Prospects and Challenges for a Large Water Cherenkov Detector for LBNE

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Long-Baseline Neutrino Experiment

Science collaboration is made up of 279 members from 57 institutions

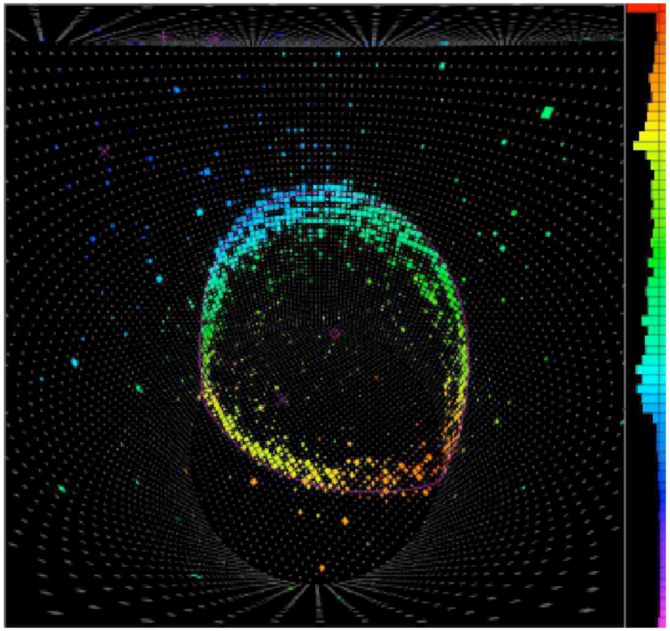
Experiment will consist of
- neutrino beam and near detector complex located at Fermilab
- far detector (water Cherenkov and/or liquid argon)* located at the DUSEL facility in South Dakota (1300 km baseline)

Earlier talk by B. Choudhary on LBNE status

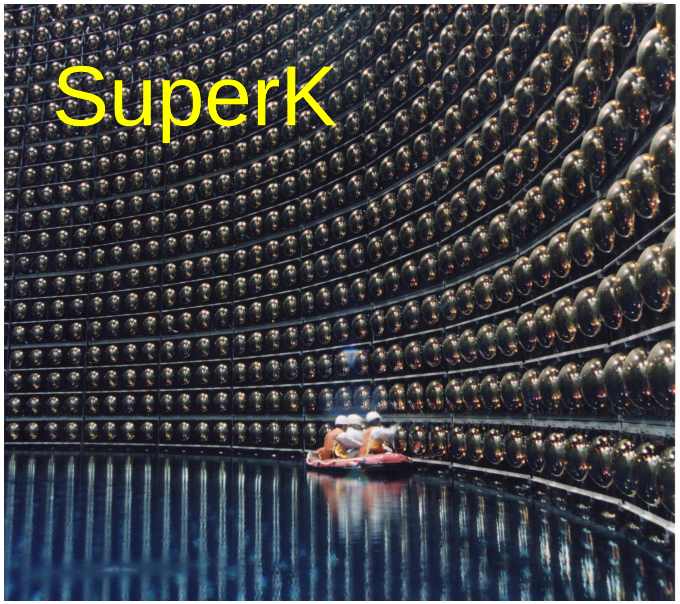
*No decision has been made on far detector technology.
3 options: water Cherenkov, liquid argon, or one of each
This talk assumes water Cherenkov option

Water Cherenkov Detectors

Image Cherenkov rings produced by charged particles traveling through water



Suitable for a wide range of physics topics: low (MeV-scale) and high (GeV-scale) energy



Key detector parameters:
- Size
- Light collection (PMT QE, photocathode coverage, attenuation length)

Technology is well-understood

LBNE WC Detector Requirements

1) At least 200 ktons of mass

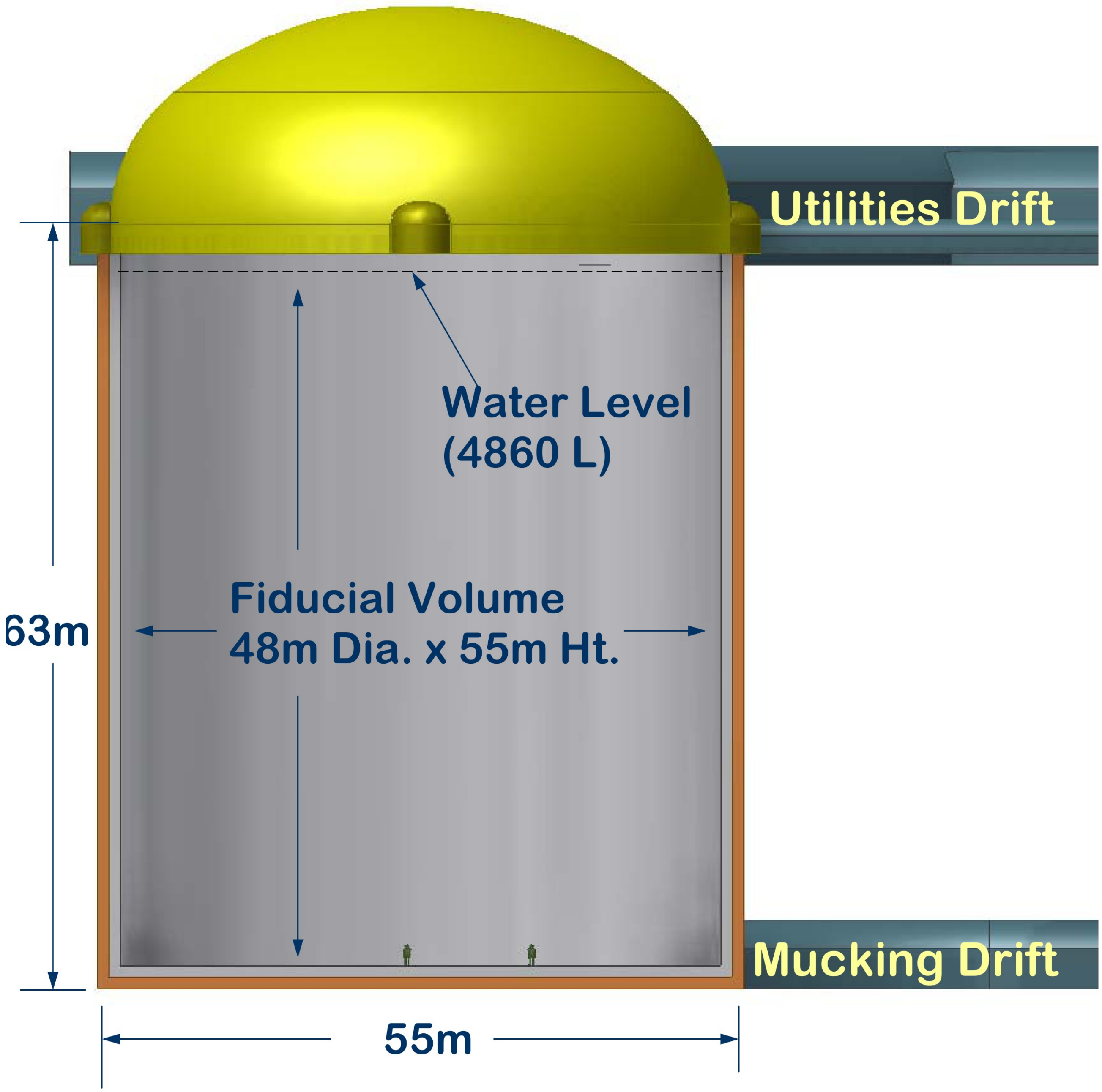
2) Multiple modules:
- Detector dimensions limited by cavern engineering, PMT pressure performance, and light attenuation.
- Allows 100% live time.

