Long-Baseline Neutrino Experiment

Robert J. Wilson

13 June 2012

Fermilab Users Meeting

LBNE Science Collaboration

- ~350 members, >55 institutions (4 international)
- Co-spokespersons Bob Svoboda (UC-Davis) & Milind Diwan (BNL)
- LBNE Project Manager Jim Strait (Fermilab), Project Scientist Mary Bishai (BNL)

Physics Objectives

- **COMPREHENSIVE PROGRAM TO MEASURE NEUTRINO OSCILLATIONS**
- 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 detectors
  - Proton decay measurement
  - Astrophysics -- supernova ν burst

Neutrino Oscillations

Measurements:

ν_e appearance in a ν_μ beam

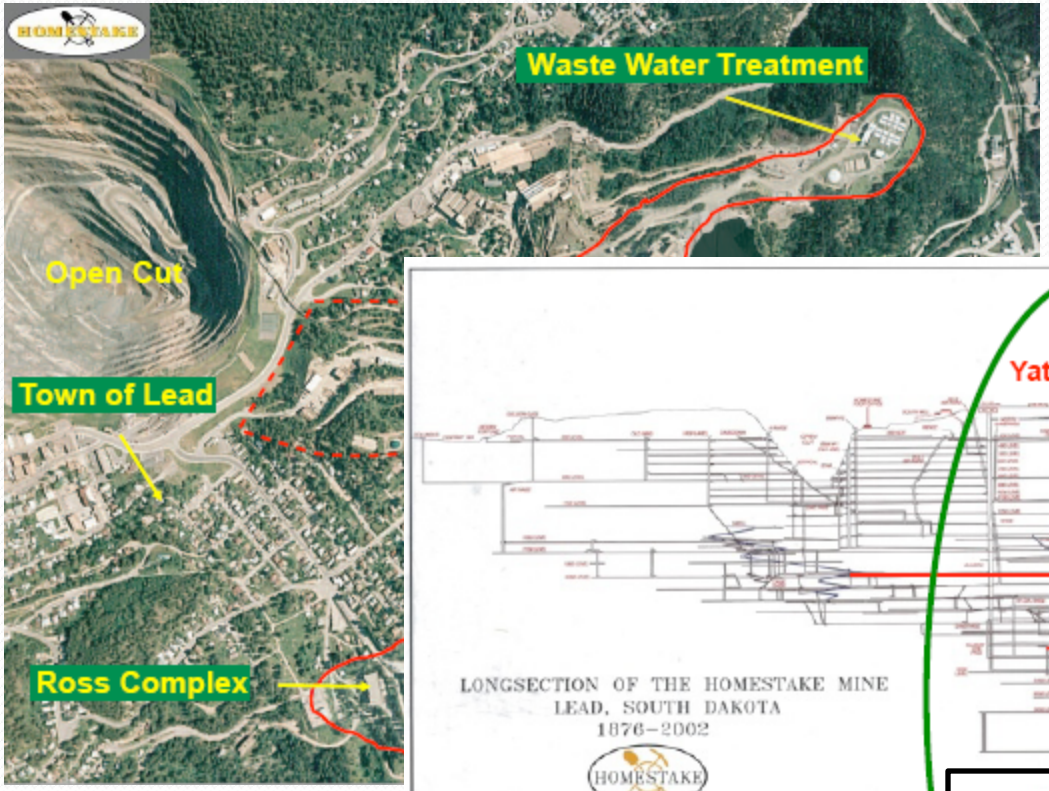
ν_μ disappearance from a ν_μ beam

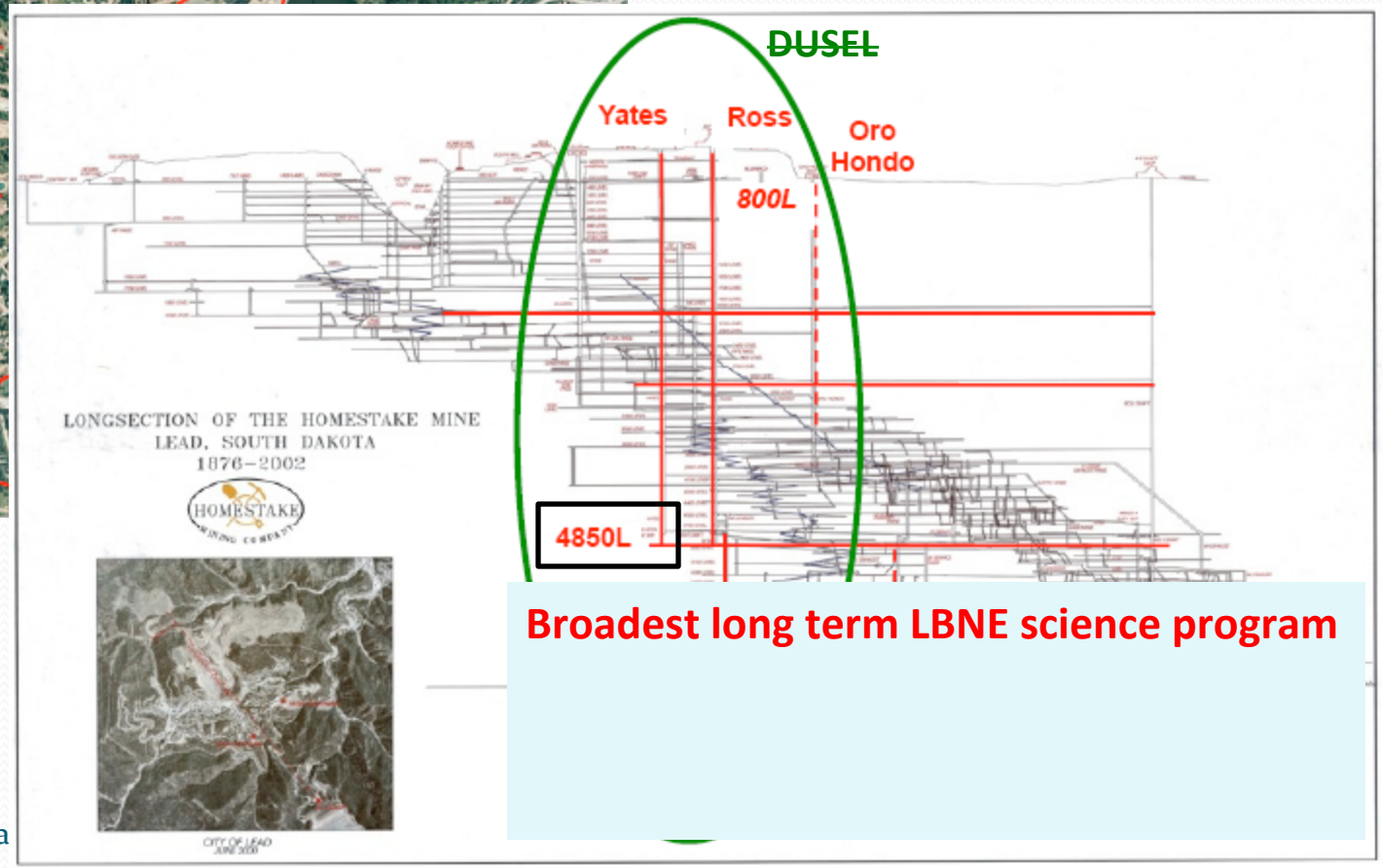
- Next generation(s) of neutrino experiments should not focus on single parameter measurements – even δ_{CP}
- A comprehensive program, must have the ability to
  - observe spectral distortion due to oscillations – peak and valley
  - observe different behavior for neutrinos and antineutrinos – direct evidence of CPV
- **Non-zero and large θ_{13} => event rate is high enough to achieve this**

LBNE: 1300 km Beam Path

- Optimal baseline for oscillation parameter measurements independent of other experiments
- New beam line – allows for future higher power beam

