Recent Results on Neutrino Oscillations & New Physics Searches at MicroBooNE

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on behalf of the MicroBooNE Collaboration

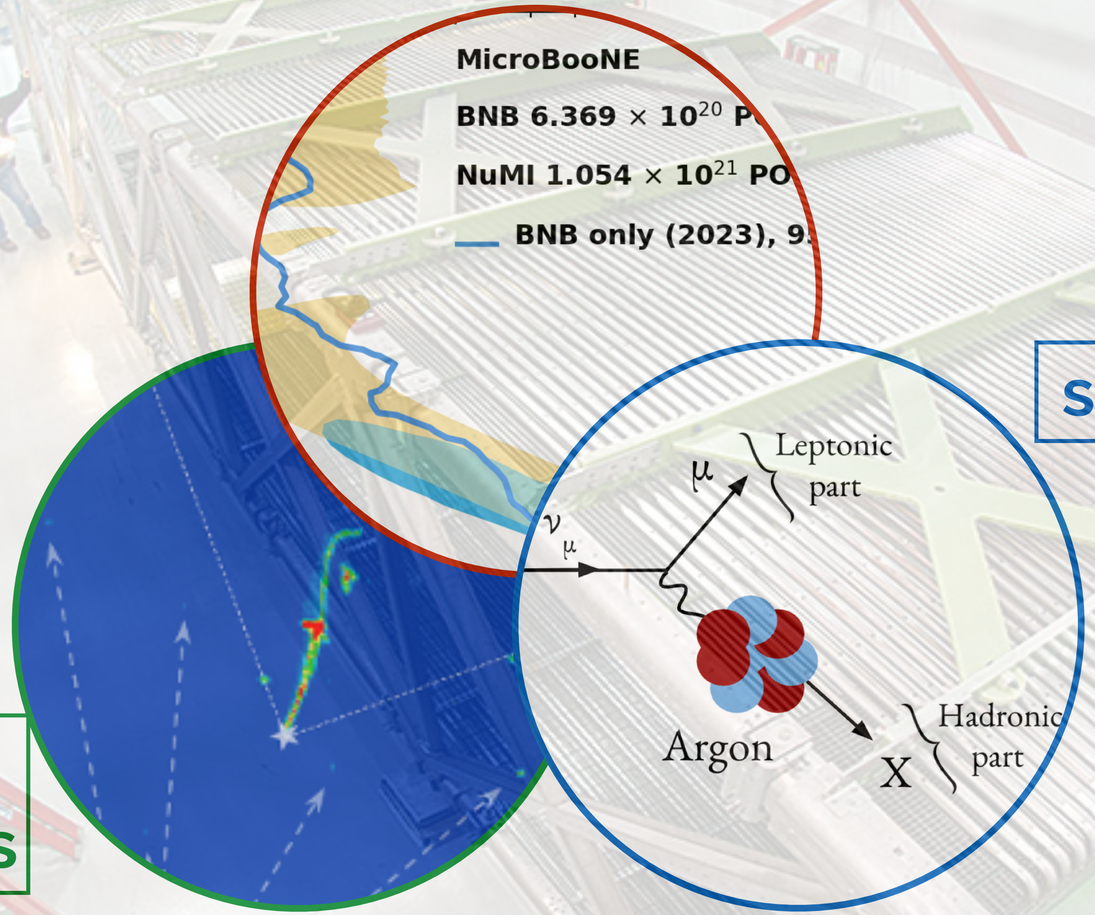
Brookhaven National Laboratory

Neutrino 2026
June 22, 2026

Brookhaven National Laboratory

MicroBooNE Physics Program

neutrino oscillation & beyond the standard model physics searches



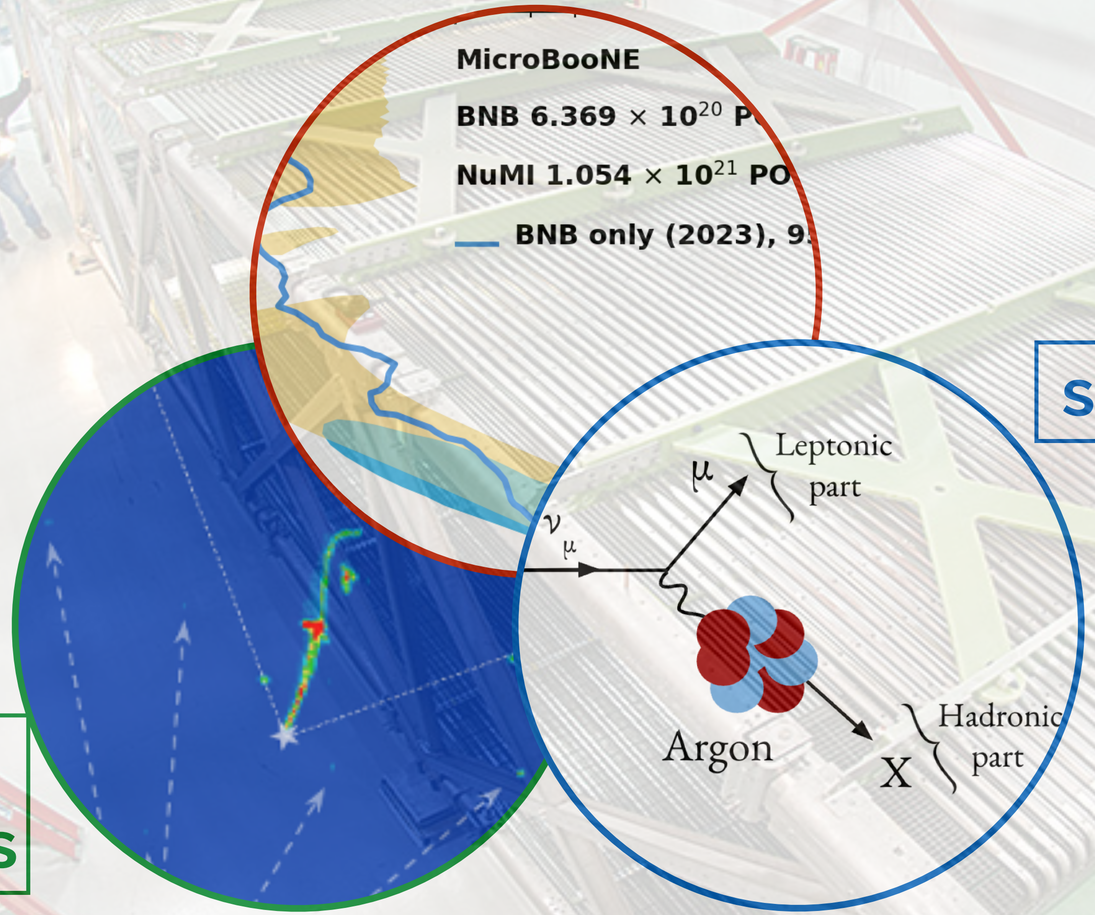
study ν-Ar interactions

advancing LArTPC technology capabilities

MicroBooNE Physics Program

neutrino oscillation & beyond the standard model physics searches

this talk!



advancing LArTPC technology capabilities

study ν-Ar interactions

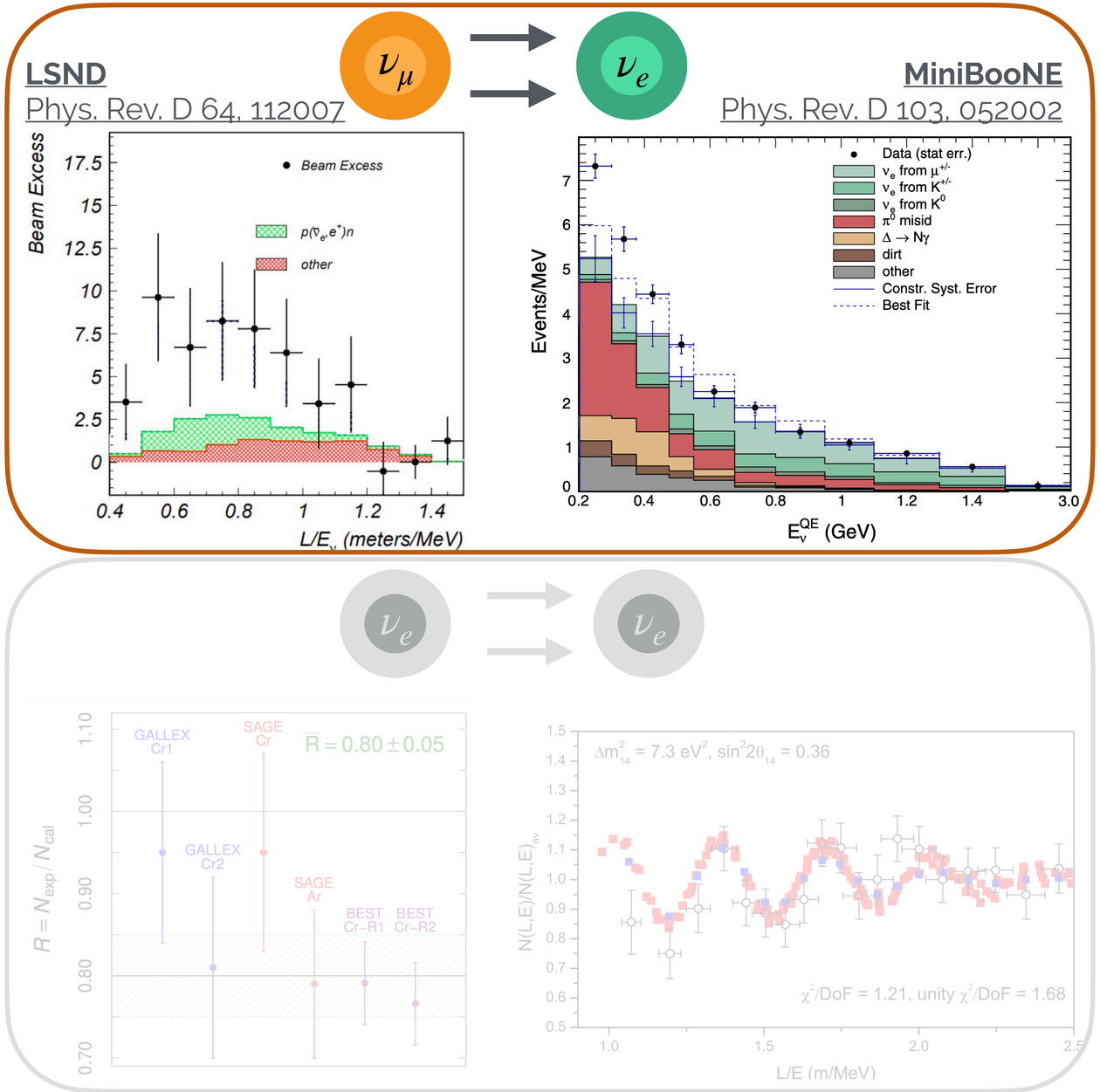
Patrick Green's talk on Wednesday!

Short Baseline Neutrino Anomalies

- LSND and MiniBooNE observed an **excess of ν_e**, which can be interpreted as **appearance of ν_e from ν_μ**

- radiochemical gallium detectors and a reactor neutrino experiment observed a **deficit of ν_e**, which can be interpreted as **disappearance of ν_e from ν_e source**

- all these anomalies happen at L/E of $\mathcal{O}(1)$ m/MeV with large Δm^2: **hinting towards a sterile neutrino**



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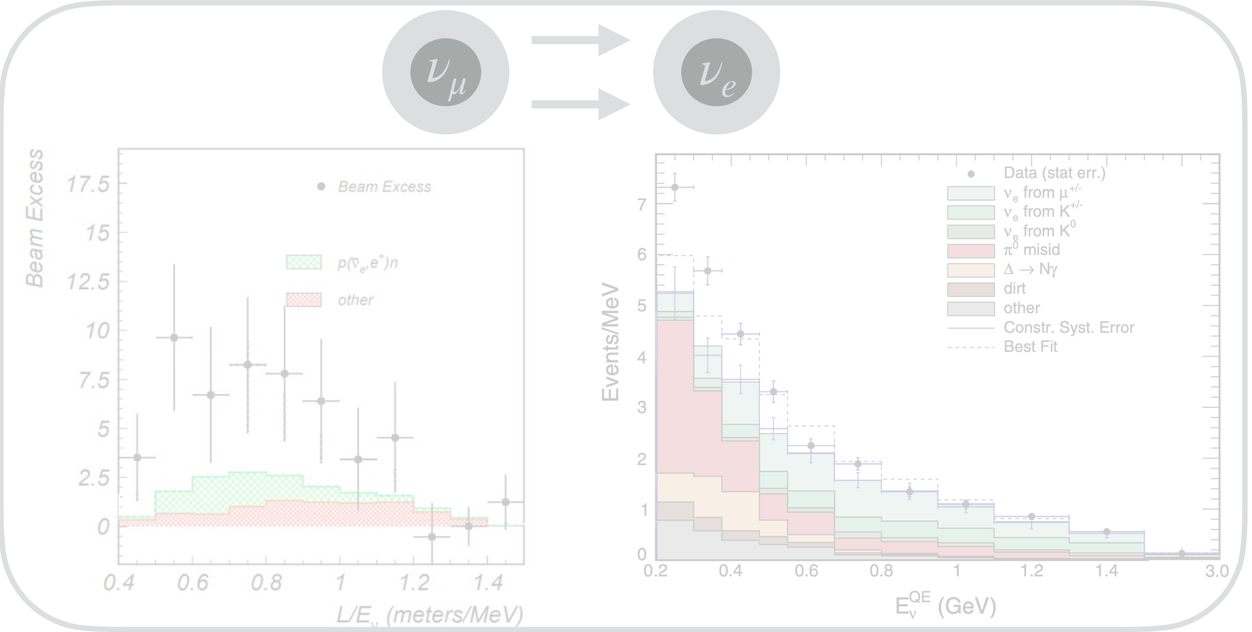

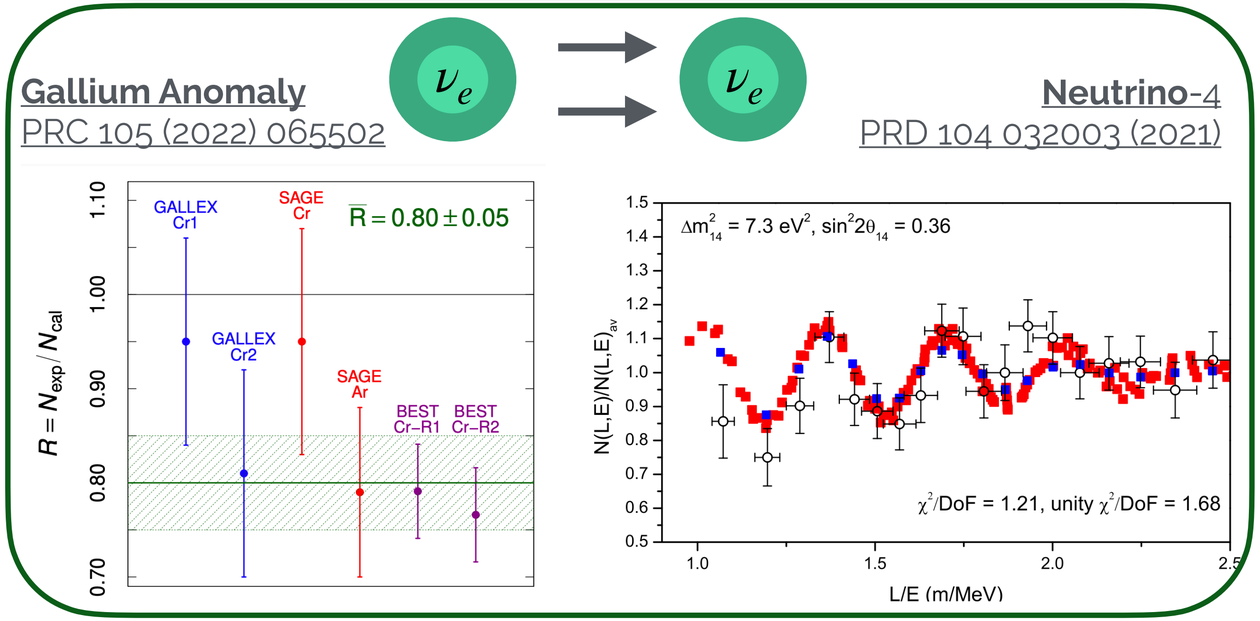

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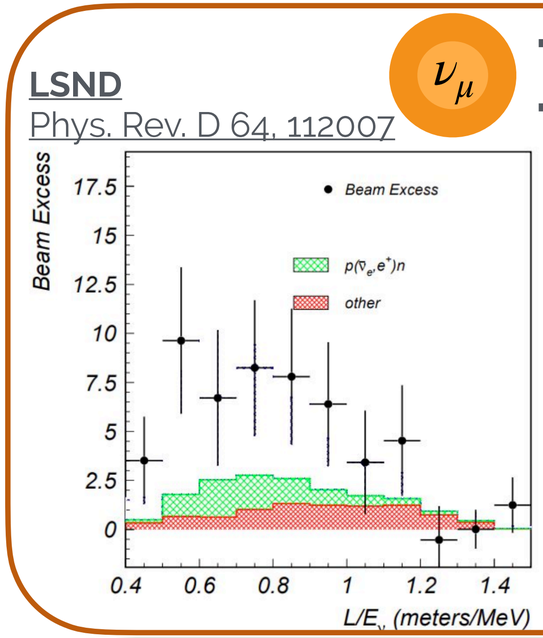
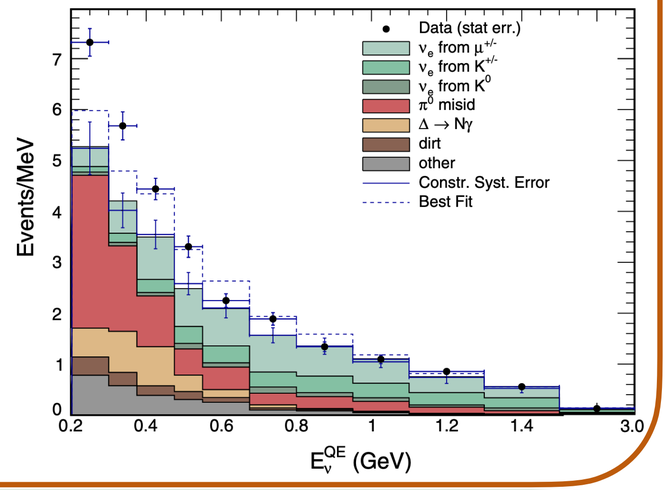
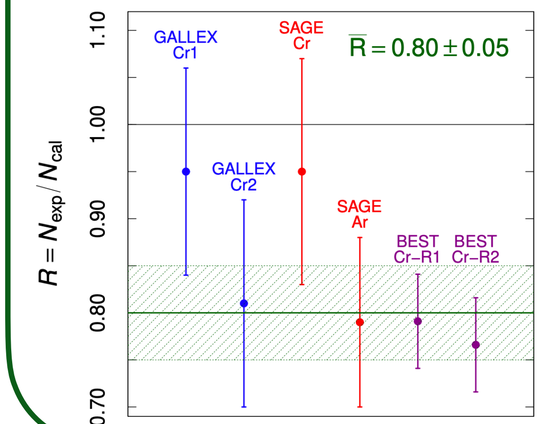
LSND
Phys. Rev. D 64, 112007



