Status of the Sterile Neutrino(s)

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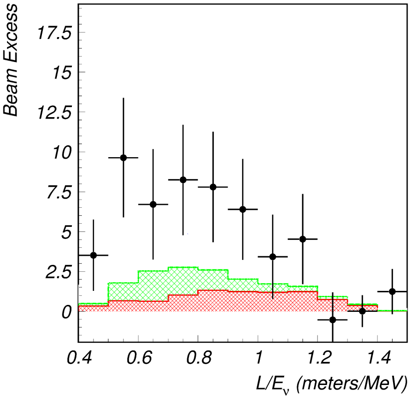
Recent Developments in Neutrino Physics and Astrophysics
10th Anniversary of Borexino
LNGS and GSSI, Assergi and L'Aquila, Italy, 4-7 September 2017

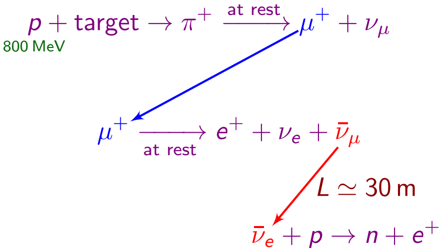
LSND

[PRL 75 (1995) 2650; PRC 54 (1996) 2685; PRL 77 (1996) 3082; PRD 64 (2001) 112007]

$\bar{\nu}_\mu \to \bar{\nu}_e$ $\qquad$ $20\,\text{MeV} \leq E \leq 52.8\,\text{MeV}$



- Well-known and pure source of $\bar{\nu}_\mu$



$$\underset{800\,\text{MeV}}{p} + \text{target} \to \pi^+ \xrightarrow{\text{at rest}} \mu^+ + \nu_\mu$$

$$\mu^+ \xrightarrow[\text{at rest}]{} e^+ + \nu_e + \bar{\nu}_\mu$$

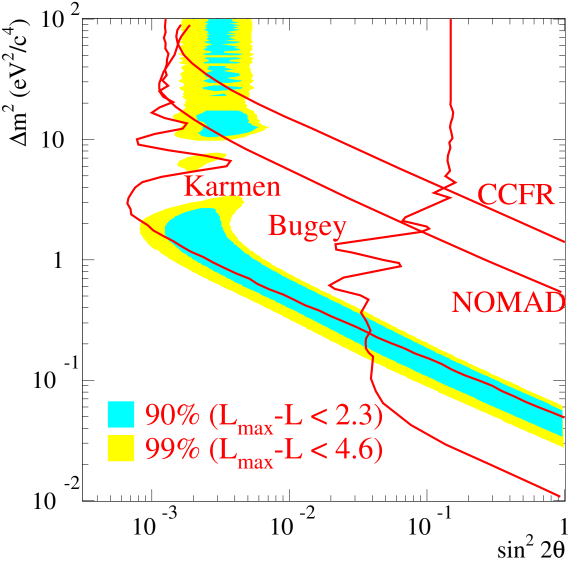
$L \simeq 30\,\text{m}$

$$\bar{\nu}_e + p \to n + e^+$$

Well-known detection process of $\bar{\nu}_e$

- $\approx 3.8\sigma$ excess
- But signal not seen by KARMEN at $L \simeq 18\,\text{m}$ with the same method

[PRD 65 (2002) 112001]

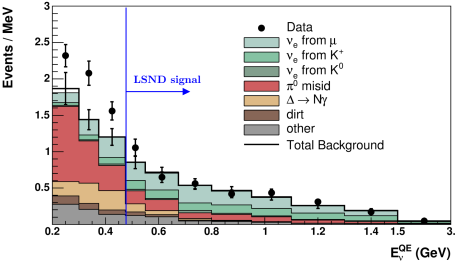


$$\Delta m^2_{\text{SBL}} \gtrsim 3 \times 10^{-2}\,\text{eV}^2 \gg \Delta m^2_{\text{ATM}} \simeq 2.5 \times 10^{-3}\,\text{eV}^2 \gg \Delta m^2_{\text{SOL}}$$

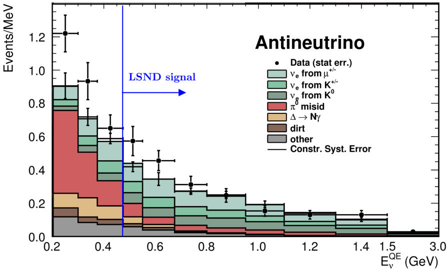
MiniBooNE

$L \simeq 541\,\text{m}$ $200\,\text{MeV} \leq E \lesssim 3\,\text{GeV}$

$\nu_\mu \to \nu_e$ [PRL 102 (2009) 101802]



$\bar{\nu}_\mu \to \bar{\nu}_e$ [PRL 110 (2013) 161801]



- Purpose: check LSND signal.
- Different L and E.
- Similar L/E (oscillations).
- No money, no Near Detector.
- LSND signal: $E > 475\,\text{MeV}$.
- Agreement with LSND signal?
- CP violation?
- Low-energy anomaly! ⇒ MicroBooNE

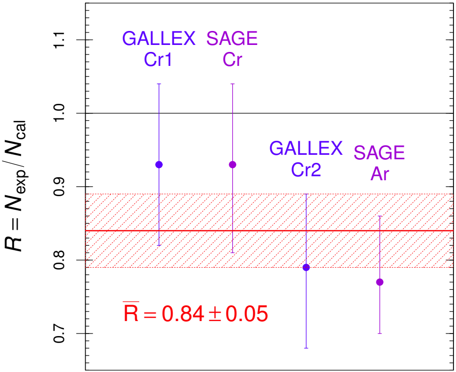
Gallium Anomaly

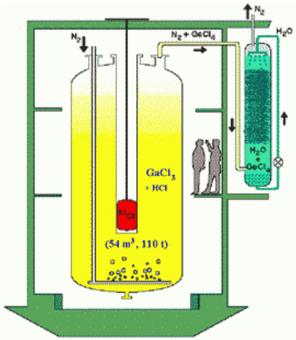
Gallium Radioactive Source Experiments: GALLEX and SAGE

ν_e Sources: $e^- + {}^{51}\text{Cr} \to {}^{51}\text{V} + \nu_e$ $\quad e^- + {}^{37}\text{Ar} \to {}^{37}\text{Cl} + \nu_e$

$E \simeq 0.75\,\text{MeV}$ $\quad E \simeq 0.81\,\text{MeV}$

Test of Solar ν_e Detection: $\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-$





$\approx 2.9\sigma$ deficit

$\langle L \rangle_{\text{GALLEX}} = 1.9\,\text{m}$ $\quad \langle L \rangle_{\text{SAGE}} = 0.6\,\text{m}$

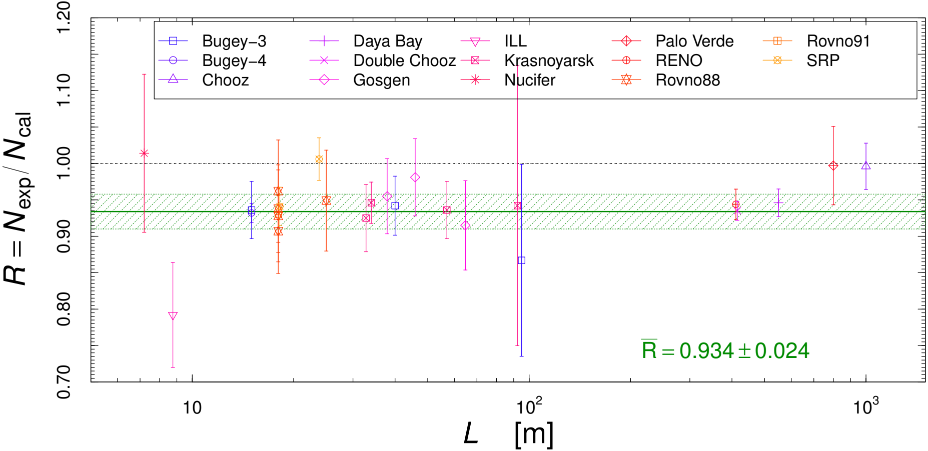
$\Delta m^2_{\text{SBL}} \gtrsim 1\,\text{eV}^2 \gg \Delta m^2_{\text{ATM}} \gg \Delta m^2_{\text{SOL}}$

