Opportunities and Status: Long-Baseline Neutrino Experiment in the US

Milind Diwan

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BROOKHAVEN NATIONAL LABORATORY

Office of Science U.S. DEPARTMENT OF ENERGY

Outline

- Scientific Motivation for a new accelerator neutrino oscillation experiment.
- How much flux, energy, event rate can we get ? What limitations ?
- Strategies and Optimization of a new experiment.
- What is the physics agenda for LBNE ?
- Description and Status of implementing the Long-Baseline Neutrino Experiment (LBNE in US).

Long-Baseline Neutrino Experiment Collaboration

Alabama: S. Habib, I. Stancu

Argonne: Z. Djurcic, G. Drake., M. Goodman, V. Guarino, S. Magill, J. Paley, H. Sahoo, L. Suter, R. Talaga

Boston: E. Hazen, E. Kearns, S. Linden

Brookhaven: M. Bishai, R. Brown, H. Chen, K. Chen, M. Diwan, J. Dolph, G. Geronimo, R. Gill, R. Hackenburg, R. Hahn, S. Hans, Z. Isvan, D. Jaffe, S.H. Kettell, F. Lanni, S. Li, Y. Li, L. Littenberg, J. Ling, G. Mahler, W. Marciano, W. Morse, Z. Parsa, V. Radeka, S. Rescia, N. Samios, R. Sharma, N. Simos, J. Sondericker, J. Stewart, H. Themann, C. Thorn, B. Viren, E. Worcester, M. Yeh, B. Yu, C. Zhang

Cambridge: A. Blake, J. Marshall, M. Thomson

Catania/INFN: V. Bellini, F. La Zia, F. Mammoliti, R. Potenza

Chicago: E. Blucher, D. Schmitz, M. Strait, M. Wetstein

Colorado: S. Coleman, R. Johnson, S. Johnson, A. Marino, E. Zimmerman

Colorado State: M. Bass, B.E. Berger, J. Brack, N. Buchanan, D. Cherdack, J. Harton, W. Johnston, W. Toki, T. Wachala, D. Warner, R.J. Wilson

Columbia: R. Carr, L. Camillieri, C.Y. Chi, G. Karagiorgi, M. Shaevitz, W. Sippach, W. Willis

Dakota State: B. Szczerbinska

Davis: M. Bergevin, H. Berns, R. Breedon, J. Felde, C. Grant, C. Maesano, M. Tripanthi, R. Svoboda, M. Szydagis

Drexel: C. Lane, M.Thiesse

Duke: T. Akiri, J. Fowler, A. Himmel, Z. Li, K. Scholberg, C. Walter

Duluth: R. Gran, A. Habig

Fermilab: M. Andrews, B. Baller, R. Bernstein, E. Berman, V. Bocean, A. Chen, S. Childress, A. Drozhdin, C. Escobar, H. Greenlee, A. Hahn, R. Hatcher, S. Hays, A. Heavey, J. Howell, P. Huhr, J. Hylen, C. James, M. Johnson, J. Johnstone, H. Jostlein, T. Junk, B. Kayser, M. Kirby, G. Koizumi, B. Lundberg, T. Lundin, P. Mantsch, A. Marchionni, E . McCluskey, N. Mokhov, C. Moore, D. Montanari, J. Morfin, B. Norris, V. Papadimitriou, R. Plunkett, C. Polly, S. Pordes, O. Prokofiev, J.L. Raaf, R. Rajendran, G. Rameika, B. Rebel, D. Reitzner, K. Riesselmann, R. Rucinski, R. Schmidt, P. Shanahan, T. Shaw, M. Stancari, A. Stefanik, J. Strait, S. Striganov, S. Tariq, K. Vaziri, G. Velev, T. Wyman, G. Zeller, R. Zwaska

Hawai'i: S. Dye, J. Kumar, J. Learned, J. Maricic, S. Matsuno, R. Meyhandan, R. Milincic, S. Pakvasa, M. Rosen, G. Varner

Houston: L. Whitehead

Indian Universities: V. Bhatnagar, B. Bhuyan [IIT(G)], B. Choudhary, R. Gandhi (HRI), A. Kumar, S. Mandal (DU); S. Sahijpal(PU), V. Singh (BHU)

Indiana: M. Baird, B. Baptista, W. Fox, M. Messier, S. Mufson, J. Musser, E. Niner, R. Tayloe, J. Urheim, D. Whittington

Iowa State: I. Anghel, G.S. Davies, M.C. Sanchez, T. Xin

Irvine: G. Carminati, W. Kropp, M. Smy, H. Sobel

Kansas State: T. Bolton, G. Horton-Smith, D. McKee

Kavli IPMU/Tokyo: M. Vagins, R. Wendell

LBL: B. Fujikawa, V.M. Gehman, R. Kadel, D. Taylor

Livermore: A. Bernstein, S. Dazeley

London: A. Holin, A. Perch, J. Thomas

Los Alamos: L. Bartoszek, J. Boissevain, S. Elliott, A. Friedland, G. Garvey, E. Guardincerri, T. Haines, D. Lee, W. Louis, C. Mauger, G. Mills, Z. Pavlovic, J. Ramsey, M. Ronquest, G. Sinnis, W. Sondheim, R. Van de Water, H. White, K. Yarritu

Louisiana: R. Imlay, J. Insler, T. Kutter, W. Metcalf, M. Tzanov

Maryland: E. Blaufuss, S. Eno, R. Hellauer, G. Sullivan

Michigan State: E. Arrieta-Diaz, C. Bromberg, D. Edmunds, J. Huston, B. Page

Minnesota: D. Demuth M. Marshak, W. Miller

MIT: W. Barletta, J. Conrad, B. Jones, T. Katori, R. Lanza, A. Prakash

NGA: S. Malys, S. Usman

Northwestern: A. de Gouvea, L. Fields, H. Schellman

Notre Dame: J. Losecco

Oxford: G. Barr, J. de Jong, A. Weber

Pennsylvania: S. Grullon , P. Keener, J. Klein, K. Lande, T. Latorre, A. Mann, M. Newcomer, S. Seibert, R. vanBerg

Pittsburgh: D. Naples, V. Paolone

Princeton: K. McDonald

Rensselaer: J. Napolitano

Rochester: L. Loiacono, K. McFarland, G. Perdue

Sanfordlab: M. Headley, J. Heise, D. Taylor, J. Willhite

Sheffield: V. Kudryavtsev, J. Perkin, M. Richardson, M. Robinson, N. Spooner, L. Thompson

SLAC: M. Convery, M. Graham, D. Muller

SDSMT: X. Bai, C. Christofferson, R. Corey, D. Tiedt

SMU: T. Coan, T. Liu, J. Ye

South Carolina: H. Duyang, J. Libo, B. Mercurio, S. Mishra, R. Petti, C. Rosenfeld, X. Tian

South Dakota: D. Barker, J. Goon, D. Mei, W. Wei, C. Zhang

South Dakota State: B. Bleakley, K. McTaggert

Sussex: L. Falk, J. Hartnell, S. Peeters, A. Waldron,

Syracuse: M. Artuso, J. Asaadi, S. Blusk, T. Skwarnicki, M. Soderberg, S. Stone

Tennessee: W. Bugg, T. Handler, A. Hatzikoutelis

Texas: S. Kopp, K. Lang, R. Mehdiyev

Tufts: J. Coelho, H. Gallagher, W. Mann, N. Mayer, J. Schneps

UCLA: D. Cline, K. Lee, Y. Meng, A. Teymourian, H. Wang, L. Winslow

Virginia Tech: E. Guarnaccia, J. Link, C. Mariani

Washington: S. Enomoto, J. Kaspar, N. Tolich

William and Mary: R. McKeown, X. Qian, W. Wang

Wisconsin: B. Balantekin, F. Feyzi, L. Greenler, K. Heeger, B. Paulos, D. Wahl

Yale: C. Adams, F. Cavanna, E. Church, B. Fleming, R. Guenette, O. Palamara, K. Partyka, A. Szelc

366 collaborators, 65 institutions (54 US). Organized and integrated with project management. A DOE funded project management has ~50 individuals from various institutions.

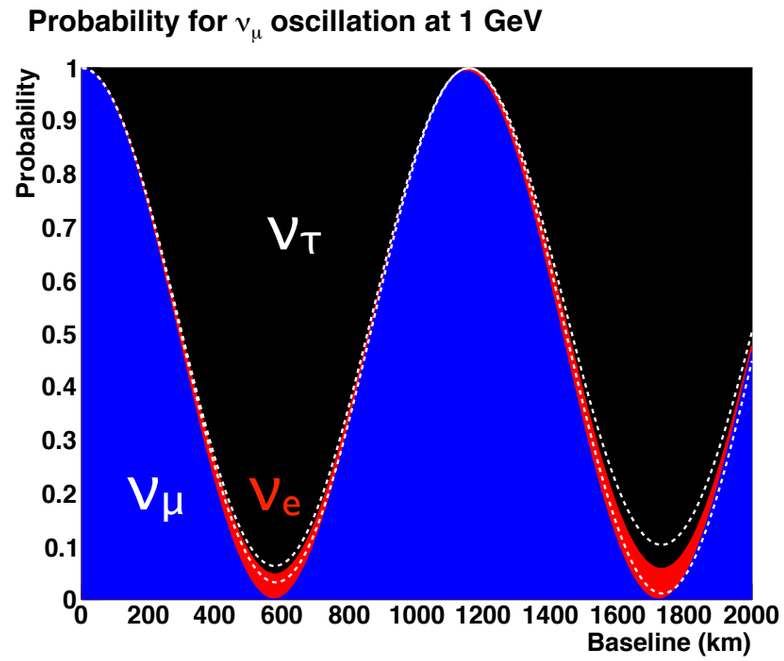
21 February 2013 (366)

Scientific Motivation

- Broad: Neutrino Oscillation is a new sensitive interference phenomena with as yet unknown implications for fundamental physics. An unmatched portal into any new nonstandard sector with light fermions because neutrinos can mix with neutral spin 1/2 particles and oscillations over long baselines are extraordinarily sensitive to tiny effects. e.g. 1002.4452
- Neutrino Properties: The current picture of neutrino properties is based on only a handful of direct measurements. Future precision experiments need to test the full 3-generation picture and test for models of mass and mixing.
- CP violation: Demonstration of CP violation may be a gateway to the relationship between quarks and leptons and the baryon asymmetry of the Universe.

Neutrino Oscillations Strategy

Measurements:
ν_e (ν_τ) appearance in a ν_μ beam
ν_μ disappearance from a ν_μ beam



- Next generation(s) of neutrino experiments cannot simply focus on single parameter measurements – even δ_{CP}
- A <u>comprehensive</u> program, must have the ability to
  - observe spectral distortion due to oscillations – peak and valley
  - observe different behavior for neutrinos and antineutrinos – direct evidence of CP Violation
- **Known non-zero and large θ_{13}=> event rate is high enough to achieve this with a long-baseline experiment (>1000 km with a broad band beam)**

