STATUS OF GLOBAL STERILE NEUTRINO FITS

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Outline

- Motivation for sterile neutrinos
- Global fit results
- Incorporating the latest IceCube analysis

Neutrino oscillation.

- Nobel prize awarded for neutrino oscillation in 2015.
  - Awarded to the SNO and Super-K experiments for solving the solar neutrino problem and observing atmospheric neutrino oscillation.
- Two neutrino oscillation formula is:

$$P(\nu_a \rightarrow \nu_b) = \delta_{ab} - \sin^2(2\theta_{ab}) \sin^2\left([1.27 \text{ GeV eV}^{-2} \text{ km}^{-1}]\Delta m^2 \frac{L}{E}\right)$$

The mixing angle (amplitude)

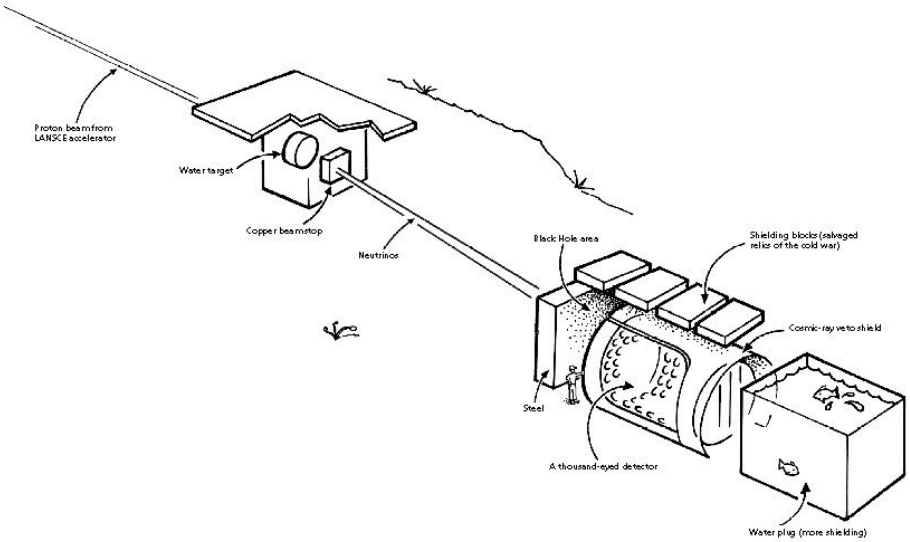
The mass splitting

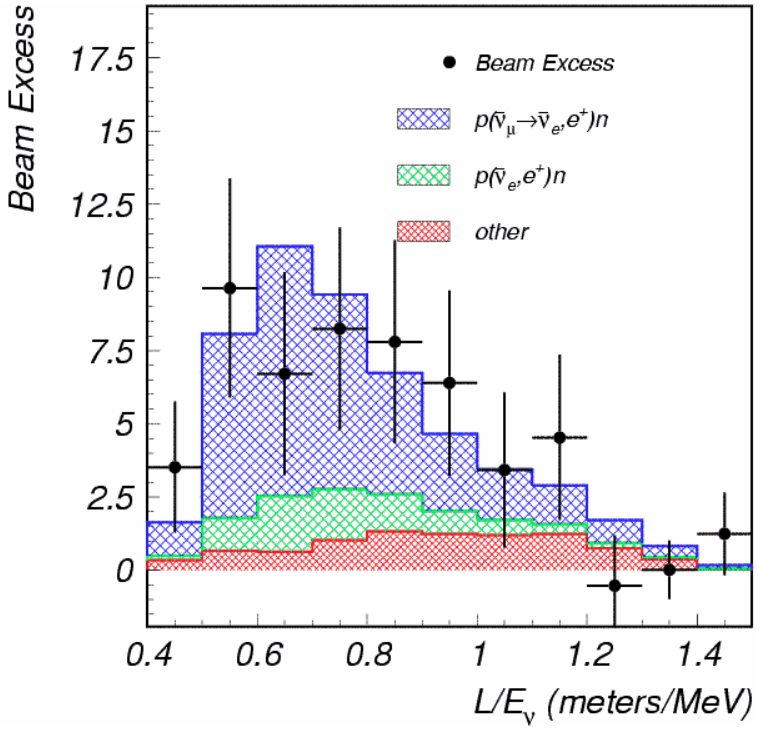
$$\Delta m^2 = |m_1^2 - m_2^2|$$

(frequency)

