LBNE Status

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LBNE Project Director

2nd ESSnuSB Open Meeting
26-27 May 2014

Outline

- LBNE Science Goals
- LBNE Project Overview
- Description LBNE Project and Development Status
  - Beamline and PIP-II
  - Near Detector System
  - Far Detector
  - Civil Engineering (Conventional Facilities)
- Schedule
- P5 Report

LBNE Collaboration

505 (379 US + 126 non-US) members,
88 (54 US + 34 non-US institutions), 8 countries

UFABC
Alabama
Argonne
Banaras
Boston
Brookhaven
Cambridge
Catania/INFN
CBPF
Charles U
Chicago
Cincinatti
Colorado
Colorado State
Columbia
Czech Technical U
Dakota State
Delhi
Davis
Drexel
Duke
Duluth
Fermilab
FZU
Goias
Gran Sasso
GSSI
HRI
Hawaii
Houston
IIT Guwati
Indiana
Iowa State
Irvine
Kansas State
Kavli/IPMU-Tokyo
Lancaster
Lawrence Berkeley NL
Livermore NL
Liverpool
London UCL
Los Alamos NL
Louisiana State
Manchester
Maryland

Michigan State
Milano
Milano/Bicocca
Minnesota
MIT
Napoli
NGA
New Mexico
Northwestern
Notre Dame
Oxford
Padova
Panjab
Pavia
Pennsylvania
Pittsburgh
Princeton
Rensselaer
Rochester
Rutherfod Lab
Sanford Lab
Sheffield
SLAC
South Carolina
South Dakota
South Dakota State
SDSMT
Southern Methodist
Sussex
Syracuse
Tennessee
Texas, Arlington
Texas, Austin
Tufts
UCLA
UEFS
UNICAMP
UNIFAL
Virginia Tech
Warwick
Washington
William and Mary
Wisconsin
Yale
Yerevan

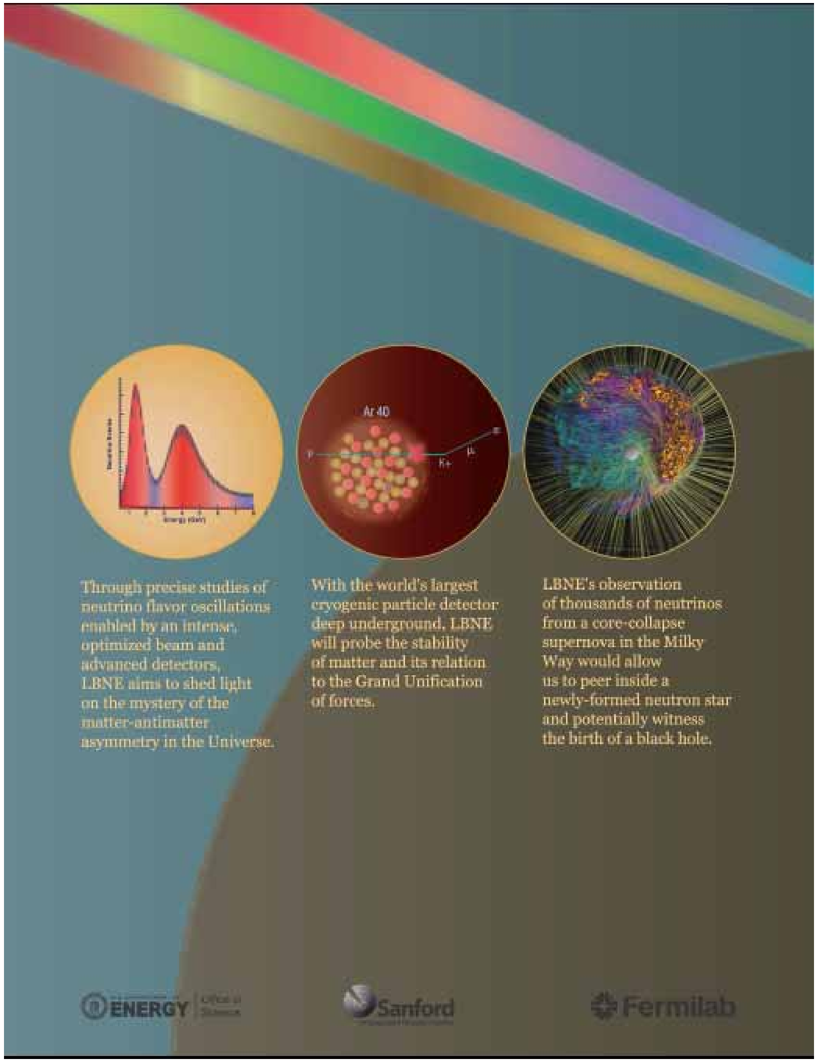
- Since December 2012:
  - Collaboration has increase in size by more 40%
  - Non-US fraction more than doubled

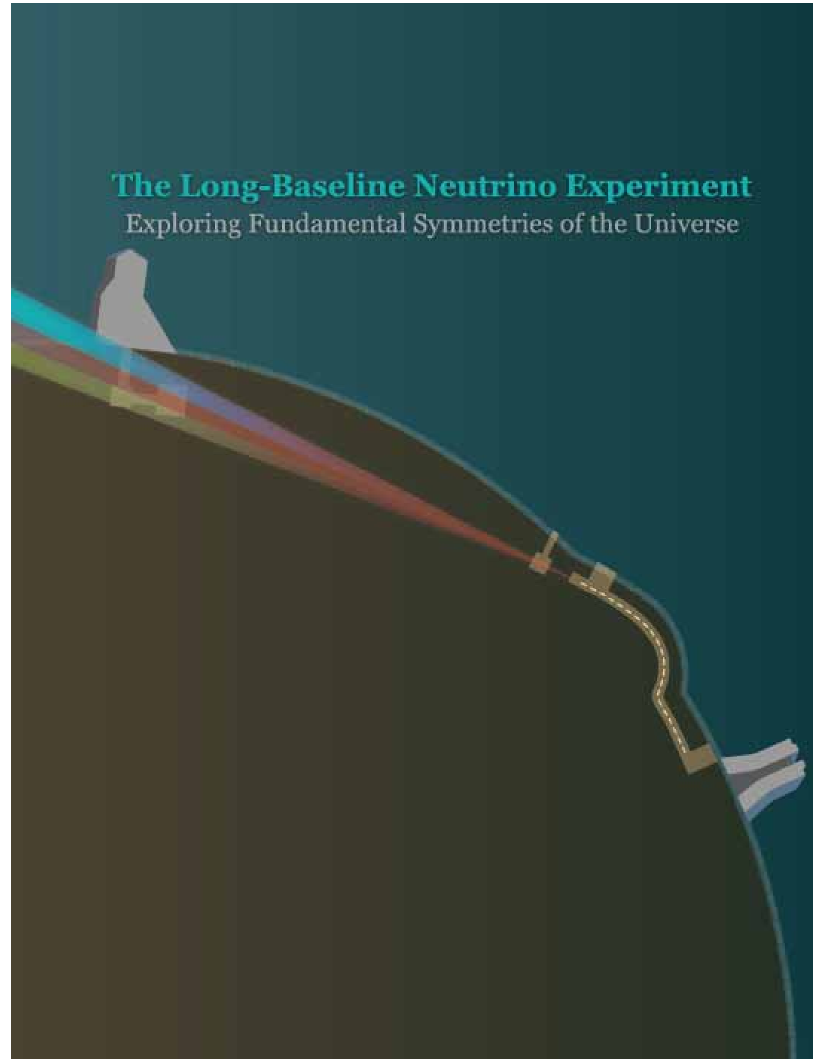
LBNE Science Objectives

- LBNE is a comprehensive program to measure neutrino oscillations
  - Directly determine CP violation in the leptonic sector
  - Measure the CP phase δ
  - Determine the neutrino mass hierarchy
  - Determine the θ_{23} octant and other precision measurements
  - Testing the 3-flavor mixing paradigm
  - Precision measurements of neutrino interactions with matter
  - Search for new physics (non-standard interactions, sterile neutrinos)
- … and other fundamental physics enabled by a massive, underground detector
  - Search for nucleon decays
  - Measurement of neutrinos from core collapse supernovae
  - Measurements with atmospheric neutrinos

LBNE Science Book

http://lbne.fnal.gov/





arXiv:1307.7335v3 [hep-ex] 22 Apr 2014

Importance of LBNE Science

The science of LBNE has been widely recognized to be a top priority.

The Long-Baseline Neutrino Experiment (LBNE) will measure the mass hierarchy and is uniquely positioned to determine whether leptons violate CP. Future multi-megawatt beams aimed at LBNE, such as those from Project X at Fermilab, would enable studies of CP violation in neutrino oscillations with conclusive accuracy. An underground LBNE detector would also permit the study of atmospheric neutrinos, proton decay, and precision measurement of any galactic supernova explosion. This represents a vibrant global program with the U.S. as host.

