

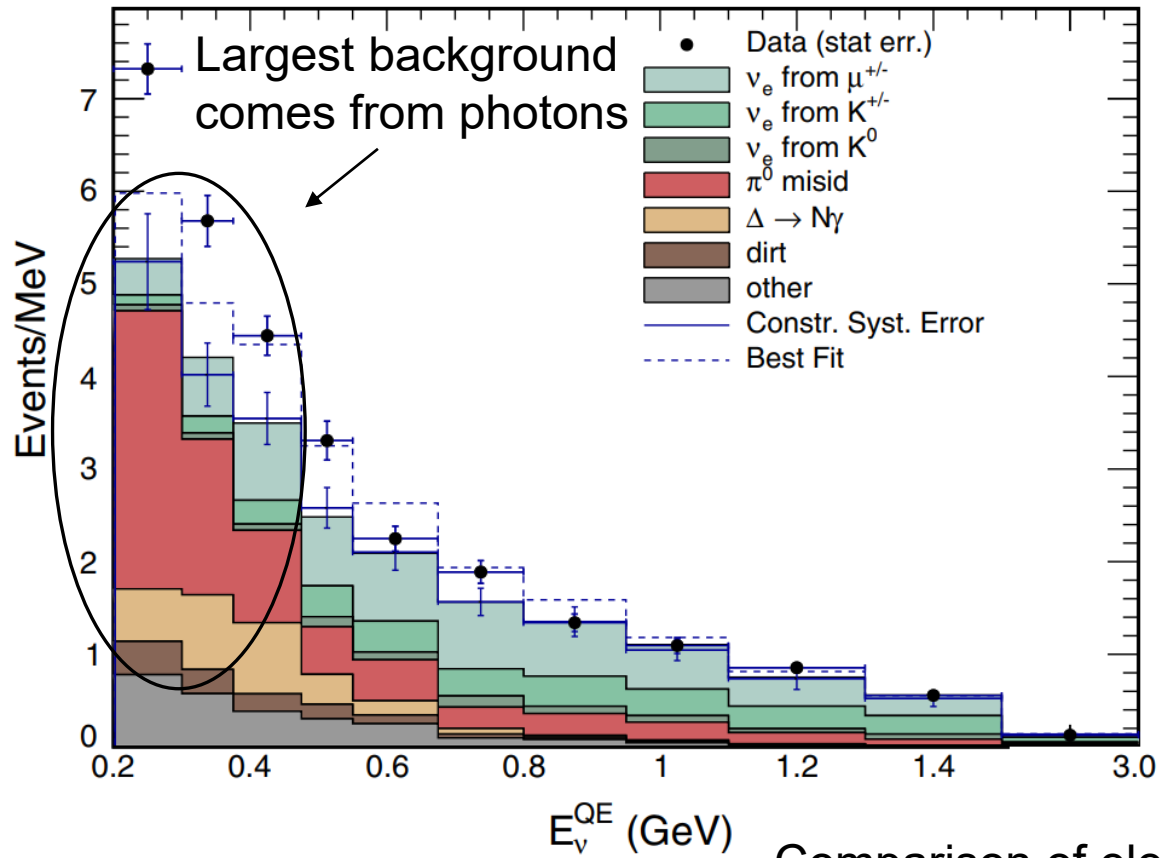
# Investigations of the MiniBooNE anomaly and sterile neutrinos with MicroBooNE

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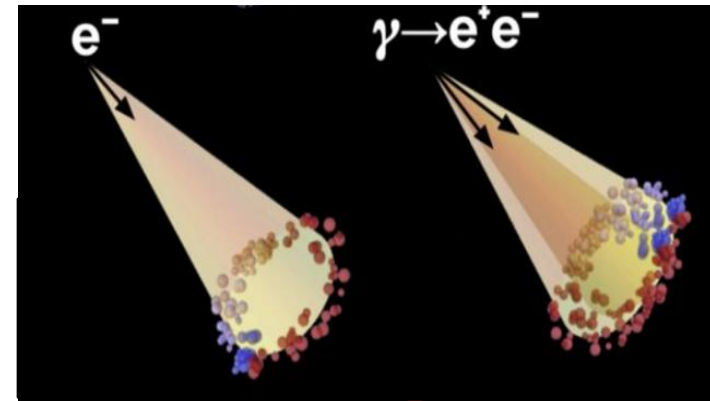
Richard Diurba (Bern) for the MicroBooNE Collaboration  
IRN Fall Meeting  
November 2025

# MiniBooNE's Anomalous Results

- MiniBooNE was a short-baseline neutrino detector in the Booster Neutrino Beam.
- An excess of  $4.8\sigma$  was observed of electron neutrino-like events, most noticeable at  $E < 500$  MeV.



Mineral oil-based Cherenkov detector can mis-identify electrons and photons.

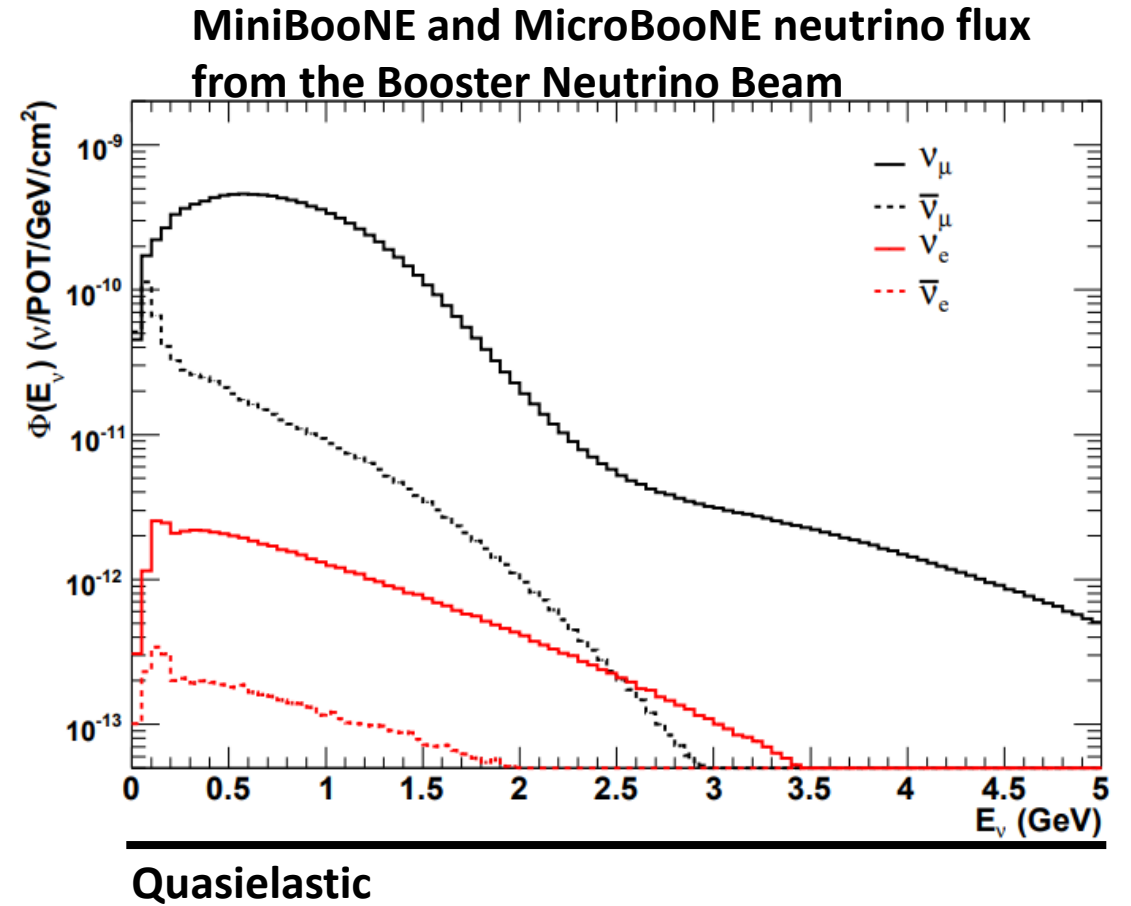
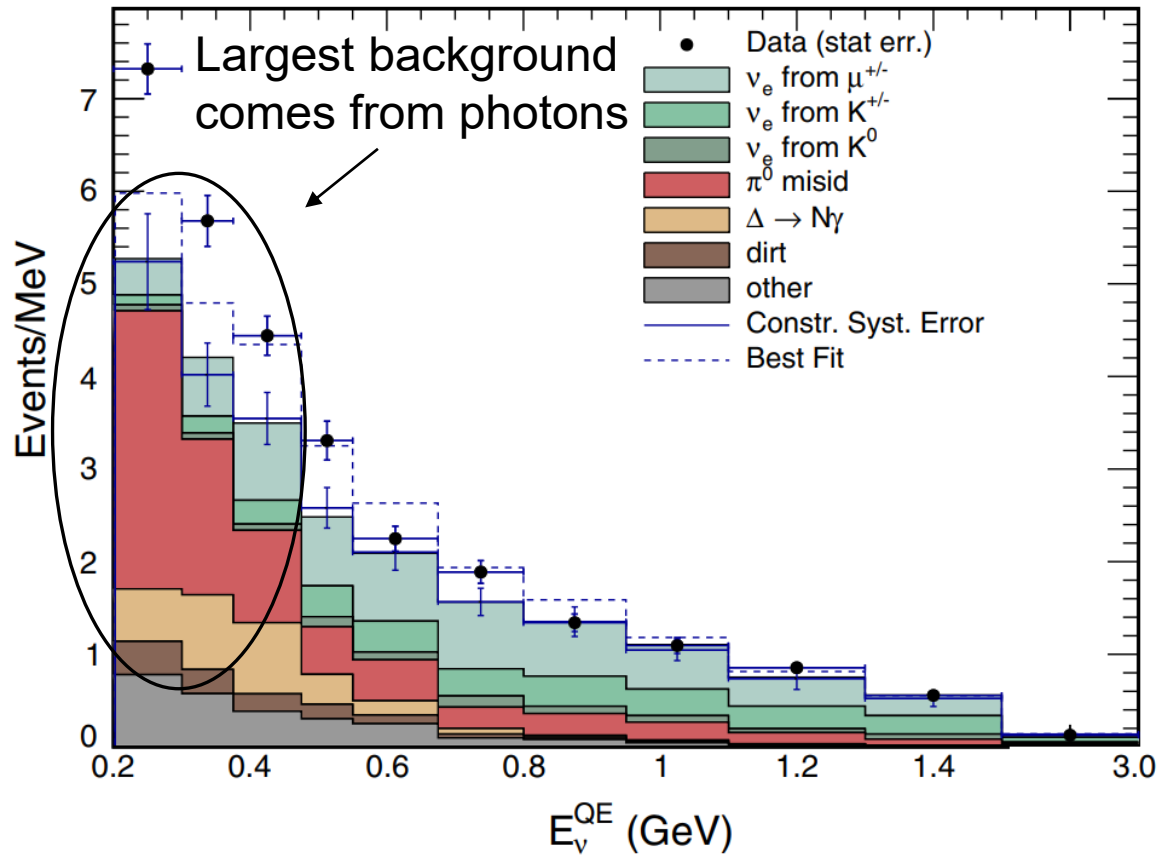


Comparison of electron neutrino-like data compared to prediction.

[\*Phys. Rev. D\* \*\*103\*\*, 052002](#)

# MiniBooNE's Anomalous Results

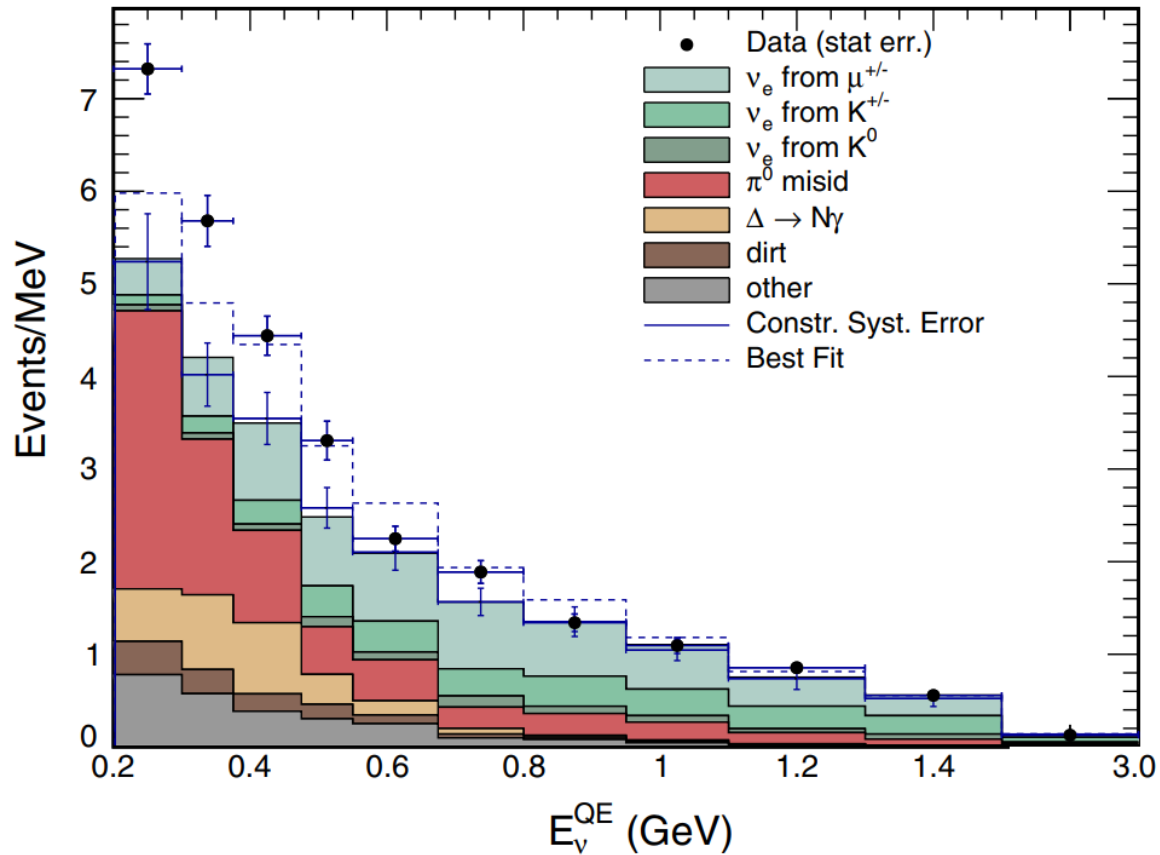
- Pion production can occur at these energies, leading to showers that mimic electrons.



[\*Phys. Rev. D\* \*\*103\*\*, 052002](#)

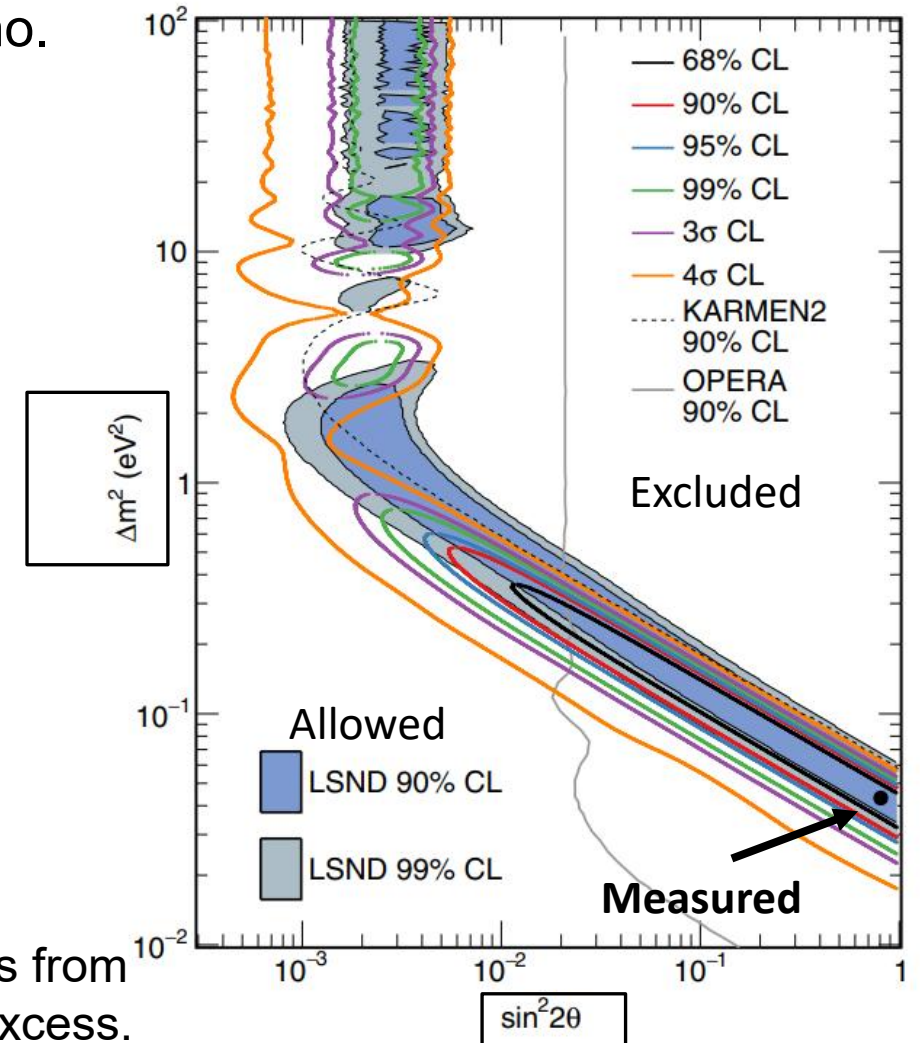
# MiniBooNE's Oscillation Contours

- An excess of  $4.8\sigma$  was observed of electron neutrino-like events, most noticeable at  $E < 500$  MeV.
- Can be explained by the addition of a fourth sterile neutrino.



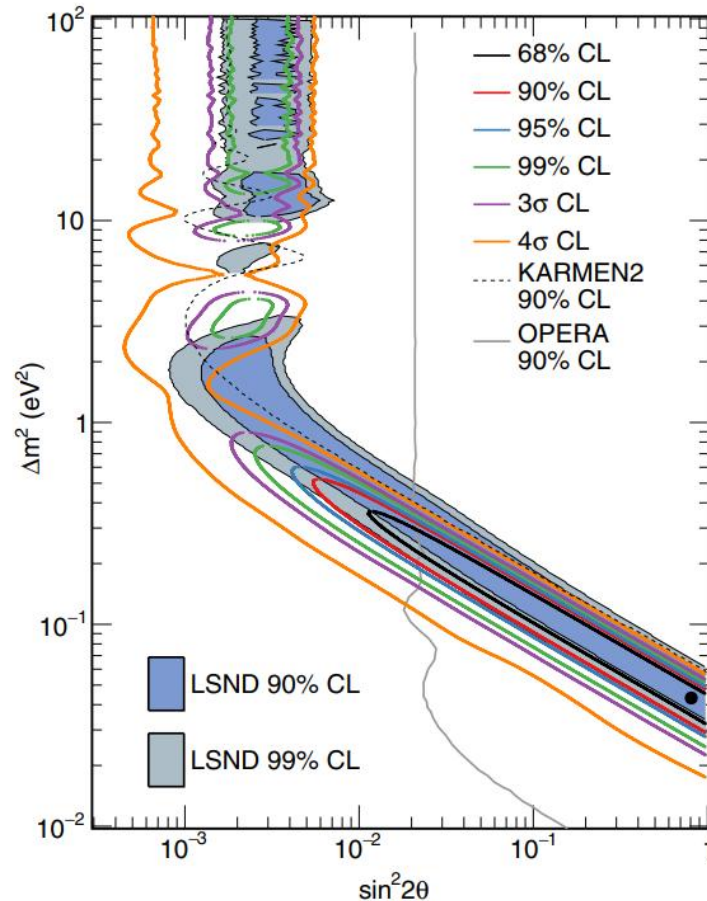
[\*Phys. Rev. D\* \*\*103\*\*, 052002](#)

Oscillation contours from electron neutrino excess.



