Status of the eV Sterile Neutrino Oscillations

Alvaro Hernandez Cabezudo

[arXiv:1803.10661]

In collaboration with: Mona Dentler, Joachim Kopp, Pedro Machado, Michele Maltoni, Ivan Martinez-Soler and Thomas Schwetz.

karlsruher Institut für Technologie

alvaro.cabezudo@kit.edu

September 3, 2018

Neutrino Oscillation Anomalies

Massive Neutrinos $\Rightarrow$

Oscillations in a 3ν framework

$$U_{PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$\Delta m^2_{sol}\,,\ \Delta m^2_{atm}$$

Neutrino Oscillation Anomalies

Massive Neutrinos $\Rightarrow$

Oscillations in a 3ν framework

$$U_{PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$\Delta m^2_{sol}\,,\ \Delta m^2_{atm}$$

Anomalies

Oscillations in a 3+1 ν framework

$$\begin{aligned} &\text{LSND}: && \overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{e} \\ &\text{Gallium}: && \nu_e \to \nu_e \\ &\text{Reactor}: && \bar{\nu}_e \to \bar{\nu}_e \end{aligned} \quad \Rightarrow \quad U_{\text{mix}} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{pmatrix}$$

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

Reactor Anomaly

Deficit of measured events with respect to the theoretical predictions.

Reactor Anomaly

Deficit of measured events with respect to the theoretical predictions.

New Physics	VS	**Nuclear Physics**
Sterile Oscillation		Flux predictions

Reactor Anomaly

Deficit of measured events with respect to the theoretical predictions.

