THE UNIVERSITY OF CHICAGO

Status of Short Baseline Oscillation Analysis

Joseph Zennamo

Neutrino Short Baseline Meeting

CERN

September 26, 2014

Introduction

We have recently released a detailed tech-note describing the methods that we use to compute the SBN sensitivity curves (SBN-DocDB 87)

The analysis software is flexible, and able to be quickly adapted to new inputs (such as uncertainties and backgrounds)

BUT, the sensitivity curves are only as good as the inputs used to create them

Experimental Sensitivity to Oscillations

When probing how sensitive our experiment is to oscillations we compare oscillated and null hypotheses over the phase space

This is done by building a χ^2 surface using:

$$\chi^2 = \sum_{i,j} [N_i^{null} - N_i^{osc}(\Delta m^2, \sin^2 2\theta)] \times (E_{ij}^{\text{total}})^{-1} \times [N_j^{null} - N_j^{osc}(\Delta m^2, \sin^2 2\theta)]$$

Where the two inputs to the χ^2 is the number of events in each bin and the overall uncertainties on those values

To achieve realistic sensitivities we need to include both of these contributions

Event Distributions

The number of events in each energy bin is created by carefully studying the backgrounds for each analysis:

$$N^{\mu}_{Tot} = (N^{\mu}_{intrinsic} + N^{\mu}_{cosmic} + N^{\mu}_{dirt})$$

$$N^{e}_{Tot} = (N^{e}_{intrinsic} + N^{e}_{cosmic} + N^{e}_{dirt})$$

Event Distributions

The number of events in each energy bin is created by carefully studying the backgrounds for each analysis:

$$N^{\mu}_{Tot} = (N^{\mu}_{intrinsic} + N^{\mu}_{cosmic} + \cancel{N^{\mu}_{dirt}})$$
$$N^{e}_{Tot} = (N^{e}_{intrinsic} + N^{e}_{cosmic} + N^{e}_{dirt})$$

The intrinsic backgrounds have been studied using BNB beam MC, and the cosmic and dirt backgrounds are currently being actively studied

It is important to remember that as we add backgrounds to the analyses, we will need to understand **how to build the corresponding error matrix**

Full Covariance Matrix

The total matrix is composed of many parts which are built individually:

$$E^{\text{total}} = E^{\text{stat}} + E^{\text{flux}} + E^{\text{cross section}} + E^{\text{cosmic bkgd}} + E^{\text{dirt bkgd}} + E^{\text{detector}}$$

We have already started addressing some of these components, **BUT** there exist certain matrices that are non-trivial to create:

$$E^{\text{total}} = {\color{green}E^{\text{stat}} + E^{\text{flux}}} + {\color{gold}E^{\text{cross section}}} + {\color{red}E^{\text{cosmic bkgd}} + E^{\text{dirt bkgd}} + E^{\text{detector}}}$$

As we build the backgrounds we need to simultaneously think about how to assess the uncertainties on these samples and how we can build their matrices

Matrices Construction

The methods that we have used to build the flux matrices in the past are generic and the same methods will be used to build the rest of the remaining matrices

This methodology is documented in two SBN tech-notes, DocDB #23 and 87

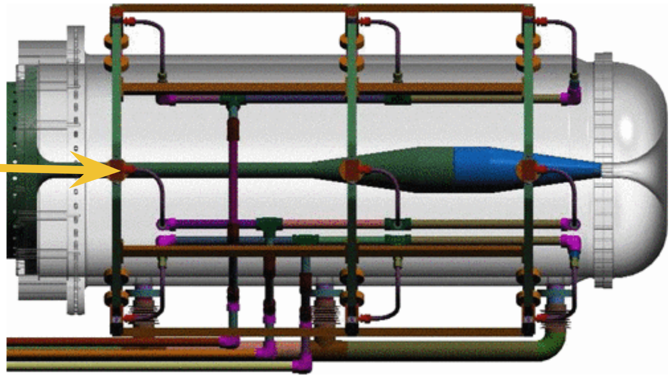
We will now go through how we construct the flux covariance matrices and how we have integrated these into the sensitivity estimates

Systematic Uncertainty: Flux

To assess the uncertainties associated with the neutrino flux we leverage work that has already been done by the MiniBooNE collaboration

The uncertainties that we take into account:

