Search for a Single Photon Anomalous Excess in MicroBooNE

Guanqun Ge, Columbia University

On Behalf of the MicroBooNE collaboration

New Perspectives, August 17th 2021

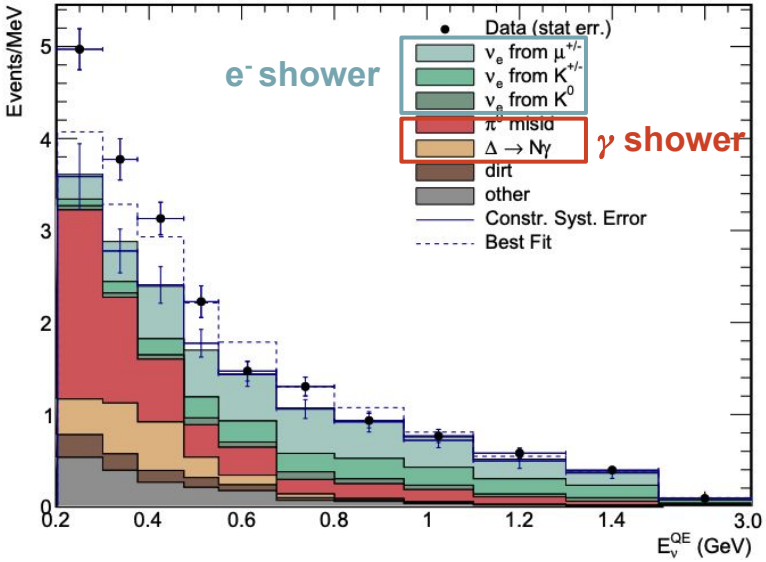
Fermilab NSF μBooNE Nevis Laboratories Columbia University

Overview

- Where does it all start?
- Single photon analysis flow
- Background modeling cross-check
- Sensitivity Evaluation

Where does it all start?

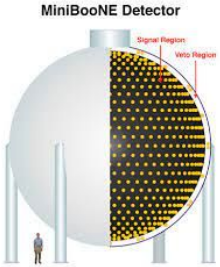
It started with LSND observing a 3.8σ excess in anti-ν_e charge-current quasielastic (CCQE) events in the neutrino oscillation measurement, followed by the excess in low-energy region in ν_e CCQE-like events in MiniBooNE measurement.

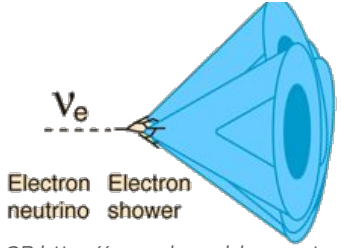


Phys. Rev. Lett. 121, 221801 (2018)

Given that MiniBooNE is a Cherenkov detector and doesn't have the e^- to photon identification capability, possible interpretations include

- Excess in e^-
- Excess in photon



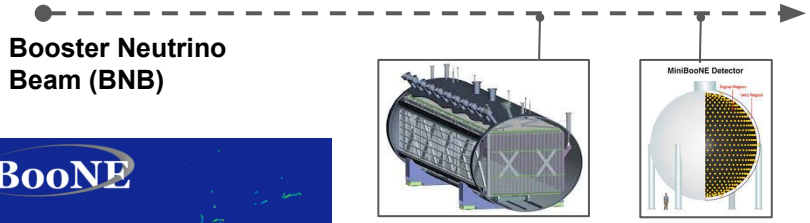


Both photon and electron produce fuzzy rings

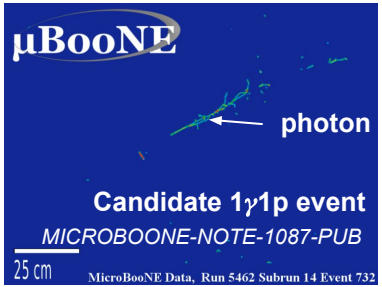
CR:http://superb150.blogspot.com/2012/12/cherenkov-radiation-light-booms.html

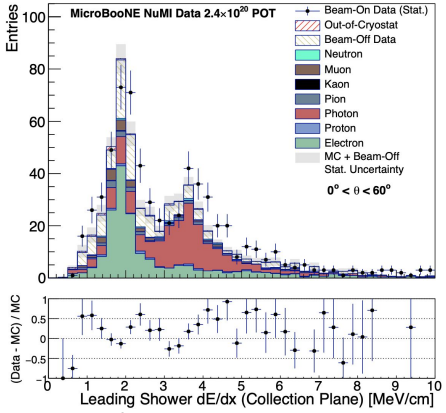
Where does it all start? - MicroBooNE experiment

To resolve the MiniBooNE LEE, MicroBooNE is proposed, which is a liquid argon time projection chamber detector, and shares the same neutrino beam with MiniBooNE.

