LBNF/DUNE-US Project Update for the National Laboratory Director's Council

Chris Mossey, Project Director, LBNF/DUNE-US

LBNF Project partners:

- US/DOE
- Brazil/FAPESP-UNICAMP
- CERN
- India/DAE
- Poland/WUST
- Switzerland/SERI, and
- UK/UKRI-STFC

plus the DUNE international Collaboration and consortia

Outline

- Project Background
- Project Scope and Tailoring Strategy
- CD-1RR Preparation Status Review Considerations
- Status Updates
    - Far Site
    - Near Site
- Summary

Project Background

The 2014 US Particle Physics Project Prioritization Panel (P5) endorsed a global particle physics program

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

- Build a world-class neutrino program
- Host it as a global project
- Upgrade Fermilab accelerator complex to provide >1 MW proton beam

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.

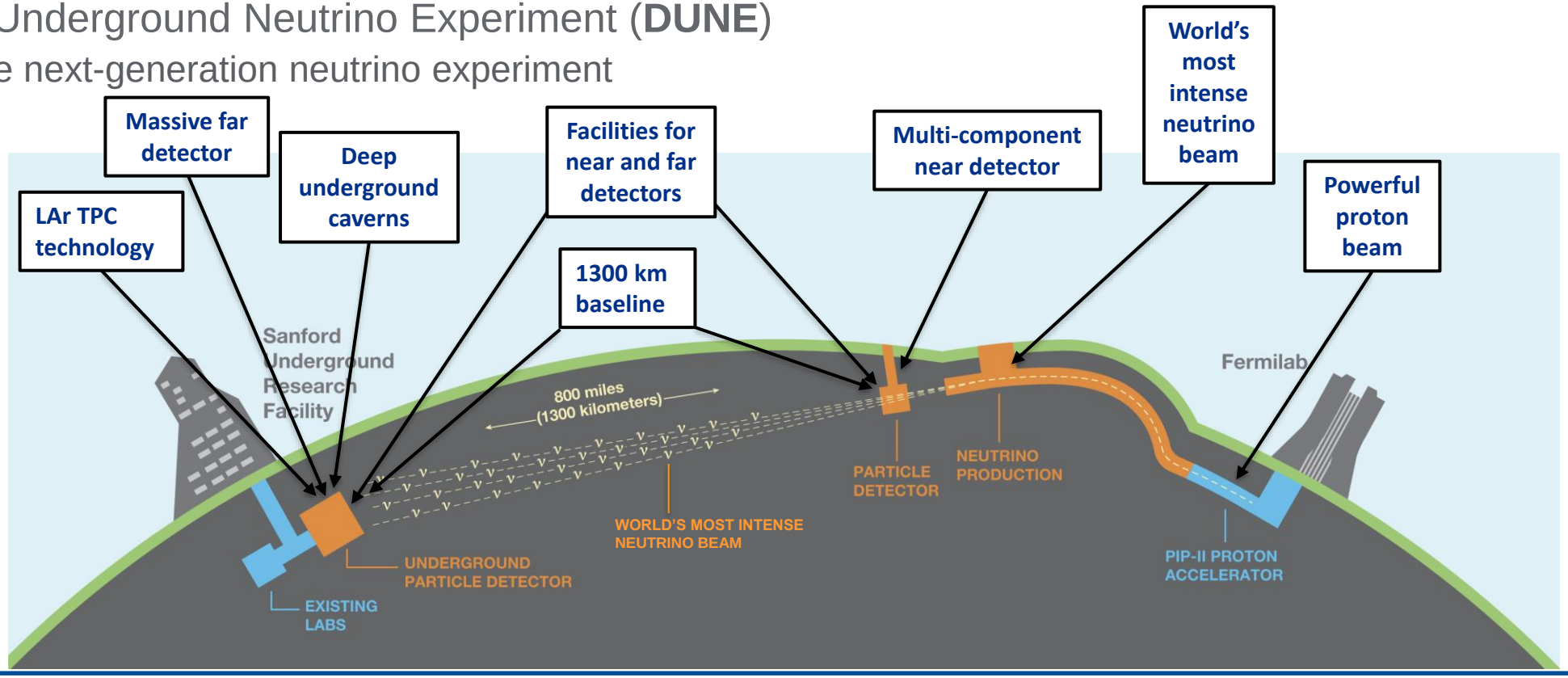
Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.

European Strategy Update

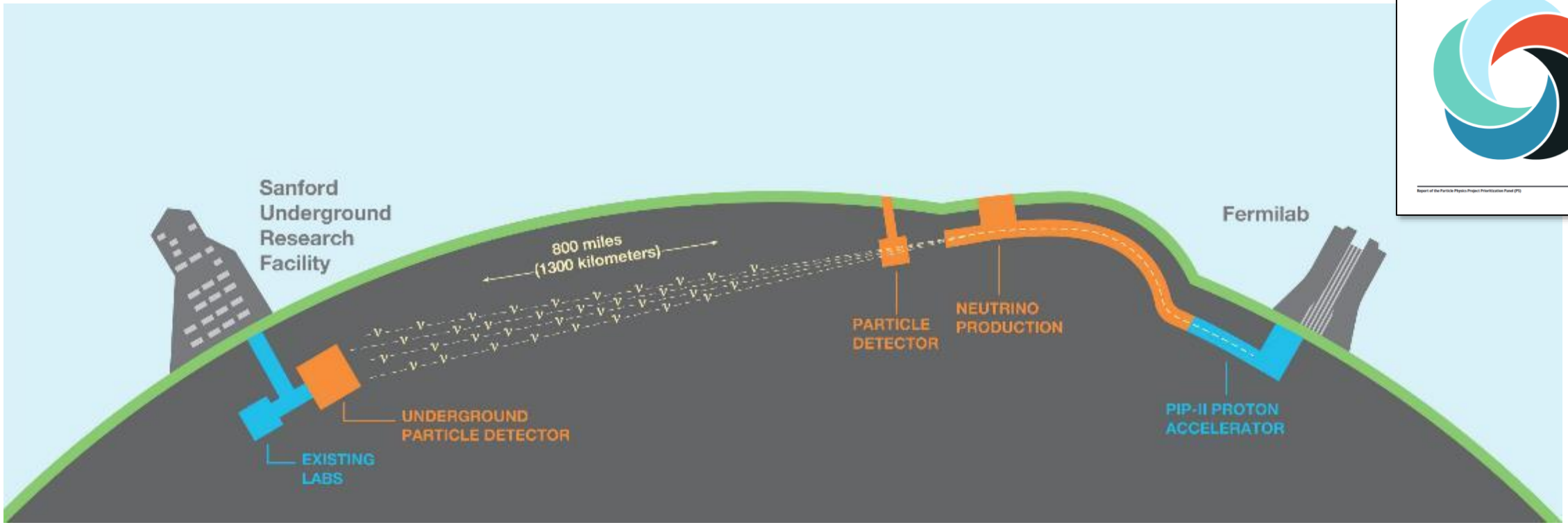
The US neutrino program is supported by the European Strategy

PIP-II / LBNF / DUNE delivers…

- Powerful proton beams (**PIP-II**)
  - 1.2 MW upgradable to multi-MW in energy range of 60-120 GeV to enable world's most intense neutrino beam
- Dual-site detector facilities (**LBNF**)
  - Deep underground caverns (1.5 km) to support 4 x 17 kt liquid argon volume detectors
  - A long baseline (1300 km) neutrino beam, with wideband capability
- Deep Underground Neutrino Experiment (**DUNE**)
  - The next-generation neutrino experiment



Implementing the P5 Vision - Deep Underground Neutrino Experiment



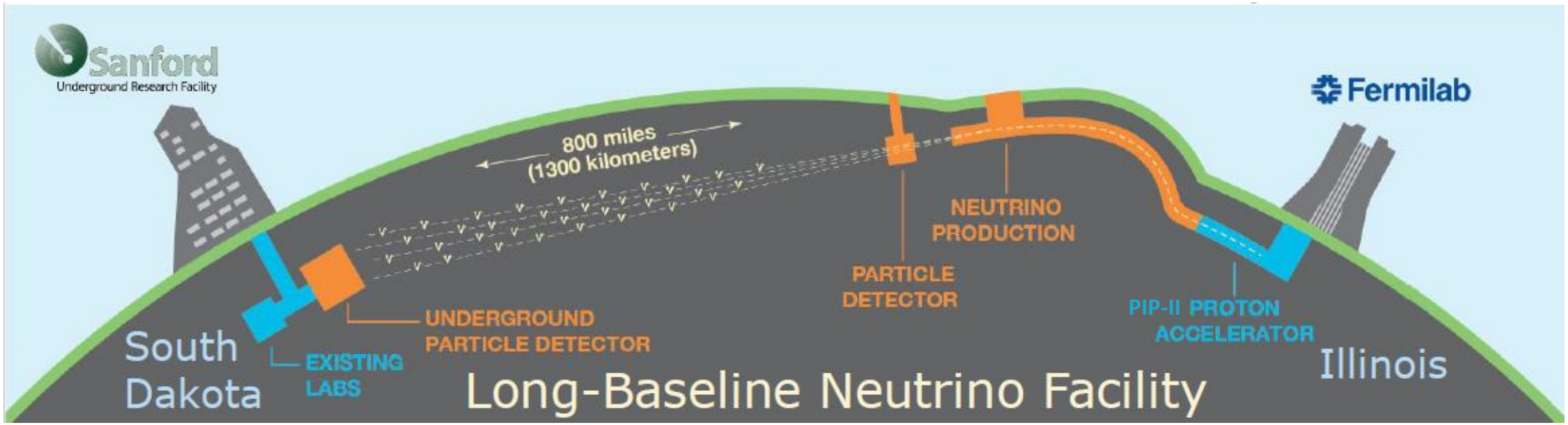
Origin of matter. Investigate leptonic CP violation. Are neutrinos the reason the universe is made of matter?

Neutron star and black hole formation. Ability to observe neutrinos from supernovae events and perhaps watch formation of black holes in real time.

Unification of forces. Investigate nucleon decay, advance unified theory of energy and matter.

