Neutrino Mixing

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(A) Neutrino fluxes and event ratios

Events (observed/expected) from accelerator ν_μ experiments.

Some neutrino oscillation experiments compare the flux in two or more detectors. This is usually quoted as the ratio of the event rate in the far detector to the expected rate based on an extrapolation from the near detector in the absence of oscillations.

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.71 ± 0.08	[1] AHN	06A	K2K	K2K to Super-K
0.64 ± 0.05	[2] MICHAEL	06	MINS	All charged current events
$0.71^{+0.08}_{-0.09}$	[3] ALIU	05	K2K	KEK to Super-K
$0.70^{+0.10}_{-0.11}$	[4] AHN	03	K2K	KEK to Super-K

[1] Based on the observation of 112 events when $158.1^{+9.2}_{-8.6}$ were expected without oscillations. Including not only the number of events but also the shape of the energy distribution, the evidence for oscillation is at the level of about 4.3 σ. Supersedes ALIU 05.
[2] This ratio is based on the observation of 215 events compared to an expectation of 336 ± 14 without oscillations. See also ADAMSON 08.
[3] This ratio is based on the observation of 107 events at the far detector 250 km away from KEK, and an expectation of 151^{+12}_{-10}.
[4] This ratio is based on the observation of 56 events with an expectation of $80.1^{+6.2}_{-5.4}$.

Events (observed/expected) from reactor $\overline{\nu}_e$ experiments.

The quoted values are the ratios of the measured reactor $\overline{\nu}_e$ event rate at the quoted distances, and the rate expected without oscillations. The expected rate is based on the experimental data for the most significant reactor fuels (^{235}U, ^{239}Pu, ^{241}Pu) and on calculations for ^{238}U.

A recent re-evaluation of the spectral conversion of electron to $\overline{\nu}_e$ in MUELLER 11 results in an upward shift of the reactor $\overline{\nu}_e$ spectrum by 3% and, thus, might require revisions to the ratios listed in this table.

VALUE	DOCUMENT ID		TECN	COMMENT
$0.944\pm0.007\pm0.003$	[1] AN	13	DAYA	DayaBay, LIng Ao/Ao II reactors
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.944\pm0.016\pm0.040$	[2] ABE	12	DCHZ	Chooz reactors
$0.920\pm0.009\pm0.014$	[3] AHN	12	RENO	Yonggwang reactors
$0.940\pm0.011\pm0.004$	[4] AN	12	DAYA	DayaBay, LIng Ao/Ao II reactors
$1.08\pm0.21\pm0.16$	[5] DENIZ	10	TEXO	Kuo-Sheng reactor, 28 m
$0.658\pm0.044\pm0.047$	[6] ARAKI	05	KLND	Japanese react. $\sim$ 180 km
$0.611\pm0.085\pm0.041$	[7] EGUCHI	03	KLND	Japanese react. $\sim$ 180 km
$1.01\pm0.024\pm0.053$	[8] BOEHM	01		Palo Verde react. 0.75–0.89 km
$1.01\pm0.028\pm0.027$	[9] APOLLONIO	99	CHOZ	Chooz reactors 1 km

0.987±0.006±0.037	[10] GREENWOOD	96		Savannah River, 18.2 m
0.988±0.004±0.05	ACHKAR	95	CNTR	Bugey reactor, 15 m
0.994±0.010±0.05	ACHKAR	95	CNTR	Bugey reactor, 40 m
0.915±0.132±0.05	ACHKAR	95	CNTR	Bugey reactor, 95 m
0.987±0.014±0.027	[11] DECLAIS	94	CNTR	Bugey reactor, 15 m
0.985±0.018±0.034	KUVSHINN...	91	CNTR	Rovno reactor
1.05 ±0.02 ±0.05	VUILLEUMIER	82		Gösgen reactor
0.955±0.035±0.110	[12] KWON	81		$\overline{\nu}_e p \rightarrow e^+ n$
0.89 ±0.15	[12] BOEHM	80		$\overline{\nu}_e p \rightarrow e^+ n$

[1] AN 13 use six identical detectors, with three placed near the reactor cores (flux-weighted baselines of 470 and 576 m) and the remaining three at the far hall (at the flux averaged distance of 1648 m from all six reactor cores) to determine the mixing angle θ_{13} using the $\overline{\nu}_e$ observed interaction rate ratios. This rate-only analysis excludes the no-oscillation hypothesis at 7.7 standard deviations. The value of $\Delta m^2_{31} = 2.32 \times 10^{-3}$ eV^2 was assumed in the analysis. This is an improved result (2.5 times increase in statistics) compared to AN 12.

[2] ABE 12 determine the $\overline{\nu}_e$ interaction rate in a single detector, located 1050 m from the cores of two reactors. The rate normalization is fixed by the results of the Bugey4 reactor experiment, thus avoiding any dependence on possible very short baseline oscillations.

[3] AHN 12 use two identical detectors, placed at flux weighted distances of 408.56 m and 1433.99m from six reactor cores, to determine the $\overline{\nu}_e$ interaction rate ratio.

[4] AN 12 use six identical detectors with three placed near the reactor cores (flux-weighted baselines of 470 m and 576 m) and the remaining three at the far hall (at the flux averaged distance of 1648 m from all six reactor cores) to determine the $\overline{\nu}_e$ interaction rate ratios. Superseded by AN 13.

[5] DENIZ 10 observe reactor $\overline{\nu}_e e$ scattering with recoil kinetic energies 3–8 MeV using CsI(Tl) detectors. The observed rate is consistent with the Standard Model prediction, leading to a constraint on $\sin^2\theta_W = 0.251 \pm 0.031(\text{stat})\pm0.024(\text{sys})$.

[6] Updated result of KamLAND, including the data used in EGUCHI 03. Note that the survival probabilities for different periods are not directly comparable because the effective baseline varies with power output of the reactor sources involved, and there were large variations in the reactor power production in Japan in 2003.

[7] EGUCHI 03 observe reactor neutrino disappearance at $\sim$ 180 km baseline to various Japanese nuclear power reactors.

[8] BOEHM 01 search for neutrino oscillations at 0.75 and 0.89 km distance from the Palo Verde reactors.

[9] APOLLONIO 99, APOLLONIO 98 search for neutrino oscillations at 1.1 km fixed distance from Chooz reactors. They use $\overline{\nu}_e p \rightarrow e^+ n$ in Gd-loaded scintillator target. APOLLONIO 99 supersedes APOLLONIO 98. See also APOLLONIO 03 for detailed description.

[10] GREENWOOD 96 search for neutrino oscillations at 18 m and 24 m from the reactor at Savannah River.

[11] DECLAIS 94 result based on integral measurement of neutrons only. Result is ratio of measured cross section to that expected in standard *V-A* theory. Replaced by ACHKAR 95.

[12] KWON 81 represents an analysis of a larger set of data from the same experiment as BOEHM 80.

Atmospheric neutrinos

Neutrinos and antineutrinos produced in the atmosphere induce μ-like and e-like events in underground detectors. The ratio of the numbers of the two kinds of events is defined as μ/e. It has the advantage that systematic effects, such as flux uncertainty, tend to cancel, for both experimental and theoretical values of the ratio. The "ratio of the ratios" of experimental to theoretical μ/e, $R(\mu/e)$, or that of experimental to theoretical μ/total, $R(\mu/\text{total})$ with total = μ+e, is reported below. If the actual value is not unity, the value obtained in a given experiment may depend on the experimental conditions. In addition, the measured "up-down asymmetry" for μ ($N_{up}(\mu)/N_{down}(\mu)$) or e ($N_{up}(e)/N_{down}(e)$) is reported. The expected "up-down asymmetry" is nearly unity if there is no neutrino oscillation.

R(μ/e) = (Measured Ratio μ/e) / (Expected Ratio μ/e)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.658 \pm 0.016 \pm 0.035$	[1] ASHIE	05	SKAM	sub-GeV
$0.702^{+0.032}_{-0.030} \pm 0.101$	[2] ASHIE	05	SKAM	multi-GeV
$0.69 \pm 0.10 \pm 0.06$	[3] SANCHEZ	03	SOU2	Calorimeter raw data
	[4] FUKUDA	96B	KAMI	Water Cherenkov
$1.00 \pm 0.15 \pm 0.08$	[5] DAUM	95	FREJ	Calorimeter
$0.60^{+0.06}_{-0.05} \pm 0.05$	[6] FUKUDA	94	KAMI	sub-GeV
$0.57^{+0.08}_{-0.07} \pm 0.07$	[7] FUKUDA	94	KAMI	multi-Gev
	[8] BECKER-SZ...	92B	IMB	Water Cherenkov

[1] ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring e-like events with 0.1 GeV/c < p_e and μ-like events 0.2 GeV/c < p_μ, both having a visible energy < 1.33 GeV. These criteria match the definition used by FUKUDA 94.

[2] ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring events with visible energy > 1.33 GeV and partially-contained events. All partially-contained events are classified as μ-like.

[3] SANCHEZ 03 result is based on an exposure of 5.9 kton yr, and updates ALLISON 99 result. The analyzed data sample consists of fully-contained e-flavor and μ-flavor events having lepton momentum > 0.3 GeV/c.

[4] FUKUDA 96B studied neutron background in the atmospheric neutrino sample observed in the Kamiokande detector. No evidence for the background contamination was found.

[5] DAUM 95 results are based on an exposure of 2.0 kton yr which includes the data used by BERGER 90B. This ratio is for the contained and semicontained events. DAUM 95 also report $R(\mu/e) = 0.99 \pm 0.13 \pm 0.08$ for the total neutrino induced data sample which includes upward going stopping muons and horizontal muons in addition to the contained and semicontained events.

[6] FUKUDA 94 result is based on an exposure of 7.7 kton yr and updates the HIRATA 92 result. The analyzed data sample consists of fully-contained e-like events with $0.1 < p_e < 1.33$ GeV/c and fully-contained μ-like events with $0.2 < p_\mu < 1.5$ GeV/c.

[7] FUKUDA 94 analyzed the data sample consisting of fully contained events with visible energy > 1.33 GeV and partially contained μ-like events.

[8] BECKER-SZENDY 92B reports the fraction of nonshowering events (mostly muons from atmospheric neutrinos) as $0.36 \pm 0.02 \pm 0.02$, as compared with expected fraction $0.51 \pm$

0.01 ± 0.05. After cutting the energy range to the Kamiokande limits, BEIER 92 finds $R(\mu/e)$ very close to the Kamiokande value.

R(ν_μ) = (Measured Flux of ν_μ) / (Expected Flux of ν_μ)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.84±0.12	[1] ADAMSON	06	MINS	MINOS atmospheric
0.72±0.026±0.13	[2] AMBROSIO	01	MCRO	upward through-going
0.57±0.05 ±0.15	[3] AMBROSIO	00	MCRO	upgoing partially contained
0.71±0.05 ±0.19	[4] AMBROSIO	00	MCRO	downgoing partially contained + upgoing stopping
0.74±0.036±0.046	[5] AMBROSIO	98	MCRO	Streamer tubes
	[6] CASPER	91	IMB	Water Cherenkov
	[7] AGLIETTA	89	NUSX	
0.95±0.22	[8] BOLIEV	81		Baksan
0.62±0.17	CROUCH	78		Case Western/UCI

[1] ADAMSON 06 uses a measurement of 107 total neutrinos compared to an expected rate of 127 ± 13 without oscillations.

[2] AMBROSIO 01 result is based on the upward through-going muon tracks with $E_\mu > 1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration, is 6.17 years. The first error is the statistical error, the second is the systematic error, dominated by the theoretical error in the predicted flux.

[3] AMBROSIO 00 result is based on the upgoing partially contained event sample. It came from 4.1 live years of data taking with the full detector, from April 1994 to February 1999. The average energy of atmospheric muon neutrinos corresponding to this sample is 4 GeV. The first error is statistical, the second is the systematic error, dominated by the 25% theoretical error in the rate (20% in the flux and 15% in the cross section, added in quadrature). Within statistics, the observed deficit is uniform over the zenith angle.

[4] AMBROSIO 00 result is based on the combined samples of downgoing partially contained events and upgoing stopping events. These two subsamples could not be distinguished due to the lack of timing information. The result came from 4.1 live years of data taking with the full detector, from April 1994 to February 1999. The average energy of atmospheric muon neutrinos corresponding to this sample is 4 GeV. The first error is statistical, the second is the systematic error, dominated by the 25% theoretical error in the rate (20% in the flux and 15% in the cross section, added in quadrature). Within statistics, the observed deficit is uniform over the zenith angle.

[5] AMBROSIO 98 result is for all nadir angles and updates AHLEN 95 result. The lower cutoff on the muon energy is 1 GeV. In addition to the statistical and systematic errors, there is a Monte Carlo flux error (theoretical error) of ±0.13. With a neutrino oscillation hypothesis, the fit either to the flux or zenith distribution independently yields $\sin^2 2\theta = 1.0$ and $\Delta(m^2) \sim$ a few times 10^{-3} eV^2. However, the fit to the observed zenith distribution gives a maximum probability for χ^2 of only 5% for the best oscillation hypothesis.

[6] CASPER 91 correlates showering/nonshowering signature of single-ring events with parent atmospheric-neutrino flavor. They find nonshowering ($\approx \nu_\mu$ induced) fraction is 0.41 ± 0.03 ± 0.02, as compared with expected 0.51 ± 0.05 (syst).

[7] AGLIETTA 89 finds no evidence for any anomaly in the neutrino flux. They define ρ = (measured number of ν_e's)/(measured number of ν_μ's). They report ρ(measured)=ρ(expected) = $0.96^{+0.32}_{-0.28}$.

[8] From this data BOLIEV 81 obtain the limit $\Delta(m^2) \leq 6 \times 10^{-3}$ eV^2 for maximal mixing, $\nu_\mu \not\to \nu_\mu$ type oscillation.

R(μ/total) = (Measured Ratio μ/total) / (Expected Ratio μ/total)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$1.1^{+0.07}_{-0.12}\pm0.11$	[1] CLARK	97	IMB	multi-GeV

[1] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cherenkov detector with visible energy > 0.95 GeV.

$N_{up}(\mu)/N_{down}(\mu)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.71\ \pm0.06$	[1] ADAMSON	12B	MINS	contained-vertex muons
$0.551^{+0.035}_{-0.033}\pm0.004$	[2] ASHIE	05	SKAM	multi-GeV

[1] ADAMSON 12B reports the atmospheric neutrino results obtained with MINOS far detector in 2,553 live days (an exposure of 37.9 kton·yr). This result is obtained with a sample of high resolution contained-vertex muons. The quoted error is statistical only.

[2] ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring μ-like events with visible energy > 1.33 GeV and partially-contained events. All partially-contained events are classified as μ-like. Upward-going events are those with $-1 <$ cos(zenith angle) < -0.2 and downward-going events are those with 0.2< cos(zenith angle) <1. The μ-like up-down ratio for the multi-GeV data deviates from 1 (the expectation for no atmospheric ν_μ oscillations) by more than 12 standard deviations.

$N_{up}(e)/N_{down}(e)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.961^{+0.086}_{-0.079}\pm0.016$	[1] ASHIE	05	SKAM	multi-GeV

[1] ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring e-like events with visible energy > 1.33 GeV. Upward-going events are those with $-1 <$ cos(zenith angle) < -0.2 and downward-going events are those with 0.2 < cos(zenith angle) < 1. The e-like up-down ratio for the multi-GeV data is consistent with 1 (the expectation for no atmospheric ν_e oscillations).

