Accelerator neutrino searches for eV-scale sterile neutrinos

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Introduction

- I will give a brief review of the main accelerator-based neutrino experimental searches for eV-scale sterile neutrinos
  - Both short-baseline and long-baseline searches

- Appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$
- Disappearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ and $\nu_\mu \rightarrow \nu_\mu$
- NC Disappearance: $1 - (\nu_\mu \rightarrow \nu_s)$

- I'll predominantly stick with published results but will include a couple of results presented this summer

- I'll close with a few comments on future measurements

Parameter dependencies

- Expanded 4x4 PMNS matrix has the following form:

$$\begin{pmatrix} & U_{PMNS} & & U_{e4} \\ & & & U_{\mu 4} \\ & & & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

- Appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$
  - Sensitive to both θ_{14} and θ_{24}
- Disappearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ and $\nu_\mu \rightarrow \nu_\mu$
  - Sensitive to θ_{24}
- NC Disappearance: $1 - (\nu_\mu \rightarrow \nu_s)$
  - Sensitive to θ_{24} and θ_{34}

3+1 hypothesis:

$$|U_{e4}|^2 = \sin^2\theta_{14}$$

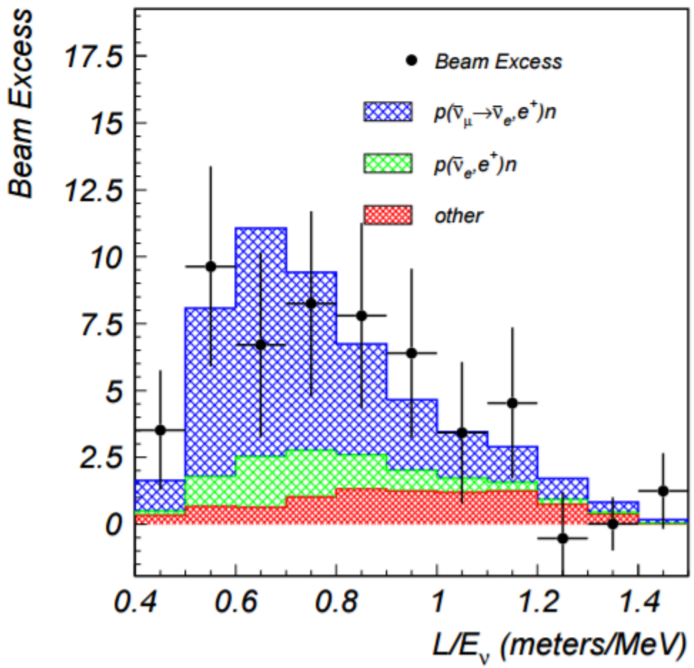
$$|U_{\mu 4}|^2 = \sin^2\theta_{24}\cos^2\theta_{14}$$

$$|U_{\tau 4}|^2 = \sin^2\theta_{34}\cos^2\theta_{24}$$

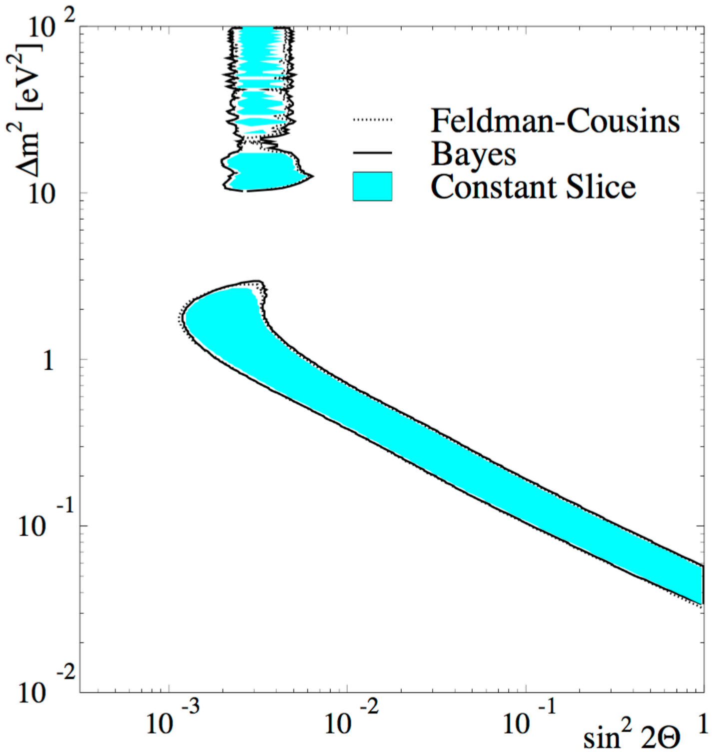
All depend on a new mass splitting Δm^2_{41}

