

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 $\tau = \text{Stable}$

g

or gluon

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

Mass $m = 0$ [a]

SU(3) color octet

W

$$J = 1$$

Charge = ± 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] $(10.68 \pm 0.12) \%$		—
$e^+ \nu$	$(10.72 \pm 0.16) \%$		40212
$\mu^+ \nu$	$(10.57 \pm 0.22) \%$		40211
$\tau^+ \nu$	$(10.74 \pm 0.27) \%$		40192
hadrons	$(67.96 \pm 0.35) \%$		—
$\pi^+ \gamma$	< 8	$\times 10^{-5}$	95% 40211
$D_s^+ \gamma$	< 1.3	$\times 10^{-3}$	95% 40187
cX	$(33.6 \pm 2.7) \%$		—
$c\bar{s}$	$(31^{+13}_{-11}) \%$		—
invisible	[c] $(1.4 \pm 2.8) \%$		—



$$J = 1$$

$$\text{Charge} = 0$$

$$\text{Mass } m = 91.1876 \pm 0.0021 \text{ GeV } [d]$$

$$\text{Full width } \Gamma = 2.4952 \pm 0.0023 \text{ GeV}$$

$$\Gamma(\ell^+ \ell^-) = 83.984 \pm 0.086 \text{ MeV } [b]$$

$$\Gamma(\text{invisible}) = 499.0 \pm 1.5 \text{ MeV } [e]$$

$$\Gamma(\text{hadrons}) = 1744.4 \pm 2.0 \text{ MeV}$$

$$\Gamma(\mu^+ \mu^-) / \Gamma(e^+ e^-) = 1.0009 \pm 0.0028$$

$$\Gamma(\tau^+ \tau^-) / \Gamma(e^+ e^-) = 1.0019 \pm 0.0032 [f]$$

Average charged multiplicity

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

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

$$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$$

$$A_{FB}^{(0\mu)} = 4 \pm 7$$

$$A_{FB}^{(0s)} = 9.8 \pm 1.1$$

$$A_{FB}^{(0c)} = 7.16 \pm 0.36$$

$$A_{FB}^{(0b)} = 10.02 \pm 0.19$$

Z DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$e^+ e^-$	(3.363 \pm 0.004) %		45594
$\mu^+ \mu^-$	(3.366 \pm 0.007) %		45594
$\tau^+ \tau^-$	(3.370 \pm 0.008) %		45559
$\ell^+ \ell^-$	[b] (3.3658 \pm 0.0023) %		—
invisible	(20.00 \pm 0.06) %		—
hadrons	(69.91 \pm 0.06) %		—

$(u\bar{u} + c\bar{c})/2$	(10.1 ±1.1) %		—
$(d\bar{d} + s\bar{s} + b\bar{b})/3$	(16.6 ±0.6) %		—
$c\bar{c}$	(11.76 ±0.33) %		—
$b\bar{b}$	(15.14 ±0.05) %		—
$b\bar{b}b\bar{b}$	(3.6 ±1.3) × 10 ⁻⁴		—
ggg	< 1.1	%	CL=95% —
$\pi^0\gamma$	< 5.2	× 10 ⁻⁵	CL=95% 45594
$\eta\gamma$	< 5.1	× 10 ⁻⁵	CL=95% 45592
$\omega\gamma$	< 6.5	× 10 ⁻⁴	CL=95% 45590
$\eta'(958)\gamma$	< 4.2	× 10 ⁻⁵	CL=95% 45589
$\gamma\gamma$	< 5.2	× 10 ⁻⁵	CL=95% 45594
$\gamma\gamma\gamma$	< 1.0	× 10 ⁻⁵	CL=95% 45594
$\pi^\pm W^\mp$	[<i>h</i>] < 7	× 10 ⁻⁵	CL=95% 10128
$\rho^\pm W^\mp$	[<i>h</i>] < 8.3	× 10 ⁻⁵	CL=95% 10103
$J/\psi(1S)X$	(3.51 ^{+0.23} _{-0.25}) × 10 ⁻³	S=1.1	—
$\psi(2S)X$	(1.60 ±0.29) × 10 ⁻³		—
$\chi_{c1}(1P)X$	(2.9 ±0.7) × 10 ⁻³		—
$\chi_{c2}(1P)X$	< 3.2	× 10 ⁻³	CL=90% —
$\Upsilon(1S)X + \Upsilon(2S)X$ + $\Upsilon(3S)X$	(1.0 ±0.5) × 10 ⁻⁴		—
$\Upsilon(1S)X$	< 4.4	× 10 ⁻⁵	CL=95% —
$\Upsilon(2S)X$	< 1.39	× 10 ⁻⁴	CL=95% —
$\Upsilon(3S)X$	< 9.4	× 10 ⁻⁵	CL=95% —
$(D^0/\bar{D}^0)X$	(20.7 ±2.0) %		—
$D^\pm X$	(12.2 ±1.7) %		—
$D^*(2010)^\pm X$	[<i>h</i>] (11.4 ±1.3) %		—
$D^{*'}(2629)^\pm X$	searched for		—
$B_s^0 X$	seen		—
$B_c^+ X$	searched for		—
anomalous γ + hadrons	[<i>i</i>] < 3.2	× 10 ⁻³	CL=95% —
$e^+e^-\gamma$	[<i>i</i>] < 5.2	× 10 ⁻⁴	CL=95% 45594
$\mu^+\mu^-\gamma$	[<i>i</i>] < 5.6	× 10 ⁻⁴	CL=95% 45594
$\tau^+\tau^-\gamma$	[<i>i</i>] < 7.3	× 10 ⁻⁴	CL=95% 45559
$\ell^+\ell^-\gamma\gamma$	[<i>j</i>] < 6.8	× 10 ⁻⁶	CL=95% —
$q\bar{q}\gamma\gamma$	[<i>j</i>] < 5.5	× 10 ⁻⁶	CL=95% —
$\nu\bar{\nu}\gamma\gamma$	[<i>j</i>] < 3.1	× 10 ⁻⁶	CL=95% 45594
$e^\pm\mu^\mp$	LF [<i>h</i>] < 1.7	× 10 ⁻⁶	CL=95% 45594
$e^\pm\tau^\mp$	LF [<i>h</i>] < 9.8	× 10 ⁻⁶	CL=95% 45576
$\mu^\pm\tau^\mp$	LF [<i>h</i>] < 1.2	× 10 ⁻⁵	CL=95% 45576
pe	L,B < 1.8	× 10 ⁻⁶	CL=95% —
$p\mu$	L,B < 1.8	× 10 ⁻⁶	CL=95% —

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

H^0 Mass $m > 114.3$ 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 $m > 90.1$ 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% ($p\bar{p}$ 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% ($p\bar{p}$ 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% ($p\bar{p}$ 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% ($p\bar{p}$ 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% ($p\bar{p}$ 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 $\nu\bar{\nu}$ 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.