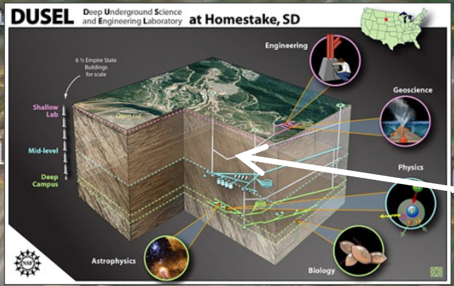
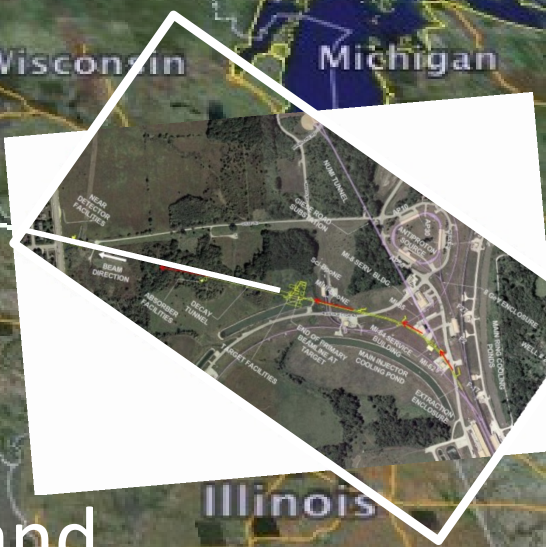
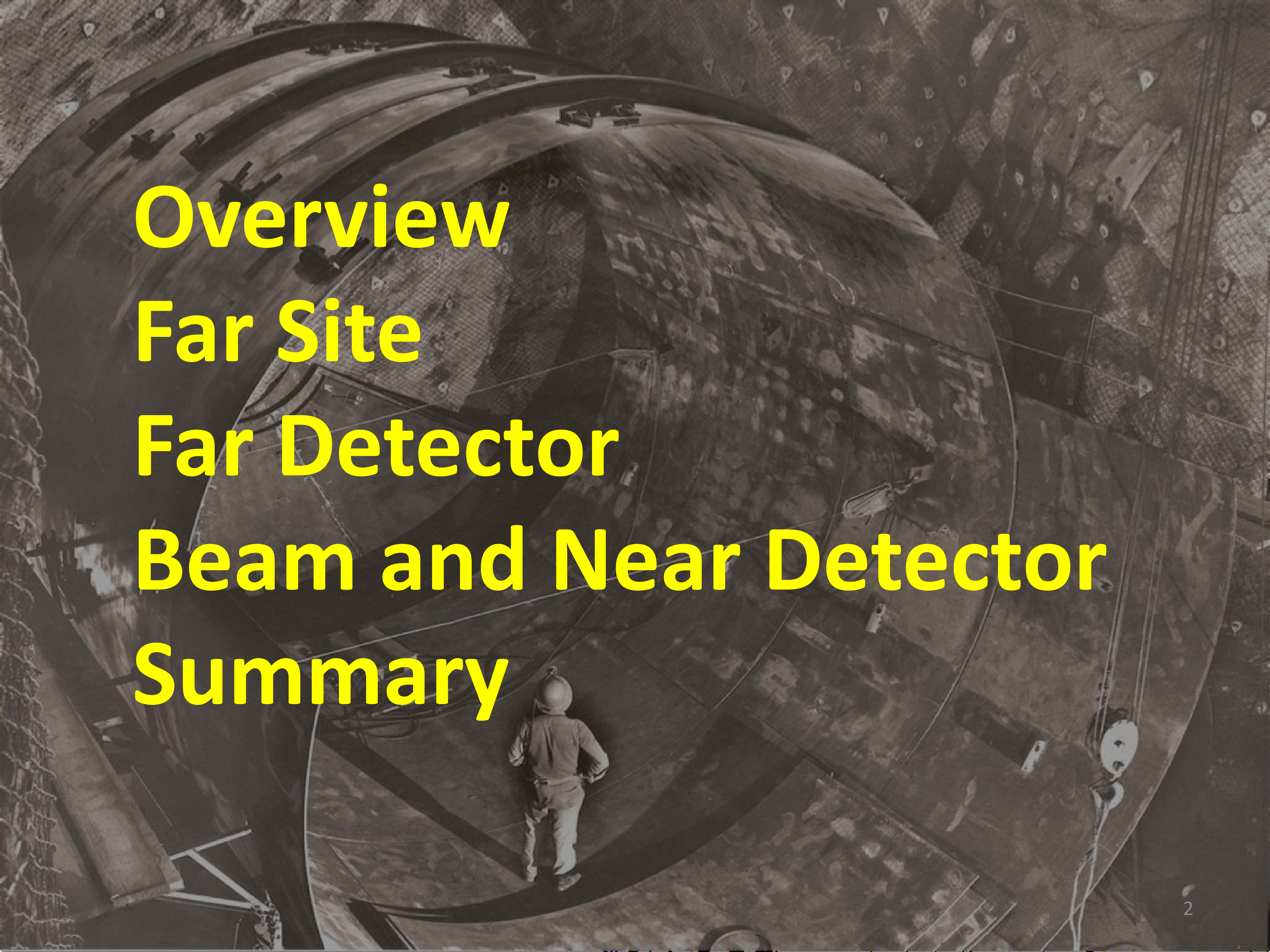
Status of LBNE





Robert Svoboda
GLA2011, Jyväskylä, Finland



Overview

Far Site

Far Detector

Beam and Near Detector

Summary

Beam: 700 kW, 60-120 GeV, 5 years ν + 5 years $\bar{\nu}$
on-axis, wide band, upgradable to 2.3 MW

Baseline: 1300 km FNAL to Homestake

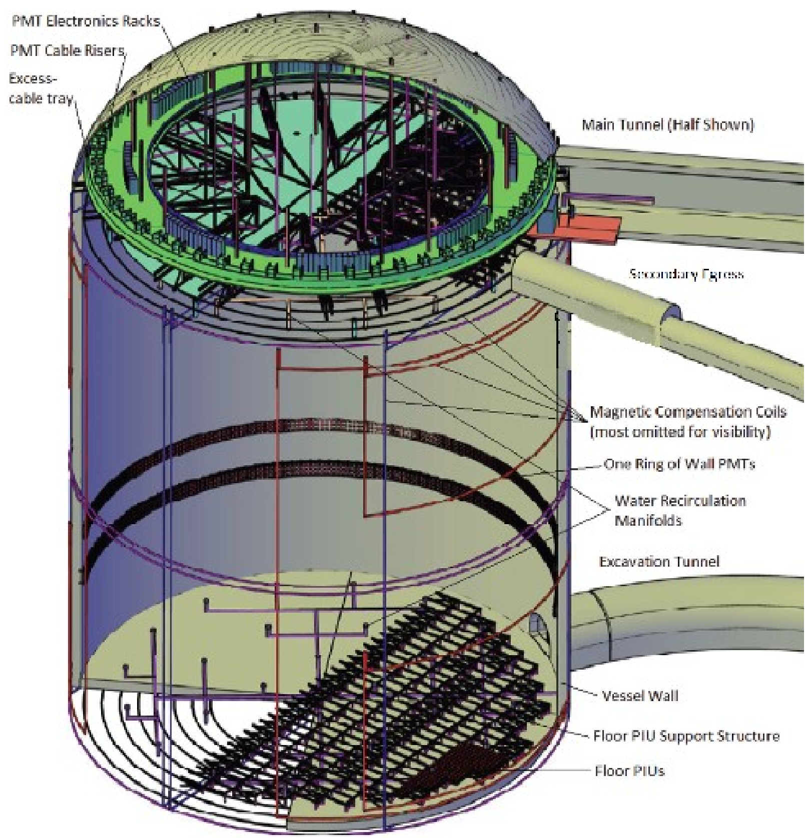
Far Site: Underground location to facilitate broad program

Near Site: on current Fermilab property

Configurations: several options under study for beam, near, and far detectors

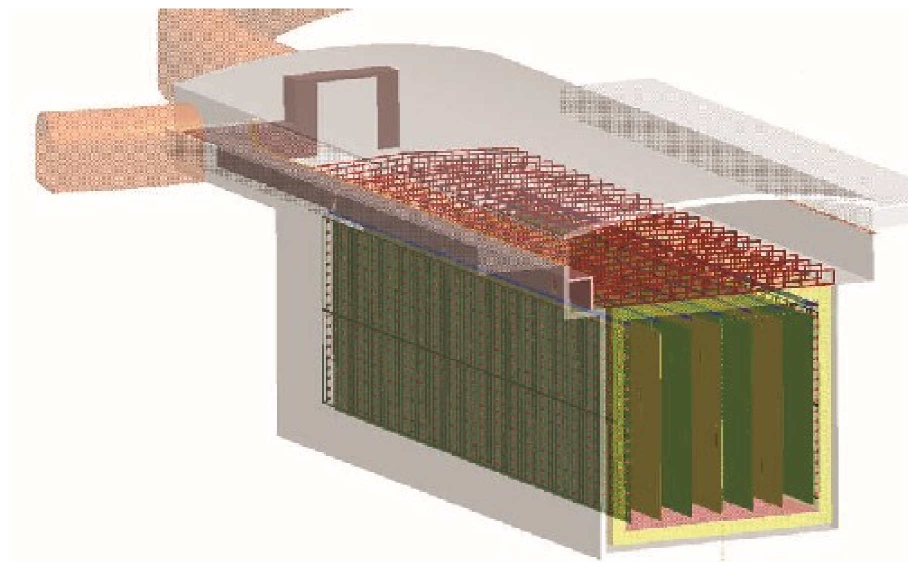
OVERVIEW: Two Far Detector Options

200 kT water Cherenkov



One 200 kT fiducial WC detector
Located at the **4850 foot level**

34 kT liquid argon



Two 17 kT fiducial LAr detectors
To be located at a new drive-in site at **800 foot level**. (one detector shown here)

Long-Baseline Neutrino Experiment Collaboration

Alabama: J. Goon, I Stancu

Argonne: M. D'Agostino, G. Drake. Z. Djurcic, M. Goodman, X. Huang, V. Guarino, J. Paley, R. Talaga, M. Wetstein

Boston: E. Hazen**,** E. Kearns, S. Linden, J. Stone

Brookhaven: M. Bishai, R. Brown, H. Chen, M. Diwan, J. Dolph, G. Geronimo, R. Gill, R. Hackenberg, R. Hahn, S. Hans, D. Jaffe, S. Junnarkar, J.S. Kettell, F. Lanni, L. Littenberg, J. Ling, D. Makowiecki, W. Marciano, W. Morse, Z. Parsa, C. Pearson, V. Radeka, S. Rescia, T. Russo, N. Samios,R. Sharma, N. Simos, J. Sondericker, J. Stewart, H. Tanaka, C. Thorn, B. Viren, Z. Wang, S. White, L. Whitehead, M. Yeh, B. Yu

Caltech: R. McKeown, X. Qian, C. Zhang

Cambridge: A. Blake, M. Thomson

Catania/INFN: V. Bellini, G. Garilli, R. Potenza, M. Trovato

Chicago: E. Blucher

Colorado: S. Coleman, R. Johnson, A. Marino, M. Tzanov, E. Zimmerman

Colorado State: M. Bass, B. Berger, J. Brack, N. Buchanan, J. Harton, V. Kravtsov, W. Toki, D. Warner, R. Wilson

Columbia: R. Carr, L. Camillieri, C.Y. Chi, G. Karagiorgi, C. Mariani, M. Shaevitz, W. Sippach, W. Willis

Crookston: D. Demuth

Dakota State: B. Szcerbinska

Davis: M. Bergevin, R. Breedon, J. Felde, P. Gupta, M. Tripanthi, R. Svoboda

Drexel: C. Lane, J. Maricic, R. Milincic, K. Zbiri

Duke: T. Akiri, J. Fowler, K. Scholberg, C. Walter, R. Wendell

Duluth: R. Gran, A. Habig

Fermilab: D. Allspach, M. Andrews, B. Baller, E. Berman, D. Boehnlein, M. Campbell, A. Chen, S. Childress, B. DeMaat, A. Drozhdin, T. Dykhuis, C. Escobar, A. Hahn, S. Hays, A. Heavey, J. Howell, P. Huhr, J. Hylen, C. James, M. Johnson, J. Johnstone, T. Junk, B. Kayser, G. Koizumi, T. Lackowski, P. Lucas, B. Lundberg, T. Lundin, P. Mantsch, E. McCluskey, N. Mokhov, C. Moore, J. Morfin, B. Norris, V. Papadimitriou, R. Plunkett, C. Polly, S. Pordes, O. Prokofiev, J. Raaf, G. Rameika, B. Rebel, D. Reitzner, K. Riesselmann, R. Rucinski, R. Schmidt, D. Schmitz, P. Shanahan, M. Stancari, J. Strait, S. Striganov, K. Vaziri, G. Velev, G. Zeller, R. Zwaska

Hawaii: S. Dye, J. Kumar, J. Learned, S. Matsuno, S. Pakvasa, M. Rosen, G. Varner

Indian Universities: V. Singh (BHU); B. Choudhary, S. Mandal (DU); B. Bhuyan [IIT(G)]; V. Bhatnagar, A. Kumar, S. Sahijpal(PU)

Indiana: W. Fox, C. Johnson, M. Messier, S. Mufson, J. Musser, R. Tayloe, J. Urheim

Iowa State: M. Sanchez

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Irvine: G. Carminati, W. Kropp, M. Smy, H. Sobel

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

LBL: R. Kadel, B. Fujikawa, D. Taylor

Livermore: A. Bernstein, R. Bionta, S. Dazeley, S. Ouedraogo

London-UCL: J. Thomas

Los Alamos: S. Elliott, A. Friedland, V. Gehman, G. Garvey, T. Haines, D. Lee, W. Louis, C. Mauger, G. Mills, A. Norrick, Z. Pavlovic, G. Sinnis, W. Sondheim, R. Van de Water, H. White

Louisiana State: W. Coleman, T. Kutter, W. Metcalf, M. Tzanov

Maryland: E. Blaufuss, R. Hellauer, T. Straszheim, G. Sullivan

Michigan State: E. Arrieta-Diaz**,** C. Bromberg, D. Edmunds, J. Huston, B. Page

Minnesota: M. Marshak, W. Miller

MIT: W. Barletta, J. Conrad, T. Katori, R. Lanza, L. Winslow

NGA: S. Malys, S. Usman

New Mexico: B. Becker, J. Mathews

Notre Dame: J. Losecco

Oxford: G. Barr, J. DeJong, A. Weber

Pennsylvania: J. Klein, K. Lande, A. Mann, M. Newcomer, S. Seibert, R. vanBerg

Pittsburgh: D. Naples, V. Paolone

Princeton: Q. He, K. McDonald

Rensselaer: D. Kaminski, J. Napolitano, S. Salon, P. Stoler

Rochester: R. Bradford, K. McFarland

SDMST: X. Bai, R. Corey

SMU: T. Liu, J. Ye

South Carolina: H. Duyang, S. Mishra, R. Petti, C. Rosenfeld

South Dakota State: B. Bleakley, K. McTaggert

Syracuse: M. Artuso, S. Blusk, T. Skwarnicki, M. Soderberg, S. Stone

Texas: S. Kopp, K. Lang, R. Mehdiyev

Tufts: H. Gallagher, T. Kafka, W. Mann, J. Schnepps

UCLA: K. Arisaka, D. Cline, K. Lee, Y. Meng, F. Sergiampietri, H. Wang

Virginia Tech: E. Guarnaccia**,** J. Link, D. Mohapatra, R. Raghavan

Washington: H. Berns, S. Enomoto, J. Kaspar, N. Tolich, H.K. Tseung

Wisconsin: B. Balantekin, F. Feyzi, K. Heeger, A. Karle, R. Maruyama, D. Webber, C. Wendt

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

22 April 2011

~300 physicists and engineers, 55 institutions

This Talk

- Will present present state of design of the experiment. Nothing is yet completely fixed, but options have been narrowed down and work is ongoing to evaluate cost and schedule.
- You will be shown the current plans assuming that the U.S. NSF does *not* participate. NSF had been asked to pay ~10% of LBNE construction costs and operate DUSEL. Now the U.S. Dept of Energy (DOE) is planning to bear the full construction cost and be responsible for facility operations. This is assumed in all slides.
- A decision was made by DOE to, at least initially, continue evaluation for ***only*** the Homestake site. A formal review was held at SLAC in March under a "blue ribbon" panel commissioned by the Director of the Office of Science (all science, not just HEP). All slides and schedules assume usage of the Homestake site.

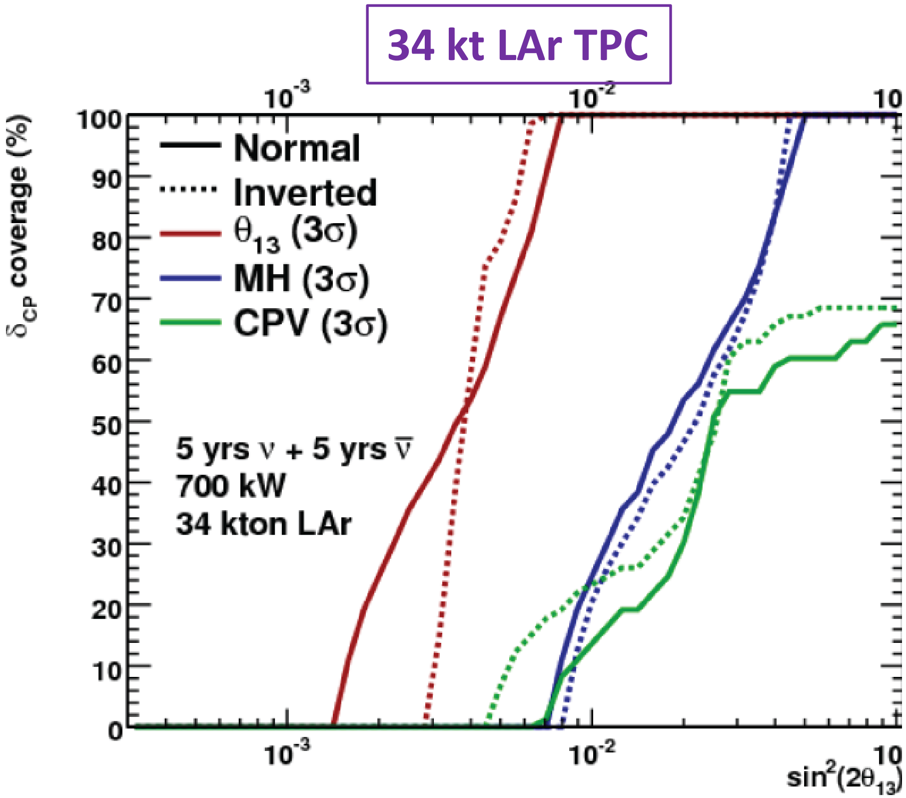
Physics Research Goals of LBNE

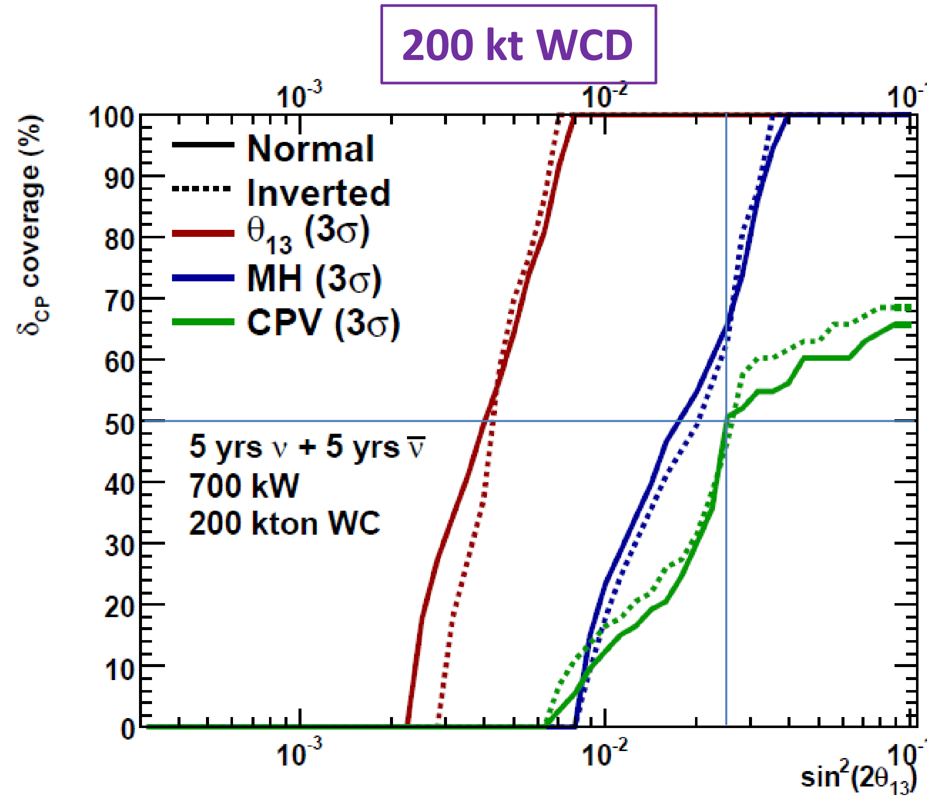
The primary science objectives of the LBNE Project are:

1. A search for, and precision measurements of, the parameters that govern $\nu_\mu \rightarrow \nu_e$ oscillations. This includes measurement of the third mixing angle θ_{13}, for whose value only an upper bound is currently known, and if θ_{13} is large enough, measurement of the CP-violating phase δ and determining of the mass ordering (sign of Δm^2_{32}).
2. Precision measurements of θ_{23} and $|\Delta m^2_{32}|$ in the ν_μ disappearance channel.
3. Search for proton decay, yielding a significant improvement in current limits on the partial lifetime of the proton (τ/BR) in one or more important candidate decay modes, e.g. $p \rightarrow e + \pi^0$ or $p \rightarrow K^+ \nu$.
4. Detection and measurement of the neutrino flux from a core collapse supernova within our galaxy, should one occur during the lifetime of LBNE.

Though outside of the primary objectives, the far detector placed at the proposed depth could enable studies of atmospheric ν physics, and with additional upgrades, studies of day/night ^{8}B solar ν physics and relic supernova neutrinos.

