LBNF/DUNE-US Current Status

Chris Mossey, Project Director, LBNF/DUNE-US

21 March 2023

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v5

The Long-baseline Neutrino Facility supporting the Deep Underground Neutrino Experiment

LBNF and DUNE were proposed in response to the 2014 P5 report and the 2013 European Particle Physics Strategy

- **LBNF** – a **highly capable neutrino science platform**
  - U.S. provides all conventional facility requirements to support an internationally led experiment
  - International partners provide key technology/in-kind contributions:
    - Cryostats – from CERN
    - Cryogenic Systems – supported by CERN/Brazil/Poland/Switzerland
    - Target/Beamline – key components from UK/CERN/Japan

The **LBNF** is a global platform analogous to the LHC

LBNF Partners

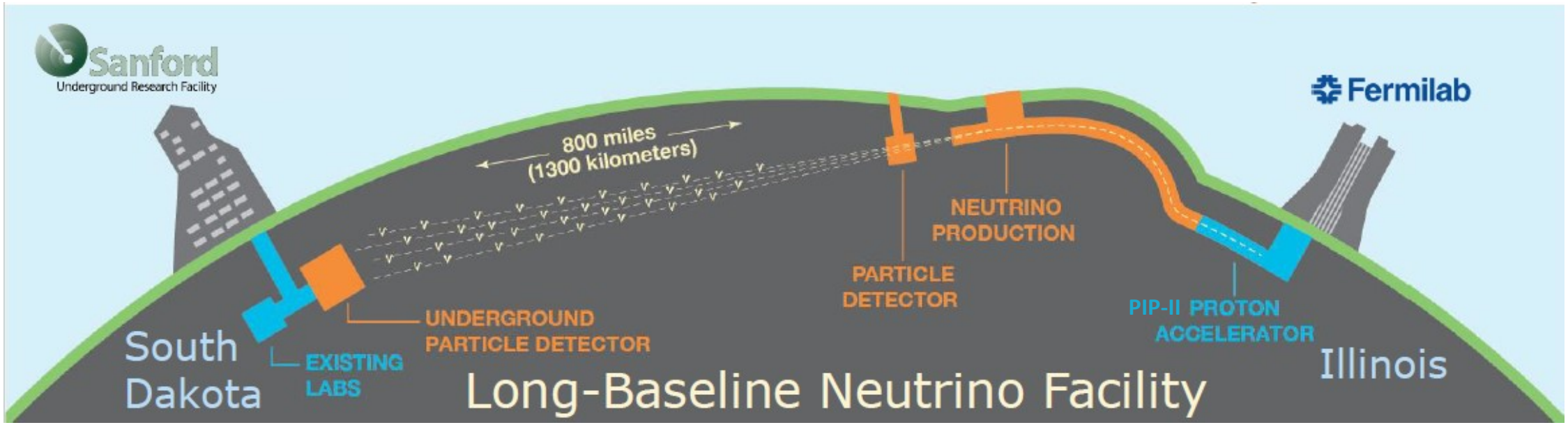
- **DUNE** – a **best-in-class neutrino** experiment, designed, constructed, and operated by an international collaboration
  - The U.S., along with multiple international funding agencies, contribute to the near and far detectors

DUNE-US is analogous to US-CMS or US-ATLAS

- Fermilab serves as **host laboratory** for the international collaboration

LBNF/DUNE represents a new model and global approach to physics in U.S.

The DOE Project supports the LBNF/DUNE model, relying on International Partnerships



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

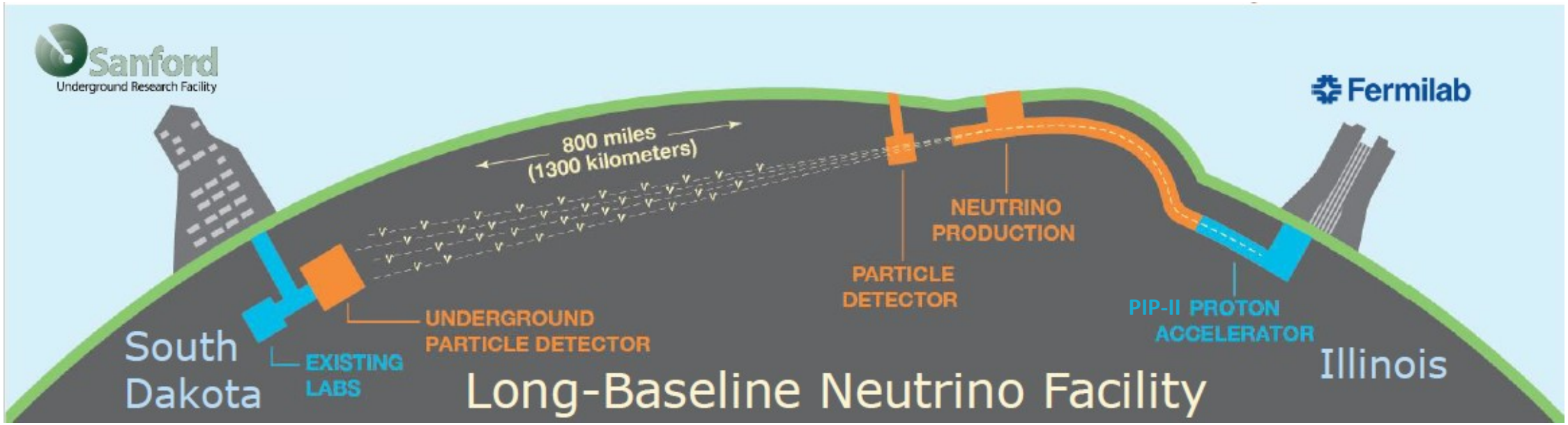
LBNF

- **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 DOE Project supports the LBNF/DUNE model, relying on International Partnerships



DOE LBNF/DUNE-US Project

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

LBNF

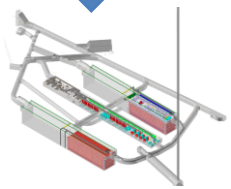
- **DUNE-US** – U.S. contribution to the international DUNE experiment
- **International DUNE** - partner contributions to the international DUNE experiment

