Future Long Baseline Neutrino Experiments

Physics Department Symposium, 10/2/2007

Mary Bishai for the BNL Neutrino Working Group *

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* $\approx$ **50 members from BNL Physics, CAD, Chemistry, and several Universities.**

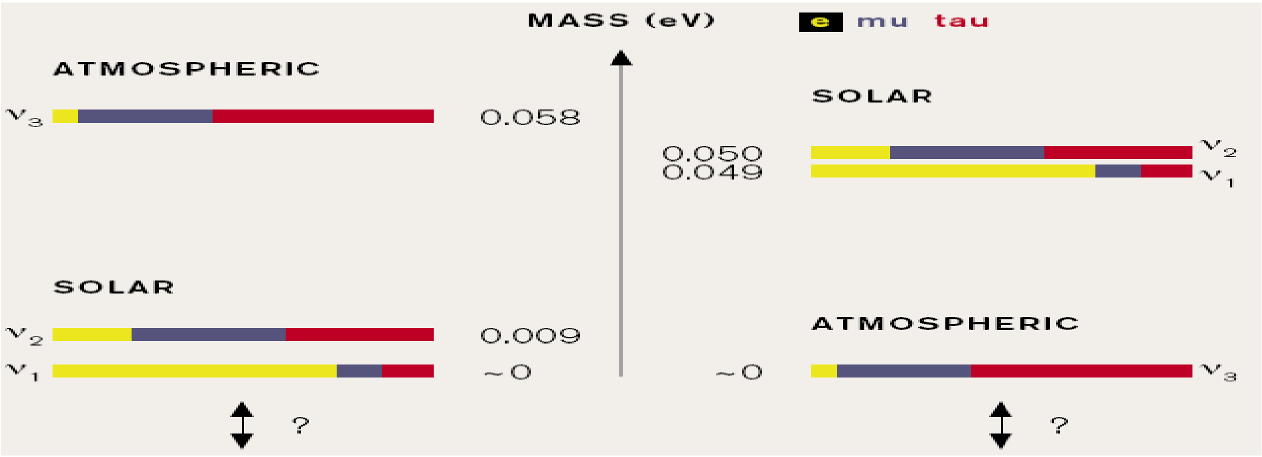
Group Leaders: Milind Diwan, Bill Marciano.

Neutrino Mysteries...

1) Why does the neutrino have mass, why so small? *Beyond the SM physics.*

2) What is the mass hierarchy (sign of Δm^2_{31})?

Absolute neutrino mass can only be measured in $\beta\beta$ decay if hierarchy is normal



Normal(?) Inverted (?)

3) How small is $\sin^2\theta_{13}$?: The amount of ν_e in ν_3 is unknown; $\leq$ 2.5% at 90% C.L. *Direct link to GUT scale physics*

4) IS CP VIOLATED IN THE NEUTRINO SECTOR?: If $\theta_{13} \neq 0 \& \delta_{cp} \neq 0, \pi$ then CP is violated in the neutrino sector.

A well designed long baseline accelerator ν expt. can address 2), 3), 4)

