

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

W

$$J = 1$$

Charge = ± 1 e

Mass $m = 80.399 \pm 0.023$ 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] $(10.80 \pm 0.09) \%$		—
$e^+ \nu$	$(10.75 \pm 0.13) \%$		40199
$\mu^+ \nu$	$(10.57 \pm 0.15) \%$		40199
$\tau^+ \nu$	$(11.25 \pm 0.20) \%$		40180
hadrons	$(67.60 \pm 0.27) \%$		—
$\pi^+ \gamma$	< 8	$\times 10^{-5}$	95% 40199
$D_s^+ \gamma$	< 1.3	$\times 10^{-3}$	95% 40175
cX	$(33.4 \pm 2.6) \%$		—
$c\bar{s}$	$(31^{+13}_{-11}) \%$		—
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

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

Couplings to leptons

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

$$g_V^u = 0.29^{+0.10}_{-0.08}$$

$$g_V^d = -0.33^{+0.05}_{-0.07}$$

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

$$g_A^u = 0.50^{+0.04}_{-0.07}$$

$$g_A^d = -0.524^{+0.050}_{-0.030}$$

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

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

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

Asymmetry parameters [g]

$$\begin{aligned}
 A_e &= 0.1515 \pm 0.0019 \\
 A_\mu &= 0.142 \pm 0.015 \\
 A_\tau &= 0.143 \pm 0.004 \\
 A_s &= 0.90 \pm 0.09 \\
 A_c &= 0.670 \pm 0.027 \\
 A_b &= 0.923 \pm 0.020
 \end{aligned}$$

Charge asymmetry (%) at Z pole

$$\begin{aligned}
 A_{FB}^{(0\ell)} &= 1.71 \pm 0.10 \\
 A_{FB}^{(0u)} &= 4 \pm 7 \\
 A_{FB}^{(0s)} &= 9.8 \pm 1.1 \\
 A_{FB}^{(0c)} &= 7.07 \pm 0.35 \\
 A_{FB}^{(0b)} &= 9.92 \pm 0.16
 \end{aligned}$$

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
$\tau^+ \tau^-$	(3.367 \pm 0.008) %		45559
$\ell^+ \ell^-$	[b] (3.3658 \pm 0.0023) %		—
invisible	(20.00 \pm 0.06) %		—
hadrons	(69.91 \pm 0.06) %		—
$(u\bar{u} + c\bar{c})/2$	(11.6 \pm 0.6) %		—
$(d\bar{d} + s\bar{s} + b\bar{b})/3$	(15.6 \pm 0.4) %		—
$c\bar{c}$	(12.03 \pm 0.21) %		—
$b\bar{b}$	(15.12 \pm 0.05) %		—
$b\bar{b}b\bar{b}$	(3.6 \pm 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
$\pi^\pm W^\mp$	[h] < 7	$\times 10^{-5}$ CL=95%	10150
$\rho^\pm W^\mp$	[h] < 8.3	$\times 10^{-5}$ CL=95%	10124
$J/\psi(1S)X$	(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%	—	
$(D^0/\bar{D}^0) X$		(20.7 ± 2.0)	%	—	
$D^\pm X$		(12.2 ± 1.7)	%	—	
$D^*(2010)^\pm X$	[h]	(11.4 ± 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		—	
$B^+ X$	[i]	(6.08 ± 0.13)	%	—	
$B_s^0 X$	[i]	(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	[i]	(1.38 ± 0.22)	%	—	
anomalous γ + hadrons	[j]	< 3.2	$\times 10^{-3}$ CL=95%	—	
$e^+ e^- \gamma$	[j]	< 5.2	$\times 10^{-4}$ CL=95%	45594	
$\mu^+ \mu^- \gamma$	[j]	< 5.6	$\times 10^{-4}$ CL=95%	45594	
$\tau^+ \tau^- \gamma$	[j]	< 7.3	$\times 10^{-4}$ CL=95%	45559	
$l^+ l^- \gamma \gamma$	[k]	< 6.8	$\times 10^{-6}$ CL=95%	—	
$q\bar{q}\gamma\gamma$	[k]	< 5.5	$\times 10^{-6}$ CL=95%	—	
$\nu\bar{\nu}\gamma\gamma$	[k]	< 3.1	$\times 10^{-6}$ CL=95%	45594	
$e^\pm \mu^\mp$	LF	[h]	< 1.7	$\times 10^{-6}$ CL=95%	45594
$e^\pm \tau^\mp$	LF	[h]	< 9.8	$\times 10^{-6}$ CL=95%	45576
$\mu^\pm \tau^\mp$	LF	[h]	< 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	

Higgs Bosons — H^0 and H^\pm , Searches for

The limits for H_1^0 and A_0 refer to the m_h^{\max} benchmark scenario for the supersymmetric parameters.

H^0 Mass $m > 114.4$ GeV, CL = 95%

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 [1]

Mass $m > 93.4$ GeV, CL = 95% $\tan\beta > 0.4$

H^\pm Mass $m > 79.3$ GeV, CL = 95%

See the Particle Listings for a Note giving details of Higgs Bosons.

Heavy Bosons Other Than Higgs Bosons, Searches for

Additional W Bosons

W' with standard couplings decaying to $e\nu$

Mass $m > 1.000 \times 10^3$ GeV, CL = 95%

Additional Z Bosons

Z'_{SM} with standard couplings

Mass $m > 1.030 \times 10^3$ GeV, CL = 95% ($p\bar{p}$ direct search)

Mass $m > 1500$ 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% ($p\bar{p}$ direct search)

Mass $m > 998$ 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 $m > 892$ GeV, CL = 95% ($p\bar{p}$ direct search)

Mass $m > 781$ 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 $m > 878$ GeV, CL = 95% ($p\bar{p}$ direct search)

Mass $m > 475$ 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 $m > 904$ GeV, CL = 95% ($p\bar{p}$ direct search)

Mass $m > 619$ GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m > 299$ GeV, CL = 95% (1st generation, pair prod.)

Mass $m > 298$ GeV, CL = 95% (1st gener., single prod.)

Mass $m > 316$ GeV, CL = 95% (2nd gener., pair prod.)

Mass $m > 73$ GeV, CL = 95% (2nd gener., single prod.)

Mass $m > 229$ GeV, CL = 95% (3rd gener., pair prod.)

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

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] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [i] 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 (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009/#FRACZ).
- [j] See the Z Particle Listings for the γ energy range used in this measurement.
- [k] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.
- [l] The limits assume no invisible decays.