Long Baseline Neutrino Experiment (LBNE)

Gina Rameika

PAC Presentation

June 24, 2009

U.S. DEPARTMENT OF ENERGY

Fermilab

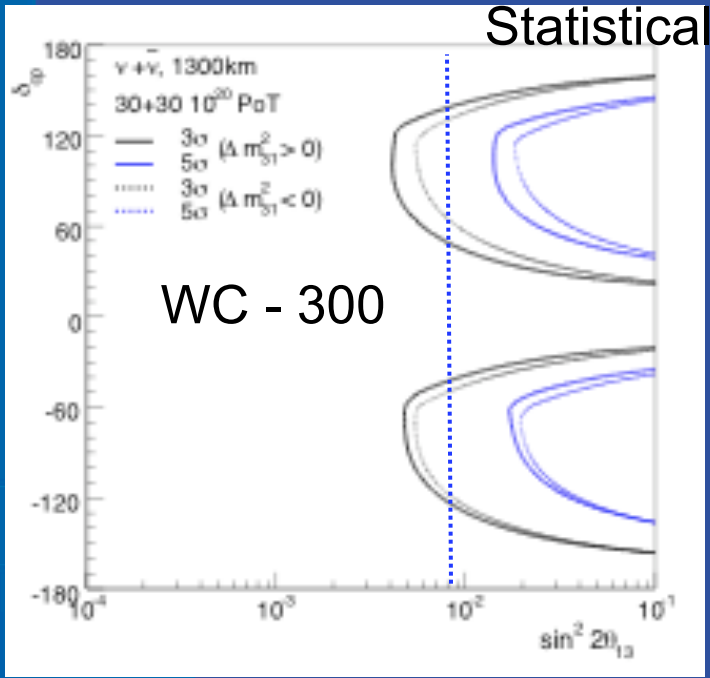
Outline

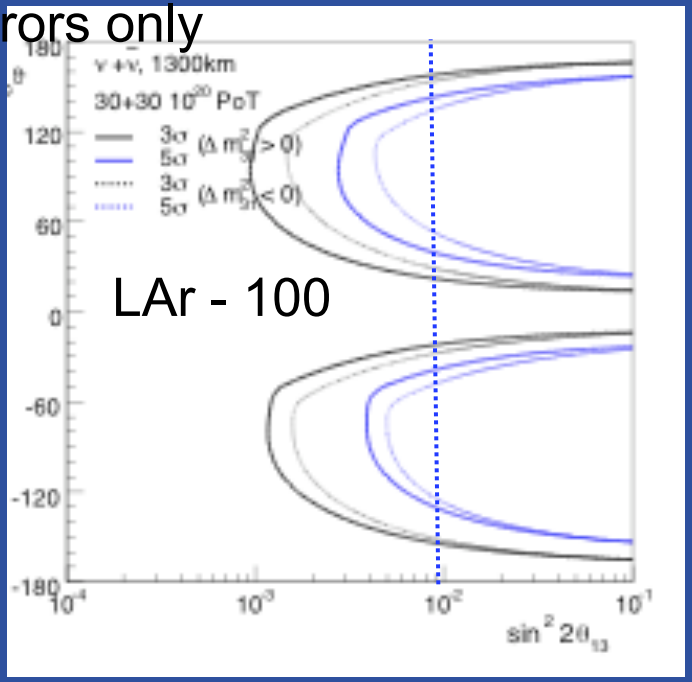
- Introduction – What is LBNE ?
- Project Organization and Status
- Detectors : Far and Near
- The Nu Beam
- Budgets, Manpower requirements, resources

2006-2007 US Long Baseline Study

- Main Conclusions
  - 1300 km baseline is superior to the possible baselines in NuMI
  - Two detector technologies should be considered

Statistical errors only





New Beam, Large Detectors ➔ Big Project ➔ Potential Big Payoff

Fermilab

Proposal for a very large water Cherenkov detector

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Physics Department, Brookhaven National Laboratory, Upton, NY 11973

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J. Stone
Physics Department, Boston University, Boston, MA 02215, USA

(Dated: June 5, 2007)

Abstract

We propose that a very large water Cherenkov detector with mass in the range of ~ 1000 kton be built at the National Science Foundation's Deep Underground Science and Engineering Laboratory (DUSEL) and that Fermi National Accelerator Laboratory take the lead in the design and construction of this detector facility. Such a detector facility will be a landmark scientific endeavor. It has the dynamic range in energy, and background reduction capability needed for a broad attack on the physics of nucleon decay, neutrino oscillations, and supernova neutrinos, three areas of profound scientific interest highlighted in recent National Academy, HEPAP, and APS Reports. Recent Homestake Collaboration preliminary engineering studies have shown that there are no technical obstacles to building this detector at depths as great ~ 6000 feet. An international collaboration with deep expertise can be assembled to build this detector in a relatively short period. This project is of the correct scale, scientific importance, and timing to be a major focus of the US High Energy Physics Program before the International Linear Collider and fulfills the requirement of investment in a facilities that maximizes the discovery potential during the next two decades.

LAr5 -
A Liquid Argon Neutrino Detector
for
Long Baseline Neutrino Physics

March 13, 2008

A 1st step in a Long Term Program

Contributors and Potential Collaborators

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Tufts University

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Yale University

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Spring 2008 – P5 Report

The Intensity Frontier

The accelerator-based neutrino program

- Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for understanding the evolution of the universe. The US can build on the unique capabilities and infrastructure at Fermilab, together with the proposed DUSEL, the Deep Underground Science and Engineering Laboratory proposed for the Homestake Mine, to develop a world-leading program in neutrino science. Such a program will require a multi-megawatt proton source at Fermilab.

- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

U.S. DEPARTMENT OF ENERGY
Office of Science

Intensity Frontier
Accelerator Based Neutrino Program

- DOE OHEP proceeding to develop a conceptual design for an accelerator long-baseline neutrino experiment
- Planning to get CD-0 approval by the end of CY 2008
  - Fermilab will have overall project management
  - Brookhaven will have responsibility for detector
- Expectation is that detector will be located at DUSEL and the beam line at Fermilab.
- Complete CD-1 by late 2009/early 2010.
  - Explore alternatives for detector (technology, size, location)
  - Explore alternatives for beamline (power, location)
  - Cost/benefit analysis - scientific reaches, cost ranges, etc.
- DOE OHEP & ONP collaborating with NSF
  - On Detector R&D
  - On development of a MOU for collaboration on nuclear and particle physics experiments.
  - First Joint Oversight Group (JOG) meeting scheduled for Dec 10th

Charge from DOE – February 2009

From: Blazey, Gerald
To: Young-Kee Kim ; Vigdor, Steven
Cc: Blazey, Gerald ; Procario, Michael
Sent: Wednesday, February 25, 2009 4:09 PM
Subject: Informal LBNE Scope

Scope of Work for LBNE CD1 Planning

We would like to see Fermilab and Brookhaven form a well integrated, effective team to develop the CD1 documentation for a Long Baseline Neutrino Experiment (LBNE). The LBNE is comprised of a neutrino beam line, a near detector, and a far detector. The target time frame for completion of the CD1 documentation is the third quarter of FY 2010.

Based on expertise, experience, and expressed interest we envision the following responsibilities. Fermilab will have overall responsibility for the documentation. In terms of major LBNE components, Fermilab has responsibility for the beamline and the near detector, while Brookhaven has responsibility for the far detector. The two institutions should jointly develop a preliminary plan for CD1 documentation by March 16, 2009.

- FNAL Responsibility :
  - Project Management
  - Beam
  - Near Detector
- BNL Responsibility
  - Far Detector

As required, the CD1 documentation should include an alternatives analysis and cost range estimate. The analysis should be performed for source intensity and location; detector size, technology, location and depth; and operational scenarios for multi-detector, multi-location options. This is not meant to be an exhaustive list.

The proposed plan should address management structure and personnel and resource requirements for completion of a CD1. The institutions should propose a project structure which will efficiently and without duplication develop the CD1 documentation and which will ensure communications with the NSF sponsored DUSEL project and the self-organized large detector collaboration. The proposal should list the type of personnel needed to complete CD1 documentation as well as the funds needed for contracts, travel, and appropriate short-term R&D.

The Self-Organized Science Collaboration

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Collaboration Vision Statement

The primary goal of this collaboration is to perform a world-leading long-baseline neutrino oscillation experiment that will reach unprecedented sensitivity and precision for addressing the neutrino mass hierarchy, CP violation in neutrino mixing, and the value of the mixing parameter θ_{13}. This experiment will require the development and construction of new facilities that will also provide new capabilities to search for nucleon decay, observe neutrinos emitted by supernovae in our galaxy and beyond, and other important topics in physics and astrophysics.

The concept for this experiment includes a high-intensity neutrino beam generated at Fermilab and a large underground detector facility at the DUSEL site in Lead, South Dakota. The neutrino beam will be generated by a high-power proton beam that exceeds present capabilities, and the neutrino beam configuration must be optimized for the baseline and neutrino oscillation parameters. We have identified two detector technologies with the potential to achieve our science goals: water Cerenkov (WC) and liquid Argon (LA) Time Projection Chamber. Recent studies have indicated that total detector masses of >300kTon (fiducial) for WC or >50kTon (fiducial) for LA are suitable. We envision that the detector facility would consist of several detector modules, and an ideal experiment might be a mixture of WC and LA detector modules due to their complementary capabilities.

Achieving these goals will require an extension of present-day technologies on a challenging time-scale to insure that the US program maintains a competitive advantage. Our current anticipated schedule is to be ready to begin beamline and detector construction as early as FY13. This schedule will require immediate establishment of vigorous R&D and engineering efforts towards development of the beamline and both WC and LA detector technologies.

Comment on the Collaboration

- The collaboration has a common vision on the science
  - Large Detectors offer multiple science opportunities
    - Accelerator Neutrino Physics (once you have a beam)
    - Proton Decay (once you have enough mass)
    - Supernova detection (if your detector is there when it happens)
    - If you try hard : relic supernovae, solar neutrinos, geoneutrinos,…
    - Be ready for surprises and new ideas
- There is passionate debate on the detector technology

Deep Underground Science and Engineering Laboratory (DUSEL S4)

Development of Technical Designs for Potential Candidates for the DUSEL Suite of Experiments

PROGRAM SOLICITATION
NSF 09-500

National Science Foundation

Directorate for Mathematical & Physical Sciences
Division of Physics

Directorate for Engineering
Civil, Mechanical and Manufacturing Innovation

Directorate for Geosciences
Division of Earth Sciences

Full Proposal Deadline(s) (due by 5 p.m. proposer's local time):

January 09, 2009

3 year proposals

To develop Preliminary Designs

(more than CD-1, less than CD-2)

Proposals were due January 9, 2009

Water Cerenkov – S4

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE (If not in response to a program announcement/solicitation enter NSF 09-1)
NSF 09-500 01/09/09

FOR NSF USE ONLY
NSF PROPOSAL NUMBER
0919550

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)
PHY - UNDERGROUND PHYSICS

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946036494

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
University of California-Davis

AWARDEE ORGANIZATION CODE (IF KNOWN)
0013136000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
OR/Sponsored Programs
1850 Research Park Dr., Ste 300
Davis, CA 95618-0000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

PERFORMING ORGANIZATION CODE (IF KNOWN)

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **A Proposal to Design a Megaton-Scale Water Cerenkov Detector for the Deep Underground Science and Engineering Lab**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,883,647	36 months	06/01/09	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT
Physics

PI/PD FAX NUMBER
530-752-4717

PI/PD POSTAL ADDRESS
OR/Sponsored Programs
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CO-PI/PD				

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Electronic Signature

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A Proposal to Design a Megaton-Scale Water Cerenkov Detector for the Deep Underground Science and Engineering Lab

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1. Lawrence Livermore National Laboratory
2. Brookhaven National Laboratory
3. University of Maryland
4. CCPM, Marseilles
5. LAL, Orsay
6. University of Wisconsin, Madison
7. Argonne National Laboratory
8. Lawrence Berkeley National Laboratory
9. Rensselaer Polytechnic Institute
10. Boston University
11. University of Pennsylvania
12. University of California, Irvine
13. Drexel University
14. Fermi National Accelerator Laboratory
15. Los Alamos National Laboratory
16. California Institute of Technology
17. University of Minnesota
18. University of South Carolina
19. APC, Paris, University of Paris Diderot
20. Duke University
21. University of California, Davis
22. LAPP, Annecy

48 names

22 institutions

R. Svoboda - PI

Includes a near detector task – FNAL, LANL

Liquid Argon – S4

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE (If not in response to a program announcement/solicitation enter NSF 09-1)
NSF 09-500 01/09/09

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PHY - UNDERGROUND PHYSICS

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EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN): 416007513

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IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE: University of Minnesota-Twin Cities

AWARDEE ORGANIZATION CODE (IF KNOWN): 0023879000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE:
200 OAK ST SE
MINNEAPOLIS, MN 55455-5200

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE:

PERFORMING ORGANIZATION CODE (IF KNOWN):

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE:

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT: Collaborative Research: Design of a Next Generation Liquid Argon Detector

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 2,460,489	36 months	07/01/09	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
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☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☒ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
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PI/PD DEPARTMENT: School of Physics and Astronomy

PI/PD FAX NUMBER: 612-624-4578

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CO-PI/PD Niki Saoulidou	DPhil	2003	202-293-1382	niki@fnal.gov
CO-PI/PD				
CO-PI/PD				

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M. Marshak - PI

1.4 Collaboration Organization: This proposal is an initiative of the DUSEL Long Baseline Detector Collaboration (LBDC). The LBDC intends to pursue both WC and LAr technologies with S4 Proposals because (a) both technologies have uncertainties, (b) the physics of the two detector types may be complementary and (c) the long-term nature of DUSEL suggests that its experimental program will evolve over time. The project organization for the NGLArD is described in Section 5.0. The Principal and Senior Investigators of this NGLArD Collaboration and their areas of focus are:

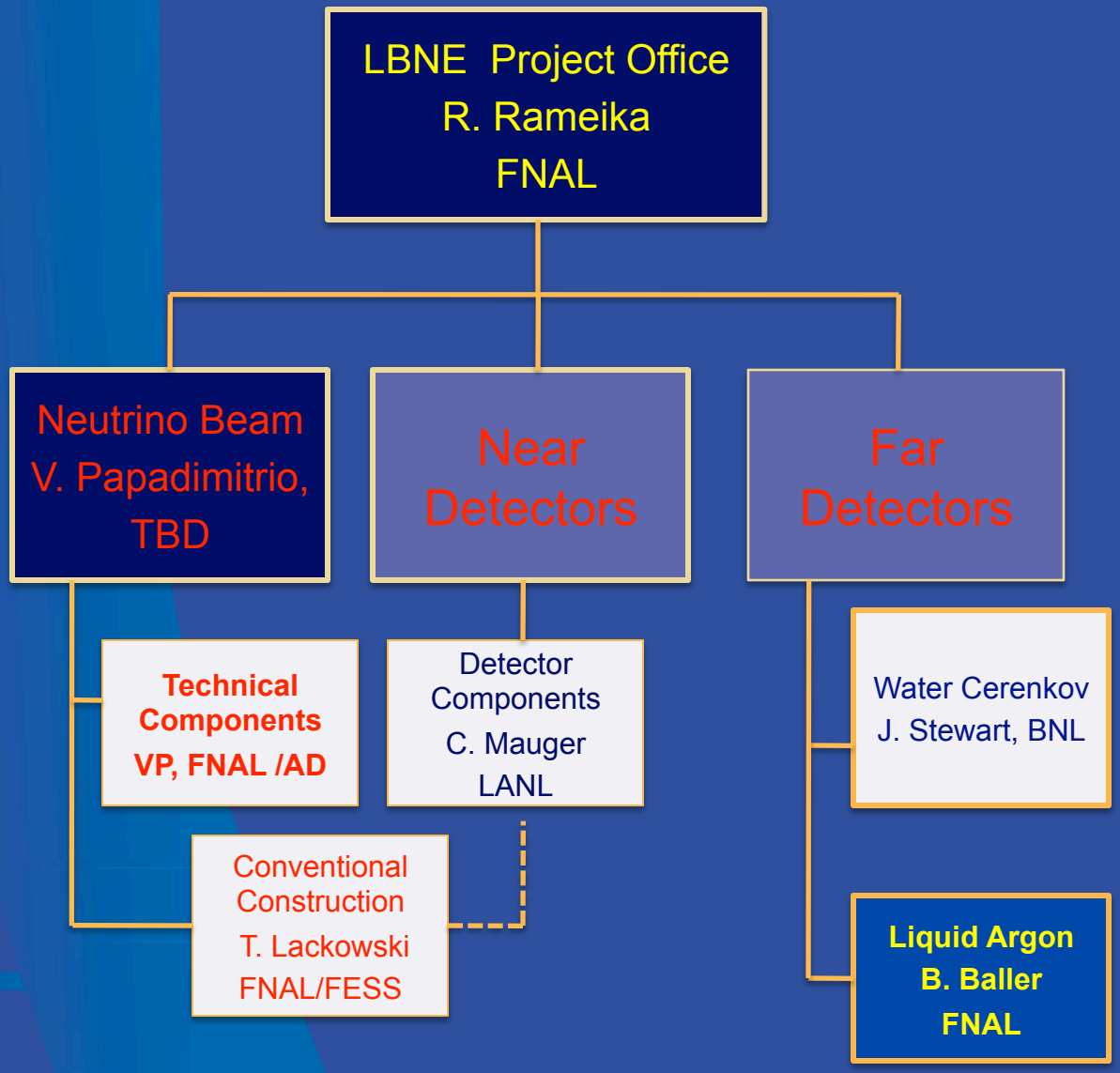
Institution	Linkage	Investigators	Areas of Focus
Brookhaven	Subcontract to Yale	F. Lanni	Electronics
CNA Engineering*	Subcontract to UMN	L. Petersen	Underground Engineering and Coordination
Colorado State U.	Linked Proposal	Norm Buchanan	Materials Testing
Dunham Associates*	Subcontract to CNA	Dale Holland	Electrical and Mechanical Engineering
Fermilab	No cost subcontract to UMN	R. Plunkett, R. Rameika, N. Saoulidou	Cryogenics
Indiana University	Linked Proposal	C. Bower, M. Messier, S. Mufson, J. Musser, J. Urheim	Cryostat
Itasca Consulting*	Subcontract to CNA	Christine deTournay	Rock Modeling
Michigan State U.	Subcontract to UMN	Carl Bromberg	Electronics
Miller Dunwoodie Architects*	Subcontract to CNA	Greg Hulne	Space Design, Code Compliance, EH&S
Saint Mary's University	Subcontract to UMN	Paul Nienaber	Education and Outreach
Tufts University	Subcontract to Minnesota	H. Gallagher, W. Mann, J. Schneps, T. Kafka	Simulations, Physics Analysis
UCLA	Linked Proposal	K. Arisaka, D. Cline, F. Sergiampetri, H. Wang	TPC, PMT and HV
University of Minnesota-Duluth	Linked Proposal	A. Habig, R. Gran	Physics, Education & Outreach, Physics
University of Minnesota-Twin Cities Physics	This Proposal	D. Cronin-Hennessy, M. Marshak, W. Miller, R. Poling	Coordination, Installation, Safety and Health
University of Minnesota-Twin Cities ME	This Proposal	T. Chase, T. Simon	Cryogenics
U. Texas-Dallas	Subcontract to UCLA	A. Farago, E. Fenyves	TPC, PMT and HV
Yale University	Linked Proposal	B. Fleming	Cryogenics, Physics

