1. Motivation

- MiniBooNE Cherenkov detector along the booster neutrino beam
- Observed low energy excess (LEE) of neutrinos.
- Use data from MiniBooNE, a liquid argon time projection chamber (LArTPC), to test an explanation as neutral current (NC) $\Delta$ radiative decay
- $\Delta$ Standard Model prediction for $\Delta \rightarrow N'$ would explain the excess

2. Eventweight Method and Samples

- The EventWeight (event reweighting) method is used to evaluate flux and cross-section systematic uncertainties.
- Limitation in that events cannot be weighted into existence, but sufficiently large samples should negate this
- This method is most optimal given limited allocated computing resources.
- We vary 56 parameters of GENIE uncertainty and 12 parameters of our NC $\Delta$ radiative decay
- The final stage samples for our 2$\nu$p, 2$\nu$p, 1$\nu$p, and 1$\nu$p channels are extracted and split into sub channels for different signals.
- GENIE is used for monte-carlo generation of events and for cross-section uncertainties. We utilize GENIE v3 with a custom MiniBooNE central value tune.
- A combined GENIE variation is used including a set of approved GENIE uncertainties including quasi-elastic, meson exchange current, resonant, non-resonant, hadronization and final state interaction processes.
- Delta resonance signal uncertainties were excluded as they correspond to our final measurement.
- Individual GENIE parameters are also studied but are not included in fits or final covariance matrices.

3. Fitting Module

- SBNFit (short baseline neutrino fit) is a module built for the SBN project enabling for fitting which utilizes fractional covariance matrices.
- Fractional covariance matrices contain the statistical and systematic uncertainties and systematic correlations among different bins and samples
- Correlation matrices are the covariance of a bin divided by the standard deviation of the two components, and are useful for visualization.

4. Constraint

- We evaluate the level of constraint on the uncertainty of the final 1$\nu$p signal by considering the NC (neutral current) $x^2$ sideband (2$\nu$p) measurement using the following method.
- Form a matrix of 1$\nu$p backgrounds and 2$\nu$p selection ($M_{ij}$).
- For the 2$\nu$p portion assume $\chi^2_{data} = \sum N_{data}^2$, and $\chi^2_{data} = N_{MC}^2$
- Calculate a new matrix $(M_{ij})^{-1}_\text{new} = M_{ij}^{-1} + 1/N_{MC}$ and re-invert for constrained uncertainty on the 1$\nu$p bins.

5. Results

- "GENIE All" (the combined GENIE variation) includes a number of highly correlated parameters for our backgrounds i.e. NC Resonance Axial Mass, so the constraint is powerful (3.11 reduction factor)
- Flux variations have smaller uncertainties and aren't specific to our signal so the constraint is only somewhat effective (1.40 reduction factor)

### Table: Top 10 highest uncertainties after constraint in 1$\nu$p

<table>
<thead>
<tr>
<th>Variation Description</th>
<th>Unconstrained</th>
<th>Constrained</th>
<th>Unconstrained</th>
<th>Constrained</th>
<th>Unconstrained</th>
<th>Constrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>All gen. variations</td>
<td>42.6%</td>
<td>10.41%</td>
<td>10.41%</td>
<td>2.22%</td>
<td>2.22%</td>
<td>4.48%</td>
</tr>
<tr>
<td>Fractional cross section for N-change exchange</td>
<td>9.58%</td>
<td>4.53%</td>
<td>10.41%</td>
<td>4.53%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All misc. for NC resonance $x^2$ deviation</td>
<td>7.83%</td>
<td>4.53%</td>
<td>7.83%</td>
<td>4.53%</td>
<td></td>
<td></td>
</tr>
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<td>4.53%</td>
<td></td>
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</tr>
<tr>
<td>Skin depth/energy current point/space conductor</td>
<td>9.58%</td>
<td>4.53%</td>
<td>9.58%</td>
<td>4.53%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary hadron SW Central Spine Violation for $e$</td>
<td>9.58%</td>
<td>4.53%</td>
<td>9.58%</td>
<td>4.53%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References:
3. M. Shavevitz, "Constraining the nue background using the observed numu events." MicroBooNE DocDB: 7635, 2017