DUNE CD1 Refresh:
GLoBES Configurations, and Sensitivity studies

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Combined LB Task Force Meeting
Monday April 6th, 2015

Outline

- GLoBES
- Study parameters
  - Assumptions
  - Oscillation parameters
  - Non-oscillation systematics
- GLoBES inputs
  - Fluxes
  - Cross sections
  - Smearing
  - Efficiencies
- Spectra comparisons
- Using this GLoBES setup

Analysis Basics

- What do we measure?
  - Number of ν interactions as a function of reconstructed neutrino energy
  - Convolution of (flux) x (osc. prob.) x (xsec) x (nuclear effects) x (efficiency) x (energy smearing)
- Hypothesis testing
  - Compare data to simulation (e.g. χ^2 test)
  - Adjust parameters of interest (oscillation parameters) until the simulation best describes the data (min $\Delta\chi^2$)
  - Also allow nuisance parameters to fluctuate
  - Determine likelihood that data is consistent/inconsistent with the null hypothesis
  - Determine probabilist confidence intervals for fit parameter values
- What to do in the absence of data?
  - "Make up" data based on simulations and specific values for parameter(s) of interest
  - Toy MC throws: Randomly fluctuate all free parameters and statistics within priors many, many times
  - Asimov data set: use the simulated prediction, i.e. the median simulation

GLoBES

- These studies have a lot of free parameters
- There are a lot of measurements and scenarios to explore
- Fitting requires quickly propagating parameter changes to spectral differences
- How do we quickly generate spectra for each scenario, and set of free parameters?
  - Normally build simulations event-by-event
  - GLoBES produces binned spectra based on inputs by convolving all the inputs (nuclear effects included in xsec or energy smearing)
  - Allows the production of spectra without detailed simulations
  - Very fast, but at the expense of some detail
- We have detailed simulations to construct GLoBES inputs

Study Parameters: Basics

- Beams:
  - Reference beam
  - Current "best" beam
  - Expected optimization
  - Perfect focusing

  (Reference beam, Current "best" beam, Expected optimization, Perfect focusing:) See Beam Talk

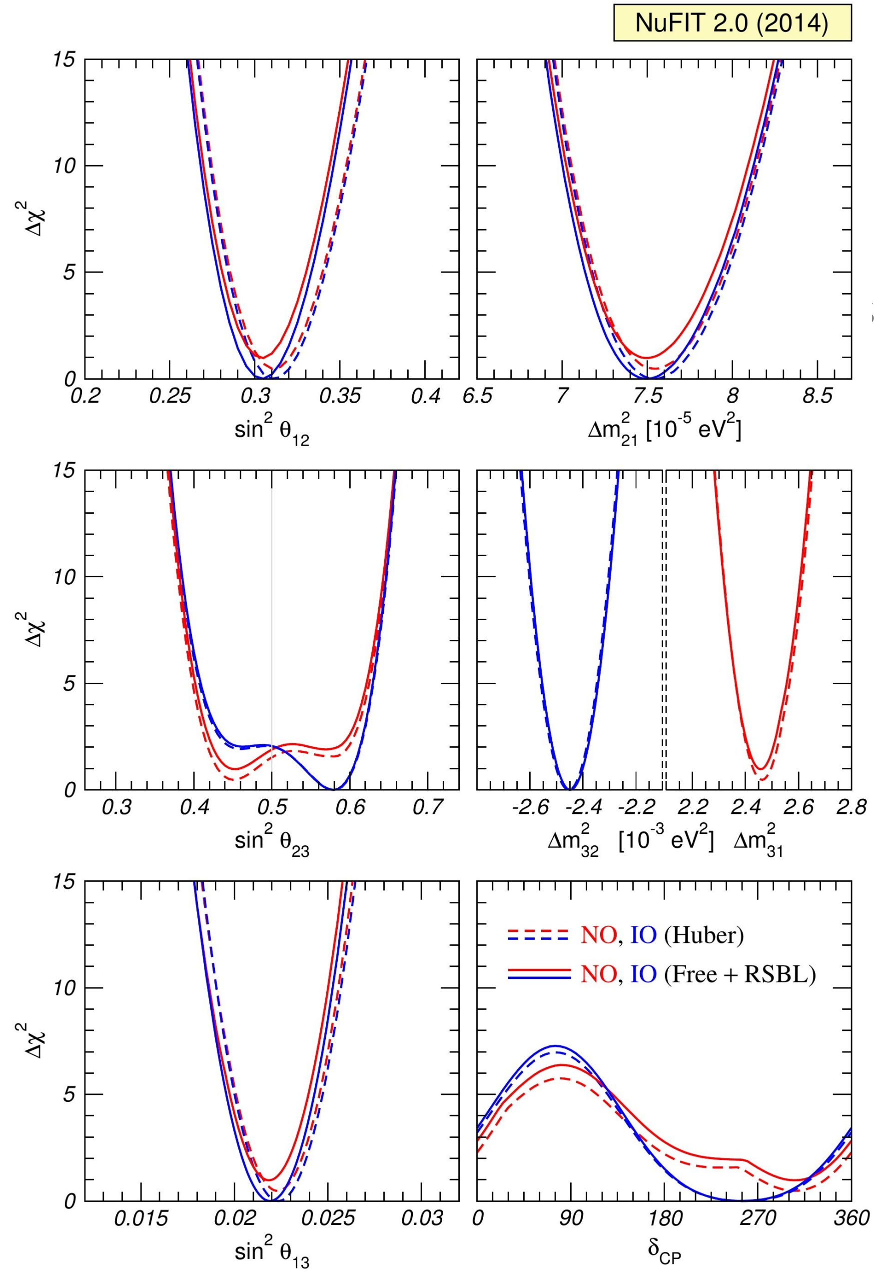
  - Power and POT (needed for GLoBES)

