Current Short-Baseline Experiments

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17th International Neutrino Summer School — UC Santa Barbara

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Recap: Short-Baseline Anomalies

- Short-baseline experiments study neutrinos at L/E at roughly 1m/MeV or less, before standard neutrino oscillations have any significant effect
- Oscillatory affects observed at this scale imply an additional, sterile neutrino state with a large mass splitting (e.g. $\Delta m^2 \sim 1$ eV^2)
- Several experiments have observed anomalies in this region
  - LSND observed an excess of $\bar{\nu}_e$ in a $\bar{\nu}_\mu$ source from μ^+ decay at rest
  - MiniBooNE observed an excess of ν_e in the Fermilab Booster Neutrino Beam (BNB), which is primarily ν_μ — although data in tension with fitted oscillation signal shape
  - Gallium experiments (SAGE, GALLEX, BEST) observed a deficit of ν_e from radioactive sources — although no apparent baseline dependence
- Other experiments probing similar regions of oscillation phase space have null results

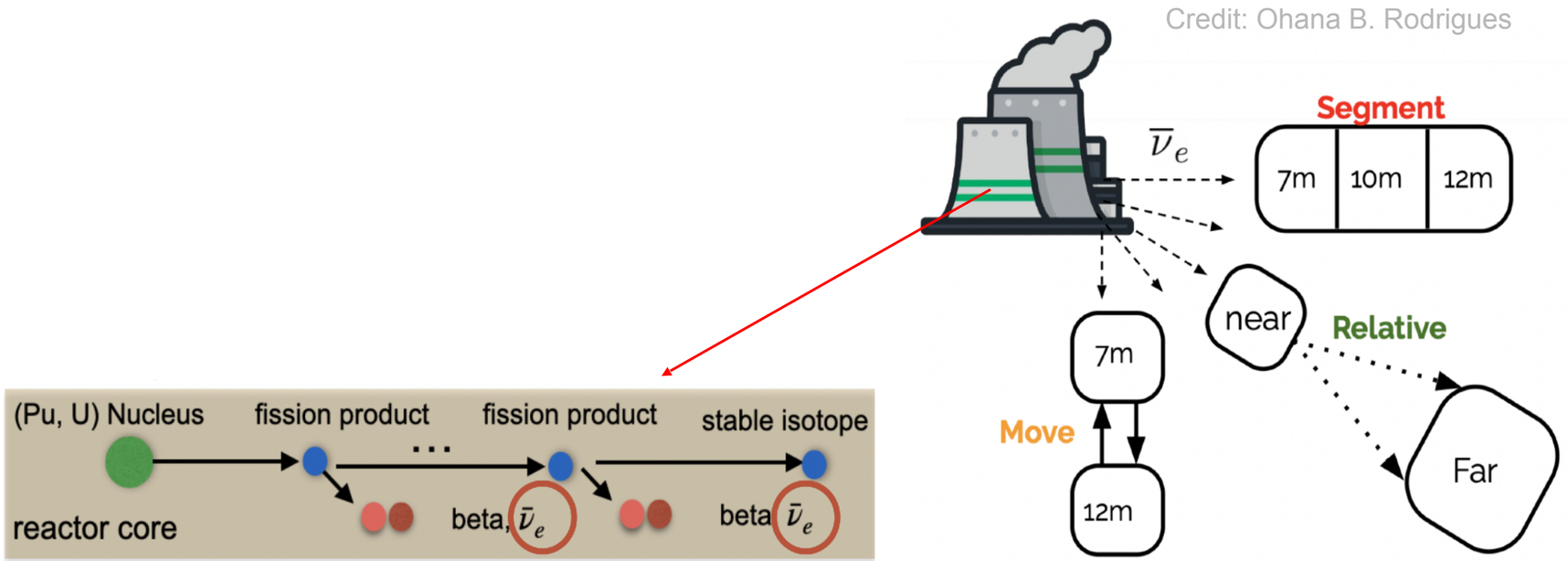
Current Short-Baseline Experiments

- The short-baseline experimental program continues with the goals of addressing the existing anomalies and testing theories that could explain them
  - Often alongside other physics goals, including neutrino–nucleus interaction measurements and searches for other BSM physics
- Will talk about several of these today
  - JSNS2 — a follow-up to LSND
  - MicroBooNE — a follow-up to MiniBooNE
  - SBN Program — enables short-baseline searches with dedicated near and far detectors
- But first, a bit more about reactor neutrino experiments…

Short-Baseline Reactor Experiments

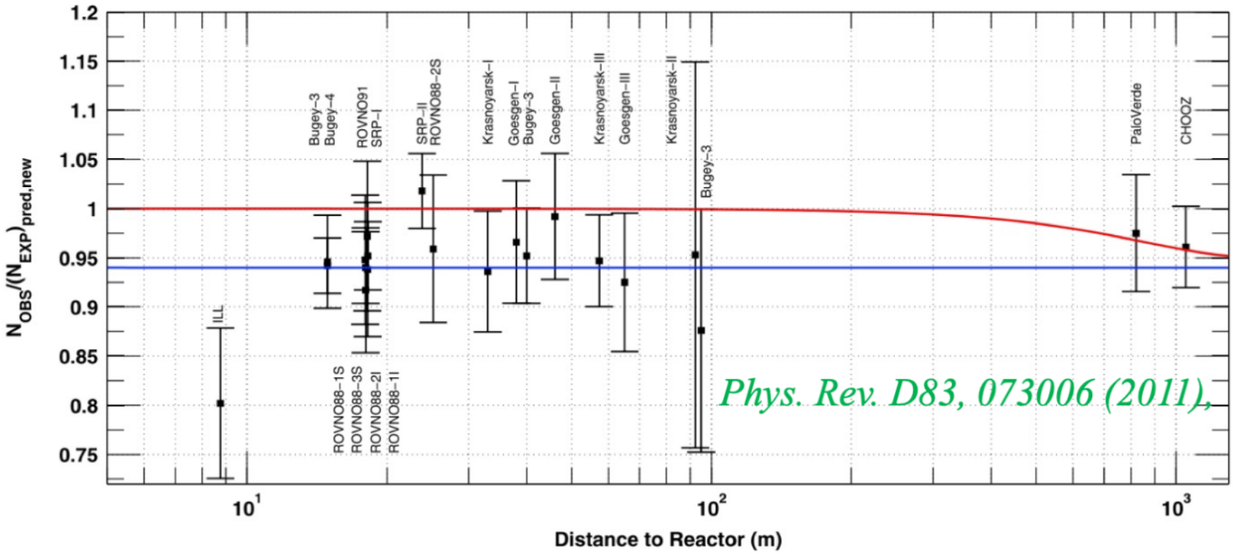
Reactor Neutrino Experiments

- Nuclear reactors are powerful sources of $\bar{\nu}_e$ produced during nuclear fission, predominantly from ^{235}U, ^{238}U, ^{239}P, and ^{241}Pu
- Use models of the nuclear fission processes to predict the $\bar{\nu}_e$ flux from the reactor, and compare to measurements at different baselines



Reactor Neutrino Anomalies

- In the ~2010s, a number of short-baseline reactor neutrino experiments reported a deficit of $\bar{\nu}_e$ observed, at about ~5%
- This spurred additional measurements as well as improved modeling of reactor fluxes
- With updated modeling, the deficit has essentially resolved and is largely not considered "anomalous" anymore



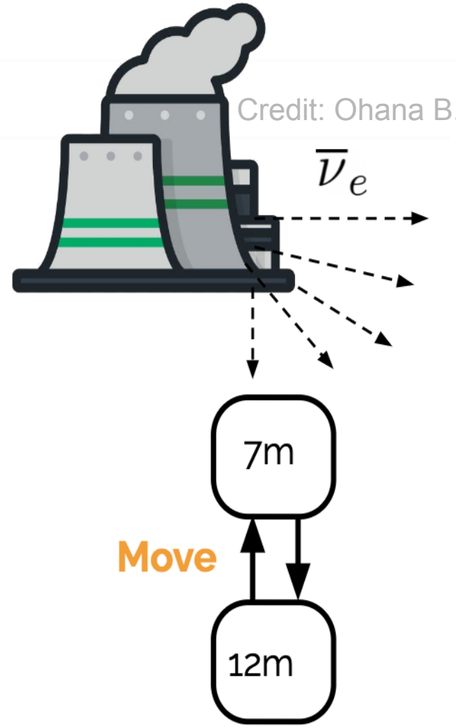
mean averaged ratio:

$\bar{R} = 0.943 \pm 0.024$

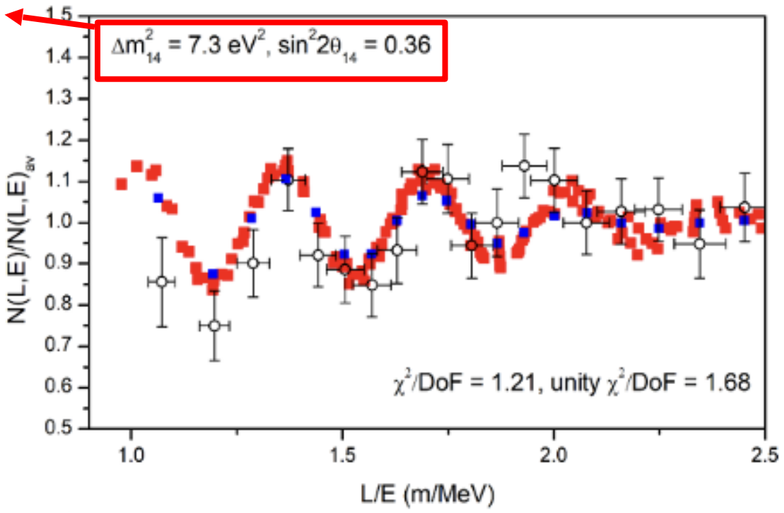
- Huber-Mueller model Phys. Rev. C 83, 054615 (2011), Phys. Rev. C 85, 029901 (2012)
- Estienne-Fallot summation model Phys. Rev. Lett. 123, no. 2, 022502 (2019)
- Hayen-Kostensalo-Severijns-Suhonen model Phys. Rev. C 100, 054323 (2019)
- Recent Kurchatov Institute measurements arXiv:2103.01684

Reactor Neutrino 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 ~2.9σ



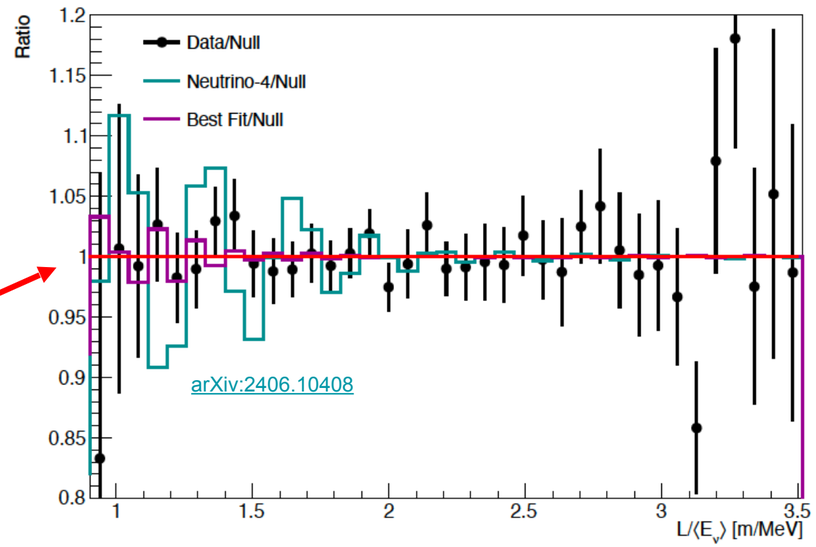
Not near any of the standard neutrino oscillation parameters



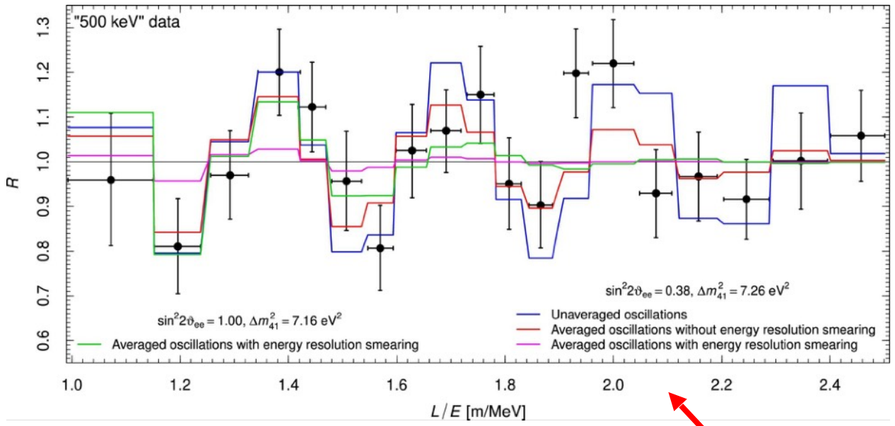
Reactor Neutrino Anomaly: Neutrino-4

- However, the methodologies have been questioned and other reactors see no similar signal
- See also: arXiv:2006.13147

Inadequate statistical approach?



PLB 816, 136214 (2021)

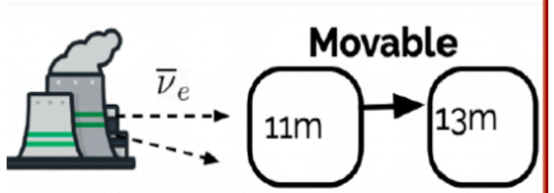


Incorrect inclusion of detector effects and backgrounds?

- Neutrino-4 collaboration has not yet addressed these concerns

Follow-Ups to Neutrino-4

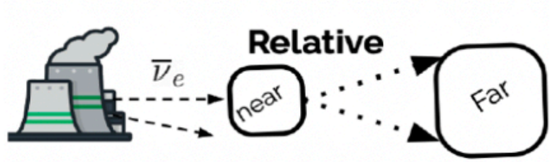
DANSS



- 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)

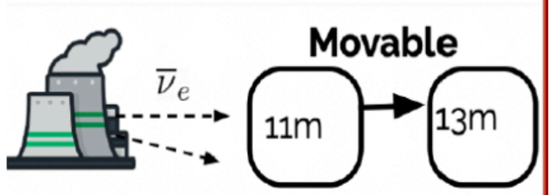
PROSPECT

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

PRL 134, 151802 (2025)

Follow-Ups to Neutrino-4

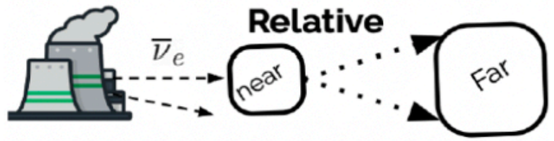
DANSS



- Movab… in Rus…
- Sits be… reacto…
- Positio… 2-3 times a week

PLB 787, 56 (2018)

NEOS+RENO



…(RENO) of data taken

PRD 105, L111101 (2022)

STEREO

- 334 days of data
- 9.4 to 11.1 m baselines

Nature 613, 256 (2023)

PROSPECT

…h reactor …L (USA)

…s of data

- 7-9 m baselines

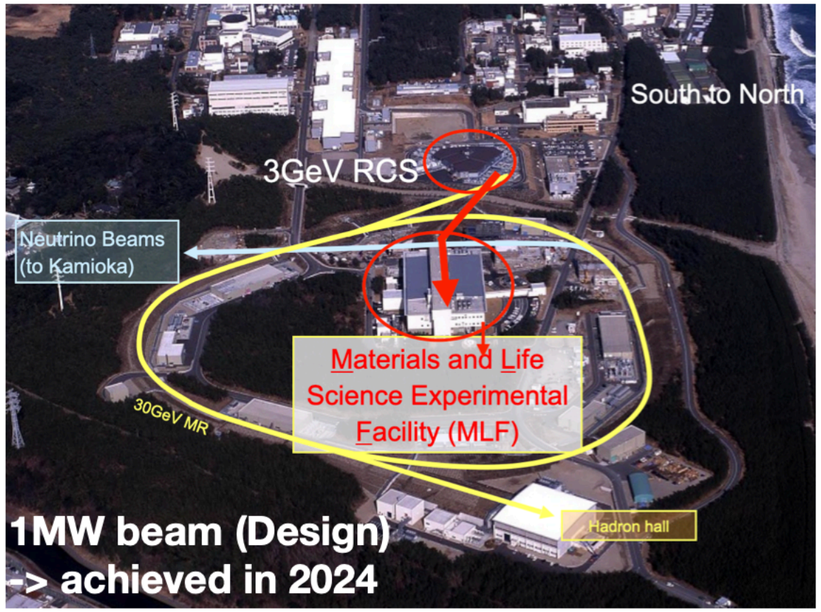
PRL 134, 151802 (2025)