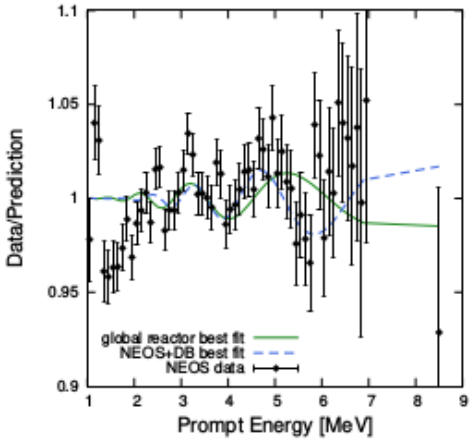
New Physics VS **Nuclear Physics**

Sterile Oscillation | Flux predictions

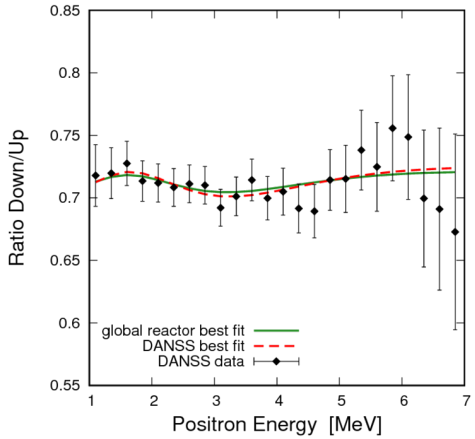
New experimental data

Ratios of measured spectra, independent of flux predictions

NEOS

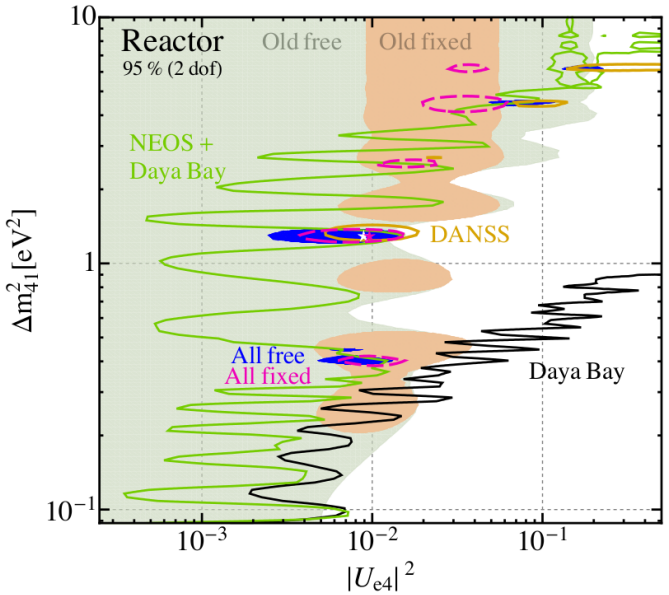


DANSS



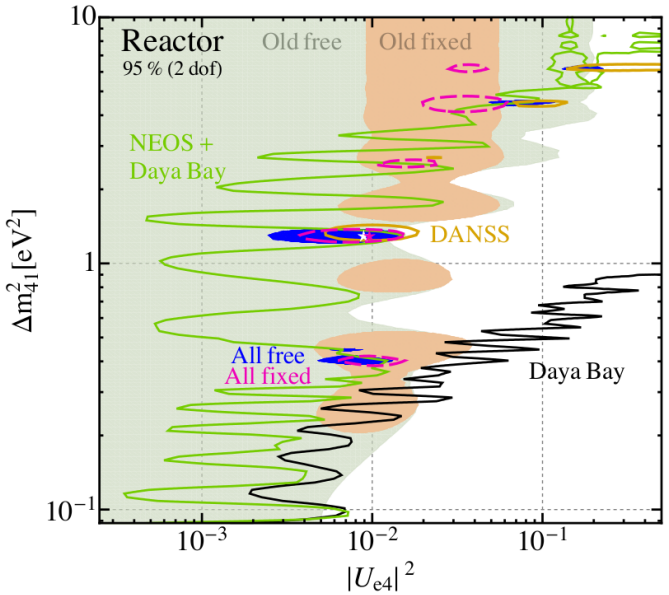
$\bar{\nu}_e \to \bar{\nu}_e$ Disappearance

Reactor Global Analysis



$\bar{\nu}_e \to \bar{\nu}_e$ Disappearance

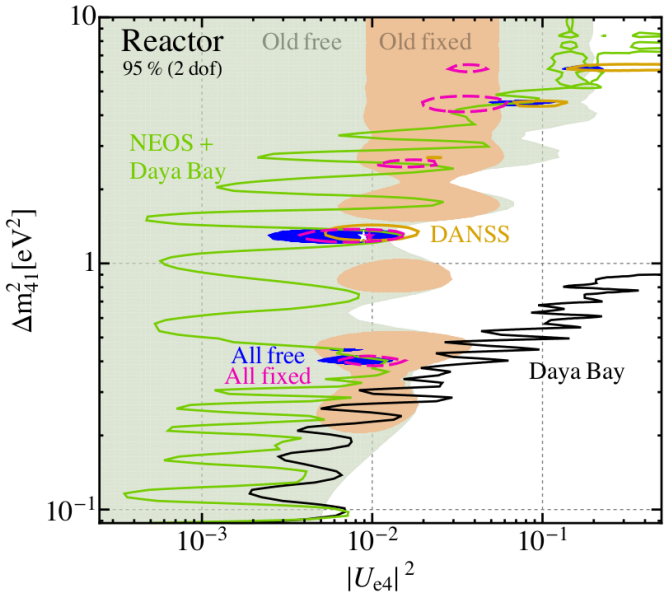
Reactor Global Analysis



Analysis	Δm^2_{41} [eV^2]	$\lvert U^2_{e4}\rvert$	χ^2_{min}/dof	$\Delta\chi^2$(no-osc)	significance
DANSS+NEOS	1.3	0.00964	$74.4/(84-2)$	13.6	3.3σ
all reactor (flux-free)	1.3	0.00887	$185.8/(233-5)$	11.5	2.9σ
all reactor (flux-fixed)	1.3	0.00964	$196.0/(233-3)$	15.5	3.5σ