	MI prot/pulse	Energy	Cycle time	Beam power (MW)	Uptime&efficiency		pot/year
	7.50E+13	120	1.2	1.20E+00	0.56		1.10E+21
	7.50E+13	80	0.9	1.07E+00	0.56		1.47E+21
	7.50E+13	60	0.7	1.03E+00	0.56		1.89E+21

- The units: apply (@norm) factor of 1.017718×10^{17} to get the right units
- FD Mass: 40 kt
- Exposure: 6yrs ($3\nu/3\bar{\nu}$; ~300 ktMWyr) or 12yrs ($6\nu/6\bar{\nu}$; ~600 ktMWyr)
- Energy ranges: $0.5 < E_\nu^{reco} < 20$ GeV; $0 < E_\nu^{true} < 120$ GeV

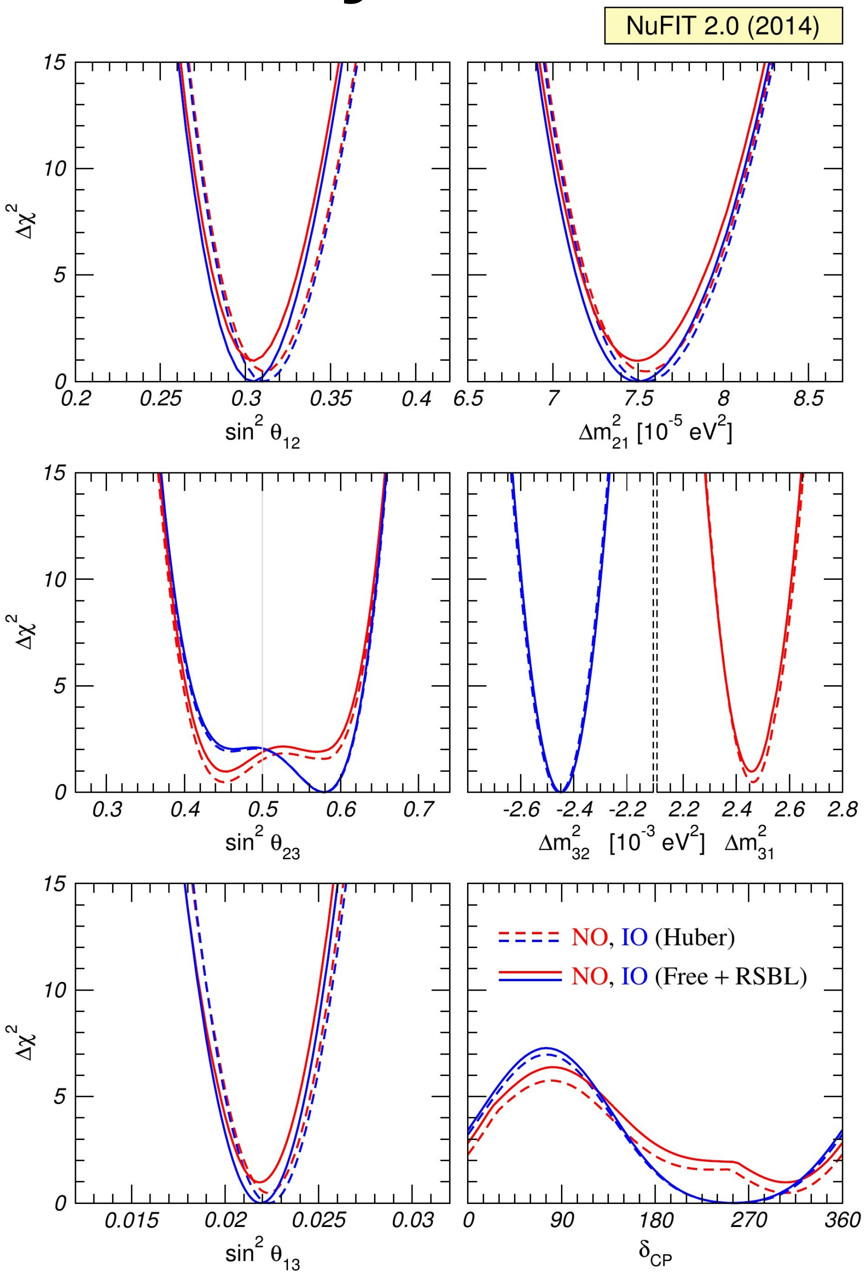
Study Parameters: Oscillations

- Nominal oscillation parameter values:
  - NuFit 2014 numbers http://www.nu-fit.org/?q=node/92
  - δ_{cp} = 0.0
  - θ_{12} = 0.5843
  - θ_{23} = 0.738 (0.864 IH)
  - θ_{13} = 0.148
  - $\Delta m_{21} = 7.5\mathrm{x}10^{-5}$
  - $\Delta m_{21} = 2.457\mathrm{x}10^{-3}$
    ($-2.449\mathrm{x}10^{-3}$ IH)



<u>Note</u>: Same inputs as the LOI

Study Parameters: Oscillations



- Oscillation parameter uncertainties:
  - Assume gaussian uncertainties
  - Define 1σ range as 1/3rd of the 3σ range
  - No prior on δ_{cp}
  - $\delta\theta_{12}$ = 2.3%
  - $\delta\theta_{23}$ = 5.9% (4.9% IH)
  - $\delta\theta_{13}$ = 2.5%
  - $\delta\Delta m_{21}$ = 2.4%
  - $\delta\Delta m_{21}$ = 2.0% (1.9% IH)

Highly Asymmetric

Study Parameters: Non-Oscillation Systematics

- FHC/RHC $\nu_\mu/\bar{\nu}_\mu$ Disappearance
  - Signal $\nu_\mu + \bar{\nu}_\mu$: 5%
  - Background NC: 10%
  - Background $\nu_\tau/\bar{\nu}_\tau$: 20%
- FHC/RHC $\nu_e/\bar{\nu}_e$ Appearance
  - Signal $\nu_e + \bar{\nu}_e$: 2%
  - Background $\nu_e + \bar{\nu}_e$: 5%
  - Background NC + $\nu_\mu + \bar{\nu}_\mu$: 5%
  - Background $\nu_\tau/\bar{\nu}_\tau$: 20%
- Consider FHC and RHC beams separately