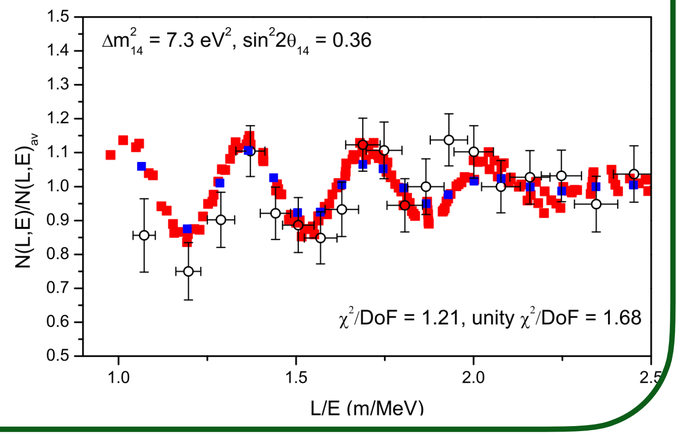
MiniBooNE
Phys. Rev. D 103, 052002



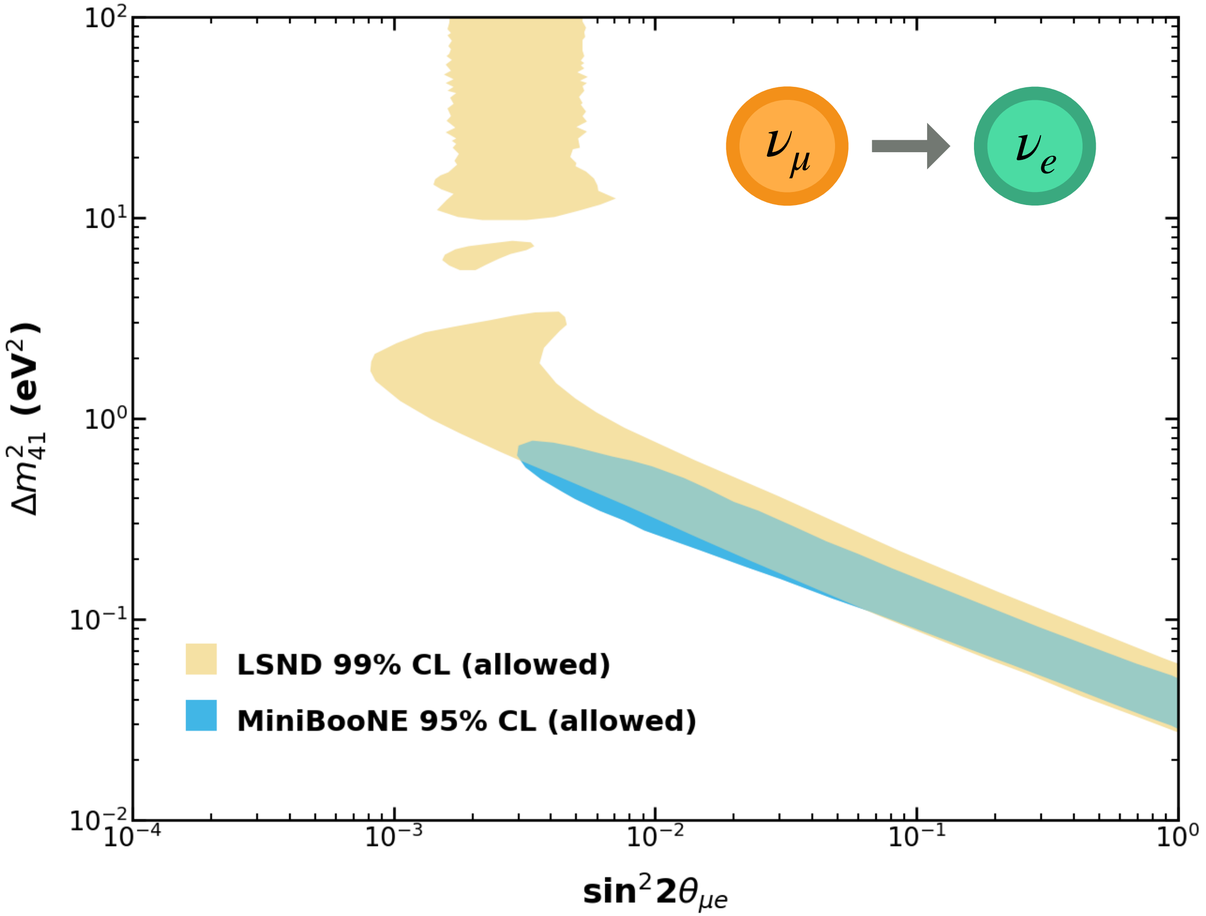
Gallium Anomaly
PRC 105 (2022) 065502

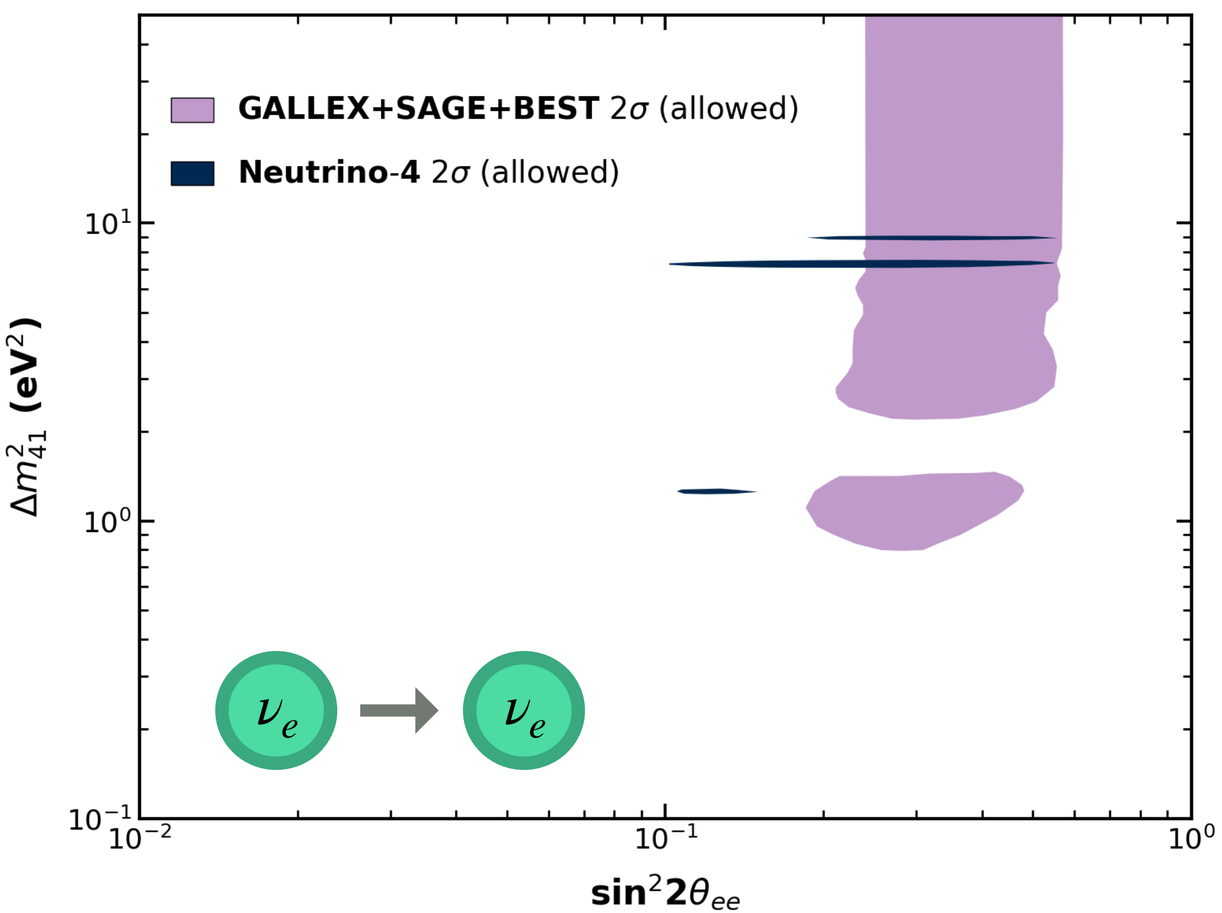


Neutrino-4
PRD 104 032003 (2021)



Short Baseline Neutrino Anomalies: Allowed Regions

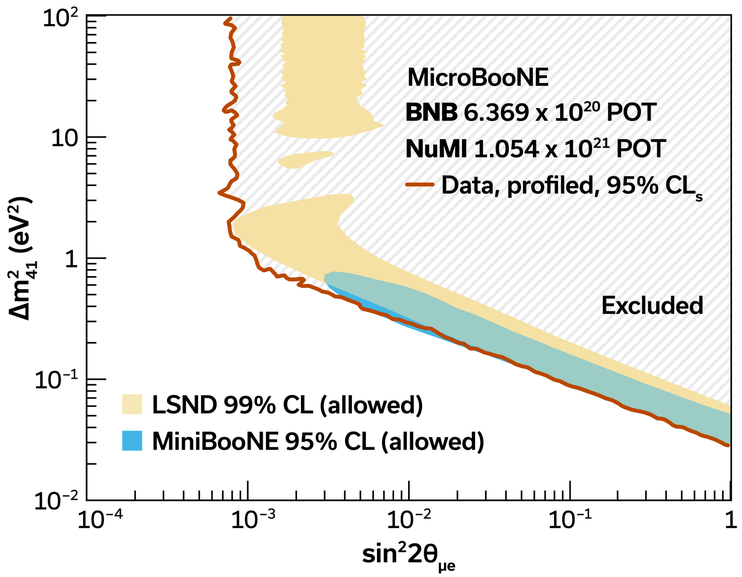


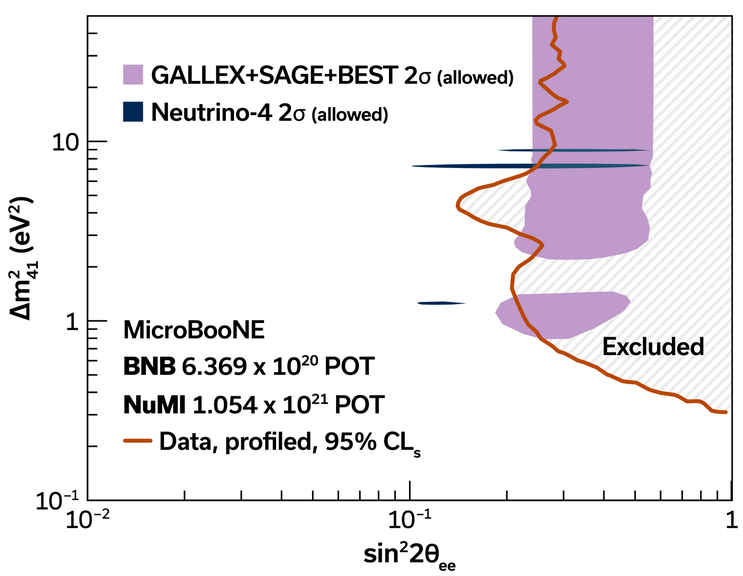


these ν_e appearance and disappearance anomalies point to a **similar Δm^2 scale**, and the oscillation hypothesis provides a plausible explanation for all of them

MicroBooNE's new sterile neutrino search result

Nature 648 64-69 (2025)





- MicroBooNE's recent search for sterile neutrino is much improved from our previous 2023 result
- *how have we achieved such improvements?*

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Search for light sterile neutrinos with two neutrino beams at MicroBooNE

The MicroBooNE Collaboration

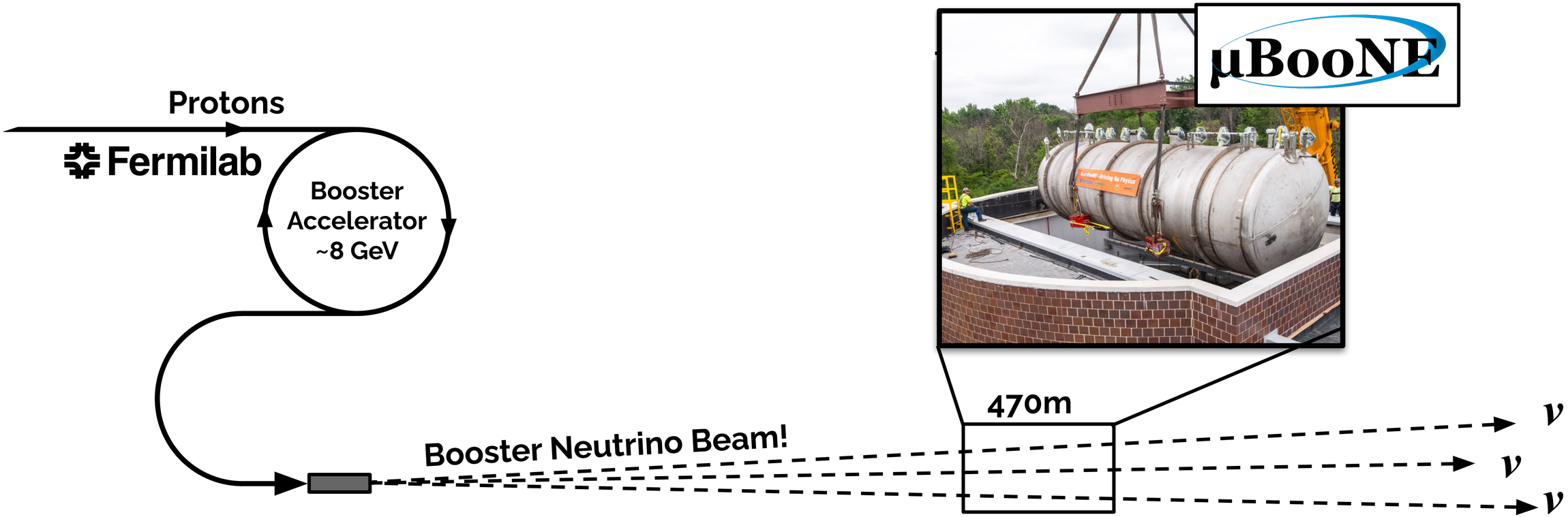
Nature **648**, 64–69 (2025) | Cite this article

34k Accesses | **10** Citations | **576** Altmetric | Metrics

Abstract

The existence of three distinct neutrino flavours, ν_e, ν_μ and ν_τ, is a central tenet of the Standard Model of particle physics[1,2]. Quantum-mechanical interference can allow a neutrino of one initial flavour to be detected sometime later as a different flavour, a process called neutrino oscillation. Several anomalous observations inconsistent with this three-flavour picture have motivated the hypothesis that an additional neutrino state exists, which does not interact directly with matter, termed as 'sterile' neutrino, ν_s (refs. [3,4,5,6,7,8,9]). This includes anomalous observations from the Liquid Scintillator Neutrino Detector (LSND)[3] experiment and Mini-Booster Neutrino Experiment (MiniBooNE)[4,5], consistent with $\nu_\mu \rightarrow \nu_e$ transitions at a distance inconsistent with the three-neutrino picture. Here we use data obtained from the MicroBooNE liquid-argon time projection chamber[10] in two accelerator neutrino beams to exclude the single light sterile neutrino interpretation of the LSND and MiniBooNE anomalies at the 95% confidence level (CL). Moreover, we rule out a notable portion of the parameter space that could explain the gallium anomaly[6,7,8]. This is one of the first measurements to use two accelerator neutrino beams to break a degeneracy between ν_e appearance and disappearance, which would otherwise weaken the sensitivity to the sterile neutrino hypothesis. We find no evidence for either $\nu_\mu \rightarrow \nu_e$ flavour transitions or ν_e disappearance that would indicate non-standard flavour oscillations. Our results indicate that previous anomalous observations consistent with $\nu_\mu \rightarrow \nu_e$ transitions cannot be explained by introducing a single sterile neutrino state.

3+1 Sterile Neutrino Search: Two beam lines



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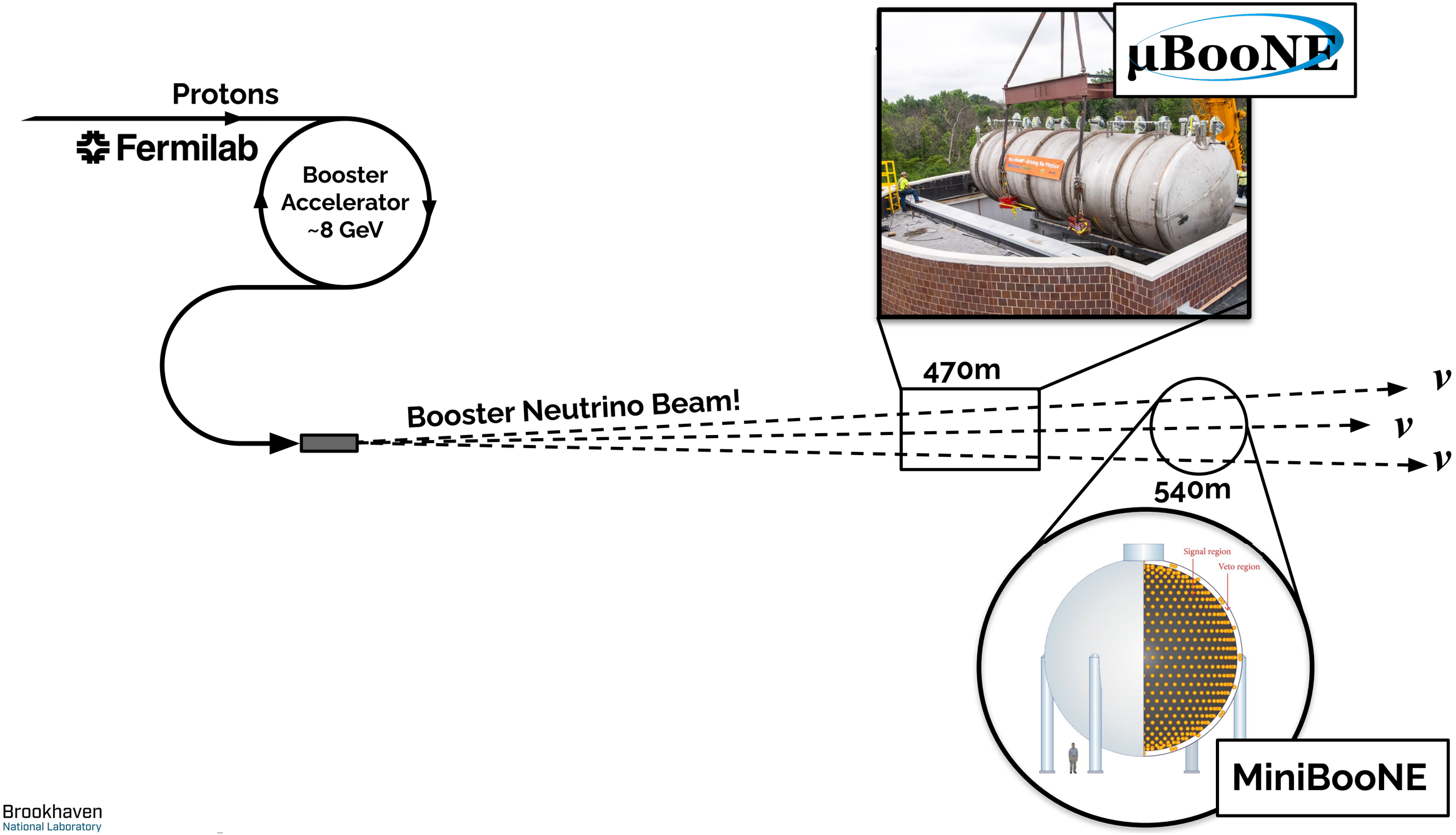

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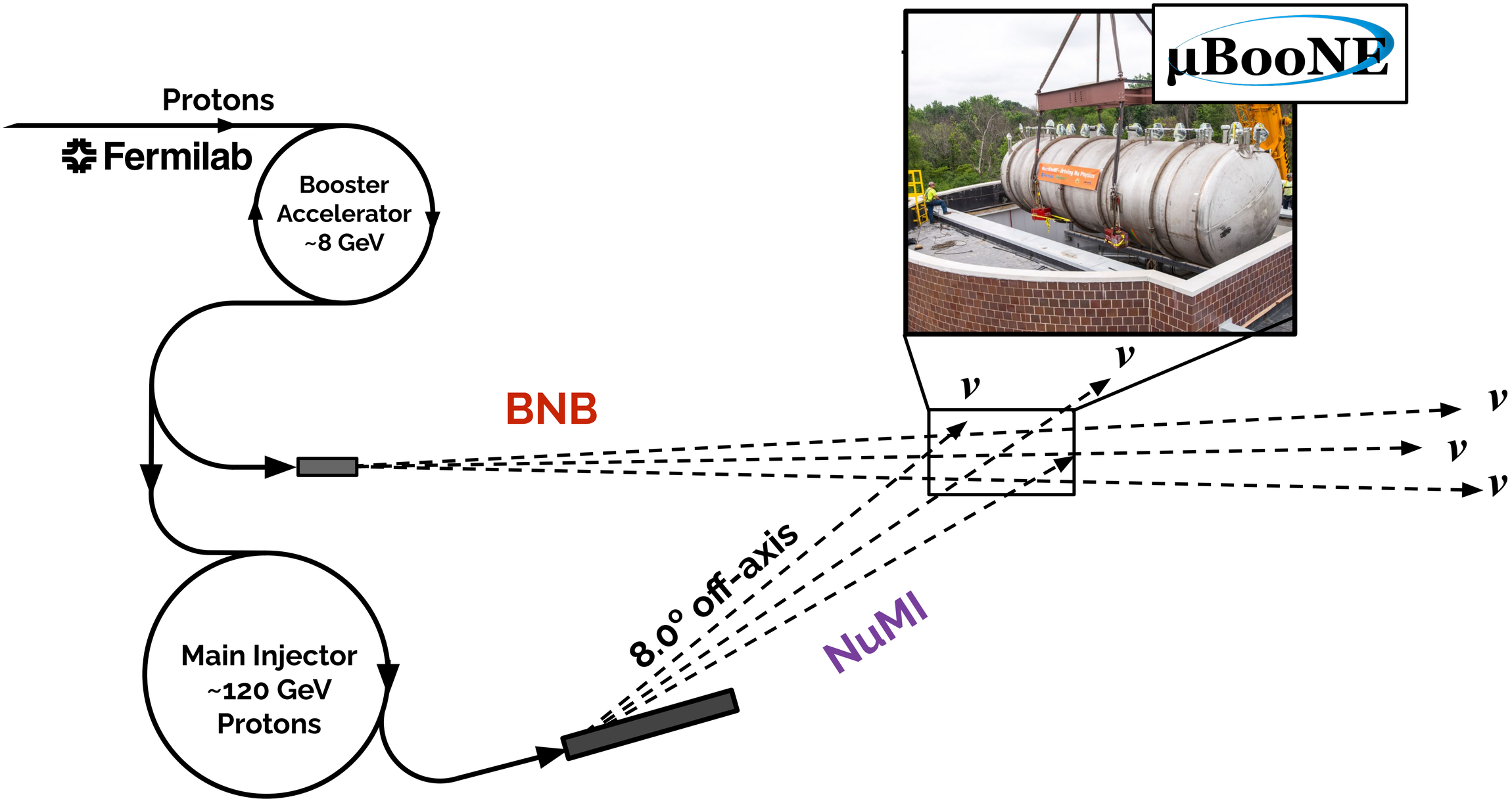
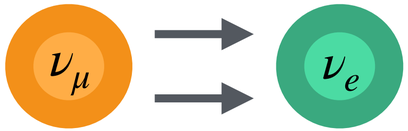


