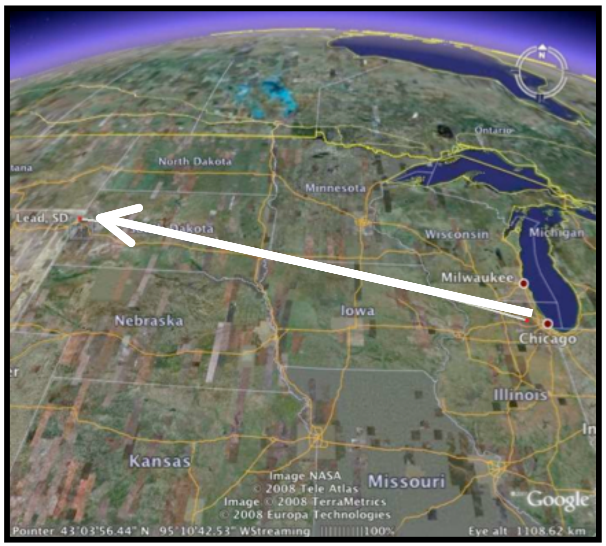
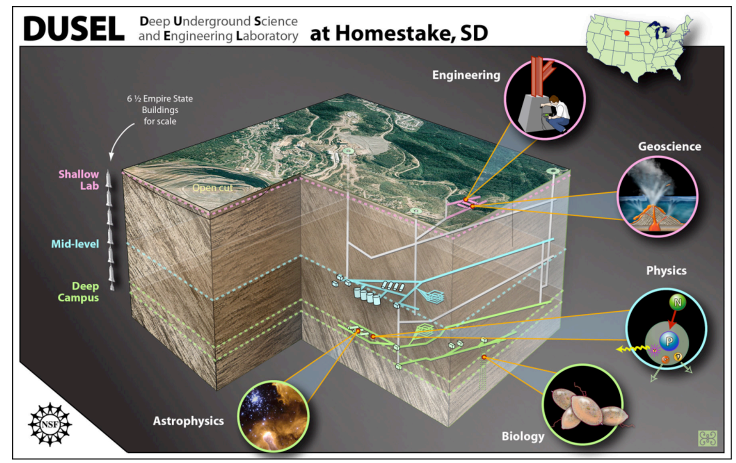
LBNE

Long Baseline Neutrino Experiment



Sam Zeller
LANL

NDM09, Madison
September 4, 2009



- looking beyond T2K and NOvA
- efforts to expand U.S.-based ν program to longer baselines (~1000 km)
- proposal to send intense beam of ν's from FNAL → DUSEL (Homestake)

What We Know

- have known that ν's oscillate and have mass for >10 years
- have made great progress

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}\, e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}\, e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

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solar ν + KAMLAND

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$\sin^2 2\theta_{12} = 0.87 \pm 0.03$

$\Delta m^2_{21} = (7.6 \pm 0.2) \times 10^{-5}\ \mathrm{eV}^2$

Los Alamos

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atmospheric ν
& long baseline
ν_μ **disappearance**

solar ν + KAMLAND

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$\sin^2 2\theta_{23} > 0.92$
$\Delta m^2_{32} = (2.43 \pm 0.13) \times 10^{-3}\ \mathrm{eV}^2$

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atmospheric ν & long baseline ν_μ **disappearance**

reactor

solar ν + KAMLAND

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$\sin^2 2\theta_{13} < 0.19$ (90% CL)

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long baseline ν_e **appearance**

atmospheric ν & long baseline ν_μ **disappearance**

reactor

solar ν + KAMLAND

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$\delta_{CP} = ??$

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atmospheric ν & long baseline ν_μ **disappearance**

reactor

long baseline ν_e **appearance**

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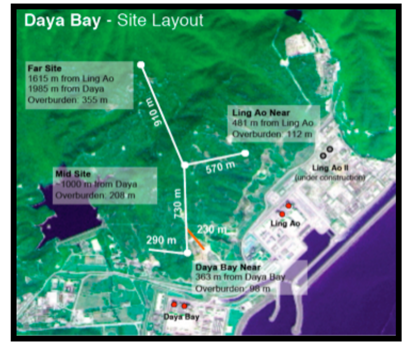
- three remaining parameters:
  - θ_{13}
  - ν mass hierarchy
  - CP violating phase, δ_{CP}

Phase I

- reactor experiments ($\overline{\nu}_e$ disappearance) (R. McKeown's talk)

Double CHOOZ
(M. Worcester's talk)



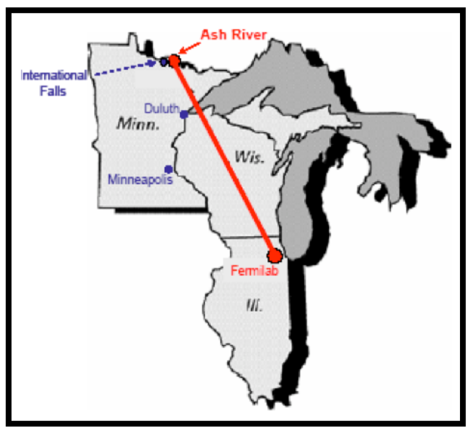
Daya Bay
(B. Viren's talk)

- long baseline accelerator-based ν experiments (ν_e appearance) (J. Paley's talk)

will probe $\sin^2 2\theta_{13} \sim 0.01$

at least a factor of 10 over present CHOOZ limit!

T2K (295 km, 2.5^0 OA)



NOvA (810 km, 0.9^0 OA)

Phase II

- an extensive and even more ambitious program is required to study ν oscillations beyond present program

- if θ_{13} is large enough, hope to expand this program …

  - give more precise information on θ_{13}
  - determine ν mass hierarchy
  - explore CP violation!

already starting to think about this now
& how phase II experiments might tackle

How?

- study of $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ oscillations over **even longer** baselines (sub-dominant is preferred channel)

$$P(\nu_\mu \to \nu_e) \cong \sin^2 2\theta_{13}\, T_1 - \alpha \sin 2\theta_{13}\, T_2 + \alpha \sin 2\theta_{13}\, T_3 + \alpha^2 T_4$$

$$T_1 = \sin^2\theta_{23} \frac{\sin^2[(1-x_\nu)\Delta]}{(1-x_\nu)^2} \quad ,$$

$$T_2 = \sin\delta \sin 2\theta_{12} \sin 2\theta_{23} \sin\Delta \frac{\sin(x_\nu \Delta)}{x_\nu} \frac{\sin[(1-x_\nu)\Delta]}{(1-x_\nu)} \quad ,$$

$$T_3 = \cos\delta \sin 2\theta_{12} \sin 2\theta_{23} \cos\Delta \frac{\sin(x_\nu \Delta)}{x_\nu} \frac{\sin[(1-x_\nu)\Delta]}{(1-x_\nu)} \quad ,$$

$$T_4 = \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(x_\nu \Delta)}{x_\nu^2} \quad .$$

$$\alpha \equiv \Delta m^2_{21}/\Delta m^2_{31} \sim 1/30 \qquad x_\nu \equiv \frac{2\sqrt{2} G_F N_e E}{\Delta m^2}$$

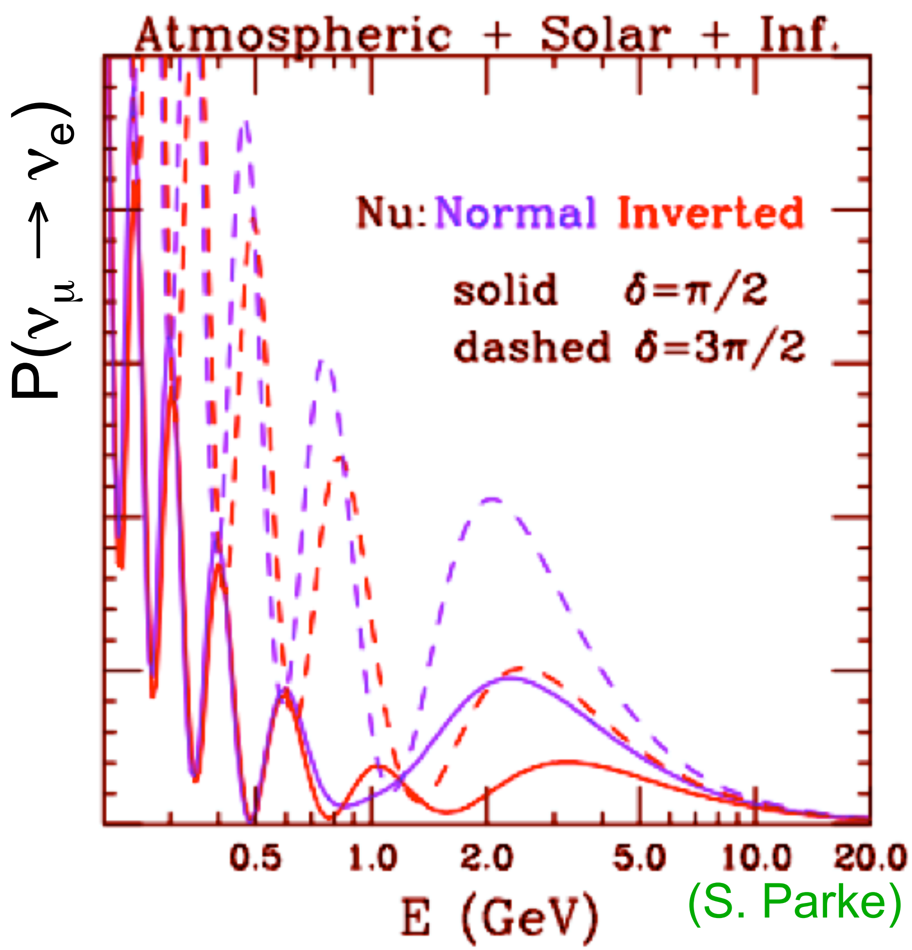
- allows meas of θ_{13} and δ_{CP}

- can also determine ν mass hierarchy from matter effects

In Practise, This is Complex

total $P(\nu_\mu \rightarrow \nu_e)$ in matter

- $\sin^2 2\theta_{13} = 0.04$
- L = 1200 km

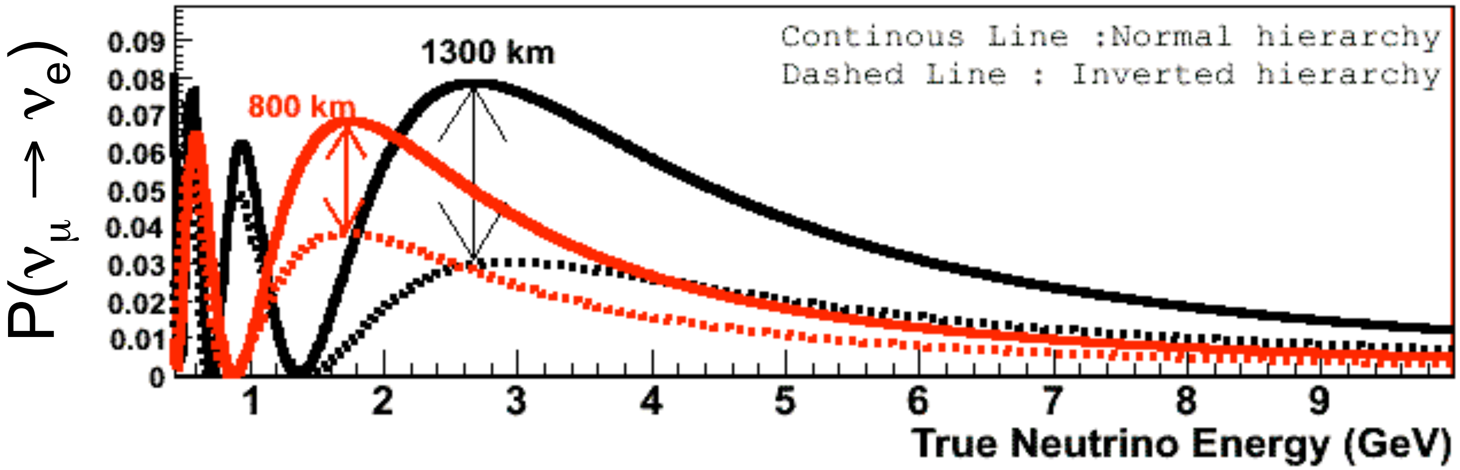


(S. Parke)

- rich structure depending on the ν mass hierarchy and δ_{CP}
- requires information from both 1st & 2nd oscillation maxima to resolve these ambiguities

(spectral information and $\bar{\nu}$)

Why Longer Baselines?



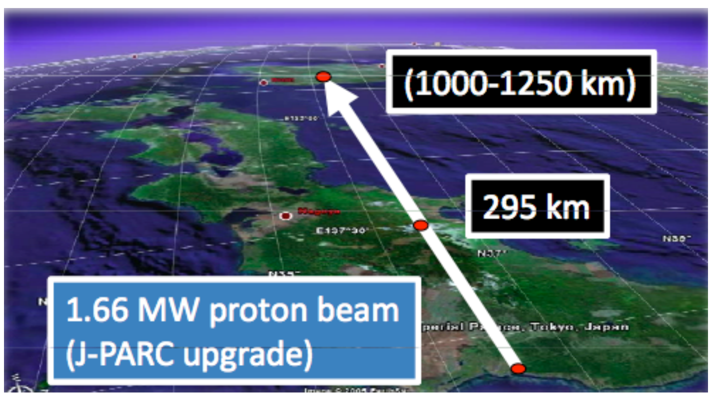
- with increasing L:
  - 1st and 2nd oscillation maxima at higher energy
    (more favorable region, larger stats, away from larger nuclear effects)
  - larger matter effects
    (increasing the potential for the determination of ν mass hierarchy

Phase II Experiments

(1) longer baselines (~1000 km)
(2) have access to both 1st & 2nd osc max (to remove degeneracies)

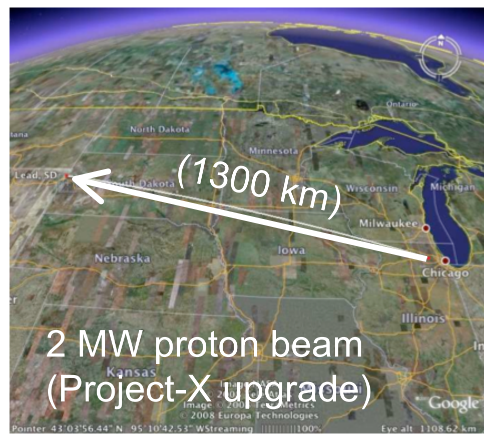
→ significant reach beyond present generation of LBL ν exps

T2KK
(295 km, 1050 km)



- NBB
- study 1st and 2nd osc max separately
- 2 detectors at 2 different OA locations (2.5^0 OA @ 295 km, 1^0 OA @ 1050 km)

LBNE
(1300 km)



θ_{13}
mass hierarchy
CP violation

- WBB
- study both 1st and 2nd osc with single detector at a fixed baseline

Phase II Experiments

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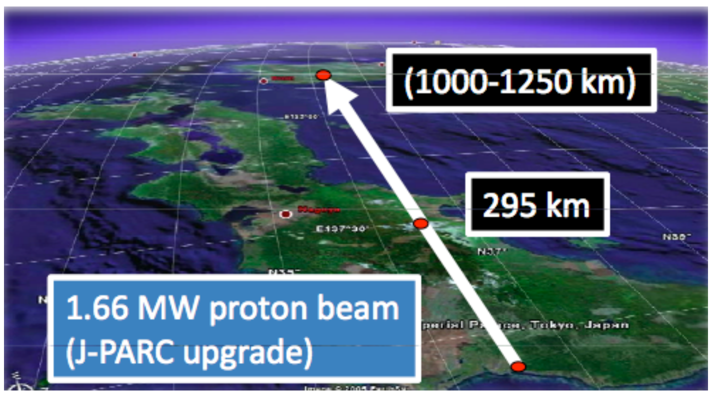

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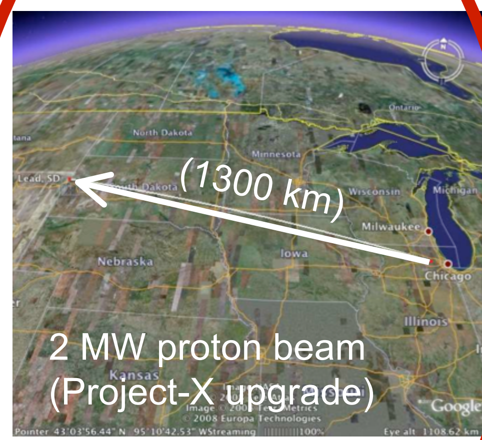
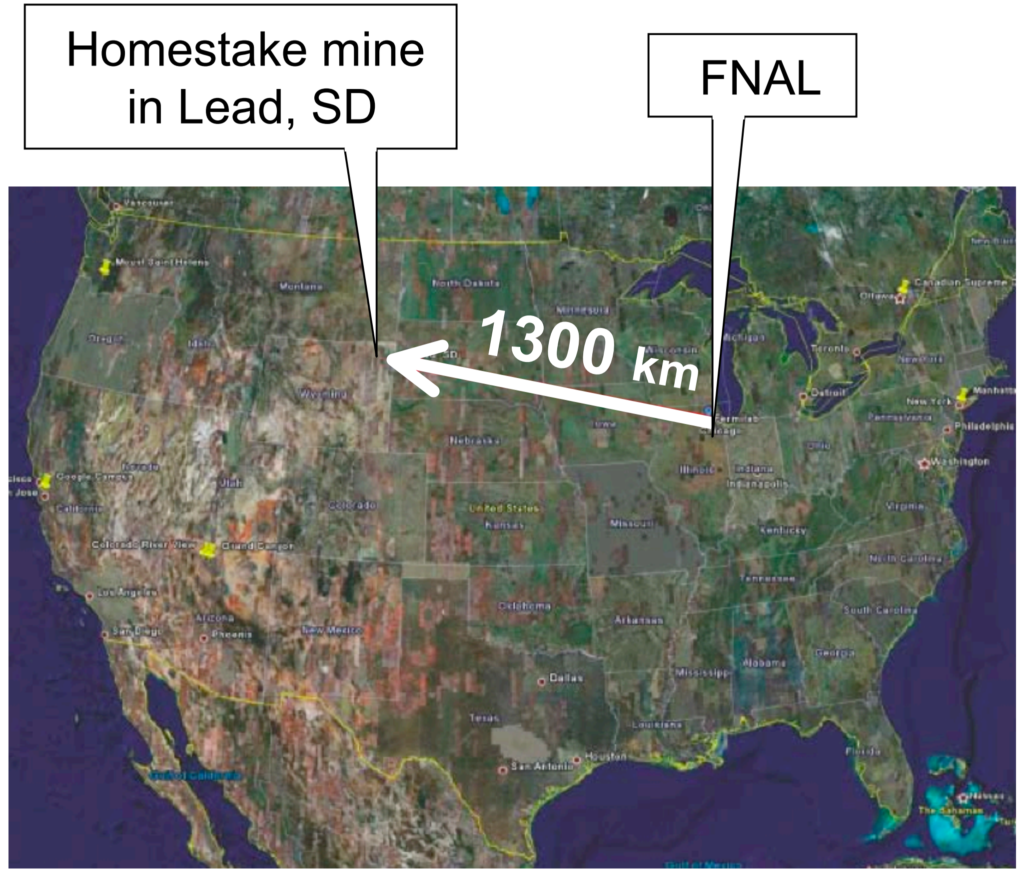


- WBB
- study both 1st and 2nd osc with single detector at a fixed baseline

will focus on U.S.-based program (LBNE) in this talk

LBNE

- idea is to send intense ν, $\bar{\nu}$ beams from Fermilab
- long baseline (1300 km)
- very massive detectors (100's kton) in a deep underground laboratory
    - water Cerenkov
    - liquid Argon TPC



new beam → long baseline → large detectors → big project → potential big payoff !

