Calibration of the LBNE Water Cherenkov Detector

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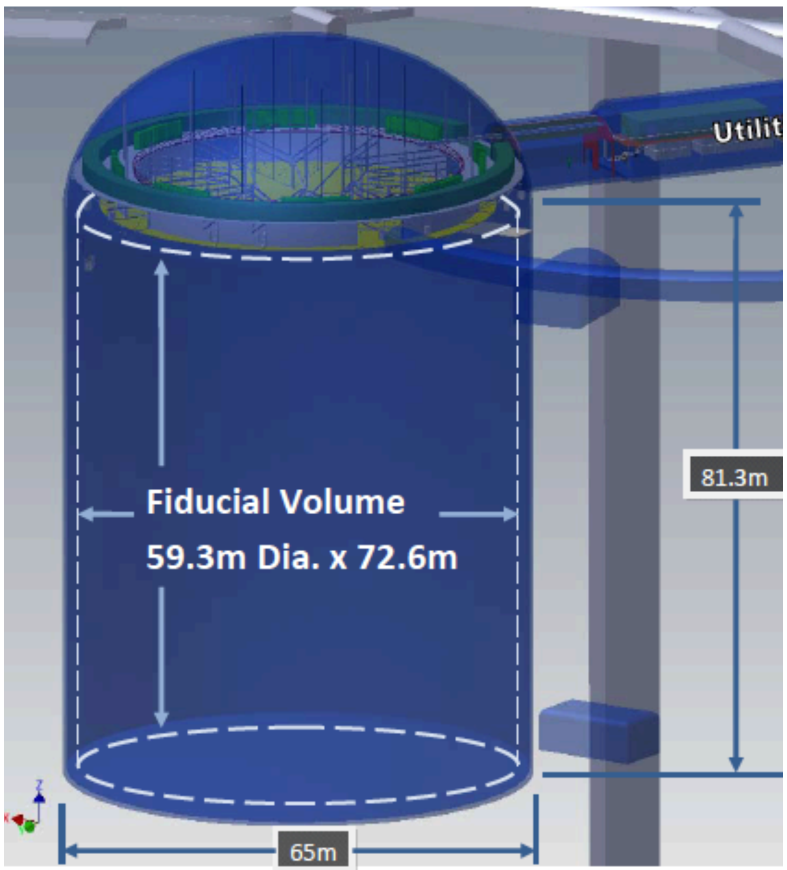
The LBNE Water Cherenkov Detector



- Super Kamiokande provided a solid technical basis for the LBNE WCD
- Single 200 kTon fiducial volume detector
- 29,000 12” high QE PMTs with light collectors (~40% gain in light collection)
- 20% “effective” photo-coverage
- Top Veto System
- Energy range 5 MeV - 5 GeV

Calibration Systems

- Water properties
  - scattering and absorption (<2% uncertainty in attenuation length for 100m water)
- PMT calibration
  - timing < 1ns from 0.1 PE - 100 PE
  - pulse height < 10% from 0.1 PE to 100 PE
  - relative QE <10% (in-situ)
- Energy calibration 5 MeV - 5 GeV
  - resolution 5%/sqrt(E_{GeV}) and 50%/sqrt(E_{MeV})
  - absolute scale 2%

Water Properties

- Scattering and absorption of light affect energy resolution, vertex resolution, particle identification capability

$$I = I_0 \exp(-l/l_0)$$

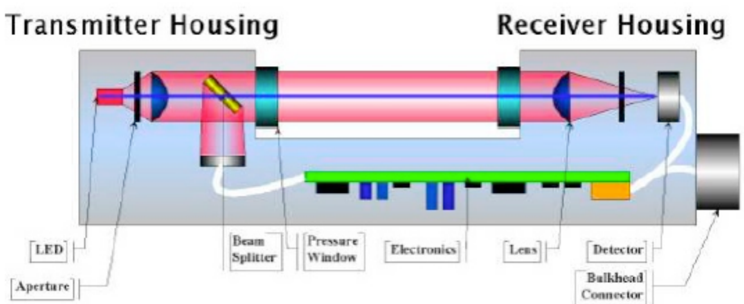
$$1/l_0 = 1/l_{abs} + 1/l_{scatt}$$

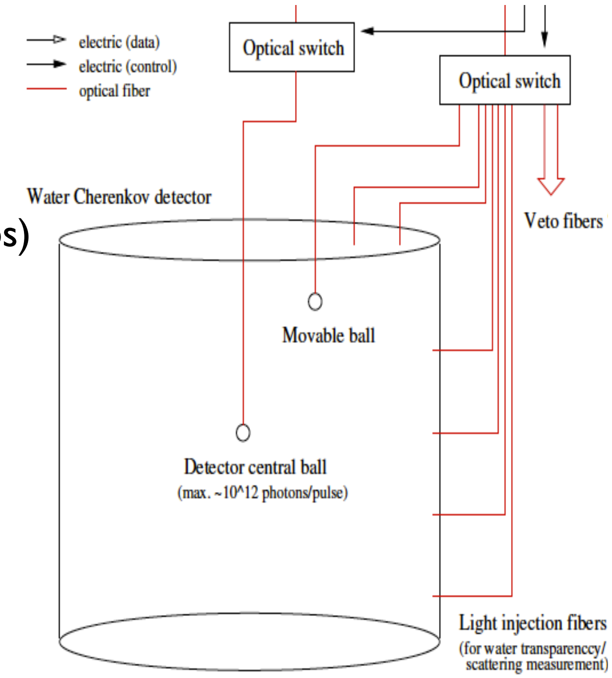
- The larger the detector the more important is understanding of its optical properties
- Affects vertex resolution, particle id, energy resolution

Water Transparency

LLNL

- Determine attenuation length <2% for 100m water (scattering and absorption)
- External (local) high precision system
  - 3-9m path length in controlled environment
  - measures absorption + scattering
- Internal real-time system
  - portable point sampling (C-Star from WetLabs)



