KALBFLEISCH	79	PRL 43 1361	+Baggett, Fowler+	(FNAL, PURD, BELL)
BEG	78	PR D17 1395	+Marciano, Ruderman	(ROCK, COLU)
BLIETSCHAU	78	NP B133 205	+Deden, Hasert, Krenz+	(Gargamelle Collab.)
BARNES	77	PRL 38 1049	+Carmony, Dauwe, Fernandez+	(PURD, ANL)
LEE	77C	PR D16 1444	+Shrock	(STON)
ALSPECTOR	76	PRL 36 837	+	(BNL, PURD, CIT, FNAL, ROCK)
BELLOTTI	76	LNC 17 553	+Cavalli, Fiorini, Rollier	(MILA)
CLARK	74	PR D9 533	+Elioff, Frisch, Johnson, Kerth, Shen+	(LBL)
KIM	74	PR D9 3050	+Mather, Okubo	(ROCH)
BERNSTEIN	63	PR 132 1227	+Ruderman, Feinberg	(NYU, COLU)

ν_τ

$J = \frac{1}{2}$

Existence indirectly established from τ decay data combined with ν reaction data. See for example FELDMAN 81. ALBRECHT 92Q rules out $J=3/2$ by establishing that the ρ^- is not in a pure $H_\rho=-1$ helicity state in $\tau^- \rightarrow \rho^- \nu_\tau$.

Not in general a mass eigenstate. See note on neutrinos in the ν_e section above.

ν_τ MASS

Applies to ν_3, the primary mass eigenstate in ν_τ. Would also apply to any other ν_j which mixes strongly in ν_τ and has sufficiently small mass that it can occur in the respective decays. (This would be nontrivial only for a hypothetical $j \geq 4$, given the ν_e and ν_μ mass limits above.) See also the Listings in the Neutrino Bounds from Astrophysics and Cosmology section.

VALUE (MeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 31	95	19	[1] ALBRECHT	92M	ARG	E^{ee}_{cm}= 9.4–10.6 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 75	95		[2] BALEST	93	CLEO	E^{ee}_{cm}= 10.6 GeV
< 32.6	95	113	[3] CINABRO	93	CLEO	$E^{ee}_{cm} \approx$ 10.6 GeV
< 0.3 or > 35			[4] DOLGOV	93	COSM	Nucleosynthesis
< 0.74			[5] ENQVIST	93	COSM	Nucleosynthesis
< 0.003			[6,7] MAYLE	93	ASTR	SN 1987A cooling
< 0.025–0.030			[7,8] BURROWS	92	ASTR	SN 1987A cooling
< 0.3			[9] FULLER	91	COSM	Nucleosynthesis
< 0.5 or > 25			[10] KOLB	91	COSM	Nucleosynthesis
< 0.42			[9] LAM	91	COSM	Nucleosynthesis
< 0.028–0.15			[11] NATALE	91	ASTR	SN 1987A
< 0.028			[7] GANDHI	90	ASTR	SN 1987A
< 0.014 or > 34			[7,12] GRIFOLS	90B	ASTR	SN 1987A
< 0.06			[7,13] GAEMERS	89		SN 1987A
< 35	95	12	[14] ALBRECHT	88B	ARG	Repl. by ALBRECHT 92M
< 76	95	13	[15] ABACHI	87	HRS	E^{ee}_{cm}= 29 GeV
< 85	95		[16] CSORNA	87B	CLEO	E^{ee}_{cm}= 10–11 GeV
< 84	95	10	[17] ABACHI	86	HRS	Repl. by ABACHI 87
< 70	95	102	[18] ALBRECHT	85I	ARG	E^{ee}_{cm}= 10 GeV
<125	95	3	[19] BURCHAT	85	MRK2	E^{ee}_{cm}= 29 GeV
<143	95	22	[20] MATTEUZZI	85	MRK2	E^{ee}_{cm}= 29 GeV
<157	95	4	[21] MILLS	85	DLCO	E^{ee}_{cm}= 29 GeV
<250	95		[22] BLOCKER	82D	MRK2	E^{ee}_{cm}= 5.2 GeV
<250	95	594	[23,24] BACINO	79B	DLCO	E^{ee}_{cm}= 3.5–7.4 GeV

[1] ALBRECHT 92M reports measurement of a slightly lower τ mass, which has the effect of reducing the ν_τ mass reported in ALBRECHT 88B. Bound is from analysis of $\tau^- \rightarrow 3\pi^- 2\pi^+ \nu_\tau$ mode.