LBNE Science

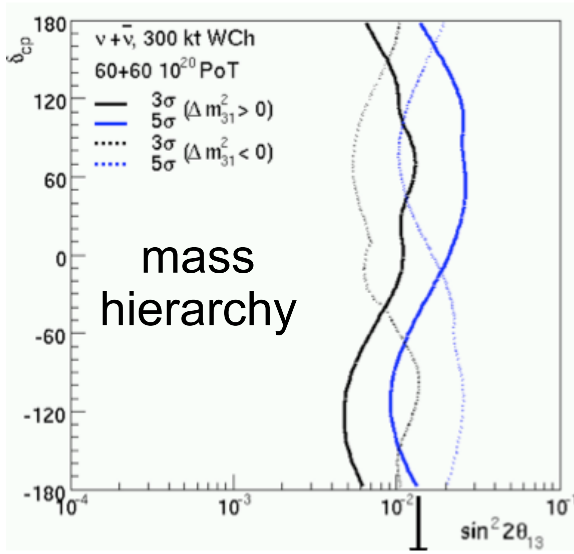
• there is a lot you can do with super-sensitive large detectors under thousands of feet of rock!

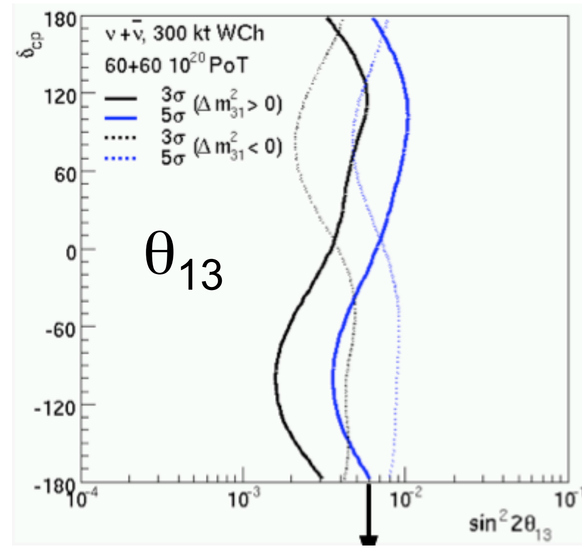
Los Alamos

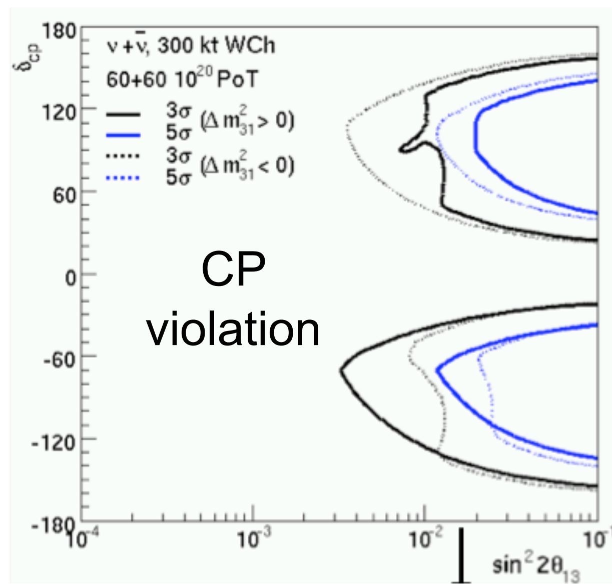
LBNE Science

(M. Dierckxsens, 2008)

- θ_{13}
- ν mass hierarchy
- CP phase δ







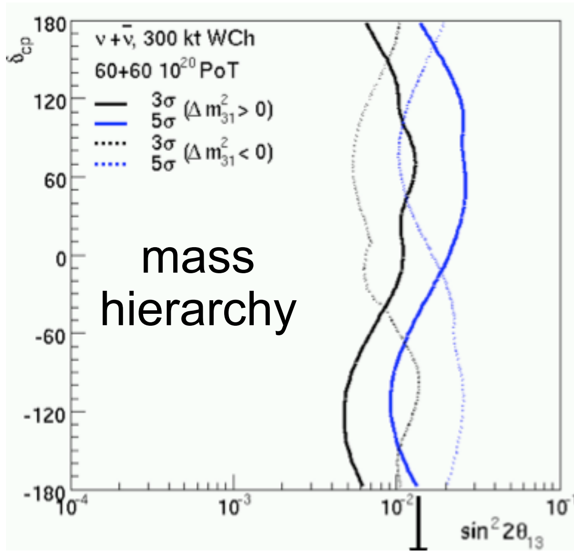
significant reach in physics sensitivity beyond the present generation of LB ν oscillation experiments

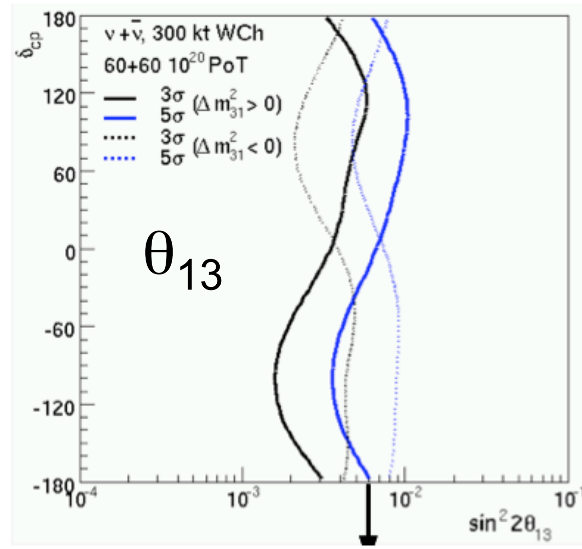
assuming 300 kton H_2O, 120 GeV $\nu + \bar{\nu}$

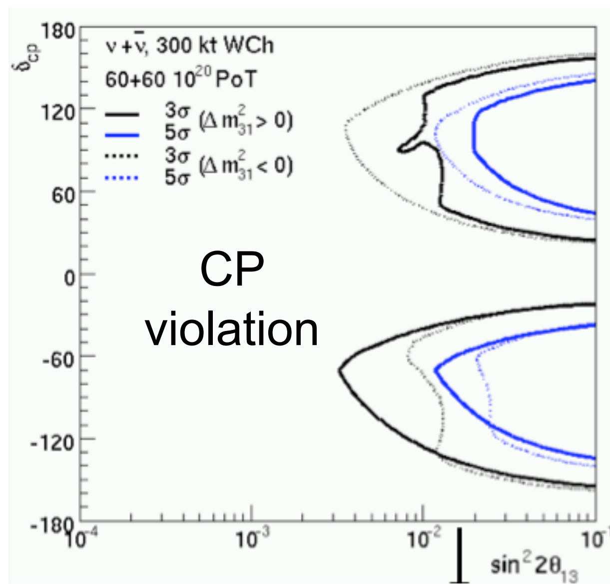
LBNE Science

(M. Dierckxsens, 2008)

- θ_{13}
- ν mass hierarchy
- CP phase δ





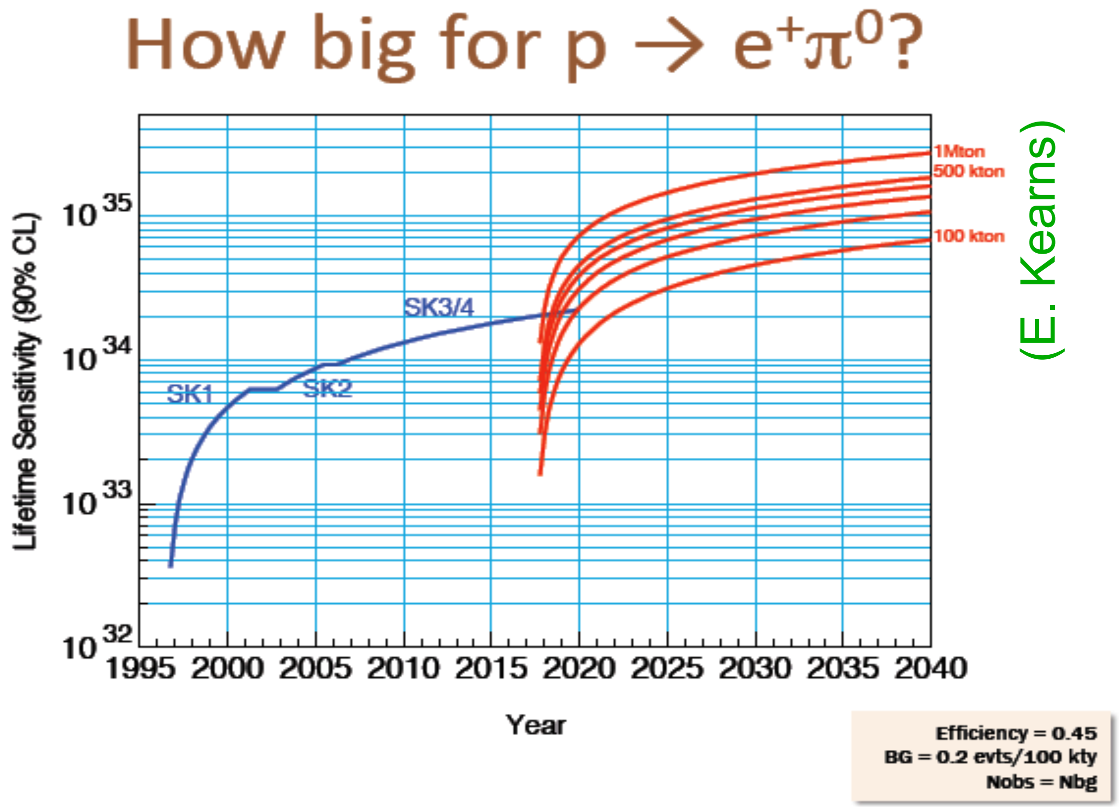


- can establish finite θ_{13} at 3σ if $\sin^2 2\theta_{13} \gtrsim 0.005$ (all δ_{CP})
- measure mass hierarchy and δ_{CP} if $\sin^2 2\theta_{13} > 0.01$

assuming
300 kton H_2O,
120 GeV
$\nu + \bar{\nu}$

LBNE Science

- θ_{13}
- ν mass hierarchy
- CP phase δ
- proton decay



(E. Kearns)

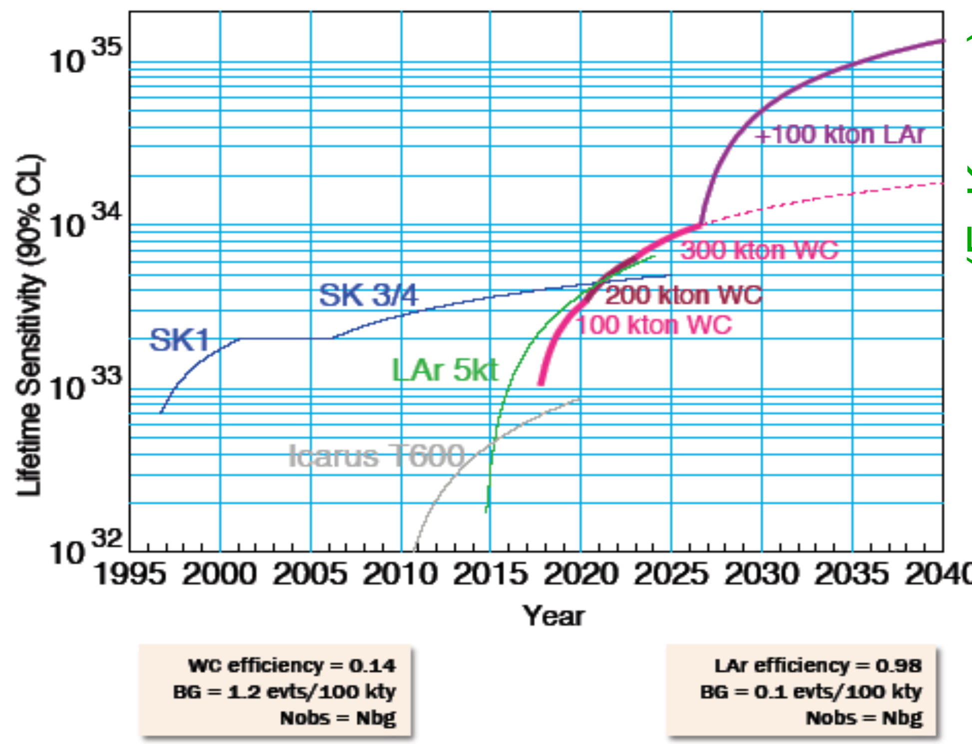
- current limit $\tau_{1/2}$ > 8.2 x 10^{33} yrs (Super-K I+II)
- H_2O Č most sensitive to this decay mode
- with a large detector can push limits to 10^{35} yr

LBNE Science

- θ_{13}
- ν mass hierarchy
- CP phase δ

- proton decay

$p \rightarrow K^+\nu$



(E. Kearns)

- K^+ is below Č threshold
- here, lAr does better

LBNE Science

- θ_{13}
- ν mass hierarchy
- CP phase δ

- proton decay

- supernova ν's

highly complementary
- H_2O: $\bar{\nu}_e$
- lAr: ν_e (enhanced by osc)

100 kt H_2O, SN@10 kpc

Interaction	Rates ($\times 10^4$)
$\bar{\nu}_e + p \rightarrow n + e^+$	2.3
$\nu + e \rightarrow \nu + e$	0.1
$\nu_x + {}^{16}O \rightarrow {}^{16}O + \nu_x$	0.05
$\nu_x + {}^{16}O \rightarrow {}^{16}F + e$	0.2

100 kt of LAr, SN @ 10 kpc

Interaction	Rates ($\times 10^4$)
ν_e CC (^{40}Ar, $^{40}K^*$)	2.5
ν_x NC ($^{40}Ar^*$)	3.0
ν_x ES	0.1
anti-ν_e CC (^{40}Ar, $^{40}Cl^*$)	0.054

LBNE Science

- θ_{13}
- ν mass hierarchy
- CP phase δ

- proton decay

- supernova ν's

- solar ν detection
  (pp flux)

LBNE Science

- θ_{13}
- ν mass hierarchy
- CP phase δ

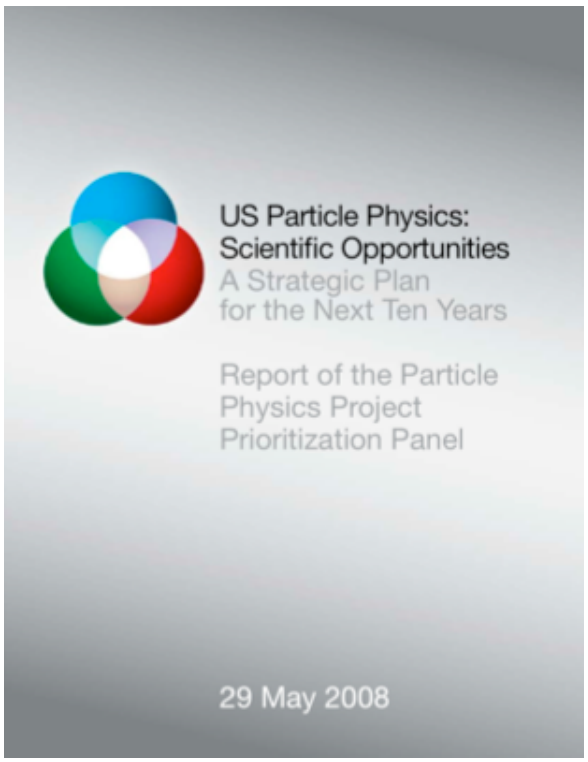
- need large detector for LBL osc physics

- proton decay
- supernova ν's
- solar ν detection
  (pp flux)

- if at same time, also in low background environment, then these additional physics capabilities come "for free"

physics potential
of a very large
underground detector
is extremely rich!

Launched with P5

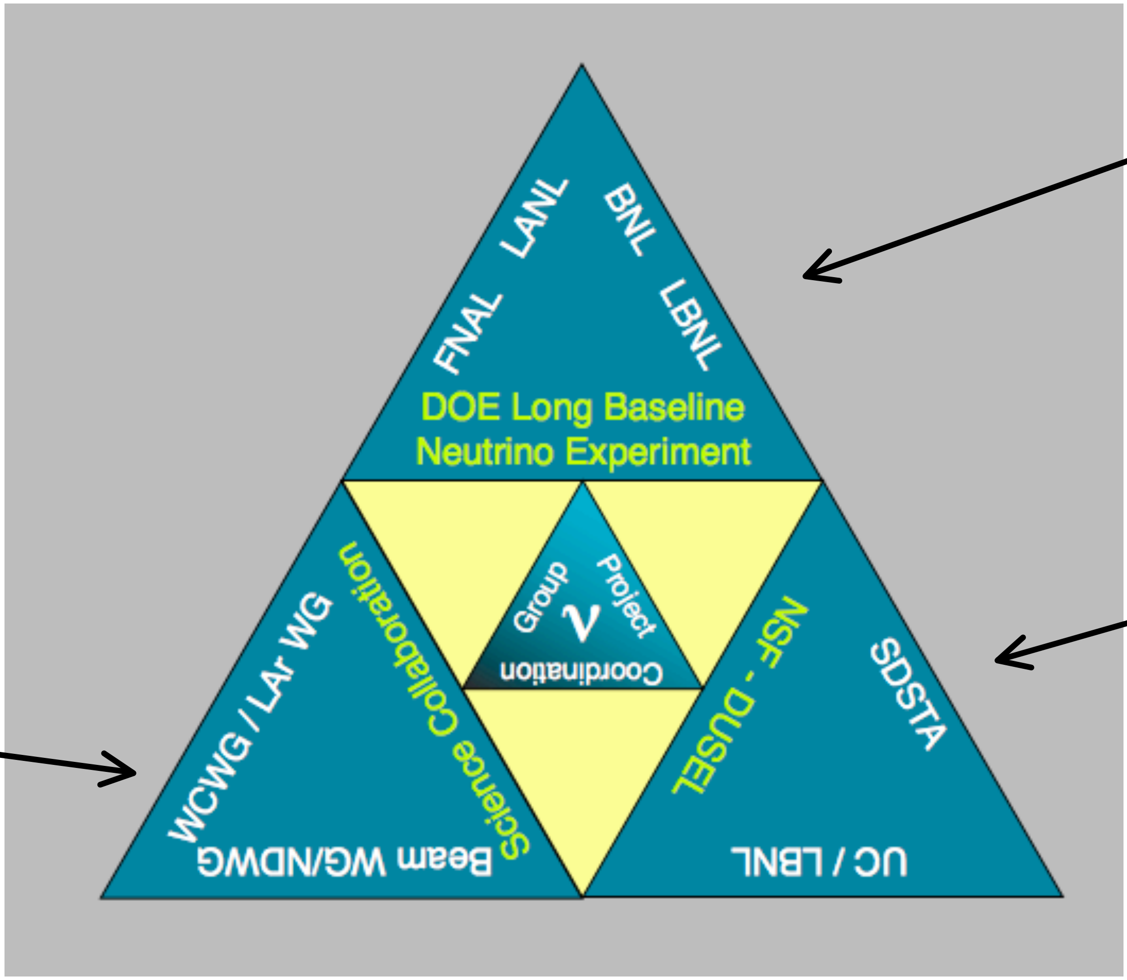


- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

- both NSF and DOE sponsoring our efforts

Big Project Requires Coordination

working together



DOE project offices have been established

oversee effort for DUSEL design & construction within NSF MREFC

formal science collab has been formed (self-organized)

LBNE Collaboration (Aug 2009)

currently ~150 people from 33 institutions

Argonne National Laboratory
M. Goodman, M. Sanchez, M. Wetstein

Brookhaven National Laboratory
M. Bishai, R. Brown, H. Chen, G. de Geronimo, M. Diwan, R. Hackenberg, R. Hahn, S. Hans, D. Jaffe, S. Junnarkar, S. Kettell, F. Lanni, D. Makowiecki, B. Marciano, W. Morse, Z. Parsa, C. Pearson, V. Radeka, S. Rescia, J. Sondericker, J. Stewart, C. Thorn, B. Viren, M. Yeh, B. Yu

