GAUGE AND HIGGS BOSONS

γ (photon)

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

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 1 \times 10^{-46}$ e (mixed charge)
Charge $q < 1 \times 10^{-35}$ e (single charge)
Mean life τ = Stable

---

g or gluon

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

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

---

graviton

$J = 2$

Mass $m < 1.76 \times 10^{-23}$ eV

W

$J = 1$

Charge $= \pm 1$ e
Mass $m = 80.377 \pm 0.012$ GeV [b]
W/Z mass ratio $= 0.88145 \pm 0.00013$
$m_Z - m_W = 10.811 \pm 0.012$ 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)
$\ell^+ \nu$	[c]	(10.86± 0.09) %		–
$e^+ \nu$		(10.71± 0.16) %		40188
$\mu^+ \nu$		(10.63± 0.15) %		40188
$\tau^+ \nu$		(11.38± 0.21) %		40169
hadrons		(67.41± 0.27) %		–

$\pi^+\gamma$	$<$ 7	$\times 10^{-6}$	95%	40188
$D_s^+\gamma$	$<$ 1.3	$\times 10^{-3}$	95%	40164
cX	(33.3 $\pm$ 2.6) %			–
$c\overline{s}$	(31 $^{+13}_{-11}$) %			–
invisible	[d] (1.4 $\pm$ 2.9) %			–
$\pi^+\pi^+\pi^-$	$<$ 1.01	$\times 10^{-6}$	95%	40188

Z

$J = 1$

Charge = 0
Mass $m = 91.1876 \pm 0.0021$ GeV [e]
Full width $\Gamma = 2.4955 \pm 0.0023$ GeV
$\Gamma(\ell^+\ell^-) = 83.984 \pm 0.086$ MeV [c]
$\Gamma(\text{invisible}) = 499.0 \pm 1.5$ MeV [f]
$\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$ MeV
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.0001 \pm 0.0024$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0020 \pm 0.0032$ [g]

Average charged multiplicity

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

Couplings to quarks and leptons

$g_V^\ell = -0.03783 \pm 0.00041$
$g_V^u = 0.266 \pm 0.034$
$g_V^d = -0.38^{+0.04}_{-0.05}$
$g_A^\ell = -0.50123 \pm 0.00026$
$g_A^u = 0.519^{+0.028}_{-0.033}$
$g_A^d = -0.527^{+0.040}_{-0.028}$
$g^{\nu_\ell} = 0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [h]

$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.670 \pm 0.027$
$A_b = 0.923 \pm 0.020$

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)
$e^+ e^-$	[i]	(3.3632±0.0042) %		45594
$\mu^+ \mu^-$	[i]	(3.3662±0.0066) %		45594
$\tau^+ \tau^-$	[i]	(3.3696±0.0083) %		45559
$\ell^+ \ell^-$	[c,i]	(3.3658±0.0023) %		–
$\ell^+ \ell^- \ell^+ \ell^-$	[j]	(4.55 ±0.17) × 10^{-6}		45594
invisible	[i]	(20.000 ±0.055) %		–
hadrons	[i]	(69.911 ±0.056) %		–
$(u\overline{u}+c\overline{c})/2$		(11.6 ±0.6) %		–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 ±0.4) %		–
$c\overline{c}$		(12.03 ±0.21) %		–
$b\overline{b}$		(15.12 ±0.05) %		–
$b\overline{b}\,b\overline{b}$		(3.6 ±1.3) × 10^{-4}		–
$g\,g\,g$		< 1.1 %	CL=95%	–
$\pi^0\gamma$		< 2.01 × 10^{-5}	CL=95%	45594
$\eta\gamma$		< 5.1 × 10^{-5}	CL=95%	45592
$\rho^0\gamma$		< 2.5 × 10^{-5}	CL=95%	45591
$\omega\gamma$		< 6.5 × 10^{-4}	CL=95%	45590
$\eta'(958)\gamma$		< 4.2 × 10^{-5}	CL=95%	45589
$\phi\gamma$		< 9 × 10^{-7}	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
$\pi^\pm W^\mp$	[k]	< 7 × 10^{-5}	CL=95%	10169
$\rho^\pm W^\mp$	[k]	< 8.3 × 10^{-5}	CL=95%	10143
$J/\psi(1S)$X		(3.51 $^{+0.23}_{-0.25}$) × 10^{-3}	S=1.1	–
$J/\psi(1S)\gamma$		< 1.4 × 10^{-6}	CL=95%	45541
$\psi(2S)$X		(1.60 ±0.29) × 10^{-3}		–
$\psi(2S)\gamma$		< 4.5 × 10^{-6}	CL=95%	45519
$J/\psi(1S)\,J/\psi(1S)$		< 2.2 × 10^{-6}	CL=95%	45489
$\chi_{c1}(1P)$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%	–
$\Upsilon(1S)\gamma$		< 2.8 × 10^{-6}	CL=95%	45103
$\Upsilon(2S)$X		< 1.39 × 10^{-4}	CL=95%	–

