LBNF/DUNE Status

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HEPAP Meeting

02 November 2021

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

- P5 Background
- Project Scope
- DUNE Collaboration
- CD-1R Reaffirmation review
- Project Tailoring Strategy
- Project Status
  - Far Site
  - Near Site
- Summary

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

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 accelerat

The 2020 Update of the European Particle Physics Strategy

Europe, and CERN through the Neutrino Platform .....should continue to collaborate with the United States and other international partners towards the successful implementation of the Long Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE).

European Strategy Update

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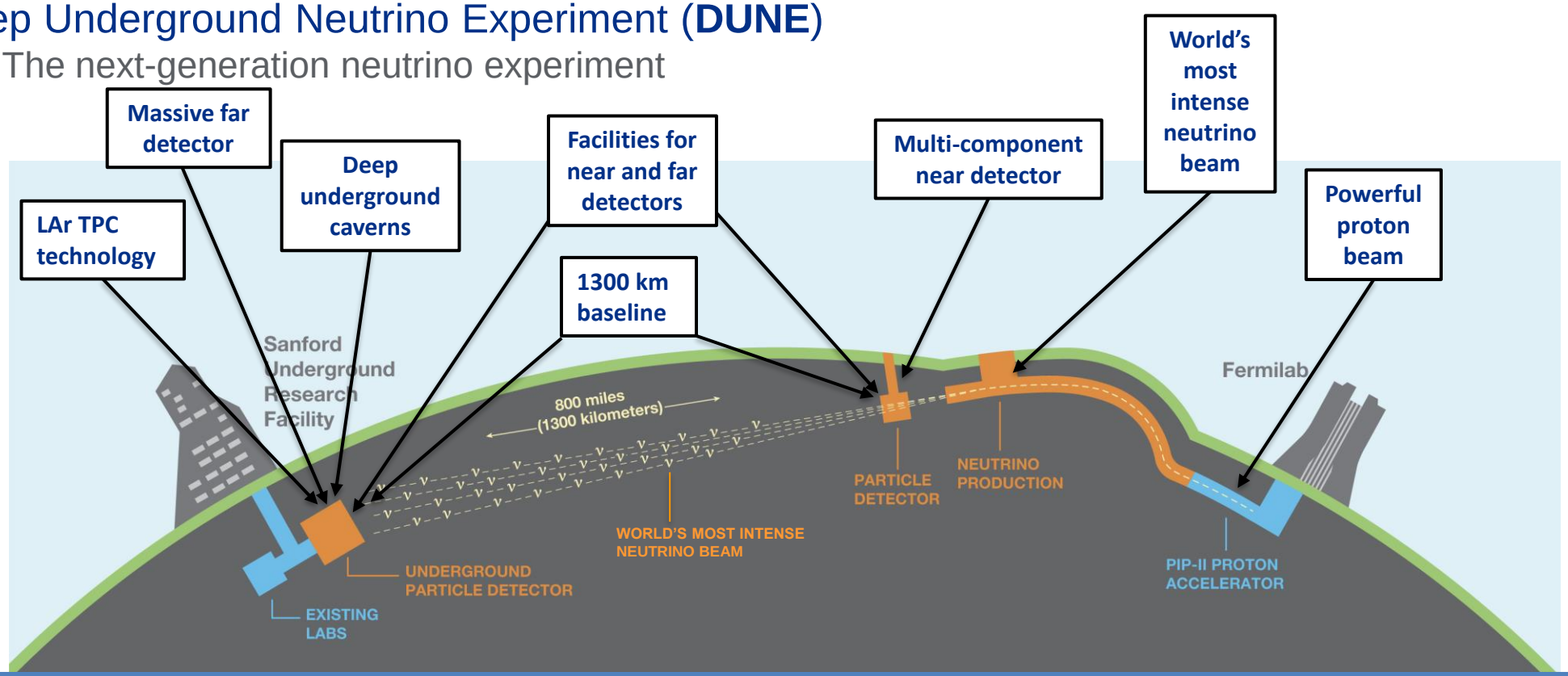
ment Plan II (PIP-II) should proceed immediately, followed by construction,
>1 MW by the time of first operation of the new long-baseline neutrino facility.

European Strategy Update

The US neutrino program is supported by the European Strategy

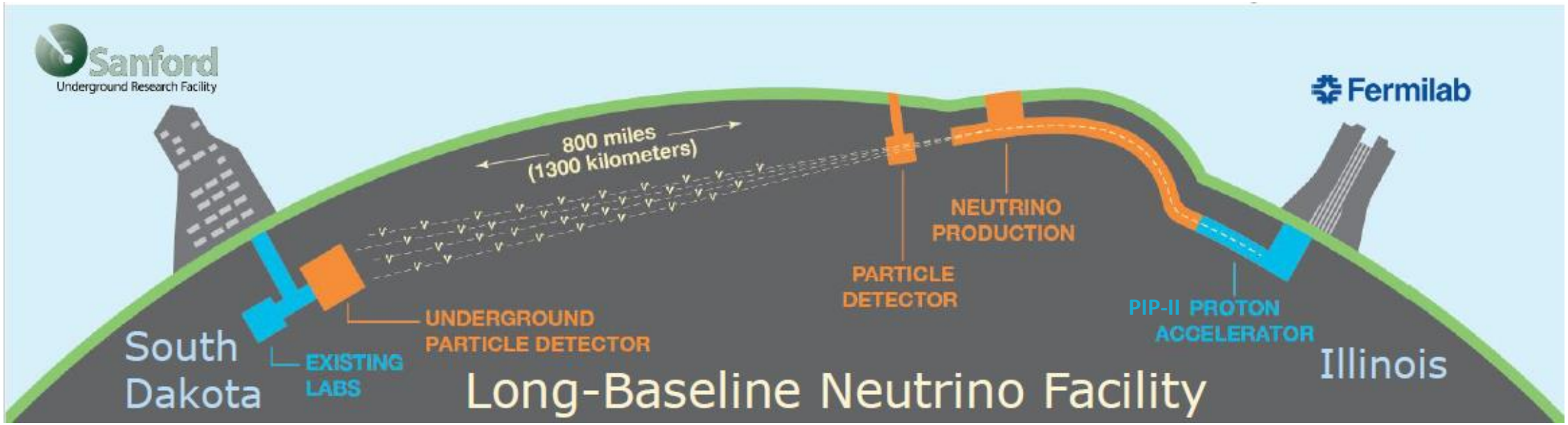
PIP-II / LBNF / DUNE delivers…

- 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



LBNF and PIP-II will enable the United States to host the global high energy physics community to advance world class 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 DUNE experiment
- **International DUNE** - International contributions to the DUNE experiment

DUNE

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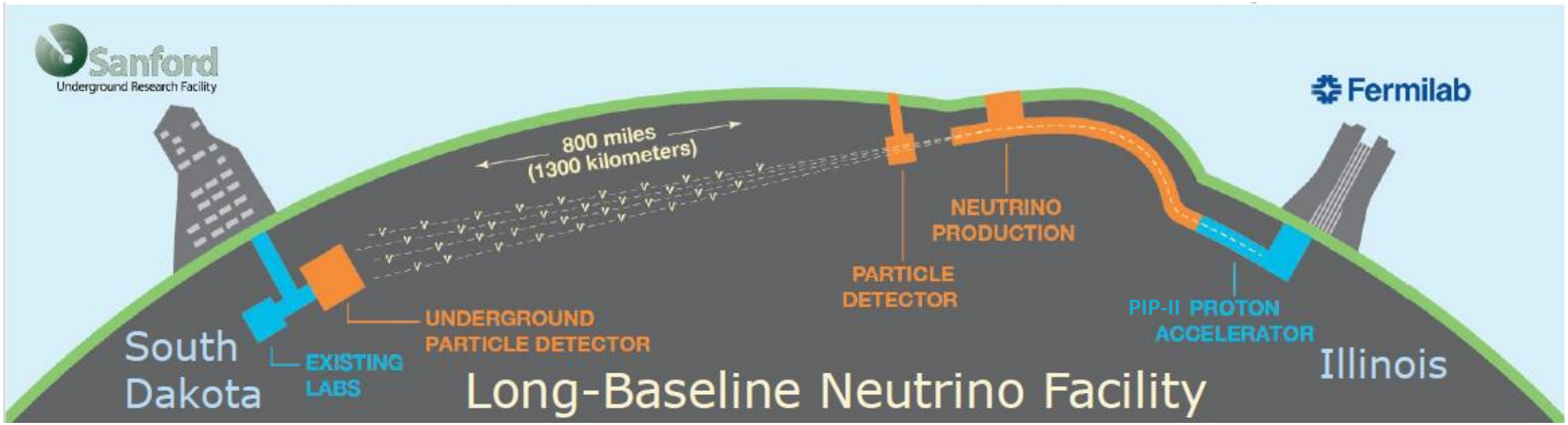

- **Long Baseline Neutrino Facility** – facilities with partner in-kind contributions

