

# LEPTONS

e

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

Mass  $m = (548.57990946 \pm 0.00000022) \times 10^{-6}$  u

Mass  $m = 0.510998928 \pm 0.000000011$  MeV

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

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

Magnetic moment anomaly

$$(g-2)/2 = (1159.65218076 \pm 0.00000027) \times 10^{-6}$$

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

Electric dipole moment  $d < 10.5 \times 10^{-28}$  e cm, CL = 90%

Mean life  $\tau > 4.6 \times 10^{26}$  yr, CL = 90% [a]

μ

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

Mass  $m = 0.1134289267 \pm 0.0000000029$  u

Mass  $m = 105.6583715 \pm 0.00000035$  MeV

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

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

$$c\tau = 658.6384$$
 m

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

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

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

## Decay parameters [b]

$$\rho = 0.74979 \pm 0.00026$$

$$\eta = 0.057 \pm 0.034$$

$$\delta = 0.75047 \pm 0.00034$$

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

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

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

$$\xi'' = 0.7 \pm 0.4$$

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

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

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

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

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

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

$\mu^-$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$P$ (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
<b>Lepton Family number (LF) violating modes</b>			
$e^- \nu_e \bar{\nu}_\mu$	LF [f] $< 1.2$	%	90% 53
$e^- \gamma$	LF $< 5.7$	$\times 10^{-13}$	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  $m = 1776.82 \pm 0.16$  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 $^- \geq 0$ neutrals $\geq 0 K^0 \nu_\tau$ ("1-prong")	(85.35 $\pm$ 0.07) %	S=1.3	–
particle $^- \geq 0$ neutrals $\geq 0 K_L^0 \nu_\tau$	(84.71 $\pm$ 0.08) %	S=1.3	–
$\mu^- \bar{\nu}_\mu \nu_\tau$ [g]	(17.41 $\pm$ 0.04) %	S=1.1	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]	(17.83 $\pm$ 0.04) %		888
$e^- \bar{\nu}_e \nu_\tau \gamma$ [e]	( 1.75 $\pm$ 0.18 ) %		888
$h^- \geq 0 K_L^0 \nu_\tau$	(12.06 $\pm$ 0.06) %	S=1.2	883
$h^- \nu_\tau$	(11.53 $\pm$ 0.06) %	S=1.2	883
$\pi^- \nu_\tau$ [g]	(10.83 $\pm$ 0.06) %	S=1.2	883
$K^- \nu_\tau$ [g]	( 7.00 $\pm$ 0.10 ) $\times 10^{-3}$	S=1.1	820
$h^- \geq 1$ neutrals $\nu_\tau$	(37.10 $\pm$ 0.10) %	S=1.2	–
$h^- \geq 1 \pi^0 \nu_\tau$ (ex. $K^0$ )	(36.58 $\pm$ 0.10) %	S=1.2	–
$h^- \pi^0 \nu_\tau$	(25.95 $\pm$ 0.09) %	S=1.1	878
$\pi^- \pi^0 \nu_\tau$ [g]	(25.52 $\pm$ 0.09) %	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]	( 4.29 $\pm$ 0.15 ) $\times 10^{-3}$		814
$h^- \geq 2 \pi^0 \nu_\tau$	(10.87 $\pm$ 0.11) %	S=1.2	–
$h^- 2 \pi^0 \nu_\tau$	( 9.52 $\pm$ 0.11 ) %	S=1.1	862
$h^- 2 \pi^0 \nu_\tau$ (ex. $K^0$ )	( 9.36 $\pm$ 0.11 ) %	S=1.2	862
$\pi^- 2 \pi^0 \nu_\tau$ (ex. $K^0$ ) [g]	( 9.30 $\pm$ 0.11 ) %	S=1.2	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 $\pm$ 2.3 ) $\times 10^{-4}$		796
$h^- \geq 3 \pi^0 \nu_\tau$	( 1.35 $\pm$ 0.07 ) %	S=1.1	–
$h^- \geq 3 \pi^0 \nu_\tau$ (ex. $K^0$ )	( 1.26 $\pm$ 0.07 ) %	S=1.1	–
$h^- 3 \pi^0 \nu_\tau$	( 1.19 $\pm$ 0.07 ) %		836
$\pi^- 3 \pi^0 \nu_\tau$ (ex. $K^0$ ) [g]	( 1.05 $\pm$ 0.07 ) %		836

