

LEPTONS

e

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

$$\text{Mass } m = (548.579909070 \pm 0.000000016) \times 10^{-6} \text{ u}$$

$$\text{Mass } m = 0.5109989461 \pm 0.0000000031 \text{ MeV}$$

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

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

Magnetic moment anomaly

$$(g-2)/2 = (1159.65218091 \pm 0.00000026) \times 10^{-6}$$

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

$$\text{Electric dipole moment } d < 0.11 \times 10^{-28} \text{ e cm, CL} = 90\%$$

$$\text{Mean life } \tau > 6.6 \times 10^{28} \text{ yr, CL} = 90\% \text{ [a]}$$

 μ

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

$$\text{Mass } m = 0.1134289257 \pm 0.0000000025 \text{ u}$$

$$\text{Mass } m = 105.6583745 \pm 0.0000024 \text{ MeV}$$

$$\text{Mean life } \tau = (2.1969811 \pm 0.0000022) \times 10^{-6} \text{ s}$$

$$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$$

$$c\tau = 658.6384 \text{ m}$$

$$\text{Magnetic moment anomaly } (g-2)/2 = (11659209 \pm 6) \times 10^{-10}$$

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

$$\text{Electric dipole moment } d = (-0.1 \pm 0.9) \times 10^{-19} \text{ e cm}$$

Decay parameters [b]

$$\rho = 0.74979 \pm 0.00026$$

$$\eta = 0.057 \pm 0.034$$

$$\delta = 0.75047 \pm 0.00034$$

$$\xi P_{\mu} = 1.0009^{+0.0016}_{-0.0007} \text{ [c]}$$

$$\xi P_{\mu} \delta / \rho = 1.0018^{+0.0016}_{-0.0007} \text{ [c]}$$

$$\xi' = 1.00 \pm 0.04$$

$$\xi'' = 0.98 \pm 0.04$$

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

$$\alpha'/A = (-10 \pm 20) \times 10^{-3}$$

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

$$\beta'/A = (2 \pm 7) \times 10^{-3}$$

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

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] $(6.0 \pm 0.5) \times 10^{-8}$		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 < 4.2	$\times 10^{-13}$	90% 53
$e^- e^+ e^-$	LF < 1.0	$\times 10^{-12}$	90% 53
$e^- 2\gamma$	LF < 7.2	$\times 10^{-11}$	90% 53

τ

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

Mass $m = 1776.86 \pm 0.12$ MeV

$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 2.8 \times 10^{-4}$, CL = 90%

Mean life $\tau = (290.3 \pm 0.5) \times 10^{-15}$ s

$$c\tau = 87.03 \mu\text{m}$$

Magnetic moment anomaly > -0.052 and < 0.013 , CL = 95%

$\text{Re}(d_\tau) = -0.220$ to 0.45×10^{-16} e cm, CL = 95%

$\text{Im}(d_\tau) = -0.250$ to 0.0080×10^{-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%

$\tau^\pm \rightarrow \pi^\pm K_S^0 \nu_\tau$ (RATE DIFFERENCE) / (RATE SUM) =
 $(-0.36 \pm 0.25)\%$

Decay parameters

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

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

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

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

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

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

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

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

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

$$\begin{aligned}
 (\delta\xi)(e \text{ or } \mu) &= 0.746 \pm 0.021 \\
 (\delta\xi)(e) &= 0.734 \pm 0.028 \\
 (\delta\xi)(\mu) &= 0.778 \pm 0.037 \\
 \xi(\pi) &= 0.993 \pm 0.022 \\
 \xi(\rho) &= 0.994 \pm 0.008 \\
 \xi(a_1) &= 1.001 \pm 0.027 \\
 \xi(\text{all hadronic modes}) &= 0.995 \pm 0.007 \\
 \bar{\eta}(\mu) \text{ PARAMETER} &= -1.3 \pm 1.7 \\
 \xi_\kappa(e) \text{ PARAMETER} &= -0.4 \pm 1.2 \\
 \xi_\kappa(\mu) \text{ PARAMETER} &= 0.8 \pm 0.6
 \end{aligned}$$