R(up/down; μ) = (Measured up/down; μ) / (Expected up/down; μ)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.62\pm0.05\pm0.02$	[1] ADAMSON	12B	MINS	contained-vertex muons
$0.62^{+0.19}_{-0.14}\pm0.02$	[2] ADAMSON	06	MINS	atmospheric ν with far detector

[1] ADAMSON 12B reports the atmospheric neutrino results obtained with MINOS far detector in 2,553 live days (an exposure of 37.9 kton·yr). This result is obtained with a sample of high resolution contained-vertex muons. The expected ratio is calculated with no neutrino oscillation.

[2] ADAMSON 06 result is obtained with the MINOS far detector with an exposure of 4.54 kton yr. The expected ratio is calculated with no neutrino oscillation.

$N(\mu^+)/N(\mu^-)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.46^{+0.05}_{-0.04}$	[1,2] ADAMSON	12B	MINS	contained-vertex muons
$0.63^{+0.09}_{-0.08}$	[1,3] ADAMSON	12B	MINS	ν-induced rock-muons

[1] ADAMSON 12B reports the atmospheric neutrino results obtained with MINOS far detector in 2,553 live days (an exposure of 37.9 kton·yr). The muon charge ratio $N(\mu^+)/N(\mu^-)$ represents the $\overline{\nu}_\mu/\nu_\mu$ ratio.

[2] This result is obtained with a charge-separated sample of high resolution contained-vertex muons. The quoted error is statistical only.

[3] This result is obtained with a charge-separated sample of high resolution neutrino-induced rock-muons. The quoted error is statistical only.

$R(\mu^+/\mu^-)$ = (Measured $N(\mu^+)/N(\mu^-)$) / (Expected $N(\mu^+)/N(\mu^-)$)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.93 \pm 0.09 \pm 0.09$	[1,2] ADAMSON	12B	MINS	contained-vertex muons
$1.29^{+0.19}_{-0.17} \pm 0.16$	[1,3] ADAMSON	12B	MINS	ν-induced rock-muons
$1.03 \pm 0.08 \pm 0.08$	[1,4] ADAMSON	12B	MINS	contained
$1.39^{+0.35}_{-0.46}{}^{+0.08}_{-0.14}$	[5] ADAMSON	07	MINS	Upward and horizontal μ with far detector
$0.96^{+0.38}_{-0.27} \pm 0.15$	[6] ADAMSON	06	MINS	atmospheric ν with far detector

[1] ADAMSON 12B reports the atmospheric neutrino results obtained with MINOS far detector in 2,553 live days (an exposure of 37.9 kton·yr). The muon charge ratio $N(\mu^+)/N(\mu^-)$ represents the $\overline{\nu}_\mu/\nu_\mu$ ratio. As far as the same oscillation parameters are used for νs and $\overline{\nu}$s, the expected $\overline{\nu}_\mu/\nu_\mu$ ratio is almost entirely independent of any input oscillations.

[2] This result is obtained with a charge-separated sample of high resolution contained-vertex muons.

[3] This result is obtained with a charge-separated sample of high resolution neutrino-induced rock-muons.

[4] The charge-separated samples of high resolution contained-vertex muons and neutrino-induced rock-muons are combined to obtain this result which is consistent with unity.

[5] ADAMSON 07 result is obtained with the MINOS far detector in 854.24 live days, based on neutrino-induced upward-going and horizontal muons. This result is consistent with *CPT* conservation.

[6] ADAMSON 06 result is obtained with the MINOS far detector with an exposure of 4.54 kton yr, based on contained events. The expected ratio is calculated by assuming the same oscillation parameters for neutrinos and antineutrinos.

Solar neutrinos

Solar neutrinos are produced by thermonuclear fusion reactions in the Sun. Radiochemical experiments measure particular combinations of fluxes from various neutrino-producing reactions, whereas water-Cherenkov experiments mainly measure a flux of neutrinos from decay of ^{8}B. Solar neutrino fluxes are composed of all active neutrino species, ν_e, ν_μ, and ν_τ. In addition, some other mechanisms may cause antineutrino components in solar neutrino fluxes. Each measurement method is sensitive to a particular component or a combination of components of solar neutrino fluxes. For details, see Section 13.4 of Reviews, Tables, and Plots.

ν_e Capture Rates from Radiochemical Experiments

1 SNU (Solar Neutrino Unit) = 10^{-36} captures per atom per second.

VALUE (SNU)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$73.4\ ^{+6.1}_{-6.0}\ ^{+3.7}_{-4.1}$	[1] KAETHER	10		GALX reanalysis
$67.6 \pm 4.0 \pm 3.2$	[2] KAETHER	10		GNO+GALX reanalysis combined
$65.4\ ^{+3.1}_{-3.0}\ ^{+2.6}_{-2.8}$	[3] ABDURASHI...	09	SAGE	$^{71}Ga \rightarrow {}^{71}Ge$
$62.9\ ^{+5.5}_{-5.3} \pm 2.5$	[4] ALTMANN	05	GNO	$^{71}Ga \rightarrow {}^{71}Ge$
$69.3 \pm 4.1 \pm 3.6$	[5] ALTMANN	05	GNO	GNO + GALX combined
$77.5 \pm 6.2\ ^{+4.3}_{-4.7}$	[6] HAMPEL	99	GALX	$^{71}Ga \rightarrow {}^{71}Ge$
$2.56 \pm 0.16 \pm 0.16$	[7] CLEVELAND	98	HOME	$^{37}Cl \rightarrow {}^{37}Ar$

[1] KAETHER 10 reports the reanalysis results of a complete GALLEX data (GALLEX I+II+III+IV, reported in HAMPEL 99) based on the event selection with a new pulse shape analysis, which provides a better background reduction than the rise time analysis adopted in HAMPEL 99.

[2] Combined result of GALLEX I+II+III+IV reanalysis and GNO I+II+III (ALTMANN 05).

[3] ABDURASHITOV 09 reports a combined analysis of 168 extractions of the SAGE solar neutrino experiment during the period January 1990 through December 2007, and updates the ABDURASHITOV 02 result. The data are consistent with the assumption that the solar neutrino production rate is constant in time. Note that a $\sim$ 15% systematic uncertainty in the overall normalization may be added to the ABDURASHITOV 09 result, because calibration experiments for gallium solar neutrino measurements using intense ^{51}Cr (twice by GALLEX and once by SAGE) and ^{37}Ar (by SAGE) result in an average ratio of 0.87 ± 0.05 of the observed to calculated rates.

[4] ALTMANN 05 reports the complete result from the GNO solar neutrino experiment (GNO I+II+III), which is the successor project of GALLEX. Experimental technique of GNO is essentially the same as that of GALLEX. The run data cover the period 20 May 1998 through 9 April 2003.

[5] Combined result of GALLEX I+II+III+IV (HAMPEL 99) and GNO I+II+III.

[6] HAMPEL 99 report the combined result for GALLEX I+II+III+IV (65 runs in total), which update the HAMPEL 96 result. The GALLEX IV result (12 runs) is $118.4 \pm 17.8 \pm 6.6$ SNU. (HAMPEL 99 discuss the consistency of partial results with the mean.) The GALLEX experimental program has been completed with these runs. The total run data cover the period 14 May 1991 through 23 January 1997. A total of 300 ^{71}Ge events were observed. Note that a $\sim$ 15% systematic uncertainty in the overall normalization may be added to the HAMPEL 99 result, because calibration experiments for gallium solar neutrino measurements using intense ^{51}Cr (twice by GALLEX and once by SAGE) and ^{37}Ar (by SAGE) result in an average ratio of 0.87 ± 0.05 of the observed to calculated rates.

[7] CLEVELAND 98 is a detailed report of the ^{37}Cl experiment at the Homestake Mine. The average solar neutrino-induced ^{37}Ar production rate from 108 runs between 1970 and 1994 updates the DAVIS 89 result.

ϕ_{ES} (^{8}B)

^{8}B solar-neutrino flux measured via νe elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross-section difference, $\sigma(\nu_{\mu,\tau} e) \sim 0.16\sigma(\nu_e e)$. If the ^{8}B solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is $\sim$ 0.16 times of ν_e.

VALUE (10^6 cm^{-2}s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$2.32\pm0.04\pm0.05$	[1] ABE	11	SKAM	SK-III average flux
$2.41\pm0.05{}^{+0.16}_{-0.15}$	[2] ABE	11	SKAM	SK-II average flux
$2.38\pm0.02\pm0.08$	[3] ABE	11	SKAM	SK-I average flux
$2.77\pm0.26\pm0.32$	[4] ABE	11B	KLND	average flux
$2.4\ \pm0.4\ \pm0.1$	[5] BELLINI	10A	BORX	average flux
$1.77{}^{+0.24}_{-0.21}{}^{+0.09}_{-0.10}$	[6] AHARMIM	08	SNO	Phase III
$2.38\pm0.05{}^{+0.16}_{-0.15}$	[7] CRAVENS	08	SKAM	average flux
$2.35\pm0.02\pm0.08$	[8] HOSAKA	06	SKAM	average flux
$2.35\pm0.22\pm0.15$	[9] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape not constrained
$2.34\pm0.23{}^{+0.15}_{-0.14}$	[9] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape constrained
$2.39{}^{+0.24}_{-0.23}\pm0.12$	[10] AHMAD	02	SNO	average flux
$2.39\pm0.34{}^{+0.16}_{-0.14}$	[11] AHMAD	01	SNO	average flux
$2.80\pm0.19\pm0.33$	[12] FUKUDA	96	KAMI	average flux
2.70 ± 0.27	[12] FUKUDA	96	KAMI	day flux
$2.87{}^{+0.27}_{-0.26}$	[12] FUKUDA	96	KAMI	night flux

[1] ABE 11 reports the Super-Kamiokande-III results for 548 live days from August 4, 2006 to August 18, 2008. The analysis threshold is 5.0 MeV, but the event sample in the 5.0–6.5 MeV total electron range has a total live time of 298 days.

[2] ABE 11 recalculated the Super-Kamiokande-II results using ^{8}B spectrum of WINTER 06A.

[3] ABE 11 recalculated the Super-Kamiokande-I results using ^{8}B spectrum of WINTER 06A.

[4] ABE 11B use a 123 kton·day exposure of the KamLAND liquid scintillation detector to measure the ^{8}B solar neutrino flux. They utilize $\nu - e$ elastic scattering above a reconstructed-energy threshold of 5.5 MeV, corresponding to 5 MeV electron recoil energy. 299 electron recoil candidate events are reported, of which 157 ± 23.6 are assigned to background.

[5] BELLINI 10A reports the Borexino result with 3 MeV energy threshold for scattered electrons. The data correspond to 345.3 live days with a target mass of 100 t, between July 15, 2007 and August 23, 2009.

[6] AHARMIM 08 reports the results from SNO Phase III measurement using an array of ^{3}He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the ^{8}B shape.

[7] CRAVENS 08 reports the Super-Kamiokande-II results for 791 live days from December 2002 to October 2005. The photocathode coverage of the detector is 19% (reduced from

40% of that of Super-Kamiokande-I due to an accident in 2001). The analysis threshold for the average flux is 7 MeV.

[8] HOSAKA 06 reports the final results for 1496 live days with Super-Kamiokande-I between May 31, 1996 and July 15, 2001, and replace FUKUDA 02 results. The analysis threshold is 5 MeV except for the first 280 live days (6.5 MeV).

[9] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The *CC*, *ES*, and *NC* events were statistically separated. In one method, the ^{8}B energy spectrum was not constrained. In the other method, the constraint of an undistorted ^{8}B energy spectrum was added for comparison with AHMAD 02 results.

[10] AHMAD 02 reports the ^{8}B solar-neutrino flux measured via νe elastic scattering above the kinetic energy threshold of 5 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001, and updates AHMAD 01 results.

[11] AHMAD 01 reports the ^{8}B solar-neutrino flux measured via νe elastic scattering above the kinetic energy threshold of 6.75 MeV. The data correspond to 241 live days with SNO between November 2, 1999 and January 15, 2001.

[12] FUKUDA 96 results are for a total of 2079 live days with Kamiokande II and III from January 1987 through February 1995, covering the entire solar cycle 22, with threshold $E_e > 9.3$ MeV (first 449 days), > 7.5 MeV (middle 794 days), and > 7.0 MeV (last 836 days). These results update the HIRATA 90 result for the average ^{8}B solar-neutrino flux and HIRATA 91 result for the day-night variation in the ^{8}B solar-neutrino flux. The total data sample was also analyzed for short-term variations: within experimental errors, no strong correlation of the solar-neutrino flux with the sunspot numbers was found.

ϕ_{CC} (^{8}B)

^{8}B solar-neutrino flux measured with charged-current reaction which is sensitive exclusively to ν_e.

VALUE (10^6 cm^{-2}s^{-1})	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$1.67^{+0.05}_{-0.04}{}^{+0.07}_{-0.08}$	[1] AHARMIM	08	SNO	Phase III
$1.68\pm0.06^{+0.08}_{-0.09}$	[2] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape not const.
$1.72\pm0.05\pm0.11$	[2] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape constrained
$1.76^{+0.06}_{-0.05}\pm0.09$	[3] AHMAD	02	SNO	average flux
$1.75\pm0.07^{+0.12}_{-0.11}\pm0.05$	[4] AHMAD	01	SNO	average flux

[1] AHARMIM 08 reports the results from SNO Phase III measurement using an array of ^{3}He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the ^{8}B shape.

[2] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The *CC*, *ES*, and *NC* events were statistically separated. In one method, the ^{8}B energy spectrum was not constrained. In the other method, the constraint of an undistorted ^{8}B energy spectrum was added for comparison with AHMAD 02 results.

[3] AHMAD 02 reports the SNO result of the ^{8}B solar-neutrino flux measured with charged-current reaction on deuterium, $\nu_e d \rightarrow ppe^-$, above the kinetic energy threshold of 5 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001, and updates AHMAD 01 results. The complete description of the SNO Phase I data set is given in AHARMIM 07.

[4] AHMAD 01 reports the first SNO result of the ^{8}B solar-neutrino flux measured with the charged-current reaction on deuterium, $\nu_e d \rightarrow ppe^-$, above the kinetic energy threshold of 6.75 MeV. The data correspond to 241 live days with SNO between November 2, 1999 and January 15, 2001.

ϕ_{NC} (^{8}B)

^{8}B solar neutrino flux measured with neutral-current reaction, which is equally sensitive to ν_e, ν_μ, and ν_τ.

VALUE (10^6 cm^{-2}s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$5.25 \pm 0.16 {}^{+0.11}_{-0.13}$	[1] AHARMIM	13	SNO	All three phases combined
$5.140 {}^{+0.160}_{-0.158} {}^{+0.132}_{-0.117}$	[2] AHARMIM	10	SNO	Phase I+II, low threshold
$5.54 {}^{+0.33}_{-0.31} {}^{+0.36}_{-0.34}$	[3] AHARMIM	08	SNO	Phase III, prop. counter + PMT
$4.94 \pm 0.21 {}^{+0.38}_{-0.34}$	[4] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape not const.
$4.81 \pm 0.19 {}^{+0.28}_{-0.27}$	[4] AHARMIM	05A	SNO	Salty D_2O; ^{8}B shape constrained
$5.09 {}^{+0.44}_{-0.43} {}^{+0.46}_{-0.43}$	[5] AHMAD	02	SNO	average flux; ^{8}B shape const.
$6.42 \pm 1.57 {}^{+0.55}_{-0.58}$	[5] AHMAD	02	SNO	average flux; ^{8}B shape not const.

[1] AHARMIM 13 obtained this result from a combined analysis of the data from all three phases, SNO-I, II, and III. The measurement of the ^{8}B flux mostly comes from the NC signal, however, CC contribution is included in the fit.