LBNF

- **DUNE-US** – U.S. contribution to the DUNE experiment
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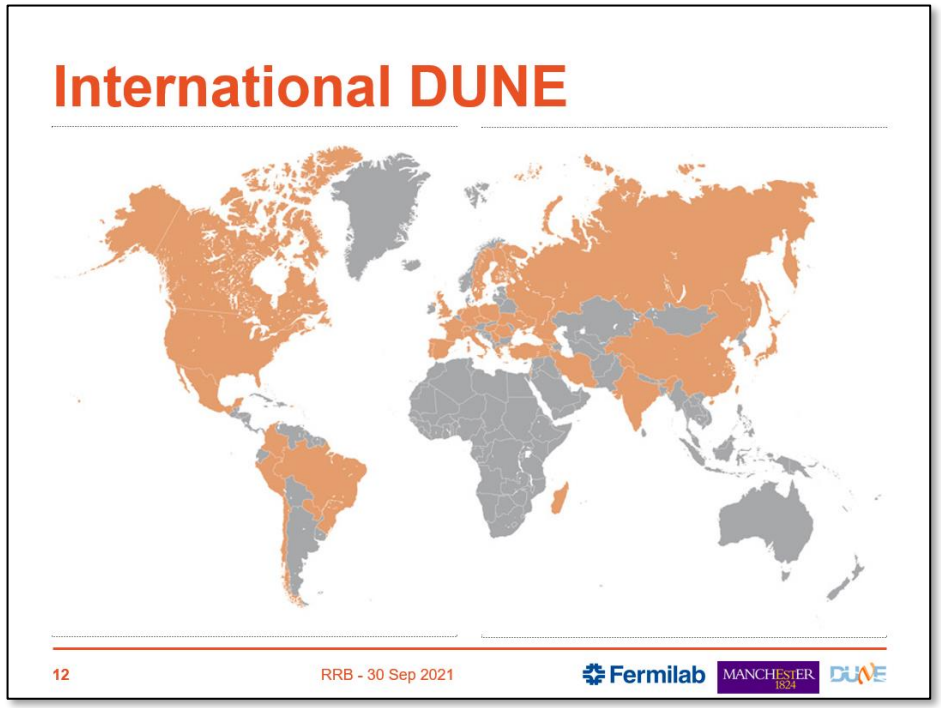
DUNE

LBNF and DUNE-US are one DOE O413.3B Project

The DUNE experiment is managed by the international DUNE Collaboration



Collaboration statistics

- 1,427 collaborators, 48% U.S./52% non-US
- 218 institutions from 37 countries + CERN

Demographics (not including computing)

- Facility/Senior staff: 679
- Post Docs: 253
- Grad Students: 326
- Engineers: 159

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

CD-1R “Reaffirmation” Review

- The project’s estimated cost, with full underground facilities to support the near detector and 4 x 17 kton far detector modules, an upgradeable 1.2MW beam, and U.S. contributions to support DUNE’s near detector and the first two 17 kton far detector modules is ~$3B.
- This will require a DOE CD-1R reaffirmation review, which is being planned in the spring 2022 timeframe to establish a new cost range.
- HEP provided updated annual funding guidance in August 2021 to support this plan.
- In close coordination with our international partners and DUNE collaboration leadership, the project has implemented the funding profile, with the following sequenced objectives:

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

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.

Project Tailoring Strategy

- The project has implemented a “subproject” strategy that will allow portions of the overall DOE project scope to be baselined as soon as technically ready.
  - This is a preferred “packaging approach” that DOE is increasingly requiring for complex “billion dollar” scale projects (including PIP-II)
  - Addresses the variation in maturity between different project elements – for example, Far Site conventional facilities are ready to baseline now, while other project elements (e.g., near detector) are still maturing
  - The CD-2/3 DOE review for the excavation subproject is 10-12 January 2022.

- There are five subprojects planned:
  - Three at the far site: 1) Far Site Excavation, 2) Far Site Building & Site Infrastructure, and 3) Far Detectors/Cryogenic Infrastructure
  - Two at the near site: 1) Conventional facilities & beamline and 2) Near Detector
  - See next slide for summary of subprojects and maturity

Far Site Excavation Subproject DOE CD-2/3 baseline review will be in January 2022

Subprojects Implementation, Maturity, and Baselining Strategy

	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, 55% complete**	**100%**	Scheduled Jan 2022
FAR SITE	FSCF-BSI	Far Site Conventional Facilities – Building & Site Infrastructure	All Far Site (FS) conventional facilities (CF) support infrastructure **Master contract, with not to exceed costs, in place**	**100%**	2023
FAR SITE	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. **Proposals in hand for Phase 1 of main cryo system**	90% (FD1) 30% (FD2) 25% (C)	2022 or 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) **Request for Proposals for CF under DOE review**	**100%** (CF) 67% (BL)	2022 or 2023
NEAR SITE	ND	Near Detector	Near Detector (ND) including integration/installation and cryogenic systems	30%	2023 to 2025

Subproject approach allows the project to employ a "baseline when ready" strategy

Project Status Update

The far site at Sanford Underground Research Facility (SURF) , Lead, SD

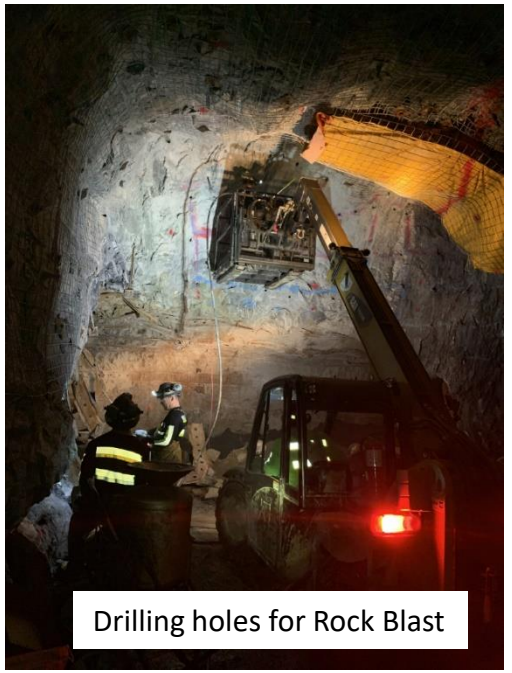
Project Status at the Far Site

Conventional Facilities Construction

- ✓ **Reliability Project** upgrades to SURF[1] – complete ($41M). Significant infrastructure upgrades, including refurbished shaft and new hoist system.
- ✓ **Pre-excavation phase** – complete ($125M). Equipment and systems to move excavated rock from one mile underground to the surface and deposit in the Open Cut.
  - ► All construction work has completed on schedule and with low change order rate (< 6%) despite three-week SURF shutdown due to COVID.

- **Excavation phase** – underway ($200M). Construction of three DUNE caverns and new ventilation shaft. Work started in April 2021; plan to finish April 2024. Contractor is performing very well.
  - ► Ready to start installation of utility systems (HVAC, electrical, etc) as soon as excavation is completed in 2024; master contract is already in place.


Depositing rock in Open Cut


Drilling holes for Rock Blast

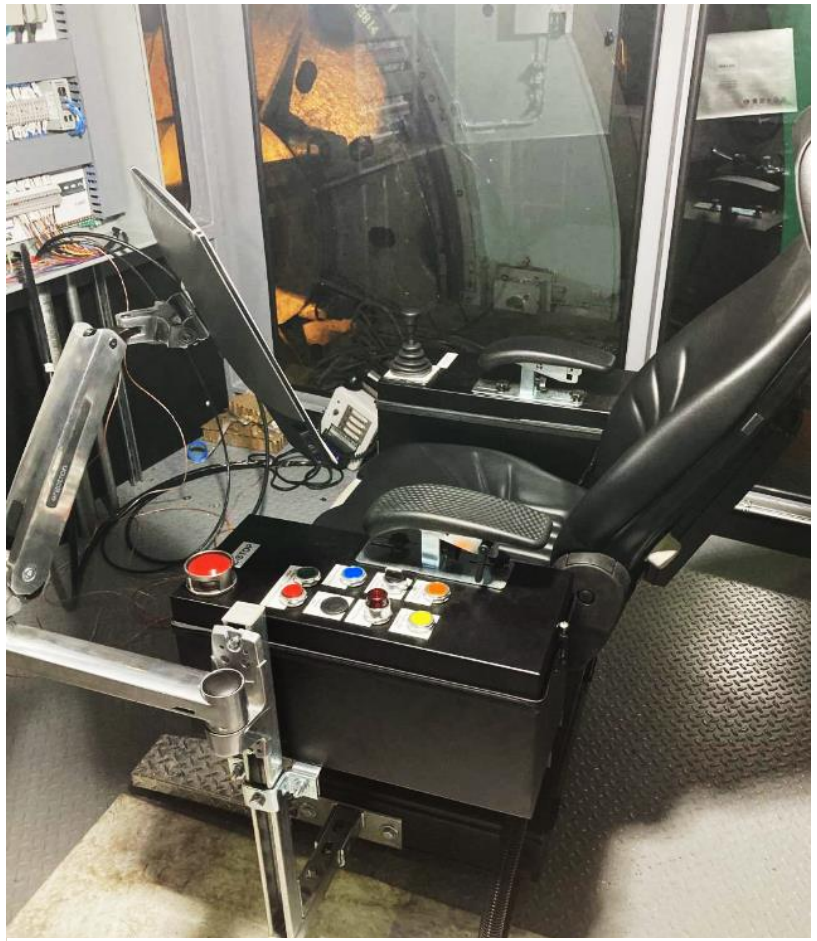
[1]**SURF** = Sanford Underground Research Facility, Lead, SD

