

Number of Light Neutrino Types

The neutrinos referred to in this section are those of the Standard $SU(2) \times U(1)$ 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, Γ_{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, $(\Gamma_\nu/\Gamma_\ell)_{\text{SM}} = 1.991 \pm 0.001$, is used instead of $(\Gamma_\nu)_{\text{SM}}$ to determine the number of light neutrino types:

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

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 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 $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. 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 ± 0.028 of that expected for 3 light neutrino generations [1].

Experiments at $p\bar{p}$ colliders also placed limits on N_ν by determining the total Z width from the observed ratio of $W^\pm \rightarrow \ell^\pm\nu$ to $Z \rightarrow \ell^+\ell^-$ 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

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Number from e^+e^- Colliders

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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 $\Gamma_\nu/\Gamma_\ell = 1.9908 \pm 0.0015$.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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
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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 $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. All are obtained from LEP runs in the E_{cm}^{ee} range 88–94 GeV.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
3.00±0.06 OUR AVERAGE			
3.01±0.08	ACCIARRI	99R L3	1998 LEP run
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 ν Types

(“light” means $<$ about 1 MeV). See also OLIVE 81. For a review of limits based on Nucleosynthesis, Supernovae, and also on terrestrial experiments, see DENEGRI 90. Also see “Big-Bang Nucleosynthesis” in this Review.

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>COMMENT</u>
• • • We do not use the following data for averages, fits, limits, etc. • • •		
$2 < N_\nu < 4$	LISI	99 BBN