[SAGE, PRC 73 (2006) 045805; PRC 80 (2009) 015807;
Laveder et al, Nucl.Phys.Proc.Suppl. 168 (2007) 344,
MPLA 22 (2007) 2499, PRD 78 (2008) 073009,
PRC 83 (2011) 065504]

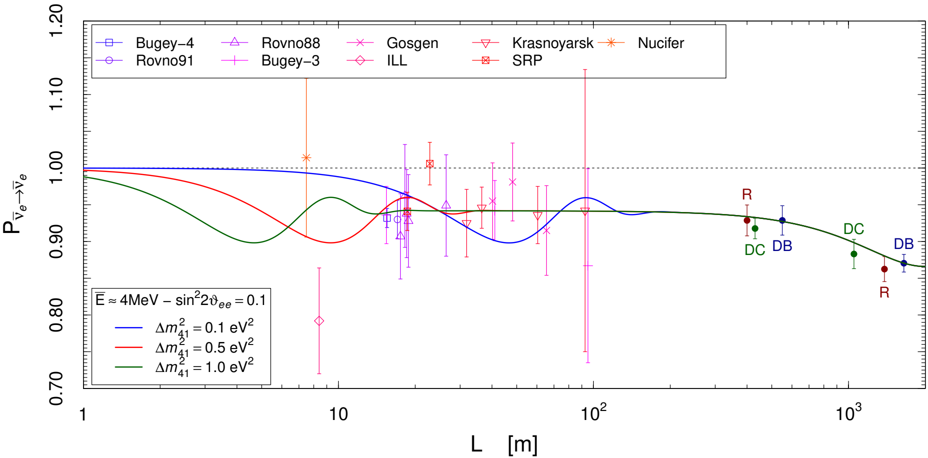
Reactor Electron Antineutrino Anomaly

[Mention et al, PRD 83 (2011) 073006]

New reactor $\bar{\nu}_e$ fluxes [Mueller et al, PRC 83 (2011) 054615; Huber, PRC 84 (2011) 024617]



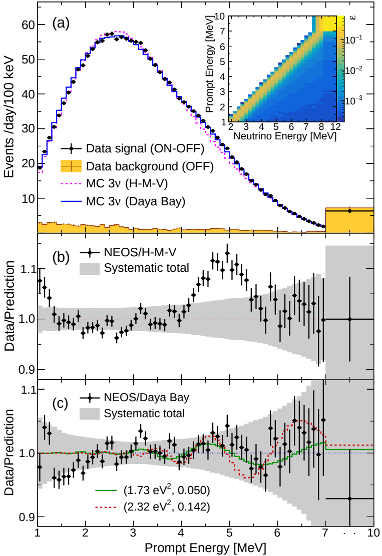
$\approx 2.8\sigma$ deficit



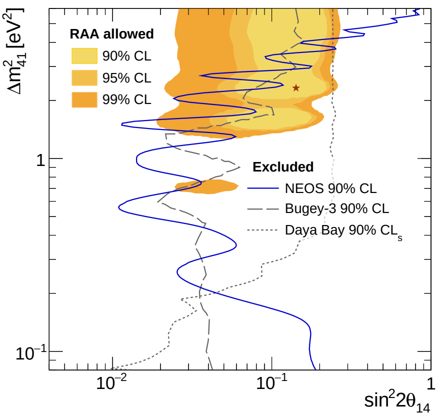
$$\Delta m^2_{\text{SBL}} \gtrsim 0.5\,\text{eV}^2 \gg \Delta m^2_{\text{ATM}} \gg \Delta m^2_{\text{SOL}}$$

NEOS

[PRL 118 (2017) 121802 (arXiv:1610.05134)]



- Hanbit Nuclear Power Complex in Yeong-gwang, Korea.
- Thermal power of 2.8 GW.
- Detector: a ton of Gd-loaded liquid scintillator in a gallery approximately 24 m from the reactor core.
- The measured antineutrino event rate is 1976 per day with a signal to background ratio of about 22.



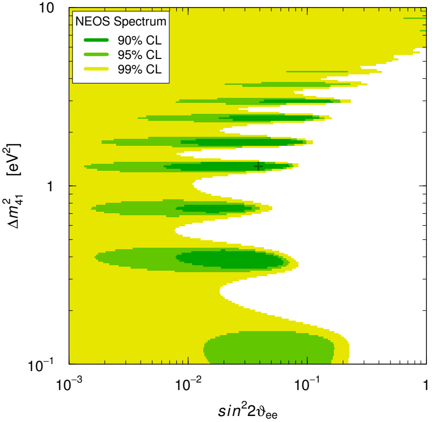
Raster Scan

[NEOS, PRL 118 (2017) 121802 (arXiv:1610.05134)]

Best Fits:

$\Delta m^2_{41} = 1.7\,\text{eV}^2 \quad \sin^2 2\theta_{14} = 0.05$

$\Delta m^2_{41} = 1.3\,\text{eV}^2 \quad \sin^2 2\theta_{14} = 0.04$



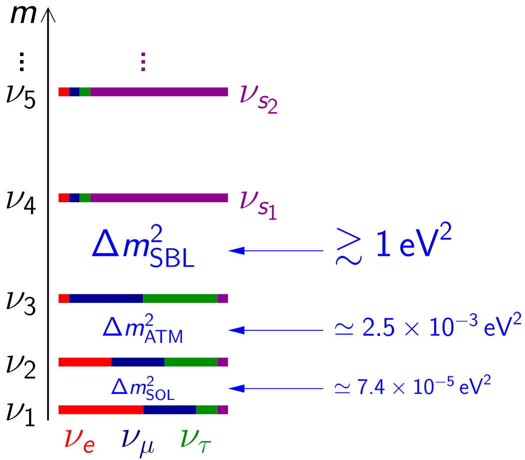
2-D χ^2 Analysis

$\chi^2_{\text{no osc.}} - \chi^2_{\text{min}} = 6.5$

χ^2 distribution: $\approx 2.1\sigma$ anomaly

NEOS Monte Carlo: $\approx 1.2\sigma$ anomaly

Beyond Three-Neutrino Mixing: Sterile Neutrinos



Terminology:	a eV-scale sterile neutrino
means:	a eV-scale massive neutrino which is mainly sterile

Effective 3+1 SBL Oscillation Probabilities

Appearance ($\alpha \neq \beta$)

$$P^{\text{SBL}}_{\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\beta} \simeq \sin^2 2\vartheta_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$\sin^2 2\vartheta_{\alpha\beta} = 4|U_{\alpha 4}|^2 |U_{\beta 4}|^2$$

Disappearance

$$P^{\text{SBL}}_{\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\alpha} \simeq 1 - \sin^2 2\vartheta_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$\sin^2 2\vartheta_{\alpha\alpha} = 4|U_{\alpha 4}|^2 \left(1 - |U_{\alpha 4}|^2\right)$$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & \boxed{U_{e4}} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & \boxed{U_{\mu 4}} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & \boxed{U_{\tau 4}} \\ U_{s1} & U_{s2} & U_{s3} & \boxed{U_{s4}} \end{pmatrix}$$