LBNF and PIP-II will enable the United States to host the global high energy physics community to advance world class discovery science into the fundamental nature of matter

The LBNF/DUNE vision is achieved by a groundbreaking international partnership



- **Long Baseline Neutrino Facility** – facilities with partner in-kind contributions

LBNF

- **DUNE-US** – U.S. contribution to the international DUNE experiment
- **International DUNE** - partner contributions to the international DUNE experiment

DUNE

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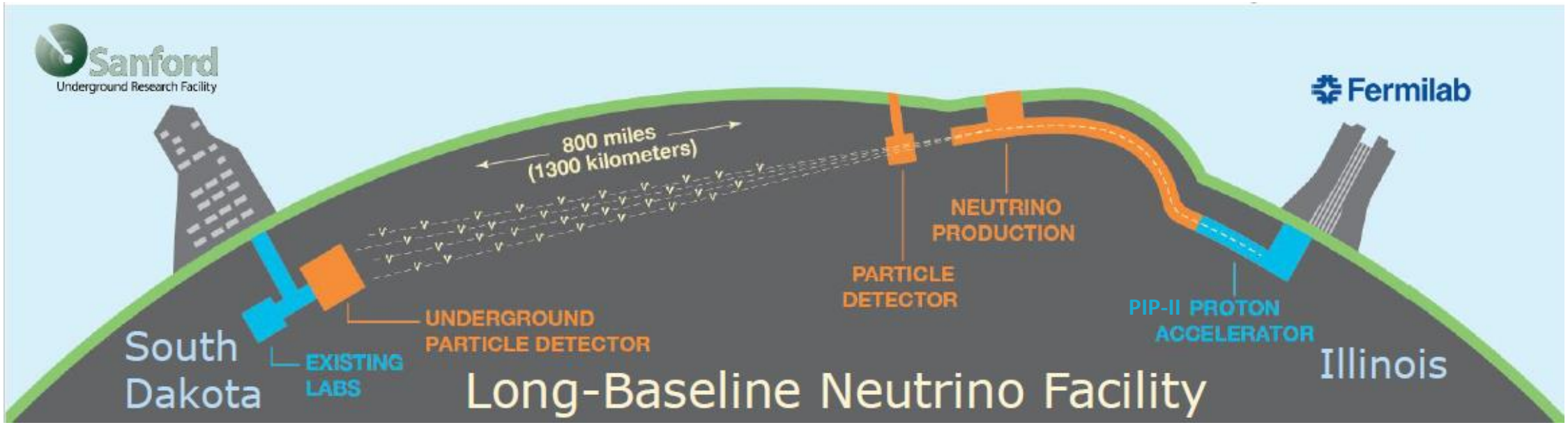


LBNF/DUNE-US Project

- **Long Baseline Neutrino Facility** – facilities with partner in-kind contributions

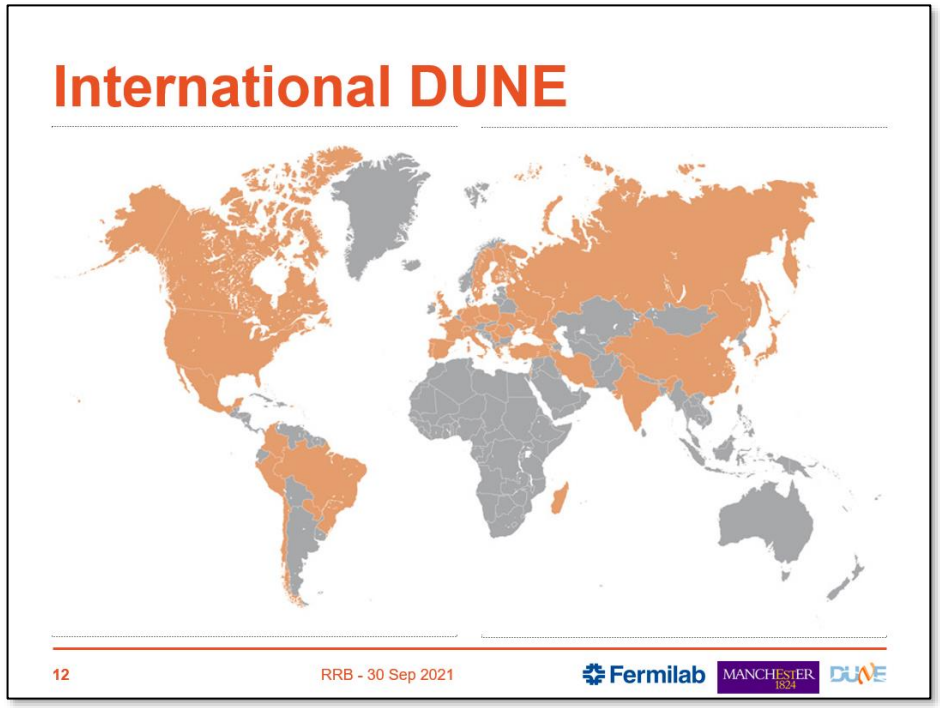
LBNF

- **DUNE-US** – U.S. contribution to the international DUNE experiment
- **International DUNE** - partner contributions to the international DUNE experiment

DUNE

LBNF and DUNE-US are one DOE Order 413.3B Project

The DUNE experiment is managed by the international DUNE Collaboration



Collaboration statistics (as of Oct 2021)

- 1,432 collaborators, 48% U.S./52% non-US
- 217 institutions from 37 countries including CERN

Demographics (not including computing)

- Facility/Senior staff: 676
- Post Docs: 240
- Grad Students: 319
- Engineers: 158

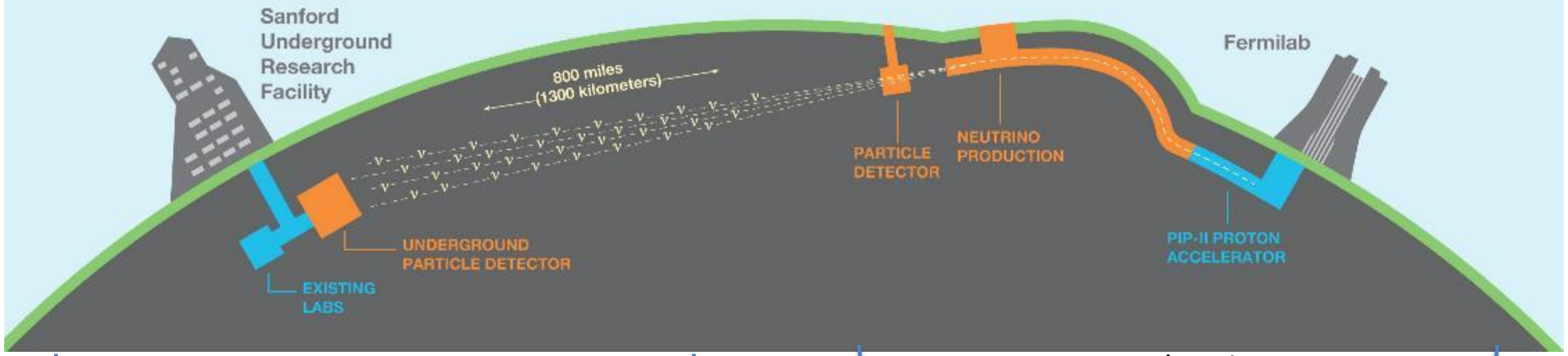
DUNE will be the first internationally conceived and operated mega-science experiment hosted by the Department of Energy in the United States

Project Scope and Tailoring Strategy

Project Scope - Delivered at Two Sites through Five Subprojects

Far Site – SURF in Lead, SD
Facility/Infrastructure and Far Detectors

Near Site – FNAL in Batavia, IL
Facility/Infrastructure, Neutrino Beamline, and Near Detectors



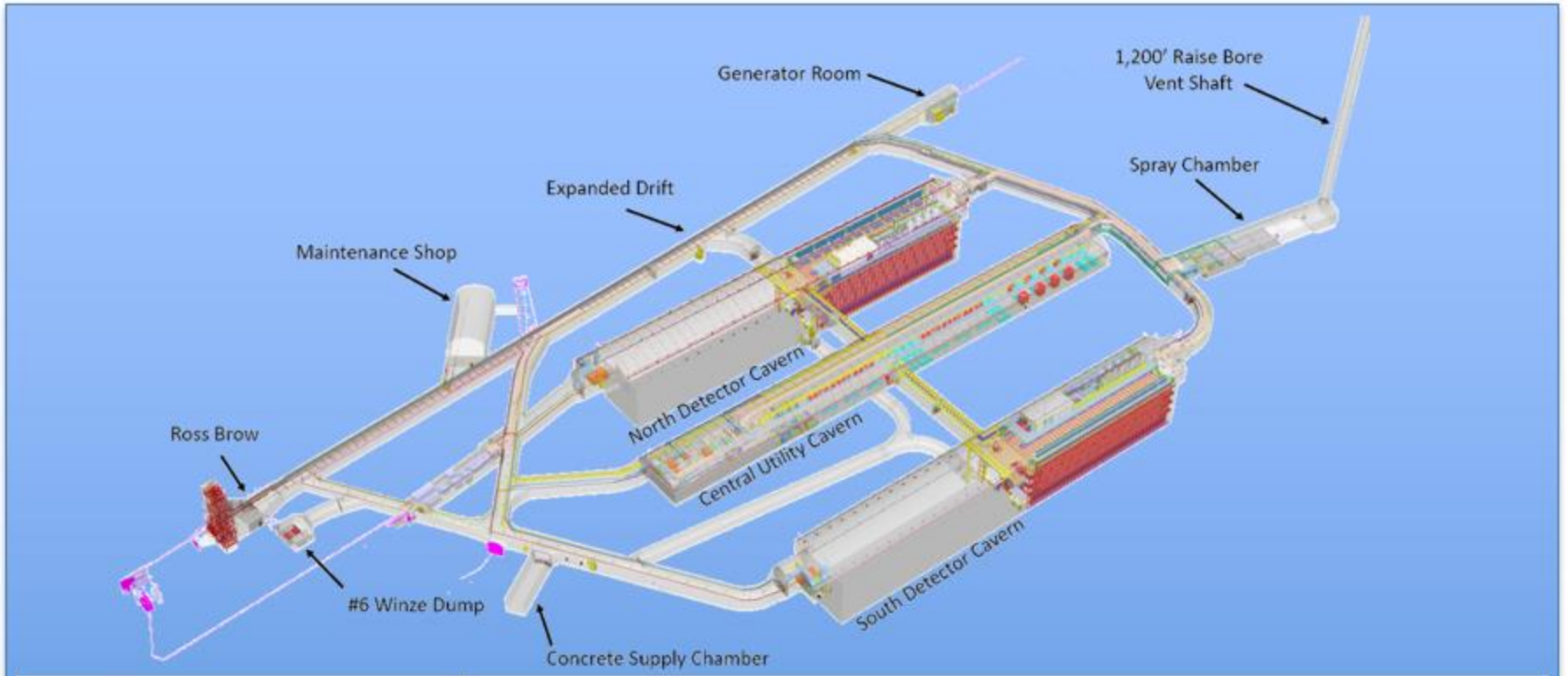
Three subprojects

- **FSCF-EXC** – Far Site Excavation
- **FSCF-BSI** – Far Site Building & Site Infrastructure
- **FDC** – Far Detectors and Cryogenic Infrastructure

