

LEPTONS

e

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

$$\text{Mass } m = (548.579909065 \pm 0.000000016) \times 10^{-6} \text{ u}$$

$$\text{Mass } m = 0.51099895000 \pm 0.00000000015 \text{ MeV}$$

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

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

Magnetic moment anomaly

$$(g-2)/2 = (1159.65218062 \pm 0.00000012) \times 10^{-6}$$

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

$$\text{Electric dipole moment } d < 0.041 \times 10^{-28} \text{ e cm, CL} = 90\%$$

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

 μ

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

$$\text{Mass } m = 0.1134289259 \pm 0.00000000025 \text{ u}$$

$$\text{Mass } m = 105.6583755 \pm 0.0000023 \text{ MeV}$$

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

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

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

$$\text{Magnetic moment anomaly } (g-2)/2 = (11659205.9 \pm 2.2) \times 10^{-10}$$

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

$$\text{Electric dipole moment } |d| < 1.8 \times 10^{-19} \text{ e cm, CL} = 95\%$$

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 < 3.1	$\times 10^{-13}$	90% 53
$e^- e^+ e^-$	LF < 1.0	$\times 10^{-12}$	90% 53
$e^- 2\gamma$	LF < 7.2	$\times 10^{-11}$	90% 53



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

Mass $m = 1776.93 \pm 0.09$ 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 = -0.057 to 0.024 , CL = 95%

$\text{Re}(d_\tau) = -0.185$ to 0.061×10^{-16} e cm, CL = 95%

$\text{Im}(d_\tau) = -0.103$ to 0.0230×10^{-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.

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

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

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

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

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

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

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

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

$$\begin{aligned}
(\delta\xi)(e \text{ or } \mu) &= 0.746 \pm 0.021 \\
(\delta\xi)(e) &= 0.734 \pm 0.028 \\
(\delta\xi)(\mu) &= 0.778 \pm 0.037 \\
\xi(\pi) &= 0.993 \pm 0.022 \\
\xi(\rho) &= 0.994 \pm 0.008 \\
\xi(a_1) &= 1.001 \pm 0.027 \\
\xi(\text{all hadronic modes}) &= 0.995 \pm 0.007 \\
\xi'(\mu) &= 0.2 \pm 1.0 \\
\bar{\eta}(\mu) &= -1.3 \pm 1.7 \\
(\xi\kappa)(e \text{ or } \mu) &= 0.5 \pm 0.4 \\
(\xi\kappa)(e) &= -0.4 \pm 1.2 \\
(\xi\kappa)(\mu) &= 0.8 \pm 0.6
\end{aligned}$$

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 $^- \geq 0$ neutrals $\geq 0K^0\nu_\tau$ (“1-prong”)	(85.24 $\pm$ 0.06) %		—
particle $^- \geq 0$ neutrals $\geq 0K_L^0\nu_\tau$	(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
$h^- \geq 0K_L^0 \nu_\tau$	(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	(37.00 $\pm$ 0.09) %		—
$h^- \geq 1\pi^0 \nu_\tau$ (ex. K^0)	(36.50 $\pm$ 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
$\pi^- \pi^0 \text{non-}\rho(770) \nu_\tau$	(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

