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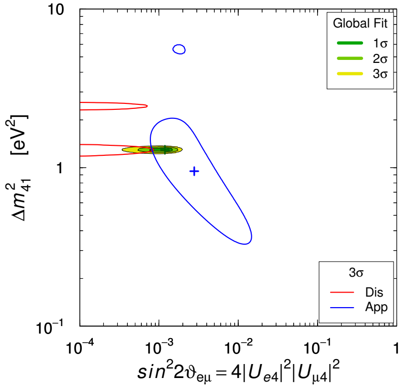
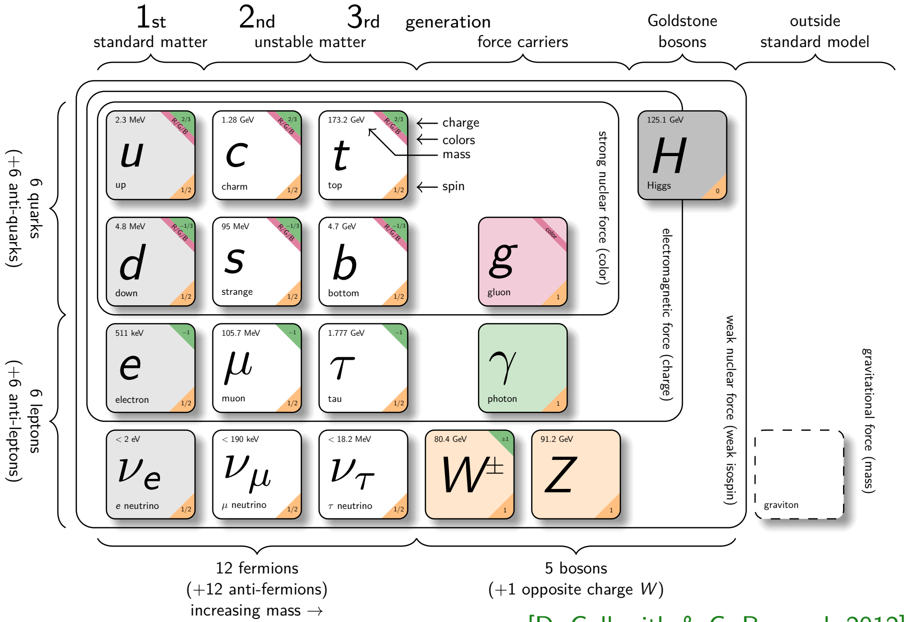
Light sterile neutrino: the 2018 status

The Magnificent CEνNS, Chicago, 03/11/2018

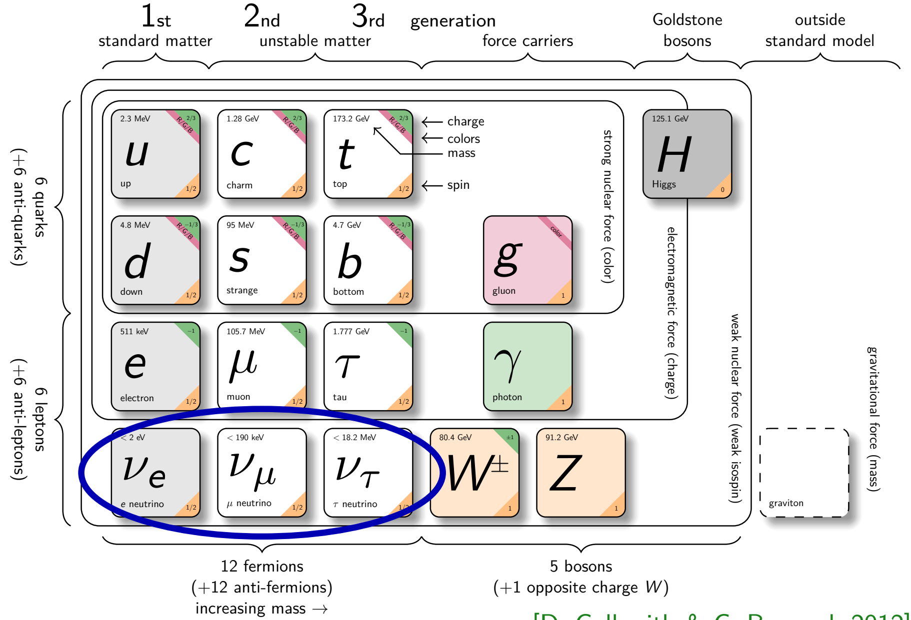

10
1
10−1
10−4
10−3
10−2
10−1
1
Δm²41 [eV²]
sin²2ϑeμ = 4|Ue4|²|Uμ4|²
Global Fit
1σ
2σ
3σ
3σ
Dis
App

The Standard Model of Particle Physics



[D. Galbraith & C. Burgard, 2012]

The Standard Model of Particle Physics



[D. Galbraith & C. Burgard, 2012]

Three Neutrino Oscillations

$$\nu_\alpha = \sum_{k=1}^{3} U_{\alpha k}\nu_k \quad (\alpha = e, \mu, \tau)$$

$U_{\alpha k}$ described by 3 mixing angles θ_{12}, θ_{13}, θ_{23} and one CP phase δ_{CP}

Current knowledge of the 3 active ν mixing: [de Salas et al. (2018)]

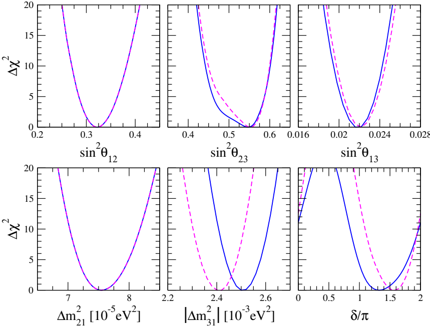
NO: Normal Ordering, $m_1 < m_2 < m_3$

IO: Inverted Ordering, $m_3 < m_1 < m_2$

$$\begin{aligned}
\Delta m^2_{21} &= (7.55^{+0.20}_{-0.16}) \cdot 10^{-5}\ \mathrm{eV}^2 \\
|\Delta m^2_{31}| &= (2.50 \pm 0.03) \cdot 10^{-3}\ \mathrm{eV}^2\ (\mathrm{NO}) \\
&= (2.42^{+0.03}_{-0.04}) \cdot 10^{-3}\ \mathrm{eV}^2\ (\mathrm{IO})
\end{aligned}$$

$$\begin{aligned}
\sin^2(\theta_{12}) &= 0.320^{+0.020}_{-0.016} \\
\sin^2(\theta_{13}) &= 0.0216^{+0.008}_{-0.007}\ (\mathrm{NO}) \\
&= 0.0222^{+0.007}_{-0.008}\ (\mathrm{IO}) \\
\sin^2(\theta_{23}) &= 0.547^{+0.020}_{-0.030}\ (\mathrm{NO}) \\
&= 0.551^{+0.018}_{-0.030}\ (\mathrm{IO})
\end{aligned}$$