With completion of reliability and pre-excavation work and award of excavation contract, the largest far site project cost uncertainties have been largely eliminated

All Reliability Upgrade Projects were Completed in April 2021

1930-era Control System - Foot Pedals, Analog Gauges, and Hand Levers - replaced with state-of-the-art digital control system

New Hoist Control System



New Hoist Control Center with Flat Screen Monitors and Joystick Controls

New Hoist Climate Control Cabs for cage and skip systems

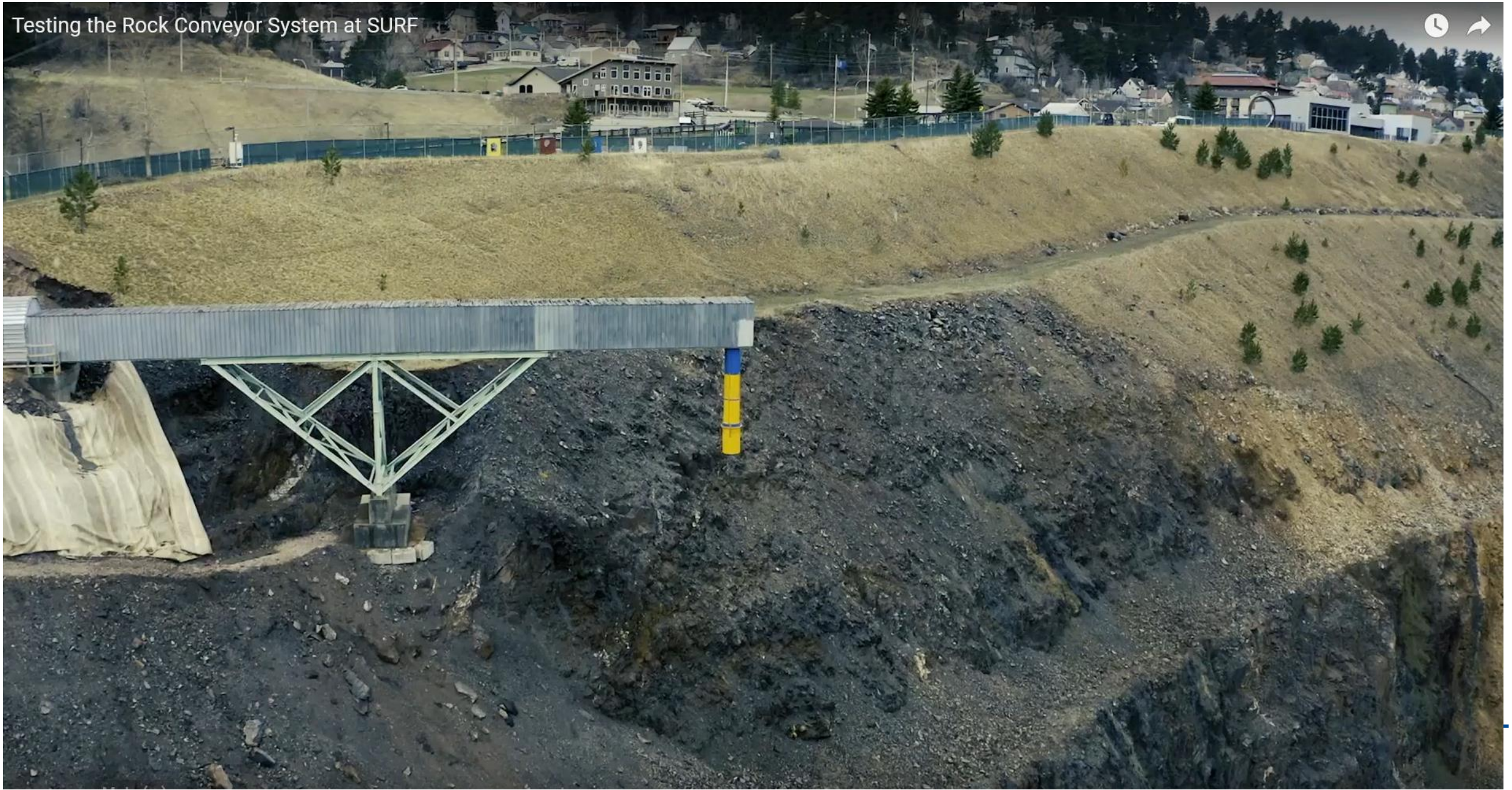
New Hoist Components – Motors and Brake Shoes

