LEPTONS

e

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

Mass $m = (548.57990945 \pm 0.00000024) \times 10^{-6}$ u
Mass $m = 0.51099892 \pm 0.00000004$ MeV
$\left|m_{e^+} - m_{e^-}\right|/m < 8 \times 10^{-9}$, CL = 90%
$\left|q_{e^+} + q_{e^-}\right|/e < 4 \times 10^{-8}$
Magnetic moment $\mu = 1.001159652187 \pm 0.000000000004\ \mu_B$
$(g_{e^+} - g_{e^-}) / g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$
Electric dipole moment $d = (0.07 \pm 0.07) \times 10^{-26}\ e\,\text{cm}$
Mean life $\tau > 4.6 \times 10^{26}$ yr, CL = 90% [a]

μ

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

Mass $m = 0.1134289264 \pm 0.0000000030$ u
Mass $m = 105.658369 \pm 0.000009$ MeV
Mean life $\tau = (2.19703 \pm 0.00004) \times 10^{-6}$ s
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.654$ m
Magnetic moment $\mu = 1.0011659203 \pm 0.0000000007\ e\hbar/2m_\mu$
$(g_{\mu^+} - g_{\mu^-}) / g_{\text{average}} = (-2.6 \pm 1.6) \times 10^{-8}$
Electric dipole moment $d = (3.7 \pm 3.4) \times 10^{-19}\ e\,\text{cm}$

Decay parameters [b]

$\rho = 0.7518 \pm 0.0026$
$\eta = -0.007 \pm 0.013$
$\delta = 0.749 \pm 0.004$
$\xi P_\mu = 1.003 \pm 0.008$ [c]
$\xi P_\mu \delta/\rho > 0.99682$, CL = 90% [c]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.7 \pm 0.4$
$\alpha/\text{A} = (0 \pm 4) \times 10^{-3}$
$\alpha'/\text{A} = (0 \pm 4) \times 10^{-3}$
$\beta/\text{A} = (4 \pm 6) \times 10^{-3}$
$\beta'/\text{A} = (2 \pm 6) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

μ^+ modes are charge conjugates of the modes below.

μ^- **DECAY MODES**			Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$			$\approx 100\%$			53
$e^- \overline{\nu}_e \nu_\mu \gamma$		[d]	(1.4 ± 0.4) %			53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[e]	$(3.4 \pm 0.4) \times 10^{-5}$			53
Lepton Family number (*LF*) violating modes						
$e^- \nu_e \overline{\nu}_\mu$	*LF*	[f]	< 1.2	%	90%	53
$e^- \gamma$	*LF*		< 1.2	$\times 10^{-11}$	90%	53
$e^- e^+ e^-$	*LF*		< 1.0	$\times 10^{-12}$	90%	53
$e^- 2\gamma$	*LF*		< 7.2	$\times 10^{-11}$	90%	53

$\boxed{\tau}$

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

Mass $m = 1776.99^{+0.29}_{-0.26}$ MeV
$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 3.0 \times 10^{-3}$, CL = 90%
Mean life $\tau = (290.6 \pm 1.1) \times 10^{-15}$ s
$c\tau = 87.11$ μm
Magnetic moment anomaly > -0.052 and < 0.058, CL = 95%
$\text{Re}(d_\tau) = -0.22$ to 0.45×10^{-16} $e\,$cm, CL = 95%
$\text{Im}(d_\tau) = -0.25$ to 0.008×10^{-16} $e\,$cm, CL = 95%

Weak dipole moment

$\text{Re}(d^w_\tau) < 0.50 \times 10^{-17}$ $e\,$cm, CL = 95%
$\text{Im}(d^w_\tau) < 1.1 \times 10^{-17}$ $e\,$cm, CL = 95%

Weak anomalous magnetic dipole moment

$\text{Re}(\alpha^w_\tau) < 1.1 \times 10^{-3}$, CL = 95%
$\text{Im}(\alpha^w_\tau) < 2.7 \times 10^{-3}$, CL = 95%

Decay parameters

See the τ Particle Listings for a note concerning τ-decay parameters.

