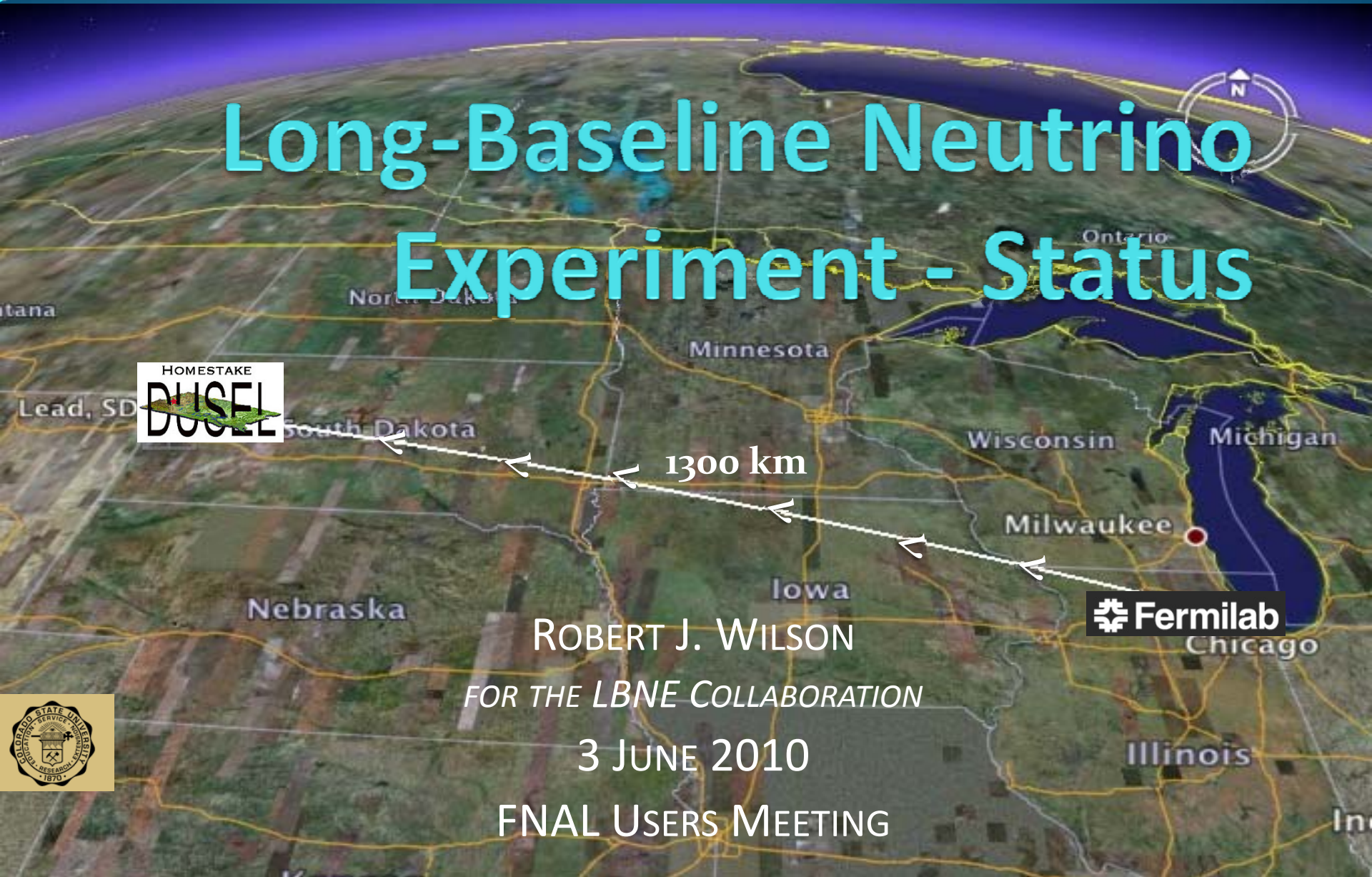
Long-Baseline Neutrino Experiment - Status



ROBERT J. WILSON

FOR THE LBNE COLLABORATION

3 JUNE 2010

FNAL USERS MEETING

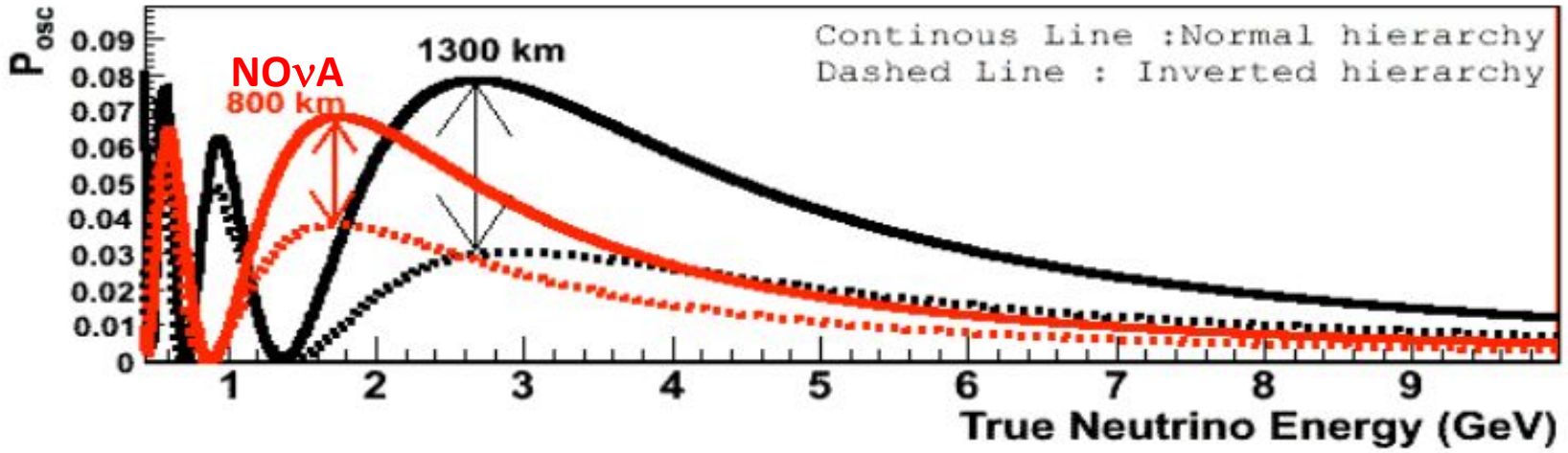
Overview

- Physics Objectives
- Status
  - DOE
  - LBNE DUSEL
  - LBNE Project
  - LBNE Science Collaboration
  - Beams & Detectors Configurations
- Sensitivity
- Summary

Physics Objectives

- **CP Violation in neutrino sector**
  - How: $\nu_\mu \rightarrow \nu_e$ à la MINOS, T2K & NOνA (see R. Zwaska, S. Budd talks) - but longer baseline and wide band low energy beam
- **…and other missing pieces of the neutrino puzzle**
  - Resolve the neutrino mass hierarchy
  - Precision measurements of oscillation parameters (mixing angles, mass differences)
  - Precision neutrino interactions studies (near detector)
- **… and other fundamental physics enabled by massive detectors**
  - Proton decay measurement
  - Astrophysics
    - Solar neutrinos – direct MSW effect measurement (day/night)
    - Supernova ν burst flux & relic neutrinos from past supernovae
    - Ultra High Energy neutrinos
    - Neutrinos from dark matter…

Long(er) Baseline



- Fermilab – Homestake (South Dakota) = 1300 km
- Wide Band Low Energy Beam – information from both 1st & 2nd maxima
- All neutrino parameters measured in the same detector complex

Status

Strong support at DOE

D. Kovar, Fermilab Users Meeting, June 2010

U.S. DEPARTMENT OF ENERGY
Office of Science

U.S. Intensity Frontier Program: The Neutrino Program

Envisioned "world-class" intensity frontier program entails evolution of the Fermilab accelerator complex

- MINOS/Minerva → NOvA (700kW) → LBNE (700kW) → SLBNE (2000 kW)
- Accelerator infrastructure allow: SLBNE → neutrino factory → muon collider (regain the Energy Frontier)

Envisioned "world-class" intensity frontier program also entails development of an underground detector

- LBNE need a large underground detector (~100-300 ktons)
- A large detector (~300 kton) at the right depth (~5000 ft) detector can also do proton decay
- Physics goals: searches for CP violation and proton decay at factors of 10-100 greater sensitivity

Goals are ambitious and will take significant combined (DOE, NSF, other countries) resources

- NSF is proposing a Deep Underground Science and Engineering Laboratory (DUSEL)
- Europeans have a large underground detector in their strategic planning
- Japanese are also interested in the science
- Indian government has expressed an interest in participation.

DOE and NSF have had discussion with OMB and OSTP on how to coordinate planning

- NSF is supporting the preliminary design of the DUSEL facility and a suite of experiments
- DOE HEP has CD-0 approval for the LBNE (neutrino beam /near and far (large underground) detectors)
  - Working towards CD-1 approval in FY11.
- DOE and NSF are working together to coordinate their efforts, avoid duplication, and optimize their investments.
  - Holding frequent Joint Oversight Group meetings.
- DOE Undersecretary Koonin and NSF Director Bement submitted joint statement indicating support

Science
Project ↔ Collaboration ↔ DUSEL

- Borromean Rings: Removing any one leaves two unlinked rings
- **LBNE Project - DOE Project initiated by CD-0 (Jan. 2010)**
  - DOE will "steward" LBNE
  - Project Manager=Jim Strait (FNAL) + Project Scientist=Gina Rameika (FNAL)
- **DUSEL LBNE – Part of the NSF laboratory**
  - NSF will "steward" the Homestake DUSEL facility & contribute to LBNE
  - DUSEL LBNE Lead Scientist=Richard Kadel (LBNL)
- **LBNE Science Collaboration – scientists to use the facility**
  - Advise on the configuration to achieve the best science
  - Executive Committee & Institution Board established
  - Co-spokesmen elected late 2009=Bob Svoboda (UC-Davis) + Milind Diwan (BNL)

http://en.wikipedia.org/wiki/File:Borromean_Rings_Illusion.png

Project Timeline

(Jim Strait)

- Currently early in the project planning phase.
- Received DOE CD-0 (Approve "Mission Need") Jan. 2010
- Working towards CD-1 Review (Conceptual design, preliminary cost and schedule range) Dec. 2010
- CD-1 (assuming successful CD-1 review) Apr. 2011
- Schedule for CD-2 (Project baseline) *depending on funding...*
  Winter 2012/3 ~ Summer 2013
- CD-3 (start construction) *depending on funding... 2014 ~ 2015*
- Schedule for construction is in the process of being developed
  guess that project will be complete >~ 2020

Science Collaboration

- ~250 members, 54 institutions (3 international)
- Co-spokespersons Bob Svoboda (UC-Davis) & Milind Diwan (BNL)
- Speakers Board – THANKS!