Physics with the Neutrino Beam

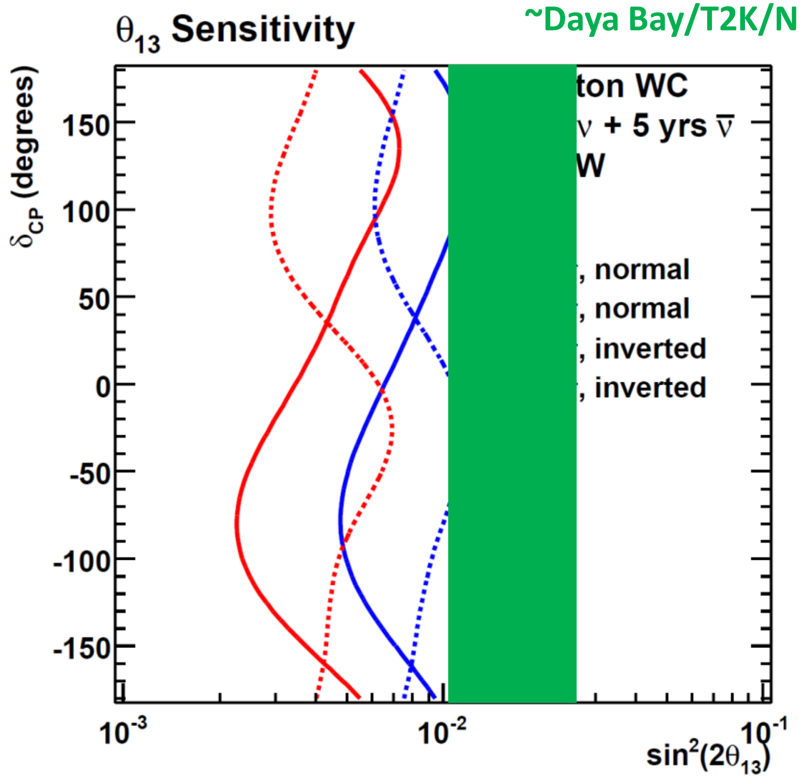




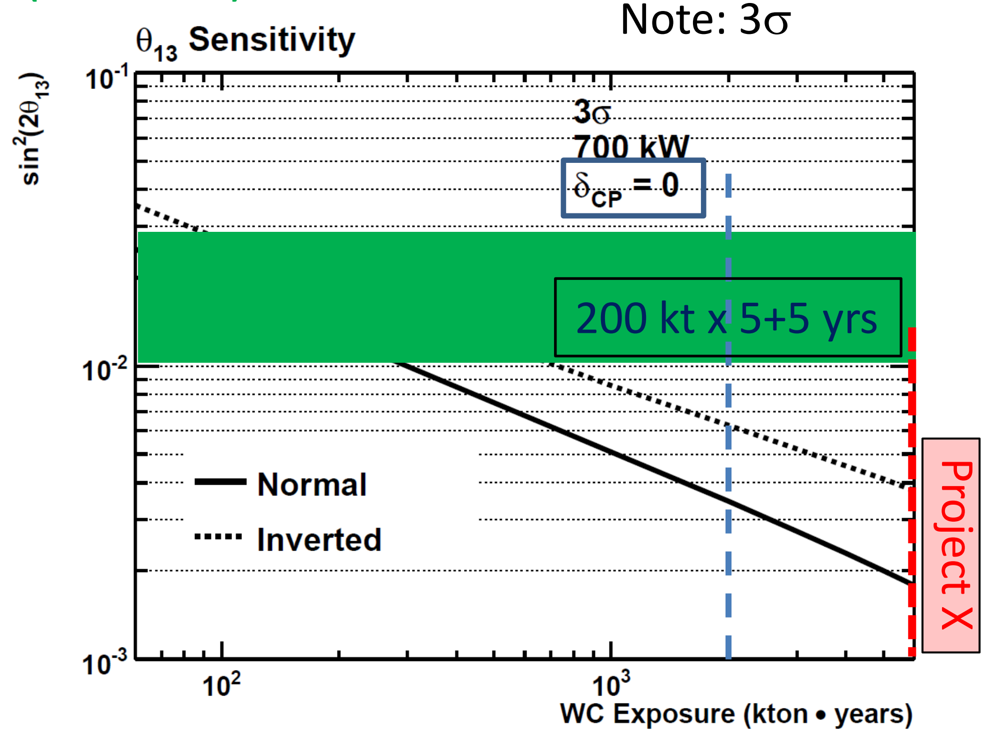
- **For beam physics: 200 kt WCD ≈ 34 kt LAr ≈ 100 kt WCD + 17 kt LAr**
  - Ongoing work to tune efficiency and signal/background may affect this equivalence
  - Will alternate WCD/LAr plots in this talk
  - 5+5 years turns out to be near optimal in shallow minimum
- **Quantitative & qualitative performance differences for some non-beam physics**

$\sin^2 2\theta_{13} \neq 0$ Sensitivity

~Daya Bay/T2K/NOvA (EuroNu2009)



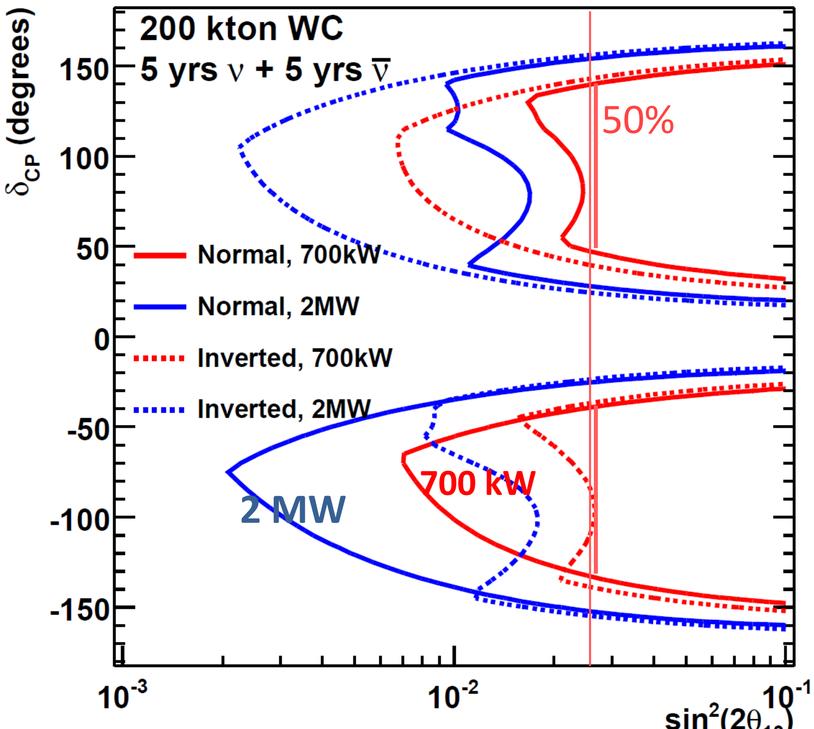
Note: 3σ



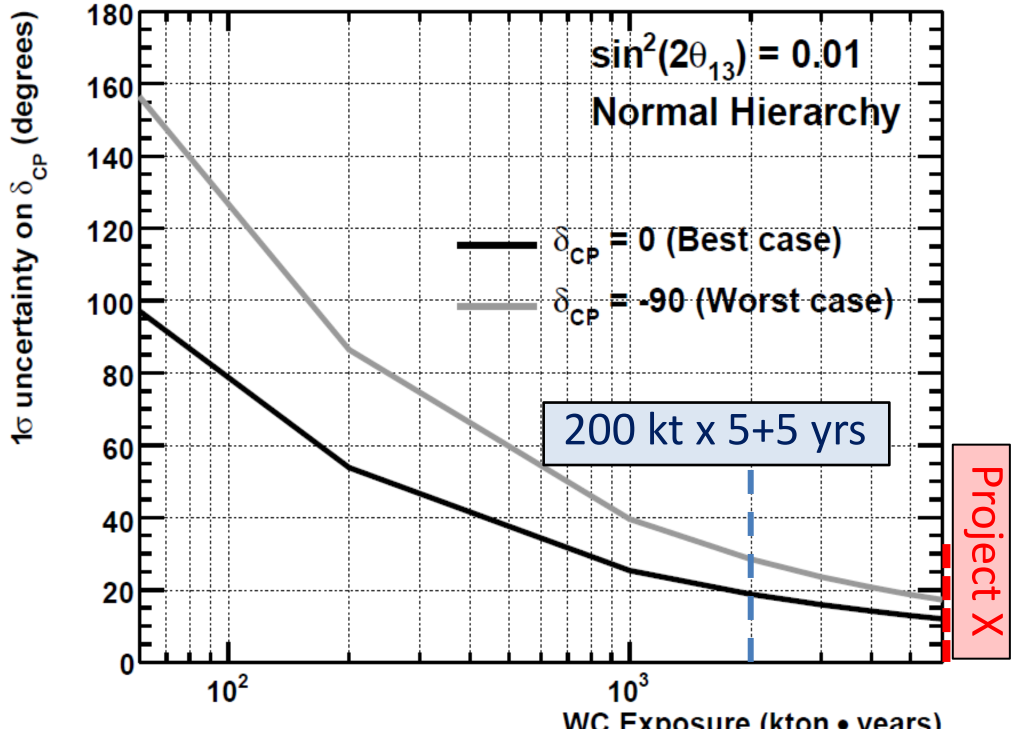
- $\sin^2 2\theta_{13}$ 3-σ sensitivity: 0.002--0.008 (~0.001--0.004 with 2 MW beam)
- While not designed as a primarily θ_{13} experiment, sensitivity is still very good, especially with Project X

CP Sensitivity

3σ exclusion of CP conserving δ_{CP}=0° or 180°



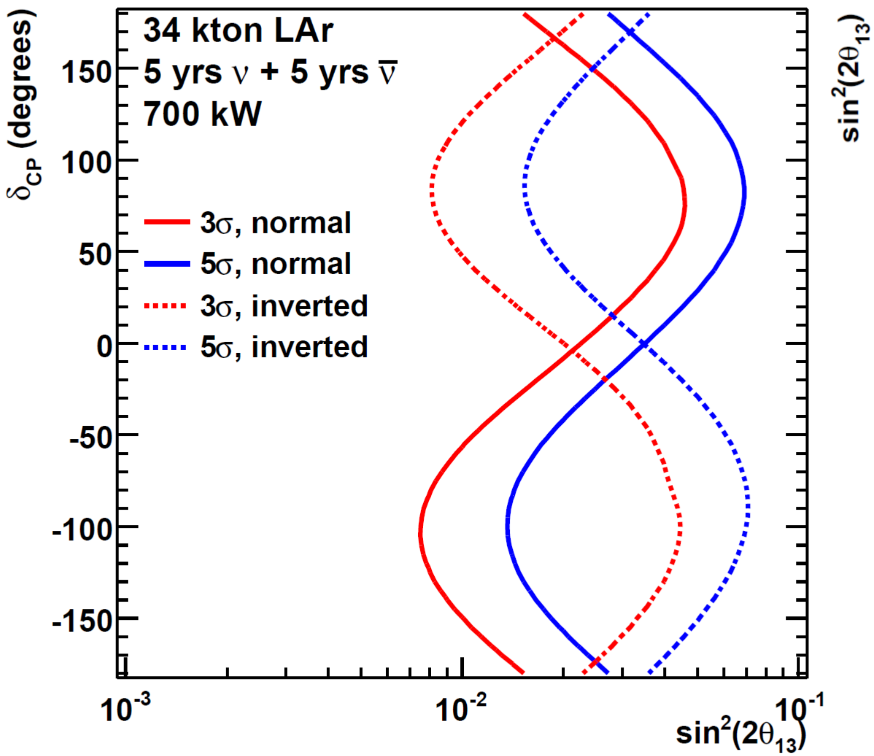
1σ resolution on δ_{CP} measurement



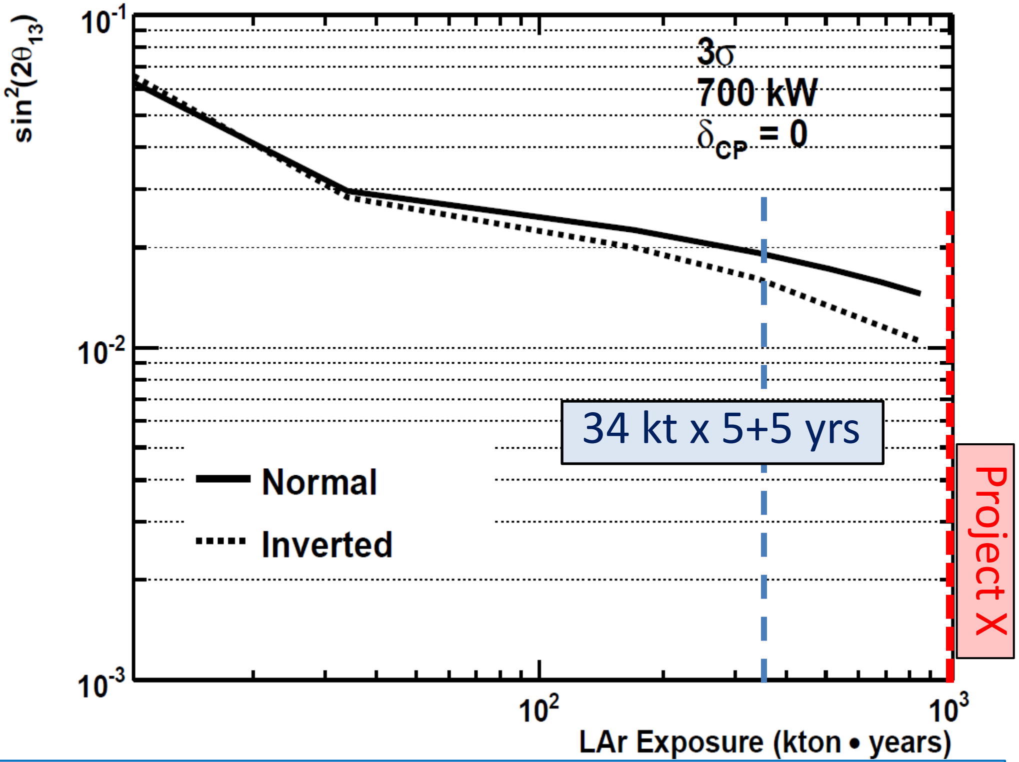
- Cover 50% δ_{CP} phase space down to $\sin^2 2\theta_{13} = 0.03$; resolution on $\delta_{CP} = \pm 19°$
- Optimal $\nu/\bar{\nu}$ running - shallow minimum around 50:50
- 2 MW beam = rapid feedback on parameter values– guide future running

MH Sensitivity

3σ/5σ exclusion of MH hypothesis



3σ exclusion of MH hypothesis

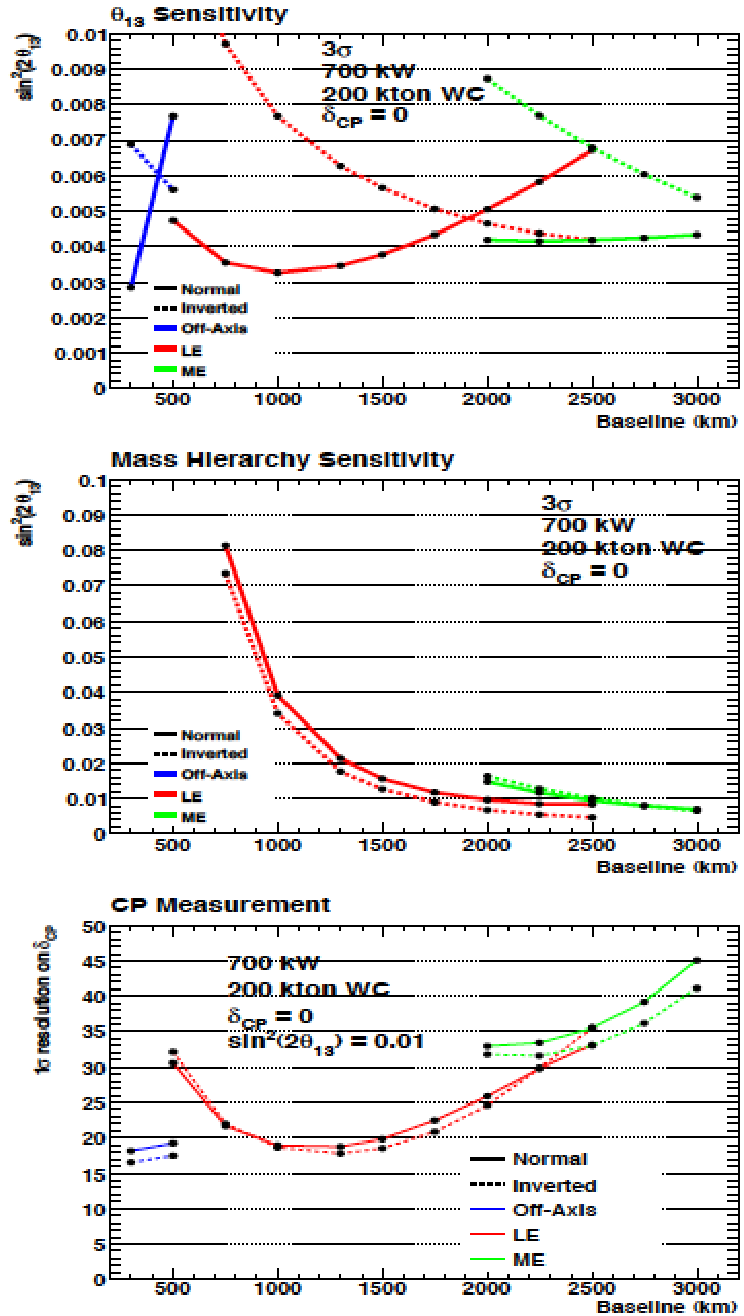


- 340 kt-y LAr exposure can resolve MH at 3σ for all δ_{CP} down to $\sin^2 2\theta_{13} = 0.04$
- Shorter baselines (NOvA, T2K) challenged by inherent degeneracies between CP-violating asymmetries and matter effects.

Homestake is at a good distance

A 1300 km baseline:

- Large matter effects
- Higher energy at oscillation peak with enhanced cross section compare to MINOS
- Interplay between θ_{13}, mass hierarchy, and CPV is complex
- Lower flux due to $1/r^2$ is important
- **FNAL-Homestake distance makes three important measurements possible with a single experimental configuration.**



(Beam retuned at each distance)

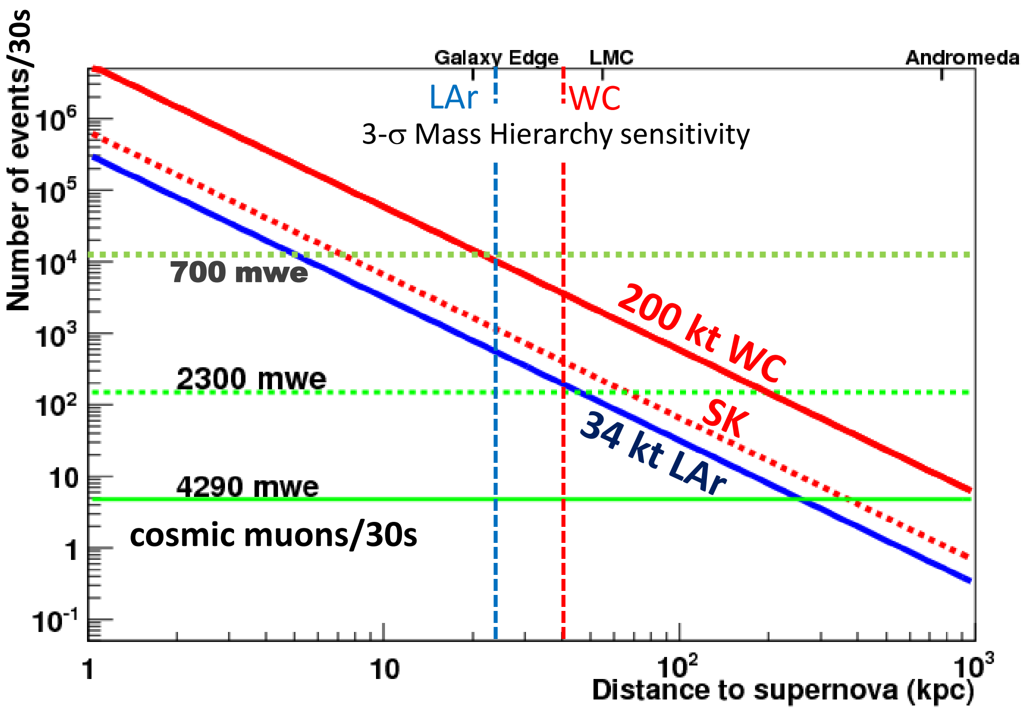
Supernova Neutrinos

- When a star's core collapses ~99% of the gravitational binding energy of the proto-neutron star goes into ν's
- SN at galactic core (10 kpc)
  $\Rightarrow$ tens of thousands of interactions
  in tens of seconds
- **Large detectors can discriminate between core collapse models**

Sanduleak -69° 202 $\rightarrow$ SN 1987A

"You don't have to be lucky, you just have to be patient."

SN Rates and Reach



Significant difference in model event rate prediction - but still large

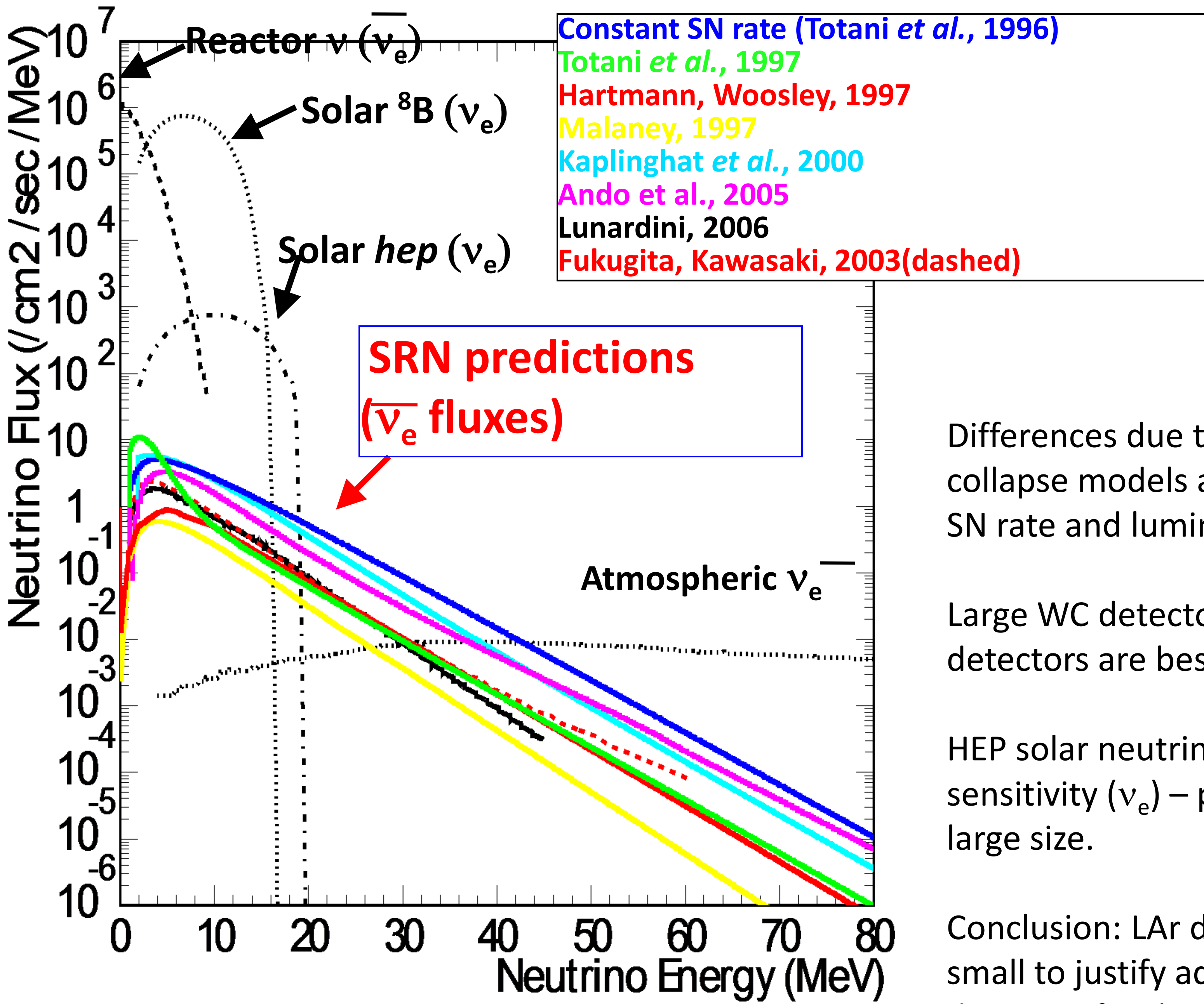
Channel	Events, "Livermore" model	Events, "GKVM" model
$\nu_e + {}^{40}\mathrm{Ar} \to e^- + {}^{40}\mathrm{K}^*$	2308	2848
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \to e^+ + {}^{40}\mathrm{Cl}^*$	194	134
$\nu_x + e^- \to \nu_x + e^-$	296	178
Total	2798	3160

Table 5–6: Event rates for different models in two 17 kt modules of LAr.

Channel	Events, "Livermore" model	Events, "GKVM" model
$\bar{\nu}_e + p \to e^+ + n$	50272	30442
$\nu_x + e^- \to \nu_x + e^-$	1198	774
$\nu_e + {}^{16}\mathrm{O} \to e^- + {}^{16}\mathrm{F}$	170	748
$\bar{\nu}_e + {}^{16}\mathrm{O} \to e^+ + {}^{16}\mathrm{N}$	1379	968
$\nu_x + {}^{16}\mathrm{O} \to \nu_x + {}^{16}\mathrm{O}^*$	2	0.5
Total	53021	32932

Table 8–1: Event rates for different models in 200 kton of water.

- **Larger detector mass -> further reach**
- Could potentially resolve Mass Hierarchy to 3-σ out to Galaxy Edge (both LAr & WC) if "spectral swap" features observed
- In a hybrid WCD+Lar: Good spectral information of νe from LAr will help resolve flavor content of the primarily νe-bar in WCD



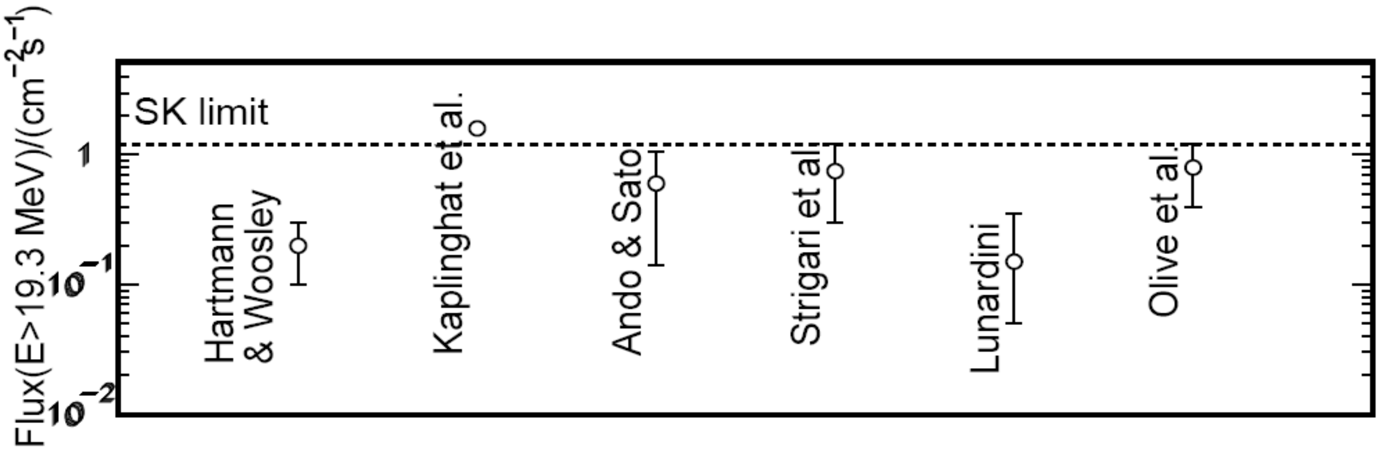
Differences due to core collapse models and assumed SN rate and luminosity

Large WC detector or LS detectors are best.

