Updated MiniBooNE Neutrino Oscillation Results within the Context of Global Fits to Short-Baseline Neutrino Data

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Outline

- LSND
- MiniBooNE
  - Old Data
  - New Data
- Global Fits
  - 3+1 Model
  - 3+1+Decay

LSND

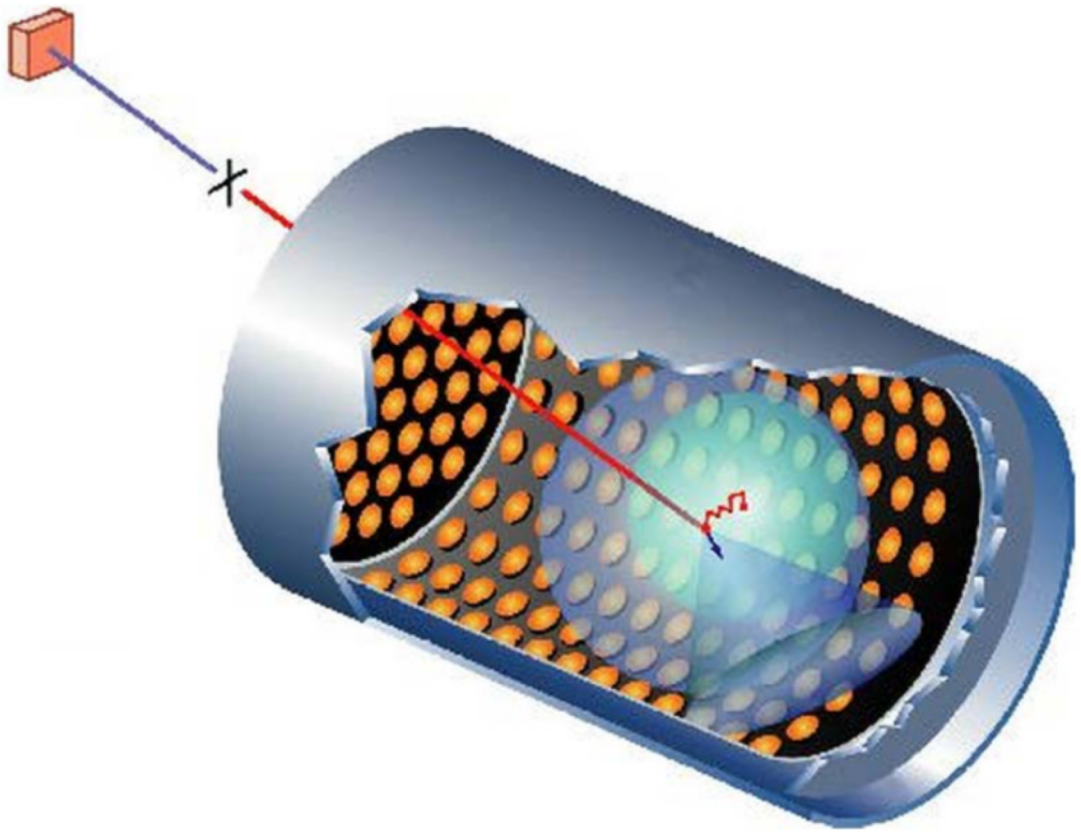
Liquid Scintillator Neutrino Detector

- LSND used a 800 MeV proton beam to impinge a target to create π^+, which would then decay-at-rest to a μ^+, which also decayed-at-rest:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \boxed{\bar{\nu}_\mu}$$

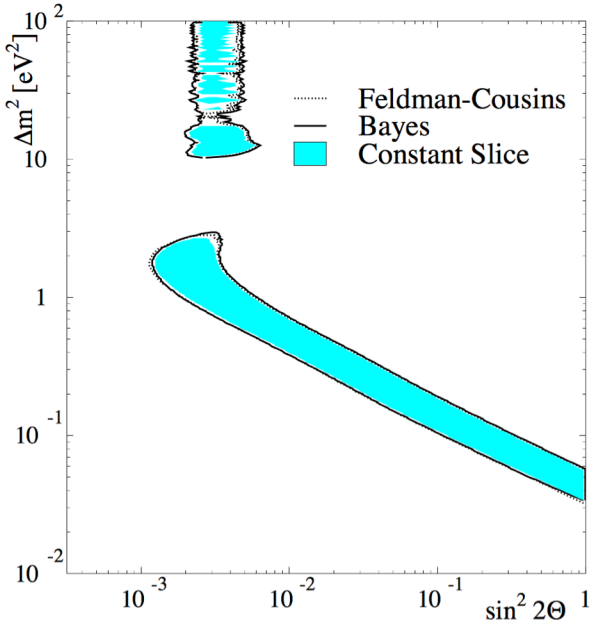
- Searched for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- Observed a 3.8σ excess of $87.9 \pm 22.4 \pm 6.0$ $\bar{\nu}_e$-like events above background.

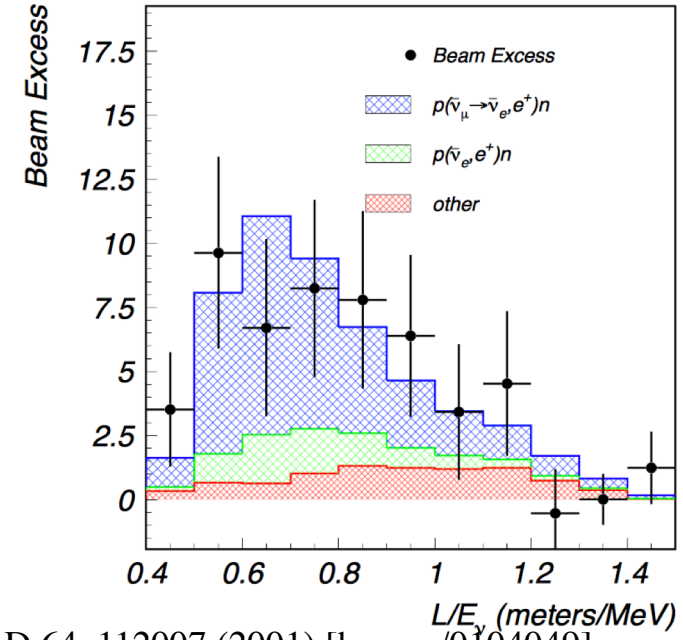


Liquid Scintillator Neutrino Detector

If interpreted as an oscillation from a two neutrino model, the results have a best fit of $\sin^2(2\theta) = 0.003$ and $\Delta m^2 = 1.2\ \mathrm{eV}^2$.

Would require at least one additional (sterile) neutrino





A. Aguilar-Arevalo et al. [LSND Collaboration], Phys. Rev. D 64, 112007 (2001) [hep-ex/0104049].

MINIBOONE

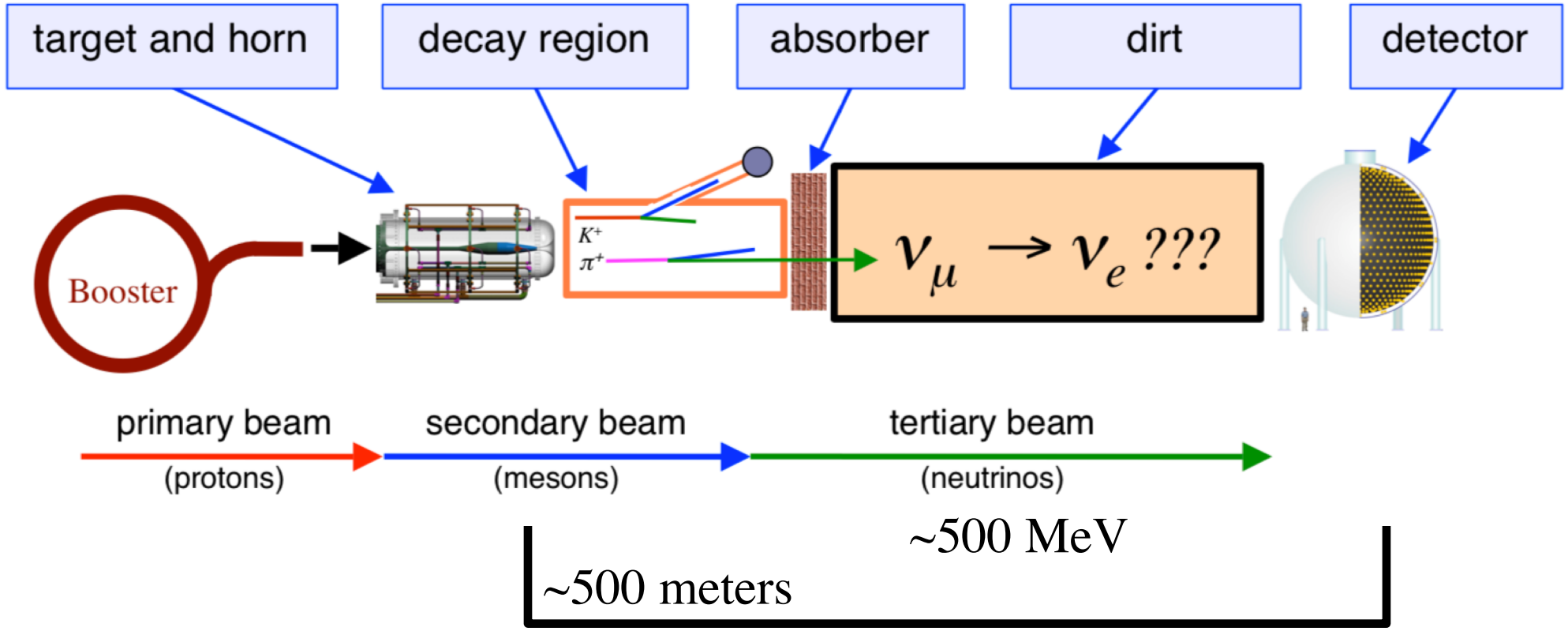
MiniBooNE

MiniBooNE was proposed to investigate the LSND anomaly. MinibooNE differed from LSND in several ways:

- Was Decay-in-Flight (DIF)
- Could choose between $\nu_\mu \rightarrow \nu_e$ or $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation searches
- $\sim 15\times$ larger energy and baseline, kept L/E approximately equal
- Higher backgrounds than LSND, but more statistics

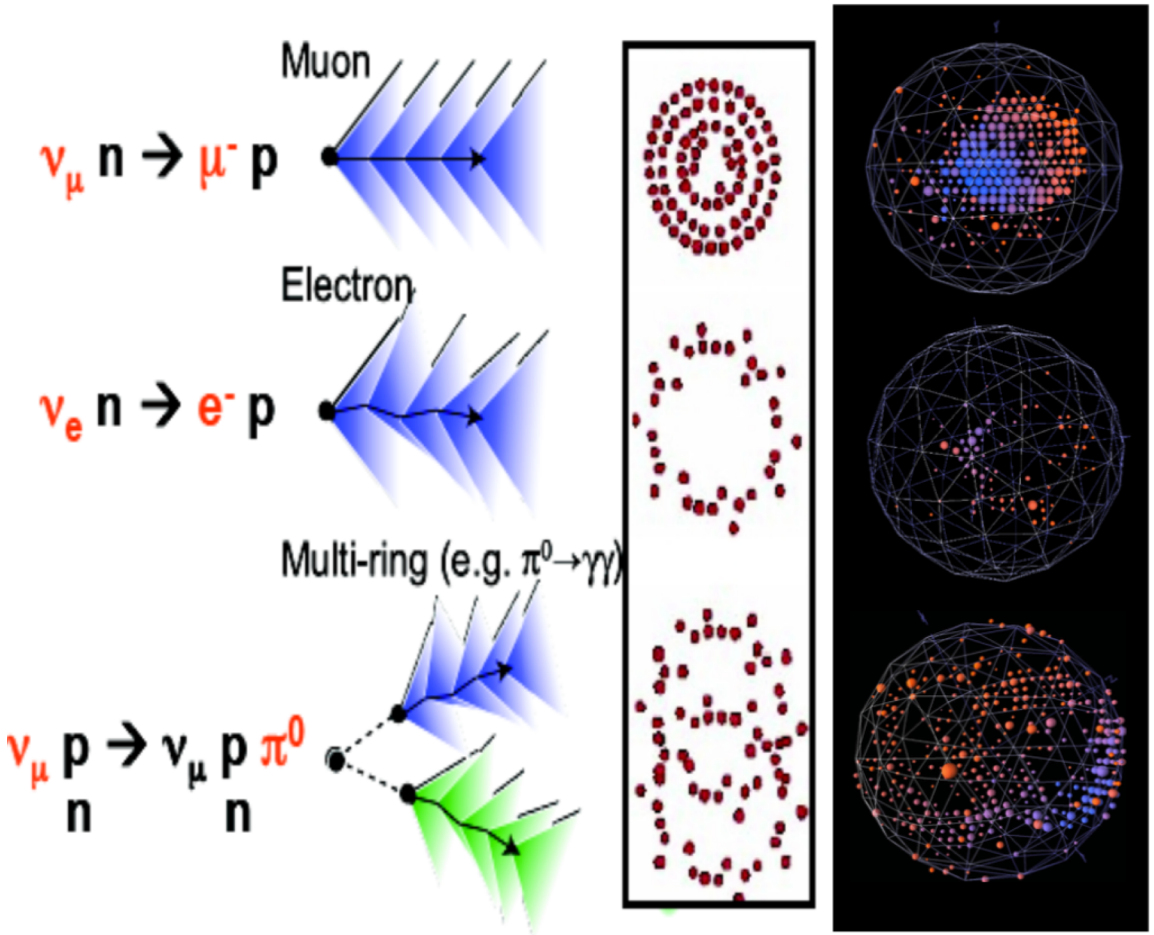
$$P\left(\nu_\mu \rightarrow \nu_e\right) = \sin^2(2\theta)\sin^2(1.27\frac{\Delta m^2 L}{E_\nu})$$

MiniBooNE


target and horn
decay region
absorber
dirt
detector
Booster
K^+
π^+
$\nu_\mu \rightarrow \nu_e$???
primary beam
(protons)
secondary beam
(mesons)
tertiary beam
(neutrinos)
~500 MeV
~500 meters

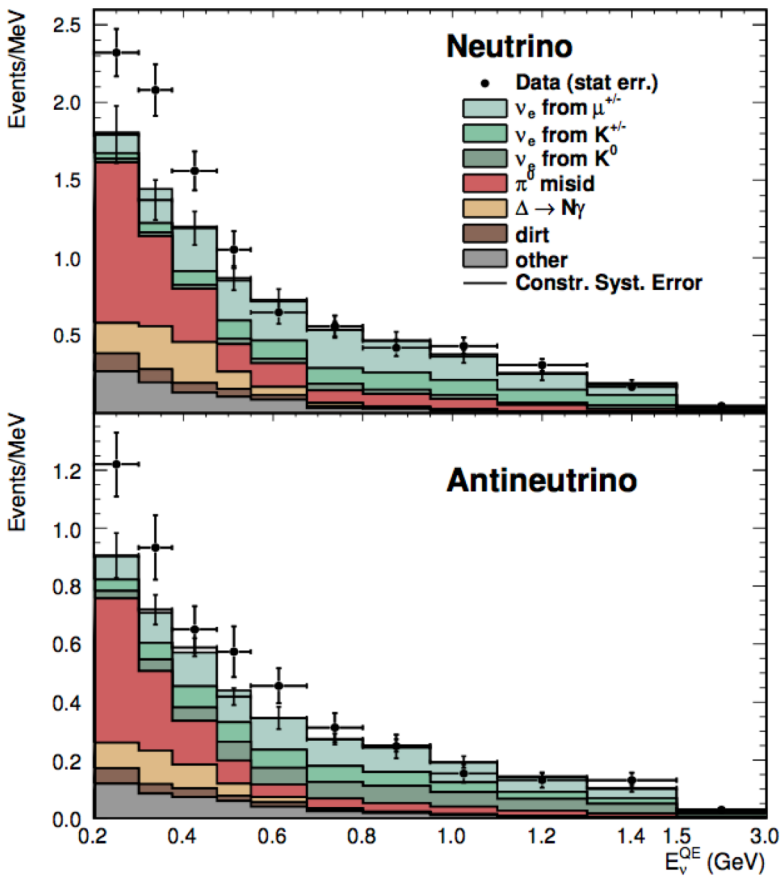
MiniBooNE

- Three typical event signatures
  - ν_μCCQE events deposits a sharp ring of photons to PMTs
  - ν_eCCQE events leaves a fuzzy ring
  - ν_μNC produce π^0, which decays to 2γ which leave a fuzzy ring each.
- Cannot distinguish between electron and single photon



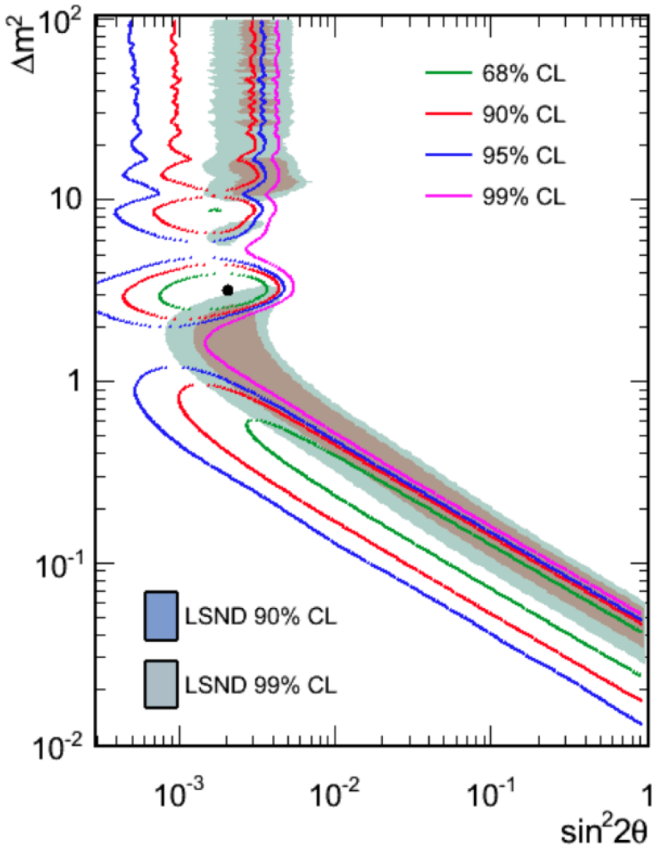
MiniBooNE – Old Results

- Neutrino mode saw an excess of 160.0 ± 47.8 above the null, primarily under 475 MeV, and almost none above
- Antineutrino mode saw an excess of 78.4 ± 28.5 events, both above and below 475 MeV
- Antineutrino mode was consistent with LSND, but neutrino mode saw some tension.