DUNE

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

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

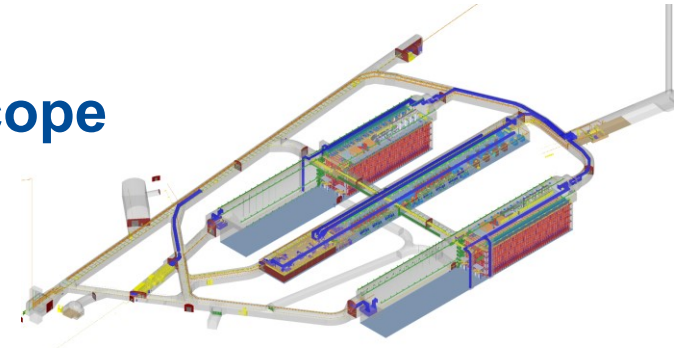
1.5 km down

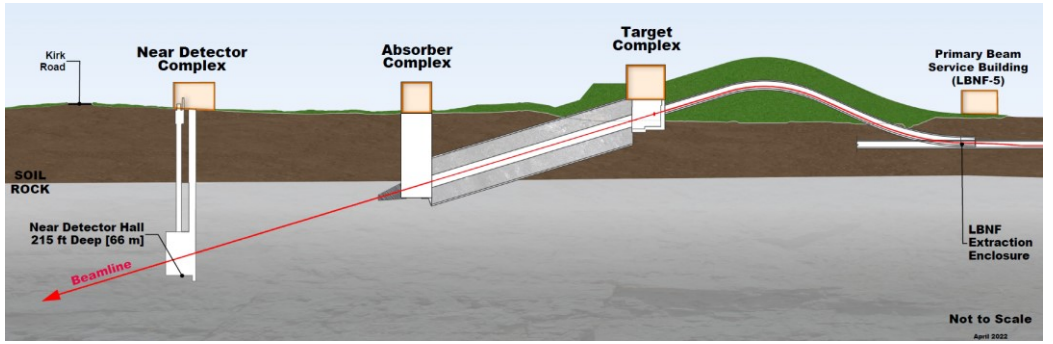


LBNF caverns

- SURF is located at the former Homestake Gold Mine, in Lead SD
- Property was transferred in 2006 to the 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 where the LBNF facilities are being constructed from SDSTA

LBNF/DUNE-US Project Scope





LBNF/DUNE-US Project Scope — Far Site — Near Site

	Component	DOE Project Scope (meets 2014 P5 minimum to proceed – Phase I)	Phase II Requirements (meets 2014 P5 goal)
Near Site	Conventional Facilities	• Constructed to support 2.4MW primary and neutrino beamline • Constructed to support underground Ph I & II Near Detector	• None
	Neutrino Beamline	• Wide-band output neutrino beam, 1.2MW initially, designed to be upgradeable to 2.4MW	• 2.4MW capable target and new horns • New decay pipe window • Some additional cooling and instrumentation
	Near Detector	• US contribution to the DUNE Near Detector (Ph I)	• US contribution to more capable Near Detector (Ph II)
Far Site	Conventional Facilities	• Surface and underground facilities & infrastructure for 4 detector modules	• None
	Cryostats	• For 2 detector modules (CERN)	• For 2 detector modules
	Cryogenics	• 3 x nitrogen units; 35 kton liquid argon for detector modules	• 1 x nitrogen unit; 35 kton liquid argon for detector modules
	Far Detector	• US contributions to 2 x DUNE LAr TPC modules	• US contributions to 2 x DUNE LAr TPC modules

Project scope is unchanged since inception of LBNF and DUNE in 2015
Facility scope supports Phase II

Increase in LBNF/DUNE-US Estimated Costs since 2015

- In 2015, the expected DOE project cost range was $1.2B to $1.86B with an upper cost limit of $2.79B.
- By late 2018, due to a variety of cost drivers (discussed on next slide), it was apparent that the project's cost would exceed the established upper cost limit.
- The project began the process to "reaffirm" the project's scope, capabilities, and estimated costs in close coordination with DOE HEP, DOE SC, the DUNE collaboration, and our national and international partners.
- The review process objectives included:
  - Reaffirm the alternative and scope selected in 2015 (e.g., 1.2MW upgradeable beamline, capable ND, 20kt fiducial underground LAr TPC at first oscillation maximum)
  - Implement a subproject execution strategy
  - Reset the point estimate and cost range based on finalized international agreements and significantly greater project maturity and cost certainty.
- DOE S-4 formally approved the CD-1R "reaffirmation" milestone on 16 February 2023.

Main Cost Growth Drivers from 2015

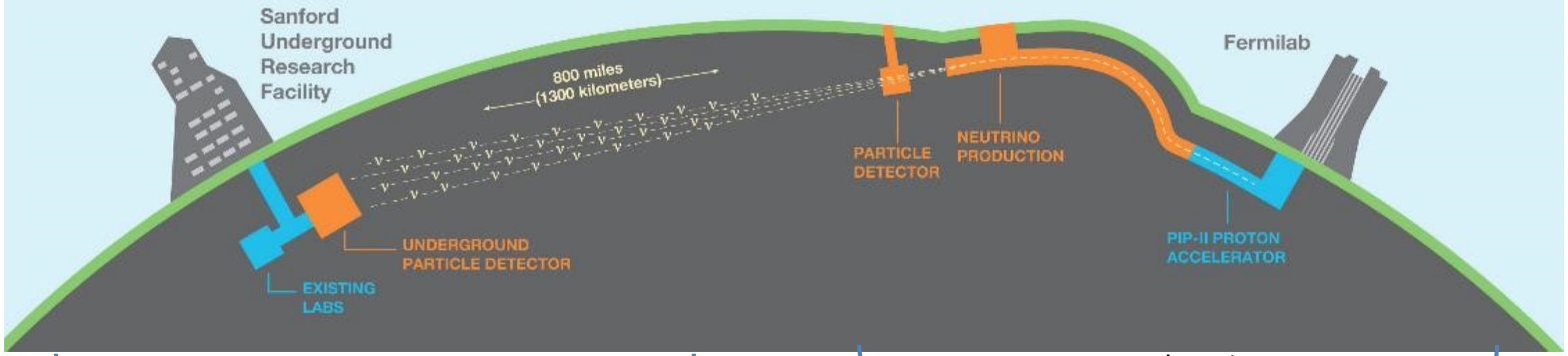
Driver	Description
The cost and complexities of the far site conventional facilities construction was underestimated (+~$300M)	• Condition of legacy mining site at SURF required unplanned investments. • Costs of underground construction and supporting infrastructure were underestimated.
The cost of detector installation was assumed to be off project (+~$200M)	• When the installation cost estimates were matured, they could not be handled by the program "off-project." In 2019, HEP directed that all installation costs be funded by the project.
Stretched out funding raised costs due to escalation and longer execution period (+~$300M)	• Project did not receive funding profile assumed in 2015; delays in execution have significant escalation impacts on a decade long mega-project.
Full understanding of needed project scope (+~$200M)	• Project scope need to be increased, particularly for Near Detector and near site conventional facilities, to address performance and safety issues.
Gaps in planned assumptions regarding partner participation caused scope to be later assumed by DOE project (+~$100M)	• Gaps in LBNF and DUNE scope were added to project to reduce risks.
DOE reviews recommended significantly raising the contingency level (+~400M)	• Was 34% of the estimated cost in 2015; now is 40% of the cost estimate. • Increased due to both cost growth and as a fraction of the cost estimate.

