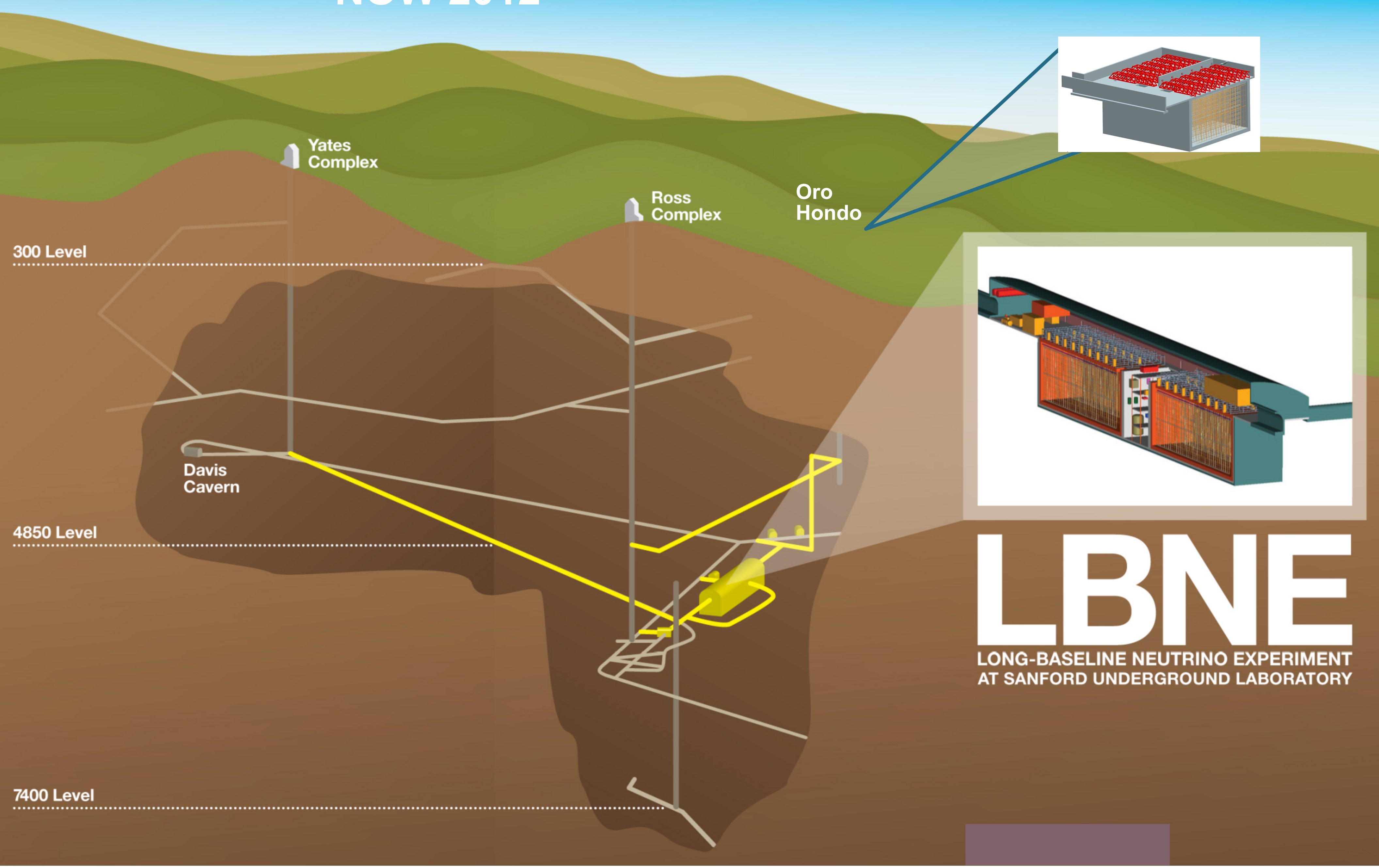
The Long-Baseline Neutrino Experiment

Kate Scholberg, Duke University

NOW 2012



Long-Baseline Neutrino Experiment Collaboration

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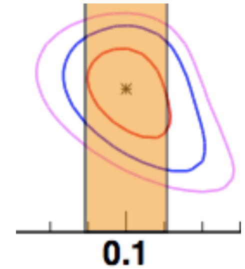
Yale: E.Church, B.Fleming, R.Guenette, K.Partyka, A.Szelc

347 Members
59 Institutions
25 US States
5 Countries

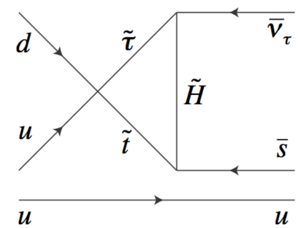
19 July 2012 (347)

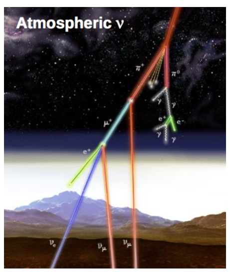
Physics Motivations

- Mass hierarchy and CP violation



- Baryon number violation





- Atmospheric neutrinos (oscillations)

- Supernova burst neutrinos

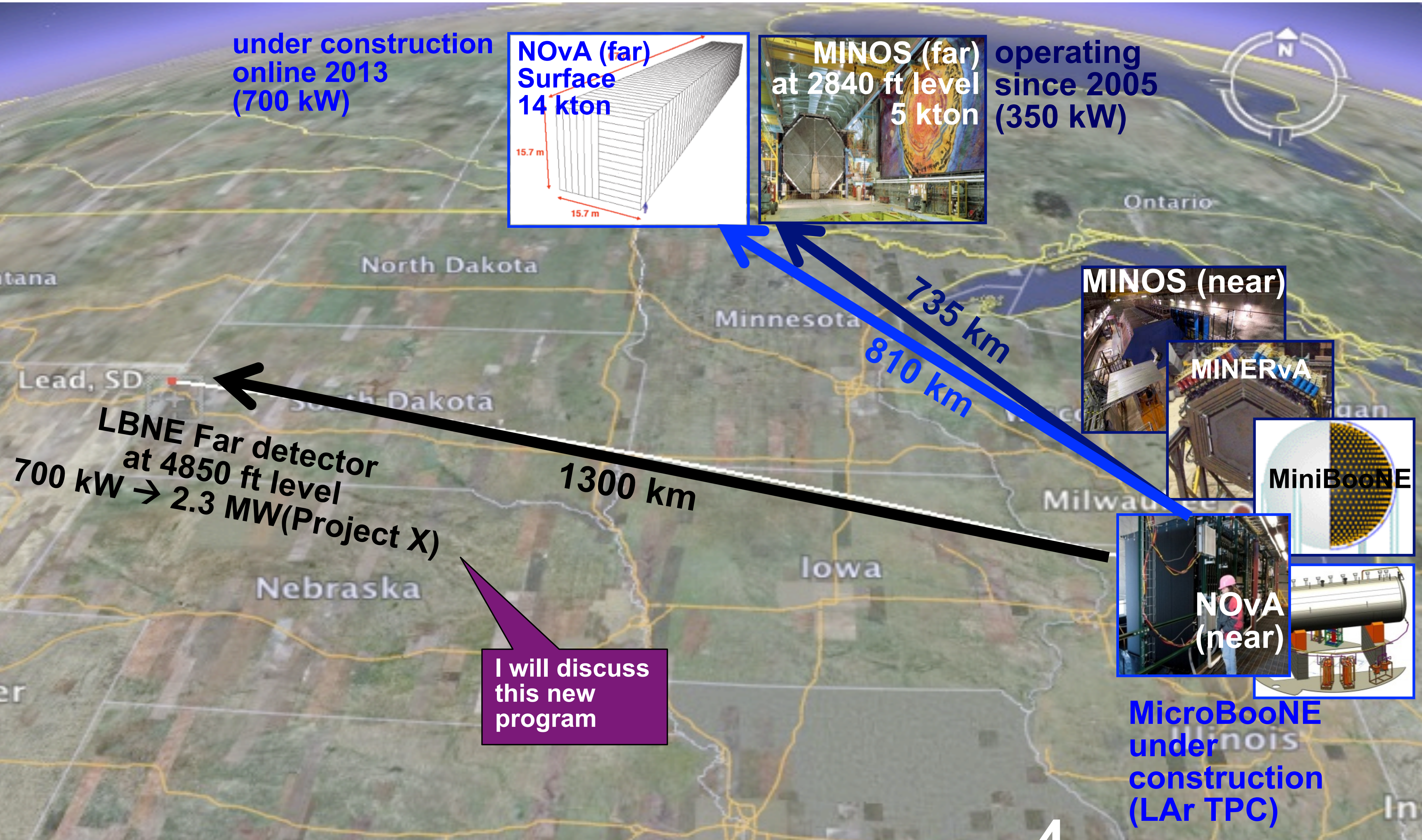
- Supernova relic neutrinos

- Solar neutrinos

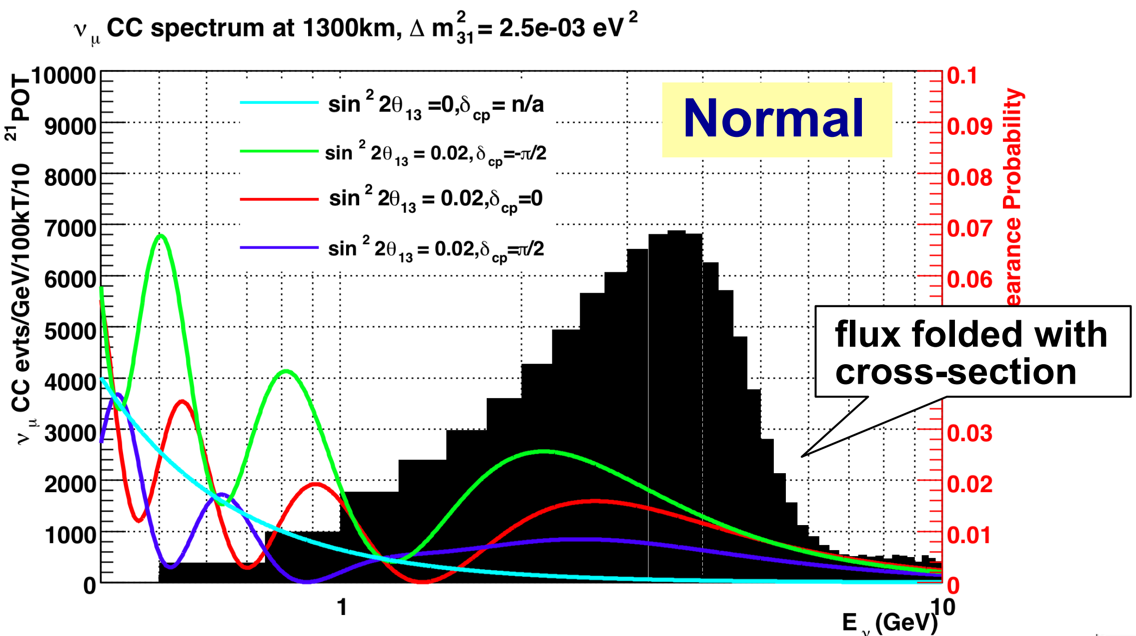
...

