Building for Discovery: LBNF & PIP-II

Lia Merminga

HEPAP

22 November 2019

In partnership with:
India/DAE
Italy/INFN
UK/STFC
France/CEA/Irfu, CNRS/IN2P3

Outline

- LBNF/DUNE/PIP-II in P5 Context
- LBNF Project Overview & Status
- PIP-II Project Overview & Status
- International Partnerships
- Summary

2014 P5 endorsed a global particle physics program

PIP-II

Building for Discovery

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

- 2014 P5 Report:
  - 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.

PIP-II

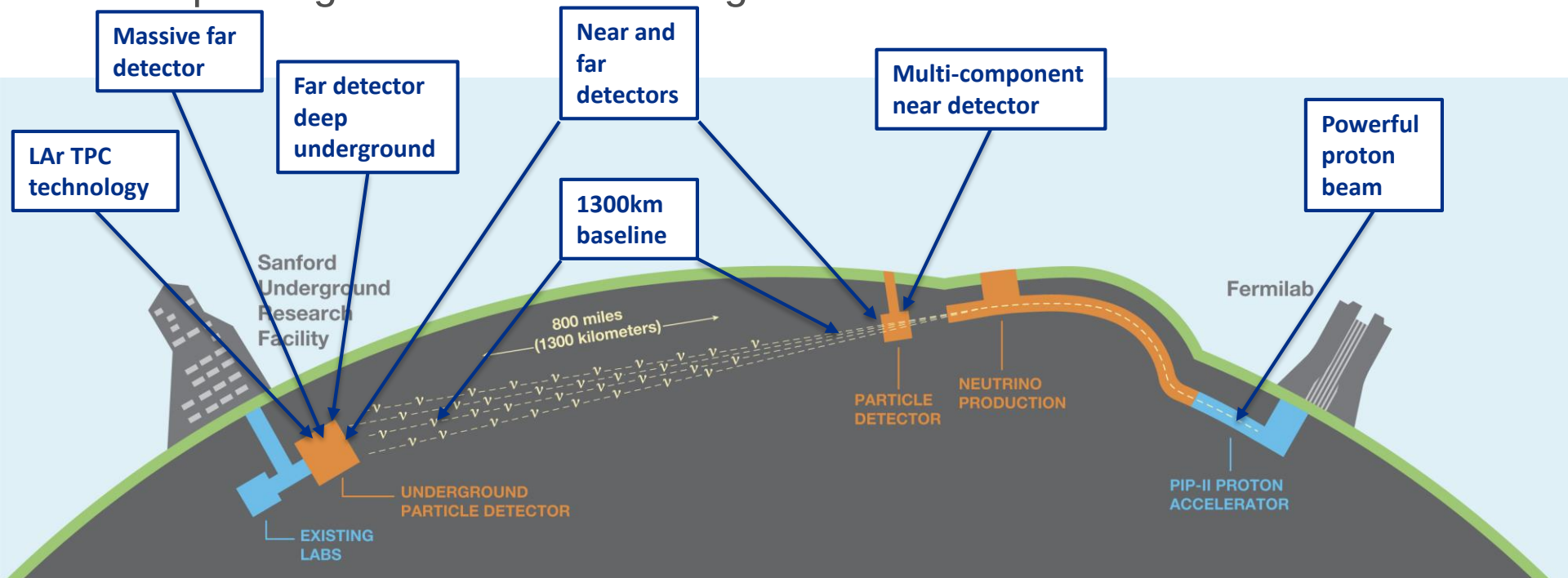
2014 P5 Report Requires ….

"The minimum requirements to proceed are the identified capability to reach an exposure of at least ***120 kt·MW·year*** *by the* ***2035*** *time frame, the far detector* ***situated underground*** *with cavern space for expansion to at least 40 kt* ***LAr*** *fiducial volume, and* ***1.2 MW beam power*** *upgradeable to multi-megawatt power. The experiment should have the demonstrated capability to search for* ***supernova neutrino (SN) bursts*** *and for* ***proton decay****, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime."* **P5 Report**

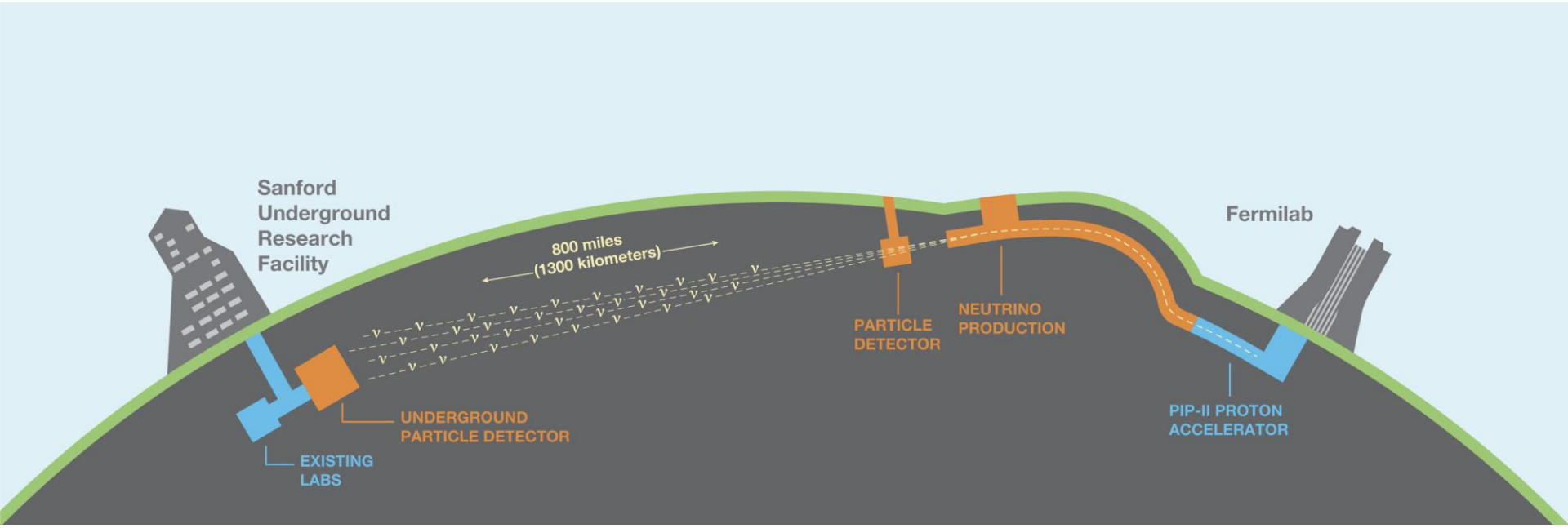
PIP-II

PIP-II / LBNF / DUNE Delivers….

- Powerful proton beams (**PIP-II**)
  - 1.2 MW upgradable to multi-MW (2.4 MW Phase 2) to enable world's most intense neutrino beam with wideband capability
- Dual-site detector facilities (**LBNF**)
  - Deep underground caverns (1.5 km) to support 2 x 17 kt liquid argon volume from day one, expandable to 4 x 17 kt
  - A long baseline (1300 km) neutrino beam
- Deep Underground Neutrino Experiment (**DUNE**)
  - Liquid Argon TPCs – the next-generation neutrino detector



The Long-Baseline Neutrino Facility (LBNF) supporting the international Deep Underground Neutrino Experiment (DUNE)



"The LBNF/DUNE project will be the first internationally conceived, constructed, and operated mega-science project hosted by the Department of Energy in the United States" - DOE

LBNF and DUNE bring the world together to discover new neutrino properties, just as CERN brought the world together to discover the Higgs

Define: Two US Projects & One Global Experiment

Facilities

- LBNF/US-DUNE: a ‘DOE project’ with international contributions through partnerships
- PIP-II: a ‘DOE project’ with international contributions through partnerships

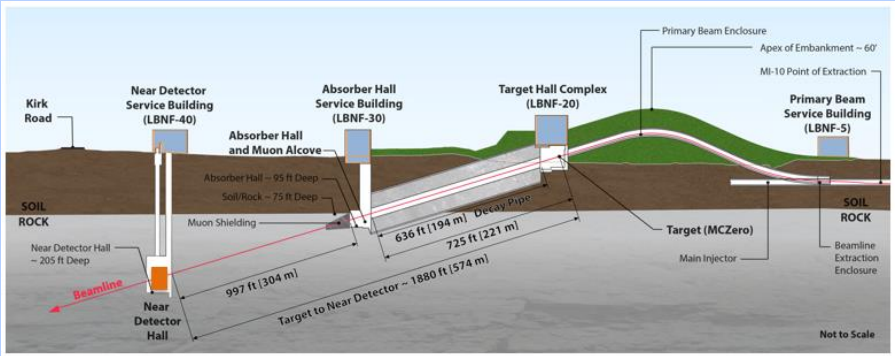
Experiment

- DUNE: an ‘international project’ with contributions from DOE and international partners