Cost drivers understood and addressed. Project is 31% complete with $1.8B in work remaining (ETC) with 40% contingency.

DOE 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

Subproject Design Maturity is generally well beyond CD-2/3 Milestone Requirements

	Subproj Abbrev	Subproject Title	Subproject Scope	Final Design Maturity	CD-2/3 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	**100%**	✓ **Completed Jan 2022**
FAR SITE	FSCF-BSI	Far Site Conventional Facilities – Building & Site Infrastructure	All Far Site (FS) conventional facilities (CF) support infrastructure	**100%**	✓ **Completed Nov 2022**
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.	92% (FD1) 91% (FD2) 90% (C)	**Scheduled Sep 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) 70% (BL)	Planned late 2023
NEAR SITE	ND	Near Detector	Near Detector (ND) including integration/installation and cryogenic systems	42%	TBD 2024 to 2025

50% of project is at final design status; overall project design status is at 91% - well beyond CD-2/3 maturity

Planned Critical Decision Timeline Summary

21 Mar 2023

	Subproject	CD	Q1 2022	//	Q3 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023	Q4 2023	Q1 2024	Q2 2024	Q3 2024	//	Q2 2025	//	Q4 2025
	All	CD-1RR			✓ **IPR 11-15 Jul**		✓ **ESAAB 19 Jan**										
Far Site	**Excavation**	CD-2/3	✓ **IPR 10 - 12 Jan**		✓ **ESAAB 19 Aug**												
	Building & Site Infra	CD-2/3				✓ **IPR 15-17 Nov**	**ESAAB 23 Mar**										
	Far Detectors and Cryo	CD-3a				✓ **IPR 8 Nov**	✓ **ESAAB 21 Feb**										
		CD-2/3							**IPR 12-15 Sep**		ESAAB TBD						
Near Site	**Conven. Facilties and Beamline**	CD-3a				✓ **IPR 6 Dec**	**ESAAB 23 Mar**										
		CD-2/3								IPR TBD		ESAAB TBD					
	Near Detector	CD-2									IPR TBD		ESAAB TBD				
		CD-3													IPR TBD		ESAAB TBD

DOE critical milestone review

DOE critical decision (ESAAB) timeframe

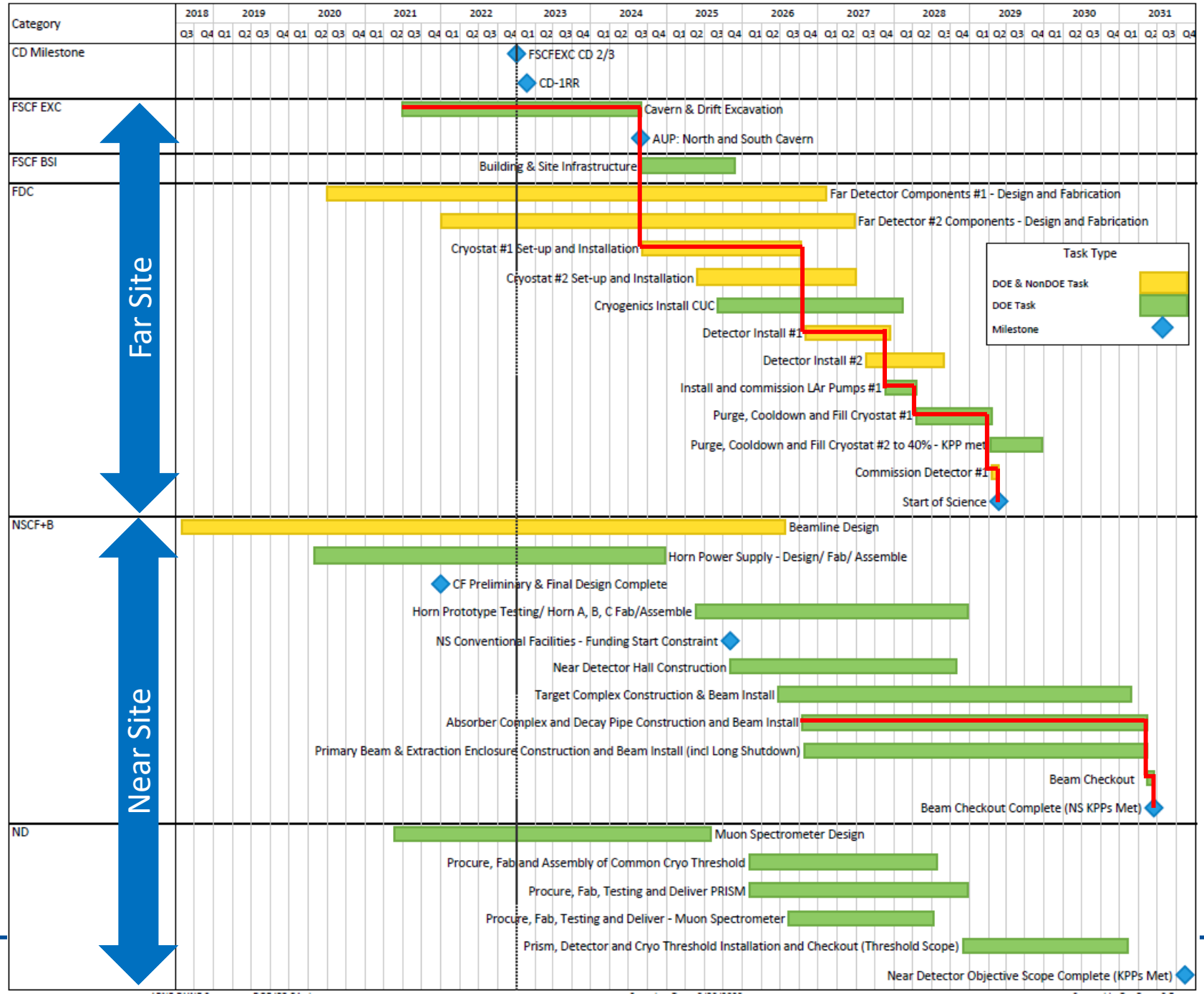
Notes:

Quarters shown are calendar year

Bolded dates are set with DOE

Each subproject will also have a CD-4 milestone review (not shown).