Boston University
E. Hazen, E. Kearns, J. Raaf, J. Stone

University of California, Davis
J. Felde, R. Svoboda, M. Tripathi

University of California, Irvine
B. Kropp, M. Smy, H. Sobel

University of California, Los Angeles
K. Arisaka, D. Cline, Y. Meng, F. Sergiampietri, H. Wang

Caltech
R. McKeown

University of Catania and INFN, Catania
V. Bellini, R. Potenza

University of Chicago
E. Blucher, M. Dierckxsens

Colorado State University
B. Berger, N. Buchanan, W. Toki, R. Wilson

Columbia University
L. Camilleri, C. Chi, C. Mariani, M. Shaevitz, W. Sippach, W. Willis

Drexel University
C. Lane, J. Maricic

Duke University
J. Fowler, K. Scholberg, C. Walter

Fermilab
D. Allspach, B. Baller, S. Childress, P. Hurh, J. Hylen, G. Koizumi, T. Lackowski, C. Laughton, P. Lucas, B. Lundberg, P. Mantsch, J. Morfin, V. Papadimitriou, R. Plunkett, S. Pordes, G. Rameika, B. Rebel, K. Riesselmann, R. Schmitt, D. Schmitz, P. Shanahan, R. Zwaska

Indiana University
C. Bower, W. Fox, M. Messier, J. Musser, J. Urheim

Kansas State University
T. Bolton, G. Horton-Smith

Lawerence Berkeley Laboratory
B. Fujikawa, R. Kadel

Lawrence Livermore National Laboratory
A. Bernstein, R. Bionta, S. Dazeley, S. Oeudraogo

Los Alamos National Laboratory
G. Garvey, T. Haines, W. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White, G. Zeller

Louisiana State University
T. Kutter, W. Metcalf, J. Nowak

University of Maryland
E. Blaufuss, G. Sullivan

Michigan State University
E. Arrieta-Diaz, C. Bromberg, D. Edmunds, J. Houston, B. Page

University of Minnesota
M. Marshak, W. Miller

University of Minnesota, Duluth
R. Gran, A. Habig

MIT
W. Barletta, J. Conrad, P. Fisher

University of Pennsylvania
J. Klein, K. Lande, M. Newcomer, R. Van Berg

Rensselaer Polytechnic Institute
D. Kaminski, J. Napolitano, S. Salon, P. Stoler

Princeton University
K. McDonald, Q. He

South Carolina University
S. Mishra, R. Petti, C. Rosenfeld

Institute for Physics & Mathematics of the Universe, U. Tokyo
M. Vagins

Tufts University
H. Gallagher, T. Kafka, T. Mann, J. Schneps

University of Wisconsin, Madison
B. Balantekin, F. Feyzi, L. Gladstone, K. Heeger, A. Karle, R. Maruyama, P. Sandstrom, C. Wendt

Yale University
B. Fleming, M. Soderberg

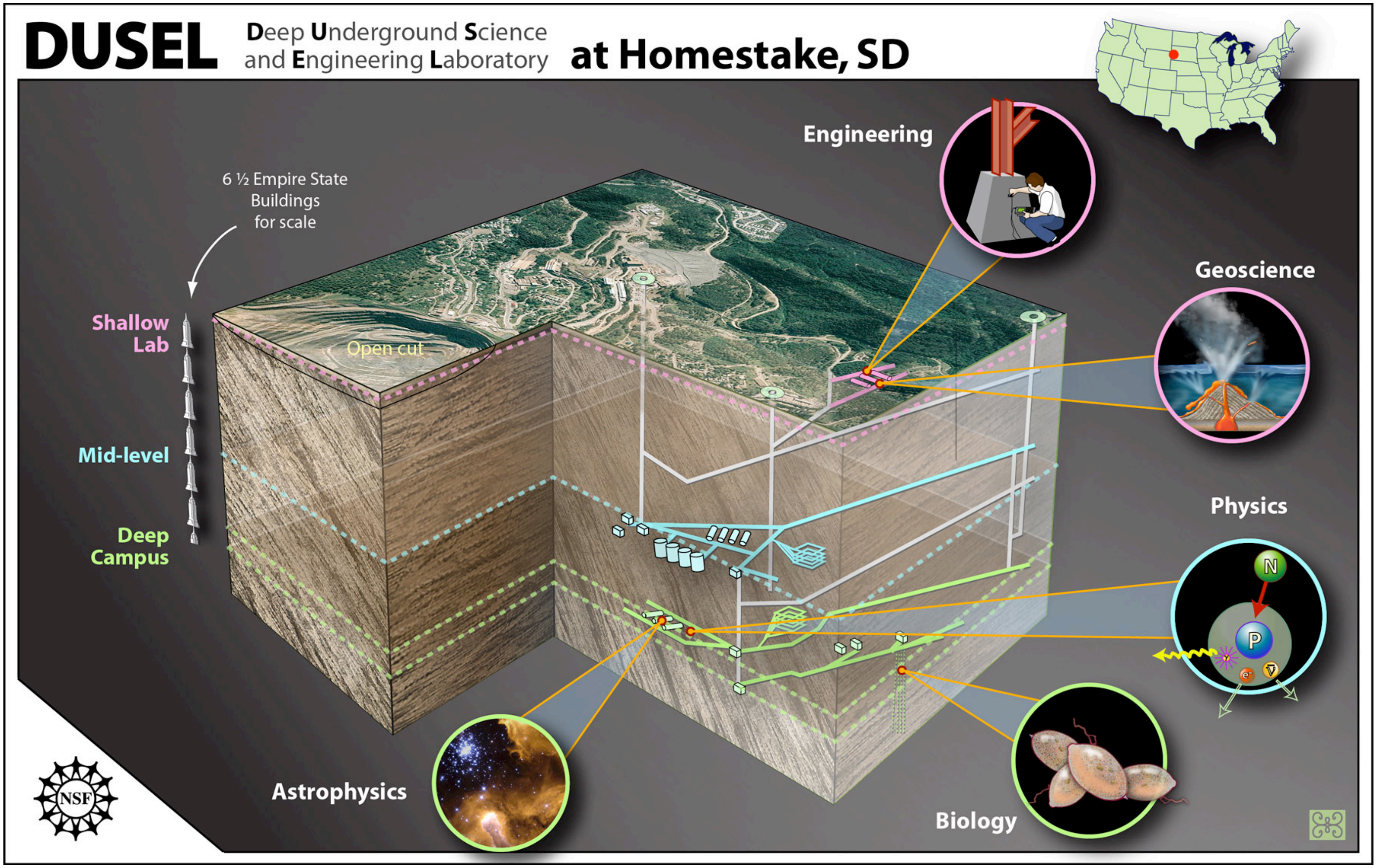
LBNE Collaboration Meetings

collab meeting @ UC Davis, Feb 2009

- **BNL**
  Oct. 15, 2008
- **UC, Davis**
  Feb. 26-28, 2009
- **Fermilab**
  July 15-17, 2009
- + one coming up in October
  (will mention more details later)

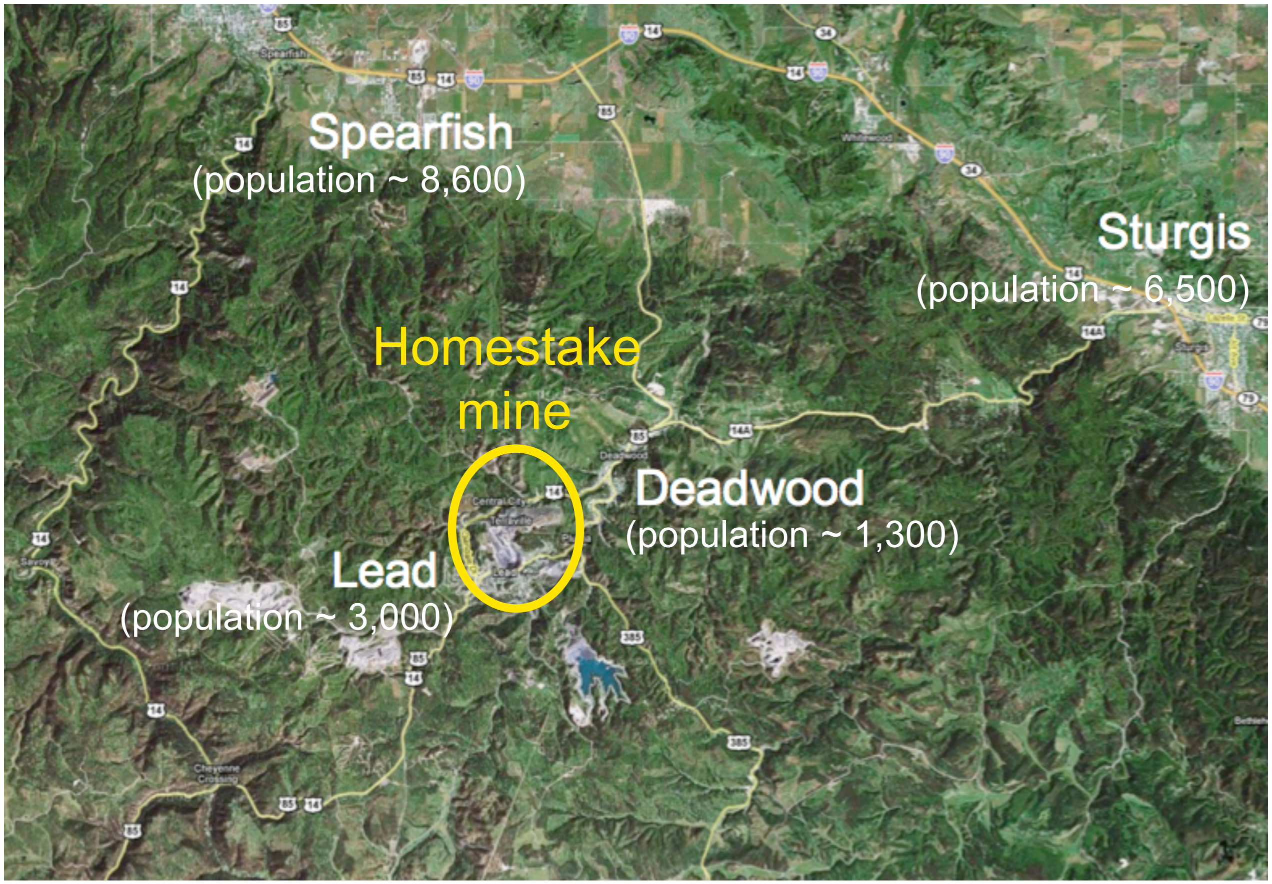
preferred location for the LBNE far detector ….

DUSEL (Sanford Lab/Homestake)



part of NSF's major research equipment and facility construction effort (MREFCE)

Where is Homestake?



- mine is situated in middle of Black Hills in western SD
  - facility is an old gold mine
  - extracted over 42 million ounces of gold (6 semi trucks) over the course of 126 years
- 27 miles north of Mt. Rushmore
- 40 miles from Rapid City

Attributes of Homestake

- state now owns free and clear
  (long term access)

- concentrated, focused facility for underground science
  (without disruption from mining - no competing uses for its infrastructure)

- access to unusual depths for deep science
  (up to 8000 ft)

- large excavations which can hold a variety of exp'l programs
  (with the ability to expand in capacity and depth)

- low radioactivity rock
  (important for dark matter, $0\nu\beta\beta$, solar ν experiments, etc.)

particularly attractive place to do science

Not Just Physics

multi-disciplinary laboratory (http://www-nsd.lbl.gov/homestake/)

- mass hierarchy
- CP violation
- solar ν's
- supernova ν's
- proton decay
- $0\nu\beta\beta$
- dark matter

} physics

- biology
- geology
- engineering
- education & outreach

C. Anderson (Black Hills State U.)
sampling "interesting" fungus at 2000 L

G. Rastogi *et al*, "Isolation and Characterization of Cellulose Degrading Bacteria from Deep Subsurface of the Homestake Gold Mine", J. Ind. MicroBiol. Biotech, **36**, 585 (2009)

Major Milestones

- **2002** process for underground lab starts
- **2003** Homestake mine closed & sealed
- **2007** NSF selects Homestake!
- **2007** Sanford Lab startup
  - $50M (SD) + $70M (T. Denny Sanford)
  - re-entry begins (rehab of shafts & hoists)
  - dewatering & site preparation
  - enables early start for science

- **2010** DUSEL PDR submission
- **2011** NSB review
- **2013** earliest construction start, if approved

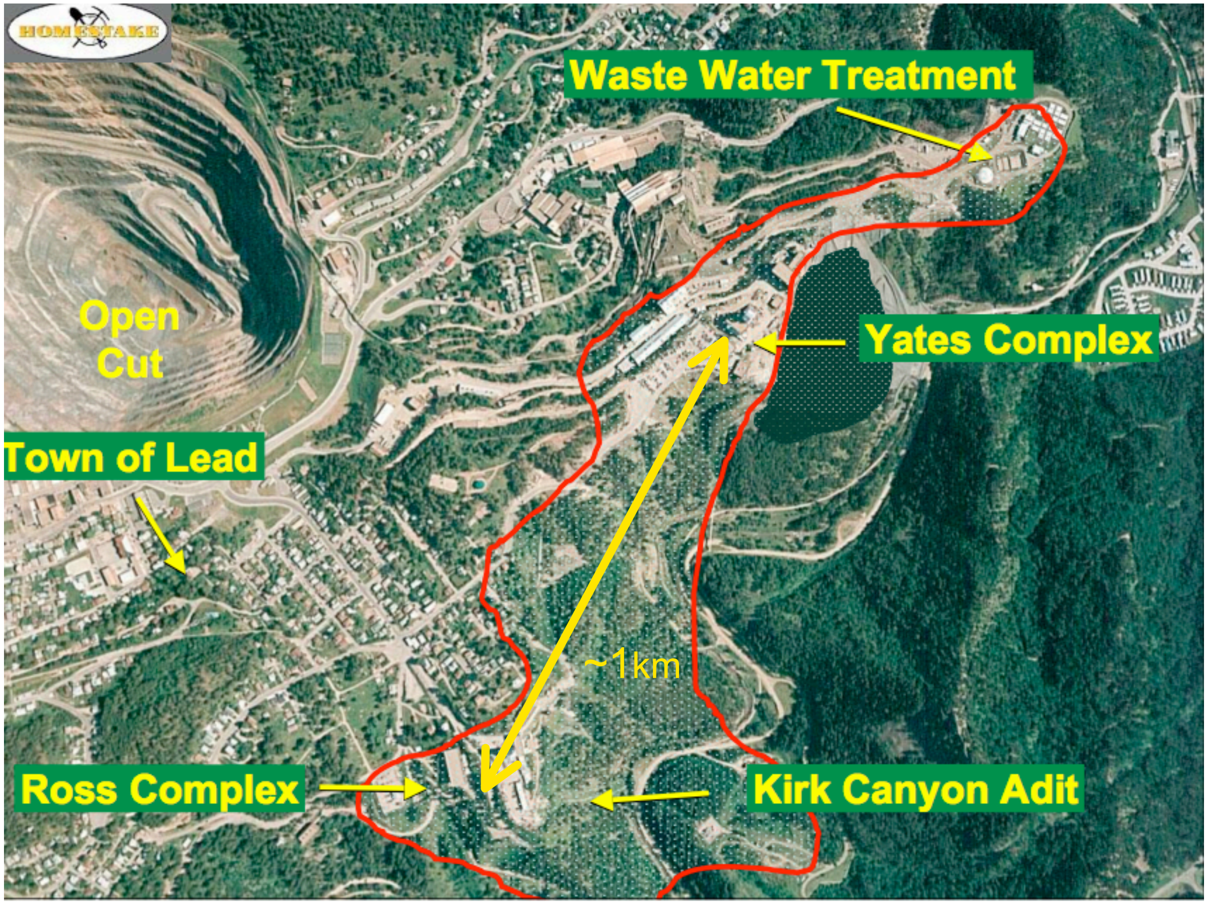
Barrick donates mine
to state of SD (April 2006)

T. Denny Sanford
cuts ribbon (June 2006)

Aerial View

property donation includes:

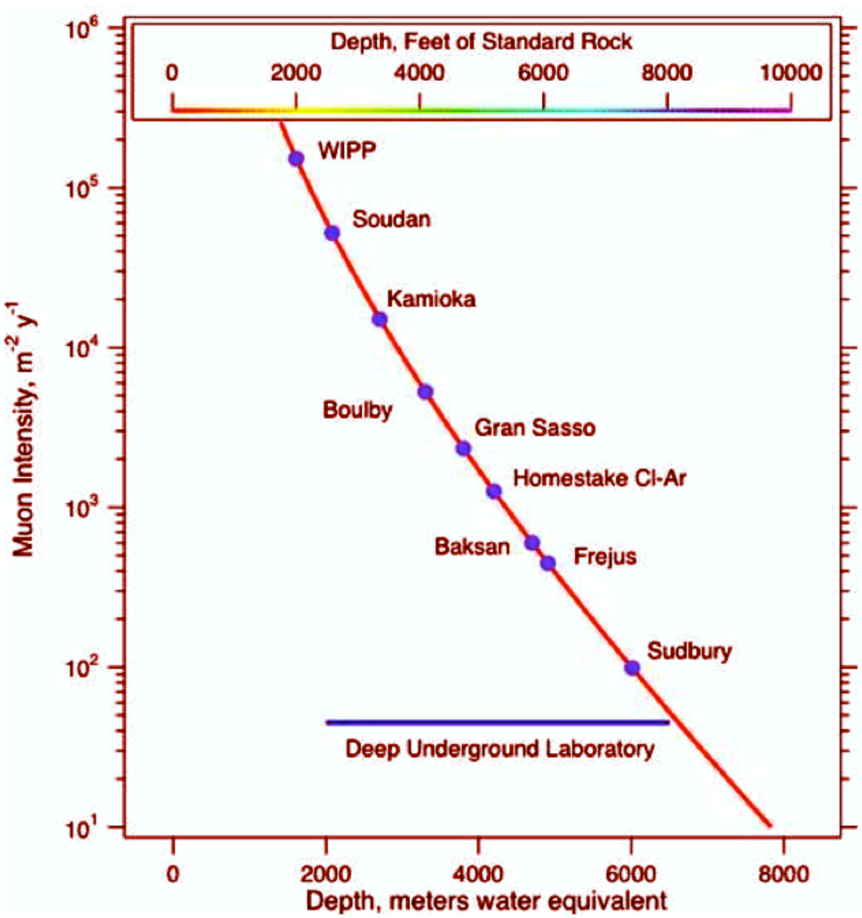
- 186 acres
  at the surface
- >20 existing buildings
- 800 acres of
  underground workings
- 370 miles of shafts
  and tunnels at 60 levels