$\rho^\tau(e \text{ or } \mu) = 0.745 \pm 0.008$
$\rho^\tau(e) = 0.747 \pm 0.010$
$\rho^\tau(\mu) = 0.763 \pm 0.020$
$\xi^\tau(e \text{ or } \mu) = 0.985 \pm 0.030$
$\xi^\tau(e) = 0.994 \pm 0.040$
$\xi^\tau(\mu) = 1.030 \pm 0.059$
$\eta^\tau(e \text{ or } \mu) = 0.013 \pm 0.020$
$\eta^\tau(\mu) = 0.094 \pm 0.073$
$(\delta\xi)^\tau(e \text{ or } \mu) = 0.746 \pm 0.021$
$(\delta\xi)^\tau(e) = 0.734 \pm 0.028$
$(\delta\xi)^\tau(\mu) = 0.778 \pm 0.037$
$\xi^\tau(\pi) = 0.993 \pm 0.022$
$\xi^\tau(\rho) = 0.994 \pm 0.008$
$\xi^\tau(a_1) = 1.001 \pm 0.027$
$\xi^\tau(\text{all hadronic modes}) = 0.995 \pm 0.007$

τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutrals" stands for γ's and/or π^0's.

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^-$ ≥ 0 neutrals $\geq 0 K^0 \nu_\tau$ ("1-prong")		(85.35 ± 0.07) %	S=1.1	–
particle$^-$ ≥ 0 neutrals $\geq 0 K^0_L \nu_\tau$		(84.72 ± 0.07) %	S=1.1	–
$\mu^- \overline{\nu}_\mu \nu_\tau$	[g]	(17.36 ± 0.06) %		885
$\mu^- \overline{\nu}_\mu \nu_\tau \gamma$	[e]	$(3.6 \pm0.4) \times 10^{-3}$		885
$e^- \overline{\nu}_e \nu_\tau$	[g]	(17.84 ± 0.06) %		888
$e^- \overline{\nu}_e \nu_\tau \gamma$	[e]	(1.75 ± 0.18) %		888
$h^- \geq 0 K^0_L \nu_\tau$		(12.30 ± 0.11) %	S=1.4	883
$h^- \nu_\tau$		(11.75 ± 0.11) %	S=1.4	883
$\pi^- \nu_\tau$	[g]	(11.06 ± 0.11) %	S=1.4	883
$K^- \nu_\tau$	[g]	$(6.86\pm0.23) \times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ		(36.92 ± 0.14) %	S=1.1	–
$h^- \pi^0 \nu_\tau$		(25.87 ± 0.13) %	S=1.1	878
$\pi^- \pi^0 \nu_\tau$	[g]	(25.42 ± 0.14) %	S=1.1	878
$\pi^- \pi^0$ non-$\rho(770) \nu_\tau$		$(3.0 \pm3.2) \times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g]	$(4.50\pm0.30) \times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$		(10.77 ± 0.15) %	S=1.1	–

$h^- 2\pi^0 \nu_\tau$		$(9.39\pm0.14)\ \%$	S=1.1	862
$h^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$		$(9.23\pm0.14)\ \%$	S=1.1	862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	$(9.17\pm0.14)\ \%$	S=1.1	862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$, scalar		$< 9 \times 10^{-3}$	CL=95%	862
$\pi^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$, vector		$< 7 \times 10^{-3}$	CL=95%	862
$K^- 2\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	$(5.8\pm2.3) \times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$		$(1.37\pm0.11)\ \%$	S=1.1	–
$h^- 3\pi^0 \nu_\tau$		$(1.21\pm0.10)\ \%$		836
$\pi^- 3\pi^0 \nu_\tau (\text{ex.}K^0)$	[g]	$(1.08\pm0.10)\ \%$		836
$K^- 3\pi^0 \nu_\tau (\text{ex.}K^0, \eta)$	[g]	$(3.8\ ^{+2.2}_{-2.0}) \times 10^{-4}$		766
$h^- 4\pi^0 \nu_\tau (\text{ex.}K^0)$		$(1.6\pm0.6) \times 10^{-3}$		800
$h^- 4\pi^0 \nu_\tau (\text{ex.}K^0,\eta)$	[g]	$(1.0\ ^{+0.6}_{-0.5}) \times 10^{-3}$		800
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma\ \nu_\tau$		$(1.56\pm0.04)\ \%$		820
$K^- \geq 1\ (\pi^0 \text{ or } K^0 \text{ or } \gamma)\ \nu_\tau$		$(8.74\pm0.35) \times 10^{-3}$		–