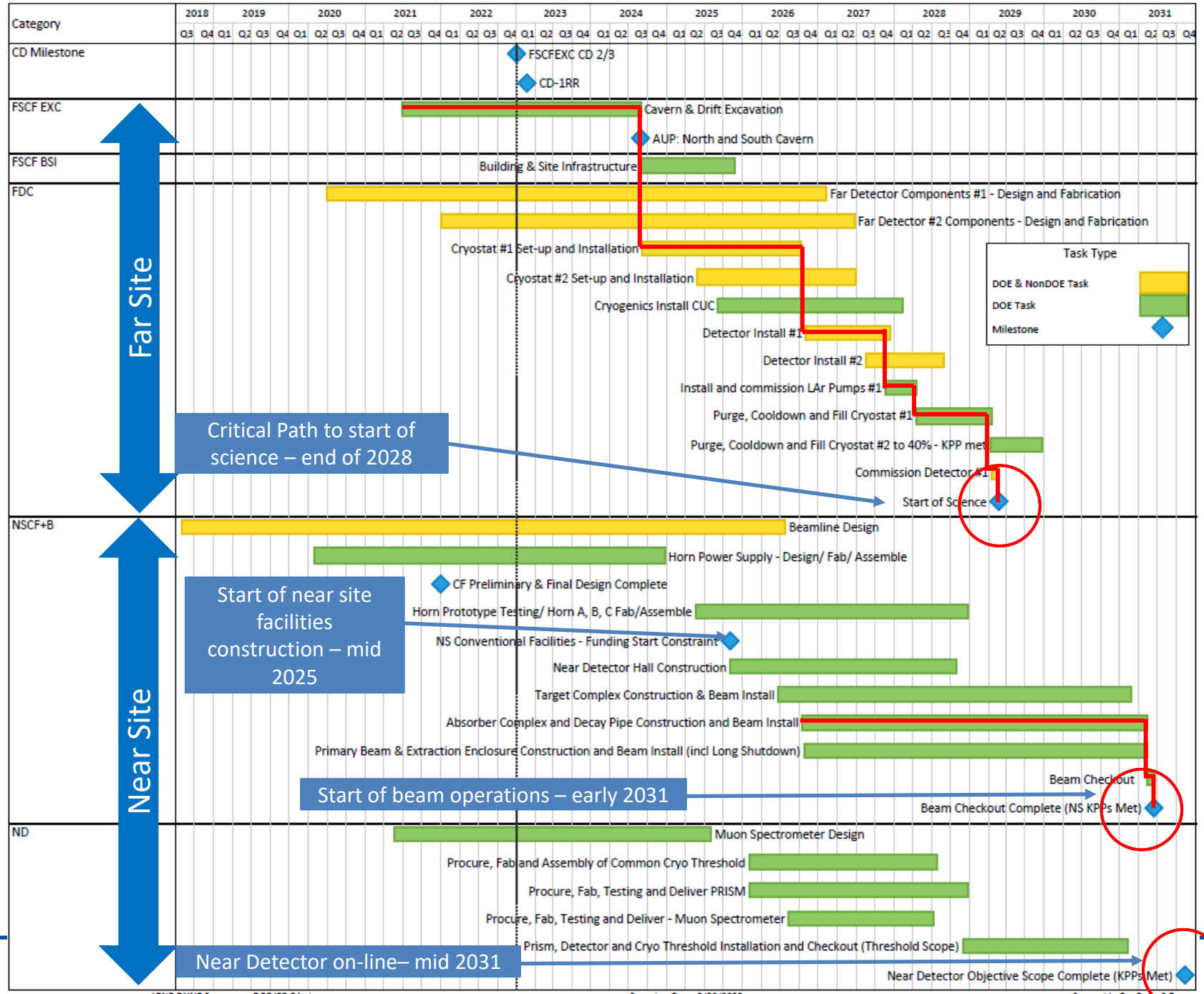
Summary Schedule with Critical Paths through Start of Science (FD1) and Beam-on



Favorable execution schedule enabled by new DOE funding profile in March 2022

Notes:
- Fiscal Year display
- Early completion dates shown

Summary Schedule with Critical Paths through Start of Science (FD1) and Beam-on



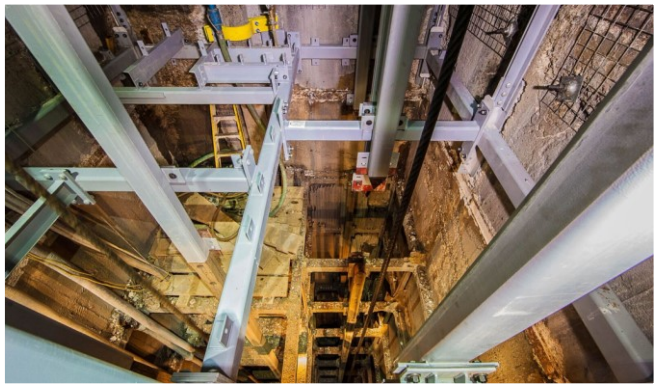
Favorable execution schedule enabled by new DOE funding profile in March 2022

Notes:
- Fiscal Year display
- Early completion dates shown

Project Execution Status

Far Site Execution Status

- ✓ **Reliability Work** – Upgrades to SURF infrastructure. Significant upgrades, including refurbished shaft and new hoist systems.
  - ✓ 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 Work** – Equipment and systems to move excavated rock from one mile underground to the surface and deposit it in the Open Cut.
  - ✓ Empty and repair Ore Pass
  - ✓ Replace Skip loading system at 4850L
  - ✓ Replace Rock Crusher system
  - ✓ Rehabilitate underground Tramway
  - ✓ Install four 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