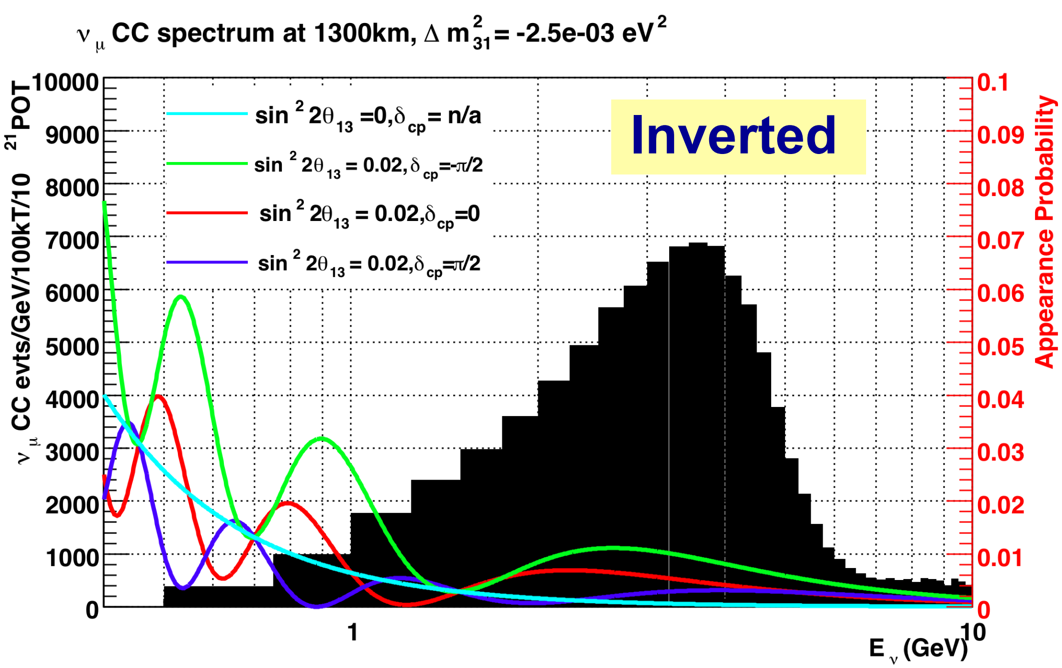
LBNE: Next-Generation Oscillation Experiment in the U.S.

MINOS(2005-~2015) → NOvA(2013-~2022)

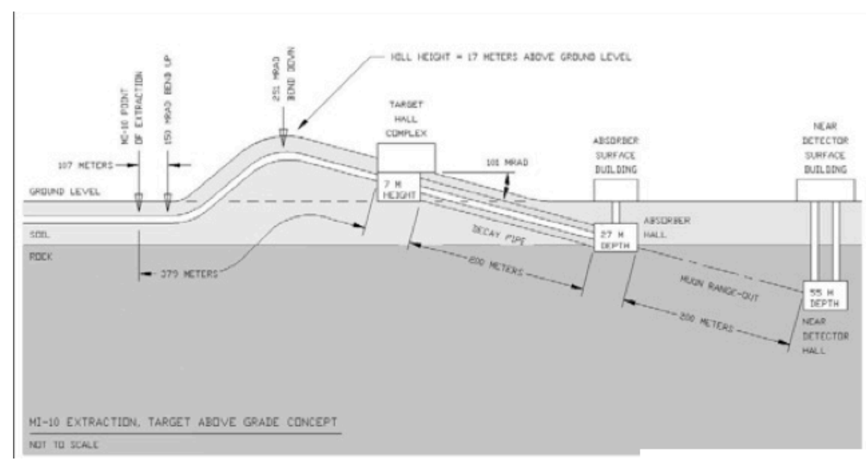


LBNE beam





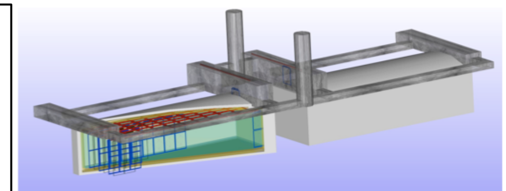
1300 km baseline,
new 700 kW beam,
6.8 x 10^{20} POT/year
designed to cover oscillation maxima

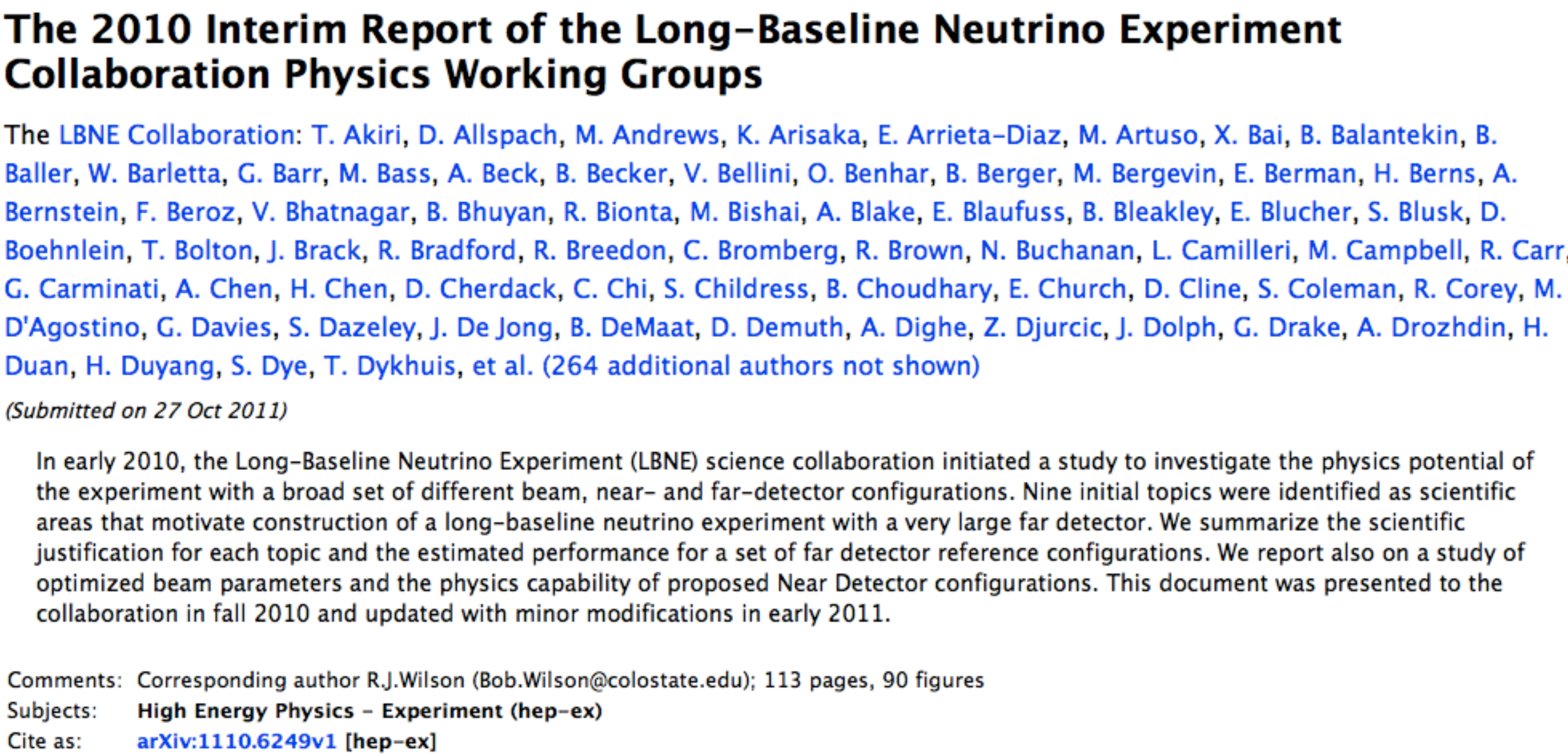


LBNE Physics Study

2010 2011 2012

Under consideration:
100-300 kt water Cherenkov, 17-51 kt LAr
(collaboration preference for combination)




The 2010 Interim Report of the Long-Baseline Neutrino Experiment Collaboration Physics Working Groups

The LBNE Collaboration: T. Akiri, D. Allspach, M. Andrews, K. Arisaka, E. Arrieta-Diaz, M. Artuso, X. Bai, B. Balantekin, B. Baller, W. Barletta, G. Barr, M. Bass, A. Beck, B. Becker, V. Bellini, O. Benhar, B. Berger, M. Bergevin, E. Berman, H. Berns, A. Bernstein, F. Beroz, V. Bhatnagar, B. Bhuyan, R. Bionta, M. Bishai, A. Blake, E. Blaufuss, B. Bleakley, E. Blucher, S. Blusk, D. Boehnlein, T. Bolton, J. Brack, R. Bradford, R. Breedon, C. Bromberg, R. Brown, N. Buchanan, L. Camilleri, M. Campbell, R. Carr, G. Carminati, A. Chen, H. Chen, D. Cherdack, C. Chi, S. Childress, B. Choudhary, E. Church, D. Cline, S. Coleman, R. Corey, M. D'Agostino, G. Davies, S. Dazeley, J. De Jong, B. DeMaat, D. Demuth, A. Dighe, Z. Djurcic, J. Dolph, G. Drake, A. Drozhdin, H. Duan, H. Duyang, S. Dye, T. Dykhuis, et al. (264 additional authors not shown)

(Submitted on 27 Oct 2011)

In early 2010, the Long-Baseline Neutrino Experiment (LBNE) science collaboration initiated a study to investigate the physics potential of the experiment with a broad set of different beam, near- and far-detector configurations. Nine initial topics were identified as scientific areas that motivate construction of a long-baseline neutrino experiment with a very large far detector. We summarize the scientific justification for each topic and the estimated performance for a set of far detector reference configurations. We report also on a study of optimized beam parameters and the physics capability of proposed Near Detector configurations. This document was presented to the collaboration in fall 2010 and updated with minor modifications in early 2011.

