LEPTONS

\( J = \frac{1}{2} \)

**\( e \)**

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

Mass \( m = 0.5109989461 \pm 0.000000031 \) MeV

\[
\left| m_{e^+} - m_{e^-} \right| / m < 8 \times 10^{-9}, \text{ CL = 90\%} \\
\left| q_{e^+} + q_{e^-} \right| / e < 4 \times 10^{-8}
\]

Magnetic moment anomaly

\[
\frac{(g-2)/2}{\langle g \rangle} = (1159.65218091 \pm 0.0000026) \times 10^{-6}
\]

Electric dipole moment

\[
d < 0.11 \times 10^{-28} \text{ e cm}, \text{ CL = 90\%}
\]

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

**\( \mu \)**

Mass \( m = 0.1134289257 \pm 0.000000025 \) u

Mass \( m = 105.6583745 \pm 0.0000024 \) MeV

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

\[
\frac{\tau_{\mu^+}/\tau_{\mu^-}}{\langle \tau \rangle} = 1.00002 \pm 0.00008
\]

\[
\frac{c\tau}{\langle \tau \rangle} = 658.6384 \text{ m}
\]

Magnetic moment anomaly

\[
\frac{(g-2)/2}{\langle g \rangle} = (11659209 \pm 6) \times 10^{-10}
\]

Electric dipole moment

\[
d = (-0.1 \pm 0.9) \times 10^{-19} \text{ e cm}
\]

**Decay parameters** [b]

\[
\rho = 0.74979 \pm 0.00026
\]

\[
\eta = 0.057 \pm 0.034
\]

\[
\delta = 0.75047 \pm 0.00034
\]

\[
\xi_P = 1.0009^{+0.0016}_{-0.0007} \text{ [c]}
\]

\[
\xi_P \delta / \rho = 1.0018^{+0.0016}_{-0.0007} \text{ [c]}
\]

\[
\xi' = 1.00 \pm 0.04
\]

\[
\xi'' = 0.98 \pm 0.04
\]

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

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

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

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

\[
\bar{\eta} = 0.02 \pm 0.08
\]
\( \mu^+ \) modes are charge conjugates of the modes below.

### \( \mu^- \) Decay Modes

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Fraction (( \Gamma_i / \Gamma ))</th>
<th>Confidence level (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e^- \nu_e \nu_\mu )</td>
<td>( \approx 100% )</td>
<td>53</td>
</tr>
<tr>
<td>( e^- \nu_e \nu_\mu \gamma )</td>
<td>[d] ( (6.0 \pm 0.5) \times 10^{-8} )</td>
<td>53</td>
</tr>
<tr>
<td>( e^- \nu_e \nu_\mu e^+ e^- )</td>
<td>[e] ( (3.4 \pm 0.4) \times 10^{-5} )</td>
<td>53</td>
</tr>
</tbody>
</table>

#### Lepton Family Number (LF) Violating Modes

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>LF</th>
<th>Fraction</th>
<th>Confidence level (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e^- \nu_e \nu_\mu )</td>
<td>( LF )</td>
<td>( [f] &lt; 1.2 )</td>
<td>90% 53</td>
</tr>
<tr>
<td>( e^- \gamma )</td>
<td>( LF )</td>
<td>( &lt; 4.2 \times 10^{-13} )</td>
<td>90% 53</td>
</tr>
<tr>
<td>( e^- e^+ e^- )</td>
<td>( LF )</td>
<td>( &lt; 1.0 \times 10^{-12} )</td>
<td>90% 53</td>
</tr>
<tr>
<td>( e^- 2\gamma )</td>
<td>( LF )</td>
<td>( &lt; 7.2 \times 10^{-11} )</td>
<td>90% 53</td>
</tr>
</tbody>
</table>

#### Decay Parameters

See the \( \tau \) Particle Listings for a note concerning \( \tau \)-decay parameters.

\[ \rho(e \text{ or } \mu) = 0.745 \pm 0.008 \]
\[ \rho(e) = 0.747 \pm 0.010 \]
\[ \rho(\mu) = 0.763 \pm 0.020 \]
\[ \xi(e \text{ or } \mu) = 0.985 \pm 0.030 \]
\[ \xi(e) = 0.994 \pm 0.040 \]
\[ \xi(\mu) = 1.030 \pm 0.059 \]
\[ \eta(e \text{ or } \mu) = 0.013 \pm 0.020 \]
\[ \eta(\mu) = 0.094 \pm 0.073 \]
\[(\delta \xi)(e \text{ or } \mu) = 0.746 \pm 0.021\]
\[(\delta \xi)(e) = 0.734 \pm 0.028\]
\[(\delta \xi)(\mu) = 0.778 \pm 0.037\]
\[\xi(\pi) = 0.993 \pm 0.022\]
\[\xi(\rho) = 0.994 \pm 0.008\]
\[\xi(a_1) = 1.001 \pm 0.027\]
\[\xi(\text{all hadronic modes}) = 0.995 \pm 0.007\]
\[\overline{\eta}(\mu) \text{ PARAMETER } = -1.3 \pm 1.7\]
\[\xi_K(e) \text{ PARAMETER } = -0.4 \pm 1.2\]
\[\xi_K(\mu) \text{ PARAMETER } = 0.8 \pm 0.6\]

