# Using GLoBES for BNL very long baseline neutrino oscillation experiment

## Overview of Summer Student Project

Mark Dierckxsens

Neutrino Working Group Meeting, August 25, 2005

# Outline

# GLoBES = General Long Baseline Experiment Simulator

- Fast simulation package for long baseline and reactor experiments
- Developed by P. Huber, M. Lindner, W. Winter from *Technische Universität München*
- Package consists of two parts:
  1. abstract experiment definition language
  2. set of C-libraries
- Download it from: `http://www.ph.tum.de/~globes`

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- a rule consists of signal and background, made up of one or more "channels". Also include efficiencies and normalization and shape systematic errors.
- a channel is the mapping between a specific neutrino flavor produced onto a reconstructed flavor (i.e. a certain physics process)
- predicts the relevant flux at a certain distance after oscillations, calculating matter densities, getting event rates through cross sections, applying efficiencies and energy smearing.

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- Some limitations:
  - Neutrino sources with geometrical (sun, atmospheric) or strong time dependencies (supernovae) can not be described.
  - Does not generate events

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- standard functions to calculate $\chi^2$:
  - add parameter (and $\rho$) uncertainties through penalty terms to $\chi^2$
  - $\chi^2$ without correlations for a certain set of parameters
  - $\chi^2$ with correlations: projections onto n-parameter space using local minimizer in full parameter space.
  - minimizer (local) in full parameter space.

1. Introduction
2. VLBNO inputs
   - Producing inputs & summer student project
   - Neutrino Fluxes
   - Cross Sections
   - Energy Smearing
3. VLBNO results
4. Reactor Experiment
5. Outlook & Conclusions

# VLBNO inputs & Summer Student Project

- Producing VLBNO inputs:
  - Milind was in contact with Partick Huber over the last few months
  - Milind send flux and reconstructed spectra to Patrick
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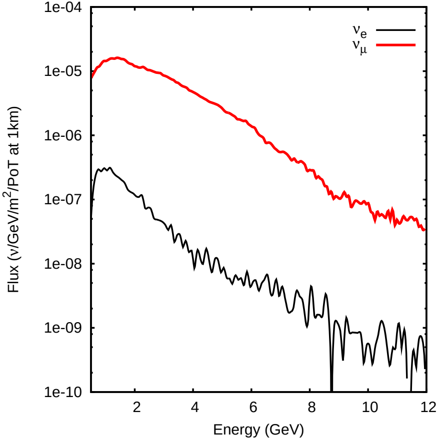
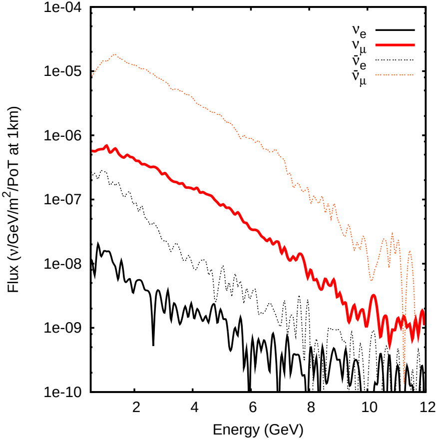
- Overview of Summer Student Project
  - Project: Get acquainted with GLoBES and reproduce results.
  - Student: Christine Lewis from Columbia University.
  - Most of the plots shown here are made by Christine
  - Her summer research paper can be found at: `http://nwg.phy.bnl.gov/papers/clewis.ps`

