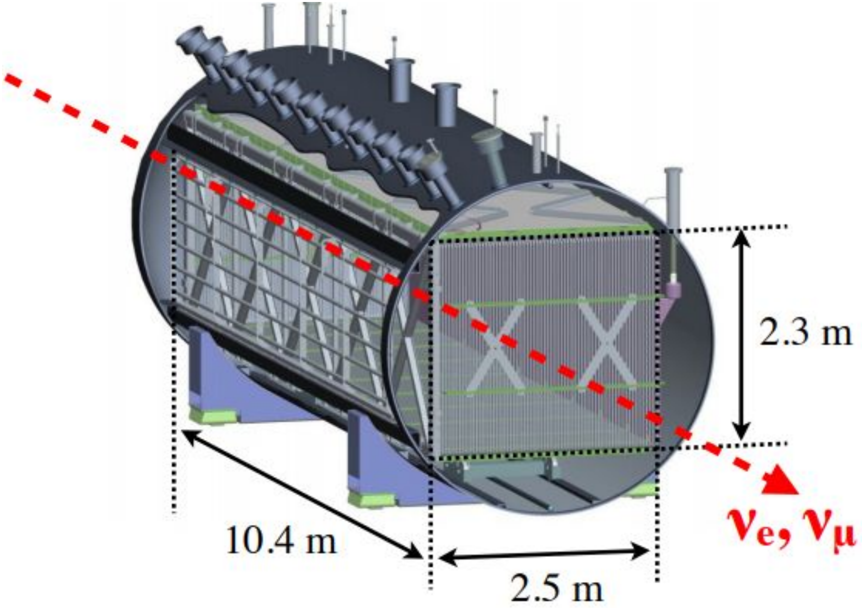
A Charged-Current ν_μ Veto for the Inclusive ν_e Analysis in MicroBooNE

Erin Yandel
University of California - Santa Barbara

New Perspectives
August 25, 2020

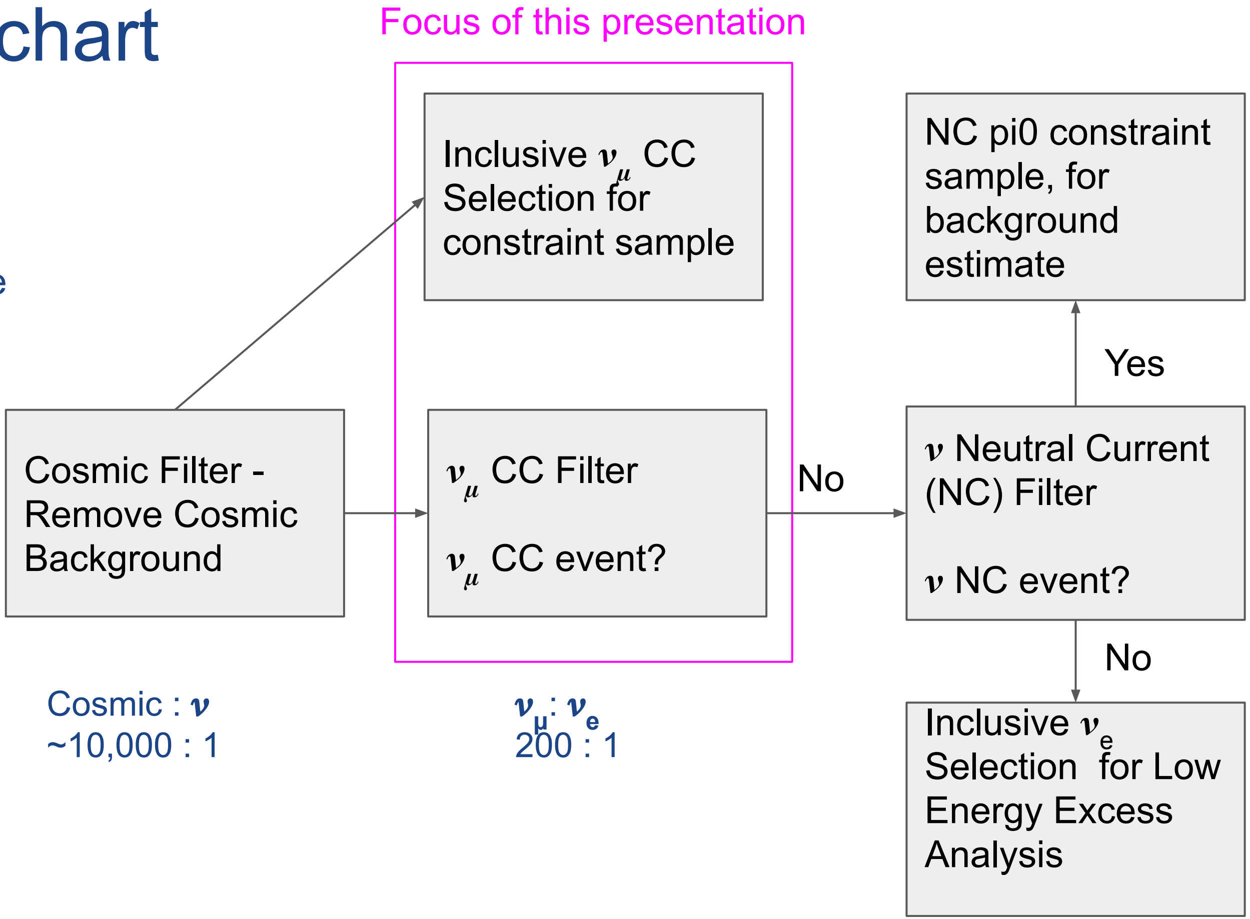
MicroBooNE

- 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 ν_e analysis
- See Lauren Yates's July 21 New Perspectives talk [“Five Years of MicroBooNE and Beyond in Ten Minutes”] for more details



