DPF 2019 - Boston, MA

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

Kathryn Sutton

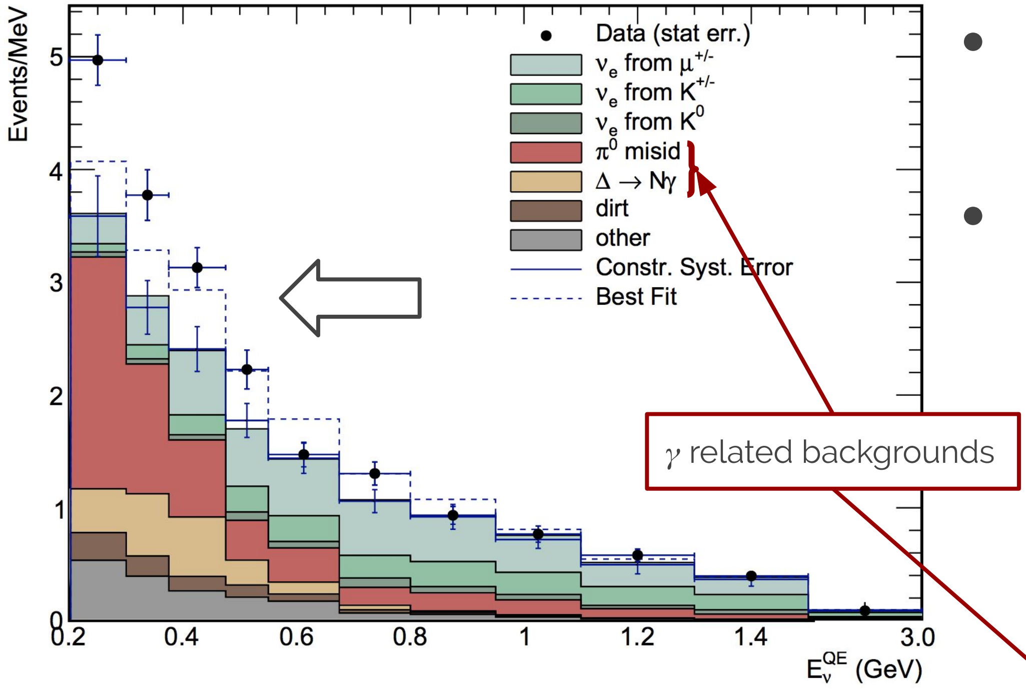
On behalf of the MicroBooNE Collaboration

July 30th 2019

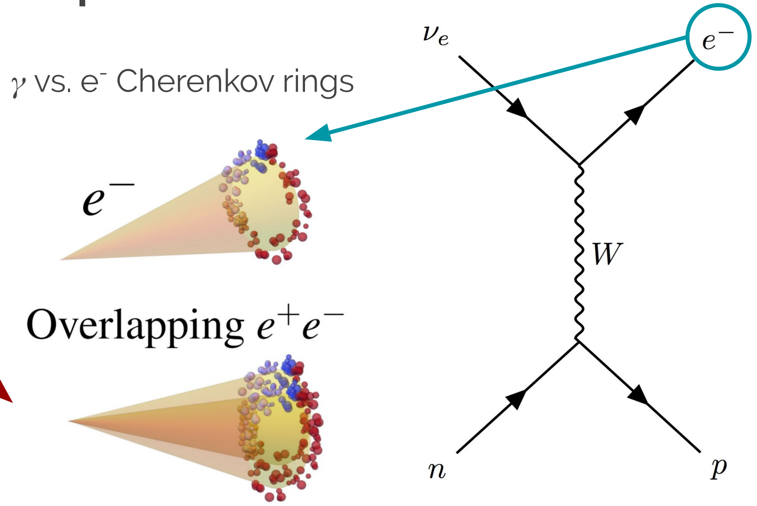
NEVIS LABORATORIES
COLUMBIA UNIVERSITY

μBooNE

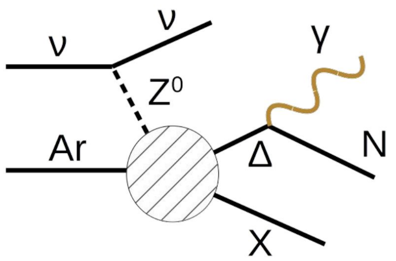
MiniBooNE Low Energy Excess (LEE)



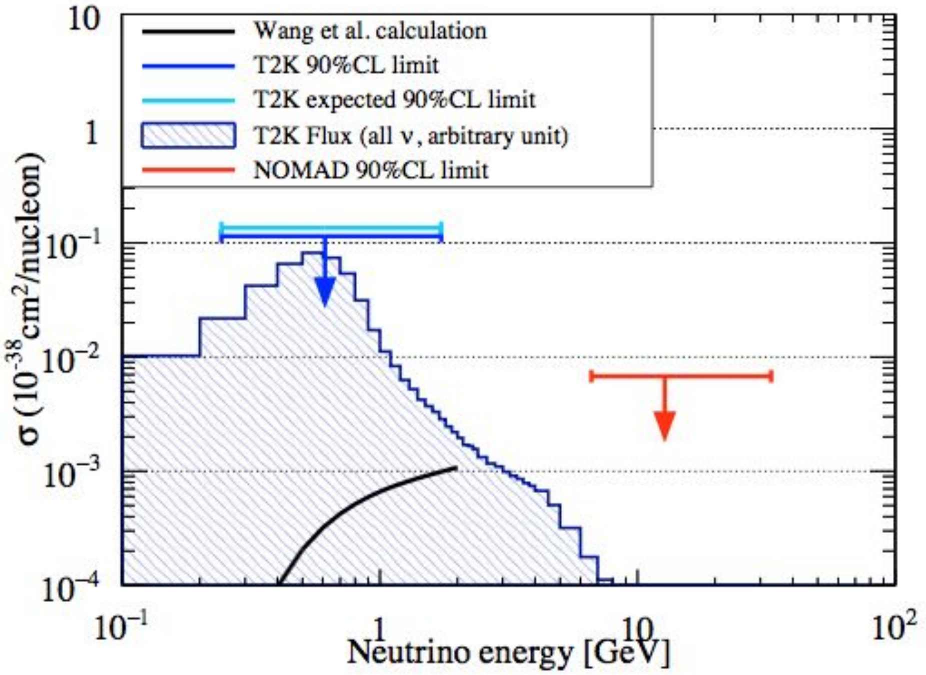
- MiniBooNE - **Cherenkov detector** along the Booster Neutrino Beam (BNB) at FNAL operating since 2002
- **Observed excess of neutrinos at low energy**, 2018 updated results: Phys. Rev. Lett. 121, 221801(2018)
- **Photon-like and electron-like interpretations**



NC Δ Radiative Decay: What We Know

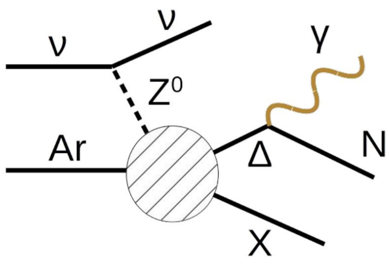


arXiv:1902.03848



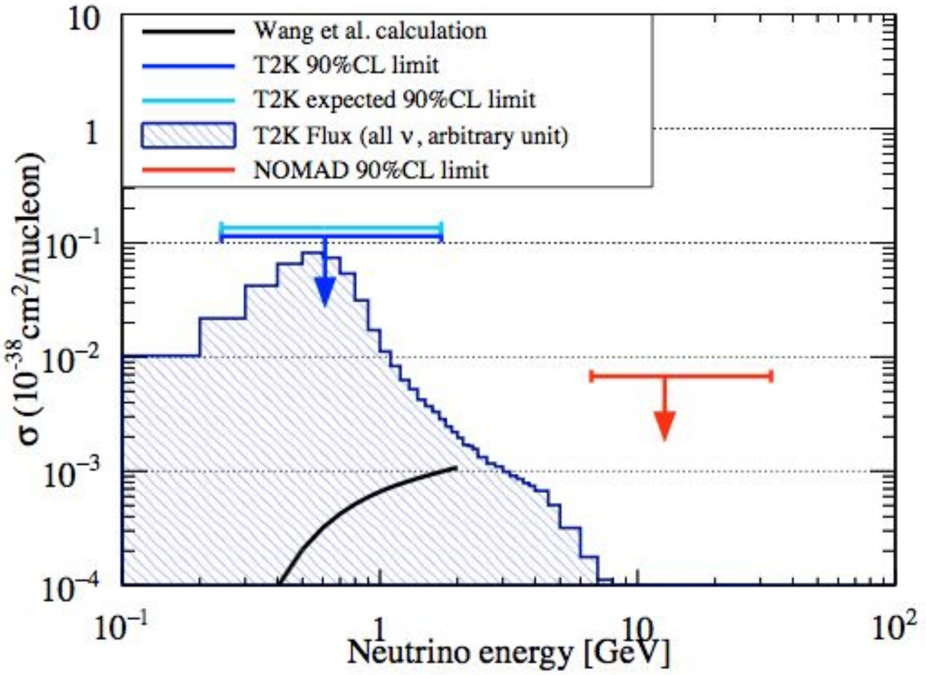
- Neutral current (NC) Δ resonant production followed by Δ radiative decay is a **SM source of single photons**
  - $\Delta \rightarrow N\gamma$ (0.6%) is subdominant to $\Delta \rightarrow N\pi^0$ (99.4%)
- 2019 limit set by T2K: arXiv:1902.03848
- **Large associated cross-section uncertainty**