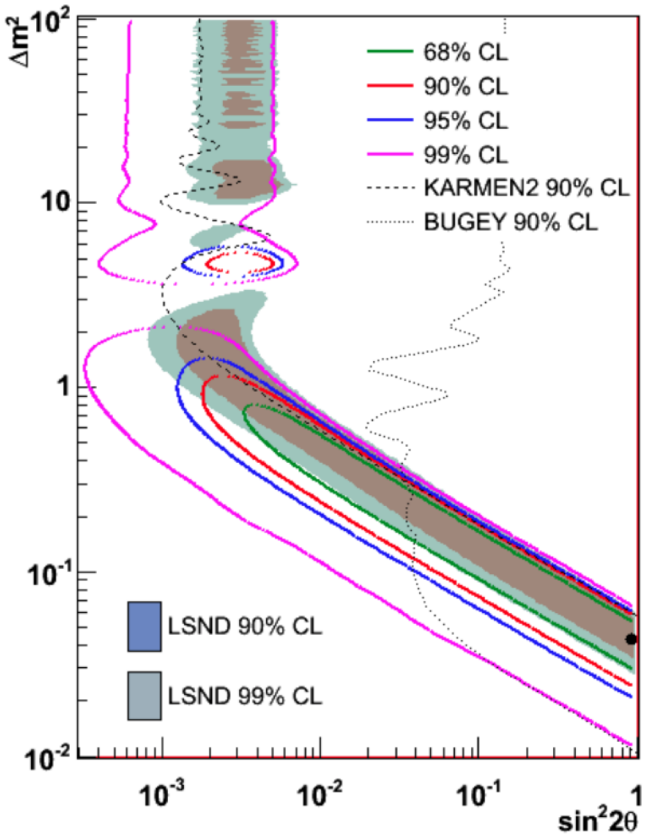


MiniBooNE – Old Results

Neutrino Mode



Anti-Neutrino Mode

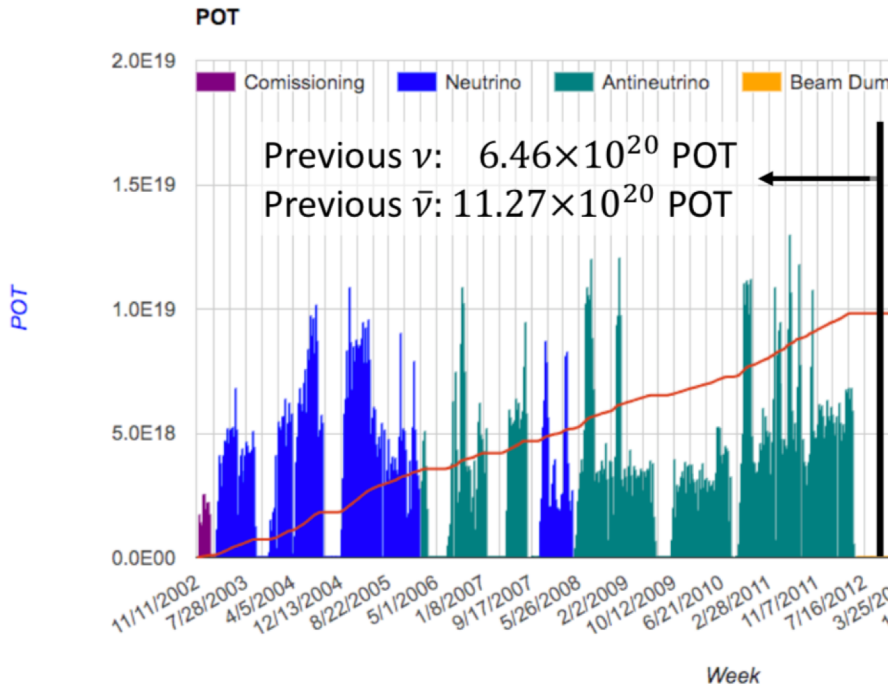


MiniBooNE – New Data Set

Up to 2012

ν mode: 6.46×10^{20}POT

$\bar{\nu}$ mode: 11.27×10^{20}POT

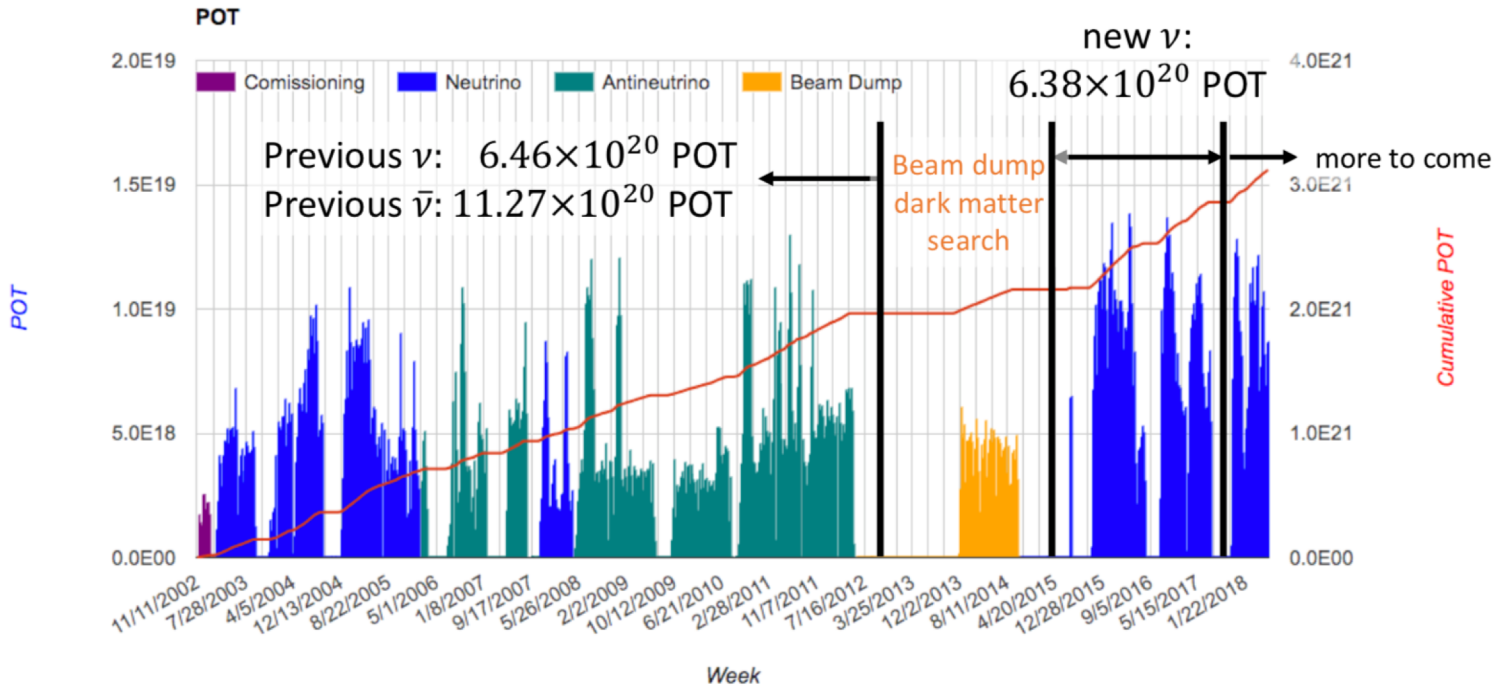


MiniBooNE – New Data Set

Up to 2012
ν mode: 6.46×10^{20}POT
$\bar{\nu}$ mode: 11.27×10^{20}POT

Doubled ν data!

Now 2012
ν mode: 12.84×10^{20}POT
$\bar{\nu}$ mode: 11.27×10^{20}POT

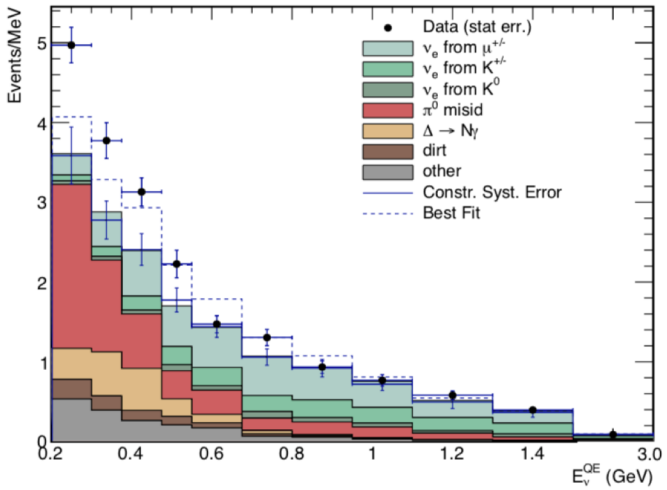


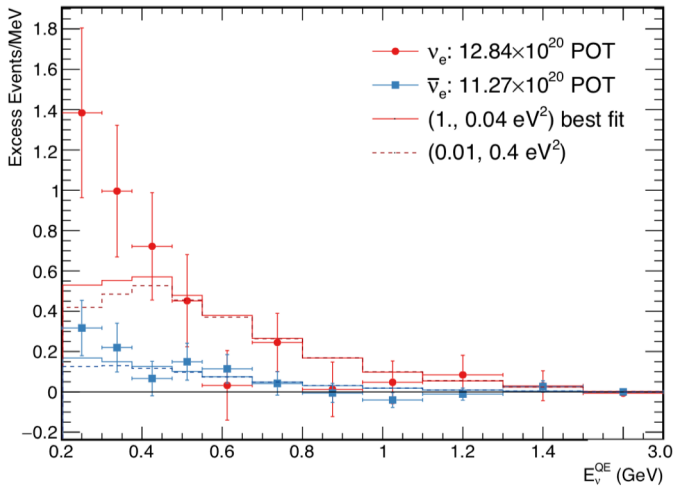
MiniBooNE – New Data Set

Total neutrino data observes an excess of 381.2 ± 85.2 (4.5σ) ν_e-like events.

Combined with antineutrino data, total excess is 460.5 ± 95.8 (4.8σ)

Neutrino and Antineutrino excess become consistent with each other.