[2] BALEST 93 derive limit by comparing their m_τ measurement (which depends on m_{ν_τ}) to BAI 92 and BACINO 78B m_τ threshold measurements.

[3] CINABRO 93 bound comes from analysis of $\tau^- \rightarrow 3\pi^- 2\pi^+ \nu_\tau$ and $\tau^- \rightarrow 2\pi^- \pi^+ 2\pi^0 \nu_\tau$ decay modes.

[4] DOLGOV 93 assumes neutrino lifetime >100 s. For Majorana neutrinos, the low mass limit is 0.5 MeV. KAWANO 92 points out that these bounds can be overcome for a Dirac neutrino if it possesses a magnetic moment.

[5] ENQVIST 93 bases limit on the fact that thermalized wrong-helicity Dirac neutrinos would speed up expansion of early universe, thus reducing the primordial abundance. FULLER 91 exploits the same mechanism but in the older calculation obtains a larger production rate for these states, and hence a lower limit. Neutrino lifetime assumed to exceed nucleosynthesis time, ∼ 1 s.

[6] MAYLE 93 recalculates cooling rate enhancement by escape of wrong-helicity Dirac neutrinos using the Livermore Supernova Explosion Code, obtains more restrictive result than the "very conservative" BURROWS 92 limit because of higher core temperature.

[7] There would be an increased SN 1987A cooling rate if Dirac neutrino mass is included; this does not apply for Majorana neutrinos. Limit is on $\sqrt{m^2_{\nu_\mu} + m^2_{\nu_\tau}}$, and error becomes very large if ν_τ is nonrelativistic, which occurs near the lab limit of 31 MeV. RAJPOOT 93 notes that limit could be evaded with new physics.

[8] BURROWS 92 limit for Dirac neutrinos only.

[9] Assumes neutrino lifetime >1 s. For Dirac neutrinos. See also ENQVIST 93.

[10] KOLB 91 exclusion region is for Dirac neutrino with lifetime >1 s; other limits are given.

[11] NATALE 91 published result multiplied by $\sqrt{8}\sqrt{4}$ at the advice of the author.

[12] GRIFOLS 90B estimated error is a factor of 3.

[13] GAEMERS 89 published result (< 0.03) corrected via the GANDHI 91 erratum.

[14] ALBRECHT 88 bound comes from analysis of $\tau \rightarrow 5\pi^\pm \nu_\tau$ decay mode. Same data reanalyzed with revised τ mass in ALBRECHT 92M.

[15] Bound comes from analysis of $\tau \rightarrow 5\pi^\pm (\pi^0) \nu_\tau$ decay mode in 13 decay events.

[16] CSORNA 87B also quote result as 31 ± 25 ± 20 MeV. Bound comes from analysis of $\tau \rightarrow 3\pi^\pm (\pi^0) \nu_\tau$ decay mode.

[17] Bound comes from analysis of $\tau \rightarrow 5\pi^\pm \pi^0 \nu_\tau$ decay mode (5 events) and to a lesser extent from $\tau \rightarrow 5\pi^\pm \nu_\tau$ mode (5 events).

[18] Bound comes from analysis of $\tau \rightarrow 3\pi^\pm \nu_\tau$ decay mode.

[19] Bound comes from analysis of $\tau \rightarrow 5\pi^\pm (\pi^0) \nu_\tau$ decay.

[20] Bound comes from analysis of $\tau \rightarrow 3\pi^\pm \pi^0 \nu_\tau$ decay mode.

[21] Bound comes from analysis of $\tau \rightarrow K^\pm K^\mp \pi^\pm \nu_\tau$ decay mode.

[22] Bound comes from analysis of $\tau \rightarrow \pi \nu_\tau$ decay mode.

[23] Bound comes from analysis of leptonic decay spectrum.

[24] BACINO 79B experiment rules out V+A decay, disfavors pure V or A, and is in good agreement with $V-A$.

ν_3 (MEAN LIFE) / MASS

These limits often apply to ν_μ (ν_2) also.