\(\tau^+\) modes are charge conjugates of the modes below. “\(h^\pm\)” stands for \(\pi^\pm\) or \(K^\pm\). “\(l\)” stands for \(e\) or \(\mu\). “Neutrals” stands for \(\gamma\)’s and/or \(\pi^0\)’s.

\[
\begin{array}{|l|c|c|}
\hline
\text{Modes with one charged particle} & \text{Fraction (}\Gamma/l/\Gamma) & \text{Confidence level (MeV/c)} \\
\hline
\text{particle}^- \geq 0 \text{ neutrals} \geq 0K^0_{\nu_T} & (85.24 \pm 0.06) \% & - \\
\text{particle}^- \geq 0 \text{ neutrals} \geq 0K^0_{\nu_T} & (84.58 \pm 0.06) \% & - \\
\mu^- \overline{\nu}_\mu \nu_T & [g] (17.39 \pm 0.04) \% & 885 \\
\mu^- \overline{\nu}_\mu \gamma & [e] (3.67 \pm 0.08) \times 10^{-3} & 885 \\
e^- \overline{\nu}_e \nu_T & [g] (17.82 \pm 0.04) \% & 888 \\
e^- \overline{\nu}_e \gamma & [e] (1.83 \pm 0.05) \% & 888 \\
h^- \geq 0K^0_{\nu_T} & (12.03 \pm 0.05) \% & 883 \\
h^- \nu_T & (11.51 \pm 0.05) \% & 883 \\
\pi^- \nu_T & [g] (10.82 \pm 0.05) \% & 883 \\
K^- \nu_T & [g] (6.96 \pm 0.10) \times 10^{-3} & 820 \\
h^- \geq 1 \text{ neutrals} \nu_T & (37.01 \pm 0.09) \% & - \\
h^- \geq 1\pi^0\nu_T (\text{ex.}K^0) & (36.51 \pm 0.09) \% & - \\
h^- \pi^0 \nu_T & (25.93 \pm 0.09) \% & 878 \\
\pi^- \pi^0 \nu_T & [g] (25.49 \pm 0.09) \% & 878 \\
\pi^- \pi^0 \text{non-\(\rho\)(770)} \nu_T & (3.0 \pm 3.2) \times 10^{-3} & 878 \\
K^- \pi^0 \nu_T & [g] (4.33 \pm 0.15) \times 10^{-3} & 814 \\
h^- \geq 2\pi^0\nu_T & (10.81 \pm 0.09) \% & - \\
h^- \geq 2\pi^0\nu_T & (9.48 \pm 0.10) \% & 862 \\
h^- \geq 2\pi^0\nu_T (\text{ex.}K^0) & (9.32 \pm 0.10) \% & 862 \\
\pi^- 2\pi^0\nu_T (\text{ex.}K^0) & [g] (9.26 \pm 0.10) \% & 862 \\
\pi^- 2\pi^0\nu_T (\text{ex.}K^0) & < 9 \times 10^{-3} & \text{CL=95}\% & 862 \\
\text{scalar} \pi^- 2\pi^0\nu_T (\text{ex.}K^0), & < 7 \times 10^{-3} & \text{CL=95}\% & 862 \\
\text{vector} K^- 2\pi^0\nu_T (\text{ex.}K^0) & [g] (6.5 \pm 2.2) \times 10^{-4} & 796 \\
\hline
\end{array}
\]
\[ h^{-} \geq 3\pi^0 \nu_{\tau} \triangleq (1.34 \pm 0.07)\% \]

\[ h^{-} \geq 3\pi^0 \nu_{\tau} \text{(ex. } K^0) \triangleq (1.25 \pm 0.07)\% \]

\[ h^{-} \geq 3\pi^0 \nu_{\tau} \text{(ex. } K^0, \eta) \triangleq (1.18 \pm 0.07)\% \]

\[ \pi^{-} 3\pi^0 \nu_{\tau} \text{(ex. } K^0) \triangleq (1.04 \pm 0.07)\% \]

\[ K^{-} 3\pi^0 \nu_{\tau} \text{(ex. } K^0, \eta) \triangleq (4.8 \pm 2.1) \times 10^{-4} \]

\[ h^{-} 4\pi^0 \nu_{\tau} \text{(ex. } K^0) \triangleq (1.6 \pm 0.4) \times 10^{-3} \]

\[ h^{-} 4\pi^0 \nu_{\tau} \text{(ex. } K^0, \eta) \triangleq (1.1 \pm 0.4) \times 10^{-3} \]

\[ a_1(1260)_{\nu_{\tau}} \rightarrow \pi^{-} \gamma \nu_{\tau} \triangleq (3.8 \pm 1.5) \times 10^{-4} \]

\[ K^{-} \geq 0 \pi^0 \leq 0 K^0 \geq 0 \gamma \nu_{\tau} \triangleq (1.552 \pm 0.029)\% \]

\[ K^{-} \geq 1 \left( \pi^0 \text{ or } K^0 \text{ or } \gamma \right) \nu_{\tau} \triangleq (8.59 \pm 0.28) \times 10^{-3} \]

