\( \pi^\pm \)

\[ G(J^P) = 1^-(0^-) \]

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters B204 1 (1988).

### \( \pi^\pm \) MASS

The most accurate charged pion mass measurements are based upon x-ray wavelength measurements for transitions in \( \pi^- \)-mesonic atoms. The observed line is the blend of three components, corresponding to different K-shell occupancies. JECKELMANN 94 revisits the occupancy question, with the conclusion that two sets of occupancy ratios, resulting in two different pion masses (Solutions A and B), are equally probable. We choose the higher Solution B since only this solution is consistent with a positive mass-squared for the muon neutrino, given the precise muon momentum measurements now available (DAUM 91, ASSAMAGAN 94, and ASSAMAGAN 96) for the decay of pions at rest. Earlier mass determinations with pi-mesonic atoms may have used incorrect K-shell screening corrections.

Measurements with an error of > 0.005 MeV have been omitted from this Listing.

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(139.57018 \pm 0.00035) OUR FIT</td>
<td>Error includes scale factor of 1.2.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(139.57018 \pm 0.00035) OUR AVERAGE</td>
<td>Error includes scale factor of 1.2.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.57071 (\pm 0.00053)</td>
<td>LENZ 98 CNTR –</td>
<td>pionic N2-atoms gas target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.56995 (\pm 0.00035)</td>
<td>JECKELMANN 94 CNTR –</td>
<td>(\pi^-) atom, Soln. B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\bullet \bullet \bullet ) We do not use the following data for averages, fits, limits, etc. (\bullet \bullet \bullet )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.57022 (\pm 0.00014)</td>
<td>ASSAMAGAN 96 SPEC +</td>
<td>(\pi^+ \rightarrow \mu^+ \nu\mu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.56782 (\pm 0.00037)</td>
<td>JECKELMANN 94 CNTR –</td>
<td>(\pi^-) atom, Soln. A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.56996 (\pm 0.00067)</td>
<td>DAUM 91 SPEC +</td>
<td>(\pi^+ \rightarrow \mu^+ \nu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.56752 (\pm 0.00037)</td>
<td>JECKELMANN 86b CNTR –</td>
<td>Mesonic atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.5704 (\pm 0.0011)</td>
<td>ABELA 84 SPEC +</td>
<td>See DAUM 91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.5664 (\pm 0.0009)</td>
<td>LU 80 CNTR –</td>
<td>Mesonic atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.5686 (\pm 0.0020)</td>
<td>CARTER 76 CNTR –</td>
<td>Mesonic atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139.5660 (\pm 0.0024)</td>
<td>MARUSHEN... 76 CNTR –</td>
<td>Mesonic atoms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 LENZ 98 result does not suffer K-electron configuration uncertainties as does JECKELMANN 94.
2 JECKELMANN 94 Solution B (dominant 2-electron K-shell occupancy), chosen for consistency with positive \( m^2_{\nu\mu} \).
3 ASSAMAGAN 96 measures the \( \mu^+ \) momentum \( p_{\mu} \) in \( \pi^+ \rightarrow \mu^+ \nu\mu \) decay at rest to be \( 29.79200 \pm 0.00011 \) MeV/c. Combined with the \( \mu^+ \) mass and the assumption \( m_{\nu\mu} = 0 \), this gives the \( \pi^+ \) mass above; if \( m_{\nu\mu} > 0 \), \( m_{\pi^+} \) given above is a lower limit.

Combined instead with \( m_{\mu} \) and (assuming \( CPT \)) the \( \pi^- \) mass of JECKELMANN 94, \( p_{\mu} \) gives an upper limit on \( m_{\nu\mu} \) (see the \( \nu\mu \)).
4 JECKELMANN 94 Solution A (small 2-electron K-shell occupancy) in combination with either the DAUM 91 or ASSAMAGAN 94 pion decay muon momentum measurement yields a significantly negative $m_{\nu\mu}^2$. It is accordingly not used in our fits.

5 The DAUM 91 value includes the ABELA 84 result. The value is based on a measurement of the $\mu^+$ momentum for $\pi^+$ decay at rest, $p_{\mu^+} = 29.79179 \pm 0.00053$ MeV, uses $m_\mu = 105.658389 \pm 0.000034$ MeV, and assumes that $m_{\nu\mu} = 0$. The last assumption means that in fact the value is a lower limit. 

6 JECKELMANN 86 gives $m_{\pi^-}/m_e = 273.12677(71)$. We use $m_e = 0.51099906(15)$ MeV from COHEN 87. The authors note that two solutions for the probability distribution of K-shell occupancy fit equally well, and use other data to choose the lower of the two possible $\pi^\pm$ masses.