Two subprojects

- **NSCF+B** – Near Site Conventional Facilities + Beamline
- **ND** – Near Detectors

DOE Project Scope – Far Site



WBS/Subproject	Scope
131.FSCFEXC/FSCF-Excavation	Project management, preliminary and final design, reliability/infrastructure upgrades, pre-excavation systems, and excavation work to support 4 detector modules.
131.FSCFBSI/FSCF-Building & Site Infrastructure	Project management, preliminary and final design, and construction of surface and underground utilities, and infrastructure outfitting of spaces for detector modules.
131.FDC/Far Detectors and Far Site Cryogenic Infrastructure	DUNE-US contributions to two DUNE detector modules; two cryostats & associated liquid argon; cryogenic systems to support two detector modules; installation and integration for two detector modules and cryogenic infrastructure

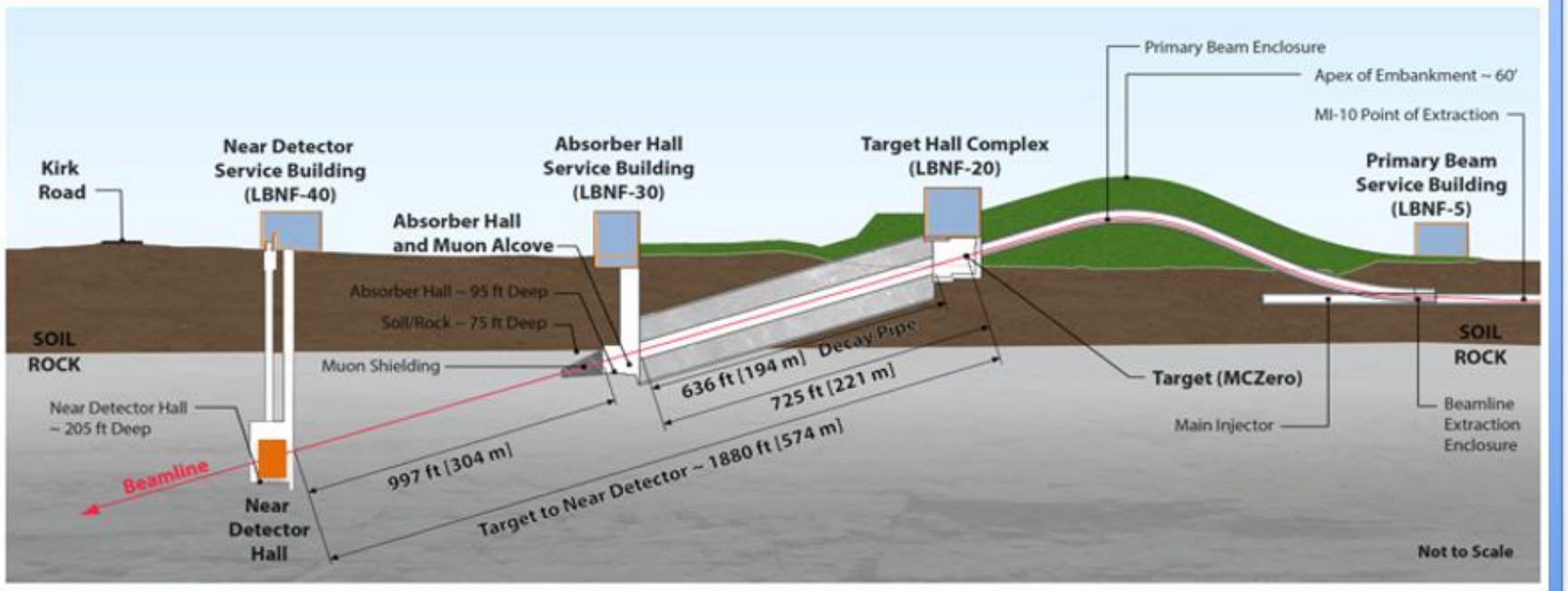
At the far site, the LBNF project scope includes committed in-kind contributions from:

- CERN – Membrane cryostats and portions of argon receiving facility (tanks)
- Brazil/UNICAMP – Argon purification and recirculation systems
- Switzerland/SERI – Argon condensing system
- Poland/WUST – Internal cryogenics systems

Project “Far Site” is at Sanford Underground Research Facility (SURF) in Lead, SD

- SURF is located at the former Homestake Gold Mine, in Lead SD
- Property was transferred to South Dakota Science and Technology Authority (SDSTA), a quasi-public agency, to create and operate an underground science facility
- SDSTA operates SURF under a cooperative agreement with DOE HEP
- DOE has leased areas in which LBNF facilities will be constructed from SDSTA; construction easements are also in place to allow access and temporary use of various areas
- FRA has a memorandum of understanding with SDSTA with respect to LBNF/DUNE-US project support, services, and responsibilities
  - The MOU established a Joint Coordination Team, which meets biweekly and ensures any coordination issues are resolved in a timely manner

DOE Project Scope – Near Site



WBS/Subproject	Scope
131.NSCFB/NSCF + Beamline	1.2MW primary and neutrino beam, upgradable to 2.4MW; facility to support 1.2MW upgradable beamline and ND Complex
131.ND/Near Detector	DUNE-US contributions to Phase 1 Near Detector; LAr and LHe systems to support ND; installation and integration for detector and cryogenic systems.

At the near site, the LBNF project scope includes committed in-kind contributions from:

- UK/RAL – Neutrino target and baffle, design of cooling system
- India/BARC – Dipole and quadrupole primary beam magnets
- China/IHEP – Corrector primary beam magnets
- Japan/KEK – Prototyping hatch cover and stripline feed throughs
- CERN – LAr cryogenic components

Project Tailoring Strategy – Implementation of Subprojects

- Subproject tailoring strategy allows portions of overall DOE project scope to be baselined as soon as technically ready.
  - Addresses variation in maturity across the broad diversity of project scope – for example, Far Site conventional facilities are ready to baseline now, while near detector is still maturing
  - Preferred approach for complex “billion dollar” scale projects with broad scope and is supported by DOE Order 413.3B
  - Our approach is informed by lessons learned from other “mega-projects”

- FSCF-EXC subproject CD-2/3 approval must be received by June 2022 to ensure excavation work can continue to completion without risk of delay.

Subproject Design Maturity towards CD-2 Independent Project Review

	Subproj Abbrev	Subproject Title	Subproject Scope	Design Maturity	Proposed CD-2 IPR
FAR SITE	FSCF-EXC	Far Site Conventional Facilities - Excavation	All Far Site (FS) conventional facilities (CF) reliability, pre-excavation, and excavation including all detector caverns **Construction underway, >50% complete**	**100%**	Jan 2022
	FSCF-BSI	Far Site Conventional Facilities – Building & Site Infrastructure	All Far Site (FS) conventional facilities (CF) support infrastructure **Master contract, with not to exceed cost limit, in place**	**100%**	Late 2022
	FDC	Far Detector 1, Far Detector 2 + Cryogenics	Far Detector 1 (FD1), Far Detector 2 (FD2), including integration/installation, and all cryogenic infrastructure (C) and LAr fluids.	90% (FD1) 45% (FD2) 25% (C)	2023
NEAR SITE	NSCF+B	Near Site Conventional Facilities + Beamline	All Near Site (NS) conventional facilities (CF) including beamline facilities, detector cavern and support infrastructure; primary and neutrino beamline (B)	**100%** (CF) 69% (BL)	2022 or 2023
	ND	Near Detector	Near Detector (ND) including integration/installation and cryogenic systems	30%	2023 to 2025

New Funding Guidance has been implemented by Project ("Reference Profile")

- HEP provided updated annual funding guidance in August 2021.
- In close coordination with DUNE collaboration leadership and our international partners, the project has implemented the funding profile, with the following overarching objectives:

1. Complete construction of Far Detector 1 and Far Detector 2 – early 2029
   - ► *Enables start of supernova, proton decay, and atmospheric neutrino science*
2. Complete construction Primary and Neutrino Beamline - 2031
   - ► *Enables start of oscillation physics*
3. Complete construction of Near Detector – early 2032
   - ► *Enables understanding of systematics for initial oscillation physics objectives*