# Input fluxes for $\nu$ and $\bar{\nu}$ running

## Neutrino running

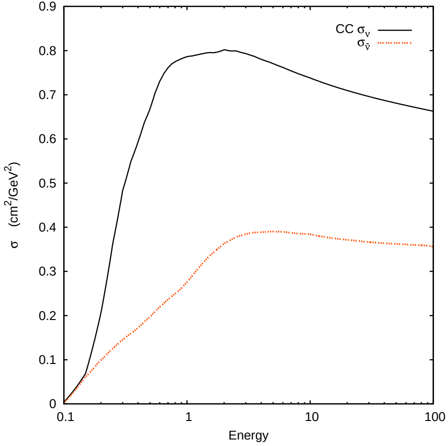



## Anti-neutrino running

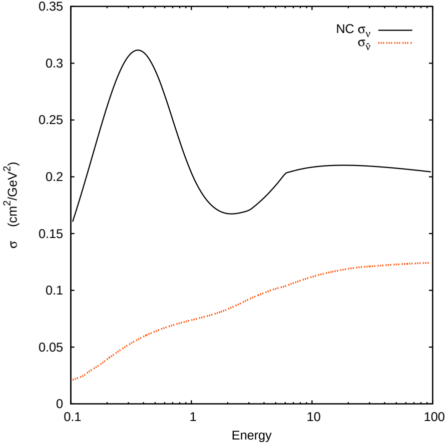


# Input Cross Section Files

CC x-section $\frac{1}{E}\frac{\mathrm{d}\sigma}{\mathrm{d}E}$

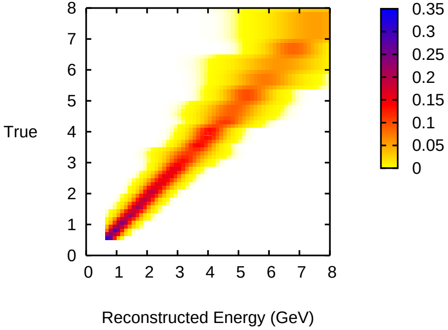



NC x-section $\frac{1}{E}\frac{\mathrm{d}\sigma}{\mathrm{d}E}$

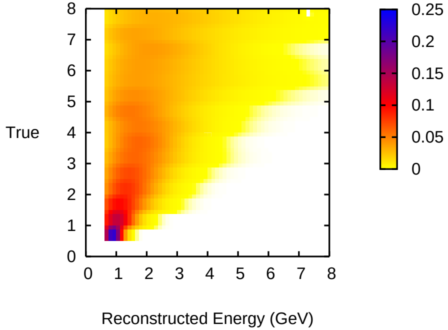


# Energy Smearing Input Files

$\nu_e n \longrightarrow e^- p$ (CC QE)




$\nu_\mu N \longrightarrow \nu_\mu N \pi^0$ (NC PI)



# $\nu_\mu$ disappearance spectra

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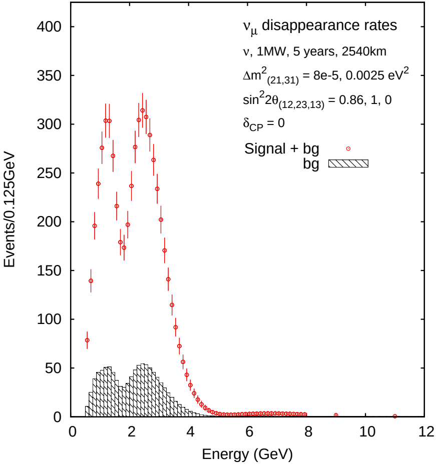


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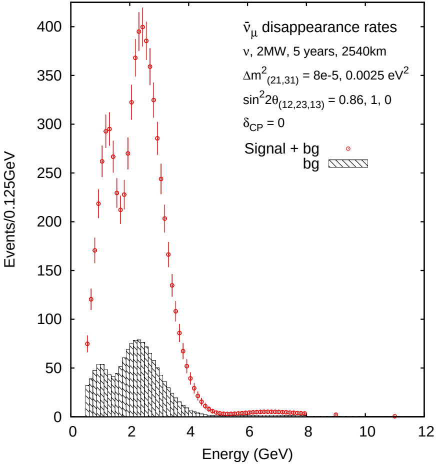
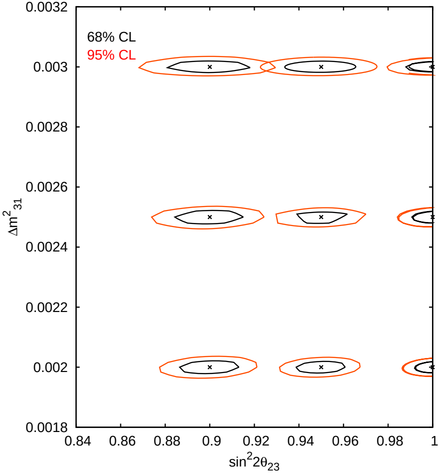


