A Data Driven Method of Background Estimation at NOνA
DPF Meeting 2013, Santa Cruz, CA

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August 16th, 2013
Outline

- Oscillation analysis at NOνA
- Muon Removed Charged Current (MRCC) – A data driven method of background estimation
- Summary
Oscillation Analysis

* NOνA can observe oscillations in two channels using a predominantly $\nu_\mu$ beam:
  * $\nu_\mu$ disappearance
  * $\nu_e$ appearance

* We have a two detector configuration
  * The Near Detector (ND), 1km from the target, used to measure composition of the un-oscillated beam
  * Far Detector (FD), 810km from the source, observes the oscillated beam
Oscillation Analysis

\[ N \rightarrow N' \]
\[ W \rightarrow \nu_\mu \mu \]
\[ \nu_\mu \text{ Charged Current} \]

\[ N \rightarrow N' \]
\[ Z \rightarrow \nu_l \nu_l \]
\[ \nu_l \text{ Neutral Current} \]

\[ N \rightarrow N' \]
\[ W \rightarrow \nu_e e \]
\[ \nu_e \text{ Charged Current} \]
Oscillation Analysis

ND Decomposition

Extrapolation
Oscillation Analysis

- ND Decomposition
- Extrapolation
- Extraction of Oscillation Parameters with FD Data
The Near Detector

* Functionally identical to the FD (14kt), though much smaller at 300 tons
* The environment is quite different from the FD
  * Underground – small cosmic background
  * Very intense neutrino beam
  * Line source at ND vs point source at the FD
  * Decomposition and background estimation methods exploit these features of the ND
There is no $\nu_e$ appearance signal in the Near Detector.

Anything our $\nu_e$ PIDs select as “signal” in the ND, is background.

Near Detector provides a “background only” sample for $\nu_e$ appearance analysis that can be extrapolated to the FD.
Event Topologies At NOνA

\[ \nu_\mu + n \rightarrow \mu + p \]

\[ \nu_e + n \rightarrow e + p \]

\[ \nu + X \rightarrow \nu + X' \]

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Muon Removed Charged Current (MRCC)

* Muon Removed Charged Current events are $\nu_\mu$ CC interactions where the muon is removed from the event
* MRCC events give us a well-understood sample of hadronic showers
* Muon removal can be performed on Monte Carlo as well as data
* $\nu_\mu$ CC events without the muon look a lot like Neutral Current events, which are the main background to the $\nu_e$ analysis

![NC](image1)
![CC](image2)
![MRCC](image3)
MRCC Event Construction

∗ The muon track is selected using the muon PID (see Michael Baird’s talk on \( \nu_\mu \) analysis at NO\( \nu \)A)

∗ The hits that belong to the muon track are removed from the event

Monte Carlo
Truth

Track
Reconstruction

Simple Muon
Removal
Separating Muon Energy And Hadronic Energy

* To avoid removing extra energy from event, muon tracks must be “cleaned up”
* We define a “vertex region” starting from the interaction vertex where it’s very likely that the muon shares hits with hadronic energy
* If $\frac{dE}{dx}$ falls to levels consistent with muon energy deposition, and stays there for the next few planes, vertex region is over.
Muon Removal with CleanUp

* In the vertex region, instead of removing all energy in a cell, only 1 MIP is removed (the characteristic energy deposited by a minimum ionizing particle like muon).
If muon removal is perfect, all of muon energy from the event should be removed and none of the energy from hadrons should be removed.
MRCC Similarity To Neutral Currents

* We have done several checks to test the likeness of MRCC events to NC events
* MRCC and NC samples look similar in low as well as high level variables
MRCC Analysis Flow

- The NC background estimation is done bin by bin:

\[ NC^{BG} = \frac{NC^{MC}}{MRCC^{MC}} \times MRCC^{Data} \]

- Many systematic effects cancel in the ratio, resulting in a more accurate estimate of background.

- Uncertainties on neutrino cross-section parameters are large – therefore data-driven methods are important.

- MRCC gives us one such handle.

- CC hadronic showers are, however, different from NC hadronic showers.

- Systematic effects accounted for include parameters like axial mass \( M_a \), non-resonance background cross-sections, pion mean-free path etc.
The Background We Are Trying To Predict Is Small...

Library Matching based $\nu_e$ PID

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ANN based $\nu_e$ PID uses shower shape variables
Computing The Ratio

The error bars include statistical error and systematic error due to uncertainty on modelling parameters.
Performance Of The MRCC Method

- Using the computed ratios, we can predict the NC background in data
- To see the performance of the method, we used a statistically independent set of Monte Carlo as pseudo-data
- The data set is equivalent to $2.2 \times 10^{19} \text{ POT}$ which amounts to $\sim 2$ weeks of Full Near Detector data at 700kW
The error bands include statistical error and systematic error due to uncertainty on modelling parameters.
Summary

- We have multiple Near Detector background estimators in the works
- Muon Removed Charged Current is a data driven method of estimating neutral current rates in Near Detector
- The method gives results consistent with Monte Carlo truth
- Can estimate NC background to 10% error with < 1 month of full Near Detector data
- We are excited to see it applied to our data!
Back Up
Examples Of Systematic Effects

* Effect of changing the axial mass in resonance interactions on NC and MRCC samples

![Graph showing examples of systematic effects](image-url)
Examples Of Systematic Effects

* Effect of changing the axial mass in elastic Neutral Current interactions on NC and MRCC samples

![Graph of Neutrino Energy vs Events for NC and MRCC](image)

![Graph of Neutrino Energy vs Events for NC and MRCC](image)
NC Background Prediction ANN $\nu_e$ PID Bins

Ratio NC/MRCC computed in ANN $\nu_e$ PID bins

NC Background prediction in ANN $\nu_e$ PID using MRCC