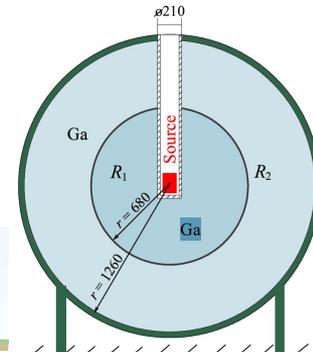


# Short-Baseline Neutrino Experiments

Erin Yandel (Los Alamos National Laboratory)  
9th Vietnam School on Neutrinos  
July 24, 2025



# Outline

1. What does “short-baseline” mean?
2. Why study neutrinos over short baselines?
3. Anomalies
  - a. Sterile neutrinos
  - b. Other possibilities
4. Current short-baseline experiments
  - a. Addressing the Anomalies
  - b. Outside the Anomalies
5. The future for short-baseline

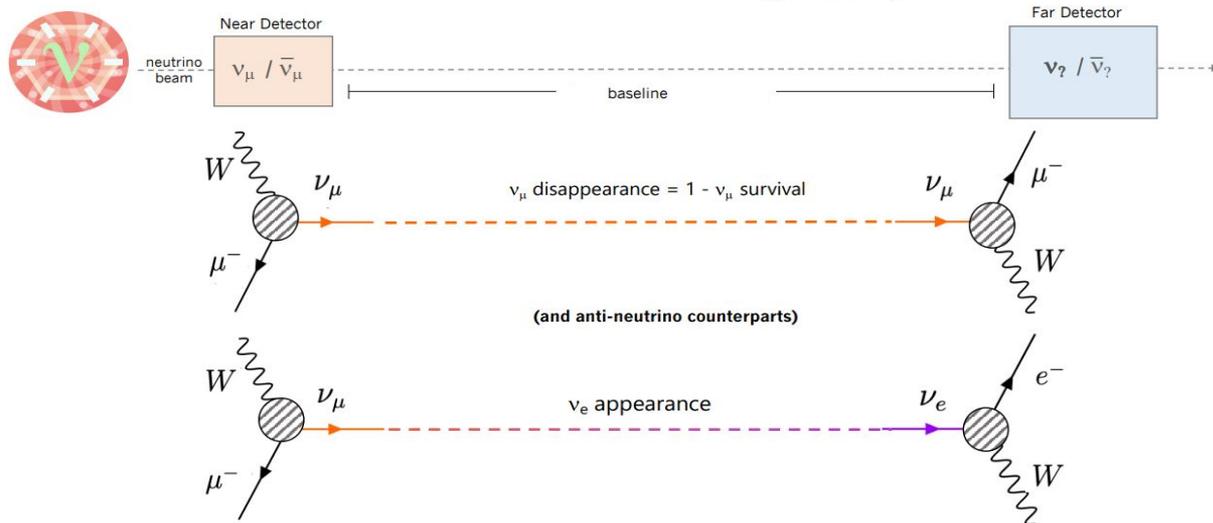
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# Reminder: Neutrino Oscillations

- Oscillate flavors due to different flavor eigenstates vs mass eigenstates
- Non-zero neutrino masses not predicted by SM
  - a number of neutrino experiments to characterize this phenomenon

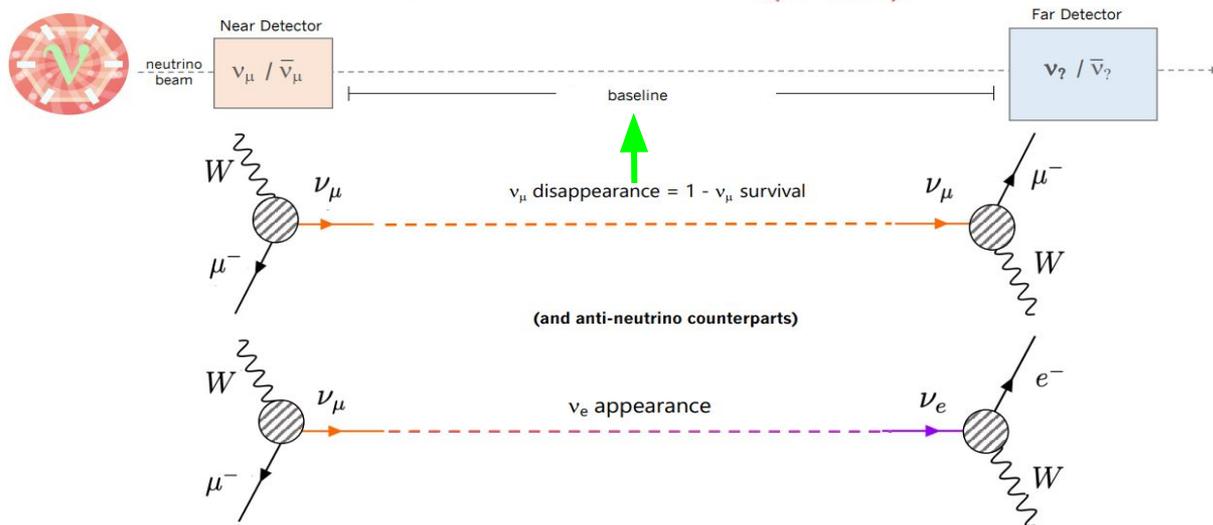
$$P_{e\mu}(L) = \sin^2 2\theta \sin^2 \left( \frac{\Delta m^2 L}{4E_\nu} \right)$$



# Reminder: Neutrino Oscillations

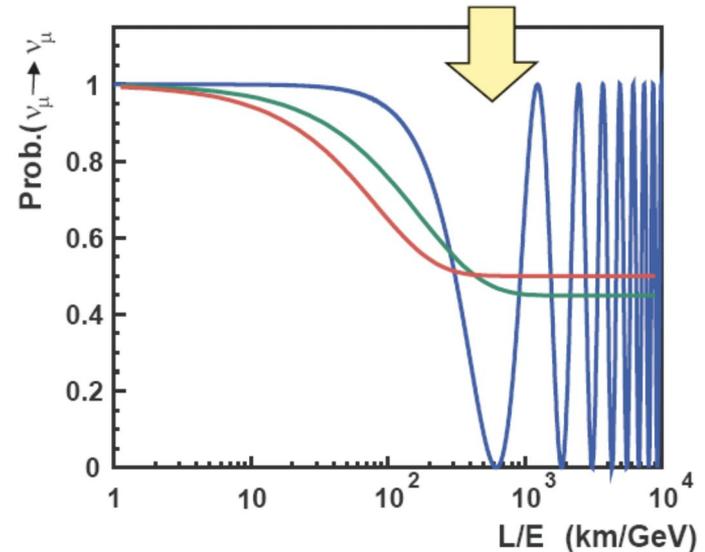
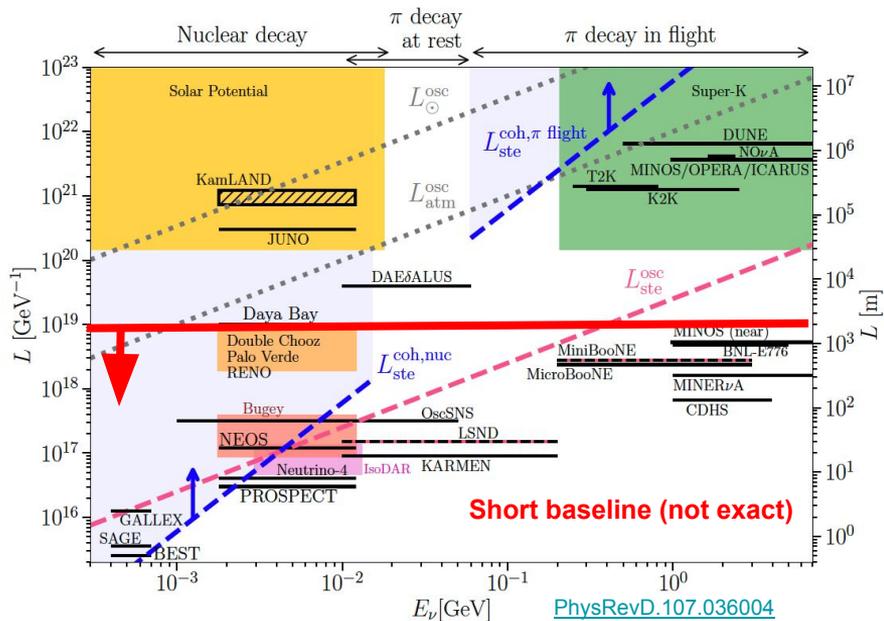
- Distance from initial measurement (“near detector”) to final measurement (“far detector”) over which the neutrino is allowed oscillate
- In equation:  $L =$  “baseline”

$$P_{e\mu}(L) = \sin^2 2\theta \sin^2 \left( \frac{\Delta m^2 L}{4E_\nu} \right)$$



# How do we define "short"?

- "Short-Baseline" = detectors close enough to the source that no (standard) oscillation has occurred yet
  - **small L/E**



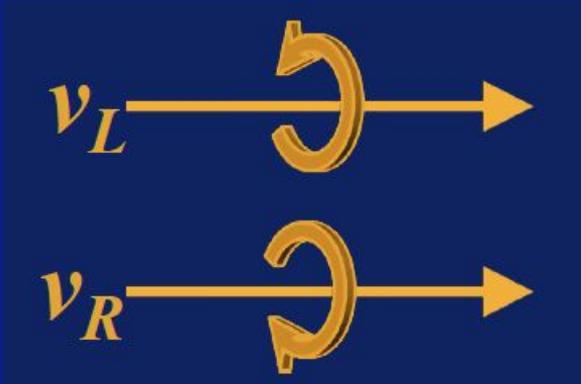
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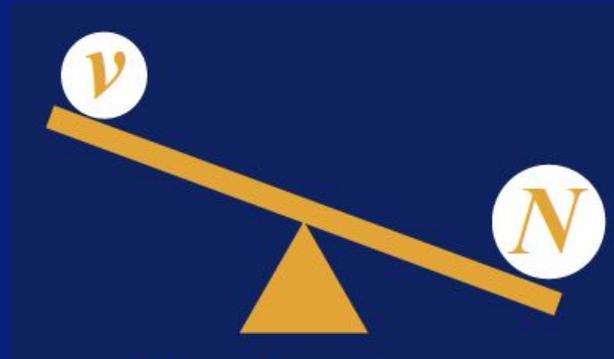
# The Puzzle of Neutrino Mass

Neutrino masses have a number of mysteries that short-baseline experiments can probe by searching for new neutrino states at different oscillation parameters

For neutrinos to gain mass from the same mechanism as all other particles they must have currently-unseen right-handed states



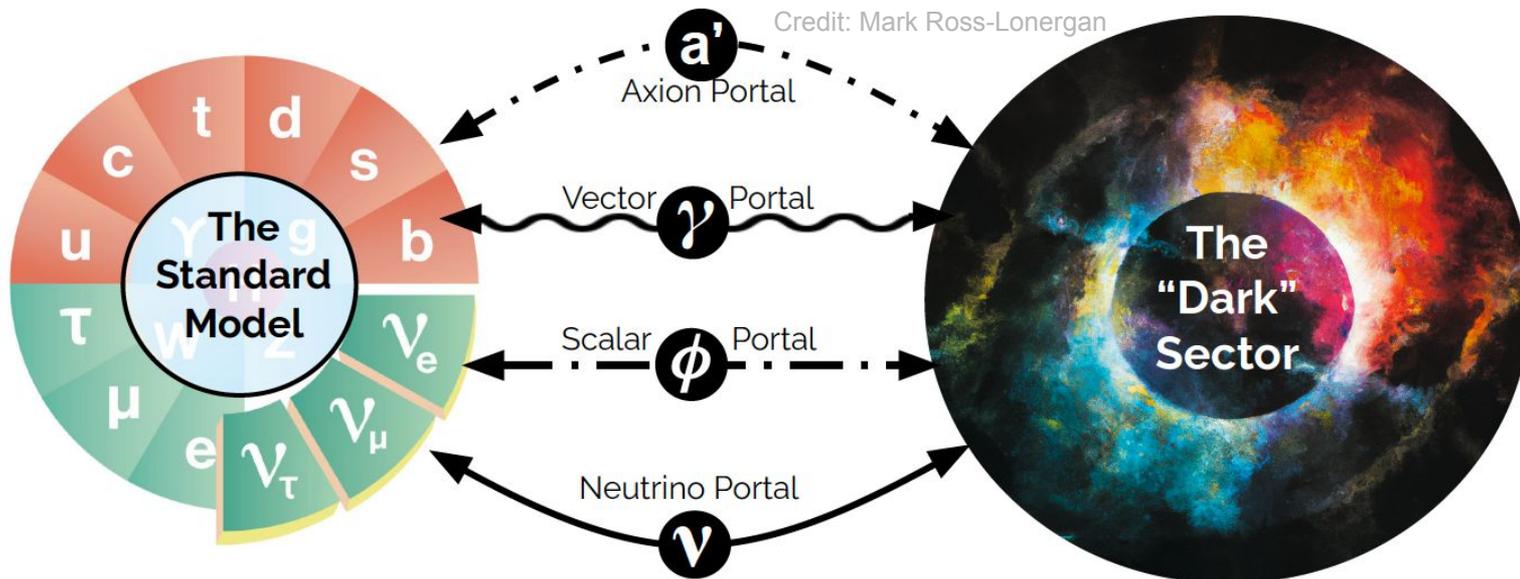
Neutrinos are unnaturally light. Implies they gain mass from an alternative system such as the proposed “see-saw” with currently-unseen large mass states



# Portals to Dark Sectors

Neutrinos can “mix” with dark matter through a number of “portals” that can be probed at short baselines

Credit: Mark Ross-Lonegan



**ν Neutrino Portal**

$$\mathcal{L} \supset -y^\alpha L_\alpha H N + \text{h.c.}$$

**φ Scalar Portal**

$$\mathcal{L} \supset (A S + \lambda S^2) H^\dagger H$$

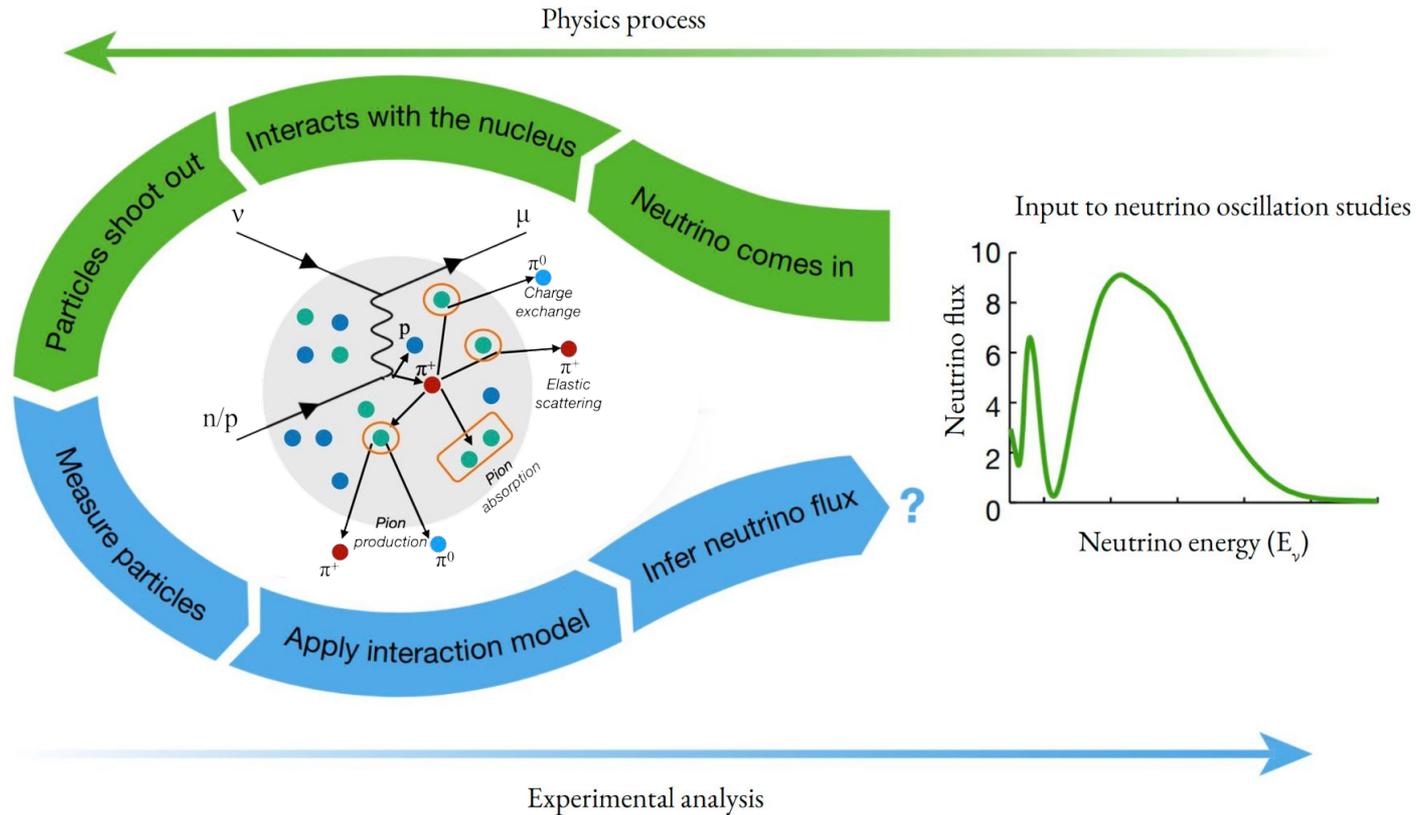
**γ Vector Portal**

$$\mathcal{L} \supset \epsilon F'_{\mu\nu} B^{\mu\nu}$$

**a' Axion Portal**

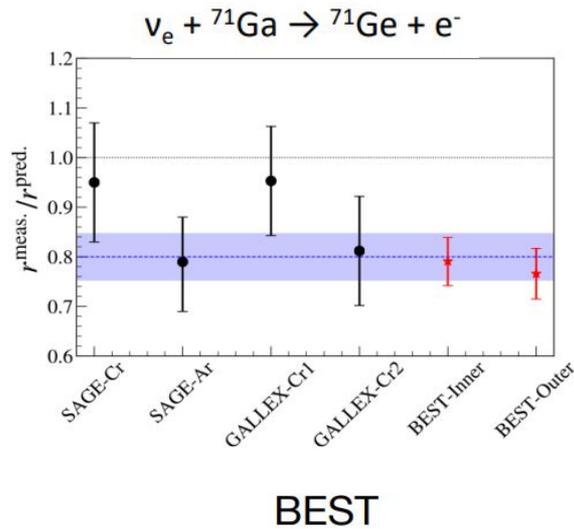
$$\mathcal{L} \supset c_{GG} \frac{\alpha_s a}{4\pi f} G_{\mu\nu}^a \tilde{G}^{a,\mu\nu}$$

