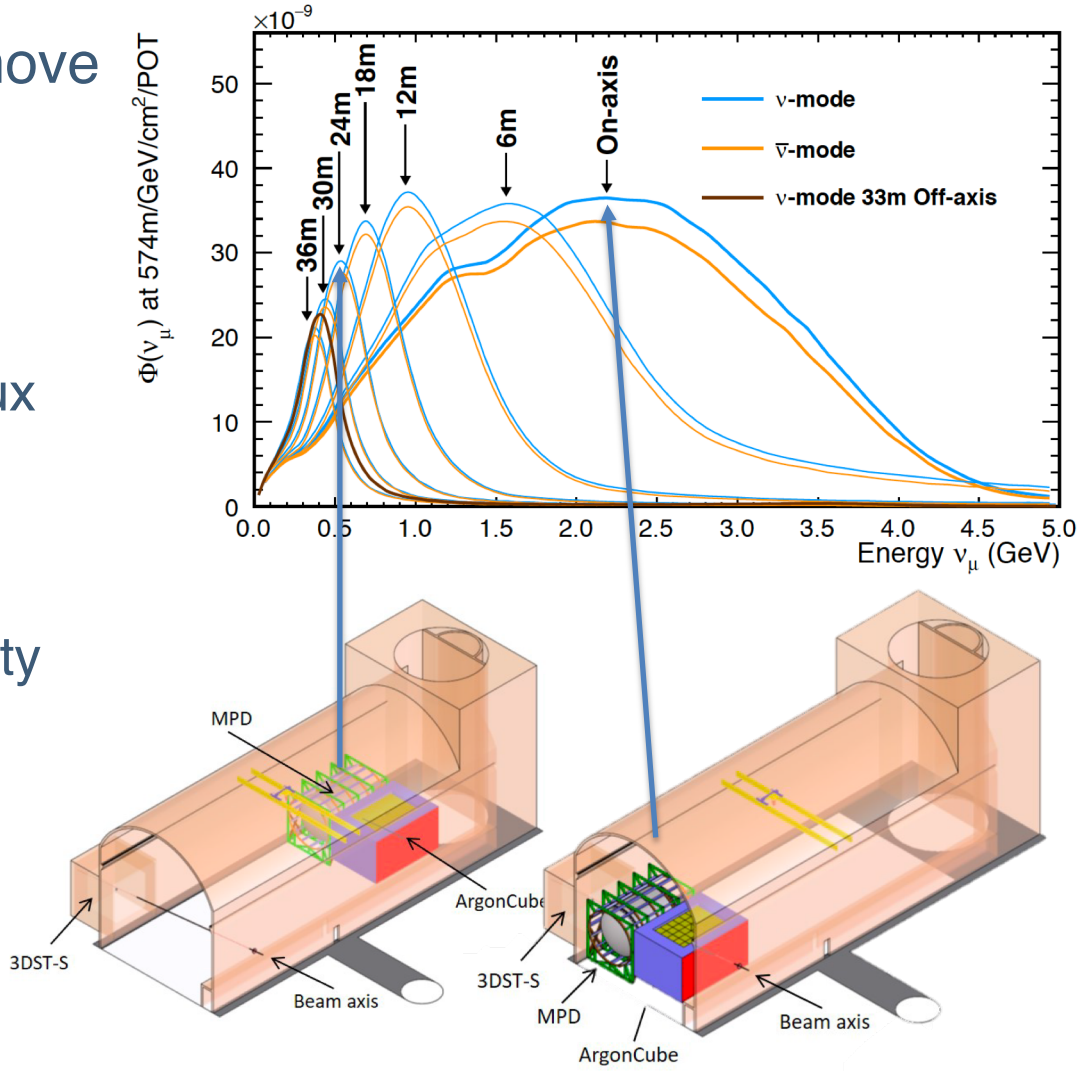
DUNE Near Detector

- Composite detector
- Goal: constrain flux and cross-section systematic uncertainties



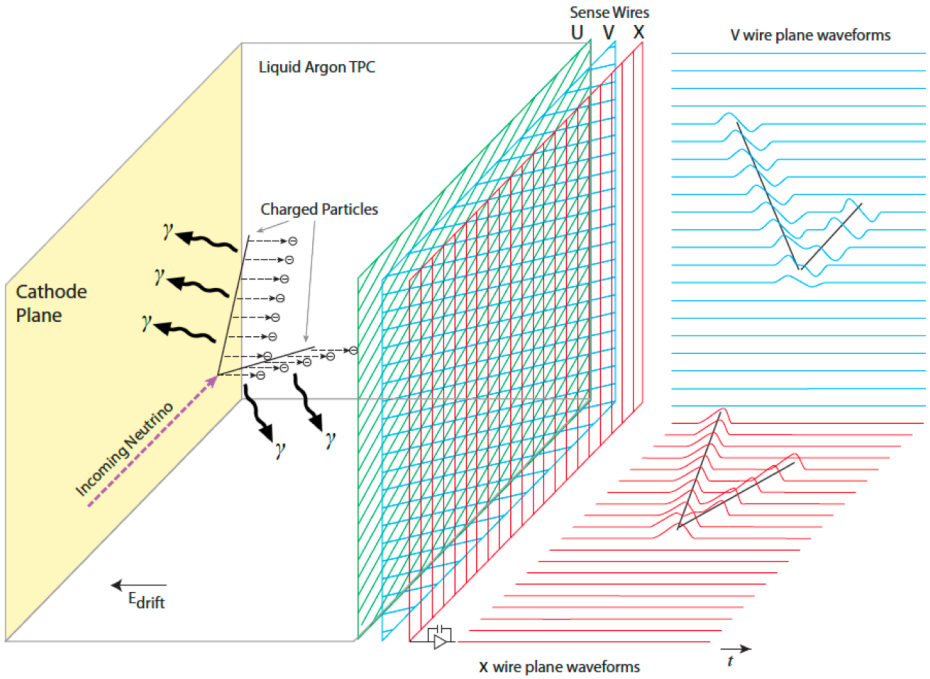
DUNE Near Detector – DUNE Prism

- ArgonCube and MPD move off axis to sample flux
  - 30m off axis proposed motion
  - Allows to deconvolve flux and cross section
- 3DST-S does not move
  - Beam monitor for stability