First hints for $\delta_{\mathrm{CP}} \simeq 3/2\pi$

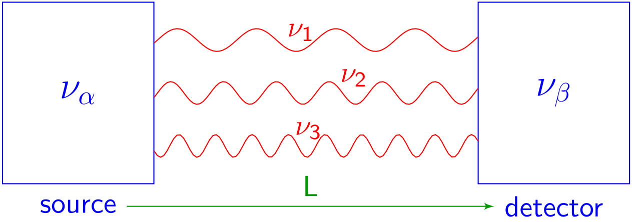


see also: http://globalfit.astroparticles.es

Two types of neutrinos

flavor neutrinos ν_α | $|\nu_\alpha\rangle = U_{\alpha k}|\nu_k\rangle$ | massive neutrinos ν_k

$$|\nu(t=0)\rangle = |\nu_\alpha\rangle = U_{\alpha 1}|\nu_1\rangle + U_{\alpha 2}|\nu_2\rangle + U_{\alpha 3}|\nu_3\rangle$$



$$|\nu(t>0)\rangle = |\nu_\beta\rangle = U_{\alpha 1}\, e^{-iE_1 t}|\nu_1\rangle + U_{\alpha 2}\, e^{-iE_2 t}|\nu_2\rangle + U_{\alpha 3}\, e^{-iE_3 t}|\nu_3\rangle \neq |\nu_\alpha\rangle$$

$E_k^2 = p^2 + m_k^2 \longleftarrow$ define $\longrightarrow t = L$

$$P_{\nu_\alpha \to \nu_\beta}(L) = |\langle \nu_\alpha | \nu(L)\rangle|^2 = \sum_{k,j} U_{\beta k} U^*_{\alpha k} U^*_{\beta j} U_{\alpha j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E}\right)$$

$$\Delta m^2_{ij} = m_i^2 - m_j^2$$

A large family

In principle, previous discussion is valid for N neutrinos

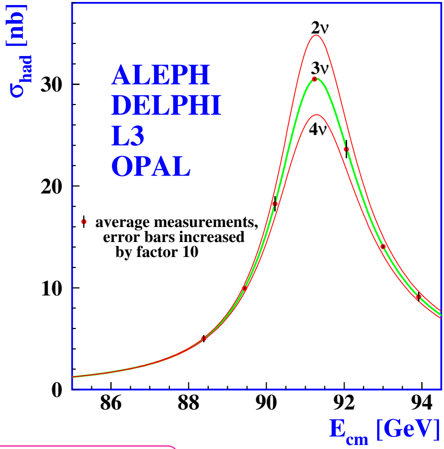
only constraint: there are exactly three flavor neutrinos in the SM

[LEP, Phys. Rept. 427 (2006) 257, arXiv:hep-ex/0509008]

$$N_\nu^{(Z)} = 2.9840 \pm 0.0082$$

through the measurement of the Z resonance

$$e^+e^- \longrightarrow Z \longrightarrow \sum_{a=e,\mu,\tau} \nu_a\bar{\nu}_a$$



neutrinos $\alpha > 3$ must be sterile

sterile neutrino = SM singlet: no couplings with other SM particles

A large family

In principle, previous discussion is valid for N neutrinos

$N \times N$ mixing matrix, N flavor neutrinos, N massive neutrinos

$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \\ |\nu_{s_1}\rangle \\ \cdots \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & \vdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} & \\ \cdots & & & & \ddots \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \\ |\nu_4\rangle \\ \cdots \end{pmatrix}$$

A large family

In principle, previous discussion is valid for N neutrinos

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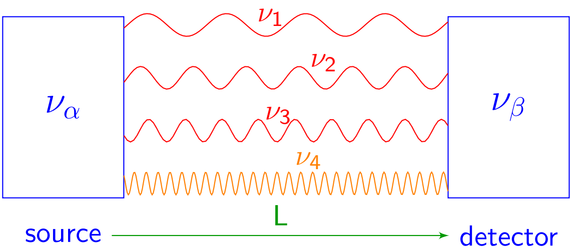
Our case will be 3 (active)+1 (sterile), a perturbation of 3 neutrinos case

$m_4 \gg m_\ell$
$\ell = 1, 2, 3$

$\Delta m^2_{41} \simeq 1\ \text{eV}^2$
$\simeq \Delta m^2_{42}$
$\simeq \Delta m^2_{43}$



6 angles

3 Dirac CP phases

3 Majorana CP phases

Short BaseLine (SBL)

$$P_{\nu_\alpha \to \nu_\beta}(L) = |\langle \nu_\alpha | \nu(L) \rangle|^2 = \sum_{k,j} U_{\beta k} U^*_{\alpha k} U^*_{\beta j} U_{\alpha j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E}\right)$$

If $m_4 \gg m_\ell$, faster oscillations

ν_4 oscillations are averaged in most neutrino oscillation experiments

Effect of 4th neutrino only visible as global normalization

Short BaseLine (SBL) oscillations: $\frac{\Delta m^2_{41} L}{E} \simeq 1$

At SBL, oscillations due to Δm^2_{21} and $|\Delta m^2_{31}|$ do not develop

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APPearance ($\alpha \neq \beta$)

source of $\overset{(-)}{\nu}_\alpha$

detect different flavor $\overset{(-)}{\nu}_\beta$

Short BaseLine (SBL)

$$P_{\nu_\alpha \to \nu_\beta}(L) = |\langle \nu_\alpha | \nu(L) \rangle|^2 = \sum_{k,j} U_{\beta k} U^*_{\alpha k} U^*_{\beta j} U_{\alpha j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E}\right)$$

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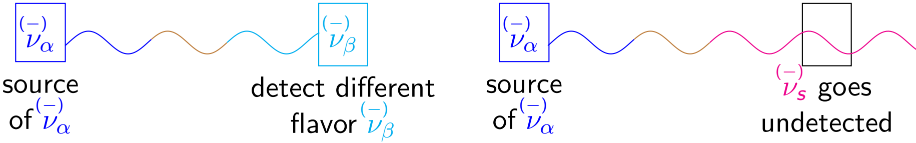
APPearance ($\alpha \neq \beta$) DISappearance



Short BaseLine (SBL)

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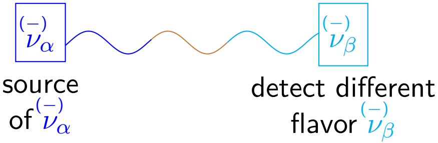
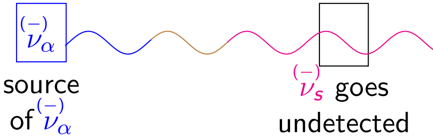


DISappearance



CP violation cannot be observed in SBL experiments!

New mixings in the 3+1 scenario

4×4 mixing matrix:
$$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} \end{pmatrix}$$

New mixings in the 3+1 scenario

$$4 \times 4 \text{ mixing matrix: } \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} \end{pmatrix} \quad \vartheta_{14} \quad \vartheta_{24} \quad \vartheta_{34}$$

New mixings in the 3+1 scenario

4 × 4 mixing matrix: $$\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s_1 1} & U_{s_1 2} & U_{s_1 3} & U_{s_1 4} \end{pmatrix}$$ ϑ_{14} ϑ_{24} ϑ_{34}

DISappearance

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

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

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

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

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

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

New mixings in the 3+1 scenario

4 × 4 mixing matrix: $\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s_11} & U_{s_12} & U_{s_13} & U_{s_14} \end{pmatrix}$ ϑ_{14} ϑ_{24} ϑ_{34}

DISappearance

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

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

$$|U_{\mu4}|^2 = \cos^2 \vartheta_{14} \sin^2 \vartheta_{24}$$

APPearance

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

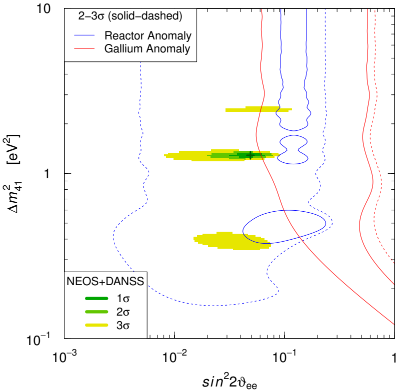
$$\sin^2 2\vartheta_{\alpha\beta} = 4|U_{\alpha4}|^2|U_{\beta4}|^2$$

$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ LSND MiniBooNE KARMEN OPERA ...

