LBNE

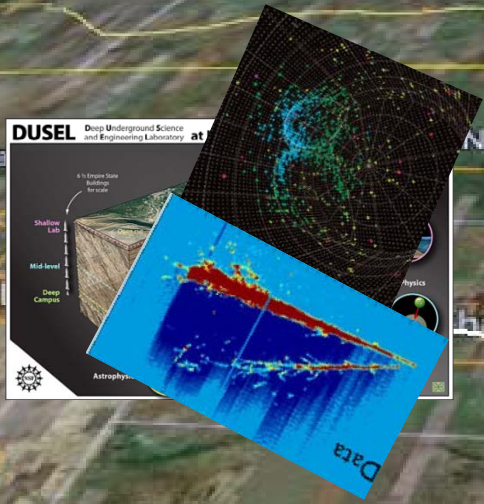
Jim Strait
Fermilab

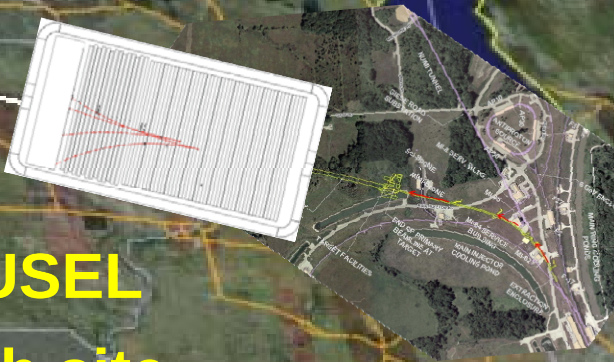
DOE Annual Science & Review
July 12-14, 2010

Outline

- Overview of LBNE (experiment, collaboration and project) and DUSEL
- Technical progress in developing the Conceptual Designs for LBNE
- Physics capabilities of LBNE
  - Beam-base neutrino oscillation measurements
  - Proton decay
- Approaching configuration decisions: Water vs. LAr and more
- Summary

Long Baseline Neutrino Experiment





New Neutrino Beam at Fermilab…

…Directed towards NSF’s proposed DUSEL

Precision Near Detector on the Fermilab site

100 kT fiducial volume Water Cherenkov Far Detector

17 kT fiducial volume Liquid Argon TPC Far Detector

LBNE and DUSEL

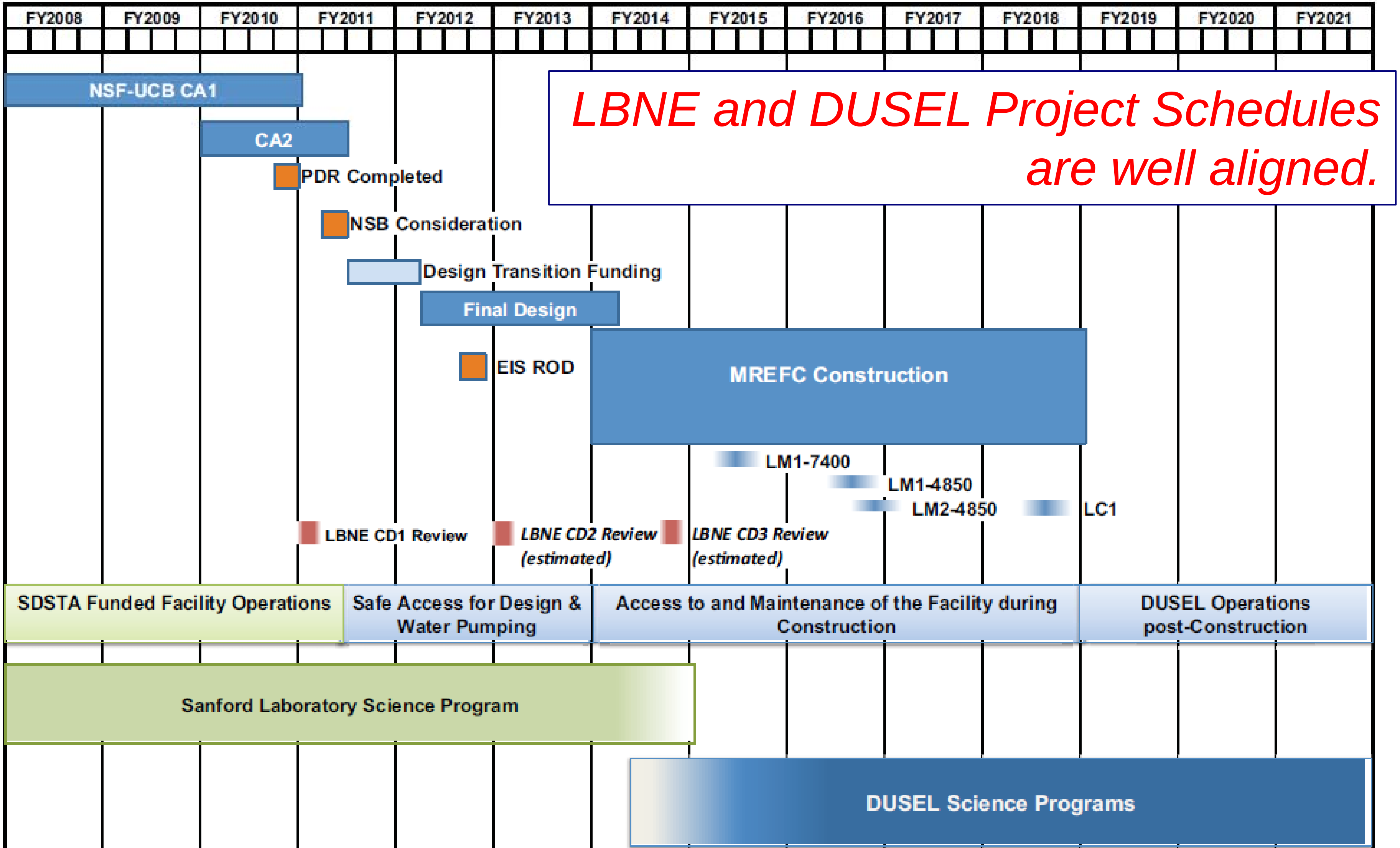
- NSF & DOE have formed the DUSEL Physics Joint Oversight Group (JOG), and have agreed:
  - NSF will steward DUSEL facility
  - DOE OHEP will steward LBNE, including beam line, near and far detectors
  - NSF will contribute to LBNE detector (& cavity)
- Good communication and cooperation has developed between DUSEL and LBNE:
  - Periodic meetings of Joint Agency Project Group involving DOE, NSF, DUSEL, LBNE, and Lab and UCB management
  - Laboratory Oversight Group formed
  - Regular DUSEL-LBNE coordination meetings
  - Growing integration of DUSEL and LBNE teams for civil construction planning

LBNE Project Time Line

- DOE CD-0 (Approve Mission Need) January 2010
- CD-1 Review (Conceptual design, preliminary cost and schedule range) December 2010
- CD-1 (assuming successful CD-1 review) April 2011
- CD-2 (Project baseline)
  depending on funding . . . mid/late FY2013
- CD-3 (start construction)
  depending on funding . . . 2014 ~ 2015
- Schedule for construction under development
  => estimate that project will be complete $\gtrsim$ 2020

Kevin Lesko, HEPAP, 3 June 2010

Milestone Schedule through Construction



 *these are 30% PD, non-optimized Beneficial Occupancy Estimates

Goals of LBNE

High-sensitivity measurement of ν_μ -> ν_e oscillations:

- Measure $\sin^2(2\theta_{13})$ to << 0.01
- Determine the mass hierarchy:
  Are ν_1 and ν_2 lighter or heavier than ν_3?
- Search for CP violation in the neutrino sector

Use very massive neutrino detectors for:

- Improved limits (or discovery!) of proton decay
- Measurements using astrophysical neutrinos:
  - Neutrinos from a supernova in (or near) our galaxy
  - Diffuse supernova neutrino flux
  - Atmospheric neutrinos
  - Solar neutrinos
- Further measurements of ν_μ disappearance

Precision neutrino cross-section measurements with Near Detector

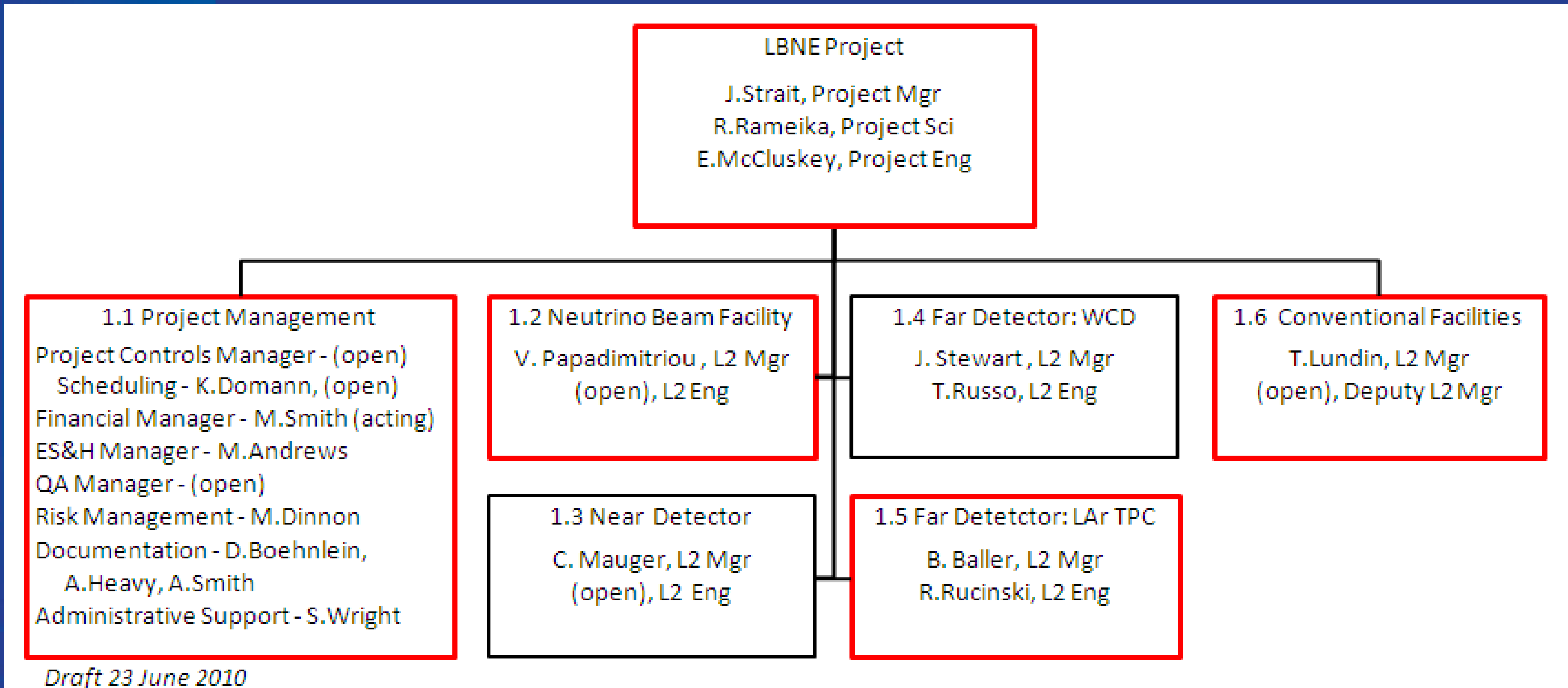
Long-Baseline Neutrino Experiment Collaboration