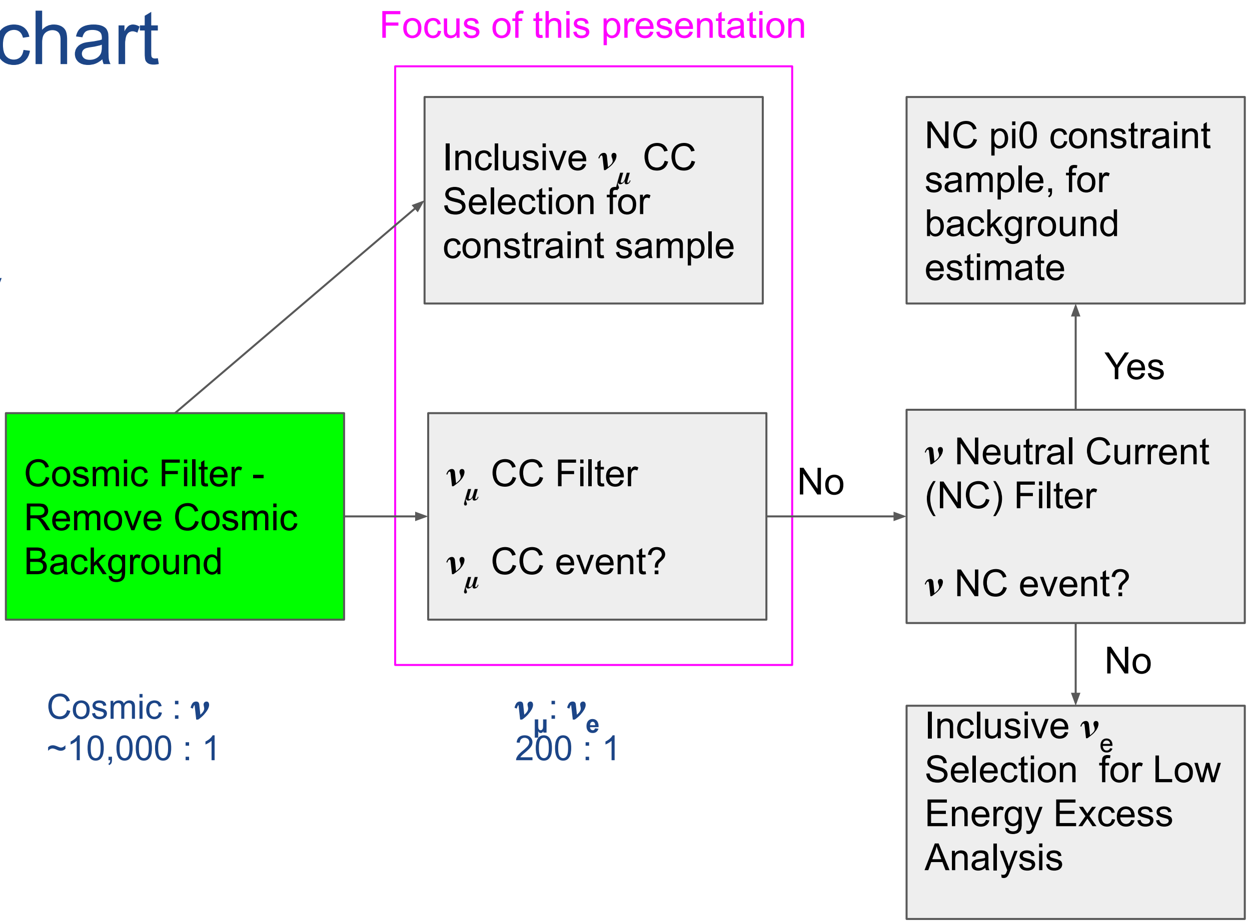
ν_e Analysis Flowchart

overwhelming ν_μ Charged-Current (CC) and cosmic background in the inclusive ν_e selection needed for the low energy excess analysis



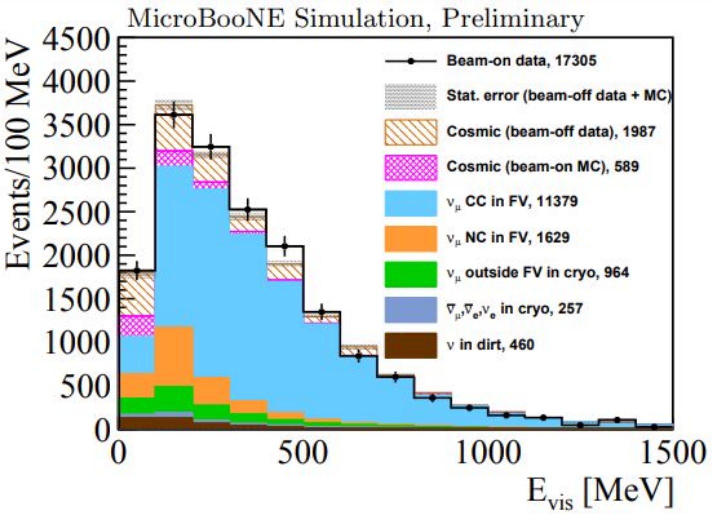
ν_e Analysis Flowchart

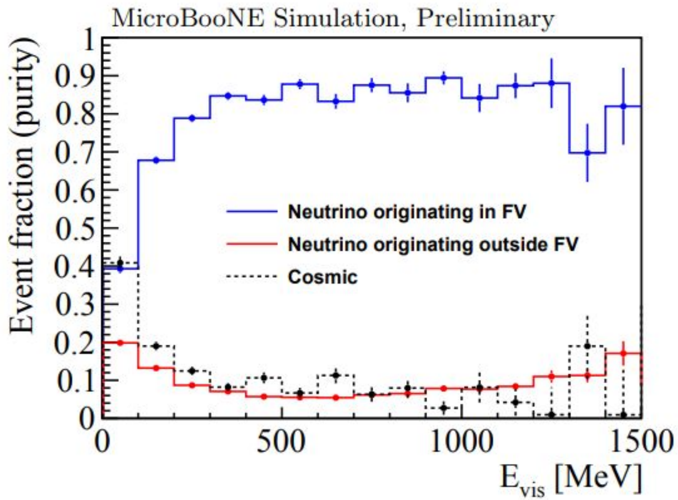
overwhelming ν_μ CC and cosmic background in the inclusive ν_e selection needed for the low energy excess analysis



Cosmic Removal

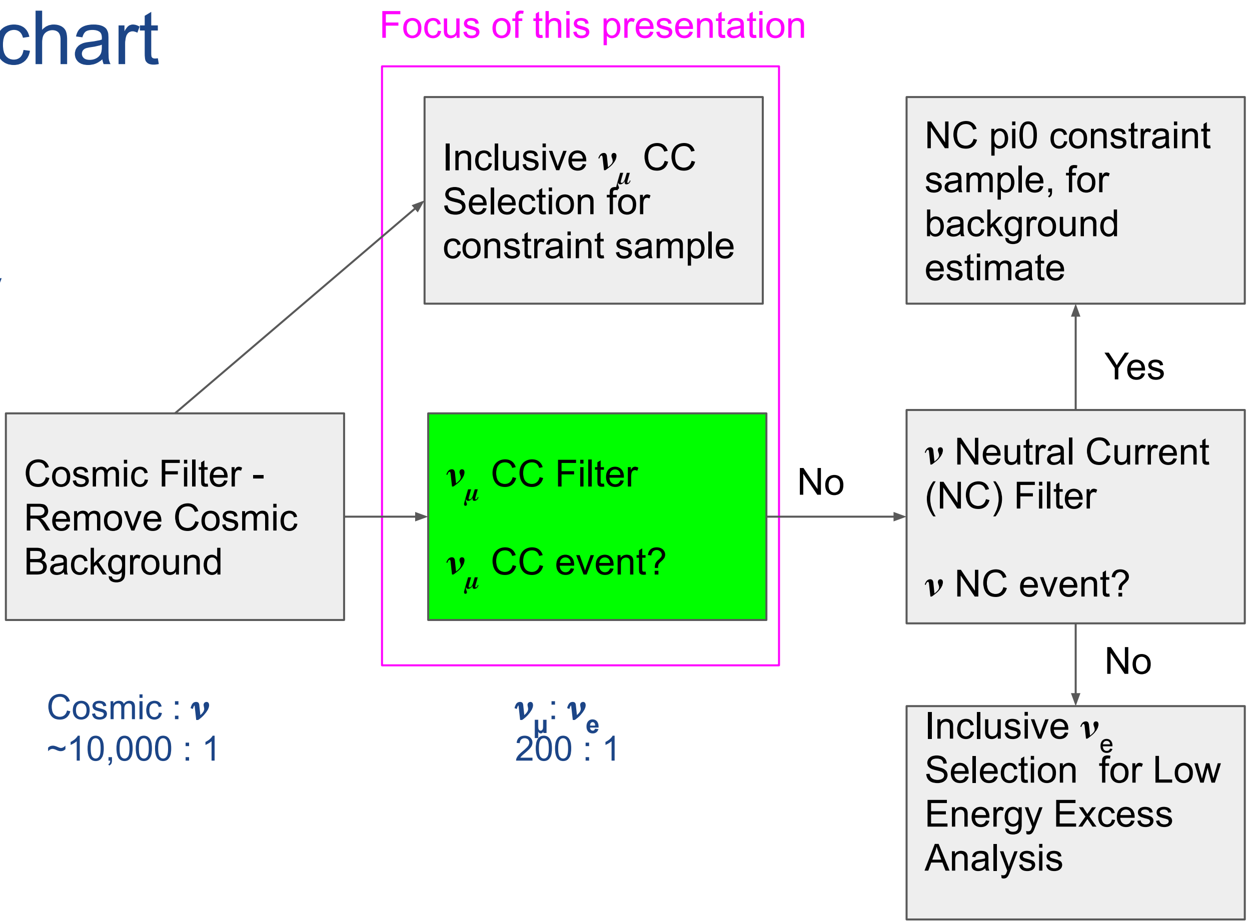
- With a surface-level detector like MicroBooNE, cosmic rays are a major background
- Before event selection, Wire-Cell Cosmic Rejection (MICROBOONE-NOTE-1084-PUB) are used to remove 98.6% of cosmic events
- Raises ν:Cosmic ratio to 7.6:1 (from 10,000:1 at raw data level)
- Muon Neutrino in a 3cm Fiducial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