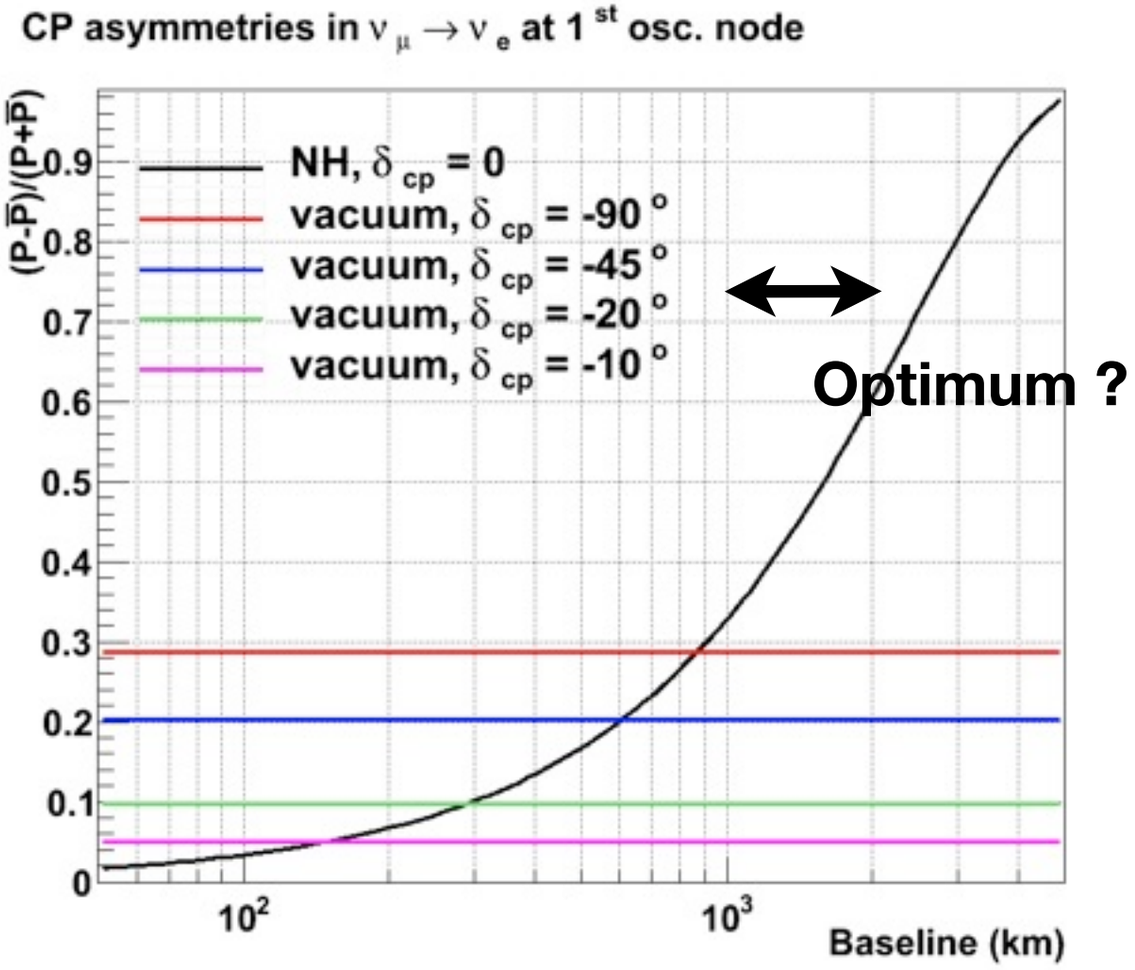
Must pick baseline first

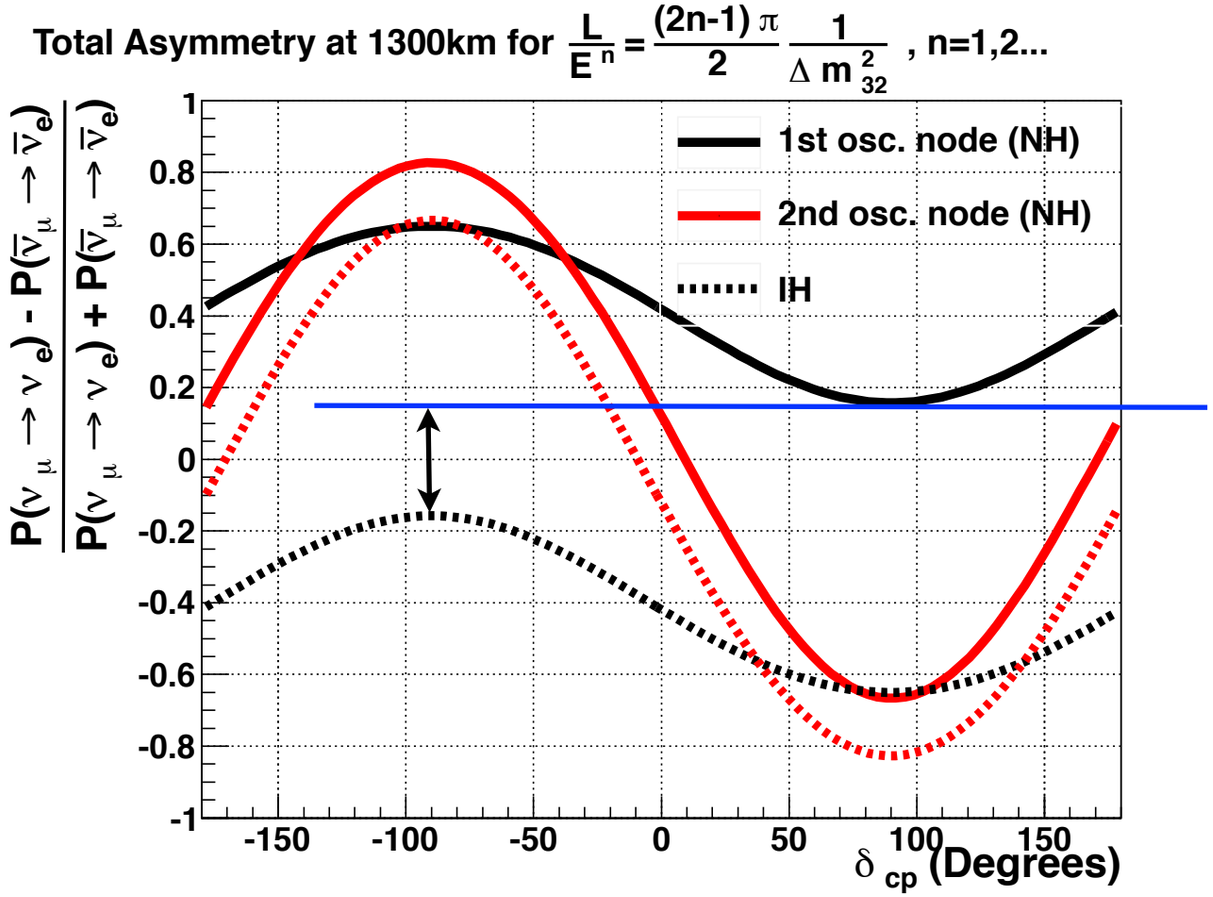
LBNE Science Objectives

- **COMPREHENSIVE PROGRAM TO MEASURE NEUTRINO OSCILLATIONS**
- Discover and characterize CP Violation in the neutrino sector
- …and other missing pieces of the neutrino puzzle
  - Resolve the neutrino mass hierarchy unambiguously
  - Precision measurements of oscillation parameters (mixing angles, mass differences)
  - Precision neutrino interaction studies (near detector)
  - New physics (non-standard interactions, sterile neutrinos)
- … and other fundamental physics enabled by massive underground detectors
  - Proton decay measurement
  - Astrophysics -- supernova ν burst

Underground placement makes a qualitative improvement by reducing risk and opening new physics opportunities.

Baseline Optimization





L/E = 515 km/GeV $\sin^2 2\theta_{13}$=0.1

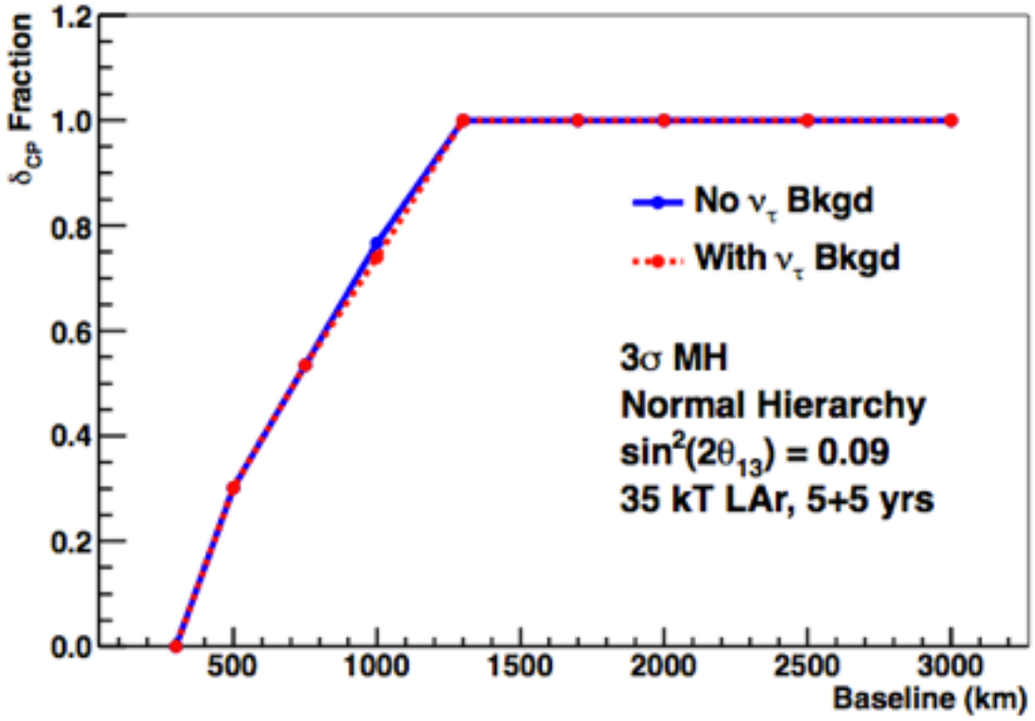
Mary Bishai

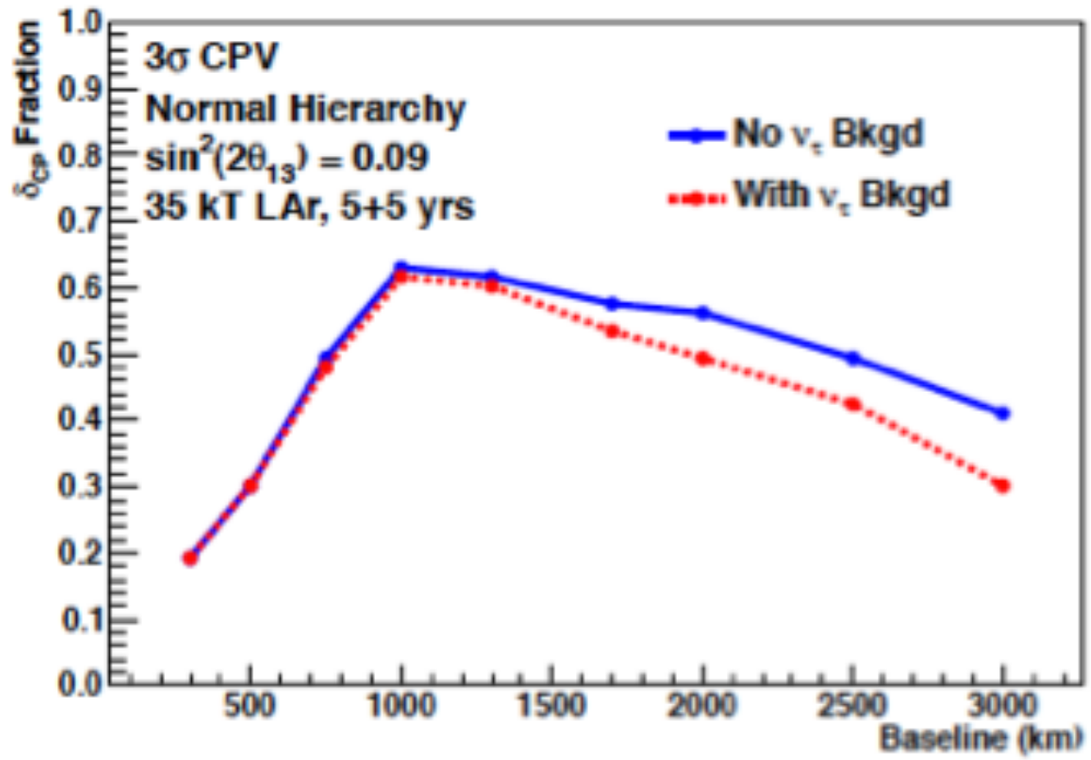
Optimum is achieved when the asymmetry due to the matter effect is larger than the largest CP effect, but does not saturate the total asymmetry.

At the first maximum at optimum baseline there is no degeneracy.

LBNE beam/baseline optimization

Detailed calculation with horn based realistic beam optimization at each baseline and assumption of liquid argon TPC of 35 kt. Assume 120 GeV Protons at 700kW.



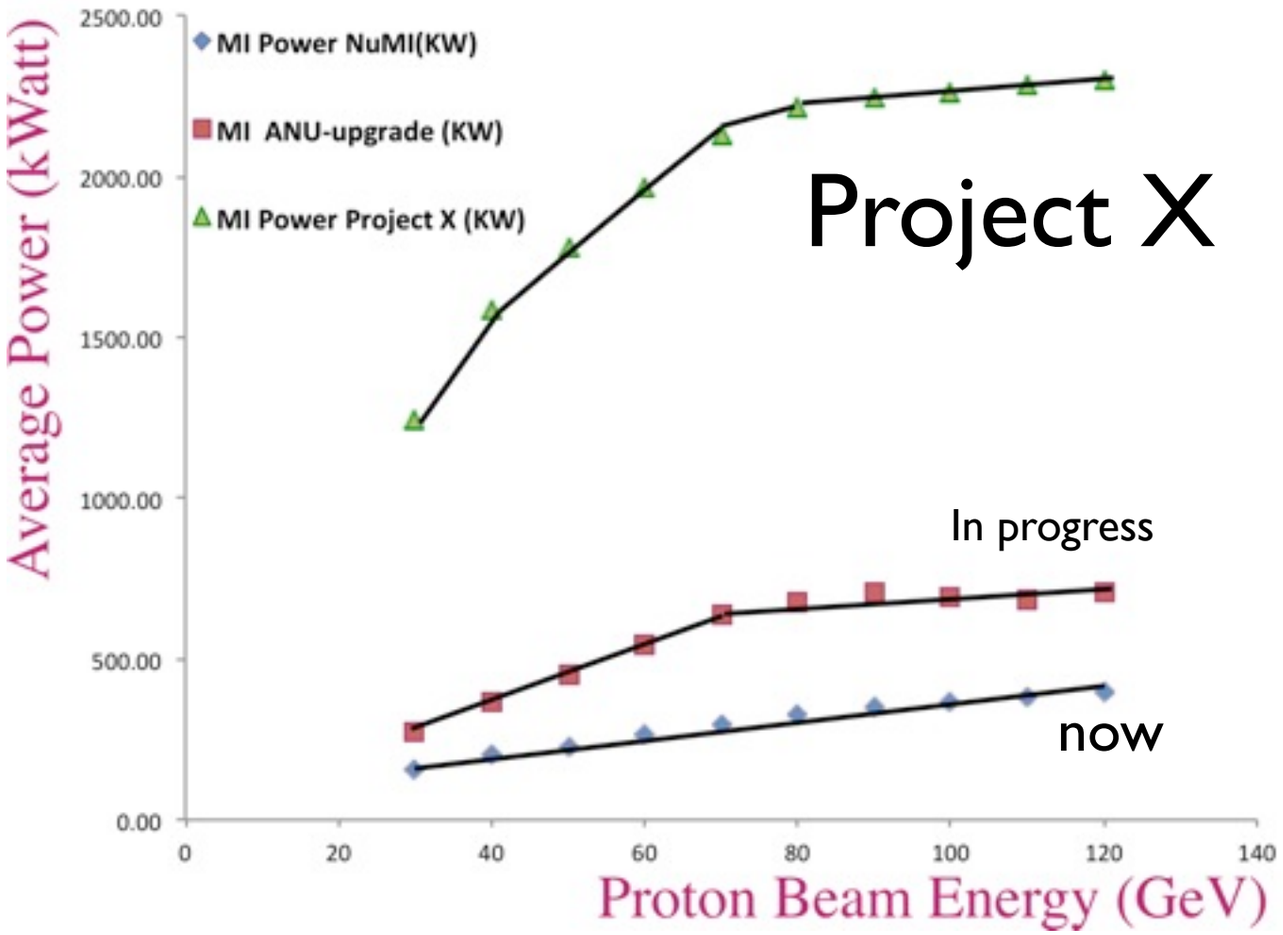


- Left: Fraction of δ_{CP} for which MH can be determined at 3 σ level or greater
- Right: Fraction of δ_{CP} for which CPV can be determined at 3 σ level or greater (regardless of knowledge of MH.)