2) Depth > 1000 m.w.e. for long-baseline physics (>4000 m.w.e. for low-energy physics)

3) PMT coverage sufficient for reconstruction and particle identification; greater coverage enhances low-energy physics

4) Water purification to maintain transparency

LBNE Water Cherenkov Design



2 x 100 kton modules

Each module:
- Total water mass of 138 ktons
- Fiducial mass of 100 ktons
- ~50,000 10” PMTs (~20% coverage)

Water Cherenkov Detectors

Detector	Fiducial Mass (ktons)	# PMTs (diameter, cm)	Coverage (%)	pe/MeV	Dates
IMB-1	3.3	2048 (12.5)	1	0.25	1982-1985
IMB-2	3.3	2048 (20)	4.5	1.1	1987-1990
Kam-I	0.88/0.78	1000/948 (50)	20	3.4	1986-1990
Kam-II	1.04	948 (50)	20	3.4	1993-1998
SK-I	22.5	11146 (50)	39	6	1996-2001
SK-II	22.5	5182 (50)	19	3	2002-2005
SK-III	22.5	11129 (50)	39	6	2006-?
SNO	1 D_20 / 1.7 H_20	9438 (20)	54	9	1999-2006

PDG, J. Phys. G 37, 075021 (2010)

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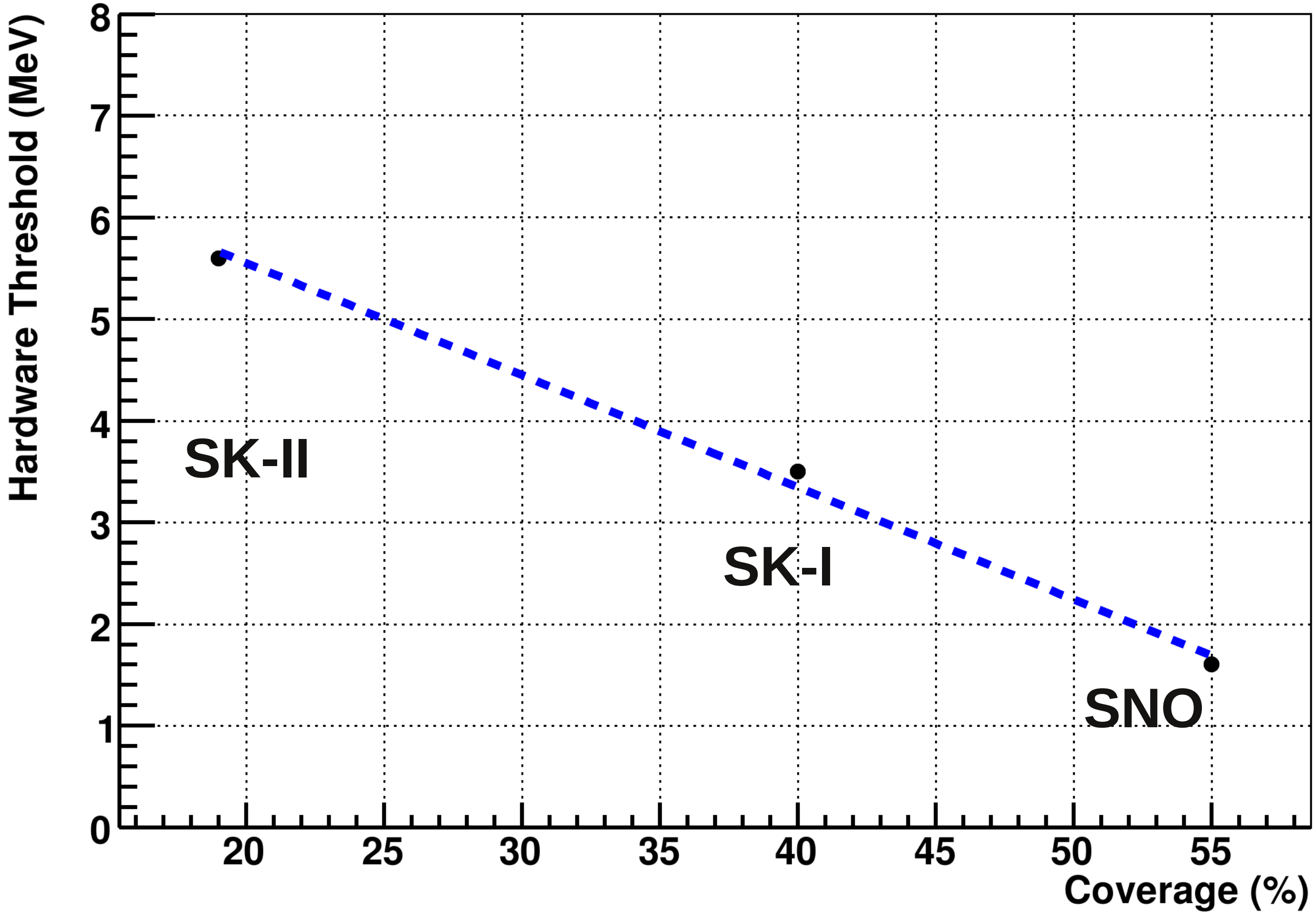
LBNE (1 module)	100	50000 (25)	20	3	Future

PMT Coverage



Relationship between threshold and PMT coverage

Background rate will also affect the threshold

Depth Requirement

Long-baseline physics:
Expect ~10000 CC events/year/100 kton

Need >1000 m.w.e so that beam signal rate is comparable to cosmic rate

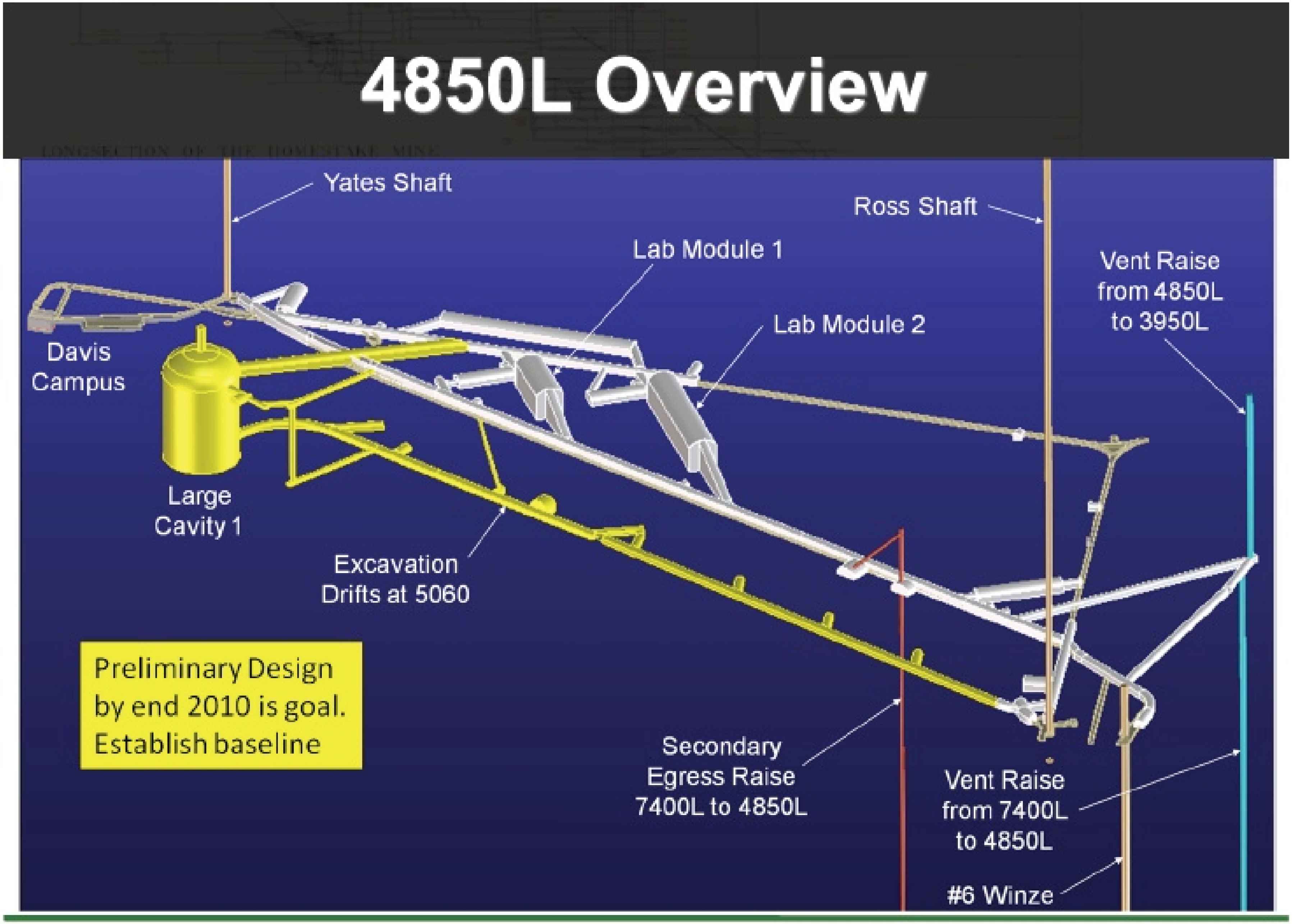
Rate(Hz)	In-time cosmics/yr	Depth (mwe)
500 kHz	5×10^7	0
3 kHz	300,000	265
400 Hz	40,000	880
5 Hz	500	2300
1.3 Hz	130	2960
0.60 Hz	60	3490
0.26 Hz	26	3620
0.09 Hz	9	4290