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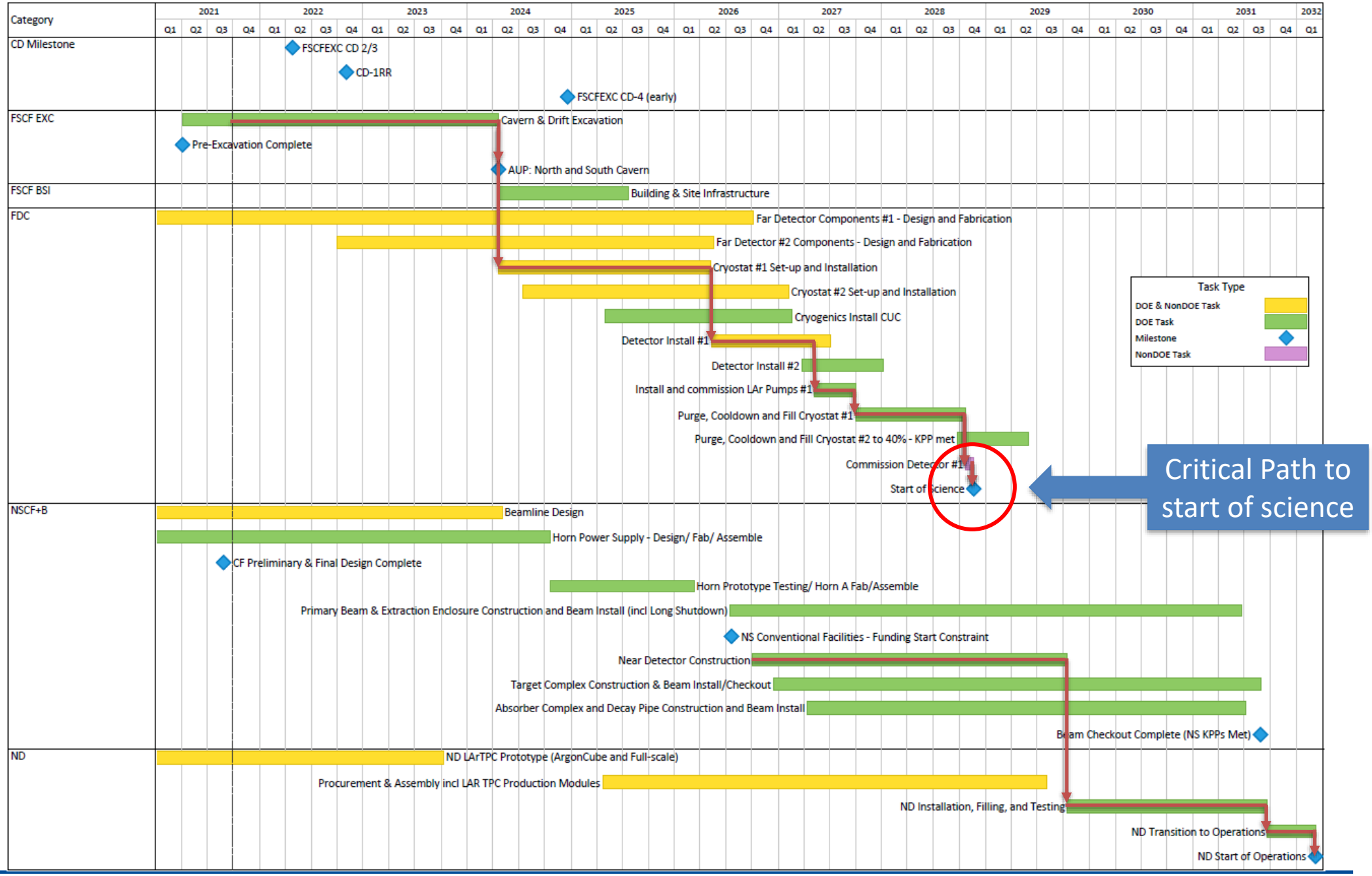
2. Complete construction Primary and Neutrino Beamline - 2031
   - ► *Enables start of oscillation physics*
3. Complete construction of Near Detector – early 2032
   - ► *Enables understanding of systematics for initial oscillation physics objectives*

Technically limited schedule, for excavation (underway), cryostat assembly starting in 2024, and detector installation starting in 2025

Funding limited schedule. Beamline and Near Detector construction can be accelerated 2.5 to 3 years with higher peaked funding profile.

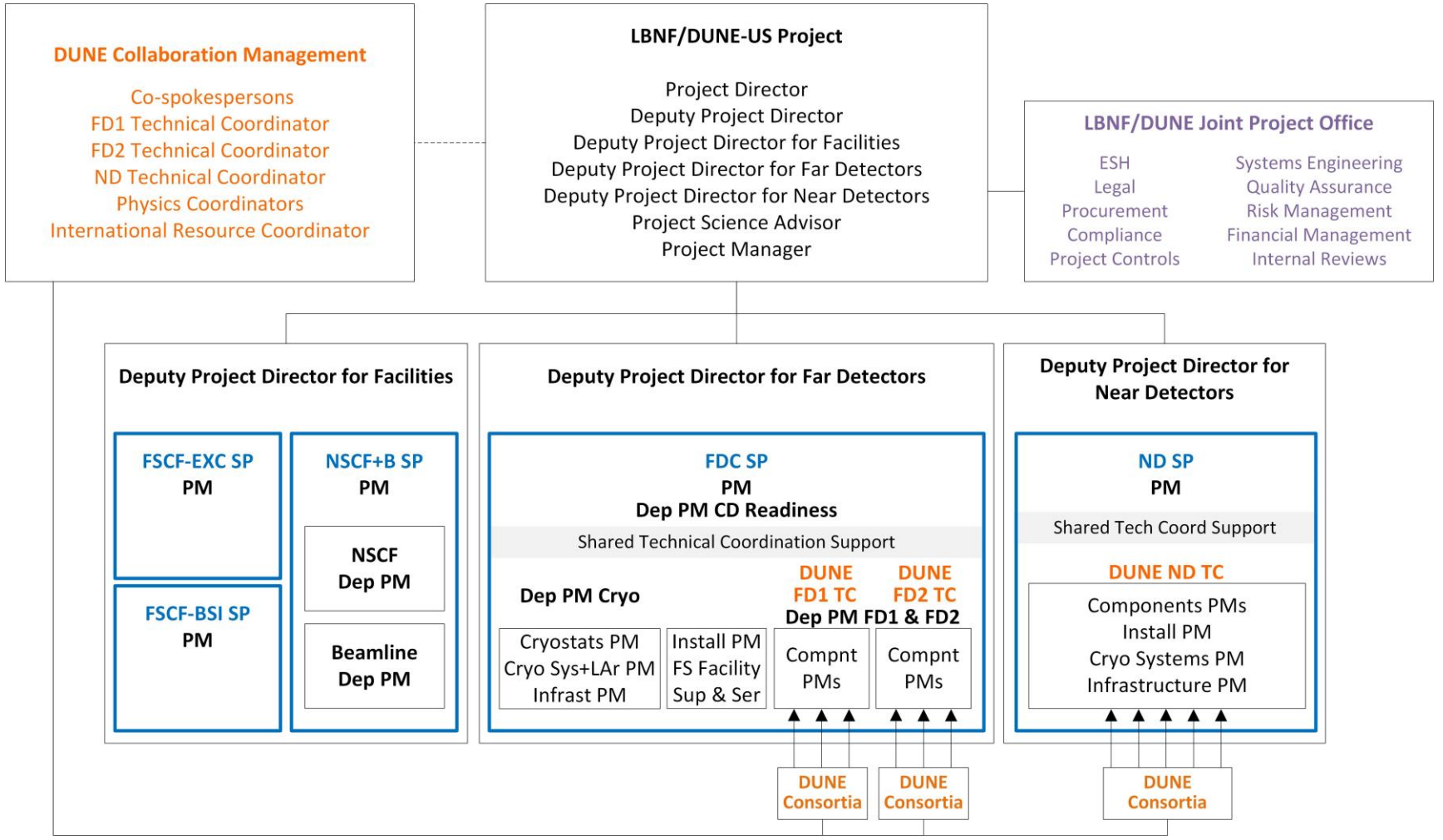
Schedule Summary With Critical Paths through each site



Notes:
- October 2021 reporting cycle
- Based on “reference” profile
- Pending baselining

Revised Construction Project Organization implemented in July 2021

- Organization is deliverable-focused and significantly improves alignment
  - Clear lines of responsibility, authority, and accountability
  - Aligned with subproject execution strategy
  - Much stronger interfaces with DUNE Technical Coordinators and consortia



CD-1RR Preparation Status Review Considerations

Critical Decisions – History and Status Overview

- **CD-0** (approved 8 Jan 2010)
- **CD-1** (approved 10 Dec 2012) for “Long-baseline Neutrino Experiment” – beamline and surface detector
- **CD-1R** (approved 5 Nov 2015) after P5 called for increased scope and a fully international experiment
- **CD-3A** (approved 1 Jun 2016) to start excavation at the far site.
- **CD-3A** Revision (approved 27 Oct 2020) to reduce the scope within cost envelope due to cost growth
  - **Excavation work is under contract and is proceeding well.**
- **CD-2/3** for FSCF-EXC Subproject (ESAAB planned Jun 2022) – to complete excavation.
  - **Agreement with SC leadership to pursue FSCF-EXC CD-2/3 prior to CD-1RR (all other subproject critical decision approvals must be after CD-1RR approval)**
- **CD-1RR** (ESAAB planned 4QFY22)
  - **Growth of the cost estimates requires the project to reaffirm alternative selected in CD-1R, establish new cost and schedule ranges, and lay out overall subproject tailoring strategy**
- **CD-2/3** for remaining subprojects (as required)
- **CD-4** – upon approval of last subproject CD-4 (projected 2032)

Project Costs and Cost Drivers are now understood – 1 of 2

- Largest project cost elements (conventional facilities) are mature and well understood
  - Far Site conventional facilities costs, including excavation, have been stable since late 2018.
    - Excavation work is under contract
    - Have “not to exceed” cost limit for BSI work under CM/GC contract
  - Near Site conventional facilities design is final; have two cost estimates in hand and will have third independent cost estimate by CD-1RR review.
- Project scope is finalized and stable
  - Integration/installation has been added to project scope
  - Near Detector phase 1 scope has been finalized in close coordination with DUNE collaboration and DOE HEP.
    - Project ND Scope = ND LAr + TMS + SAND + PRISM