VALUE (s/eV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$>2.8 \times 10^{15}$	[25,26] BLUDMAN	92	ASTR	$m_\nu <$ 50 eV
$< 10^{-12}$ or $> 5 \times 10^4$	[27] DODELSON	92	ASTR	m_ν=1–300 keV
	[28] GRANEK	91	COSM	Decaying L^0
	[29] WALKER	90	ASTR	m_ν= 0.03 – ∼ 2 MeV
$>6.3 \times 10^{15}$	[26,30] CHUPP	89	ASTR	$m_\nu <$ 20 eV
$>1.7 \times 10^{15}$	[26] KOLB	89	ASTR	$m_\nu <$ 20 eV
	[31] TERASAWA	88	COSM	m_μ= 30–70 MeV
	[32] KAWASAKI	86	COSM	m_ν >10 MeV
	[33] LINDLEY	85	COSM	m_ν > 10 MeV
	[34] BINETRUY	84	COSM	$m_\nu \sim$ 1 MeV
	[35] SARKAR	84	COSM	m_ν= 10–100 MeV
	[36] HENRY	81	ASTR	m_ν= 16–20 eV
	[37] KIMBLE	81	ASTR	m_ν= 10–100 eV
	[38] REPHAELI	81	ASTR	m_ν= 30–150 eV
	[39] DERUJULA	80	ASTR	m_ν= 10–100 eV
$>2 \times 10^{21}$	[40] STECKER	80	ASTR	m_ν= 10–100 eV
	[41] DICUS	78	COSM	m_ν= 0.5–30 MeV
$<3 \times 10^{-11}$	[42] FALK	78	ASTR	m_ν <10 MeV
	[43] COWSIK	77	ASTR	

[25] BLUDMAN 92 sets additional limits by this method for higher mass ranges. Cosmological limits are also obtained.

[26] Nonobservation of γ's in coincidence with ν's from SN 1987A. Results should be divided by the $\tau_\nu \rightarrow \gamma X$ branching ratio.

[27] DODELSON 92 range is for wrong-helicity keV mass Dirac ν's from the core of neutron star in SN 1987A decaying to ν's that would have interacted in KAM2 or IMB detectors.

[28] GRANEK 91 considers heavy neutrino decays to $\gamma \nu_L$ and $3\nu_L$, where m_{ν_L} <100 keV. Lifetime is calculated as a function of heavy neutrino mass, branching ratio into $\gamma \nu_L$, and m_{ν_L}.

[29] WALKER 90 uses SN 1987A γ flux limits after 289 days to find $m_\tau > 1.1 \times 10^{15}$ eV s.

[30] CHUPP 89 should be multiplied by a branching ratio (about 1) and a detection efficiency (about 1/4), and pertains to radiative decay of any neutrino to a lighter or sterile neutrino.

[31] TERASAWA 88 finds only $10^2 < \tau < 10^4$ allowed for 30–70 MeV ν's from primordal nucleosynthesis.

[32] KAWASAKI 86 concludes that light elements in primordal nucleosynthesis would be destroyed by radiative decay of neutrinos with 10 MeV$< m_\nu <$1 GeV unless $\tau \lesssim 10^4$ s.

[33] LINDLEY 85 considers destruction of cosmologically-produced light elements, and finds $\tau < 2 \times 10^3$ s for 10 MeV $< m_\nu <$100 MeV. See also LINDLEY 79.

[34] BINETRUY 84 finds $\tau < 10^8$ s for neutrinos in a radiation-dominated universe.

[35] SARKAR 84 finds $\tau <$ 20 s at m_ν=10 MeV, with higher limits for other m_ν, and claims that all masses between 1 MeV and 50 MeV are ruled out.

[36] HENRY 81 uses UV flux from clusters of galaxies to find $\tau > 1.1 \times 10^{25}$ s for radiative decay.

[37] KIMBLE 81 uses extreme UV flux limits to find $\tau > 10^{22}$–10^{23} s.

[38] REPHAELI 81 consider ν decay γ effect on neutral H in early universe; based on M31 HI concludes $\tau > 10^{24}$ s.

[39] DERUJULA 80 finds $\tau > 3 \times 10^{23}$ s based on CDM neutrino decay contribution to UV background.

[40] STECKER 80 limit based on UV background; result given is $\tau > 4 \times 10^{22}$ s at $m_\nu = 20$ eV.

[41] DICUS 78 considers effect of ν decay photons on light-element production, and finds lifetime must be less than "hours." See also DICUS 77.

[42] FALK 78 finds lifetime constraints based on supernova energetics.

[43] COWSIK 77 considers varity of scenarios. For neutrinos produced in the big bang, present limits on optical photon flux require $\tau > 10^{23}$ s for $m_\nu \sim 1$ eV. See also COWSIK 79 and GOLDMAN 79.