GAUGE AND HIGGS BOSONS

γ (photon) $\qquad\qquad I(J^{PC}) = 0,1(1^{--})$

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

g or gluon $\qquad\qquad I(J^P) = 0(1^-)$

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

graviton $\qquad\qquad J = 2$

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

W $\qquad\qquad J = 1$

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.

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) %			40192
$\mu^+ \nu$		(10.63 ± 0.15) %			40192
$\tau^+ \nu$		(11.38 ± 0.21) %			40173
hadrons		(67.41 ± 0.27) %			−
$\pi^+ \gamma$		< 7	$\times 10^{-6}$	95%	40192
$D_s^+ \gamma$		< 1.3	$\times 10^{-3}$	95%	40168

$c\,X$	$(33.3 \pm 2.6\ )\,\%$	–
$c\,\overline{s}$	$(31\ ^{+13}_{-11}\ )\,\%$	–
invisible	[c] $(\ 1.4 \pm 2.9\ )\,\%$	–

$\boxed{Z}$ $\qquad\qquad\qquad J = 1$

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

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

Couplings to quarks and leptons

$g_V^\ell = -0.03783 \pm 0.00041$
$g_V^u = 0.25^{+0.07}_{-0.06}$
$g_V^d = -0.33^{+0.05}_{-0.06}$
$g_A^\ell = -0.50123 \pm 0.00026$
$g_A^u = 0.50^{+0.04}_{-0.06}$
$g_A^d = -0.523^{+0.050}_{-0.029}$
$g^{\nu\ell} = 0.5008 \pm 0.0008$
$g^{\nu e} = 0.53 \pm 0.09$
$g^{\nu\mu} = 0.502 \pm 0.017$

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
$\ell^+\ell^-$	[b]	(3.3658$\pm$0.0023) %			—
$\ell^+\ell^-\ell^+\ell^-$	[h]	(3.30 $\pm$0.31) $\times 10^{-6}$		S=1.1	45594
invisible		(20.00 $\pm$0.06) %			—
hadrons		(69.91 $\pm$0.06) %			—
$(u\overline{u}+c\overline{c})/2$		(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
$\omega\gamma$		< 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]	< 7 $\times 10^{-5}$		CL=95%	10162
$\rho^\pm W^\mp$	[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	—
$\psi(2S)$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		< 4.4 $\times 10^{-5}$		CL=95%	—
$\Upsilon(2S)$X		< 1.39 $\times 10^{-4}$		CL=95%	—
$\Upsilon(3S)$X		< 9.4 $\times 10^{-5}$		CL=95%	—
$(D^0/\overline{D}^0)$ X		(20.7 $\pm$2.0) %			—
$D^\pm$X		(12.2 $\pm$1.7) %			—
$D^*(2010)^\pm$X	[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	[j]	(6.08 $\pm$0.13) %			—
B^0_sX	[j]	(1.59 $\pm$0.13) %			—
B^+_cX		searched for			—
Λ^+_cX		(1.54 $\pm$0.33) %			—

$\Xi_c^0 X$			seen			—
$\Xi_b X$			seen			—
b-baryon X		[j]	(1.38	± 0.22	) %	—
anomalous $\gamma +$ 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%	—
$q \overline{q} \gamma \gamma$		[l] <	5.5	$\times 10^{-6}$	CL=95%	—
$\nu \overline{\nu} \gamma \gamma$		[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 $\qquad J = 0$

Mass $m = 125.09 \pm 0.24$ GeV

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States $= 1.17 \pm 0.17$ (S = 1.2)

$W W^* = 0.81 \pm 0.16$

$Z Z^* = 1.15^{+0.27}_{-0.23}$ (S = 1.2)

$\gamma \gamma = 1.17^{+0.19}_{-0.17}$

$b \overline{b} = 0.85 \pm 0.29$

$\mu^+ \mu^- < 7.0$, CL = 95%

$\tau^+ \tau^- = 0.79 \pm 0.26$

$Z \gamma < 9.5$, CL = 95%

$t \overline{t} H^0$ Production $= 2.5^{+0.9}_{-0.8}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
invisible	<58 %	95%	—

Neutral Higgs Bosons, Searches for

Searches for a Higgs Boson with Standard Model Couplings
Mass $m > 122$ and none 128–710 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 $m > 3.240 \times 10^3$ 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%   ($p\overline{p}$ 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 $m > 2.620 \times 10^3$ 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 $m > 2.510 \times 10^3$ 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 $m > 830$ 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 $m > 740$ GeV, CL $= 95\%$ (3rd gener., pair prod.)
    (See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m > 3.750 \times 10^3$ GeV, CL $= 95\%$

Axigluon

Mass $m > 3.360 \times 10^3$ 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] 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 $Z \to b\overline{b}$ 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 (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.