

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

$|m_{e^+} - m_{e^-}|/m < 8 \times 10^{-9}$, CL = 90%

$|q_{e^+} + q_{e^-}|/e < 4 \times 10^{-8}$

Magnetic moment $\mu = 1.0011596521859 \pm 0.00000000000038 \mu_B$

$(g_{e^+} - g_{e^-}) / g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$

Electric dipole moment $d = (0.07 \pm 0.07) \times 10^{-26}$ e 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 $\mu = 1.0011659208 \pm 0.0000000006 e\hbar/2m_{\mu}$

$(g_{\mu^+} - g_{\mu^-}) / g_{\text{average}} = (-0.11 \pm 0.12) \times 10^{-8}$

Electric dipole moment $d = (3.7 \pm 3.4) \times 10^{-19}$ e cm

Decay parameters [b]

$\rho = 0.7509 \pm 0.0010$

$\eta = 0.001 \pm 0.024$ (S = 2.0)

$\delta = 0.7495 \pm 0.0012$

$\xi P_{\mu} = 1.003 \pm 0.008$ [c]

$\xi P_{\mu} \delta / \rho > 0.99682$, CL = 90% [c]

$\xi' = 1.00 \pm 0.04$

$\xi'' = 0.7 \pm 0.4$

$\alpha/A = (0 \pm 4) \times 10^{-3}$

$\alpha'/A = (0 \pm 4) \times 10^{-3}$

$\beta/A = (4 \pm 6) \times 10^{-3}$

$\beta'/A = (1 \pm 5) \times 10^{-3}$

$\bar{\eta} = 0.02 \pm 0.08$

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

μ^- DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	P (MeV/c)
$e^- \bar{\nu}_e \nu_\mu$	$\approx 100\%$		53
$e^- \bar{\nu}_e \nu_\mu \gamma$	[d] $(1.4 \pm 0.4)\%$		53
$e^- \bar{\nu}_e \nu_\mu e^+ e^-$	[e] $(3.4 \pm 0.4) \times 10^{-5}$		53
Lepton Family number (LF) violating modes			
$e^- \nu_e \bar{\nu}_\mu$	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



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

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 $\tau = (290.6 \pm 1.0) \times 10^{-15}$ s

$c\tau = 87.11$ μm

Magnetic moment anomaly > -0.052 and < 0.013 , 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

$\text{Re}(d_\tau^W) < 0.50 \times 10^{-17}$ e cm, CL = 95%

$\text{Im}(d_\tau^W) < 1.1 \times 10^{-17}$ e cm, CL = 95%

Weak anomalous magnetic dipole moment

$\text{Re}(\alpha_\tau^W) < 1.1 \times 10^{-3}$, CL = 95%

$\text{Im}(\alpha_\tau^W) < 2.7 \times 10^{-3}$, CL = 95%

Decay parameters

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

$\rho^\tau(e \text{ or } \mu) = 0.745 \pm 0.008$

$\rho^\tau(e) = 0.747 \pm 0.010$

$\rho^\tau(\mu) = 0.763 \pm 0.020$

$\xi^\tau(e \text{ or } \mu) = 0.985 \pm 0.030$

$\xi^\tau(e) = 0.994 \pm 0.040$

$\xi^\tau(\mu) = 1.030 \pm 0.059$

$\eta^\tau(e \text{ or } \mu) = 0.013 \pm 0.020$

$\eta^\tau(\mu) = 0.094 \pm 0.073$

$(\delta\xi)^\tau(e \text{ or } \mu) = 0.746 \pm 0.021$

$(\delta\xi)^\tau(e) = 0.734 \pm 0.028$

$$\begin{aligned}
 (\delta\xi)^\tau(\mu) &= 0.778 \pm 0.037 \\
 \xi^\tau(\pi) &= 0.993 \pm 0.022 \\
 \xi^\tau(\rho) &= 0.994 \pm 0.008 \\
 \xi^\tau(a_1) &= 1.001 \pm 0.027 \\
 \xi^\tau(\text{all hadronic modes}) &= 0.995 \pm 0.007
 \end{aligned}$$