7 These values are scaled with a new wavelength-energy conversion factor $V\lambda = 1.23984244(37) \times 10^{-6}$ eV m from COHEN 87. The LU 80 screening correction relies upon a theoretical calculation of inner-shell refilling rates.

8 This MARUSHENKO 76 value used at the authors' request to use the accepted set of calibration $\gamma$ energies. Error increased from 0.0017 MeV to include QED calculation error of 0.0017 MeV (12 ppm).

9 The DAUM 91 value assumes that $m_{\nu\mu} = 0$ and uses our $m_\mu = 105.658389 \pm 0.000034$ MeV.

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.91157 \pm 0.00067</td>
<td>9 DAUM 91 SPEC + $\pi^+ \rightarrow \mu^+ \nu$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.911 \pm 0.0011</td>
<td>ABELA 84 SPEC See DAUM 91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.925 \pm 0.025</td>
<td>BOOTH 70 CNTR + Magnetic spect.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.881 \pm 0.035</td>
<td>145 HYMAN 67 HEBC + $K^-$ He</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements with an error $> 0.05$ MeV have been omitted from this Listing.

<table>
<thead>
<tr>
<th>VALUE (units $10^{-8}$ s)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 \pm 5</td>
<td>AYRES 71 CNTR</td>
<td></td>
</tr>
</tbody>
</table>

A test of CPT invariance.

<table>
<thead>
<tr>
<th>VALUE ($10^{-8}$ s)</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6033 \pm 0.0005 OUR AVERAGE</td>
<td>KOPTEV 95 SPEC + Surface $\mu^+$'s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.60361 \pm 0.00052</td>
<td>NUMAO 95 SPEC + Surface $\mu^+$'s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.60231 \pm 0.00050 \pm 0.00084</td>
<td>DUNAITSEV 73 CNTR +</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.609 \pm 0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurements with an error $> 0.02 \times 10^{-8}$ s have been omitted.
\[ \frac{\tau_{\pi^+} - \tau_{\pi^-}}{\tau_{\text{average}}} \]

A test of \( CPT \) invariance.

### VALUE (units \( 10^{-4} \))

<table>
<thead>
<tr>
<th>VALUE</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5 ± 7.1</td>
<td>AYRES 71</td>
<td>CNTR</td>
</tr>
</tbody>
</table>

- We do not use the following data for averages, fits, limits, etc.

\( \pi^- \) modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the appropriate Search sections (Massive Neutrino Peak Search Test, \( A^0 \) (axion), and Other Light Boson (\( X^0 \)) Searches, etc.).

### \( \pi^+ \) DECAY MODES

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fraction ( (\Gamma_i/\Gamma) )</th>
<th>Confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_1 )</td>
<td>( \mu^+ \nu_\mu )</td>
<td>[a] ((99.98770 \pm 0.00004)%)</td>
</tr>
<tr>
<td>( \Gamma_2 )</td>
<td>( \mu^+ \nu_\mu \gamma )</td>
<td>[b] ((2.00 \pm 0.25) \times 10^{-4})</td>
</tr>
<tr>
<td>( \Gamma_3 )</td>
<td>( e^+ \nu_e )</td>
<td>[a] ((1.230 \pm 0.004) \times 10^{-4})</td>
</tr>
<tr>
<td>( \Gamma_4 )</td>
<td>( e^+ \nu_e \gamma )</td>
<td>[b] ((1.61 \pm 0.23) \times 10^{-7})</td>
</tr>
<tr>
<td>( \Gamma_5 )</td>
<td>( e^+ \nu_e \pi^0 )</td>
<td>((1.036 \pm 0.006) \times 10^{-8})</td>
</tr>
<tr>
<td>( \Gamma_6 )</td>
<td>( e^+ \nu_e e^+ e^- )</td>
<td>((3.2 \pm 0.5) \times 10^{-9})</td>
</tr>
<tr>
<td>( \Gamma_7 )</td>
<td>( e^+ \nu_e \nu \pi^0 )</td>
<td>(&lt; 5 \times 10^{-6}) 90%</td>
</tr>
</tbody>
</table>