HEP solar neutrinos limits LAr sensitivity (ν_e) – plus need for large size.

Conclusion: LAr detector too small to justify added costs of deep site for this physics

Published SK limit on diffuse SN flux compared with several models

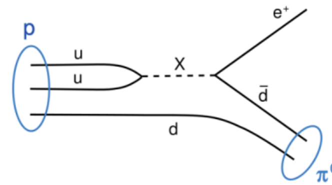


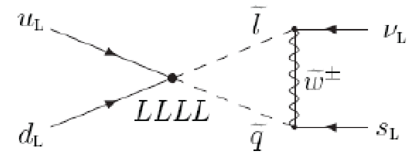
The Homestake muon rate an order of magnitude smaller than Kamioka, so expect 15.5 MeV threshold instead of 19.3 MeV. **This enhances signal by 40% in addition to just detector mass scaling.**

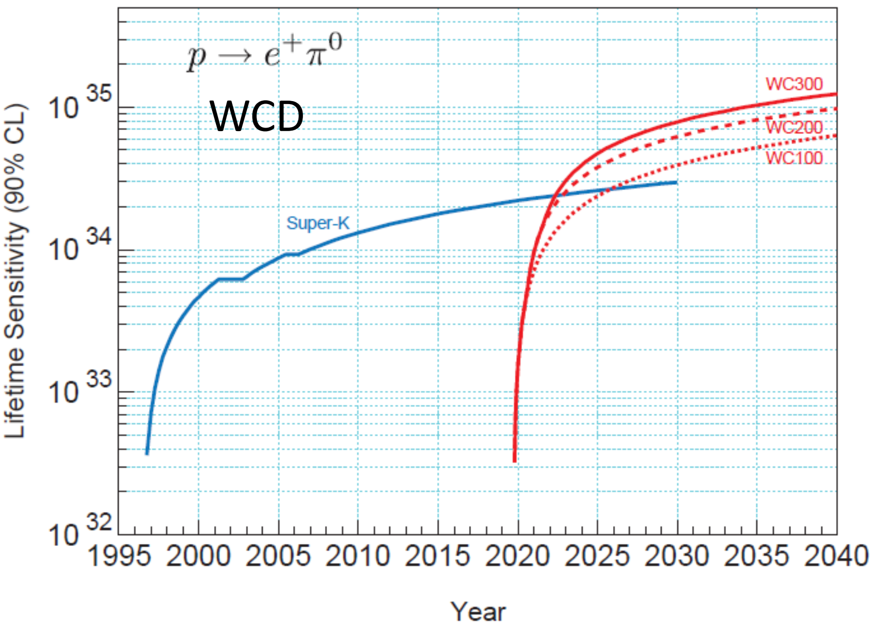
Due to geomagnetic latitude, atmospheric neutrino rate per kton is 50% higher at Homestake as compared to Kamioka. **This enhances background by 50%.**

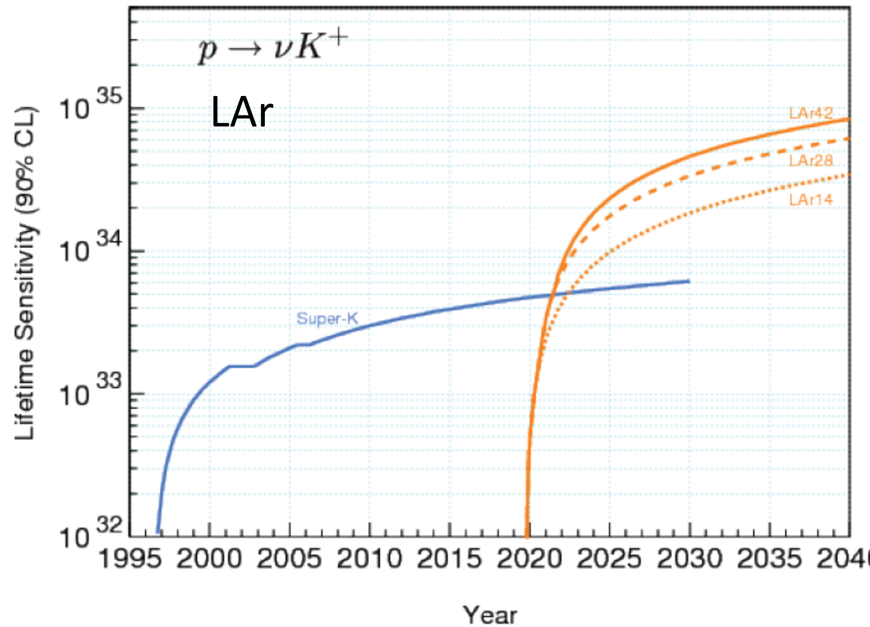
Reference Configuration Number	Expected Annual SRN Signal (events/year)	Expected Annual Background (events/year)	Years of LBNE Data Needed for a 3.0-σ Signal Assuming Maximum SRN Flux	Years of LBNE Data Needed for a 3.0-σ Signal Assuming Minimum SRN Flux
Baseline	2 – 27	187	2.9	526
+ PMTs	3 – 35	214	2.0	268
+ PMTs + Gd	9 – 50	43	0.19	1.3

Proton Decay



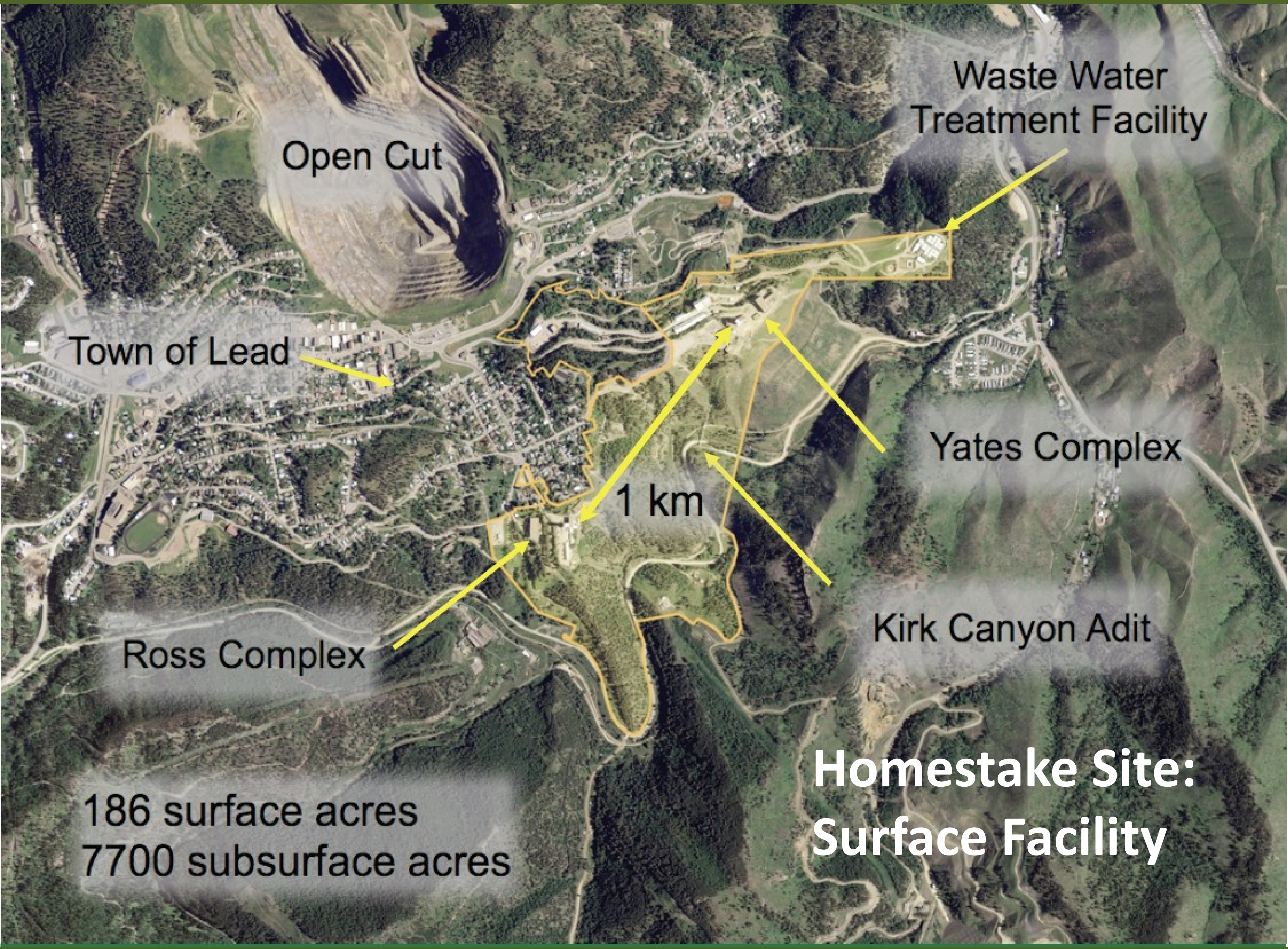






- $e^+\pi^0$: WC200 reach ~10^{35} in 20 years -- 7.5x SK current; 5x SK ultimate
- $\bar{\nu}K^+$: LAr34 reach ~7×10^{34} in 20 years -- 23x SK current; 10x SK ultimate
- Detector mass is the main issue, backgrounds also come into play

The Far Site

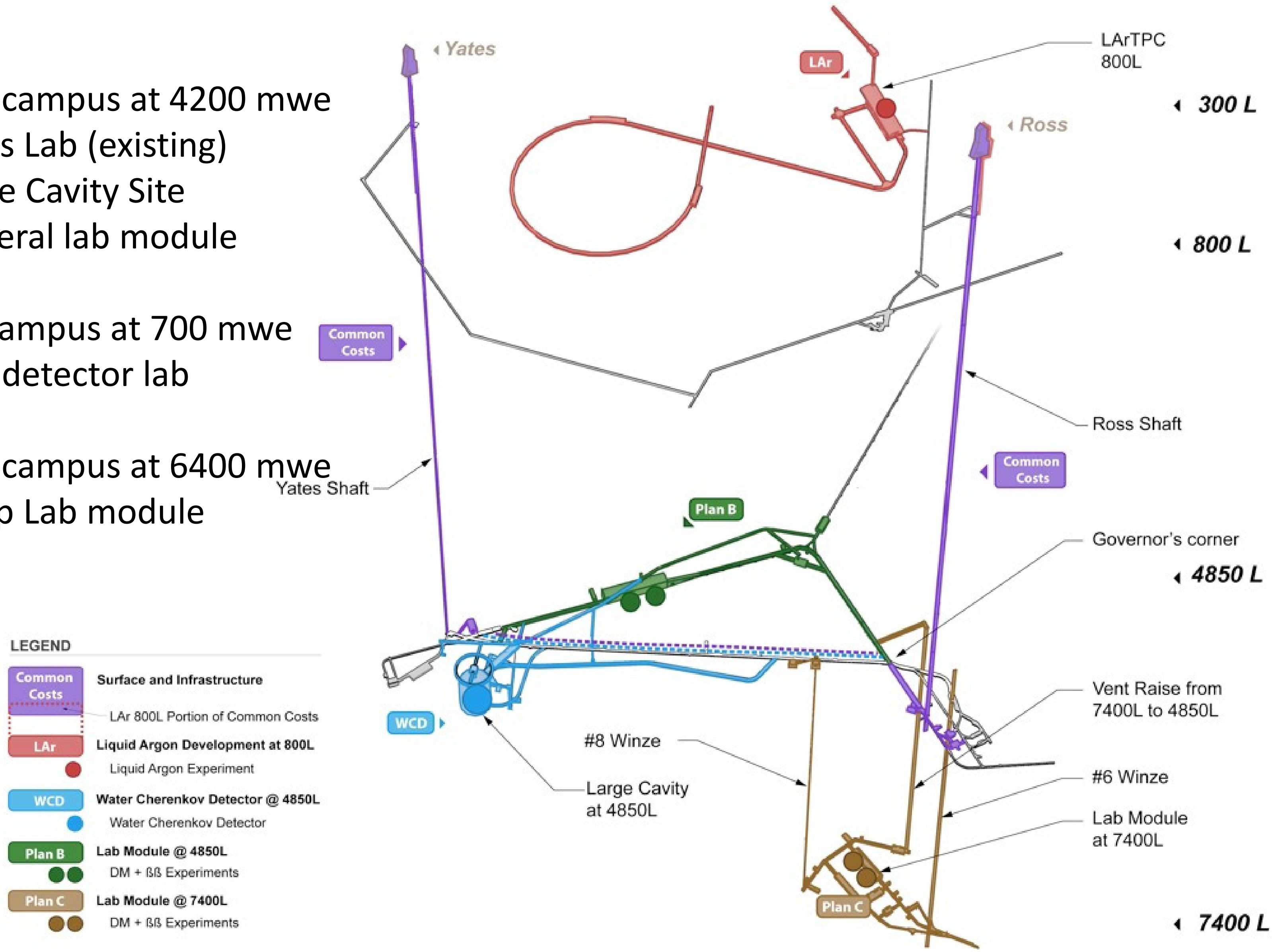

Waste Water
Treatment Facility
Open Cut
Town of Lead
Yates Complex
1 km
Kirk Canyon Adit
Ross Complex
Homestake Site:
Surface Facility
186 surface acres
7700 subsurface acres

OVERVIEW: Underground Lab Basic Layout

4850 campus at 4200 mwe
- Davis Lab (existing)
- Large Cavity Site
- General lab module

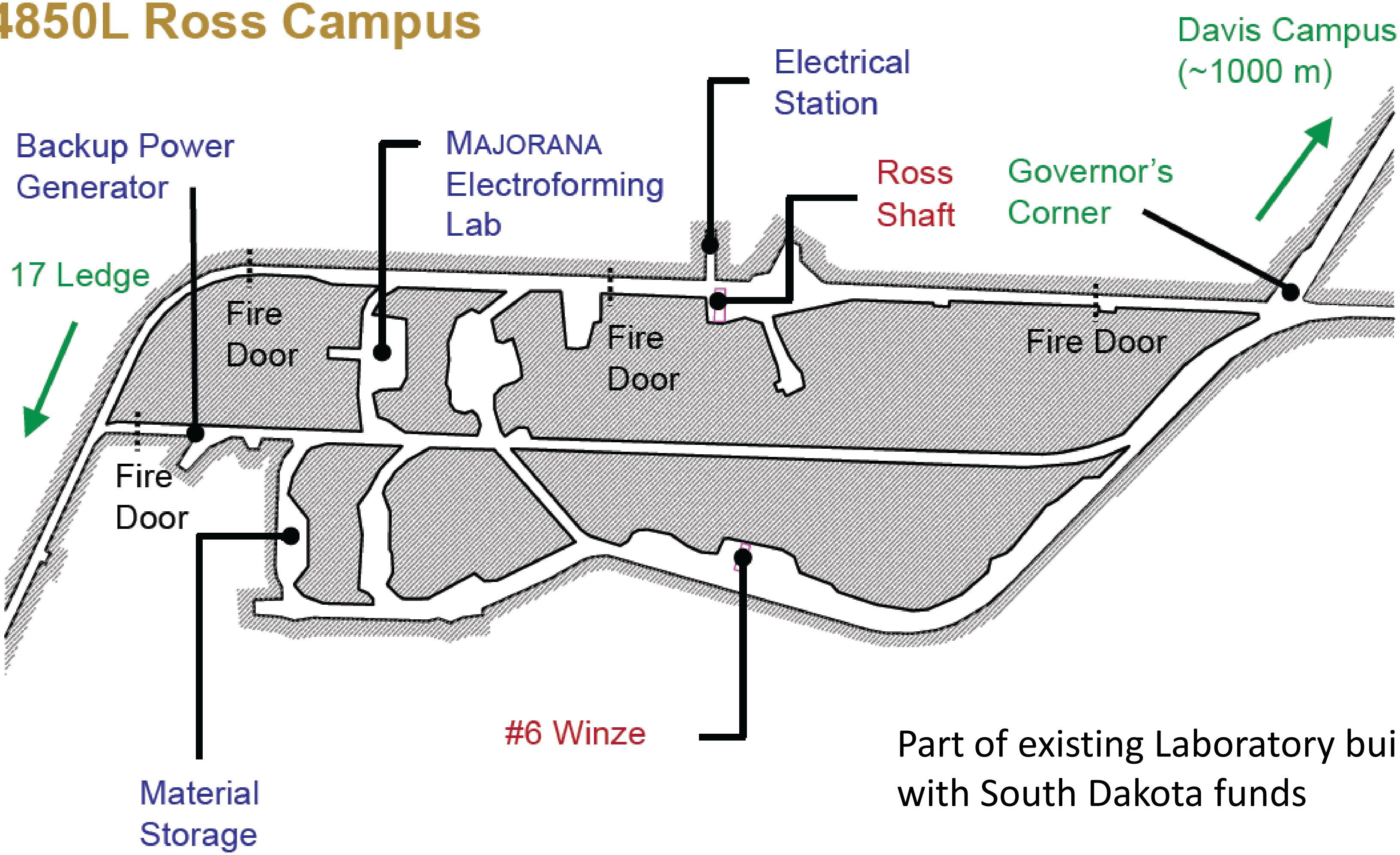
800 campus at 700 mwe
- LAr detector lab

7400 campus at 6400 mwe
- Deep Lab module



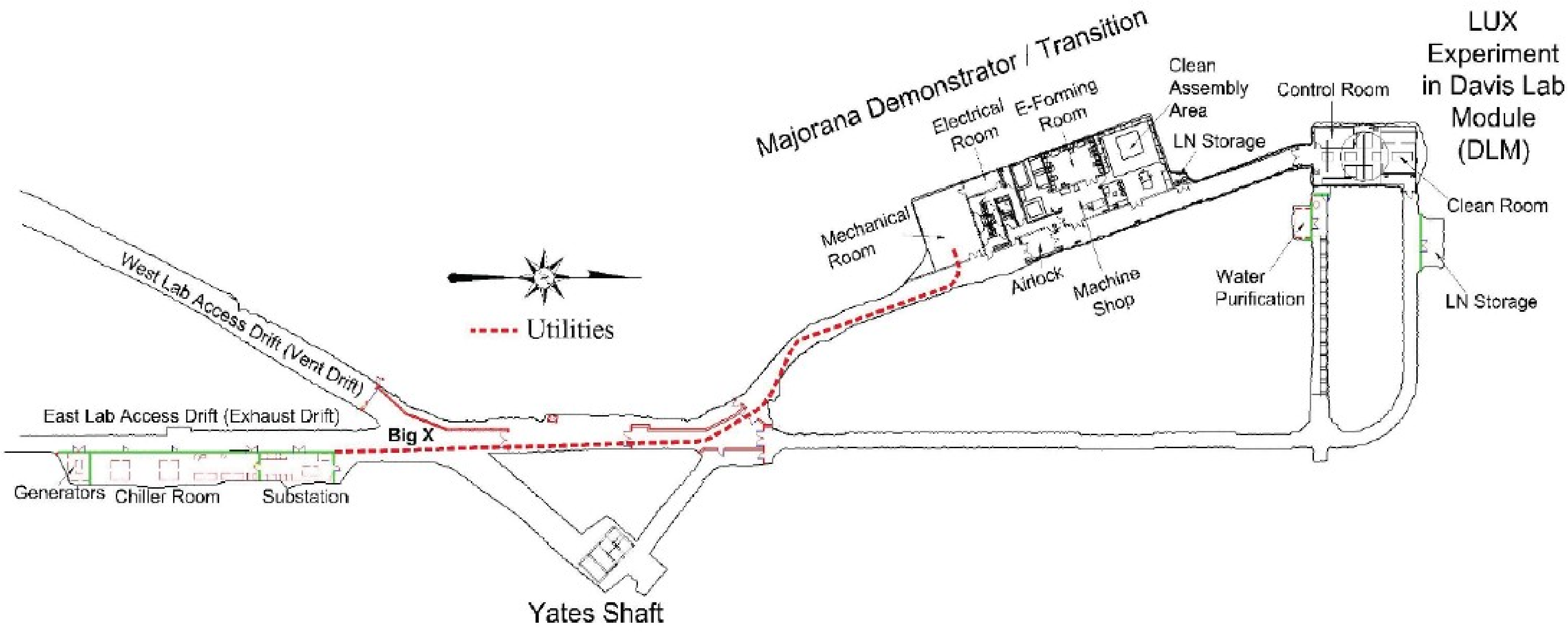
Sanford Laboratory Ross Campus

4850L Ross Campus



Part of existing Laboratory built with South Dakota funds

Davis Campus, 4850 Level



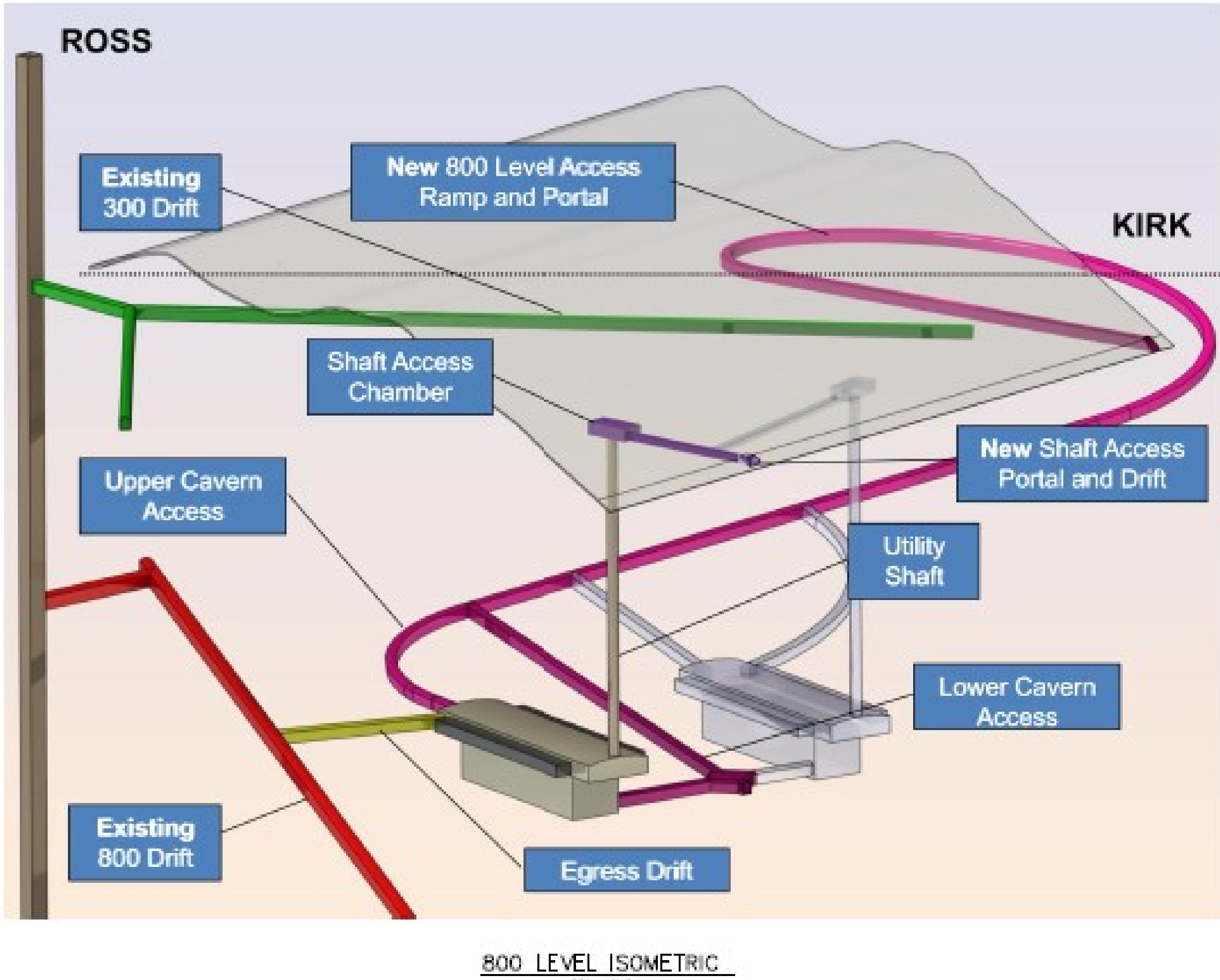
Majorana cleanroom

Transition Cavern

Shotcreting the Davis cavern

LAr 800 level lab at Homestake

- 24-34kt cavern at 800 level
- Space on surface for cyrogenics system
- Drive-in access for experiment installation
- Experimental utilities: power, ventilation for cryogenic safety



- Why 800 level?
- SN detection, atmospheric neutrinos detection improved
- Critical for proton decay

Depth Requirements for Proton Decay: Liquid Argon

- A unique feature of LAr detectors are their ability to reconstruct the K^+ decay from the SUSY-motivated decay mode $p \rightarrow \nu K^+$. This would allow sensitivity to this mode five times that of Super-Kamiokande over a 10 year run.
- The most significant background expected is from CR muons that make a K^o_L that enters the detector from the outside and then charge exchanges into a K^+.