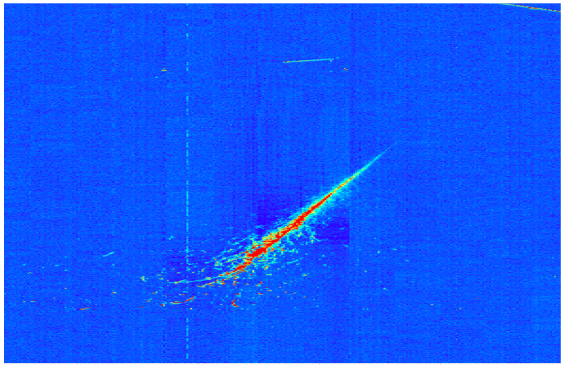


DUNE Far Detectors

- Liquid Argon Time Projection Chamber
- Charged particles produce ionisation charge and scintillation light
- Electric field across TPC volume
  - Ionisation electrons drifted towards anode readout plane
  - Charge signal induced on readout plane
  - DUNE SP: 2D projection of ionization read out from 3 planes of wires, time is 3rd dimension

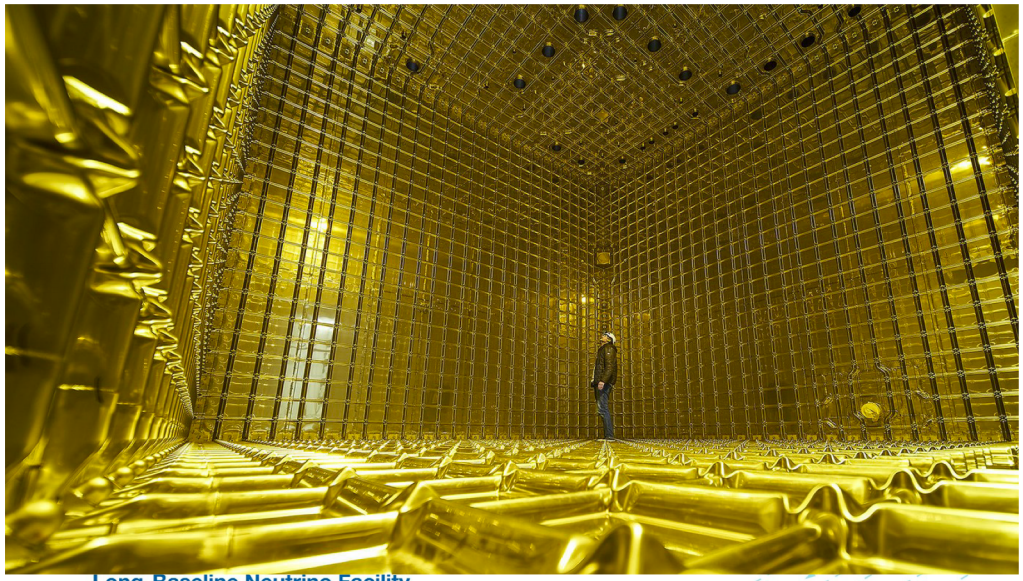


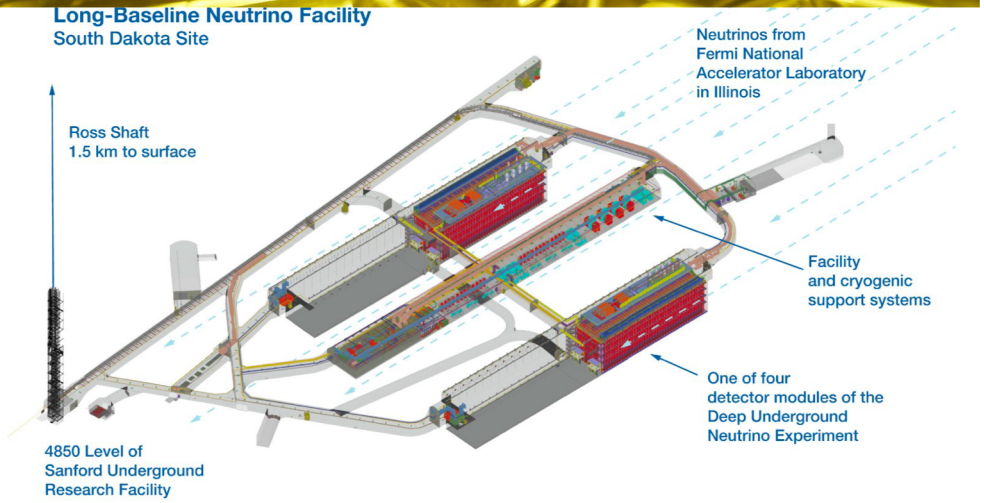
"The digital bubble chamber"