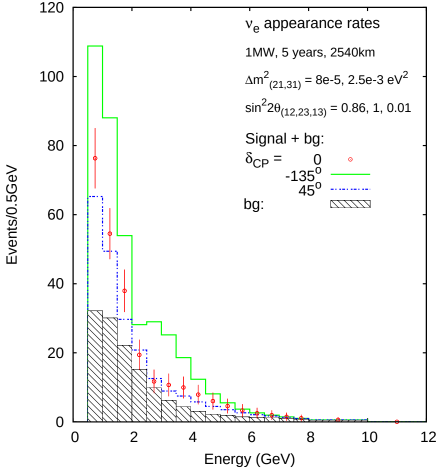
# $\nu_\mu$ disappearance measurements

- varied $\Delta m^2_{31}$ and $\sin^2 2\theta_{23}$.
- for the other parameters:
  - $\Delta m^2_{21} = 8.0 \pm 0.4\ 10^{-5}\ \mathrm{eV}^2$
  - $\sin^2 2\theta_{12} = 0.86 \pm 0.07$
  - 10% background error
  - matter density: average PREM model $\pm 5\%$
  - $\sin^2 2\theta_{13} = 0$ & $\delta_{CP} = 0$



# $\nu_e$ appearance spectra

## Neutrino running

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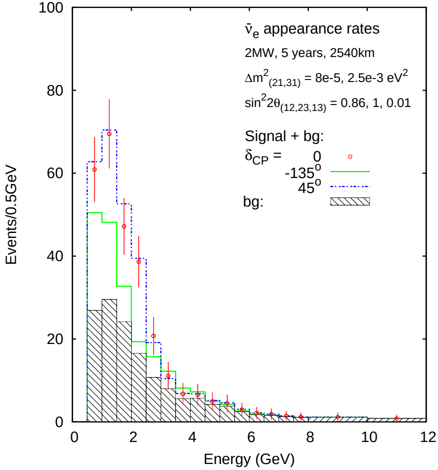

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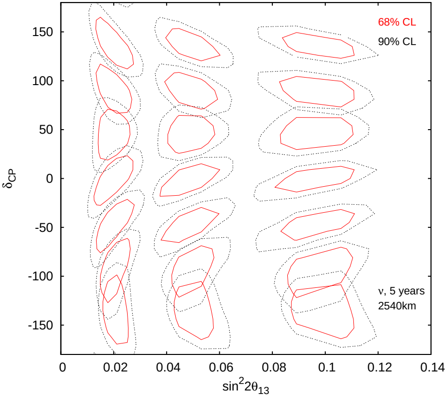
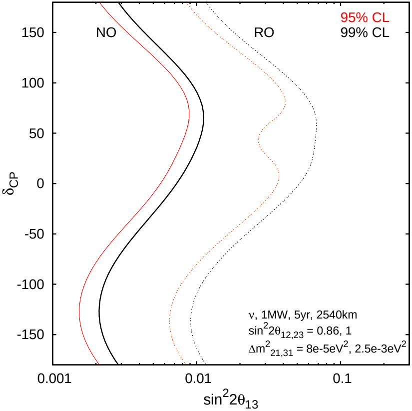
  - matter density: average PREM model $\pm 5\%$
  - GLoBES fits app. and disapp spectra simultaneous: errors on $\Delta m^2_{31}$ and $\sin^2 2\theta_{23}$ from VLBNO



