SURF Roundtable

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Big Science Questions to address underground

A broad range of physics topics benefit from low-background environment available underground

- Neutrino properties
  - Is leptogenesis a viable explanation of the observed matter anti-matter asymmetry?
- Neutrinos as probes of other phenomena
  - What are dynamics of supernova explosions?
- Nucleon decay
  - Do protons decay, providing evidence for GUTs?
- Dark matter
  - Can we detect dark matter particles directly?
- Quantum information science
  - Can greatly reduced cosmic ray background enable significant progress in quantum computing?
- etc

How to investigate leptogenesis

Ideally, you would produce heavy neutrinos (N) and measure their leptonic decays. Probably much too massive to be possible.

Alternative: build a ”circumstantial case”

1) Other ideas don’t seem to work.
2) Search for CP violation in neutrino sector
3) Search for neutrinoless double beta decay, to demonstrate that neutrinos are their own antiparticles

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Connection of CPV in neutrino oscillations to CPV in heavy neutrinos is model dependent, but there are models in which δ_{CP} can play a dominant role in leptogenesis (Moffat, Pascoli, Petcov, and Turner, arXiv:1809.08251)

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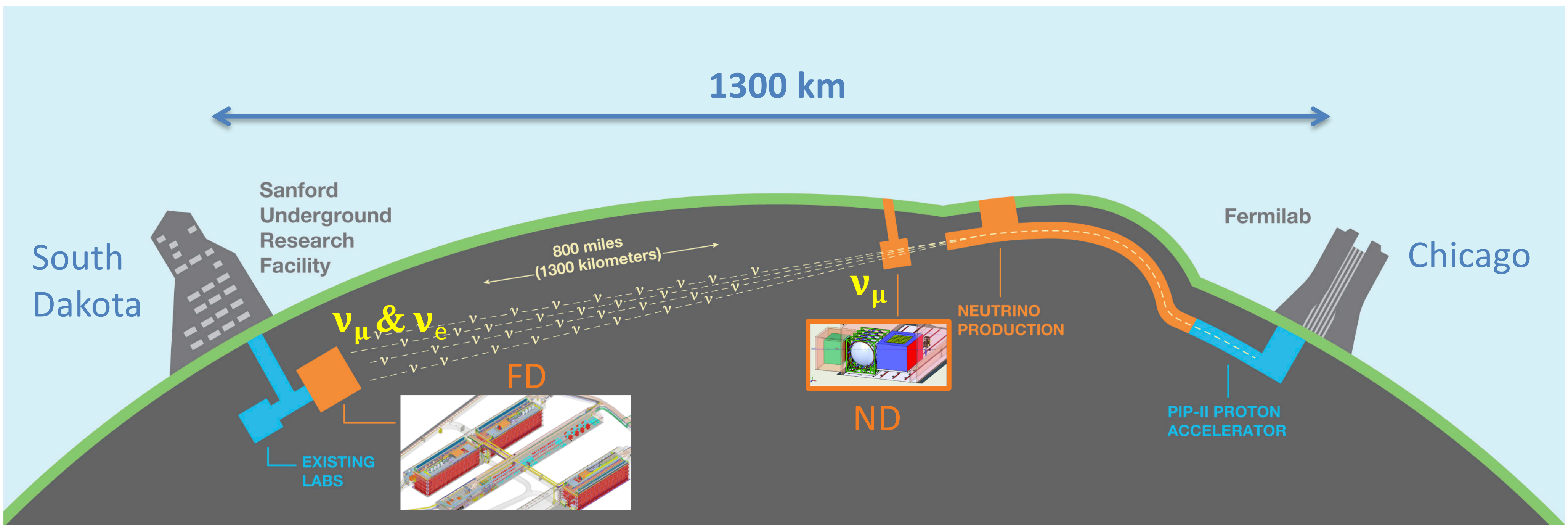
3) Search for neutrinoless double beta decay, to demonstrate that neutrinos are their own antiparticles ← several speakers will address in detail.

   – Question: What is best strategy for $0\nu\beta\beta$ decay if hierarchy is normal. and what facilities will be needed?