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

quadratically suppressed!

for small $|U_{e4}|^2$, $|U_{\mu4}|^2$


2–3σ (solid–dashed)
Reactor Anomaly
Gallium Anomaly
NEOS+DANSS
1σ
2σ
3σ
Δm^2_{41} [eV^2]
$sin^2 2\vartheta_{ee}$
10
1
10^{-1}
10^{-3}
10^{-2}
10^{-1}
1

Gallium anomaly

[SAGE, 2006][Laveder, 2007][Giunti&Laveder, 2011]

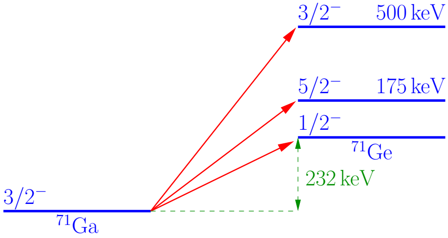
$L \simeq 1.9$ m $\quad L \simeq 0.6$ m

Gallium radioactive source experiments: GALLEX and SAGE

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

$E \simeq 0.75$ MeV $\qquad E \simeq 0.81$ MeV

In the detector: $\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-$



cross sections of
the transitions from

[Krofcheck et al., PRL 55 (1985) 1051]

[Frekers et al., PLB 706 (2011) 134]

Gallium anomaly

[SAGE, 2006][Laveder, 2007][Giunti&Laveder, 2011]

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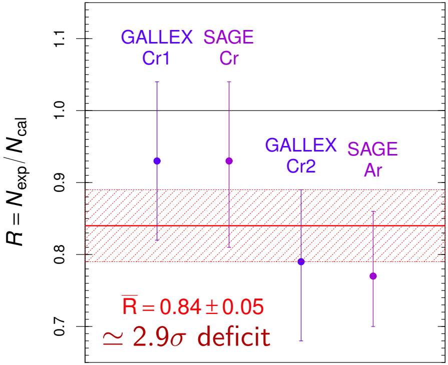
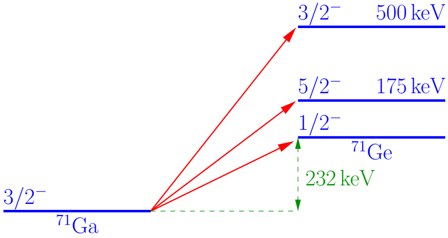
$E \simeq 0.75$ MeV $E \simeq 0.81$ MeV

In the detector: $\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-$

Test detection of solar ν_e





cross sections of the transitions from

[Krofcheck et al., PRL 55 (1985) 1051]

[Frekers et al., PLB 706 (2011) 134]

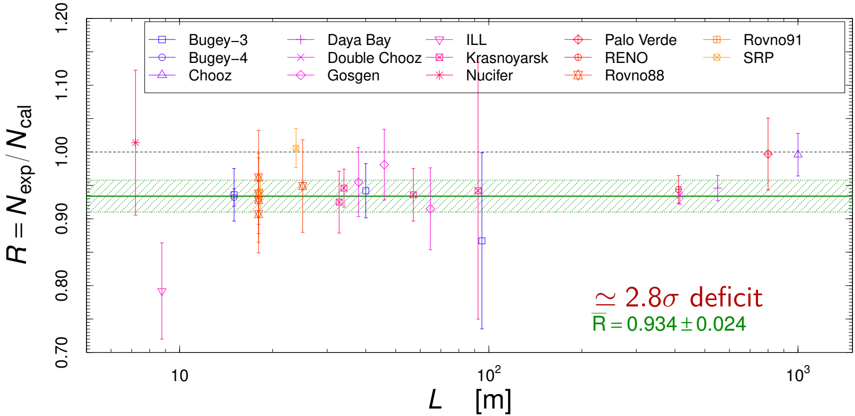
Reactor Antineutrino Anomaly (RAA)

[PRD 83 (2011) 073006]

2011: new reactor $\bar{\nu}_e$ fluxes by Huber and Mueller+ (HM)

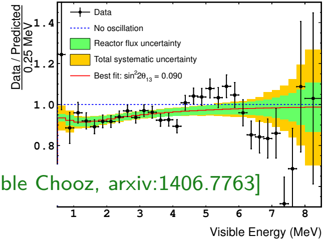
[Huber, PRC 84 (2011) 024617] [Mueller et al., PRC 83 (2011) 054615]

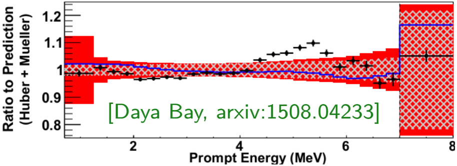
Previous reactor rates evaluated with new fluxes ⇒ deficit

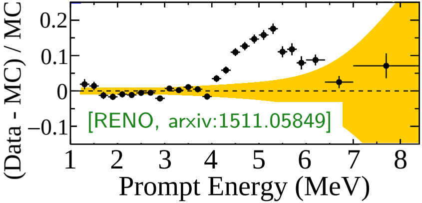


Suppression at detector due to active-sterile oscillations?

Can we trust the HM fluxes?







2014:

bump in the spectrum around 5 MeV!

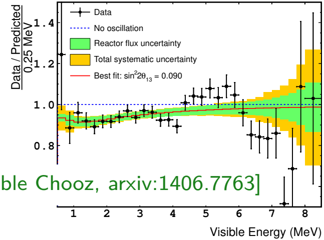
cannot be explained by SBL oscillations

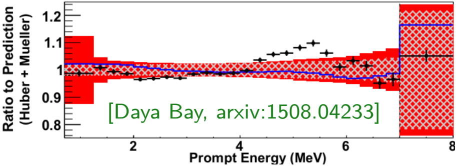
(averaged at the observed distances)

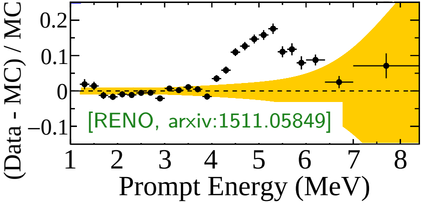
many attempts of possible explanations,

how to clarify the issue?

Can we trust the HM fluxes?







2014:

bump in the spectrum around 5 MeV!

cannot be explained by SBL oscillations

(averaged at the observed distances)

many attempts of possible explanations, how to clarify the issue?

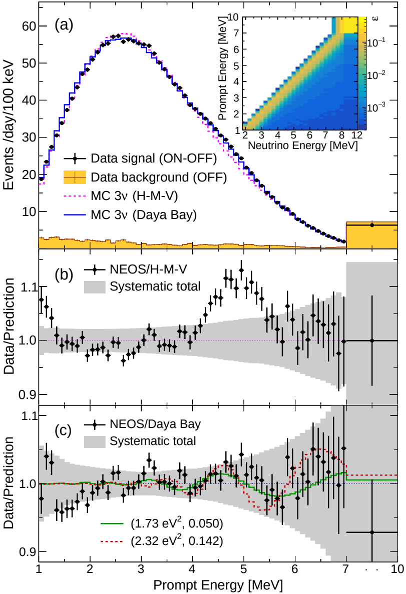
Model independent information!