New 1,700HP AC Motors

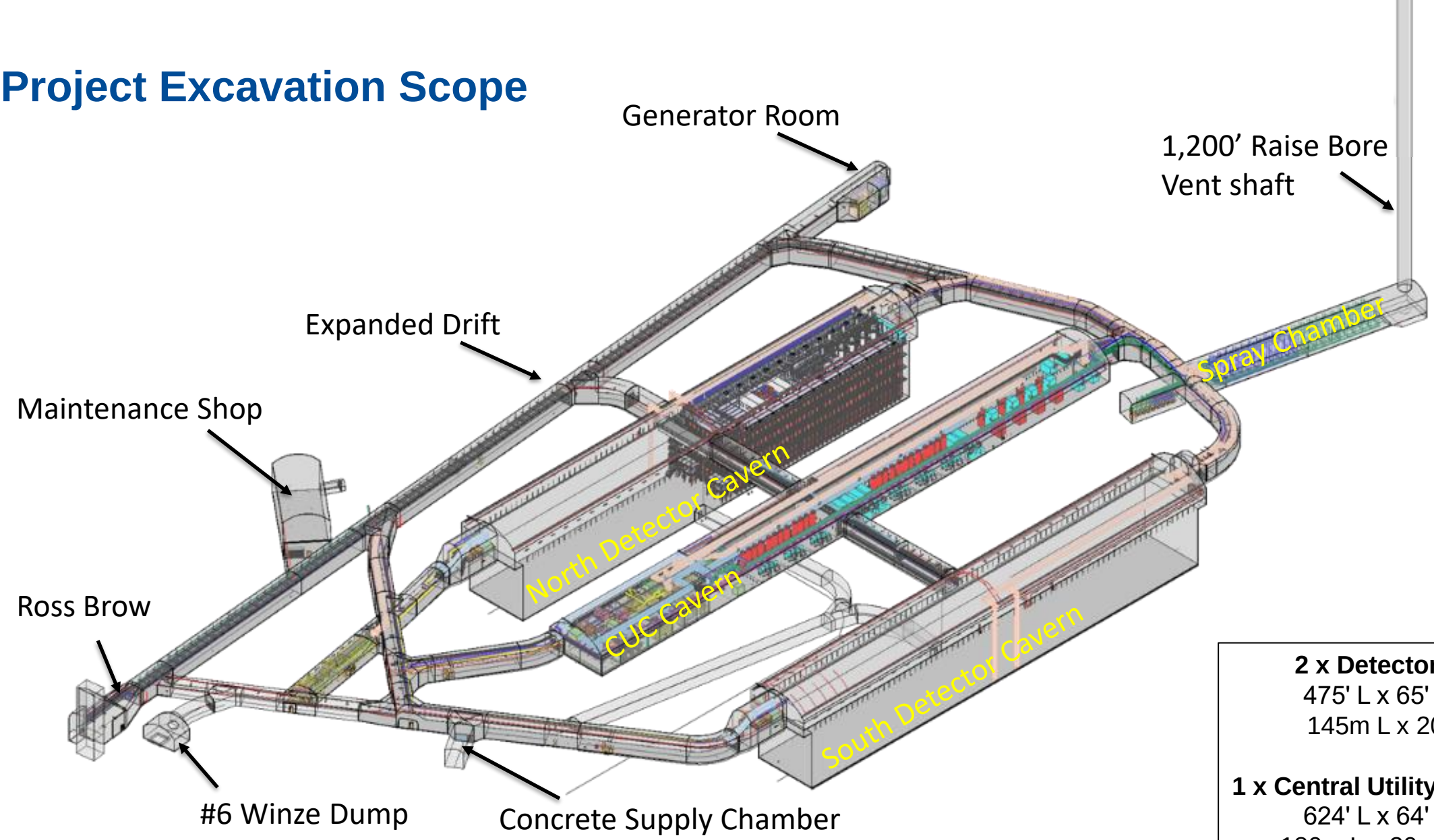
New Service Hoist Brake Shoes

Video courtesy of Matt Kapust, SDSTA

Pre-Excavation Work Completion - First Test of Rock Handling System – May 2021



Project Excavation Scope

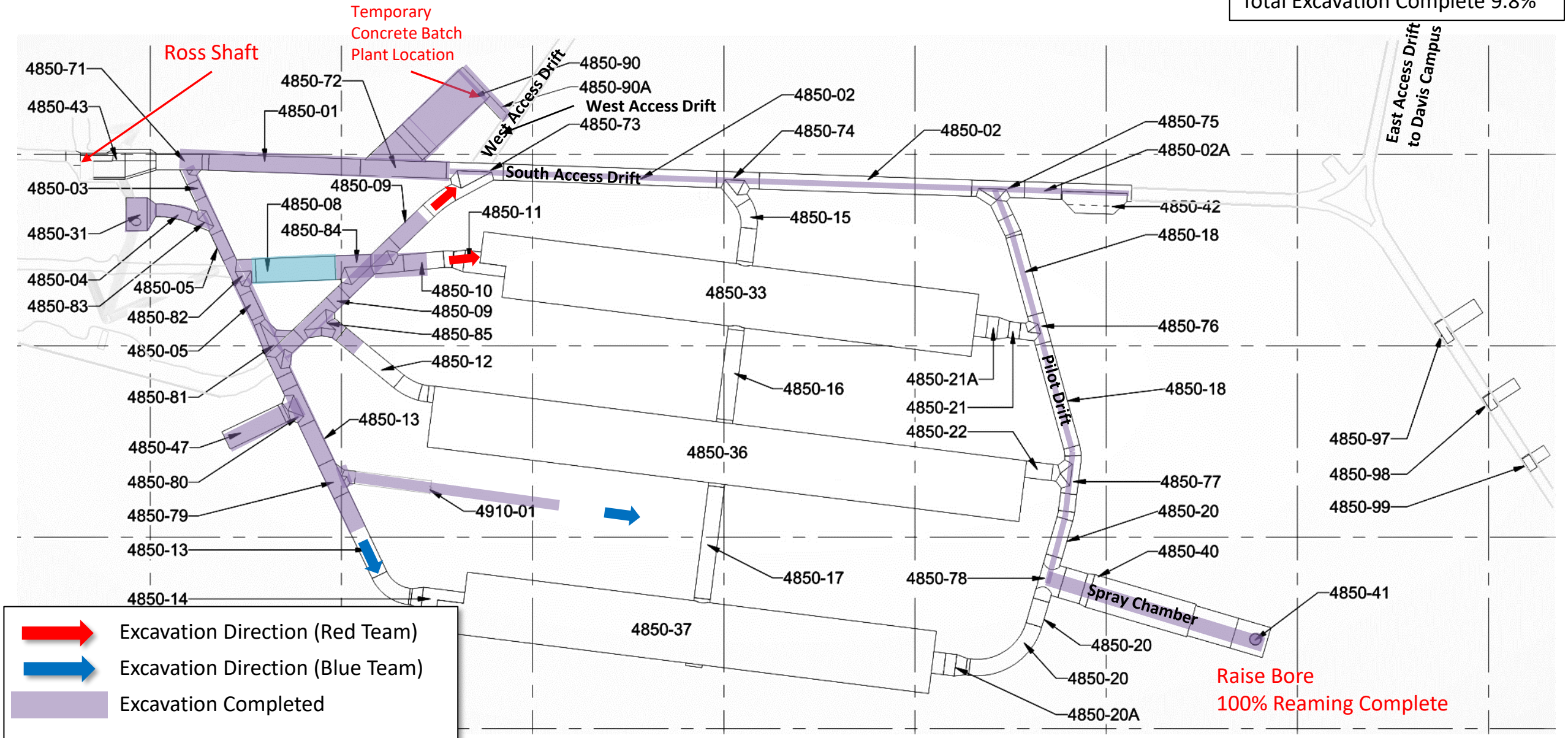


2 x Detector Caverns:
475' L x 65' W x 92’ H
145m L x 20m x 28m

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

Overall Excavation Status as of 31 October

Total Excavation Complete 9.8%



Excavation Direction (Red Team)

Excavation Direction (Blue Team)

Excavation Completed

Excavation and Shotcrete Complete

Concrete Complete

LBNF/DUNE

Reaming of 1200’ Raise Bore Ventilation Shaft was completed on 4 October 2021

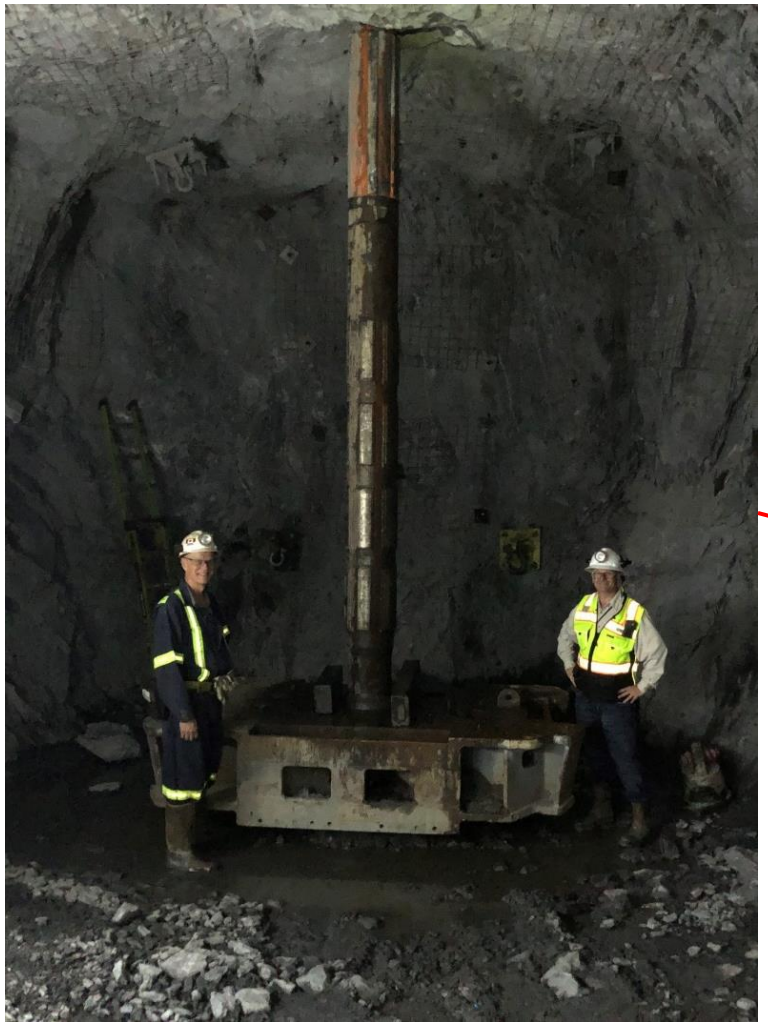
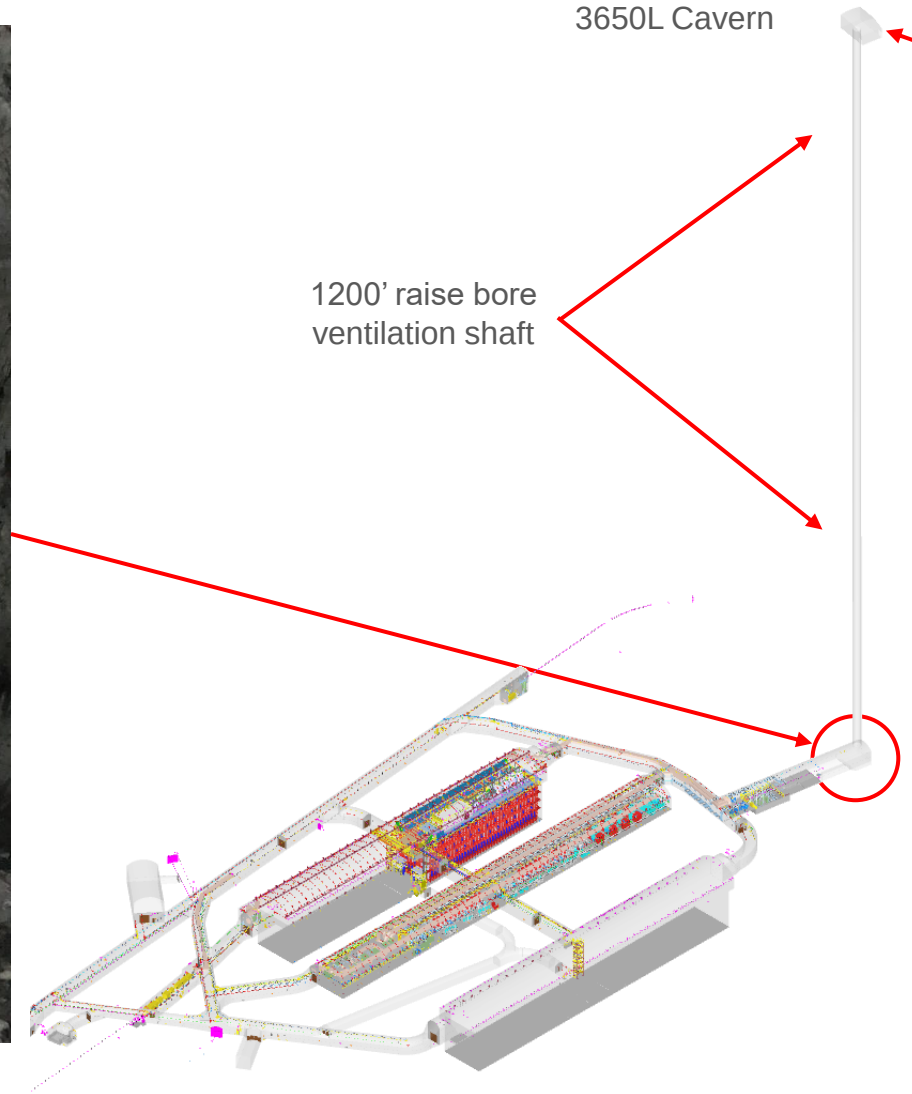