Physics	Depth (mwe)
Long-baseline accelerator	1,000
Proton Decay	$>$ 3,000
Day/Night ^{8}B Solar ν	$\sim$ 4,300
Supernova burst	3,500
Relic supernova	4,300
Atmospheric ν	2,400

4850' (4290 mwe) level is deep enough for all physics goals

Cosmic rate at 4850' is ~0.1 Hz per 100 kton module

4850' Level


4850L Overview
Yates Shaft
Ross Shaft
Lab Module 1
Lab Module 2
Vent Raise from 4850L to 3950L
Davis Campus
Large Cavity 1
Excavation Drifts at 5060
Preliminary Design by end 2010 is goal. Establish baseline
Secondary Egress Raise 7400L to 4850L
Vent Raise from 7400L to 4850L
#6 Winze

PMT Requirements

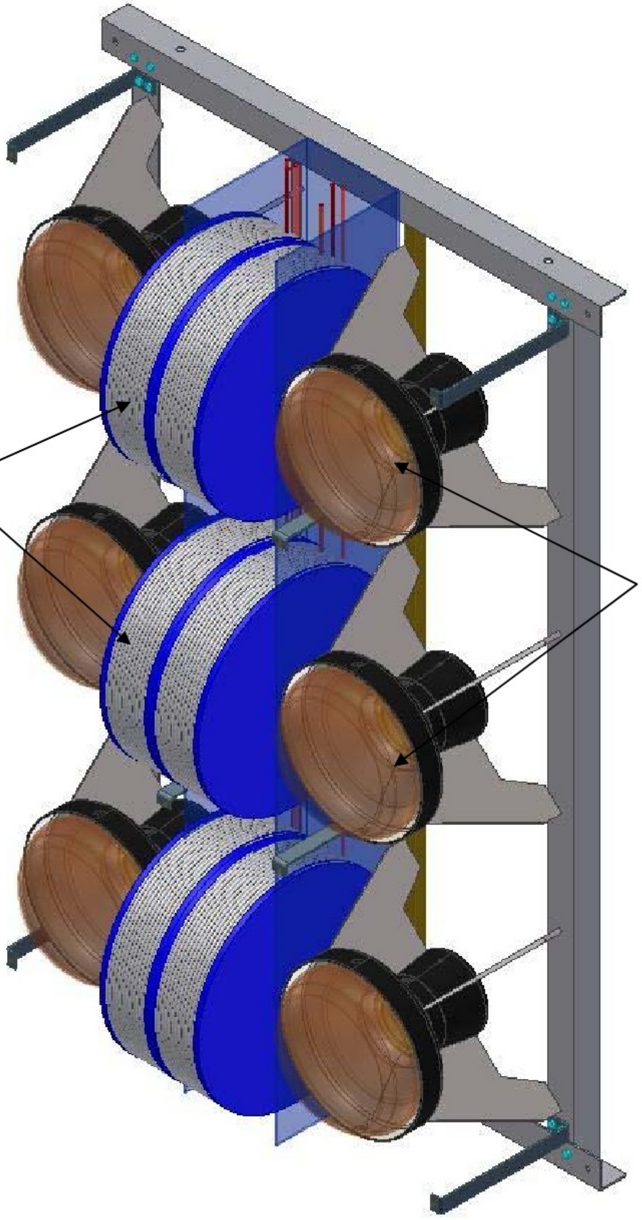
- Quantum efficiency > 20%
- Wavelength range 300 to 600 nm
- TTS ~3.2ns
- Afterpulsing <5%, prepulsing<1%
- Charge resolution 50%
- Gain 10^7 at <2000 V
- Dark rate 2500 Hz at 13 C
- Low flashing rate
- Long term stability, electrically and mechanically up to 20 years
- Pressure resistance up to 0.7 MPa (floor of detector is ~0.6 MPa)

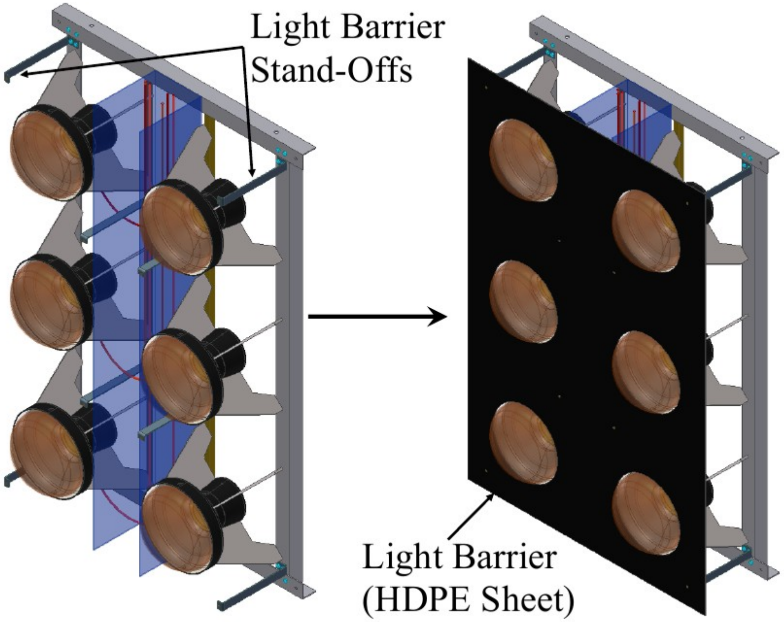
PMTs under study

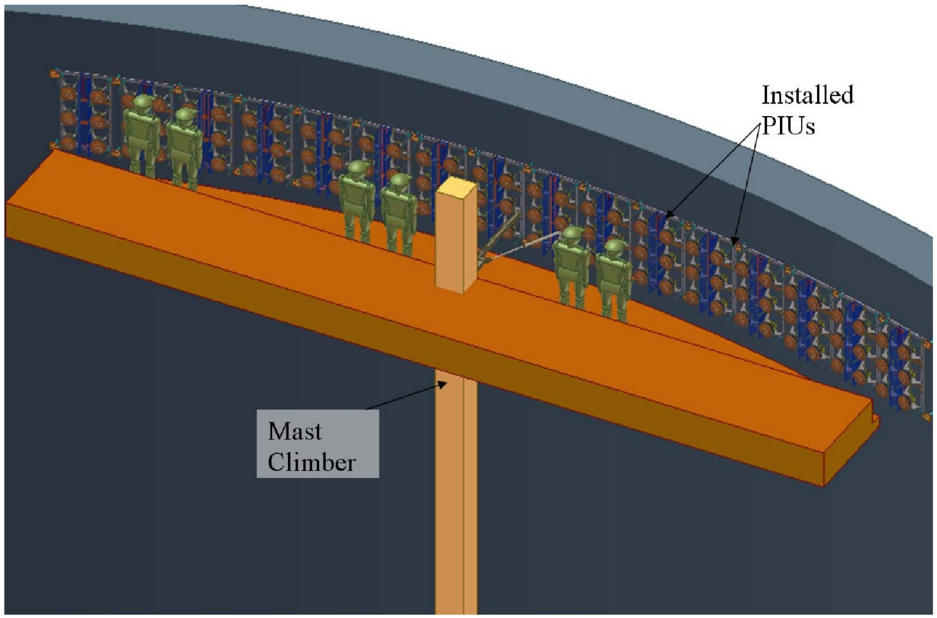
	10 inch R7081	20 inch R3600	9 in ET D739KB
Number	~50000	~14000	56500
QE*CE	25%*80%	20%*70%	>30%*80%
rise time	4 ns	10 ns	4.5 ns
dia/effective area	253mm/220mm	508/460	231mm/210mm
Tube length	24.5 cm	68 cm	24.8cm
Weight	1150 gm	8000 gm	1070 gm
Vol.	~5 lt	~50 lt	~3.9 lt
pressure rating	0.7Mpa	0.6Mpa	0.2Mpa
intra-tube-dist	485 mm	916 mm	456mm
∢ coverage/pmt	0.5 deg	1.1 deg	0.47 deg
∢granularity	1.1 deg	2.1 deg	1.0 deg