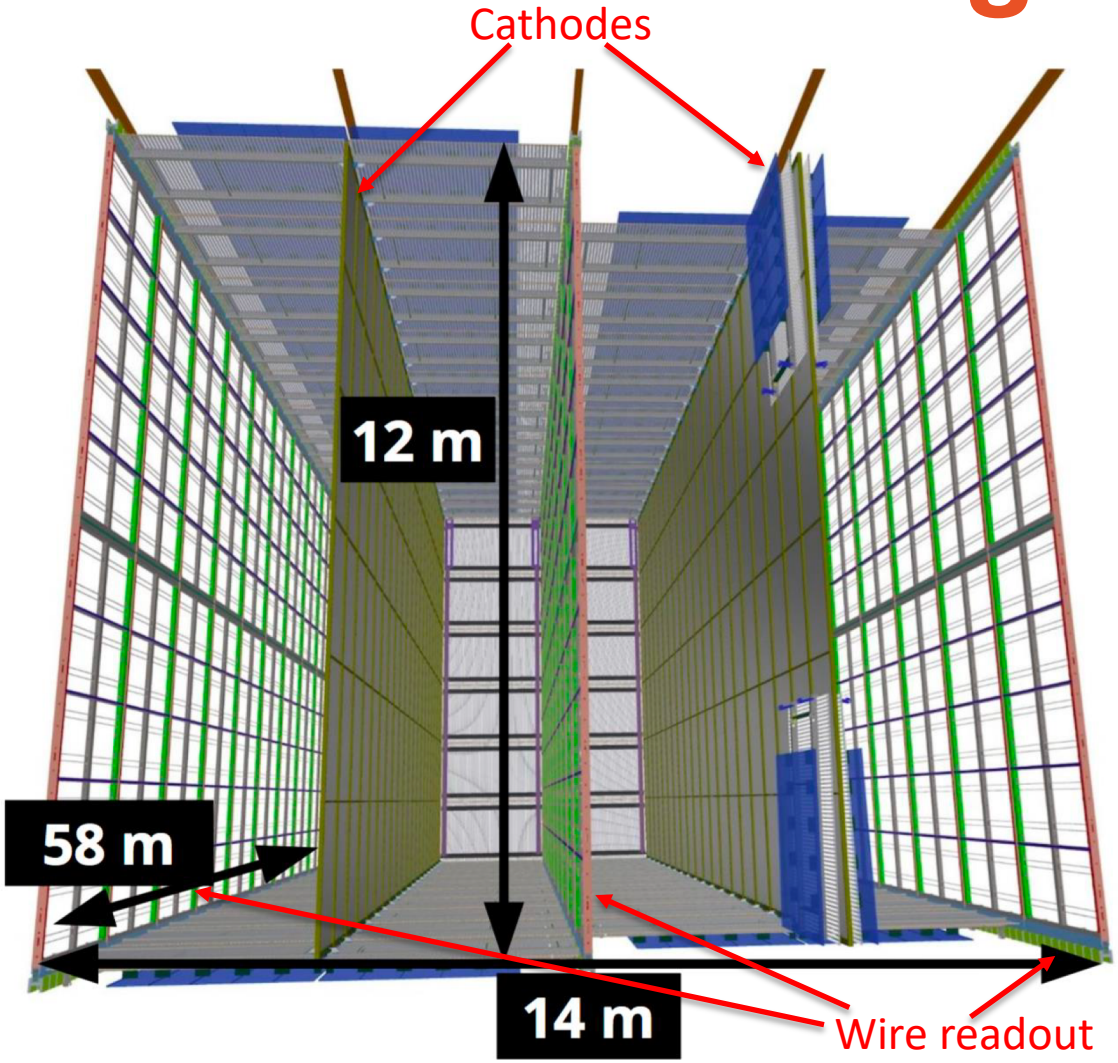
DUNE Far Detector

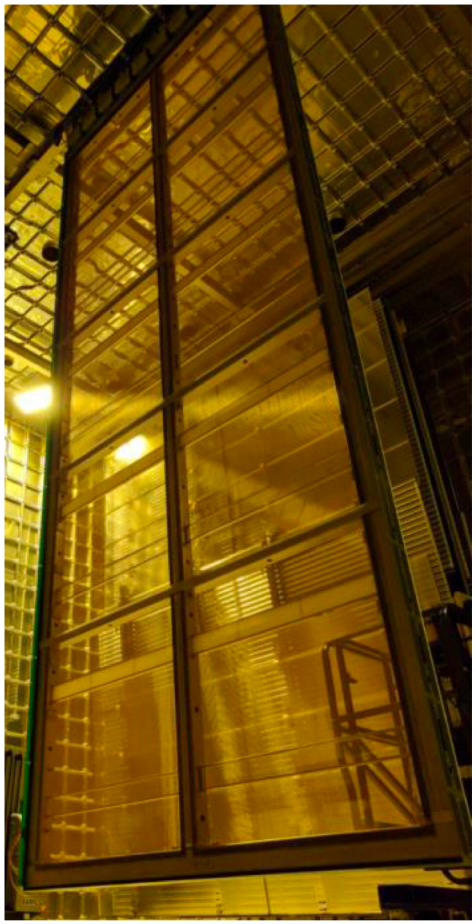
- Sanford Underground Research Facility
  - South Dakota
  - 1.5km underground
- 4 x 10kt modules
  - Membrane cryostat
  - Cryostat: 62m x 19m x 18m
  - 17kt total LAr per module
  - Staged installation
- Groundbreaking July 2017
  - Work ongoing!





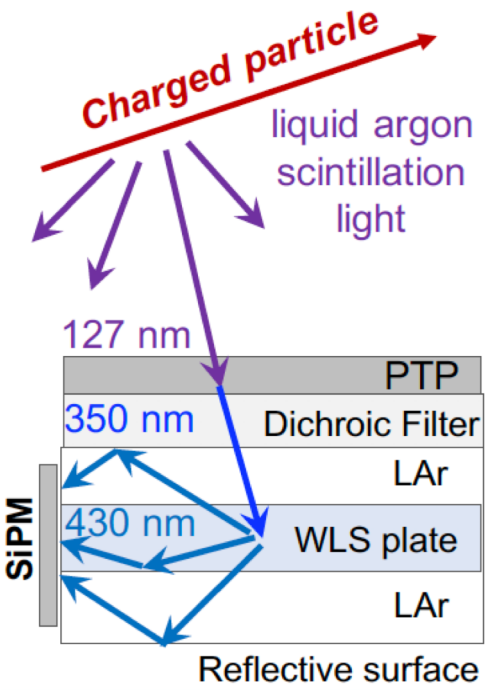
Far Detector – Single Phase

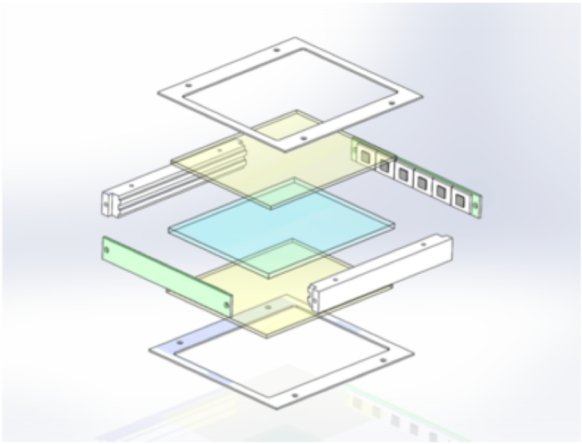


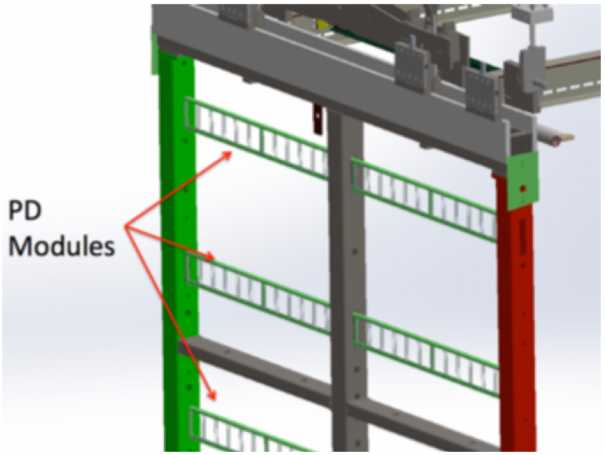


Far Detector – Single Phase Photon Detection system

- X-ARAPUCA “light trap”
  - Increase active area of SiPM
  - Dichroic filter + wavelength shifter
  - Highly reflective interior
  - Acrylic guides shifted light to SiPMs
- 6000 supercells of 48.8 cm x 10 cm x 0.8 cm
- Inserted in APA frames