Alabama: J. Goon, I Stancu
Argonne: M. D'Agostino, G. Drake. Z. Djurcic, M. Goodman, X. Huang, V. Guarino, J. Paley, R. Talaga, M. Wetstein
Boston: E. Hazen**,** E. Kearns, J. Raaf, J. Stone
Brookhaven: M. Bishai, R. Brown, H. Chen, **M. Diwan**, J. Dolph, G. Geronimo, R. Gill, R. Hackenberg, R. Hahn, S. Hans, D. Jaffe, S. Junnarkar, J.S. Kettell, F. Lanni, L. Littenberg, D. Makowiecki, W. Marciano, W. Morse, Z. Parsa, C. Pearson, V. Radeka, S. Rescia, T. Russo, N. Samios,R. Sharma, N. Simos, J. Sondericker, J. Stewart, H. Tanaka, C. Thorn, B. Viren, Z. Wang, S. White, L. Whitehead, M. Yeh, B. Yu
Caltech: R. McKeown
Cambridge: A. Blake, M. Thomson
Catania/INFN: V. Bellini, G. Garilli, R. Potenza, M. Trovato
Chicago: E. Blucher
Colorado: A. Marino, M. Tzanov, E. Zimmerman
Colorado State: B. Berger, J. Harton, W. Toki, R. Wilson
Columbia: L. Camillieri, C.Y. Chi, C. Mariani, M. Shaevitz, W. Sippach, W. Willis
Crookston: D. Demuth
Dakota State: B. Szcerbinska
Davis: R. Breedon, T. Classen, J. Felde, M. Tripanthi, **R. Svoboda**
Drexel: C. Lane, J. Maricic, R. Milincic, K. Zbiri
Duke: J. Fowler, **J. Prendki,** K. Scholberg, C. Walter
Duluth: R. Gran, A. Habig
Fermilab: D. Allspach, B. Baller, D. Boehnlein, S. Childress, T. Dykhuis, A. Hahn, P. Huhr, J. Hylen, M. Johnson, T. Junk, B. Kayser, G. Koizumi, T. Lackowski, C. Laughton, P. Lucas, B. Lundberg, P. Mantsch, J. Morfin, V. Papadimitriou, R. Plunkett, C. Polly, S. Pordes, G. Rameika, B. Rebel, D. Reitzner, K. Riesselmann, R. Schmidt, D. Schmitz, P. Shanahan, J. Strait, K. Vaziri, G. Velev, G. Zeller, R. Zwaska
Hawaii: S. Dye, J. Kumar, J. Learned, S. Matsuno, S. Pakvasa, M. Rosen, G. Varner
Indian Universities: V. Bhatnagar, B. Bhuyan, B. Choudhary, P. Gupta, A. Kumar, S. Mandal, S. Sahijpal, V. Singh
Indiana: C. Bower, W. Fox, M. Messier, J. Musser, R. Tayloe, J. Urheim
Iowa State: M. Sanchez
IPMU/Tokyo: M. Vagins
Irvine: W. Kropp, M. Smy, H. Sobel
Kansas State: T. Bolton, G. Horton-Smith
LBNL: R. Kadel, B. Fujikawa, D. Taylor
Livermore: A. Bernstein, R. Bionta, S. Dazeley, S. Ouedraogo
London-UCL: J. Thomas
Los Alamos: S. Elliot, V. Gehman, G. Garvey, T. Haines, D. Lee, W. Louis, C. Mauger, G. Mills, Z. Pavlovic, G. Sinnis, R. Van de Water, H. White
Louisiana State: N. Buchanan, T. Kutter, W. Metcalf, J. Nowak
Maryland: E. Blaufuss, R. Hellauer, T. Straszheim, G. Sullivan
Michigan State: E. Arrieta-Diaz**,** C. Bromberg, D. Edmunds, J. Huston, B. Page
Minnesota: M. Marshak, W. Miller
MIT: W. Barletta, J. Conrad, R. Lanza, P. Fisher
NGA: S. Malys, S. Usman
New Mexico: B. Becker, J. Mathews
Notre Dame: J. Losecco
Oxford: G. Barr, J. DeJong, A. Weber
Pennsylvania: J. Klein, K. Lande, A. Mann, M. Newcomer, R. vanBerg
Pittsburgh: D. Naples, V. Paolone
Princeton: Q. He, K. McDonald
Rensselaer: D. Kaminski, J. Napolitano, S. Salon, P. Stoler
Rochester: R. Bradford, K. McFarland
SDMST: X. Bai, R. Corey
SMU: J. Ye
South Carolina: S. Mishra, R. Petti, C. Rosenfeld
South Dakota State: K. McTaggert
Texas: S. Kopp, K. Lang, R. Mehdiyev
Tufts: H. Gallagher, T. Kafka, W. Mann, J. Schnepps
UCLA: K. Arisaka, D. Cline, K. Lee, Y. Meng, F. Sergiampietri, H. Wang
Virginia Tech: J. Link
Washington: S. Enomoto, J. Kaspar, N. Tolich, H.K. Tseung
Wisconsin: B. Balantekin, F. Feyzi, K. Heeger, A. Karle, R. Maruyama, D. Webber, C. Wendt
Yale: B. Fleming, M. Soderberg, J. Spitz

262 Scientists and Engineers
59 Institutions
… And still growing!

4 June 2010

LBNE Project Organization



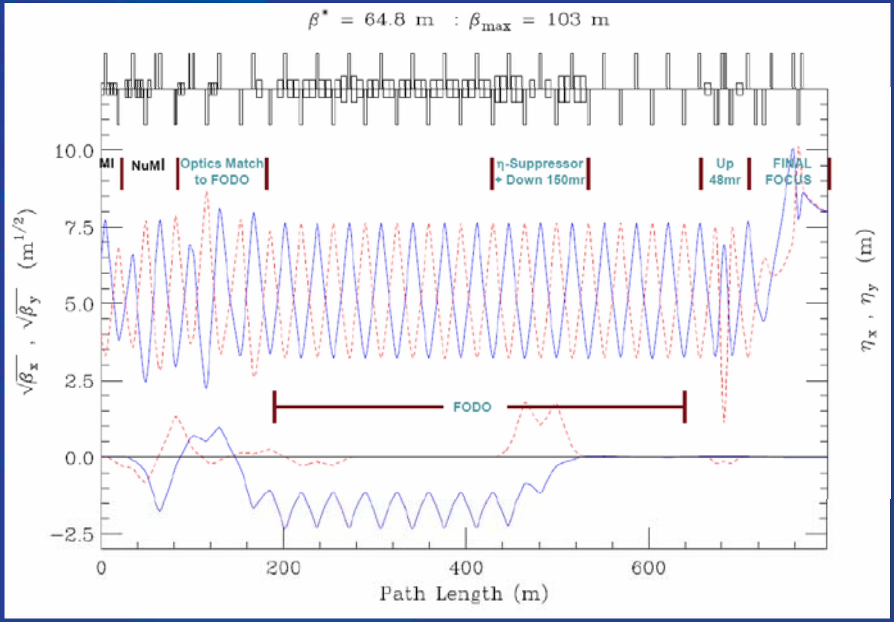
- Fermilab has overall responsibility, and is lead lab for the beam, LAr TPC Far Detector, and Conventional Facilities
- BNL is lead lab for Water Cherenkov Far Detector
- LANL is lead lab for Near Detector

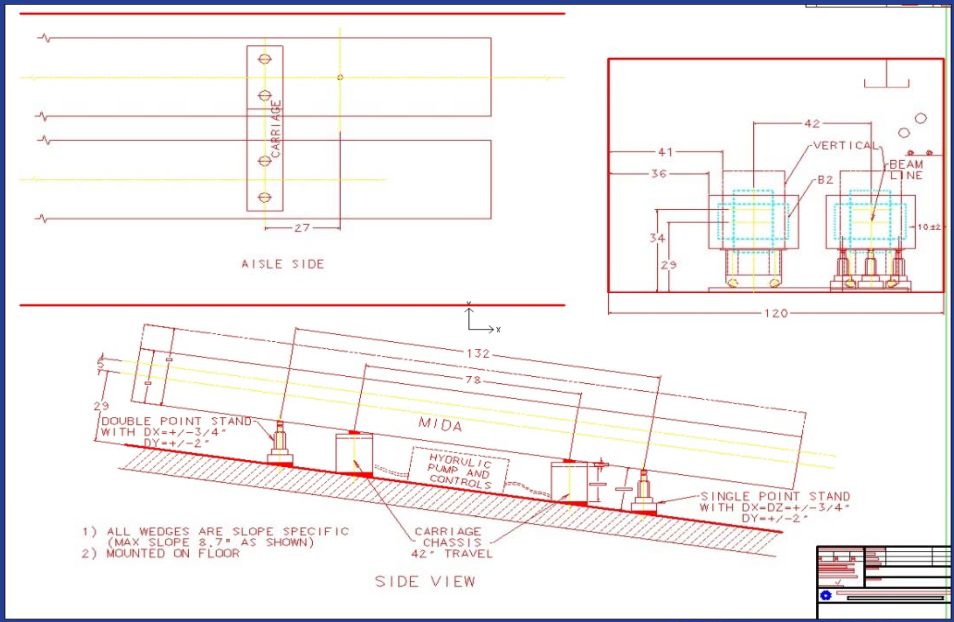
WBS 1.2 - New neutrino beam at Fermilab

- Led by Fermilab with collaboration support.
- Horn-focused ν beam, driven by Main Injector.
- Primary beam tunable 60 to 120 GeV
- Designed for initial P_{beam} = 0.7 MW, upgradeable to ≥2 MW.