Photo of start of reaming at 4850L – 13 July 2021



12’ reamer head at breakthrough at 3650L Cavern – 4 Oct 2021

Completion of excavation for the raise bore retires most significant excavation risk

Far Site Excavation Process

Setting out the Blasting Pattern

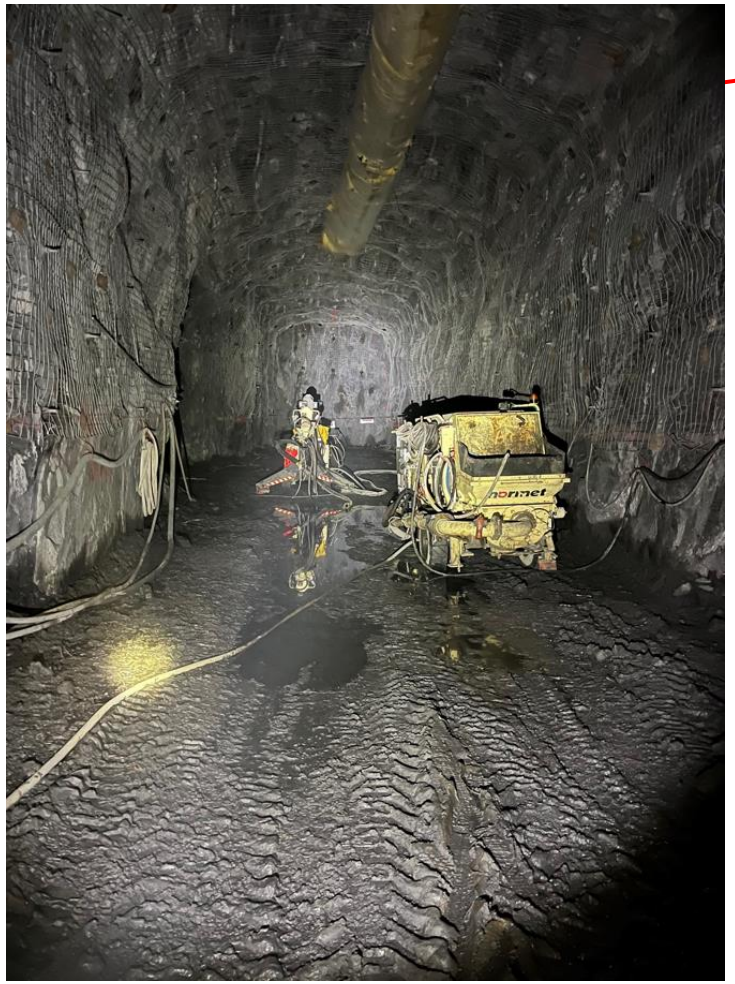
Drilling Charge Holes in the 4850-81 Face

Far Site Excavation Process

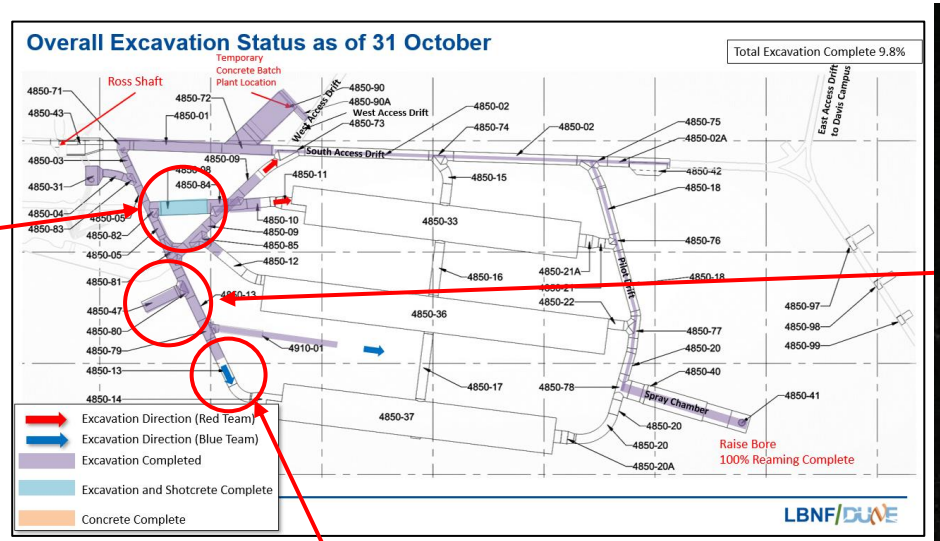
Moving “muck” to the ore bin, to be loaded in skip and moved to surface, crushed, and conveyed to the Open Cut