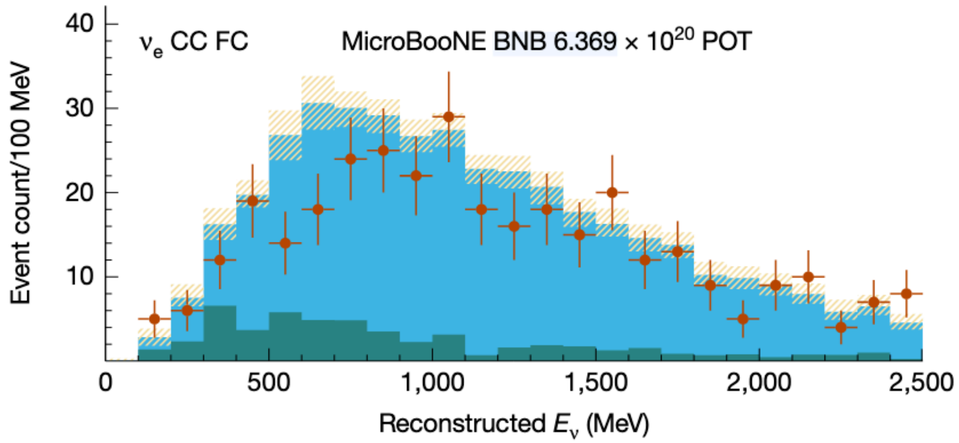
3+1 Sterile Neutrino Search: ν_e appearance search

Nature 648 64-69 (2025)

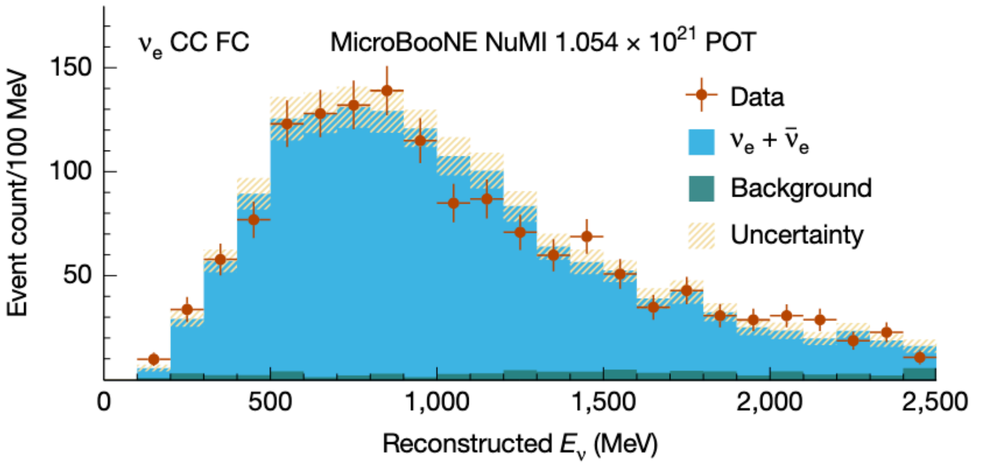


- after updating our information using larger statistic sideband data (ν_μ and π^0) to reduce uncertainties, **we look for an excess in the ν_e**
- no excess observed over the expected background, both in BNB and NuMI
- *but why do we need both beams?*

BNB CC ν_e



NuMI CC ν_e



3+1 Sterile Neutrino Search: degeneracy

- we consider three main oscillation channels

beam detector

$\nu_\mu \rightarrow \nu_e$ appearance

$\nu_e \rightarrow \nu_e$ disappearance

$\nu_\mu \rightarrow \nu_\mu$ disappearance

} …and these two effects can *cancel each other* at certain oscillation parameters

- BNB and NuMI have different amount of intrinsic ν_e: BNB with **0.6%** and NuMI with **4%**

- **using both beams simultaneously breaks this degeneracy!**

3+1 Sterile Neutrino Search: degeneracy

Nature 648 64-69 (2025)

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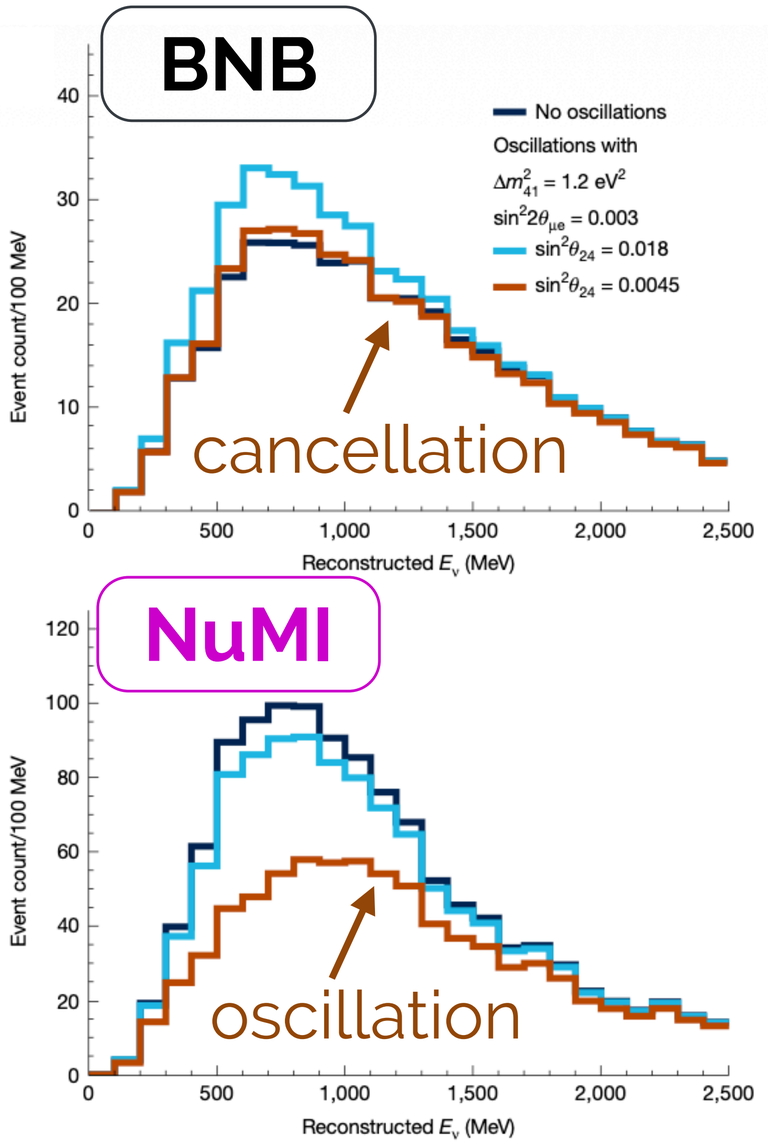
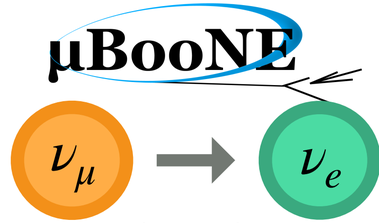


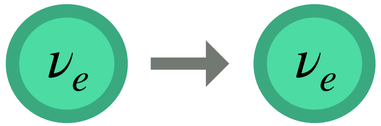
3+1 Sterile Neutrino Search: BNB-only result (2023)



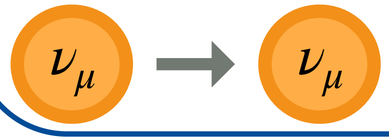
PRL 130 011801 (2023)

BNB-only Result (2023)

appearance

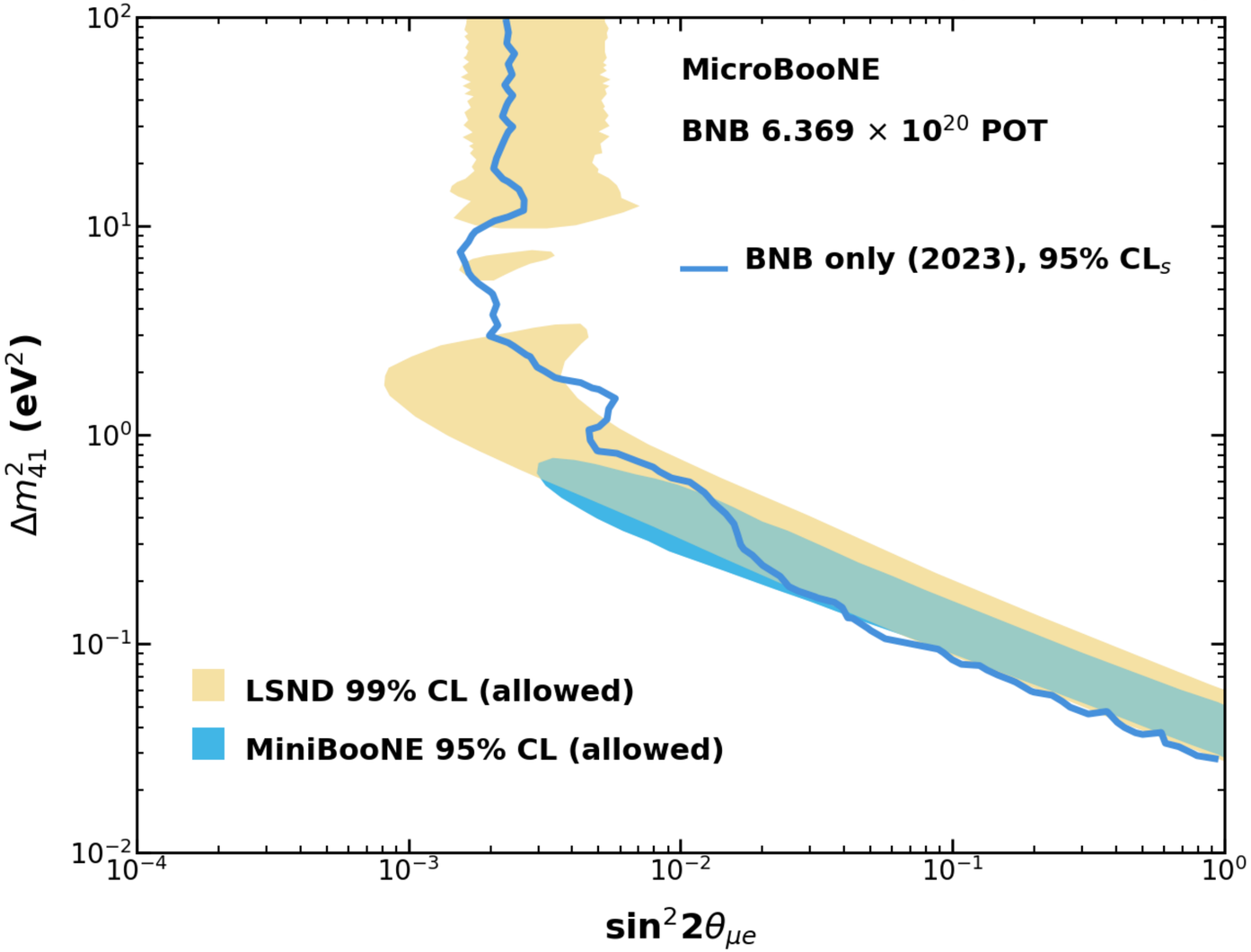


disappearance



disappearance

2023 result is not strong enough to exclude the allowed regions *due to the degeneracy*



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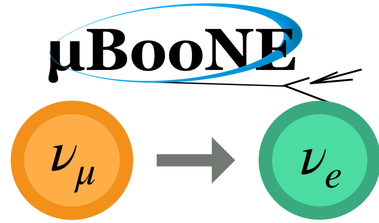

Nature 648 64-69 (2025)

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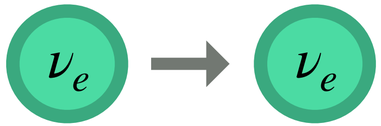
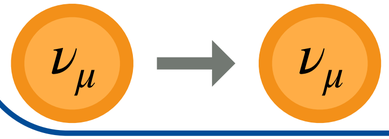
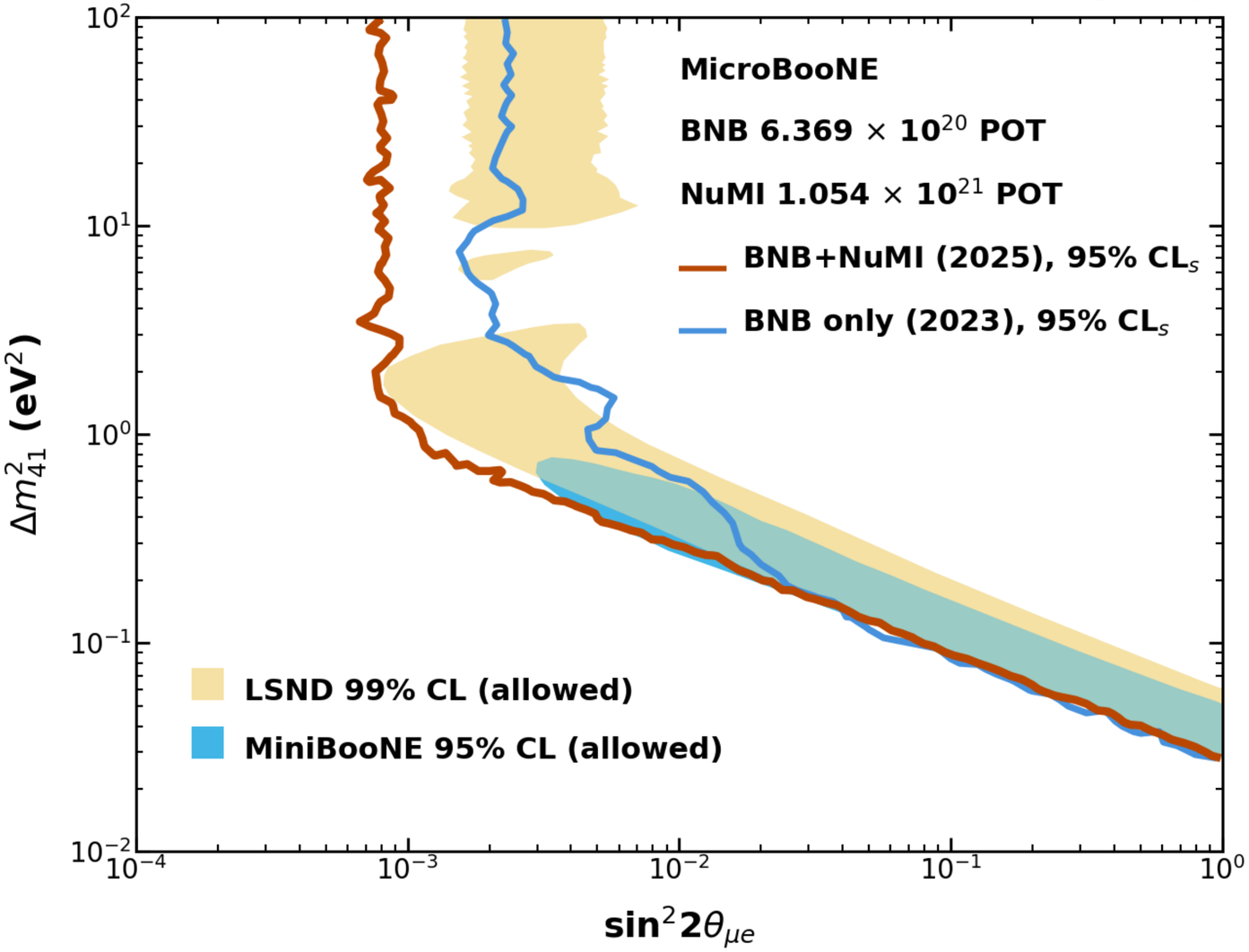


disappearance



disappearance

in ν_e appearance channel, MicroBooNE excludes LSND and MiniBooNE allowed region at the 95% CL by mitigating degeneracy



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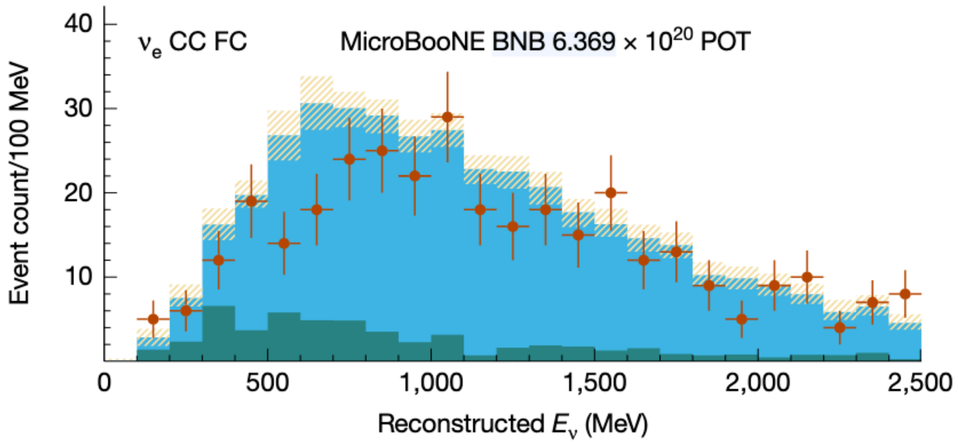
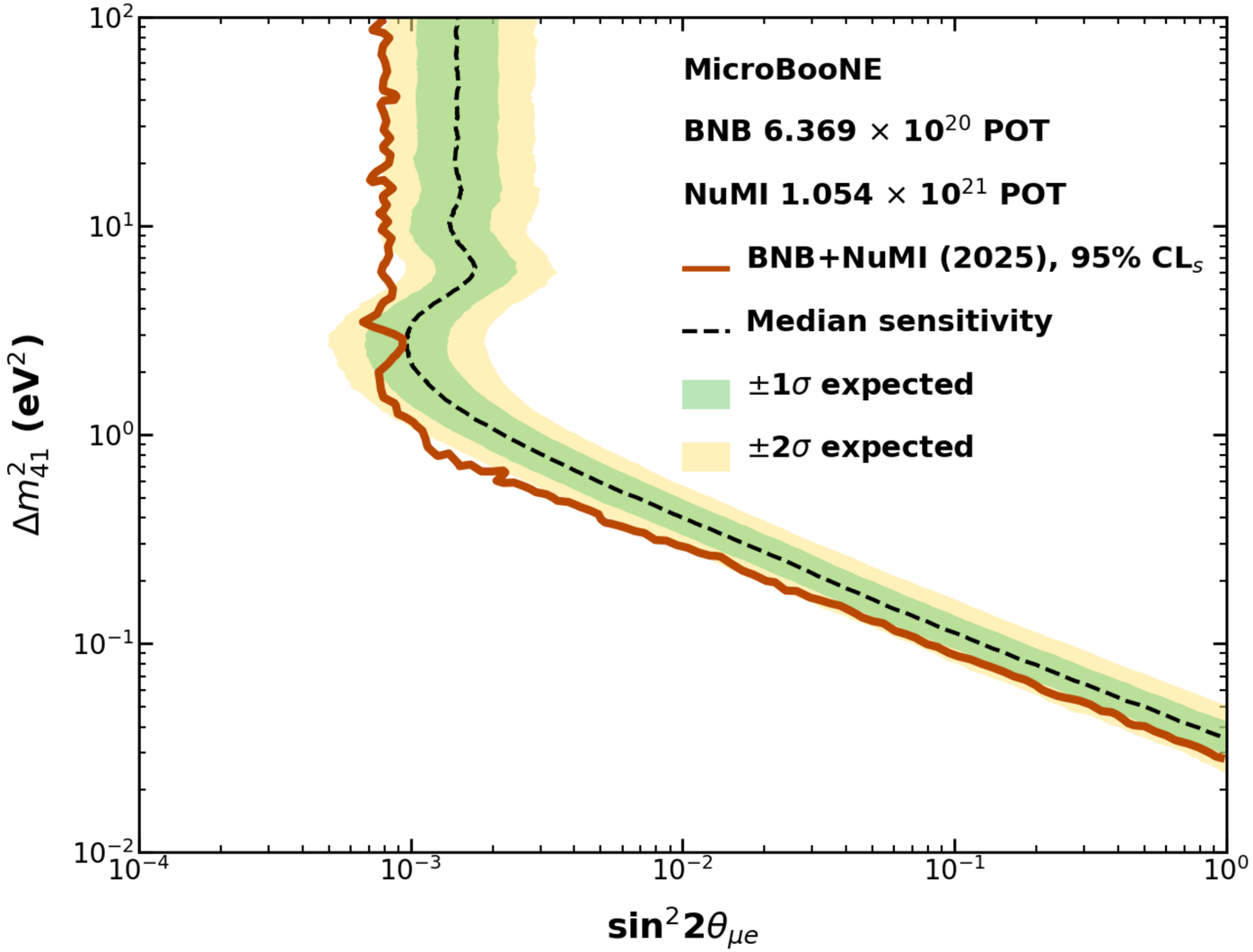


data exclusion is stronger than median sensitivity: driven by deficit in BNB ν_e sample



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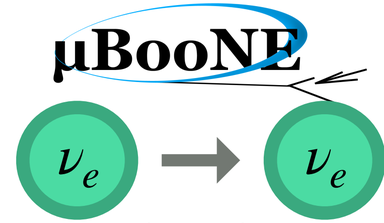