$K^- 2\pi^0 \nu_\tau (\text{ex. } K^0)$	[g]	$(6.5 \pm 2.2) \times 10^{-4}$	796
$h^- \geq 3\pi^0 \nu_\tau$		$(1.34 \pm 0.07) \%$	—
$h^- \geq 3\pi^0 \nu_\tau (\text{ex. } K^0)$		$(1.25 \pm 0.07) \%$	—
$h^- 3\pi^0 \nu_\tau$		$(1.18 \pm 0.07) \%$	836
$\pi^- 3\pi^0 \nu_\tau (\text{ex. } K^0)$	[g]	$(1.04 \pm 0.07) \%$	836
$K^- 3\pi^0 \nu_\tau (\text{ex. } K^0, \eta)$	[g]	$(4.8 \pm 2.1) \times 10^{-4}$	766
$h^- 4\pi^0 \nu_\tau (\text{ex. } K^0)$		$(1.6 \pm 0.4) \times 10^{-3}$	800
$h^- 4\pi^0 \nu_\tau (\text{ex. } K^0, \eta)$	[g]	$(1.1 \pm 0.4) \times 10^{-3}$	800
$a_1(1260) \nu_\tau \rightarrow \pi^- \gamma \nu_\tau$		$(4.0 \pm 1.5) \times 10^{-4}$	—
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma \nu_\tau$		$(1.552 \pm 0.029) \%$	820
$K^- \geq 1(\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau$		$(8.59 \pm 0.28) \times 10^{-3}$	—
Modes with K^0's			
$K_S^0 (\text{particles})^- \nu_\tau$		$(9.43 \pm 0.28) \times 10^{-3}$	—
$h^- \bar{K}^0 \nu_\tau$		$(9.87 \pm 0.14) \times 10^{-3}$	812
$\pi^- \bar{K}^0 \nu_\tau$	[g]	$(8.38 \pm 0.14) \times 10^{-3}$	812
$\pi^- \bar{K}^0$		$(5.4 \pm 2.1) \times 10^{-4}$	812
$(\text{non-}K^*(892)^-) \nu_\tau$			
$K^- K^0 \nu_\tau$	[g]	$(1.486 \pm 0.034) \times 10^{-3}$	737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(2.99 \pm 0.07) \times 10^{-3}$	737
$h^- \bar{K}^0 \pi^0 \nu_\tau$		$(5.32 \pm 0.13) \times 10^{-3}$	794
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	[g]	$(3.82 \pm 0.13) \times 10^{-3}$	794
$\bar{K}^0 \rho^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$	612
$K^- K^0 \pi^0 \nu_\tau$	[g]	$(1.50 \pm 0.07) \times 10^{-3}$	685
$\pi^- \bar{K}^0 \geq 1\pi^0 \nu_\tau$		$(4.08 \pm 0.25) \times 10^{-3}$	—
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau (\text{ex. } K^0)$	[g]	$(2.6 \pm 2.3) \times 10^{-4}$	763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4} \text{ CL}=95\%$	619
$\pi^- K^0 \bar{K}^0 \nu_\tau$		$(1.55 \pm 0.24) \times 10^{-3}$	682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g]	$(2.35 \pm 0.06) \times 10^{-4}$	682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g]	$(1.08 \pm 0.24) \times 10^{-3}$	682
$\pi^- K_L^0 K_L^0 \nu_\tau$		$(2.35 \pm 0.06) \times 10^{-4}$	682
$\pi^- K^0 \bar{K}^0 \pi^0 \nu_\tau$		$(3.6 \pm 1.2) \times 10^{-4}$	614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	[g]	$(1.82 \pm 0.21) \times 10^{-5}$	614
$K^{*-} K^0 \pi^0 \nu_\tau \rightarrow \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(1.08 \pm 0.21) \times 10^{-5}$	—
$f_1(1285) \pi^- \nu_\tau \rightarrow \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(6.8 \pm 1.5) \times 10^{-6}$	—
$f_1(1420) \pi^- \nu_\tau \rightarrow \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(2.4 \pm 0.8) \times 10^{-6}$	—
$\pi^- K_S^0 K_L^0 \pi^0 \nu_\tau$	[g]	$(3.2 \pm 1.2) \times 10^{-4}$	614
$\pi^- K_L^0 K_L^0 \pi^0 \nu_\tau$		$(1.82 \pm 0.21) \times 10^{-5}$	614
$K^- K_S^0 K_S^0 \nu_\tau$		$< 6.3 \times 10^{-7} \text{ CL}=90\%$	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)	(1.94 $\pm$ 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