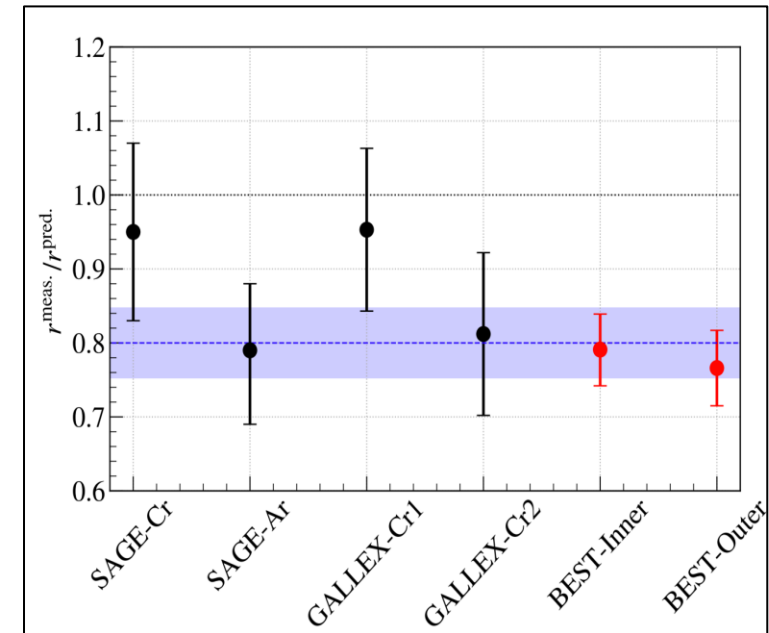
# Global Picture of Sterile Neutrinos (2015)

- MiniBooNE forms a global community with LSND and Gallium radioactive decay anomalies.



Oscillation contours from LSND muon antineutrino and MiniBooNE electron neutrino excess.

[\*Phys. Rev. Lett.\* \*\*128\*\*, 232501](#)

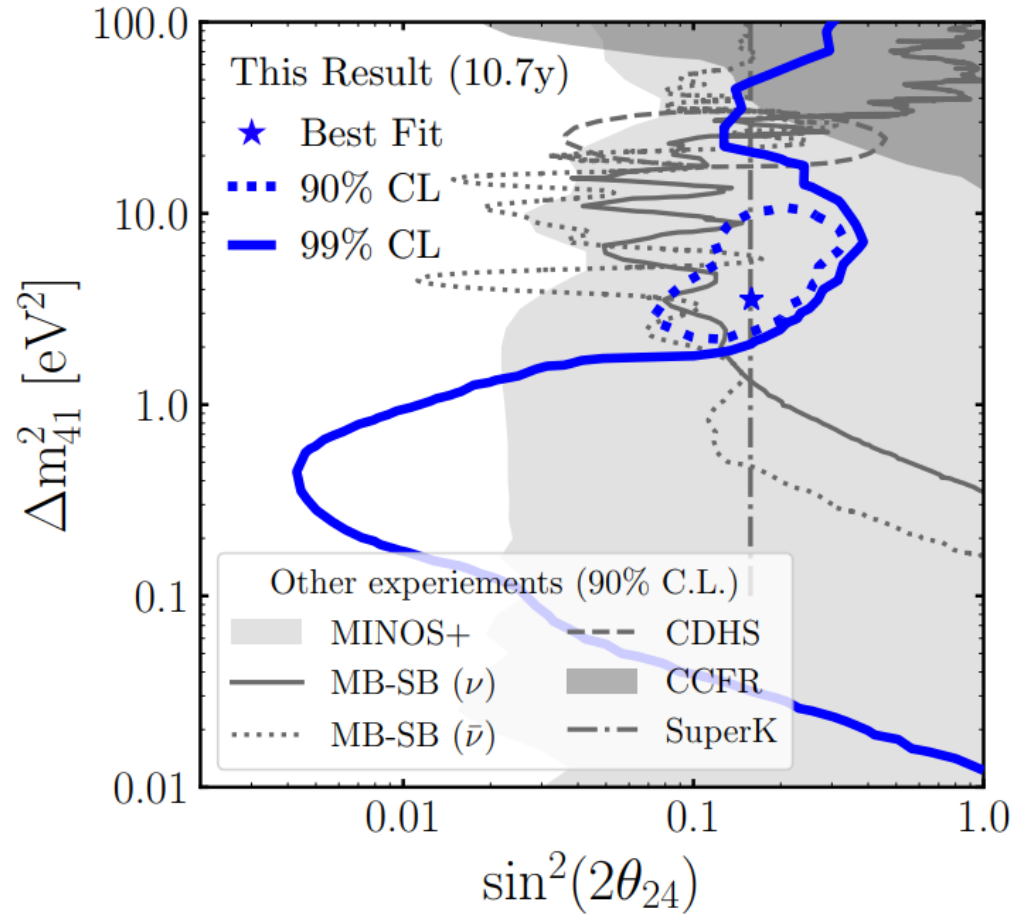


Rate of electron neutrino disappearance compared to expectation.

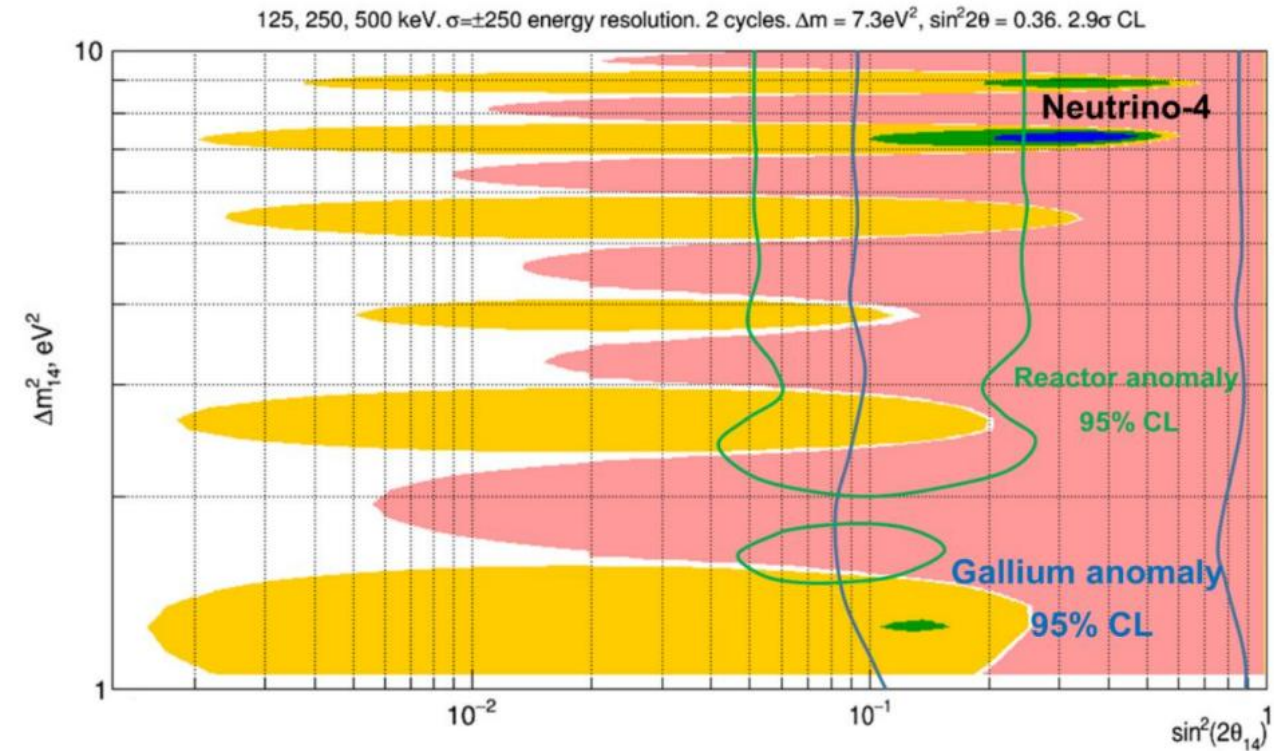
# Global Picture of Sterile Neutrinos (Now)

- Two more experiments show indications of sterile neutrinos.

**IceCube (Atmospherics, [Phys. Rev. Lett. 133, 201804](#))**

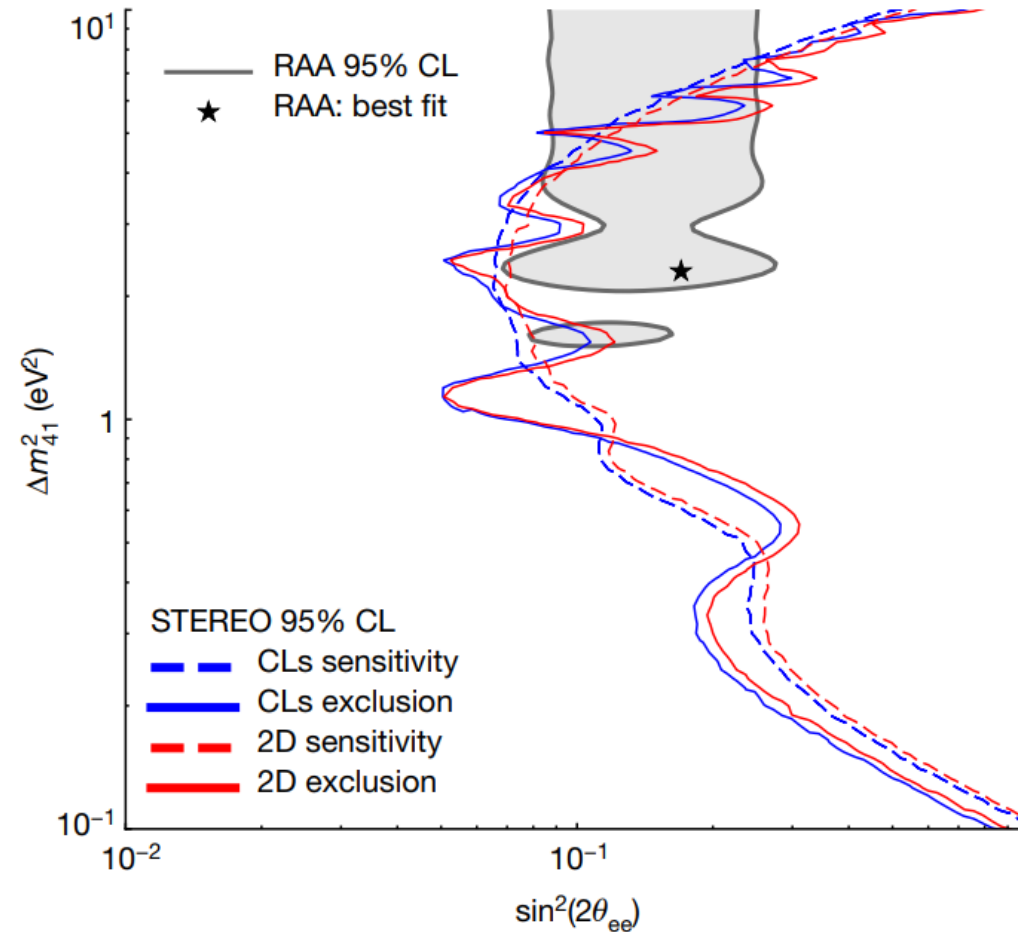


**Neutrino-4 (Reactor, [Phys. Rev. D 104, 032003](#))**



# Global Picture of Sterile Neutrinos (Now)

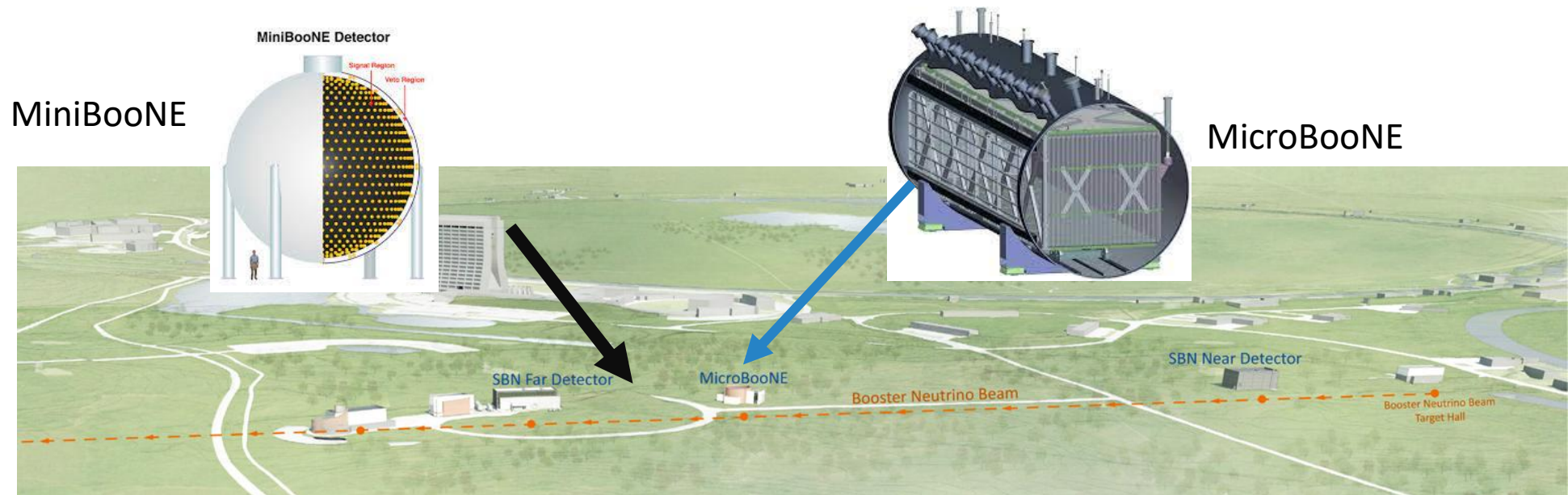
- STEREO shows no evidence of sterile neutrinos.
  - Excludes NEUTRINO-4 and RENO to more than  $2.75\sigma$ .



*Nature* **613**, 257–261 (2023)

# MicroBooNE

- MicroBooNE collected Booster Neutrino Beam data from 2015-2020.
  - The first large-scale LArTPC experiment in the United States.
- Objectives:
  1. Search for explanations of the MiniBooNE anomaly.
  2. Measure precision neutrino cross sections to understand neutrino-nucleus scattering.
  3. Develop liquid argon time projection chamber technology on path to DUNE.



# MicroBooNE

- MicroBooNE was a wire-based 85-kiloton liquid argon time projection chamber.
- It operated from 2015-2020.

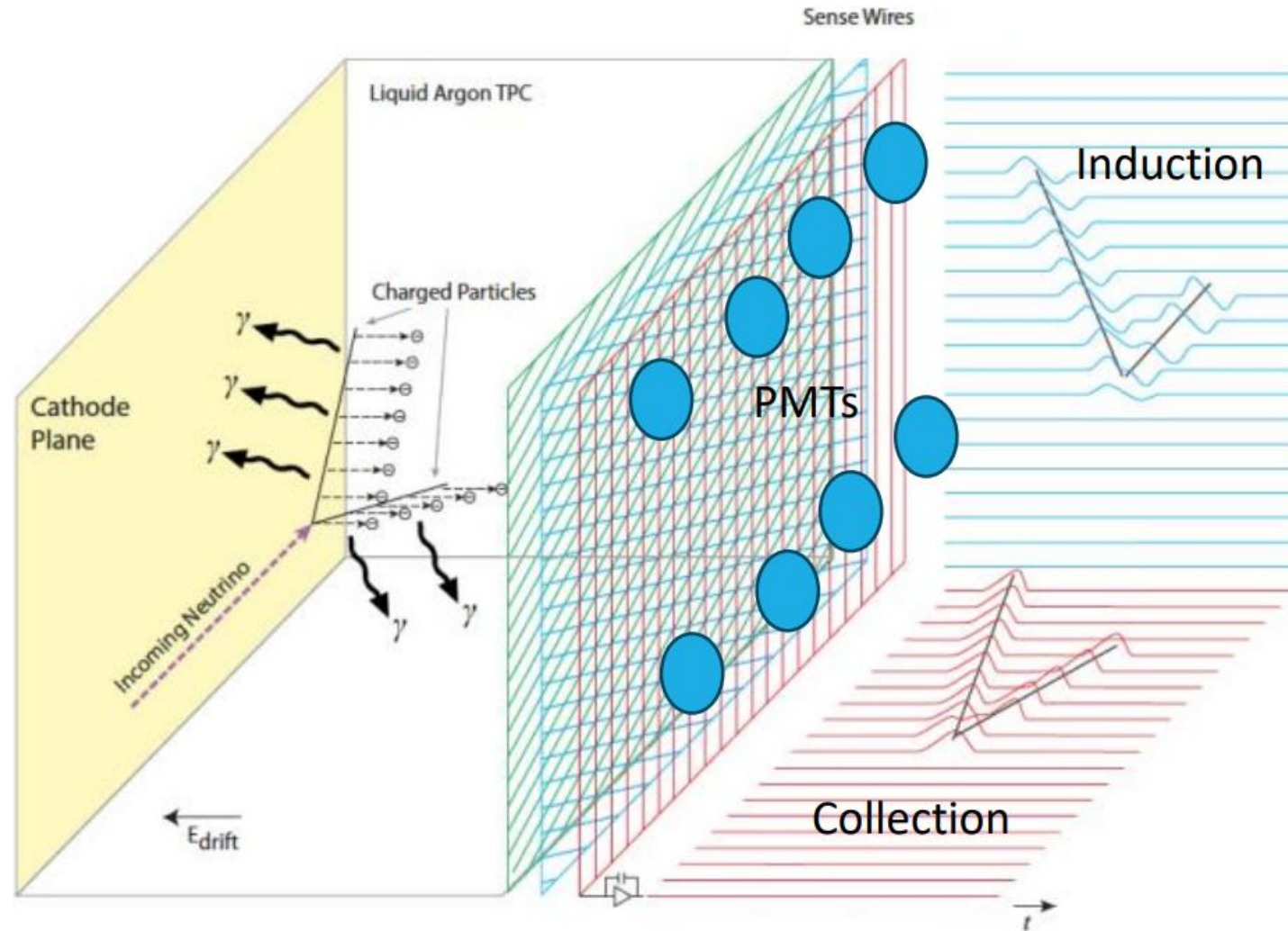


Cylindrical cryostat on support system covered in insulating foam during operation.



The wire readout plane of MicroBooNE.

# Concept of MicroBooNE's Detector Technology



# MicroBooNE's Electron/Photon Separation

- Electrons and photons produce different signatures in argon, addressing MiniBooNE backgrounds.
- The  $dE/dx$  of photons is 2 MIPs and of electrons it is 1 MIP at the shower vertex.