**Modes with \( K^0 \)'s**

\[ K^0_{S} \text{ (particles)}^{-} \nu_{\tau} \triangleq (9.43 \pm 0.28) \times 10^{-3} \]

\[ h^{-} K^0_{S} \nu_{\tau} \triangleq (9.87 \pm 0.14) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \nu_{\tau} \triangleq (8.38 \pm 0.14) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \nu_{\tau} \triangleq (5.4 \pm 2.1) \times 10^{-4} \]

\[ (\text{non-}K^* \text{(892)}^-) \nu_{\tau} \triangleq (1.486 \pm 0.034) \times 10^{-3} \]

\[ K^{-} K^0 \geq 0 \pi^0 \nu_{\tau} \triangleq (2.99 \pm 0.07) \times 10^{-3} \]

\[ h^{-} K^0_{S} \pi^0 \nu_{\tau} \triangleq (5.32 \pm 0.13) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \pi^0 \nu_{\tau} \triangleq (3.82 \pm 0.13) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \nu_{\tau} \triangleq (2.2 \pm 0.5) \times 10^{-3} \]

\[ K^{-} K^0 \geq 0 \pi^0 \nu_{\tau} \triangleq (1.50 \pm 0.07) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \geq 1 \pi^0 \nu_{\tau} \triangleq (4.08 \pm 0.25) \times 10^{-3} \]

\[ \pi^{-} K^0_{S} \geq 0 \pi^0 \nu_{\tau} \triangleq (2.6 \pm 2.3) \times 10^{-4} \]

**Notes:**

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq 1.6 \times 10^{-4} \text{ CL=95\%} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (1.55 \pm 0.24) \times 10^{-3} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (2.35 \pm 0.06) \times 10^{-4} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (1.08 \pm 0.24) \times 10^{-3} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (2.35 \pm 0.06) \times 10^{-4} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (3.6 \pm 1.2) \times 10^{-4} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (1.82 \pm 0.21) \times 10^{-5} \]

\[ K^{-} K^0 \pi^0 \nu_{\tau} \leq (1.08 \pm 0.21) \times 10^{-5} \]

\[ \pi^{-} K^0_{S} \pi^0 \nu_{\tau} \rightarrow \pi^{-} K^0_{S} \pi^0 \nu_{\tau} \]

\[ f_1(1285) \rightarrow \pi^{-} K^0_{S} \pi^0 \nu_{\tau} \]

\[ f_1(1420) \rightarrow \pi^{-} K^0_{S} \pi^0 \nu_{\tau} \]

\[ \pi^{-} K^0_{S} K^0_{L} \pi^0 \nu_{\tau} \triangleq (3.2 \pm 1.2) \times 10^{-4} \]

\[ \pi^{-} K^0_{L} K^0_{L} \pi^0 \nu_{\tau} \triangleq (1.82 \pm 0.21) \times 10^{-5} \]

\[ K^{-} K^0_{S} \nu_{\tau} \leq 6.3 \times 10^{-7} \text{ CL=90\%} \]
\[
K^- K^0 S K^0 S \pi^0 \nu_{\tau} \quad < 4.0 \times 10^{-7} \quad \text{CL=90\%} \quad 337
\]
\[
K^0 h^+ h^- h^- > 0 \text{ neutrals } \nu_{\tau} \quad < 1.7 \times 10^{-3} \quad \text{CL=95\%} \quad 760
\]
\[
K^0 h^+ h^- h^- \nu_{\tau} \quad [g] \quad (2.5 \pm 2.0) \times 10^{-4} \quad 760
\]