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 $^- \geq 0$ neutrals $\geq 0K^0 \nu_\tau$ (“1-prong”)	(85.24 \pm 0.06) %		–
particle $^- \geq 0$ neutrals $\geq 0K^0_L \nu_\tau$	(84.58 \pm 0.06) %		–
$\mu^- \bar{\nu}_\mu \nu_\tau$	[g] (17.39 \pm 0.04) %		885
$\mu^- \bar{\nu}_\mu \nu_\tau \gamma$	[e] (3.67 \pm 0.08) $\times 10^{-3}$		885
$e^- \bar{\nu}_e \nu_\tau$	[g] (17.82 \pm 0.04) %		888
$e^- \bar{\nu}_e \nu_\tau \gamma$	[e] (1.83 \pm 0.05) %		888
$h^- \geq 0K^0_L \nu_\tau$	(12.03 \pm 0.05) %		883
$h^- \nu_\tau$	(11.51 \pm 0.05) %		883
$\pi^- \nu_\tau$	[g] (10.82 \pm 0.05) %		883
$K^- \nu_\tau$	[g] (6.96 \pm 0.10) $\times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ	(37.01 \pm 0.09) %		–
$h^- \geq 1\pi^0 \nu_\tau$ (ex. K^0)	(36.51 \pm 0.09) %		–
$h^- \pi^0 \nu_\tau$	(25.93 \pm 0.09) %		878
$\pi^- \pi^0 \nu_\tau$	[g] (25.49 \pm 0.09) %		878
$\pi^- \pi^0$ non- $\rho(770) \nu_\tau$	(3.0 \pm 3.2) $\times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g] (4.33 \pm 0.15) $\times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$	(10.81 \pm 0.09) %		–
$h^- 2\pi^0 \nu_\tau$	(9.48 \pm 0.10) %		862
$h^- 2\pi^0 \nu_\tau$ (ex. K^0)	(9.32 \pm 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau$ (ex. K^0)	[g] (9.26 \pm 0.10) %		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] (6.5 \pm 2.2) $\times 10^{-4}$		796

$h^- \geq 3\pi^0 \nu_\tau$		(1.34 ± 0.07) %	–
$h^- \geq 3\pi^0 \nu_\tau$ (ex. K^0)		(1.25 ± 0.07) %	–
$h^- 3\pi^0 \nu_\tau$		(1.18 ± 0.07) %	836
$\pi^- 3\pi^0 \nu_\tau$ (ex. K^0)	[g]	(1.04 ± 0.07) %	836
$K^- 3\pi^0 \nu_\tau$ (ex. K^0 , η)	[g]	(4.8 ± 2.1) × 10 ⁻⁴	765
$h^- 4\pi^0 \nu_\tau$ (ex. K^0)		(1.6 ± 0.4) × 10 ⁻³	800
$h^- 4\pi^0 \nu_\tau$ (ex. K^0, η)	[g]	(1.1 ± 0.4) × 10 ⁻³	800
$a_1(1260) \nu_\tau \rightarrow \pi^- \gamma \nu_\tau$		(3.8 ± 1.5) × 10 ⁻⁴	–
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma \nu_\tau$		(1.552 ± 0.029) %	820
$K^- \geq 1 (\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau$		(8.59 ± 0.28) × 10 ⁻³	–