Baseline choice

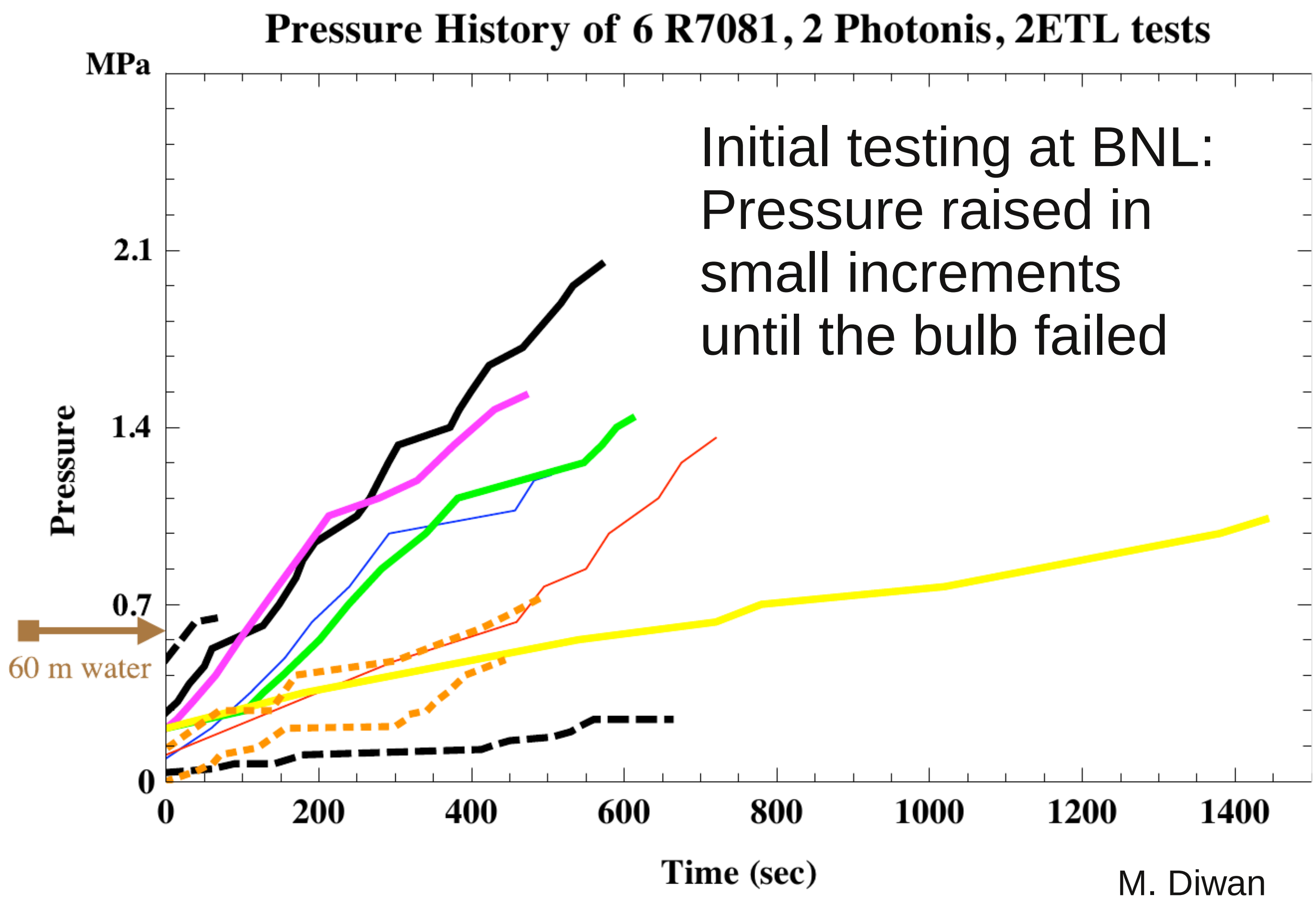
PMT Support Structure







PMT Failure

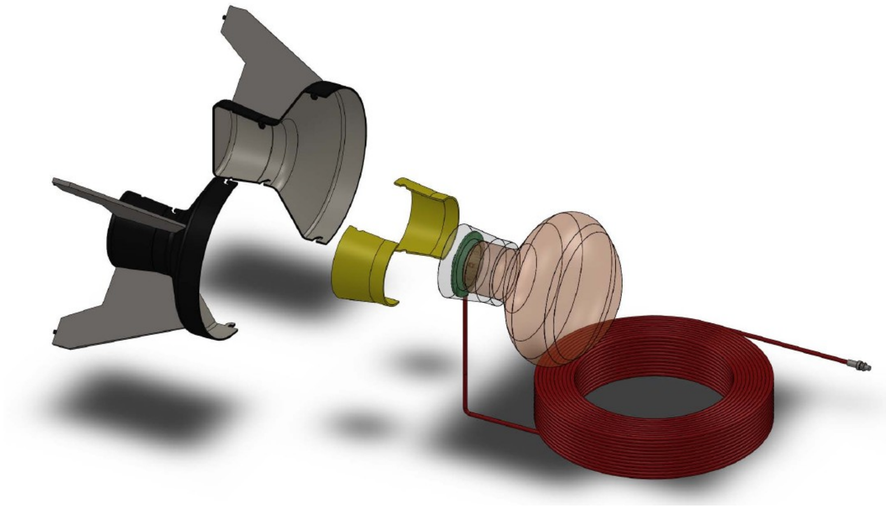


Understand individual PMT response to pressure:
Testing in a dedicated pressure vessel at BNL instrumented with pressure sensors and a fast motion camera

PMT Failure

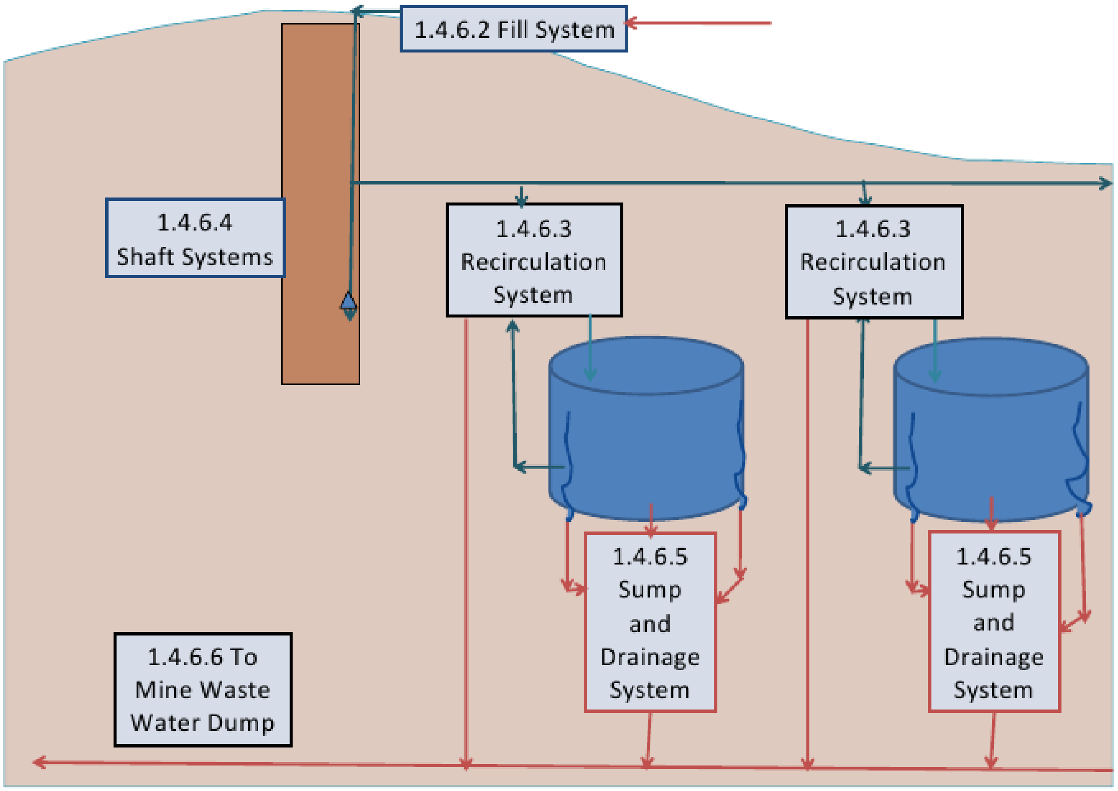
Prevent a single PMT implosion from inducing failure in other PMTs

