NuFIT 3.2: Three-neutrino fit based on data available in January 2018

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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 the various one- and two-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 3.1 are marked by the "⇒" tag.

Solar experiments

- *External information*: Standard Solar Model [3].
- Chlorine total rate [4], 1 data point.
- Gallex & GNO total rates [5], 2 data points.
- SAGE total rate [6], 1 data point.
- SK1 full energy and zenith spectrum [7], 44 data points.
- SK2 full energy and day/night spectrum [8], 33 data points.
- SK3 full energy and day/night spectrum [9], 42 data points.
- SK4 2055-day day-night asymmetry [10] and 2365-day energy spectrum [11], 24 data points.
- SNO combined analysis [12], 7 data points.
- Borexino Phase-I 741-day low-energy data [13], 33 data points.
- Borexino Phase-I 246-day high-energy data [14], 6 data points.
- Borexino Phase-II 408-day low-energy data [15], 42 data points.

Atmospheric experiments

- *External information*: Atmospheric neutrino fluxes [16].
- IceCube/DeepCore 3-year data [17, 18], 64 data points.

Reactor experiments

- KamLAND separate DS1, DS2, DS3 spectra [19] with Daya-Bay reactor ν fluxes [20], 69 data points.
- Double-Chooz FD-I/ND and FD-II/ND spectral ratios, with 455-day (FD-I), 363-day (FD-II) and 258-day (ND) exposures [21], 56 data points.
- Daya-Bay 1230-day EH2/EH1 and EH3/EH1 spectral ratios [22], 70 data points.
- Reno 1500-day FD/ND spectral ratios [23], 26 data points.

Accelerator experiments

- MINOS 10.71×10^{20} pot ν_μ-disappearance data [24], 39 data points.
- MINOS 3.36×10^{20} pot $\bar{\nu}_\mu$-disappearance data [24], 14 data points.
- MINOS 10.6×10^{20} pot ν_e-appearance data [25], 5 data points.
- MINOS 3.3×10^{20} pot $\bar{\nu}_e$-appearance data [25], 5 data points.
- T2K 14.93×10^{20} pot ν_μ-disappearance data [26], 55 data points.
- T2K 14.93×10^{20} pot ν_e-appearance data [26], 39 data points.
- T2K 7.62×10^{20} pot $\bar{\nu}_\mu$-disappearance data [26], 55 data points.
- T2K 7.62×10^{20} pot $\bar{\nu}_e$-appearance data [26], 23 data points.

$\Rightarrow$ NOνA 8.85×10^{20} pot ν_μ-disappearance data [27], 72 data points.

$\Rightarrow$ NOνA 8.85×10^{20} pot ν_e-appearance data [27], 19 data points.

Description of the χ^2 data tables

We provide two gzip-compressed files (one for Normal and one for Inverted Ordering) containing the χ^2 data tables for our global analysis. Each file is divided into 21 sections, identified by a unique tag and corresponding to a particular one- or two-dimensional projections. 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	1st column	2nd column	3rd column
1	`# T13/T12`	$\sin^2\theta_{13}$	$\sin^2\theta_{12}$	$\Delta\chi^2$
2	`# T13/DMS`	$\sin^2\theta_{13}$	$\log_{10}(\Delta m^2_{21} / [\text{eV}^2])$	$\Delta\chi^2$
3	`# T12/DMS`	$\sin^2\theta_{12}$	$\log_{10}(\Delta m^2_{21} / [\text{eV}^2])$	$\Delta\chi^2$
4	`# T13/T23`	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	$\Delta\chi^2$
5	`# T13/DMA`	$\sin^2\theta_{13}$	$\Delta m^2_{3\ell} / [10^{-3}\ \text{eV}^2]$	$\Delta\chi^2$
6	`# T23/DMA`	$\sin^2\theta_{23}$	$\Delta m^2_{3\ell} / [10^{-3}\ \text{eV}^2]$	$\Delta\chi^2$

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

References

[1] I. Esteban, M. C. Gonzalez-Garcia, M. Maltoni, I. Martinez-Soler and T. Schwetz, *Updated fit to three neutrino mixing: exploring the accelerator-reactor complementarity*, 1611.01514.

