Prospects for Deep Underground Science in the US

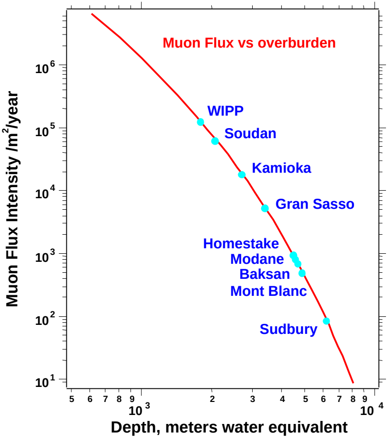
Neutrino Telescopes 2011, Venice, Italy. March 15-18, 2011

Mary Bishai (for DUSEL & LBNE collaborations)
Brookhaven National Laboratory

March 17, 2011

Outline

UNDERGROUND SCIENCE AT THE HOMESTAKE MINE



History of Science at the Homestake Mine, SD

1967: Ray Davis from BNL installs a large detector, containing 615 tons of tetrachloroethylene (cleaning fluid), 1.6km underground in Homestake mine, SD.

Ray Davis

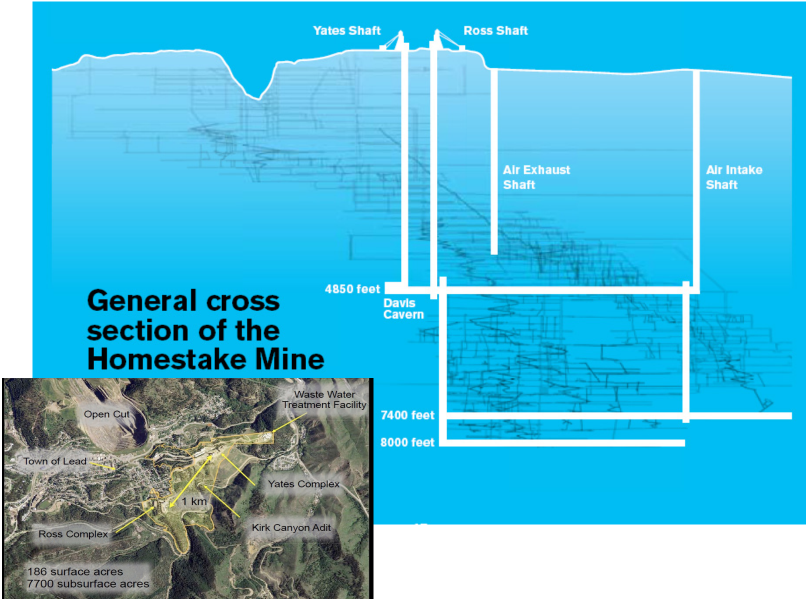
1. $\nu_e^{sun} + ^{37}CL \rightarrow e^- + ^{37}Ar$, $\tau(^{37}Ar) = 35$ days.
2. Number of Ar atoms $\approx$ number of ν_e^{sun} interactions.

Results: 1969 - 1993 Measured 2.5 $\pm$ 0.2 SNU (1 SNU = 1 neutrino interaction per second for 10^{36} target atoms) while theory predicts 8 SNU. This is a ν_e^{sun} deficit of 69%.

Solar ν_e disappearance $\Rightarrow$

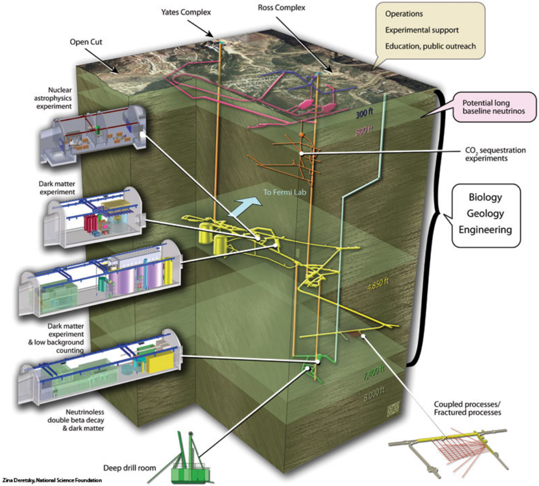
first experimental hint of oscillations

Cross-section of the Homestake Mine



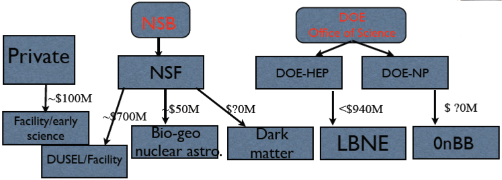
Deep Underground Science and Engineering Laboratory