Study shock wave, eventually test an entire PMT module



Navy facility in RI:
- 15 m diameter vessel
- 500,000 gallon capacity
- can reach 6.9 bar (bottom of detector is ~6 bar)

Water System



Requirements:
- atten. length>80 m
- Water temperature 13C

100 days to fill one module

20-25 days to circulate entire volume

Event Rates

Physics	Rate/100kton/yr	Energy Range
Beam	10000 CC (w/osc)	0.5-10 GeV
Supernova @10 kpc	20000 (10 sec)	>5 MeV
Relic Supernova	1-13	10-30 MeV
Atmospheric ν	10000	1-100 GeV
Solar ν	15000	>7 MeV

Gadolinium Option

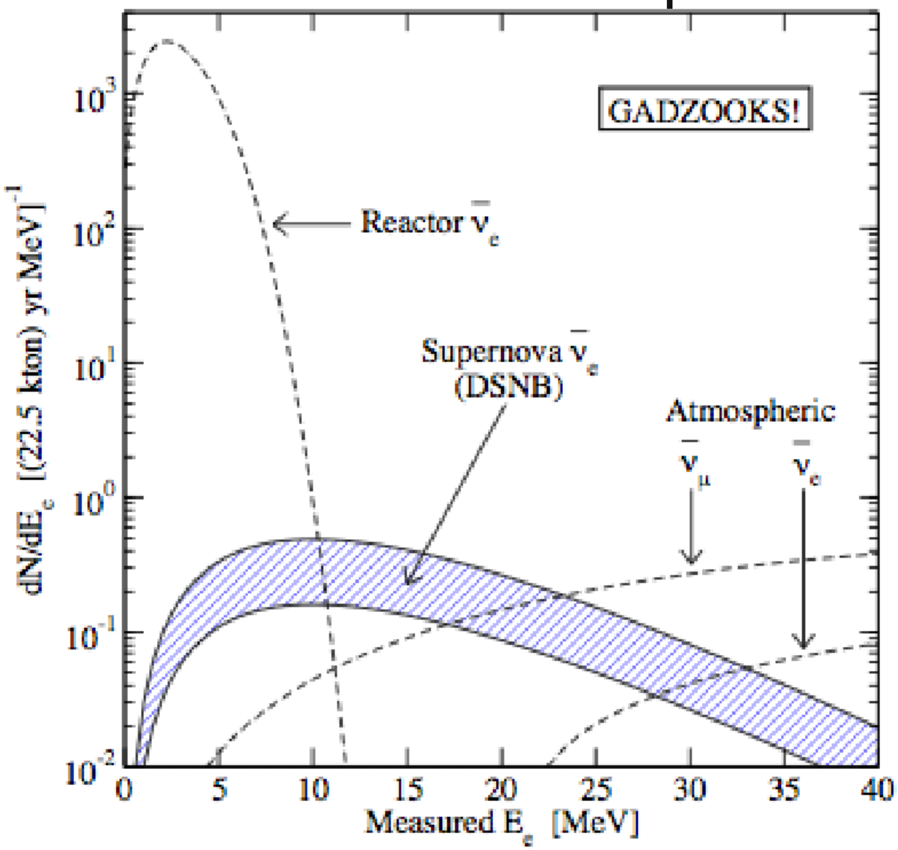
Dissolving Gd in the water enhances detection of relic supernova neutrinos:

$$\bar{\nu}_e p \rightarrow e^+ n$$

8 MeV gamma cascade from n capture on Gd greatly improves background rejection

NOT part of the baseline design, but keeping the option open

Gd in SuperK:

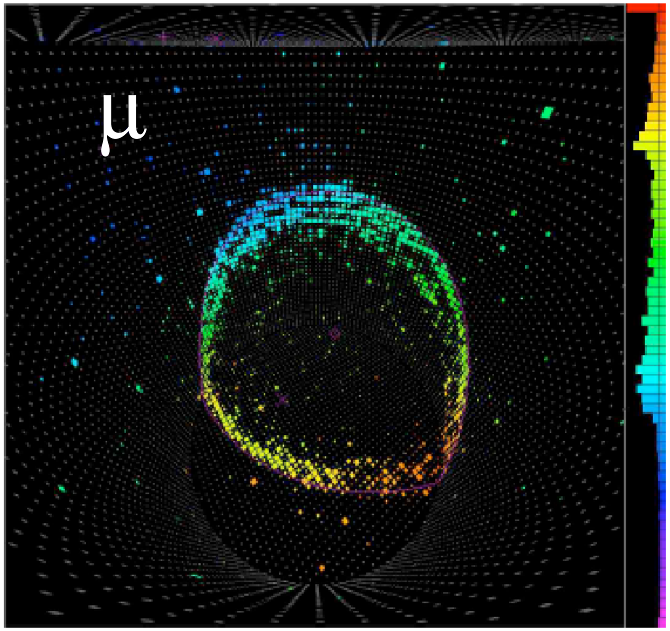


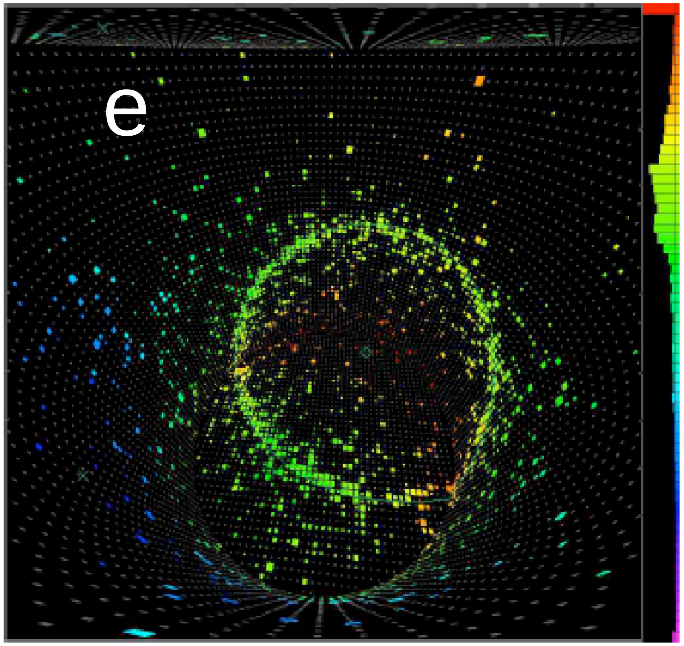
Performance Requirements

Largely based on SuperK performance – these goals are modest!