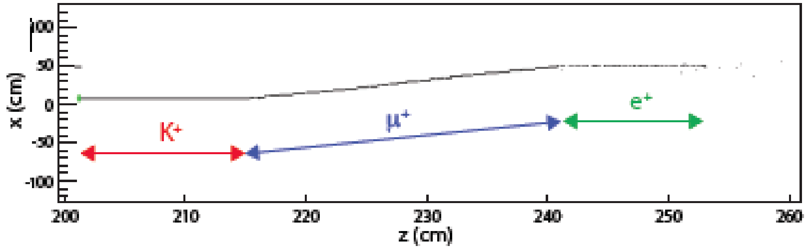
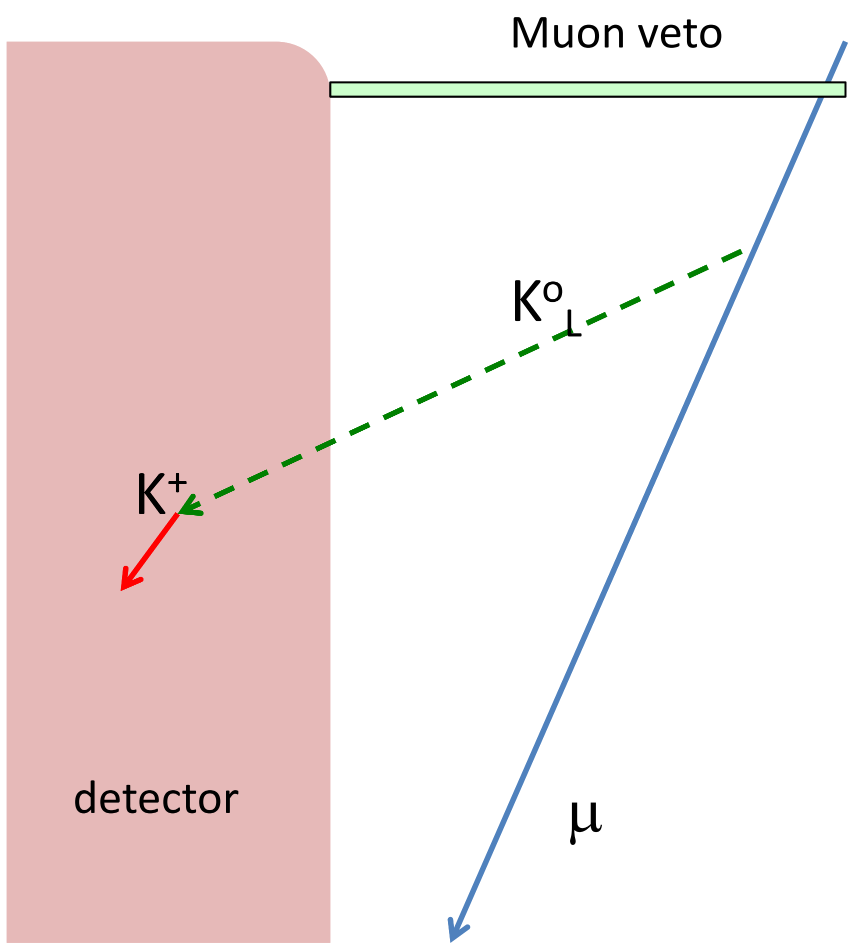


Figure 4–4: LArSoft simulation of an example $K^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain.

Requirement for Muon veto

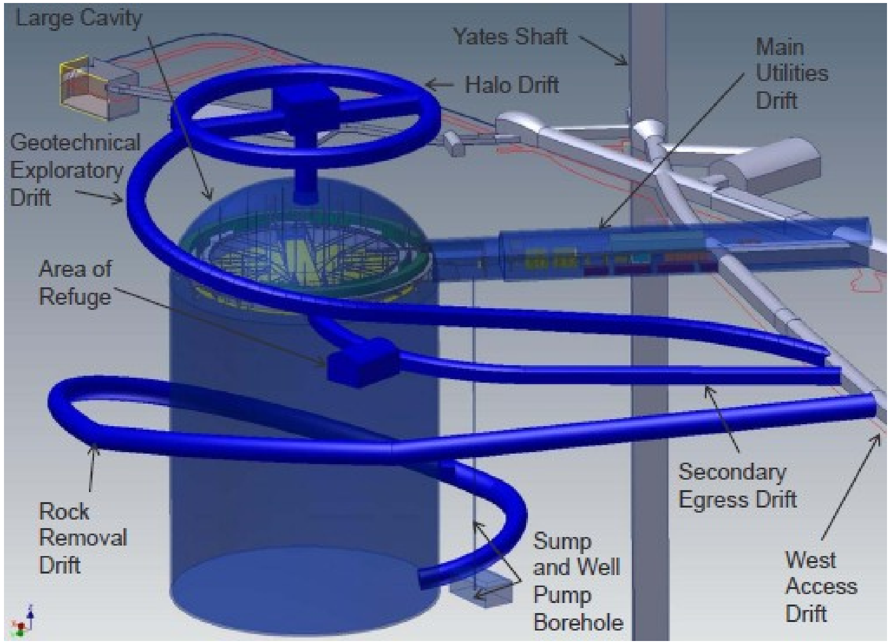
- Without a muon veto, a fiducial volume cut of 5-7 meters from the wall is predicted to be necessary
- With an effective veto this can be significantly reduced.
- At 800 feet, a muon veto is planned that would retain roughly 80% of the FV.
- Conclusion: with a sufficiently well-designed muon veto, 800 feet should be sufficient. This is currently the driving factor in the depth requirement.



WCD Conventional Facilities (CF) at Homestake

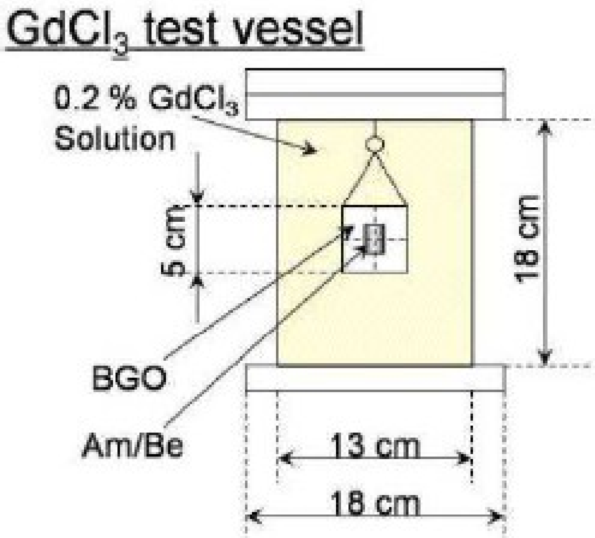
WCD CF based on requirements of experiment

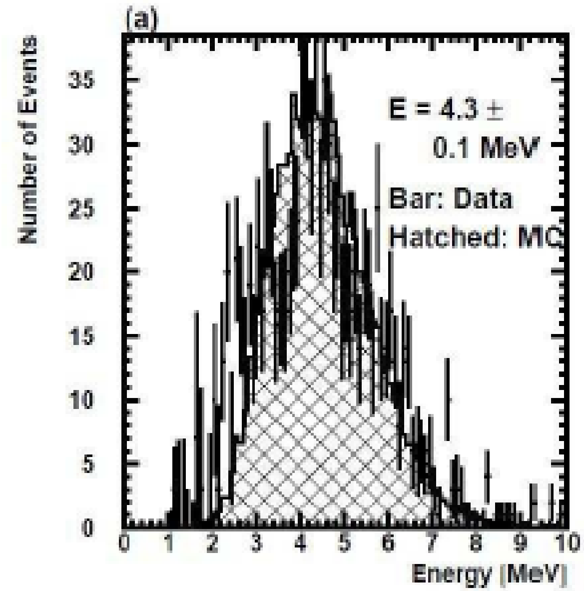
- 150kt-200kt cavern at 4850 level
- Space on surface for water fill system, underground for water recirculation system
- Experimental utilities: power, water for tank, drainage of leak & native water from the tank, drainage for tank maintenance



4850 level location driven by potential for low energy neutrino measurements now and in future upgrades. Cosmological SN neutrinos, solar neutrinos, geoneutrinos.

Addition of Gadolinium





Tests with Super-Kamiokande have shown that neutron tagging via gadolinium in the water is feasible.

Case Study document details the increased light collection needed for LBNE. Roughly a factor of two is desirable to achieve good efficiency

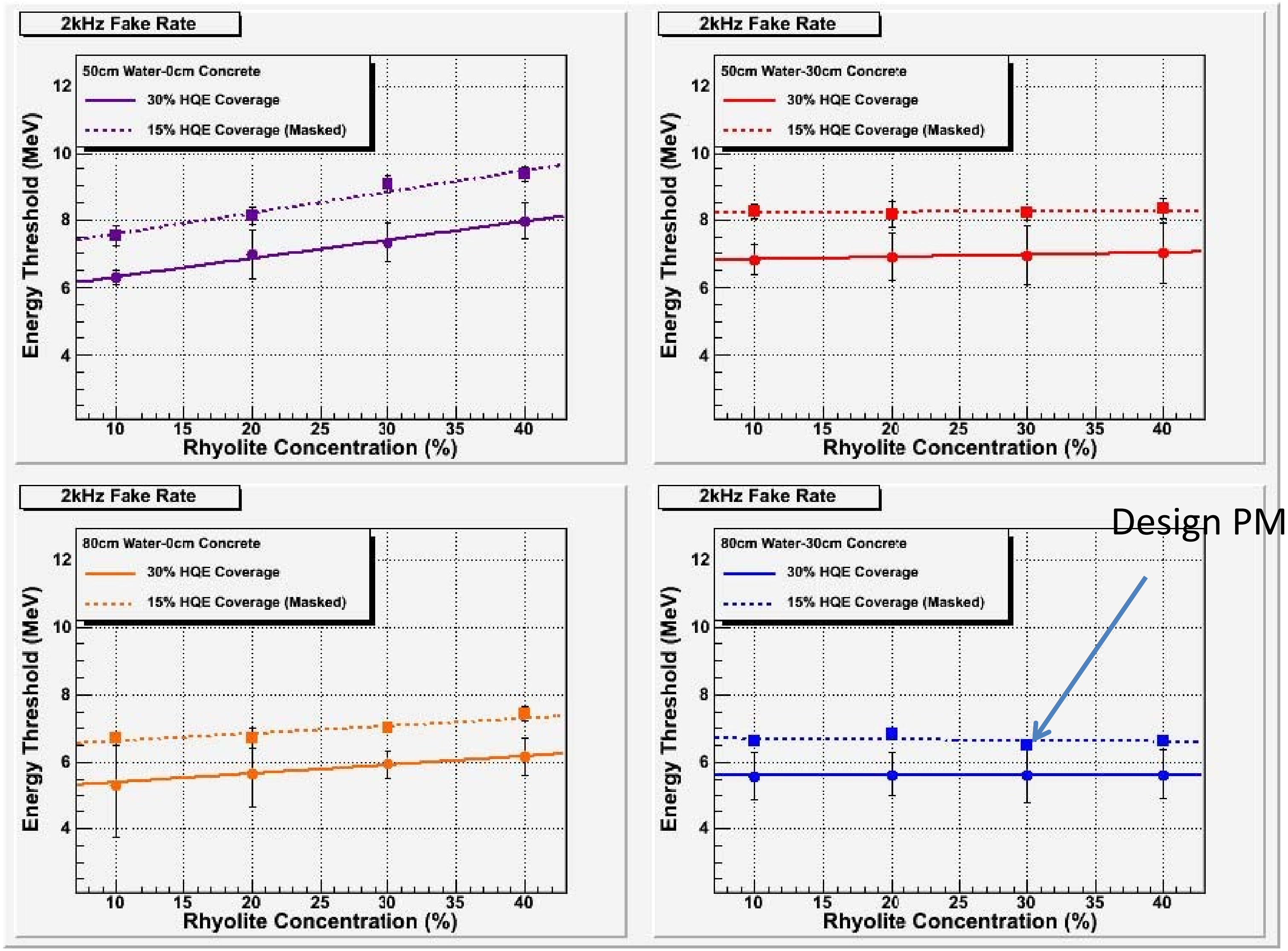
Low Energy Physics: Radiopurity

For the WC detector option, extensive hit-level studies have been done of the effects of radiopurity on detector energy threshold performance.

Concentrations			
Material	U	Th	K
Amphibolite	0.16 ppm	0.20 ppm	0.154%
Rhyolite	8.67 ppm	12.2 ppm	2.82%
60% - 40% Mix	3.564 ppm	5 ppm	1.22%
Concrete	2.02 ppm	1.87 ppm	0.23%
PMT Glass	67 ppb	25 ppb	16 ppm

Table 1: Concentrations of radioactive elements in materials[2][3]

Threshold independent of rock with 80 cm buffer. Nominal threshold with design coverage is ~6.7 MeV. No concrete liner BETTER since Homestale rock has quite good radiopurity compared to typical concrete.



With concrete liner

Without concrete liner

The Far Detectors

Detector Mass Requirements

- The 200 kT mass selected for a WC detector is driven by the statistics necessary to address the physics goals in a ten year run, for $\sin^2 2\theta_{13}$ in the range of current experimental sensitivity.
- If $\sin^2 2\theta_{13}$ is outside this range, LBNE has enough sensitivity to make the most sensitive search for this parameter.
- The smaller 34 kT mass for LAr is based on the ability to use non-QECC events to look for $\nu_\mu \rightarrow \nu_e$ oscillations due to event ID and NC rejection.

	WC (ν mode)	WC ($\bar{\nu}$ mode)
No oscillations:		
QE signal	27,947	18,220
non-QE background	5,884	3,767
wrong-sign background	–	2,725
With oscillations:		
QE signal	8,955	5,500
non-QE background	1,888	1,133
wrong-sign background	–	1,366

Table 6–3: Number of ν_μ and $\overline{\nu_\mu}$ events expected in a 200 kton WC detector for 5 years each of neutrino and antineutrino running in a 700 kW beam. Rates have been integrated over the region from $0 - 10$ GeV. The signal samples are assumed to be ν_μ ($\overline{\nu_\mu}$) QE events in the case of neutrino (antineutrino) mode running. Wrong-sign backgrounds refer to ν_μ events in the antineutrino mode beam.

	LAr (ν mode)	LAr ($\bar{\nu}$ mode)
No oscillations:		
CC signal	26,040	10,248
NC background	51	23
wrong-sign background	–	3,110
With oscillations:		
CC signal	8,489	3,182
NC background	51	23
wrong-sign background	–	1,791

Table 5–3: Number of ν_μ and $\overline{\nu_\mu}$ events expected in a 34 kt LAr detector for 5 years each of neutrino and antineutrino running in a 700 kW beam [3]. Rates have been integrated over the region from $0 - 10$ GeV. The signal samples are assumed to be ν_μ ($\overline{\nu_\mu}$) CC events in the case of neutrino (antineutrino) mode running. Wrong-sign backgrounds refer to ν_μ events in the antineutrino mode beam.

Event rates for numu and numubar events in LAr (bottom) and WC (top).

These tables indicate why sensitivities are similar in this mode. The wrong-sign background in LAr is compensated by the reduced background from non-QE/NC

	WC (ν mode)	WC ($\bar{\nu}$ mode)
Normal mass hierarchy:		
Oscillated ν_e+$\overline{\nu_e}$	484	180
Beam ν_e+$\overline{\nu_e}$	218	115
NC	276	118
Mis-identified ν_μ CC	15	7
Inverted mass hierarchy:		
Oscillated ν_e+$\overline{\nu_e}$	212	261
Beam ν_e+$\overline{\nu_e}$	221	114
NC	276	118
Mis-identified ν_μ CC	15	7

Table 6–1: Number of ν_e and $\overline{\nu_e}$ events expected in a 200 kton WC detector in 5 years each of neutrino and antineutrino running in a 700 kW beam. Rates have been integrated over the region from 0.5 – 12 GeV. In correspondence with Figure 6–1, this assumes $\sin^2 2\theta_{13} = 0.04$ and $\delta_{CP} = 0$.

	LAr (ν mode)	LAr ($\bar{\nu}$ mode)
Normal mass hierarchy:		
oscillated ν_e+$\overline{\nu_e}$	497	112
beam ν_e+$\overline{\nu_e}$	326	168
NC	81	34
mis-identified CC	162	52
Inverted mass hierarchy:		
oscillated ν_e+$\overline{\nu_e}$	212	261
beam ν_e+$\overline{\nu_e}$	329	167
NC	81	34
mis-identified CC	162	52

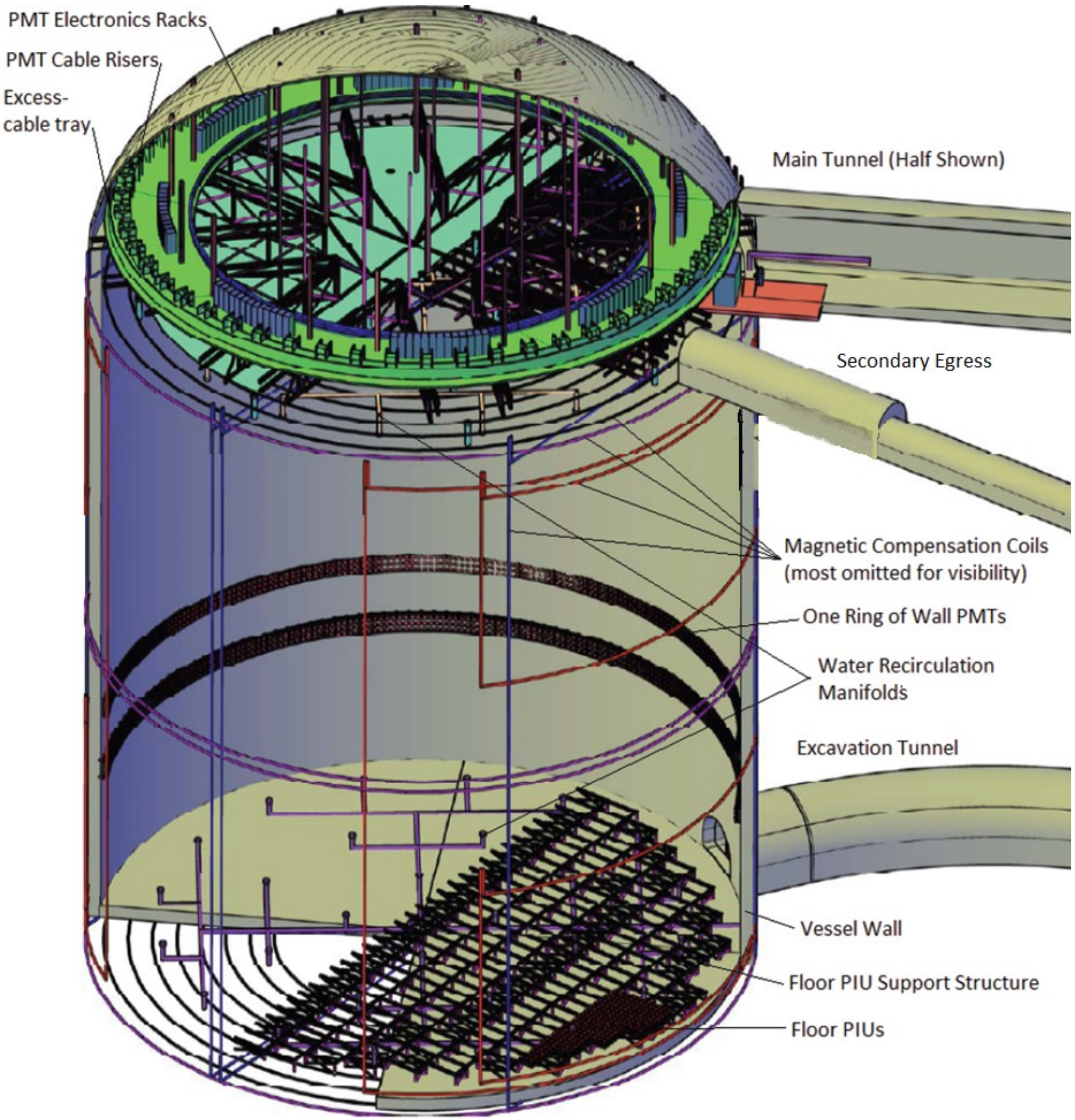
Table 5–1: Number of ν_e and $\overline{\nu_e}$ events expected in a 34-kt LAr detector at 1300 km in 5 years each of neutrino and antineutrino running in a 700 kW beam [3]. Rates have been integrated over the region from 0.5 – 60 GeV. Like Figure 5–4, this assumes $\sin^2 2\theta_{13} = 0.04$ and $\delta_{CP} = 0$.

Event rates for nue and nuebar events in LAr (bottom) and WC (top).

Note the difference in the background components for the two detector types.

A measurement with two different detector types would be complimentary – the systematic uncertainties in the background are quite different.