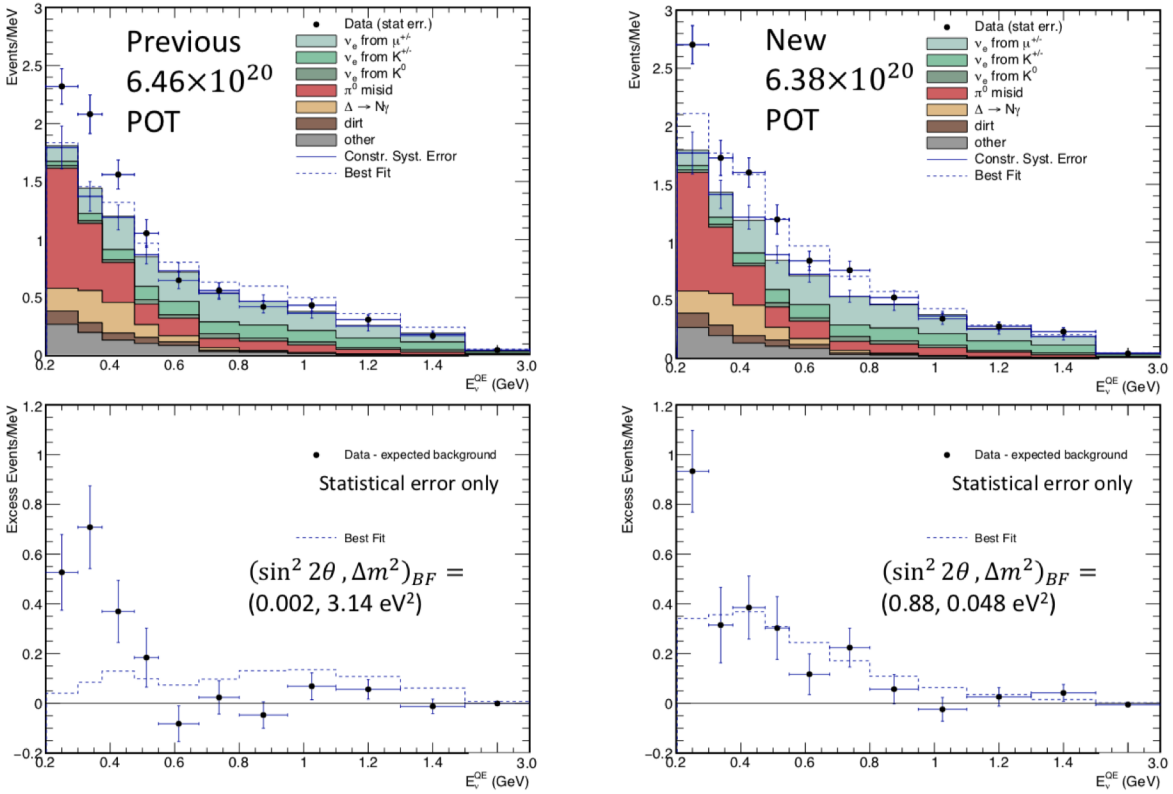




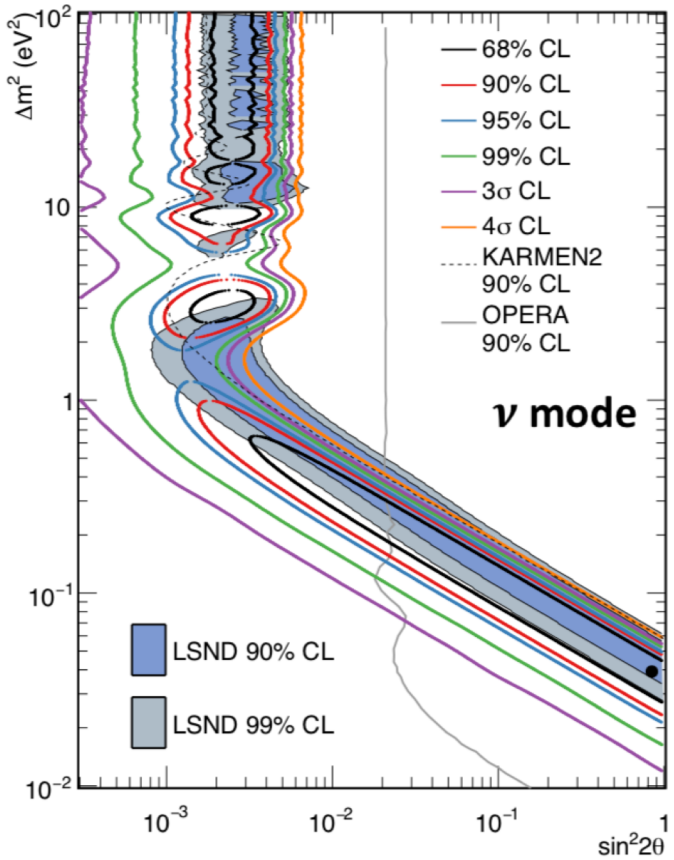
A.A. Aguilar-Arevalo et al. [MiniBooNE Collaboration], arXiv:1805.12028

MiniBooNE – New Data Set

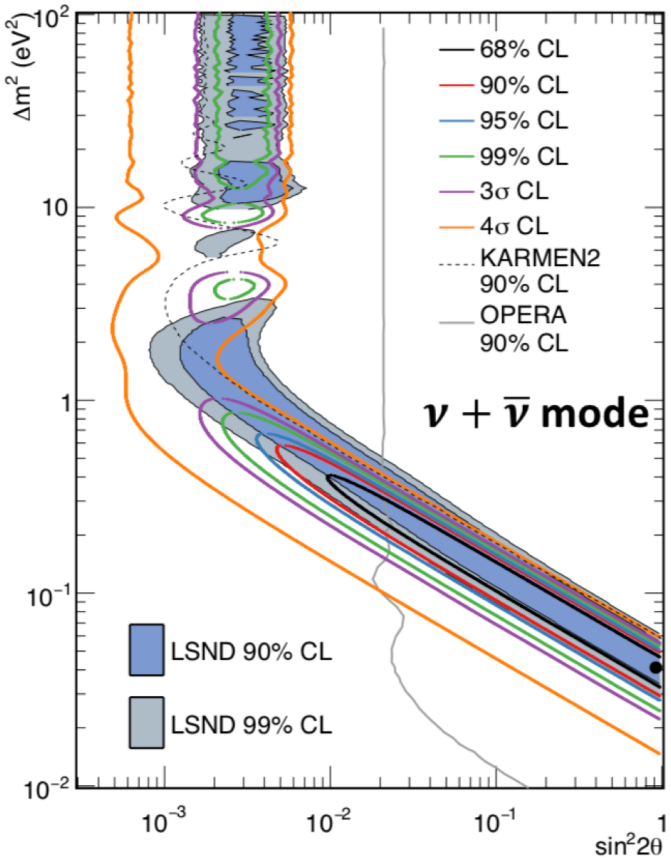
Comparing Old and New neutrino data, we find the two distributions to be consistent (KS test = 76%)



MiniBooNE – New Data Set



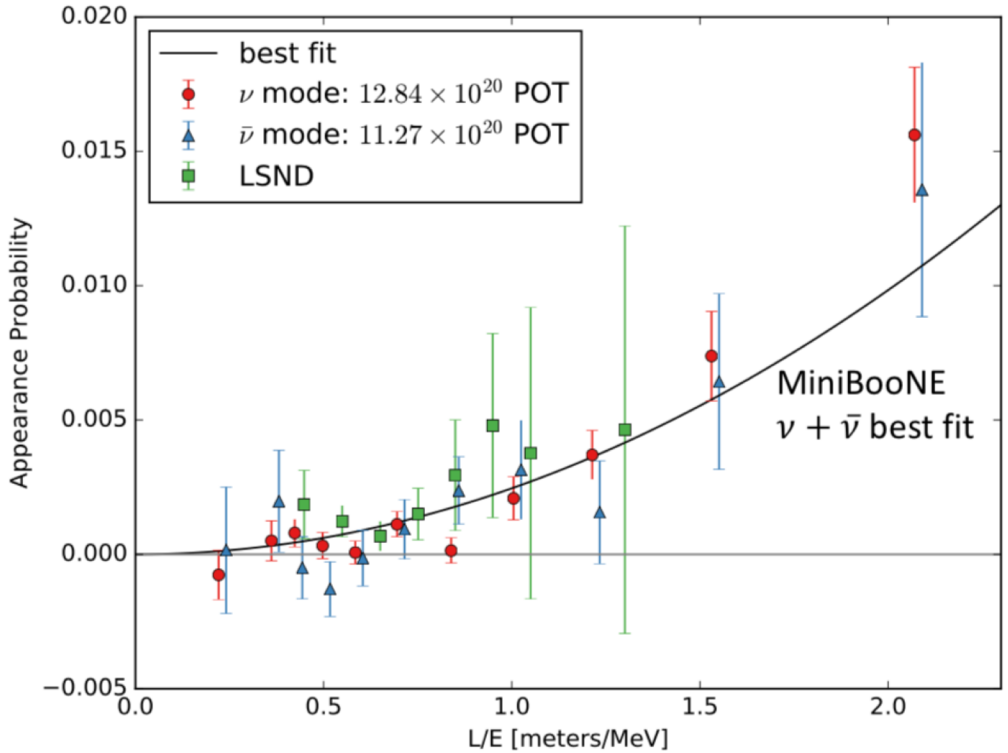
$(\Delta m^2, \sin^2 2\theta) = (0.037\ \mathrm{eV}^2, 0.958)$
$\chi^2/ndf = 10.0/6.6$ (prob = 15.4%)



$(\Delta m^2, \sin^2 2\theta) = (0.041\ \mathrm{eV}^2, 0.958)$
$\chi^2/ndf = 19.5/15.4$ (prob = 20.1%)

MiniBooNE – New Data Set

- The MiniBooNE excess is now consistent with LSND's excess.
- Combined fit of MiniBooNE + LSND data gives a significance of 6.1σ



MiniBooNE – Summary

- MiniBooNE has doubled it's neutrino mode data set
- Neutrino and antineutrino data are now consistent with LSND oscillations
- MiniBooNE will continue to take data, and future analysis will include improve on background constraints.
- MicroBooNE will confirm if excess is due to electrons or photons.