* See the LBNE SciOp for more details

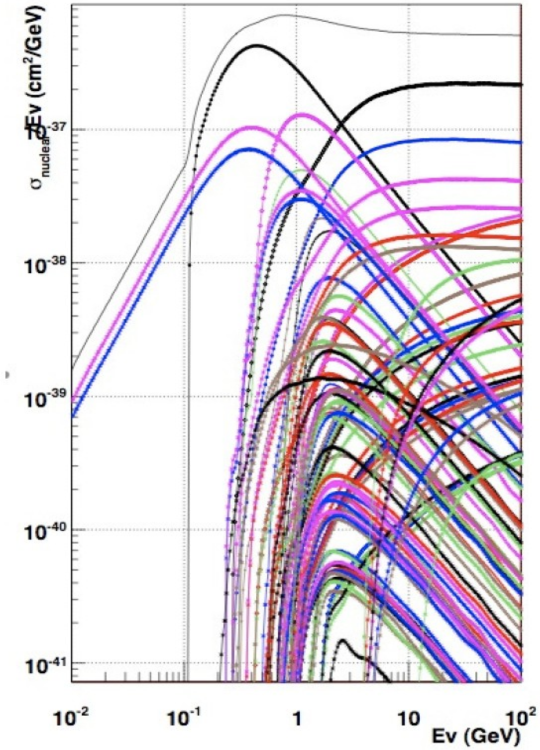
- Justifications
  - Flux known to ~5%; $\nu_\mu/\bar{\nu}_\mu$ constrains $\nu_e/\bar{\nu}_e$
  - Assume FHC and RHC are uncorrelated
  - Additional 2% on ν_e signal for $E(\sigma(\nu_e)/\sigma(\nu_\mu))$
  - Large uncertainty on $\sigma(\nu_\tau)/\sigma(\nu_\mu)$
  - Uncertainty on $\pi^\pm/\pi^0$ production for NC-like backgrounds
- Correlations
  - Signal norm. params. for each sample **UNcorrelated** (4 total)
  - NC correlated for FHC+RHC $\nu_\mu/\bar{\nu}_\mu$ dis.
  - NC + $\nu_\mu + \bar{\nu}_\mu$ corr. for FHC+RHC $\nu_e/\bar{\nu}_e$ app.
  - ν_τ production correlated across all samples
  - Beam in FHC and RHC ν_e uncorrelated

Study Parameters: Variations

- Beams
  - Variations in beam design
  - See talk from the beam group
- Run Plan
  - Detector construction schedule
  - Beam upgrades
  - $\nu/\bar{\nu}$ run ratio
- Oscillation parameter assumptions
  - Future uncertainties estimates
  - Mass Hierarchy
  - θ_{23} Octant
- Changes to oscillation parameter central values for: θ_{13}, θ_{23}, Δm^2_{31}
- Non-oscillation systematics
  - Altered normalization priors
  - Shape systematics
  - Detailed systematics
    - Fast MC + MGT
    - GENIE cross section reweights
    - Beam optics
  - A lot more to do, but not on CD1r timescales

GLoBES Inputs:
Flux and Cross Sections

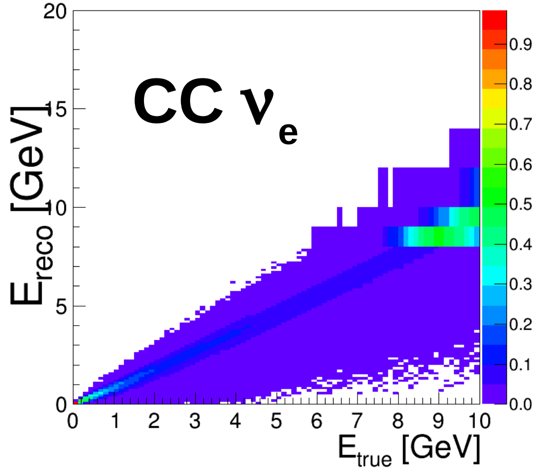
- Nominal Flux
  - 80 GeV protons
  - 204m x 4m He filled decay pipe
  - 230kA horn current
  - 1.07 MW
  - 1.47×10^{21} POT/yr
  - Be target, -45 cm from horn 1
- Multiple alternate fluxes
  - Will have the 4 flux options implemented
  - Easy to add new ones
- Cross sections
  - GENIE 2.8.4
  - Inclusive CC and NC
  - ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$, ν_τ, and $\bar{\nu}_\tau$

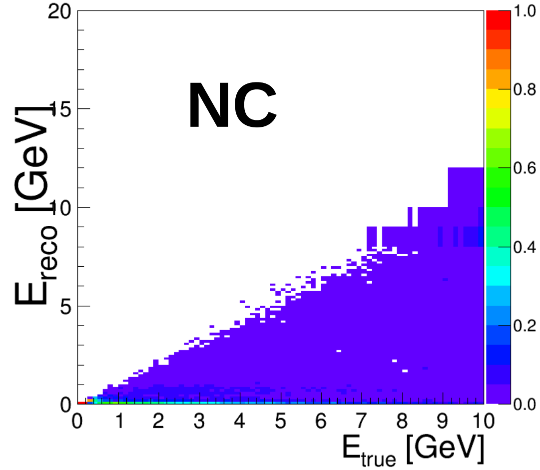


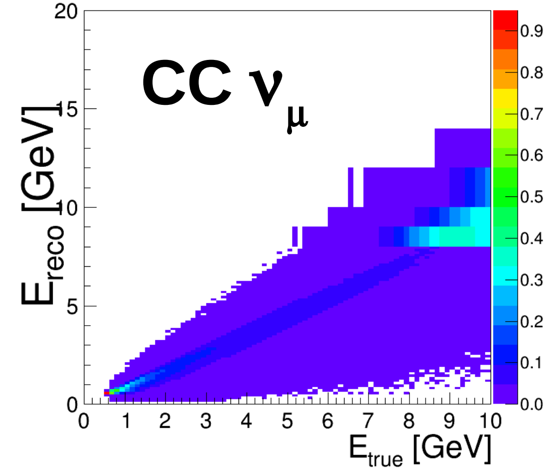
GENIE Cross Sections

GLoBES Inputs:
Energy Smearing ($E_\nu^{true} \rightarrow E_\nu^{reco}$)