$\bar{\nu}_e \to \bar{\nu}_e$ Disappearance

Reactor Global Analysis

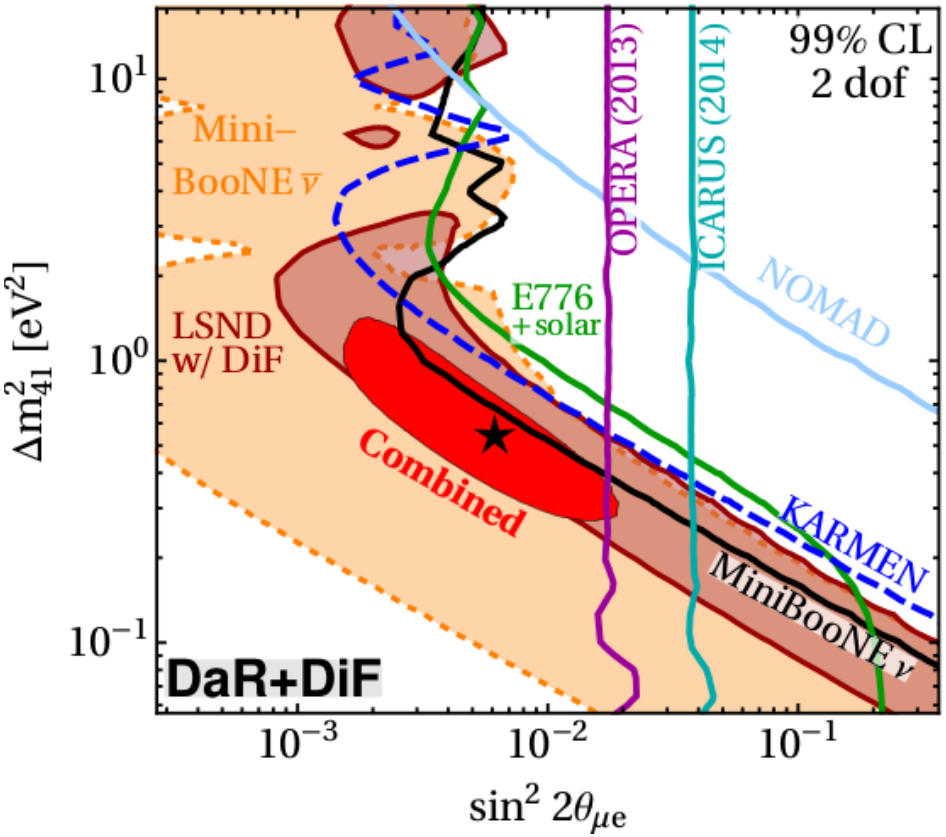


Analysis	Δm^2_{41} [eV^2]	$\lvert U^2_{e4}\rvert$	χ^2_{min}/dof	$\Delta\chi^2$(no-osc)	significance
DANSS+NEOS	1.3	0.00964	$74.4/(84-2)$	13.6	3.3σ
all reactor (flux-free)	1.3	0.00887	$185.8/(233-5)$	11.5	2.9σ
all reactor (flux-fixed)	1.3	0.00964	$196.0/(233-3)$	15.5	3.5σ

Reactor anomaly confirmed by ratios of measured spectra **independently** of flux predictions

LSND & MiniBooNE Anomalies

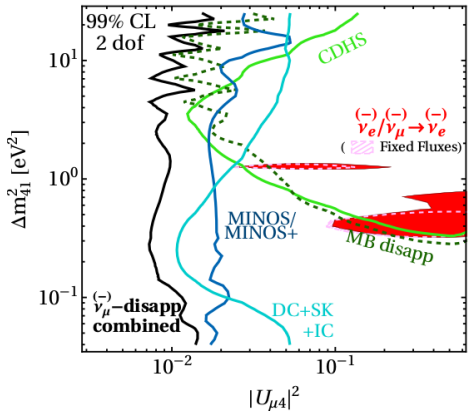
Global $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ Analysis



$$\sin^2 2\theta_{\mu e} \propto |U_{\mu 4}|^2 |U_{e4}|^2$$

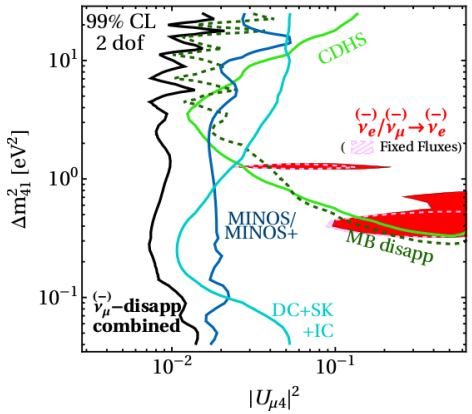
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ vs $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$ Tension