Modes with K^0's

$K^0_S (\text{particles})^- \nu_\tau$		$(9.2\pm0.4) \times 10^{-3}$	S=1.1	–
$h^- \overline{K}^0 \nu_\tau$		$(1.05\pm0.04)\ \%$	S=1.1	812
$\pi^- \overline{K}^0 \nu_\tau$	[g]	$(8.9\pm0.4) \times 10^{-3}$	S=1.1	812
$\pi^- \overline{K}^0 (\text{non-}K^*(892)^-) \nu_\tau$		$< 1.7 \times 10^{-3}$	CL=95%	812
$K^- K^0 \nu_\tau$	[g]	$(1.54\pm0.16) \times 10^{-3}$		737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(3.09\pm0.24) \times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		$(5.2\pm0.4) \times 10^{-3}$		794
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[g]	$(3.7\pm0.4) \times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		$(2.2\pm0.5) \times 10^{-3}$		612
$K^- K^0 \pi^0 \nu_\tau$	[g]	$(1.55\pm0.20) \times 10^{-3}$		685
$\pi^- \overline{K}^0 \geq 1\pi^0 \nu_\tau$		$(3.2\pm1.0) \times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$		$(2.6\pm2.4) \times 10^{-4}$		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4}$	CL=95%	619
$\pi^- K^0 \overline{K}^0 \nu_\tau$		$(1.59\pm0.29) \times 10^{-3}$	S=1.1	682
$\pi^- K^0_S K^0_S \nu_\tau$	[g]	$(2.4\pm0.5) \times 10^{-4}$		682
$\pi^- K^0_S K^0_L \nu_\tau$	[g]	$(1.10\pm0.28) \times 10^{-3}$	S=1.1	682
$\pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau$		$(3.1\pm2.3) \times 10^{-4}$		614
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	614
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$		$(3.1\pm1.2) \times 10^{-4}$		614
$K^0 h^+ h^- h^- \geq 0 \text{ neutrals}\ \nu_\tau$		$< 1.7 \times 10^{-3}$	CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$		$(2.3\pm2.0) \times 10^{-4}$		760

Modes with three charged particles

$h^- h^- h^+ \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(15.19 ± 0.07) %	S=1.1	861
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+ \pi^-$) ("3-prong")		(14.57 ± 0.07) %	S=1.1	861
$h^- h^- h^+ \nu_\tau$		(10.01 ± 0.09) %	S=1.2	861
$h^- h^- h^+ \nu_\tau$ (ex.K^0)		(9.65 ± 0.09) %	S=1.2	861
$h^- h^- h^+ \nu_\tau$ (ex.K^0,ω)		(9.60 ± 0.09) %	S=1.2	861
$\pi^- \pi^+ \pi^- \nu_\tau$		(9.47 ± 0.10) %	S=1.2	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)		(9.16 ± 0.10) %	S=1.2	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0), non-axial vector		< 2.4 %	CL=95%	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0,ω)	[g]	(9.12 ± 0.10) %	S=1.2	861
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.19 ± 0.10) %	S=1.3	–
$h^- h^- h^+ \geq 1$ neutrals ν_τ (ex. $K^0_S \to \pi^+ \pi^-$)		(4.92 ± 0.09) %	S=1.3	–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.53 ± 0.09) %	S=1.3	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex.K^0)		(4.35 ± 0.09) %	S=1.3	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)		(2.62 ± 0.09) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		(4.37 ± 0.09) %	S=1.3	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		(4.25 ± 0.09) %	S=1.3	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0,ω)	[g]	(2.51 ± 0.09) %	S=1.2	834
$h^- h^- h^+ 2\pi^0 \nu_\tau$		$(5.5 \pm 0.4) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0)		$(5.4 \pm 0.4) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0,ω,η)	[g]	$(1.1 \pm 0.4) \times 10^{-3}$		797
$h^- h^- h^+ 3\pi^0 \nu_\tau$	[g]	$(2.3 \pm 0.8) \times 10^{-4}$	S=1.5	749
$K^- h^+ h^- \geq 0$ neutrals ν_τ		$(6.9 \pm 0.4) \times 10^{-3}$	S=1.3	794
$K^- h^+ \pi^- \nu_\tau$ (ex.K^0)		$(4.8 \pm 0.4) \times 10^{-3}$	S=1.5	794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		$(1.07 \pm 0.22) \times 10^{-3}$		763
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		$(5.0 \pm 0.4) \times 10^{-3}$	S=1.3	794
$K^- \pi^+ \pi^- \geq 0\pi^0 \nu_\tau$ (ex.K^0)		$(3.9 \pm 0.4) \times 10^{-3}$	S=1.3	794
$K^- \pi^+ \pi^- \nu_\tau$		$(3.8 \pm 0.4) \times 10^{-3}$	S=1.6	794
$K^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)	[g]	$(3.3 \pm 0.4) \times 10^{-3}$	S=1.6	794
$K^- \rho^0 \nu_\tau \to K^- \pi^+ \pi^- \nu_\tau$		$(1.6 \pm 0.6) \times 10^{-3}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		$(1.18 \pm 0.25) \times 10^{-3}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		$(6.5 \pm 2.4) \times 10^{-4}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0,η)	[g]	$(5.9 \pm 2.4) \times 10^{-4}$		763
$K^- \pi^+ K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$	CL=95%	685
$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(1.97 \pm 0.18) \times 10^{-3}$	S=1.1	685
$K^- K^+ \pi^- \nu_\tau$	[g]	$(1.55 \pm 0.07) \times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	$(4.2 \pm 1.6) \times 10^{-4}$	S=1.1	618
$K^- K^+ K^- \geq 0$ neut. ν_τ		$< 2.1 \times 10^{-3}$	CL=95%	472