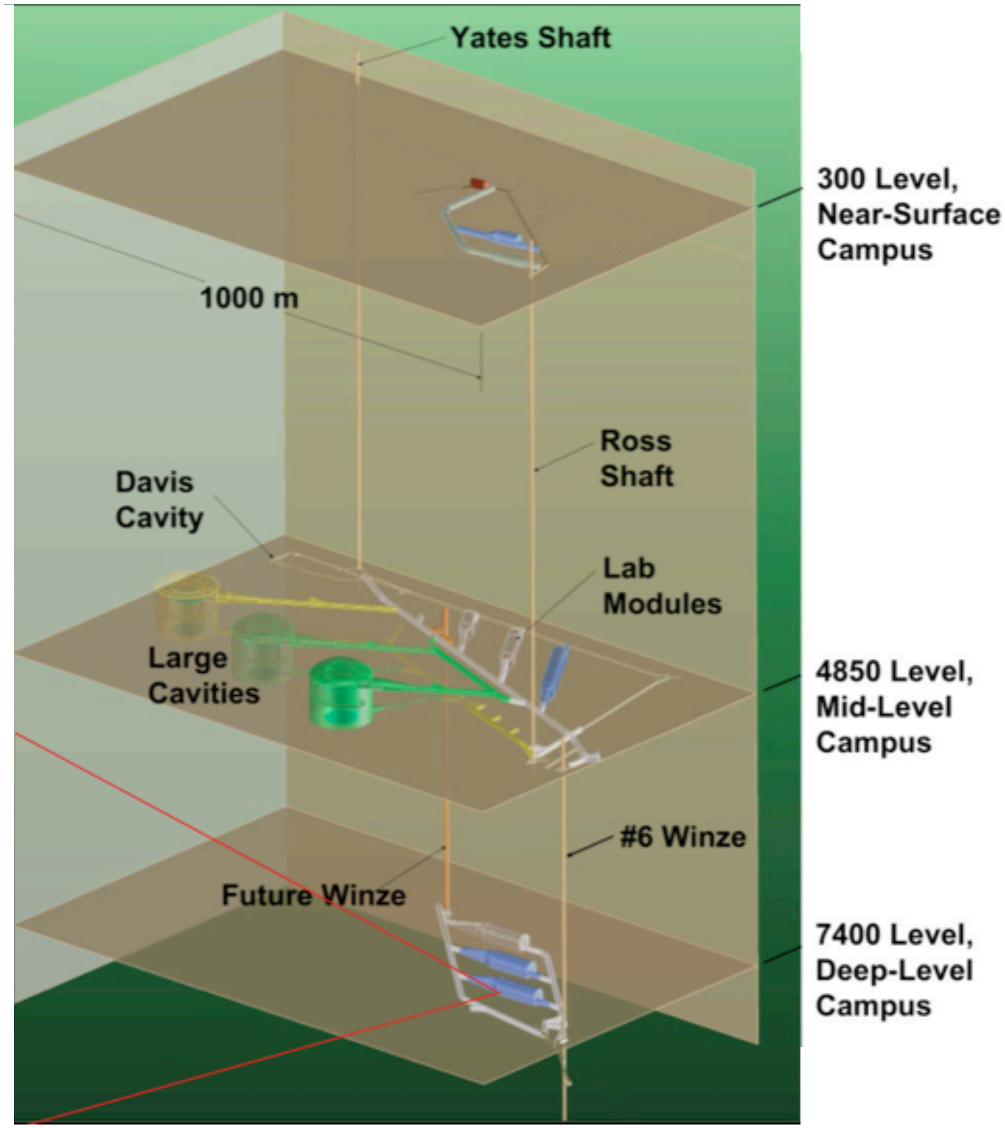


all has been deeded to the state and is owned by SD

Three Major Campuses

- series of campuses; multiple levels

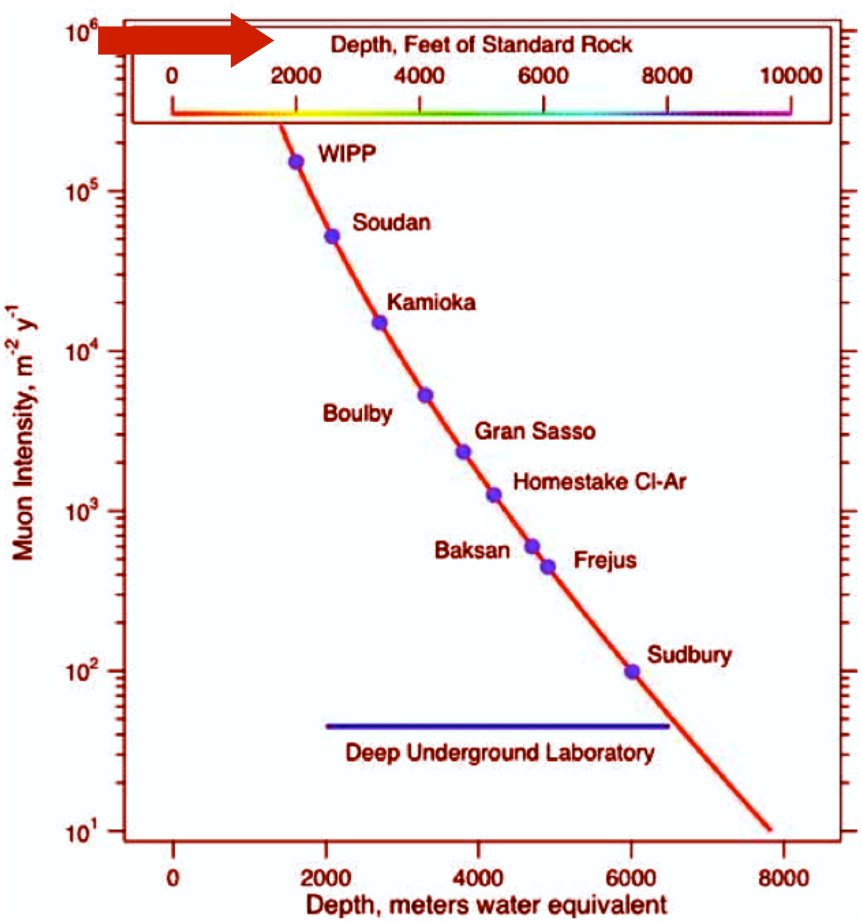


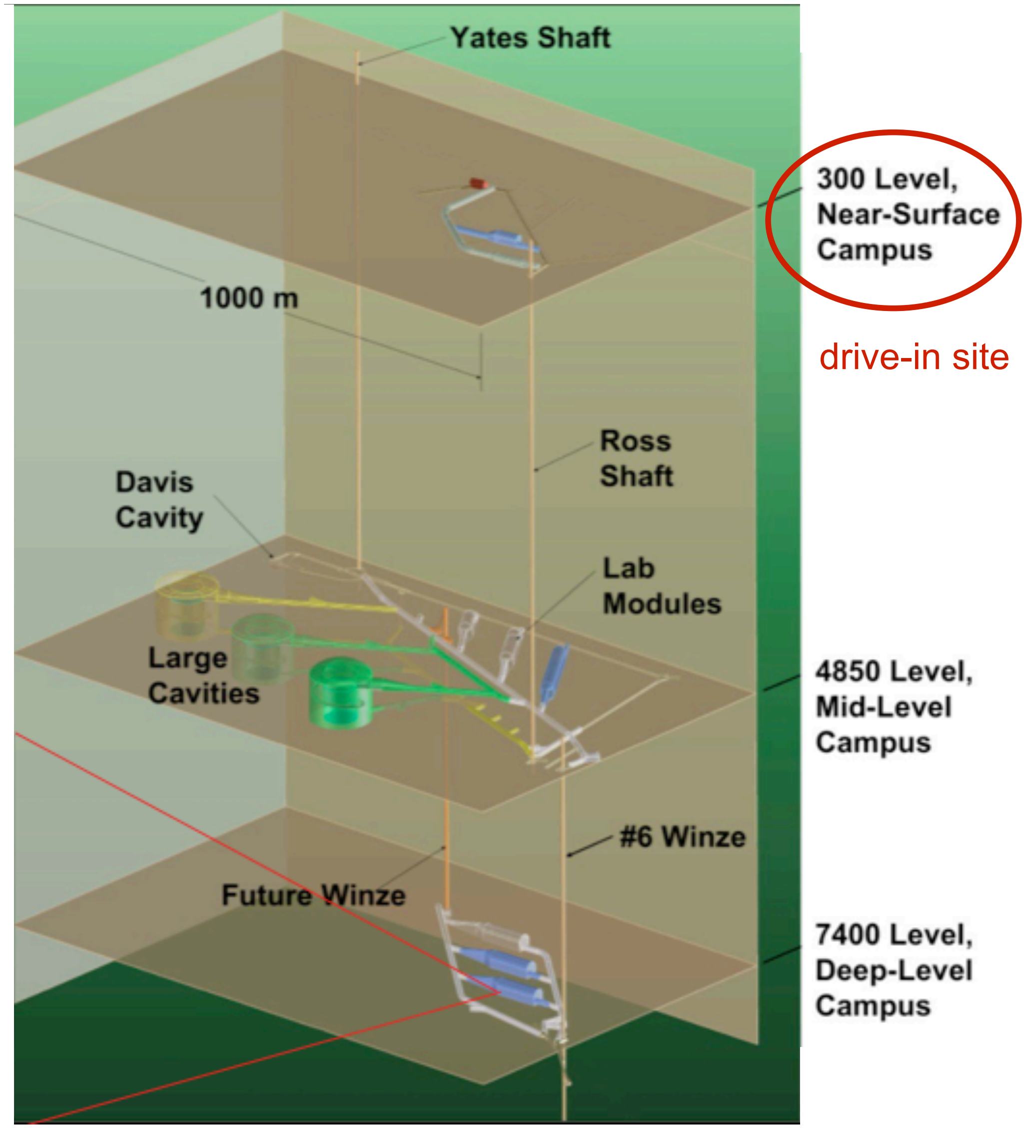


(DUSEL CDR, January 2007, www-nsd.lbl.gov/homestake)

Three Major Campuses

- series of campuses; multiple levels





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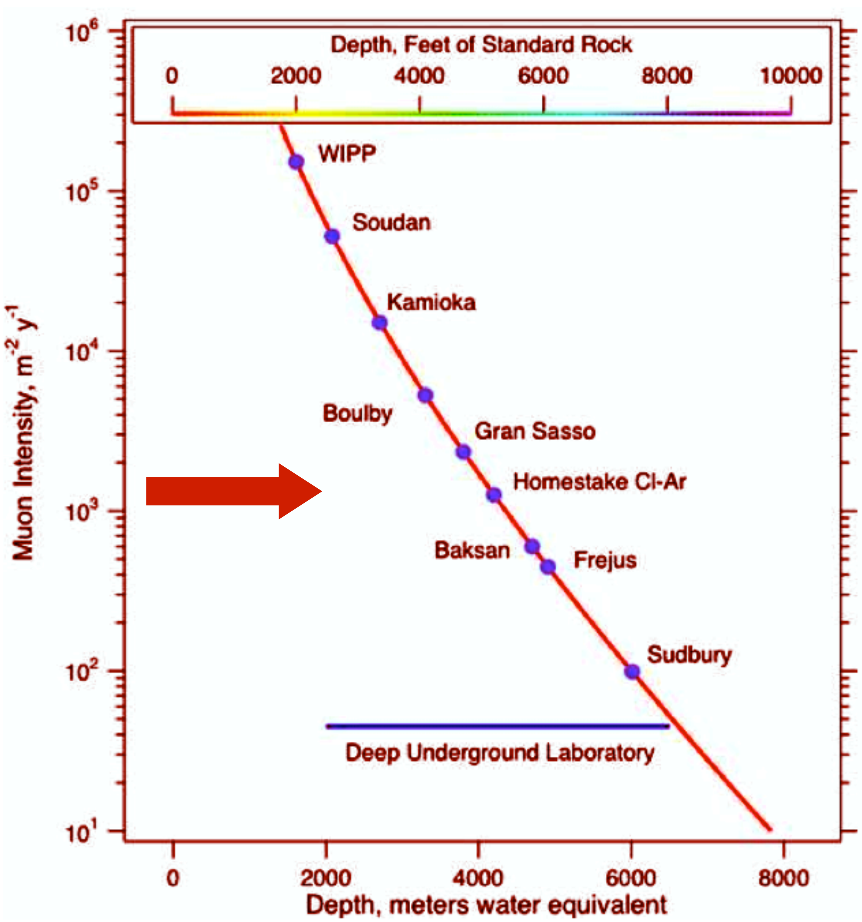

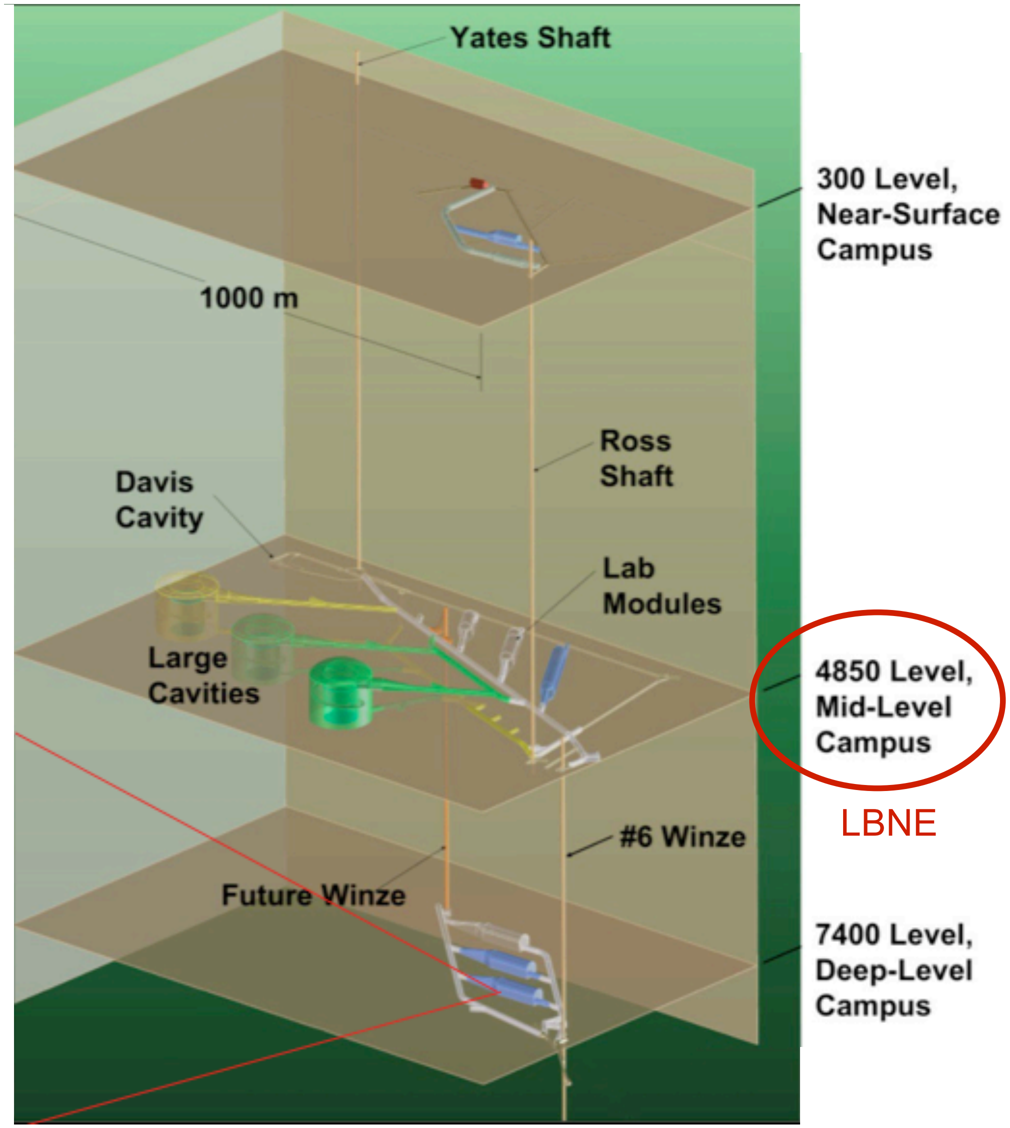

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Three Major Campuses

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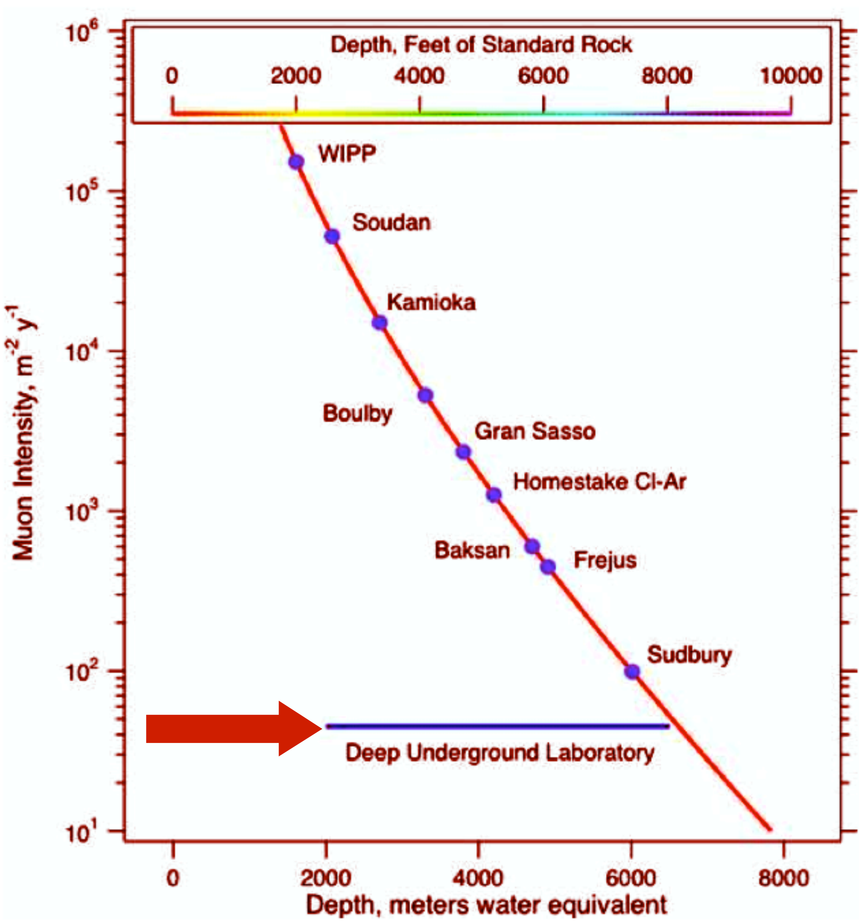
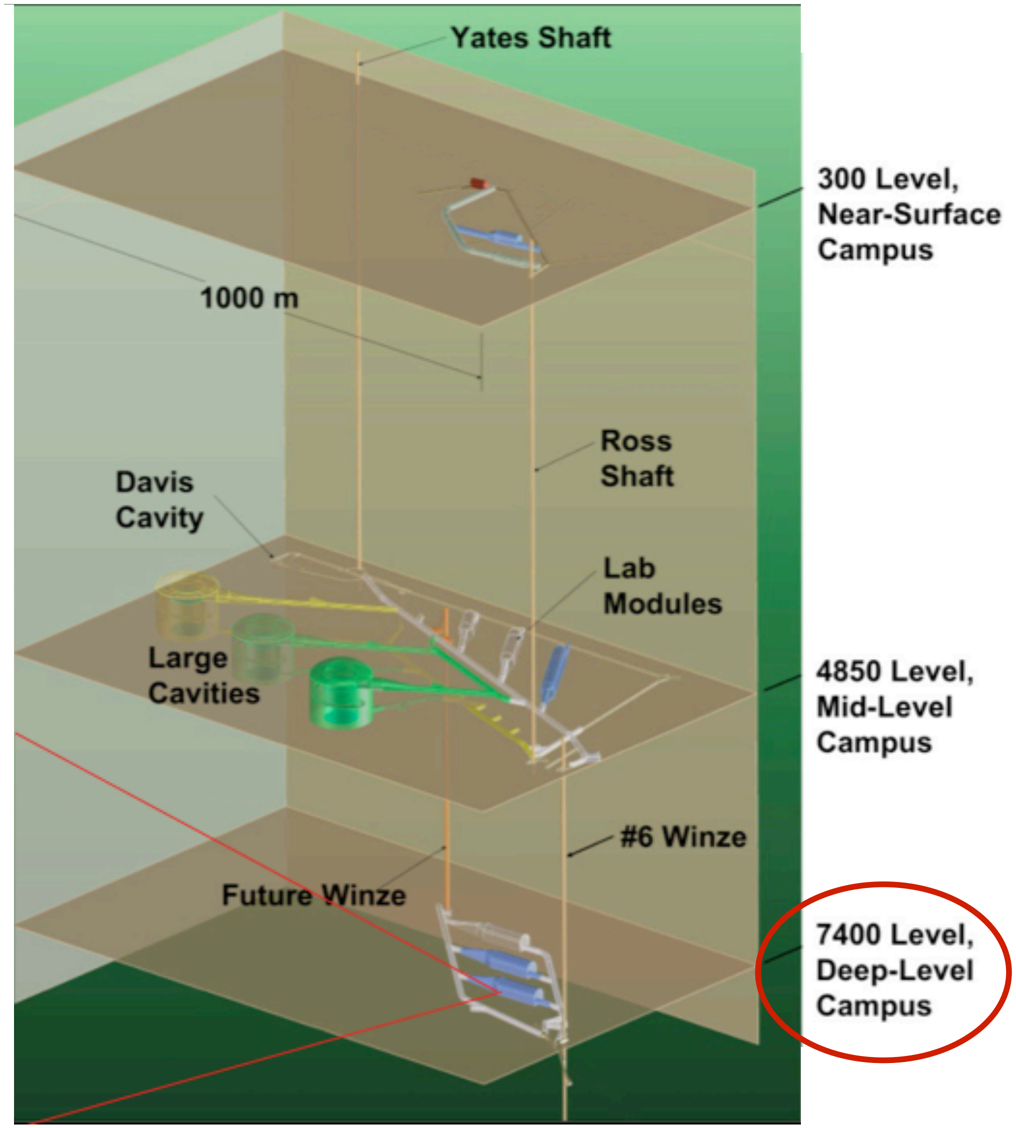