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

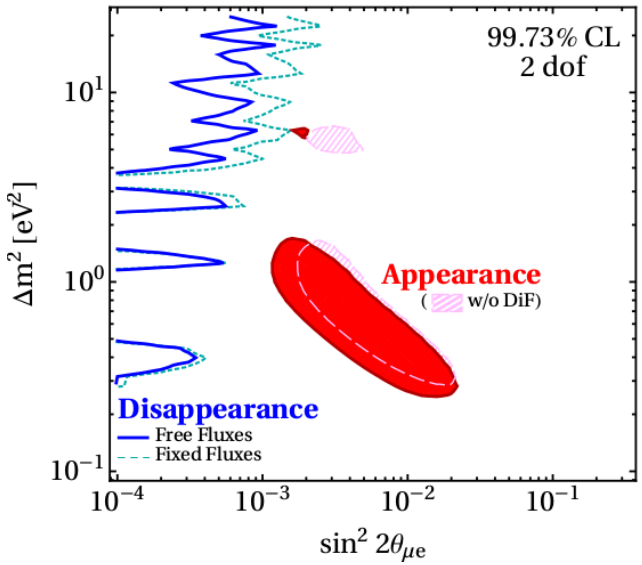


$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ vs $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$ Tension

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

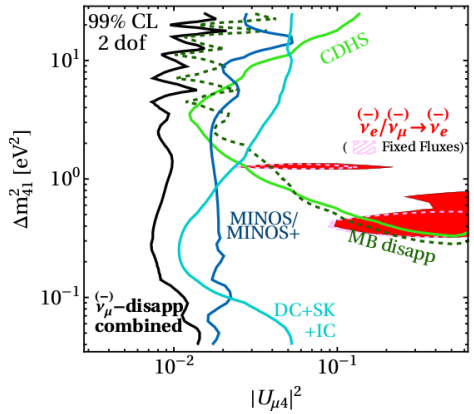


$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ vs $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$ Tension

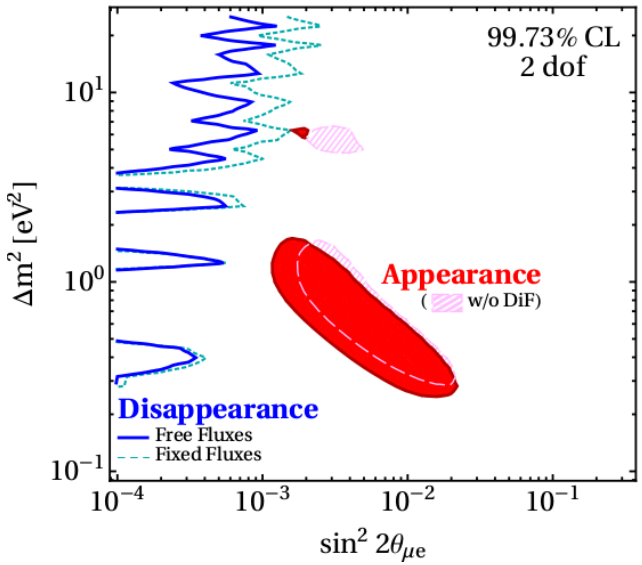


$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ vs $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$ Tension

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



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



Analysis	$\Delta\chi^2_{\mathrm{app-disapp}}$	p-value
Global	29.6	$\mathbf{3.7 \times 10^{-7}}$
w/o Reactors	20.3	3.9×10^{-5}

The tension is independent of the Reactor Anomaly

Summary

Global Analysis of the Sterile Neutrino Oscillations in the $3 + 1\,\nu$ framework.

This project has received funding/support from the European Unions Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 674896.

Summary

Global Analysis of the Sterile Neutrino Oscillations in the $3 + 1\,\nu$ framework.

- Reactor anomaly is confirmed at the level of 2.9σ independently of the flux predictions.

This project has received funding/support from the European Unions Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 674896.

Summary

Global Analysis of the Sterile Neutrino Oscillations in the $3+1\,\nu$ framework.

- Reactor anomaly is confirmed at the level of 2.9σ independently of the flux predictions.
- The LNSD anomaly, found in the channel $\overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{e}$, is in big tension with the constrains coming from $\overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{\mu}$. This result is independent of the reactor anomaly.

This project has received funding/support from the European Unions Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 674896.