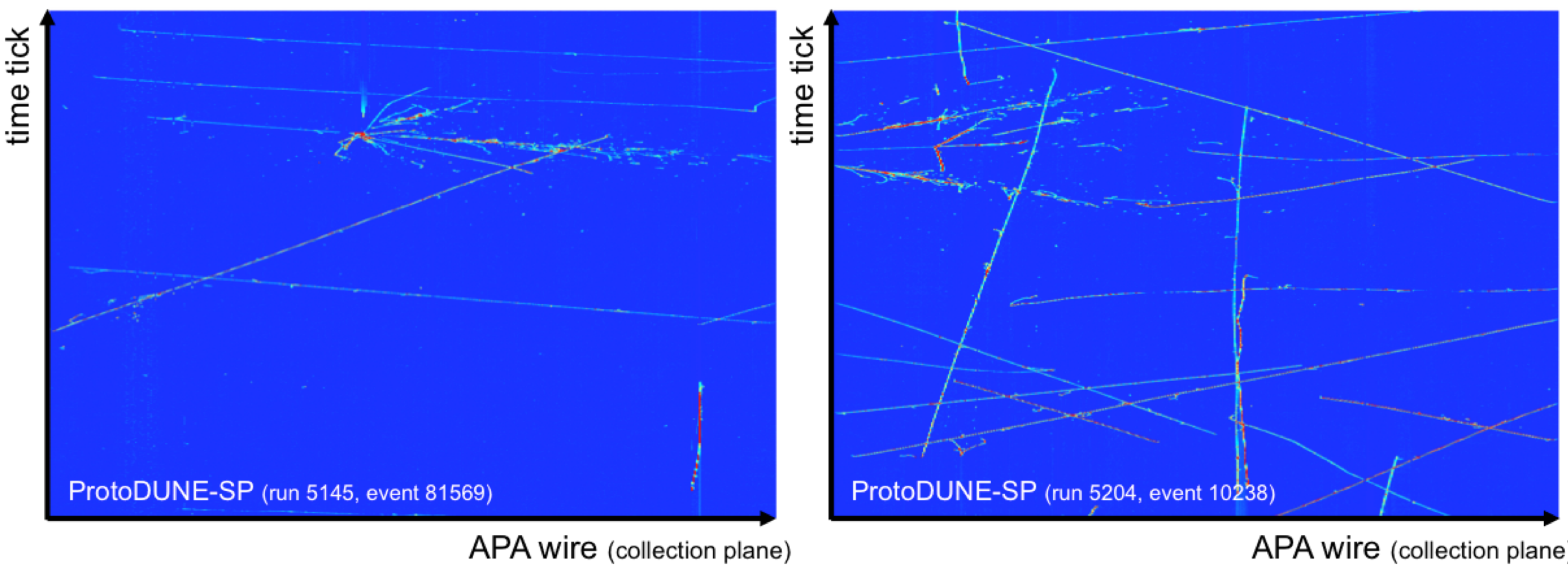
LBNF/DUNE Overview

- Muon neutrinos/antineutrinos from high-power proton beam
  - 1.2 MW from day one; upgradeable to 2.4 MW
- Massive underground Liquid Argon Time Projection Chambers
  - full DUNE scope is 4 x 17 kt (> 40 kt fiducial)
- Near detector to characterize the beam (100s of millions of neutrino interactions)



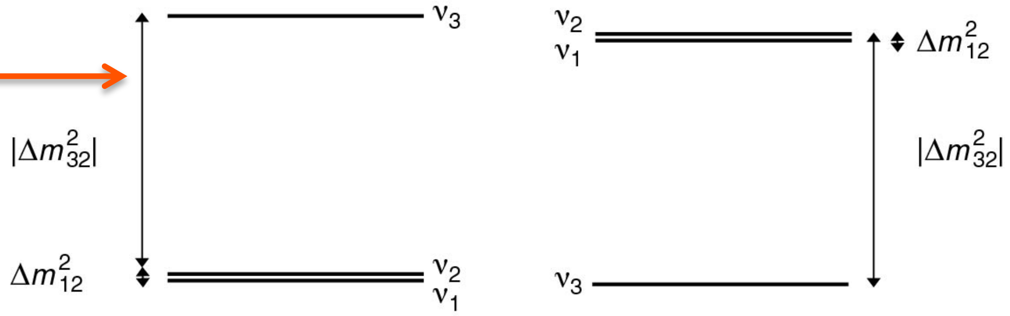
DUNE Science

Unique combination of world's most intense wide-band neutrino beam, a deep underground site, and massive LAr detectors enables broad science program addressing some of the most fundamental questions in particle physics.