LBNE WC simulations are in progress and being validated against SuperK simulation

- Vertex resolution 30 cm for single ring events
- Angular resolution 1.5°-3° over an energy range from 100 MeV to several GeV
- Energy resolution for single muons and electrons should be much better than 4.5%/sqrt(E)
- e/μ separation
- Recognize two rings with >90% efficiency when the opening angle is >20°



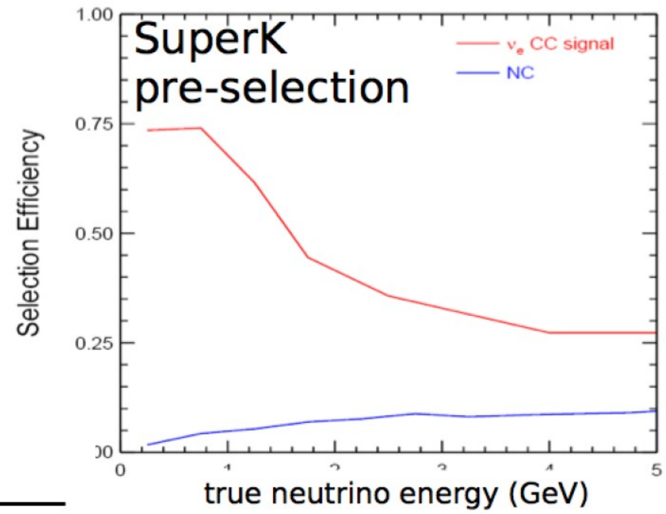


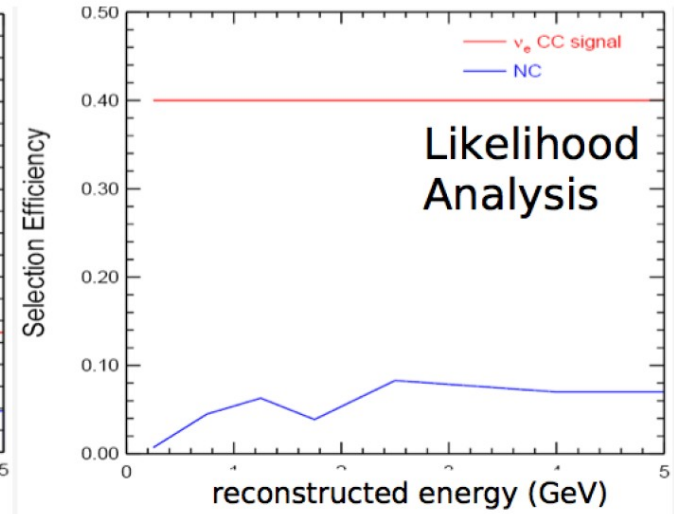
ν_e appearance

Select single ring, e-like events

Assume CCQE for reco energy:

$$E_\nu = \frac{E_{lepton} m_N - \frac{1}{2} m_{lepton}^2}{m_N - E_{lepton} + p_{lepton} \cos\theta_{lepton}}$$





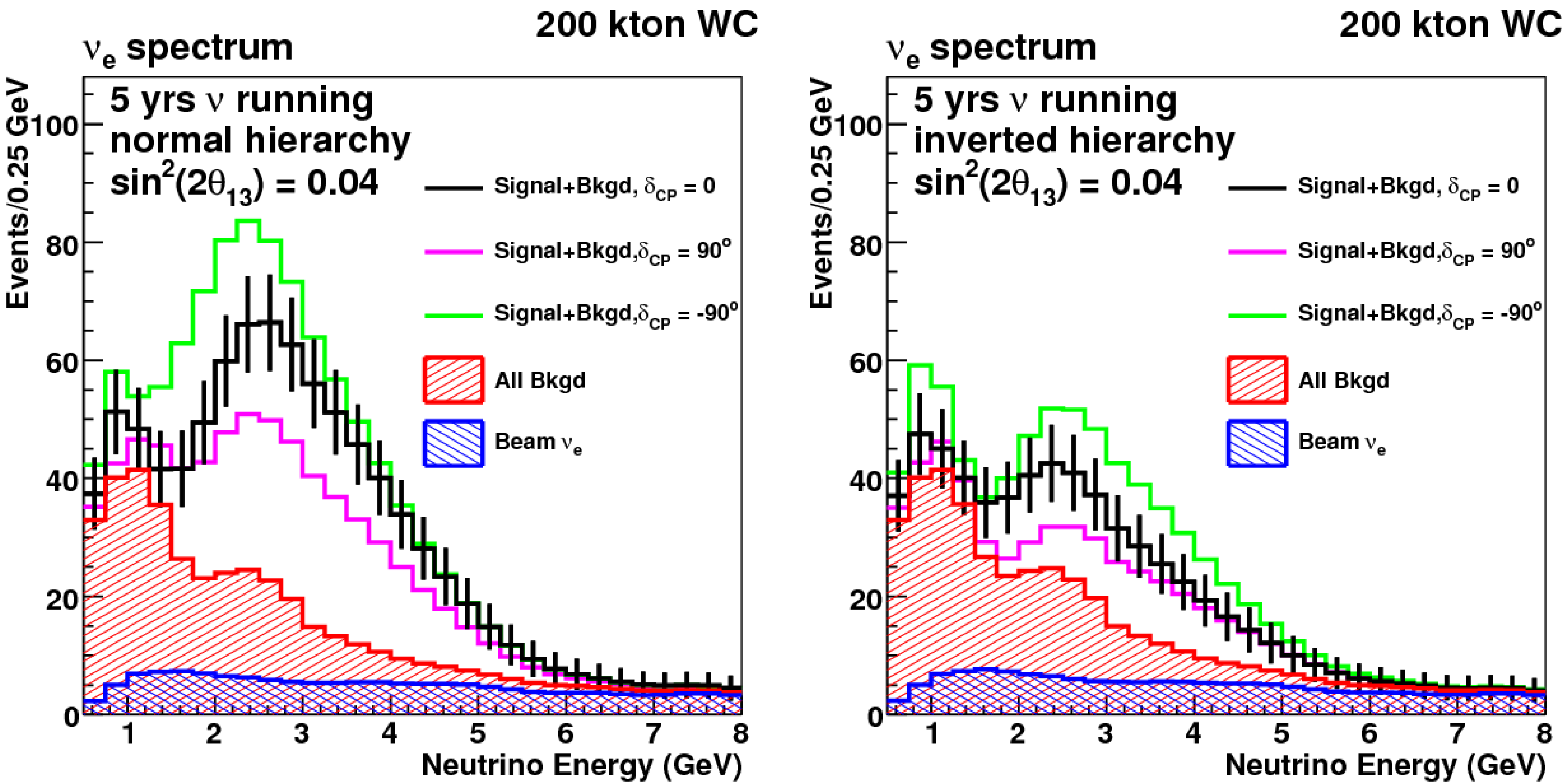
Signal and background efficiencies based on SuperK simulation and reconstruction

Uses a specialized fitter to identify π^0 backgrounds

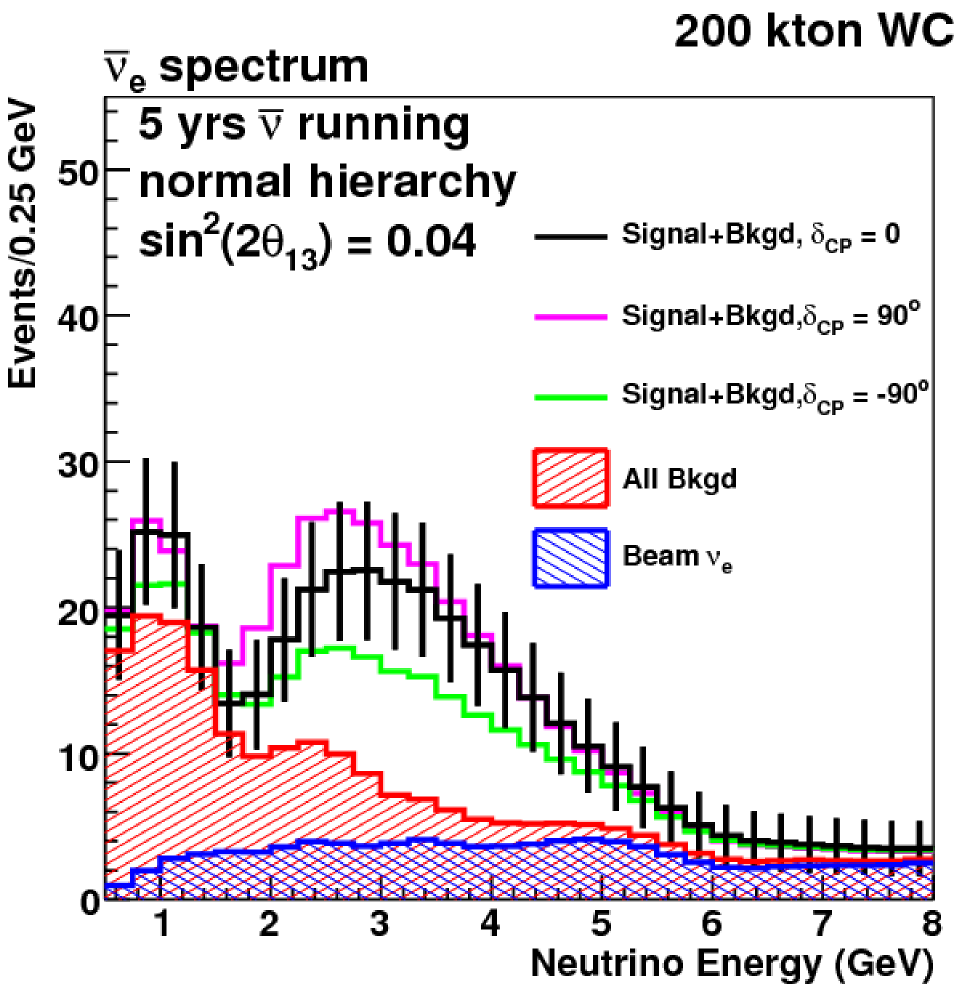
Total signal efficiency is 16% (28%) at 2 (0.8) GeV