**Modes with three charged particles**

\[
h^- h^- h^- \geq 0 \text{ neutrals } \geq 0K^0 L \nu_{\tau} \quad (15.20 \pm 0.06) \% \quad 861
\]
\[
h^- h^- h^- \geq 1 \text{ neutrals } \nu_{\tau} \quad (14.55 \pm 0.06) \% \quad 861
\]
\[
(\text{ex. } K^0 S \rightarrow \pi^+ \pi^-)
\]
\[
(\text{\textquotedblright}3\text{-prong\textquotedblright})
\]
\[
h^- h^- h^- \nu_{\tau} \quad (9.80 \pm 0.05) \% \quad 861
\]
\[
h^- h^- h^- \nu_{\tau} (\text{ex. } K^0) \quad (9.46 \pm 0.05) \% \quad 861
\]
\[
h^- h^- h^- \nu_{\tau} (\text{ex. } K^0, \omega) \quad (9.43 \pm 0.05) \% \quad 861
\]
\[
\pi^- \pi^+ \pi^- \nu_{\tau} \quad (9.31 \pm 0.05) \% \quad 861
\]
\[
\pi^- \pi^- \pi^- \nu_{\tau} (\text{ex. } K^0) \quad (9.02 \pm 0.05) \% \quad 861
\]
\[
\pi^- \pi^- \pi^- \nu_{\tau} (\text{ex. } K^0) \quad < 2.4 \% \quad \text{CL=95\%} \quad 861
\]
\[
\text{non-axial vector} \quad \pi^- \pi^- \pi^- \nu_{\tau} (\text{ex. } K^0, \omega) \quad [g] \quad (8.99 \pm 0.05) \% \quad 861
\]
\[
h^- h^- h^- \geq 1 \text{ neutrals } \nu_{\tau} \quad (5.29 \pm 0.05) \% \quad 834
\]
\[
h^- h^- h^- \geq 1 \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (5.09 \pm 0.05) \% \quad 834
\]
\[
h^- h^- h^- h^+ \pi^0 \nu_{\tau} \quad (4.76 \pm 0.05) \% \quad 834
\]
\[
h^- h^- h^- h^+ \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (4.57 \pm 0.05) \% \quad 834
\]
\[
h^- h^- h^- h^+ \pi^0 \nu_{\tau} (\text{ex. } K^0, \omega) \quad (2.79 \pm 0.07) \% \quad 834
\]
\[
\pi^- \pi^- \pi^- \pi^0 \nu_{\tau} \quad (4.62 \pm 0.05) \% \quad 834
\]
\[
\pi^- \pi^- \pi^- \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (4.49 \pm 0.05) \% \quad 834
\]
\[
\pi^- \pi^- \pi^- \pi^0 \nu_{\tau} (\text{ex. } K^0, \omega) \quad [g] \quad (2.74 \pm 0.07) \% \quad 834
\]
\[
h^- h^- h^- \geq 2 \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (5.17 \pm 0.31) \times 10^{-3} \quad 797
\]
\[
h^- h^- h^- h^+ 2 \pi^0 \nu_{\tau} \quad (5.05 \pm 0.31) \times 10^{-3} \quad 797
\]
\[
h^- h^- h^- h^+ 2 \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (4.95 \pm 0.31) \times 10^{-3} \quad 797
\]
\[
h^- h^- h^- h^+ 2 \pi^0 \nu_{\tau} (\text{ex. } K^0, \omega, \eta) \quad [g] \quad (10 \pm 4) \times 10^{-4} \quad 797
\]
\[
h^- h^- h^- h^+ 3 \pi^0 \nu_{\tau} \quad (2.13 \pm 0.30) \times 10^{-4} \quad 749
\]
\[
2 \pi^- \pi^+ \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (1.95 \pm 0.30) \times 10^{-4} \quad 749
\]
\[
2 \pi^- \pi^+ \pi^0 \nu_{\tau} (\text{ex. } K^0, \omega, f_1(1285)) \quad (1.7 \pm 0.4) \times 10^{-4} \quad 749
\]
\[
2 \pi^- \pi^+ \pi^0 \nu_{\tau} (\text{ex. } K^0, \eta, f_1(1285)) \quad (1.4 \pm 2.7) \times 10^{-5} \quad 749
\]