Water Cherenkov Detector Overview

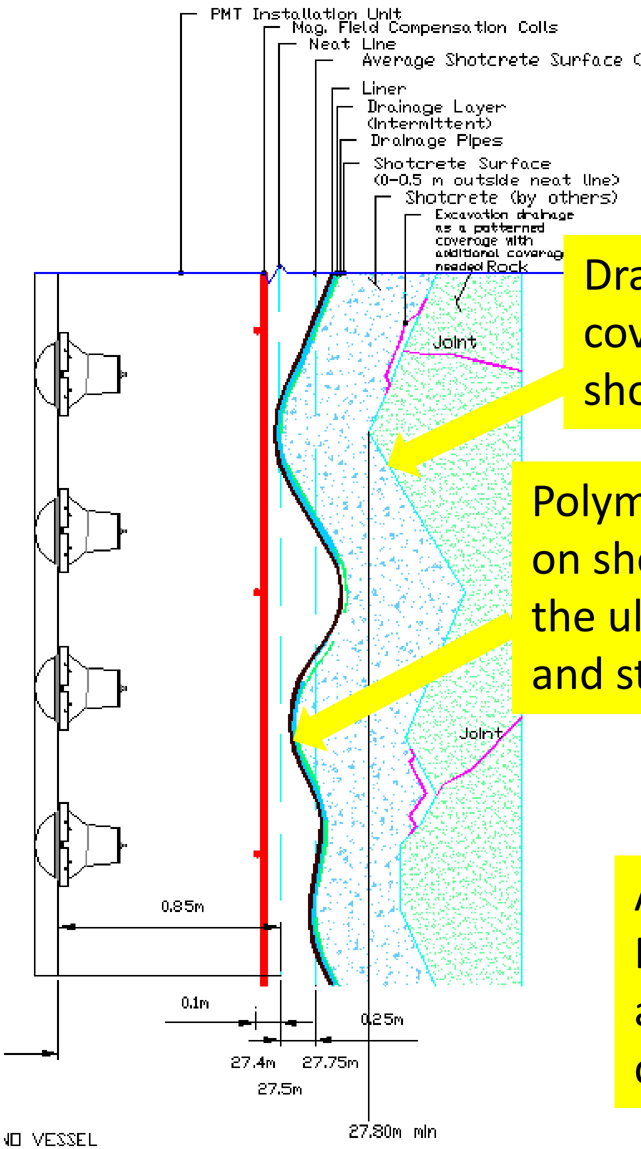


Main Detector Components

- Large Cavern
- Water Vessel
- Ultra-pure water system
- PMTs with Electronics

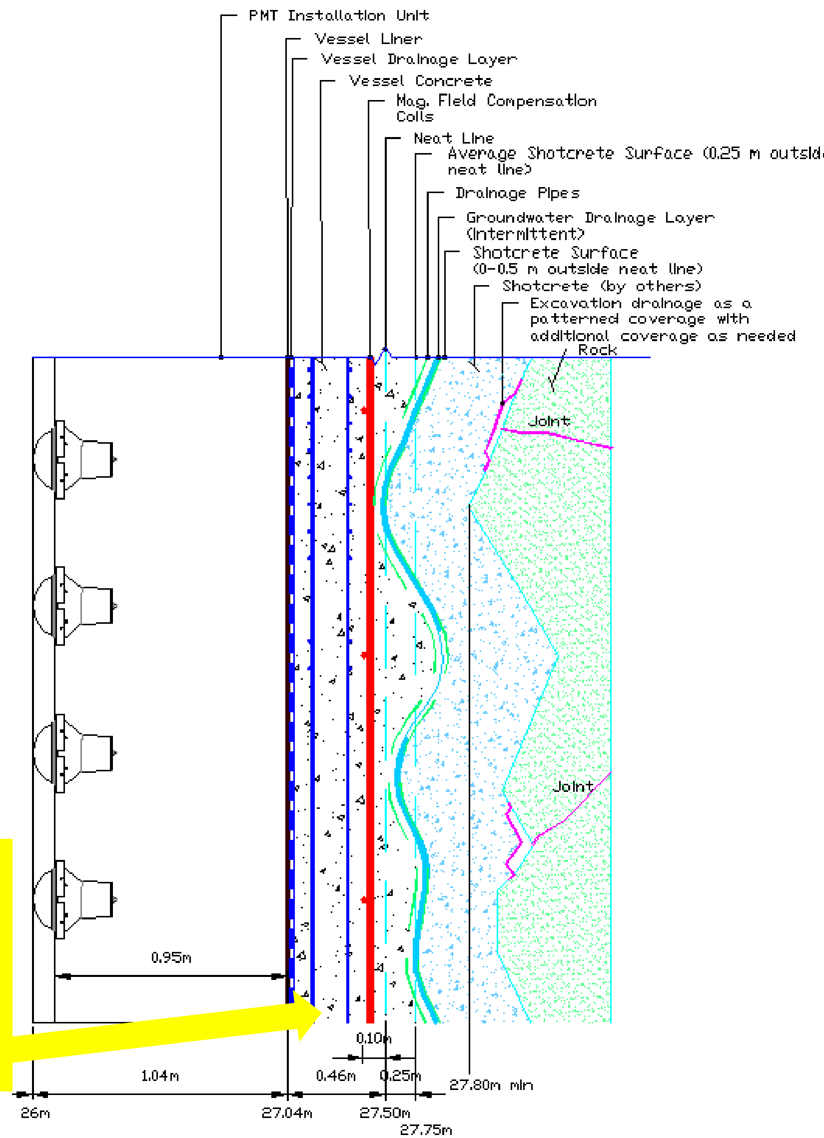
- 2 sizes under consideration: 150 kt or 200 kt fiducial mass (7-9 x SuperK)
- PMT + light collectors give photon detection efficiency equivalent to SuperK II

Water Containment



Drainage mat covered with shotcrete

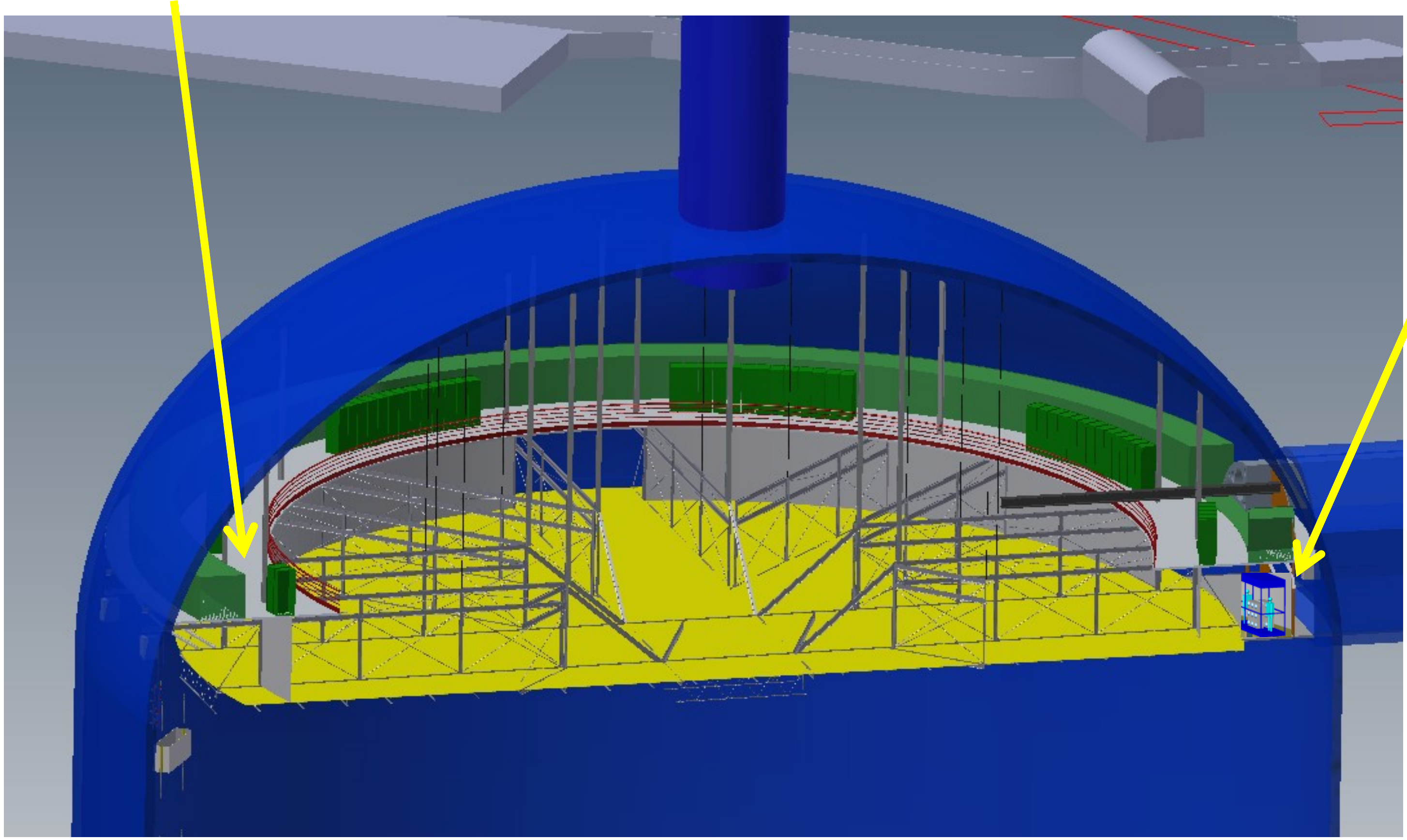
Polymer membrane on shotcrete protects the ultra-pure water and stops leakage



Alternate design: Polymer membrane against 14” poured concrete vessel.

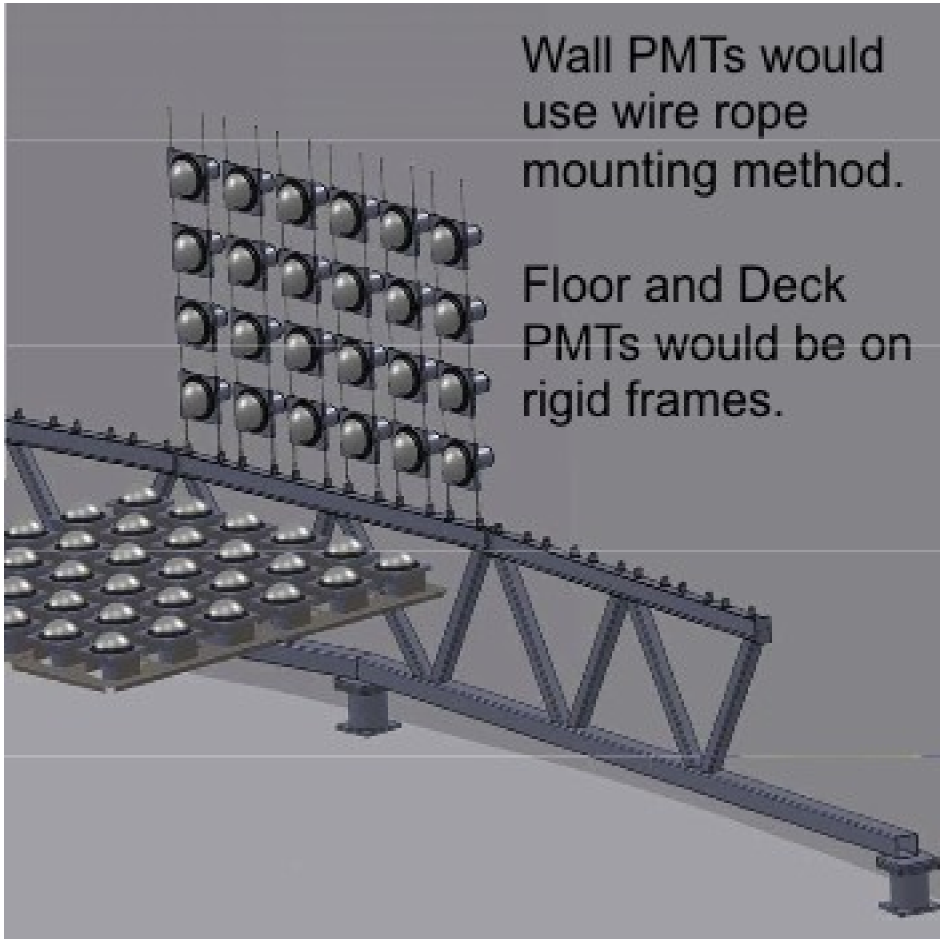
Water Cherenkov Detector Deck

- Spans the 65m diameter cavern, suspended from the dome.
- Provides a light-tight, air-tight barrier for the detector.
- Balcony (8 m wide) provides space to mount electronics.

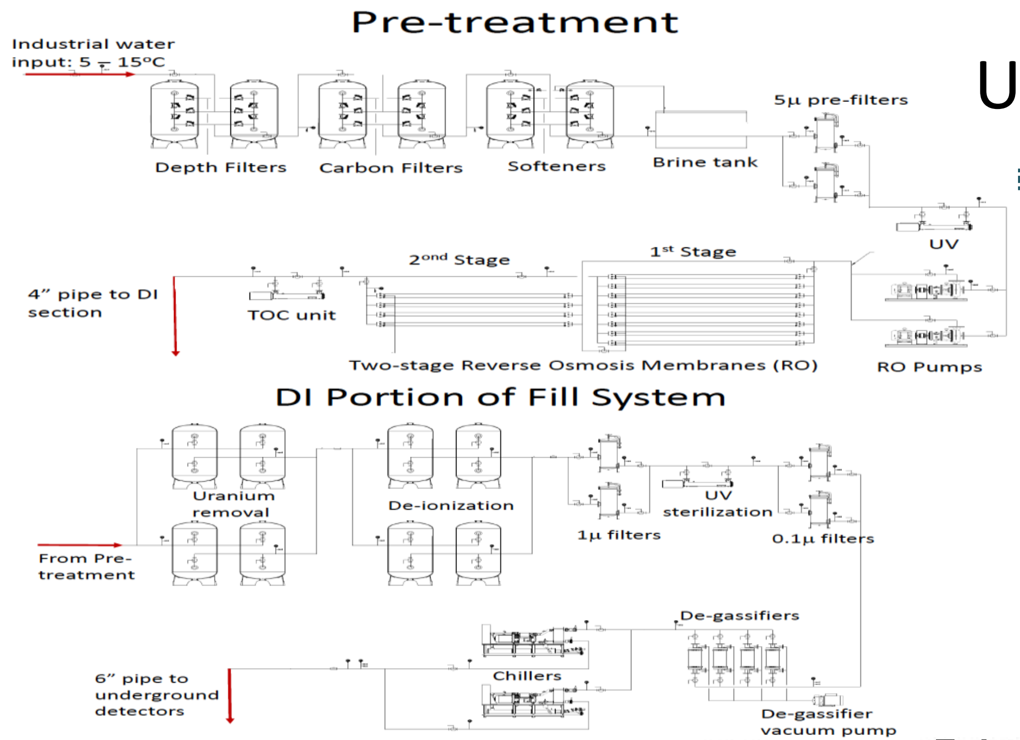


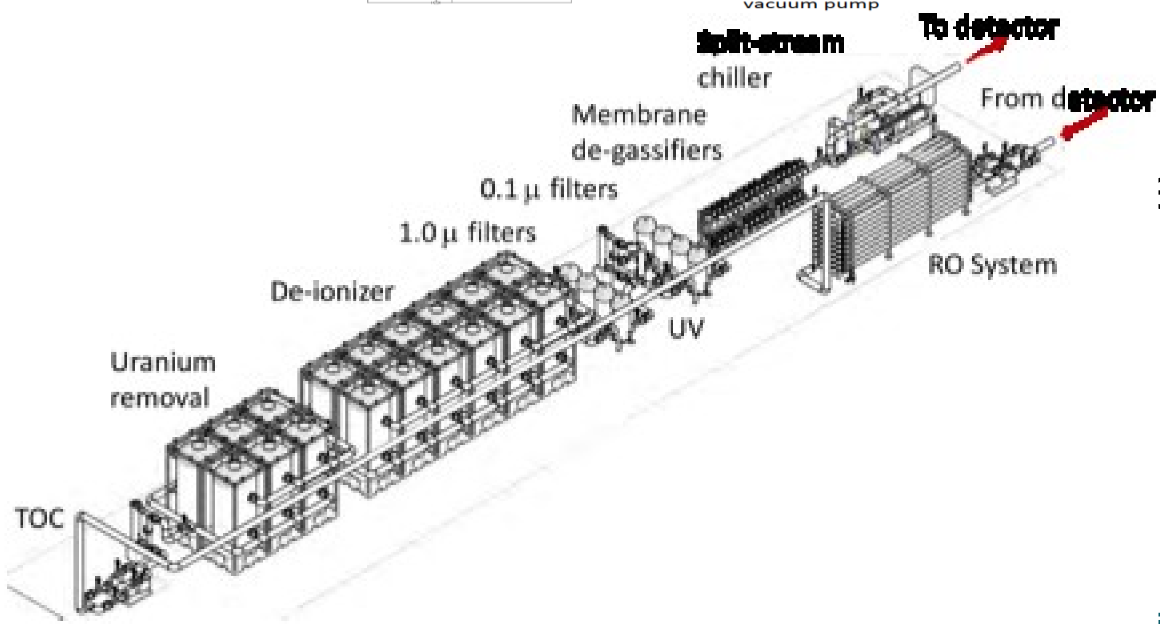
Gondola under balcony for access to detector wall

Phototube System



- 23,000 (29,000) 12” HQE PMTs in 150 kt (200 kt) detector
  - Will be catalogue item this year
  - Competing 11” tube also available this year
- Light collectors will be used
  - Winston cones or scintillator plates
  - 40% increase in light assumed
  - Both can achieve >50%
- HQE PMTs + light collectors give photon detection efficiency equivalent to SuperK II.





Ultra-Pure Water System

125 gal/min fill system

- takes industrial water
- filters and removes minerals
- Removes gasses, U/Th and sterilizes
- 4.5 to 6 months to fill

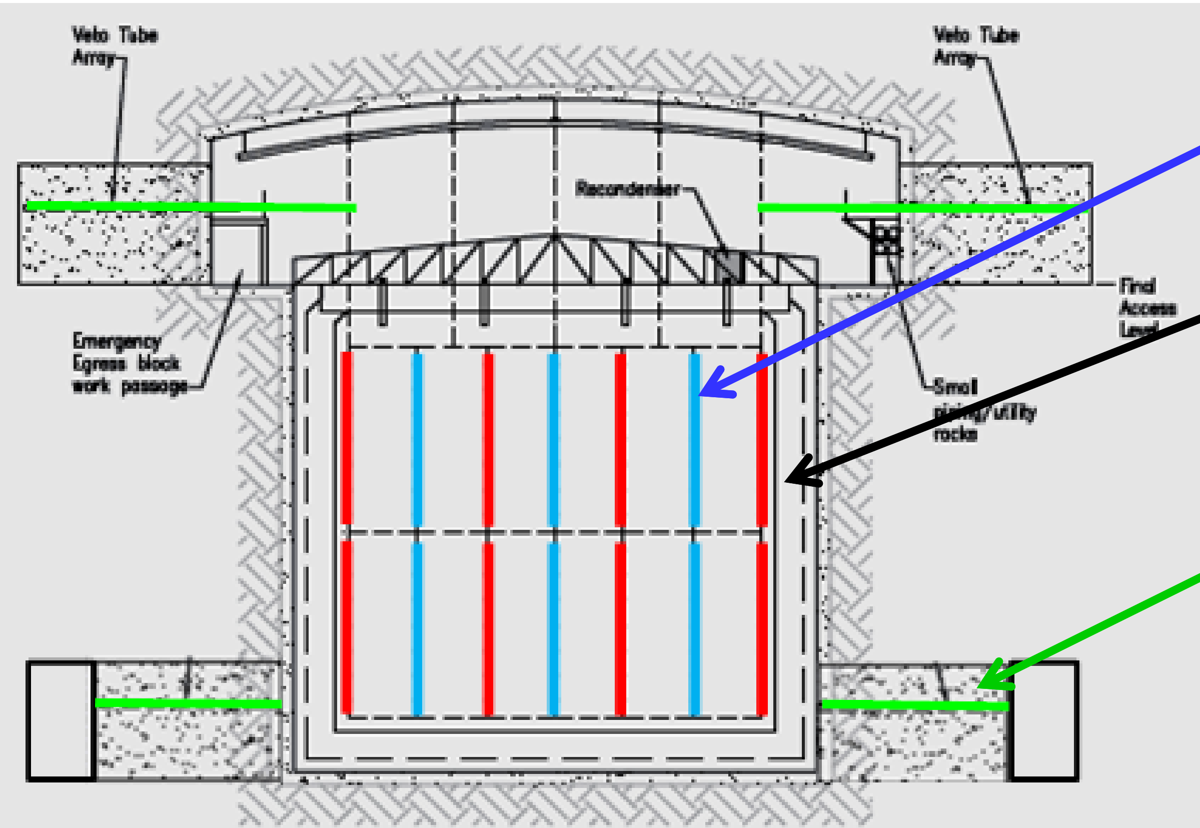
00-1200 gal/min
ecirculation system

Filters and sterilizes the water

Removes U/Th and gasses

Removes heat

Liquid Argon TPC Overview



- Alternating Cathode and Anode Plane Assemblies (CPA, APA).
- Foam-insulated cryostat inside concrete containment vessel (membrane cryostat)
- Veto system to tag cosmic rays passing through the adjacent rock.
- Photon detectors provide t=0 for non-beam physics.
- Two detectors, 12-17 kt each, in a common cavern at the 800 level.

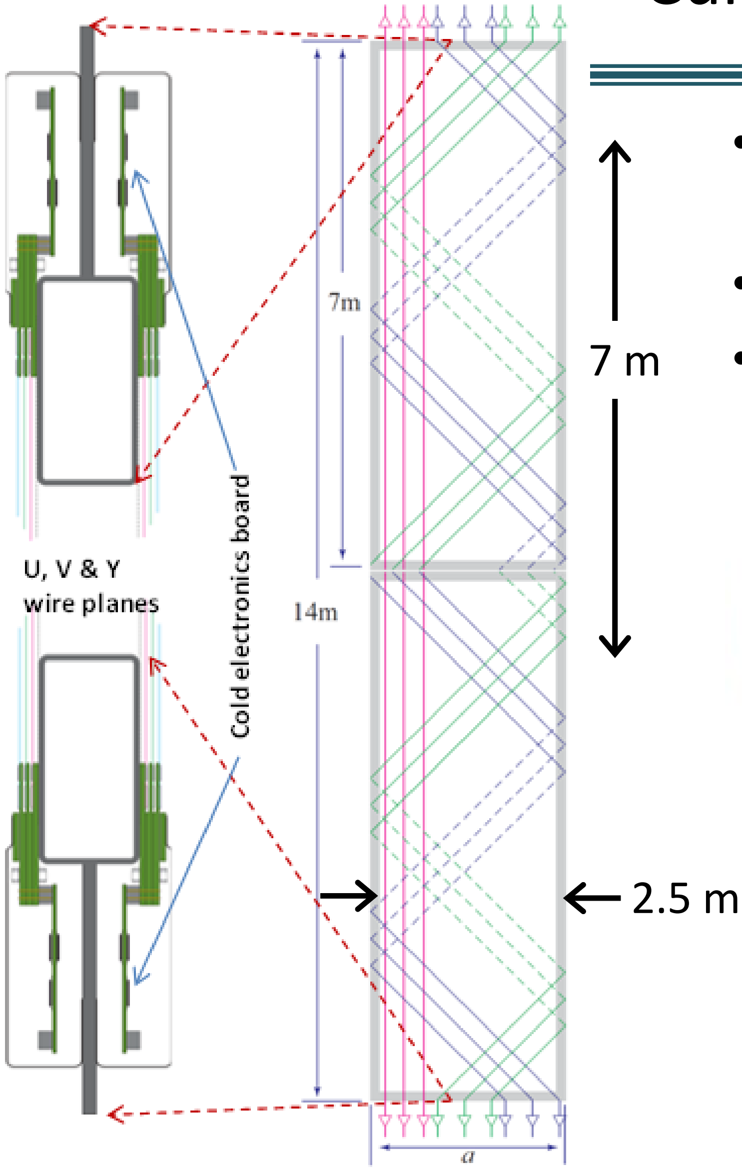
<u>At this meeting:</u>

Cold Electronics: Veljko Radeka

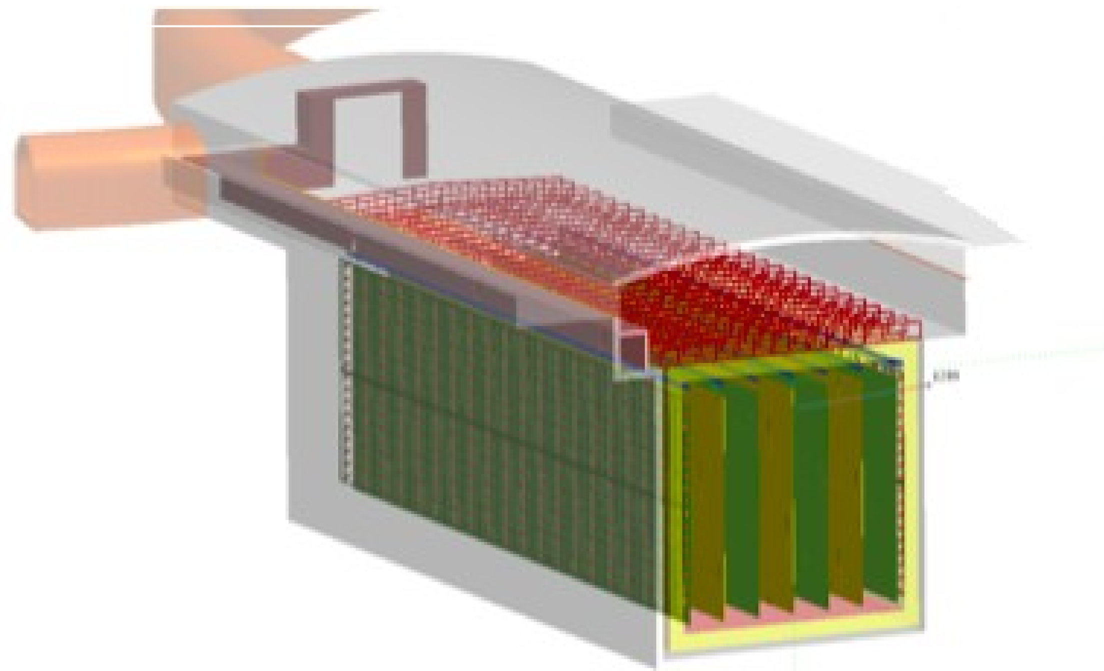
Light Guides: Ben Jones

LBNE LAr detector and 1kT prototype: Bruce Baller

Current TPC Design



- Modular APA design: 3 views on a 2.5 m x 7 m frame, mounted 2 high in cryostat
- 3 or 5 mm wire pitch
- 3.75 m or 2.5 m drift cell



LAr Prototyping Program

LBNE LAr development builds on world-wide R&D program

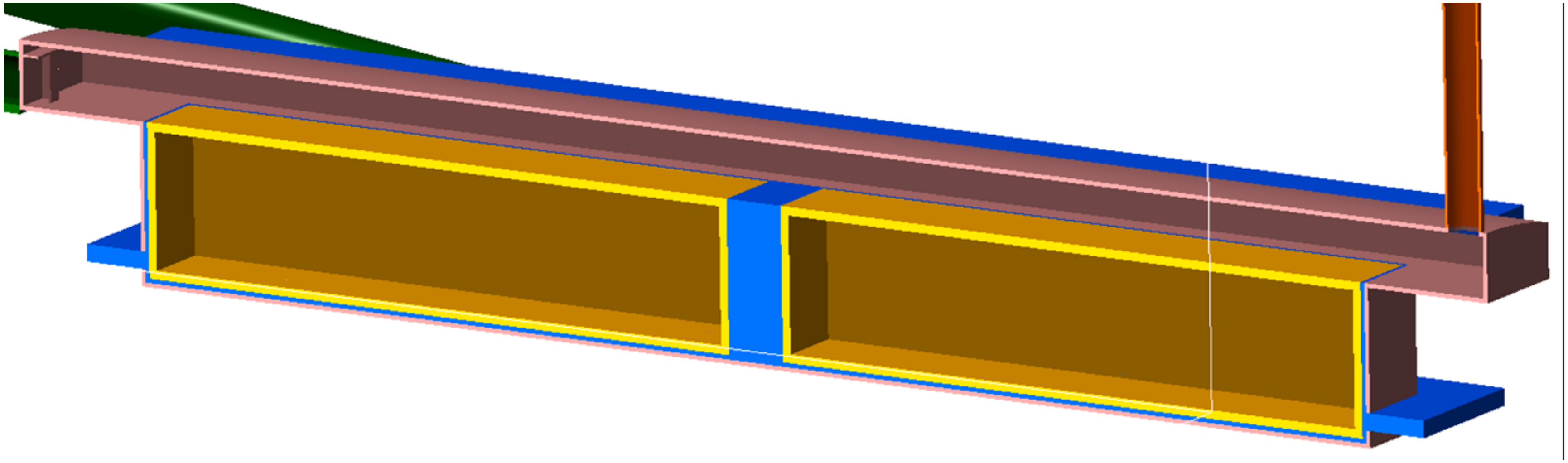
LBNE-specific prototyping program includes:

- 3 x 3 m^2 membrane cryostat wall panel – testing in progress
- 3 x 3 x 3 m^3 membrane cryostat prototype
  - Understand cryostat technology
  - Verify purity in this cryostat
  - Preliminary design complete; operational in 2012
- kton-scale full engineering prototype
  - Full engineering prototype of complete detector system
  - Leverage DZero infrastructure to minimize construction cost and time, and operating cost.
  - Early planning stage; schedule depends on funding, but could be operational in 2014.

