

GAUGE AND HIGGS BOSONS

γ (photon)

$$I(J^{PC}) = 0,1(1^{--})$$

$$\text{Mass } m < 1 \times 10^{-18} \text{ eV}$$

$$\text{Charge } q < 1 \times 10^{-35} e$$

$$\text{Mean life } \tau = \text{Stable}$$

**g
or gluon**

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

$$\text{Mass } m = 0 \text{ [a]}$$

$$\text{SU}(3) \text{ color octet}$$

graviton

$$J = 2$$

$$\text{Mass } m < 6 \times 10^{-32} \text{ eV}$$

W

$$J = 1$$

$$\text{Charge} = \pm 1 e$$

$$\text{Mass } m = 80.385 \pm 0.015 \text{ GeV}$$

$$W/Z \text{ mass ratio} = 0.88153 \pm 0.00017$$

$$m_Z - m_W = 10.803 \pm 0.015 \text{ GeV}$$

$$m_{W^+} - m_{W^-} = -0.2 \pm 0.6 \text{ GeV}$$

$$\text{Full width } \Gamma = 2.085 \pm 0.042 \text{ GeV}$$

$$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$$

$$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$$

$$\langle N_p \rangle = 0.92 \pm 0.14$$

$$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$$

W^- modes are charge conjugates of the modes below.

W^+ DECAY MODES	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$\ell^+ \nu$	[b]	$(10.86 \pm 0.09) \%$		—
$e^+ \nu$		$(10.71 \pm 0.16) \%$		40192
$\mu^+ \nu$		$(10.63 \pm 0.15) \%$		40192
$\tau^+ \nu$		$(11.38 \pm 0.21) \%$		40173
hadrons		$(67.41 \pm 0.27) \%$		—
$\pi^+ \gamma$	< 7	$\times 10^{-6}$	95%	40192

$D_s^+ \gamma$	< 1.3	$\times 10^{-3}$	95%	40168
cX	(33.3 ± 2.6)	%		—
$c\bar{s}$	$(31 \pm_{-11}^{+13})$	%		—
invisible	$[c] (1.4 \pm 2.9)$	%		—



$$J = 1$$

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

$$\langle N_{\text{charged}} \rangle = 20.76 \pm 0.16 \quad (S = 2.1)$$

Couplings to quarks and leptons

$$g_V^\ell = -0.03783 \pm 0.00041$$

$$g_V^u = 0.25 \pm_{-0.06}^{+0.07}$$

$$g_V^d = -0.33 \pm_{-0.06}^{+0.05}$$

$$g_A^\ell = -0.50123 \pm 0.00026$$

$$g_A^u = 0.50 \pm_{-0.06}^{+0.04}$$

$$g_A^d = -0.523 \pm_{-0.029}^{+0.050}$$

$$g^{\nu\ell} = 0.5008 \pm 0.0008$$

$$g^{\nu e} = 0.53 \pm 0.09$$

$$g^{\nu\mu} = 0.502 \pm 0.017$$

Asymmetry parameters ^[g]