# Neutrino-Nucleus Interactions

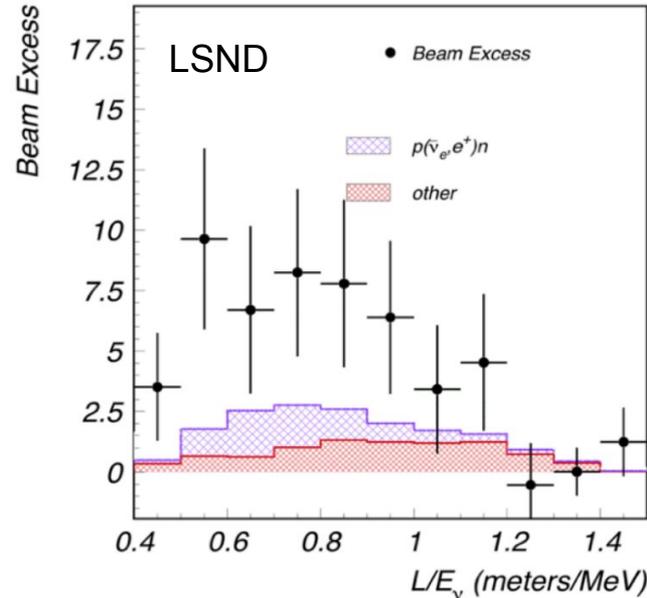


# Anomalies

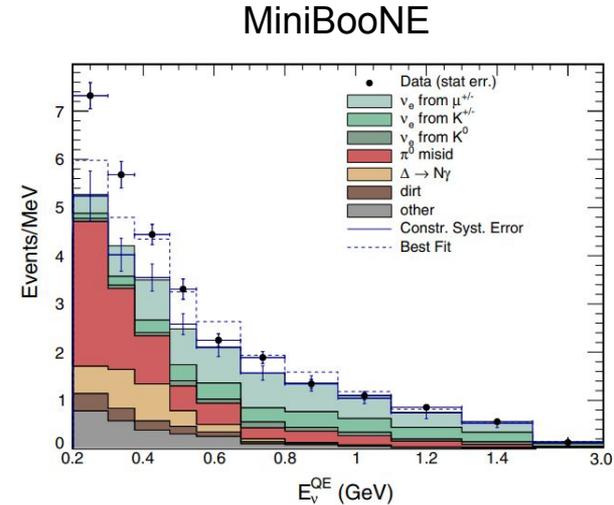
We've seen anomalies across a number of short-baseline experiments



[Phys. Rev. C 105, 065502 \(2022\)](#)



[Phys. Rev. Lett. 75, 2650 \(1995\)](#)



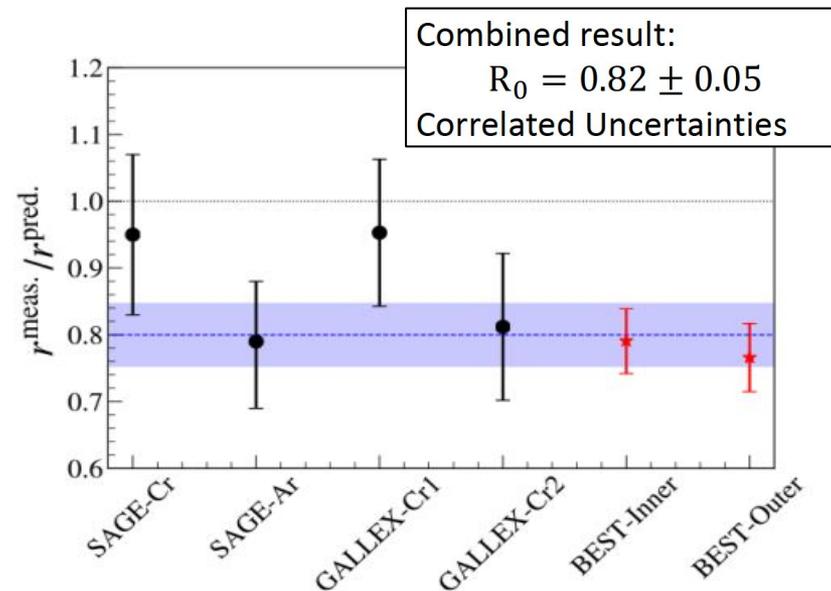
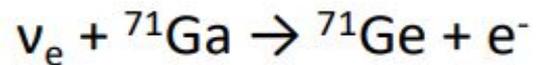
[Phys. Rev. D 103, 052002 \(2021\)](#)

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# Gallium Anomaly

Three gallium experiments see a ~20% deficit of  $^{71}\text{Ge}$  from  $\nu_e$



**BEST**

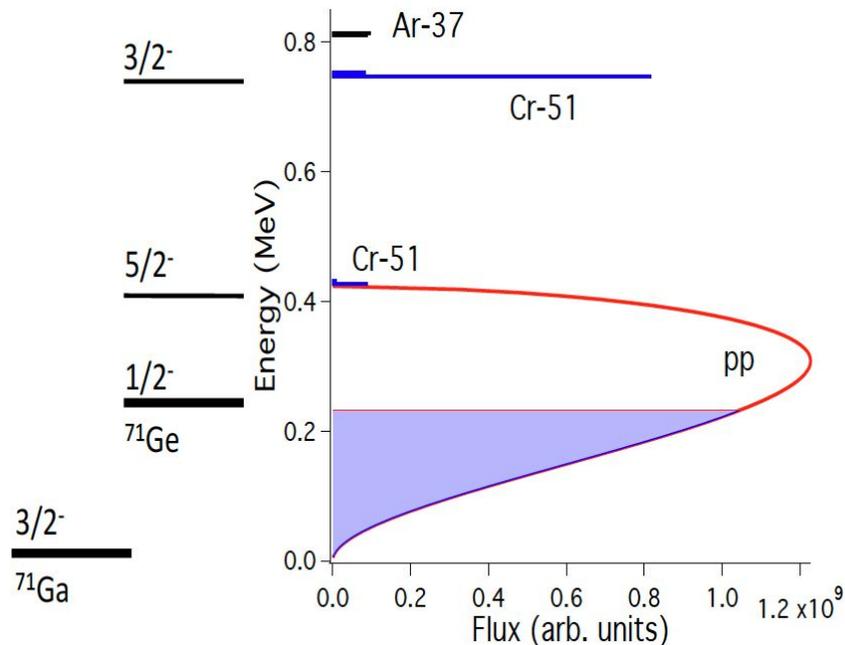
[Phys. Rev. C 105, 065502 \(2022\)](#)

# Gallium Anomaly

Three gallium experiments see a ~20% deficit of  $^{71}\text{Ge}$  from  $\nu_e$

Mid-1980s - Early 2000s:

- The Soviet-American Gallium Experiment (SAGE)
- The Gallium Experiment (GALLEX)
- Measure low-energy neutrinos from proton-proton fusion within the Sun using Ga as a target
- Well-predicted flux from the known solar luminosity



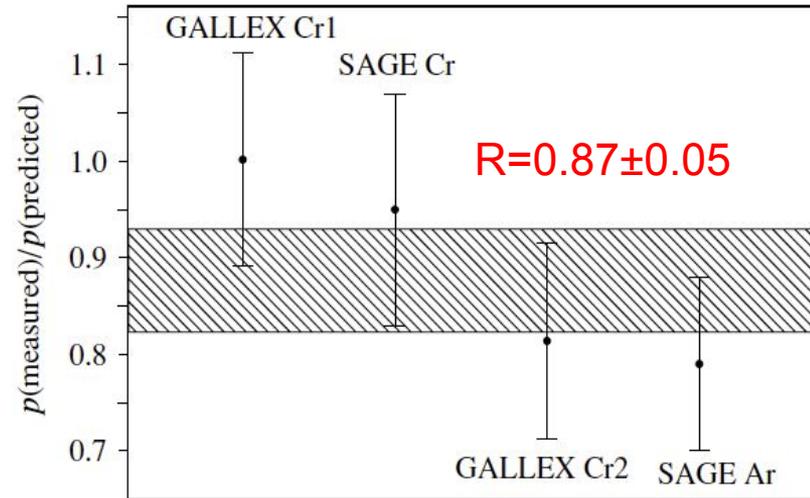
# Gallium Anomaly

Three gallium experiments see a ~20% deficit of  $^{71}\text{Ge}$  from  $\nu_e$

Mid-1980s - Early 2000s:

- See a 8-18% deficit of neutrinos.
- Statistics are limited and so results are somewhat inconclusive

[PRC 73 \(2006\) 045805](#), [PRC 80 \(2009\) 015807](#)

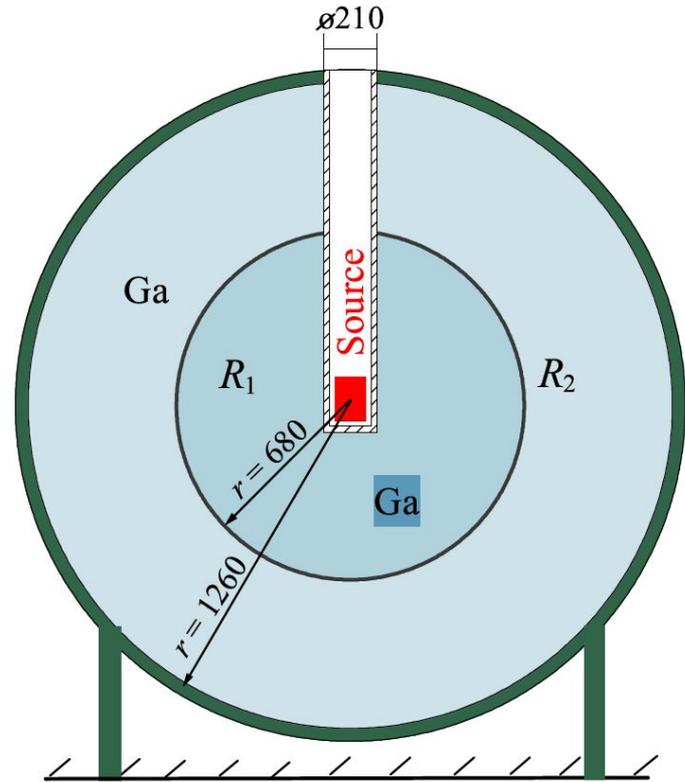
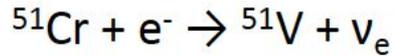


# Gallium Anomaly

Three gallium experiments see a ~20% deficit of  $^{71}\text{Ge}$  from  $\nu_e$

2011+:

- Baksan Experiment on Sterile Transitions (BEST) designed as a high-sensitivity test of the Ga anomaly
- Use Chromium neutrino source in center of Ga volume

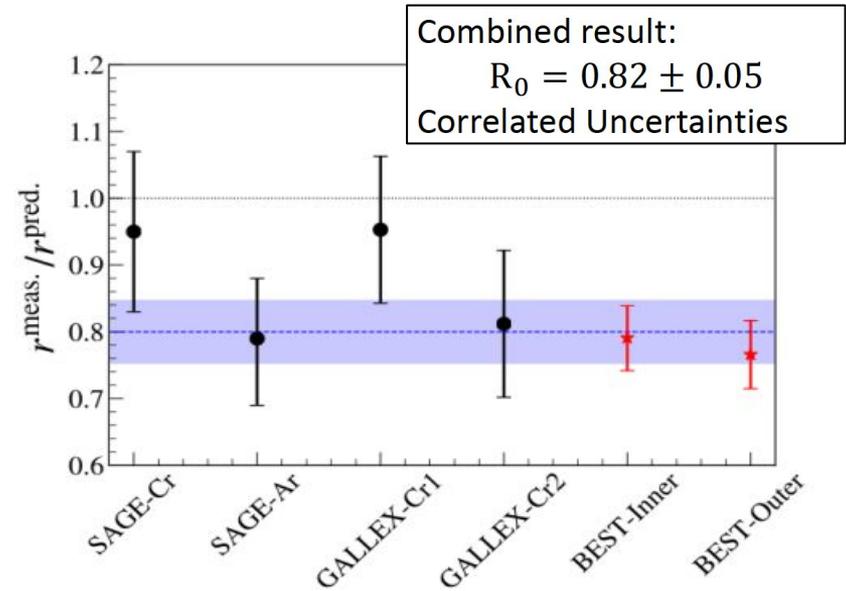


# Gallium Anomaly

Three gallium experiments see a ~20% deficit of  $^{71}\text{Ge}$  from  $\nu_e$

2011+:

- BEST results see ~20% deficit
- Higher statistical precision
- Reaffirm Ga anomaly is real
- Number of potential explanations but does not provide strong evidence for any one



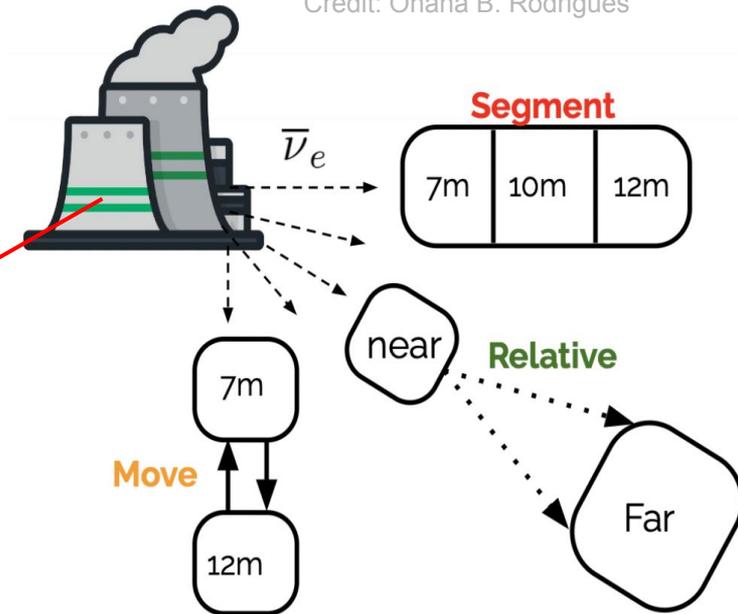
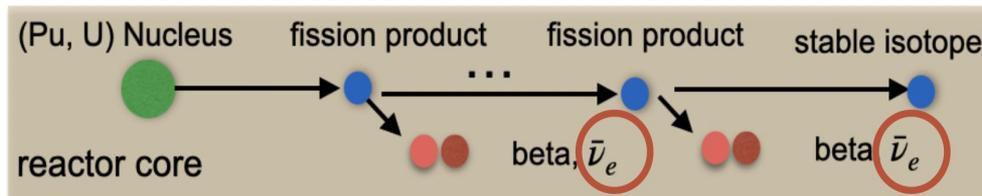
**BEST**

[Phys. Rev. C 105, 065502 \(2022\)](#)

# Reactor Anomaly

- Nuclear reactors create electron antineutrinos as part of the fission process
  - 99% produced by fission of  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{239}\text{Pu}$ ,  $^{241}\text{Pu}$
  - $\sim 6 \bar{\nu}_e$  per fission
- Can then use various methods to calculate  $\bar{\nu}_e$  rate at different baselines
- High flux, non-directed source at very short baselines

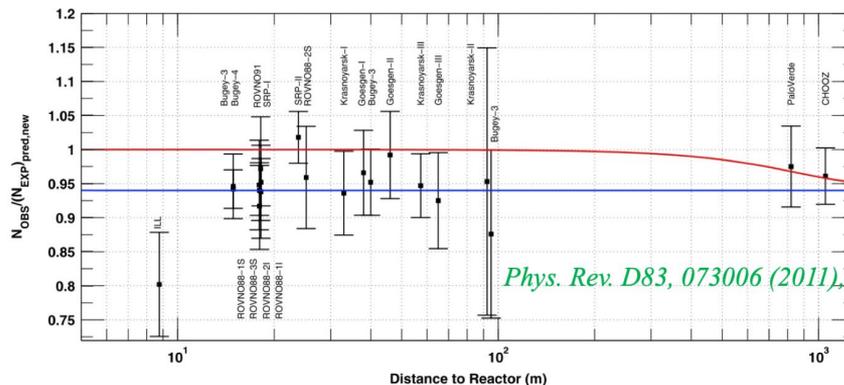
Credit: Ohana B. Rodrigues



# Reactor Anomaly

~2010s:

- Neutrino measurements at nuclear reactors showed a deficit of  $\bar{\nu}_e \rightarrow \nu_e$  events
- Continued measurements and reevaluation of modeling lead to increasingly better data-MC agreement
- The deficit is now almost entirely gone, largely not considered “anomalous” anymore



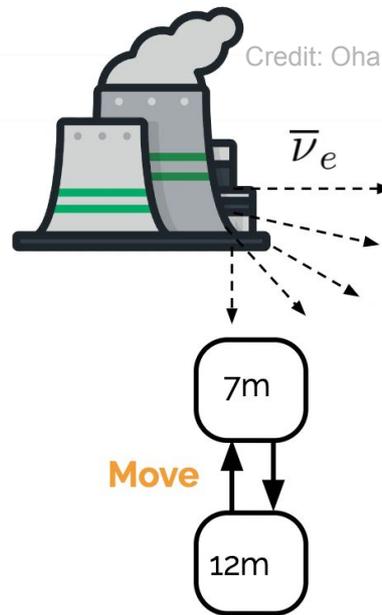
$\sim 1\sigma$

mean averaged ratio:  
 $\bar{R} = 0.943 \pm 0.024$

- Huber-Mueller model [Phys. Rev. C 83, 054615 \(2011\)](#), [Phys. Rev. C 85, 029901 \(2012\)](#)
- Estienne-Fallot summation model [Phys. Rev. Lett. 123, no. 2, 022502 \(2019\)](#)
- Hayen-Kostensalo-Severijns-Suhonen model [Phys. Rev. C 100, 054323 \(2019\)](#)
- Recent Kurchatov Institute measurements [arXiv:2103.01684](#)

# Reactor Anomaly: Neutrino-4

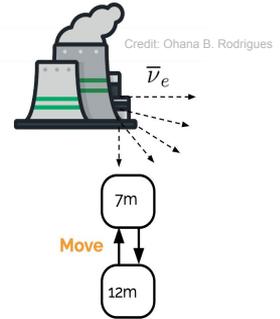
- However, one anomalous reactor signal still remains
- Neutrino-4
  - 100 MWth commercial reactor in Russia
  - 334 days reactor on data
  - Movable between two baselines



