

GAUGE AND HIGGS BOSONS

γ (photon)

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

Mass $m < 1 \times 10^{-18}$ eV

Charge $q < 1 \times 10^{-35}$ e

Mean life $\tau =$ Stable

**g
or gluon**

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

Mass $m = 0$ [a]

SU(3) color octet

graviton

$$J = 2$$

Mass $m < 6 \times 10^{-32}$ eV

W

$$J = 1$$

Charge = ± 1 e

Mass $m = 80.379 \pm 0.012$ GeV

W/Z mass ratio = 0.88153 ± 0.00017

$m_Z - m_W = 10.803 \pm 0.015$ GeV

$m_{W^+} - m_{W^-} = -0.029 \pm 0.028$ GeV

Full width $\Gamma = 2.085 \pm 0.042$ GeV

$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$

$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$

$\langle N_p \rangle = 0.92 \pm 0.14$

$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$

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

W^+ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	P (MeV/c)
$\ell^+ \nu$	[b] $(10.86 \pm 0.09) \%$		—
$e^+ \nu$	$(10.71 \pm 0.16) \%$		40189
$\mu^+ \nu$	$(10.63 \pm 0.15) \%$		40189
$\tau^+ \nu$	$(11.38 \pm 0.21) \%$		40170
hadrons	$(67.41 \pm 0.27) \%$		—

$\pi^+ \gamma$	< 7	$\times 10^{-6}$	95%	40189
$D_s^+ \gamma$	< 1.3	$\times 10^{-3}$	95%	40165
cX	$(33.3 \pm 2.6) \%$			—
$c\bar{s}$	$(31^{+13}_{-11}) \%$			—
invisible	[c] $(1.4 \pm 2.9) \%$			—

Z

$$J = 1$$

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

$$\langle N_{\text{charged}} \rangle = 20.76 \pm 0.16 \quad (S = 2.1)$$

Couplings to quarks and leptons

$$g_V^\ell = -0.03783 \pm 0.00041$$

$$g_V^u = 0.18 \pm 0.05$$

$$g_V^d = -0.35^{+0.05}_{-0.06}$$

$$g_A^\ell = -0.50123 \pm 0.00026$$

$$g_A^u = 0.50^{+0.04}_{-0.05}$$

$$g_A^d = -0.514^{+0.050}_{-0.029}$$

$$g^{\nu\ell} = 0.5008 \pm 0.0008$$

$$g^{\nu e} = 0.53 \pm 0.09$$

$$g^{\nu\mu} = 0.502 \pm 0.017$$

Asymmetry parameters [g]