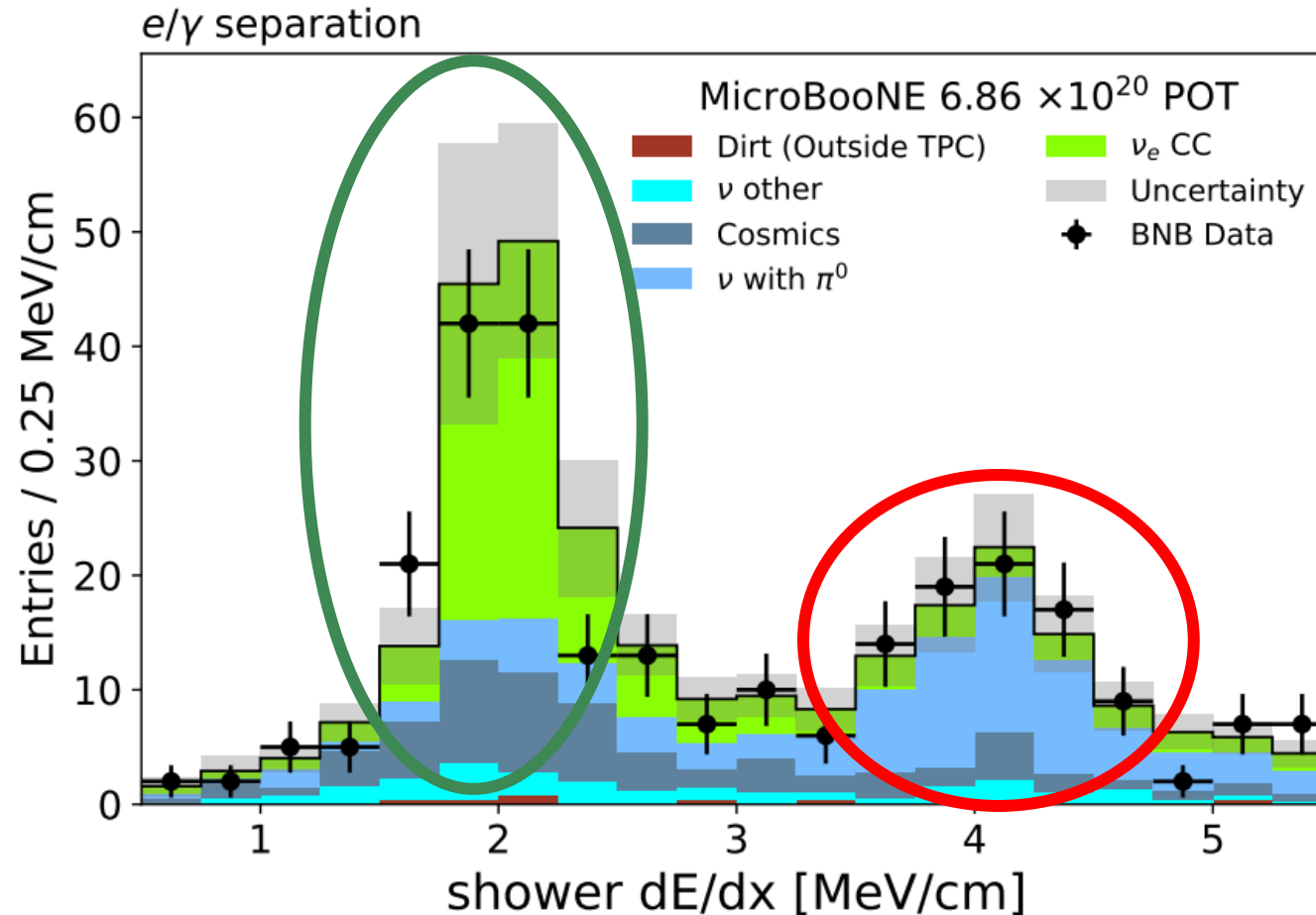
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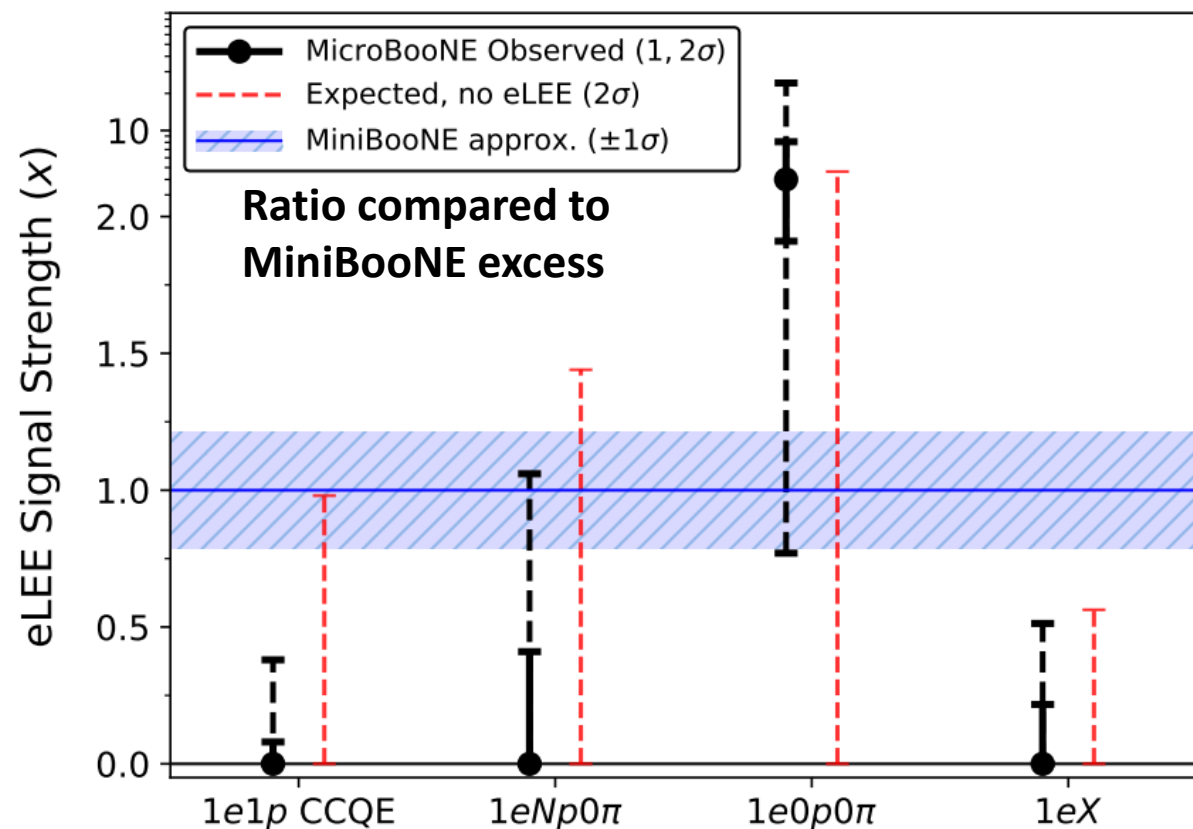
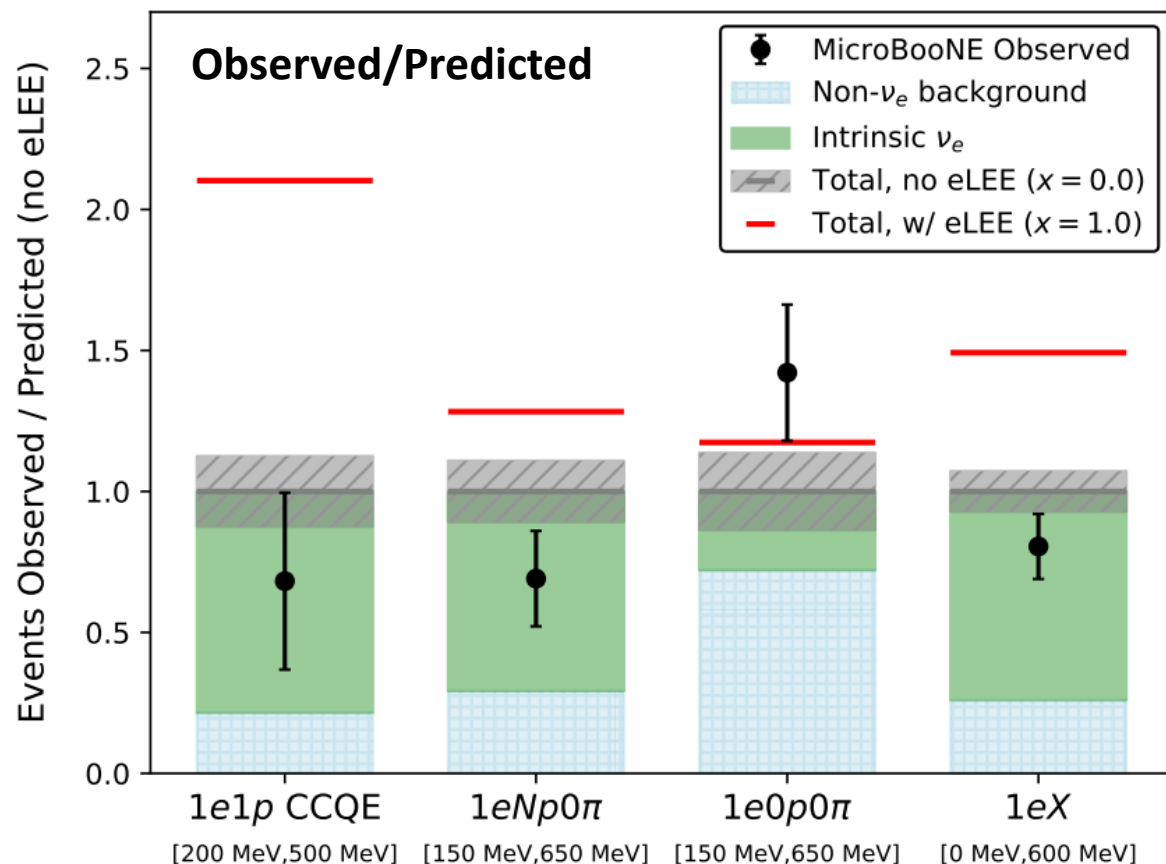
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*Phys. Rev. D* **105**, 112004

# Initial Search for a MicroBooNE Signal

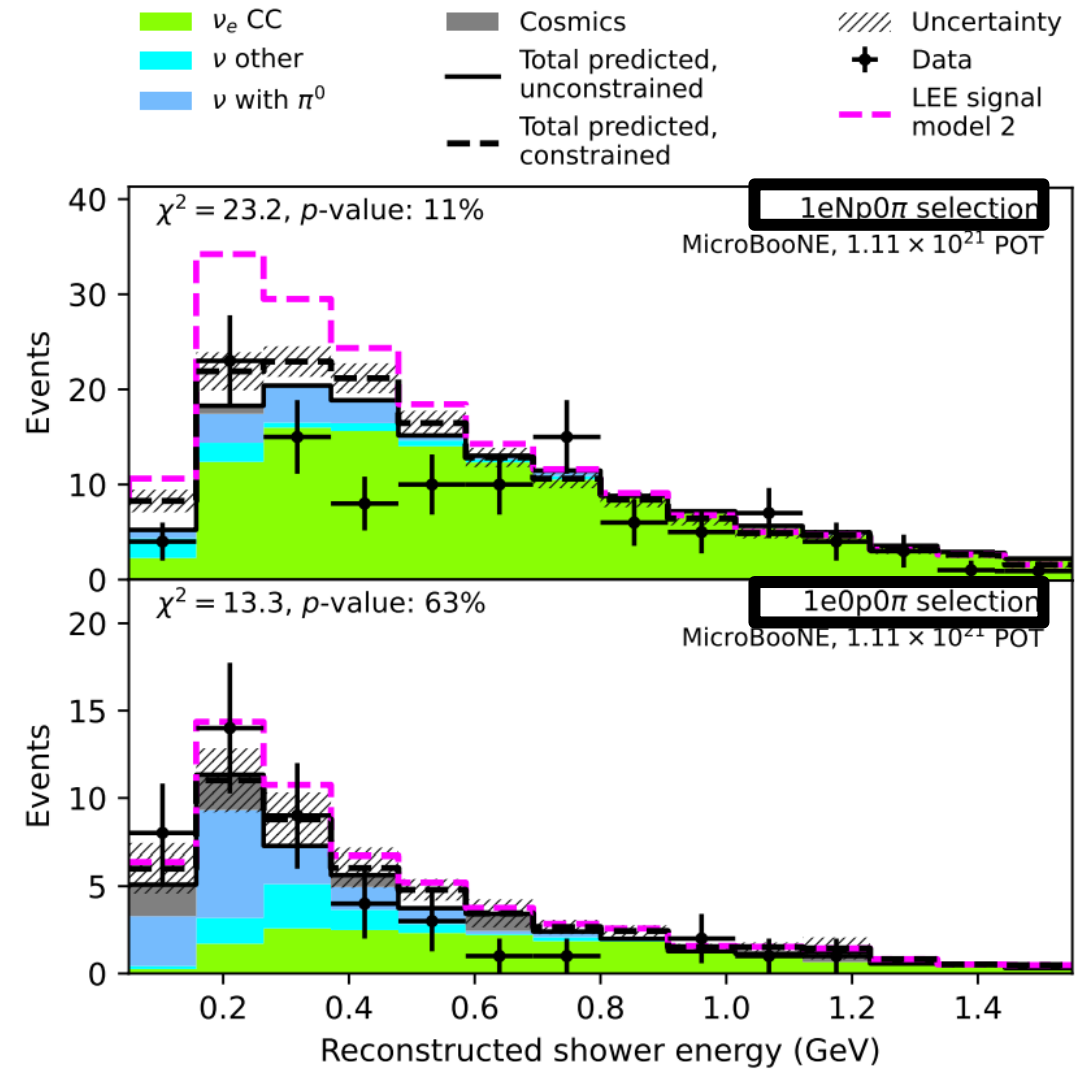
- MicroBooNE analyzed the first three years of data for various electron neutrino-like signals.
- The most comparable to MiniBooNE's analysis looked at  $1eNp0\pi$  and  $1e1p0\pi$ .
  - However, even the inclusive analysis saw a deficit.



*Phys. Rev. Lett.* **128**, 241801

# Final Search for Pionless CC Excess

- We recently released the full five-year dataset results for the mesonless channel.
  - Double the statistics as previous search.
  - Includes cosmic veto using scintillator strips.
- Analysis includes improved MiniBooNE model that unfolds shower kinematics and neutrino energy.
- No excess was observed.
- Slight excess in second bin when looking at channel with no protons ( $>40$  MeV).
- Has a  $2.4\sigma$  **deficit** across the full  $1eNp0\pi$  energy range.

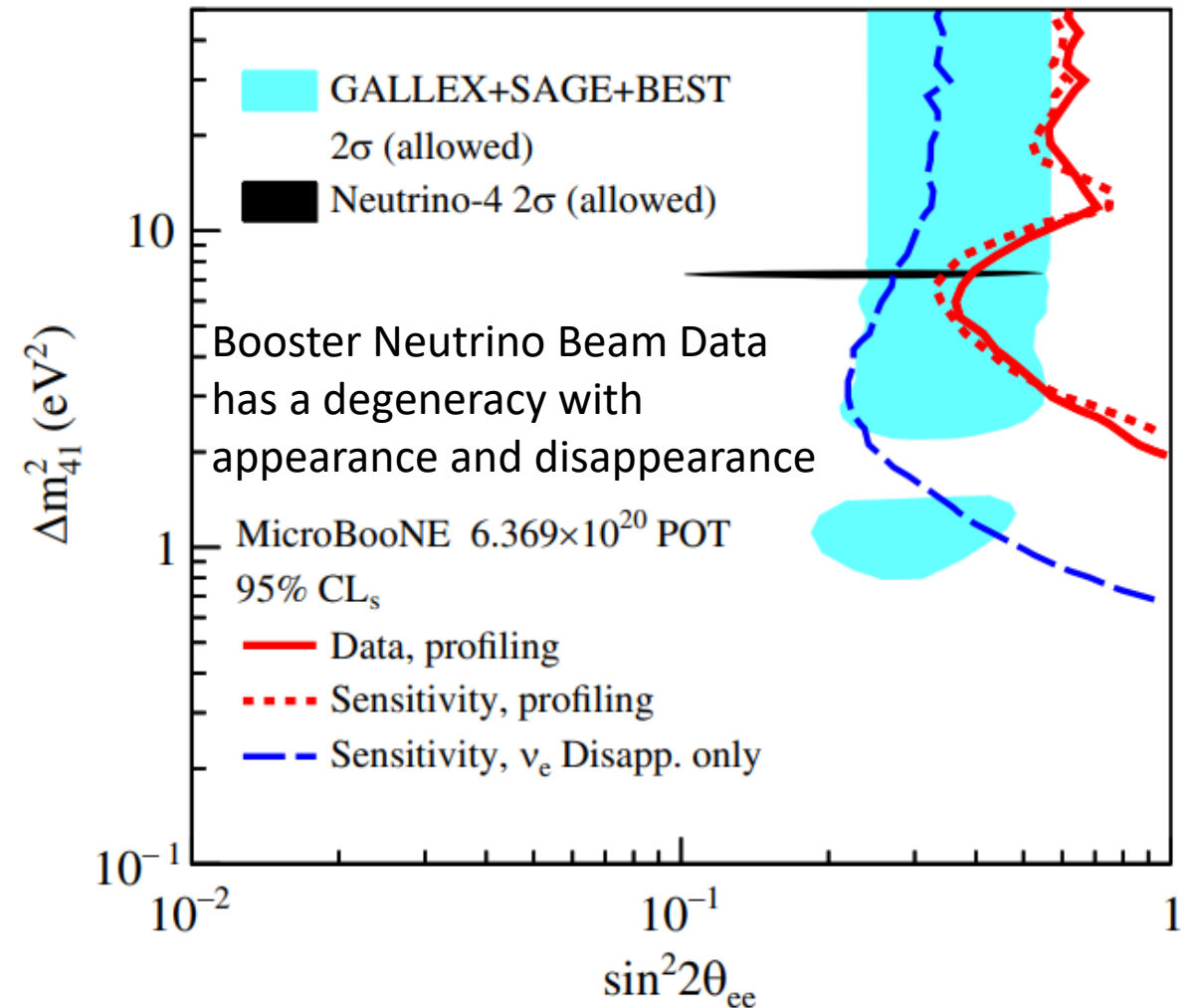
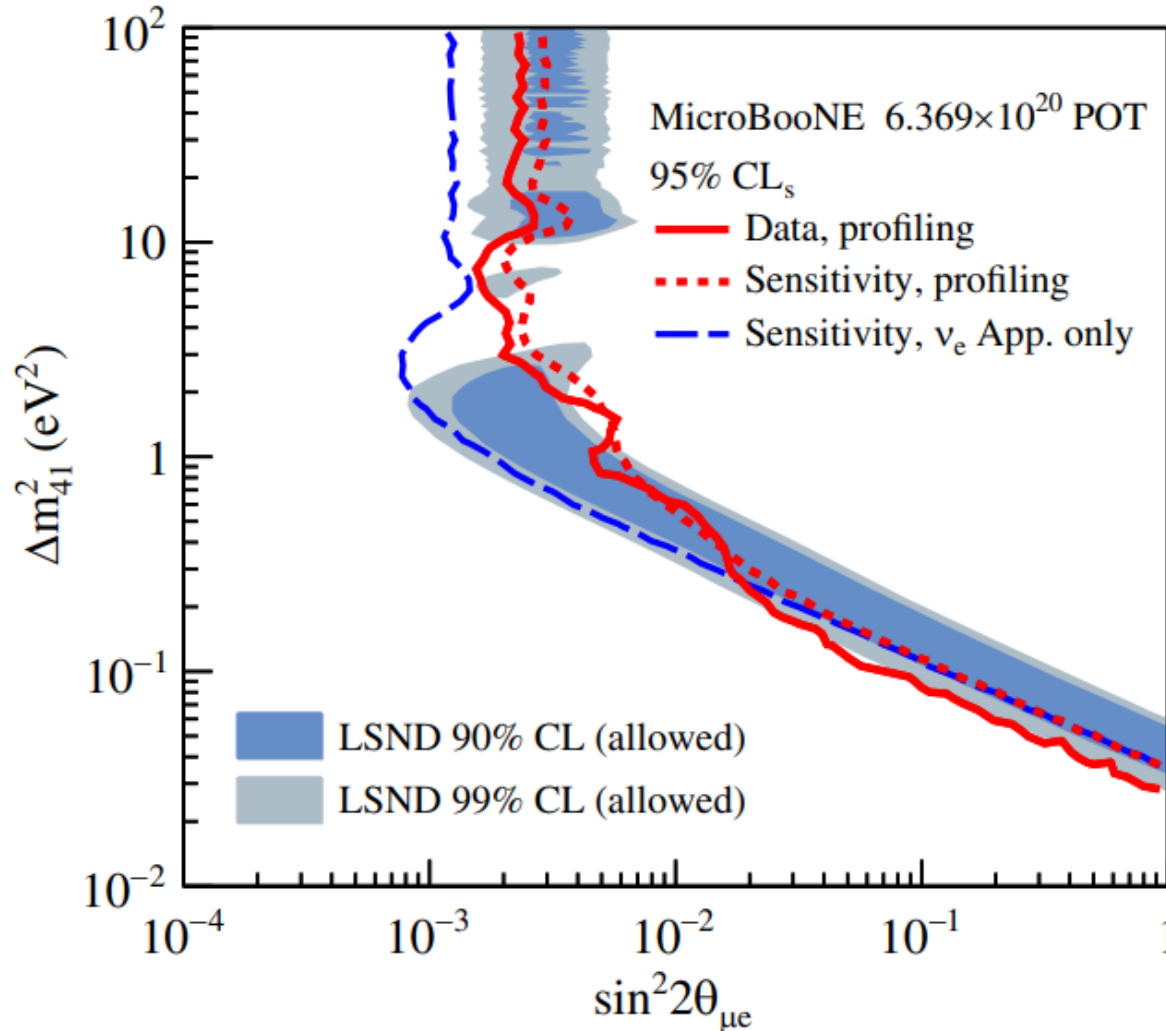