ν_e Analysis Flowchart

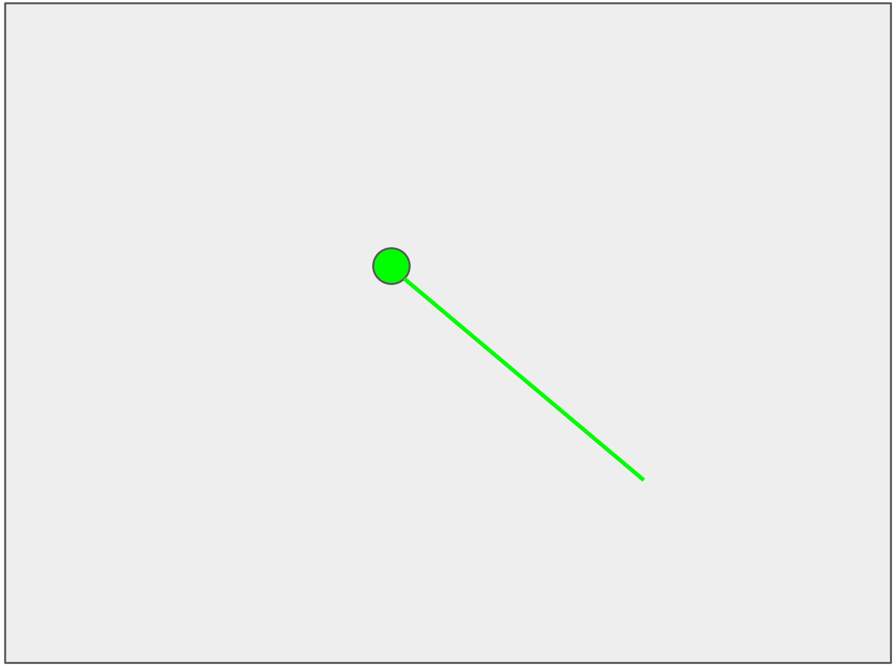
overwhelming ν_μ CC and cosmic background in the inclusive ν_e selection needed for the low energy excess analysis



ν_μ CC Filter

Use to remove ν_μ CC events for ν_e selection, want high ν_μ CC efficiency and low ν_e mis-ID

Strategy: identify a muon track associated with neutrino vertex

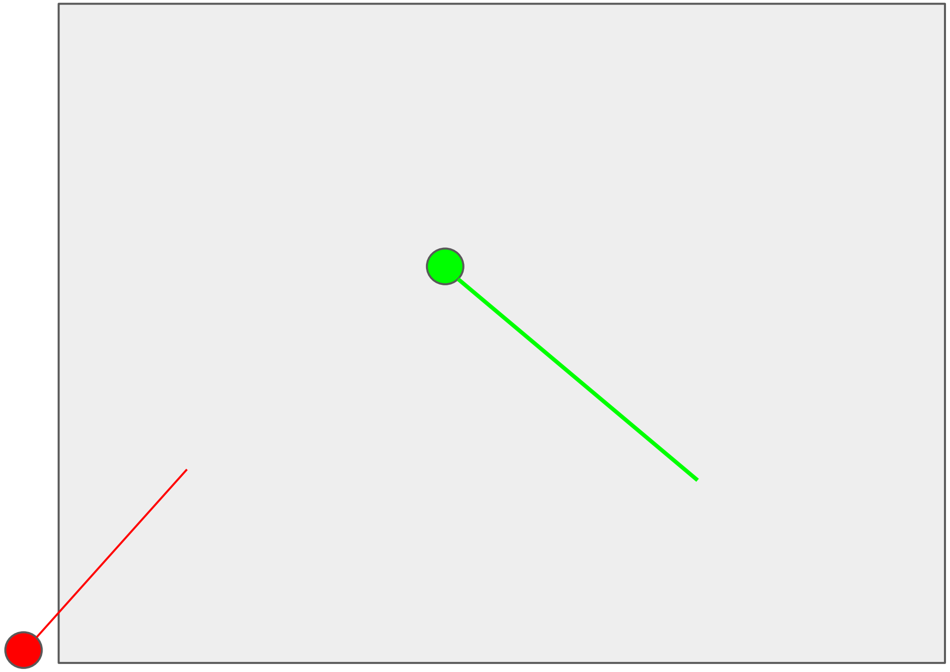


ν_μ CC Filter

Use to remove ν_μ CC events for ν_e selection, want high ν_μ CC efficiency and low ν_e mis-ID