NC Δ Radiative Decay: LEE Interpretation



arXiv:1902.03848

- Interested in Δ resonant production + radiative decay to as photon-like interpretation of LEE
- MiniBooNE would require a **factor of 3 enhancement to the SM rate** to explain excess. We use unfolding to translate that prediction to MicroBooNE: MICROBOONE-NOTE-1043-PUB



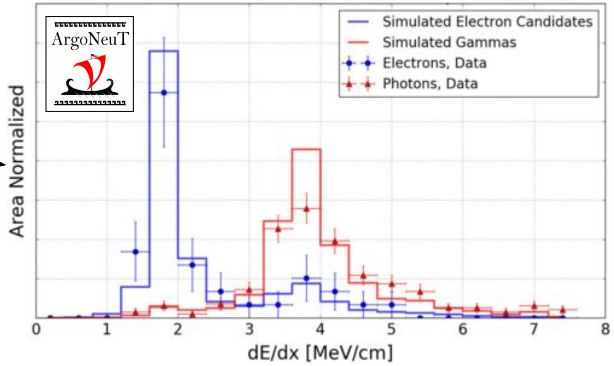
Reconstruction in MicroBooNE

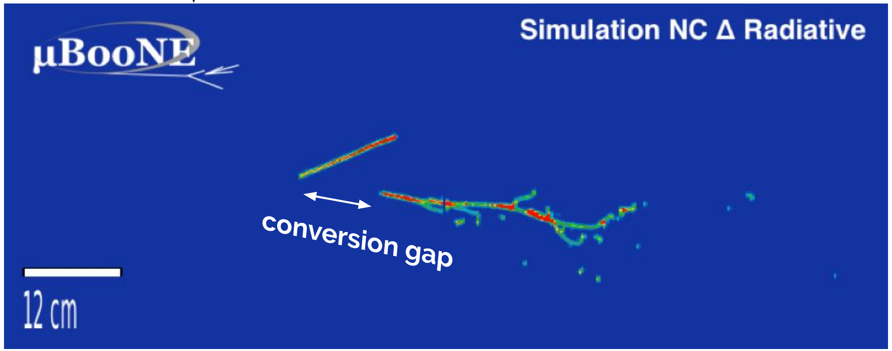
1. Take Pandora reconstructed tracks and showers

PRD 95, 072005 (2017)

e^-/γ separation for showers from:

- dE/dx
- photon conversion distance





- **LArTPC**'s combine time information from PMTs and hits on the wire planes to create 3D reconstructed images
- **Pandora multi-algorithm pattern recognition software** to reconstruct tracks and showers from hits: Eur.Phys.J. C78 (2018) no.1, 82

MicroBooNE Single Photon Analysis Overview

1. Take Pandora **reconstructed tracks and showers**

2. Find candidate vertices with **topological selection** and pre-selection cuts

3. Remove background using **2 tailored Boosted Decision Trees**:
-Cosmic Rejection
-BNB (Neutrino) Background Rejection

3.5 Additional background filtering with **Deep Learning** techniques

4. Goal is a **high sensitivity search for NC Δ Radiative Decays**, as an interpretation of the MiniBooNE LEE

MicroBooNE Single Photon Analysis Overview

1. Take Pandora **reconstructed tracks and showers**

2. Find candidate vertices with **topological selection** and pre-selection cuts

3. Remove background using **2 tailored Boosted Decision Trees**:
-Cosmic Rejection
-BNB (Neutrino) Background Rejection

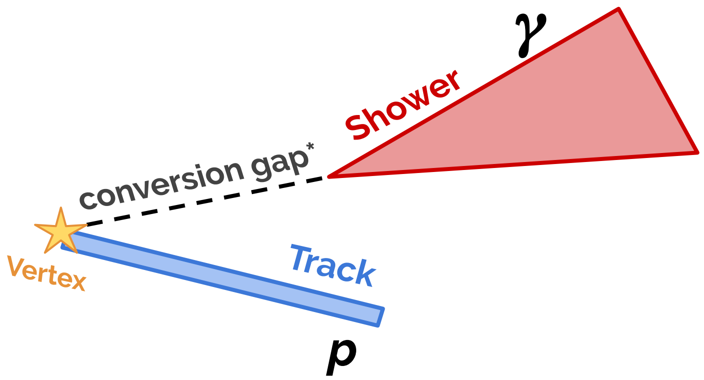
3.5 Additional background filtering with **Deep Learning** techniques

4. Goal is a **high sensitivity search for NC Δ Radiative Decays**, as an interpretation of the MiniBooNE LEE

Topological Selections

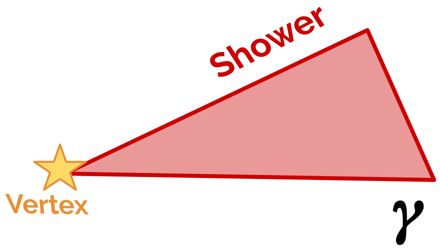
2.Find candidate vertices with topological selection

*γ conversion length in Ar ~14cm



1γ1p is our primary analysis. The existence of a short proton-like track improves reconstruction efficiency.

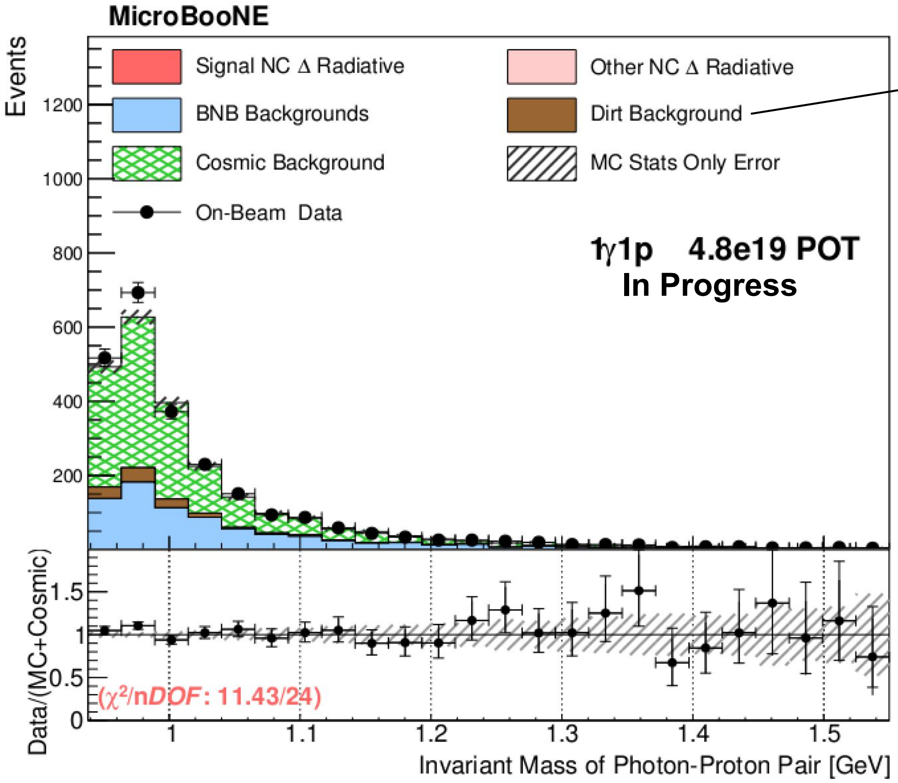
- **45.3%** of true 1γ events
- **26%** reconstruction efficiency with 1 track and 1 shower requirement and pre-selection cuts