SBL

- 6 mixing angles
- 3 Dirac CP phases
- 3 Majorana CP phases

- CP violation is not observable in SBL experiments!
- Observable in LBL accelerator exp. sensitive to Δm^2_{ATM} [de Gouvea et al, PRD 91 (2015) 053005, PRD 92 (2015) 073012, arXiv:1605.09376; Palazzo et al, PRD 91 (2015) 073017, PLB 757 (2016) 142; Kayser et al, JHEP 1511 (2015) 039, JHEP 1611 (2016) 122] and solar exp. sensitive to Δm^2_{SOL} [Long, Li, CG, PRD 87, 113004 (2013) 113004]

Common Parameterization of 4 × 4 Mixing Matrix

$$U = \left[W^{34} R^{24} W^{14} R^{23} W^{13} R^{12}\right] \mathrm{diag}\left(1, e^{i\lambda_{21}}, e^{i\lambda_{31}}, e^{i\lambda_{41}}\right)$$

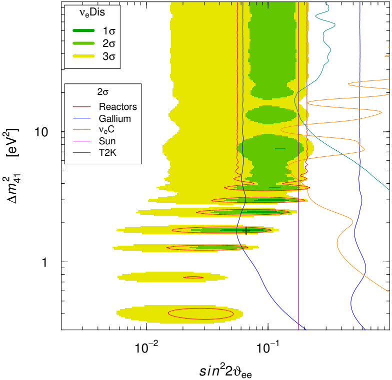
$$= \begin{pmatrix} c_{12} c_{13} c_{14} & s_{12} c_{13} c_{14} & c_{14} s_{13} e^{-i\delta_{13}} & s_{14} e^{-i\delta_{14}} \\ \cdots & \cdots & \cdots & c_{14} s_{24} \\ \cdots & \cdots & \cdots & c_{14} c_{24} s_{34} e^{-i\delta_{34}} \\ \cdots & \cdots & \cdots & c_{14} c_{24} c_{34} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{i\lambda_{21}} & 0 & 0 \\ 0 & 0 & e^{i\lambda_{31}} & 0 \\ 0 & 0 & 0 & e^{i\lambda_{41}} \end{pmatrix}$$

$$|U_{e4}|^2 = \sin^2\vartheta_{14} \quad \Rightarrow \quad \sin^2 2\vartheta_{ee} = 4|U_{e4}|^2 \left(1 - |U_{e4}|^2\right) = \sin^2 2\vartheta_{14}$$

$$|U_{\mu4}|^2 = \cos^2\vartheta_{14} \sin^2\vartheta_{24} \simeq \sin^2\vartheta_{24} \Rightarrow \sin^2 2\vartheta_{\mu\mu} = 4|U_{\mu4}|^2 \left(1 - |U_{\mu4}|^2\right) \simeq \sin^2 2\vartheta_{24}$$

Global ν_e and $\bar{\nu}_e$ Disappearance

[Gariazzo, CG, Laveder, Li, JHEP 1706 (2017) 135 (arXiv:1703.00860)]



- KARMEN+LSND ν_e–^{12}C

  [Conrad, Shaevitz, PRD 85 (2012) 013017]
  [CG, Laveder, PLB 706 (2011) 20]

- Solar ν_e + KamLAND $\bar{\nu}_e$

  [Li et al, PRD 80 (2009) 113007, PRD 86 (2012) 113014]
  [Palazzo, PRD 83 (2011) 113013, PRD 85 (2012) 077301]

- T2K Near Detector ν_e disappearance

  [T2K, PRD 91 (2015) 051102]

- $\Delta\chi^2_{\text{NO}}/\text{NDF}_{\text{NO}} = 14.1/2 \Rightarrow \approx 3.3\sigma$ anom.

- Best Fit: $\Delta m^2_{41} = 1.7\,\text{eV}^2$

  $\sin^2 2\vartheta_{ee} = 0.066 \quad \Leftrightarrow \quad |U_{e4}|^2 = 0.017$

- $\chi^2_{\text{min}}/\text{NDF} = 163.0/174 \Rightarrow \text{GoF} = 71\%$

Tritium Beta-Decay: $^3\text{H} \to {}^3\text{He} + e^- + \bar{\nu}_e$

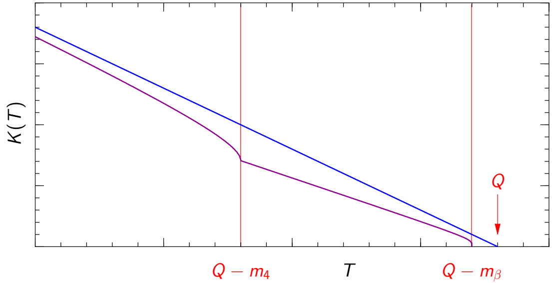
$$Q = M_{^3\text{H}} - M_{^3\text{He}} - m_e = 18.58\,\text{keV}$$

$$\frac{d\Gamma}{dT} = \frac{(\cos\vartheta_C\, G_F)^2}{2\pi^3}\, |\mathcal{M}|^2\, F(E)\, p\, E\, K^2(T)$$

$$\frac{K^2(T)}{Q-T} = \sum_k |U_{ek}|^2 \sqrt{(Q-T)^2 - m_k^2}\,\theta(Q-T-m_k)$$

$$m_4 \gg m_{1,2,3} \Rightarrow \simeq \left(1 - |U_{e4}|^2\right)\sqrt{(Q-T)^2 - m_\beta^2}\,\theta(Q-T-m_\beta)$$

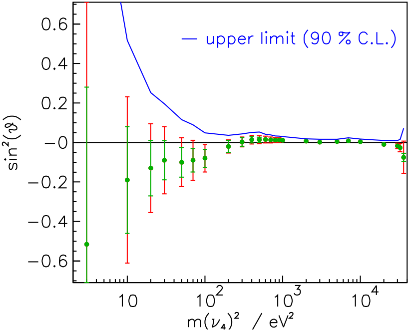
$$+|U_{e4}|^2\sqrt{(Q-T)^2 - m_4^2}\,\theta(Q-T-m_4)$$



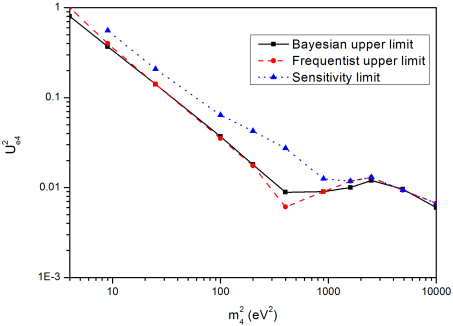
$$m_\beta^2 = \sum_{k=1}^{3} |U_{ek}|^2 m_k^2$$

Mainz and Troitsk Limit on $\Delta m^2_{41} \simeq m^2_4$

$$m_4 \gg m_{1,2,3} \quad \Longrightarrow \quad \Delta m^2_{41} \equiv m^2_4 - m^2_1 \simeq m^2_4$$



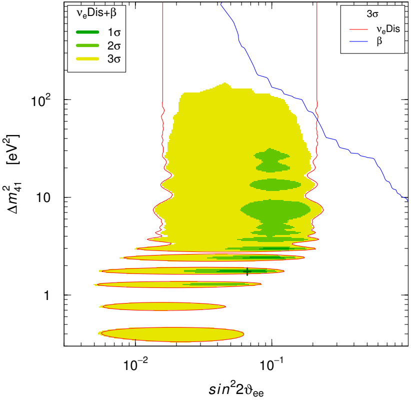
[Kraus, Singer, Valerius, Weinheimer, EPJC 73 (2013) 2323]



[Belesev et al, JPG 41 (2014) 015001]

Global ν_e and $\bar{\nu}_e$ Disappearance + β Decay

[Gariazzo, CG, Laveder, Li, JHEP 1706 (2017) 135 (arXiv:1703.00860)]