- The LBNE design with 1300 km, 120 GeV proton beam, and a LAr TPC detector is economical for a comprehensive oscillation program

- **Any other choice will necessitate larger detectors or higher beam intensity**

Fermilab current/future capabilities



Project X parameters

Accelerator Stage	Energy	Current	Duty Factor	Power Available
CW LINAC	3 GeV	1 mA	CW	3000 kW
Pulsed LINAC	8 GeV	43 μA	4.33ms/0.1sec	350 kW
8 GeV Upgrade	8 GeV	500 μA	6.67ms/0.066sec	4000 kW
Main Injector	60 GeV	35 μA	9.5μS/0.7sec	2100 kW
Main Injector	120 GeV	19 μA	9.5μS/1.3sec	2300 kW

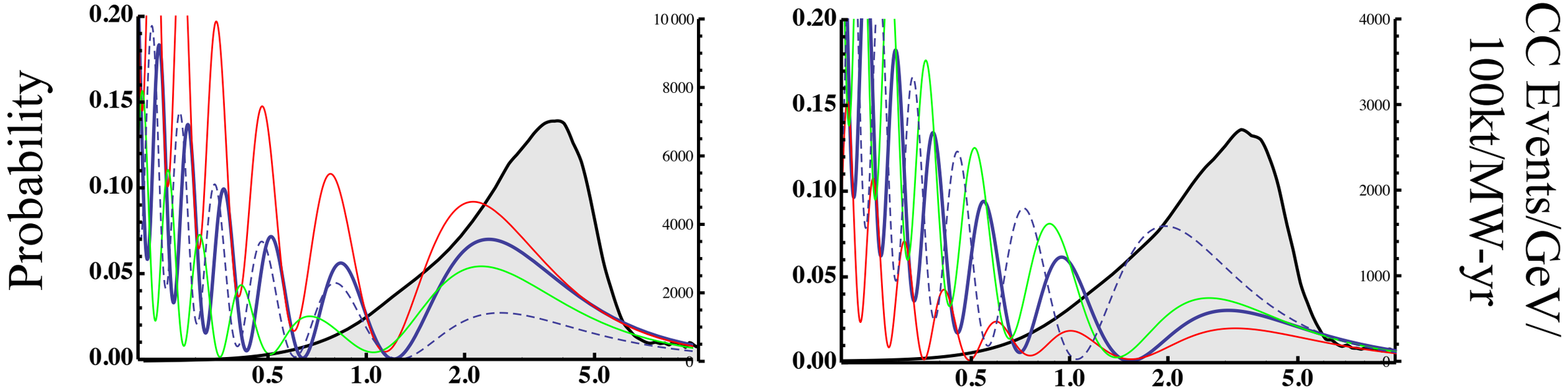
S. Holmes

- Main Injector is the main source of high energy protons. Current values:9.5μsec/2.2 sec, 3.3×10^{13}protons/pulse
- Upgrade project from 400 kW to 700 kW is funded and in progress. Upgrade adds energy flexibility for constant power

Oscillation and Beam Spectrum. As designed for LBNE

Neutrino

Anti-Neutrino



θ_{13}= 9°, δ_{CP} r:+90, b: 0, g: -90, dashed: Inverted Hierarchy, L: 1300 km

- With 700 kW of 120 GeV protons from the Main Injector, we have designed a beam optimized for the 0.5 to 5 GeV. (yr=2 10^7sec)
- Event rate (anti)neutrino 2000(700)evts/10kt/yr @0.7 MW
- Electron (anti)neutrino ~50(~18)/evt/10kt/yr @0.7 MW
- The baseline and energy allows us to measure the spectral distortion and disentangle MH from CPV. Measure asymmetries of event rates versus energy for both polarities.

Long Baseline Neutrino Experiment

Full-LBNE

Complete conceptual design for all aspects of full-LBNE

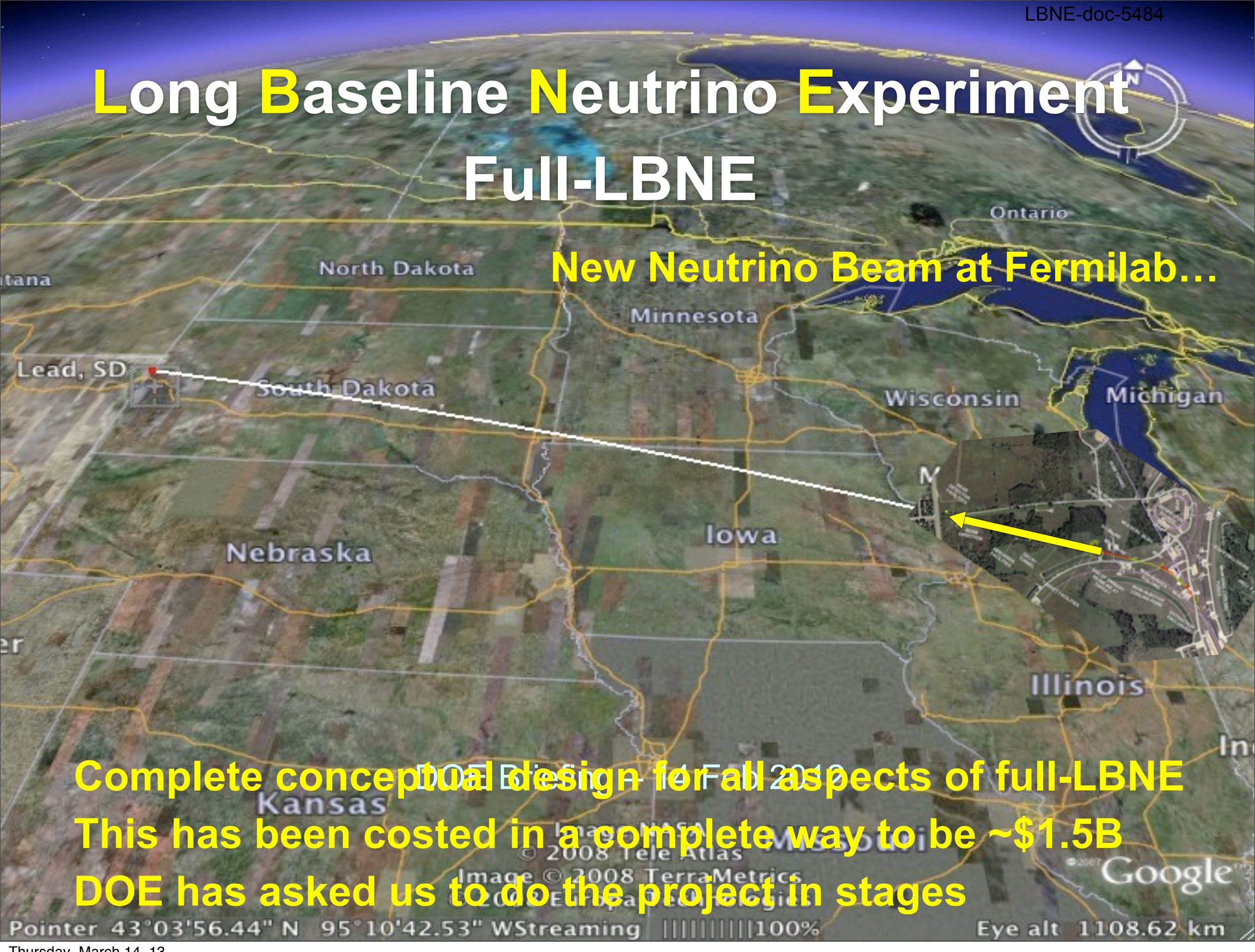
This has been costed in a complete way to be ~$1.5B

DOE has asked us to do the project in stages

Long Baseline Neutrino Experiment

Full-LBNE

New Neutrino Beam at Fermilab…



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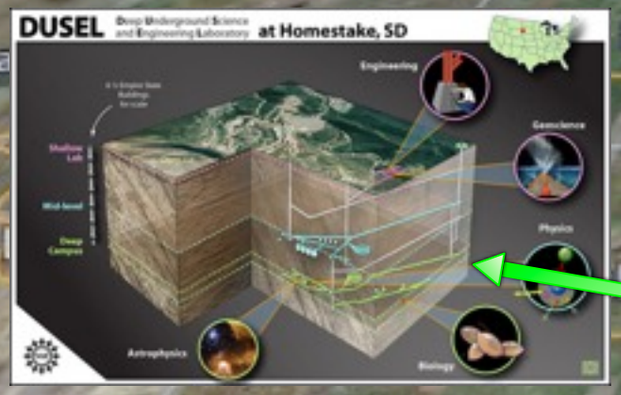
Long Baseline Neutrino Experiment

Full-LBNE



New Neutrino Beam at Fermilab…

Directed towards a distant detector

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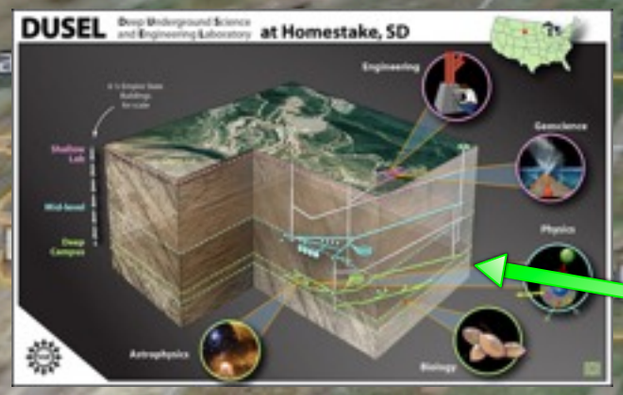
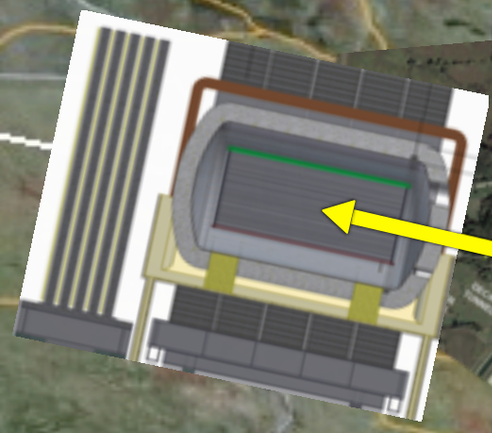
Long Baseline Neutrino Experiment

Full-LBNE



New Neutrino Beam at Fermilab…
Precision Near Detector on the Fermilab site



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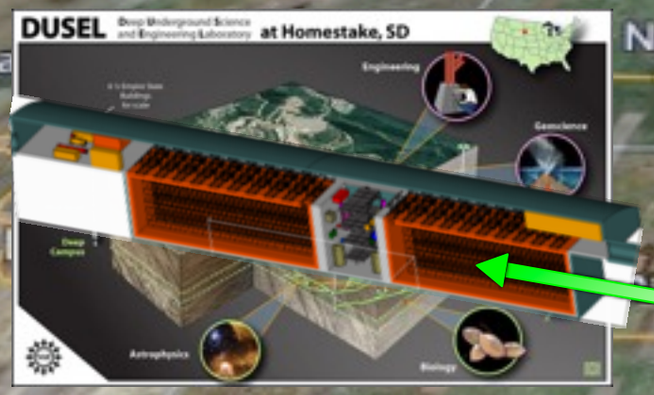

New Neutrino Beam at Fermilab…
Precision Near Detector
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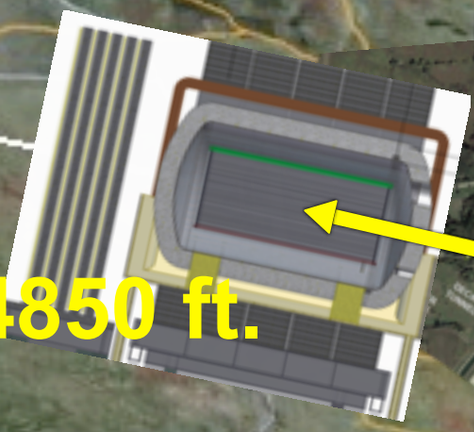
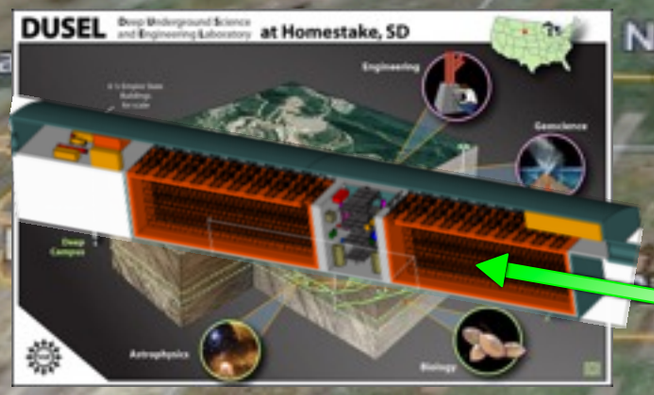


Directed towards a distant detector
35 kton Liquid Argon TPC Far Detector 4850 ft.

Complete conceptual design for all aspects of full-LBNE
This has been costed in a complete way to be ~$1.5B
DOE has asked us to do the project in stages

Long Baseline Neutrino Experiment

Full-LBNE



New Neutrino Beam at Fermilab…
Precision Near Detector on the Fermilab site

Directed towards a distant detector

35 kton Liquid Argon TPC Far Detector 4850 ft.