* Participation subject to procurement process and regulations

13 institutions

31 researchers

LBNE : Project Definition Phase (pre CD-0 – CD-1)



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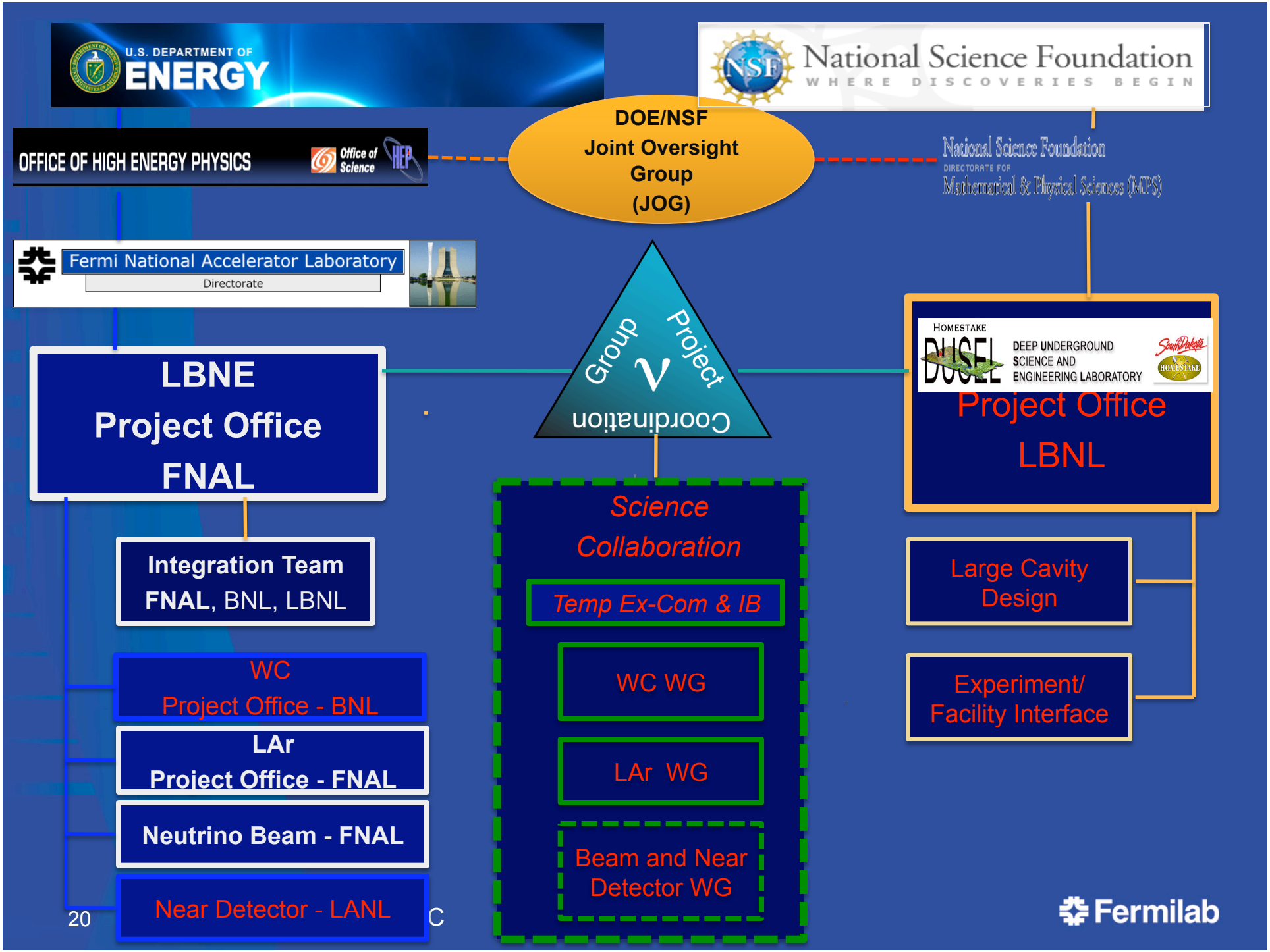
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National Science Foundation
WHERE DISCOVERIES BEGIN
OFFICE OF HIGH ENERGY PHYSICS
Office of Science
HEP
DOE/NSF
Joint Oversight
Group
(JOG)
National Science Foundation
DIRECTORATE FOR
Mathematical & Physical Sciences (MPS)
Fermi National Accelerator Laboratory
Directorate
Group
Project
Coordination
HOMESTAKE
DEEP UNDERGROUND
SCIENCE AND
ENGINEERING LABORATORY
Project Office
LBNL
LBNE
Project Office
FNAL
Integration Team
FNAL, BNL, LBNL
WC
Project Office - BNL
LAr
Project Office - FNAL
Neutrino Beam - FNAL
Near Detector - LANL
Science
Collaboration
Temp Ex-Com & IB
WC WG
LAr WG
Beam and Near
Detector WG
Large Cavity
Design
Experiment/
Facility Interface

C

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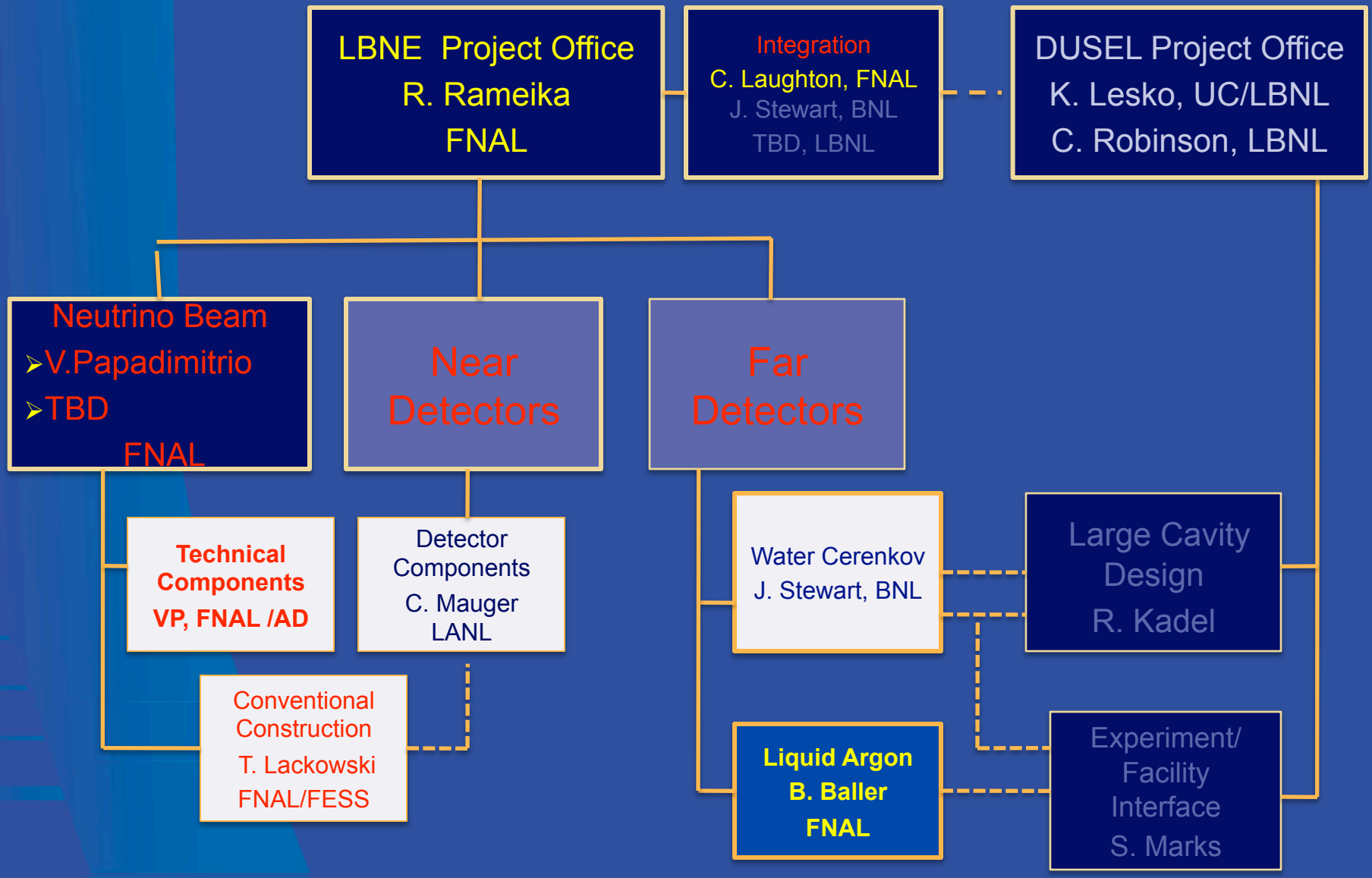
LBNE : Project Definition Phase (pre CD-0 – CD-1)



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The CD-1 Plan

- Making a plan that did not duplicate effort that was proposed to be done under the S4 or S3 (DUSEL at LBNL) proved to be challenging
- Posted a 1st draft by March 16
- Discussed it with DOE (Procario, Blazey)
- They requested that we do a better job
  - Visited LANL, LBNL, BNL
  - Scrubbed numbers
  - Clarified many issues about resource availability
- Posted 2nd draft May 20
  - Got more feed back, to keep improving it
- In the process - $15M ARRA funding had to be integrated into the plan
- Plan has been developed without knowing the specific CD-0 project scope

A bit more guidance…

From "Blazey, Gerald" <Gerald.Blazey@science.doe.gov>
Sent Friday, May 22, 2009 10:08 am
To Regina Rameika <rameika@fnal.gov>
Cc "Procario, Michael" <Michael.Procario@science.doe.gov> , "Blazey, Gerald" <Gerald.Blazey@science.doe.gov> , "Rosenberg, Eli" <Eli.Rosenberg@science.doe.gov>
Subject Comments on Draft Document

1) In general we would like the majority of the document and effort to focus only on neutrino oscillations. In fact we would suggest reserving all discussion of proton decay and astronomy to a penultimate chapter (just after Cost Estimate Methodology) titled something like "Ancillary Measurements and Incremental Costs". Here the document could discuss the incremental costs of placing the detector at depth for proton decay, expansion to 500kton+, electronics for astronomy, etc. This is necessary to be consistent with OHEP Mission Need for oscillations and CPV only.

2) The introduction should soften the assumption about DUSEL as the location. So for the third sentence we would prefer: "For the purpose of developing a conceptual design and cost estimate for the project elements we choose the benchmark configuration of a far detector located in the Deep…" followed by an inserted sentence: "Other configurations and locations will be investigated in the alternatives analysis." We want to assiduously avoid the impression that DOE has already made a decision. In that sense, we also don't want to overly prejudge a Fermilab decision as well.

3) In the same sense , in the org charts we need to deemphasize the JOG, at the very least make the connecting lines dotted, to suggest advisory only.

4) In "Project Scope" the doubling of the detector masses for proton decay is news to us! We had thought that 300ktons and 10 years lead to significant improvements. Please relegate this notion to the "Ancillary Measurements" mentioned above. Similarly please remove the reference to proton decay in the first sentence of "Project Structure and Coordination."

While one can understand that there are certain procedures and protocols associated with the CD process, it has been challenging to construct this plan to satisfaction of the collaboration

Status

- Mission Need Documentation for CD-0 has been prepared and is under review in DOE
- Project Management teams at FNAL and BNL are beginning to be staffed
- A plan for developing the documentation required for CD-1 has been developed
  - http://lbne-docdb.fnal.gov
  - **LBNE Document 26-v2**
  - User name : LBNE ; ask me if you want the password
- $15 M of ARRA funding is being directed to LBNE to accelerate the CD-0 to CD-1 process
  - Need to define milestones and deliverables
  - Get to CD-1 by the end of 2010
- The Science Collaboration is awaiting funding from the NSF S-4 awards

DRAFT 6-19-09
Fermilab, Long Baseline Neutrino Experiment (LBNE)

ARRA Milestones

Section A: Contractor Recovery Act Schedule or Milestone Requirements

LBNE Project Office at FNAL Established	August, 2009
Preliminary Cost Range for Neutrino Beam Conventional Facilities Estimated	September, 2009
Initiate Development of Far Detector Configuration Documents	October, 2009
Initiate Conceptual Design Report Studies	November, 2009
Initiate Near Detector Technology Studies	December, 2009
Conduct Internal Review of Progress on Liquid Argon Detector Design	February, 2010
Conduct an Internal Review of Progress on Project Design	March, 2010
Conduct an Internal Review of Far Detector Technology Options	July, 2010
Conduct an Internal Review of Progress on Project Documentation	September, 2010

Deliverables : Documentation

Section B: Contractor Recovery Act Performance Outcomes and Measures

Neutrino Beam Requirements Document	January, 2010
Near Detector Requirements Document	February, 2010
Draft System Level Function and Requirements Document for Neutrino Beam Conventional Facilities	March, 2010
Operational Risk Management Register	April, 2010
Liquid Argon Detector Requirements Document	April, 2010
Preliminary Geotechnical Investigation Report	May, 2010
Neutrino Beam Value Engineering Report	June, 2010
Liquid Argon Detector Risks Entered into Risk Management	June, 2010

Initial Cost Estimate for Neutrino Beam Conventional Construction	July, 2010
Initial Configuration Documents for Far Detectors	August, 2010
Initial Cost Estimates for Far Detector Configurations	September, 2010
Initial Alternatives Analysis Document	October, 2010
Draft Conceptual Design Report	November, 2010
Environmental Documents	December, 2010
Section C: Contractor Recovery Act Deliverables	
CD-1 Required Documents Ready for Review	December 31,2010

Incredible amount of work to accomplish in < 18 months

Brookhaven National Lab, Long Baseline Neutrino Experiment

Section A: Contractor Recovery Act Schedule or Milestone Requirements

LBNE Project Office at BNL Established	August, 2009
Initiate Development of a Water Cerenkov Far Detector Configuration Document	November, 2009
Conduct Internal Review of Progress on Water Cerenkov Detector Design	February, 2010
Participate in Internal Review of Progress on Project Design	March, 2010
Participate in Internal Review of Far Detector Technology Options	July, 2010
Participate in Internal Review of Progress on Project Documentation	September, 2010
Conduct a Second Internal Review of Progress on Water Cerenkov Detector Design	October, 2010

Section B: Contractor Recovery Act Performance Outcomes and Measures

Preliminary Documentation for First Detector Design Review	February, 2010
Water Cerenkov Detector Requirements Document	April, 2010
Water Cerenkov Detector Risks Entered into Risk Management	June, 2010

Section C: Contractor Recovery Act Deliverables

CD-1 Required Documents delivered to FNAL LBNE Project Office	November, 2010

Similar tasks at BNL

$ 6M of the ARRA funds to BNL (WC Project Management And design; TPC and cryo work on LAr)

Large Far Detectors

DRAFT 6-19-09
Fermilab, Long Baseline Neutrino Experiment (LBNE)

Section A: Contractor Recovery Act Schedule or Milestone Requirements

LBNE Project Office at FNAL Established	August, 2009
Preliminary Cost Range for Neutrino Beam Conventional Facilities Estimated	September, 2009
Initiate Development of Far Detector Configuration Documents	October, 2009
Initiate Conceptual Design Report Studies	November, 2009
Initiate Near Detector Technology Studies	December, 2009
Conduct Internal Review of Progress on Liquid Argon Detector Design	February, 2010
Conduct an Internal Review of Progress on Project Design	March, 2010
Conduct an Internal Review of Far Detector Technology Options	July, 2010
Conduct an Internal Review of Progress on Project Documentation	September, 2010

