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. See also the Listings in the Neutrino Bounds from Astrophysics and Cosmology section.

VALUE (eV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
OUR LIMIT		[1] PDG 94	RVUE	See the note below.
< 7.2	95	[2] WEINHEIMER 93	SPEC	^{3}H β decay
<11.7	95	[3] HOLZSCHUH 92B	SPEC	^{3}H β decay
<13.1	95	[4] KAWAKAMI 91	SPEC	^{3}H β decay
< 9.3	95	[5] ROBERTSON 91	SPEC	^{3}H β decay
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		[6] VANDYCK 93		$m_{^3\text{H}} - m_{^3\text{He}}$
< 8.0	95	[7] DECMAN 92	CNTR	^{3}H β decay
<14	95	AVIGNONE 90	ASTR	Supernova SN 1987A
<23		LOREDO 89	ASTR	SN 1987A
		ABBOTT 88	ASTR	Supernova SN 1987A
<29	95	[8] KAWAKAMI 88	SPEC	Repl. by KAWAKAMI 91
		[9] SPERGEL 88	ASTR	Supernova SN 1987A
17 to 40		[10] BORIS 87	SPEC	$\overline{\nu}_e$, ^{3}H β decay
<27	95	[11] WILKERSON 87	SPEC	$\overline{\nu}_e$, ^{3}H β decay
<18	95	[12] FRITSCHI 86	SPEC	Repl. by HOLZSCHUH 92B

[1] PDG 94 formal upper limit, as obtained from the m^2 average in the next section, is 5.1 eV at the 95%CL. Caution is urged in interpreting this result, since the m^2 average is positive with only a 3.5% probability. If the weighted average m^2 were forced to zero, the limit would increase to 7.0 eV.

[2] WEINHEIMER 93 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.

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

[4] KAWAKAMI 91 experiment uses tritium-labeled arachidic acid. This result may be obtained from the $m^2_{\nu_1}$ limit by combining the errors in quadrature and using the method described in the Probability, Statistics, and Monte Carlo section in Chapter III of this *Review*. This was also done in ROBERTSON 91, although the authors report a different procedure.

[5] ROBERTSON 91 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_1} 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.

[6] VANDYCK 93 is a new measurement of the atomic masses of ^{3}H and ^{3}He. The authors note that "The excellent agreement with recent results from beta spectrometers lends strong support for new (upper) limits on the (electron) neutrio's rest mass."

[7] DECMAN 92 was not published in a refereed journal, so we do not use it in our compilation, but we include it for the reader's convenience. If it were included our limit would be reduced to 4.9 eV, but the average m^2 would be positive with only a 1.1% probability.

[8] KAWAKAMI 88 multiply their statistical error by the appropriate factor for 95% CL when $m^2 > 0$ is required (1.74), add this linearly to their unmultiplied systematic error (173 eV^2) and add the m^2 value (223 eV^2) to obtain their 95% CL limit (m<29 eV). To adjust for our quadratic addition of errors and our multiplication of both the statistical and systematic errors by the factor 1.645 we set the systematic error to 269 eV^2 to yield the same limit.

[9] SPERGEL 88 rule out masses greater than 16 eV.

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

[11] WILKERSON 87 multiply both statistical and systematic errors by 1.645 (for 95% CL), add them in quadrature and add the (negative) m^2 value (-57 eV^2) to obtain their 95% CL limit (m<27 eV).

[12] FRITSCHI 86 multiply their statistical error by 1.645 (for 95% CL), add this linearly to their unmultiplied systematic error (204 eV^2) and do NOT add in the m^2 value (-11 eV^2) to obtain their 95% CL limit (m<18 eV). To adjust for our quadratic addition of errors, and our multiplication of both the statistical and systematic errors by the factor 1.645, we set the systematic error to 178 eV^2.

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)	*DOCUMENT ID*	*TECN*	*COMMENT*
$-$ 54± 30 OUR AVERAGE			
$-$ 39± 34± 15	[13] WEINHEIMER 93	SPEC	^{3}H β decay
$-$ 24± 48± 61	[14] HOLZSCHUH 92B	SPEC	^{3}H β decay
$-$ 65± 85± 65	[15] KAWAKAMI 91	SPEC	$\overline{\nu}_e$, tritium
$-$147± 68± 41	[16] ROBERTSON 91	SPEC	$\overline{\nu}_e$, tritium
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$-$ 72± 41± 30	[17] DECMAN 92	SPEC	^{3}H β decay
223±244±269	[18] KAWAKAMI 88	SPEC	Repl. by KAWAKAMI 91
$-$ 57±453±118	[19] WILKERSON 87	SPEC	Repl. by ROBERTSON 91
$-$ 11± 63±178	[20] FRITSCHI 86	SPEC	Repl. by HOLZSCHUH 92B

[13] WEINHEIMER 93 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.

[14] HOLZSCHUH 92B source is a monolayer of tritiated hydrocarbon.

[15] KAWAKAMI 91 experiment uses tritium-labeled arachidic acid.

[16] ROBERTSON 91 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_1} 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.

[17] DECMAN 92 was not published in a refereed journal, so we do not use it in our compilation, but we include it for the reader's convenience. If it were included, our average would be -58 ± 26 eV^2.

[18] KAWAKAMI 88 multiply their statistical error by the appropriate factor for 95% CL when $m^2 > 0$ is required (1.74), add this linearly to their unmultiplied systematic error (173 eV^2) and add the m^2 value (223 eV^2) to obtain their 95% CL limit (m<29 eV). To adjust for our quadratic addition of errors and our multiplication of both the statistical and systematic errors by the factor 1.645 we set the systematic error to 269 eV^2 to yield the same limit.

[19] WILKERSON 87 multiply both statistical and systematic errors by 1.645 (for 95% CL), add them in quadrature and add the (negative) m^2 value (-57 eV^2) to obtain their 95% CL limit (m<27 eV).

[20] FRITSCHI 86 multiply their statistical error by 1.645 (for 95% CL), add this linearly to their unmultiplied systematic error (204 eV^2) and do NOT add in the m^2 value (-11 eV^2) to obtain their 95% CL limit (m<18 eV). To adjust for our quadratic addition of errors, and our multiplication of both the statistical and systematic errors by the factor 1.645, we set the systematic error to 178 eV^2.

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

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. • • •				
<1250		[21] YASUMI 83	CNTR	ν, ^{163}Ho
<1300		ANDERSEN 82	CNTR	ν, ^{163}Ho
< 4.5×10^5	90	CLARK 74	ASPK	K_{e3} decay
<4100	67	BECK 68	CNTR	ν, ^{22}Na

[21] Assumes upper limit on *Q*-value reported by ANDERSEN 82. Replaced by YASUMI 86.

ν_1 CHARGE

VALUE (units: electron charge)	*DOCUMENT ID*	*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$<2 \times 10^{-15}$	[22] BARBIELLINI 87	ASTR	Supernova SN 1987A
$<1 \times 10^{-13}$	BERNSTEIN 63	ASTR	Solar energy losses

[22] 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*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
>278	90	[23] LOSECCO 87B	IMB

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