LBNE

NEUTRINO2014
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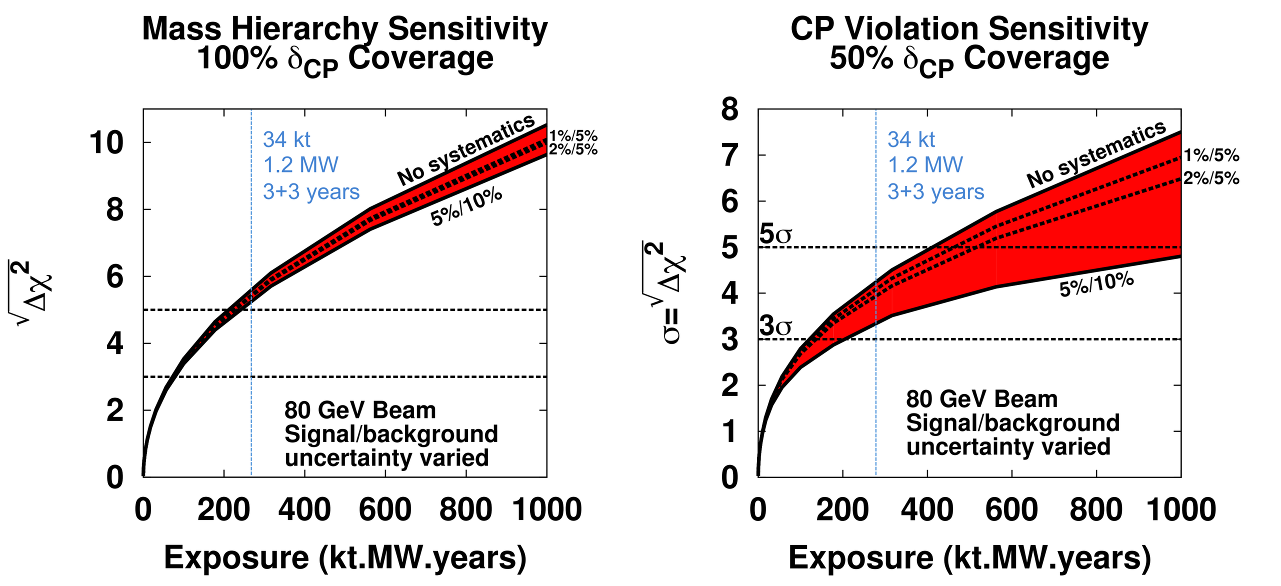
Systematic Uncertainty in LBNE Measurements of Long-Baseline Neutrino Oscillation

Methods to Estimate Systematic Uncertainty in LBNE

- Experience with previous and current long-baseline neutrino oscillation experiments
- GLoBES-based sensitivity calculations with signal and background normalization uncertainty
  - Uncertainty uncorrelated between far detector samples
  - Near detector constraints put in by hand
  - Energy scale uncertainty not included
- Fast Monte Carlo (FastMC)
  - Full simulation of neutrino flux and interactions with parameterized detector response
  - Reweighting technique allows study of systematic uncertainties
  - Modified GLoBES calculations with input from FastMC approximate 3-flavor analysis
- Monte Carlo Simulation (LArSoft)
  - Functional simulation: many existing simulated data samples in LBNE geometries
  - Reconstruction work in progress
  - LBNE wire-wrapping introduces ambiguity which complicates reconstruction relative to other LArTPCs

Normalization Uncertainty in GLoBES Calculations

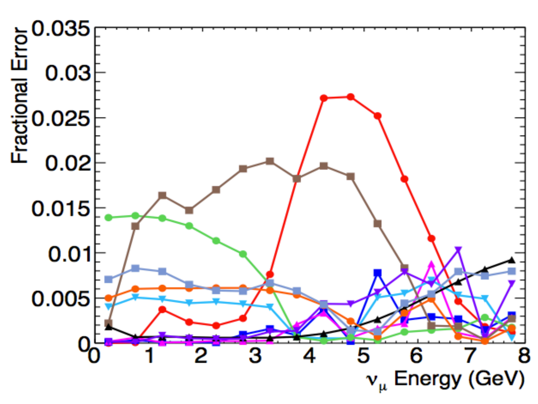


- Signal and background normalization uncertainties are treated as *uncorrelated* between the four modes ($\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu$)
- Statistically limited for exposures <100 kt.MW.years
- Uncertainty of 1-2% in signal and 5% in background normalization are needed for discovery of CP violation with exposure of <500 kt.MW.years