[2] AHARMIM 10 reports this result from a joint analysis of SNO Phase I+II data with the "effective electron kinetic energy" threshold of 3.5 MeV. This result is obtained with a "binned-histogram unconstrained fit" where binned probability distribution functions of the neutrino signal observables were used without any model constraints on the shape of the neutrino spectrum.

[3] AHARMIM 08 reports the results from SNO Phase III measurement using an array of ^{3}He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the ^{8}B shape.

[4] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The *CC*, *ES*, and *NC* events were statistically separated. In one method, the ^{8}B energy spectrum was not constrained. In the other method, the constraint of an undistorted ^{8}B energy spectrum was added for comparison with AHMAD 02 results.

[5] AHMAD 02 reports the first SNO result of the ^{8}B solar-neutrino flux measured with the neutral-current reaction on deuterium, $\nu_\ell d \rightarrow np\nu_\ell$, above the neutral-current reaction threshold of 2.2 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001. The complete description of the SNO Phase I data set is given in AHARMIM 07.

$\phi_{\nu_\mu+\nu_\tau}$ (^{8}B)

Nonelectron-flavor active neutrino component (ν_μ and ν_τ) in the ^{8}B solar-neutrino flux.

VALUE (10^6 cm^{-2}s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$3.26\pm0.25^{+0.40}_{-0.35}$	[1] AHARMIM	05A	SNO	From ϕ_{NC}, ϕ_{CC}, and ϕ_{ES}; ^{8}B shape not const.
$3.09\pm0.22^{+0.30}_{-0.27}$	[1] AHARMIM	05A	SNO	From ϕ_{NC}, ϕ_{CC}, and ϕ_{ES}; ^{8}B shape constrained
$3.41\pm0.45^{+0.48}_{-0.45}$	[2] AHMAD	02	SNO	From ϕ_{NC}, ϕ_{CC}, and ϕ_{ES}
3.69 ± 1.13	[3] AHMAD	01		Derived from SNO+SuperKam, water Cherenkov

[1] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The *CC*, *ES*, and *NC* events were statistically separated. In one method, the ^{8}B energy spectrum was not constrained. In the other method, the constraint of an undistorted ^{8}B energy spectrum was added for comparison with AHMAD 02 results.

[2] AHMAD 02 deduced the nonelectron-flavor active neutrino component (ν_μ and ν_τ) in the ^{8}B solar-neutrino flux, by combining the charged-current result, the νe elastic-scattering result and the neutral-current result. The complete description of the SNO Phase I data set is given in AHARMIM 07.

[3] AHMAD 01 deduced the nonelectron-flavor active neutrino component (ν_μ and ν_τ) in the ^{8}B solar-neutrino flux, by combining the SNO charged-current result (AHMAD 01) and the Super-Kamiokande νe elastic-scattering result (FUKUDA 01).

Total Flux of Active ^{8}B Solar Neutrinos

Total flux of active neutrinos (ν_e, ν_μ, and ν_τ).

VALUE (10^6 cm^{-2}s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$5.25\ \pm0.16\ {}^{+0.11}_{-0.13}$	[1] AHARMIM	13	SNO	All three phases combined
$5.046{}^{+0.159}_{-0.152}{}^{+0.107}_{-0.123}$	[2] AHARMIM	10	SNO	From ϕ_{NC} in Phase I+II, low threshold
$5.54\ {}^{+0.33}_{-0.31}\ {}^{+0.36}_{-0.34}$	[3] AHARMIM	08	SNO	ϕ_{NC} in Phase III
$4.94\ \pm0.21\ {}^{+0.38}_{-0.34}$	[4] AHARMIM	05A	SNO	From ϕ_{NC}; ^{8}B shape not const.
$4.81\ \pm0.19\ {}^{+0.28}_{-0.27}$	[4] AHARMIM	05A	SNO	From ϕ_{NC}; ^{8}B shape constrained
$5.09\ {}^{+0.44}_{-0.43}\ {}^{+0.46}_{-0.43}$	[5] AHMAD	02	SNO	Direct measurement from ϕ_{NC}
$5.44\ \pm0.99$	[6] AHMAD	01		Derived from SNO+SuperKam, water Cherenkov

[1] AHARMIM 13 obtained this result from a combined analysis of the data from all three phases, SNO-I, II, and III. The measurement of the ^{8}B flux mostly comes from the NC signal, however, CC contribution is included in the fit.

[2] AHARMIM 10 reports this result from a joint analysis of SNO Phase I+II data with the "effective electron kinetic energy" threshold of 3.5 MeV. This result is obtained with the assumption of unitarity, which relates the NC, CC, and ES rates. The data were fit with the free parameters directly describing the total ^{8}B neutrino flux and the energy-dependent ν_e survival probability.

[3] AHARMIM 08 reports the results from SNO Phase III measurement using an array of ^{3}He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the ^{8}B shape.

[4] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The CC, ES, and NC events were statistically separated. In one method, the ^{8}B energy spectrum was not constrained. In the other method, the constraint of an undistorted ^{8}B energy spectrum was added for comparison with AHMAD 02 results.

[5] AHMAD 02 determined the total flux of active ^{8}B solar neutrinos by directly measuring the neutral-current reaction, $\nu_\ell d \rightarrow np\nu_\ell$, which is equally sensitive to ν_e, ν_μ, and ν_τ. The complete description of the SNO Phase I data set is given in AHARMIM 07.

[6] AHMAD 01 deduced the total flux of active ^{8}B solar neutrinos by combining the SNO charged-current result (AHMAD 01) and the Super-Kamiokande νe elastic-scattering result (FUKUDA 01).

Day-Night Asymmetry (^{8}B)

$A = (\phi_{\rm night} - \phi_{\rm day}) / \phi_{\rm average}$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.063 \pm 0.042 \pm 0.037$	[1] CRAVENS	08	SKAM	Based on ϕ_{ES}
$0.021 \pm 0.020 {}^{+0.012}_{-0.013}$	[2] HOSAKA	06	SKAM	Based on ϕ_{ES}
$0.017 \pm 0.016 {}^{+0.012}_{-0.013}$	[3] HOSAKA	06	SKAM	Fitted in the LMA region
$-0.056 \pm 0.074 \pm 0.053$	[4] AHARMIM	05A	SNO	From salty SNO ϕ_{CC}
$-0.037 \pm 0.063 \pm 0.032$	[4] AHARMIM	05A	SNO	From salty SNO ϕ_{CC}; const. of no ϕ_{NC} asymmetry
$0.14 \pm 0.063 {}^{+0.015}_{-0.014}$	[5] AHMAD	02B	SNO	Derived from SNO ϕ_{CC}
$0.07 \pm 0.049 {}^{+0.013}_{-0.012}$	[6] AHMAD	02B	SNO	Const. of no ϕ_{NC} asymmetry

[1] CRAVENS 08 reports the Super-Kamiokande-II results for 791 live days from December 2002 to October 2005. The photocathode coverage of the detector is 19% (reduced from 40% of that of Super-Kamiokande-I due to an accident in 2001). The analysis threshold for the day and night fluxes is 7.5 MeV.

[2] HOSAKA 06 reports the final results for 1496 live days with Super-Kamiokande-I between May 31, 1996 and July 15, 2001, and replace FUKUDA 02 results. The analysis threshold is 5 MeV except for the first 280 live days (6.5 MeV).

[3] This result with reduced statistical uncertainty is obtained by assuming two-neutrino oscillations within the LMA (large mixing angle) region and by fitting the time variation of the solar neutrino flux measured via ν_e elastic scattering to the variations expected from

neutrino oscillations. For details, see SMY 04. There is an additional small systematic error of ± 0.0004 coming from uncertainty of oscillation parameters.

[4] AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, with 176.5 days of the live time recorded during the day and 214.9 days during the night. This result is obtained with the spectral distribution of the CC events not constrained to the ^{8}B shape.

[5] AHMAD 02B results are based on the charged-current interactions recorded between November 2, 1999 and May 28, 2001, with the day and night live times of 128.5 and 177.9 days, respectively. The complete description of the SNO Phase I data set is given in AHARMIM 07.

[6] AHMAD 02B results are derived from the charged-current interactions, neutral-current interactions, and νe elastic scattering, with the total flux of active neutrinos constrained to have no asymmetry. The data were recorded between November 2, 1999 and May 28, 2001, with the day and night live times of 128.5 and 177.9 days, respectively. The complete description of the SNO Phase I data set is given in AHARMIM 07.

ϕ_{ES} (^{7}Be)

^{7}Be solar-neutrino flux measured via ν_e elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross-section difference, $\sigma(\nu_{\mu,\tau} e) \sim 0.2\ \sigma(\nu_e e)$. If the ^{7}Be solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is ~ 0.2 times that of ν_e.

VALUE (10^{9} cm^{-2} s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.10 ± 0.15	[1] BELLINI	11A	BORX	average flux

[1] BELLINI 11A reports the ^{7}Be solar neutrino flux measured via $\nu - e$ elastic scattering. The data correspond to 740.7 live days between May 16, 2007 and May 8, 2010, and also correspond to 153.6 ton·year fiducial exposure. BELLINI 11A measured the 862 keV ^{7}Be solar neutrino flux, which is an 89.6% branch of the ^{7}Be solar neutrino flux, to be $(2.78 \pm 0.13) \times 10^{9}$ cm^{-2} s^{-1}. Supercedes ARPESELLA 08A.

ϕ_{ES} (pep)

pep solar-neutrino flux measured via ν_e elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross section difference, $\sigma(\nu_{\mu,\tau}\ e) \sim\ 0.2\ \sigma(\nu_e e)$. If the pep solar-neutrino flux involves non-electron flavor active neutrinos, their contribution to the flux is $\sim$ 0.2 times that of ν_e.

VALUE (10^{8} cm^{-2}s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.0 ± 0.2	[1] BELLINI	12A	BORX	average flux

[1] BELLINI 12A reports 1.44 MeV pep solar-neutrino flux measured via ν_e elastic scattering. The data were collected between January 13, 2008 and May 9, 2010, corresponding to 20,4009 ton·day fiducial exposure. The listed flux value is calculated from the observed rate of pep solar neutrino interactions in Borexino ($3.1 \pm 0.6 \pm 0.3$ counts/(day·100 ton)) and the corresponding rate expected for no neutrino flavor oscillations (4.47 ± 0.05 counts/(day·100 ton)), using the SSM prediction for the pep solar neutrino flux of $(1.441 \pm 0.012) \times 10^{8}$ cm^{-2}s^{-1}.

ϕ_{ES} (CNO)

CNO solar-neutrino flux measured via ν_e elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross section difference, $\sigma(\nu_{\mu,\tau}\ e) \sim\ 0.2\ \sigma(\nu_e\, e)$. If the CNO solar-neutrino flux involves non-electron flavor active neutrinos, their contribution to the flux is $\sim$ 0.2 times that of ν_e.

VALUE (10^8 cm^{-2}s^{-1})	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<7.7	90	[1] BELLINI	12A	BORX	MSW-LMA solution assumed

[1] BELLINI 12A reports an upper limit of the CNO solar neutrino flux measured via ν_e elastic scattering. The data were collected between January 13, 2008 and May 9, 2010, corresponding to 20,409 ton·day fiducial exposure.

$\phi_{CC}(pp)$

pp solar-neutrino flux measured with charged-current reaction which is sensitive exclusively to ν_e.

VALUE (10^{10} cm^{-2} s^{-1})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.38±0.47	[1] ABDURASHI...	09	FIT	Fit existing solar-ν data

[1] ABDURASHITOV 09 reports the pp solar-neutrino flux derived from the Ga solar neutrino capture rate by subtracting contributions from ^{8}B, ^{7}Be, *pep* and CNO solar neutrino fluxes determined by other solar neutrino experiments as well as neutrino oscillation parameters determined from available world neutrino oscillation data.

ϕ_{ES} (hep)

hep solar-neutrino flux measured via νe elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross-section difference, $\sigma(\nu_{\mu,\tau}\, e) \sim 0.16\sigma(\nu_e\, e)$. If the hep solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is $\sim$ 0.16 times of ν_e.

VALUE (10^3 cm^{-2}s^{-1})	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<73	90	[1] HOSAKA	06	SKAM

[1] HOSAKA 06 result is obtained from the recoil electron energy window of 18–21 MeV, and updates FUKUDA 01 result.

$\phi_{\overline{\nu}_e}$ (^{8}B)

Searches are made for electron antineutrino flux from the Sun. Flux limits listed here are derived relative to the BS05(OP) Standard Solar Model ^{8}B solar neutrino flux (5.69×10^6 cm^{-2} s^{-1}), with an assumption that solar $\overline{\nu}_e$s follow an unoscillated ^{8}B neutrino spectrum.

VALUE (%)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.013	90	BELLINI	11	BORX	$E_{\overline{\nu}_e} > 1.8$ MeV
<1.9	90	[1] BALATA	06	CNTR	$1.8 < E_{\overline{\nu}_e} < 20.0$ MeV
<0.72	90	AHARMIM	04	SNO	$4.0 < E_{\overline{\nu}_e} < 14.8$ MeV
<0.022	90	EGUCHI	04	KLND	$8.3 < E_{\overline{\nu}_e} < 14.8$ MeV
<0.7	90	GANDO	03	SKAM	$8.0 < E_{\overline{\nu}_e} < 20.0$ MeV
<1.7	90	AGLIETTA	96	LSD	$7 < E_{\overline{\nu}_e} < 17$ MeV

[1] BALATA 06 obtained this result from the search for $\overline{\nu}_e$ interactions with Counting Test Facility (the prototype of the Borexino detector).

(B) Three-neutrino mixing parameters

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$\sin^2(2\theta_{12})$

VALUE	DOCUMENT ID		TECN	COMMENT
$0.846^{+0.021}_{-0.021}$	[1] GANDO	13	FIT	KamLAND + global solar + SBL + accelerator: 3ν
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.839^{+0.021}_{-0.023}$	[2,3] AHARMIM	13	FIT	global solar: 2ν
$0.846^{+0.033}_{-0.029}$	[3,4] AHARMIM	13	FIT	global solar: 3ν
$0.851^{+0.023}_{-0.020}$	[3,5] AHARMIM	13	FIT	KamLAND + global solar: 3ν
0.847 ± 0.021	[6] GANDO	13	FIT	KamLAND + global solar: 3ν
$0.877^{+0.049}_{-0.060}$	[7] GANDO	13	FIT	KamLAND: 3ν
0.85 ± 0.02	[8] ABE	11	FIT	KamLAND + global solar: 2ν
$0.84^{+0.03}_{-0.02}$	[9] ABE	11	FIT	global solar: 2ν
$0.85^{+0.04}_{-0.03}$	[10] ABE	11	FIT	KamLAND + global solar: 3ν
$0.85^{+0.04}_{-0.05}$	[11] ABE	11	FIT	global solar: 3ν
$0.861^{+0.022}_{-0.018}$	[12] BELLINI	11A	FIT	KamLAND + global solar: 2ν
$0.869^{+0.024}_{-0.022}$	[13] BELLINI	11A	FIT	global solar: 2ν
$0.857^{+0.023}_{-0.025}$	[14] GANDO	11	FIT	KamLAND + solar: 3ν
$0.846^{+0.064}_{-0.073}$	[15] GANDO	11	FIT	KamLAND: 3ν
$0.861^{+0.026}_{-0.022}$	[16,17] AHARMIM	10	FIT	KamLAND + global solar: 2ν
$0.861^{+0.024}_{-0.031}$	[16,18] AHARMIM	10	FIT	global solar: 2ν
$0.869^{+0.026}_{-0.024}$	[16,19] AHARMIM	10	FIT	KamLAND + global solar: 3ν
$0.869^{+0.031}_{-0.037}$	[16,20] AHARMIM	10	FIT	global solar: 3ν
0.92 ± 0.05	[21] ABE	08A	FIT	KamLAND
0.87 ± 0.04	[22] ABE	08A	FIT	KamLAND + global fit
0.87 ± 0.03	[23] AHARMIM	08	FIT	KamLAND + global solar
$0.85^{+0.04}_{-0.06}$	[24] HOSAKA	06	FIT	KamLAND + global solar
$0.85^{+0.06}_{-0.05}$	[25] HOSAKA	06	FIT	SKAM+SNO+KamLAND
$0.86^{+0.05}_{-0.07}$	[26] HOSAKA	06	FIT	SKAM+SNO
$0.86^{+0.03}_{-0.04}$	[27] AHARMIM	05A	FIT	KamLAND + global solar

0.75–0.95	[28] AHARMIM	05A	FIT	global solar
0.82 ±0.05	[29] ARAKI	05	FIT	KamLAND + global solar
0.82 ±0.04	[30] AHMED	04A	FIT	KamLAND + global solar
0.71–0.93	[31] AHMED	04A	FIT	global solar
$0.85\ ^{+0.05}_{-0.07}$	[32] SMY	04	FIT	KamLAND + global solar
$0.83\ ^{+0.06}_{-0.08}$	[33] SMY	04	FIT	global solar
$0.87\ ^{+0.07}_{-0.08}$	[34] SMY	04	FIT	SKAM + SNO
0.62–0.88	[35] AHMAD	02B	FIT	global solar
0.62–0.95	[36] FUKUDA	02	FIT	global solar

[1] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND, global solar neutrino, short-baseline (SBL) reactor, and accelerator data, assuming CPT invariance. Supersedes GANDO 11.