Far Detector Site : Homestake mine





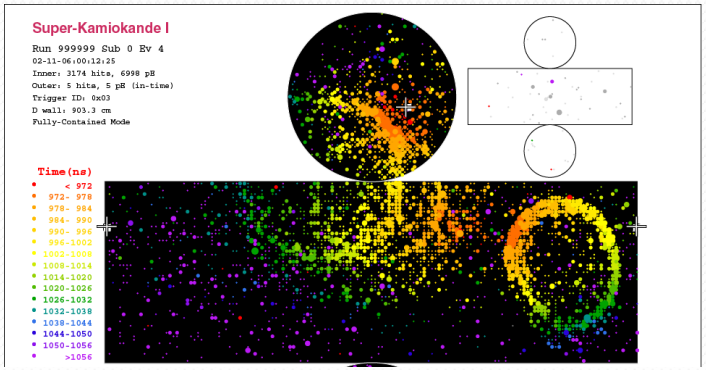
Broadest long term LBNE science program

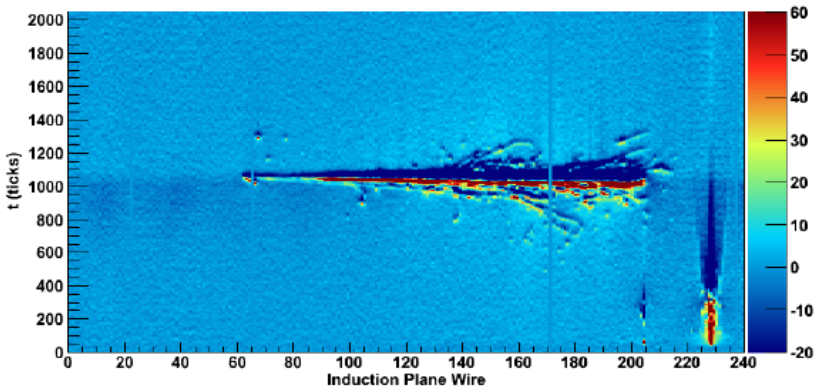
Tale of Two (Far Detector) Technologies

- **Water Cherenkov (200 kt)**
  - 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

?

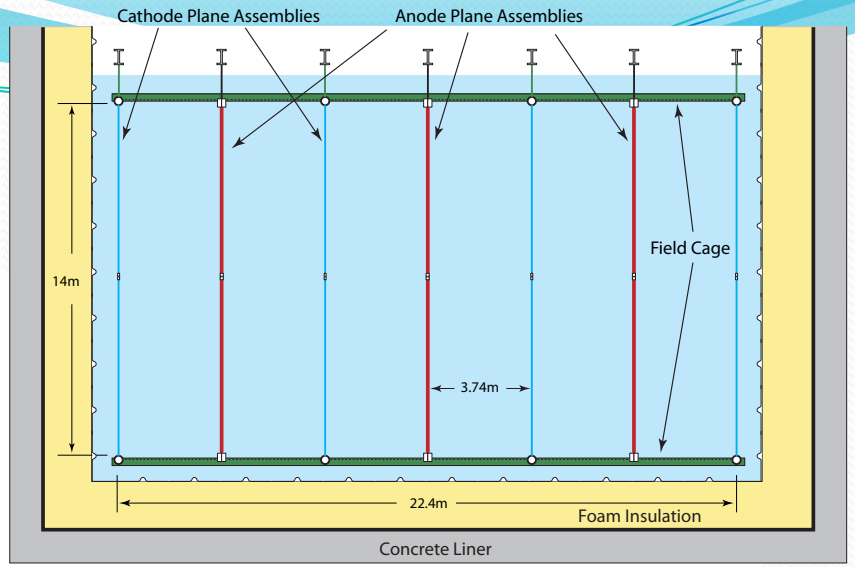
- **Liquid Argon TPC (34 kt)**
  - Bubble chamber-like imaging; detailed event topology with few mm resolution
  - Very high efficiency and background rejection ⇒ ~6x lower mass than WC
  - 600 ton ICARUS now operating at Gran Sasso
  - No free protons for nucleon decay or inverse beta-decay studies; excellent for kaon ID

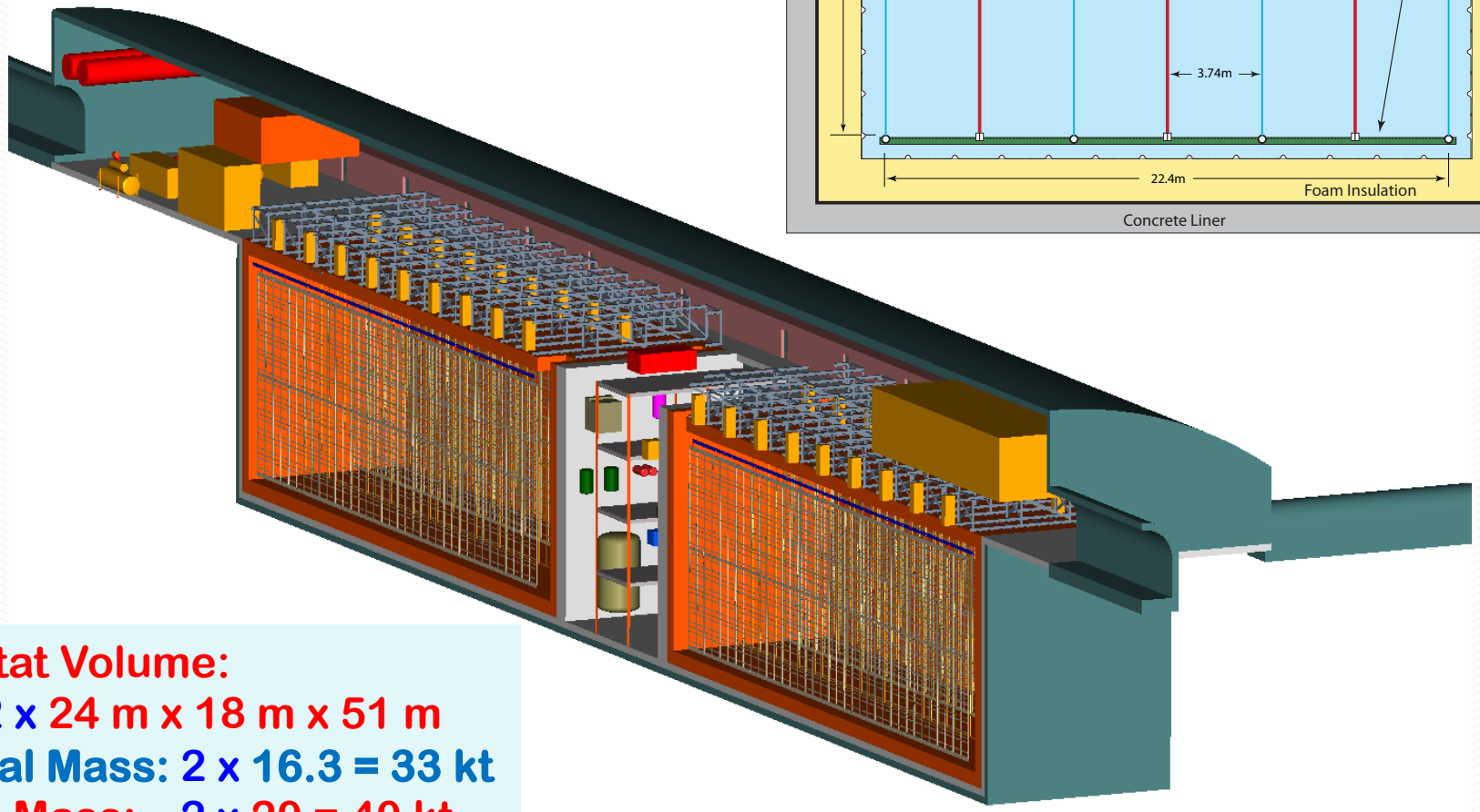




January 2012

Liquid Argon TPC



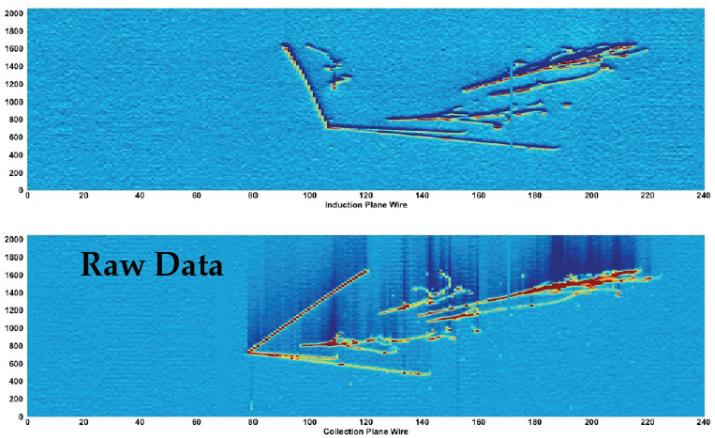


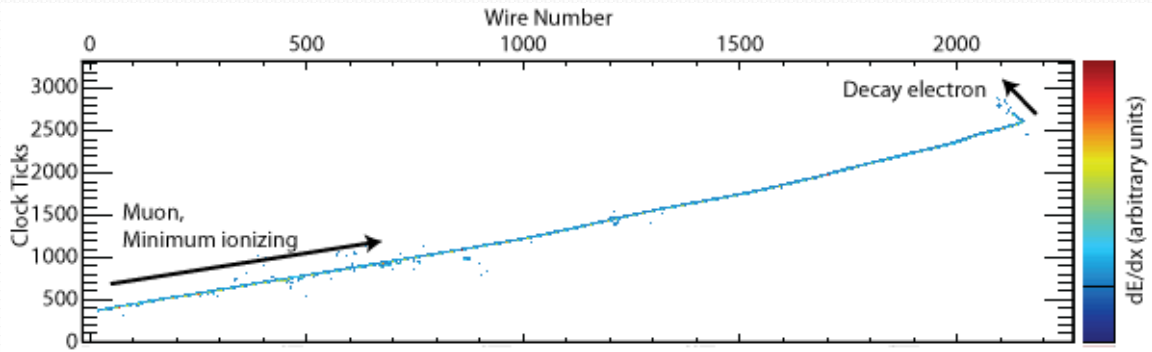
Cryostat Volume:
2 x 24 m x 18 m x 51 m
Fiducial Mass: 2 x 16.3 = 33 kt
Active Mass: 2 x 20 = 40 kt

