Report on LBNF/DUNE-US Project Plan

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DUNE Co-spokesperson

Snowmass Summer Study - Seattle
18 July 2022

Outline

- Brief intro to LBNF/DUNE
- DUNE in the International Context
- DOE Critical Decision Process
- Status of CD Process for LBNF/DUNE-US
- Outcome of last week's Independent Project Review
- Summary and Outlook

4 specific 2014 P5 recommendations related to future accelerator neutrino program

CERN Jan 2020

FNAL May 2022

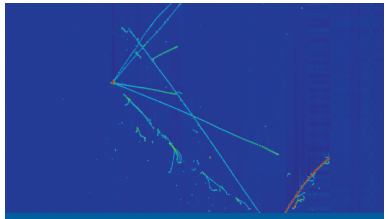
Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

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.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

The ICARUS detector was installed in its Fermilab research hall in 2018.

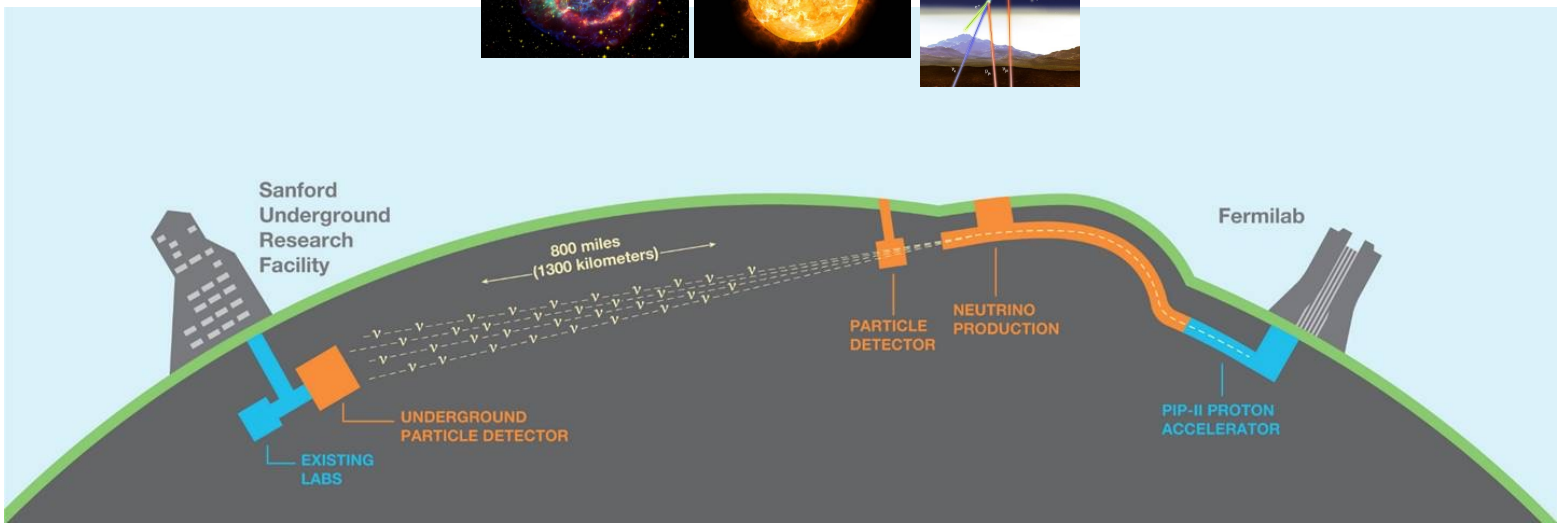


This image shows the particle tracks resulting from the interaction of a neutrino with liquid argon inside the MicroBooNE detector.