Comments: Corresponding author R.J.Wilson (Bob.Wilson@colostate.edu); 113 pages, 90 figures
Subjects: **High Energy Physics - Experiment (hep-ex)**
Cite as: **arXiv:1110.6249v1 [hep-ex]**

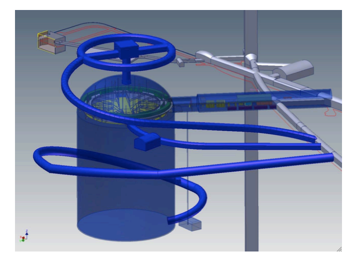
A lot has happened since then...

2010 2011 2012

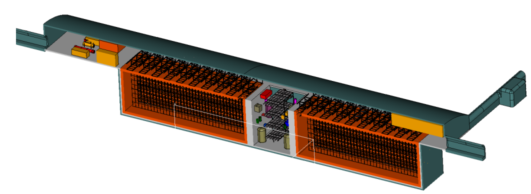
National Science Foundation will not build DUSEL

Further reports affirming science case (NRC/BPA, Marx/Reichenadter)

Becomes clear that both technologies are not affordable

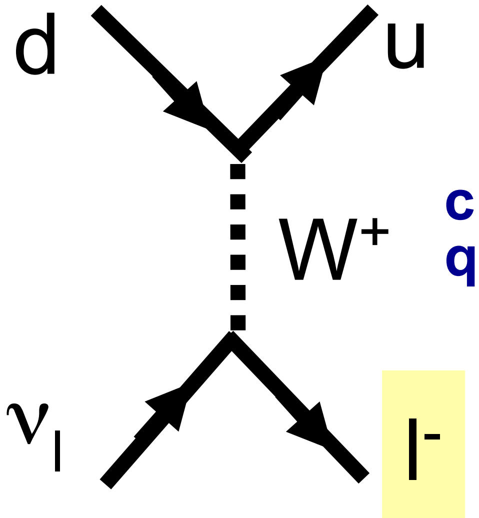


vs



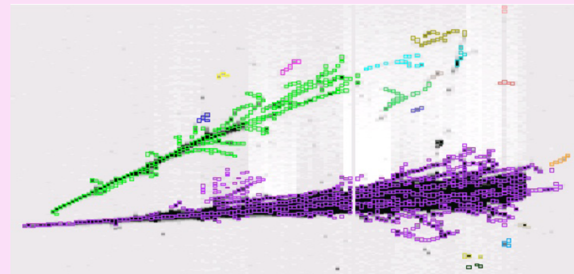
What you're looking for experimentally:

electron flavor appearance **on top of background**
(NC, beam ν_e, mis-ids)

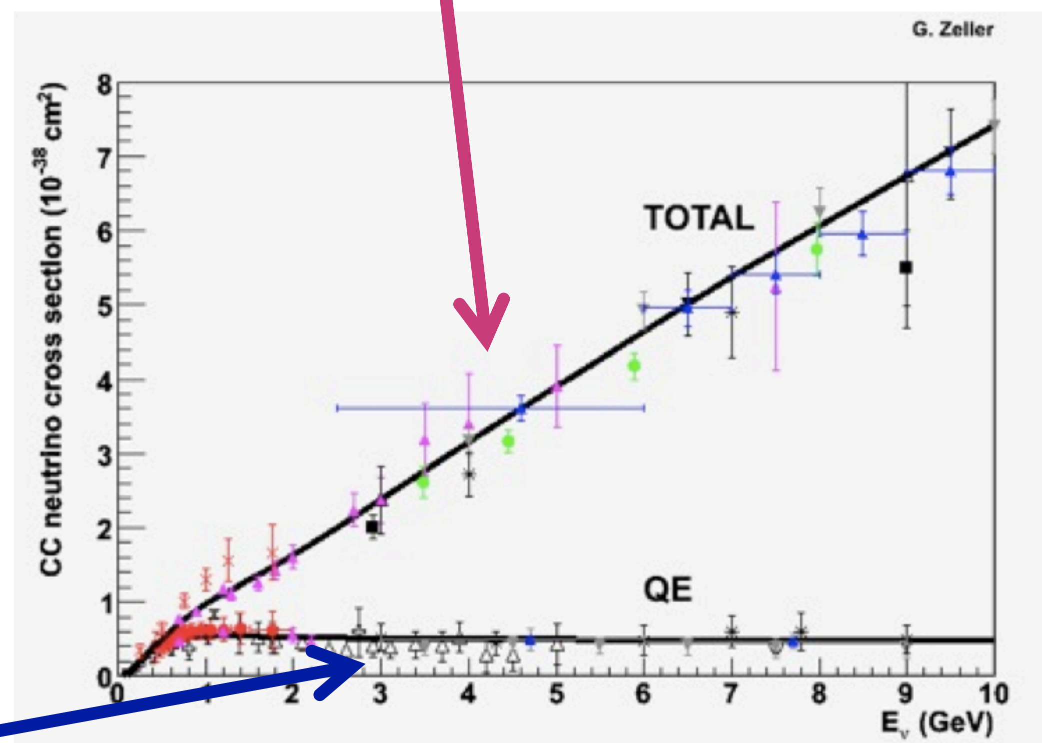


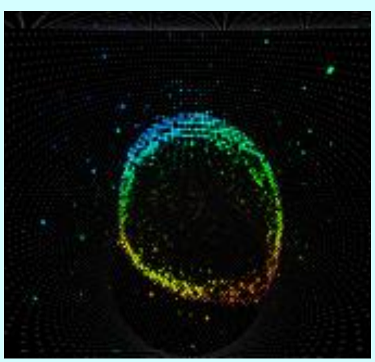
charged-current quasi-elastic

$$\nu_l + N \rightarrow l^{\pm} + N'$$



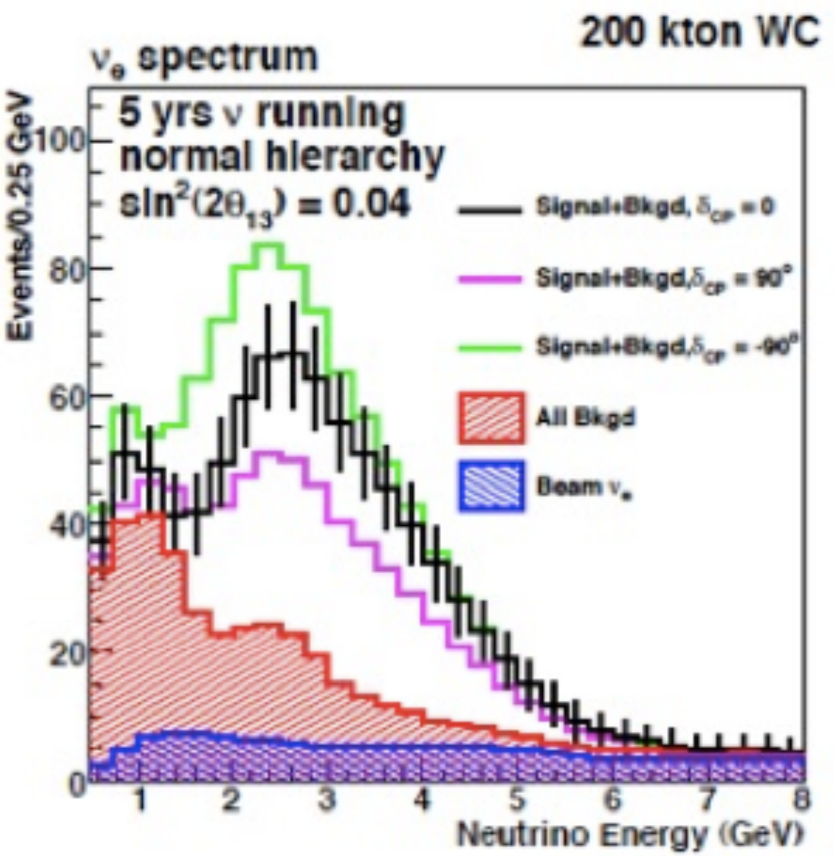
A LAr detector (in principle) reconstructs everything