Liquid Scintillator Neutrino Detector

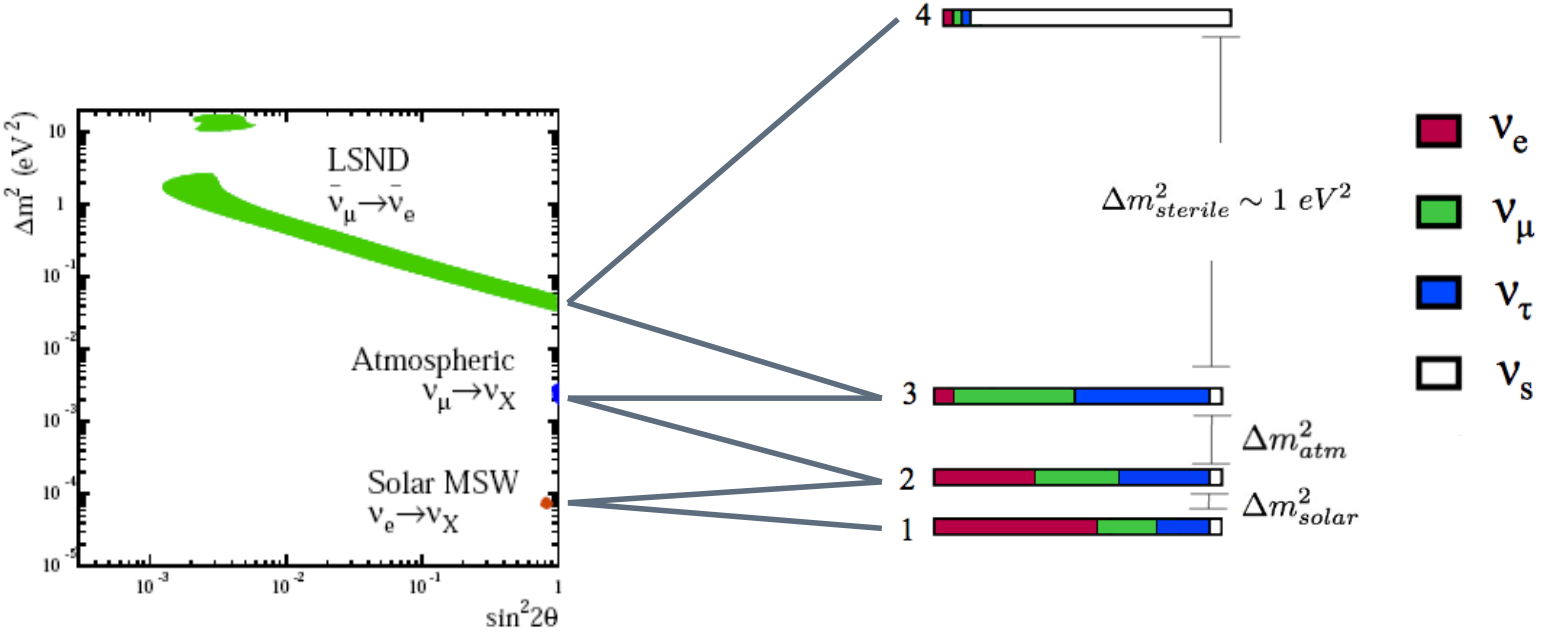
- Short base-line experiment
- 3.8σ excess of $\bar{\nu}_e$





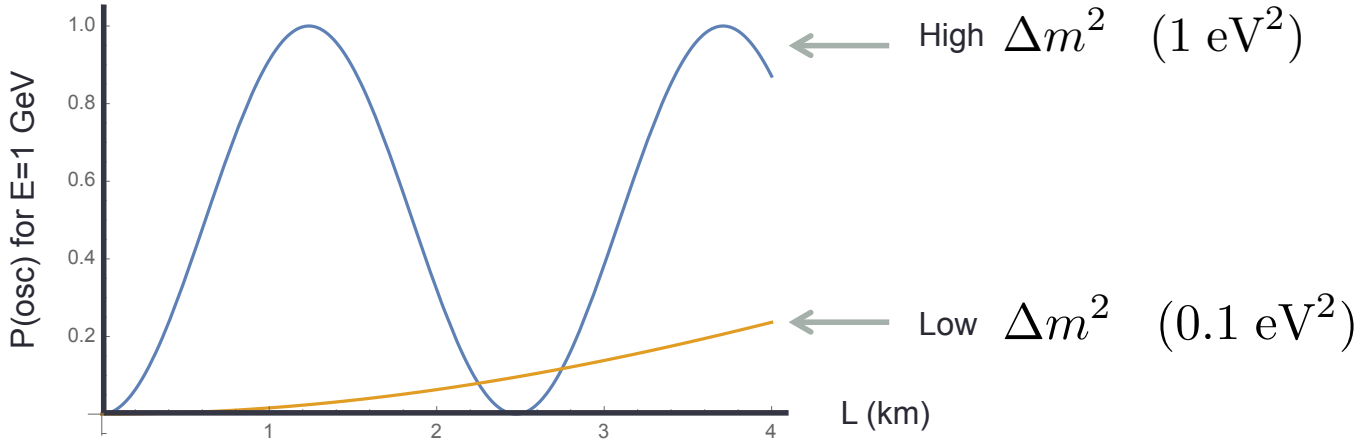
Another kind of neutrino.

- Three distinct mass splittings implies four neutrinos.