- Generated using the Fast MC
- Plots E_ν^{reco} vs E_ν^{true} and normalize bins of E_ν^{true}

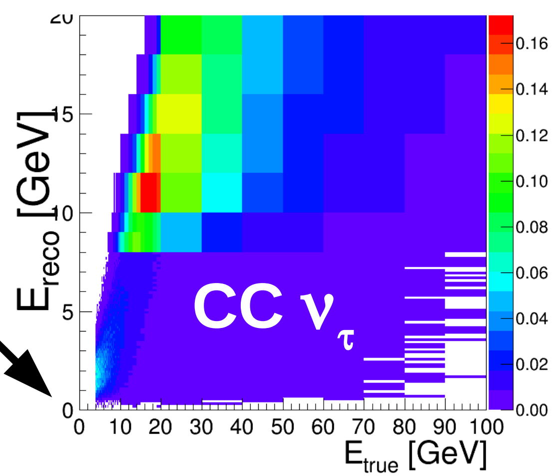




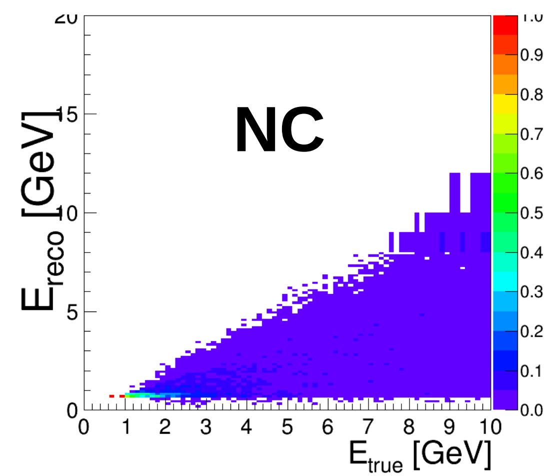


ν_e Appearance

- One for each ν flavor
- Smears using $0 < \mathbf{E_\nu^{true}} < 100$ GeV
- Built from selected events