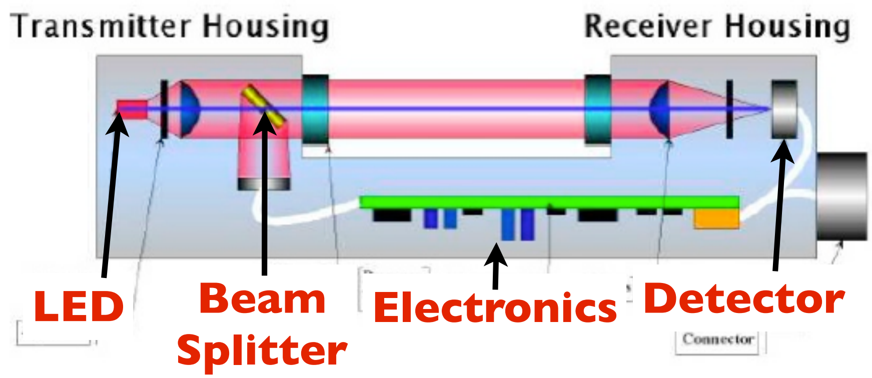


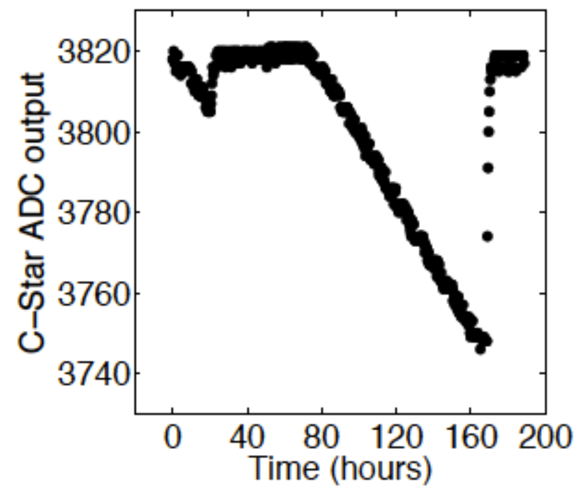
IDEAL at UC Irvine

- Internal light sources (multiple depths for stratification)
  - stratification of water volume
- muon analysis (wavelength range of interest)

Portable C-Star System

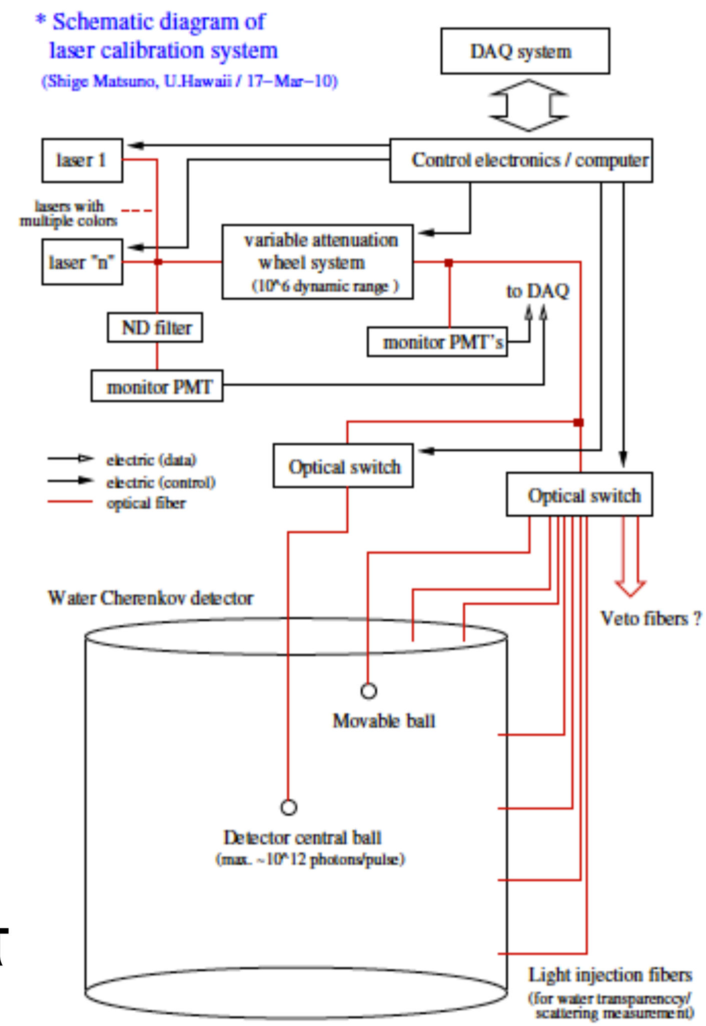
- Used by Daya Bay
- 650, 530, 470, and 370 nm available
- Very stable: 14 bit adc with ~2 cts noise
- Current model has 25 cm path length
- Would work with manufacturer to increase path length (need ~1-2 meter for LBNE)
- Inexpensive ($5k USD) for off-the-shelf model