Projecting LBNE Systematic Uncertainty from MINOS and T2K

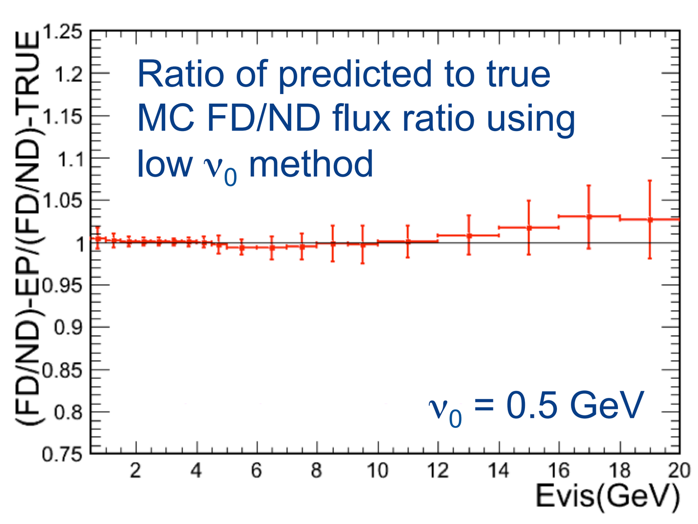
Source of Uncertainty	MINOS Effect on ν_e Signal	MINOS Notes	T2K Effect on ν_e Signal	T2K Notes	Projected LBNE Effect on ν_e Signal	LBNE Notes	Comments
Beam	0.3%	Wide band; appearance peak energy ~3 GeV	2.9% (includes all ND effects)	Narrow band; appearance peak energy ~0.6 GeV	2%	Wide band; appearance peak energy ~3 GeV	• Correlated between ν_e/ν_μ so expect some cancellation in LBNE 3-flavor analysis • Spectral analysis increases sensitivity to beam variations
Fiducial Volume	2.4%	4 kt fiducial	1%	22.5 kt fiducial	1%	34 kt fiducial	• Fiducial volume less uncertain in large detector
Energy Scale (ν_μ)	3.5%	Steel/ scintillator sampling calorimeter (FD)	Included in beam syst.	Water Cerenkov detector (FD)	-	Totally-active liquid argon TPC (FD)	• Included in 5% ν_μ disappearance signal normalization uncertainty for LBNE • No uncorrelated uncertainty for ν_e in LBNE 3-flavor analysis
Energy Scale (ν_e)	2.7%		3.4% (includes all FD effects)		2%		• Based on detector calibration • Totally active LBNE LAr TPC more precise energy scale than MINOS sampling calorimeter or T2K WCD • Hadronic part correlated between ν_e/ν_μ so expect some cancellation in LBNE 3-flavor analysis
Simulation (Cross-sections, hadronization model, FSI)	2.7% (primarily hadronization model)	Identical ND	7.5% (primarily cross-sections)	Non-identical (scintillator tracker) ND	~2%	In design; nominally non-identical (straw-tube tracker) ND	• Hadronization model correlated between ν_e/ν_μ so expect some cancellation in LBNE 3-flavor analysis • Cross-sections may contribute more to LBNE than MINOS if ND non-identical • Cross-section uncertainties smaller for LBNE energies than T2K energies • Spectral analysis in LBNE provides extra constraint
Total signal error	5.7%		8.8%		~3.5%		• Uncorrelated ν_e signal error: 1-2%