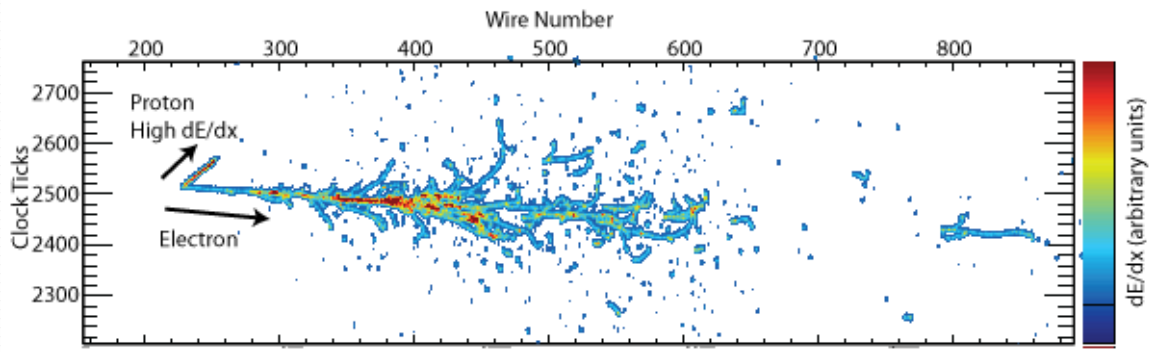
NOνA 15.6 m x 15.6 m x 68 m

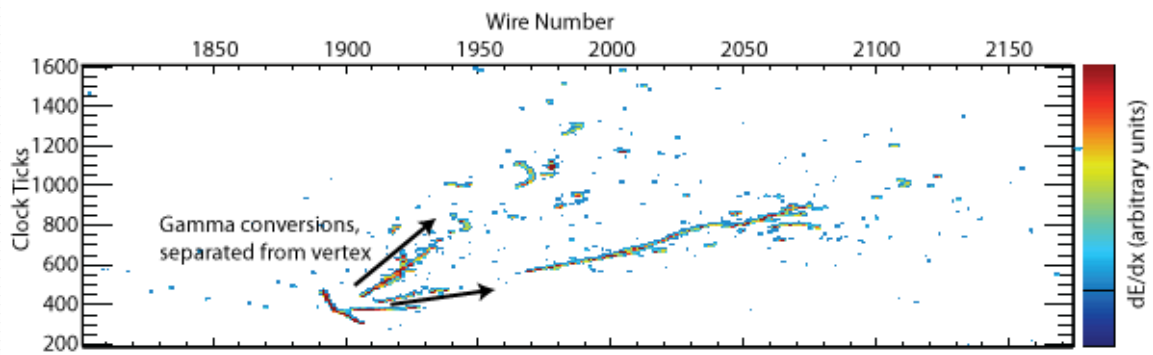
GEANT4 simulation of LArTPC neutrino interactions

ArgoNeuT Neutrino Event

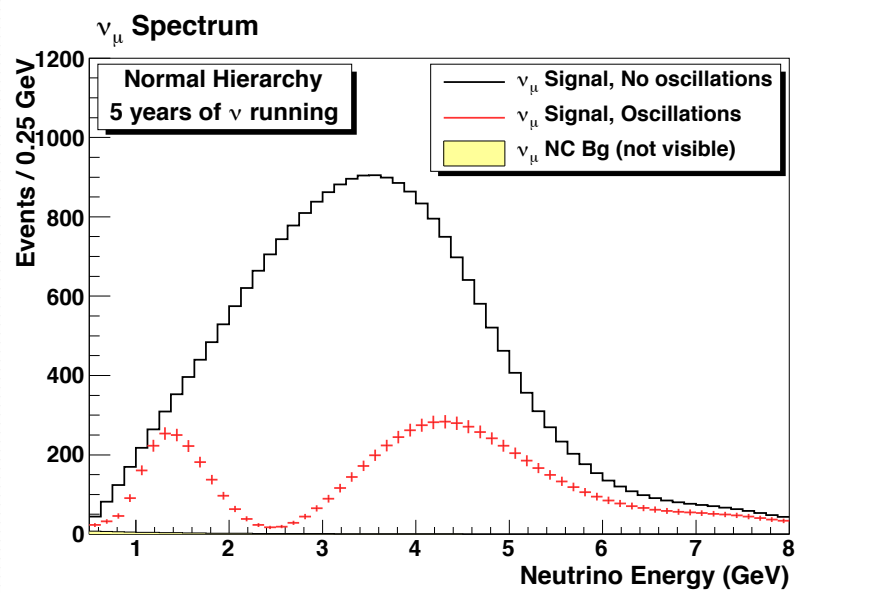


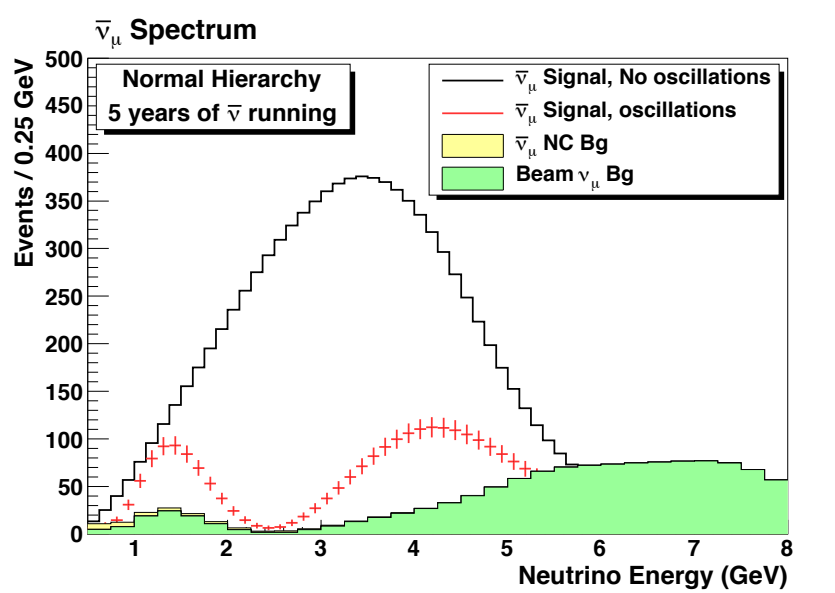






Neutrino Disappearance





- Neutrino Beam similar to NuMI low energy tune but optimized for longer baseline and background reduction
- Expected spectra in 34 kt LAr TPC with and without oscillations for 5 years running with neutrino (left) or antineutrinos (right)
- Clear (bi-nodal) oscillation spectrum

An Eventful 18 months for LBNE

Winter 2010/11 - NSF DUSEL terminated

Spring 2011

- DOE assures us that NSF DUSEL is not *required* for LBNE
- DOE Review Panel on cost effectiveness of Homestake
  - LBNE design/costs believable; urges FD technology choice
- NAS panel reiterates importance of the science

Summer 2011

- Indication of non-zero/large θ_{13} from T2K, MINOS

Fall 2011

- More hints of non-zero/large θ_{13} from Double CHOOZ
- Intensive performance/cost comparison of Water Cerenkov and LAr TPC
- (External) Scientific Capability Review Committee set up to advise

Eventful contd.