$\Upsilon(2S)\gamma$			$<$ 1.7		$\times 10^{-6}$	CL=95%	45043
$\Upsilon(3S)$X			$<$ 9.4		$\times 10^{-5}$	CL=95%	–
$\Upsilon(3S)\gamma$			$<$ 4.8		$\times 10^{-6}$	CL=95%	45006
$\Upsilon(1,2,3S)\,\Upsilon(1,2,3S)$			$<$ 1.5		$\times 10^{-6}$	CL=95%	–
$(D^0/\overline{D}^0)$ X			(20.7	±2.0) %			–
$D^{\pm}$X			(12.2	±1.7) %			–
$D^*(2010)^{\pm}$X		[k]	(11.4	±1.3) %			–
$D_{s1}(2536)^{\pm}$X			(3.6	±0.8) $\times 10^{-3}$			–
$D_{sJ}(2573)^{\pm}$X			(5.8	±2.2) $\times 10^{-3}$			–
$D^{*\prime}(2629)^{\pm}$X			searched for				–
B^+X		[l]	(6.08	±0.13) %			–
B_s^0X		[l]	(1.59	±0.13) %			–
B_c^+X			searched for				–
Λ_c^+X			(1.54	±0.33) %			–
Ξ_c^0X			seen				–
Ξ_bX			seen				–
b-baryon X		[l]	(1.38	±0.22) %			–
anomalous $\gamma+$ hadrons		[n]	$<$ 3.2		$\times 10^{-3}$	CL=95%	–
$e^+e^-\gamma$		[n]	$<$ 5.2		$\times 10^{-4}$	CL=95%	45594
$\mu^+\mu^-\gamma$		[n]	$<$ 5.6		$\times 10^{-4}$	CL=95%	45594
$\tau^+\tau^-\gamma$		[n]	$<$ 7.3		$\times 10^{-4}$	CL=95%	45559
$\ell^+\ell^-\gamma\gamma$		[o]	$<$ 6.8		$\times 10^{-6}$	CL=95%	–
$q\overline{q}\gamma\gamma$		[o]	$<$ 5.5		$\times 10^{-6}$	CL=95%	–
$\nu\overline{\nu}\gamma\gamma$		[o]	$<$ 3.1		$\times 10^{-6}$	CL=95%	45594
$e^{\pm}\mu^{\mp}$	LF	[k]	$<$ 7.5		$\times 10^{-7}$	CL=95%	45594
$e^{\pm}\tau^{\mp}$	LF	[k]	$<$ 5.0		$\times 10^{-6}$	CL=95%	45576
$\mu^{\pm}\tau^{\mp}$	LF	[k]	$<$ 6.5		$\times 10^{-6}$	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 $J = 0$

was H^0

Mass $m = 125.25 \pm 0.17$ GeV (S = 1.5)
Full width $\Gamma = 3.2^{+2.4}_{-1.7}$ MeV (assumes equal on-shell and off-shell effective couplings)

H Signal Strengths in Different Channels

Combined Final States $= 1.03 \pm 0.04$
$WW^* = 1.00 \pm 0.08$
$ZZ^* = 1.02 \pm 0.08$
$\gamma\gamma = 1.10 \pm 0.07$
$c\overline{c}$ Final State $= 8 \pm 22$ (S = 1.9)

$b\overline{b} = 0.99 \pm 0.12$
$\mu^+\mu^- = 1.21 \pm 0.35$
$\tau^+\tau^- = 0.91 \pm 0.09$
$\gamma^*\gamma$ Final State $= 1.5 \pm 0.5$
Fermion coupling (κ_F) $= 0.95 \pm 0.05$
Gauge boson coupling (κ_V) $= 1.035 \pm 0.031$
$t\overline{t}H$ Production $= 1.10 \pm 0.18$
tH production $= 6 \pm 4$
H Production Cross Section in pp Collisions at $\sqrt{s} = 13$ TeV $=$ 56.9 ± 3.4 pb