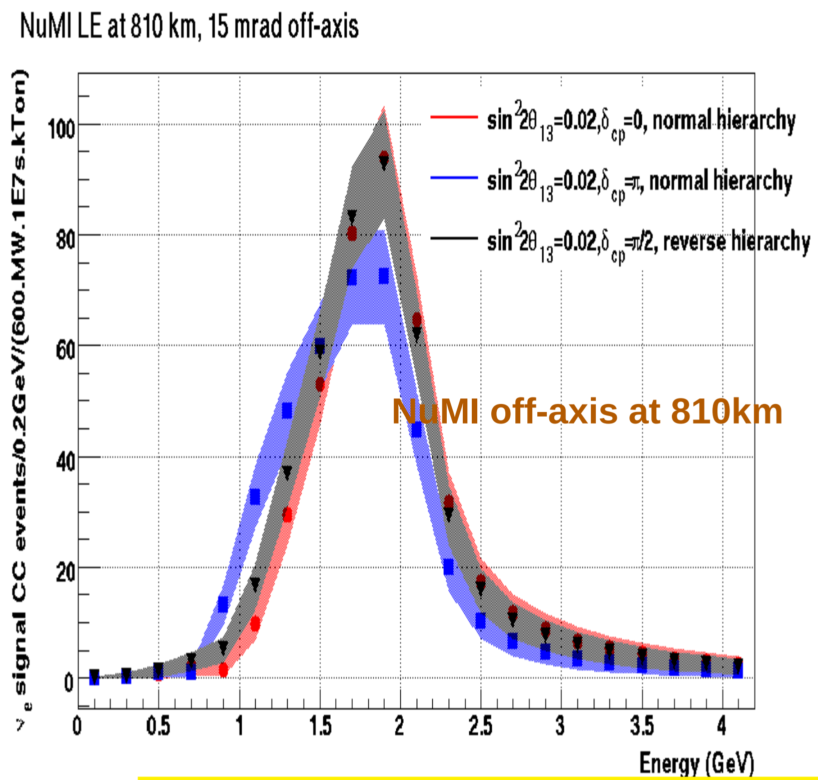
Searching for $\nu_\mu \rightarrow \nu_e$

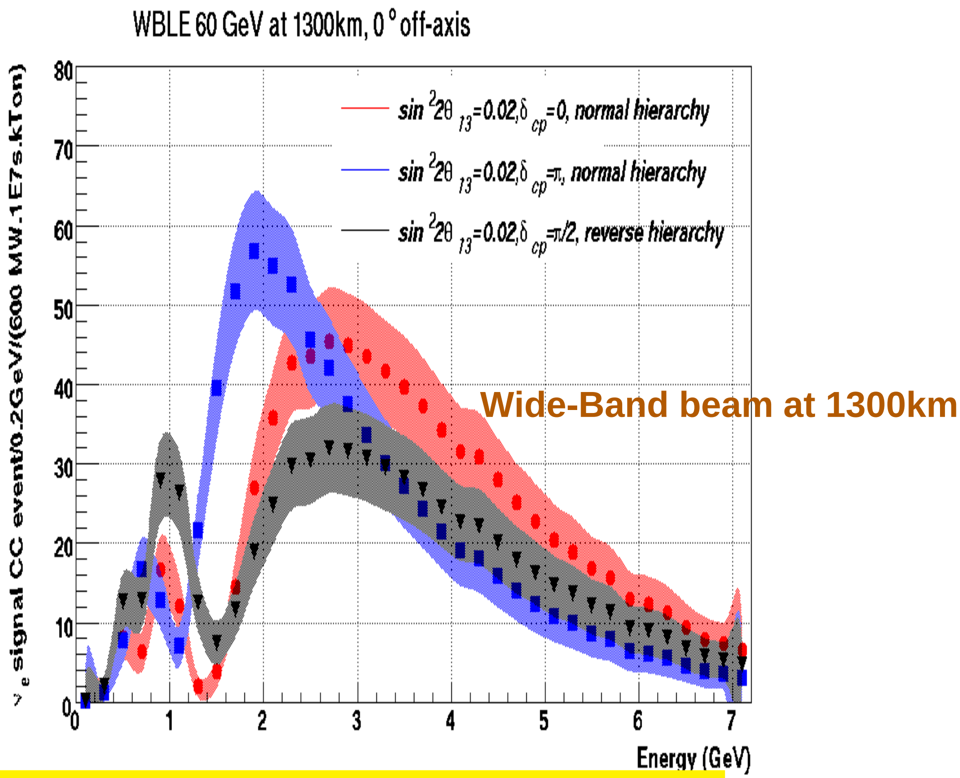
Sensitive to δ_{cp}, θ_{13} and the mass hierarchy:

Assuming an exposure of 350 kT.MW.yr, no detector effects, $P(\nu_\mu \rightarrow \nu_e) \sim 1\%$:

—- $\sin^2 2\theta_{13} = 0.02$, $\delta_{cp} = 0$, normal hierarchy, —- $\sin^2 2\theta_{13} = 0.02$, $\delta_{cp} = \pi$, normal hierarchy