DUNE Science Program

- Neutrino Oscillation Physics
  - **Search for leptonic (neutrino) CP Violation**
  - Resolve the mass ordering
    ($m_3 > m_{1,2}$ or $m_{1,2} > m_3$)
  - Precision oscillation physics
    - Parameter measurements, θ_{23} octant
    - **Testing the current 3-neutrino model, non-standard interactions, …**



- Supernova burst physics and astrophysics
  - 3000 ν_e events in 10 sec from SN at 10 kpc
- Beyond the Standard Model physics, including nucleon decay

+ many other topics (ν interaction physics with near detector, atmospheric neutrinos, sterile neutrinos, WIMP searches, Lorentz invariance tests, solar neutrinos, etc.)

P5 Recommendations

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

For a long-baseline oscillation experiment, based on the science Drivers and what is practically achievable in a major step forward, we set as the goal a mean sensitivity to CP violation[2] of better than 3σ (corresponding to 99.8% confidence level for a detected signal) over more than 75% of the range of possible values of the unknown CP-violating phase δ_{CP}. By current estimates, this goal corresponds to an exposure of 600 kt*MW*yr assuming systematic uncertainties of 1% and 5% for the signal and background, respectively. With a wideband neutrino beam produced by a proton beam with power of 1.2 MW, this exposure implies a far detector with fiducal mass of more than 40 kilotons (kt) of liquid argon (LAr) and a suitable near detector. The minimum requirements to proceed are the identified capability to reach an exposure of at least 120 kt*MW*yr by the 2035 timeframe, the far detector situated underground with cavern space for expansion to at least 40 kt LAr fiducial volume, and 1.2 MW beam power upgradable to multi-megawatt power. The experiment should have the demonstrated capability to search for supernova (SN) bursts and for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.

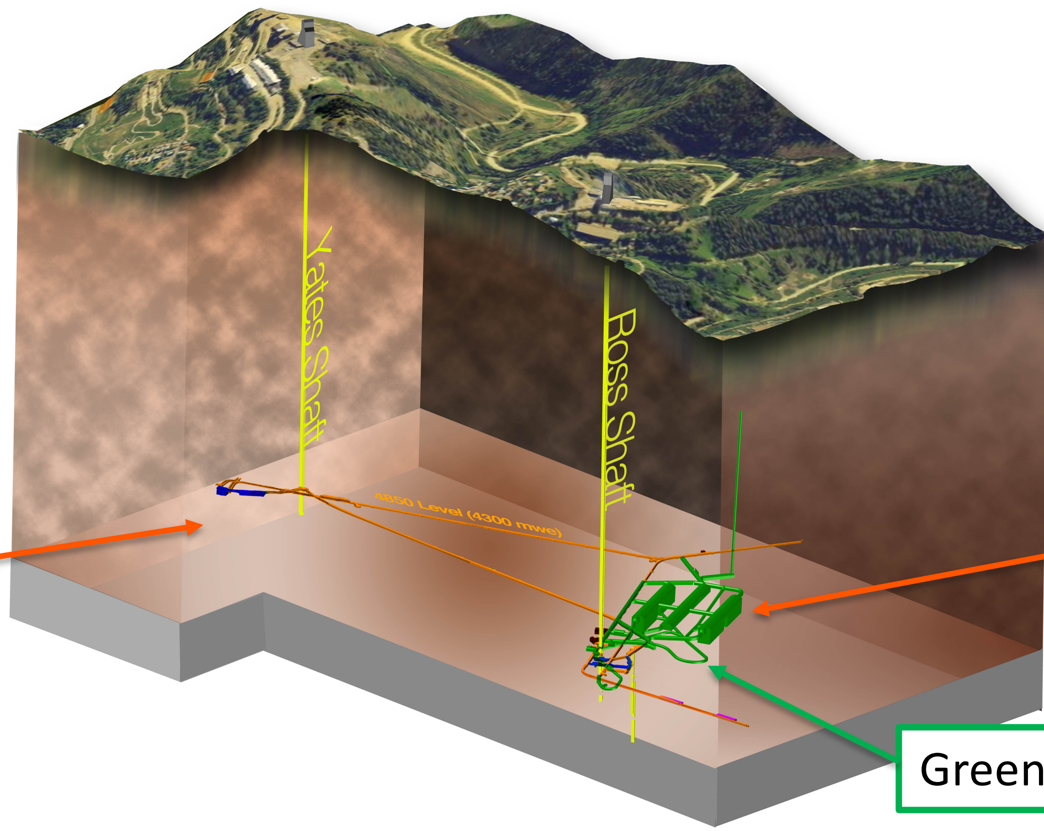
Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

