GAUGE AND HIGGS BOSONS

**$\gamma$**

$I(J^{PC}) = 0.1(1^- - -)$

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 1 \times 10^{-35}$ e
Mean life $\tau = $ Stable

**$g$ or gluon**

$I(J^P) = 0(1^-)$

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

**graviton**

$J = 2$

Mass $m < 7 \times 10^{-32}$ eV

**$W$**

$J = 1$

Charge = $\pm 1$ e
Mass $m = 80.385 \pm 0.015$ GeV
$m_Z - m_W = 10.4 \pm 1.6$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.085 \pm 0.042$ GeV
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_p \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$
W− modes are charge conjugates of the modes below.

<table>
<thead>
<tr>
<th>W+ DECAY MODES</th>
<th>Fraction (Γ_i/Γ)</th>
<th>Confidence level (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ℓ+ ν</td>
<td>[b] (10.80 ± 0.09)%</td>
<td>-</td>
</tr>
<tr>
<td>e+ ν</td>
<td>(10.75 ± 0.13)%</td>
<td>40192</td>
</tr>
<tr>
<td>μ+ ν</td>
<td>(10.57 ± 0.15)%</td>
<td>40192</td>
</tr>
<tr>
<td>τ+ ν</td>
<td>(11.25 ± 0.20)%</td>
<td>40173</td>
</tr>
<tr>
<td>hadrons</td>
<td>(67.60 ± 0.27)%</td>
<td>-</td>
</tr>
<tr>
<td>π+ γ</td>
<td>&lt; 8 × 10^{-5}</td>
<td>95% 40192</td>
</tr>
<tr>
<td>D_s+ γ</td>
<td>&lt; 1.3 × 10^{-3}</td>
<td>95% 40168</td>
</tr>
<tr>
<td>cX</td>
<td>(33.4 ± 2.6)%</td>
<td>-</td>
</tr>
<tr>
<td>cΣ</td>
<td>(31 +13 _11)%</td>
<td>-</td>
</tr>
<tr>
<td>invisible</td>
<td>[c] (1.4 ± 2.9)%</td>
<td>-</td>
</tr>
</tbody>
</table>

Z

Charge = 0
Mass m = 91.1876 ± 0.0021 GeV [d]
Full width Γ = 2.4952 ± 0.0023 GeV
Γ(ℓ+ ℓ−) = 83.984 ± 0.086 MeV [b]
Γ(invisible) = 499.0 ± 1.5 MeV [e]
Γ(hadrons) = 1744.4 ± 2.0 MeV
Γ(μ+ μ−)/Γ(e+ e−) = 1.0009 ± 0.0028
Γ(τ+ τ−)/Γ(e+ e−) = 1.0019 ± 0.0032 [f]

Average charged multiplicity
⟨N_{charged}⟩ = 20.76 ± 0.16  (S = 2.1)

Couplings to leptons

\[ g_ℓ^V = -0.03783 ± 0.00041 \]
\[ g_ℓ^U = 0.25 ± 0.07 \]
\[ g_ℓ^d = -0.33 ± 0.05 \]
\[ g_μ^A = -0.50123 ± 0.00026 \]
\[ g_μ^V = 0.50 ± 0.04 \]
\[ g_μ^d = -0.523 ± 0.050 \]
\[ g_τ^ℓ = 0.5008 ± 0.0008 \]
\[ g_τ^e = 0.53 ± 0.09 \]
\[ g_τ^μ = 0.502 ± 0.017 \]
### Asymmetry parameters \([g]\)

\[
\begin{align*}
A_e &= 0.1515 \pm 0.0019 \\
A_\mu &= 0.142 \pm 0.015 \\
A_\tau &= 0.143 \pm 0.004 \\
A_s &= 0.90 \pm 0.09 \\
A_c &= 0.670 \pm 0.027 \\
A_b &= 0.923 \pm 0.020
\end{align*}
\]

### Charge asymmetry (%) at Z pole

\[
\begin{align*}
A_{(0\ell)}^{(FB)} &= 1.71 \pm 0.10 \\
A_{(0u)}^{(FB)} &= 4 \pm 7 \\
A_{(0s)}^{(FB)} &= 9.8 \pm 1.1 \\
A_{(0c)}^{(FB)} &= 7.0 \pm 0.35 \\
A_{(0b)}^{(FB)} &= 9.92 \pm 0.16
\end{align*}
\]