Report of the 2013 "Snowmass" Summer Study

f. Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

The Science Drivers:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

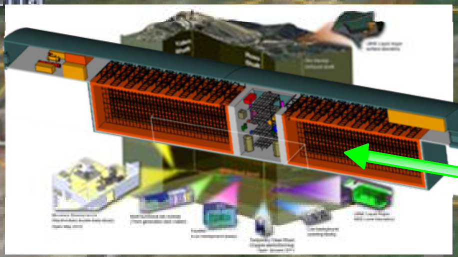
P5 Report, May 2014

The European Strategy for Particle Physics, Update 2013

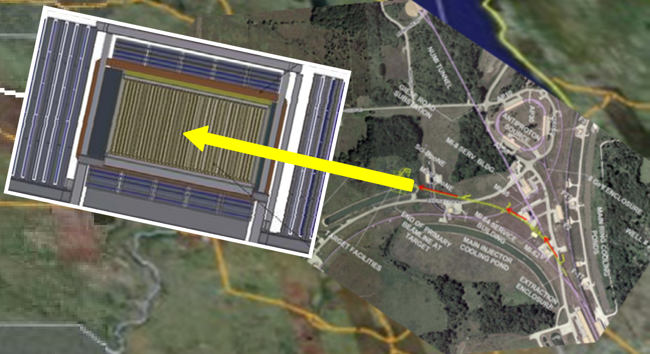
Long Baseline Neutrino Experiment

New Neutrino Beam at Fermilab…

Precision Near Detector
on the Fermilab site



1300 km



…aimed at the Sanford Underground
Research Facility (SURF)
in Lead, South Dakota

≥35 kton Liquid Argon TPC Far Detector
at a depth of 4850 feet (4300 m.w.e.)

And all the Conventional Facilities required to support the
beam and detectors

Image NASA
© 2008 Tele Atlas
Image © 2008 TerraMetrics
© 2008 Europa Technologies

Pointer 43°03'56.44" N 95°10'42.53" W Streaming ||||||||| 100% Eye alt 1108.62 km

Building on Substantial Investments

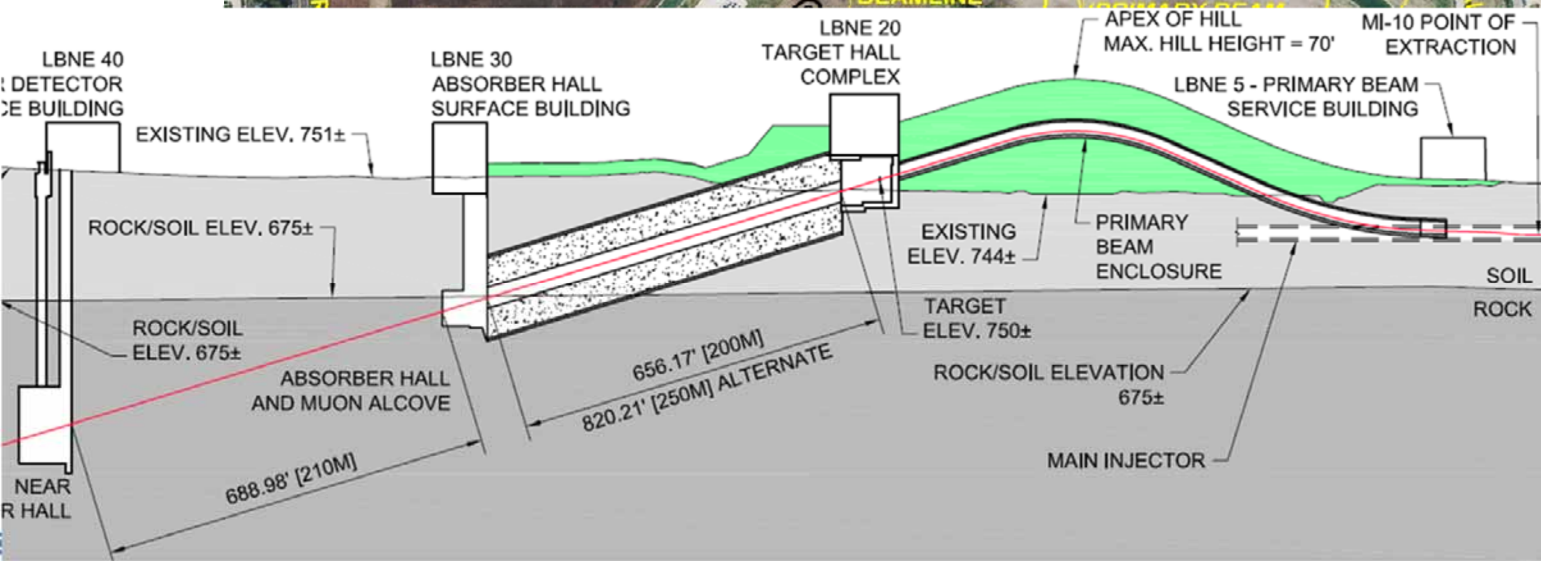
Significant investments have already been made in both Fermilab and SURF facilities, which provide a platform for LBNE.

- Beam power upgrade 400 kW → 700 kW in progress.
- Further upgrade to 1.2 MW is planned for the start of LBNE, and a subsequent upgrade to >2 MW is possible.
- Civil engineering design has been launched and core borings completed for neutrino beamline and far detector cavern.
- World class laboratory now in operation at 4850 foot depth (4300 m.w.e.) at SURF.
- Renovations of the main shafts at SURF are in progress to support excavation for LBNE caverns.
- Over $100M of State of South Dakota and private funds already invested in SURF, in addition to investments by U.S. government funding agencies.

Evolving Scope of the LBNE Project

- LBNE is developing as an international partnership, with the goal of delivering an initial project consisting of:
  - A neutrino beamline, operating initially at 1.2 MW,
  - A highly-capable near detector system,
  - A ≥10 kt fiducial mass far detector underground at SURF
  - Conventional facilities including a cavern for a full ≥ 35 kt fiducial mass detector far detector system.
  - The designs of the near and far detectors and of the beam will incorporate concepts from new partners.
- The planned project allows for future upgrades:
  - The beamline is designed to upgradeable to ≥2.3 MW proton beam power
  - Future detector module(s) can be installed in the underground cavern.

