Lepton & Quark Full Listings

ν_μ

ν_2 (MEAN LIFE) / MASS

These limits often apply to ν_τ (ν_3) also.

VALUE (s/eV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
>15.4	90		[12] KRAKAUER	91	CNTR	ν_μ, $\overline{\nu}_\mu$ at LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$> 2.8 \times 10^{15}$			[13,14] BLUDMAN	92	ASTR	$m_\nu < 50$ eV
none 10^{-12} – 5×10^{4}			[15] DODELSON	92	ASTR	m_ν=1–300 keV
$> 6.3 \times 10^{15}$			[14,16] CHUPP	89	ASTR	$m_\nu < 20$ eV
$> 1.7 \times 10^{15}$			[14] KOLB	89	ASTR	$m_\nu < 20$ eV
			[17,18] HATSUDA	88	ASTR	
$> 3.3 \times 10^{14}$			[19,20] VONFEILIT...	88	ASTR	
> 0.11	90	0	[21] FRANK	81	CNTR	$\nu\overline{\nu}$ LAMPF
			[22] HENRY	81	ASTR	m_ν= 16–20 eV
			[23] KIMBLE	81	ASTR	m_ν= 10–100 eV
			[24] REPHAELI	81	ASTR	m_ν= 30–150 eV
			[25] DERUJULA	80	ASTR	m_ν= 10–100 eV
$> 2 \times 10^{21}$			[26] STECKER	80	ASTR	m_ν= 10–100 eV
$> 1.0 \times 10^{-2}$	90	0	[21] BLIETSCHAU	78	HLBC	ν_μ, CERN GGM
$> 1.7 \times 10^{-2}$	90	0	[21] BLIETSCHAU	78	HLBC	$\overline{\nu}_\mu$, CERN GGM
$> 2.2 \times 10^{-3}$	90	0	[21] BARNES	77	DBC	ν, ANL 12-ft
$> 3. \times 10^{-3}$	90	0	[21] BELLOTTI	76	HLBC	ν, CERN GGM
$> 1.3 \times 10^{-2}$	90	1	[21] BELLOTTI	76	HLBC	$\overline{\nu}$, CERN GGM

[12] KRAKAUER 91 quotes the limit $\tau/m_{\nu_1} > (0.75a^2 + 21.65a + 26.3)$ s/eV, where a is a parameter describing the asymmetry in the neutrino decay defined as $dN_\gamma/d\cos\theta = (1/2)(1 + a\cos\theta)$ The parameter $a = 0$ for a Majorana neutrino, but can vary from -1 to 1 for a Dirac neutrino. The bound given by the authors is the most conservative (which applies for $a = -1$).

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

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

[15] 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.

[16] 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.

[17] Model-dependent theoretical analysis.

[18] HATSUDA 88 argues that previous bounds on radiative decays of neutrinos produced in supernovae explosions may not be valid (because $\nu_H \to \gamma\nu$ might be dominated by processes such as $\nu_H e \to \nu e$ if e number density is high enough), and that, in fact, a neutrino mean life/mass of 0.2–0.6 s/eV may be consistent with the data.

[19] Model-dependent theoretical analysis of SN 1987A neutrinos.

[20] Limit applies to ν_τ also.

[21] These experiments look for $\nu_\mu \to \nu_e\gamma$ or $\overline{\nu}_\mu \to \overline{\nu}_e\gamma$.

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

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

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

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

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

$|(v - c)/c|$ ($v \equiv \nu_2$ VELOCITY)

Expected to be zero for massless neutrino, but also tests whether photons and neutrinos have the same limiting velocity in vacuum.

VALUE (units 10^{-4})	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<0.4	95	9800	KALBFLEISCH	79	SPEC		
<2.0	99	77	ALSPECTOR	76	SPEC	0	>5 GeV ν
<4.0	99	26	ALSPECTOR	76	SPEC	0	<5 GeV ν

ν_2 MAGNETIC MOMENT

Must vanish for Majorana neutrino or purely chiral massless Dirac neutrino. The value of the magnetic moment for the standard SU(2)×U(1) electroweak theory extended to include massive neutrinos (see FUJIKAWA 80) is $\mu_\nu = 3eG_F m_\nu/(8\pi^2\sqrt{2}) = (3.2 \times 10^{-19}) m_\nu \mu_B$ where m_ν is in eV and $\mu_B = e\hbar/2m_e$ is the Bohr magneton. Given the upper bound $m_{\nu_2} < 0.27$ MeV, it follows that for the extended standard electroweak theory, $\mu(\nu_2) < 0.86 \times 10^{-13}\ \mu_B$.