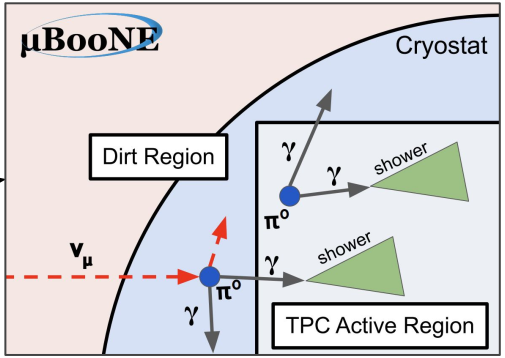
1γ0p is more difficult, but provides a secondary dataset for comparison and verification

- **54.7%** of true 1γ events
- **9%** reconstruction efficiency with 0 track and 1 shower requirement and pre-selection cuts

1γ1p Pre-Selection Cuts Stage



Pre-selection cuts applied



2.Find candidate vertices with topological selection

- NC Δ radiative simulated events with **3x SM prediction**
- Signal NC Δ radiative separated from other NC Δ radiative with truth-level reconstructability requirements
- Dominated by **BNB** (neutrino) and **cosmic** backgrounds, subleading background contributions from **dirt** interactions
- **4.8e19 POT** is the current unblinded data: <5% of MicroBooNE total expected on-beam data (13.2e20POT)

MicroBooNE Single Photon Analysis Overview

1. Take Pandora **reconstructed tracks and showers**

2. Find candidate vertices with **topological selection** and pre-selection cuts

3. Remove background using **2 tailored Boosted Decision Trees**:
-Cosmic Rejection
-BNB (Neutrino) Background Rejection

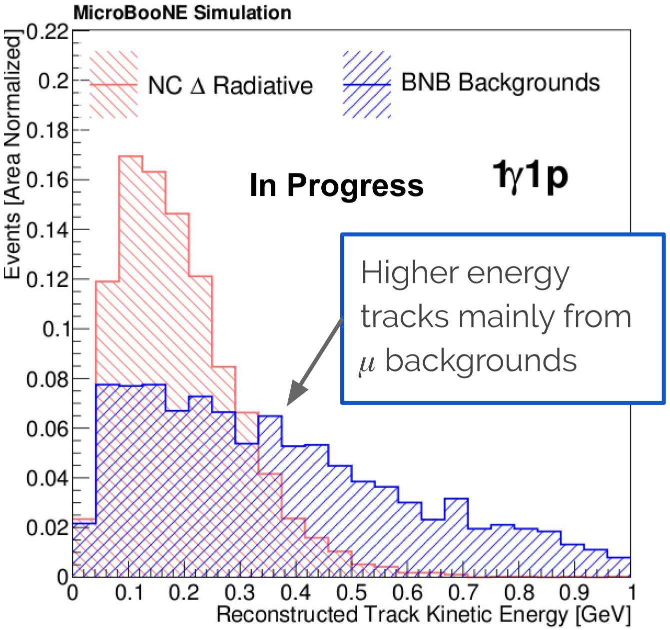
3.5 Additional background filtering with **Deep Learning** techniques

4. Goal is a **high sensitivity search for NC Δ Radiative Decays**, as an interpretation of the MiniBooNE LEE

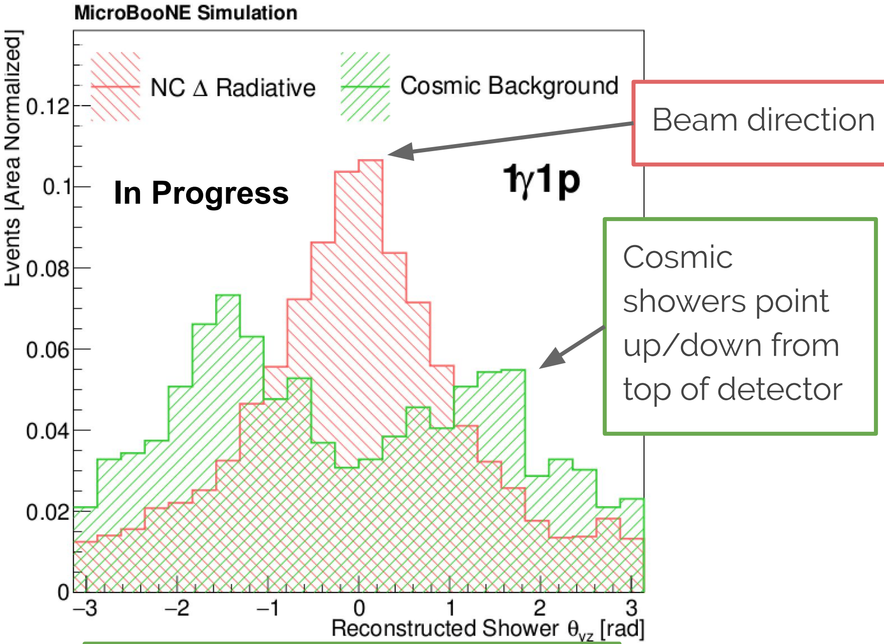
Dual Boosted Decision Trees (BDT's)

3. Remove background using 2 tailored Boosted Decision Trees

- BDT's train on kinematic and calorimetric variables → output a score per event from background-like to signal-like
- Train two BDT's for **BNB** (neutrino) and **cosmic backgrounds** with the **NC Δ radiative signal**



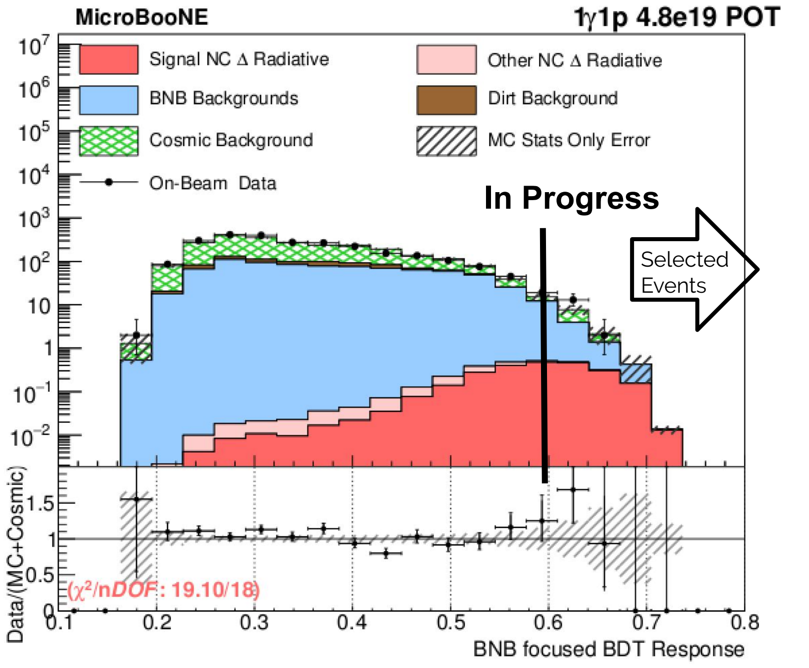
11 BNB BDT Training Variables



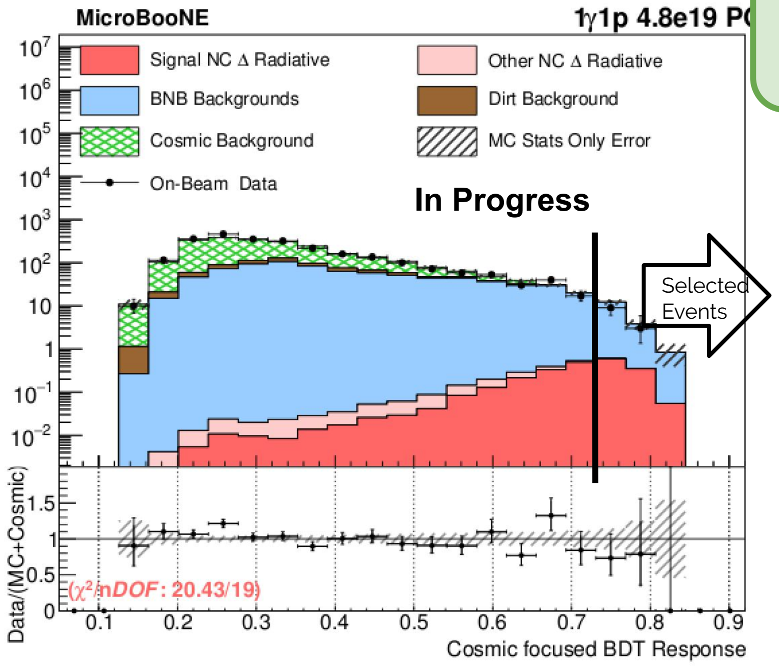
13 Cosmic BDT Training Variables

Dual Boosted Decision Tree Cuts

3. Remove background using 2 tailored Boosted Decision Trees



BNB background-like ← → Signal Like



Cosmic background-like ← → Signal Like

Train two BDTs independently to target BNB and cosmic backgrounds, **BDT cuts optimized simultaneously** → keep only events that pass both cuts for final selection.