WBS 1.2 - New neutrino beam at Fermilab

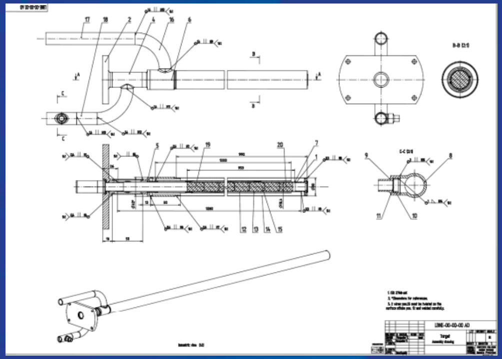
- Primary beam line design is well advanced:
  - Optics design has been set
  - Main magnet types have been chosen
  - Beam laid out to thread through the busy area between the 8 GeV lines, NuMI beam, and Main Injector
  - Vacuum system and instrumentation designs
  - Installation planning proceding

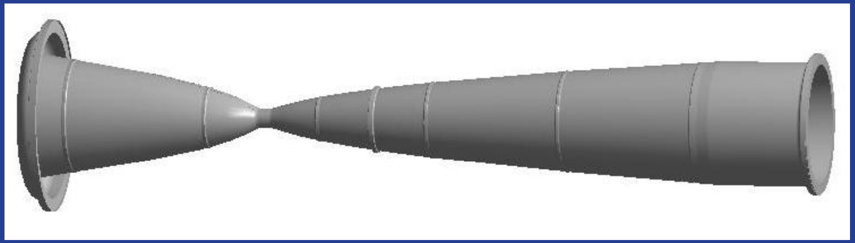




WBS 1.2 - New neutrino beam at Fermilab

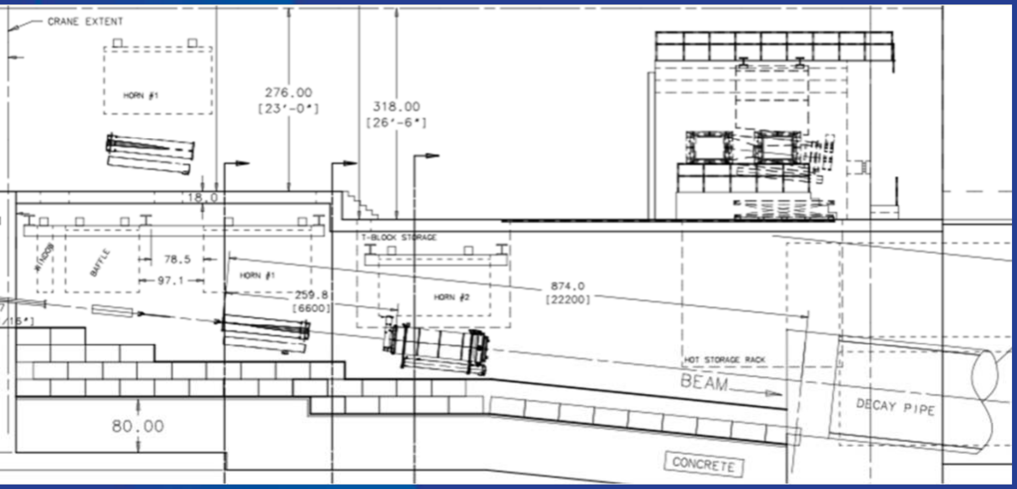
- Good progress on neutrino beam design.
  - Target design development with IHEP Protvino (graphite) and RAL (Beryllium).
  - Target material irradiation studies with BNL/BLIP
  - Target cooling studies with ANL
  - Horn system optimization work with BNL … 2-horn system chosen.
  - Horn conductor engineering and modeling is advancing well.
  - Remote handling planning with ORNL

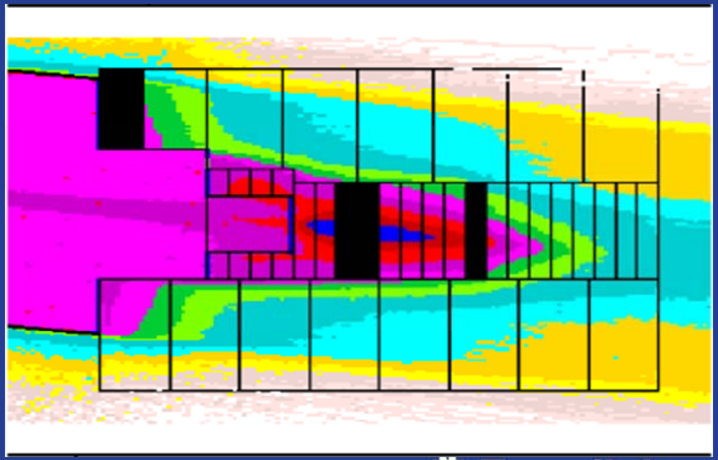




WBS 1.2 - New neutrino beam at Fermilab

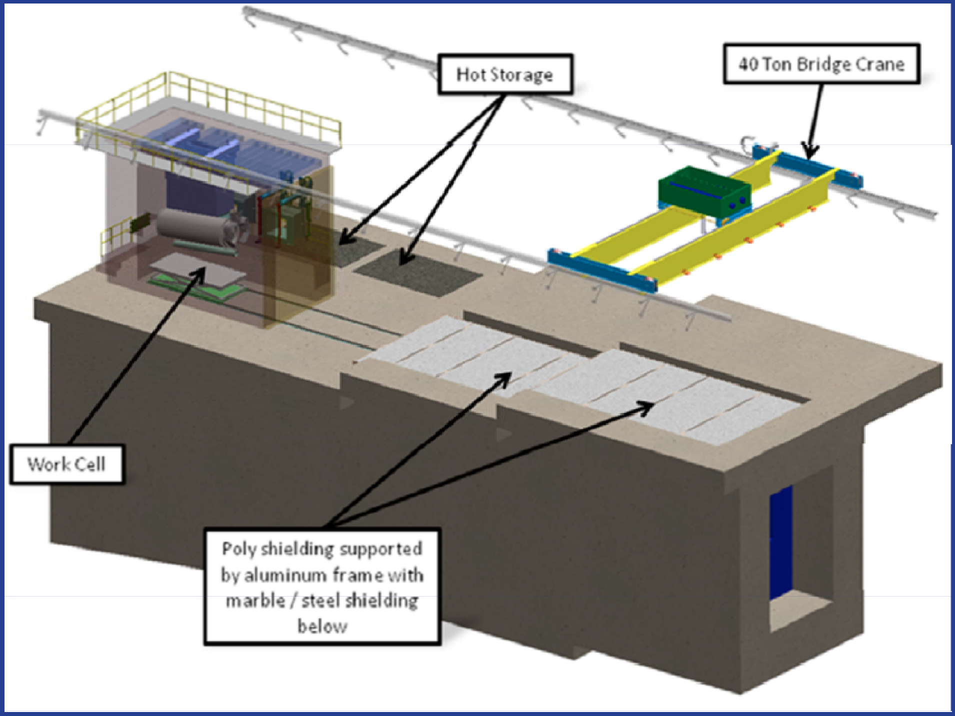
- Good progress on neutrino beam design.
  - Decay pipe dimension set (4 m ID, 250 m length)
  - Decay pipe cooling system preferred and alternate designs chosen
  - Hadron absorber engineering and modeling proceeding well.





WBS 1.2 - New neutrino beam at Fermilab

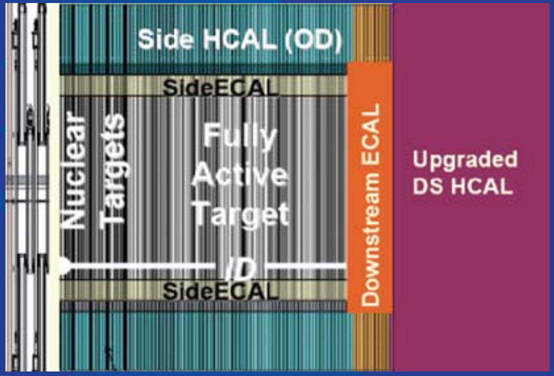
- Good progress on neutrino beam design.
  - Shielding and tritium calculations are advancing, based on measurements and experience with NuMI.
  - Requirements given to Conventional Facilities group to design beam enclosures and surface buildings.



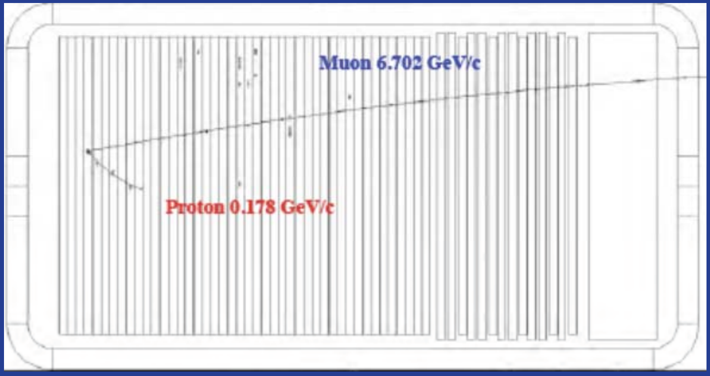
WBS 1.3 – Near Detector

- Led by LANL with collaboration support
- Small FNAL role
- Neutrino detector to measure un-oscillated beam spectrum and neutrino cross sections needed to make the oscillation measurements.
- Currently concentrating on physics studies to precisely define what is needed
- Several options under consideration:

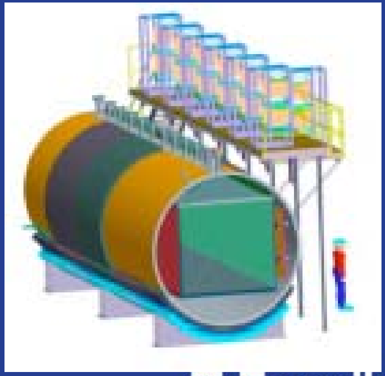
Scintillator tracker



Straw-tube tracker

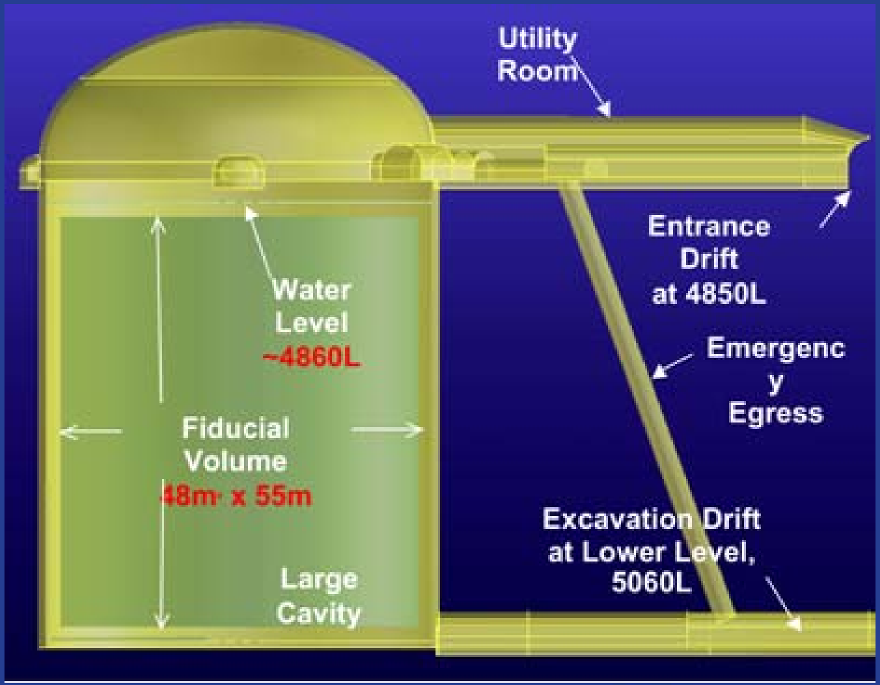


LAr TPC



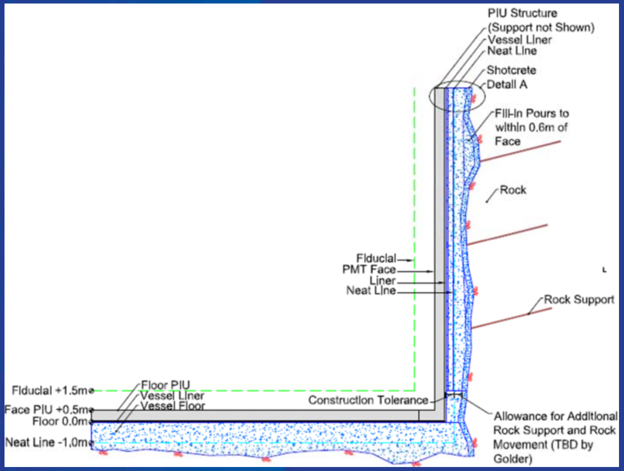
WBS 1.4 – Water Cherenkov Detector

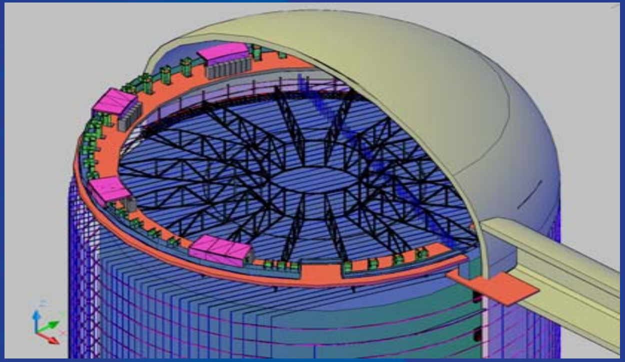
- Led by BNL with collaboration support.
- Fermilab leads the PMT effort, and is active on the water system design and simulations.
- Close coordination with NSF S4-funded design effort => integrated effort.
- Designing 100 kT Fiducial Volume "Modules," each ~ 4x Super-K

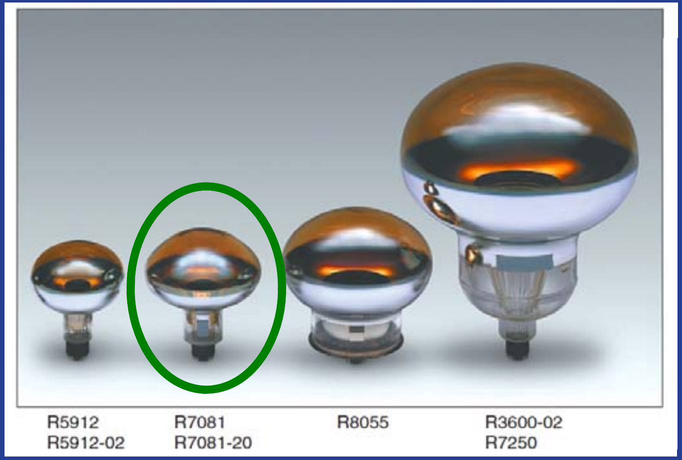


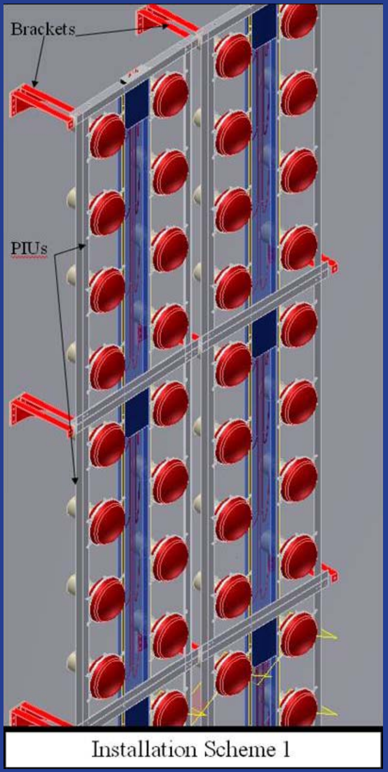
WBS 1.4 – Water Cherenkov Detector

- Active work on
  - Water tank and deck
  - Water system
  - Understanding PMT supply
  - PMT mounting systems









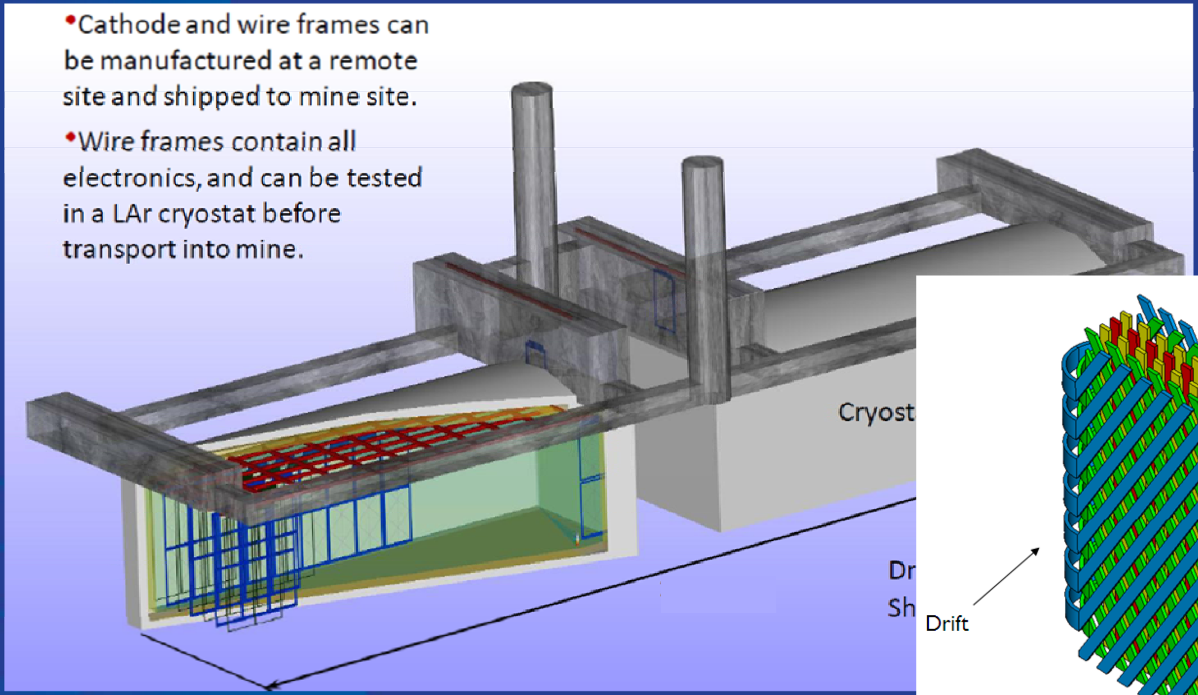
WBS 1.5 – LAr TPC

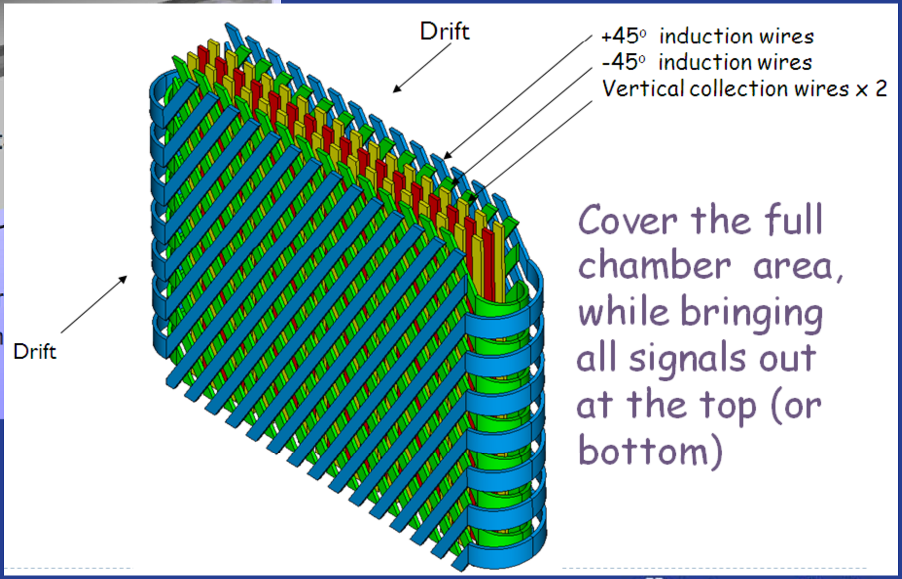
- Led by Fermilab with collaboration support.
- BNL has important role in electronics and TPC mechanical engineering.
- Designing ~17 kT fiducial volume modules ≅ same as 100 kT Water Cherenkov for oscillation physics.
- Cryostat and Cryogenic System engineering studies done mainly by contracts with outside firms (quasi-industrial products)
- Engineering options under study:
  - Evacuable (modular) vs. Non-evacuable* (membrane) cryostat
  - Vacuum vs. Passive* thermal insulation
  - Depth 4850 ft vs. 800* ft vs. 300 ft.
  - Cold* vs. Warm front-end electronics