Initial Cost Estimate for Neutrino Beam Conventional Construction	July, 2010
Initial Configuration Documents for Far Detectors	August, 2010
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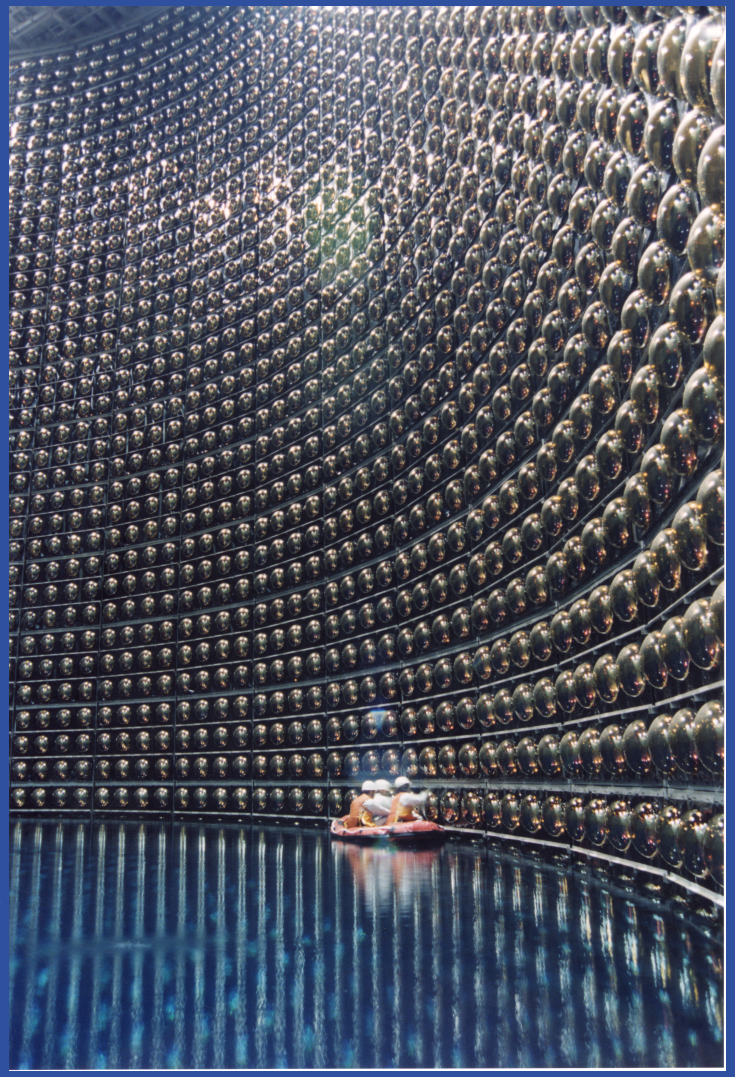
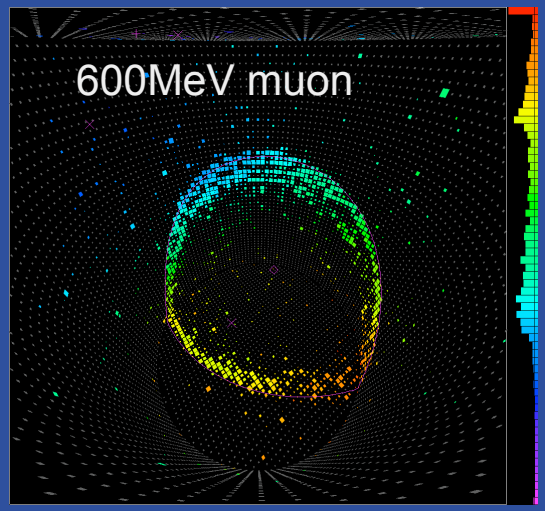
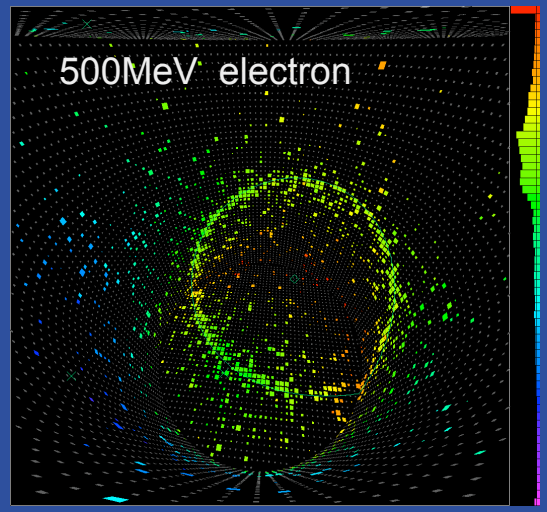
For CD-1 we need to have a baseline configuration, with alternatives evaluated

Far Detector : Water Cerenkov

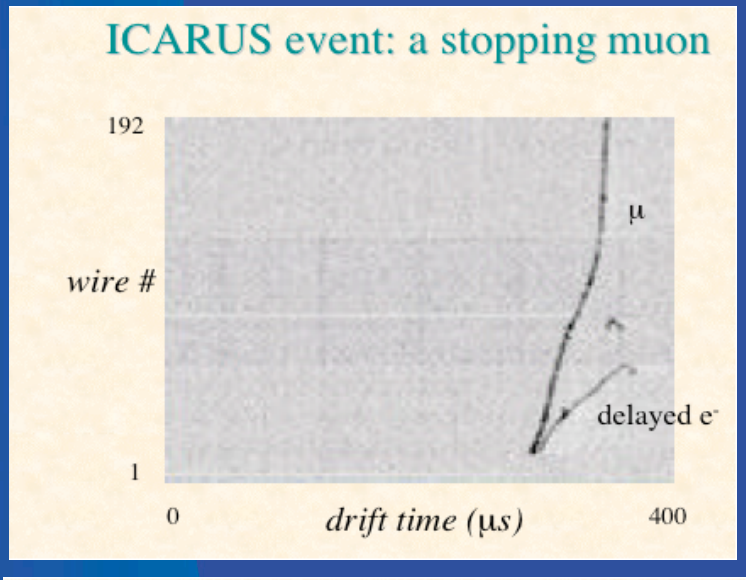
- Super-K
  - 13K 20” PMT
  - 40% coverage
  - 50 kT total mass
  - 39 m diameter
  - 42 m height
- LBNE
  - 60 K 10” PMT per 100kT FV module (25%)
  - ~55 m diameter
  - ~60 m height

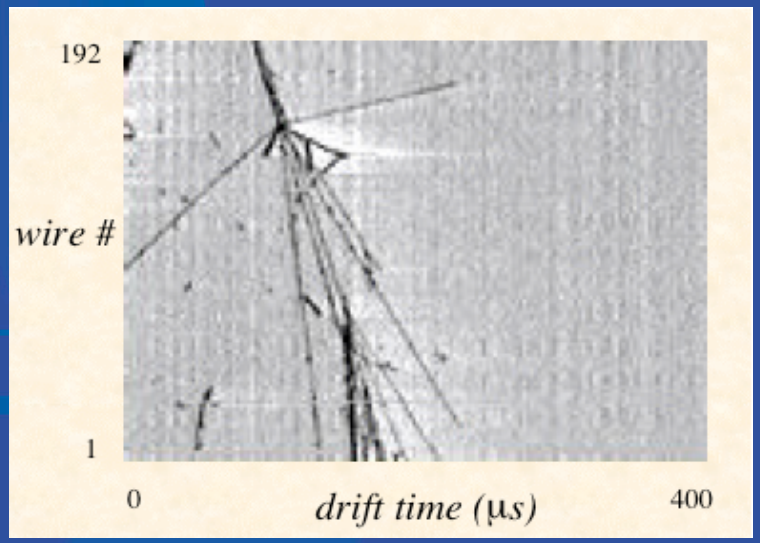




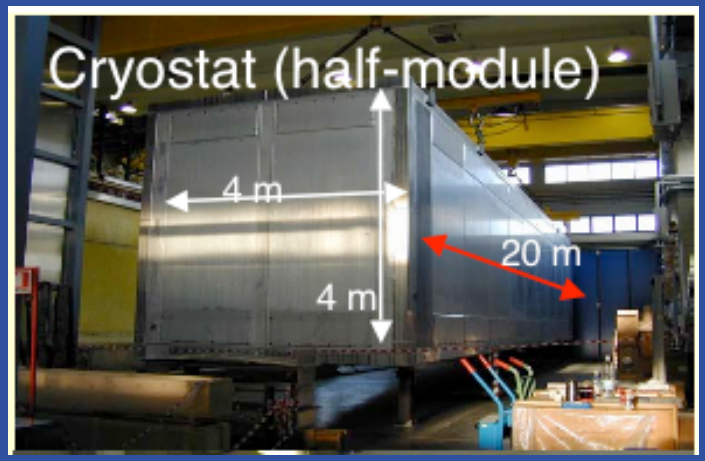


Far Detector : Liquid Argon





- LAr potential
  - Efficiency ~80%
  - e/π^0/γ identification – low NC bkgd
- Proof of Principle at large scale lacking
  - ICARUS T-300 x 2
  - Many challenges



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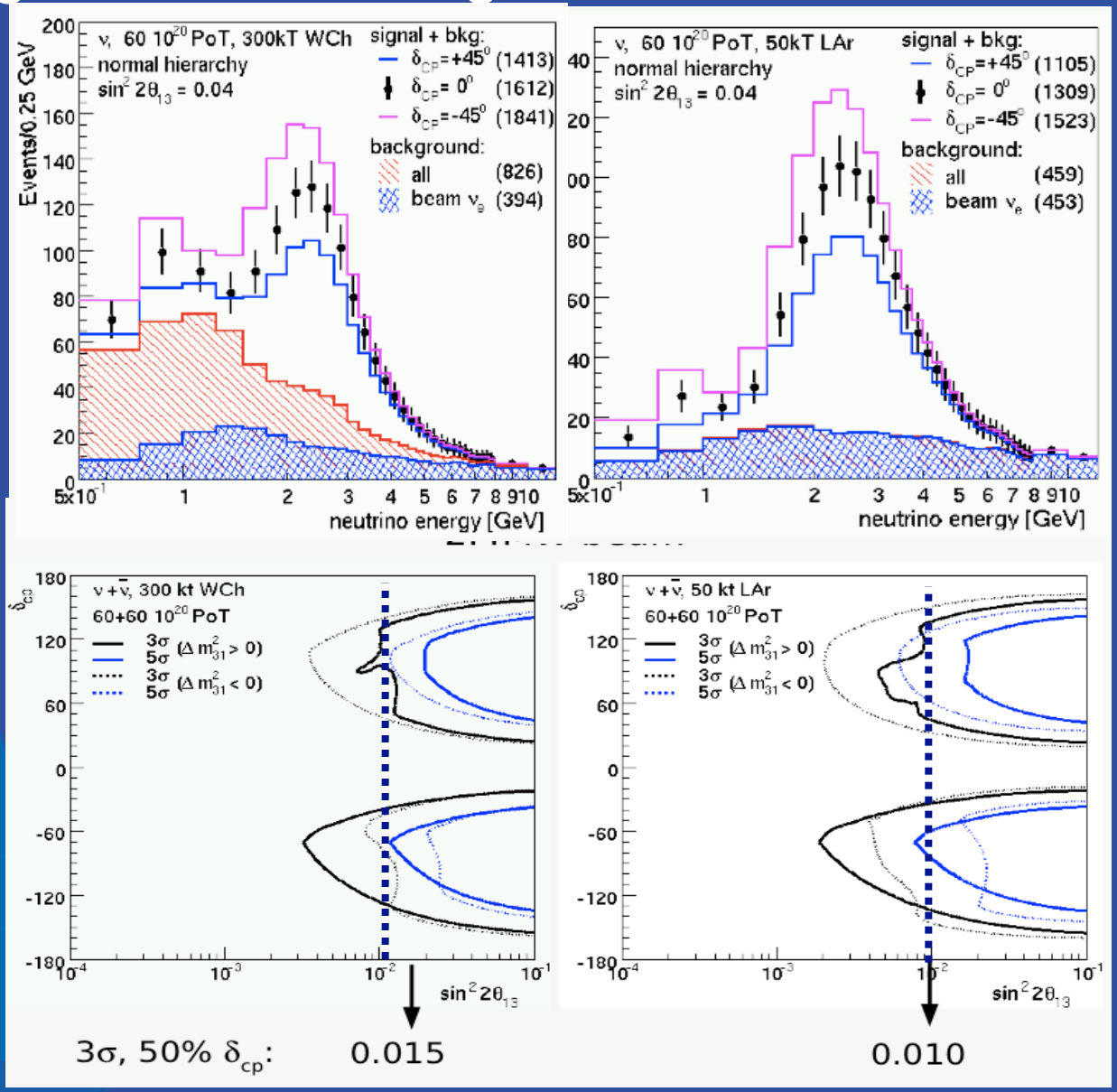
Signals and backgrounds for WC vs. LAr



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Motivation – high efficiency ➔ smaller detector

	Values of $\sin^2 2\theta_{13}$ where you have	$\sin^2 2\theta_{13} \neq 0$ 3σ, all δ_{cp}	sign(Δm^2_{31}) 3σ, all δ_{cp}	CPV 3σ, 50% δ_{cp}
Water Cherenkov	300kt, 1.2MW	0.008	0.018	0.030
	300kt, 2.4MW	0.006	0.012	0.015
	600kt, 2.4MW	0.004	0.010	0.008
Liquid Argon	50kt, 1.2MW	0.007	0.014	0.018
	50kt, 2.4MW	0.005	0.011	0.010
	100kt, 2.4MW	0.003	0.008	0.003

Need ~6x smaller LAr to obtain similar sensitivities to WCh
Small NC bkg contamination will affect LAr, in particular CPV

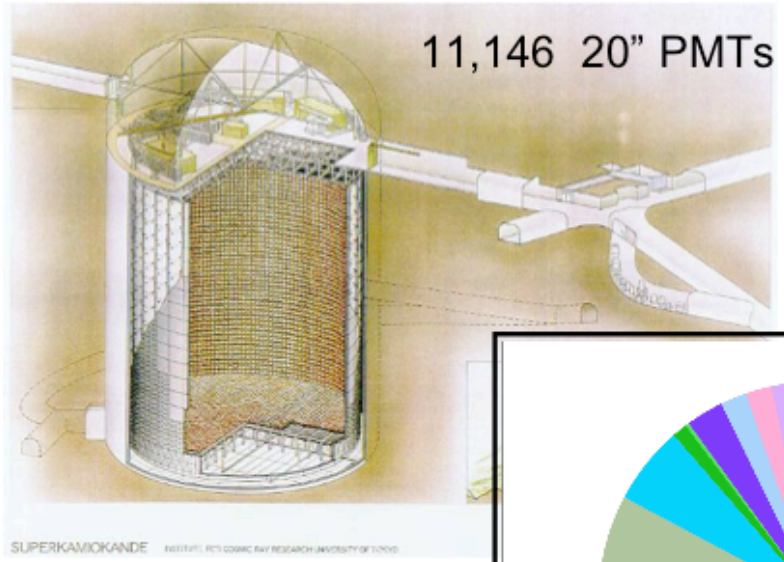
From M. Dierckxsens

Large Far Detectors

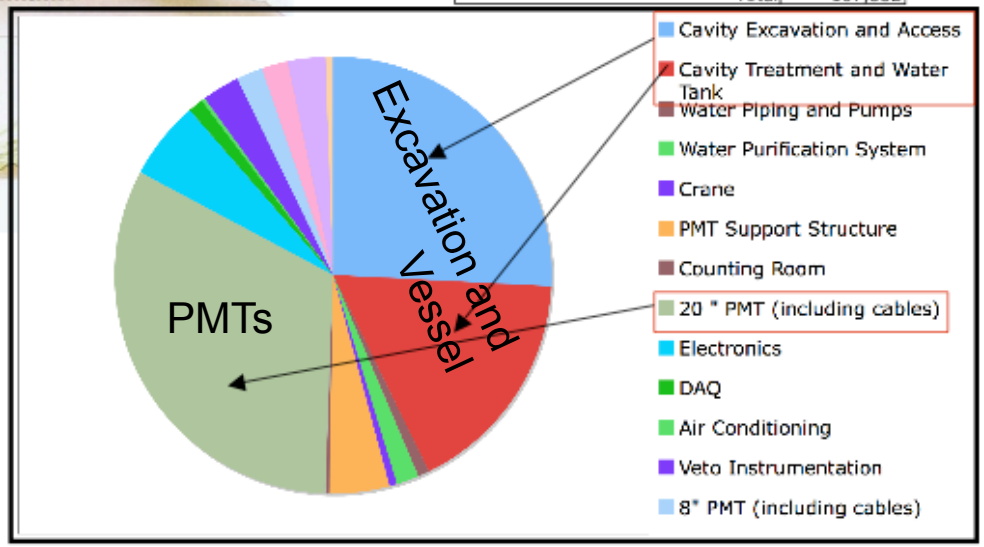
- Deep underground
  - Coupled to the Underground Laboratory Infrastructure
  - Major cavity excavations ➔ cost, schedule, safety considerations
  - Maximizes the scientific productivity
- Shallow site
  - *May* have less severe infrastructure requirements
  - Construction *may* have less cost, schedule, safety considerations
  - Limits scientific productivity
  - WC technology won't work
  - LAr technology may work

Super-K Cost Drivers

50 kT Total Volume



	1996 K$
Cavity Excavation and Access	27,640
Cavity Treatment and Water Tank	18,400
Water Piping and Pumps	630
Water Purification System	1,850
Crane	760
PMT Support Structure	4,580
Counting Room	330
20 " PMT (including cables)	34,670
Electronics	6,330
DAQ	1,090
Air Conditioning	210
Veto Instrumentation	3,000
8" PMT (including cables)	2,262
Computer Building	1,860
Main Building	3,000
Power Station	720
Total	107,332



