

GAUGE AND HIGGS BOSONS

γ (photon)

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

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

W

$$J = 1$$

Charge = ± 1 e

Mass $m = 80.379 \pm 0.012$ GeV

W/Z mass ratio = 0.88147 ± 0.00013

$m_Z - m_W = 10.809 \pm 0.012$ GeV

$m_{W^+} - m_{W^-} = -0.029 \pm 0.028$ 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.

W^+ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	ρ (MeV/c)
$\ell^+ \nu$	[b] $(10.86 \pm 0.09) \%$		–
$e^+ \nu$	$(10.71 \pm 0.16) \%$		40189
$\mu^+ \nu$	$(10.63 \pm 0.15) \%$		40189
$\tau^+ \nu$	$(11.38 \pm 0.21) \%$		40170
hadrons	$(67.41 \pm 0.27) \%$		–

$\pi^+ \gamma$	< 7	$\times 10^{-6}$	95%	40189
$D_s^+ \gamma$	< 1.3	$\times 10^{-3}$	95%	40165
cX	$(33.3 \pm 2.6) \%$			—
$c\bar{s}$	$(31 \text{ }^{+13}_{-11}) \%$			—
invisible	[c]	$(1.4 \pm 2.9) \%$		—

Z

$$J = 1$$

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

$\Gamma(\mu^+ \mu^-) / \Gamma(e^+ e^-) = 1.0009 \pm 0.0028$

$\Gamma(\tau^+ \tau^-) / \Gamma(e^+ e^-) = 1.0020 \pm 0.0032$ [f]

Average charged multiplicity

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

Couplings to quarks and leptons

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

$$g_V^u = 0.266 \pm 0.034$$

$$g_V^d = -0.38 \text{ }^{+0.04}_{-0.05}$$

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

$$g_A^u = 0.519 \text{ }^{+0.028}_{-0.033}$$

$$g_A^d = -0.527 \text{ }^{+0.040}_{-0.028}$$

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

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

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

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)
$e^+ e^-$	[h] (3.3632±0.0042) %		45594
$\mu^+ \mu^-$	[h] (3.3662±0.0066) %		45594
$\tau^+ \tau^-$	[h] (3.3696±0.0083) %		45559
$\ell^+ \ell^-$	[b,h] (3.3658±0.0023) %		—
$\ell^+ \ell^- \ell^+ \ell^-$	[i] (4.58 ±0.26) × 10 ⁻⁶		45594
invisible	[h] (20.000 ±0.055) %		—
hadrons	[h] (69.911 ±0.056) %		—
($u\bar{u} + c\bar{c}$)/2	(11.6 ±0.6) %		—
($d\bar{d} + s\bar{s} + b\bar{b}$)/3	(15.6 ±0.4) %		—
$c\bar{c}$	(12.03 ±0.21) %		—
$b\bar{b}$	(15.12 ±0.05) %		—
$b\bar{b}b\bar{b}$	(3.6 ±1.3) × 10 ⁻⁴		—
$g g g$	< 1.1	% CL=95%	—
$\pi^0 \gamma$	< 2.01	× 10 ⁻⁵ CL=95%	45594
$\eta \gamma$	< 5.1	× 10 ⁻⁵ CL=95%	45592
$\rho^0 \gamma$	< 2.5	× 10 ⁻⁵ CL=95%	45591
$\omega \gamma$	< 6.5	× 10 ⁻⁴ CL=95%	45590
$\eta'(958) \gamma$	< 4.2	× 10 ⁻⁵ CL=95%	45589
$\phi \gamma$	< 9	× 10 ⁻⁷ CL=95%	45588
$\gamma \gamma$	< 1.46	× 10 ⁻⁵ CL=95%	45594
$\pi^0 \pi^0$	< 1.52	× 10 ⁻⁵ CL=95%	45594
$\gamma \gamma \gamma$	< 2.2	× 10 ⁻⁶ CL=95%	45594
$\pi^\pm W^\mp$	[j] < 7	× 10 ⁻⁵ CL=95%	10167
$\rho^\pm W^\mp$	[j] < 8.3	× 10 ⁻⁵ CL=95%	10142
$J/\psi(1S) X$	(3.51 ^{+0.23} _{-0.25}) × 10 ⁻³	S=1.1	—
$J/\psi(1S) \gamma$	< 2.3	× 10 ⁻⁶ CL=95%	45541
$\psi(2S) X$	(1.60 ±0.29) × 10 ⁻³		—
$\psi(2S) \gamma$	< 4.5	× 10 ⁻⁶ CL=95%	45519
$\chi_{c1}(1P) X$	(2.9 ±0.7) × 10 ⁻³		—
$\chi_{c2}(1P) X$	< 3.2	× 10 ⁻³ CL=90%	—
$\Upsilon(1S) X + \Upsilon(2S) X$ + $\Upsilon(3S) X$	(1.0 ±0.5) × 10 ⁻⁴		—