$$A_e = 0.1515 \pm 0.0019$$

$$A_\mu = 0.142 \pm 0.015$$

$$A_\tau = 0.143 \pm 0.004$$

$$A_s = 0.90 \pm 0.09$$

$$A_c = 0.670 \pm 0.027$$

$$A_b = 0.923 \pm 0.020$$

Charge asymmetry (%) at Z pole

$$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$$

$$A_{FB}^{(0u)} = 4 \pm 7$$

$$A_{FB}^{(0s)} = 9.8 \pm 1.1$$

$$A_{FB}^{(0c)} = 7.07 \pm 0.35$$

$$A_{FB}^{(0b)} = 9.92 \pm 0.16$$

Z DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
e^+e^-	(3.363 $\pm$ 0.004) %		45594
$\mu^+\mu^-$	(3.366 $\pm$ 0.007) %		45594
$\tau^+\tau^-$	(3.370 $\pm$ 0.008) %		45559
$\ell^+\ell^-$	[<i>b</i>] (3.3658 $\pm$ 0.0023) %		—
$\ell^+\ell^-\ell^+\ell^-$	[<i>h</i>] (3.30 $\pm$ 0.31) $\times 10^{-6}$	S=1.1	45594
invisible	(20.00 $\pm$ 0.06) %		—
hadrons	(69.91 $\pm$ 0.06) %		—
$(u\bar{u}+c\bar{c})/2$	(11.6 $\pm$ 0.6) %		—
$(d\bar{d}+s\bar{s}+b\bar{b})/3$	(15.6 $\pm$ 0.4) %		—
$c\bar{c}$	(12.03 $\pm$ 0.21) %		—
$b\bar{b}$	(15.12 $\pm$ 0.05) %		—
$b\bar{b}b\bar{b}$	(3.6 $\pm$ 1.3) $\times 10^{-4}$		—
ggg	< 1.1	% CL=95%	—
$\pi^0\gamma$	< 2.01	$\times 10^{-5}$ CL=95%	45594
$\eta\gamma$	< 5.1	$\times 10^{-5}$ CL=95%	45592
$\omega\gamma$	< 6.5	$\times 10^{-4}$ CL=95%	45590
$\eta'(958)\gamma$	< 4.2	$\times 10^{-5}$ CL=95%	45589
$\gamma\gamma$	< 1.46	$\times 10^{-5}$ CL=95%	45594
$\pi^0\pi^0$	< 1.52	$\times 10^{-5}$ CL=95%	45594
$\gamma\gamma\gamma$	< 1.0	$\times 10^{-5}$ CL=95%	45594
$\pi^\pm W^\mp$	[<i>i</i>] < 7	$\times 10^{-5}$ CL=95%	10162
$\rho^\pm W^\mp$	[<i>i</i>] < 8.3	$\times 10^{-5}$ CL=95%	10136
$J/\psi(1S)X$	(3.51 $^{+0.23}_{-0.25}$) $\times 10^{-3}$	S=1.1	—
$J/\psi(1S)\gamma$	< 2.6	$\times 10^{-6}$ CL=95%	45541
$\psi(2S)X$	(1.60 $\pm$ 0.29) $\times 10^{-3}$		—
$\chi_{c1}(1P)X$	(2.9 $\pm$ 0.7) $\times 10^{-3}$		—
$\chi_{c2}(1P)X$	< 3.2	$\times 10^{-3}$ CL=90%	—
$\Upsilon(1S)X + \Upsilon(2S)X$ $+ \Upsilon(3S)X$	(1.0 $\pm$ 0.5) $\times 10^{-4}$		—
$\Upsilon(1S)X$	< 3.4	$\times 10^{-6}$ CL=95%	—
$\Upsilon(2S)X$	< 6.5	$\times 10^{-6}$ CL=95%	—
$\Upsilon(3S)X$	< 5.4	$\times 10^{-6}$ CL=95%	—
$(D^0/\bar{D}^0)X$	(20.7 $\pm$ 2.0) %		—
$D^\pm X$	(12.2 $\pm$ 1.7) %		—
$D^*(2010)^\pm X$	[<i>i</i>] (11.4 $\pm$ 1.3) %		—
$D_{s1}(2536)^\pm X$	(3.6 $\pm$ 0.8) $\times 10^{-3}$		—
$D_{sJ}(2573)^\pm X$	(5.8 $\pm$ 2.2) $\times 10^{-3}$		—
$D^{*'}(2629)^\pm X$	searched for		—
B^+X	[<i>j</i>] (6.08 $\pm$ 0.13) %		—
B_s^0X	[<i>j</i>] (1.59 $\pm$ 0.13) %		—
B_c^+X	searched for		—

$\Lambda_c^+ X$		(1.54 ± 0.33) %		—
$\Xi_c^0 X$		seen		—
$\Xi_b^- X$		seen		—
b -baryon X	[j]	(1.38 ± 0.22) %		—
anomalous γ + hadrons	[k]	< 3.2	$\times 10^{-3}$ CL=95%	—
$e^+ e^- \gamma$	[k]	< 5.2	$\times 10^{-4}$ CL=95%	45594
$\mu^+ \mu^- \gamma$	[k]	< 5.6	$\times 10^{-4}$ CL=95%	45594
$\tau^+ \tau^- \gamma$	[k]	< 7.3	$\times 10^{-4}$ CL=95%	45559
$\ell^+ \ell^- \gamma \gamma$	[l]	< 6.8	$\times 10^{-6}$ CL=95%	—
$q \bar{q} \gamma \gamma$	[l]	< 5.5	$\times 10^{-6}$ CL=95%	—
$\nu \bar{\nu} \gamma \gamma$	[l]	< 3.1	$\times 10^{-6}$ CL=95%	45594
$e^\pm \mu^\mp$	LF [i]	< 7.5	$\times 10^{-7}$ CL=95%	45594
$e^\pm \tau^\mp$	LF [i]	< 9.8	$\times 10^{-6}$ CL=95%	45576
$\mu^\pm \tau^\mp$	LF [i]	< 1.2	$\times 10^{-5}$ CL=95%	45576
$p e$	L,B	< 1.8	$\times 10^{-6}$ CL=95%	45589
$p \mu$	L,B	< 1.8	$\times 10^{-6}$ CL=95%	45589

