GAUGE AND HIGGS BOSONS

γ

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

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 5 \times 10^{-30}$ 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 $= \pm 1$ e
Mass $m = 80.398 \pm 0.025$ GeV
$m_Z - m_W = 10.4 \pm 1.6$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.141 \pm 0.041$ GeV
$\left\langle N_{\pi^\pm} \right\rangle = 15.70 \pm 0.35$
$\left\langle N_{K^\pm} \right\rangle = 2.20 \pm 0.19$
$\left\langle N_p \right\rangle = 0.92 \pm 0.14$
$\left\langle N_{\text{charged}} \right\rangle = 19.39 \pm 0.08$

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 ± 0.09) %		−
$e^+ \nu$		(10.75 ± 0.13) %		40199
$\mu^+ \nu$		(10.57 ± 0.15) %		40199
$\tau^+ \nu$		(11.25 ± 0.20) %		40179
hadrons		(67.60 ± 0.27) %		−
$\pi^+ \gamma$		$< 8 \times 10^{-5}$	95%	40199
$D_s^+ \gamma$		$< 1.3 \times 10^{-3}$	95%	40175
$c X$		(33.4 ± 2.6) %		−
$c\bar{s}$		$(31 \, {}^{+13}_{-11})$ %		−
invisible	[c]	(1.4 ± 2.8) %		−

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

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

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

Couplings to leptons

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

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

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

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

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

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) %			—
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%	—
$\pi^0 \gamma$		< 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%	10125
$J/\psi(1S)X$		(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) %			—

$D^*(2010)^\pm X$		[h]	(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			$-$
$B^+ X$			(6.10	± 0.14	) %	$-$
$B_s^0 X$			(1.56	± 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			(1.38	± 0.22	) %	$-$
anomalous $\gamma +$ hadrons		[i] $<$	3.2		$\times 10^{-3}$ CL=95%	$-$
$e^+ e^- \gamma$		[i] $<$	5.2		$\times 10^{-4}$ CL=95%	45594
$\mu^+ \mu^- \gamma$		[i] $<$	5.6		$\times 10^{-4}$ CL=95%	45594
$\tau^+ \tau^- \gamma$		[i] $<$	7.3		$\times 10^{-4}$ CL=95%	45559
$\ell^+ \ell^- \gamma\gamma$		[j] $<$	6.8		$\times 10^{-6}$ CL=95%	$-$
$q\bar{q}\gamma\gamma$		[j] $<$	5.5		$\times 10^{-6}$ CL=95%	$-$
$\nu\bar{\nu}\gamma\gamma$		[j] $<$	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 [k]

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 $= 95\%$
W_R — right-handed W
   Mass $m > 715$ GeV, CL $= 90\%$ (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings
   Mass $m > 923$ GeV, CL $= 95\%$ ($p\overline{p}$ 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 $= 95\%$ ($p\overline{p}$ direct search)
   Mass $m > 860$ 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 $m > 822$ GeV, CL $= 95\%$ ($p\overline{p}$ 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 $m > 822$ GeV, CL $= 95\%$ ($p\overline{p}$ 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 $m > 891$ GeV, CL $= 95\%$ ($p\overline{p}$ direct search)
   Mass $m > 619$ GeV, CL $= 95\%$ (electroweak fit)

Scalar Leptoquarks

Mass $m > 256$ GeV, CL $= 95\%$ (1st generation, pair prod.)
Mass $m > 298$ GeV, CL $= 95\%$ (1st gener., single prod.)
Mass $m > 251$ 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 $\nu\overline{\nu}$ 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] The value is for the sum of the charge states or particle/antiparticle states indicated.

[i] See the Z Particle Listings for the γ energy range used in this measurement.

[j] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

[k] The limits assume no invisible decays.