—- $\sin^2 2\theta_{13} = 0.02$, $\delta_{cp} = -\pi/2$, reverse hierarchy

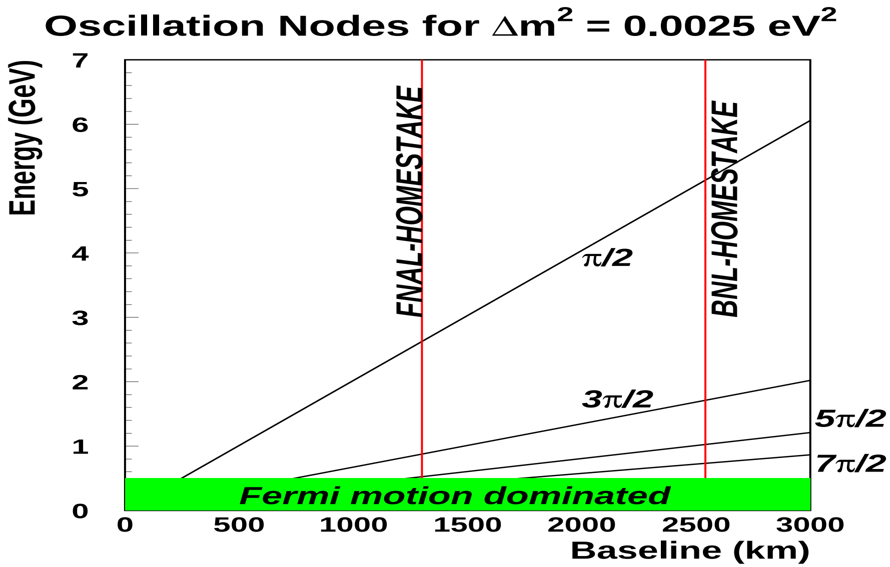




Wide-band beam spectral information = resolves degeneracies

Why a long baseline?

Long baseline $\longrightarrow$ more oscillation nodes observed. Oscillation at higher ν energies $\longrightarrow$ bigger interaction cross-sections