GLOBAL FITS

$\bar{\nu}_\mu \to \bar{\nu}_e$ or $\nu_\mu \to \nu_e$

LSND: $\bar{\nu}_\mu \to \bar{\nu}_e$

KARMEN: $\bar{\nu}_\mu \nrightarrow \bar{\nu}_e$

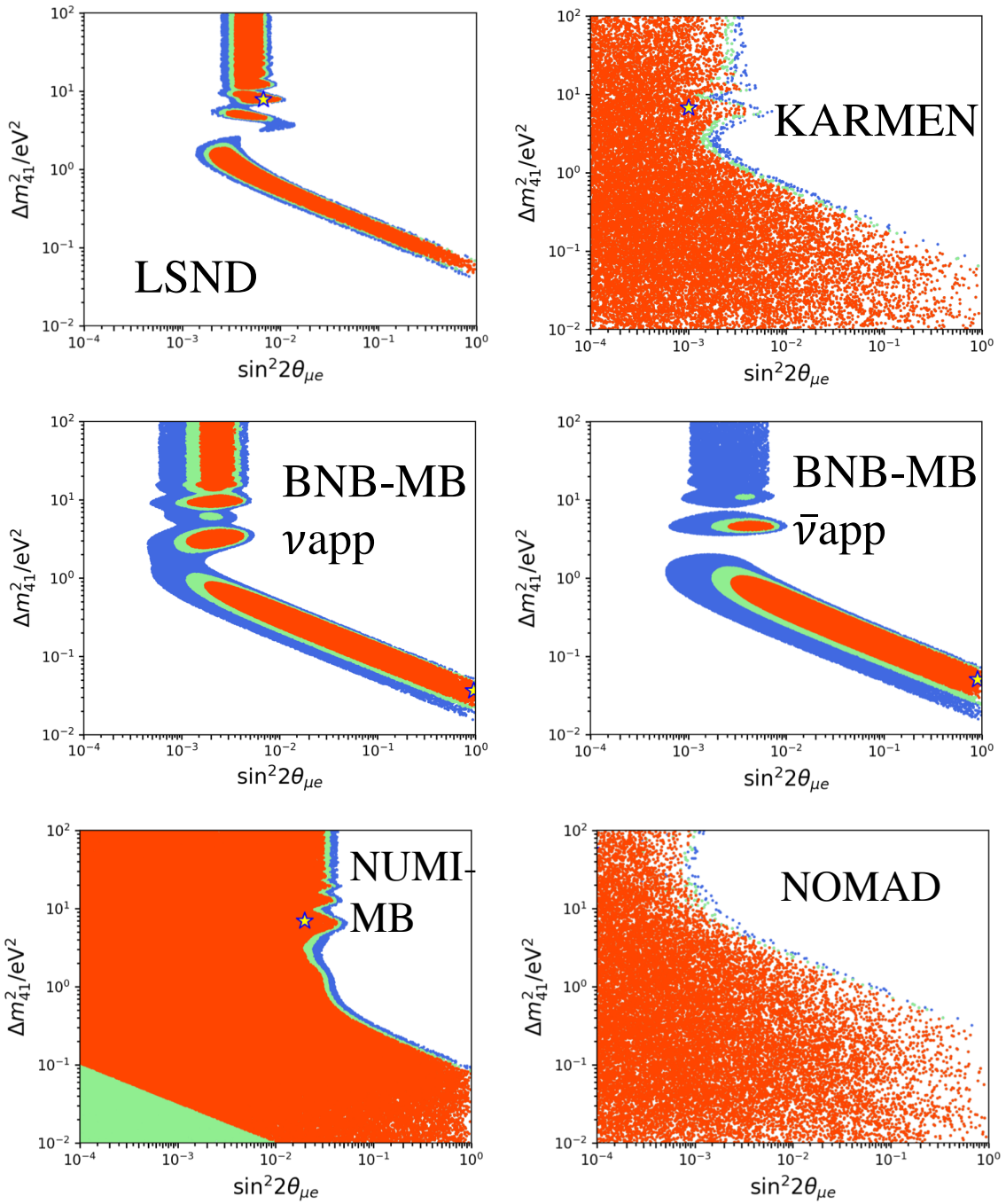
MiniBooNE:

BNB: $\nu_\mu \to \nu_e$

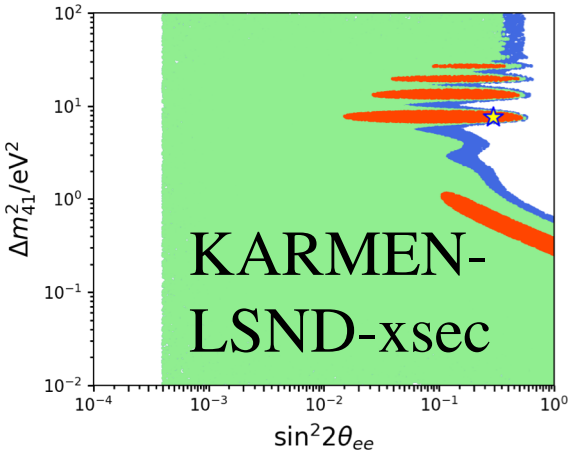
$\bar{\nu}_\mu \to \bar{\nu}_e$

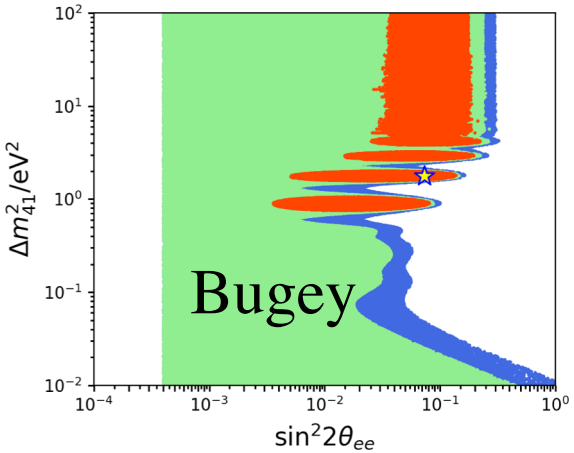
NuMI: $\nu_\mu \nrightarrow \nu_e$

NOMAD: $\nu_\mu \nrightarrow \nu_e$



$\nu_e \to \nu_e$ or $\bar{\nu}_e \to \bar{\nu}_e$

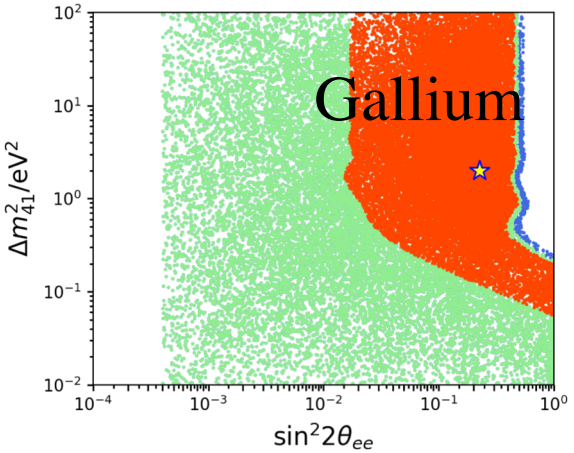




KARMEN/LSND: $\nu_e \nrightarrow \nu_e$

BUGEY: $\bar{\nu}_e \to \bar{\nu}_e$

Gallium: $\nu_e \to \nu_e$



$\nu_\mu \to \nu_\mu$ or $\bar{\nu}_\mu \to \bar{\nu}_\mu$

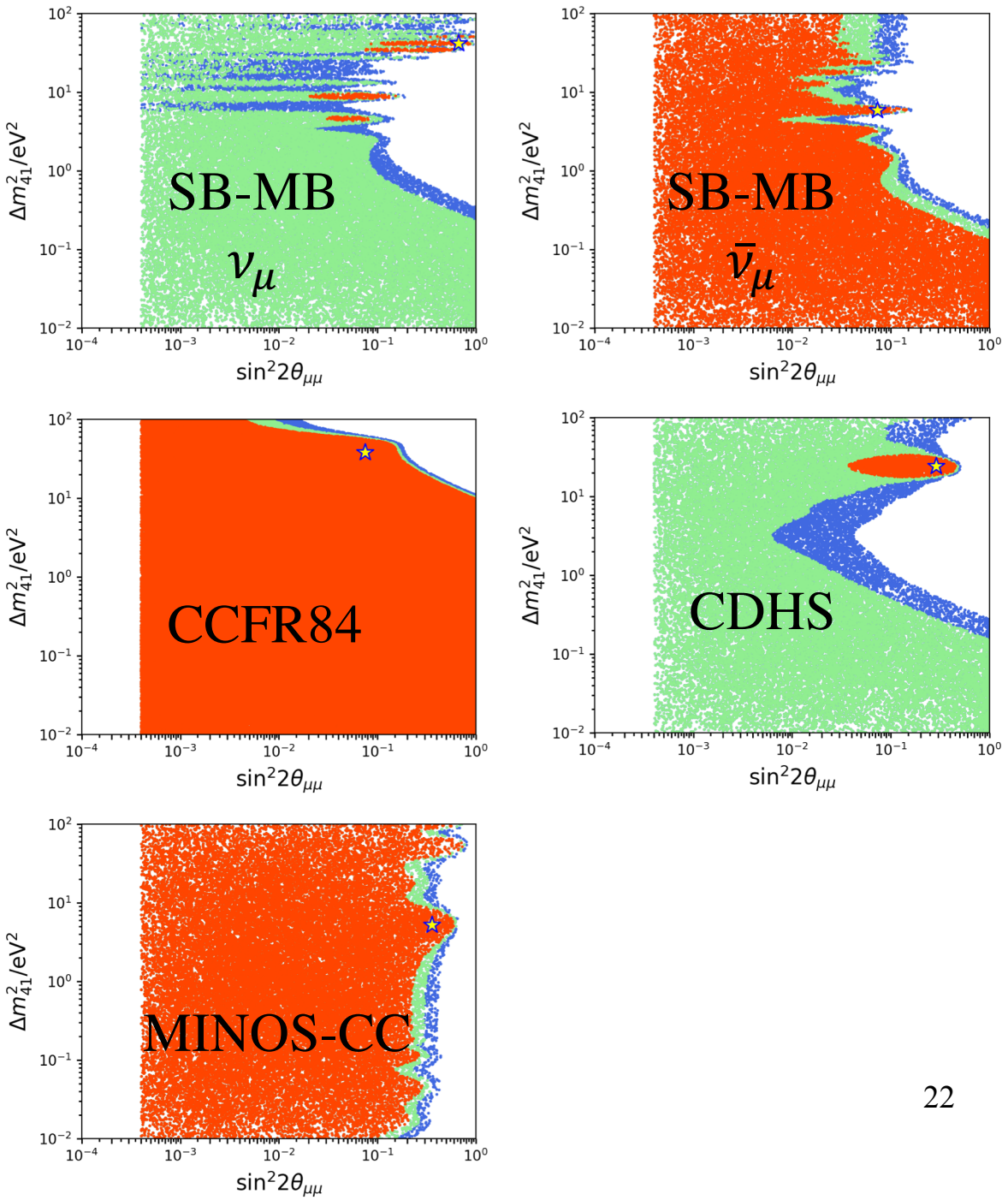
SciBooNE-MB: $\nu_\mu \nrightarrow \nu_\mu$
$\bar{\nu}_\mu \nrightarrow \bar{\nu}_\mu$