MicroBooNE Single Photon Analysis Overview

1. Take Pandora **reconstructed tracks and showers**

2. Find candidate vertices with **topological selection** and pre-selection cuts

3. Remove background using **2 tailored Boosted Decision Trees**:
-Cosmic Rejection
-BNB (Neutrino) Background Rejection

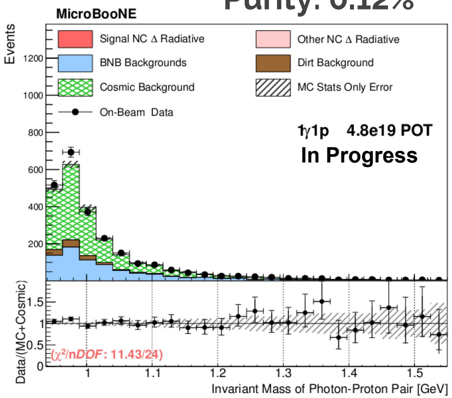
3.5 Additional background filtering with **Deep Learning** techniques

4. Goal is a **high sensitivity search for NC Δ Radiative Decays**, as an interpretation of the MiniBooNE LEE

1γ1p Final Selection

4. Goal is a high sensitivity search for NC *Δ* Radiative Decays

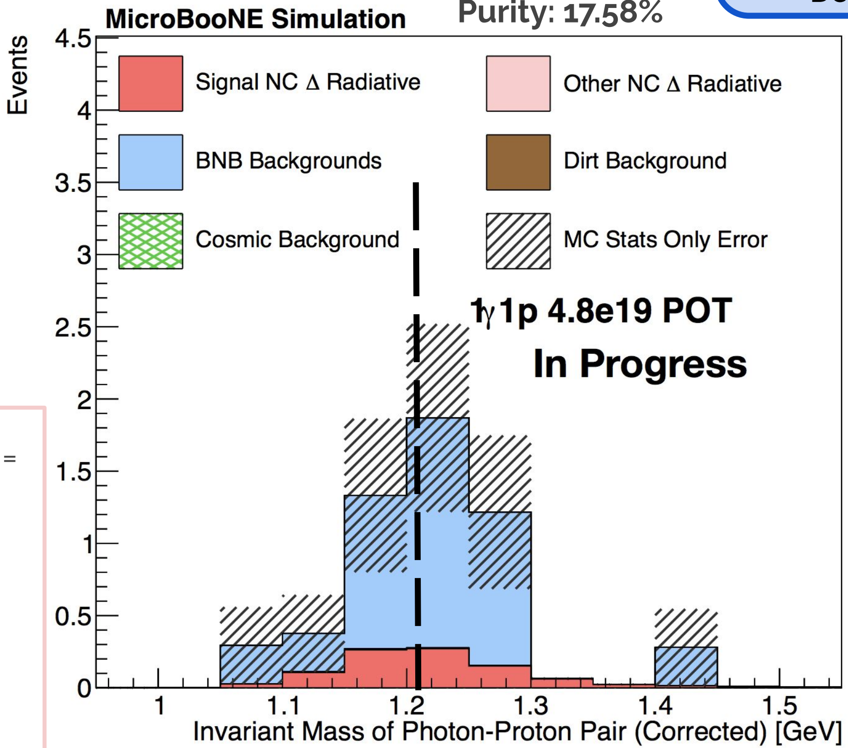
Purity: 0.12%



Pre-selection cuts applied

Apply BDT cuts

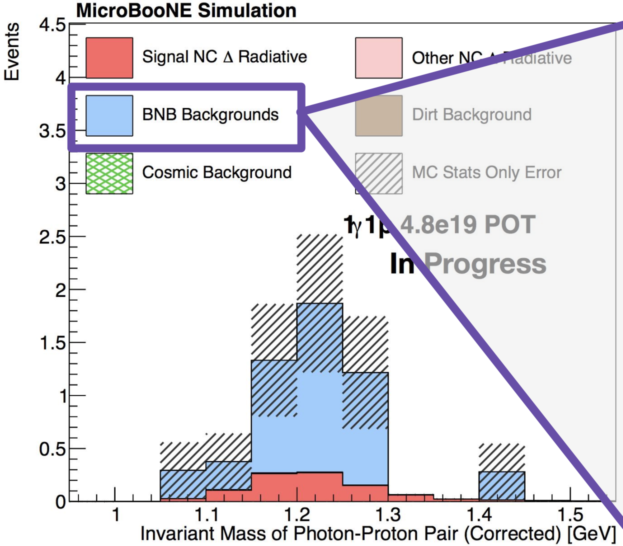
Purity: 17.58%

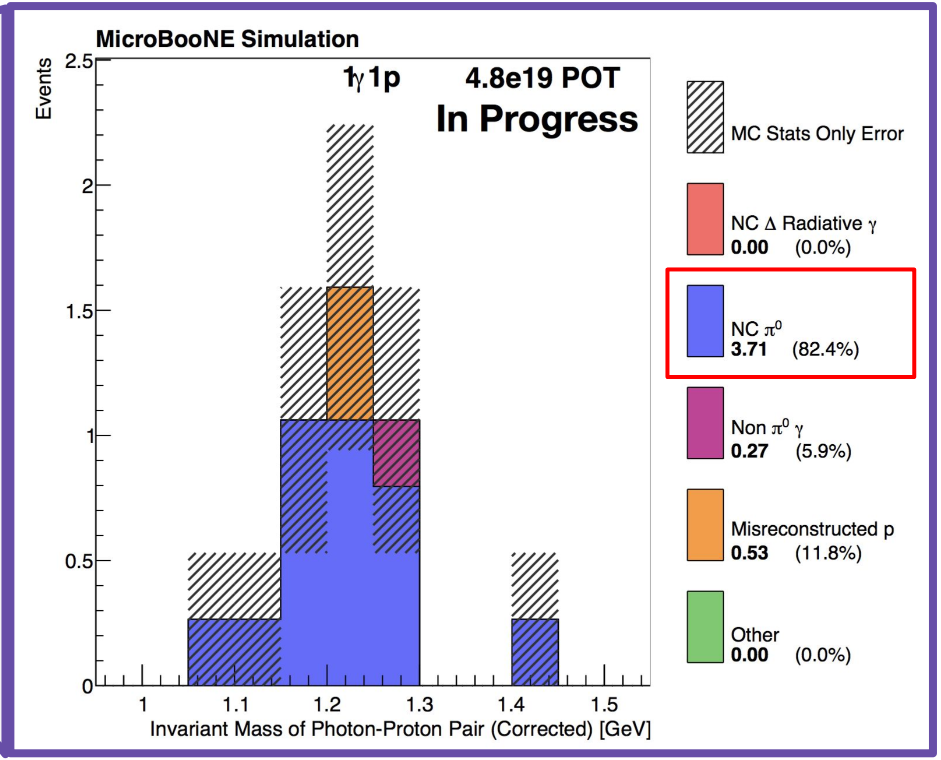


After both Cosmic + BNB BDT cuts applied

- **Predicted m_Δ = 1.21 ± 0.13 GeV**, expected m_Δ = 1.232 GeV
- Apply reconstructed **shower energy correction** to account for bias toward lower reconstructed than true energy
- **Strong rejection of cosmic and dirt backgrounds**