Rebuilt Ross Shaft

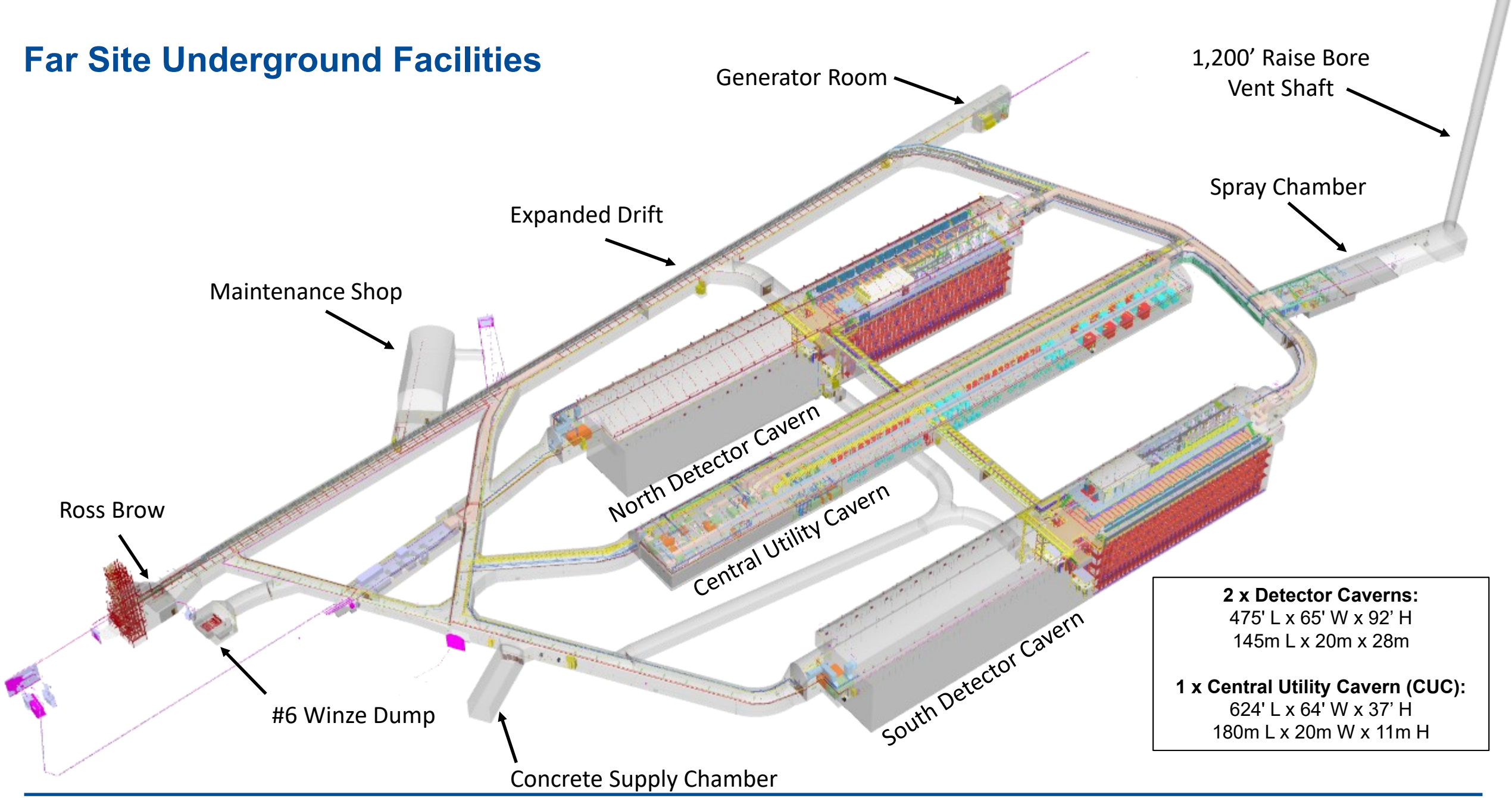
New Ross Hoist Brake Shoes, motors, control systems