Strategy: identify a muon track associated with neutrino vertex

1. reconstructed neutrino vertex is inside the TPC

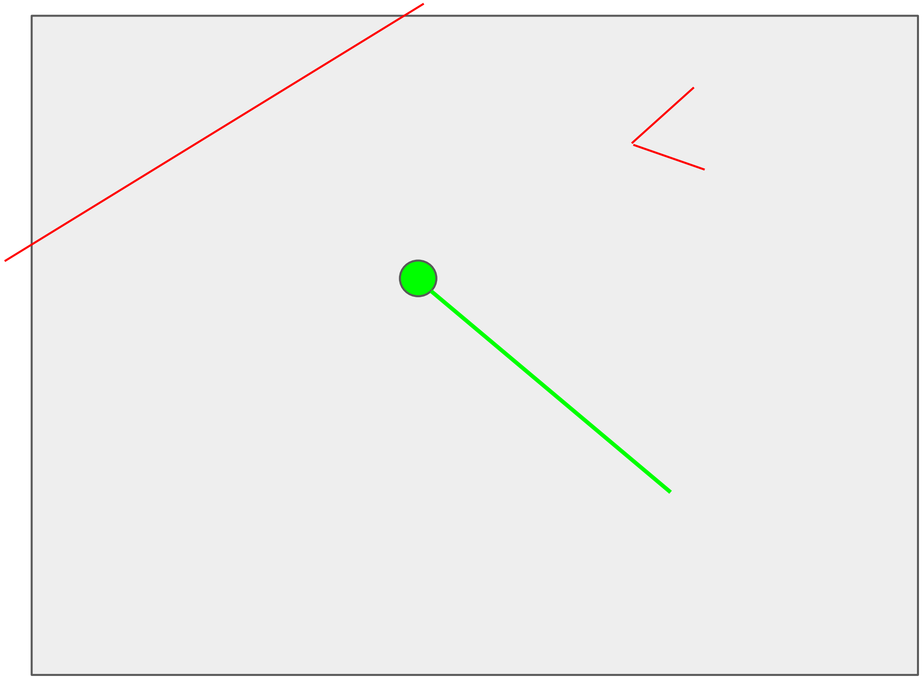


ν_μ CC Filter

Use to remove ν_μ CC events for ν_e selection, want high ν_μ CC efficiency and low ν_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

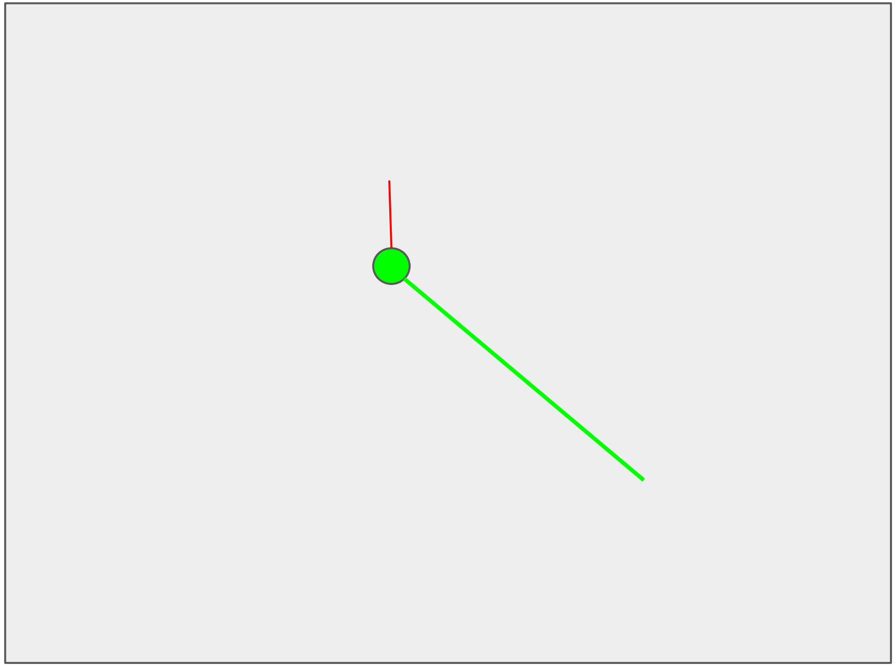


ν_μ CC Filter

Use to remove ν_μ CC events for ν_e selection, want high ν_μ CC efficiency and low ν_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

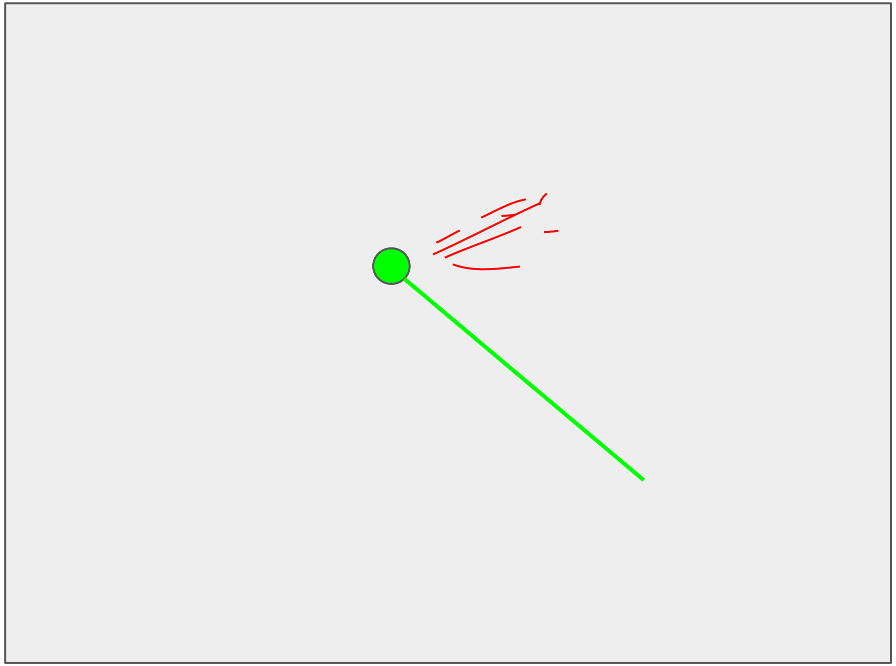


ν_μ CC Filter

Use to remove ν_μ CC events for ν_e selection, want high ν_μ CC efficiency and low ν_e mis-ID

Strategy: identify a muon track associated with neutrino vertex

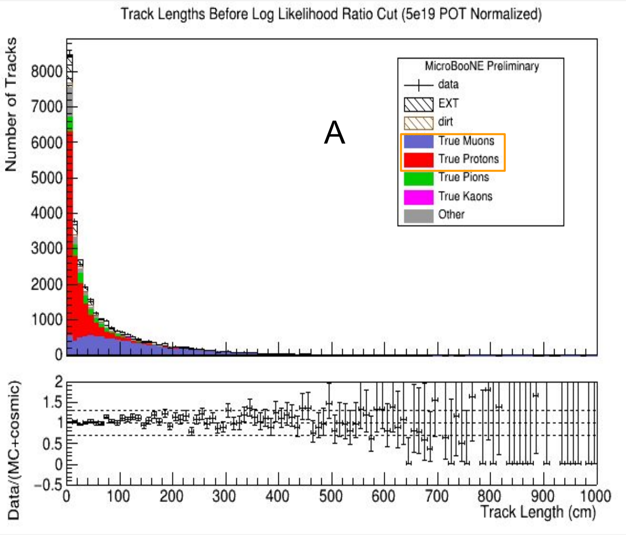
1. reconstructed neutrino vertex is inside the TPC
2. At least one track associated with reconstructed neutrino vertex
3. At least one of these tracks has log likelihood ratios consistent with a muon
    a. Muon/Proton
    b. Muon/Proton for tracks exiting the TPC
    c. Muon/Pion
4. “Track-like” (μ-like)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

