

# 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

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

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

$$\text{Electric dipole moment } d < 0.87 \times 10^{-28} \text{ e cm, CL} = 90\%$$

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

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]

$$\rho = 0.74979 \pm 0.00026$$

$$\eta = 0.057 \pm 0.034$$

$$\delta = 0.75047 \pm 0.00034$$

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

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

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

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

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

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

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

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

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

$\mu^+$  modes are charge conjugates of the modes below.

$\mu^-$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$\rho$ (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
<b>Lepton Family number (LF) violating modes</b>			
$e^- \nu_e \bar{\nu}_\mu$	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

$\tau$

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

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  $0.45 \times 10^{-16}$  e cm, CL = 95%

$\text{Im}(d_\tau) = -0.250$  to  $0.0080 \times 10^{-16}$  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  $\tau$  Particle Listings for a note concerning  $\tau$ -decay parameters.

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

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

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

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

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

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

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

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

$$\begin{aligned}
 (\delta\xi)(e \text{ or } \mu) &= 0.746 \pm 0.021 \\
 (\delta\xi)(e) &= 0.734 \pm 0.028 \\
 (\delta\xi)(\mu) &= 0.778 \pm 0.037 \\
 \xi(\pi) &= 0.993 \pm 0.022 \\
 \xi(\rho) &= 0.994 \pm 0.008 \\
 \xi(a_1) &= 1.001 \pm 0.027 \\
 \xi(\text{all hadronic modes}) &= 0.995 \pm 0.007
 \end{aligned}$$

$\tau^\pm$  modes are charge conjugates of the modes below. “ $h^\pm$ ” stands for  $\pi^\pm$  or  $K^\pm$ . “ $\ell$ ” stands for e or  $\mu$ . “Neutrals” stands for  $\gamma$ 's and/or  $\pi^0$ 's.

$\tau^-$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Scale factor/ Confidence level	$p$ (MeV/c)
<b>Modes with one charged particle</b>			
particle <sup>-</sup> $\geq 0$ neutrals $\geq 0 K^0 \nu_\tau$ (“1-prong”)	(85.24 $\pm$ 0.06 ) %		–
particle <sup>-</sup> $\geq 0$ neutrals $\geq 0 K_L^0 \nu_\tau$	(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] ( 3.68 $\pm$ 0.10 ) $\times 10^{-3}$		885
$e^- \bar{\nu}_e \nu_\tau$	[g] (17.82 $\pm$ 0.04 ) %		888
$e^- \bar{\nu}_e \nu_\tau \gamma$	[e] ( 1.84 $\pm$ 0.05 ) %		888
$h^- \geq 0 K_L^0 \nu_\tau$	(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 $\nu_\tau$	(37.00 $\pm$ 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 $\pm$ 0.07 ) %		–
$h^- \geq 3 \pi^0 \nu_\tau$ (ex. $K^0$ )	( 1.25 $\pm$ 0.07 ) %		–
$h^- 3 \pi^0 \nu_\tau$	( 1.18 $\pm$ 0.07 ) %		836
$\pi^- 3 \pi^0 \nu_\tau$ (ex. $K^0$ )	[g] ( 1.04 $\pm$ 0.07 ) %		836

$K^- 3\pi^0 \nu_\tau$ (ex. $K^0$ , $\eta$ )	[g]	$(4.8 \pm 2.1) \times 10^{-4}$	765
$h^- 4\pi^0 \nu_\tau$ (ex. $K^0$ )		$(1.6 \pm 0.4) \times 10^{-3}$	800
$h^- 4\pi^0 \nu_\tau$ (ex. $K^0, \eta$ )	[g]	$(1.1 \pm 0.4) \times 10^{-3}$	800
$a_1(1260) \nu_\tau \rightarrow \pi^- \gamma \nu_\tau$		$(3.8 \pm 1.5) \times 10^{-4}$	—
$K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma \nu_\tau$		$(1.552 \pm 0.029) \%$	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**