#### Lepton Family number (\( LF \)) or Lepton number (\( L \)) violating modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fraction ( (\Gamma_i/\Gamma) )</th>
<th>Confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_8 )</td>
<td>( \mu^+ \bar{\nu}_e )</td>
<td>( L ) [c] (&lt; 1.5 \times 10^{-3}) 90%</td>
</tr>
<tr>
<td>( \Gamma_9 )</td>
<td>( \mu^+ \nu_e )</td>
<td>( LF ) [c] (&lt; 8.0 \times 10^{-3}) 90%</td>
</tr>
<tr>
<td>( \Gamma_{10} )</td>
<td>( \mu^- e^+ e^- \nu )</td>
<td>( LF ) (&lt; 1.6 \times 10^{-6}) 90%</td>
</tr>
</tbody>
</table>
[a] Measurements of $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ always include decays with $\gamma$’s, and measurements of $\Gamma(e^+\nu_e\gamma)$ and $\Gamma(\mu^+\nu_\mu\gamma)$ never include low-energy $\gamma$’s. Therefore, since no clean separation is possible, we consider the modes with $\gamma$’s to be subreactions of the modes without them, and let $[\Gamma(e^+\nu_e) + \Gamma(\mu^+\nu_\mu)]/\Gamma_{\text{total}} = 100\%$.

[b] See the Particle Listings below for the energy limits used in this measurement; low-energy $\gamma$’s are not included.

[c] Derived from an analysis of neutrino-oscillation experiments.

## \(\pi^+\) BRANCHING RATIOS

\[
\Gamma(e^+\nu_e)/\Gamma_{\text{total}}
\]

See note [a] in the list of $\pi^+$ decay modes just above, and see also the next block of data. See also the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D^+_s\) Listings.

<table>
<thead>
<tr>
<th>VALUE (units (10^{-4}))</th>
<th>DOCUMENT ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.230 ± 0.004 OUR EVALUATION</td>
<td></td>
</tr>
</tbody>
</table>

\[
[\Gamma(e^+\nu_e) + \Gamma(e^+\nu_e\gamma)]/[\Gamma(\mu^+\nu_\mu) + \Gamma(\mu^+\nu_\mu\gamma)] = (\Gamma_3+\Gamma_4)/(\Gamma_1+\Gamma_2)
\]

See note [a] in the list of $\pi^+$ decay modes above. See NUMAO 92 for a discussion of $e$-$\mu$ universality. See also the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D^+_s\) Listings.

<table>
<thead>
<tr>
<th>VALUE (units (10^{-4}))</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.230 ± 0.004 OUR AVERAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2346 ± 0.0035 ± 0.0036</td>
<td>120k</td>
<td>CZAPEK 93</td>
<td>CALO</td>
<td>Stopping $\pi^+$</td>
</tr>
<tr>
<td>1.2265 ± 0.0034 ± 0.0044</td>
<td>190k</td>
<td>BRITTON 92</td>
<td>CNTR</td>
<td>Stopping $\pi^+$</td>
</tr>
<tr>
<td>1.218 ± 0.014</td>
<td>32k</td>
<td>BRYMAN 86</td>
<td>CNTR</td>
<td>Stopping $\pi^+$</td>
</tr>
</tbody>
</table>

● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●

1.273 ± 0.028 11k 13 DICAPUA 64 CNTR

1.21 ± 0.07 ANDERSON 60 SPEC

13 DICAPUA 64 has been updated using the current mean life.

\[
\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\text{total}}
\]

Note that measurements here do not cover the full kinematic range.

<table>
<thead>
<tr>
<th>VALUE (units (10^{-4}))</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 ± 0.24 ± 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 BRESSI 98</td>
<td>CALO</td>
<td>+</td>
<td>Stopping $\pi^+$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●

1.24 ± 0.25 26 CASTAGNOLI 58 EMUL KE$_\mu$ < 3.38 MeV

14 BRESSI 98 result is given for $E_\gamma > 1$ MeV only. Result agrees with QED expectation, $2.283 \times 10^{-4}$ and does not confirm discrepancy of earlier experiment CASTAGNOLI 58.
\(\Gamma(e^+\nu_e\gamma)/\Gamma_{\text{total}}\)

Note that measurements here do not cover the full kinematic range.

<table>
<thead>
<tr>
<th>VALUE (units (10^{-8}))</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.1 (\pm 2.3)</td>
<td></td>
<td>15 BOLOTOV 90b</td>
<td>SPEC</td>
<td>17 GeV (\pi^- \rightarrow e^-\nu_e\gamma)</td>
</tr>
</tbody>
</table>

\(\bullet \bullet \bullet \) We do not use the following data for averages, fits, limits, etc. \(\bullet \bullet \bullet \)

5.6 \(\pm 0.7\) 226 16 STETZ 78 SPEC \(P_e > 56\) MeV/c

3.0 143 DEPOMMIER 63b CNTR (KE) \(e^+\gamma > 48\) MeV

15 BOLOTOV 90b is for \(E_\gamma > 21\) MeV, \(E_e > 70 - 0.8 E_\gamma\).

16 STETZ 78 is for an \(e^-\gamma\) opening angle > 132°. Obtains 3.7 when using same cutoffs as DEPOMMIER 63b.

\(\Gamma(e^+\nu_e\pi^0)/\Gamma_{\text{total}}\)

