NuFIT 5.3: Three-neutrino fit based on data available in March 2024

Ivan Esteban,[a] M. C. Gonzalez-Garcia,[b,c,d] Michele Maltoni,[e] Thomas Schwetz,[f] Albert Zhou[f]

[a] *Center for Cosmology and AstroParticle Physics (CCAPP) and Department of Physics, Ohio State University, Columbus, Ohio 43210, USA*

[b] *Departament de Física Quàntica i Astrofísica and Institut de Ciencies del Cosmos, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Spain*

[c] *Institució Catalana de Recerca i Estudis Avançats (ICREA), Pg. Lluis Companys 23, 08010 Barcelona, Spain.*

[d] *C.N. Yang Institute for Theoretical Physics, State University of New York at Stony Brook, Stony Brook, NY 11794-3840, USA*

[e] *Instituto de Física Teórica UAM/CSIC, Calle de Nicolás Cabrera 13–15, Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain*

[f] *Institut für Astroteilchenphysik, Karlsruher Institut für Technologie (KIT), D-76021 Karlsruhe, Germany*

E-mail: esteban.6@osu.edu, maria.gonzalez-garcia@stonybrook.edu, michele.maltoni@csic.es, schwetz@kit.edu, albert.zhou@kit.edu

ABSTRACT: We present updated results for our global analysis of solar, atmospheric, reactor, and accelerator neutrino data in the framework of three-neutrino oscillations. We also provide χ^2 tables for various one-, two- and three-dimensional projections of the global analysis. If you use these results, please refer to both [1] and [2]. Data sets which have been updated with respect to NuFIT 5.2 are marked by the "⇒" tag.

Solar experiments

⇒ *External information*: Standard Solar Models [3].
- Chlorine total rate [4], 1 data point.
- Gallex & GNO total rates [5], 2 data points.
- SAGE total rate [6], 1 data point.
- SK1 1496-day energy and zenith spectrum [7], 44 data points.
- SK2 791-day energy and day/night spectrum [8], 33 data points.
- SK3 548-day energy and day/night spectrum [9], 42 data points.
⇒ SK4 2970-day energy and day/night spectrum [10], 46 data points.
- SNO combined analysis [11], 7 data points.
- Borexino Phase-I 741-day low-energy data [12], 33 data points.
- Borexino Phase-I 246-day high-energy data [13], 6 data points.
- Borexino Phase-II 1292-day low-energy data [14], 192 data points.
⇒ Borexino Phase-III 1432-day low-energy data [15], 120 data points.

Atmospheric experiments

- *External information*: Atmospheric neutrino fluxes [16].
- IceCube/DeepCore 3-year data [17, 18], 64 data points.
⇒ SK1-5 484.2 kiloton-year data [19], χ^2 map [20] added to our global analysis.

Reactor experiments

- KamLAND separate DS1, DS2, DS3 spectra [21] with Daya Bay reactor ν fluxes [22], 69 data points.
- Double-Chooz FD/ND spectral ratio, with 1276-day (FD), 587-day (ND) exposures [23], 26 data points.
- Daya Bay 3158-day separate EH1, EH2, EH3 spectra [24], 78 data points.
- Reno 2908-day FD/ND spectral ratio [25], 45 data points.

Accelerator experiments

- MINOS 10.71×10^{20} pot ν_μ-disappearance data [26], 39 data points.
- MINOS 3.36×10^{20} pot $\bar{\nu}_\mu$-disappearance data [26], 14 data points.
- MINOS 10.6×10^{20} pot ν_e-appearance data [27], 5 data points.
- MINOS 3.3×10^{20} pot $\bar{\nu}_e$-appearance data [27], 5 data points.
- T2K 19.7×10^{20} pot ν_μ-disappearance data [28], 35 data points.
- T2K 19.7×10^{20} pot ν_e-appearance data [28], 23 data points for the CCQE and 16 data points for the CC1π samples.
- T2K 16.3×10^{20} pot $\bar{\nu}_\mu$-disappearance data [28], 35 data points.
- T2K 16.3×10^{20} pot $\bar{\nu}_e$-appearance data [28], 23 data points.
- NOvA 13.6×10^{20} pot ν_μ-disappearance data [29], 76 data points.
- NOvA 13.6×10^{20} pot ν_e-appearance data [29], 13 data points.
- NOvA 12.5×10^{20} pot $\bar{\nu}_\mu$-disappearance data [29], 76 data points.
- NOvA 12.5×10^{20} pot $\bar{\nu}_e$-appearance data [29], 13 data points.