LSND

- The story of the 1eV^2 scale sterile (anti)neutrino starts with LSND
- Saw an excess of electron-like events in short-baseline $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - Beam came from stopped pion decay



Excess: $87.9 \pm 22.4 \pm 6.0$

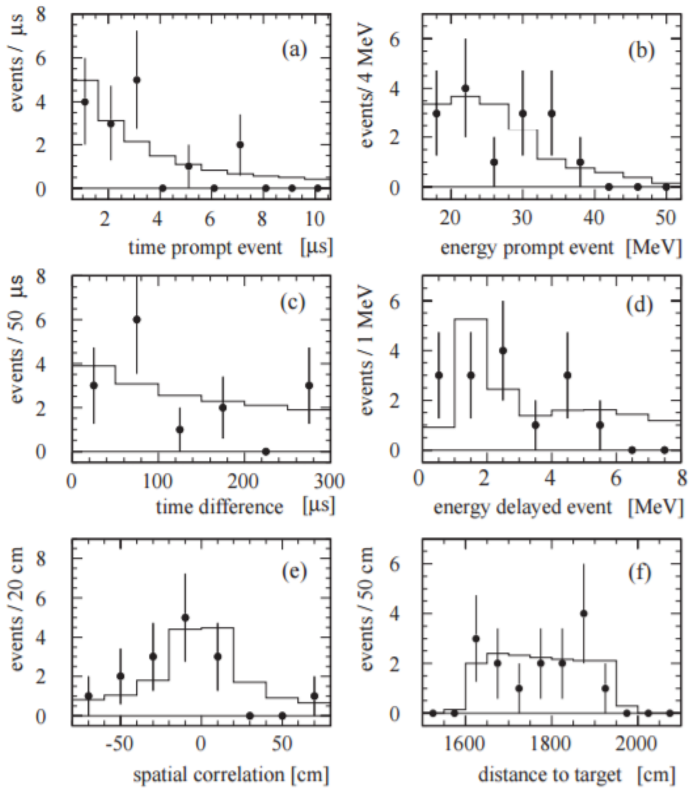


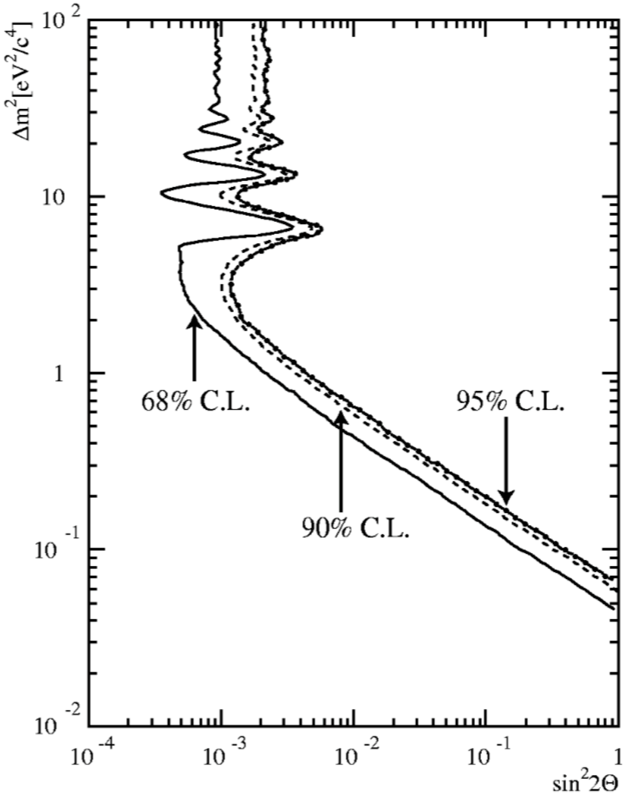
$$\sin^2 2\theta = \sin^2 2\theta_{14} \sin^2 \theta_{24}$$

A. Aguilar-Arevalo et al. Phys. Rev. D64 (2001), p. 112007.

KARMEN2

- KARMEN2 also searched for short-baseline $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations but saw no signal