$$A_e = 0.1515 \pm 0.0019$$

$$A_\mu = 0.142 \pm 0.015$$

$$A_\tau = 0.143 \pm 0.004$$

$$A_s = 0.90 \pm 0.09$$

$$A_c = 0.670 \pm 0.027$$

$$A_b = 0.923 \pm 0.020$$

Charge asymmetry (%) at Z pole

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

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

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

$$A_{FB}^{(0c)} = 7.07 \pm 0.35$$

$$A_{FB}^{(0b)} = 9.92 \pm 0.16$$

Z DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$e^+ e^-$	[h] (3.3632±0.0042) %		45594
$\mu^+ \mu^-$	[h] (3.3662±0.0066) %		45594
$\tau^+ \tau^-$	[h] (3.3696±0.0083) %		45559
$\ell^+ \ell^-$	[b,h] (3.3658±0.0023) %		—
$\ell^+ \ell^- \ell^+ \ell^-$	[i] (3.5 ±0.4) × 10 ⁻⁶	S=1.7	45594
invisible	[h] (20.000 ±0.055) %		—
hadrons	[h] (69.911 ±0.056) %		—
($u\bar{u} + c\bar{c}$)/2	(11.6 ±0.6) %		—
($d\bar{d} + s\bar{s} + b\bar{b}$)/3	(15.6 ±0.4) %		—
$c\bar{c}$	(12.03 ±0.21) %		—
$b\bar{b}$	(15.12 ±0.05) %		—
$b\bar{b}b\bar{b}$	(3.6 ±1.3) × 10 ⁻⁴		—
ggg	< 1.1	% CL=95%	—
$\pi^0 \gamma$	< 2.01	× 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
$\phi \gamma$	< 8.3	× 10 ⁻⁶ CL=95%	45588
$\gamma \gamma$	< 1.46	× 10 ⁻⁵ CL=95%	45594
$\pi^0 \pi^0$	< 1.52	× 10 ⁻⁵ CL=95%	45594
$\gamma \gamma \gamma$	< 2.2	× 10 ⁻⁶ CL=95%	45594
$\pi^\pm W^\mp$	[j] < 7	× 10 ⁻⁵ CL=95%	10167
$\rho^\pm W^\mp$	[j] < 8.3	× 10 ⁻⁵ CL=95%	10142
$J/\psi(1S)X$	(3.51 ^{+0.23} / _{-0.25}) × 10 ⁻³	S=1.1	—
$J/\psi(1S)\gamma$	< 2.6	× 10 ⁻⁶ CL=95%	45541
$\psi(2S)X$	(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		—
$\Upsilon(1S)X$	< 3.4	× 10 ⁻⁶ CL=95%	—
$\Upsilon(2S)X$	< 6.5	× 10 ⁻⁶ CL=95%	—

$\Upsilon(3S)X$		< 5.4	$\times 10^{-6}$	CL=95%	—
$(D^0/\bar{D}^0)X$		(20.7 \pm 2.0)) %		—
$D^\pm X$		(12.2 \pm 1.7)) %		—
$D^*(2010)^\pm X$	[j]	(11.4 \pm 1.3)) %		—
$D_{s1}(2536)^\pm X$		(3.6 \pm 0.8)	$\times 10^{-3}$		—
$D_{sJ}(2573)^\pm X$		(5.8 \pm 2.2)	$\times 10^{-3}$		—
$D^{*'}(2629)^\pm X$		searched for			—
B^+X	[k]	(6.08 \pm 0.13)) %		—
B_s^0X	[k]	(1.59 \pm 0.13)) %		—
B_c^+X		searched for			—
Λ_c^+X		(1.54 \pm 0.33)) %		—
Ξ_c^0X		seen			—
Ξ_b^-X		seen			—
b -baryon X	[k]	(1.38 \pm 0.22)) %		—
anomalous γ + hadrons	[l]	< 3.2	$\times 10^{-3}$	CL=95%	—
$e^+e^-\gamma$	[l]	< 5.2	$\times 10^{-4}$	CL=95%	45594
$\mu^+\mu^-\gamma$	[l]	< 5.6	$\times 10^{-4}$	CL=95%	45594
$\tau^+\tau^-\gamma$	[l]	< 7.3	$\times 10^{-4}$	CL=95%	45559
$\ell^+\ell^-\gamma\gamma$	[n]	< 6.8	$\times 10^{-6}$	CL=95%	—
$q\bar{q}\gamma\gamma$	[n]	< 5.5	$\times 10^{-6}$	CL=95%	—
$\nu\bar{\nu}\gamma\gamma$	[n]	< 3.1	$\times 10^{-6}$	CL=95%	45594
$e^\pm\mu^\mp$	LF	[j]	< 7.5	$\times 10^{-7}$	CL=95% 45594
$e^\pm\tau^\mp$	LF	[j]	< 9.8	$\times 10^{-6}$	CL=95% 45576
$\mu^\pm\tau^\mp$	LF	[j]	< 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