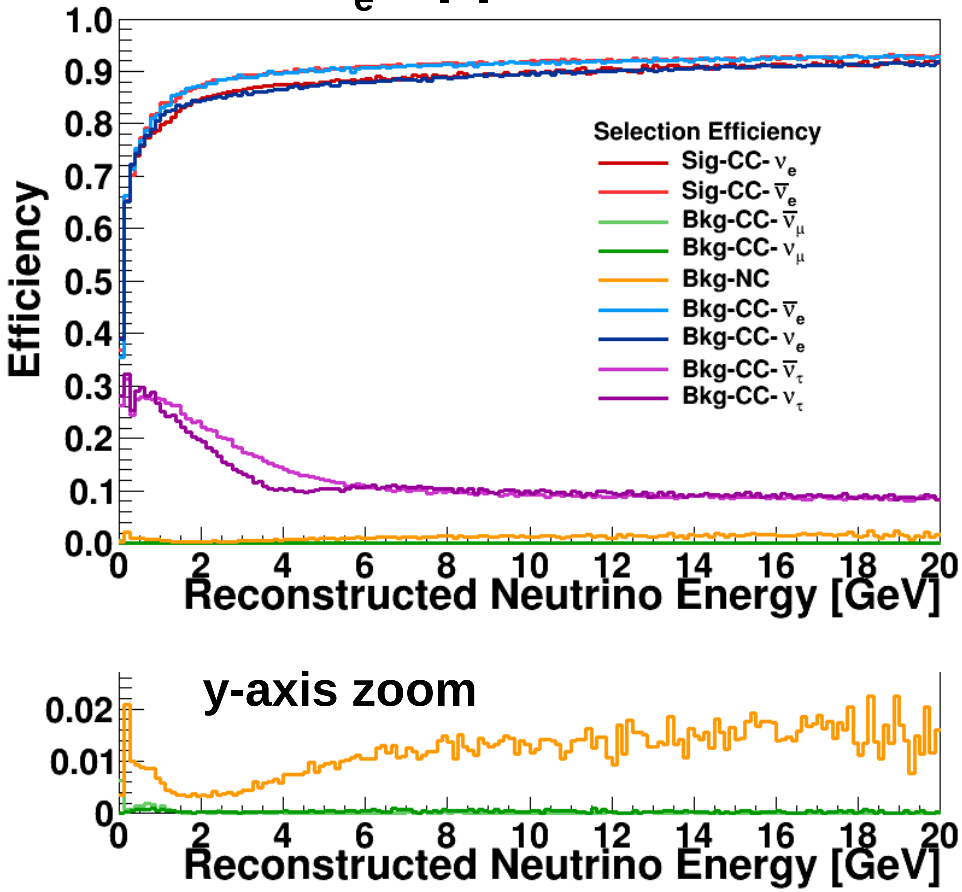
ν_μ Disappearance



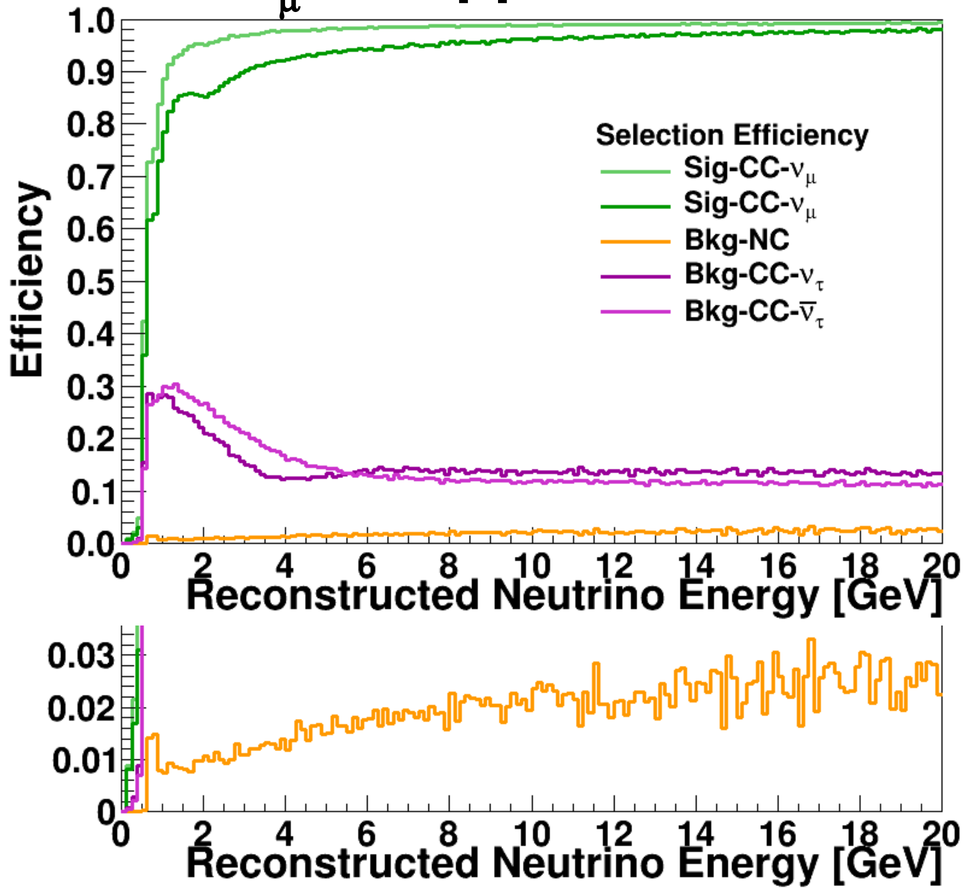
GLoBES Inputs: Efficiencies

- Generated using the Fast MC
- Ratio: (Fact MC selected events) / (total events)

ν_e Appearance



ν_μ Disappearance

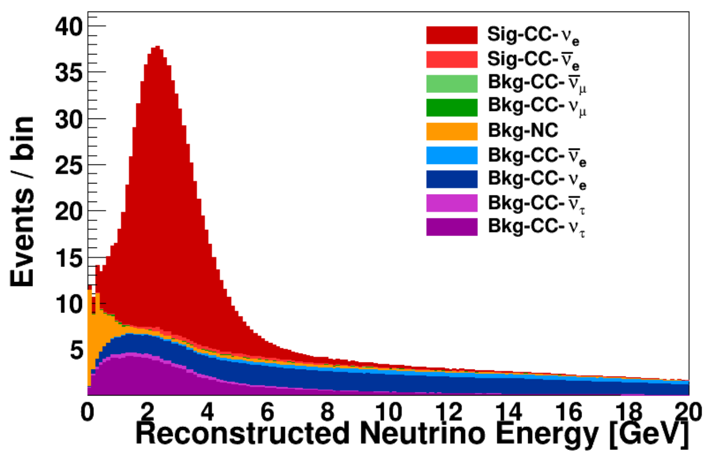


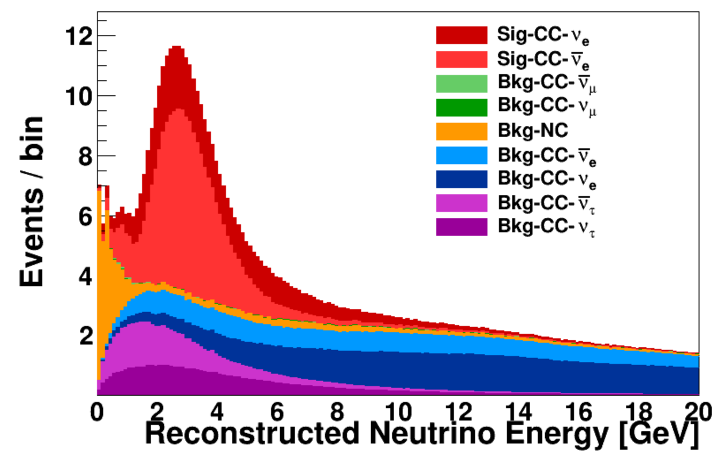
GLoBES Inputs:
Efficiencies – We Can Do Better!