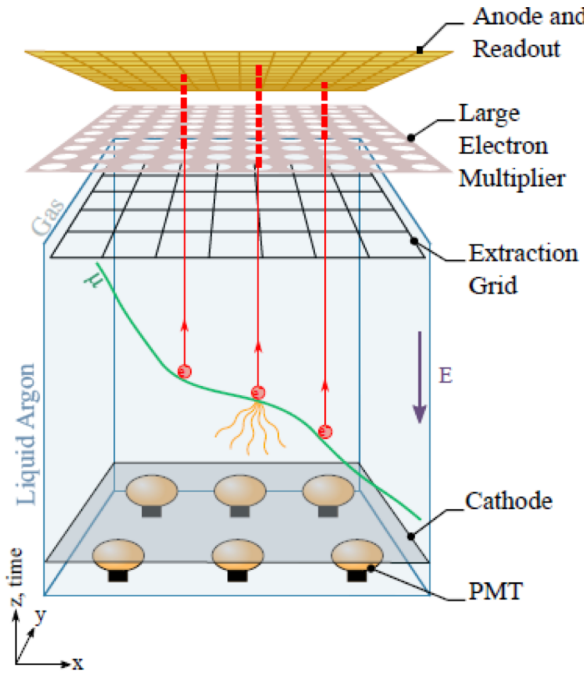


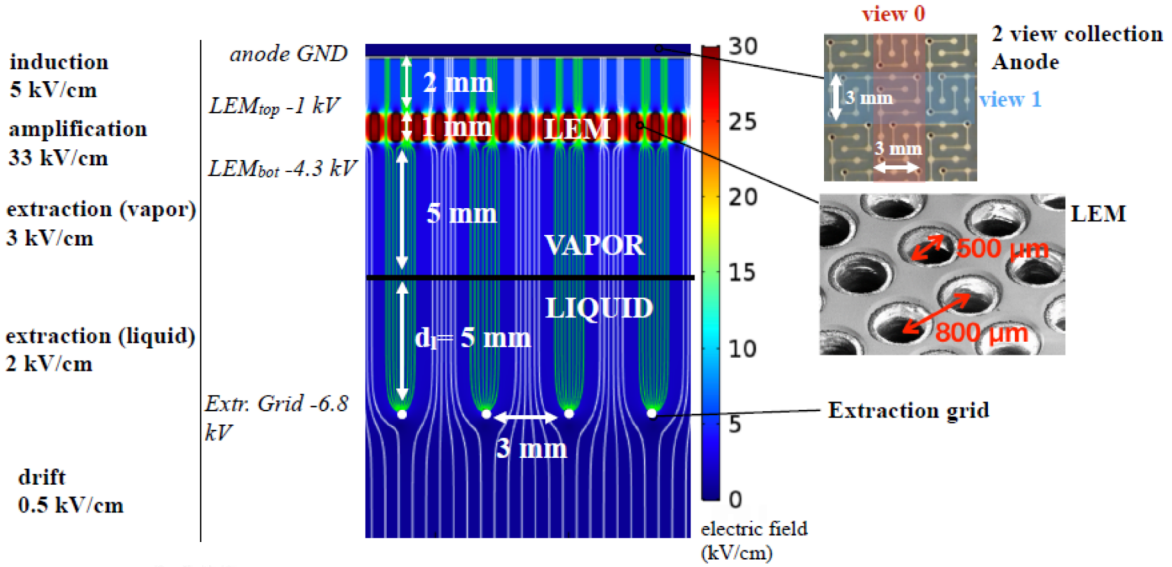


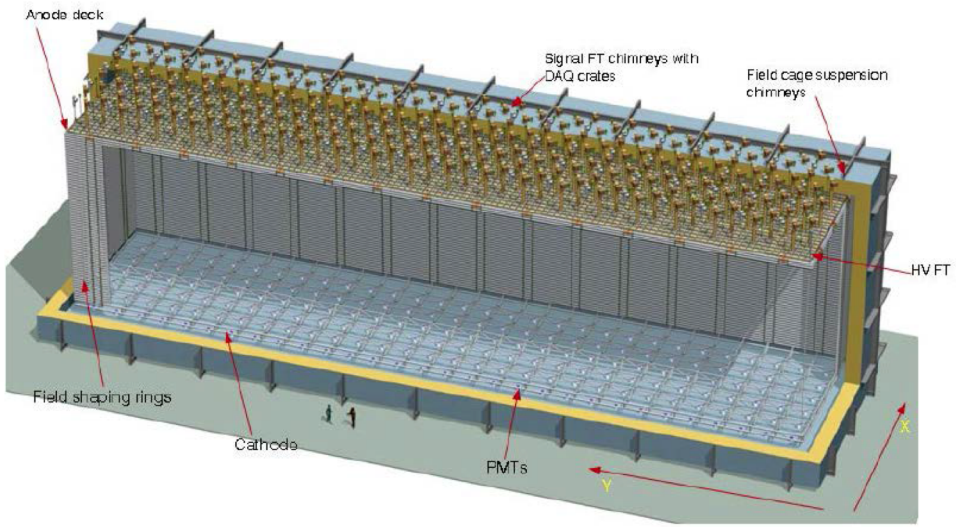


Dual Phase

- LAr target
- Gas readout
  - Benefit from charge multiplication in gas



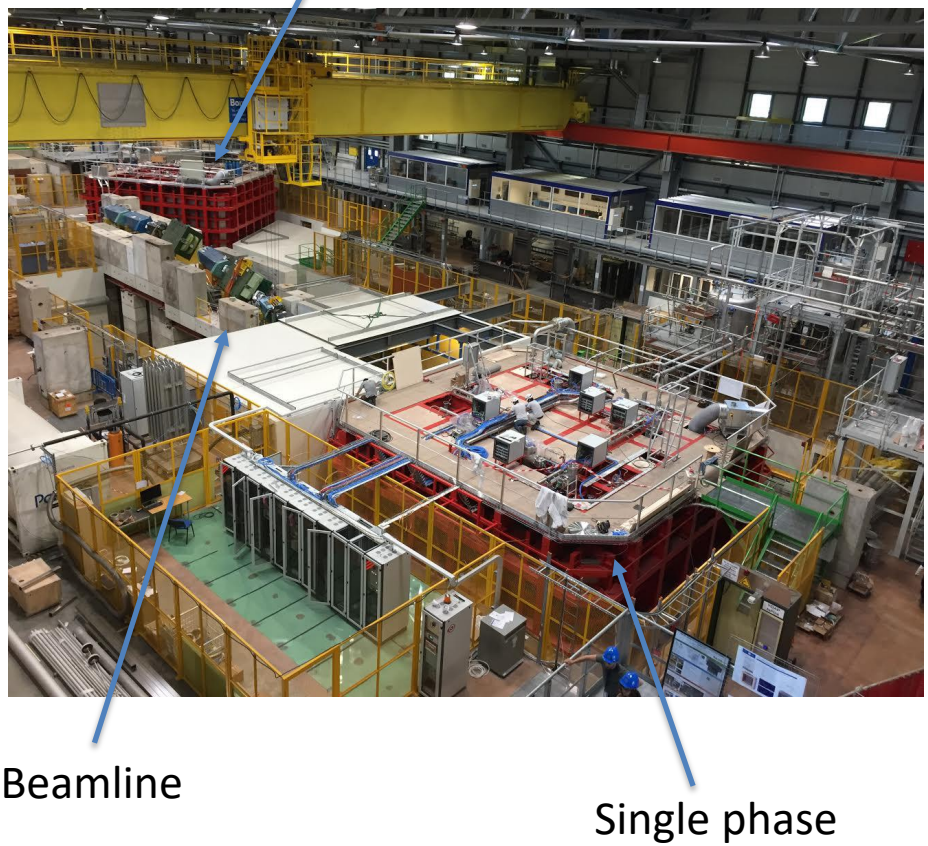




ProtoDUNE

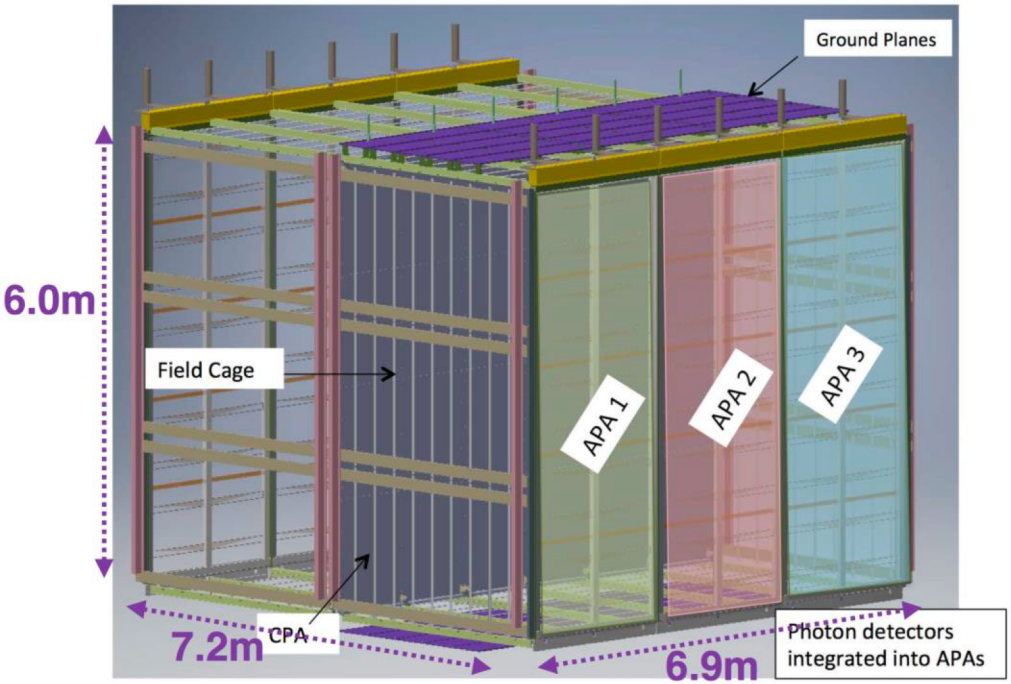
See also Stefania's presentation: 12:30pm

- Two ~1kt LArTPCs in a charged particle test beam, at CERN
- Goals:
  - Collect test beam data to measure the response of DUNE readout technology to different particles
  - Test production and installation methods
  - Use data to validate the detector designs