Long-Baseline Neutrino Facility (LBNF)

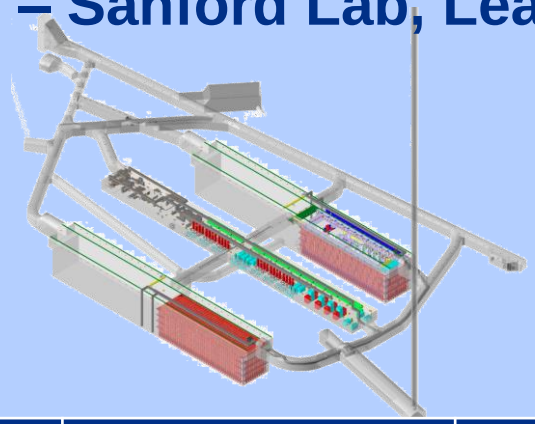
LBNF Project Scope and Future Capability

Near Site – Batavia, IL



Near Site Component	Project Scope	Future Capability
Primary and Neutrino Beamline	- Primary p-beam @ 60-120GeV extracted from MI - 1.2MW beam power, upgradeable to 2.4 MW	2.4MW capable, with new targets, horns, add'l select cooling and shielding
Conventional Facilities	- Four surface support buildings - Near Detector Hall	In project scope
DUNE ND	Prioritized Day One Components	Full ND Reference Design

Far Site – Sanford Lab, Lead, SD



Far Site Component	Project Scope	Future Capability
Conventional Facilities	- Surface & u/g infrastructure, utilities - Two caverns for detectors - Central utility cavern	In project scope
Cryostat; cryogenics	Two modules; LN2 refrig. LAr purification / recirc	Two addn'l LAr TPC detectors and supporting Infrastructure
Argon	35 ktons	
DUNE FD	Two detectors	

LBNF Far Site: Status

1. Sanford Lab Reliability Projects
- Ross shaft rehab
- Hoist motor rebuilds, more…

In Execution

2. Pre-Exc Const
- Rock disposal systems
- Ross headframe upgrade, more…

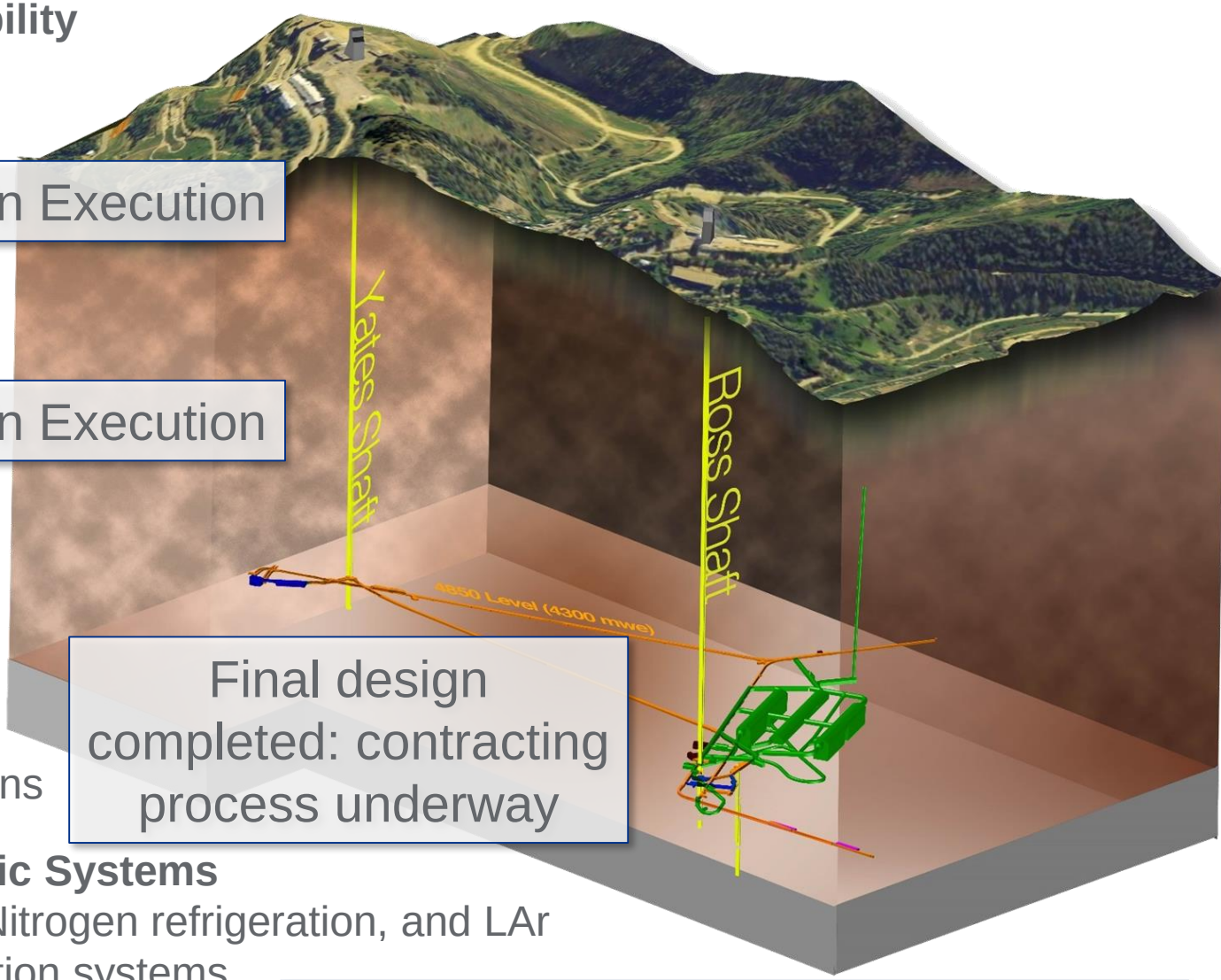
In Execution

3. Exc & Surface Construction
Brow/Drifts/Utilities/ Surface building/Caverns

Final design completed: contracting process underway

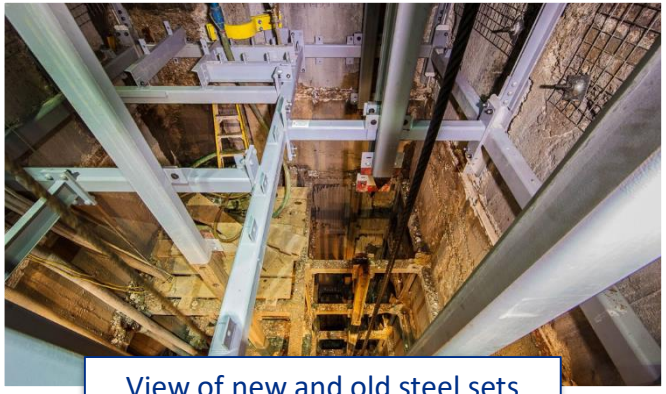
4. Cryostats/Cryogenic Systems
Membrane cryostats, Nitrogen refrigeration, and LAr circulation and purification systems