Argonne
Alabama
Boston University
Brookhaven
Caltech
Cambridge
Catania
Columbia
Chicago
Colorado
Colorado State
Columbia
Crookston
Davis
Drexel
Duke
Duluth
Fermilab
Hawaii
Indian Group
Indiana
Iowa State
IPMU-Tokyo
Irvine
Kansas State
Lawrence Berkeley National Lab
Livermore

London UCL
Los Alamos
Louisiana State
Maryland
Michigan State
Minnesota
MIT
NGA
New Mexico
Notre Dame
Oxford
Pennsylvania
Pittsburgh
Princeton
Rensselaer
Rochester
South Carolina
South Dakota State
SDSMT
Southern Methodist
Texas
Tufts
UCLA
Virginia Tech
Washington
Wisconsin
Yale

Physics Working Group

Topical Group Conveners:

Long-Baseline Mary Bishai & Sam Zeller • Mass Hierarchy and CP violation • θ_{13} measurement • Precision Oscillation parameters • New Phenomena	**Short-Baseline Physics Roberto Petti** • Required for LB physics • Other opportunities
Proton decay **Ed Kearns**	**Atmospheric Neutrinos** **Hugh Gallagher**
Galactic SN Burst Flux **Kate Scholberg**	**Geoneutrinos and Reactor neutrinos** **Nikolai Tolich**
Diffuse SN Flux Mark Vagins	**UHE Neutrinos Erik Blaufuss**
Solar Neutrinos Michael Smy	**PWG Coordinator Bob Wilson**

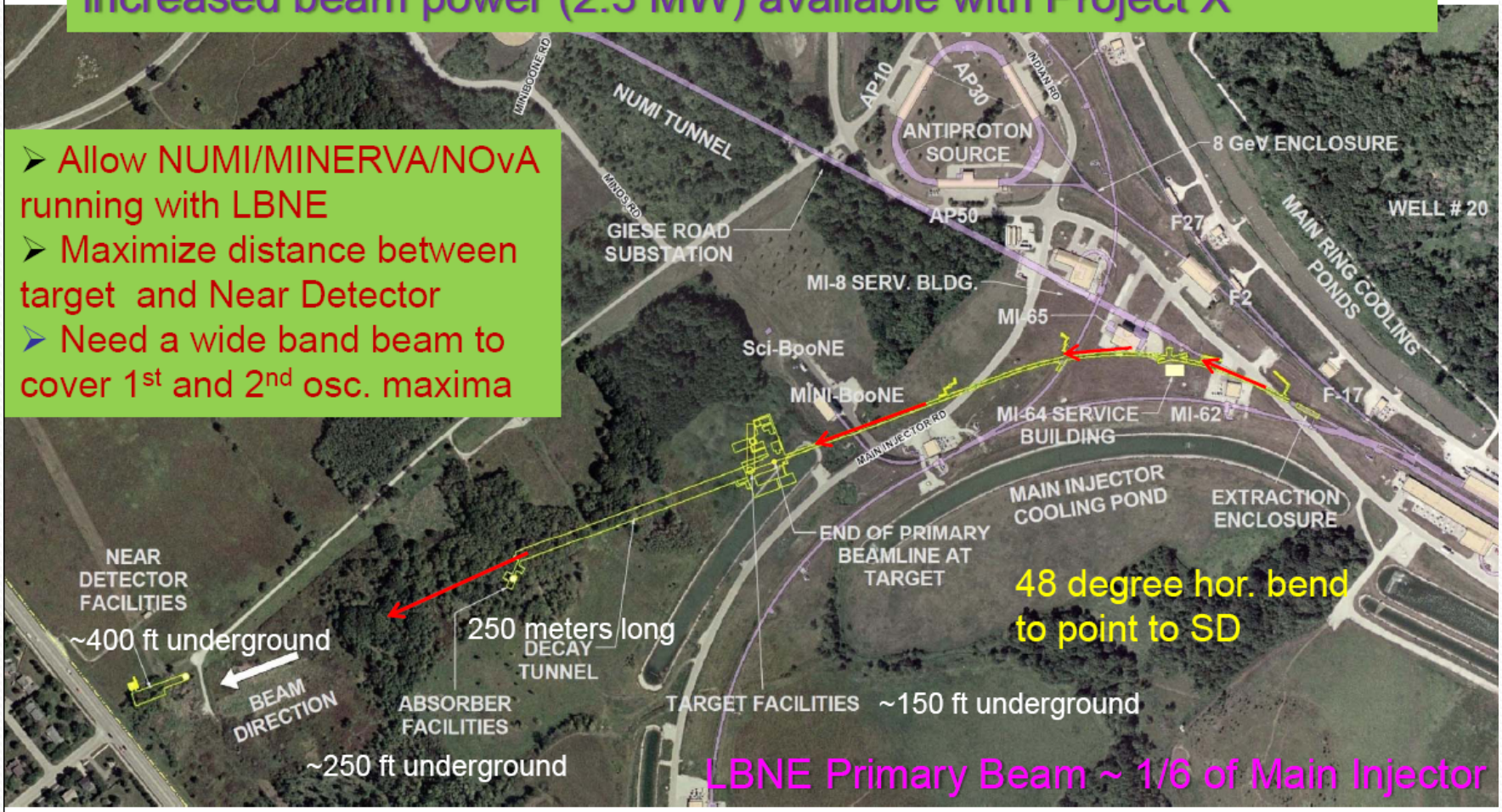
- Formed in just the last few months
- Contribute to the project CDR, esp. Vol. I (G. Rameika)
- Major task : PWG Physics Report building on much past work – late summer
- Primary input to the collaboration's detector configuration recommendation

Beam & Detector Groups

- Great progress in the beam and detector groups
- NSF DUSEL S4 + DOE funds
- Performance and cost and schedule range needed for CD-1
- Selection of a “reference” beam/detector designs for CD-1 review
- Performance/cost/risk will inform trade-offs between components of the project

The Neutrino Beam Facility at Fermilab

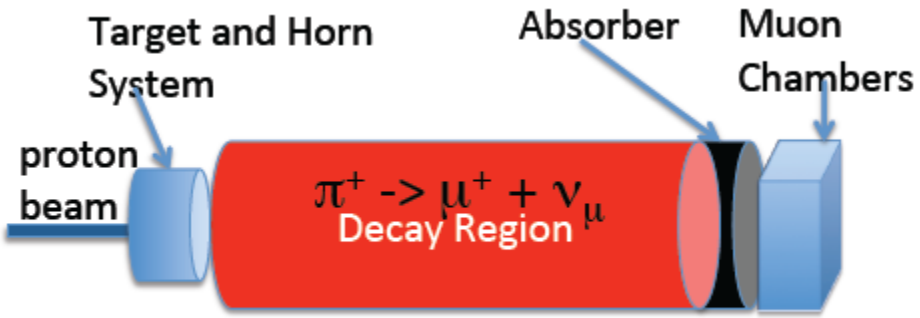
Start with a 700 kW beam, and then take profit of the significantly increased beam power (2.3 MW) available with Project X



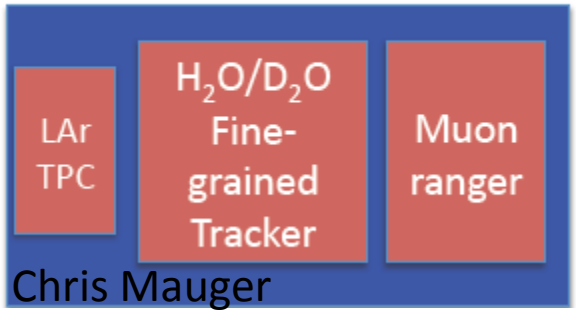
Primary beam energy (protons from the Main Injector) from 60 to 120 GeV