New power distribution

Rock conveyor system to move rock to Open Cut

Significant work has already been accomplished at the Far Site

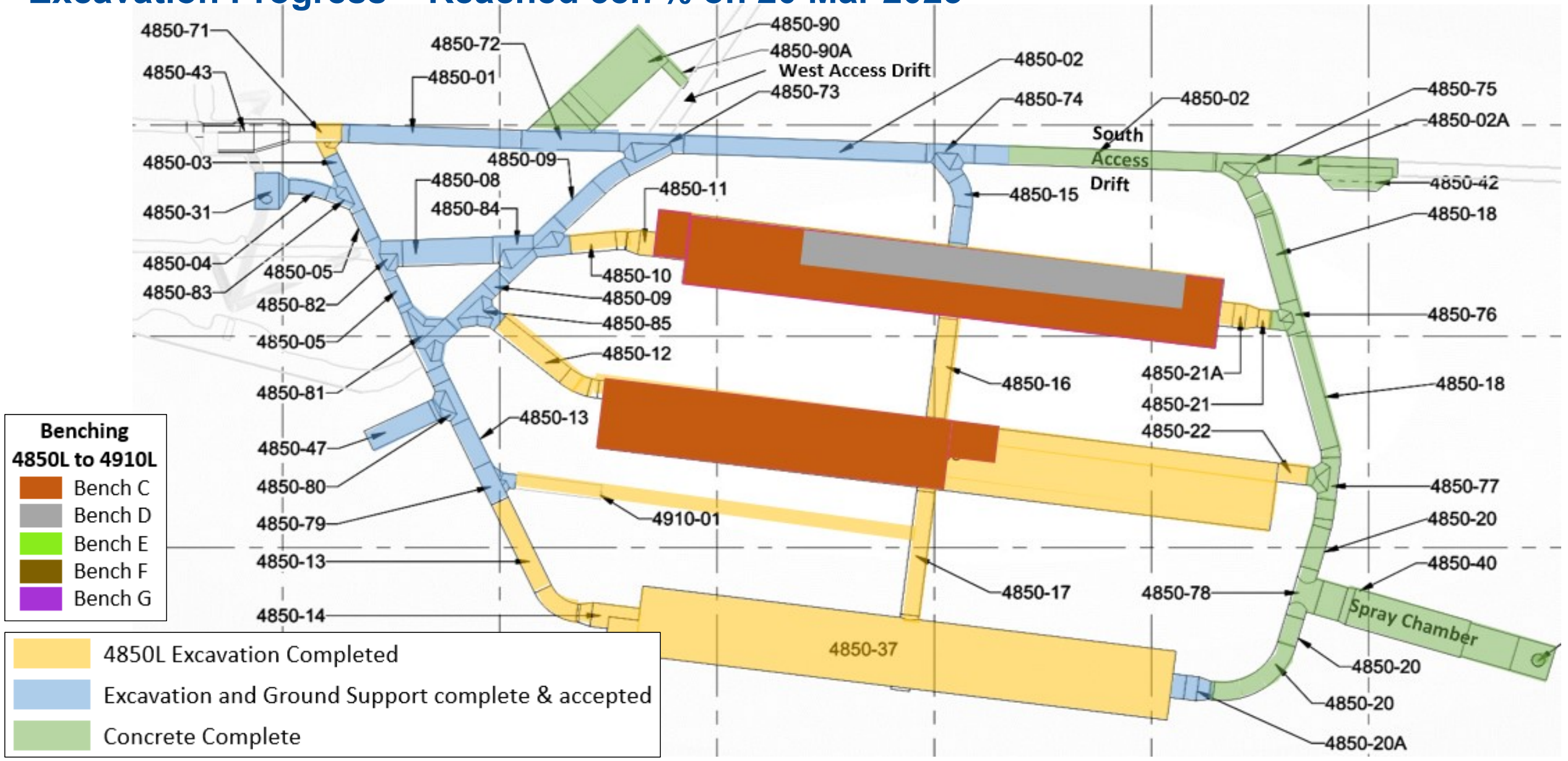
Far Site Underground Facilities



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

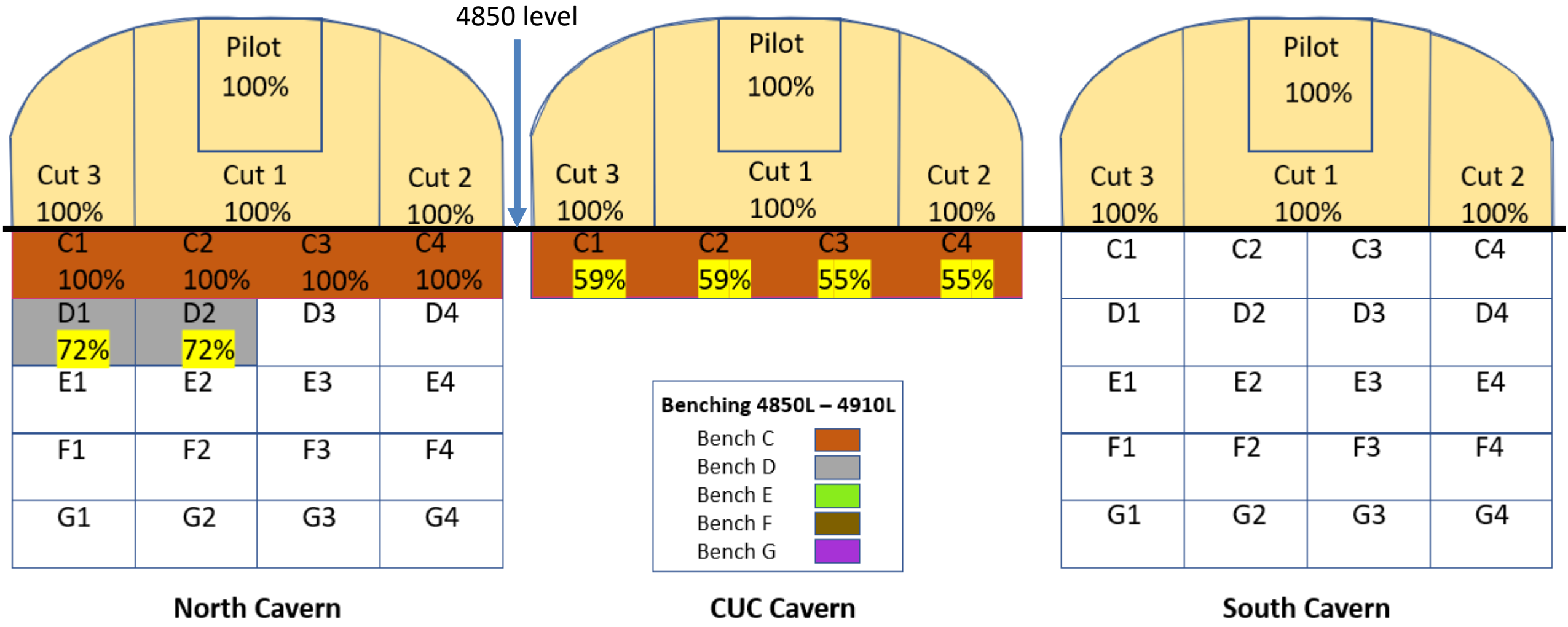
1 x Central Utility Cavern (CUC):
624' L x 64' W x 37’ H
180m L x 20m W x 11m H

Excavation Progress – Reached 58.7% on 20 Mar 2023



All excavation work is under firm-fixed price construction contract and proceeding on cost and on schedule

Main Excavation Focus is now on “Benching down” in each cavern from 4850L



58.7% of in-situ rock volume removed as of 20 Mar 2023

North Detector Cavern – West End

Photo by Matt Kapust, SDSTA; 19 Jan 2023

Drilling holes for blast charges for bench C (left) and removing muck (right) in North Detector Cavern (4850-33) west end

North Detector Cavern

Removing blasted rock for bench D in North Cavern (4850-33)

North Cavern (4850-33) East End Monorail Alignment

Central Utility Cavern

Finishing Cut 2 and testing Rock Bolts in Central Utility Cavern (4850-36)

Installing CT Rock Bolts in Central Utility Cavern (4850-36)

South Detector Cavern

Extending monorails that will support material handling cranes in South Detector Cavern (4850-37)

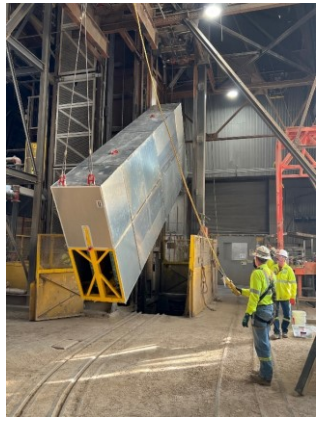
Far Detector/Cryogenic Infrastructure Status

- ✓ Progressing with construction of “Module 0” prototypes for FD1 and FD2 at CERN
  - Prototypes use the actual, full-size components that will be installed at SURF
  - Prototypes continue to work exceptionally well
  - Logistics test to move APAs from Europe to a mile underground at SURF successfully completed
- ✓ CERN agreements for both cryostats finalized; fabrication of first cryostat is underway
- ✓ Nitrogen System Cryogenic Infrastructure contract
  - In process of awarding contract with major global vendor; prices are set
  - Contract will provide 3 nitrogen refrigeration units for Phase I scope; only need one more unit for Phase II
    - This unit is included as an option the contract
- ✓ Argon purification systems mostly to be provided as in-kind contributions and have been extensively prototyped and proven; agreements with partners in place.
- ✓ Argon for two detector modules (17,700 tons each) is included in project scope/budget.