Systematic Uncertainty in LBNE Beam Flux



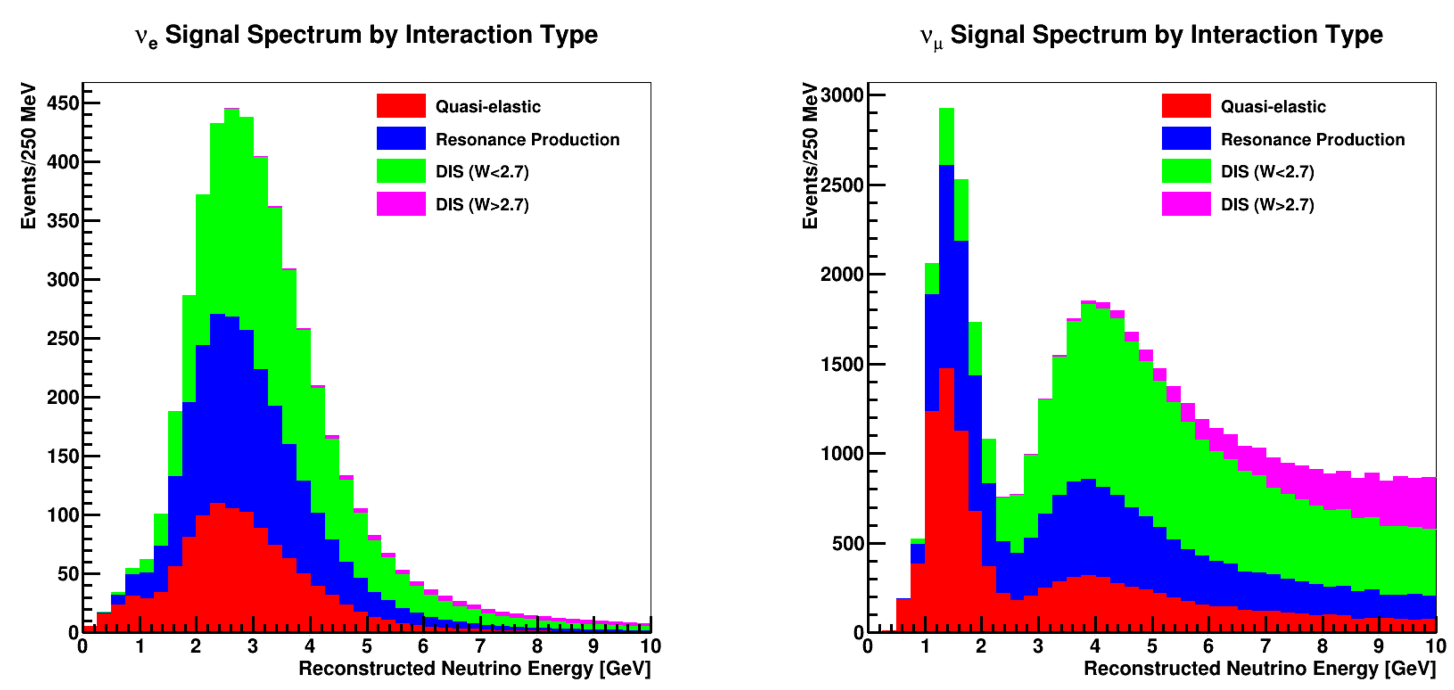
- Study effect on beam flux of the variation of beam alignment and performance parameters within tolerances:
  - <3% uncertainty in FD flux
  - <1% uncertainty in FD/ND flux ratio
- Beam poster: "Beam Simulations for the Long Baseline Neutrino Experiment"

- Low ν_0 method: use events with low hadronic-energy deposition to determine ν_μ FD/ND flux ratio
- Preliminary analysis of FGT ND:
  - 1-2% uncertainty in FD/ND flux ratio
  - ND poster: "Fine-Grained Tracker as a Near Detector for LBNE"



Neutrino Interactions in LBNE

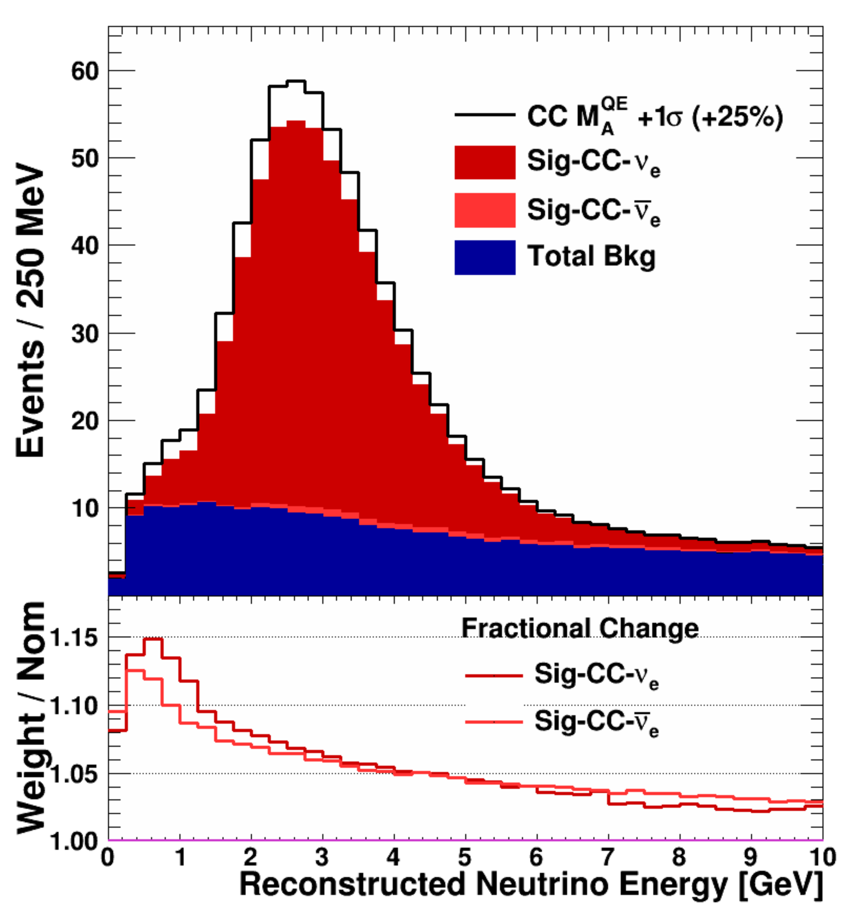
- More than 75% of neutrino interactions in LBNE are non-quasi-elastic, with significant hadronic-energy deposition
- Since the hadronic energy scale is independent of lepton flavor, expect significant cancellation of hadronic energy-scale uncertainty in the 3-flavor analysis