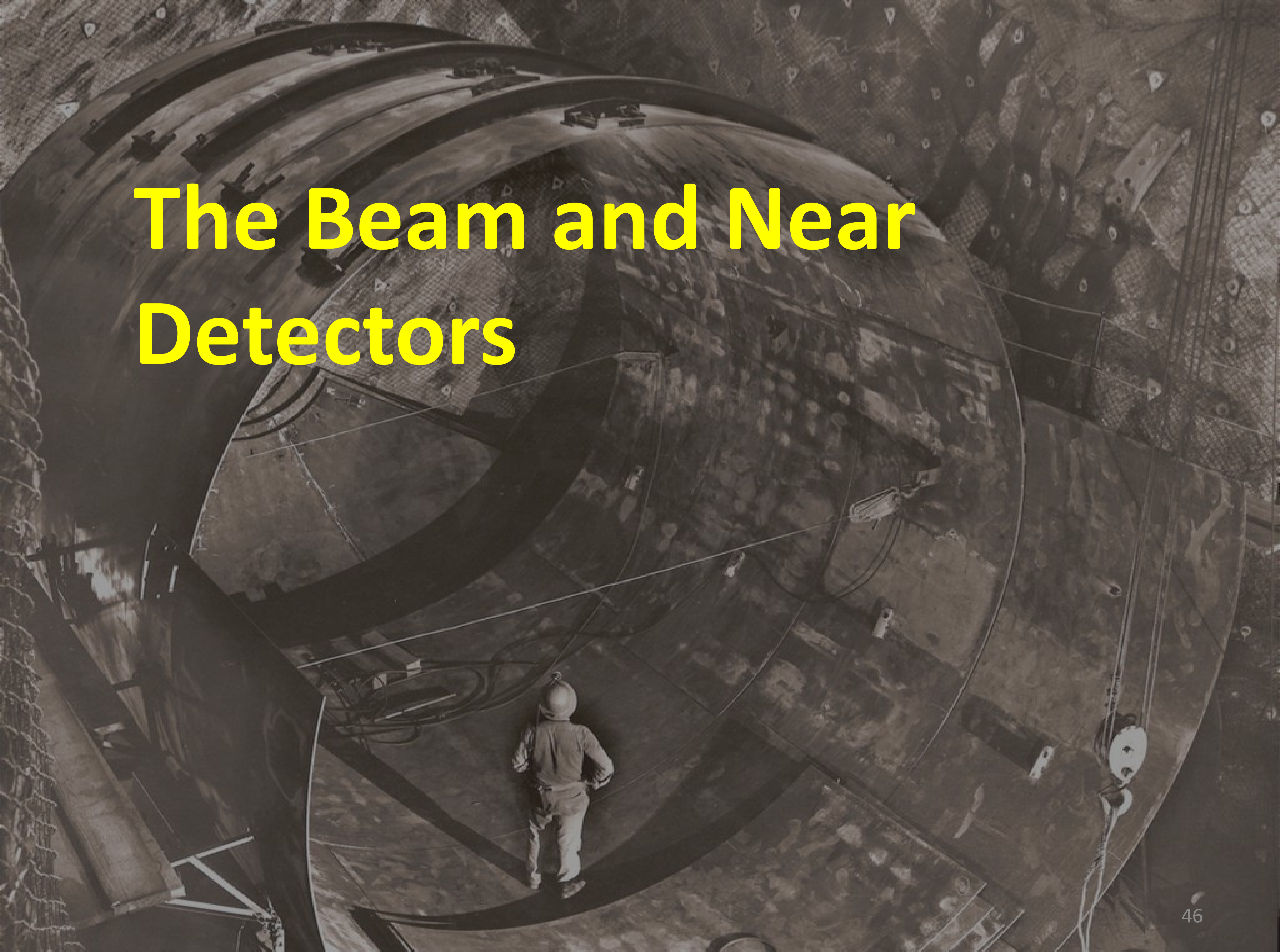
- **This meeting:** See Talk by Brian Rebel on LAPD and Bruce Baller's talk on the 1kT prototype.

LAr Detector Size

- Active volume of each detector:
  20-22.5 m wide (depending on drift length)
  14 m high
  33-55 m long (depending on fiducial mass)
- Two detectors end-to-end in common cavern



The Beam and Near Detectors



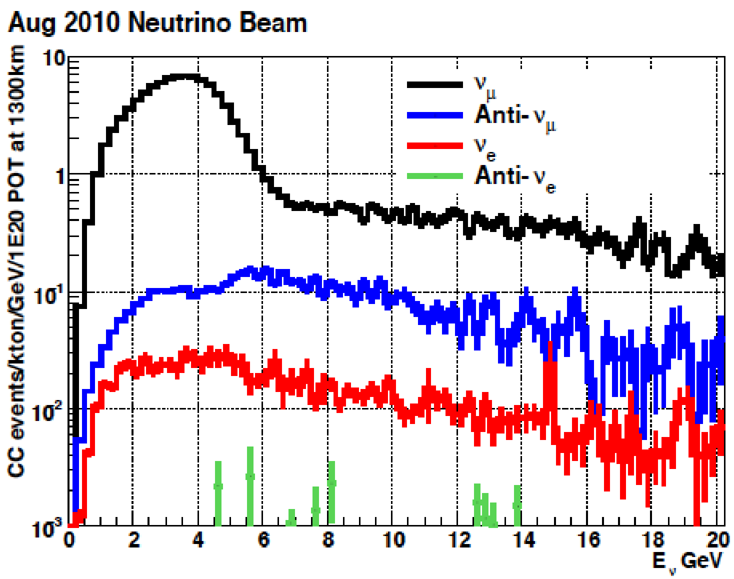
Beam Reference Design

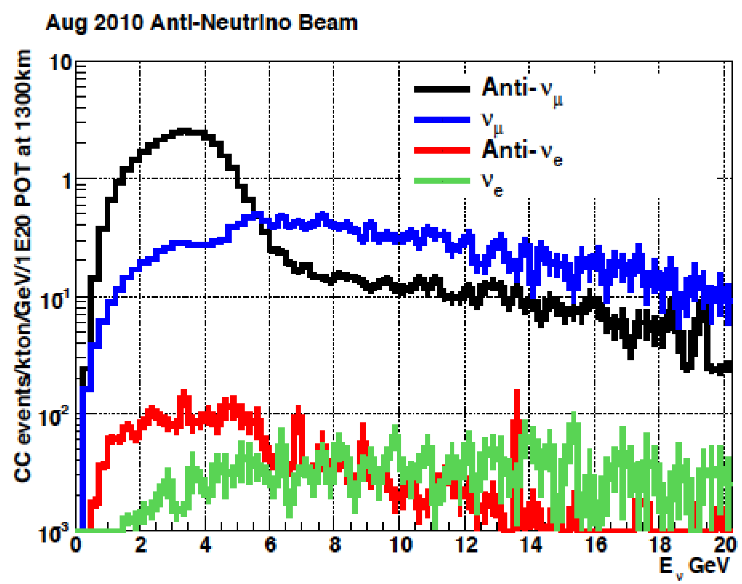
The LBNE design selected for physics studies maximizes the ν_e appearance signal at 1300km.

Target: Carbon target, r=0.6cm, l=80cm, $\rho = 2.1$ g/cm^3. Located -30cm from Horn1.

Horns: 2 Al NuMI Horns, 6m apart, 250 kA.

Decay Pipe: r=2m, l=280m, He filled/evacuated.



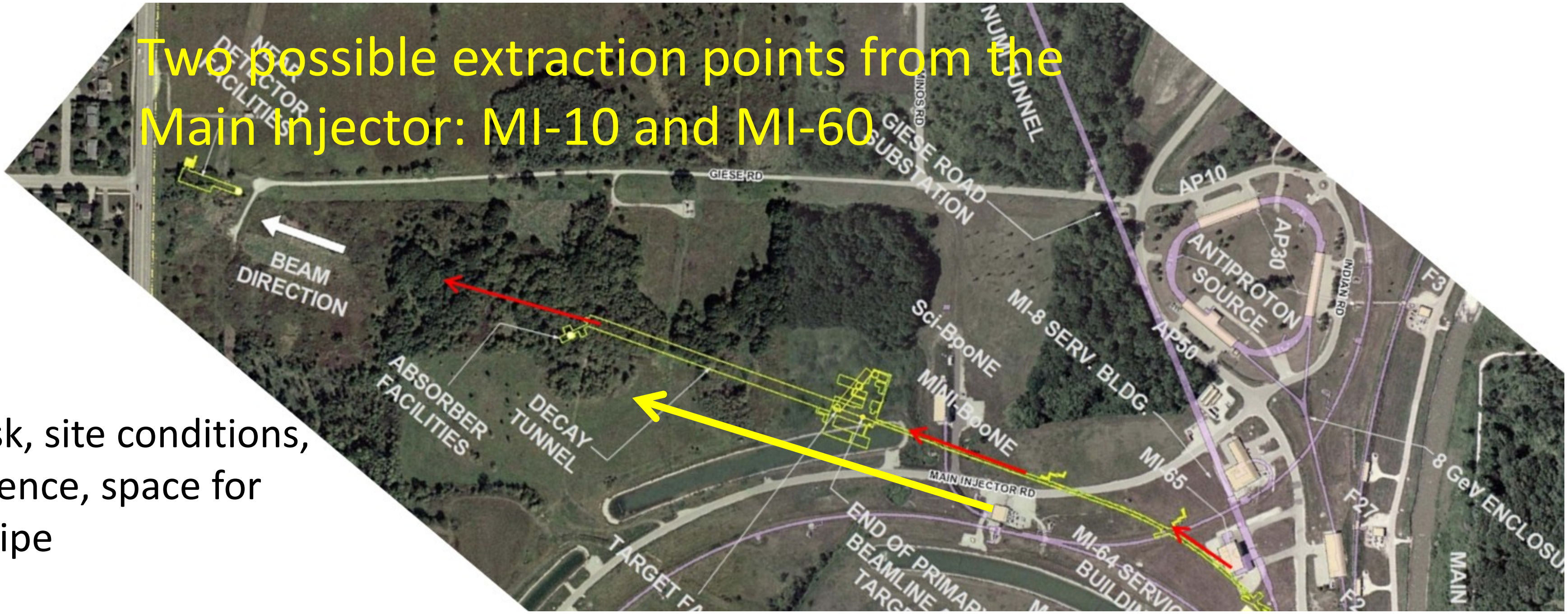


Oscillation CC rates/(100 kT.MW.yr):

ν beam, $\Delta m^2_{31} = +2.5 \times 10^{-3}$eV^2 , $\delta_{cp} = 0$, $\sin^2 2\theta_{13} = 0.04$

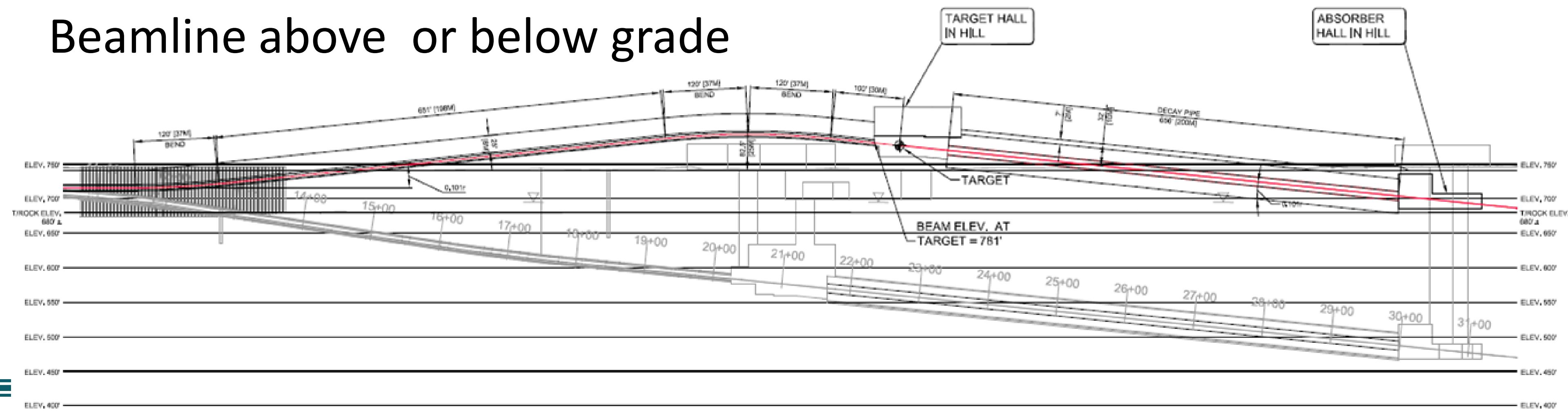
Beam Tune	ν_μ	ν_μ osc	ν_e beam	$\nu_\mu \rightarrow \nu_e$	$\nu_\mu \rightarrow \nu_\tau$
Low-Energy (LE)	29K	11K	260	560	140

OVERVIEW: Four options for the neutrino beam



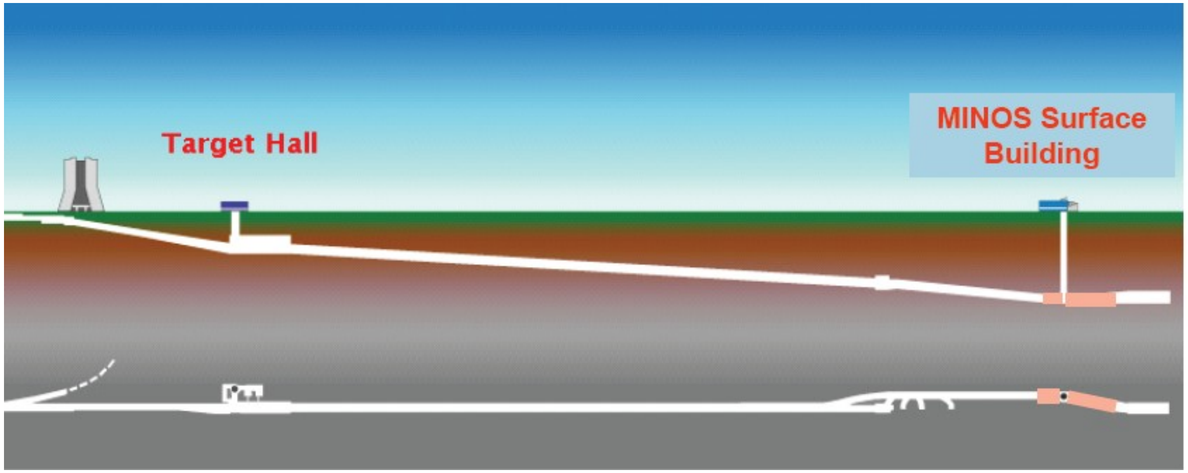
Cost, risk, site conditions, interference, space for decay pipe

Beamline above or below grade



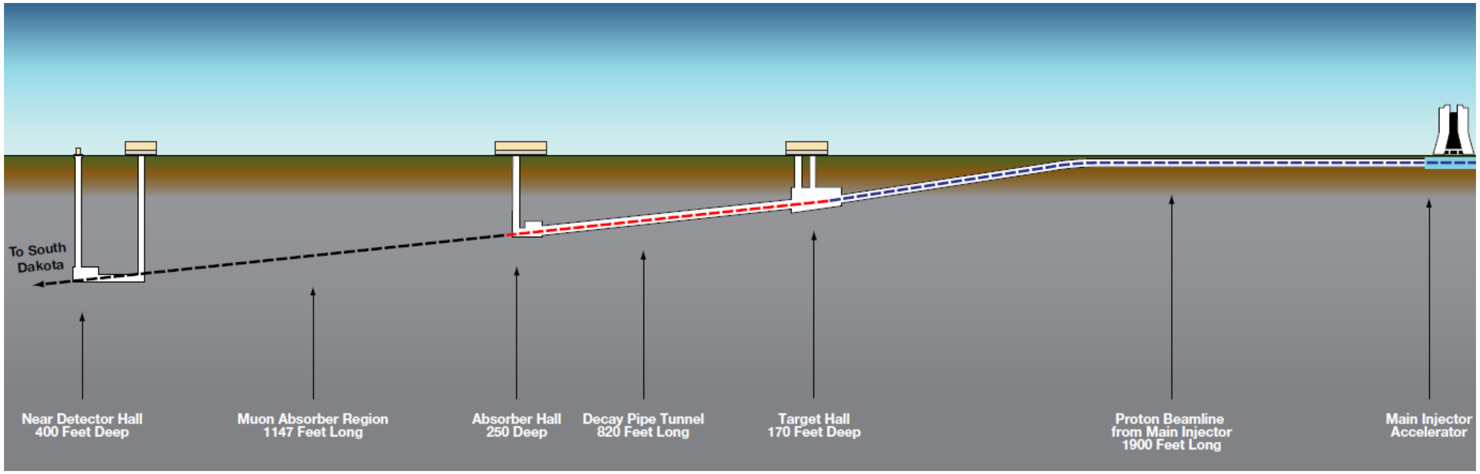
CF at Fermilab

- Initial designs laid out like NuMI beam and ND facilities, but with ND isolated from Absorber

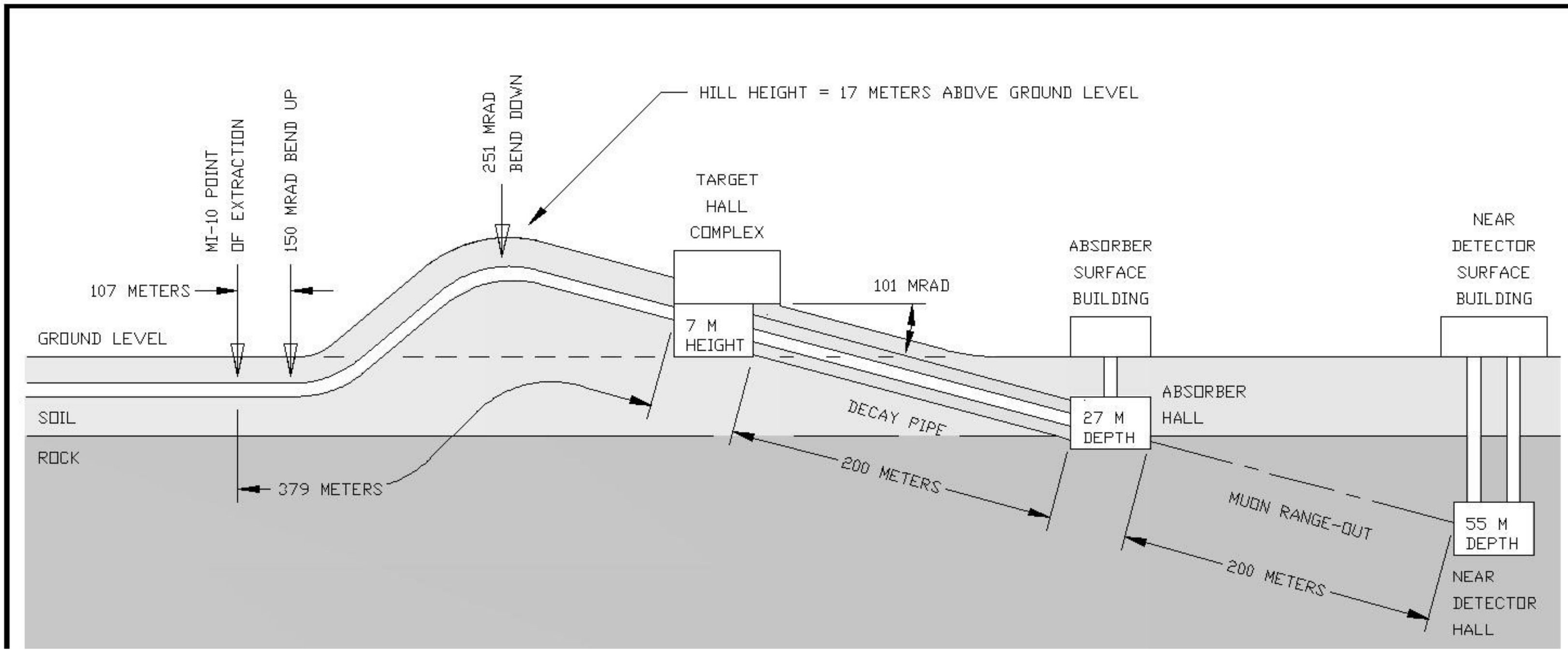


NuMI/MINOS

LBNE



Most Cost Effective: MI-10, Shallow



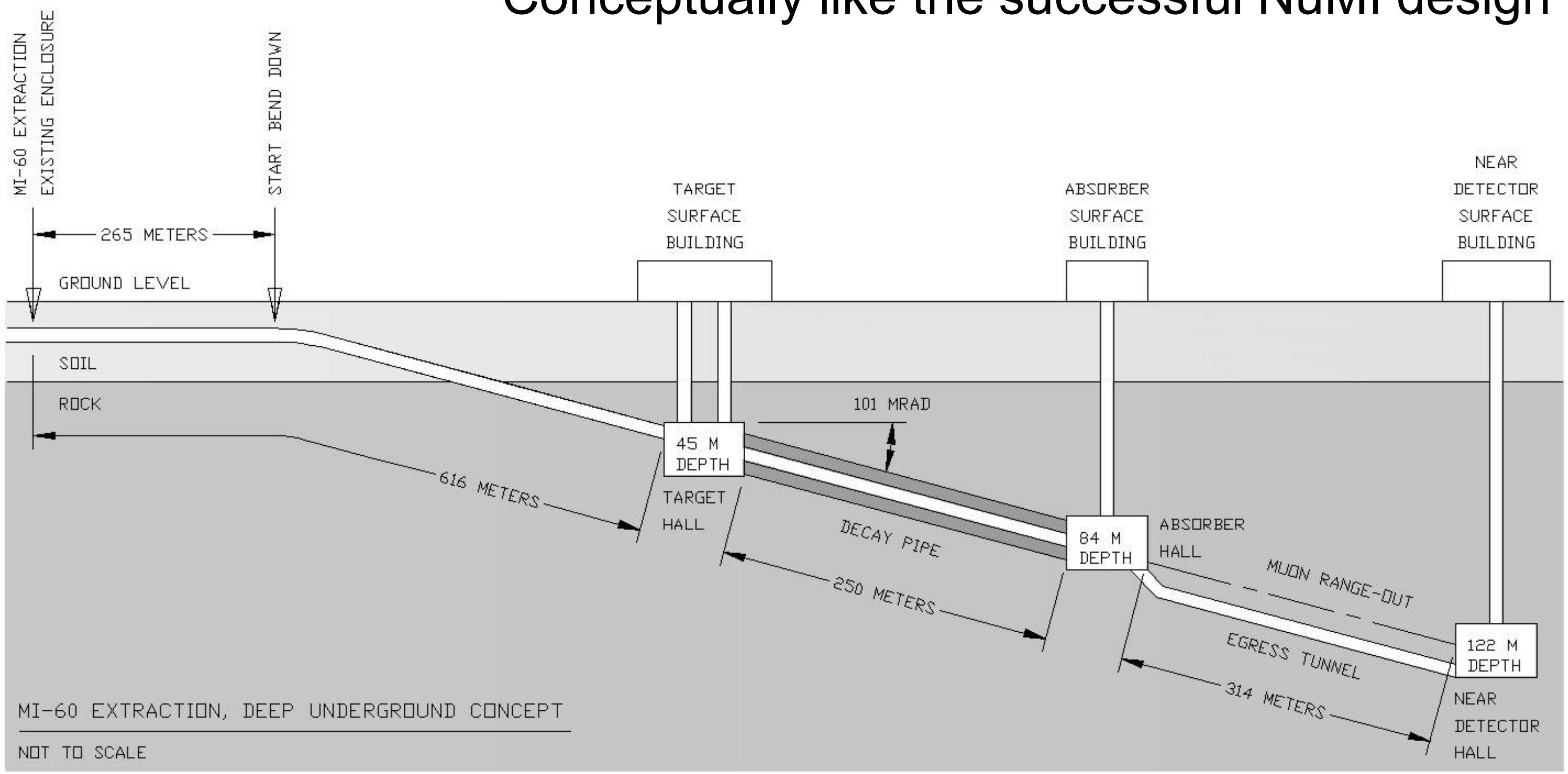
Under evaluation:

- Integration with other uses for MI-10
- Radiation issues with target above grade
- Stability of beam and target support structure

No known insurmountable problems, but further study required to prove feasibility.