# $\nu_e$ exclusion limits - I

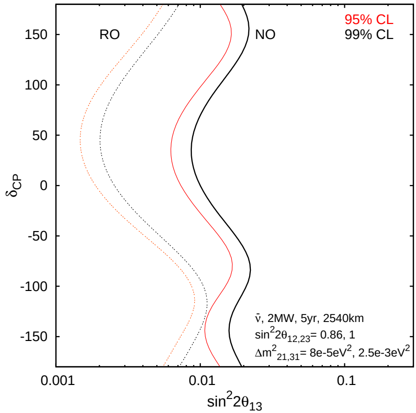
- the value of $\sin^2 2\theta_{13}$ that can be excluded up to a certain CL in the case $\theta_{13} = 0^\circ$ for different values of $\delta_{CP}$.
- errors on other parameters same as before

Neutrino Running

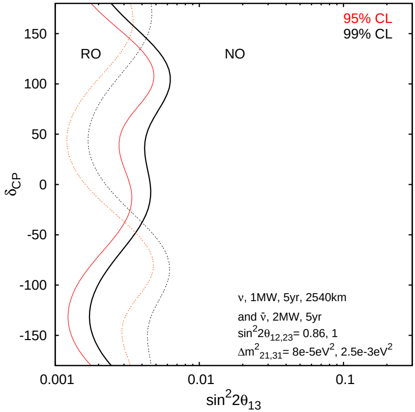


# $\nu_e$ exclusion limits - II

## Anti-neutrino running




## Neutrino & Anti-neutrino Combined



# Sensitivity to the mass hierarchy

- Disclaimer: this is not the correct way to do this!
- it is similar to what Raj Gandhi does
- it is fast to calculate

$$\begin{aligned} \sigma_\pm &= \sqrt{sig_\pm + bg_\pm} \\ s &= \frac{|sig_+ - sig_-|}{\sqrt{\sigma_+^2 + \sigma_-^2}} \end{aligned}$$

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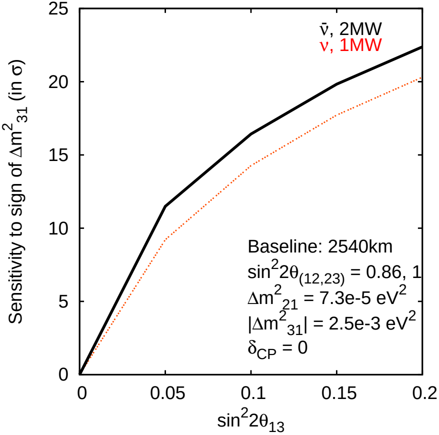
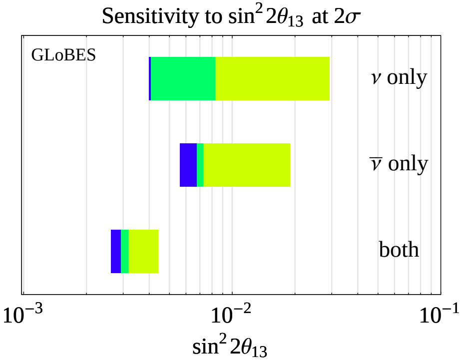


# Some plots made by Patrick Huber

- blue: systematics only
- green: including correlations
- yellow: including degeneracies



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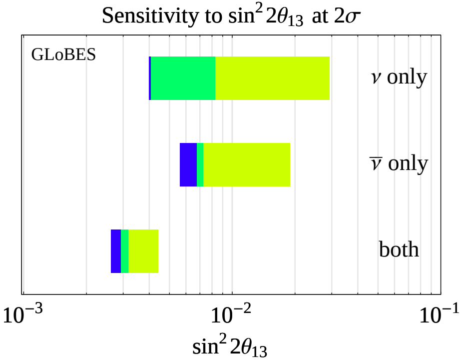
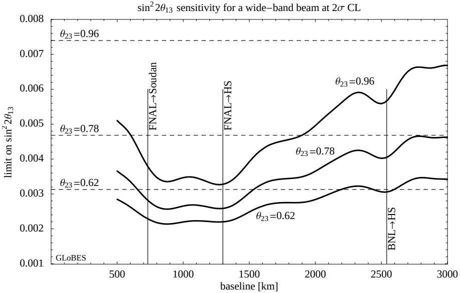



