# Constraining the NC $\pi^0$ Background for MicroBooNE's Single-Photon Search

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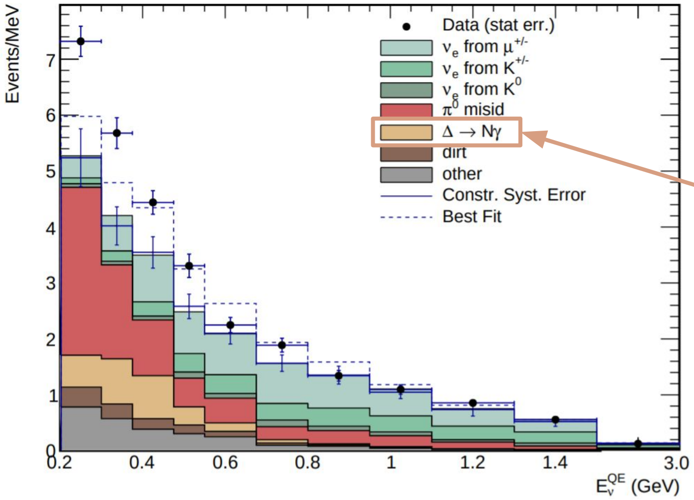
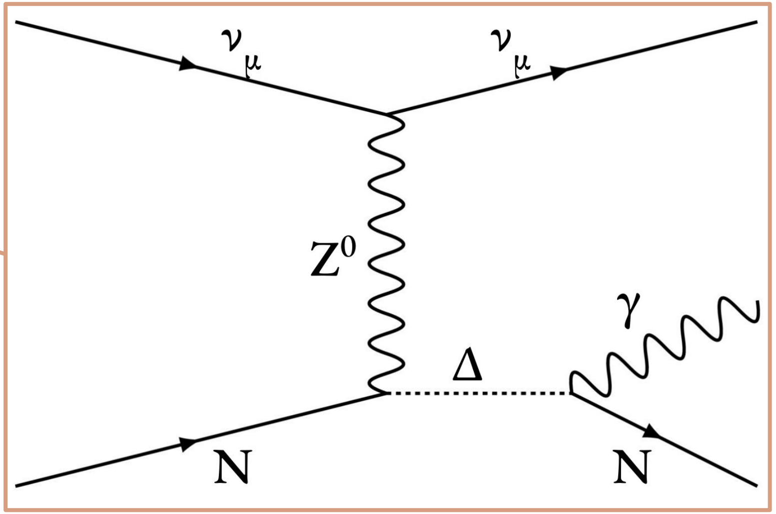
μBooNE

# MiniBooNE Low-Energy Excess

- Observed excess of electron neutrino-like events below 600 MeV
- Cherenkov detector; difficulty distinguishing photons and electrons
- MicroBooNE is searching for $\Delta \rightarrow N\gamma$ to investigate photon-like hypothesis
  - See talk by M. Ross-Lonergan