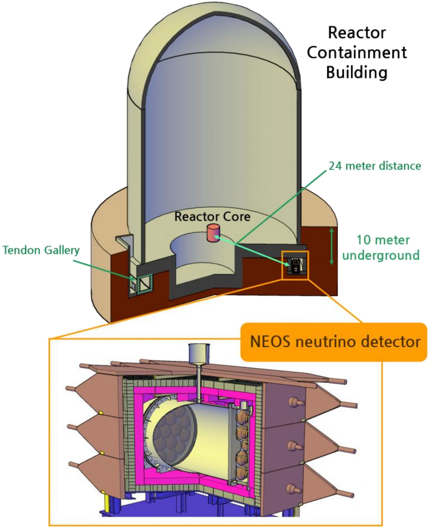
(i.e. take ratio of spectra at different distances)

NEOS

[PRL 118 (2017) 121802]

Single detector experiment



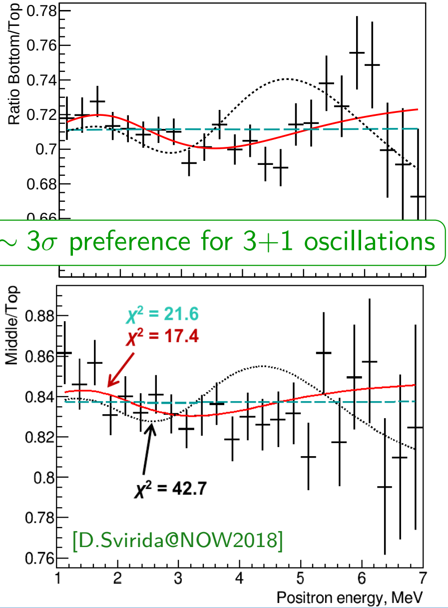


Ratio to DayaBay measurement to be model independent

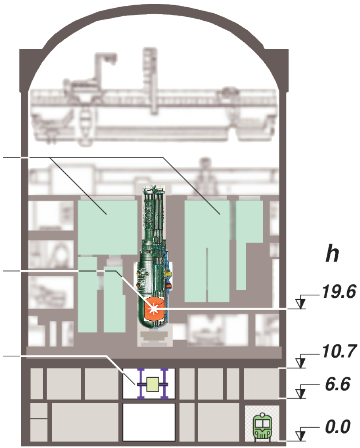
DANSS

[arxiv:1804.04046]

Single movable detector



$\sim 3\sigma$ preference for 3+1 oscillations

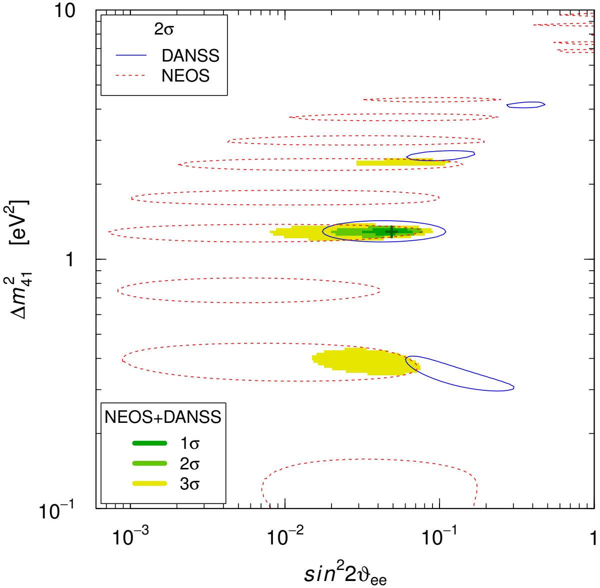


Detector can be at $\sim$ 10.5, $\sim$ 11.5 or $\sim$ 12.5 m from reactor core

Model-independent fit of $\overset{(-)}{\nu}_e$ DIS

[SG et al., PLB 782 (2018) 13]

NEOS + DANSS



The NEOS and DANSS region perfectly overlap at

$\Delta m^2_{41} \simeq 1.3\ \text{eV}^2$

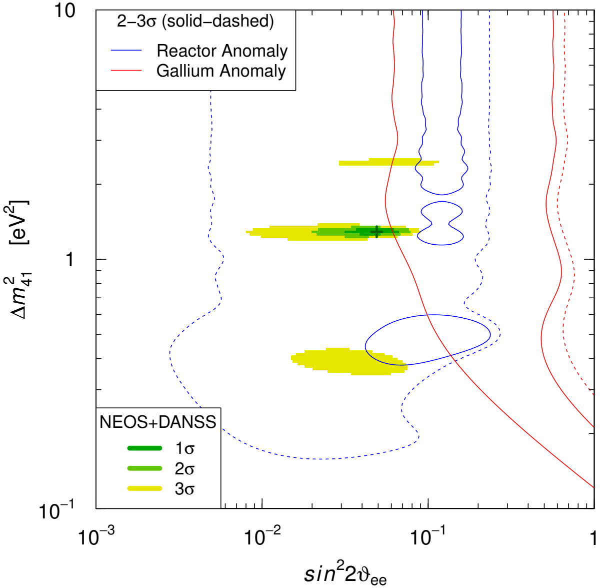
$\sin^2 2\vartheta_{ee} \simeq 0.05$

$\sin^2 \vartheta_{14} \simeq 0.01$

Model-independent fit of $\overset{(-)}{\nu}_e$ DIS

[SG et al., PLB 782 (2018) 13]

DANSS + NEOS + RAA + Gallium

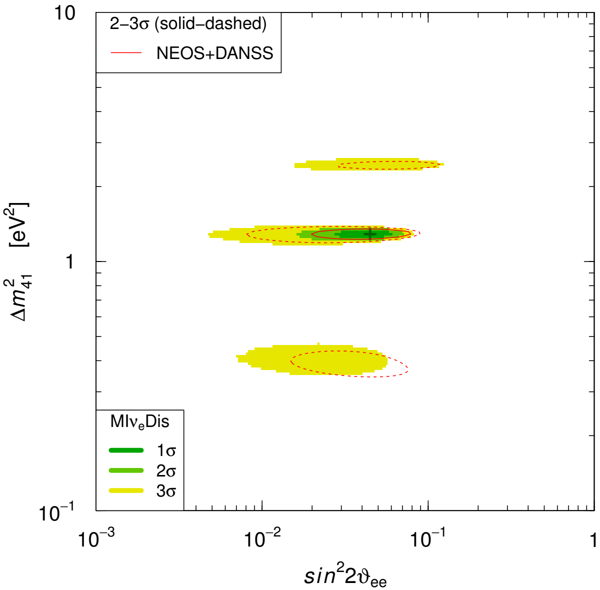


DANSS + NEOS
do not agree with
Gallium and RAA

Model-independent fit of $\overset{(-)}{\nu}_e$ DIS

[SG et al., PLB 782 (2018) 13]

All data:

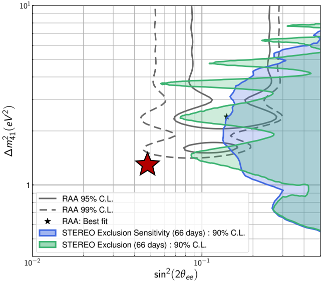


Fit dominated by DANSS + NEOS

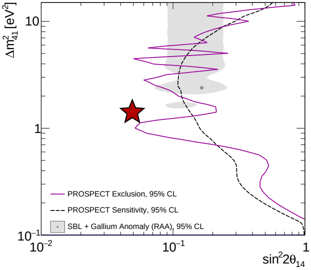
More to come...