τ^+ modes are charge conjugates of the modes below. “ h^\pm ” stands for π^\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 $\geq 0K^0\nu_\tau$ (“1-prong”)	(85.33 \pm 0.08) %	S=1.4	–
particle ⁻ ≥ 0 neutrals $\geq 0K_L^0\nu_\tau$	(84.69 \pm 0.09) %	S=1.4	–
$\mu^- \bar{\nu}_\mu \nu_\tau$	[g] (17.36 \pm 0.05) %		885
$\mu^- \bar{\nu}_\mu \nu_\tau \gamma$	[e] (3.6 \pm 0.4) $\times 10^{-3}$		885
$e^- \bar{\nu}_e \nu_\tau$	[g] (17.84 \pm 0.05) %		888
$e^- \bar{\nu}_e \nu_\tau \gamma$	[e] (1.75 \pm 0.18) %		888
$h^- \geq 0K_L^0 \nu_\tau$	(12.14 \pm 0.07) %	S=1.1	883
$h^- \nu_\tau$	(11.59 \pm 0.06) %	S=1.1	883
$\pi^- \nu_\tau$	[g] (10.90 \pm 0.07) %	S=1.1	883
$K^- \nu_\tau$	[g] (6.91 \pm 0.23) $\times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ	(37.05 \pm 0.12) %	S=1.3	–
$h^- \geq 1\pi^0 \nu_\tau$ (ex. K^0)	(36.51 \pm 0.12) %	S=1.3	–
$h^- \pi^0 \nu_\tau$	(25.95 \pm 0.10) %	S=1.1	878
$\pi^- \pi^0 \nu_\tau$	[g] (25.50 \pm 0.10) %	S=1.1	878
$\pi^- \pi^0$ non- $\rho(770) \nu_\tau$	(3.0 \pm 3.2) $\times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g] (4.52 \pm 0.27) $\times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$	(10.81 \pm 0.14) %	S=1.5	–
$h^- 2\pi^0 \nu_\tau$	(9.47 \pm 0.12) %	S=1.3	862
$h^- 2\pi^0 \nu_\tau$ (ex. K^0)	(9.31 \pm 0.12) %	S=1.3	862
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0)	[g] (9.25 \pm 0.12) %	S=1.3	862
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0), scalar	< 9 $\times 10^{-3}$	CL=95%	862
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0), vector	< 7 $\times 10^{-3}$	CL=95%	862
$K^- 2\pi^0 \nu_\tau$ (ex. K^0)	[g] (5.8 \pm 2.3) $\times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$	(1.33 \pm 0.07) %	S=1.1	–
$h^- \geq 3\pi^0 \nu_\tau$ (ex. K^0)	(1.25 \pm 0.07) %	S=1.1	–
$h^- 3\pi^0 \nu_\tau$	(1.17 \pm 0.08) %	S=1.1	836
$\pi^- 3\pi^0 \nu_\tau$ (ex. K^0)	[g] (1.04 \pm 0.08) %	S=1.1	836
$K^- 3\pi^0 \nu_\tau$ (ex. K^0 , η)	[g] (4.2 \pm 2.1) $\times 10^{-4}$		766

$h^- 4\pi^0 \nu_\tau$ (ex. K^0)	(1.6 ± 0.4) × 10 ⁻³		800
$h^- 4\pi^0 \nu_\tau$ (ex. K^0, η)	[g] (1.0 ± 0.4) × 10 ⁻³		800
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma \nu_\tau$	(1.57 ± 0.04) %	S=1.1	820
$K^- \geq 1 (\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau$	(8.78 ± 0.33) × 10 ⁻³		—

Modes with K^0 's

K_S^0 (particles) ⁻ ν_τ	(9.27 ± 0.34) × 10 ⁻³	S=1.1	—
$h^- \bar{K}^0 \nu_\tau$	(1.05 ± 0.04) %	S=1.1	812
$\pi^- \bar{K}^0 \nu_\tau$	[g] (9.0 ± 0.4) × 10 ⁻³	S=1.1	812
$\pi^- \bar{K}^0$	< 1.7 × 10 ⁻³	CL=95%	812
(non- $K^*(892)^-$) ν_τ			
$K^- K^0 \nu_\tau$	[g] (1.53 ± 0.16) × 10 ⁻³		737
$K^- K^0 \geq 0\pi^0 \nu_\tau$	(3.07 ± 0.24) × 10 ⁻³		737
$h^- \bar{K}^0 \pi^0 \nu_\tau$	(5.3 ± 0.4) × 10 ⁻³		794
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	[g] (3.8 ± 0.4) × 10 ⁻³		794
$\bar{K}^0 \rho^- \nu_\tau$	(2.2 ± 0.5) × 10 ⁻³		612
$K^- K^0 \pi^0 \nu_\tau$	[g] (1.54 ± 0.20) × 10 ⁻³		685
$\pi^- \bar{K}^0 \geq 1\pi^0 \nu_\tau$	(3.2 ± 1.0) × 10 ⁻³		—
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$	(2.6 ± 2.4) × 10 ⁻⁴		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$	< 1.6 × 10 ⁻⁴	CL=95%	619
$\pi^- K^0 \bar{K}^0 \nu_\tau$	(1.60 ± 0.31) × 10 ⁻³	S=1.2	682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g] (2.4 ± 0.5) × 10 ⁻⁴		682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g] (1.12 ± 0.30) × 10 ⁻³	S=1.2	682
$\pi^- K^0 \bar{K}^0 \pi^0 \nu_\tau$	(3.1 ± 2.3) × 10 ⁻⁴		614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	< 2.0 × 10 ⁻⁴	CL=95%	614
$\pi^- K_S^0 K_L^0 \pi^0 \nu_\tau$	(3.1 ± 1.2) × 10 ⁻⁴		614
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ	< 1.7 × 10 ⁻³	CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$	(2.3 ± 2.0) × 10 ⁻⁴		760