January, 2012

- Far detector technology decision made
- Cost and schedule for a 34 kt LArTPC at Homestake 4850' level and a new 700 kW beam submitted to DOE Office of Science

March, 2012

- Proposed budget profile does not fit anticipated DOE budget; Fermilab tasked to prepare plans for *affordable* phases, which could include "alternate configurations"
- Daya Bay (followed shortly by RENO) confirms *large* θ_{13}

June, 2012

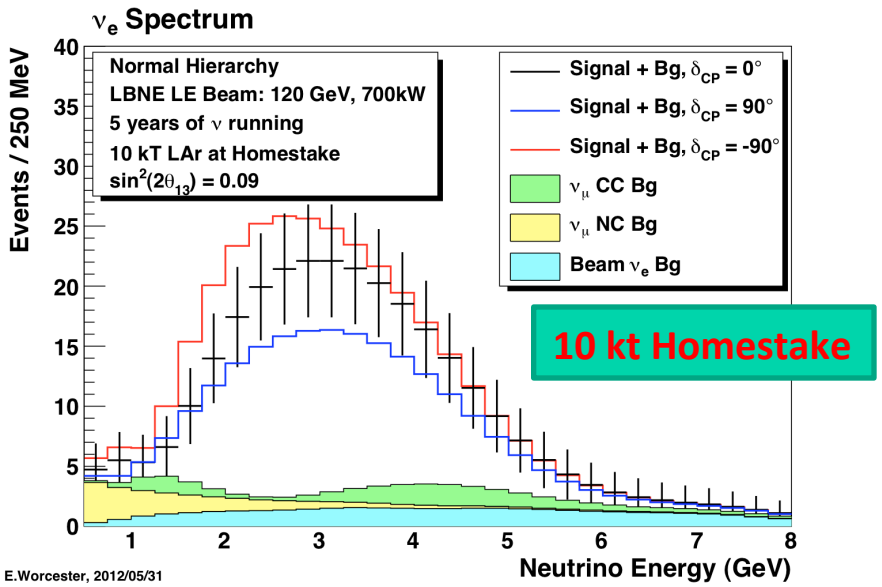
- Fermilab-convened Steering Group identifies three phasing plans that fall within the guidelines for an affordable first phase:

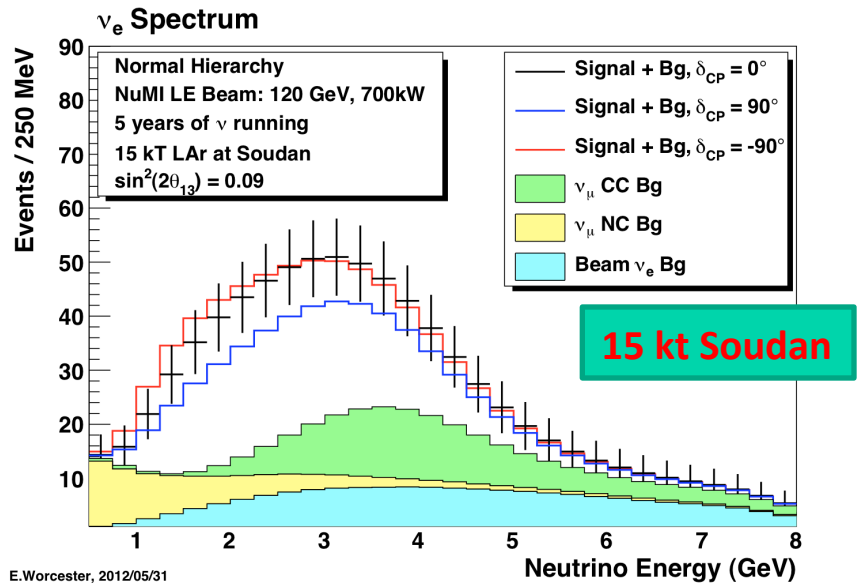
LBNE Reconfiguration Phase 1 Options

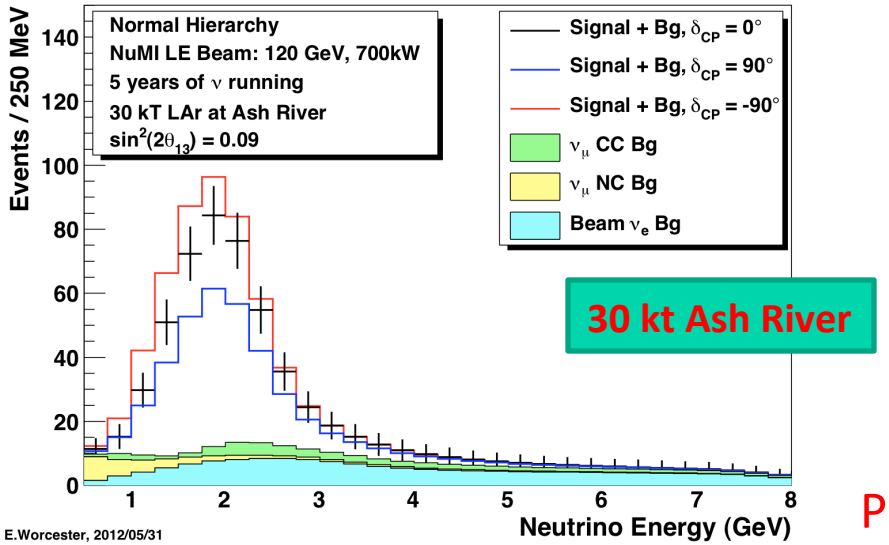
Interim report of the LBNE Reconfiguration Steering Group, R. Svoboda, Neutrino 2012, Kyoto

- New 700 kW beam line to **Homestake**, no Near Detector, 10 kt Far Detector (on surface unless additional funding obtained)
- Use existing NuMI beam and build a 15 kt detector underground at the MINOS site in the **Soudan** Mine.
- Use existing NuMI beam and build a 30 kt detector on the surface at the NOVA site at **Ash River.**