@ various states of design/acquisition



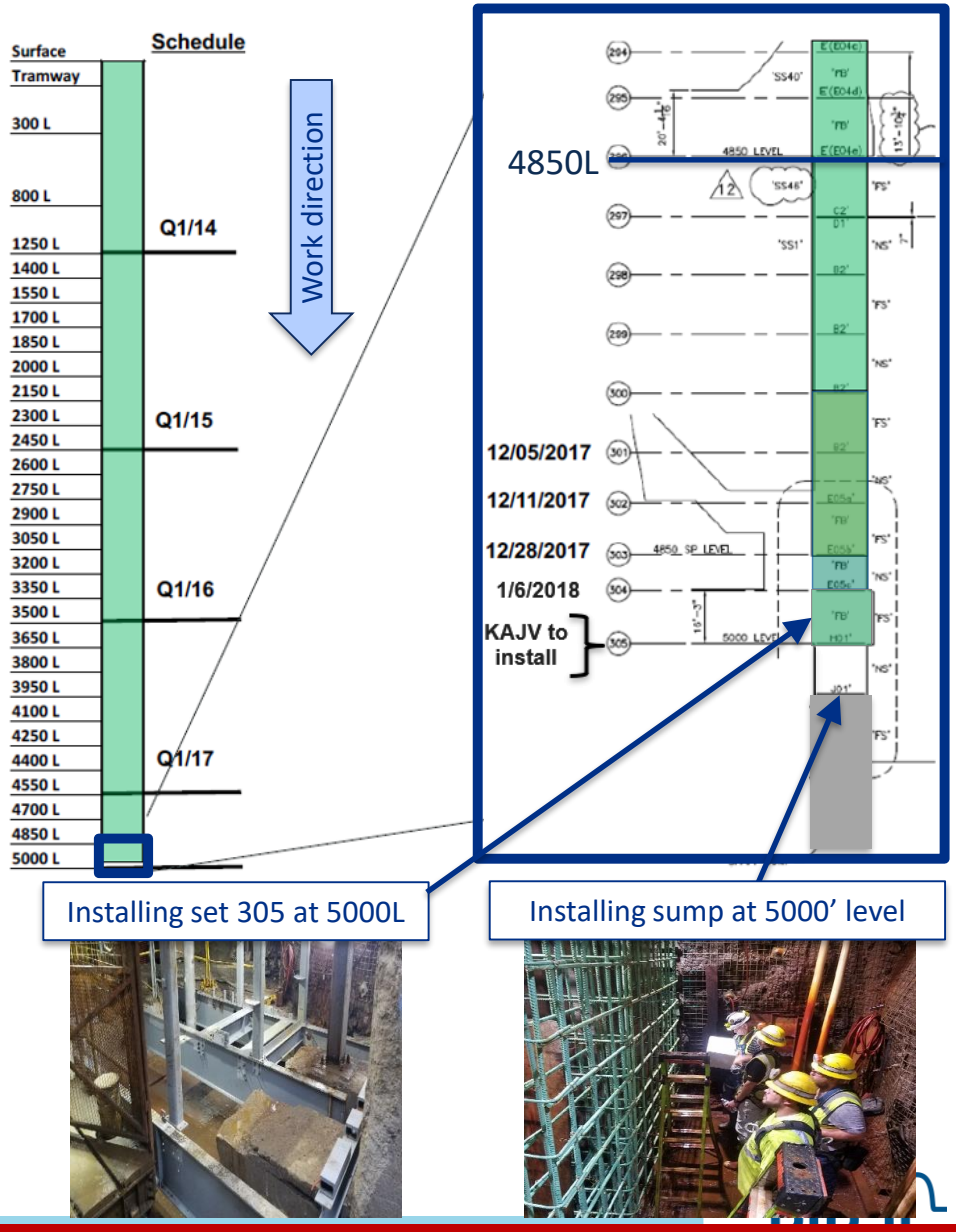
Key Reliability Project – Ross Shaft Rehabilitation

- Earlier this month, have completed installation of all 305 steel sets.
- Shaft is now **fully operational** from Ross headframe to 5000L @ 500 fpm.



View of new and old steel sets

New skips to move rock up shaft



Installing set 305 at 5000L

Installing sump at 5000' level

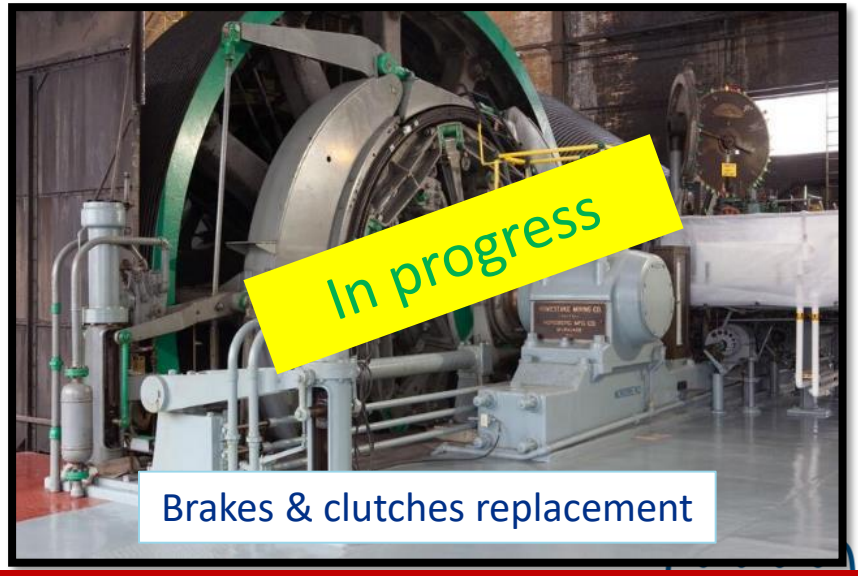
Fully Operational Ross shaft to support LBNF/DUNE

Other LBNF reliability projects: all under contract

Oro Hondo fan VFD replacement

Refuge chamber capacity increase

Hoist motor rehabilitation

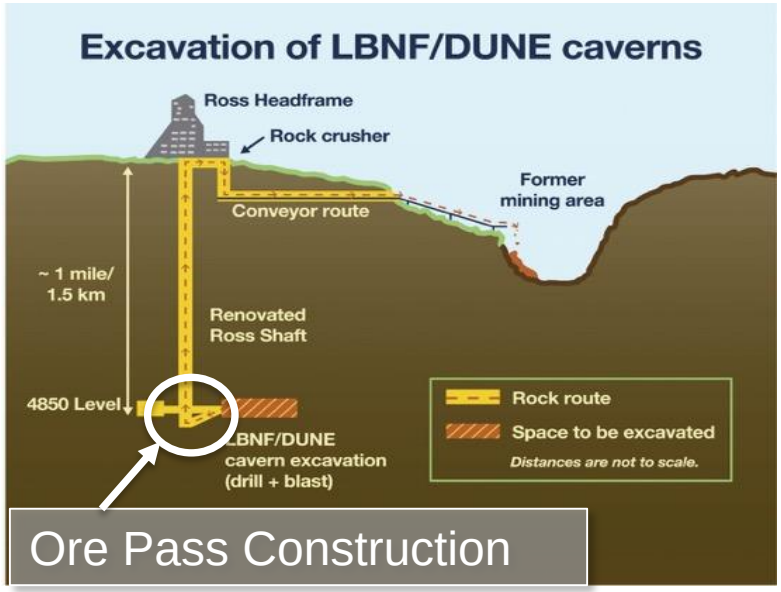


Brakes & clutches replacement

All projects on track to be completed prior to start of excavation

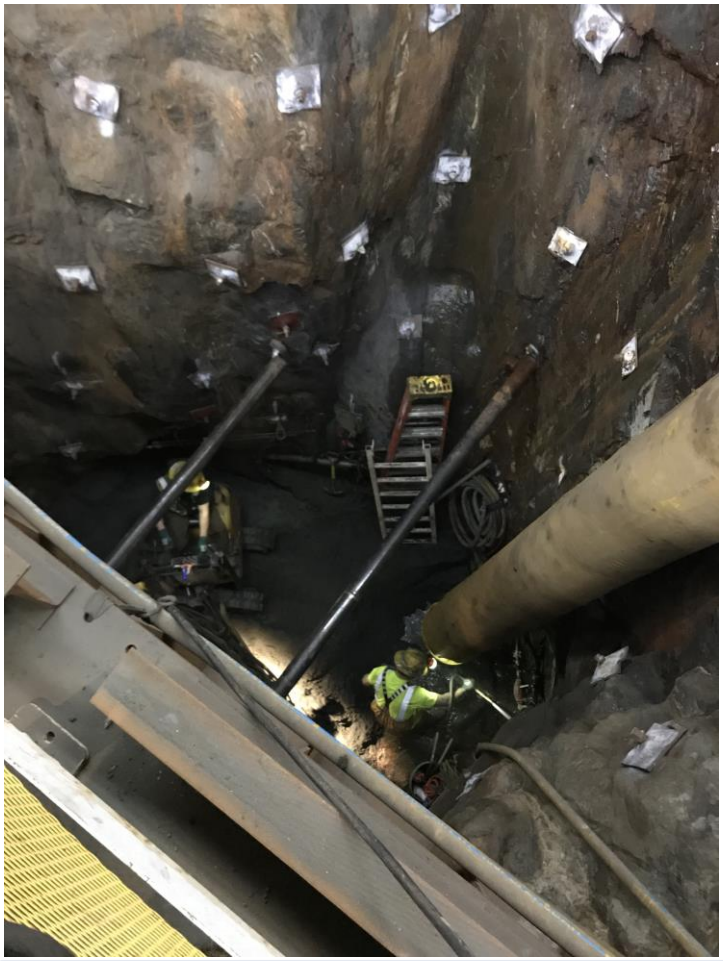
Pre-Excavation Construction Progress – 1 of 5

All work necessary to move ~800,000 tons of excavated rock to the surface, crush it, and transport it to the Open Cut in Lead, SD.