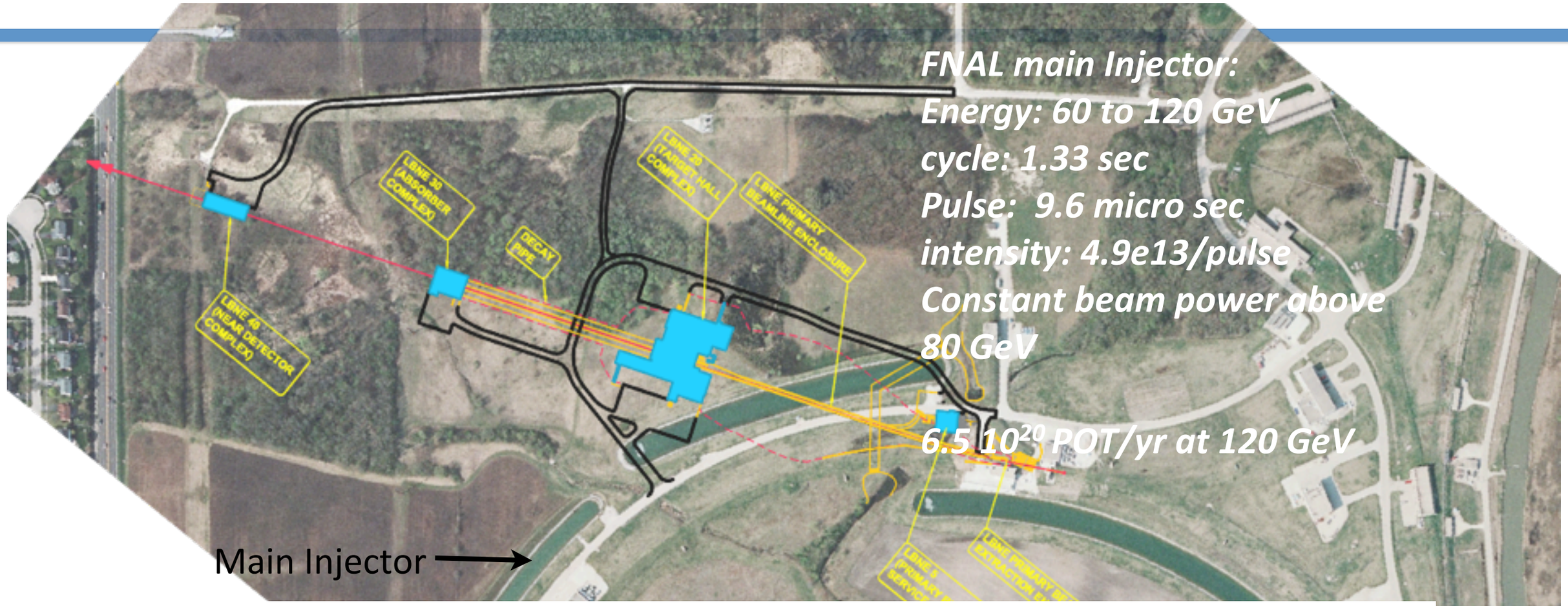
And all the Conventional Facilities required to support the beam and detectors

Complete conceptual design for all aspects of full-LBNE

This has been costed in a complete way to be ~$1.5B

DOE has asked us to do the project in stages

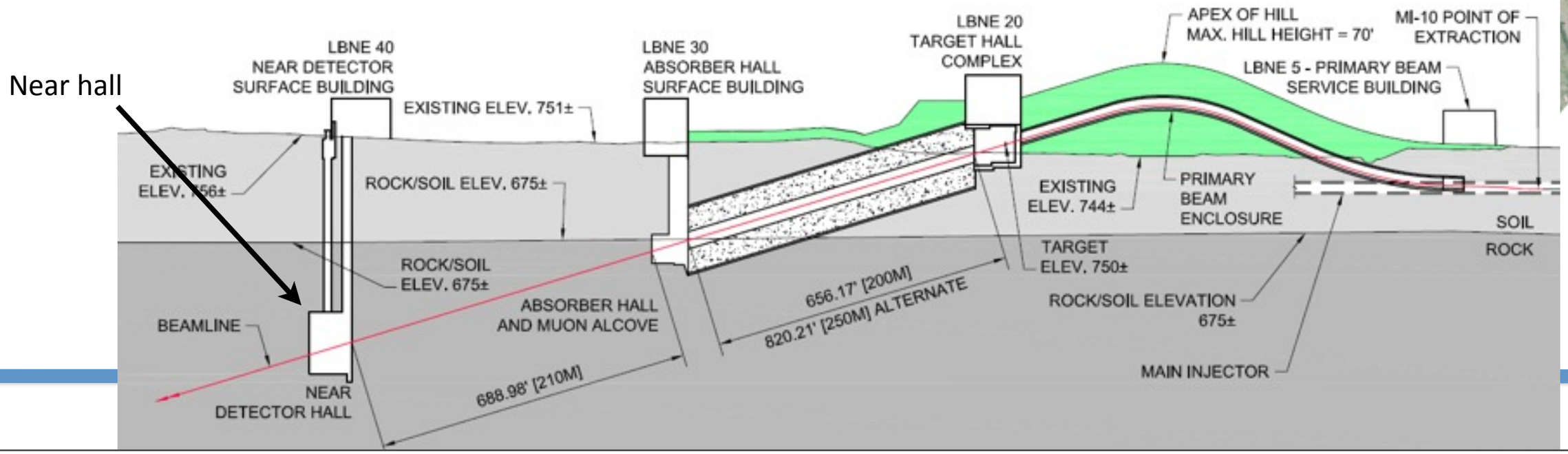
The LBNE New Beam Design (advanced)



FNAL main Injector:
Energy: 60 to 120 GeV
cycle: 1.33 sec
Pulse: 9.6 micro sec
intensity: 4.9e13/pulse
Constant beam power above 80 GeV

6.5 10^{20} POT/yr at 120 GeV

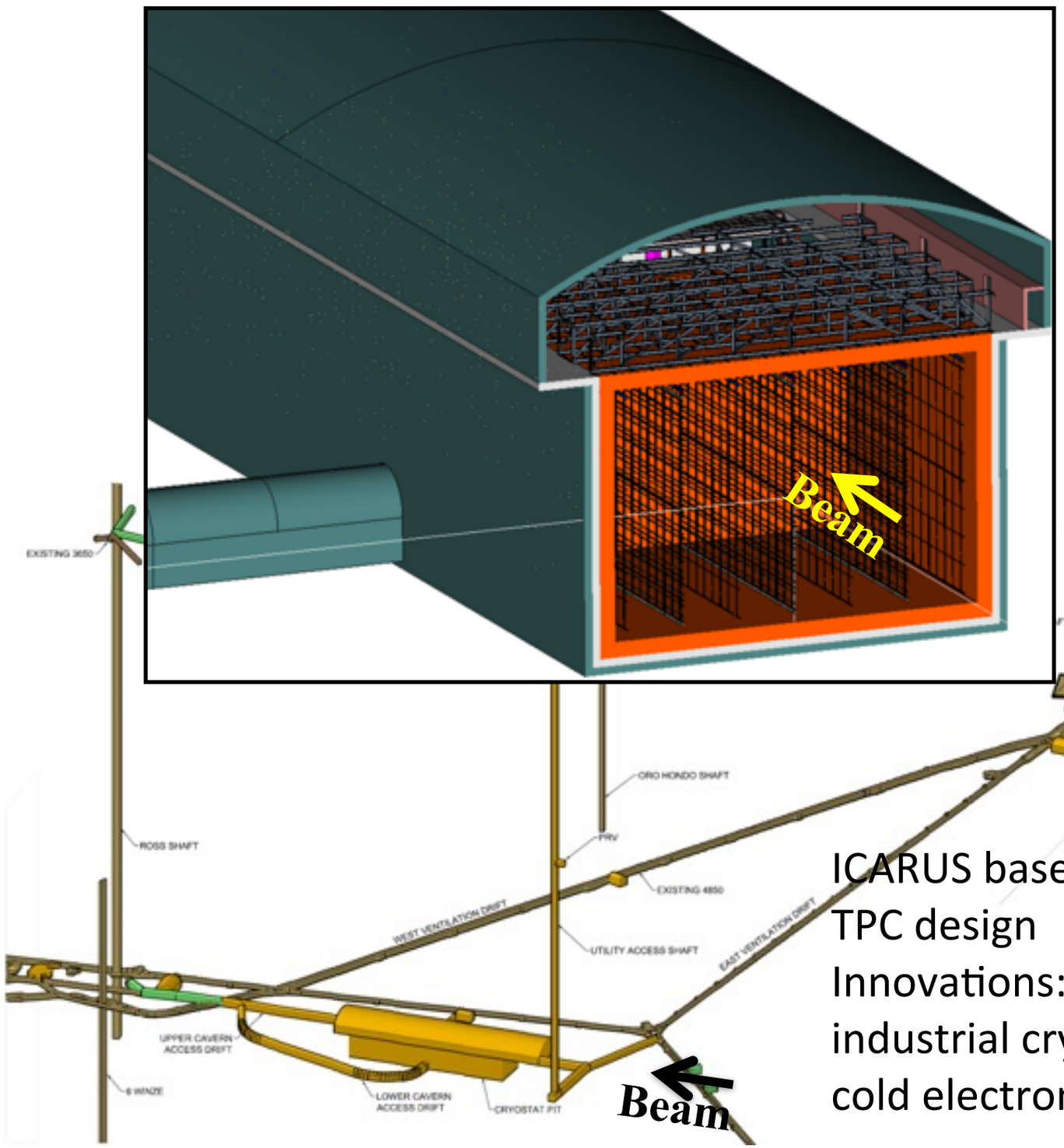
Less expensive and better for safety than the deep design



1. WILSON HALL - 16 WEST (BEFORE)

1. WILSON HALL - 16 WEST (AFTER)

Far Detector Design at depth:
LAr TPC Detector at 4850 ft



ICARUS based TPC design
Innovations:
industrial cryostat, cold electronics

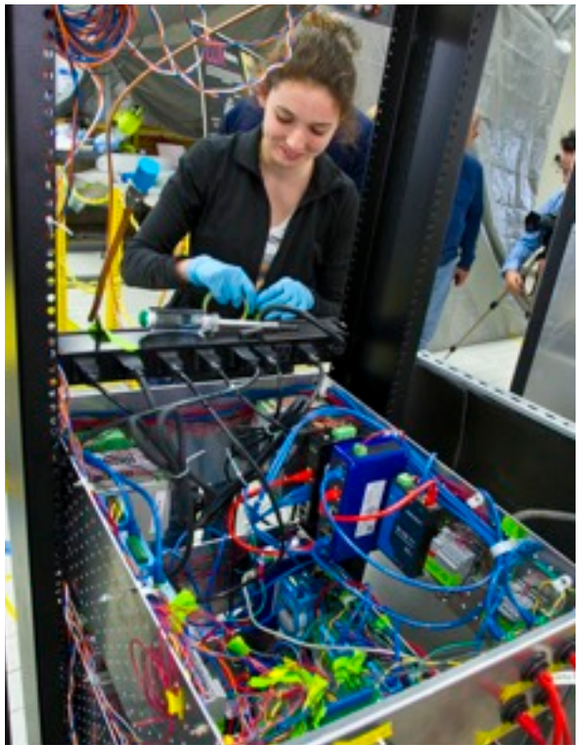
- Two detectors in a common cavern at 4850 ft. depth
- Active volume of each detector: 22.4 x 14 x 45.6 m^3
- 35 kt fiducial mass
- TPC design:
  - 3.7 m drift length
  - 5 mm wire spacing
  - three stereo views
  - 2X108 anode chambers
  - 2 X 275k channels
  - S/N ~ 10

Challenges for scale up are under control : Purity, installation, safety

Status of the Homestake site

What is the current status of SURF?

- FY 2012
  - Facility
    - Facility Dewatered below the 6000 foot level Complete ✓
    - Yates promoted to primary access Complete ✓
    - Davis Laboratory Outfitting Complete ✓
    - Ross Shaft Rehab - design completed and reviewed, rehabilitation Initiated (still provides secondary egress)
  - Science
    - LUX Dark Matter, Majorana Demonstrator Neutrinoless Double Beta Decay, & CUBED - Installing ✓
    - LBNE 10 kt Conceptual Design Completed ✓
    - Proposals for DIANA, LZ, LBC under review, some funding announced
- FY 2013 - 15
  - Facility
    - Ross Shaft Rehab continues, first ~ 400 feet done.
  - Science
    - LUX and MJD anticipated to be taking data
    - LZ R&D funded in the US and Great Britain ✓
    - LBNE - CD1 approved December 2012 ✓
    - Site-visit by DIANA Project ✓

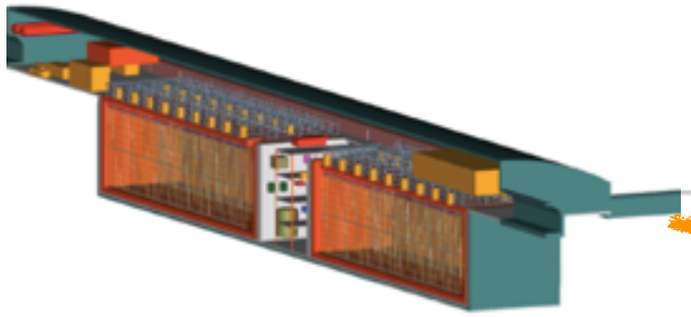


From: Kevin Lesko

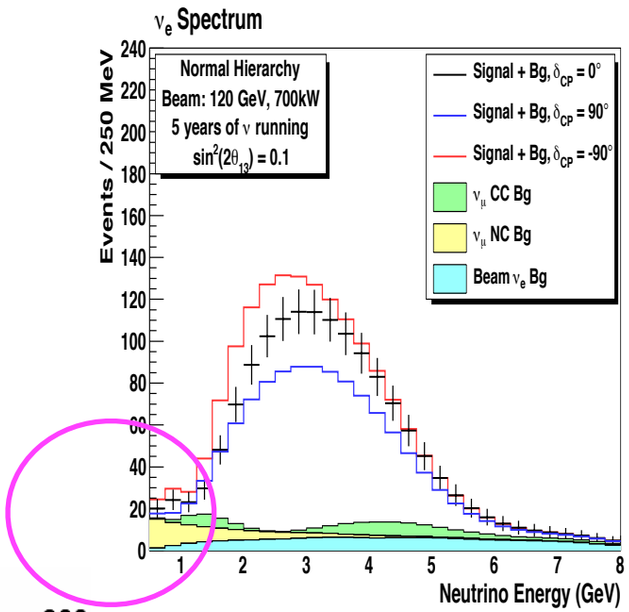
SURF Science Infrastructure: 4850L

4850L Sanford Laboratory

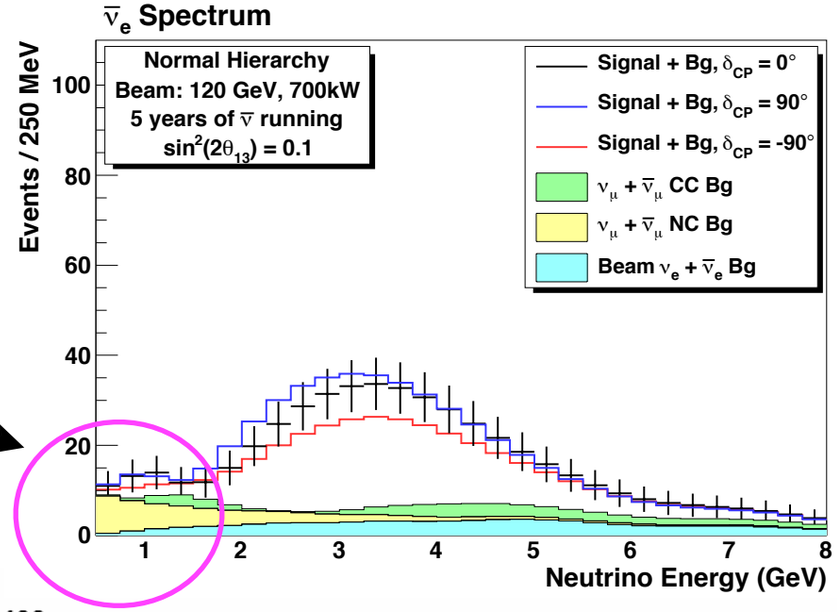
Underground LBNE detector:
Ventilation issues and conceptual design understood.
Working on updated cost estimate.