*Reference Design

WBS 1.5 – LAr TPC

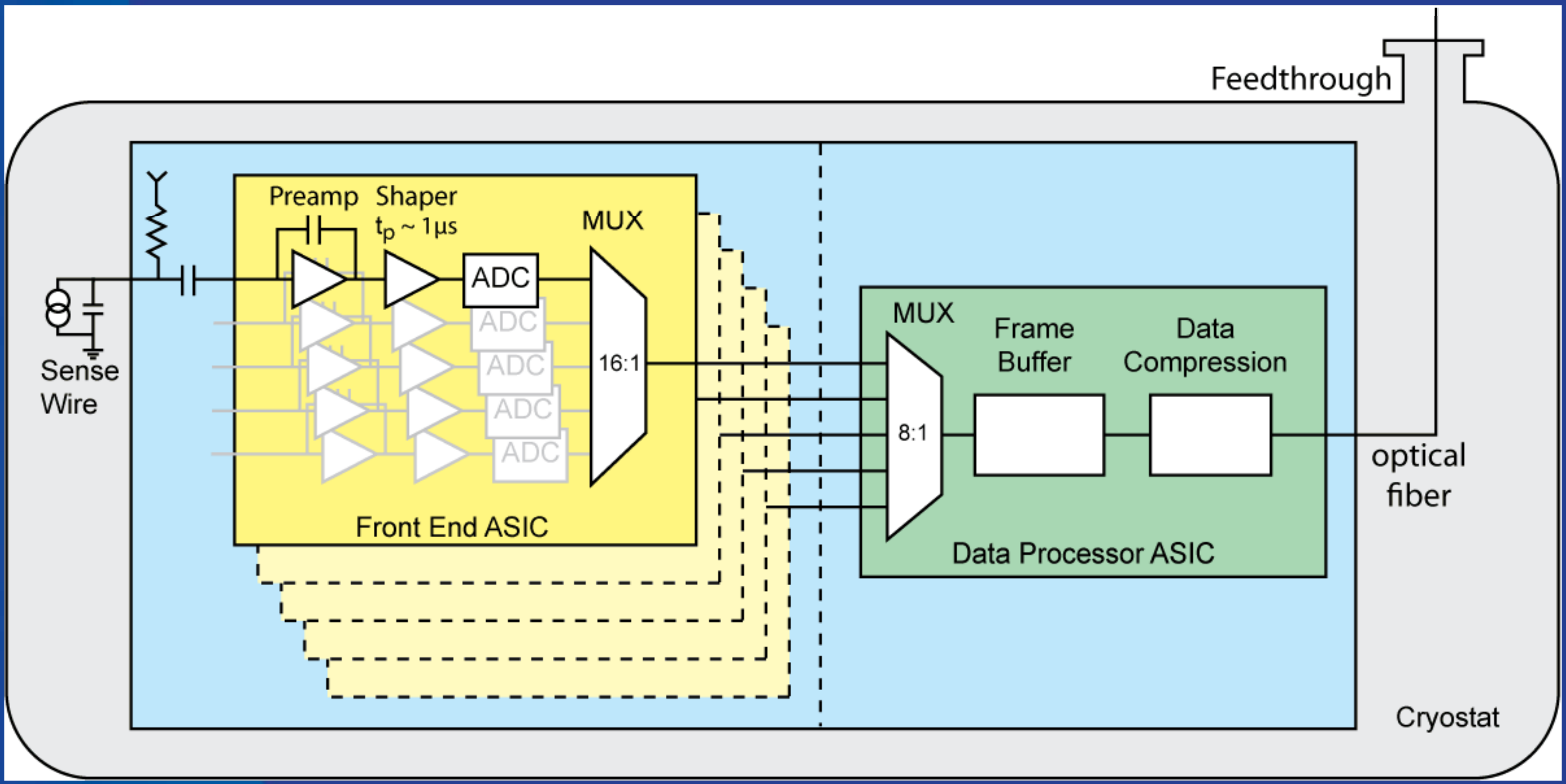
- Rectangular cryostat with possible 2nd cavern for LAr storage or 2nd detector
- TPC design – Anode Plane Assemblies





WBS 1.5 – LAr TPC

- Cold Electronics Block Diagram



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LAr Integrated R&D Plan

- The LBNE LAr TPC development benefits from work outside the Project that is part of the LAr Integrated R&D Plan.

<u>2009 Recommendation</u>

The laboratory should develop a detailed plan for development of the LAr/TPC technology with clear milestones for each aspect of this plan by the end of year. MicroBooNE should be considered as part of this development.

Integrated Plan for LArTPC neutrino detectors in the US

1 Executive Summary

We present an integrated R&D plan aimed at demonstrating the ability to build a very large Liquid Argon Time Projection Chamber (LArTPC), on a scale suitable for use as a Far Detector for the LBNE neutrino oscillation experiment. This plan adopts current LArTPC R&D-related activities and proposes new ones to address questions that go beyond those being answered by the current efforts. We have employed a risk evaluation strategy to identify questions that can be answered (or risks that can be mitigated) through one or more R&D steps.

In summary form, the plan consists of the following pre-existing components:

- The Materials Test Stand program, now in operation at Fermilab, addressing questions pertaining to maintenance of argon purity
- Exisiting electronics test stands at FNAL and BNL
- The Liquid Argon Purity Demonstrator (LAPD) now being assembled at Fermilab
- The ArgoNeuT prototype LArTPC, now running in the NuMI beam
- The MicroBooNE experiment, proposed as a physics experiment that will advance our understanding of the LArTPC technology, now completing its conceptual design phase.
- A software development effort that is well integrated across present and planned LArTPC detectors.

We are proposing to add to these efforts the following:

- A membrane cryostat mechanical prototype to evaluate and gain expertise with this technology.
- An installation and integration prototype, to understand issues pertaining to detector assembly, particularly in an underground environment.
- A $\sim 5\%$ scale electronics systems test to understand system-wide issues as well as individual component reliability.
- A calibration test stand that would consist of a small TPC to be exposed to a test beam for calibration studies, relevant for evaluation of physics sensitivities.

We have developed a timeline and milestones for achieving these goals as discussed in Section 4. The proposed activities necessary for the final design of LAr20 are complete by CD3 in 2014.

LAr Integrated R&D Plan

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

- Task force: 10 from U.S. & Italy
  - Development: Sep – Dec 09
  - Director's review – 23 Nov 09
  - Submitted to DOE – 21 Dec 09
- Plan elements:
  - Materials Test Stand at Fermilab – Argon purity
  - Electronics Test Stands at Fermilab and BNL
  - Liquid Argon Purity Demonstrator at Fermilab – Test purity in 30 T capacity, non-evacuable cryostat.
  - ArgoNeuT – Measure real neutrino interactions to use do develop reconstruction algorithms
  - MicroBooNE – Scale up to 2.6 m drift; construct and perform full physics experiment and analysis
  - LArSoft - Software development program to support analysis of ArgoNeuT, MicroBooNE and LBNE data.

LAr Integrated R&D Plan

- Additional plan elements:
  - Membrane Cryostat prototype – to evaluate and gain experience with this technology.
  - Installation and Integration prototype – to understand installation issues in a realistic environment for a large underground detector.
  - ~5% scale electronics systems test – to understand system-wide issues and component reliability.
  - Test beam module.
- The Integrated Plan is being executed as planned, subject to funding availability.

LAr Integrated R&D Plan - Milestones

Integrated Plan Milestones								
	30t LAPD	ArgoNeuT	MicroBooNE	30t Cryostat Prototype	Installation Mock-up	~5% Electronics Test	LBNE LAr20	Calibration Test
FY09Q3	Procurement	Running						
FY09Q4	Installation	Running						
FY10Q1		Running						
FY10Q2		Running	CD1					
FY10Q3	Results							
FY10Q4			CD2/3a	Procurement				
FY11Q1					Procurement			
FY11Q2			CD3b	Installation			CD1	
FY11Q4					Cryostat mock-up complete	Procurement		
FY12						Running	CD2	
FY13					Complete	Complete		
FY14							CD3	
FY15								
FY16								
FY17 FY18							 CD4	 Running

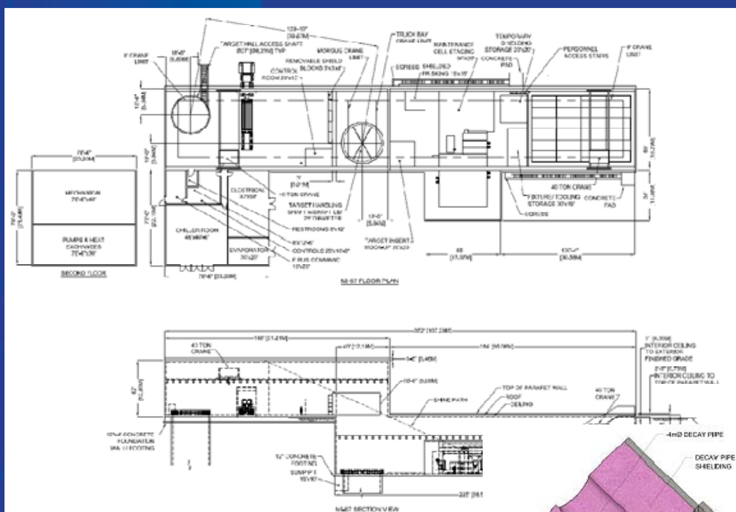
Table 1: Milestones in the Integrated plan needed to achieve CD3 by 2014 and CD4 by 2018.

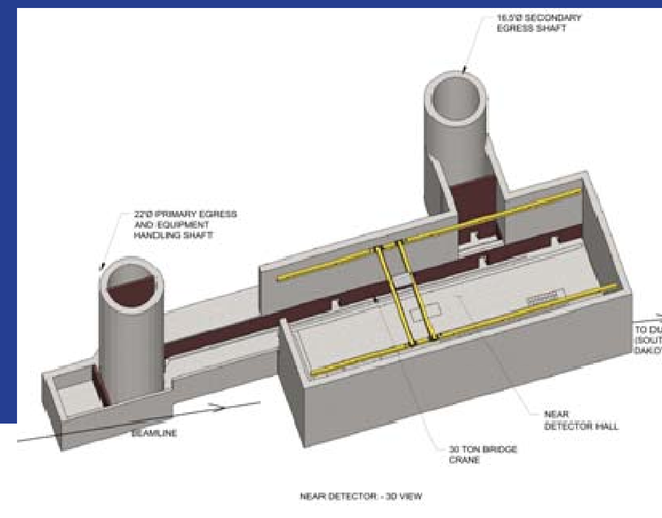
WBS 1.6 – Conventional Facilities

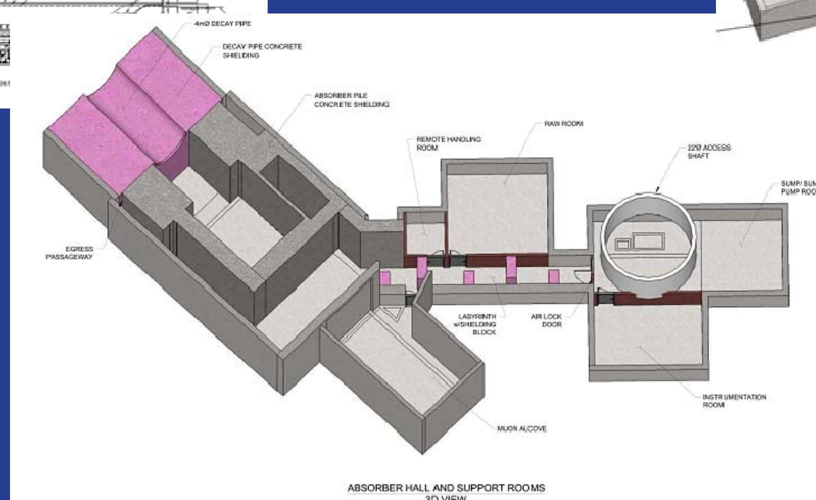
- Led by Fermilab, with input from the rest of the Project and the Collaboration.
- LBNE is responsible for underground and surface facilities at the near and far sites.
- Very close coordination with all other sub-projects is required.
- Very close coordination with DUSEL is required for all work at the far site.