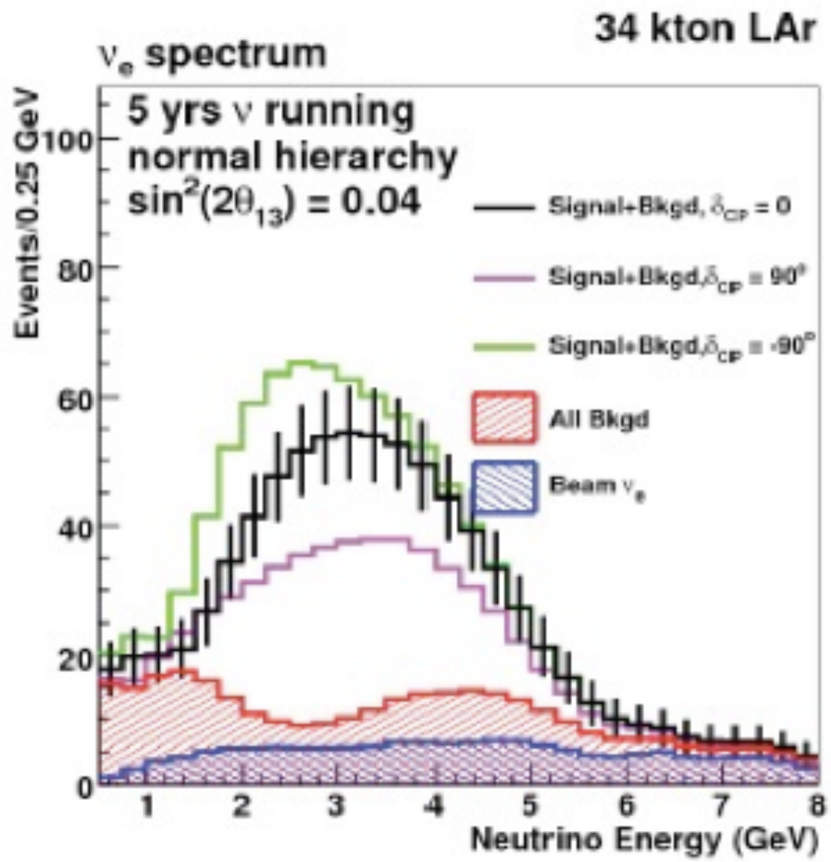




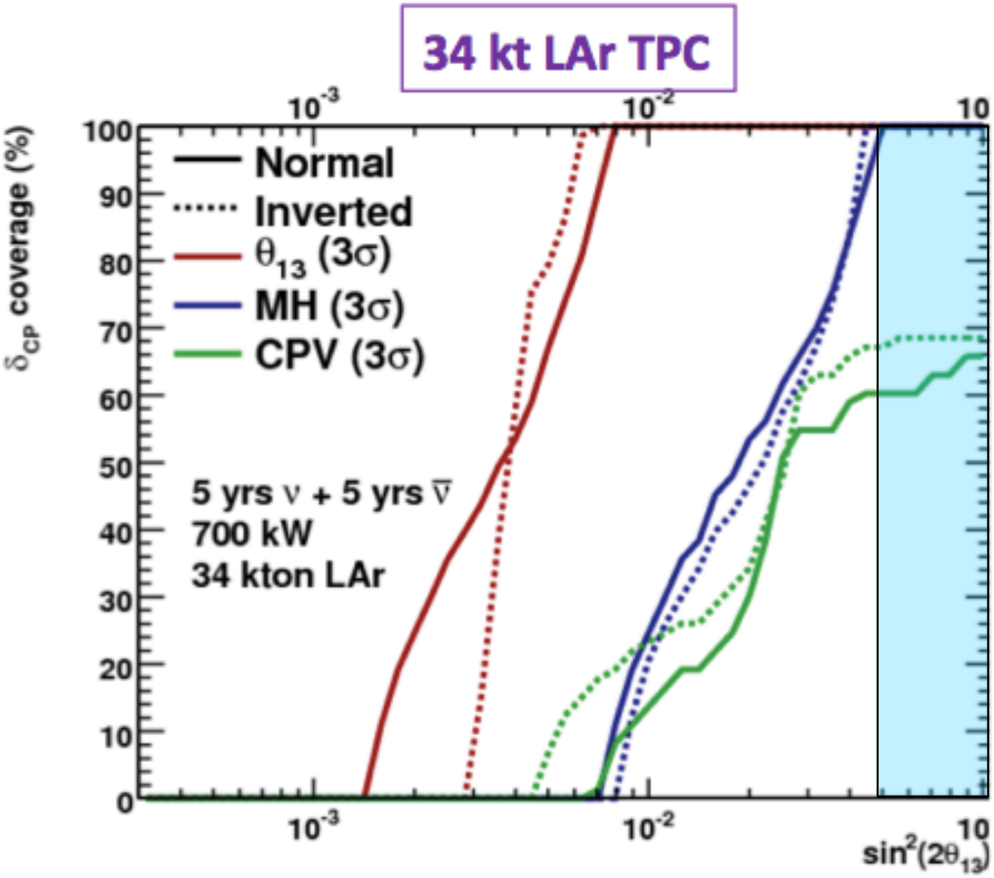
A WCh detector needs to cut hard to select clean QE events

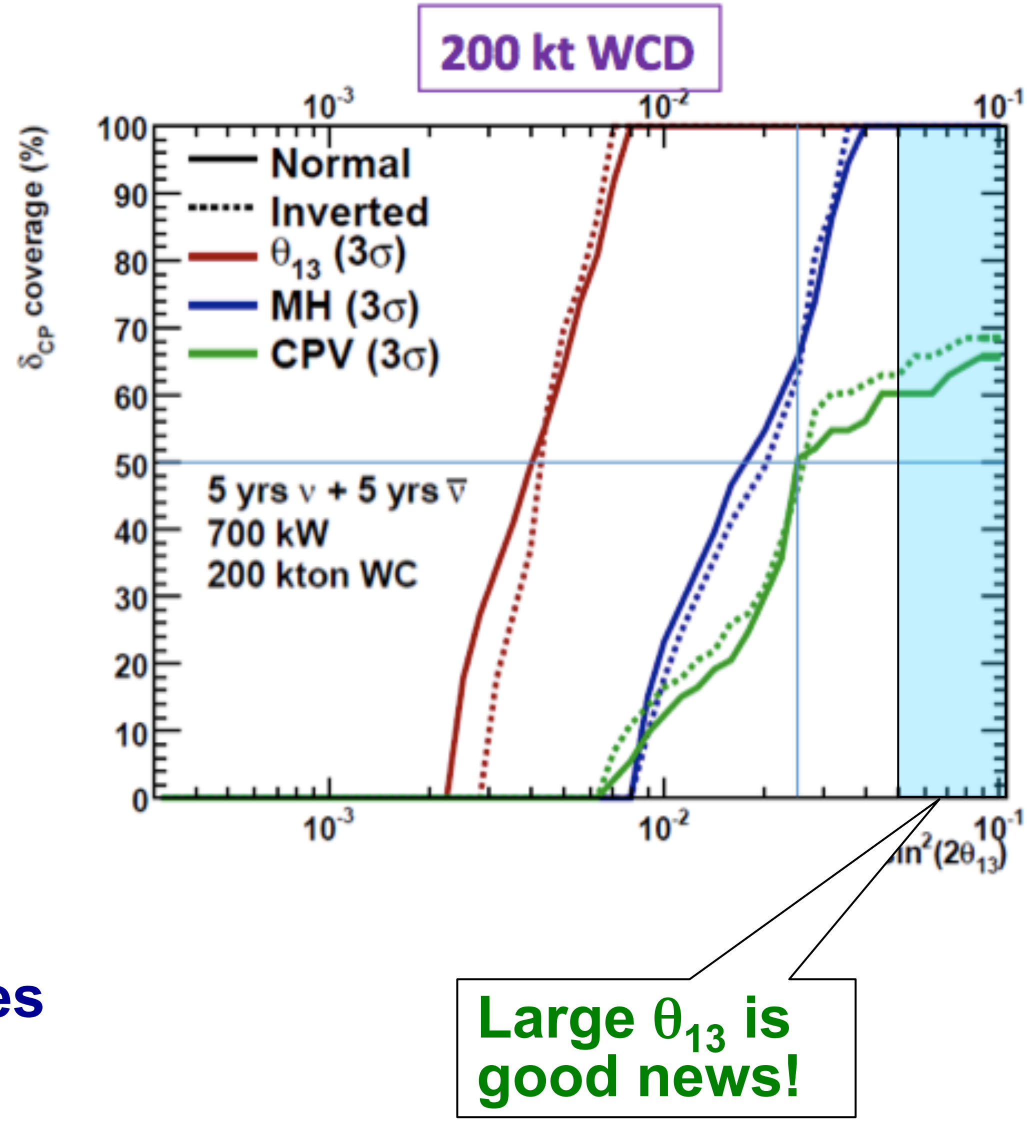
34 kton LAr ~ 200 kt WCD because of better LAr efficiency: detector sizes for technology choice set for ~ equal oscillation sensitivity