LBNE Beamline Design

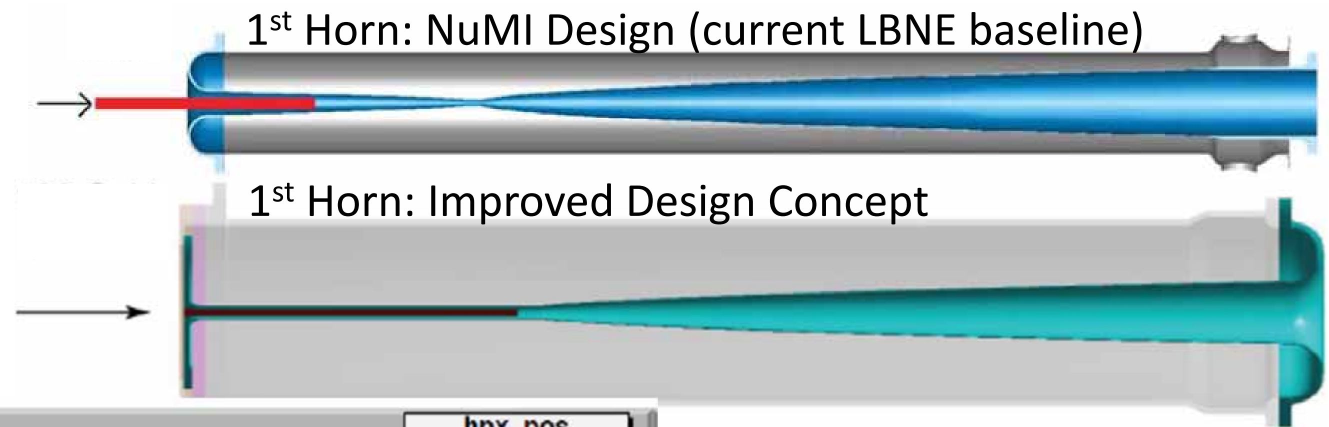


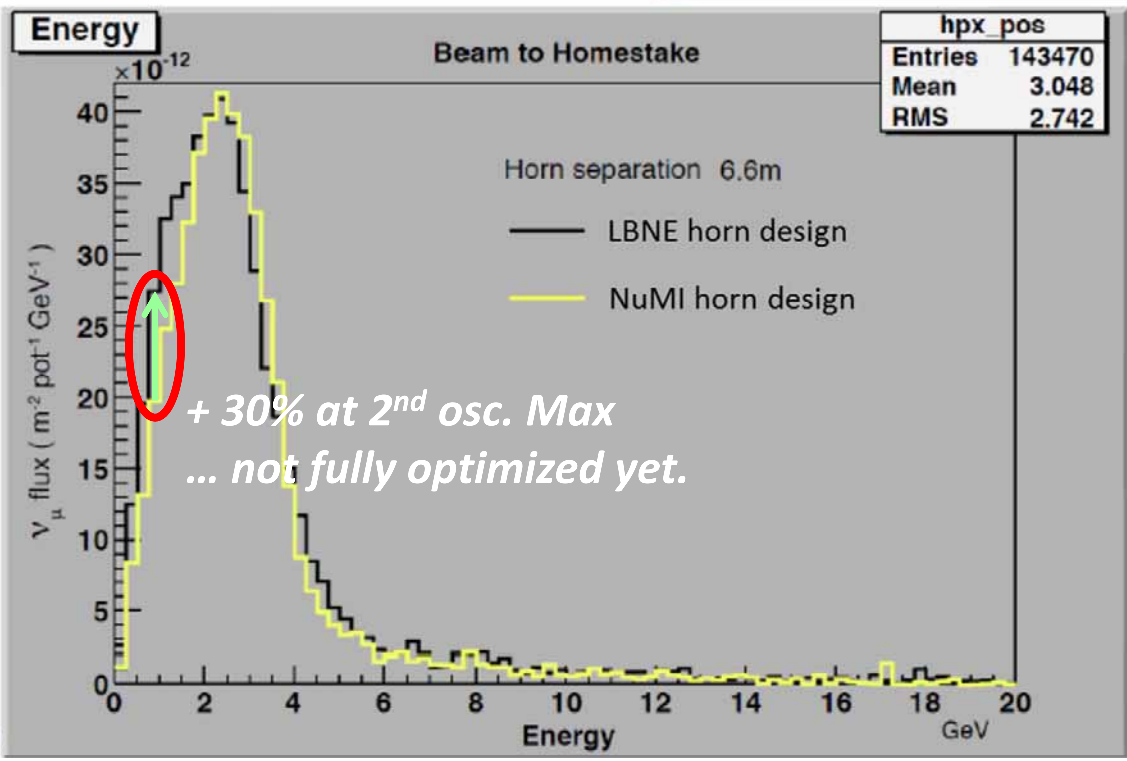
Beam Improvements Under Consideration

Changes	0.5-2 GeV		2-5 GeV		Extra Cost
Horn current 200 kA $\rightarrow$ 230 kA	1.00		1.12		\$0
Proton beam 120 $\rightarrow$ 80 GeV,700 kW	1.14	34%	1.05	31%	\$0
Target graphite $\rightarrow$ Be	1.10		1.00		$<$ 1 M\$
DP Air $\rightarrow$ He *Recently approved*	1.07		1.11		$\sim$ 8 M\$
DP diameter 4 m $\rightarrow$ 6 m	1.06		1.02		$\sim$ 17 M\$
DP length 200 m $\rightarrow$ 250 m	1.04		1.12		$\sim$ 30 M\$
Total	1.48		1.50		

- Target/horn system can be replaced with more advanced designs as they become available.
- Decay pipe design must be fixed at the beginning.
- First four improvements appear technically and financially feasible.
- The last two proposals regarding the decay pipe diameter and length are still under study.

Further Improvements: More Efficient Focusing

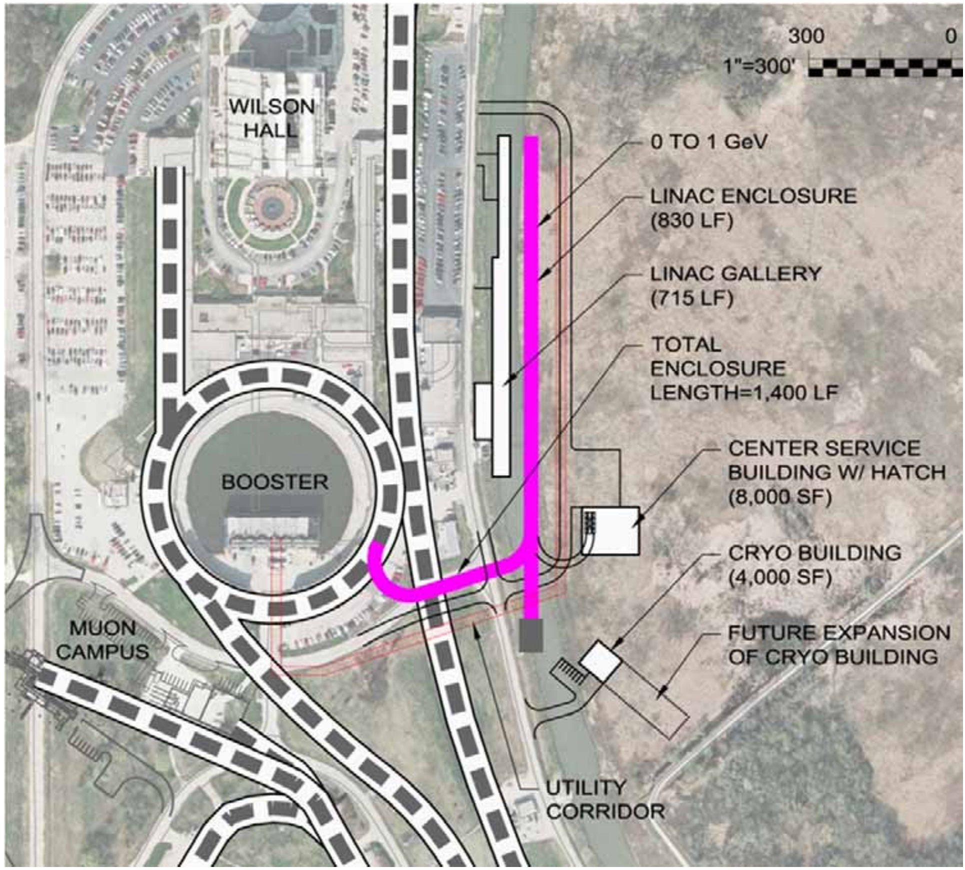




This is an excellent opportunity for new collaborators to significantly improve the capabilities of LBNE.

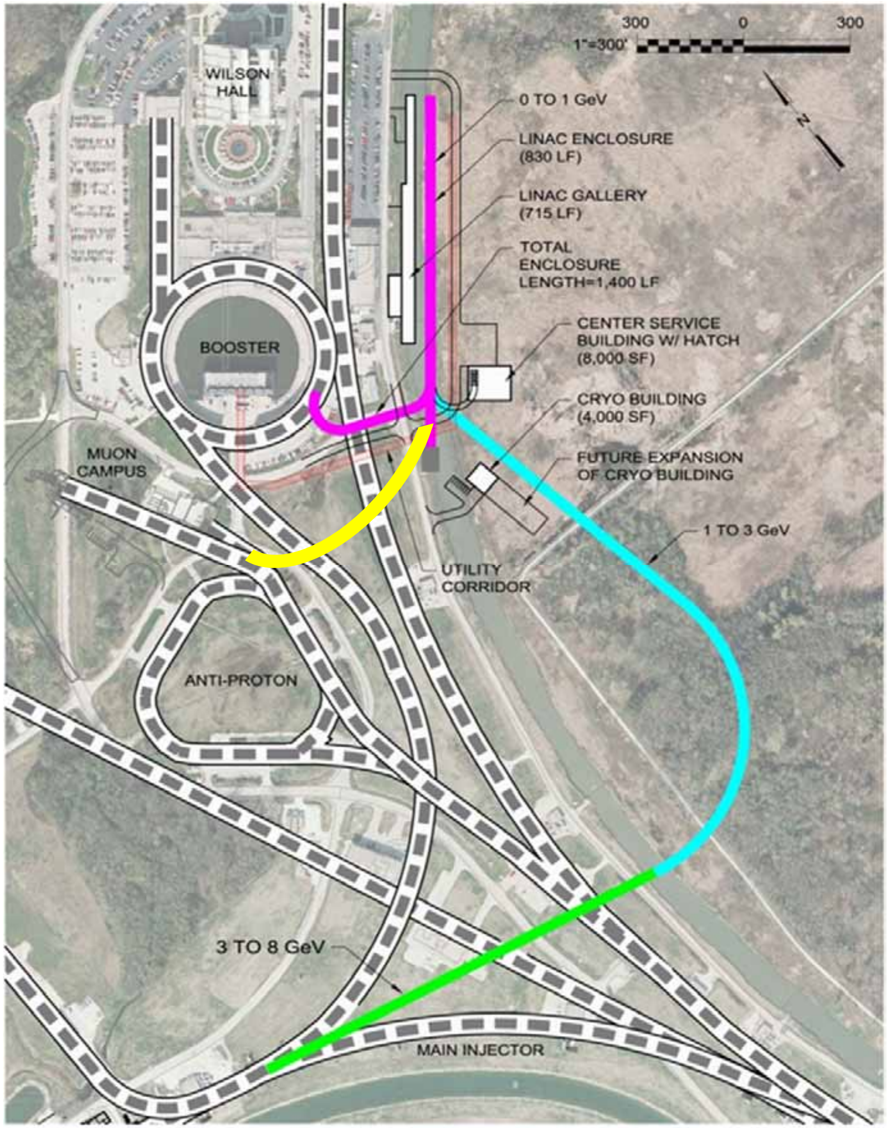
Proton Improvement Plan-II (PIP-II)