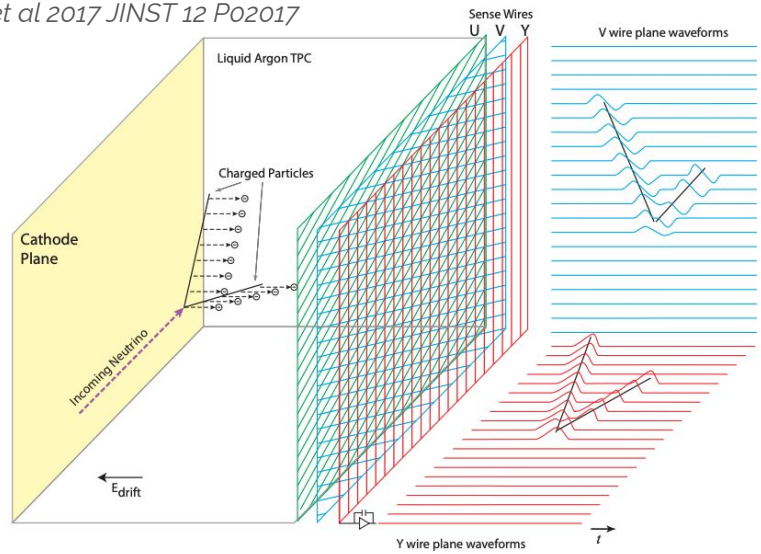


R. Acciarri et al 2017 JINST 12 P02017



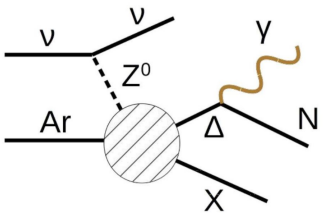


arXiv:2101.04228

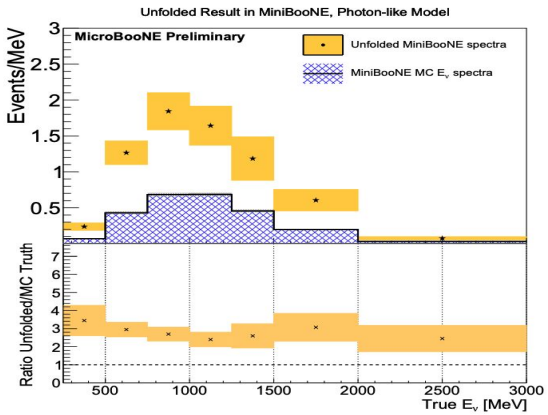


With the whole detector acting as a calorimeter, **MicroBooNE has good separation power between e⁻ and photons**

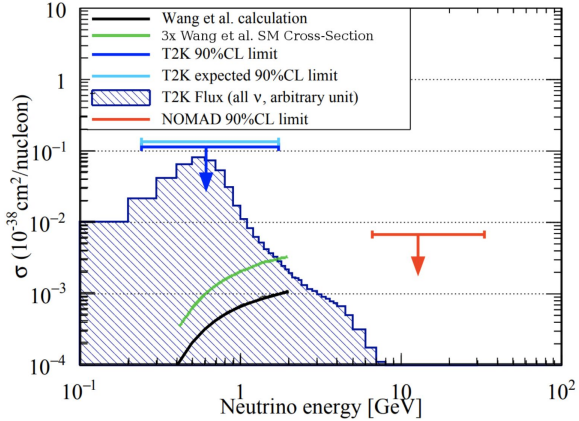
Where does it all start? - photon interpretation



MICROBOONE-NOTE-1043-PUB



J. Phys. G: Nucl. Part. Phys. 46 (2019) 08LT01

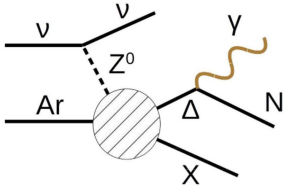


- MicroBooNE 1γ search is focused on excess of photon from neutral current **(NC) Δ resonance (1232MeV)** production and its radiative decay ($\Delta \rightarrow \gamma$ + N)
- Unfolding result of the MiniBooNE LEE under the hypothesis of increased photon from NC Δ production and decay has suggested a **flat normalization raise of NC $\Delta \rightarrow \gamma$ + N** is sufficient to reproduce the excess, which is later determined to be **~3x**
- T2K has measured their limit on total NC1γ cross section (flux-averaged) which is **O(x100) of the GENIE prediction**

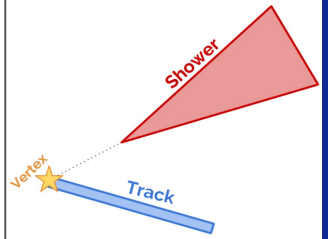
Single Photon Analysis Flow

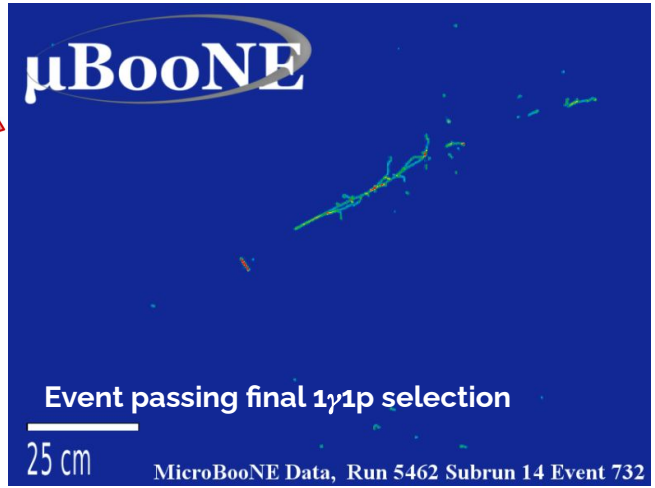
The NC radiative decay ($\Delta \rightarrow \gamma$ + N) will create two topologies in MicroBooNE detector due to the fact that neutral particles do not ionize argon and thus leave trace in the detector:

- 1 shower + 1 track (when nucleon is proton)
- 1 shower + 0 track (when nucleon is neutron)



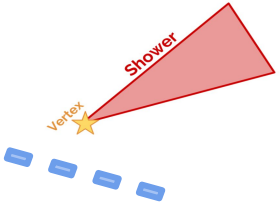
1γ1p

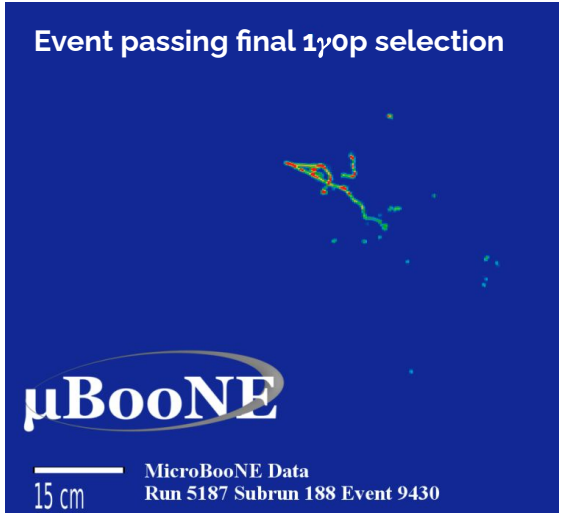




MICROBOONE-NOTE-1087-PUB

1γ0p





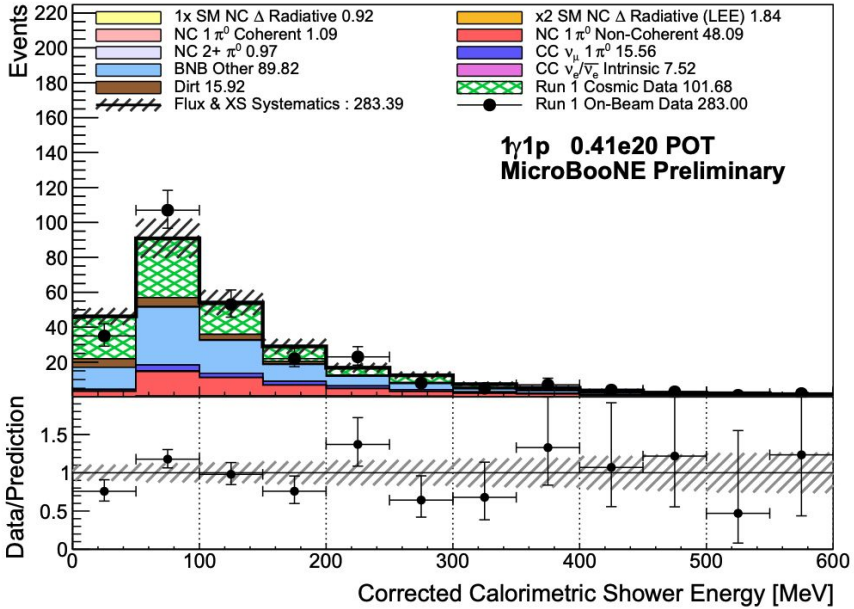
MICROBOONE-NOTE-1087-PUB

Single Photon Analysis Flow

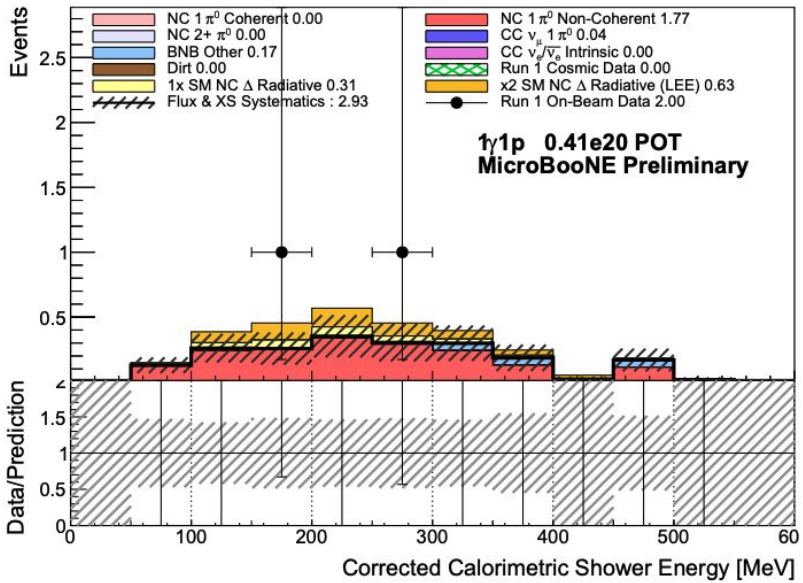
The analysis is developed with 5% of MicroBooNE full Run 1-5 dataset due to blind analysis policy, and the flow is as follows:

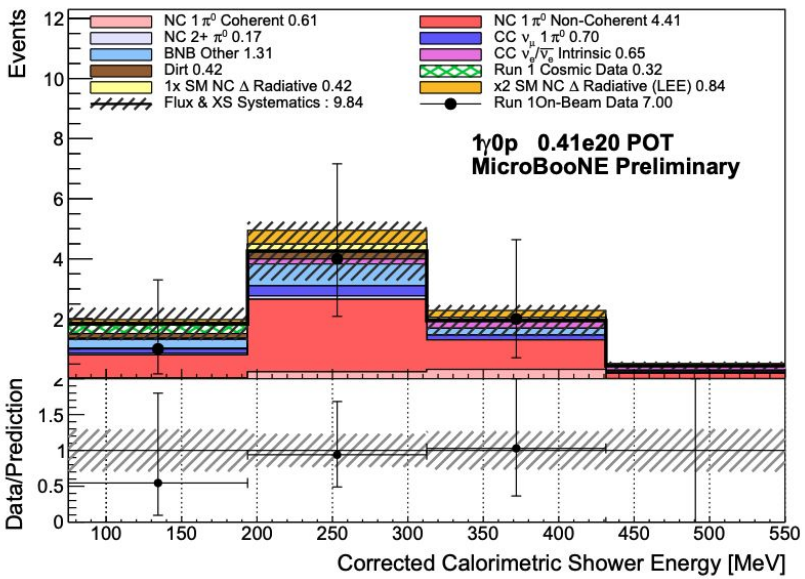
1. Topology Cut: require event topology to match 1 shower+1 track or 1 shower+0 track
2. Pre-selection Cut: remove badly reconstructed or obvious background by cutting on shower/track energy, shower/track containment etc.
3. Multivariable Boosted Decision Trees (BDTs) targeting different backgrounds:
   a. $1\gamma 1p$ has 5 BDTs
      i. Cosmic rejection BDT
      ii. ν_e BDT
      iii. NC π^0 BDT, Second Shower Veto BDT
      iv. Other BNB BDT
   b. $1\gamma 0p$ has 3 BDTs:
      i. Cosmic BDT
      ii. NC π^0 BDT
      iii. Other BNB BDT

$1\gamma 1p$ after Pre-selection Cut



1γ Search Final Distributions with 5% dataset

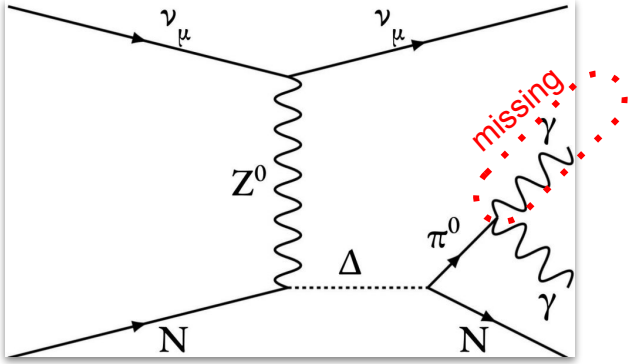


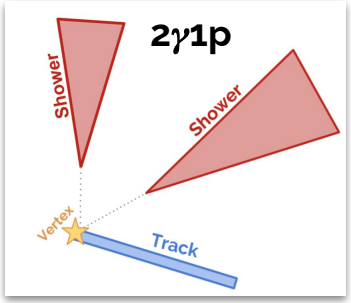


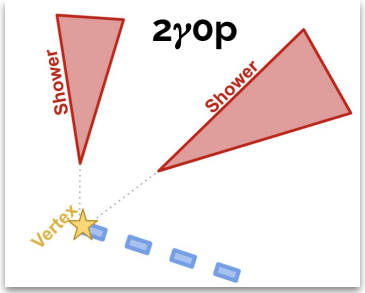
- Final distribution with 5% dataset (including LEE prediction - extra 2x GENIE-predicted NC Δ radiative decay events)
- **Purity of the signal has greatly improved** from 0.6% after pre-selection cut to 32% at final stage in 1γ1p
- **NC π^0 event comprise majority of the background** in both selections

Background validation → 2γ Selections

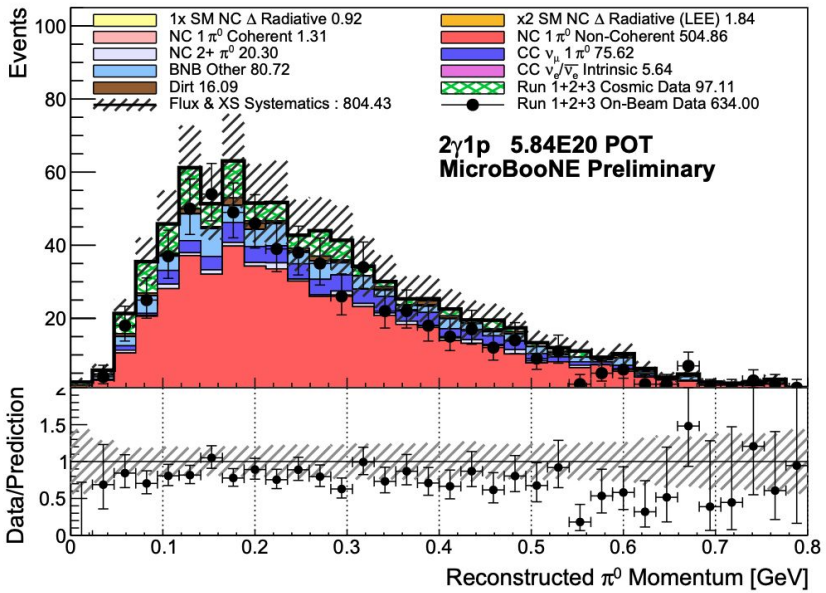
- It's not surprising that NC π^0 is the major background in 1γ from Δ decay search:
  - $\Delta \rightarrow \gamma$ + N has an expected branching ratio (BR) of ~0.6%
  - $\Delta \rightarrow \pi^0$ + N has an expected BR of ~99.4%
  - When one photon from π^0 decay is too low energy to be reconstructed or exists the detector or pair-produces very far from the vertex, $\Delta \rightarrow \pi^0$ events can mimic the 1γ signal
- Dedicated 2γ selections focusing on 2γ1p and 2γ0p topologies, using the same analysis framework as 1γ selections and MicroBooN Run 1-3 dataset