Use transverse momentum cuts (kNN based discriminant)

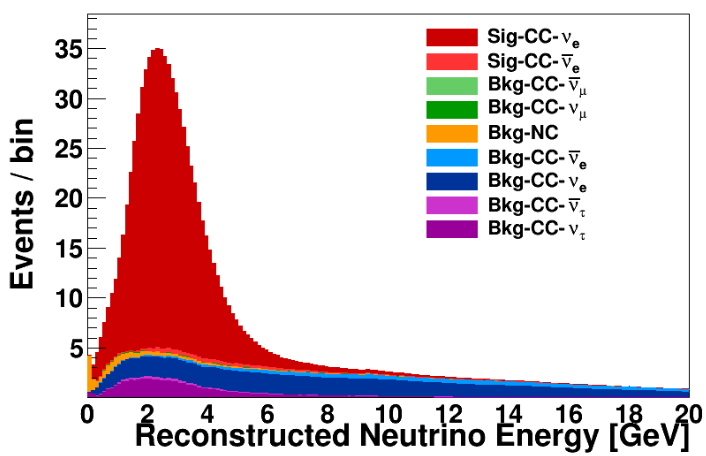
ν_e Appearance **$\bar{\nu}_e$ Appearance**

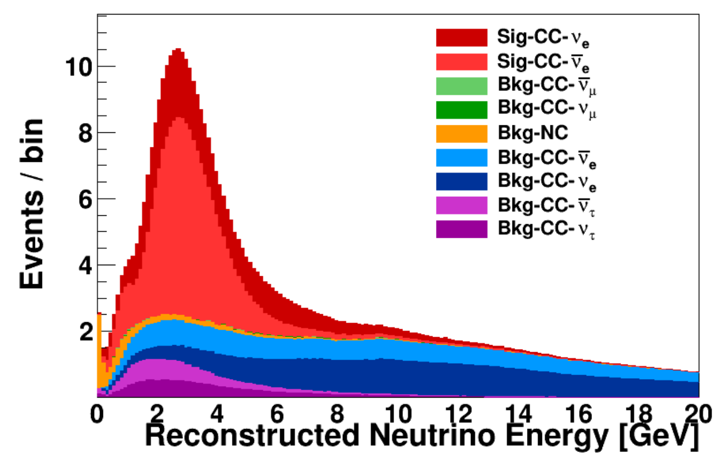
No Cuts





Both Cuts (NC and ν_τ)

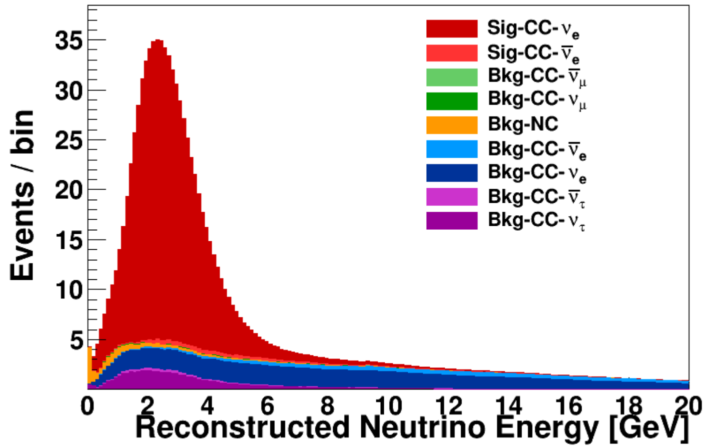


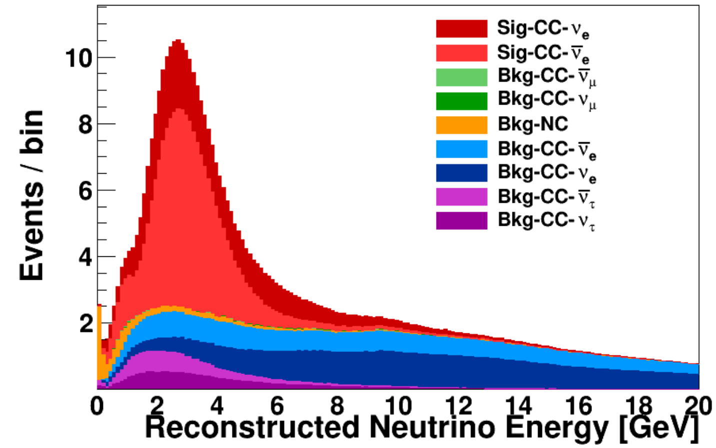


Energy Spectra Comparisons

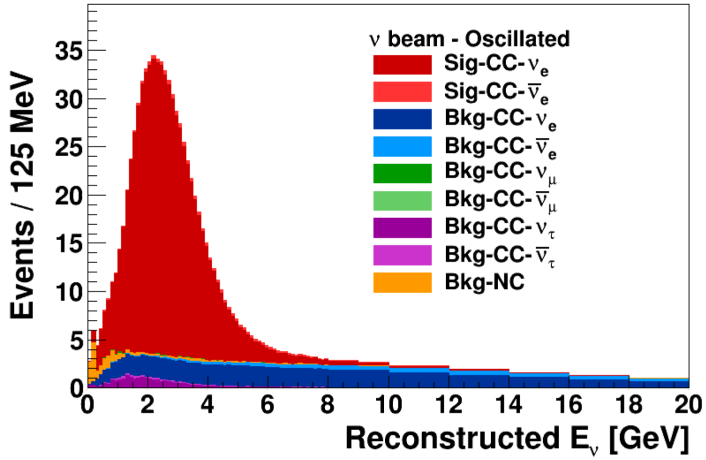
ν_e Appearance | $\bar{\nu}_e$ Appearance

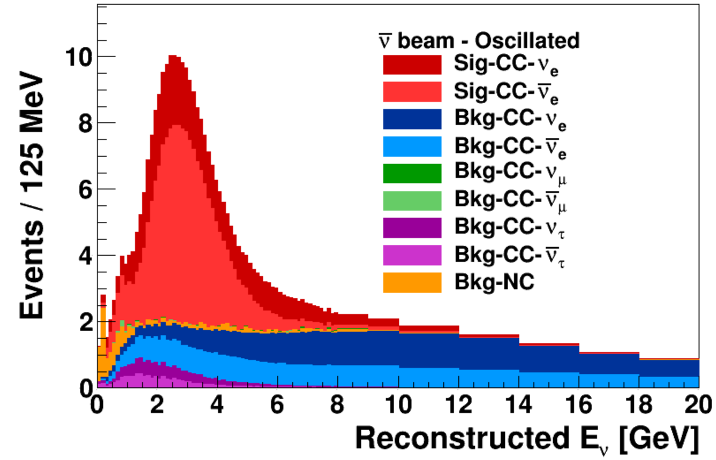
Fast MC





GLoBES





Notes: Different fluxes, and different oscillation parameters

How to Use this GLoBES Setup

- There is a tarball of all the required files on docdb
  - Must be used from the /lbne/app/ area at FNAL
  - GLoBES config uses relative paths for inputs
  - Some included (.inc) files have absolute paths set for certain inputs
- Copy default GLoBES configuration and change:
  - Fluxes
  - Efficiencies (w/ and w/o transverse momentum cuts)
  - Oscillation parameter central values and uncertainties
  - Non-oscillation systematic uncertainties
  - Run plan (run time, $\nu/\bar{\nu}$ ratio, detector mass)

