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 τ = Stable

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g or gluon

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

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

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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
W/Z mass ratio $= 0.88153 \pm 0.00017$
$m_Z - m_W = 10.803 \pm 0.015$ 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
cX		(33.3 ± 2.6) %			–
$c\overline{s}$		$(31\ ^{+13}_{-11})$ %			–
invisible	[c]	(1.4 ± 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

$g_V^\ell = -0.03783 \pm 0.00041$
$g_V^u = 0.18 \pm 0.05$
$g_V^d = -0.35^{+0.05}_{-0.06}$
$g_A^\ell = -0.50123 \pm 0.00026$
$g_A^u = 0.50^{+0.04}_{-0.05}$
$g_A^d = -0.514^{+0.050}_{-0.029}$
$g^{\nu_\ell} = 0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

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]	(3.5	± 0.4)	$\times 10^{-6}$	S=1.7	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%	–
$\pi^0\gamma$		< 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
$\phi\gamma$		< 8.3		$\times 10^{-6}$	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
$\pi^\pm W^\mp$	[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	–
$J/\psi(1S)\gamma$		< 2.6		$\times 10^{-6}$	CL=95%	45541
$\psi(2S)$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		< 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%	–
$(D^0/\overline{D}^0)$ X		(20.7	± 2.0) %			–
$D^\pm$X		(12.2	± 1.7) %			–
$D^*(2010)^\pm$X	[i]	(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		[j]	(6.08 ±0.13) %			–
B_s^0X		[j]	(1.59 ±0.13) %			–
B_c^+X			searched for			–
Λ_c^+X			(1.54 ±0.33) %			–
Ξ_c^0X			seen			–
Ξ_bX			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
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 $m = 125.09 \pm 0.24$ GeV
Full width $\Gamma < 0.013$ GeV, CL = 95%

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States $= 1.10 \pm 0.11$
$WW^* = 1.08^{+0.18}_{-0.16}$
$ZZ^* = 1.29^{+0.26}_{-0.23}$
$\gamma\gamma = 1.16 \pm 0.18$
$b\overline{b} = 0.82 \pm 0.30$ (S = 1.1)
$\mu^+\mu^- = 0.1 \pm 2.5$
$\tau^+\tau^- = 1.12 \pm 0.23$
$Z\gamma < 9.5$, CL = 95%
$t\overline{t}H^0$ 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
$\phi(1020)\gamma$	$< 1.4 \times 10^{-3}$	95%	62541
$e\mu$	$< 3.5 \times 10^{-4}$	95%	62545
$e\tau$	$< 6.9 \times 10^{-3}$	95%	62532
$\mu\tau$	< 1.51 %	95%	62532
invisible	<28 %	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 $m > 4.070 \times 10^3$ 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 $m >$ 3.360 $\times 10^3$ 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 $m >$ 3.050 $\times 10^3$ 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 $m >$ 2.740 $\times 10^3$ 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 $m >$ 2.810 $\times 10^3$ GeV, CL = 95% (pp direct search)

Scalar Leptoquarks

Mass $m >$ 1050 GeV, CL = 95% (1st generation, pair prod.)
Mass $m >$ 1755 GeV, CL = 95% (1st generation, single prod.)
Mass $m >$ 1000 GeV, CL = 95% (2nd generation, pair prod.)
Mass $m >$ 660 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 $m >$ 6000 GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m >$ 5100 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 (HFLAV, http://www.slac.stanford.edu/xorg/hflav/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.