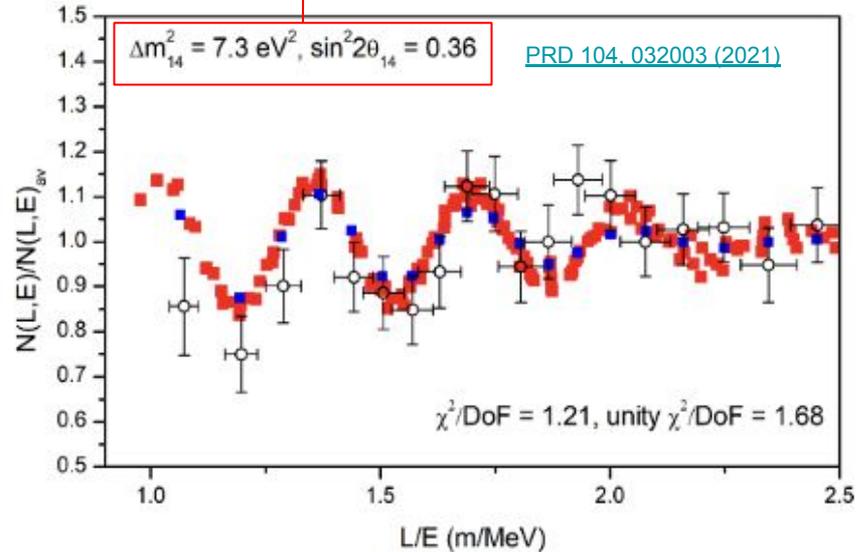
Credit: Ohana B. Rodrigues

# Reactor Anomaly: Neutrino-4

- However, one anomalous reactor signal still remains
- Neutrino-4
  - 100 MWth commercial reactor in Russia
  - 334 days reactor on data
  - Movable between two baselines
- In 2021, claimed to have seen non-zero oscillation signal at  $\sim 2.9\sigma$



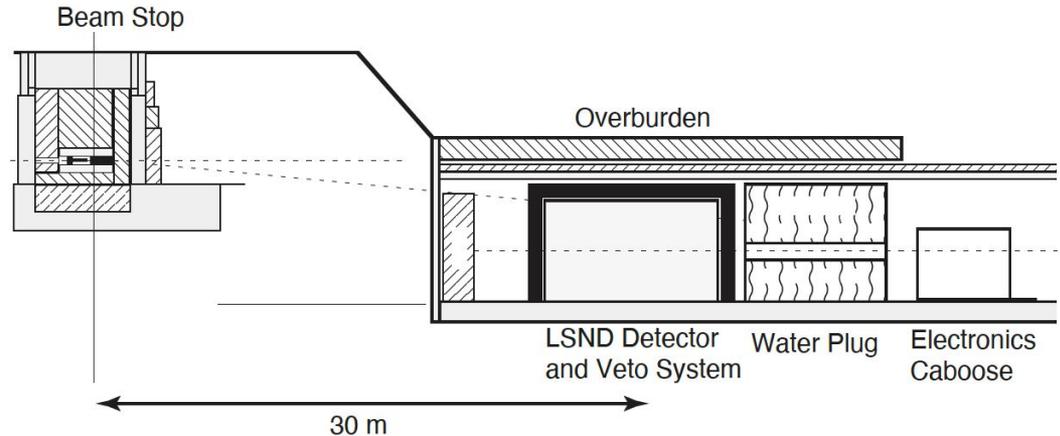
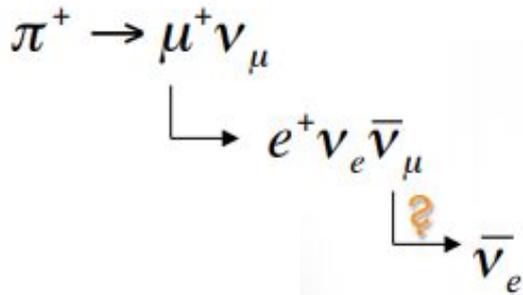
Not near any of the standard neutrino oscillation parameters



# LSND Appearance Signal

1995 - 2001:

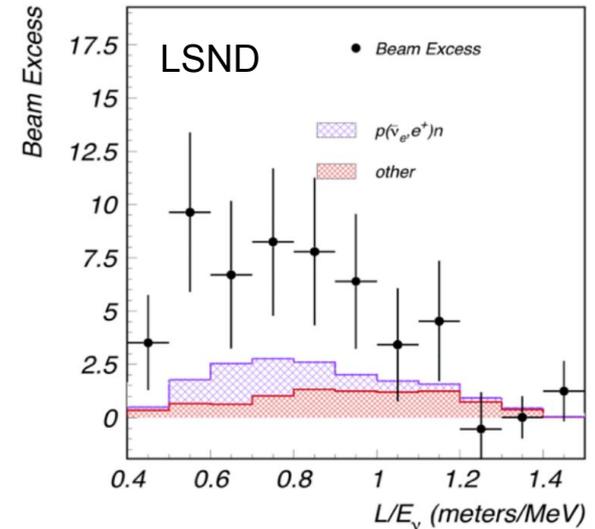
- Liquid Scintillator Neutrino Detector (LSND) at Los Alamos National Laboratory
- $\mu^+$  decay-at-rest experiment
- Looking at  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$  oscillation events



# LSND Appearance Signal

## 1995 - 2001:

- Saw an excess of  $87.9 \pm 22.4 \pm 6.0$   $\bar{\nu}_e p \rightarrow e^+ n$  events
- Energies of  $\sim 50$  MeV
  - $L/E \sim 0.5 - 1$  m/MeV
- Suggests a neutrino mass  $> 0.4$  eV/c<sup>2</sup>
  - Much higher than currently known limits!
- Limited statistics required follow-up studies

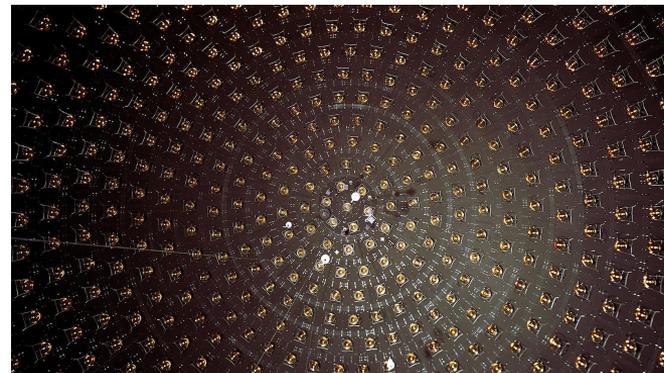


[PRL 75, 2650 \(1995\)](#), [PRL 81, 1774 \(1998\)](#), [PRD 64, 112007 \(2001\)](#)

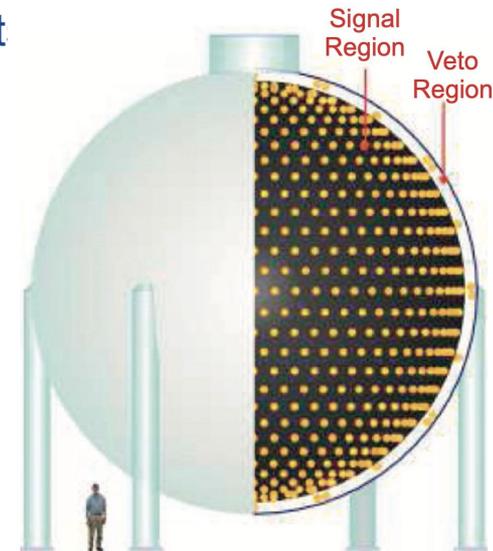
# MiniBooNE Low Energy Excess (LEE) Anomaly

**2002 - 2021:**

- Mini Booster Neutrino Experiment (MiniBooNE)
- Mineral-oil cherenkov neutrino detector built to test LSND result



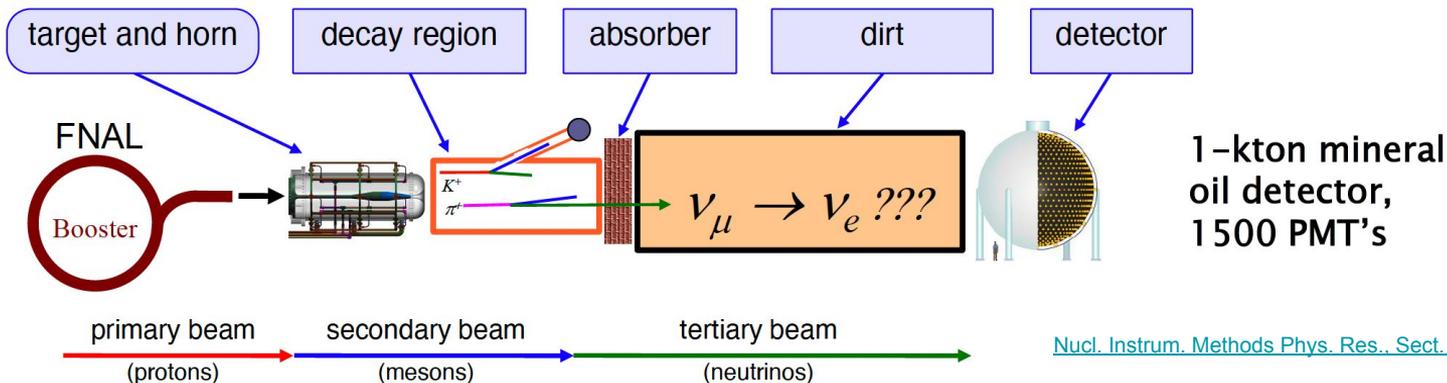
[MiniBooNE the band meets MiniBooNE the experiment](#)



# MiniBooNE Low Energy Excess (LEE) Anomaly

- MiniBooNE located on the Booster Neutrino Beam (BNB) at Fermilab
  - peaks at around 700 MeV neutrino energy
- 540m downstream of neutrino production target
- Higher energy + longer baseline + different detector technology = sensitive to same range of  $L/E$  ( $\sim 1$   $eV^2$ ) as LSND but has very different backgrounds

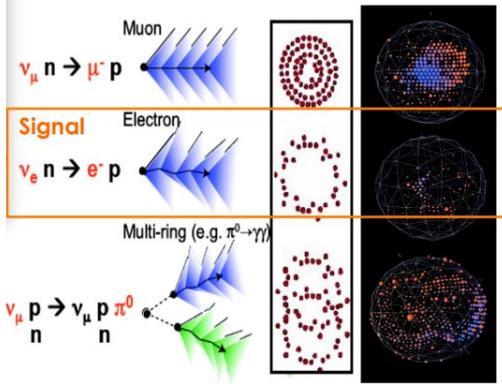
LSND:  $E \sim 30$  MeV       $L \sim 30$  m       $L/E \sim 1$   
 MiniBooNE:  $E \sim 500$  MeV       $L \sim 500$  m       $L/E \sim 1$



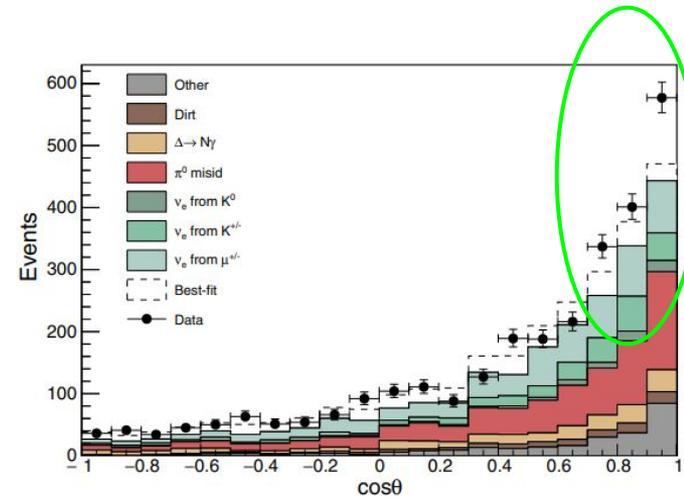
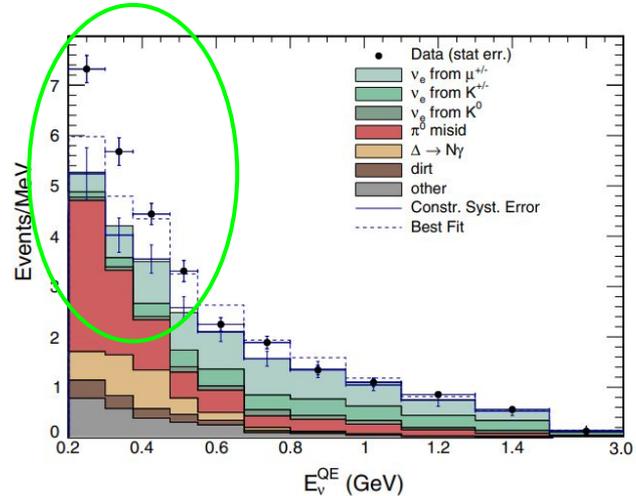
# MiniBooNE Low Energy Excess (LEE) Anomaly

- With data collected from 2002 to 2019, sees a  $4.8\sigma$  excess of  $\nu_e$  candidate events
- neutrino energies of about 200-800 MeV
- ~forward-going angles
- Consistent with LSND under multiple possible explanations

Three main event signatures:



Cherenkov ring topology provides PID

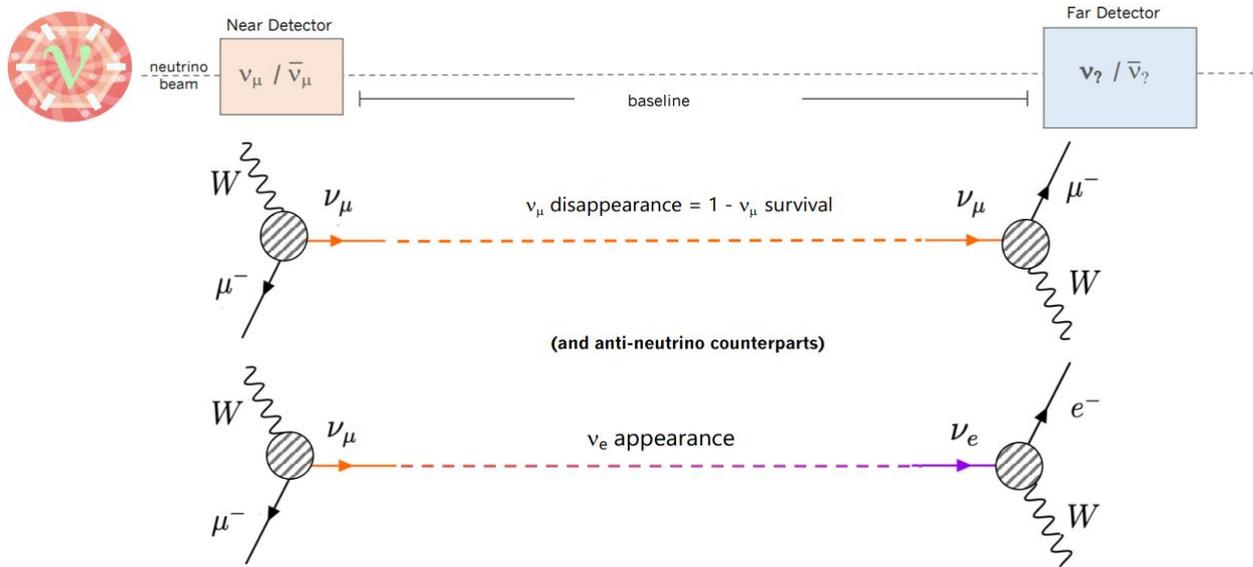


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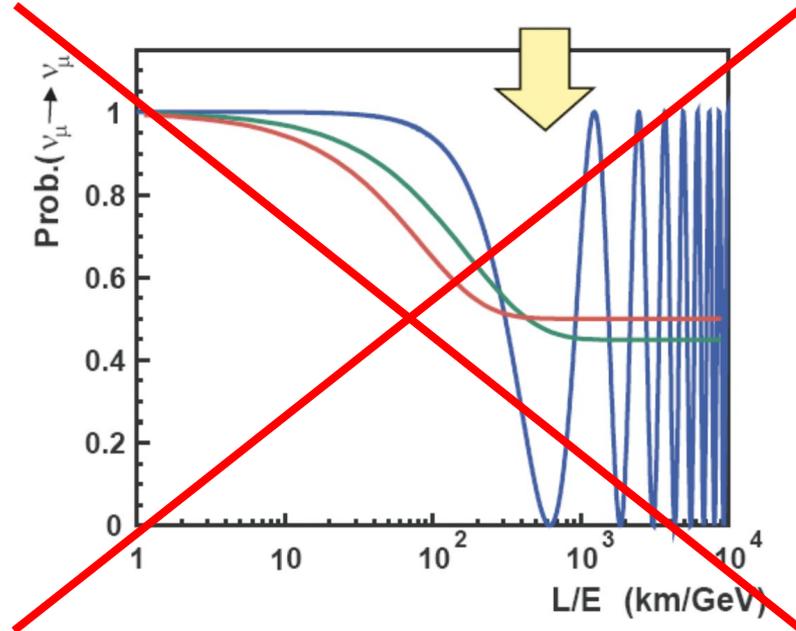
# Sterile Neutrinos?

- What if these anomalies truly come from neutrino oscillations?
  - Gallium: electron neutrino disappearance
  - LSND and MiniBooNE: electron neutrino appearance
  - Neutrino-4: Oscillatory signal



# Sterile Neutrinos?

- But it's **short-baseline** → No standard oscillations!



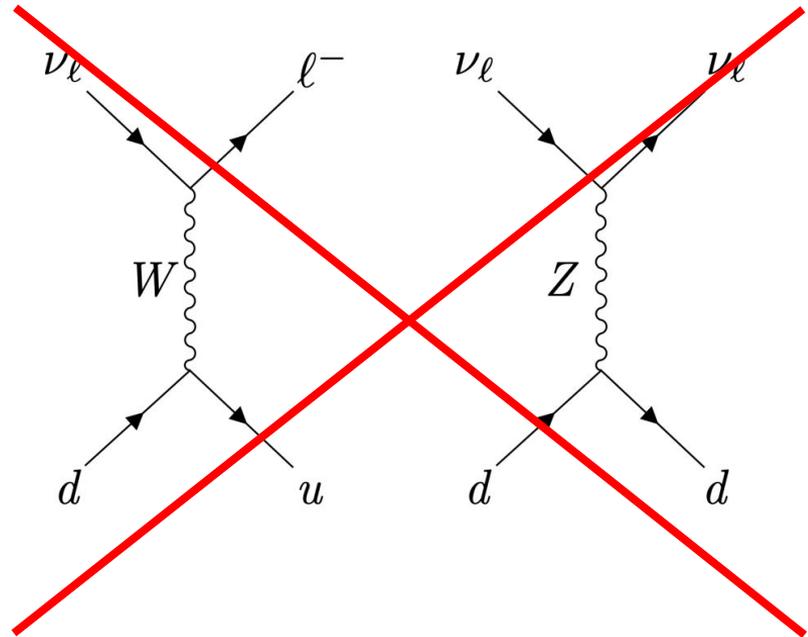
# Sterile Neutrinos?