July 10, 2007: the National Science Foundation (NSF) selected the University California-Berkeley to produce a techincal design for DUSEL at Homestake Mine, SD



Current Status of Homestake DUSEL

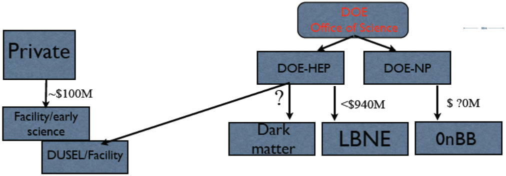
DUSEL funding profile pre Dec 2010



NSF: National Science Foundation, NSB: National Science Board, DOE: US department of Energy, HEP: High Energy Physics, NP: Nuclear Physics

Current Status of Homestake DUSEL

After NSF decision:



NSF: National Science Foundation, NSB: National Science Board, DOE: US department of Energy, HEP: High Energy Physics, NP: Nuclear Physics

Dec 2010: NSB recommended terminating the 2011 NSF funds for DUSEL facility development. Patricular concern about the funding model in which NSF bears most of the costs for the facility.

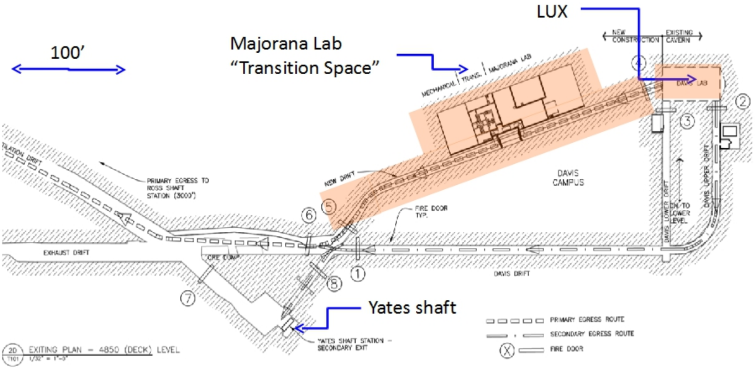
NSF has agreed to maintain funding for Homestake dewatering and associated costs till end of FY11..

Mar 2010: *DOE establishes review committee to advise on how or if the DOE should pursue the Homestake site as a laboratory for the program in neutrino physics, double beta decay, and dark matter.*

Input from the community critical. Decision by May 2010 .

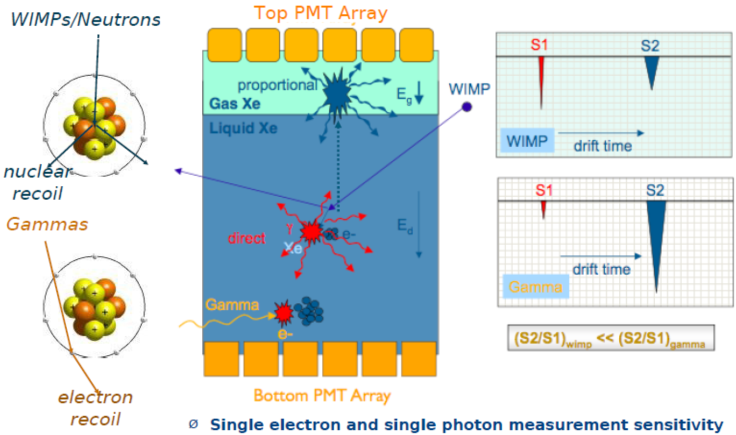
DOE HEP continues to pursue LBNE independent of DUSEL