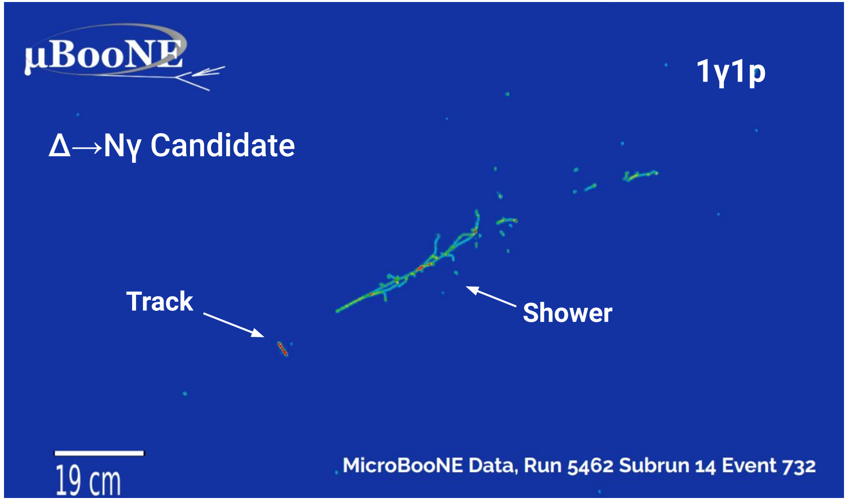


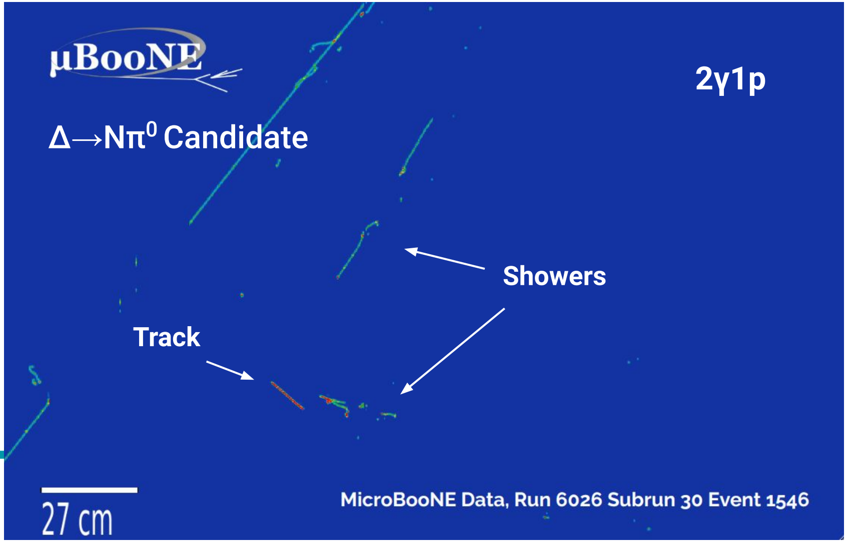

https://arxiv.org/abs/2006.16883



# Neutral Current (NC) $\pi^0$

- NC $\pi^0$s comprise **~80% of backgrounds** for the NC Δ radiative decay search
  - Δ→Nγ branching ratio: ~0.6%
  - Δ→Nπ branching ratio: ~99.4%
- NC $\pi^0$ events in which only one photon is reconstructed look nearly identical to Δ radiative decays
- One-shower, one-track topology (1γ1p) vs. two-shower, one-track (2γ1p) topology
- Plan: use single-photon analysis framework to select NC $\pi^0$ events for **data-driven rate constraint**



# Analysis Flow

## 1. Signal Topology

- Start with reconstructed tracks and showers [2]
- Select events with two showers (2γ) and one track (1p)