[2] AHARMIM 13 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data.

[3] AHARMIM 13 global solar neutrino data include SNO's all-phases-combined analysis results on the total active ^{8}B neutrino flux and energy-dependent ν_e survival probability parameters, measurements of Cl (CLEVELAND 98), Ga (ABDURASHITOV 09 which contains combined analysis with GNO (ALTMANN 05 and Ph.D. thesis of F. Kaether)), and ^{7}Be (BELLINI 11A) rates, and ^{8}B solar-neutrino recoil electron measurements of SK-I (HOSAKA 06) zenith, SK-II (CRAVENS 08) and SK-III (ABE 11) day/night spectra, and Borexino (BELLINI 10A) spectra.

[4] AHARMIM 13 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.45×10^{-3} eV^2, using global solar neutrino data.

[5] AHARMIM 13 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.45×10^{-3} eV^2, using global solar neutrino and KamLAND (GANDO 11) data. CPT invariance is assumed.

[6] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND and global solar neutrino data, assuming CPT invariance. Supersedes GANDO 11.

[7] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND data. Supersedes GANDO 11.

[8] ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. CPT invariance is assumed.

[9] ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, and SAGE data.

[10] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. The normal neutrino mass hierarchy and CPT invariance are assumed.

[11] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.

[12] BELLINI 11A obtained this result by a two-neutrino oscillation analysis using KamLAND, Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ^{8}B flux was left free. CPT invariance is assumed.

[13] BELLINI 11A obtained this result by a two-neutrino oscillation analysis using Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino

(BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ^{8}B flux was left free.

[14] GANDO 11 obtain this result with three-neutrino fit using the KamLAND + solar data. Superseded by GANDO 13.

[15] GANDO 11 obtain this result with three-neutrino fit using the KamLAND data only. Superseded by GANDO 13.

[16] AHARMIM 10 global solar neutrino data include SNO's low-energy-threshold analysis survival probability day/night curves, SNO Phase III integral rates (AHARMIM 08), Cl (CLEVELAND 98), SAGE (ABDURASHITOV 09), Gallex/GNO (HAMPEL 99, ALTMANN 05), Borexino (ARPESELLA 08A), SK-I zenith (HOSAKA 06), and SK-II day/night spectra (CRAVENS 08).

[17] AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[18] AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data.

[19] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[20] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data.

[21] ABE 08A obtained this result by a rate + shape + time combined geoneutrino and reactor two-neutrino fit for Δm^2_{21} and $\tan^2\theta_{12}$, using KamLAND data only. Superseded by GANDO 11.

[22] ABE 08A obtained this result by means of a two-neutrino fit using KamLAND, Homestake, SAGE, GALLEX, GNO, SK (zenith angle and E-spectrum), the SNO χ^2-map, and solar flux data. *CPT* invariance is assumed. Superseded by GANDO 11.

[23] The result given by AHARMIM 08 is $\theta = (34.4^{+1.3}_{-1.2})^\circ$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino data including those of Borexino (ARPESELLA 08A) and Super-Kamiokande-I (HOSAKA 06), and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[24] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using SK ν_e data, CC data from other solar neutrino experiments, and KamLAND data (ARAKI 05). *CPT* invariance is assumed.

[25] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the data from Super-Kamiokande, SNO (AHMAD 02 and AHMAD 02B), and KamLAND (ARAKI 05) experiments. *CPT* invariance is assumed.

[26] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data.

[27] The result given by AHARMIM 05A is $\theta = (33.9 \pm 1.6)^\circ$. This result is obtained by a two-neutrino oscillation analysis using SNO pure deuteron and salt phase data, SK ν_e data, Cl and Ga CC data, and KamLAND data (ARAKI 05). *CPT* invariance is assumed. AHARMIM 05A also quotes $\theta = (33.9^{+2.4}_{-2.2})^\circ$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2 2\,\theta = 0.86^{+0.05}_{-0.06}$.

[28] AHARMIM 05A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in figure 35a of AHARMIM 05A. AHARMIM 05A also quotes $\tan^2\theta = 0.45^{+0.09}_{-0.08}$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2 2\,\theta = 0.86^{+0.05}_{-0.07}$.

[29] ARAKI 05 obtained this result by a two-neutrino oscillation analysis using KamLAND and solar neutrino data. *CPT* invariance is assumed. The 1σ error shown here is translated from the number provided by the KamLAND collaboration, $\tan^2\theta = 0.40^{+0.07}_{-0.05}$. The

corresponding number quoted in ARAKI 05 is $\tan^2\theta = 0.40^{+0.10}_{-0.07}$ ($\sin^2 2\,\theta = 0.82 \pm 0.07$), which envelops the 68% CL two-dimensional region.

[30] The result given by AHMED 04A is $\theta = (32.5^{+1.7}_{-1.6})^\circ$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (EGUCHI 03). *CPT* invariance is assumed. AHMED 04A also quotes $\theta = (32.5^{+2.4}_{-2.3})^\circ$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2 2\,\theta = 0.82 \pm 0.06$.

[31] AHMED 04A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 5(a) of AHMED 04A. The best-fit point is $\Delta(m^2) = 6.5 \times 10^{-5}$ eV^2, $\tan^2\theta = 0.40$ ($\sin^2 2\,\theta = 0.82$).

[32] The result given by SMY 04 is $\tan^2\theta = 0.44 \pm 0.08$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (IANNI 03). *CPT* invariance is assumed.

[33] SMY 04 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The 1σ errors are read from Fig. 6(a) of SMY 04.

[34] SMY 04 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data. The 1σ errors are read from Fig. 6(a) of SMY 04.

[35] AHMAD 02B obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4(b) of AHMAD 02B. The best fit point is $\Delta(m^2) = 5.0 \times 10^{-5}$ eV^2 and $\tan\theta = 0.34$ ($\sin^2 2\,\theta = 0.76$).

[36] FUKUDA 02 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4 of FUKUDA 02. The best fit point is $\Delta(m^2) = 6.9 \times 10^{-5}$ eV^2 and $\tan^2\theta = 0.38$ ($\sin^2 2\,\theta = 0.80$).

Δm^2_{21}

VALUE (10^{-5} eV^2)	DOCUMENT ID		TECN	COMMENT
7.53±0.18	[1] GANDO	13	FIT	KamLAND + global solar + SBL + accelerator: 3ν
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$5.13^{+1.29}_{-0.96}$	[2,3] AHARMIM	13	FIT	global solar: 2ν
$5.13^{+1.49}_{-0.98}$	[3,4] AHARMIM	13	FIT	global solar: 3ν
$7.46^{+0.20}_{-0.19}$	[3,5] AHARMIM	13	FIT	KamLAND + global solar: 3ν
$7.53^{+0.19}_{-0.18}$	[6] GANDO	13	FIT	KamLAND + global solar: 3ν
$7.54^{+0.19}_{-0.18}$	[7] GANDO	13	FIT	KamLAND: 3ν
7.6 ± 0.2	[8] ABE	11	FIT	KamLAND + global solar: 2ν
$6.2\ ^{+1.1}_{-1.9}$	[9] ABE	11	FIT	global solar: 2ν
7.7 ± 0.3	[10] ABE	11	FIT	KamLAND + global solar: 3ν
$6.0\ ^{+2.2}_{-2.5}$	[11] ABE	11	FIT	global solar: 3ν
$7.50^{+0.16}_{-0.24}$	[12] BELLINI	11A	FIT	KamLAND + global solar: 2ν
$5.2\ ^{+1.5}_{-0.9}$	[13] BELLINI	11A	FIT	global solar: 2ν
$7.50^{+0.19}_{-0.20}$	[14] GANDO	11	FIT	KamLAND + solar: 3ν
7.49 ± 0.20	[15] GANDO	11	FIT	KamLAND: 3ν

$7.59^{+0.20}_{-0.21}$	[16,17] AHARMIM	10	FIT	KamLAND + global solar: 2ν
$5.89^{+2.13}_{-2.16}$	[16,18] AHARMIM	10	FIT	global solar: 2ν
7.59 ± 0.21	[16,19] AHARMIM	10	FIT	KamLAND + global solar: 3ν
$6.31^{+2.49}_{-2.58}$	[16,20] AHARMIM	10	FIT	global solar: 3ν
$7.58^{+0.14}_{-0.13}\pm0.15$	[21] ABE	08A	FIT	KamLAND
7.59 ± 0.21	[22] ABE	08A	FIT	KamLAND + global solar
$7.59^{+0.19}_{-0.21}$	[23] AHARMIM	08	FIT	KamLAND + global solar
$8.0\ \pm0.3$	[24] HOSAKA	06	FIT	KamLAND + global solar
$8.0\ \pm0.3$	[25] HOSAKA	06	FIT	SKAM+SNO+KamLAND
$6.3\ ^{+3.7}_{-1.5}$	[26] HOSAKA	06	FIT	SKAM+SNO
5–12	[27] HOSAKA	06	FIT	SKAM day/night in the LMA region
$8.0\ ^{+0.4}_{-0.3}$	[28] AHARMIM	05A	FIT	KamLAND + global solar LMA
3.3–14.4	[29] AHARMIM	05A	FIT	global solar
$7.9\ ^{+0.4}_{-0.3}$	[30] ARAKI	05	FIT	KamLAND + global solar
$7.1\ ^{+1.0}_{-0.3}$	[31] AHMED	04A	FIT	KamLAND + global solar
3.2–13.7	[32] AHMED	04A	FIT	global solar
$7.1\ ^{+0.6}_{-0.5}$	[33] SMY	04	FIT	KamLAND + global solar
$6.0\ ^{+1.7}_{-1.6}$	[34] SMY	04	FIT	global solar
$6.0\ ^{+2.5}_{-1.6}$	[35] SMY	04	FIT	SKAM + SNO
2.8–12.0	[36] AHMAD	02B	FIT	global solar
3.2–19.1	[37] FUKUDA	02	FIT	global solar

[1] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND, global solar neutrino, short-baseline (SBL) reactor, and accelerator data, assuming CPT invariance. Supersedes GANDO 11.

[2] AHARMIM 13 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data.

[3] AHARMIM 13 global solar neutrino data include SNO's all-phases-combined analysis results on the total active ^{8}B neutrino flux and energy-dependent ν_e survival probability parameters, measurements of Cl (CLEVELAND 98), Ga (ABDURASHITOV 09 which contains combined analysis with GNO (ALTMANN 05 and Ph.D. thesis of F. Kaether)), and ^{7}Be (BELLINI 11A) rates, and ^{8}B solar-neutrino recoil electron measurements of SK-I (HOSAKA 06) zenith, SK-II (CRAVENS 08), and SK-III (ABE 11) day/night spectra, and Borexino (BELLINI 10A) spectra.

[4] AHARMIM 13 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.45×10^{-3} eV^2, using global solar neutrino data.

[5] AHARMIM 13 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.45×10^{-3} eV^2, using global solar neutrino and KamLAND data (GANDO 11). CPT invariance is assumed.

[6] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND and global solar neutrino data, assuming CPT invariance. Supersedes GANDO 11.

[7] GANDO 13 obtained this result by a three-neutrino oscillation analysis using KamLAND data. Supersedes GANDO 11.

[8] ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. CPT invariance is assumed.

[9] ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, and SAGE data.

[10] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. The normal neutrino mass hierarchy and CPT invariance are assumed.

[11] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.

[12] BELLINI 11A obtained this result by a two-neutrino oscillation analysis using KamLAND, Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ^{8}B flux was left free. CPT invariance is assumed.

[13] BELLINI 11A obtained this result by a two-neutrino oscillation analysis using Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ^{8}B flux was left free.

[14] GANDO 11 obtain this result with three-neutrino fit using the KamLAND + solar data. Superseded by GANDO 13.

[15] GANDO 11 obtain this result with three-neutrino fit using the KamLAND data only. Supersedes ABE 08A.

[16] AHARMIM 10 global solar neutrino data include SNO's low-energy-threshold analysis survival probability day/night curves, SNO Phase III integral rates (AHARMIM 08), CI (CLEVELAND 98), SAGE (ABDURASHITOV 09), Gallex/GNO (HAMPEL 99, ALTMANN 05), Borexino (ARPESELLA 08A), SK-I zenith (HOSAKA 06), and SK-II day/night spectra (CRAVENS 08).

[17] AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[18] AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data.

[19] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[20] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data.

[21] ABE 08A obtained this result by a rate + shape + time combined geoneutrino and reactor two-neutrino fit for Δm^2_{21} and $\tan^2\theta_{12}$, using KamLAND data only. Superseded by GANDO 11.

[22] ABE 08A obtained this result by means of a two-neutrino fit using KamLAND, Homestake, SAGE, GALLEX, GNO, SK (zenith angle and E-spectrum), the SNO χ^2-map, and solar flux data. *CPT* invariance is assumed. Superseded by GANDO 11.

[23] AHARMIM 08 obtained this result by a two-neutrino oscillation analysis using all solar neutrino data including those of Borexino (ARPESELLA 08A) and Super-Kamiokande-I (HOSAKA 06), and KamLAND data (ABE 08A). *CPT* invariance is assumed.

[24] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (ARAKI 05). *CPT* invariance is assumed.

[25] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the data from Super-Kamiokande, SNO (AHMAD 02 and AHMAD 02B), and KamLAND (ARAKI 05) experiments. *CPT* invariance is assumed.

[26] HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data.

[27] HOSAKA 06 obtained this result from the consistency between the observed and expected day-night flux asymmetry amplitude. The listed 68% CL range is derived from the 1σ boundary of the amplitude fit to the data. Oscillation parameters are constrained to be in the LMA region. The mixing angle is fixed at $\tan^2\theta = 0.44$ because the fit depends only very weekly on it.

[28] AHARMIM 05A obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (ARAKI 05). *CPT* invariance is assumed. AHARMIM 05A also quotes $\Delta(m^2) = (8.0^{+0.6}_{-0.4}) \times 10^{-5}$ eV^2 as the error enveloping the 68% CL two-dimensional region.