EARLY SCIENCE AT SANFORD LAB: Dark Matter and $0\nu\beta\beta$



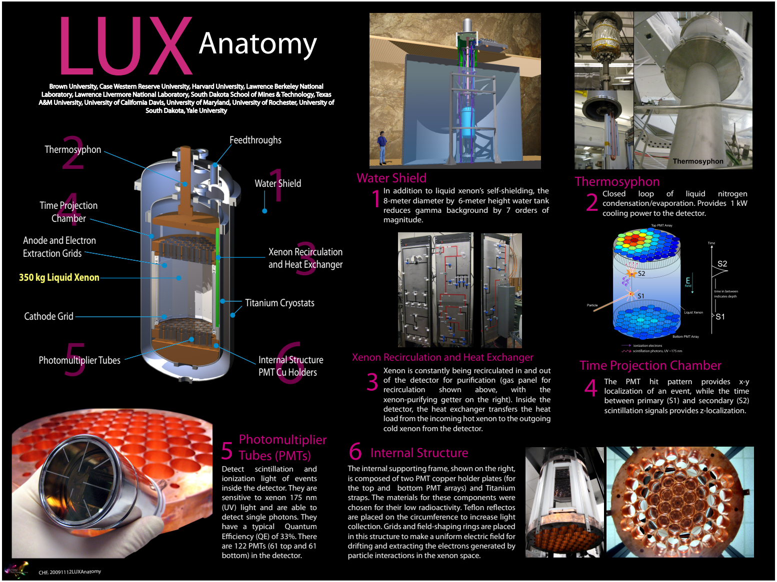
Detecting WIMPS with Xenon Detectors

see talk by E. Aprile



- Single electron and single photon measurement sensitivity
- > 99.5% ER rejection via Ionization/Scintillation ratio (S2/S1)
- 3D event-by-event imaging with millimeter spatial resolution

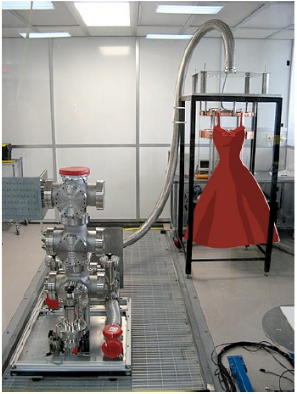
Large Underground Xenon (LUX)



The LUX Detector at Sanford Lab

from Carlos Hernandez Faham

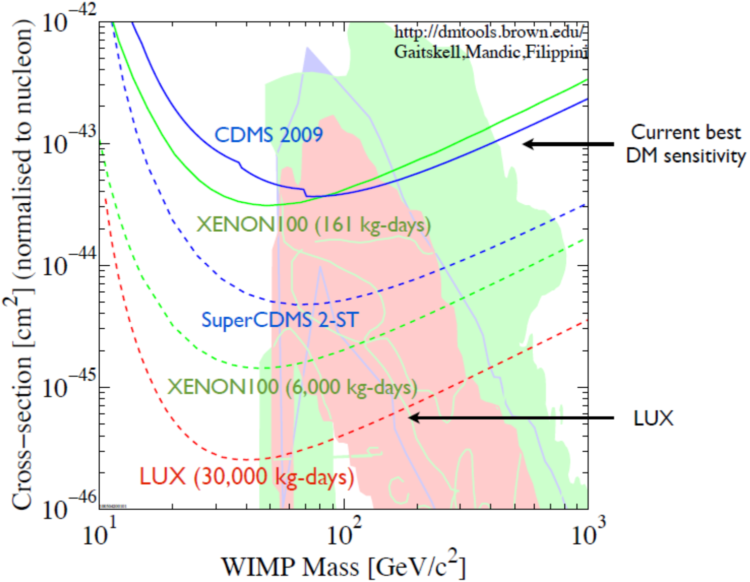
The dress rehearsal



- Full-scale LUX assembly and deployment
- **Duplicate** of the underground layout
  - Smaller water tank (3 m)
  - Cleanroom class 1,000 (will be relocated underground)
- LUX operations since November 2009

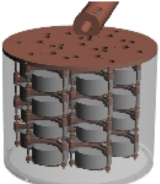
LUX deployed underground in 2011

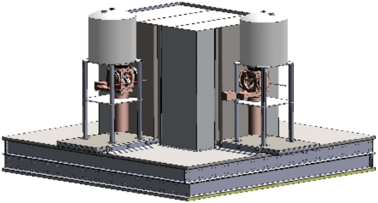
LUX Sensitivities



$0\nu\beta\beta$ at Homestake: The MAJORANA Demonstrator

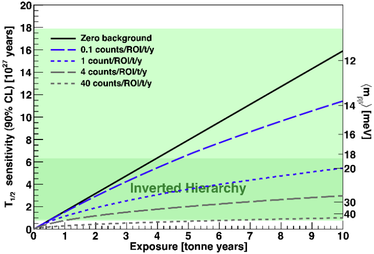
Goal: demonstrate background low enough for a tonne Ge Expt:





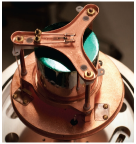
The MAJORANA demonstrator:

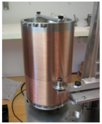
- **Up to 30kg of 89% enriched Ge crystals. Point-contact detectors.**
- **Low background cryostat from ultra-clean electroformed Cu**
- **Compact low-background passive Cu and Pb shield with active muon veto**
- **Go deep: will be located at 4850' level in Sanford Lab.**



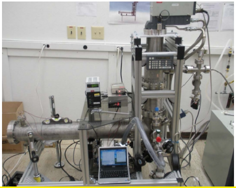
MKD electroforming lab completed at 4850' level

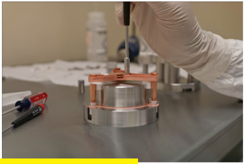
MJD Progress (2)





- **1.07** Successful test of detector - MJD front-end, cable (full 42” parylene cable).
- **1.07** First batch of 19 natGe detectors UG.
- **1.08** Operation of thermosiphon
- **1.08** Fabrication, cleaning, assembly of prototype string parts
- **1.09** Detailed shield and glove box designs.
- **1.10** Revised Gretina and Struck digitizer firmware, testing underway.
- **S4** Detailed depth justification document.





2 cryostats and up to 7 strings of enrGe deployed by 2014

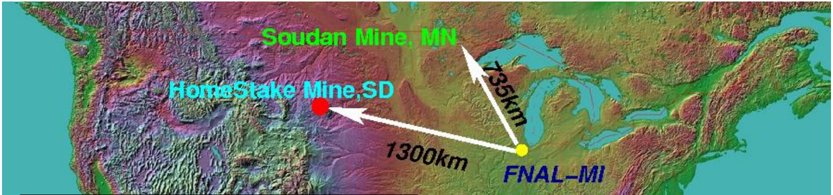
Status of DUSEL Stakeholders from Kevin Lesko

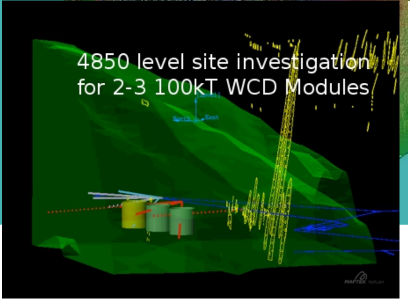
- With the $4M NSF award for FY2011:
  - SDSTA should be able to maintain critical on-site activities to preserve the site through September 2011
  - SDSTA will decide on Davis Campus outfitting contract ($7.5M) at the March 2011 Board meeting: positive outcome is anticipated
  - Outfitting the Davis Campus will enable LUX and Majorana Demonstrator to move into the DLM and DTA in fall 2011
  - On-going Early Science Program is anticipated to continue

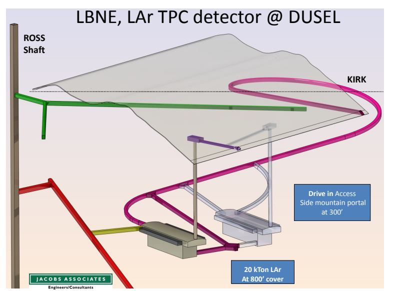
SDSTA: South Dakota Science and Technology Authority, created by the state of SD in 2004 to convert Homestake Mine into a research Laboratory.

The Long-Baseline Neutrino Experiment

A Long-Baseline Neutrino Experiment (LBNE) from Fermilab to large scale neutrino detectors at Homestake is now being designed. CDR late 2011.