\[
K^- h^+ h^- \geq 0 \text{ neutrals } \nu_{\tau} \quad (6.29 \pm 0.14) \times 10^{-3} \quad 794
\]
\[
K^- h^+ \pi^- \nu_{\tau} (\text{ex. } K^0) \quad (4.37 \pm 0.07) \times 10^{-3} \quad 794
\]
\[
K^- h^+ \pi^- \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (8.6 \pm 1.2) \times 10^{-4} \quad 763
\]
\[
K^- \pi^+ \pi^- \geq 0 \text{ neutrals } \nu_{\tau} \quad (4.77 \pm 0.14) \times 10^{-3} \quad 794
\]
\[
K^- \pi^+ \pi^- \geq 0 \pi^0 \nu_{\tau} (\text{ex. } K^0) \quad (3.73 \pm 0.13) \times 10^{-3} \quad 794
\]
\[
K^- \pi^+ \pi^- \nu_{\tau} \quad (3.45 \pm 0.07) \times 10^{-3} \quad 794
\]
\[
K^- \pi^+ \pi^- \nu_{\tau} (\text{ex. } K^0) \quad (2.93 \pm 0.07) \times 10^{-3} \quad 794
\]
\[ K^{-}\pi^{+}\pi^{-}\nu_{\tau} \text{ (ex. } K^{0},\omega) \quad \text{[g]} \quad (2.93 \pm 0.07) \times 10^{-3} \quad 794 \]
\[ K^{-}\rho^{0}\nu_{\tau} \rightarrow K^{-}\pi^{+}\pi^{-}\nu_{\tau} \quad (1.4 \pm 0.5) \times 10^{-3} \quad - \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \quad (1.31 \pm 0.12) \times 10^{-3} \quad 763 \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0}) \quad (7.9 \pm 1.2) \times 10^{-4} \quad 763 \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\eta) \quad (7.6 \pm 1.2) \times 10^{-4} \quad 763 \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\omega) \quad (3.7 \pm 0.9) \times 10^{-4} \quad 763 \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\omega,\eta) \quad (3.9 \pm 1.4) \times 10^{-4} \quad 763 \]
\[ K^{-}\pi^{+}K^{-} \geq 0 \text{ neut. } \nu_{\tau} \quad < 9 \times 10^{-4} \text{ CL}=95\% \quad 685 \]
\[ K^{-}\pi^{+}K^{-} \geq 0 \text{ neut. } \nu_{\tau} \quad (1.496 \pm 0.033) \times 10^{-3} \quad 685 \]
\[ K^{-}\pi^{+}K^{-}\nu_{\tau} \quad (1.435 \pm 0.027) \times 10^{-3} \quad 685 \]
\[ K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \quad (6.1 \pm 1.8) \times 10^{-5} \quad 618 \]
\[ K^{-}\pi^{+}K^{-}\nu_{\tau} \quad (2.2 \pm 0.8) \times 10^{-5} \quad S=5.4 \quad 472 \]
\[ K^{-}\pi^{+}K^{-}\nu_{\tau} \text{ (ex. } \phi) \quad < 2.5 \times 10^{-6} \text{ CL}=90\% \quad - \]
\[ K^{-}\pi^{+}K^{-}\pi^{-}\nu_{\tau} \quad < 4.8 \times 10^{-6} \text{ CL}=90\% \quad 345 \]
\[ \pi^{-}\pi^{-} \geq 0 \text{ neut. } \nu_{\tau} \quad < 2.5 \times 10^{-3} \text{ CL}=95\% \quad 794 \]
\[ e^{-}e^{-}\pi^{-}\nu_{\tau} \quad (2.8 \pm 1.5) \times 10^{-5} \quad 888 \]
\[ \mu^{-}e^{-}\pi^{-}\nu_{\tau} \quad < 3.6 \times 10^{-5} \text{ CL}=90\% \quad 885 \]

**Modes with five charged particles**

\[3h^{-}2h^{+} \geq 0 \text{ neutrals } \nu_{\tau} \quad (9.9 \pm 0.4) \times 10^{-4} \quad 794\]
\[ (\text{ex. } K^{0}_{S} \rightarrow \pi^{-}\pi^{+}) \quad ("5-prong") \]
\[3h^{-}2h^{+}\nu_{\tau} \text{ (ex. } K^{0}) \quad (8.29 \pm 0.31) \times 10^{-4} \quad 794 \]
\[3\pi^{-}2\pi^{+}\nu_{\tau} \text{ (ex. } K^{0},\omega) \quad (8.27 \pm 0.31) \times 10^{-4} \quad 794 \]
\[3\pi^{-}2\pi^{+}\nu_{\tau} \text{ (ex. } K^{0},\omega,\nu,\nu) \quad [g] \quad (7.75 \pm 0.30) \times 10^{-4} \quad - \]
\[f_{1}(1285) \]
\[K^{-}2\pi^{-}2\pi^{+}\nu_{\tau} \text{ (ex. } K^{0}) \quad [g] \quad (6 \pm 12) \times 10^{-7} \quad 716 \]
\[K^{+}3\pi^{-}\pi^{+}\nu_{\tau} \quad < 5.0 \times 10^{-6} \text{ CL}=90\% \quad 716 \]
\[K^{+}2\pi^{-}\pi^{+}\nu_{\tau} \quad < 4.5 \times 10^{-7} \text{ CL}=90\% \quad 528 \]
\[3h^{-}2h^{+}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0}) \quad (1.65 \pm 0.11) \times 10^{-4} \quad 746 \]
\[3\pi^{-}2\pi^{+}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0}) \quad (1.63 \pm 0.11) \times 10^{-4} \quad 746 \]
\[3\pi^{-}2\pi^{+}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\eta) \quad (1.11 \pm 0.10) \times 10^{-4} \quad - \]
\[f_{1}(1285) \]
\[3\pi^{-}2\pi^{+}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\eta,\omega,\nu,\nu) \quad [g] \quad (3.8 \pm 0.9) \times 10^{-5} \quad - \]