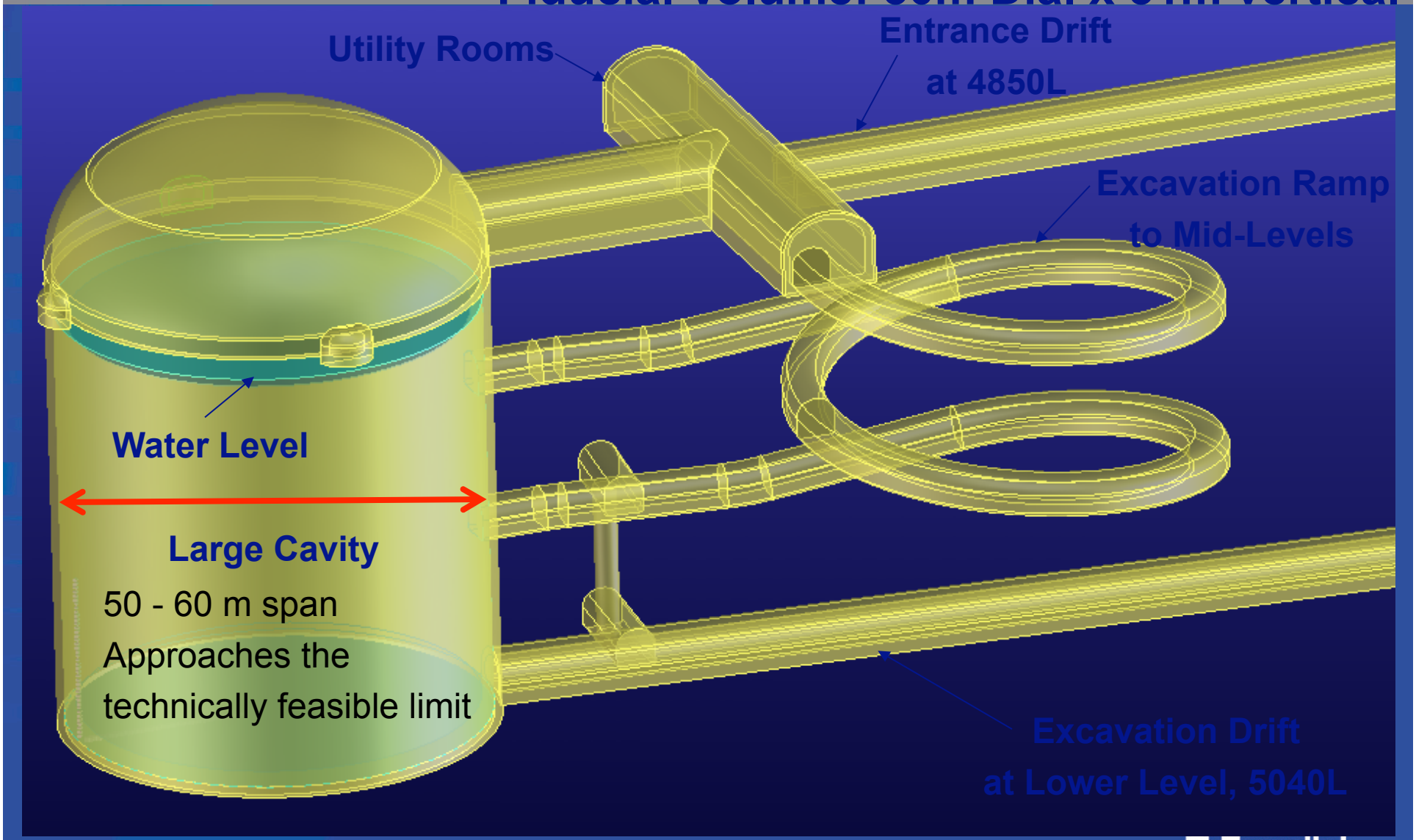
$110 M in 1996

Unlikely in DOE accounting $s

Large Cavity, Water Cerenkov Detector

Water: 53m Dia. x 54m vertical,

Fiducial Volume: 50m Dia. x 51m vertical



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4850 Level Conceptual Layout

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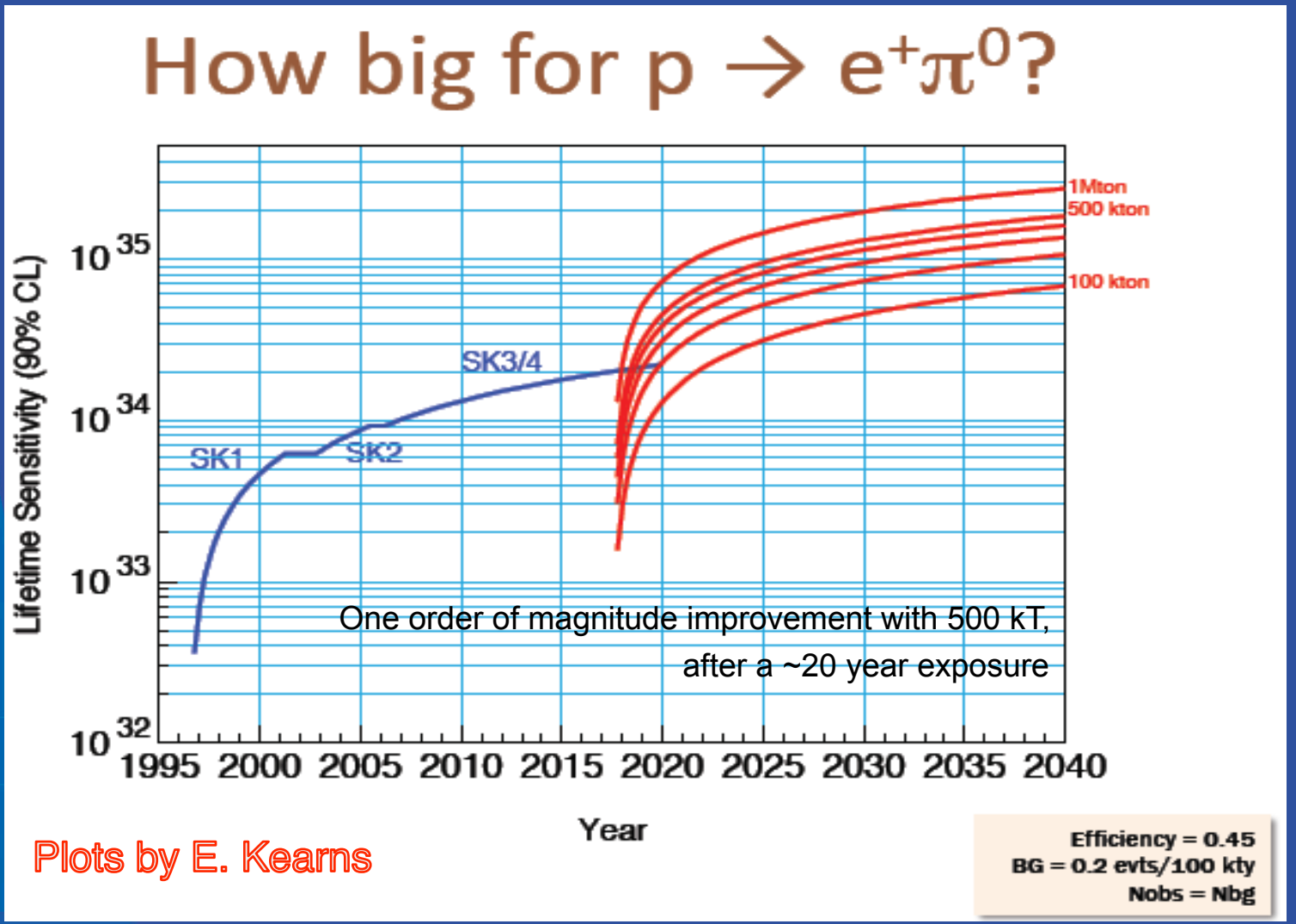
Proton Decay - Water



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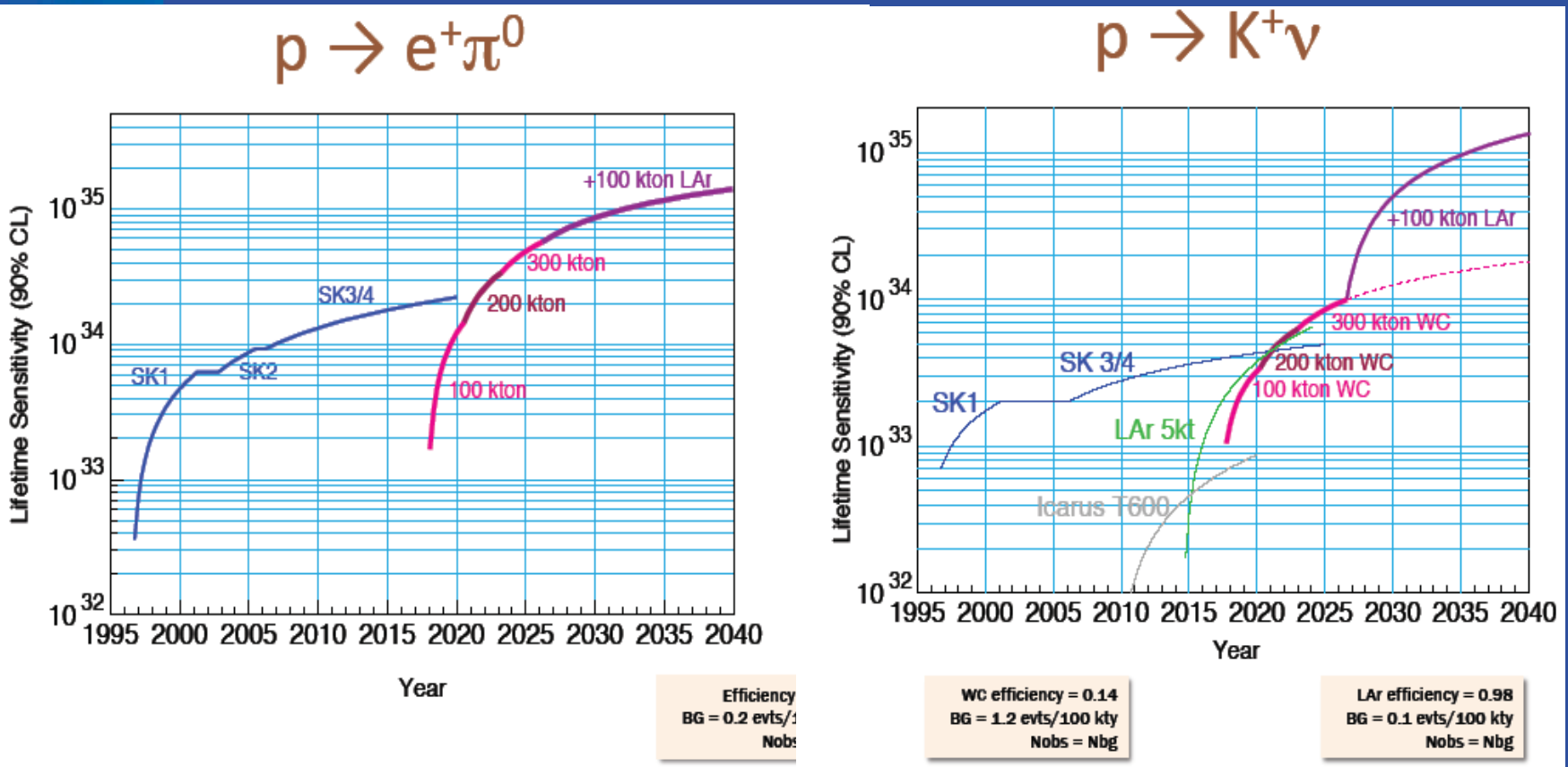
Proton Decay - LAr



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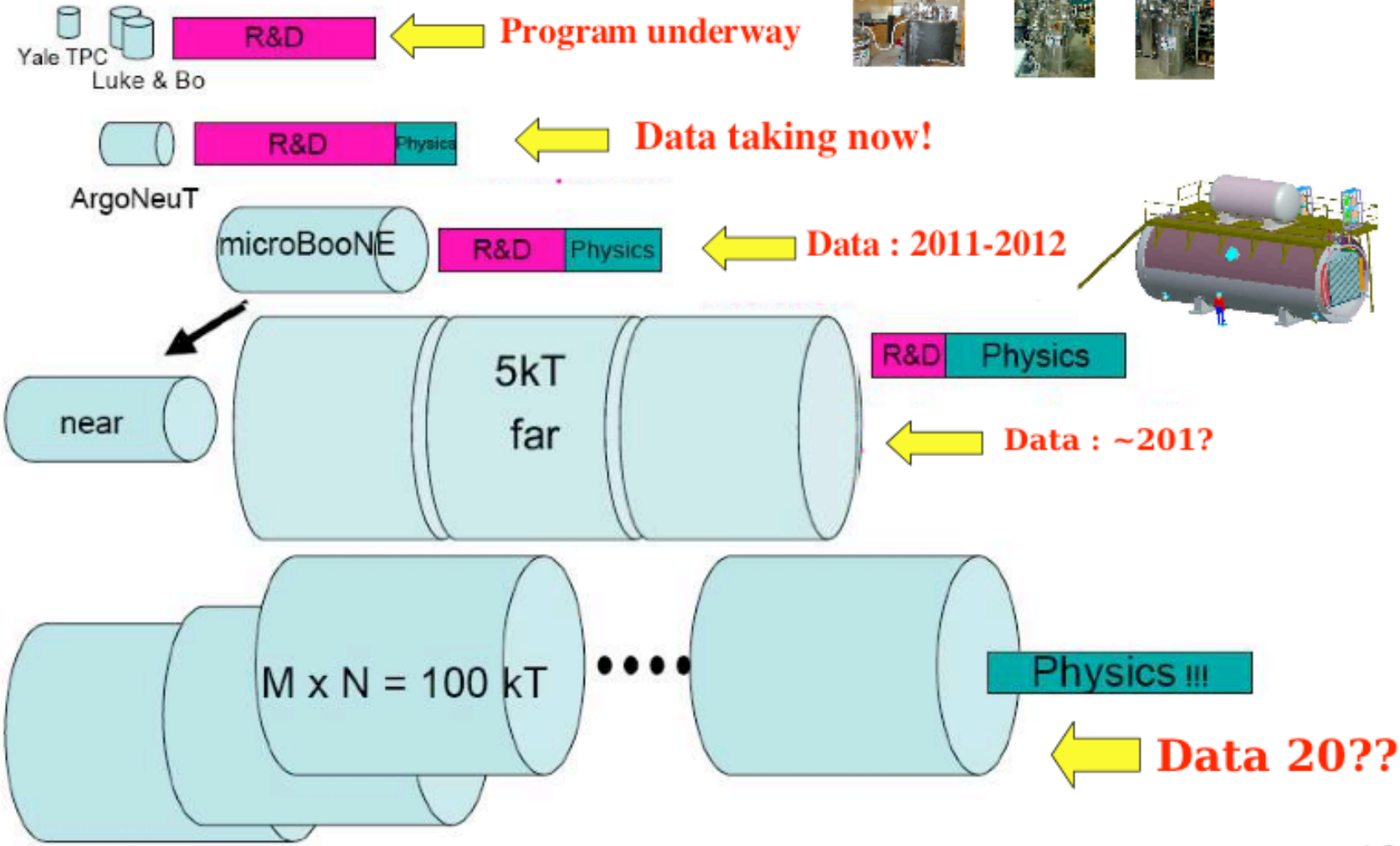
The Big Question

- How does *one* (collaboration, committee, laboratory, funding agency…) decide what's the best technology?
  - Water Cerenkov – brute force
    - Basic technology is proven
    - Some factors are not a large extrapolation, others are (more later)
    - Performance for a small ν_e appearance signal in the presence of a large background is what drives the size requirement
  - Liquid Argon – elegant but unknowns
    - Performance has been demonstrated on a small scale
    - Need to extrapolate technology to larger scale

Liquid Argon TPC R&D program in the US



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R&D | Physics

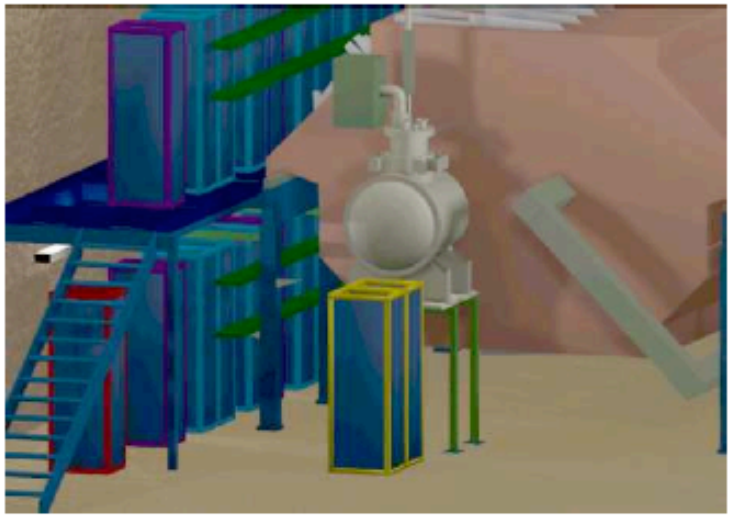
ArgoNeuT

Joint NSF/DOE project

0.3 ton active volume

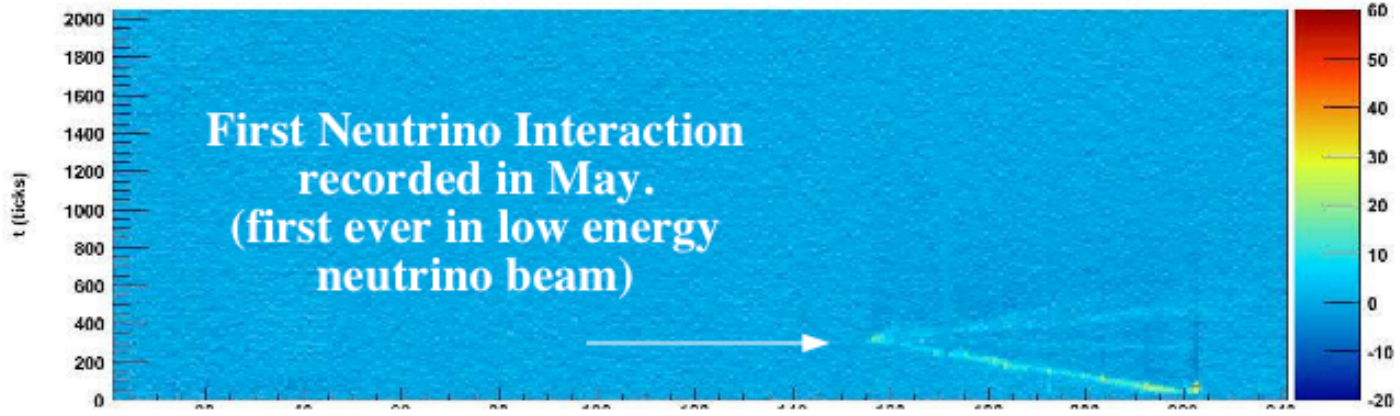
0.5 x 0.5 x 1.0 m^3 TPC; 500 channels

- See neutrino interactions (~150 evts/day)
- Long term running conditions
- Underground siting issues