<table>
<thead>
<tr>
<th>Z DECAY MODES</th>
<th>(\text{Fraction } (\Gamma_i/\Gamma))</th>
<th>Scale factor/Confidence level</th>
<th>(\rho) (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e^+e^-)</td>
<td>(3.363 (\pm 0.004) ) %</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>(\mu^+\mu^-)</td>
<td>(3.366 (\pm 0.007) ) %</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>(\tau^+\tau^-)</td>
<td>(3.370 (\pm 0.008) ) %</td>
<td>45599</td>
<td></td>
</tr>
<tr>
<td>(\ell^+\ell^-)</td>
<td>[(b)] (3.3658 (\pm 0.0023) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\ell^+\ell^-\ell^+\ell^-)</td>
<td>[(h)] (4.2 (\pm 0.9) (-0.8) (\times 10^{-6}) %</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td>(20.00 (\pm 0.06) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hadrons</td>
<td>(69.91 (\pm 0.06) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>((u\overline{u} + c\overline{c})/2)</td>
<td>(11.6 (\pm 0.6) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>((d\overline{d} + s\overline{s} + b\overline{b})/3)</td>
<td>(15.6 (\pm 0.4) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c\overline{c})</td>
<td>(12.03 (\pm 0.21) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b\overline{b})</td>
<td>(15.12 (\pm 0.05) ) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b\overline{b}b\overline{b})</td>
<td>(3.6 (\pm 1.3) (\times 10^{-4}) %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g\ g\ g)</td>
<td>&lt; 1.1 %</td>
<td>CL=95%</td>
<td></td>
</tr>
<tr>
<td>(\pi^0\gamma)</td>
<td>&lt; 5.2 (\times 10^{-5}) CL=95%</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>(\eta\gamma)</td>
<td>&lt; 5.1 (\times 10^{-5}) CL=95%</td>
<td>45592</td>
<td></td>
</tr>
<tr>
<td>(\omega\gamma)</td>
<td>&lt; 6.5 (\times 10^{-4}) CL=95%</td>
<td>45590</td>
<td></td>
</tr>
<tr>
<td>(\eta'\gamma)</td>
<td>&lt; 4.2 (\times 10^{-5}) CL=95%</td>
<td>45589</td>
<td></td>
</tr>
<tr>
<td>(\gamma\gamma)</td>
<td>&lt; 5.2 (\times 10^{-5}) CL=95%</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>(\gamma\gamma)</td>
<td>&lt; 1.0 (\times 10^{-5}) CL=95%</td>
<td>45594</td>
<td></td>
</tr>
<tr>
<td>(\pi^\pm W^\mp)</td>
<td>[(i)] &lt; 7 (\times 10^{-5}) CL=95%</td>
<td>10162</td>
<td></td>
</tr>
<tr>
<td>(\rho^\pm W^\mp)</td>
<td>[(i)] &lt; 8.3 (\times 10^{-5}) CL=95%</td>
<td>10136</td>
<td></td>
</tr>
<tr>
<td>(J/\psi(1S)X)</td>
<td>(3.51 (\pm 0.23) (-0.25) (\times 10^{-3}) S=1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\psi(2S)X)</td>
<td>(1.60 (\pm 0.29) (\times 10^{-3})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\chi_{c1}(1P)X)</td>
<td>(2.9 (\pm 0.7) (\times 10^{-3})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[ \chi_{c2}(1P)X \quad < \quad 3.2 \times 10^{-3} \quad \text{CL=90\%} \quad - \]
\[ \Upsilon(1S) X + \Upsilon(2S) X \quad \quad \quad \quad ( \quad 1.0 \pm 0.5 \quad ) \times 10^{-4} \quad - \]
\[ \Upsilon(1S)X \quad < \quad 4.4 \times 10^{-5} \quad \text{CL=95\%} \quad - \]
\[ \Upsilon(2S)X \quad < \quad 1.39 \times 10^{-4} \quad \text{CL=95\%} \quad - \]
\[ \Upsilon(3S)X \quad < \quad 9.4 \times 10^{-5} \quad \text{CL=95\%} \quad - \]
\[ (D^0 / \overline{D^0}) X \quad (20.7 \pm 2.0) \% \quad - \]
\[ D^\pm X \quad (12.2 \pm 1.7) \% \quad - \]
\[ D^*(2010)^\pm X \quad [\ell] \quad (11.4 \pm 1.3) \% \quad - \]
\[ D^+_s(2536)^\pm X \quad (3.6 \pm 0.8) \times 10^{-3} \quad - \]
\[ D_s^+(2573)^\pm X \quad (5.8 \pm 2.2) \times 10^{-3} \quad - \]
\[ D^+(2629)^\pm X \quad \text{searched for} \quad - \]
\[ B^\pm X \quad [\ell] \quad (6.08 \pm 0.13) \% \quad - \]
\[ B^0_s X \quad [\ell] \quad (1.59 \pm 0.13) \% \quad - \]
\[ B^\mp X \quad \text{searched for} \quad - \]
\[ \Lambda^+ X \quad (1.54 \pm 0.33) \% \quad - \]
\[ \Xi^0_c X \quad \text{seen} \quad - \]
\[ \Xi^0_b X \quad \text{seen} \quad - \]
\[ b-\text{baryon X} \quad [\ell] \quad (1.38 \pm 0.22) \% \quad - \]
\[ \text{anomalous } \gamma^+ \text{ hadrons} \quad [k] \quad < \quad 3.2 \times 10^{-3} \quad \text{CL=95\%} \quad - \]
\[ e^+ e^- \gamma \quad [k] \quad < \quad 5.2 \times 10^{-4} \quad \text{CL=95\%} \quad 45594 \]
\[ \mu^+ \mu^- \gamma \quad [k] \quad < \quad 5.6 \times 10^{-4} \quad \text{CL=95\%} \quad 45594 \]
\[ \tau^+ \tau^- \gamma \quad [k] \quad < \quad 7.3 \times 10^{-4} \quad \text{CL=95\%} \quad 45559 \]
\[ e^\pm \mu^\mp \quad \text{LF} \quad [\ell] \quad < \quad 1.7 \times 10^{-6} \quad \text{CL=95\%} \quad 45594 \]
\[ e^\pm \tau^\mp \quad \text{LF} \quad [\ell] \quad < \quad 9.8 \times 10^{-6} \quad \text{CL=95\%} \quad 45576 \]
\[ \mu^\pm \tau^\mp \quad \text{LF} \quad [\ell] \quad < \quad 1.2 \times 10^{-5} \quad \text{CL=95\%} \quad 45576 \]
\[ \nu \gamma^+ \gamma \quad [\ell] \quad < \quad 3.1 \times 10^{-6} \quad \text{CL=95\%} \quad 45594 \]