V. Papadimitriou, May 2010

Near Detector Complex

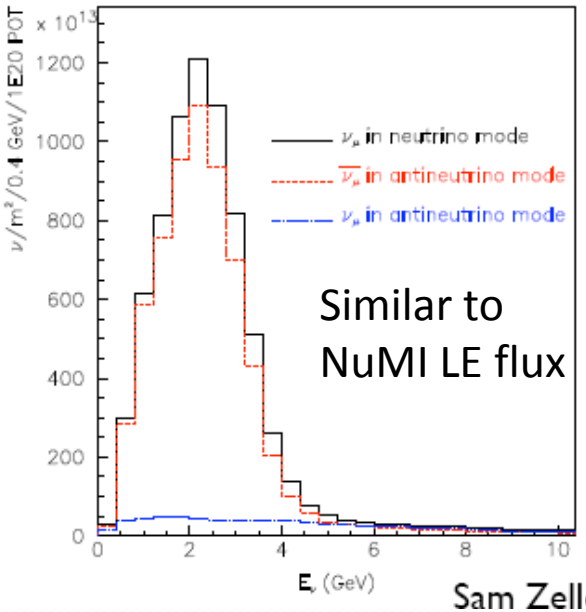


?? tbd



Events per ton per 10^{20} pot

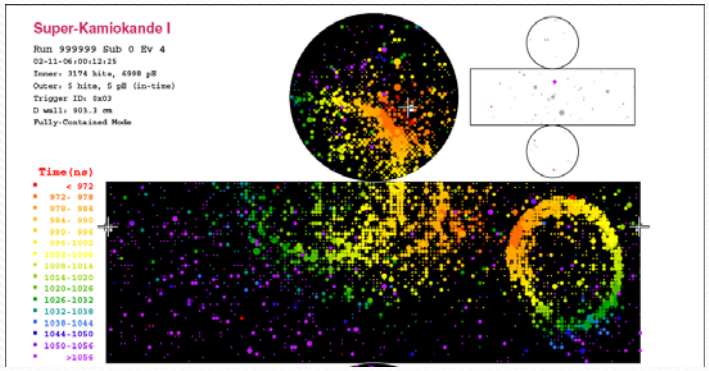
Production mode	H_2O	Ar	Ar/H_2O ratio
CC QE ($\nu_\mu n \rightarrow \mu^- p$)	18,977	23,152	1.22
NC elastic ($\nu_\mu N \rightarrow \nu_\mu N$)	7,094	7,165	1.01
CC resonant π^+ ($\nu_\mu N \rightarrow \mu^- N \pi^+$)	25,821	24,014	0.93
CC resonant π^0 ($\nu_\mu n \rightarrow \mu^- p \pi^0$)	6,308	7,696	1.22
NC resonant π^0 ($\nu_\mu N \rightarrow \nu_\mu N \pi^0$)	6,261	6,198	0.99
NC resonant π^+ ($\nu_\mu p \rightarrow \nu_\mu n \pi^+$)	2,694	2,182	0.81
NC resonant π^- ($\nu_\mu n \rightarrow \nu_\mu p \pi^-$)	2,325	2,930	1.26
CC DIS ($\nu_\mu N \rightarrow \mu^- X$, $W > 2$)	29,989	31,788	1.06
NC DIS ($\nu_\mu N \rightarrow \nu_\mu X$, $W > 2$)	10,183	10,285	1.01
CC coherent π^+ ($\nu_\mu A \rightarrow \mu^- A \pi^+$)	1,505	1,505	1.01
NC coherent π^0 ($\nu_\mu A \rightarrow \nu_\mu A \pi^0$)	790	790	1.01
NC resonant radiative decay ($N^* \rightarrow N\gamma$)	41		
Inverse Muon Decay ($\nu_\mu e \rightarrow \mu^- \nu_e$)	6	6	1.00
$\nu_\mu e^- \rightarrow \nu_\mu e^-$	11	11	1.00
Other	17,023	17,193	1.01
Total CC	94,948	100,645	1.06
Total NC+CC	129,028	134,189	1.04



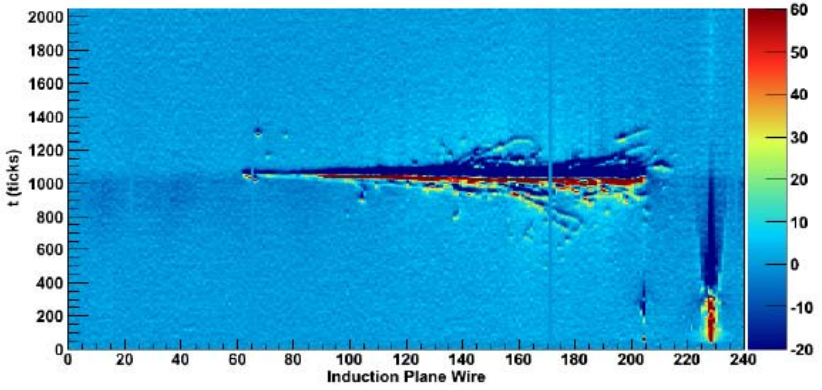
Sam Zeller

Two Far Detector Technologies

- **Water Cherenkov**
  - Tried-and-true technology and physics productivity: 50,000 ton Super-Kamiokande/T2K
  - Low cost sensitive medium; photosensor "off-the-shelf"
  - Free protons for nucleon decay and inverse beta-decay ν interactions
  - Could be supplemented with gadolinium for low energy ν physics



- **Liquid Argon TPC**
  - Bubble chamber-like imaging; detailed event topology with few mm resolution
  - Very high efficiency and background rejection ⇒ ~6x lower mass than WC
  - 600 ton ICARUS now operating at Gran Sasso
  - No free protons for nucleon decay or inverse beta-decay studies; excellent for kaon ID



Far Detector Depth Requirements

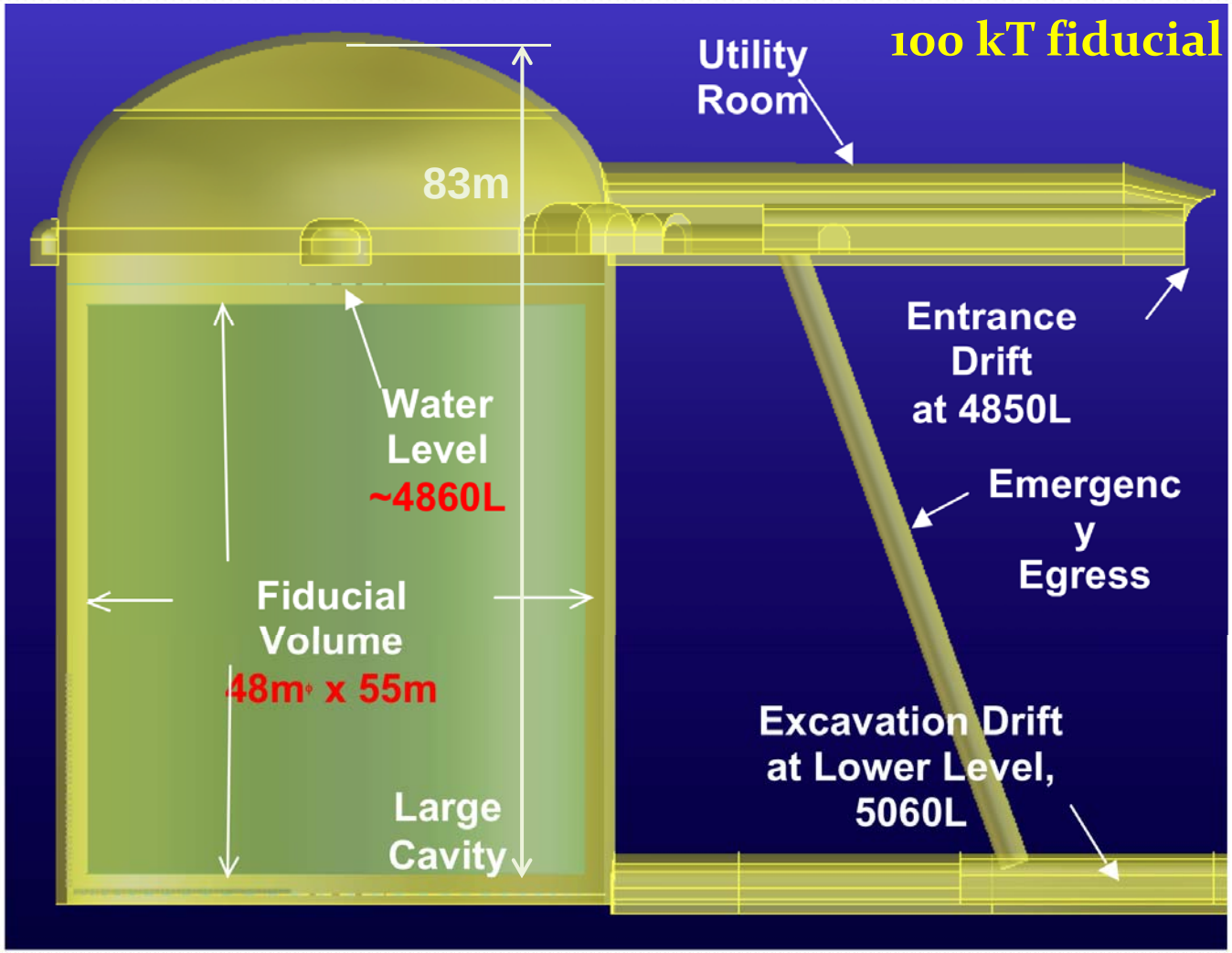
Fermilab-TM-2424-E, BNL-81896-2008-IR

Physics	Water Cherenkov (mwe*)	Liquid Argon (mwe*)
Long Baseline Accelerator	1000	0-1000
$p \rightarrow K^{+}\tilde{\nu}$	>3000	>3000(veto?)
Day/Night ^{8}B Solar ν	~4300	~4300
Supernova Burst	3500	3500
Diffuse ν from Supernova	4300	>2500
Atmospheric ν	2400	2400