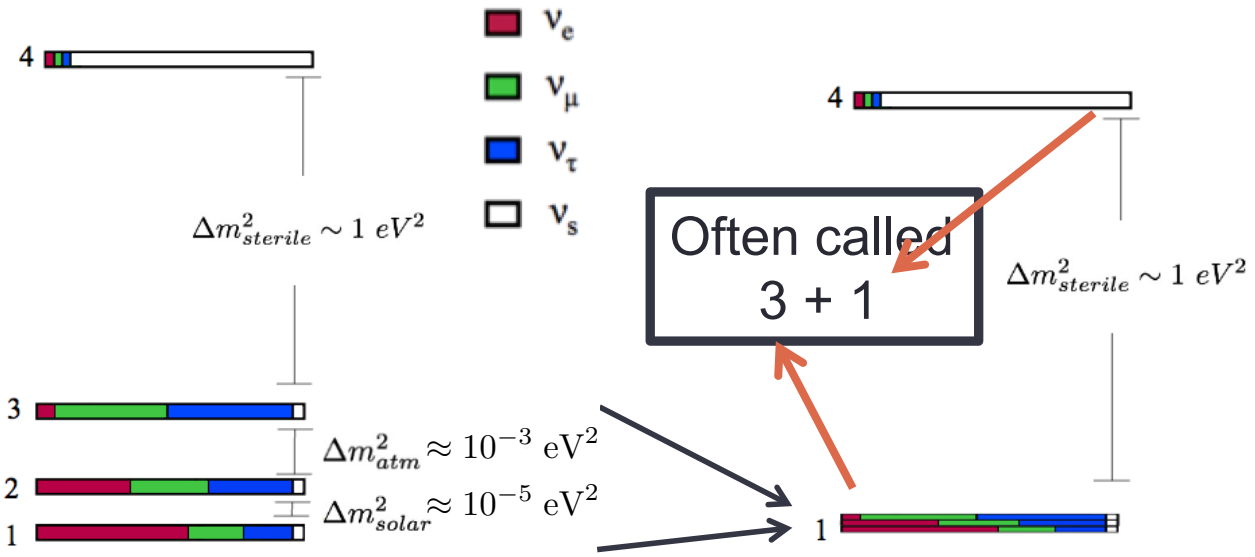
Short base-lines

- The oscillation is parameterised by L/E
- The Δm^2 sets the frequency, and thus…
  - The length scale of the oscillation, and
  - The energy scale of the oscillation.



Short base-line approximation.

- In short base-line experiments, the solar and atmospheric mass splittings can be approximated to zero.



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Global fits

- There are many more short base-line experiments.
  - Some see anomalies.
  - Some do not.
- How do we make sense of all this data?
- Combine them into a global fit.
  - Fitting a single model to all the experimental data simultaneously.

Appearance experiments

- ν_e and $\bar{\nu}_e$ appearance:

  - LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - MiniBooNE $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
    $\nu_\mu \rightarrow \nu_e$
  - NuMI in MB $\nu_\mu \rightarrow \nu_e$
  - NOMAD $\nu_\mu \rightarrow \nu_e$
  - KARMEN $\nu_\mu \rightarrow \nu_e$

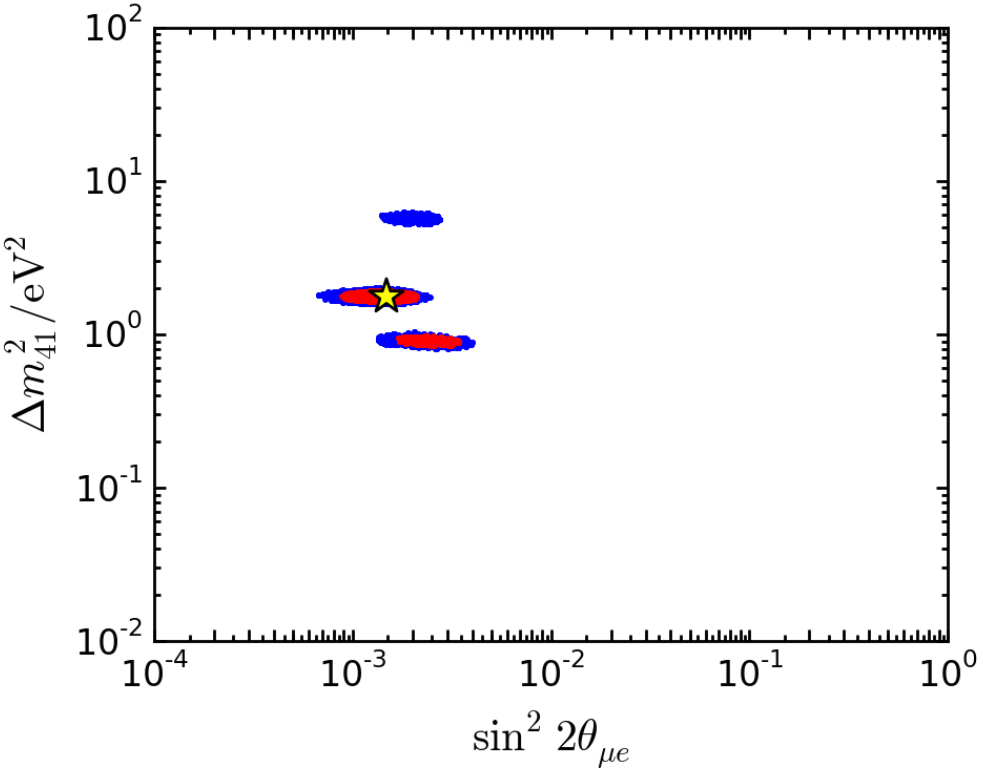
Disappearance experiments

- ν_μ and $\bar{\nu}_\mu$
  - MINOS CC $\bar{\nu}_\mu \nrightarrow \bar{\nu}_\mu$
  - SciBooNE/MiniBooNE
    $\bar{\nu}_\mu \nrightarrow \bar{\nu}_\mu$
    $\nu_\mu \nrightarrow \nu_\mu$
  - CCFR84 $\nu_\mu \nrightarrow \nu_\mu$
  - CDHS $\nu_\mu \nrightarrow \nu_\mu$