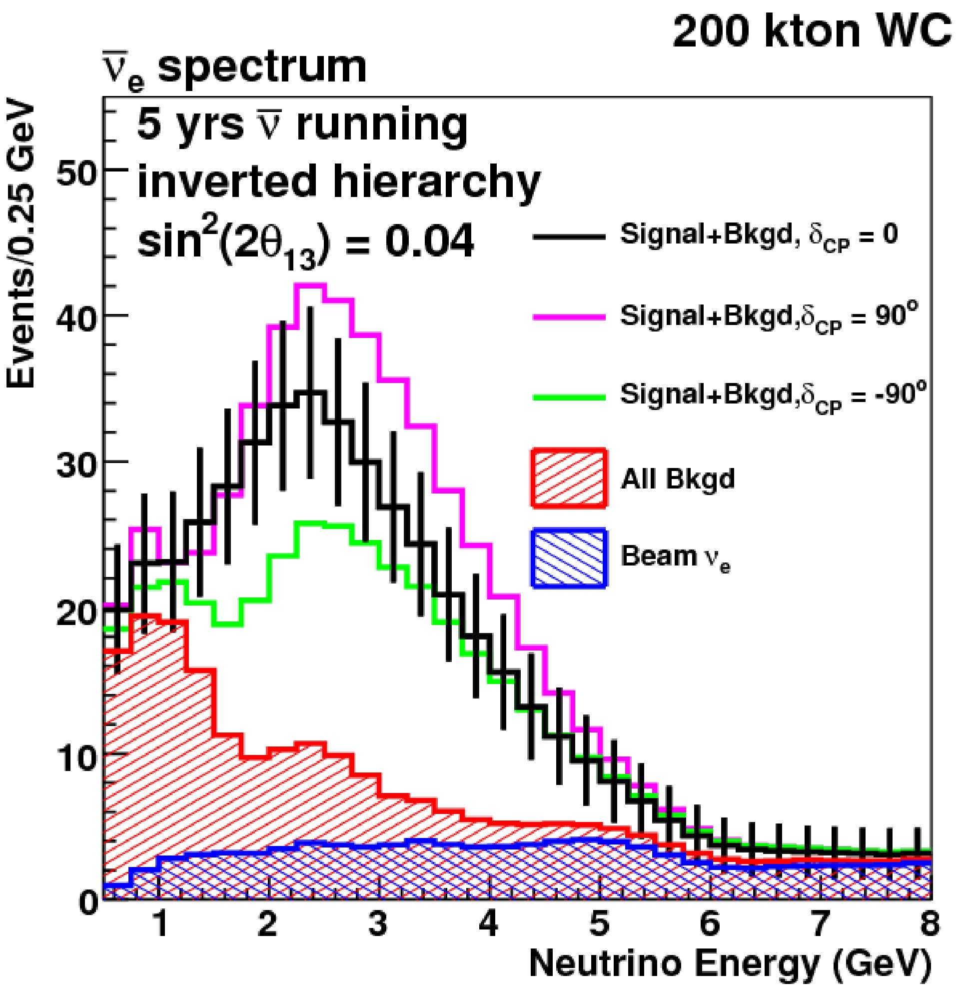
Proof of principle, has not yet been optimized for LBNE