## 2. Reject Backgrounds

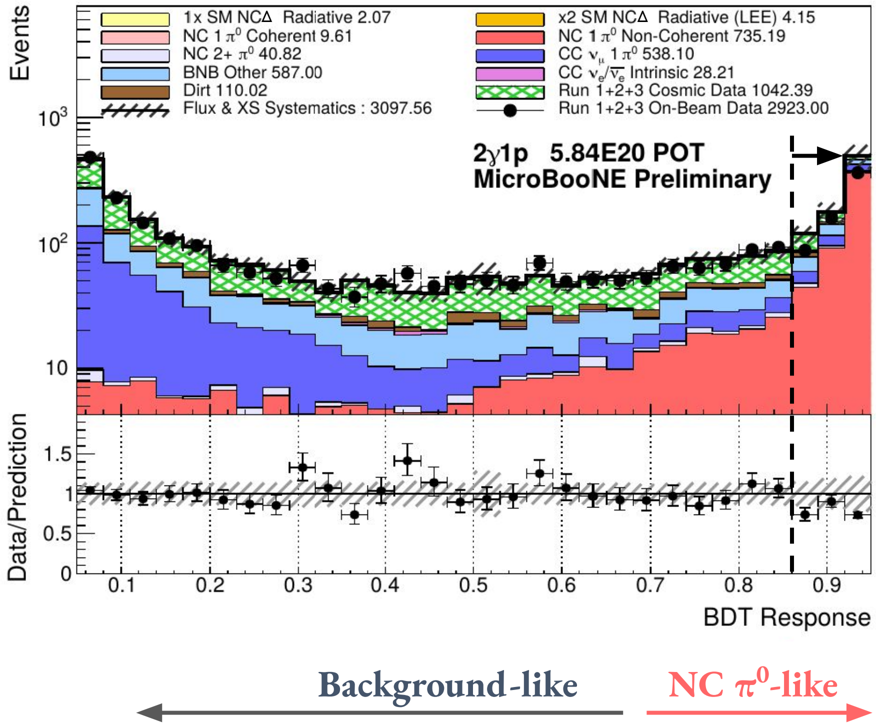
- Use tailored Boosted Decision Tree (BDT) [3] trained on background events
- Reject backgrounds by cutting on BDT response

## 3. High-Stats NC $\pi^0$ Selection

- Result is the world's highest-stats NC $\pi^0$ selection on argon
- Constrain single-photon NC $\pi^0$ background

[2] Acciarri, R. et. al. The Pandora multi-algorithm approach to automated pattern recognition of cosmic-ray muon and neutrino events in the MicroBooNE detector. *The European Physical Journal C*, *78*(1), 1-25.
[3] Chen, T., He, T., Benesty, M., Khotilovich, V., & Tang, Y. (2015). Xgboost: extreme gradient boosting. *R package version 0.4-2*, 1-4.

