

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

A REVIEW GOES HERE – Check our WWW List of Reviews

Number from $e^+ e^-$ Colliders

Number of Light ν Types

VALUE	DOCUMENT ID	TECN
2.9840 ± 0.0082	¹ LEP-SLC	06 RVUE
• • • We do not use the following data for averages, fits, limits, etc. • • •		
3.00 ± 0.05	² LEP	92 RVUE

¹ Combined fit from ALEPH, DELPHI, L3 and OPAL Experiments.

² 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 88–209 GeV.

VALUE	DOCUMENT ID	TECN	COMMENT
2.92 ± 0.05 OUR AVERAGE	Error includes scale factor of 1.2.		
2.84 ± 0.10 ± 0.14	ABDALLAH	05B DLPH	$\sqrt{s} = 180\text{--}209$ GeV
2.98 ± 0.05 ± 0.04	ACHARD	04E L3	1990–2000 LEP runs
2.86 ± 0.09	HEISTER	03C ALEP	$\sqrt{s} = 189\text{--}209$ GeV
2.69 ± 0.13 ± 0.11	ABBIENDI,G	00D OPAL	1998 LEP run
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. • • •			
2.84 ± 0.15 ± 0.14	ABREU	00Z DLPH	1997–1998 LEP runs
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 terrestrial experiments, see DENEGRI 90.

Also see “Big-Bang Nucleosynthesis” in this *Review*.

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 4.10	95	³ MORESCO	12 COSM	

< 5.79	95	⁴ XIA	12	COSM	
< 4.08	95	MANGANO	11	COSM	BBN
$0.9 < N_\nu < 8.2$		⁵ ICHIKAWA	07	COSM	
$3 < N_\nu < 7$	95	⁶ CIRELLI	06	COSM	
$2.7 < N_\nu < 4.6$	95	⁷ HANNESTAD	06	COSM	
$3.6 < N_\nu < 7.4$	95	⁶ SELJAK	06	COSM	
< 4.4		⁸ CYBURT	05	COSM	
< 3.3		⁹ BARGER	03C	COSM	
$1.4 < N_\nu < 6.8$		¹⁰ CROTTY	03	COSM	
$1.9 < N_\nu < 6.6$		¹⁰ PIERPAOLI	03	COSM	
$2 < N_\nu < 4$		LISI	99	COSM	BBN
< 4.3		OLIVE	99	COSM	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	COSM	High D/H quasar abs.
< 3.9		FIELDS	96	COSM	BBN; high ⁴ He and ⁷ Li
< 4.5		KERNAN	96	COSM	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		¹¹ SHVARTSMAN	69		Cosmology
		HOYLE	64		Cosmology

³ Limit on the number of light neutrino types from observational Hubble parameter data with seven-year WMAP data, SPT, and the most recent estimate of H_0 . Best fit is 3.45 ± 0.65 .

⁴ Limit on the number of light neutrino types from the CFHTLS combined with seven-year WMAP data and a prior on the Hubble parameter. Best fit is $4.17^{+1.62}_{-1.26}$. Limit is relaxed to $3.98^{+2.02}_{-1.20}$ when small scales affected by non-linearities are removed.

⁵ Constrains the number of neutrino types from recent CMB and large scale structure data. No priors on other cosmological parameters are used.

⁶ Constrains the number of neutrino types from recent CMB, large scale structure, Lyman-alpha forest, and SN1a data. The slight preference for $N_\nu > 3$ comes mostly from the Lyman-alpha forest data.

⁷ Constrains the number of neutrino types from recent CMB and large scale structure data. See also HAMANN 07.

⁸ Limit on the number of neutrino types based on ⁴He 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.

⁹ 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.

¹⁰ 95% confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, and HST data.

¹¹ SHVARTSMAN 69 limit inferred from his equations.