WBS 1.6 – Conventional Facilities

- Underground and surface facilities for beam and near detector – design work proceding well.







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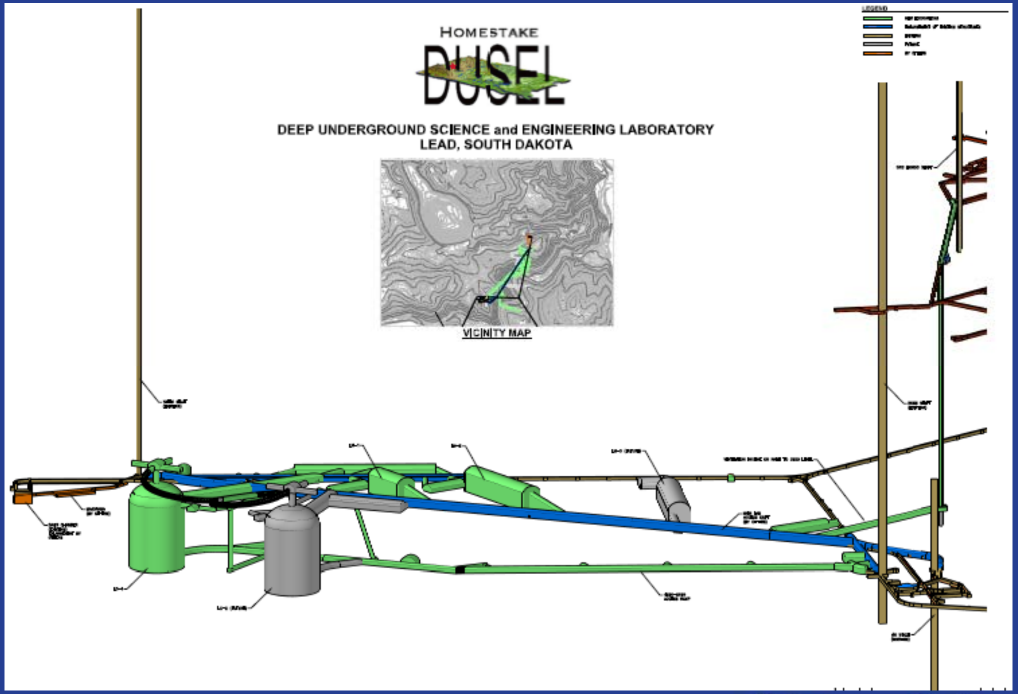
WBS 1.6 – Conventional Facilities

- Underground and surface civil engineering for LBNE-specific facilities on/in the DUSEL site.
- Currently rely on DUSEL for Large Cavity design for Water Cherenkov Detector.
- Design for 2 caverns, but with infrastructure to enable a 3rd.



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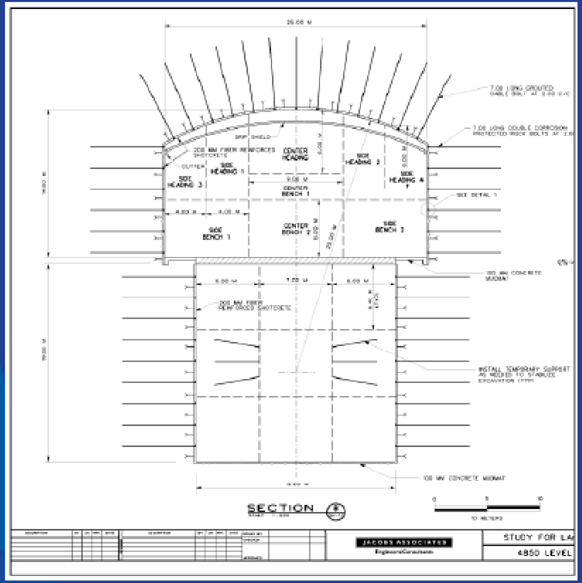
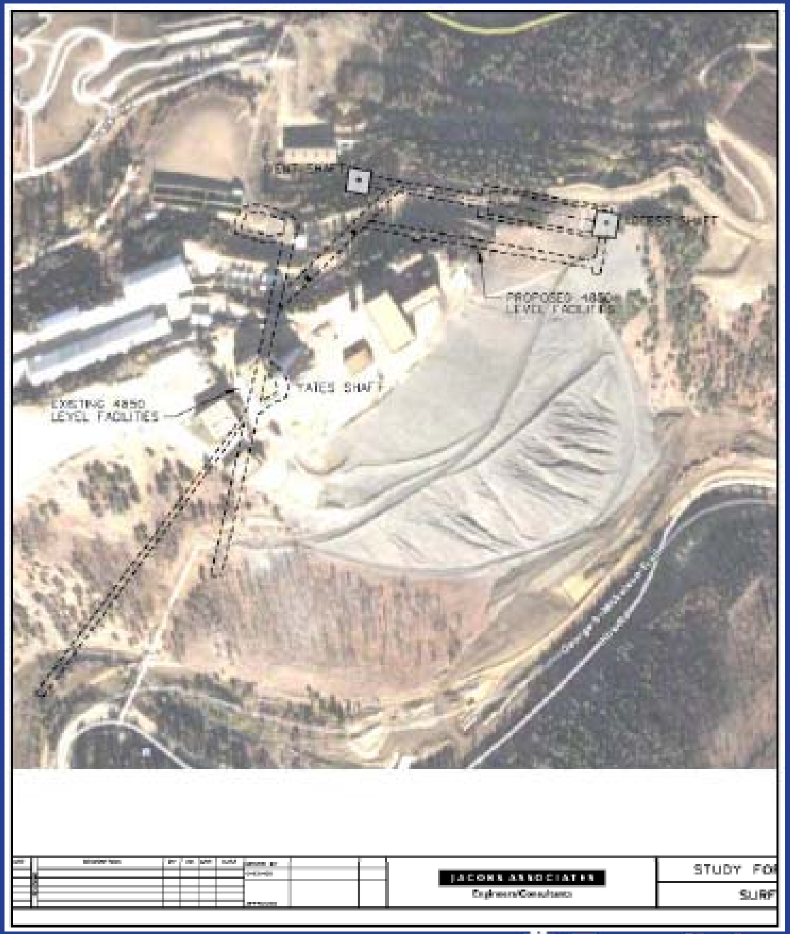
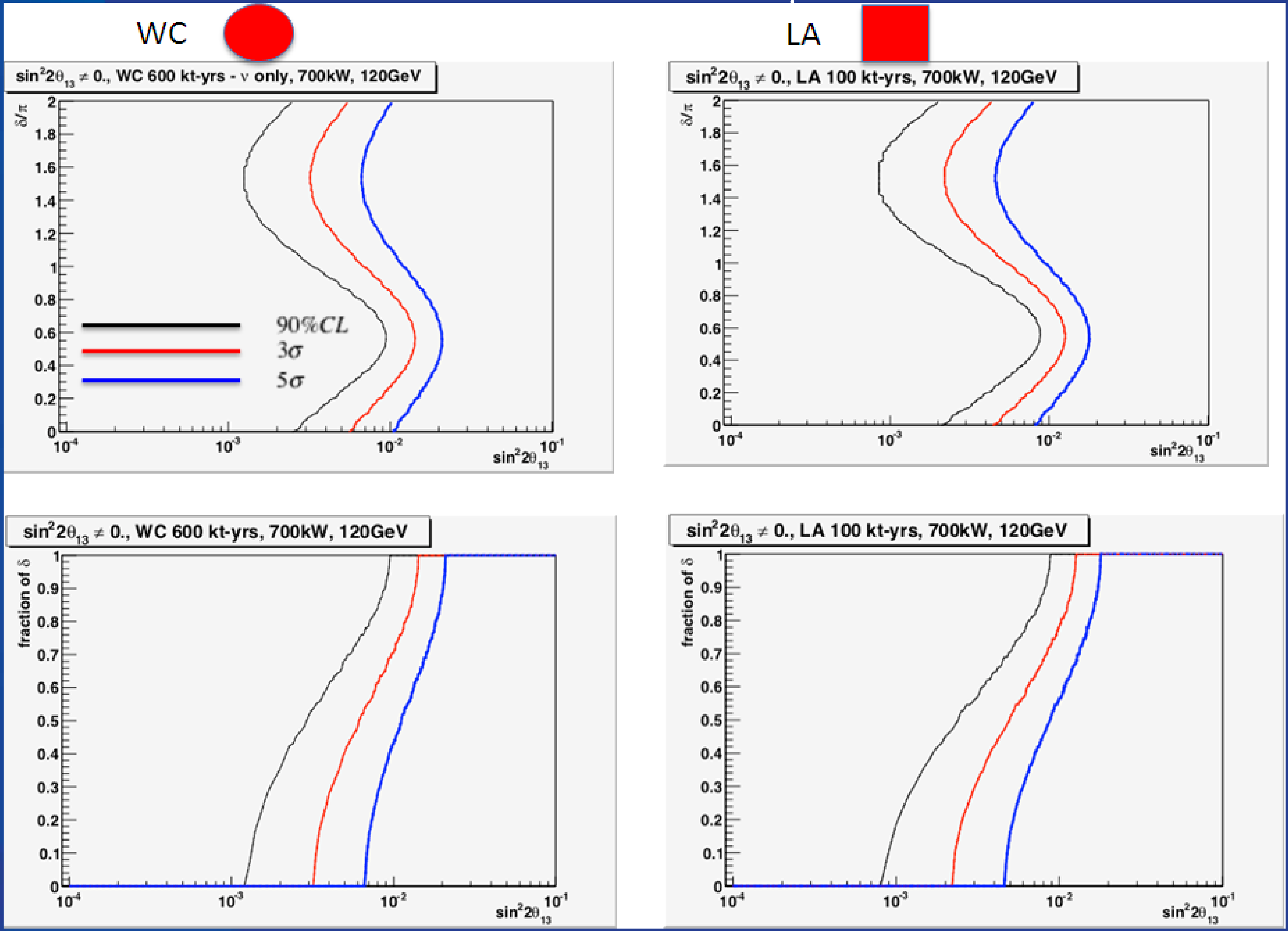
WBS 1.6 – Conventional Facilities