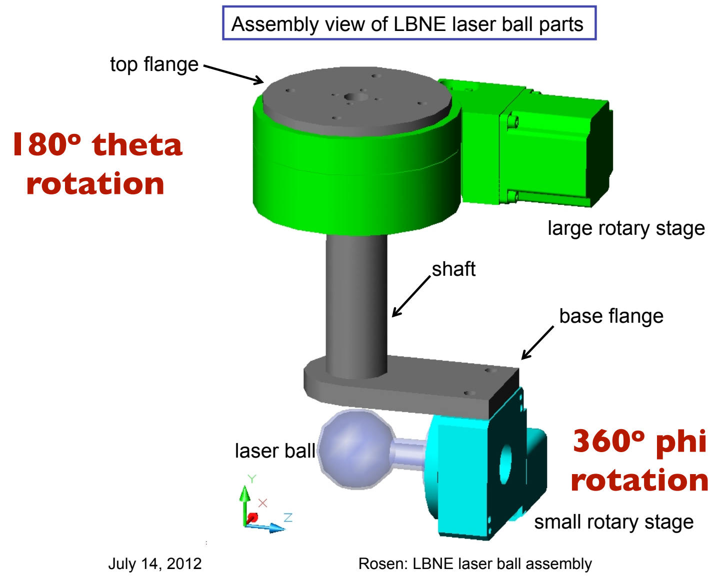


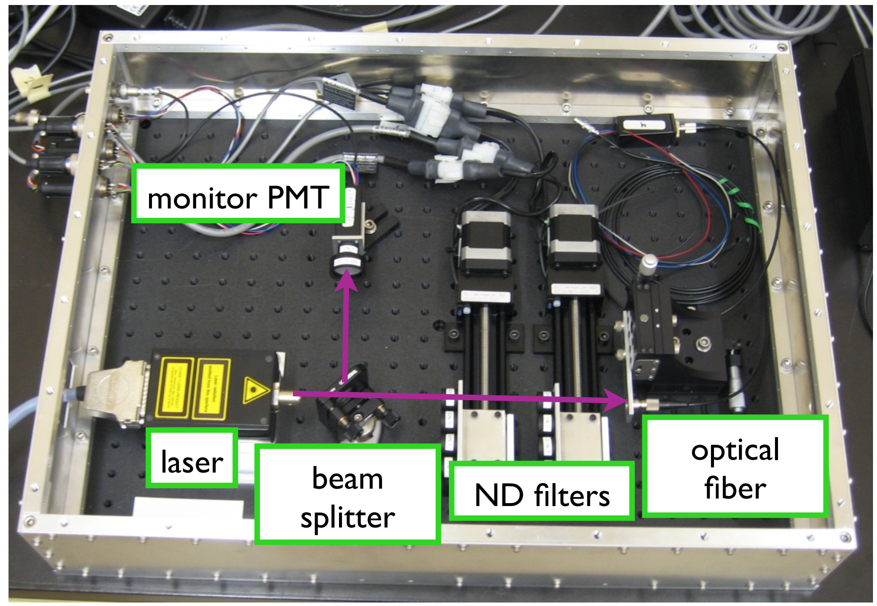
PMT Calibration System

- Pulse height and timing similar to Super Kamiokande
- For relative QE measurement desire to have movable, isotropic light source
- U. Hawaii R&D project to develop highly isotropic light source and test stand to characterize the laser ball in 4π



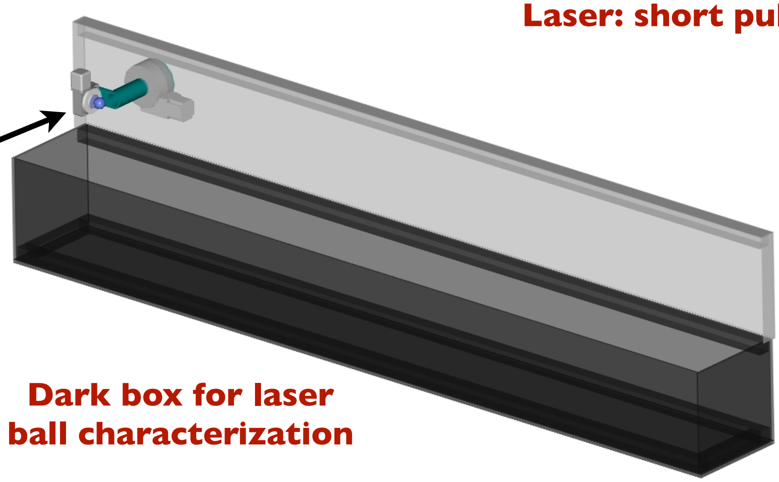
U. Hawaii Test Stand





Laser: short pulse, high rep rate blue laser

Rotary stage. Laser ball installed in dark box

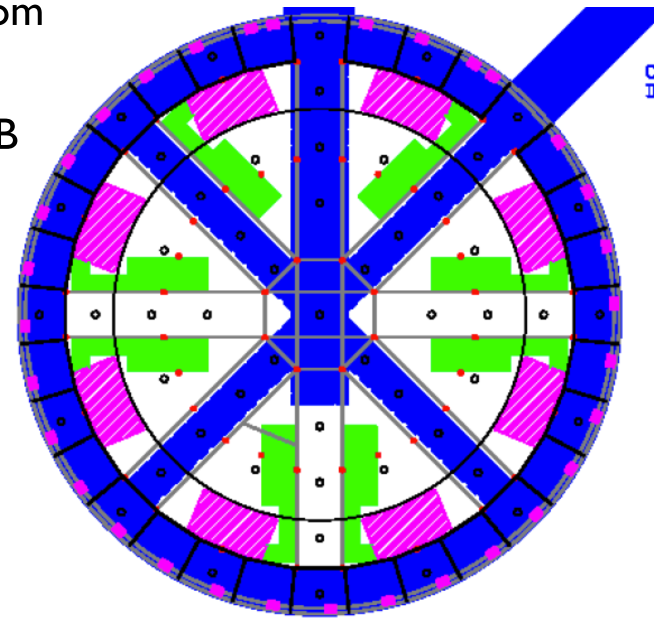


Four 1cm PMTs to measure laser ball isotropy.

Dark box for laser ball characterization

Energy Calibration

- Radioactive sources at low energies
  - ^{16}N (Q=10.4 MeV: 66% 6.1 MeV γ, 28% 10.4 MeV β£) from ^{16}O (neutrons from DT generator) [Super-K]
  - ^{8}Li (0.8s 1/2 life) (β spectrum 13 MeV) DT source and ^{11}B target. Tagged via delayed alpha decay of Be. [SNO]
  - pT source $^{3}H(p,\gamma)^{4}He$ (19.8 MeV mono-energetic γ's) [SNO]
  - deck had ~40 calibration ports 8 radials + 16 azimuthal near fiducial volume edge + central port



- Natural events at high energies
  - Michel electrons, pion zero, stopping muons
  - Muon rate expected to be ~0.1-0.2 Hz
- Risk mitigation electron accelerator for high energies (100 MeV - 1 GeV)

Energy Calibration Requirements for a far water Cherenkov Detector in Neutrino Long Baseline Experiments

J. Insler, T. Kutter
LSU

Hyper-K Open Meeting
23. August 2012

Introduction

- How well do we need to calibrate the energy response of the LBNE far detector to measure relevant physics parameters ?