★ = current DANSS+NEOS best fit
[SG et al., PLB 782 (2018) 13]

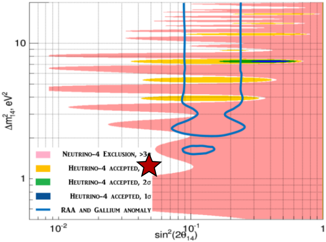
[STEREO, arxiv:1806.02096]



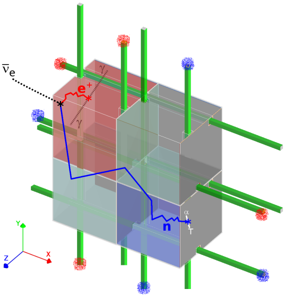
[PROSPECT, arxiv:1806.02784]

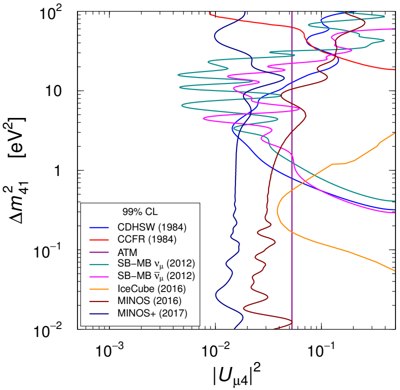


[Neutrino-4, arxiv:1809.10561]



[SoLiD, arxiv:1806.02461]



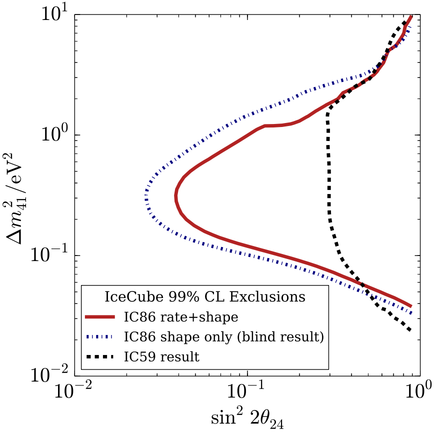

99% CL
CDHSW (1984)
CCFR (1984)
ATM
SB–MB νμ (2012)
SB–MB ν̄μ (2012)
IceCube (2016)
MINOS (2016)
MINOS+ (2017)
Δm^2_{41} [eV^2]
$|U_{\mu4}|^2$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}

IceCube and DeepCore

IceCube $\mathcal{O}(10\text{ km}) \lesssim L \lesssim \mathcal{O}(10^4\text{ km})$

$\sim 2 \times 10^4$ High energy μ events

$320\text{ GeV} < E < 20\text{ TeV}$



[PRL 117 (2016) 071801]

IceCube and DeepCore

IceCube $\mathcal{O}(10\text{ km}) \lesssim L \lesssim \mathcal{O}(10^4\text{ km})$ **DeepCore**

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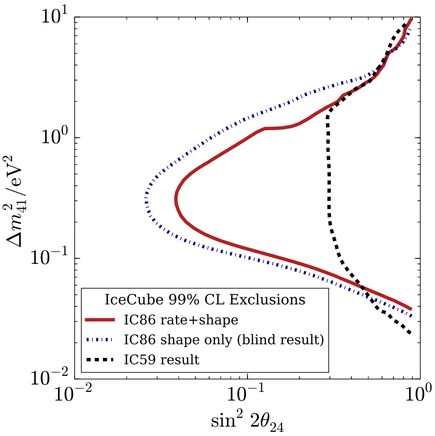
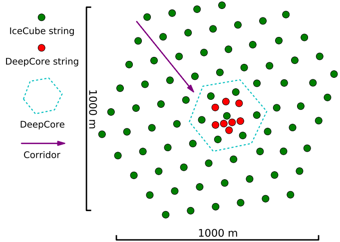
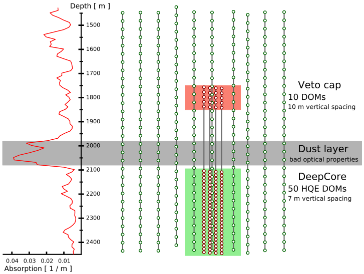


[PRL 117 (2016) 071801]





IceCube and DeepCore

IceCube

$\mathcal{O}(10 \text{ km}) \lesssim L \lesssim \mathcal{O}(10^4 \text{ km})$

DeepCore

$\sim 2 \times 10^4$ High energy μ events

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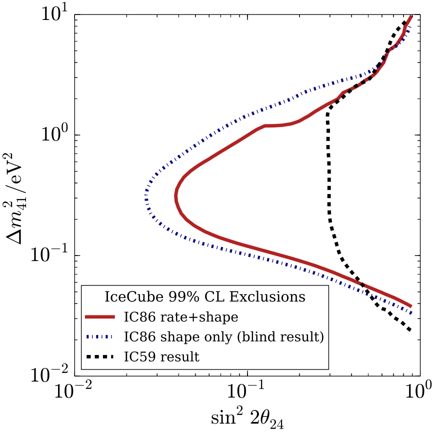
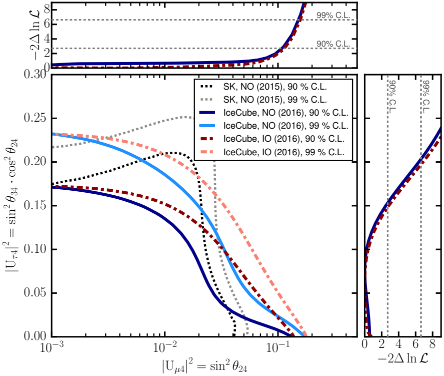


[PRL 117 (2016) 071801]

$\sim 5 \times 10^3$ tracklike events

$6 \text{ GeV} \lesssim E \lesssim 60 \text{ GeV}$



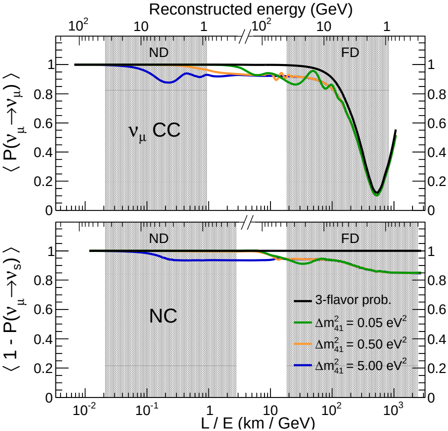
[PRD 95 (2017) 112002]

Both also constrain $|U_{\tau 4}|^2$

MINOS & MINOS+

Near (ND, $\simeq$ 500 m) and far (FD, $\simeq$ 800 km) detector

$1\ \text{GeV} \lesssim E \lesssim 40\ \text{GeV}$, peak at 3 GeV



[PRL 117 (2016) 151803]: far-to-near ratio

[arxiv:1710.06488]: full two-detectors fit

MINOS & MINOS+

Near (ND, $\simeq$ 500 m) and far (FD, $\simeq$ 800 km) detector

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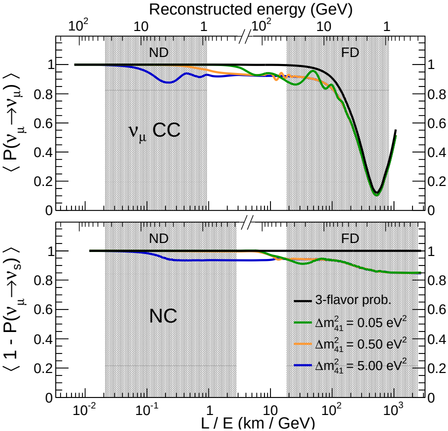
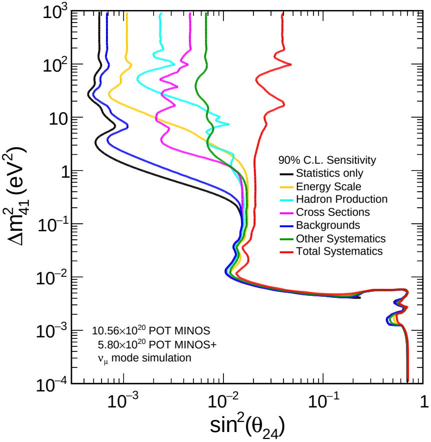


