ν_e

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

Not in general a mass eigenstate. See note on neutrino properties above.

These limits apply to ν_1, the primary mass eigenstate in ν_e. They would also apply to any other ν_j which mixes strongly in ν_e and has sufficiently small mass that it can occur in the respective decay. The neutrino mass may be of a Dirac or Majorana type; the former conserves total lepton number while the latter violates it. Either would violate lepton family number, since nothing forces the neutrino mass eigenstates to coincide with the neutrino interaction eigenstates. For limits on a Majorana ν_e mass, see the section on "Searches for Massive Neutrinos and Lepton Mixing," part (C), entitled "Searches for Neutrinoless Double-β Decay."

The square of the neutrino mass $m^2_{\nu_e}$ is measured in tritium beta decay experiments by fitting the shape of the beta spectrum near the endpoint; results are given in one of the tables in this section. In many experiments, it has been found to be significantly negative. In the 1994 edition of this *Review*, it was noted that the combined probability of a positive result was 3.5%. The problem has been exacerbated by the precise and careful experiments reported in two new papers (BELESEV 95 and STOEFFL 95). Both groups conclude that unknown effects cause the accumulation of events in the electron spectrum near its end point. If the fitting hypothesis does not account for this, unphysical values for $m^2_{\nu_e}$ are obtained. BELESEV 95 obtain their value for $m^2_{\nu_e}$ and limit for m_{ν_e} (4.35 eV at 95% CL) under the assumption that a certain narrow region is free of both high-energy and low-energy anomalies. Including the endpoint accumulation (they find no low-energy anomaly), STOEFFL 95 find a value for $m^2_{\nu_e}$ which is more than 5 standard deviations negative, and report a Bayesian limit of 7 eV for m_{ν_e} which is obtained by setting $m^2_{\nu_e} = 0$. Given the status of the tritium results, we find no clear way to set a meaningful limit on m_{ν_e}. On the other hand, a mass as large as 10–15 eV would probably cause detectable spectrum distortions near the endpoint.

The spread of arrival times of the neutrinos from SN 1987A, coupled with the measured neutrino energies, should provide a simple time-of-flight limit on m_{ν_e}. This statement, clothed in various degrees of sophistication, has been the basis for a very large number of papers. The LOREDO 89 limit (23 eV) is among the most conservative and involves few assumptions; as such, it is probably a safe limit. We list this limit below as "used," but conclude that a limit about half this size is justified by the tritium decay experiments.

ν_e MASS

Most of the data from which these limits are derived are from β^- decay experiments in which a $\overline{\nu}_e$ is produced, so that they really apply to $m_{\overline{\nu}_1}$. Assuming *CPT* invariance, a limit on $m_{\overline{\nu}_1}$ is the same as a limit on m_{ν_1}. Results from studies of electron capture transitions, given below "$m_{\nu_1} - m_{\overline{\nu}_1}$", give limits on m_{ν_1} itself. OUR EVALUATION of the present status of the tritium decay experiments is discussed in the above minireview.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 15 OUR EVALUATION					
< 23		LOREDO	89	ASTR	SN 1987A
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.35	95	[1] BELESEV	95	SPEC	^{3}H β decay
< 12.4	95	[2] CHING	95	SPEC	^{3}H β decay
< 92	95	[3] HIDDEMANN	95	SPEC	^{3}H β decay
15^{+32}_{-15}		HIDDEMANN	95	SPEC	^{3}H β decay
< 19.6	95	KERNAN	95	ASTR	SN 1987A
< 7.0	95	[4] STOEFFL	95	SPEC	^{3}H β decay
<460	68	[5] YASUMI	94	CNTR	*e* capture in ^{163}Ho
< 7.2	95	[6] WEINHEIMER	93	SPEC	^{3}H β decay
< 11.7	95	[7] HOLZSCHUH	92B	SPEC	^{3}H β decay
< 13.1	95	[8] KAWAKAMI	91	SPEC	^{3}H β decay
< 9.3	95	[9] ROBERTSON	91	SPEC	^{3}H β decay
< 14	95	AVIGNONE	90	ASTR	SN 1987A
< 16		SPERGEL	88	ASTR	SN 1987A
17 to 40		[10] BORIS	87	SPEC	$\overline{\nu}_e$, ^{3}H β decay

[1] BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. A fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly) plus a monochromatic line 7–15 eV below the endpoint yields $m^2_\nu = -4.1 \pm 10.9$ eV^2, leading to this Bayesian limit.