Modes with three charged particles

$h^- h^- h^+ \geq 0$ neutrals $\geq 0K_L^0 \nu_\tau$	(15.22 ± 0.09) %	S=1.4	861
$h^- h^- h^+ \geq 0$ neutrals ν_τ	(14.59 ± 0.08) %	S=1.4	861
(ex. $K_S^0 \rightarrow \pi^+ \pi^-$) ("3-prong")			
$h^- h^- h^+ \nu_\tau$	(9.87 ± 0.08) %	S=1.3	861
$h^- h^- h^+ \nu_\tau$ (ex. K^0)	(9.51 ± 0.08) %	S=1.3	861
$h^- h^- h^+ \nu_\tau$ (ex. K^0, ω)	(9.47 ± 0.08) %	S=1.3	861
$\pi^- \pi^+ \pi^- \nu_\tau$	(9.33 ± 0.08) %	S=1.3	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. K^0)	(9.02 ± 0.08) %	S=1.3	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] (8.99 ± 0.08) %	S=1.3	861
$h^- h^- h^+ \geq 1$ neutrals ν_τ	(5.34 ± 0.06) %	S=1.1	—
$h^- h^- h^+ \geq 1\pi^0 \nu_\tau$ (ex. K^0)	(5.06 ± 0.06) %	S=1.1	—
$h^- h^- h^+ \pi^0 \nu_\tau$	(4.73 ± 0.07) %	S=1.2	834

$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0)	(4.55±0.06) %	S=1.2	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)	(2.78±0.08) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	(4.59±0.07) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)	(4.46±0.06) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω) [g]	(2.69±0.08) %	S=1.2	834
$h^- h^- h^+ \geq 2\pi^0 \nu_\tau$ (ex. K^0)	(5.14±0.34) × 10 ⁻³	S=1.1	—
$h^- h^- h^+ 2\pi^0 \nu_\tau$	(5.02±0.34) × 10 ⁻³	S=1.1	797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex. K^0)	(4.92±0.34) × 10 ⁻³	S=1.1	797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex. K^0, ω, η) [g]	(9 ±4) × 10 ⁻⁴		797
$h^- h^- h^+ 3\pi^0 \nu_\tau$ [g]	(2.2 ±0.5) × 10 ⁻⁴		749
$K^- h^+ h^- \geq 0$ neutrals ν_τ	(6.79±0.35) × 10 ⁻³	S=1.3	794
$K^- h^+ \pi^- \nu_\tau$ (ex. K^0)	(4.86±0.32) × 10 ⁻³	S=1.4	794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)	(8.5 ±1.2) × 10 ⁻⁴		763
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ	(5.2 ±0.4) × 10 ⁻³	S=1.5	794
$K^- \pi^+ \pi^- \geq 0\pi^0 \nu_\tau$ (ex. K^0)	(4.1 ±0.4) × 10 ⁻³	S=1.5	794
$K^- \pi^+ \pi^- \nu_\tau$	(3.9 ±0.4) × 10 ⁻³	S=1.6	794
$K^- \pi^+ \pi^- \nu_\tau$ (ex. K^0) [g]	(3.33±0.35) × 10 ⁻³	S=1.6	794
$K^- \rho^0 \nu_\tau \rightarrow K^- \pi^+ \pi^- \nu_\tau$	(1.6 ±0.6) × 10 ⁻³		—
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$	(1.32±0.14) × 10 ⁻³		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)	(7.9 ±1.2) × 10 ⁻⁴		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, η) [g]	(7.3 ±1.2) × 10 ⁻⁴		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω)	(3.7 ±0.9) × 10 ⁻⁴		763
$K^- \pi^+ K^- \geq 0$ neut. ν_τ	< 9 × 10 ⁻⁴	CL=95%	685
$K^- K^+ \pi^- \geq 0$ neut. ν_τ	(1.59±0.10) × 10 ⁻³	S=1.4	685
$K^- K^+ \pi^- \nu_\tau$ [g]	(1.53±0.10) × 10 ⁻³	S=1.4	685
$K^- K^+ \pi^- \pi^0 \nu_\tau$ [g]	(6.1 ±2.0) × 10 ⁻⁵	S=1.1	618
$K^- K^+ K^- \geq 0$ neut. ν_τ	< 2.1 × 10 ⁻³	CL=95%	472
$K^- K^+ K^- \nu_\tau$	< 3.7 × 10 ⁻⁵	CL=90%	472
$K^- K^+ K^- \pi^0 \nu_\tau$	< 4.8 × 10 ⁻⁶	CL=90%	346
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ	< 2.5 × 10 ⁻³	CL=95%	794
$e^- e^- e^+ \bar{\nu}_e \nu_\tau$	(2.8 ±1.5) × 10 ⁻⁵		888
$\mu^- e^- e^+ \bar{\nu}_\mu \nu_\tau$	< 3.6 × 10 ⁻⁵	CL=90%	885

