Charged Current Neutral Pion Production at MicroBooNE

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University of Michigan
12th International Workshop
On Neutrino-Nucleus Interactions
In the Few GeV Region
L’Aquila, Italy
October 2018.
Sources of Photon Production

- At BNB energies, most originate from Decay of $\Delta$ to $\pi^0$.
- Sources we classify as background:
  - Radiative delta decay ($\Delta \rightarrow \gamma + N$)
  - $\pi^0$ from re-scattering (charge exchange)
  - Higher mass resonances.
- Further sources:
  - Anomalous (constrained by radiative delta decay).
  - Nuclear de-excitation (sub 10 MeV).

Dominant at BNB Energies

$0.5\% \text{ BR}$
Photon Detection with LArTPCs

- Electron-gamma separation one of the hallmarks of LArTPCs.
- Measure energy deposition along a particle’s trajectory.
- Gammas pair-produce into two electrons, $dE / dx$. profile follows 2 electrons.
- **Challenge is reconstructing showers from gammas**

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Colton’s Talk

This Talk
CC $\pi^0$ Production with Neutrinos

- Many energy ranges and target media explored.
- Nuclear effects expected to scale as $A^{2/3}$ cross-section as $N$.
- Argon largest nucleus measured to date!
Focus on MiniBooNE: same beam line as MicroBooNE.

MiniBooNE signal: $\nu_\mu + CH \rightarrow \mu^- + \pi^0 + \text{plus no other mesons.}$

MicroBooNE: $\nu_\mu + CH \rightarrow \mu^- + \pi^0 + X$
Event Selection

Trigger

Tracking Reco.

Cosmic Rejection

Shower Reco

At Least 1 Shower Sample

At least 2 Shower Sample

BNB data taking

Expected interaction numbers per $1.6 \times 10^{20}$ POT

$\nu_\mu$ CC inclusive: $\sim 45k$

CC $1\mu$ Np: $\sim 25k$
Event Selection

- Covered in Anne’s Talk!

- Trigger
- Tracking Reco.
- Cosmic Rejection
- Shower Reco

- At Least 1 Shower Sample
- At Least 2 Shower Sample

Look for Light in this Window

Photon ID happens later

Muon Identified with MicroBooNE Tracking Algs
Charge Scale Calibration

- Use a combination of cosmic and neutrino induced muons to calibrate dQ/dx and dE/dx.
- Gross correction of position dependent detector response.
- Performed on collection plane only.

See MicroBooNE Public Note 1038
Event Selection

- Combination of geometric, PMT and containment cuts to eliminate hits of non-neutrino origin.

**Trigger, Tracking Reco.**

- Muon must have a hit charge consistent with MIP

**Cosmic Rejection**

- Cosmic rejection based on muon hit charge consistency with MIP

**Shower Reco**

- At Least 1 Shower Sample

- At Least 2 Shower Sample
Event Selection

- Hit clusters sorted into “track like” and “shower like.”
- Hit clusters must point back to neutrino vertex.
- OpenCV Image recognition.

**Shower Reco**

- At Least 1 Shower Sample
-_sorted charge
- Clustered Charge

**Tracking Reco.**

- Conservative clustering to avoid energy from cosmics

**Cosmic Rejection**

- 92% (avg.)
- 63% (avg.)

<table>
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<th>Shower Purity</th>
<th>Shower Completeness</th>
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D. Caratelli, Columbia U., Ph.D. Thesis

Joel Mousseau: NuInt 2018
Shower Reconstruction

- Threshold for distinguishing track / shower hits about 50 MeV.
- Consequence of high purity, and track-nature of low energy showers.
- Results in a lower efficiency of reconstructing low-energy showers, but high purity.
Event Selection

- Given low efficiency of second shower, we split the analysis into a single shower and two shower selection.

- At least 1 shower is higher efficiency.
- At least 2 shower used as cross check.

Joel Mousseau: NuInt 2018
Single Shower Selection

- Measure conversion length of single photon to ensure it is a photon.
- Exclude first bin (large number of non-photons).
- Measured conversion length agrees with Simulation.
- Single shower Efficiency (Purity) 17% (53%).
• Final set of selection cuts removes cosmic background

• If two showers in the event, the higher energy shower is selected.

• Overlap exists between 1 and 2 shower samples.

• Each cut ~85% efficient.
Using two showers with similar cuts correct for missing energy from clustering and hit-thresholding using MC.

Plot diphoton invariant mass, confirm $\pi^0$ mass in data and MC.

Two shower efficiency (purity): 6% (64%).
Remaining backgrounds are cosmic, and other resonant events contributing to the single $\pi^0$ production.

Estimate these backgrounds directly from GENIE (45% of events).
# Systematic Uncertainties

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<thead>
<tr>
<th>Type</th>
<th>% Error</th>
<th>Affected Measurement</th>
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<tbody>
<tr>
<td>Flux</td>
<td>16%</td>
<td>Flux division, Background Estimation</td>
</tr>
<tr>
<td>Cross-Section</td>
<td>17%</td>
<td>Background Estimation Efficiency Correction</td>
</tr>
<tr>
<td>Detector Modeling</td>
<td>21%</td>
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<tr>
<td><strong>TOTAL</strong></td>
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## Systematic Uncertainties

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- Major sources of detector modeling uncertainty:
  - Induced charge on neighboring wires.
  - Diffusion of charge as it propagates along the drift direction.
  - Modeling of scintillation light.

- Improvements will come from:
  - Newer MicroBooNE simulation and calibration.
  - Improved shower reco. to detect lower energy showers lead to higher efficiency.
Results (At Least 1 Shower)

- First ever measurement on Ar.

\[ \left\langle \sigma_{\nu\mu}^{CC} \pi^0 \right\rangle_\Phi = (1.94 \pm 0.16 \text{ [stat.]} \pm 0.60 \text{ [syst.]}) \times 10^{-38} \text{ cm}^2/\text{Ar} \]
• Compare our result on Argon, to ANL and MiniBooNE results on C and D.
• Starting to probe differences between how different models predict $A$ scaling.
• Currently, lack sensitivity to differences in FSI modeling.
Future Measurements

- Large investment in improving MicroBooNE’s detector simulation and reconstruction.
- New image recognition, machine learning techniques promise better shower reconstruction, ability to detect lower energy showers.

- Much more data in further MicroBooNE runs (x8 more).
- Enables a differential measurement of $\pi^0$ in $\pi^0$ and $\mu$ variables.
Conclusions

• MicroBooNE has performed a world’s first measurement of neutrino induced $\pi^0$ production on argon.

• Measured with both single and two photon sub-samples.
  • Both measurements consistent.
  • Select single photon as primary result due to larger efficiency.

• Currently see reasonable agreement with GENIE’s A scaling.

• Sensitivity limited by detector model and reconstruction.
  • Improving detector model, including signal modeling.
  • Improving reconstruction, including the ability to detect low energy showers.
Thank you for Your Attention!

All MicroBooNE Public Notes Available Here:
http://microboone.fnal.gov/public-notes/
Energy Correction and Mass Peak

- Corrections applied:
  - Add energy from hits below threshold.

- Add energy from clusters mis-id as track or cosmic.

- Both corrections derived from MC.

- Do not correct for un-contained clusters.
One and Two Shower Comparison

- At least one shower: $1.94 \pm 0.16 \text{ (stat.) } \times 10^{-38} \text{ cm}^2 / \text{ Ar}$
- At least two showers: $1.91 \pm 0.24 \text{ (stat.) } \times 10^{-38} \text{ cm}^2 / \text{ Ar}$

88.5% of 2 shower Events