- p+Be→π^+ production
- p+Be→π^- production
- p+Be→K^+ production
- p+Be→K^- production
- p+Be→K^0 production
- Beam focusing
- Secondary interactions
- Non-target hadron production

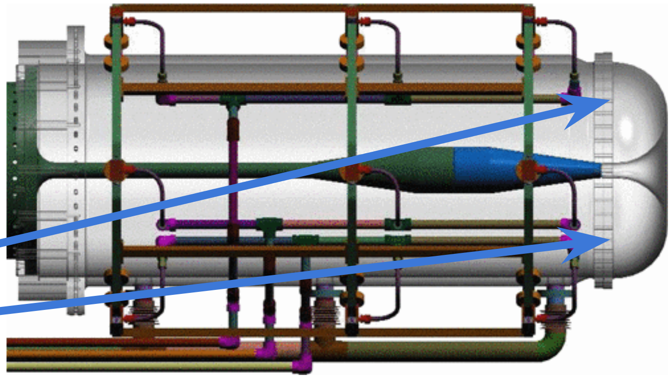


Systematic Uncertainty: Flux

To assess the uncertainties associated with the neutrino flux we leverage work that has already been done by the MiniBooNE collaboration

The uncertainties that we take into account:

- p+Be→π^+ production
- p+Be→π^- production
- p+Be→K^+ production
- p+Be→K^- production
- p+Be→K^0 production
- Beam focusing
- Secondary interactions
- Non-target hadron production

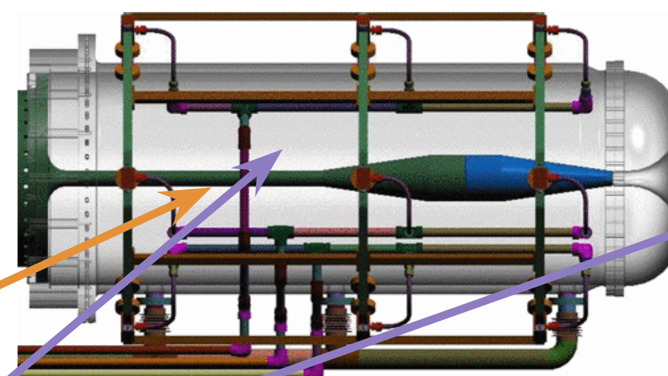


Systematic Uncertainty: Flux

To assess the uncertainties associated with the neutrino flux we leverage work that has already been done by the MiniBooNE collaboration

The uncertainties that we take into account:

- $p+Be \rightarrow \pi^+$ production
- $p+Be \rightarrow \pi^-$ production
- $p+Be \rightarrow K^+$ production
- $p+Be \rightarrow K^-$ production
- $p+Be \rightarrow K^0$ production
- Beam focusing
- Secondary interactions
- Non-target hadron production



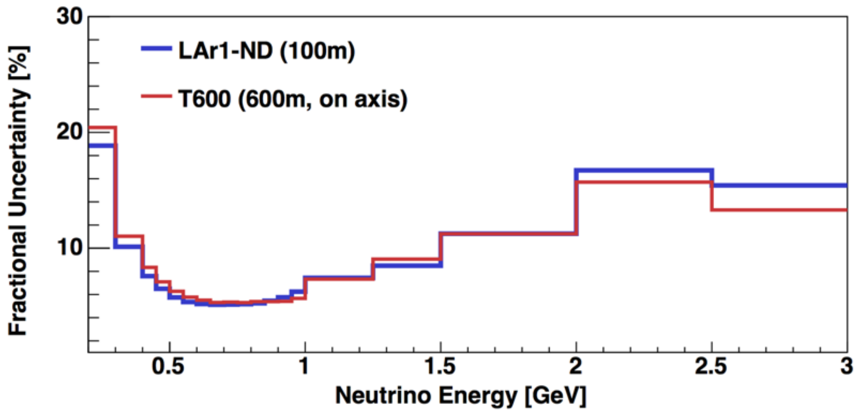
Systematic Uncertainty: Flux

To assess the uncertainties associated with the neutrino flux we leverage work that has already been done by the MiniBooNE collaboration