Modes with K^0 's

K_S^0 (particles) ⁻ ν_τ		(9.43 ± 0.28) × 10 ⁻³	–
$h^- \bar{K}^0 \nu_\tau$		(9.87 ± 0.14) × 10 ⁻³	812
$\pi^- \bar{K}^0 \nu_\tau$	[g]	(8.38 ± 0.14) × 10 ⁻³	812
$\pi^- \bar{K}^0$		(5.4 ± 2.1) × 10 ⁻⁴	812
(non- $K^*(892)^-$) ν_τ			
$K^- K^0 \nu_\tau$	[g]	(1.486 ± 0.034) × 10 ⁻³	737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		(2.99 ± 0.07) × 10 ⁻³	737
$h^- \bar{K}^0 \pi^0 \nu_\tau$		(5.32 ± 0.13) × 10 ⁻³	794
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	[g]	(3.82 ± 0.13) × 10 ⁻³	794
$\bar{K}^0 \rho^- \nu_\tau$		(2.2 ± 0.5) × 10 ⁻³	612
$K^- K^0 \pi^0 \nu_\tau$	[g]	(1.50 ± 0.07) × 10 ⁻³	685
$\pi^- \bar{K}^0 \geq 1\pi^0 \nu_\tau$		(4.08 ± 0.25) × 10 ⁻³	–
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. K^0)	[g]	(2.6 ± 2.3) × 10 ⁻⁴	763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		< 1.6 × 10 ⁻⁴ CL=95%	619
$\pi^- K^0 \bar{K}^0 \nu_\tau$		(1.55 ± 0.24) × 10 ⁻³	682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g]	(2.35 ± 0.06) × 10 ⁻⁴	682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g]	(1.08 ± 0.24) × 10 ⁻³	682
$\pi^- K_L^0 K_L^0 \nu_\tau$		(2.35 ± 0.06) × 10 ⁻⁴	682
$\pi^- K^0 \bar{K}^0 \pi^0 \nu_\tau$		(3.6 ± 1.2) × 10 ⁻⁴	614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	[g]	(1.82 ± 0.21) × 10 ⁻⁵	614
$K^{*-} K^0 \pi^0 \nu_\tau \rightarrow$ $\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		(1.08 ± 0.21) × 10 ⁻⁵	–
$f_1(1285) \pi^- \nu_\tau \rightarrow$ $\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		(6.8 ± 1.5) × 10 ⁻⁶	–
$f_1(1420) \pi^- \nu_\tau \rightarrow$ $\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		(2.4 ± 0.8) × 10 ⁻⁶	–
$\pi^- K_S^0 K_L^0 \pi^0 \nu_\tau$	[g]	(3.2 ± 1.2) × 10 ⁻⁴	614
$\pi^- K_L^0 K_L^0 \pi^0 \nu_\tau$		(1.82 ± 0.21) × 10 ⁻⁵	614
$K^- K_S^0 K_S^0 \nu_\tau$		< 6.3 × 10 ⁻⁷ CL=90%	466