$K^- 3\pi^0 \nu_\tau$ (ex. $K^0$ , $\eta$ )	[g] ( 4.8 $\pm$ 2.2 ) $\times 10^{-4}$		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
$K^- \geq 0 \pi^0 \geq 0 K^0 \geq 0 \gamma \nu_\tau$	( 1.572 $\pm$ 0.033 ) %	S=1.1	820
$K^- \geq 1 (\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau$	( 8.72 $\pm$ 0.32 ) $\times 10^{-3}$	S=1.1	—

### Modes with $K^0$ 's

$K_S^0$ (particles) $^- \nu_\tau$	( 9.2 $\pm$ 0.4 ) $\times 10^{-3}$	S=1.5	—
$h^- \bar{K}^0 \nu_\tau$	( 1.00 $\pm$ 0.05 ) %	S=1.8	812
$\pi^- \bar{K}^0 \nu_\tau$	[g] ( 8.4 $\pm$ 0.4 ) $\times 10^{-3}$	S=2.1	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] ( 1.59 $\pm$ 0.16 ) $\times 10^{-3}$		737
$K^- K^0 \geq 0 \pi^0 \nu_\tau$	( 3.18 $\pm$ 0.23 ) $\times 10^{-3}$		737
$h^- \bar{K}^0 \pi^0 \nu_\tau$	( 5.6 $\pm$ 0.4 ) $\times 10^{-3}$		794
$\pi^- \bar{K}^0 \pi^0 \nu_\tau$	[g] ( 4.0 $\pm$ 0.4 ) $\times 10^{-3}$		794
$\bar{K}^0 \rho^- \nu_\tau$	( 2.2 $\pm$ 0.5 ) $\times 10^{-3}$		612
$K^- K^0 \pi^0 \nu_\tau$	[g] ( 1.59 $\pm$ 0.20 ) $\times 10^{-3}$		685
$\pi^- \bar{K}^0 \geq 1 \pi^0 \nu_\tau$	( 3.2 $\pm$ 1.0 ) $\times 10^{-3}$		—
$\pi^- \bar{K}^0 \pi^0 \pi^0 \nu_\tau$	( 2.6 $\pm$ 2.4 ) $\times 10^{-4}$		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$	< 1.6 $\times 10^{-4}$	CL=95%	619
$\pi^- K^0 \bar{K}^0 \nu_\tau$	( 1.7 $\pm$ 0.4 ) $\times 10^{-3}$	S=1.8	682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g] ( 2.31 $\pm$ 0.17 ) $\times 10^{-4}$	S=1.9	682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g] ( 1.2 $\pm$ 0.4 ) $\times 10^{-3}$	S=1.8	682
$\pi^- K^0 \bar{K}^0 \pi^0 \nu_\tau$	( 3.1 $\pm$ 2.3 ) $\times 10^{-4}$		614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	( 1.60 $\pm$ 0.30 ) $\times 10^{-4}$		614
$\pi^- K_S^0 K_L^0 \pi^0 \nu_\tau$	( 3.1 $\pm$ 1.2 ) $\times 10^{-4}$		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
$K^0 h^+ h^- h^- \nu_\tau$	( 2.3 $\pm$ 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 $\pm$ 0.08 ) %	S=1.3	861
$h^- h^- h^+ \geq 0$ neutrals $\nu_\tau$	(14.57 $\pm$ 0.07 ) %	S=1.3	861
(ex. $K_S^0 \rightarrow \pi^+ \pi^-$ ) ("3-prong")			
$h^- h^- h^+ \nu_\tau$	( 9.80 $\pm$ 0.07 ) %	S=1.2	861
$h^- h^- h^+ \nu_\tau$ (ex. $K^0$ )	( 9.46 $\pm$ 0.06 ) %	S=1.2	861
$h^- h^- h^+ \nu_\tau$ (ex. $K^0, \omega$ )	( 9.42 $\pm$ 0.06 ) %	S=1.2	861
$\pi^- \pi^+ \pi^- \nu_\tau$	( 9.31 $\pm$ 0.06 ) %	S=1.2	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0$ )	( 9.02 $\pm$ 0.06 ) %	S=1.1	861
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0$ ), non-axial vector	< 2.4 %	CL=95%	861