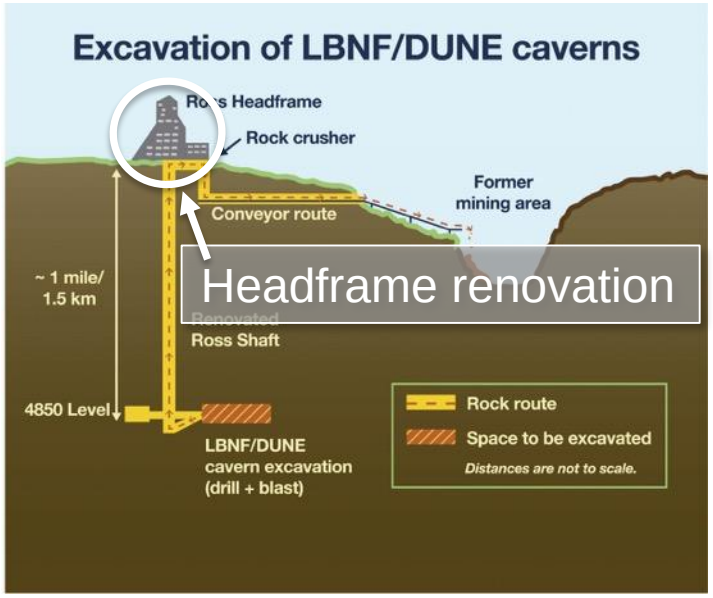
Ore Pass Construction

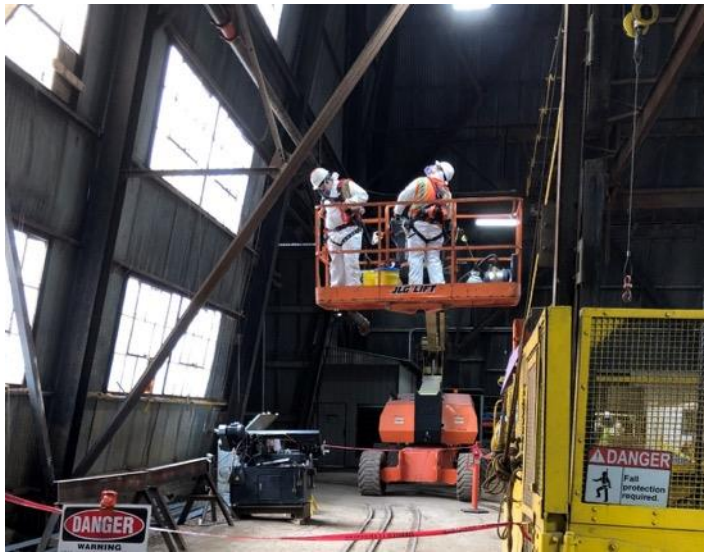
Staging equipment at 4850L

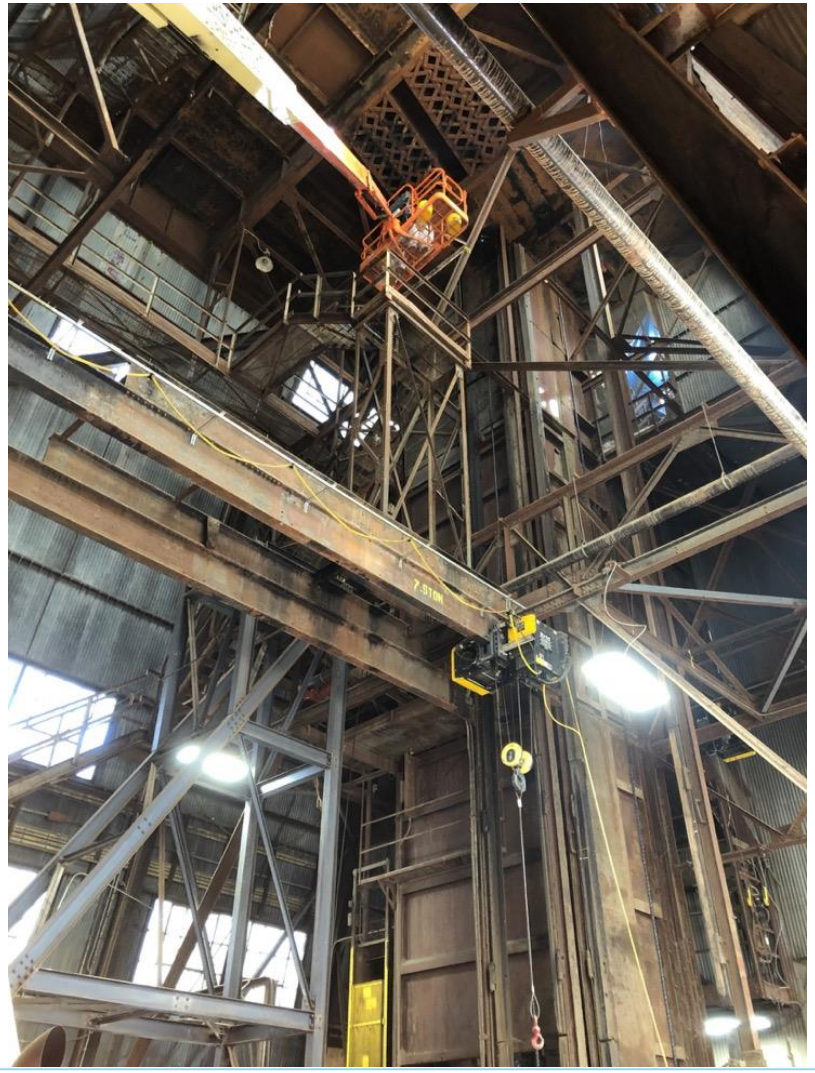


Removing muck from one of two ore passes that will load skips to move rock to surface

Pre-Excavation Construction Progress – 2 of 5



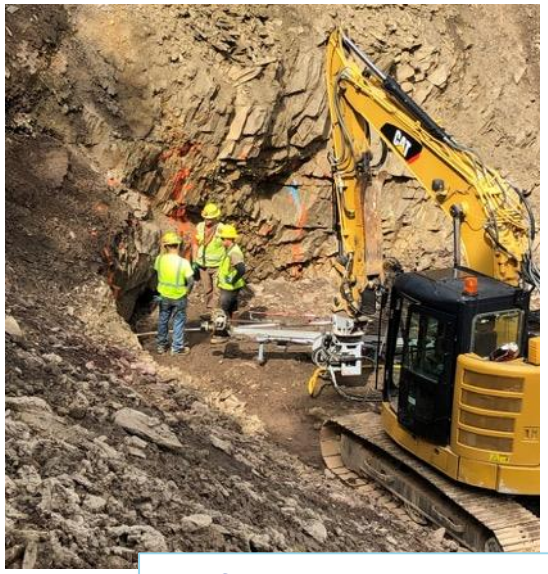




Reinforcing the structural steel in headframe to support the Ross Shaft cages and skips to meet modern codes

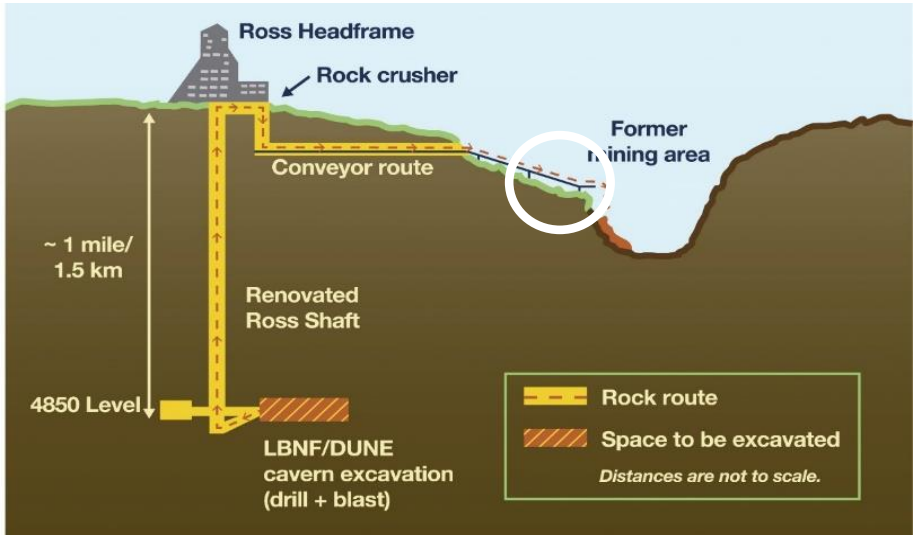
Pre-Excavation Construction Progress – 3 of 5

Renovating and making safe tramway to support rock transport conveyor



Refurbishing the 2400’ long tramway that the 4100’ rock conveyor will be installed in to move rock to the open cut in downtown Lead, SD