<table>
<thead>
<tr>
<th>VALUE (units (10^{-8}))</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.036 (\pm 0.006) OUR AVERAGE</td>
<td></td>
<td>17,18 POCANIC 04</td>
<td>PIBE</td>
<td>+</td>
<td>(\pi) decay at rest</td>
</tr>
<tr>
<td>1.026 (\pm 0.039)</td>
<td>1224</td>
<td>19 MCFARLANE 85</td>
<td>CNTR</td>
<td>+</td>
<td>Decay in flight</td>
</tr>
<tr>
<td>1.00 (\pm 0.08)</td>
<td>332</td>
<td>37 DEPOMMIER 68</td>
<td>CNTR</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>1.07 (\pm 0.21)</td>
<td>38</td>
<td>20 BACASTOW 65</td>
<td>OSPK</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>1.10 (\pm 0.26)</td>
<td>43</td>
<td>20 BERTRAM 65</td>
<td>OSPK</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>1.1 (\pm 0.2)</td>
<td>36</td>
<td>20 DUNAITSEV 65</td>
<td>CNTR</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>0.97 (\pm 0.2)</td>
<td>20 BARTLETT 64</td>
<td>OSPK</td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(\bullet \bullet \bullet \) We do not use the following data for averages, fits, limits, etc. \(\bullet \bullet \bullet \)

1.15 \(\pm 0.22\) 52 DEPOMMIER 63 CNTR + See DEPOMMIER 68

17 POCANIC 04 normalizes to \(e^+\nu_e\) decays, using the PDG 2004 value \(B(\pi^- \rightarrow e^+\nu_e) = (1.230 \pm 0.004) \times 10^{-4}\). We add their statistical \((0.004 \times 10^{-8})\), systematic \((0.004 \times 10^{-8})\) and systematic error due to the uncertainty of \(B(\pi^- \rightarrow e^+\nu_e) (0.003 \times 10^{-8})\) in quadrature.

18 This result can be used to calculate \(V_{ud}\) from pion beta decay: \(V_{ud}^{PIBETA} = 0.9728 \pm 0.0030\).

19 MCFARLANE 85 combines a measured rate \((0.394 \pm 0.015)/s\) with 1982 PDG mean life.

20 DEPOMMIER 68 says the result of DEPOMMIER 63 is at least 10% too large because of a systematic error in the \(\pi^0\) detection efficiency, and that this may be true of all the previous measurements (also V. Soergel, private communication, 1972).

\(\Gamma(e^+\nu_e\pi^0\gamma)/\Gamma(\mu^+\nu_\mu)\)

<table>
<thead>
<tr>
<th>VALUE (units (10^{-9}))</th>
<th>CL%</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 (\pm 0.5) (\pm 0.2)</td>
<td>98</td>
<td>EGLI 89</td>
<td>SPEC</td>
<td>Uses (R_{PCAC} = 0.068 \pm 0.004)</td>
<td></td>
</tr>
</tbody>
</table>

\(\bullet \bullet \bullet \) We do not use the following data for averages, fits, limits, etc. \(\bullet \bullet \bullet \)

0.46 \(\pm 0.16\) \(\pm 0.07\) 21 BARANOV 92 SPEC Stopped \(\pi^+\)

< 4.8 90 KORENCH... 76b SPEC

< 34 90 KORENCH... 71 OSPK

21 This measurement by BARANOV 92 is of the structure-dependent part of the decay. The value depends on values assumed for ratios of form factors.
\[ \frac{\Gamma(e^+ \nu_e \nu_\pi)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{7}}{\Gamma} \]

\[ \frac{\Gamma(e^+ \tau^+ \nu_\tau)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{8}}{\Gamma} \]

Forbidden by total lepton number conservation. See the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D_s^+\) Listings.

\[ \frac{\Gamma(\mu^+ \nu_\mu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{9}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \frac{\Gamma(\mu^- e^+ e^+ \nu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{10}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \pi^+ \rightarrow \mu^+ \nu \]

Tests the Lorentz structure of leptonic charged weak interactions.

\[ \pi^+ \rightarrow \mu^+ \nu \]

\[ \pi^\pm \quad \text{FORM FACTORS} \]

\[ F_{V}, \text{VECTOR FORM FACTOR} \]

\[ \frac{\Gamma_{e^+ \nu_e \nu_\pi}}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{7}}{\Gamma} \]

\[ \frac{\Gamma(e^+ \nu_e \nu_\pi)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{8}}{\Gamma} \]