(DUSEL CDR, January 2007, www-nsd.lbl.gov/homestake)

DeWatering

4550L submersible pumps in action

- mine was slowly filling with water until last year when SDSTA began pumping out
- pumping out at rate of 1500 gallons/min

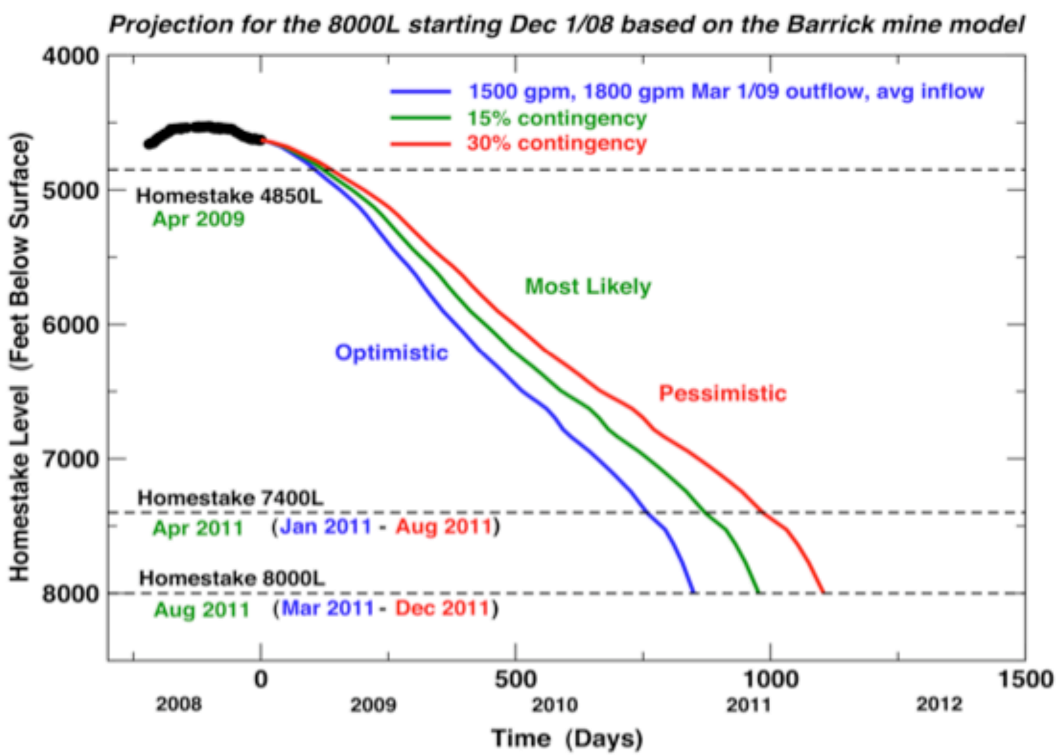
- 4850 L reached (May 13, 2009)
  - 600M gallons H_2O pumped from mine
- had not been accessed since the mine was sealed shut in 2003
- currently at 4,992 level
  (http://www.sanfordlab.org)

T. Denny Sanford & Gov. Mike Rounds

DeWatering

4550L submersible pumps in action

- mine was slowly filling with water until last year when SDSTA began pumping out
- pumping out at rate of 1500 gallons/min



- will have to remove 4M ton water to get from 4850 to 7400 L
- should reach 7400 L sometime in 2011

LBNE Depth Requirements

Rate(Hz)	In-time cosmics/yr	Depth (mwe)
500 kHz	5×10^7	0
3 kHz	300,000	265
400 Hz	40,000	880
5 Hz	500	2300
1.3 Hz	130	2960
0.60 Hz	60	3490
0.26 Hz	26	3620
0.09 Hz	9	4290

CR rates for 50m height/diameter detector

- variety of ν physics possible in a single detector drives the requirement to larger depths
  - want to reduce CR & CR spallation products

A. Bernstein *et al.*, arXiv:0907.4183 [hep-ex]

Physics	Water	Argon
Long-Baseline Accelerator	1000 mwe	0-1000 mwe
$p \to K^+ \bar{\nu}$	>3000 mwe	>3000 mwe
Day/Night ^{8}B Solar ν	~4300 mwe	~4300 mwe
Supernova burst	3500 mwe	3500 mwe
Relic supernova	4300 mwe	> 2500 mwe
Atmospheric ν	2400 mwe	2400 mwe

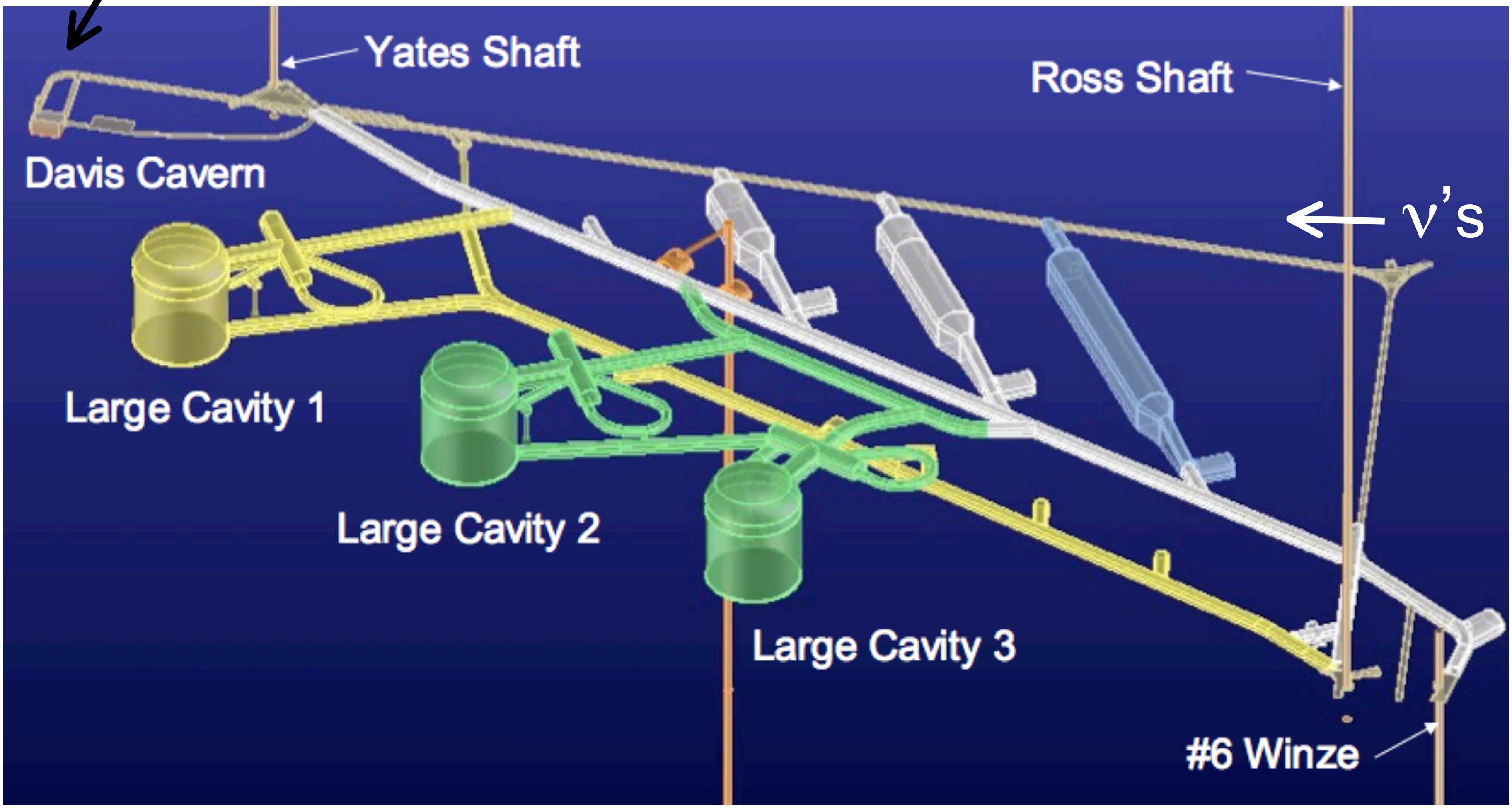
- none of the physics signatures requires a depth greater than 4850 ft (4290 mwe)

- **4850 ft depth** is sufficient to carry out an excellent physics program & takes best advantage of infrastructure & rock conditions at Homestake

Proposed 4850 L Campus

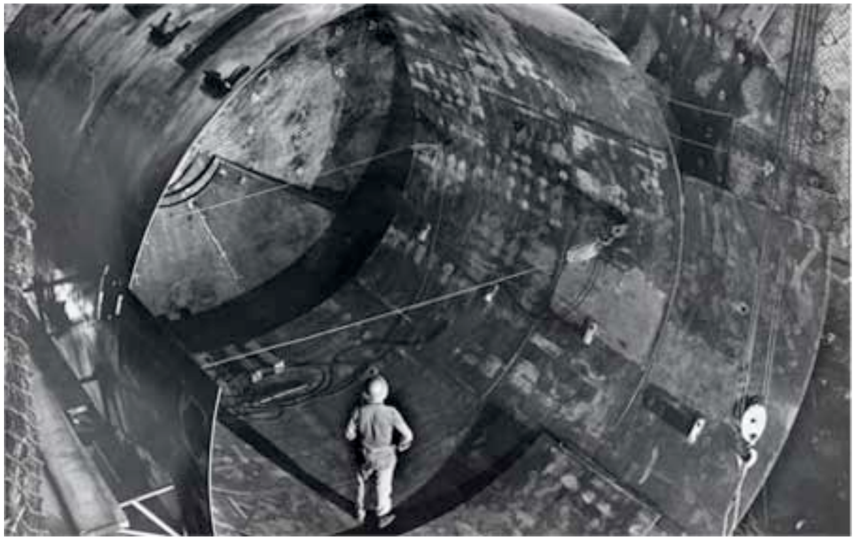
(conceptual layout)

Ray Davis cavern



Legacy of Science at Homestake

- 2002 Nobel Prize awarded to Davis for his Chlorine Experiment at Homestake's 4850 level.



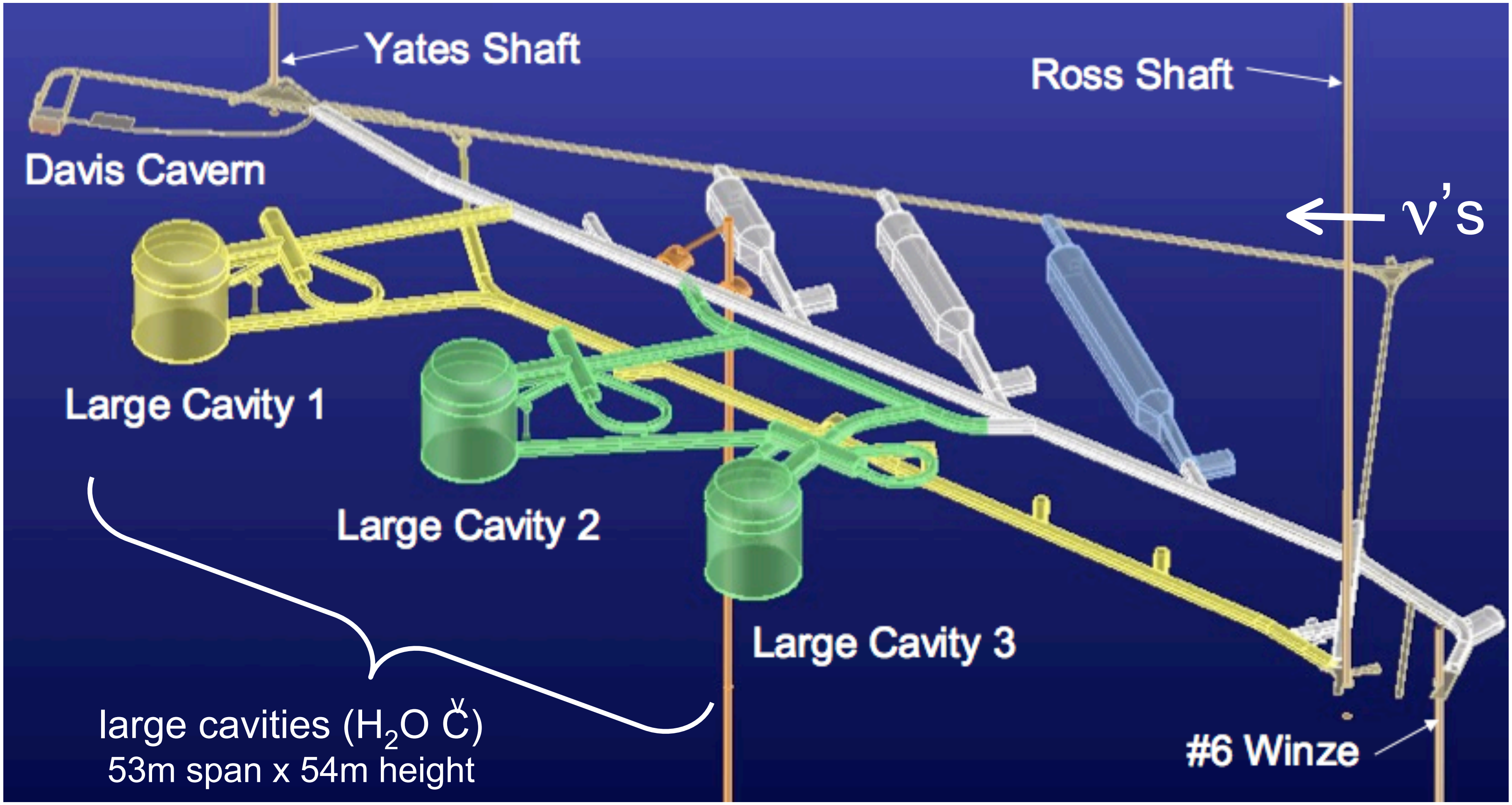
Ray Davis solar ν experiment under construction at Homestake in 1965 (100,000 gallons cleaning fluid)

Davis cavern: ~9m W x 8m H x 15m L

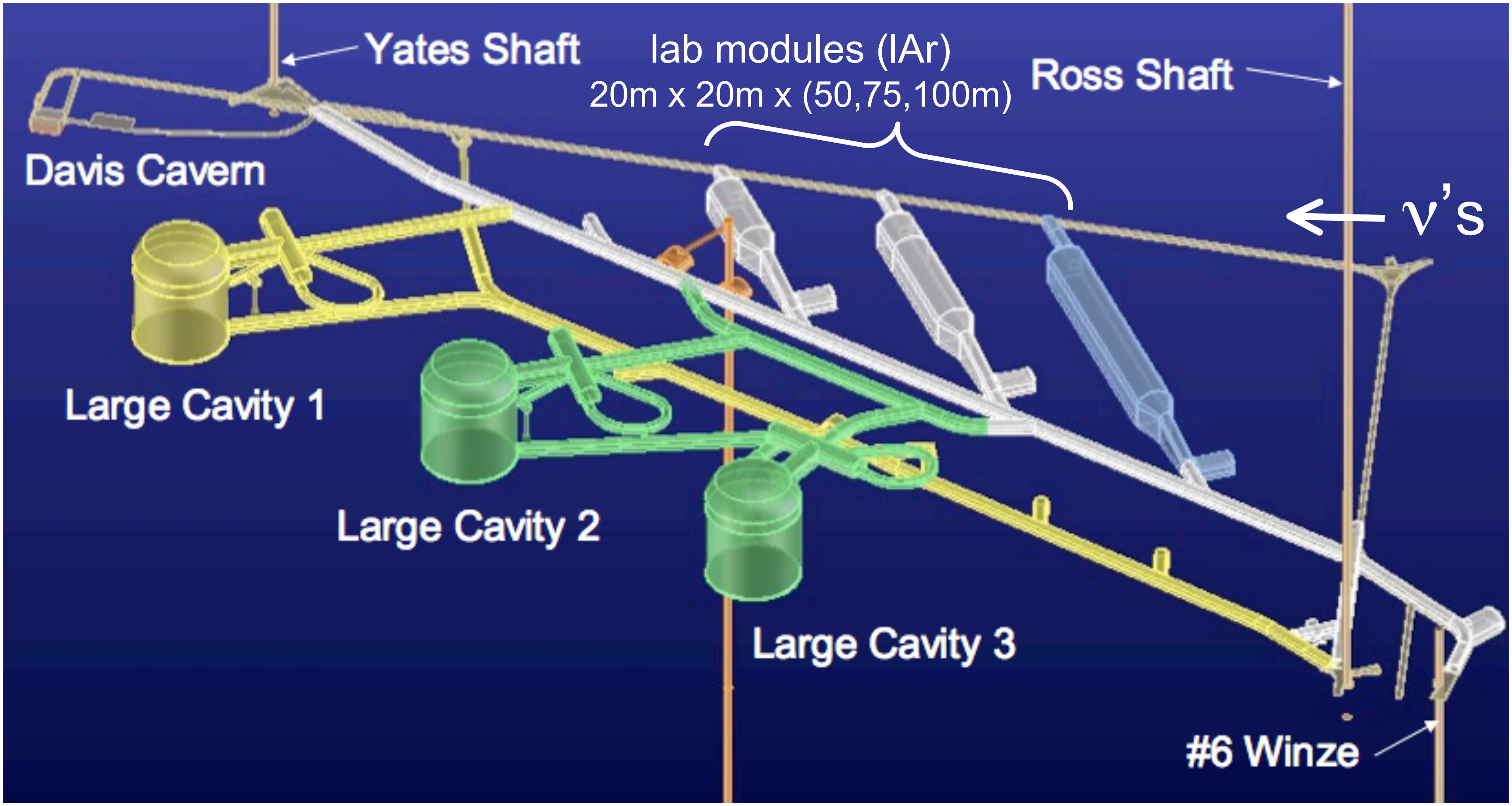
- Davis cavern is now dry
- SDSTA to host "early physics":
  - LUX (dark matter)
  - Majorana demonstrator (0νββ)

  (R. Johnson's talk on Monday)

