Constraining Systematic Uncertainties for the Electron-Neutrino Search at MicroBooNE

Marianette Wospakrik, on behalf of the MicroBooNE collaboration
Fermi National Accelerator Laboratory

MICROBOONE EXPERIMENT

- MicroBooNE is a Liquid Argon Time Projection Chamber (LARTPC) designed to investigate the anomalous excess of low energy events observed by MiniBooNE
- This low energy excess (LEE) can be due to either electron-like or photon-like events

REFERENCES:
1. Systematics constraint is provided by
2. Cross Section
3. Flux
4. Detector Response

Unisim: systematic parameters are varied one at a time by one standard deviation
Multisim: all systematic parameters are varied randomly using their assumed probability distribution. Correlations between systematic uncertainties are automatically taken into account

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Method</th>
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<tbody>
<tr>
<td>Cross Section</td>
<td>Multisim</td>
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<td>Multisim</td>
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<tr>
<td>Detector Response</td>
<td>Unisim</td>
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</table>

Impact on detector systematics is at a percent level. We treat the detector systematics as uncorrelated using dedicated variation samples.

SYSTEMATICS

Two approaches used to estimate the uncertainties: unisim and multisim.

Unisim: systematic parameters are varied one at a time by one standard deviation
Multisim: all systematic parameters are varied randomly using their assumed probability distribution. Correlations between systematic uncertainties are automatically taken into account

The covariance matrix correlating the variation in the measured number of events between bins is calculated as follows:

\[
E_{ij} = \frac{1}{N} \sum_{s} \left( N_{s} - \bar{N}_{s} \right) \left( N_{s}^{i} - \bar{N}_{s}^{i} \right)
\]

We construct a (fractional) covariance matrix correlating the systematics between the \( \nu_{e} \) and \( \nu_{\mu} \) selections

CONSTRANT ESTIMATION

1. Systematics constraint is provided by the correlation elements between the \( \nu_{e} \) and \( \nu_{\mu} \) events.
2. By assuming that the observed events (\( N_{\text{obs}} \)) is equal to the predicted events (\( N_{\text{pred}} \)), the constraint power can be estimated by fitting the MC events with the statistical uncertainties in each bin of the spectrum.
3. Method demonstrates the best estimation of the constraint power: systematics reduction of up to ~50% in flux, cross section, and detector response systematics at the low energy region where it is most needed.

SENSITIVITY ESTIMATION

- The sensitivity of the selection to the MiniBooNE unfolded LEE signal is calculated by generating toy experiments under 2 hypothesis:
  - \( H_0 \) is the Standard Model hypothesis
  - \( H_1 \) is the MiniBooNE unfolded LEE hypothesis.
- Calculation uses the \( \chi^{2}_{\text{MC}} \) formalism that approximates Poisson statistical errors for the covariance matrix diagonals.
- Scaled to the current open data, \( 6.9 \times 10^{20} \text{POT} \).
- No systematics attached to the unfolded LEE signal.
- The median sensitivity to rule out the standard model in favor of the MiniBooNE LEE signal model is \( 2.3 \sigma \).
- The \( \nu_{e} \) and \( \nu_{\mu} \) selection improves the sensitivity from 1.8 to 2.3

FLUX AND CROSS SECTION SYSTEMATICS CORRELATION

Flux systematics correlation is highest in the low-energy, where the uncertainties from model parameterization for Be target \( r^+ \) production cross section dominates.

SUMMARY & OUTLOOK

- MicroBooNE \( \nu_{e} \) measurement leverages multiple channels to validate and constrain \( \nu_{e} \) flux and cross section uncertainties, particularly in the low energy region.
- The uncertainties formalism includes correlations between \( \nu_{e} \) and \( \nu_{\mu} \) by multisim method, which are then exploited in the fit to test the sensitivity.
- The use of the high-statistics \( \nu_{e} \) selection improves the median sensitivity to the MiniBooNE LEE signal hypothesis to \( 2.3 \sigma \).
- Ongoing data-analysis on full dataset (\( 1.25 \times 10^{21} \text{POT} \)) is expected to improve the measurement. 

STAY TUNED!

REFERENCES
1. MicroBooNE Collaboration, MICROBOONE-NOTE-1043-PUB
2. MicroBooNE Collaboration, MICROBOONE-NOTE-1074-PUB
3. MicroBooNE Collaboration, MICROBOONE-NOTE-1075-PUB