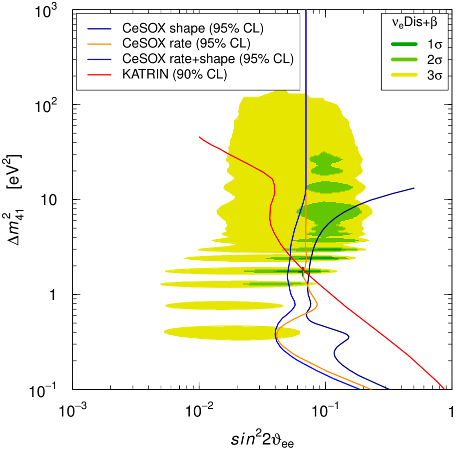


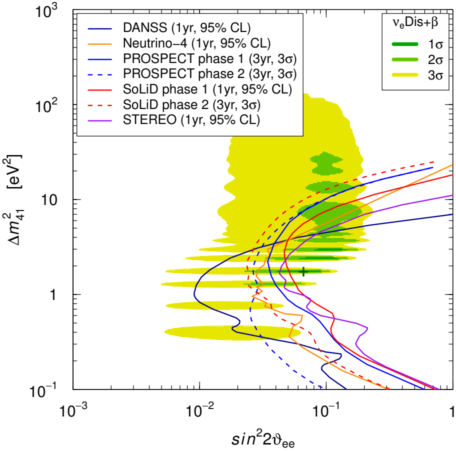
- Best Fit: $\Delta m^2_{41} = 1.7\,\text{eV}^2$
  $\sin^2 2\vartheta_{ee} = 0.066 \quad \Leftrightarrow \quad |U_{e4}|^2 = 0.017$

- $2\,\text{cm} \lesssim \dfrac{L^{\text{osc}}_{41}}{E\,[\text{MeV}]} \lesssim 7\,\text{m}$ at 3σ

- $0.0050 \lesssim \sin^2 2\vartheta_{ee} \lesssim 0.23$ at 3σ

The Race for ν_e and $\bar{\nu}_e$ Disappearance



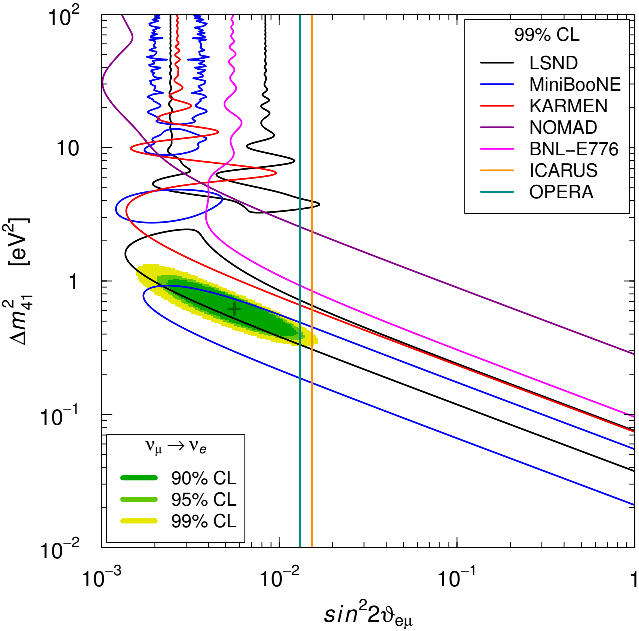


CeSOX (Gran Sasso, Italy) $^{144}\mathrm{Ce} \to \bar{\nu}_e$
BOREXINO: $L \simeq$ 5-12m [Vivier@TAUP2015]

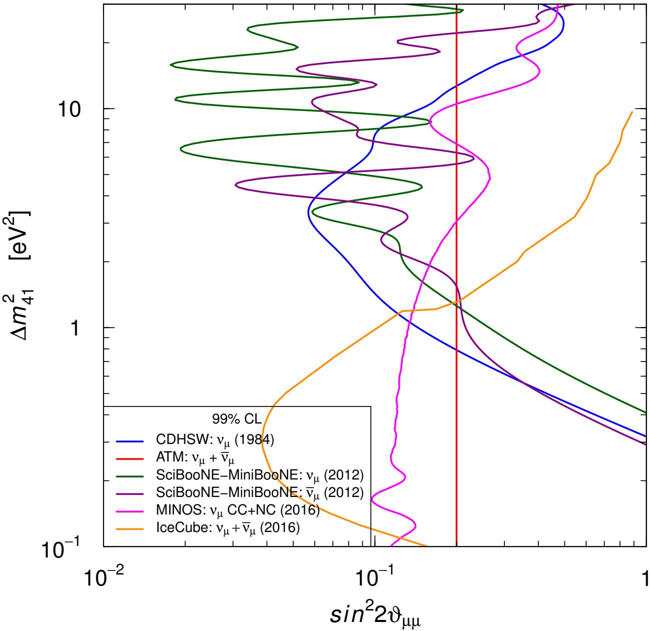
KATRIN (Karlsruhe, Germany) $^{3}\mathrm{H} \to \bar{\nu}_e$
[Drexlin@NOW2016]

DANSS (Kalinin, Russia) $L \simeq$ 10-12m [arXiv:1606.02896]
Neutrino-4 (RIAR, Russia) $L \simeq$ 6-11m [JETP 121 (2015) 578]
PROSPECT (ORNL, USA) $L \simeq$ 7-12m [arXiv:1512.02202]
SoLid (SCK-CEN, Belgium) $L \simeq$ 5-8m [arXiv:1510.07835]
STEREO (ILL, France) $L \simeq$ 8-12m [arXiv:1602.00568]

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



ν_μ and $\bar{\nu}_\mu$ Disappearance



3+1 Appearance-Disappearance Tension

ν_e DIS

$\sin^2 2\vartheta_{ee} \simeq 4|U_{e4}|^2$

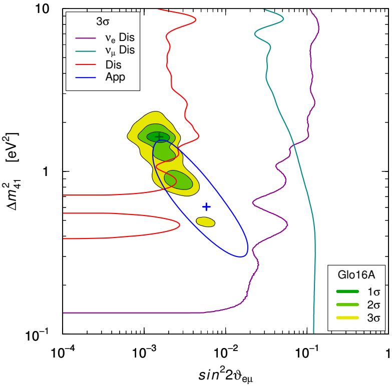
ν_μ DIS

$\sin^2 2\vartheta_{\mu\mu} \simeq 4|U_{\mu4}|^2$

$\nu_\mu \to \nu_e$ APP

$$\sin^2 2\vartheta_{e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2 \simeq \frac{1}{4}\sin^2 2\vartheta_{ee}\sin^2 2\vartheta_{\mu\mu}$$

[Okada, Yasuda, IJMPA 12 (1997) 3669; Bilenky, CG, Grimus, EPJC 1 (1998) 247]

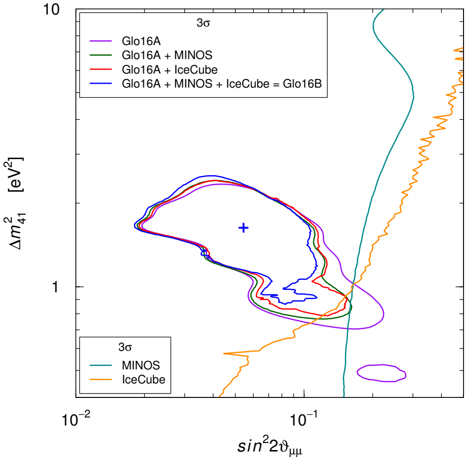


- $\nu_\mu \to \nu_e$ is quadratically suppressed!
- Glo16A = 2016 data except MINOS and IceCube [Gariazzo, CG, Laveder, Li, JHEP 1706 (2017) 135]
- $\Delta\chi^2_{\text{NO}}/\text{NDF}_{\text{NO}} = 53.1/3 \Rightarrow \approx 6.7\sigma$ anom.
- Best Fit: $\Delta m^2_{41} = 1.6\,\text{eV}^2$

