Standard Model. The Standard Model value for Γ_ν, however, is uncertain by about 1% due to the unknown top quark mass. In order to reduce this uncertainty, the Standard Model value for the ratio of the neutrino to charged leptonic partial widths, $(\Gamma_\nu/\Gamma_\ell)_{\rm SM} = 1.992 \pm 0.003$, is used instead 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 $N_\nu = 2.985 \pm 0.023 \pm 0.004$, where the first error is the combined statistical and systematic uncertainty and the second is the uncertainty from allowing the top quark mass to vary between 100 and 200 GeV.

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 and the top quark mass, 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 $e^+e^- \rightarrow \nu\overline{\nu}\gamma$. 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 since been measured at LEP by the ALEPH, L3, and OPAL experiments [3], and the combined result is $N_\nu = 2.97 \pm 0.17$.

Experiments at $p\overline{p}$ colliders also placed limits on N_ν by determining the total Z width from the observed ratio of $W^\pm \rightarrow \ell^\pm\nu$ to $Z \rightarrow \ell^+\ell^-$ events [5]. 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 Full Listings for the Z Boson, and the Standard Model value Γ_ν/Γ_ℓ = 1.992 ± 0.003.

VALUE	DOCUMENT ID	TECN	COMMENT
2.983±0.025 OUR EVALUATION	Combined fit to all Z data.		
2.994±0.023 OUR AVERAGE	Error includes scale factor of 1.1.		
3.057±0.040	[1,2] ABREU 94	DLPH	1990–1992 LEP runs
2.981±0.050	[1,2] ACCIARRI 94	L3	1990–1992 LEP runs
2.946±0.045	[1,2] AKERS 94	OPAL	1989–1992 LEP runs
2.983±0.034	[1,2] BUSKULIC 94	ALEP	1989–1992 LEP runs
2.8 ±0.6	[3] ABRAMS 89B	MRK2	$E^{ee}_{\rm cm}$= 91 GeV at SLC
• • • We do not use the following data for averages, fits, limits, etc. • • •			
2.97 ±0.05	BUSKULIC 93J	ALEP	Repl. by BUSKULIC 94
2.97 ±0.07	[1] DECAMP 92B	ALEP	Repl. by BUSKULIC 93J
3.00 ±0.05	[4] LEP 92	RVUE	
2.93 ±0.04 ±0.07	[1] ABREU 91F	DLPH	Repl. by ABREU 94
3.05 ±0.10	[1] ADEVA 91E	L3	Repl. by ACCIARRI 94
3.05 ±0.09 ±0.005	[1,5] ALEXANDER 91F	OPAL	Repl. by AKERS 94
3.12 ±0.24 ±0.25	AARNIO 90	DLPH	
2.97 ±0.26	[3] ABREU 90	DLPH	
3.23 ±0.29	[6] ADEVA 90D	L3	
3.01 ±0.11	ADEVA 90I	L3	
3.3 ±0.7	[6] AKRAWY 90	OPAL	
2.73 ±0.26 $^{+0.02}_{-0.04}$	[6,7] AKRAWY 90E	OPAL	
3.09 ±0.19 $^{+0.06}_{-0.12}$	[3,7] AKRAWY 90E	OPAL	
3.35 ±0.41	[6] DECAMP 90B	ALEP	
3.01 ±0.15 ±0.05	[3,7] DECAMP 90D	ALEP	
2.91 ±0.13	DECAMP 90P	ALEP	
2.4 ±0.4 ±0.5	[3] AARNIO 89	DLPH	

[1] Simultaneous fits to all measured Z data.
[2] Analysis based on $\geq$ 1.1 million visible Z decays from LEP runs through 1992.
[3] These papers assume standard model couplings.
[4] Simultaneous fits to all measured cross section data from all four LEP experiments.
[5] Second error is from uncertainty in top and Higgs mass.
[6] These papers measure leptonic widths and are more model independent. However, they divide the measured invisible width via the Standard Model width for neutrinos. Such results are less precise, as discussed in the minireview.
[7] The second error is due to theoretical uncertainties.

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 $Z \rightarrow \nu\overline{\nu}\gamma$. All are obtained from LEP runs in the $E^{ee}_{\rm cm}$ range 88–94 GeV.

VALUE	DOCUMENT ID	TECN	COMMENT
2.97±0.17 OUR AVERAGE			
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
3.0 ±0.4 ±0.2	AKRAWY 91D	OPAL	

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.

VALUE	DOCUMENT ID	TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •		
< 3.3	WALKER 91	COSM
< 3.4	OLIVE 90	COSM
< 5.2	ELLIS 86	COSM
< 4	STEIGMAN 86	COSM
< 4	YANG 84	COSM
< 4	YANG 79	COSM
< 7	STEIGMAN 77	COSM
	PEEBLES 71	COSM
<16	[8] SHVARTSMAN 69	COSM
	HOYLE 64	COSM

[8] 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	[9] OLIVE 81C	COSM
<20	[9] STEIGMAN 79	COSM

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