Most Conservative: MI-60, deep

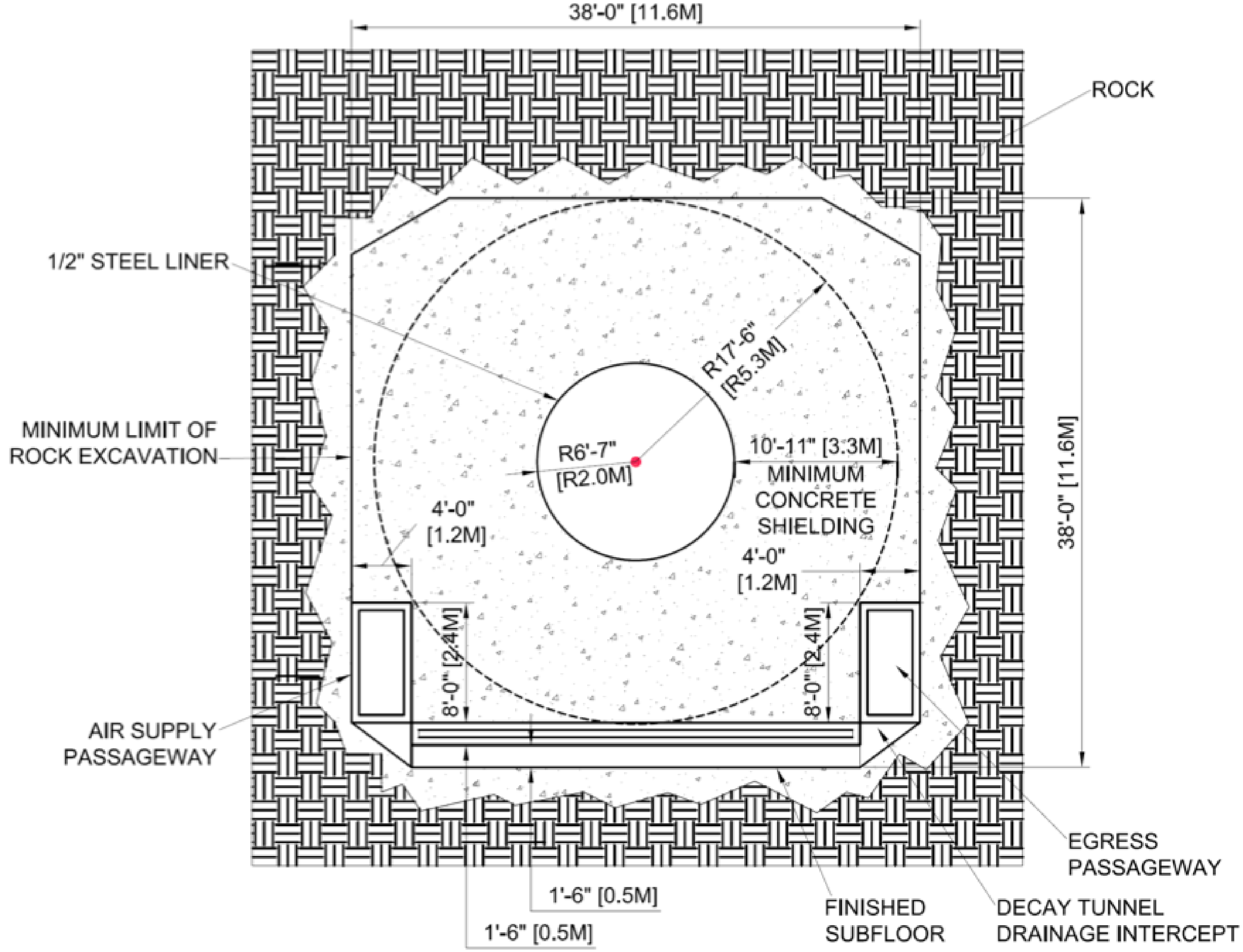
Conceptually like the successful NuMI design



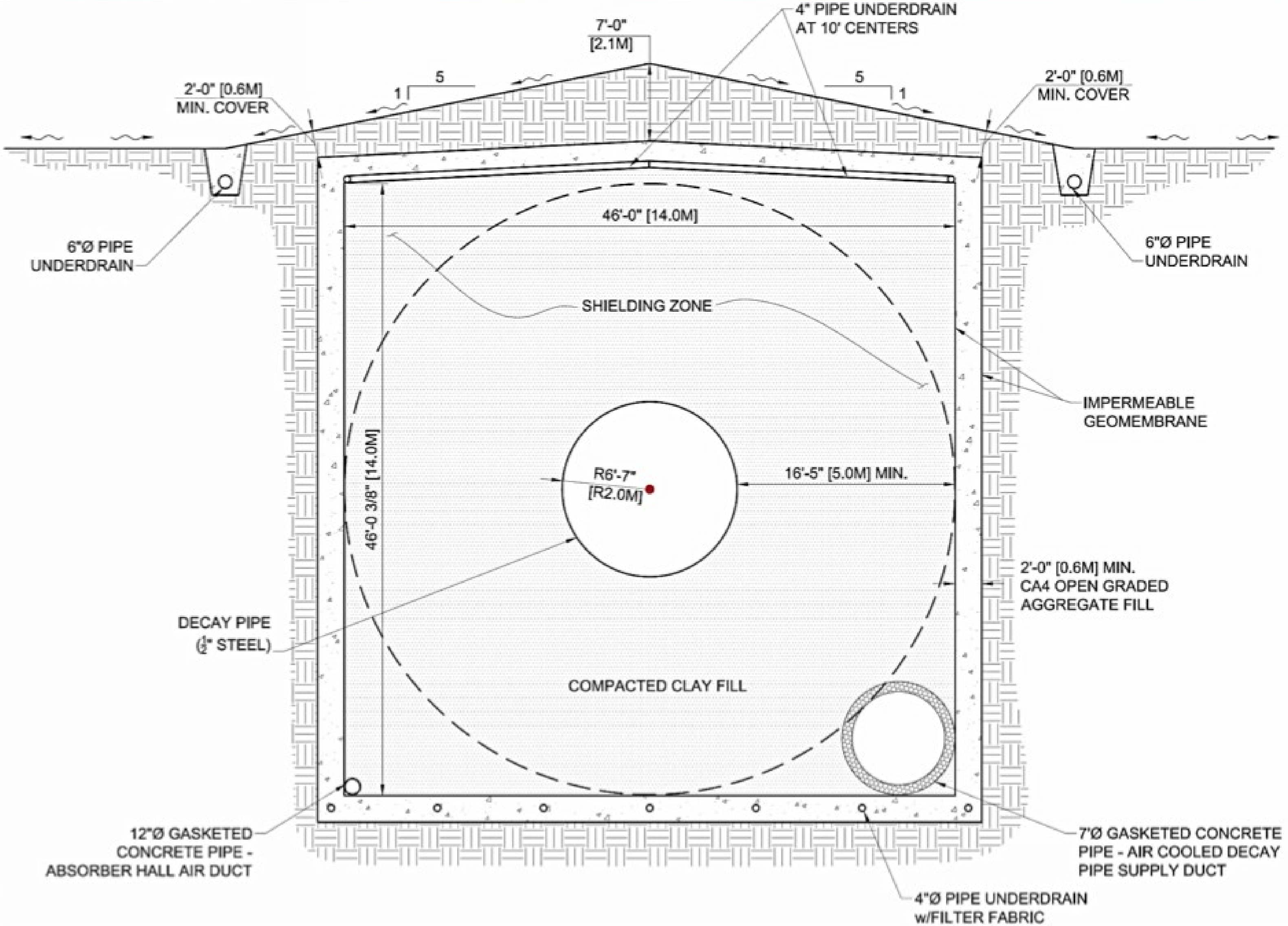
- Longer primary proton beamline
- Significant excavation deep underground

  => Substantially higher cost

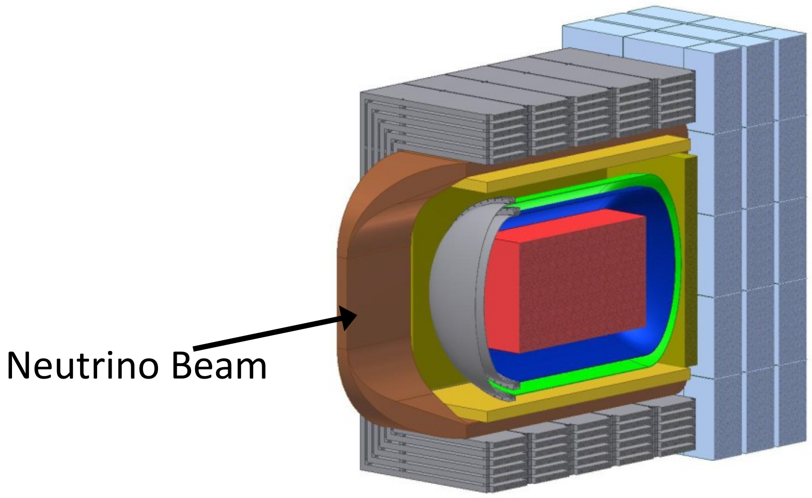
Design Evolution and Options
MI-60 Deep – Decay Pipe Section

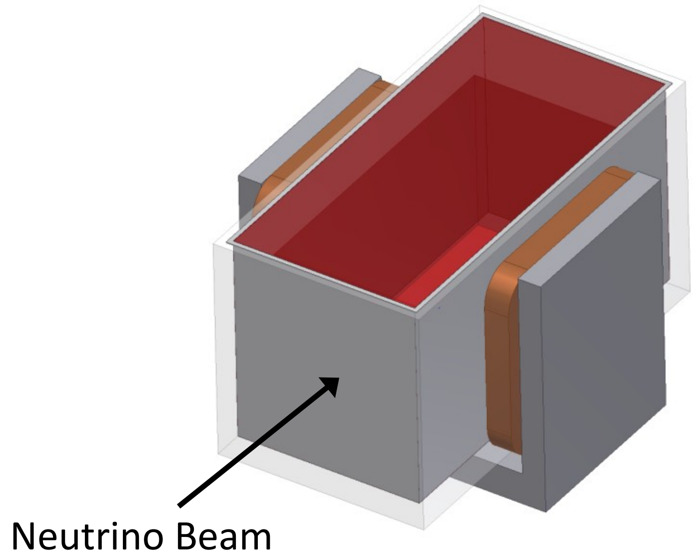


Design Evolution and Options
MI-10 Shallow – Decay Pipe Section



Near Neutrino Detector Options: LAr Far Detector





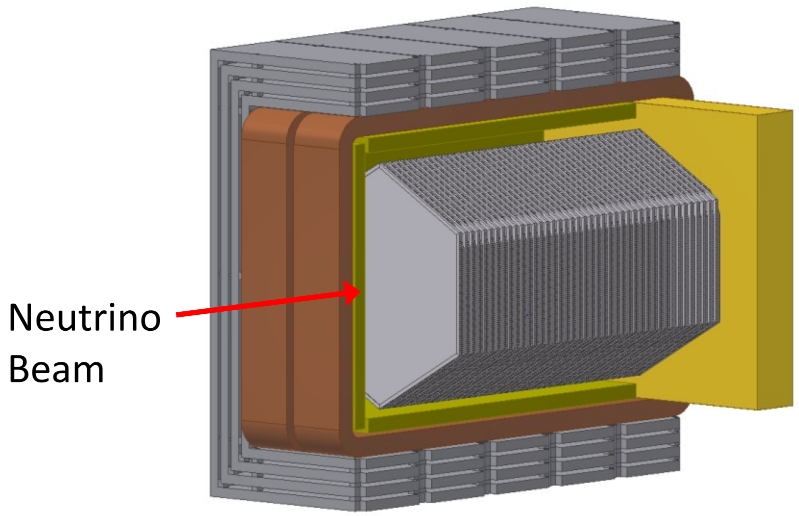
TPC Tracker

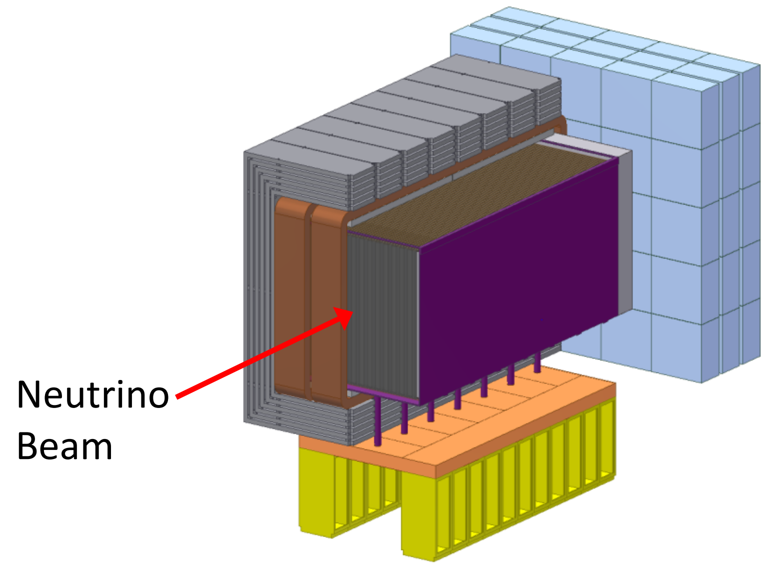
- 0.4 T dipole
- Small TPC (13 tons)
- Instrumented dipole yoke and downstream EM and hadron calorimeters

LAr Membrane Tracker

- 0.4 T dipole (central field)
- Larger TPC (350 tons)
- Full containment of hadrons and EM showers
- Mimics far detector.

Near Neutrino Detector Options: H_2O Far Detector





Scintillator Tracker

- 0.4 T dipole
- MINERvA(-like) scintillator strips – totally active.
- Embedded H_2O and D_2O targets
- Instrumented dipole yoke and downstream EM calorimeter.

Straw Tube Tracker

- 0.4 T dipole
- Low-density straw tube tracker (based on NOMAD design)
- Embedded H_2O and D_2O targets
- Instrumented dipole yoke and downstream EM calorimeter.

Where to now?

- We are promised a clear decision by DOE as to what extent (if any) they will use the Homestake site – not only for LBNE but for all the "underground" science experiments – very soon. Report of the review committee will be public next week. This decision needs to be made in time for FY13 budget request, this summer.
- A decision on which technology to pursue (water or liquid argon) will be made as soon as possible – delayed due to NSF and DUSEL uncertainty. **Collaboration would like to pursue both** – but probably too expensive without **significant** international participation.
- Next Science Collaboration meeting July 13-15 at Fermilab. "Observers" welcome, as are new collaborators!

Backup Slides

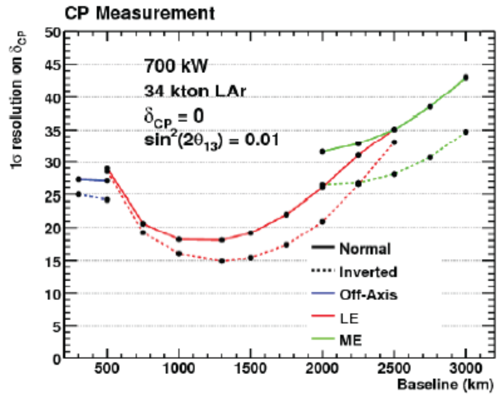


Figure 6–2: Sensitivity of LBNE to neutrino the CP-violating phase δ with the LAr40 Far Detector, as a function of baseline for on-axis "low" (red) and "medium" energy (green) beam configurations, as well as for an off-axis beam (blue).

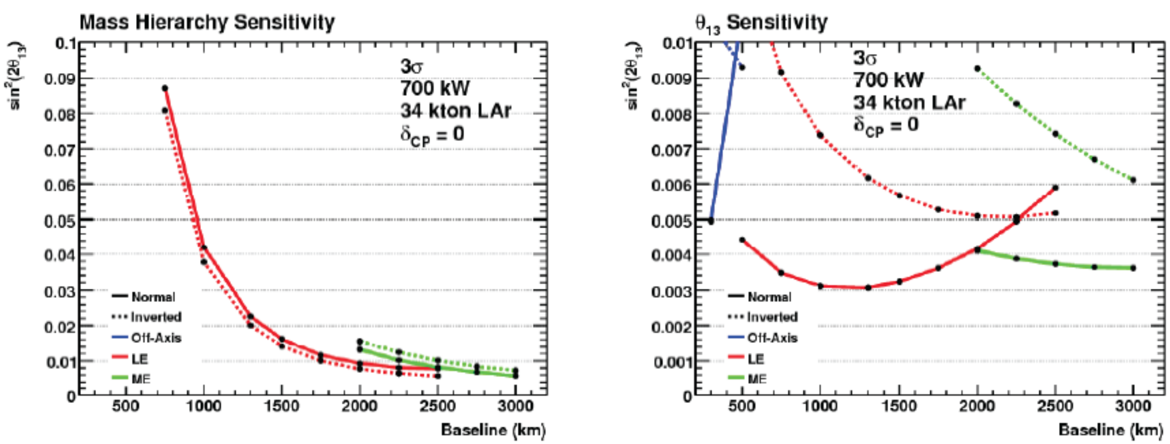


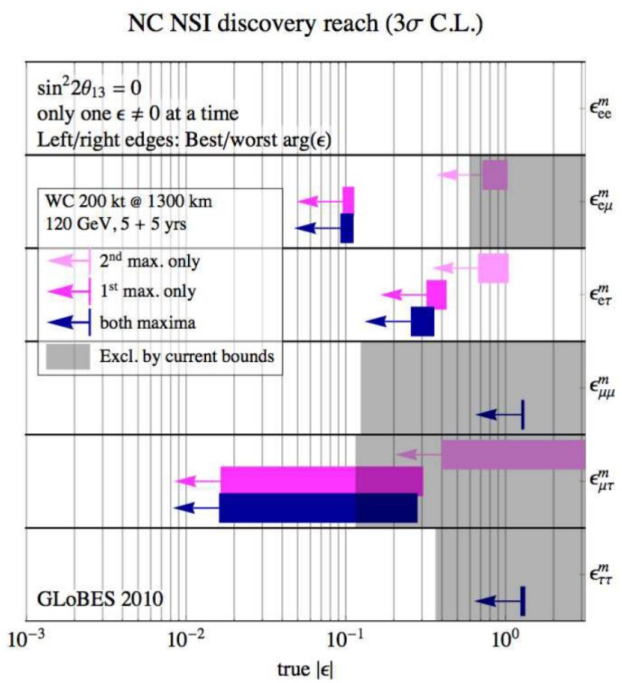
Figure 6–1: Sensitivity of LBNE to neutrino mass hierarchy (left) and θ_{13} (right) with the LAr40 Far Detector, as a function of baseline for on-axis "low" (red) and "medium" energy (green) beam configurations, as well as for an off-axis beam (blue).

Baseline and beam options for LAr show that 1300 km is still a near optimal distance.

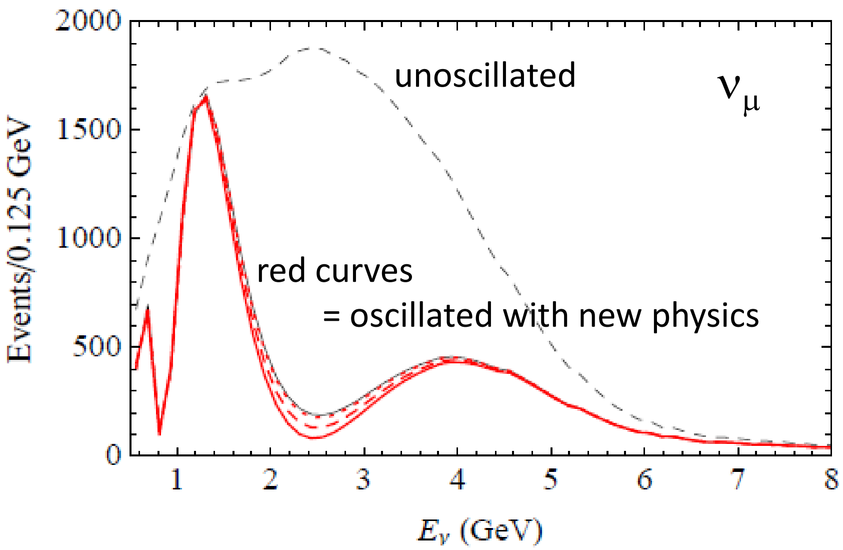
Note: possible shorter baseline experiments may not be able to determine mass ordering, especially off-axis.