- Effort started in context of WCD and before θ_{13} was known with aim to develop a detector calibration strategy

→Focus on beam physics measurements
  - θ_{13}
  - CP violation
  - Mass hierarchy

Method

- Use GloBES to calculate sensitivities
  As function of
  - energy resolution
  - energy bias

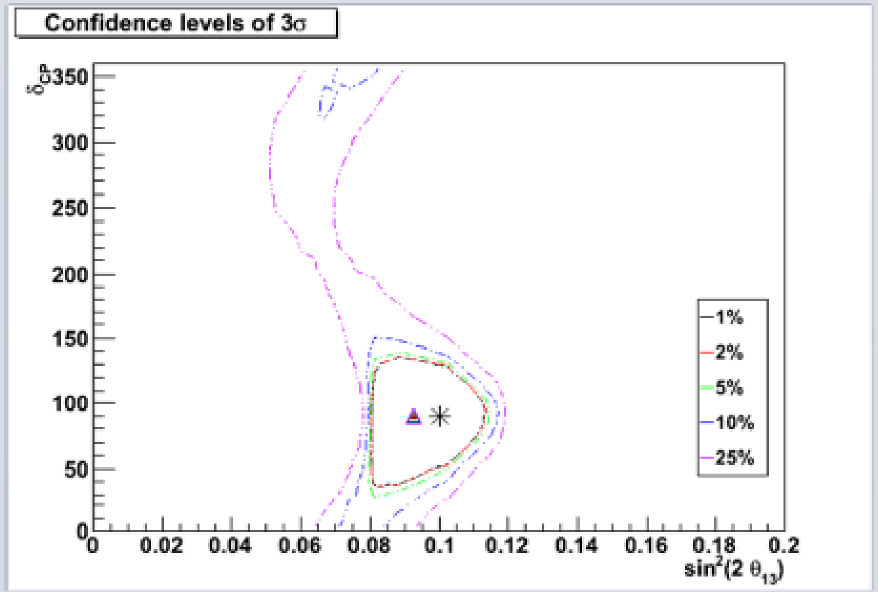
- Developed independent approach (toy data analysis) to calculate sensitivities
  - Allows outputs and cross checks at intermediate stages
  - determine effect of energy resolution and energy bias on sensitivities

GLoBES Results

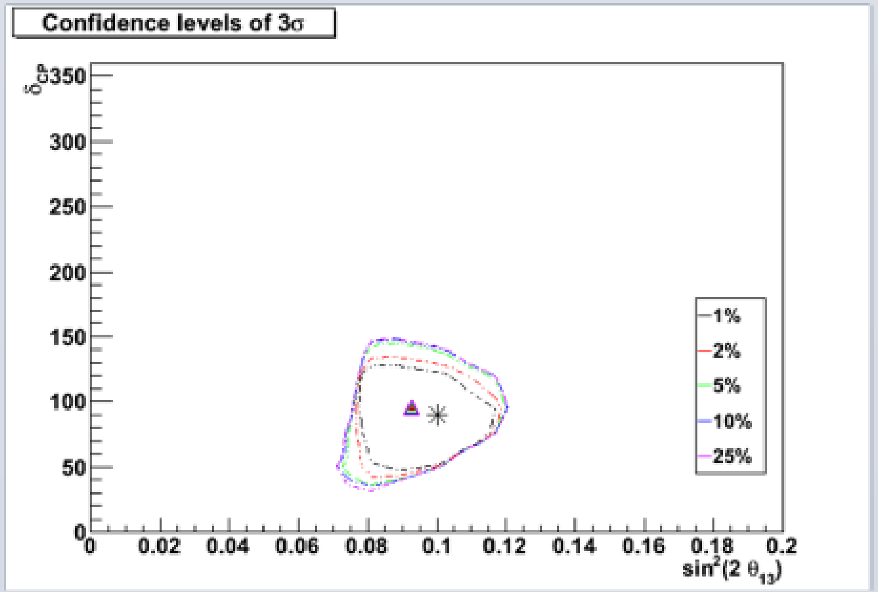
Assumes 5 years of ν running, $\sin^2 2\theta_{13} = 0.1$ and $\delta_{CP} = 90^\circ$

WC, 200 kt

Sensitivity to Energy Resolution

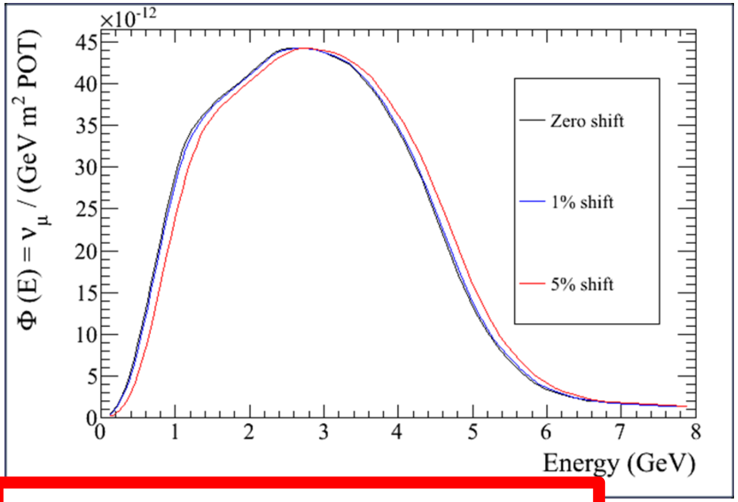


Sensitivity to Energy Bias

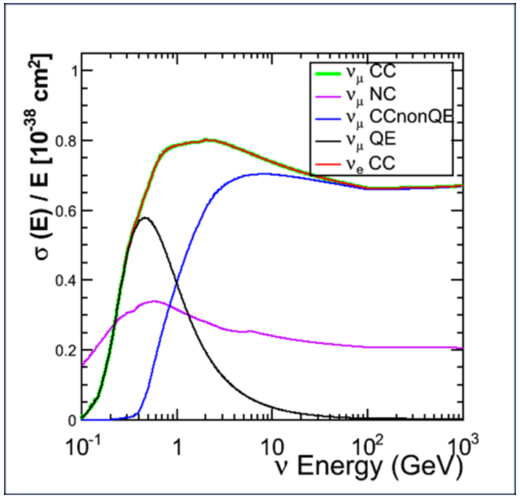


Independent Approach

- Compute event rates from same inputs as used for GLoBES study
  - neutrino fluxes



cross sections



efficiencies

ν_e signal: 13.7%

backgrounds to ν_e :