- But it's **short-baseline** → No standard oscillations!
- Requires the existence of a **4th neutrino**

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{pmatrix}$$

# Sterile Neutrino Model

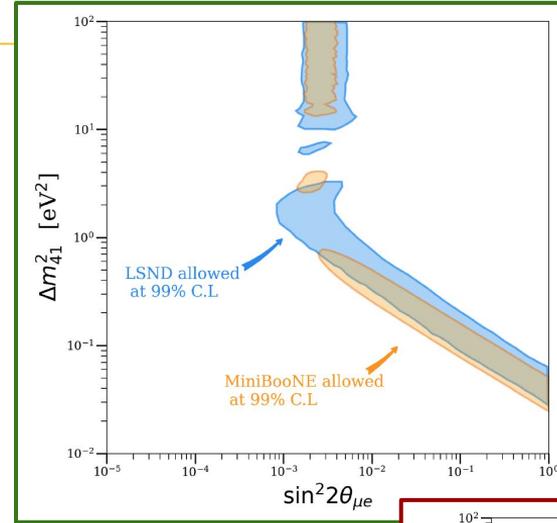
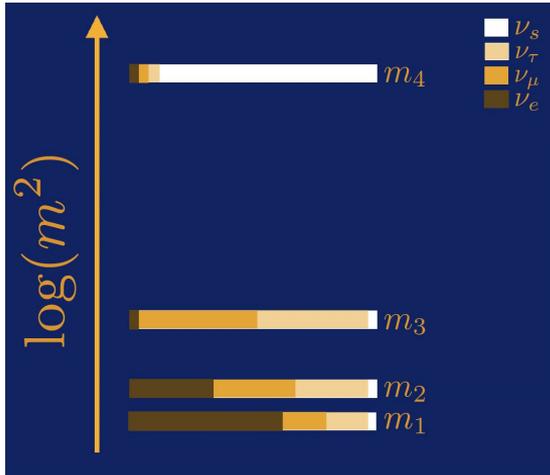
- New neutrino means **never detected before**
- We detect neutrinos through their weak interactions
- New neutrino must be **sterile**
- **Sterile:** No electric charge, no color charge, **no weak interactions**
- Only detection possible is through oscillation to one of the 3 known flavors



# Sterile Neutrino Model

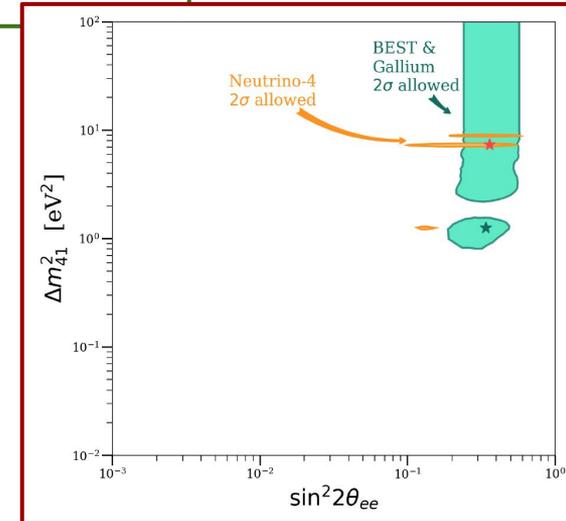
- Evaluate anomalies under the sterile neutrino hypothesis
- All give  $\Delta m^2 \sim O(1\text{eV}^2)$

$$P_{e\mu}(L) = \sin^2 2\theta \sin^2 \left( \frac{\Delta m^2 L}{4E_\nu} \right)$$



$\nu_e$  appearance

$\nu_e$  disappearance



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# Not Sterile Neutrinos?

All anomalies are *consistent* with a sterile neutrino hypothesis but none provide a “smoking gun” result:

# Not Sterile Neutrinos?

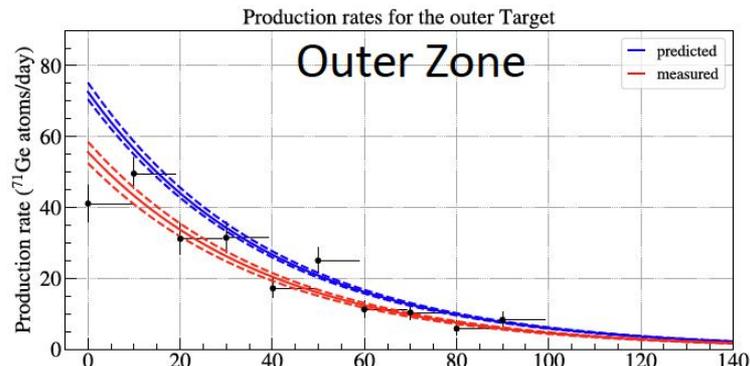
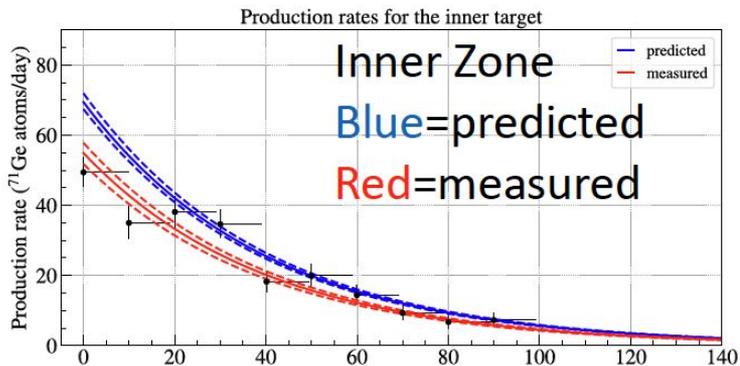
All anomalies are *consistent* with a sterile neutrino hypothesis but none provide a “smoking gun” result:

- BEST does not see any dependence on oscillation length

Note:  $\frac{0.77 \pm 0.05}{0.79 \pm 0.05} = 0.97 \pm 0.07$

Similar deficits observed in both zones

[Phys. Rev. C 105, 065502 \(2022\)](#)



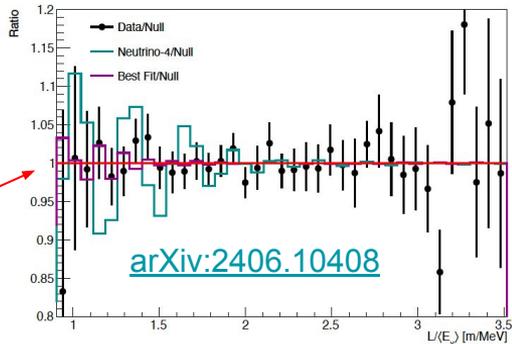
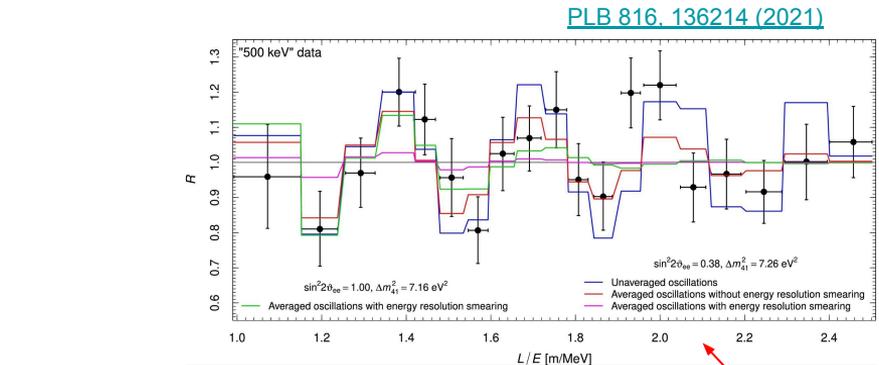
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- Neutrino-4 methodologies have been questioned and other reactors see no similar signal

See also:  
[arXiv:2006.13147](https://arxiv.org/abs/2006.13147)

Inadequate statistical approach?

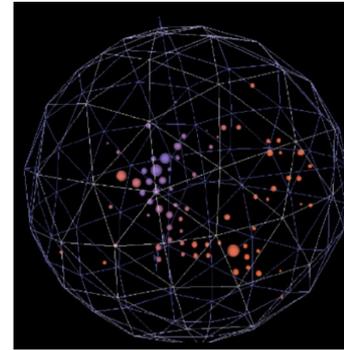


Incorrect inclusion of detector effects and backgrounds?

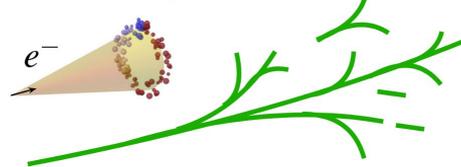
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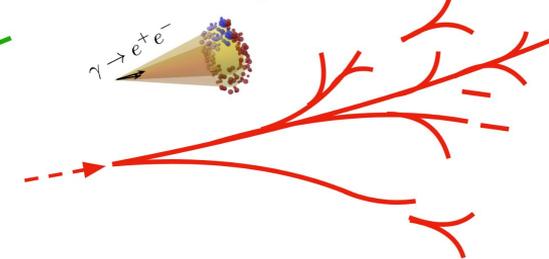
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**Electron Shower**



**Photon Shower**



# Not Sterile Neutrinos?

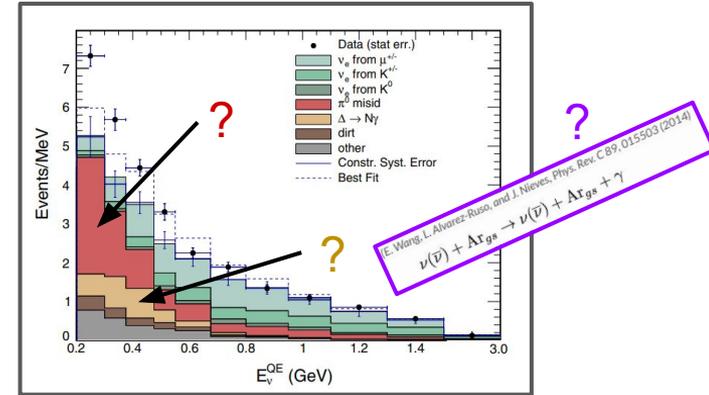
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- Neutrino-4 methodologies have been questioned and other reactors see no similar signal
- MiniBooNE’s LEE has ambiguity in its source

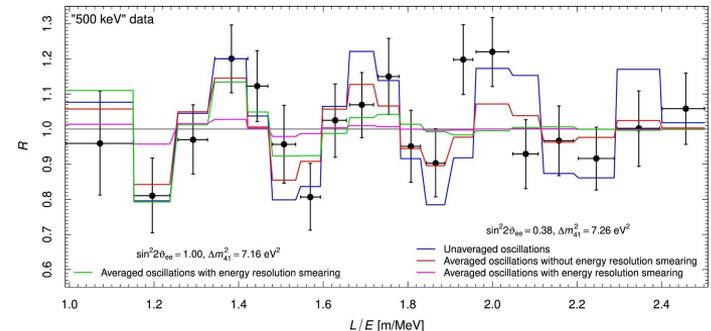
**So what else could these be?**

# Not New Physics At All?

- Backgrounds could be modelled incorrectly
  - Data has no new physics, we just predicted incorrectly
- Input could be wrong
  - Predicted neutrino flux could be off from real source
- Methodology could be flawed
  - Efficiencies miscalculated
  - Incorrect statistical treatment of data
  - Detector effects not accounted for
- All experiments claim to have corrected or checked for these. And many do new studies when a concern is raised. But something could always slip past.



PLB 816, 136214 (2021)



# Other New Physics

New models come out to explain one or more of these anomalies all the time

Snowmass White Paper on Light Sterile Neutrinos  
[J. Phys. G: Nucl. Part. Phys. 51 120501 \(2024\)](#)

Category	Model	Signature	Anomalies				References
			LSND	MiniBooNE	Reactors	Sources	
Flavor transitions Secs. 3.1.1-3.1.3, 3.1.5	(3+1) oscillations	oscillations	✓	✓	✓	✓	Reviews and global fits [93, 103, 105, 106] [151, 155]
	(3+1) w/ invisible sterile decay	oscillations w/ $\nu_4$ invisible decay	✓	✓	✓	✓	
	(3+1) w/ sterile decay	$\nu_4 \rightarrow \phi\nu_e$	✓	✓	✓	✓	[159–162, 270]
Matter effects Secs. 3.1.4, 3.1.7	(3+1) w/ anomalous matter effects	$\nu_\mu \rightarrow \nu_e$ via matter effects	✓	✓	✗	✗	[143, 147, 271–273]
	(3+1) w/ quasi-sterile neutrinos	$\nu_\mu \rightarrow \nu_e$ w/ resonant $\nu_4$ matter effects	✓	✓	✓	✓	[148]
Flavor violation Sec. 3.1.6	Lepton-flavor-violating $\mu$ decays	$\mu^+ \rightarrow e^+ \nu_n \bar{\nu}_e$	✓	✗	✗	✗	[174, 175, 274]
	neutrino-flavor-changing bremsstrahlung	$\nu_\mu A \rightarrow e \phi A$	✓	✓	✗	✗	[275]
Decays in flight Sec. 3.2.3	Transition magnetic mom., heavy $\nu$ decay	$N \rightarrow \nu\gamma$	✗	✓	✗	✗	[207]
	Dark sector heavy neutrino decay	$N \rightarrow \nu(X \rightarrow e^+e^-)$ or $N \rightarrow \nu(X \rightarrow \gamma\gamma)$	✗	✓	✗	✗	[208]
Neutrino Scattering Secs. 3.2.1, 3.2.2	neutrino-induced upscattering	$\nu A \rightarrow NA$ , $N \rightarrow \nu e^+e^-$ or $N \rightarrow \nu\gamma\gamma$	✓	✓	✗	✗	[205, 206, 209–216]
	neutrino dipole upscattering	$\nu A \rightarrow NA$ , $N \rightarrow \nu\gamma$	✓	✓	✗	✗	[40, 185, 187, 188, 190, 193, 233, 276]
Dark Matter Scattering Sec. 3.2.4	dark particle-induced upscattering	$\gamma$ or $e^+e^-$	✗	✓	✗	✗	[217]
	dark particle-induced inverse Primakoff	$\gamma$	✓	✓	✗	✗	[217]

## New Physics Explanations of the MiniBooNE Excess

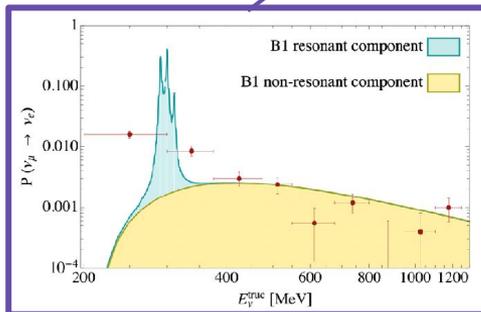
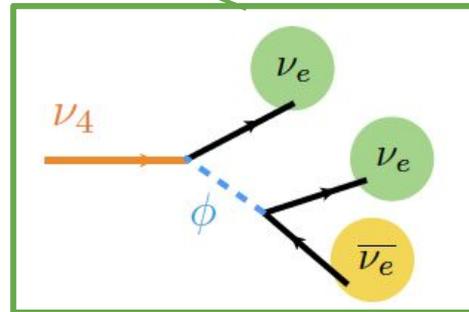
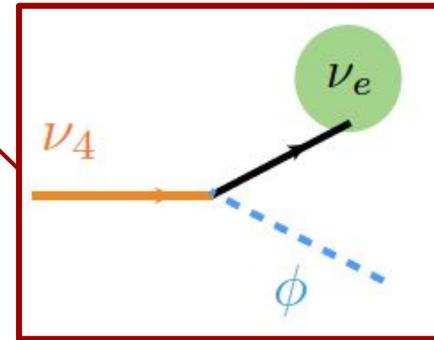
Category	Model	Final state	LEE signal properties			LSND	References
			energy dist.	angular dist.	timing		
Flavor transitions	SBL oscillations	$e^-$	✓	✓	✓	✓	Reviews and global fits [22–24, 56, 57]
	SBL oscillations with invisible sterile decay	$e^-$	✓	✓	✓	✓	[58, 59]
	SBL oscillations with anomalous matter effects	$e^-$	✓	✓	✓	✓	[60–65]
	neutrino-flavor-changing bremsstrahlung	$e^-$	✓	–	✓	✓	[66]
Decays in flight	SBL oscillations with visible sterile decay	$e^-$	✓	✓	✓	✓	[67–71]
	heavy neutrino decay	$\gamma, \gamma\gamma$ $e^+e^-$	✓	✗	✗	✗	[72, 73]
Scattering	neutrino-induced upscattering	$\gamma, \gamma\gamma$ $e^+e^-$	✓	✗ (vector) ✓ (scalar) ✓ (TMM)	✓	✗ (vector) ✓ (scalar) ✓ (TMM)	vector [36–41] scalar [42–44] TMM [74–84]
	dark particle-induced upscattering	$\gamma, \gamma\gamma$ $e^+e^-$	✓	model dependent	✓	✗	[85]

# Variations on Sterile Neutrinos

Snowmass White Paper on Light Sterile Neutrinos  
[J. Phys. G: Nucl. Part. Phys. 51 120501 \(2024\)](#)

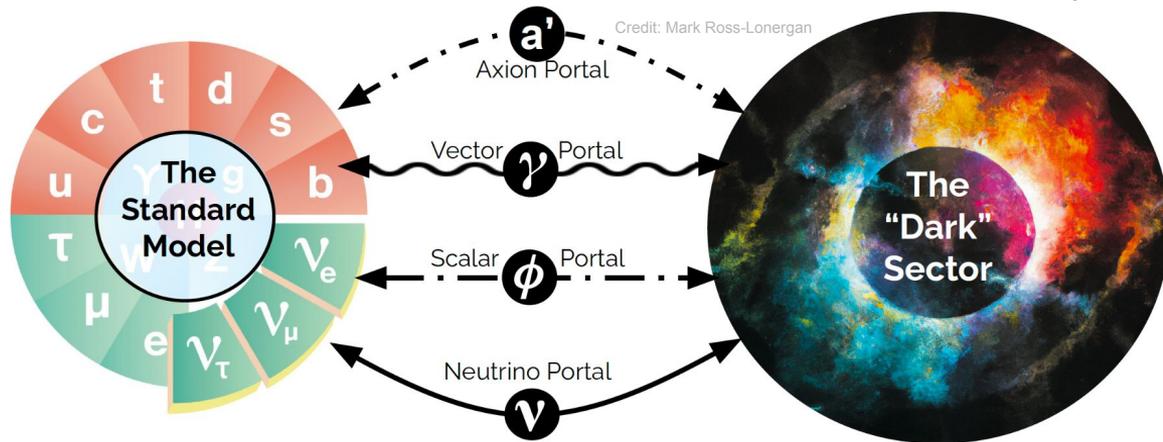
Category	Model	Signature	Anomalies				References
			LSND	MiniBooNE	Reactors	Sources	
Flavor transitions Secs. 3.1.1-3.1.3, 3.1.5	(3+1) oscillations	oscillations	✓	✓	✓	✓	Reviews and global fits [93, 103, 105, 106] [151, 155]
	(3+1) w/ invisible sterile decay	oscillations w/ $\nu_4$ invisible decay	✓	✓	✓	✓	
	(3+1) w/ sterile decay	$\nu_4 \rightarrow \phi \nu_e$	✓	✓	✓	✓	[159–162, 270]
Matter effects Secs. 3.1.4, 3.1.7	(3+1) w/ anomalous matter effects	$\nu_\mu \rightarrow \nu_e$ via matter effects	✓	✓	✗	✗	[143, 147, 271–273]
	(3+1) w/ quasi-sterile neutrinos	$\nu_\mu \rightarrow \nu_e$ w/ resonant $\nu_s$ matter effects	✓	✓	✓	✓	[148]

“Vanilla” 3+1 model not the only version of a sterile neutrino possible



# Dark Sector Portals

Dark matter candidates are common. Even sterile neutrinos count (neutrino portal).