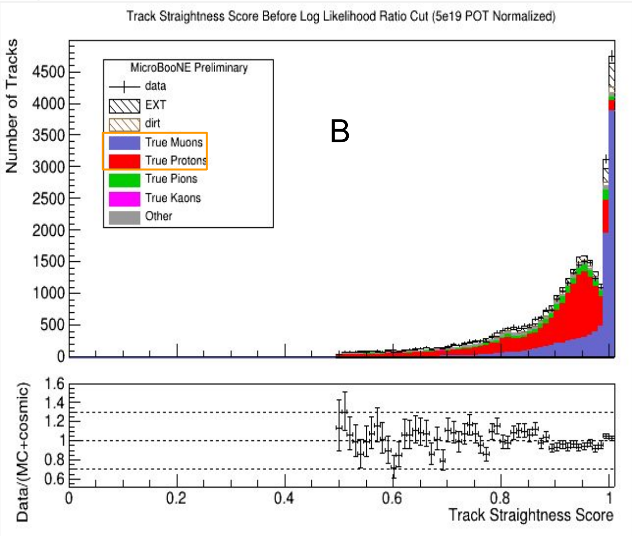


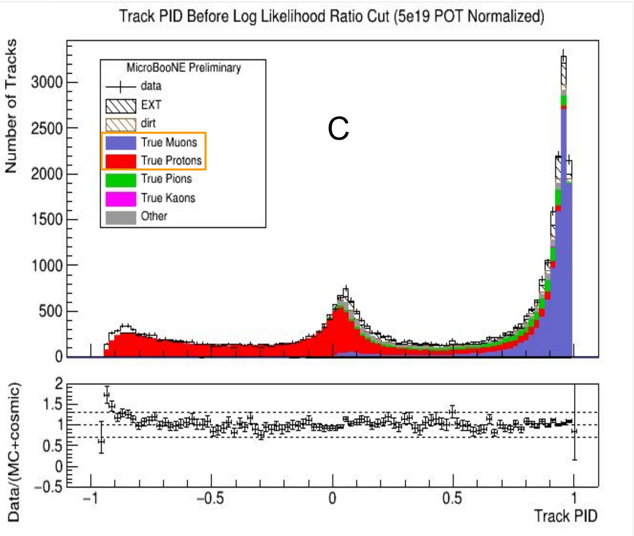
Log Likelihood Ratios: Muon/Proton

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

$$R_{Likelihood} = \frac{P(Muon)}{P(Proton)} = \frac{A_{Muon} * B_{Muon} * C_{Muon}}{A_{Proton} * B_{Proton} * C_{Proton}}$$





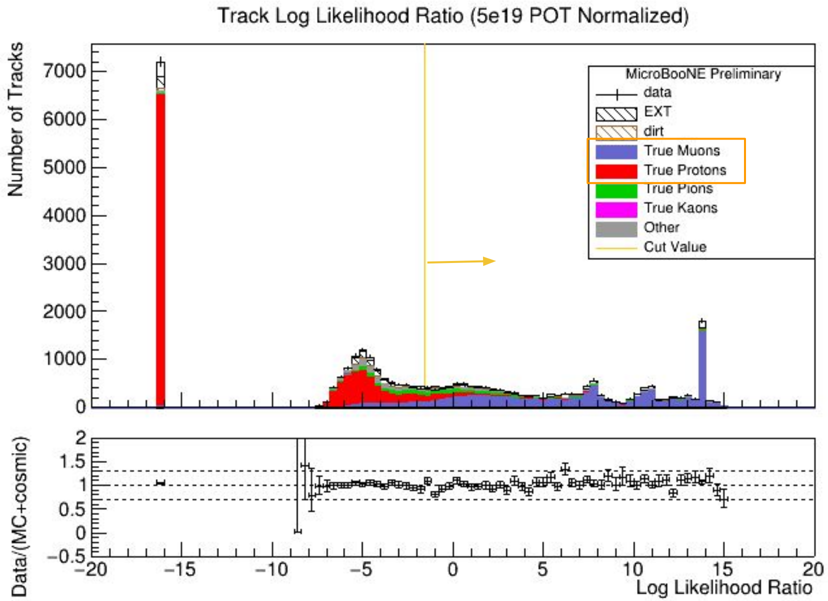


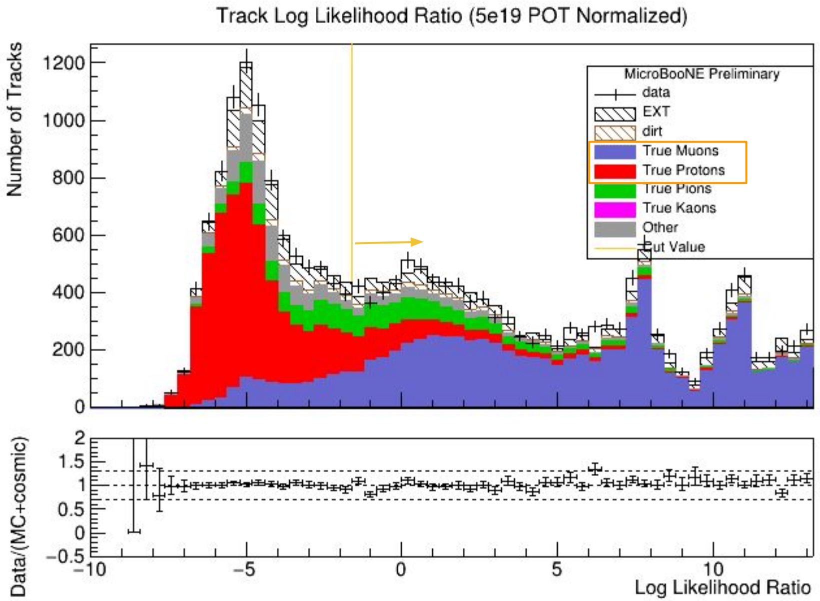
EXT = beam-off (cosmics only) data
Dirt = ν interaction outside the TPC

Log Likelihood Ratios: Muon/Proton

Efficiency: 84%   MisID: 24%

Main mode of misID: charged pion selected as muon





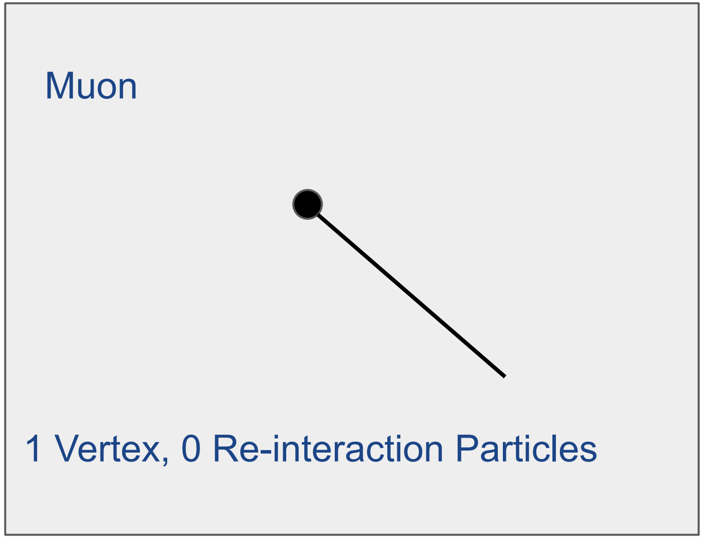
Two large bins from corrections for Prob(muon)=0 or Prob(proton)=0 - avoid divide by 0 or log(0) errors