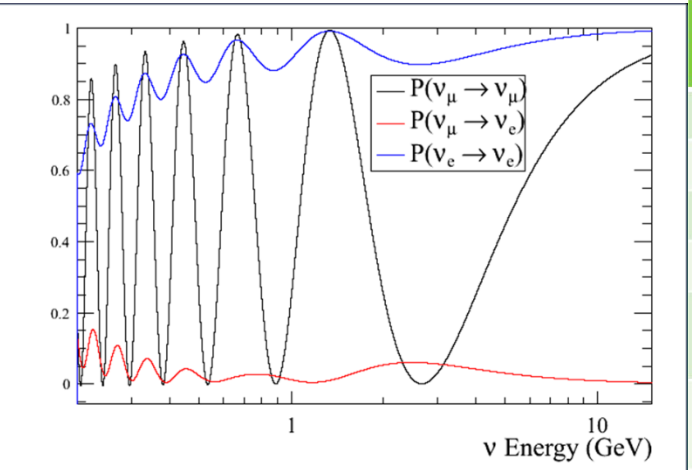
ν_μ CC: 0.23%

ν_μ NC: 0.34%

ν_e beam bkg: 9.6%

Energy bias: shift of energies by X%·2.6 GeV (peak flux)

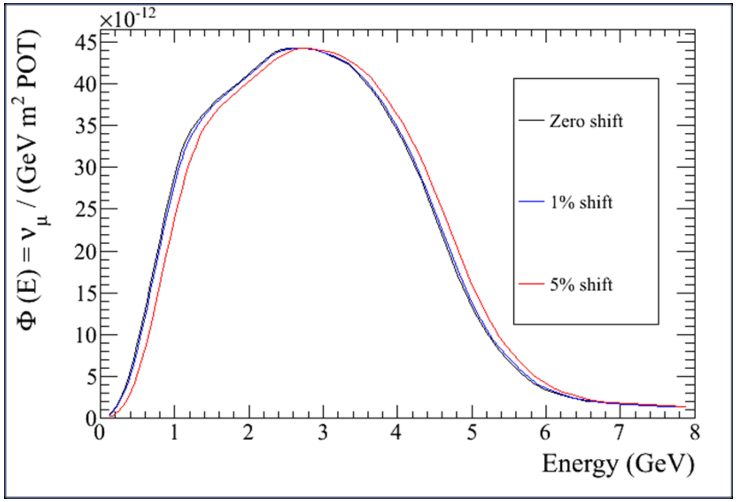
Analytical calculation of oscillation probabilities

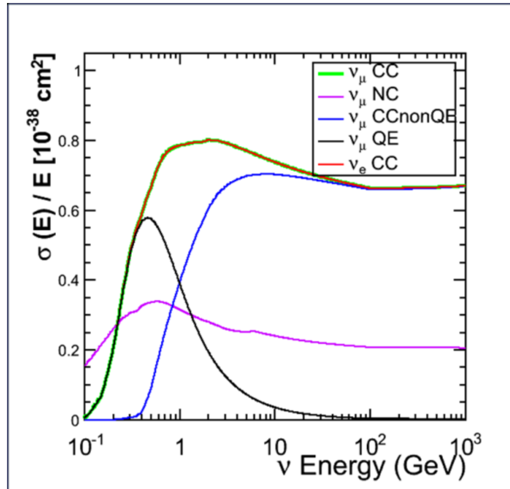


Oscillation Parameter	Value
θ_{13}	0.16 rad
δ_{CP}	$\pi/2$ rad
θ_{12}	0.58 rad
θ_{23}	$\pi/4$ rad
Δm^2_{31}	$2.6 \times 10^{-3}\ eV^2$
Δm^2_{21}	$7.9 \times 10^{-5}\ eV^2$

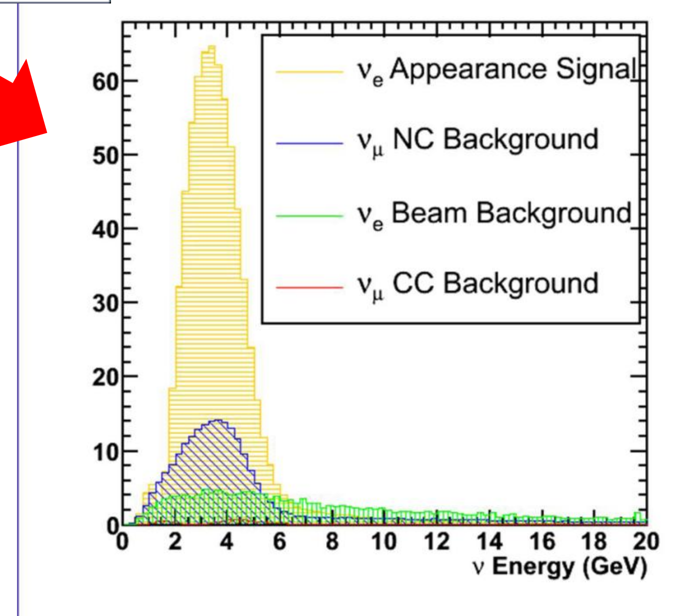
Independent Approach

- Compute event rates from same inputs as used for GLoBES study
  - neutrino fluxes cross sections efficiencies (see next page)





