A Charged-Current $\nu_\mu$ Veto for the Inclusive $\nu_e$ Analysis in MicroBooNE

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New Perspectives
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MicroBooNE

- MicroBooNE is a surface-level neutrino experiment based at Fermilab that utilizes a LArTPC
- Collecting data since October 2015
- Primary goal is to understand the low energy excess seen by MiniBooNE through conducting an inclusive $\nu_e$ analysis
- See Lauren Yates’s July 21 New Perspectives talk “Five Years of MicroBooNE and Beyond in Ten Minutes” for more details
\( \nu_e \) Analysis Flowchart

overwhelming \( \nu_\mu \) Charged-Current (CC) and cosmic background in the inclusive \( \nu_e \) selection needed for the low energy excess analysis

Focus of this presentation

- Inclusive \( \nu_\mu \) CC Filter
  - \( \nu_\mu \) CC event?
    - Yes
      - \( \nu_\mu \) Neutral Current (NC) Filter
    - No
      - NC \( \pi^0 \) constraint sample, for background estimate

- Inclusive \( \nu_e \) Selection for Low Energy Excess Analysis

Cosmic Filter - Remove Cosmic Background

\( \nu \) Cosmic :

- \( \nu \) : \( \nu_\mu \) 
  - \( \sim 10,000 : 1 \)

- \( \nu_\mu \) : \( \nu_e \)
  - 200 : 1
$\nu_e$ Analysis Flowchart

Focus of this presentation

1. Cosmic Filter - Remove Cosmic Background
2. $\nu_\mu$ CC Filter
   - $\nu_\mu$ CC event?
   - $\nu_\mu$ CC event? Yes
     - $\nu_\mu$ CC Filter
     - $\nu_\mu$ CC event? No
     - $\nu_\nu$ inclusive constraint sample, for background estimate
       - NC pi0 constraint sample, for background estimate
         - $\nu$ Neutral Current (NC) Filter
           - $\nu$ NC event? No
           - Inclusive $\nu_e$ Selection for Low Energy Excess Analysis

overwhelming $\nu_\mu$ CC and cosmic background in the inclusive $\nu_e$ selection needed for the low energy excess analysis

Cosmic : $\nu$
- $\approx 10,000 : 1$

$\nu_\mu : \nu_e$
- $200 : 1$
Cosmic Removal

- With a surface-level detector like MicroBooNE, cosmic rays are a major background.
- Before event selection, Wire-Cell Cosmic Rejection (MICROBOONE-NOTE-1084-PUB) are used to remove 98.6% of cosmic events.
- Raises $\nu$:Cosmic ratio to 7.6:1 (from 10,000:1 at raw data level).
- Muon Neutrino in a 3cm Fiducial Volume ($\nu_\mu$-CC-in-FV) Efficiency: 81%
\( \nu_e \) Analysis Flowchart

overwhelming \( \nu_\mu \) CC and cosmic background in the inclusive \( \nu_e \) selection needed for the low energy excess analysis

Focus of this presentation

Inclusive \( \nu_\mu \) CC Selection for constraint sample

Yes

\( \nu \) Neutral Current (NC) Filter

No

Inclusive \( \nu_e \) Selection for Low Energy Excess Analysis

Cosmic Filter - Remove Cosmic Background

\( \nu_\mu \) CC Filter

\( \nu_\mu \) CC event?

\( \nu_\mu : \nu_e \approx 10,000 : 1 \)

\( \nu_\mu : \nu_e \approx 200 : 1 \)

\( \nu_\mu \) CC event?

Yes

NC pi0 constraint sample, for background estimate

No

Focus of this presentation

Cosmic : \( \nu \)

~10,000 : 1
$\nu_\mu$ CC Filter

Use to remove $\nu_\mu$ CC events for $\nu_e$ selection, want high $\nu_\mu$ CC efficiency and low $\nu_e$ mis-ID

Strategy: identify a muon track associated with neutrino vertex
Use to remove $\nu_\mu$ CC events for $\nu_e$ selection, want high $\nu_\mu$ CC efficiency and low $\nu_e$ mis-ID

Strategy: identify a muon track associated with neutrino vertex
1. reconstructed neutrino vertex is inside the TPC
\( \nu_\mu \) CC Filter

Use to remove \( \nu_\mu \) CC events for \( \nu_e \) selection, want high \( \nu_\mu \) CC efficiency and low \( \nu_e \) mis-ID

Strategy: identify a muon track associated with neutrino vertex

1. reconstructed neutrino vertex is inside the TPC
2. At least one track associated with reconstructed neutrino vertex
\( \nu_\mu \) CC Filter

Use to remove \( \nu_\mu \) CC events for \( \nu_e \) selection, want high \( \nu_\mu \) CC efficiency and low \( \nu_e \) mis-ID

Strategy: identify a muon track associated with neutrino vertex
1. reconstructed neutrino vertex is inside the TPC
2. At least one track associated with reconstructed neutrino vertex
3. At least one of these tracks has log likelihood ratios consistent with a muon
   a. Muon/Proton
   b. Muon/Proton for tracks exiting the TPC
   c. Muon/Pion
**ν**

**ν**<sub>μ</sub> CC Filter

Use to remove ν<sub>μ</sub> CC events for ν<sub>e</sub> selection, want high ν<sub>μ</sub> CC efficiency and low ν<sub>e</sub> mis-ID