Phase 1 ν_e Spectra





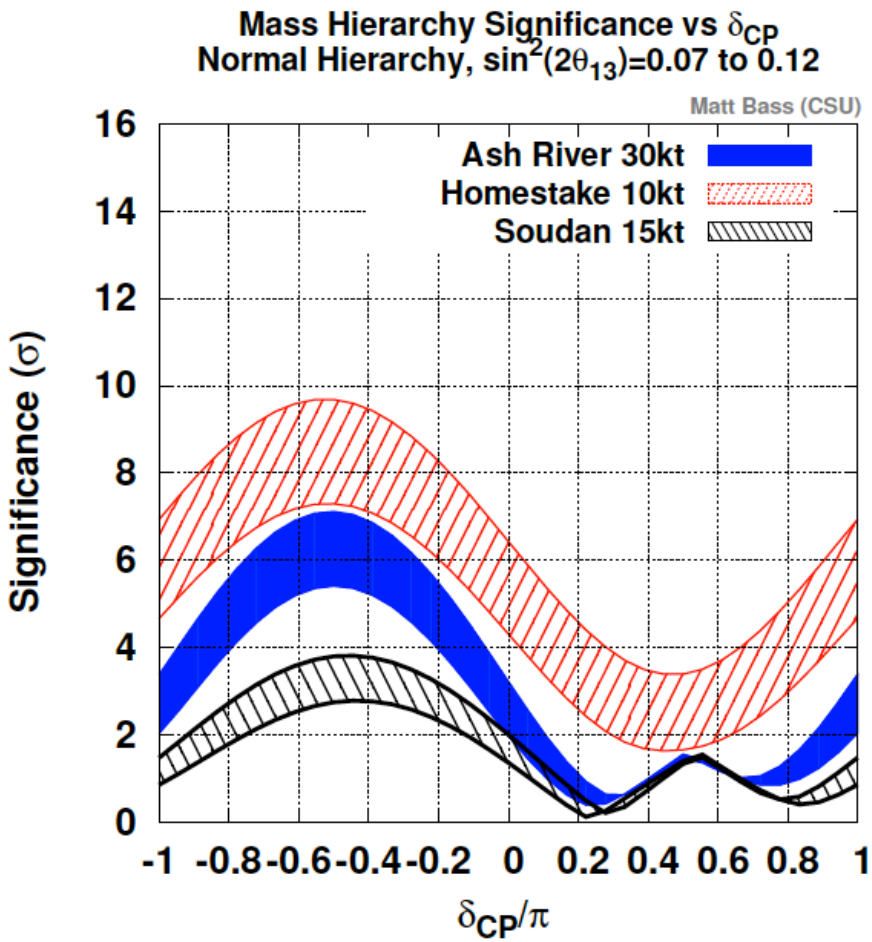


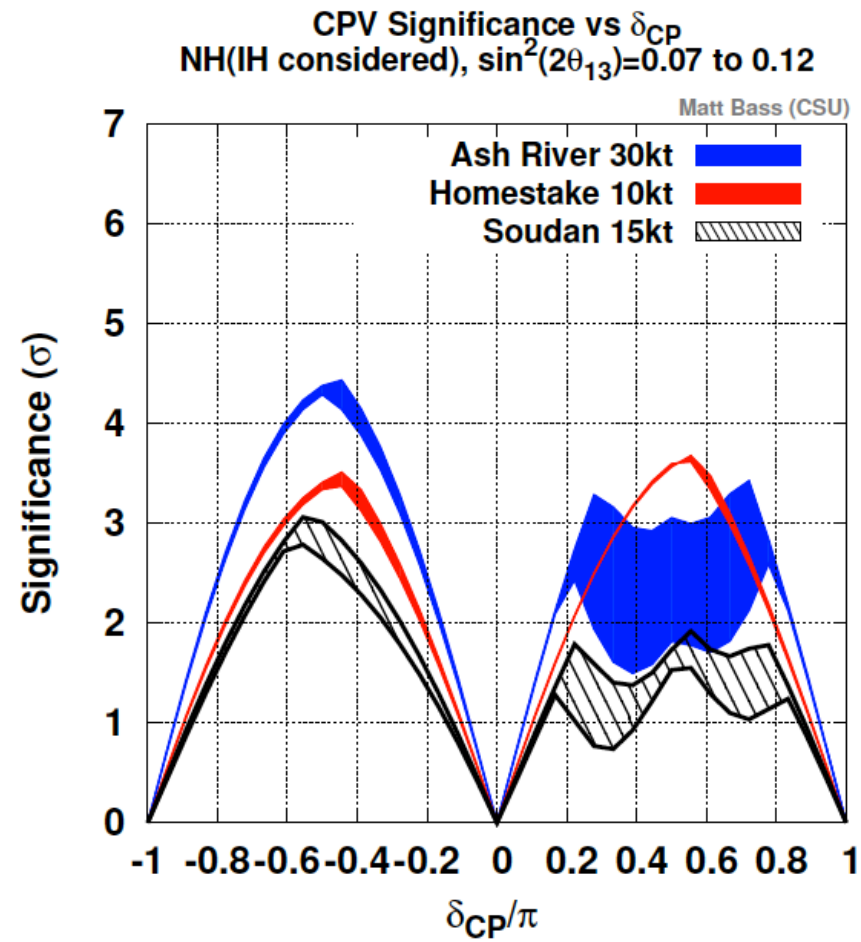
Mis-ID ν_μ CC
Mis-ID ν_μ NC
Intrinsic ν_e