LBNF and DUNE are designed to meet the P5 goals.

DUNE Far Site

Ross Campus of 4850 ft level of Sanford Underground Research Facility

Davis Campus:
- LUX
- Majorana demo.
- …
- **LZ**

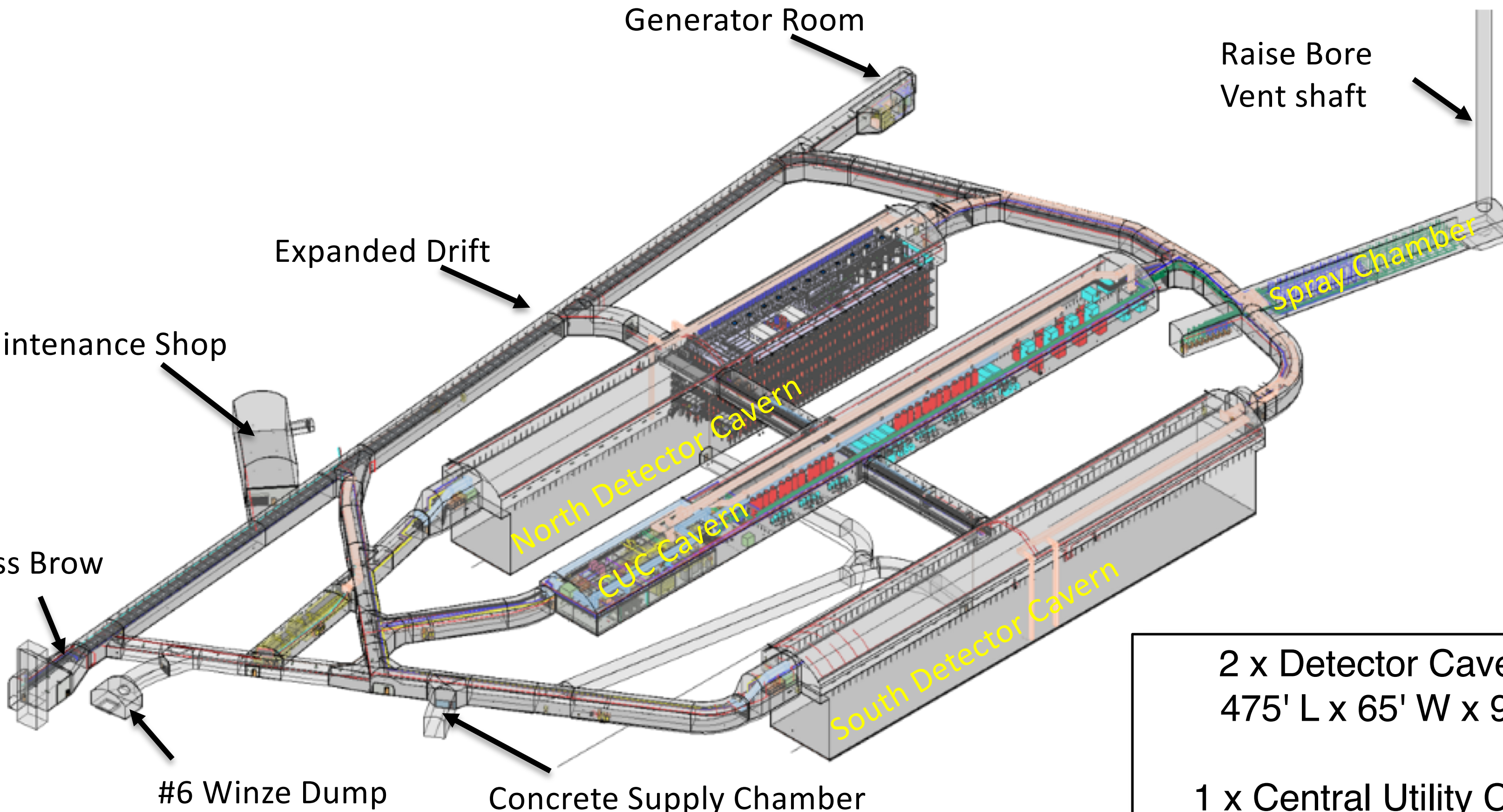


Ross Campus:
- CASPAR
- …
- **DUNE**

Green = new construction

(Why 4850? See A. Bernstein et al., ``Report on the Depth Requirements for a Massive Detector at Homestake,'' [arXiv:0907.4183 [hep-ex]].)

LBNF Excavation Scope



2 x Detector Caverns:
475' L x 65' W x 92' H

1 x Central Utility Cavern (CUC):
624' L x 64' W x 37' H

LBNF/DUNE Groundbreaking, 21 July 2017

Far Site Conventional Facilities Status

Reliability Projects

- ✓ Refuge Chamber Capacity Increase – Complete
- ✓ Oro Hondo Fan VFD Replacement – Complete
- ✓ Ross Crusher Roof Replacement – Complete
- ✓ Ross Shaft Cage Replacement – Complete
- ✓ Ross Shaft Skips Replacement – Complete
- ✓ Ross Hoist Motor Replacement – Complete
- ✓ Ross Hoist Bearing/Bushing Refurb – Complete
- ✓ Ross Hoist Mech/Electrical Components Upgrades – Complete
- ✓ Ross Shaft Rehabilitation – Substantially Complete

Pre-Excavation Projects