$K^- K^+ K^- \nu_\tau$		$< 3.7 \times 10^{-5}$	CL=90%	472
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$	CL=95%	794
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$		888
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		$< 3.6 \times 10^{-5}$	CL=90%	885

Modes with five charged particles

$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^- \pi^+$) ("5-prong")		$(1.00 \pm 0.06) \times 10^{-3}$		794
$3h^- 2h^+ \nu_\tau$ (ex. K^0)	[g]	$(8.2 \pm 0.6) \times 10^{-4}$		794
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex. K^0)	[g]	$(1.81 \pm 0.27) \times 10^{-4}$		746
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 1.1 \times 10^{-4}$	CL=90%	687

Miscellaneous other allowed modes

$(5\pi)^- \nu_\tau$		$(8.0 \pm 0.7) \times 10^{-3}$		800
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 2.4 \times 10^{-6}$	CL=90%	683
$X^- (S=-1) \nu_\tau$		(2.91 ± 0.08) %	S=1.1	–
$K^*(892)^- \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.42 ± 0.18) %	S=1.4	665
$K^*(892)^- \nu_\tau$		(1.29 ± 0.05) %		665
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		542
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		656
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		656
$(\overline{K}^*(892)\pi)^- \nu_\tau \to \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4.7 \pm 1.1) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$		$(1.7 \pm 2.6) \times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$		$(1.5 ^{+1.4}_{-1.0}) \times 10^{-3}$		326
$K^*_0(1430)^- \nu_\tau$		$< 5 \times 10^{-4}$	CL=95%	328
$K^*_2(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$		$< 1.4 \times 10^{-4}$	CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g]	$(1.74 \pm 0.24) \times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$		$(1.5 \pm 0.5) \times 10^{-4}$		746
$\eta K^- \nu_\tau$	[g]	$(2.7 \pm 0.6) \times 10^{-4}$		720
$\eta K^*(892)^- \nu_\tau$		$(2.9 \pm 0.9) \times 10^{-4}$		511
$\eta K^- \pi^0 \nu_\tau$		$(1.8 \pm 0.9) \times 10^{-4}$		665
$\eta \overline{K}^0 \pi^- \nu_\tau$		$(2.2 \pm 0.7) \times 10^{-4}$		661
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%	744
$\eta \pi^- \pi^+ \pi^- \nu_\tau$		$(2.3 \pm 0.5) \times 10^{-4}$		744
$\eta a_1(1260)^- \nu_\tau \to \eta \pi^- \rho^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$		$< 1.1 \times 10^{-4}$	CL=95%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	559