[2] CHING 95 quotes results previously given by SUN 93; no experimental details are given. A possible explanation for consistently negative values of m^2_ν is given.

[3] HIDDEMANN 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. Bayesian limit calculated from the weighted mean $m^2_\nu = 221 \pm 4244$ eV^2 from the two runs listed below.

[4] STOEFFL 95 (LLNL) result is the Bayesian limit obtained from the m^2_ν errors given below but with m^2_ν set equal to 0. The anomalous endpoint accumulation leads to a value of m^2_ν which is negative by more than 5 standard deviations.

[5] The YASUMI 94 (KEK) limit results from their measurement $m_\nu = 110^{+350}_{-110}$ eV.

[6] WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.

[7] HOLZSCHUH 92B (Zurich) result is obtained from the measurement $m^2_\nu = -24 \pm 48 \pm 61$ (1σ errors), in eV^2, using the PDG prescription for conversion to a limit in m_ν.

[8] KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid. This result is the Bayesian limit obtained from the m^2_ν limit with the errors combined in quadrature. This was also done in ROBERTSON 91, although the authors report a different procedure.

[9] ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_ν lies between 17 and 40 eV. However, the probability of a positive m^2 is only 3% if statistical and systematic error are combined in quadrature.

[10] See also comment in BORIS 87B and erratum in BORIS 88.

ν_e MASS SQUARED

The tritium experiments actually measure mass squared. A combined limit on mass must therefore be obtained from the weighted average of the results shown here. The recent results are in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88, erratum)] that m_{ν_1} lies between 17 and 40 eV. The BORIS 87 result is excluded because of the controversy over the possibly large unreported systematic errors; see BERGKVIST 85B, BERGKVIST 86, SIMPSON 84, and REDONDO 89. However, the average for the new experiments given below implies only a 3.5% probability that m^2 is positive. See HOLZSCHUH 92 for a review of the recent direct m_{ν_1} measurements.

VALUE (eV^2)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
− 27± 20 OUR AVERAGE		Error includes scale factor of 4.2. See the ideogram below.		
− 22± 4.8		[11] BELESEV 95	SPEC	^3H β decay
−130± 20 ±15	95	[12] STOEFFL 95	SPEC	^3H β decay
− 31± 75 ±48		[13] SUN 93	SPEC	^3H β decay
− 39± 34 ±15		[14] WEINHEIMER 93	SPEC	^3H β decay
− 24± 48 ±61		[15] HOLZSCHUH 92B	SPEC	^3H β decay
− 65± 85 ±65		[16] KAWAKAMI 91	SPEC	^3H β decay
−147± 68 ±41		[17] ROBERTSON 91	SPEC	^3H β decay
• • • We do not use the following data for averages, fits, limits, etc. • • •				
129±6010		[18] HIDDEMANN 95	SPEC	^3H β decay
313±5994		[18] HIDDEMANN 95	SPEC	^3H β decay

[11] BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. This value comes from a fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly), including the effects of an apparent peak 7–15 eV below the endpoint.

[12] STOEFFL 95 (LLNL) uses a gaseous source of molecular tritium. An anomalous pileup of events at the endpoint leads to the negative value for m^2_ν. The authors acknowledge that "the negative value for the best fit of m^2_ν has no physical meaning" and discuss possible explanations for this effect.

[13] SUN 93 uses a tritiated hydrocarbon source. See also CHING 95.