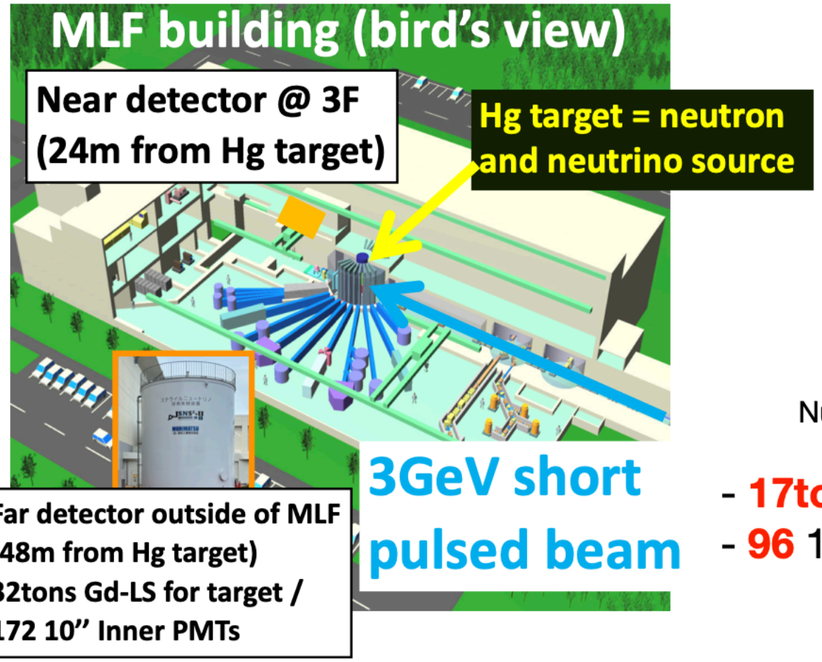
All found null results! None see evidence of oscillation or anomalies

JSNS2

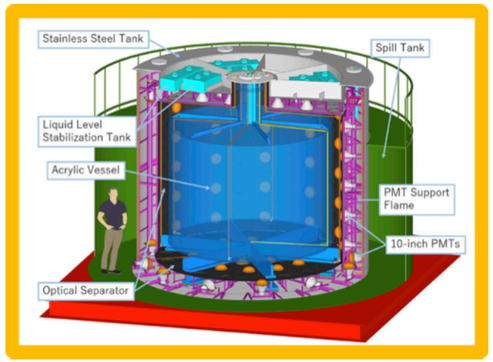
JSNS2

- JSNS2 is a follow-up to LSND currently running in Japan





Near detector



Nucl. Instrum. Methods A 1014 165742 (2021)

- **17tons** Gd-LS+DIN for target
- **96** 10" PMTs for the Inner Detector

JSNS2

- It largely follows an LSND-like design, with a similar neutrino source
- In the early stages of data analysis for their near detector, and recently finished construction of and now commissioning a far detector
- Too soon to tell yet whether they see any anomalies! Stay tuned

2022 + 2024 Physics run
(1.95×10^{22} POT)

JSNS² Preliminary

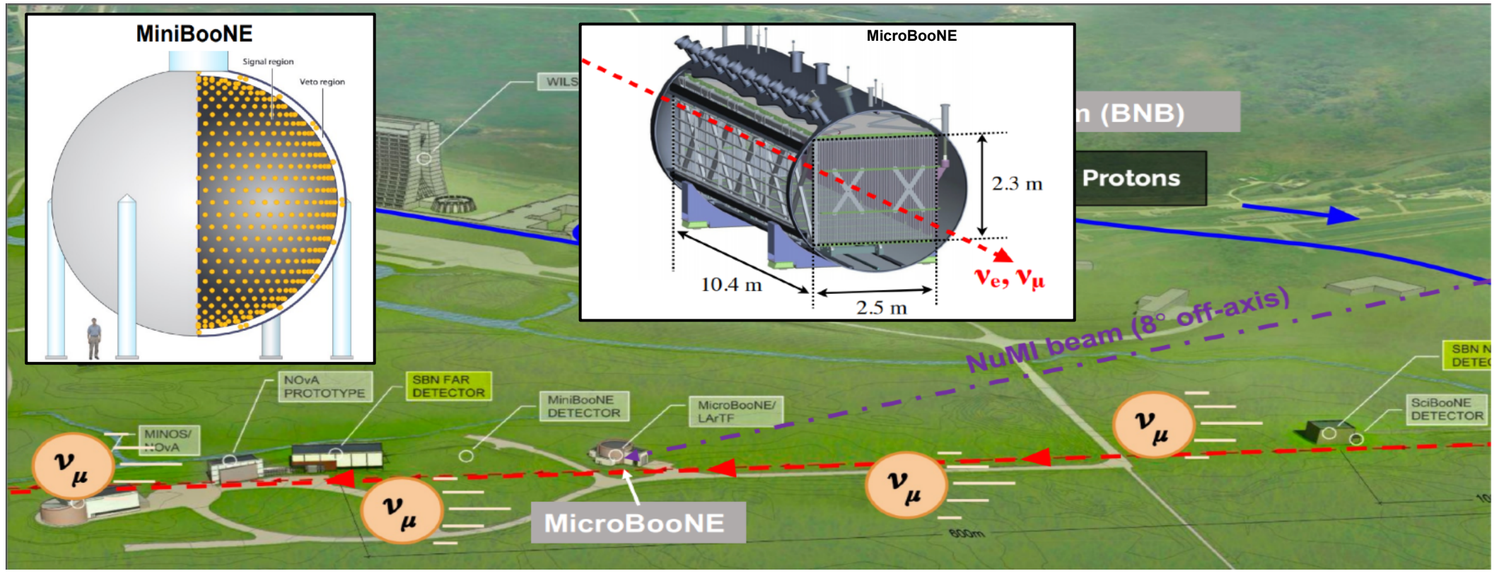
	Observed events	Prediction events
Total	**8**	**8.9 +- 1.6**
JSNS² Bkg.		**6.1 +- 1.0**
LSND excess (scaled)		**2.8 +- 1.3**

- LSND $\bar{\nu}_e$ excess is normalized to compare with JSNS² data set

MicroBooNE

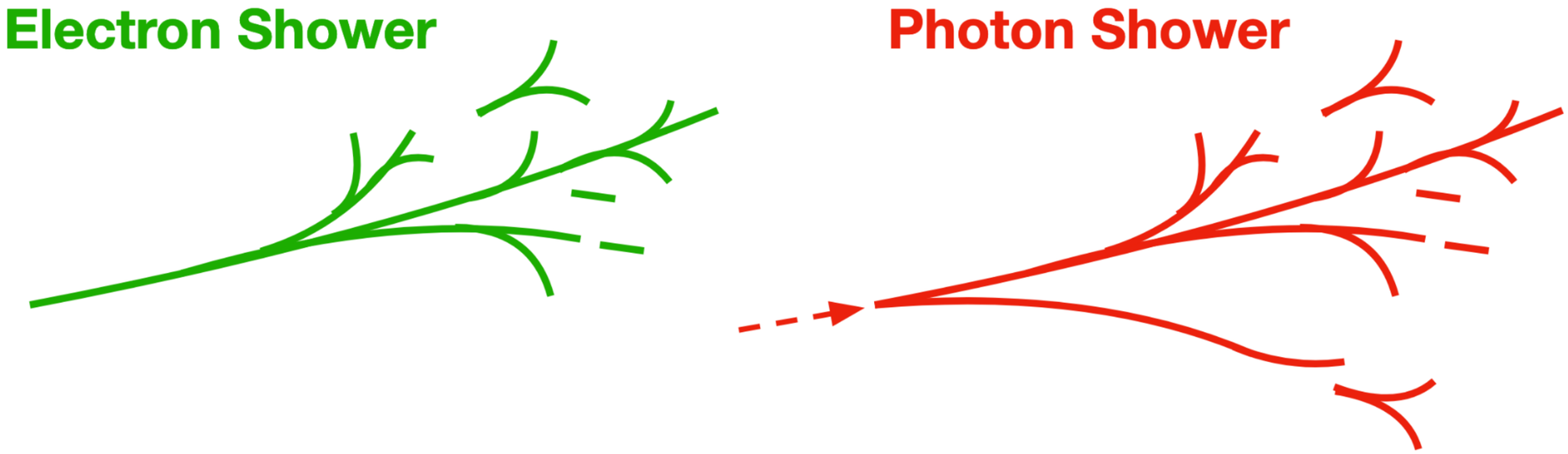
MicroBooNE

- 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, recorded ~0.5M neutrino events; now decommissioned
- Primary design goal is to understand the LEE anomaly seen by MiniBooNE



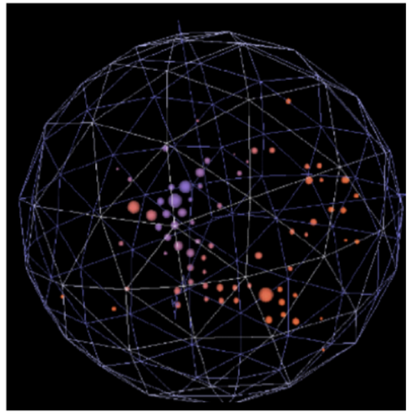
MicroBooNE: Resolving MiniBooNE's Ambiguity