LBNF → Facility

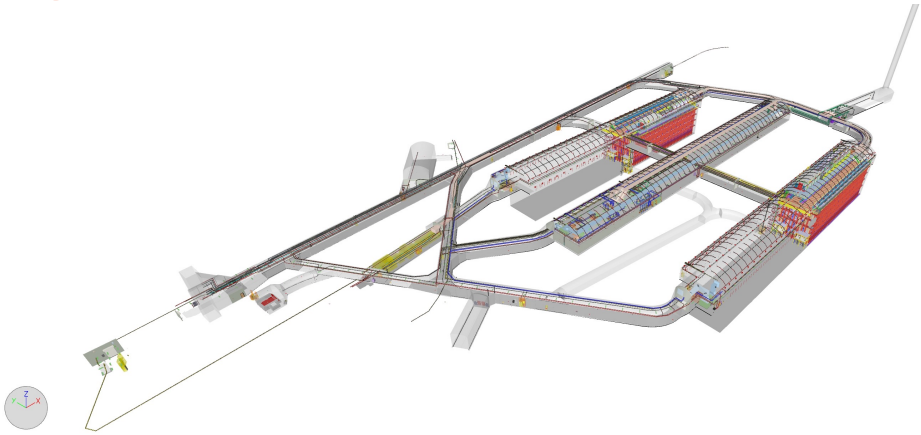
DUNE → Experiment

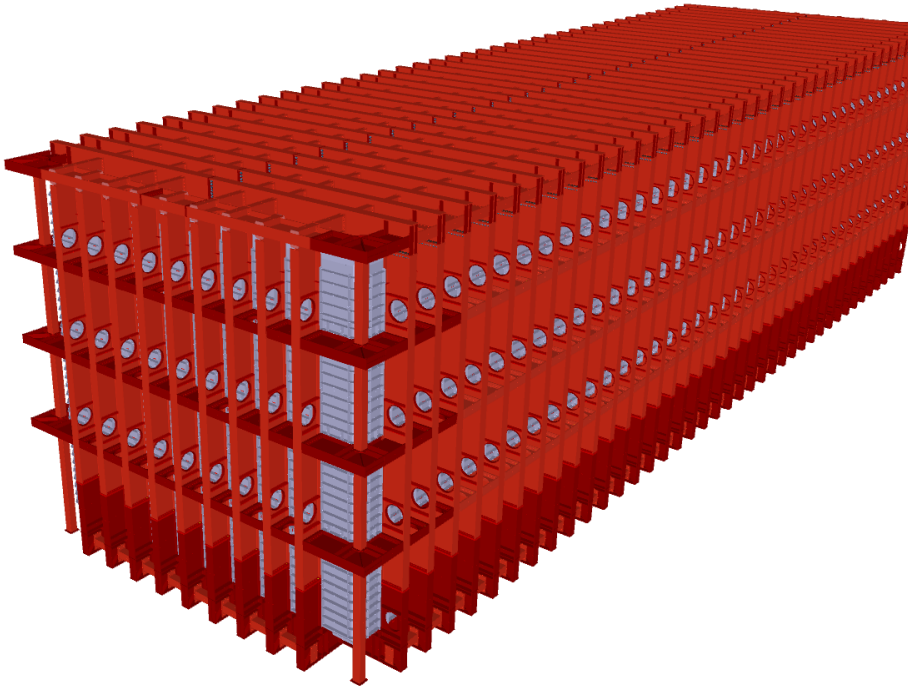
DUNE Physics Goals

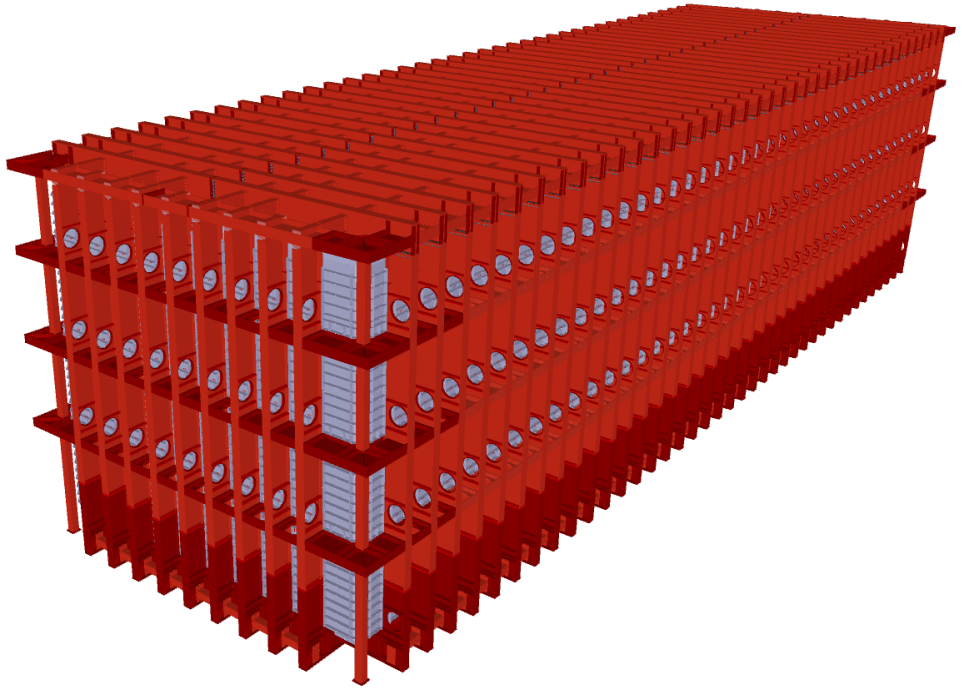


- Unambiguous, high precision measurements of Δm^2_{32}, δ_{CP}, $\sin^2\theta_{23}$, $\sin^2 2\theta_{13}$ in a single experiment
- Discovery sensitivity to CP violation, mass ordering, θ_{23} octant over a wide range of parameter values
- Sensitivity to MeV-scale neutrinos, such as from a galactic supernova burst
- Low backgrounds for sensitivity to BSM physics including baryon number violation