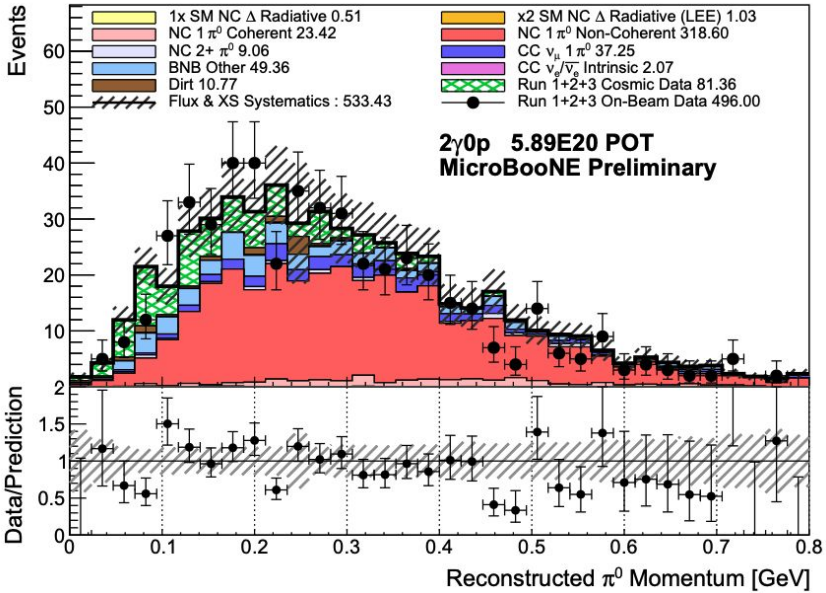






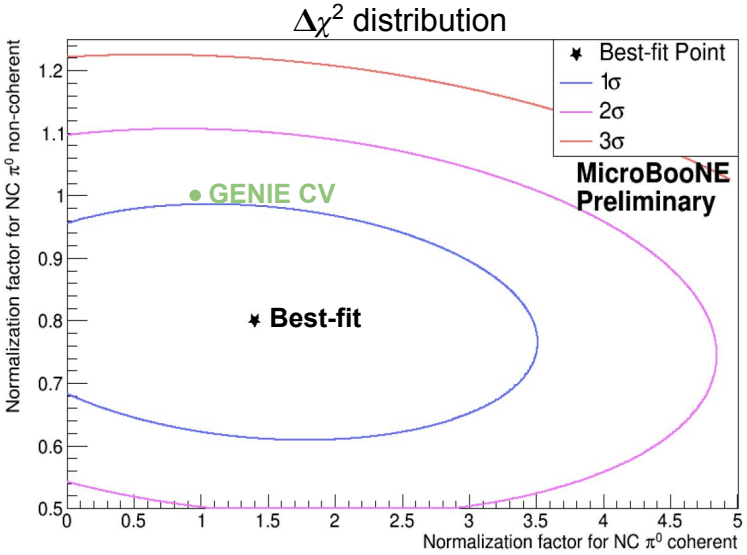
Background validation - 2γ Final Distributions





- High-statistics measurement, high purity of NC π^0 (~60%) in both selections
- With flux and cross section uncertainty, **data and MC CV agree reasonably well**
- **~20% and ~7% data deficit** observed in 2γ1p and 2γ0p respectively

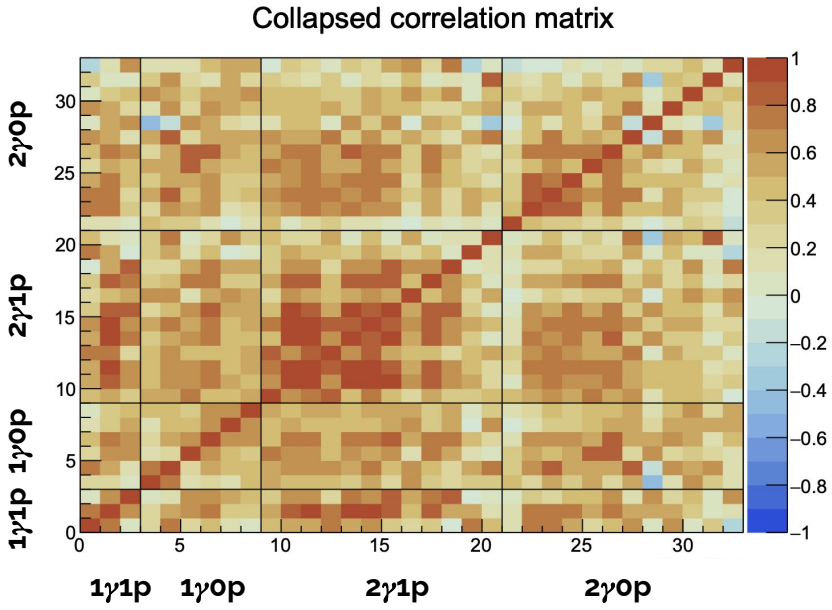
Background validation - In-situ NC π^0 Correction?



