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 $\tau =$ Stable

g (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 $m = 80.3625 \pm 0.0077$ GeV [b]
W/Z mass ratio $= 0.88136 \pm 0.00015$
$m_Z - m_W = 10.818 \pm 0.013$ GeV
$m_{W^+} - m_{W^-} = -0.029 \pm 0.028$ GeV
Full width $\Gamma = 2.14 \pm 0.05$ GeV (S = 1.7)
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_p \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$

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) %		40181
$\mu^+ \nu$		(10.63± 0.15) %		40181
$\tau^+ \nu$		(11.38± 0.21) %		40162
hadrons		(67.41± 0.27) %		–
$\pi^+ \gamma$		$< 1.9 \times 10^{-6}$	95%	40181

$\rho^+\gamma$	$<$ 5.2	$\times 10^{-6}$	95%	40178
$K^+\gamma$	$<$ 1.7	$\times 10^{-6}$	95%	40180
$D_s^+\gamma$	$<$ 6	$\times 10^{-4}$	95%	40157
cX	(33.0 $\pm$ 1.2) %			–
$c\overline{s}$	(31 $^{+13}_{-11}$) %			–
invisible	[d] (1.4 $\pm$ 2.8) %			–
$\pi^+\pi^+\pi^-$	$<$ 1.01	$\times 10^{-6}$	95%	40181

Z

$J = 1$

Charge = 0
Mass $m = 91.1879 \pm 0.0020$ GeV [e]
Full width $\Gamma = 2.4955 \pm 0.0023$ GeV
$\Gamma(\ell^+\ell^-) = 83.984 \pm 0.086$ MeV [c]
$\Gamma(\text{invisible}) = 499.3 \pm 1.5$ 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

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

$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.07 \pm 0.35$
$A_{FB}^{(0b)} = 9.92 \pm 0.16$
$\sin^2(\theta_{\text{eff}}) = 0.23148 \pm 0.00012$

***Z* DECAY MODES**		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$e^+ e^-$		(3.3632±0.0042) %		45594
$\mu^+ \mu^-$		(3.3662±0.0066) %		45594
$\tau^+ \tau^-$		(3.3696±0.0083) %		45559
$\ell^+ \ell^-$	[c]	(3.3658±0.0023) %		–
$\ell^+ \ell^- \ell^+ \ell^-$	[i]	(4.55 ±0.17) × 10^{-6}		45594
invisible		(20.000 ±0.055) %		–
hadrons		(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
$\rho^0\gamma$		< 4.0 × 10^{-6}	CL=95%	45591
$\omega\gamma$		< 3.9 × 10^{-6}	CL=95%	45591
$\eta'(958)\gamma$		< 4.2 × 10^{-5}	CL=95%	45589
$\phi\gamma$		< 7 × 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
$\pi^\pm W^\mp$	[j]	< 7 × 10^{-5}	CL=95%	10176
$\rho^\pm W^\mp$	[j]	< 8.3 × 10^{-5}	CL=95%	10151
$J/\psi(1S)$X		(3.51 $^{+0.23}_{-0.25}$) × 10^{-3}	S=1.1	–
$J/\psi(1S)\gamma$		< 6 × 10^{-7}	CL=95%	45541
$\psi(2S)$X		(1.60 ±0.29) × 10^{-3}		–
$\psi(2S)\gamma$		< 1.3 × 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%	–
$\Upsilon(1S)\gamma$		< 1.1 × 10^{-6}	CL=95%	45103

$\Upsilon(2S)X$			< 1.39	$\times 10^{-4}$	CL=95%	–
$\Upsilon(2S)\gamma$			< 1.3	$\times 10^{-6}$	CL=95%	45043
$\Upsilon(3S)X$			< 9.4	$\times 10^{-5}$	CL=95%	–
$\Upsilon(3S)\gamma$			< 2.4	$\times 10^{-6}$	CL=95%	45006
$\Upsilon(1,2,3S)\,\Upsilon(1,2,3S)$			< 1.5	$\times 10^{-6}$	CL=95%	–
$K^0_S\gamma$			< 3.1	$\times 10^{-6}$	CL=95%	45593
$D^0\gamma$			< 4.0	$\times 10^{-6}$	CL=95%	45575
$(D^0/\overline{D}^0)\,X$			(20.7 ±2.0) %			–
$D^\pm X$			(12.2 ±1.7) %			–
$D^*(2010)^\pm X$		[j]	(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		[k]	(6.08 ±0.13) %			–
$B^0_s X$		[k]	(1.59 ±0.13) %			–
$B^+_c X$			searched for			–
$\Lambda^+_c X$			(1.54 ±0.33) %			–
$\Xi^0_c X$			seen			–
$\Xi_b X$			seen			–
b-baryon X		[k]	(1.38 ±0.22) %			–
anomalous $\gamma+$ 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%	–
$q\overline{q}\gamma\gamma$		[n]	< 5.5	$\times 10^{-6}$	CL=95%	–
$\nu\overline{\nu}\gamma\gamma$		[n]	< 3.1	$\times 10^{-6}$	CL=95%	45594
$e^\pm\mu^\mp$	LF	[j]	< 1.9	$\times 10^{-7}$	CL=95%	45594
$e^\pm\tau^\mp$	LF	[j]	< 5.0	$\times 10^{-6}$	CL=95%	45577
$\mu^\pm\tau^\mp$	LF	[j]	< 6.5	$\times 10^{-6}$	CL=95%	45577
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 $m = 125.13 \pm 0.11$ GeV (S = 1.5)
Full width $\Gamma = 3.0^{+1.5}_{-0.7}$ MeV (assumes equal on-shell and off-shell effective couplings)

