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 $m = 80.425 \pm 0.038$ GeV
$m_Z - m_W = 10.763 \pm 0.038$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.124 \pm 0.041$ 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]	(10.68 ± 0.12) %		–
$e^+ \nu$		(10.72 ± 0.16) %		40212
$\mu^+ \nu$		(10.57 ± 0.22) %		40212
$\tau^+ \nu$		(10.74 ± 0.27) %		40193
hadrons		(67.96 ± 0.35) %		–
$\pi^+ \gamma$		$< 8 \times 10^{-5}$	95%	40212
$D_s^+ \gamma$		$< 1.3 \times 10^{-3}$	95%	40188
cX		(33.6 ± 2.7) %		–
$c\overline{s}$		$(31\ ^{+13}_{-11}\ )$ %		–
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

$\langle N_{charged} \rangle = 21.07 \pm 0.11$

Couplings to leptons

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

Asymmetry parameters [g]

$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.666 \pm 0.036$
$A_b = 0.926 \pm 0.024$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.04 \pm 0.36$
$A_{FB}^{(0b)} = 10.01 \pm 0.17$

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) %		–

$(u\overline{u}+c\overline{c})/2$			(10.1	± 1.1	) %			–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$			(16.6	± 0.6	) %			–
$c\overline{c}$			(11.81	± 0.33	) %			–
$b\overline{b}$			(15.13	± 0.05	) %			–
$b\overline{b}\,b\overline{b}$			(3.6	± 1.3	) $\times 10^{-4}$			–
$g\,g\,g$			$<$ 1.1		%		CL=95%	–
$\pi^0\gamma$			$<$ 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%	10127
$\rho^\pm W^\mp$		[h]	$<$ 8.3		$\times 10^{-5}$		CL=95%	10101
$J/\psi(1S)$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_s^0X			seen					–
B_c^+X			searched for					–
anomalous γ + 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
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

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% $\quad \tan\beta > 1$

$H^{\pm}$ 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 $m >$ 786 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 $m >$ 690 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 $m >$ 595 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 680 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 $m >$ 590 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 350 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 $m >$ 620 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 619 GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m >$ 242 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.