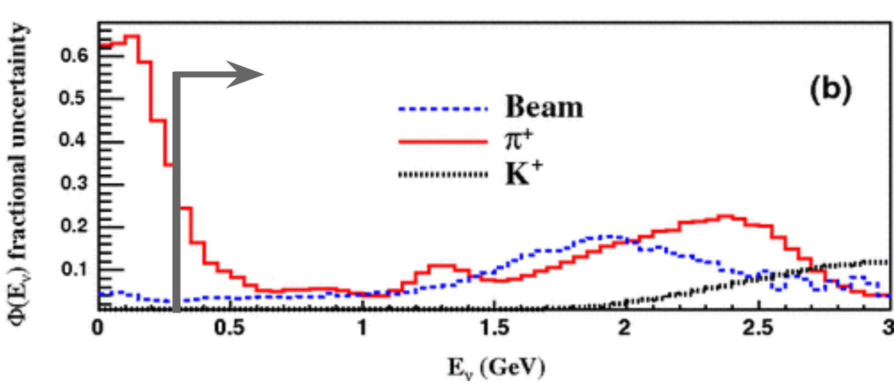
The uncertainties that we take into account:

- p+Be→π⁺ production
- p+Be→π⁻ production
- p+Be→K⁺ production
- p+Be→K⁻ production
- p+Be→K⁰ production
- Beam focusing
- Secondary interactions
- Non-target hadron production

Flux Uncertainty Estimates



Published MiniBooNE Flux Uncertainty



Flux Covariance Matrix

To build a full covariance matrix we will address each systematic uncertainty by comparing how these will change the distribution of events from the nominal distribution

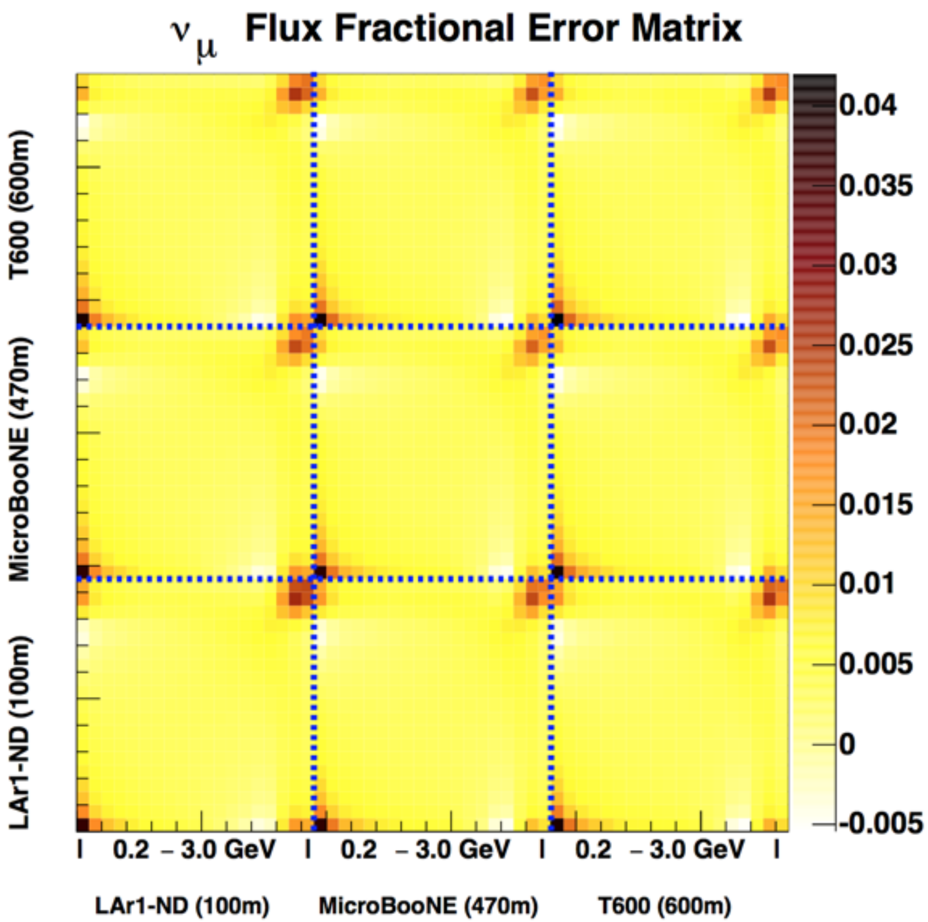
This comparison is turned into a covariance matrix by using:

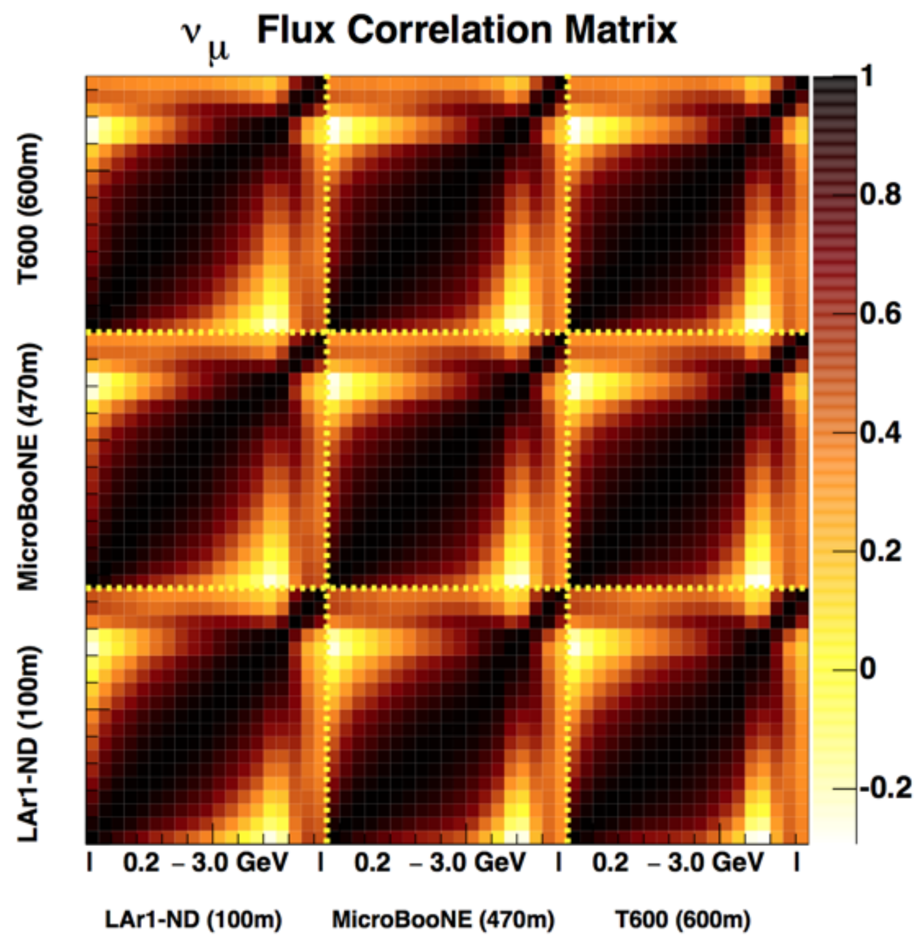
$$E_{i,j} = \frac{1}{\mathcal{N}} \sum_{m=1}^{\mathcal{N}} [N_{\mathrm{CV}}^{i} - N_{m}^{i}] \times [N_{\mathrm{CV}}^{j} - N_{m}^{j}]$$

Where the covariance matrix is binned in terms of detector-energy bins, such that we know the detector-to-detector and bin-to-bin correlations

Muon Disappearance Covariance Matrix

In the muon disappearance analysis this matrix shows a very high level of correlation from detector to detector