- Independent studies for LAr cavities
- Conceptual design studies done for 4850 ft and 300 ft
- Design for 800 ft recently launched

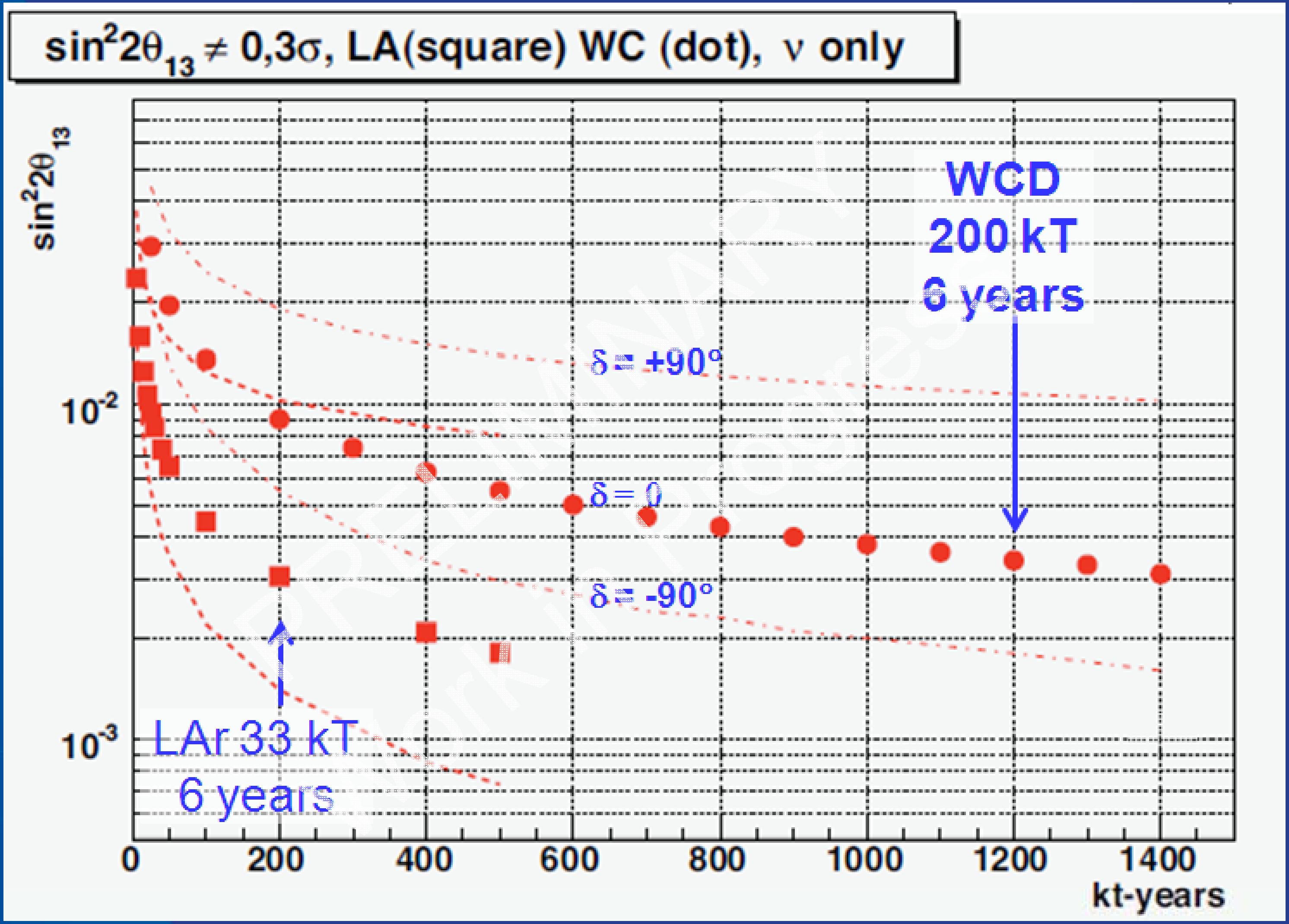




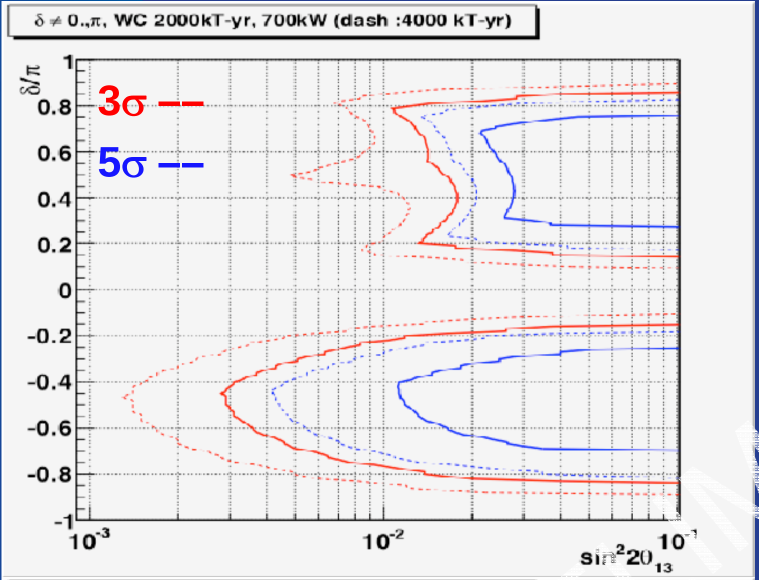
LBNE Physics Reach: ν_μ -> ν_e appearance

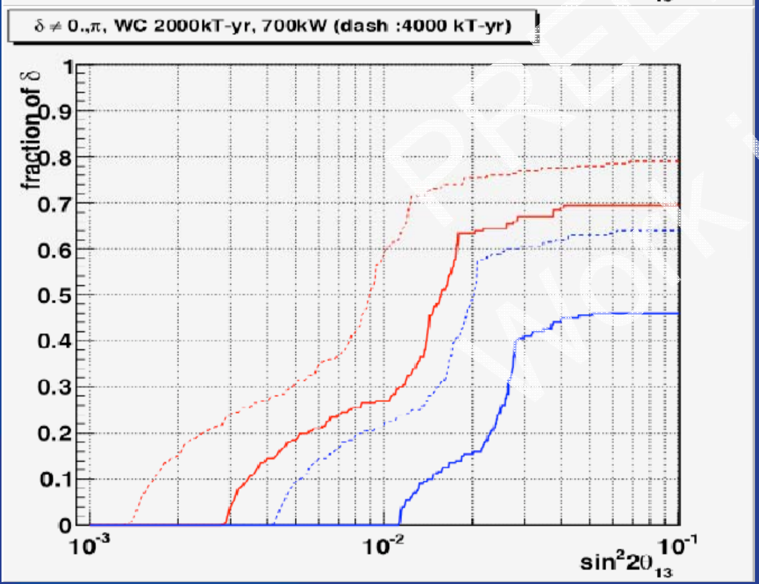


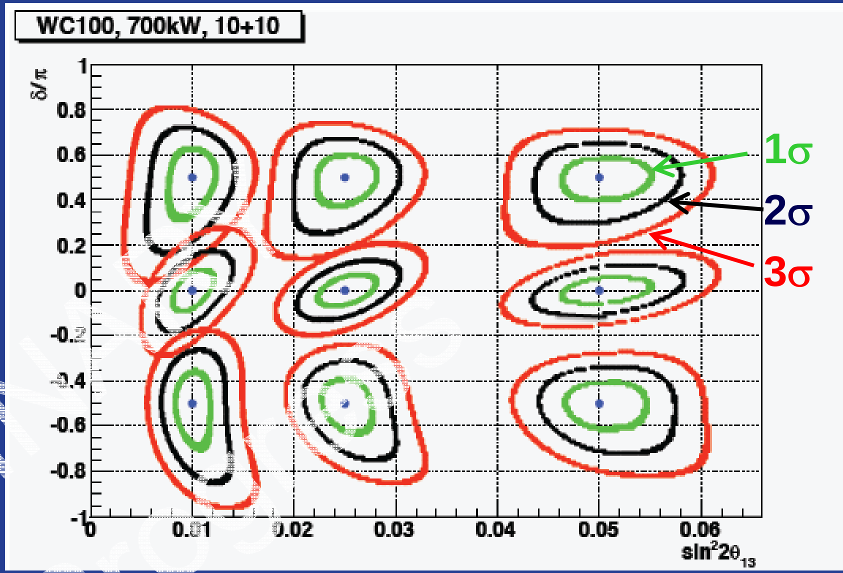
LBNE Physics Reach: ν_μ -> ν_e appearance

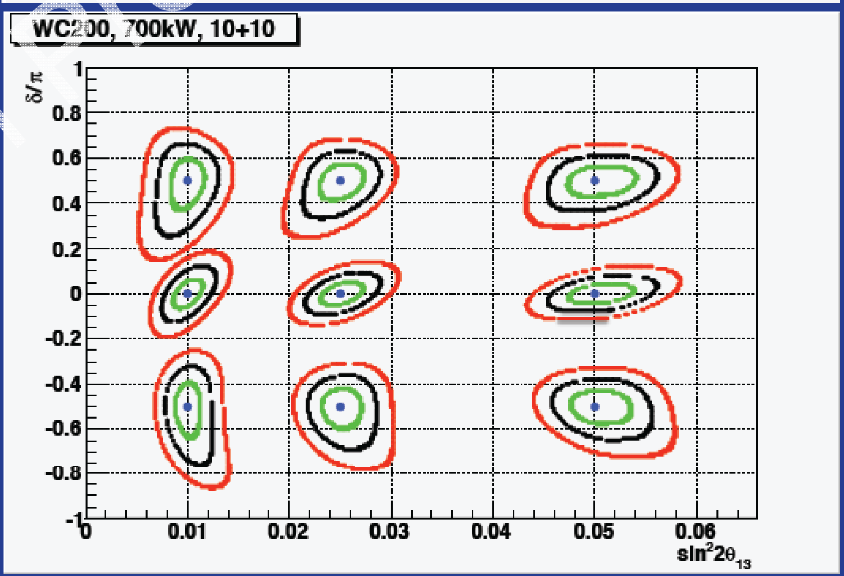


LBNE Physics Reach: CP Violation









LBNE Physics Reach – Proton Decay

Background: events/100 kt•yr

	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \rightarrow e^+\pi^0$	45%	0.2	45% ?	0.1
$p \rightarrow \nu K^+$	14%	0.6	97%	0.1
$p \rightarrow \mu^+ K^0$	8%	0.8	47%	0.2
n-nbar	10%	21		

No advantage for LAr over water for e^+pi^0: efficiency dominated by nuclear absorption of the pi^0 – for both.