Collaboration: University of L'Aquila, Fermilab, Gran Sasso Lab, Michigan State, University of Texas at Austin, Yale

Going underground early 2009



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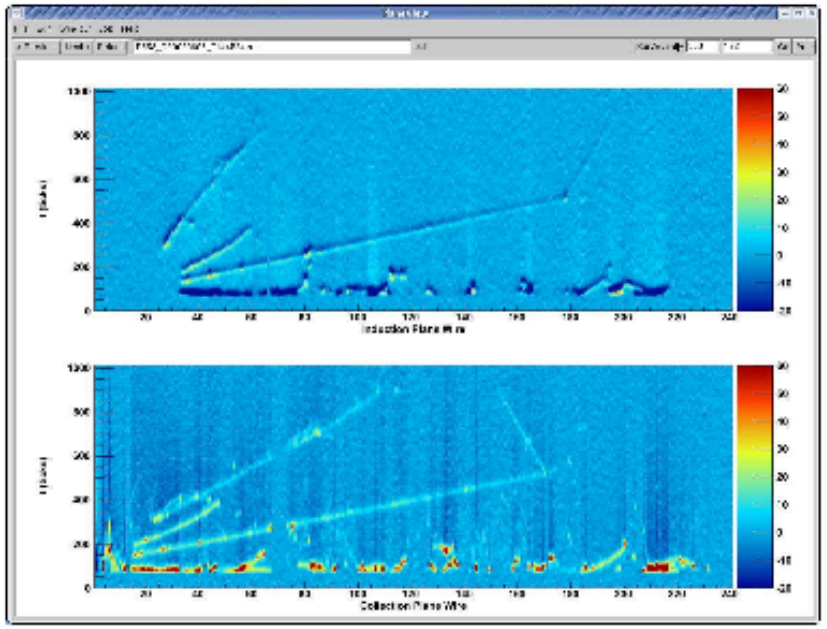
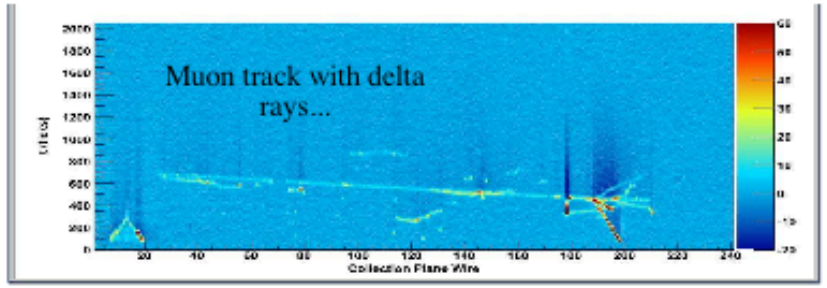
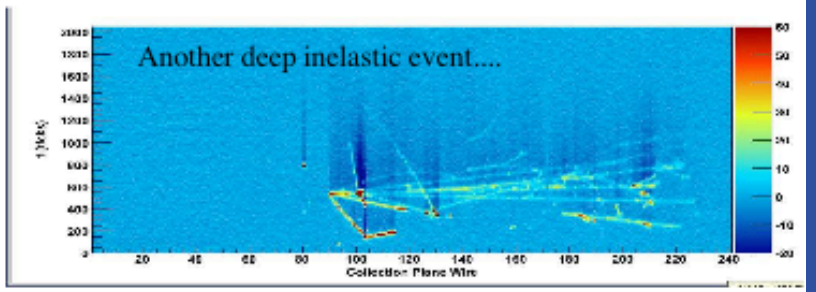


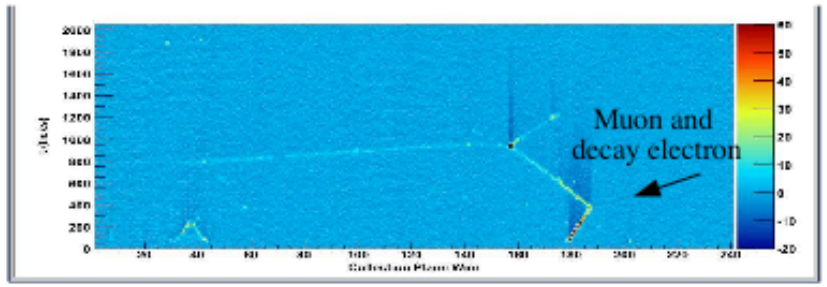
Deep Inelastic event

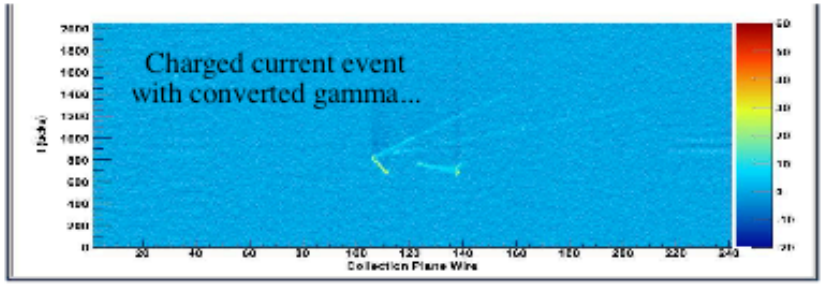
Induction plane

Collection plane









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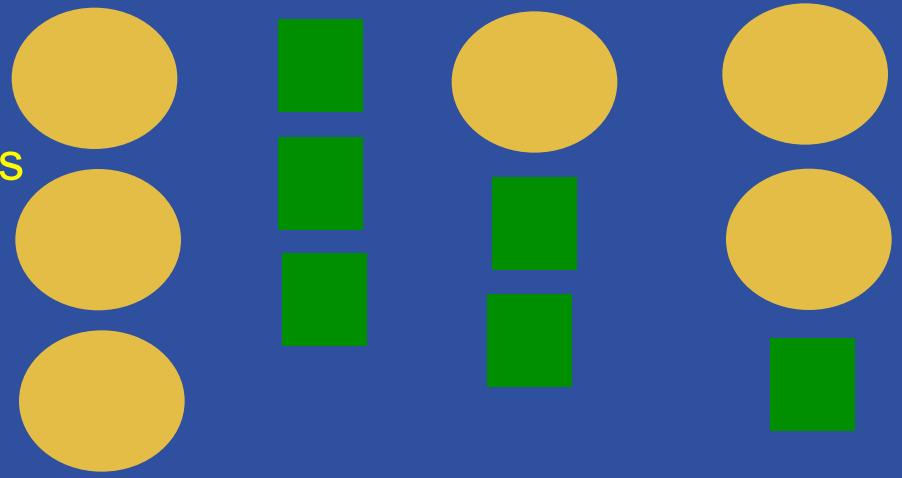
Extrapolation to Large Scales

- The success of ArgoNeuT is really exciting, but we have a long way to go in developing a plan for a large detector
  - Technical risks
  - Unknown Cost
  - Safety issues
- The proven performance of Super-K goes a long way towards having confidence in the WC technology
  - Not just scaling (50 ➔ 120 kT)
    - 13K PMTs ➔ 180K PMTs for 300 kT
  - Unknown costs
  - Procurement issues
- We need a plan to evaluate the technologies in a logical, transparent, apples to apples way

Configurations

	kilotons	
	WC	LAr
Physics Equality	300	50
Physics Module	100	17
Total Module	120	20
Dimensions	~55m diameter, ~60m height	16x16x60 m3 module;20x20x 80cavern

One can imagine 4 potential configurations



How can we optimize?

Equivalent categories of evaluation

Target	Water	Liquid Argon
Cavern	upright cylinder, mailbox?	rectangular,soup can?,upright cylinder?
Primary Containment	Precast Concrete Liner, Poured Concrete?, Stainless Steel vessel?	insulated,non-evacuated Stainless Steel vessel, evacuable option(?)
Systems	water delivery, purification,temperature control, doping(?)	Cryogenic delivery, refrigeration, purification
Infrastructure Requirements	auxilliary rooms for systems	auxilliary rooms for systems, secondary containment, venting for ODH

Target	Water	Liquid Argon
Active Detector	PMT's, light collectors, implosion protoection, bases, HV, Cables(?), support structure	TPC, HV, Cables, support structure; PMTs for triggering and timing
Electronics	preamps in/out? of H20	pre-amps in liquid (cold)?
Calibration and Instrumentation	lasers, lamps, fibers, sources?	source?, purity monitors
Simulations	Neutrino Flux, Cross sections, Event Rates	
Reconstruction	rings	tracks

Need to determine the cost drivers and potential show stoppers

Costing Process – Priority on Cost Drivers

- Both Detectors
  - Cavity and Infrastructure Excavations
- Water
  - PMT's (60K per module)
  - PMT support structure
  - Electronics *
  - Purification and Environmental Control
- Liquid Argon
  - LAr (~$1M/kton)
  - Cryo system, ODH mitigation
  - Electronics *

*Everyone says electronics should be cheap – but current estimates for both LAr and WC are still at $50-$100/channel

Cavern Excavation Costs

- Preliminary estimates for 100kT (120k m^3) at Homestake
  - February 2008 (P5 at SLAC)
    - $28 M (No rock disposal, contingency)
  - August 2008 (M. Laurenti at FNAL)
    - $90 M (with rock disposal estimate, contingency)
      - $750/$m^3$
- MINOS – Soudan Experience
  - Rock Excavation only :
    - 1994 Proposal Estimate : $3.3 M
    - FY2000 actual : $7M for 11,500 m^3
    - Escalate to FY08 : $780/$m^3$
- Chris Laughton Recent Project Search
  - $500 - $ 1000 / m^3

PMTs

Prepared for CD-0 briefing to DOE in November

my current understanding

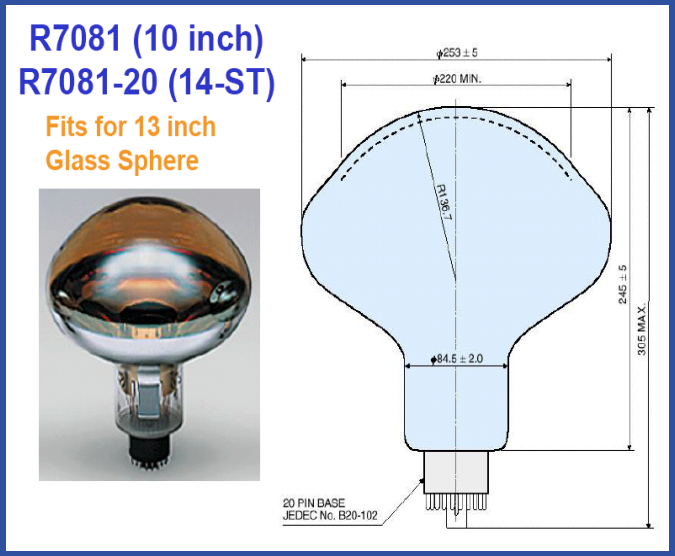
	"proposal" Jan-07	MD_P5 Feb-08	RR Nov-08
PMT cost	880	933	1250
shipping			130
base			150
testing			25
cables	77	86	80
electronics	120	127	80
support structure	165		150
pressure shields			150
reflectors			30
hardware			20
installation		175	23
Total per PMT	1242	1321	2088

*

*Ice cube

PMT's

- 300 kT detector ➔ ~ 180 K 10" tubes for 25% coverage
- There is only one manufacturer
  - Production capacity
  - Delivery schedule
  - Unit cost + shipping
- *IF* the per channel cost is
  - $2000 (no contingency) ➔
    - $120M per module
- Need to reduce this
  - Electronics
  - Cable
  - ? Where can you get the most bang?



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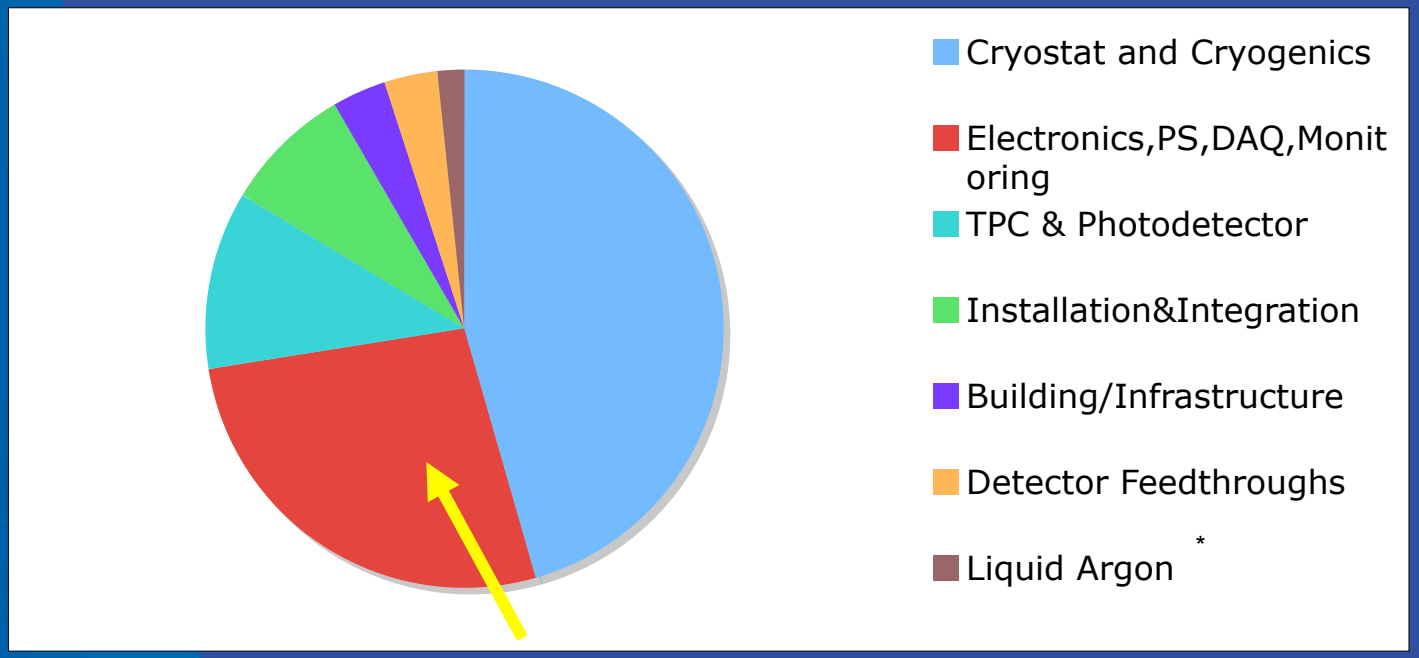
Liquid Argon Cost Scaling

- *ICARUS*
  - *Hard to extract costs - true R&D over many years*
- FLARE - 2004
- FLARE Revision/submission to NuSAG - 2005
- ArgoNeut - actual
- MicroBooNE - proposal/estimate
- LAr5 – Guesstimates

- All have been for on or near surface construction
- The next few slides are some work done last fall – not updated since……

MicroBooNE Proposal (FY09$)

- Base Cost (no contingency) ~$12M [M&S + SWF]
- 100t (0.1kT) active mass → $120M/kT !
  - Cannot extrapolate to larger mass



10k channels : ~$125/channel for Front End Readout

* *Cost of liquid argon is insignificant*

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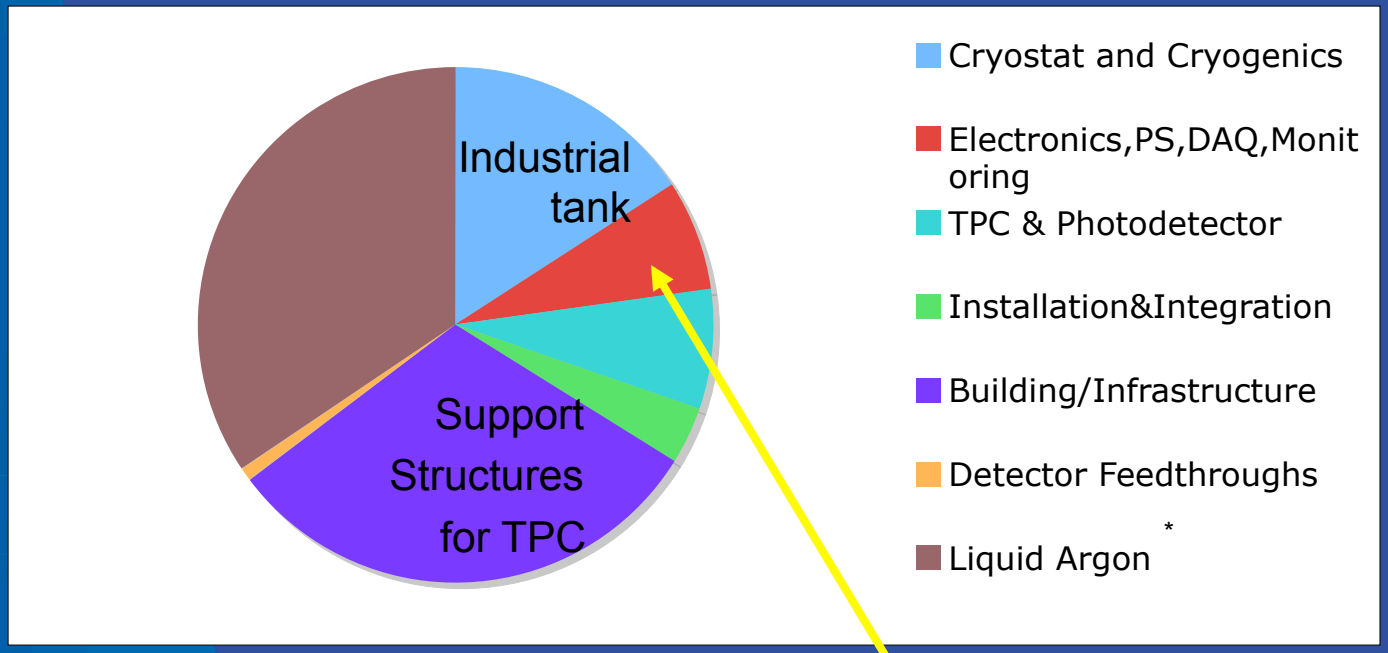
FLARE LOI (2004)

- ~50 kT, 4 m drift, 300k readout channels
- $111M [no contingency, no EDIA]
  - Add 25% EDIA + inflation to FY09 → ~$166M → $3.3M/kT!
  - Seems reasonable : what are the assumptions that don't scale?