Project Costs and Cost Drivers are now understood – 2 of 2

- International contributions are committed
  - All LBNF international contributions are covered by binding legal agreements; Project Planning Documents being finalized.
  - DUNE partner contributions to detectors are coordinated by DUNE collaboration leadership and memorialized in consortia annexes to the Multi-institutional MOU.
    - All Phase 1 scope has been accounted for and commitment uncertainty has been estimated and included as a factor in the CD-1RR cost range considerations.
- Realistic Funding Profile
  - HEP is confident that the recently implemented funding profile is more realistic than previous guidance and is working with SC to reduce uncertainty prior to CD-1RR review. Impact of a “minimal profile” has been included in CD-1RR cost range calculation.
- Risks/uncertainty
  - Have prototyped most significant detector risks, including HV field (300 kV), argon purity, cold electronics, cryostat design/penetrations, and full size APAs.
  - Have significantly increased overall project contingency to 40%

Status Updates - Far Site

LBNF Construction Status - Far Site Conventional Facilities

- ✓ **Reliability Project** upgrades to SURF – virtually complete. Significant infrastructure upgrades, including refurbished shaft and new hoist system.
  - ✓ Refuge Chamber Capacity Increase
  - ✓ Oro Hondo Fan VFD Replacement
  - ✓ Ross Crusher Roof Reinforcement
  - ✓ Ross Shaft Cage Replacement
  - ✓ Ross Shaft Skips Replacement
  - ✓ Ross Hoist Motor Replacement
  - ✓ Ross Hoist Bearing/Bushing Refurbishment
  - ✓ Ross Hoist Mech/Elect Components Upgrade
  - ✓ Ross Shaft Rehabilitation
- ✓ **Pre-excavation phase** – complete. Equipment and systems to move excavated rock from one mile underground to the surface and deposit in the Open Cut.
  - ✓ Empty and repair Ore Pass
  - ✓ Replace Skip loading system at 4850L
  - ✓ Replace Rock Crusher system
  - ✓ Rehabilitate underground Tramway
  - ✓ Install new conveyor systems
  - ✓ Structural reinforcement of Ross Headframe
  - ✓ Upgrade power capacity at Ross Substation
  - ✓ Install Shaft Utilities
  - ✓ Excavate 3650L cavern and drift to spray chamber

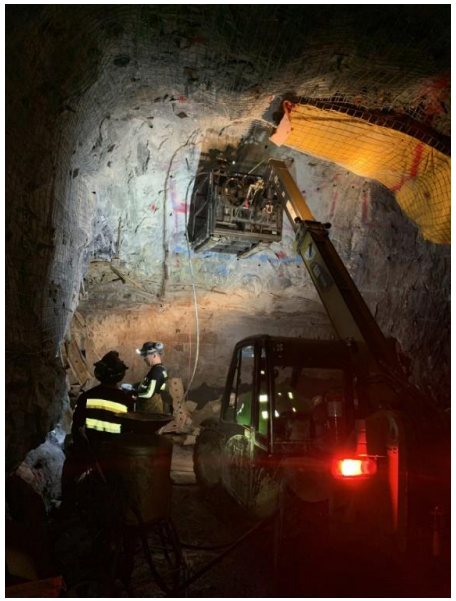
New Service Hoist Brake Shoes

Depositing rock in Open Cut

LBNF Construction Status - Far Site Conventional Facilities

- **Excavation phase** – underway now. Construction of three DUNE caverns and new ventilation shaft. Work started in April 2021; plan to finish April 2024.
  - Total of ~150 personnel working under contract during the phase; 60 pieces of equipment

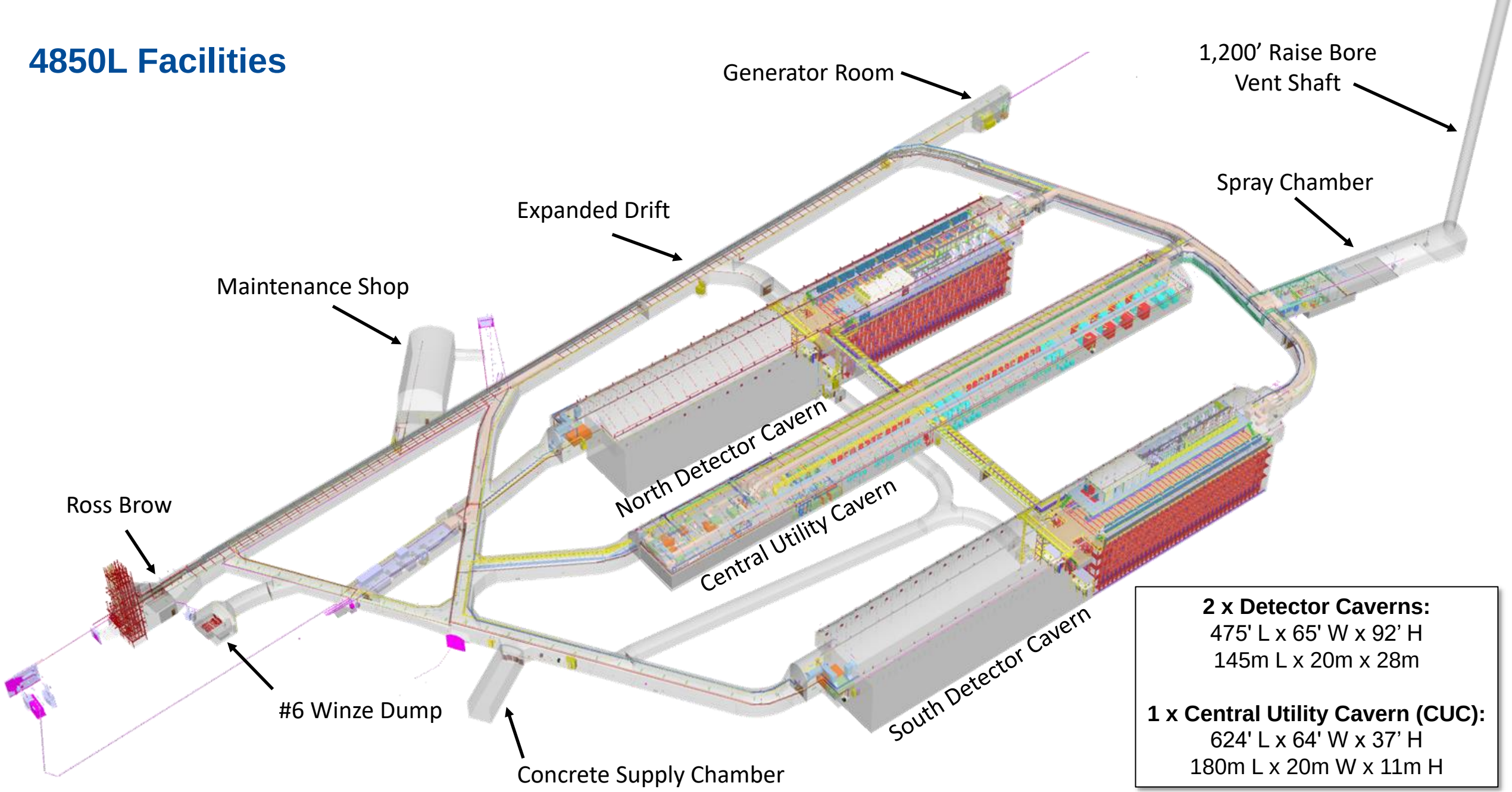
- **BSI phase** - ready to start installation of utility systems (HVAC, electrical, etc.) as soon as excavation is completed in 2024.



Drilling holes for Rock Blast

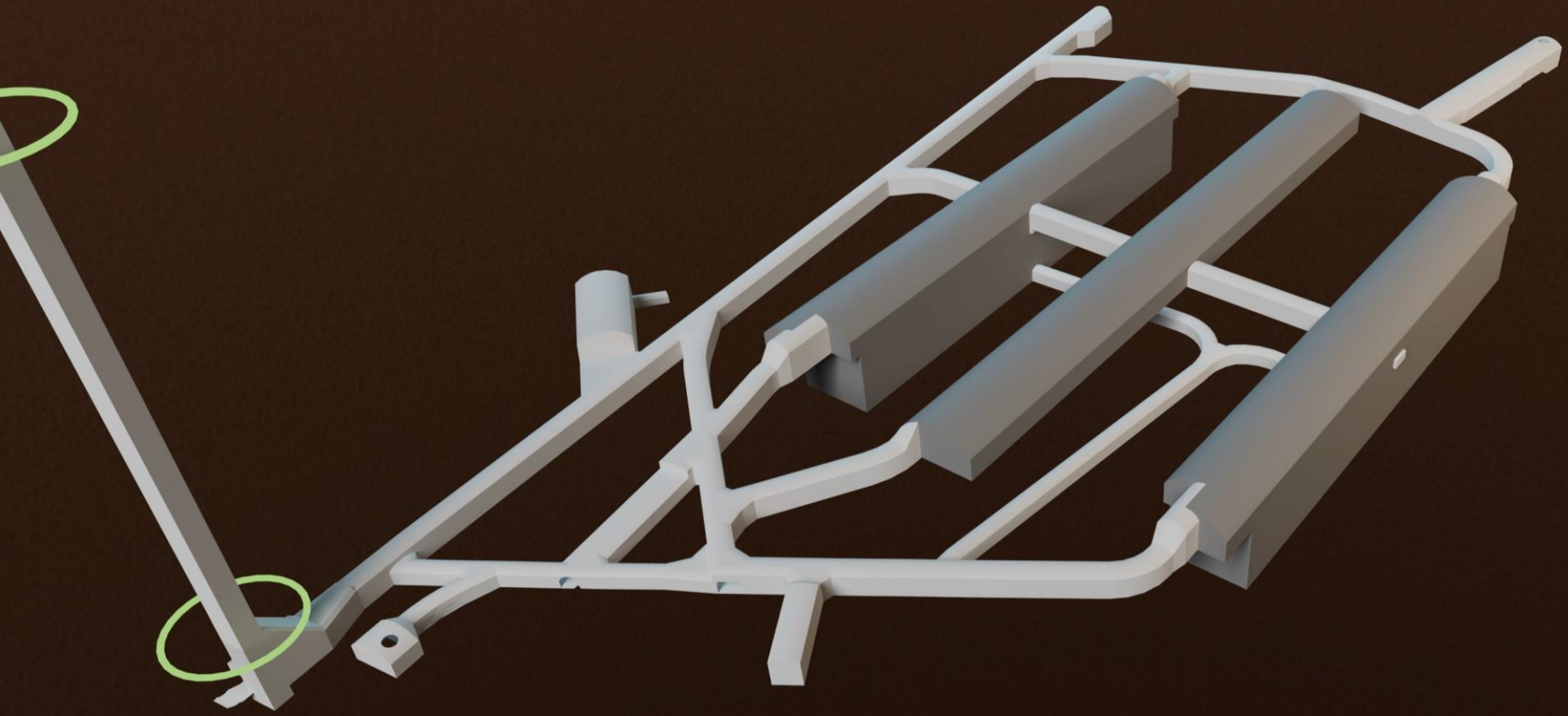
Installing rock bolts and welded-wire fabric for ground control