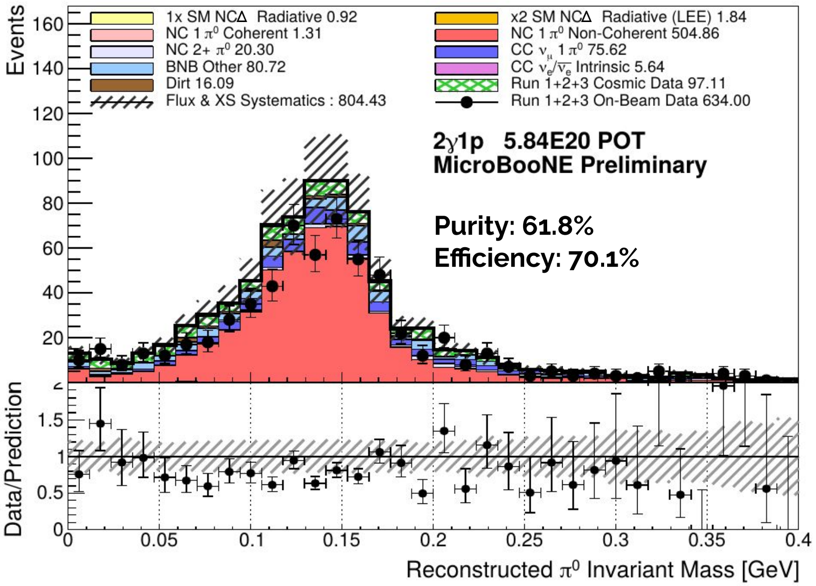
# Boosted Decision Tree

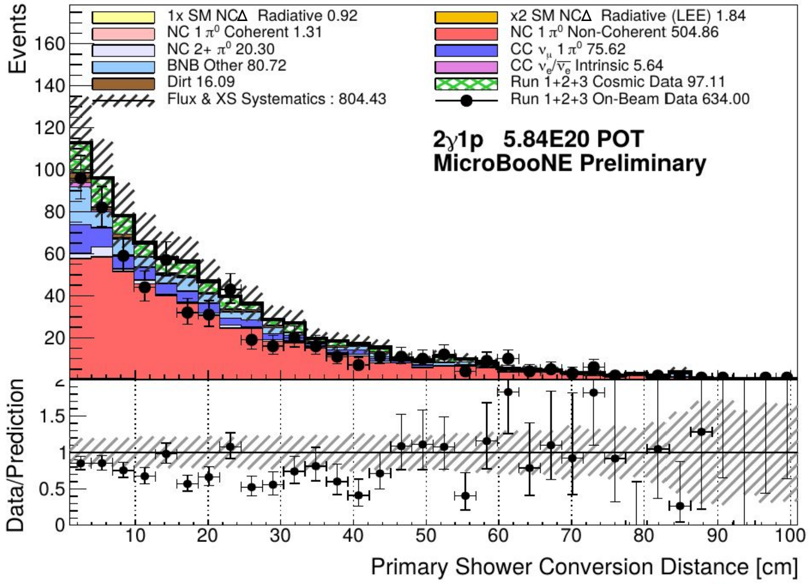



- Train Boosted Decision Tree (BDT) to reject backgrounds
- Input simulated kinematic and geometric variables
  - Shower energy, shower conversion distance, track length, etc.
- BDT learns to separate signal and background based on input variables
- Cut on BDT response (score) to maximize efficiency times purity in the final selection

# Final Selection

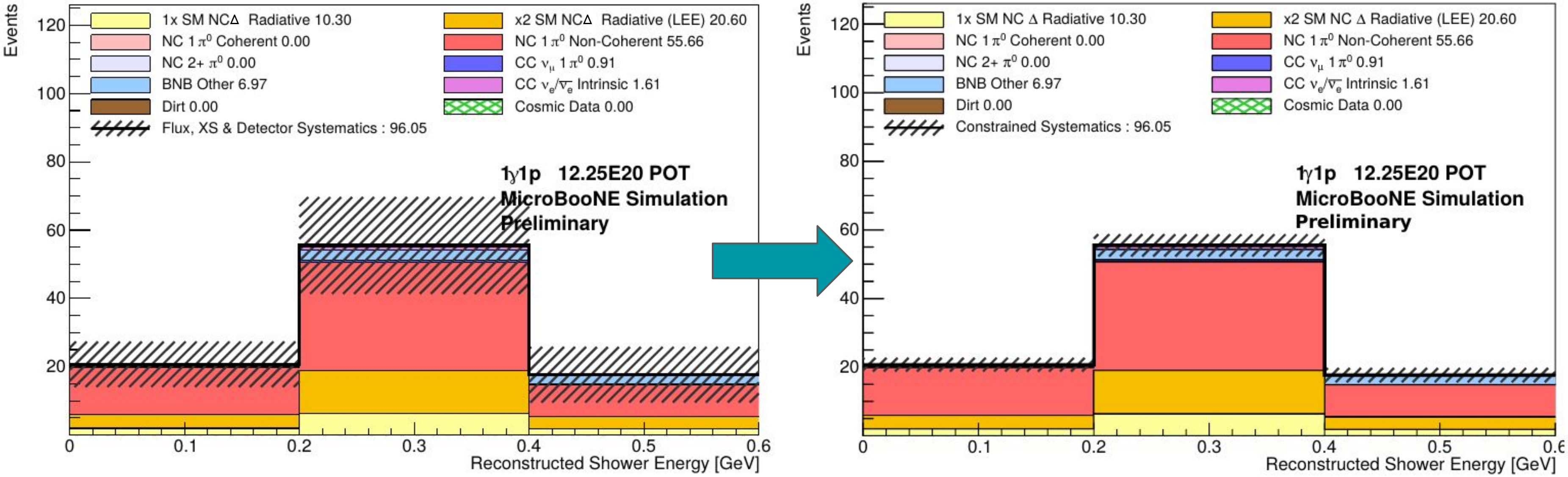
- ~20% difference between number of selected data events and MC prediction
  - Consistent with 1σ lower bound on interaction model estimate
- Gaussian-plus-linear fit to mass peak data gives a mean of 138.9 ± 2.1 MeV