Thinking Forward

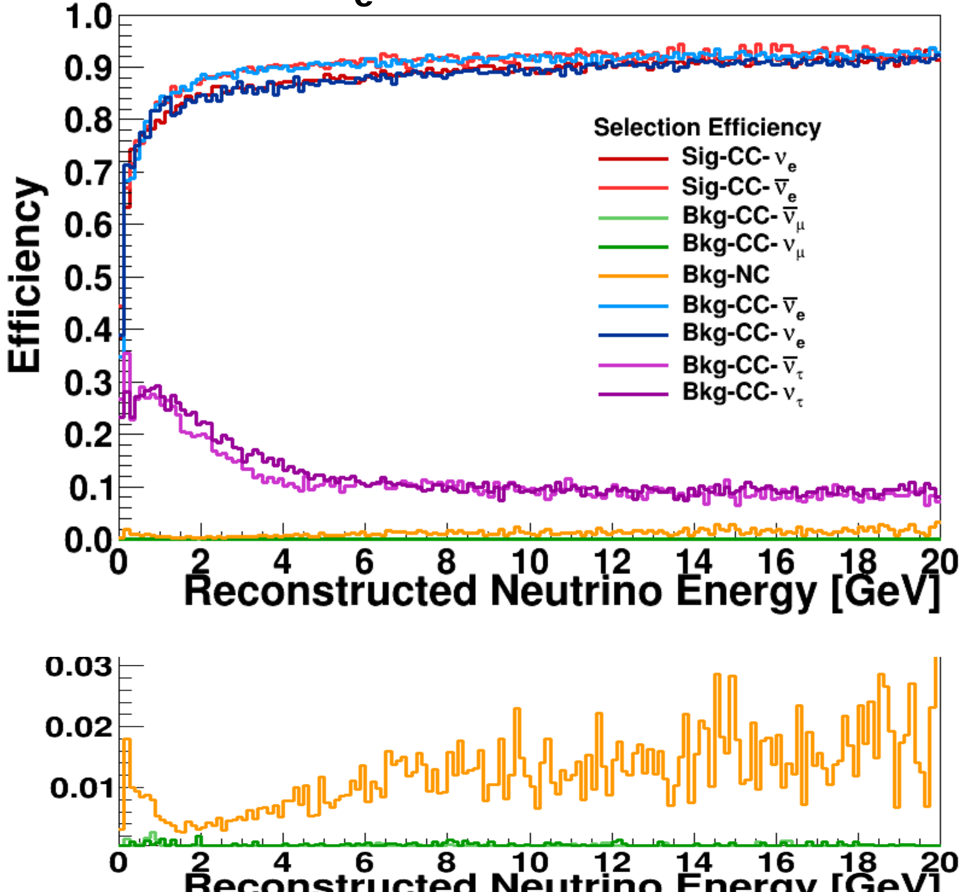
- Since we have detailed inputs, can we move beyond GLoBES?
  - Yes, but it will take some work
  - More study variations
  - Inclusion of detailed non-oscillation systematics
  - Use of oscillation parameter $\Delta\chi^2$ priors
- See talk in the Systematics Session for more details