*1 mwe (meters-water-equivalent) ~ 1.15' of rock density=2.9 gm/cc

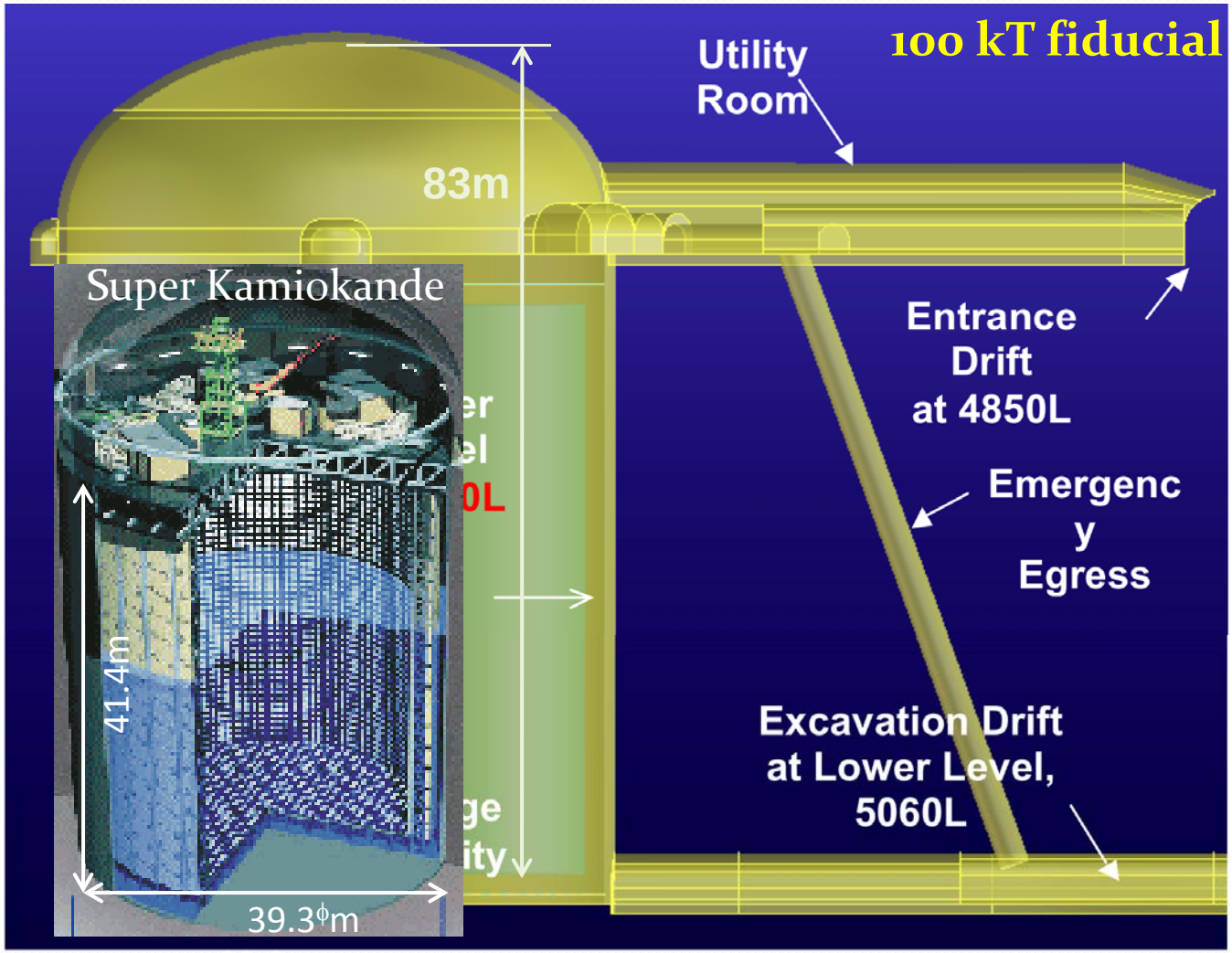
- No physics needs greater than Homestake 4850' level (4200 mwe)

Water Cherenkov Detector



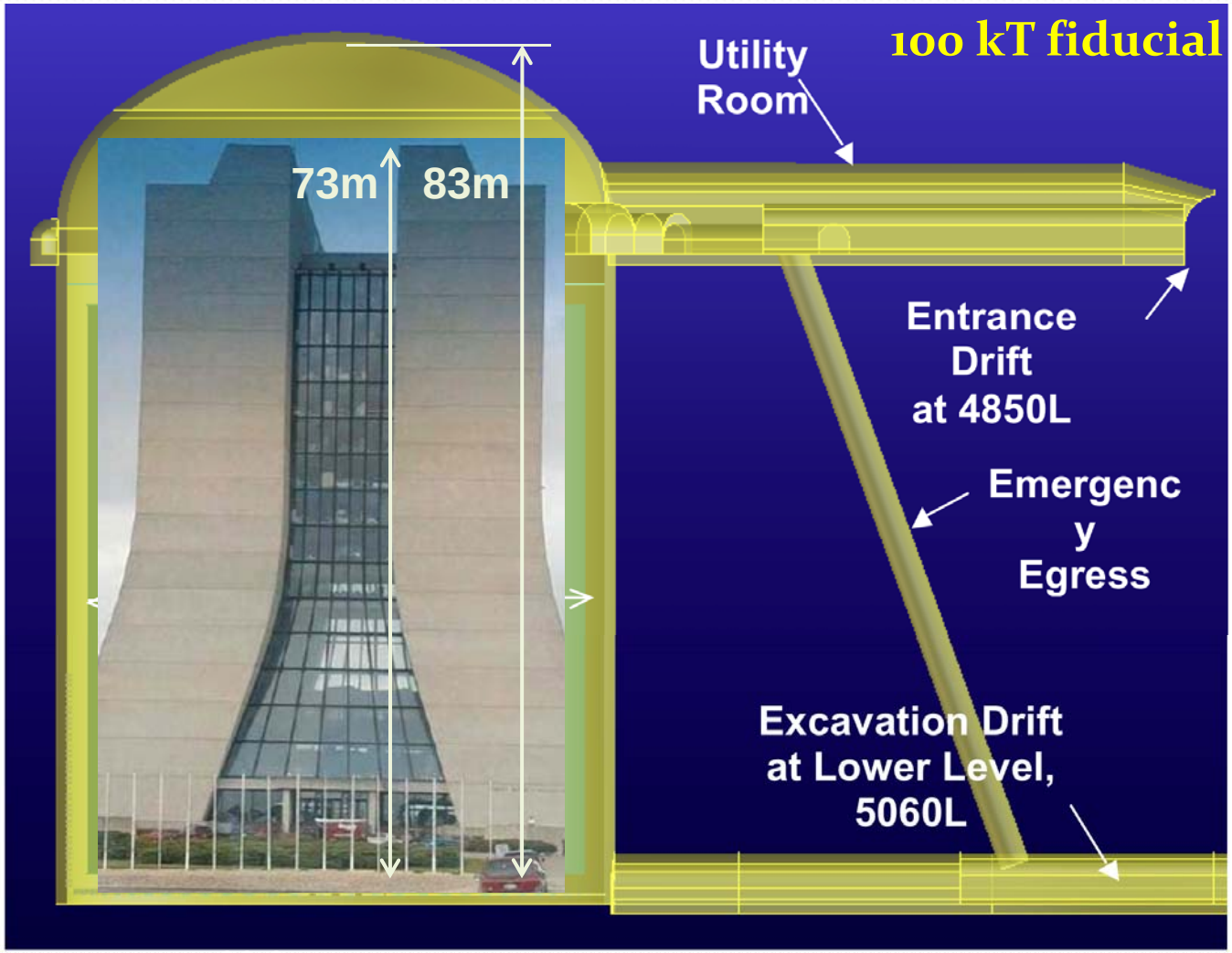
Project Manager:
Jim Stewart (BNL)

Water Cherenkov Detector



Project Manager:
Jim Stewart (BNL)

Water Cherenkov Detector



Project Manager:
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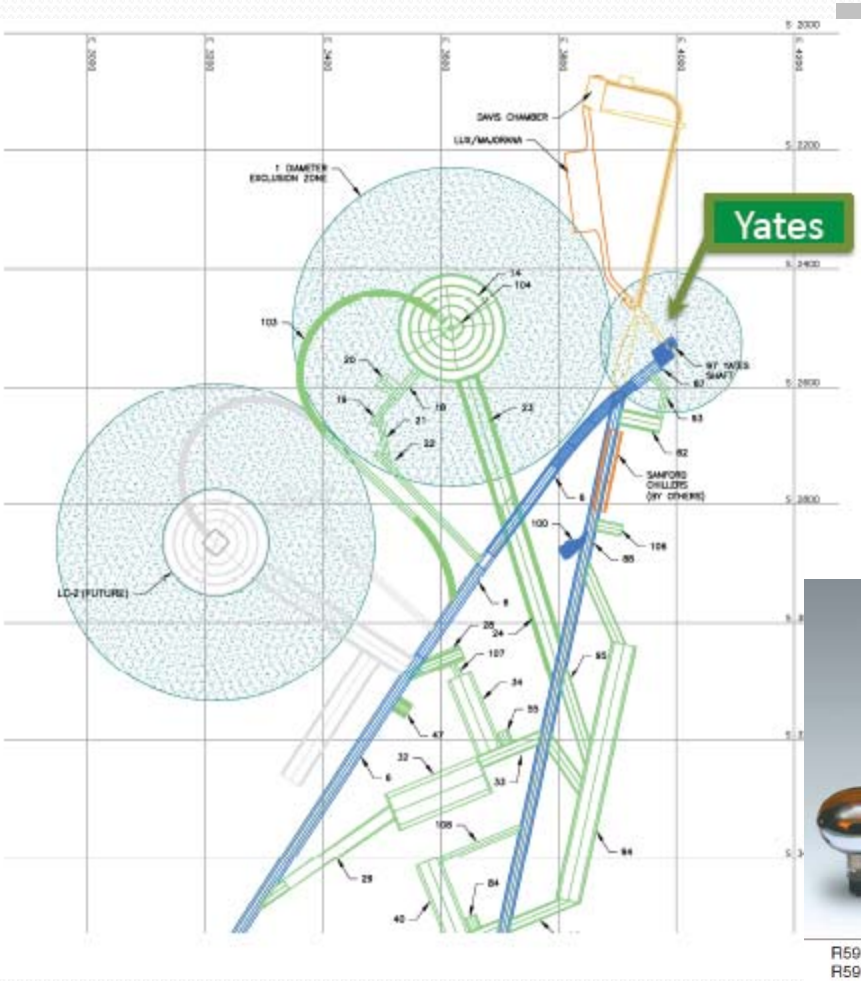
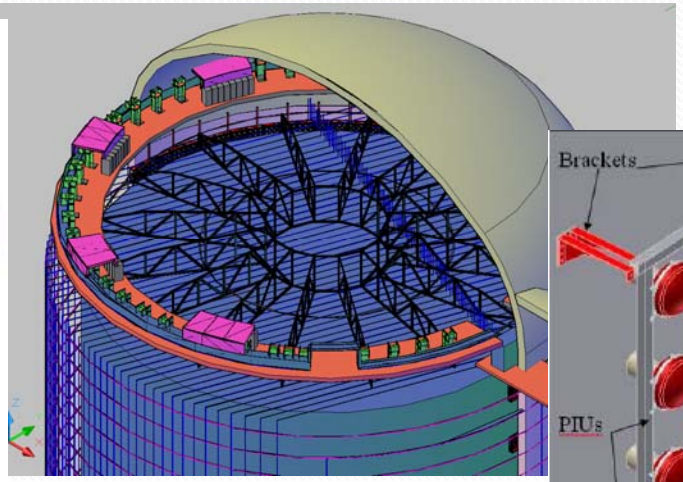
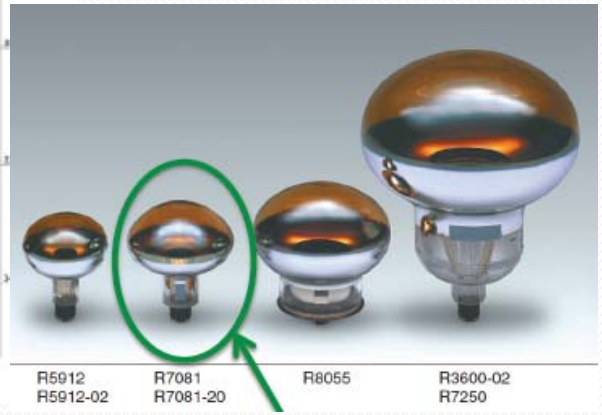
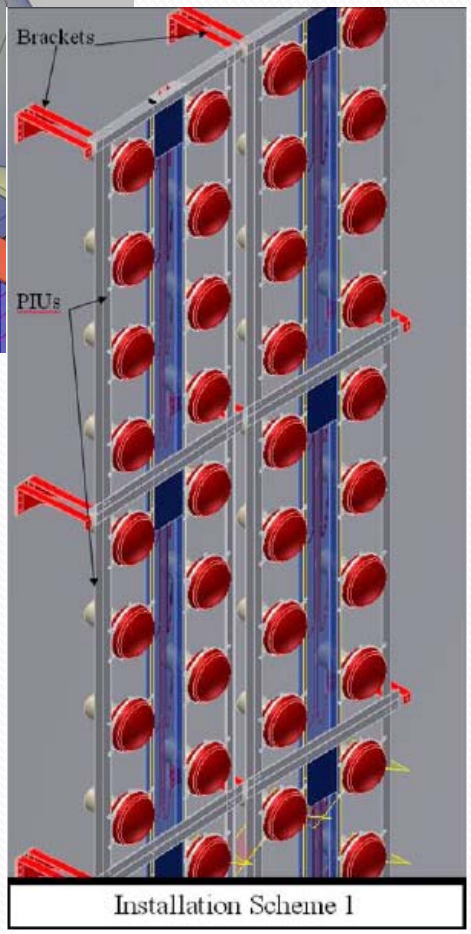
Water Cherenkov Detector