[PRL 117 (2016) 151803]: far-to-near ratio

[arxiv:1710.06488]: full two-detectors fit

Systematics:

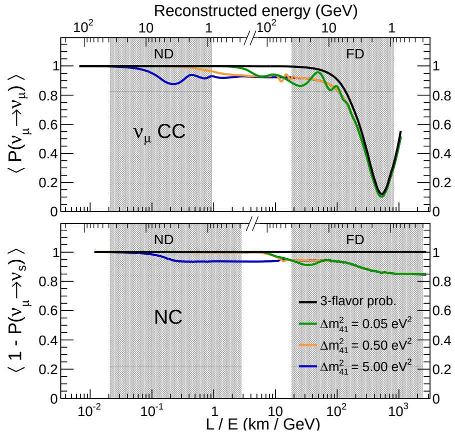


[arxiv:1710.06488]

MINOS & MINOS+

Near (ND, $\simeq$ 500 m) and far (FD, $\simeq$ 800 km) detector

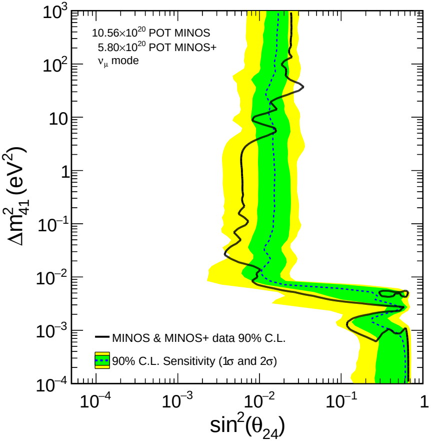
1 GeV $\lesssim E \lesssim$ 40 GeV, peak at 3 GeV



[PRL 117 (2016) 151803]: far-to-near ratio

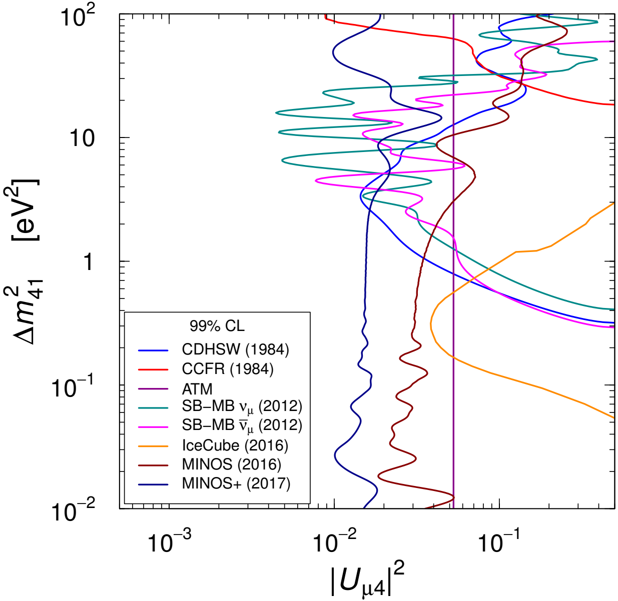
[arxiv:1710.06488]: full two-detectors fit

Sensitivity and exclusion limit:

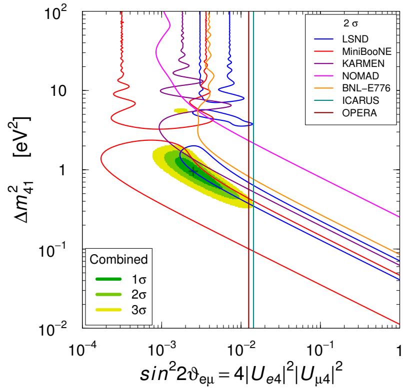


[arxiv:1710.06488]

Global fit of $\overset{(-)}{\nu}_\mu$ DIS



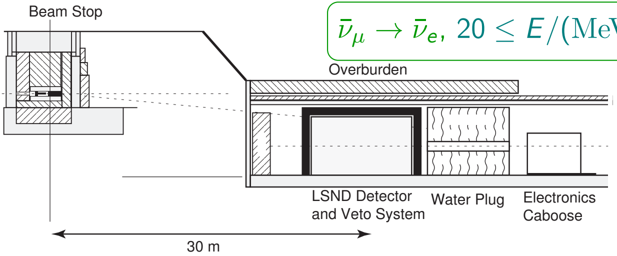
MINOS(+)
dominates
at small Δm^2_{41}


2 σ
LSND
MiniBooNE
KARMEN
NOMAD
BNL–E776
ICARUS
OPERA
Combined
1σ
2σ
3σ
10^2
10
1
10^{-1}
10^{-2}
Δm^2_{41} [eV^2]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$sin^2 2\vartheta_{e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2$

LSND

[PRD 64 (2001) 112007]

$\bar{\nu}_\mu \to \bar{\nu}_e$, $20 \le E/(\mathrm{MeV}) \le 52.8$



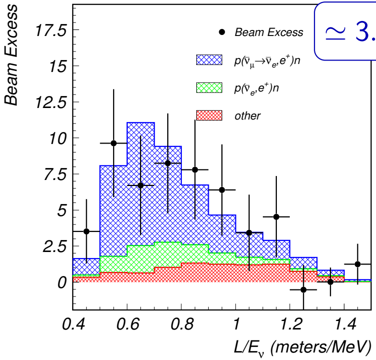
well known source of $\bar{\nu}_\mu$:

$$p + \mathrm{target} \to \pi^+ \xrightarrow{\text{at rest}} \mu^+ + \nu_\mu$$

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

$L \simeq 30$ m

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



$\simeq 3.8\sigma$

No signal seen in KARMEN ($L \simeq 18$ m)

[PRD 65 (2002) 112001]

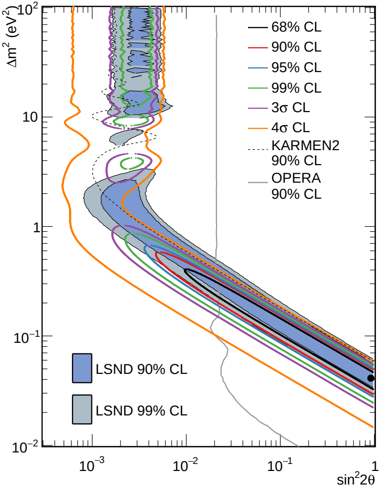
MiniBooNE

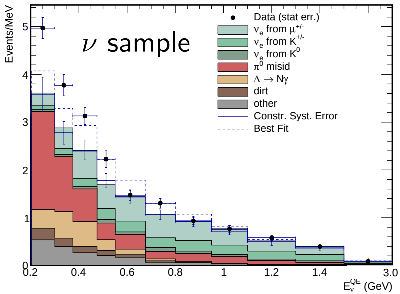
[arxiv:1805.12028]

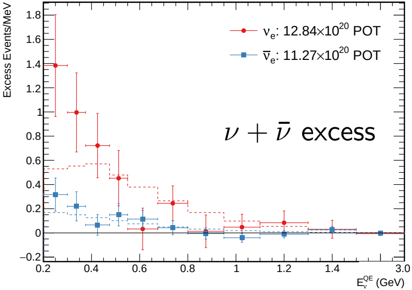
purpose: check LSND signal

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

no money, no near detector







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[arxiv:1805.12028]