The LBNE Collaboration

Institutions: Alabama, ANL, Boston, BNL, Caltech, Cambridge, Catania/INFN, Chicago, CU-Boulder, Colorado State, Columbia, Crookston, Dakota State, UC Davis, Drexel, Duke, Duluth, FNAL, Hawaii, Indian Universities, Indiana, Iowa State, IPMU/Tokyo, UC Irvine, Kansas State, LANL, LBL, LLNL, LBL, UCLA, London-UCL, Louisiana State, Maryland, Michigan State, Minnesota, MIT, NGA, New Mexico, Notre Dame, Oxford, Pennsylvania, Pittsburgh, Princeton, RPI, Rochester, SDMST, S. Carolina, South Dakota State, Syracuse, Tennessee, Texas, Tufts, Virginia Tech, Washington, Wisconsin, Yale

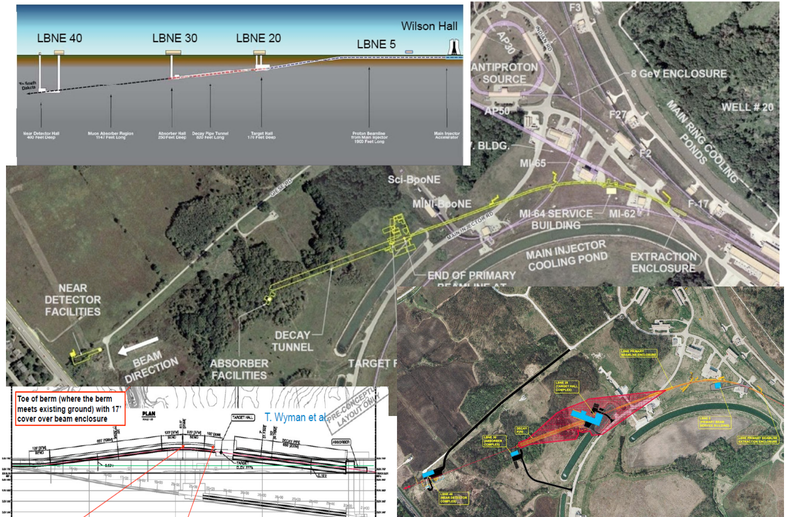
55 institutions, $\sim$ 280 members from 5 countries.

The LBNE Beam at Fermiab

see S. Parke's talk

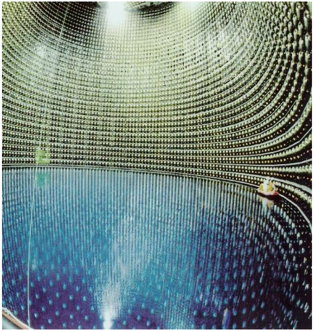
The LBNE project will start with a 700kW beam with 80-120 GeV p

In the future will profit from the 2.3 MW Project X beam

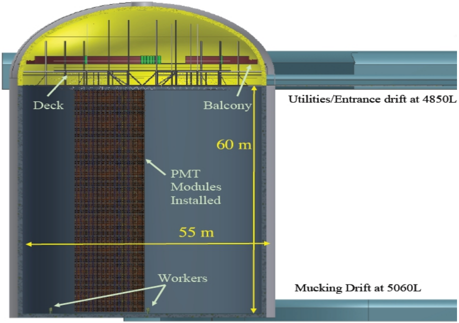


LBNE Detectors: Water Cerenkov

SuperKamiokande : 50kt



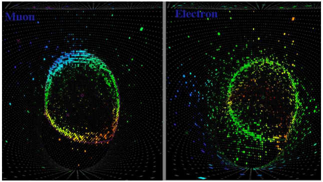
LBNE WCD $\sim$ 120 kt module X 2



100kt (fiducial), $\approx$ 55m diameter, $\approx$ 60m height, 30K 10-12" HQE PMTs (15% coverage)

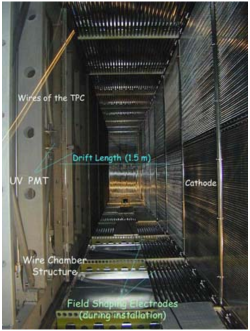
Known technology 3 $-$ 4$\times$ SuperK

Large NC π^0 backgrounds, low eff.

