GAUGE AND HIGGS BOSONS

γ

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

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 $m = 80.385 \pm 0.015$ 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	$\times 10^{-5}$	95%	40192
$D_s^+\gamma$	$<$ 1.3	$\times 10^{-3}$	95%	40168
cX	(33.3 $\pm$ 2.6) %			–
$c\overline{s}$	(31 $^{+13}_{-11}$) %			–
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
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.0009 \pm 0.0028$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0019 \pm 0.0032$ [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 ±0.004) %		45594
$\mu^+ \mu^-$		(3.366 ±0.007) %		45594
$\tau^+ \tau^-$		(3.370 ±0.008) %		45559
$\ell^+ \ell^-$	[b]	(3.3658±0.0023) %		–
$\ell^+ \ell^- \ell^+ \ell^-$	[h]	(4.2 $^{+0.9}_{-0.8}$) $\times 10^{-6}$		45594
invisible		(20.00 ±0.06) %		–
hadrons		(69.91 ±0.06) %		–
$(u\overline{u}+c\overline{c})/2$		(11.6 ±0.6) %		–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 ±0.4) %		–
$c\overline{c}$		(12.03 ±0.21) %		–
$b\overline{b}$		(15.12 ±0.05) %		–
$b\overline{b}\,b\overline{b}$		(3.6 ±1.3) $\times 10^{-4}$		–
$g\,g\,g$		< 1.1 %	CL=95%	–
$\pi^0\gamma$		< 5.2 $\times 10^{-5}$	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
$\gamma\gamma$		< 5.2 $\times 10^{-5}$	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 ±0.29) $\times 10^{-3}$		–
$\chi_{c1}(1P)$X		(2.9 ±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 ±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 ±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	) $\times 10^{-3}$		–
$D^{*\prime}(2629)^{\pm}$X			searched for				–
B^+X		[j]	(6.08	$\pm$0.13	) %		–
B_s^0X		[j]	(1.59	$\pm$0.13	) %		–
B_c^+X			searched for				–
Λ_c^+X			(1.54	$\pm$0.33	) %		–
Ξ_c^0X			seen				–
Ξ_bX			seen				–
b-baryon X		[j]	(1.38	$\pm$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]	$<$ 1.7		$\times 10^{-6}$	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
pe	*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 $m = 125.7 \pm 0.4$ GeV

H^0 Signal Strengths in Different Channels

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

$WW^* = 0.87^{+0.24}_{-0.22}$

$ZZ^* = 1.11^{+0.34}_{-0.28}$ (S = 1.3)

$\gamma\gamma = 1.58^{+0.27}_{-0.23}$

$b\overline{b} = 1.1 \pm 0.5$

$\tau^+\tau^- = 0.4 \pm 0.6$

$Z\gamma < 9.5$, CL = 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% $\quad \tan\beta > 0.4$

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

W_R (Right-handed W Boson)

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

Additional Z Bosons

$Z'_{\rm SM}$ with standard couplings

Mass $m > 2.590 \times 10^3$ GeV, CL = 95% (pp direct search)

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

Z_{LR} of $\mathrm{SU(2)}_L \times \mathrm{SU(2)}_R \times \mathrm{U(1)}$ (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 $\mathrm{SO(10)} \rightarrow \mathrm{SU(5)} \times \mathrm{U(1)}_\chi$ (with $g_\chi = e/\cos\theta_W$)

Mass $m > 1.970 \times 10^3$ GeV, CL = 95% (pp direct search)

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

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

Mass $m > 2.260 \times 10^3$ GeV, CL = 95% (pp direct search)

Mass $m >$ 476 GeV, CL = 95% (electroweak fit)
Z_η of $E_6 \rightarrow$ SU(3)×SU(2)×U(1)×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 $m >$ 525 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.