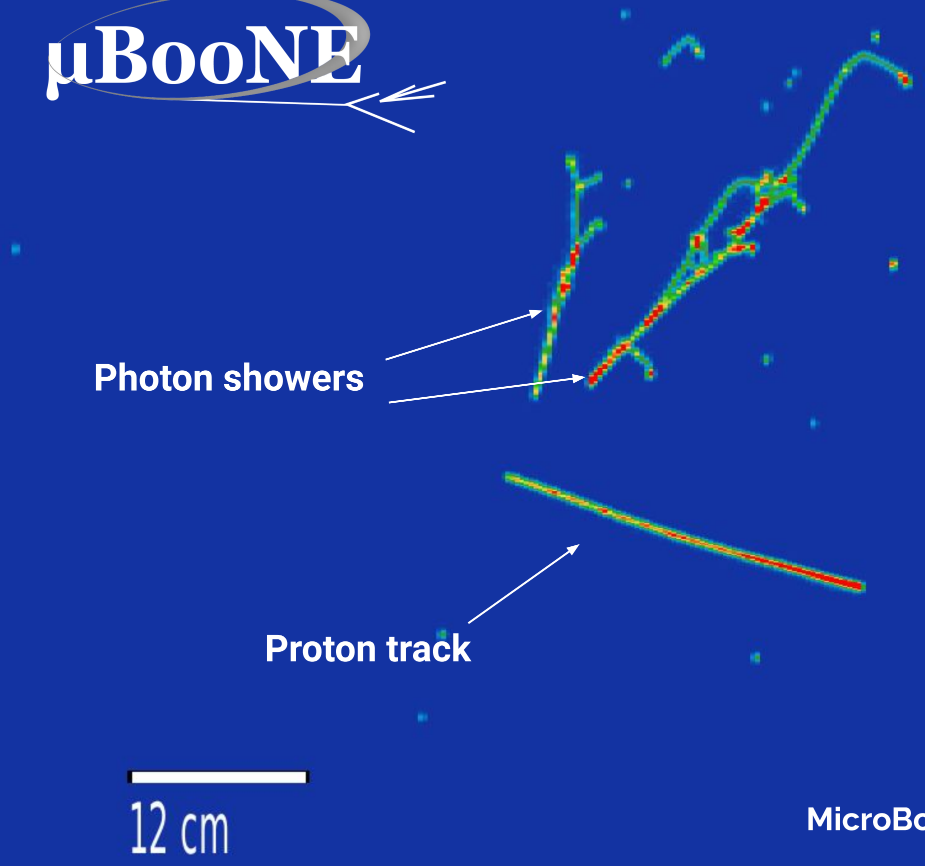


# Constraint Result

- NC $\pi^0$ constraint provides a large reduction in correlated interaction uncertainties
- Significantly improves sensitivity to photon-like LEE signal





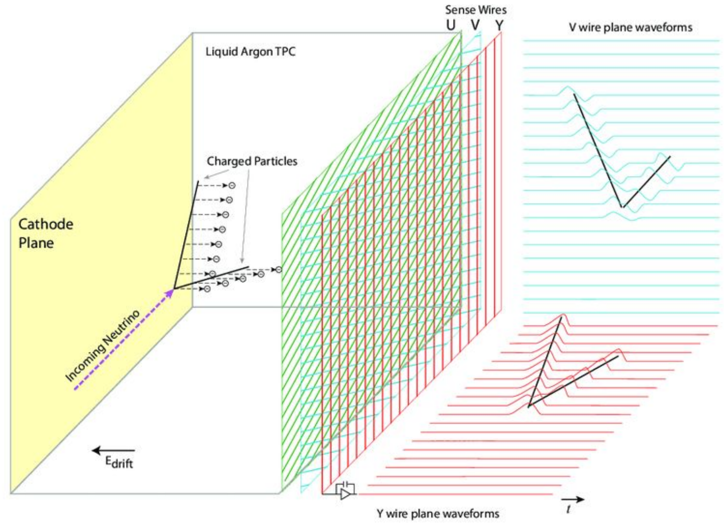

- Demonstrated world's highest-stats NC $\pi^0$ selection on Argon
  - Still more data to process!
- Constraint provides a significant reduction in single-photon systematics