*Phys. Rev. Lett.* **135**, 081802

# Current MicroBooNE Oscillation Contours

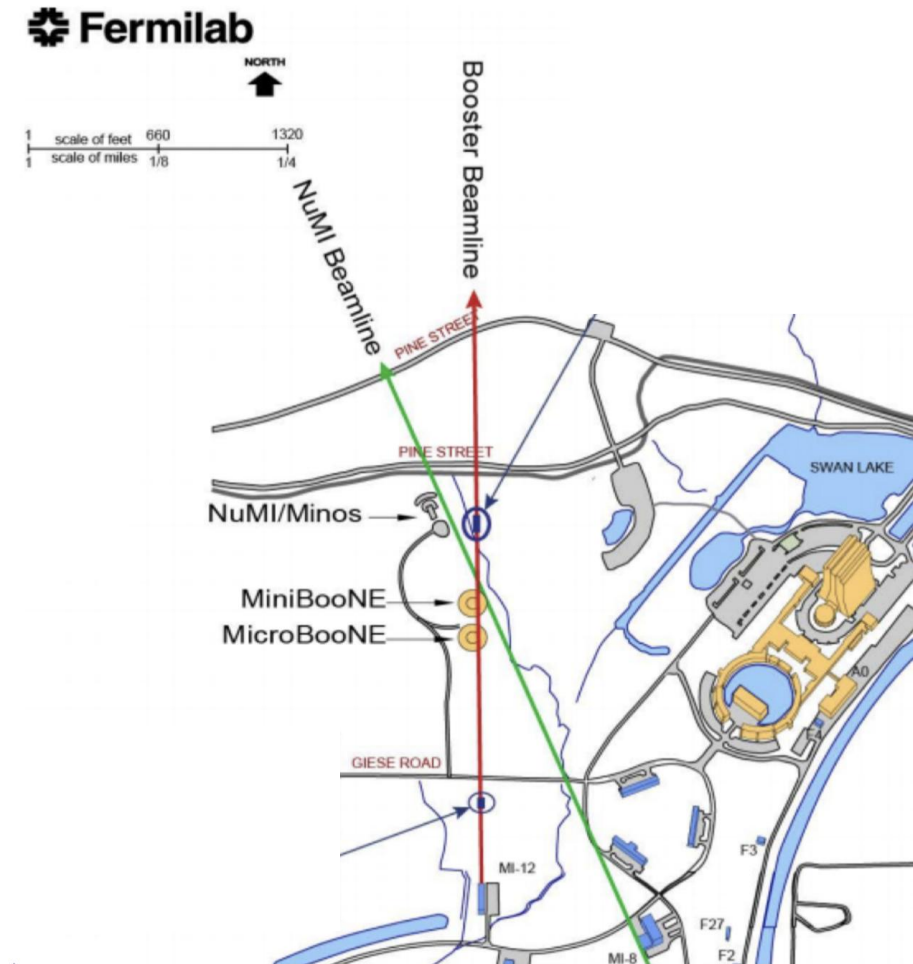
- Oscillation curves made with inclusive electron neutrino result.

[\*Phys. Rev. Lett.\* \*\*130\*\*, 011801](#)



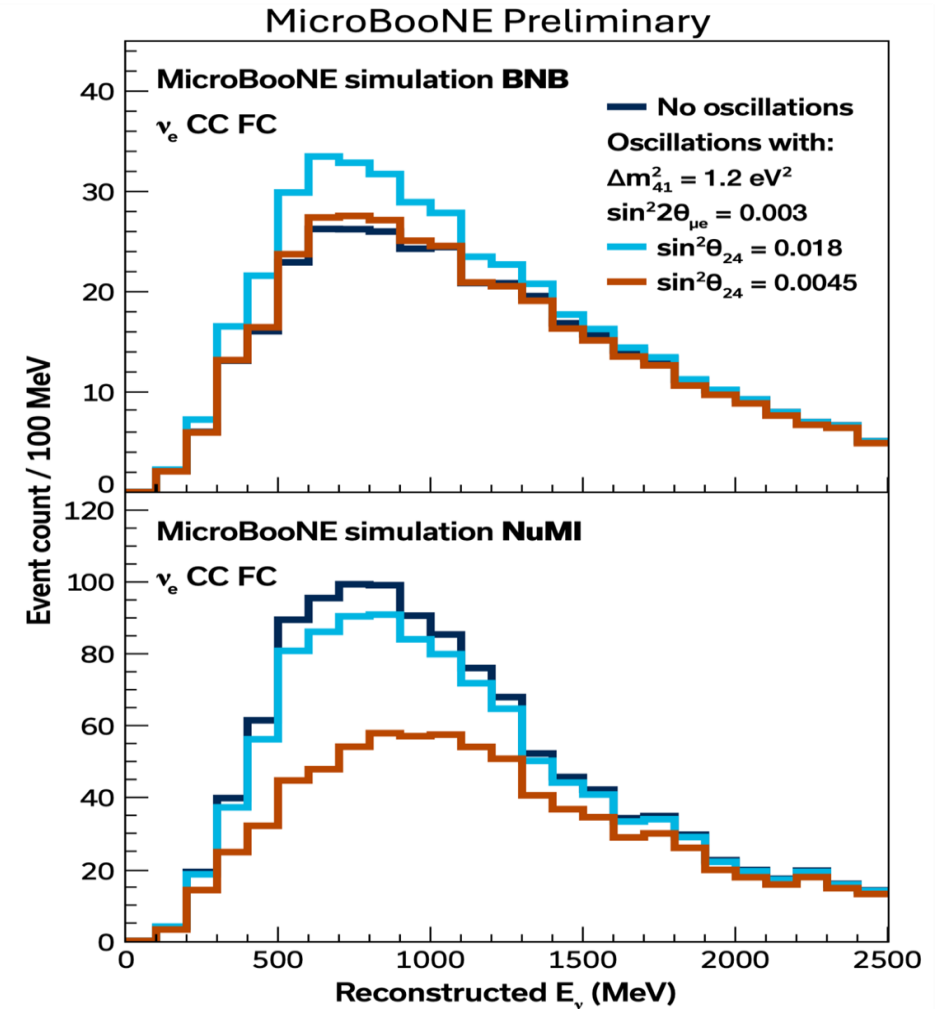
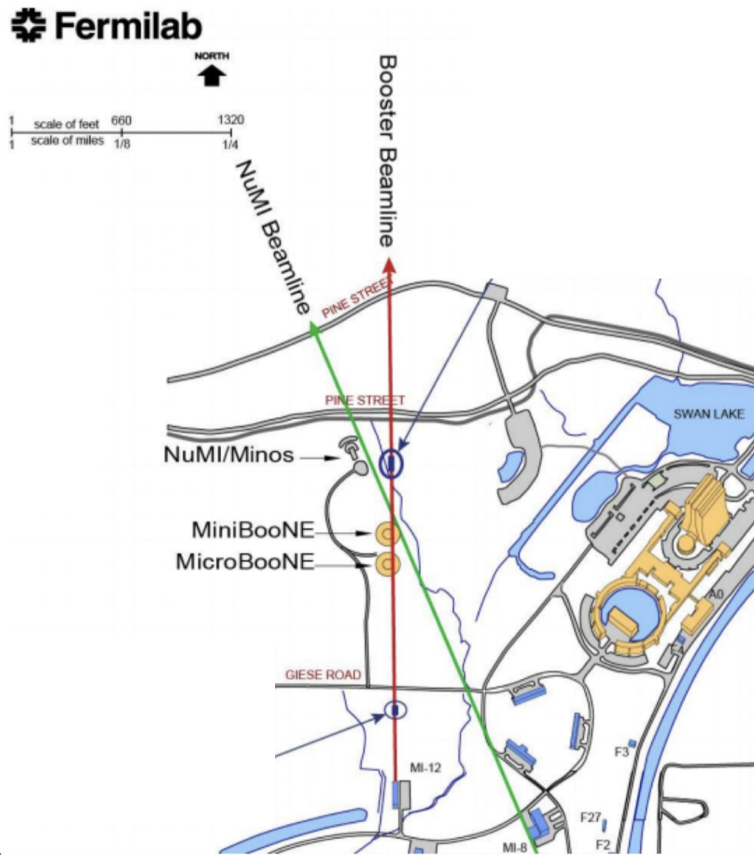
# MicroBooNE Combined Beam Oscillation Program

- MicroBooNE observes two beams.
- It is on-axis with the Booster Neutrino Beam.
  - The same one used for the MiniBooNE result.
- The higher-energy NuMI beam is off-axis at 8 degrees at a different baseline and a slightly higher energy.



# MicroBooNE Combined Beam Oscillation Program

- The two beams produce different spectrums.
- Allows for appearance and disappearance to be disentangled.



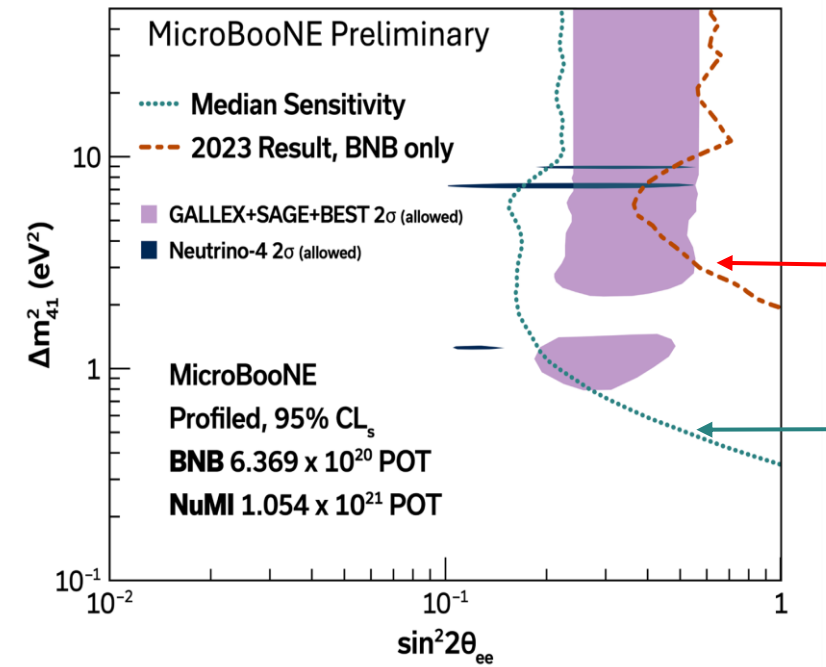
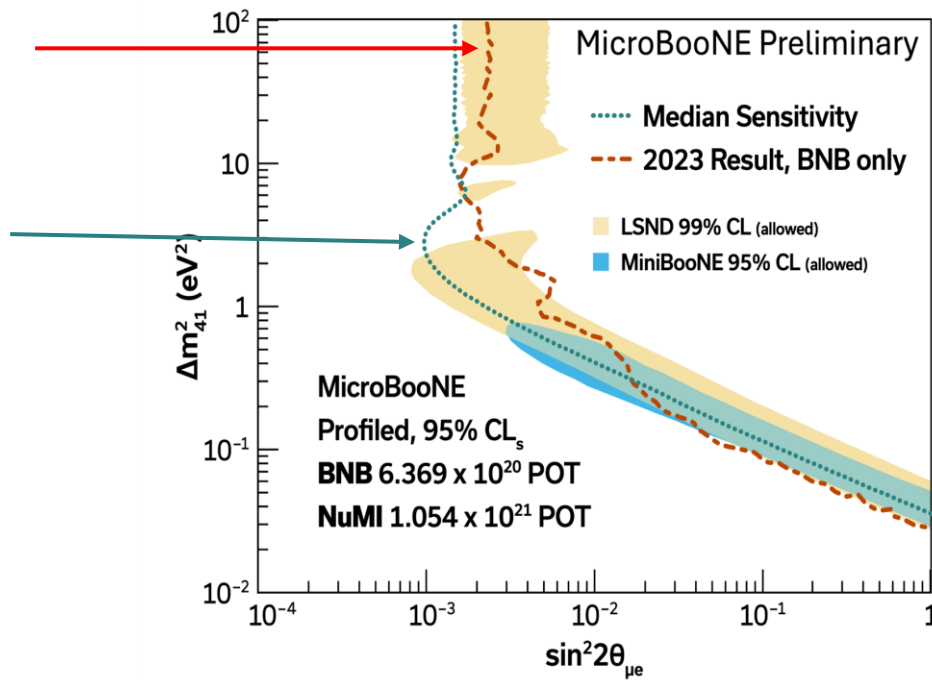
Expected event rate of electron neutrinos at both beams for different sterile mixing parameters.

# MicroBooNE Combined Beam Oscillation Program

- A future combined analysis could break the degeneracy and can provide the sensitivities of only considering only appearance and disappearance.