Modes with five charged particles

$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \rightarrow \pi^- \pi^+$) ("5-prong")	(1.02±0.04) × 10 ⁻³	S=1.1	794
$3h^- 2h^+ \nu_\tau$ (ex. K^0) [g]	(8.38±0.35) × 10 ⁻⁴	S=1.1	794
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex. K^0) [g]	(1.78±0.27) × 10 ⁻⁴		746
$3h^- 2h^+ 2\pi^0 \nu_\tau$	< 1.1 × 10 ⁻⁴	CL=90%	687

Miscellaneous other allowed modes

$(5\pi)^- \nu_\tau$	$(7.6 \pm 0.5) \times 10^{-3}$	S=1.1	800
$4h^- 3h^+ \geq 0$ neutrals ν_τ	$< 3.0 \times 10^{-7}$	CL=90%	683
("7-prong")			
$4h^- 3h^+ \nu_\tau$	$< 4.3 \times 10^{-7}$	CL=90%	683
$4h^- 3h^+ \pi^0 \nu_\tau$	$< 2.5 \times 10^{-7}$	CL=90%	612
$X^-(S=-1) \nu_\tau$	$(2.95 \pm 0.07) \%$	S=1.1	—
$K^*(892)^- \geq 0$ neutrals \geq	$(1.42 \pm 0.18) \%$	S=1.4	665
$0K_L^0 \nu_\tau$			
$K^*(892)^- \nu_\tau$	$(1.29 \pm 0.05) \%$		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
$\bar{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ	$(3.8 \pm 1.7) \times 10^{-3}$		656
$\bar{K}^*(892)^0 \pi^- \nu_\tau$	$(2.2 \pm 0.5) \times 10^{-3}$		656
$(\bar{K}^*(892)\pi)^- \nu_\tau \rightarrow$	$(1.0 \pm 0.4) \times 10^{-3}$		—
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$			
$K_1(1270)^- \nu_\tau$	$(4.7 \pm 1.1) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$	$(1.7 \pm 2.6) \times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$	$(1.5 \begin{smallmatrix} +1.4 \\ -1.0 \end{smallmatrix}) \times 10^{-3}$		326
$K_0^*(1430)^- \nu_\tau$	$< 5 \times 10^{-4}$	CL=95%	326
$K_2^*(1430)^- \nu_\tau$	$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$	$< 1.4 \times 10^{-4}$	CL=95%	798
$\eta \pi^- \pi^0 \nu_\tau$	[g] $(1.77 \pm 0.24) \times 10^{-3}$		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
$\eta \bar{K}^0 \pi^- \nu_\tau$	$(2.2 \pm 0.7) \times 10^{-4}$		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
$\eta a_1(1260)^- \nu_\tau \rightarrow \eta \pi^- \rho^0 \nu_\tau$	$< 3.9 \times 10^{-4}$	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
$f_1(1285) \pi^- \nu_\tau$	$(4.1 \pm 0.8) \times 10^{-4}$		408
$f_1(1285) \pi^- \nu_\tau \rightarrow$	$(1.3 \pm 0.4) \times 10^{-4}$		—
$\eta \pi^- \pi^+ \pi^- \nu_\tau$			
$\pi(1300)^- \nu_\tau \rightarrow (\rho \pi)^- \nu_\tau \rightarrow$	$< 1.0 \times 10^{-4}$	CL=90%	—
$(3\pi)^- \nu_\tau$			