**Miscellaneous other allowed modes**

\[(5\pi^{-}\nu_{\tau}) \quad (7.8 \pm 0.5) \times 10^{-3} \quad 800\]
\[4h^{-}3h^{+} \geq 0 \text{ neutrals } \nu_{\tau} \quad < 3.0 \times 10^{-7} \text{ CL}=90\% \quad 682\]
\[ ("7-prong") \]
\[4h^{-}3h^{+}\nu_{\tau} \quad < 4.3 \times 10^{-7} \text{ CL}=90\% \quad 682\]
\begin{align*}
4h^- 3h^+ \pi^0 \nu_r &< 2.5 \times 10^{-7} \text{ CL=90\%} \quad 612 \\
X^- (S=−1) \nu_r &< (2.92 \pm 0.04)\% \quad - \\
K^*(892)^- \geq 0 \text{ neutrals} \quad & (1.42 \pm 0.18)\% \quad S=1.4 \quad 665 \\
0K^0 \nu_r &< (1.20 \pm 0.07)\% \quad S=1.8 \quad 665 \\
K^*(892)^- \nu_r &< (7.82 \pm 0.26) \times 10^{-3} \quad - \\
K^*(892)^0 K^- \geq 0 \text{ neutrals} \nu_r &< (3.2 \pm 1.4) \times 10^{-3} \quad 542 \\
K^*(892)^0 K^- \nu_r &< (2.1 \pm 0.4) \times 10^{-3} \quad 542 \\
\bar{K}^*(892)^0 \pi^- \geq 0 \text{ neutrals} \nu_r &< (3.8 \pm 1.7) \times 10^{-3} \quad 655 \\
\bar{K}^*(892)^0 \pi^- \nu_r &< (2.2 \pm 0.5) \times 10^{-3} \quad 655 \\
(\bar{K}^*(892)^0 \pi^-) \nu_r &< (1.0 \pm 0.4) \times 10^{-3} \quad - \\
K_1(1270)^- \nu_r &< (4.7 \pm 1.1) \times 10^{-3} \quad 433 \\
K_1(1400)^- \nu_r &< (1.7 \pm 2.6) \times 10^{-3} \quad S=1.7 \quad 335 \\
K^*(1410)^- \nu_r &< (1.5 \pm 1.4) \times 10^{-3} \quad 326 \\
K_s^*(1430)^- \nu_r &< 5 \times 10^{-4} \text{ CL=95\%} \quad 317 \\
K^*_2(1430)^- \nu_r &< 3 \times 10^{-3} \text{ CL=95\%} \quad 317 \\
\eta \pi^- \nu_r &< 9.9 \times 10^{-5} \text{ CL=95\%} \quad 797 \\
\eta \pi^- \pi^0 \nu_r &< (1.39 \pm 0.07) \times 10^{-3} \quad 778 \\
\eta \pi^- \pi^0 \pi^0 \nu_r &< (2.0 \pm 0.4) \times 10^{-4} \quad 746 \\
\eta K^- \nu_r &< (1.55 \pm 0.08) \times 10^{-4} \quad 719 \\
\eta K^*(892)^- \nu_r &< (1.38 \pm 0.15) \times 10^{-4} \quad 511 \\
\eta K^- \pi^0 \nu_r &< (4.8 \pm 1.2) \times 10^{-5} \quad 665 \\
\eta K^- \pi^0 \nu_r &< 3.5 \times 10^{-5} \text{ CL=90\%} \quad - \\
\eta \bar{K}^0 \pi^- \nu_r &< (9.4 \pm 1.5) \times 10^{-5} \quad 661 \\
\eta \bar{K}^0 \pi^- \pi^0 \nu_r &< 5.0 \times 10^{-5} \text{ CL=90\%} \quad 590 \\
\eta \bar{K}^0 \bar{K}^0 \nu_r &< 9.0 \times 10^{-6} \text{ CL=90\%} \quad 430 \\
\eta \pi^+ \pi^- \pi^- \geq 0 \text{ neutrals} \nu_r &< 3 \times 10^{-3} \text{ CL=90\%} \quad 744 \\
\eta \pi^+ \pi^- \nu_r \quad & \text{(ex. K}\^0\text{)} \quad (2.20 \pm 0.13) \times 10^{-4} \quad 744 \\
\eta \pi^+ \pi^- \nu_r \quad & \text{(ex. K}\^0, f_1(1285)) \quad (9.9 \pm 1.6) \times 10^{-5} \quad - \\
\eta a_1(1260)^- \nu_r \rightarrow \eta \pi^- \rho^0 \nu_r &< 3.9 \times 10^{-4} \text{ CL=90\%} \quad - \\
\eta \eta \pi^- \nu_r &< 7.4 \times 10^{-6} \text{ CL=90\%} \quad 637 \\
\eta \eta \pi^- \pi^0 \nu_r &< 2.0 \times 10^{-4} \text{ CL=95\%} \quad 559 \\
\eta \eta K^- \nu_r &< 3.0 \times 10^{-6} \text{ CL=90\%} \quad 382 \\
\eta^0(958) \pi^- \nu_r &< 4.0 \times 10^{-6} \text{ CL=90\%} \quad 620 \\
\eta^0(958) \pi^- \pi^0 \nu_r &< 1.2 \times 10^{-5} \text{ CL=90\%} \quad 591 \\
\eta(958) K^- \nu_r &< 2.4 \times 10^{-6} \text{ CL=90\%} \quad 495 \\
\phi \pi^- \nu_r &< (3.4 \pm 0.6) \times 10^{-5} \quad 585 \\
\phi K^- \nu_r &< (4.4 \pm 0.6) \times 10^{-5} \quad 445 \\
f_1(1285) \pi^- \nu_r &< (3.9 \pm 0.5) \times 10^{-4} \quad S=1.9 \quad 408 \\
f_1(1285) \pi^- \pi^- \nu_r &< \eta \pi^- \pi^+ \pi^- \nu_r &< (1.18 \pm 0.07) \times 10^{-4} \quad S=1.3 \quad - 
\end{align*}
\[ f_1(1285) \pi^- \nu_\tau \to 3 \pi^- 2 \pi^+ \nu_\tau \]
\[ \pi(1300)^- \nu_\tau \to (\rho \pi^-) \nu_\tau \to (3\pi^-) \nu_\tau \]
\[ \pi(1300)^- \nu_\tau \to (\pi\pi)_{S-wave} \nu_\tau \to (3\pi^-) \nu_\tau \]
\[ h^- \omega \geq 0 \text{ neutrals } \nu_\tau \]
\[ h^- \omega \nu_\tau \]
\[ K^- \omega \nu_\tau \]
\[ h^- \omega \pi^0 \nu_\tau \]
\[ h^- \omega 2\pi^0 \nu_\tau \]
\[ \pi^- \omega 2\pi^0 \nu_\tau \]
\[ h^- 2\omega \nu_\tau \]
\[ 2h^- h^+ \omega \nu_\tau \]
\[ 2\pi^- \pi^+ \omega \nu_\tau (\text{ex. } K^0) \]