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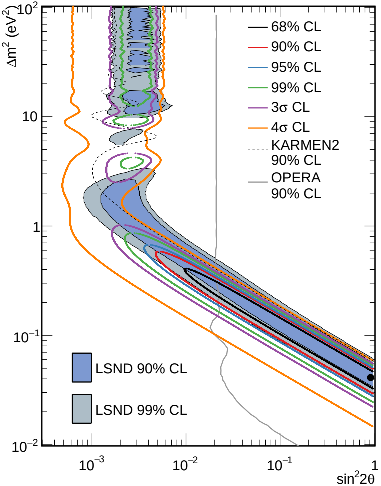
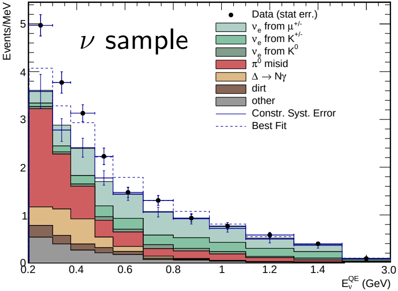
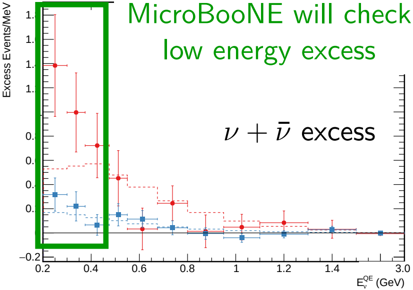


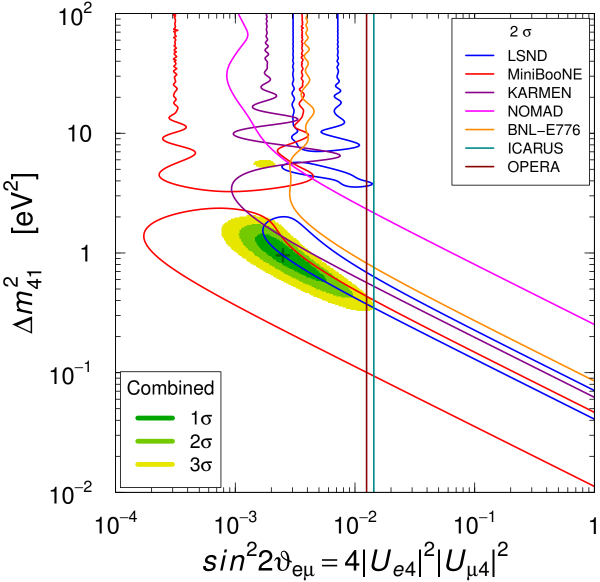




MicroBooNE will check low energy excess

Global fit of $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ APP

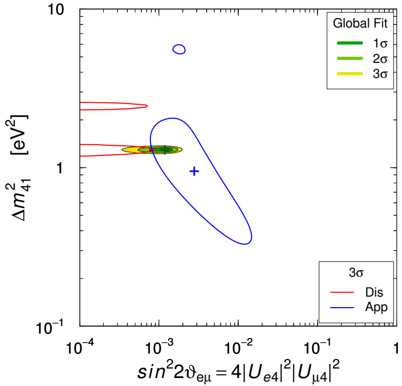
[SG+, preliminary]



ICARUS and OPERA exclude MiniBooNE best fit

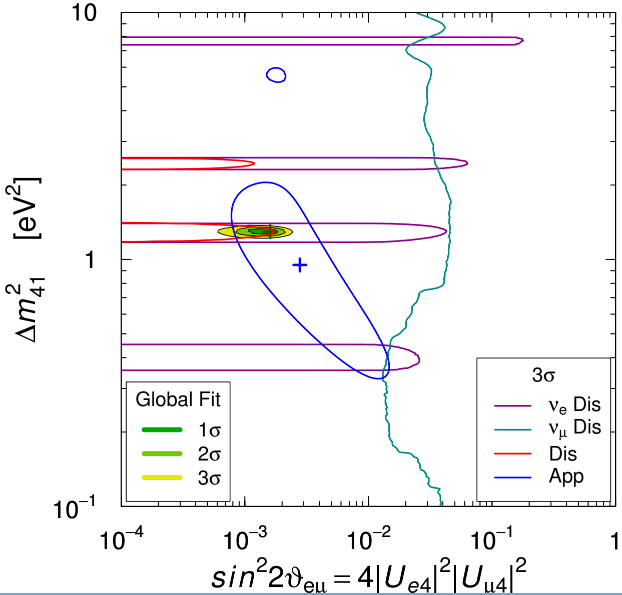
LSND and MiniBooNE only partially in agreement

KARMEN cuts part of LSND region


Global Fit
1σ
2σ
3σ
3σ
Dis
App
10
1
10^−1
10^−4
10^−3
10^−2
10^−1
1
Δm²₄₁ [eV²]
sin²2ϑ_eμ = 4|U_e4|²|U_μ4|²

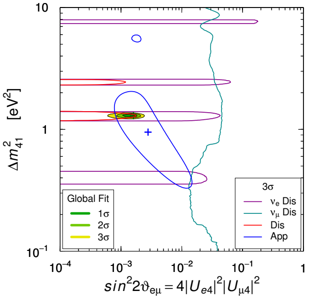
APPearance - DISappearance tension

Without 2018 data:

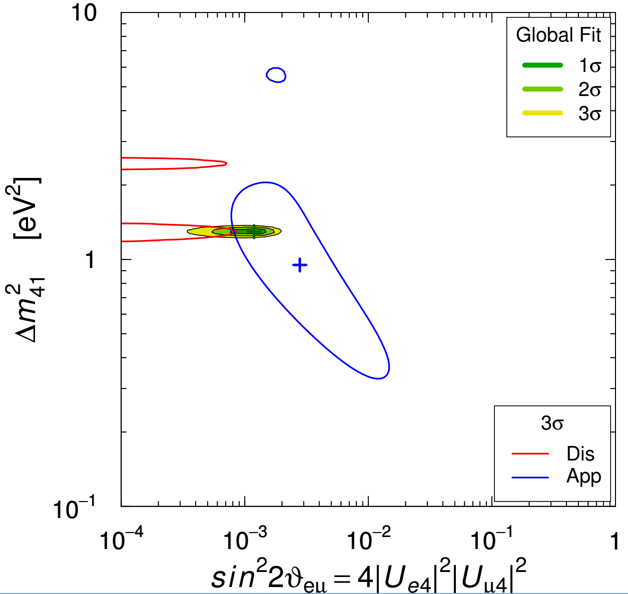


APPearance - DISappearance tension

Without 2018 data:



Status after Neutrino 2018:



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[SG+, preliminary]