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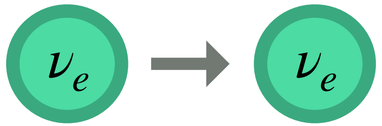
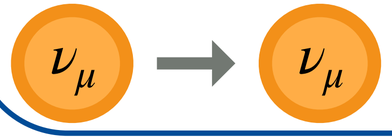


disappearance



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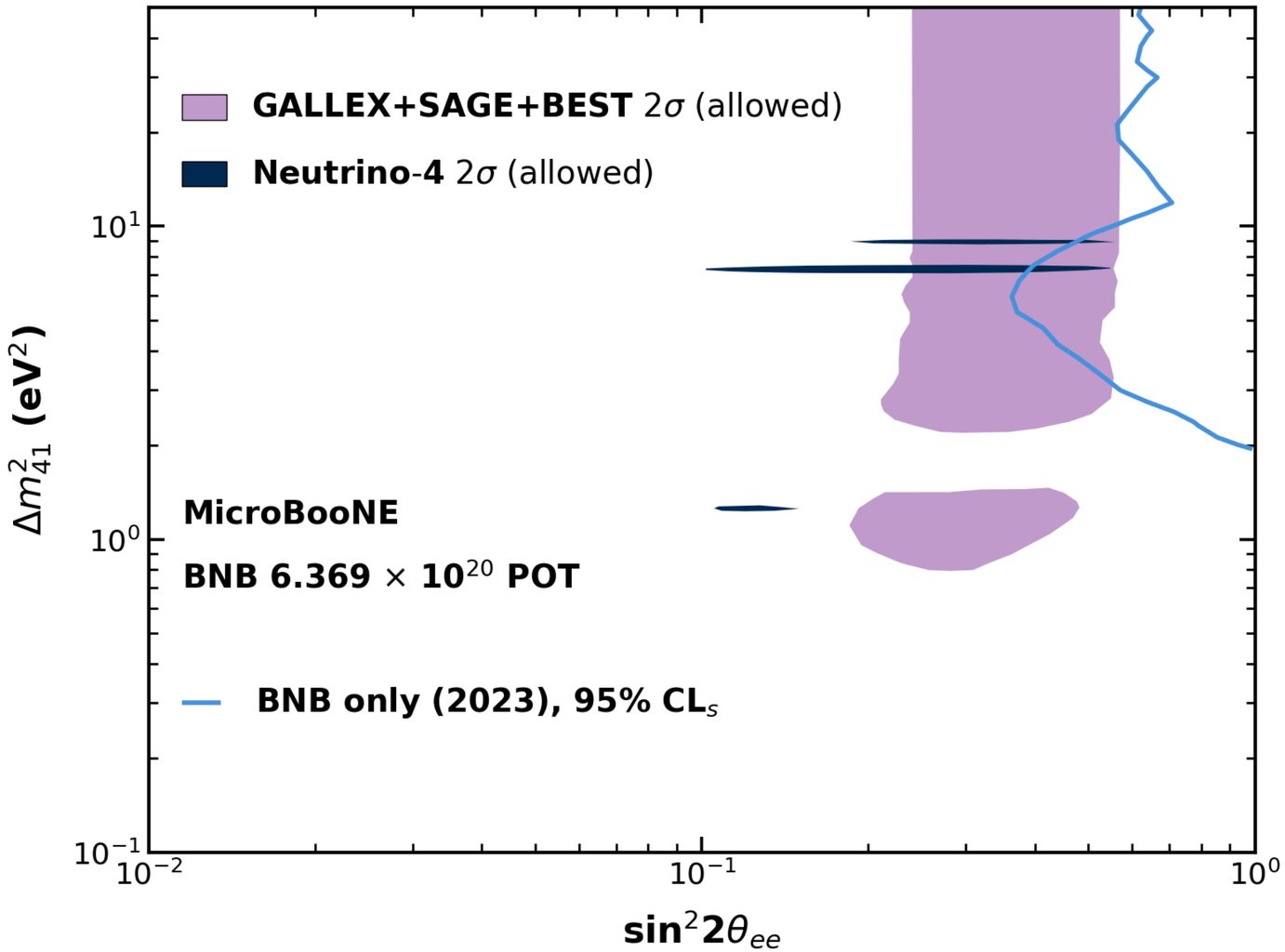
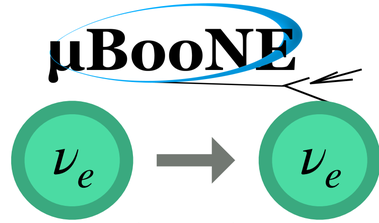


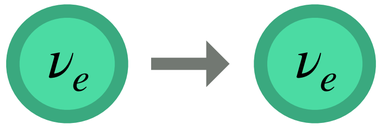
3+1 Sterile Neutrino Search: BNB+NuMI result



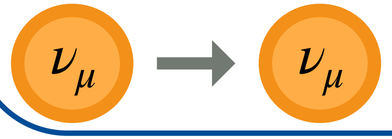
Nature 648 64-69 (2025)

BNB+NuMI Result

appearance

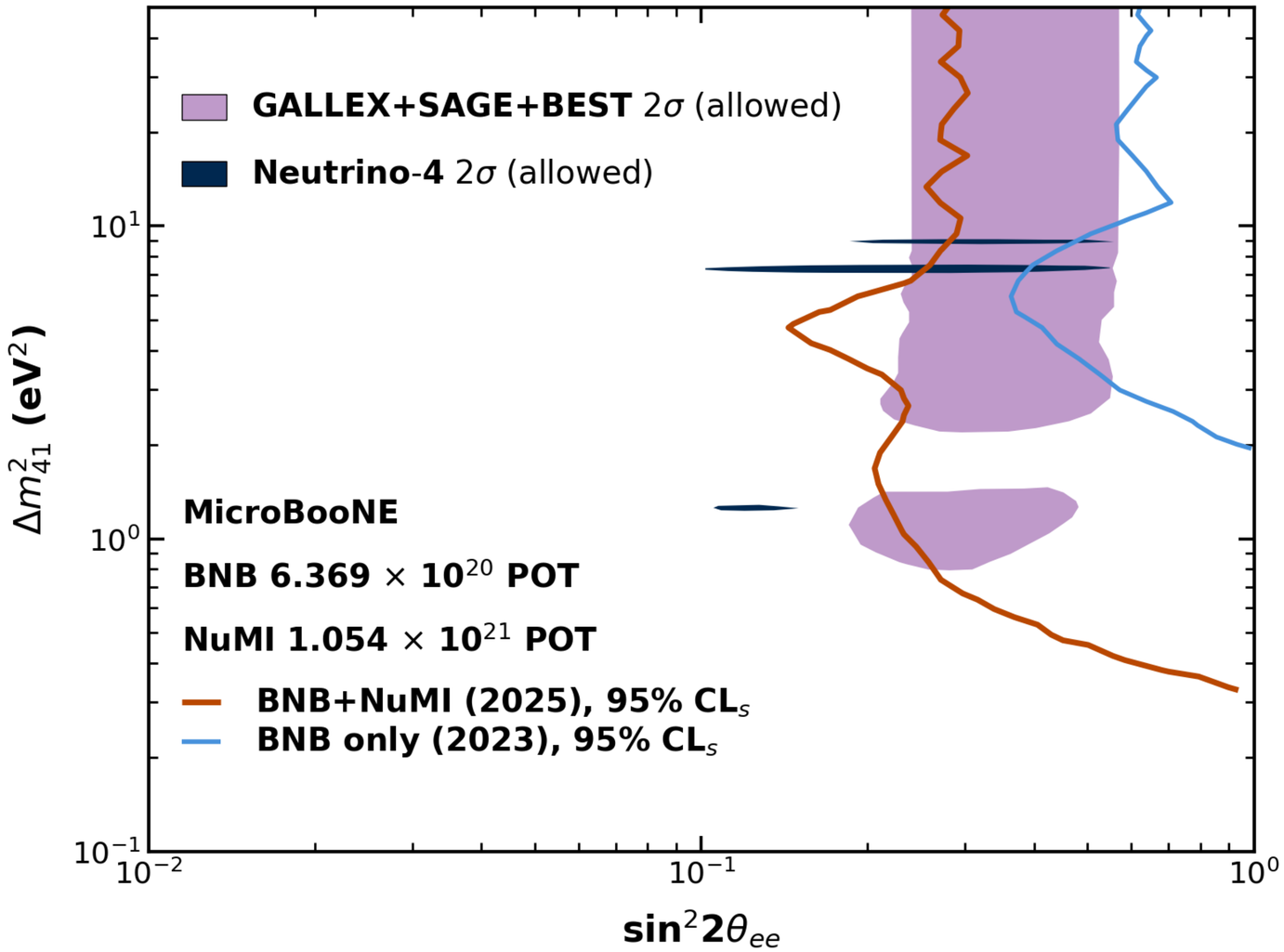


disappearance



disappearance

in ν_e disappearance channel, MicroBooNE excludes most of Gallium allowed region and part of Neutrino-4 allowed region



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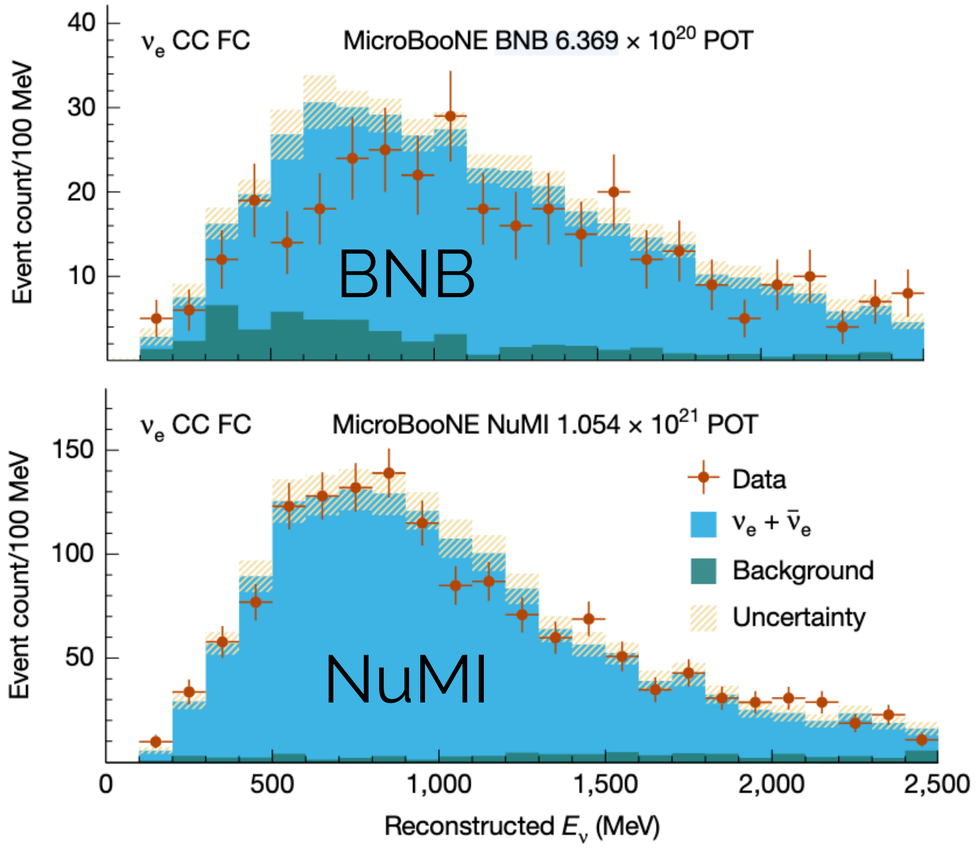
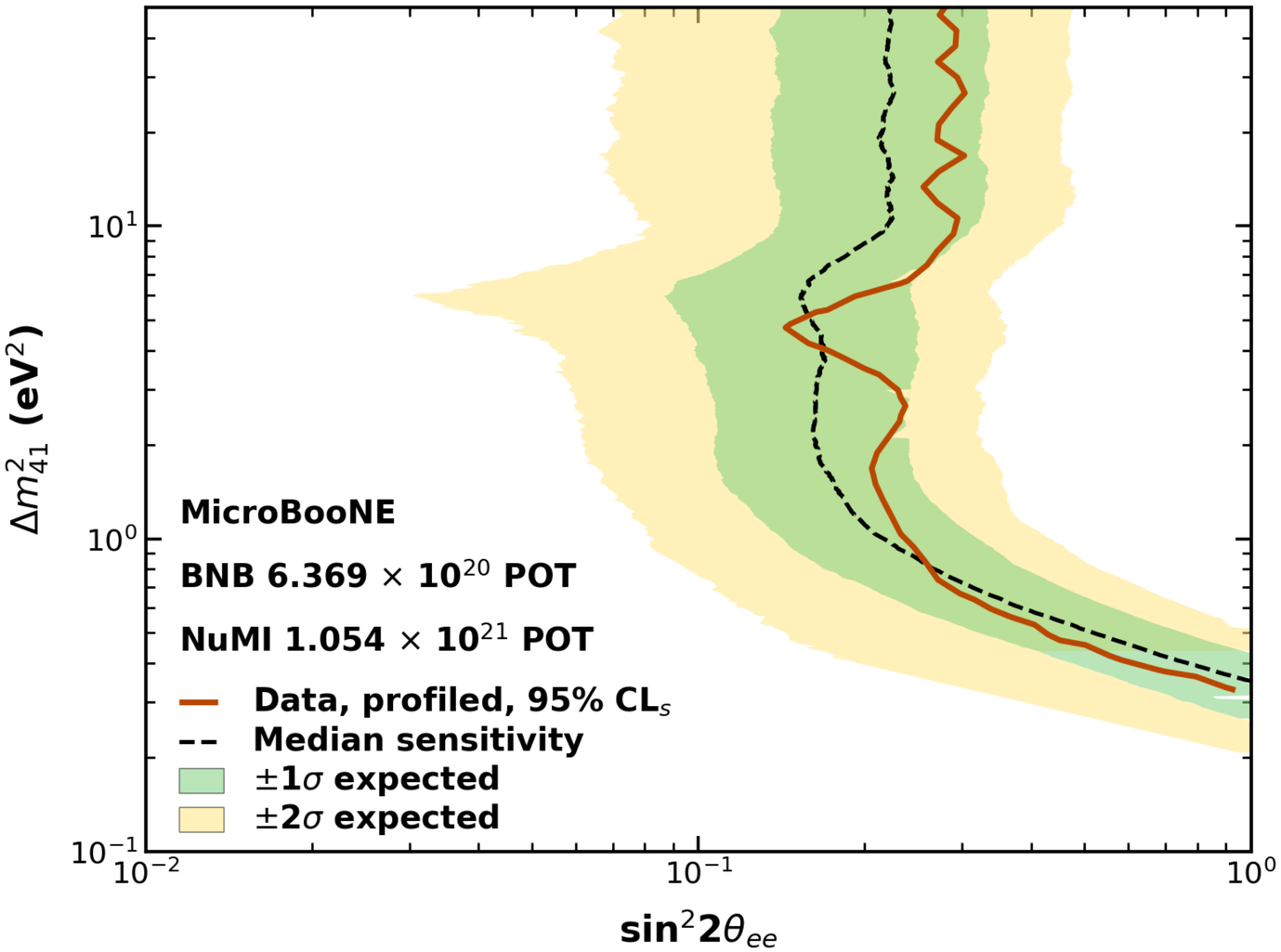
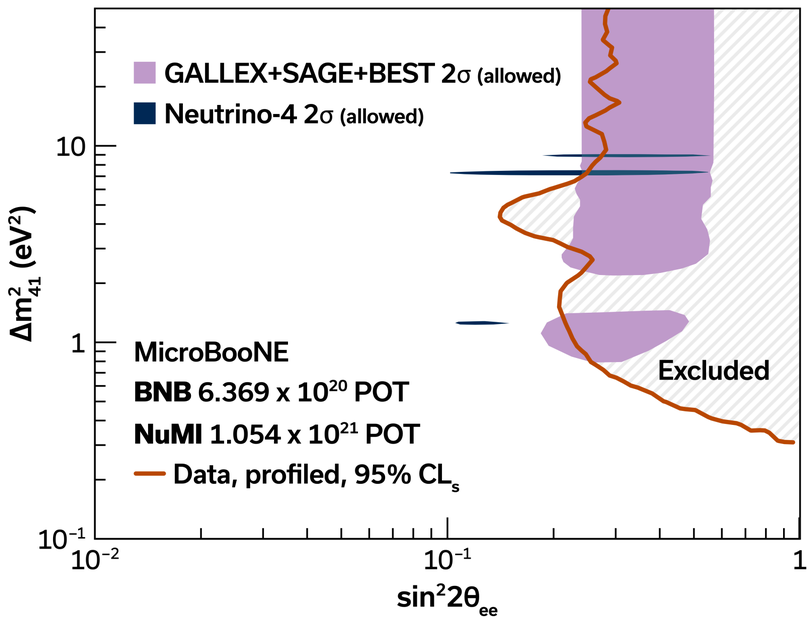


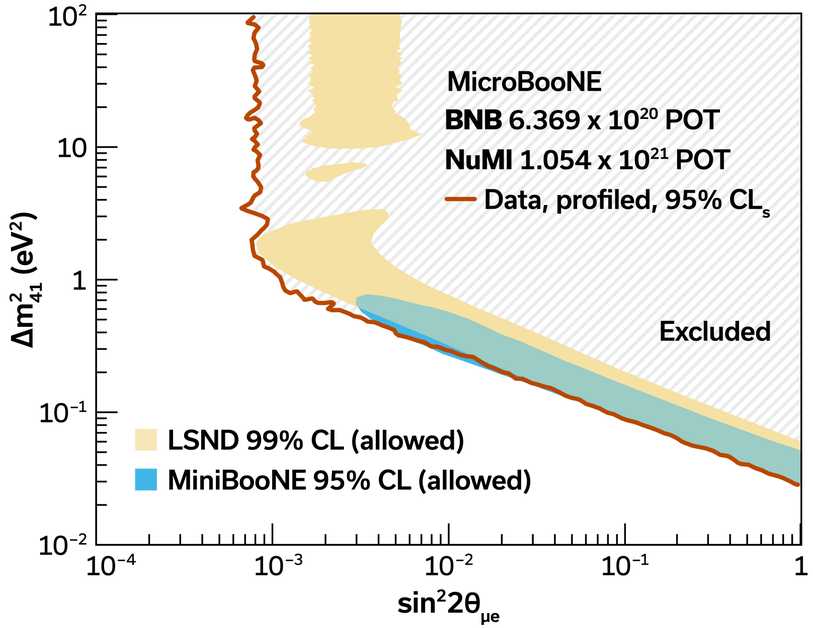
data exclusion is slightly weaker than median sensitivity: driven by deficit in BNB ν_e sample

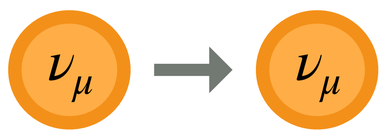
Nature 648 64-69 (2025)

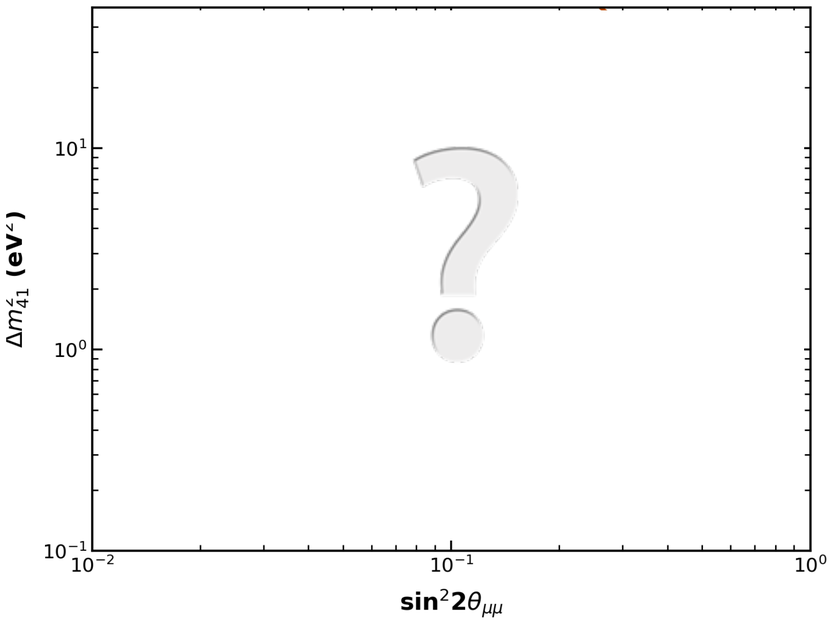


3+1 Sterile Neutrino Search: What about ν_μ disappearance?