$K_S^0$ (particles) $^- \nu_\tau$		$(9.44 \pm 0.28) \times 10^{-3}$	—
$h^- \bar{K}^0 \nu_\tau$		$(9.87 \pm 0.14) \times 10^{-3}$	812
$\pi^- \bar{K}^0 \nu_\tau$	[g]	$(8.40 \pm 0.14) \times 10^{-3}$	812
$\pi^- \bar{K}^0$		$(5.4 \pm 2.1) \times 10^{-4}$	812
(non- $K^*(892)^-$ ) $\nu_\tau$			
$K^- K^0 \nu_\tau$	[g]	$(1.48 \pm 0.05) \times 10^{-3}$	737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(2.98 \pm 0.08) \times 10^{-3}$	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
$\pi^- \bar{K}^0 \geq 1\pi^0 \nu_\tau$		$(4.08 \pm 0.25) \times 10^{-3}$	—
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex. $K^0$ )	[g]	$(2.6 \pm 2.3) \times 10^{-4}$	763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4}$ 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]	$(2.33 \pm 0.07) \times 10^{-4}$	682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g]	$(1.08 \pm 0.24) \times 10^{-3}$	682
$\pi^- K_L^0 K_L^0 \nu_\tau$		$(2.33 \pm 0.07) \times 10^{-4}$	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
$K^- K_S^0 K_S^0 \nu_\tau$		$< 6.3 \times 10^{-7}$ 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 $\nu_\tau$		$< 1.7 \times 10^{-3}$ 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 $\geq 0 K_L^0 \nu_\tau$	(15.21 $\pm$ 0.06 ) %	861
$h^- h^- h^+ \geq 0$ neutrals $\nu_\tau$	(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. $K^0, \omega$ )	( 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. $K^0$ ),	< 2.4 %	CL=95% 861
non-axial vector		
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0, \omega$ ) [g]	( 8.99 $\pm$ 0.05 ) %	861
$h^- h^- h^+ \geq 1$ neutrals $\nu_\tau$	( 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. $K^0, \omega$ )	( 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. $K^0, \omega$ ) [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. $K^0, \omega, \eta$ ) [g]	( 10 $\pm$ 4 ) $\times 10^{-4}$	797
$h^- h^- h^+ 3 \pi^0 \nu_\tau$	( 2.12 $\pm$ 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. $K^0, \eta$ , $f_1(1285)$ )	( 1.7 $\pm$ 0.4 ) $\times 10^{-4}$	–
$2 \pi^- \pi^+ 3 \pi^0 \nu_\tau$ (ex. $K^0, \eta$ , $\omega, f_1(1285)$ ) [g]	( 1.4 $\pm$ 2.7 ) $\times 10^{-5}$	–
$K^- h^+ h^- \geq 0$ neutrals $\nu_\tau$	( 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 $\nu_\tau$	( 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. $K^0, \omega$ ) [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

$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0$ )	$(7.9 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0, \eta$ )	$(7.6 \pm 1.2) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0, \omega$ )	$(3.7 \pm 0.9) \times 10^{-4}$	763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0, \omega, \eta$ ) [g]	$(3.9 \pm 1.4) \times 10^{-4}$	763
$K^- \pi^+ K^- \geq 0$ neut. $\nu_\tau$	$< 9 \times 10^{-4}$ CL=95%	685
$K^- K^+ \pi^- \geq 0$ 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
$K^- K^+ K^- \nu_\tau$	$(2.2 \pm 0.8) \times 10^{-5}$ S=5.4	472
$K^- K^+ K^- \nu_\tau$ (ex. $\phi$ )	$< 2.5 \times 10^{-6}$ CL=90%	–
$K^- K^+ K^- \pi^0 \nu_\tau$	$< 4.8 \times 10^{-6}$ CL=90%	345
$\pi^- K^+ \pi^- \geq 0$ neut. $\nu_\tau$	$< 2.5 \times 10^{-3}$ 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 $\nu_\tau$	$(9.9 \pm 0.4) \times 10^{-4}$	794
(ex. $K_S^0 \rightarrow \pi^- \pi^+$ )		
(“5-prong”)		
$3h^- 2h^+ \nu_\tau$ (ex. $K^0$ )	$(8.22 \pm 0.32) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. $K^0, \omega$ )	$(8.21 \pm 0.31) \times 10^{-4}$	794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. $K^0, \omega$ , $f_1(1285)$ ) [g]	$(7.69 \pm 0.30) \times 10^{-4}$	–
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (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. $K^0$ )	$(1.64 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. $K^0$ )	$(1.62 \pm 0.11) \times 10^{-4}$	746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. $K^0, \eta$ , $f_1(1285)$ )	$(1.11 \pm 0.10) \times 10^{-4}$	–
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. $K^0, \eta$ , $\omega$ , $f_1(1285)$ ) [g]	$(3.8 \pm 0.9) \times 10^{-5}$	–
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (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 $\nu_\tau$	$< 3.0 \times 10^{-7}$ CL=90%	682
(“7-prong”)		
$4h^- 3h^+ \nu_\tau$	$< 4.3 \times 10^{-7}$ CL=90%	682
$4h^- 3h^+ \pi^0 \nu_\tau$	$< 2.5 \times 10^{-7}$ CL=90%	612
$X^-(S=-1) \nu_\tau$	$(2.92 \pm 0.04) \%$	–
$K^*(892)^- \geq 0$ neutrals $\geq$	$(1.42 \pm 0.18) \%$ S=1.4	665
$0K_L^0 \nu_\tau$		