H^0

$J = 0$

Mass $m = 125.18 \pm 0.16$ GeV

Full width $\Gamma < 0.013$ GeV, CL = 95%

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States = 1.10 ± 0.11

$WW^* = 1.08^{+0.18}_{-0.16}$

$ZZ^* = 1.14^{+0.15}_{-0.13}$

$\gamma\gamma = 1.16 \pm 0.18$

$b\bar{b} = 0.95 \pm 0.22$

$\mu^+\mu^- = 0.0 \pm 1.3$

$\tau^+\tau^- = 1.12 \pm 0.23$

$Z\gamma < 6.6$, CL = 95%

$t\bar{t}H^0$ Production = $2.3^{+0.7}_{-0.6}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^+ e^-$	$< 1.9 \times 10^{-3}$	95%	62592
$J/\psi \gamma$	$< 1.5 \times 10^{-3}$	95%	62553
$\Upsilon(1S) \gamma$	$< 1.3 \times 10^{-3}$	95%	62234
$\Upsilon(2S) \gamma$	$< 1.9 \times 10^{-3}$	95%	62190
$\Upsilon(3S) \gamma$	$< 1.3 \times 10^{-3}$	95%	62163
$\phi(1020) \gamma$	$< 1.4 \times 10^{-3}$	95%	62587
$e \mu$	$< 3.5 \times 10^{-4}$	95%	62592
$e \tau$	$< 6.9 \times 10^{-3}$	95%	62579
$\mu \tau$	$< 1.43 \%$	95%	62579
invisible	$< 24 \%$	95%	—

Neutral Higgs Bosons, Searches for

Searches for a Higgs Boson with Standard Model Couplings

Mass $m > 122$ and none 128–1000 GeV, CL = 95%

The limits for H_1^0 and A^0 in supersymmetric models refer to the m_h^{\max} benchmark scenario for the supersymmetric parameters.

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

Mass $m > 92.8$ GeV, CL = 95%

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

Mass $m > 93.4$ GeV, CL = 95% $\tan\beta > 0.4$

Charged Higgs Bosons (H^\pm and $H^{\pm\pm}$), Searches for

H^\pm Mass $m > 80$ GeV, CL = 95%

New Heavy Bosons (W' , Z' , leptoquarks, etc.), Searches for

Additional W Bosons

W' with standard couplings

Mass $m > 4.100 \times 10^3$ GeV, CL = 95% ($p\bar{p}$ direct search)

W_R (Right-handed W Boson)

Mass $m > 715$ GeV, CL = 90% (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings

Mass $m > 4.500 \times 10^3$ GeV, CL = 95% (pp direct search)

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 $m > 1162$ 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 $m > 4.100 \times 10^3$ GeV, CL = 95% (pp direct search)

Z_ψ of $E_6 \rightarrow SO(10) \times U(1)_\psi$ (with $g_\psi = e/\cos\theta_W$)

Mass $m > 3.800 \times 10^3$ GeV, CL = 95% (pp direct search)

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 $m > 3.900 \times 10^3$ GeV, CL = 95% (pp direct search)

Scalar Leptoquarks

Mass $m > 1050$ GeV, CL = 95% (1st generation, pair prod.)

Mass $m > 1755$ GeV, CL = 95% (1st generation, single prod.)

Mass $m > 1080$ GeV, CL = 95% (2nd generation, pair prod.)

Mass $m > 660$ GeV, CL = 95% (2nd generation, single prod.)

Mass $m > 850$ GeV, CL = 95% (3rd generation, pair prod.)

(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m > 6000$ GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m > 5500$ GeV, CL = 95%

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] This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).
- [i] Here ℓ indicates e or μ .
- [j] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [k] This value is updated using the product of (i) the $Z \rightarrow b\bar{b}$ fraction from this listing and (ii) the b -hadron fraction in an unbiased sample of weakly decaying b -hadrons produced in Z -decays provided by the Heavy Flavor Averaging Group (HFLAV, http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ).
- [l] See the Z Particle Listings for the γ energy range used in this measurement.
- [n] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.
- [o] The limits assume no invisible decays.