$\Upsilon(1S)X$		< 3.4	$\times 10^{-6}$	CL=95%	—	
$\Upsilon(1S)\gamma$		< 2.8	$\times 10^{-6}$	CL=95%	45103	
$\Upsilon(2S)X$		< 6.5	$\times 10^{-6}$	CL=95%	—	
$\Upsilon(2S)\gamma$		< 1.7	$\times 10^{-6}$	CL=95%	45043	
$\Upsilon(3S)X$		< 5.4	$\times 10^{-6}$	CL=95%	—	
$\Upsilon(3S)\gamma$		< 4.8	$\times 10^{-6}$	CL=95%	45006	
$(D^0/\bar{D}^0)X$		(20.7 \pm 2.0)) %		—	
$D^\pm X$		(12.2 \pm 1.7)) %		—	
$D^*(2010)^\pm X$	[j]	(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			—	
$B^+ X$	[k]	(6.08 \pm 0.13)) %		—	
$B_s^0 X$	[k]	(1.59 \pm 0.13)) %		—	
$B_c^+ X$		searched for			—	
$\Lambda_c^+ X$		(1.54 \pm 0.33)) %		—	
$\Xi_c^0 X$		seen			—	
$\Xi_b X$		seen			—	
b -baryon X	[k]	(1.38 \pm 0.22)) %		—	
anomalous γ + hadrons	[l]	< 3.2	$\times 10^{-3}$	CL=95%	—	
$e^+ e^- \gamma$	[l]	< 5.2	$\times 10^{-4}$	CL=95%	45594	
$\mu^+ \mu^- \gamma$	[l]	< 5.6	$\times 10^{-4}$	CL=95%	45594	
$\tau^+ \tau^- \gamma$	[l]	< 7.3	$\times 10^{-4}$	CL=95%	45559	
$\ell^+ \ell^- \gamma \gamma$	[n]	< 6.8	$\times 10^{-6}$	CL=95%	—	
$q\bar{q}\gamma\gamma$	[n]	< 5.5	$\times 10^{-6}$	CL=95%	—	
$\nu\bar{\nu}\gamma\gamma$	[n]	< 3.1	$\times 10^{-6}$	CL=95%	45594	
$e^\pm \mu^\mp$	LF	[j]	< 7.5	$\times 10^{-7}$	CL=95%	45594
$e^\pm \tau^\mp$	LF	[j]	< 9.8	$\times 10^{-6}$	CL=95%	45576
$\mu^\pm \tau^\mp$	LF	[j]	< 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

$$J = 0$$

$$\text{Mass } m = 125.10 \pm 0.14 \text{ GeV}$$

$$\text{Full width } \Gamma < 0.013 \text{ GeV, CL} = 95\% \quad (\text{assumes equal on-shell and off-shell effective couplings})$$

