GAUGE AND HIGGS BOSONS

γ

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

Mass $m < 2 \times 10^{-16}$ 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 $m = 80.423 \pm 0.039$ GeV
$m_Z - m_W = 10.764 \pm 0.039$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.118 \pm 0.042$ GeV
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_p \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.41 \pm 0.15$

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) %		40211
$\tau^+ \nu$		(10.74 ± 0.27) %		40192
hadrons		(67.96 ± 0.35) %		–
$\pi^+ \gamma$		$< 8 \times 10^{-5}$	95%	40211
$D_s^+ \gamma$		$< 1.3 \times 10^{-3}$	95%	40187
$c X$		(33.6 ± 2.7) %		–
$c \bar{s}$		$(31 {}^{+13}_{-11})$ %		–
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

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

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]

$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.666 \pm 0.036$
$A_b = 0.928 \pm 0.031$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.16 \pm 0.36$
$A_{FB}^{(0b)} = 10.02 \pm 0.19$

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) %			–
$c\overline{c}$			(11.76 ± 0.33) %			–
$b\overline{b}$			(15.14 ± 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%	10128
$\rho^{\pm}W^{\mp}$		[h]	$< 8.3 \times 10^{-5}$		CL=95%	10103
$J/\psi(1S)X$			$(3.51 {}^{+0.23}_{-0.25}) \times 10^{-3}$	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 ± 2.0) %			–
$D^{\pm}X$			(12.2 ± 1.7) %			–
$D^*(2010)^{\pm}X$		[h]	(11.4 ± 1.3) %			–
$D^{*\prime}(2629)^{\pm}X$			searched for			–
B^0_sX			seen			–
B^+_cX			searched for			–
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
pe	*L,B*		$< 1.8 \times 10^{-6}$		CL=95%	–
$p\mu$	*L,B*		$< 1.8 \times 10^{-6}$		CL=95%	–

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

H^0 Mass $m >$ 114.3 GeV, CL = 95%

H^0_1 in Supersymmetric Models ($m_{H^0_1} < m_{H^0_2}$)

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

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

Mass $m >$ 90.1 GeV, CL = 95% $\tan\beta > 1$

$H^{\pm}$ Mass $m >$ 71.5 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' 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 $m >$ 290 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.