$K^*(892)^- \nu_\tau$	( 1.20 ± 0.07 ) %	S=1.8	665
$K^*(892)^- \nu_\tau \rightarrow \pi^- \bar{K}^0 \nu_\tau$	( 7.83 ± 0.26 ) × 10 <sup>-3</sup>		–
$K^*(892)^0 K^- \geq 0$ neutrals $\nu_\tau$	( 3.2 ± 1.4 ) × 10 <sup>-3</sup>		542
$K^*(892)^0 K^- \nu_\tau$	( 2.1 ± 0.4 ) × 10 <sup>-3</sup>		542
$\bar{K}^*(892)^0 \pi^- \geq 0$ neutrals $\nu_\tau$	( 3.8 ± 1.7 ) × 10 <sup>-3</sup>		655
$\bar{K}^*(892)^0 \pi^- \nu_\tau$	( 2.2 ± 0.5 ) × 10 <sup>-3</sup>		655
$(\bar{K}^*(892) \pi)^- \nu_\tau \rightarrow$ $\pi^- \bar{K}^0 \pi^0 \nu_\tau$	( 1.0 ± 0.4 ) × 10 <sup>-3</sup>		–
$K_1(1270)^- \nu_\tau$	( 4.7 ± 1.1 ) × 10 <sup>-3</sup>		433
$K_1(1400)^- \nu_\tau$	( 1.7 ± 2.6 ) × 10 <sup>-3</sup>	S=1.7	335
$K^*(1410)^- \nu_\tau$	( 1.5 <sup>+ 1.4</sup> <sub>- 1.0</sub> ) × 10 <sup>-3</sup>		320
$K_0^*(1430)^- \nu_\tau$	< 5	× 10 <sup>-4</sup> CL=95%	317
$K_2^*(1430)^- \nu_\tau$	< 3	× 10 <sup>-3</sup> CL=95%	317
$\eta \pi^- \nu_\tau$	< 9.9	× 10 <sup>-5</sup> CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g] ( 1.39 ± 0.07 ) × 10 <sup>-3</sup>		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$	[g] ( 1.9 ± 0.4 ) × 10 <sup>-4</sup>		746
$\eta K^- \nu_\tau$	[g] ( 1.55 ± 0.08 ) × 10 <sup>-4</sup>		719
$\eta K^*(892)^- \nu_\tau$	( 1.38 ± 0.15 ) × 10 <sup>-4</sup>		511
$\eta K^- \pi^0 \nu_\tau$	[g] ( 4.8 ± 1.2 ) × 10 <sup>-5</sup>		665
$\eta K^- \pi^0$ (non- $K^*(892)$ ) $\nu_\tau$	< 3.5	× 10 <sup>-5</sup> CL=90%	–
$\eta \bar{K}^0 \pi^- \nu_\tau$	[g] ( 9.4 ± 1.5 ) × 10 <sup>-5</sup>		661
$\eta \bar{K}^0 \pi^- \pi^0 \nu_\tau$	< 5.0	× 10 <sup>-5</sup> CL=90%	590
$\eta K^- K^0 \nu_\tau$	< 9.0	× 10 <sup>-6</sup> CL=90%	430
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals $\nu_\tau$	< 3	× 10 <sup>-3</sup> CL=90%	744
$\eta \pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0$ )	[g] ( 2.19 ± 0.13 ) × 10 <sup>-4</sup>		744
$\eta \pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0, f_1(1285)$ )	( 9.9 ± 1.6 ) × 10 <sup>-5</sup>		–
$\eta a_1(1260)^- \nu_\tau \rightarrow \eta \pi^- \rho^0 \nu_\tau$	< 3.9	× 10 <sup>-4</sup> CL=90%	–
$\eta \eta \pi^- \nu_\tau$	< 7.4	× 10 <sup>-6</sup> CL=90%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$	< 2.0	× 10 <sup>-4</sup> CL=95%	559
$\eta \eta K^- \nu_\tau$	< 3.0	× 10 <sup>-6</sup> CL=90%	382
$\eta'(958) \pi^- \nu_\tau$	< 4.0	× 10 <sup>-6</sup> CL=90%	620
$\eta'(958) \pi^- \pi^0 \nu_\tau$	< 1.2	× 10 <sup>-5</sup> CL=90%	591
$\eta'(958) K^- \nu_\tau$	< 2.4	× 10 <sup>-6</sup> CL=90%	495
$\phi \pi^- \nu_\tau$	( 3.4 ± 0.6 ) × 10 <sup>-5</sup>		585
$\phi K^- \nu_\tau$	[g] ( 4.4 ± 1.6 ) × 10 <sup>-5</sup>		445
$f_1(1285) \pi^- \nu_\tau$	( 3.9 ± 0.5 ) × 10 <sup>-4</sup>	S=1.9	408
$f_1(1285) \pi^- \nu_\tau \rightarrow$ $\eta \pi^- \pi^+ \pi^- \nu_\tau$	( 1.18 ± 0.07 ) × 10 <sup>-4</sup>	S=1.3	–
$f_1(1285) \pi^- \nu_\tau \rightarrow$ $3\pi^- 2\pi^+ \nu_\tau$	[g] ( 5.2 ± 0.4 ) × 10 <sup>-5</sup>		–
$\pi(1300)^- \nu_\tau \rightarrow (\rho \pi)^- \nu_\tau \rightarrow$ $(3\pi)^- \nu_\tau$	< 1.0	× 10 <sup>-4</sup> CL=90%	–