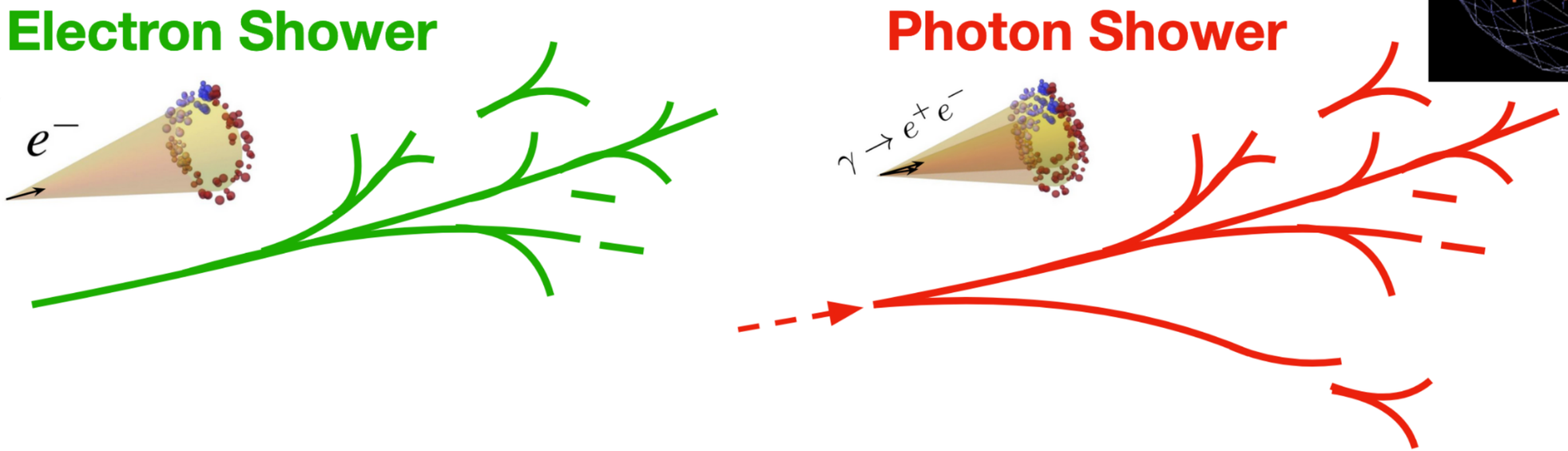
- Recall that the MiniBooNE detector cannot easily differentiate electrons and photons
- Electromagnetic showers come from a cascade of gamma rays, electrons, and positrons
- These cascades can be started by an electron/positron directly, or when a photon pair produces ($\gamma \rightarrow e^+e^-$)



MicroBooNE: Resolving MiniBooNE's Ambiguity

- Recall that the MiniBooNE detector cannot easily differentiate electrons and photons
- MiniBooNE sees Cherenkov light from many small segments of an electromagnetic shower
- These combine to give MiniBooNE a "fuzzy ring" in either case

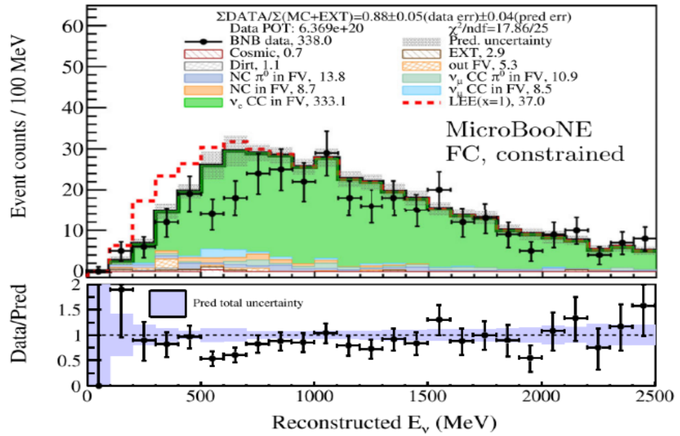


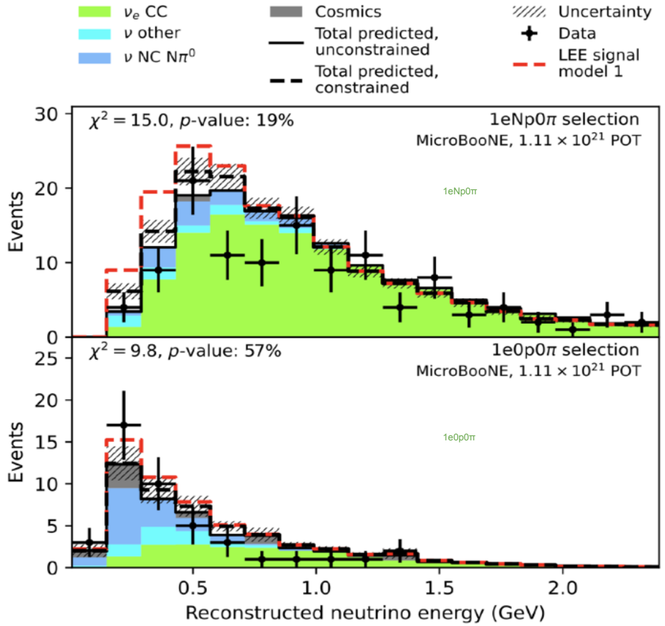


MicroBooNE: Electron Searches

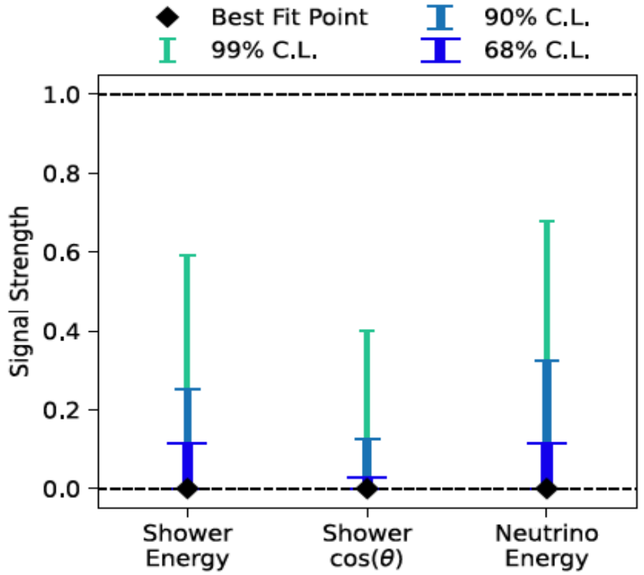
- Three ν_e CC searches for four event classes
- Rejects electrons as LEE explanation at > 97% CL
- Recently, updated results with a pion-less ν_e CC search using the full MicroBooNE BNB dataset and more models
- See no sign of a MiniBooNE-like excess with electrons

Phys. Rev. D **105**, 112005 (2022)