CCFR84: $\nu_\mu \nrightarrow \nu_\mu$

CDHS: $\nu_\mu \nrightarrow \nu_\mu$

MINOS: $\overline{\nu_\mu} \nrightarrow \overline{\nu_\mu}$

ATM: $\nu_\mu \nrightarrow \nu_\mu$



3+1: All Data

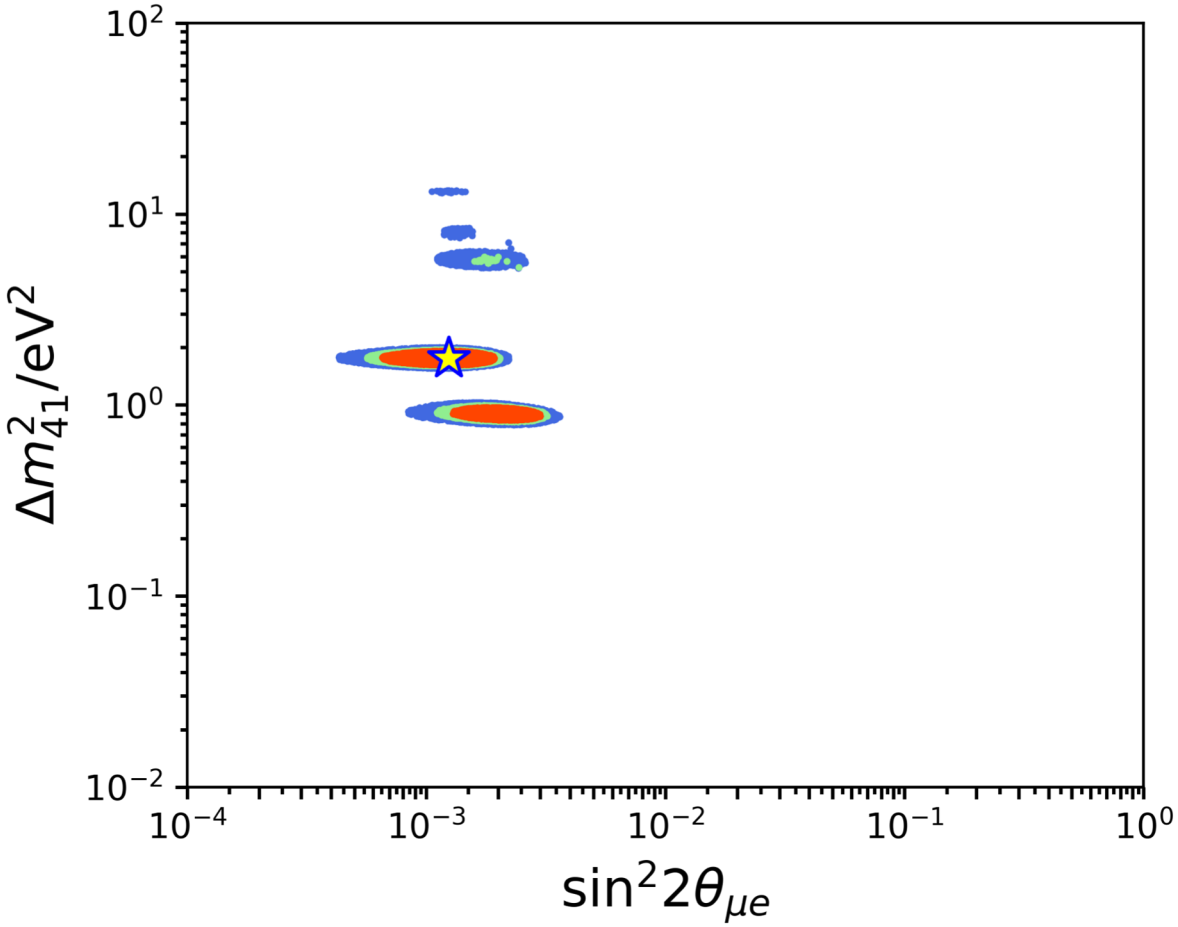
Best fit:

$$\Delta m^2_{41} = 1.75 \text{ eV}$$
$$|U_{e4}| = 0.159$$
$$|U_{\mu 4}| = 0.110$$

$$\sin^2(2\theta_{\mu e}) = 1.24\times10^{-3}$$

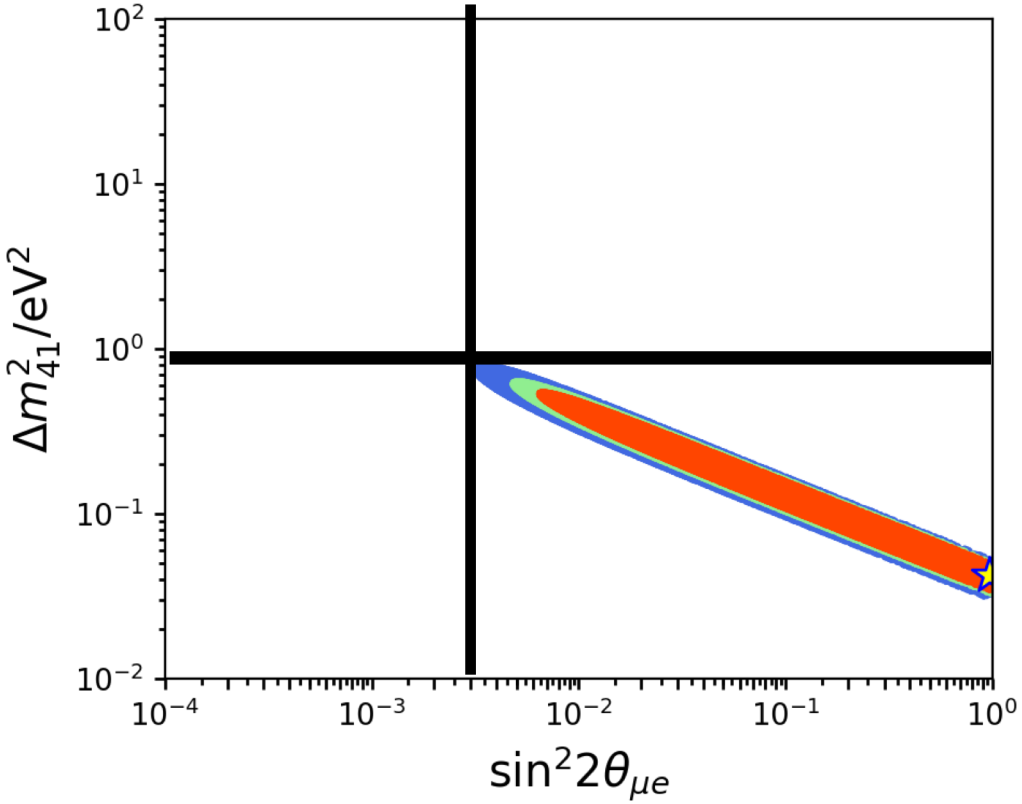
$$\chi^2 = 297 \text{ (318 dof)}$$
$$\chi^2_{null} = 329 \text{ (315 dof)}$$