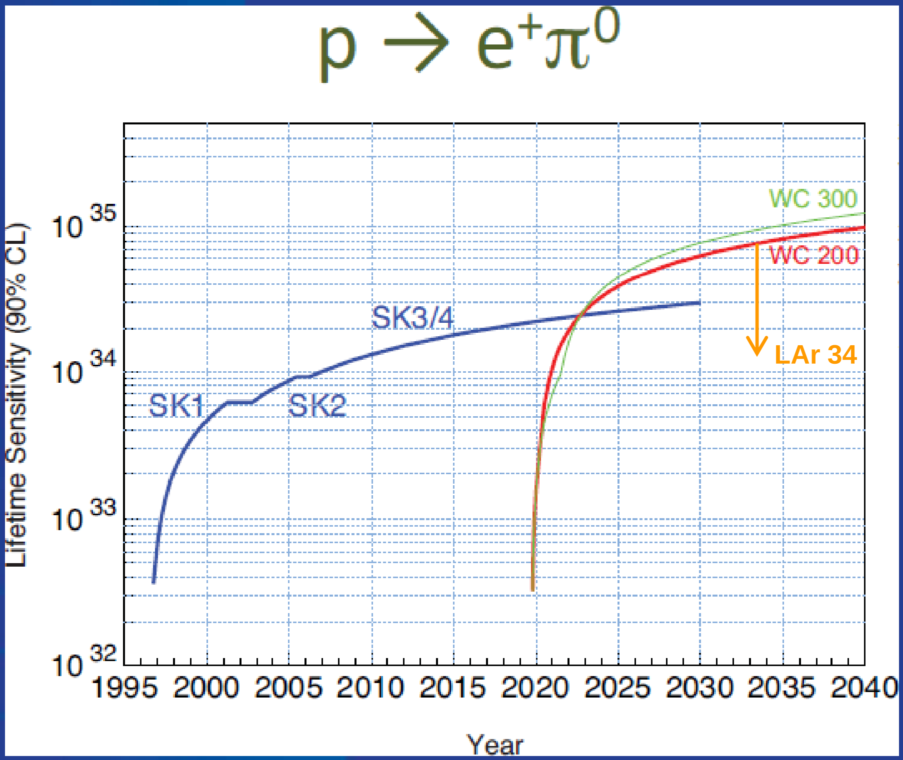
LAr $e^+\pi^0$ efficiency seems too high: estimate of nuclear effects [A. Rubbia group] may not be on equal footing as ^{16}O by Super-K.

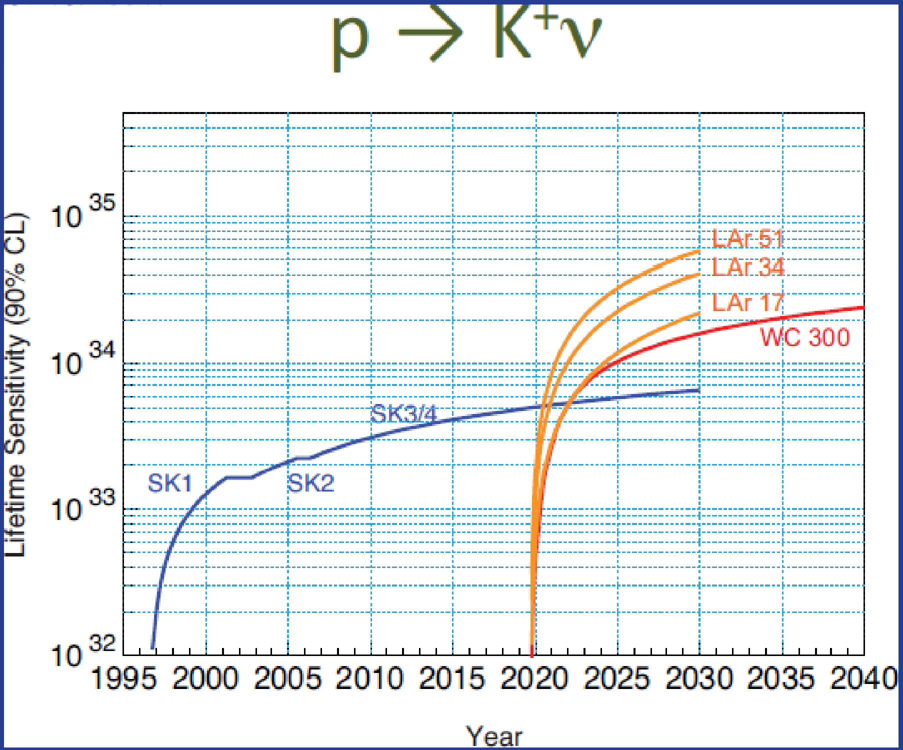
Big advantage for LAr over water for $K^+\nu$: K^+ is below Cherenkov threshold but can be identified by dE/dx in LAr TPC.

LAr could do well with n-nbar: spherical multipion final state.

Ed Kearns, LBNE Collab. Mtg., 27 May 2010.

LBNE Physics Reach – Proton Decay





Ed Kearns, LBNE Collab. Mtg.,
27 May 2010.

LBNE Configuration Decisions

- LBNE has many configuration choices, for example:
  - Water Cherenkov Detector vs. LAr TPC
  - Near Detector configuration
  - Investment in beam vs. near detector vs. far detector.
  - Detector mass vs. photocathode coverage
- Approach: Build an experimental complex to deliver the best possible science.
- Based on the DOE mission need statement and the NSF objectives for DUSEL Physics, we consider that Neutrino oscillations and proton decay should be most strongly considered in choosing the configuration for “the best possible science.”

LBNE Configuration Decisions

Inputs to the decision:

1) Determine physics sensitivities based on simulations of signal and background for each configuration.
2) Conduct risk analysis (technical, cost and schedule) for each detector technology and far-detector depth.
3) Estimate cost and schedule for each configuration.
4) Normalize far detector mass to common cost.
5) Estimate physics reach = f(t) for each configuration.

LBNE Configuration Decisions

- Plan – Constitute the Collaboration Executive Committee as an advisory committee charged to:
  - Evaluate the “input data”
  - Weigh the relative importance of the inputs
  - Produce a consensus report making recommendations concerning the configuration of experimental complex.
  - “Too early to decide” is a possible outcome for some choices prior to CD-2.

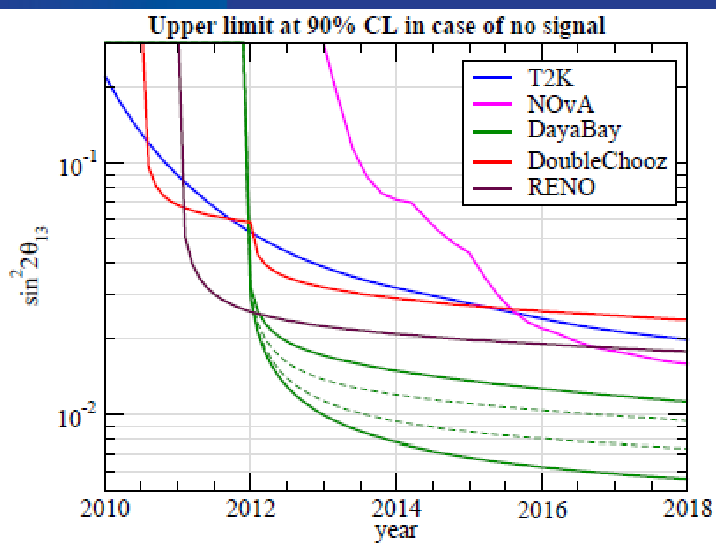
Summary

- LBNE, together with DUSEL, are planning a world-leading program in neutrino oscillations, proton decay and neutrino astrophysics.
- Major progress has been made in the past year:
  - Roles and relationships have been defined and established between DOE and NSF and between the DUSEL and LBNE Projects. The DUSEL and LBNE Projects are developing a strong partnership.
  - A strong LBNE Project Team is in place and is working well. Fermilab, BNL and LANL are committed to the Project.
  - The LBNE Science Collaboration is growing rapidly and working in close cooperation with the LBNE Project Team and DUSEL.
  - Serious progress is being made in developing the Conceptual Design, as well as other prerequisites for CD-1.

END

Neutrino Physics Strategy

- LBNE, as currently planned, is sensitive to CP violation discovery ($\delta \neq 0$ or π at $\geq 3\sigma$) for $\sin^2 2\theta_{13} \gtrsim 0.01$.
- By CD-2 (mid-2013) we are likely to have seen θ_{13} if $\sin^2 2\theta_{13} \gtrsim 0.05$, or have a limit $\lesssim 0.025$.
- θ_{13} limits/discovery potential are likely to improve modestly between CD-2 and CD-3 (late 2014 or early 2015).



M.Mezzetto, T.Schwetz, arXiv:1003.5800v1 [hep-ph] 30 Mar 2010

Figure 18. Evolution of the θ_{13} sensitivity limit as a function of time (90% CL), i.e., the 90% CL limit which will be obtained if the true θ_{13} is zero. The four curves for Daya Bay correspond to different assumptions on the achieved systematic uncertainty, from weakest to strongest sensitivity: 0.6% correlated among detector modules at one site, 0.38% correlated, 0.38% uncorrelated among modules, 0.18% uncorrelated.

Neutrino Physics Strategy

If $\sin^2 2\theta_{13}$ is not known to be > 0.01 at CD-2 or CD-3 we could:

- Continue the project to search for ν_e appearance, pushing to the lowest possible θ_{13}, and to execute the rest of the LBNE program. Utilize the higher beam power from Project X when it becomes available to extend the reach.
- Build the far detectors to focus on proton decay and neutrino astrophysics, but not build the beam until θ_{13} is found by others.
- Continue project planning, but wait to start construction until θ_{13} is found by others.

Neutrino Physics Strategy

- Build low-energy neutrino factory, based on the Project X beam and aimed at DUSEL.
  - θ_{13} discovery down to $\sin^2 2\theta_{13} \sim 10^{-4}$ and CP violation discovery down to $\sin^2 2\theta_{13} \sim 10^{-3}$.
  - International Design Study RDR due in 2012/2013, progress on Muon Accelerator Program => basis for decision.
  - Requires magnetized detectors at DUSEL, which could be optimized also for proton decay and neutrino astrophysics.
- Take advantage of new ideas that may arise.

Substantial study, and consultation with the funding agencies and the broader HEP community would be required to determine the best path to take.