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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 $m = 80.419 \pm 0.056$ GeV
$m_Z - m_W = 10.76 \pm 0.05$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.12 \pm 0.05$ GeV
$\langle N_{charged} \rangle = 19.3 \pm 0.4$

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

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+ \nu$	[b]	(10.56 ± 0.14) %		–
$e^+ \nu$		(10.66 ± 0.20) %		40205
$\mu^+ \nu$		(10.49 ± 0.29) %		40205
$\tau^+ \nu$		(10.4 ± 0.4) %		40185
hadrons		(68.5 ± 0.6) %		–
$\pi^+ \gamma$		$< 7 \times 10^{-5}$	95%	40205
$D_s^+ \gamma$		$< 1.3 \times 10^{-3}$	95%	–
cX		(35 ± 4) %		–
$c\overline{s}$		$(32\ ^{+13}_{-11})$ %		–
invisible	[c]	(1.4 ± 2.8) %		–

Z

$J = 1$

Charge = 0
Mass $m = 91.1882 \pm 0.0022$ GeV [d]
Full width $\Gamma = 2.4952 \pm 0.0026$ GeV
$\Gamma(\ell^+\ell^-) = 84.057 \pm 0.099$ MeV [b]
$\Gamma(\text{invisible}) = 499.4 \pm 1.7$ MeV [e]
$\Gamma(\text{hadrons}) = 1743.8 \pm 2.2$ MeV
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 0.9999 \pm 0.0032$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0012 \pm 0.0036$ [f]

Average charged multiplicity

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

Couplings to leptons

$g_V^\ell = -0.03795 \pm 0.00071$
$g_A^\ell = -0.50145 \pm 0.00030$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [g]

$A_e = 0.152 \pm 0.004$ (S = 1.2)
$A_\mu = 0.102 \pm 0.034$
$A_\tau = 0.141 \pm 0.006$
$A_c = 0.66 \pm 0.11$
$A_b = 0.91 \pm 0.05$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.82 \pm 0.11$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.01 \pm 0.45$
$A_{FB}^{(0b)} = 10.03 \pm 0.22$

Z DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
e^+e^-		(3.367 ±0.005) %		45594
$\mu^+\mu^-$		(3.367 ±0.008) %		45593
$\tau^+\tau^-$		(3.371 ±0.009) %		45559
$\ell^+\ell^-$	[b]	(3.3688±0.0026) %		–
invisible		(20.02 ±0.06) %		–
hadrons		(69.89 ±0.07) %		–
$(u\overline{u}+c\overline{c})/2$		(10.1 ±1.1) %		–

$(d\overline{d}+s\overline{s}+b\overline{b})/3$			(16.6	$\pm$0.6	) %		–
$c\overline{c}$			(11.68	$\pm$0.34	) %		–
$b\overline{b}$			(15.13	$\pm$0.05	) %		–
$b\overline{b}\,b\overline{b}$			(4.2	$\pm$1.6	) $\times 10^{-4}$		–
$g\,g\,g$		<	1.1		%	CL=95%	–
$\pi^0\,\gamma$		<	5.2		$\times 10^{-5}$	CL=95%	45593
$\eta\,\gamma$		<	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%	45588
$\gamma\,\gamma$		<	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%	10139
$\rho^\pm\,W^\mp$		[h] <	8.3		$\times 10^{-5}$	CL=95%	10114
$J/\psi(1S)$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	$\pm$2.0	) %		–
$D^\pm$X			(12.2	$\pm$1.7	) %		–
$D^*(2010)^\pm$X		[h]	(11.4	$\pm$1.3	) %		–
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%	45593
$\tau^+\,\tau^-\,\gamma$		[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%	45593
$e^\pm\,\tau^\mp$	*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%	–
$p\,\mu$	*L,B*	<	1.8		$\times 10^{-6}$	CL=95%	–

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

H^0 Mass $m >$ 95.3 GeV, CL = 95%

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

Mass $m >$ 82.6 GeV, CL = 95%

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

Mass $m >$ 84.1 GeV, CL = 95% $\tan\beta > 1$

$H^\pm$ Mass $m >$ 69.0 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 $m >$ 715 GeV, CL = 90% (electroweak fit)

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 $m >$ 898 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 $m >$ 564 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 $m >$ 545 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 $m >$ 294 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 $m >$ 365 GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m >$ 225 GeV, CL = 95% (1st generation, pair prod.)
Mass $m >$ 200 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 $m >$ 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*] 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.