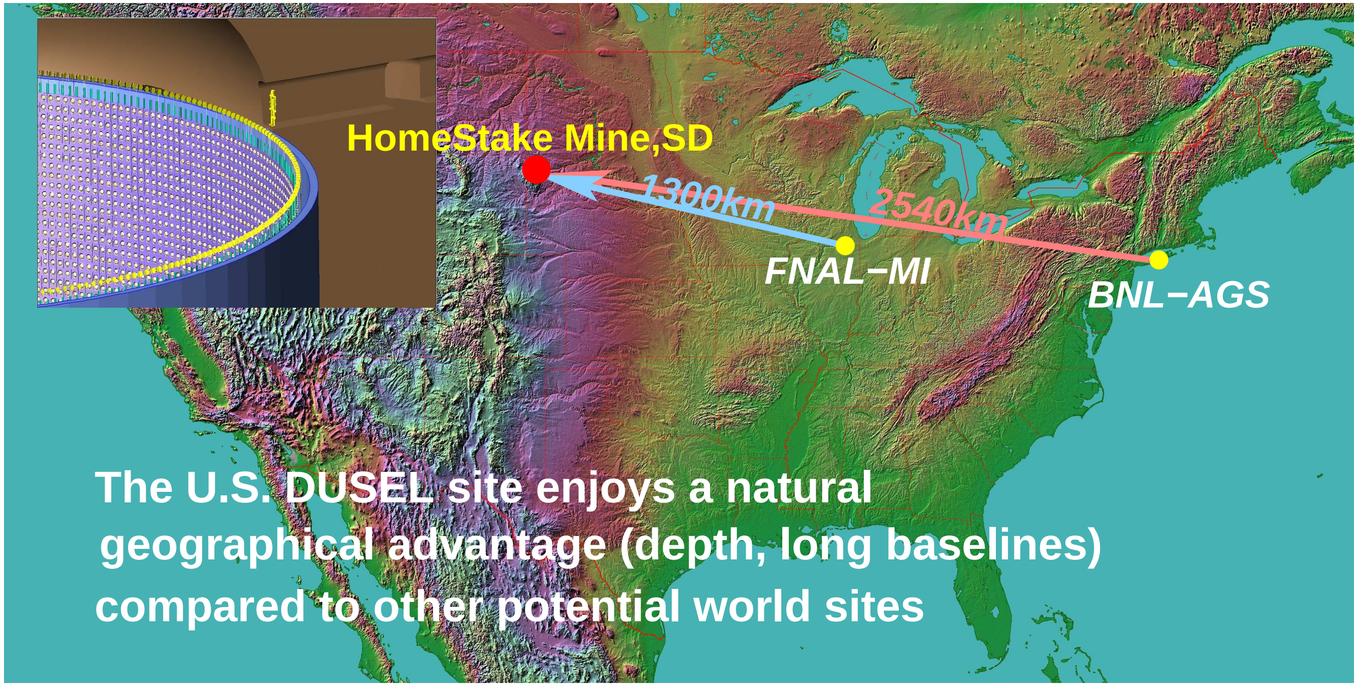


Baseline, L, (km)

Longer flight paths = larger matter effects for resolving mass hierarchy and increasing sensitivity to new physics.

CP asymmetry $\sim L$, but flux $\sim L^{-2}$, $\Rightarrow$ sensitivity to CPV is independent of L (hep-ph/0108181). BUT longer L = better S/B for CP violation.

BNL Experimental Goals



Develop very large (~ 500 kT) multipurpose detectors and mega-watt class conventional neutrino beams to be used for very long baseline neutrino experiments directed to the site of NSF's Deep Underground Science and Engineering Laboratory (DUSEL).

U.S. Long Baseline ν Study

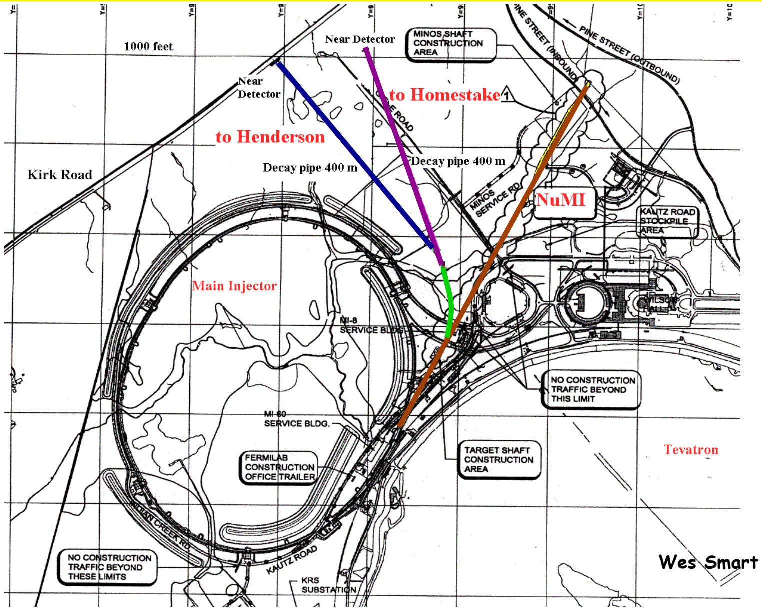
- **Sally Dawson (BNL) and Hugh Montegomery (FNAL) launched a joint study in late 2005.** *Milind Diwan (BNL) and Gina Rameika (FNAL) co-leaders.*
- **On March 3, 2007, the Neutrino Advisory Group (NuSAG) of HEPAP/NSAC was charged with addressing the next generation neutrino beam and detectors. NuSAG requests input from study group.**
- **Extensive documentation at http://nwg.phy.bnl.gov/fnal-bnl.**
- *Final report released May, 2007.* **BNL-77973-2007-IR, FNAL-0801-AD-E, arXiv:0705.4396.**

  The Study results heavily utilized in the preparation of the NuSAG report.