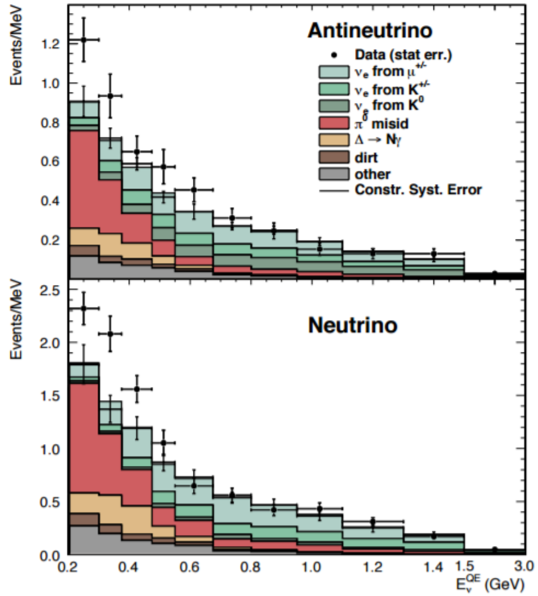


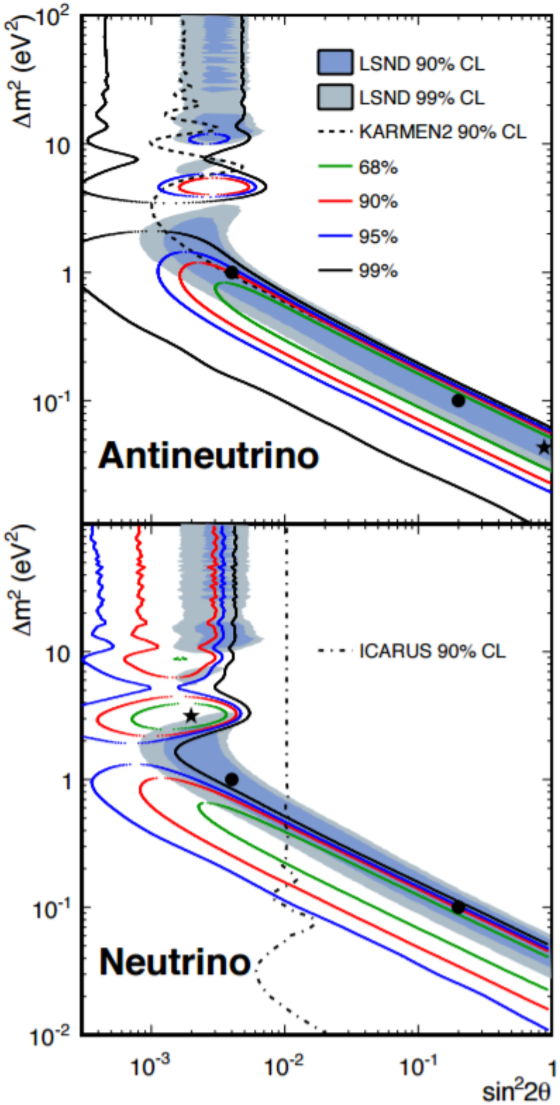


Church et al. Phys. Rev. D66 (2002), p. 013001.

MiniBooNE

- Short-baseline experiment searching for oscillations $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$
- Low energy excesses seen in both neutrino and antineutrino modes
- No disappearance signal seen