$\pi(1300)^- \nu_\tau \rightarrow$	$< 1.9$	$\times 10^{-4}$	CL=90%	–
$((\pi\pi)_{S\text{-wave}} \pi)^- \nu_\tau \rightarrow$				
$(3\pi)^- \nu_\tau$				
$h^- \omega \geq 0$ neutrals $\nu_\tau$	$( 2.40 \pm 0.08 )$	%		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] $( 7.1 \pm 1.6 )$	$\times 10^{-5}$		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.

$e^- \gamma$	<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%	–
$\mu^-$ 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% <sup>[h]</sup> Decay to  $\nu W$ .

### $L^\pm$ – 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*.

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

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

$$\sin^2(\theta_{23}) = 0.51 \pm 0.04 \quad (\text{normal mass hierarchy})$$

$$\sin^2(\theta_{23}) = 0.50 \pm 0.04 \quad (\text{inverted mass hierarchy})$$

$$\Delta m_{32}^2 = (2.45 \pm 0.05) \times 10^{-3} \text{ eV}^2 [i] \quad (\text{normal mass hierarchy})$$

$$\Delta m_{32}^2 = (2.52 \pm 0.05) \times 10^{-3} \text{ eV}^2 [i] \quad (\text{inverted mass hierarchy})$$

$$\sin^2(\theta_{13}) = (2.10 \pm 0.11) \times 10^{-2}$$

### 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  $\nu_L$  coupling to  $e, \mu, \tau$ ; conservative case( $\tau$ ))

Mass  $m > 80.5$  GeV, CL = 95%

(Majorana  $\nu_L$  coupling to  $e, \mu, \tau$ ; conservative case( $\tau$ ))

## NOTES

- [a] This is the best limit for the mode  $e^- \rightarrow \nu\gamma$ . The best limit for “electron disappearance” is  $6.4 \times 10^{24}$  yr.
- [b] See the “Note on Muon Decay Parameters” in the  $\mu$  Particle Listings for definitions and details.
- [c]  $P_\mu$  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  $\gamma$  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  $\tau$ .
- [h]  $L^\pm$  mass limit depends on decay assumptions; see the Full Listings.
- [i] The sign of  $\Delta m_{32}^2$  is not known at this time. The range quoted is for the absolute value.