4850L Facilities



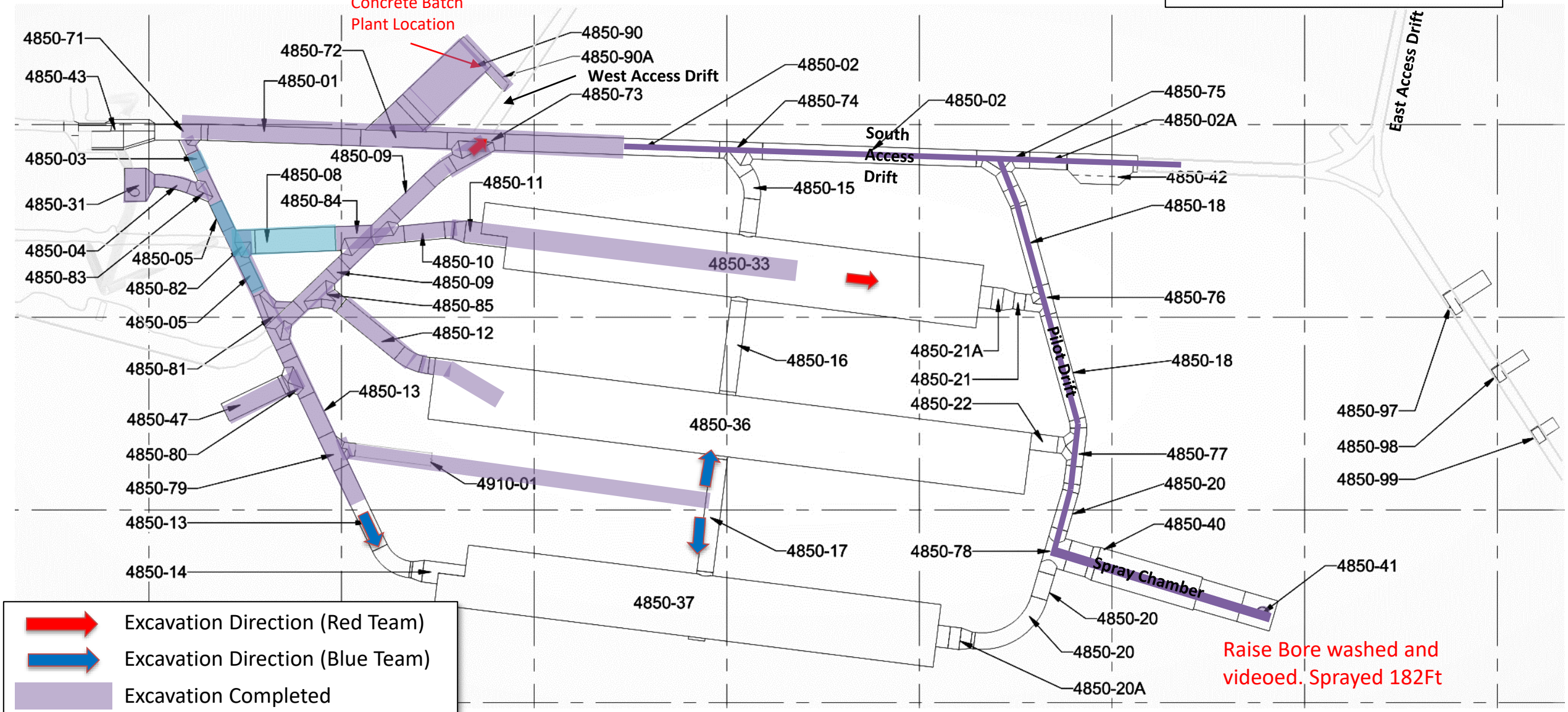
2 x Detector Caverns:
475' L x 65' W x 92’ H
145m L x 20m x 28m

1 x Central Utility Cavern (CUC):
624' L x 64' W x 37’ H
180m L x 20m W x 11m H



Excavation Status

Total Excavation Complete 14.0%
As of 20 Dec 2021

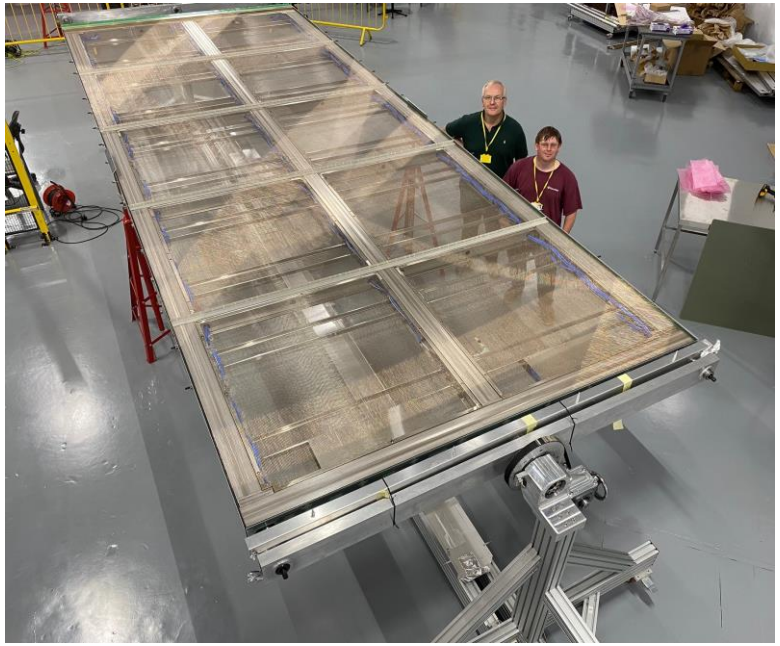


Raise Bore washed and videoed. Sprayed 182Ft

LBNF/DUNE

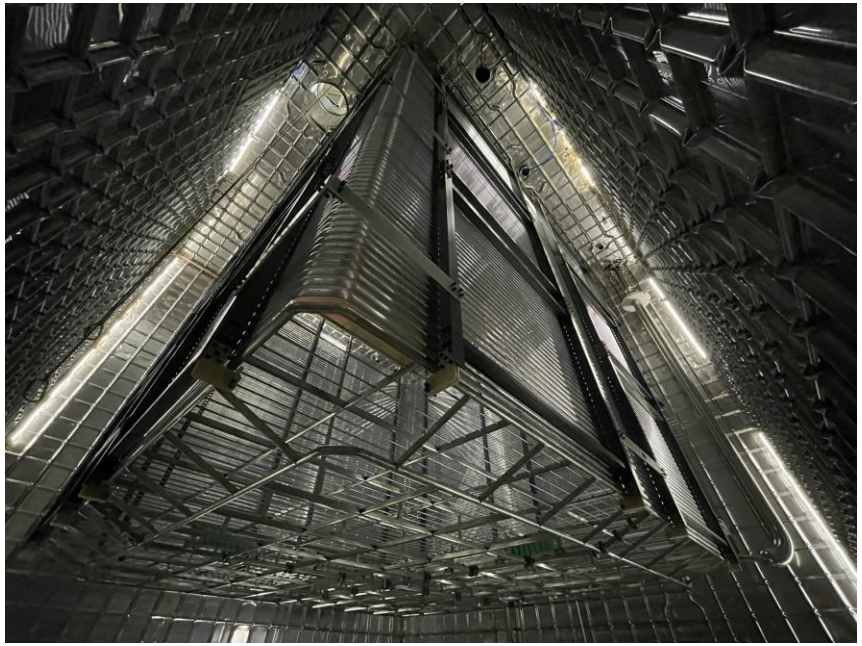
DUNE Far Detectors Status

- 1st far detector module to be based on Anode Plane Assembly (APA) technology with horizontal drift
- 2nd far detector module to be based on Charge Readout Plane (CRP) technology with vertical drift
- CERN Neutrino Platform has operated two 8m x 8m x 8m prototypes to mature and prove technology
  - Module 0 prototype for APA technology currently under construction (ProtoDUNE II)
  - CRP technology is rapidly maturing and has attracted additional international partners



APAs for Module 0 ProtoDUNE being tested at Daresbury Laboratory, UK. One 2.3m x 6.3m APA is shown; UK to provide 130 APAs.

NP-02 and NP-04 ProtoDUNE 8m x 8m x 8m detector prototypes at CERN.