Single Beam

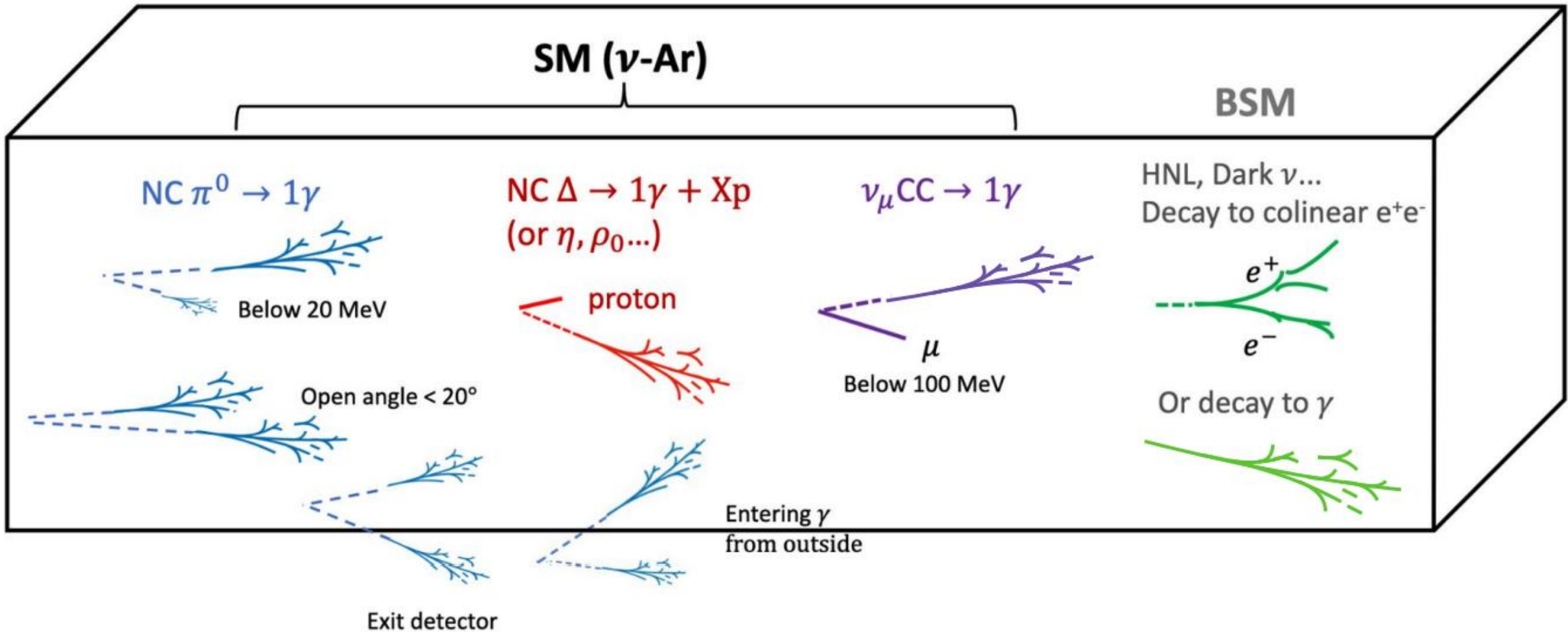
Two Beams



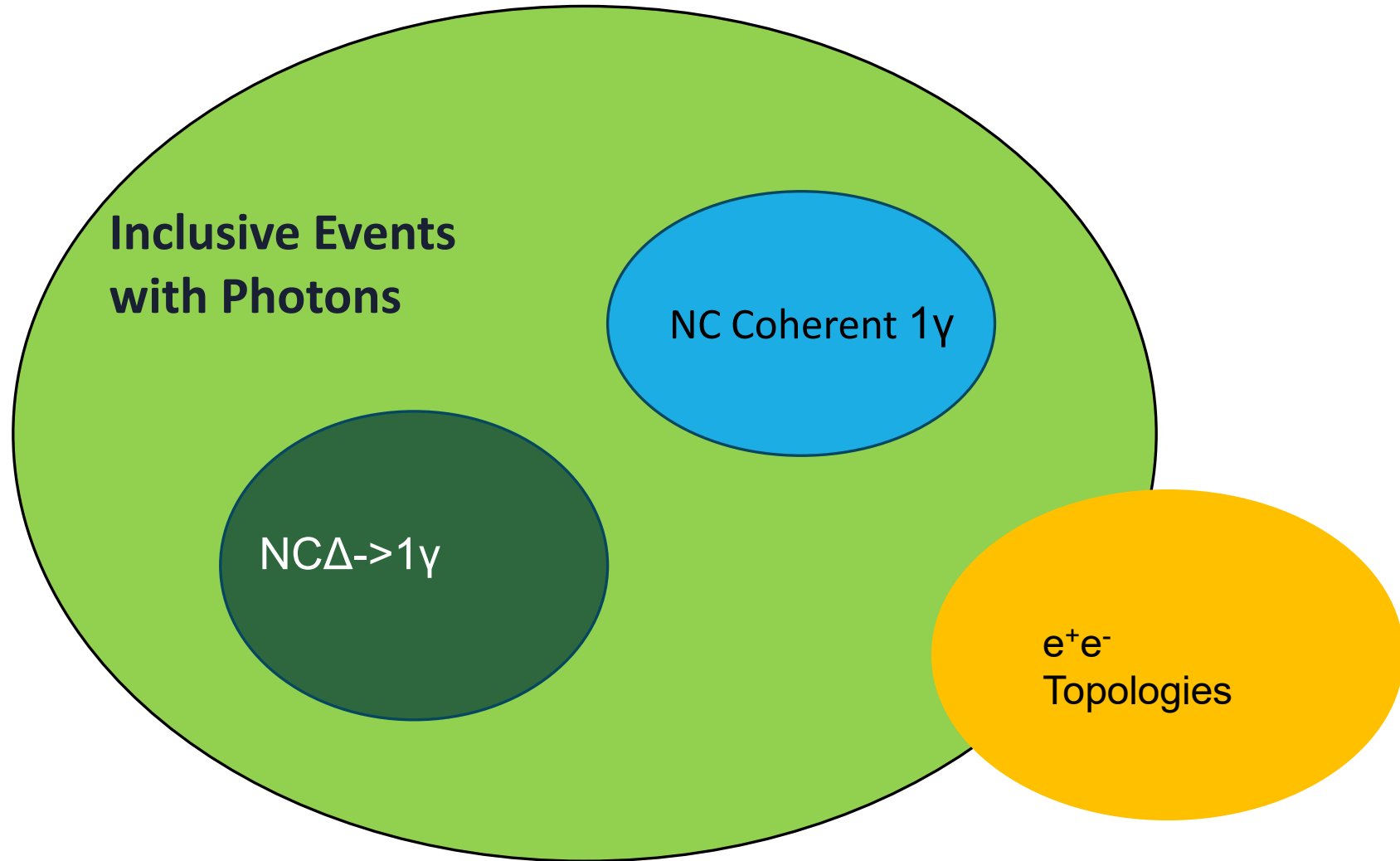
Single Beam

Two Beams

# Searches for Photon-Like Explanations

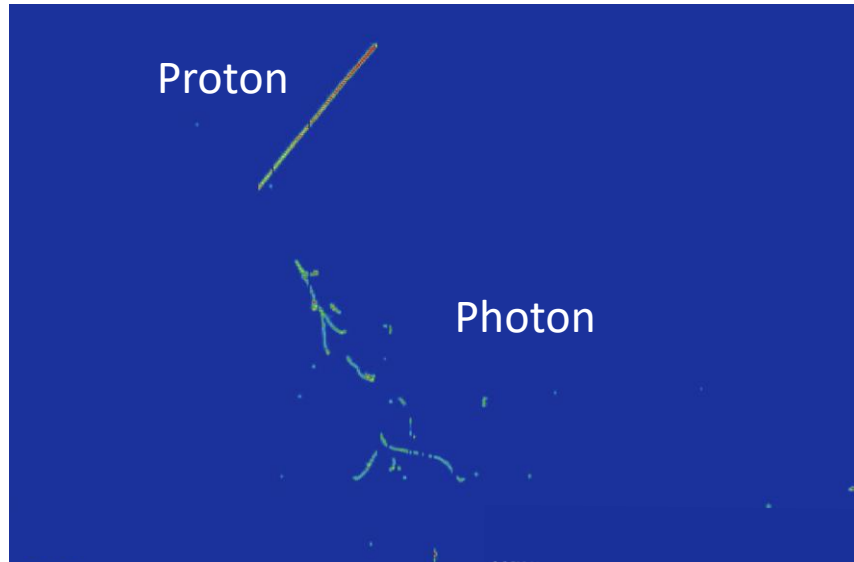


# Searches for Photon-Like Explanations



# Searches for NC $\Delta$ Excess

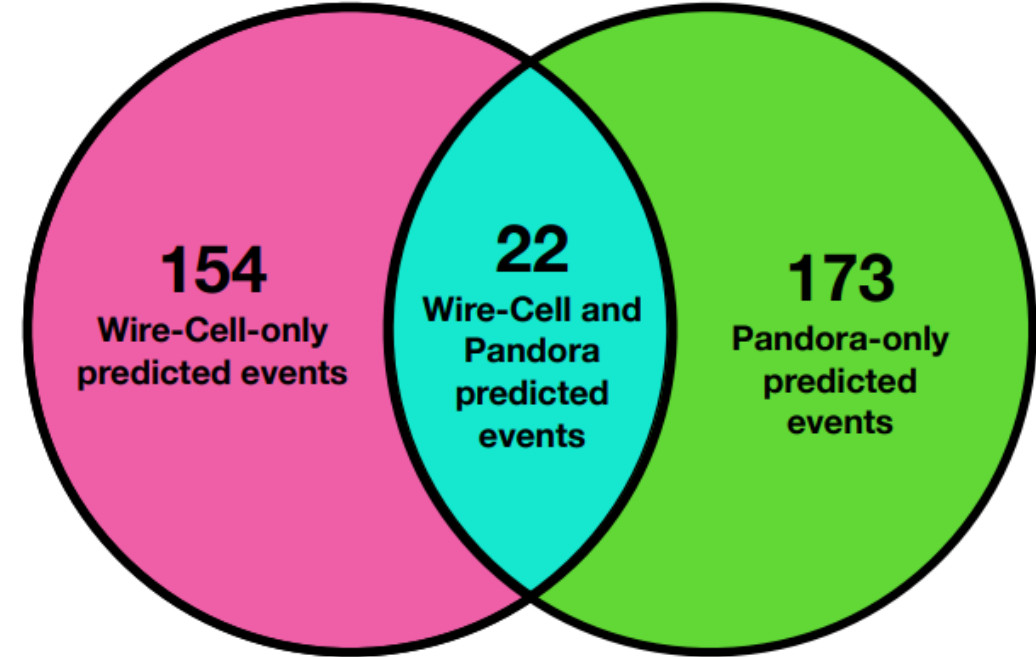
- Could an excess of photons explain the MiniBooNE excess?
- First search looked for a NC $\Delta \rightarrow 1\gamma$  interaction channel.
- Combined analysis with two reconstruction packages.



Data event with a  $\Delta^+$  decaying to  $1\gamma 0p$ .  
A  $0p$  channel with  $\Delta^0$  is also possible.

**Wire-Cell Selection**  
( $1\gamma Np$  and  $1\gamma 0p$  combined)

**Pandora Selection**  
( $1\gamma 1p$  and  $1\gamma 0p$  combined)

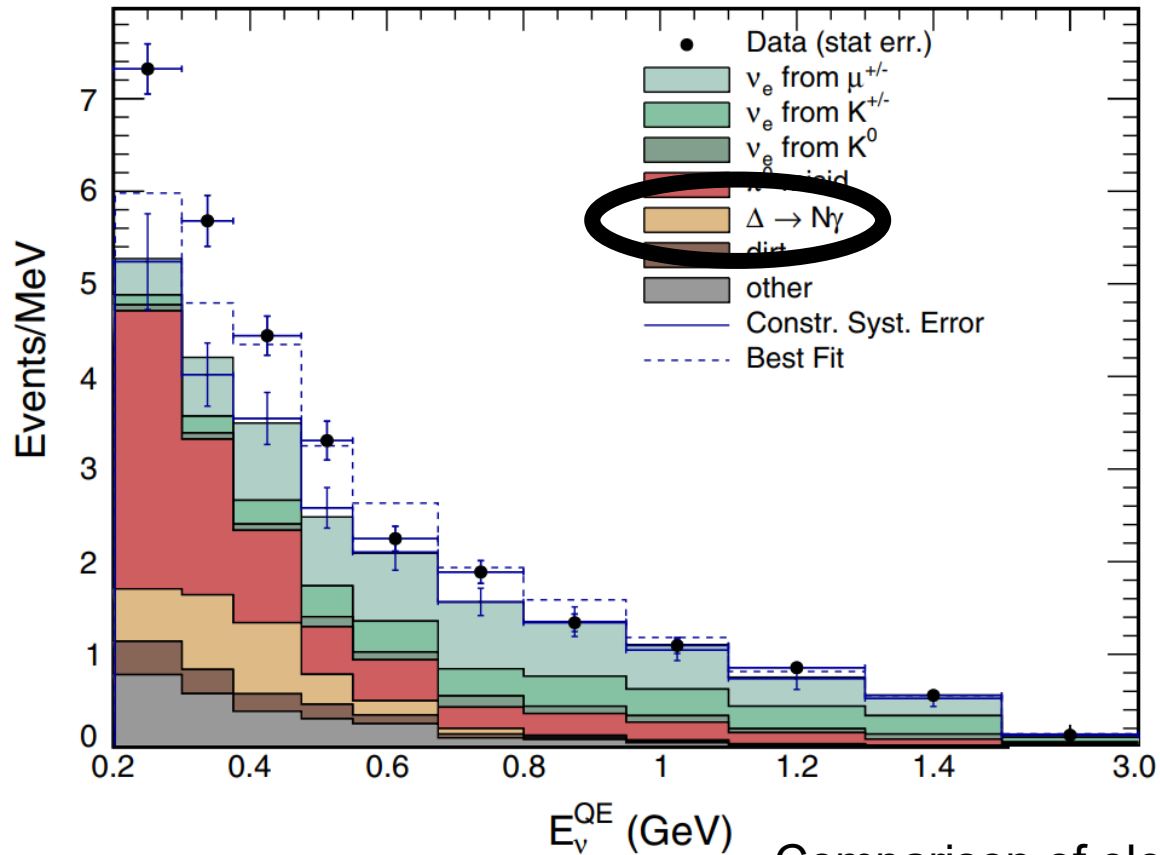


	WC	Pandora	WC	Pandora	Combined
	$1\gamma Np$	$1\gamma 1p$	$1\gamma 0p$	$1\gamma 0p$	
NC $\Delta \rightarrow N\gamma$ eff.	4.09%	4.24%	8.79%	5.52%	19.64%
NC $\Delta \rightarrow N\gamma$ pur.	9.60%	14.84%	7.50%	3.98%	6.37%

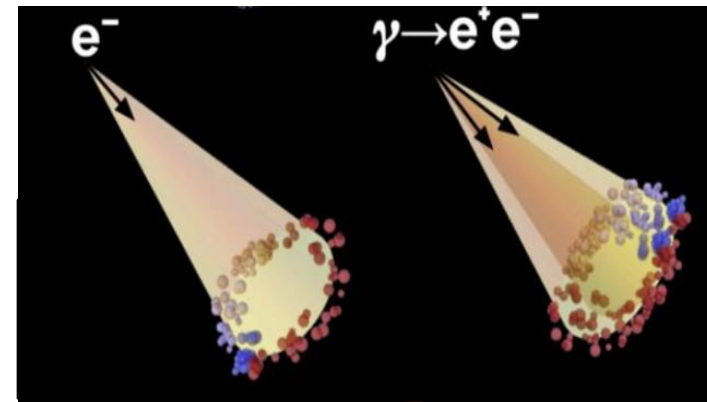
[arXiv:2502.05750](https://arxiv.org/abs/2502.05750)

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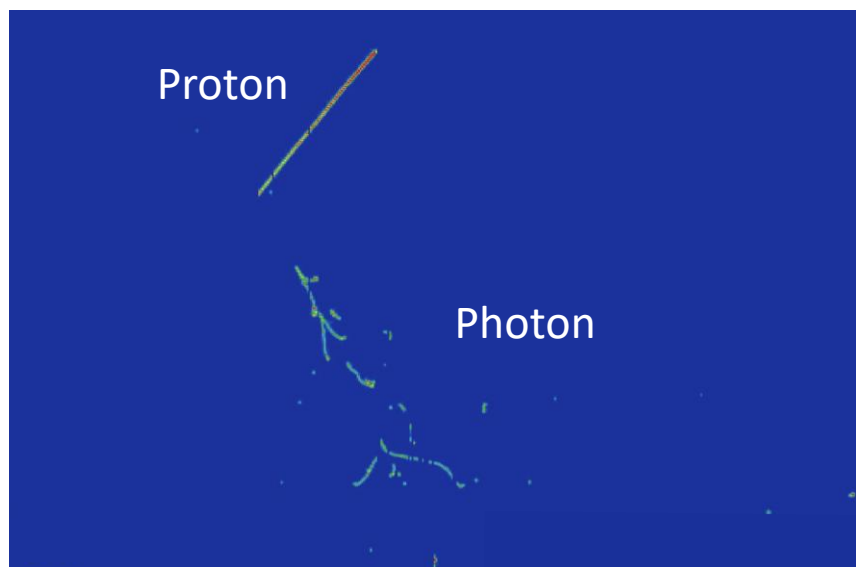


Comparison of electron neutrino-like data compared to prediction.

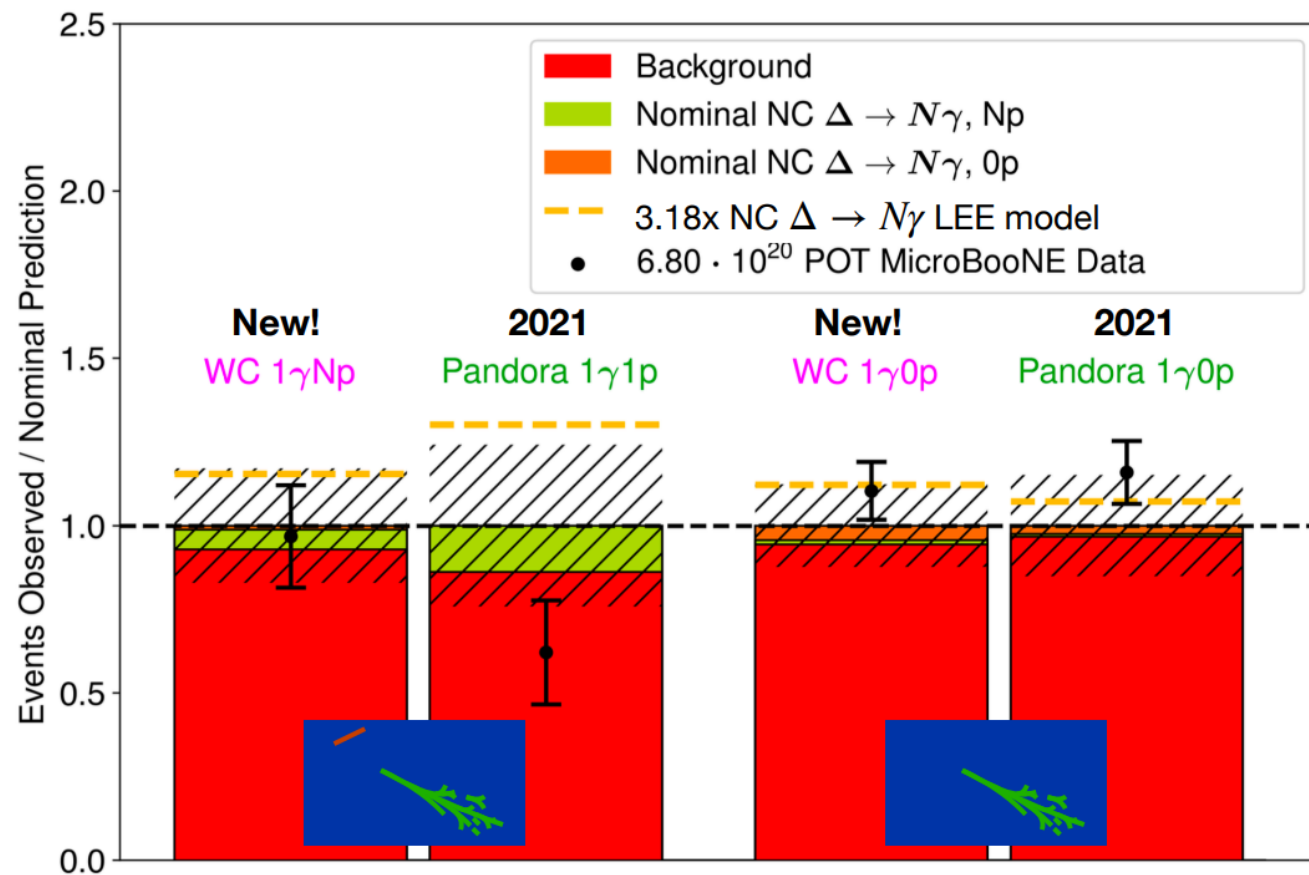
[\*Phys. Rev. D\* \*\*103\*\*, 052002](#)

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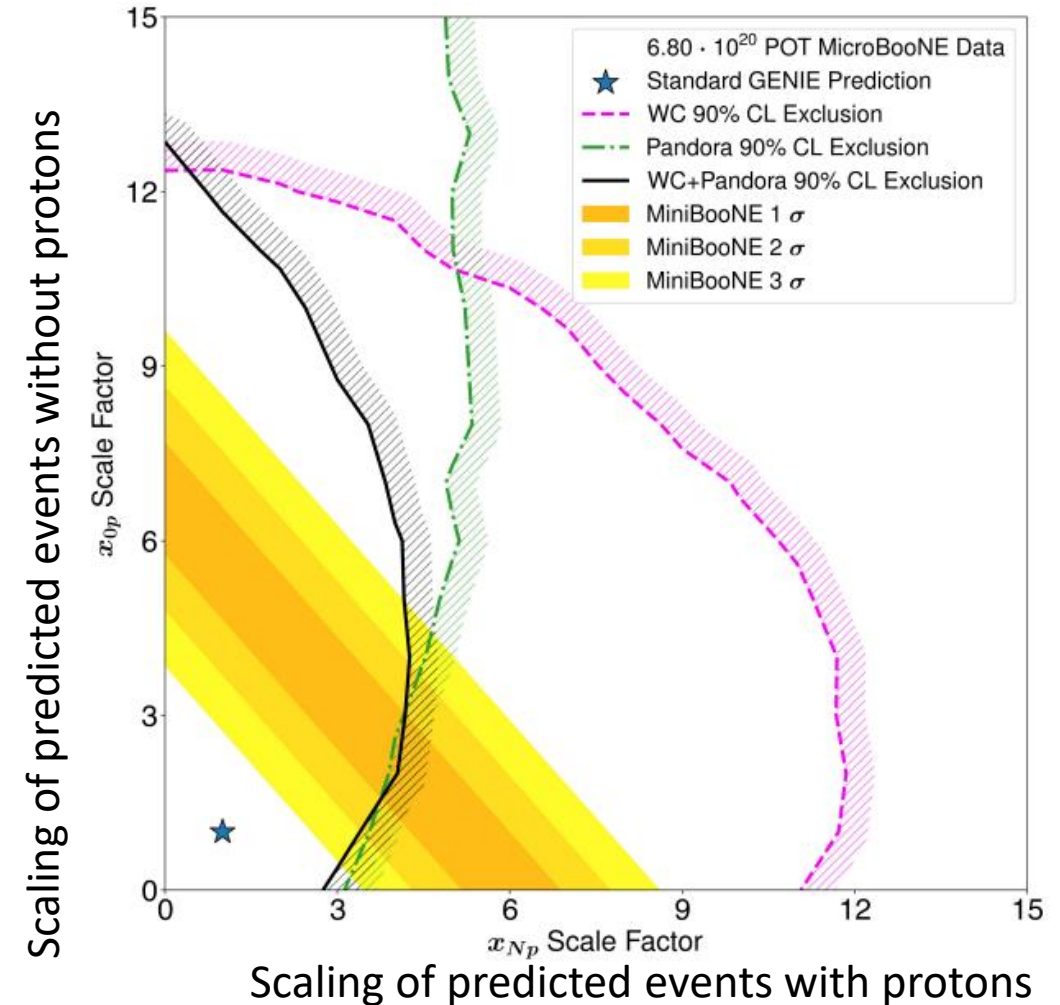
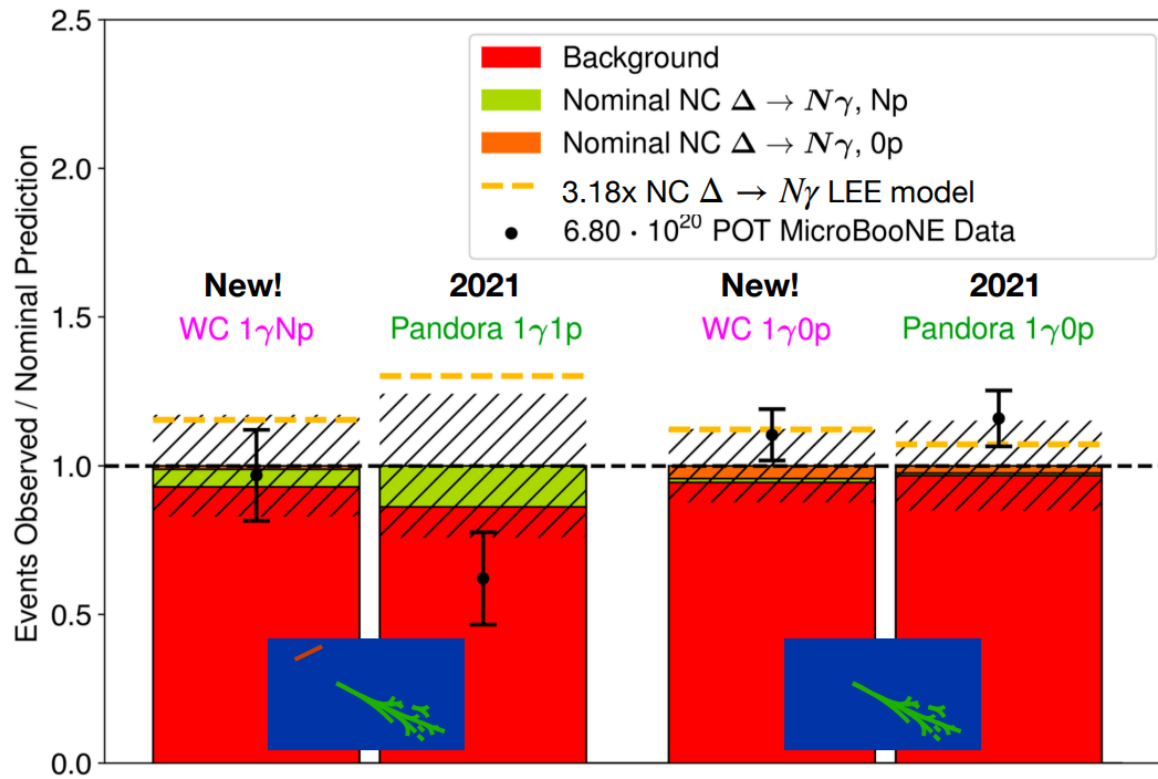
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# Searches for Photon-Like Explanations