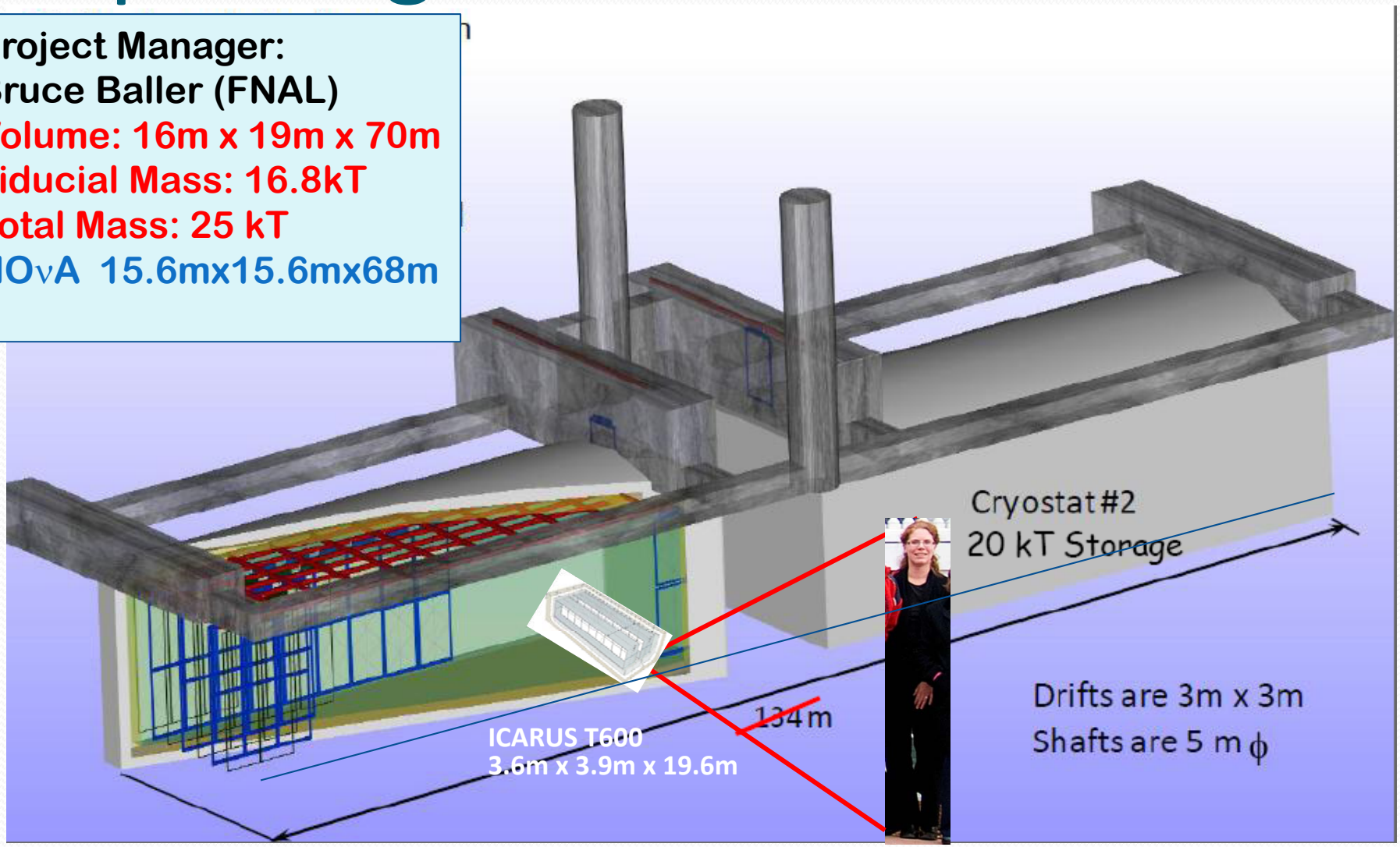




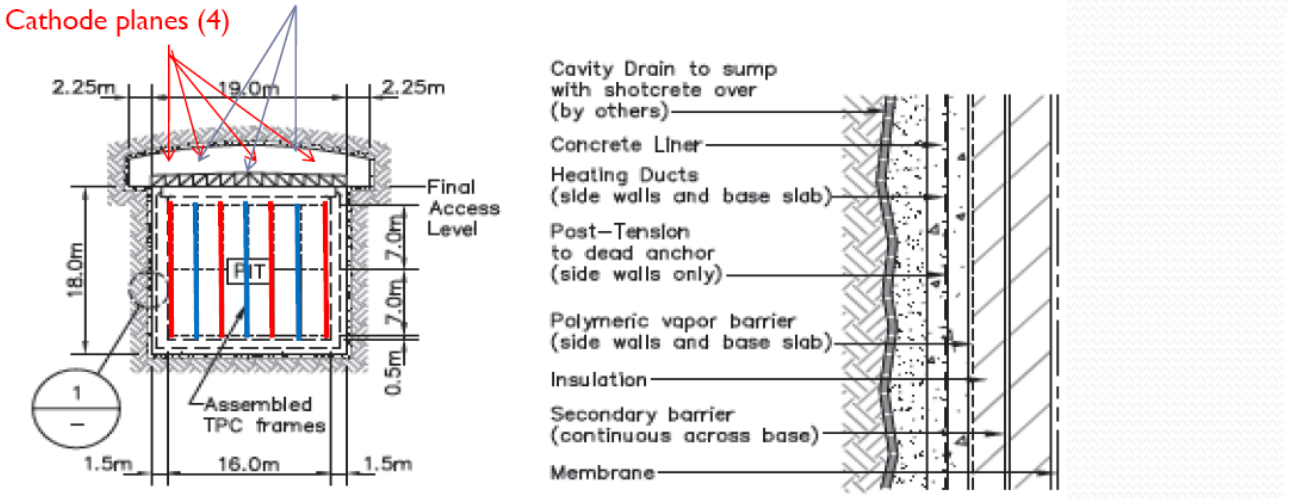


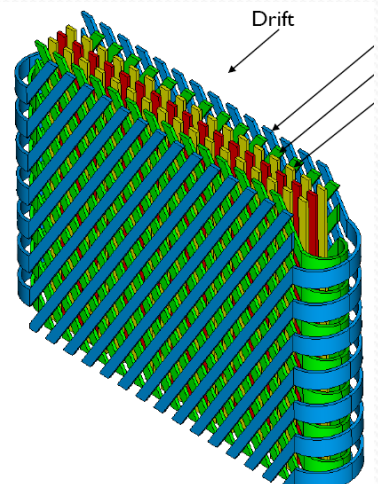
Liquid Argon TPC

Project Manager:
Bruce Baller (FNAL)
Volume: 16m x 19m x 70m
Fiducial Mass: 16.8kT
Total Mass: 25 kT
NOνA 15.6mx15.6mx68m