Pre-Excavation Construction Progress – 4 of 5



Clearing path for elevated conveyor to open cut

Rerouting power underground so elevated conveyor can cross state highway

PIP-II

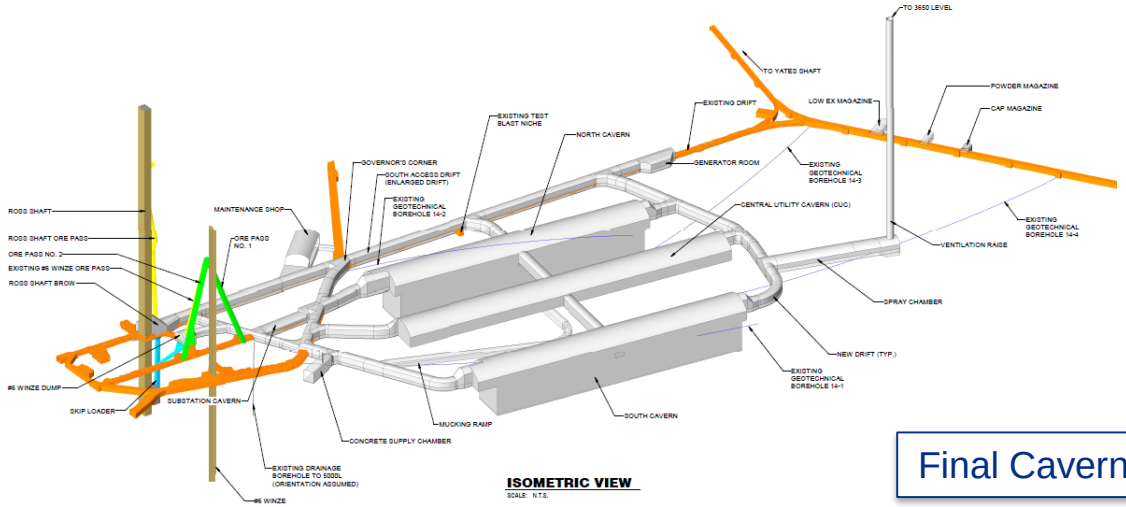
Pre-Excavation Construction Progress – 5 of 5

Upgrading power to Ross complex at SURF to support LBNF/DUNE systems: new 20 MVA transformer and 12.5 kV power feeds

Pre-excavation work proceeding on cost and on schedule, scheduled to be completed Dec 2020

Excavation/Buildings & Site Infrastructure Constr'n

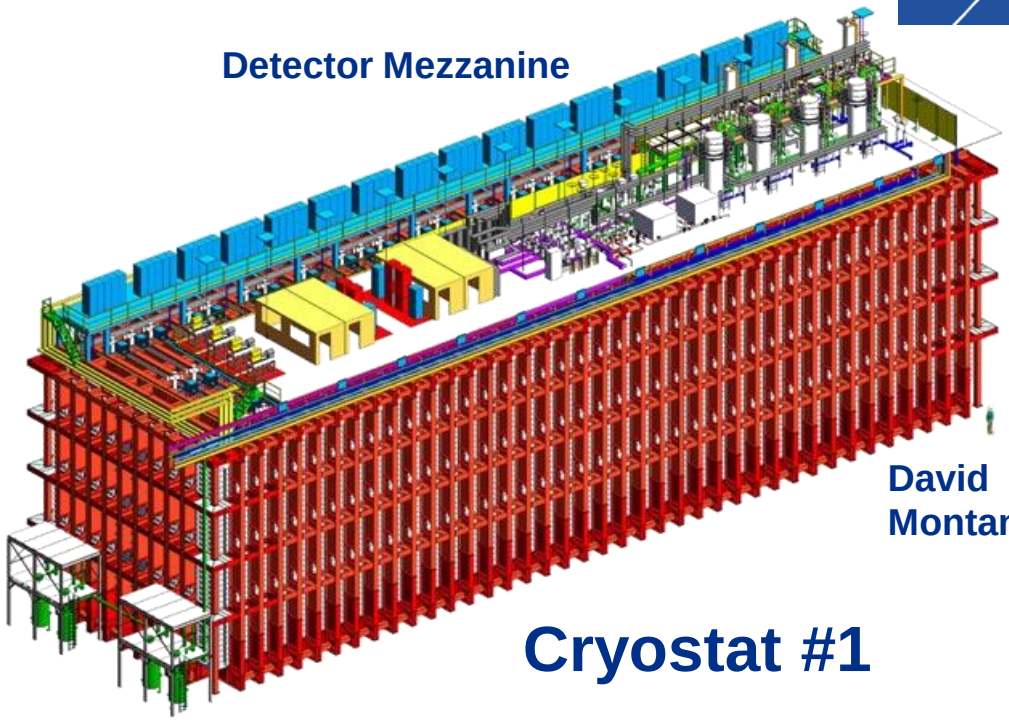
- Final design completed in May 2019.
  - 316,806 in-situ cubic yards of rock (~800,000 tons) to be excavated
  - 185,686 square feet (4.3 acres) finished floor in caverns
- RFP for excavation work (~75% of remaining CF work) was put out for bids by CM/GC contractor (Kiewit-Alberici JV) in Oct
- Bids to be in hand in early February 2020, before CD-2 review; award planned July 2020 – major milestone



Final Cavern layout and design

Cryostat and cryogenics

- **Cryostat**
  - First cryostat engineered and provided by CERN
  - Warm structure final design completed in Nov 2018; informed and proven by protoDUNE experience.
  - Membrane design by GTT completed in Apr 2019



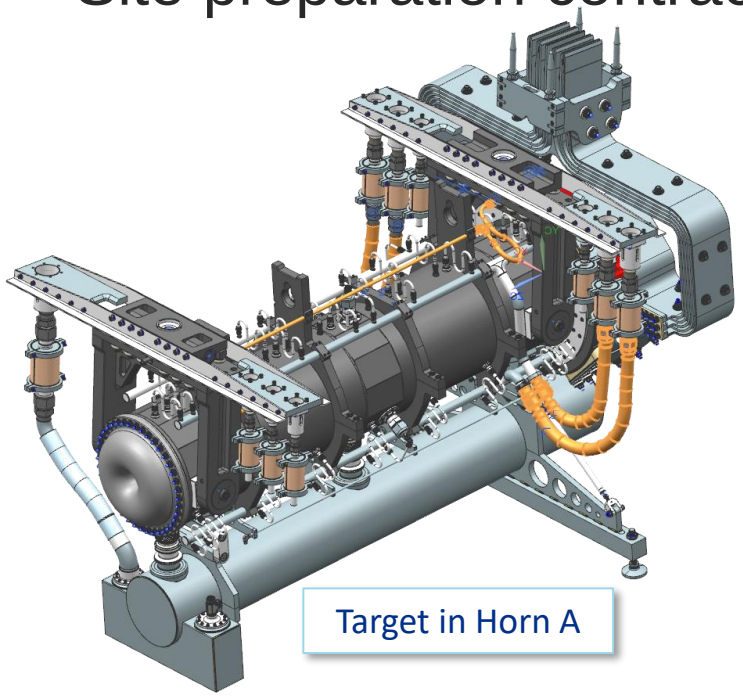
Cryostat #1

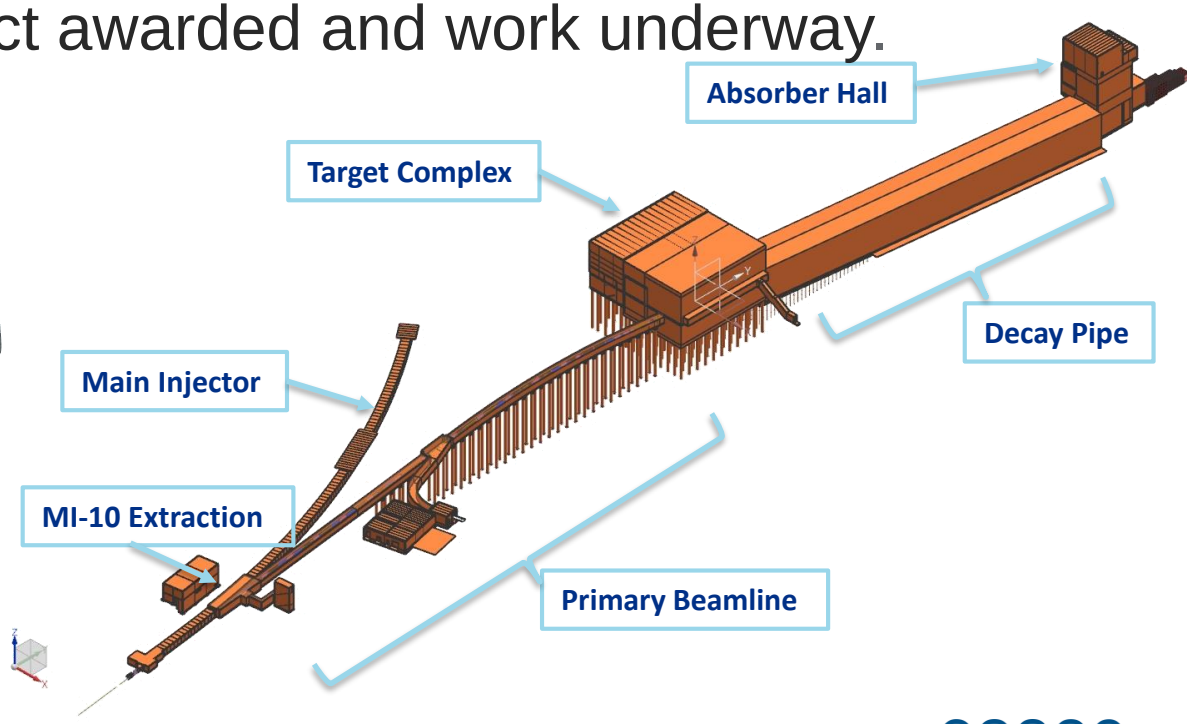
- **Nitrogen System**
  - To be procured via contract, required in September 2022.
- **Argon Cryogenic Systems**
  - Advancing designs and working on in-kind contributions.