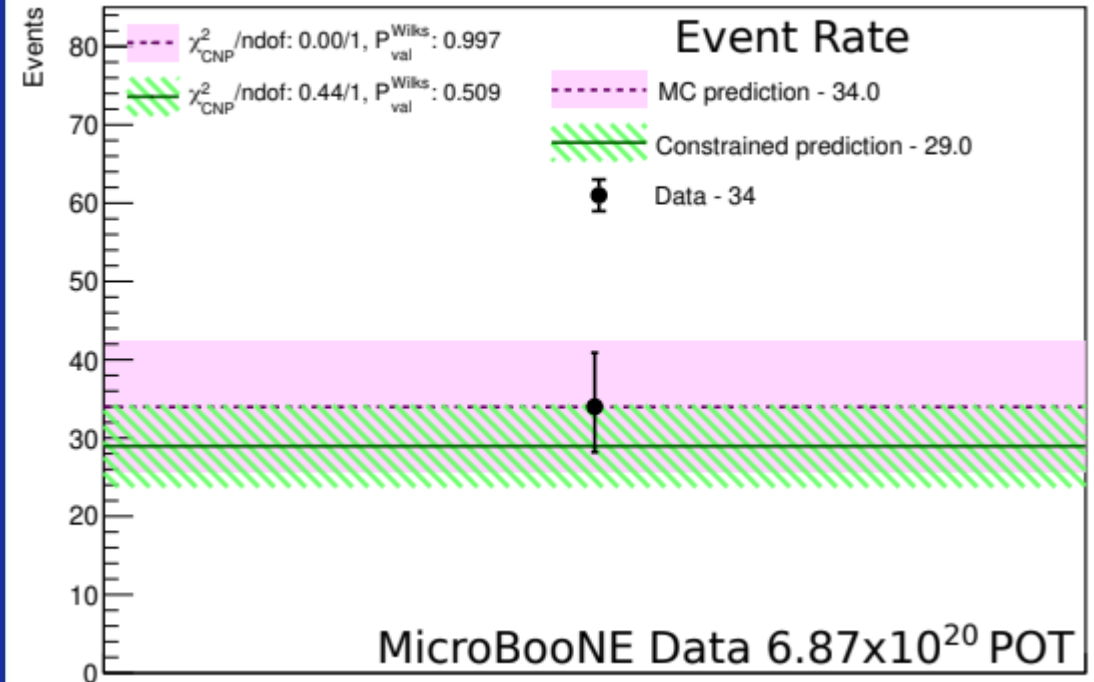
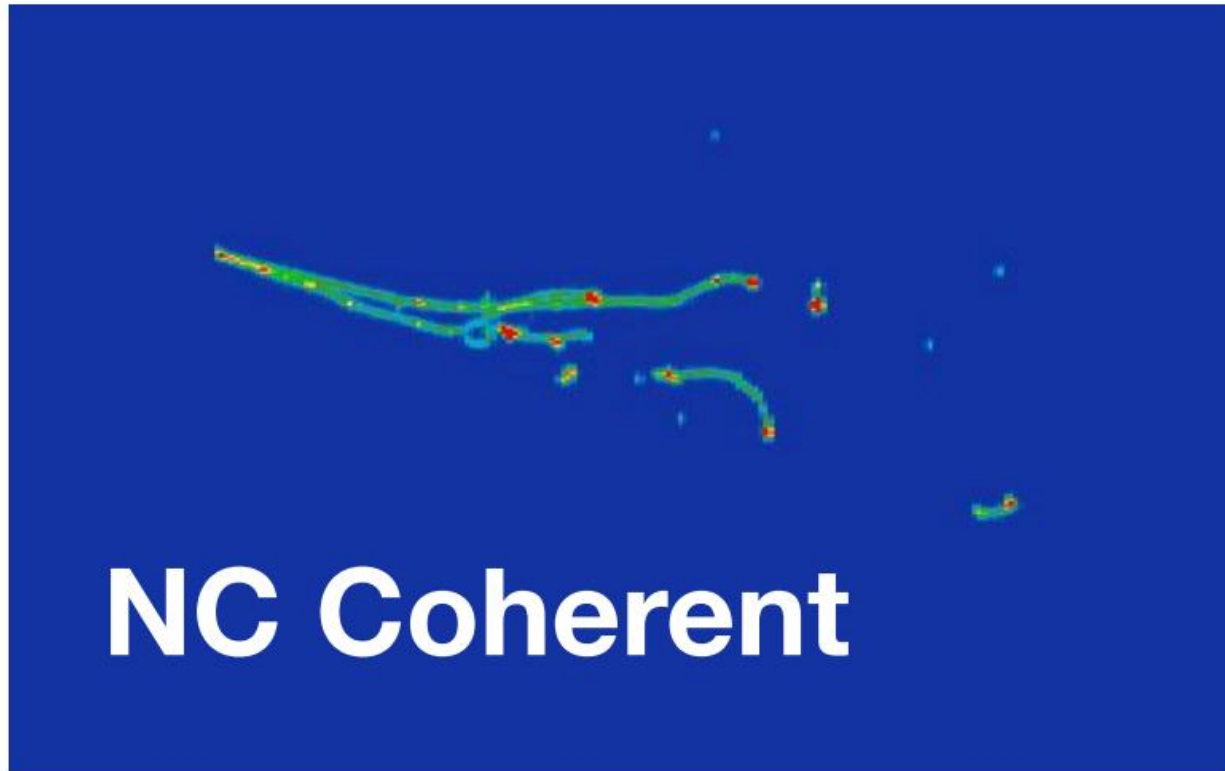
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[arXiv:2502.05750](https://arxiv.org/abs/2502.05750)

# Search for Neutral Current Coherent Scattering

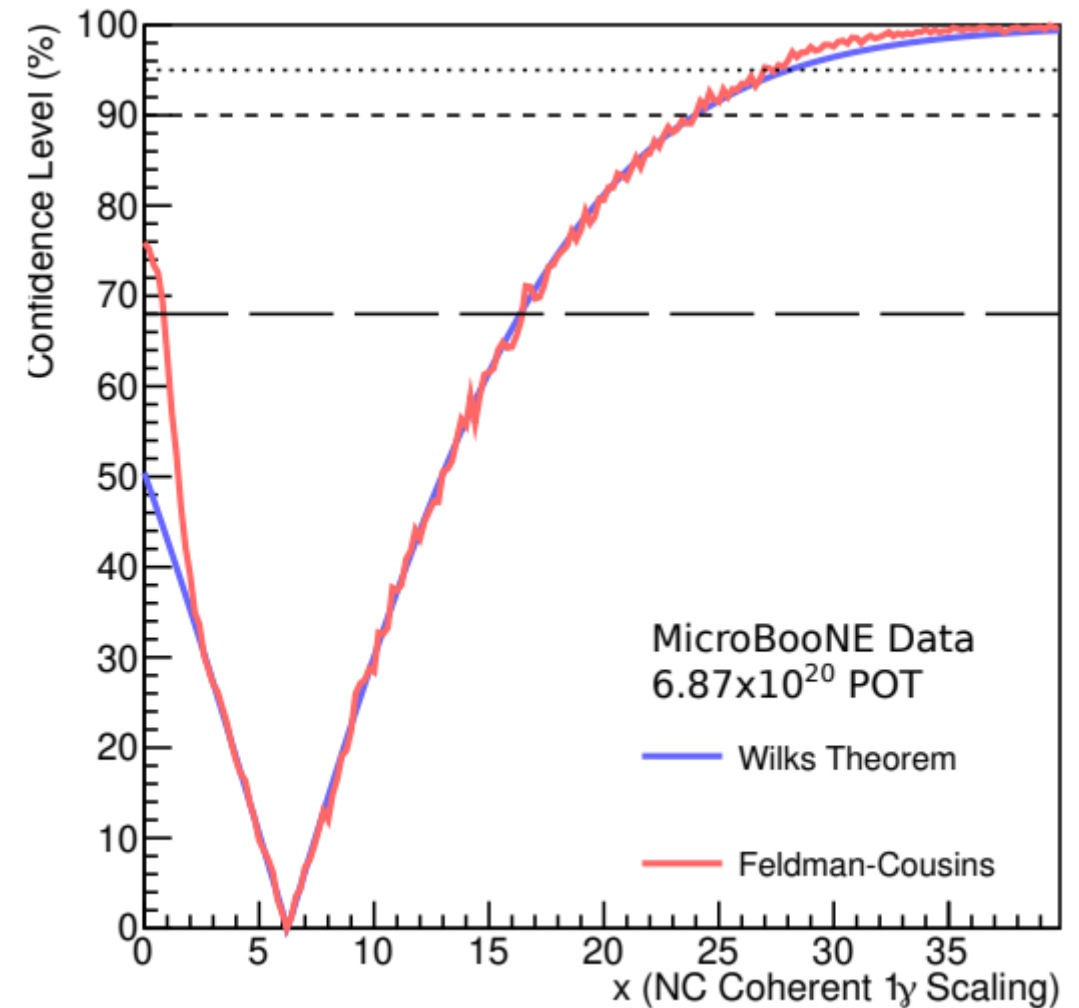
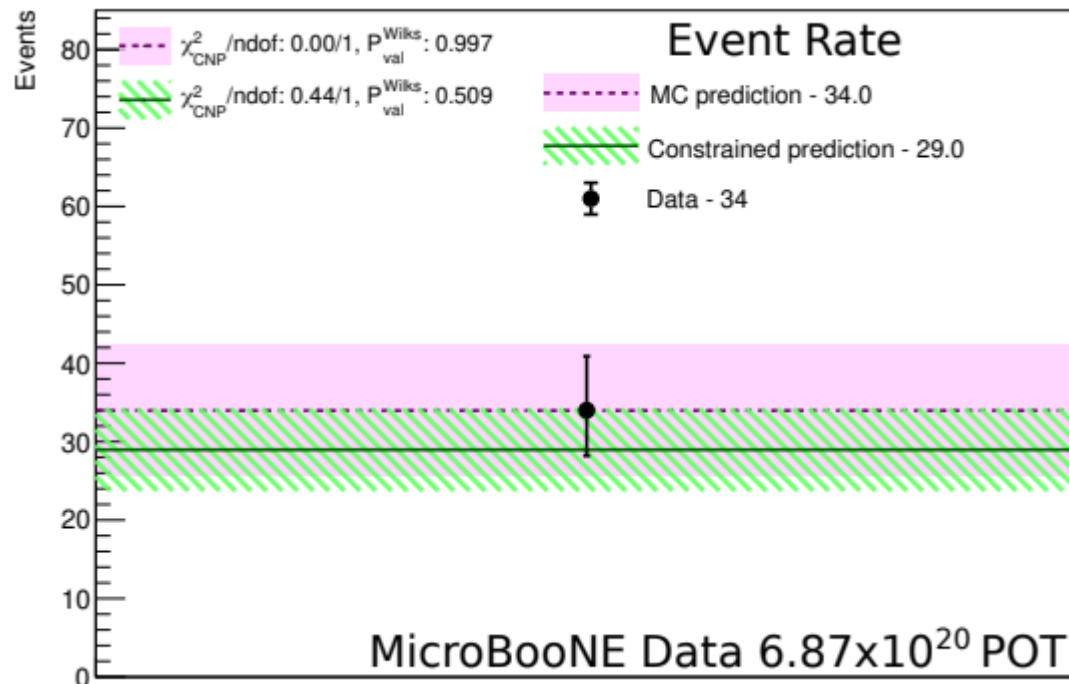
- Coherent searches allow for a focus on 0p states.
- Rare with only one event per three months of data.



# Search for Neutral Current Coherent Scattering

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- Rare with only one event per three months of data.
- Measured limit on cross section at  $1.41\text{E-}41\text{ cm}^2$ .

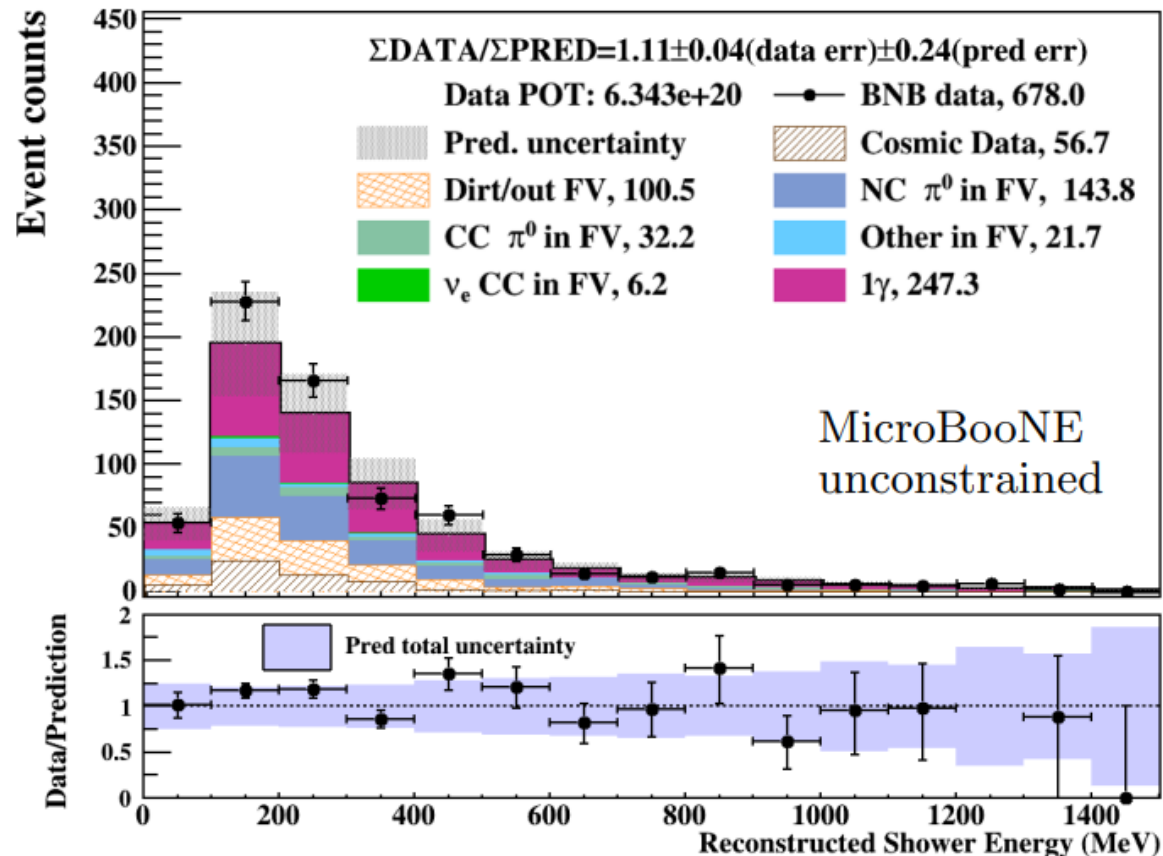
○ World's first limit.



[arXiv:2502.06091](https://arxiv.org/abs/2502.06091)

# Inclusive Photon Selection

- The MiniBooNE excess could be from a generic excess of photons.
  - Includes channels from previous analysis, photons from outside the volume, and events with muons below MiniBooNE's signal definition.

