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 $m_\nu < m_Z/2$. The limits are on the number of neutrino families or species, including ν_e, ν_μ, ν_τ

THE NUMBER OF LIGHT NEUTRINO TYPES FROM COLLIDER EXPERIMENTS

Revised April 1998 by D. Karlen (Carleton University).

The most precise measurements of the number of light neutrino types, N_ν, come from studies of Z production in e^+e^- collisions. At the time of this report, the most recent (preliminary) combined analysis of the four LEP experiments [1] included over 16 million visible Z decays. The invisible partial width, $\Gamma_{\rm inv}$, is determined from these data by subtracting the measured visible partial widths, corresponding to Z decays into quarks and charged leptons, from the total Z width. The invisible width is assumed to be due to N_ν light neutrino species each contributing the neutrino partial width Γ_ν as given by the Standard Model. In order to reduce the model dependence, the Standard Model value for the ratio of the neutrino to charged leptonic partial widths, $(\Gamma_\nu/\Gamma_\ell)_{\rm SM} = 1.991 \pm 0.001$, is used instead of $(\Gamma_\nu)_{\rm SM}$ to determine the number of light neutrino types:

$$N_\nu = \frac{\Gamma_{\rm inv}}{\Gamma_\ell}\left(\frac{\Gamma_\ell}{\Gamma_\nu}\right)_{\rm SM}$$

The combined LEP result is $N_\nu = 2.993 \pm 0.011$.

In the past, when only small samples of Z decays had been recorded by the LEP experiments and by the Mark II at SLC, the uncertainty in N_ν was reduced by using Standard Model fits to the measured hadronic cross sections at several center-of-mass energies near the Z resonance. Since this method is much more dependent on the Standard Model, the approach described above is favored.

Before the advent of the SLC and LEP, limits on the number of neutrino generations were placed by experiments at lower-energy e^+e^- colliders by measuring the cross section of the process $e^+e^- \to \nu\overline{\nu}\gamma$. The ASP, CELLO, MAC, MARK J, and VENUS experiments observed a total of 3.9 events above background [2], leading to a 95% CL limit of $N_\nu < 4.8$. This process has a much larger cross section at center-of-mass energies near the Z mass and has been measured at LEP by the ALEPH, DELPHI, L3, and OPAL experiments [3]. These experiments have observed several thousand such events, and the combined result is $N_\nu = 3.00 \pm 0.09$.

Experiments at $p\overline{p}$ colliders also placed limits on N_ν by determining the total Z width from the observed ratio of $W^\pm \to \ell^\pm\nu$ to $Z \to \ell^+\ell^-$ events [4]. This involved a calculation that assumed Standard Model values for the total W width and the ratio of W and Z leptonic partial widths, and used an estimate of the ratio of Z to W production cross sections. Now that the Z width is very precisely known from the LEP experiments, the approach is now one of those used to determine the W width.

References

1. The LEP Collaborations, the LEP Electroweak Working Group, and the SLD Heavy Flavor Group, CERN/PPE/97-154. (Based upon published and preliminary electroweak results).
2. VENUS: K. Abe *et al.*, Phys. Lett. **B232**, 431 (1989);
ASP: C. Hearty *et al.*, Phys. Rev. **D39**, 3207 (1989);
CELLO: H.J. Behrend *et al.*, Phys. Lett. **B215**, 186 (1988);
MAC: W.T. Ford *et al.*, Phys. Rev. **D33**, 3472 (1986);
MARK J: H. Wu, Ph.D. Thesis, Univ. Hamburg (1986).

3. L3: M. Acciarri *et al.*, CERN/PPE/98-25 (submitted to Phys. Lett. B);
   DELPHI: P. Abreu *et al.*, Z. Phys. **C74**, 577 (1997);
   OPAL: R. Akers *et al.*, Z. Phys. **C65**, 47 (1995);
   ALEPH: D. Buskulic *et al.*, Phys. Lett. **B313**, 520 (1993).
4. UA1: C. Albajar *et al.*, Phys. Lett. **B198**, 271 (1987);
   UA2: R. Ansari *et al.*, Phys. Lett. **B186**, 440 (1987).

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 88–94 GeV.

VALUE	DOCUMENT ID		TECN	COMMENT
3.07±0.12 OUR AVERAGE				
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
3.24±0.46±0.22	ADEVA	92	L3	1990 LEP run
3.14±0.24±0.12	ADRIANI	92E	L3	1991 LEP run
• • • We do not use the following data for averages, fits, limits, etc. • • •				
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
• • • We do not use the following data for averages, fits, limits, etc. • • •			
< 4.9	COPI	97	COSM
< 3.6	[2] HATA	97B	COSM
< 4.0	[3] OLIVE	97	COSM
< 4.7	[2] CARDALL	96B	COSM
< 3.9	[3] FIELDS	96	COSM

< 4.5	[2] KERNAN	96	COSM
< 3.6	[4] OLIVE	95	COSM
< 3.3	WALKER	91	COSM
< 3.4	OLIVE	90	COSM
< 4	YANG	84	COSM
< 4	YANG	79	COSM
< 7	STEIGMAN	77	COSM
	PEEBLES	71	COSM
<16	[5] SHVARTSMAN	69	COSM
	HOYLE	64	COSM

[2] Limit based on high D/H from quasar absorption systems.
[3] Limit based on high ^{4}He and ^{7}Li.
[4] OLIVE 95 limit assumes the existence of at least three (massless) neutrinos.
[5] 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	[6] OLIVE	81C	COSM
<20	[6] STEIGMAN	79	COSM

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

REFERENCES FOR Limits on Number of Light Neutrino Types

ABREU	97J	ZPHY C74 577	P. Abreu+	(DELPHI Collab.)
COPI	97	PR D55 3389	C.J. Copi, D.N. Schramm, M.S. Turner	(CHIC)
HATA	97B	PR D55 540	N. Hata, G. Steigman, S. Bludman+	(OSU, PENN)
OLIVE	97	ASP 7 27	+Thomas	(MINN, FLOR)
ADAM	96C	PL B380 471	+Adye, Agasi, Ajinenko, Aleksan+	(DELPHI Collab.)
CARDALL	96B	APJ 472 435	+Fuller	(UCSD)
FIELDS	96	New Ast 1 77	+Kainulainen, Olive+	(NDAM, CERN, MINN, FLOR)
KERNAN	96	PR D54 3681	P.S. Kernan, S. Sarkar	(CASE, OXFTP)
AKERS	95C	ZPHY C65 47	+Alexander, Allison+	(OPAL Collab.)
OLIVE	95	PL B354 357	+Steigman	(MINN, OSU)
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.)
LEP	92	PL B276 247	+ALEPH, DELPHI, L3, OPAL	(LEP Collabs.)
WALKER	91	APJ 376 51	+Steigman, Schramm, Olive+	(HSCA, OSU, CHIC, MINN)
DENEGRI	90	RMP 62 1	+Sadoulet, Spiro	(CERN, UCB, SACL)
OLIVE	90	PL B236 454	+Schramm, Steigman, Walker	(MINN, CHIC, OSU, HARV)
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		(PRIN)
Princeton Univ. Press (1971)				
SHVARTSMAN	69	JETPL 9 184		(MOSU)
		Translated from ZETFP 9 315.		
HOYLE	64	Nature 203 1108	+Tayler	(CAMB)