Backup Slides

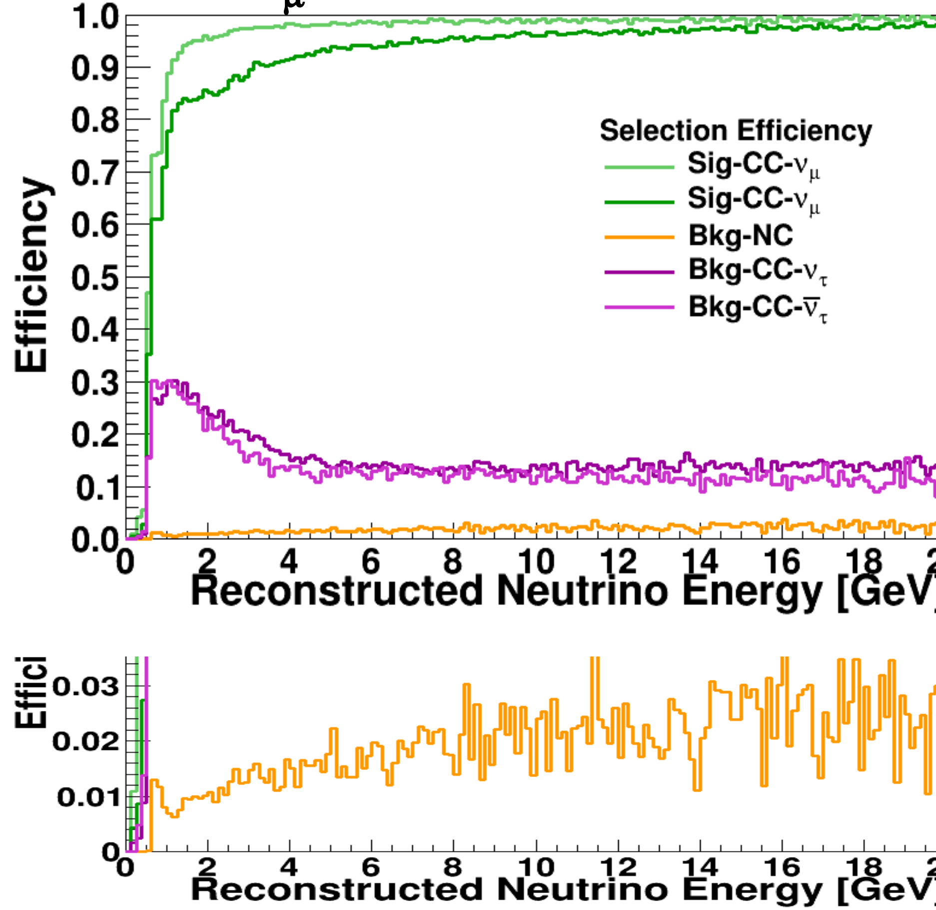
GLoBES Inputs: Efficiencies

- Generated using the Fast MC
- Ratio: (Fact MC selected events) / (total events)

$\bar{\nu}_e$ Appearance



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

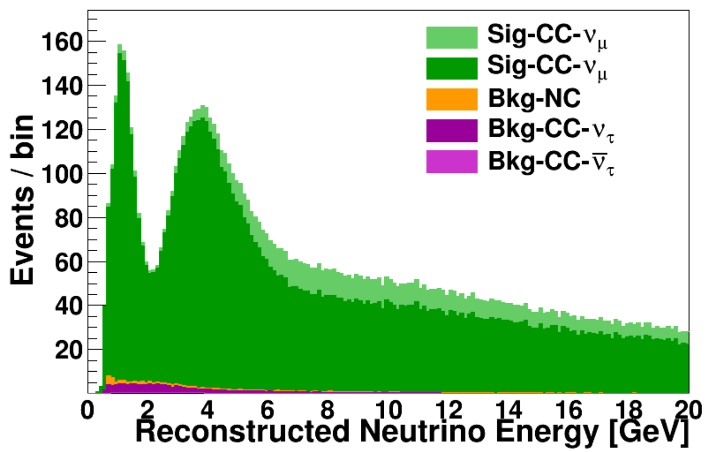


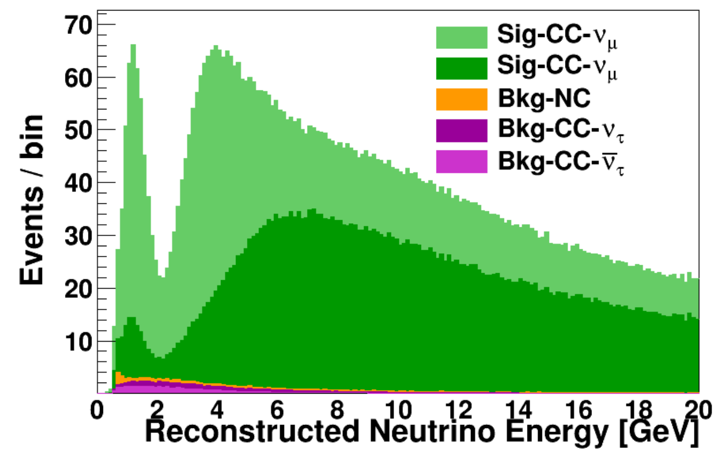
Energy Spectra Comparisons

ν_μ Disappearance

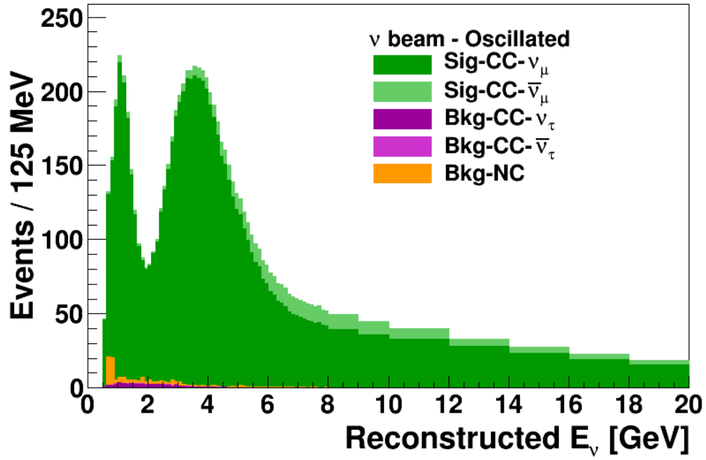
$\bar{\nu}_\mu$ Disappearance

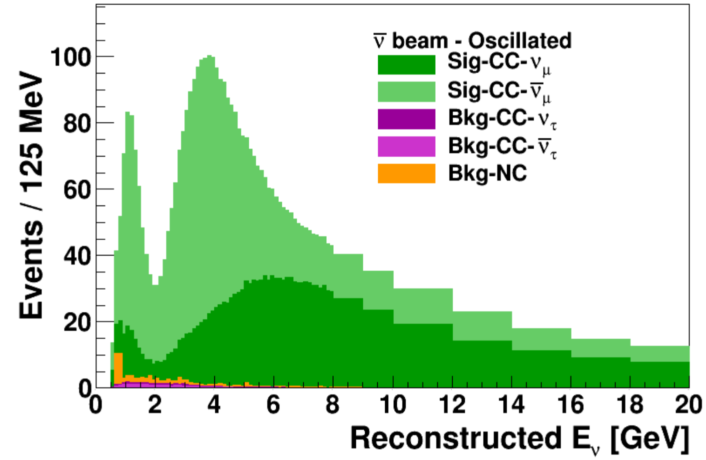
Fast MC





GLoBES





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ν_μ **Disappearance** | $\bar{\nu}_\mu$ **Disappearance**

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Both Cuts (NC and ν_τ)