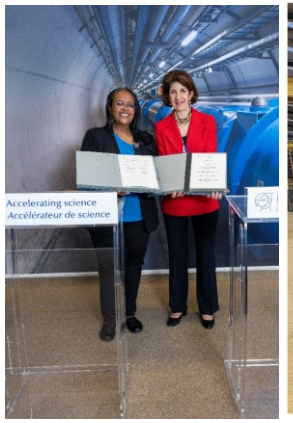
CERN Neutrino Platform

More in Francesco Lanni and Sam Zeller talks

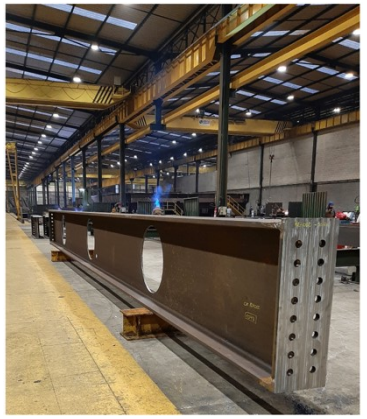
FD1 and FD2 prototypes at CERN



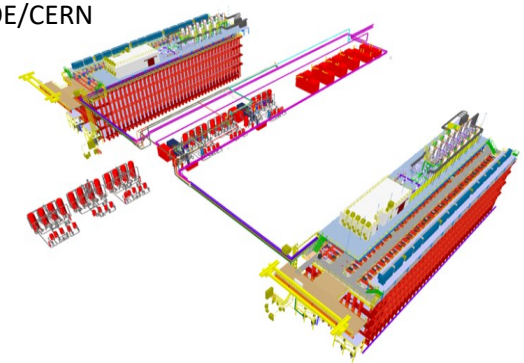
APA transport test at SURF



Signature ceremony DOE/CERN



Cryostat fabrication underway

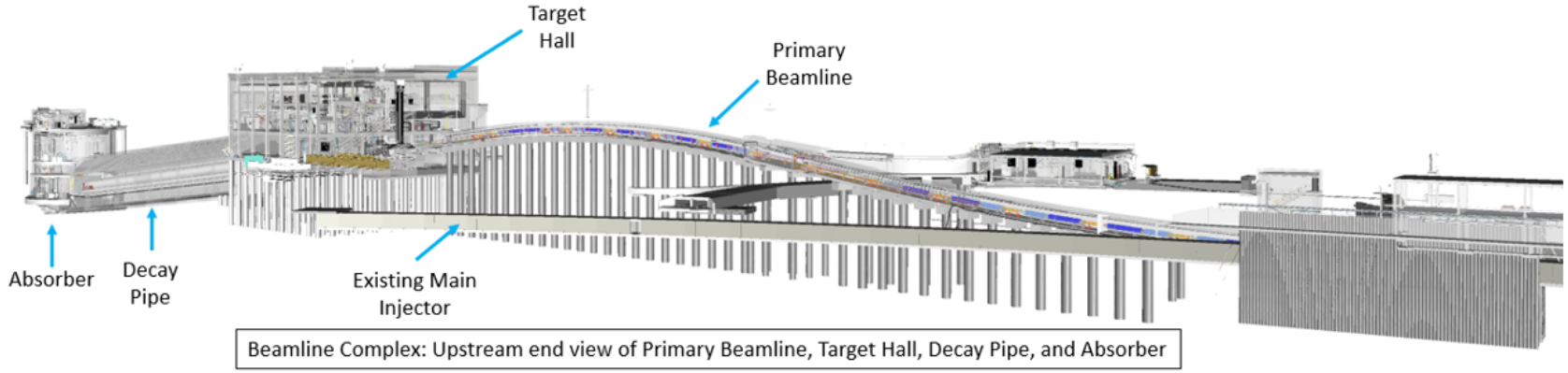


Cryogenic Infrastructure

Major risks eliminated through protoDUNE. Award of N2 contract provides cost certainty for cryogenics infrastructure for Phase I and II.

Near Site Execution Status

- ✓ Beamline design at 70% final design status; prototyping well advanced, building on experience from NuMI beamline.

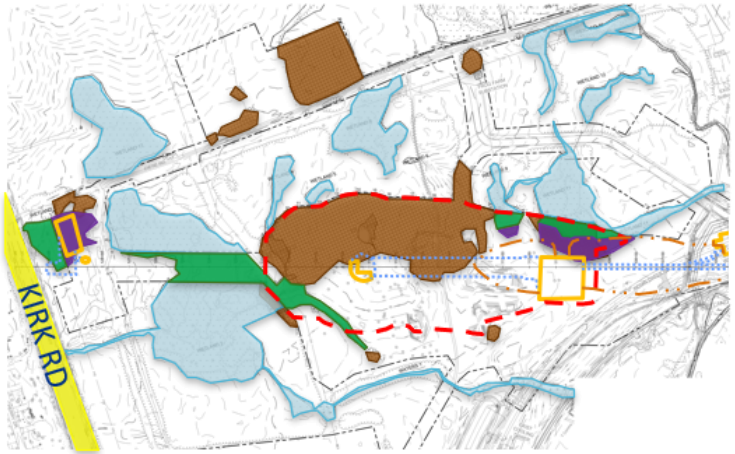


Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

- ✓ Conventional Facilities design is at 100% final design status; additional independent cost estimate has been completed.
  - – Key contract documents currently under DOE review.
  - – Initial site work was completed 2020; next phase to start this fall.


New culvert system (with fish channel) to reroute Indian Creek


Power distribution system installation

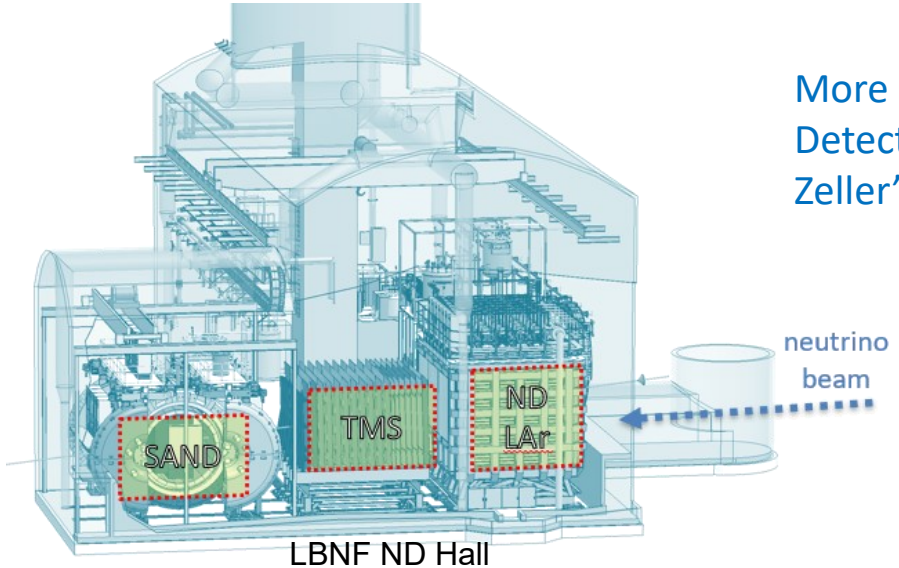


Additional site preparation work to start fall 2023

Future Excavation Limit
Future Toe of Embankment
Future Surface Structure
Future Underground Structure
Tree Removal
Wetland Not Impacted
Wetland Temporarily Impacted* (7.71 ac)
Wetland Permanently Impacted* (0.96 ac)
*- Impacts offset with offsite wetland bank credits

