# 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 $\nu_e$, $\nu_\mu$, $\nu_\tau$

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## Number from $e^+ e^-$ Colliders

### Number of Light $\nu$ 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 $\Gamma_\nu/\Gamma_\ell = 1.9908 \pm 0.0015$.

| 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 $\nu$ 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 |
|---|---|---|---|
| **3.00±0.08 OUR AVERAGE** | | | |
| 2.98±0.07±0.07 | ACCIARRI 98G | L3 | LEP 1991–1994 |
| 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. • • • | | | |
| 3.1 ±0.6 ±0.1 | ADAM 96C | DLPH | $\sqrt{s}$ = 130, 136 GeV |

## Limits from Astrophysics and Cosmology

### Number of Light $\nu$ 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


| | | | | |
|---|---|---|---|---|
| ACCIARRI | 98G | PL B431 199 | M. Acciarri+ | (L3 Collab.) |
| 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.) |
| 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) |