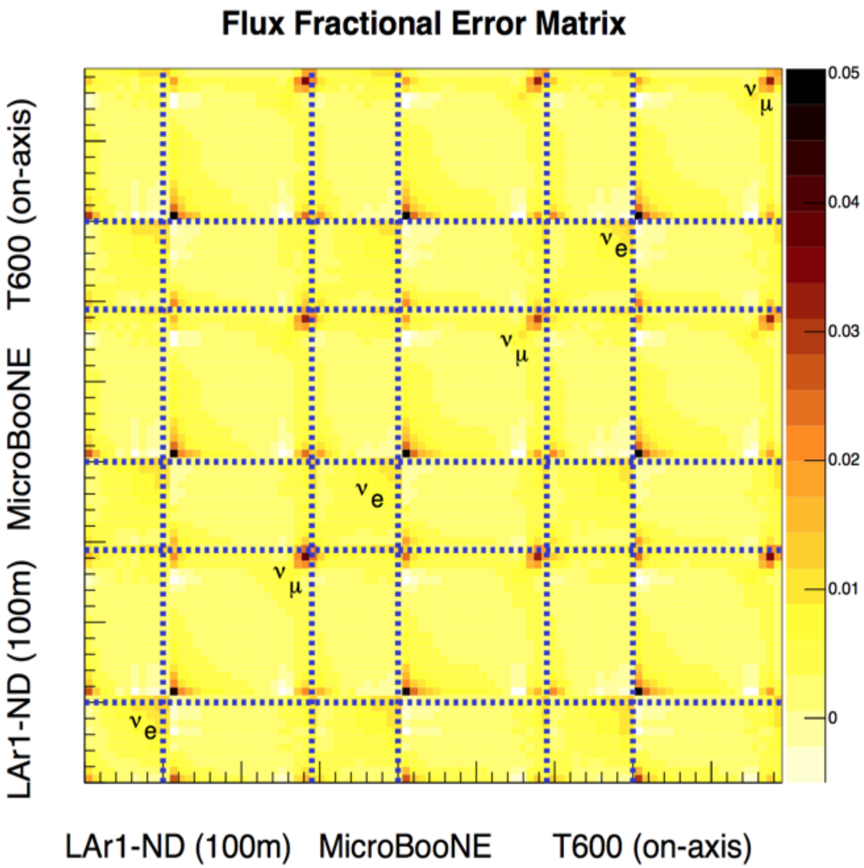


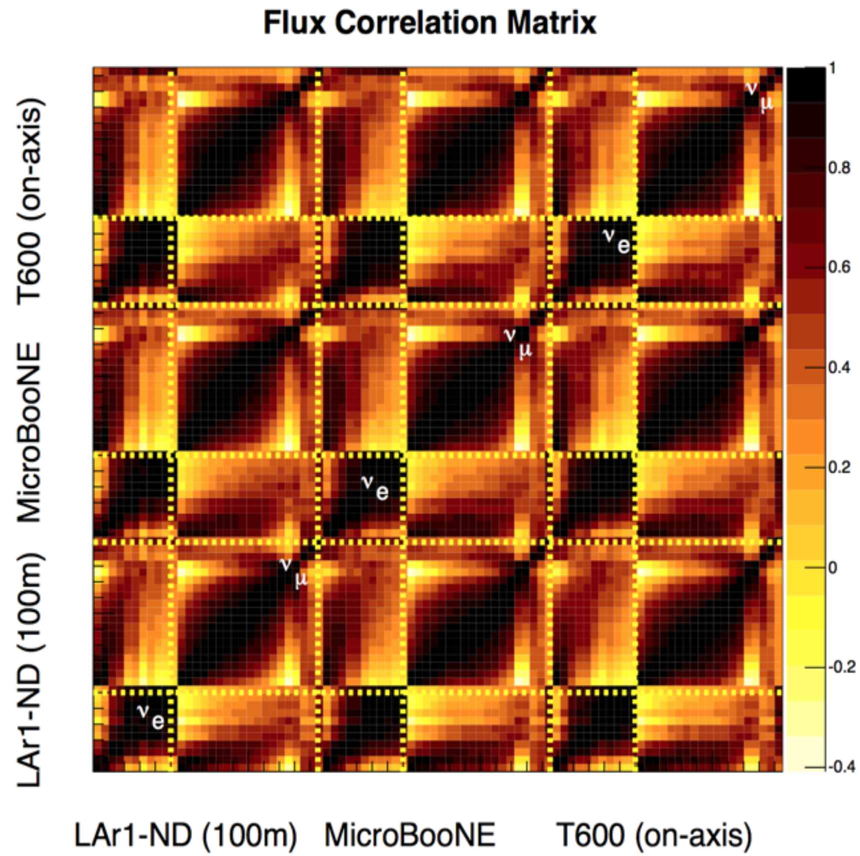
Electron Appearance Covariance Matrix

C. Adams

The electron appearance analysis includes both an electron and muon sample in the matrix

From this matrix we can see how these samples are correlated bin-to-bin and detector-to-detector





Shape Only Analyses

Due to the fact that we have not included all the systematics associated with the normalization we will present only Shape Only analyses

