GAUGE AND HIGGS BOSONS

γ

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

Mass $m < 6 \times 10^{-16}$ eV, CL = 99.7%
Charge $q < 5 \times 10^{-30}$ e
Mean life τ = Stable

g or gluon

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

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

W

$J = 1$

Charge = ± 1 e
Mass $m = 80.33 \pm 0.15$ GeV
$m_Z - m_W = 10.85 \pm 0.15$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.07 \pm 0.06$ GeV

W^- modes are charge conjugates of the modes below.

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+\nu$	[b]	(10.8 ± 0.4) %		40110
$e^+\nu$		(10.8 ± 0.4) %		40110
$\mu^+\nu$		(10.4 ± 0.6) %		40110
$\tau^+\nu$		(10.9 ± 1.0) %		40110
hadrons		(67.9 ± 1.5) %		–
$\pi^+\gamma$		$< 5 \times 10^{-4}$	95%	40110

Z

$J = 1$

Charge = 0
Mass $m = 91.187 \pm 0.007$ GeV [c]
Full width $\Gamma = 2.490 \pm 0.007$ GeV
$\Gamma(\ell^+\ell^-) = 83.83 \pm 0.27$ MeV [b]
$\Gamma(\text{invisible}) = 498.3 \pm 4.2$ MeV [d]
$\Gamma(\text{hadrons}) = 1740.7 \pm 5.9$ MeV
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.000 \pm 0.005$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 0.998 \pm 0.005$ [e]

Average charged multiplicity

$\langle N_{charged} \rangle = 20.99 \pm 0.14$

Couplings to leptons

$g_V^{\ell} = -0.0376 \pm 0.0012$
$g_A^{\ell} = -0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [f]

$A_e = 0.156 \pm 0.008$ (S = 1.2)
$A_\tau = 0.145 \pm 0.009$
$A_c = 0.59 \pm 0.19$
$A_b = 0.89 \pm 0.11$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.59 \pm 0.18$
$A_{FB}^{(0s)} = 13 \pm 4$
$A_{FB}^{(0c)} = 7.22 \pm 0.67$
$A_{FB}^{(0b)} = 9.92 \pm 0.35$

Z DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^+ e^-$		(3.366±0.008) %		45600
$\mu^+ \mu^-$		(3.367±0.013) %		45600
$\tau^+ \tau^-$		(3.360±0.015) %		45600
$\ell^+ \ell^-$	[b]	(3.366±0.006) %		45600
invisible		(20.01 ±0.16) %		–
hadrons		(69.90 ±0.15) %		–
$(u\overline{u}+c\overline{c})/2$		(9.6 ±1.3) %		–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(16.9 ±0.9) %		–
$c\overline{c}$		(11.0 ±0.7) %		–
$b\overline{b}$		(15.46 ±0.14) %		–
$\pi^0 \gamma$		$< 5.2 \times 10^{-5}$	95%	45600
$\eta \gamma$		$< 5.1 \times 10^{-5}$	95%	45600
$\omega \gamma$		$< 6.5 \times 10^{-4}$	95%	45600
$\eta'(958) \gamma$		$< 4.2 \times 10^{-5}$	95%	45600
$\gamma \gamma$		$< 5.2 \times 10^{-5}$	95%	45600
$\gamma \gamma \gamma$		$< 1.0 \times 10^{-5}$	95%	45600
$\pi^\pm W^\mp$	[g]	$< 7 \times 10^{-5}$	95%	10300
$\rho^\pm W^\mp$	[g]	$< 8.3 \times 10^{-5}$	95%	10300