- Fermilab plans to replace the existing 400 MeV linac with a new 800 MeV superconducting linac, which will increase the beam power to LBNE to 1.2 MW.
- Plan to build this concurrently with LBNE => deliver 1.2 MW to LBNE from t = 0.
- This plan is based on well-developed SRF technology and appears to be financially feasible.
- Developing an international partnership for its construction
- Strong support from DOE … and P5



Flexible Platform for the Future

- PIP-II Inherent Capability
  - ~200 kW @ 800 MeV
- x10 Mu2e sensitivity
- Future upgrade would provide ≥ 2 MW to LBNE
- Flexibility for future experiments



Measurements of muons post-absorber

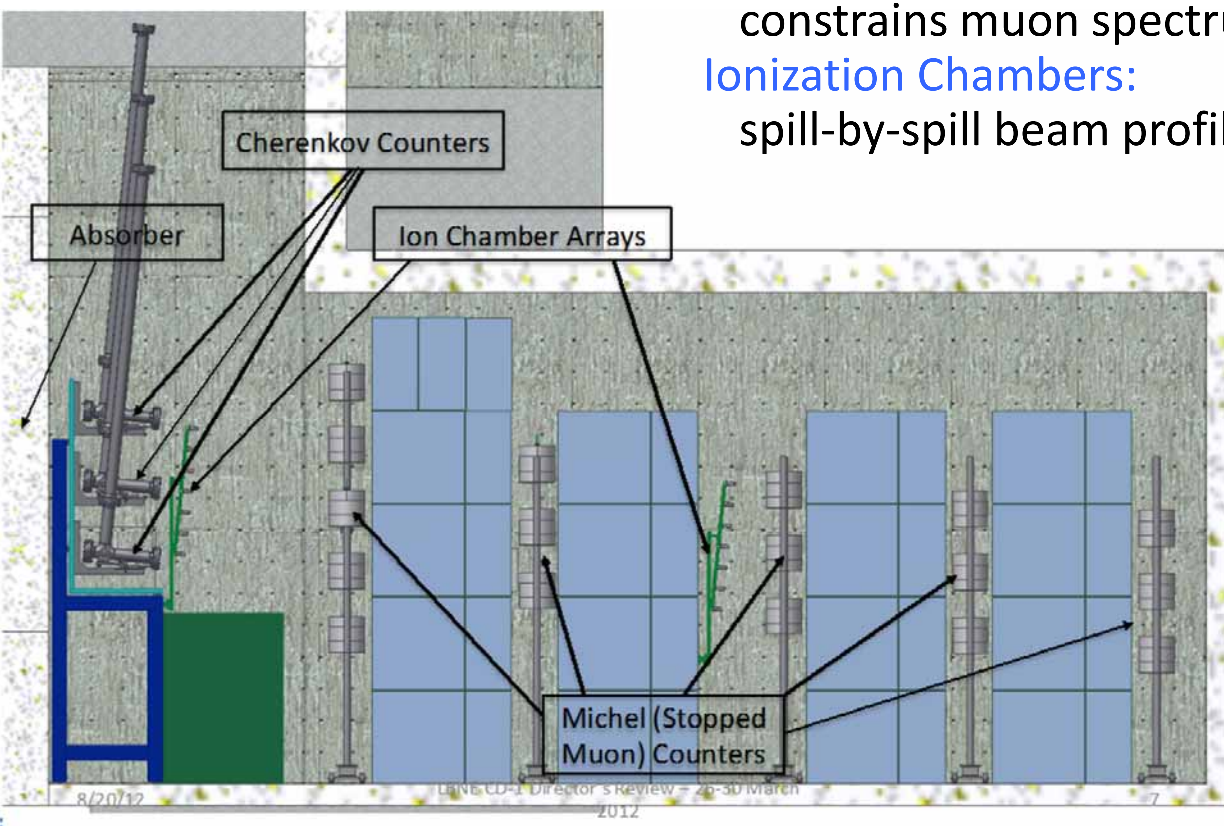
$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

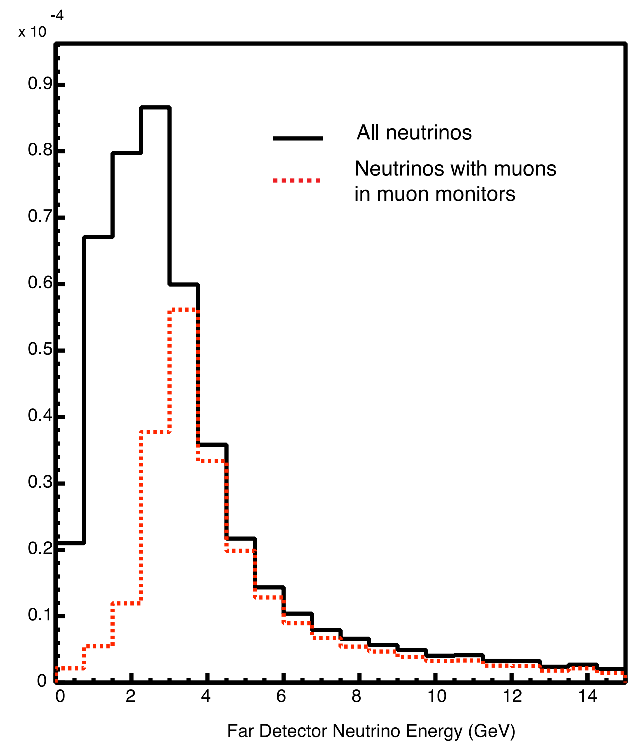
- $E_\nu=(0\text{-}0.43)E_\pi$
- $E_\mu=E_\pi\text{-}E_\nu=(0.57\text{-}1.0)E_\pi$

Cherenkov Detectors:
- measure all muons above a variable threshold
- constrains muon spectrum (correlated with E_ν)

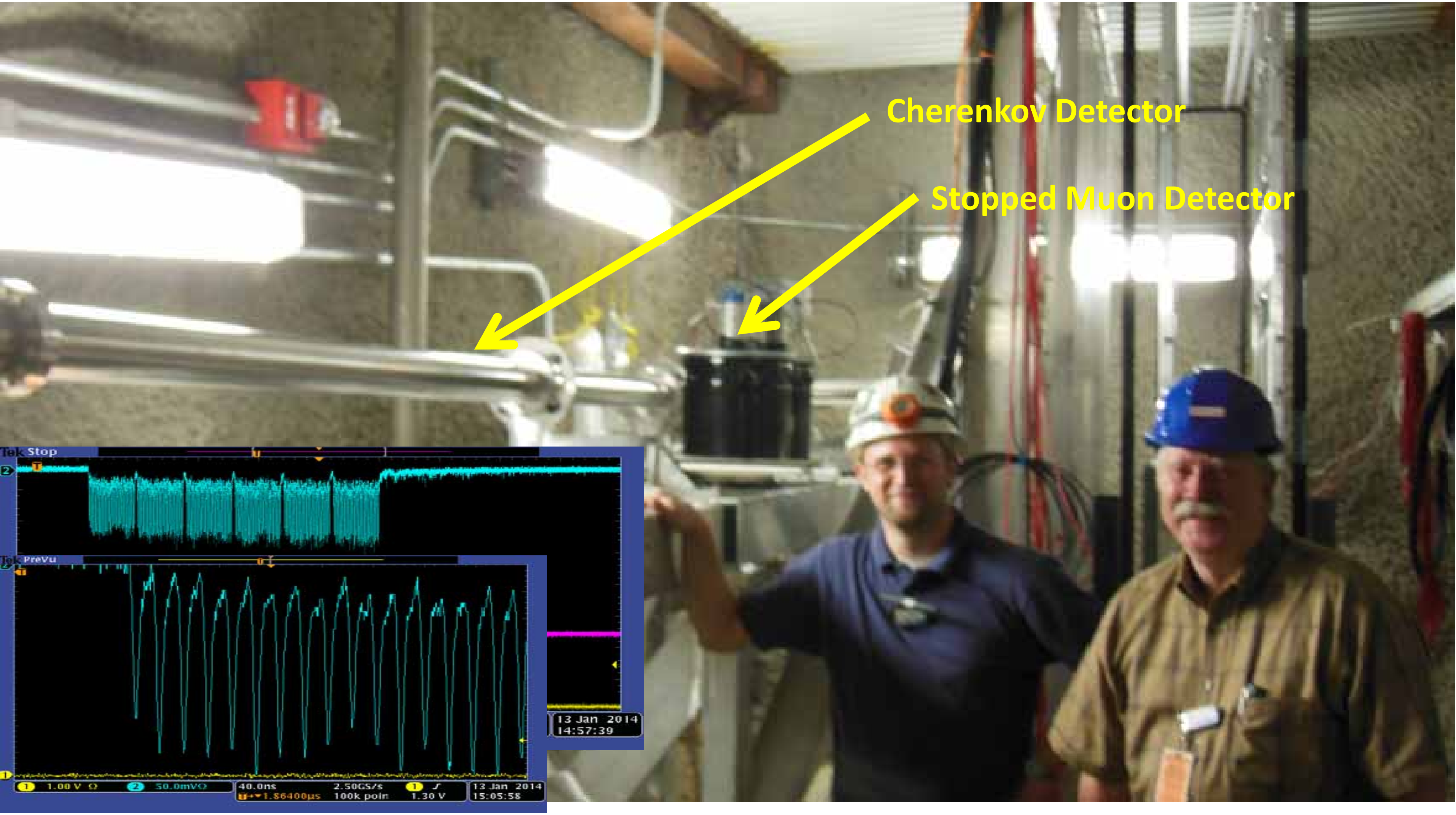
Michel Decay Detectors:
- measure muons that stop at a given depth in material
- constrains muon spectrum