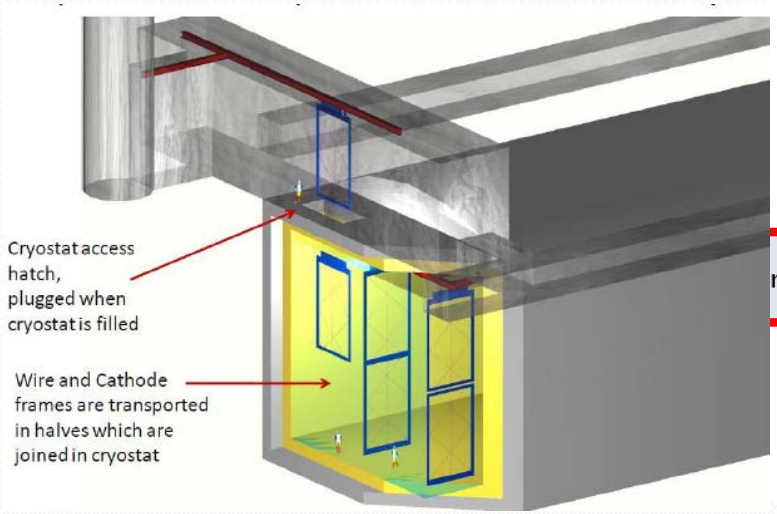


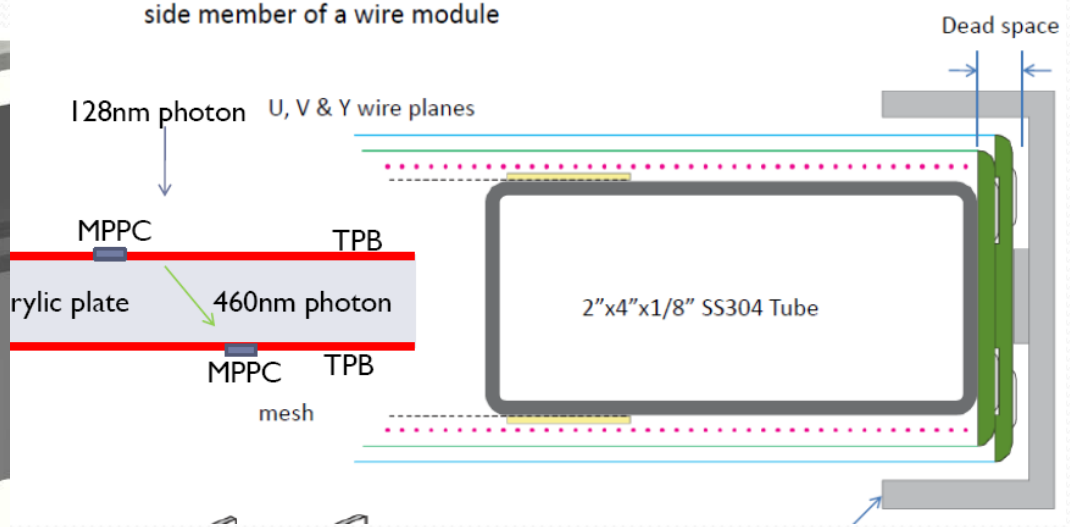
Liquid Argon TPC





side member of a wire module





Physics Report FD Configurations

Technology	Depth	Detail
Three x 100 kton* WC	4850’	15% pmt† coverage
		30% pmt† coverage
		30% pmt† coverage + Gd
Three x 17 kton* LAr TPC	4850’	Scintillation photon trigger
	300’/800’	No photon trigger
Two x 100 kton* WC AND **One** x 17 kton* LAr TPC	4850’ 300’/800’	15% pmt† coverage
		30% pmt† coverage
		30% pmt† coverage + Gd
One x 100 kton* WC AND **Two** x 17 FV kton* LAr TPC	4850’ 300’/800’	30% pmt† coverage + Gd No photon trigger

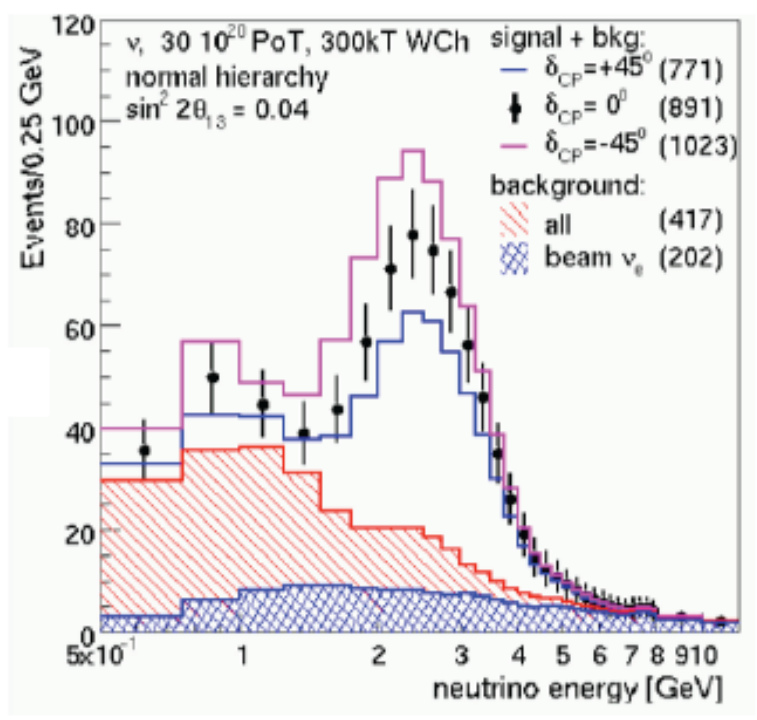
* fiducial volume † 10 inch High-QE PMT’s

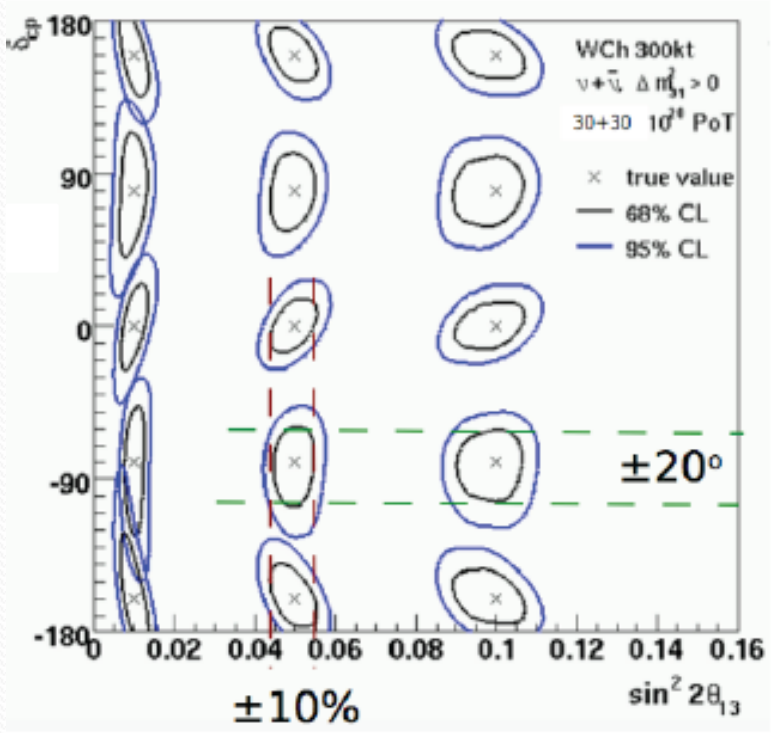
Project Far Detector Configurations

	WCD @ 4850	LAr @ 4850	LAr @ 300/800
a)	2 x 100 kT		
b)		2 x 20 kT	
c)			2 x 20 kT
d)	1 x 100 kT	1 x 20 kT	
e)	1 x 100 kT		1 x 20 kT

Physics Sensitivity

CP Signal & Sensitivity

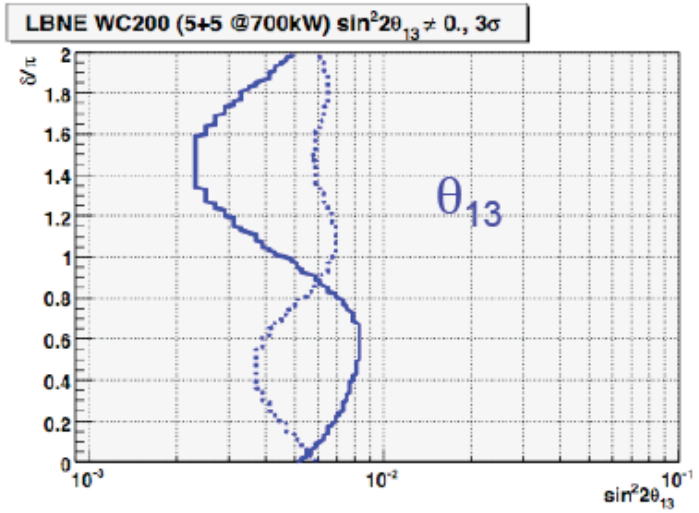


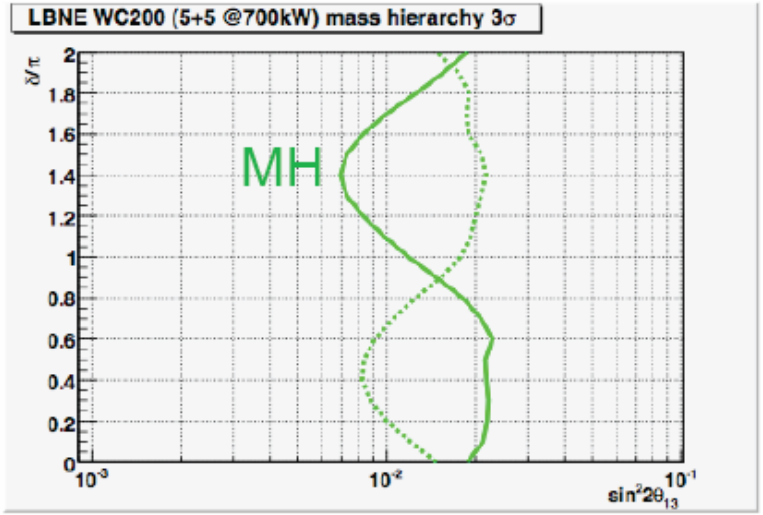


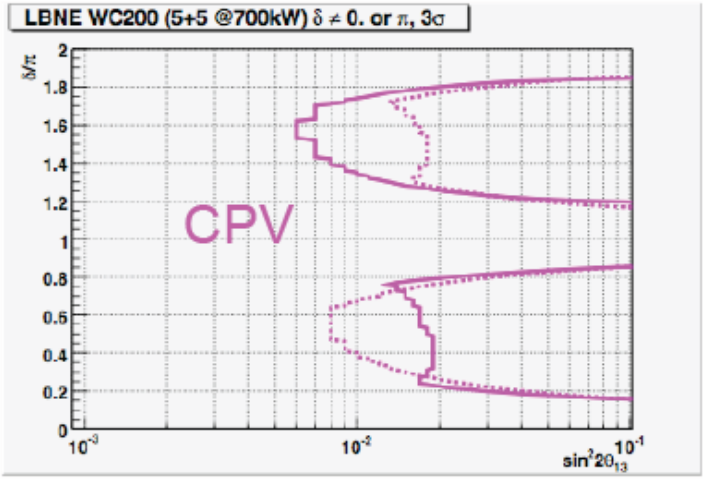
300 kT Water Cherenkov (~50kT LAr TPC) 700 kW – 4yrs ν + 4 yrs $\bar{\nu}$