$K^- \rho^0 \nu_\tau \rightarrow$	$(1.4 \pm 0.5) \times 10^{-3}$	—
$K^- \pi^+ \pi^- \nu_\tau$		
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$	$(1.31 \pm 0.12) \times 10^{-3}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex. } K^0)$	$(7.9 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex. } K^0, \eta)$	$(7.6 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex. } K^0, \omega)$	$(3.7 \pm 0.9) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau (\text{ex. } K^0, \omega, \eta) [g]$	$(3.9 \pm 1.4) \times 10^{-4}$	763
$K^- \pi^+ K^- \geq 0 \text{ neut. } \nu_\tau$	$< 9 \times 10^{-4} \text{ CL}=95\%$	685
$K^- K^+ \pi^- \geq 0 \text{ neut. } \nu_\tau$	$(1.496 \pm 0.033) \times 10^{-3}$	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
$K^- K^+ K^- \nu_\tau$	$(2.2 \pm 0.8) \times 10^{-5} \text{ S}=5.4$	472
$K^- K^+ K^- \nu_\tau (\text{ex. } \phi)$	$< 2.5 \times 10^{-6} \text{ CL}=90\%$	—
$K^- K^+ K^- \pi^0 \nu_\tau$	$< 4.8 \times 10^{-6} \text{ CL}=90\%$	346
$\pi^- K^+ \pi^- \geq 0 \text{ neut. } \nu_\tau$	$< 2.5 \times 10^{-3} \text{ CL}=95\%$	794
$e^- e^- e^+ \bar{\nu}_e \nu_\tau$	$(2.8 \pm 1.5) \times 10^{-5}$	888
$\mu^- e^- e^+ \bar{\nu}_\mu \nu_\tau$	$< 3.2 \times 10^{-5} \text{ CL}=90\%$	885
$\pi^- e^- e^+ \nu_\tau$	seen	883
$\pi^- \mu^- \mu^+ \nu_\tau$	$< 1.14 \times 10^{-5} \text{ CL}=90\%$	870

Modes with five charged particles

$3h^- 2h^+ \geq 0 \text{ neutrals } \nu_\tau$	$(9.9 \pm 0.4) \times 10^{-4}$	794
(ex. $K_S^0 \rightarrow \pi^- \pi^+$)		
(“5-prong”)		
$3h^- 2h^+ \nu_\tau (\text{ex. } K^0)$	$(8.29 \pm 0.31) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau (\text{ex. } K^0, \omega)$	$(8.27 \pm 0.31) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau (\text{ex. } K^0, \omega, f_1(1285))$	$[g] (7.75 \pm 0.30) \times 10^{-4}$	—
$K^- 2\pi^- 2\pi^+ \nu_\tau (\text{ex. } K^0)$	$[g] (6 \pm 12) \times 10^{-7}$	716
$K^+ 3\pi^- \pi^+ \nu_\tau$	$< 5.0 \times 10^{-6} \text{ CL}=90\%$	716
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$	$< 4.5 \times 10^{-7} \text{ CL}=90\%$	528
$3h^- 2h^+ \pi^0 \nu_\tau (\text{ex. } K^0)$	$(1.65 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex. } K^0)$	$(1.64 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex. } K^0, \eta, f_1(1285))$	$(1.11 \pm 0.10) \times 10^{-4}$	—
$3\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex. } K^0, \eta, \omega, f_1(1285))$	$[g] (3.8 \pm 0.9) \times 10^{-5}$	—
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau (\text{ex. } K^0)$	$[g] (1.1 \pm 0.6) \times 10^{-6}$	657
$K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$	$< 8 \times 10^{-7} \text{ CL}=90\%$	657
$3h^- 2h^+ 2\pi^0 \nu_\tau$	$< 3.4 \times 10^{-6} \text{ CL}=90\%$	687