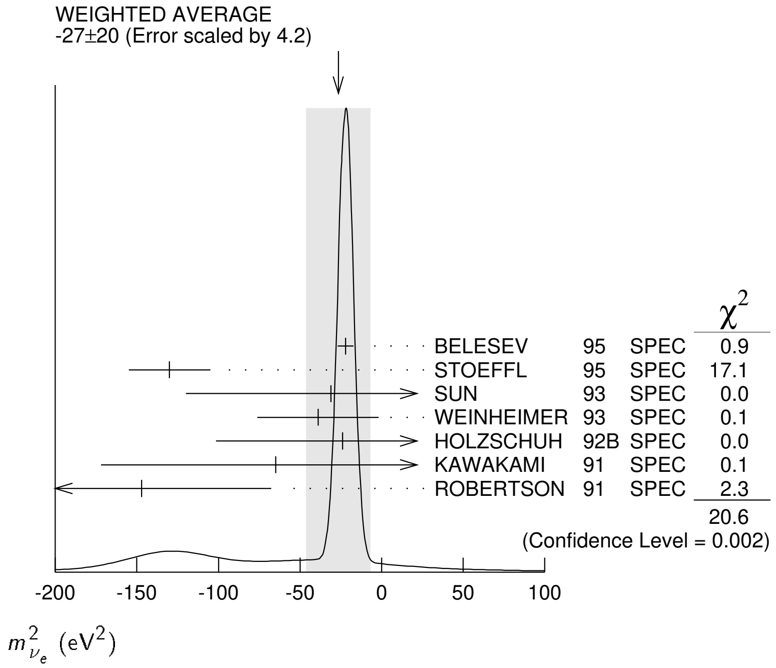
[14] WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.

[15] HOLZSCHUH 92B (Zurich) source is a monolayer of tritiated hydrocarbon.

[16] KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid.

[17] ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_ν lies between 17 and 40 eV. However, the probability of a positive m^2_ν is only 3% if statistical and systematic error are combined in quadrature.

[18] HIDDEMANN 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. They quote measurements from two data sets.



$m_{\nu_1} - m_{\overline{\nu}_1}$

These are measurement of m_{ν_1} (in contrast to $m_{\overline{\nu}_1}$, given above). The masses can be different for a Dirac neutrino in the absense of CPT invariance. The test is not very strong.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<$ 225	95	SPRINGER	87	CNTR	ν, ^{163}Ho
$<$ 550	68	YASUMI	86	CNTR	ν, ^{163}Ho
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.5 \times 10^{5}$	90	CLARK	74	ASPK	K_{e3} decay
$<$4100	67	BECK	68	CNTR	ν, ^{22}Na

ν_1 CHARGE

VALUE (units: electron charge)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2 \times 10^{-15}$	[19] BARBIELLINI	87	ASTR	SN 1987A
$<1 \times 10^{-13}$	BERNSTEIN	63	ASTR	Solar energy losses

[19] Precise limit depends on assumptions about the intergalactic or galactic magnetic fields and about the direct distance and time through the field.

ν_1 MEAN LIFE

VALUE (s)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[20] COWSIK	89	ASTR	m_ν = 1–50 MeV
		[21] RAFFELT	89	RVUE	$\overline{\nu}$ (Dirac, Majorana)
		[22] RAFFELT	89B	ASTR	
$>$278	90	[23] LOSECCO	87B	IMB	
$> 1.1 \times 10^{25}$		[24] HENRY	81	ASTR	m_ν= 16–20 eV
$> 10^{22}$–10^{23}		[25] KIMBLE	81	ASTR	m_ν= 10–100 eV

[20] COWSIK 89 use observations of supernova SN 1987A to set the limit for the lifetime of a neutrino with $1 < m < 50$ MeV decaying through $\nu_H \rightarrow \nu_1 e e$ to be $\tau > 4 \times 10^{15} \exp(-m/5\ \text{MeV})$ s.

[21] RAFFELT 89 uses KYULDJIEV 84 to obtain $\tau m^3 > 3 \times 10^{18}$ s eV^3 (based on $\overline{\nu}_e e^-$ cross sections). The bound is not valid if electric and magnetic transition moments are equal for Dirac neutrinos.