MicroBooNE Data, Run 15318 Subrun 159 Event 7958

# Backup

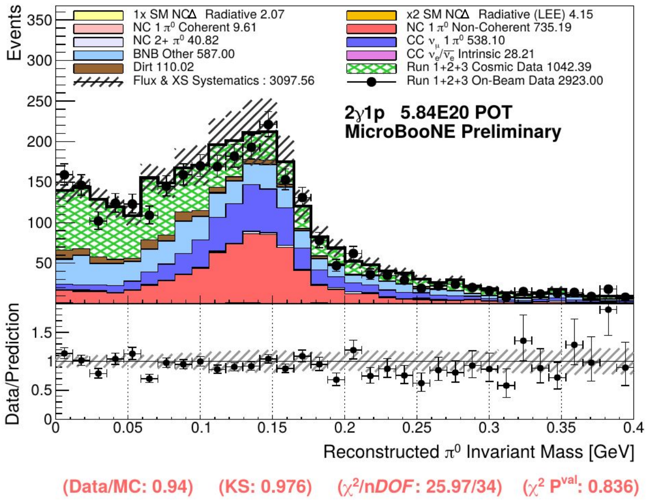
# MicroBooNE

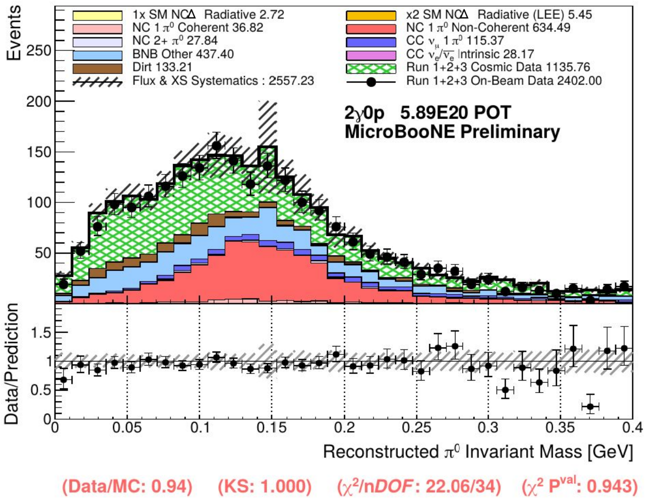
- 170-ton (89 ton active volume) Liquid Argon Time Projection Chamber (LArTPC)
- Operating along Fermilab's Booster Neutrino Beam (BNB) since 2015
- Primary goal: investigation of the MiniBooNE Low-Energy Excess (LEE)