Miscellaneous other allowed modes

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

$4h^-3h^+\nu_\tau$	< 4.3	$\times 10^{-7}\text{CL}=90\%$	682
$4h^-3h^+\pi^0\nu_\tau$	< 2.5	$\times 10^{-7}\text{CL}=90\%$	612
$X^-(S=-1)\nu_\tau$	$(2.92 \pm 0.04) \%$		—
$K^*(892)^- \geq 0 \text{ neutrals} \geq 0K_L^0\nu_\tau$	$(1.42 \pm 0.18) \%$	$S=1.4$	665
$K^*(892)^-\nu_\tau$	$(1.20 \pm 0.07) \%$	$S=1.8$	665
$K^*(892)^-\nu_\tau \rightarrow \pi^-\bar{K}^0\nu_\tau$	$(7.82 \pm 0.26) \times 10^{-3}$		—
$K^*(892)^0 K^- \geq 0 \text{ neutrals} \nu_\tau$	$(3.2 \pm 1.4) \times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$	$(2.1 \pm 0.4) \times 10^{-3}$		542
$\bar{K}^*(892)^0 \pi^- \geq 0 \text{ neutrals} \nu_\tau$	$(3.8 \pm 1.7) \times 10^{-3}$		656
$\bar{K}^*(892)^0 \pi^- \nu_\tau$	$(2.2 \pm 0.5) \times 10^{-3}$		656
$(\bar{K}^*(892)\pi)^-\nu_\tau \rightarrow \pi^-\bar{K}^0\pi^0\nu_\tau$	$(1.0 \pm 0.4) \times 10^{-3}$		—
$K_1(1270)^-\nu_\tau$	$(4.7 \pm 1.1) \times 10^{-3}$		447
$K_1(1400)^-\nu_\tau$	$(1.7 \pm 2.6) \times 10^{-3}$	$S=1.7$	335
$K^*(1410)^-\nu_\tau$	$(1.5 \pm 1.4) \times 10^{-3}$		326
$K_0^*(1430)^-\nu_\tau$	< 5	$\times 10^{-4}\text{CL}=95\%$	317
$K_2^*(1430)^-\nu_\tau$	< 3	$\times 10^{-3}\text{CL}=95\%$	315
$\eta\pi^-\nu_\tau$	< 9.9	$\times 10^{-5}\text{CL}=95\%$	797
$\eta\pi^-\pi^0\nu_\tau$	[g] $(1.39 \pm 0.07) \times 10^{-3}$		778
$\eta\pi^-\pi^0\pi^0\nu_\tau$	[g] $(1.9 \pm 0.4) \times 10^{-4}$		746
$\eta K^-\nu_\tau$	[g] $(1.55 \pm 0.08) \times 10^{-4}$		720
$\eta K^*(892)^-\nu_\tau$	$(1.38 \pm 0.15) \times 10^{-4}$		511
$\eta K^-\pi^0\nu_\tau$	[g] $(4.8 \pm 1.2) \times 10^{-5}$		665
$\eta K^-\pi^0(\text{non-}K^*(892))\nu_\tau$	< 3.5	$\times 10^{-5}\text{CL}=90\%$	—
$\eta\bar{K}^0\pi^-\nu_\tau$	[g] $(9.4 \pm 1.5) \times 10^{-5}$		661
$\eta\bar{K}^0\pi^-\pi^0\nu_\tau$	< 5.0	$\times 10^{-5}\text{CL}=90\%$	590
$\eta K^-K^0\nu_\tau$	< 9.0	$\times 10^{-6}\text{CL}=90\%$	430
$\eta\pi^+\pi^-\pi^- \geq 0 \text{ neutrals} \nu_\tau$	< 3	$\times 10^{-3}\text{CL}=90\%$	744
$\eta\pi^-\pi^+\pi^-\nu_\tau(\text{ex.}K^0)$	[g] $(2.20 \pm 0.13) \times 10^{-4}$		744
$\eta\pi^-\pi^+\pi^-\nu_\tau(\text{ex.}K^0,f_1(1285))$	$(9.9 \pm 1.6) \times 10^{-5}$		—
$\eta a_1(1260)^-\nu_\tau \rightarrow \eta\pi^-\rho^0\nu_\tau$	< 3.9	$\times 10^{-4}\text{CL}=90\%$	—
$\eta\eta\pi^-\nu_\tau$	< 7.4	$\times 10^{-6}\text{CL}=90\%$	637
$\eta\eta\pi^-\pi^0\nu_\tau$	< 2.0	$\times 10^{-4}\text{CL}=95\%$	559
$\eta\eta K^-\nu_\tau$	< 3.0	$\times 10^{-6}\text{CL}=90\%$	382
$\eta'(958)\pi^-\nu_\tau$	< 4.0	$\times 10^{-6}\text{CL}=90\%$	620
$\eta'(958)\pi^-\pi^0\nu_\tau$	< 1.2	$\times 10^{-5}\text{CL}=90\%$	591
$\eta'(958)K^-\nu_\tau$	< 2.4	$\times 10^{-6}\text{CL}=90\%$	495
$\phi\pi^-\nu_\tau$	$(3.4 \pm 0.6) \times 10^{-5}$		585
$\phi K^-\nu_\tau$	[g] $(4.4 \pm 1.6) \times 10^{-5}$		445
$f_1(1285)\pi^-\nu_\tau$	$(3.9 \pm 0.5) \times 10^{-4}$	$S=1.9$	408
$f_1(1285)\pi^-\nu_\tau \rightarrow \eta\pi^-\pi^+\pi^-\nu_\tau$	$(1.18 \pm 0.07) \times 10^{-4}$	$S=1.3$	—