[22] RAFFELT 89B analyze stellar evolution and exclude the region $3 \times 10^{12} < \tau m^3 < 3 \times 10^{21}$ s eV^3.

[23] LOSECCO 87B assumes observed rate of 2.1 SNU (solar neutrino units) comes from sun while 7.0 ± 3.0 is theory.

[24] HENRY 81 uses UV flux from clusters of galaxies to find limit for radiative decay.

[25] KIMBLE 81 uses extreme UV flux limits.

ν_1 (MEAN LIFE) / MASS

VALUE (s/eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>300	90	[26] REINES	74	CNTR	$\overline{\nu}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 2.8 \times 10^{15}$		[27,28] BLUDMAN	92	ASTR	$m_\nu < 50$ eV
$>$ 6.4	90	[29] KRAKAUER	91	CNTR	$\overline{\nu}$ at LAMPF
$> 6.3 \times 10^{15}$		[28,30] CHUPP	89	ASTR	$m_\nu < 20$ eV
$> 1.7 \times 10^{15}$		[28] KOLB	89	ASTR	$m_\nu < 20$ eV
$> 8.3 \times 10^{14}$		[31] VONFEILIT...	88	ASTR	
$>$ 22	68	[32] OBERAUER	87		$\overline{\nu}_R$ (Dirac)
$>$ 38	68	[32] OBERAUER	87		$\overline{\nu}$ (Majorana)
$>$ 59	68	[32] OBERAUER	87		$\overline{\nu}_L$ (Dirac)
$>$ 30	68	KETOV	86	CNTR	$\overline{\nu}$ (Dirac)
$>$ 20	68	KETOV	86	CNTR	$\overline{\nu}$ (Majorana)
$> 7 \times 10^{9}$		[33] RAFFELT	85	ASTR	
$> 2 \times 10^{21}$		[34] STECKER	80	ASTR	m_ν= 10–100 eV

[26] REINES 74 looked for ν_e of nonzero mass decaying to a neutral of lesser mass + γ. Used liquid scintillator detector near fission reactor. Finds lab lifetime $6. \times 10^7$ s or more. Above value of (mean life)/mass assumes average effective neutrino energy of 0.2 MeV. To obtain the limit $6. \times 10^7$ s REINES 74 assumed that the full $\overline{\nu}_e$ reactor flux could

be responsible for yielding decays with photon energies in the interval 0.1 MeV – 0.5 MeV. This represents some overestimate so their lower limit is an over-estimate of the lab lifetime (P. Vogel, private communication, 1984).

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

[28] Nonobservation of γ's in coincidence with ν's from SN 1987A.

[29] KRAKAUER 91 quotes the limit $\tau/m_{\nu_1} > (0.3a^2 + 9.8a + 15.9)$ s/eV, where a is a parameter describing the asymmetry in the neutrino decay defined as $dN_\gamma/d\cos\theta = (1/2)(1 + a\cos\theta)$ $a=0$ 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 $a = -1$).

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

[32] OBERAUER 87 bounds are from comparison of observed and expected rate of reactor neutrinos.

[33] RAFFELT 85 limit is from solar x- and γ-ray fluxes.

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

$|(v - c)/c|$ ($v \equiv \nu_1$ VELOCITY)

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

VALUE (units 10^{-8})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
<1	17	[35] STODOLSKY	88	ASTR	SN 1987A

[35] STODOLSKY 88 result based on <10 hr between $\overline{\nu}_e$ detection in IMB and KAMI detectors and beginning of light signal. Inclusion of the problematic 5 neutrino events from FREJ (four hours later) does not change the result.