[2] I. Esteban, M. C. Gonzalez-Garcia, A. Hernandez-Cabezudo, M. Maltoni, I. Martinez-Soler and T. Schwetz, "NuFIT 3.2 (2018)." http://www.nu-fit.org.

[3] N. Vinyoles, A. M. Serenelli, F. L. Villante, S. Basu, J. Bergström, M. C. Gonzalez-Garcia et al., *A new Generation of Standard Solar Models*, *Astrophys. J.* **835** (2017) 202, [1611.09867].

[4] B. T. Cleveland et al., *Measurement of the solar electron neutrino flux with the Homestake chlorine detector*, *Astrophys. J.* **496** (1998) 505–526.

[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) 47–54, [1001.2731].

[6] SAGE collaboration, J. N. Abdurashitov et al., *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, J. Hosaka et al., *Solar neutrino measurements in Super-Kamiokande-I*, *Phys. Rev.* **D73** (2006) 112001, [hep-ex/0508053].

[8] Super-Kamiokande collaboration, J. Cravens et al., *Solar neutrino measurements in Super-Kamiokande-II*, *Phys. Rev.* **D78** (2008) 032002, [0803.4312].

[9] Super-Kamiokande collaboration, K. Abe et al., *Solar neutrino results in Super-Kamiokande-III*, *Phys. Rev.* **D83** (2011) 052010, [1010.0118].

[10] Y. Nakano, *^{8}B solar neutrino spectrum measurement using Super-Kamiokande IV*. PhD thesis, Tokyo U., 2016-02.

[11] Y. Nakano, "Solar neutrino results from Super-Kamiokande." Talk given at the *38th International Conference on High Energy Physics*, Chicago, USA, August 3–10, 2016.

[12] SNO collaboration, B. Aharmim et al., *Combined Analysis of all Three Phases of Solar Neutrino Data from the Sudbury Neutrino Observatory*, 1109.0763.

[13] BOREXINO collaboration, G. Bellini et al., *Precision measurement of the 7Be solar neutrino interaction rate in Borexino*, *Phys. Rev. Lett.* **107** (2011) 141302, [1104.1816].

[14] BOREXINO collaboration, G. Bellini et al., *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].

[15] BOREXINO collaboration, G. Bellini et al., *Neutrinos from the primary proton–proton fusion process in the Sun*, *Nature* **512** (2014) 383–386.

[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, M. Aartsen et al., *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, J. P. Yañez et al., "IceCube Oscillations: 3 years muon neutrino disappearance data." http://icecube.wisc.edu/science/data/nu_osc.

[19] KAMLAND collaboration, A. Gando et al., *Reactor On-Off Antineutrino Measurement with KamLAND*, *Phys. Rev.* **D88** (2013) 033001, [1303.4667].

[20] DAYA BAY collaboration, F. P. An et al., *Improved Measurement of the Reactor Antineutrino Flux and Spectrum at Daya Bay*, *Chin. Phys.* **C41** (2017) 013002, [1607.05378].

[21] A. Cabrera Serra, "Double Chooz Improved Multi-Detector Measurements." Talk given at the *CERN EP colloquium*, CERN, Switzerland, September 20, 2016.

[22] DAYA BAY collaboration, F. P. An et al., *Measurement of electron antineutrino oscillation based on 1230 days of operation of the Daya Bay experiment*, *Phys. Rev.* **D95** (2017) 072006, [1610.04802].

[23] H. Seo, "New Results from RENO." Talk given at the *EPS Conference on High Energy Physics*, Venice, Italy, July 5–12, 2017.

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

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

[26] A. Izmaylov, "T2K Neutrino Experiment. Recent Results and Plans." Talk given at the *Flavour Physics Conference*, Quy Nhon, Vietnam, August 13–19, 2017.

[27] A. Radovic, "Latest oscillation results from NOvA." Joint Experimental-Theoretical Physics Seminar, Fermilab, USA, January 12, 2018.