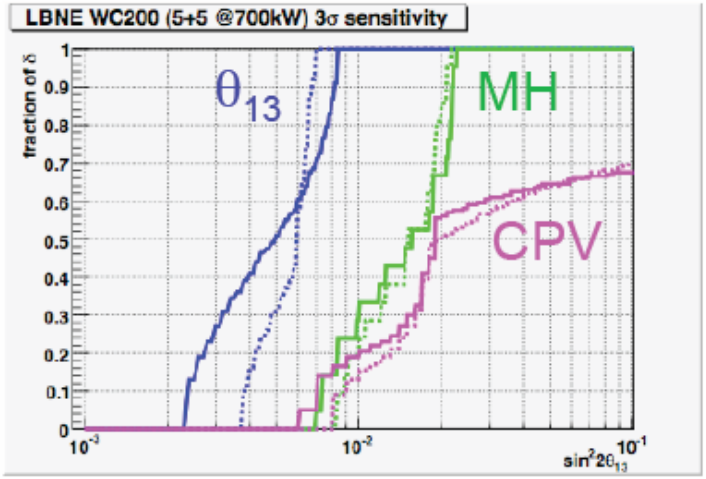
200 kt WC, 5+5 yr, 700 kW

3σ









(G. Rameika, docdb #803)

(36.5+36.5)x10^{20} POT

S. Zeller, LBL PWG, 05/27/10

Put Your Money on Supernovae

LBNE Collaboration meeting - Deadwood, SD 25-28 May 2010

Summary

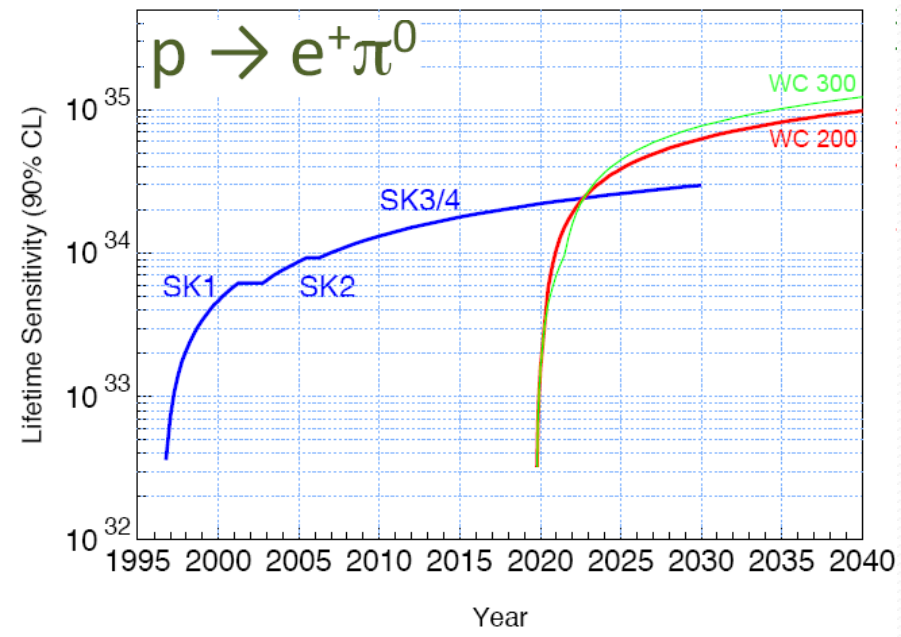
- CD-0 has put FNAL firmly into the drivers seat and LBNE is accelerating up the on-ramp
- LBNE project is preparing a CDR for December CD-1 review
- LBNE science collaboration is preparing a “physics report” to guide a preferred detector configuration recommendation for this fall

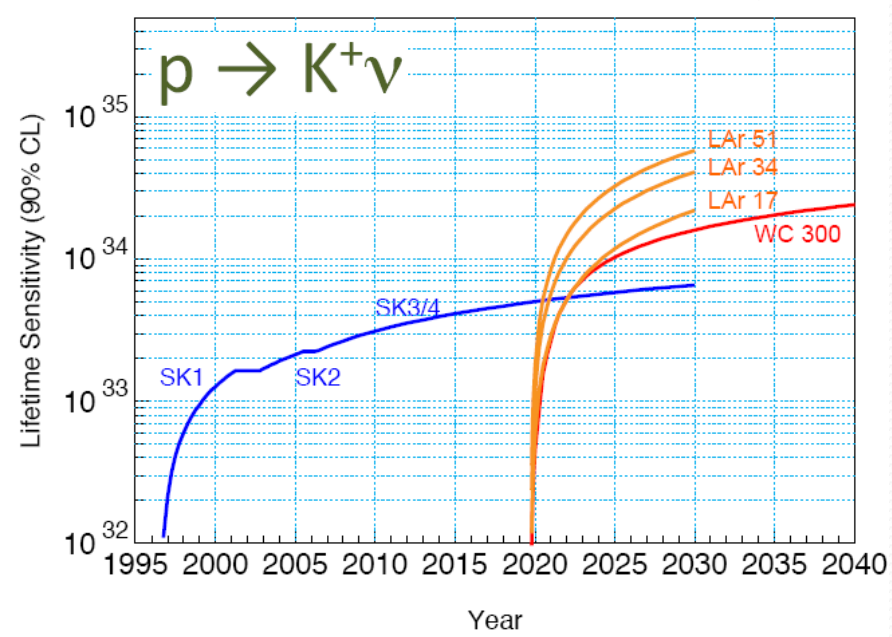
- Project X : 700 kW $\rightarrow$ >2 MW – all the better!

Supplementary Slides

Proton Decay

Ed Kearns (BU)





- Super-Kamiokande will have >20 years operation before LBNE turn-on
- Liquid Argon TPC significantly better for kaon modes

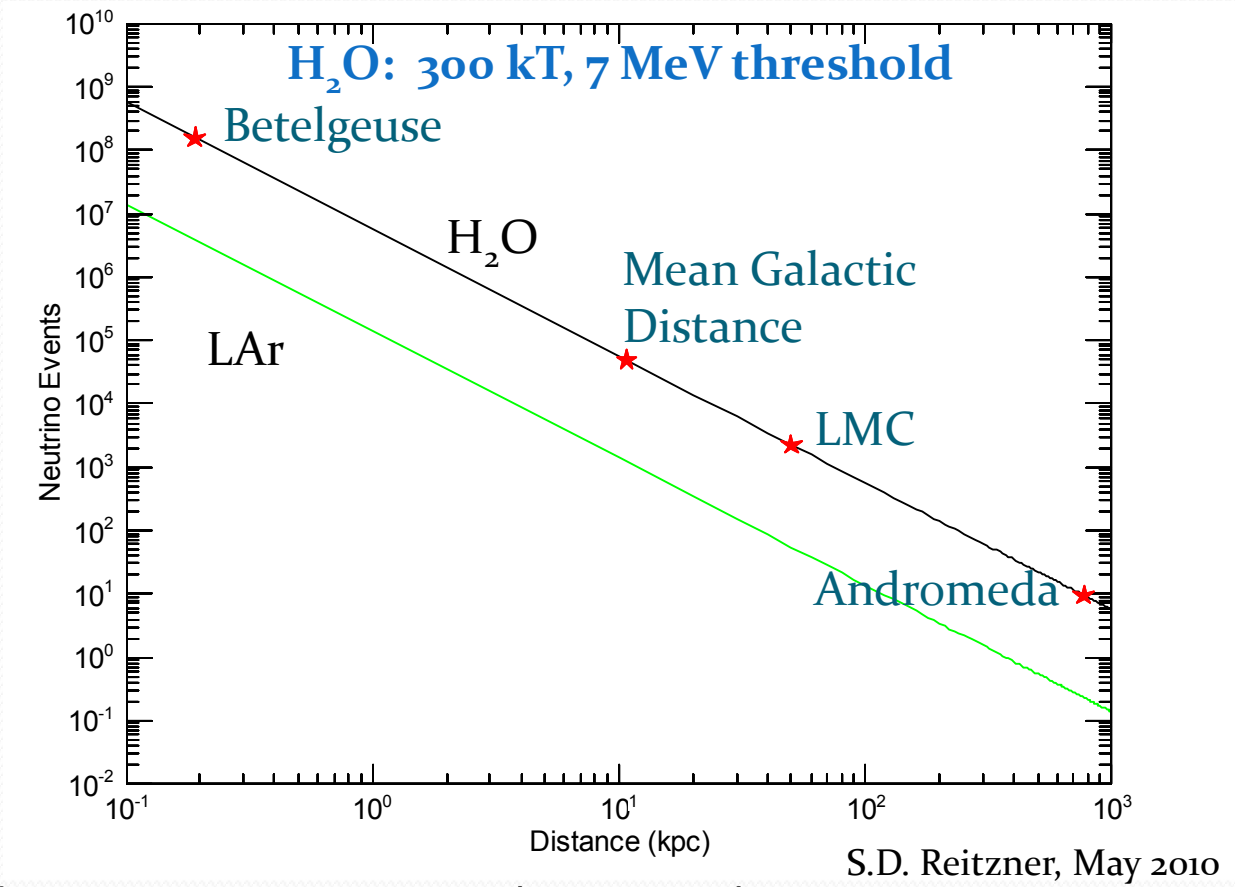
Supernova

- When a star's core collapses, ~99% of the gravitational binding energy of the proto-nstar goes into v's of *all flavors with ~MeV energies*
- SN at galactic core (10 kpc) $\Rightarrow$ tens of thousands of interactions in 100 kT WCD in tens of seconds
- Larger detector mass -> extragalactic reach