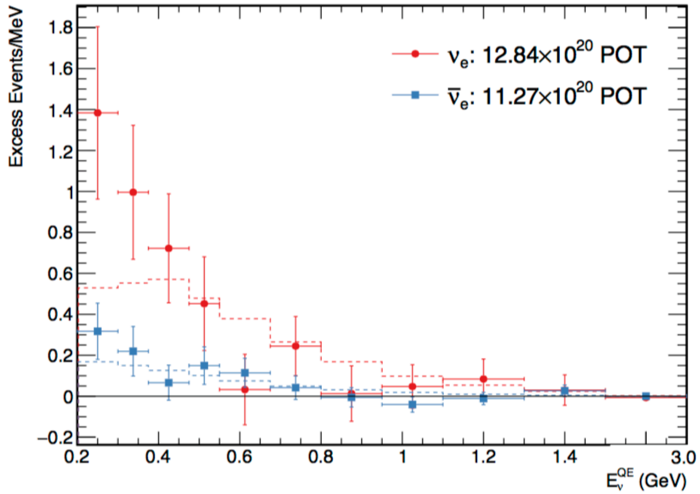


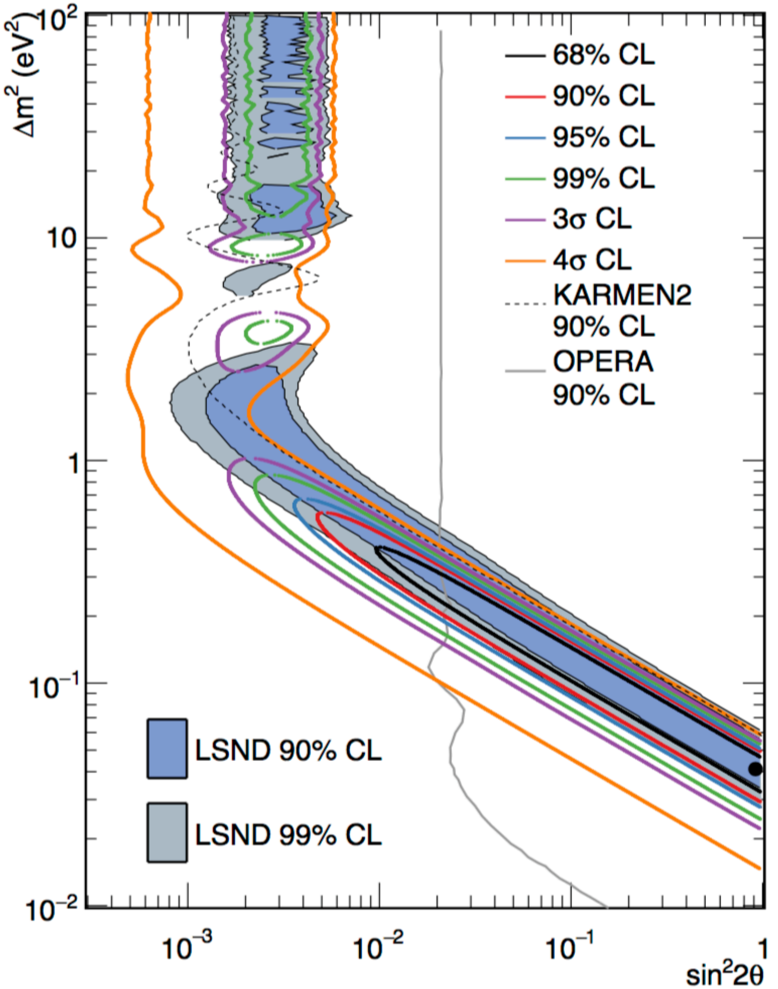
A. Aguilar-Arevalo et al. Phys. Rev. Lett. 110 (2013), p. 161801.

MiniBooNE at Neutrino 2018

- Analysis repeated with the full data exposure (neutrino-mode sample doubled)

- The integrated excess remains and stands at 4.8σ combined from neutrino and antineutrino mode



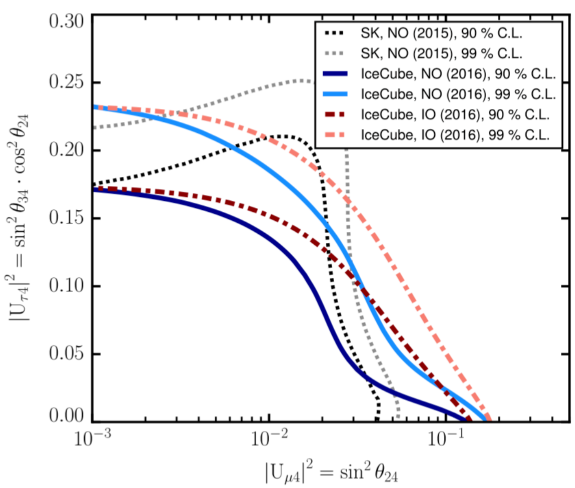


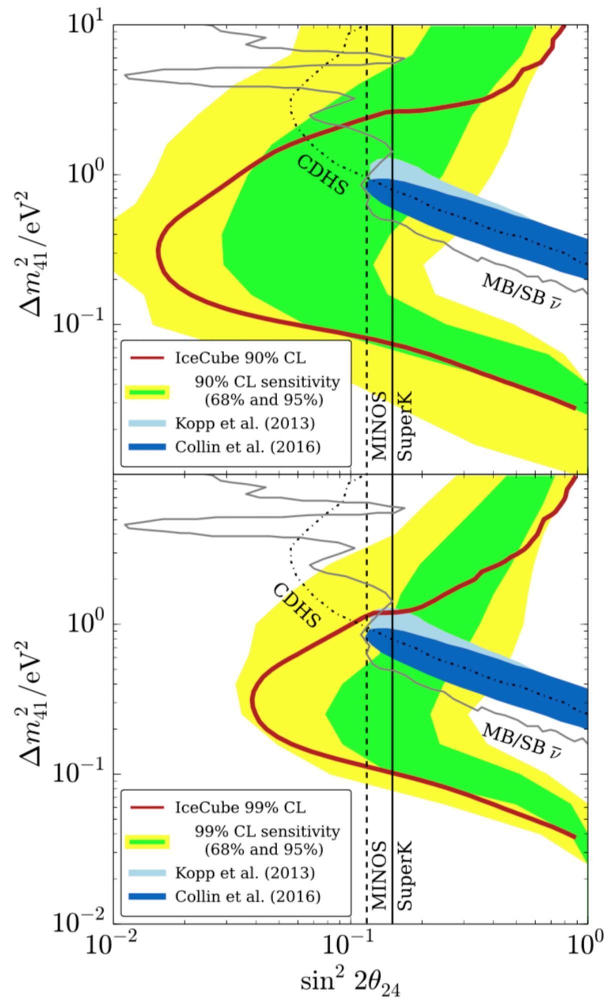
A. Aguilar-Arevalo et al. arXiv:1805.12028 (2018)