**Lepton Family number (LF), Lepton number (L), or Baryon number (B) violating modes**

\( L \) means lepton number violation (e.g. \( \tau^- \to e^+ \pi^- \pi^- \)). Following common usage, LF means lepton family violation and not lepton number violation (e.g. \( \tau^- \to e^- \pi^+ \pi^- \)). \( B \) means baryon number violation.

\[ e^- \gamma \quad LF \quad < 3.3 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- \gamma \quad LF \quad < 4.4 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- \pi^0 \quad LF \quad < 8.0 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- \pi^0 \quad LF \quad < 1.1 \quad \times 10^{-7} \quad CL=90% \]
\[ e^- \ K^0 \quad LF \quad < 2.6 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- K^0 \quad LF \quad < 2.3 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- \eta \quad LF \quad < 9.2 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- \eta \quad LF \quad < 6.5 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- \rho^0 \quad LF \quad < 1.8 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- \rho^0 \quad LF \quad < 1.2 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- \omega \quad LF \quad < 4.8 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- \omega \quad LF \quad < 4.7 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- K^+(892) \quad LF \quad < 3.2 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- K^+(892) \quad LF \quad < 5.9 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- K^+(892) \quad LF \quad < 3.4 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- K^+(892) \quad LF \quad < 7.0 \quad \times 10^{-8} \quad CL=90% \]
\[ e^- \eta'(958) \quad LF \quad < 1.6 \quad \times 10^{-7} \quad CL=90% \]
\[ \mu^- \eta'(958) \quad LF \quad < 1.3 \quad \times 10^{-7} \quad CL=90% \]
\[ e^- f_0(980) \to e^- \pi^+ \pi^- \quad LF \quad < 3.2 \quad \times 10^{-8} \quad CL=90% \]
\[ \mu^- f_0(980) \to \mu^- \pi^+ \pi^- \quad LF \quad < 3.4 \quad \times 10^{-8} \quad CL=90% \]