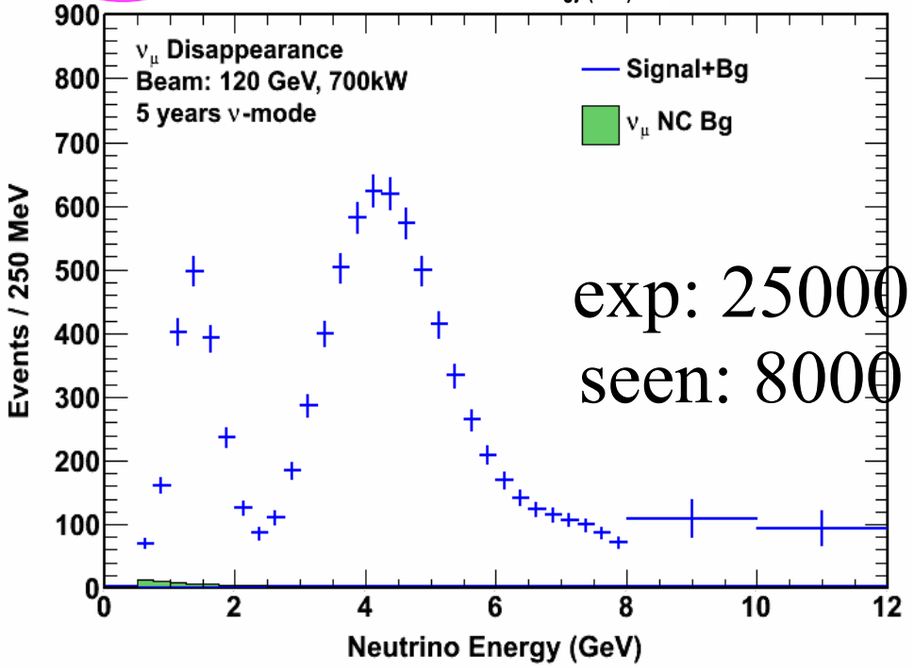
1300 km expectation with 35 kTon

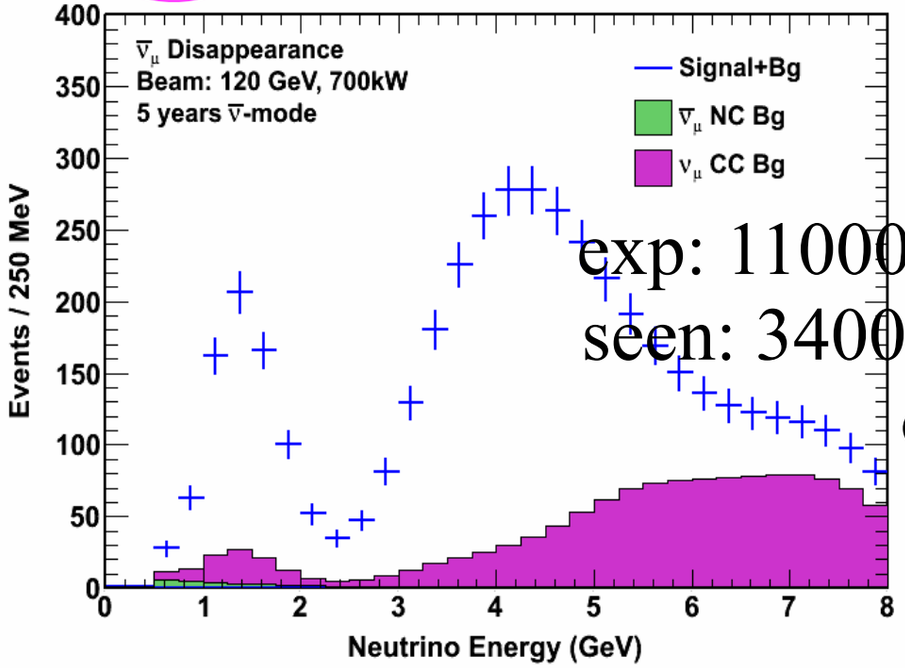


These events are very important



For each bin, conversion fraction of electrons can be calculated. Matter effect can be substracted to obtain explicit CP signal.





Potential surprises:

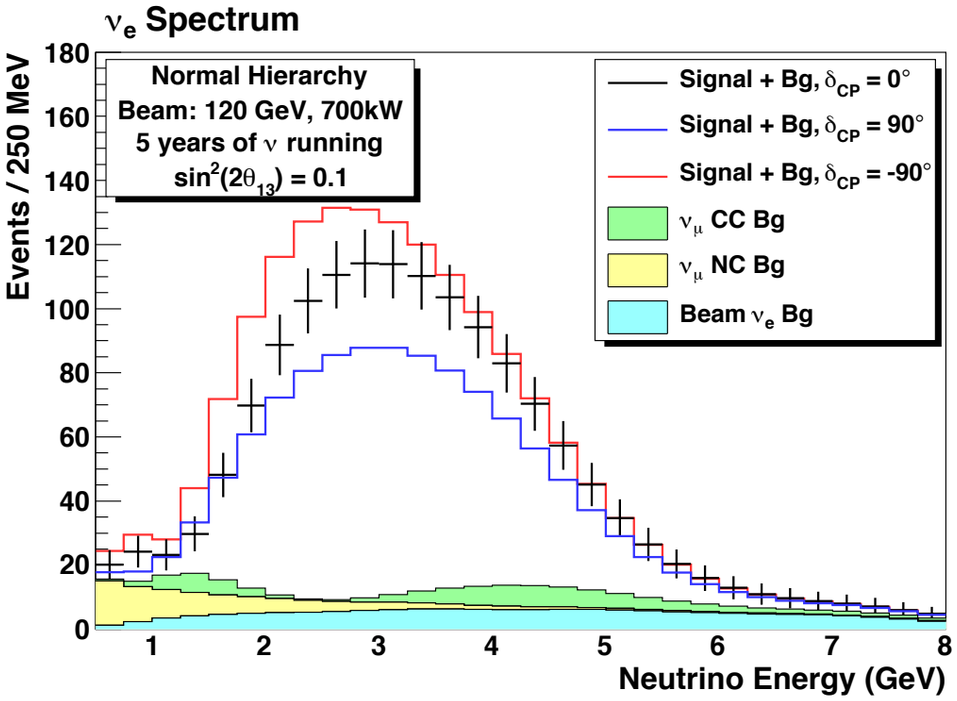
Matter effect is not what is expected !

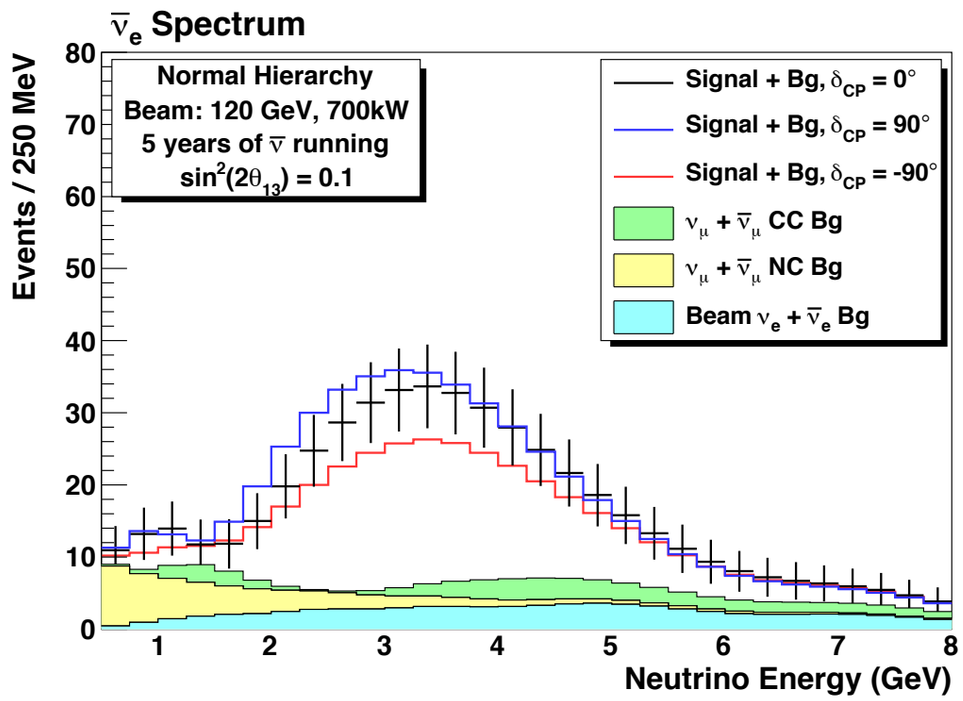
CPV does not have the proper energy 1/E dependence.

- With 1300 km the full structure of oscillations is visible in the energy spectrum. This spectral structure provides the unambiguous parameter sensitivity in a single experiment. Node zero important for new physics.

LBNE 35 kTon performance

1074





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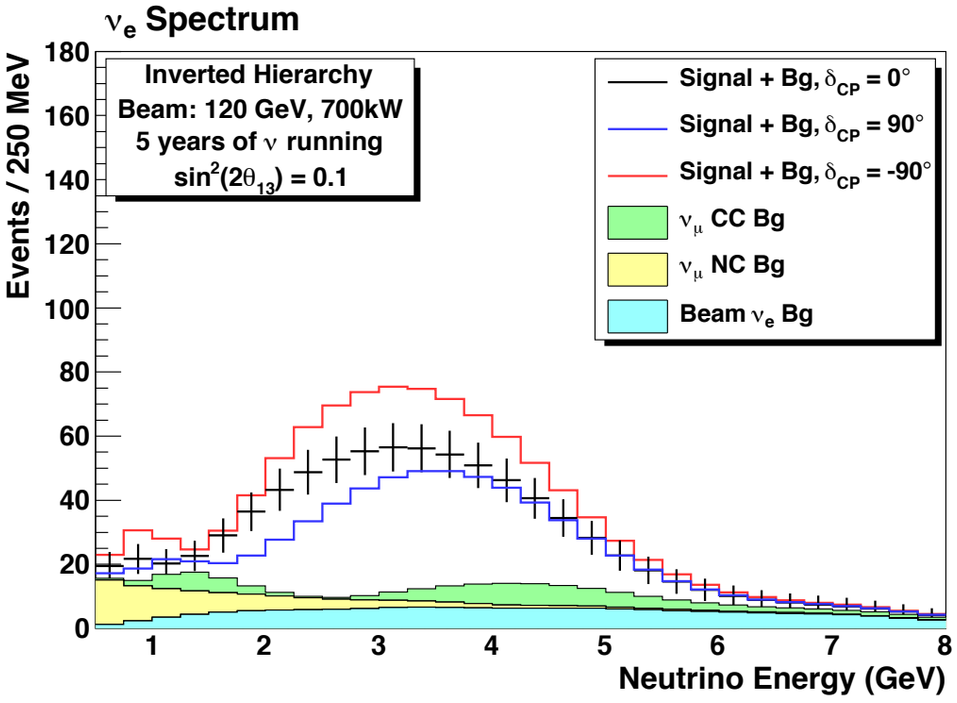
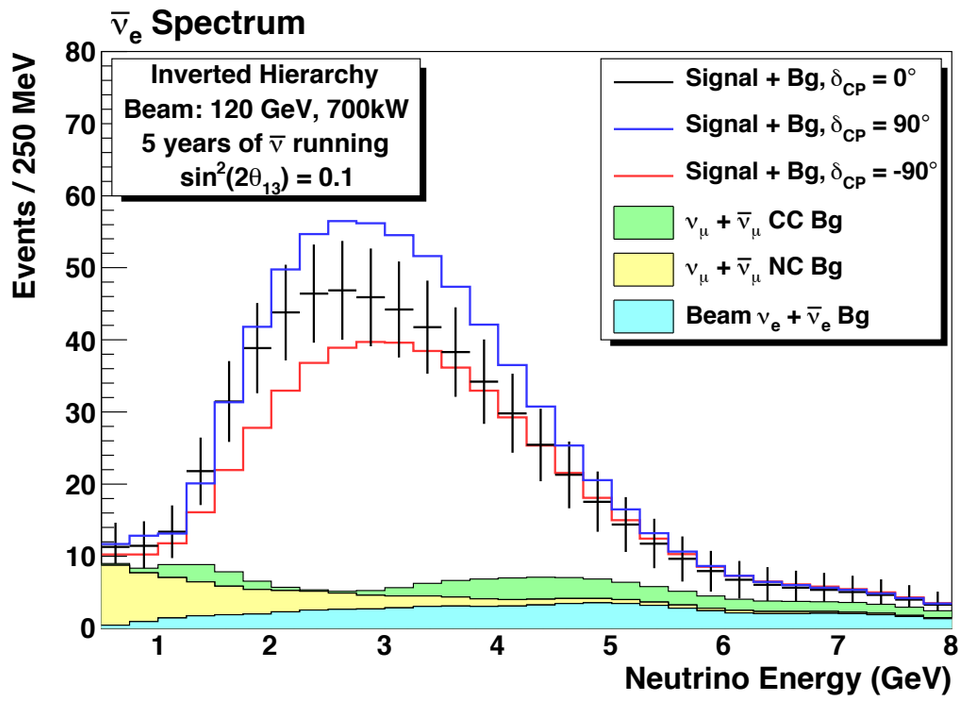
477