$\pi^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0, \omega$ )	[g]	( 8.99 $\pm$ 0.06 ) %	S=1.1	861
$h^- h^- h^+ \geq 1$ neutrals $\nu_\tau$		( 5.39 $\pm$ 0.07 ) %	S=1.2	–
$h^- h^- h^+ \geq 1 \pi^0 \nu_\tau$ (ex. $K^0$ )		( 5.09 $\pm$ 0.06 ) %	S=1.2	–
$h^- h^- h^+ \pi^0 \nu_\tau$		( 4.76 $\pm$ 0.06 ) %	S=1.2	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. $K^0$ )		( 4.57 $\pm$ 0.06 ) %	S=1.2	834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. $K^0, \omega$ )		( 2.79 $\pm$ 0.08 ) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		( 4.62 $\pm$ 0.06 ) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0$ )		( 4.48 $\pm$ 0.06 ) %	S=1.2	834
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0, \omega$ )	[g]	( 2.70 $\pm$ 0.08 ) %	S=1.2	834
$h^- h^- h^+ \geq 2 \pi^0 \nu_\tau$ (ex. $K^0$ )		( 5.21 $\pm$ 0.32 ) $\times 10^{-3}$		–
$h^- h^- h^+ 2 \pi^0 \nu_\tau$		( 5.08 $\pm$ 0.32 ) $\times 10^{-3}$		797
$h^- h^- h^+ 2 \pi^0 \nu_\tau$ (ex. $K^0$ )		( 4.98 $\pm$ 0.32 ) $\times 10^{-3}$		797
$h^- h^- h^+ 2 \pi^0 \nu_\tau$ (ex. $K^0, \omega, \eta$ )	[g]	( 1.0 $\pm$ 0.4 ) $\times 10^{-3}$		797
$h^- h^- h^+ 3 \pi^0 \nu_\tau$	[g]	( 2.3 $\pm$ 0.6 ) $\times 10^{-4}$	S=1.2	749
$2 \pi^- \pi^+ 3 \pi^0 \nu_\tau$ (ex. $K^0$ )		( 2.1 $\pm$ 0.4 ) $\times 10^{-4}$		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. $K^0, \eta, \omega, f_1(1285)$ )	<	5.8 $\times 10^{-5}$	CL=90%	–
$K^- h^+ h^- \geq 0$ neutrals $\nu_\tau$		( 6.35 $\pm$ 0.24 ) $\times 10^{-3}$	S=1.5	794
$K^- h^+ \pi^- \nu_\tau$ (ex. $K^0$ )		( 4.38 $\pm$ 0.19 ) $\times 10^{-3}$	S=2.7	794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0$ )		( 8.7 $\pm$ 1.2 ) $\times 10^{-4}$	S=1.1	763
$K^- \pi^+ \pi^- \geq 0$ neutrals $\nu_\tau$		( 4.85 $\pm$ 0.21 ) $\times 10^{-3}$	S=1.4	794
$K^- \pi^+ \pi^- \geq 0 \pi^0 \nu_\tau$ (ex. $K^0$ )		( 3.75 $\pm$ 0.19 ) $\times 10^{-3}$	S=1.5	794
$K^- \pi^+ \pi^- \nu_\tau$		( 3.49 $\pm$ 0.16 ) $\times 10^{-3}$	S=1.9	794
$K^- \pi^+ \pi^- \nu_\tau$ (ex. $K^0$ )	[g]	( 2.94 $\pm$ 0.15 ) $\times 10^{-3}$	S=2.2	794
$K^- \rho^0 \nu_\tau \rightarrow K^- \pi^+ \pi^- \nu_\tau$		( 1.4 $\pm$ 0.5 ) $\times 10^{-3}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		( 1.35 $\pm$ 0.14 ) $\times 10^{-3}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0$ )		( 8.1 $\pm$ 1.2 ) $\times 10^{-4}$		763
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex. $K^0, \eta$ )	[g]	( 7.8 $\pm$ 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
$K^- \pi^+ K^- \geq 0$ neut. $\nu_\tau$	<	9 $\times 10^{-4}$	CL=95%	685
$K^- K^+ \pi^- \geq 0$ neut. $\nu_\tau$		( 1.50 $\pm$ 0.06 ) $\times 10^{-3}$	S=1.8	685
$K^- K^+ \pi^- \nu_\tau$	[g]	( 1.44 $\pm$ 0.05 ) $\times 10^{-3}$	S=1.9	685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	( 6.1 $\pm$ 2.5 ) $\times 10^{-5}$	S=1.4	618
$K^- K^+ K^- \nu_\tau$		( 2.1 $\pm$ 0.8 ) $\times 10^{-5}$	S=5.4	471
$K^- K^+ K^- \nu_\tau$ (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 $\nu_\tau$ (ex. $K_S^0 \rightarrow \pi^- \pi^+$ ) ("5-prong")	( 1.02 $\pm$ 0.04 ) $\times 10^{-3}$	S=1.1	794
$3h^- 2h^+ \nu_\tau$ (ex. $K^0$ )	[g] ( 8.39 $\pm$ 0.35 ) $\times 10^{-4}$	S=1.1	794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. $K^0, \omega$ )	( 8.3 $\pm$ 0.4 ) $\times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau$ (ex. $K^0, \omega$ , $f_1(1285)$ )	( 7.7 $\pm$ 0.4 ) $\times 10^{-4}$		—
$K^- 2\pi^- 2\pi^+ \nu_\tau$	< 2.4 $\times 10^{-6}$	CL=90%	715
$K^+ 3\pi^- \pi^+ \nu_\tau$	< 5.0 $\times 10^{-6}$	CL=90%	715
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$	< 4.5 $\times 10^{-7}$	CL=90%	528
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex. $K^0$ )	[g] ( 1.78 $\pm$ 0.27 ) $\times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex. $K^0$ )	( 1.65 $\pm$ 0.10 ) $\times 10^{-4}$		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. $K^0, \eta$ , $\omega, f_1(1285)$ )	( 3.6 $\pm$ 0.9 ) $\times 10^{-5}$		—
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$	< 1.9 $\times 10^{-6}$	CL=90%	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**