$\eta'(958)\pi^-\nu_\tau$		$<$ 7.4	$\times 10^{-5}$	CL=90%	620
$\eta'(958)\pi^-\pi^0\nu_\tau$		$<$ 8.0	$\times 10^{-5}$	CL=90%	591
$\phi\pi^-\nu_\tau$		$<$ 2.0	$\times 10^{-4}$	CL=90%	585
$\phi K^-\nu_\tau$		$<$ 6.7	$\times 10^{-5}$	CL=90%	445
$f_1(1285)\pi^-\nu_\tau$		(5.8 $\pm$2.3)	$\times 10^{-4}$		408
$f_1(1285)\pi^-\nu_\tau \to \eta\pi^-\pi^+\pi^-\nu_\tau$		(1.3 $\pm$0.4)	$\times 10^{-4}$		–
$\pi(1300)^-\nu_\tau \to (\rho\pi)^-\nu_\tau \to (3\pi)^-\nu_\tau$		$<$ 1.0	$\times 10^{-4}$	CL=90%	–
$\pi(1300)^-\nu_\tau \to ((\pi\pi)_{S-\text{wave}}\pi)^-\nu_\tau \to (3\pi)^-\nu_\tau$		$<$ 1.9	$\times 10^{-4}$	CL=90%	–
$h^-\omega \geq 0$ neutrals ν_τ		(2.38$\pm$0.08) %			708
$h^-\omega\nu_\tau$	[g]	(1.94$\pm$0.07) %			708
$h^-\omega\pi^0\nu_\tau$	[g]	(4.4 $\pm$0.5)	$\times 10^{-3}$		684
$h^-\omega 2\pi^0\nu_\tau$		(1.4 $\pm$0.5)	$\times 10^{-4}$		644
$2h^-h^+\omega\nu_\tau$		(1.20$\pm$0.22)	$\times 10^{-4}$		641

Lepton Family number (*LF*), Lepton number (*L*), or Baryon number (*B*) violating modes

L means lepton number violation (*e.g.* $\tau^- \to e^+\pi^-\pi^-$). Following common usage, *LF* means lepton family violation *and not* lepton number violation (*e.g.* $\tau^- \to e^-\pi^+\pi^-$). *B* means baryon number violation.

$e^-\gamma$	*LF*	$<$ 2.7	$\times 10^{-6}$	CL=90%	888
$\mu^-\gamma$	*LF*	$<$ 1.1	$\times 10^{-6}$	CL=90%	885
$e^-\pi^0$	*LF*	$<$ 3.7	$\times 10^{-6}$	CL=90%	883
$\mu^-\pi^0$	*LF*	$<$ 4.0	$\times 10^{-6}$	CL=90%	880
$e^-K^0_S$	*LF*	$<$ 9.1	$\times 10^{-7}$	CL=90%	819
$\mu^-K^0_S$	*LF*	$<$ 9.5	$\times 10^{-7}$	CL=90%	815
$e^-\eta$	*LF*	$<$ 8.2	$\times 10^{-6}$	CL=90%	804
$\mu^-\eta$	*LF*	$<$ 9.6	$\times 10^{-6}$	CL=90%	800
$e^-\rho^0$	*LF*	$<$ 2.0	$\times 10^{-6}$	CL=90%	719
$\mu^-\rho^0$	*LF*	$<$ 6.3	$\times 10^{-6}$	CL=90%	715
$e^-K^*(892)^0$	*LF*	$<$ 5.1	$\times 10^{-6}$	CL=90%	665
$\mu^-K^*(892)^0$	*LF*	$<$ 7.5	$\times 10^{-6}$	CL=90%	660
$e^-\overline{K}^*(892)^0$	*LF*	$<$ 7.4	$\times 10^{-6}$	CL=90%	665
$\mu^-\overline{K}^*(892)^0$	*LF*	$<$ 7.5	$\times 10^{-6}$	CL=90%	660
$e^-\phi$	*LF*	$<$ 6.9	$\times 10^{-6}$	CL=90%	596
$\mu^-\phi$	*LF*	$<$ 7.0	$\times 10^{-6}$	CL=90%	590
$e^-e^+e^-$	*LF*	$<$ 2.9	$\times 10^{-6}$	CL=90%	888
$e^-\mu^+\mu^-$	*LF*	$<$ 1.8	$\times 10^{-6}$	CL=90%	882
$e^+\mu^-\mu^-$	*LF*	$<$ 1.5	$\times 10^{-6}$	CL=90%	882
$\mu^-e^+e^-$	*LF*	$<$ 1.7	$\times 10^{-6}$	CL=90%	885
$\mu^+e^-e^-$	*LF*	$<$ 1.5	$\times 10^{-6}$	CL=90%	885