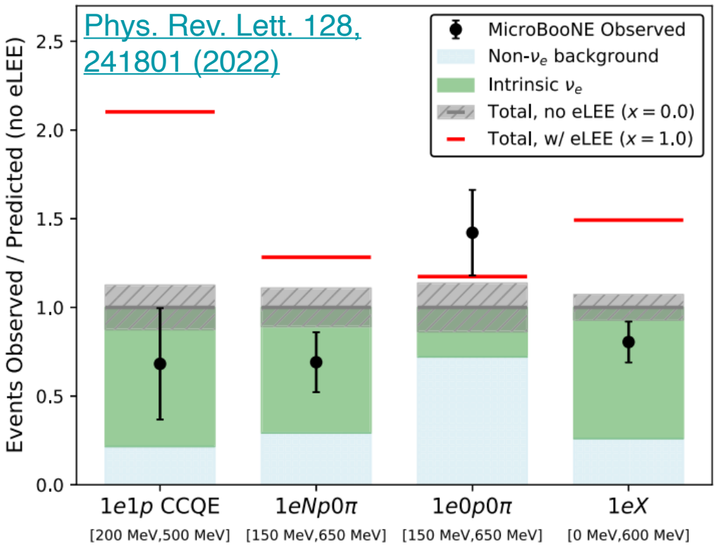




Phys. Rev. Lett. **135**, 081802

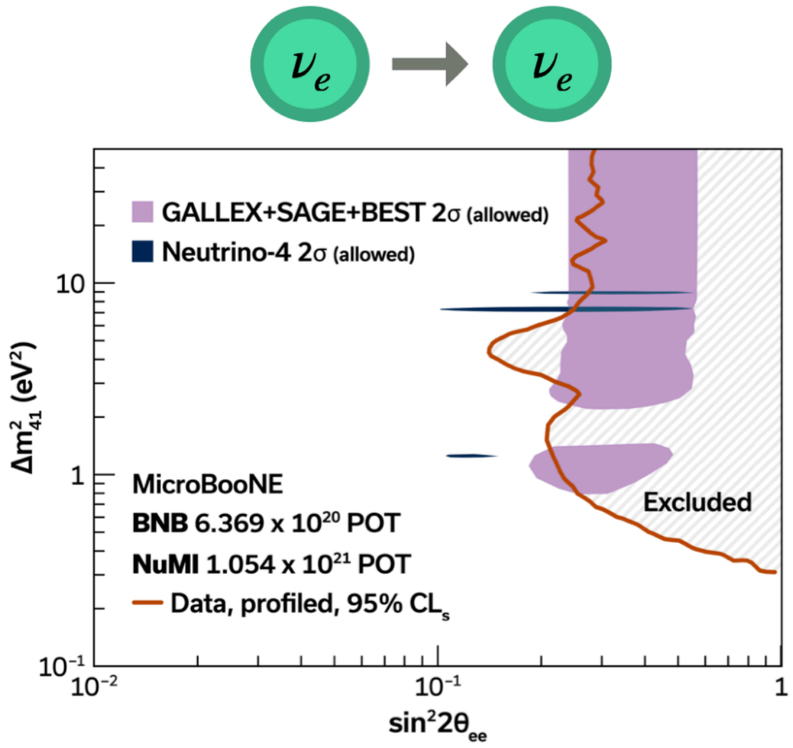


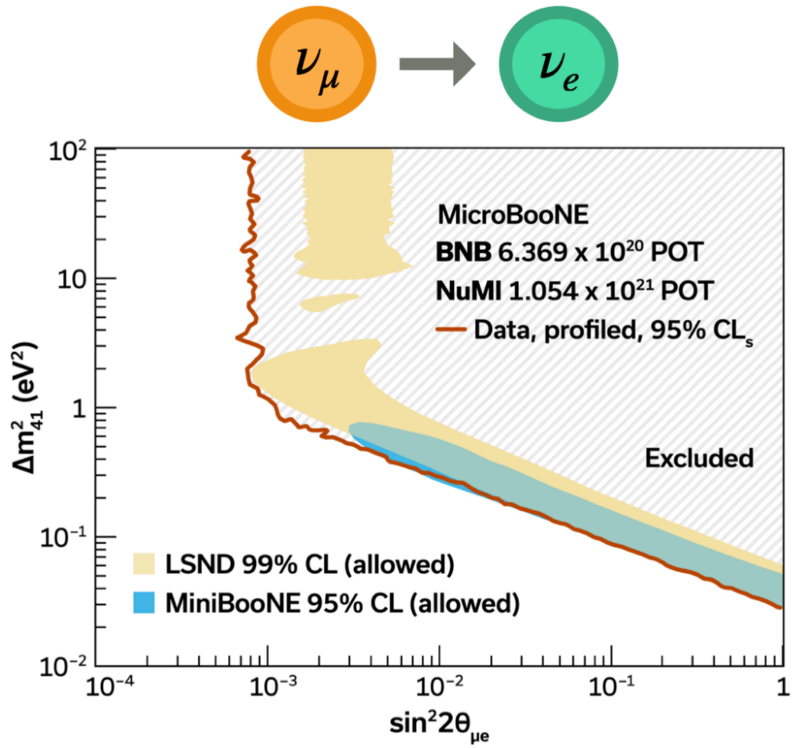
Phys. Rev. Lett. 128, 241801 (2022)

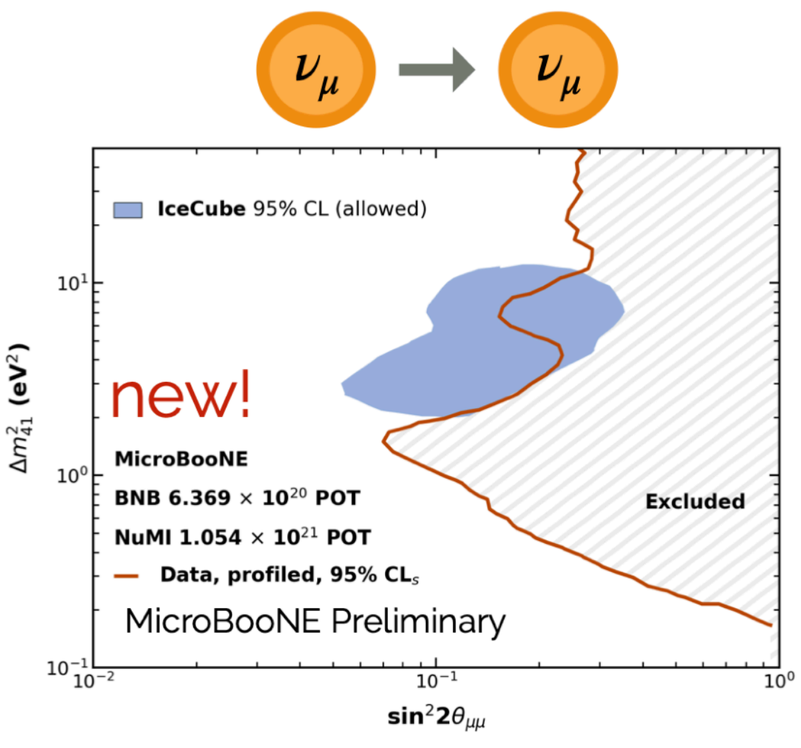


MicroBooNE: Oscillation Results

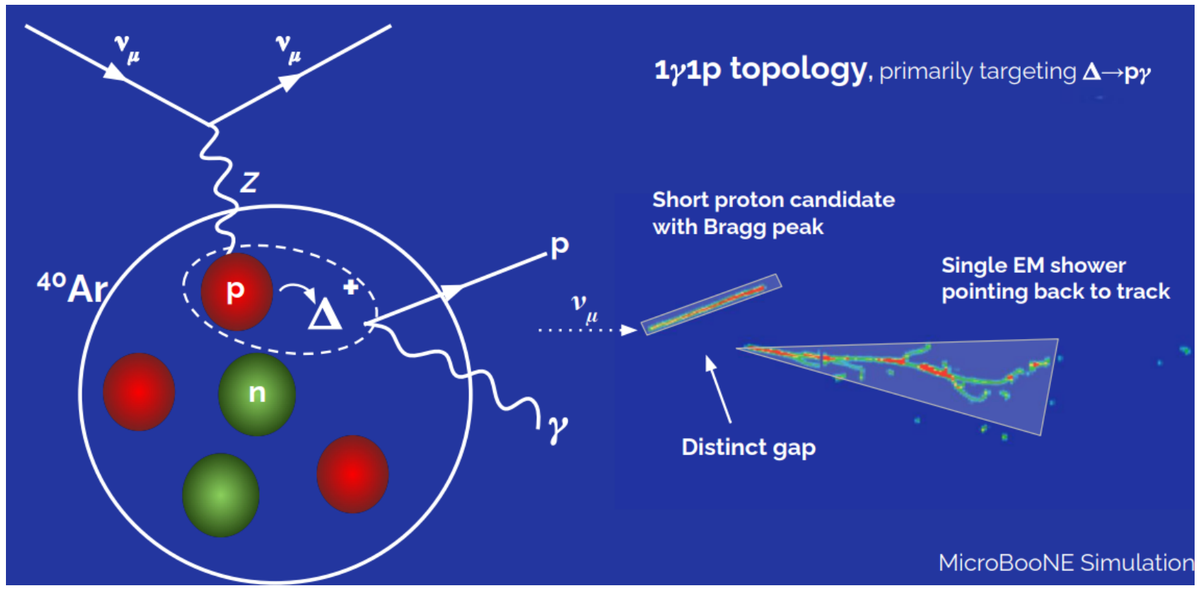
- MicroBooNE has also tested specifically 3+1 oscillation hypotheses, utilizing both beams that it can see: BNB and NuMI
- These results significantly constrain electron neutrino disappearance (e.g. BEST) as well as muon to electro neutrino appearance (e.g. LSND and MiniBooNE)