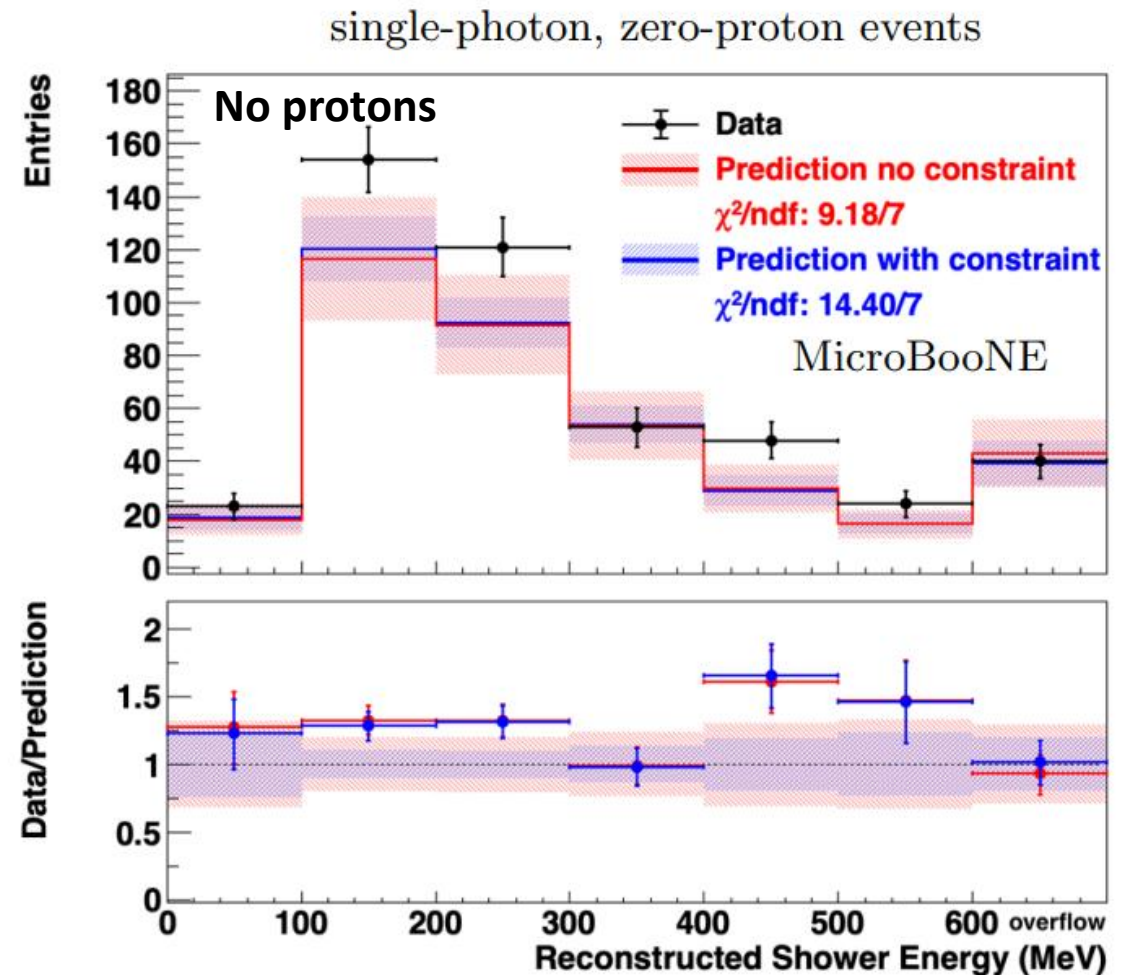
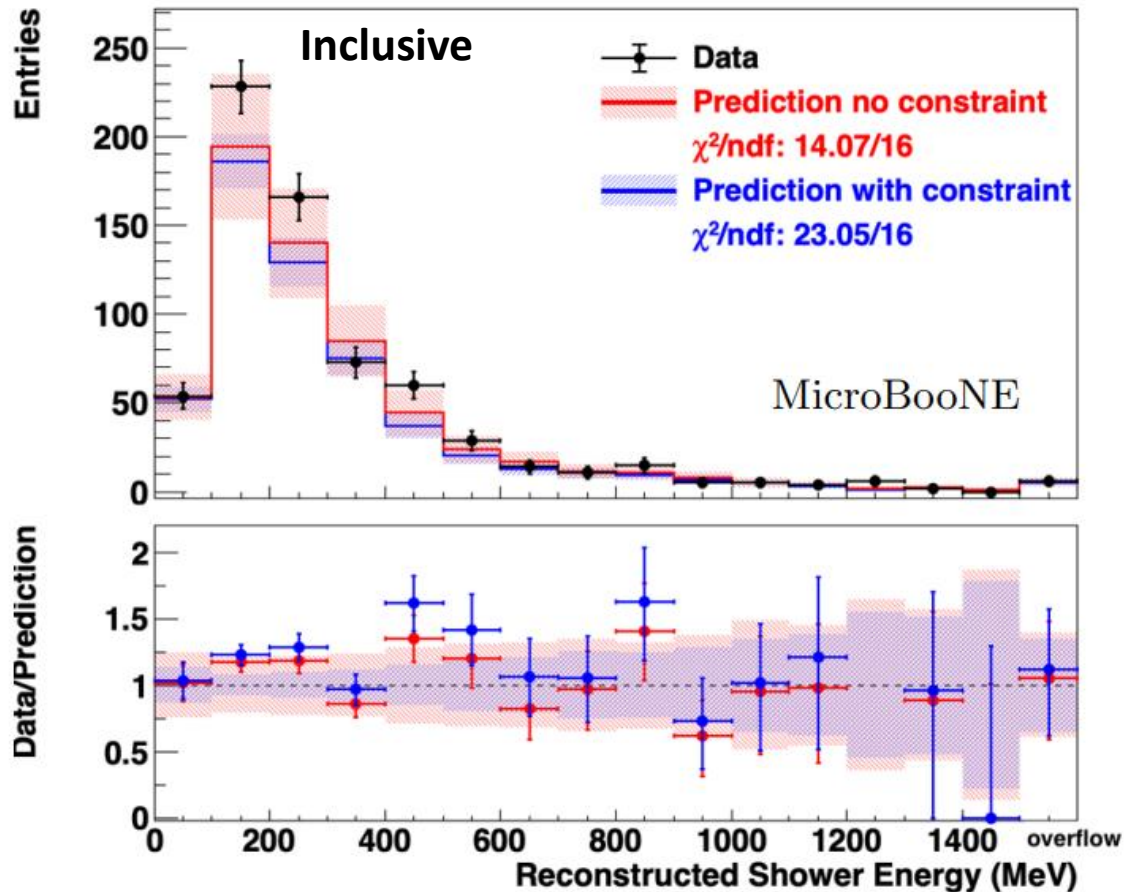


[arXiv:2502.06064](https://arxiv.org/abs/2502.06064)

# Inclusive Photon Selection

- Analysis divided between a selection with protons and without protons (Threshold: 35 MeV).
  - Excess observed in the 0p selection at the  $2\sigma$ -level.

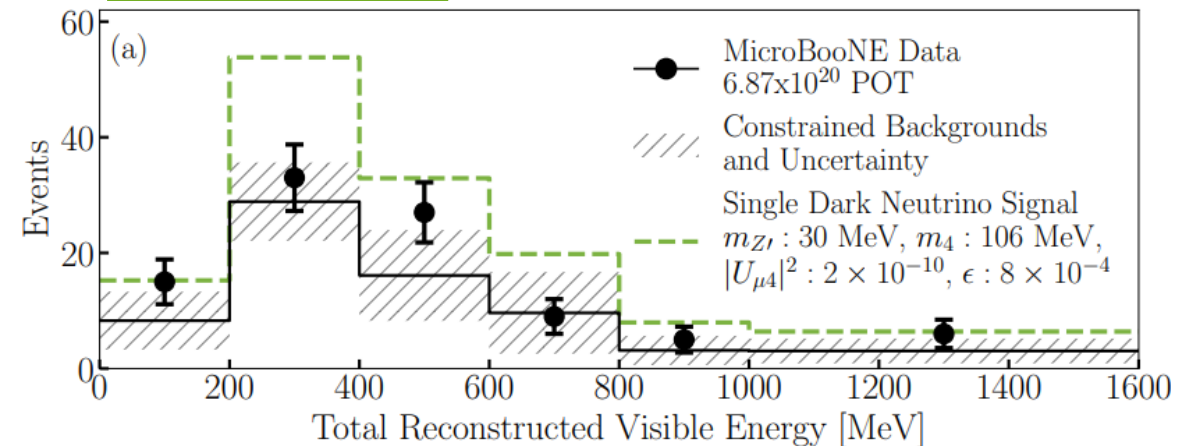
[arXiv:2502.06064](https://arxiv.org/abs/2502.06064)



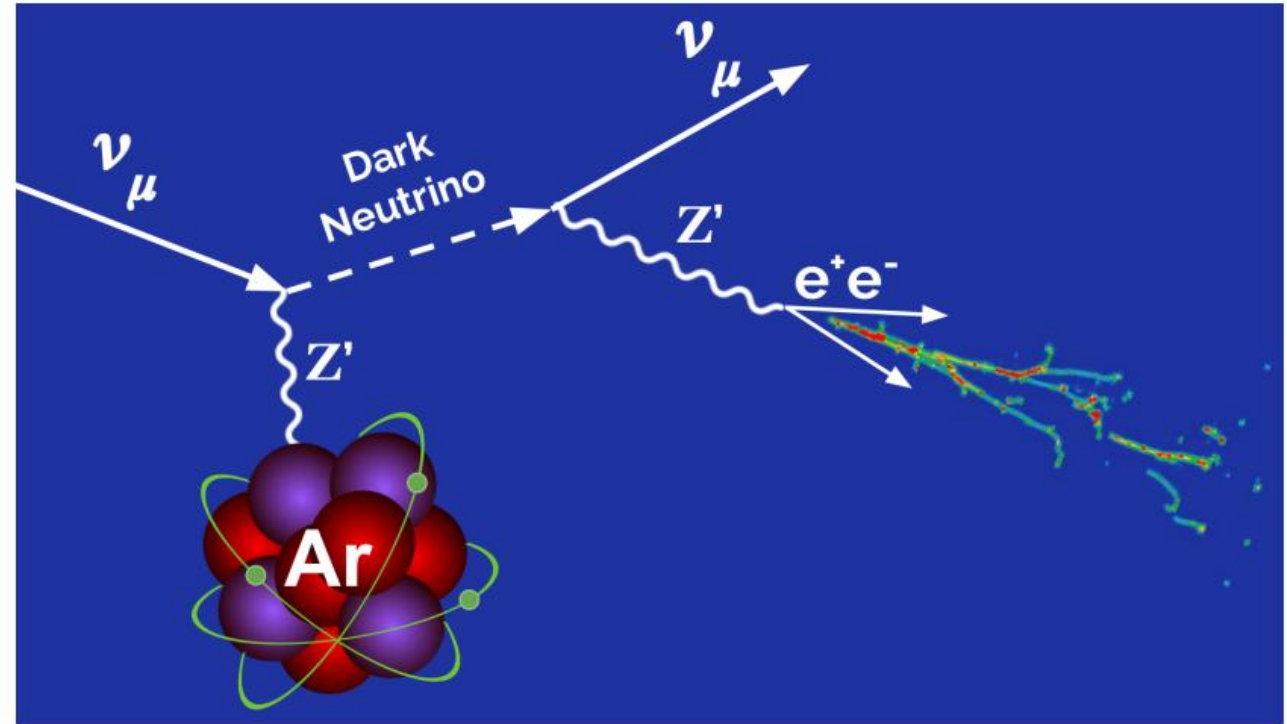
# Searches for Electron-Positron Pair

- Possibly a muon neutrino is producing an electron-positron pair that mimic an electron neutrino event.
- In this analysis, we probe a model involving a new  $Z'$ .

[arXiv:2502.10900](https://arxiv.org/abs/2502.10900)



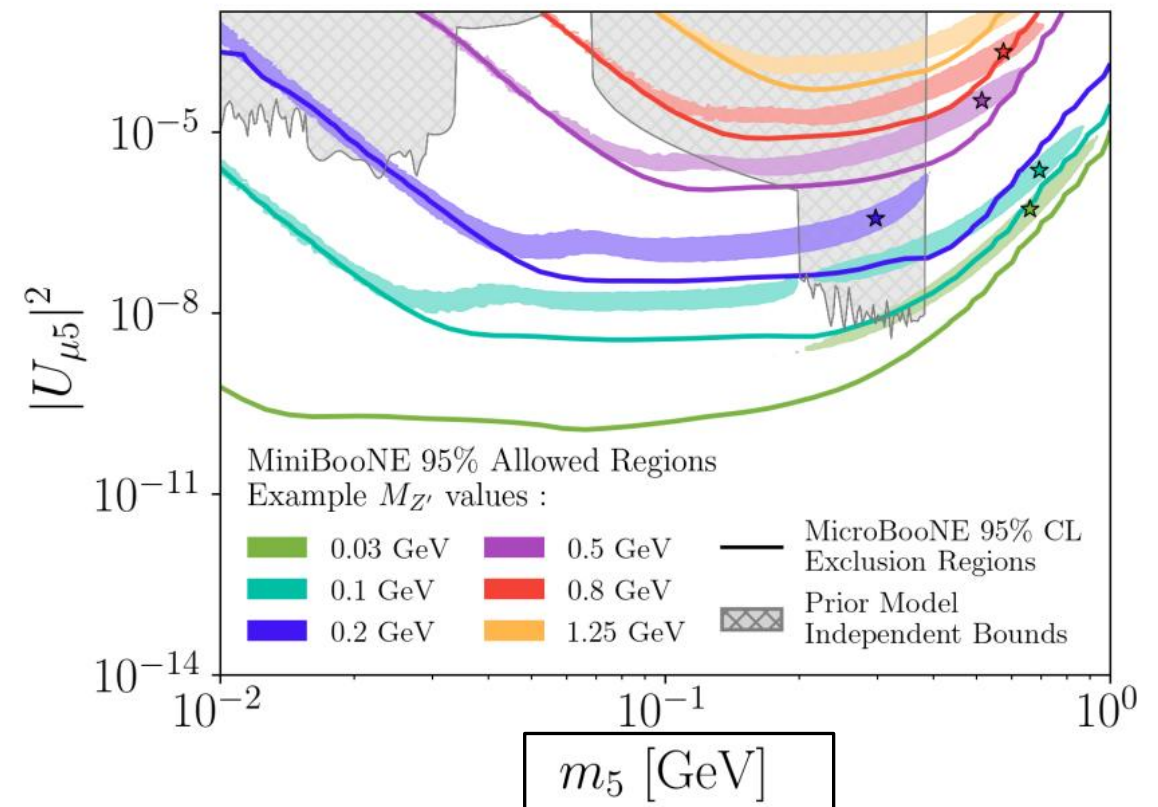
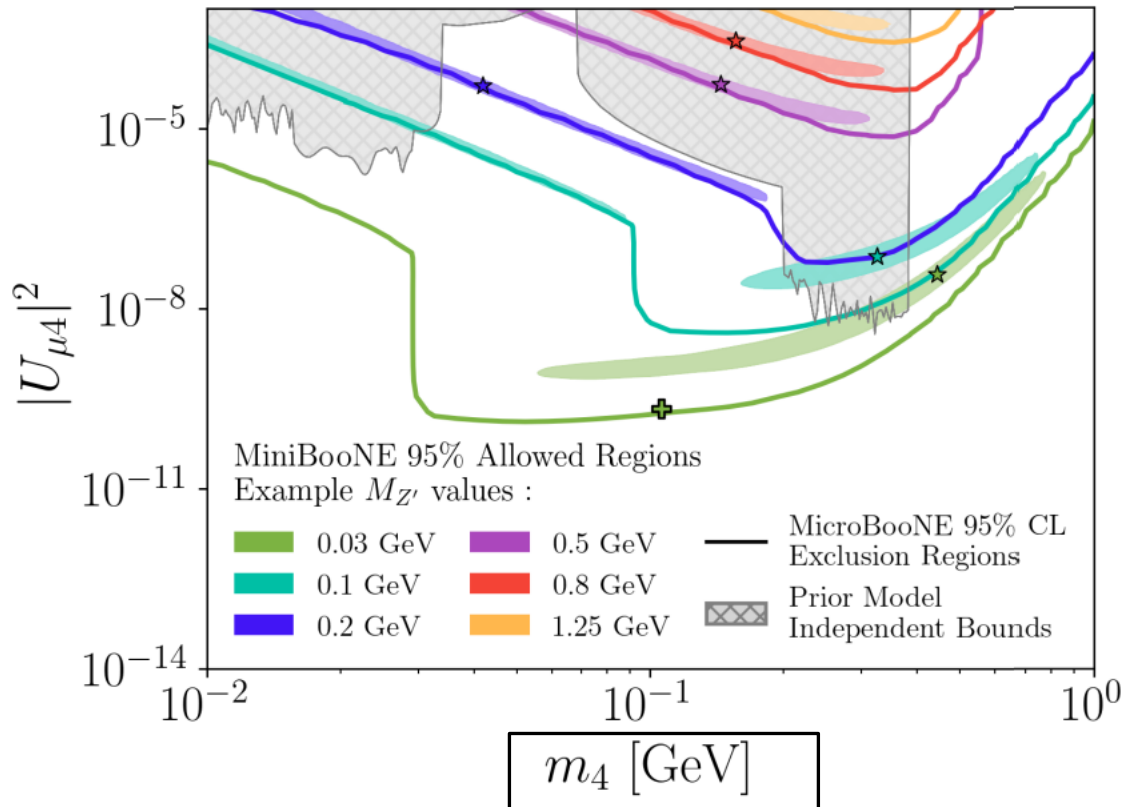
Reconstructed energy of all events that pass an electron-positron pair selection.



# Searches for Electron-Positron Pair

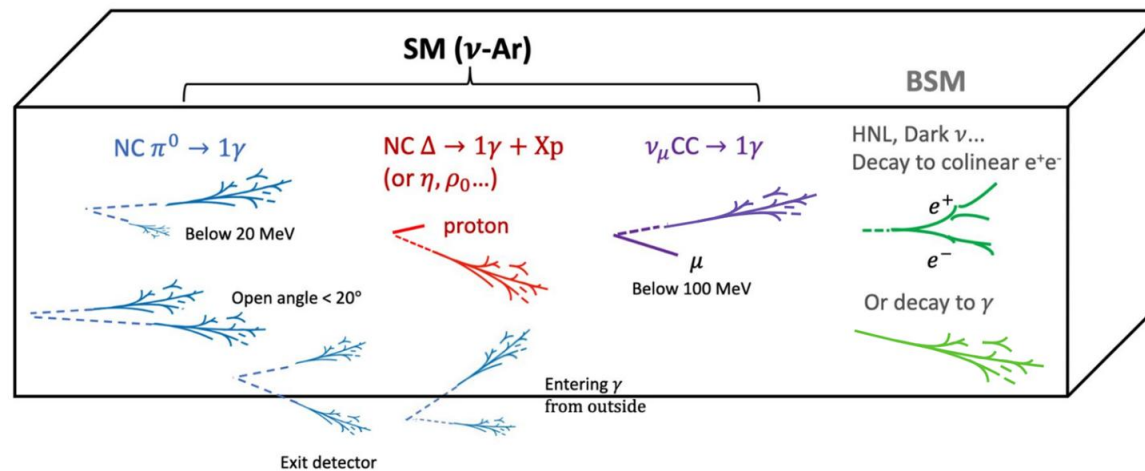
- Exclusion limits placed on either models with 3+1 neutrinos or 3+2 neutrinos.
- MicroBooNE data excludes all phase space for MiniBooNE anomaly to be explained this way.

[arXiv:2502.10900](https://arxiv.org/abs/2502.10900)



# Conclusion

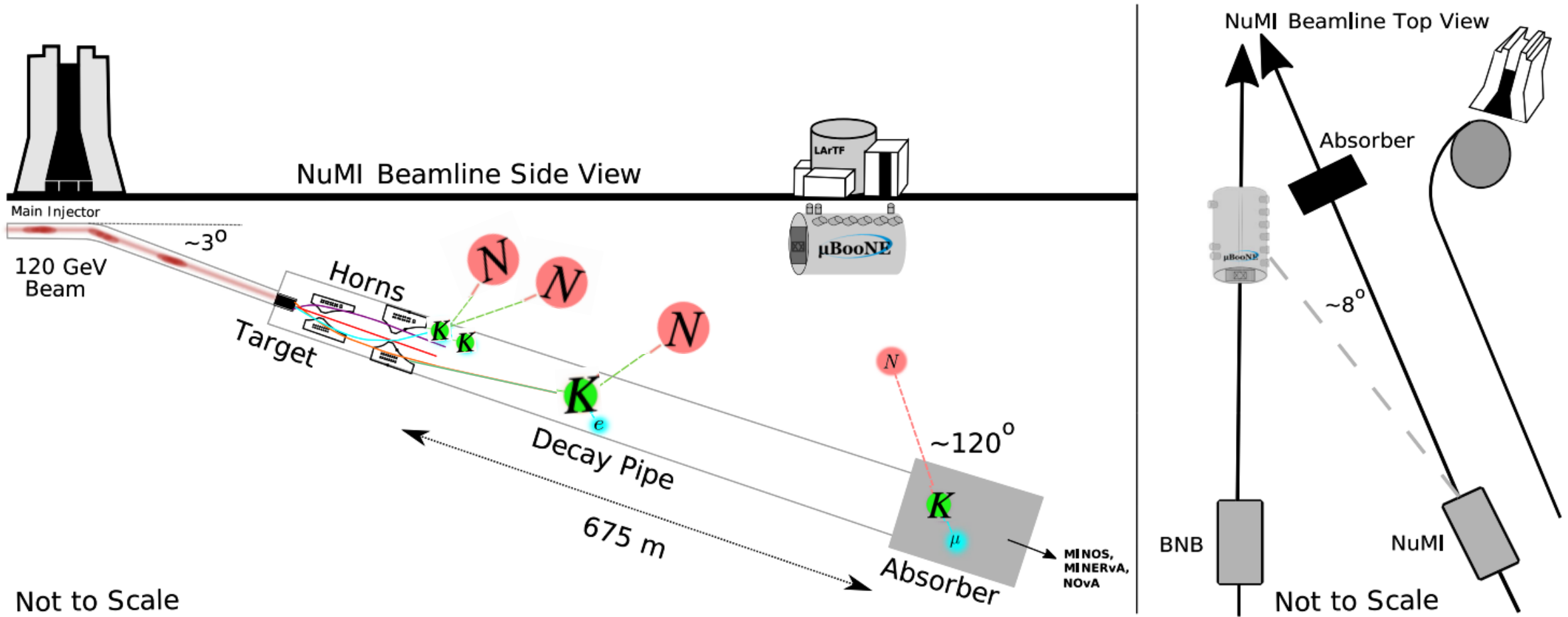
- MicroBooNE has explored the MiniBooNE excess through a diverse set of channels.
  - Has not found evidence explainable by electron-like neutrino events.
  - However, there is an excess of single photon events without protons in the final state.
  - Pioneering study looking for a  $e^+e^-$  final state as a BSM explanation of the MiniBooNE anomaly.
- Many more studies to go! Thanks!