To do this we will want to factorize the covariance matrix:

$$E_{i,j} = E_{i,j}^{shape} + E_{i,j}^{mixed} + E_{i,j}^{norm}$$

These can be defined as:

$$E_{i,j}^{shape} = E_{i,j} - \frac{N_j}{N_T}\sum_{k=1}^{n} E_{i,k} - \frac{N_i}{N_T}\sum_{k=1}^{n} E_{k,j} + \frac{N_i N_j}{N_T^2}\sum_{kl}^{n} E_{k,l}$$

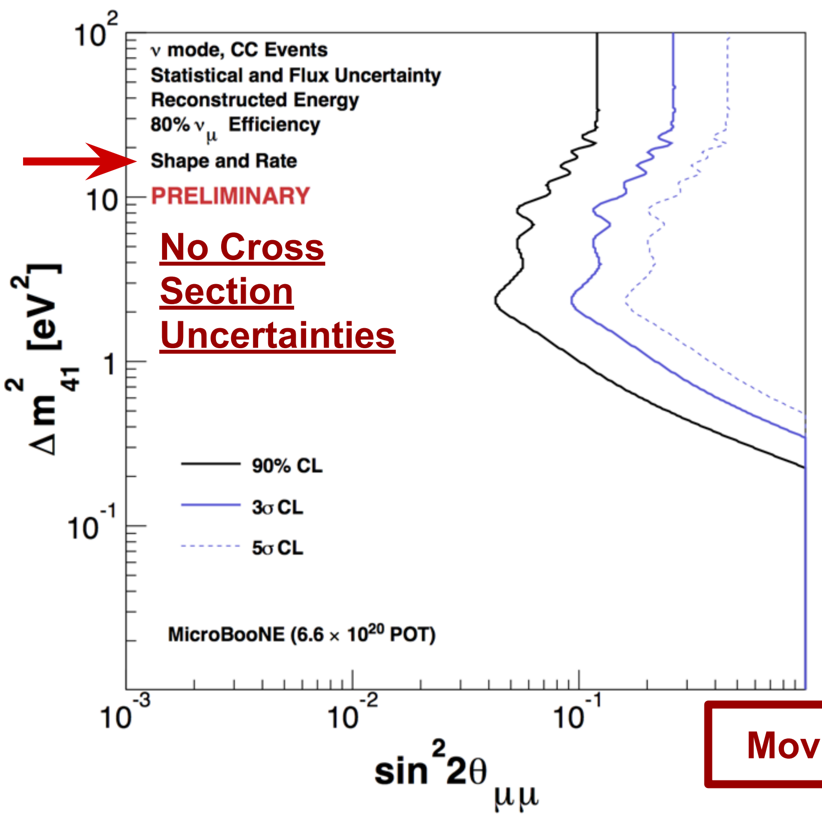
$$E_{i,j}^{mixed} = \frac{N_j}{N_T}\sum_{k=1}^{n} E_{i,k} + \frac{N_i}{N_T}\sum_{k=1}^{n} E_{k,j} - 2\frac{N_i N_j}{N_T^2}\sum_{kl}^{n} E_{k,l}$$

$$E_{i,j}^{norm} = \frac{N_i N_j}{N_T^2}\sum_{kl}^{n} E_{k,l}.$$

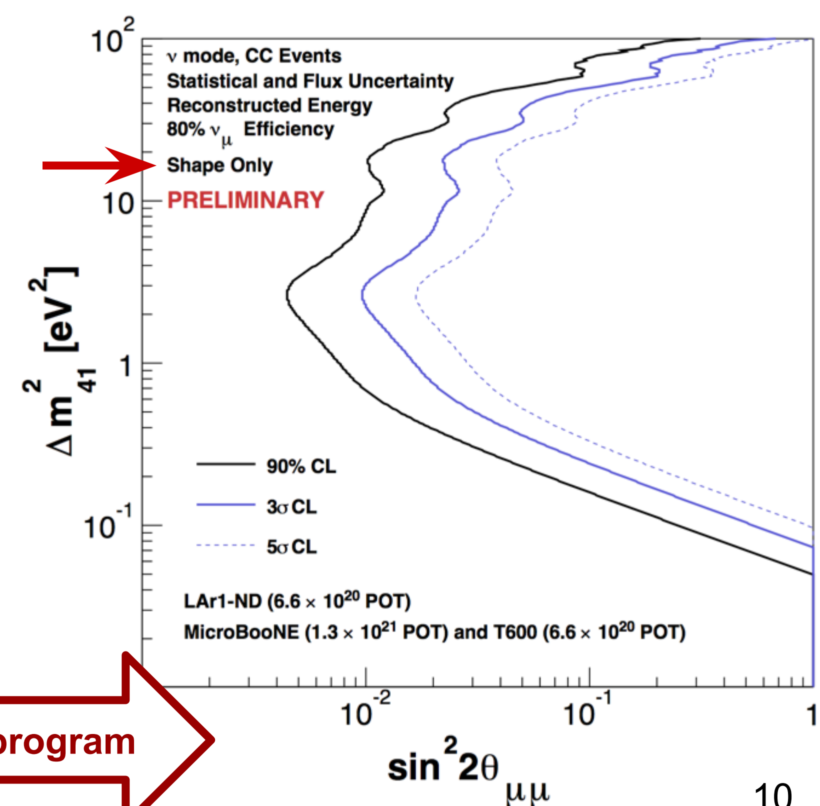
When we build the matrix we subtract the normalization component from the total matrix and then use the near detector rates to scale the far detector rates