LOI assumed FEE for ~$3/channel

* *Cost of liquid argon is now a cost driver*

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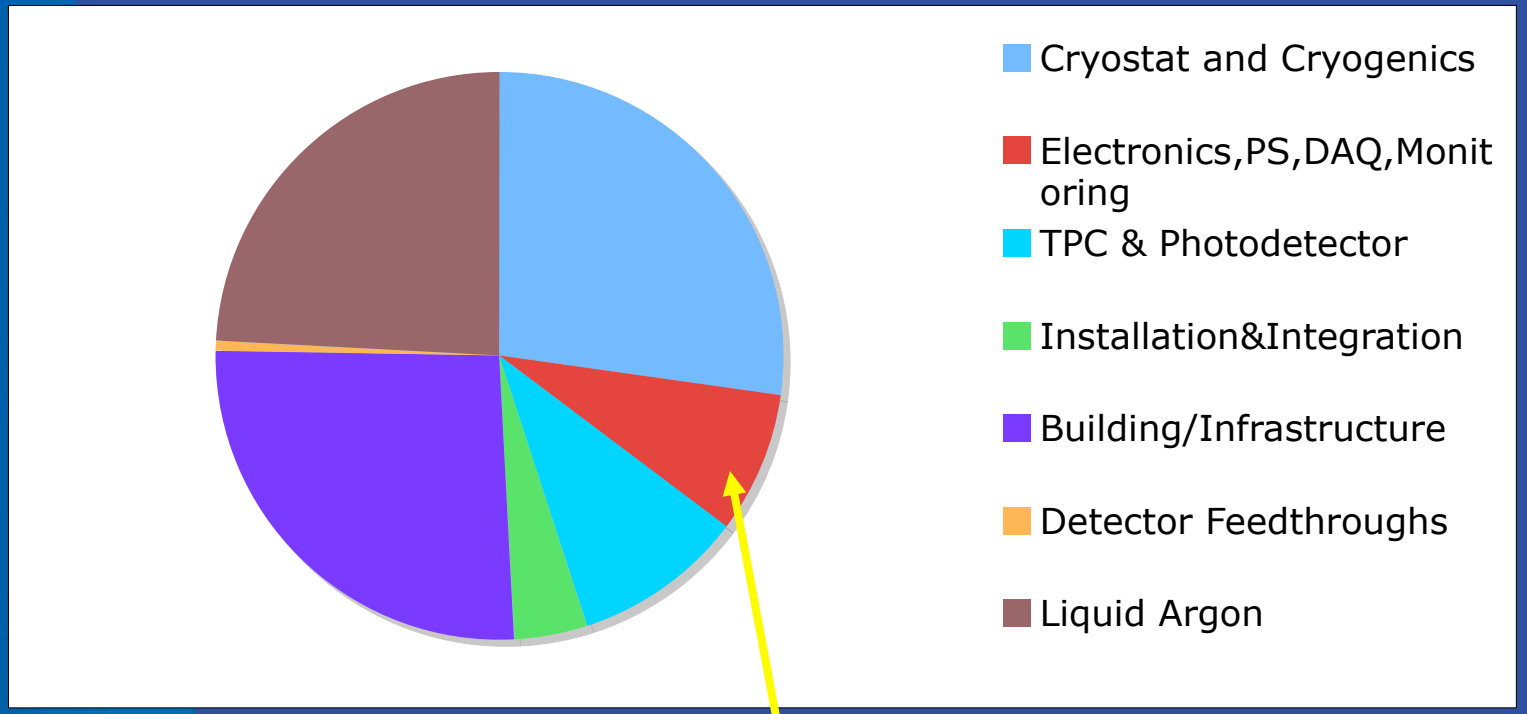
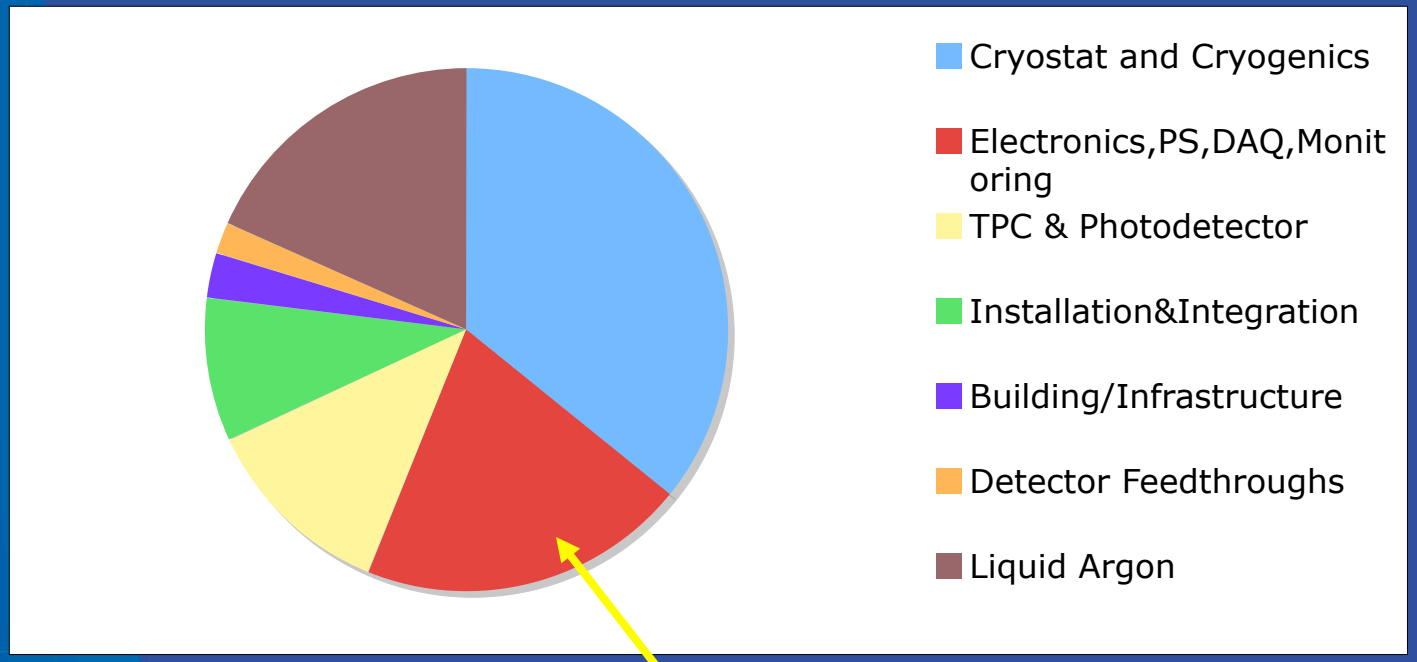
15kT revision for NuSAG (2005)

- Base estimate at $60M
  - Add EDIA and inflation → $86M → $6M/kT



2008 : “Propose” LAr5 Step

- Combination of large detector and small detector costs : $35M Base (no contingency)



54k channels at $50/channel

Used this model to scale to 7 and 10 kT….

Cost evolution : Goal

- A large detector for CP violation, PDK(Kν), supernova …
  - Need 30 - 100 kT
  - $100 M < TPC < $300M
- ~ $3M/kT (FY09$, pre-contingency)
- Plus Cavity and Infrastructure

Proposal for assembling a cost estimate – a Project Driven Task

- Design teams determine the labor (SWF) requirements
  - In appropriate units : hours, days, months or years
  - At Laboratories, universities or for contracted services
  - For
    - Design
    - Procurement/Fabrication
    - Construction
    - Testing
    - Installation
    - Pre-commissioning
    - Preparation of documentation
    - Preparation for and participation in reviews

- Design teams determine the costs (M&S) for procurements of materials and services (that are not costed above)
  - Include construction of facilities required for fabrication, testing, storage, staging, etc.
- Labor costs need to be separated by the institution where the work will be carried out
- Costs for non-oscillation physics need to be called out incrementally
- Estimates should be done at the WBS level most appropriate to the stage of the design
- Estimates will be submitted to the Project Office

- The Project Office will
  - Collect the standard labor rates and overheads at each proposed institution
  - Assemble the cost in FY10 dollars, and do a preliminary attempt to schedule and apply inflation
- The 1st pass at this will be to cost a single
  - 100 kT (FV) WC module located at 4850'
  - 20kT (TV) LAr module(s) at 4850'
- The 2nd pass will be to scale the scope to include
  - 300 kT FV WC (2 – 3 modules)
  - 50 kT FV LAr (3 x 20), 300'
  - Include incremental costs for the non-oscillation physics

Proposal for Evaluating Detector Performance – a Science Collaboration driven task (with help from FNAL-CD)

- Need to use common tools and (possibly) framework for
  - Neutrino Flux (Gfluka, MARS)
  - Neutrino Interactions (Neugen, GENIE)
  - Cross checking with two packages is good
  - Flux and cross-sections give event rates for signals and background
- Detector simulations (G4) determine
  - Reconstruction efficiencies
  - Particle ID and mid-ID
  - Energy resolution

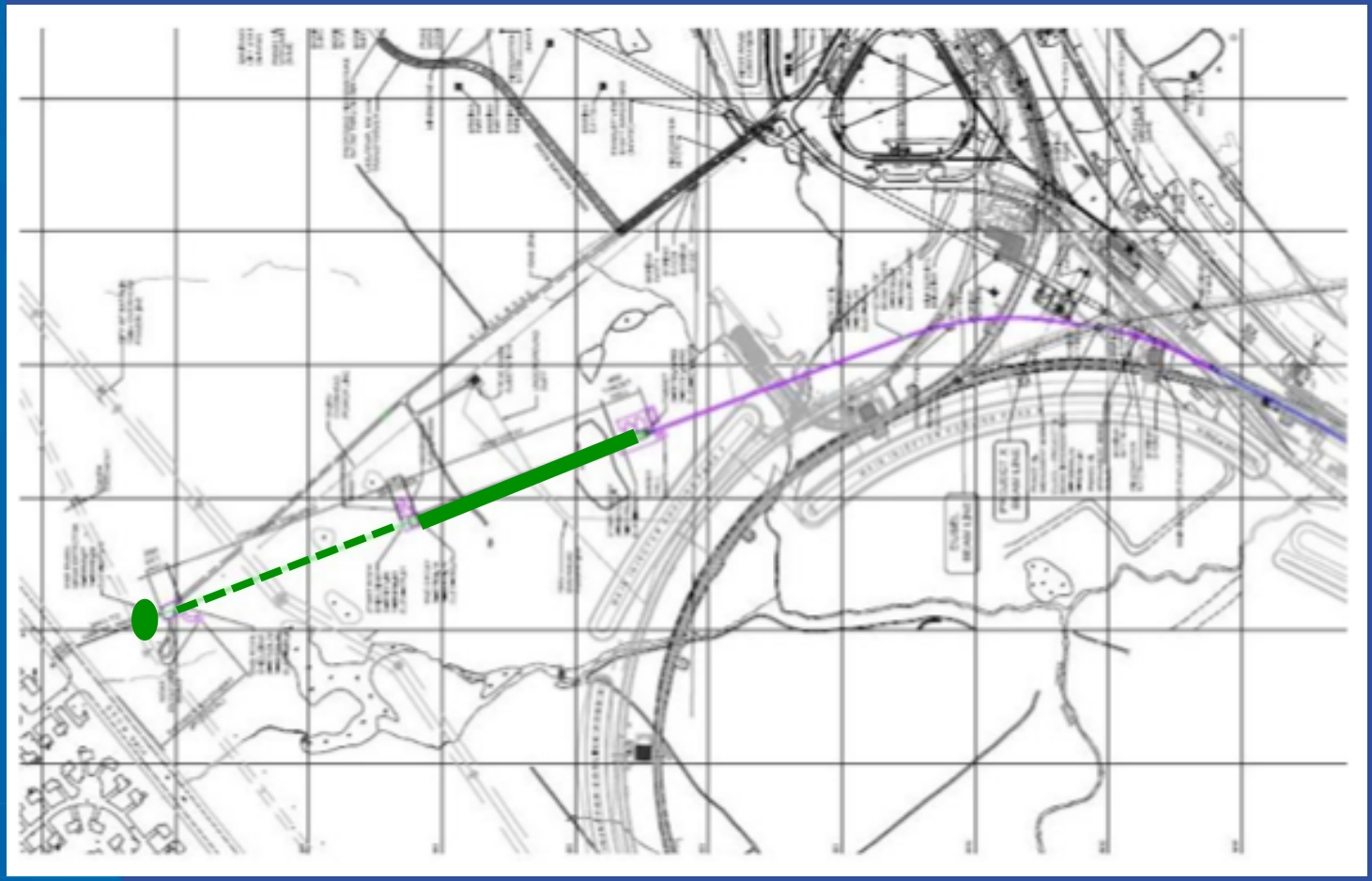
- Common tools for calculating sensitivities :
  - Neutrino Oscillations
    - FNAL-fast for quick evaluation of configurations
    - GLOBES for “final” evaluation and comparison
      - Agree ahead of time on
        - the masses that will be compared,
        - POT’s and how they are split neutrino and anti-neutrino
        - Neutrino beam configuration
        - Sensitivity level – 3, 5 σ
- Make similar considerations for proton decay and supernovae

Near Detector

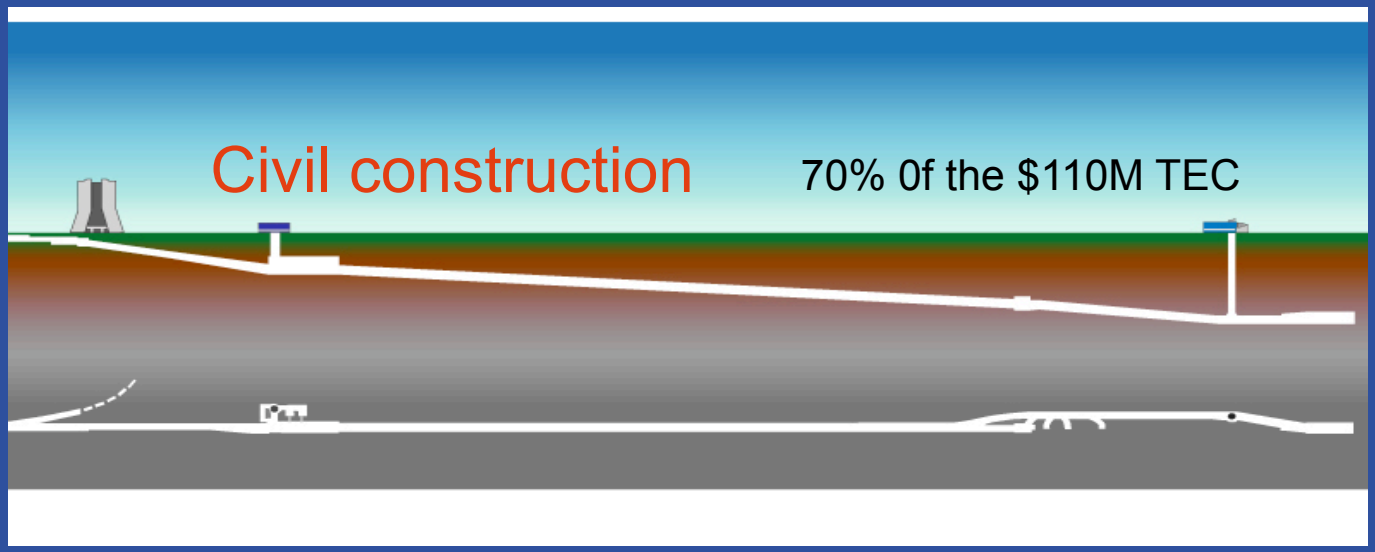
- ND Working Group has been active for several months
  – gathering together experience from many experiments
  – past, current and planned
    - MINOS, MiniBooNE, SciBooNE, K2K/T2K, Minerva, MicroBooNE…
    - Lead by Los Alamos, collaboration wide interest is growing
    - We need to make sure the scope doesn't grow accordingly
- Requirements and design will depend on how it is planned to be used in the analysis
- Most likely a hybrid of fine grained detectors, and target material to match the far detector will emerge as a strawman for the CD-1 process