$K^- K_S^0 K_S^0 \pi^0 \nu_\tau$	< 4.0	$\times 10^{-7}$ CL=90%	337
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ	< 1.7	$\times 10^{-3}$ CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$	[g] (2.5 \pm 2.0)	$\times 10^{-4}$	760
Modes with three charged particles			
$h^- h^- h^+ \geq 0$ neutrals $\geq 0 K_L^0 \nu_\tau$	(15.20 \pm 0.06)	%	861
$h^- h^- h^+ \geq 0$ neutrals ν_τ	(14.55 \pm 0.06)	%	861
(ex. $K_S^0 \rightarrow \pi^+ \pi^-$) ("3-prong")			
$h^- h^- h^+ \nu_\tau$	(9.80 \pm 0.05)	%	861
$h^- h^- h^+ \nu_\tau$ (ex. K^0)	(9.46 \pm 0.05)	%	861
$h^- h^- h^+ \nu_\tau$ (ex. K^0, ω)	(9.43 \pm 0.05)	%	861
$\pi^- \pi^+ \pi^- \nu_\tau$	(9.31 \pm 0.05)	%	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. K^0)	(9.02 \pm 0.05)	%	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 \pm 0.05)	%	861
$h^- h^- h^+ \geq 1$ neutrals ν_τ	(5.29 \pm 0.05)	%	–
$h^- h^- h^+ \geq 1 \pi^0 \nu_\tau$ (ex. K^0)	(5.09 \pm 0.05)	%	–
$h^- h^- h^+ \pi^0 \nu_\tau$	(4.76 \pm 0.05)	%	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0)	(4.57 \pm 0.05)	%	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)	(2.79 \pm 0.07)	%	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	(4.62 \pm 0.05)	%	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)	(4.49 \pm 0.05)	%	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω)	[g] (2.74 \pm 0.07)	%	834
$h^- h^- h^+ \geq 2 \pi^0 \nu_\tau$ (ex. K^0)	(5.17 \pm 0.31)	$\times 10^{-3}$	–
$h^- h^- h^+ 2 \pi^0 \nu_\tau$	(5.05 \pm 0.31)	$\times 10^{-3}$	797
$h^- h^- h^+ 2 \pi^0 \nu_\tau$ (ex. K^0)	(4.95 \pm 0.31)	$\times 10^{-3}$	797
$h^- h^- h^+ 2 \pi^0 \nu_\tau$ (ex. K^0, ω, η)	[g] (10 \pm 4)	$\times 10^{-4}$	797
$h^- h^- h^+ 3 \pi^0 \nu_\tau$	(2.13 \pm 0.30)	$\times 10^{-4}$	749
$2 \pi^- \pi^+ 3 \pi^0 \nu_\tau$ (ex. K^0)	(1.95 \pm 0.30)	$\times 10^{-4}$	749
$2 \pi^- \pi^+ 3 \pi^0 \nu_\tau$ (ex. K^0, η , $f_1(1285)$)	(1.7 \pm 0.4)	$\times 10^{-4}$	–
$2 \pi^- \pi^+ 3 \pi^0 \nu_\tau$ (ex. K^0, η , $\omega, f_1(1285)$)	[g] (1.4 \pm 2.7)	$\times 10^{-5}$	–
$K^- h^+ h^- \geq 0$ neutrals ν_τ	(6.29 \pm 0.14)	$\times 10^{-3}$	794
$K^- h^+ \pi^- \nu_\tau$ (ex. K^0)	(4.37 \pm 0.07)	$\times 10^{-3}$	794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)	(8.6 \pm 1.2)	$\times 10^{-4}$	763
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ	(4.77 \pm 0.14)	$\times 10^{-3}$	794
$K^- \pi^+ \pi^- \geq 0 \pi^0 \nu_\tau$ (ex. K^0)	(3.73 \pm 0.13)	$\times 10^{-3}$	794
$K^- \pi^+ \pi^- \nu_\tau$	(3.45 \pm 0.07)	$\times 10^{-3}$	794
$K^- \pi^+ \pi^- \nu_\tau$ (ex. K^0)	(2.93 \pm 0.07)	$\times 10^{-3}$	794

$K^- \pi^+ \pi^- \nu_\tau$ (ex. K^0, ω)	[g]	$(2.93 \pm 0.07) \times 10^{-3}$	794
$K^- \rho^0 \nu_\tau \rightarrow$ $K^- \pi^+ \pi^- \nu_\tau$		$(1.4 \pm 0.5) \times 10^{-3}$	–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		$(1.31 \pm 0.12) \times 10^{-3}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0)		$(7.9 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, η)		$(7.6 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω)		$(3.7 \pm 0.9) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. K^0, ω, η) [g]		$(3.9 \pm 1.4) \times 10^{-4}$	763
$K^- \pi^+ K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$ CL=95%	685
$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(1.496 \pm 0.033) \times 10^{-3}$	685
$K^- K^+ \pi^- \nu_\tau$	[g]	$(1.435 \pm 0.027) \times 10^{-3}$	685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	$(6.1 \pm 1.8) \times 10^{-5}$	618
$K^- K^+ K^- \nu_\tau$		$(2.2 \pm 0.8) \times 10^{-5}$ S=5.4	472
$K^- K^+ K^- \nu_\tau$ (ex. ϕ)		$< 2.5 \times 10^{-6}$ CL=90%	–
$K^- K^+ K^- \pi^0 \nu_\tau$		$< 4.8 \times 10^{-6}$ CL=90%	345
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$ CL=95%	794
$e^- e^- e^+ \bar{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$	888
$\mu^- e^- e^+ \bar{\nu}_\mu \nu_\tau$		$< 3.6 \times 10^{-5}$ CL=90%	885