- sensitivity to $\sin^2 2\theta_{13}$ as function of baseline
- dashed line is T2HK



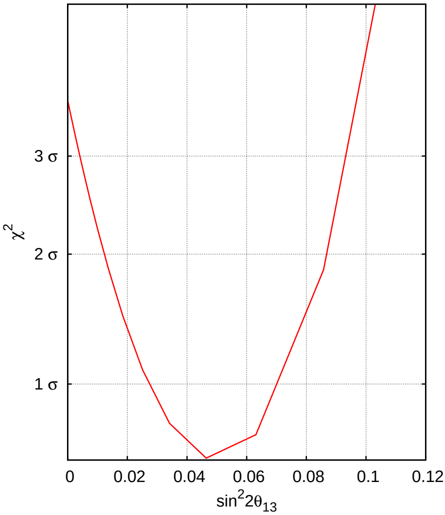
# Measurement of $\sin^2 2\theta_{13}$ with a reactor experiment

Reactor example in GLoBES used :

- power = 4 GW
- baseline = 1.7km
- detector mass = 20t
- 5 years running

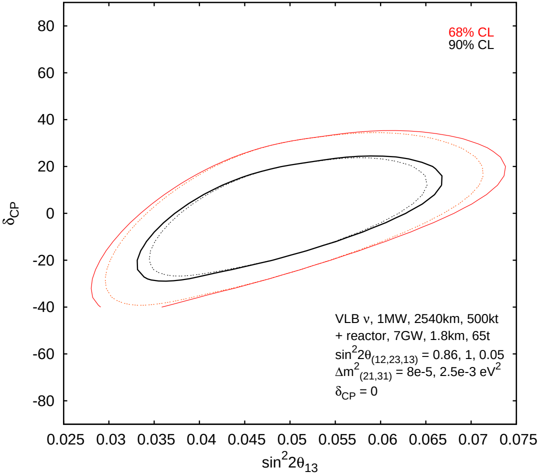
Errors on input parameters :

- $\Delta m^2_{21} = 8.0 \pm 0.4\ 10^{-5}\ \mathrm{eV}^2$
- $\sin^2 2\theta_{12} = 0.86 \pm 0.07$
- $\Delta m^2_{31} = 2.5 \pm 0.3\ 10^{-3}\ \mathrm{eV}^2$
- $\sin^2 2\theta_{23} = 0.86 \pm 0.13$
- no matter effects
- $\sin^2 2\theta_{13} = 0.05$



# Combination of reactor and VLBNO experiments

- reactor: same as previous slide
- VLBNO: 1 year neutrino running
- input errors are same as before



# Plans for the near term future

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- Patrick Huber will visit week of Sept 12
- Write a paper with results using GLoBES (e.g. baseline dependency)
- Make VLBNO inputs publicly available

# Plans for the longer term future

- small request in detector R&D for GLoBES development
- 0.25 FTE first year for putting everything in place
- 0.1 FTE thereafter for maintaining input files (e.g. including improvements from Chiaki Yanagisawa and full UNO reconstruction, other detector setups, etc.)
- some money for expanding our current cluster with a few additional nodes.

# Conclusions

- GLoBES package is a very useful tool for neutrino oscillation experiments
- Easy to change input parameters
- Allow for a "fair" comparison between and combination among experiments
- It is a popular tool and many experiments have input files available
- We are working together with Patrick Huber to make files for VLBNO experiment publicly available
- Christine Lewis, our summer student was very helpful in speeding the use of GLoBES here at BNL up.