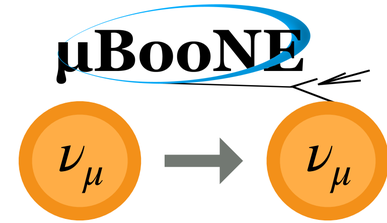






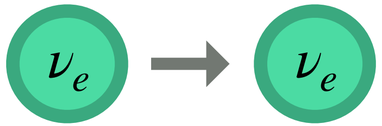
- MicroBooNE detects three main oscillation channels, but only showed two so far: ν_e appearance and ν_e disappearance
- these results rely on powerful ν_μ constraints to reduce systematic uncertainty of ν_e measurements ; whereas systematic uncertainty on the absolute CC ν_μ rate and shape is large and unconstrained
- ***we show ν_μ disappearance result today to complete the picture***

3+1 Sterile Neutrino Search: BNB+NuMI result

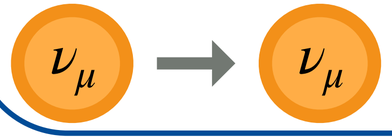


BNB+NuMI Result

appearance



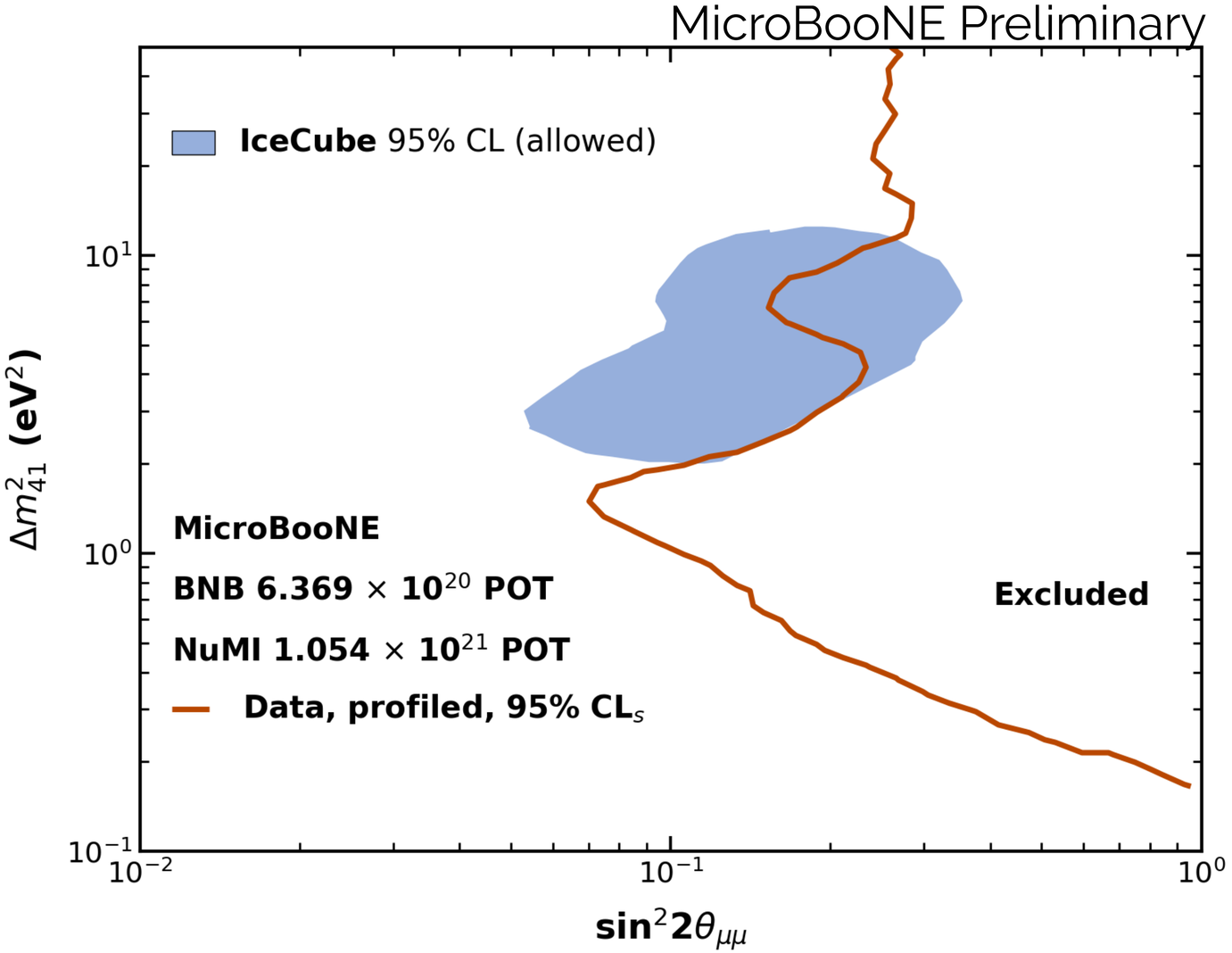
disappearance



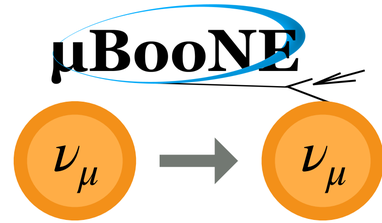
disappearance

NEW RESULT!

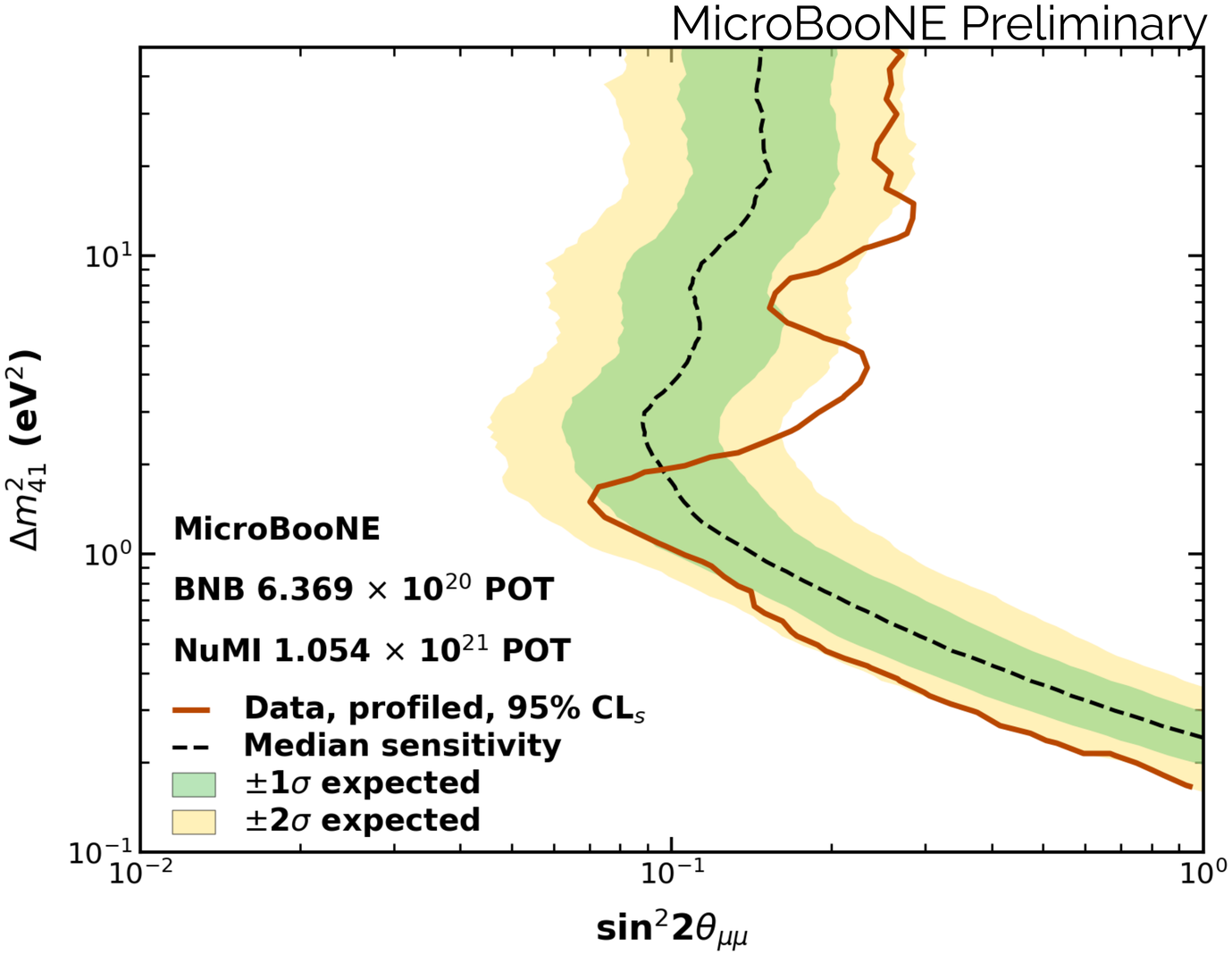
MicroBooNE excludes part of IceCube allowed region



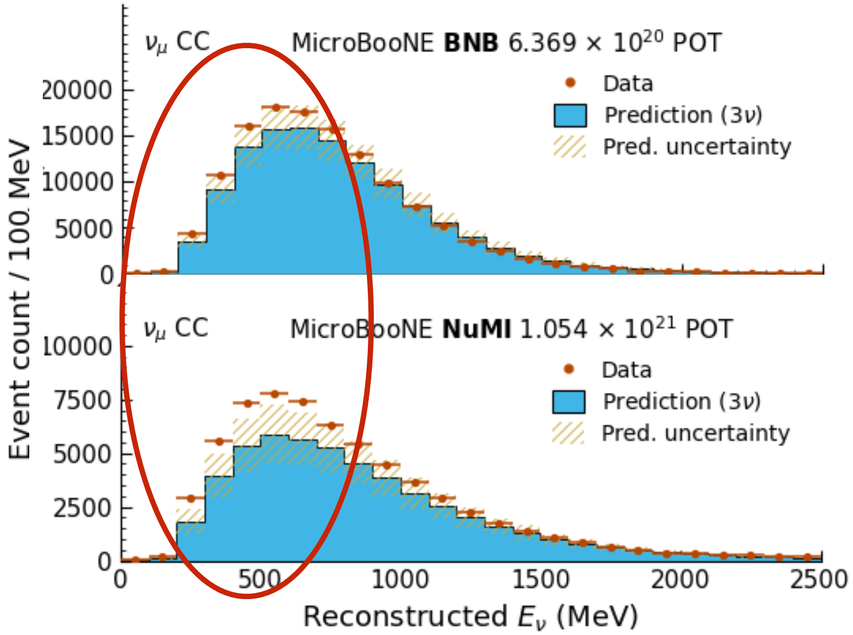
3+1 Sterile Neutrino Search: BNB+NuMI result



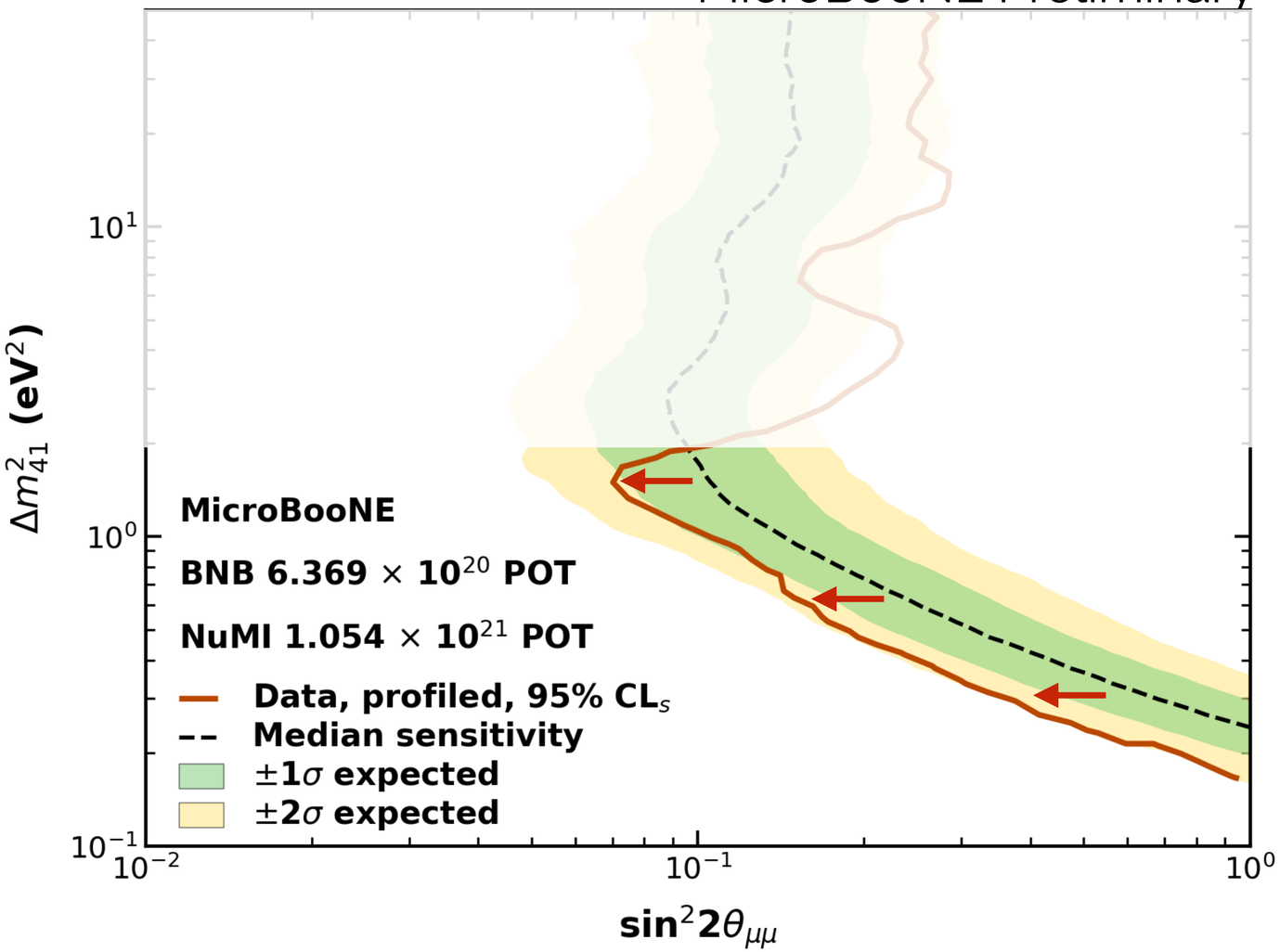
data exclusion is weaker than median sensitivity in high Δm^2 region, and slightly stronger in low Δm^2 region



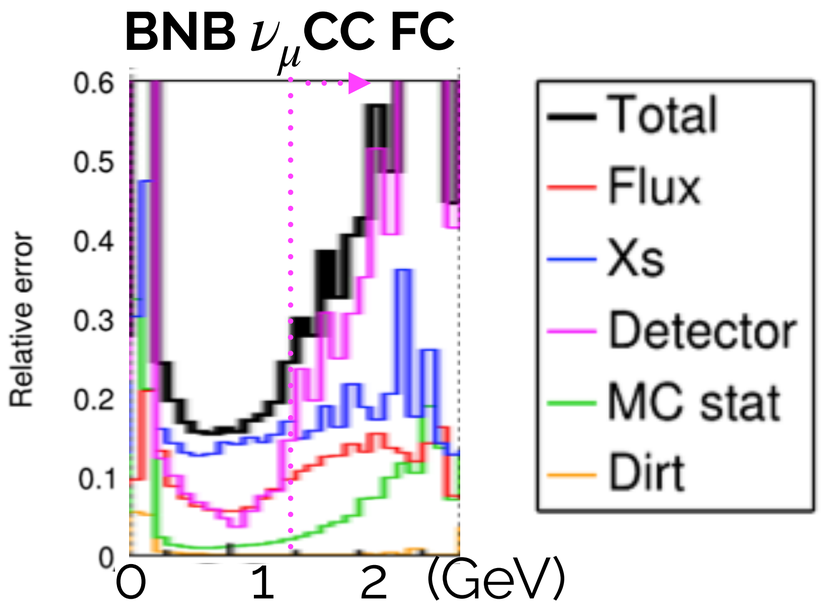
3+1 Sterile Neutrino Search: BNB+NuMI result



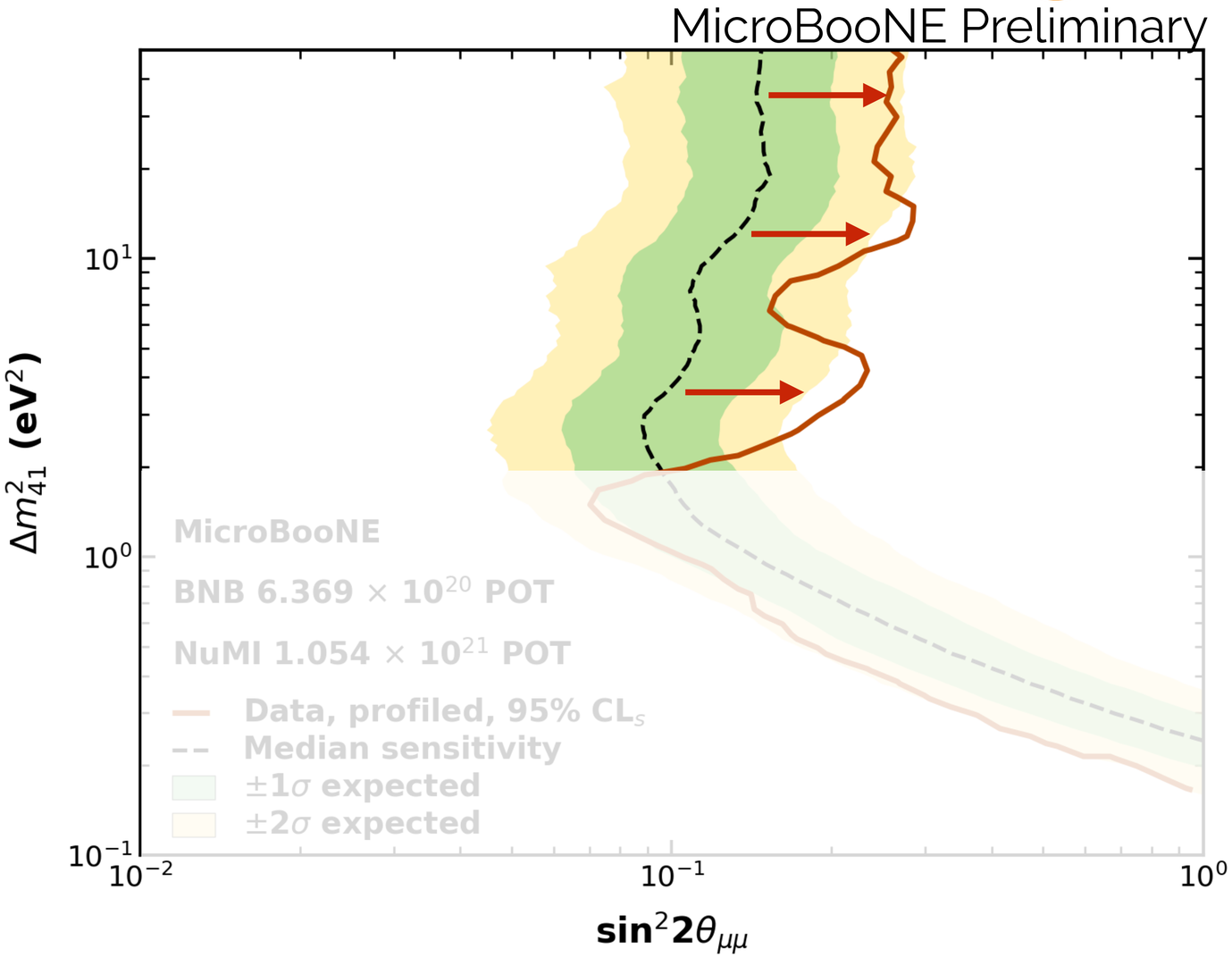
low Δm^2 region (<~1 eV²) is where the oscillation maximum sits at lower energy portion of the ν_μ spectrum, where we have the data excess → stronger limit



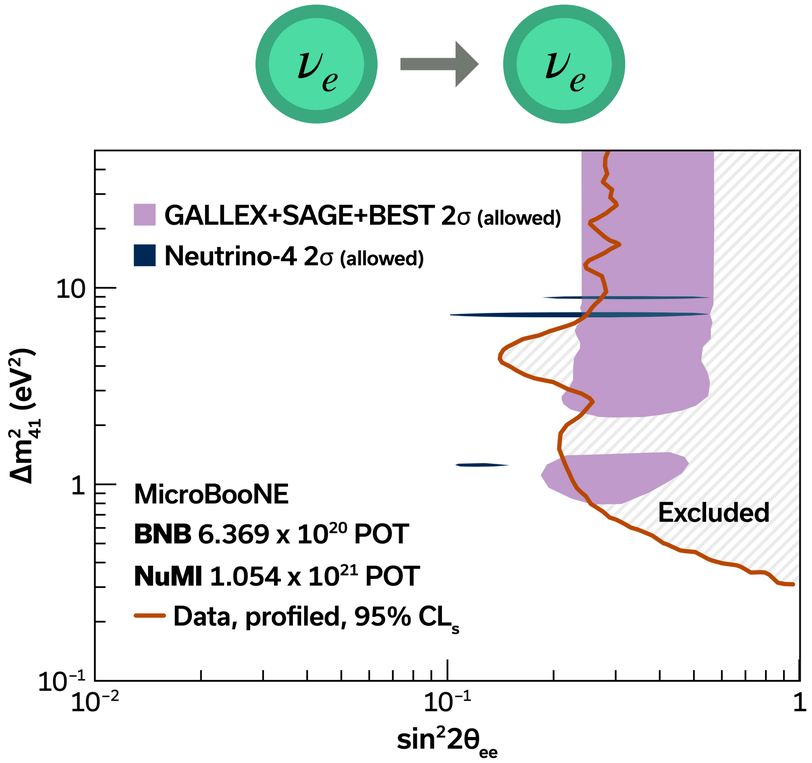
3+1 Sterile Neutrino Search: BNB+NuMI result