- ν_e and $\bar{\nu}_e$
  - Bugey $\bar{\nu}_e \nrightarrow \bar{\nu}_e$
  - GALLEX/SAGE
    $\nu_e \nrightarrow \nu_e$
  - KARMEN/LSND x-sec
    $\nu_e \nrightarrow \nu_e$

3 + 1

arXiv: 1602.00671

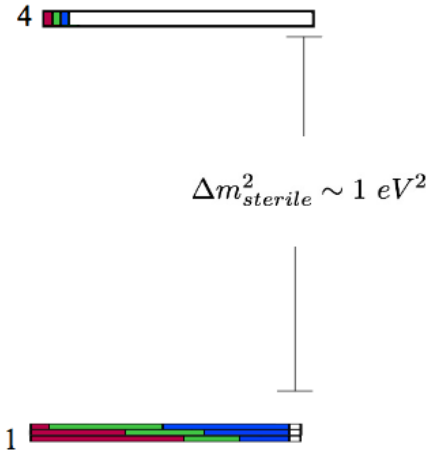


Best fit point:

$$\Delta m^2_{41} : 1.75\ \mathrm{eV}^2$$
$$\sin^2 2\theta_{\mu e} : 1.45 \times 10^{-3}$$
$$\chi^2 : 306.81 \quad (312\ \mathrm{dof})$$
$$\chi^2_{\mathrm{null}} : 359.15 \quad (315\ \mathrm{dof})$$
$$\Delta\chi^2 : 52.34 \quad (3\ \mathrm{dof})$$

Red: 90% CL

Blue: 99% CL



3 + 1

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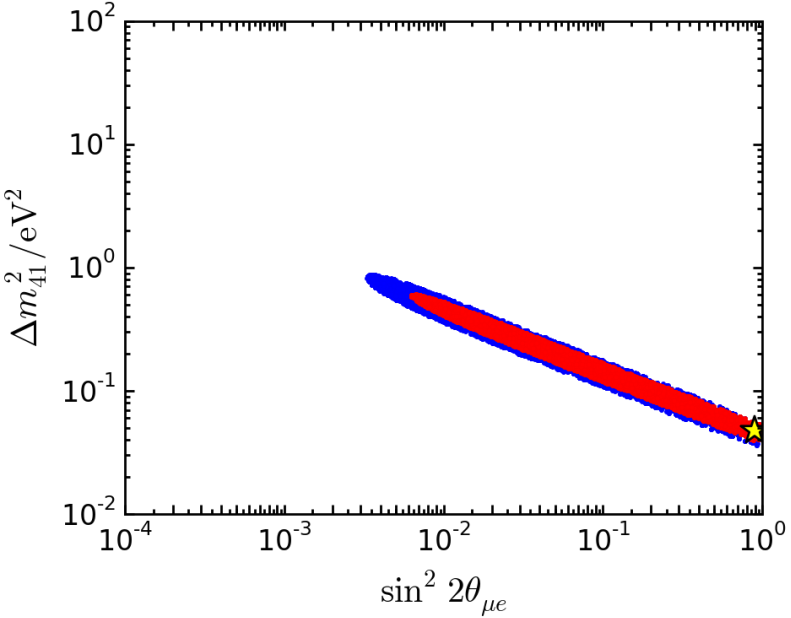
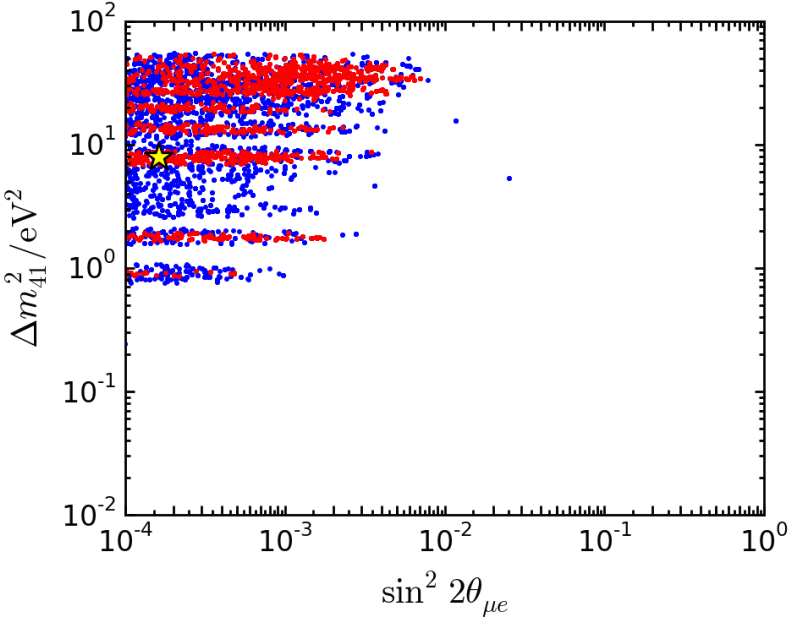
Appearance only datasets



Disappearance only datasets



Disagreement between these datasets.