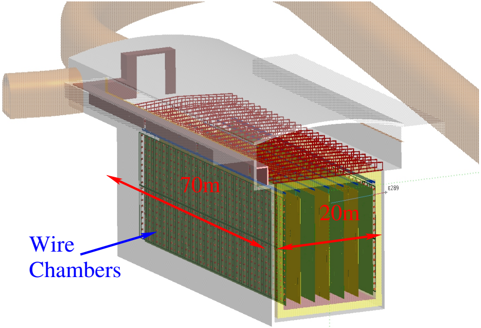


DUSEL Detectors: Liquid Argon TPC

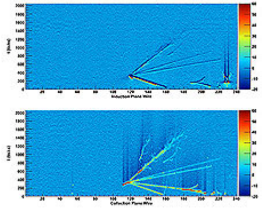
ICARUS : 0.6kt



LBNE LAr : 17kt module X 2



ArgoNeuT (175 litre) prototype in the NuMI beam $\longrightarrow$



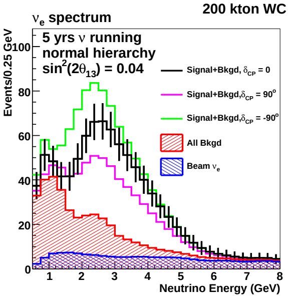
High efficiency and purity

Requires 30$\times$ scale-up - challenging.

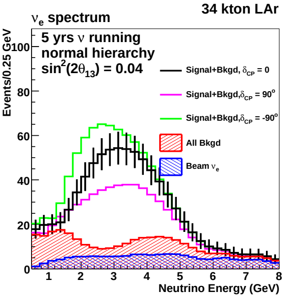
LBNE spectra and event rates

On-axis wide-band beam (NuMI focusing). Water Cerenkov response is based on the SuperK MC. LAr is modeled as a near-perfect detector. *Exposure is 3.5 MW. yr ν with* $\mathbf{\sin^2 2\theta_{13} = 0.04}$:

200 kt WCD



34 kt LAr



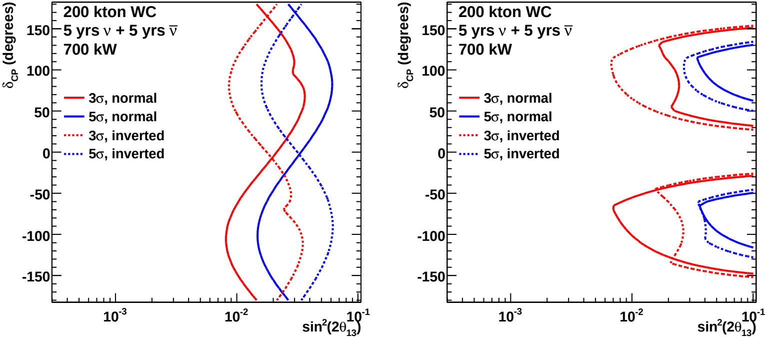
Interaction rates per 100kT.MW.yr ($0.5 < E_\nu < 20$ GeV)

ν_μ CC	ν_μ CC osc	ν_e CC beam	$\nu_\mu \rightarrow \nu_e$ CC	$\nu_\mu \rightarrow \nu_\tau$ CC
29K	11K	260	560	140

Measurements of CPV and MH in LBNE

200 kt WCD detector and 5 yrs of ν + 5 yrs of $\bar{\nu}$ running with 700kW:

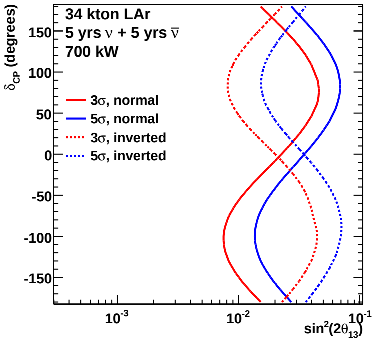
Mass Hierarchy **CP Violation**

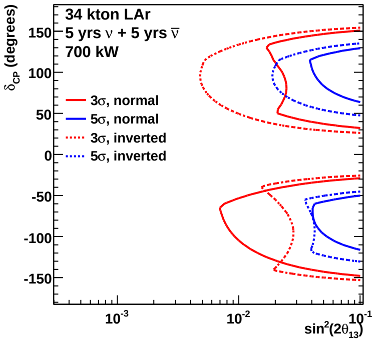


Measurements of CPV and MH in LBNE

34 kt LAr detector and 5 yrs of ν + 5 yrs of $\bar{\nu}$ running with 700kW:

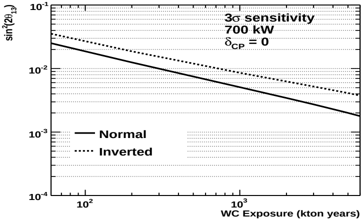
Mass Hierarchy **CP Violation**



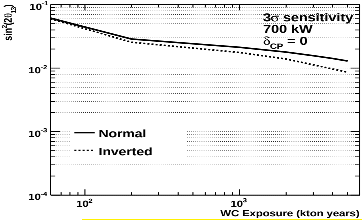


Ultimate ν Oscillation Sensitivities

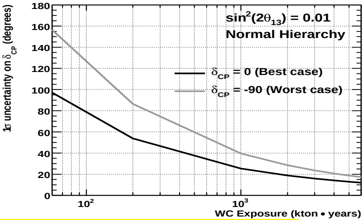
$\sin^2 2\theta_{13}$ Sensitivity at 3σ



MH Sensitivity at 3σ

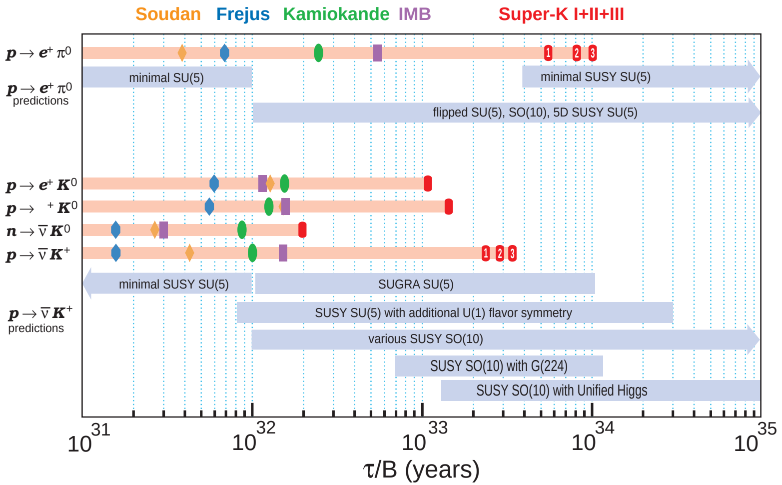


Resolution of δ_{cp}



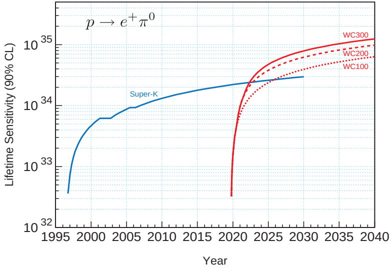
Sensitivity to MH and CPV at 3σ for $\sin^2 2\theta_{13} \geq 0.01$

Proton Decay Limits

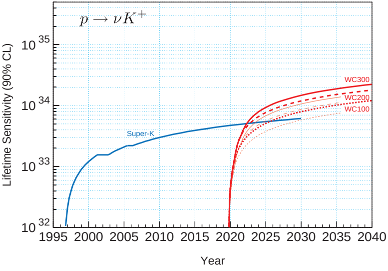


Proton Decay at LBNE

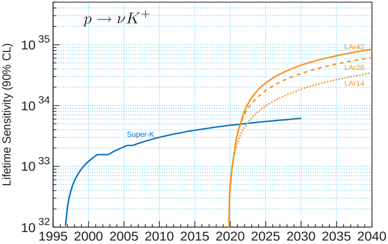
$p \longrightarrow e^+\pi^0$ WCD



$p \longrightarrow K^+\nu$ WCD

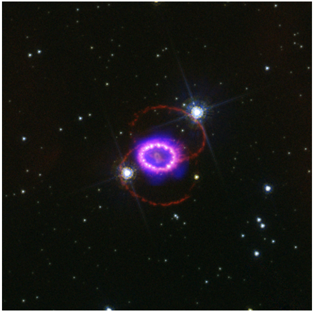


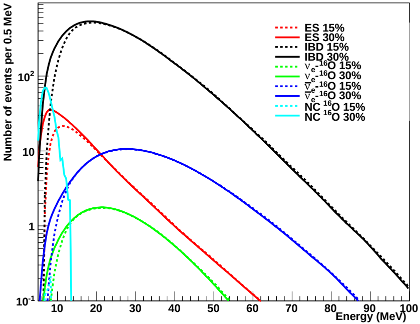
$p \longrightarrow K^+\nu$ LAr



SuperNova Burst Neutrinos

SN ν from 10 kpc, Rates in 100 kt WCD.