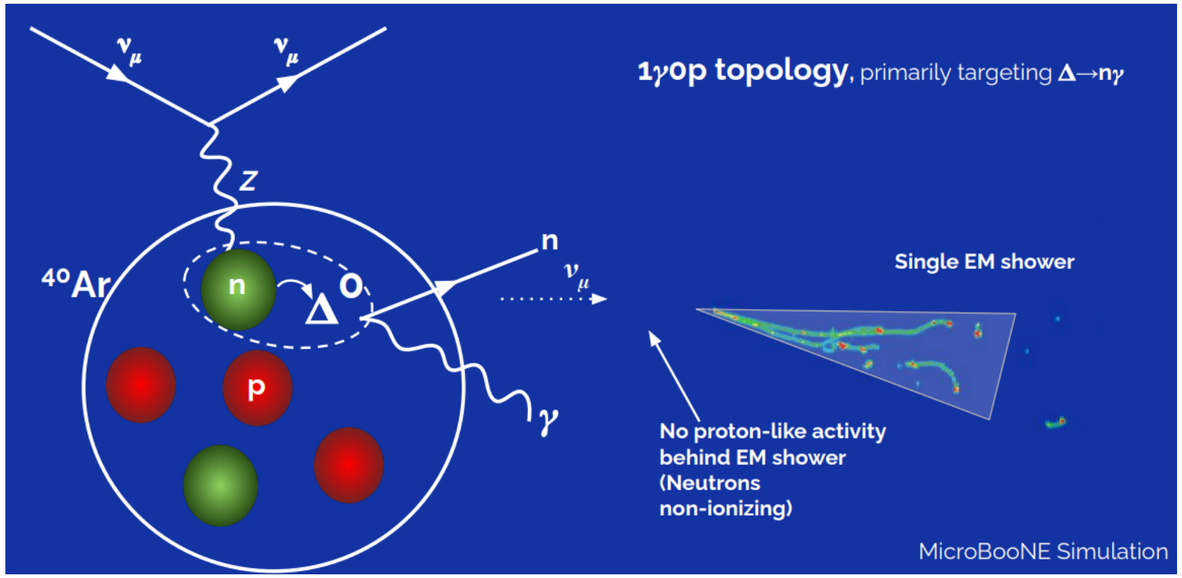




MicroBooNE: Photon-Like Searches



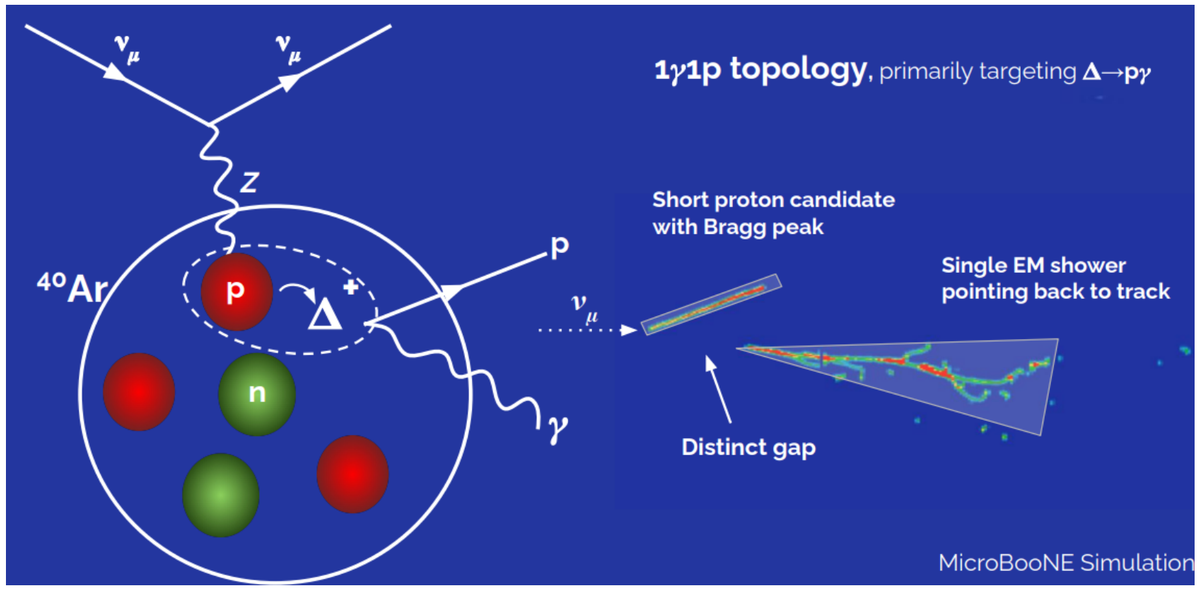
Heavily constrained



Currently Allowed!

Need further probes.

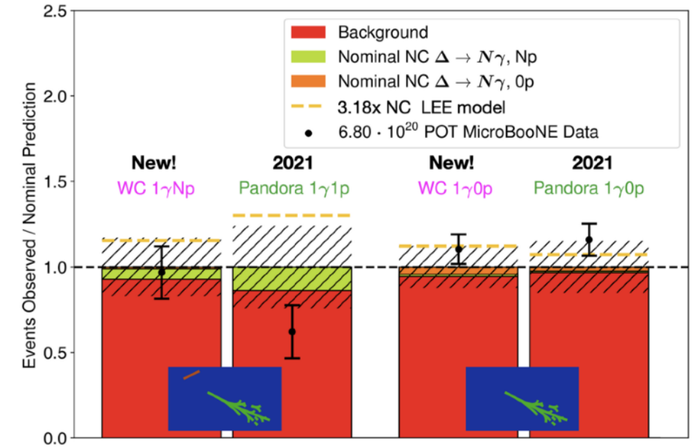
MicroBooNE: Photon-Like Searches

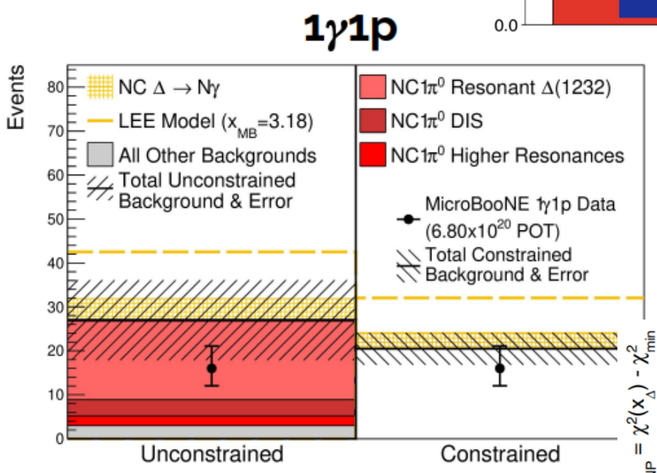


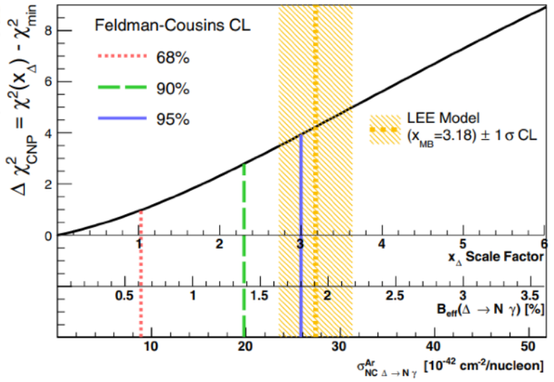
Heavily constrained

Phys. Rev. Lett. 128, 111801 (2022)