Installing rock bolts and welded-wire fabric for ground control

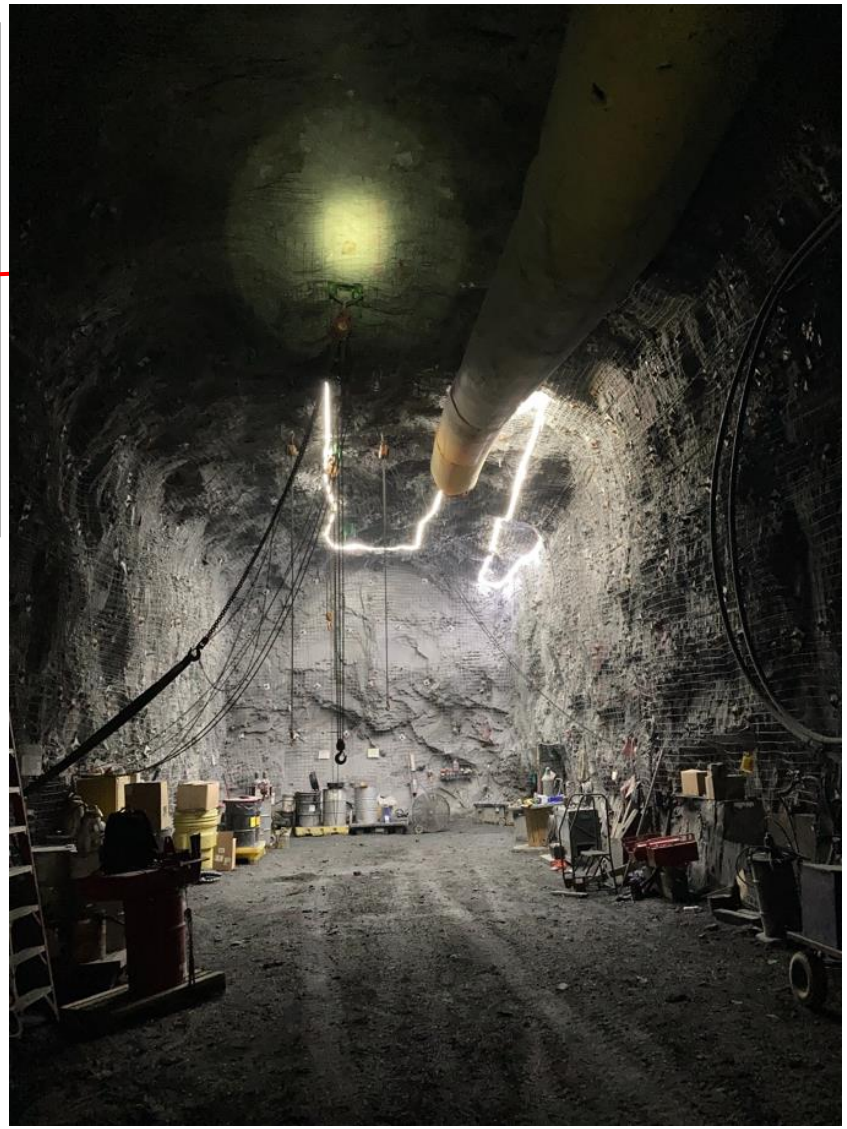
Excavation Status Photos



Setting Up the Robotic Shotcrete Machine



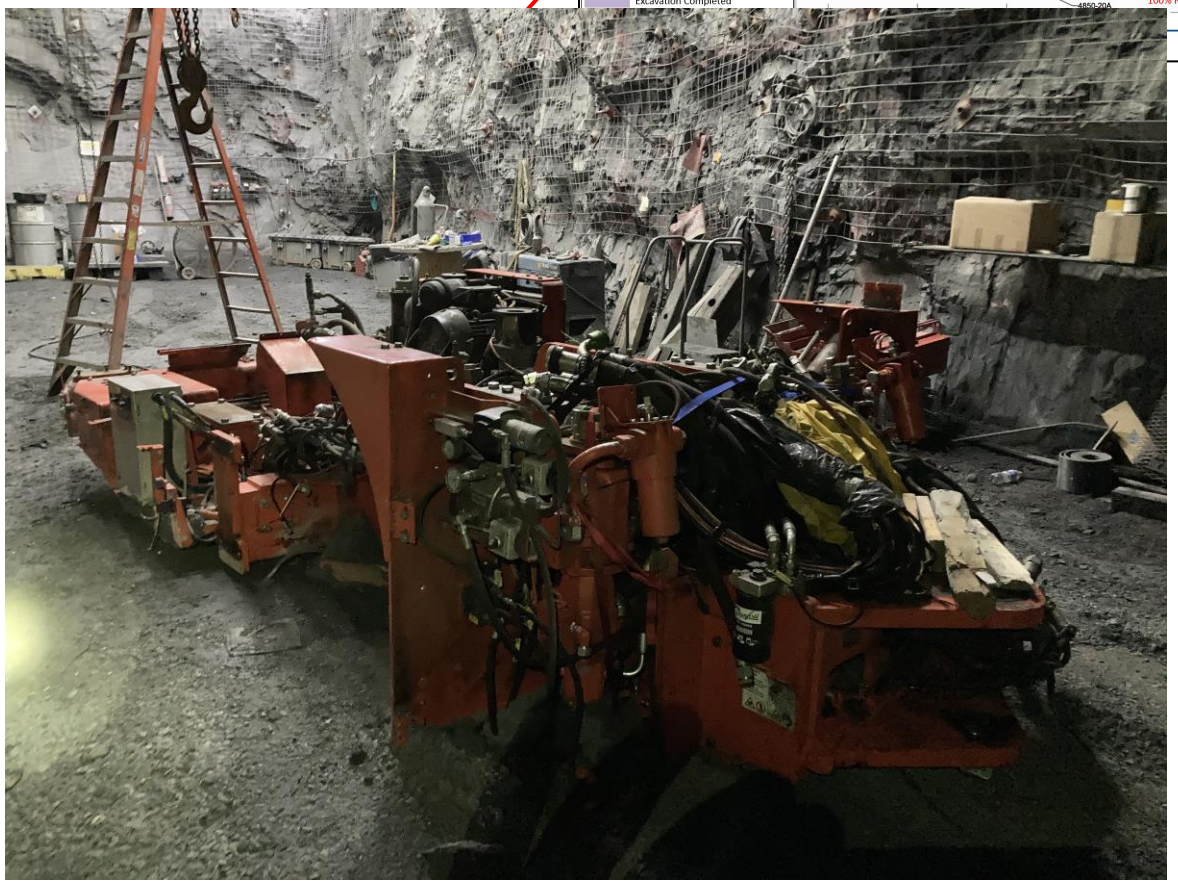
Surveyor mapping the 4850-13S Heading



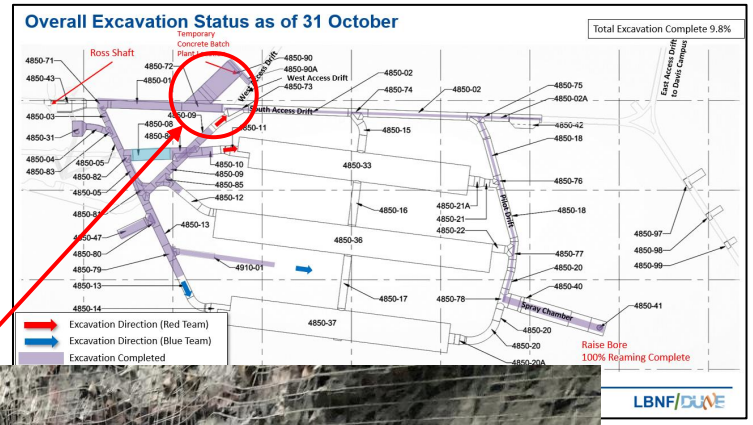
Permanent Concrete Batch Plant (4850-47)

Completion of Maintenance Chamber allows Larger Equipment for Main Cavern Excavation to Begin Movement Underground

Sandvik 422i Jumbo on surface

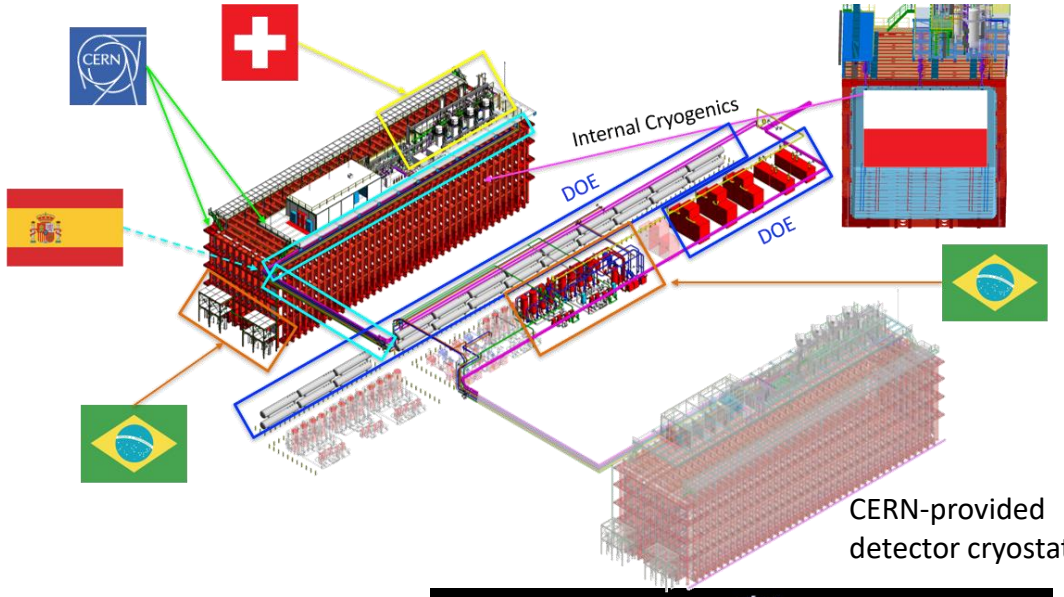


Sandvik 422i Jumbo being reassembled at 4850L in new maintenance cavern

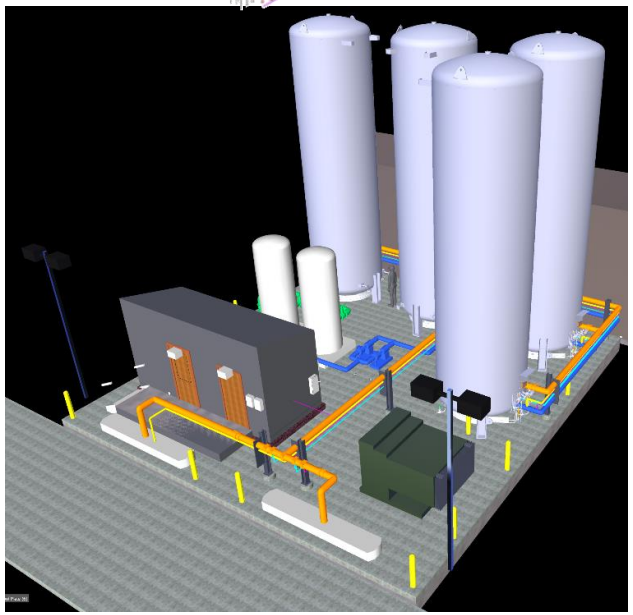


Project Status at Far Site

- **Cryostats and Cryogenics Infrastructure**
  - ✓ Initial proposals (“phase 1”) for nitrogen refrigeration cryogenics system contract have been received and are under negotiations for award
    - Phase 2 award planned in early 2022
  - ✓ CERN Council has provided commitment an additional second cryostat
  - ✓ Partner commitments in place for liquid argon circulation and purification systems.
  - Will create contracts to purchase 34 ktons of argon in 2025 when needed to fill cryostats