$f_1(1285)\pi^-\nu_\tau \rightarrow 3\pi^-2\pi^+\nu_\tau$	[g]	$(5.2 \pm 0.4) \times 10^{-5}$	—
$\pi(1300)^-\nu_\tau \rightarrow (\rho\pi)^-\nu_\tau \rightarrow (3\pi)^-\nu_\tau$	< 1.0	$\times 10^{-4}$ CL=90%	—
$\pi(1300)^-\nu_\tau \rightarrow ((\pi\pi)_{S\text{-wave}}\pi)^-\nu_\tau \rightarrow (3\pi)^-\nu_\tau$	< 1.9	$\times 10^{-4}$ CL=90%	—
$h^-\omega \geq 0$ 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
$h^-\omega 2\pi^0\nu_\tau$	$(1.4 \pm 0.5) \times 10^{-4}$		644
$\pi^-\omega 2\pi^0\nu_\tau$	[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
$2\pi^-\pi^+\omega\nu_\tau$ (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.

$e^-\gamma$	LF	< 3.3	$\times 10^{-8}$ CL=90%	888
$e^-\gamma\gamma$	LF	< 2.5	$\times 10^{-4}$ CL=90%	888
$\mu^-\gamma$	LF	< 4.2	$\times 10^{-8}$ CL=90%	885
$\mu^-\gamma\gamma$	LF	< 5.8	$\times 10^{-4}$ CL=90%	885
$e^-\pi^0$	LF	< 8.0	$\times 10^{-8}$ CL=90%	883
$\mu^-\pi^0$	LF	< 1.1	$\times 10^{-7}$ CL=90%	880
$e^-K_S^0$	LF	< 2.6	$\times 10^{-8}$ CL=90%	819
$\mu^-K_S^0$	LF	< 2.3	$\times 10^{-8}$ CL=90%	815
$e^-\eta$	LF	< 9.2	$\times 10^{-8}$ CL=90%	804
$\mu^-\eta$	LF	< 6.5	$\times 10^{-8}$ CL=90%	800
$e^-\rho^0$	LF	< 2.2	$\times 10^{-8}$ CL=90%	719
$\mu^-\rho^0$	LF	< 1.7	$\times 10^{-8}$ CL=90%	715
$e^-\omega$	LF	< 2.4	$\times 10^{-8}$ CL=90%	716
$\mu^-\omega$	LF	< 3.9	$\times 10^{-8}$ CL=90%	711
$e^-K^*(892)^0$	LF	< 1.9	$\times 10^{-8}$ CL=90%	665
$\mu^-K^*(892)^0$	LF	< 2.9	$\times 10^{-8}$ CL=90%	659
$e^-\bar{K}^*(892)^0$	LF	< 1.7	$\times 10^{-8}$ CL=90%	665
$\mu^-\bar{K}^*(892)^0$	LF	< 4.3	$\times 10^{-8}$ CL=90%	659
$e^-\eta'(958)$	LF	< 1.6	$\times 10^{-7}$ CL=90%	630
$\mu^-\eta'(958)$	LF	< 1.3	$\times 10^{-7}$ CL=90%	625
$e^-f_0(980) \rightarrow e^-\pi^+\pi^-$	LF	< 3.2	$\times 10^{-8}$ CL=90%	—

