Number of Neutrino Types and Sum of Neutrino Masses

The neutrinos referred to in this section are those of the Standard SU(2)×U(1) Electroweak Model possibly extended to allow nonzero neutrino masses. Light neutrinos are those with $m < m_Z/2$. The limits are on the number of neutrino mass eigenstates, including ν_1, ν_2, and ν_3.

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Number from $e^+ e^-$ Colliders

Number of Light ν Types

Our evaluation uses the invisible and leptonic widths of the Z boson from our combined fit shown in the Particle Listings for the Z Boson, and the Standard Model value Γ_ν/Γ_ℓ = 1.9908 ± 0.0015.

VALUE	*DOCUMENT ID*		*TECN*
2.994±0.012 OUR EVALUATION	Combined fit to all LEP data.		
• • • We do not use the following data for averages, fits, limits, etc. • • •			
3.00 ±0.05	[1] LEP	92	RVUE

[1] Simultaneous fits to all measured cross section data from all four LEP experiments.

Number of Light ν Types from Direct Measurement of Invisible Z Width

In the following, the invisible Z width is obtained from studies of single-photon events from the reaction $e^+ e^- \rightarrow \nu\overline{\nu}\gamma$. All are obtained from LEP runs in the E^{ee}_{cm} range 88–209 GeV.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
2.92±0.06 OUR AVERAGE				
2.98±0.05±0.04	ACHARD	04E	L3	1990-2000 LEP runs
2.86 ± 0.09	HEISTER	03C	ALEP	$\sqrt{s}$=189–209 GeV
2.69±0.13±0.11	ABBIENDI,G	00D	OPAL	1998 LEP run
2.84±0.15±0.14	ABREU	00Z	DLPH	1997–1998 LEP runs
2.89±0.32±0.19	ABREU	97J	DLPH	1993–1994 LEP runs
2.68±0.20±0.20	BUSKULIC	93L	ALEP	1990–1991 LEP runs
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.01±0.08	ACCIARRI	99R	L3	1991–1998 LEP runs
3.1 ±0.6 ±0.1	ADAM	96C	DLPH	$\sqrt{s}$ = 130, 136 GeV

Limits from Astrophysics and Cosmology

Number of Light ν Types

("light" means < about 1 MeV). See also OLIVE 81. For a review of limits based on Nucleosynthesis, Supernovae, and also on terrestial experiments, see DENEGRI 90. Also see "Big-Bang Nucleosynthesis" in this *Review*.

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •			

< 3.3	[2] BARGER	03C	COSM	
$1.4 < N_\nu < 6.8$	[3] CROTTY	03	COSM	
< 3.6	[4] CYBURT	03	COSM	
$1.9 < N_\nu < 7.0$	[5] HANNESTAD	03B	COSM	
$1.9 < N_\nu < 6.6$	[3] PIERPAOLI	03	COSM	
$2 < N_\nu < 4$	LISI	99		BBN
< 4.3	OLIVE	99		BBN
< 4.9	COPI	97		Cosmology
< 3.6	HATA	97B		High D/H quasar abs.
< 4.0	OLIVE	97		BBN; high ^{4}He and ^{7}Li
< 4.7	CARDALL	96B		Cosmology, High D/H quasar abs.
< 3.9	FIELDS	96		Cosmology, BBN; high ^{4}He and ^{7}Li
< 4.5	KERNAN	96		Cosmology, High D/H quasar abs.
< 3.6	OLIVE	95		BBN; ≥ 3 massless ν
< 3.3	WALKER	91		Cosmology
< 3.4	OLIVE	90		Cosmology
< 4	YANG	84		Cosmology
< 4	YANG	79		Cosmology
< 7	STEIGMAN	77		Cosmology
	PEEBLES	71		Cosmology
<16	[6] SHVARTSMAN	69		Cosmology
	HOYLE	64		Cosmology

[2] Limit on the number of neutrino types based on combination of WMAP data and big-bang nucleosynthesis. The limit from WMAP data alone is 8.3. See also KNELLER 01. $N_\nu \geq 3$ is assumed to compute the limit.

[3] 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, and HST data.

[4] Limit on the number of neutrino types based on ^{4}He abundance assuming a baryon density fixed by the WMAP data. Limit relaxes to 5.2 if D/H is used instead of ^{4}He. See also CYBURT 01. $N_\nu \geq 3$ is assumed to compute the limit.

[5] 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, HST data, and SN1a data.

[6] SHVARTSMAN 69 limit inferred from his equations.

Number Coupling with Less Than Full Weak Strength

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
<20	[7] OLIVE	81C	COSM
<20	[7] STEIGMAN	79	COSM

[7] Limit varies with strength of coupling. See also WALKER 91.