IceCube

- Not an accelerator neutrino detector, but still probes a combination of $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ and $\nu_\mu \rightarrow \nu_\mu$
  - Reliant on a matter effect resonance at high energy for neutrinos traversing Earth
  - Strong exclusion of the sterile neutrino hypothesis in the 0.1 - 2.0 eV^2 range

- Deep-core search sets limits on θ_{24} and θ_{34}
  - At $\Delta m^2_{41} = 1 eV^2$

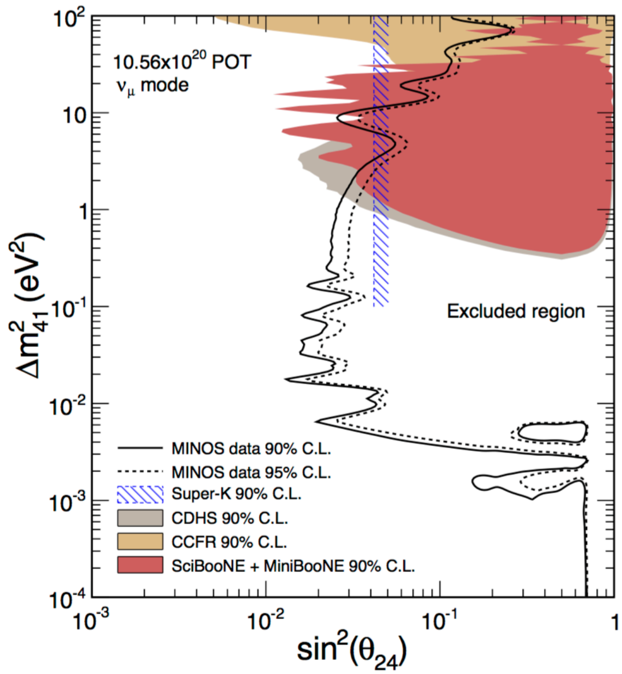




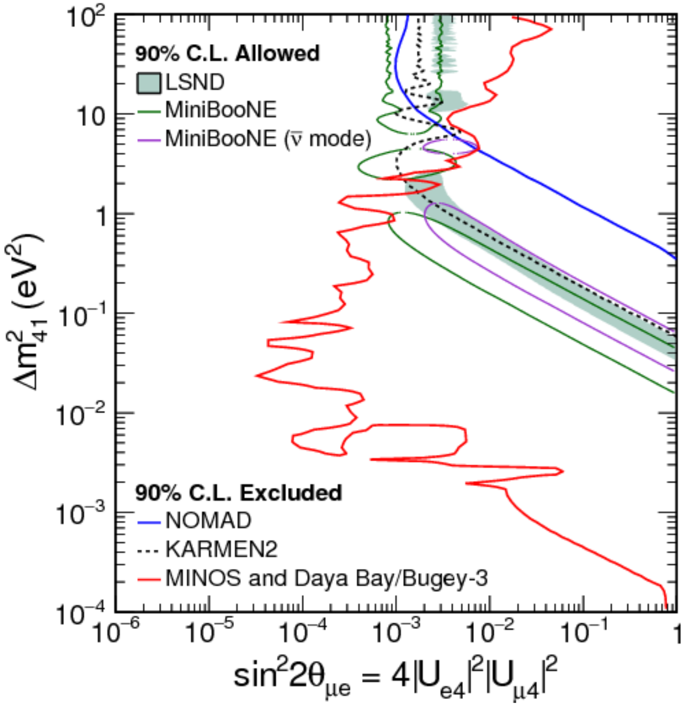
M. G. Aartsen et al. Phys. Rev. Lett. 117, 071801 (2016)
M. G. Aartsen et al. Phys. Rev. D. 95, 112002 (2017)

MINOS

- MINOS probes sterile neutrinos through two channels:
  - Charged-current muon neutrino disappearance
  - Neutral-current disappearance
  - Also performed a combined analysis with Daya Bay (+Bugey-3)