- ✓ Empty & Repair Ore Pass – Complete
- ✓ Replace Skip Loading System – Complete / Commissioning
- ✓ Replace/Restore Rock Crushing System – Complete / Commissioning
- ✓ Rehabilitate the Existing Tramway – Complete
- ✓ Install New Conveyor System – Complete / under commissioning
- ✓ Install additional Electrical Capacity at Ross Substation – Complete
- ✓ Structural Reinforcement of Ross Headframe – Complete
- ✓ Install Shaft Utilities – Complete
- ✓ Early Ventilation Improvements - Complete

Excavation Project Preparation

- ✓ Limited Notice to Proceed - Complete
- ✓ Leased Local Office & Equipment Yard – Complete
- ✓ Mobilization of Mining Equipment – Complete
- ✓ Local Community & Small Business Engagement – Complete
- ✓ Mobilization of Key Field & Staff Resources – Complete
- ✓ Communication Plans & Alignment Meetings - Complete
- ✓ Excavation Cost Loaded Baseline Schedule – Complete
- ✓ Approve TMI Training, ESH Plans, QA/QC Plans, Build Plans – Complete
- ✓ Builders Risk and SDSTA insurance policies - in place

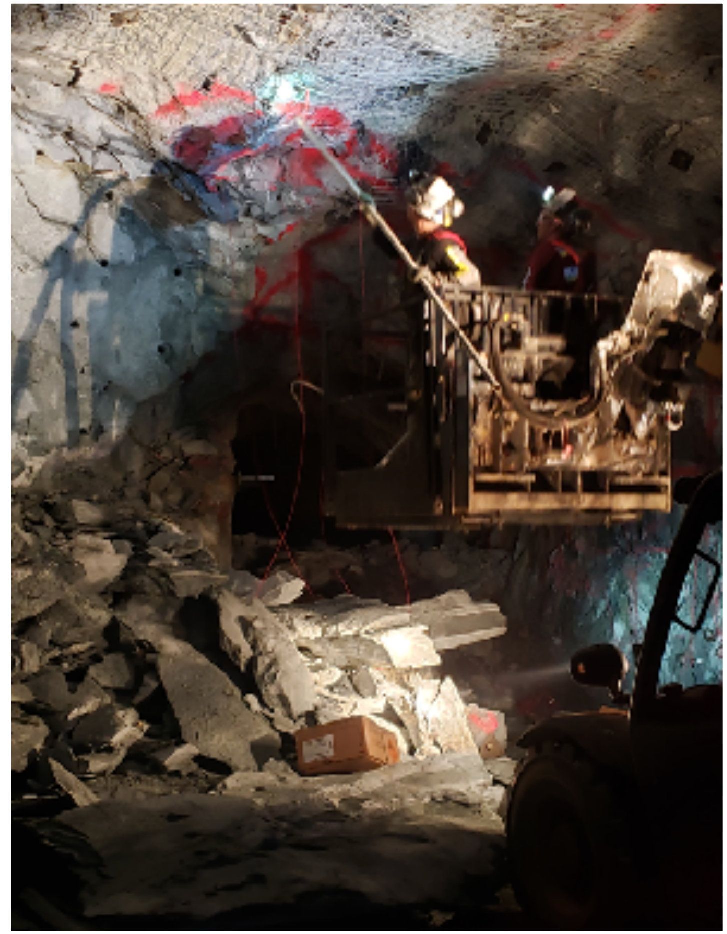
Main excavation phase officially began on 5 April 2021, on schedule