- Extract normalization factors for NC π^0 coherent and non-coherent events (N_{coh}, $N_{non\text{-}coh}$)
- Fit to $2\gamma 1p$ and $2\gamma 0p$ $\cos(\theta_{\pi 0})$ distributions simultaneously
- Best fit is found at (N_{coh} = 1.4, $N_{non\text{-}coh}$ = 0.8) with χ^2/dof= 2.73/4 and p^{value}=0.603
- χ^2/dof of data evaluated with GENIE central value (CV) is 6.97/6 and p^{val}=0.324

- While GENIE CV (N_{coh} = 1, $N_{non\text{-}coh}$ = 1) sits outside the 1σ region of the data-derived uncertainty, **data is consistent with MC CV given large GENIE uncertainty**
- Instead of correcting GENIE prediction of NC π^0, simultaneous fit of both 1γ and 2γ selections is performed to constrain background in 1γ selection

Signal Extraction



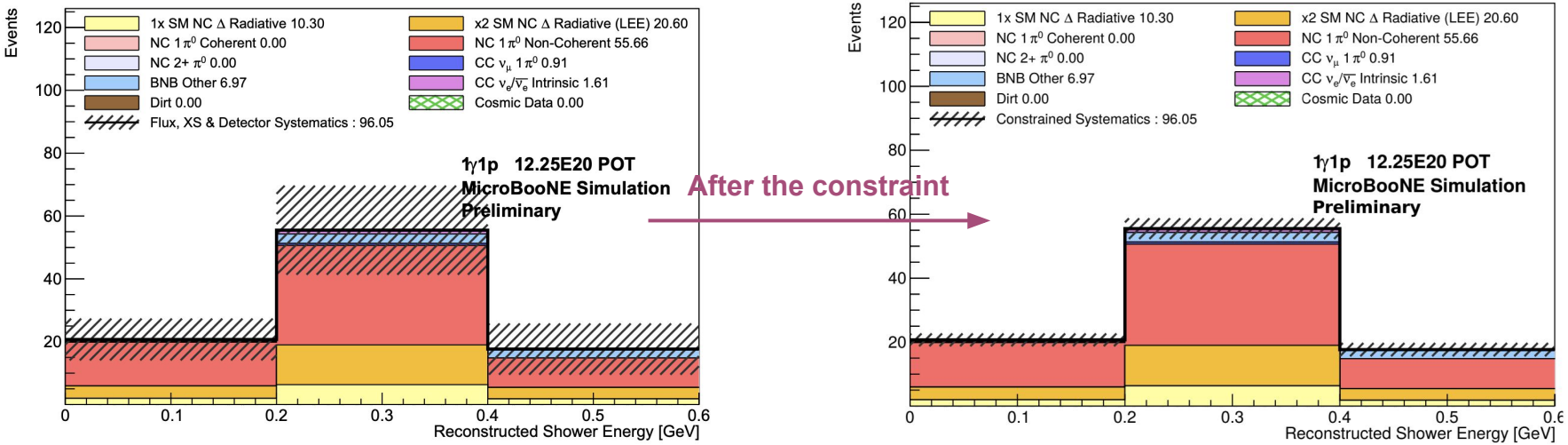
The 1γ and 2γ selections are highly correlated since majority of both 1γ and 2γ are NC π^0s and that majority of the NC π^0 are from Δ decay

A simultaneous fit to 1γ and 2γ final selections side-by-side to **extract the scaling of branching ratio (BR) of NC Δ radiative decay (x_Δ)** is performed, which makes use of the strong correlations between 1γ and 2γ selections to

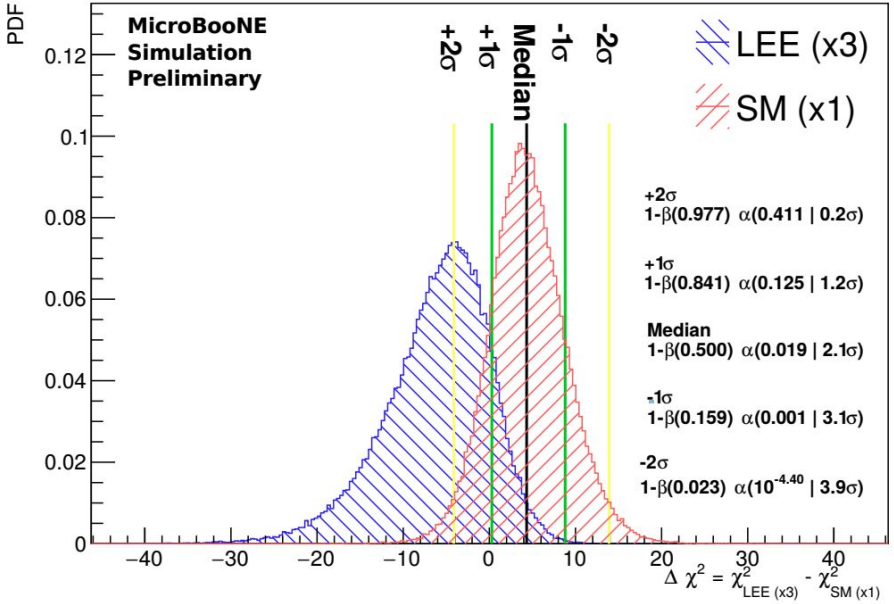
- Indirectly constrain the selected 1γ rate predictions
- Effectively reduce the systematic uncertainty in 1γ selection