  Released July 27th, 2007 at http://www.science.doe.gov/hep/hepap_report.shtm
- **Numerous presentations by M. Diwan, M. Dierckxsens, M. Bishai, and B. Viren in the U.S., Europe, and Japan.**

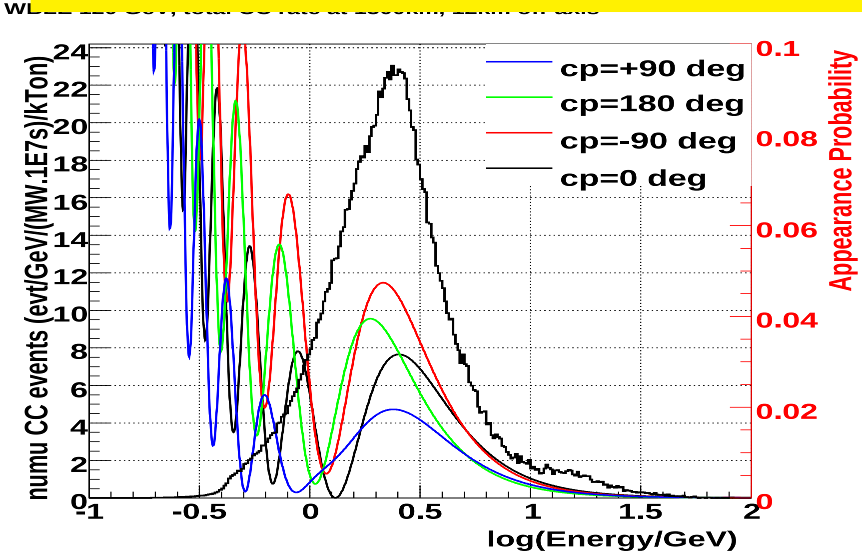
Highlights from The Study Report

A DUSEL beamline can be sited at FNAL



Established flux, event rates from a

120 GeV FNAL-MI wide-band beam



A 300kT water Cerenkov detector

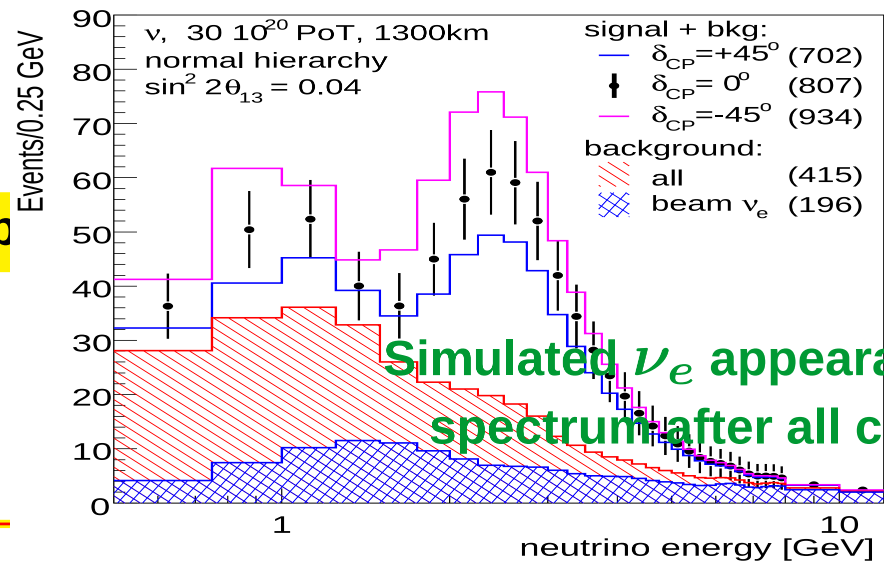
(known technology, known cost)