arxiv:2502.05750







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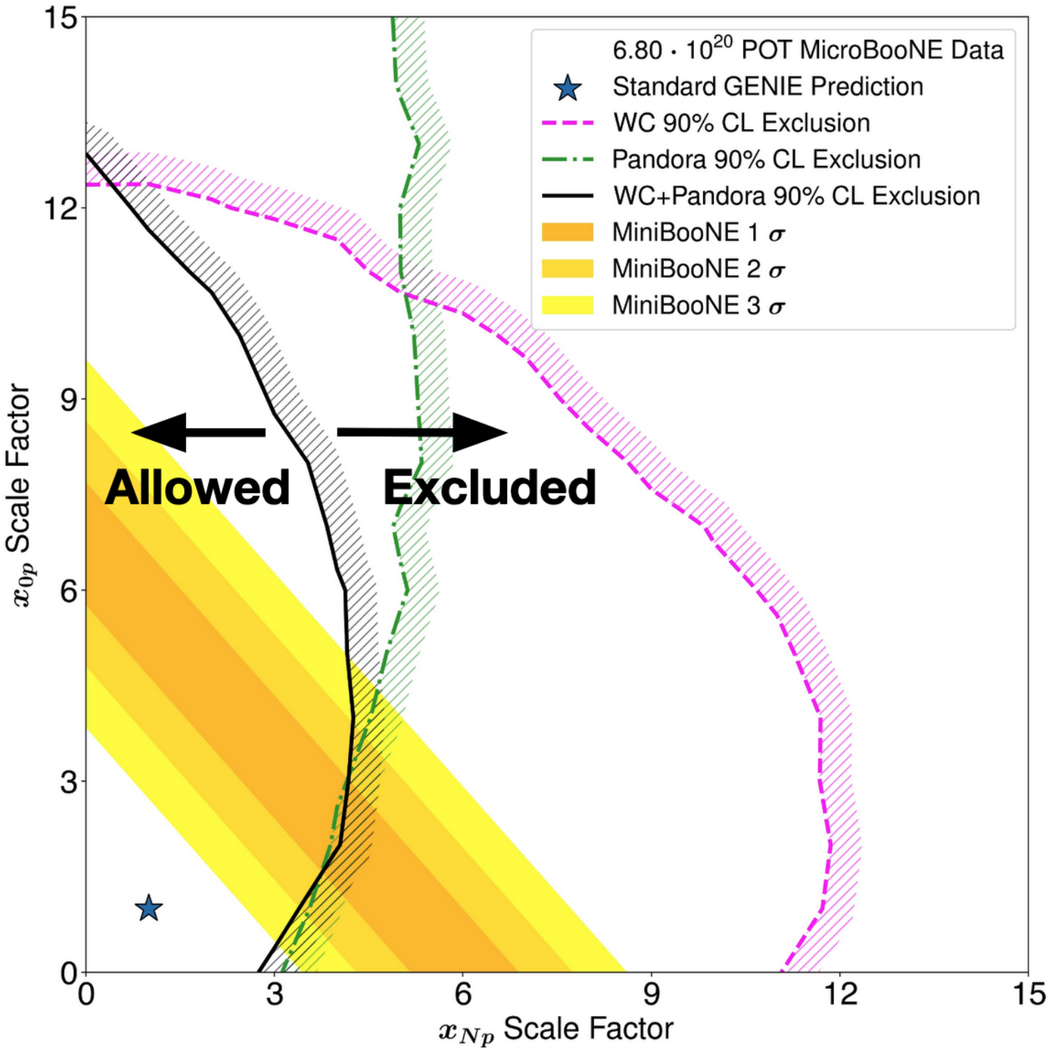
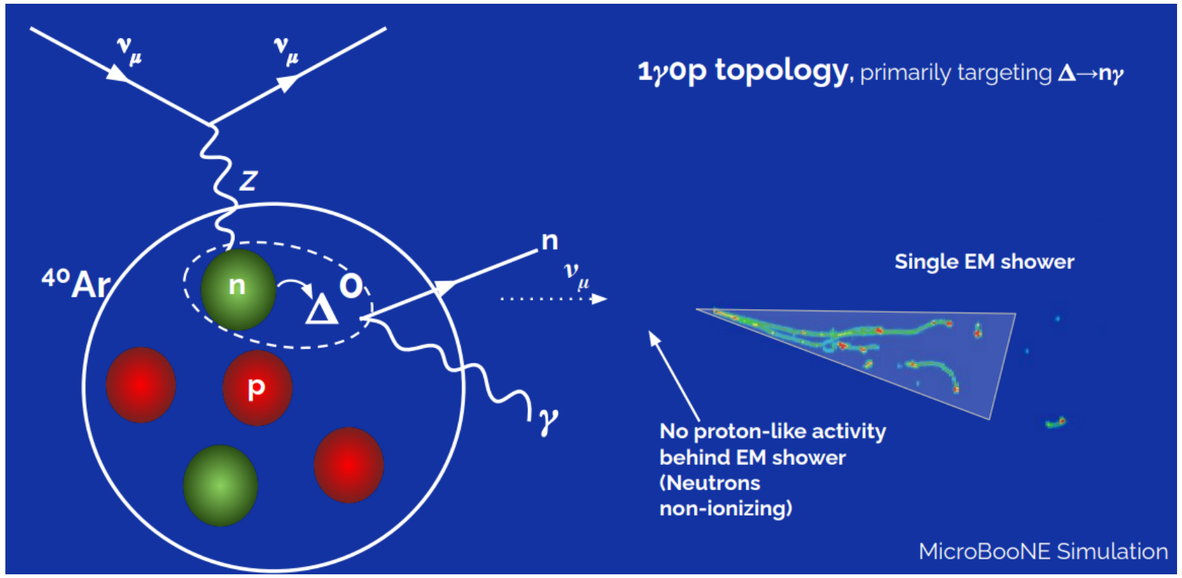
arxiv:2502.05750



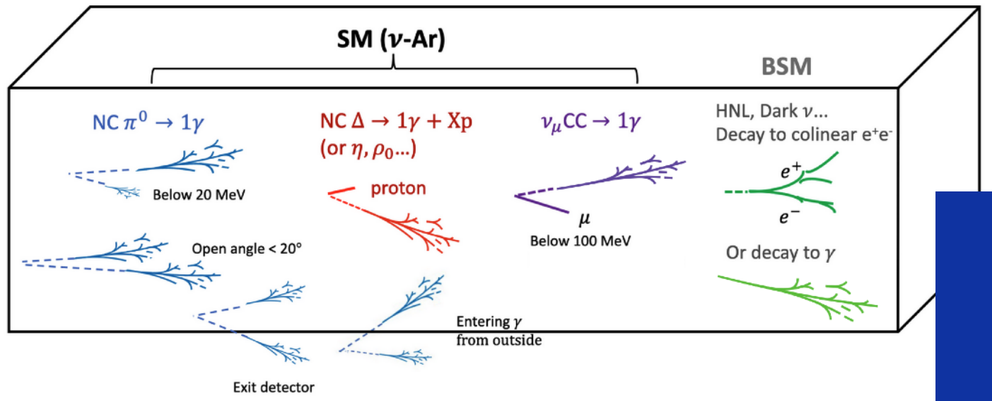


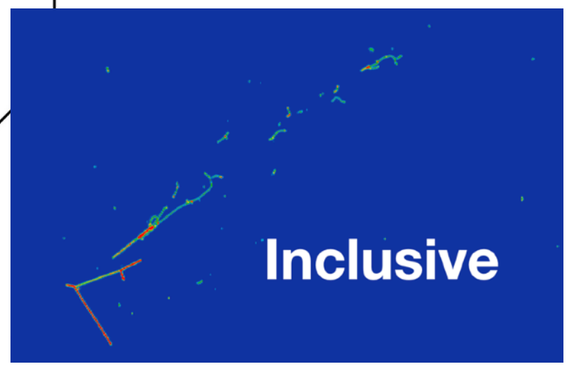
Currently Allowed!

Need further probes.

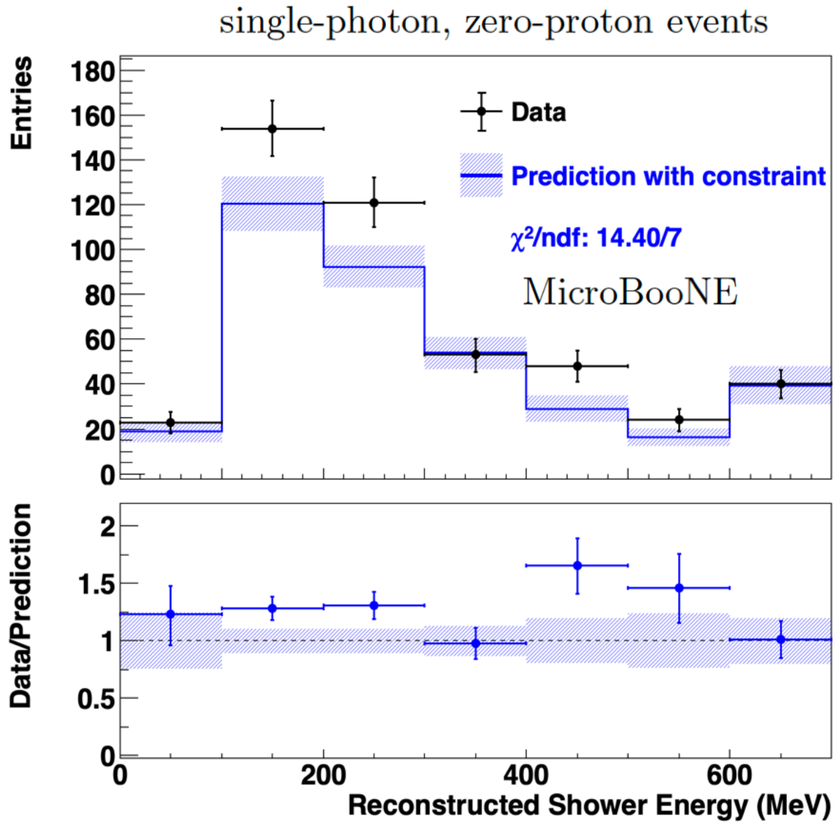
MicroBooNE: Photon-Like Searches

- Inclusive search for single photons
- See hint of excess (2.2σ) 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