ProtoDUNE success provides validation of detector technology and plan for cryostat and cryogenic systems. Partnership with CERN essential for the success of LBNF.

LBNF Near Site (NS)

- Neutrino beamline target concept finalized working with RAL-UK
- NS CF: Key milestone reached on Aug 30, with >$25M A/E design contract awarded; preliminary design complete by Mar 2020
- Site preparation contract awarded and work underway.





LBNF Near Site Groundbreaking – Nov 14, 2019

International In-Kind Contributions for LBNF

System	Partner
Cryostat #1 + cryo mezzanine supports/platform Surface Receiving Facilities (2 tanks)	
Target	
Magnets – Dipoles & Quadrupoles	
Condensers System #1	

Discussions underway with several other International Partners

LBNF international contributions through partnerships: committed 38 %; discussion underway 37 %; to begin discussion 25%

LBNF/DUNE Working Schedule

- **Cavern construction**:
  - Turn over first (north) detector cavern in October 2022 followed by construction of first cryostat (approximately one year for warm structure then one year for membrane installation).
  - Second (south) detector cavern turn over in July 2023, followed by construction of second cryostat (warm structure + membrane).

- **Detector installation**:
  - Start of Detector 1 Installation in north cavern: August 2024. Detector construction approximately one year, followed by approximately one year to fill with LAr.
  - Start of Detector 2 Installation in south cavern: August 2025.

- **Dynamic process, evolving quickly, with many variables:**
  - Will obtain final construction schedule from contractor in Feb 2020.
  - Working schedule will be updated as part of final U.S. DOE funding profile and project baselining process in 2020.

LBNF/DUNE Cost

- All DOE project costs with updated risk and contingency analyses – sum to ~$2.5B.
  - ➔ Within June 2019 HEP project guidance of $2.6B.

- Next steps toward CD-2:
  - Continue to refine and reduce costs and schedule – multiple Value Engineering analyses underway
  - Fermilab is continuing, under DOE leadership and guidance, to close LBNF international in-kind gaps.

Proton Improvement Plan – II (PIP-II)

P5 Report defines PIP-II Mission

PIP-II *will enable the world's most intense beam of neutrinos to the international LBNF/DUNE project, and a broad physics research program, powering new discoveries for decades to come*.

PIP-II linac will provide:

Beam Power

- Meeting the needs for the start of DUNE (1.2 MW proton beam)
- Upgradeable to multi-MW capability

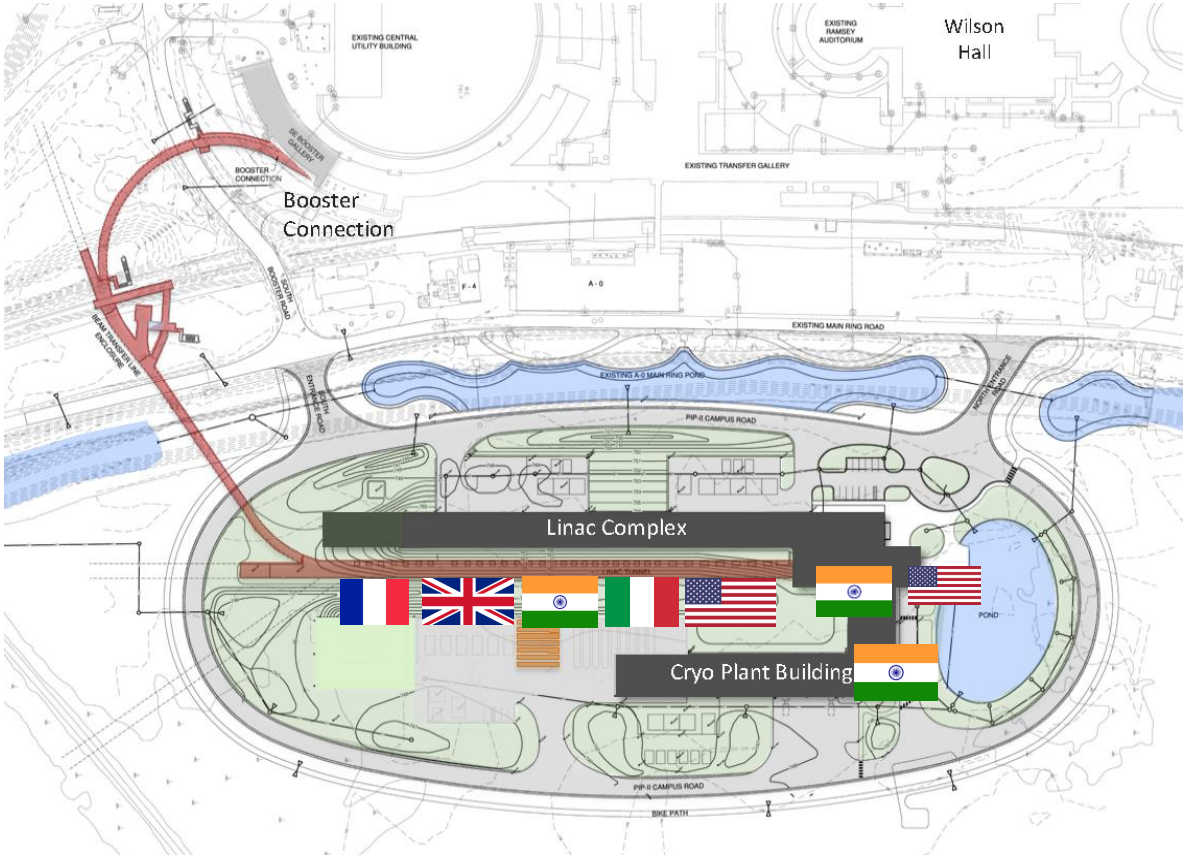
Flexibility

- Compatible with CW-operations which greatly increases the linac output
- Customized beams for specific science needs
- High-power beam to multiple users simultaneously