$R(E) = \Phi(E)\ \sigma(E)\ P(E)$



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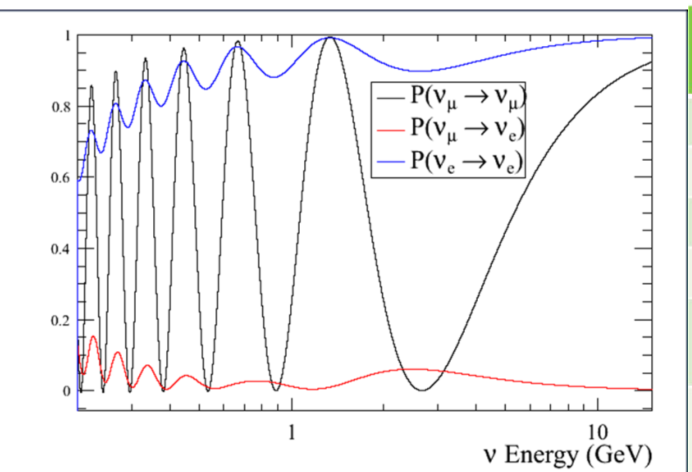

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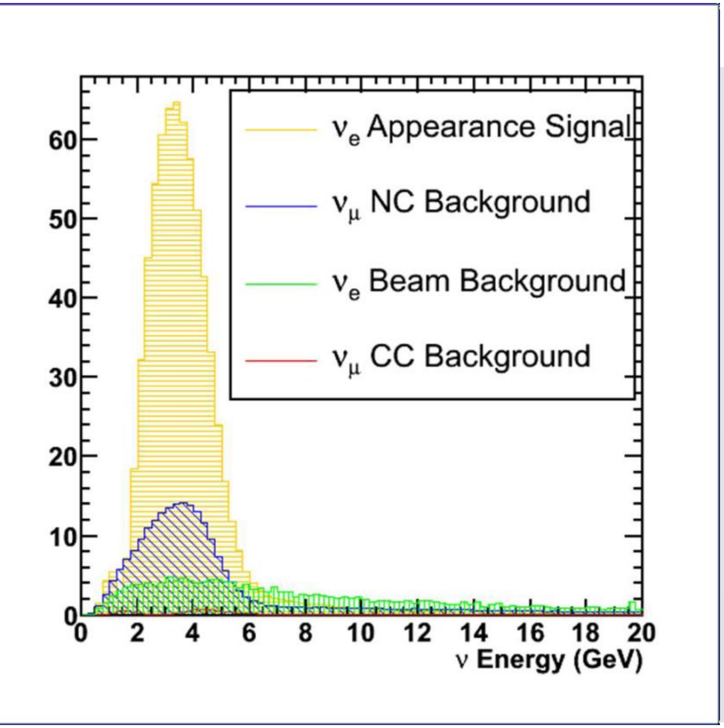
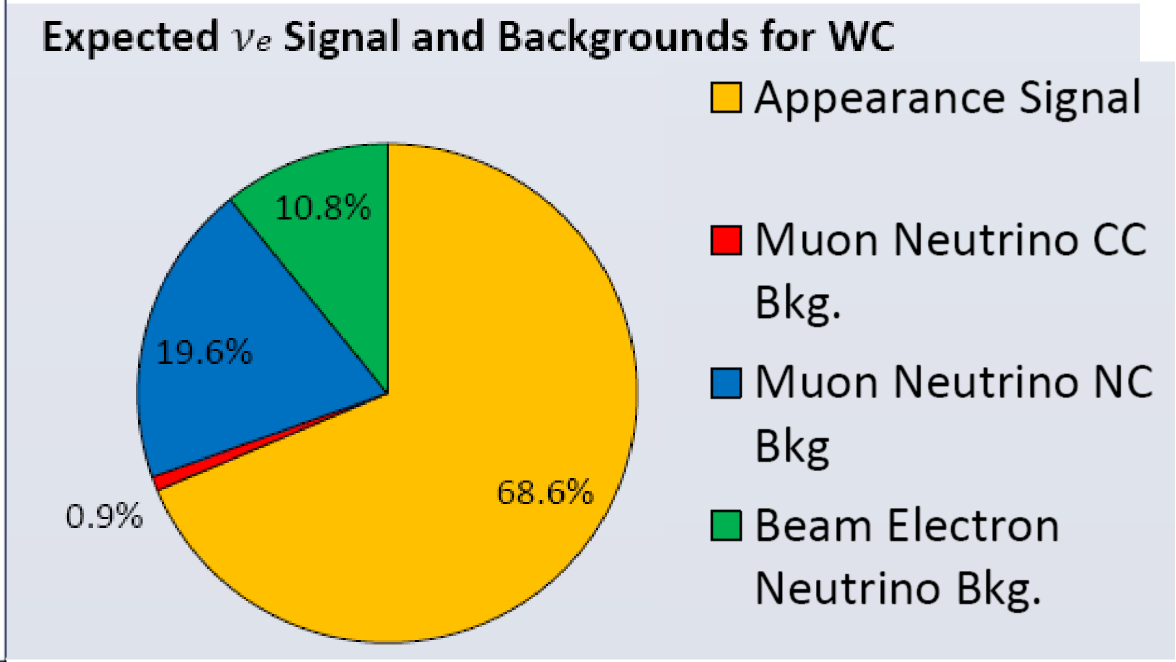
Expected Signal and Backgrounds

Integrated rates from 0.5 – 8 GeV and scaled by detector efficiencies





$\Delta\chi^2$ Calculation

$$\Delta\chi^2 = 2 \cdot \Sigma\left(N_\nu \cdot \ln\frac{N_\nu}{N_{\nu_{Expected}}} + N_{\nu_{Expected}} - N_\nu\right)$$