[29] AHARMIM 05A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in figure 35a of AHARMIM 05A. AHARMIM 05A also quotes $\Delta(m^2) = (6.5^{+4.4}_{-2.3}) \times 10^{-5}$ eV^2 as the error enveloping the 68% CL two-dimensional region.

[30] ARAKI 05 obtained this result by a two-neutrino oscillation analysis using KamLAND and solar neutrino data. *CPT* invariance is assumed. The 1σ error shown here is provided by the KamLAND collaboration. The error quoted in ARAKI 05, $\Delta(m^2) = (7.9^{+0.6}_{-0.5}) \times 10^{-5}$, envelops the 68% CL two-dimensional region.

[31] AHMED 04A obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (EGUCHI 03). *CPT* invariance is assumed. AHMED 04A also quotes $\Delta(m^2) = (7.1^{+1.2}_{-0.6}) \times 10^{-5}$ eV^2 as the error enveloping the 68% CL two-dimensional region.

[32] AHMED 04A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 5(a) of AHMED 04A. The best-fit point is $\Delta(m^2) = 6.5 \times 10^{-5}$ eV^2, $\tan^2\theta = 0.40$ ($\sin^2 2\,\theta = 0.82$).

[33] SMY 04 obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (IANNI 03). *CPT* invariance is assumed.

[34] SMY 04 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The 1σ errors are read from Fig. 6(a) of SMY 04.

[35] SMY 04 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data. The 1σ errors are read from Fig. 6(a) of SMY 04.

[36] AHMAD 02B obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4(b) of AHMAD 02B. The best fit point is $\Delta(m^2) = 5.0 \times 10^{-5}$ eV^2 and $\tan\theta = 0.34$ ($\sin^2 2\,\theta = 0.76$).

[37] FUKUDA 02 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4 of FUKUDA 02. The best fit point is $\Delta(m^2) = 6.9 \times 10^{-5}$ eV^2 and $\tan^2\theta = 0.38$ ($\sin^2 2\,\theta = 0.80$).

$\sin^2(2\theta_{23})$

The reported limits below correspond to the projection onto the $\sin^2(2\theta_{23})$ axis of the 90% CL contours in the $\sin^2(2\theta_{23}) - \Delta m^2_{32}$ plane presented by the authors. Unless otherwise specified, the limits are 90% CL and the reported uncertainties are 68% CL. If the result is reported as $\sin^2(\theta_{23})$ we convert it to $\sin^2(2\theta_{23})$ and choose the quadrant that represents the more conservative value.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.999^{+0.001}_{-0.018}}$		[1] ABE	14	T2K	3ν osc.; normal mass hierarchy
$\mathbf{1.000^{+0.000}_{-0.017}}$		[1] ABE	14	T2K	3ν osc.; inverted mass hierarchy
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.97\ ^{+0.03}_{-0.06}$	90	[2] ADAMSON	14	MINS	3ν osc., normal hierarchy
$0.97\ ^{+0.03}_{-0.09}$	90	[2] ADAMSON	14	MINS	3ν osc.; inverted mass hierarchy
>0.73		[3] AARTSEN	13B	ICCB	DeepCore, 2ν oscillation
>0.963	68	[4] ABE	13G	T2K	3ν osc.; normal mass hierarchy
$0.95\ ^{+0.035}_{-0.036}$		[5] ADAMSON	13B	MINS	Beam + Atmospheric; identical ν & $\overline{\nu}$
0.84 - 1.0		[6] ABE	12A	T2K	off-axis beam
>0.75		[7] ADAMSON	12	MINS	$\overline{\nu}$ beam
>0.815		[8,9] ADAMSON	12B	MINS	MINOS atmospheric
>0.78		[8,10] ADAMSON	12B	MINS	MINOS pure atmospheric ν
>0.67		[8,10] ADAMSON	12B	MINS	MINOS pure atmospheric $\overline{\nu}$
>0.51		[11] ADRIAN-MAR..	12	ANTR	atmospheric ν with deep see telescope
>0.95		[12] ABE	11C	SKAM	Super-Kamiokande
>0.90		ADAMSON	11	MINS	2ν osc.; maximal mixing
$0.86\ ^{+0.11}_{-0.12}$		[13] ADAMSON	11B	MINS	$\overline{\nu}$ beam
>0.965		[14] WENDELL	10	SKAM	3ν osc. with solar terms; θ_{13}=0
>0.95		[15] WENDELL	10	SKAM	3ν osc.; normal mass hierarchy
>0.93		[16] WENDELL	10	SKAM	3ν osc.; inverted mass hierarchy
>0.85		ADAMSON	08A	MINS	MINOS
>0.2		[17] ADAMSON	06	MINS	atmospheric ν with far detector
>0.59		[18] AHN	06A	K2K	KEK to Super-K
>0.7		[19] MICHAEL	06	MINS	MINOS
>0.58		[20] ALIU	05	K2K	KEK to Super-K
>0.6		[21] ALLISON	05	SOU2	
>0.92		[22] ASHIE	05	SKAM	Super-Kamiokande
>0.80		[23] AMBROSIO	04	MCRO	MACRO
>0.90		[24] ASHIE	04	SKAM	L/E distribution
>0.30		[25] AHN	03	K2K	KEK to Super-K
>0.45		[26] AMBROSIO	03	MCRO	MACRO
>0.77		[27] AMBROSIO	03	MCRO	MACRO
>0.50		[28] SANCHEZ	03	SOU2	Soudan-2 Atmospheric
>0.80		[29] AMBROSIO	01	MCRO	upward μ
>0.82		[30] AMBROSIO	01	MCRO	upward μ
>0.45		[31] FUKUDA	99C	SKAM	upward μ

>0.70	[32] FUKUDA	99D	SKAM	upward μ
>0.30	[33] FUKUDA	99D	SKAM	stop μ / through
>0.82	[34] FUKUDA	98C	SKAM	Super-Kamiokande
>0.30	[35] HATAKEYAMA	98	KAMI	Kamiokande
>0.73	[36] HATAKEYAMA	98	KAMI	Kamiokande
>0.65	[37] FUKUDA	94	KAMI	Kamiokande

[1] ABE 14 results are based on ν_μ disappearance using three-neutrino oscillation fit. The confidence intervals are derived from one dimensional profiled likelihoods. ABE 14 reported results as $\sin^2(\theta_{23}) = 0.514^{+0.055}_{-0.056}$ (0.511 ± 0.055), assuming normal (inverted) mass hierarchy.

[2] ADAMSON 14 uses a complete set of accelerator and atmospheric data. The analysis combines the ν_μ disappearance and ν_e appearance data using three-neutrino oscillation fit. The fit results are obtained for normal and inverted mass hierarchy assumptions. The best fit is for lower θ_{23} quadrant and inverted mass hierarchy.

[3] AARTSEN 13B obtained this result by a two-neutrino oscillation analysis using 20–100 GeV muon neutrino sample from a total of 318.9 days of live-time measurement with the low-energy subdetector DeepCore of the IceCube neutrino telescope.

[4] The best fit value is $\sin^2(\theta_{23}) = 0.514 \pm 0.082$. Superseded by ABE 14.

[5] ADAMSON 13B obtained this result from ν_μ and $\overline{\nu}_\mu$ disappearance using ν_μ (10.71×10^{20} POT) and $\overline{\nu}_\mu$ (3.36×10^{20} POT) beams, and atmospheric (37.88kton-years) data from MINOS The fit assumed two-flavor neutrino hypothesis and identical ν_μ and $\overline{\nu}_\mu$ oscillation parameters. Superseded by ADAMSON 14.

[6] ABE 12A obtained this result by a two-neutrino oscillation analysis. The best-fit point is $\sin^2(2\theta_{23}) = 0.98$.

[7] ADAMSON 12 is a two-neutrino oscillation analysis using antineutrinos. The best fit value is $\sin^2(2\theta_{23}) = 0.95^{+0.10}_{-0.11} \pm 0.01$.

[8] ADAMSON 12B obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 37.9 kton·yr atmospheric neutrino data with the MINOS far detector.

[9] The best fit point is $\Delta m^2 = 0.0019$ eV^2 and $\sin^2 2\theta = 0.99$. The 90% single-parameter confidence interval at the best fit point is $\sin^2 2\theta > 0.86$.

[10] The data are separated into pure samples of νs and $\overline{\nu}$s, and separate oscillation parameters for νs and $\overline{\nu}$s are fit to the data. The best fit point is (Δm^2, $\sin^2 2\theta$) = (0.0022 eV^2, 0.99) and ($\Delta\overline{m}^2$, $\sin^2 2\overline{\theta}$) = (0.0016 eV^2, 1.00). The quoted result is taken from the 90% C.L. contour in the (Δm^2, $\sin^2 2\theta$) plane obtained by minimizing the four parameter log-likelihood function with respect to the other oscillation parameters.

[11] ADRIAN-MARTINEZ 12 measured the oscillation parameters of atmospheric neutrinos with the ANTARES deep sea neutrino telescope using the data taken from 2007 to 2010 (863 days of total live time).

[12] ABE 11C obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande-I+II+III atmospheric neutrino data. ABE 11C also reported results under a two-neutrino disappearance model with separate mixing parameters between ν and $\overline{\nu}$, and obtained $\sin^2 2\theta > 0.93$ for ν and $\sin^2 2\theta > 0.83$ for $\overline{\nu}$ at 90% C.L.

[13] ADAMSON 11B obtained this result by a two-neutrino oscillation analysis of antineutrinos in an antineutrino enhanced beam with 1.71×10^{20} protons on target. This results is consistent with the neutrino measurements of ADAMSON 11 at 2% C.L.

[14] WENDELL 10 obtained this result ($\sin^2\theta_{23} = 0.407$–$0.583$) by a three-neutrino oscillation analysis using the Super-Kamiokande-I+II+III atmospheric neutrino data, assuming $\theta_{13} = 0$ but including the solar oscillation parameters Δm^2_{21} and $\sin^2\theta_{12}$ in the fit.

[15] WENDELL 10 obtained this result ($\sin^2\theta_{23} = 0.43$–0.61) by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m^2_{21} = 0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.

[16] WENDELL 10 obtained this result ($\sin^2\theta_{23}$ = 0.44–0.63) by a three-neutrino oscillation analysis with one mass scale dominance (Δm^2_{21} = 0) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.

[17] ADAMSON 06 obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 4.54 kton yr atmospheric neutrino data with the MINOS far detector.

[18] Supercedes ALIU 05.

[19] MICHAEL 06 best fit is for maximal mixing. See also ADAMSON 08.

[20] The best fit is for maximal mixing.

[21] ALLISON 05 result is based upon atmospheric neutrino interactions including upward-stopping muons, with an exposure of 5.9 kton yr. From a two-flavor oscillation analysis the best-fit point is $\Delta m^2 = 0.0017$ eV^2 and $\sin^2(2\theta) = 0.97$.

[22] ASHIE 05 obtained this result by a two-neutrino oscillation analysis using 92 kton yr atmospheric neutrino data from the complete Super-Kamiokande I running period.

[23] AMBROSIO 04 obtained this result, without using the absolute normalization of the neutrino flux, by combining the angular distribution of upward through-going muon tracks with $E_\mu > 1$ GeV, N_{low} and N_{high}, and the numbers of InDown + UpStop and InUp events. Here, N_{low} and N_{high} are the number of events with reconstructed neutrino energies < 30 GeV and > 130 GeV, respectively. InDown and InUp represent events with downward and upward-going tracks starting inside the detector due to neutrino interactions, while UpStop represents entering upward-going tracks which stop in the detector. The best fit is for maximal mixing.

[24] ASHIE 04 obtained this result from the L(flight length)/E(estimated neutrino energy) distribution of ν_μ disappearance probability, using the Super-Kamiokande-I 1489 live-day atmospheric neutrino data.

[25] There are several islands of allowed region from this K2K analysis, extending to high values of Δm^2. We only include the one that overlaps atmospheric neutrino analyses. The best fit is for maximal mixing.

[26] AMBROSIO 03 obtained this result on the basis of the ratio R = N_{low}/N_{high}, where N_{low} and N_{high} are the number of upward through-going muon events with reconstructed neutrino energy < 30 GeV and > 130 GeV, respectively. The data came from the full detector run started in 1994. The method of FELDMAN 98 is used to obtain the limits.

[27] AMBROSIO 03 obtained this result by using the ratio R and the angular distribution of the upward through-going muons. R is given in the previous note and the angular distribution is reported in AMBROSIO 01. The method of FELDMAN 98 is used to obtain the limits. The best fit is to maximal mixing.

[28] SANCHEZ 03 is based on an exposure of 5.9 kton yr. The result is obtained using a likelihood analysis of the neutrino L/E distribution for a selection μ flavor sample while the e-flavor sample provides flux normalization. The method of FELDMAN 98 is used to obtain the allowed region. The best fit is $\sin^2(2\theta) = 0.97$.

[29] AMBROSIO 01 result is based on the angular distribution of upward through-going muon tracks with $E_\mu > 1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration is 6.17 years. The best fit is obtained outside the physical region. The method of FELDMAN 98 is used to obtain the limits. The best fit is for maximal mixing.

[30] AMBROSIO 01 result is based on the angular distribution and normalization of upward through-going muon tracks with $E_\mu > 1$ GeV. See the previous footnote.

[31] FUKUDA 99C obtained this result from a total of 537 live days of upward through-going muon data in Super-Kamiokande between April 1996 to January 1998. With a threshold of $E_\mu > 1.6$ GeV, the observed flux is $(1.74 \pm 0.07 \pm 0.02) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is $\sin^2(2\theta) = 0.95$.

[32] FUKUDA 99D obtained this result from a simultaneous fitting to zenith angle distributions of upward-stopping and through-going muons. The flux of upward-stopping muons of

minimum energy of 1.6 GeV measured between April 1996 and January 1998 is $(0.39 \pm 0.04 \pm 0.02) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. This is compared to the expected flux of $(0.73 \pm 0.16$ (theoretical error)) $\times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is to maximal mixing.

[33] FUKUDA 99D obtained this result from the zenith dependence of the upward-stopping/through-going flux ratio. The best fit is to maximal mixing.

[34] FUKUDA 98C obtained this result by an analysis of 33.0 kton yr atmospheric neutrino data. The best fit is for maximal mixing.

[35] HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_\mu > 1.6$ GeV, the observed flux of upward through-going muons is $(1.94 \pm 0.10^{+0.07}_{-0.06}) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. This is compared to the expected flux of $(2.46 \pm 0.54$ (theoretical error)) $\times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is for maximal mixing.

[36] HATAKEYAMA 98 obtained this result from a combined analysis of Kamiokande contained events (FUKUDA 94) and upward going muon events. The best fit is $\sin^2(2\theta) = 0.95$.

[37] FUKUDA 94 obtained the result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande. The best fit is for maximal mixing.

Δm^2_{32}

The sign of Δm^2_{32} is not known at this time. Only the absolute value is quoted below. Unless otherwise specified, the ranges below correspond to the projection onto the Δm^2_{32} axis of the 90% CL contours in the $\sin^2(2\theta_{23}) - \Delta m^2_{32}$ plane presented by the authors. If uncertainties are reported with the value, they correspond to one standard deviation uncertainty.