**$\nu$  Neutrino Portal**  
 $\mathcal{L} \supset -y^\alpha L_\alpha H N + \text{h.c.}$

- Light 3+1 sterile Neutrino
- Heavy Neutral Leptons

**$\phi$  Scalar Portal**  
 $\mathcal{L} \supset (A S + \lambda S^2) H^\dagger H$

- Higgs Portal Scalars

**$\gamma$  Vector Portal**  
 $\mathcal{L} \supset \epsilon F'_{\mu\nu} B^{\mu\nu}$

- Light Dark Matter
- Millicharged Particles

**$a'$  Axion Portal**  
 $\mathcal{L} \supset c_{GG} \frac{\alpha_s}{4\pi} \frac{a}{f} G_{\mu\nu}^a \tilde{G}^{a, \mu\nu}$

- Heavy QCD Axions

**$\nu \gamma$  Combined and Non-Minimal Portals**

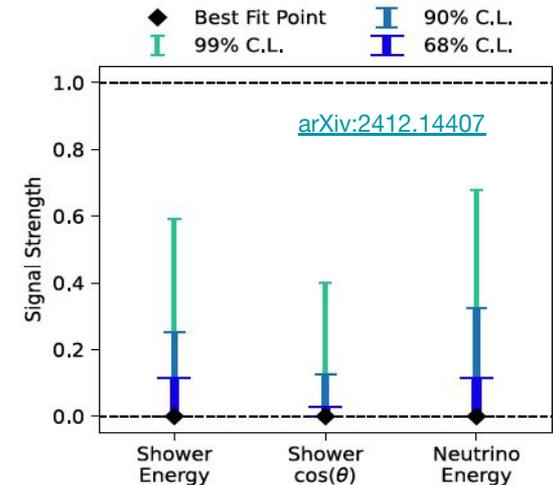
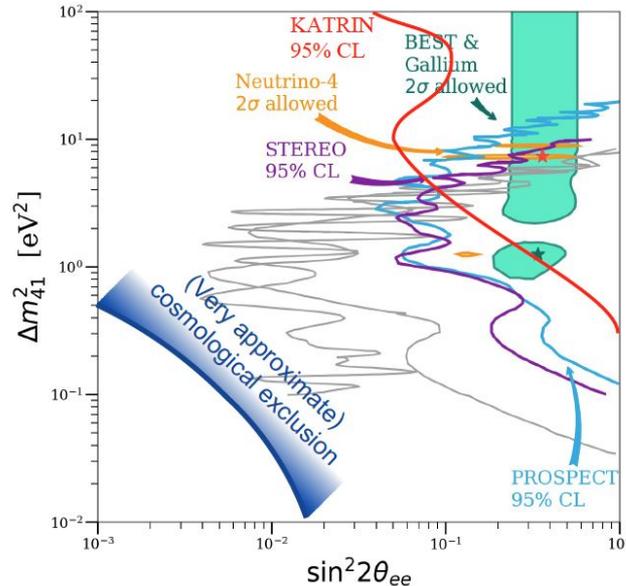
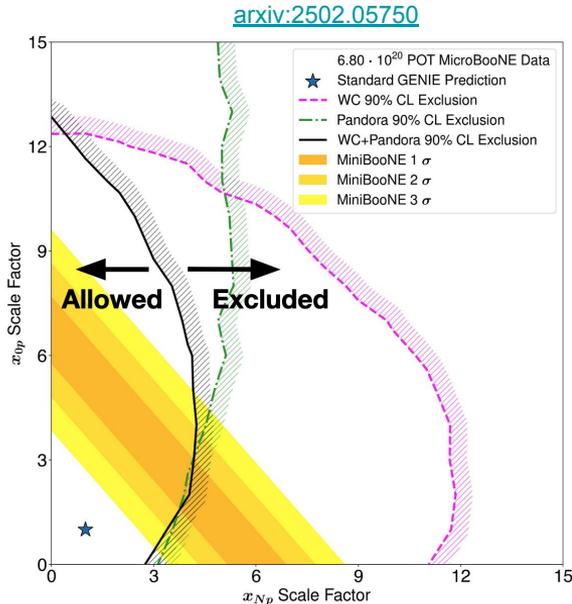
Just a few examples.  
Many more models to investigate!

# Outline

1. What does “short-baseline” mean?
2. Why study neutrinos over short baselines?
3. Anomalies
  - a. Sterile neutrinos
  - b. Other possibilities
4. **Current short-baseline experiments**
  - a. **Addressing the Anomalies**
  - b. Outside the Anomalies
5. The future for short-baseline

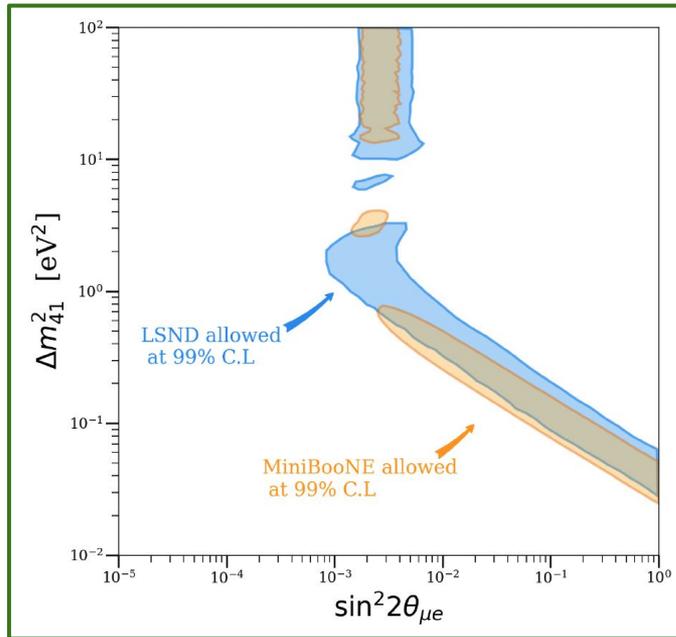
# Addressing the Anomalies

A number of new short-baseline experiments have done follow-up searches for explanations to the anomalies

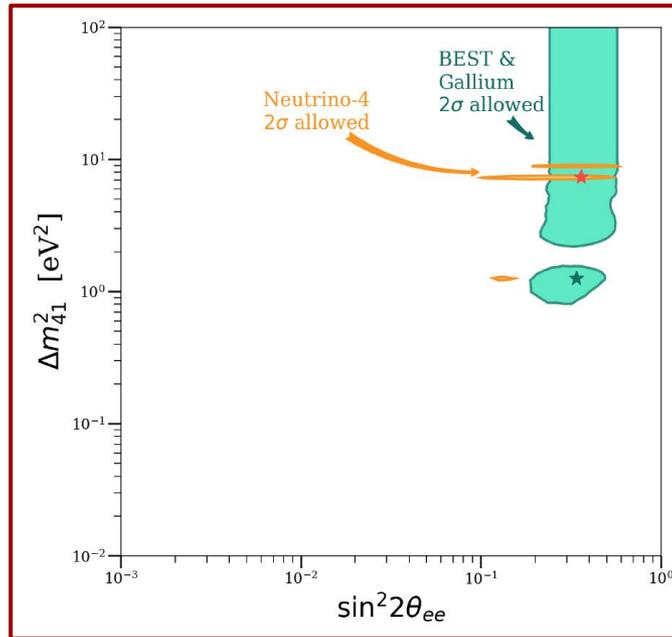


# Putting Limits on Sterile Neutrinos

$\nu_e$  appearance



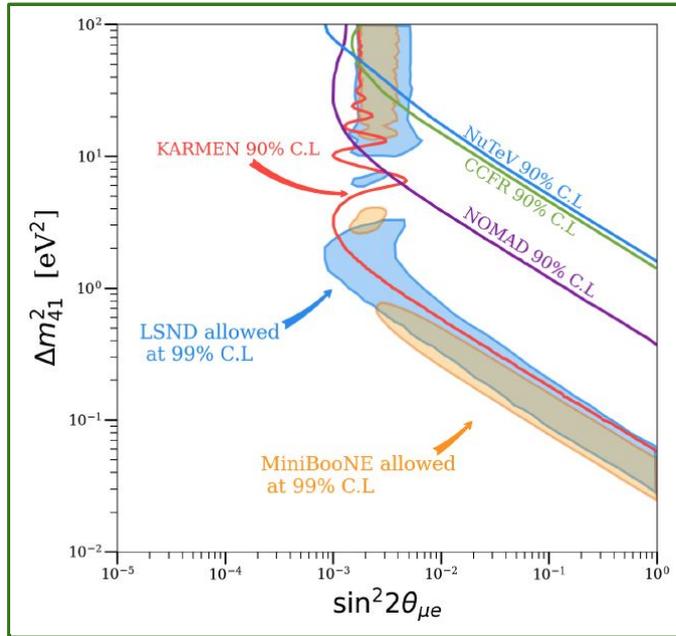
$\nu_e$  disappearance



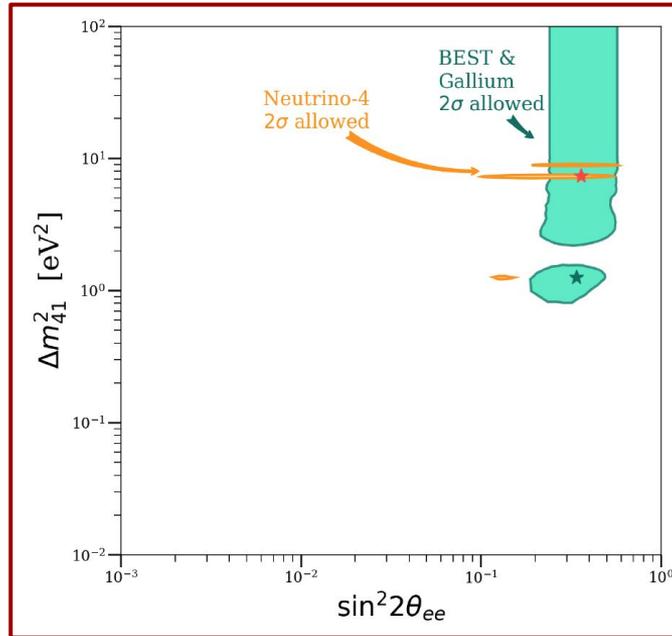
More experiments have done sterile oscillation searches to try to narrow down this phase-space

# Putting Limits on Sterile Neutrinos

$\nu_e$  appearance



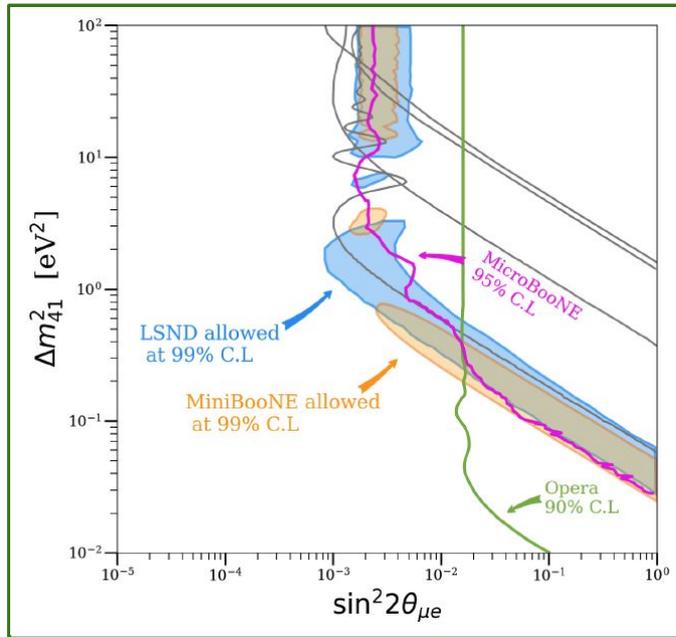
$\nu_e$  disappearance



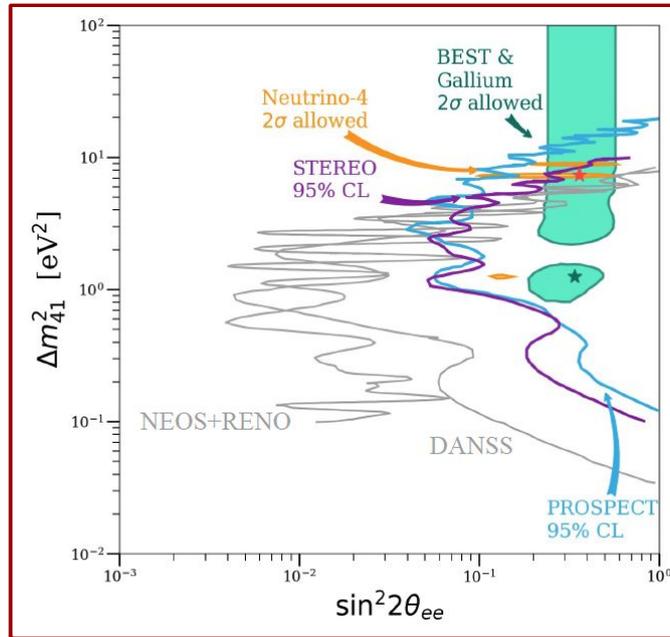
- **KARMEN**  
[PRD 65, 112001 \(2002\)](https://arxiv.org/abs/hep-ex/0106033)
- **CCFR**  
[PRL 52, 1384 \(1984\)](https://arxiv.org/abs/hep-ex/9303023)
- **NuTeV**  
[PRL 89, 011804 \(2002\)](https://arxiv.org/abs/hep-ex/0106033)
- **NOMAD**  
[PLB 570, 19 \(2003\)](https://arxiv.org/abs/hep-ex/0206012)

# Putting Limits on Sterile Neutrinos

$\nu_e$  appearance



$\nu_e$  disappearance



## Appearance Exclusions

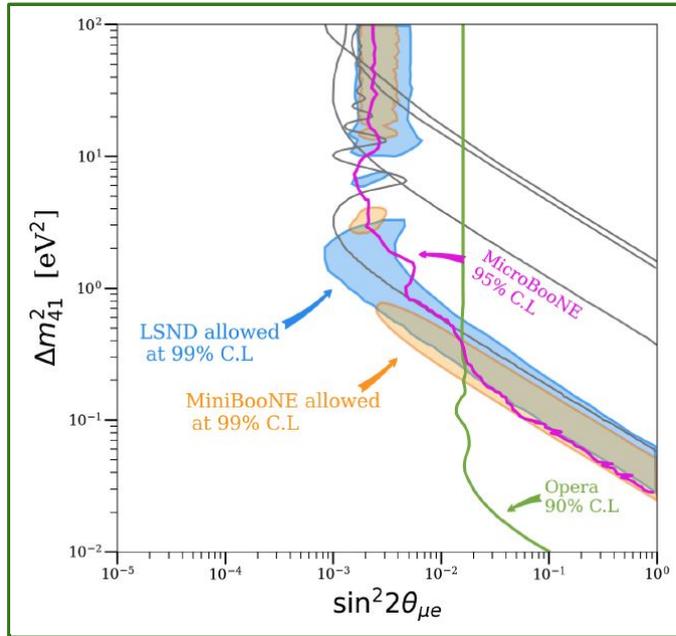
- OPERA  
[PRD 100. 051301 \(2019\)](#)
- MicroBooNE  
[PRL 130. 011801 \(2023\)](#)

## Disappearance Exclusions

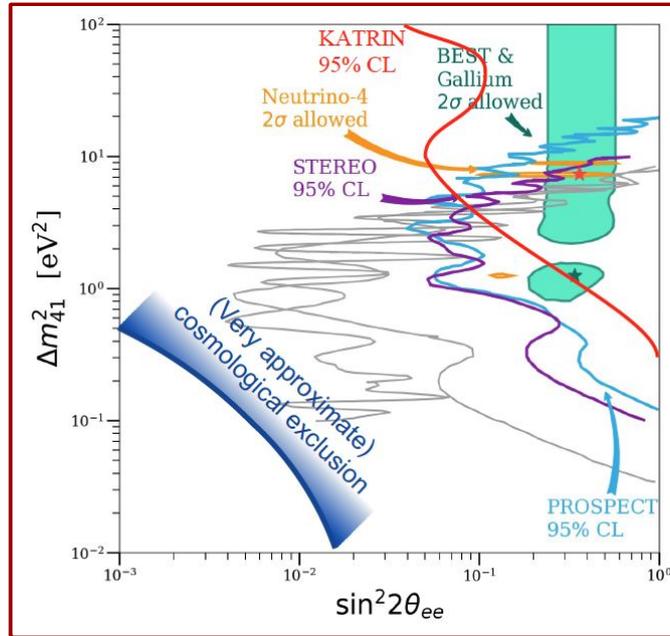
- STEREO  
[Nature 613. 257 \(2023\)](#)
- PROSPECT  
[PRL 134. 151802 \(2025\)](#)
- DANSS  
[PLB 787. 56 \(2018\)](#)
- NEOS+RENO  
[PRD 105. L111101 \(2022\)](#)