Preliminary: LBNE Physics Working Group

Phase 1 Mass Hierarchy and CP Violation Sensitivity

Preliminary: LBNE Physics Working Group

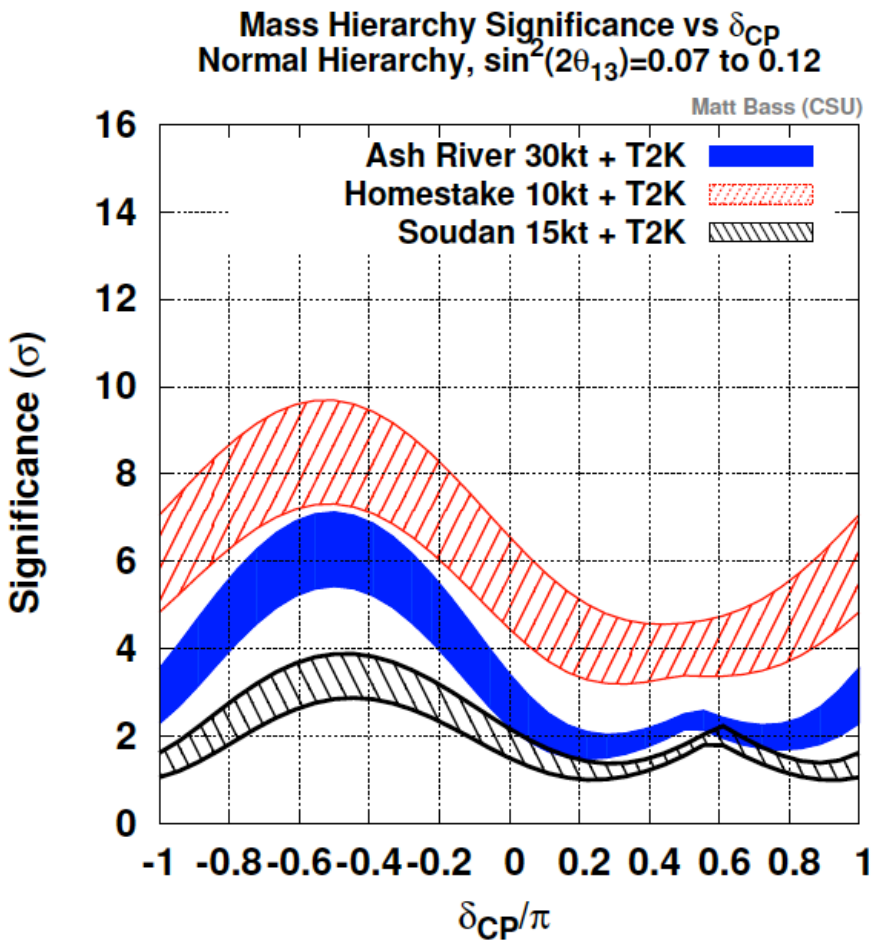


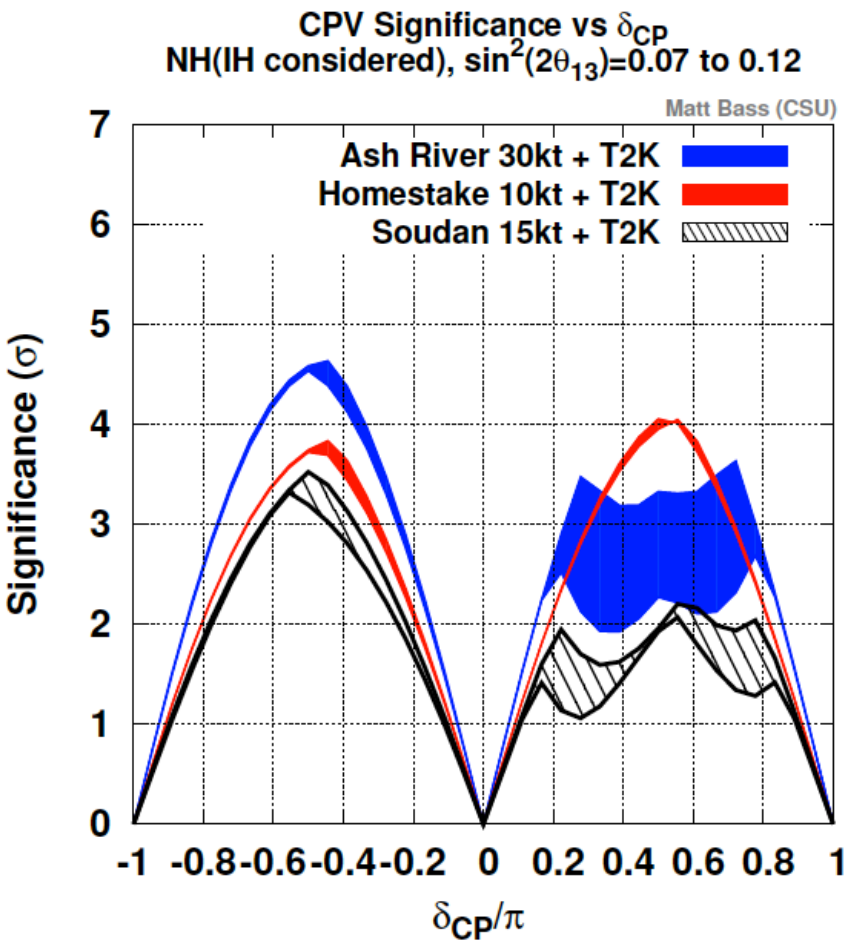


5 years neutrino + 5 years antineutrino

Sensitivity including T2K with 5.5×10^{21} pot

Preliminary: LBNE Physics Working Group





5 years neutrino + 5 years antineutrino

Performance of Phase 1 Options

Phase 1 Option		15 kton Soudan (underground)	30 kton Ash River (surface)	10 kton Homestake (surface)
Phase 1 Science Capabilities assuming 6×10^{21} protons on target or 10 years with 700 kW	Mass Hierarchy: fraction of δ_{CP} at 3σ	0.17 (0.38)	0.47 (0.50)	0.81 (1.00)
	CP Violation: fraction of δ_{CP} at 3σ	0.05 (0.23)	0.27 (0.55)	0.27 (0.45)
	Resolution of δ_{CP} $\delta = 0, 90^o$	$23^o, 30^o$ $(14^o, 26^o)$	$18^o, 29^o$ $(13^o, 25^o)$	$17^o, 30^o$ $(12^o, 25^o)$
	Proton Decay $p \rightarrow K\nu$ 90% CL in 10 years	1×10^{34} years	No	No
	Number of observed neutrinos from a supernova explosion at a distance of 10 kiloparsecs	1,300	No	No
	Atmospheric neutrinos Mass Hierarchy in 10 years	$1.5\ \sigma$	No	No
	Precision Measurements: $\sigma(\theta_{13})$ for $\delta=\pi/2$ Neutrino $\sigma(\theta_{23})$ Anti neutrino $\sigma(\theta_{23})$ Neutrino $\sigma(\Delta m_{31}^2)$ $(10^{-3}eV^2)$ Anti neutrino $\sigma(\Delta m_{31}^2)$ $(10^{-3}eV^2)$	0.60^o 1.1^o 1.3^o 0.036 0.055	0.40^o 0.74^o 1.1^o 0.035 0.050	0.40^o 0.69^o 0.97^o 0.025 0.040
Phase 1 Risks	Work in progress	Geotechnical studies for the underground detector	Cosmic ray backgrounds in a surface detector	Cosmic ray backgrounds in a surface detector

Comparison of Phase 1 Options

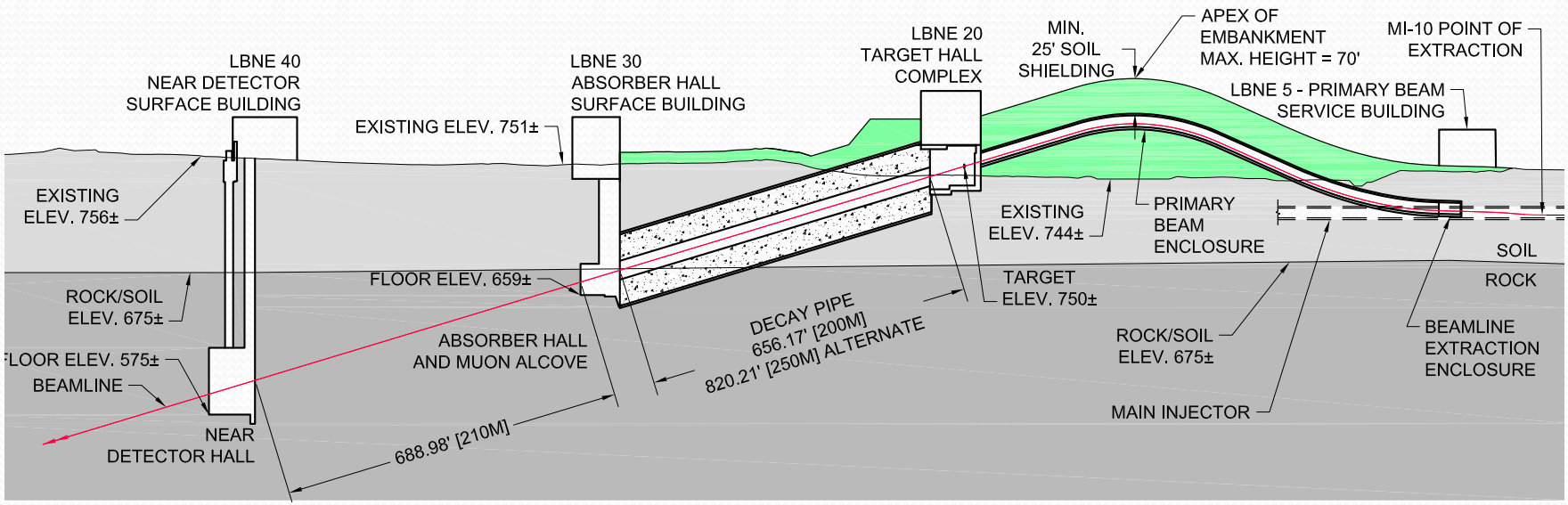
Homestake (10 kt)	Soudan (15 kt)	Ash River (30 kt)
• Excellent mass ordering reach. Good CPV reach with no *a priori* knowledge of ordering • Explicit reconstruction of oscillations due to long distance and broad band • Potential for underground physics, but would cost ~15% more. Possible delay until Phase 2 • Clear Phase 2 path. Beam upgradable to full Project-X intensity (>2 MW); underground lab available • Surface could be ~10% more expensive than other options. Possible CR muon risk on surface	• Broadest Phase 1 physics program. Includes both beam and underground physics • CR muon background risk mitigated • Weaker beam physics based program than other options due to shorter baseline and non-optimal on-axis beam • Existing beam, upgradable to ~1.1 MW with significant additional investment • Phase 2 could include additional mass at Soudan or Ash River	• Best Phase 1 CPV sensitivity for current value of θ_{13} in combination with T2K and NOVA results • Excellent mass ordering sensitivity in half the δ_{CP} range • No potential for underground physics in Phase 1 • Possible CR muon risk on surface • Existing beam, upgradable to ~1.1 MW with significant additional investment • Phase 2 could include additional mass at Soudan or Ash River

Conclusions

- An new intense neutrino beam from Fermilab will enable, *in a single experiment*, unequalled measurements of mass hierarchy, evidence of CP violation in the lepton sector, and the potential to reveal new physics
- Due to funding availability LBNE will be divided into phases
- The Steering Group, in its Interim Report, "strongly favored the option to build a new beamline to Homestake with an initial 10 kton LAr-TPC detector on the surface"; a decision is expected soon
- The LBNE Science Collaboration will continue to investigate phase 1 options for underground siting of the far detector and a fully capable near detector through other funding sources

Backup

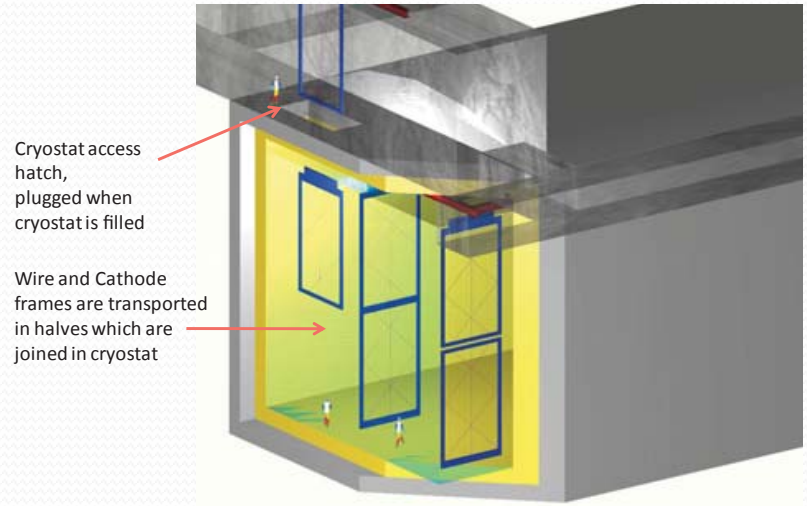
LBNE : Near Site Schematic



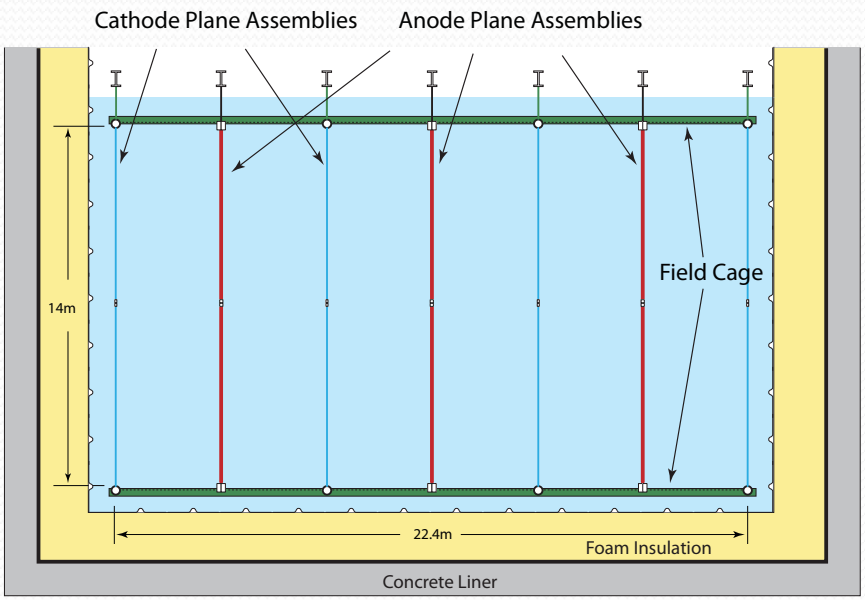
LBNE : Near Site Layout

LBNE 33 kt LAr TPC

installation of APAs inside the crypstat



Parameter	Value
Active (Fiducial) Mass	40 (33) kton
Number of Detector Modules (Cryostats)	2
Drift Cell Configuration within Module	3 wide $\times$ 2 high $\times$ 18 long drift cells
Drift Cell Dimensions	2 $\times$ 3.7 m wide (drift) $\times$ 7 m high $\times$ 2.5 m long
Detector Module Dimensions	22.4 m wide $\times$ 14 m high $\times$ 45.6 m long
Anode Wire Spacing	$\sim$5 mm
Wire Planes (Orientation from vertical)	Grid (0°), Induction 1 (45°), Induction 2 (-45°), Collection (0°)
Drift Electric Field	500 V/cm
Maximum Drift Time	2.3 ms



