GAUGE AND HIGGS BOSONS

\(\gamma\)

\[ I(J^{PC}) = 0.1(1 - -) \]

Mass \(m < 2 \times 10^{-16} \text{ eV}\)
Charge \(q < 5 \times 10^{-30} \text{ e}\)
Mean life \(\tau = \text{Stable}\)

\(g\)

or gluon

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

Mass \(m = 0 \) \([a]\)
SU(3) color octet

\(W\)

\[ J = 1 \]

Charge = \(\pm 1 \text{ e}\)
Mass \(m = 80.423 \pm 0.039 \text{ GeV}\)
\(m_Z - m_W = 10.764 \pm 0.039 \text{ GeV}\)
\(m_{W^+} - m_{W^-} = -0.2 \pm 0.6 \text{ GeV}\)
Full width \(\Gamma = 2.118 \pm 0.042 \text{ GeV}\)
\[ \langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35 \]
\[ \langle N_{K^\pm} \rangle = 2.20 \pm 0.19 \]
\[ \langle N_p \rangle = 0.92 \pm 0.14 \]
\[ \langle N_{\text{charged}} \rangle = 19.41 \pm 0.15 \]

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

\[
\begin{array}{|c|c|c|}
\hline
\text{\(W^+\) DECAY MODES} & \text{Fraction (\(\Gamma_f/\Gamma\))} & \text{Confidence level (MeV/c)} \\
\hline
\ell^+\nu & [b] & (10.68 \pm 0.12)\% & - \\
e^+\nu & & (10.72 \pm 0.16)\% & 40212 \\
\mu^+\nu & & (10.57 \pm 0.22)\% & 40211 \\
\tau^+\nu & & (10.74 \pm 0.27)\% & 40192 \\
hadrons & & (67.96 \pm 0.35)\% & - \\
\pi^+\gamma & < 8 \times 10^{-5} & 95\% & 40211 \\
D^+_s\gamma & < 1.3 \times 10^{-3} & 95\% & 40187 \\
cX & (33.6 \pm 2.7)\% & - \\
c\bar{s} & (31 \pm 13 -11)\% & - \\
\text{invisible} & [e] & (1.4 \pm 2.8)\% & - \\
\hline
\end{array}
\]
$J = 1$

Charge = 0
Mass $m = 91.1876 \pm 0.0021$ GeV [d]
Full width $\Gamma = 2.4952 \pm 0.0023$ GeV
$\Gamma(\ell^+ \ell^-) = 83.984 \pm 0.086$ MeV [b]
$\Gamma(\text{invisible}) = 499.0 \pm 1.5$ MeV [e]
$\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$ MeV
$\Gamma(\mu^+ \mu^-)/\Gamma(e^+ e^-) = 1.0009 \pm 0.0028$
$\Gamma(\tau^+ \tau^-)/\Gamma(e^+ e^-) = 1.0019 \pm 0.0032$ [f]

**Average charged multiplicity**
$\langle N_{\text{charged}} \rangle = 21.07 \pm 0.11$

**Couplings to leptons**
$g_V = -0.03783 \pm 0.00041$
$g_A = -0.50123 \pm 0.00026$
$g^{\nu e} = 0.53 \pm 0.09$
$g^{\nu \mu} = 0.502 \pm 0.017$

**Asymmetry parameters** [g]
$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.666 \pm 0.036$
$A_b = 0.928 \pm 0.031$

**Charge asymmetry (%) at Z pole**
$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.16 \pm 0.36$
$A_{FB}^{(0b)} = 10.02 \pm 0.19$

**Z 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>$e^+ e^-$</td>
<td>(3.363 $\pm 0.004$) %</td>
<td>45594</td>
</tr>
<tr>
<td>$\mu^+ \mu^-$</td>
<td>(3.366 $\pm 0.007$) %</td>
<td>45594</td>
</tr>
<tr>
<td>$\tau^+ \tau^-$</td>
<td>(3.370 $\pm 0.008$) %</td>
<td>45559</td>
</tr>
<tr>
<td>$\ell^+ \ell^-$</td>
<td>[b] (3.3658$\pm 0.0023$) %</td>
<td>-</td>
</tr>
<tr>
<td>invisible</td>
<td>(20.00 $\pm 0.06$) %</td>
<td>-</td>
</tr>
<tr>
<td>hadrons</td>
<td>(69.91 $\pm 0.06$) %</td>
<td>-</td>
</tr>
</tbody>
</table>
\[ \frac{u\bar{u} + c\bar{c}}{2} \]
\[ \frac{d\bar{d} + s\bar{s} + b\bar{b}}{3} \]
\[ c\bar{c} \]
\[ b\bar{b} \]
\[ b\bar{b}b\bar{b} \]
\[ \gamma^0 \gamma \]
\[ \eta \gamma \]
\[ \omega \gamma \]
\[ \eta' \gamma \]
\[ \gamma_\gamma \]
\[ \pi^\pm W^\mp \]
\[ \rho^\pm W^\mp \]
\[ J/\psi(1S)X \]
\[ \psi(2S)X \]
\[ \chi_{c1}(1P)X \]
\[ \chi_{c2}(1P)X \]
\[ \Upsilon(1S)X + \Upsilon(2S)X \]
\[ \Upsilon(3S)X \]
\[ (D^0 / \bar{D}^0)X \]
\[ D^\pm X \]
\[ D^*(2010)^\pm X \]
\[ B^0 S \]
\[ B^+ S \]
\[ \text{anomalous } \gamma + \text{ hadrons} \]
\[ e^+ e^- \]
\[ \mu^+ \mu^- \]
\[ \tau^+ \tau^- \]
\[ \ell^+ \ell^- \gamma \]
\[ q\bar{q} \gamma \gamma \]
\[ \nu\bar{\nu} \gamma \gamma \]
\[ e^\pm \mu^\mp \]
\[ e^\pm \tau^\mp \]
\[ \mu^\pm \tau^\mp \]
\[ p\bar{e} \]
\[ p\mu \]