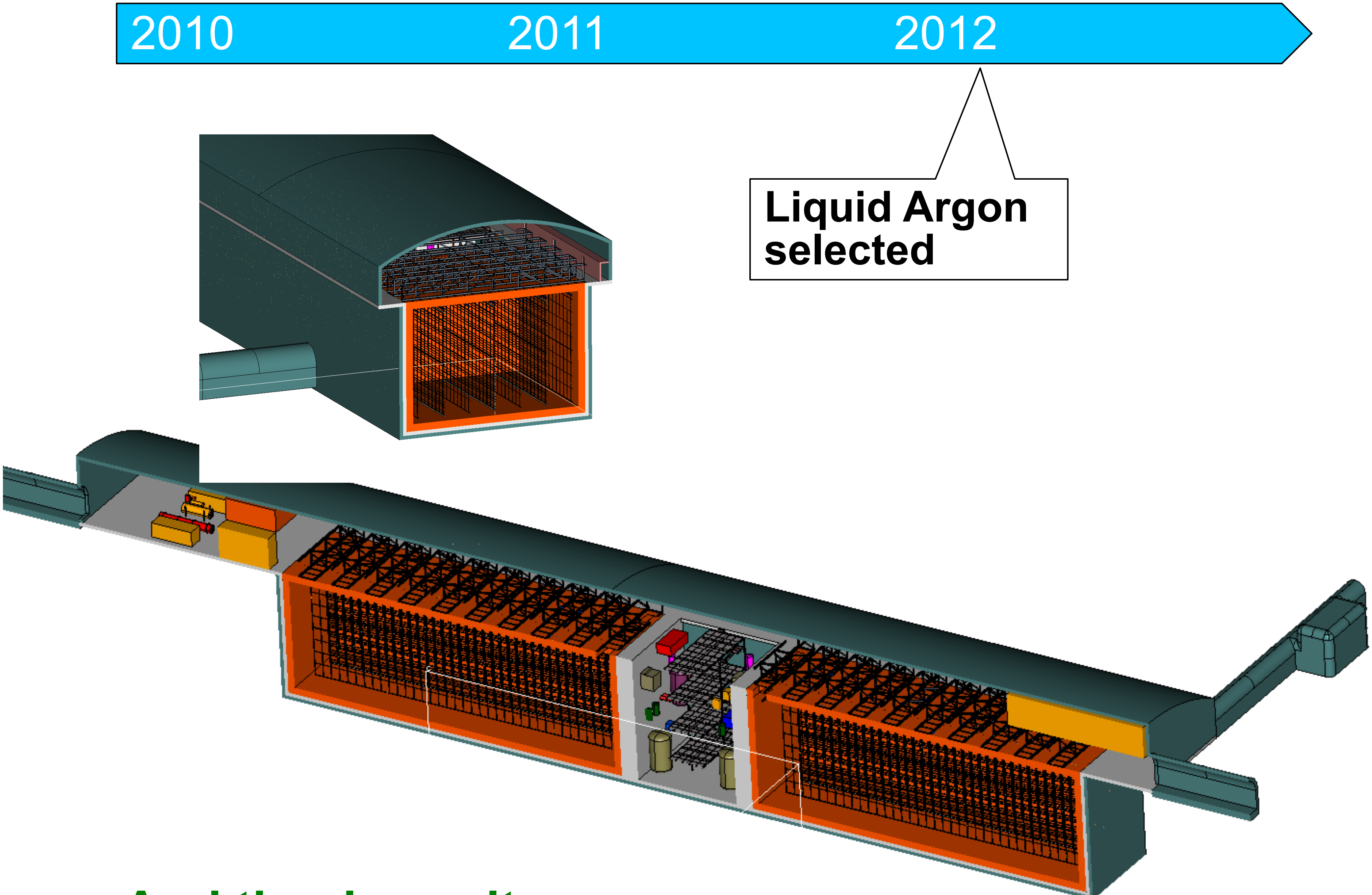


Sensitivity to oscillation parameters





Similar oscillation sensitivities
(by construction)



And the deep site (4850 ft at Homestake) is favored

Signal	Energy range	Expected Signal Rate per kton of LAr (s^{-1} $kton^{-1}$)
Beam neutrinos (CP violation/ mass hierarchy)	~ GeV	5 x 10^{-4} osc ν_e in beam window
Proton decay	~ GeV	< 2 x 10^{-9}
Atmospheric neutrinos	0.1-10 GeV	~10^{-5}
Supernova burst neutrinos	few-50 MeV	~3 @ 10 kpc over ~30 secs
Solar neutrinos	few-15 MeV	4 x 10^{-5}
Supernova relic neutrinos	20-50 MeV	< 2 x 10^{-9}

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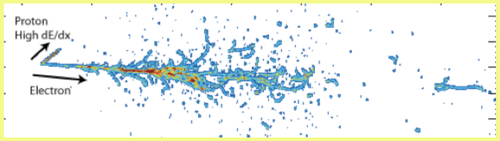
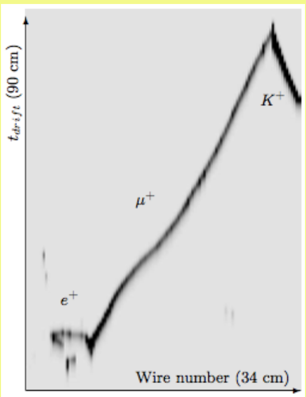
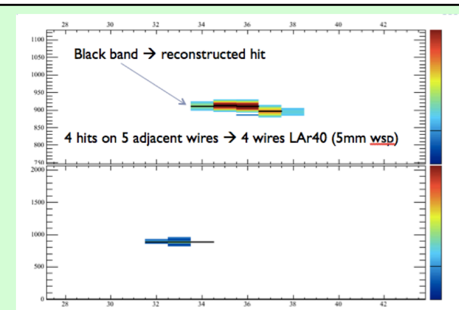




handsome, distinctive events



crummy little stubs

Signal	Energy range	Expected Signal Rate per kton of LAr (s^{-1} $kton^{-1}$)
Beam neutrinos (CP violation/ mass hierarchy)	~ GeV	5×10^{-4} osc ν_e in beam window
Proton decay	~ GeV	$< 2 \times 10^{-9}$
Atmospheric neutrinos	0.1-10 GeV	$\sim 10^{-5}$
Supernova burst neutrinos	few-50 MeV	~3 @ 10 kpc over ~30 secs
Solar neutrinos	few-15 MeV	$\sim 4 \times 10^{-5}$
Supernova relic neutrinos	20-50 MeV	$< 2 \times 10^{-9}$

Easy to pick from bg due to beam time & direction

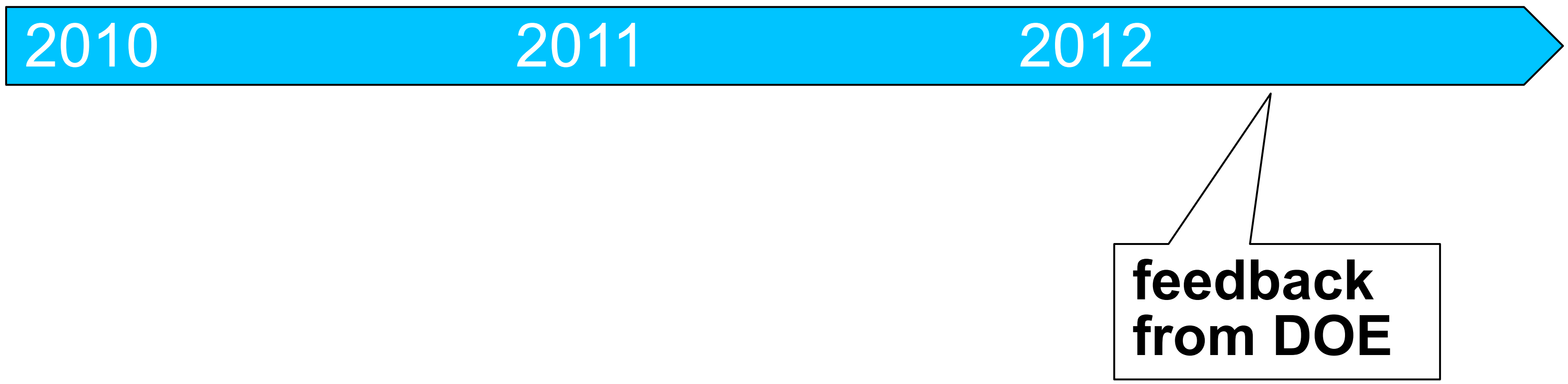
Easy to pick from bg, but highly intolerant of bg

Easy to pick, somewhat more tolerant of bg

Potentially harder to select (esp. low energy end) *but arrive in a burst* (and bg can be well known)

Hard to select *and* intolerant of bg

Very hard to select *and* intolerant of bg



Dr. Brinkman (DOE Office of Science Director) to Pier Oddone (Fermilab Director):

Based on our considerations, we cannot support the LBNE project as it is currently configured. This decision is not a negative judgment about the importance of the science, but rather it is a recognition that the peak cost of the project cannot be accommodated in the current budget climate or that projected for the next decade.

In order to advance this activity on a sustainable path, I would like Fermilab to lead the development of an affordable and phased approach that will enable important science results at each phase.

LBNE Reconfiguration

http://www.fnal.gov/directorate/lbne_reconfiguration

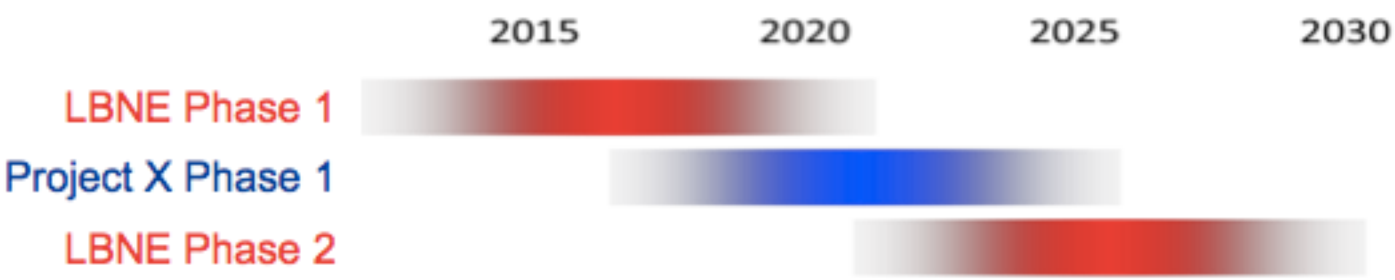
Report of Reconfiguration Steering Committee, 3 viable options

- Using the existing NuMI beamline in the low energy configuration with a **30 kton** liquid argon time projection chamber (LAr-TPC) **surface detector** 14 mrad off-axis at Ash River in Minnesota, **810 km** from Fermilab.