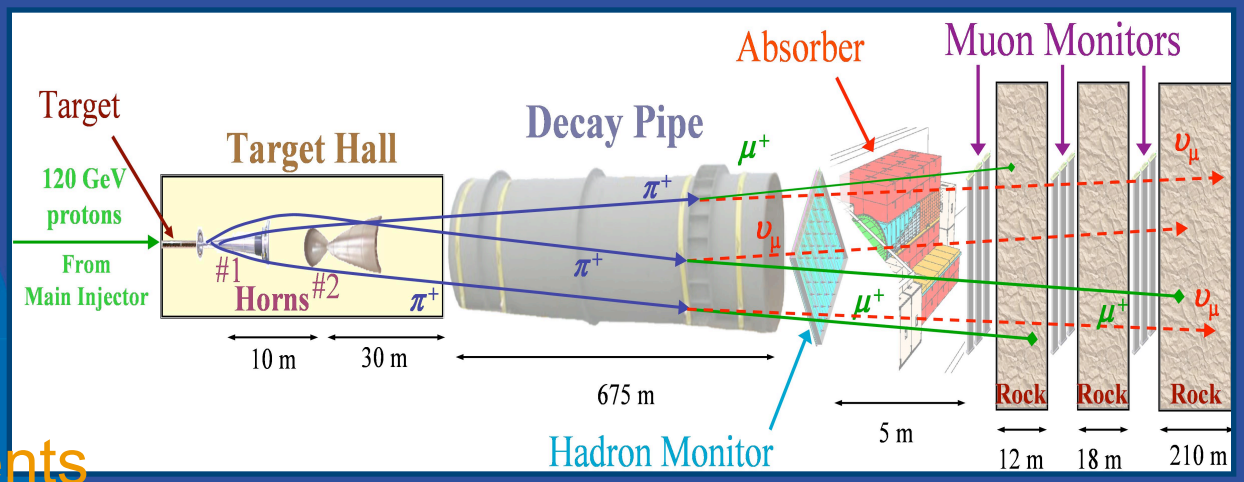
A Nu Beam to Homestake

Beam trajectory to Homestake



Experience from NuMI





Technical Components

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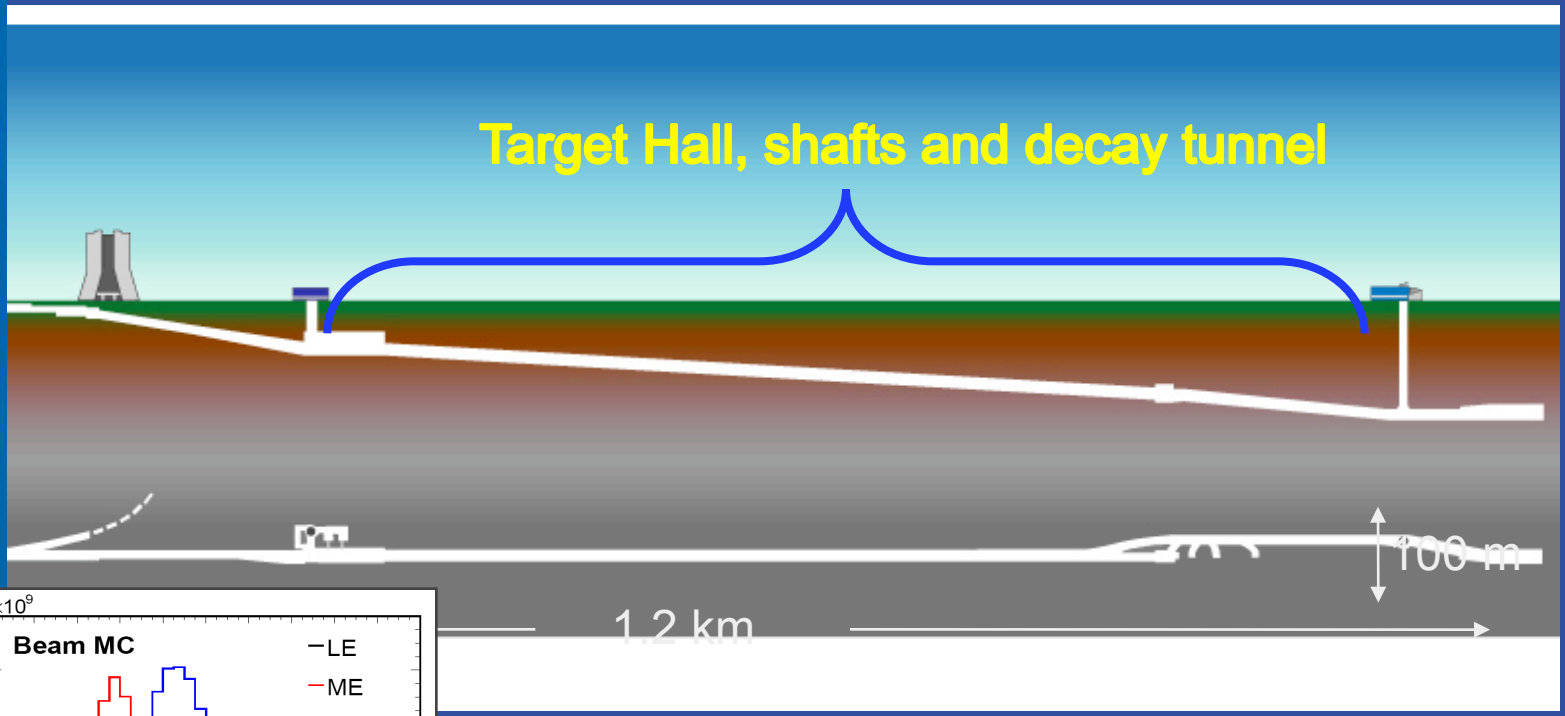
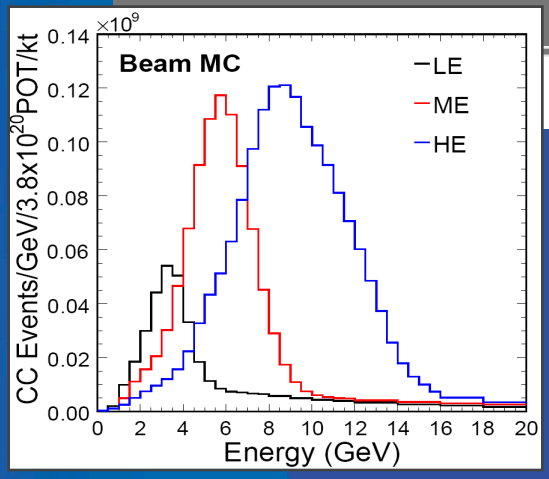
Civil Construction Cost Drivers





Initial parameters for NuMI set to maximize neutrinos at ~10 GeV → long decay tunnel

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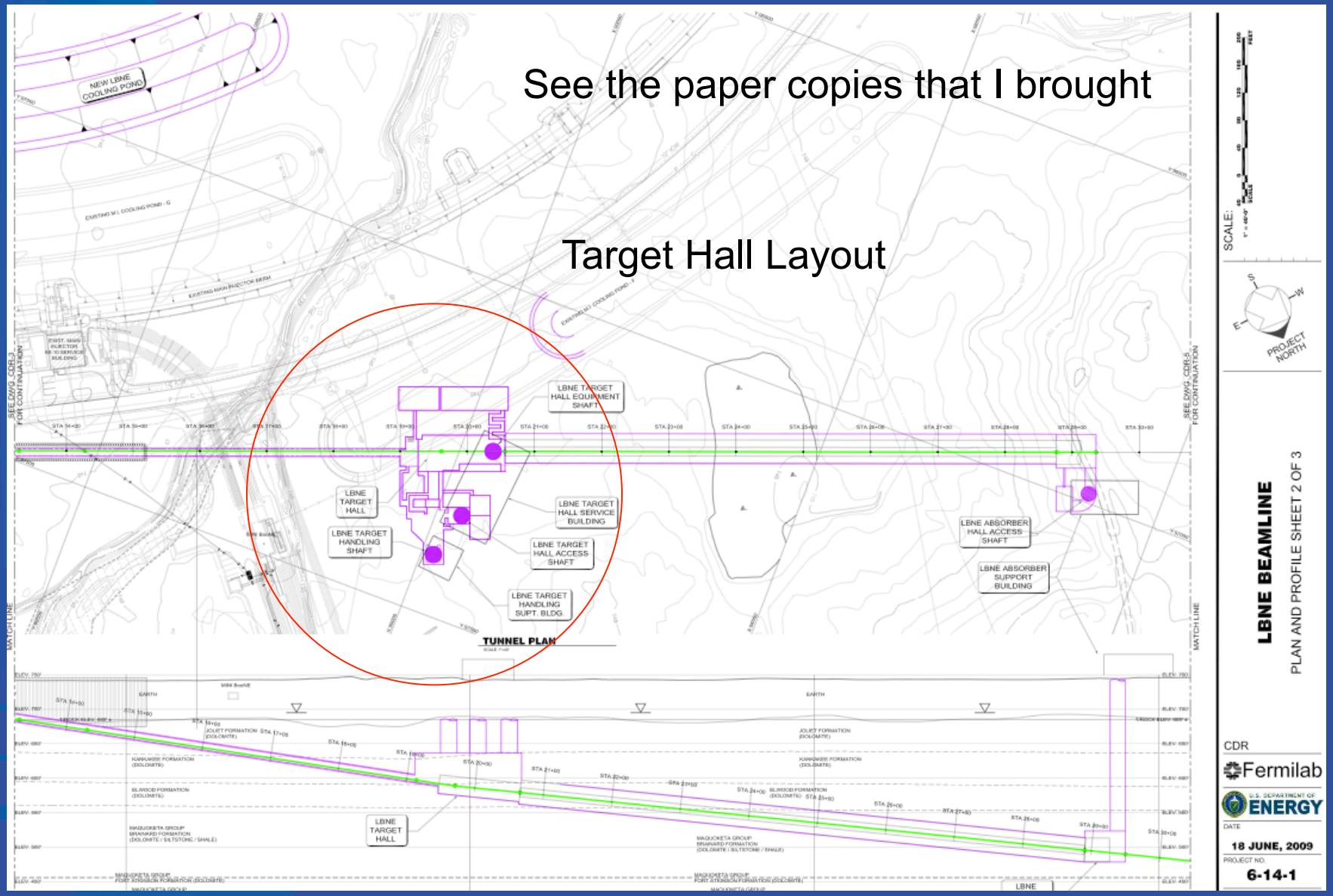
Design Considerations

- NuMI
  - Beam power – 400 kW
  - Decay length for high energy
    - Used a TBM
    - Continuous tunnel
  - Technical lessons learned
    - Corrosion
    - Tritium
- Nu beam to Homestake
  - Beam power – 2 MW
  - Optimization for low energy
    - Shorter, wider
    - No TBM
    - Separate ND Hall
  - Target Hall
    - Component replacement
    - Tritium mitigation

See the paper copies that I brought

Target Hall Layout



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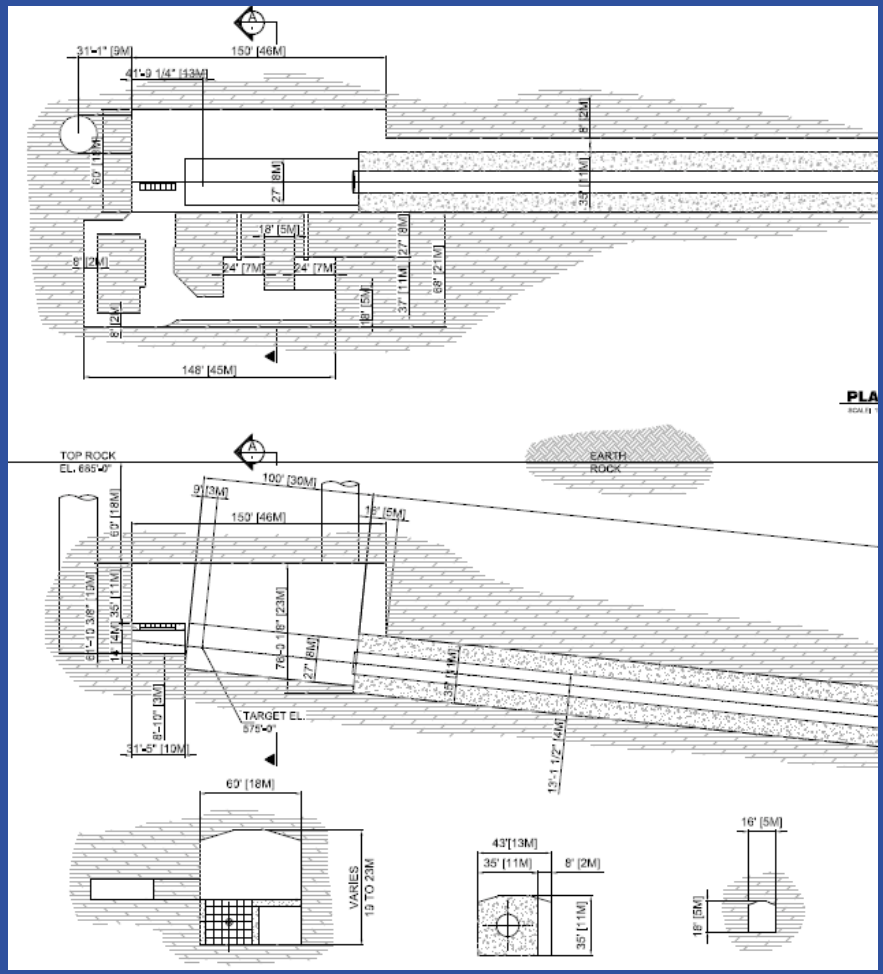
Target Hall Design

- Requirements
  - Safe and efficient exchange of targets and horns
    - Design depends on required frequency of repair
    - How long will the target last?
  - Work area for repairs
  - Dehumidification to mitigate tritium production



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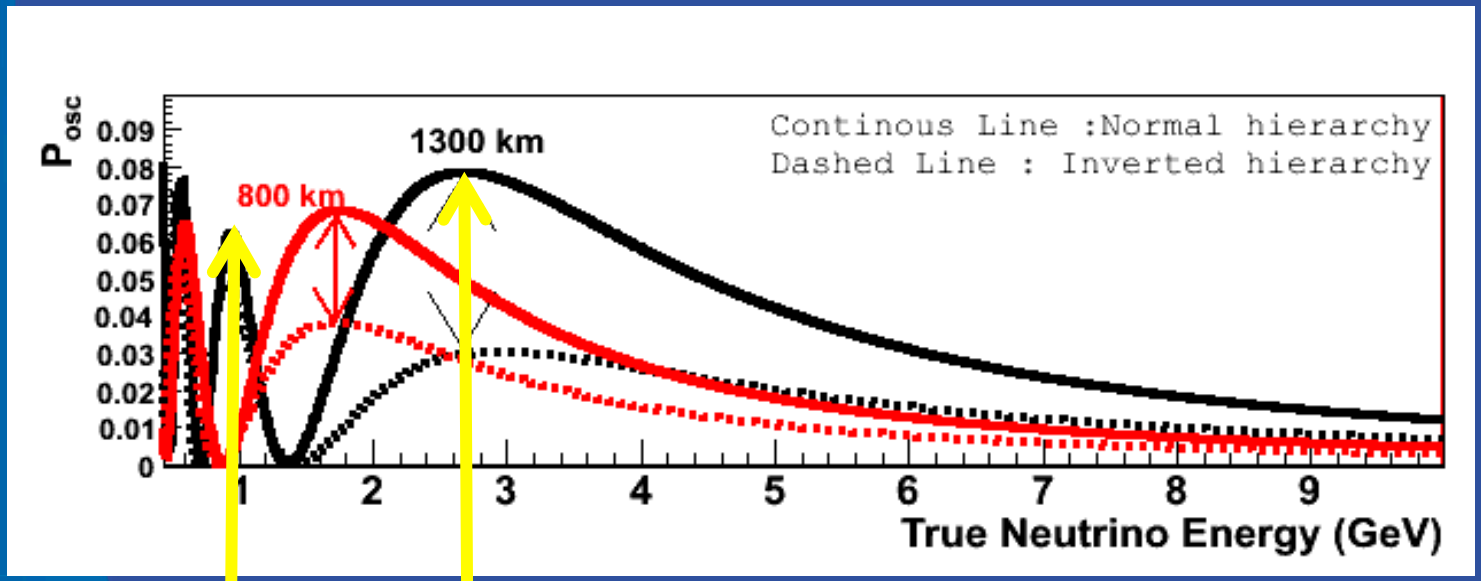
Beam Design Requirements