$J/\psi(1S)X$			$(3.80 \pm 0.27) \times 10^{-3}$				–
$\psi(2S)X$			$(1.60 \pm 0.33) \times 10^{-3}$				–
$\chi_{c1}(1P)X$			$(6.0 \pm 1.9) \times 10^{-3}$				–
ΥX			$(1.0 \pm 0.5) \times 10^{-4}$				–
$(D^0/\overline{D}^0)$ X			(20.7 ± 2.0) %				–
$D^{\pm}X$			(12.2 ± 1.7) %				–
$D^*(2010)^{\pm}X$		[g]	(11.4 ± 1.3) %				–
B_s^0X			seen				–
anomalous $\gamma+$ hadrons		[h]	$<$ 3.2		$\times 10^{-3}$	95%	–
$e^+e^-\gamma$		[h]	$<$ 5.2		$\times 10^{-4}$	95%	45600
$\mu^+\mu^-\gamma$		[h]	$<$ 5.6		$\times 10^{-4}$	95%	45600
$\tau^+\tau^-\gamma$		[h]	$<$ 7.3		$\times 10^{-4}$	95%	45600
$\ell^+\ell^-\gamma\gamma$		[i]	$<$ 6.8		$\times 10^{-6}$	95%	45600
$q\overline{q}\gamma\gamma$		[i]	$<$ 5.5		$\times 10^{-6}$	95%	–
$\nu\overline{\nu}\gamma\gamma$		[i]	$<$ 3.1		$\times 10^{-6}$	95%	45600
$e^{\pm}\mu^{\mp}$	*LF*	[g]	$<$ 1.7		$\times 10^{-6}$	95%	45600
$e^{\pm}\tau^{\mp}$	*LF*	[g]	$<$ 9.8		$\times 10^{-6}$	95%	45600
$\mu^{\pm}\tau^{\mp}$	*LF*	[g]	$<$ 1.7		$\times 10^{-5}$	95%	45600

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

H^0 Mass $m >$ 58.4 GeV, CL = 95%

H_1^0 in Supersymmetric Models ($m_{H_1^0} < m_{H_2^0}$) [j]

Mass $m >$ 44 GeV, CL = 95%

A^0 Pseudoscalar Higgs Boson in Supersymmetric Models [j]

Mass $m >$ 24.3 GeV, CL = 95% $\tan\beta > 1$, $m_t < 200$ GeV

$H^{\pm}$ Mass $m >$ 43.5 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_R — right-handed W
Mass $m >$ 406 GeV, CL = 90%
(assuming light right-handed neutrino)

W' with standard couplings decaying to $e\nu$, $\mu\nu$
Mass $m >$ 652 GeV, CL = 95%

Additional Z Bosons

Z'_{SM} with standard couplings
Mass $m >$ 505 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 779 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 $m >$ 445 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 389 GeV, CL = 95% (electroweak fit)

Z_χ of $\mathrm{SO}(10) \rightarrow \mathrm{SU}(5) \times \mathrm{U}(1)_\chi$
(coupling constant derived from G.U.T.)
Mass $m >$ 425 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 321 GeV, CL = 95% (electroweak fit)

Z_ψ of $E_6 \rightarrow \mathrm{SO}(10) \times \mathrm{U}(1)_\psi$
(coupling constant derived from G.U.T.)
Mass $m >$ 415 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 160 GeV, CL = 95% (electroweak fit)

Z_η of $E_6 \rightarrow \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1) \times \mathrm{U}(1)_\eta$
(coupling constant derived from G.U.T.);
charges are $Q_\eta = \sqrt{3/8}Q_\chi - \sqrt{5/8}Q_\psi$)
Mass $m >$ 440 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 182 GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m >$ 116 GeV, CL = 95% (1st generation, pair prod.)
Mass $m >$ 230 GeV, CL = 95% (1st gener., single prod.)
Mass $m >$ 97 GeV, CL = 95% (2nd gener., pair prod.)
Mass $m >$ 73 GeV, CL = 95% (2nd gener., single prod.)
Mass $m >$ 45 GeV, CL = 95% (3rd gener., pair prod.)
(The second, fourth, and fifth limits above are for charge $-1/3$, weak isoscalar.)

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*] 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.

[*d*] This partial width takes into account Z decays into $\nu\overline{\nu}$ and any other possible undetected modes.

[*e*] This ratio has not been corrected for the τ mass.

[*f*] Here $A \equiv 2 g_V g_A / (g_V^2 + g_A^2)$.

[*g*] The value is for the sum of the charge states of particle/antiparticle states indicated.

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

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

[*j*] The limits assume no invisible decays.