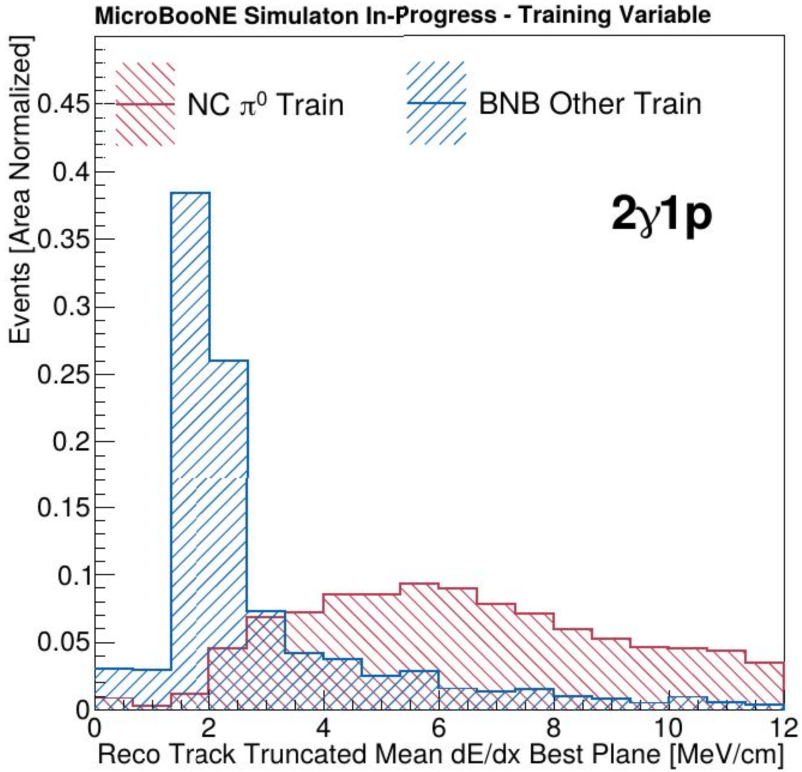
# Pre-Selection Distributions

- Before BDTs, apply some conservative pre-selection cuts
  - Shower energies, conversion distance, etc.
- Signal (red) dominated by off-beam (green) and on-beam backgrounds (blue and brown)



# BDT Training




- Train BDT on various kinematic and calorimetric variables in simulation
- Training variables chosen based on separation power between signal and background
- Example: track dE/dx (left)
  - dE/dx: energy deposition per unit length
  - Separates events with proton-like track for 2g1p selection
  - Peak at 2 MeV/cm mostly from muon tracks

# Pre-Selection Cuts

- 2g1p pre-selection cuts:
  - 5 cm fiducial volume on vertex
  - Both shower conversion distances > 1 cm
  - Leading shower energy > 30 MeV
  - Subleading shower energy > 20 MeV
  - Distance from track start point to vertex < 10 cm
- 2g0p pre-selection cuts:
  - 5 cm fiducial volume on vertex
  - Leading shower energy > 30 MeV
  - Subleading shower energy > 20 MeV