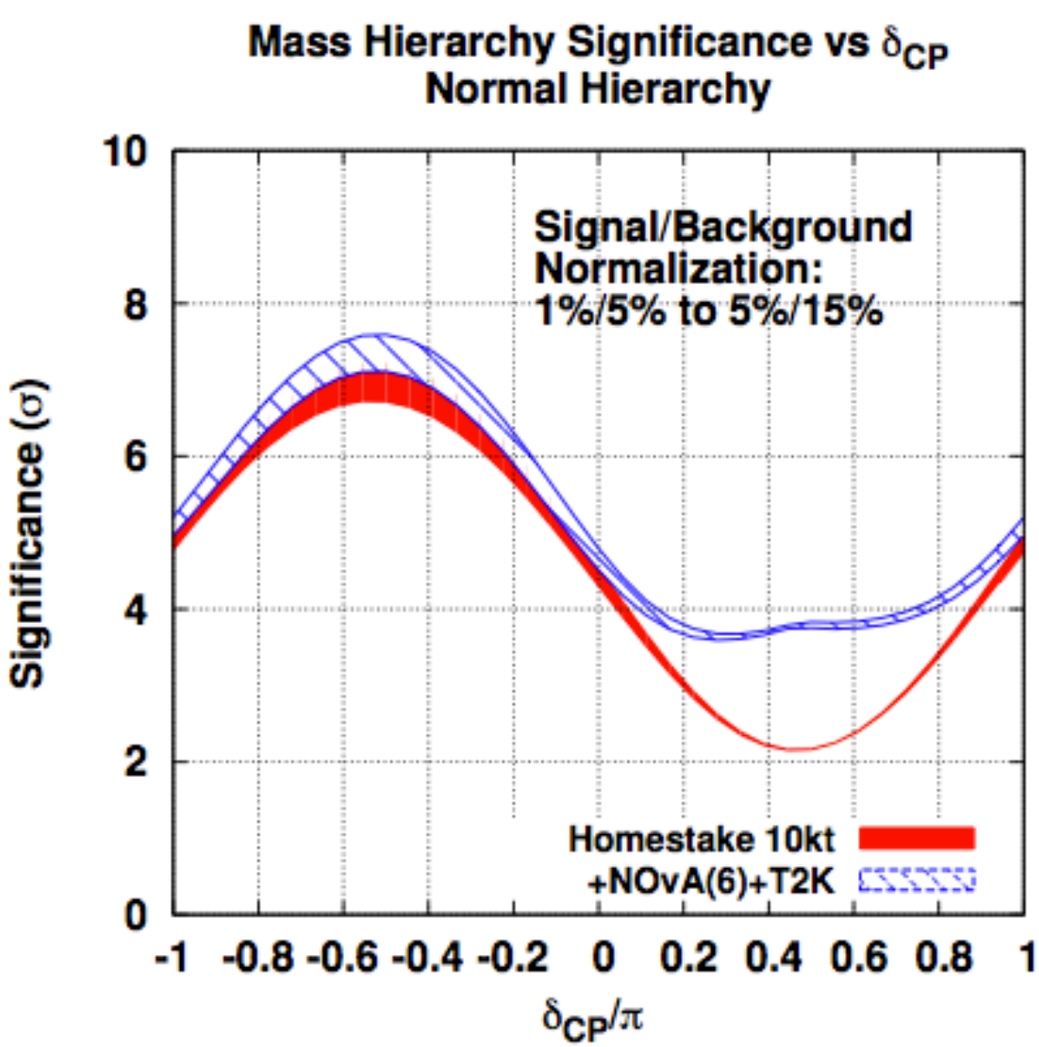
440

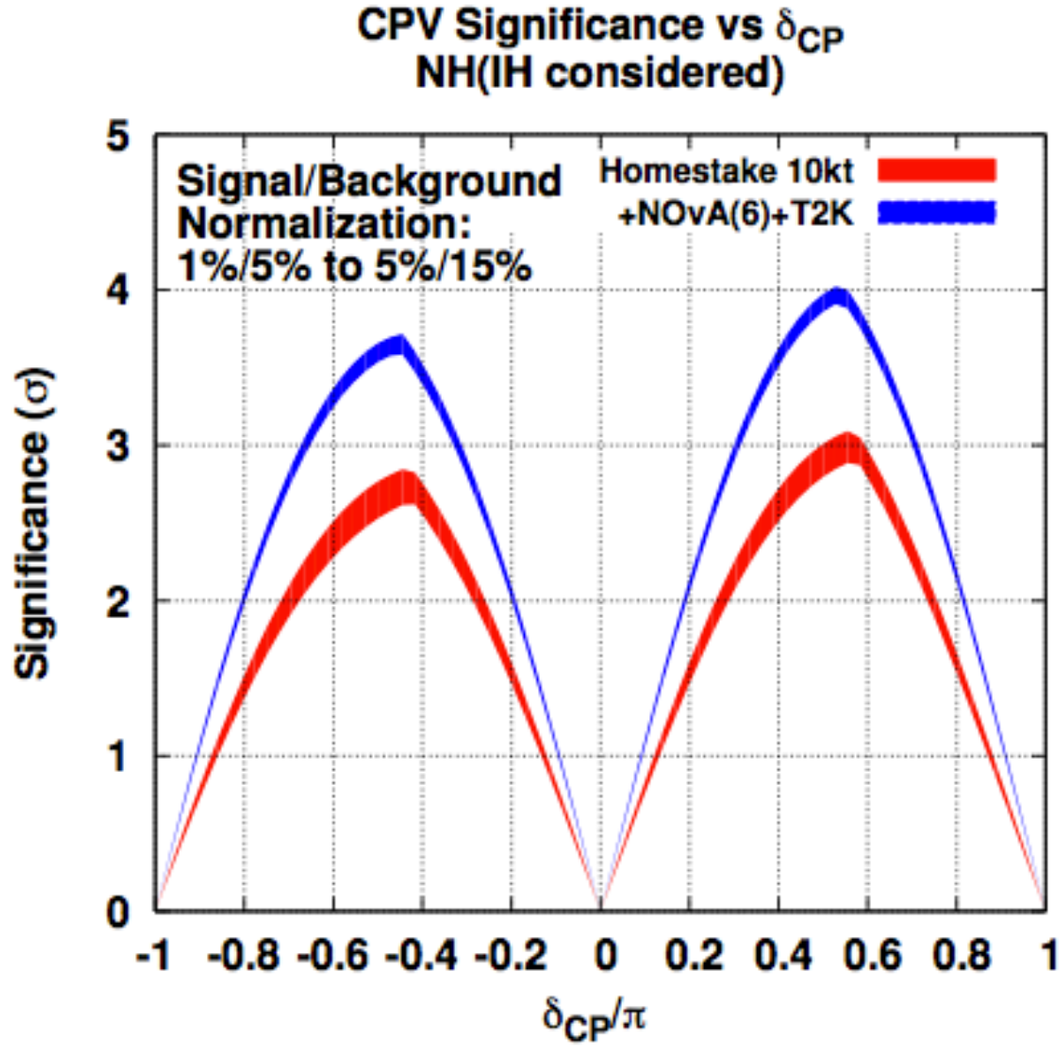
Small tau background expected.

LBNE staging

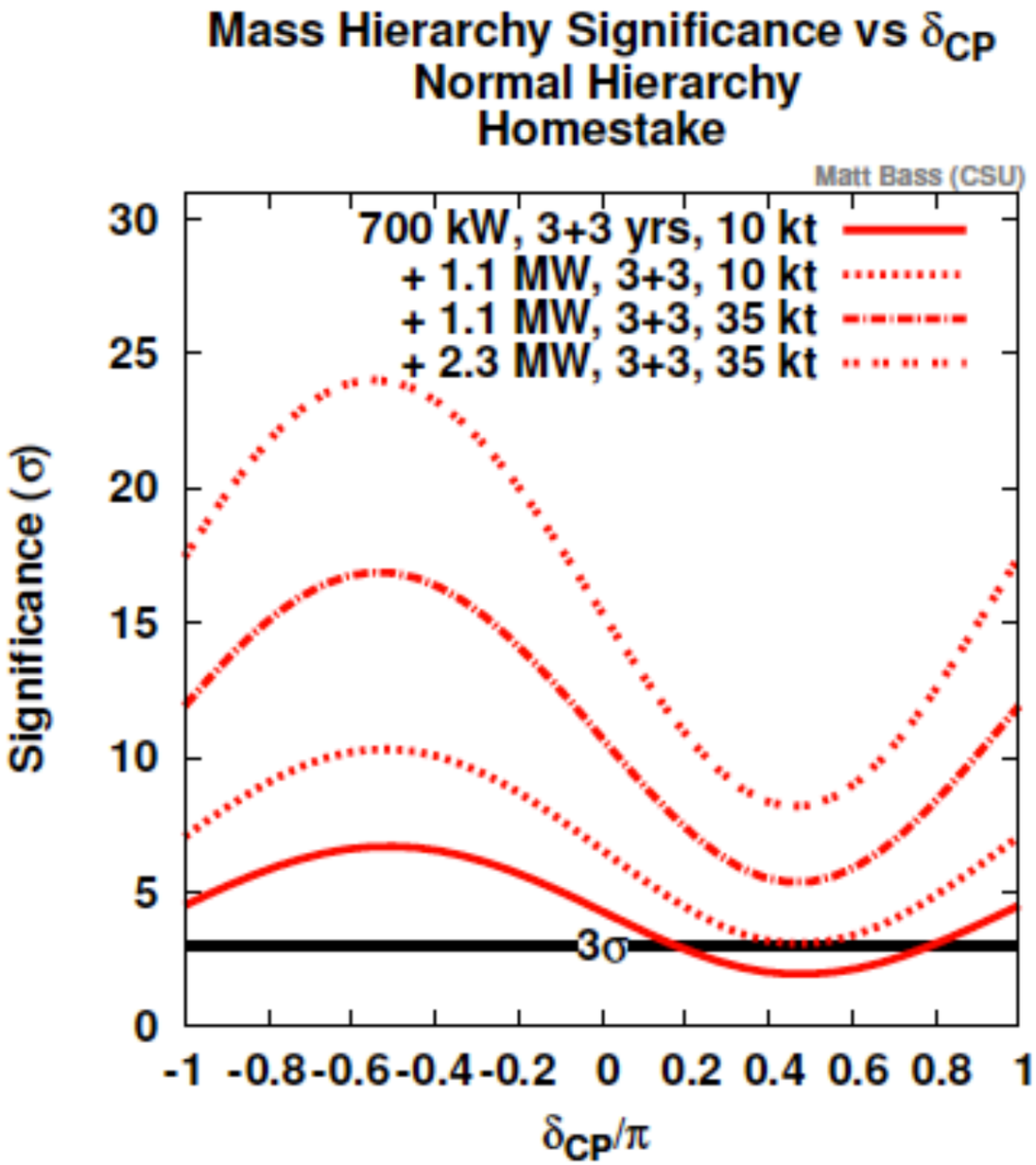
- DOE has asked us to phase LBNE with the first phase ~$850M
- We have chosen to proceed with the most important aspect of the experiment:1300 km baseline and the full capability beam. To keep the project cost down we chose to consider a 10 kt LAr detector on the surface. This is not a final choice.
- Construction will start on the beam first with site investigation to begin this year !
- The goal of the first phase is to place this detector underground and have a full capability near detector.
- New partnerships will enable this expanded scope in a timely way. The DOE is very supportive of this strategy.