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Limit on Total ν MASS, m_{tot}

(Defined in the above note), of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary, we have generalized the results reported so they apply to m_{tot}. For other limits, see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85.

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<$ 0.75	[8] BARGER	04	COSM	
$<$ 1.0	[9] CROTTY	04	COSM	
$<$ 1.0	[10] HANNESTAD	03B	COSM	
$<$ 0.7	[11] SPERGEL	03	COSM	WMAP
$<$ 1.8	[12] ELGAROY	02	ASTR	2dF Galaxy Redshift Survey
$<$ 0.9	[13] LEWIS	02	COSM	
$<$ 4.2	[14] WANG	02	COSM	CMB
$<$ 2.7	[15] FUKUGITA	00	COSM	
$<$ 5.5	[16] CROFT	99	ASTR	Ly α power spec
$<$180	SZALAY	74	COSM	
$<$132	COWSIK	72	COSM	
$<$280	MARX	72	COSM	
$<$400	GERSHTEIN	66	COSM	

[8] Constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the Sloan Digital Sky Survey and the 2dF galaxy redshift survey, WMAP and 27 other CMB experiments and measurements by the HST Key project.

[9] Constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the Sloan Digital Sky Survey, the 2dF galaxy redshift survey, WMAP and ACBAR. The limit is strengthened to 0.6 eV when measurements by the HST Key project and supernovae data are included.

[10] Constrains the fractional contribution of neutrinos to the total matter density in the Universe from WMAP data combined with other CMB measurements, the 2dfGRS data, HST data, and SN1a data.

[11] Constrains the fractional contribution of neutrinos to the total matter density in the Universe from WMAP data combined with other CMB measurements, the 2dfGRS data, and Lyman α data. The limit does not noticeably change if the Lyman α data are not used.

[12] ELGAROY 02 constrains the fractional contribution of neutrinos to the total matter density in the Universe from the power spectrum of fluctuations derived from the 2 Degree Field Galaxy Redshift Survey. Assumes $\Omega_{\text{matter}} < 0.5$ and a spectral index of 1.0. Limit softens to $m_\nu < 2.2$ eV for n=1.0 $\pm$ 0.1.

[13] LEWIS 02 constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the CMB, HST Key project, 2dF galaxy redshift survey, supernovae type Ia, and BBN.

[14] WANG 02 constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the CMB and other cosmological data sets such as galaxy clustering and the Lyman α forest.

[15] FUKUGITA 00 is a limit on neutrino masses from structure formation. The constraint is based on the clustering scale σ_8 and the COBE normalization and leads to a conservative limit of 0.9 eV assuming 3 nearly degenerate neutrinos. The quoted limit is on the sum of the light neutrino masses.

[16] CROFT 99 result based on the power spectrum of the Ly α forest. If $\Omega_{\text{matter}} < 0.5$, the limit is improved to $m_\nu < 2.4$ (Ω_{matter}/0.17–1) eV.

Limits on MASSES of Light Stable Right-Handed ν (with necessarily suppressed interaction strengths)

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<$100–200	[17] OLIVE	82	COSM	Dirac ν
$<$200–2000	[17] OLIVE	82	COSM	Majorana ν

[17] Depending on interaction strength G_R where $G_R < G_F$.

Limits on MASSES of Heavy Stable Right-Handed ν (with necessarily suppressed interaction strengths)

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$>$ 10	[18] OLIVE	82	COSM	G_R/G_F <0.1
$>$100	[18] OLIVE	82	COSM	G_R/G_F <0.01

[18] These results apply to heavy Majorana neutrinos and are summarized by the equation: m_ν >1.2 GeV (G_F/G_R). The bound saturates, and if G_R is too small no mass range is allowed.

