Number of Light Neutrino Types

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 $m_\nu \ll m_{Z^0}$. The limits are on the number of neutrino families or species, including ν_e, ν_μ, ν_τ

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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 Full Listings for the Z Boson, and the Standard Model value Γ_ν/Γ_ℓ = 1.992 ± 0.003.

VALUE	DOCUMENT ID		TECN	COMMENT
2.983±0.025 OUR EVALUATION Combined fit to all Z data.				
2.994±0.023 OUR AVERAGE Error includes scale factor of 1.1.				
3.057±0.040	[1,2] ABREU	94	DLPH	1990–1992 LEP runs
2.981±0.050	[1,2] ACCIARRI	94	L3	1990–1992 LEP runs
2.946±0.045	[1,2] AKERS	94	OPAL	1989–1992 LEP runs
2.983±0.034	[1,2] BUSKULIC	94	ALEP	1989–1992 LEP runs
2.8 ±0.6	[3] ABRAMS	89B	MRK2	E^{ee}_{cm}= 91 GeV at SLC
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.97 ±0.05	BUSKULIC	93J	ALEP	Repl. by BUSKULIC 94
2.97 ±0.07	[1] DECAMP	92B	ALEP	Repl. by BUSKULIC 93J
3.00 ±0.05	[4] LEP	92	RVUE	
2.93 ±0.04 ±0.07	[1] ABREU	91F	DLPH	Repl. by ABREU 94
3.05 ±0.10	[1] ADEVA	91E	L3	Repl. by ACCIARRI 94
3.05 ±0.09 ±0.005	[1,5] ALEXANDER	91F	OPAL	Repl. by AKERS 94
3.12 ±0.24 ±0.25	AARNIO	90	DLPH	
2.97 ±0.26	[3] ABREU	90	DLPH	
3.23 ±0.29	[6] ADEVA	90D	L3	
3.01 ±0.11	ADEVA	90I	L3	
3.3 ±0.7	[6] AKRAWY	90	OPAL	
2.73 ±0.26 $^{+0.02}_{-0.04}$	[6,7] AKRAWY	90E	OPAL	
3.09 ±0.19 $^{+0.06}_{-0.12}$	[3,7] AKRAWY	90E	OPAL	
3.35 ±0.41	[6] DECAMP	90B	ALEP	
3.01 ±0.15 ±0.05	[3,7] DECAMP	90D	ALEP	
2.91 ±0.13	DECAMP	90P	ALEP	
2.4 ±0.4 ±0.5	[3] AARNIO	89	DLPH	

[1] Simultaneous fits to all measured Z data.
[2] Analysis based on $\geq$ 1.1 million visible Z decays from LEP runs through 1992.
[3] These papers assume standard model couplings.
[4] Simultaneous fits to all measured cross section data from all four LEP experiments.
[5] Second error is from uncertainty in top and Higgs mass.
[6] These papers measure leptonic widths and are more model independent. However, they divide the measured invisible width via the Standard Model width for neutrinos. Such results are less precise, as discussed in the minireview.
[7] The second error is due to theoretical uncertainties.

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 $Z \rightarrow \nu\overline{\nu}\gamma$. All are obtained from LEP runs in the E^{ee}_{cm} range 88–94 GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
2.97±0.17 OUR AVERAGE				
2.68±0.20±0.20	BUSKULIC	93L	ALEP	1990–1991 LEP runs
3.24±0.46±0.22	ADEVA	92	L3	1990 LEP run
3.14±0.24±0.12	ADRIANI	92E	L3	1991 LEP run
3.0 ±0.4 ±0.2	AKRAWY	91D	OPAL	

*CITATION: L. Montanet et al., Physical Review D50, 1173 (1994) and 1995 off-year partial update for the 1996 edition (URL: http://pdg.lbl.gov/)

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.