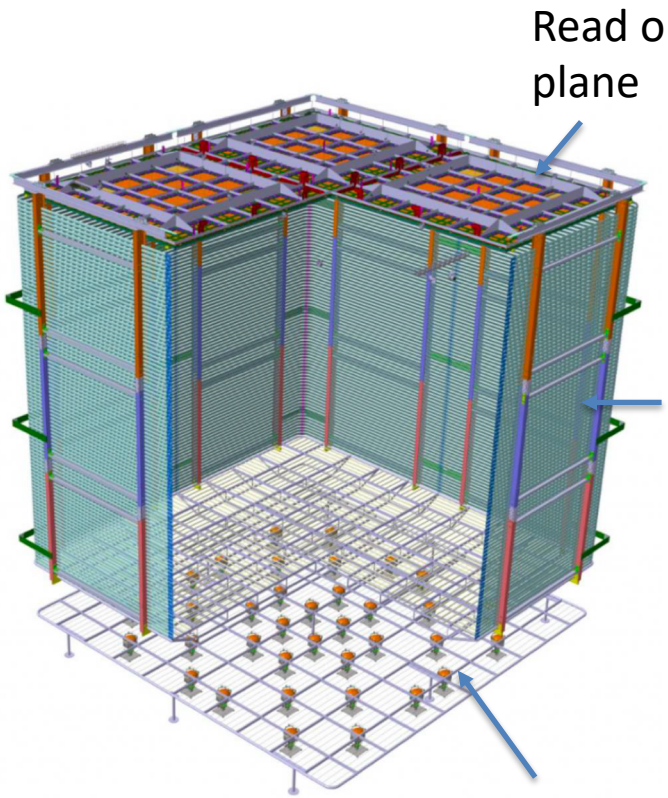


ProtoDUNE Detectors

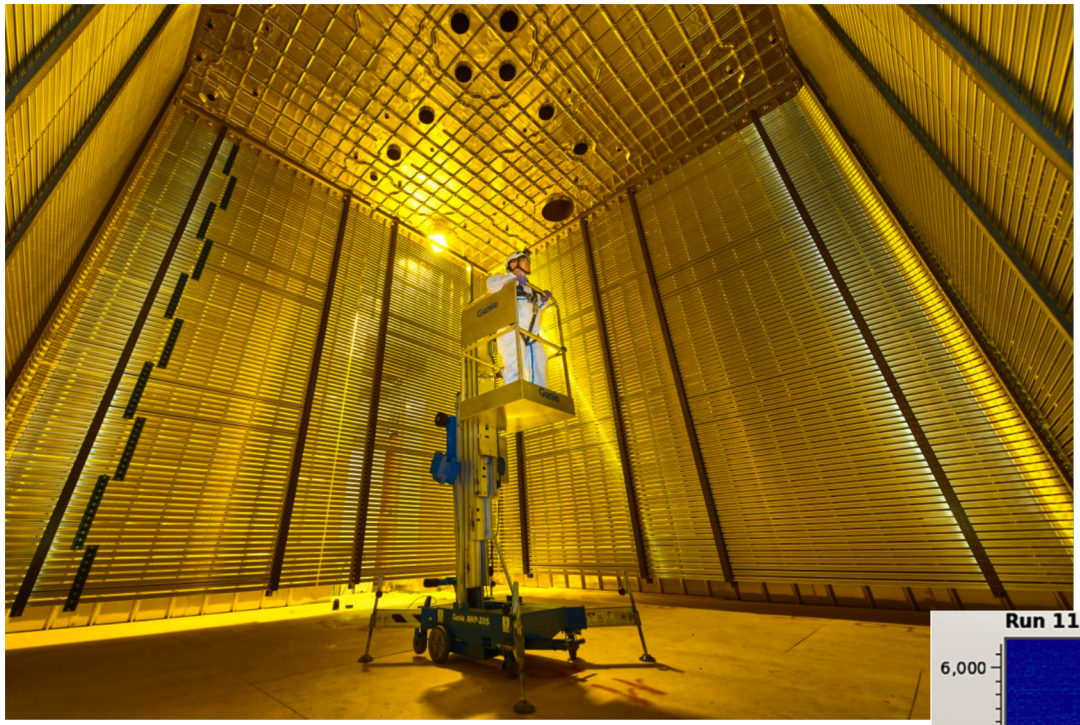
- Single phase TPC

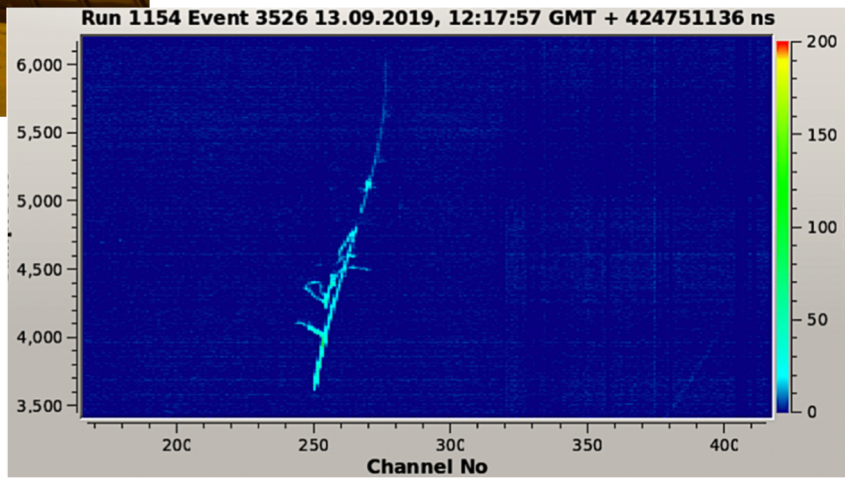


- Dual phase TPC



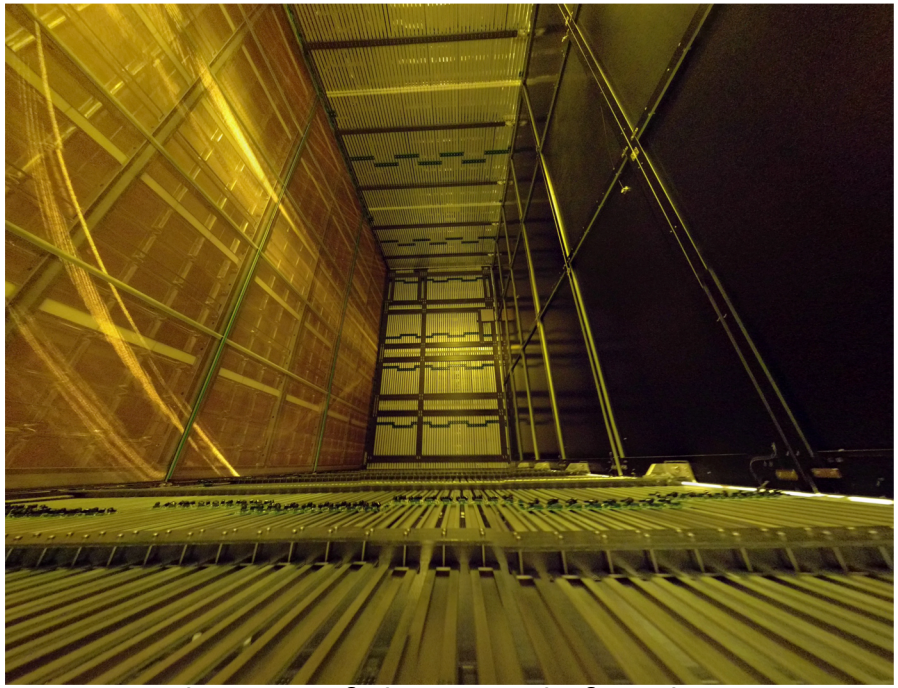
ProtoDUNE - Dual Phase





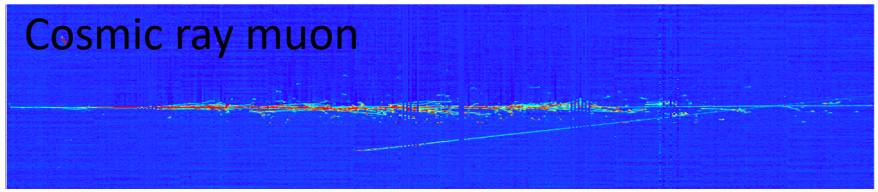
- LAr filling completed - August 2019
- Currently taking cosmic data!