Ionization Chambers:
- spill-by-spill beam profile



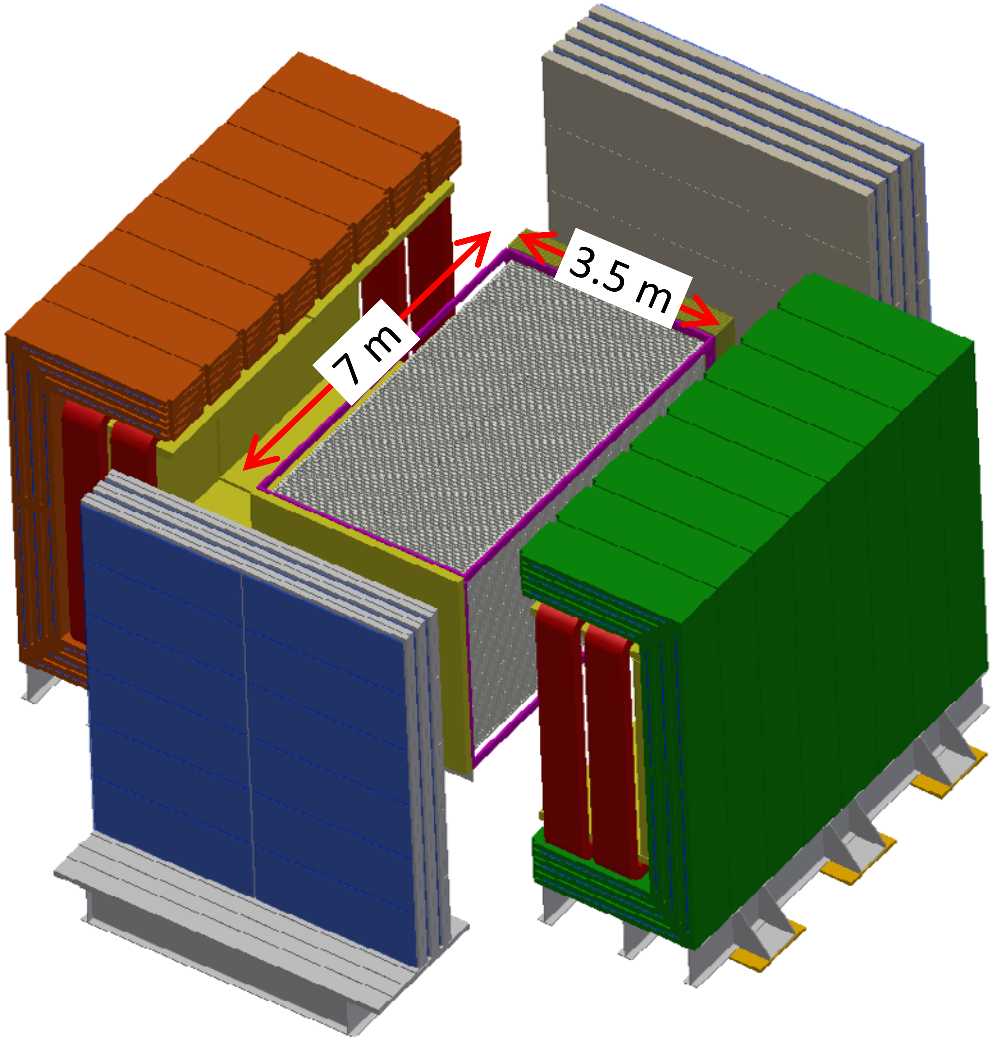


Prototype Muon Detectors in NuMI Beamline



Near Neutrino Detector

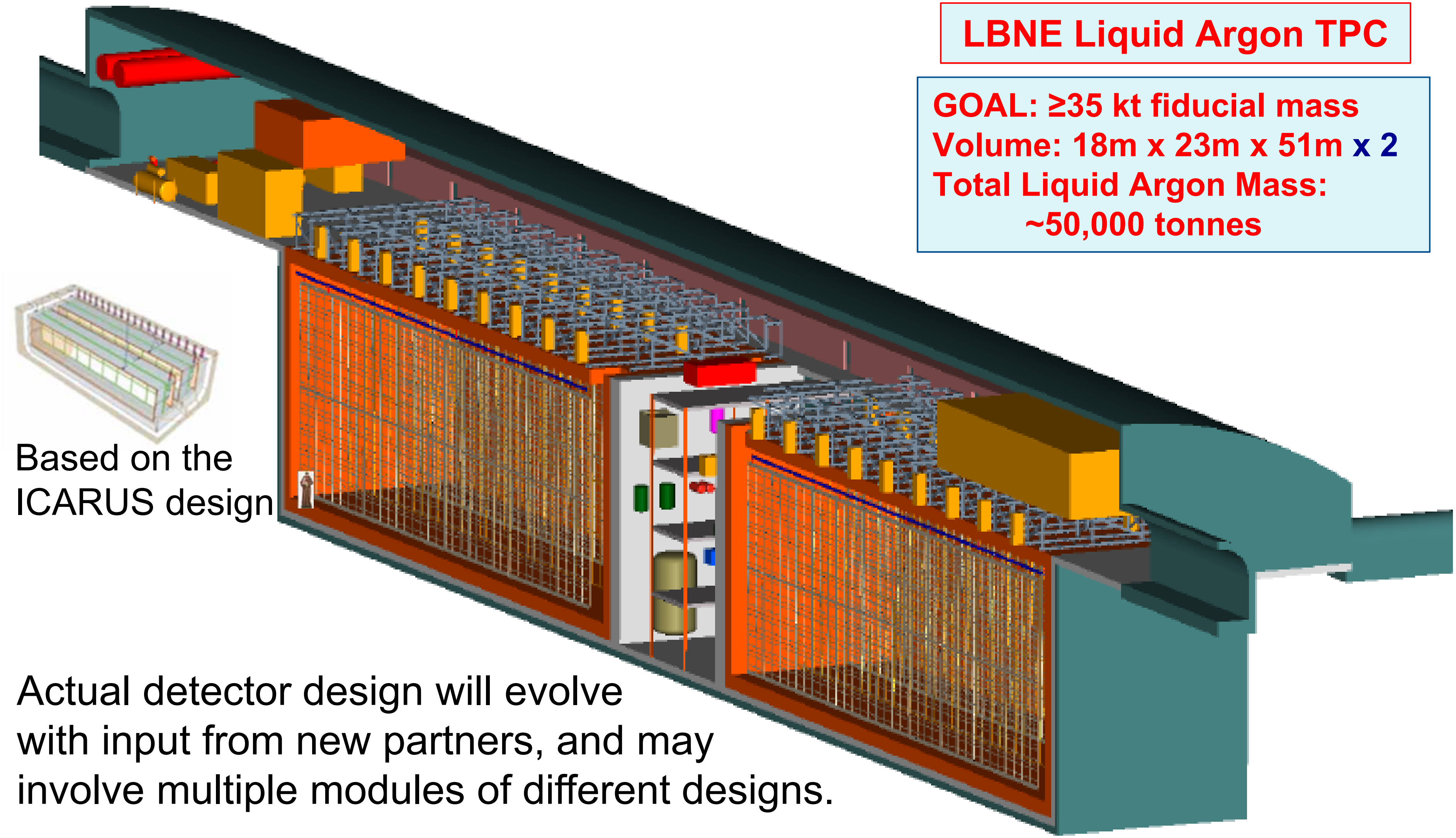
- Proposed by collaborators from the Indian institutions
- High precision straw-tube tracker with embedded high-pressure argon gas targets
- 4π electromagnetic calorimeter and muon identification systems
- Large-aperture dipole magnet