VALUE (μ_B)	CL%	DOCUMENT ID		TECN	COMMENT
$<8.5 \times 10^{-10}$	90	AHRENS	90	CNTR	$\nu_\mu e \to \nu_\mu e$
<7.4 × 10^{-10}	90	[27] KRAKAUER	90	CNTR	LAMPF (ν_μ, $\overline{\nu}_\mu$)e elast.
$<9.5 \times 10^{-10}$	90	ABE	87B	CNTR	$\nu_\mu e \to \nu_\mu e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1 \times 10^{-8}$	95	[28] DORENBOS...	91	CHRM	$\nu_\mu e \to \nu_\mu e$
$<2 \times 10^{-12}$	95	[29] RAFFELT	90	ASTR	Red giant luminosity
$<1 \times 10^{-11}$		[30] RAFFELT	89B	ASTR	Cooling helium stars
$<1.1 \times 10^{-11}$		[30,31] FUKUGITA	87	ASTR	Cooling helium stars
$<6 \times 10^{-14}$		[32] NUSSINOV	87	ASTR	Cosmic EM backgrounds
$<4 \times 10^{-11}$		LYNN	81	ASTR	
$<8.5 \times 10^{-11}$		[31] BEG	78	ASTR	Stellar plasmons
$<8.1 \times 10^{-9}$		[33] KIM	74	RVUE	$\overline{\nu}_\mu e \to \overline{\nu}_\mu e$
$<1 \times 10^{-10}$		[34] BERNSTEIN	63	ASTR	Cooling white dwarfs

[27] KRAKAUER 90 experiment fully reported in ALLEN 93.

[28] DORENBOSCH 91 corrects an incorrect statement in DORENBOSCH 89 that the ν_2 magnetic moment is $< 1 \times 10^{-9}$ at the 95%CL. DORENBOSCH 89 measures both $\nu_\mu e$ and $\overline{\nu}_\mu e$ elastic scattering and assume $\mu(\nu_\mu) = \mu(\overline{\nu}_\mu)$.

[29] RAFFELT 90 limit applies for a diagonal magnetic moment of a Dirac neutrino, or for a transition magnetic moment of a Majorana neutrino. In the latter case, the same analysis gives $< 1.4 \times 10^{-12}$. Limit at 95%CL obtained from δM_c.

[30] Significant dependence on details of stellar properties.

[31] If $m_{\nu_2} < 10$ keV.

[32] For m_{ν_2} = 8–200 eV. NUSSINOV 87 examines transition magnetic moments for $\nu_\mu \to \nu_e$ and obtain $< 3 \times 10^{-15}$ for $m_{\nu_2} > 16$ eV and $< 6 \times 10^{-14}$ for $m_{\nu_2} > 4$ eV.

[33] KIM 74 is a theoretical analysis of $\overline{\nu}_\mu$ reaction data.

[34] If $m_{\nu_2} < 1$ keV.

NONSTANDARD CONTRIBUTIONS TO NEUTRINO SCATTERING

We report limits on the so-called neutrino charge radius squared in this section. This quantity is not an observable, physical quantity and this is reflected in the fact that it is gauge dependent (see LEE 77C). It is not necessarily positive. A more general interpretation of the experimental results is that they are limits on certain nonstandard contributions to neutrino scattering.

VALUE (10^{-32} cm^2)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
-1.1 ± 1.0	[35] AHRENS	90	CNTR	$\nu_\mu e$ elas scat
-0.3 ± 1.5	[35] DORENBOS...	89	CHRM	$\nu_\mu e$ elas scat

[35] Result is obtained from reanalysis given in ALLEN 91, followed by our reduction to obtain 1σ errors.