$$\Delta\chi^2_{null-min}(\text{dof}) = 32 \text{ (3)}$$

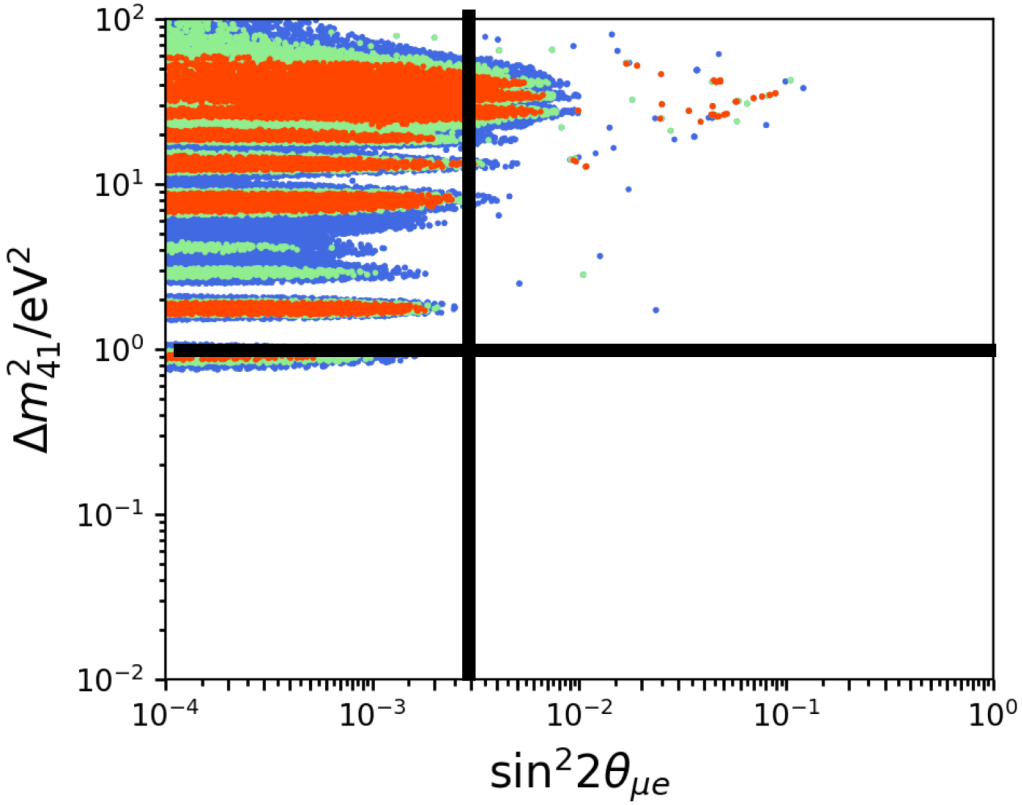


Tension

Appearance

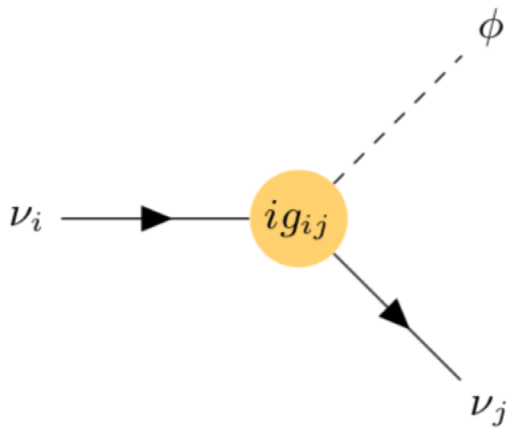


Disappearance



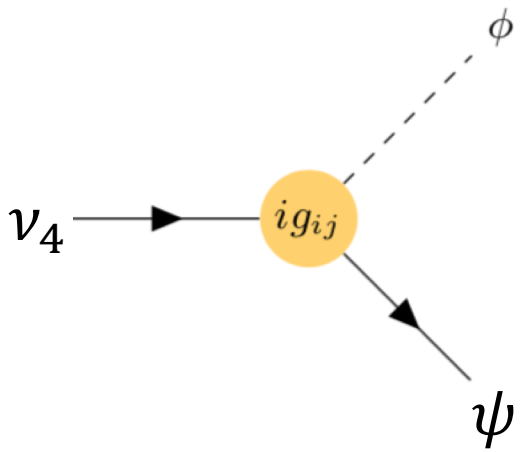
3+1+DECAY (PRELIMINARY)

Sterile Neutrino Decay



Visible Decay

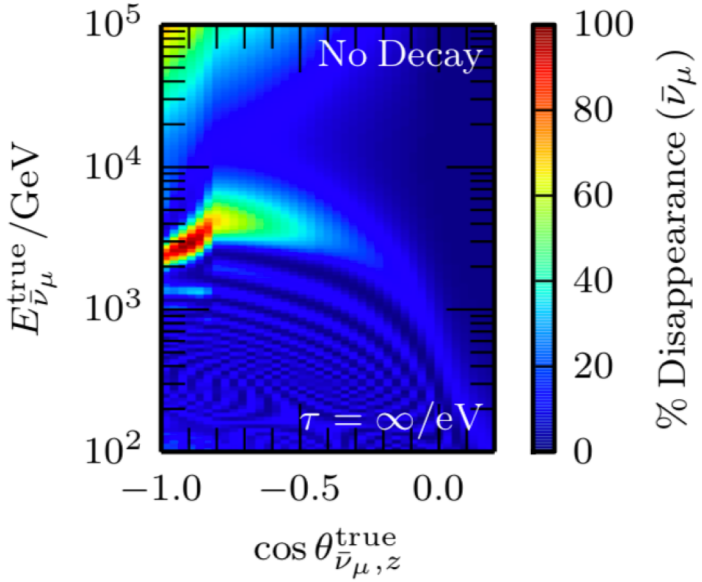
Our Model



Invisible Decay

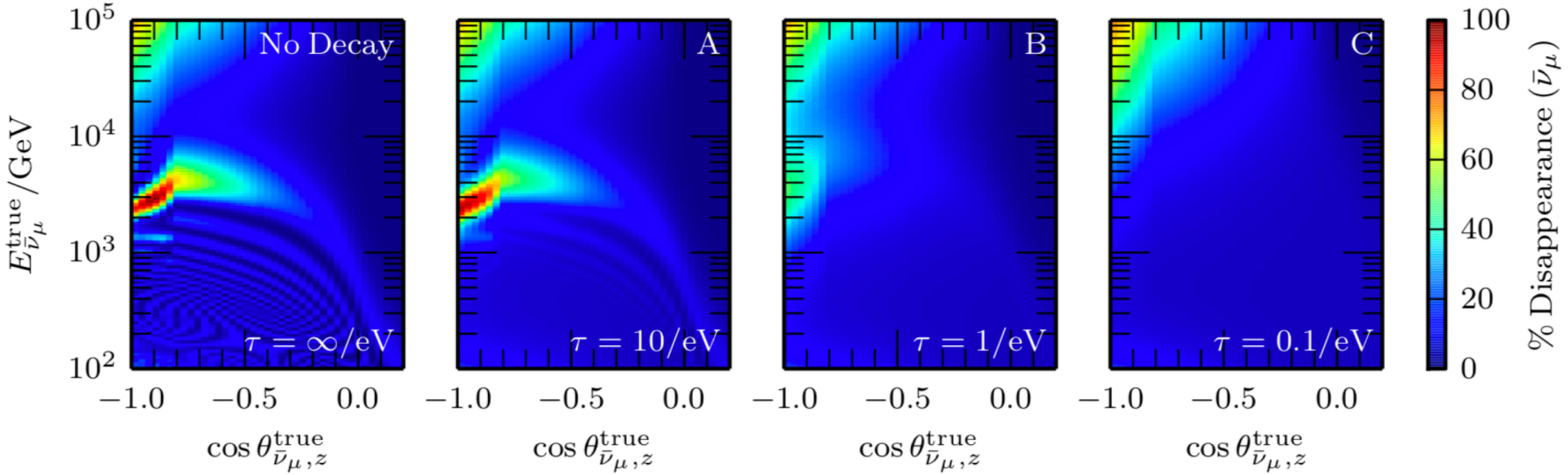
Sterile Neutrino Decay - Motivation

- As an example, consider IceCube's Sterile Neutrino Search. Due to matter effects, a sterile neutrino in the preferred parameter spaces would lead to resonance effects that would strengthen atmospheric ν_μ disappearance.



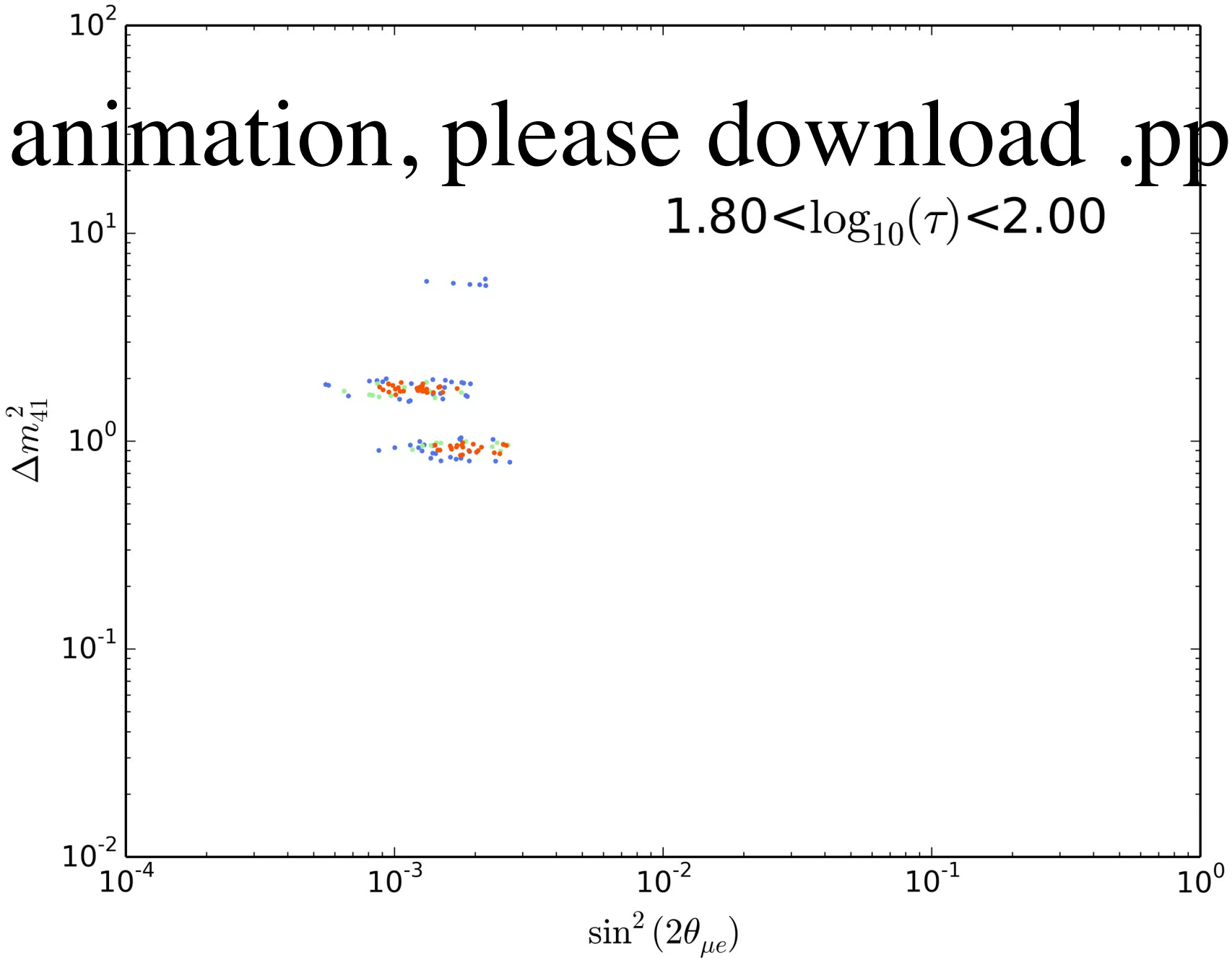
Sterile Neutrino Decay - Motivation

- But giving ν_4 a finite lifetime would result in decoherence in neutrino propagation, resulting in no enhancement in ν_μ disappearance.