14 Sept 2021

(from C. Mossey)

Far Site Construction Status

TMI Drilling Blast Holes with Single Boom Jumbo



Explosive Technician Loading Blast Holes

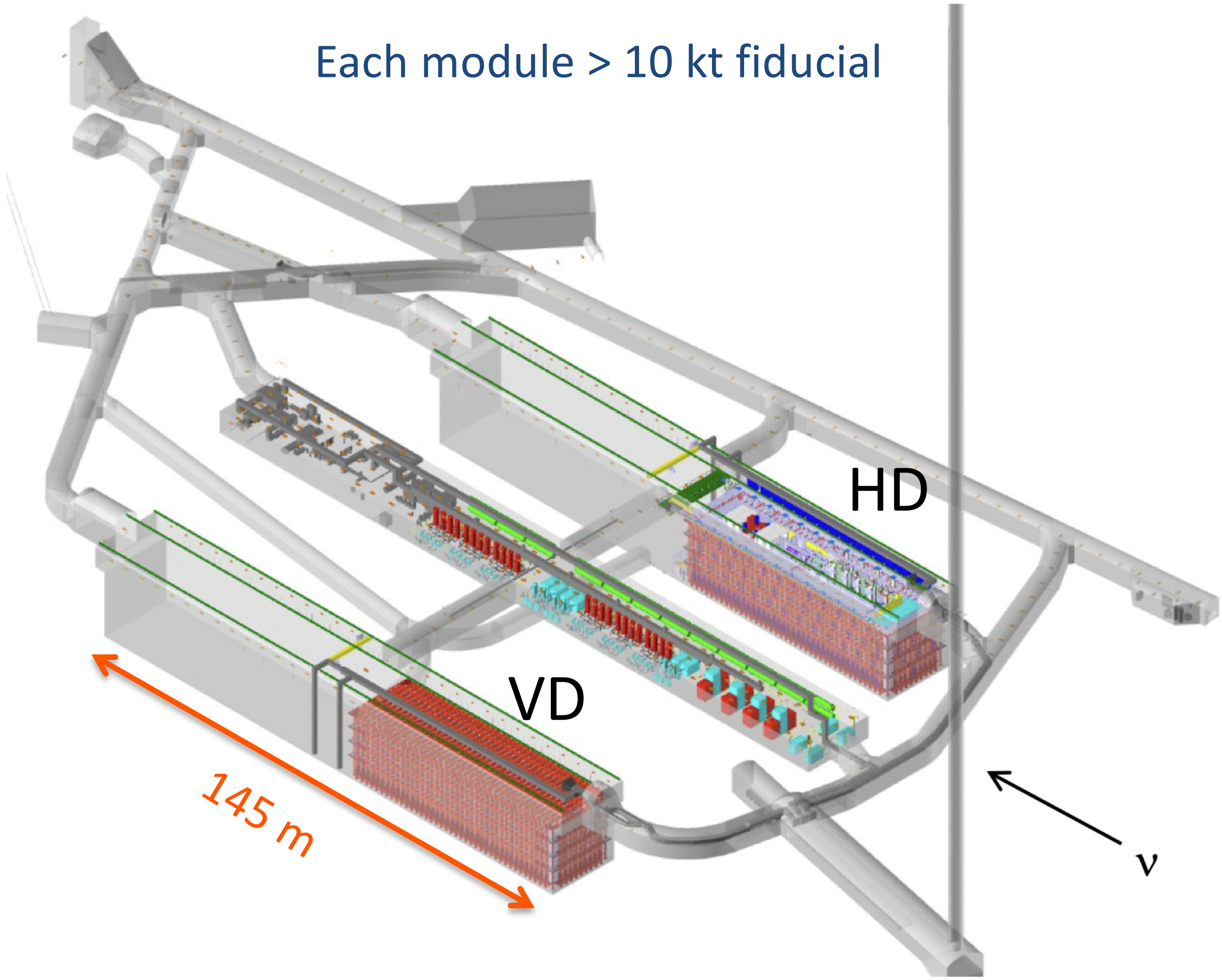
Far Site Construction Status

Muck pile, post blast, for electrical substation cavern

Moving muck and dumping through grizzly into ore pass to be loaded on skips to move to surface