can meet the physics goals of this exp

120 GeV wide-band @ 1300km

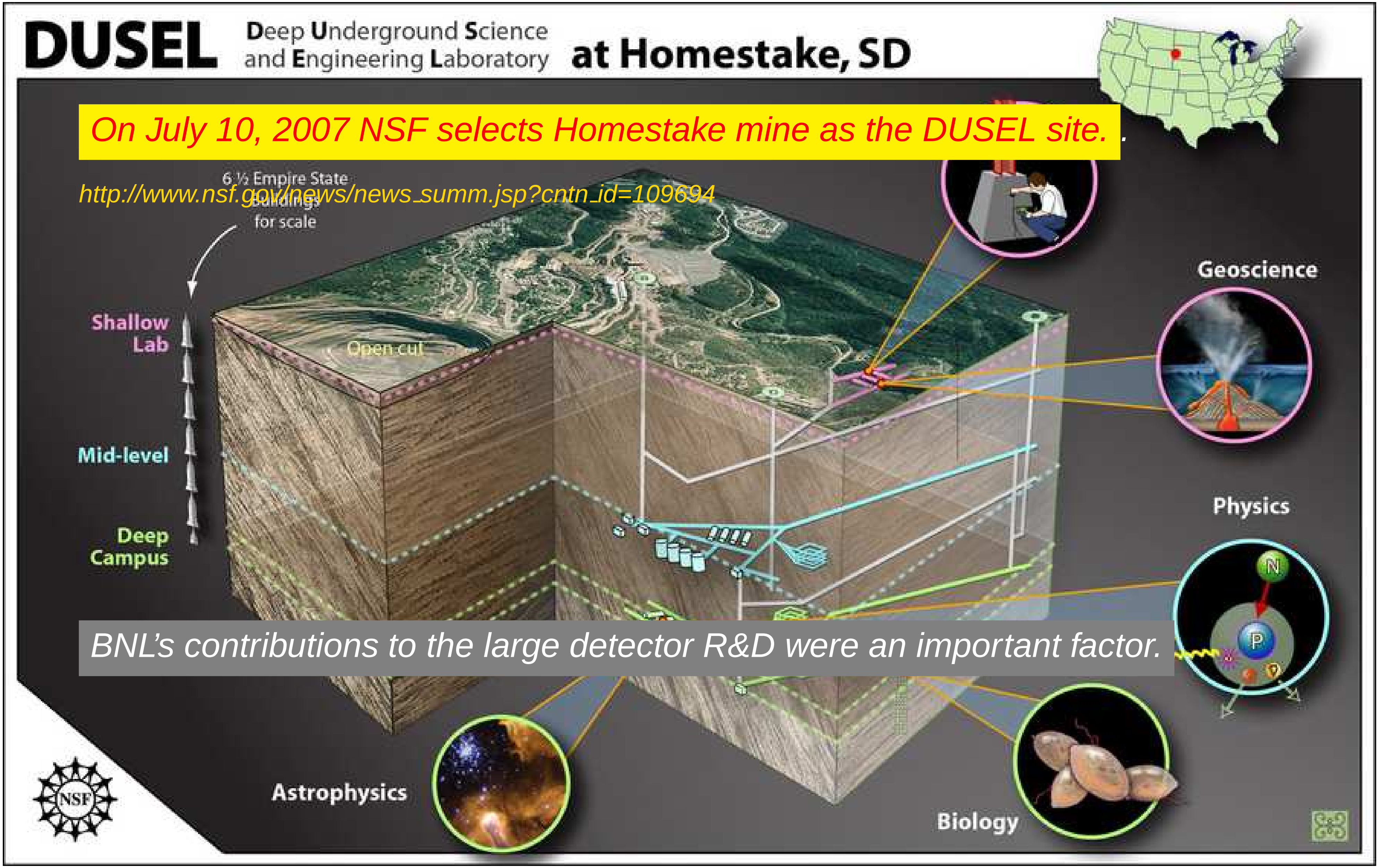
1.2 MW beam $\times$ 3 yrs

$P(\nu_\mu \rightarrow \nu_e) = 2\% \longrightarrow$



Simulated ν_e appearance spectrum after all cuts

DUSEL Process & Status



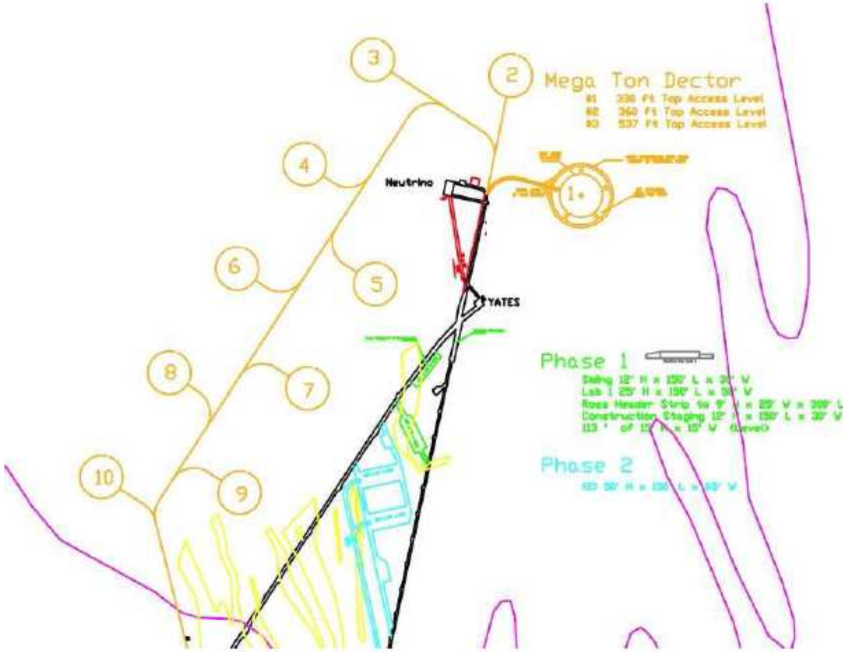
On July 10, 2007 NSF selects Homestake mine as the DUSEL site.

http://www.nsf.gov/news/news_summ.jsp?cntn_id=109694

BNL's contributions to the large detector R&D were an important factor.

Homestake Detector Proposal

BNL-76798-2006-IR



Modular detector system deployed at the 4850 ft level,

Each module is a 100kT fiducial Water Cerenkov (53m dia/h) with 25% photodetector coverage (12" PMTs). Initial deployment of 3 modules, upgradable to 10.

Cosmic rate is $\sim$ 0.1Hz/Module

Cost estimate: $115M/module

6 yrs construction for first 100 kT; 8 yrs for 300 kT.

List of Accomplishments

- **The basic idea of sending a high intensity wide-band conventional neutrino beam to a very large underground detector $>$ 1000km has now been accepted** *as the best option for searching for CP violation in the neutrino sector and resolving the mass hierarchy.*
- **BNL was a key participant in the DUSEL process as a proponent of Homestake DUSEL. NSF process completed with Homestake mine chosen by an NSF panel as the DUSEL site.**
- **Examination of FNAL based beam and detector simulations completed with the US Long Baseline Neutrino Expt. report.**
- **Preliminary proposal for a 300 kT detector in Homestake complete. Document is part of the US Long Baseline study.**

NuSAG Recommendations

Recommendation 1. The US should prepare to proceed with a long baseline neutrino oscillation program to extend sensitivity to $\sin^2 2\theta_{13}$, to determine the mass ordering of the neutrino spectrum, and to search for CP violation in the neutrino sector. Planning and R&D should be ready for a technology decision and a decision to proceed when the next round of results on $\sin^2 2\theta_{13}$ becomes available, which could be as early as 2012. A review of the international program in neutrino oscillations and the opportunities for international collaboration should be included in the decision to proceed.

Recommendation 2. Research and development towards an intense, conventional neutrino beam suitable for these experiments should be supported. This R&D may be to support intensity upgrades to the existing NuMI beam, as well as development of a new beam directed towards DUSEL, which would likely employ the wide-band beam approach.

Recommendation 3. Research and development required to build a large water Cherenkov detector should be supported, particularly addressing questions of minimum required photocathode coverage, cost, and timescale.

Recommendation 4. A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.