Zander Moss, et al., arXiv:1711.05921 [hep-ph] (2017).

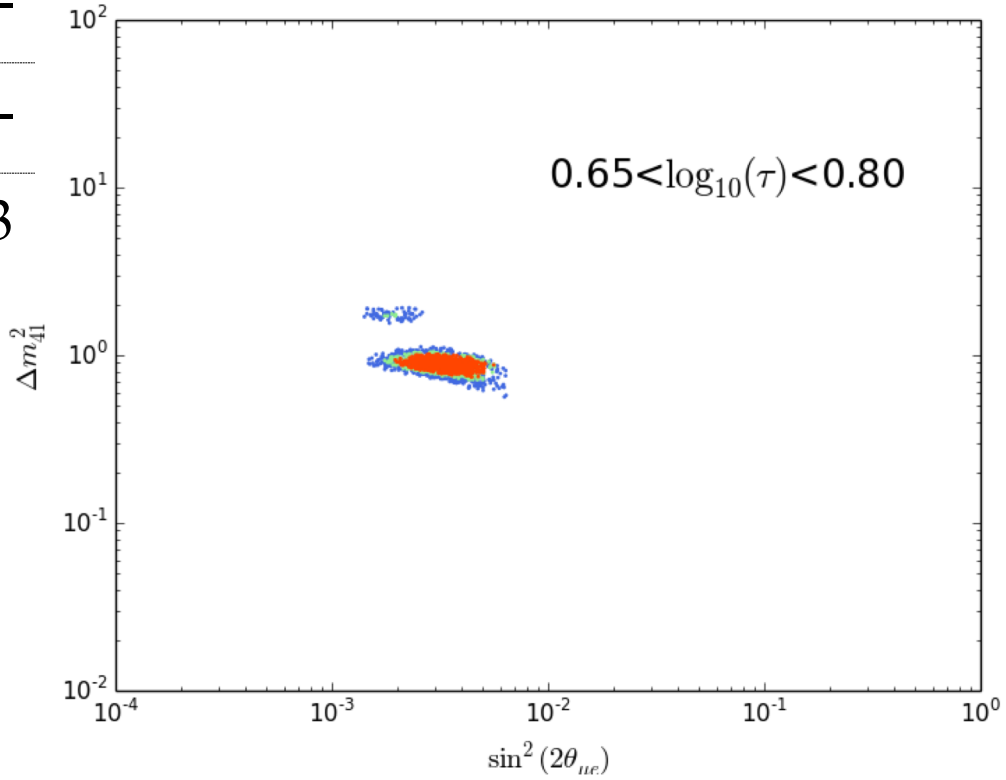
For animation, please download .pptx file



Sterile Neutrino Decay - Best Fit

Best Fit	$\Delta m^2 (eV^2)$	$\lvert U_{e4} \rvert$	$\lvert U_{\mu 4} \rvert$	$\tau\ (eV^{-1})$
Null	---	---	---	---
3+1	1.75	0.16	0.11	---
3+1+Decay	0.89	0.21	0.14	5.3

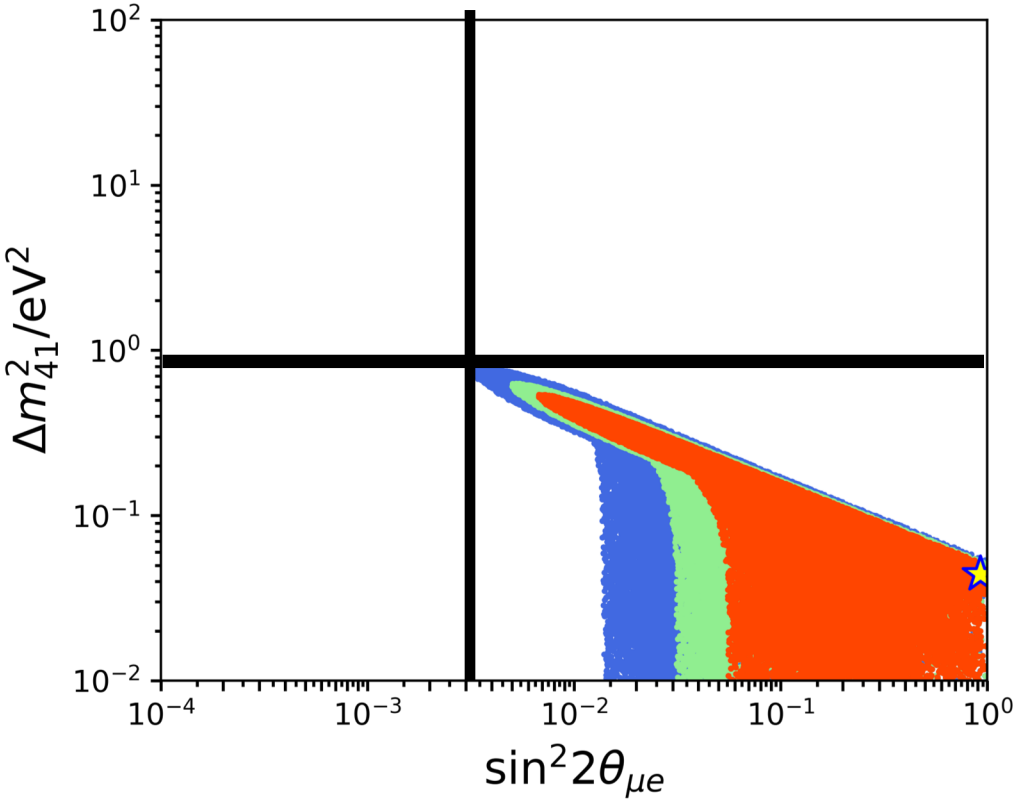
Best Fit	Min. χ^2(dof)	$\Delta\chi^2$(dof)
Null	328.8 (315)	---
3+1	297.1 (312)	31.7 (3)
3+1+Decay	290.6 (311)	38.2 (4)



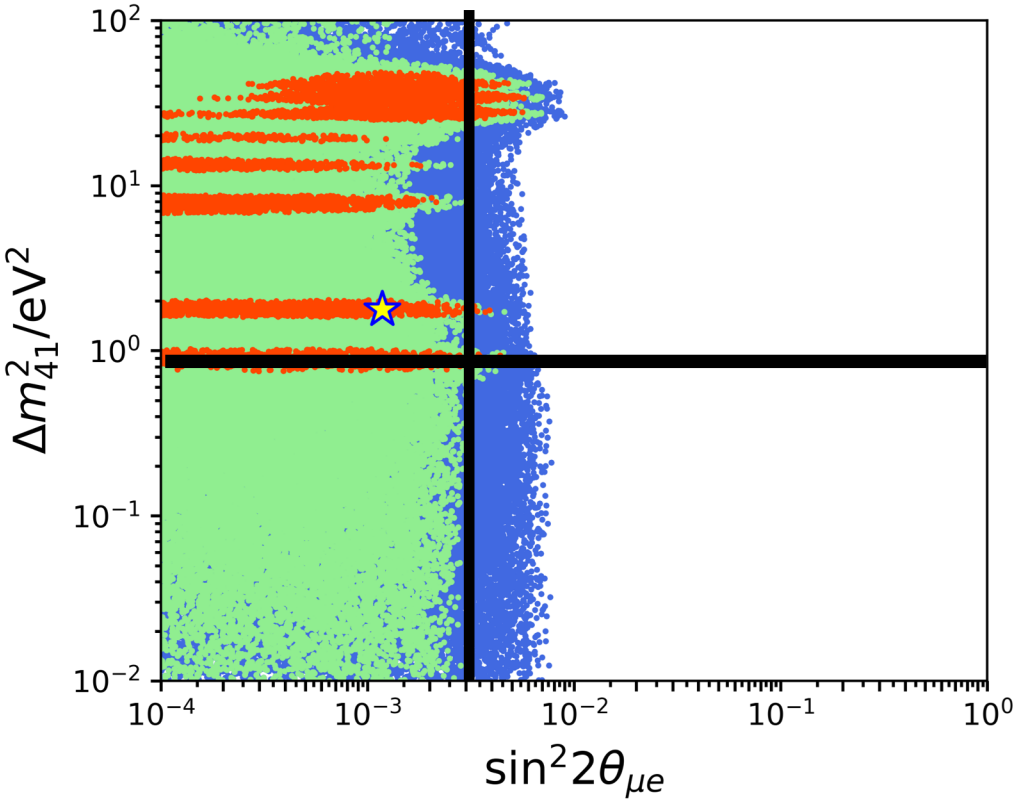
DOES DECAY RELIEVE TENSION?

Tension is still there

Appearance



Disappearance



Conclusion

- MiniBooNE
  - Neutrino data doubled
  - Confirms previous neutrino and antineutrino anomaly to 4.8σ
  - MiniBooNE excess is consistent with self and LSND.
- Sterile Neutrino Global Fit
  - Introduced in an attempt to relieve tensions seen in global fit
  - Best fit of $\tau \approx 5\ eV^{-1}$ found
  - Modest relief in tension

Future

- MiniBooNE will continue to collect neutrino data as the SBN program proceeds. Improvements in analysis await.
- Await to see from MicroBooNE to see if excess is due to ν_e or photons.
- Expand global fits to include new reactor experiments, such as NEOS and DANSS, and incorporate IceCube. Paper coming soon!
- Refine neutrino decay model.

THANK YOU!
QUESTIONS?