Two Cryostats for the facility



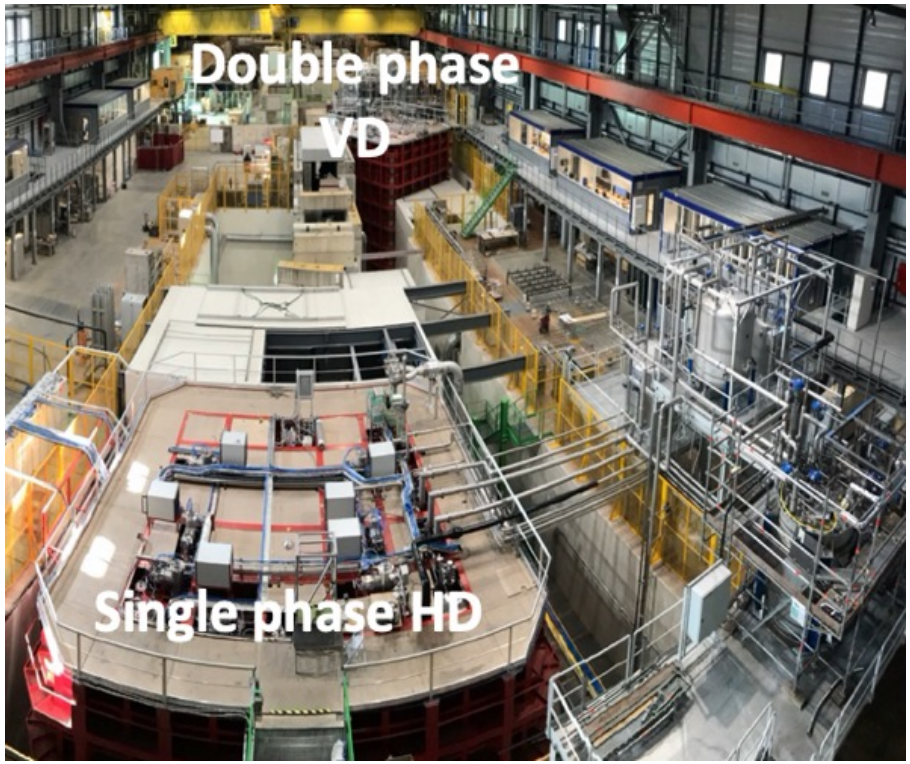




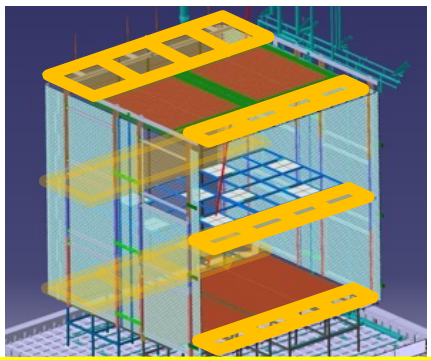
CERN Neutrino Platform

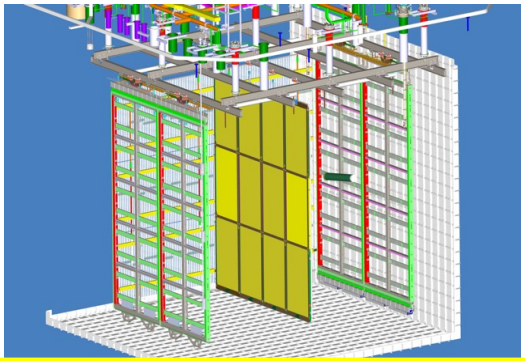
- Major contribution to the program from CERN
  - Enabled prototyping full scale components
  - Developed data acquisition
  - Collected data from cosmic rays and the charged particle beams

2017-2020



2021 SP - VD

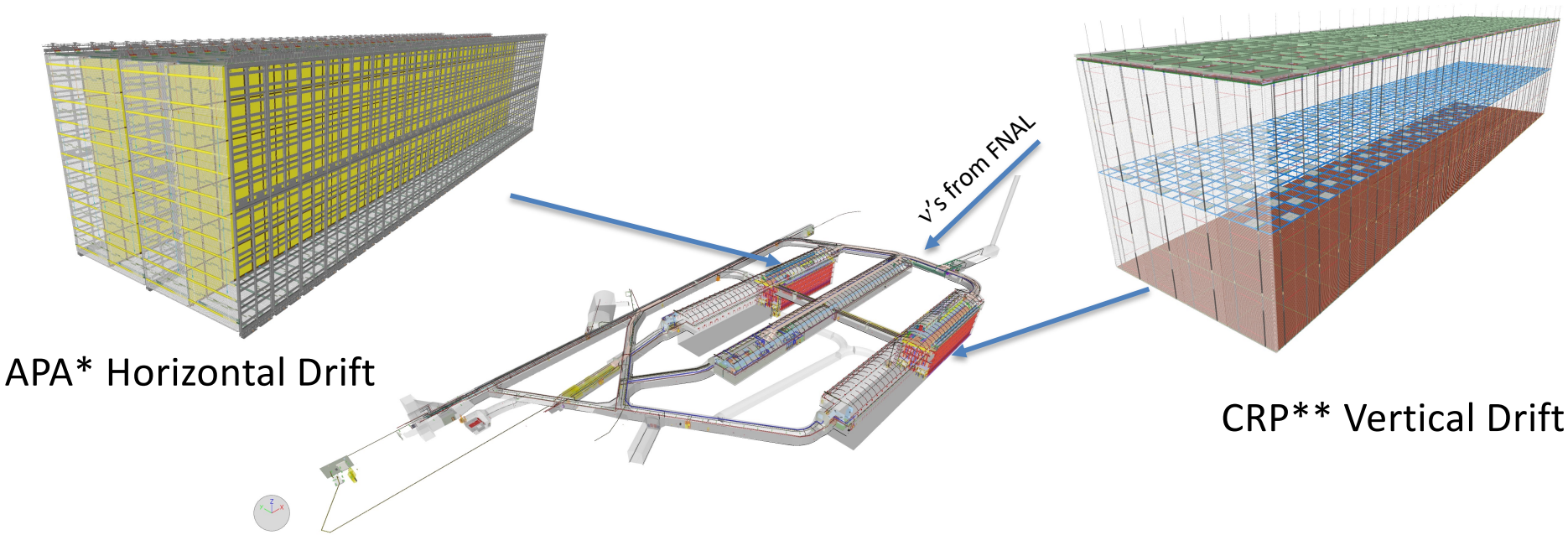




2022 - 2024 Full scale production quality modules

DUNE – Phase I

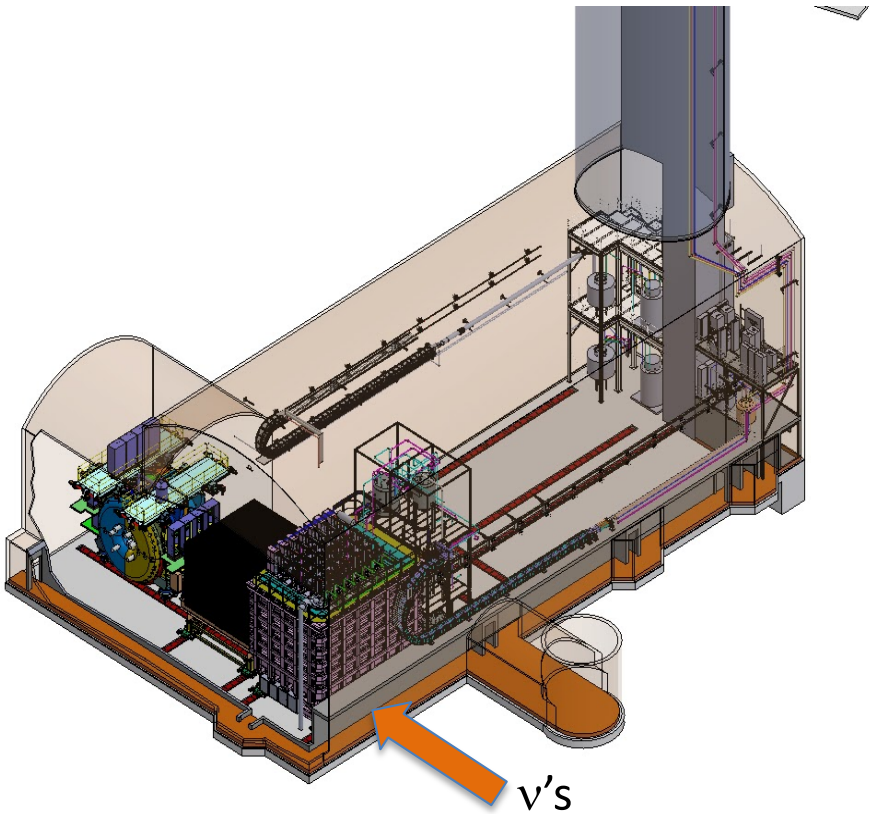
- LBNF will provide caverns for 4 detector modules at SURF
  - 1st detector to be installed in NE cavern has horizontal drift (like ICARUS and MicroBooNE)
  - 2nd detector will go into SE cavern and has vertical drift (capitalizing on elements of the dual phase development)



