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 August 1999 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. The invisible partial width, $\Gamma_{\rm inv}$, is determined 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:

$$N_{\nu} = \frac{\Gamma_{\rm inv}}{\Gamma_{\ell}} \left(\frac{\Gamma_{\ell}}{\Gamma_{\nu}}\right)_{\rm SM} . \tag{1}$$

Created: 12/18/2000 15:05

The combined result from the four LEP experiments is $N_{\nu} = 2.984 \pm 0.008$ [1].

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 centerof-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 $e^+e^- \to \nu \bar{\nu} \gamma$. 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 $N_{\nu} = 3.00 \pm 0.08$. The same process has been measured by the LEP experiments at center-of-mass energies approaching 100 GeV above the Z mass, in searches for new physics. Combined, the measured cross section is 0.965 \pm 0.028 of that expected for 3 light neutrino generations [1].

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 and the LEP Electroweak Working Group, as reported by J. Mnich at the International Europhysics Conference, Tampere, Finland (July 1999).
- 2. VENUS: K. Abe et al., Phys. Lett. **B232**, 431 (1989);

Created: 12/18/2000 15:05

- 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).
- L3: M. Acciarri et al., Phys. Lett. B431, 199 (1998);
 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).
- 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 $\Gamma_{\nu}/\Gamma_{\ell}=1.9908\pm0.0015$.

<u>VALUE</u>
2.994±0.012 OUR EVALUATION

• • • We do not use the following data for averages, fits, limits, etc. • • • 0.05DOCUMENT ID
Combined fit to all LEP data.

• • • We do not use the following data for averages, fits, limits, etc. • • • 0.05

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 $e^+e^- \to \nu \overline{\nu} \gamma$. All are obtained from LEP runs in the $E^{ee}_{\rm CM}$ range 88–94 GeV.

VALUE	DOCUMENT ID	TECN	COMMENT
3.00±0.06 OUR AVERAGE			
3.01 ± 0.08	ACCIARRI	99R L3	1998 LEP run
$2.98 \pm 0.07 \pm 0.07$	ACCIARRI	98G L3	LEP 1991-1994
$2.89 \pm 0.32 \pm 0.19$	ABREU	97」DLPH	1993-1994 LEP runs
$3.23 \pm 0.16 \pm 0.10$	AKERS	95c OPAL	1990-1992 LEP runs
$2.68 \pm 0.20 \pm 0.20$	BUSKULIC	93L ALEP	1990-1991 LEP runs
• • • We do not use the following	data for averages	s, fits, limits,	etc. • • •
$3.1 \pm 0.6 \pm 0.1$	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*.

Also see Big-Bailg Nucleosynthesis in this Review.

VALUE

DOCUMENT ID

COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • • • $2 < N_{\nu} < 4$ LISI

99

BBN

HTTP://PDG.LBL.GOV Page 3 Created: 12/18/2000 15:05

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

< 4.3	OLIVE	99	BBN
< 4.9	COPI	97	Cosmology
< 3.6	HATA		High D/H quasar abs.
< 4.0	OLIVE	97	BBN; high ⁴ He and ⁷ Li
< 4.7	CARDALL	96 B	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; \geq 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	² SHVARTSMAN	۱69	Cosmology
	HOYLE	64	Cosmology

 $^{^2\,\}mbox{SHVARTSMAN}$ 69 limit inferred from his equations.

Number Coupling with Less Than Full Weak Strength

VALUE	DOCUMENT ID		<u>TECN</u>	
• • • We do not use the following	data for averages	, fits,	, limits, etc. • • •	
<20	³ OLIVE	81 C	COSM	
<20	³ STEIGMAN	79	COSM	
³ Limit varies with strength of co	oupling. See also \	NALŁ	KER 91.	

REFERENCES FOR Limits on Number of Light Neutrino Types

ACCIARRI	99R	PL B470 268	M. Acciarri et al.	(L3 Collab.)
LISI	99	PR D59 123520	E. Lisi, S. Sarkar, F.L. Villante	
OLIVE	99	ASP 11 403	K.A. Olive, D. Thomas	
ACCIARRI	98G	PL B431 199	M. Acciarri <i>et al.</i>	(L3 Collab.)
ABREU	97J	ZPHY C74 577	P. Abreu <i>et al.</i>	(DELPHI Collab.)
COPI	97	PR D55 3389	C.J. Copi, D.N. Schramm, M.S. Turner	(CHIC)
HATA	97B	PR D55 540	N. Hata <i>et al.</i>	(OSU, PENN)
OLIVE	97	ASP 7 27	K.A. Olive, D. Thomas	(MINN, FLOR)
ADAM	96C	PL B380 471	W. Adam <i>et al.</i>	(DELPHI Collab.)
CARDALL	96B	APJ 472 435	C.Y. Cardall, G.M. Fuller	(UCSD)
FIELDS	96	New Ast 1 77	B.D. Fields <i>et al.</i> (NDAN	$M,\;CERN,\;MINN+)$
KERNAN	96	PR D54 3681	P.S. Kernan, S. Sarkar	(CASE, OXFTP)
AKERS	95C	ZPHY C65 47	R. Akers <i>et al.</i>	(OPAL Collab.)
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, D	ELPHI, L3, OPAL)
WALKER	91	APJ 376 51		SCA, OSU , $CHIC+$)
DENEGRI	90	RMP 62 1	D. Denegri, B. Sadoulet, M. Spiro	
OLIVE	90	PL B236 454	K.A. Olive <i>et al.</i> (MI	INN, CHIC, OSU+)
YANG	84	APJ 281 493	J. Yang <i>et al.</i>	(CHIC, BART)
OLIVE	81	APJ 246 557	K.A. Olive <i>et al.</i>	(CHIC, BART)
OLIVE	81C	NP B180 497	K.A. Olive, D.N. Schramm, G. Steigma	
STEIGMAN	79	PRL 43 239	G. Steigman, K.A. Olive, D.N. Schrami	$m \qquad (BART+)$
YANG	79	APJ 227 697	J. Yang et al. (C	
STEIGMAN	77	PL 66B 202	G. Steigman, D.N. Schramm, J.R. Gun	n (YALE, CHIC+)
PEEBLES	71	Physical Cosmology	P.Z. Peebles	(PRIN)
		Press (1971)		
SHVARTSMAN	1 69	JETPL 9 184	V.F. Shvartsman	(MOSU)
HOYLE	64	Translated from ZETFP Nature 203 1108	F. Hoyle, R.J. Tayler	(CAMB)

Created: 12/18/2000 15:05