MicroBooNE's Search for a Photon-Like Low Energy Excess

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On behalf of the MicroBooNE Collaboration
New Perspectives
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Intro to MicroBooNE

- 170 ton **liquid argon time projection chamber** (LArTPC), operating along Fermilab's Booster Neutrino Beam (BNB) since 2015
- One of the key goals is a test of the **MiniBooNE low-energy excess**
MiniBooNE Low Energy Excess

- **MiniBooNE** is a Cherenkov detector along the BNB, operating since 2002.
- Observed **excess of neutrinos at low energy** [1]
- **Photon-like** and **electron-like interpretations**

MiniBooNE Low Energy Excess

- Photon-like and electron-like interpretations

Photon backgrounds

NC Δ Radiative Decay

- Neutral Current (NC) $\Delta \rightarrow N\gamma$ is a **Standard Model (SM)** source of single photons.
- Never measured directly in neutrinos before
- 2019 T2K 90% C.L. [2] is $\text{O}(100x)$ the SM prediction
- **3x SM prediction** of $\Delta \rightarrow N\gamma$ could explain MiniBooNE Low Energy Excess [3]

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NC Δ Radiative Decay in MicroBooNE

Incoming neutrino

\[ \begin{align*}
\nu & \rightarrow \nu \\
Z^0 & \rightarrow \Delta \rightarrow N \\
Ar & \rightarrow X
\end{align*} \]
NC $\Delta$ Radiative Decay in MicroBooNE

Incoming neutrino

\[ \nu \rightarrow v + Z^0 + X \]

\[ Z^0 \rightarrow Y + N \]

\[ Ar \rightarrow \Delta + X \]
NC $\Delta$ Radiative Decay in MicroBooNE
NC $\Delta$ Radiative Decay in MicroBooNE
Single Photon Topologies in MicroBooNE

Selected data $1\gamma 1p$ NC $\Delta$ radiative signal candidate with 1 shower

MicroBooNE Data, Run 5462 Subrun 14 Event 732
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$1\gamma 1p$ Topological Selection
Single Photon Topologies in MicroBooNE

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MicroBooNE Data
Run 5187 Subrun 188 Event 9430
Single Photon Topologies in MicroBooNE

Selected data $1\gamma 0p$ NC $\Delta$ radiative signal candidate with 1 shower

$\gamma$

MicroBooNE Data
Run 5187 Subrun 188 Event 9430

$1\gamma 0p$ Topological Selection
Selection Stages

1. Take reconstructed tracks and showers [4]
2. Find candidate vertices matching $1\gamma$ topologies
3. Apply pre-selection cuts to remove obvious backgrounds
4. Remove backgrounds using tailored boosted decision trees (BDTs)

Goal is a high sensitivity search for NC $\Delta \rightarrow N\gamma$ events over background prediction, fit to an excess using in-situ NC $\pi^0$ constraint

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Topological Selection Stage

- Showing results using 5% sample unblinded data, full data set is ~25x larger
- $1\gamma 1p$ topological selection (1 track + 1 shower)
- NC $\Delta$ radiative simulated events with 3x SM prediction
- Strongly dominated by cosmic, dirt, and BNB charged current (CC) $\nu_\mu$ backgrounds
- Signal:background ~1:700

Reconstructed $\Delta$ Invariant Mass $M_\Delta = 1.232$ GeV
Similarly dominated by backgrounds for $1\gamma 0p$ (1 shower) topology.
Selection Stages

1. Take reconstructed tracks and showers [4]
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Goal is a high sensitivity search for NC $\Delta \rightarrow N\gamma$ events over background prediction, fit to an excess using in-situ NC $\pi^0$ constraint
Selection Stages

**Take reconstructed tracks and showers [4]**

- **Find candidate vertices matching 1\(\gamma\) topologies**
- **Remove backgrounds using tailored boosted decision trees (BDTs)**

**Goal is a high sensitivity search for NC \(\Delta \rightarrow N\gamma\) events over background prediction, fit to an excess using in-situ NC \(\pi^0\) constraint**

**Apply pre-selection cuts to remove obvious backgrounds**

**Apply fiducial and calorimetric cuts targeting cosmic, dirt, and CC backgrounds**
Selection Stages

1. Take reconstructed tracks and showers [4]
2. Find candidate vertices matching $1\gamma$ topologies
3. Apply pre-selection cuts to remove obvious backgrounds
4. Remove backgrounds using tailored boosted decision trees (BDTs)

Goal is a high sensitivity search for NC $\Delta \rightarrow N\gamma$ events over background prediction, fit to an excess using in-situ NC $\pi^0$ constraint
Background Rejection BDTs