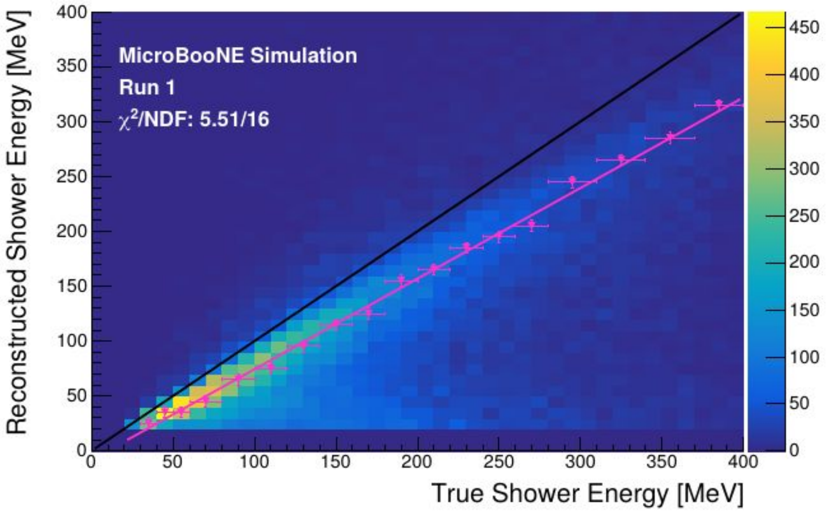
# Training Variables

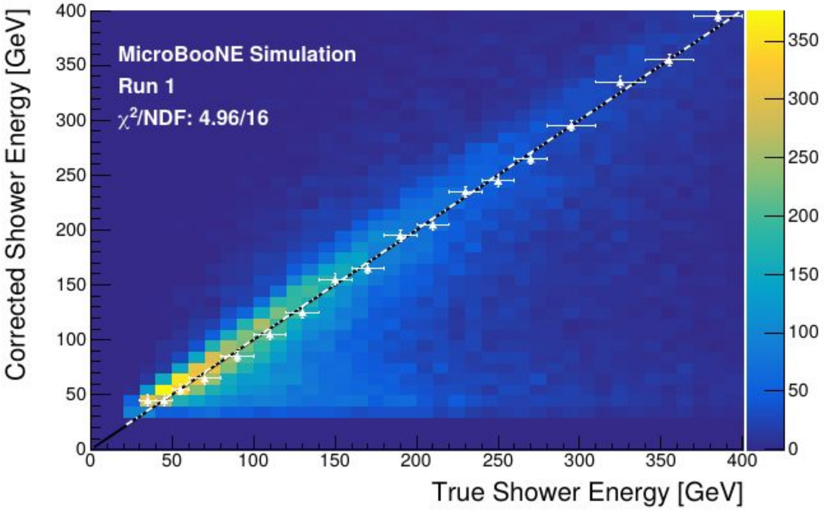
- 2g1p Training variables:
  - Both shower conversion distances
  - Both shower impact parameters
  - Track length
  - Track $\theta_{yz}$
  - Distance from track end point to nearest TPC wall
  - Track mean truncated dE/dx (shown here)
  - Ratio of track start/end dE/dx
- 2g0p Training variables:
  - Both shower conversion distances
  - Both shower impact parameters
  - Both shower energies
  - Both ratios of shower length/energy
  - Leading shower $\theta_{yz}$
  - Pandora neutrino slice score

# Shower Energy Correction

- Shower energy losses due to misclustering and thresholding effects
- Shower energy correction factor derived from fit to reco vs. true shower energy

$$E_{\mathrm{corr}} = (1.21 \pm 0.03)E_{\mathrm{reco}} - (-9.88 \pm -4.86)\ \mathrm{MeV}$$



# BNB Other Backgrounds

- Percentages relative to BNB Other, which comprise ~10% of final selection
- Single largest component is cosmic contamination
- Other large backgrounds include general CC events, η's, and "other"

| Background | Percentage |
|---|---|
| $\pi^0$ Charge Exchange | 11.9 |
| CC Multi-$\pi^0$ | 5.3 |
| CC Other | 14.7 |
| NC Other | 6.3 |
| $\eta$ | 18.8 |
| Overlay | 28.3 |
| Other | 14.8 |

# CC $\pi^0$ Backgrounds

- Percentages relative to CC $\pi^0$, which comprise ~10% of final selection
- Most have track matched to proton, not muon
  - Muon tracks sometimes not reconstructed
  - Looks exactly like signal

| Background | Percentage |
|---|---|
| Proton track | 49.6 |
| Muon track | 11.5 |
| Shower Mis-ID | 31.4 |
| Overlay | 2.2 |
| Other | 5.4 |

# Interaction Types

- ~80% resonant interactions in both 2γ1p and 2γ0p
- More coherent in 0p selection

| | Resonant | DIS | QE | Coherent | MEC |
|---|---|---|---|---|---|
| $2\gamma 1p$ | | | | | |
| Pre-Selection | 81.3% | 16.3% | 1.3% | 1.31% | 0.06% |
| Final Selection | 85.2% | 13.2% | 1.2% | 0.28% | 0.07% |
| $2\gamma 0p$ | | | | | |
| Pre-Selection | 79.1% | 14.9% | 0.52% | 5.5% | 0.02% |
| Final Selection | 79.2% | 13.5% | 0.45% | 6.8% | 0.00% |