Note : DUNE Science begins when FD1 is filled and turned on and recording tracks

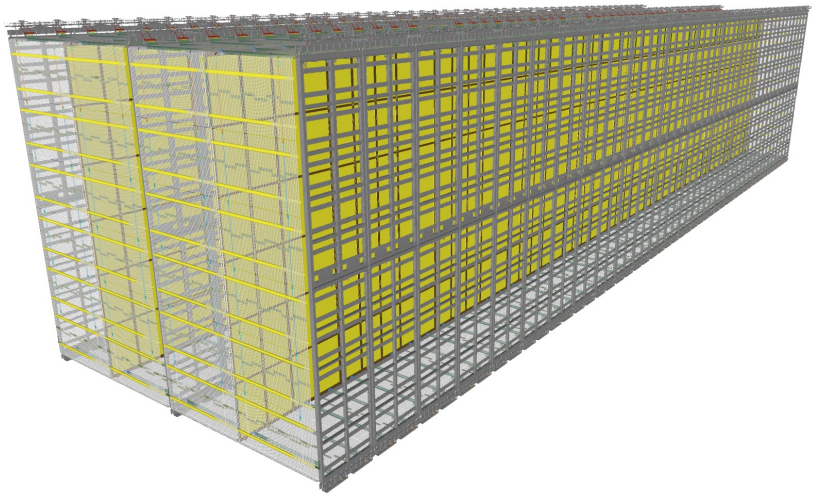
*Anode Plane Assemblies
**Charge Readout Planes

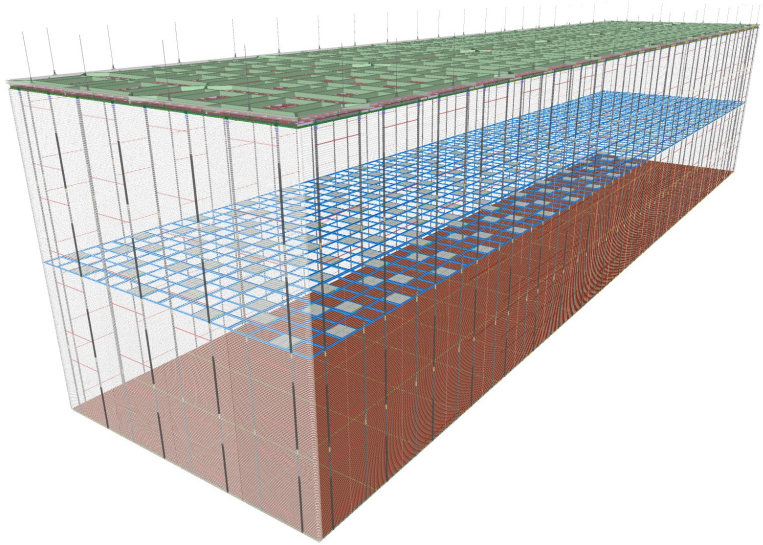
DUNE – Phase I



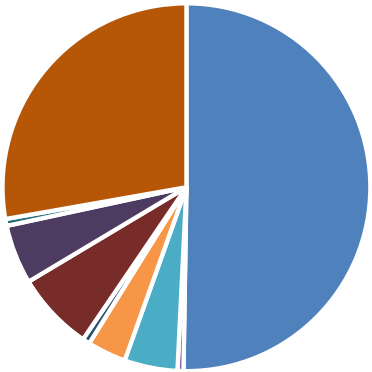
- Near Detector Complex houses a set of detectors that work in concert with each other to predict the far detector spectrum and monitor the beam stability.
- These include
  - A liquid argon TPC (ND-LAr) plus a Muon Spectrometer (TMS) ; these can move off-axis (PRISM system)
  - An on-axis detector (SAND) ; will make precision measurements of multiple channels of neutrino interactions, leading to more control of systematics ; monitors the beam stability when the ND-LAr+TMS are off-axis