  $|U_{e4}|^2 = 0.027 \quad |U_{m4}|^2 = 0.015$
- $\chi^2_{\text{min}}/\text{NDF} = 288.4/250 \Rightarrow \text{GoF} = 4.8\%$
- $\chi^2_{\text{PG}}/\text{NDF}_{\text{PG}} = 13.4/2 \Rightarrow \text{GoF}_{\text{PG}} = 0.13\%$
- Similar tension in 3+2, 3+3, ..., 3+N_s

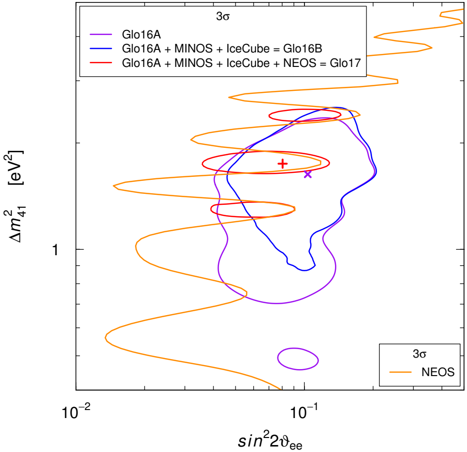
  [CG, Zavanin, MPLA 31 (2015) 1650003]

Effects of MINOS and IceCube



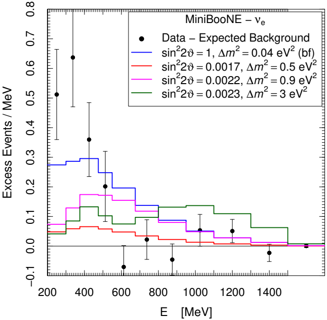
- IceCube effect in agreement with
  Collin, Arguelles, Conrad, Shaevitz, PRL 117 (2016) 221801
- Best Fit: $\Delta m^2_{41} = 1.6\,\text{eV}^2 \quad |U_{e4}|^2 = 0.028 \quad |U_{\mu 4}|^2 = 0.014$
- $\chi^2_{\text{min}}/\text{NDF} = 556.9/525 \Rightarrow \text{GoF} = 16\%$
- $\chi^2_{\text{PG}}/\text{NDF}_{\text{PG}} = 14.4/2 \Rightarrow \text{GoF}_{\text{PG}} = 0.075\%$ ← Strong tension!

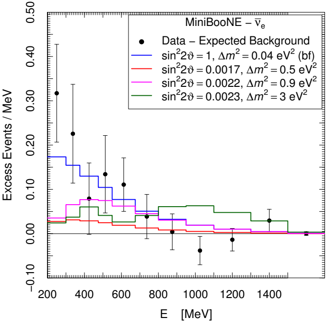
Effects of NEOS

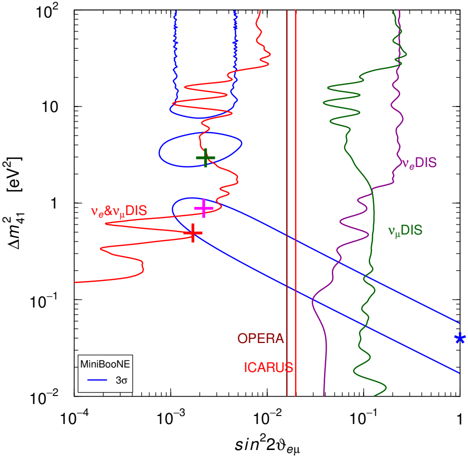


- Best Fit: $\Delta m^2_{41} = 1.7\,\text{eV}^2$ $|U_{e4}|^2 = 0.021$ $|U_{\mu 4}|^2 = 0.016$
- $\chi^2_{\text{min}}/\text{NDF} = 622.1/585 \Rightarrow \text{GoF} = 14\%$
- $\chi^2_{\text{PG}}/\text{NDF}_{\text{PG}} = 17.2/2 \Rightarrow \text{GoF}_{\text{PG}} = 0.019\%$ ← Strong tension!

MiniBooNE Low-Energy Anomaly



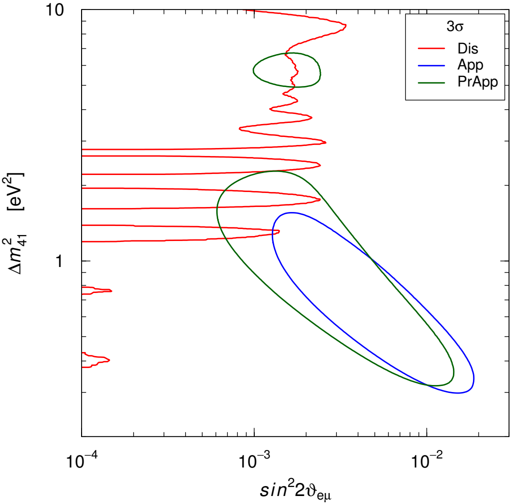




- Fit of MB low-energy excess requires small Δm^2_{41} and large $\sin^2 2\vartheta_{e\mu}$, in contradiction with disappearance data.
- Parameter goodness of fit of MB low-energy excess vs all other data: 6×10^{-6}

Global → Pragmatic

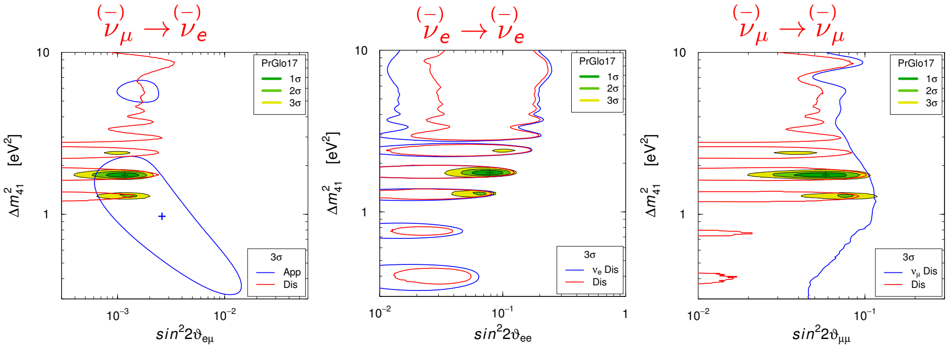
[CG, Laveder, Li, Long, PRD 88 (2013) 073008]



- App: all Appearance data
- PrApp: all Appearance data, except MiniBooNE low-energy bins

Pragmatic Global 3+1 Fit

[Gariazzo, CG, Laveder, Li, JHEP 1706 (2017) 135 (arXiv:1703.00860)]

