# $\nu_e$

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

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

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## $\nu_e$ MASS

Most of the data from which these limits are derived are from $\beta^-$ 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 $m_{\nu_1}$. Results from studies of electron capture transitions, given below "$m_{\nu_1} - m_{\overline{\nu}_1}$", give limits on $m_{\nu_1}$ 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 $\beta$ decay |
| < 12.4 | 95 | [2] CHING | 95 | SPEC | $^3$H $\beta$ decay |
| < 92 | 95 | [3] HIDDEMANN | 95 | SPEC | $^3$H $\beta$ decay |
| $15\ ^{+32}_{-15}$ | | HIDDEMANN | 95 | SPEC | $^3$H $\beta$ decay |
| < 19.6 | 95 | KERNAN | 95 | ASTR | SN 1987A |
| < 7.0 | 95 | [4] STOEFFL | 95 | SPEC | $^3$H $\beta$ decay |
| <460 | 68 | [5] YASUMI | 94 | CNTR | $e$ capture in $^{163}$Ho |
| < 7.2 | 95 | [6] WEINHEIMER | 93 | SPEC | $^3$H $\beta$ decay |
| < 11.7 | 95 | [7] HOLZSCHUH | 92B | SPEC | $^3$H $\beta$ decay |
| < 13.1 | 95 | [8] KAWAKAMI | 91 | SPEC | $^3$H $\beta$ decay |
| < 9.3 | 95 | [9] ROBERTSON | 91 | SPEC | $^3$H $\beta$ 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 $\beta$ 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 $m_\nu^2 = -4.1 \pm 10.9$ 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 $m_\nu^2$ is given.

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

[4] STOEFFL 95 (LLNL) result is the Bayesian limit obtained from the $m_\nu^2$ errors given below but with $m_\nu^2$ set equal to 0. The anomalous endpoint accumulation leads to a value of $m_\nu^2$ 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 $\beta$ 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 $m_\nu^2 = -24 \pm 48 \pm 61$ ($1\sigma$ errors), in eV$^2$, using the PDG prescription for conversion to a limit in $m_\nu$.

[8] KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid. This result is the Bayesian limit obtained from the $m_\nu^2$ 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 $m_\nu$ 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.

## $\nu_e$ 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 $m_{\nu_1}$ 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 $m_{\nu_1}$ measurements.

| *VALUE* (eV$^2$) | | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|---|
| **$-27 \pm 20$ OUR AVERAGE** | | | Error includes scale factor of 4.2. See the ideogram below. | | | |
| $-22 \pm 4.8$ | | | [11] BELESEV | 95 | SPEC | $^3$H $\beta$ decay |
| $-130 \pm 20 \pm 15$ | | 95 | [12] STOEFFL | 95 | SPEC | $^3$H $\beta$ decay |
| $-31 \pm 75 \pm 48$ | | | [13] SUN | 93 | SPEC | $^3$H $\beta$ decay |
| $-39 \pm 34 \pm 15$ | | | [14] WEINHEIMER | 93 | SPEC | $^3$H $\beta$ decay |
| $-24 \pm 48 \pm 61$ | | | [15] HOLZSCHUH | 92B | SPEC | $^3$H $\beta$ decay |
| $-65 \pm 85 \pm 65$ | | | [16] KAWAKAMI | 91 | SPEC | $^3$H $\beta$ decay |
| $-147 \pm 68 \pm 41$ | | | [17] ROBERTSON | 91 | SPEC | $^3$H $\beta$ decay |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $129 \pm 6010$ | | | [18] HIDDEMANN | 95 | SPEC | $^3$H $\beta$ decay |
| $313 \pm 5994$ | | | [18] HIDDEMANN | 95 | SPEC | $^3$H $\beta$ 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 $m_\nu^2$. The authors acknowledge that "the negative value for the best fit of $m_\nu^2$ has no physical meaning" and discuss possible explanations for this effect.

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

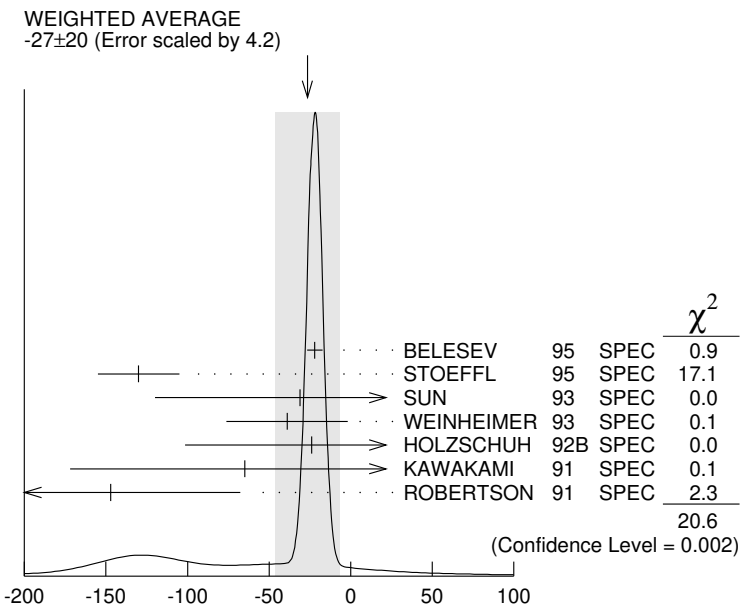
[14] WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium $\beta$ spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.