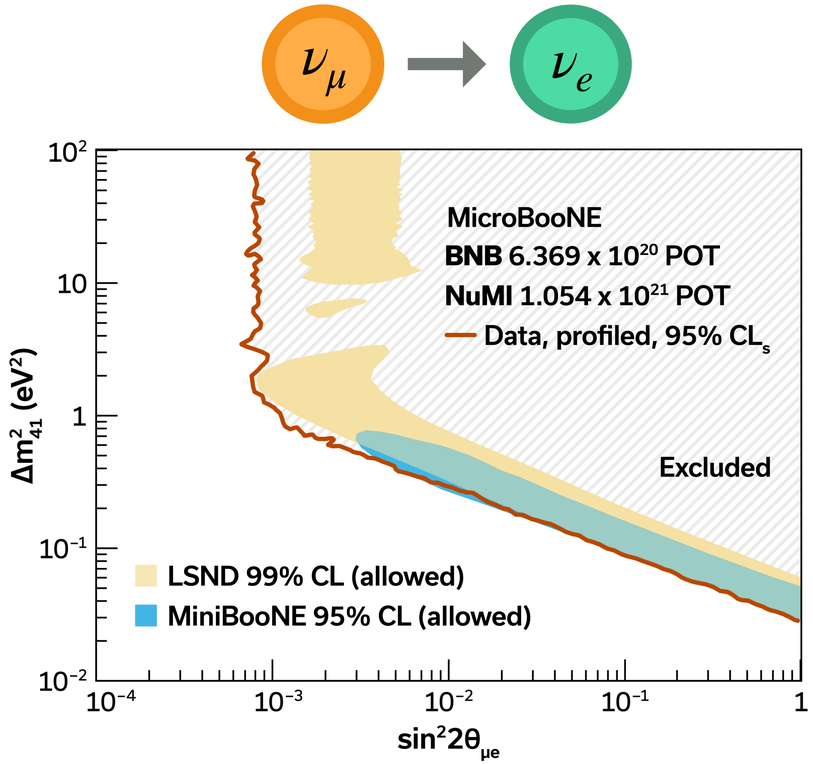


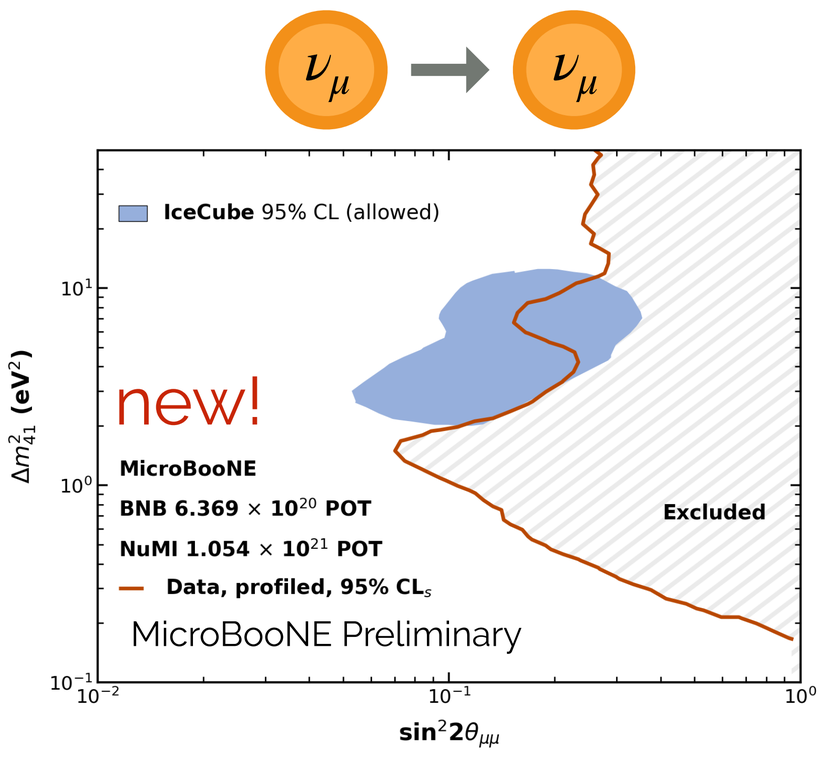
high Δm^2 region (>~1 eV²) is where oscillations reach higher energies and eventually average out as a pure rate effect, and our conservative detector systematics over-cover the data fluctuation



3+1 Sterile Neutrino Search: BNB+NuMI result



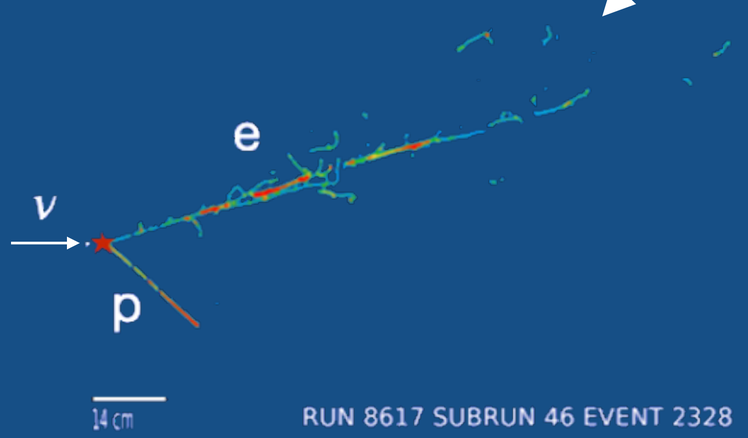




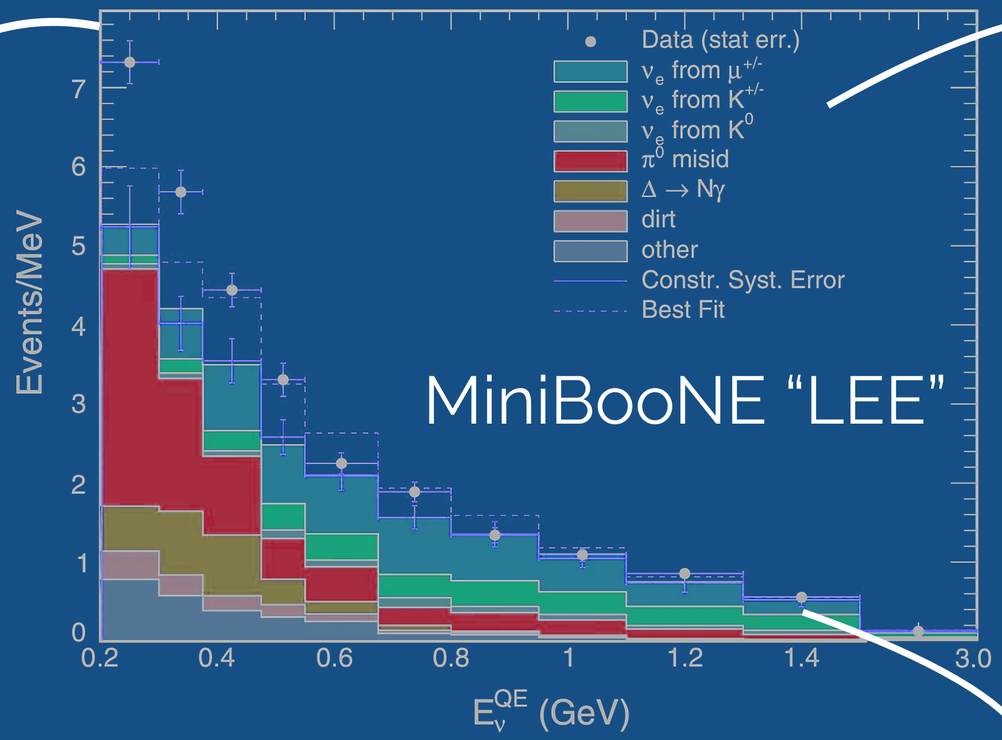
- MicroBooNE has now completed the full 3+1 program, all three oscillation channels measured in one detector
- all consistent with no sterile neutrino, with limited sensitivity in certain channels
- but the question still remains: *then what were the anomalies?*

MicroBooNE's "Low Energy Excess" Search

electron?

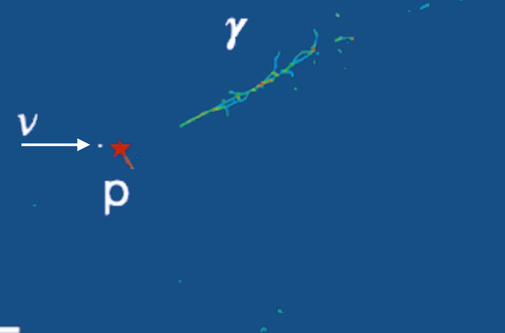


RUN 8617 SUBRUN 46 EVENT 2328



MiniBooNE "LEE"

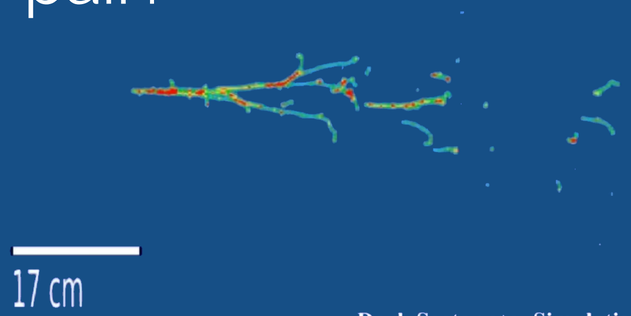
single photon?



MicroBooNE Data, Run 5462 Subrun 14 Event 732

e^+e^- opening angle 5.6°
e^+e^- energy 617 MeV

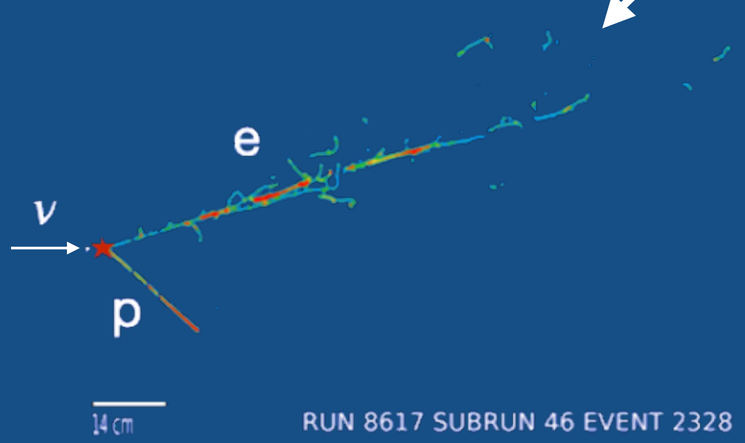
e^+e^- pair?



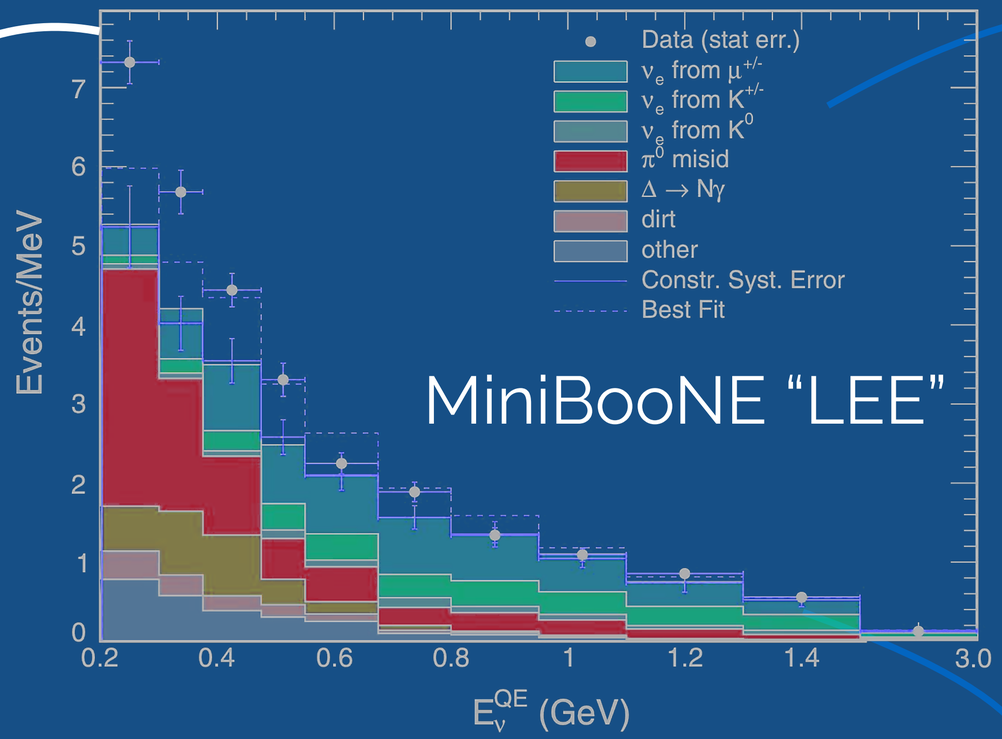
Dark Sector e^+e^- Simulation

MicroBooNE's "Low Energy Excess" Search

electron?



RUN 8617 SUBRUN 46 EVENT 2328



single photon?

disfavored!

[PRD 105 112003 (2022)](#)
[PRD 105 112004 (2022)](#)
[PRD 105 112005 (2022)](#)
[PRL 128 241801 (2022)](#)
[PRL 135 081802 (2025)](#)

[PRL 130 011801 (2023)](#)
[Nature 648 64-69 (2025)](#)

e^+e^- pair?

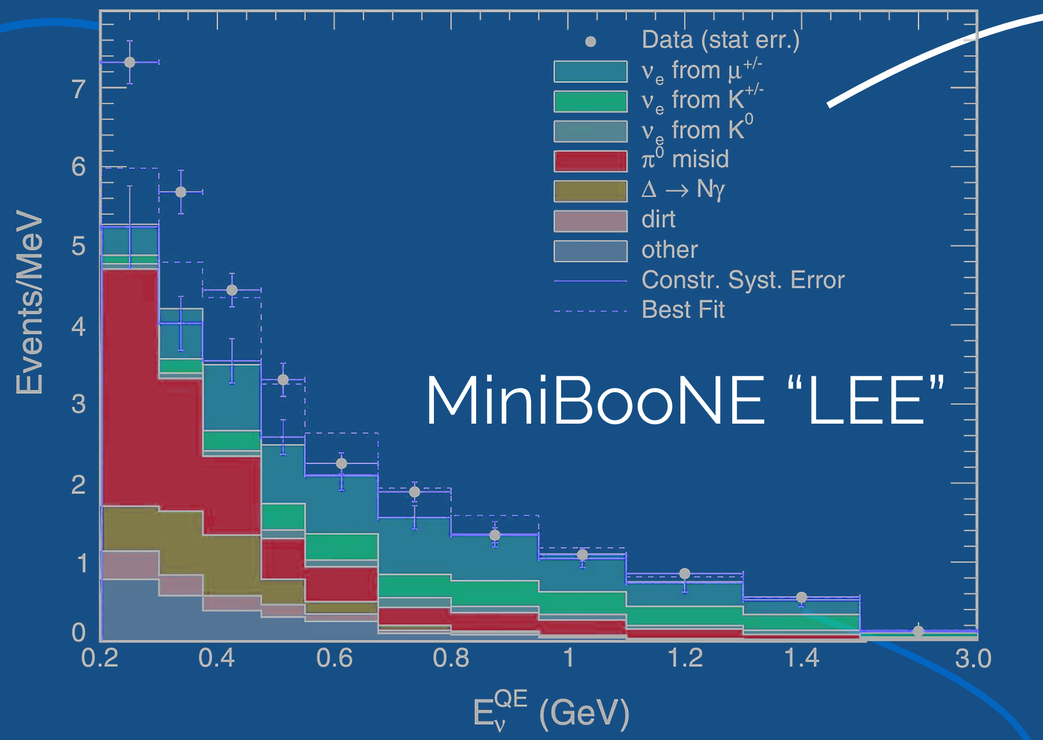
MicroBooNE's "Low Energy Excess" Search

electron?

RUN 8617 SUBRUN 46 EVENT 2328

14 cm

disfavored!



e^+e^- pair?

e^+e^- opening angle 5.6°
e^+e^- energy 617 MeV

17 cm

Dark Sector e^+e^- Simulation

single photon?

25 cm

MicroBooNE Data, Run 5462 Subrun 14 Event 732

disfavored most popular SM process explanations:

NC Δ → 1γ

PRL 128 111801 (2022)

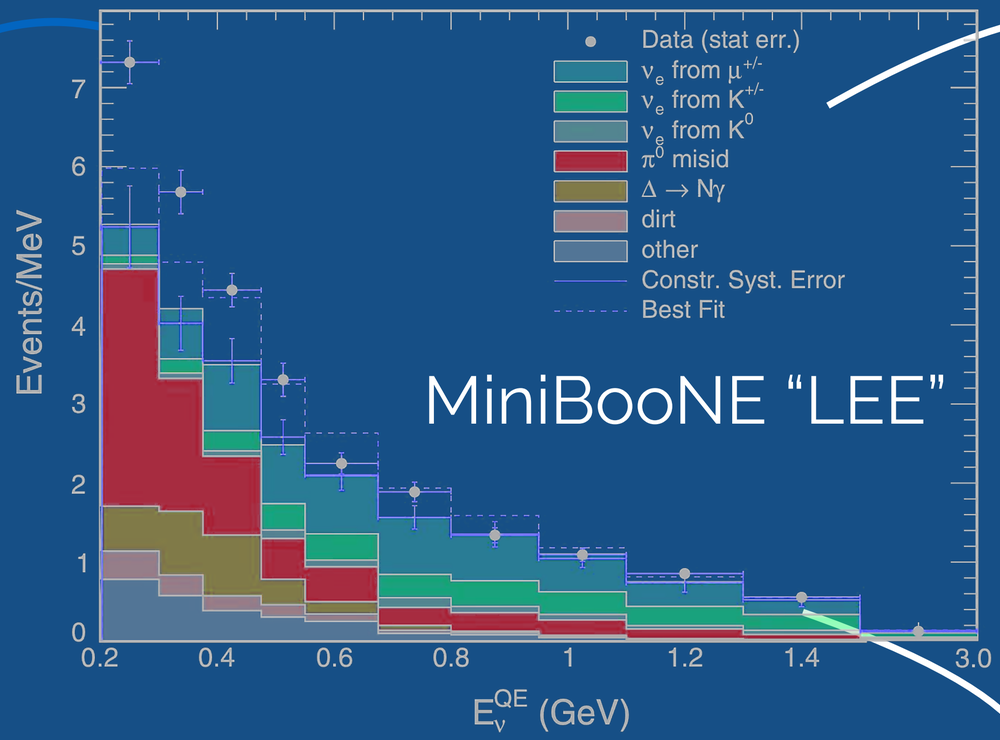
NC coherent 1γ

arXiv:2502.06091

MicroBooNE's "Low Energy Excess" Search

electron?

disfavored!

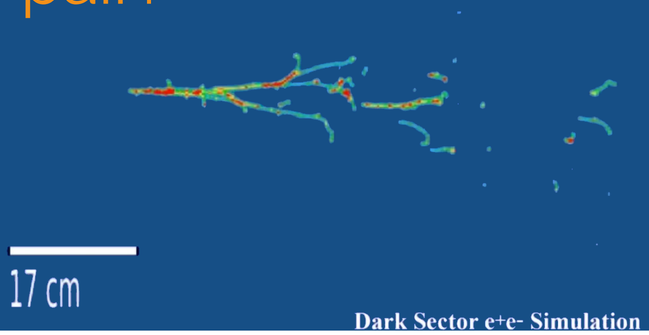


e^+e^- opening angle 5.6°
e^+e^- energy 617 MeV

single photon?

disfavored most popular SM process explanations

e^+e^- pair?