# Putting Limits on Sterile Neutrinos

$\nu_e$  appearance



$\nu_e$  disappearance



## Appearance Exclusions

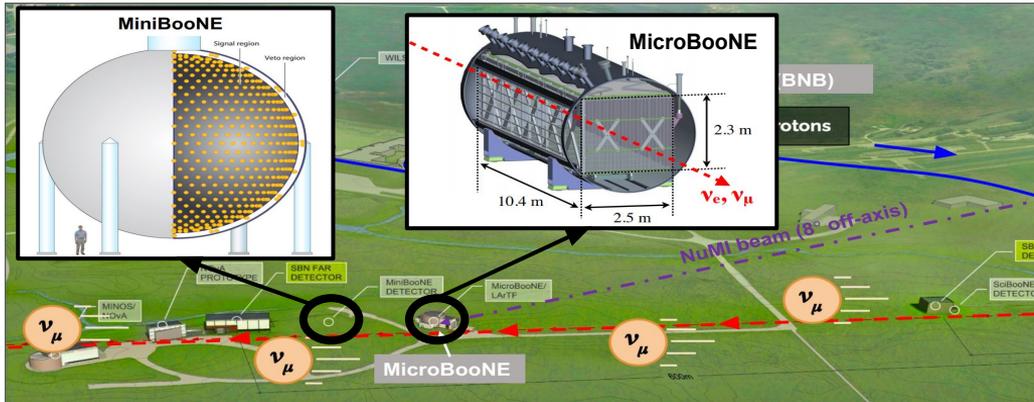
- OPERA  
[PRD 100.051301 \(2019\)](#)
- MicroBooNE  
[PRL 130.011801 \(2023\)](#)

## Disappearance Exclusions

- STEREO  
[Nature 613.257 \(2023\)](#)
- PROSPECT  
[PRL 134.151802 \(2025\)](#)
- DANSS  
[PLB 787.56 \(2018\)](#)
- NEOS+RENO  
[PRD 105.L111101 \(2022\)](#)
- KATRIN  
Tritium  $\beta$  endpoint  
[arXiv:/2503.18667](#)
- Cosmology  
 $\Lambda$ CDM  
[PRD 104.123524 \(2021\)](#)

# MicroBooNE

- MicroBooNE is a surface-level, 85 tonne Liquid Argon Time Projection Chamber (LArTPC) neutrino experiment
- Sits only 70 m away from MiniBooNE on the BNB
- Collected data 2015 - 2021
  - ~0.5M neutrino events
- Now decommissioned
- Primary design goal is to understand the LEE anomaly seen by MiniBooNE



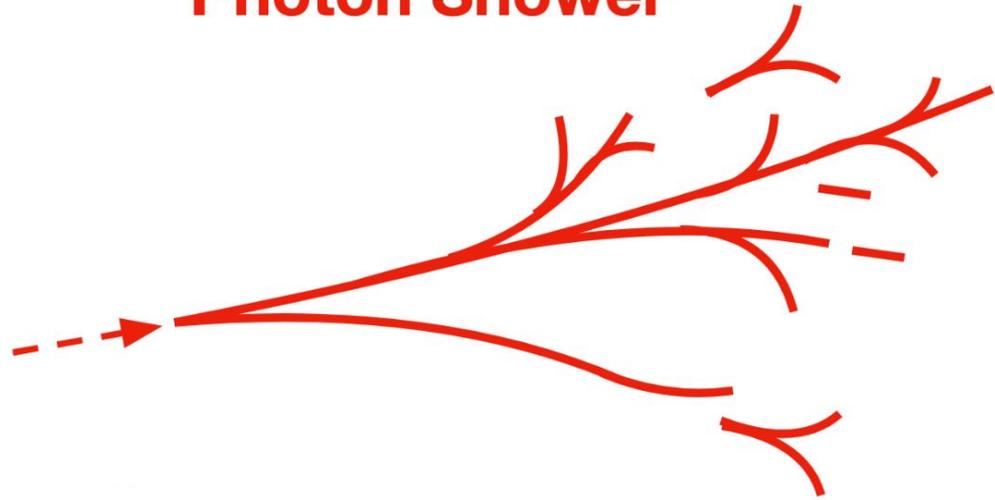
# MiniBooNE LEE Ambiguity

- Electromagnetic showers come from a cascade of gamma rays, electrons, and positrons
- These cascades can be started by an electron/positron directly, or when a photon pair produces ( $\gamma \rightarrow e^+e^-$ )

## Electron Shower

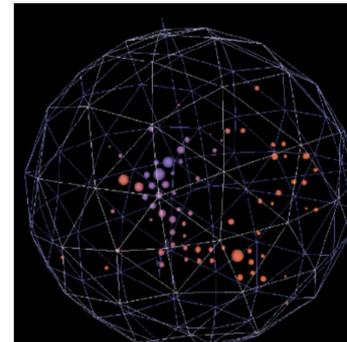


## Photon Shower



# MiniBooNE LEE Ambiguity

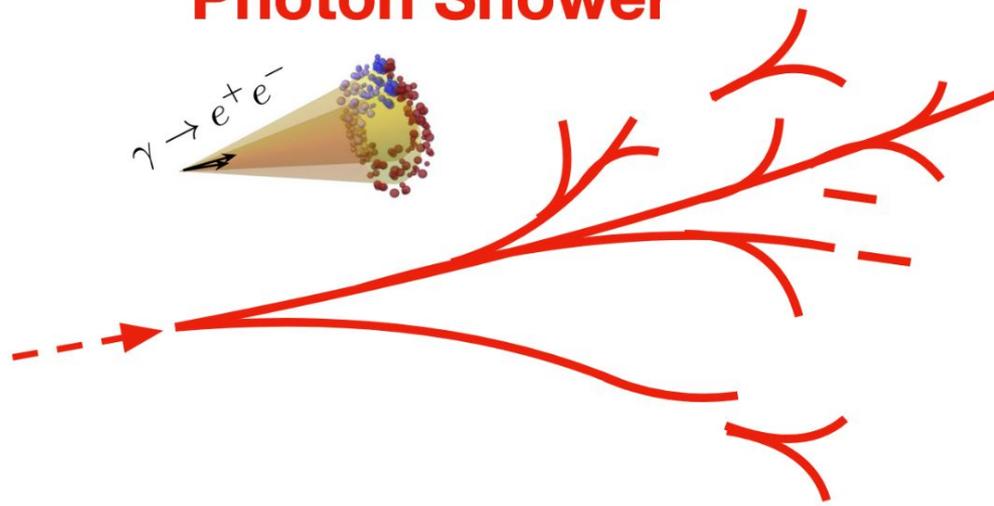
- MiniBooNE sees Cherenkov light from many small segments of an electromagnetic shower
- These combine to give MiniBooNE a “fuzzy ring” in either case



## Electron Shower

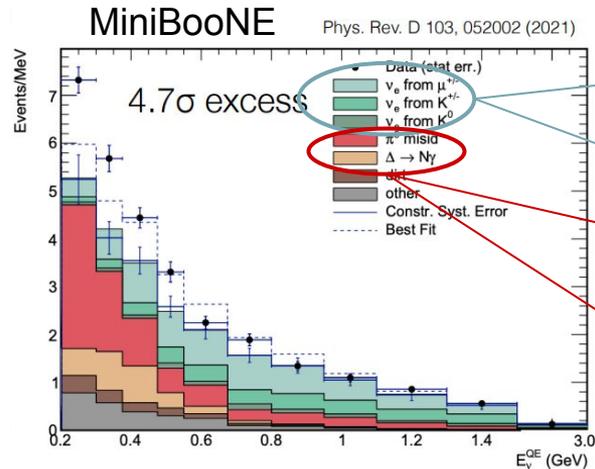


## Photon Shower

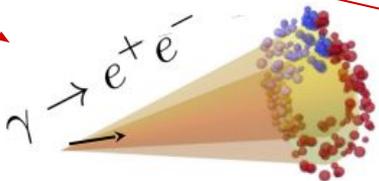
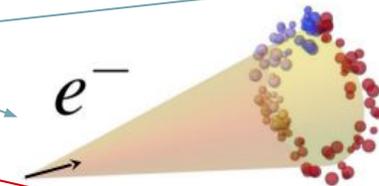


# Testing the MiniBooNE LEE with MicroBooNE

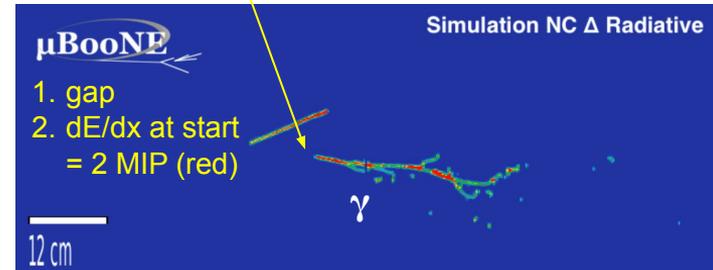
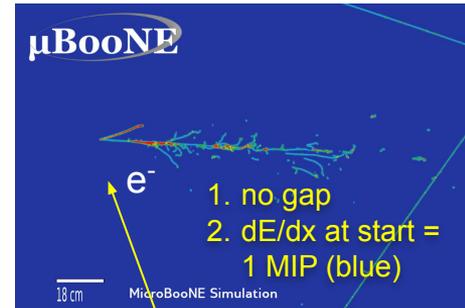
MicroBooNE LArTPC can distinguish  $e^-$  and  $\gamma$ , allowing to probe into the nature of the excess.



MiniBooNE

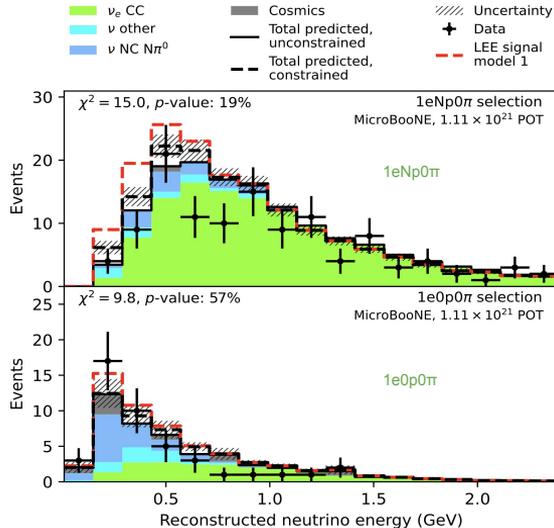


MicroBooNE

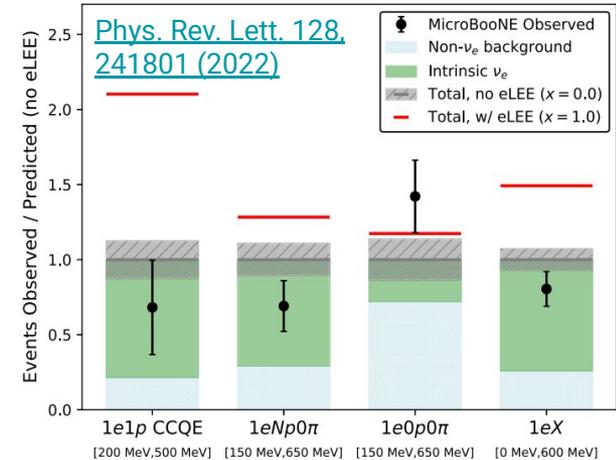
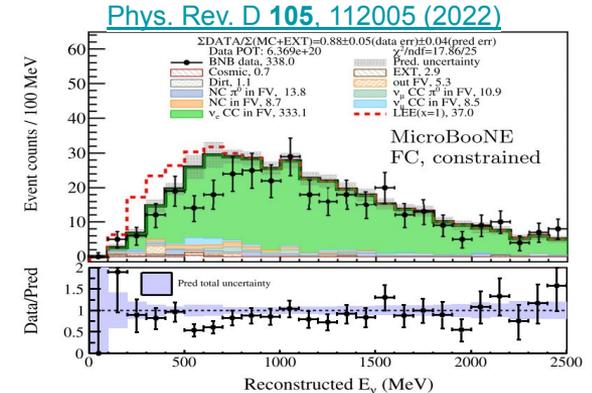
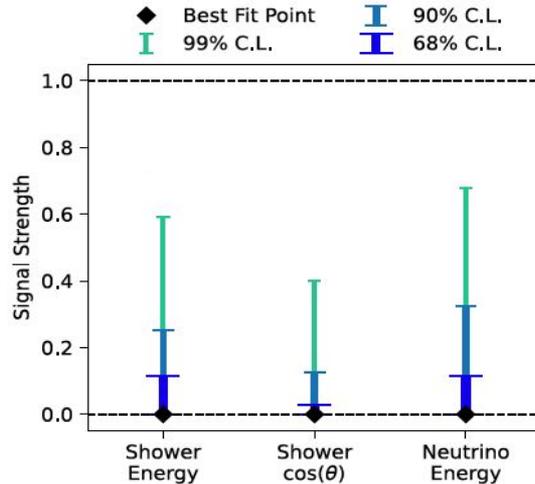


# MicroBooNE's Electron Searches

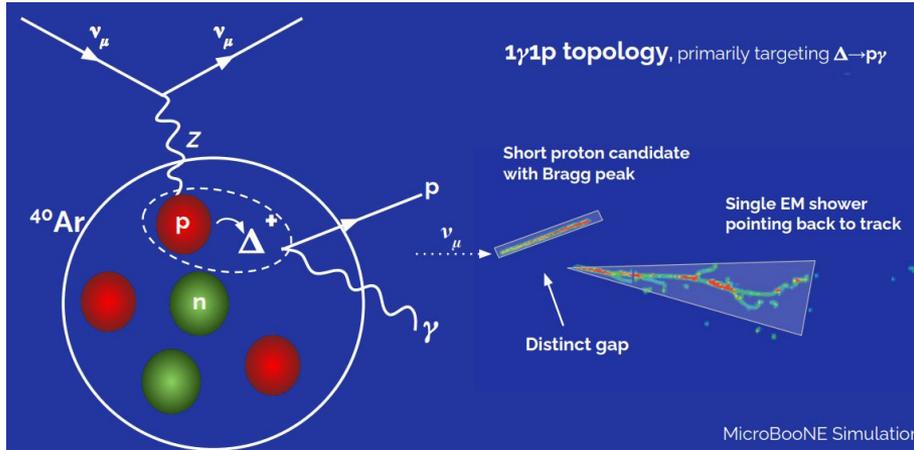
- 3  $\nu_e$  CC searches for four event classes (1e0p, 1e1p, 1eNp, 1eX)
  - Rejects electrons as LEE explanation at > 97% CL
- Recently, updated results with a pion-less  $\nu_e$  CC search using the full MicroBooNE BNB dataset and more LEE models
- See no sign of a MiniBooNE-like excess with electrons



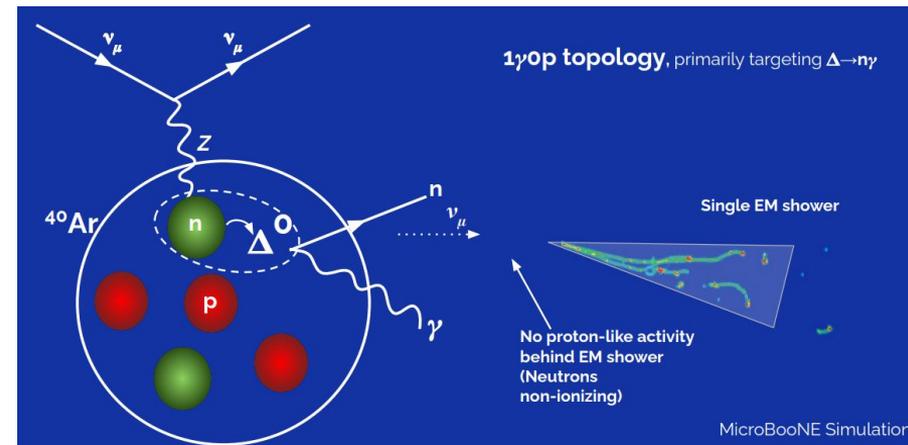
[arXiv:2412.14407](https://arxiv.org/abs/2412.14407)



# MicroBooNE's Photon-like Searches



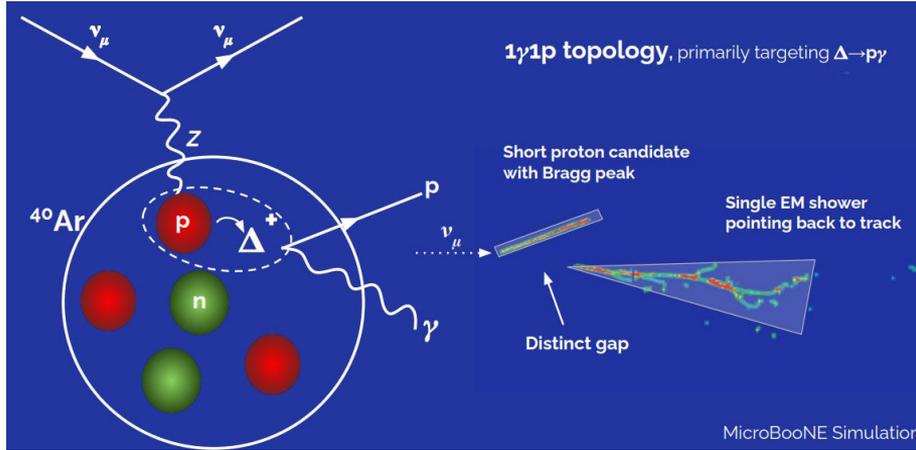
**Heavily constrained**



**Currently Allowed!**  
**Need further probes.**

# MicroBooNE's Photon-like Searches

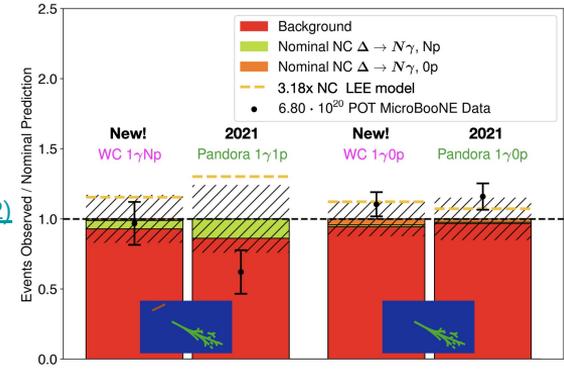
X



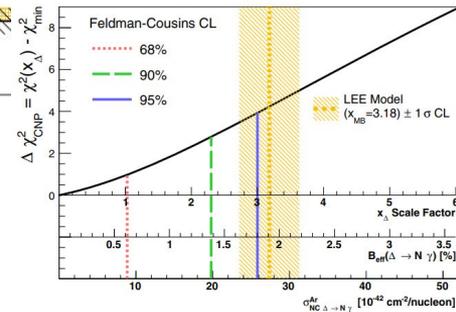
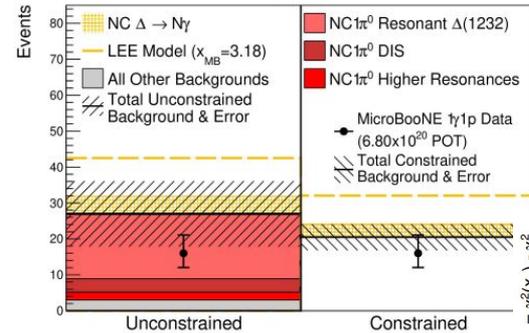
Heavily constrained