Signal Extraction

The systematic uncertainty reduction in 1γ selection (for full dataset - 12.25x10^{20} POT)



Final Sensitivity Projection



x_Δ: the scaling of branching ratio (BR) of NC Δ radiative decay

SM: GENIE CV prediction (x_Δ = 1)

LEE: extra 2x GENIE-predicted NC Δ radiative events on top of GENIE CV prediction (x_Δ = 3)

With MicroBooNE full Run1-5 dataset:

- The median significance of rejecting the LEE hypothesis (x_Δ = 3) in favor of SM hypothesis (x_Δ = 1), assuming SM is true is 2.1σ

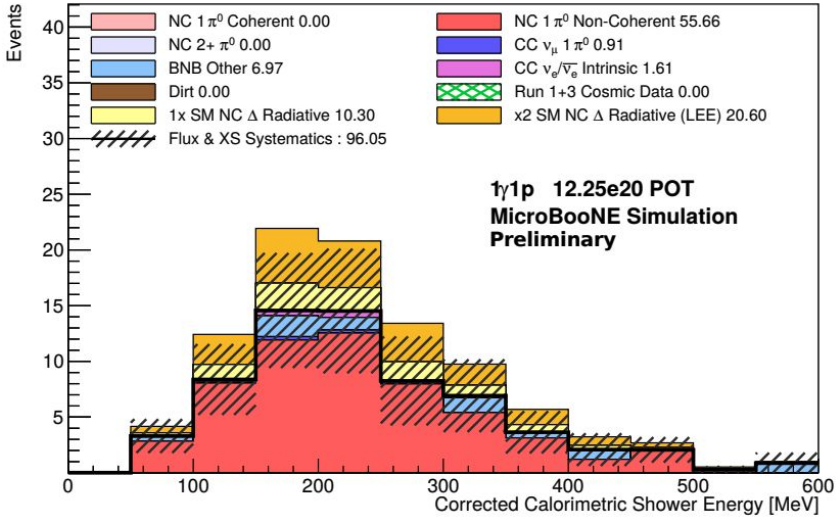
Takeaways

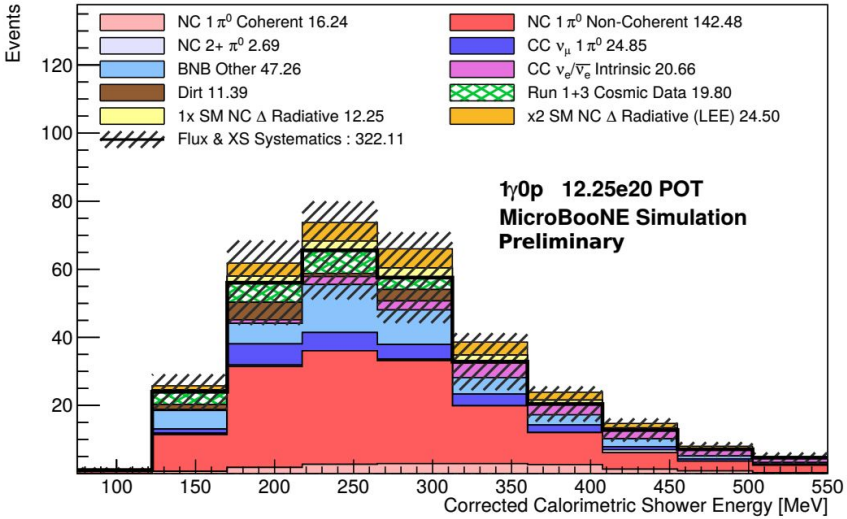
- Produced the world's highest sensitivity to neutrino-induced NC Δ radiative decay with neutrino beam energy below 1 GeV
- Showed high potential of this analysis in probing the hypothesis of anomalous NC Δ radiative photon excess for MiniBooNE LEE interpretation
- Developed with 5% of the MicroBooNE full dataset, the 1γ part of the analysis will soon be allowed access to MicroBooNE Run1-3 data **(x15 more statistics**)
- Yielded the world's **highest-statistics NC π^0 sample**
  - Data deficit in 2γ1p has motivated a cross section extraction for the NC π^0 events
- Same framework is being explored to do coherent single photon search
- Watch out for our new result soon!

Thank you!