Far Detector Partners

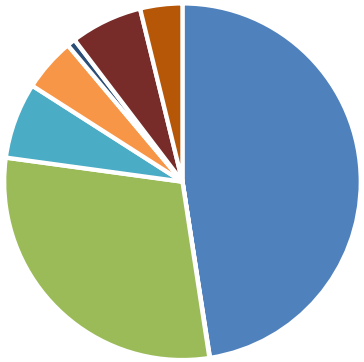




FD1 - Direct M&S



FD2 - Direct M&S



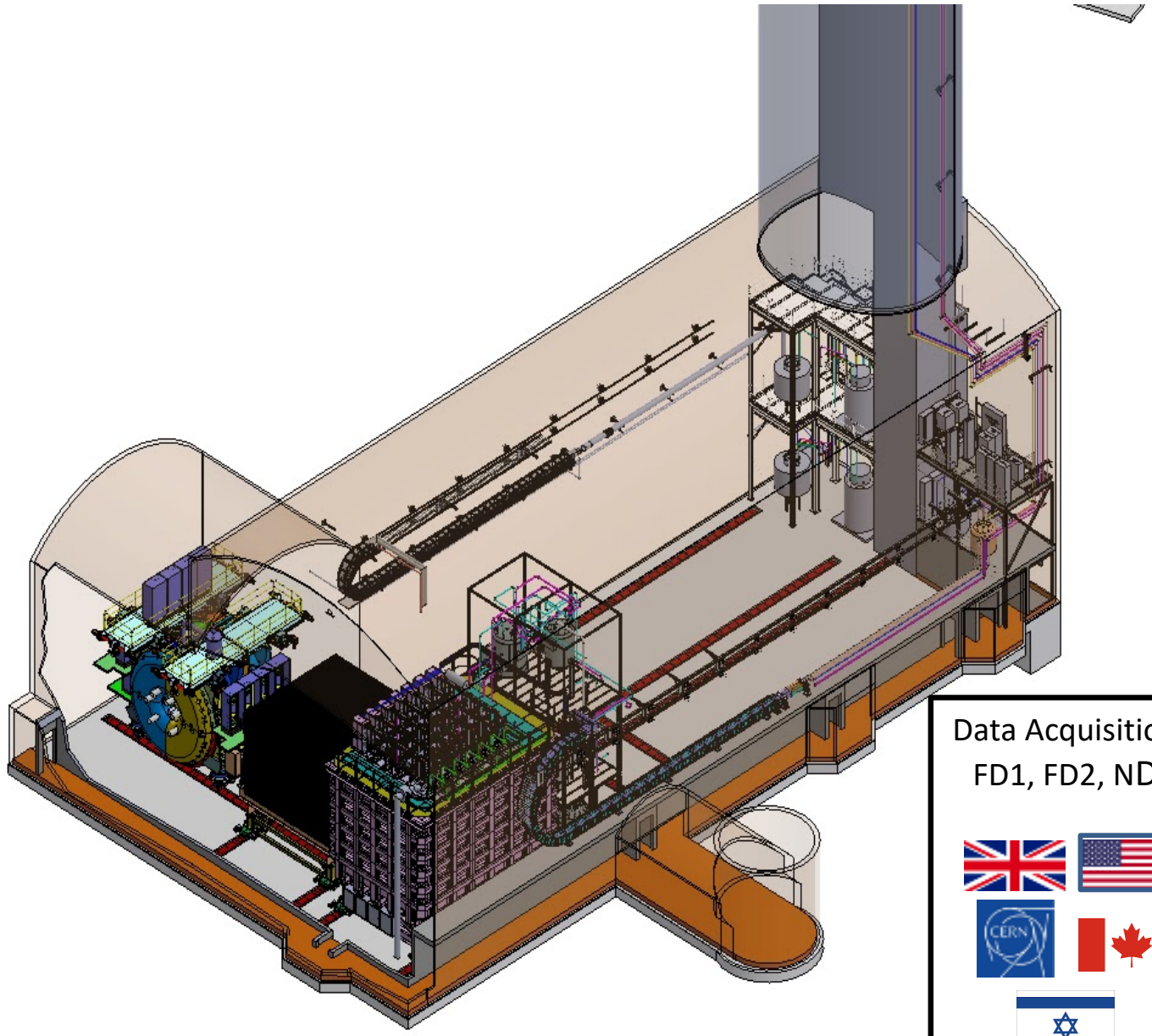
All scope defined in Consortia Annexes to Multi-institutional MOU

Near Detector Partners

SAND

TMS

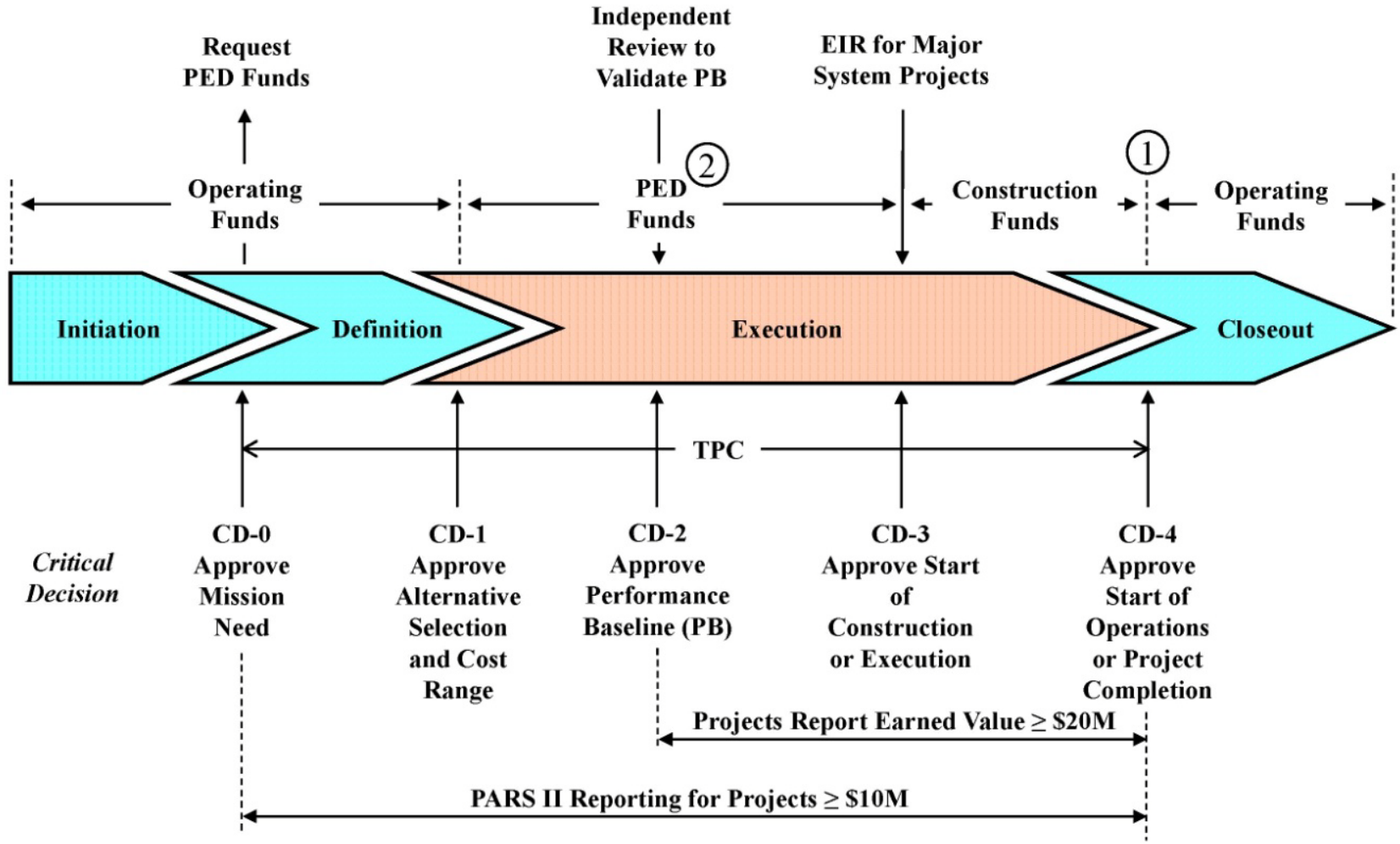
ND-LAr



Data Acquisition
FD1, FD2, ND

DOE Critical Decision (CD) Process

- All DOE Capital Asset projects greater than $50M are required to be managed under the DOE 413.b Program and Project Management for the Acquisition of Capital Assets