$\mu^- \mu^+ \mu^-$	*LF*	$<$	1.9	$\times 10^{-6}$	CL=90%	873
$e^- \pi^+ \pi^-$	*LF*	$<$	2.2	$\times 10^{-6}$	CL=90%	877
$e^+ \pi^- \pi^-$	*L*	$<$	1.9	$\times 10^{-6}$	CL=90%	877
$\mu^- \pi^+ \pi^-$	*LF*	$<$	8.2	$\times 10^{-6}$	CL=90%	866
$\mu^+ \pi^- \pi^-$	*L*	$<$	3.4	$\times 10^{-6}$	CL=90%	866
$e^- \pi^+ K^-$	*LF*	$<$	6.4	$\times 10^{-6}$	CL=90%	813
$e^- \pi^- K^+$	*LF*	$<$	3.8	$\times 10^{-6}$	CL=90%	813
$e^+ \pi^- K^-$	*L*	$<$	2.1	$\times 10^{-6}$	CL=90%	813
$e^- K^0_S K^0_S$	*LF*	$<$	2.2	$\times 10^{-6}$	CL=90%	736
$e^- K^+ K^-$	*LF*	$<$	6.0	$\times 10^{-6}$	CL=90%	739
$e^+ K^- K^-$	*L*	$<$	3.8	$\times 10^{-6}$	CL=90%	739
$\mu^- \pi^+ K^-$	*LF*	$<$	7.5	$\times 10^{-6}$	CL=90%	800
$\mu^- \pi^- K^+$	*LF*	$<$	7.4	$\times 10^{-6}$	CL=90%	800
$\mu^+ \pi^- K^-$	*L*	$<$	7.0	$\times 10^{-6}$	CL=90%	800
$\mu^- K^0_S K^0_S$	*LF*	$<$	3.4	$\times 10^{-6}$	CL=90%	696
$\mu^- K^+ K^-$	*LF*	$<$	1.5	$\times 10^{-5}$	CL=90%	699
$\mu^+ K^- K^-$	*L*	$<$	6.0	$\times 10^{-6}$	CL=90%	699
$e^- \pi^0 \pi^0$	*LF*	$<$	6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	*LF*	$<$	1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta \eta$	*LF*	$<$	3.5	$\times 10^{-5}$	CL=90%	699
$\mu^- \eta \eta$	*LF*	$<$	6.0	$\times 10^{-5}$	CL=90%	654
$e^- \pi^0 \eta$	*LF*	$<$	2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	*LF*	$<$	2.2	$\times 10^{-5}$	CL=90%	784
$\overline{p} \gamma$	*L,B*	$<$	3.5	$\times 10^{-6}$	CL=90%	641
$\overline{p} \pi^0$	*L,B*	$<$	1.5	$\times 10^{-5}$	CL=90%	632
$\overline{p} 2\pi^0$	*L,B*	$<$	3.3	$\times 10^{-5}$	CL=90%	604
$\overline{p} \eta$	*L,B*	$<$	8.9	$\times 10^{-6}$	CL=90%	475
$\overline{p} \pi^0 \eta$	*L,B*	$<$	2.7	$\times 10^{-5}$	CL=90%	360
e^- light boson	*LF*	$<$	2.7	$\times 10^{-3}$	CL=95%	–
μ^- light boson	*LF*	$<$	5	$\times 10^{-3}$	CL=95%	–

Heavy Charged Lepton Searches

$L^\pm$ – charged lepton

Mass $m >$ 100.8 GeV, CL = 95% [h]   Decay to νW.

$L^{\pm}$ – stable charged heavy lepton

Mass $m >$ 102.6 GeV, CL = 95%

ν_e

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

The following results are obtained using neutrinos associated with e^+ or e^-. See the Note on "Electron, muon, and tau neutrino listings" in the Particle Listings.

Mass $m <$ 3 eV Interpretation of tritium beta decay experiments is complicated by anomalies near the endpoint, and the limits are not without ambiguity.

Mean life/mass, $\tau/m_\nu > 7 \times 10^9$ s/eV [i] (solar)

Mean life/mass, $\tau/m_\nu >$ 300 s/eV, CL = 90% [i] (reactor)

Magnetic moment $\mu < 1.0 \times 10^{-10}\ \mu_B$, CL = 90%

ν_μ

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

The following results are obtained using neutrinos associated with μ^+ or μ^-. See the Note on "Electron, muon, and tau neutrino listings" in the Particle Listings.