Reliability

- Fully modernizing the front-end of the Fermilab accelerator complex

PIP-II Scope Overview



800 MeV H− linac
- Warm Front End
- SRF section

Linac-to-Booster transfer line
- 3-way beam split

Upgraded Booster
- 20 Hz, 800 MeV injection
- New injection area

Upgraded Recycler & Main Injector
- RF in both rings

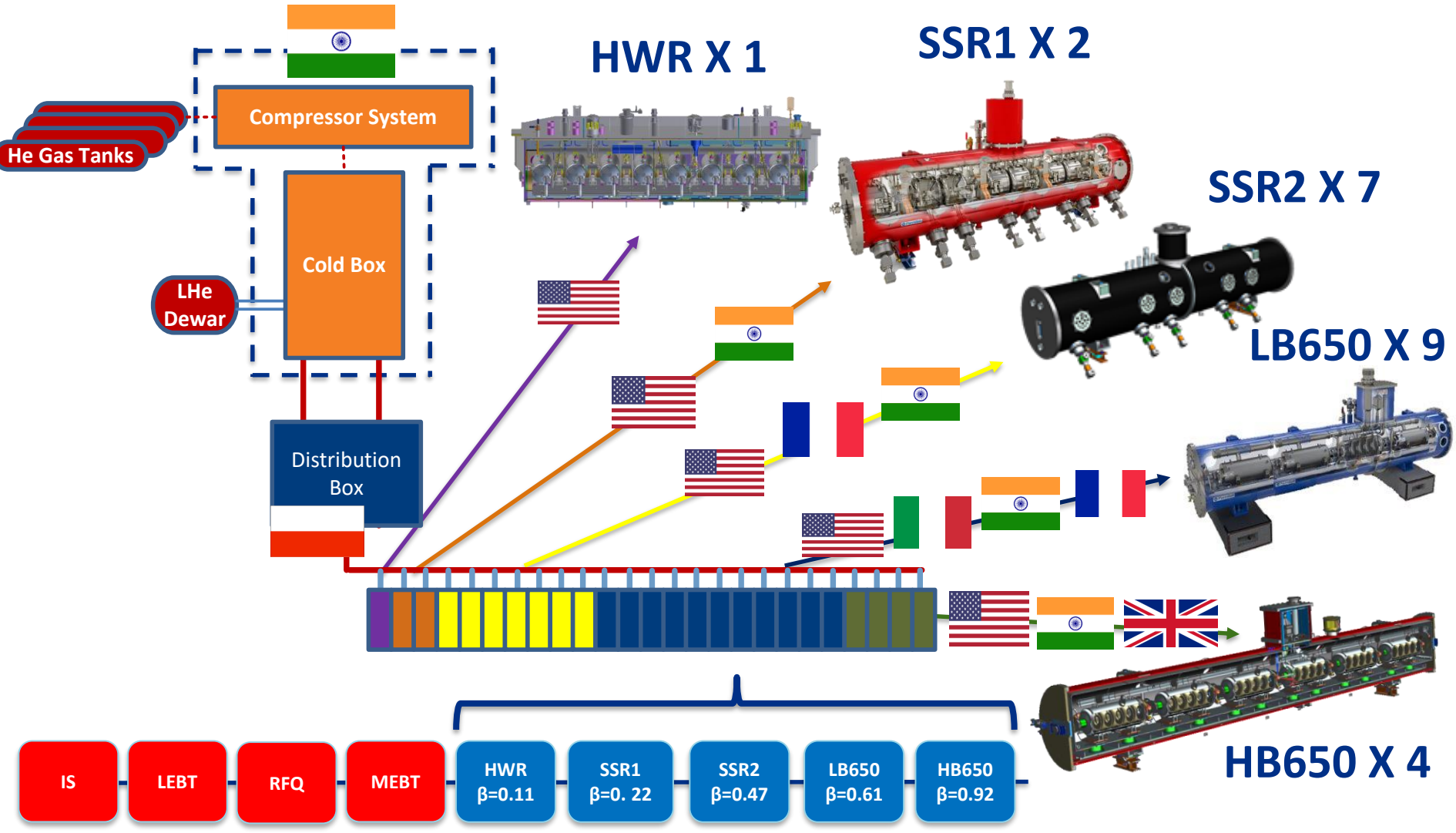
Conventional facilities
- Site preparation
- Cryoplant Building
- Linac Complex
- Booster Connection

The PIP-II scope enables the accelerator complex to reach 1.2 MW proton beam on LBNF target.

PIP-II Injector Test Facility (PIP2IT)

PIP-II Injector Test Facility retires a significant number of technical risks – complete in FY20

PIP-II SRF Linac & Areas of International Interest



PIP-II is the first U.S. accelerator project to be built with major international contributions

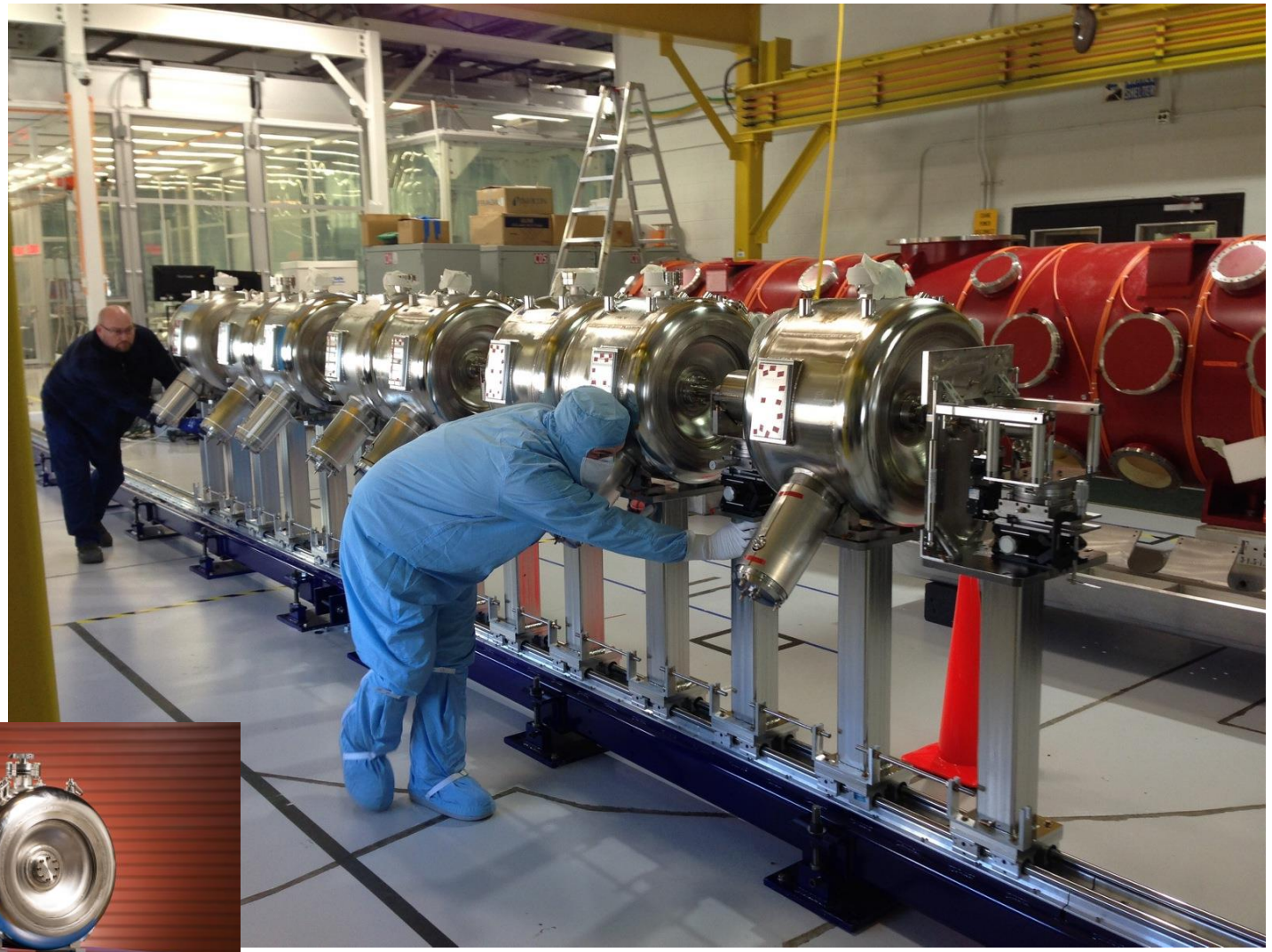
Half-Wave Resonator Cryomodule Fabrication by Argonne NATIONAL LABORATORY

HWR cryomodule arrived at Fermilab 16-Aug-2019.

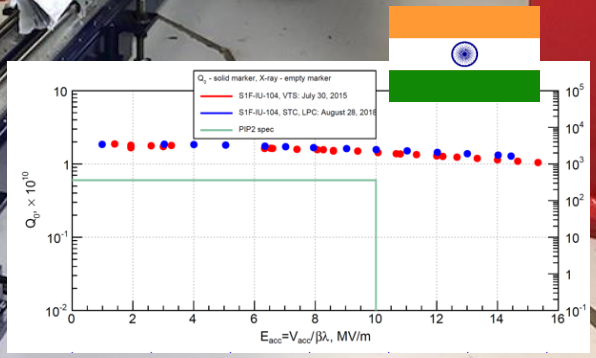
HWR Transported to PIP2IT

HWR Installed at PIP2IT

PIP-II leverages FNAL leadership in SRF technology – pushes state of the art in high gradient, high Qo, CW designs