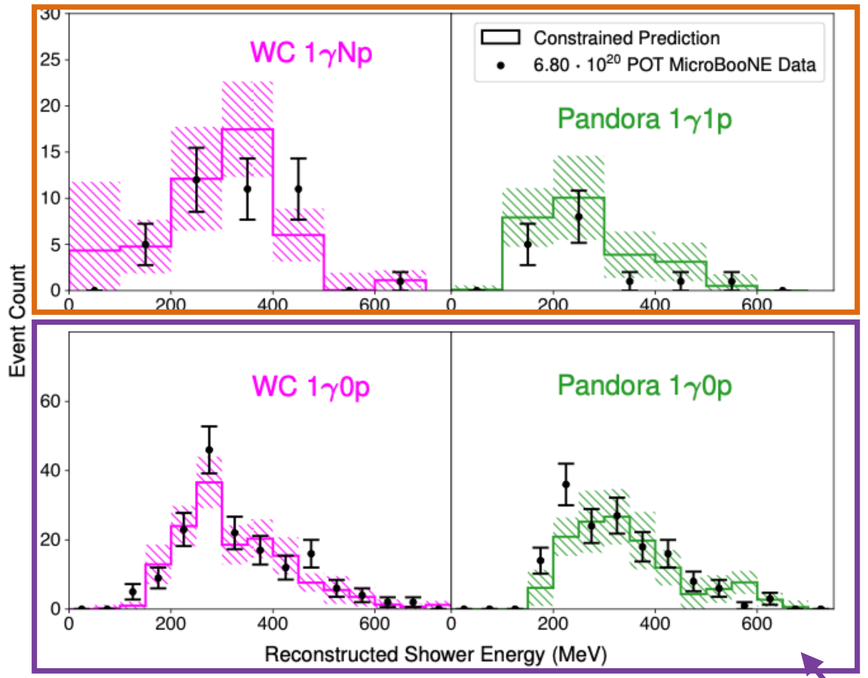


remaining signatures to probe: other **single photon** processes, or ***e+e-* pair** production with new physics

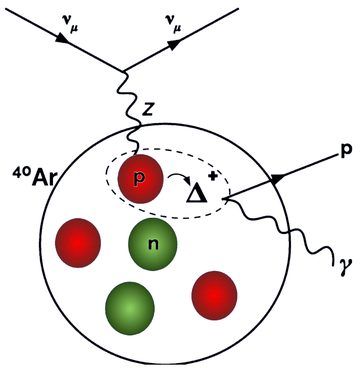
MicroBooNE's "Low Energy Excess" Search: Single Photons

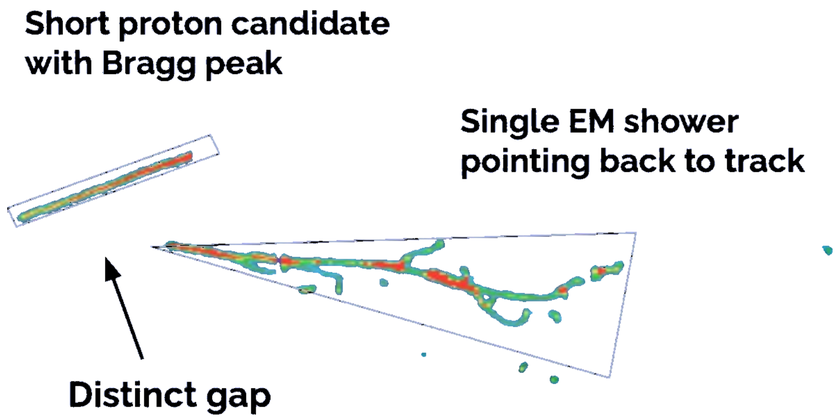
PRD 112 L091101 (2025)

- improved from our 2021 result, NC $\Delta \rightarrow 1\gamma$ SM background search by doubling selection efficiency and enabling much enhanced sensitivity for $1\gamma 0p$ topology
- data are found to be consistent with the nominal prediction

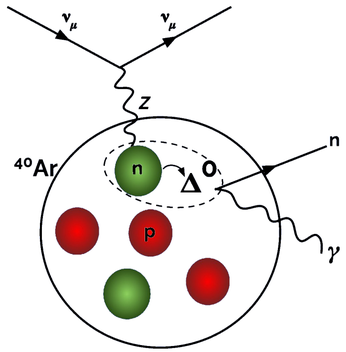


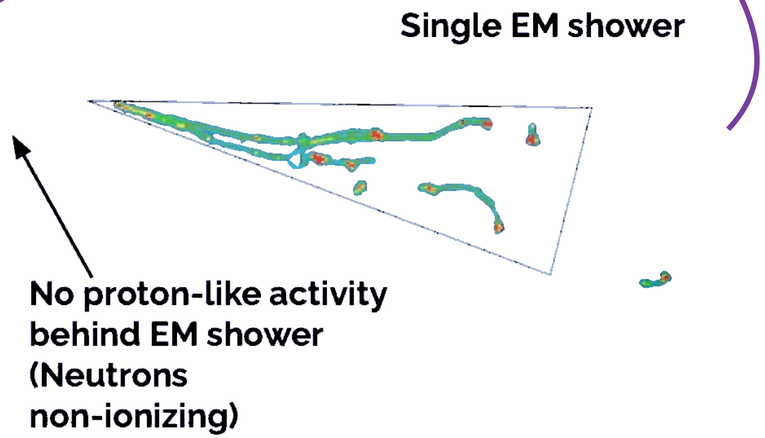
$1\gamma Np$ topology



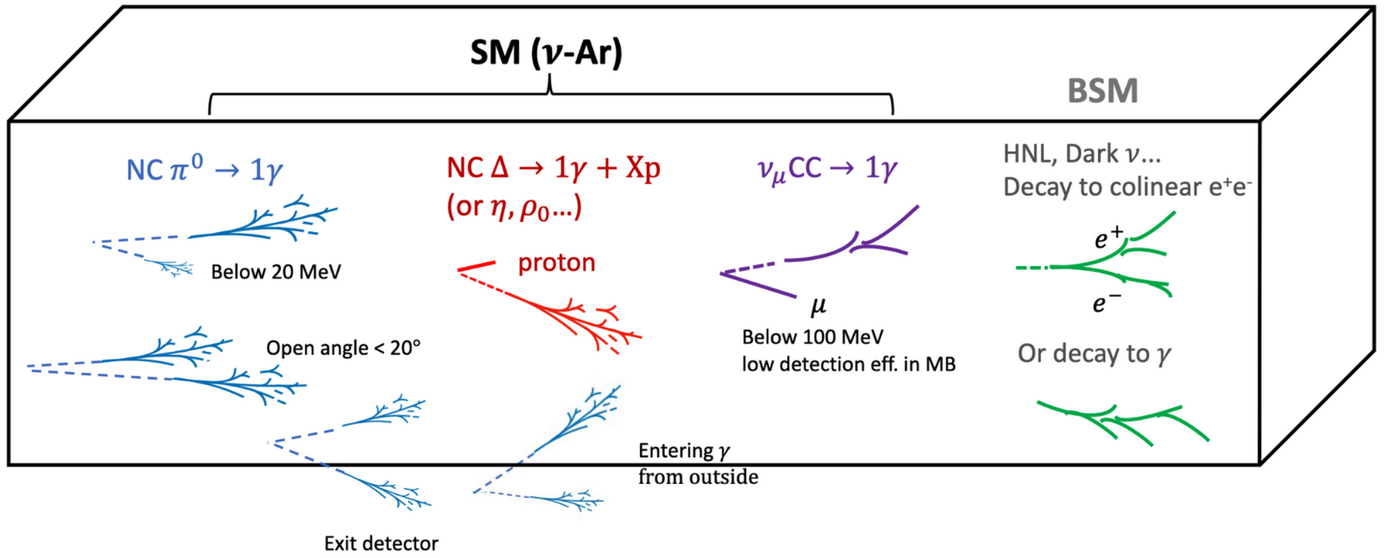


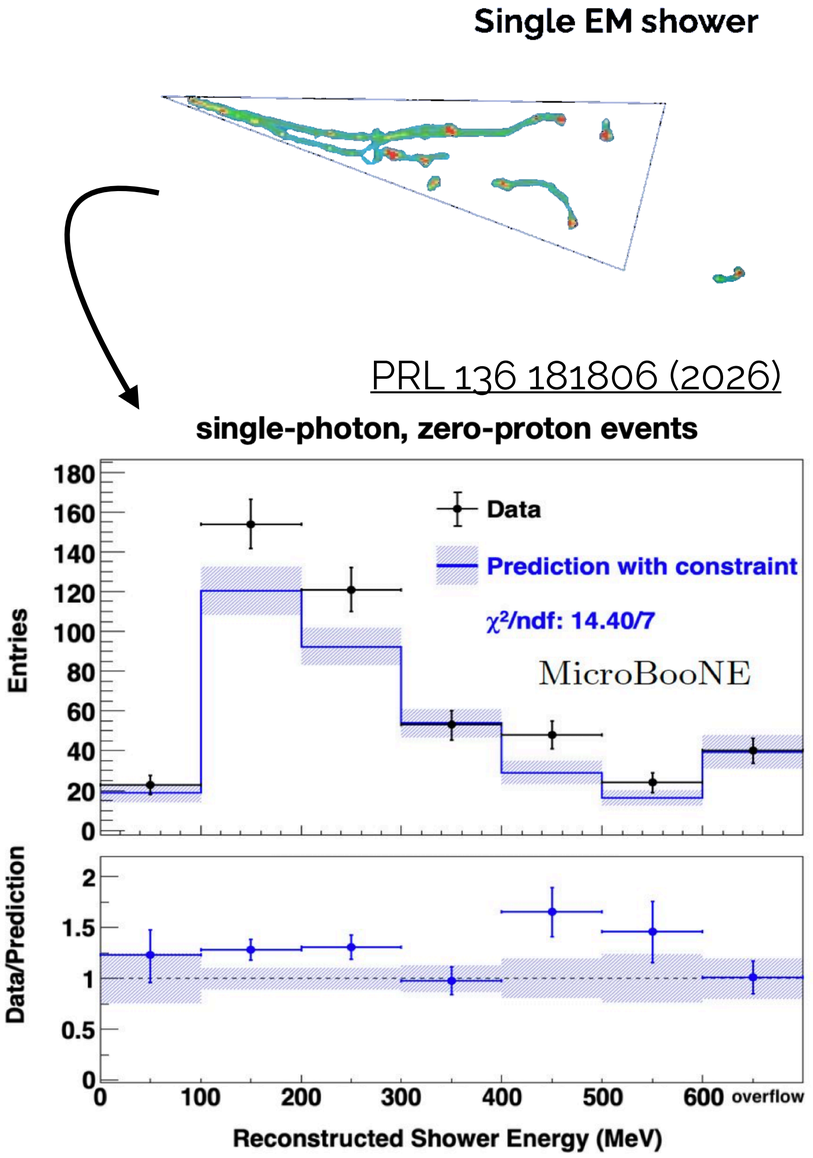
$1\gamma 0p$ topology





MicroBooNE's "Low Energy Excess" Search: Single Photons

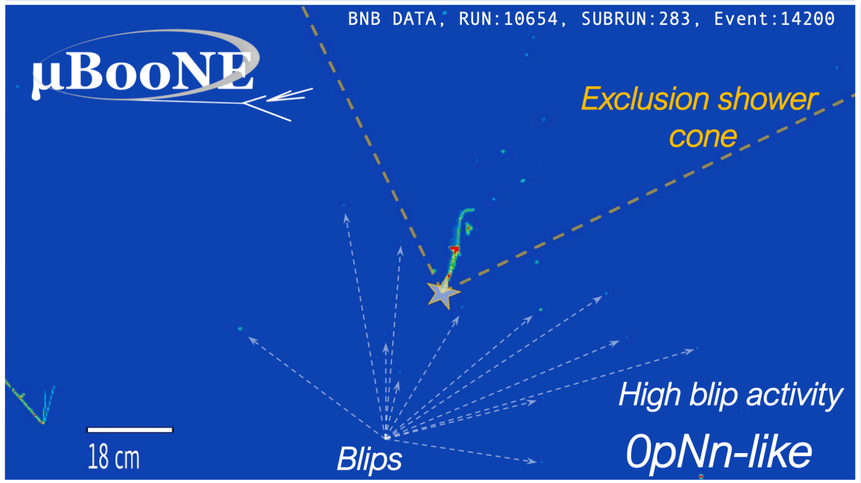


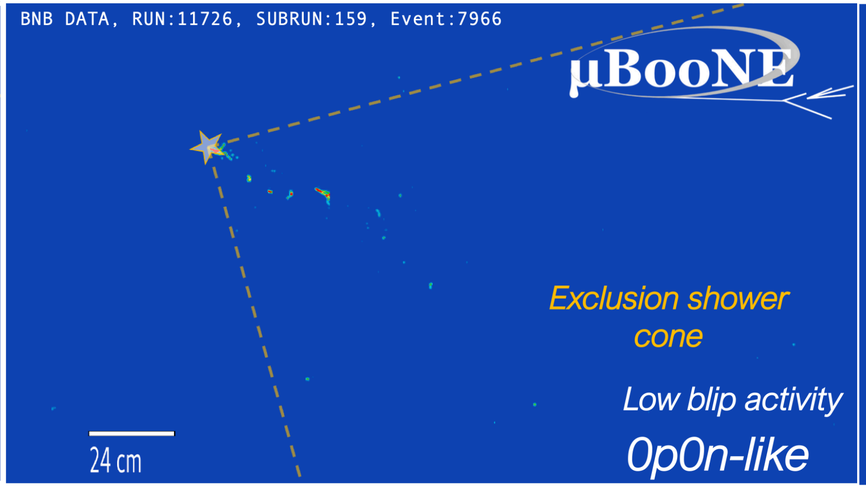


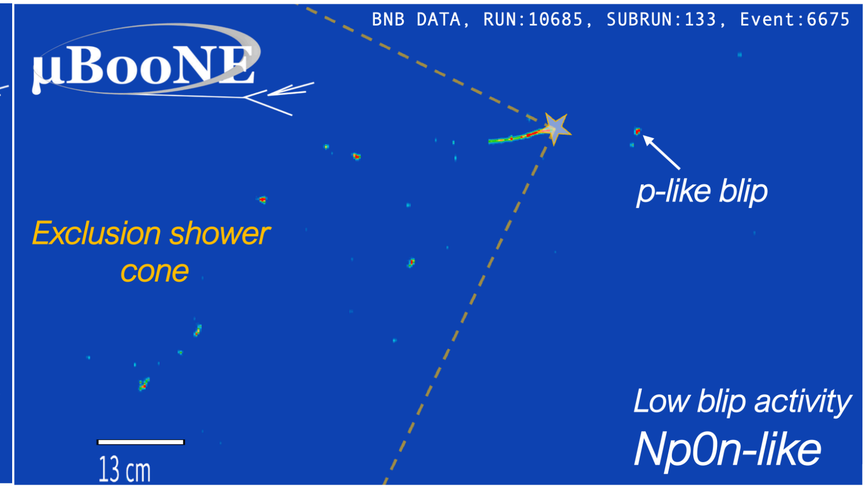
- instead of searching for specific process, also casted a wide net on single photon channel *no matter the origin:* **inclusive** single photon search

  - low energy zero-proton subsample shows an excess with **2σ local significance**, motivating more detailed investigations

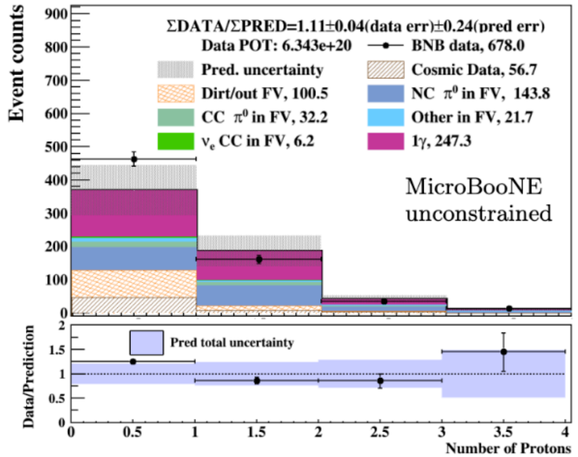
MicroBooNE's "Low Energy Excess" Search: Single Photons



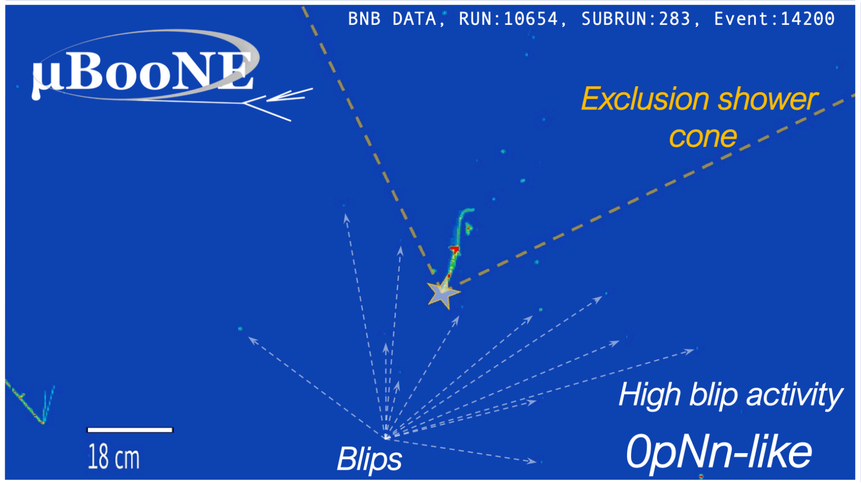


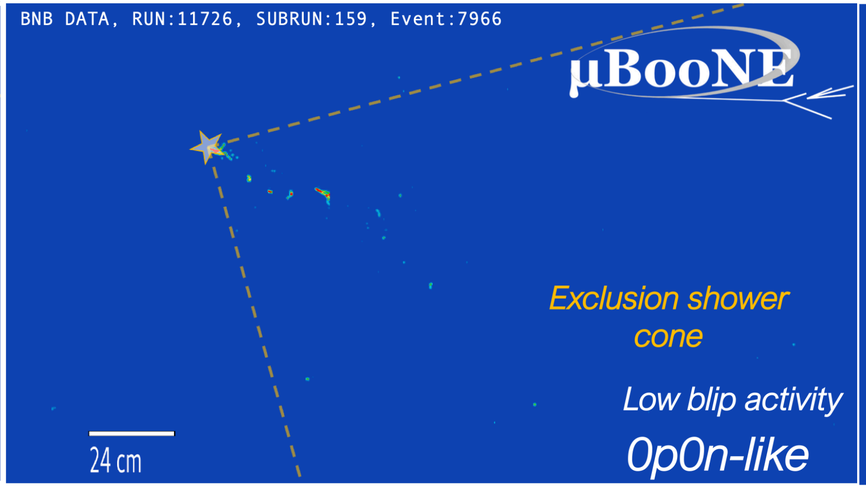


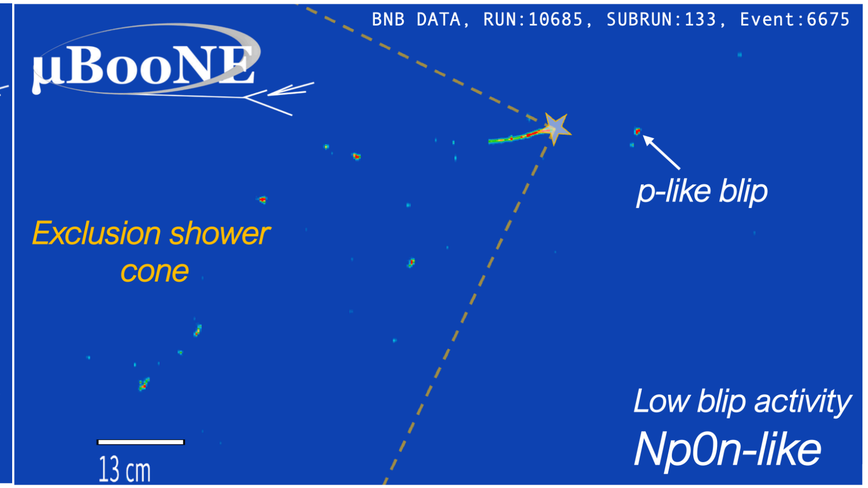
- reconstruction of MeV-scale features in LArTPC (**blips**) can reveal formerly unidentified final-state particles near isolated single showers
  - diffuse low-energy (0-3 MeV) blips: inelastic scattering of final state neutrons
  - higher-energy blips upstream of the isolated shower: final state protons
- this new technique can provide accurate understanding of the features observed in the inclusive single photon analysis



MicroBooNE's "Low Energy Excess" Search: Single Photons







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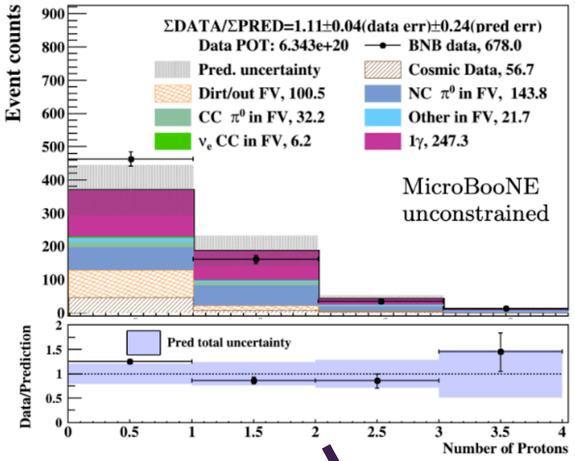
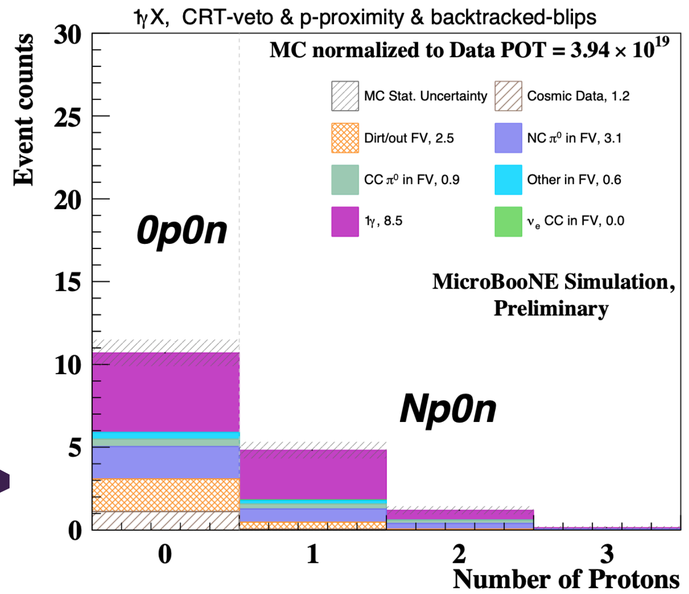
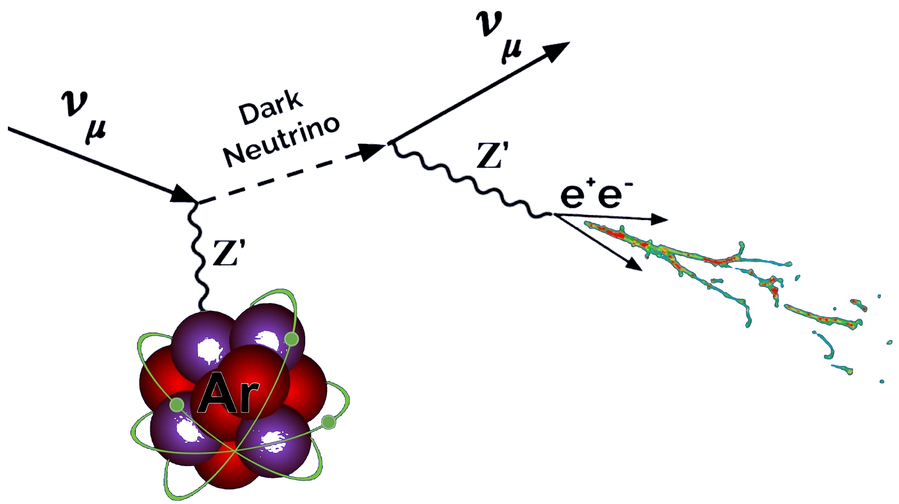