Modes with five charged particles

$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K_S^0 \rightarrow \pi^- \pi^+$) ("5-prong")		$(9.9 \pm 0.4) \times 10^{-4}$	794
$3h^- 2h^+ \nu_\tau$ (ex. K^0)		$(8.29 \pm 0.31) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. K^0, ω)		$(8.27 \pm 0.31) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. K^0, ω , $f_1(1285)$)	[g]	$(7.75 \pm 0.30) \times 10^{-4}$	–
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex. K^0)	[g]	$(6 \pm 12) \times 10^{-7}$	716
$K^+ 3\pi^- \pi^+ \nu_\tau$		$< 5.0 \times 10^{-6}$ CL=90%	716
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$		$< 4.5 \times 10^{-7}$ CL=90%	528
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex. K^0)		$(1.65 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)		$(1.63 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0, η , $f_1(1285)$)		$(1.11 \pm 0.10) \times 10^{-4}$	–
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0, η , $\omega, f_1(1285)$)	[g]	$(3.8 \pm 0.9) \times 10^{-5}$	–
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. K^0)	[g]	$(1.1 \pm 0.6) \times 10^{-6}$	657
$K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$		$< 8 \times 10^{-7}$ CL=90%	657
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 3.4 \times 10^{-6}$ CL=90%	687

Miscellaneous other allowed modes

$(5\pi)^- \nu_\tau$		$(7.8 \pm 0.5) \times 10^{-3}$	800
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 3.0 \times 10^{-7}$ CL=90%	682
$4h^- 3h^+ \nu_\tau$		$< 4.3 \times 10^{-7}$ CL=90%	682

