Number of Neutrino Types

NODE=S007
NODE=S007

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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NODE=S007

Number from $e^+ e^-$ Colliders

NODE=S007210

Number of Light ν Types

NODE=S007NE
NODE=S007NE

VALUE	DOCUMENT ID		TECN
2.9840±0.0082	[1] LEP-SLC	06	RVUE
• • • We do not use the following data for averages, fits, limits, etc. • • •			
3.00 ±0.05	[2] LEP	92	RVUE

[1] Combined fit from ALEPH, DELPHI, L3 and OPAL Experiments.
[2] Simultaneous fits to all measured cross section data from all four LEP experiments.

NODE=S007NE;LINKAGE=AL
NODE=S007NE;LINKAGE=R

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

NODE=S007NI
NODE=S007NI

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.

NODE=S007NI

VALUE	DOCUMENT ID		TECN	COMMENT
2.92±0.05 OUR AVERAGE Error includes scale factor of 1.2.				
2.84±0.10±0.14	ABDALLAH	05B	DLPH	$\sqrt{s}$ = 180–209 GeV
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
2.89±0.32±0.19	ABREU	97J	DLPH	1993–1994 LEP runs
3.23±0.16±0.10	AKERS	95C	OPAL	1990–1992 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. • • •				
2.84±0.15±0.14	ABREU	00Z	DLPH	1997–1998 LEP runs
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

NODE=S007215

Number of Light ν Types

NODE=S007N
NODE=S007N

("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*.

NODE=S007N

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.9 < N_\nu < 8.2$		[3] ICHIKAWA	07	COSM	
$3 < N_\nu < 7$	95	[4] CIRELLI	06	COSM	
$2.7 < N_\nu < 4.6$	95	[5] HANNESTAD	06	COSM	
$3.6 < N_\nu < 7.4$	95	[4] SELJAK	06	COSM	
< 4.4		[6] CYBURT	05	COSM	
< 3.3		[7] BARGER	03C	COSM	
$1.4 < N_\nu < 6.8$		[8] CROTTY	03	COSM	
$1.9 < N_\nu < 6.6$		[8] 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	COSM	High D/H quasar abs.
< 3.9		FIELDS	96	COSM	BBN; high ^{4}He and ^{7}Li
< 4.5		KERNAN	96	COSM	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		[9] SHVARTSMAN	69		Cosmology
		HOYLE	64		Cosmology

[3] Constrains the number of neutrino types from recent CMB and large scale structure data. No priors on other cosmological parameters are used.
NODE=S007N;LINKAGE=IC

[4] Constrains the number of neutrino types from recent CMB, large scale structure, Lyman-alpha forest, and SN1a data. The slight preference for $N_\nu > 3$ comes mostly from the Lyman-alpha forest data.
NODE=S007N;LINKAGE=CI

[5] Constrains the number of neutrino types from recent CMB and large scale structure data. See also HAMANN 07.
NODE=S007N;LINKAGE=HN

[6] Limit on the number of neutrino types based on ^{4}He and D/H abundance assuming a baryon density fixed to the WMAP data. Limit relaxes to 4.6 if D/H is not used or to 5.8 if only D/H and the CMB are used. See also CYBURT 01 and CYBURT 03.
NODE=S007N;LINKAGE=CB

[7] 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.
NODE=S007N;LINKAGE=GC

[8] 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, and HST data.
NODE=S007N;LINKAGE=PH

[9] SHVARTSMAN 69 limit inferred from his equations.
NODE=S007N;LINKAGE=Q

Number Coupling with Less Than Full Weak Strength

NODE=S007NSW
NODE=S007NSW

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
<20	[10] OLIVE	81C	COSM
<20	[10] STEIGMAN	79	COSM

[10] Limit varies with strength of coupling. See also WALKER 91.
NODE=S007NSW;LINKAGE=A