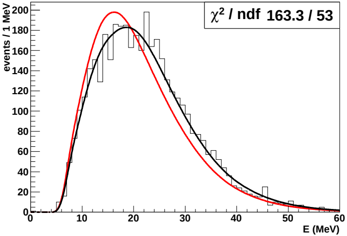
Channel	LAr 17kt Events
$\nu_e + ^{40}\mathrm{Ar} \rightarrow e^- + ^{40}\mathrm{K}^*$	1154
$\bar{\nu}_e + ^{40}\mathrm{Ar} \rightarrow e^+ + ^{40}\mathrm{Cl}^*$	97
$\nu_x + e^- \rightarrow \nu_x + e^-$	148
Total	1397

Channel	WCD 100kt Events
$\bar{\nu}_e + p \rightarrow e^+ + n$	27116
$\nu_x + e^- \rightarrow \nu_x + e^-$	868
$\nu_e + ^{16}\mathrm{O} \rightarrow e^- + ^{16}\mathrm{F}$	88
$\bar{\nu}_e + ^{16}\mathrm{O} \rightarrow e^+ + ^{16}\mathrm{N}$	700
$\nu_x + ^{16}\mathrm{O} \rightarrow \nu_x + ^{16}\mathrm{O}^*$	513
Total	29284

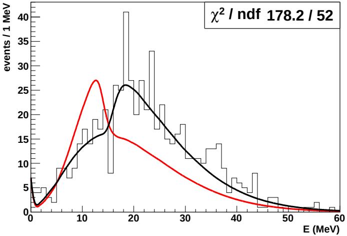
SNB Neutrino Spectra and the MH

The SR neutrino spectra from 10 kpc observed in the LBNE detectors for normal hierarchy and the fit to the opposite hierarchy:

100 kt WCD - mostly $\bar{\nu}_e$

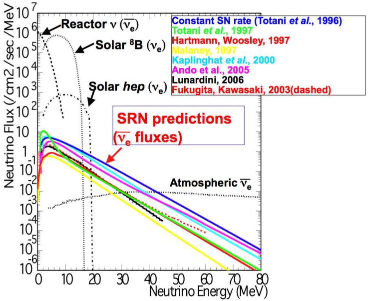


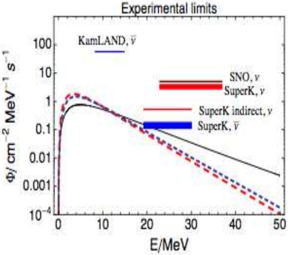
17 kt LAr - mostly ν_e



Some ability to distinguish the MH - backgrounds yet to be evaluated

SuperNova Relic Neutrinos





Reference Configuration	Expected Annual SRN Signal (events/year)	Expected Annual Background (events/year)	Years of LBNE Data Needed for a 3.0-σ Signal Assuming Maximum/Minimum SRN Flux
300kt WCD 30%	5 – 52	320	1.3/144
300kt WCD 30% + Gd	13 – 74	64	0.13/0.9
100kt WCD + 100kt WCD-Gd + 17kt LAr	5 – 39	114	0.35/3
100kt WCD-Gd + 34 kt LAr	4 – 27	21	0.32/3

Summary and Conclusions

- **Using funding from the state of South Dakota, Denny Sanford, and the NSF, an underground laboratory has been established in Homestake Mine, the deepest mine in the western hemisphere.**
- **Although NSF has withdrawn 2011 financing for developing the DUSEL Facility at Homestake mine, funding for dewatering and associated costs will continue till end of FY11.**
- **Early deep science such as LUX and Majorana Demonstrator is already proceeding at Sanford Laboratory and is anticipated to continue.**
- **DOE HEP continues to pursue LBNE independent of DUSEL. The conceptual design of LBNE will be completed by end of 2011.**
- **The LBNE project will significantly improve on existing neutrino oscillation experiments. Sensitivity to CPV will improve by an order of magnitude over existing experiments.**
- **The LBNE deep underground detectors will significantly improve proton decay limits, SuperNova burst and relic neutrino sensitivities**