\text{Citation: K. Hagiwara et al. (Particle Data Group), Phys. Rev. D 66, 010001 (2002) (URL: http://pdg.lbl.gov)}
Higgs Bosons — $H^0$ and $H^\pm$, Searches for

$H^0$ Mass $m > 114.3$ GeV, CL = 95%

$H^0_1$ in Supersymmetric Models ($m_{H^0_1} < m_{H^0_2}$)
Mass $m > 89.8$ GeV, CL = 95%

$A^0$ Pseudoscalar Higgs Boson in Supersymmetric Models $^k$
Mass $m > 90.1$ GeV, CL = 95% $\tan\beta > 1$

$H^\pm$ Mass $m > 71.5$ GeV, CL = 95%

See the Particle Listings for a Note giving details of Higgs Bosons.

Heavy Bosons Other Than Higgs Bosons, Searches for

Additional $W$ Bosons
$W'$ with standard couplings decaying to $e\nu, \mu\nu$
Mass $m > 786$ GeV, CL = 95%
$W_R$ — right-handed $W$
Mass $m > 715$ GeV, CL = 90% (electroweak fit)

Additional $Z$ Bosons
$Z'_{SM}$ with standard couplings
Mass $m > 690$ GeV, CL = 95% ($\rho\bar{\rho}$ direct search)
Mass $m > 1500$ GeV, CL = 95% (electroweak fit)
$Z_{LR}$ of $SU(2)_L \times SU(2)_R \times U(1)$
(with $g_L = g_R$)
Mass $m > 630$ GeV, CL = 95% ($\rho\bar{\rho}$ direct search)
Mass $m > 860$ GeV, CL = 95% (electroweak fit)
$Z_\chi$ of $SO(10) \rightarrow SU(5) \times U(1)_\chi$ (with $g_\chi = e/\cos\theta_W$
Mass $m > 595$ GeV, CL = 95% ($\rho\bar{\rho}$ direct search)
Mass $m > 680$ GeV, CL = 95% (electroweak fit)
$Z_\psi$ of $E_6 \rightarrow SO(10) \times U(1)_\psi$ (with $g_\psi = e/\cos\theta_W$
Mass $m > 590$ GeV, CL = 95% ($\rho\bar{\rho}$ direct search)
Mass $m > 350$ GeV, CL = 95% (electroweak fit)
$Z_{\eta}$ of $E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_\eta$ (with $g_\eta = e/\cos\theta_W$
Mass $m > 620$ GeV, CL = 95% ($\rho\bar{\rho}$ direct search)
Mass $m > 619$ GeV, CL = 95% (electroweak fit)
Scalar Leptoquarks

Mass $m > 242$ GeV, CL = 95% (1st generation, pair prod.)
Mass $m > 290$ GeV, CL = 95% (1st gener., single prod.)
Mass $m > 202$ GeV, CL = 95% (2nd gener., pair prod.)
Mass $m > 73$ GeV, CL = 95% (2nd gener., single prod.)
Mass $m > 148$ GeV, CL = 95% (3rd gener., pair prod.)

(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Axions ($A^0$) and Other Very Light Bosons, Searches for

The standard Peccei-Quinn axion is ruled out. Variants with reduced couplings or much smaller masses are constrained by various data. The Particle Listings in the full Review contain a Note discussing axion searches.

The best limit for the half-life of neutrinoless double beta decay with Majoron emission is $> 7.2 \times 10^{24}$ years (CL = 90%).

NOTES

[a] Theoretical value. A mass as large as a few MeV may not be precluded.
[b] $\ell$ indicates each type of lepton (e, $\mu$, and $\tau$), not sum over them.
[c] This represents the width for the decay of the $W$ boson into a charged particle with momentum below detectability, $p < 200$ MeV.
[d] The $Z$-boson mass listed here corresponds to a Breit-Wigner resonance parameter. It lies approximately 34 MeV above the real part of the position of the pole (in the energy-squared plane) in the $Z$-boson propagator.
[e] This partial width takes into account $Z$ decays into $\nu\bar{\tau}$ and any other possible undetected modes.
[f] This ratio has not been corrected for the $\tau$ mass.
[g] Here $A \equiv 2g_V g_{A}/(g_V^2 + g_A^2)$.
[h] The value is for the sum of the charge states or particle/antiparticle states indicated.
[i] See the $Z$ Particle Listings for the $\gamma$ energy range used in this measurement.
[j] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.
[k] The limits assume no invisible decays.