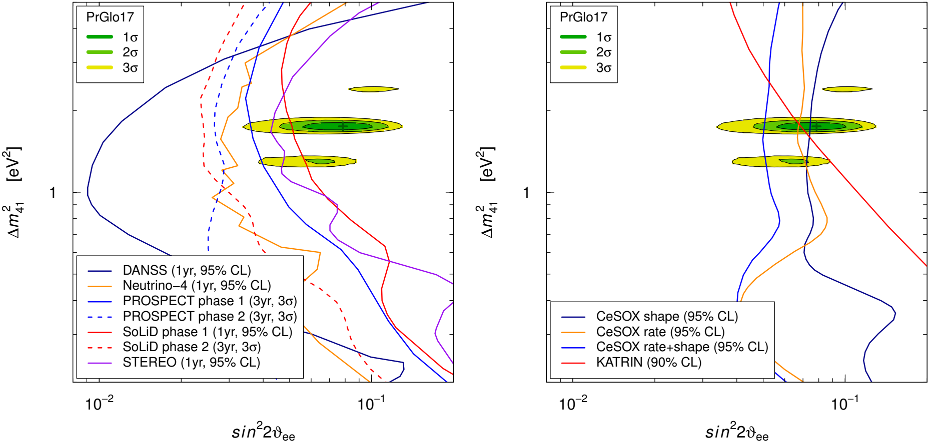


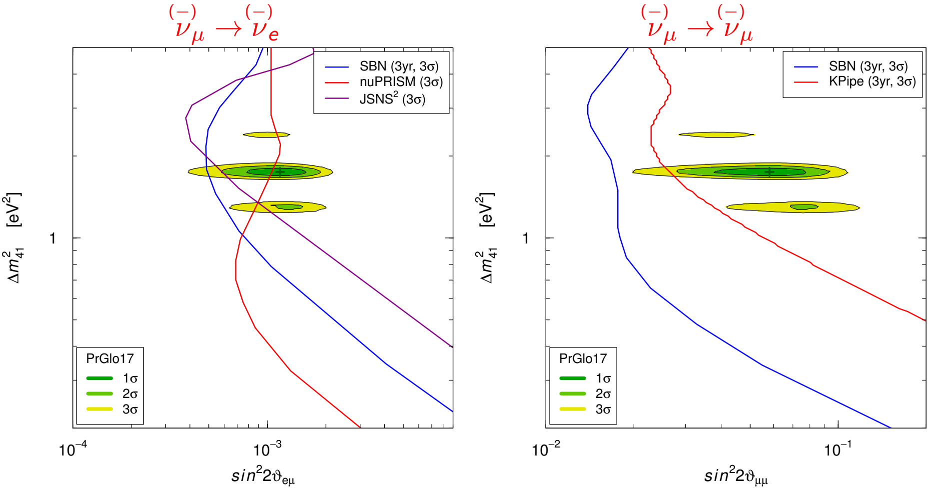
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$ $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$

- $\Delta\chi^2_{\text{NO}}/\text{NDF}_{\text{NO}} = 47.4/4 \Rightarrow \approx 6.1\sigma$ anomaly
- Best Fit: $\Delta m^2_{41} = 1.7\,\text{eV}^2$ $|U_{e4}|^2 = 0.020$ $|U_{\mu4}|^2 = 0.015$
- $\chi^2_{\text{min}}/\text{NDF} = 595.1/579 \Rightarrow \text{GoF} = 31\%$
- $\chi^2_{\text{PG}}/\text{NDF}_{\text{PG}} = 7.2/2 \Rightarrow \text{GoF}_{\text{PG}} = 2.7\%$ ← Mild tolerable tension!

The Race for the Light Sterile

$$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$$

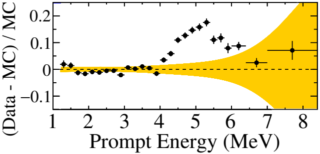




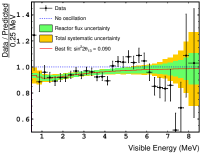
$\overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{e}$

$\overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{\mu}$

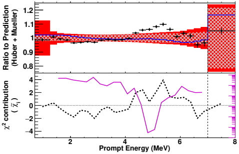
Reactor Antineutrino 5 MeV Bump



[RENO, arXiv:1511.05849]

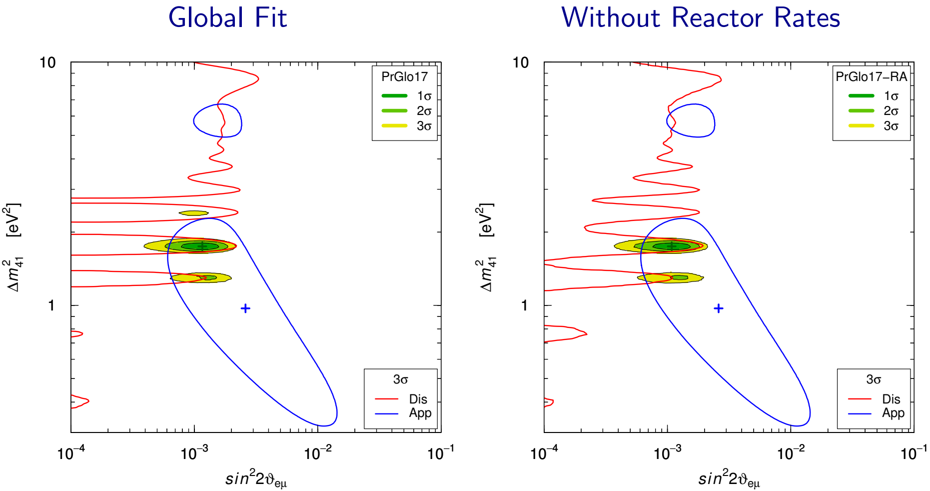


[Double Chooz, arXiv:1406.7763]



[Daya Bay, arXiv:1508.04233]

- Cannot be explained by neutrino oscillations (SBL oscillations are averaged in Double Chooz, Daya Bay, RENO).
- Very likely due to theoretical miscalculation of the spectrum.
- $\sim 3\%$ effect on total flux, but if it is an excess it increases the anomaly!
- No post-bump complete calculation of the neutrino fluxes.
- Saclay-Huber flux calculation uncertainty is about 2.5%.
- Increasing the flux uncertainty is a game that one can play, but there are only guesses, e.g. about 5%. [Hayes and Vogel, 2016]
- Better to exclude the reactor rates from the global fit. [suggestion of Pedro Machado at WIN 2017]



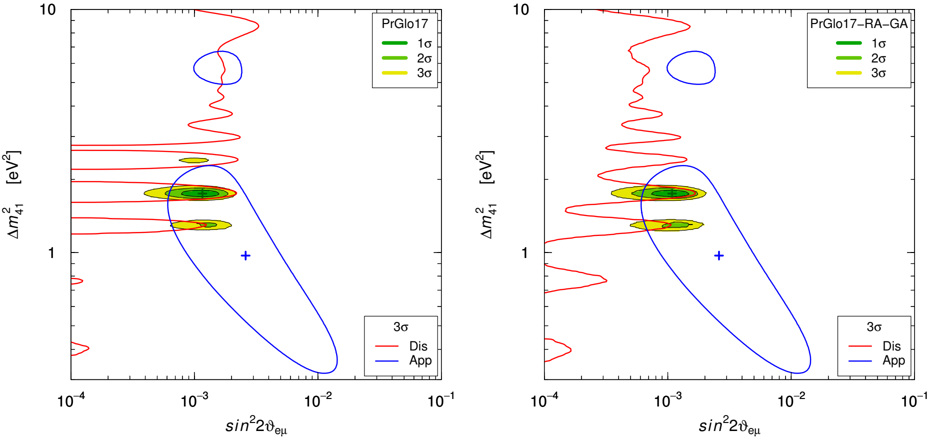
Global Fit

Without Reactor Rates

The Reactor Antineutrino Anomaly has small impact on the global fit.

Global Fit

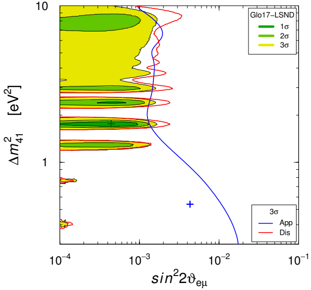
Without Reactor Rates and Gallium Data



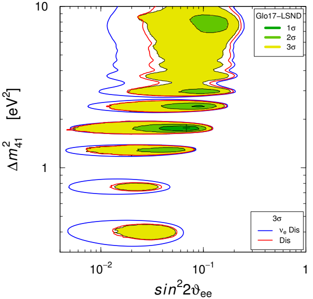
Given the current constraints, only the LSND signal is crucial for a positive indication in favor of active-sterile SBL oscillations.