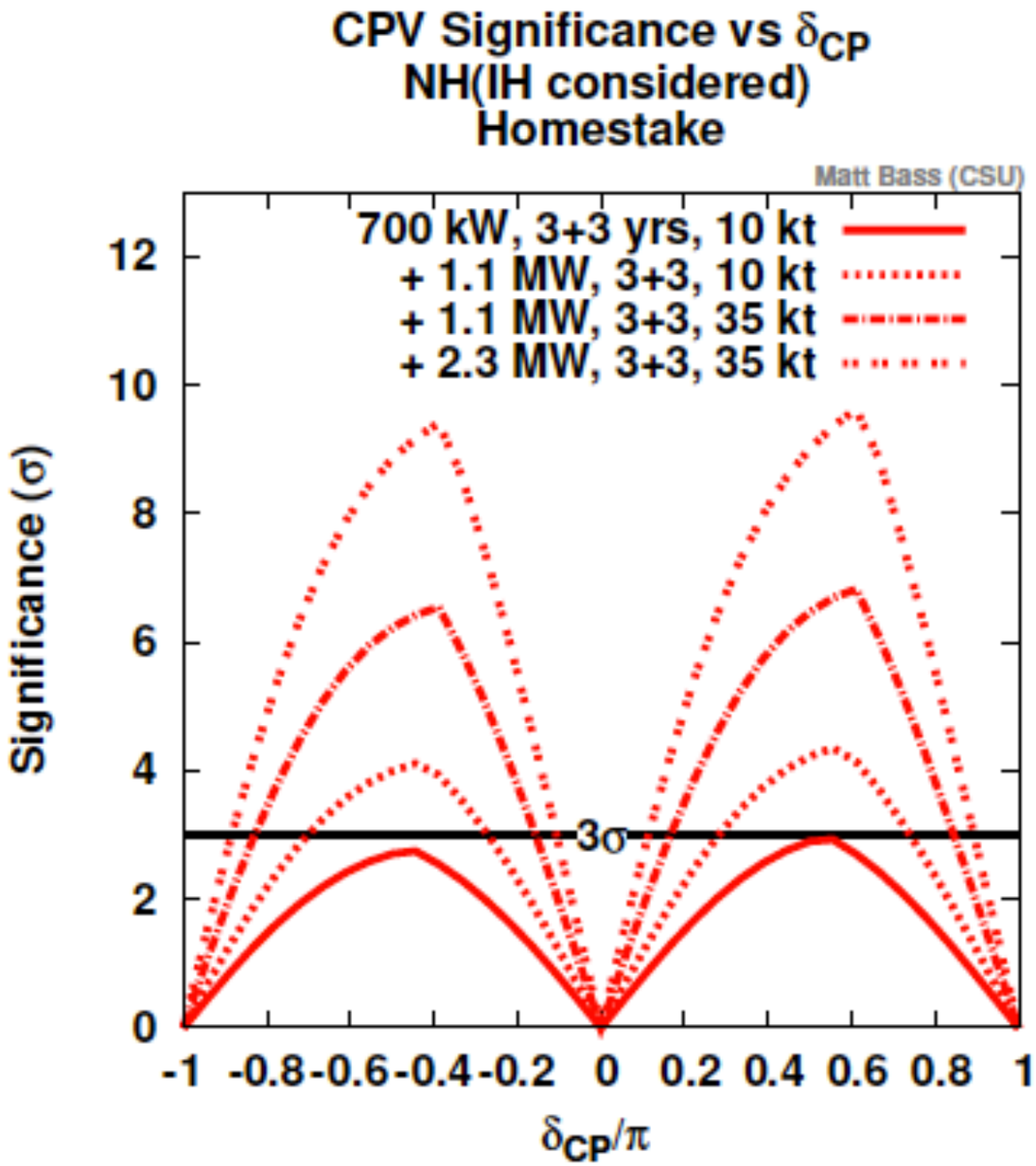
LBNE-Phase 1





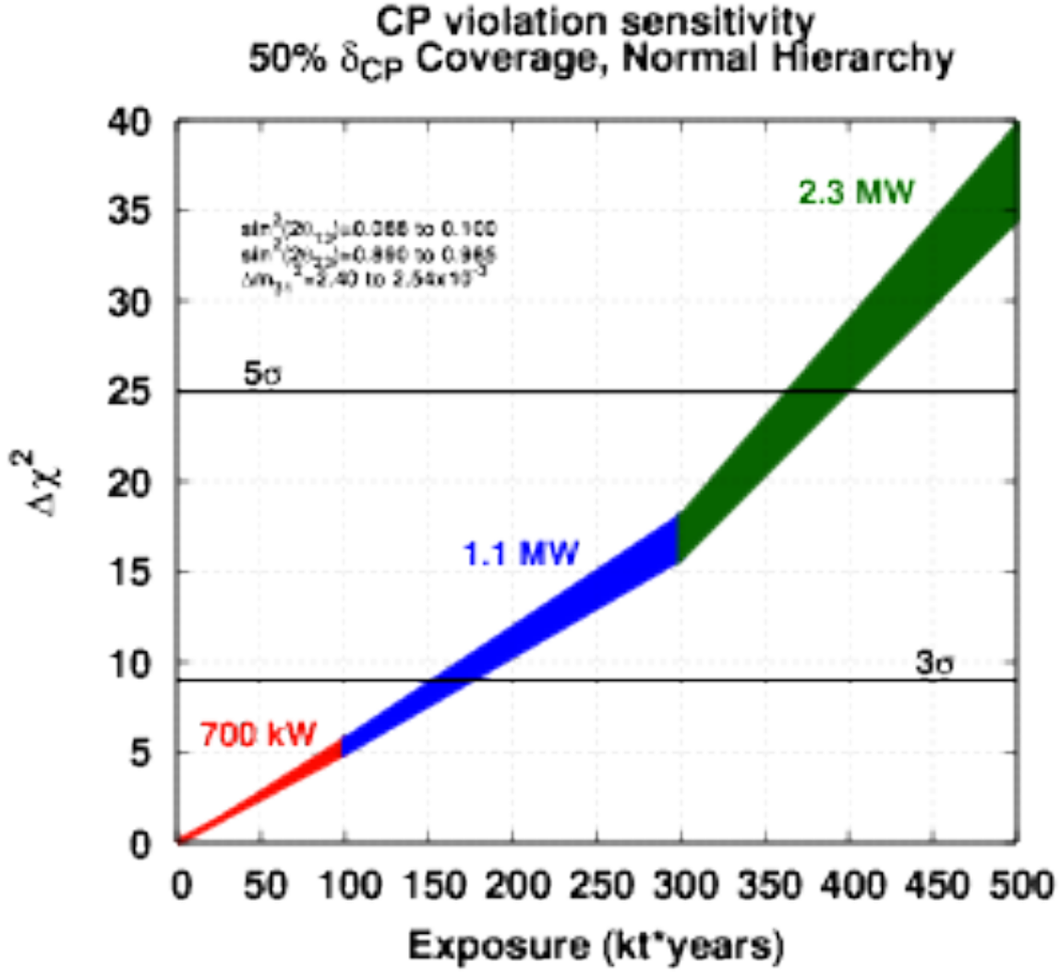
- Hierarchy resolution complete in combination with other data.
- Preliminary measurement of the CP phase.
- Assumption of 700 kW is conservative. One should expect continuing accelerator and beam improvements during the same time.
- Large improvements to the beam are possible with aggressive technical improvements.

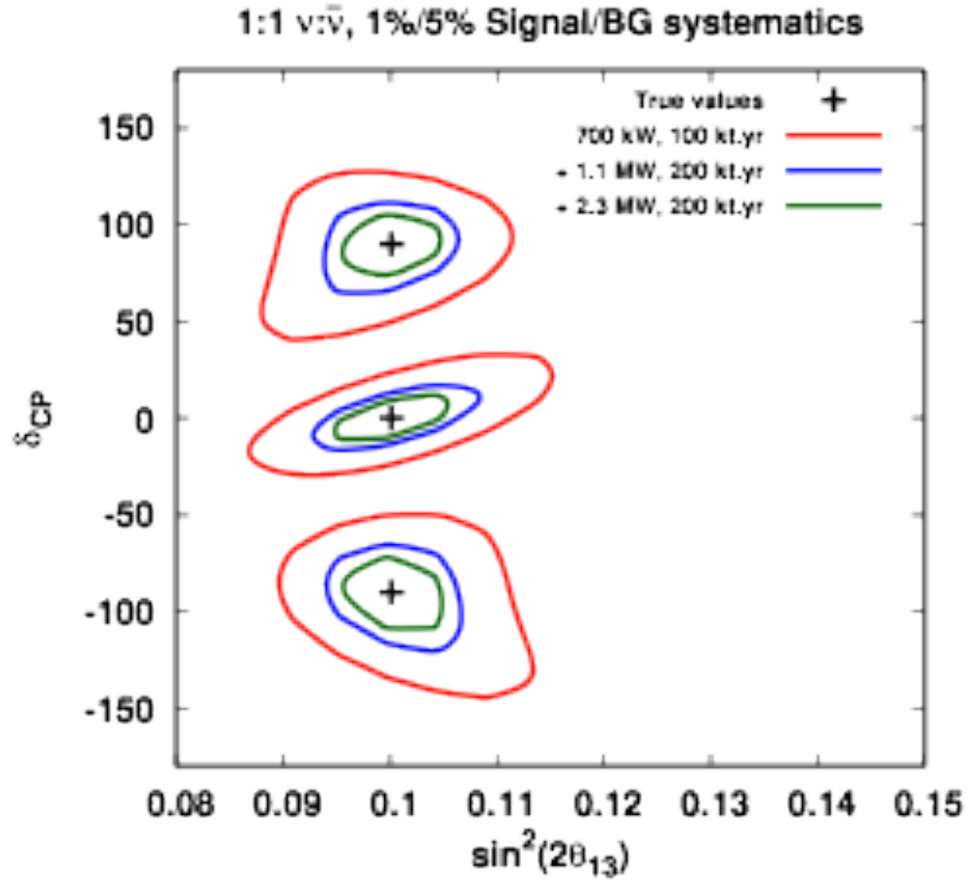




LBNE sensitivity will grow with exposure and beam upgrades. These are for extremely conservative beam design.

LBNE long range neutrino plan.
LBNE and Project X are great partners.





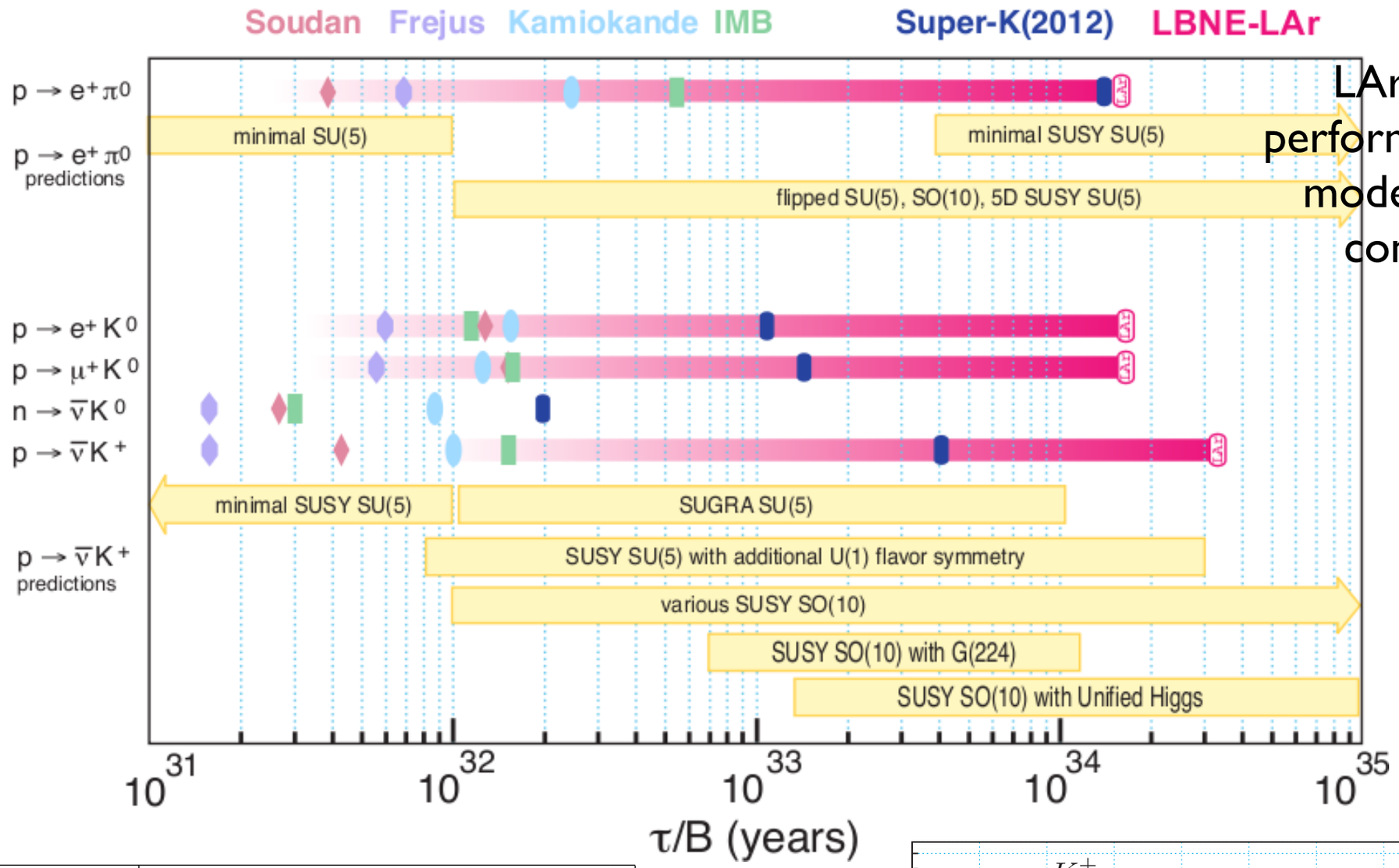
Once the LBNE beamline is built, the long range plan includes:

- increasing far detector to 35 kt in phases and
- increasing beam intensity to 2.3 MW in phases.

This will get us to 5 σ CPV evidence for 50% of the phase space and a ±(7°-10°) measurement of the CP phase. (approaching the CKM matrix precision)

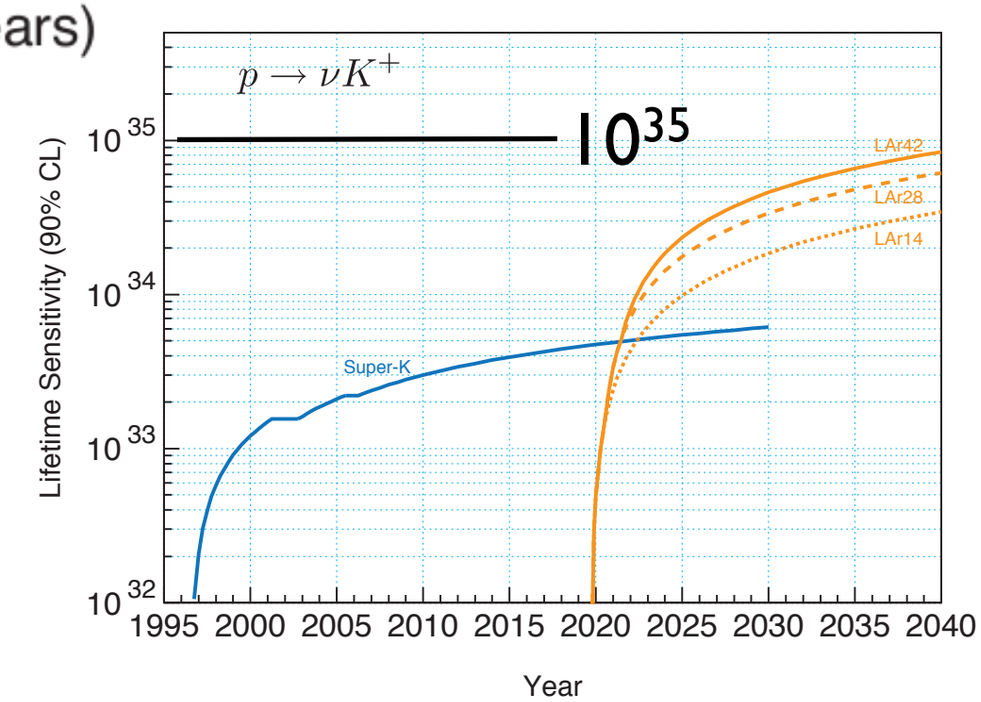
Definitively solve the octant if $\theta_{23} \sim 40$ deg.