NOTES:
1. Operating Funds may be used prior to CD-4 for transition, startup, and training costs.
2. PED funds can be used after CD-3 for design.

Next Steps

January 2010 -> Mission Need

Excerpt from
Mission Need Statement for a
Long Baseline Neutrino Experiment (LBNE)

Office of High Energy Physics
Office of Science

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to support exploration of the physical universe through the discovery and study of the elementary constituents of matter and energy and the nature of space and time. These areas of research are an integral component for the advancement of all science and technology and an expression of society's timeless intellectual quest to understand the universe. The Standard Model of particle physics represents an unprecedentedly successful description of the elementary particles and their interactions; however, we know this model is incomplete and our present understanding indicates the existence of a more fundamental underlying theory. Elucidating this deeper theory requires a broad research program at the complementary and interrelated Energy, Intensity, and Cosmic Frontiers of particle physics.

At the Intensity Frontier, intense particle beams are utilized to investigate the properties of neutrinos and rare processes, both probes of new physics. Results from the last decade conclusively demonstrate that the three known neutrinos have nonzero mass, mix with one another, and oscillate between generations-properties which represent tantalizing hints of physics beyond the Standard Model. Cosmology indicates that the neutrino mass is less than one-millionth that of the electron, yet oscillation studies from experiments find tiny, but nonzero, mass differences between neutrino generations and large values for two of the three mixing angles. Currently, the individual masses are unknown and only an upper limit exists for the third angle.

The recent progress in neutrino physics has laid the basis for new discovery opportunities. As a fundamental physical constant, measurement of the unknown third mixing angle is of great interest and will influence the direction and evolution of an international neutrino program. Determining the relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model. The study and observation of the different behavior of neutrinos and antineutrinos traversing matter will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance. A popular hypothesis asserts that the asymmetry arises from neutrino interactions and is the subject of intense research.

The Office of High Energy Physics proposes construction of an experiment comprised of a large detector illuminated by a distant, intense neutrino source and a much smaller detector located close to the source. The far detector must be at a long distance from the neutrino source to increase sensitivity to neutrino oscillations and have sufficient sensitivity (through increased size and technological innovation or both) to improve neutrino detection. A new intense neutrino source, pointing towards the detector, is also needed along with a nearby detector to measure the initial composition of the neutrino beam. The increased research capabilities afforded by a long baseline (distance between the detector and the neutrino source) neutrino experiment will enable a world-class program in neutrino physics that can measure fundamental physical parameters, explore physics beyond the Standard Model, and better elucidate the nature of matter and antimatter.

1

Preliminary Critical Decisions

CD-0 Approve Mission Need	1st quarter FY 2010
CD-1 Approve Alternative and Cost Range	1st quarter FY 2011
CD-2 Approve Performance Baseline	3rd quarter FY 2012
CD-3 Approve Start of Construction	1st quarter FY 2014
CD-4 Approve Start of Operations	2nd quarter FY 2020

Even, not knowing the value of θ_{13}, the community and DOE were ready to explore the unknown

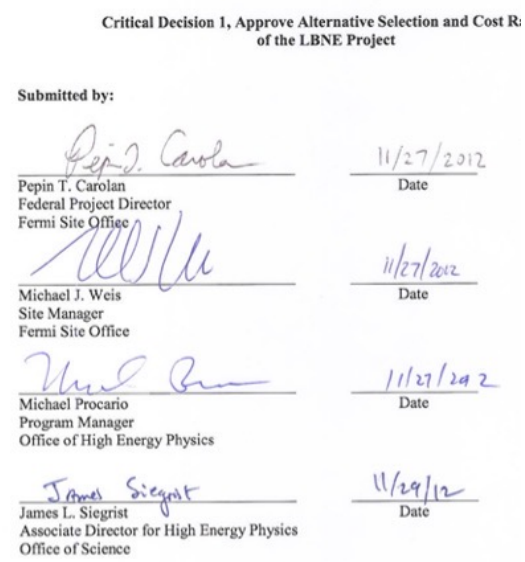
θ_{13} is large and we PROCEED

Critical Decision 1
Approve Alternative Selection and Cost Range
of the
Long Baseline Neutrino Experiment (LBNE) Project
(Line Item Project 11-SC-40)
at the
Fermi National Accelerator Laboratory and
Sanford Underground Research Facility
Office of High Energy Physics
Office of Science

Description of Scope	Threshold Key Performance Parameter (KPP)	Objective KPP
Primary Beam Power to produce neutrinos directed to the far detector site	Capable of delivering 700 kiloWatts , with beamline hardware commissioning complete.	
Long-Baseline Distance between neutrino source and far detector	1,000-1,500 kilometers	
Liquid Argon Far Detector	Operational capability installed for a 10 kiloton detector and demonstration of threshold performance by observation of cosmic ray interactions.	Additional detector mass and/or underground siting, facilitated by non-DOE in-kind contributions
Near Detector	Tertiary Muon Detector components tested in NUMI beam.	Near Detector facilitated by non-DOE in-kind contributions