ν_1 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 $\mu_\nu = 3eG_F m_\nu/(8\pi^2\sqrt{2}) = (3.20 \times 10^{-19}) m_\nu \mu_B$ where m_ν is in eV and $\mu_B = e\hbar/2m_e$ is the Bohr magneton. Given the upper bound $m_{\nu_1} < 7.3$ eV, it follows that for the extended standard electroweak theory, $\mu(\nu_1) < 2.3 \times 10^{-18}\ \mu_B$. Current experiments are not yet challenging this limit. There is considerable controversy over the validity of many of the claimed upper limits on the magnetic moment from the astrophysical data. For example, VOLOSHIN 90 states that "in connection with the astrophysical limits on μ_ν, ... there is by now a general consensus that contrary to the initial claims (BARBIERI 88, LATTIMER 88, GOLDMAN 88, NOTZOLD 88), essentially no better than quoted limits (from previous constraints) can be derived from detection of the neutrino flux from the supernova SN1987A." See VOLOSHIN 88 and VOLOSHIN 88C.

VALUE ($10^{-10}\ \mu_B$)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 1.8	90	[36] DERBIN	94	CNTR	Reactor $\overline{\nu}_e e \to \overline{\nu}_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.003–0.0005		[37] GOYAL	95		SN 1987A
< 7.7	95	MOURAO	92	ASTR	HOME/KAM2 ν rates
< 2.4	90	[38] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \to \overline{\nu}_e e$
<10.8	90	[39] KRAKAUER	90	CNTR	LAMPF $\nu_e e \to \nu_e e$
< 0.02	95	[40] RAFFELT	90	ASTR	Red giant luminosity
< 0.1		[41] RAFFELT	89B	ASTR	Cooling helium stars
< 0.02–0.08		[41,42,43] BARBIERI	88	ASTR	SN 1987A
		[44] FUKUGITA	88	COSM	Primordial magn. fields
< 0.01		[42,43,45] GOLDMAN	88	ASTR	SN 1987A
< 0.005		[41,43] LATTIMER	88	ASTR	SN 1987A
≤ 0.015		[41,43] NOETZOLD	88	ASTR	SN 1987A
≤ .3		[41] RAFFELT	88B	ASTR	He burning stars
< 0.11		[41] FUKUGITA	87	ASTR	Cooling helium stars
< 0.4		LYNN	81	ASTR	
< 0.1–0.2		MORGAN	81	COSM	^{4}He abundance
< 0.85		BEG	78	ASTR	Stellar plasmons
< 0.6		[46] SUTHERLAND	76	ASTR	Red giants + degen. dwarfs
< 1		BERNSTEIN	63	ASTR	Cooling white dwarfs
<14		COWAN	57	CNTR	Reactor $\overline{\nu}_e$

[36] DERBIN 94 supersedes DERBIN 93.
[37] GOYAL 95 assume that helicity flip via μ_ν would result in faster cooling and hence shorter burst from SN1987A. Limit is based on the assumed presence of a pion condensate or quark core in the remanant.
[38] VIDYAKIN 92 limit is from a $e\overline{\nu}_e$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2\theta_W = 0.23$ as input.
[39] KRAKAUER 90 experiment fully reported in ALLEN 93.
[40] 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.
[41] Significant dependence on details of stellar models.
[42] A limit of 10^{-13} is obtained with even more model-dependence.
[43] These papers have assumed that the right-handed neutrino is inert; see BARBIERI 88B.
[44] FUKUGITA 88 find magnetic dipole moments of any two neutrino species are bounded by $\mu < 10^{-16}$ $[10^{-9}\ G/B_0]$ where B_0 is the present-day intergalactic field strength.
[45] Some dependence on details of stellar models.
[46] We obtain above limit from SUTHERLAND 76 using their limit $f < 1/3$.

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)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.9±2.7		ALLEN	93	CNTR	LAMPF $\nu_e e \rightarrow \nu_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<2.3	95	MOURAO	92	ASTR	HOME/KAM2 ν rates
<7.3	90	[47] VIDYAKIN	92	CNTR	Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$
1.1±2.3		ALLEN	91	CNTR	Repl. by ALLEN 93
		[48] GRIFOLS	89B	ASTR	SN 1987A

[47] VIDYAKIN 92 limit is from a $e\overline{\nu}_e$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2\theta_W = 0.23$ as input.
[48] GRIFOLS 89B sets a limit of $\langle r^2 \rangle < 0.2 \times 10^{-32}$ cm^2 for right-handed neutrinos.