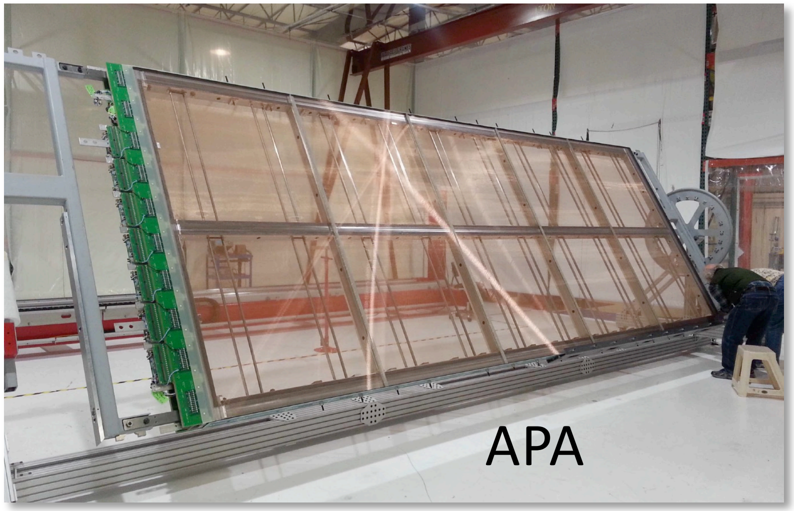
DUNE Far Detector

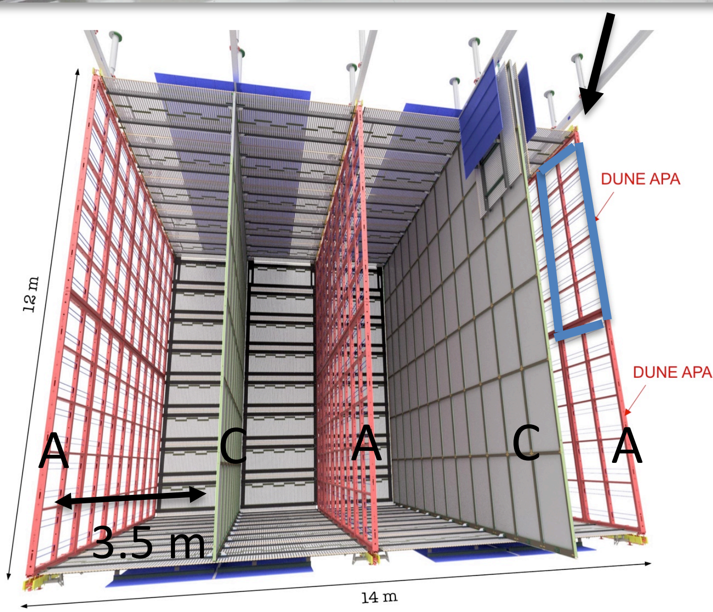
- Four separate 17 kt (> 10 kt fiducial) LAr TPCs
- 4 identically sized cryostats: module 1 – horizontal drift (HD), module 2 – vertical drift (VD); technology for modules 3, 4 undetermined