3 + 1

arXiv: 1602.00671

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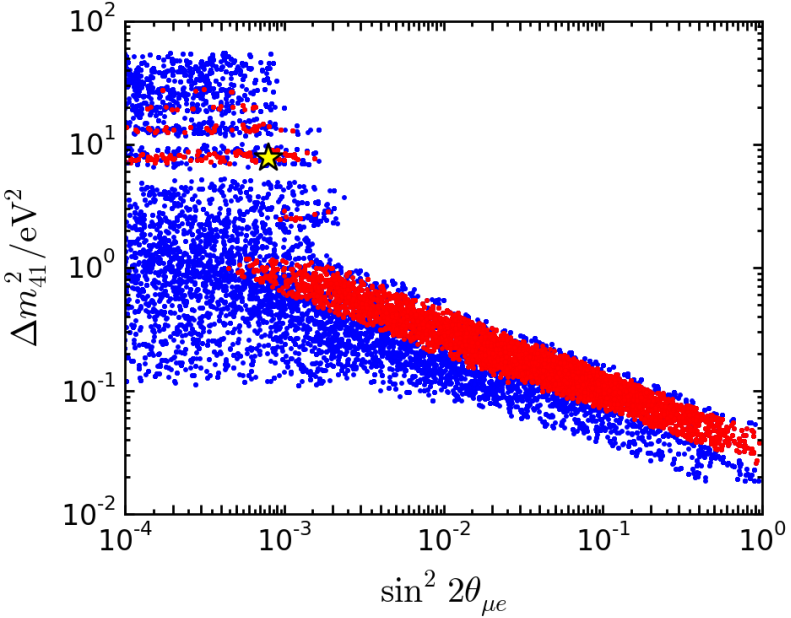
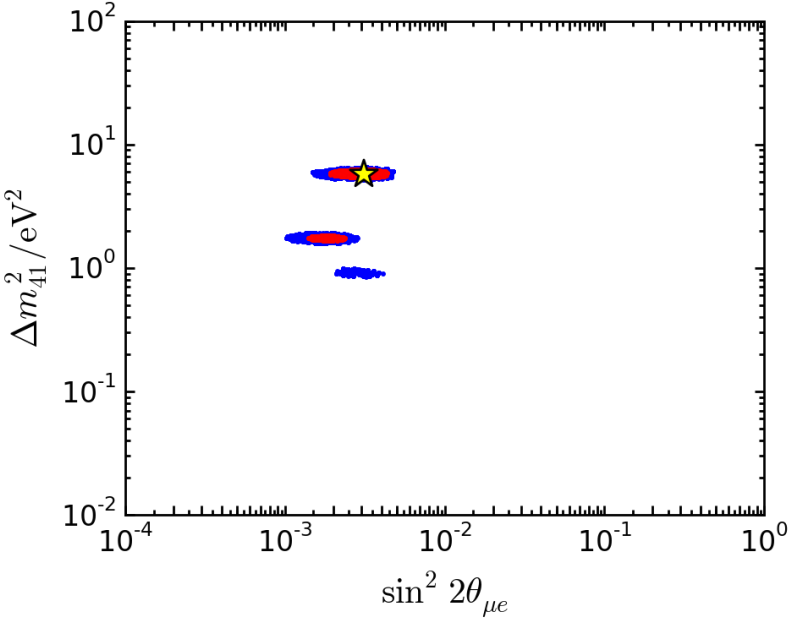
Neutrino only datasets