$\mu^- f_0(980) \rightarrow \mu^- \pi^+ \pi^-$	LF	< 3.4	$\times 10^{-8}$ CL=90%	—
$e^- \phi$	LF	< 2.0	$\times 10^{-8}$ CL=90%	596
$\mu^- \phi$	LF	< 2.3	$\times 10^{-8}$ CL=90%	590
$e^- e^+ e^-$	LF	< 2.7	$\times 10^{-8}$ CL=90%	888
$e^- \mu^+ \mu^-$	LF	< 2.7	$\times 10^{-8}$ CL=90%	882
$e^+ \mu^- \mu^-$	LF	< 1.7	$\times 10^{-8}$ CL=90%	882
$\mu^- e^+ e^-$	LF	< 1.8	$\times 10^{-8}$ CL=90%	885
$\mu^+ e^- e^-$	LF	< 1.5	$\times 10^{-8}$ CL=90%	885
$\mu^- \mu^+ \mu^-$	LF	< 1.9	$\times 10^{-8}$ CL=90%	873
$e^- \pi^+ \pi^-$	LF	< 2.3	$\times 10^{-8}$ CL=90%	877
$e^+ \pi^- \pi^-$	L	< 2.0	$\times 10^{-8}$ CL=90%	877
$\mu^- \pi^+ \pi^-$	LF	< 2.1	$\times 10^{-8}$ CL=90%	866
$\mu^+ \pi^- \pi^-$	L	< 3.9	$\times 10^{-8}$ CL=90%	866
$e^- \pi^+ K^-$	LF	< 3.7	$\times 10^{-8}$ CL=90%	813
$e^- \pi^- K^+$	LF	< 3.1	$\times 10^{-8}$ CL=90%	813
$e^+ \pi^- K^-$	L	< 3.2	$\times 10^{-8}$ CL=90%	813
$e^- K_S^0 K_S^0$	LF	< 7.1	$\times 10^{-8}$ CL=90%	736
$e^- K^+ K^-$	LF	< 3.4	$\times 10^{-8}$ CL=90%	739
$e^+ K^- K^-$	L	< 3.3	$\times 10^{-8}$ CL=90%	739
$\mu^- \pi^+ K^-$	LF	< 8.6	$\times 10^{-8}$ CL=90%	800
$\mu^- \pi^- K^+$	LF	< 4.5	$\times 10^{-8}$ CL=90%	800
$\mu^+ \pi^- K^-$	L	< 4.8	$\times 10^{-8}$ CL=90%	800
$\mu^- K_S^0 K_S^0$	LF	< 8.0	$\times 10^{-8}$ CL=90%	696
$\mu^- K^+ K^-$	LF	< 4.4	$\times 10^{-8}$ CL=90%	699
$\mu^+ K^- K^-$	L	< 4.7	$\times 10^{-8}$ 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%	653
$e^- \pi^0 \eta$	LF	< 2.4	$\times 10^{-5}$ CL=90%	798
$\mu^- \pi^0 \eta$	LF	< 2.2	$\times 10^{-5}$ CL=90%	784
$\rho e^- e^-$	L,B	< 3.0	$\times 10^{-8}$ CL=90%	641
$\bar{\rho} e^+ e^-$	L,B	< 3.0	$\times 10^{-8}$ CL=90%	641
$\bar{\rho} e^+ \mu^-$	L,B	< 2.0	$\times 10^{-8}$ CL=90%	635
$\bar{\rho} e^- \mu^+$	L,B	< 1.8	$\times 10^{-8}$ CL=90%	635
$\rho \mu^- \mu^-$	L,B	< 4.0	$\times 10^{-8}$ CL=90%	618
$\bar{\rho} \mu^+ \mu^-$	L,B	< 1.8	$\times 10^{-8}$ CL=90%	618
$\bar{\rho} \gamma$	L,B	< 3.5	$\times 10^{-6}$ CL=90%	641
$\bar{\rho} \pi^0$	L,B	< 1.5	$\times 10^{-5}$ CL=90%	632
$\bar{\rho} 2\pi^0$	L,B	< 3.3	$\times 10^{-5}$ CL=90%	604
$\bar{\rho} \eta$	L,B	< 8.9	$\times 10^{-6}$ CL=90%	475
$\bar{\rho} \pi^0 \eta$	L,B	< 2.7	$\times 10^{-5}$ CL=90%	360
$\Lambda \pi^-$	L,B	< 4.7	$\times 10^{-8}$ CL=90%	525
$\bar{\Lambda} \pi^-$	L,B	< 4.3	$\times 10^{-8}$ CL=90%	525