$\pi(1300)^- \nu_\tau \rightarrow$	< 1.9	$\times 10^{-4}$	CL=90%	—
$((\pi\pi)_{S\text{-wave}} \pi)^- \nu_\tau \rightarrow$				
$(3\pi)^- \nu_\tau$				
$h^- \omega \geq 0$ neutrals ν_τ	(2.39±0.09) %		S=1.2	708
$h^- \omega \nu_\tau$	[g] (1.99±0.08) %		S=1.2	708
$K^- \omega \nu_\tau$	(4.1 ±0.9) $\times 10^{-4}$			610
$h^- \omega \pi^0 \nu_\tau$	[g] (4.1 ±0.4) $\times 10^{-3}$			684
$h^- \omega 2\pi^0 \nu_\tau$	(1.4 ±0.5) $\times 10^{-4}$			644
$2h^- h^+ \omega \nu_\tau$	(1.20±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. $\tau^- \rightarrow e^+ \pi^- \pi^-$). Following common usage, *LF* means lepton family violation *and not* lepton number violation (e.g. $\tau^- \rightarrow e^- \pi^+ \pi^-$). *B* means baryon number violation.

$e^- \gamma$	LF	< 1.1	$\times 10^{-7}$	CL=90%	888
$\mu^- \gamma$	LF	< 6.8	$\times 10^{-8}$	CL=90%	885
$e^- \pi^0$	LF	< 1.9	$\times 10^{-7}$	CL=90%	883
$\mu^- \pi^0$	LF	< 4.1	$\times 10^{-7}$	CL=90%	880
$e^- K_S^0$	LF	< 9.1	$\times 10^{-7}$	CL=90%	819
$\mu^- K_S^0$	LF	< 9.5	$\times 10^{-7}$	CL=90%	815
$e^- \eta$	LF	< 2.4	$\times 10^{-7}$	CL=90%	804
$\mu^- \eta$	LF	< 1.5	$\times 10^{-7}$	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
$e^- \bar{K}^*(892)^0$	LF	< 7.4	$\times 10^{-6}$	CL=90%	665
$\mu^- \bar{K}^*(892)^0$	LF	< 7.5	$\times 10^{-6}$	CL=90%	660
$e^- \eta'(958)$	LF	< 1.0	$\times 10^{-6}$	CL=90%	630
$\mu^- \eta'(958)$	LF	< 4.7	$\times 10^{-7}$	CL=90%	625
$e^- \phi$	LF	< 6.9	$\times 10^{-6}$	CL=90%	596
$\mu^- \phi$	LF	< 7.0	$\times 10^{-6}$	CL=90%	590
$e^- e^+ e^-$	LF	< 2.0	$\times 10^{-7}$	CL=90%	888
$e^- \mu^+ \mu^-$	LF	< 2.0	$\times 10^{-7}$	CL=90%	882
$e^+ \mu^- \mu^-$	LF	< 1.3	$\times 10^{-7}$	CL=90%	882
$\mu^- e^+ e^-$	LF	< 1.9	$\times 10^{-7}$	CL=90%	885
$\mu^+ e^- e^-$	LF	< 1.1	$\times 10^{-7}$	CL=90%	885
$\mu^- \mu^+ \mu^-$	LF	< 1.9	$\times 10^{-7}$	CL=90%	873
$e^- \pi^+ \pi^-$	LF	< 1.2	$\times 10^{-7}$	CL=90%	877
$e^+ \pi^- \pi^-$	L	< 2.7	$\times 10^{-7}$	CL=90%	877
$\mu^- \pi^+ \pi^-$	LF	< 2.9	$\times 10^{-7}$	CL=90%	866
$\mu^+ \pi^- \pi^-$	L	< 7	$\times 10^{-8}$	CL=90%	866
$e^- \pi^+ K^-$	LF	< 3.2	$\times 10^{-7}$	CL=90%	813