H^0

$J = 0$

Mass $m = 125.09 \pm 0.24$ GeV
Full width $\Gamma < 1.7$ GeV, CL = 95%

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States = 1.10 ± 0.11
 $W W^* = 1.08^{+0.18}_{-0.16}$
 $Z Z^* = 1.29^{+0.26}_{-0.23}$
 $\gamma \gamma = 1.16 \pm 0.18$
 $b \bar{b} = 0.82 \pm 0.30$ (S = 1.1)
 $\mu^+ \mu^- < 7.0$, CL = 95%
 $\tau^+ \tau^- = 1.12 \pm 0.23$
 $Z \gamma < 9.5$, CL = 95%
 $t \bar{t} H^0$ Production = $2.3^{+0.7}_{-0.6}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^+ e^-$	< 1.9 $\times 10^{-3}$	95%	62545
$J/\psi \gamma$	< 1.5 $\times 10^{-3}$	95%	62507
$\Upsilon(1S) \gamma$	< 1.3 $\times 10^{-3}$	95%	62187
$\Upsilon(2S) \gamma$	< 1.9 $\times 10^{-3}$	95%	62143
$\Upsilon(3S) \gamma$	< 1.3 $\times 10^{-3}$	95%	62116
$\mu \tau$	< 1.51 %	95%	62532
invisible	<58 %	95%	—

Neutral Higgs Bosons, Searches for

Searches for a Higgs Boson with Standard Model Couplings

Mass $m > 122$ and none 128–1000 GeV, CL = 95%

The limits for H_1^0 and A^0 in supersymmetric models refer to the $m_h^{\max}$ 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 ^[n]

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

Charged Higgs Bosons ($H^\pm$ and $H^{\pm\pm}$), Searches for

$H^\pm$ Mass $m > 80$ GeV, CL = 95%

New Heavy Bosons (W' , Z' , leptoquarks, etc.), Searches for

Additional W Bosons

W' with standard couplings

Mass $m > 3.710 \times 10^3$ GeV, CL = 95% (pp direct search)

W_R (Right-handed W Boson)

Mass $m > 715$ GeV, CL = 90% (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings

Mass $m > 2.900 \times 10^3$ GeV, CL = 95% (pp direct search)

Mass $m > 1.500 \times 10^3$ 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% ($p\bar{p}$ direct search)

Mass $m > 1162$ GeV, CL = 95% (electroweak fit)

Z_χ of $SO(10) \rightarrow SU(5) \times U(1)_\chi$ (with $g_\chi = e/\cos\theta_W$)

Mass $m > 2.620 \times 10^3$ GeV, CL = 95% (pp direct search)

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

Z_ψ of $E_6 \rightarrow SO(10) \times U(1)_\psi$ (with $g_\psi = e/\cos\theta_W$)

Mass $m > 2.570 \times 10^3$ GeV, CL = 95% (pp direct search)

Mass $m > 476$ GeV, CL = 95% (electroweak fit)

Z_η of $E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_\eta$ (with $g_\eta = e/\cos\theta_W$)

Mass $m > 1.870 \times 10^3$ GeV, CL = 95% (pp direct search)

Mass $m > 619$ GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m > 1050$ GeV, CL = 95% (1st generation, pair prod.)

Mass $m > 304$ GeV, CL = 95% (1st generation, single prod.)

Mass $m > 1000$ GeV, CL = 95% (2nd generation, pair prod.)

Mass $m > 73$ GeV, CL = 95% (2nd generation, single prod.)

Mass $m > 740$ GeV, CL = 95% (3rd generation, pair prod.)

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

Diquarks

Mass $m > 4700$ GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m > 3600$ GeV, CL = 95%

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] ℓ indicates each type of lepton (e , μ , and τ), 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 τ mass.
- [g] Here $A \equiv 2g_V g_A / (g_V^2 + g_A^2)$.

[*h*] Here ℓ indicates e or μ .

[*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 $Z \rightarrow b\bar{b}$ 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/PDG_2009/#FRACZ).

[*k*] See the Z Particle Listings for the γ energy range used in this measurement.

[*l*] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

[*n*] The limits assume no invisible decays.