Based on Poisson statistics

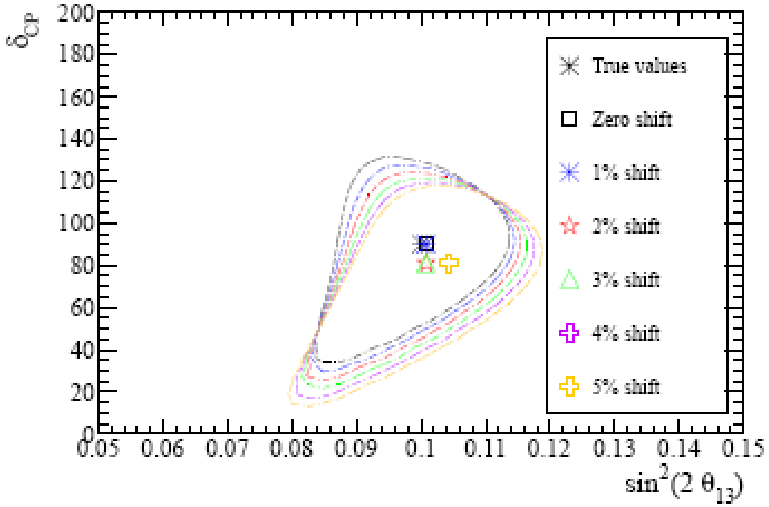
NOTE: include energy bias and resolution at far detector only
→relative uncertainty between near and far detector after accounting for near-far propagation effects

NOTE: simpler procedure than GLoBES' numerical marginalization over all oscillation and nuisance parameters

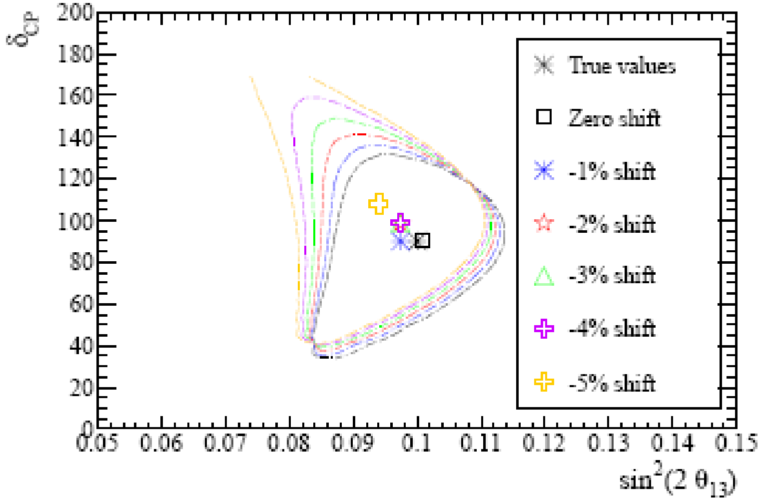
Results

Assumes 5 years of ν running, $\sin^2\theta_{13}$ = 0.1, and δ_{CP} = 90°, normal hierarchy

Energy bias :positive shift



Energy bias : negative shift



Energy resolution

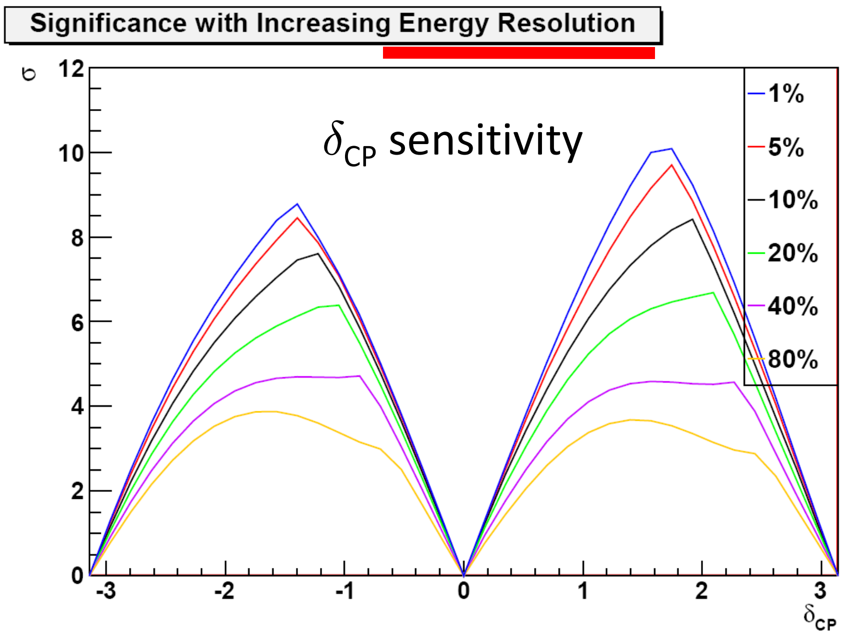
Results consistent with GLoBES study

Metric for measuring improvement in sensitivity: change in 3 σ contour area (normal hierarchy)