ν_μ Disappearance

A single detector muon disappearance analysis is not sensitive to sterile neutrino oscillations, and when we include the constraints that the additional detectors provide we can see the level of improvement that can be achieved



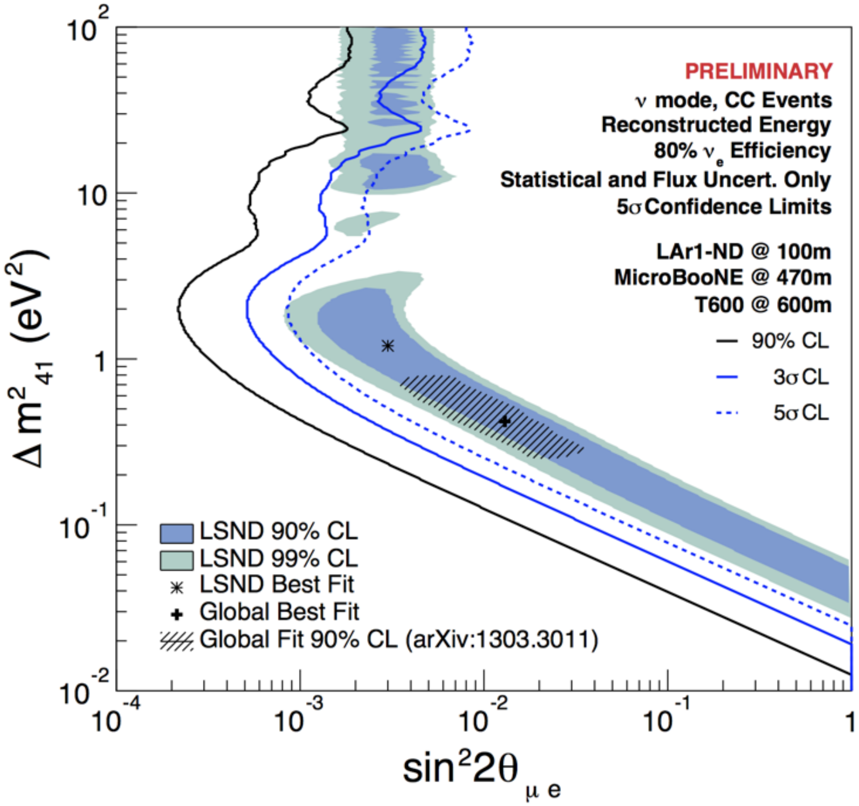
Moving to the full program



ν_e Appearance

This analysis uses the assumption that all three detectors will have the same exposure of 6.6E20 POT

With this we will be able to cover the global best fit region at greater than 5σ and we will be able to probe a majority of the LSND allowed region



Conclusion

Work moving towards realistic sensitivities has begun: Corey, Daniele, and Joel will be giving updates on these uncertainties

The flux matrices are solid starting point for us to build off of

To create realistic sensitivities it will be necessary that we understand how to create each matrix and work it into the sensitivity calculation

$$E^{\text{total}} = E^{\text{stat}} + E^{\text{flux}} + E^{\text{cross section}} + E^{\text{cosmic bkgd}} + E^{\text{dirt bkgd}} + E^{\text{detector}}$$