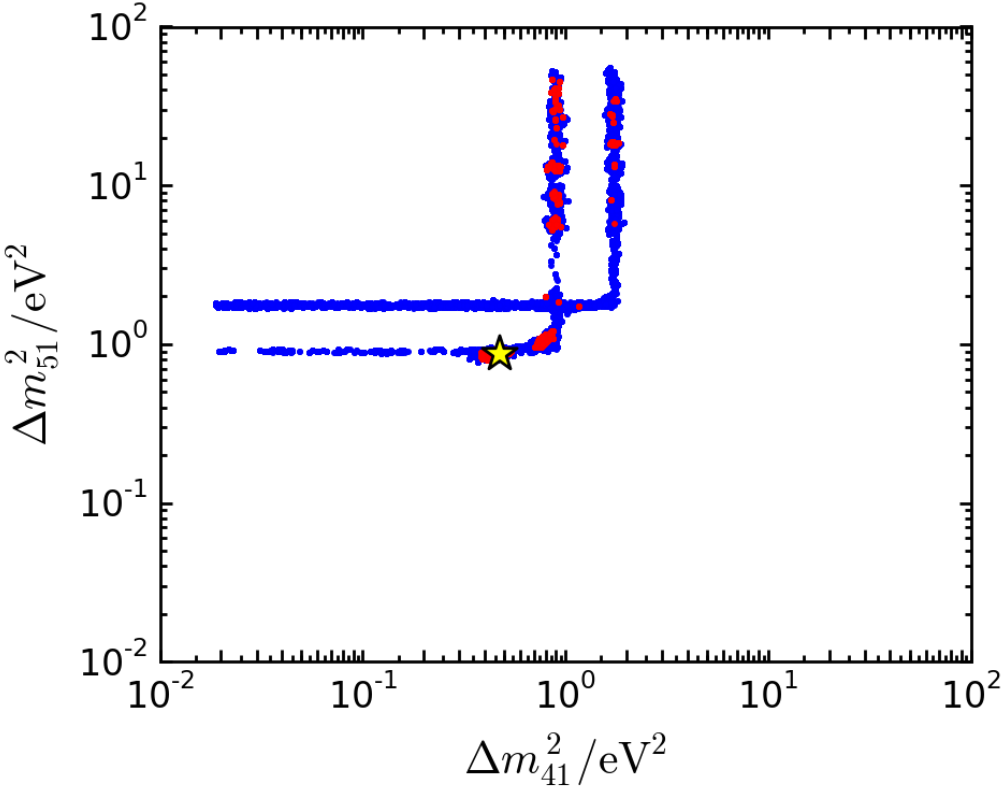
Anti-neutrino only datasets



Disagreement between these datasets.

3 + 2

arXiv: 1602.00671



Best fit point:

$$\chi^2 : 302.16 \quad (308 \text{ dof})$$

$$\chi^2_{\text{null}} : 359.15 \quad (315 \text{ dof})$$

Red: 90% CL

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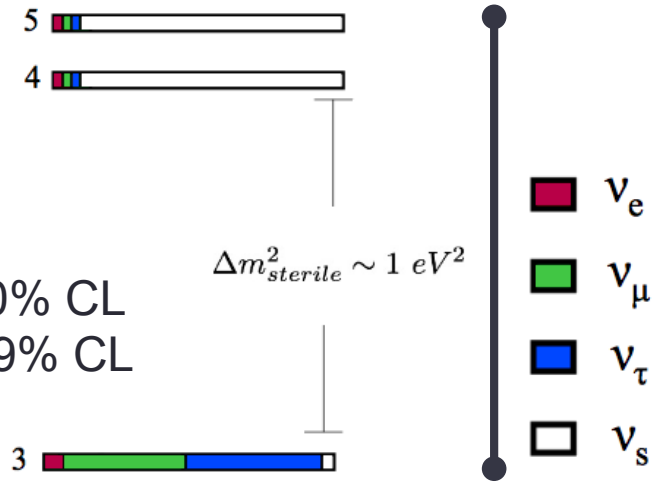

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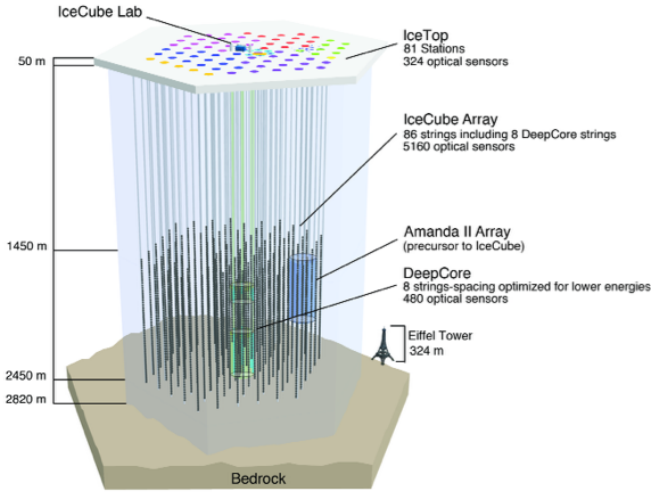
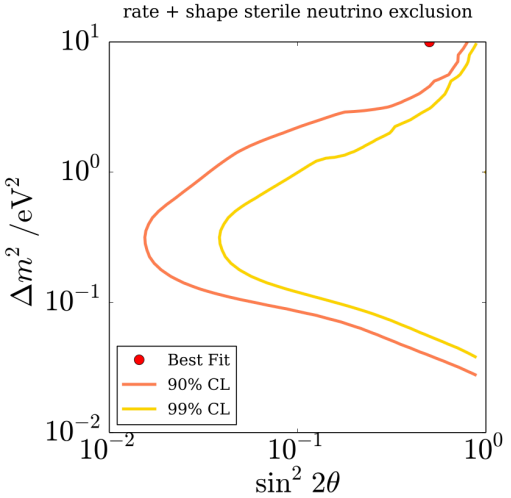
IceCube sterile neutrino search



- Gigaton ice Cherenkov detector at the south pole.
- Atmospheric neutrinos are used in the sterile neutrino search.
- These travel through the earth before they reach IceCube.
  - Base-line too long for normal oscillations to be resolved.
- The MSW matter effect causes a resonant depletion in the flux of $\bar{\nu}_\mu$