Access to New Physics

Non-Standard Interactions

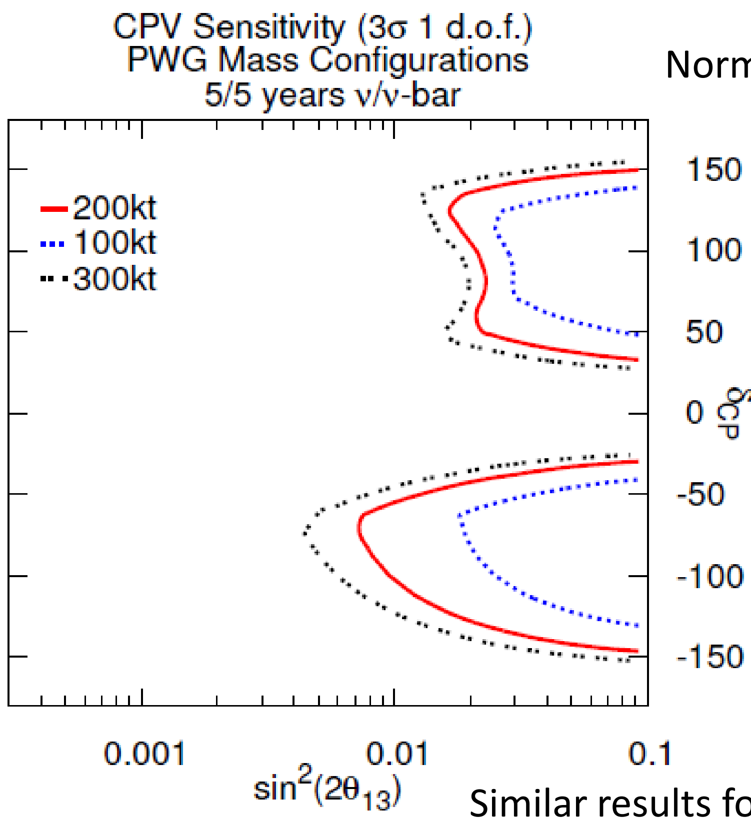


Long-Range Flavor Interactions

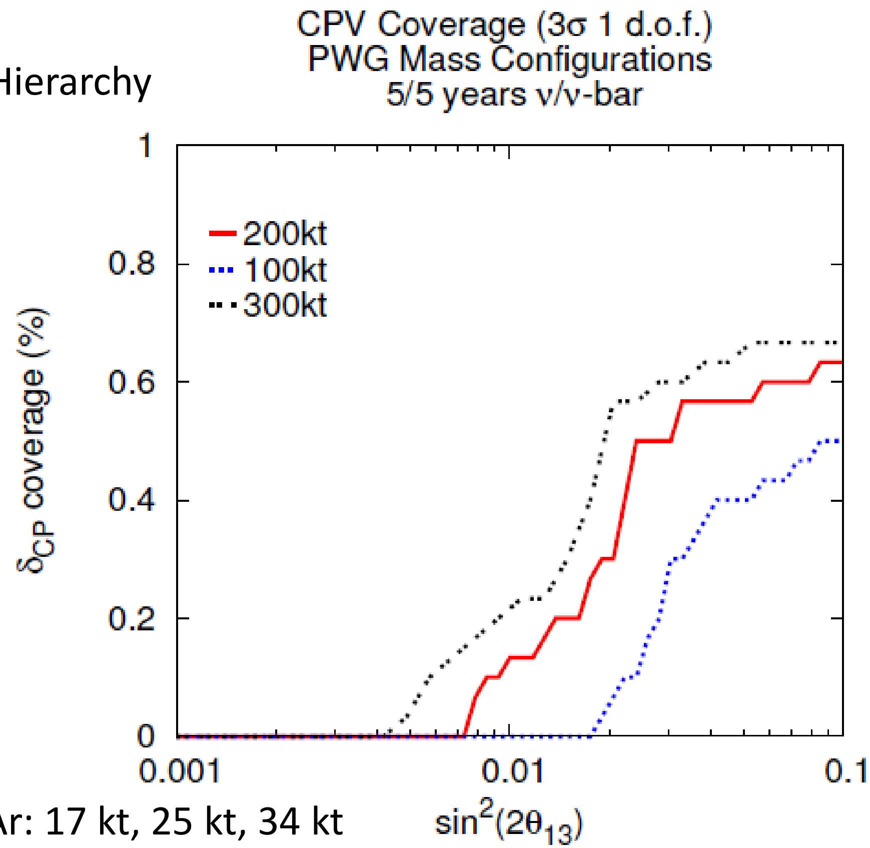


- Improve NSI bounds ~x2 in e–μ, ~x10 in μ–τ
- Long range interaction sensitivity better than precision tests of gravity

CP Sensitivity – Target Mass



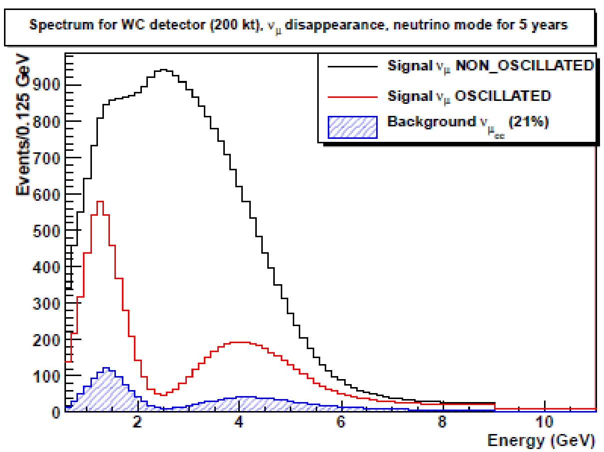
Normal Hierarchy

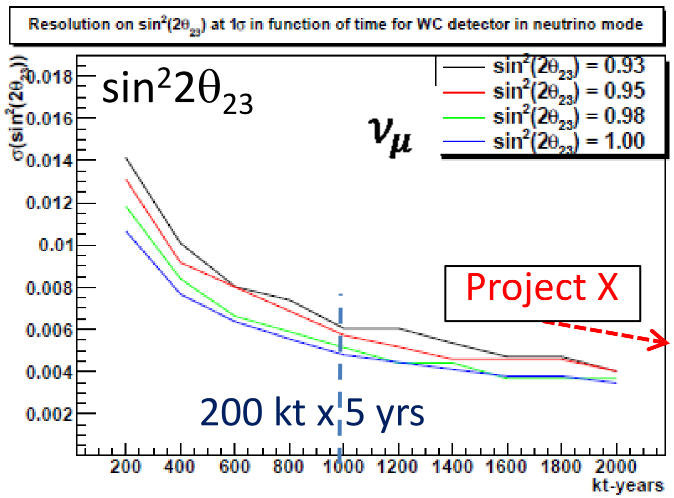


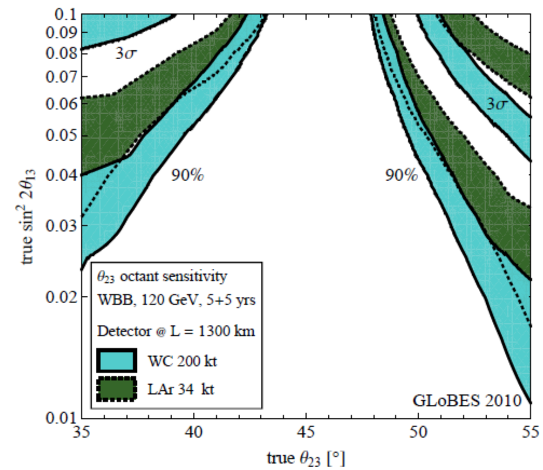
Similar results for LAr: 17 kt, 25 kt, 34 kt

- Adding mass an effective way to improve sensitivity – adding later is difficult
- More mass helps all non-beam physics

$\nu_\mu/\bar{\nu}_\mu$ Disappearance







- $\sin^2 2\theta_{23}$ to ~0.6% and Δm_{31}^2 to ~0.8% precision in 5-year ν run
  - "Competitive" to NOνA full run
- Clear multiple oscillation pattern due to very long baseline
- Resolve θ_{23} octant degeneracy for angles < 40° if $\sin^2 2\theta_{13} > 0.075$ (WCD slightly better)
  - NOνA cannot due to $\sin^2 2\theta_{23}$ and δ_{CP} correlations (would combine w/ Daya Bay)

Expected Backgrounds for $p \rightarrow e^{+}\pi^{0}$

Calculated: **2.1 +/- 0.9 ev/Mton/yr**

Measured*
in LE beam: **1.63 (+0.42/-0.33 stat) (+0.45/-0.51 syst.) ev/Mton/yr**

- Super-Kamiokande currently has **NO** candidates at 0.141 Mton-yr
- A 0.2 Mton detector would have ~4 background events after 10 years.
- **Can this be improved?**

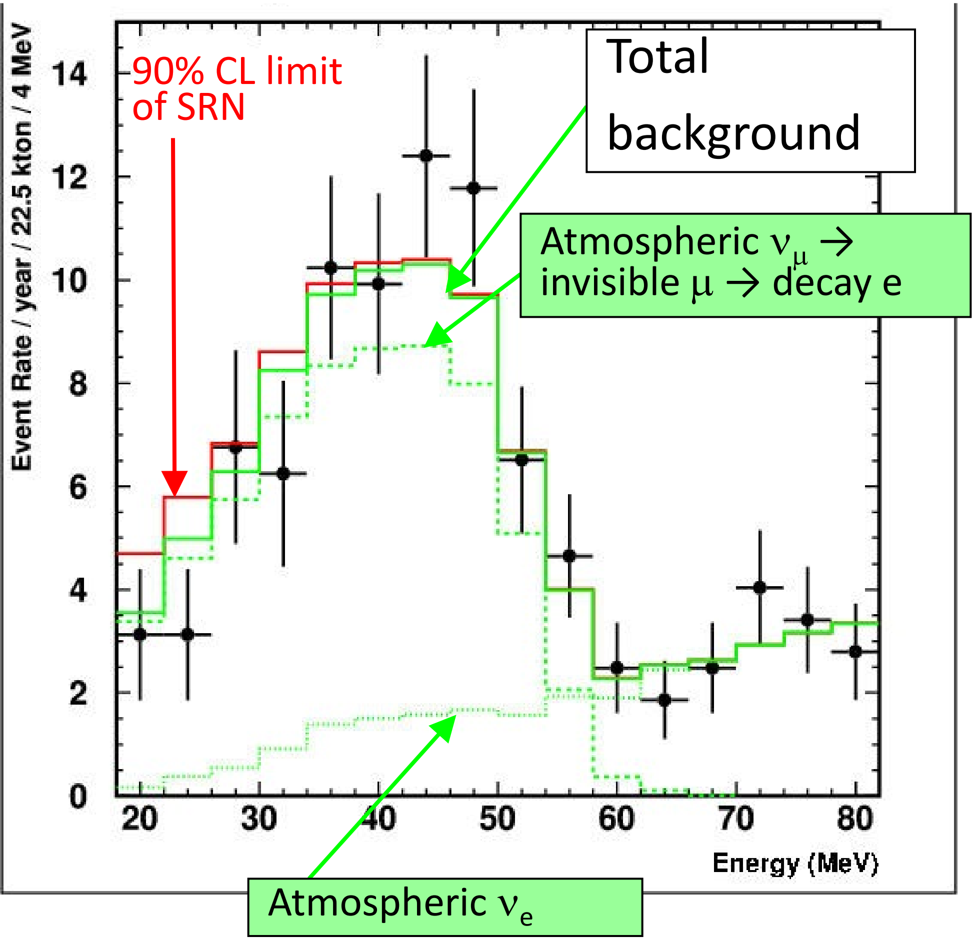
Higher resolution and improved detector capabilities have improved backgrounds in the past.

	ε x B_{meson}	BKG (/Mtonyr)	BG (/yr)
IMB3	0.48	26	0.087
KAM-I	0.53	<15	<0.015
KAM-II	0.45	<8	<0.008
Super-K	0.44	2.1	0.047

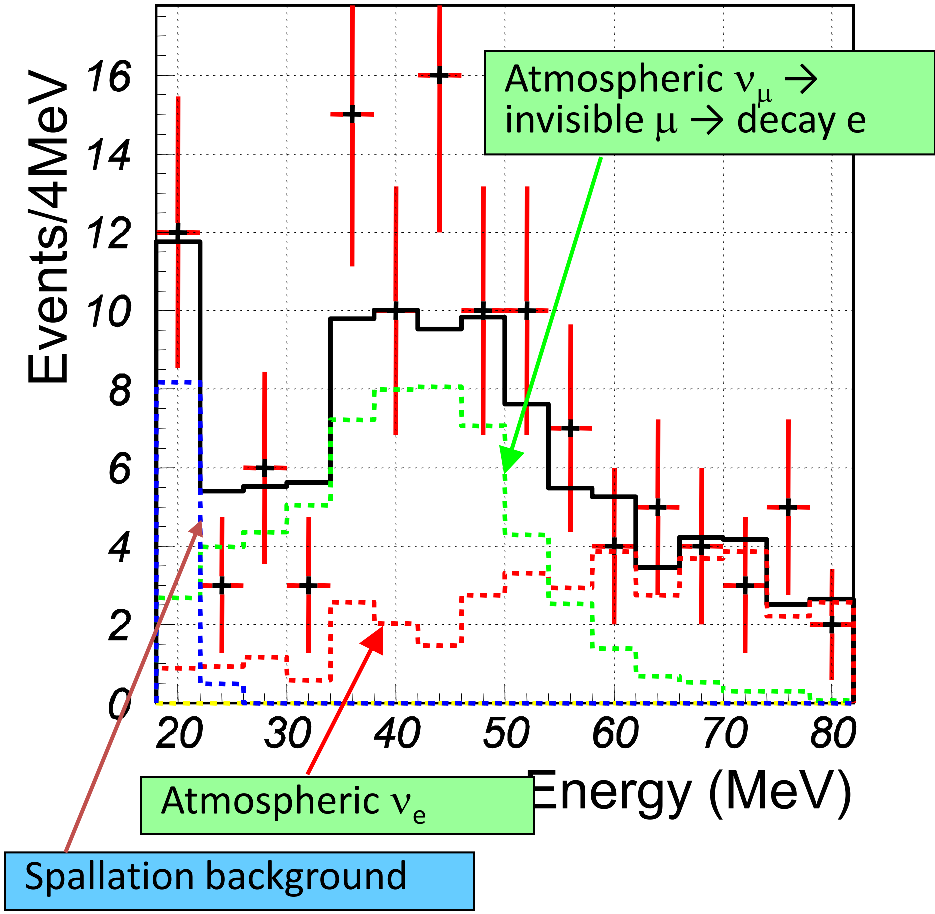
*PRL 102:141801 (2009)

SRN results of SK-I and SK-II

SK-I (1496days)



SK-II (791 days)



Observed spectra are consistent with estimated backgrounds.

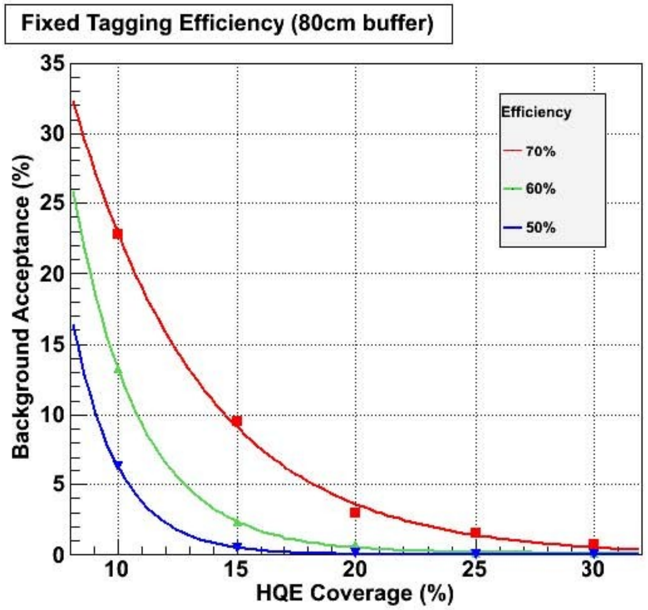
Searches are limited by the invisible muon background (SK-I) and the spallation background (SK-II)..

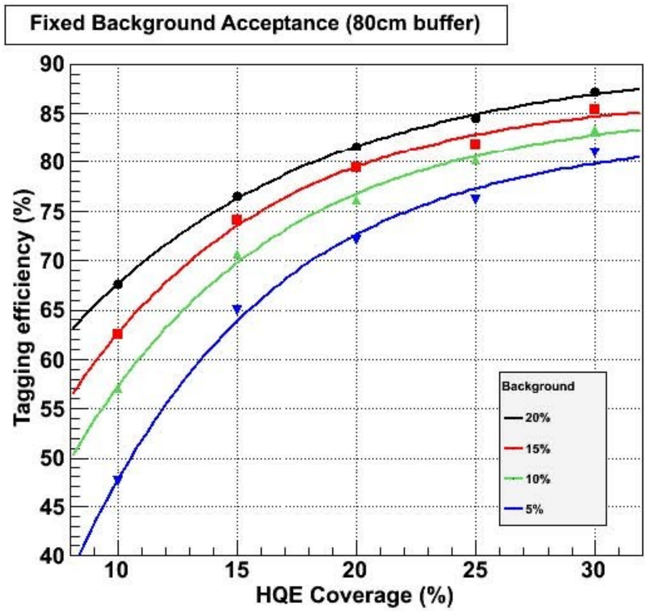
Hit level simulations show that at 12% coverage detection of Gd capture is marginal. Includes effects of gammas from glass, rock, and radon, plus dark noise.

Coverage	background@70% efficiency
12%	15%
24%	1.5%

Coverage	efficiency@ 5% mid-ID
12%	55%
24%	77%

Driver is reduction of background from “stealth” muons by tagging actual IBDK events.

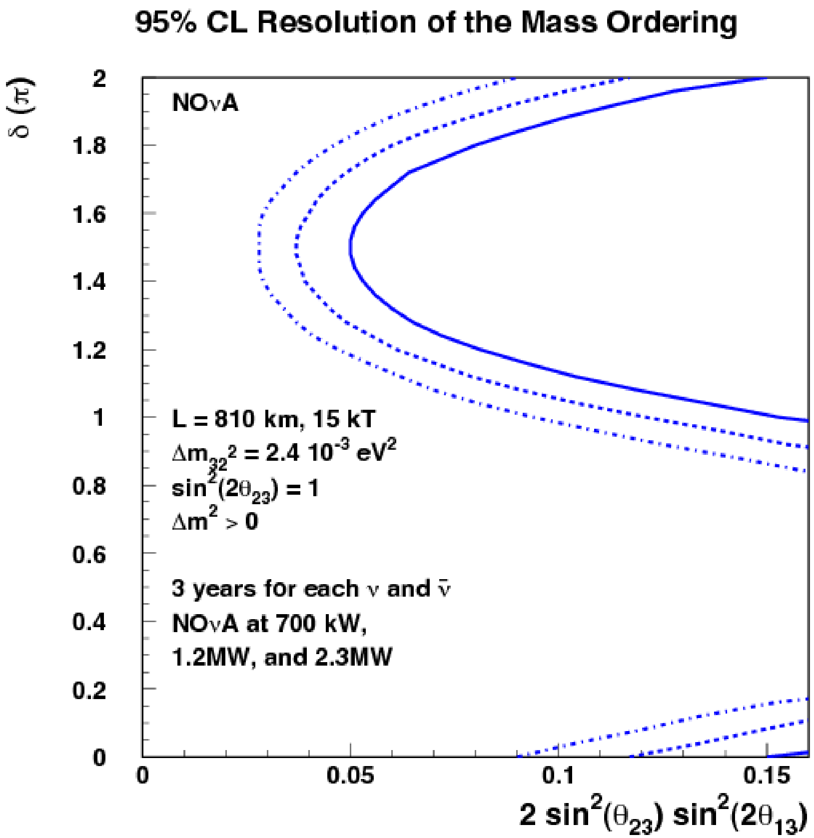


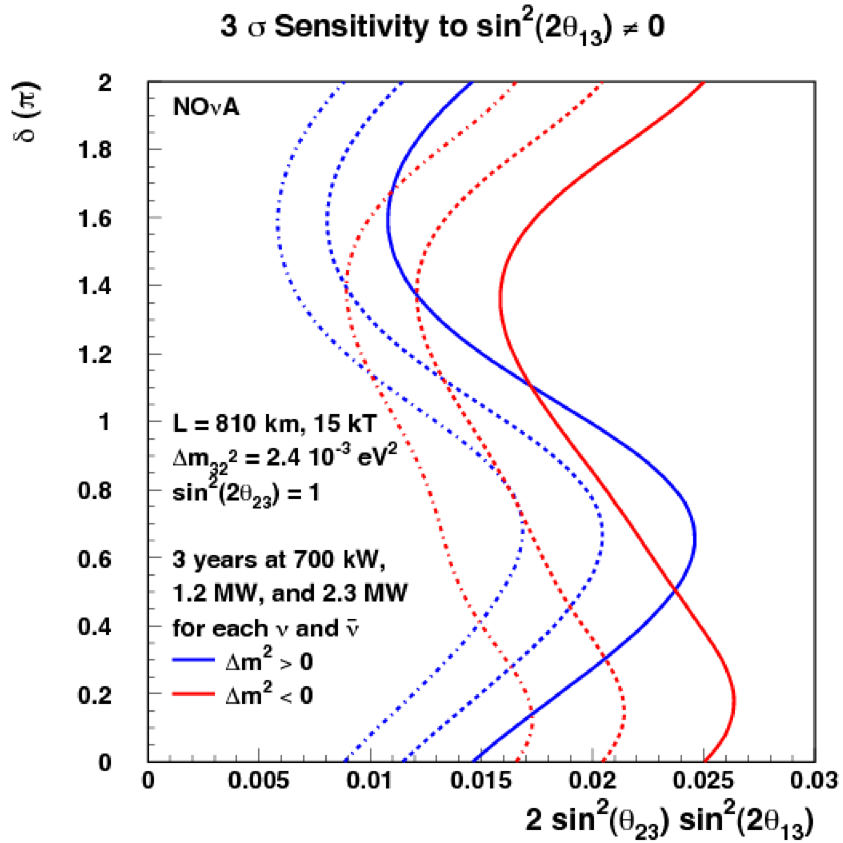


NOνA

NH

Note: Figure caption says “2-sigma”





http://www-nova.fnal.gov/plots_and_figures/plots_and_figures.html#020_Theta13_Mass_Hierarchy_CP_phase

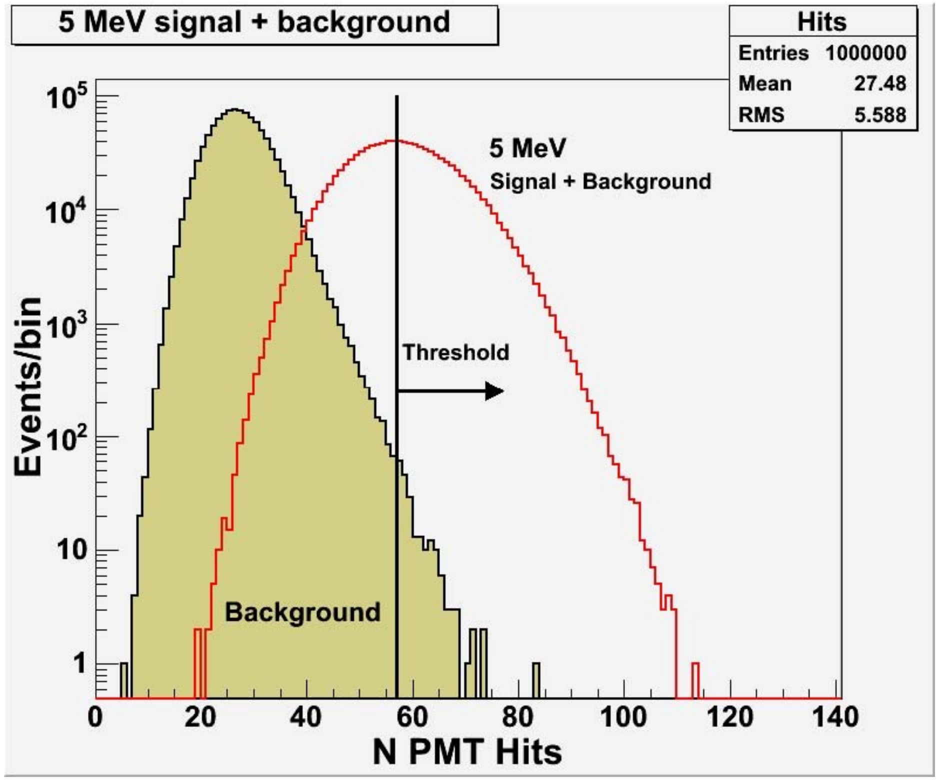
From Bueno, et al arXiv:hep-ph/0701101v1

Depth	Channel	Background source N_b^0 (particles/year) Neutron	K^0	Λ	Cosmogenic background reduction: Distance cut d (m)	Fiducial mass (kton)	Background N_b (events/year)
$\simeq$0.5 km w.e.	$p \to \pi^+ \bar{\nu}$	570	–	–	1.5	92	76
(188 m rock)	$n \to \pi^0 \bar{\nu}$	450	–	8	1.7	91	46
FLUKA	$p \to K^+ \bar{\nu}$	–	135	–	6.6	66	0.1
$\simeq$ 1 km w.e.	$p \to \pi^+ \bar{\nu}$	200	–	–	0.7	96	77
(377 m rock)	$n \to \pi^0 \bar{\nu}$	130	–	2.3	0.75	96	47
FLUKA	$p \to K^+ \bar{\nu}$	–	39	–	5.45	71	0.1
$\simeq$ 3 km w.e.	$p \to \pi^+ \bar{\nu}$	4.0	–	–	0	100	4.0
(1.13 km rock)	$n \to \pi^0 \bar{\nu}$	2.6	–	–	0	100	2.6
FLUKA	$p \to K^+ \bar{\nu}$	–	0.74	–	1.8	90	0.1
Under the hill	$p \to \pi^+ \bar{\nu}$	2900	–	–	2.7	85	76
(see Figure 8)	$n \to \pi^0 \bar{\nu}$	2300	–	–	2.9	84	46
GEANT4	$p \to K^+ \bar{\nu}$	–	36–360	–	5.4–7.5	72–62	0.1
Under the hill	$p \to \pi^+ \bar{\nu}$	430	–	–	1.3	93	76
+ two veto planes	$n \to \pi^0 \bar{\nu}$	340	–	–	1.5	92	46
GEANT4	$p \to K^+ \bar{\nu}$	–	5–54	–	3.65–5.75	80–70	0.1
Under the hill	$p \to \pi^+ \bar{\nu}$	170	–	–	0.6	97	77
+ three veto planes	$n \to \pi^0 \bar{\nu}$	140	–	–	0.8	95	46
GEANT4	$p \to K^+ \bar{\nu}$	–	2–20	–	2.8–5	85–74	0.1

TABLE IX: Cosmogenic background for three selected channels: estimated number of background events per year that survive a kinematic selection. The contamination coming from neutrons, kaons and lambdas interactions at different detector depths are shown. For each detector depth, the radial cut distance and the final fiducial volume to reduce cosmogenic background to the level of the irreducible atmospheric background (resp. 78.2 for $p \to \pi^+ \bar{\nu}$, 47.4 for $n \to \pi^0 \bar{\nu}$ and 0.1 for $p \to K^+ \bar{\nu}$ for an exposure of 100 kton×year) is listed. The range for kaon background is reflecting uncertainty on kaon yields due to differences between FLUKA and GEANT4 results.

Threshold estimates

Taking into account PMT coverage, dark noise, gammas from the rock and PMT glass and radon in the water, simulations were done for the threshold achievable for a given “fake rate” of background events



South Dakota's commitment to science

S.D. Legislature:	**$ 50,303,000**
H.U.D. Grant:	**$ 10,000,000**
Denny Sanford donation:	**$ 70,000,000**
Total state commitment:	**$130,303,000***

•*Note: Sanford gift includes $5 million for Sanford Center for Science Education construction and $15 million endowment for operating it.*