Far Detector

LBNE Liquid Argon TPC

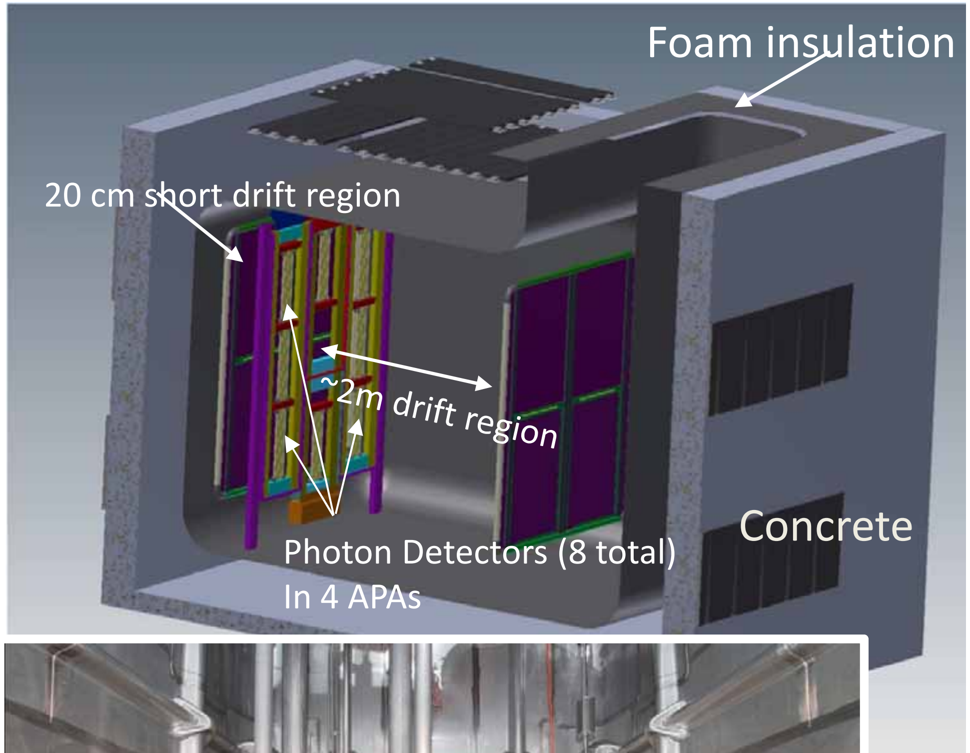
GOAL: ≥35 kt fiducial mass
Volume: 18m x 23m x 51m x 2
Total Liquid Argon Mass:
~50,000 tonnes

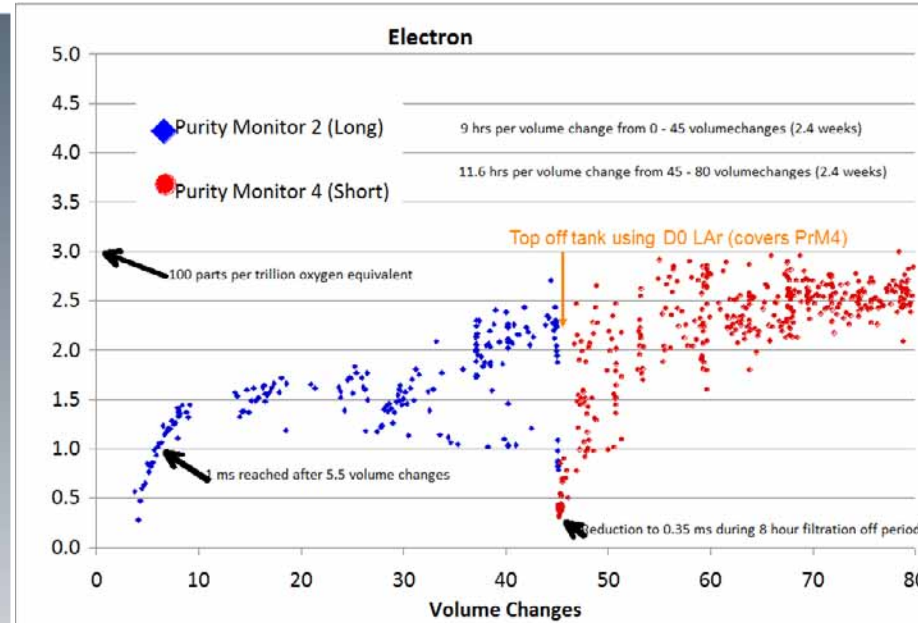


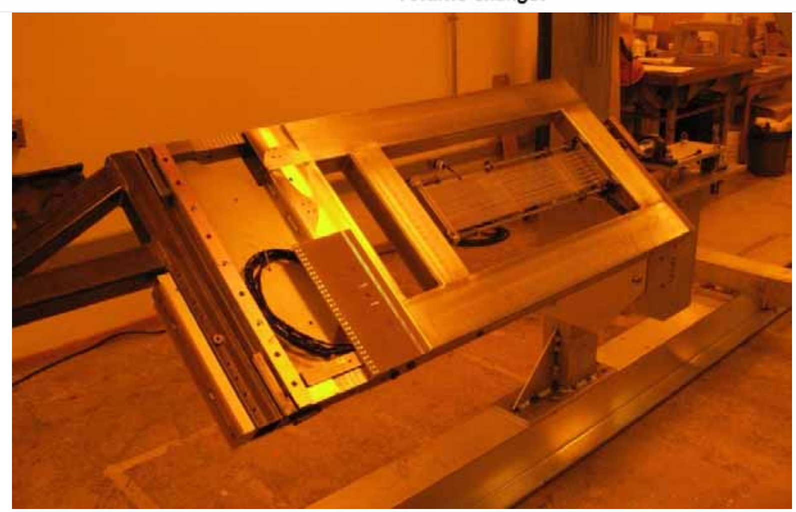
Based on the ICARUS design

Actual detector design will evolve with input from new partners, and may involve multiple modules of different designs.