Mass $m <$ 0.19 MeV, CL = 90%

Mean life/mass, $\tau/m_\nu >$ 15.4 s/eV, CL = 90%

Magnetic moment $\mu < 6.8 \times 10^{-10}\ \mu_B$, CL = 90%

ν_τ

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

The following results are obtained using neutrinos associated with τ^+ or τ^-. See the Note on "Electron, muon, and tau neutrino listings" in the Particle Listings.

Mass $m <$ 18.2 MeV, CL = 95%

Magnetic moment $\mu < 3.9 \times 10^{-7}\ \mu_B$, CL = 90%

Electric dipole moment $d < 5.2 \times 10^{-17}\ e\,$cm, CL = 95%

Number of Neutrino Types and Sum of Neutrino Masses

Number $N = 2.994 \pm 0.012$ (Standard Model fits to LEP data)

Number $N = 2.92 \pm 0.07$ (Direct measurement of invisible Z width)

Neutrino Mixing

There is now compelling evidence that neutrinos have nonzero mass from the observation of neutrino flavor change, both from the study of atmospheric neutrino fluxes by SuperKamiokande, and from the study of solar neutrino cross sections by SNO (charged and neutral currents) and SuperKamiokande (elastic scattering). The flavor change observed in solar neutrinos has been confirmed by the KamLAND experiment using reactor antineutrinos.

Solar Neutrinos

Detectors using gallium ($E_\nu \gtrsim 0.2$ MeV), chlorine ($E_\nu \gtrsim 0.8$ MeV), and Cherenkov effect in water ($E_\nu \gtrsim 5$ MeV) measure significantly lower neutrino rates than are predicted from solar models. From the determination by SNO of the ^{8}B solar neutrino flux via elastic scattering, charged-current process interactions, and neutral-current interactions, one can determine the flux of non-ν_e active neutrinos to be $\phi(\nu_{\mu\tau}) = (3.41^{+0.66}_{-0.64}) \times 10^6\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, providing a $5.3\,\sigma$ evidence for neutrino flavor change. A global analysis of the solar neutrino data, including the KamLAND results that confirm the effect using reactor antineutrinos, favors large mixing angles and $\Delta(m^2) \simeq (6\text{–}9) \times 10^{-5}\ \mathrm{eV}^2$. See the Note "Solar Neutrinos" in the Listings and the review "Neutrino Mass, Mixing, and Flavor Change."

Atmospheric Neutrinos

Underground detectors observing neutrinos produced by cosmic rays in the atmosphere have measured a ν_μ/ν_e ratio much less than expected, and also a deficiency of upward going ν_μ compared to downward. This can be explained by oscillations leading to the disappearance of ν_μ with $\Delta m^2 \approx (1\text{–}3) \times 10^{-3}\ \mathrm{eV}^2$ and almost full mixing between ν_μ and ν_τ. The effect has been confirmed by the K2K experiment using accelerator neutrinos. See the review "Neutrino Mass, Mixing, and Flavor Change."

Heavy Neutral Leptons, Searches for

For excited leptons, see Compositeness Limits below.

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 90.3 GeV, CL = 95%
(Dirac ν_L coupling to e, μ, τ; conservative case(τ))

Mass $m >$ 80.5 GeV, CL = 95%
(Majorana ν_L coupling to e, μ, τ; conservative case(τ))

NOTES

[*a*] This is the best limit for the mode $e^- \rightarrow \nu\gamma$. The best limit for "electron disappearance" is 6.4×10^{24} yr.

[*b*] See the "Note on Muon Decay Parameters" in the μ Particle Listings for definitions and details.

[*c*] P_μ is the longitudinal polarization of the muon from pion decay. In standard $V-A$ theory, $P_\mu = 1$ and $\rho = \delta = 3/4$.

[*d*] This only includes events with the γ energy $>$ 10 MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[*e*] See the relevant Particle Listings for the energy limits used in this measurement.

[*f*] A test of additive vs. multiplicative lepton family number conservation.

[*g*] Basis mode for the τ.

[*h*] $L^\pm$ mass limit depends on decay assumptions; see the Full Listings.

[*i*] Limit assumes radiative decay of neutrino.