VALUE (10^{-3} eV^2)	*DOCUMENT ID*		*TECN*	*COMMENT*
2.52±0.07 OUR FIT	Assuming inverted mass hierarchy			
2.44±0.06 OUR FIT	Assuming normal mass hierarchy			
2.51 ± 0.10	[1] ABE	14	T2K	3ν osc.; normal mass hierarchy
2.56 ± 0.10	[1] ABE	14	T2K	3ν osc.; inverted mass hierarchy
2.37 ± 0.09	[2] ADAMSON	14	MINS	3ν osc., accel. and atmspheric; normal mass hierarchy
$2.41^{+0.12}_{-0.09}$	[2] ADAMSON	14	MINS	3ν osc., accel. and atmspheric; inverted mass hierarchy
$2.54^{+0.19}_{-0.20}$	[3] AN	14	DAYA	3ν osc.; normal mass hierarchy
$2.64^{+0.19}_{-0.20}$	[3] AN	14	DAYA	3ν osc.; inverted mass hierarchy
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$2.3\ ^{+0.6}_{-0.5}$	[4] AARTSEN	13B	ICCB	DeepCore, 2ν oscillation
$2.44^{+0.17}_{-0.15}$	[5] ABE	13G	T2K	3ν osc.; normal mass hierarchy
$2.41^{+0.09}_{-0.10}$	[6] ADAMSON	13B	MINS	2ν osc.; beam + atmospheric; identical ν & $\overline{\nu}$
2.2–3.1	[7] ABE	12A	T2K	off-axis beam
$2.62^{+0.31}_{-0.28} \pm 0.09$	[8] ADAMSON	12	MINS	$\overline{\nu}$ beam
1.35–2.55	[9,10] ADAMSON	12B	MINS	MINOS atmospheric
1.4–5.6	[9,11] ADAMSON	12B	MINS	MINOS pure atmospheric ν
0.9–2.5	[9,11] ADAMSON	12B	MINS	MINOS pure atmospheric $\overline{\nu}$

1.8–5.0	[12] ADRIAN-MAR..12		ANTR	atm. ν with deep see telescope
1.3–4.0	[13] ABE	11C	SKAM	atmospheric $\overline{\nu}$
$2.32^{+0.12}_{-0.08}$	ADAMSON	11	MINS	2ν oscillation; maximal mixing
$3.36^{+0.46}_{-0.40}$	[14] ADAMSON	11B	MINS	$\overline{\nu}$ beam
<3.37	[15] ADAMSON	11C	MINS	MINOS
1.9–2.6	[16] WENDELL	10	SKAM	3ν osc.; normal mass hierarchy
1.7–2.7	[16] WENDELL	10	SKAM	3ν osc.; inverted mass hierarchy
2.43 ± 0.13	ADAMSON	08A	MINS	MINOS
0.07–50	[17] ADAMSON	06	MINS	atmospheric ν with far detector
1.9–4.0	[18,19] AHN	06A	K2K	KEK to Super-K
2.2–3.8	[20] MICHAEL	06	MINS	MINOS
1.9–3.6	[18] ALIU	05	K2K	KEK to Super-K
0.3–12	[21] ALLISON	05	SOU2	
1.5–3.4	[22] ASHIE	05	SKAM	atmospheric neutrino
0.6–8.0	[23] AMBROSIO	04	MCRO	MACRO
1.9 to 3.0	[24] ASHIE	04	SKAM	L/E distribution
1.5–3.9	[25] AHN	03	K2K	KEK to Super-K
0.25–9.0	[26] AMBROSIO	03	MCRO	MACRO
0.6–7.0	[27] AMBROSIO	03	MCRO	MACRO
0.15–15	[28] SANCHEZ	03	SOU2	Soudan-2 Atmospheric
0.6–15	[29] AMBROSIO	01	MCRO	upward μ
1.0–6.0	[30] AMBROSIO	01	MCRO	upward μ
1.0–50	[31] FUKUDA	99C	SKAM	upward μ
1.5–15.0	[32] FUKUDA	99D	SKAM	upward μ
0.7–18	[33] FUKUDA	99D	SKAM	stop μ / through
0.5–6.0	[34] FUKUDA	98C	SKAM	Super-Kamiokande
0.55–50	[35] HATAKEYAMA	98	KAMI	Kamiokande
4–23	[36] HATAKEYAMA	98	KAMI	Kamiokande
5–25	[37] FUKUDA	94	KAMI	Kamiokande

[1] ABE 14 results are based on ν_μ disappearance using three-neutrino oscillation fit. The confidence intervals are derived from one dimensional profiled likelihoods. In ABE 14 the inverted mass hierarchy result is reported as $\Delta m^2_{13} = (2.48 \pm 0.10) \times 10^{-3}$ eV^2 which we converted to Δm^2_{32} by adding PDG 14 value of $\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}$ eV^2.

[2] ADAMSON 14 uses a complete set of accelerator and atmospheric data. The analysis combines The analysis combines the ν_μ disappearance and ν_e appearance data using three-neutrino oscillation fit. The fit results are obtained for normal and inverted mass hierarchy assumptions.

[3] AN 14 uses six identical detectors, with three placed near the reactor cores (flux-weighted baselines of 512 and 561 m) and the remaining three at the far hall (at the flux averaged distance of 1579 m from all six reactor cores) to determine prompt energy spectra and derive $\Delta m^2_{ee} = (2.59^{+0.19}_{-0.20}) \times 10^{-3}$ eV^2. Assuming the normal (inverted) hierarchy, the fitted $\Delta m^2_{32} = (2.54^{+0.19}_{-0.20}) \times 10^{-3}$ $((2.64^{+0.19}_{-0.20}) \times 10^{-3})$ eV^2.

[4] AARTSEN 13B obtained this result by a two-neutrino oscillation analysis using 20–100 GeV muon neutrino sample from a total of 318.9 days of live-time measurement with the low-energy subdetector DeepCore of the IceCube neutrino telescope.

[5] Based on the observation of 58 ν_μ events with 205 $\pm$ 17(syst) expected in the absence of neutrino oscillations. Superseded by ABE 14.

[6] ADAMSON 13B obtained this result from ν_μ and $\overline{\nu}_\mu$ disappearance using ν_μ (10.71×10^{20} POT) and $\overline{\nu}_\mu$ (3.36×10^{20} POT) beams, and atmospheric (37.88 kton-years) data from MINOS. The fit assumed two-flavor neutrino hypothesis and identical ν_μ and $\overline{\nu}_\mu$ oscillation parameters.

[7] ABE 12A obtained this result by a two-neutrino oscillation analysis. The best-fit point is $\Delta m^2_{32} = 2.65 \times 10^{-3}$ eV^2.

[8] ADAMSON 12 is a two-neutrino oscillation analysis using antineutrinos.

[9] ADAMSON 12B obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 37.9 kton·yr atmospheric neutrino data with the MINOS far detector.

[10] The 90% single-parameter confidence interval at the best fit point is $\Delta m^2 = 0.0019 \pm 0.0004$ eV^2.

[11] The data are separated into pure samples of νs and $\overline{\nu}$s, and separate oscillation parameters for νs and $\overline{\nu}$s are fit to the data. The best fit point is (Δm^2, $\sin^2 2\theta$) = (0.0022 eV^2, 0.99) and ($\Delta \overline{m}^2$, $\sin^2 2\overline{\theta}$) = (0.0016 eV^2, 1.00). The quoted result is taken from the 90% C.L. contour in the (Δm^2, $\sin^2 2\theta$) plane obtained by minimizing the four parameter log-likelihood function with respect to the other oscillation parameters.

[12] ADRIAN-MARTINEZ 12 measured the oscillation parameters of atmospheric neutrinos with the ANTARES deep sea neutrino telescope using the data taken from 2007 to 2010 (863 days of total live time).

[13] ABE 11C obtained this result by a two-neutrino oscillation analysis with separate mixing parameters between neutrinos and antineutrinos, using the Super-Kamiokande-I+II+III atmospheric neutrino data. The corresponding 90% CL neutrino oscillation parameter range obtained from this analysis is $\Delta m^2 = 1.7$–3.0×10^{-3} eV^2.

[14] ADAMSON 11B obtained this result by a two-neutrino oscillation analysis of antineutrinos in an antineutrino enhanced beam with 1.71×10^{20} protons on target. This results is consistent with the neutrino measurements of ADAMSON 11 at 2% C.L.

[15] ADAMSON 11C obtains this result based on a study of antineutrinos in a neutrino beam and assumes maximal mixing in the two-flavor approximation.

[16] WENDELL 10 obtained this result by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m^2_{21} = 0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.

[17] ADAMSON 06 obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 4.54 kton yr atmospheric neutrino data with the MINOS far detector.

[18] The best fit in the physical region is for $\Delta m^2 = 2.8 \times 10^{-3}$ eV^2.

[19] Supercedes ALIU 05.

[20] MICHAEL 06 best fit is 2.74×10^{-3} eV^2. See also ADAMSON 08.

[21] ALLISON 05 result is based on an atmospheric neutrino observation with an exposure of 5.9 kton yr. From a two-flavor oscillation analysis the best-fit point is $\Delta m^2 = 0.0017$ eV^2 and $\sin^2 2\,\theta = 0.97$.

[22] ASHIE 05 obtained this result by a two-neutrino oscillation analysis using 92 kton yr atmospheric neutrino data from the complete Super-Kamiokande I running period. The best fit is for $\Delta m^2 = 2.1 \times 10^{-3}$ eV^2.

[23] AMBROSIO 04 obtained this result, without using the absolute normalization of the neutrino flux, by combining the angular distribution of upward through-going muon tracks with $E_\mu > 1$ GeV, N_{low} and N_{high}, and the numbers of InDown + UpStop and InUp events. Here, N_{low} and N_{high} are the number of events with reconstructed neutrino energies < 30 GeV and > 130 GeV, respectively. InDown and InUp represent events with downward and upward-going tracks starting inside the detector due to neutrino interactions, while UpStop represents entering upward-going tracks which stop in the detector. The best fit is for $\Delta m^2 = 2.3 \times 10^{-3}$ eV^2.

[24] ASHIE 04 obtained this result from the L(flight length)/E(estimated neutrino energy) distribution of ν_μ disappearance probability, using the Super-Kamiokande-I 1489 live-day atmospheric neutrino data. The best fit is for $\Delta m^2 = 2.4 \times 10^{-3}$ eV^2.

[25] There are several islands of allowed region from this K2K analysis, extending to high values of Δm^2. We only include the one that overlaps atmospheric neutrino analyses. The best fit is for $\Delta m^2 = 2.8 \times 10^{-3}$ eV^2.

[26] AMBROSIO 03 obtained this result on the basis of the ratio R = N_{low}/N_{high}, where N_{low} and N_{high} are the number of upward through-going muon events with reconstructed neutrino energy $<$ 30 GeV and $>$ 130 GeV, respectively. The data came from the full detector run started in 1994. The method of FELDMAN 98 is used to obtain the limits. The best fit is for $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2.

[27] AMBROSIO 03 obtained this result by using the ratio R and the angular distribution of the upward through-going muons. R is given in the previous note and the angular distribution is reported in AMBROSIO 01. The method of FELDMAN 98 is used to obtain the limits. The best fit is for $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2.

[28] SANCHEZ 03 is based on an exposure of 5.9 kton yr. The result is obtained using a likelihood analysis of the neutrino L/E distribution for a selection μ flavor sample while the *e*-flavor sample provides flux normalization. The method of FELDMAN 98 is used to obtain the allowed region. The best fit is for $\Delta m^2 = 5.2 \times 10^{-3}$ eV^2.

[29] AMBROSIO 01 result is based on the angular distribution of upward through-going muon tracks with $E_\mu > 1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration is 6.17 years. The best fit is obtained outside the physical region. The method of FELDMAN 98 is used to obtain the limits.

[30] AMBROSIO 01 result is based on the angular distribution and normalization of upward through-going muon tracks with $E_\mu > 1$ GeV. See the previous footnote.

[31] FUKUDA 99C obtained this result from a total of 537 live days of upward through-going muon data in Super-Kamiokande between April 1996 to January 1998. With a threshold of $E_\mu > 1.6$ GeV, the observed flux is $(1.74 \pm 0.07 \pm 0.02) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is for $\Delta m^2 = 5.9 \times 10^{-3}$ eV^2.

[32] FUKUDA 99D obtained this result from a simultaneous fitting to zenith angle distributions of upward-stopping and through-going muons. The flux of upward-stopping muons of minimum energy of 1.6 GeV measured between April 1996 and January 1998 is $(0.39 \pm 0.04 \pm 0.02) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. This is compared to the expected flux of $(0.73 \pm 0.16$ (theoretical error)$) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is for $\Delta m^2 = 3.9 \times 10^{-3}$ eV^2.

[33] FUKUDA 99D obtained this result from the zenith dependence of the upward-stopping/through-going flux ratio. The best fit is for $\Delta m^2 = 3.1 \times 10^{-3}$ eV^2.

[34] FUKUDA 98C obtained this result by an analysis of 33.0 kton yr atmospheric neutrino data. The best fit is for $\Delta m^2 = 2.2 \times 10^{-3}$ eV^2.

[35] HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_\mu > 1.6$ GeV, the observed flux of upward through-going muons is $(1.94 \pm 0.10^{+0.07}_{-0.06}) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. This is compared to the expected flux of $(2.46 \pm 0.54$ (theoretical error)$) \times 10^{-13}$ cm^{-2}s^{-1}sr^{-1}. The best fit is for $\Delta m^2 = 2.2 \times 10^{-3}$ eV^2.

[36] HATAKEYAMA 98 obtained this result from a combined analysis of Kamiokande contained events (FUKUDA 94) and upward going muon events. The best fit is for $\Delta m^2 = 13 \times 10^{-3}$ eV^2.

[37] FUKUDA 94 obtained the result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande. The best fit is for $\Delta m^2 = 16 \times 10^{-3}$ eV^2.

$\sin^2(2\theta_{13})$

At present time direct measurements of $\sin^2(2\theta_{13})$ are derived from the reactor $\overline{\nu}_e$ disappearance at distances corresponding to the Δm^2_{32} value, i.e. L ∼ 1km. Alternatively, limits can also be obtained from the analysis of the solar neutrino data and accelerator-based $\nu_\mu \rightarrow \nu_e$ experiments.