$e^- \pi^- K^+$	<i>LF</i>	< 1.7	$\times 10^{-7}$	CL=90%	813
$e^+ \pi^- K^-$	<i>L</i>	< 1.8	$\times 10^{-7}$	CL=90%	813
$e^- K_S^0 K_S^0$	<i>LF</i>	< 2.2	$\times 10^{-6}$	CL=90%	736
$e^- K^+ K^-$	<i>LF</i>	< 1.4	$\times 10^{-7}$	CL=90%	739
$e^+ K^- K^-$	<i>L</i>	< 1.5	$\times 10^{-7}$	CL=90%	739
$\mu^- \pi^+ K^-$	<i>LF</i>	< 2.6	$\times 10^{-7}$	CL=90%	800
$\mu^- \pi^- K^+$	<i>LF</i>	< 3.2	$\times 10^{-7}$	CL=90%	800
$\mu^+ \pi^- K^-$	<i>L</i>	< 2.2	$\times 10^{-7}$	CL=90%	800
$\mu^- K_S^0 K_S^0$	<i>LF</i>	< 3.4	$\times 10^{-6}$	CL=90%	696
$\mu^- K^+ K^-$	<i>LF</i>	< 2.5	$\times 10^{-7}$	CL=90%	699
$\mu^+ K^- K^-$	<i>L</i>	< 4.8	$\times 10^{-7}$	CL=90%	699
$e^- \pi^0 \pi^0$	<i>LF</i>	< 6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	<i>LF</i>	< 1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta \eta$	<i>LF</i>	< 3.5	$\times 10^{-5}$	CL=90%	700
$\mu^- \eta \eta$	<i>LF</i>	< 6.0	$\times 10^{-5}$	CL=90%	654
$e^- \pi^0 \eta$	<i>LF</i>	< 2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	<i>LF</i>	< 2.2	$\times 10^{-5}$	CL=90%	784
$\bar{p} \gamma$	<i>L,B</i>	< 3.5	$\times 10^{-6}$	CL=90%	641
$\bar{p} \pi^0$	<i>L,B</i>	< 1.5	$\times 10^{-5}$	CL=90%	632
$\bar{p} 2\pi^0$	<i>L,B</i>	< 3.3	$\times 10^{-5}$	CL=90%	604
$\bar{p} \eta$	<i>L,B</i>	< 8.9	$\times 10^{-6}$	CL=90%	475
$\bar{p} \pi^0 \eta$	<i>L,B</i>	< 2.7	$\times 10^{-5}$	CL=90%	360
$\Lambda \pi^-$	<i>L,B</i>	< 7.2	$\times 10^{-8}$	CL=90%	526
$\bar{\Lambda} \pi^-$	<i>L,B</i>	< 1.4	$\times 10^{-7}$	CL=90%	526
e^- light boson	<i>LF</i>	< 2.7	$\times 10^{-3}$	CL=95%	—
μ^- light boson	<i>LF</i>	< 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%

Neutrino Properties

See the note on “Neutrino properties listings” in the Particle Listings.

Mass $m < 2$ eV (tritium decay)

Mean life/mass, $\tau/m > 300$ s/eV, CL = 90% (reactor)

Mean life/mass, $\tau/m > 7 \times 10^9$ s/eV (solar)

Mean life/mass, $\tau/m > 15.4$ s/eV, CL = 90% (accelerator)

Magnetic moment $\mu < 0.9 \times 10^{-10} \mu_B$, CL = 90% (reactor)

Number of Neutrino Types

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

Number $N = 2.93 \pm 0.05$ ($S = 1.2$) (Direct measurement of invisible Z width)

Neutrino Mixing

The following values are obtained through data analyses based on the 3-neutrino mixing scheme described in the review “Neutrino mass, mixing, and flavor change” by B. Kayser in this *Review*.

$$\sin^2(2\theta_{12}) = 0.86^{+0.03}_{-0.04}$$

$$\Delta m_{21}^2 = (8.0^{+0.4}_{-0.3}) \times 10^{-5} \text{ eV}^2$$

The ranges below for $\sin^2(2\theta_{23})$ and Δm_{32}^2 correspond to the projections onto the appropriate axes of the 90% CL contours in the $\sin^2(2\theta_{23})$ - Δm_{32}^2 plane.

$$\sin^2(2\theta_{23}) > 0.92$$

$$\Delta m_{32}^2 = 1.9 \text{ to } 3.0 \times 10^{-3} \text{ eV}^2 [i]$$

$$\sin^2(2\theta_{13}) < 0.19, \text{ CL} = 90\%$$

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 $e^- \bar{\nu}_e \nu_\mu$ and $e^- \bar{\nu}_e \nu_\mu \gamma$ 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] The sign of Δm_{32}^2 is not known at this time. The range quoted is for the absolute value.