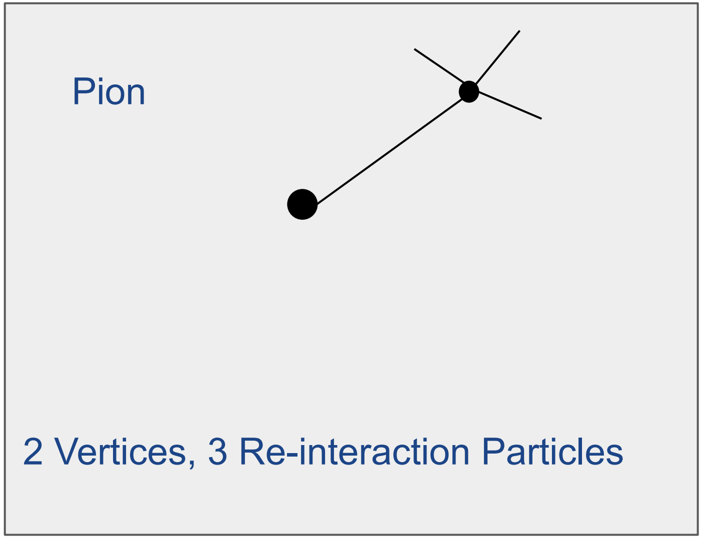
Log Likelihood Ratios: Muon/Pion

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

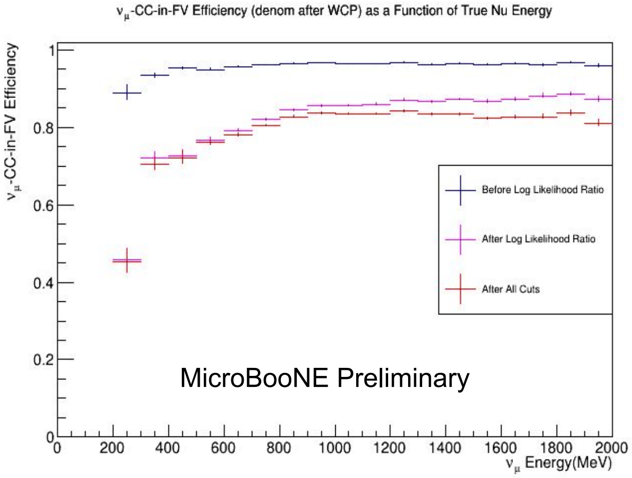




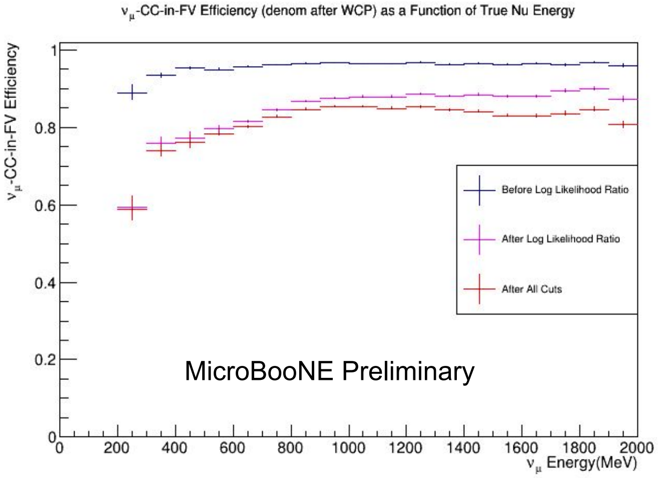
Non-Contained Muon/Proton Log Likelihood Ratio