ν_e REFERENCES

BELESEV 95 PL B350 263 +Bleule, Geraskin, Golubev+ (INRM, KIAE)
CHING 95 IJMP A10 2841 +Ho, Liang, Mao, Chen, Sun (CST, BEIJT, CIAE)
GOYAL 95 PL B346 312 +Dutta, Choudhury (DELH)
HIDDEMANN 95 JP G21 639 +Daniel, Schwentker (MUNT)
KERNAN 95 NP B437 243 +Krauss (CASE)
STOEFFL 95 PRL 75 3237 +Decman (LLNL)
DERBIN 94 PAN 57 222 (PNPI)
Translated from YAF 57 236.
YASUMI 94 PL B334 229 +Maezawa, Shima, Inagaki+ (KEK, TSUK, KYOT+)
ALLEN 93 PR D47 11 +Chen, Doe, Hausammann+ (UCI, LANL, ANL, UMD)
DERBIN 93 JETPL 57 768 +Chernyi, Popeko, Muratova+ (PNPI)
Translated from ZETFP 57 755.
SUN 93 CJNP 15 261 +Liang, Chen, Si+ (CIAE, CST, BEIJT)
WEINHEIMER 93 PL B300 210 +Przyrembel, Backe+ (MANZ)
BLUDMAN 92 PR D45 4720 (CFPA)
HOLZSCHUH 92 RPP 55 1035 (ZURI)
HOLZSCHUH 92B PL B287 381 +Fritschi, Kuendig (ZURI)
MOURAO 92 PL B285 364 +Pulido, Ralston (LISB, LISBT, CERN, KANS)
VIDYAKIN 92 JETPL 55 206 +Vyrodov, Gurevich, Koslov+ (KIAE)
Translated from ZETFP 55 212.
ALLEN 91 PR D43 R1 +Chen, Doe, Hausammann (UCI, LANL, UMD)
KAWAKAMI 91 PL B256 105 +Kato, Ohshima+ (INUS, TOHOK, TINT, KOBE, KEK)
KRAKAUER 91 PR D44 R6 +Talaga, Allen, Chen+ (LAMPF E225 Collab.)
ROBERTSON 91 PRL 67 957 +Bowles, Stephenson, Wark, Wilkerson, Knapp (LASL, LLL)
AVIGNONE 90 PR D41 682 +Collar (SCUC)
KRAKAUER 90 PL B252 177 +Talaga, Allen, Chen+ (LAMPF E225 Collab.)
RAFFELT 90 PRL 64 2856 (MPIM)
VOLOSHIN 90 NP B (Proc. Suppl) 19 433 (ITEP)
Neutrino 90 Conference
CHUPP 89 PRL 62 505 +Vestrand, Reppin (UNH, MPIM)
COWSIK 89 PL B218 91 +Schramm, Hoflich (WUSL, TATA, CHIC, MPIM)
GRIFOLS 89B PR D40 3819 +Masso (BARC)
KOLB 89 PRL 62 509 +Turner (CHIC, FNAL)
LOREDO 89 ANYAS 571 601 +Lamb (CHIC)
RAFFELT 89 PR D39 2066 (PRIN, UCB)
RAFFELT 89B APJ 336 61 +Dearborn, Silk (UCB, LLL)
REDONDO 89 PR C40 368 +Robertson (LANL)
BARBIERI 88 PRL 61 27 +Mohapatra (PISA, UMD)
BARBIERI 88B PL B213 69 +Mohapatra, Yanagida (PISA, UMD, MICH)