Proton Decay



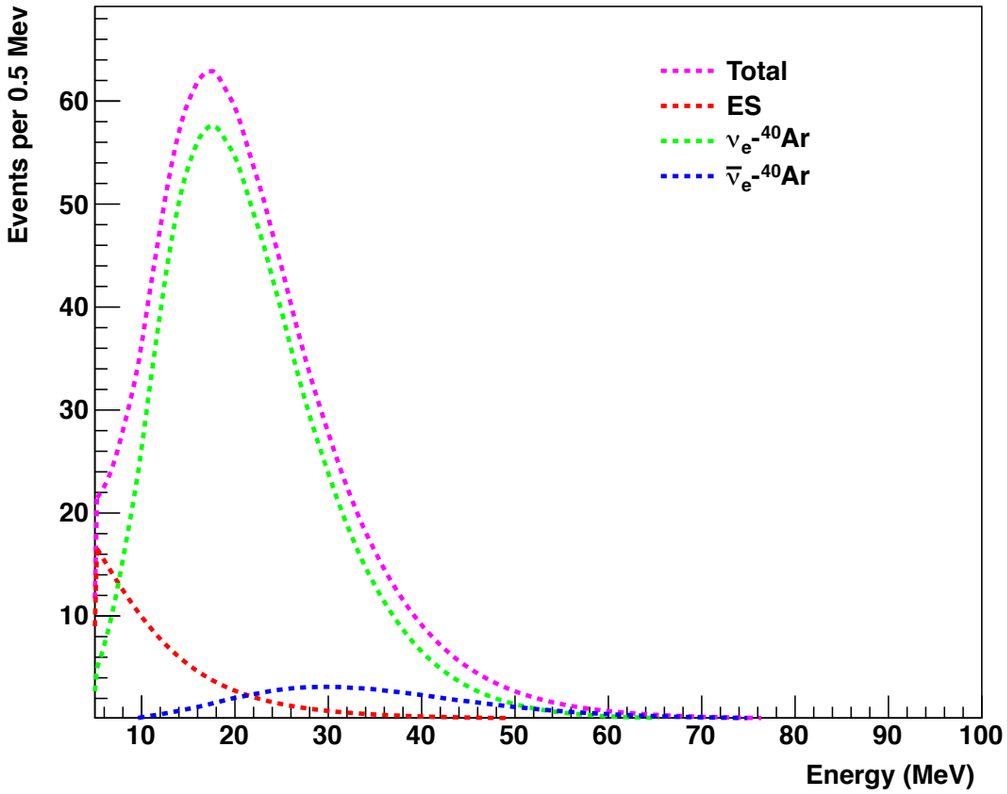
LAr inclusive performance on B-L modes might be competitive

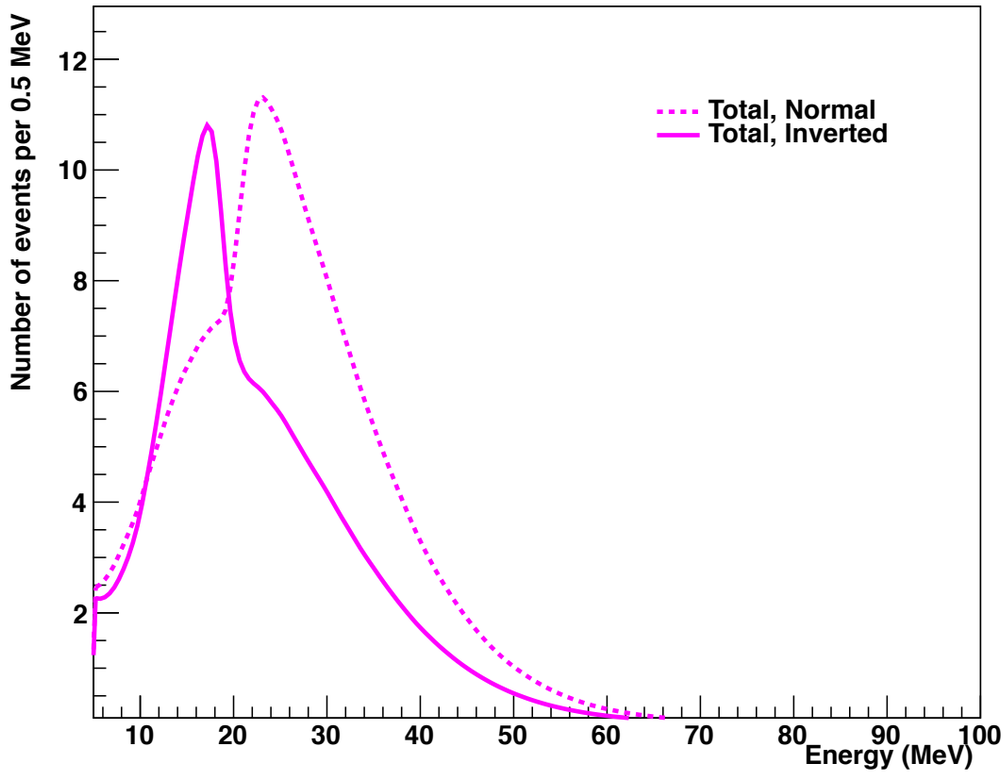
Mode	Efficiency	Background Rate (evts/100 kton-y)
B-L		
$p \to e^+\pi^0$	45%	0.1
$p \to \nu K^+$	97%	0.1
$p \to \mu^+ K^0$	47%	< 0.2
B+L		
$p \to \mu^-\pi^+ K^+$	97%	0.1
$p \to e^+ K^+$	96%	< 0.2
$\Delta B = 2$		
$N\bar{N} \to n(\pi)$	TBD	TBD



Measurement is well justified, but any hint of SUSY from the LHC or other experiments will make this a must do experiment

Supernova





Channel	Events, "Livermore" model	Events, "GKVM" model
$\nu_e + ^{40}\mathrm{Ar} \rightarrow e^- + ^{40}\mathrm{K}^*$	2308	2848
$\bar{\nu}_e + ^{40}\mathrm{Ar} \rightarrow e^+ + ^{40}\mathrm{Cl}^*$	194	134
$\nu_x + e^- \rightarrow \nu_x + e^-$	296	178
Total	2794	3160

@10 kpc

Table 6–7: Supernova burst neutrino event rates for different models in 34 kton of LAr.

Liquid Argon is sensitive to electron neutrinos. Water is sensitive to electron anti-neutrinos. Must have 10 MeV threshold for this physics. Need R&D on threshold and spallation backgrounds.

Conclusion

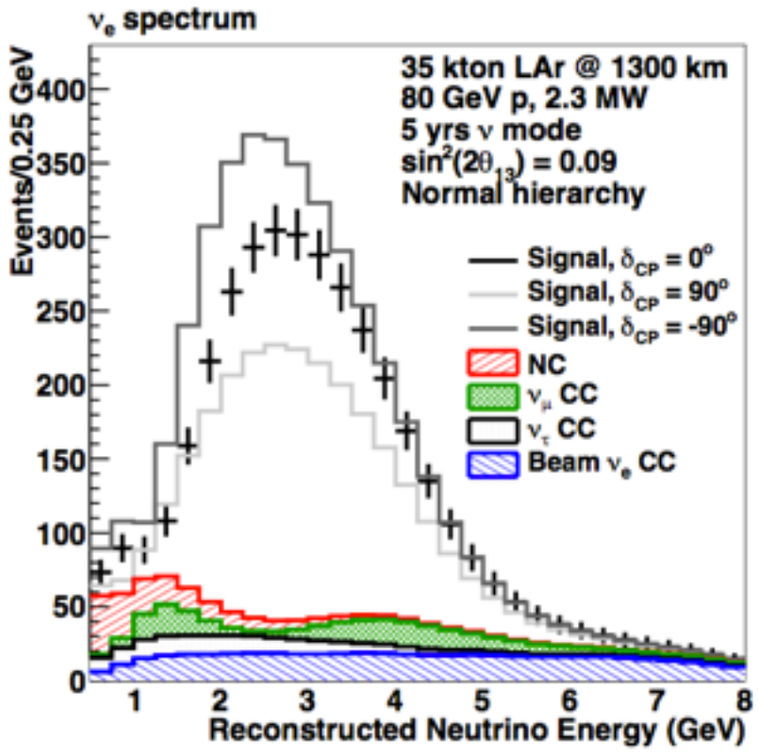
- We started discussing a future US Long-Baseline program after the oscillation discovery. In ~2000 we realized that CP violation was not an unreasonable goal.
  - CP violation was the stretch goal of the program, and it was found to require a large underground detector.
  - 2003 discovery of solar LMA. Critical for feasibility !
  - 2008 Decision in US to invest in development of a program.
  - 2012 Discovery of θ_{13}~ 9 deg. → CD1 approval for LBNE from DOE.

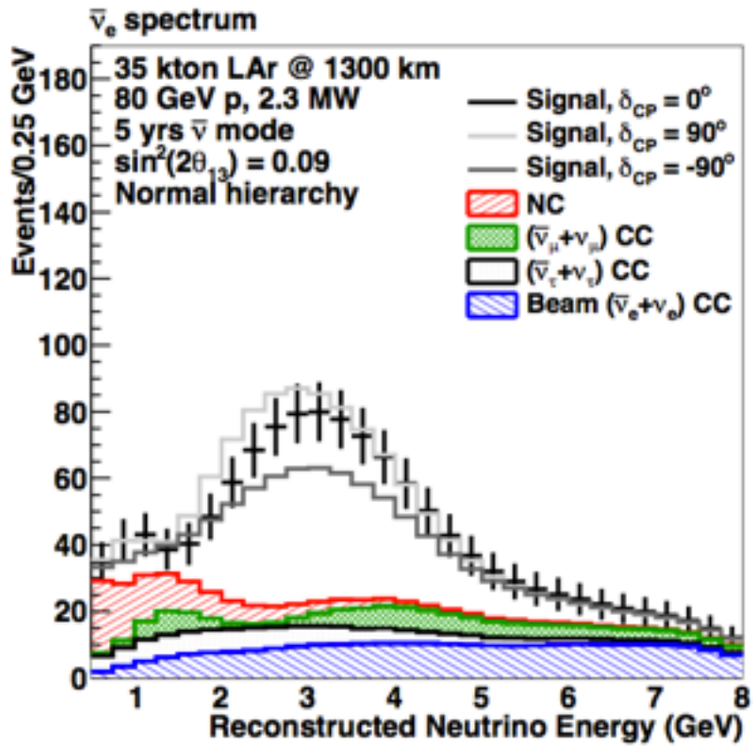
Miracles

- The US program now has all the essential elements (optimum baseline, high intensity accelerator, operating underground laboratory) for a broad attack on the physics of neutrino oscillations and CP violation, and nucleon decay and astrophysics with a new technology detector.
- The LBNE collaboration and project are well-organized and ready to construct and operate. The US/DOE is proceeding with the plan for construction in stages. These would be accelerated with additional partnerships.

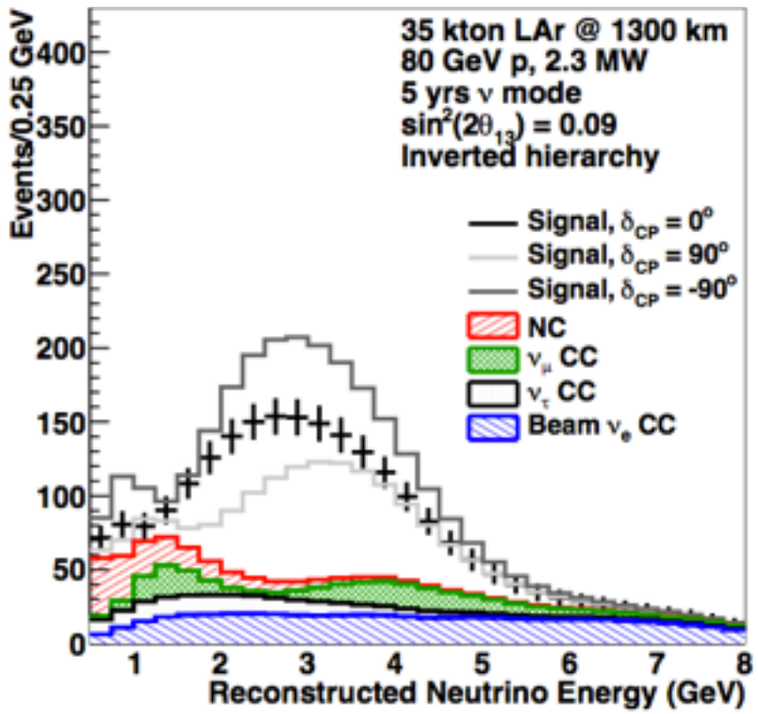
LBNE ultimate dataset with 35 kt and 2.3 MW (Project X)

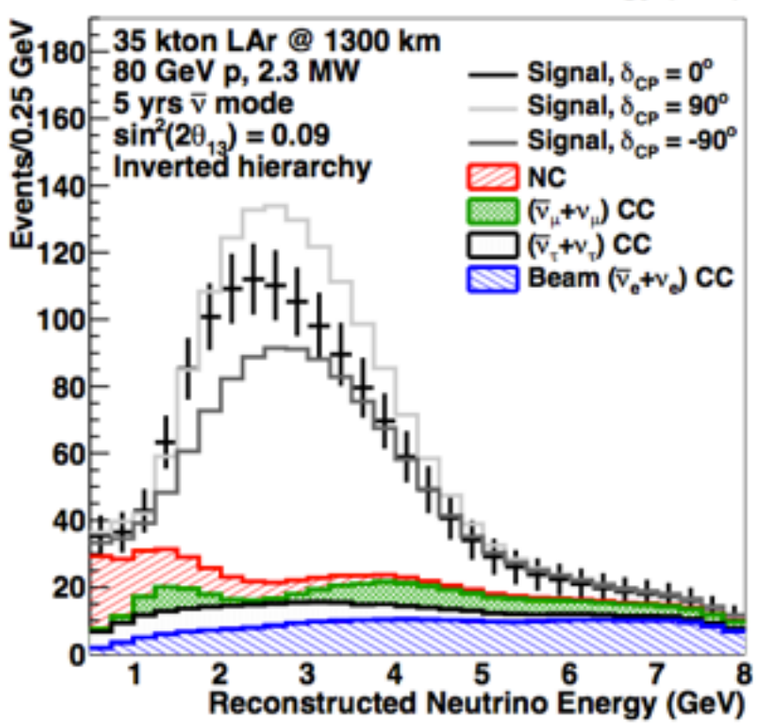
NH





IH





Prediction for 3-generation flavor oscillation is precise and testable with LBNE

Near Detector Design: Straw tube tracker or a small Liquid Argon TPC; both magnetized.