Remaining Backgrounds



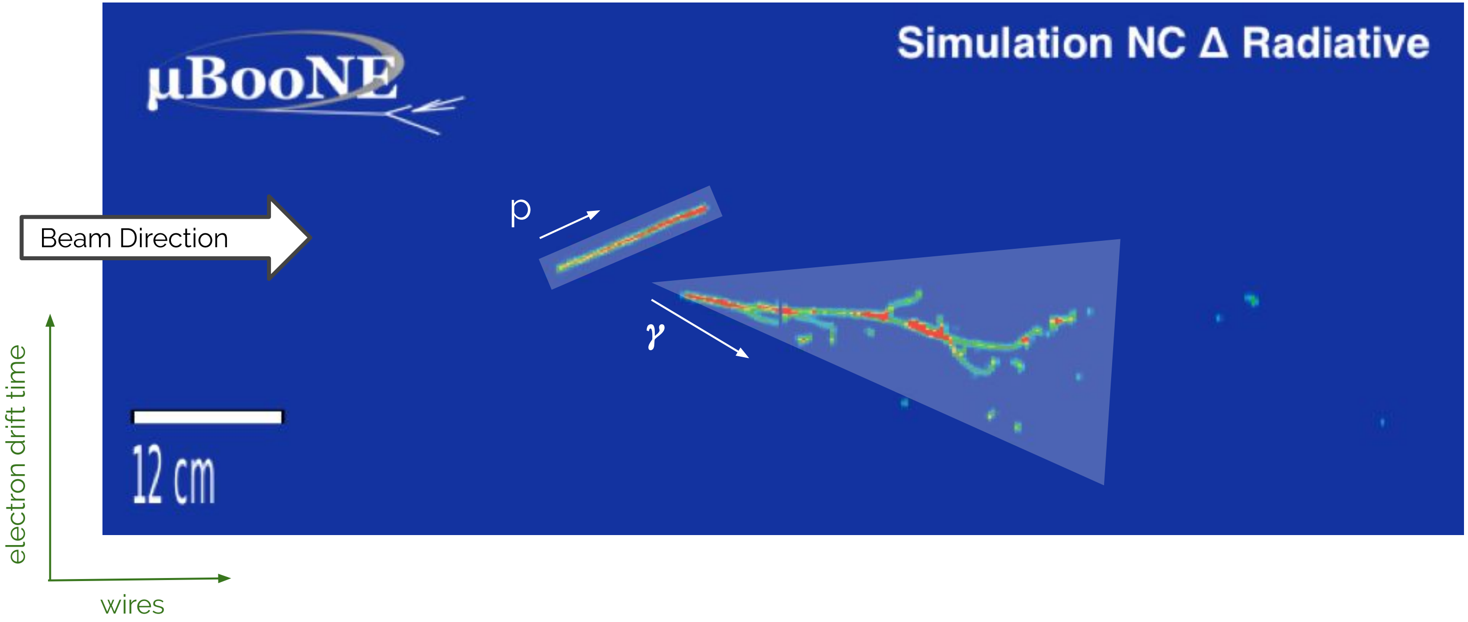


NC π^0 background:

$$\nu_\mu + p \rightarrow \nu_\mu + \Delta^+ \rightarrow p + \pi^0 \rightarrow \gamma + \gamma$$

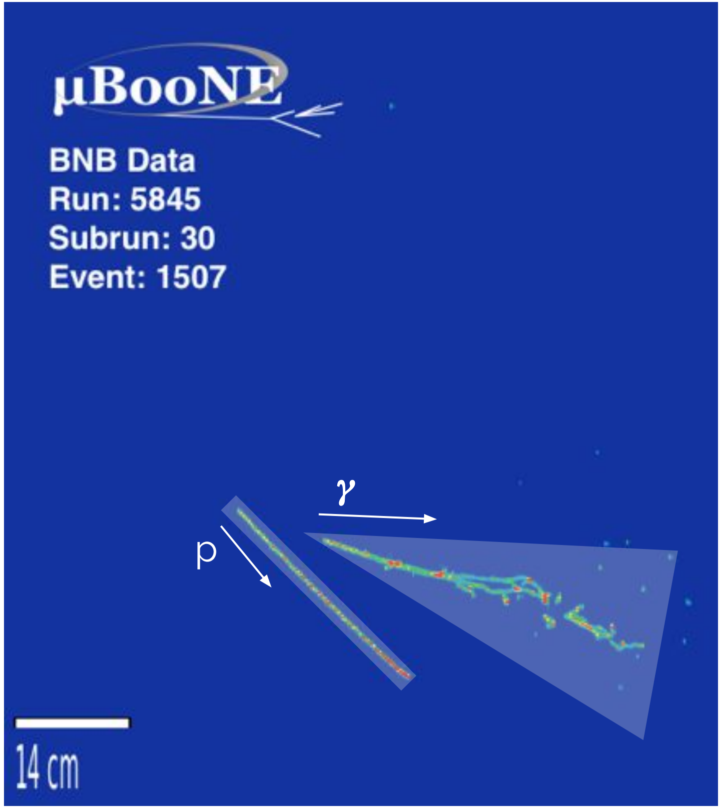
Dominant background is mis-identified NC π^0 events in which one shower is not reconstructed or associated to the vertex → dual approach with targeted NC π^0 **second shower search** and NC π^0 **sideband constraint**

NC Δ Radiative Decay in MicroBooNE: Selected Simulated Event



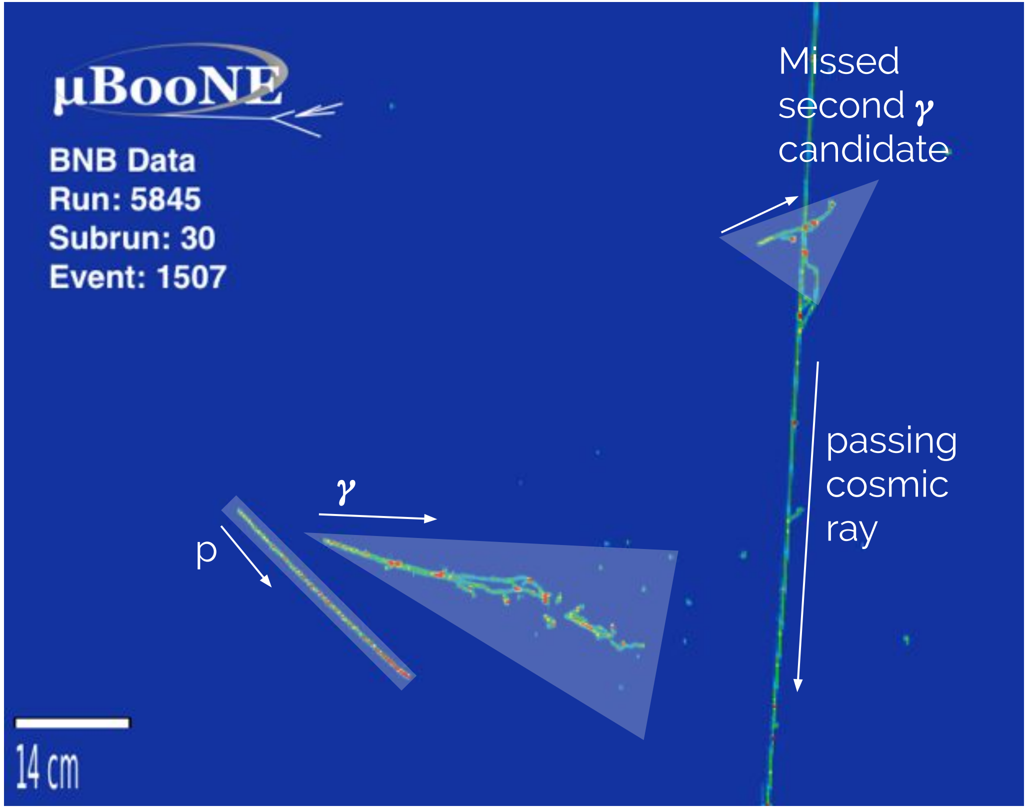
Simulated Δ→pγ event that passes the final selection

NC Δ Radiative Decay in MicroBooNE: Selected Data Event



Data event that passes the final selection as a $\Delta \rightarrow p\gamma$ candidate event

NC Δ Radiative Decay in MicroBooNE: Selected Data Event



Second shower candidate likely from $\pi^0 \rightarrow \gamma + \gamma$ is **missed in reconstruction** because of coincident cosmic ray