35 t Prototype Cryostat and Prototype TPC Detector

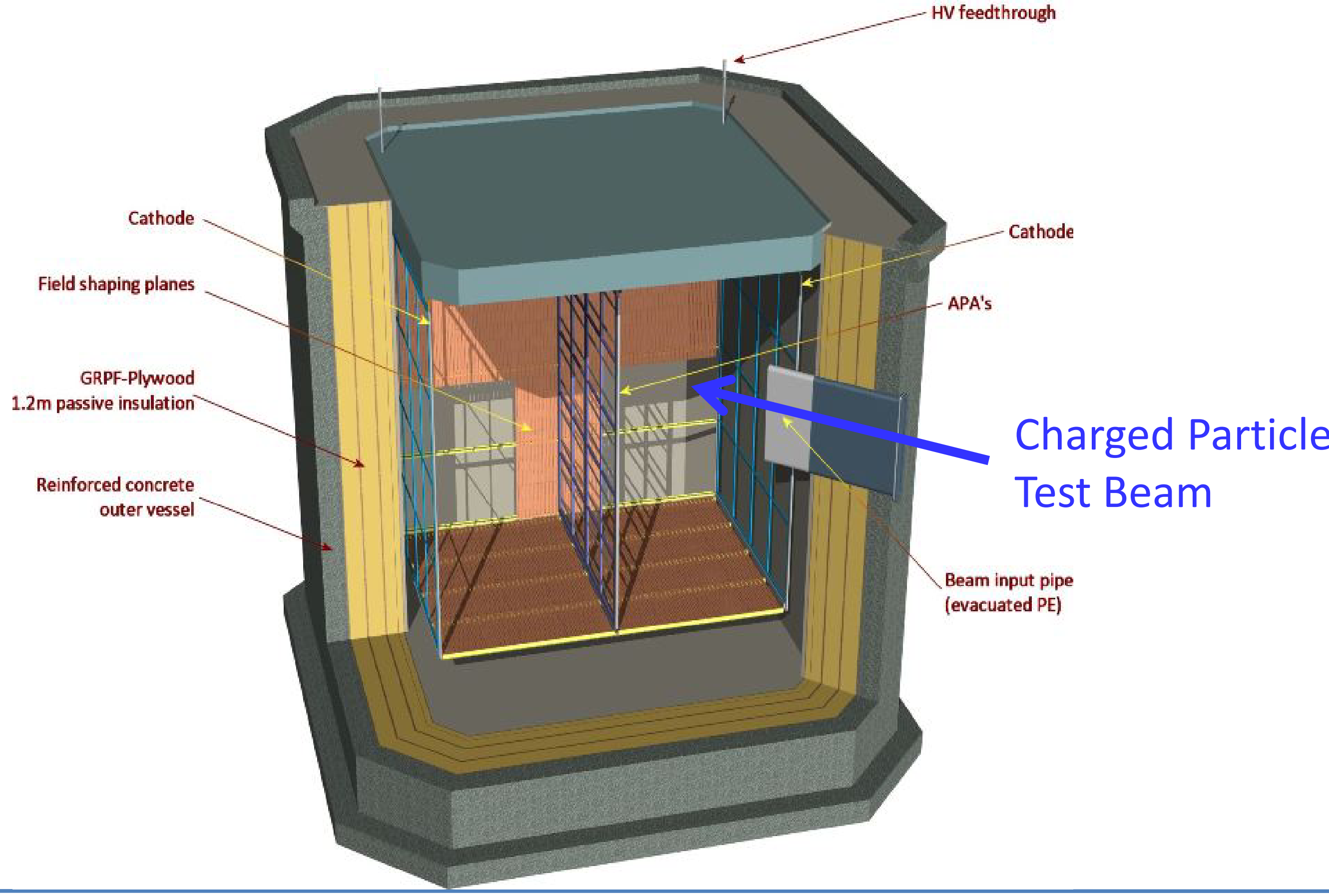




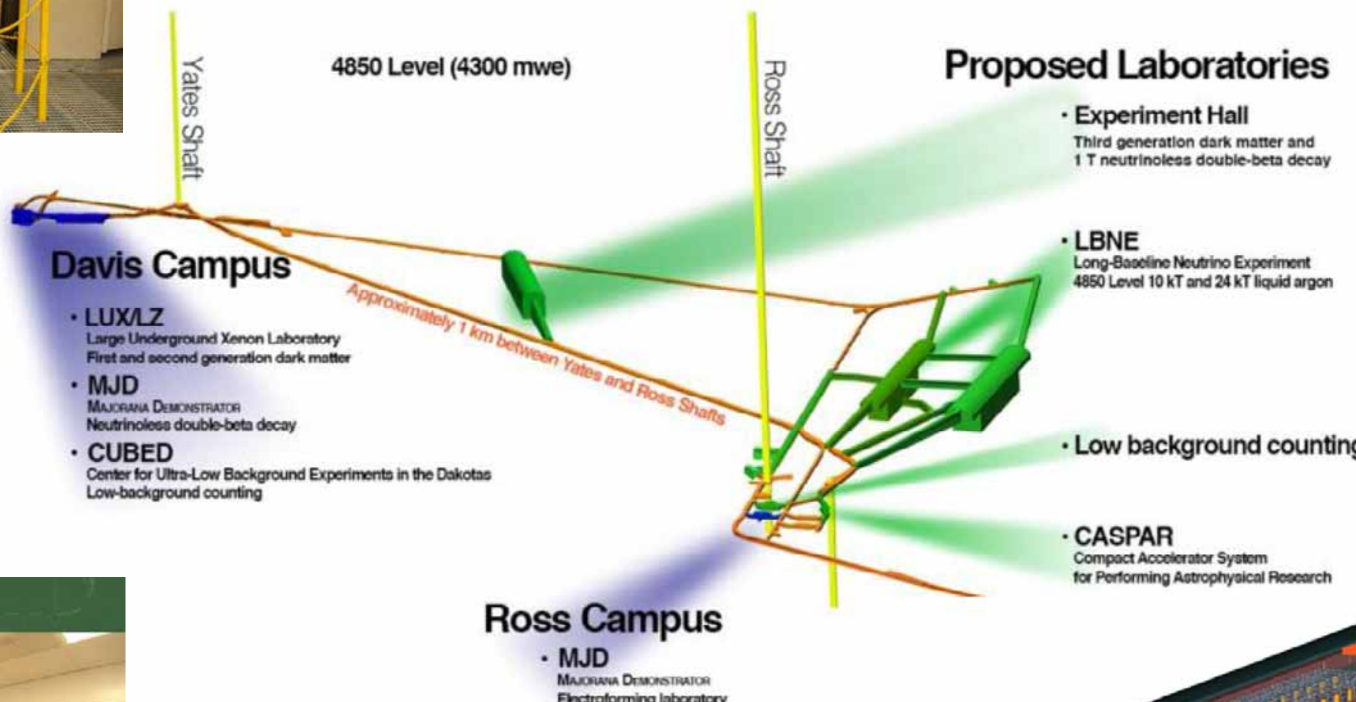


Full-Scale Prototype in LBNO-DEMO Cryostat

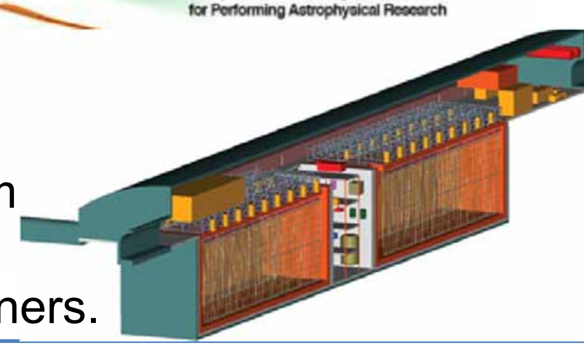
- Together with CERN and the LBNO Collaboration, we are developing a plan to test full-scale LBNE drift cell(s) in the 8x8x8 m^3 cryostat to be built at CERN as part of WA105.



Planned Location of LBNE Cavern(s)



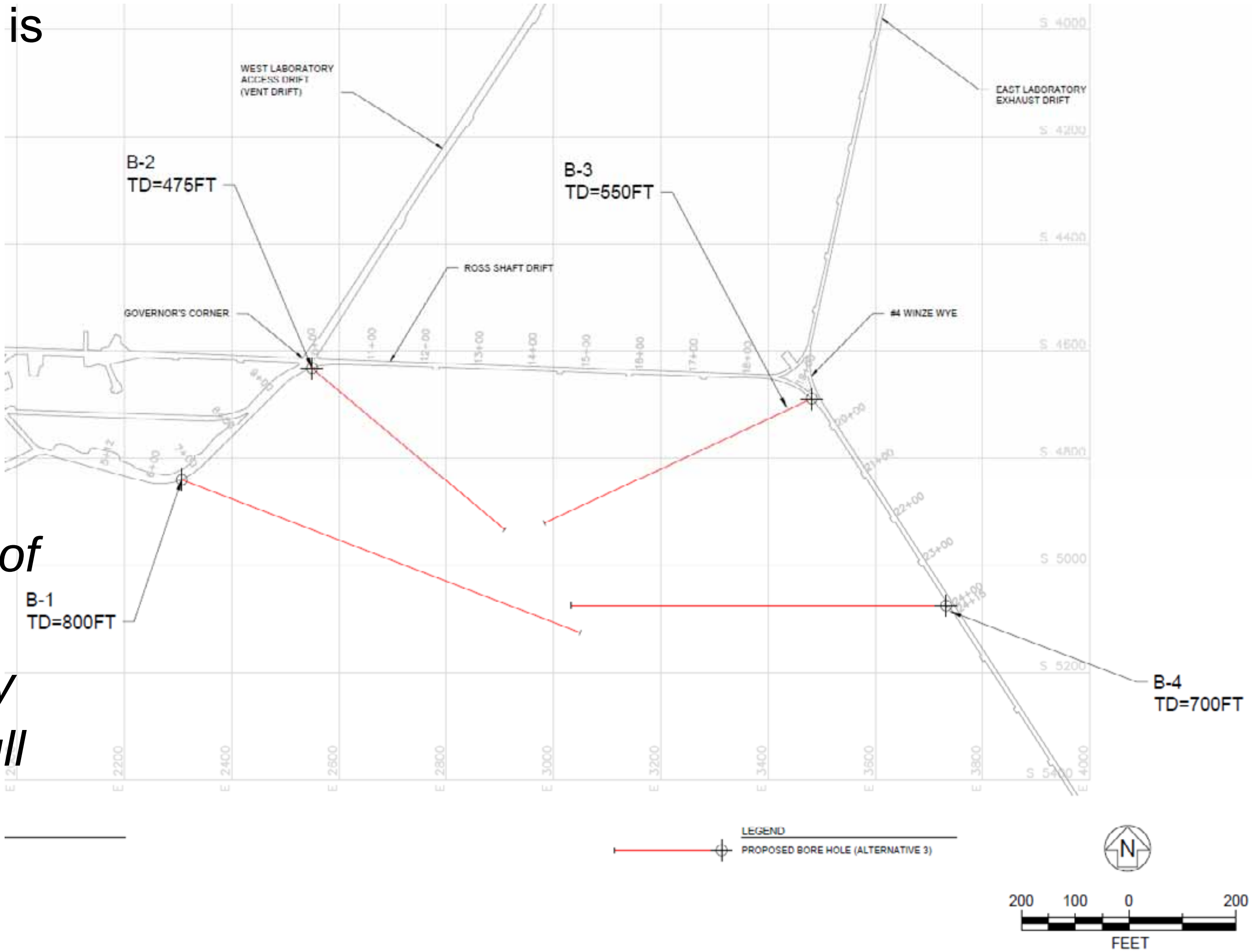
Actual layout will follow from detector design(s) agreed upon with international partners.



