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

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g or gluon

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

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

W

$J = 1$

Charge $= \pm 1$ e
Mass $m = 80.41 \pm 0.10$ GeV
$m_Z - m_W = 10.78 \pm 0.10$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.06 \pm 0.06$ 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]	(10.74±0.33) %		–
$e^+ \nu$		(10.9 ±0.4) %		40205
$\mu^+ \nu$		(10.2 ±0.5) %		40205
$\tau^+ \nu$		(11.3 ±0.8) %		40185
hadrons		(67.8 ±1.0) %		–
$\pi^+ \gamma$		$< 2.2 \times 10^{-4}$	95%	40205

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

$\langle N_{charged} \rangle = 21.00 \pm 0.13$

Couplings to leptons

$g_V^\ell = -0.0377 \pm 0.0007$
$g_A^\ell = -0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [f]

$A_e = 0.1519 \pm 0.0034$
$A_\mu = 0.102 \pm 0.034$
$A_\tau = 0.143 \pm 0.008$
$A_c = 0.59 \pm 0.19$
$A_b = 0.89 \pm 0.11$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.59 \pm 0.18$
$A_{FB}^{(0u)} = 4.0 \pm 7.3$
$A_{FB}^{(0s)} = 9.9 \pm 3.1 \quad (S = 1.2)$
$A_{FB}^{(0c)} = 7.32 \pm 0.58$
$A_{FB}^{(0b)} = 10.02 \pm 0.28$

Z DECAY MODES			Fraction (Γ_i/Γ)		Confidence level	(p MeV/c)
$e^+ e^-$			(3.366 ± 0.008) %			45594
$\mu^+ \mu^-$			(3.367 ± 0.013) %			45593
$\tau^+ \tau^-$			(3.360 ± 0.015) %			45559
$\ell^+ \ell^-$		[b]	(3.366 ± 0.006) %			–
invisible			(20.01 ± 0.16) %			–
hadrons			(69.90 ± 0.15) %			–
$(u\overline{u}+c\overline{c})/2$			(10.1 ± 1.1) %			–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$			(16.6 ± 0.6) %			–
$c\overline{c}$			(12.4 ± 0.6) %			–
$b\overline{b}$			(15.16 ± 0.09) %			–
$g\,g\,g$			< 1.1	%	95%	–
$\pi^0\gamma$			< 5.2	$\times 10^{-5}$	95%	45593
$\eta\gamma$			< 5.1	$\times 10^{-5}$	95%	45592
$\omega\gamma$			< 6.5	$\times 10^{-4}$	95%	45590
$\eta'(958)\gamma$			< 4.2	$\times 10^{-5}$	95%	45588
$\gamma\gamma$			< 5.2	$\times 10^{-5}$	95%	45594
$\gamma\gamma\gamma$			< 1.0	$\times 10^{-5}$	95%	45594
$\pi^\pm W^\mp$		[g]	< 7	$\times 10^{-5}$	95%	10139
$\rho^\pm W^\mp$		[g]	< 8.3	$\times 10^{-5}$	95%	10114
$J/\psi(1S)$X			(3.66 ± 0.23)	$\times 10^{-3}$		–
$\psi(2S)$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	$\times 10^{-3}$	90%	–
$\Upsilon(1S)$ X + $\Upsilon(2S)$ X + $\Upsilon(3S)$ X			(1.0 ± 0.5)	$\times 10^{-4}$		–
$\Upsilon(1S)$X			< 5.5	$\times 10^{-5}$	95%	–
$\Upsilon(2S)$X			< 1.39	$\times 10^{-4}$	95%	–
$\Upsilon(3S)$X			< 9.4	$\times 10^{-5}$	95%	–
$(D^0/\overline{D}^0)$ 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 γ + hadrons		[h]	< 3.2	$\times 10^{-3}$	95%	–
$e^+ e^- \gamma$		[h]	< 5.2	$\times 10^{-4}$	95%	45594
$\mu^+ \mu^- \gamma$		[h]	< 5.6	$\times 10^{-4}$	95%	45593
$\tau^+ \tau^- \gamma$		[h]	< 7.3	$\times 10^{-4}$	95%	45559
$\ell^+ \ell^- \gamma\gamma$		[i]	< 6.8	$\times 10^{-6}$	95%	–
$q\overline{q}\gamma\gamma$		[i]	< 5.5	$\times 10^{-6}$	95%	–
$\nu\overline{\nu}\gamma\gamma$		[i]	< 3.1	$\times 10^{-6}$	95%	45594
$e^\pm \mu^\mp$	*LF*	[g]	< 1.7	$\times 10^{-6}$	95%	45593
$e^\pm \tau^\mp$	*LF*	[g]	< 9.8	$\times 10^{-6}$	95%	45576
$\mu^\pm \tau^\mp$	*LF*	[g]	< 1.2	$\times 10^{-5}$	95%	45576

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

H^0 Mass $m >$ 77.5 GeV, CL = 95%

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

Mass $m >$ 62.5 GeV, CL = 95%

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

Mass $m >$ 62.5 GeV, CL = 95% $\quad \tan\beta > 1$

$H^\pm$ Mass $m >$ 54.5 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 $m >$ 549 GeV
(assuming light right-handed neutrino)

W' with standard couplings decaying to $e\nu$, $\mu\nu$
Mass $m >$ 720 GeV, CL = 95%

Additional *Z* Bosons

$Z'_{\rm SM}$ with standard couplings
Mass $m >$ 690 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 779 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 $m >$ 389 GeV, CL = 95% (electroweak fit)

Z_χ of $SO(10) \rightarrow SU(5) \times U(1)_\chi$
(coupling constant derived from G.U.T.)
Mass $m >$ 595 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 321 GeV, CL = 95% (electroweak fit)

Z_ψ of $E_6 \rightarrow SO(10) \times U(1)_\psi$
(coupling constant derived from G.U.T.)
Mass $m >$ 590 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 160 GeV, CL = 95% (electroweak fit)

Z_η of $E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_\eta$
(coupling constant derived from G.U.T.);
charges are $Q_\eta = \sqrt{3/8}Q_\chi - \sqrt{5/8}Q_\psi$)
Mass $m >$ 620 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 182 GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m >$ 225 GeV, CL = 95% (1st generation, pair prod.)
Mass $m >$ 237 GeV, CL = 95% (1st gener., single prod.)
Mass $m >$ 119 GeV, CL = 95% (2nd gener., pair prod.)
Mass $m >$ 73 GeV, CL = 95% (2nd gener., single prod.)
Mass $m >$ 99 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*] 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 $A \equiv 2g_V g_A/(g_V^2+g_A^2)$.

[*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.