- Want a wide band beam cover the 1st and 2nd oscillation maximum

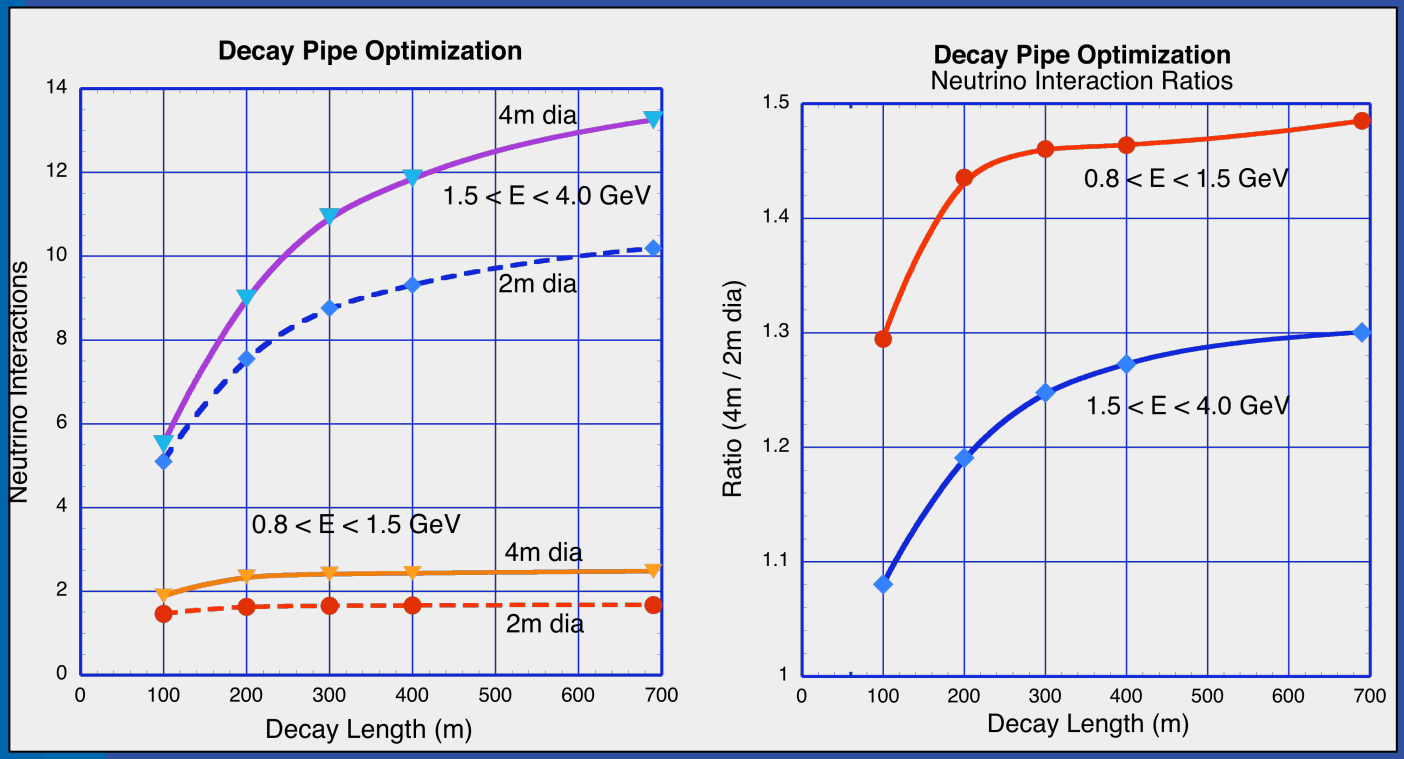


0.8 GeV 2.7 GeV

Above 10 GeV

Is not very useful

Decay Pipe and Tunnel



NuMI : 2 m diameter pipe, 7m diameter tunnel (shielding and passage), 750 m length

LBNE : 4 m diameter pipe, ~9 diameter tunnel,250 m length

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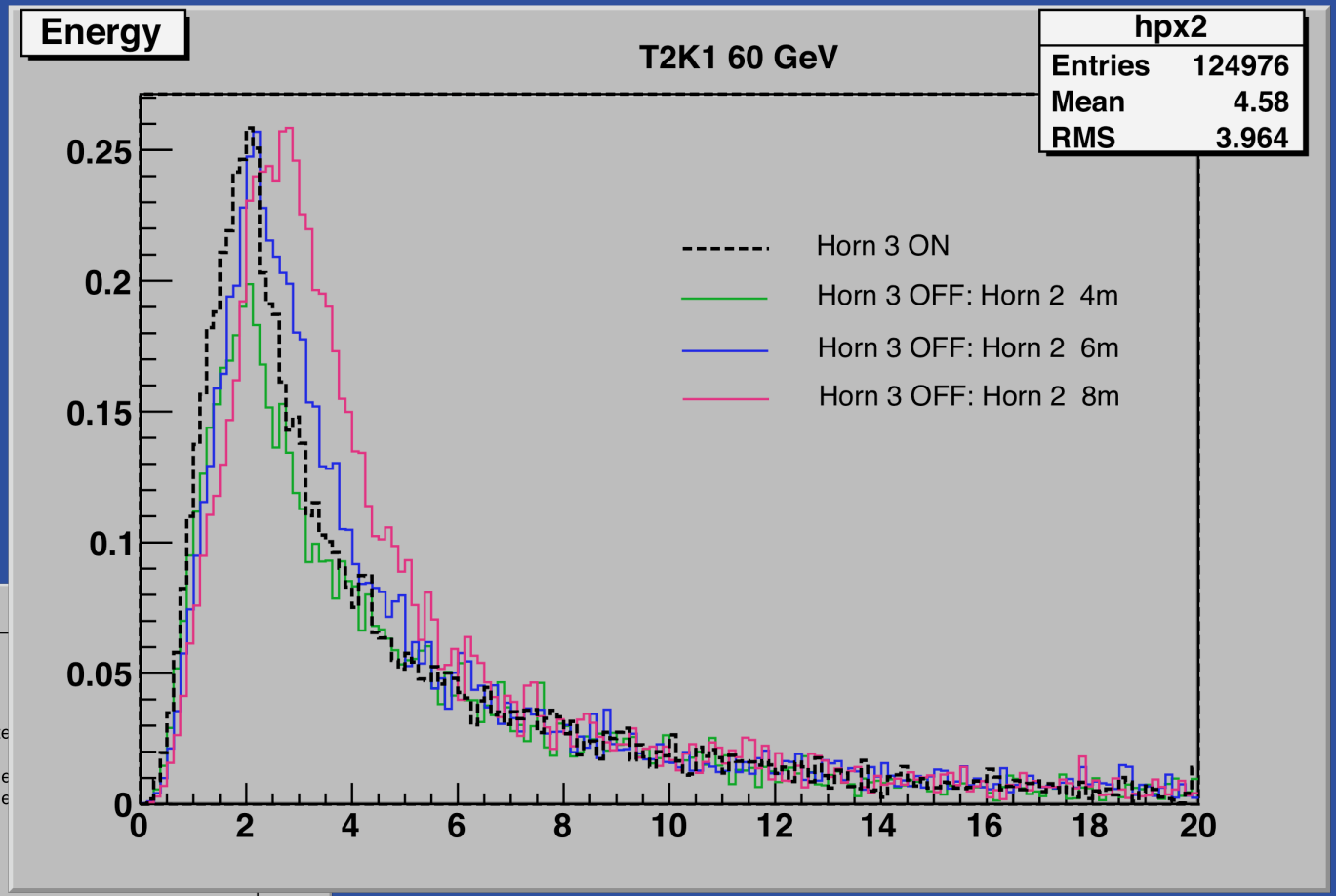
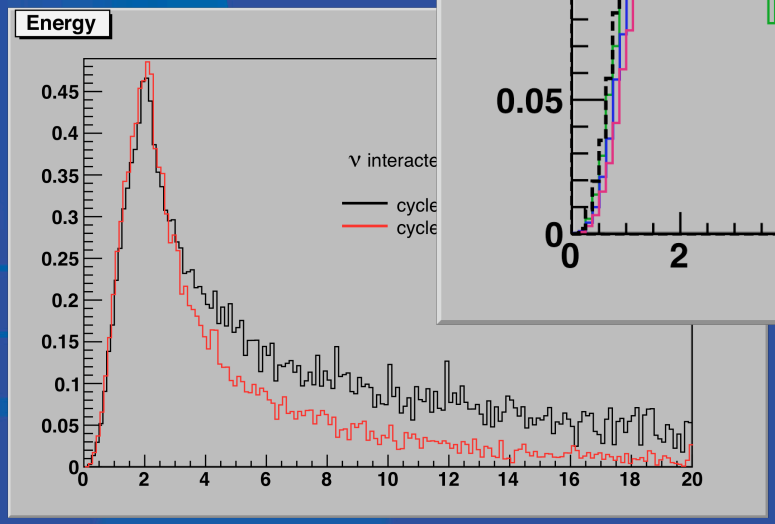
Optimizing the neutrino spectrum





Reduce high energy tail;
enhance low energy

Pre-conceptual Design

- Drawing package ready to go out for a cost estimate – mid July
  - Separate experts will estimate the conventional surface buildings and outfitting (surface and underground)
  - Tunneling and mining experts will estimate the excavation
- Preliminary cost estimate will be available in Fall
- Site borings will be done this Fall also

CD-1 Plan :
Budgets, Manpower Requirements

FY09

NO DATA SHOULD BE ENTERED ON THIS SHEET!!

			FY09					
WBS	Task name		Labor (FTE)					
		Sum no	Technical			Administrative		
			W	A	N	W	A	N
1	**LBNE**							
SWF								
1.1	Project Management	7.3	1.80	2.10	0.00	1.00	0.40	2.00
1.2	Neutrino Beam	2.9	1.00	1.90	0.00	0.00	0.00	0.00
1.3	Near Detector	0.0	0.00	0.00	0.00	0.00	0.00	0.00
1.4	Water Cerenkov Detector	3.5	0.00	1.50	2.00	0.00	0.00	0.00
1.5	Liquid Argon Detector	3.4	1.45	1.90	0.00	0.00	0.00	0.00
	FTE Totals		4.25	7.4	2	1	0.4	2
	fraction of year	0.3333						
	$(K)	**1592**	**425**	**740**	**200**	**67**	**27**	**133**
	Total $(K) for SWF - LBNE	**1925**						
	Total $(K) for SWF - Base	2177						
M&S		Travel	Project Office Support	Contract Engineering	Contract Services	Materials Procurement	Other	Total M&S
1.1	Project Management	65	130	0	0	0	0	195
1.2	Neutrino Beam	15	0	360	400	0	0	775
1.3	Near Detector	10	0	0	0	0	0	10
1.4	Water Cerenkov Detector	35	0	680	0	0	3.8	719
1.5	Liquid Argon Detector	20	0	310	0	307	0	637
	Total M&S	145	130	1350	400	307	3.8	**2336**

FY09 Scientific effort

WBS	Task name	Scientists			RA/Post-doc			Sum Sci
		W	A	N	W	A	N	
1	**LBNE**							
SWF								
1.1	Project Management	2.55	1.05	0.00	0.00	0.00	0.00	3.60
1.2	Neutrino Beam	1.40	0.60	2.00	0.00	0.00	0.40	4.40
1.3	Near Detector	0.33	1.00	0.00	0.00	1.00	0.50	2.83
1.4	Water Cerenkov Detector	1.84	2.15	0.00	0.00	0.00	2.00	5.99
1.5	Liquid Argon Detector	2.30	4.10	0.00	0.00	0.00	1.00	7.40
	FTE Totals	8.42	8.9	2	0	1	3.9	
	fraction of year							
	$(K)	842	890	200	0	50	195	
		33	100	0	0	100	50	**283** $K
		LANL on LBNE for FY09 only					50	
							General RA on project	

FY10

NO DATA SHOULD BE ENTERED ON THIS SHEET!!

			FY10					
WBS	Task name		Labor (FTE)					
		Sum nor	Technical			Administrative		
			W	A	N	W	A	N
1	**LBNE**							
SWF								
1.1	Project Management	12.05	4.75	0.80	1.00	1.00	3.50	1.00
1.2	Neutrino Beam	7.00	1.70	5.30	0.00	0.00	0.00	0.00
1.3	Near Detector	0.25	0.00	0.25	0.00	0.00	0.00	0.00
1.4	Water Cerenkov Detector	7.65	1.85	3.80	2.00	0.00	0.00	0.00
1.5	Liquid Argon Detector	8.10	3.00	4.10	1.00	0.00	0.00	0.00
	FTE Totals		**11.3**	14.25	4	1	3.5	1
	fraction of year	1						
	$(K)		**3390**	**4275**	**1200**	**200**	**700**	**200**

Total $(K) for SWF - LBNE	**10040**
Total $(K) for SWF - Base	7647

M&S		Travel	Project Office Support	Contract Engineering	Contract Services	Materials Procurement	Other	Total M&S
1.1	Project Management	190	90	0	200	0	0	480
1.2	Neutrino Beam	0	0	500	1500	0	0	2000
1.3	Near Detector	0	0	0	0	0	0	0
1.4	Water Cerenkov Detector	0	0	1310	0	50	6.4	1366.4
1.5	Liquid Argon Detector	0	0	840	0	300	0	1140
	Total M&S	190	90	2650	1700	350	6.4	**4986**

FY10 Scientific Effort

WBS	Task name	Scientists			RA/Post-doc			Sum Sci
		W	A	N	W	A	N	
1	**LBNE**							
SWF								
1.1	Project Management	4.05	0.50	0.00	0.00	0.00	0.00	4.55
1.2	Neutrino Beam	4.30	1.10	0.00	0.40	0.00	0.00	5.80
1.3	Near Detector	0.25	1.00	0.00	0.00	1.00	0.00	2.25
1.4	Water Cerenkov Detector	4.09	0.00	0.00	1.50	0.00	1.00	6.59
1.5	Liquid Argon Detector	2.40	4.50	0.00	1.00	0.00	1.70	9.60
	FTE Totals	15.09	7.1	0	2.9	1	2.7	**28.79**
	fraction of year							
	$(K)	4527	2130	0	435	150	405	

75

0.5 RA supported on project

Budget Summary

	FY09	FY10	Sum
SWF* supported by LBNE funds	1925	10040	11965
M&S supported by LBNE funds	2336	4986	7322
Total LBNE funds	**4260**	**15026**	**19287**
SWF supported by OHEP Base funds	2177	7647	9824

FNAL LBNE Budget	3000	5000	8000
ARRA - LBNE	12000		12000
Total FY09-10			20000

FY09 Obligations through	May		550
Un-"obligated"			163

*SWF = non-scientific manpower at FNAL and collaborating Laboratories and Universities

An additional $3M in ARRA is held back in Washington

Challenges

- Several MAJOR aspects of this project require expertise that does not reside within our laboratories and universities – mining, tunneling, underground outfitting and safety in such projects
- Many technical and scientific personnel (at the Laboratories and Universities) with the expertise to design this project are committed to other projects (NOvA, T2K, Daya Bay, Double Chooz, MicroBooNE)
- Difficult to buy scientific and technical manpower with the experience to jump right in and do the work in the time frame being put forth

Alternatives Analysis

- Many obvious alternatives have been explored, documented and discounted in previous studies, site selections, etc.
  - BNL to Homestake
  - NuMI to LAr100 at 1st and 2nd oscillation maximum
  - DUSEL at Henderson, Cascades, Soudan….
- Pulling all of this together again is not difficult, but will take significant effort
- The Conceptual Design needs to be based on actual trajectory and detector location
  - If the outcome of the alternatives analysis is different than this, we are back to square 1
- The evaluation of the detector technology requires a combination of scientific understanding of the detector performance, ability to assess costs, schedules and contingencies, evaluation and assessment of risks

Fermilab Water Cerenkov Detector Task Force

- Commissioned by Fermilab Directorate with charge

  to evaluate the current state of the detector design, determine what are the most significant and relevant issues to be resolved and to make recommendations on how Fermilab can and should contribute to the [Water Cerenkov detector design] effort

- Task force members

  Del Allspach – Process Systems Engineer, PPD/MD.
  Leo Bellantoni – Scientist, PPD/EPP.
  Steve Brice – Scientist, PPD/Neutrino (Department Head).
  Thomas Junk – Guest Scientist, PPD/CDF.
  Robert Plunkett – Scientist II, PPD/Neutrino.
  Peter Shanahan (Task Force Chair) – Scientist, PPD/Neutrino.
  Robert Tschirhart – Scientist II, CD/CDO/FPE.
  Richard Tesarek – Scientist, PPD/CDF

WCTF Approach

- Within the context of the S4 proposal, we
  - Evaluated the status of the design, including issues and challenges,
  - Evaluated the capabilities of Fermilab relating to those challenges,
  - Recommended how Fermilab could and should contribute to the WC detector design, with an emphasis on the period leading to CD-1.

Final WCTF Recommendations

- Fermilab should investigate involvement, in the context of the Science Collaboration and the LBNE project, in the design of
  - Detector Cavern and Containment vessel, as an integrated issue with light collection and detection,
  - Water handling system,
  - Calibration system, including preliminary investigation of the possibility of an *in situ* accelerator source,
  - Custom readout and high voltage electronics,
  - Project elements for the procurement, testing, assembly, and integration of large number of photo-detectors and other detector components,
  - and, in the development of simulations and reconstruction software which will be central in resolving all other design issues.

Summary

- Two main takeaways from WCTF
  - Integrate design efforts sooner than later
  - Develop simulations
- Fermilab's integration into the WC design project depends on how the project gets structured by the BNL project team, working with the expertise already identified within the collaboration, with the caveat of the LBNE vs S4 context
- Since March a WBS has been developed and Working Groups for major topics have been set up
- WG leaders have been assigned in almost all areas

Water Cerenkov Working Groups

- Water Containment - F. Feyzi, PSL/UW
- Water System – R.Bionta, LBNL, H. Sobel, UCI
- PMTs – being negotiated
- Electronics – E. Kearns (BU), R. Van Berg (Upenn)
- Simulations – C. Walters

Liquid Argon Working Groups

- Physics reach (simulations) – B. Fleming, Yale
- Cavern – C. Laughton
- Cryostat, Cryogenics, and Purification – J. Urheim, IU
- TPC/HV and Photon Detectors – H. Wang, UCLA, B. Yu, BNL
- Electronics – C. Thorne, BNL, C. Bromberg, MSU
- Installation, Commissioning, Operation – B. Miller, Minn
- Life Safety, ES&H – R. Poling, Minn

Conclusion

- This is a very challenging project to build an experiment that has potential for a big pay off
- There is a committed group of scientists willing to spend the better part of a decade to design and build this,
- To then spend another decade collecting the data,….
  - Let's hope we can analyze it quickly….

60 x 10^{20} POT in ν mode

60 x10^{20} in anti-ν mode

You don't get mass hierarch or true CP violation till you run both

Fermilab Ten-Year Plan at The Three Frontiers

(Technically Limited)

We have a long way to go….

Time to get started!

Fermilab