Critical Decision Milestone	Schedule
CD-0 Approve Mission Need	1/8/2010 (Actual)
CD-1 Approve Alternative Selection and Cost Range	1st Quarter, FY2013
CD-3a Approve Long Lead Procurement	3rd Quarter, FY2015
CD-2 Approve Performance Baseline	3rd Quarter, FY2016
CD-3b Approve Start of Construction	3rd Quarter, FY2017
CD-4 Approve Project Completion	3rd Quarter FY2025

CD-1 for LBNE


Critical Decision 1, Approve Alternative Selection and Cost R
of the LBNE Project

Submitted by:

Pepin T. Carolan
Federal Project Director
Fermi Site Office
11/27/2012
Date

Michael J. Weis
Site Manager
Fermi Site Office
11/27/2012
Date

Michael Procario
Program Manager
Office of High Energy Physics
11/27/2012
Date

James L. Siegrist
Associate Director for High Energy Physics
Office of Science
11/29/12
Date

2014 P5 Report : 4 recommendations

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

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

These minimum requirements are not met by the current LBNE project's CD-1 minimum scope. The long-baseline neutrino program plan has undergone multiple significant transformations since the 2008 P5 report. Formulated as a primarily domestic experiment, the minimal CD-1 configuration with a small, far detector on the surface has very limited capabilities. A more ambitious long-baseline neutrino facility has also been urged by the Snowmass community study and in expressions of interest from physicists in other regions. To address even the minimum requirements specified above, the expertise and resources of the international neutrino community are needed. **A change in approach is therefore required.** The activity should be reformulated under the auspices of a new international collaboration, as an internationally coordinated and internationally funded program, with Fermilab as host. There should be international participation in defining the program's scope and capabilities. The experiment should be designed, constructed, and operated by the international collaboration. The goal should be to achieve, and even exceed if physics eventually demands, the target requirements through the broadest possible international participation.

2015 CD-1R for LBNF/DUNE

Critical Decision 1, Approve Alternative Selection and Cost Range
for the
Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment
at
Fermi National Accelerator Laboratory and
Sanford Underground Research Facility

Office of High Energy Physics
Office of Science

Table 2 -LBNF/DUNE Preliminary DOE Schedule

Critical Decision Milestone	Schedule
CD-0, Approve Mission Need	1/8/2010 (Actual)
CD-1, Approve Alternative Selection and Cost Range	12/10/2012 (Actual)
CD-1, Approve Alternative Selection and Cost Range (Update)	1st Quarter, FY2016
CD-3a (1), Approve Initial Far Site Construction	2nd Quarter, FY2016
CD-3b (2), Approve Near Site Preparation/Far Site Long Lead Procurement	2nd Quarter FY2019
CD-2, Approve Performance Baseline	1st Quarter, FY2020
CD-3(3), Approve Start of Construction	1st Quarter, FY2020
CD-4 , Approve Project Completion	4th Quarter FY2030

Critical Decision 1, Approve Alternative Selection and Cost Range for the LBNF/DUNE Project

Submitted by:

Pepin T. Carolan — 10/21/2015 Date
Federal Project Director
Fermi Site Office

Michael J. Weis — 10/21/15 Date
Site Manager
Fermi Site Office

Michael Procario — 11/5/15 Date
Program Manager
Office of High Energy Physics

James L. Siegrist — 11/5/15 Date
Associate Director for High Energy Physics
Office of Science

Critical Decision 1, Approve Alternative Selection and Cost Range for the LBNF/DUNE Project

Recommendations:
The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-1, Approve Alternative Selection and Cost Range, for the LBNF/DUNE Project at Fermilab and SURF site as noted below.

ESAAB Secretariat, Office of Project Assessment — 11/5/15 Date — Yes ✓ No___

Representative, Non-Proponent SC Program Office — 11/5/15 Date — Yes ✓ No___

Representative, Office of Budget — 11/5/15 Date — Yes ✓ No___

Representative, Non-Proponent SC Program Office — 11/5/15 Date — Yes ✓ No___

Representative, Office of Project Management Oversight and Assessment — 11/5/15 Date — Yes ✓ No___

Concurrence:

Patricia M. Dehmer — 11/5/15 Date — Yes ✓ No___
Acting Director, Office of Science

Approval:

Based on the information presented in this document and at the ESAAB review, I approve Critical Decision 1, Approve Alternative Selection and Cost Range for the LBNF/DUNE Project.

Franklin M. Orr, Jr. — 11/5/15 Date
Under Secretary for Science and Energy

Definition of Phases

- **Phase I:**
  - Accomplished with PIP-II, LBNF/DUNE-US, and DUNE International Partners
  - Meets P5 minimum requirements to proceed by 2035 timeframe
  - Same project scope as proposed at CD-1R in July 2015
- **Phase II** (future, not part of project)
  - Increased mass at Far Detector
  - More Capable Near Detector (MCND)
  - Increased beam power by Booster replacement

	LBNF/DUNE-US Project + DUNE Int'l Project	
Capability Description	**Phase I**	**Phase II**
Beamline		
1.2MW (includes 2.4MW infrastructure)	X	
2.4MW		X[1]
Far Detectors		
FD1 – 17 kton	X	
FD2 – 17 kton	X	
FD3		X
FD4		X
Near Detectors[2]		
ND LAr	X	
TMS	X	
SAND	X	
MCND (ND GAr)		X

Note 1: requires upgrades to LBNF neutrino target and upgrades to Fermilab accelerator complex. The LBNF facility is built to support 2.4MW in Phase I.
Note 2: Near Detector Subproject threshold scope provides "day 1" requirements to start the DUNE experiment

What and Why CD-1RR ?