### Higgs Bosons — \( H^0 \) and \( H^\pm \)

**\( H^0 \)**

Mass \( m = 125.9 \pm 0.4 \) GeV

**\( H^0 \) signal strengths in different channels\[^n^\]**

Combined Final States = 1.07 ± 0.26 \( (S = 1.4) \)

\( WW^* \) Final State = 0.88 ± 0.33 \( (S = 1.1) \)

\( ZZ^* \) Final State = 0.89 ± 0.30

\( \gamma \gamma \) Final State = 1.65 ± 0.33

\( b \overline{b} \) Final State = 0.5 ± 0.8

\( \tau^+ \tau^- \) Final State = 0.1 ± 0.7

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**Citation:** J. Beringer et al. (Particle Data Group), PR **D86**, 010001 (2012) and 2013 partial update for the 2014 edition (URL: http://pdg.lbl.gov)
\[H^0 \text{ DECAY MODES}\]

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Fraction ((\Gamma_i/\Gamma))</th>
<th>(p) (MeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(WW^*)</td>
<td>seen</td>
<td>−</td>
</tr>
<tr>
<td>(ZZ^*)</td>
<td>seen</td>
<td>−</td>
</tr>
<tr>
<td>(\gamma\gamma)</td>
<td>seen</td>
<td>−</td>
</tr>
<tr>
<td>(b\bar{b})</td>
<td>possibly seen</td>
<td>−</td>
</tr>
<tr>
<td>(\tau^+\tau^-)</td>
<td>possibly seen</td>
<td>−</td>
</tr>
</tbody>
</table>

**Mass Limits for the Standard Model Higgs**

Mass \(m > 122\) and none 127–600 GeV, CL = 95%

The limits for \(H_1^0\) and \(A^0\) in supersymmetric models refer to the \(m_{H_1}^\text{max}\) benchmark scenario for the supersymmetric parameters.