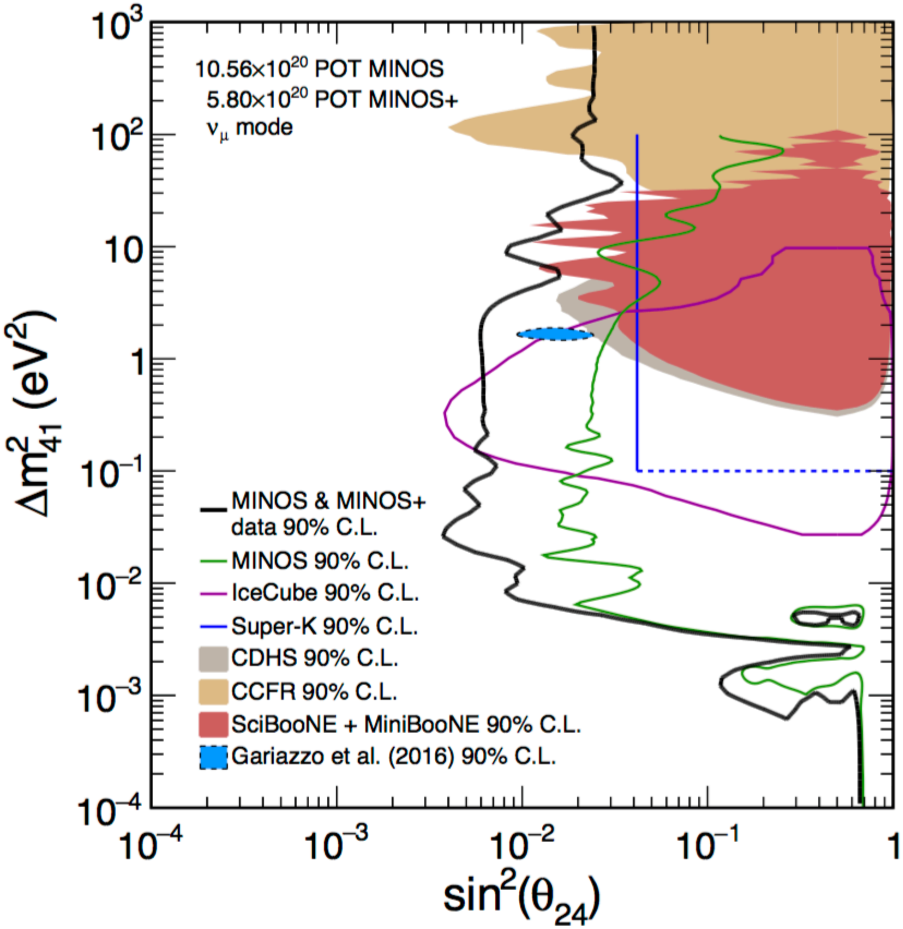
P. Adamson et al., Phys. Rev. Lett. 117, 151803 (2016).



P. Adamson et al., Phys. Rev. Lett. 117, 151801 (2016).

MINOS+ at Neutrino 2018

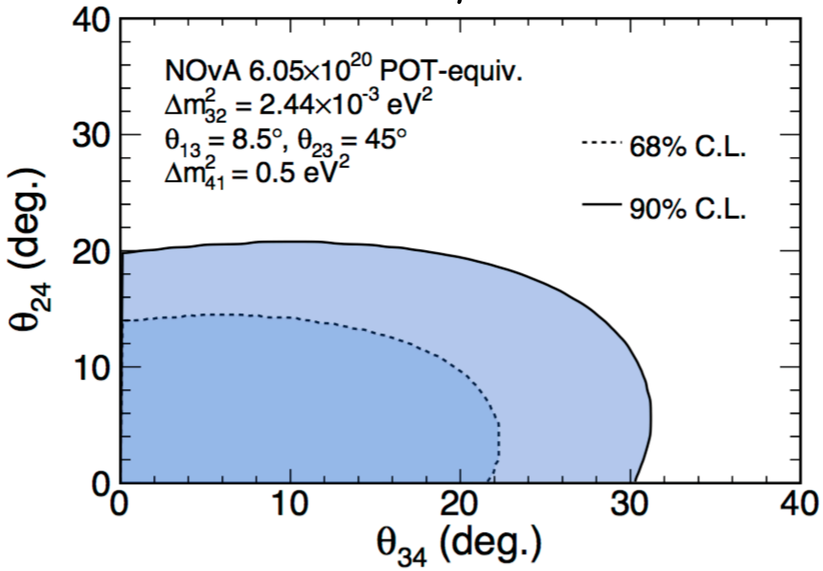
- Updated result containing first two years of MINOS+ data
- Updated analysis technique and inclusion of two years of MINOS+ data
- Strong exclusion of the sterile neutrino hypothesis



