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 $= \pm 1$ e
Mass $m = 80.379 \pm 0.012$ GeV
W/Z mass ratio $= 0.88147 \pm 0.00013$
$m_Z - m_W = 10.809 \pm 0.012$ 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	p (MeV/c)
$\ell^+ \nu$	[b]	(10.86 ± 0.09) %		$-$
$e^+ \nu$		(10.71 ± 0.16) %		40189
$\mu^+ \nu$		(10.63 ± 0.15) %		40189
$\tau^+ \nu$		(11.38 ± 0.21) %		40170
hadrons		(67.41 ± 0.27) %		$-$

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

$\boxed{Z}$ $\hspace{5cm} J = 1$

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

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

Couplings to quarks and leptons

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

$g_V^u = 0.266 \pm 0.034$

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

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

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

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

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

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

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

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$\pm$0.0042) %			45594
$\mu^+ \mu^-$	[h]	(3.3662$\pm$0.0066) %			45594
$\tau^+ \tau^-$	[h]	(3.3696$\pm$0.0083) %			45559
$\ell^+ \ell^-$	[b,h]	(3.3658$\pm$0.0023) %			—
$\ell^+ \ell^- \ell^+ \ell^-$	[i]	(4.58 $\pm$0.26) $\times 10^{-6}$			45594
invisible	[h]	(20.000 $\pm$0.055) %			—
hadrons	[h]	(69.911 $\pm$0.056) %			—
$(u\overline{u}+c\overline{c})/2$		(11.6 $\pm$0.6) %			—
$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 $\pm$0.4) %			—
$c\overline{c}$		(12.03 $\pm$0.21) %			—
$b\overline{b}$		(15.12 $\pm$0.05) %			—
$b\overline{b}b\overline{b}$		(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
$\rho^0 \gamma$		< 2.5	$\times 10^{-5}$	CL=95%	45591
$\omega \gamma$		< 6.5	$\times 10^{-4}$	CL=95%	45590
$\eta'(958) \gamma$		< 4.2	$\times 10^{-5}$	CL=95%	45589
$\phi \gamma$		< 9	$\times 10^{-7}$	CL=95%	45588
$\gamma \gamma$		< 1.46	$\times 10^{-5}$	CL=95%	45594
$\pi^0 \pi^0$		< 1.52	$\times 10^{-5}$	CL=95%	45594
$\gamma \gamma \gamma$		< 2.2	$\times 10^{-6}$	CL=95%	45594
$\pi^\pm W^\mp$	[j] < 7		$\times 10^{-5}$	CL=95%	10167
$\rho^\pm W^\mp$	[j] < 8.3		$\times 10^{-5}$	CL=95%	10142
$J/\psi(1S)X$		(3.51 $^{+0.23}_{-0.25}$) $\times 10^{-3}$		S=1.1	—
$J/\psi(1S)\gamma$		< 2.3	$\times 10^{-6}$	CL=95%	45541
$\psi(2S)X$		(1.60 $\pm$0.29) $\times 10^{-3}$			—
$\psi(2S)\gamma$		< 4.5	$\times 10^{-6}$	CL=95%	45519
$\chi_{c1}(1P)X$		(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%	$-$
$\Upsilon(1S)\gamma$			$<$ 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
$(D^0/\overline{D}^0)\,X$			(20.7 ± 2.0) %			$-$
$D^{\pm}X$			(12.2 ± 1.7) %			$-$
$D^*(2010)^{\pm}X$		[j]	(11.4 ± 1.3) %			$-$
$D_{s1}(2536)^{\pm}X$			(3.6 ± 0.8) $\times 10^{-3}$			$-$
$D_{sJ}(2573)^{\pm}X$			(5.8 ± 2.2) $\times 10^{-3}$			$-$
$D^{*\prime}(2629)^{\pm}X$			searched for			$-$
B^+X		[k]	(6.08 ± 0.13) %			$-$
$B_s^0 X$		[k]	(1.59 ± 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		[k]	(1.38 ± 0.22) %			$-$
anomalous $\gamma+$ 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%	$-$
$q\overline{q}\gamma\gamma$		[n]	$<$ 5.5	$\times 10^{-6}$	CL=95%	$-$
$\nu\overline{\nu}\gamma\gamma$		[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

$$J = 0$$

Mass $m = 125.10 \pm 0.14$ GeV

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

H^0 Signal Strengths in Different Channels

Combined Final States $= 1.10 \pm 0.11$

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

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

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

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

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

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

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

$Z\gamma < 6.6$, CL $= 95\%$

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

$H^0 H^0$ Production < 12.7

H^0 Production Cross Section in pp Collisions at $\sqrt{s} = 13$ TeV $= 57 \pm 7$ 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^0_2, A^0) in the MSSM

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

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

mass for $[m_{H^+} < m(\text{top})] > 155$ GeV
mass for $[m_{H^+} > m(\text{top})] > 180$ GeV ($\tan\beta = 10$);
> 1103 GeV ($\tan\beta = 60$)
[obtained in the m_h^{mod-} scenario]

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

Additional W Bosons

W' with standard couplings
Mass $m > 5200$ 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 $m > 4.500 \times 10^3$ 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 $m > 630$ GeV, CL $= 95\%$ ($p\overline{p}$ 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 $m > 4.100 \times 10^3$ 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 $m > 3900$ 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 $m > 3.900 \times 10^3$ GeV, CL $= 95\%$ (pp direct search)

Scalar Leptoquarks

$m > 1050$ GeV, CL $= 95\%$ (1st gen., pair prod., B(τt)=1)
$m > 1755$ GeV, CL $= 95\%$ (1st gen., single prod., B(τb)=1)
$m > 1420$ GeV, CL $= 95\%$ (2nd gen., pair prod., B(μt)=1)
$m > 660$ GeV, CL $= 95\%$ (2nd gen., single prod., B(μq)=1)
$m > 900$ GeV, CL $= 95\%$ (3rd gen., pair prod., B($e q$)=1)
$m > 740$ GeV, CL $= 95\%$ (3rd gen., single prod., B($e q$)=1)
(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m > 6000$ 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 $\nu\overline{\nu}$ 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 $Z \rightarrow b\overline{b}$ 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.