[Phys. Rev. Lett. 128, 111801 \(2022\)](https://arxiv.org/abs/2502.05750)

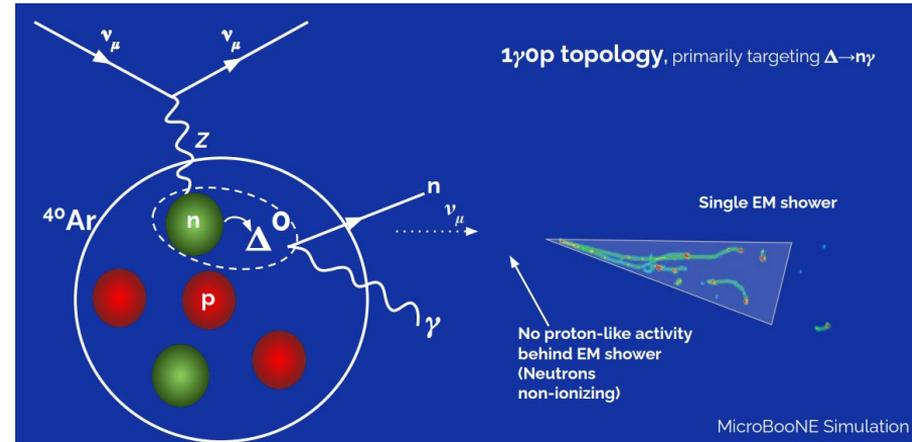
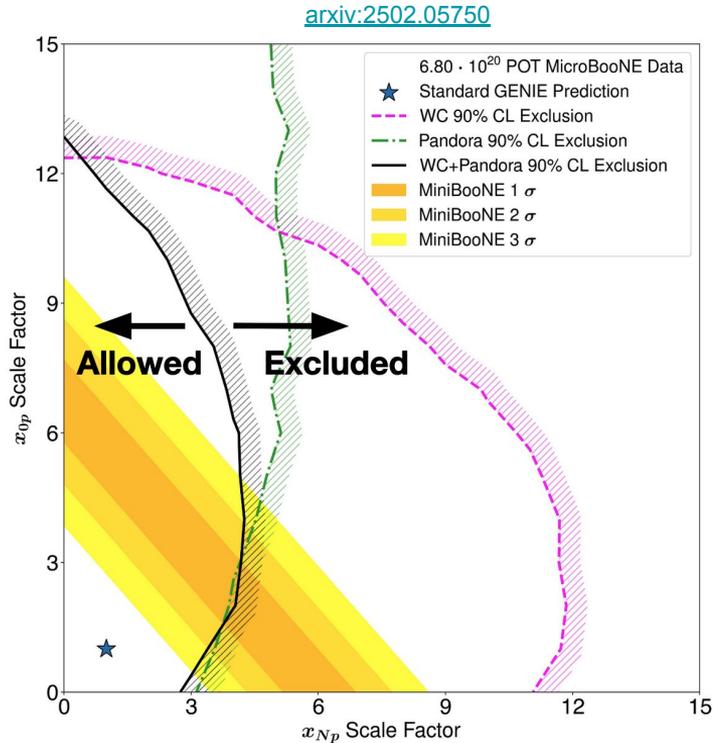
[arxiv:2502.05750](https://arxiv.org/abs/2502.05750)



1γ1p



# MicroBooNE's Photon-like Searches

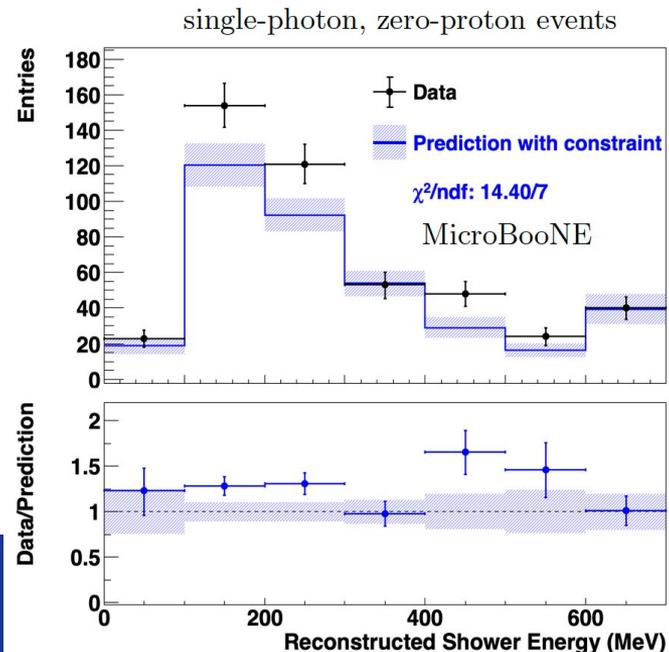
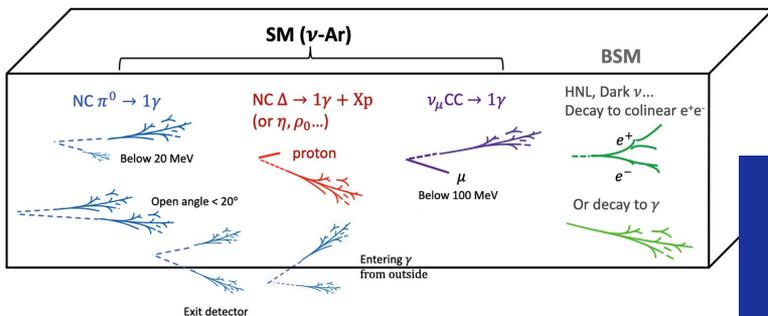


Currently Allowed!  
Need further probes.

# MicroBooNE's Photon-like Searches

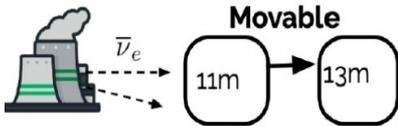
[arXiv:2502.06064](https://arxiv.org/abs/2502.06064)

- Inclusive search for single photons
- See hint of excess ( $2.2\sigma$ ) in proton-less subsample, below 600 MeV photon energy
- Kinematics compatible with MiniBooNE but exact details and source still unclear
- Further studies and investigations ongoing



# Searches for Neutrino-4

## DANSS

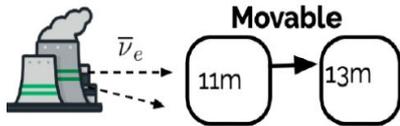


- Movable detector in Russia
- Sits below the reactor
- Position changed 2-3 times a week

[PLB 787, 56 \(2018\)](#)

# Searches for Neutrino-4

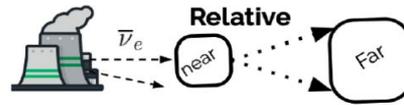
## DANSS



- Movable detector in Russia
- Sits below the reactor
- Position changed 2-3 times a week

[PLB 787, 56 \(2018\)](#)

## NEOS+RENO

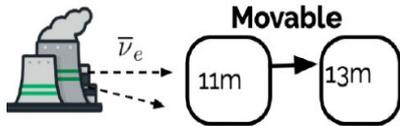


- 24 m (NEOS) and 419 m (RENO) baselines
- 180 days (NEOS) and 2,509 days (RENO) of data taken

[PRD 105, L111101 \(2022\)](#)

# Searches for Neutrino-4

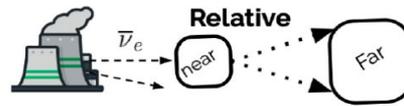
## DANSS



- Movable detector in Russia
- Sits below the reactor
- Position changed 2-3 times a week

[PLB 787, 56 \(2018\)](#)

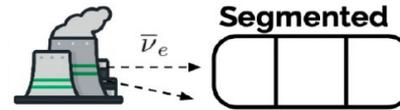
## NEOS+RENO



- 24 m (NEOS) and 419 m (RENO) baselines
- 180 days (NEOS) and 2,509 days (RENO) of data taken

[PRD 105, L111101 \(2022\)](#)

## STEREO

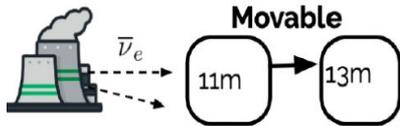


- 58.3 MWth research reactor in France
- Highly-Enriched Uranium (HEU)
- 334 days of data
- 9.4 to 11.1 m baselines

[Nature 613, 256 \(2023\)](#)

# Searches for Neutrino-4

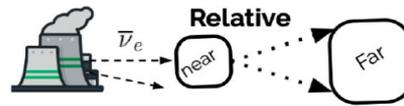
## DANSS



- Movable detector in Russia
- Sits below the reactor
- Position changed 2-3 times a week

[PLB 787, 56 \(2018\)](#)

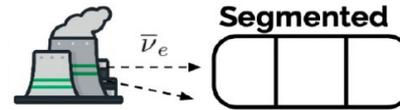
## NEOS+RENO



- 24 m (NEOS) and 419 m (RENO) baselines
- 180 days (NEOS) and 2,509 days (RENO) of data taken

[PRD 105, L111101 \(2022\)](#)

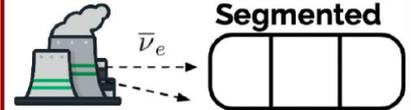
## STEREO



- 58.3 MWth research reactor in France
- Highly-Enriched Uranium (HEU)
- 334 days of data
- 9.4 to 11.1 m baselines

[Nature 613, 256 \(2023\)](#)

## PROSPECT



- 85 MWth research reactor at ORNL (USA)
- HEU
- 96 days of data
- 7-9 m baselines

[PRL 134, 151802 \(2025\)](#)

## Searches for Neutrino-4

DANSS

NEOS+RENO

STEREO

PROSPECT

All Null! None see oscillations or any hint of an anomaly.

[PLB 787, 56 \(2018\)](#)

[PRD 105, L111101  
\(2022\)](#)

[Nature 613, 256  
\(2023\)](#)

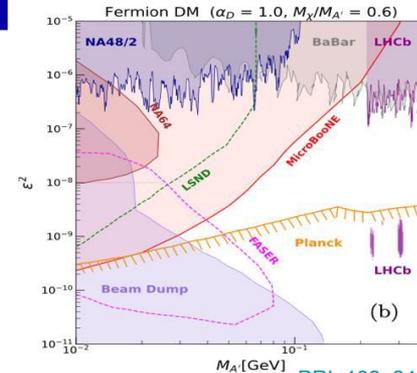
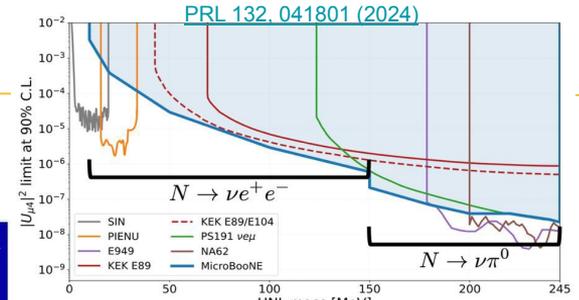
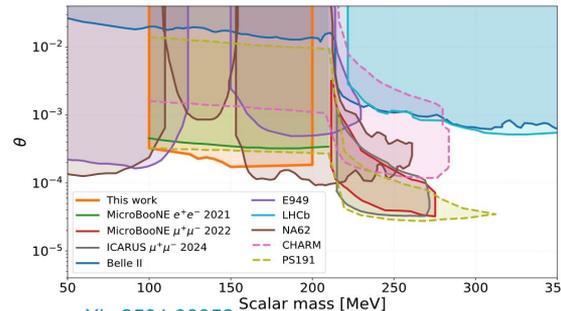
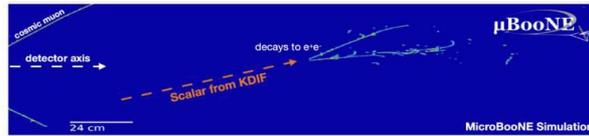
[PRL 134, 151802  
\(2025\)](#)

# Outline

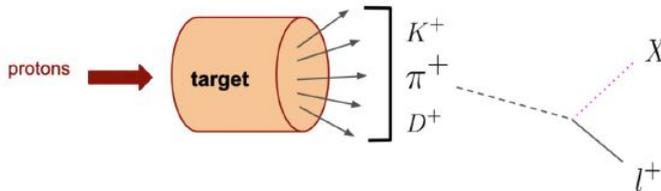
1. What does “short-baseline” mean?
2. Why study neutrinos over short baselines?
3. Anomalies
  - a. Sterile neutrinos
  - b. Other possibilities
4. Current short-baseline experiments
  - a. Addressing the Anomalies
  - b. Outside the Anomalies**
5. The future for short-baseline

# BSM Outside the Anomalies

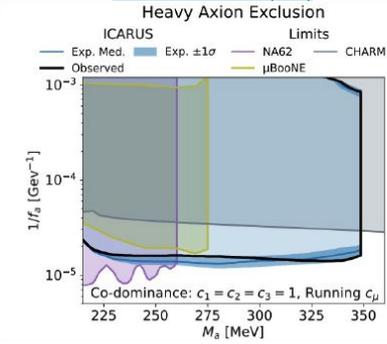
High neutrino flux and sensitivity to other possible new particles in their sources make short-baseline experiments well suited to BSM searches, even outside anomalies



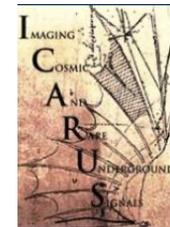
## Meson decay in flight



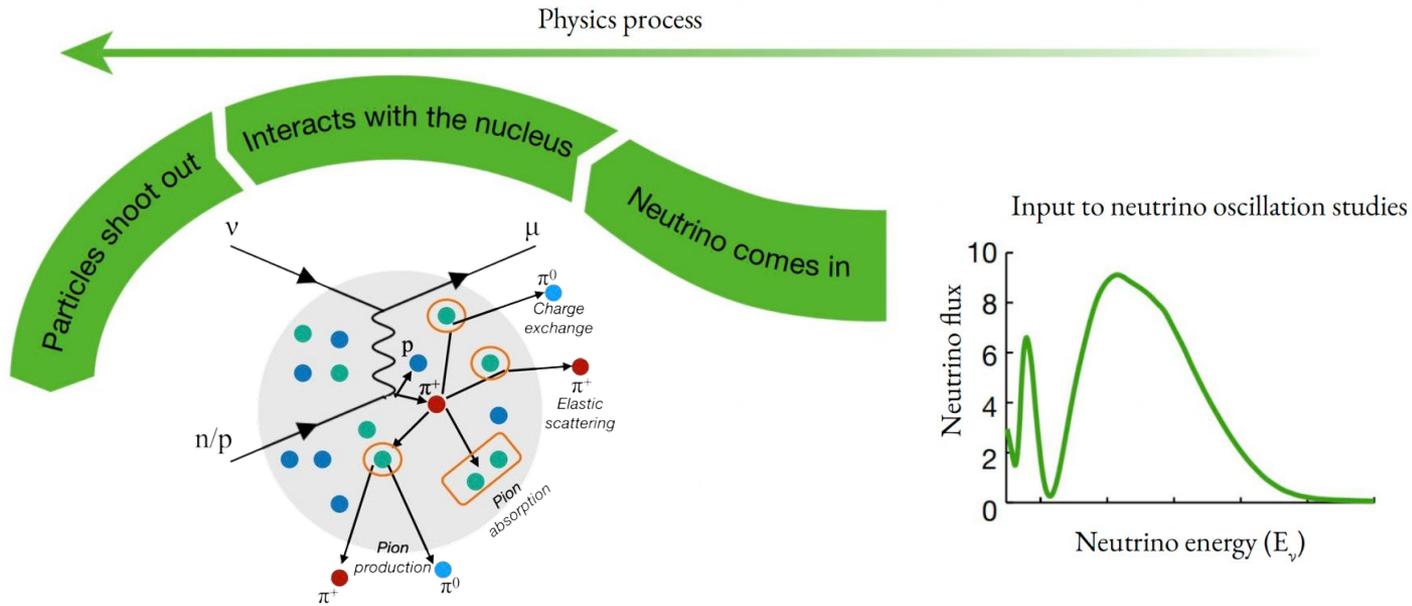
[PRL 134, 151801 \(2015\)](https://arxiv.org/abs/1311.1518)



[PRL 132, 241801 \(2014\)](https://arxiv.org/abs/1311.2418)