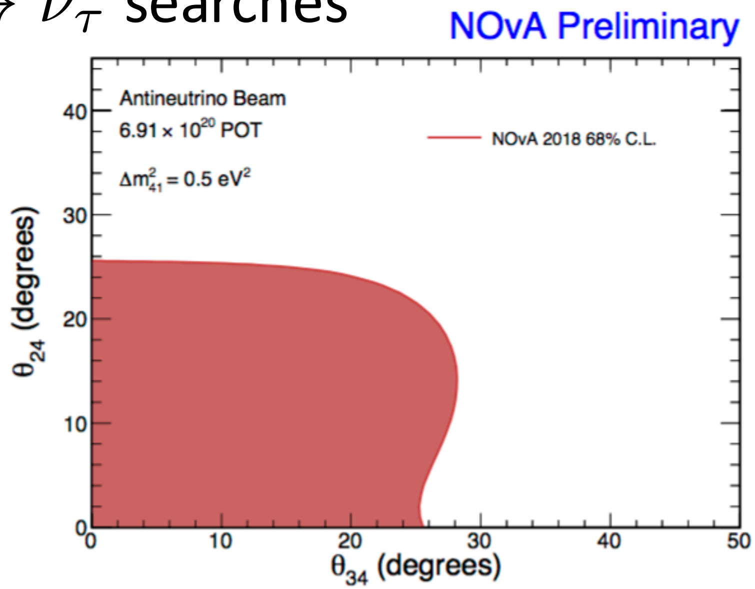
P. Adamson et al., arXiv:1710.06488 (2017).

NOvA

- NOvA has searched for the disappearance of NC interactions
  - Separate analyses for neutrino and antineutrino beam modes
  - Rate-only analysis
  - Valid for the range $0.05 < \Delta m^2_{41}\ (eV^2) < 0.5$
- No signal seen so a limit is set in the (θ_{24}, θ_{34}) parameter space
- Plans for ND $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\tau$ searches



P. Adamson et al., Phys. Rev. D. 96, 072006 (2017).

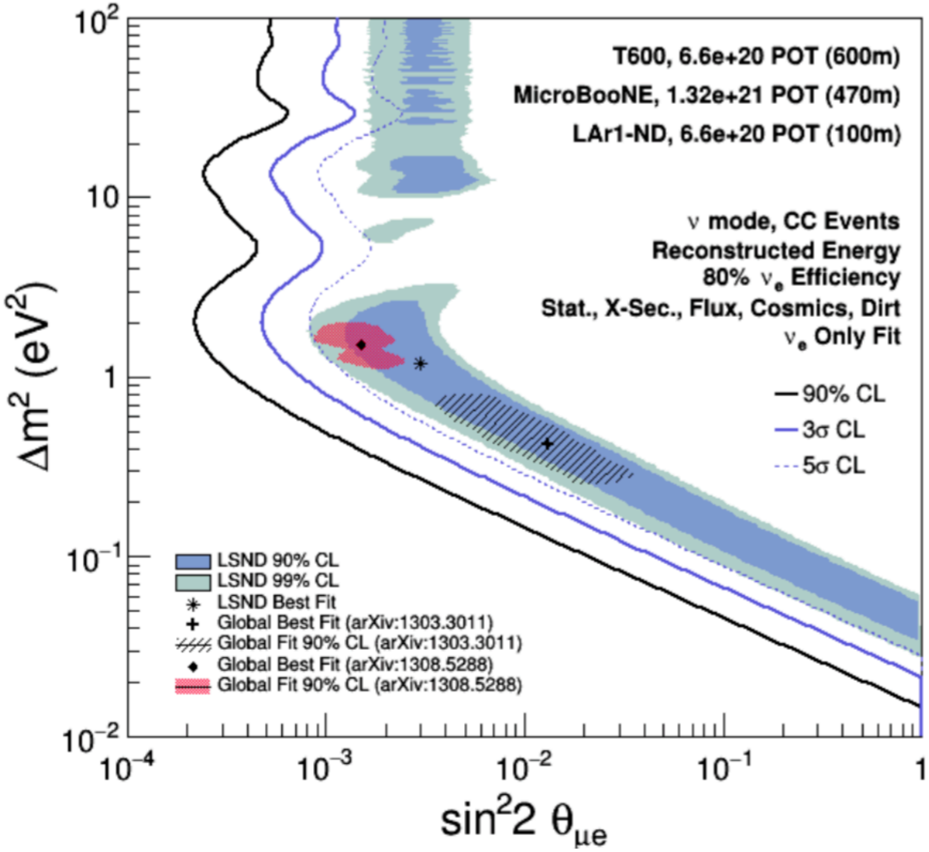


The Future

- FNAL SBN programme will consist of three detectors in the same booster beam that provided neutrinos to MiniBooNE