VALUE (units 10^{-2})	CL%	DOCUMENT ID		TECN	COMMENT
9.3± 0.8 OUR AVERAGE					
$9.0^{+0.8}_{-0.9}$		[1] AN	14	DAYA	DayaBay, Ling Ao/Ao II reactors
10.9± 3.0±2.5		[2] ABE	12B	DCHZ	Chooz reactors
11.3± 1.3±1.9		[3] AHN	12	RENO	Yonggwang reactors
• • • We do not use the following data for averages, fits, limits, etc. • • •					
9.7± 3.4±3.4		[4] ABE	13C	DCHZ	Neutron capture on hydrogen
$8.8^{+4.9}_{-3.9}$		[5] ABE	13E	T2K	Normal mass hierarchy
$10.8^{+5.9}_{-4.6}$		[5] ABE	13E	T2K	Inverted mass hierarchy
$6.4^{+4.8}_{-3.7}$		[6] ADAMSON	13A	MINS	Normal mass hierarchy
$11.7^{+6.8}_{-6.2}$		[6] ADAMSON	13A	MINS	Inverted mass hierarchy
<44	90	AGAFONOVA	13	OPER	OPERA: 3ν
<13.9	95	[7] AHARMIM	13	FIT	global solar: 3ν
8.9± 1.0±0.5		[8] AN	13	DAYA	DayaBay, LIng Ao/Ao II reactors
8.6± 4.1±3.0		[9] ABE	12	DCHZ	Chooz reactors
9.2± 1.6±0.5		[10] AN	12	DAYA	DayaBay, Ling Ao/Ao II reactors
$9.8^{+6.7}_{-6.2}$	68	[11] ABE	11	FIT	KamLAND + global solar
< 23	95	[12] ABE	11	FIT	Global solar
5 to 21	68	[13] ABE	11A	T2K	Normal mass hierarchy
6 to 25	68	[14] ABE	11A	T2K	Inverted mass hierarchy
1 to 9	68	[15] ADAMSON	11D	MINS	Normal mass hierarchy
3 to 15	68	[16] ADAMSON	11D	MINS	Inverted mass hierarchy
8 ± 3	68	[17] FOGLI	11	FIT	Global neutrino data
7.8± 6.2	68	[18] GANDO	11	FIT	KamLAND + solar: 3ν
12.4±13.3	68	[19] GANDO	11	FIT	KamLAND: 3ν
3^{+9}_{-7}	90	[20] ADAMSON	10A	MINS	Normal mass hierarchy
6^{+14}_{-6}	90	[21] ADAMSON	10A	MINS	Inverted mass hierarchy
8^{+8}_{-7}		[22,23] AHARMIM	10	FIT	KamLAND + global solar: 3ν
< 30	95	[22,24] AHARMIM	10	FIT	global solar: 3ν
< 15	90	[25] WENDELL	10	SKAM	3ν osc.; normal m hierarchy
< 33	90	[25] WENDELL	10	SKAM	3ν osc.; inverted m hierarchy
11^{+11}_{-8}		[26] ADAMSON	09	MINS	Normal mass hierarchy
18^{+15}_{-11}		[27] ADAMSON	09	MINS	Inverted mass hierarchy
6 ± 4		[28] FOGLI	08	FIT	Global neutrino data
8 ± 7		[29] FOGLI	08	FIT	Solar + KamLAND data

5 ± 5		[30] FOGLI	08	FIT	Atmospheric+LBL+CHOOZ
< 36	90	[31] YAMAMOTO	06	K2K	Accelerator experiment
< 48	90	[32] AHN	04	K2K	Accelerator experiment
< 36	90	[33] BOEHM	01		Palo Verde react.
< 45	90	[34] BOEHM	00		Palo Verde react.
< 15	90	[35] APOLLONIO	99	CHOZ	Reactor Experiment

[1] AN 14 uses six identical detectors, with three placed near the reactor cores (flux-weighted baselines of 512 and 561 m) and the remaining three at the far hall (at the flux averaged distance of 1579 m from all six reactor cores) to determine the mixing angle θ_{13} using the $\overline{\nu}_e$ observed interaction rates and energy spectra and three neutrino mixing analysis. Supersedes AN 13.

[2] ABE 12B determines the neutrino mixing angle θ_{13} using a single detector, located 1050 m from the cores of two reactors. This result is based on a spectral shape and rate analysis.

[3] AHN 12 uses two identical detectors, placed at flux weighted distances of 408.56 m and 1433.99 m from six reactor cores, to determine the mixing angle θ_{13}. This rate-only analysis excludes the no-oscillation hypothesis at 4.9 standard deviations. The value of $\Delta m^2_{31} = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2 was assumed in the analysis.

[4] ABE 13C uses delayed neutron capture on hydrogen instead of on Gd used previously. The fiducial volume is thus three times larger. The fit is based on the rate and shape analysis as in ABE 12B.

[5] ABE 13E assumes maximal θ_{23} mixing and CP phase $\delta = 0$.

[6] ADAMSON 13A results obtained from ν_e appearance, assuming $\delta = 0$, and $\sin^2(2\,\theta_{23}) = 0.957$.

[7] AHARMIM 13 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.45×10^{-3} eV^2, using global solar neutrino data. AHARMIM 13 global solar neutrino data include SNO's all-phases-combined analysis results on the total active ^{8}B neutrino flux and energy-dependent ν_e survival probability parameters, measurements of Cl (CLEVELAND 98), Ga (ABDURASHITOV 09 which contains combined analysis with GNO (ALTMANN 05 and Ph.D. thesis of F. Kaether)), and ^{7}Be (BELLINI 11A) rates, and ^{8}B solar-neutrino recoil electron measurements of SK-I (HOSAKA 06) zenith, SK-II (CRAVENS 08) and SK-III (ABE 11) day/night spectra, and Borexino (BELLINI 10A) spectra. AHARMIM 13 also reported a result combining global solar and KamLAND data, which is $\sin^2(2\,\theta_{13}) = (9.1^{+2.9}_{-3.1}) \times 10^{-2}$.

[8] AN 13 uses six identical detectors, with three placed near the reactor cores (flux-weighted baselines of 498 and 555 m) and the remaining three at the far hall (at the flux averaged distance of 1628 m from all six reactor cores) to determine the $\overline{\nu}_e$ interaction rate ratios. Superseded by AN 14.

[9] ABE 12 determines the $\overline{\nu}_e$ interaction rate in a single detector, located 1050 m from the cores of two reactors. The rate normalization is fixed by the results of the Bugey4 reactor experiment, thus avoiding any dependence on possible very short baseline oscillations. The value of $\Delta m^2_{31} = 2.4 \times 10^{-3}$ eV^2 is used in the analysis. Superseded by ABE 12B.

[10] AN 12 uses six identical detectors with three placed near the reactor cores (flux-weighted baselines of 470 m and 576 m) and the remaining three at the far hall (at the flux averaged distance of 1648 m from all six reactor cores) to determine the mixing angle θ_{13} using the $\overline{\nu}_e$ observed interaction rate ratios. This rate-only analysis excludes the no-oscillation hypothesis at 5.2 standard deviations. The value of $\Delta m^2_{31} = (2.32^{+0.12}_{-0.08}) \times 10^{-3}$ eV^2 was assumed in the analysis. Superseded by AN 13.

[11] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND

data. This result implies an upper bound of $\sin^2\theta_{13} < 0.059$ (95% CL) or $\sin^2 2\theta_{13} < 0.22$ (95% CL). The normal neutrino mass hierarchy and CPT invariance are assumed.

[12] ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to 2.4×10^{-3} eV^2, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.

[13] The quoted limit is for $\Delta m^2_{32} = 2.4 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, $\delta = 0$, and the normal mass hierarchy. For other values of δ, the 68% region spans from 0.03 to 0.25, and the 90% region from 0.02 to 0.32.

[14] The quoted limit is for $\Delta m^2_{32} = 2.4 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, $\delta = 0$, and the inverted mass hierarchy. For other values of δ, the 68% region spans from 0.04 to 0.30, and the 90% region from 0.02 to 0.39.

[15] The quoted limit is for $\Delta m^2_{32} = 2.32 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, $\delta = 0$, and the normal mass hierarchy. For other values of δ, the 68% region spans from 0.02 to 0.12, and the 90% region from 0 to 0.16.

[16] The quoted limit is for $\Delta m^2_{32} = 2.32 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, $\delta = 0$, and the inverted mass hierarchy. For other values of δ, the 68% region spans from 0.02 to 0.16, and the 90% region from 0 to 0.21.

[17] FOGLI 11 obtained this result from an analysis using the atmospheric, accelerator long baseline, CHOOZ, solar, and KamLAND data. Recently, MUELLER 11 suggested an average increase of about 3.5% in normalization of the reactor $\overline{\nu}_e$ fluxess, and using these fluxes, the fitted result becomes 0.10 ± 0.03.

[18] GANDO 11 report $\sin^2\theta_{13} = 0.020 \pm 0.016$. This result was obtained with three-neutrino fit using the KamLAND + solar data.

[19] GANDO 11 report $\sin^2\theta_{13} = 0.032 \pm 0.037$. This result was obtained with three-neutrino fit using the KamLAND data only.

[20] This result corresponds to the limit of <0.12 at 90% CL for $\Delta m^2_{32} = 2.43 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, and $\delta = 0$. For other values of δ, the 90% CL region spans from 0 to 0.16.

[21] This result corresponds to the limit of <0.20 at 90% CL for $\Delta m^2_{32} = 2.43 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, and $\delta = 0$. For other values of δ, the 90% CL region spans from 0 to 0.21.

[22] AHARMIM 10 global solar neutrino data include SNO's low-energy-threshold analysis survival probability day/night curves, SNO Phase III integral rates (AHARMIM 08), Cl (CLEVELAND 98), SAGE (ABDURASHITOV 09), Gallex/GNO (HAMPEL 99, ALTMANN 05), Borexino (ARPESELLA 08A), SK-I zenith (HOSAKA 06), and SK-II day/night spectra (CRAVENS 08).

[23] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed. This result implies an upper bound of $\sin^2\theta_{13} < 0.057$ (95% CL) or $\sin^2 2\theta_{13} < 0.22$ (95% CL).

[24] AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{31} fixed to 2.3×10^{-3} eV^2, using global solar neutrino data.

[25] WENDELL 10 obtained this result by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m^2_{21} = 0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.

[26] The quoted limit is for $\Delta m^2_{32} = 2.43 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, and $\delta = 0$. For other values of δ, the 68% CL region spans from 0.02 to 0.26.

[27] The quoted limit is for $\Delta m^2_{32} = 2.43 \times 10^{-3}$ eV^2, $\theta_{23} = \pi/2$, and $\delta = 0$. For other values of δ, the 68% CL region spans from 0.04 to 0.34.

[28] FOGLI 08 obtained this result from a global analysis of all neutrino oscillation data, that is, solar + KamLAND + atmospheric + accelerator long baseline + CHOOZ.

[29] FOGLI 08 obtained this result from an analysis using the solar and KamLAND neutrino oscillation data.

[30] FOGLI 08 obtained this result from an analysis using the atmospheric, accelerator long baseline, and CHOOZ neutrino oscillation data.

[31] YAMAMOTO 06 searched for $\nu_\mu \rightarrow \nu_e$ appearance. Assumes 2 $\sin^2(2\theta_{\mu e}) = \sin^2(2\theta_{13})$. The quoted limit is for $\Delta m^2_{32} = 1.9 \times 10^{-3}$ eV^2. That value of Δm^2_{32} is the one-σ low value for AHN 06A. For the AHN 06A best fit value of 2.8×10^{-3} eV^2, the $\sin^2(2\theta_{13})$ limit is < 0.26. Supersedes AHN 04.

[32] AHN 04 searched for $\nu_\mu \rightarrow \nu_e$ appearance. Assuming 2 $\sin^2(2\,\theta_{\mu_e}) = \sin^2(2\,\theta_{13})$, a limit on $\sin^2(2\,\theta_{\mu_e})$ is converted to a limit on $\sin^2(2\,\theta_{13})$.The quoted limit is for $\Delta m^2_{32} = 1.9 \times 10^{-3}$ eV^2. That value of Δm^2_{32} is the one-σ low value for ALIU 05. For the ALIU 05 best fit value of 2.8×10^{-3} eV^2, the $\sin^2(2\,\theta_{13})$ limit is < 0.30.

[33] The quoted limit is for $\Delta m^2_{32} = 1.9 \times 10^{-3}$ eV^2. That value of Δm^2_{32} is the 1-σ low value for ALIU 05. For the ALIU 05 best fit value of 2.8×10^{-3} eV^2, the $\sin^2 2\,\theta_{13}$ limit is < 0.19. In this range, the θ_{13} limit is larger for lower values of Δm^2_{32}, and smaller for higher values of Δm^2_{32}.

[34] The quoted limit is for $\Delta m^2_{32} = 1.9 \times 10^{-3}$ eV^2. That value of Δm^2_{32} is the 1-σ low value for ALIU 05. For the ALIU 05 best fit value of 2.8×10^{-3} eV^2, the $\sin^2 2\,\theta_{13}$ limit is < 0.23.

[35] The quoted limit is for $\Delta m^2_{32} = 2.43 \times 10^{-3}$ eV^2. That value of Δm^2_{32} is the central value for ADAMSON 08. For the ADAMSON 08 1-σ low value of 2.30×10^{-3} eV^2, the $\sin^2 2\,\theta_{13}$ limit is < 0.16. See also APOLLONIO 03 for a detailed description of the experiment.

(C) Other neutrino mixing results

The LSND collaboration reported in AGUILAR 01 a signal which is consistent with $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations. In a three neutrino framework, this would be a measurement of θ_{12} and Δm^2_{21}. This does not appear to be consistent with most of the other neutrino data. The MiniBooNE experiment, reported in AGUILAR-AREVALO 07, does a two-neutrino analysis which, assuming *CP* conservation, rules out AGUILAR 01. However, the MiniBooNE antineutrino data reported in AGUILAR-AREVALO 13A are consistent with the signal reported in AGUILAR 01. The following listings include results which might be relevant towards understanding these observations. They include searches for $\nu_\mu \rightarrow \nu_e$, $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$, sterile neutrino oscillations, and *CPT* violation.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $(\nu_\mu \rightarrow \nu_e)$

VALUE (eV^2)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.015 to 0.050	90	[1] AGUILAR-AR...	13A	MBOO	MiniBooNE
<0.34	90	[2] MAHN	12	MBOO	MiniBooNE/SciBooNE
<0.034	90	AGUILAR-AR...	07	MBOO	MiniBooNE
<0.0008	90	AHN	04	K2K	Water Cherenkov
<0.4	90	ASTIER	03	NOMD	CERN SPS
<2.4	90	AVVAKUMOV	02	NTEV	NUTEV FNAL

		[3] AGUILAR	01	LSND	$\nu\mu \rightarrow \nu_e$ osc.prob.
0.03 to 0.3	95	[4] ATHANASSO...	98	LSND	$\nu_\mu \rightarrow \nu_e$
<2.3	90	[5] LOVERRE	96		CHARM/CDHS
<0.9	90	VILAIN	94C	CHM2	CERN SPS
<0.09	90	ANGELINI	86	HLBC	BEBC CERN PS

[1] Based on $\nu_\mu \rightarrow \nu_e$ appearance of 162.0 ± 47.8 events; marginally compatible with two neutrino oscillations. The best fit value is $\Delta m^2 = 3.14$ eV^2.

[2] MAHN 12 is a combined spectral fit of MiniBooNE and SciBooNE neutrino data with the range of Δm^2 up to 25 eV^2. The best limit is 0.04 at 7 eV^2.

[3] AGUILAR 01 is the final analysis of the LSND full data set. Search is made for the $\nu_\mu \rightarrow \nu_e$ oscillations using ν_μ from π^+ decay in flight by observing beam-on electron events from $\nu_e C \rightarrow e^- X$. Present analysis results in $8.1 \pm 12.2 \pm 1.7$ excess events in the $60 < E_e < 200$ MeV energy range, corresponding to oscillation probability of $0.10 \pm 0.16 \pm 0.04\%$. This is consistent, though less significant, with the previous result of ATHANASSOPOULOS 98, which it supersedes. The present analysis uses selection criteria developed for the decay at rest region, and is less effective in removing the background above 60 MeV than ATHANASSOPOULOS 98.

[4] ATHANASSOPOULOS 98 is a search for the $\nu_\mu \rightarrow \nu_e$ oscillations using ν_μ from π^+ decay in flight. The 40 observed beam-on electron events are consistent with $\nu_e C \rightarrow e^- X$; the expected background is 21.9 ± 2.1. Authors interpret this excess as evidence for an oscillation signal corresponding to oscillations with probability $(0.26 \pm 0.10 \pm 0.05)\%$. Although the significance is only $2.3\,\sigma$, this measurement is an important and consistent cross check of ATHANASSOPOULOS 96 who reported evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations from μ^+ decay at rest. See also ATHANASSOPOULOS 98B.