ν_μ REFERENCES

ASSAMAGAN	94	PL B (subm.)	+Bronnimann, Daum+	(PSI, ZURI, VILL, VIRG)
JECKELMANN	94	PL B (accepted)	+Goudsmit, Leisi	(WABRN, VILL)
ALLEN	93	PR D47 11	+Chen, Doe, Hausammann+	(UCI, LANL, ANL, UMD)
ENQVIST	93	PL B301 376	+Uibo	(NORD)
MAYLE	93	PL B317 119	+Schramm, Turner, Wilson	(LLNL, CHIC)
RAJPOOT	93	MPL A8 1179		(CSULB)
BLUDMAN	92	PR D45 4720		(CFPA)
BURROWS	92	PRL 68 3834	+Gandhi, Turner	(ARIZ, CHIC)
DODELSON	92	PRL 68 2572	+Frieman, Turner	(FNAL, CHIC)
MAMEDOV	92	SJPN 23 339		(JINR)
		Translated from FECAY 23 767.		
ALLEN	91	PR D43 R1	+Chen, Doe, Hausammann	(UCI, LANL, UMD)
DAUM	91	PL B265 425	+Frosch, Herter, Janousch, Kettle	(VILL)
DORENBOS...	91	ZPHY C51 142	Dorenbosch, Udo, Allaby, Amaldi+	(CHARM Collab.)
FULLER	91	PR D43 3136	+Malaney	(UCSD)
GANDHI	91	PL B261 519E (erratum)	+Burrows	(ARIZ)
KRAKAUER	91	PR D44 R6	+Talaga, Allen, Chen+	(LAMPF E225 Collab.)
LAM	91	PR D44 3345	+Ng	(AST)
NATALE	91	PL B258 227		(SPIFT)
AHRENS	90	PR D41 3297	+ (BNL, BROW, HIRO, KEK, OSAK, PENN, STON)	
GANDHI	90	PL B246 149	+Burrows	(ARIZ)
Also	91	PL B261 519E (erratum)	Gandhi, Burrows	(ARIZ)
GRIFOLS	90B	PL B242 77	+Masso	(BARC, CERN)
KRAKAUER	90	PL B252 177	+Talaga, Allen, Chen+	(LAMPF E225 Collab.)
RAFFELT	90	PRL 64 2856		(MPIM)
CHUPP	89	PRL 62 505	+Vestrand, Reppin	(UNH, MPIM)
DORENBOS...	89	ZPHY C41 567	Dorenbosch, Udo, Allaby, Amaldi+	(CHARM Collab.)
GAEMERS	89	PR D40 309	+Gandhi, Lattimer	(ANIK, STON)
KOLB	89	PRL 62 509	+Turner	(CHIC, FNAL)
RAFFELT	89B	APJ 336 61	+Dearborn, Silk	(UCB, LLL)
HATSUDA	88	PL B203 462	+Lim, Yoshimura	(KEK)
VONFEILIT...	88	PL B200 580	Von Feilitzsch, Oberauer	(MUNT)
ABE	87B	PRL 58 636	+ (BNL, BROW, HIRO, KEK, OSAK, PENN, STON)	
FUKUGITA	87	PR D36 3817	+Yazaki	(KYOTY, TOKY)
NUSSINOV	87	PR D36 2278	+Rephaeli	(TELA)
JECKELMANN	86	PRL 56 1444	+Nakada, Beer+	(ETH, FRIB)
ABELA	84	PL 146B 431	+Daum, Eaton, Frosch, Jost, Kettle+	(SIN)
PDG	84	RMP 56 No. 2 Pt. II	Wohl, Cahn, Rittenberg+	(LBL, CIT, CERN)
ANDERHUB	82	PL 114B 76	+Boecklin, Hofer, Kottmann+	(ETH, SIN)
FRANK	81	PR D24 2001	+Burman+ (LASL, YALE, MIT, SACL, SIN+)	
HENRY	81	PRL 47 618	+Feldman	(JHU)
KIMBLE	81	PRL 46 80	+Bowyer, Jakobsen	(UCB)
LYNN	81	PR D23 2151		(COLU)
REPHAELI	81	PL 106B 73	+Szalay	(UCSB, CHIC)
DERUJULA	80	PRL 45 942	+Glashow	(MIT, HARV)
FUJIKAWA	80	PRL 45 963	+Shrock	(STON)
LU	80	PRL 45 1066	+Delker, Dugan, Wu, Caffrey+	(YALE, COLU, JHU)
STECKER	80	PRL 45 1460		(NASA)
DAUM	79	PR D20 2692	+Eaton, Frosch, Hirschmann+	(SIN)
Also	76	PL 60B 380	Daum, Dubal, Eaton, Frosch+	(SIN, ETH)
Also	78	PL 74B 126	Daum, Eaton, Frosch, Hirschmann+	(SIN)