$4h^- 3h^+ \pi^0 \nu_\tau$	< 2.5	$\times 10^{-7}$	CL=90%	612
$X^-(S=-1)\nu_\tau$	(2.92 ± 0.04)	%		–
$K^*(892)^- \geq 0$ neutrals \geq	(1.42 ± 0.18)	%	S=1.4	665
$0K_L^0 \nu_\tau$				
$K^*(892)^- \nu_\tau$	(1.20 ± 0.07)	%	S=1.8	665
$K^*(892)^- \nu_\tau \rightarrow \pi^- \bar{K}^0 \nu_\tau$	(7.82 ± 0.26)	$\times 10^{-3}$		–
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ	(3.2 ± 1.4)	$\times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$	(2.1 ± 0.4)	$\times 10^{-3}$		542
$\bar{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ	(3.8 ± 1.7)	$\times 10^{-3}$		655
$\bar{K}^*(892)^0 \pi^- \nu_\tau$	(2.2 ± 0.5)	$\times 10^{-3}$		655
$(\bar{K}^*(892)\pi)^- \nu_\tau \rightarrow$	(1.0 ± 0.4)	$\times 10^{-3}$		–
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$				
$K_1(1270)^- \nu_\tau$	(4.7 ± 1.1)	$\times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$	(1.7 ± 2.6)	$\times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$	$(1.5 \begin{smallmatrix} + \\ - \end{smallmatrix} \begin{smallmatrix} 1.4 \\ 1.0 \end{smallmatrix})$	$\times 10^{-3}$		326
$K_0^*(1430)^- \nu_\tau$	< 5	$\times 10^{-4}$	CL=95%	317
$K_2^*(1430)^- \nu_\tau$	< 3	$\times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$	< 9.9	$\times 10^{-5}$	CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g] (1.39 ± 0.07)	$\times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$	[g] (2.0 ± 0.4)	$\times 10^{-4}$		746
$\eta K^- \nu_\tau$	[g] (1.55 ± 0.08)	$\times 10^{-4}$		719
$\eta K^*(892)^- \nu_\tau$	(1.38 ± 0.15)	$\times 10^{-4}$		511
$\eta K^- \pi^0 \nu_\tau$	[g] (4.8 ± 1.2)	$\times 10^{-5}$		665
$\eta K^- \pi^0$ (non- $K^*(892)$) ν_τ	< 3.5	$\times 10^{-5}$	CL=90%	–
$\eta \bar{K}^0 \pi^- \nu_\tau$	[g] (9.4 ± 1.5)	$\times 10^{-5}$		661
$\eta \bar{K}^0 \pi^- \pi^0 \nu_\tau$	< 5.0	$\times 10^{-5}$	CL=90%	590
$\eta K^- K^0 \nu_\tau$	< 9.0	$\times 10^{-6}$	CL=90%	430
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ	< 3	$\times 10^{-3}$	CL=90%	744
$\eta \pi^- \pi^+ \pi^- \nu_\tau$ (ex. K^0)	[g] (2.20 ± 0.13)	$\times 10^{-4}$		744
$\eta \pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0, f_1(1285)$)	(9.9 ± 1.6)	$\times 10^{-5}$		–
$\eta a_1(1260)^- \nu_\tau \rightarrow \eta \pi^- \rho^0 \nu_\tau$	< 3.9	$\times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$	< 7.4	$\times 10^{-6}$	CL=90%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$	< 2.0	$\times 10^{-4}$	CL=95%	559
$\eta \eta K^- \nu_\tau$	< 3.0	$\times 10^{-6}$	CL=90%	382
$\eta'(958) \pi^- \nu_\tau$	< 4.0	$\times 10^{-6}$	CL=90%	620
$\eta'(958) \pi^- \pi^0 \nu_\tau$	< 1.2	$\times 10^{-5}$	CL=90%	591
$\eta'(958) K^- \nu_\tau$	< 2.4	$\times 10^{-6}$	CL=90%	495
$\phi \pi^- \nu_\tau$	(3.4 ± 0.6)	$\times 10^{-5}$		585
$\phi K^- \nu_\tau$	[g] (4.4 ± 1.6)	$\times 10^{-5}$		445
$f_1(1285) \pi^- \nu_\tau$	(3.9 ± 0.5)	$\times 10^{-4}$	S=1.9	408
$f_1(1285) \pi^- \nu_\tau \rightarrow$	(1.18 ± 0.07)	$\times 10^{-4}$	S=1.3	–
$\eta \pi^- \pi^+ \pi^- \nu_\tau$				

$f_1(1285)\pi^-\nu_\tau \rightarrow$	[g]	$(5.2 \pm 0.4) \times 10^{-5}$	—
$3\pi^-2\pi^+\nu_\tau$			
$\pi(1300)^-\nu_\tau \rightarrow (\rho\pi)^-\nu_\tau \rightarrow$	< 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		$(2.40 \pm 0.08) \%$	708
$h^-\omega\nu_\tau$		$(1.99 \pm 0.06) \%$	708
$\pi^-\omega\nu_\tau$	[g]	$(1.95 \pm 0.06) \%$	708
$K^-\omega\nu_\tau$	[g]	$(4.1 \pm 0.9) \times 10^{-4}$	610
$h^-\omega\pi^0\nu_\tau$	[g]	$(4.1 \pm 0.4) \times 10^{-3}$	684
$h^-\omega2\pi^0\nu_\tau$		$(1.4 \pm 0.5) \times 10^{-4}$	644
$\pi^-\omega2\pi^0\nu_\tau$	[g]	$(7.2 \pm 1.6) \times 10^{-5}$	644
$h^-2\omega\nu_\tau$	< 5.4	$\times 10^{-7}$ CL=90%	250
$2h^-h^+\omega\nu_\tau$		$(1.20 \pm 0.22) \times 10^{-4}$	641
$2\pi^-\pi^+\omega\nu_\tau(\text{ex.}K^0)$	[g]	$(8.4 \pm 0.6) \times 10^{-5}$	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.