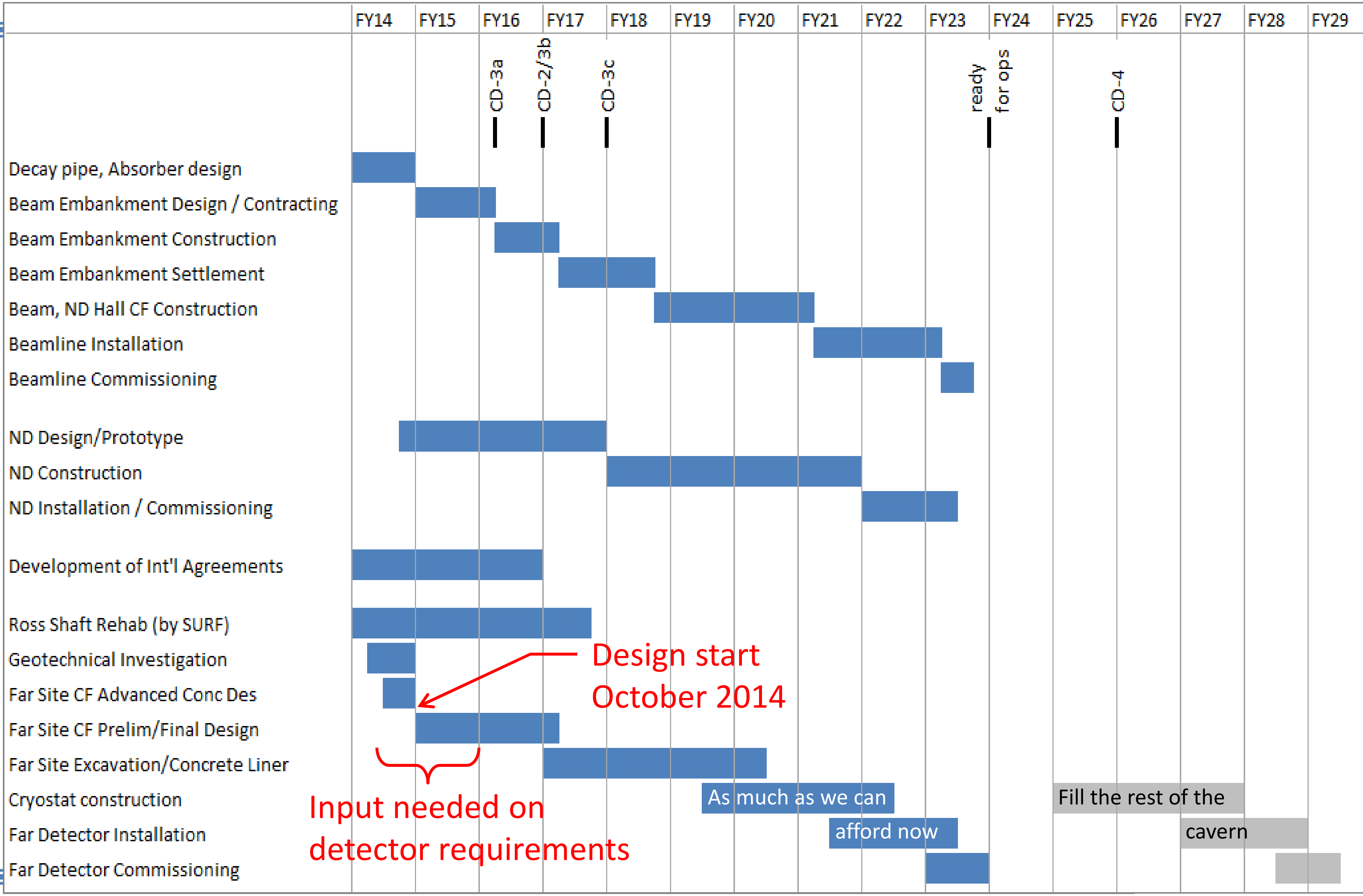
Geotechnical Site Investigation at SURF

A geotechnical site investigation program is under way to characterize the rock mass where the construction of the LBNE caverns is planned.

Four bore holes finished. Lab testing of rock samples is in process. Rock quality appears excellent. Full report due in August.



Technically Limited Schedule for International LBNE



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

Report of the Particle Physics Project Prioritization Panel (P5)

HEPAP
22 May 2014

S. Ritz

Slides: http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/P5MayHEPAP-Ritz.pdf
P5 Report: http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_DRAFT2_P5Report_WEB_052114.pdf

Science Drivers

- We distilled the eleven groups of physics questions from Snowmass* into five compelling lines of inquiry that show great promise for discovery over the next 10 to 20 years.
- The Science Drivers:
  - Use the Higgs boson as a new tool for discovery
  - **Pursue the physics associated with neutrino mass**
  - Identify the new physics of dark matter
  - Understand cosmic acceleration: dark energy and inflation
  - Explore the unknown: new particles, interactions, and physical principles
- The Drivers are deliberately not prioritized because they are intertwined, probably more deeply than is currently understood.
- A selected set of different experimental approaches that reinforce each other is required. Projects are prioritized.
- The vision for addressing each of the Drivers using a selected set of experiments – their approximate timescales and how they fit together – is given in the report.

* See Appendix D and http://www.slac.stanford.edu/econf/C1307292/

Summary (3/5)

Several significant changes in direction are recommended:

- Increase the fraction of the budget devoted to construction of new facilities.
- Reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with Fermilab as host.
- Redirect former Project-X activities and some existing accelerator R&D temporarily to improvements of the Fermilab accelerator complex that will provide proton beams with power greater than one megawatt by the time of first operation of the new long-baseline neutrino facility.
- Increase the planned investment in second-generation dark matter direct detection experiments.
- Increase particle physics funding of CMB research and projects in the context of continued multiagency partnerships.
- Realign activities in accelerator R&D with the P5 strategic plan. Redirect muon collider R&D and consult with international partners on the early termination of the MICE muon cooling R&D facility.

Summary (5/5)

- The recommendations for the unconstrained budget Scenario focus on three additional high-priority activities:
  - Develop a greatly expanded accelerator R&D program that would emphasize the ability to build very high-energy accelerators beyond the HL-LHC and ILC at dramatically lower cost.
  - Play a world-leading role in the ILC experimental program and provide critical expertise and components to the accelerator, should this exciting scientific opportunity be realized in Japan.
  - Host a large water Cherenkov neutrino detector to complement the LBNF large liquid argon detector, unifying the global long-baseline neutrino community to take full advantage of the world's highest intensity neutrino beam at Fermilab.

- With foundations set by decades of hard work and support, U.S. particle physics is poised to move forward into a new era of discovery.
- More generally, we strongly affirm the essential importance of fundamental research in all areas of science.

Project-specific Recommendations

#12-15:

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.

Figure 1
Construction and Physics Timeline

FIGURE 1 Approximate construction (blue; above line) and expected physics (green; below line) profiles for the recommended major projects, grouped by size (Large [>$200M] in the upper section, Medium and Small [<$200M] in the lower section), shown for Scenario B. The LHC: Phase 1 upgrade is a Medium project, but shown next to the HL-LHC for context. The figure does not show the suite of small experiments that will be built and produce new results regularly.

Summary and Conclusions

- Building on substantial investments already made, LBNE is developing as an international partnership to deliver:
  - A high-power neutrino beam
  - A high-resolution near detector system
  - A far detector of ≥10 kt fiducial mass in a cavern that can accommodate a ≥ 35 kt detector.
- Designs are being developed incorporating ideas of all partners and input from additional partners is welcome.
- This approach has strong support from the US and international HEP community.
- The recently released P5 report endorses this important and exciting program.