[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 $m_\nu$ lies between 17 and 40 eV. However, the probability of a positive $m_\nu^2$ 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.




$m^2_{\nu_e}$ (eV$^2$)

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

These are measurement of $m_{\nu_1}$ (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 | $\nu$, $^{163}$Ho |
| $< 550$ | 68 | YASUMI | 86 | CNTR | $\nu$, $^{163}$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 | $\nu$, $^{22}$Na |

## $\nu_1$ 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.

## $\nu_1$ MEAN LIFE

| *VALUE* (s) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [20] BILLER | 98 | ASTR | $m_\nu$= 0.05–1 eV |
| | | [21] COWSIK | 89 | ASTR | $m_\nu$ = 1–50 MeV |
| | | [22] RAFFELT | 89 | RVUE | $\overline{\nu}$ (Dirac, Majorana) |
| | | [23] RAFFELT | 89B | ASTR | |
| >278 | 90 | [24] LOSECCO | 87B | IMB | |
| $> 1.1 \times 10^{25}$ | | [25] HENRY | 81 | ASTR | $m_\nu$= 16–20 eV |
| $> 10^{22}$–$10^{23}$ | | [26] KIMBLE | 81 | ASTR | $m_\nu$= 10–100 eV |

[20] BILLER 98 use the observed TeV $\gamma$-ray spectra to set limits on the mean life of a radiatively decaying neutrino between 0.05 and 1 eV. Curve shows $\tau_\nu/B_\gamma > 0.15 \times 10^{21}$ s at 0.05 eV, $> 1.2 \times 10^{21}$ s at 0.17 eV, $> 3 \times 10^{21}$ s at 1 eV, where $B_\gamma$ is the branching ratio to photons.

[21] 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 MeV) s.

[22] 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.

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

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

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

[26] KIMBLE 81 uses extreme UV flux limits.

## $\nu_1$ (MEAN LIFE) / MASS

| *VALUE* (s/eV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **$> 7 \times 10^9$** | | [27] RAFFELT | 85 | ASTR | |
| **>300** | 90 | [28] REINES | 74 | CNTR | $\overline{\nu}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $>$ | $2.8 \times 10^{15}$ | | [29,30] | BLUDMAN | 92 | ASTR | $m_\nu < 50$ eV |
| $>$ | 6.4 | 90 | [31] | KRAKAUER | 91 | CNTR | $\overline{\nu}$ at LAMPF |
| $>$ | $6.3 \times 10^{15}$ | | [30,32] | CHUPP | 89 | ASTR | $m_\nu < 20$ eV |
| $>$ | $1.7 \times 10^{15}$ | | [30] | KOLB | 89 | ASTR | $m_\nu < 20$ eV |
| $>$ | $8.3 \times 10^{14}$ | | [33] | VONFEILIT... | 88 | ASTR | |
| $>$ | 22 | 68 | [34] | OBERAUER | 87 | | $\overline{\nu}_R$ (Dirac) |
| $>$ | 38 | 68 | [34] | OBERAUER | 87 | | $\overline{\nu}$ (Majorana) |
| $>$ | 59 | 68 | [34] | OBERAUER | 87 | | $\overline{\nu}_L$ (Dirac) |
| $>$ | 30 | 68 | | KETOV | 86 | CNTR | $\overline{\nu}$ (Dirac) |
| $>$ | 20 | 68 | | KETOV | 86 | CNTR | $\overline{\nu}$ (Majorana) |
| $>$ | $2 \times 10^{21}$ | | [35] | STECKER | 80 | ASTR | $m_\nu$= 10–100 eV |

[27] RAFFELT 85 limit is from solar x- and $\gamma$-ray fluxes. Limit depends on $\nu$ flux from $pp$, now established from GALLEX and SAGE to be $> 0.5$ of expectation.

[28] REINES 74 looked for $\nu_e$ of nonzero mass decaying to a neutral of lesser mass + $\gamma$. 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 (VOGEL 84). If so, OBERAUER 87 may be comparable or better.

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

[30] Nonobservation of $\gamma$'s in coincidence with $\nu$'s from SN 1987A.