$e^-\gamma$	<i>LF</i>	< 3.3	$\times 10^{-8}$ CL=90%	888
$\mu^-\gamma$	<i>LF</i>	< 4.4	$\times 10^{-8}$ CL=90%	885
$e^-\pi^0$	<i>LF</i>	< 8.0	$\times 10^{-8}$ CL=90%	883
$\mu^-\pi^0$	<i>LF</i>	< 1.1	$\times 10^{-7}$ CL=90%	880
$e^-K_S^0$	<i>LF</i>	< 2.6	$\times 10^{-8}$ CL=90%	819
$\mu^-K_S^0$	<i>LF</i>	< 2.3	$\times 10^{-8}$ CL=90%	815
$e^-\eta$	<i>LF</i>	< 9.2	$\times 10^{-8}$ CL=90%	804
$\mu^-\eta$	<i>LF</i>	< 6.5	$\times 10^{-8}$ CL=90%	800
$e^-\rho^0$	<i>LF</i>	< 1.8	$\times 10^{-8}$ CL=90%	719
$\mu^-\rho^0$	<i>LF</i>	< 1.2	$\times 10^{-8}$ CL=90%	715
$e^-\omega$	<i>LF</i>	< 4.8	$\times 10^{-8}$ CL=90%	716
$\mu^-\omega$	<i>LF</i>	< 4.7	$\times 10^{-8}$ CL=90%	711
$e^-K^*(892)^0$	<i>LF</i>	< 3.2	$\times 10^{-8}$ CL=90%	665
$\mu^-K^*(892)^0$	<i>LF</i>	< 5.9	$\times 10^{-8}$ CL=90%	659
$e^-\bar{K}^*(892)^0$	<i>LF</i>	< 3.4	$\times 10^{-8}$ CL=90%	665
$\mu^-\bar{K}^*(892)^0$	<i>LF</i>	< 7.0	$\times 10^{-8}$ CL=90%	659
$e^-\eta'(958)$	<i>LF</i>	< 1.6	$\times 10^{-7}$ CL=90%	630
$\mu^-\eta'(958)$	<i>LF</i>	< 1.3	$\times 10^{-7}$ CL=90%	625
$e^-f_0(980) \rightarrow e^-\pi^+\pi^-$	<i>LF</i>	< 3.2	$\times 10^{-8}$ CL=90%	—
$\mu^-f_0(980) \rightarrow \mu^-\pi^+\pi^-$	<i>LF</i>	< 3.4	$\times 10^{-8}$ CL=90%	—
$e^-\phi$	<i>LF</i>	< 3.1	$\times 10^{-8}$ CL=90%	596