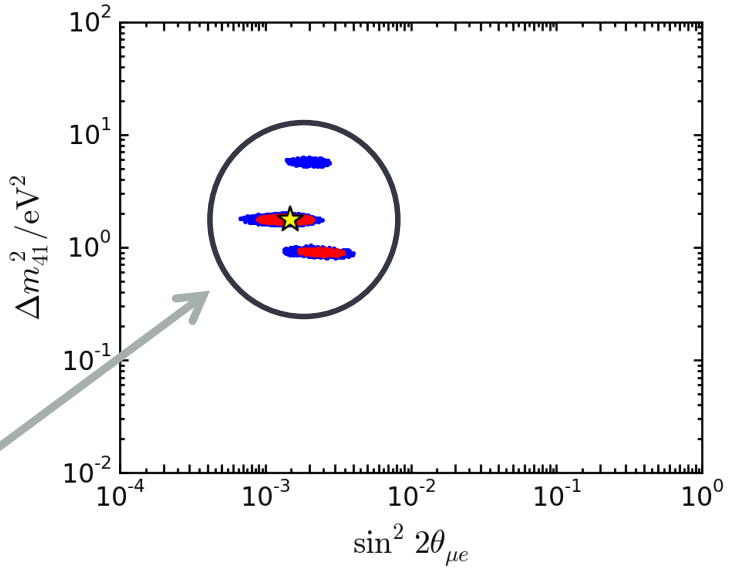


- IceCube finds no evidence of muon neutrino disappearance in 1 year of data.

Adding IceCube

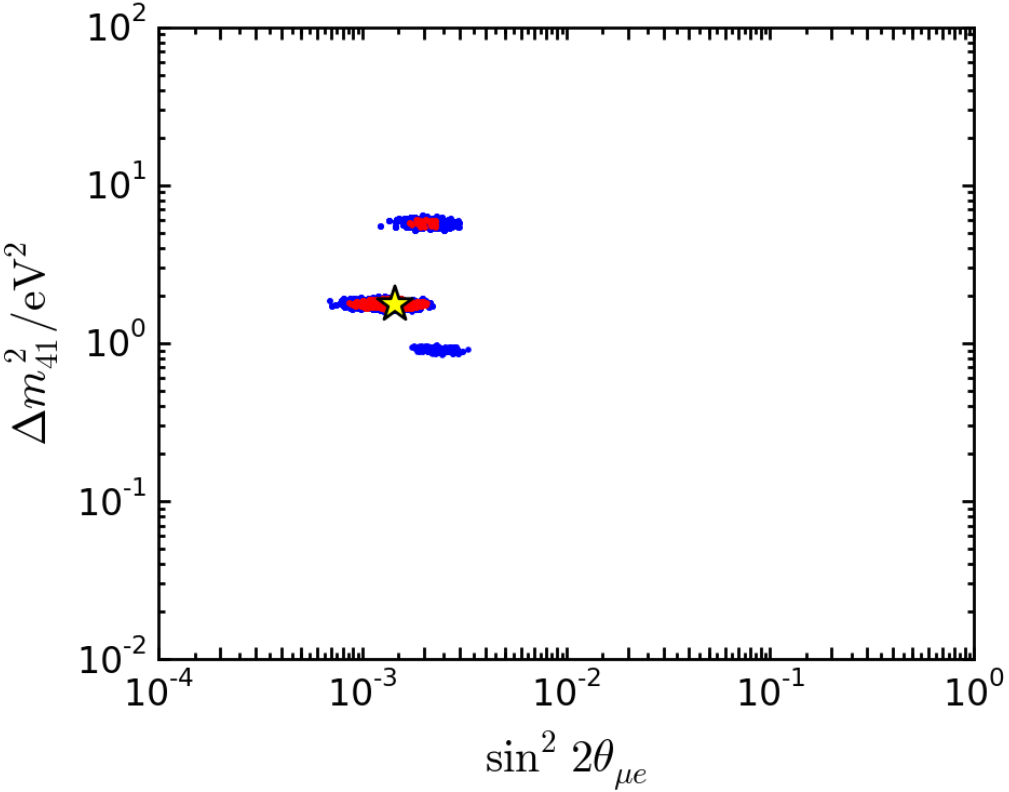
- The full IceCube sterile analysis fitting procedure is too computationally expensive to include directly into the global fit at present.

- Instead, we use the global fit to find a set of most likely points in parameter space.
  - The IceCube analysis likelihood was evaluated at these points, and the resulting χ^2 combined with the global fit.