Phys. Rev. Lett. **136**, 181806



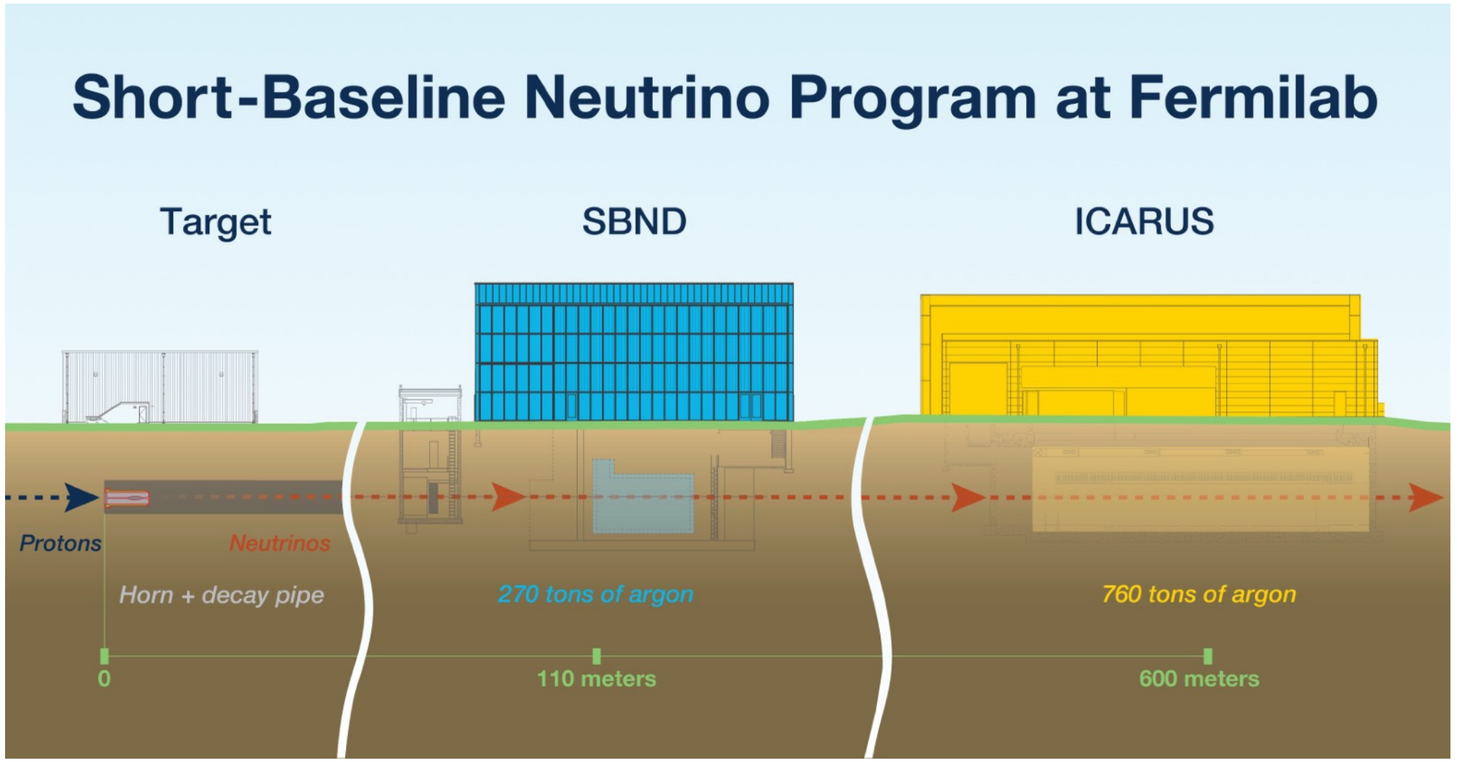
MicroBooNE

- Results so far disfavor an electron-like explanation for MiniBooNE anomaly
  - This would imply that the MiniBooNE excess is not the result of sterile oscillations
- Dedicated oscillation searches also rule out much of the MiniBooNE phase space
- Searches for photon-like explanations have shown some (mild) excesses and more work is ongoing in this area

The SBN Program at Fermilab

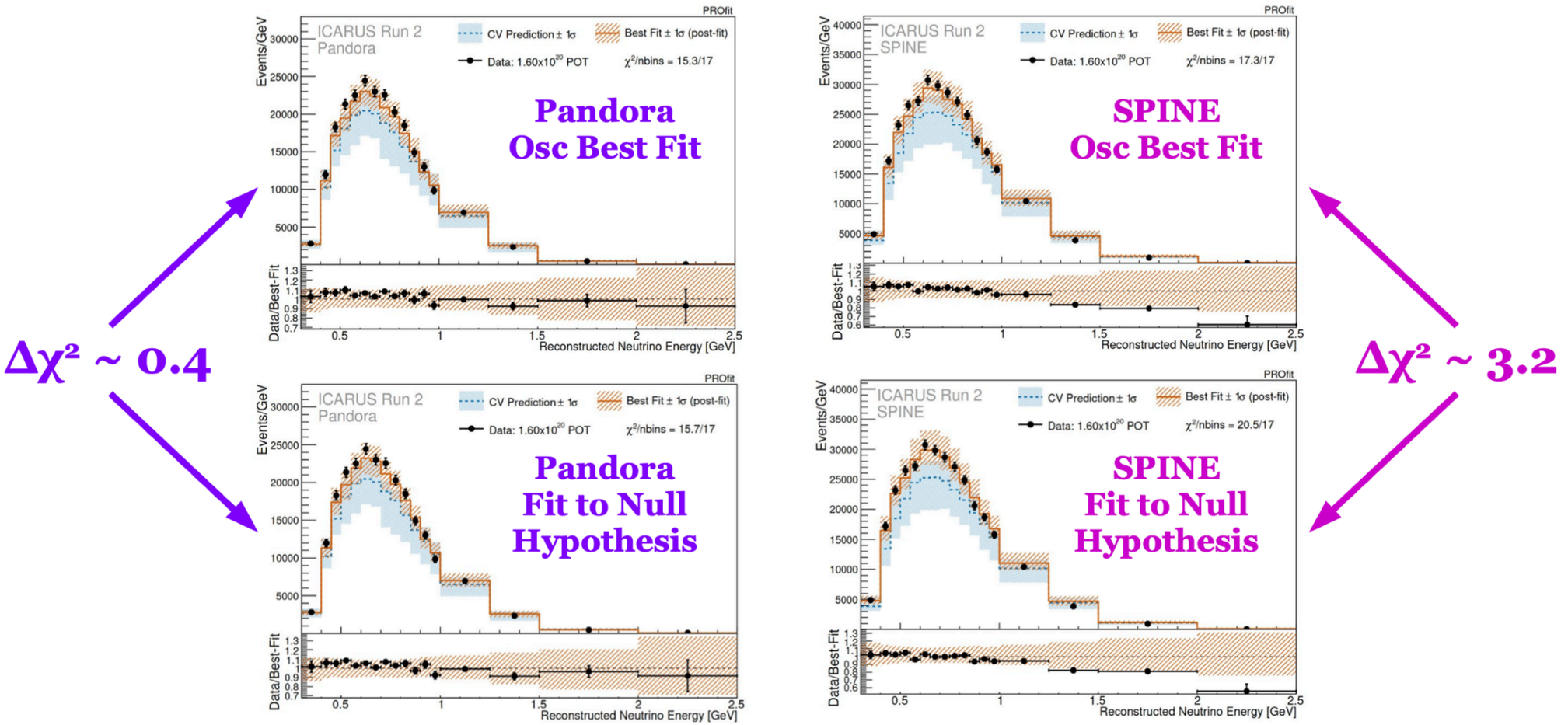
SBN Program

- The Short-Baseline Neutrino (SBN) Program at Fermilab includes SBND and ICARUS, both LArTPCs located in the BNB
- This multi-detector approach will enable sensitive searches for baseline-dependent short-baseline anomalies



ICARUS Single-Detector Analysis

- ICARUS has already performed a single-detector muon neutrino disappearance analysis, which sees no evidence of an anomaly



First Multi-Detector Analyses

- SBND and ICARUS are currently working together on the first joint SBN analyses
- SBN will eventually have the capability to probe more complex models, leveraging the near and far detectors together with the rich information provided by LArTPCs

So Now What?

What to Look Forward To

- Keep an eye out for future results from JSNS2, MicroBooNE, and SBN
- There is also proposed experiment BEST2, following up on BEST
- Honorable mentions to:
  - Sterile neutrino fits in NOvA, largely leveraging their near detector
  - Sterile neutrino fits in IceCube, probing short baseline L/E
  - Sterile neutrino searches with absolute neutrino mass measurements, where you can look for an additional kink in the energy spectrum from beta decays