Description of the χ^2 data tables

We provide four xz-compressed files, containing the χ^2 data tables for both Normal and Inverted Ordering of our global «w/o SK-atm» and «with SK-atm» analyses. Each file is divided into 22 sections, identified by a unique tag and corresponding to a particular one-, two- or three-dimensional projection. The tags and the meaning of the data columns for each section are listed below (note that $\ell = 1$ for NO and $\ell = 2$ for IO).

N°	Section tag	1$^{\text{st}}$ column	2$^{\text{nd}}$ column	3$^{\text{rd}}$ column	4$^{\text{th}}$ column
1	# T23/DMA/DCP	$\sin^2\theta_{23}$	$\Delta m_{3\ell}^2 / [10^{-3} \text{ eV}^2]$	$\delta_{\text{CP}} / [\text{deg}]$	$\Delta\chi^2$
2	# T13/T12	$\sin^2\theta_{13}$	$\sin^2\theta_{12}$	$\Delta\chi^2$	—
3	# T13/DMS	$\sin^2\theta_{13}$	$\log_{10}(\Delta m_{21}^2 / [\text{eV}^2])$	$\Delta\chi^2$	—
4	# T12/DMS	$\sin^2\theta_{12}$	$\log_{10}(\Delta m_{21}^2 / [\text{eV}^2])$	$\Delta\chi^2$	—

$N°$	Section tag	1st column	2nd column	3rd column	4th column
5	# T13/T23	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	$\Delta\chi^2$	—
6	# T13/DMA	$\sin^2\theta_{13}$	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\Delta\chi^2$	—
7	# T23/DMA	$\sin^2\theta_{23}$	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\Delta\chi^2$	—
8	# T13/DCP	$\sin^2\theta_{13}$	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—
9	# T23/DCP	$\sin^2\theta_{23}$	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—
10	# DMA/DCP	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—
11	# T12/T23	$\sin^2\theta_{12}$	$\sin^2\theta_{23}$	$\Delta\chi^2$	—
12	# T12/DCP	$\sin^2\theta_{12}$	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—
13	# T12/DMA	$\sin^2\theta_{12}$	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\Delta\chi^2$	—
14	# DMS/T23	$\log_{10}\left(\Delta m^2_{21} / [\mathrm{eV}^2]\right)$	$\sin^2\theta_{23}$	$\Delta\chi^2$	—
15	# DMS/DCP	$\log_{10}\left(\Delta m^2_{21} / [\mathrm{eV}^2]\right)$	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—
16	# DMS/DMA	$\log_{10}\left(\Delta m^2_{21} / [\mathrm{eV}^2]\right)$	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\Delta\chi^2$	—
17	# T13	$\sin^2\theta_{13}$	$\Delta\chi^2$	—	—
18	# T12	$\sin^2\theta_{12}$	$\Delta\chi^2$	—	—
19	# T23	$\sin^2\theta_{23}$	$\Delta\chi^2$	—	—
20	# DCP	$\delta_{\mathrm{CP}} / [\deg]$	$\Delta\chi^2$	—	—
21	# DMS	$\log_{10}\left(\Delta m^2_{21} / [\mathrm{eV}^2]\right)$	$\Delta\chi^2$	—	—
22	# DMA	$\Delta m^2_{3\ell} / [10^{-3}~\mathrm{eV}^2]$	$\Delta\chi^2$	—	—

References

[1] I. Esteban, M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz and A. Zhou, *The fate of hints: updated global analysis of three-flavor neutrino oscillations*, *JHEP* **09** (2020) 178 [2007.14792].

[2] I. Esteban, M.C. Gonzalez-Garcia, M. Maltoni, T. Schwetz and A. Zhou, "NuFIT 5.3 (2024)." http://www.nu-fit.org.

[3] Y. Herrera and A. Serenelli, *Standard Solar Models B23 / SF-III*, 2023. ZENODO, https://doi.org/10.5281/zenodo.10174170.

[4] B.T. Cleveland et al., *Measurement of the solar electron neutrino flux with the Homestake chlorine detector*, *Astrophys. J.* **496** (1998) 505.

[5] F. Kaether, W. Hampel, G. Heusser, J. Kiko and T. Kirsten, *Reanalysis of the GALLEX solar neutrino flux and source experiments*, *Phys. Lett.* **B685** (2010) 47 [1001.2731].

[6] SAGE collaboration, *Measurement of the solar neutrino capture rate with gallium metal. III: Results for the 2002–2007 data-taking period*, *Phys. Rev.* **C80** (2009) 015807 [0901.2200].

[7] SUPER-KAMIOKANDE collaboration, *Solar neutrino measurements in Super-Kamiokande-I*, *Phys. Rev.* **D73** (2006) 112001 [hep-ex/0508053].