MicroBooNE Single Photon Analysis Overview

1. Take Pandora **reconstructed tracks and showers**

2. Find candidate vertices with **topological selection** and pre-selection cuts

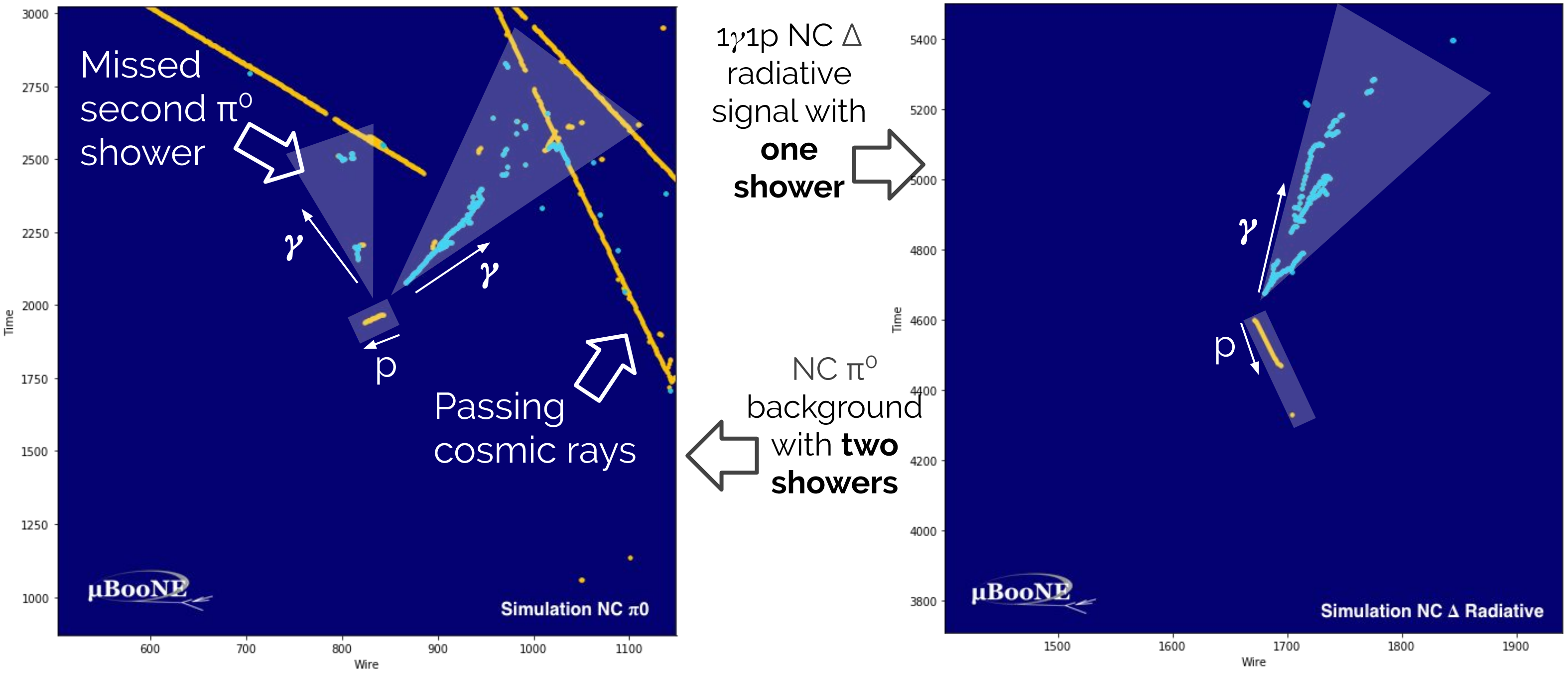
3. Remove background using **2 tailored Boosted Decision Trees**:
-Cosmic Rejection
-BNB (Neutrino) Background Rejection

3.5 Additional background filtering with **Deep Learning** techniques

4. Goal is a **high sensitivity search for NC Δ Radiative Decays**, as an interpretation of the MiniBooNE LEE

Semantic Segmentation Network (SSNet) Shower-Tagging

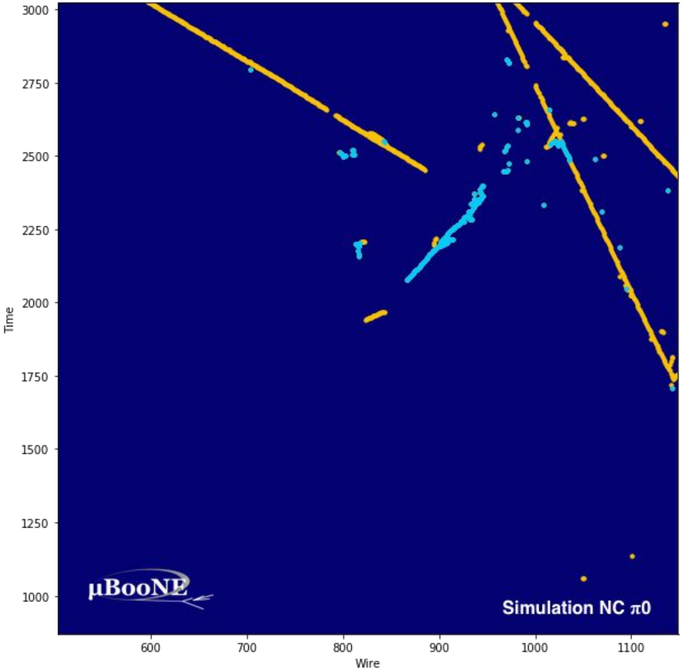
3.5 Additional background filtering using **Deep Learning** techniques



Need to identify NC π^0's where the second shower isn't associated to the vertex for background rejection

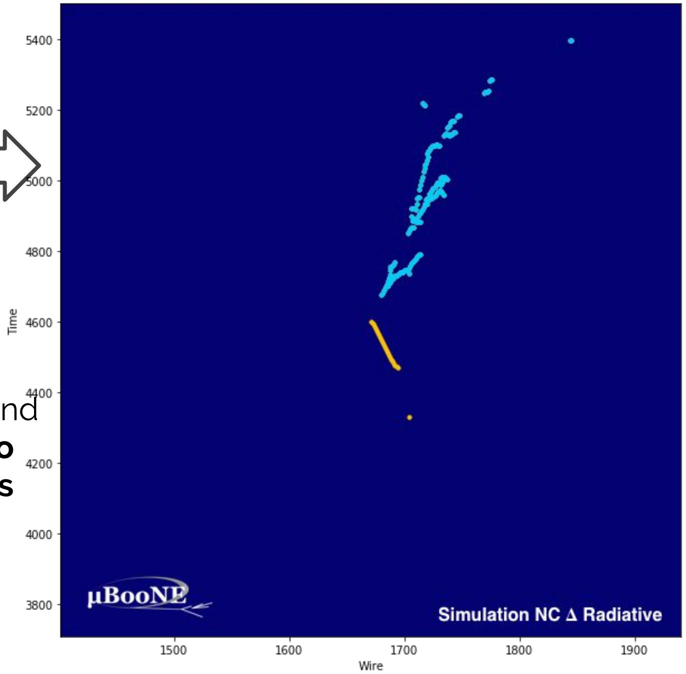
Semantic Segmentation Network (SSNet) Shower-Tagging

3.5 Additional background filtering using **Deep Learning** techniques



NC π^0 background with **two showers**

$1\gamma1p$ NC Δ radiative signal with **one shower**



- Hits-based approach augments Pandora reconstruction by targeting shower candidates
- Convolutional neural net which tags pixels as **shower-like** or **track-like**: Phys. Rev. D 99 (2019), 092001

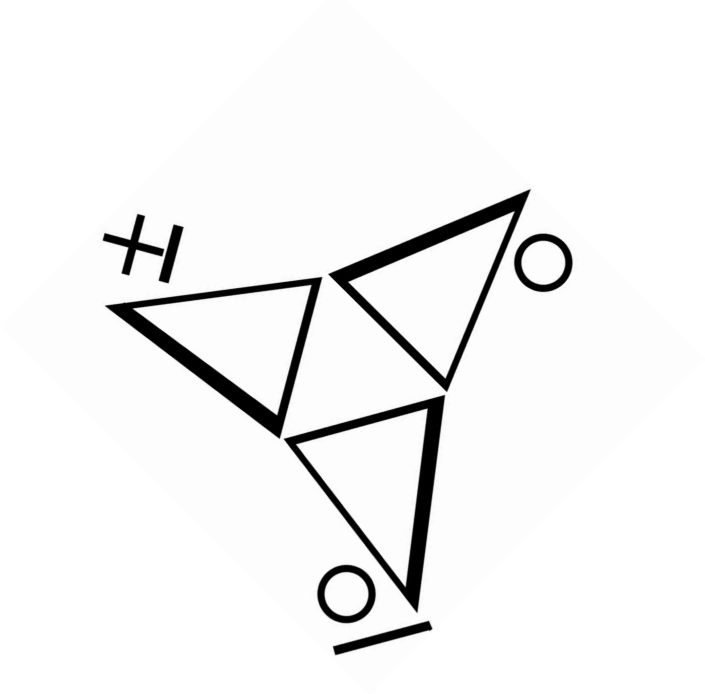
Summary and Next Steps

- Current $1\gamma 1p$ selection shows **strong rejection of cosmic and dirt backgrounds**
- Additional $1\gamma 0p$ channel increases total sensitivity but likely with higher backgrounds
- Further reducing the dominant NC π^0 background to $1\gamma 1p$ will significantly improve sensitivity:
  - **Second shower search** to identify mis-reconstructed NC π^0 events that pass current selection cuts
  - **NC π^0 sideband constraint**
- Full **systematic uncertainties** studies underway
- Working towards finalizing analysis and results!