BORIS	88	PRL 61 245 erratum	+Golutvin, Laptin+	(ITEP, ASCI)
FUKUGITA	88	PRL 60 879	+Notzold, Raffelt, Silk	(KYOTY, MPIM, UCB)
GOLDMAN	88	PRL 60 1789	+Aharanov, Alexander, Nussinov	(TELA)
LATTIMER	88	PRL 61 23	+Cooperstein	(STON, BNL)
Also	88B	PRL 61 2633 erratum	Lattimer, Cooperstein	(STON, BNL)
NOETZOLD	88	PR D38 1658		(MPIM)
NOTZOLD	88	PR D38 1658		(MPIM)
RAFFELT	88B	PR D37 549	+Dearborn	(UCB, LLL)
SPERGEL	88	PL B200 366	+Bahcall	(IAS)
STODOLSKY	88	PL B201 353		(MPIM)
VOLOSHIN	88	PL B209 360		(ITEP)
Also	88B	JETPL 47 501	Voloshin	(ITEP)
		Translated from ZETFP 47 421.		
VOLOSHIN	88C	JETPL 68 690		(ITEP)
VONFEILIT...	88	PL B200 580	Von Feilitzsch, Oberauer	(MUNT)
BARBIELLINI	87	Nature 329 21	+Cocconi	(CERN)
BORIS	87	PRL 58 2019	+Golutvin, Laptin+	(ITEP, ASCI)
Also	88	PRL 61 245 erratum	Boris, Golutvin, Laptin+	(ITEP, ASCI)
BORIS	87B	JETPL 45 333	+Golutvin, Laptin+	(ITEP)
		Translated from ZETFP 45 267.		
FUKUGITA	87	PR D36 3817	+Yazaki	(KYOTY, TOKY)
LOSECCO	87B	PR D35 2073	+Bionta, Blewitt, Bratton+	(IMB Collab.)
OBERAUER	87	PL B198 113	+von Feilitzsch, Mossbauer	(MUNT)
SPRINGER	87	PR A35 679	+Bennet, Baisden+	(LLNL)
BERGKVIST	86	Moriond Conf., Vol. M48, 465		(STOH)
KETOV	86	JETPL 44 146	+Klimov, Nikolaev, Mikaelyan+	(KIAE)
		Translated from ZETFP 44 114.		
YASUMI	86	PL B181 169	+Ando+	(KEK, OSAK, TOHOK, TSUK, KYOT, INUS+)
BERGKVIST	85B	PL 159B 408		(STOH)
RAFFELT	85	PR D31 3002		(MPIM)
KYULDJIEV	84	NP B243 387		(SOFI)
SIMPSON	84	PR D30 1110		(GUEL)
HENRY	81	PRL 47 618	+Feldman	(JHU)
KIMBLE	81	PRL 46 80	+Bowyer, Jakobsen	(UCB)
LYNN	81	PR D23 2151		(COLU)
MORGAN	81	PL 102B 247	Morgan	(SUSS)
FUJIKAWA	80	PRL 45 963	+Shrock	(STON)
LUBIMOV	80	PL 94B 266	+Novikov, Nozik, Tretyakov, Kosik	(ITEP)
Also	80	SJNP 32 154	Kozik, Lubimov, Novikov+	(ITEP)
		Translated from YAF 32 301.		
Also	81	JETP 54 616	Lubimov, Novikov, Nozik+	(ITEP)
		Translated from ZETF 81 1158.		
STECKER	80	PRL 45 1460		(NASA)
BEG	78	PR D17 1395	+Marciano, Ruderman	(ROCK, COLU)
LEE	77C	PR D16 1444	+Shrock	(STON)
SUTHERLAND	76	PR D13 2700	+Ng, Flowers+	(PENN, COLU, NYU)
CLARK	74	PR D9 533	+Elioff, Frisch, Johnson, Kerth, Shen+	(LBL)
REINES	74	PRL 32 180	+Sobel, Gurr	(UCI)
Also	78	Private Comm.	Barnes	(PURD)
BECK	68	ZPHY 216 229	+Daniel	(MPIH)
BERNSTEIN	63	PR 132 1227	+Ruderman, Feinberg	(NYU, COLU)
COWAN	57	PR 107 528	+Reines	(LANL)