H^0 Signal Strengths in Different Channels

$$\text{Combined Final States} = 1.10 \pm 0.11$$

$$W W^* = 1.08^{+0.18}_{-0.16}$$

$$Z Z^* = 1.19^{+0.12}_{-0.11}$$

$$\gamma\gamma = 1.10^{+0.10}_{-0.09}$$

$$c\bar{c} \text{ Final State} < 110, \text{ CL} = 95\%$$

$$b\bar{b} = 1.02 \pm 0.15$$

$$\mu^+ \mu^- = 0.6 \pm 0.8$$

$$\tau^+ \tau^- = 1.11 \pm 0.17$$

$$Z\gamma < 6.6, \text{ CL} = 95\%$$

$$t\bar{t} H^0 \text{ Production} = 1.28 \pm 0.20$$

$$H^0 H^0 \text{ Production} < 12.7$$

$$H^0 \text{ Production Cross Section in } pp \text{ Collisions at } \sqrt{s} = 13 \text{ TeV} = 57 \pm 7 \text{ pb}$$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^+ e^-$	$< 1.9 \times 10^{-3}$	95%	62550
$J/\psi\gamma$	$< 3.5 \times 10^{-4}$	95%	62511
$\psi(2S)\gamma$	$< 2.0 \times 10^{-3}$	95%	62495
$\Upsilon(1S)\gamma$	$< 4.9 \times 10^{-4}$	95%	62192
$\Upsilon(2S)\gamma$	$< 5.9 \times 10^{-4}$	95%	62148
$\Upsilon(3S)\gamma$	$< 5.7 \times 10^{-4}$	95%	62121
$\rho(770)\gamma$	$< 8.8 \times 10^{-4}$	95%	62547
$\phi(1020)\gamma$	$< 4.8 \times 10^{-4}$	95%	62546
$e\mu$	$< 3.5 \times 10^{-4}$	95%	62550
$e\tau$	$< 6.1 \times 10^{-3}$	95%	62537
$\mu\tau$	$< 2.5 \times 10^{-3}$	95%	62537
invisible	$< 24 \%$	95%	—

Neutral Higgs Bosons, Searches for

Mass Limits for heavy neutral Higgs bosons (H_2^0, A^0) in the MSSM

$$m > 389 \text{ GeV } (\tan\beta=10); > 1613 \text{ GeV } (\tan\beta=60), \text{ CL} = 95\% \\ [\text{obtained in the } m_h^{\text{mod}+} \text{ scenario}]$$

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

mass for $[m_{H^+} < m(\text{top})] > 155 \text{ GeV}$

mass for $[m_{H^+} > m(\text{top})] > 180 \text{ GeV}$ ($\tan\beta = 10$);

$> 1103 \text{ GeV}$ ($\tan\beta=60$)

[obtained in the $m_h^{\text{mod-}}$ scenario]

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

Additional W Bosons

W' with standard couplings

Mass $m > 5200 \text{ GeV}$, CL = 95% (pp direct search)

W_R (Right-handed W Boson)

Mass $m > 715 \text{ GeV}$, CL = 90% (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings

Mass $m > 4.500 \times 10^3 \text{ GeV}$, CL = 95% (pp direct search)

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

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

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

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

Mass $m > 4.100 \times 10^3 \text{ GeV}$, CL = 95% (pp direct search)

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

Mass $m > 3900 \text{ GeV}$, CL = 95% (pp direct search)

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 $m > 3.900 \times 10^3 \text{ GeV}$, CL = 95% (pp direct search)

Scalar Leptoquarks

$m > 1050 \text{ GeV}$, CL = 95% (1st gen., pair prod., $B(\tau t)=1$)

$m > 1755 \text{ GeV}$, CL = 95% (1st gen., single prod., $B(\tau b)=1$)

$m > 1420 \text{ GeV}$, CL = 95% (2nd gen., pair prod., $B(\mu t)=1$)

$m > 660 \text{ GeV}$, CL = 95% (2nd gen., single prod., $B(\mu q)=1$)

$m > 900 \text{ GeV}$, CL = 95% (3rd gen., pair prod., $B(e q)=1$)

$m > 740 \text{ GeV}$, CL = 95% (3rd gen., single prod., $B(e q)=1$)

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

DiquarksMass $m > 6000$ GeV, CL = 95% (E_6 diquark)**Axigluon**Mass $m > 6100$ 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] This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).
- [i] Here ℓ indicates e or μ .
- [j] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [k] 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 (HFLAV, http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ).

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

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