SSR1 Cold Mass Assembly Complete – Inserted in cryostat




Caldwell
Scheduled to be transported to PIP2IT November 2019

Conventional Facilities

Site Clearing Complete

Under special authorization
prior to CD-2/3a granted by DOE

Cryogenics Plant Building

Design Complete;
Ready for Procurement

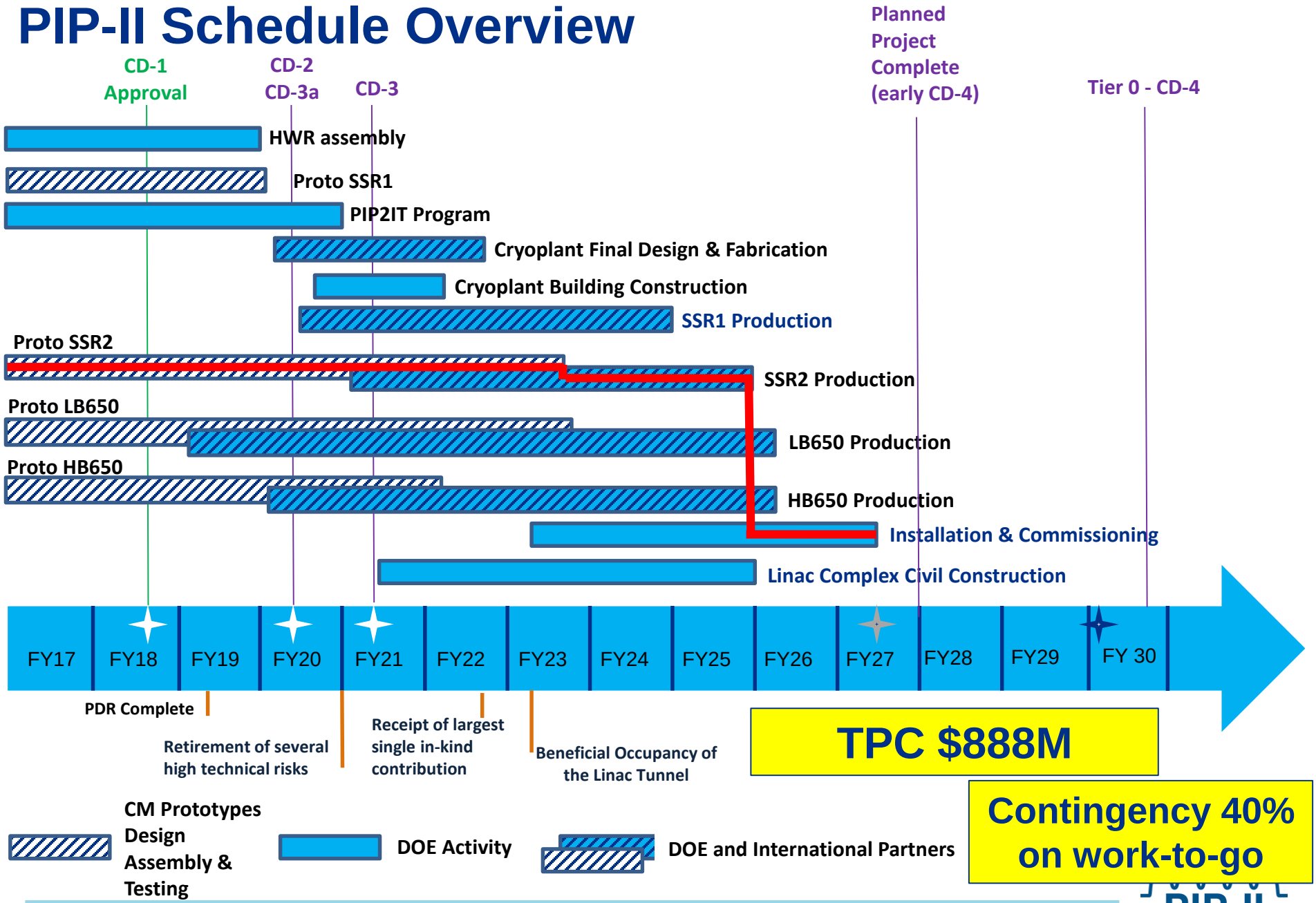
Linac Complex

Conceptual Design update underway, basis of final design

PIP-II Groundbreaking – 15 March 2019

Groundbreaking for PIP-II drew the governor of Illinois, both Illinois senators, four members of Congress from Illinois, senior leadership from DOE and the University of Chicago, and many international partners.

PIP-II Schedule Overview



International Partnerships

PIP-II International Partnership Principles

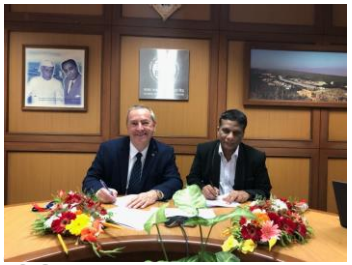
- Pursue partnerships where broader interests are aligned, specifically technology (SRF) and science (DUNE)
- Bring international institutions in early as Partners
  - Share project planning, R&D to provide joint sense of ownership
- Integrate Partners in PIP-II project management principles
- Establish International Agreements
- Establish a multi-layered governance structure
  - International Neutrino Council; PIP-II Laboratory Directors Council; PIP-II Project Executive Board

PIP-II International Partners, Expertise and Capabilities

India, Department of Atomic Energy (DAE) (started 2009)

BARC, RRCAT, VECC; also IUAC

Substantial engineering/manufacturing experience
Superconducting magnets for LHC; 2 GeV synch light source



Italy, INFN (started 2016)

Internationally recognized leader in superconducting RF technologies
SRF cavity and cryomodule fabrication for XFEL; SRF cavities for ESS

UK, UKRI (started 2017)

Substantial engineering and manufacturing experience
Construction, operation of synch light & neutron sources
SRF cavity processing and testing for ESS

France, CEA, CNRS/IN2P3 (started 2017)

Internationally recognized leader in large-scale CM assembly
CM assembly for European XFEL and ESS
SSR2 cavities and couplers for ESS

Poland, WUST (started 2018)

Substantial engineering and manufacturing experience
CDS, LLRF, QC for XFEL and ESS

PIP-II Project benefits from world-leading expertise, facilities.
"Timing is perfect"

International In-Kind Contributions for PIP-II

Subsystem (count)	Cavities	Cryomodules	RF & Cryo Systems
HWR (1)			
SSR1 (2)			
SSR2 (7)	 	 	
LB650 (11)	 		
HB650 (4)	 	 	
Cryoplant (1)			
CDS			

International partnerships are essential for the success of the PIP-II Project. No gaps in international deliverables for PIP-II

DOE Expectations for International Contributions to Office of Science (SC) Projects

- DOE **requires legally-binding agreements** in order to accept hardware contribution from a foreign partner
  - Typically Project Annexes or I-CRADAs to existing Implementing Agreements of Science & Technology (S&T) agreements
  - If legally-binding agreement is not in place by CD-2, a non-binding Statement of Interest (SOI) may be developed

- DOE **expects non-binding planning documents*** in order to baseline project
  - PPDs detail the partner scope, list of deliverables (components and documents), milestones, management processes, organizational structures, governance
  - Required by CD-2 review and bilaterally signed in advance of ESAAB

*Project Planning Documents (PPDs)

PIP-II Status Summary, Near Term Outlook

- **Director's CD-2/3a Review held July 30 – Aug 1**
  - "Excellent progress across the project …"
- **CD-2/3a IPR is scheduled Jan 28-30, 2020**
  - ICE onsite visit Feb 4-7, 2020
- **Strong technical progress, challenges encountered**
  - On track for PIP2IT beam commissioning in April 2020
  - Prototyping of cryomodules, other technical systems underway
  - Conventional Facilities site work has begun; cryoplant building design complete
- **Continue to strengthen our international partnerships**

Looking forward: the road to baselining LBNF/DUNE-US/PIP-II

PIP-II

- PIP-II CD-2 is scheduled for January 28-30 2020

LBNF

- Lock in LBNF/DUNE-US total project cost
- LBNF/DUNE-US CD-2 reviews in middle to late 2020
  - Allows PIP-II to pave the way as first DOE 413 project with significant international contributions and for LBNF to advance near site design maturity.
  - Continue to fill in international in-kind gaps
- It cements support from DOE & Congress

PIP-III

- P5 plan calls for 2.4 MW on target for neutrinos
- PIP-II gets us to 1.2 MW. Replace booster gets us to 2.4MW
- Forming a working group to assess science opportunities and technology choices
  - Co-chairs: Bob Tribble (BNL), Gianluigi Arduini (CERN)
  - Membership includes national and international experts in particle physics and accelerator technology
  - Launch WG in November
- Goal is submit white paper before Snowmass
- PIP-III schedule driven by need to meet P5 2.4 MW plan and to meet physics goals as early as possible

Summary

- Fermilab, along with its national and international Partners, is executing the P5 vision
  - LBNF/DUNE is the first internationally conceived, constructed, and operated mega-science project hosted by the Department of Energy in the United States
  - PIP-II is the “heart and soul” of Fermilab, critical to the success of the international neutrino program, and the first US accelerator project constructed with significant in-kind contributions
- While both projects face unprecedented challenges, progress has been strong on all fronts
  - Baselining PIP-II and LBNF/US-DUNE in 2020
- Through International partnerships, we are building a highly capable, world leading neutrino program, which secures US leadership in a key element of the global particle physics program

We are grateful for continuing strong support from DOE/SC, State Department, Congress, States of IL, SD, our International Partners

Many thanks to Chris Mossey and Elaine McCluskey for providing LBNF material and support.