[8] SUPER-KAMIOKANDE collaboration, *Solar neutrino measurements in Super-Kamiokande-II*, *Phys. Rev.* **D78** (2008) 032002 [0803.4312].

[9] SUPER-KAMIOKANDE collaboration, *Solar neutrino results in Super-Kamiokande-III*, *Phys. Rev.* **D83** (2011) 052010 [1010.0118].

[10] Super-Kamiokande collaboration, *Solar neutrino measurements using the full data period of Super-Kamiokande-IV*, 2312.12907.

[11] SNO collaboration, *Combined Analysis of all Three Phases of Solar Neutrino Data from the Sudbury Neutrino Observatory*, 1109.0763.

[12] Borexino collaboration, *Precision measurement of the 7Be solar neutrino interaction rate in Borexino*, *Phys. Rev. Lett.* **107** (2011) 141302 [1104.1816].

[13] Borexino collaboration, *Measurement of the solar 8B neutrino rate with a liquid scintillator target and 3 MeV energy threshold in the Borexino detector*, *Phys. Rev.* **D82** (2010) 033006 [0808.2868].

[14] Borexino collaboration, *First Simultaneous Precision Spectroscopy of pp, ^{7}Be, and pep Solar Neutrinos with Borexino Phase-II*, *Phys. Rev. D* **100** (2019) 082004 [1707.09279].

[15] BOREXINO collaboration, *Improved Measurement of Solar Neutrinos from the Carbon-Nitrogen-Oxygen Cycle by Borexino and Its Implications for the Standard Solar Model*, *Phys. Rev. Lett.* **129** (2022) 252701 [2205.15975].

[16] M. Honda, M. Sajjad Athar, T. Kajita, K. Kasahara and S. Midorikawa, *Atmospheric neutrino flux calculation using the NRLMSISE-00 atmospheric model*, *Phys. Rev.* **D92** (2015) 023004 [1502.03916].

[17] IceCube collaboration, *Determining neutrino oscillation parameters from atmospheric muon neutrino disappearance with three years of IceCube DeepCore data*, *Phys. Rev.* **D91** (2015) 072004 [1410.7227].

[18] IceCube collaboration, "IceCube Oscillations: 3 years muon neutrino disappearance data." http://icecube.wisc.edu/science/data/nu_osc.

[19] Super-Kamiokande collaboration, *Atmospheric neutrino oscillation analysis with neutron tagging and an expanded fiducial volume in Super-Kamiokande I-V*, 2311.05105.

[20] SuperKamiokande collaboration, *Atmospheric neutrino oscillation analysis with neutron tagging and an expanded fiducial volume in Super-Kamiokande I-V*, 2024. ZENODO, https://doi.org/0.5281/zenodo.8401262.

[21] KamLAND collaboration, *Reactor On-Off Antineutrino Measurement with KamLAND*, *Phys. Rev.* **D88** (2013) 033001 [1303.4667].

[22] Daya Bay collaboration, *Improved Measurement of the Reactor Antineutrino Flux and Spectrum at Daya Bay*, *Chin. Phys.* **C41** (2017) 013002 [1607.05378].

[23] T. Bezerra, "New Results from the Double Chooz Experiment." Talk given at the *XXIX International Conference on Neutrino Physics and Astrophysics*, Chicago, USA, June 22–July 2, 2020 (online conference).

[24] Daya Bay collaboration, *Precision measurement of reactor antineutrino oscillation at kilometer-scale baselines by Daya Bay*, 2211.14988.

[25] J. Yoo, "RENO." Talk given at the *XXIX International Conference on Neutrino Physics and Astrophysics*, Chicago, USA, June 22–July 2, 2020 (online conference).

[26] MINOS collaboration, *Measurement of Neutrino and Antineutrino Oscillations Using Beam and Atmospheric Data in MINOS*, *Phys. Rev. Lett.* **110** (2013) 251801 [1304.6335].

[27] MINOS collaboration, *Electron neutrino and antineutrino appearance in the full MINOS data sample*, *Phys. Rev. Lett.* (2013) [1301.4581].

[28] P. Dunne, "Latest Neutrino Oscillation Results from T2K." Talk given at the *XXIX International Conference on Neutrino Physics and Astrophysics*, Chicago, USA, June 22–July 2, 2020 (online conference).

[29] A. Himmel, "New Oscillation Results from the NOvA Experiment." Talk given at the *XXIX International Conference on Neutrino Physics and Astrophysics*, Chicago, USA, June 22–July 2, 2020 (online conference).