Combined IceCube / Global fit

arXiv:1607.00011

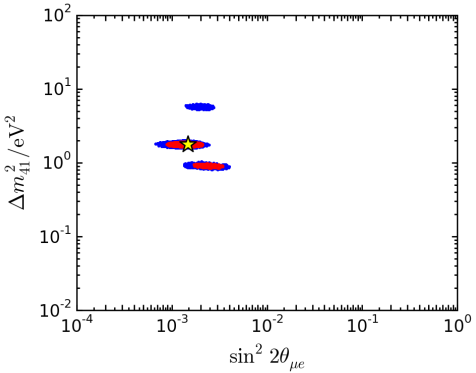


$$\chi^2 : 518.59 \quad (520\ \mathrm{dof})$$

$$\chi^2_{\mathrm{null}} : 568.84 \quad (524\ \mathrm{dof})$$

Red: 90% CL
Blue: 99% CL

Global only



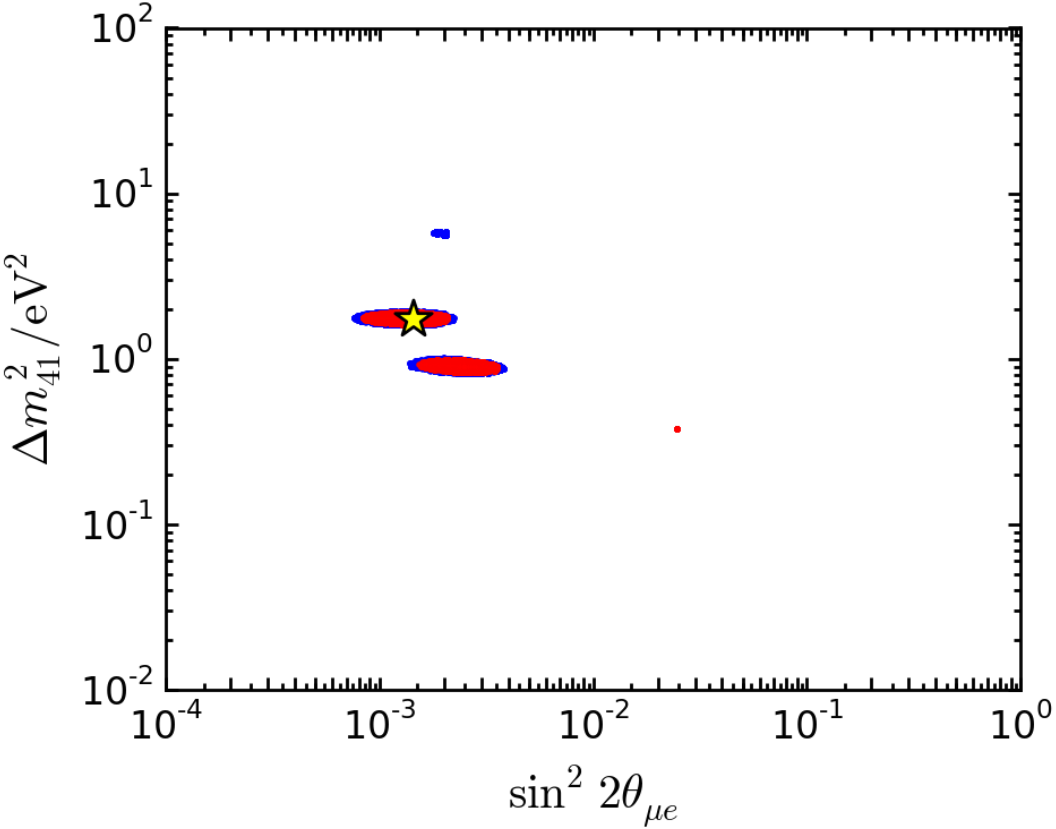
Conclusion

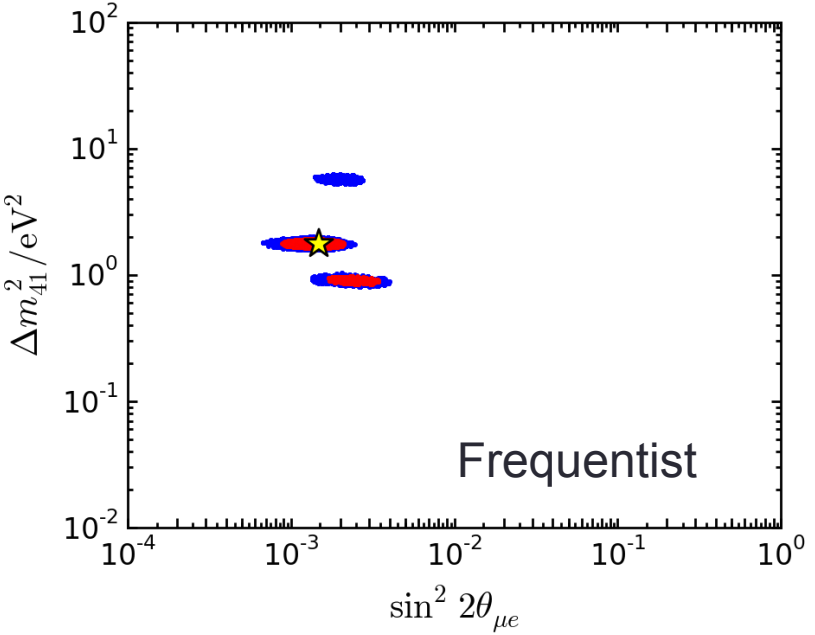
- Short base-line experiments have anomalies that do not fit a three neutrino model.
- An addition of a single sterile neutrino (3 + 1) provides a better description, but there is tension between neutrino and antineutrino data.
- The addition of two sterile neutrinos (3 + 2) does not provide a better fit.
- Tension between appearance and disappearance datasets remains an issue.
- The addition of the latest IceCube sterile neutrino search removes the $\approx 1\ eV^2$ island at 90% CL.

THANK YOU

BACKUP

3 + 1 Bayesian





Red: 90% CI
Blue: 99% CI