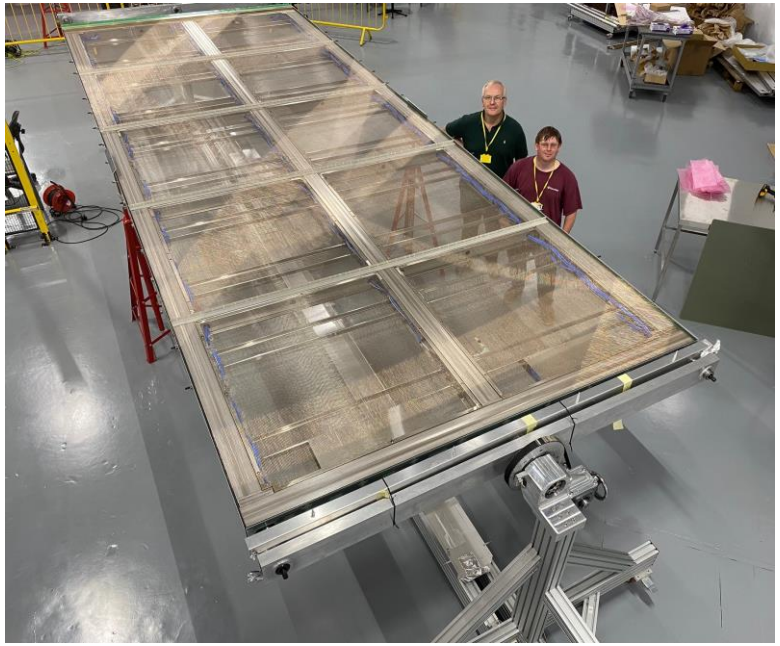
CERN-provided detector cryostats


Argon receiving station at SURF

Far Site is proceeding in technically limited fashion to transition to start of detector installation

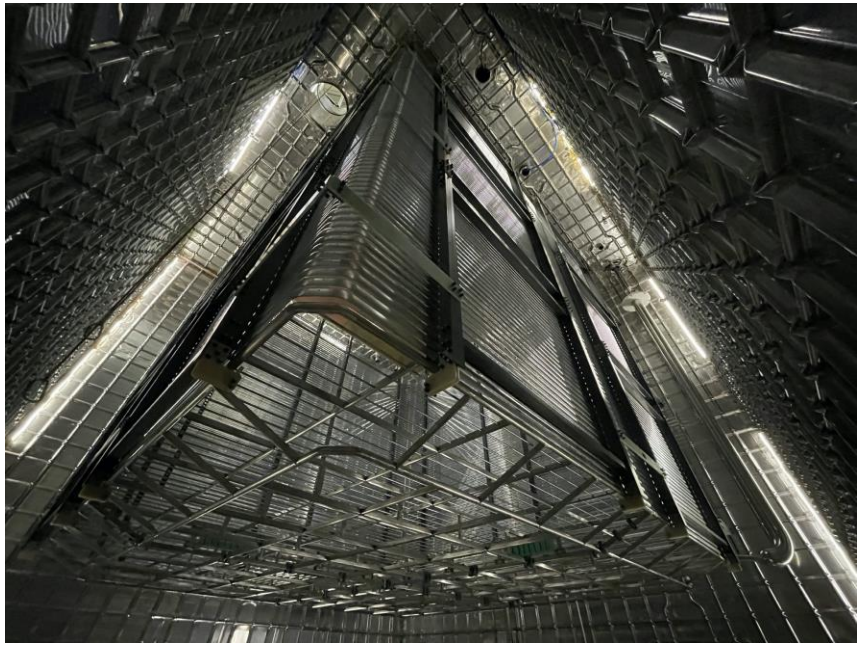
DUNE Far Detectors Status

- 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.

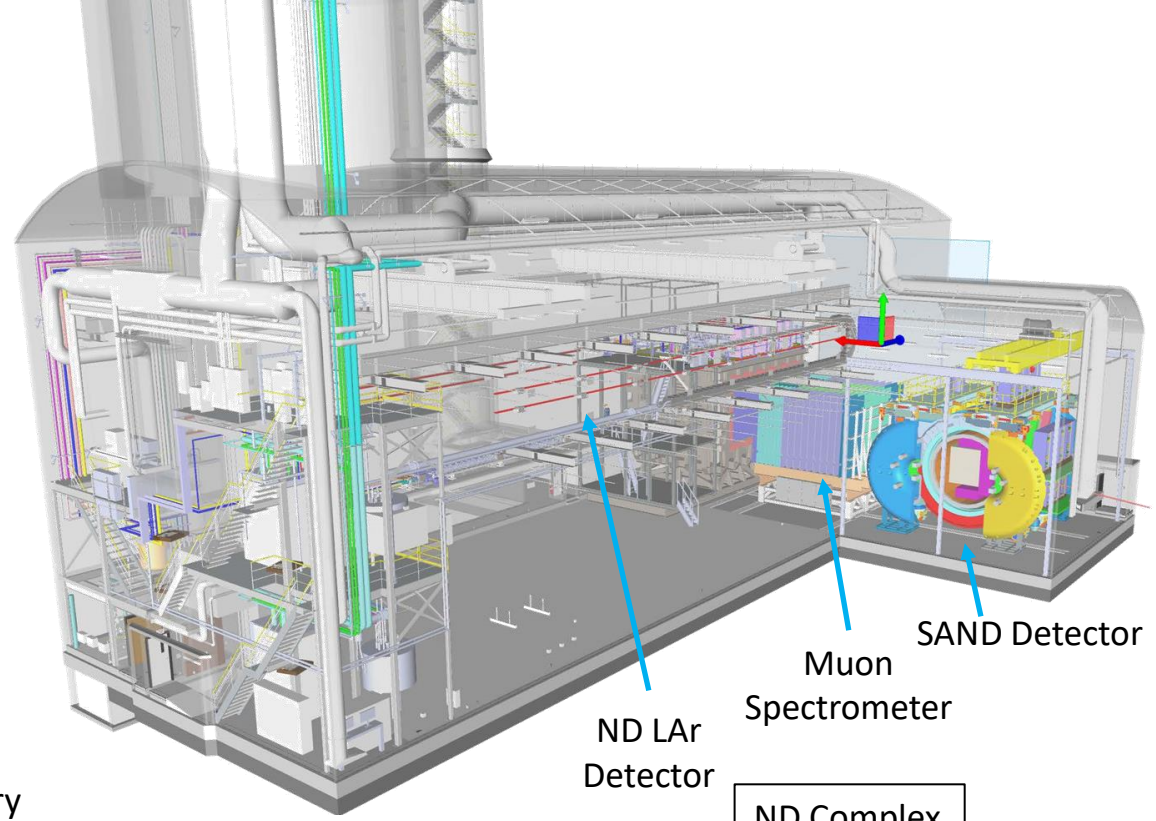
NP-02 and NP-04 ProtoDUNE 8m x 8m x 8m detector prototypes at CERN.

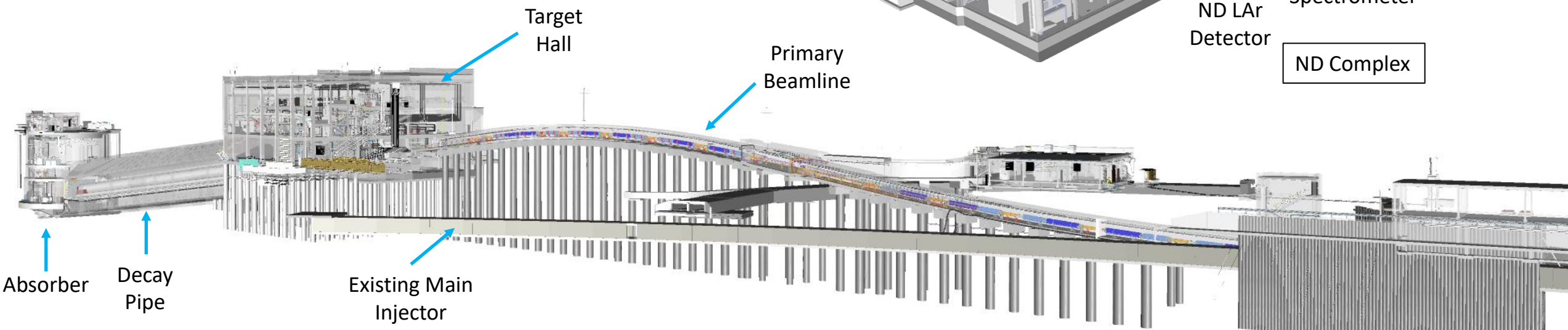


NP-02 ProtoDUNE 8m x 8m x 8m cryostat at CERN has demonstrated 300 kV across field cage for CRP detector technology

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.