***H* DECAY MODES**		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
WW^*		(25.7 $\pm$2.5) %		–
ZZ^*		(2.80$\pm$0.30) %		–
$\gamma\gamma$		(2.50$\pm$0.20) $\times 10^{-3}$		62625
$b\overline{b}$		(53 $\pm$8) %		–
e^+e^-		$< 3.6 \times 10^{-4}$	95%	62625
$\mu^+\mu^-$		(2.6 $\pm$1.3) $\times 10^{-4}$		62625
$\tau^+\tau^-$		(6.0 $^{+0.8}_{-0.7}$) %		62600
$Z\gamma$		(3.2 $\pm$1.5) $\times 10^{-3}$		29431
$Z\rho(770)$		< 1.21 %	95%	29423
$Z\phi(1020)$		$< 3.6 \times 10^{-3}$	95%	29417
$J/\psi\gamma$		$< 3.5 \times 10^{-4}$	95%	62587
$J/\psi J/\psi$		$< 1.8 \times 10^{-3}$	95%	62548
$\psi(2S)\gamma$		$< 2.0 \times 10^{-3}$	95%	62571
$\Upsilon(1S)\gamma$		$< 4.9 \times 10^{-4}$	95%	62268
$\Upsilon(2S)\gamma$		$< 5.9 \times 10^{-4}$	95%	62224
$\Upsilon(3S)\gamma$		$< 5.7 \times 10^{-4}$	95%	62197
Υ(nS) Υ(mS)		$< 1.4 \times 10^{-3}$	95%	–
$\rho(770)\gamma$		$< 8.8 \times 10^{-4}$	95%	62623
$\phi(1020)\gamma$		$< 4.8 \times 10^{-4}$	95%	62621
$e\mu$	*LF*	$< 6.1 \times 10^{-5}$	95%	62625
$e\tau$	*LF*	$< 2.2 \times 10^{-3}$	95%	62612
$\mu\tau$	*LF*	$< 1.5 \times 10^{-3}$	95%	62612
invisible		< 13 %	95%	–
γ invisible		< 2.9 %	95%	–

Neutral Higgs Bosons, Searches for

Mass limits for heavy neutral Higgs bosons (H_2^0, A^0) in the MSSM

m > 389 GeV, CL = 95% (tanβ = 10)
m > 863 GeV, CL = 95% (tanβ = 20)
m > 1157 GeV, CL = 95% (tanβ = 30)
m > 1341 GeV, CL = 95% (tanβ = 40)
m > 1496 GeV, CL = 95% (tanβ = 50)
m > 1613 GeV, CL = 95% (tanβ = 60)

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

Mass limits for m_{H^+} < m(top) in the MSSM

m > 155 GeV, CL = 95%

Mass limits for m_{H^+} > m(top) in the MSSM

m > 181 GeV, CL = 95% (tanβ = 10)
m > 249 GeV, CL = 95% (tanβ = 20)
m > 390 GeV, CL = 95% (tanβ = 30)
m > 894 GeV, CL = 95% (tanβ = 40)
m > 1017 GeV, CL = 95% (tanβ = 50)
m > 1103 GeV, CL = 95% (tanβ = 60)

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

Additional W Bosons

W' with standard couplings
Mass $m >$ 6000 GeV, CL = 95% (pp 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 $m >$ 5150 GeV, CL = 95% (pp direct search)
Z_{LR} of SU(2)$_L$×SU(2)$_R$×U(1) (with $g_L = g_R$)
Mass $m >$ 630 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 1162 GeV, CL = 95% (electroweak fit)

Z_χ of SO(10) $\rightarrow$ SU(5)×U(1)$_\chi$ (with g_χ=e/cosθ_W)
Mass $m >$ 4800 GeV, CL = 95% (pp direct search)
Z_ψ of E_6 $\rightarrow$ SO(10)×U(1)$_\psi$ (with g_ψ=e/cosθ_W)
Mass $m >$ 4560 GeV, CL = 95% (pp direct search)
Z_η of E_6 $\rightarrow$ SU(3)×SU(2)×U(1)×U(1)$_\eta$ (with g_η=e/cosθ_W)
Mass $m >$ 3.900×10^3 GeV, CL = 95% (pp direct search)

Scalar Leptoquarks

$m >$ 1800 GeV, CL = 95% (1st gen., pair prod., B(eq)=1)
$m >$ 1755 GeV, CL = 95% (1st gen., single prod., B(eq)=1)
$m >$ 1700 GeV, CL = 95% (2nd gen., pair prod., B(μq)=1)
$m >$ 660 GeV, CL = 95% (2nd gen., single prod., B(μq)=1)
$m >$ 1430 GeV, CL = 95% (3rd gen., pair prod., B(τt)=1)
$m >$ 740 GeV, CL = 95% (3rd gen., single prod., B(τb)=1)
(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m >$ 7200 GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m >$ 6600 GeV, CL = 95%

Axions (A^0) and Other Very Light Bosons, Searches for

See the review on "Axions and other similar particles."

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*] This value does not include the AALTONEN 22 measurement by CDF. See the *W* mass section in the listings for details.

[*c*] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[*d*] This represents the width for the decay of the *W* boson into a charged particle with momentum below detectability, p$<$ 200 MeV.

[*e*] 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.

[*f*] This partial width takes into account *Z* decays into $\nu\overline{\nu}$ and any other possible undetected modes.

[*g*] This ratio has not been corrected for the τ mass.

[*h*] Here $A \equiv 2g_V g_A/(g_V^2+g_A^2)$.

[*i*] 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)).

[*j*] Here ℓ indicates e or μ.

[*k*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*l*] This value is updated using the product of (i) the $Z \to b\overline{b}$ 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).

[*n*] See the *Z* Particle Listings for the γ energy range used in this measurement.

[*o*] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.