Proposed 4850 L Campus



Proposed 4850 L Campus

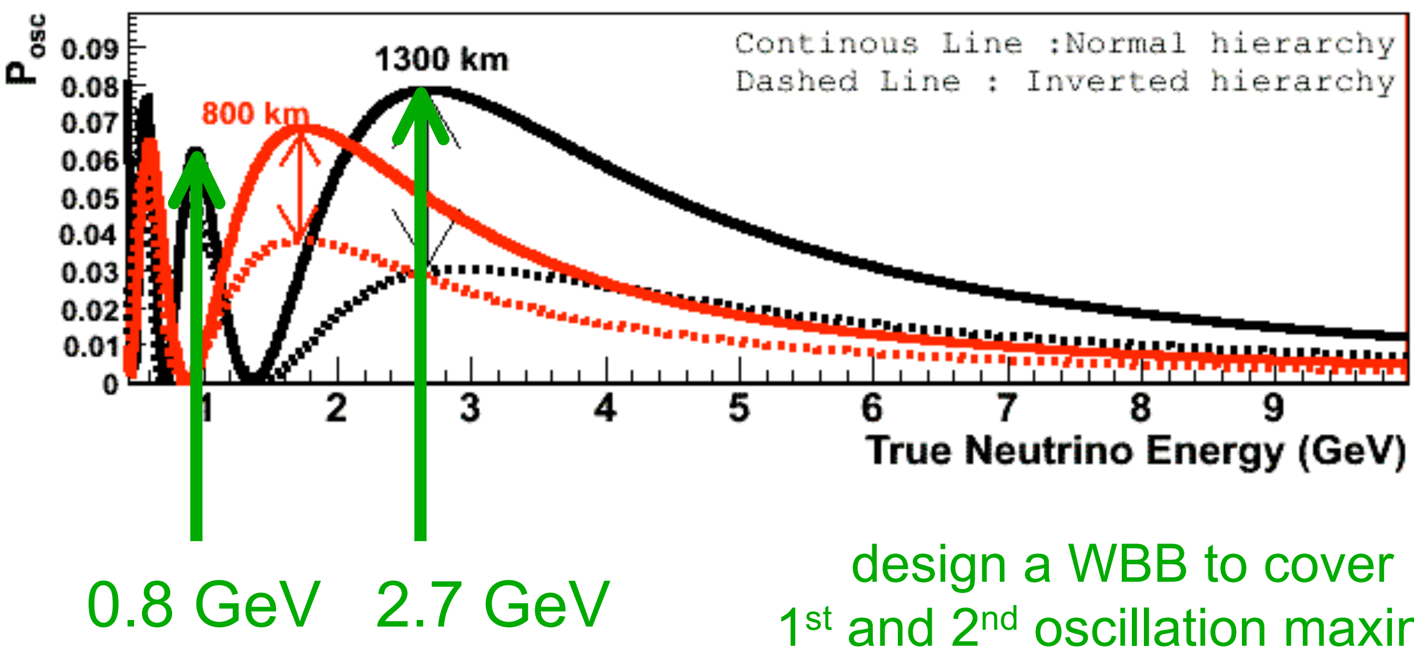


LBNE Ingredients

- so can measure θ_{13}, mass hierarchy, δ_{CP}
- long baseline and small $\nu_\mu \rightarrow \nu_e$ probability, requires:

(1) intense beam
(2) massive far detectors

(to provide sufficient event rates ideally ~100's ν_e events/yr)

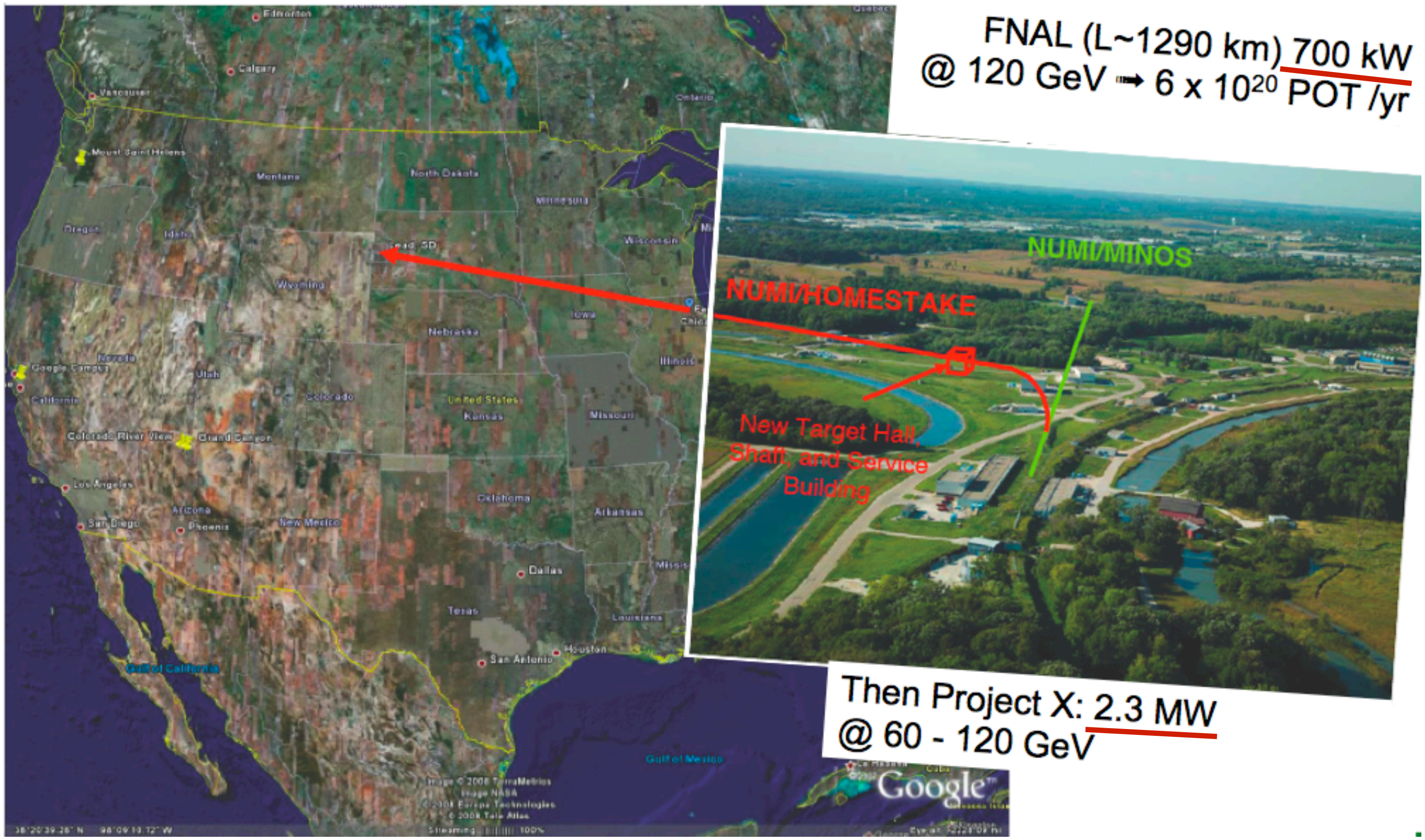


design a WBB to cover 1st and 2nd oscillation maxima

New Beam at FNAL

- beam WG lead by FNAL (V. Papadimitrio)
  - makes use of existing infrastructure at FNAL with upgrades

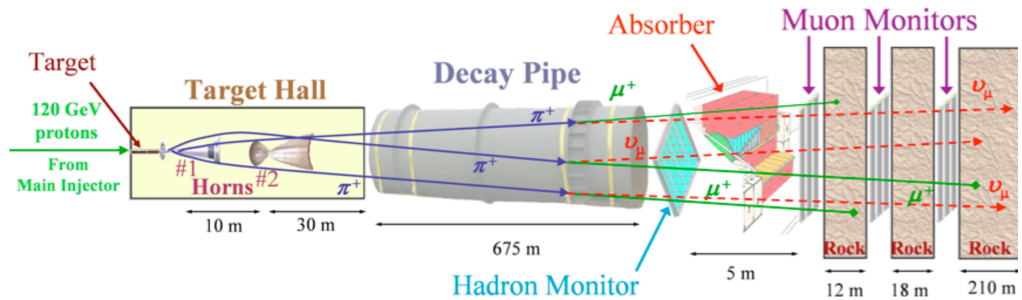
FNAL (L~1290 km) 700 kW
@ 120 GeV ➡ 6 x 10^{20} POT /yr



Then Project X: 2.3 MW
@ 60 - 120 GeV

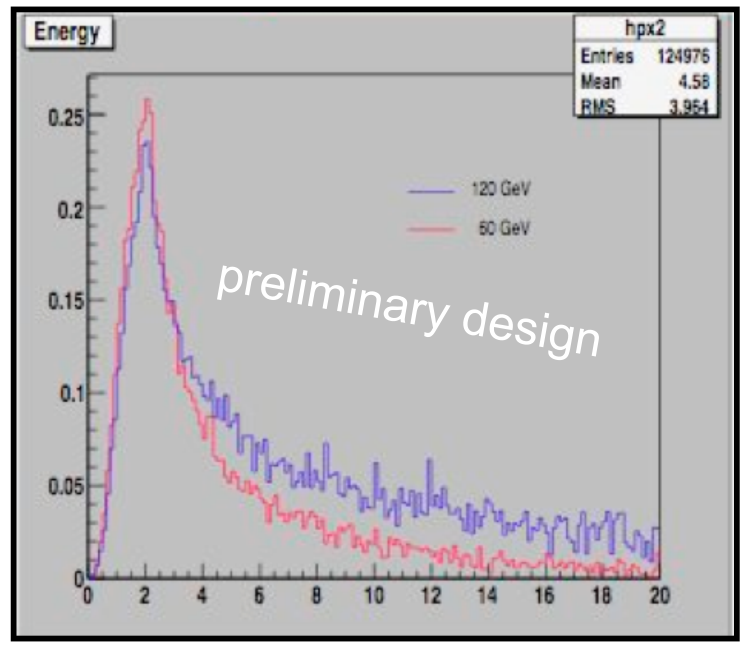
Neutrino Beam

- conceptual starting point is NuMI
  (considerable experience)



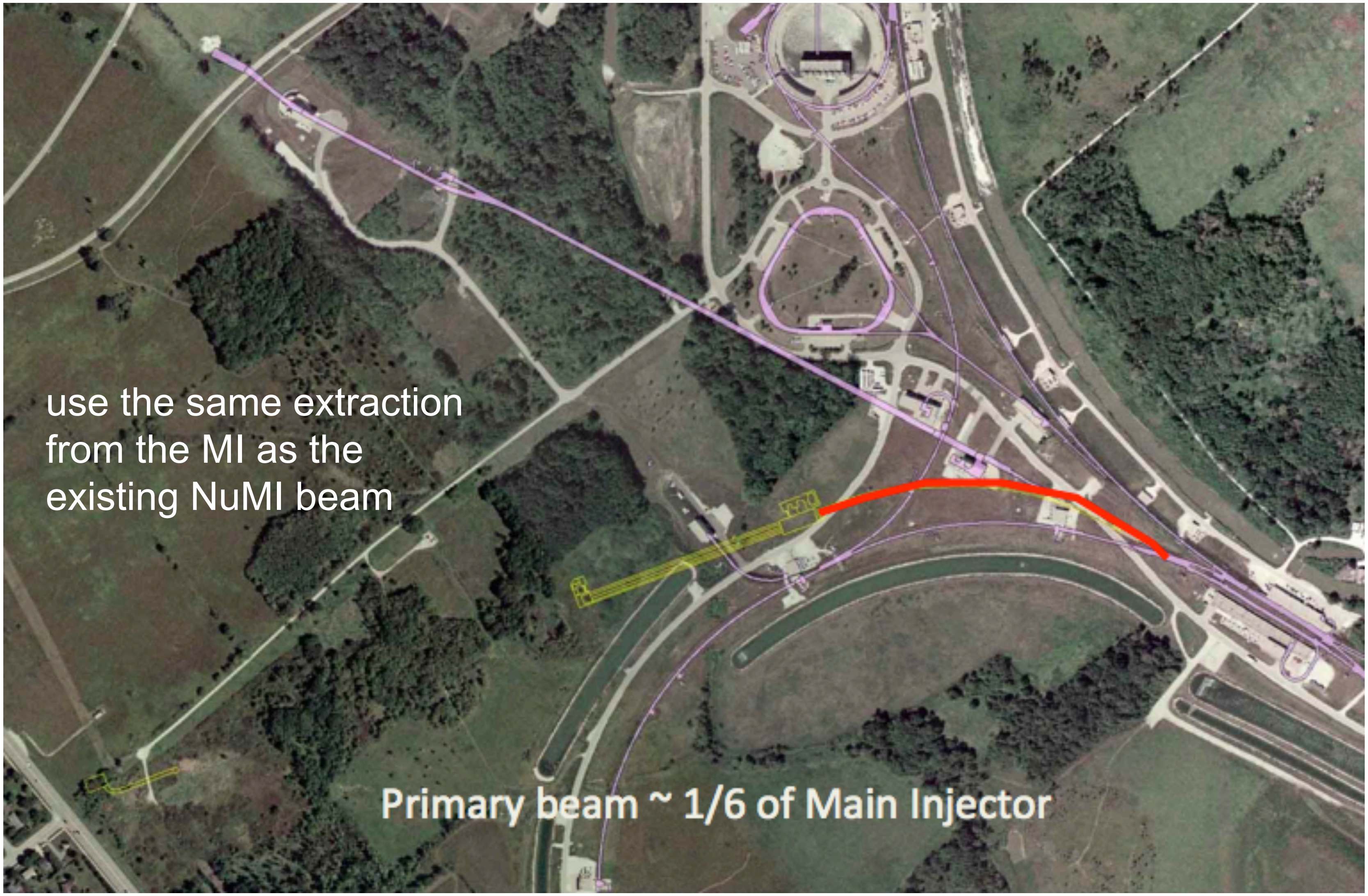
- design goal:
  - enhance low energy (2nd osc max)
  - reduce high energy tails (NC bkgs)

    - **NuMI** decay pipe: 750m long x 2m diameter
    - **LBNE** decay pipe: 250m long x 4m diameter

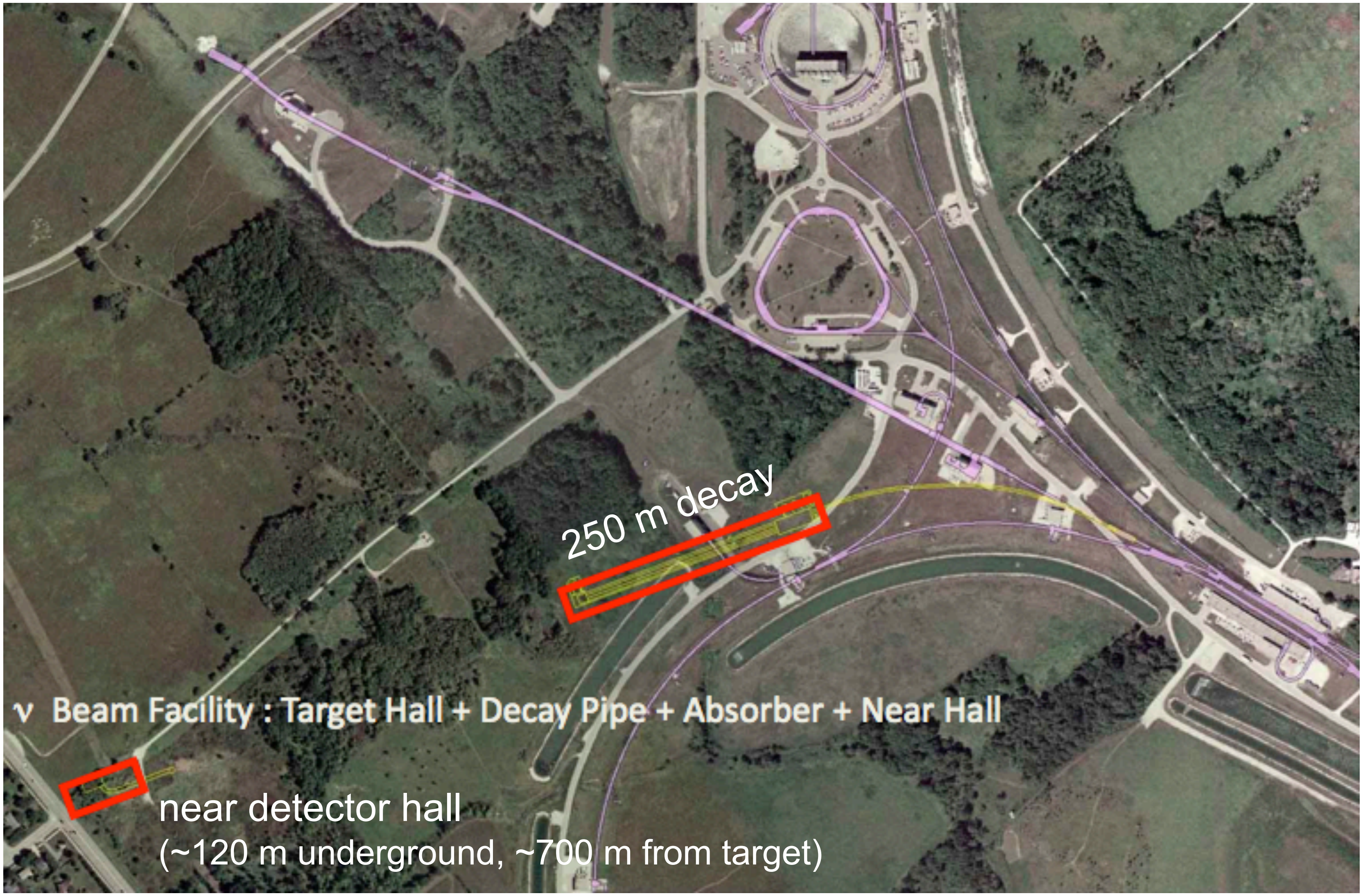


- **on-axis**: best broad-beam coverage
- still working on optimizing; preliminary cost estimates this fall