Karlsruhe Institute of Technology
Institute for Nuclear Physics (IKP)
Theoretical Astroparticle Physics

elusives

Horizon 2020
GA 674896-ELUSIVES

Status of the eV Sterile Neutrino Oscillations

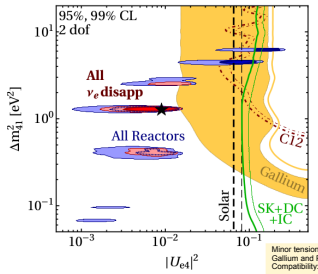
Based on [1,2]

Mona Dentler, Alvaro Hernandez-Cabezudo*, Joachim Kopp, Pedro Machado, Michele Maltoni, Ivan Martinez-Soler, Thomas Schwetz

*alvaro.cabezudo@kit.edu

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

$$P_{\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e} = 1 - 4\,|U_{e4}|^2\left(1 - |U_{e4}|^2\right)\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

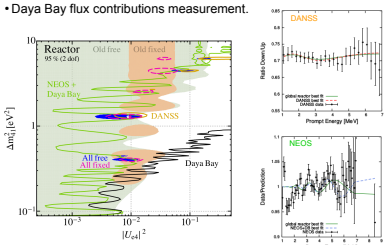


Minor tension between Gallium and Reactors. Compatibility: p-value of 9%

Analysis	Δm^2_{41} [eV^2]	$\lvert U^2_{e4}\rvert$	$\chi^2_{\min}$/dof	$\Delta\chi^2$(no-osc)	significance
DANSS+NEOS	1.3	0.00964	$74.4/(84-2)$	13.6	3.3σ
all reactor (flux-free)	1.3	0.00887	$185.8/(233-5)$	11.5	2.9σ
all reactor (flux-fixed)	1.3	0.00964	$196.0/(233-3)$	15.5	3.5σ
$\overline{\nu}_e$ disap. (flux-free)	1.3	0.00901	$542.9/(594-8)$	13.4	3.2σ
$\overline{\nu}_e$ disap. (flux-fixed)	1.3	0.0102	$552.8/(594-6)$	17.5	3.8σ

Reactor Anomaly

- Spectral information: Daya Bay, NEOS, DANSS (preliminary).
- Daya Bay flux contributions measurement.



Reactor anomaly confirmed by ratios of measured spectra - independent of flux predictions

- H_0: Sterile Oscillations & flux predictions
- H_1: No oscillation & free fluxes

Test statistics
$T \equiv \chi^2_{\min}(H_0) - \chi^2_{\min}(H_1)$

$T_{DB} = 6.3 = 2.7\sigma$ $\quad T_{\text{all reactors}} = -1.3$

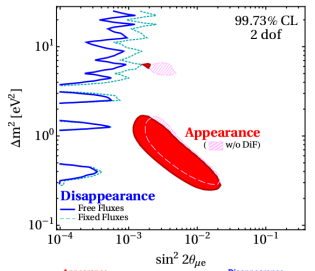
$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ vs $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu$ Tension

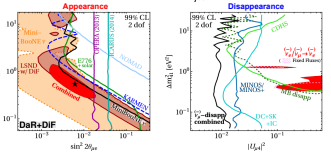
$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu} = 1 - 4\,|U_{\mu 4}|^2\left(1 - |U_{\mu 4}|^2\right)\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

$$P_{\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e} = 4\,|U_{\mu 4}|^2\,|U_{e4}|^2\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

The tension is independent of the Reactor Anomaly

Analysis	$\chi^2_{\min,\text{global}}$	$\chi^2_{\min,\text{app}}$	$\Delta\chi^2_{\text{app}}$	$\chi^2_{\min,\text{disapp}}$	$\Delta\chi^2_{\text{disapp}}$	χ^2_{PG}/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							
$\overline{\nu}_e$ dis vs app	628.6	79.1	0.8	542.9	5.8	6.6/2	3.6×10^{-2}
$\overline{\nu}_\mu$ dis vs app	564.7	79.1	12.0	468.9	4.7	16.7/2	2.3×10^{-4}
$\overline{\nu}_\mu$ dis + solar vs app	884.4	79.1	13.9	781.7	9.7	23.6/2	7.4×10^{-6}





[1] Mona Dentler, Alvaro Hernandez-Cabezudo, Joachim Kopp, Michele Maltoni, Thomas Schwetz et.al. *Sterile Neutrinos or Flux Uncertainties? - Status of the Reactor Anti-Neutrino Anomaly*, *JHEP* 11 (2017) 099, [arXiv: 1709.04294].
[2] Mona Dentler, Alvaro Hernandez-Cabezudo, Joachim Kopp, Pedro Machado, Michele Maltoni, Ivan Martinez-Soler, Thomas Schwetz. *Updated Global Analysis of Neutrino Oscillations in the Presence of eV-Scale Sterile Neutrinos* [arXiv: 1803.10661].