Forbidden by total lepton number conservation. See the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D_s^+\) Listings.

\[ \frac{\Gamma(\mu^+ \nu_\mu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{9}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \frac{\Gamma(\mu^- e^+ e^+ \nu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{10}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \pi^+ \rightarrow \mu^+ \nu \]

Tests the Lorentz structure of leptonic charged weak interactions.

\[ \pi^+ \rightarrow \mu^+ \nu \]

\[ \pi^\pm \quad \text{FORM FACTORS} \]

\[ F_{V}, \text{VECTOR FORM FACTOR} \]

\[ \frac{\Gamma_{e^+ \nu_e \nu_\pi}}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{7}}{\Gamma} \]

\[ \frac{\Gamma(e^+ \nu_e \nu_\pi)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{8}}{\Gamma} \]

Forbidden by total lepton number conservation. See the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D_s^+\) Listings.

\[ \frac{\Gamma(\mu^+ \nu_\mu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{9}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \frac{\Gamma(\mu^- e^+ e^+ \nu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{10}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \pi^+ \rightarrow \mu^+ \nu \]

Tests the Lorentz structure of leptonic charged weak interactions.

\[ \pi^+ \rightarrow \mu^+ \nu \]

\[ \pi^\pm \quad \text{FORM FACTORS} \]

\[ F_{V}, \text{VECTOR FORM FACTOR} \]

\[ \frac{\Gamma_{e^+ \nu_e \nu_\pi}}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{7}}{\Gamma} \]

\[ \frac{\Gamma(e^+ \nu_e \nu_\pi)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{8}}{\Gamma} \]

Forbidden by total lepton number conservation. See the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D_s^+\) Listings.

\[ \frac{\Gamma(\mu^+ \nu_\mu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{9}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \frac{\Gamma(\mu^- e^+ e^+ \nu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{10}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \pi^+ \rightarrow \mu^+ \nu \]

Tests the Lorentz structure of leptonic charged weak interactions.

\[ \pi^+ \rightarrow \mu^+ \nu \]

\[ \pi^\pm \quad \text{FORM FACTORS} \]

\[ F_{V}, \text{VECTOR FORM FACTOR} \]

\[ \frac{\Gamma_{e^+ \nu_e \nu_\pi}}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{7}}{\Gamma} \]

\[ \frac{\Gamma(e^+ \nu_e \nu_\pi)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{8}}{\Gamma} \]

Forbidden by total lepton number conservation. See the note on “Decay Constants of Charged Pseudoscalar Mesons” in the \(D_s^+\) Listings.

\[ \frac{\Gamma(\mu^+ \nu_\mu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{9}}{\Gamma} \]

Forbidden by lepton family number conservation.

\[ \frac{\Gamma(\mu^- e^+ e^+ \nu)}{\Gamma_{\text{total}}} \]

\[ \frac{\Gamma_{10}}{\Gamma} \]

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Tests the Lorentz structure of leptonic charged weak interactions.

\[ \pi^+ \rightarrow \mu^+ \nu \]

\[ \pi^\pm \quad \text{FORM FACTORS} \]

\[ F_{V}, \text{VECTOR FORM FACTOR} \]
**F_A, AXIAL-VECTOR FORM FACTOR**

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<td>0.0115 ± 0.0005</td>
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<td>0.0106 ± 0.0060</td>
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27 Using the vector form factor from CVC prediction, F_V = 0.0259 ± 0.0005.
28 The sign of γ = F_A / F_V is determined to be positive.
29 Only the absolute value of F_A is determined.
30 The result of STETZ 78 has a two-fold ambiguity. We take the solution compatible with later determinations.

**R, SECOND AXIAL-VECTOR FORM FACTOR**

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π± CHARGE RADIUS

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<td></td>
<td>Error includes scale factor of 1.7. See the ideogram below.</td>
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<td>0.663 ± 0.023</td>
<td>DALLY</td>
<td>82</td>
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<td>0.711 ± 0.009 ± 0.016</td>
<td>BEBEK</td>
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<td>0.678 ± 0.004 ± 0.008</td>
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<td>0.660 ± 0.024</td>
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<td>0.78 ± 0.09 − 0.10</td>
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<td>0.74 ± 0.11 − 0.13</td>
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31 BIJNENS 98 fits existing data.
WEIGHTED AVERAGE  
0.672±0.008 (Error scaled by 1.7)

\( \chi^2 \)

12.2
(Confidence Level = 0.016)

\( \pi^\pm \) charge radius

\[ \pi^\pm \] REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1988 edition Physics Letters B204 1 (1988).
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