e^- light boson	LF	< 9	$\times 10^{-4} \text{ CL}=95\%$	—
μ^- light boson	LF	< 6	$\times 10^{-4} \text{ CL}=95\%$	—

Heavy Charged Lepton Searches

$L^\pm$ – charged lepton

Mass $m > 100.8 \text{ GeV}$, CL = 95% ^[h] Decay to νW .

$L^\pm$ – stable charged heavy lepton

Mass $m > 102.6 \text{ GeV}$, CL = 95%

Neutrino Properties

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

Mass $m < 0.8 \text{ eV}$, CL = 90% (tritium decay)

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

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

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

Magnetic moment $\mu < 0.064 \times 10^{-10} \mu_B$, CL = 90% (solar
+ radiochemical)

Number of Neutrino Types

Number $N = 2.996 \pm 0.007$ (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 Masses, Mixing, and Oscillations.”

$$\sin^2(\theta_{12}) = 0.307 \pm 0.012$$

$$\Delta m_{21}^2 = (7.50 \pm 0.19) \times 10^{-5} \text{ eV}^2$$

$$\sin^2(\theta_{23}) = 0.537 \pm 0.020 \quad (S = 1.2) \quad (\text{Inverted order})$$

$$\sin^2(\theta_{23}) = 0.534^{+0.015}_{-0.019} \quad (\text{Normal order})$$

$$\begin{aligned}\Delta m_{32}^2 &= (-2.527 \pm 0.034) \times 10^{-3} \text{ eV}^2 \quad (S = 1.2) \quad (\text{Inverted order}) \\ \Delta m_{32}^2 &= (2.451 \pm 0.026) \times 10^{-3} \text{ eV}^2 \quad (\text{Normal order}) \\ \sin^2(\theta_{13}) &= (2.16 \pm 0.06) \times 10^{-2} \quad (S = 1.2) \\ \delta, \text{ } CP \text{ violating phase} &= 1.21_{-0.22}^{+0.19} \pi \text{ rad} \quad (S = 1.2) \\ \langle \Delta m_{21}^2 - \Delta \bar{m}_{21}^2 \rangle &< 1.1 \times 10^{-4} \text{ eV}^2, \text{ CL} = 99.7\% \\ \langle \Delta m_{32}^2 - \Delta \bar{m}_{32}^2 \rangle &= (-0.12 \pm 0.25) \times 10^{-3} \text{ eV}^2\end{aligned}$$

NOTES

- [a] This is the best limit for the mode $e^- \rightarrow \nu \gamma$.
- [b] See the review on “Muon Decay Parameters” for definitions and details.
- [c] P_μ is the longitudinal polarization of the muon from pion decay. For $V-A$ coupling, $P_\mu = 1$ 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.