Energy Resolution	Change in 3σ Area
5%	0%
4%	-5.6%
3%	-8.2%
2%	-9.6%
1%	-11.0%

Energy Bias	Change in 3σ Area
5%	0%
4%	-1.4%
3%	-7.4%
2%	-11.0%
1%	-12.3%

LBNE: More recent updates to reflect knowledge of θ_{13}

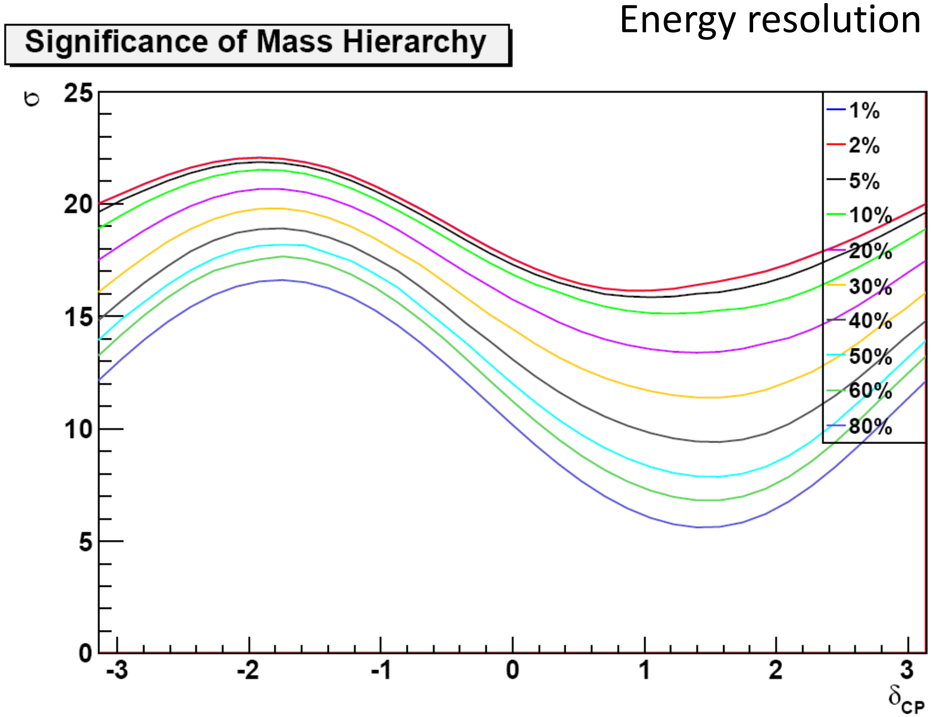


Assumes 5 years of ν and anti-ν each

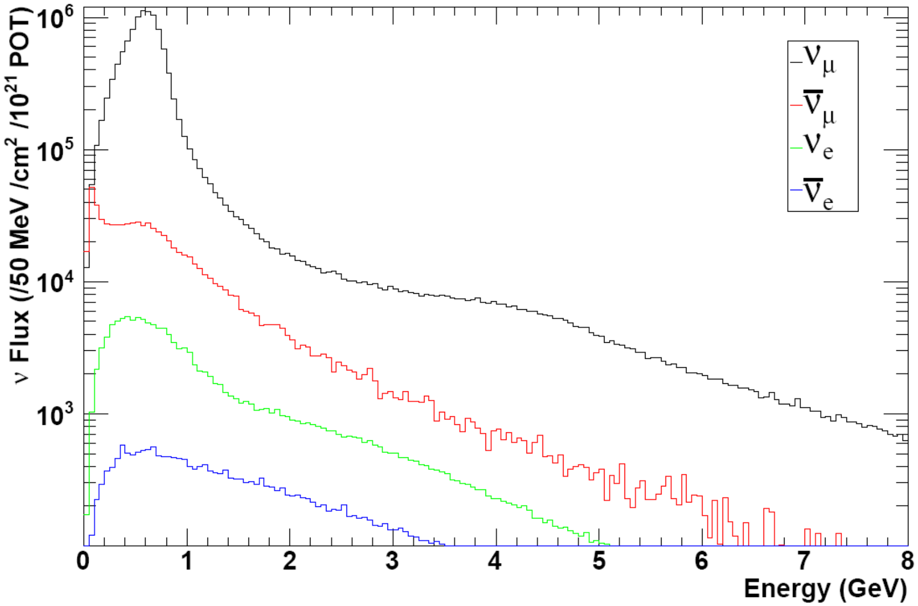
→7.3 10^{20} POT/year

→fiducial volume 200 kT

Energy resolution

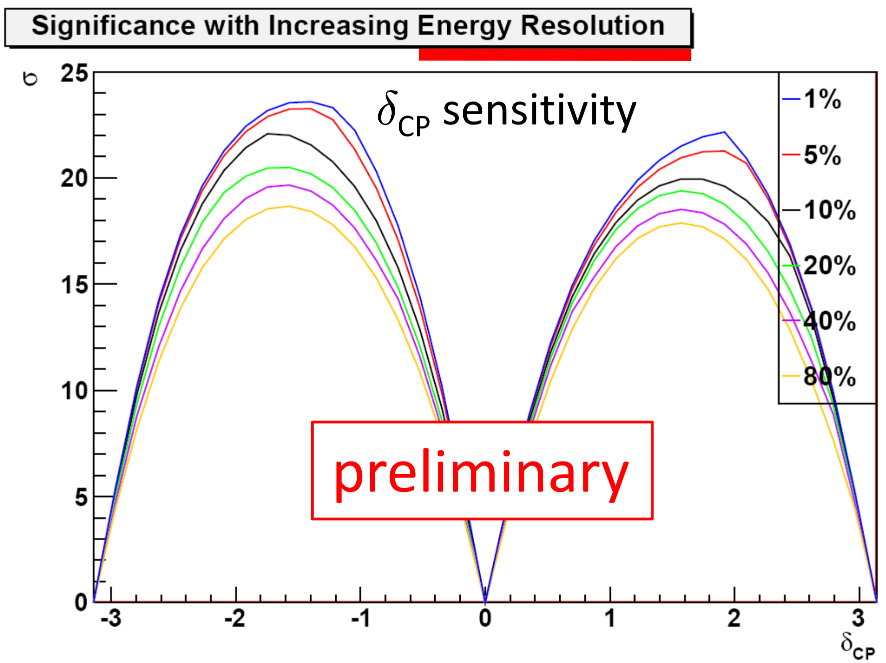


Hyper-K: T2K ν spectrum, 1.66 MW beam



Assumes 5 years of ν and anti-ν each
→34.5 10^{20} POT/year
→ fiducial volume: 560 kT

- use T2K ν and anti-ν spectra
- adjust signal and background efficiencies
- baseline, detector size, …



Summary and Outlook

- Studied effect of neutrino energy resolution and energy scale uncertainty on sensitivity to beam physics parameters
  - work done for LBNE WCD and initially w/o knowledge of θ_{13}
  - can be easily reconfigured for Hyper-K (work in progress)

Results can be used to help develop energy calibration strategy

<u>ToDo:</u>

- Study effect of oscillation parameter correlations
- Study energy calibration requirements at lower energies, e.g. relevant for SN physics