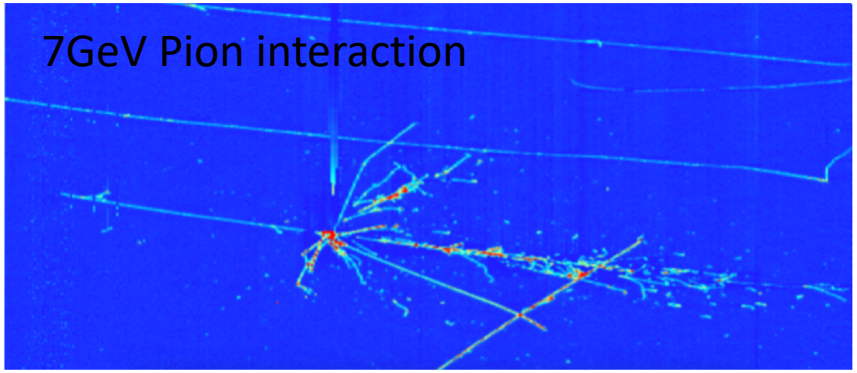
ProtoDUNE - Single Phase



Inside one of the TPC drift volumes

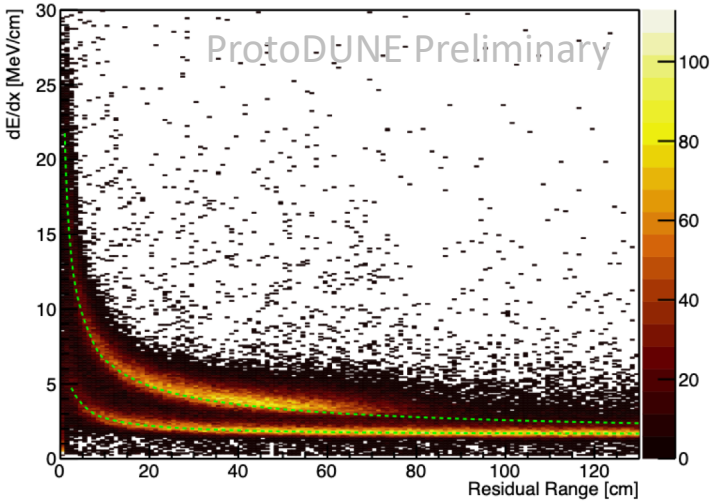
- Filled with LAr - August 2018
- Beam data taken autumn 2018:
  - Pions, protons, positrons, kaons
  - Energy momentum and resolution
- Currently taking cosmic data!
- First publication coming soon!

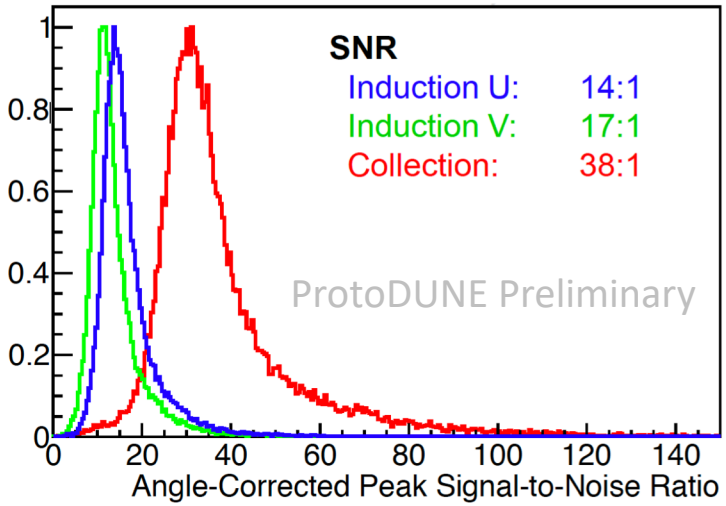




ProtoDUNE - Single Phase

- Detector performance publication forthcoming
  - LAr purity
  - Noise level and signal-to-noise ratio
  - Space charge effect and calibration
  - dE/dx for particle species: muons, pions, protons, positrons, kaons
  - Energy and momentum resolution using TPC and photon system
- Huge success for DUNE!





DUNE - Timeline

2024

Start installing first far detector module

2025

Start installing second far detector module

DUNE physics data talking starts: Atmospheric neutrinos

2026

Beam operational at 1.2MW

DUNE physics data with beam starts!

- Fiducial mass of 20kt

2027

Third far detector module added (30kt fiducial mass)

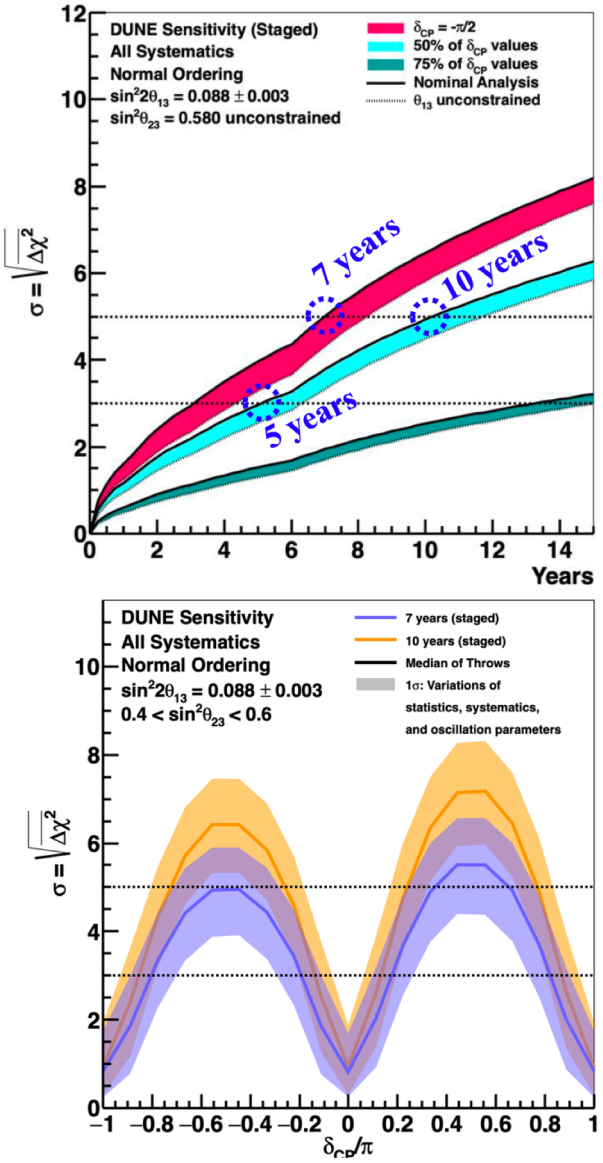
2029

Add fourth far detector module (40kt fiducial mass)