[31] 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 $a = -1$).

[32] 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.

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

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

[35] 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 | [36] STODOLSKY | 88 | ASTR | SN 1987A |
| **<0.2** | | [37] LONGO | 87 | ASTR | SN 1987A |

[36] 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.

[37] LONGO 87 argues that uncertainty between light and neutrino transit times is $\pm 3$ hr, ignoring FREJUS events.

## $\nu_1$ 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 $\mu_\nu = 3eG_F m_\nu/(8\pi^2\sqrt{2}) = (3.20\times10^{-19})m_\nu\mu_B$ where $m_\nu$ 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, $\mu(\nu_1) < 2.3\times10^{-18}\ \mu_B$. 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 $\mu_\nu$, ... 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 | [38] 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. • • • | | | | | |
| < 0.62 | | [39] ELMFORS | 97 | COSM | Depolarization in early universe plasma |
| < 3.2 | 90 | [40] GOVAERTS | 96 | | |
| < 0.003–0.0005 | | [41] GOYAL | 95 | | SN 1987A |
| < 7.7 | 95 | MOURAO | 92 | ASTR | HOME/KAM2 $\nu$ rates |
| < 2.4 | 90 | [42] VIDYAKIN | 92 | CNTR | Reactor $\overline{\nu}_e e \to \overline{\nu}_e e$ |
| <10.8 | 90 | [43] KRAKAUER | 90 | CNTR | LAMPF $\nu_e e \to \nu_e e$ |
| < 0.02 | | [44] RAFFELT | 90 | ASTR | Red giant luminosity |
| < 0.1 | | [45] RAFFELT | 89B | ASTR | Cooling helium stars |
| < 0.02–0.08 | | [45,46,47] BARBIERI | 88 | ASTR | SN 1987A |
| | | [48] FUKUGITA | 88 | COSM | Primordial magn. fields |
| < 0.01 | | [46,47,49] GOLDMAN | 88 | ASTR | SN 1987A |
| < 0.005 | | [45,47] LATTIMER | 88 | ASTR | SN 1987A |
| ≤ 0.015 | | [45,47] NOETZOLD | 88 | ASTR | SN 1987A |
| ≤ .3 | | [45] RAFFELT | 88B | ASTR | He burning stars |
| < 0.11 | | [45] 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 | | [50] SUTHERLAND | 76 | ASTR | Red giants + degen. dwarfs |
| < 1 | | BERNSTEIN | 63 | ASTR | Solar cooling |
| <14 | | COWAN | 57 | CNTR | Reactor $\overline{\nu}_e$ |

[38] DERBIN 94 supersedes DERBIN 93.

[39] ELMFORS 97 calculate the rate of depolarization in a plasma for neutrinos with a magnetic moment and use the constraints from a big-bang nucleosynthesis on additional degrees of freedom.

[40] GOVAERTS 96 limit is on $\sqrt{\Sigma\,\mu\nu_\ell^2}$, based on limits on $2\nu$ decay of ortho-positronium.

[41] GOYAL 95 assume that helicity flip via $\mu_\nu$ 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.

[42] 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.

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

[44] 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 $\delta M_c$.

[45] Significant dependence on details of stellar models.

[46] A limit of $10^{-13}$ is obtained with even more model-dependence.

[47] These papers have assumed that the right-handed neutrino is inert; see BARBIERI 88B.

[48] 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.

[49] Some dependence on details of stellar models.

[50] 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 $\nu$ rates |
| <7.3 | 90 | [51] VIDYAKIN | 92 | CNTR | Reactor $\overline{\nu}_e e \rightarrow \overline{\nu}_e e$ |
| 1.1±2.3 | | ALLEN | 91 | CNTR | Repl. by ALLEN 93 |
| | | [52] GRIFOLS | 89B | ASTR | SN 1987A |

[51] 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.

[52] GRIFOLS 89B sets a limit of $\langle r^2 \rangle < 0.2 \times 10^{-32}$ cm$^2$ for right-handed neutrinos.

## $\nu_e$ REFERENCES


| | | | | |
|---|---|---|---|---|
| BILLER | 98 | PRL 80 2992 | S.D. Biller+ | (WHIPPLE Collab.) |
| ELMFORS | 97 | NP B503 3 | P. Elmfors, K. Enqvist, G. Raffelt, G. Sigl | |
| GOVAERTS | 96 | PL B381 451 | +Van Caillie | (LOUV) |
| 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 | (KYOTU, 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 | (KYOTU, TOKY) |
| LONGO | 87 | PR D36 3276 | M.J. Longo | (MICH) |
| 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) |
| VOGEL | 84 | PR D30 1505 | P. Vogel | |
| 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. | | |

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|---|---|---|---|---|
| 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) |