VALUE	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
< 3.04	KERNAN	94	COSM
< 3.3	WALKER	91	COSM
< 3.4	OLIVE	90	COSM
< 5.2	ELLIS	86	COSM
< 4	STEIGMAN	86	COSM
< 4	YANG	84	COSM
< 4	YANG	79	COSM
< 7	STEIGMAN	77	COSM
	PEEBLES	71	COSM
<16	[8] SHVARTSMAN	69	COSM
	HOYLE	64	COSM

[8] 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	[9] OLIVE	81C	COSM
<20	[9] STEIGMAN	79	COSM

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

REFERENCES FOR Limits on Number of Light Neutrino Types

ABREU	94	NP B418 403	+Adam, Adye, Agasi+	(DELPHI Collab.)
ACCIARRI	94	ZPHY C62 551	+Adam, Adriani, Aguilar-Benitez+	(L3 Collab.)
AKERS	94	ZPHY C61 19	+Alexander, Allison+	(OPAL Collab.)
BUSKULIC	94	ZPHY C62 539	+Casper, De Bonis, Decamp, Ghez, Goy+	(ALEPH Collab.)
KERNAN	94	PRL 72 3309	+Krauss	(CASE)
BUSKULIC	93J	ZPHY C60 71	+Decamp, Goy, Lees, Minard+	(ALEPH Collab.)
BUSKULIC	93L	PL B313 520	+De Bonis, Decamp+	(ALEPH Collab.)
ADEVA	92	PL B275 209	+Adriani, Aguilar-Benitez+	(L3 Collab.)
ADRIANI	92E	PL B292 463	+Aguilar-Benitez, Ahlen, Akbari, Alcaraz+	(L3 Collab.)
DECAMP	92B	ZPHY C53 1	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
LEP	92	PL B276 247	+ALEPH, DELPHI, L3, OPAL	(LEP Collabs.)
ABREU	91F	NP B367 511	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
ADEVA	91E	ZPHY C51 179	+Adriani, Aguilar-Benitez, Akbari, Alcaraz+	(L3 Collab.)
AKRAWY	91D	ZPHY C50 373	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
ALEXANDER	91F	ZPHY C52 175	+Allison, Allport, Anderson, Arcelli+	(OPAL Collab.)
WALKER	91	APJ 376 51	+Steigman, Schramm, Olive+	(HSCA, OSU, CHIC, MINN)
AARNIO	90	PL B241 425	+Abreu, Adam, Adami+	(DELPHI Collab.)
ABREU	90	PL B241 435	+Adam, Adami+	(DELPHI Collab.)
ADEVA	90D	PL B238 122	+Adriani, Aguilar-Benitez, Akbari+	(L3 Collab.)
ADEVA	90I	PL B249 341	+Adriani, Aguilar-Benitez, Akbari, Alcarez+	(L3 Collab.)
AKRAWY	90	PL B235 379	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
AKRAWY	90E	PL B240 497	+Alexander, Allison, Allport+	(OPAL Collab.)
DECAMP	90B	PL B234 399	+Deschizeaux, Lees, Minard, Crespo+	(ALEPH Collab.)
DECAMP	90D	PL B235 399	+Deschizeaux, Lees, Minard, Crespo+	(ALEPH Collab.)
DECAMP	90P	ZPHY C48 365	+Deschizeaux, Goy, Lees+	(ALEPH Collab.)
DENEGRI	90	RMP 62 1	+Sadoulet, Spiro	(CERN, UCB, SACL)
OLIVE	90	PL B236 454	+Schramm, Steigman, Walker	(MINN, CHIC, OSU, HARV)
AARNIO	89	PL B231 539	+Abreu, Adam, Adrianos, Adye+	(DELPHI Collab.)
ABRAMS	89B	PRL 63 2173	+Adolphsen, Averill, Ballam, Barish+	(Mark II Collab.)
ELLIS	86	PL 167B 457	+Enqvist, Nanopoulos, Sarkar	(CERN, OXFTP)
STEIGMAN	86	PL B176 33	+Olive, Schramm, Turner	(BART, MINN+)
YANG	84	APJ 281 493	+Turner, Steigman, Schramm, Olive	(CHIC, BART)
OLIVE	81	APJ 246 557	+Schramm, Steigman, Turner, Yang+	(CHIC, BART)
OLIVE	81C	NP B180 497	+Schramm, Steigman	(EFI, BART)
STEIGMAN	79	PRL 43 239	+Olive, Schramm	(BART, EFI)
YANG	79	APJ 227 697	+Schramm, Steigman, Rood	(CHIC, YALE, VIRG)
STEIGMAN	77	PL 66B 202	+Schramm, Gunn	(YALE, CHIC, CIT)
PEEBLES	71	Physical Cosmology Princeton Univ. Press (1971)		(PRIN)
SHVARTSMAN	69	JETPL 9 184 Translated from ZETFP 9 315.		(MOSU)
HOYLE	64	Nature 203 1108	+Tayler	(CAMB)