NP-02 ProtoDUNE 8m x 8m x 8m cryostat at CERN has demonstrated 300 kV across field cage for CRP detector technology

Far Detectors - WBS Summary

WBS	WBS NAME	Scope/Deliverable Summary	PM	Institutions or Agency
131.FDC.01	FDC PM	Project management team responsible for managing the design, engineering, procurement, construction, inspection, commissioning, and startup of the FD1, FD2, and FS Cryo.	J Macier	FNAL
131.FDC.02	Far Detector 1 (FD1)	All phases of design, procurement and installation of 1-10kT Liquid Argon (LAr) detector to be built underground. Construction and installation of FD1 will be funded by both DOE and international partners. Includes prototyping efforts at CERN and FNAL.	J Bishop	FNAL, BNL, LBNL, ANL, LANL
131.FDC.03	Far Detector 2 (FD2)	The Far Detector 2 (FD2) project management, design, fabrication, construction, and installation, for the LBNF/DUNE-US Project. Construction and installation of FD2 will be funded by both DOE and international partners. Includes prototyping efforts at CERN and FNAL	J Bishop	FNAL, BNL, LBNL
131.FDC.04	Far Site Cryogenics Infrastructure	Design, procurement, on-site installation and testing of the Proximity, Infrastructure and Internal cryogenic systems to support two 17-kt total mass detectors. Infrastructure includes LAr procurement as well as all installation coordination activities for the coordination, QC and QA of all activities. Includes design, but not procurement of the internal cryogenics, which will be provided as In-Kind Contribution. The Proximity cryogenic system includes reliquefaction and purification sub-systems, associated instrumentation and monitoring equipment and LAR circulation pumps and pipes. The proximity cryogenics is currently a non-DOE contribution. The Infrastructure cryogenics (a DOE responsibility) includes the LN2 refrigeration and liquefaction, compressors, cold boxes, expanders, the LN2 buffer tanks underground, and LN2/GN2 distribution and return. The Infrastructure cryogenics (a DOE responsibility) also includes the Argon receiving facilities on the surface, the interconnecting piping, and the installation of the Proximity Cryogenics delivered as In-Kind-Contribution. Design, installation and testing of the process controls, GN2 purge of the cryostat insulation and cryostat pressure control system are also included.	D Montanari	FNAL
131.FDC.05	FS Integration & Installation	Integration and installation coordination at SURF. Includes M&S and labor to support cryostat installation and detector installation support for two 10kT Liquid Argon (LAr) detectors. Also including post-FSCF cavern enhancements such as bridges, stairs, mezzanines, barracks and CUC control room outfitting. Cryogenics installation activities included in 131.01.02.03.02.	J Macier	FNAL, BNL

Far Detectors - WBS Summary with National Labs + Universities (DOE-funded)

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131.FDC.03	Far Detector 2 (FD2)	The Far Detector 2 (FD2) project management, design, fabrication, construction, and installation, for the LBNF/DUNE-US Project. Construction and installation of FD2 will be funded by both DOE and international partners. Includes prototyping efforts at CERN and FNAL	J Bishop	FNAL, BNL, LBNL, CERN, UIUC, U of Iowa, U of Wisconsin, Yale, NIU, UC Santa Barbara, CSU, U of Michigan
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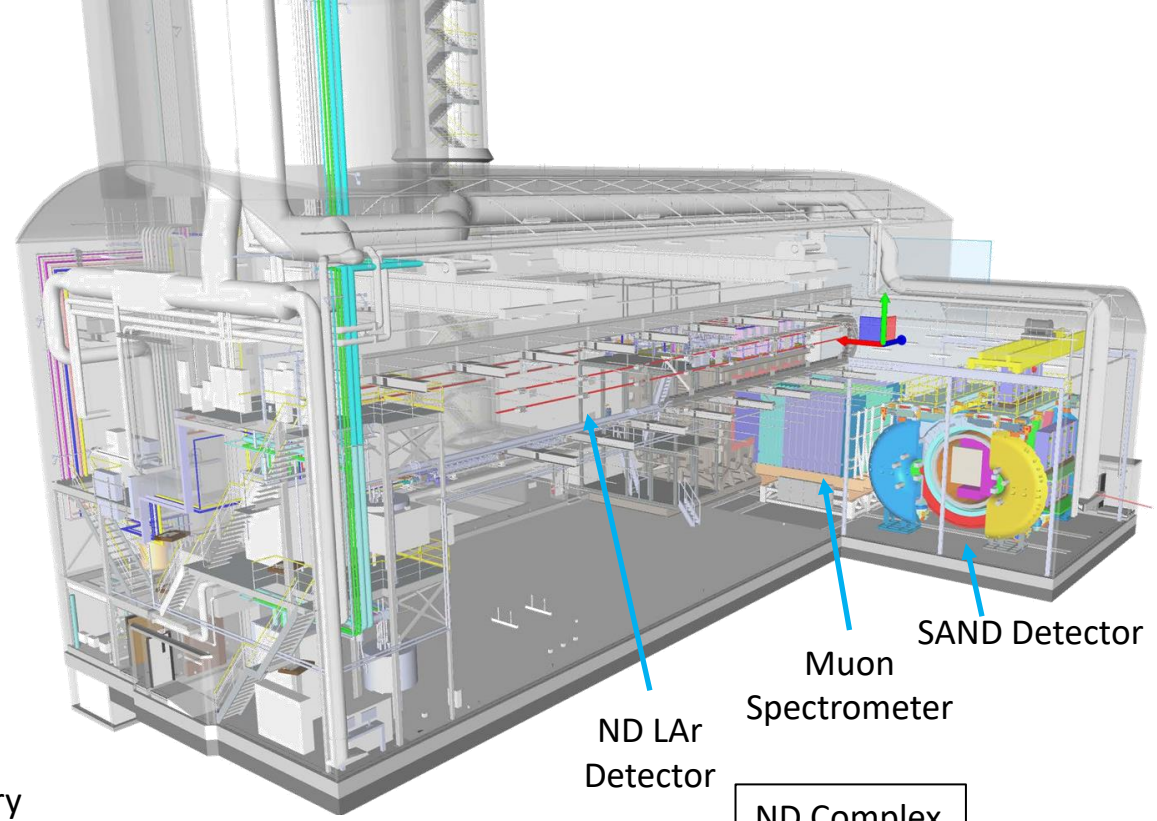
Near Detectors - WBS Summary with National Labs + Universities (DOE-funded)

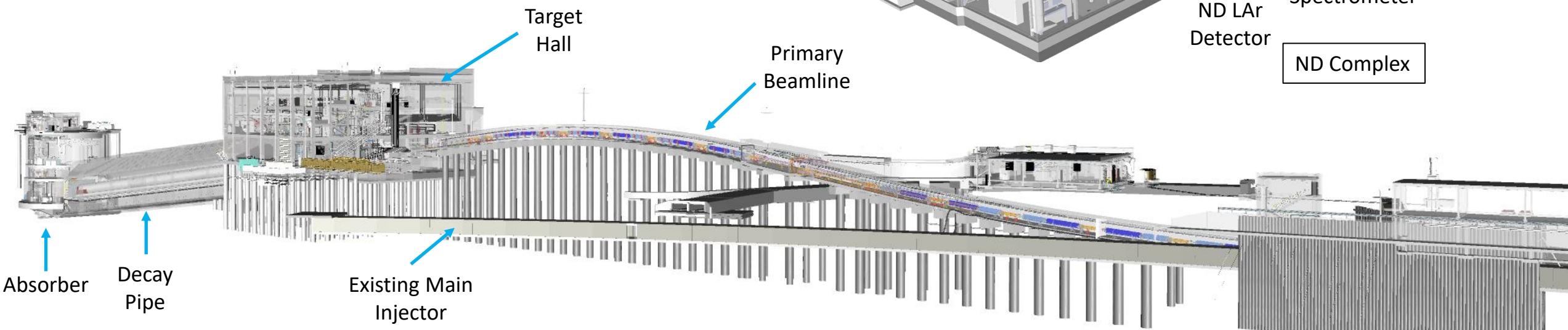
WBS	WBS NAME	Scope/Deliverable Summary	CAM	Institutions or Agency
131.ND.01	ND Project Management	Technical and administrative management of the project: Project Management, Project Controls, Systems Engineering, Lead Engineering, ESH, QA, Reviews	Kurita	SLAC, FNAL, LBNL, Kansas State, Stony Brook, Rochester
131.ND.02	ND LArTPC	Management, design, procurement/fabrication, assembly and installation of 35 Liquid Argon TPC's: High Voltage System, Charge Readout, Light Readout, Module Structure, Field Structure	Dwyer	LBNL, SLAC, FNAL, U of Bern, JINR, UH, MSU, CSU, UTexas, Rutgers, Yale, UC-Davis, UCSB, CalTect, UT Arlington,, York, UPenn
131.ND.03	ND LArTPC Cryostat	Design, procurement/fabrication, assembly and installation of a cryostat vessel to house 35 NDLAr TPCs.	Matichard	LBNL
131.ND.04	ND Muon Spectrometer (TMS)	Management, design, procurement/fabrication, assembly and installation of a muon spectrometer: magnet coils, power supplies, detector panels and associated electronics	LeCompte	SLAC, ANL, Tufts U, Wichita State, Rochester
131.ND.05	ND Beam Monitoring (SAND)	Management, design, refurbishment and/or procurement/fabrication, assembly and installation of the SAND Detector: LAr Target (GRAIN), Straw Tube Tracker, ECAL, Refurbished KLOE Magnet, Magnet Carriage Management, design, pre-assembly and test of the SAND Magnet and installation of tracker at FNAL Facility	SAND: Kurita (acting)/ Pre-Assem & Test: Creus-Prats	INFN, FNAL
131.ND.06	ND DAQ and Slow Controls	Management, design, software development and hardware for NDLAr, TMS and SAND DAQ. Management, design, software development and hardware for ND Slow Controls and System Safety Controls	DAQ: Asher Ctrls: Johnson	UK, SLAC
131.ND.07	ND PRISM Movement System	Management, design, procurement/fabrication, assembly and installation of the movement system for NDLAr and TMS: Transport rail system, motorized/non motorized rollers, TMS Data Energy Chain, NDLAr Cryo and Data Energy Chains, Monitoring Systems and Control Algorithms.	Kurita	SLAC, StonyBrook, Rochester, MSU
131.ND.08	Near Site Cryogenics Infrastructure	management, design, procurement, installation and commissioning of the external and proximity cryogenic systems needed to operate the LArTPC and SAND detectors. It includes mechanical process equipment, process controls and cryogenic safety equipment.	Creus-Prats	FNAL, LBNL
131.ND.10	ND Integration, Installation and Test	Management, design, procurement/fabrication of installation hardware; ND facility & support services, management & coordination of all ND installation, resources to support shared labor such as technicians and rigging	Matichard	LBNL, FNAL, SLAC & ND Institutions listed above

Status Updates – Near Site

Near Site Conventional Facilities Status

- Site preparation work was completed in Oct 2020
- 100% final design completed on 28 Sep 2021 for the Beamline Complex and Near Detector Complex
  - Major near site project milestone
- Construction contract documents for Beamline Complex are under DOE review.