Global Analysis without LSND

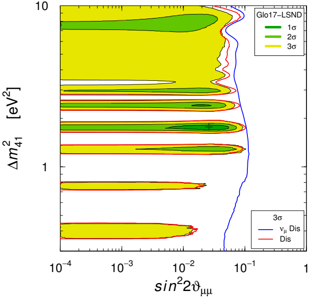
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$



$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$



$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$



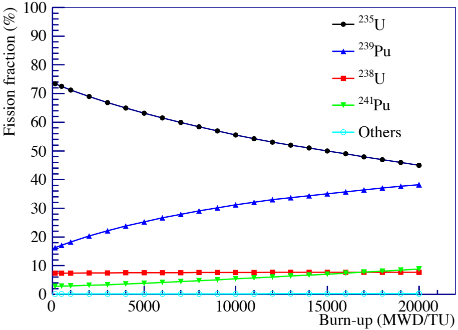
- All MiniBooNE data, including the low-energy bins
- $\Delta\chi^2_{\text{NO}}/\text{NDF}_{\text{NO}} = 17.1/4 \Rightarrow \approx 3.1\sigma$ anomaly
- Best Fit: $\Delta m^2_{41} = 1.8\,\text{eV}^2 \quad |U_{e4}|^2 = 0.017 \quad |U_{\mu4}|^2 = 0.0065$
- $\chi^2_{\text{min}}/\text{NDF} = 604.1/581 \Rightarrow \text{GoF} = 25\%$
- $\chi^2_{\text{PG}}/\text{NDF}_{\text{PG}} = 9.3/2 \Rightarrow \text{GoF}_{\text{PG}} = 0.96\%$ ← Tension!

Daya Bay Reactor Fuel Evolution

[Daya Bay, PRL 118 (2017) 251801 (arXiv:1704.01082)]

- Reactor $\bar{\nu}_e$ flux produced by the β decays of the fission products of ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu.
- Effective fission fractions:

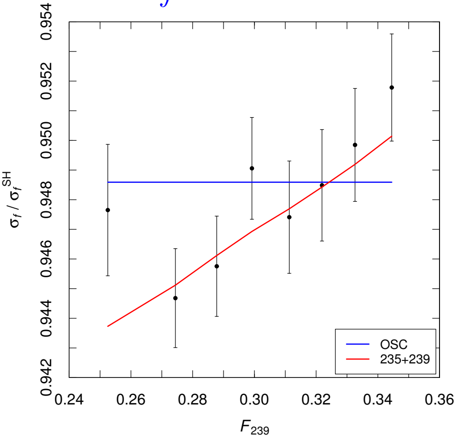
$$F_{235},\ F_{238},\ F_{239},\ F_{241}.$$

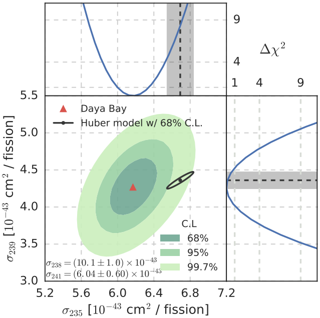


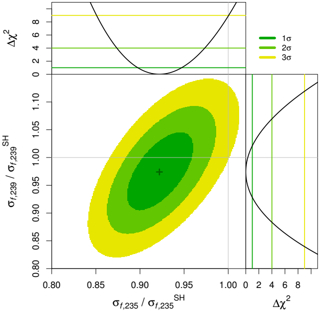
- Cross section per fission:

$$\sigma_f = \sum_{k=235,238,239,241} F_k \, \sigma_{f,k}$$

$$\sigma_{f,k} = \int dE_\nu \, \phi_k(E_\nu) \, \sigma(E_\nu)$$







- Best fit: mainly suppression of $\sigma_{f,235}$
- Equal fluxes suppression:

$$\Delta\chi^2/\mathrm{NDF} = 7.9/1$$

disfavored at 2.8σ

- Equal fluxes suppression corresponds to SBL oscillations, but theoretical flux uncertainties must be taken into account
- With theoretical flux uncertainties:

Daya Bay	^{235}U	OSC
$\chi^2_{\min}$	3.8	9.5
NDF	7	7
GoF	80%	22%

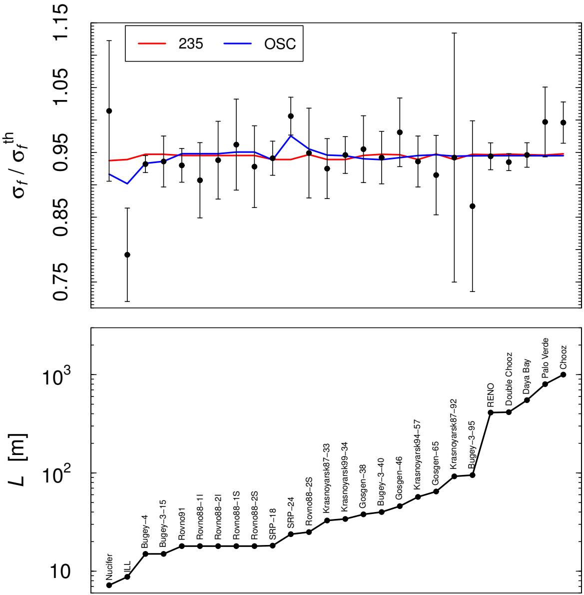
- MC: OSC disfavored at 2.6σ

[CG, X.P. Ji, M. Laveder, Y.F. Li, B.R. Littlejohn, arXiv:1708.01133]

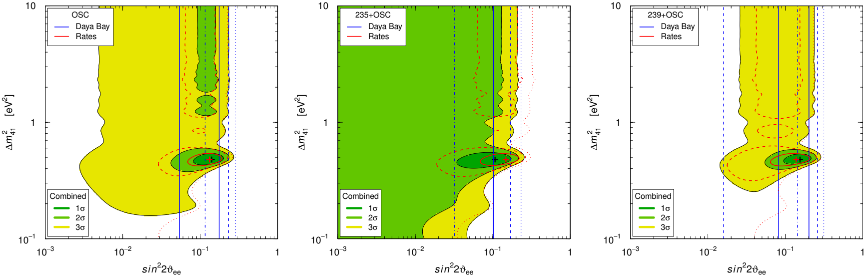
Fuel Fractions of All Reactor Experiments

All Reactors	^{235}U	OSC
χ^2_{min}	25.3	23.0
NDF	32	31
GoF	79%	85%

MC: ^{235}U disfavored at 1.7σ

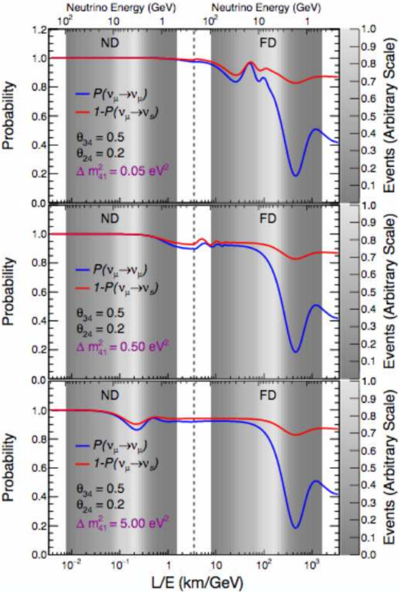


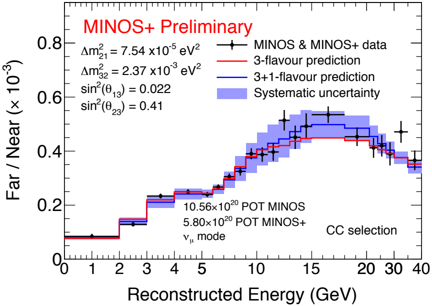
	$^{235}\mathrm{U}$	$^{235}\mathrm{U}+{}^{239}\mathrm{U}$	OSC	$^{235}\mathrm{U}$+OSC	$^{239}\mathrm{U}$+OSC
χ^2_{min}	25.3	24.8	23.0	20.2	17.5
NDF	32	31	31	30	30
GoF	79%	78%	85%	91%	100%
Δm^2_{41}	—	—	0.48	0.48	0.48
$\sin^2 2\vartheta_{ee}$	—	—	0.14	0.11	0.15
r_{235}	0.934	0.934	—	0.987	—
r_{239}	—	0.970	—	—	1.099