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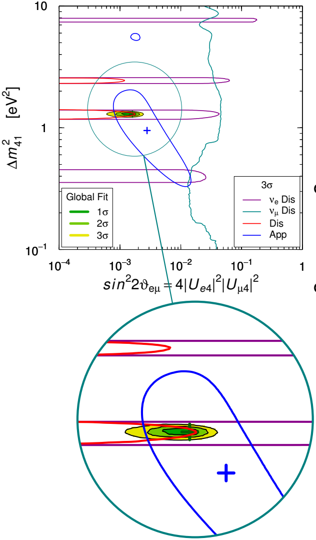
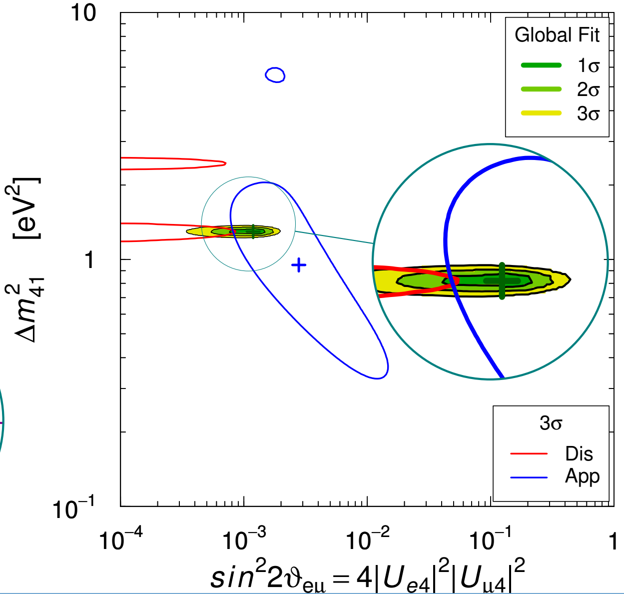


Status after Neutrino 2018:



May something be wrong?

[Dentler+, JHEP 08 (2018) 010]
(2013 data from MiniBooNE)

Analysis	$\chi^2_{\text{min,global}}$	$\chi^2_{\text{min,app}}$	$\Delta\chi^2_{\text{app}}$	$\chi^2_{\text{min,disapp}}$	$\Delta\chi^2_{\text{disapp}}$	$\chi^2_{\text{PG}}/\text{dof}$	PG
Global	1120.9	79.1	11.9	1012.2	17.7	29.6/2	3.71×10^{-7}
Removing anomalous data sets							
w/o LSND	1099.2	86.8	12.8	1012.2	0.1	12.9/2	1.6×10^{-3}
w/o MiniBooNE	1012.2	40.7	8.3	947.2	16.1	24.4/2	5.2×10^{-6}
w/o reactors	925.1	79.1	12.2	833.8	8.1	20.3/2	3.8×10^{-5}
w/o gallium	1116.0	79.1	13.8	1003.1	20.1	33.9/2	4.4×10^{-8}
Removing constraints							
w/o IceCube	920.8	79.1	11.9	812.4	17.5	29.4/2	4.2×10^{-7}
w/o MINOS(+)	1052.1	79.1	15.6	948.6	8.94	24.5/2	4.7×10^{-6}
w/o MB disapp	1054.9	79.1	14.7	947.2	13.9	28.7/2	6.0×10^{-7}
w/o CDHS	1104.8	79.1	11.9	997.5	16.3	28.2/2	7.5×10^{-7}
Removing classes of data							
$\overset{(-)}{\nu}_e$ dis vs app	628.6	79.1	0.8	542.9	5.8	6.6/2	3.6×10^{-2}
$\overset{(-)}{\nu}_\mu$ dis vs app	564.7	79.1	12.0	468.9	4.7	16.7/2	2.3×10^{-4}
$\overset{(-)}{\nu}_\mu$ dis + solar vs app	884.4	79.1	13.9	781.7	9.7	23.6/2	7.4×10^{-6}

May something be wrong?

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No improvements if MiniBooNE is not considered

May something be wrong?

[Dentler+, JHEP 08 (2018) 010]
(2013 data from MiniBooNE)

Analysis	$\chi^2_{\rm min,global}$	$\chi^2_{\rm min,app}$	$\Delta\chi^2_{\rm app}$	$\chi^2_{\rm min,disapp}$	$\Delta\chi^2_{\rm disapp}$	$\chi^2_{\rm PG}/{\rm dof}$	PG
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$\overset{(-)}{\nu}_\mu$ dis + solar vs app	884.4	79.1	13.9	781.7	9.7	23.6/2	7.4×10^{-6}

$\overset{(-)}{\nu}_\mu$ DIS also constrain $|U_{e4}|^2$, while $\overset{(-)}{\nu}_e$ DIS do not constrain $|U_{\mu4}|^2$

May something be wrong?

[Dentler+, JHEP 08 (2018) 010]
(2013 data from MiniBooNE)

Analysis	$\chi^2_{\text{min,global}}$	$\chi^2_{\text{min,app}}$	$\Delta\chi^2_{\text{app}}$	$\chi^2_{\text{min,disapp}}$	$\Delta\chi^2_{\text{disapp}}$	$\chi^2_{\text{PG}}/\text{dof}$	PG
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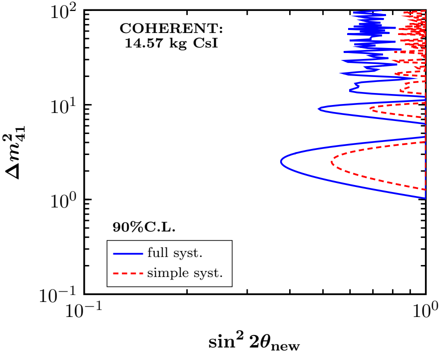
Only removing LSND or all $\overset{(-)}{\nu}_\mu$ constraints the fit is almost acceptable

No reason to do so!

Present and future...

[Papoulias+, PRD 97 (2018) 033003]



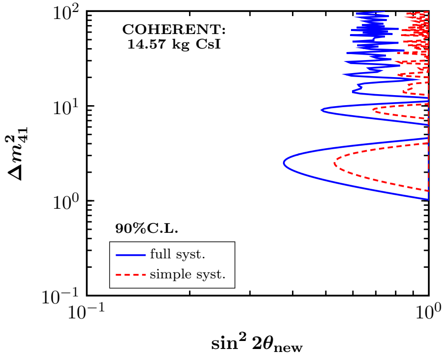
Assumption: all DIS mixing angles are equal

$$\sin^2 2\vartheta_{ee} = \sin^2 2\vartheta_{\mu\mu} = \sin^2 2\theta_{\rm new}$$

not competitive (yet)

Present and future...

[Papoulias+, PRD 97 (2018) 033003]



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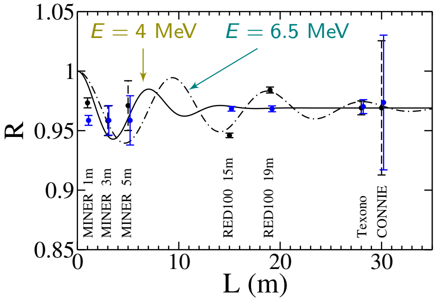
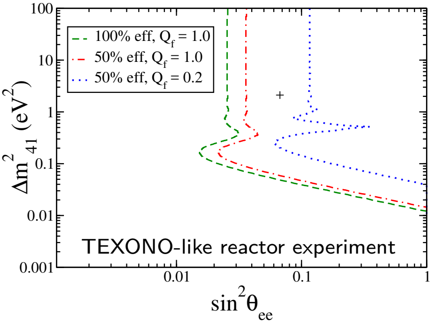
not competitive (yet)

[Cañas+, PLB 776 (2018) 451]





Conclusions

1. first model-independent hints from reactors $\overset{(-)}{\nu}_e$ DIS,
some discrepancy with Gallium anomaly and RAA

2. nothing seen in $\overset{(-)}{\nu}_\mu$ DIS
strong upper bounds on $|U_{\mu 4}|^2$,
but also first constraints on $|U_{\tau 4}|^2$

3. strong APP-DIS tension
What are LSND and MiniBooNE observing?
Systematics or LSν or new physics?

4. incoming CEνNS experiments will enter the game!

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Thank you for the attention!