$\mu^- \phi$	<i>LF</i>	< 8.4	$\times 10^{-8}$ CL=90%	590
$e^- e^+ e^-$	<i>LF</i>	< 2.7	$\times 10^{-8}$ CL=90%	888
$e^- \mu^+ \mu^-$	<i>LF</i>	< 2.7	$\times 10^{-8}$ CL=90%	882
$e^+ \mu^- \mu^-$	<i>LF</i>	< 1.7	$\times 10^{-8}$ CL=90%	882
$\mu^- e^+ e^-$	<i>LF</i>	< 1.8	$\times 10^{-8}$ CL=90%	885
$\mu^+ e^- e^-$	<i>LF</i>	< 1.5	$\times 10^{-8}$ CL=90%	885
$\mu^- \mu^+ \mu^-$	<i>LF</i>	< 2.1	$\times 10^{-8}$ CL=90%	873
$e^- \pi^+ \pi^-$	<i>LF</i>	< 2.3	$\times 10^{-8}$ CL=90%	877
$e^+ \pi^- \pi^-$	<i>L</i>	< 2.0	$\times 10^{-8}$ CL=90%	877
$\mu^- \pi^+ \pi^-$	<i>LF</i>	< 2.1	$\times 10^{-8}$ CL=90%	866
$\mu^+ \pi^- \pi^-$	<i>L</i>	< 3.9	$\times 10^{-8}$ CL=90%	866
$e^- \pi^+ K^-$	<i>LF</i>	< 3.7	$\times 10^{-8}$ CL=90%	813
$e^- \pi^- K^+$	<i>LF</i>	< 3.1	$\times 10^{-8}$ CL=90%	813
$e^+ \pi^- K^-$	<i>L</i>	< 3.2	$\times 10^{-8}$ CL=90%	813
$e^- K_S^0 K_S^0$	<i>LF</i>	< 7.1	$\times 10^{-8}$ CL=90%	736
$e^- K^+ K^-$	<i>LF</i>	< 3.4	$\times 10^{-8}$ CL=90%	738
$e^+ K^- K^-$	<i>L</i>	< 3.3	$\times 10^{-8}$ CL=90%	738
$\mu^- \pi^+ K^-$	<i>LF</i>	< 8.6	$\times 10^{-8}$ CL=90%	800
$\mu^- \pi^- K^+$	<i>LF</i>	< 4.5	$\times 10^{-8}$ CL=90%	800
$\mu^+ \pi^- K^-$	<i>L</i>	< 4.8	$\times 10^{-8}$ CL=90%	800
$\mu^- K_S^0 K_S^0$	<i>LF</i>	< 8.0	$\times 10^{-8}$ CL=90%	696
$\mu^- K^+ K^-$	<i>LF</i>	< 4.4	$\times 10^{-8}$ CL=90%	699
$\mu^+ K^- K^-$	<i>L</i>	< 4.7	$\times 10^{-8}$ 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%	699
$\mu^- \eta \eta$	<i>LF</i>	< 6.0	$\times 10^{-5}$ CL=90%	653
$e^- \pi^0 \eta$	<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
$p \mu^- \mu^-$	<i>L,B</i>	< 4.4	$\times 10^{-7}$ CL=90%	618
$\bar{p} \mu^+ \mu^-$	<i>L,B</i>	< 3.3	$\times 10^{-7}$ CL=90%	618
$\bar{p} \gamma$	<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%	525
$\bar{\Lambda} \pi^-$	<i>L,B</i>	< 1.4	$\times 10^{-7}$ CL=90%	525
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 $\mu < 0.29 \times 10^{-10} \mu_B$, CL = 90% (reactor)

Number of Neutrino Types

Number $N = 2.984 \pm 0.008$ (Standard Model fits to LEP-SLC data)

Number $N = 2.92 \pm 0.05$ ($S = 1.2$) (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 Oscillations” by K. Nakamura and S.T. Petcov in this *Review*.

$$\sin^2(\theta_{12}) = 0.307 \pm 0.013$$

$$\Delta m_{21}^2 = (7.53 \pm 0.18) \times 10^{-5} \text{ eV}^2$$

$$\sin^2(\theta_{23}) = 0.536^{+0.023}_{-0.028} \quad (\text{Inverted order})$$

$$\sin^2(\theta_{23}) = 0.512^{+0.019}_{-0.022} \quad (\text{Normal order, octant I})$$

$$\sin^2(\theta_{23}) = 0.542^{+0.019}_{-0.022} \quad (\text{Normal order, octant II})$$

$$\Delta m_{32}^2 = (-2.53 \pm 0.05) \times 10^{-3} \text{ eV}^2 \quad (S = 1.2) \quad (\text{Inverted order})$$

$$\Delta m_{32}^2 = (2.444 \pm 0.034) \times 10^{-3} \text{ eV}^2 \quad (\text{Normal order})$$

$$\sin^2(\theta_{13}) = (2.18 \pm 0.07) \times 10^{-2}$$

$$\delta, CP \text{ violating phase} = 1.37^{+0.18}_{-0.16} \pi \text{ rad}$$

$$\langle \Delta m_{21}^2 - \Delta \bar{m}_{21}^2 \rangle < 1.1 \times 10^{-4} \text{ eV}^2, \text{ CL} = 99.7\%$$

$$\langle \Delta m_{32}^2 - \Delta \bar{m}_{32}^2 \rangle = (-0.12 \pm 0.25) \times 10^{-3} \text{ eV}^2$$

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 energy of $e > 45$ MeV and energy of $\gamma > 40$ 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.