- BDTs targeting key backgrounds trained independently for each topology, cuts optimized simultaneously
- For $1\gamma 1p$ train 5 BDTs: cosmic, $\nu_e$, NC $\pi^0$, second shower $\pi^0$ mis-ID, and all other BNB backgrounds
- Here showing example of $1\gamma 1p$ NC $\pi^0$ rejection BDT response
NC $\pi^0$ Background

- NC $\pi^0 \rightarrow \gamma + \gamma$ is a key background.
- If second photon shower is missed/mis-reconstructed, looks identical to signal.

$$\nu_\mu + p \rightarrow \nu_\mu + \Delta^+$$

MicroBooNE Data, Run 5762 Subrun 114 Event 5732
Optimized BDT cut at 0.467 removes 78.8% of NC $\pi^0$ background events relative to pre-selection cuts stage. Other remaining backgrounds targeted by dedicated BDTs.
Selection Stages

- Take reconstructed tracks and showers [4]
- Find candidate vertices matching $1\gamma$ topologies
- Apply pre-selection cuts to remove obvious backgrounds
- Remove backgrounds using tailored boosted decision trees (BDTs)

Goal is a high sensitivity search for NC $\Delta \rightarrow N\gamma$ events over background prediction, fit to an excess using in-situ NC $\pi^0$ constraint
**Final Selection**

- Showing results using 5% sample unblinded data, full data set is ~25x larger
- $1\gamma1p$ final selection with topological, pre-selection, and optimized BDT cuts applied
- Strong rejection of cosmic, dirt, and CC backgrounds
- NC $\pi^0$ events comprise >85% selected backgrounds

Reconstructed Shower Energy

(Data/MC: 0.68) (KS: 0.978) ($\chi^2$/nDOF: 5.17/12) ($\chi^2$ P-val: 0.952)
Majority of sensitivity comes from $1\gamma 1p$ selection given higher purity but combined fit with $1\gamma 0p$ gives maximal sensitivity to NC Δ→Nγ.
Projected Final Selection for Full Data Set

- MC prediction for final selections scaled to expected full data set
- Showing flux, cross section, and detector systematics with constraint on systematics from in situ NC $\pi^0$ measurement
- Fit simultaneously to NC $\pi^0$ components of single photon ($1\gamma$) and dedicated NC $\pi^0$ ($2\gamma$) selections
MicroBooNE Projected Bound

- 90% C.L. for Runs 1-3
- 3x SM rate $\Delta \rightarrow N\gamma$
- 90% C.L. for Runs 1-5
- GENIE xsec
MicroBooNE Projected Bound

- $\sigma$ (10^{-42} cm^2/nucl) vs. $E_v$ [GeV]
- BNB Flux at $\mu$BooNE (a.u.)
- GENIE $\sigma$ (G18_10a_02_11a)
- Expected 90% C.L.
- Flux Averaged GENIE $\langle \sigma \rangle$
- E.Wang et al. 1311.2151
- Mean Nucleon, $C_9^\nu$ 1σ spread
- Runs 1-3 (6.9e20 POT)
- Runs 1-5 (12.3e20 POT)

$\sim$30x improvement over current best limit

90% C.L. for Runs 1-5

GENIE xsec
Summary and Conclusions

- MicroBooNE well-situated to provide world-leading constraint NC $\Delta \rightarrow N\gamma$, never directly measured in neutrinos before.
- For the full data set (12.25e20 POT), projected to exclude the MiniBooNE LEE under NC $\Delta \rightarrow N\gamma$ hypothesis at >95% C.L.
- Currently unblinding sidebands as a step towards opening the signal box for the first result with runs 1-3 (6.8e20 POT).
- Please refer to public note for more details: MICROBOONE-NOTE-1087-PUB.
Thanks!
Backup
Precuts Selection Stage

$\gamma p$ 0.41e20 POT
MicroBooNE Preliminary

(Data/MC: 1.00) (KS: 0.852) ($\chi^2$/nDOF: 16.60/18) ($\chi^2 P^{val}$: 0.550)

(Data/MC: 1.03) (KS: 0.590) ($\chi^2$/nDOF: 13.23/18) ($\chi^2 P^{val}$: 0.778)
Dirt Backgrounds
In-Situ NC $\pi^0$ Measurement

Single photon $1\gamma_0p$ and $1\gamma_1p$ selections

Complementary NC $\pi^0$ $2\gamma_0p$ and $2\gamma_1p$ selections
NC $\pi^0$ Systematics Constraint for Single Photon Selection

Constrained Systematics

Unconstrained Systematics