Following talk in this session!

Andrew Mogan: *"Constraining the Neutral Current π^0 Background for MicroBooNE's Single-Photon Search"*

Thanks!



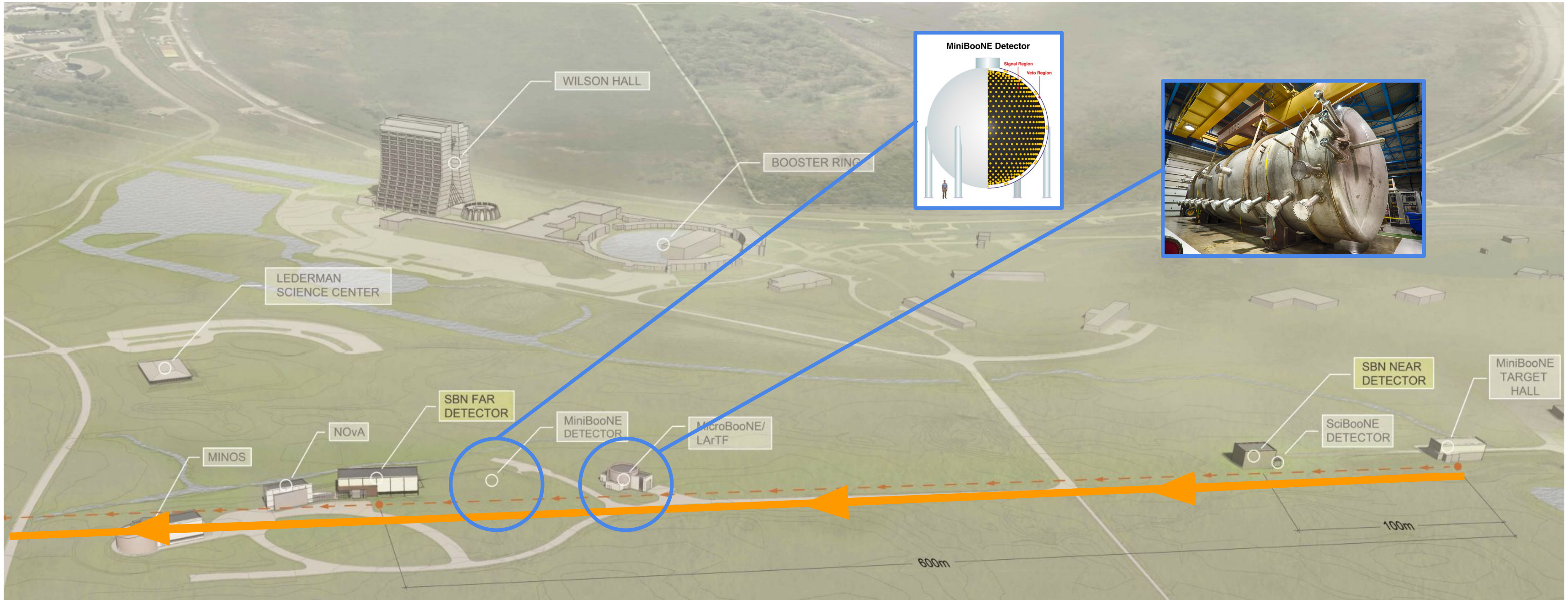
Fermilab U.S. Department of Energy Office of Science NSF FNSNF Swiss National Science Foundation Science & Technology Facilities Council The Royal Society

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by ORAU under contract number DE-SC0014664.

Backup

MicroBooNE

LArTPC operating at FNAL along the Booster Neutrino Beam (BNB) since 2015



arXiv/1503.01520

$1\gamma1p$ BDT Training Variables

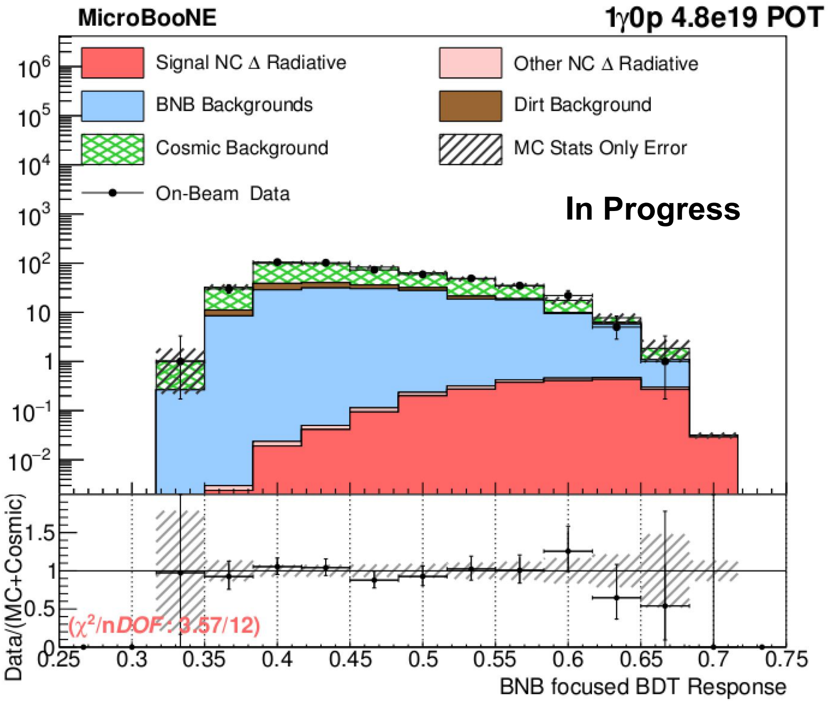
Cosmic BDT:

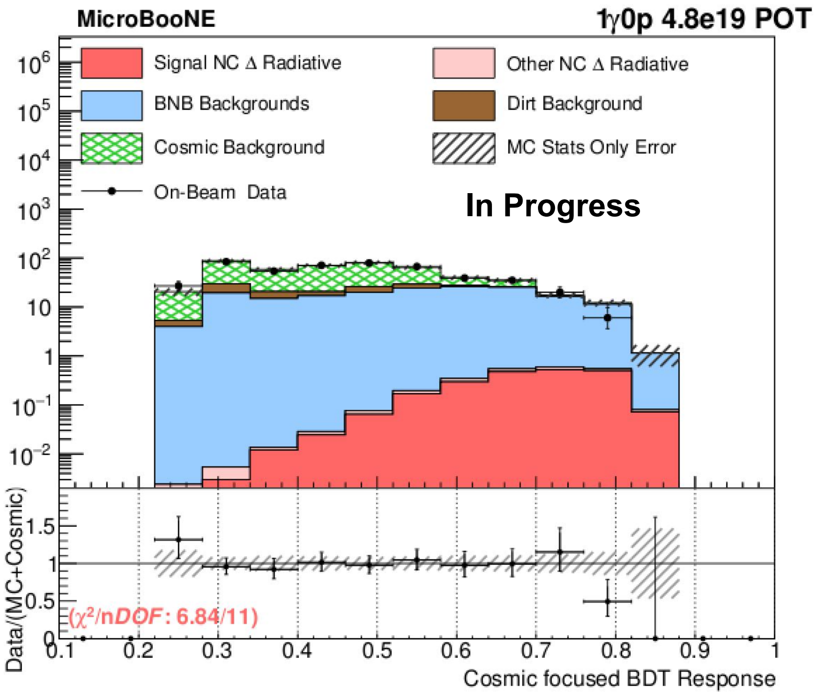
1. Truncated Mean Track dE/dx
2. Shower Energy
3. Shower Theta yz
4. Shower Conversion Dist
5. Track Kinetic Energy
6. Shower Length
7. Ratio of track dE/dx start/end
8. Shower Phi yx
9. Track Phi yx
10. Cosine between Track and Shower
11. Track Theta yz
12. Shower Median dE/dx Plane 2
13. Track Length

BNB BDT:

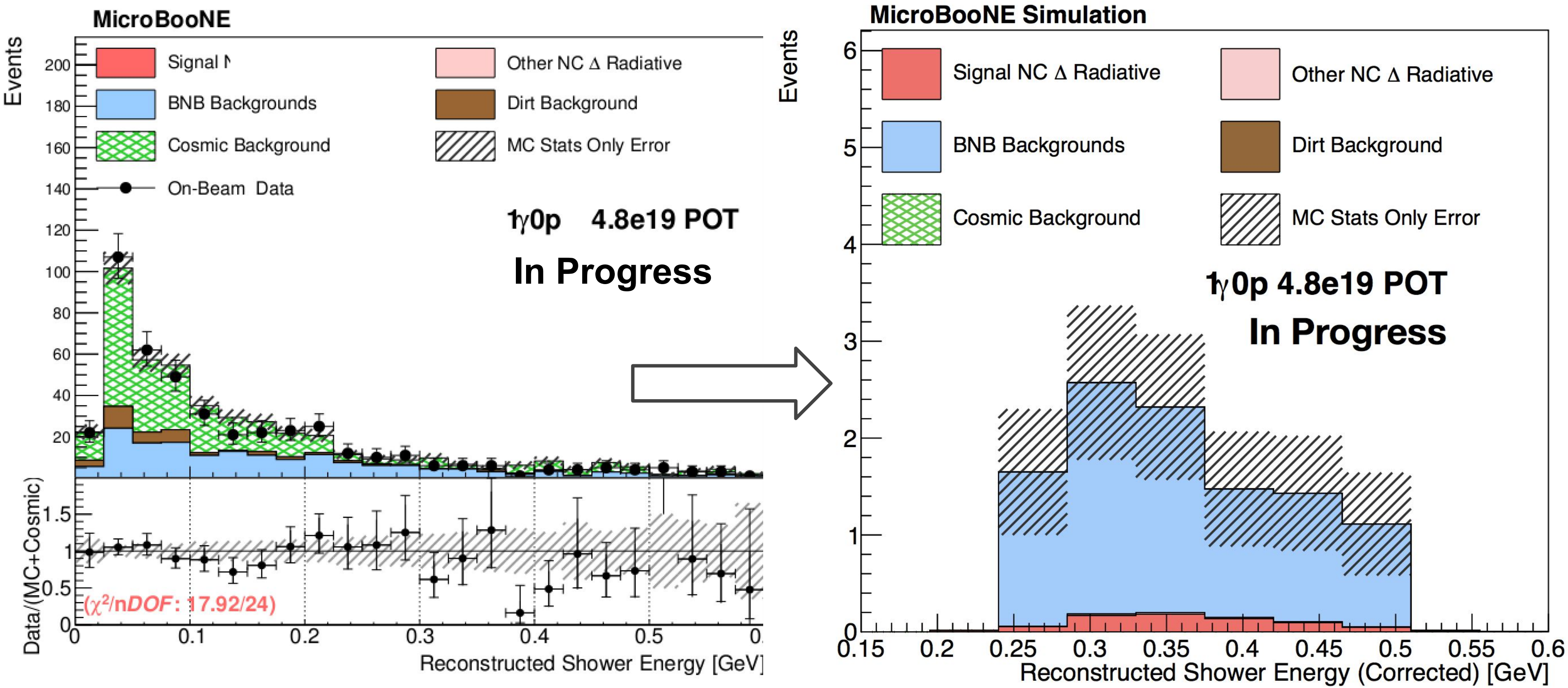
1. Truncated Mean Track dE/dx
2. Shower Energy
3. Track Kinetic Energy
4. Shower Conversion Dist
5. Shower Length
6. Ratio of track dE/dx start/end
7. Shower Median dE/dx Plane 2
8. Cosine between Track and Shower
9. Shower Theta yz
10. Shower Phi yx
11. Track Length

1γ0p BDT Responses

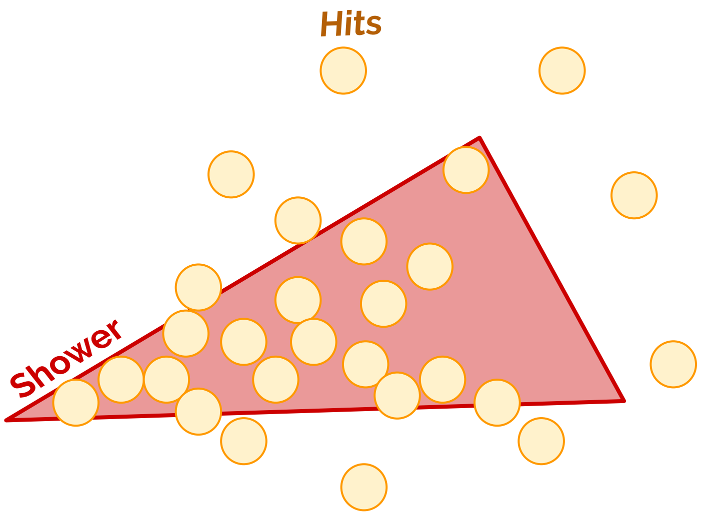




1γ0p Final Selection

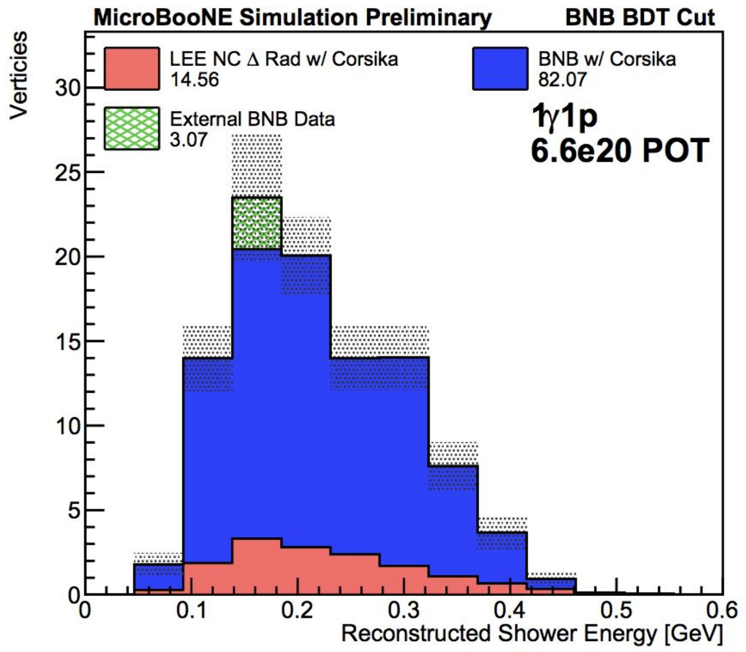


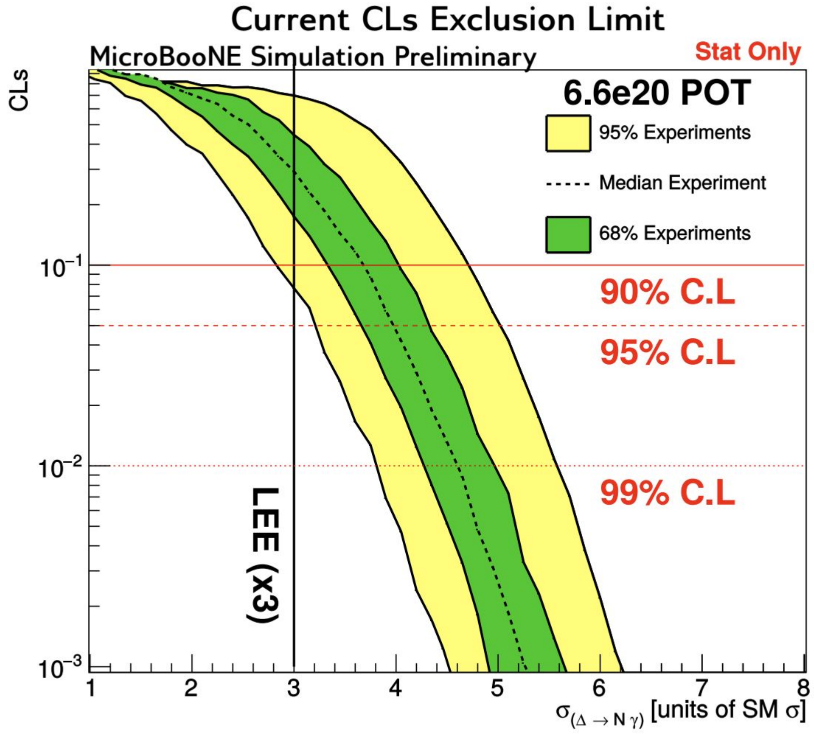
Reconstructed Shower Energy Correction



- Frequently reconstruction correctly identifies a shower and it's direction but **not all of the hits are included**
    - Missed hits → missing energy for reconstructed object
- Apply ~25% scaling to reconstructed shower energy to correct for this bias
- **Scaling derived from linear fit to reconstructed vs. true energy distribution for large sample of photons**

Neutrino 2018 Sensitivity





2018 Public Note: MICROBOONE-NOTE-1041-PUB