2032

Upgrade to 2.4MW beam

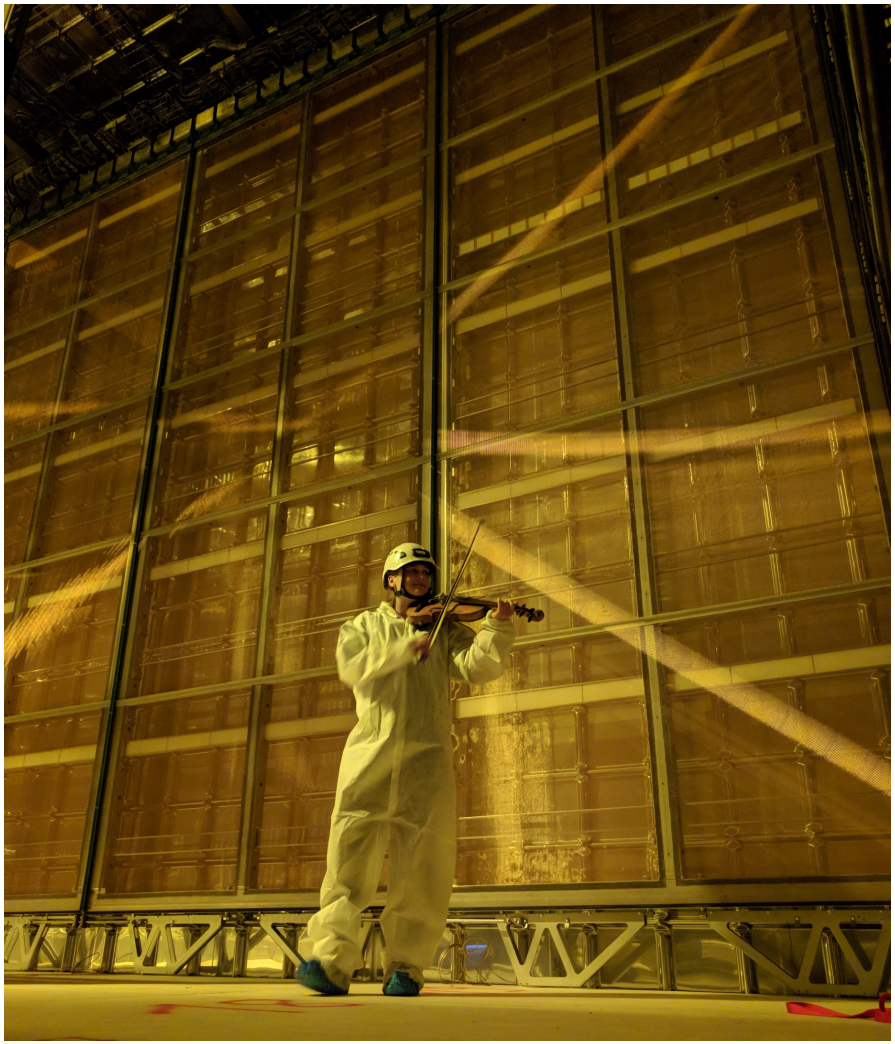
CP violation sensitivity



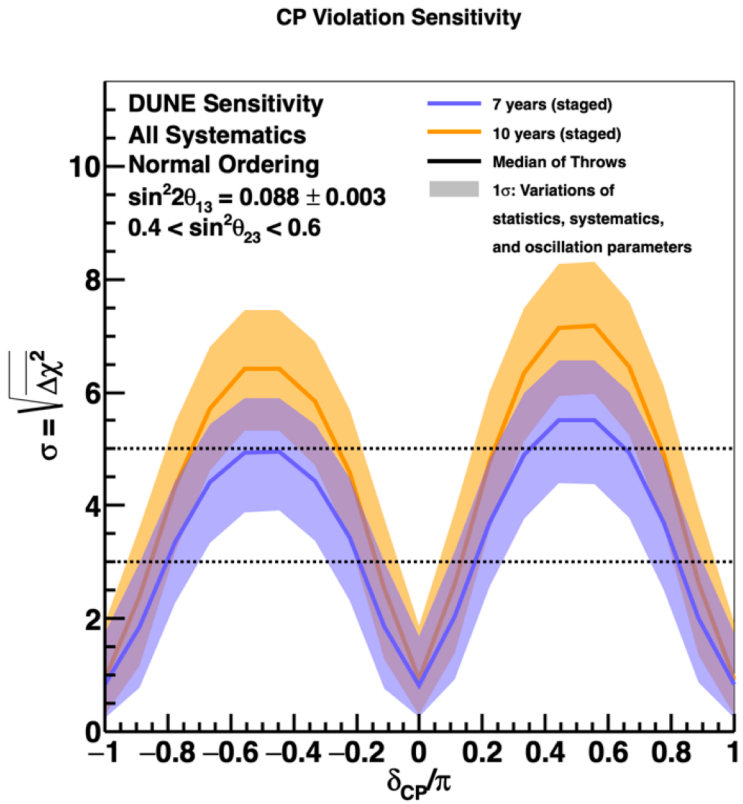
Summary

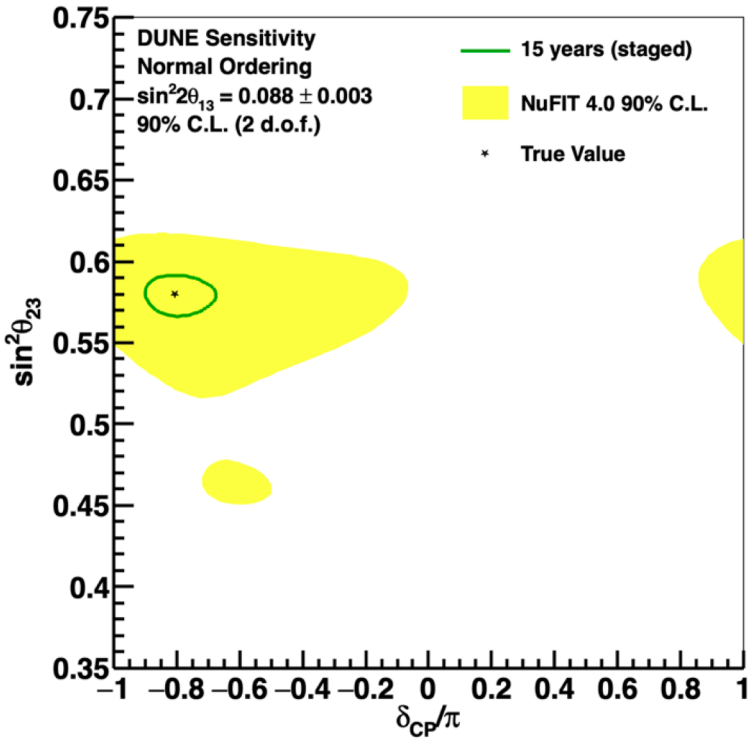
- DUNE is an international collaboration with an ambitious and rich physics program
  - Precision oscillation parameter measurements
  - CP violation
  - Supernova physics
  - BSM physics
- International contributions throughout project
  - Detector technology, construction
  - Strong global support for project
- Well on track to make the next generation of neutrino measurements!
  - Recent successes with ProtoDUNE pave the way

Thanks!



Sensitivity





Supernova: neutronization, accretion, cooling