$(5\pi)^- \nu_\tau$	( 7.6 $\pm$ 0.5 ) $\times 10^{-3}$		800
$4h^- 3h^+ \geq 0$ neutrals $\nu_\tau$ ("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
$X^-(S=-1) \nu_\tau$	( 2.87 $\pm$ 0.07 ) %	S=1.3	—
$K^*(892)^- \geq 0$ 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
$K^*(892)^- \nu_\tau \rightarrow \pi^- \bar{K}^0 \nu_\tau$	( 7.9 $\pm$ 0.5 ) $\times 10^{-3}$		—
$K^*(892)^0 K^- \geq 0$ 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
$\bar{K}^*(892)^0 \pi^- \geq 0$ neutrals $\nu_\tau$	( 3.8 $\pm$ 1.7 ) $\times 10^{-3}$		655
$\bar{K}^*(892)^0 \pi^- \nu_\tau$	( 2.2 $\pm$ 0.5 ) $\times 10^{-3}$		655
$(\bar{K}^*(892) \pi)^- \nu_\tau \rightarrow$ $\pi^- \bar{K}^0 \pi^0 \nu_\tau$	( 1.0 $\pm$ 0.4 ) $\times 10^{-3}$		—
$K_1(1270)^- \nu_\tau$	( 4.7 $\pm$ 1.1 ) $\times 10^{-3}$		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%	317
$K_2^*(1430)^- \nu_\tau$	< 3 $\times 10^{-3}$	CL=95%	316
$\eta \pi^- \nu_\tau$	< 9.9 $\times 10^{-5}$	CL=95%	797