ν_e spectrum



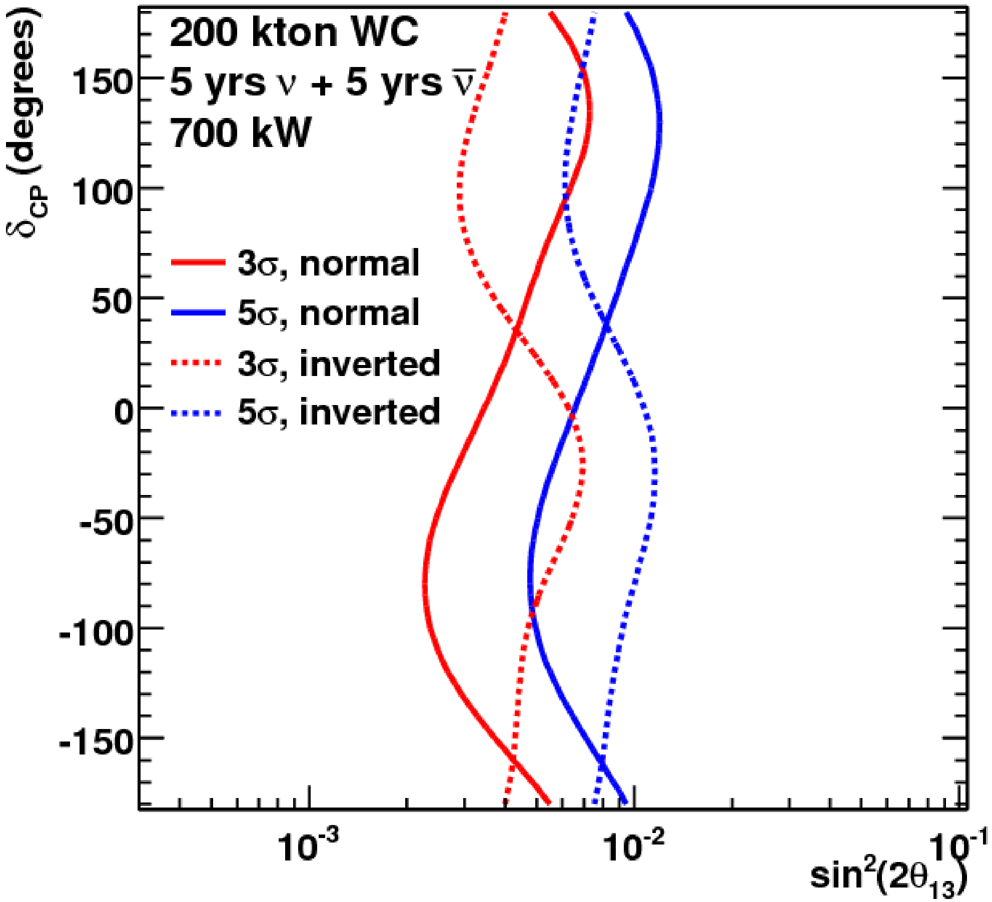
$\bar{\nu}_e$ spectrum



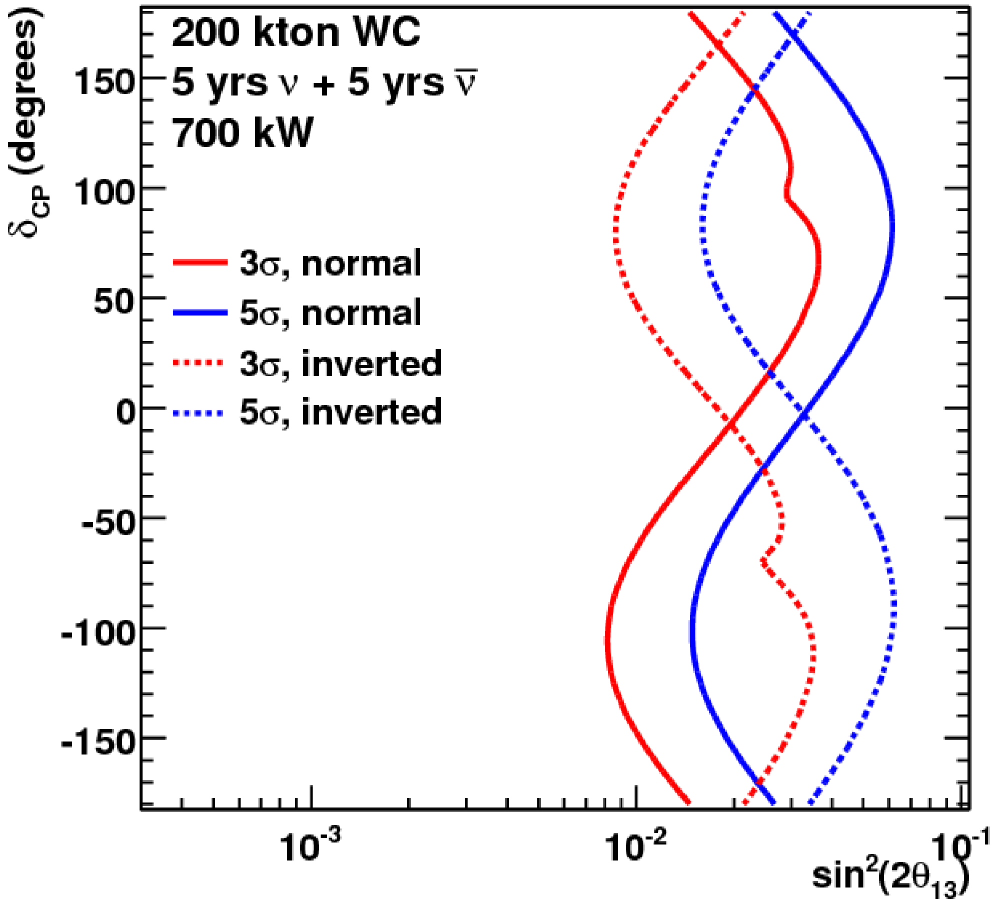


ν_e appearance

θ_{13} Sensitivity

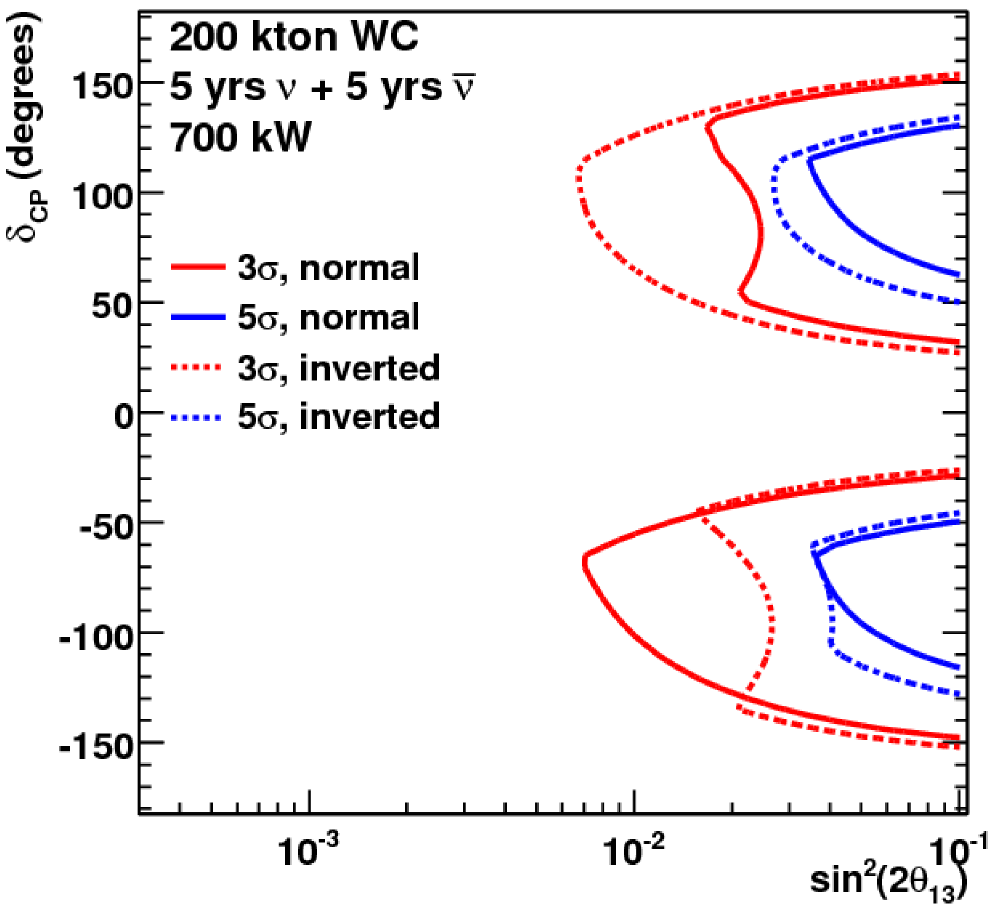


Mass Hierarchy Sensitivity

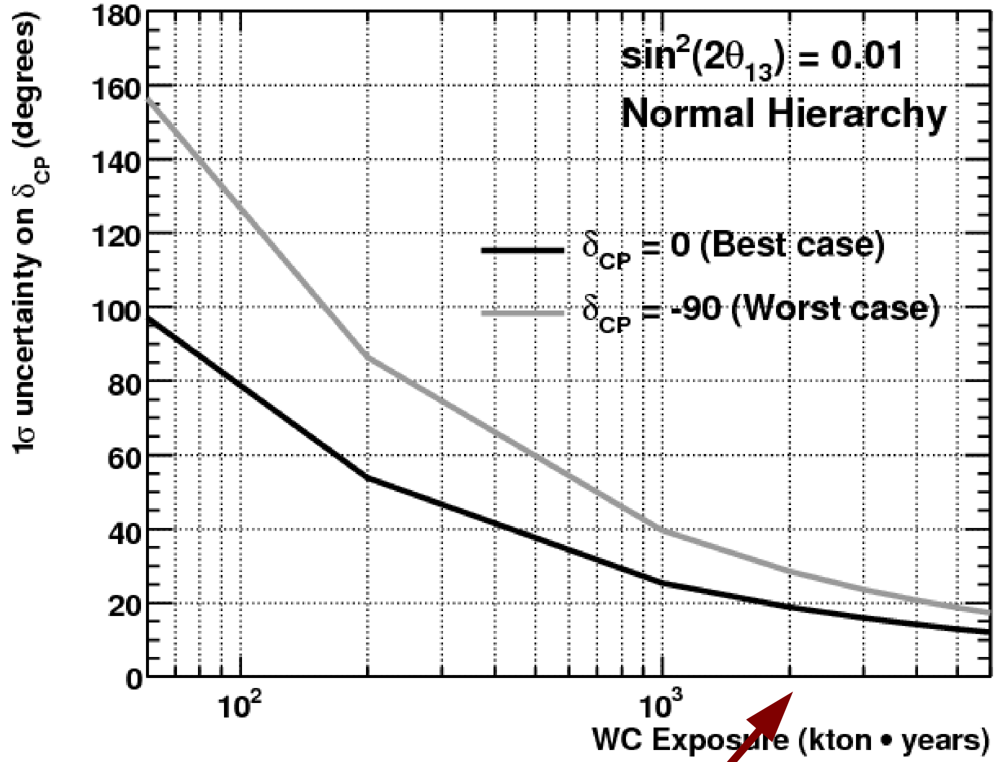


ν_e appearance

CP Sensitivity



CP 1σ resolution



200 ktons x 10 years

Timescale

Production of 100,000 PMTs: ~5 years

Cavity excavation: ~2-3 yrs per cavity

Detector construction: ~2 yrs per module

Start of DUSEL construction ~2014

Summary

- Design of water Cherenkov detector for LBNE is progressing

- In the current design, each water Cherenkov module is 100 ktons (fiducial mass), with 50000 10” PMTs, located at the 4850' level in Homestake

- PMT studies, including pressure tolerance, are ongoing

- Performance requirements for beam neutrino oscillations and other physics are well-understood thanks to SuperK