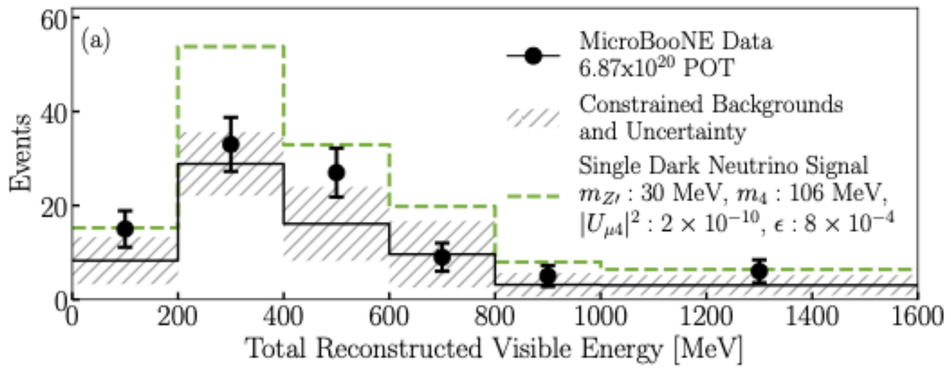
MicroBooNE Public Note 1134

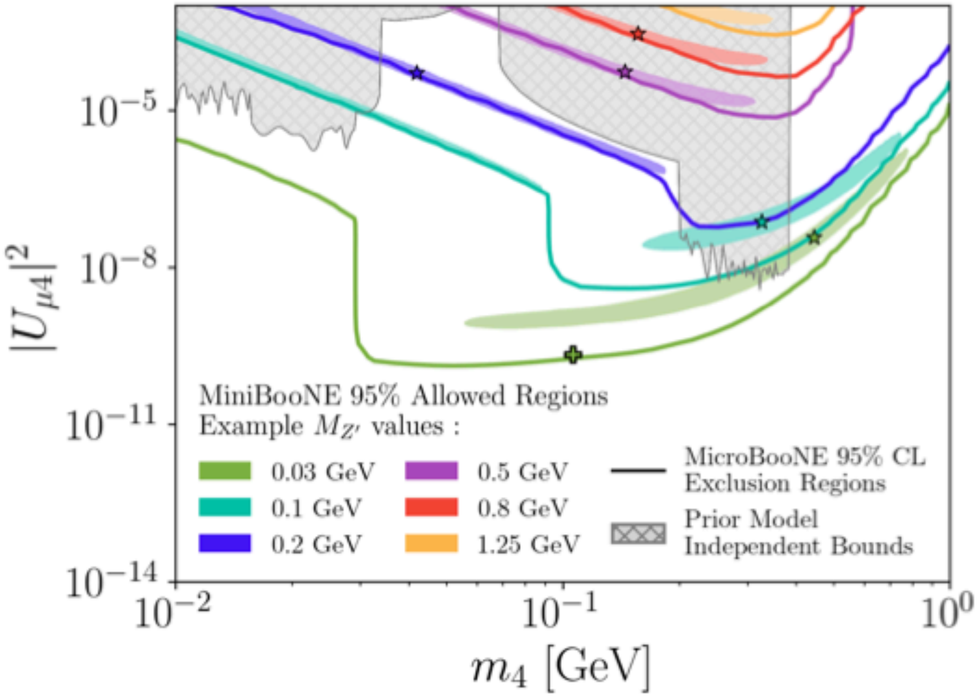


MicroBooNE's "Low Energy Excess" Search: BSM *e+e-*

PRL 136 121804 (2026)



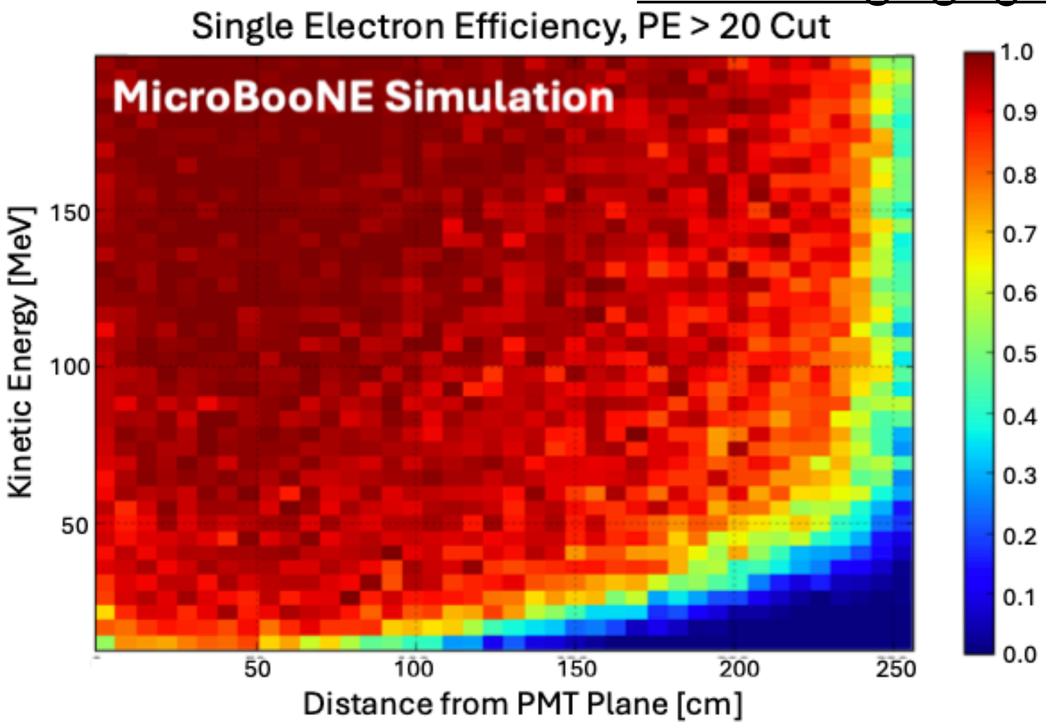




- search for forward going *e+e-* pairs from unstable dark neutrino decay
- sensitive to MiniBooNE allowed region for these models at >95% CL
- MicroBooNE places world leading exclusion limits, ruling out this interpretation of the MiniBooNE anomaly

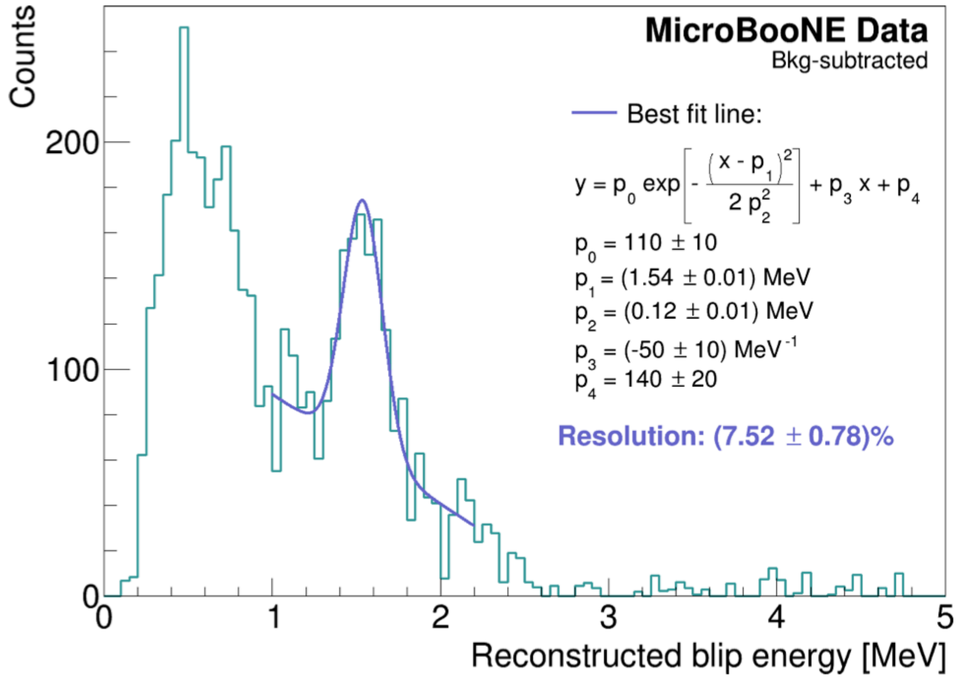
How can we do even better?

arXiv 2603.23691



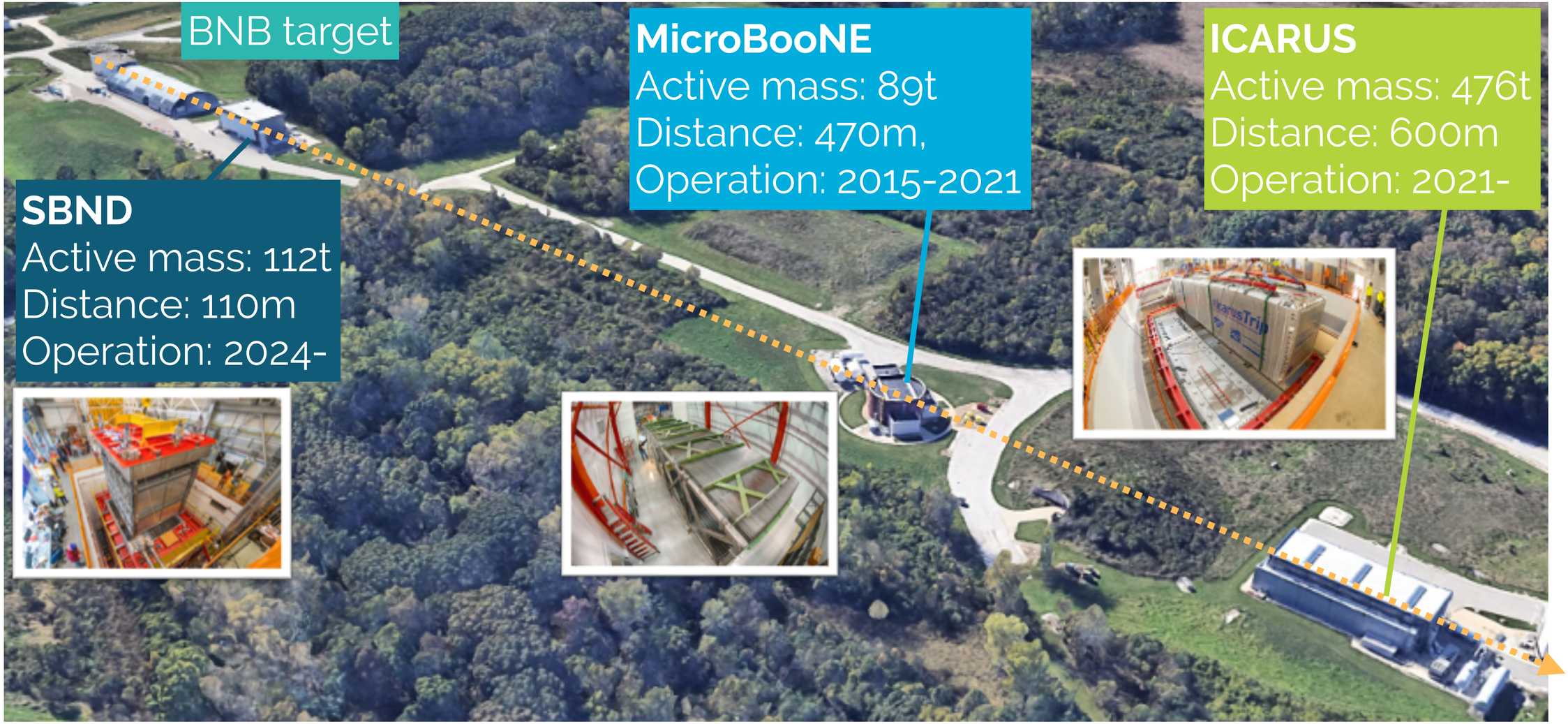
- thorough understanding of LAr **scintillation light** for robust systematic uncertainty evaluation and physics analysis

arXiv 2605.30709



- first reported measurement of **MeV-scale energy resolution** in a neutrino LArTPC (7.5% at ~1.5 MeV), using ionization charge signals from ^{208}Tl γ pair production

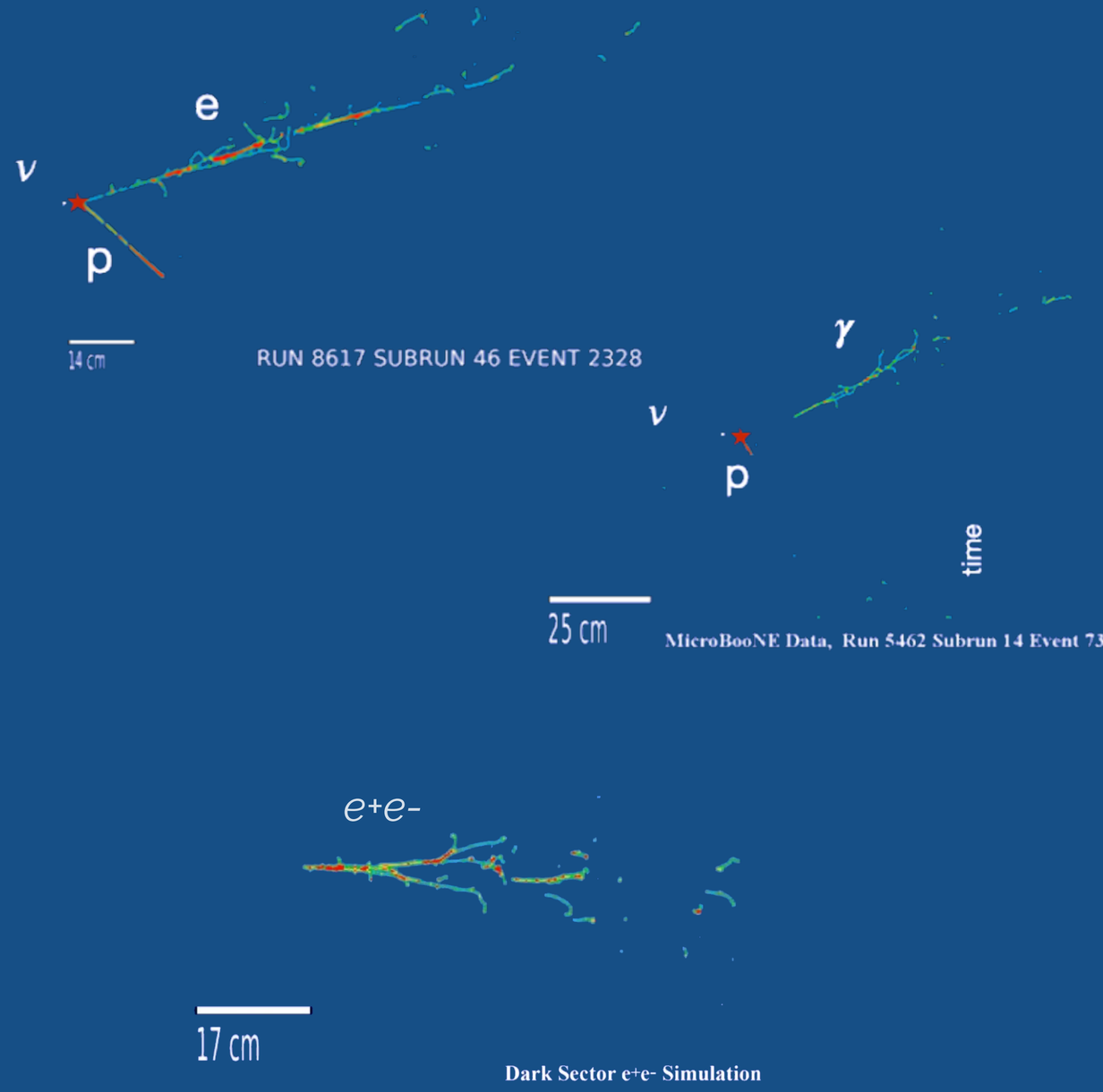
How can we do even better: SBN Program at Fermilab



- SBN program with two additional near & far LArTPC detectors, will provide a more comprehensive and sensitive exploration of sterile neutrino and other BSM physics

Conclusion

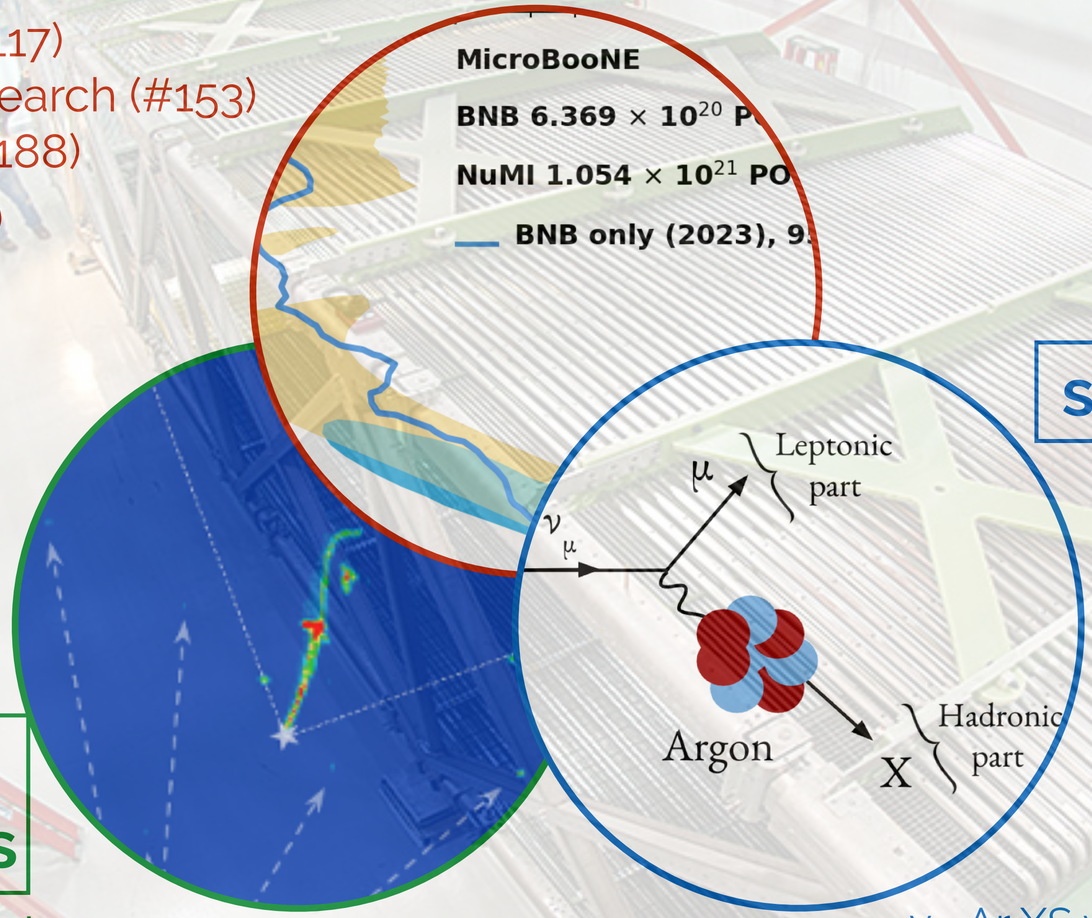
- MicroBooNE has a very active physics program
- novel “two beams in one detector” 3+1 sterile neutrino search
- extensive low energy excess searches focusing on single photon, and *e+e-* channels; with doubled dataset, usage of cosmic ray tagger, combining multiple reconstruction algorithms
- new LArTPC analysis techniques and detector understanding are under continued development
- many more exciting analyses to come!



MicroBooNE Posters

neutrino oscillation & beyond the standard model physics searches

inclusive single-photon search (#117)
NC-coherent-like single-photon search (#153)
enhanced NC delta→1γ search (#188)
light sterile neutrino search (#239)
dark sector e+e- search (#449)



study ν-Ar interactions

neutrino angle reconstruction (#110)
charged pion production (#137)
pionless ν_e XS (#139)
CCπ^0 production (#145)
kaon production (#180)
coherent pion production (#211)
ν_μ-Ar XS without pions in the final state (#285)
resonance and nuclear effect with π^0 production (#318)
ν_μ XS across proton multiplicities (#393)

advancing LArTPC technology capabilities

improving single-photon search with low E hadronic ID (#159)
MeV-scale signal energy resolution (#114)