GAUGE AND HIGGS BOSONS

γ

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

Mass $m < 6 \times 10^{-17}$ eV
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 $= \pm 1$ e
Mass $m = 80.403 \pm 0.029$ GeV
$m_Z - m_W = 10.785 \pm 0.029$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.141 \pm 0.041$ GeV
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_{p} \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.41 \pm 0.15$

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) %		40201
$\mu^+ \nu$		(10.57 ± 0.15) %		40201
$\tau^+ \nu$		(11.25 ± 0.20) %		40182
hadrons		(67.60 ± 0.27) %		–
$\pi^+ \gamma$		$< 8 \times 10^{-5}$	95%	40201
$D_s^+ \gamma$		$< 1.3 \times 10^{-3}$	95%	40177
$c X$		(33.4 ± 2.6) %		–
$c \bar{s}$		$(31 {}^{+13}_{-11})$ %		–
invisible	[c]	(1.4 ± 2.8) %		–

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 leptons

$g^{\ell}_{V} = -0.03783 \pm 0.00041$
$g^{\ell}_{A} = -0.50123 \pm 0.00026$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

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

$A^{(0\ell)}_{FB} = 1.71 \pm 0.10$
$A^{(0u)}_{FB} = 4 \pm 7$
$A^{(0s)}_{FB} = 9.8 \pm 1.1$
$A^{(0c)}_{FB} = 7.07 \pm 0.35$
$A^{(0b)}_{FB} = 9.92 \pm 0.16$

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) %		–
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) $\times 10^{-4}$		–
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%	10146
$\rho^\pm W^\mp$	[h]	< 8.3 $\times 10^{-5}$	CL=95%	10120
$J/\psi(1S)$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 ±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		(6.03 ±0.15) %		–
B^0_sX		(1.55 ±0.13) %		–
B^+_cX		searched for		–
Λ^+_cX		(1.54 ±0.33) %		–
b-baryon X		(1.51 ±0.26) %		–
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%	–
$q\overline{q}\gamma\gamma$		[j] <	5.5	$\times 10^{-6}$	CL=95%	–
$\nu\overline{\nu}\gamma\gamma$		[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
$p e$	*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

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

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

Mass $m >$ 89.8 GeV, CL = 95%

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

Mass $m >$ 90.4 GeV, CL = 95% tanβ >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 $e\nu$, $\mu\nu$

Mass $m >$ 800 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 $m >$ 825 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 1500 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 $m >$ 860 GeV, CL = 95% (electroweak fit)

Z_χ of SO(10) $\to$ $\mathrm{SU(5)} \times \mathrm{U(1)}_\chi$ (with $g_\chi = e/\cos\theta_W$)
Mass $m >$ 690 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 781 GeV, CL = 95% (electroweak fit)

Z_ψ of E_6 $\to$ $\mathrm{SO(10)} \times \mathrm{U(1)}_\psi$ (with $g_\psi = e/\cos\theta_W$)
Mass $m >$ 675 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 366 GeV, CL = 95% (electroweak fit)

Z_η of E_6 $\to$ $\mathrm{SU(3)} \times \mathrm{SU(2)} \times \mathrm{U(1)} \times \mathrm{U(1)}_\eta$ (with $g_\eta = e/\cos\theta_W$)
Mass $m >$ 720 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 $m >$ 202 GeV, CL = 95% (2nd gener., pair prod.)
Mass $m >$ 73 GeV, CL = 95% (2nd gener., single prod.)
Mass $m >$ 148 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.