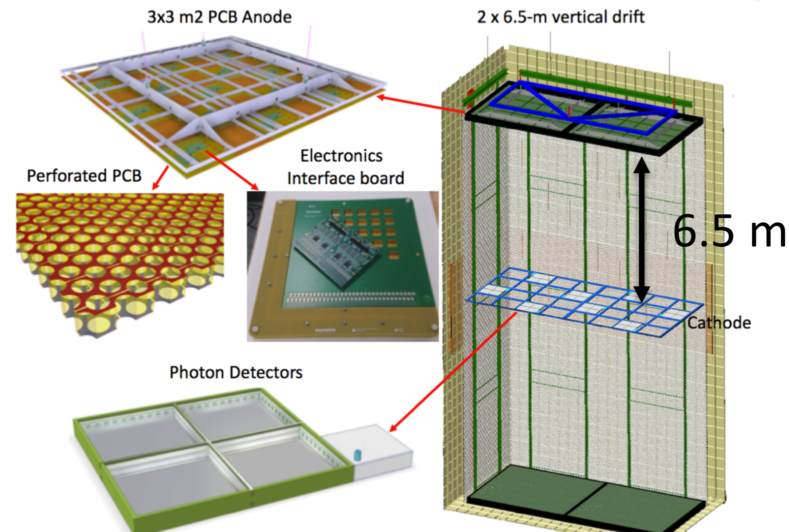
Technologies for First FD Modules

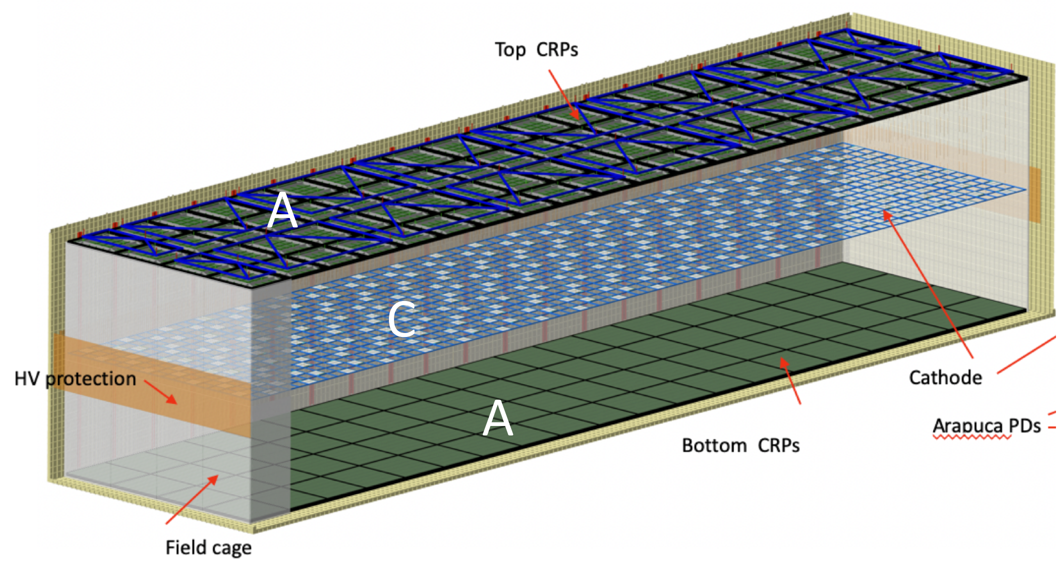
Module 1: Single Phase Horizontal Drift





Module 2: Single Phase Vertical Drift





DUNE Far Detector Strategy

- FD Module 1 will be SP Horizontal Drift (APAs) and Module 2 will be SP Vertical Drift (CRPs). These modules should be complete toward the end of the decade.
- The full experiment (4 far detector modules, complete near detector) plus 2.4 MW upgrade of the accelerator complex is required to meet P5 science goals.
- The Collaboration will continue to work to assemble resources and develop technologies to build FD Modules 3 and 4.
- Modules 3, 4 present an opportunity to explore new technologies that would expand physics scope in addition to contributing to P5 physics goals.

Module of Opportunity Workshop at BNL

- Very well attended and exciting workshop at BNL in November 2019.
- Consider advanced liquid-argon (or alternate) technologies.