# Backup Slides

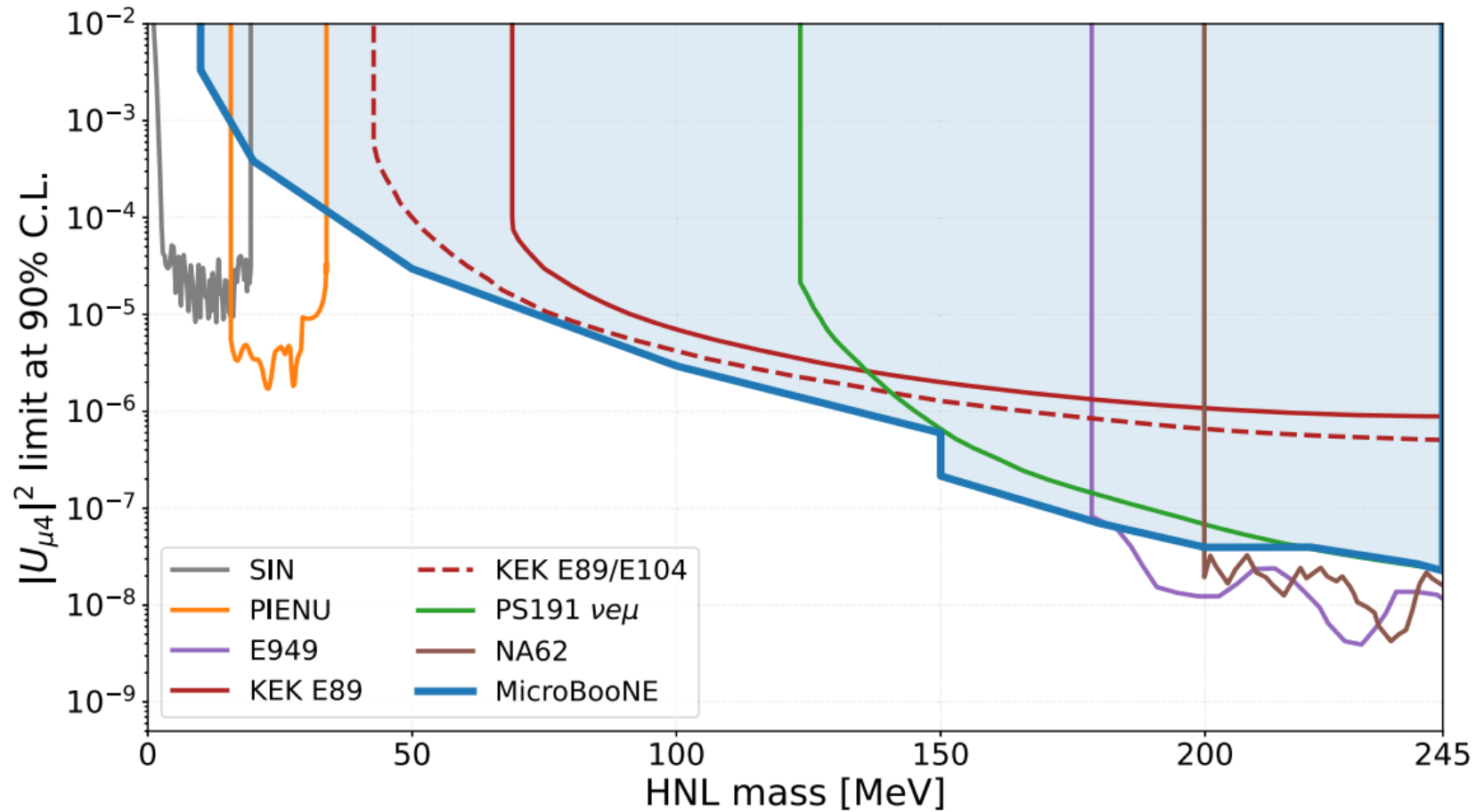
# Searches for Heavy Neutral Leptons

- NuMI beam provides access to heavy neutral leptons from kaon decays.
- Search for neutral pions and electron-positron pairs.



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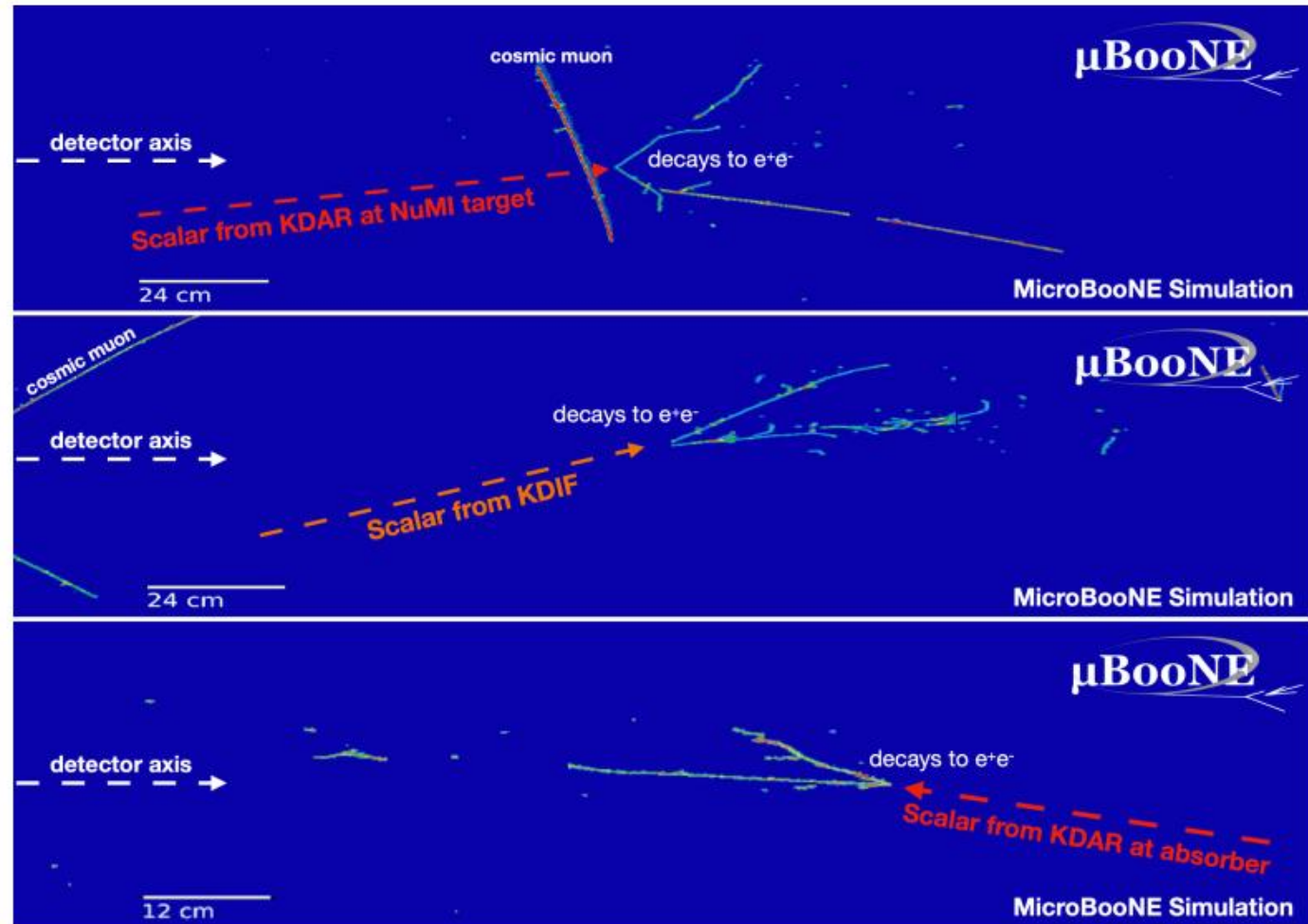
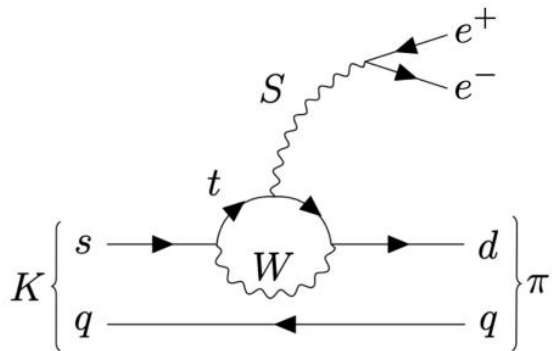
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[\*PRL\* \*\*132\*\* 041801](#)

# Near-Identical Search for Higgs Scalar

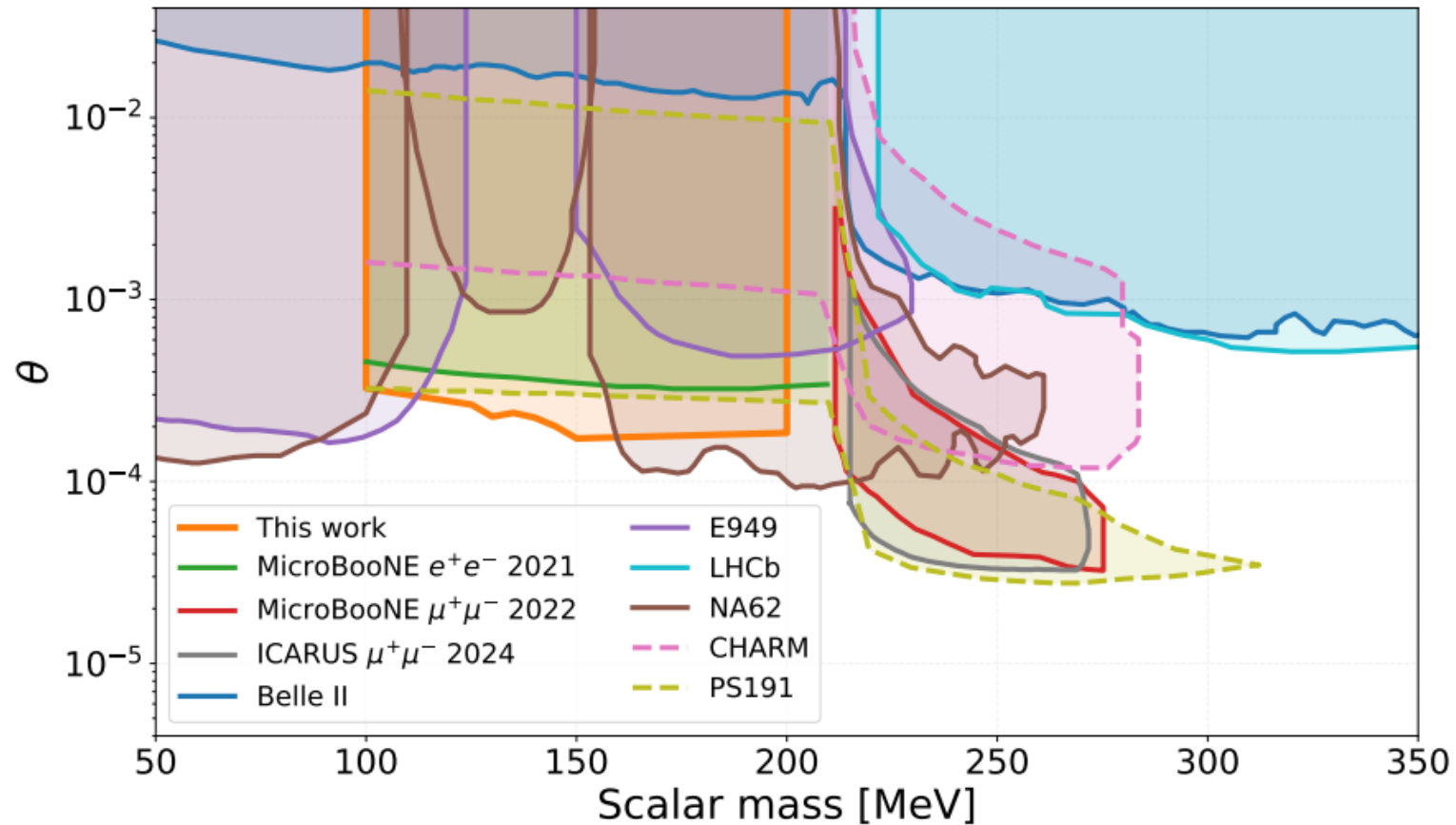
- A Higgs portal scalar can be probed using the same method looking for electron-positron pairs.



[arXiv:2501.08052](https://arxiv.org/abs/2501.08052)

# Search for Higgs Scalar

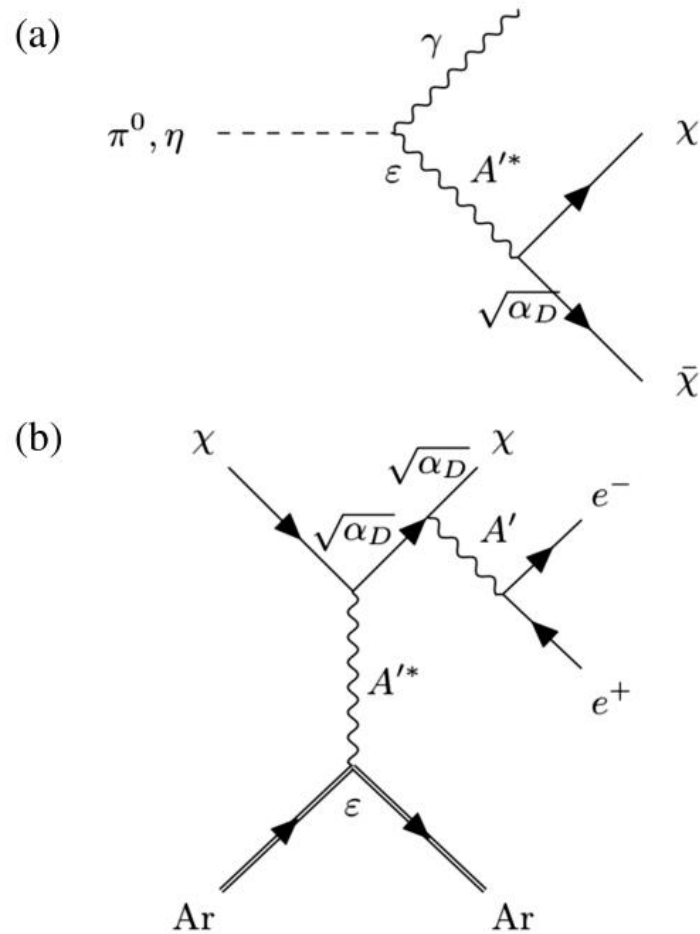
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[arXiv:2501.08052](https://arxiv.org/abs/2501.08052)

# Search for Dark Tridents

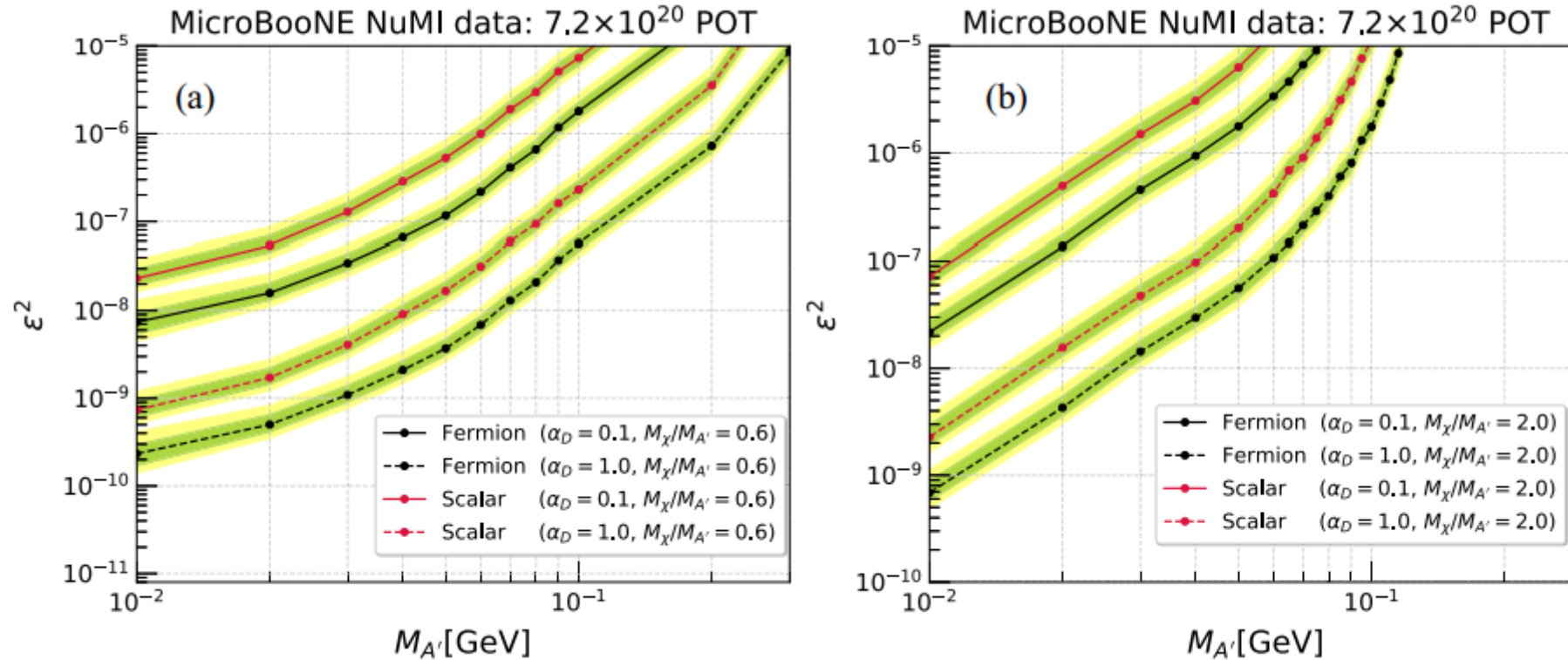
- A shower-based analysis with NuMI looks for similar interactions with a dark photon mediator ( $A'$ ).



[\*Phys. Rev. Lett.\* \*\*132\*\*, 241801](#)

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[\*Phys. Rev. Lett.\* \*\*132\*\*, 241801](#)