$\eta\pi^-\pi^0\nu_\tau$	[g]	$(1.39 \pm 0.10) \times 10^{-3}$	S=1.4	778
$\eta\pi^-\pi^0\pi^0\nu_\tau$		$(1.81 \pm 0.31) \times 10^{-4}$		746
$\eta K^-\nu_\tau$	[g]	$(1.52 \pm 0.08) \times 10^{-4}$		719
$\eta K^*(892)^-\nu_\tau$		$(1.38 \pm 0.15) \times 10^{-4}$		511
$\eta K^-\pi^0\nu_\tau$		$(4.8 \pm 1.2) \times 10^{-5}$		665
$\eta K^-\pi^0(\text{non-}K^*(892))\nu_\tau$		$< 3.5 \times 10^{-5}$	CL=90%	–
$\eta\bar{K}^0\pi^-\nu_\tau$		$(9.3 \pm 1.5) \times 10^{-5}$		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 $\nu_\tau$		$< 3 \times 10^{-3}$	CL=90%	743
$\eta\pi^-\pi^+\pi^-\nu_\tau(\text{ex.}K^0)$		$(2.25 \pm 0.13) \times 10^{-4}$		743
$\eta\pi^-\pi^+\pi^-\nu_\tau(\text{ex.}K^0, f_1(1285))$		$(9.9 \pm 1.6) \times 10^{-5}$		–
$\eta a_1(1260)^-\nu_\tau \rightarrow \eta\pi^-\rho^0\nu_\tau$		$< 3.9 \times 10^{-4}$	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
$\phi\pi^-\nu_\tau$		$(3.4 \pm 0.6) \times 10^{-5}$		585
$\phi K^-\nu_\tau$		$(3.70 \pm 0.33) \times 10^{-5}$	S=1.3	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	–
$f_1(1285)\pi^-\nu_\tau \rightarrow 3\pi^-2\pi^+\nu_\tau$		$(5.2 \pm 0.5) \times 10^{-5}$		–
$\pi(1300)^-\nu_\tau \rightarrow (\rho\pi)^-\nu_\tau \rightarrow (3\pi)^-\nu_\tau$		$< 1.0 \times 10^{-4}$	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 $\nu_\tau$		$(2.41 \pm 0.09) \%$	S=1.2	708
$h^-\omega\nu_\tau$	[g]	$(2.00 \pm 0.08) \%$	S=1.3	708
$K^-\omega\nu_\tau$		$(4.1 \pm 0.9) \times 10^{-4}$		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
$\pi^-\omega 2\pi^0\nu_\tau$		$(7.3 \pm 1.7) \times 10^{-5}$		644
$h^-2\omega\nu_\tau$		$< 5.4 \times 10^{-7}$	CL=90%	249
$2h^-h^+\omega\nu_\tau$		$(1.20 \pm 0.22) \times 10^{-4}$		641
$2\pi^-\pi^+\omega\nu_\tau$		$(8.4 \pm 0.7) \times 10^{-5}$		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
$\mu^- \gamma$	$LF$	$< 4.4$	$\times 10^{-8}$	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
$e^- \rho^0$	$LF$	$< 1.8$	$\times 10^{-8}$	CL=90%	719
$\mu^- \rho^0$	$LF$	$< 1.2$	$\times 10^{-8}$	CL=90%	715
$e^- \omega$	$LF$	$< 4.8$	$\times 10^{-8}$	CL=90%	716
$\mu^- \omega$	$LF$	$< 4.7$	$\times 10^{-8}$	CL=90%	711
$e^- K^*(892)^0$	$LF$	$< 3.2$	$\times 10^{-8}$	CL=90%	665
$\mu^- K^*(892)^0$	$LF$	$< 5.9$	$\times 10^{-8}$	CL=90%	659
$e^- \bar{K}^*(892)^0$	$LF$	$< 3.4$	$\times 10^{-8}$	CL=90%	665
$\mu^- \bar{K}^*(892)^0$	$LF$	$< 7.0$	$\times 10^{-8}$	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%	—
$e^- \phi$	$LF$	$< 3.1$	$\times 10^{-8}$	CL=90%	596
$\mu^- \phi$	$LF$	$< 8.4$	$\times 10^{-8}$	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
$\mu^- \mu^+ \mu^-$	$LF$	$< 2.1$	$\times 10^{-8}$	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%	738
$e^+ K^- K^-$	$L$	$< 3.3$	$\times 10^{-8}$	CL=90%	738
$\mu^- \pi^+ K^-$	$LF$	$< 8.6$	$\times 10^{-8}$	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 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*.

$$\sin^2(2\theta_{12}) = 0.846 \pm 0.021$$

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

$$\sin^2(2\theta_{23}) = 0.999^{+0.001}_{-0.018} \quad (\text{normal mass hierarchy})$$

$$\sin^2(2\theta_{23}) = 1.000^{+0.000}_{-0.017} \quad (\text{inverted mass hierarchy})$$

$$\Delta m_{32}^2 = (2.44 \pm 0.06) \times 10^{-3} \text{ eV}^2 [i] \quad (\text{normal mass hierarchy})$$

$$\Delta m_{32}^2 = (2.52 \pm 0.07) \times 10^{-3} \text{ eV}^2 [i] \quad (\text{inverted mass hierarchy})$$

$$\sin^2(2\theta_{13}) = (9.3 \pm 0.8) \times 10^{-2}$$

### Stable Neutral Heavy Lepton Mass Limits

Mass  $m > 45.0 \text{ GeV}$ , CL = 95% (Dirac)

Mass  $m > 39.5 \text{ GeV}$ , CL = 95% (Majorana)

### Neutral Heavy Lepton Mass Limits

Mass  $m > 90.3 \text{ GeV}$ , CL = 95%

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

Mass  $m > 80.5 \text{ GeV}$ , 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.