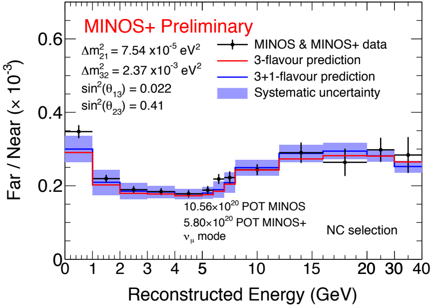


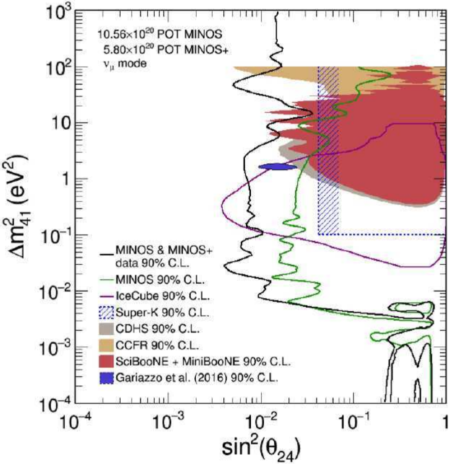
Preliminary Bound from MINOS & MINOS+

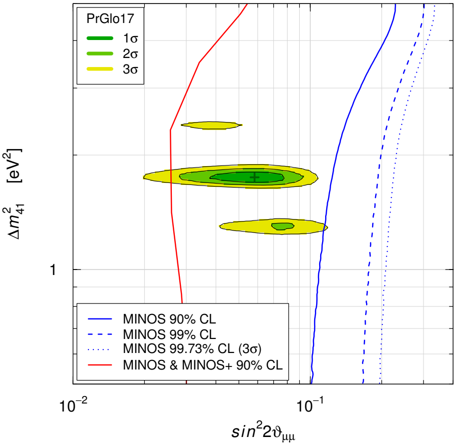
[Flanagan @ PPC2017]







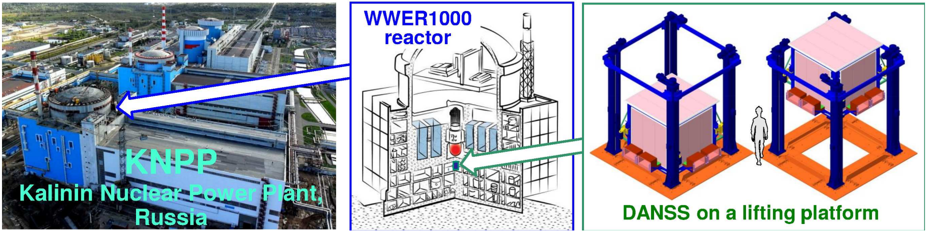

10.56×10²⁰ POT MINOS
5.80×10²⁰ POT MINOS+
νμ mode
MINOS & MINOS+ data 90% C.L.
MINOS 90% C.L.
IceCube 90% C.L.
Super-K 90% C.L.
CDHS 90% C.L.
CCFR 90% C.L.
SciBooNE + MiniBooNE 90% C.L.
Gariazzo et al. (2016) 90% C.L.
Δm^2_{41} (eV^2)
$\sin^2(\theta_{24})$
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1

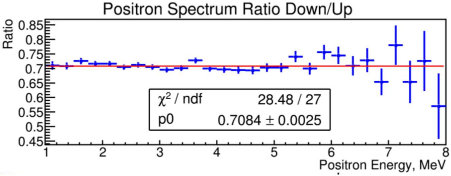

PrGlo17
1σ
2σ
3σ
MINOS 90% CL
MINOS 99% CL
MINOS 99.73% CL (3σ)
MINOS & MINOS+ 90% CL
Δm^2_{41} [eV^2]
1
10^{-2}
10^{-1}
$\sin^2 2\vartheta_{\mu\mu}$

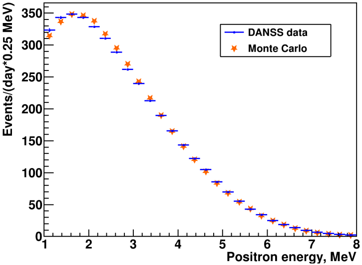
Preliminary Bound from DANSS

[Danilov @ Moriond EW 2017, Svirida @ WIN2017, Danilov @ EPS-HEP 2017]

Detector of reactor AntiNeutrino based on Solid Scintillator

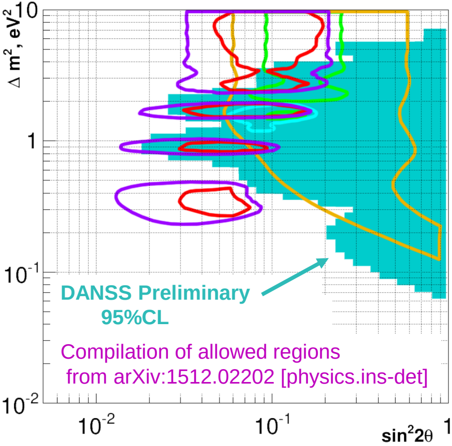






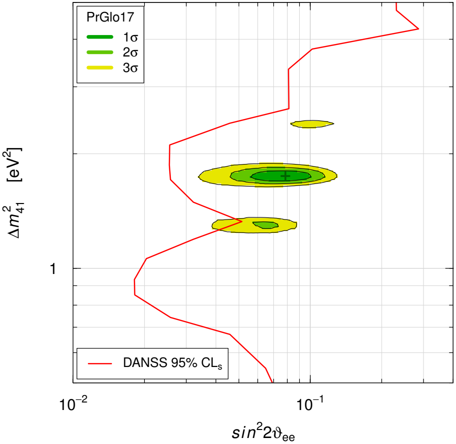
Up = 10.7 m Down = 12.7 m

No 5 MeV bump!



DANSS Preliminary
95%CL

Compilation of allowed regions
from arXiv:1512.02202 [physics.ins-det]



Conclusions

- Exciting indications of sterile neutrinos (new physics!) at the eV scale:
  - LSND $\bar{\nu}_\mu \to \bar{\nu}_e$ signal (caveat: single experimental signal).
  - Gallium ν_e disappearance (caveat: overestimated detector efficiency?).
  - Reactor $\bar{\nu}_e$ disappearance (caveat: flux calculation dependence).
- Vigorous experimental program to check conclusively in a few years:
  - ν_e and $\bar{\nu}_e$ disappearance with reactors and radioactive sources.
  - $\nu_\mu \to \nu_e$ transitions with accelerator neutrinos.
  - ν_μ disappearance with accelerator neutrinos.
- Independent tests through effect of m_4 in β-decay and $\beta\beta_{0\nu}$-decay.
- Cosmology: strong tension with $\Delta N_{\text{eff}} = 1$ and $m_4 \approx 1\,\text{eV}$. It may be solved by a non-standard cosmological mechanism.
- Possibilities for the next years:
  - Reactor and source experiments ν_e and $\bar{\nu}_e$ observe SBL oscillations: big excitement and explosion of the field.
  - Otherwise: still marginal interest to check the LSND appearance signal.
  - In any case the possibility of the existence of sterile neutrinos related to New Physics beyond the Standard Model will continue to be studied (e.g keV sterile neutrinos).