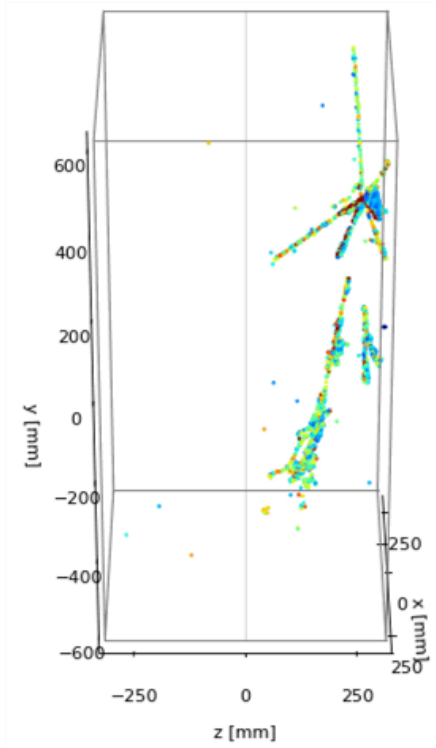


Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

Near Site Conventional Facilities are positioned to start construction upon funding availability and approval

ND-LAr Detector Status

- Near Detector ND LAr 70% scale module has been successfully tested at the University of Bern and transported to Fermilab for next phase of prototyping

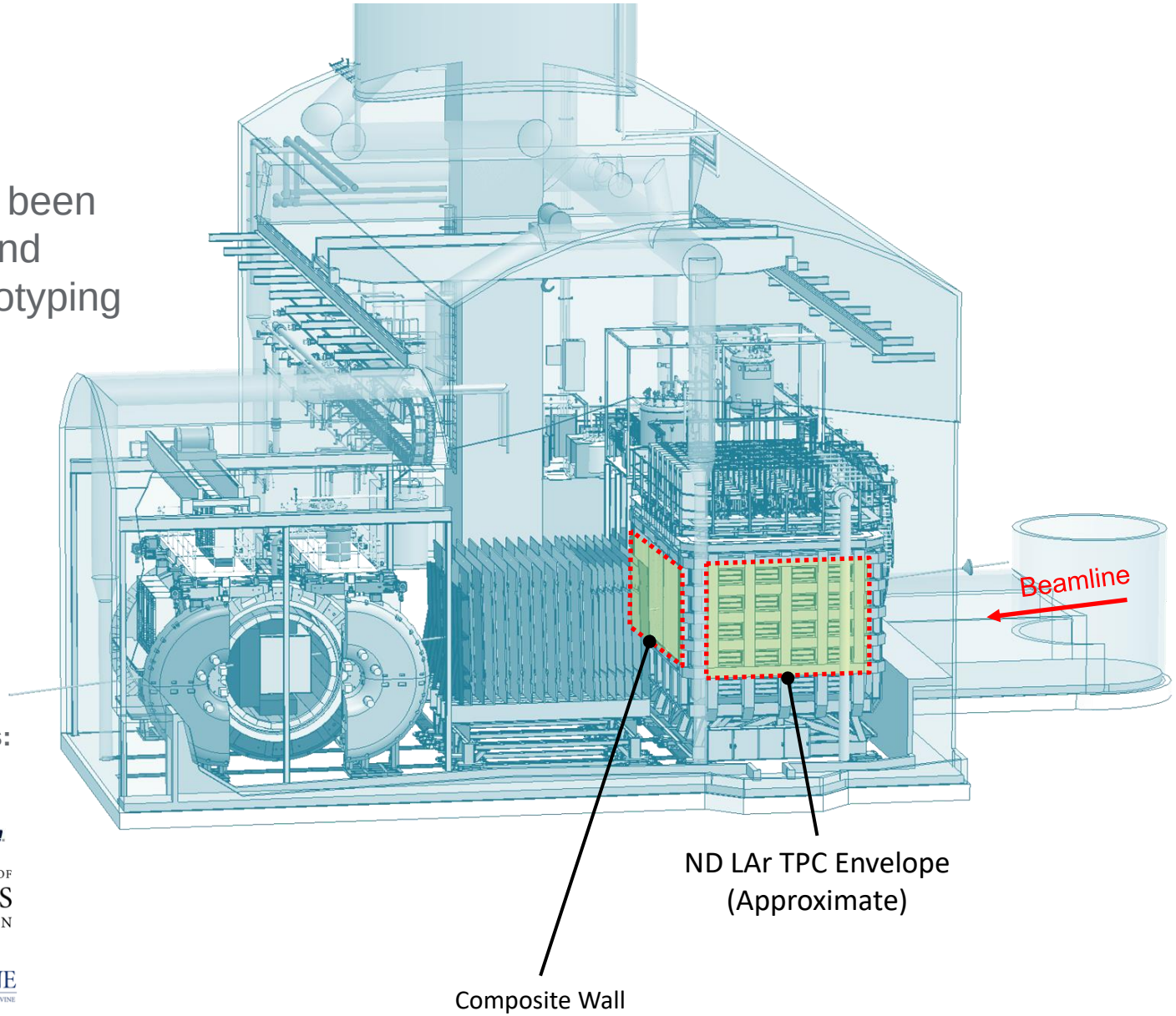


Muon interaction via a direct hit on an argon nucleus, with secondary interactions shown.

Partners International:

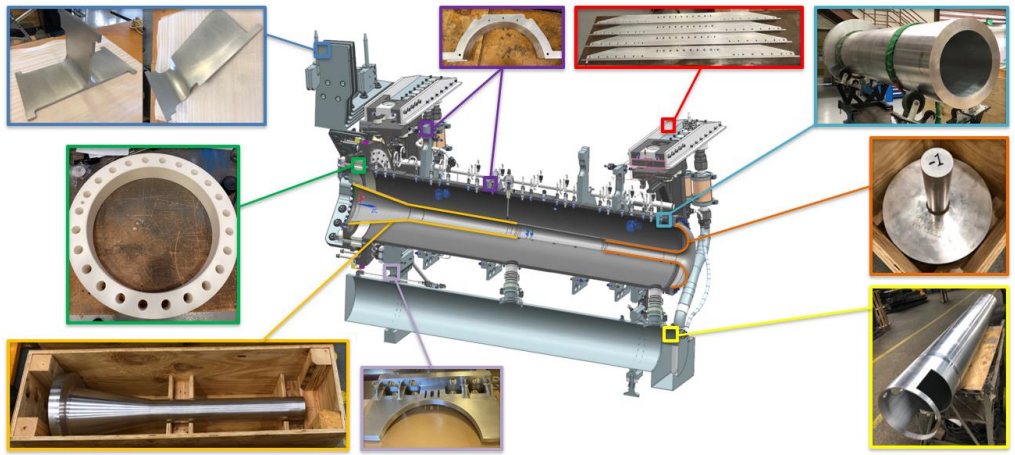
National Labs:

Key University contributors:

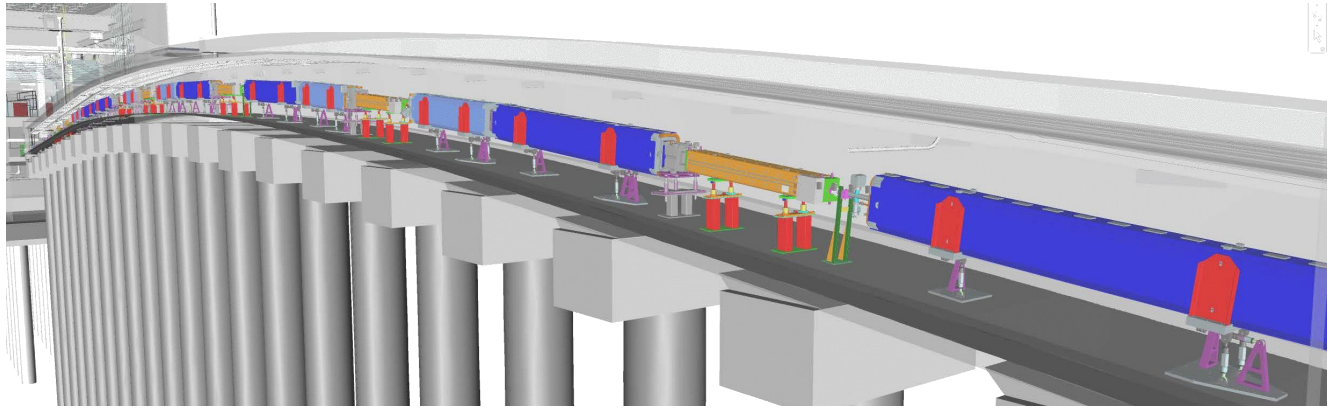


Primary and Neutrino Beamline Status

- Design progressing per plan: 69% complete as of December
  - Primary Beam Magnets – BARC
    - Preliminary design reviews completed
  - Target by UK/RAL
    - Extensive work on prototyping features of the target assembly



Horn A Prototyping



Primary Beam Magnets on piles

  - Horn A Prototype by FNAL
    - Fabrication in progress

Upcoming Events

- 10 – 12 January 2022 – DOE IPR for Excavation Subproject CD-2/3 milestone
- 12 – 14 January 2022 – DOE IPR for CD-1 “reaffirmation” Review Preparation Status
- June 2022 timeframe – DOE IPR for CD-1 “reaffirmation” milestone

Summary

- LBNF will provide a world-class platform for the global high energy physics community and the international DUNE collaboration, powered by the highly capable PIP-II accelerator.
- The project has implemented a subproject baselining strategy due to the variance in maturity of major scope elements.
- The project is planning a CD-1RR IPR in June 2022 timeframe based on lessons learned from CD-1R; drivers for increased costs are understood, project scope is finalized and stable, and a realistic funding profile has been implemented.
- The Far Site Conventional Facilities Excavation Subproject (FSCF-EXC) is ready to baseline.
- Key leadership and support provided by partner national laboratories

Thank you. Questions?