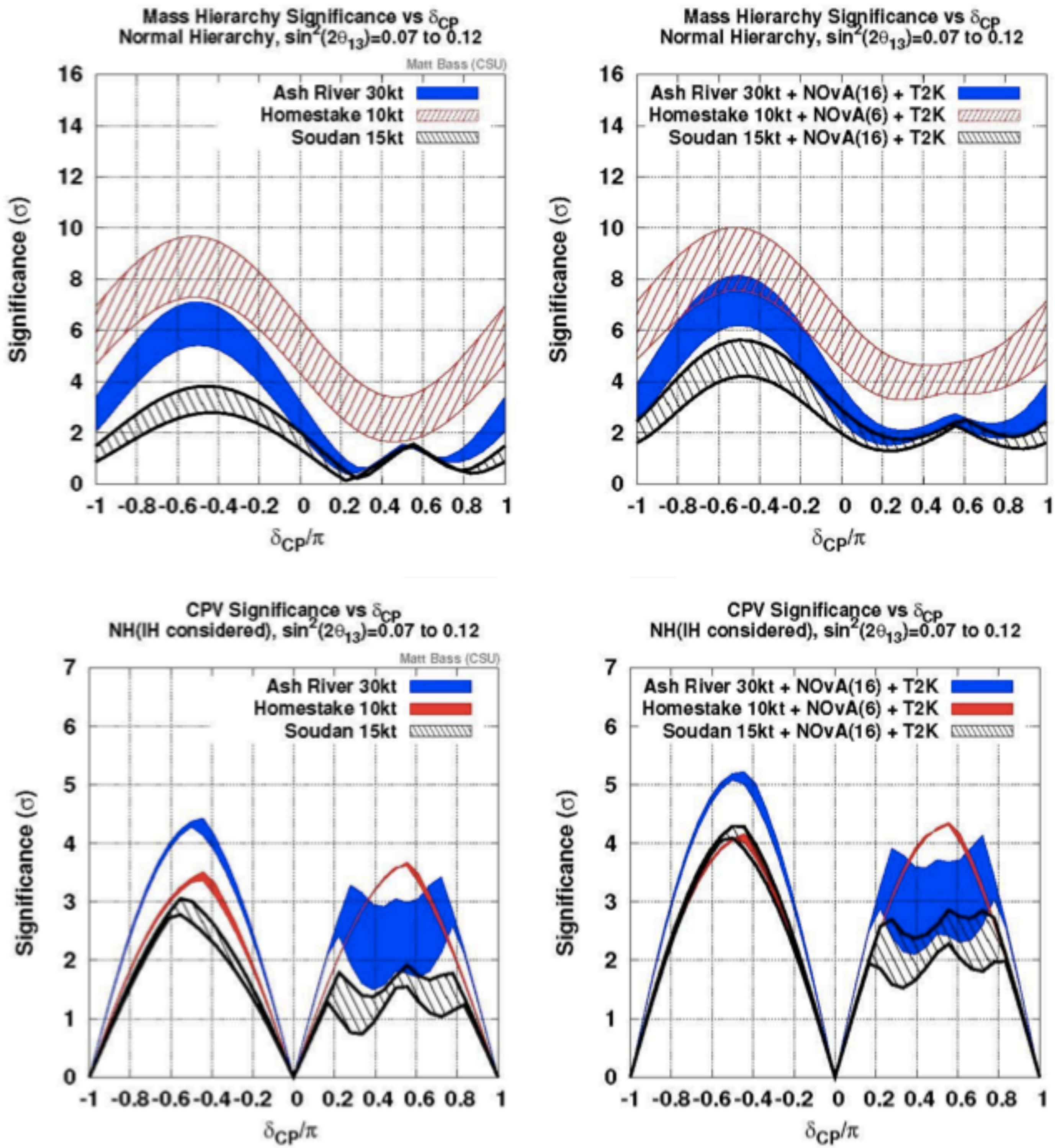
- Using the existing NuMI beamline in the low energy configuration with a **15 kton** LAr-TPC **underground (at the 2,340 ft level) detector** on-axis at the Soudan Lab in Minnesota, **735 km** from Fermilab.

- Constructing a new low energy LBNE beamline with a **10 kton** LAr-TPC **surface detector** on-axis at Homestake in South Dakota, **1,300 km** from Fermilab.

Preferred option



Mass hierarchy and CP violation reach



Comparison of Phase 1 Options

Homestake	Soudan	Ash River
• 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, 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 due to shorter baseline and on-axis beam. • Existing beam, but not upgradable to full Project X intensity without significant 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, but not upgradable to full Project X intensity without significant investment. • Phase 2 could include additional mass at Soudan or Ash River

R. Svoboda

Comparison of Phase 1 Options

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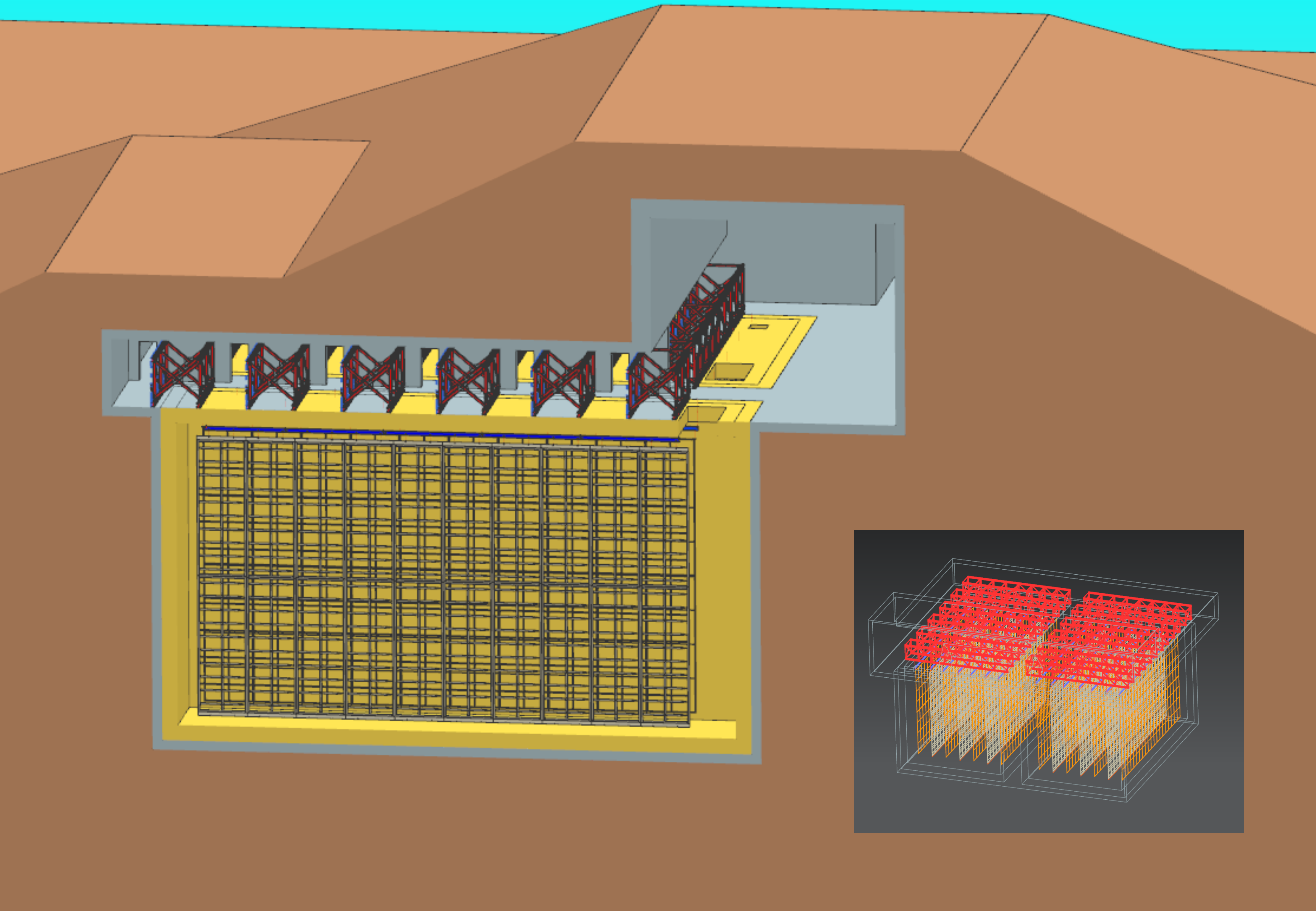
- best for beam osc
- good upgrade potential
- no Phase 1 non-beam physics
- most expensive
- CR on surface

- weakest for beam osc
- weak upgrade potential
- broad non-beam physics
- mid-range cost

- good for beam osc
- weak upgrade potential
- no non-beam physics
- lowest cost
- CR on surface

10 kton LAr on the surface at Homestake

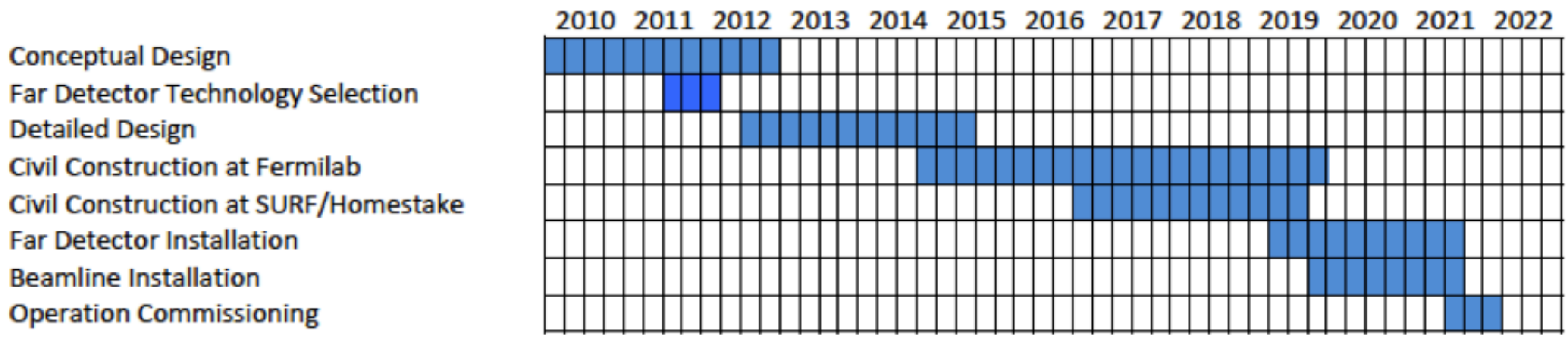


Costs after Reconfiguration

Scope	Cost (TPC)
LBNE 34 kTon@4850L and near detector	$1.440B
LBNE Phase I, 10 kTon surface	$0.789B
+Place Underground	$0.924B
+ Near Detector	$1.054B