New Beam to Homestake

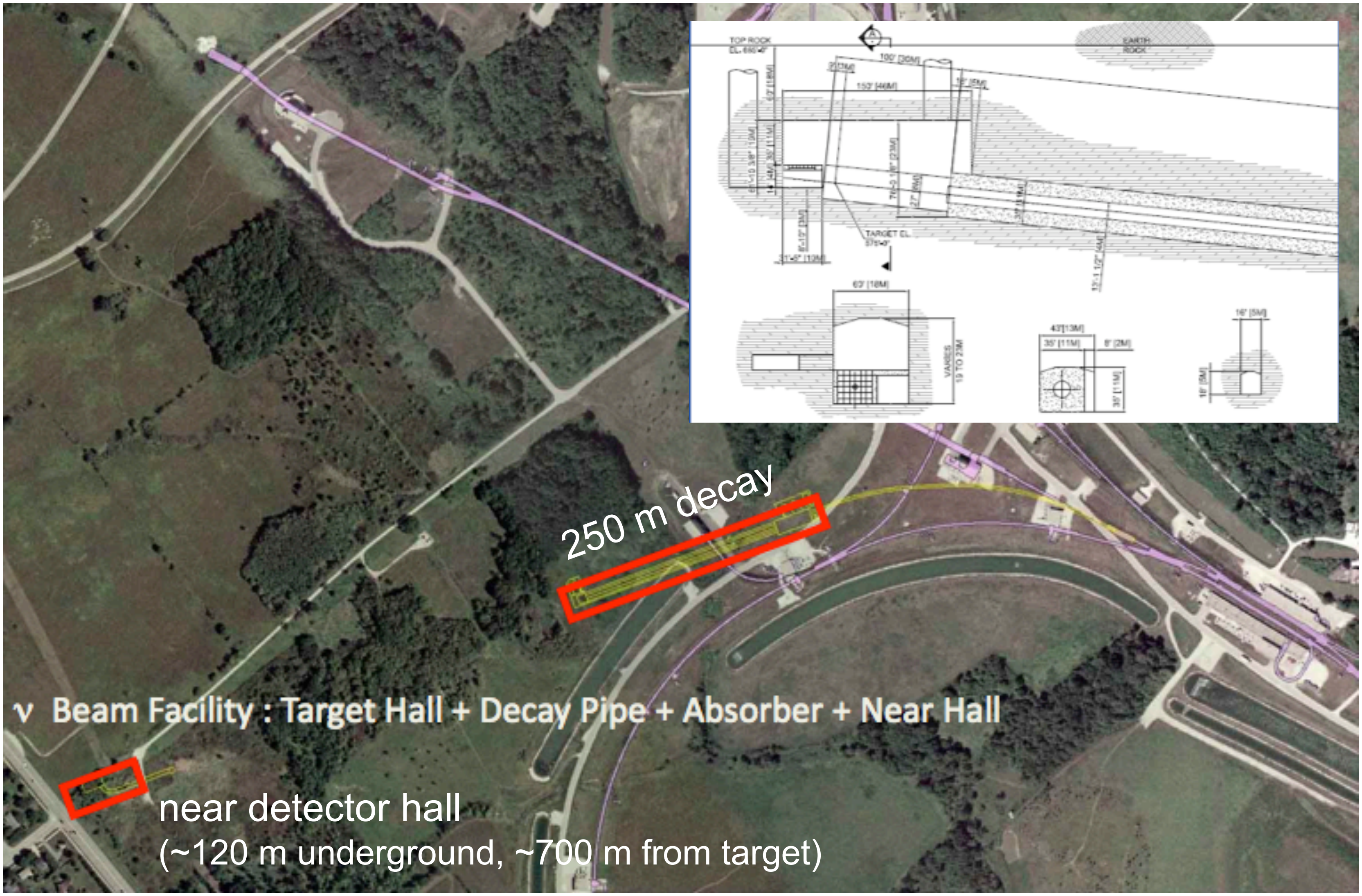


New Beam to Homestake



New Beam to Homestake

downward angle 5.8^0 to Homestake



Near Detector

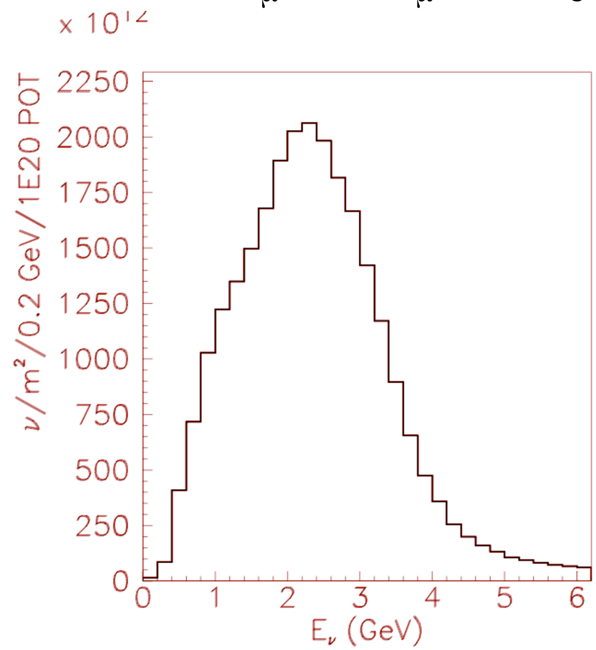
- near detector WG lead by LANL (C. Mauger)

- **main goals are to measure**:
  - intrinsic ν_e contamination in beam
  - ν_μ NC π^0 and NC γ
  - un-oscillated ν_μ spectrum
    (complicated by nuclear effects, transition region)

- both ν and $\overline{\nu}$
- same nuclear target as far detector
- dedicated flux measurements

- putting together strawman design
- developing for both H_2O Č and lAr

- flux of neutrinos at near detector (91% ν_μ, 8% $\overline{\nu}_\mu$, 1% ν_e)

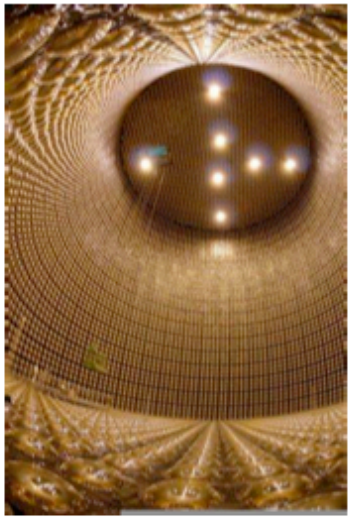


$<E_\nu> = 2.3$ GeV

Far Detector(s)

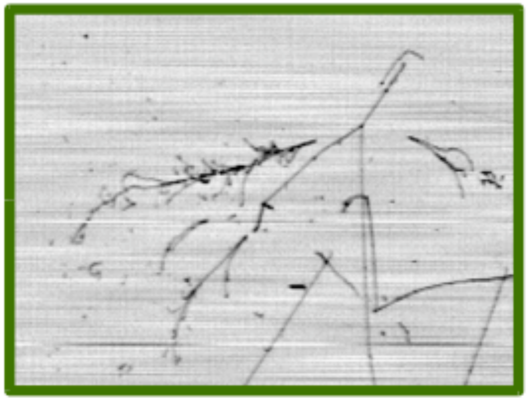
- 2 options under consideration for far detectors at DUSEL:

Water Cerenkov
imaging detector



(~100-300 kton)

Liquid Argon TPC
very fine-grained tracking detector



(~20-60 kton)

- must have a life cycle of ~10 years; both are complementary
- if affordable, combination of both detectors would be very powerful
- either one is an enormous detector …

Size?

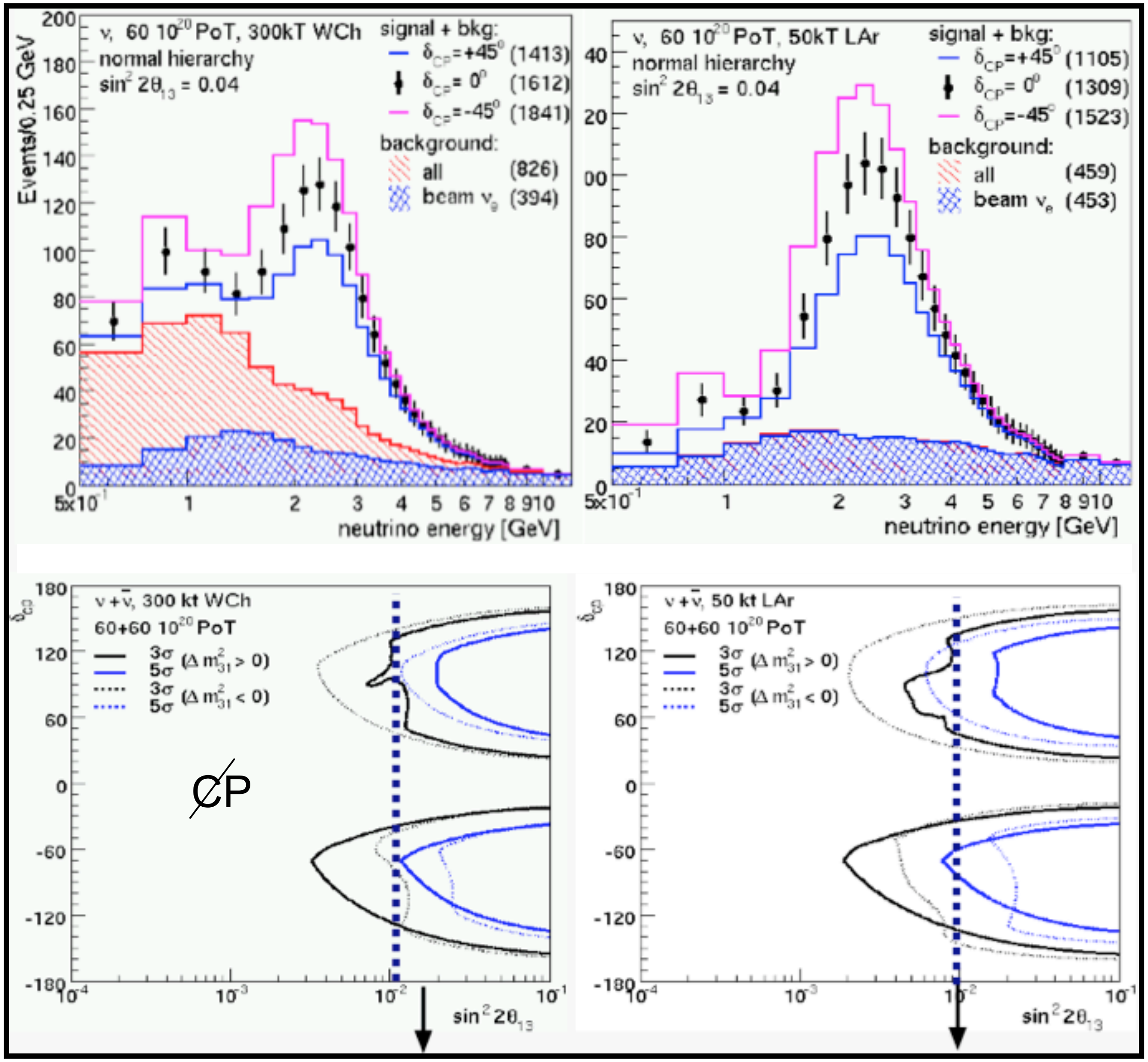
(driven by the physics)

- assuming preliminary WBB design for LBNE (based on NuMI focusing system)

- 120 GeV
- 5% bkg uncertainty
- $\nu + \bar{\nu}$

- with lAr, seems can do same amount of physics with ~1/6 the detector

300kT H_2O Cerenkov 50kT liquid argon



(M. Dierckxsens, 2008)

Pros and Cons

Water Cerenkov

- known technology
  (could be built with little R&D)
- 2-3x Super-K
- lower efficiency, higher bkgs
- excavate large caverns, PMT procurement issues

extensive experience in construction & operation
(well known technology perfected over last 3 decades)

Liquid Argon

- not proven at the required size
  (requires substantial R&D)
- 100x scale
- higher efficiency, lower bkgs
  (due to excellent e^- vs. π^0 (γ) separation)
- technical risks, safety issues, unknown cost

high granularity of detector means high ε for important physics goals

Water Cerenkov WG Leaders

J. Stewart (BNL)

- **water containment**: F. Feyzi (PSL, UW)
- **water system**: R. Bionta (LBNL), H. Sobel (UCI)
- **PMT characterization**: J. Klein (UPenn)
- **electronics**: E. Kearns (BU), R. Van de Berg (UPenn)
- **simulations**: C. Walter (Duke)

- regular meetings
- S4 proposal recently funded

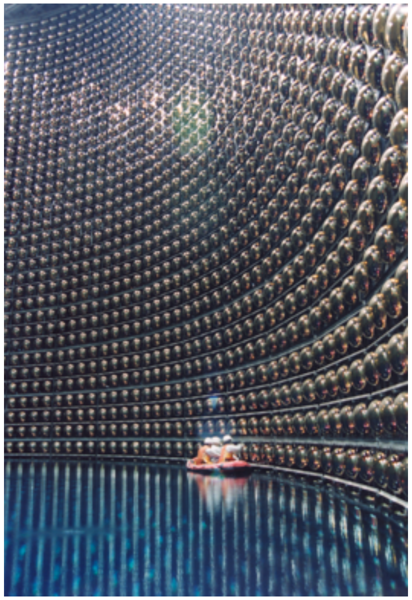
Far Detector: Water Cerenkov

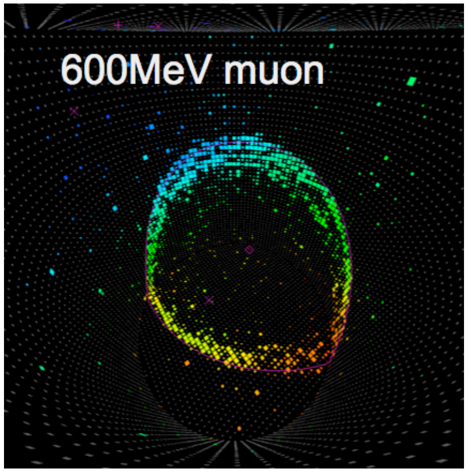
compare to largest operating water Č with
a completely man-made detector volume

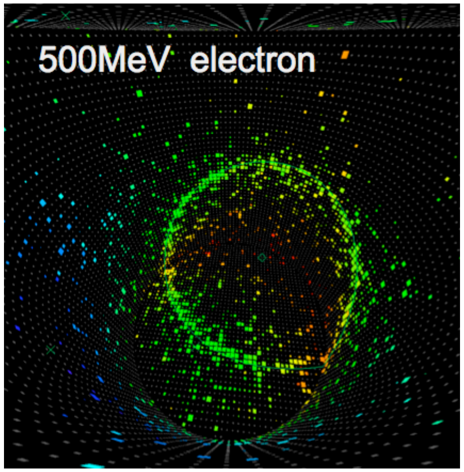
- **Super-K**
  - 50 kton total mass
  - 11k 20” PMTs
  - 40% coverage
  - 39m diameter x 42m height

- **LBNE** (subject to change)
  - 3 x 100 kton FV modules
  - 60k 10-12” PMTs (per 100 kton)
  - 25% coverage
  - 50m diameter x 50m height

2-3 x Super-K
~ twice as deep





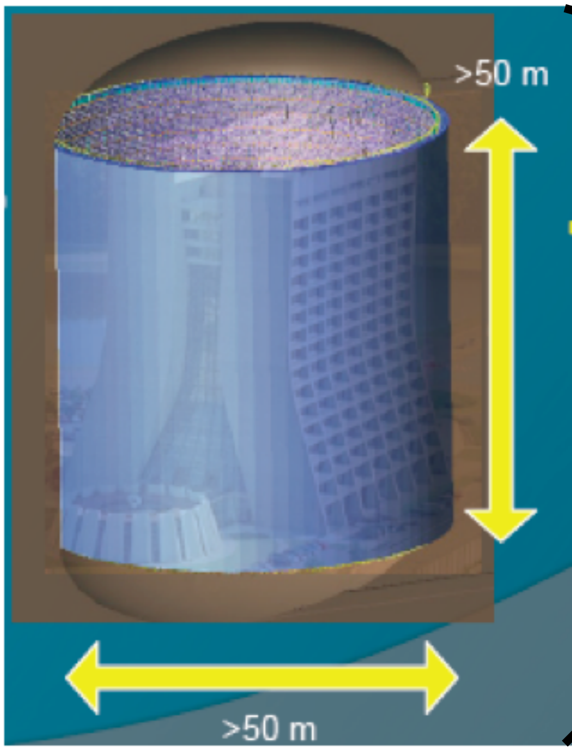


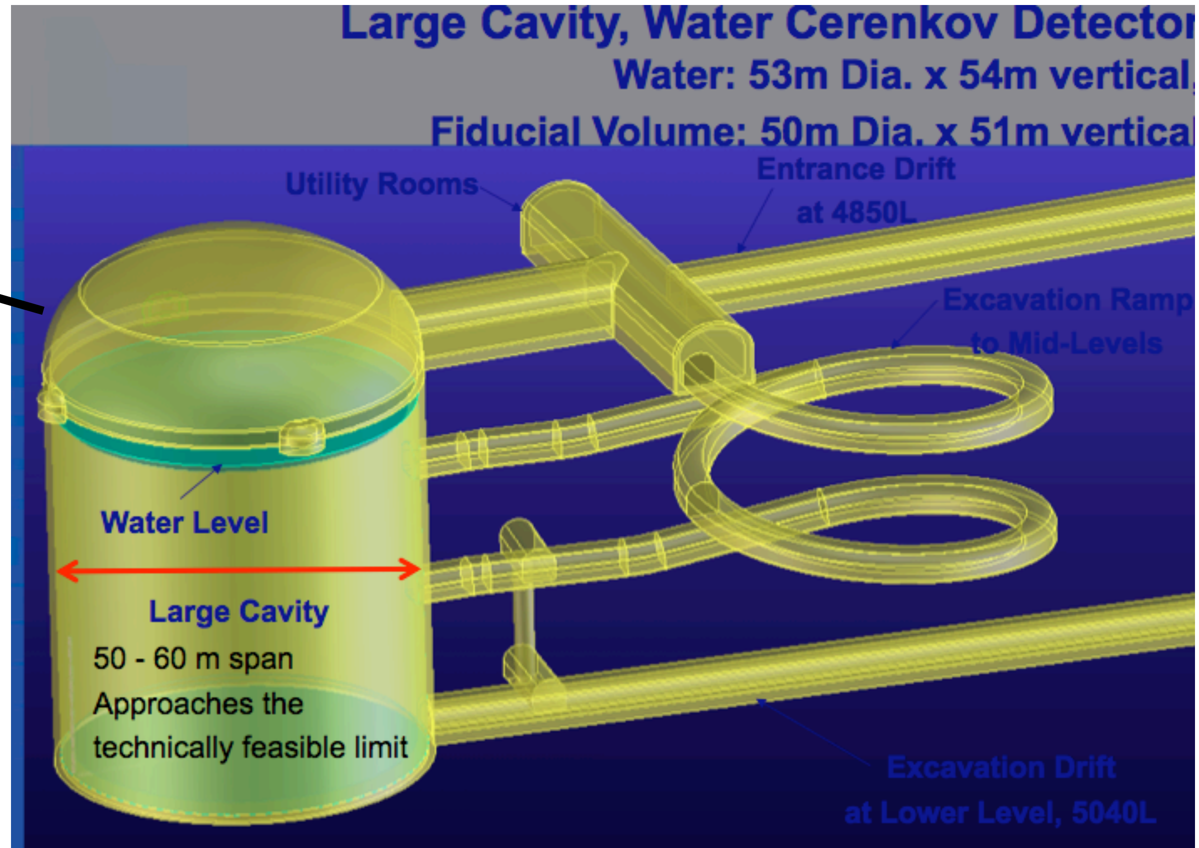
R7081 (10 inch)
R7081-20 (14-ST)
Fits for 13 inch
Glass Sphere

Large Cavity Design

R. Kadel (LBL)

- cylindrical cavern
- 1 module = 100 kton
  (3x100 kton = 300 kton)





- excavation could start as early as 2013
- ~6 yrs to complete 1st module (8 yrs for all 3)

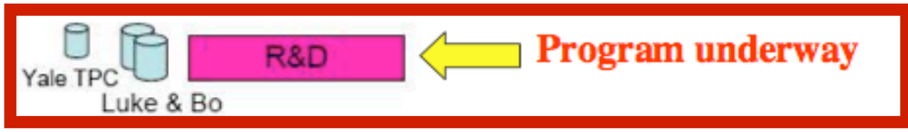
Liquid Argon WG Leaders

B. Baller (FNAL)

- **physics reach (simulations)**: B. Fleming (Yale)
- **cavern**: C. Laughton (FNAL)
- **cryostat, purification**: J. Urheim (IU)
- **TPC/HV, photon detectors**: H. Wang (UCLA), B. Yu (BNL)
- **electronics**: C. Thorne (BNL), R. C. Bromberg (MSU)
- **installation, commissioning, operation**: B. Miller (Minn)
- **life safety, ES&H**: R. Poling (Minn)