REFERENCES FOR Limits on Number of Neutrino Types and Sum of Neutrino Masses

ACHARD	04E	PL B587 16	P. Achard et al.	(L3)
BARGER	04	PL B595 55	V. Barger, D. Marfatia, A. Tregre	
CROTTY	04	PR D69 123007	P. Crotty, J. Lesgourgues, S. Pastor	
BARGER	03C	PL B566 8	V. Barger et al.	
CROTTY	03	PR D67 123005	P. Crotty, J. Lesgourgues, S. Pastor	
CYBURT	03	PL B567 227	R.H. Cyburt, B.D. Fields, K.A. Olive	
HANNESTAD	03B	JCAP 0305 004	S. Hannestad	
HEISTER	03C	EPJ C28 1	A. Heister et al.	(ALEPH Collab.)
PIERPAOLI	03	MNRAS 342 L63	E. Pierpaoli	
SPERGEL	03	APJS 148 175	D.N. Spergel et al.	
ELGAROY	02	PRL 89 061301	O. Elgaroy et al.	
LEWIS	02	PR D66 103511	A. Lewis, S. Bridle	
WANG	02	PR D65 123001	X. Wang, M. Tegmark, M. Zaldarriaga	
CYBURT	01	ASP 17 87	R.H. Cyburt, B.D. Fields, K.A. Olive	
KNELLER	01	PR D64 123506	J.P. Kneller et al.	
ABBIENDI,G	00D	EPJ C18 253	G. Abbiendi et al.	(OPAL Collab.)
ABREU	00Z	EPJ C17 53	P. Abreu et al.	(DELPHI Collab.)
FUKUGITA	00	PRL 84 1082	M. Fukugita, G.C. Liu, N. Sugiyama	
ACCIARRI	99R	PL B470 268	M. Acciarri et al.	(L3 Collab.)
CROFT	99	PRL 83 1092	R.A.C. Croft, W. Hu, R. Dave	
LISI	99	PR D59 123520	E. Lisi, S. Sarkar, F.L. Villante	
OLIVE	99	ASP 11 403	K.A. Olive, D. Thomas	
ABREU	97J	ZPHY C74 577	P. Abreu et al.	(DELPHI Collab.)
COPI	97	PR D55 3389	C.J. Copi, D.N. Schramm, M.S. Turner	(CHIC)
HATA	97B	PR D55 540	N. Hata et al.	(OSU, PENN)
OLIVE	97	ASP 7 27	K.A. Olive, D. Thomas	(MINN, FLOR)
ADAM	96C	PL B380 471	W. Adam et al.	(DELPHI Collab.)
CARDALL	96B	APJ 472 435	C.Y. Cardall, G.M. Fuller	(UCSD)
FIELDS	96	New Ast 1 77	B.D. Fields et al.	(NDAM, CERN, MINN+)
KERNAN	96	PR D54 3681	P.S. Kernan, S. Sarkar	(CASE, OXFTP)
OLIVE	95	PL B354 357	K.A. Olive, G. Steigman	(MINN, OSU)
BUSKULIC	93L	PL B313 520	D. Buskulic et al.	(ALEPH Collab.)
LEP	92	PL B276 247	LEP Collabs.	(LEP, ALEPH, DELPHI, L3, OPAL)
WALKER	91	APJ 376 51	T.P. Walker et al.	(HSCA, OSU, CHIC+)
DENEGRI	90	RMP 62 1	D. Denegri, B. Sadoulet, M. Spiro	(CERN, UCB+)
OLIVE	90	PL B236 454	K.A. Olive et al.	(MINN, CHIC, OSU+)
COWSIK	85	PL 151B 62	R. Cowsik	(TATA)
FREESE	84	NP B233 167	K. Freese, D.N. Schramm	(CHIC, FNAL)
SCHRAMM	84	PL 141B 337	D.N. Schramm, G. Steigman	(FNAL, BART)
YANG	84	APJ 281 493	J. Yang et al.	(CHIC, BART)
OLIVE	82	PR D25 213	K.A. Olive, M.S. Turner	(CHIC, UCSB)
BERNSTEIN	81	PL 101B 39	J. Bernstein, G. Feinberg	(STEV, COLU)
OLIVE	81	APJ 246 557	K.A. Olive et al.	(CHIC, BART)
OLIVE	81C	NP B180 497	K.A. Olive, D.N. Schramm, G. Steigman	(EFI+)
STEIGMAN	79	PRL 43 239	G. Steigman, K.A. Olive, D.N. Schramm	(BART+)
YANG	79	APJ 227 697	J. Yang et al.	(CHIC, YALE, VIRG)
STEIGMAN	77	PL 66B 202	G. Steigman, D.N. Schramm, J.E. Gunn	(YALE, CHIC+)
VYSOTSKY	77	JETPL 26 188	M.I. Vysotsky, A.D. Dolgov, Y.B. Zeldovich	(ITEP)
		Translated from ZETFP 26 200.		

SZALAY	76	AA 49 437	A.S. Szalay, G. Marx	(EOTV)
SZALAY	74	APAH 35 8	A.S. Szalay, G. Marx	(EOTV)
COWSIK	72	PRL 29 669	R. Cowsik, J. McClelland	(UCB)
MARX	72	Nu Conf. Budapest	G. Marx, A.S. Szalay	(EOTV)
PEEBLES	71	Physical Cosmology	P.Z. Peebles	(PRIN)
Princeton Univ. Press (1971)				
SHVARTSMAN	69	JETPL 9 184	V.F. Shvartsman	(MOSU)
		Translated from ZETFP 9 315.		
GERSHTEIN	66	JETPL 4 120	S.S. Gershtein, Y.B. Zeldovich	(KIAM)
		Translated from ZETFP 4 189.		
HOYLE	64	NAT 203 1108	F. Hoyle, R.J. Tayler	(CAMB)