$135M extra to go underground and recover non-accelerator physics

LBNE Phase 1 Schedule



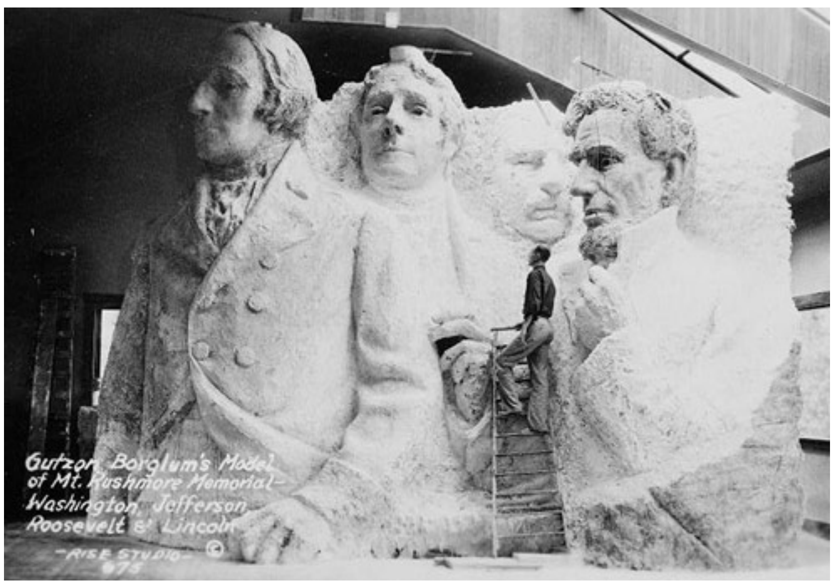
- This is the technically driven schedule. Current funding profile is expected to cause 11 month delay.
- The period up to far detector construction start offers good opportunity to seek major non-DOE and international partners.
- Deep placement of far detector as well as a near detector expansion can be accommodated in the current plan by CD2.

M. Diwan, HEPAP, August 2012

Summary

LBNE reconfiguration due to funding constraints:
10 kt LAr on the surface at 1300 km;
still has excellent CP & MH reach

Resources to go deep would vastly enrich the program;
significant potential for collaboration



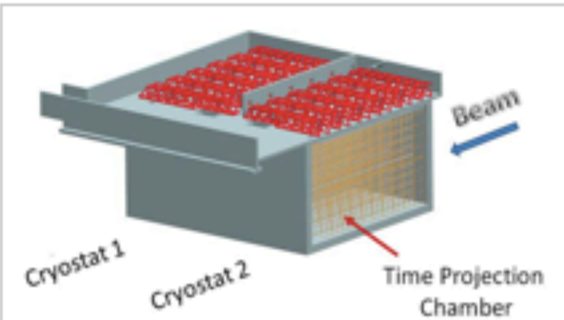
Original plan was scaled back due to insufficient funding... but final result still pretty good!

lbne.fnal.gov/symposium-oct2012.shtml

LBNE International Symposium

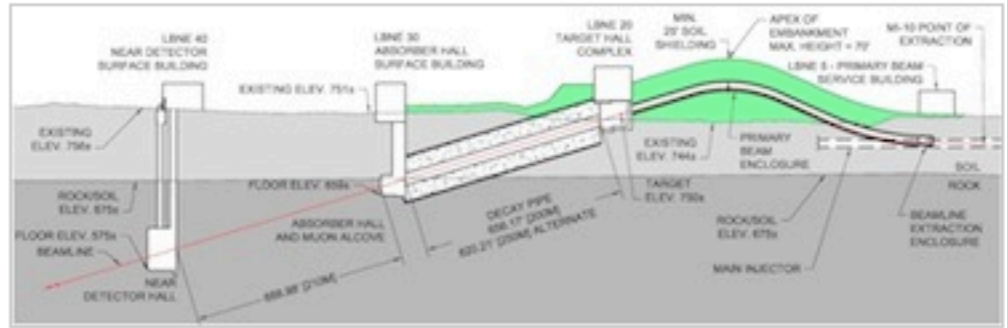
Symposium on Scientific Opportunities within LBNE

October 3, 2012
at Fermilab



Left: Ten-kiloton LAr far detector design, to be constructed in Lead, S.D.

Right: Beamline design, to be constructed at Fermilab



In conjunction with the 13th Annual Next Generation Nucleon Decay and Neutrino Detectors International Workshop (NNN12) to be held at Fermilab Oct. 4 - 6, 2012, LBNE will hold a symposium on Wednesday, Oct. 3, one day before the workshop. The primary purpose of the NNN workshop is to discuss future detectors for research on neutrino physics and nucleon decays. The symposium will focus on LBNE.

The LBNE symposium will start with a series of talks on the status of LBNE. The talks will be followed by discussions regarding potential international partnerships and research opportunities, and the impact on the LBNE science program. This symposium is planned as the first in a series, to be held over the next few years as development of LBNE continues and construction begins.

See the Agenda for more information.

Registration coming soon.

All NNN workshop participants and other scientists interested in neutrino physics are invited to attend this special one-day LBNE symposium.

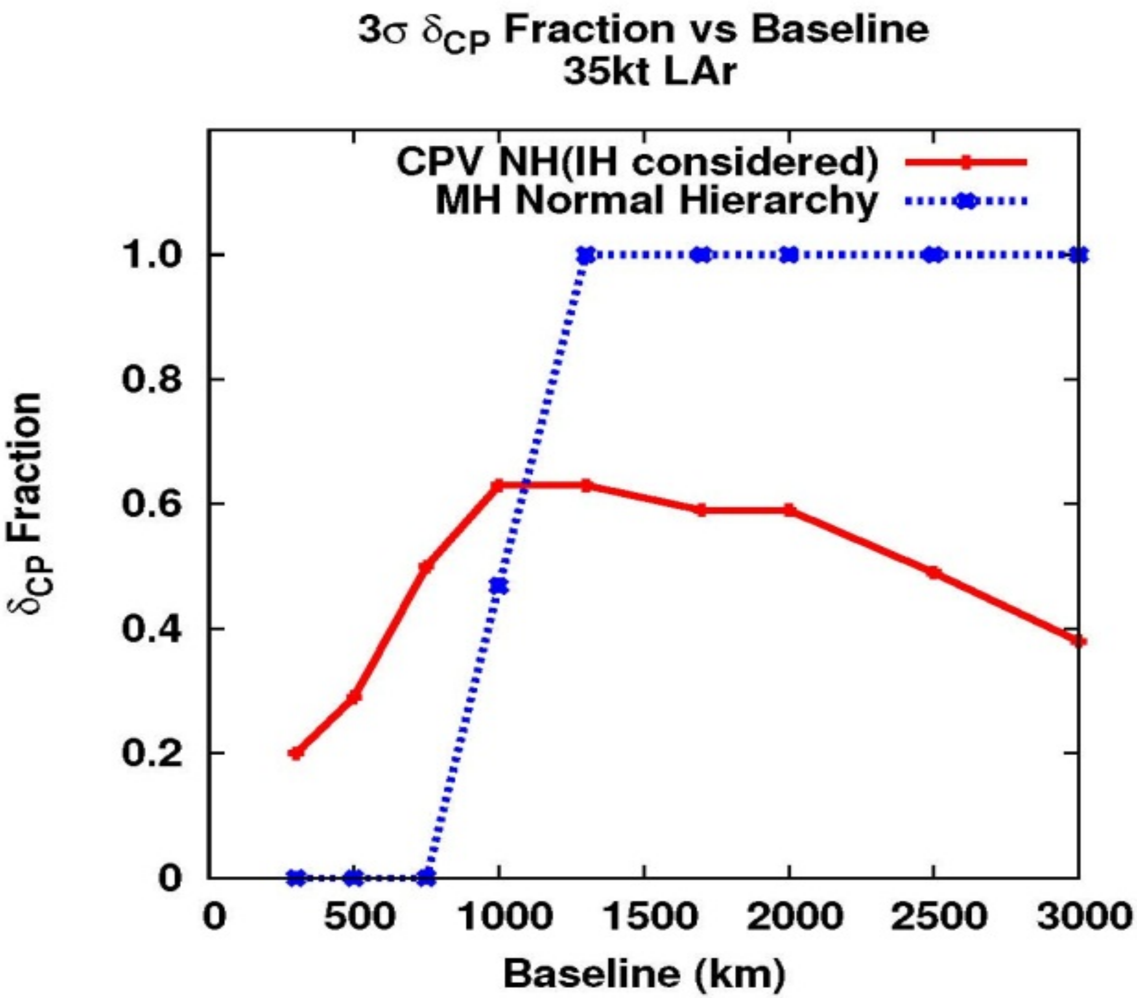
Backups/Extras

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

With these options, LBNE CD1 review planned for Oct/Nov 2012

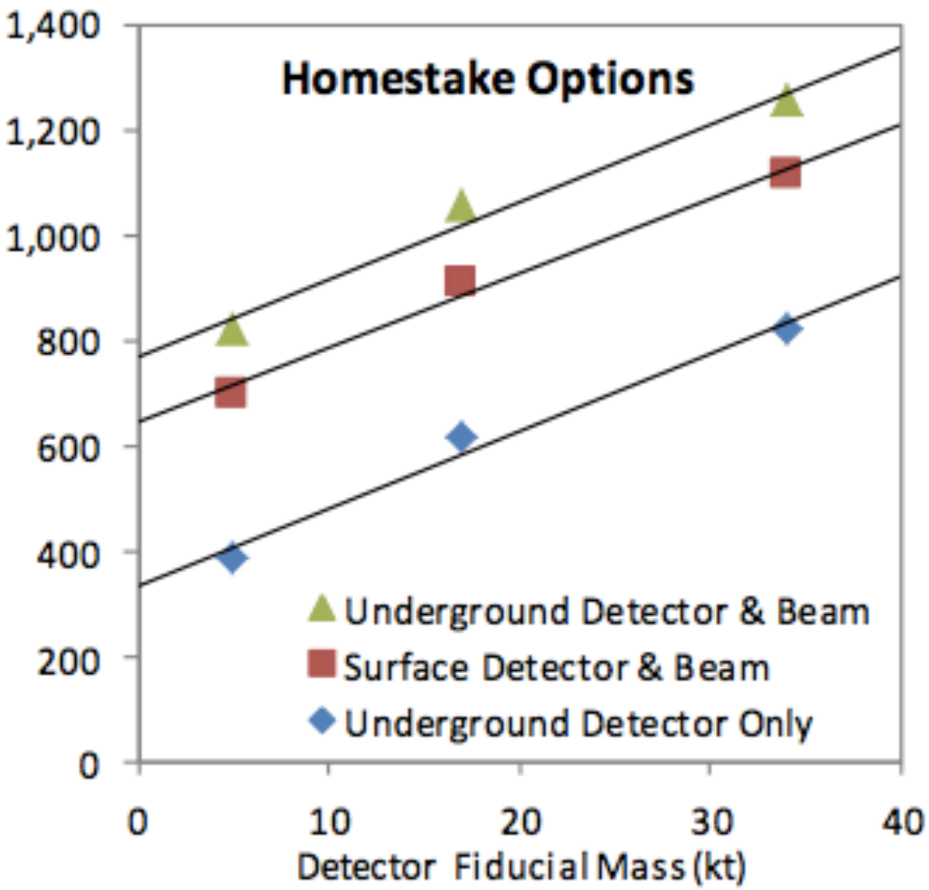
Good for beam oscillation physics, but non-beam physics lost in Phase I