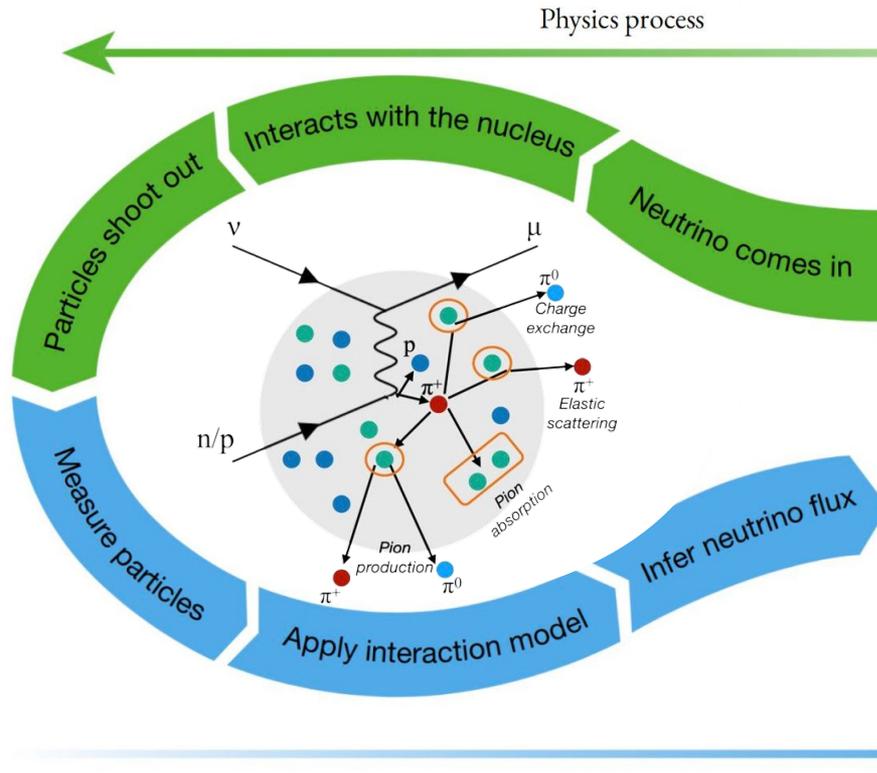


# Neutrino Cross-Sections





# Neutrino Cross-Sections

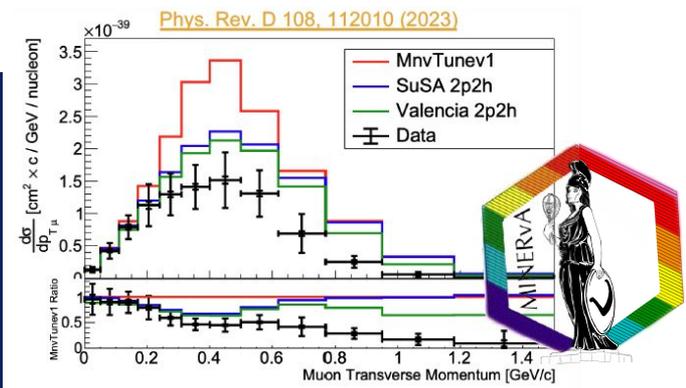
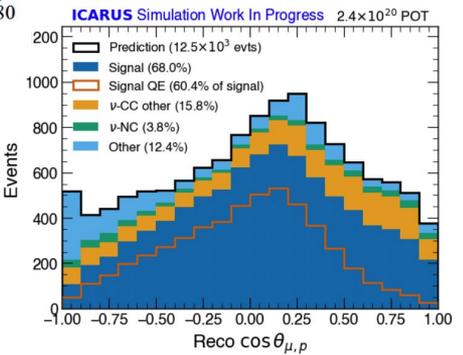
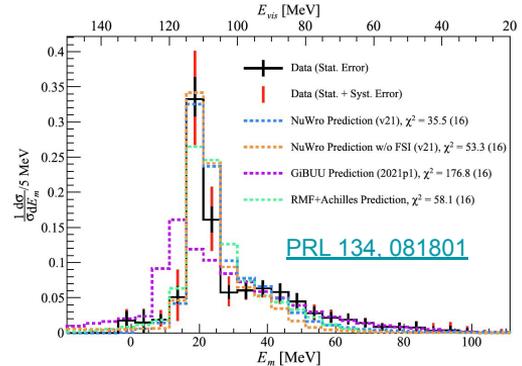
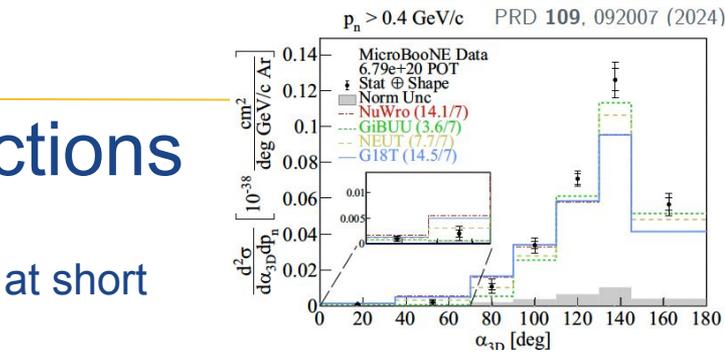
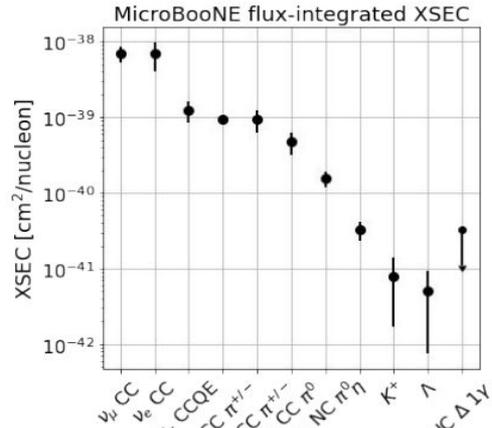


- Neutrino physics is entering a high-precision era
- Will rapidly become systematics dominated with the current models
- Updating models requires unprecedented understanding of neutrino-nucleus interactions
- Challenging
  - Broad neutrino spectra
  - Various complex interaction mechanisms

Experimental analysis

# Neutrino Cross-Sections

Often have larger neutrino fluxes at short baselines  $\rightarrow$  ability to study rare processes, get multi-dimensional measurements, etc.

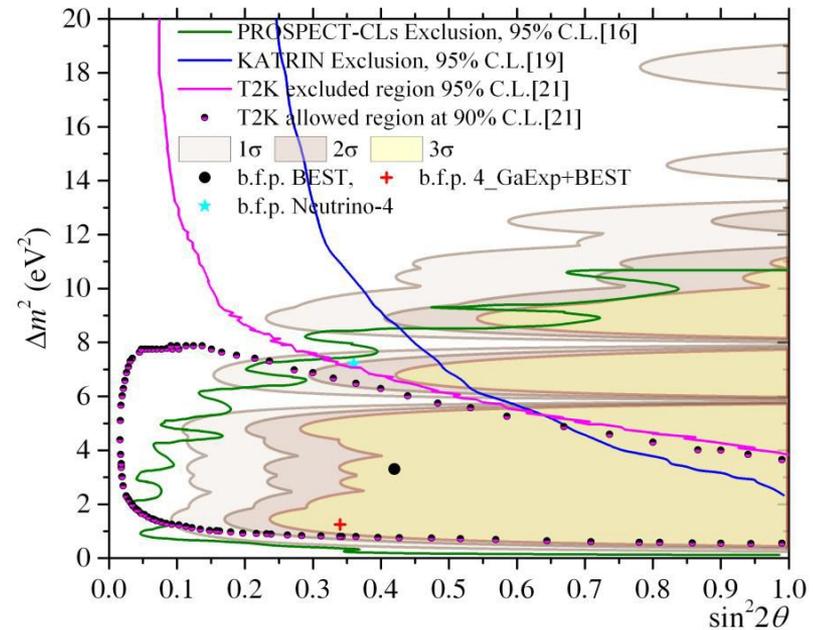
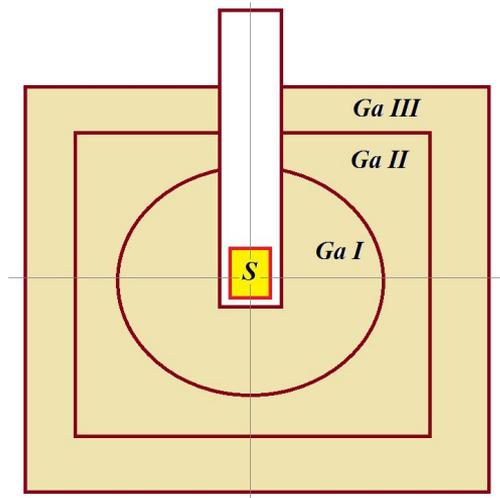


# Outline

1. What does “short-baseline” mean?
2. Why study neutrinos over short baselines?
3. Anomalies
  - a. Sterile neutrinos
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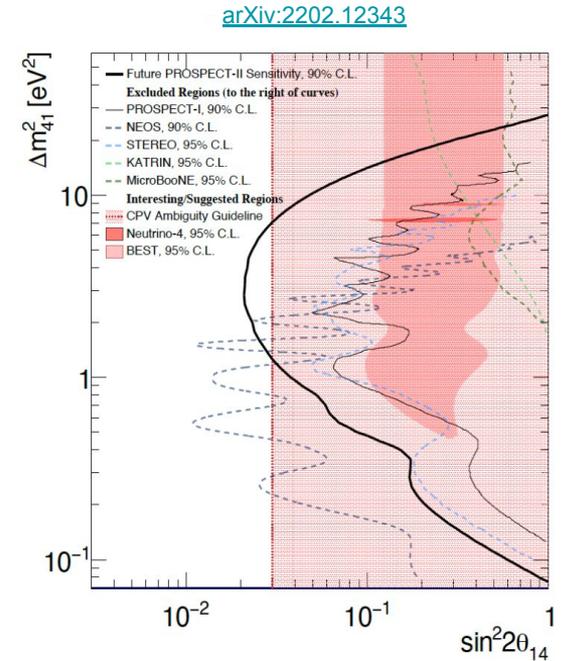
# BEST-2

- Proposed upgrade/follow-up to the BEST experiment
- 3 target zones
  - Increase L sensitivity
- $^{58}\text{Co}$  neutrino source
  - Higher energy



# TAO, Neutrino-4+, and PROSPECT-II

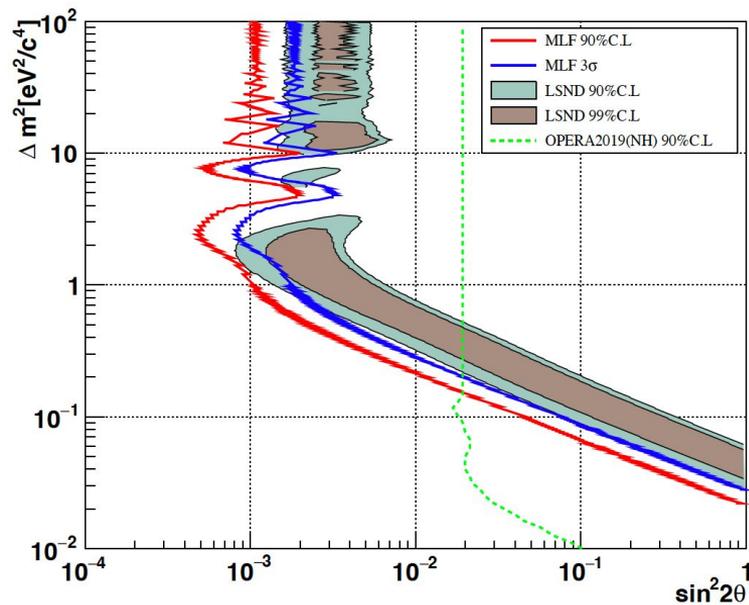
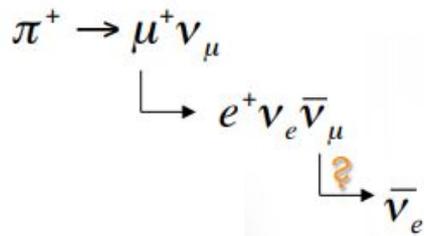
- 3 new short-baseline reactor experiments in the works
- TAO
  - satellite detector for the Jiangmen Underground Neutrino Observatory (JUNO) in China
  - Currently in R&D for new cutting-edge photosensor and liquid scintillator technology
- Neutrino-4+
  - Follow-up to Neutrino-4
  - Not much information but hopefully will address the concerns brought up by the community on first result
- PROSPECT-II
  - addresses technical issues encountered during the initial data taking period that caused a fraction of the detector PMTs to become inoperable by moving the PMTs outside the liquid scintillator volume
  - Better sensitivity at higher masses than beam experiments
  - More phase-space coverage including all phase space of Neutrino-4



# JSNS<sup>2</sup> & JSNS<sup>2</sup>-II

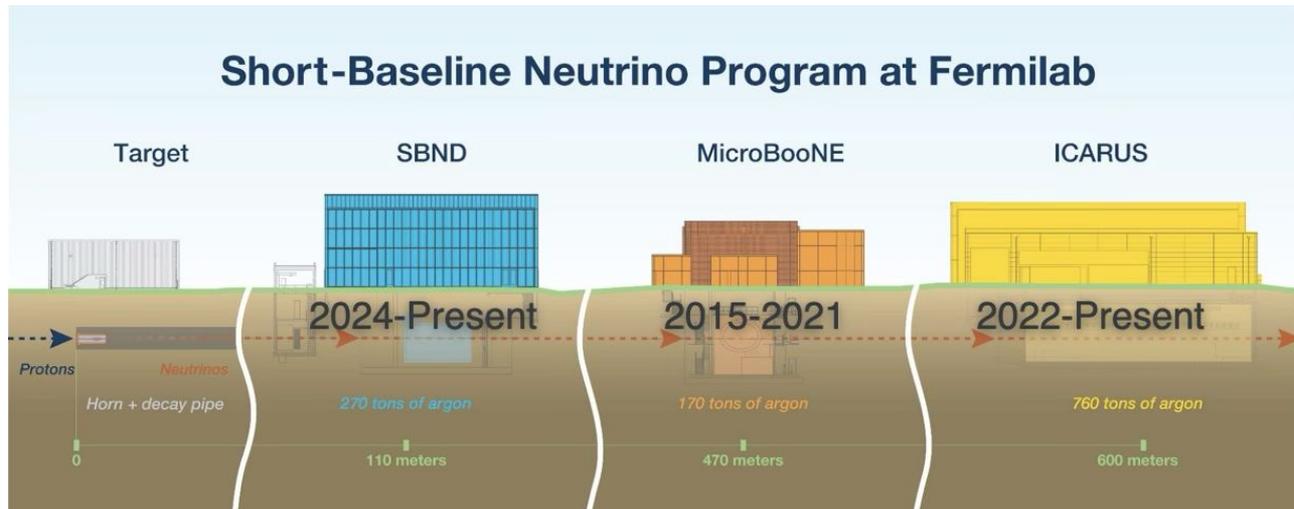
[arXiv:2012.10807](https://arxiv.org/abs/2012.10807)

- Updated version of LSND → directly test the anomaly
- Two **Gd-doped** liquid scintillator detectors at J-PARC
  - 100 times better signal-to-noise ratio
- Looking at  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$  from  $\mu^+$  decay-at-rest
- JSNS<sup>2</sup> started data-taking in 2020
  - Analysis on-going, expect to see first results soon
- JSNS<sup>2</sup>-II: Addition of a far detector
  - has been constructed
  - About to start data-taking



# The SBN Program

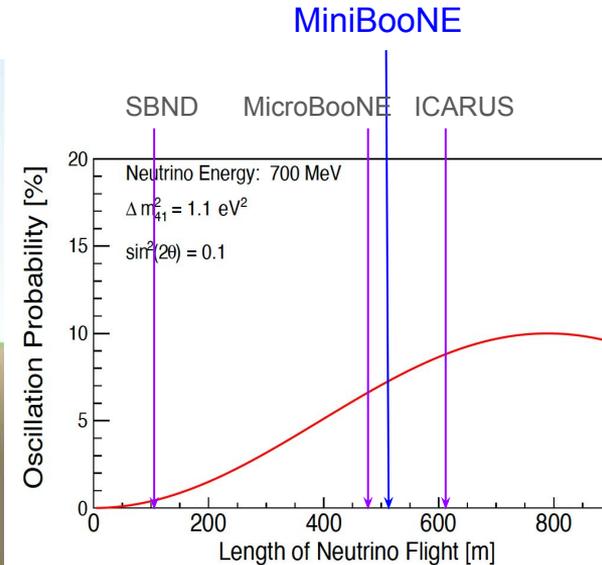
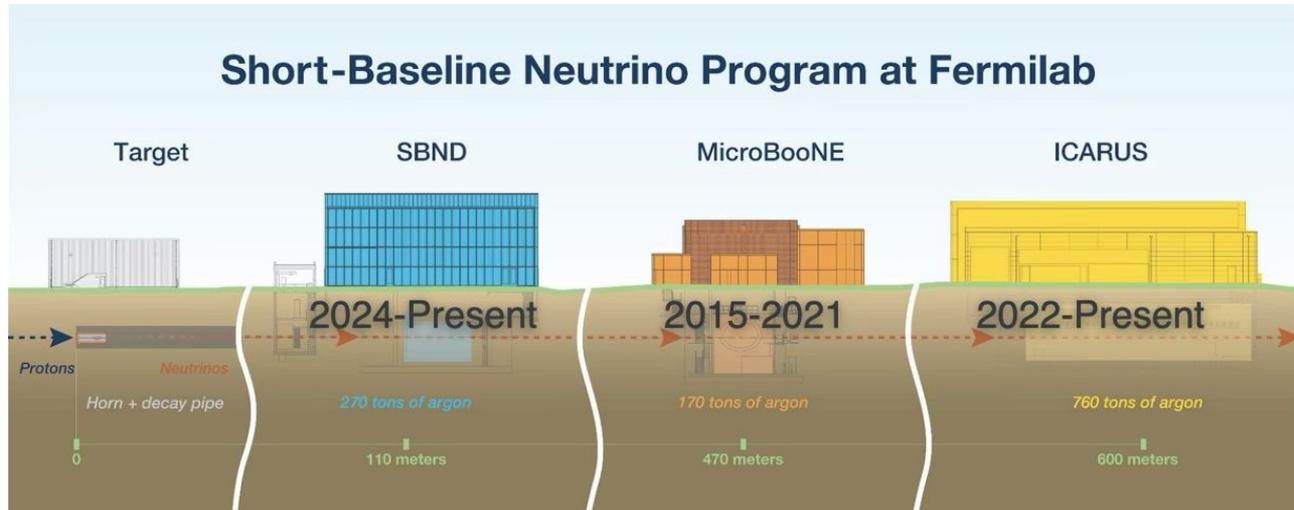
- Short-Baseline Neutrino (SBN)
- 3 detectors along the Booster Neutrino Beam (BNB, 8 GeV p) at Fermilab
  - MicroBooNE and ICARUS off-axis to the NuMI (120 GeV p) beamline as well
- Liquid Argon Time Projection Chamber (LArTPC) detectors



- 3 main physics goals:
  1. Investigate eV-scale sterile neutrino oscillations,
  2. Search for beyond the Standard Model physics and study rare processes,
  3. Neutrino interaction measurements on argon

# The SBN Program

- MicroBooNE has already finished data-taking and put out results, as we've seen, but more are on the way
- ICARUS began physics data-taking in 2022 and is working on analyzing its first few runs
- The Short-Baseline Near Detector (SBND) began physics late last year
- SBND and ICARUS expect to have a sterile oscillation analysis out soon
- ICARUS also working on Neutrino-4 check



# Summary

- Short-baseline neutrino experiments contribute a number of advantages to the neutrino community including searches for new physics and high statistics measurements of neutrino cross sections
- A number of short-baseline anomalies have cropped up over the years and are being investigated
  - eV-scale sterile neutrinos was the most popular explanation but most phase-space is being ruled out
  - New explanations and physics models are being developed and tested across a number of experiments
- Future short-baseline experiments are in the process of being designed, built, and run and expect to expand capabilities even further