Strat egy: identify a muon track associated with neutrino vertex

1. reconstructed neutrino vertex is inside the TPC
2. At least one track associated with reconstructed neutrino vertex
3. At least one of these tracks has log likelihood ratios consistent with a muon
   a. Muon/Proton
   b. Muon/Proton for tracks exiting the TPC
   c. Muon/Pion
4. “Track-like” (μ-like) vs “Shower-like” (electron-like) events
Log Likelihood Ratios: Muon/Proton

**Input:** Track Length (A), Track Straightness Score (B), Track PID (using energy loss along the trajectory) (C)

\[ R_{\text{Likelihood}} = \frac{P(\text{Muon})}{P(\text{Proton})} = \frac{A_{\text{Muon}} \times B_{\text{Muon}} \times C_{\text{Muon}}}{A_{\text{Proton}} \times B_{\text{Proton}} \times C_{\text{Proton}}} \]

**A**

Track Lengths Before Log Likelihood Ratio Cut (Set19 POT Normalized)

**B**

Track Straightness Score Before Log Likelihood Ratio Cut (Set19 POT Normalized)

**C**

Track PID Before Log Likelihood Ratio Cut (Set19 POT Normalized)

EXT = beam-off (cosmics only) data

Dirt = ν interaction outside the TPC
Log Likelihood Ratios: Muon/Proton

Efficiency: 84%  MisID: 24%
Main mode of misID: charged pion selected as muon

Two large bins from corrections for Prob(muon)=0 or Prob(proton)=0 - avoid divide by 0 or log(0) errors
Log Likelihood Ratios: Muon/Pion

Input: Track Length, Track Straightness Score, Number of Vertices, Number of Particles from Re-interaction (3rd Generation Particles)
Reduce MisID by 3%
Lose 2% Efficiency

Muon

Pion

1 Vertex, 0 Re-interaction Particles
2 Vertices, 3 Re-interaction Particles
Non-Contained Muon/Proton Log Likelihood Ratio

- Track length no longer used as input
- Only for tracks exiting the TPC
- Recover 3% efficiency - particularly at low (200-400 MeV) energies
Performance

- $\nu_\mu$ CC Efficiency: 82.4%
- $\nu_e$ CC MisID: 10.4%
- $\nu_\mu : \nu_e = 27 : 1$ (from 200:1 at raw data level)
\( \nu_e \) Analysis Flowchart

Focus of this presentation

Inclusive \( \nu_\mu \) CC Selection for constraint sample

NC pi0 constraint sample, for background estimate

Yes

No

NC Filter

NC event?

No

Inclusive \( \nu_e \) Selection for Low Energy Excess Analysis

overwhelming \( \nu_\mu \) CC and cosmic background in the inclusive \( \nu_e \) selection needed for the low energy excess analysis

Cosmic Filter - Remove Cosmic Background

\( \nu_\mu \) CC Filter

\( \nu_\mu \) CC event?

\( \nu_\mu : \nu_e \approx 10,000 : 1 \)

\( \nu_\mu : \nu_e \approx 200 : 1 \)
**νμ CC Selection**

Use as a constraint to reduce systematic error in ν_e selection, want high νμ CC Efficiency and high νμ CC Purity

**Strategy:** same as filter but focus on optimizing purity instead of misID

- Further cosmic removal using more strict Wire-Cell cosmic tagger
- Use a smaller fiducial volume to define “inside the TPC” to minimize dirt and cosmics
- Cut values of likelihood ratio functions changed from filter

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**MicroBooNE Preliminary**

78% Efficiency

90% Purity
**ν_μ** CC Constraint

High statistics ν_μ sample can be used to constrain many of the uncertainties associated with the ν_e events.

Work on constraint using this inclusive ν_μ selection for the inclusive ν_e analysis is in-progress.

Example of constraint using a toy model:
Summary

Developed for MicroBooNE Low Energy Excess Analysis:

- $\nu_\mu$ CC filter
  - 82.4% efficiency and 10.4% $\nu_e$ misID
  - help veto large $\nu_\mu$ CC background for inclusive $\nu_e$ analysis

- $\nu_\mu$ CC selection
  - 78% efficiency and 90% purity
  - use as a constraint sample for inclusive $\nu_e$ analysis

- For more details check out the public note: MICROBOONE-NOTE-1088-PUB

Thank You!
Backup
PID

- **Using Calorimetry-Likelihood PID**
  - Uses the profile of the deposited charge per unit length: dE/dx
  - The average dE/dx at a given residual range (the distance from the end of the track to the given point) depends on the particle's mass, and can therefore be used to distinguish particles
  - dE/dx information for one plane is used to determine a particle-type likelihood for each track
  - The three planes are combined by multiplying their likelihoods
Performance: With $\nu_e$ Selection

Without $\nu_\mu$ CC Filter

$\chi^2$/ndf = 30.7 / 20

$\nu_\mu$ CC : $\nu_e$ CC = 1.8 : 1

With $\nu_\mu$ CC Filter

$\chi^2$/ndf = 25.9 / 20

$\nu_\mu$ CC : $\nu_e$ CC = 0.9 : 1
\( \nu_\mu \) CC Constraint

- \( \nu_e \) statistics very low
  - Even if analysis selection was 100% would only have about 100 \( \nu_e \) events in \( 5 \text{e19 POT} \)
  - Errors can easily become unmanageable

- \( \nu_\mu \) is a much higher statistic sample
  - This selection sees almost 8500 \( \nu_\mu \) events in \( 5 \text{e19 POT} \)