H Signal Strengths in Different Channels

Combined final state $= 1.03 \pm 0.04$
$WW^* = 1.00 \pm 0.08$

$ZZ^* = 1.02 \pm 0.08$
$\gamma\gamma = 1.10 \pm 0.06$
$c\overline{c}$ final state $= -0.5 \pm 3.4$
$b\overline{b} = 0.94 \pm 0.11$
$\mu^+\mu^- = 1.31 \pm 0.29$
$\tau^+\tau^- = 0.91 \pm 0.09$
$Z\gamma = 2.2 \pm 0.7$
$\gamma^*\gamma$ final state $= 1.5 \pm 0.5$
Fermion coupling $(\kappa_F) = 0.94 \pm 0.05$
Gauge boson coupling $(\kappa_V) = 1.023 \pm 0.026$
$t\overline{t}H$ production $= 0.91^{+0.20}_{-0.18}$ (S = 1.6)
$b\overline{b}H$ production $<$ 3.7, CL = 95%
tH production $= 7.1 \pm 2.5$
HH production $<$ 2.4, CL = 95%
HHH production $<$ 760, CL = 95%
Higgs trilinear self coupling modifier $\kappa_\lambda = 3.8^{+2.1}_{-4.0}$
Higgs-gauge boson quartic coupling modifier $\kappa_{2V} = 1.02 \pm 0.23$
H production cross section in pp collisions at $\sqrt{s} = 13$ TeV = 56.8 ± 3.4 pb
H production cross section in pp collisions at $\sqrt{s} = 13.6$ TeV = 58 ± 9 pb

***H* DECAY MODES**	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
WW^*	(25.7 ±2.5) %		–
ZZ^*	(2.80±0.30) %		–
$\gamma\gamma$	(2.50±0.20) $\times 10^{-3}$		62565
$b\overline{b}$	(53 ±8) %		–
e^+e^-	< 3.0 $\times 10^{-4}$	95%	62565
$\mu^+\mu^-$	(3.0 ±0.9) $\times 10^{-4}$		62565
$\tau^+\tau^-$	(6.0 $^{+0.8}_{-0.7}$) %		62540
$Z\gamma$	(3.4 ±1.1) $\times 10^{-3}$		29339
$Z\rho(770)$	< 1.21 %	95%	29332
$Z\phi(1020)$	< 3.6 $\times 10^{-3}$	95%	29326
ZJ/ψ	< 1.9 $\times 10^{-3}$	95%	29214
$Z\psi(2S)$	< 6.6 $\times 10^{-3}$	95%	29162
$J/\psi\gamma$	< 2.0 $\times 10^{-4}$	95%	62527
$J/\psi J/\psi$	< 3.8 $\times 10^{-4}$	95%	62489
$\psi(2S)\gamma$	< 9.9 $\times 10^{-4}$	95%	62511
$\psi(2S)J/\psi$	< 2.1 $\times 10^{-3}$	95%	62473
$\psi(2S)\psi(2S)$	< 3.0 $\times 10^{-3}$	95%	62457
$\Upsilon(1S)\gamma$	< 2.5 $\times 10^{-4}$	95%	62208
$\Upsilon(1S)\Upsilon(1S)$	< 1.7 $\times 10^{-3}$	95%	61846

$\Upsilon(2S)\gamma$		$<$ 4.2	$\times 10^{-4}$	95%	62164
$\Upsilon(3S)\gamma$		$<$ 3.4	$\times 10^{-4}$	95%	62137
Υ(nS) Υ(mS)		$<$ 3.5	$\times 10^{-4}$	95%	–
$D^*\gamma$		$<$ 1.0	$\times 10^{-3}$	95%	62549
$\rho(770)\gamma$		$<$ 3.7	$\times 10^{-4}$	95%	62563
$\omega(782)\gamma$		$<$ 5.5	$\times 10^{-4}$	95%	62563
$K^*(892)\gamma$		$<$ 2.2	$\times 10^{-4}$	95%	62562
$\phi(1020)\gamma$		$<$ 3.0	$\times 10^{-4}$	95%	62561
$e\mu$	*LF*	$<$ 4.4	$\times 10^{-5}$	95%	62565
$e\tau$	*LF*	$<$ 2.0	$\times 10^{-3}$	95%	62553
$\mu\tau$	*LF*	$<$ 1.5	$\times 10^{-3}$	95%	62553
invisible		$<$ 10.7	%	95%	–
γ invisible		$<$ 1.3	%	95%	–

Neutral Higgs Bosons, Searches for

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

The results have been obtained in the M_h^{125} benchmark scenario

m $>$ 1121 GeV, CL = 95% ($\tan\beta = 10$)
m $>$ 1475 GeV, CL = 95% ($\tan\beta = 20$)
m $>$ 1677 GeV, CL = 95% ($\tan\beta = 30$)
m $>$ 1826 GeV, CL = 95% ($\tan\beta = 40$)
m $>$ 1950 GeV, CL = 95% ($\tan\beta = 50$)
m $>$ 2062 GeV, CL = 95% ($\tan\beta = 60$)

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

The results have been obtained in the m_h^{mod-} benchmark scenario

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

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

$Z'_{\rm SM}$ with standard couplings
  Mass $m >$ 5150 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% ($p\overline{p}$ 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 $m >$ 4800 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 $m >$ 4560 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 $m >$ 3.900×10^3 GeV, CL = 95% (pp direct search)

Scalar Leptoquarks

$m >$ 1800 GeV, CL = 95% (1st gen., pair prod., B(eq)=1)
$m >$ 3400 GeV, CL = 95% (1st gen., single prod., g_{de}=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)
$m >$ 1520 GeV, CL = 95% (3rd gen., pair prod., B(τt)=1)
$m >$ 1280 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*] 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 $Z \to b\overline{b}$ 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).

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

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