- Near: SBND
- Intermediate: MicroBooNE (currently running)
- Far: ICARUS T600

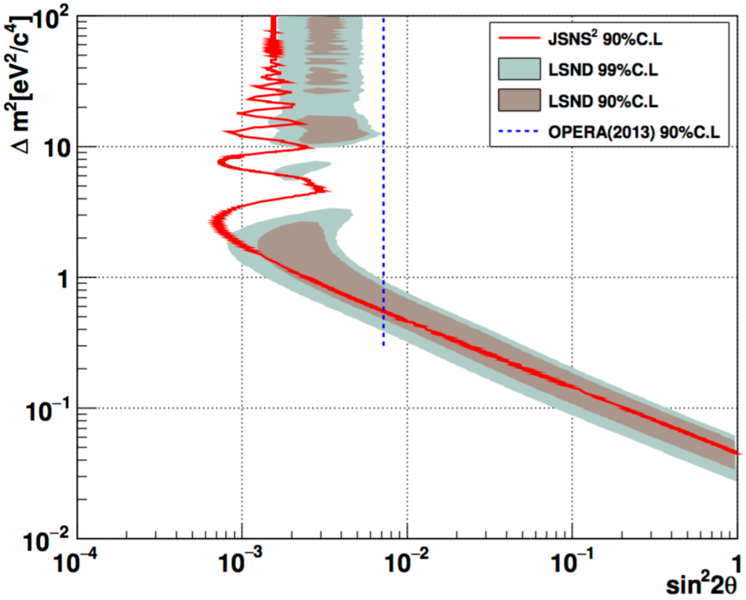
- Sensitivity to exclude LSND allowed region at 5σ



R. Acciarri et al., arXiv:1503.01520

The Future

S. Ajimura et al., arXiv:1705.08629

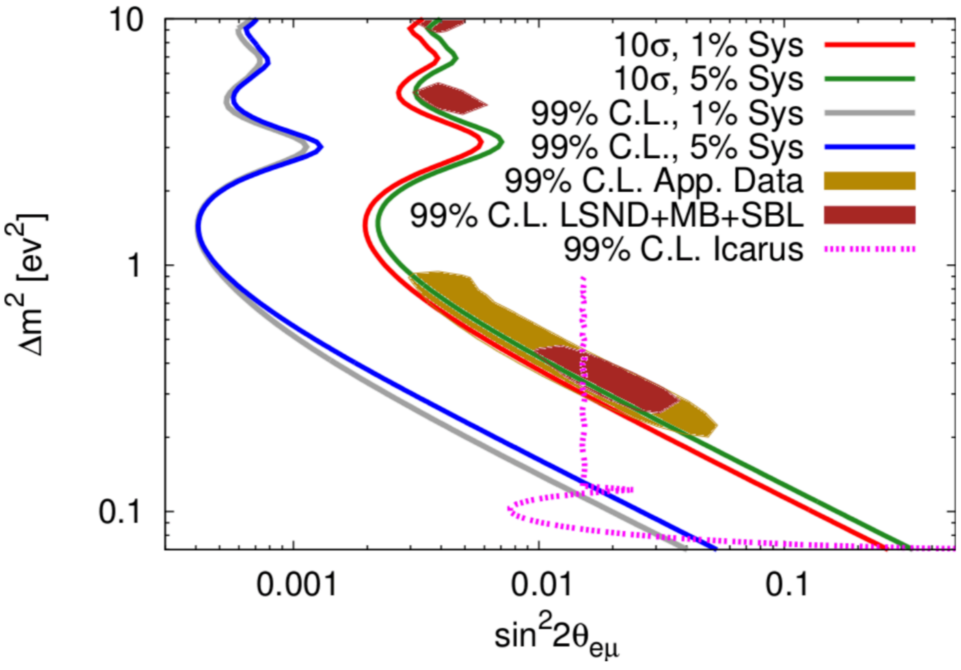


- JSNS^2 is a proposed pion decay-at-rest experiment:
  - Provides a direct test of LSND
  - First results expected in 2021

- DUNE is a next-generation neutrino oscillation experiment and will consider a number of different channels:
  - Appearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$
  - CC Disappearance: $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ and $\nu_\mu \rightarrow \nu_\mu$
  - NC Disappearance: $1 - (\nu_\mu \rightarrow \nu_s)$
  - Can hence measure all three mixing angles in a single experiment

The Future

- NuSTORM will produce a neutrino beam from stored muons
  - Very high statistics and low flux uncertainties
  - Search for short-baseline $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\mu$



D. Adey et al., JINST 12 07 (2017), P07020

Summary

- The results for eV-scale sterile neutrinos from accelerator experiments are very conflicted
  - Very strong tension for the eV^2 sterile neutrino hypothesis
- Excesses seen in (some) appearance experiments that can be analysed under a sterile neutrino hypothesis
- Many null results from both appearance and disappearance searches
- Some very high precision searches coming up in the (near) future