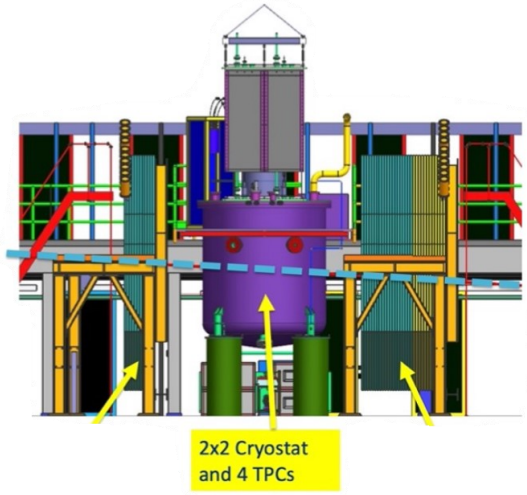
Near Detector Subproject Status

- Like for Far detectors, DUNE-US is also contributing to Near Detectors along with other international partners
- ✓ Fully instrumented 20% scale ND-LAr prototype has been successfully operated at LHEP/University of Bern
- ✓ A scale 2x2 prototype of the LAr-based near detector is being installed for testing in the Fermilab NuMI neutrino beam right now
- ✓ IERC building to support ND-LAr prototyping and construction has been completed and is currently being outfitted.

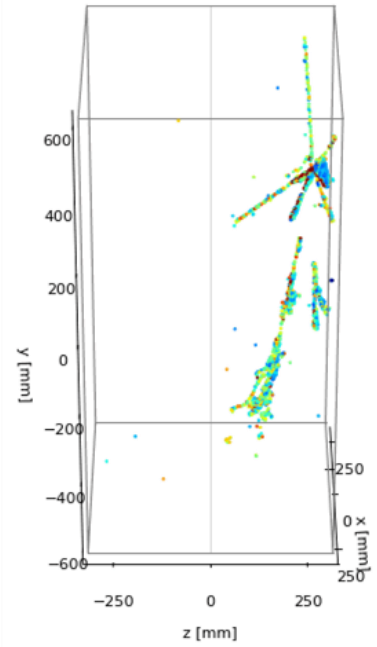


LBNF ND Hall

More on Near Detectors in Sam Zeller's talk



Location of 2x2 prototype in NuMI beam

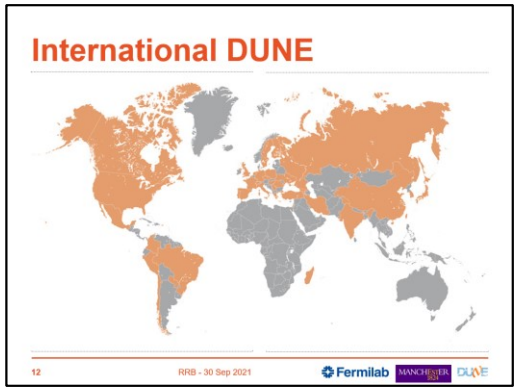


20% scale ND LAr prototype


ND LAr construction facility

Bonnie Fleming's talk

Fermilab is preparing to host the international DUNE Collaboration



- Fermilab is preparing to provide the array of services that will provide critical support for:
  - Execution of detector subprojects
  - Operations of DUNE experiment
  - Hosting of an international science collaboration
- The DUNE Host Lab Task Force, led by the Chief Research Officer (CRO) and Chief Operations Officer (COO) has been working since August. These organizations will provide key support in the following areas:
  - **CRO**:
    - Interface with DUNE collaboration, Int'l funding agencies, physics community
    - Organizes and coordinates oversight bodies, including LBNC, NSG, and RRB
  - **COO**:
    - Organizes and coordinates support through laboratory mission support organizations (eg; legal, facility, property, safety, HR, financial, procurement, project support services, etc)
- Draft task force report, addressing critical issues, has been completed. Report to be finalized by June.

Support of the LBNF/DUNE enterprise is a lab-wide priority

Challenges and Path Forward

- Unimpeded access to underground areas at far site during construction phase of project.
  - *Working with SDSTA and HEP to support an extended maintenance period for Yates shaft*
  - *All project access requirements can be met through the Ross shaft, which has been refurbished*
- Year-long continuing resolutions in FY24 or FY25 (planned incremental funding steps of +$75M and +$50M respectively)
  - *Have planned for a three-month CR every year*
  - *Have planned for additional carry-over in FY24 to maintain technically limited schedule at far site*
- Ability to ramp up and support workforce at Far Site to support next phase of work (transition from conventional facilities work to cryostat and detector installation).
  - *Have established and staffed organization to recruit and support far site workforce*
  - *Host lab task force is ensuring full range of services available (e.g., badging, housing, etc)*

Summary

- The LBNF/DUNE initiative is a groundbreaking approach for the U.S. high energy physics community.
  - LBNF, supported by CERN and our international partners and powered by the highly capable PIP-II accelerator, will provide a world-class platform for the global high energy physics community.
  - DUNE-US is contributing to the internationally conceived and led DUNE experiment
- The LBNF/DUNE-US project will deliver infrastructure needed for DUNE Phase II.
- Project scope, costs, and schedule are well understood and very mature.
  - Project design is at 91% overall, prototypes are proven.
  - International partners are committed and delivering vital contributions.
  - Far site work is well underway; key contracts in place. Ready to start near site work.
  - DOE has provided a strong funding profile to execute project efficiently and competitively.

LBNF/DUNE will establish the U.S. as the global center for neutrino physics

LBNF/DUNE represents a new approach – thank you to all of our partners for your extraordinary support!

Thank you. Questions?