- regular meetings

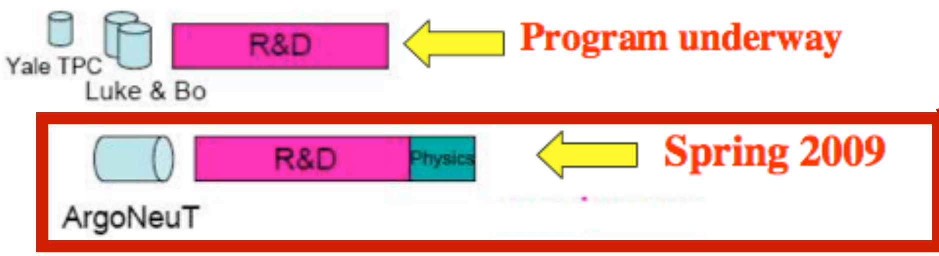
Phased Program for lAr



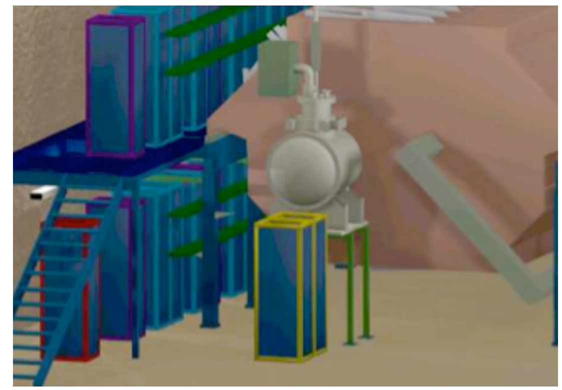
small test stands
at FNAL, Yale

• 0.01 ton

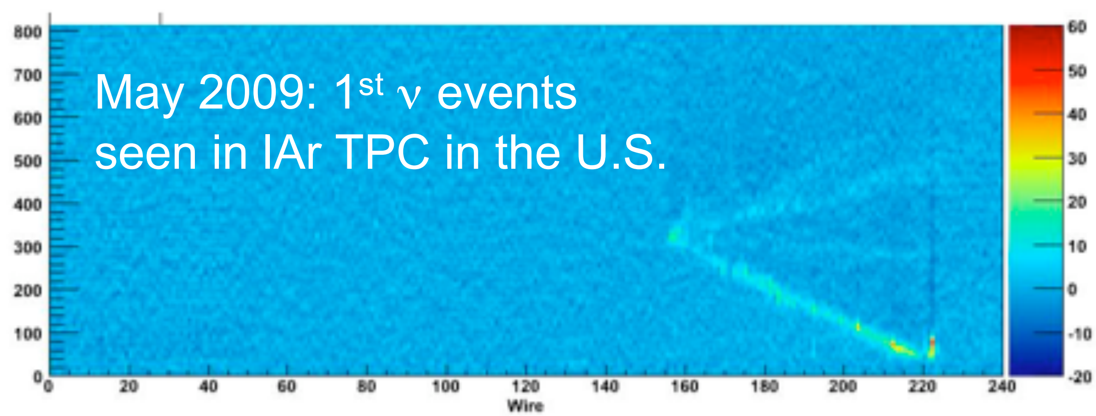
Phased Program for lAr



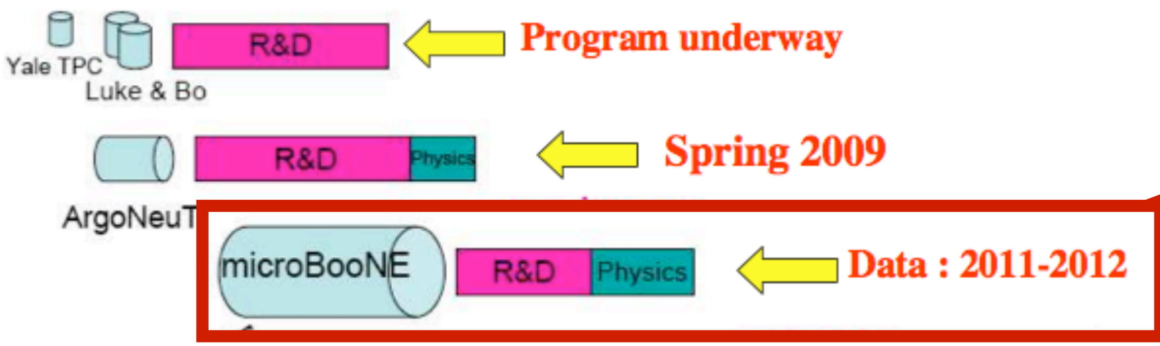
ArgoNeuT



- 0.3 ton total, 50 cm drift
- 500 channels
- funded by NSF/DOE
- NuMI beam
- largest lAr TPC currently operating in the U.S.
- goals: gain experience in operating underground & develop simulation tools

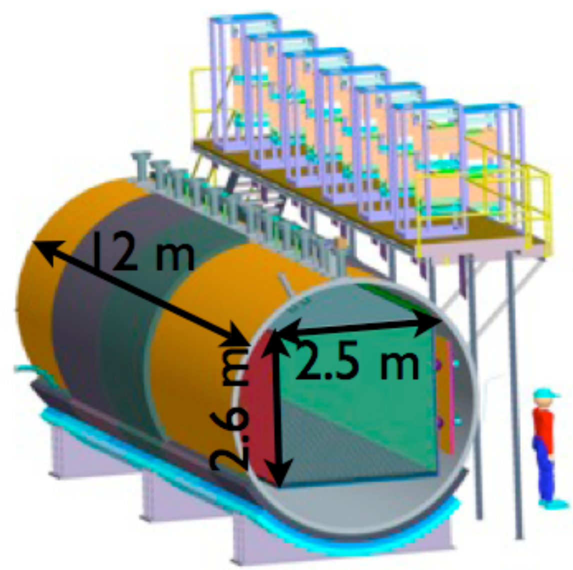


Phased Program for lAr

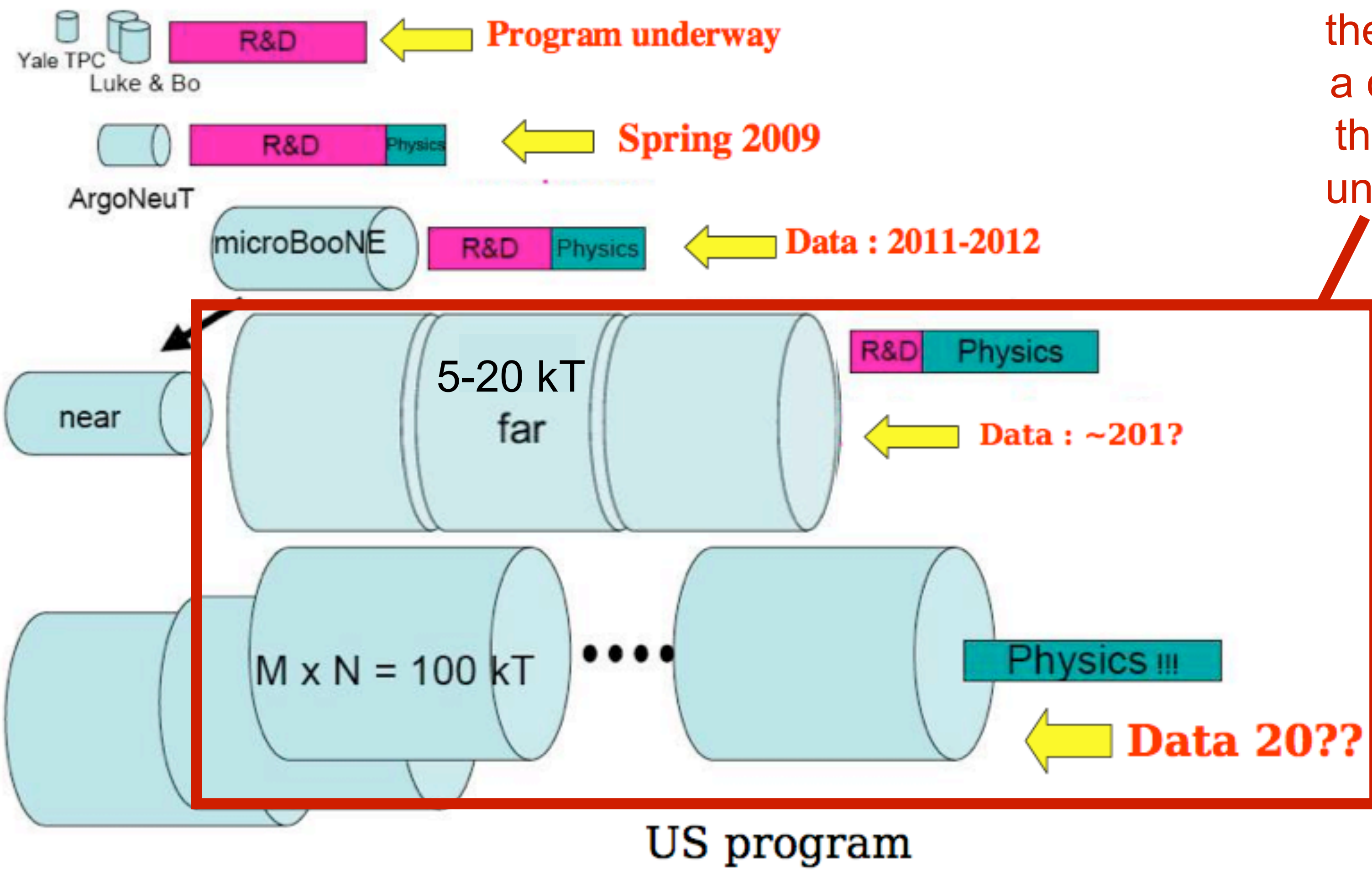


MicroBooNE

- 170 ton total, 2.5 m drift distance
- 10,000 channels
- received stage 1 approval from FNAL in design phase now (DOE CD process)
- BNB beam + off-axis ν's from NuMI
- next step in pushing the technology; R&D towards full-scale DUSEL detector



Phased Program for lAr

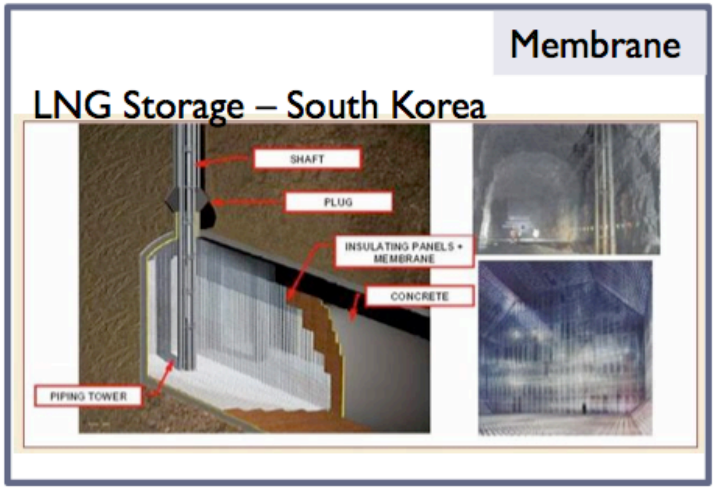


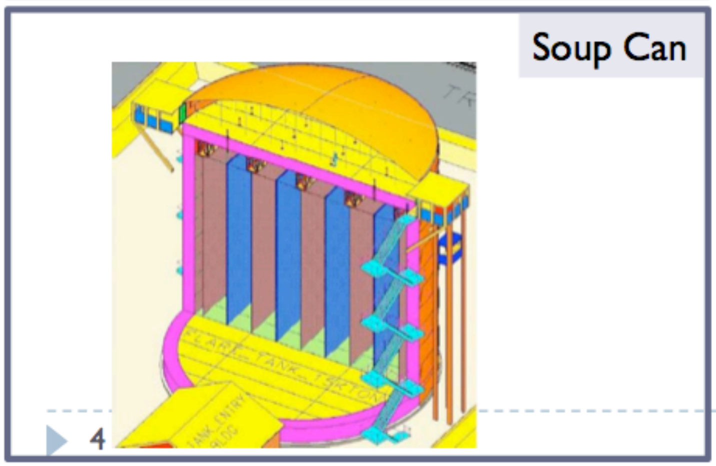
demonstration of the technology is a crucial step on the way to large underground LAr detectors

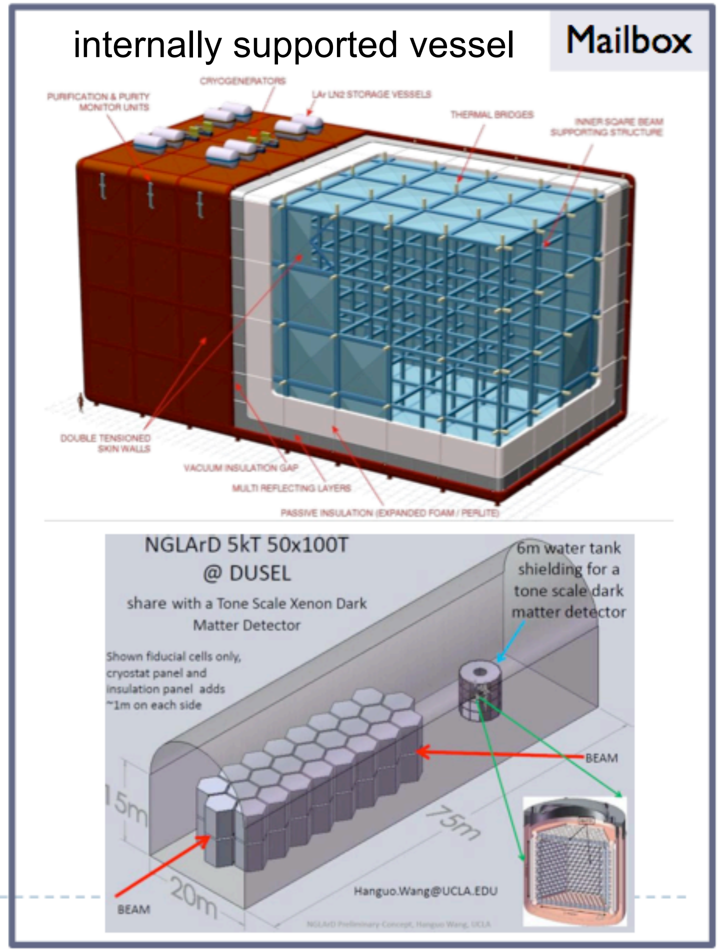
(want to approach in a staged way)

Far Detector: Liquid Argon

- several design options; lots of people actively looking into this
  (subject to change)



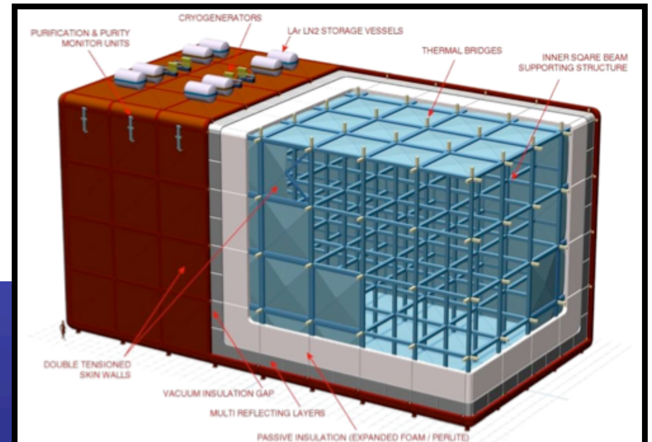




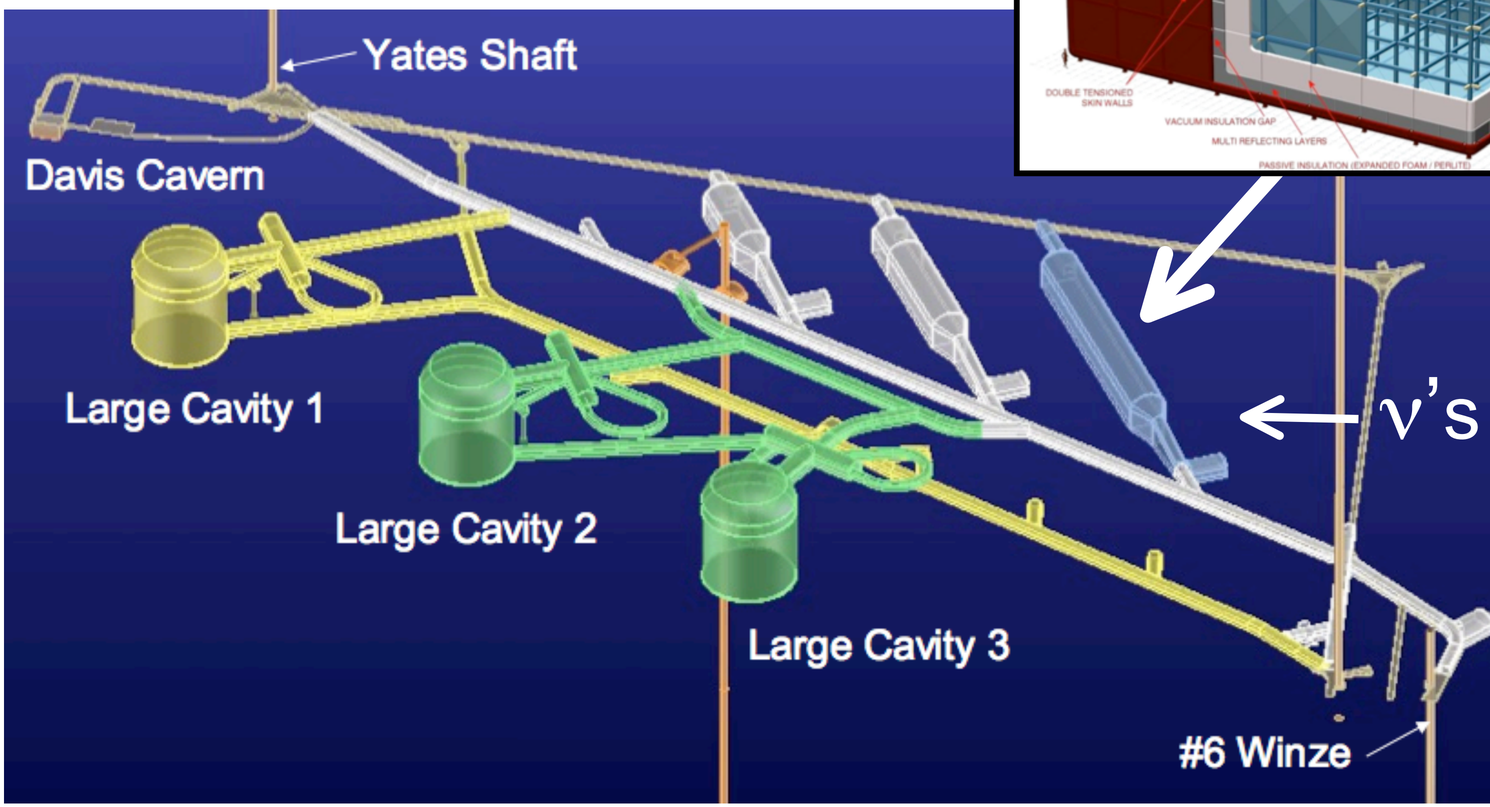
- 1st step in terms of physics for LBNE is 20 kton (17kton FV)

DUSEL Lab Modules

• lAr can fit nicely into one of planned modules
(20m wide x 20m high with vaulted ceiling)



(LANDD design,
D. Cline *et al.*,
astro-ph/0604548



4850 L campus

Timeline for LBNE Project

• currently starting the design process for the project
(includes works on the ν beamline, near detector, far detectors)

- CD-0 (hopefully) later this year
- CD-1 baseline design (2010-2012)

• we're getting going
• funding is starting to come in for this initial design work

• good time to get involved!

Find Out More

- **major workshop on DUSEL science** (Oct 1-3 in Lead, SD)
  - scientists interested in proposing underground experiments

- **LBNE collaboration meeting** (Oct 4-6 in Lead, SD)
  - those interested in long baseline ν physics
  - will include tour of the mine
  - encourage you to attend!
    (challenging problems need to work out, lively group of very smart people)

http://www.sanfordlab.org

Conclusions

- since the discovery of neutrino oscillations, our understanding of ν masses & mixing has improved dramatically
- in the near future, hope to have indications of non-zero θ_{13} $\sin^2 2\theta_{13} > 0.01$ (Double CHOOZ, Daya Bay, T2K, NOvA)
- next big goals: ν mass hierarchy, CP
- longer baselines & massive detectors
  - **LBNE** in U.S., **T2KK** in Japan
  - very challenging projects to build, but have the potential for big pay-off (+ proton decay, solar & SN ν's, surprises?)

- committed group of scientists working to design & build LBNE
  - have started thinking about next steps … come join us!