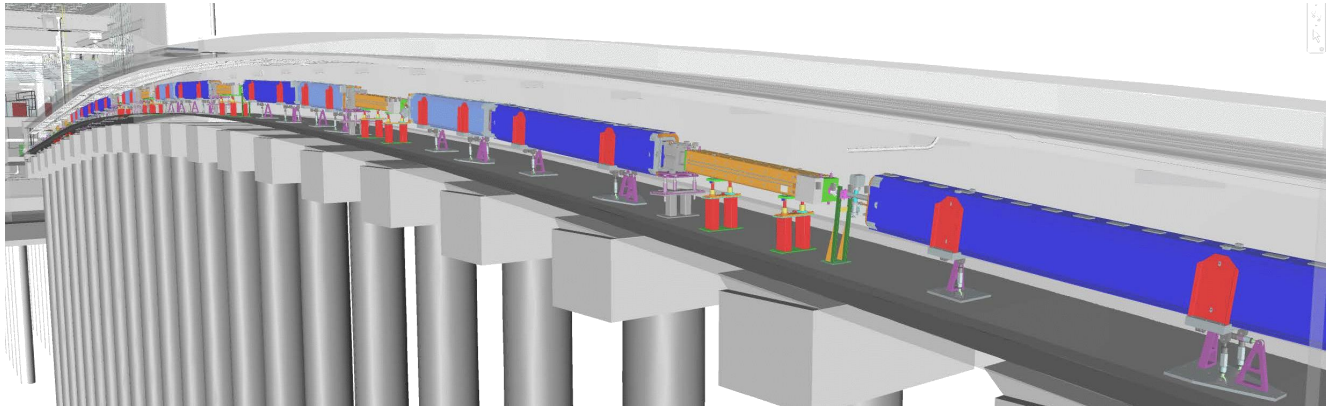


Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

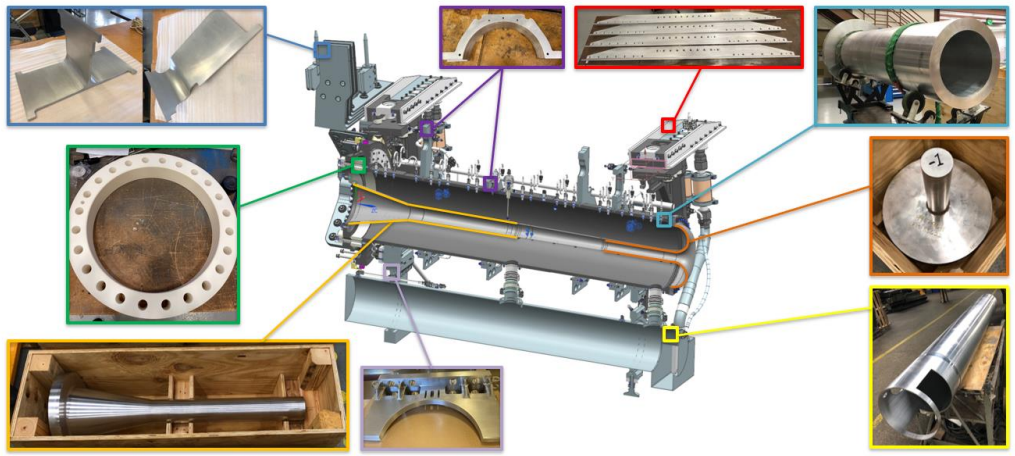
Near Site Conventional Facilities are positioned to start construction upon funding availability and approval

Primary and Neutrino Beamline Status

- Design progressing per plan: 67% complete as of September
  - Primary Beam Magnets – BARC
    - Preliminary design reviews completed
  - Target by UK/RAL
    - Extensive work on prototyping features of the target assembly



Primary Beam Magnets on piles

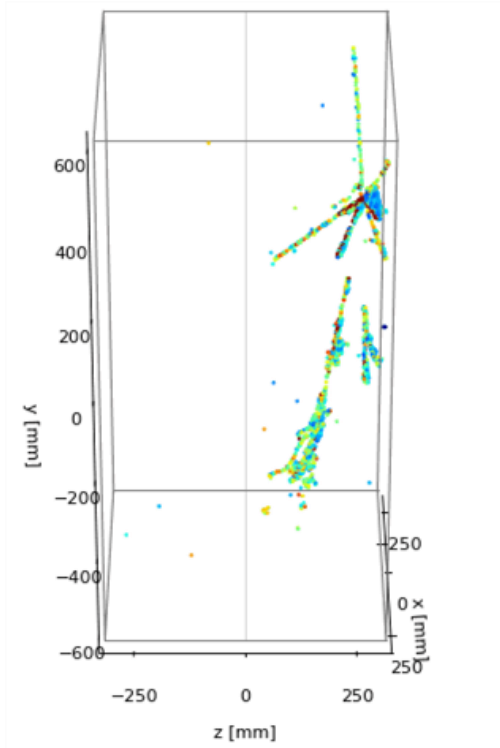


Horn A Prototyping

  - Horn A Prototype by FNAL
    - Fabrication in progress

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

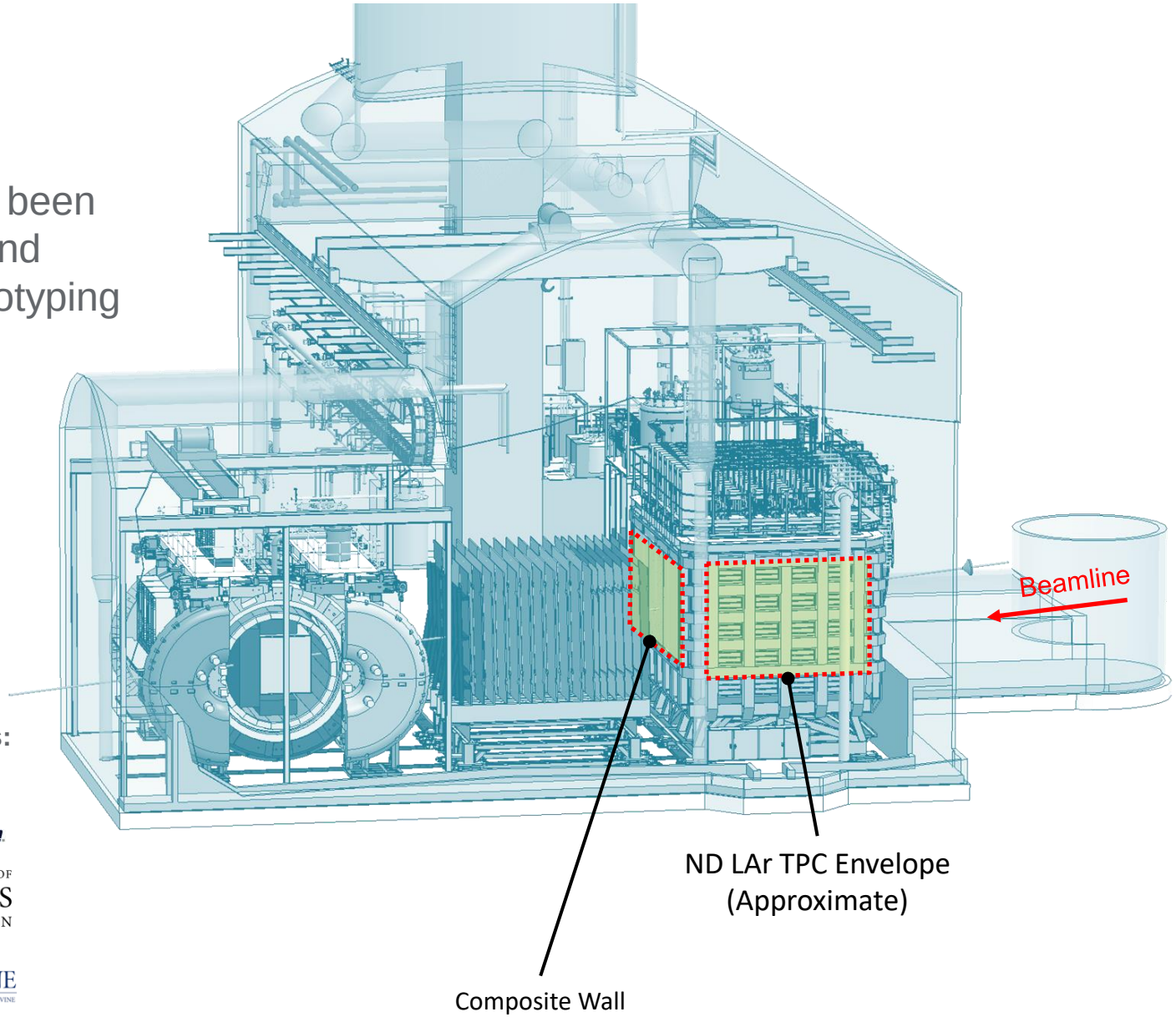


Muon interaction via a direct hit on an argon nucleus, with secondary interactions shown.

Partners International:

National Labs:

Key University contributors:



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.
- International partnerships are in place and are essential for the success of the PIP-II and LBNF/DUNE-US projects.
- Highly engaged, proactive project teams and international partners continue strong technical progress despite pandemic challenges.
- LBNF/DUNE-US has eliminated significant cost and schedule risk with the award of the main cavern excavation contract and is ready to begin baseline process in January 2022.

We greatly appreciate the HEP community commitment to complete the P5 vision and enduring strong support from the community, DOE/SC, the DUNE Collaboration and our International Partners!

Thank you. Questions?