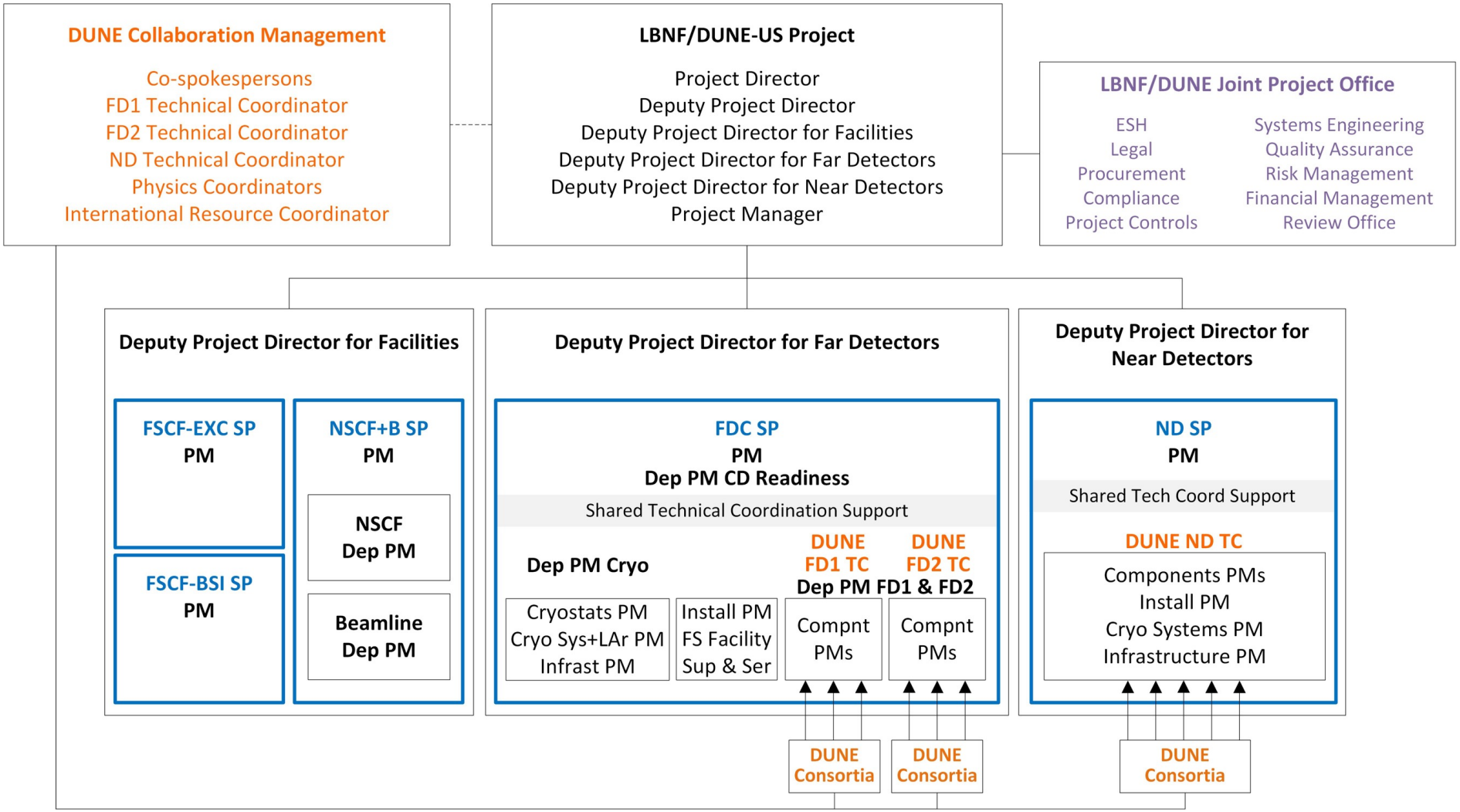
- We are still working with the original 2010 CD-0 Mission Need
- At CD-1, an initial Total Project Cost (TPC), as well as an upper and lower cost range are set
- Deep in the details of the CD Guidance is the fact that if a Project TPC exceeds 1.5x the CD-1 the upper cost range, the CD-1 approval must be reaffirmed.
- By mid-2020, for a variety of reasons, it was realized that the LBNF/DUNE-US TPC would exceed $2.7B (1.5 x the 2015 upper range of $1.8)
- The reaffirmation means setting a new cost range and a re-affirmation of the CD-1 selected alternative; in our case this is the 2015 CD-1R alternative.

Outcome of July 11-15 IPR

- IPR = Independent Project Review
- A positive review outcome is required for DOE to request the actual Critical Decision approval
  - Positive outcome generally requires an affirmative answer to all of the charge questions posed to the review team
  - Additionally, any review recommendations that are pre-requisites to the recommendation to proceed to the ESAAB* approval would need to be addressed
- Last week's review had 26 reviewers over 8 subcommittees
- Almost all charge questions were reviewed in positive
- All recommendations were reasonable and supportive for moving forward towards project baselining

*ESAAB = Energy Systems Acquisition Advisory Board

Project Management : 5 sub-projects



From Project Director Chris Mossey's review presentation

Planned Subproject CD-2/CD-3 Critical Decision Timeline Summary

Subproject	CD	Q3 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023	Q4 2023	Q1 2024	//	Q3 2024	//	Q2 2025	//	Q4 2025
FSCF-EXC $652M	CD-2/3	**ESAAB (Jul 22)**												
FSCF-BSI $181M	CD-2/3		**IPR (Nov 22)**		ESAAB									
FDC $1,059M	CD-3a		IPR (Nov 22)	ESAAB										
	CD-2/3			IPR (Mar 23)			ESAAB							
NSCFB $1,037M	CD-3a		IPR (Nov 22)	ESAAB										
	CD-2/3					IPR		ESAAB						
ND $200M	CD-2							IPR		ESAAB				
	CD-3											IPR		ESAAB

Notes

- Quarters shown are calendar year; bolded dates are set
- NSCFB tailoring plan not updated in P6 yet
- ND plan is under development

Summary and Outlook

- The 2014 P5 model for an international effort to explore the neutrino sector and more, hosted in the United States, has found reality in the LBNF/DUNE enterprise.
- The commitments of international partners to the facilities of PIP-II and LBNF and the DUNE detectors are very significant; the 2nd cryostat from CERN has enabled the realization of the Phase 1 program with 2 far detector modules – each of which has ~50% contributions from non-DOE sources and a Near Detector complex with major contributions from international partners.
- The LBNF/DUNE-US Project has achieved a major milestone with a successful Independent Project Review in support of the CD-1RR Critical Decision.
- The International DUNE Collaboration looks forward to working with the LBNF/DUNE-US project in moving through the remaining milestones which will lead to the commissioning of our physics program.
- Stay-tuned!