Steering Committee	
Young-Kee Kim, FNAL (Chair)	LBNE LOG (Lab Oversight Group) member
James Symons, LBNL	LBNE LOG (Lab Oversight Group) member
Steve Vigdor, BNL	LBNE LOG (Lab Oversight Group) member
Bob Svoboda, UC Davis	LBNE co-spokesperson
Kevin Lesko, LBNL	SURF (Sanford Underground Research Facility) head
Gary Feldman, Harvard	NOvA co-spokesperson
Mel Shochet, U.Chicago	Physics working group chair, Former HEPAP chair
Mark Reichanadter, SLAC	Engineering/Cost working group chair DOE DUSEL review committee co-chair
Charlie Baltay, Yale	P5 chair
Jon Bagger, JHU	Former HEPAP deputy chair
Ann Nelson, UW, Seattle	HEPAP member

Steering Committee: Ex-officio members	
Andy Lankford, UC Irvine	HEPAP chair, DUSEL NRC study chair
Steve Ritz, UC Santa Cruz	PASAG (Particle Astrophysics Scientific Assessment Group) chair, Fermilab PAC member
Jay Marx, Caltech	DOE DUSEL review committee co-chair
Pierre Ramond, U. Florida	DPF chair
Harry Weerts, ANL	DOE Intensity Frontier Workshop co-chair
JoAnne Hewett, SLAC	DOE Intensity Frontier Workshop co-chair
Jim Strait, FNAL	LBNE Project Manager Engineering/Cost working group deputy chair
Pier Oddone, FNAL	Director, Fermilab
Susan Seestrom, LANL	LBNE LOG (Lab Oversight Group) member