Citation: M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update
\begin{tabular}{llcc}
\hline
 & & $\mu^\pm\phi$ & $\langle 8.4 \times 10^{-8}\rangle$ \\
$e^-e^+e^-$ & 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 \\
$\mu^-e^+\mu^-$ & 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 \\
$e^-\pi^-K^+$ & L & $< 3.1$ & $\times 10^{-8}$ CL=90\% 813 \\
e$ & $\pi^0K^0$ & $L$ & $< 3.2$ & $\times 10^{-8}$ CL=90\% 813 \\
e$ & $\pi^0K^0$ & $L$ & $< 3.1$ & $\times 10^{-8}$ CL=90\% 813 \\
e & $\pi^0K^0$ & $L$ & $< 3.4$ & $\times 10^{-8}$ CL=90\% 738 \\
e & $\pi^0K^0$ & $L$ & $< 3.3$ & $\times 10^{-8}$ CL=90\% 738 \\
e & $\pi^0K^0$ & $L$ & $< 8.6$ & $\times 10^{-8}$ CL=90\% 800 \\
e & $\pi^0K^0$ & $L$ & $< 4.5$ & $\times 10^{-8}$ CL=90\% 800 \\
e & $\pi^0K^0$ & $L$ & $< 4.8$ & $\times 10^{-8}$ CL=90\% 800 \\
e & $\pi^0K^0$ & $L$ & $< 3.4$ & $\times 10^{-8}$ CL=90\% 696 \\
e & $\pi^0K^0$ & $L$ & $< 4.4$ & $\times 10^{-8}$ CL=90\% 699 \\
e & $\pi^0K^0$ & $L$ & $< 4.7$ & $\times 10^{-8}$ CL=90\% 699 \\
e & $\pi^0K^0$ & $L$ & $< 6.5$ & $\times 10^{-6}$ CL=90\% 878 \\
e & $\pi^0K^0$ & $L$ & $< 1.4$ & $\times 10^{-5}$ CL=90\% 867 \\
e & $\pi^0K^0$ & $L$ & $< 3.5$ & $\times 10^{-5}$ CL=90\% 699 \\
e & $\pi^0K^0$ & $L$ & $< 6.0$ & $\times 10^{-5}$ CL=90\% 653 \\
e & $\eta\eta$ & $L$ & $< 2.4$ & $\times 10^{-5}$ CL=90\% 798 \\
e & $\pi^0\pi^0$ & $L$ & $< 2.2$ & $\times 10^{-5}$ CL=90\% 784 \\
e & $\pi^0\pi^0$ & $L$ & $< 4.4$ & $\times 10^{-7}$ CL=90\% 618 \\
e & $\pi^0\pi^0$ & $L$ & $< 3.3$ & $\times 10^{-7}$ CL=90\% 618 \\
e & $\pi^0\pi^0$ & $L$ & $< 3.5$ & $\times 10^{-6}$ CL=90\% 641 \\
e & $\pi^0\pi^0$ & $L$ & $< 1.5$ & $\times 10^{-5}$ CL=90\% 632 \\
e & $2\pi^0$ & $L$ & $< 3.3$ & $\times 10^{-5}$ CL=90\% 604 \\
e & $\pi^0$ & $L$ & $< 8.9$ & $\times 10^{-6}$ CL=90\% 475 \\
e & $\pi^0\eta$ & $L$ & $< 2.7$ & $\times 10^{-5}$ CL=90\% 360 \\
e & $\eta\Lambda$ & $L$ & $< 7.2$ & $\times 10^{-8}$ CL=90\% 525 \\
e & $\Lambda\pi$ & $L$ & $< 1.4$ & $\times 10^{-7}$ CL=90\% 525 \\
e & $\pi^-\pi^+$ & $L$ & $< 5$ & $\times 10^{-3}$ CL=95\% 95 \\
\hline
\end{tabular}
Heavy Charged Lepton Searches

$L^\pm$ – charged lepton
Mass $m > 100.8$ GeV, CL = 95% \([h]\) 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.

$$\sin^2(\theta_{12}) = 0.307 \pm 0.013$$
$$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5} \text{ eV}^2$$
$$\sin^2(\theta_{23}) = 0.536 \pm 0.023$$ (Inverted order)
$$\sin^2(\theta_{23}) = 0.512 \pm 0.019$$ (Normal order, octant I)
$$\sin^2(\theta_{23}) = 0.542 \pm 0.019$$ (Normal order, octant II)
$$\Delta m^2_{32} = (-2.55 \pm 0.04) \times 10^{-3} \text{ eV}^2$$ (Inverted order)
$$\Delta m^2_{32} = (2.444 \pm 0.034) \times 10^{-3} \text{ eV}^2$$ (Normal order)
$$\sin^2(\theta_{13}) = (2.18 \pm 0.07) \times 10^{-2}$$
$$\delta, CP \text{ violating phase} = 1.37^{+0.18}_{-0.16} \pi \text{ rad}$$
$$\langle \Delta m^2_{21} - \overline{\Delta m^2_{21}} \rangle < 1.1 \times 10^{-4} \text{ eV}^2, \text{ CL} = 99.7\%$$
$$\langle \Delta m^2_{32} - \overline{\Delta m^2_{32}} \rangle = (-0.12 \pm 0.25) \times 10^{-3} \text{ eV}^2$$
NOTES

[a] This is the best limit for the mode $e^- \rightarrow \nu \gamma$. The best limit for “electron disappearance” is $6.4 \times 10^{24}$ 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 energy of $e > 45$ MeV and energy of $\gamma > 40$ MeV. Since the $e^- \pi^0 \nu_\mu$ and $e^- \pi^0 \nu_\mu \gamma$ 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.