REFERENCES FOR Limits on Number of Neutrino Types

NODE=S007

HAMANN	07	JCAP 0708 021	J. Hamann *et al.*		REFID=52140
ICHIKAWA	07	JCAP 0705 007	K. Ichikawa, M. Kawasaki, F. Takahashi		REFID=52141
CIRELLI	06	JCAP 0612 013	M. Cirelli *et al.*		REFID=51612
HANNESTAD	06	JCAP 0611 016	S. Hannestad, G. Raffelt		REFID=51611
LEP-SLC	06	PRPL 427 257	ALEPH, DELPHI, L3, OPAL, SLD and working groups		REFID=51219;ERROR=1
SELJAK	06	JCAP 0610 014	U. Seljak, A. Slosar, P. McDonald		REFID=51613
ABDALLAH	05B	EPJ C38 395	J. Abdallah *et al.*	(DELPHI Collab.)	REFID=50448
CYBURT	05	ASP 23 313	R.H. Cyburt *et al.*		REFID=50710
ACHARD	04E	PL B587 16	P. Achard *et al.*	(L3 Collab.)	REFID=49893
BARGER	03C	PL B566 8	V. Barger *et al.*		REFID=49488
CROTTY	03	PR D67 123005	P. Crotty, J. Lesgourgues, S. Pastor		REFID=49633
CYBURT	03	PL B567 227	R.H. Cyburt, B.D. Fields, K.A. Olive		REFID=49630
HEISTER	03C	EPJ C28 1	A. Heister *et al.*	(ALEPH Collab.)	REFID=49379
PIERPAOLI	03	MNRAS 342 L63	E. Pierpaoli		REFID=49632
CYBURT	01	ASP 17 87	R.H. Cyburt, B.D. Fields, K.A. Olive		REFID=48573
KNELLER	01	PR D64 123506	J.P. Kneller *et al.*		REFID=48430
ABBIENDI,G	00D	EPJ C18 253	G. Abbiendi *et al.*	(OPAL Collab.)	REFID=48020
ABREU	00Z	EPJ C17 53	P. Abreu *et al.*	(DELPHI Collab.)	REFID=47790
ACCIARRI	99R	PL B470 268	M. Acciarri *et al.*	(L3 Collab.)	REFID=47322
LISI	99	PR D59 123520	E. Lisi, S. Sarkar, F.L. Villante		REFID=47027
OLIVE	99	ASP 11 403	K.A. Olive, D. Thomas		REFID=47497
ABREU	97J	ZPHY C74 577	P. Abreu *et al.*	(DELPHI Collab.)	REFID=45491
COPI	97	PR D55 3389	C.J. Copi, D.N. Schramm, M.S. Turner	(CHIC)	REFID=45338
HATA	97B	PR D55 540	N. Hata *et al.*	(OSU, PENN)	REFID=45960
OLIVE	97	ASP 7 27	K.A. Olive, D. Thomas	(MINN, FLOR)	REFID=45963
ADAM	96C	PL B380 471	W. Adam *et al.*	(DELPHI Collab.)	REFID=44847
CARDALL	96B	APJ 472 435	C.Y. Cardall, G.M. Fuller	(UCSD)	REFID=45961
FIELDS	96	New Ast 1 77	B.D. Fields *et al.*	(NDAM, CERN, MINN+)	REFID=45962
KERNAN	96	PR D54 3681	P.S. Kernan, S. Sarkar	(CASE, OXFTP)	REFID=45959
AKERS	95C	ZPHY C65 47	R. Akers *et al.*	(OPAL Collab.)	REFID=44157
OLIVE	95	PL B354 357	K.A. Olive, G. Steigman	(MINN, OSU)	REFID=44357
BUSKULIC	93L	PL B313 520	D. Buskulic *et al.*	(ALEPH Collab.)	REFID=43524
LEP	92	PL B276 247	LEP Collabs.	(LEP, ALEPH, DELPHI, L3, OPAL)	REFID=41869
WALKER	91	APJ 376 51	T.P. Walker *et al.*	(HSCA, OSU, CHIC+)	REFID=41879
DENEGRI	90	RMP 62 1	D. Denegri, B. Sadoulet, M. Spiro	(CERN, UCB+)	REFID=41154
OLIVE	90	PL B236 454	K.A. Olive *et al.*	(MINN, CHIC, OSU+)	REFID=41145
YANG	84	APJ 281 493	J. Yang *et al.*	(CHIC, BART)	REFID=10534
OLIVE	81	APJ 246 557	K.A. Olive *et al.*	(CHIC, BART)	REFID=10512
OLIVE	81C	NP B180 497	K.A. Olive, D.N. Schramm, G. Steigman	(EFI+)	REFID=10514
STEIGMAN	79	PRL 43 239	G. Steigman, K.A. Olive, D.N. Schramm	(BART+)	REFID=10497
YANG	79	APJ 227 697	J. Yang *et al.*	(CHIC, YALE, VIRG)	REFID=10499
STEIGMAN	77	PL 66B 202	G. Steigman, D.N. Schramm, J.E. Gunn	(YALE, CHIC+)	REFID=10486
PEEBLES	71	Physical Cosmology, Princeton Univ. Press (1971)	P.Z. Peebles	(PRIN)	REFID=41893
SHVARTSMAN	69	JETPL 9 184, Translated from ZETFP 9 315.	V.F. Shvartsman	(MOSU)	REFID=10474
HOYLE	64	NAT 203 1108	F. Hoyle, R.J. Tayler	(CAMB)	REFID=41146