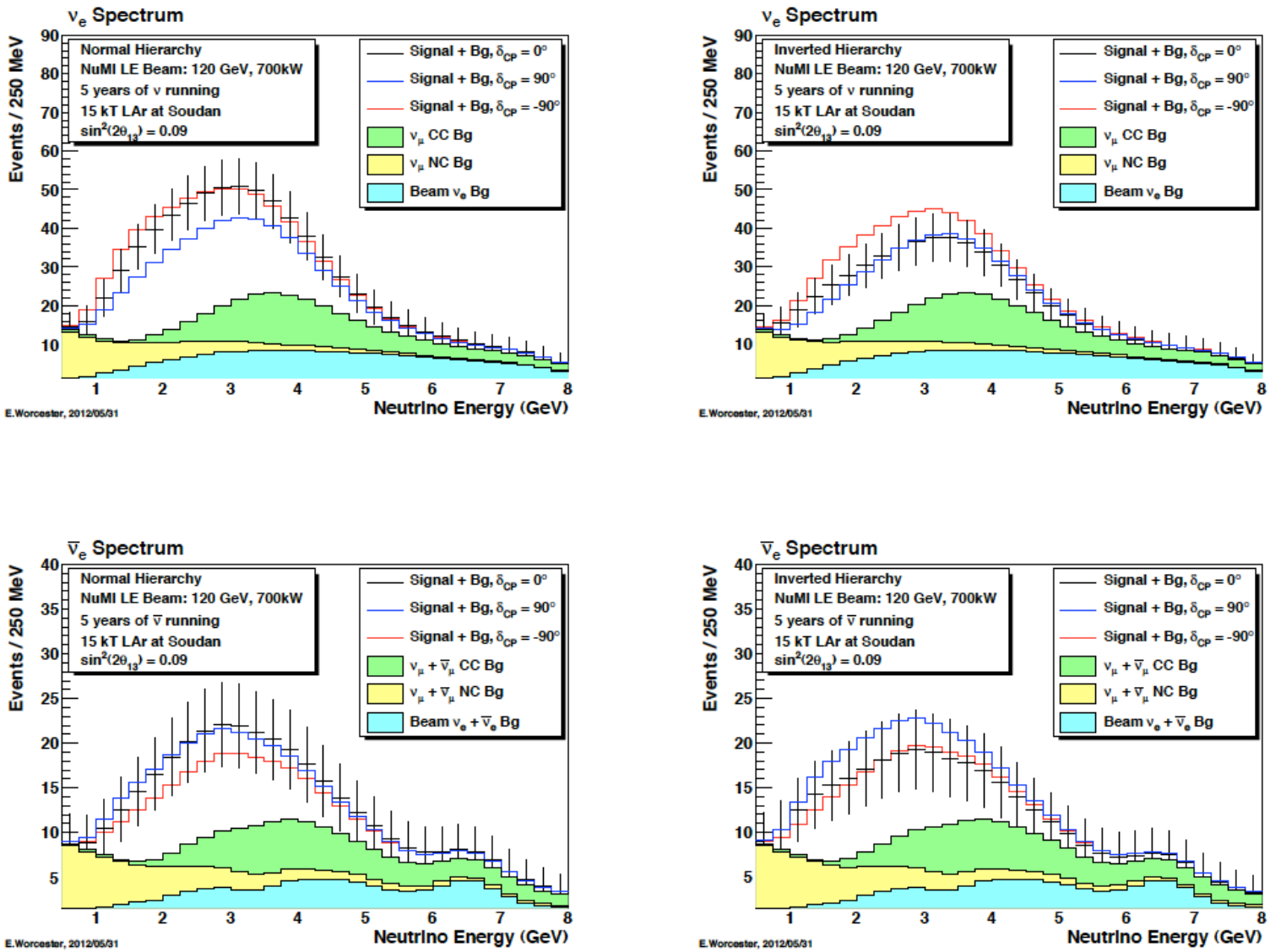


Figure 2: Spectra for a 15 kT LAr detector at Soudan

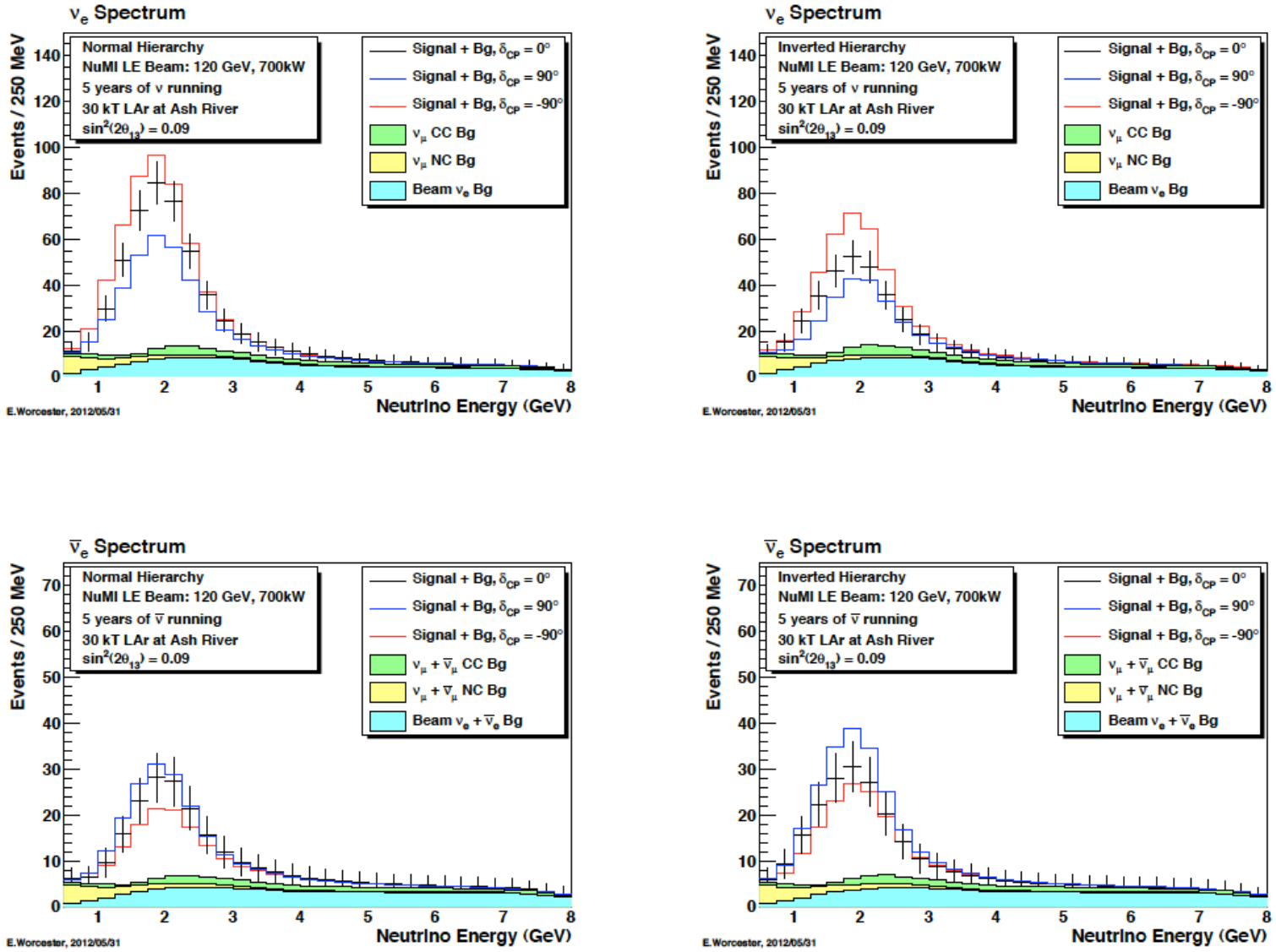
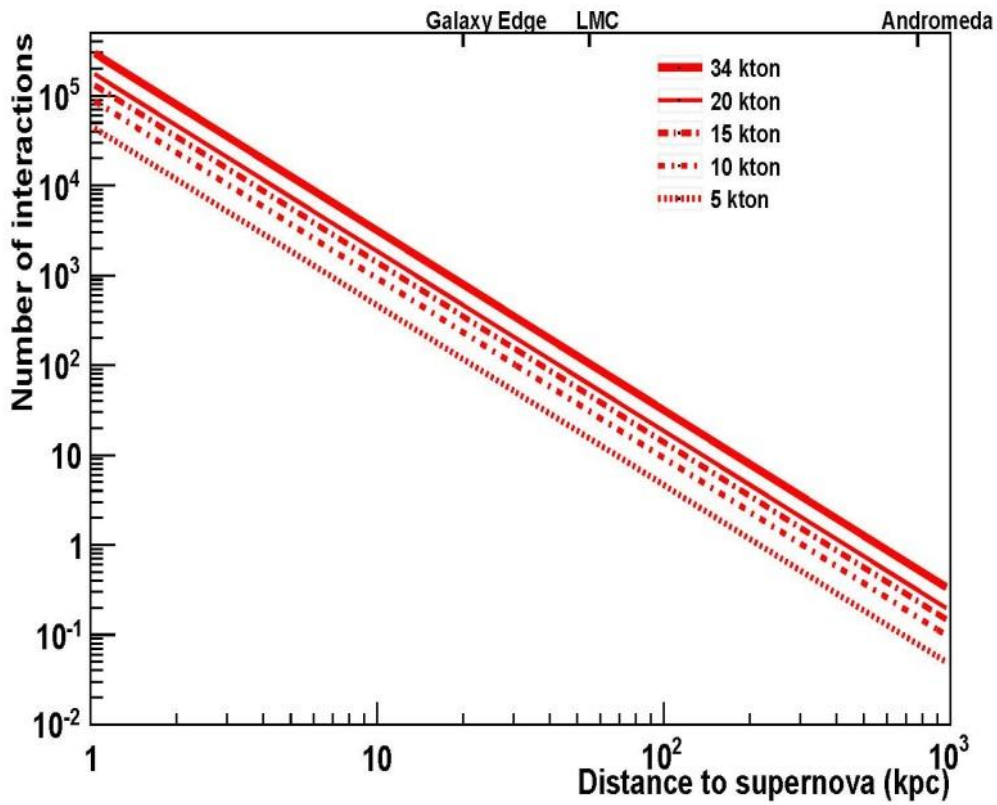


Figure 3: Spectra for a 30 kT LAr detector at Ash River

Supernova Burst Neutrinos

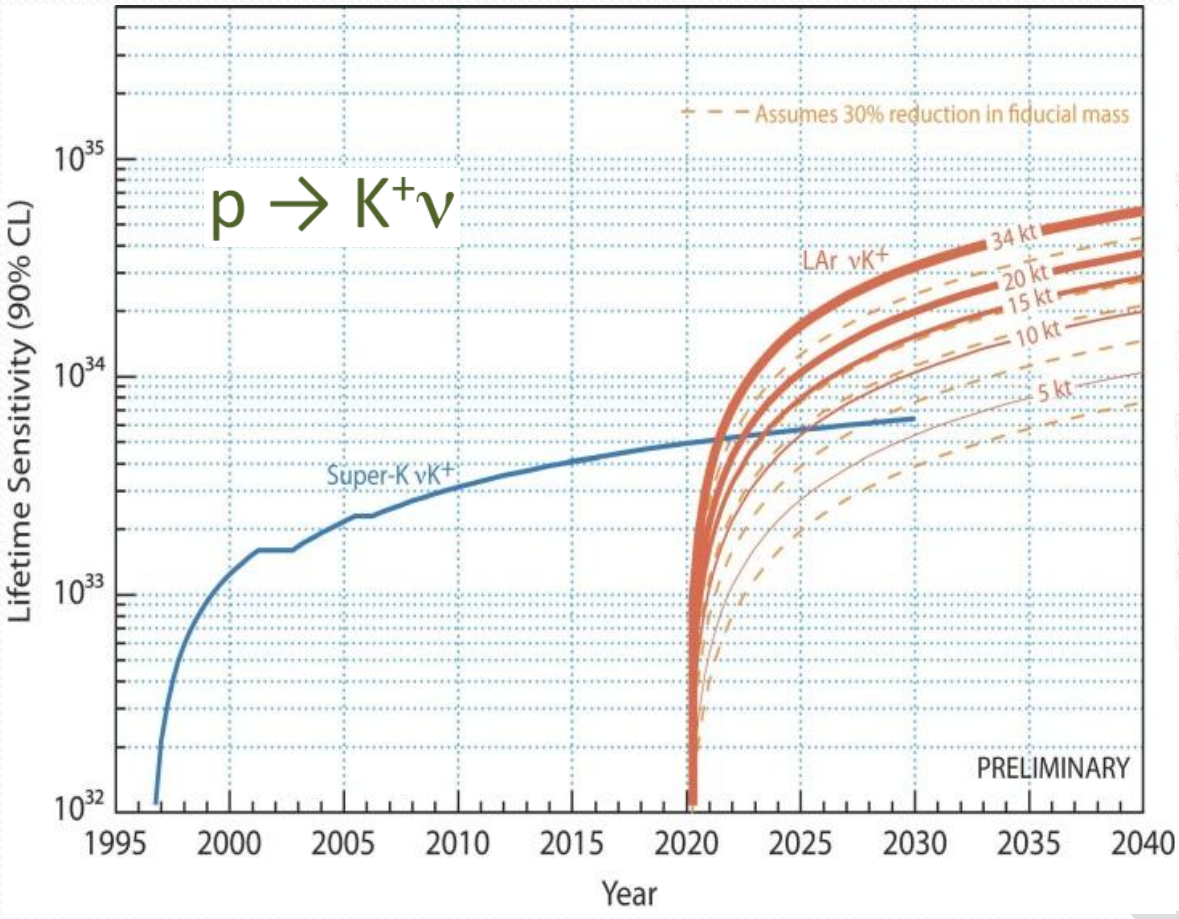
- When a star's core collapses ~99% of the gravitational binding energy of the proto-neutron star goes into ν's of *all flavors with ~MeV energies*
- # interaction from SN at galactic core (10 kpc)

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



- **SN 1987A observation of ~20 events → ~800 publications!**

LBNE Proton Decay Sensitivity



- Liquid Argon TPC significantly better than WC for kaon modes
  - becomes especially interesting if SUSY discovered at LHC