[5] LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $(\nu_\mu \rightarrow \nu_e)$

VALUE (units 10^{-3})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 7.2	90	AGAFONOVA	13	OPER	$\Delta(m^2) > 0.1$ eV^2
0.8 to 3	90	[1] AGUILAR-AR...	13A	MBOO	MiniBooNE
< 11	90	[2] ANTONELLO	13	ICAR	$\nu_\mu \rightarrow \nu_e$
< 6.8	90	[3] ANTONELLO	13A	ICAR	$\nu_\mu \rightarrow \nu_e$
<100	90	[4] MAHN	12	MBOO	MiniBooNE/SciBooNE
< 1.8	90	[5] AGUILAR-AR...	07	MBOO	MiniBooNE
<110	90	[6] AHN	04	K2K	Water Cherenkov
< 1.4	90	ASTIER	03	NOMD	CERN SPS
< 1.6	90	AVVAKUMOV	02	NTEV	NUTEV FNAL
		[7] AGUILAR	01	LSND	$\nu_\mu \rightarrow \nu_e$ osc.prob.
0.5 to 30	95	[8] ATHANASSO...	98	LSND	$\nu_\mu \rightarrow \nu_e$
< 3.0	90	[9] LOVERRE	96		CHARM/CDHS
< 9.4	90	VILAIN	94C	CHM2	CERN SPS
< 5.6	90	[10] VILAIN	94C	CHM2	CERN SPS

[1] Based on $\nu_\mu \rightarrow \nu_e$ appearance of 162.0 ± 47.8 events; marginally compatible with two neutrino oscillations. The best fit value is $\sin^2 2\theta = 0.002$.
[2] ANTONELLO 13 use the ICARUS T600 detector at LNGS and ∼ 20 GeV beam of ν_μ from CERN 730 km away to search for an excess of ν_e events. Two events are found with 3.7 ± 0.6 expected from conventional sources. This result excludes some parts of the parameter space expected by LSND. Superseded by ANTONELLO 13A.
[3] Based on four events with a background of 6.4 ± 0.9 from conventional sources with an average energy of 20 GeV and 730 km from the source of ν_μ.
[4] MAHN 12 is a combined fit of MiniBooNE and SciBooNE neutrino data.
[5] The limit is $\sin^2 2\theta < 0.9 \times 10^{-3}$ at $\Delta m^2 = 2$ eV^2. That value of Δm^2 corresponds to the smallest mixing angle consistent with the reported signal from LSND in AGUILAR 01.
[6] The limit becomes $\sin^2 2\theta < 0.15$ at $\Delta m^2 = 2.8 \times 10^{-3}$ eV^2, the bets-fit value of the ν_μ disappearance analysis in K2K.
[7] AGUILAR 01 is the final analysis of the LSND full data set of the search for the $\nu_\mu \rightarrow \nu_e$ oscillations. See footnote in preceding table for further details.
[8] ATHANASSOPOULOS 98 report (0.26 ± 0.10 ± 0.05)% for the oscillation probability; the value of $\sin^2 2\theta$ for large Δm^2 is deduced from this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions. If effect is due to oscillation, it is most likely to be intermediate $\sin^2 2\theta$ and Δm^2. See also ATHANASSOPOULOS 98B.
[9] LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.
[10] VILAIN 94C limit derived by combining the ν_μ and $\overline{\nu}_\mu$ data assuming *CP* conservation.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$

VALUE (eV^2)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.023 to 0.060	90	[1] AGUILAR-AR...	13A	MBOO	MiniBooNE
<0.16	90	[2] CHENG	12	MBOO	MiniBooNE/SciBooNE
0.03–0.09	90	[3] AGUILAR-AR...	10	MBOO	$E_\nu > 475$ MeV
0.03–0.07	90	[4] AGUILAR-AR...	10	MBOO	$E_\nu > 200$ MeV
<0.06	90	AGUILAR-AR...	09B	MBOO	MiniBooNE
<0.055	90	[5] ARMBRUSTER	02	KAR2	Liquid Sci. calor.
<2.6	90	AVVAKUMOV	02	NTEV	NUTEV FNAL
0.03–0.05		[6] AGUILAR	01	LSND	LAMPF
0.05–0.08	90	[7] ATHANASSO...	96	LSND	LAMPF
0.048–0.090	80	[8] ATHANASSO...	95		
<0.07	90	[9] HILL	95		
<0.9	90	VILAIN	94C	CHM2	CERN SPS
<0.14	90	[10] FREEDMAN	93	CNTR	LAMPF

[1] Based on $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ appearance of 78.4 ± 28.5 events. The best fit values are $\Delta m^2 = 0.043$ eV^2 and $\sin^2 2\theta = 0.88$.
[2] CHENG 12 is a combined fit of MiniBooNE and SciBooNE antineutrino data.
[3] This value is for a two neutrino oscillation analysis for excess antineutrino events with $E_\nu > 475$ MeV. The best fit is at 0.07. The allowed region is consistent with LSND reported by AGUILAR 01. Supercedes AGUILAR-AREVALO 09B.
[4] This value is for a two neutrino oscillation analysis for excess antineutrino events with $E_\nu > 200$ MeV with subtraction of the expected 12 events low energy excess seen in the neutrino component of the beam. The best fit value is 0.007 for $\Delta(m^2) = 4.4$ eV^2.
[5] ARMBRUSTER 02 is the final analysis of the KARMEN 2 data for 17.7 m distance from the ISIS stopped pion and muon neutrino source. It is a search for $\overline{\nu}_e$, detected by the

inverse β-decay reaction on protons and ^{12}C. 15 candidate events are observed, and 15.8 $\pm$ 0.5 background events are expected, hence no oscillation signal is detected. The results exclude large regions of the parameter area favored by the LSND experiment.

[6] AGUILAR 01 is the final analysis of the LSND full data set. It is a search for $\overline{\nu}_e$ 30 m from LAMPF beam stop. Neutrinos originate mainly for π^+ decay at rest. $\overline{\nu}_e$ are detected through $\overline{\nu}_e p \rightarrow e^+ n$ (20<E_{e^+} < 60 MeV) in delayed coincidence with $n p \rightarrow d\gamma$. Authors observe 87.9 $\pm$ 22.4 $\pm$ 6.0 total excess events. The observation is attributed to $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations with the oscillation probability of 0.264 $\pm$ 0.067 $\pm$ 0.045%, consistent with the previously published result. Taking into account all constraints, the most favored allowed region of oscillation parameters is a band of $\Delta(m^2)$ from 0.2–2.0 eV^2. Supersedes ATHANASSOPOULOS 95, ATHANASSOPOULOS 96, and ATHANASSOPOULOS 98.

[7] ATHANASSOPOULOS 96 is a search for $\overline{\nu}_e$ 30 m from LAMPF beam stop. Neutrinos originate mainly from π^+ decay at rest. $\overline{\nu}_e$ could come from either $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ or $\nu_e \rightarrow \overline{\nu}_e$; our entry assumes the first interpretation. They are detected through $\overline{\nu}_e p \rightarrow e^+ n$ (20 MeV <E_{e^+} <60 MeV) in delayed coincidence with $n p \rightarrow d\gamma$. Authors observe 51 $\pm$ 20 $\pm$ 8 total excess events over an estimated background 12.5 $\pm$ 2.9. ATHANASSOPOULOS 96B is a shorter version of this paper.

[8] ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 $\pm$ 0.4 events. Corresponds to an oscillation probability of $(0.34^{+0.20}_{-0.18} \pm 0.07)\%$. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.

[9] HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ and obtains only upper limits.

[10] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \rightarrow e^+ n$. FREEDMAN 93 replaces DURKIN 88.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$

VALUE (units 10^{-3})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<640	90	[1] ANTONELLO	13A	ICAR	$\overline{\nu}_e$ appearance
<150	90	[2] CHENG	12	MBOO	MiniBooNE/SciBooNE
0.4–9.0	99	[3] AGUILAR-AR...	10	MBOO	E_ν > 475 MeV
0.4–9.0	99	[4] AGUILAR-AR...	10	MBOO	E_ν > 200 MeV
< 3.3	90	[5] AGUILAR-AR...	09B	MBOO	MiniBooNE
< 1.7	90	[6] ARMBRUSTER	02	KAR2	Liquid Sci. calor.
< 1.1	90	AVVAKUMOV	02	NTEV	NUTEV FNAL
5.3$\pm$1.3$\pm$9.0		[7] AGUILAR	01	LSND	LAMPF
6.2$\pm$2.4$\pm$1.0		[8] ATHANASSO...	96	LSND	LAMPF
3–12	80	[9] ATHANASSO...	95		
< 6	90	[10] HILL	95		

[1] ANTONELLO 13A obtained the limit by assuming $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillation from the $\sim$ 2% of $\overline{\nu}_\mu$ evnets contamination in the CNGS beam.

[2] CHENG 12 is a combined fit of MiniBooNE and SciBooNE antineutrino data.

[3] This value is for a two neutrino oscillation analysis for excess antineutrino events with E_ν > 475 MeV. At 90% CL there is no solution at high $\Delta(m^2)$. The best fit is at

maximal mixing. The allowed region is consistent with LSND reported by AGUILAR 01. Supercedes AGUILAR-AREVALO 09B.

[4] This value is for a two neutrino oscillation analysis for excess antineutrino events with $E_\nu > 200$ MeV with subtraction of the expected 12 events low energy excess seen in the neutrino component of the beam. At 90% CL there is no solution at high $\Delta(m^2)$. The best fit value is 0.007 for $\Delta(m^2) = 4.4$ eV^2.

[5] This result is inconclusive with respect to small amplitude mixing suggested by LSND.

[6] ARMBRUSTER 02 is the final analysis of the KARMEN 2 data. See footnote in the preceding table for further details, and the paper for the exclusion plot.

[7] AGUILAR 01 is the final analysis of the LSND full data set. The deduced oscillation probability is $0.264 \pm 0.067 \pm 0.045$%; the value of $\sin^2 2\theta$ for large $\Delta(m^2)$ is twice this probability (although these values are excluded by other constraints). See footnote in preceding table for further details, and the paper for a plot showing allowed regions. Supersedes ATHANASSOPOULOS 95, ATHANASSOPOULOS 96, and ATHANASSOPOULOS 98.

[8] ATHANASSOPOULOS 96 reports $(0.31 \pm 0.12 \pm 0.05)$% for the oscillation probability; the value of $\sin^2 2\theta$ for large $\Delta(m^2)$ should be twice this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions.

[9] ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 ± 0.4 events. Corresponds to an oscillation probability of $(0.34^{+0.20}_{-0.18} \pm 0.07)$%. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.

[10] HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ and obtains only upper limits.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $\quad (\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_e(\overline{\nu}_e))$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.075	90	BORODOV...	92	CNTR	BNL E776
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.6	90	[1] ROMOSAN	97	CCFR	FNAL

[1] ROMOSAN 97 uses wideband beam with a 0.5 km decay region.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $\quad (\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_e(\overline{\nu}_e))$

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<1.8	90	[1] ROMOSAN	97	CCFR	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3.8	90	[2] MCFARLAND	95	CCFR	FNAL
<3	90	BORODOV...	92	CNTR	BNL E776

[1] ROMOSAN 97 uses wideband beam with a 0.5 km decay region.

[2] MCFARLAND 95 state that "This result is the most stringent to date for $250 < \Delta(m^2) < 450$ eV^2 and also excludes at 90%CL much of the high $\Delta(m^2)$ region favored by the recent LSND observation." See ATHANASSOPOULOS 95 and ATHANASSOPOULOS 96.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $(\overline{\nu}_e \not\rightarrow \overline{\nu}_e)$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.01	90	[1] ACHKAR	95	CNTR	Bugey reactor

[1] ACHKAR 95 bound is for L=15, 40, and 95 m.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ ($\overline{\nu}_e \not\rightarrow \overline{\nu}_e$)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.02	90	[1] ACHKAR	95	CNTR	For $\Delta(m^2) = 0.6$ eV^2

[1] ACHKAR 95 bound is from data for L=15, 40, and 95 m distance from the Bugey reactor.

Sterile neutrino limits from atmospheric neutrino studies

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_\mu \rightarrow \nu_s$)

ν_s means ν_τ or any sterile (noninteracting) ν.

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3000 (or <550)	90	[1] OYAMA	89	KAMI	Water Cherenkov
< 4.2 or $> 54.$	90	BIONTA	88	IMB	Flux has ν_μ, $\overline{\nu}_\mu$, ν_e, and $\overline{\nu}_e$

[1] OYAMA 89 gives a range of limits, depending on assumptions in their analysis. They argue that the region $\Delta(m^2) = (100\text{–}1000) \times 10^{-5}$ eV^2 is not ruled out by any data for large mixing.

Search for $\nu_\mu \rightarrow \nu_s$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AMBROSIO	01	MCRO	matter effects
	[2] FUKUDA	00	SKAM	neutral currents + matter effects

[1] AMBROSIO 01 tested the pure 2-flavor $\nu_\mu \rightarrow \nu_s$ hypothesis using matter effects which change the shape of the zenith-angle distribution of upward through-going muons. With maximum mixing and $\Delta(m^2)$ around 0.0024 eV^2, the $\nu_\mu \rightarrow \nu_s$ oscillation is disfavored with 99% confidence level with respect to the $\nu_\mu \rightarrow \nu_\tau$ hypothesis.

[2] FUKUDA 00 tested the pure 2-flavor $\nu_\mu \rightarrow \nu_s$ hypothesis using three complementary atmospheric-neutrino data samples. With this hypothesis, zenith-angle distributions are expected to show characteristic behavior due to neutral currents and matter effects. In the $\Delta(m^2)$ and $\sin^2 2\theta$ region preferred by the Super-Kamiokande data, the $\nu_\mu \rightarrow \nu_s$ hypothesis is rejected at the 99% confidence level, while the $\nu_\mu \rightarrow \nu_\tau$ hypothesis consistently fits all of the data sample.

CP violating phase

δ, *CP* violating phase

Measurements of δ come from atmospheric and accelarator experiments looking at ν_e appearance. We encode values between 0 and 2π, though it is equivalent to use $-\pi$ to π.

VALUE (rad)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$(0.05$ to $1.2)\pi$	90	[1] ADAMSON	14	MINS	normal mass hierarchy, $\theta_{23} > \pi/4$
$(0$ to $1.5)\pi$, $(1.9$ to $2)\pi$	90	[2] ADAMSON	13A	MINS	normal mass hierarchy, $\theta_{23} > \pi/4$

[1] Based on three-flavor formalism. Likelihood as a function of δ is also shown for the other three combinations of hierarchy and θ_{23} quadrant; all values of δ are allowed at 90% C.L.

[2] Based on ν_e appearance in MINOS and the calculated $\sin^2(2\theta_{23}) = 0.957$, $\theta_{23} > \pi/4$, and normal mass hierarchy. Likelihood as a function of δ is also shown for the other three combinations of hierarchy and θ_{23} quadrant; all values of δ are allowed at 90% C.L.

CPT tests

$\langle \Delta m^2_{21} - \Delta \overline{m}^2_{21} \rangle$

VALUE (10^{-4} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.1	99.7	[1] DEGOUVEA	05	FIT	solar vs. reactor

[1] DEGOUVEA 05 obtained this bound at the 3σ CL from the KamLAND (ARAKI 05) and solar neutrino data.

$\langle \Delta m^2_{32} - \Delta \overline{m}^2_{32} \rangle$

VALUE (10^{-3} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.6^{+2.4}_{-0.8}$	90	[1] ADAMSON	12B	MINS	MINOS atmospheric

[1] The quoted result is the single-parameter 90% C.L. interval determined from the 90% C.L. contour in the (Δm^2, $\Delta \overline{m}^2$) plane, which is obtained by minimizing the four parameter log-likelihood function with respect to the other oscillation parameters.

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