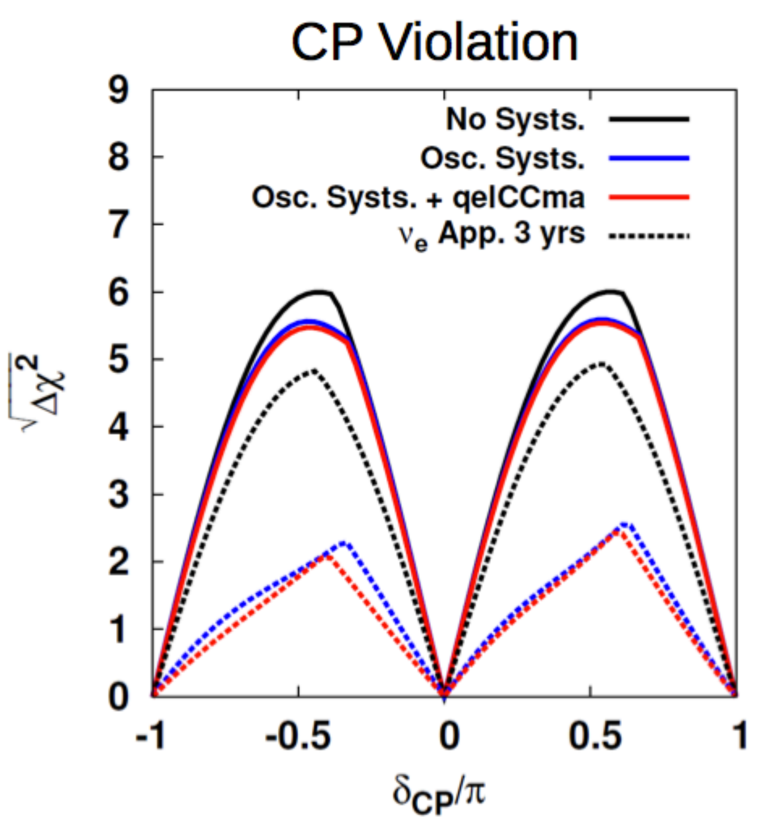
Evaluating LBNE Systematic Uncertainty with the Fast Monte Carlo Simulation

- Full simulation of neutrino flux and interactions with parameterized detector response:
  - G4LBNE beam simulation
  - GENIE ν event generator
  - Detector response based on ICARUS data and GEANT4/LArSoft simulations
- Reconstructed quantities and selection criteria based on realistic kinematics
- Allows study of LBNE sensitivity to uncertainty in cross-sections, hadronization model, final-state interactions, beam alignment, and energy reconstruction
- Preliminary results show significant cancellation of uncertainty in 3-flavor analysis for variations of a single systematic effect
- Fast MC poster: "The LBNE Fast MC"

Example: Spectral distortion induced by increasing M_A^{QE} by +1σ (+25%)



- Degradation in CPV sensitivity from systematic uncertainty is large when considering only ν_e appearance, but is significantly reduced in 3-flavor analysis



Plans for Study of LBNE Systematics

- LBNE Systematics Workshop taking place at CETUP* in July 2014
- Fast MC sensitivity calculations with combinations of systematic effects in progress
- VALOR 3-flavor analysis for LBNE in progress
- Evaluation of physics-based detector performance requirements for LBNE near and far detectors in progress
- Analysis of energy resolution, energy scale, signal selection efficiency, and background rejection efficiency using LArSoft simulation and reconstruction beginning
- Long-term goal is end-to-end analysis of LArSoft simulated data

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