100 kt water	No. of interactions
Inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ + n$	23000
CC $\nu_e + {}^{16,18}\mathrm{O} \rightarrow {}^{16,18}\mathrm{F} + \mathrm{e}^-$	1000
NC $\nu_x + {}^{16}\mathrm{O} \rightarrow \nu_x + {}^{12}\mathrm{O}^*$	1100
ES $\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$	1000
50 kt LAr	
CC $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	3100
CC $\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{Cl}^*$	260
NC $\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$	15000
ES $\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$	500

- Too bad they are so rare… 1-3 @90% c.l. in 25 yrs (Diehl et al, 2006)

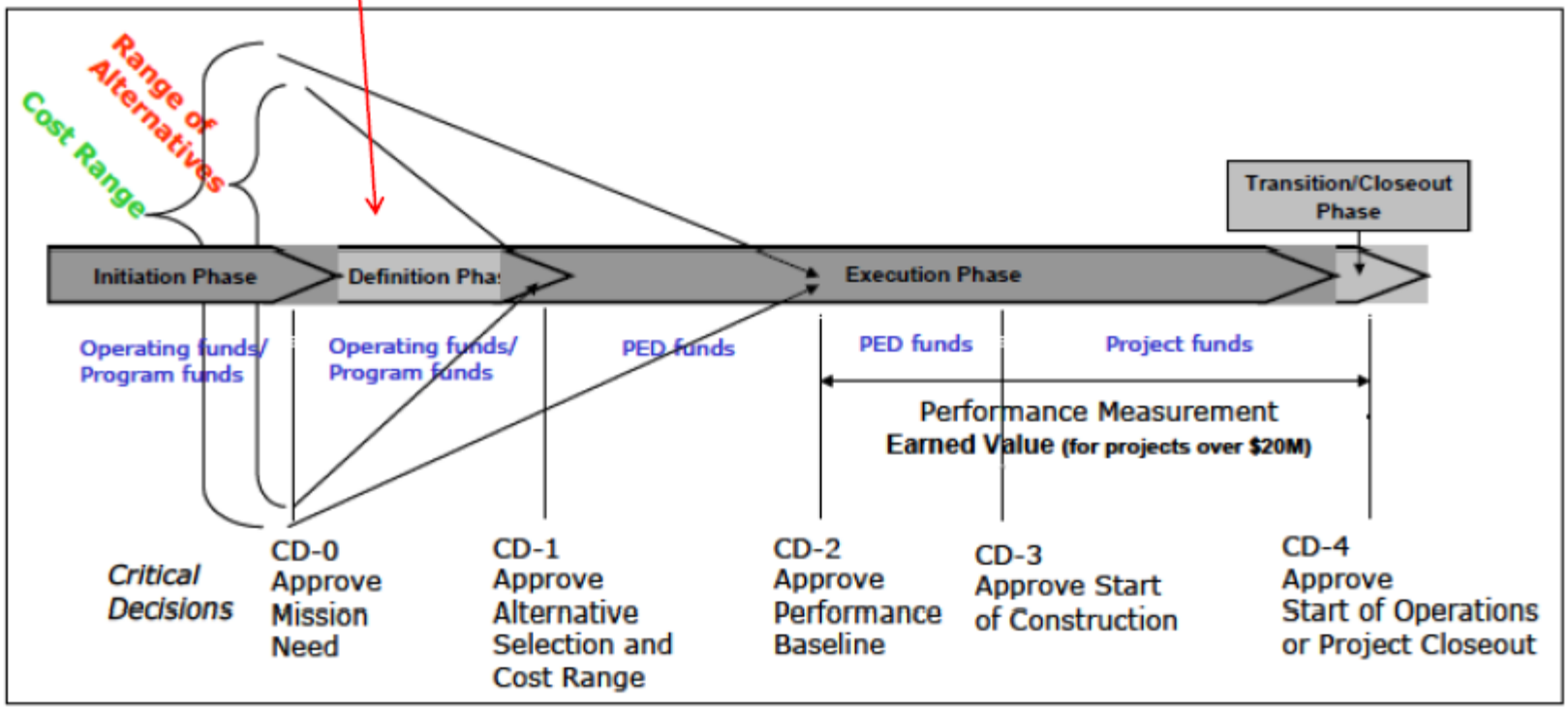
SN Neutrino Events *vs* SN Distance



- Larger detector mass -> extragalactic reach

LBNE is at this point

DOE Project Process

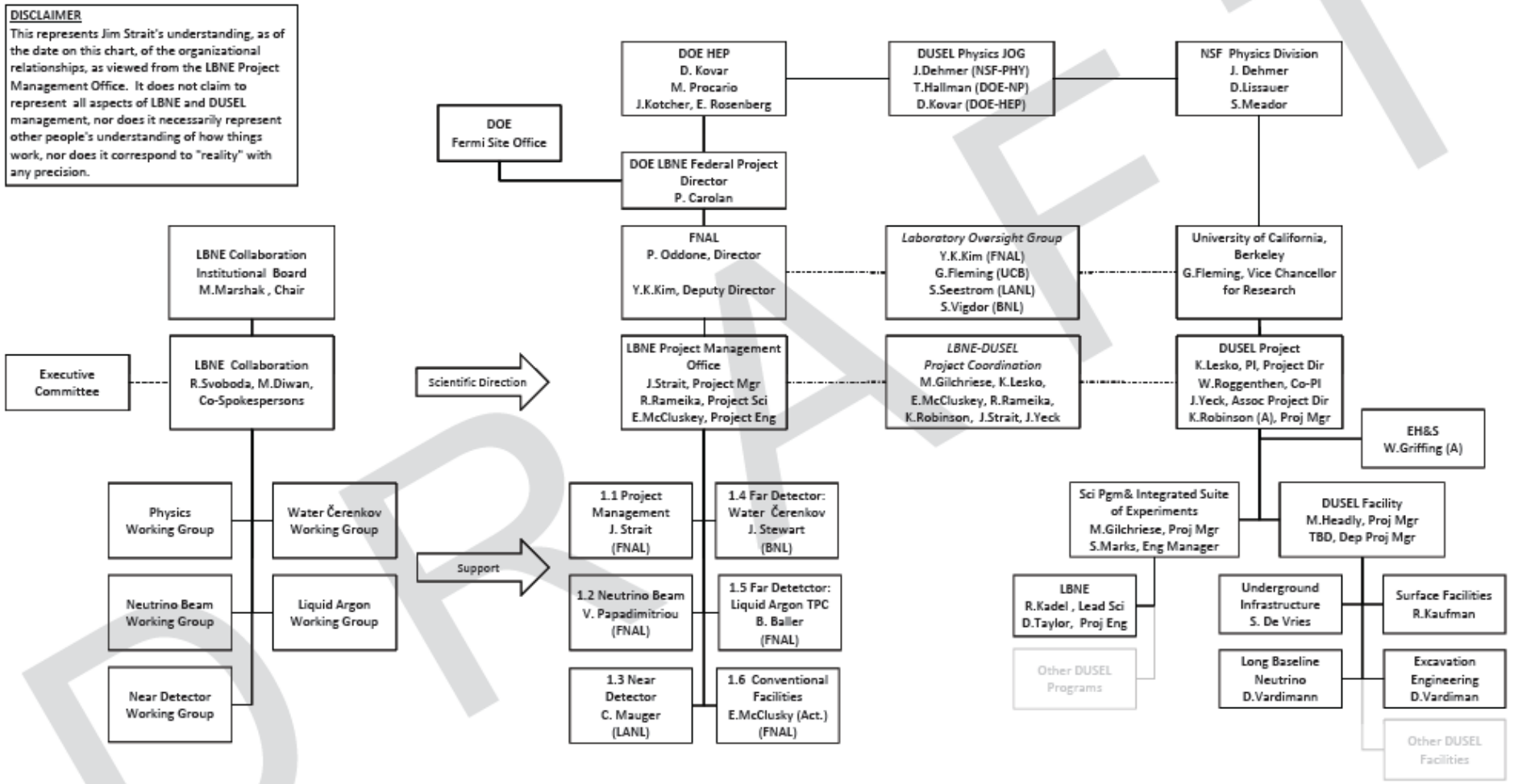


LBNE SCHEDULE 8-Jan-10 *March 2011* *Summer 2012* *Fall 2013*

LBNE Project

- **WBS 1.2 - New neutrino beam at Fermilab:**
  - **Initial proton beam power = 0.7 MW, but facility to be capable of being upgraded to ≥2 MW**
- **WBS 1.3 - Near detector**
  - **To measure un-oscillated beam spectrum and neutrino cross sections needed to make the oscillation measurements**
- **A far detector complex of ≥ 200 kT Water Cerenkov equivalent**
  - **WBS 1.4 – Water Cerenkov Detector (WCD) 100 kT "modules" placed at 4850 feet**
  - **WBS 1.5 – Liquid Argon TPC Detector (LAr) ~20 kT "modules" placed at 300/800 feet or 4850 feet**

LBNE Project



Reference Beam Design

Beam Parameter	Value
Protons per cycle	4.9×10^{13}
Cycle time (120 GeV)	1.33 sec
Pulse duration	1.0×10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Efficiency (beam to LBNE)	63%
Protons at target per year	7.3×10^{20}
Beam size at focus	0.15 cm
Beam divergence x,y	0.017 mrad

Long-Baseline Neutrino Experiment Collaboration

Alabama: J. Goon, I Stancu

Argonne: M. D'Agostino, G. Drake. Z. Djurcic, M. Goodman, 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, 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

LBL: 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, 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, C. Wendt

Yale: B. Fleming, M. Soderberg, J. Spitz

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