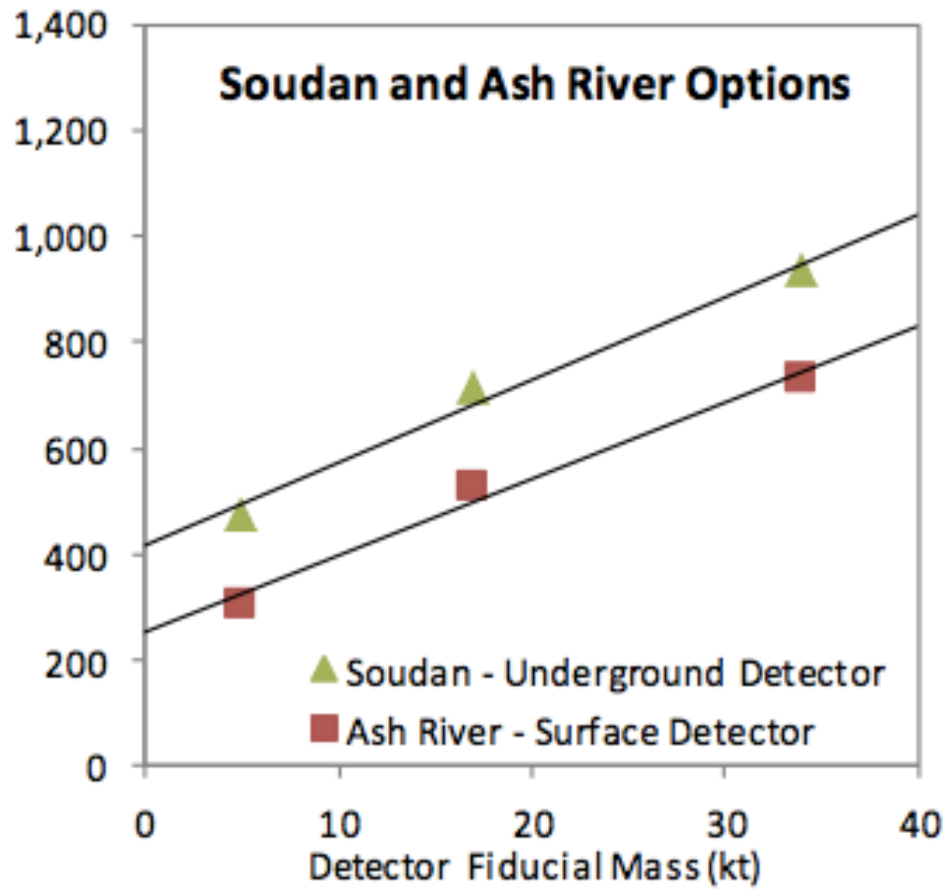
Mass hierarchy and CP sensitivity vs. baseline



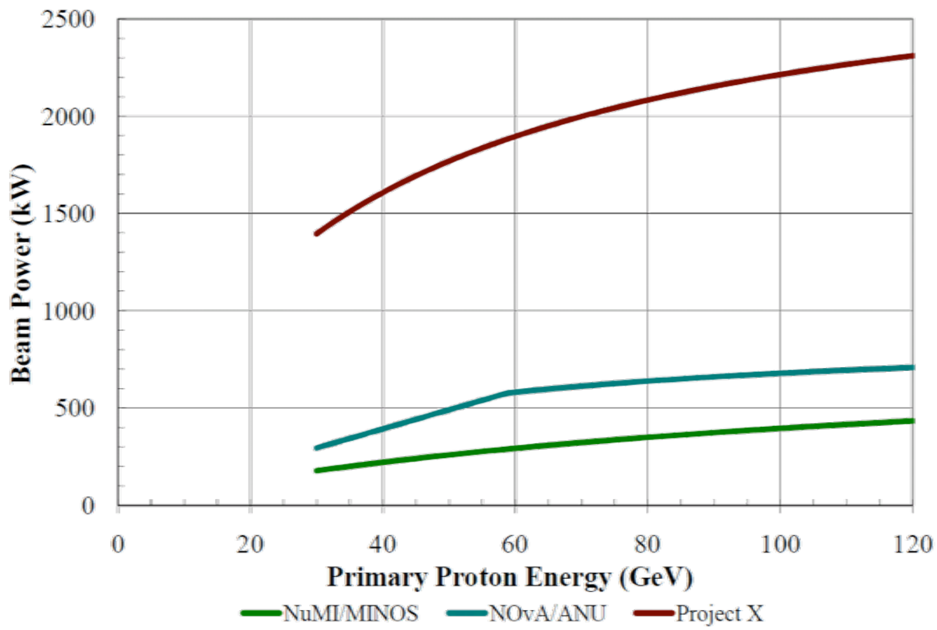
~1,300 km is nearly optimal for a combined sensitivity of CP and mass hierarchy measurements.

Cost of LBNE reconfiguration options

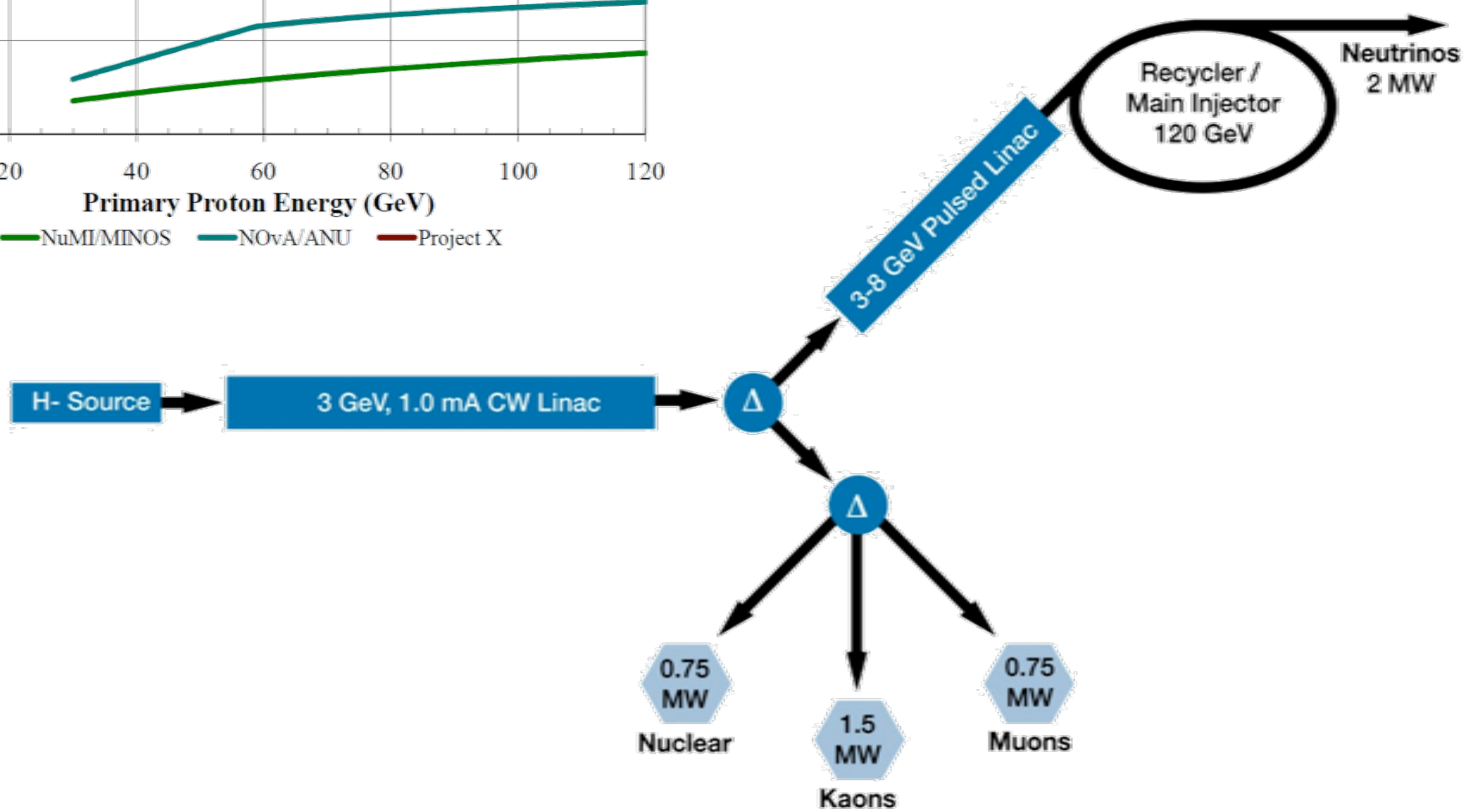




Project X



More protons for Fermilab for multiple purposes, including a high-intensity neutrino beam



Non-beam physics, possible underground