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

Before

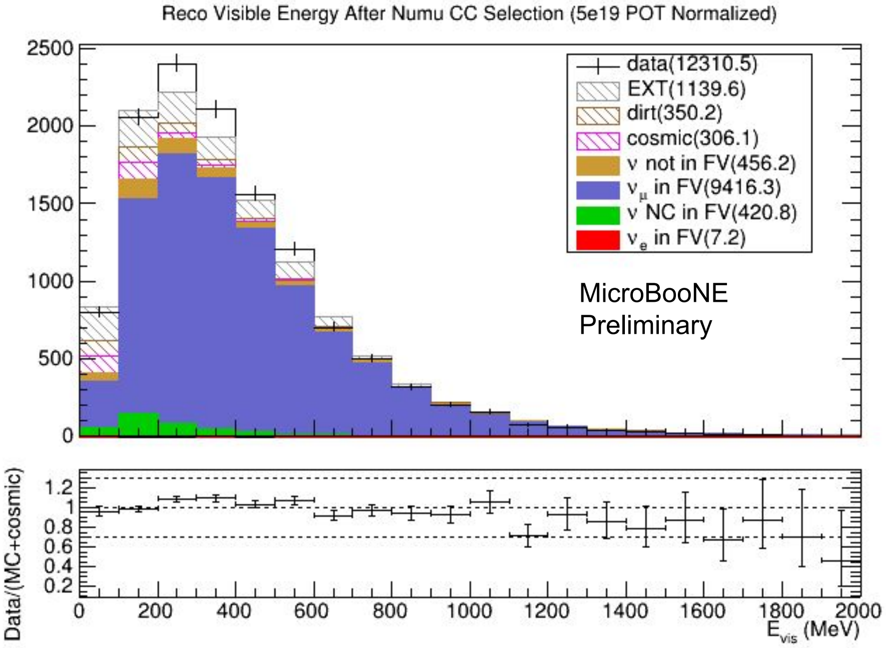


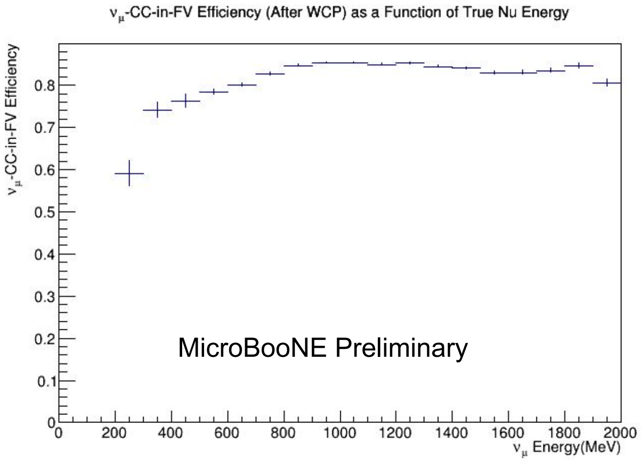
After

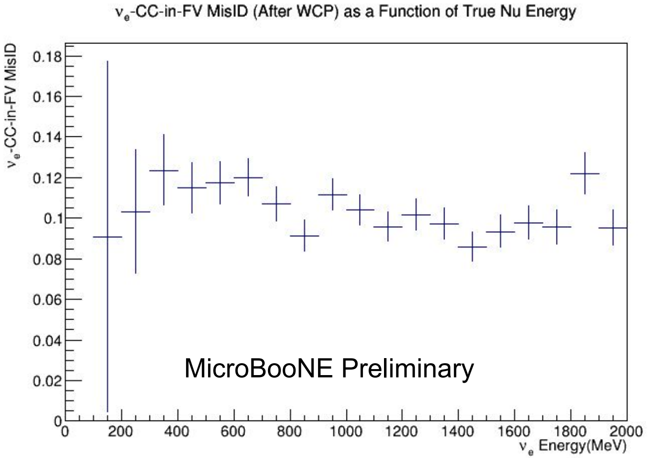


Performance

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

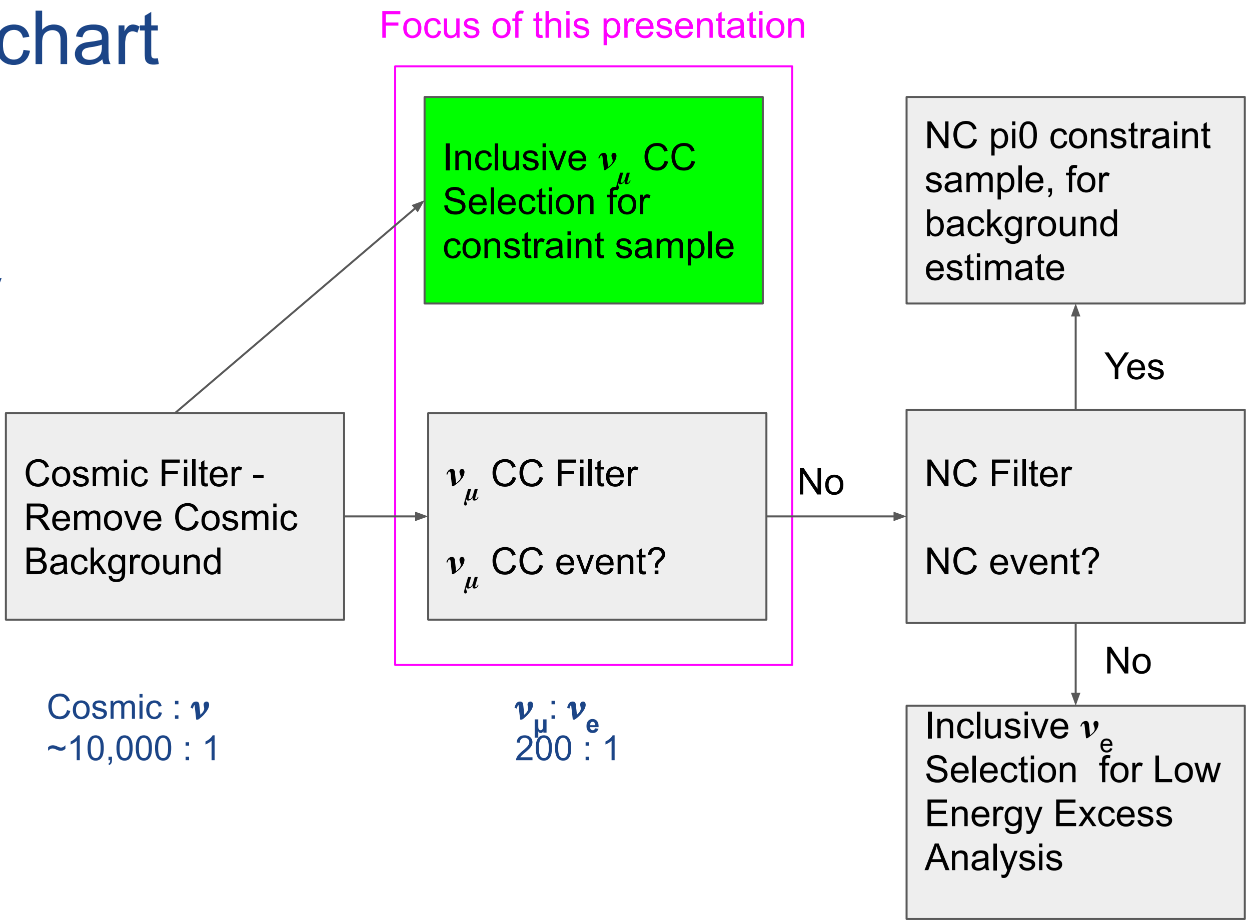






ν_e Analysis Flowchart

overwhelming ν_μ CC and cosmic background in the inclusive ν_e selection needed for the low energy excess analysis

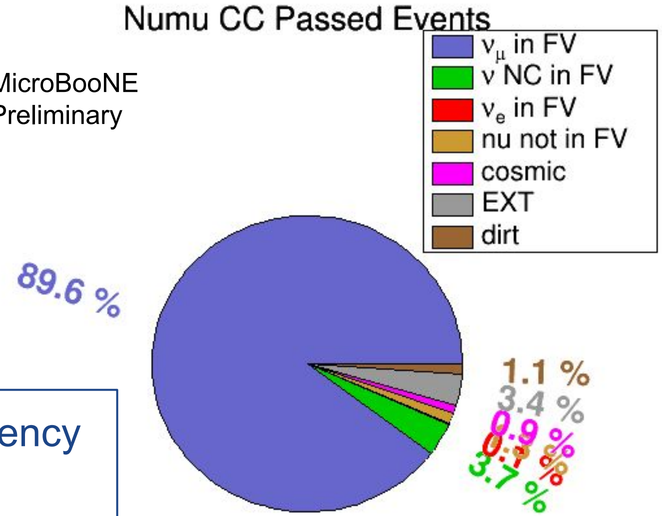


ν_μ CC Selection

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

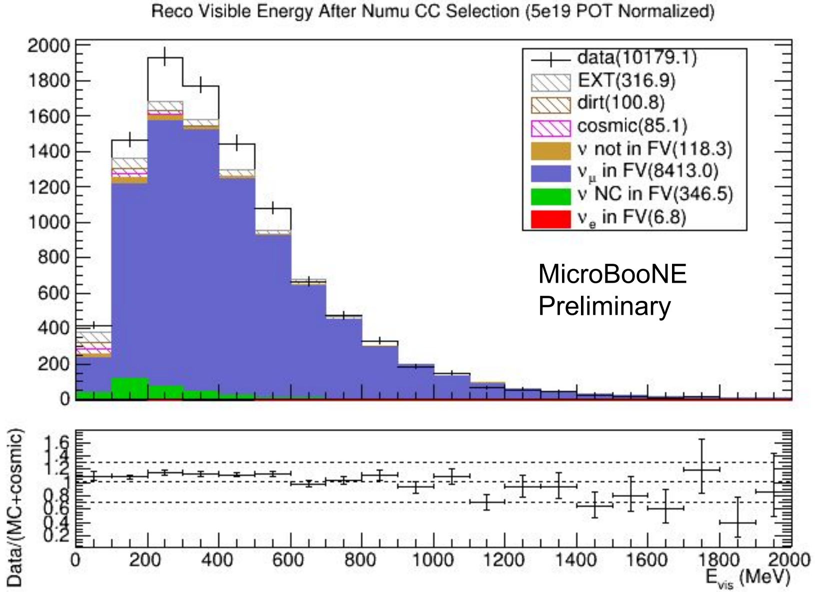
Strategy: same as filter but focus on optimizing purity instead of misID