**\(H_1^0\) in Supersymmetric Models \((m_{H_1^0} < m_{H_2^0})\)**

Mass \(m > 92.8\) GeV, CL = 95%

\[A^0\] Pseudoscalar Higgs Boson in Supersymmetric Models \([^0]\)

Mass \(m > 93.4\) GeV, CL = 95% \(\tan\beta > 0.4\)

\[H^\pm\] Mass \(m > 79.3\) GeV, CL = 95%

**Heavy Bosons Other Than Higgs Bosons, Searches for**

**Additional \(W\) Bosons**

\(W'\) with standard couplings

Mass \(m > 2.630 \times 10^3\) GeV, CL = 95%

**Additional \(Z\) Bosons**

\(Z'_\text{SM}\) with standard couplings

Mass \(m > 2.330 \times 10^3\) GeV, CL = 95% \((p\bar{p}\) direct search\)

Mass \(m > 1.500 \times 10^3\) GeV, CL = 95% \((\text{electroweak fit})\)

\(Z_{LR}\) of \(\text{SU}(2)_L\times\text{SU}(2)_R\times\text{U}(1)\) \((\text{with } g_L = g_R)\)

Mass \(m > 630\) GeV, CL = 95% \((p\bar{p}\) direct search\)

Mass \(m > 1162\) GeV, CL = 95% \((\text{electroweak fit})\)

\(Z_\chi\) of \(\text{SO}(10)\rightarrow\text{SU}(5)\times\text{U}(1)_\chi\) \((\text{with } g_\chi = e/\cos\theta_W)\)

Mass \(m > 1.970 \times 10^3\) GeV, CL = 95% \((p\bar{p}\) direct search\)

Mass \(m > 1.141 \times 10^3\) GeV, CL = 95% \((\text{electroweak fit})\)

\(Z_\psi\) of \(E_6\rightarrow\text{SO}(10)\times\text{U}(1)_\psi\) \((\text{with } g_\psi = e/\cos\theta_W)\)

Mass \(m > 2.000 \times 10^3\) GeV, CL = 95% \((p\bar{p}\) direct search\)

Mass \(m > 476\) GeV, CL = 95% \((\text{electroweak fit})\)

\(Z_{\eta}\) of \(E_6\rightarrow\text{SU}(3)\times\text{SU}(2)\times\text{U}(1)\times\text{U}(1)_\eta\) \((\text{with } g_\eta = e/\cos\theta_W)\)

Mass \(m > 1.870 \times 10^3\) GeV, CL = 95% \((p\bar{p}\) direct search\)

Mass \(m > 619\) GeV, CL = 95% \((\text{electroweak fit})\)
Scalar Leptoquarks

Mass $m > 830$ GeV, CL = 95% (1st generation, pair prod.)
Mass $m > 304$ GeV, CL = 95% (1st gener., single prod.)
Mass $m > 840$ GeV, CL = 95% (2nd gener., pair prod.)
Mass $m > 73$ GeV, CL = 95% (2nd gener., single prod.)
Mass $m > 525$ 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 $\nu \bar{\nu}$ 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] Here $\ell$ indicates $e$ or $\mu$.
[i] The value is for the sum of the charge states or particle/antiparticle states indicated.
[j] This value is updated using the product of (i) the $Z \to b\bar{b}$ fraction from this listing and (ii) the $b$-hadron fraction in an unbiased sample of weakly decaying $b$-hadrons produced in $Z$-decays provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG2009/#FRACZ).
[k] See the $Z$ Particle Listings for the $\gamma$ energy range used in this measurement.
[l] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.
[m] More precise preliminary measurements, consistent with the SM Higgs, were presented by ATLAS and CMS at EPS HEP 2013 conference, see: http://eps-hep2013.eu/program.html.
[o] The limits assume no invisible decays.