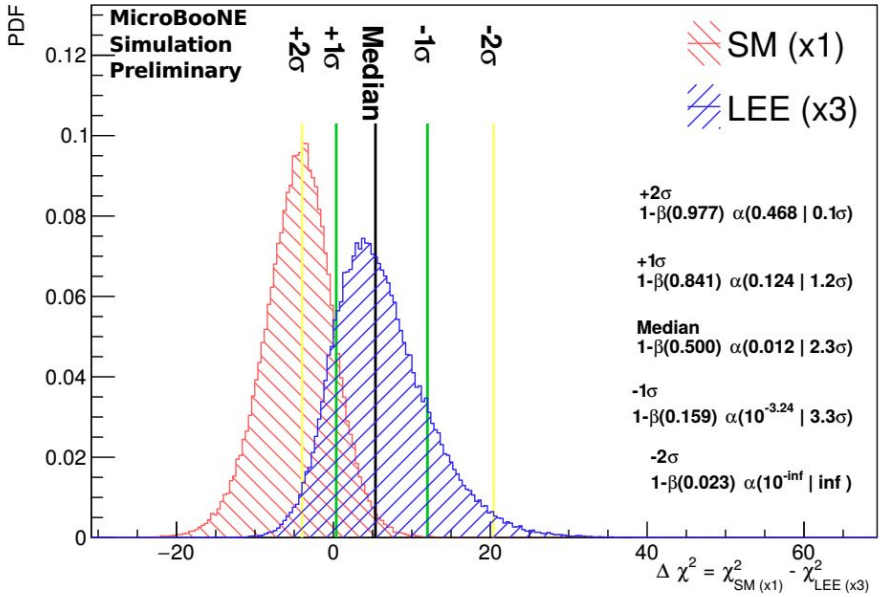
Backup Slides

1γ Final Distributions projected to full dataset





Final Sensitivity Projection



x_Δ: the scaling of branching ratio (BR) of NC Δ radiative decay

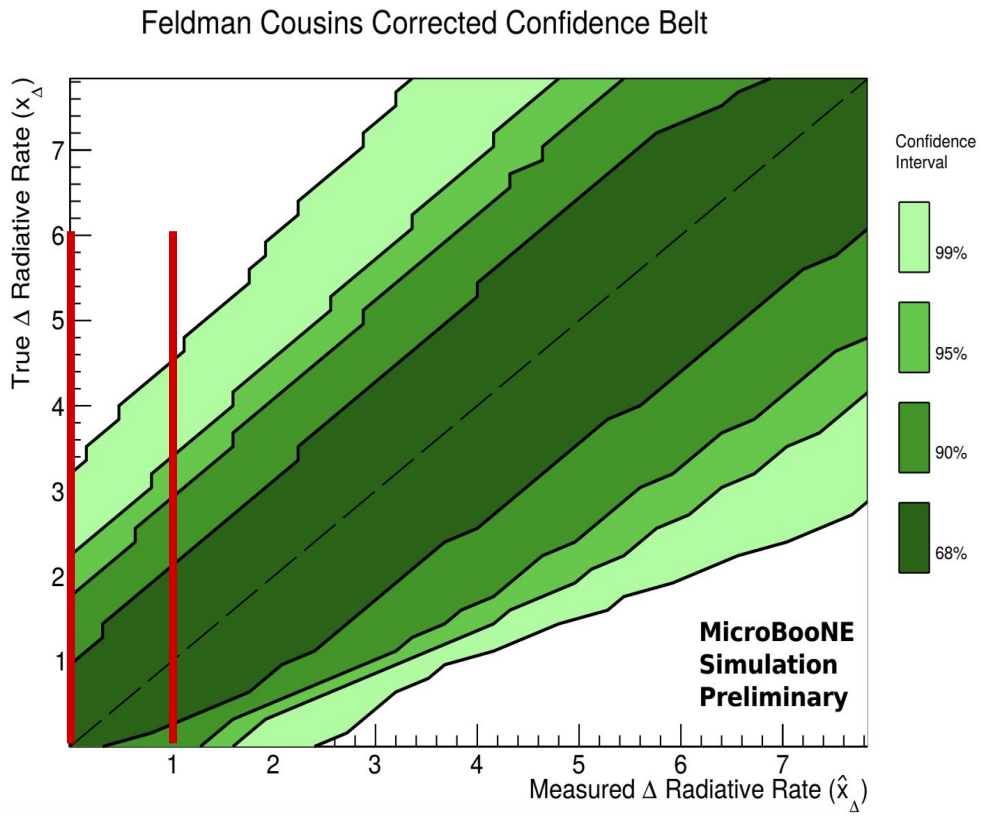
SM: GENIE CV prediction (x_Δ = 1)

LEE: extra 2x GENIE-predicted NC Δ radiative events on top of GENIE CV prediction (x_Δ = 3)

With MicroBooNE full Run1-5 dataset:

- The median significance of rejecting SM hypothesis (x_Δ = 1) in favor of LEE hypothesis (x_Δ = 3), assuming LEE is true is 2.3σ

Final Sensitivity Projection



With MicroBooNE full Run1-5 dataset, we expect:

- If no NC Δ radiative events are observed, the LEE hypothesis could be ruled out at >95% confidence level (C.L.)
- If SM NC Δ radiative prediction is observed, **the LEE hypothesis could be ruled out at >90% C.L.**

Coherent single photon search

- This framework is planned to be used for coherent single photon search, for which 1 (statistically more forward along the beam direction) shower, 0 track are expected.
- Of events satisfying $1\gamma 0p$ topology, non-negligible amount have proton tracks in truth that are not reconstructed due to low energy/unresponsive wire regions
- Current efforts focusing on vetoing events with low-energy, unreconstructed proton stubs