- 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



78% Efficiency

90% Purity

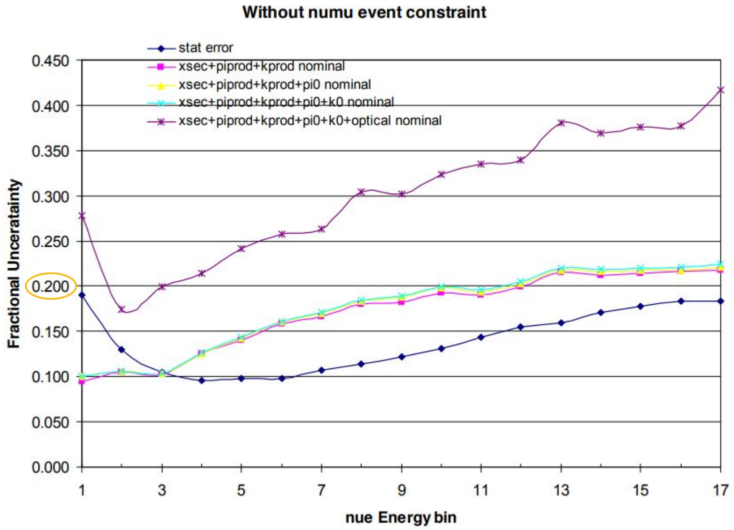


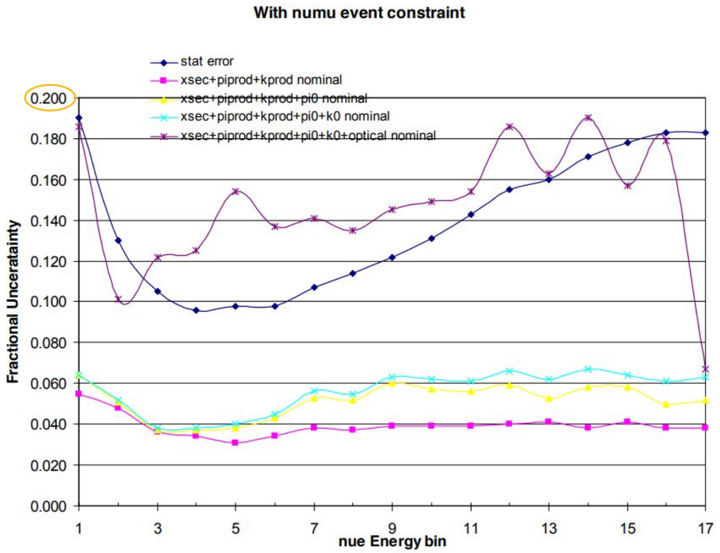
ν_μ CC Constraint

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:





Mike Shaevitz (docdb-7583)

Summary

Developed for MicroBooNE Low Energy Excess Analysis:

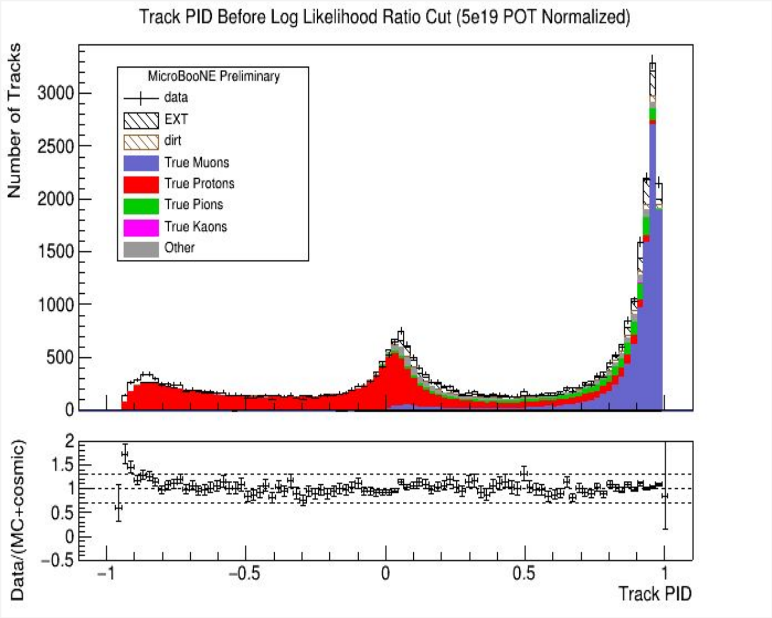
- ν_μ CC filter
  - 82.4% efficiency and 10.4% ν_e misID
  - help veto large ν_μ CC background for inclusive ν_e analysis
- ν_μ CC selection
  - 78% efficiency and 90% purity
  - use as a constraint sample for inclusive ν_e analysis
- For more details check out the public note: MICROBOONE-NOTE-1088-PUB

Thank You!

Backup

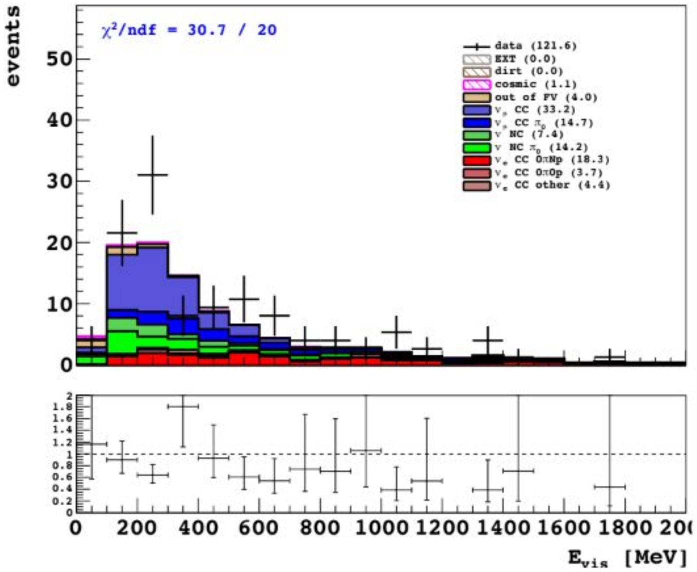
PID

- 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



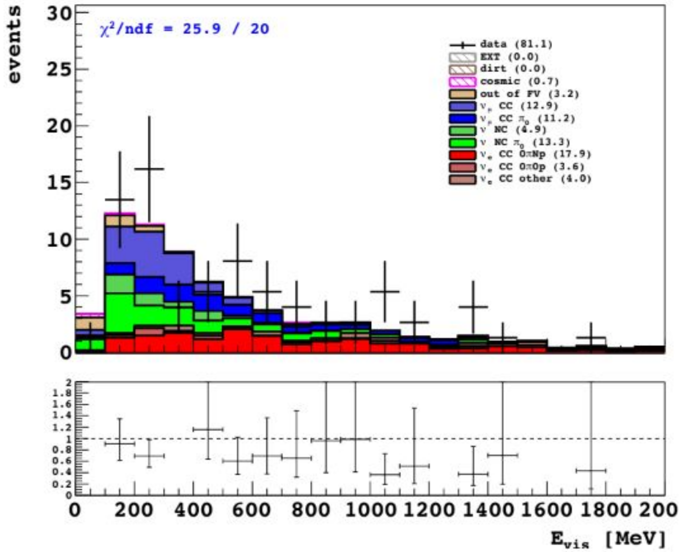
Performance: With ν_e Selection

Without ν_μCC Filter



ν_μCC : ν_eCC = 1.8 : 1

With ν_μCC Filter



ν_μCC : ν_eCC = 0.9 : 1

ν_μ CC Constraint

- ν_e statistics very low
  - Even if analysis selection was 100% would only have about 100 ν_e events in 5e19 POT
  - Errors can easily become unmanageable
- ν_μ is a much higher statistic sample
  - This selection sees almost 8500 ν_μ events in 5e19 POT