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Number of 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 $m < m_Z/2$. The limits are on the number of neutrino mass eigenstates, including ν_1, ν_2, and ν_3.

THE NUMBER OF LIGHT NEUTRINO TYPES FROM COLLIDER EXPERIMENTS

Revised August 2001 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, $(\Gamma_\nu/\Gamma_\ell)_{\rm SM} = 1.991\pm0.001$, is used instead of $(\Gamma_\nu)_{\rm SM}$ to determine the number of light neutrino types:

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

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 $e^+e^- \to \nu\overline{\nu}\gamma$. 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 $N_\nu = 3.00 \pm 0.08$. The same process has also been measured by the LEP experiments at much higher center-of-mass energies, between 130 and 208 GeV, in searches for new physics [4]. Combined, the measured cross section is 0.982 ± 0.012 (stat) of that expected for three light neutrino generations [5].

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 [6]. 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.

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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 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 $E^{ee}_{\rm cm}$ range 88–209 GeV.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
2.93±0.05 OUR AVERAGE	Error includes scale factor of 1.2.			
2.98±0.05±0.04	ACHARD	04E	L3	1990-2000 LEP runs
2.86 ± 0.09	HEISTER	03C	ALEP	$\sqrt{s}$=189–209 GeV
2.69±0.13±0.11	ABBIENDI,G	00D	OPAL	1998 LEP run
2.84±0.15±0.14	ABREU	00Z	DLPH	1997–1998 LEP runs
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. • • •				

3.01±0.08	ACCIARRI	99R L3	1991–1998 LEP runs
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	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 4.4	[2] CYBURT	05	COSM	
< 3.3	[3] BARGER	03C	COSM	
$1.4 < N_\nu < 6.8$	[4] CROTTY	03	COSM	
$1.9 < N_\nu < 7.0$	[5] HANNESTAD	03B	COSM	
$1.9 < N_\nu < 6.6$	[4] PIERPAOLI	03	COSM	
$2 < N_\nu < 4$	LISI	99		BBN
< 4.3	OLIVE	99		BBN
< 4.9	COPI	97		Cosmology
< 3.6	HATA	97B		High D/H quasar abs.
< 4.0	OLIVE	97		BBN; high ^{4}He and ^{7}Li
< 4.7	CARDALL	96B		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; ≥ 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	[6] SHVARTSMAN	69		Cosmology
	HOYLE	64		Cosmology

[2] Limit on the number of neutrino types based on ^{4}He and D/H abundance assuming a baryon density fixed to the WMAP data. Limit relaxes to 4.6 if D/H is not used or to 5.8 if only D/H and the CMB are used. See also CYBURT 01 and CYBURT 03.

[3] Limit on the number of neutrino types based on combination of WMAP data and big-bang nucleosynthesis. The limit from WMAP data alone is 8.3. See also KNELLER 01. $N_\nu \geq 3$ is assumed to compute the limit.

[4] 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, and HST data.

[5] 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, HST data, and SN1a data.

[6] 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	[7] OLIVE	81C	COSM
< 20	[7] STEIGMAN	79	COSM

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

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