

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 $\tau = \text{Stable}$

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 $= \pm 1$ e

Mass $m = 80.379 \pm 0.012$ GeV

W/Z mass ratio $= 0.88147 \pm 0.00013$

$m_Z - m_W = 10.809 \pm 0.012$ 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 | (MeV/c) <i>p</i> |
|-------------------------------------|---------------|--------------------------------|------------------|---------------------|
| $\ell^+ \nu$ | [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 \pm 13) | % | — | — |
| invisible | [c] | (1.4 \pm 2.9) % | — | — |
| $\pi^+ \pi^+ \pi^-$ | | < 1.01 $\times 10^{-6}$ | 95% | 40189 |

Z

$$J = 1$$

Charge = 0

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

Full width $\Gamma = 2.4952 \pm 0.0023$ GeV

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

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

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

$\Gamma(\mu^+ \mu^-)/\Gamma(e^+ e^-) = 1.0001 \pm 0.0024$

$\Gamma(\tau^+ \tau^-)/\Gamma(e^+ e^-) = 1.0020 \pm 0.0032$ [f]

Average charged multiplicity

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

Couplings to quarks and leptons

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

$$g_V^u = 0.266 \pm 0.034$$

$$g_V^d = -0.38^{+0.04}_{-0.05}$$

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

$$g_A^u = 0.519^{+0.028}_{-0.033}$$

$$g_A^d = -0.527^{+0.040}_{-0.028}$$

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

$$g^{\nu_e} = 0.53 \pm 0.09$$

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

Asymmetry parameters [g]

$$\begin{aligned}A_e &= 0.1515 \pm 0.0019 \\A_\mu &= 0.142 \pm 0.015 \\A_\tau &= 0.143 \pm 0.004 \\A_s &= 0.90 \pm 0.09 \\A_c &= 0.670 \pm 0.027 \\A_b &= 0.923 \pm 0.020\end{aligned}$$

Charge asymmetry (%) at Z pole

$$\begin{aligned}A_{FB}^{(0\ell)} &= 1.71 \pm 0.10 \\A_{FB}^{(0u)} &= 4 \pm 7 \\A_{FB}^{(0s)} &= 9.8 \pm 1.1 \\A_{FB}^{(0c)} &= 7.07 \pm 0.35 \\A_{FB}^{(0b)} &= 9.92 \pm 0.16\end{aligned}$$

| Z DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | p (MeV/c) |
|--------------------------------------|--|-----------------------------------|--------------|
| $e^+ e^-$ | [h] (3.3632 \pm 0.0042) % | | 45594 |
| $\mu^+ \mu^-$ | [h] (3.3662 \pm 0.0066) % | | 45594 |
| $\tau^+ \tau^-$ | [h] (3.3696 \pm 0.0083) % | | 45559 |
| $\ell^+ \ell^-$ | [b,h] (3.3658 \pm 0.0023) % | | — |
| $\ell^+ \ell^- \ell^+ \ell^-$ | [i] (4.63 \pm 0.21) $\times 10^{-6}$ | | 45594 |
| invisible | [h] (20.000 \pm 0.055) % | | — |
| hadrons | [h] (69.911 \pm 0.056) % | | — |
| $(u\bar{u} + c\bar{c})/2$ | (11.6 \pm 0.6) % | | — |
| $(d\bar{d} + s\bar{s} + b\bar{b})/3$ | (15.6 \pm 0.4) % | | — |
| $c\bar{c}$ | (12.03 \pm 0.21) % | | — |
| $b\bar{b}$ | (15.12 \pm 0.05) % | | — |
| $b\bar{b}b\bar{b}$ | (3.6 \pm 1.3) $\times 10^{-4}$ | | — |
| ggg | < 1.1 % | CL=95% | — |
| $\pi^0 \gamma$ | < 2.01 $\times 10^{-5}$ | CL=95% | 45594 |
| $\eta \gamma$ | < 5.1 $\times 10^{-5}$ | CL=95% | 45592 |
| $\rho^0 \gamma$ | < 2.5 $\times 10^{-5}$ | CL=95% | 45591 |
| $\omega \gamma$ | < 6.5 $\times 10^{-4}$ | CL=95% | 45590 |
| $\eta'(958) \gamma$ | < 4.2 $\times 10^{-5}$ | CL=95% | 45589 |
| $\phi \gamma$ | < 9 $\times 10^{-7}$ | CL=95% | 45588 |
| $\gamma \gamma$ | < 1.46 $\times 10^{-5}$ | CL=95% | 45594 |
| $\pi^0 \pi^0$ | < 1.52 $\times 10^{-5}$ | CL=95% | 45594 |
| $\gamma \gamma \gamma$ | < 2.2 $\times 10^{-6}$ | CL=95% | 45594 |
| $\pi^\pm W^\mp$ | [j] < 7 $\times 10^{-5}$ | CL=95% | 10167 |
| $\rho^\pm W^\mp$ | [j] < 8.3 $\times 10^{-5}$ | CL=95% | 10142 |

| | | | | |
|---|--------------------------------|---------------------|--------|-------|
| $J/\psi(1S)X$ | (3.51 ± 0.23) | $\times 10^{-3}$ | S=1.1 | - |
| $J/\psi(1S)\gamma$ | < 1.4 | $\times 10^{-6}$ | CL=95% | 45541 |
| $\psi(2S)X$ | (1.60 ± 0.29) | $\times 10^{-3}$ | - | - |
| $\psi(2S)\gamma$ | < 4.5 | $\times 10^{-6}$ | CL=95% | 45519 |
| $J/\psi(1S)J/\psi(1S)$ | < 2.2 | $\times 10^{-6}$ | CL=95% | 45489 |
| $\chi_{c1}(1P)X$ | (2.9 ± 0.7) | $\times 10^{-3}$ | - | - |
| $\chi_{c2}(1P)X$ | < 3.2 | $\times 10^{-3}$ | CL=90% | - |
| $\Upsilon(1S) X + \Upsilon(2S) X$ | (1.0 ± 0.5) | $\times 10^{-4}$ | - | - |
| $+ \Upsilon(3S) X$ | | | | |
| $\Upsilon(1S)X$ | < 3.4 | $\times 10^{-6}$ | CL=95% | - |
| $\Upsilon(1S)\gamma$ | < 2.8 | $\times 10^{-6}$ | CL=95% | 45103 |
| $\Upsilon(2S)X$ | < 6.5 | $\times 10^{-6}$ | CL=95% | - |
| $\Upsilon(2S)\gamma$ | < 1.7 | $\times 10^{-6}$ | CL=95% | 45043 |
| $\Upsilon(3S)X$ | < 5.4 | $\times 10^{-6}$ | 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% | - |
| $(D^0/\bar{D}^0)X$ | (20.7 ± 2.0) | % | - | - |
| $D^\pm X$ | (12.2 ± 1.7) | % | - | - |
| $D^*(2010)^\pm X$ | [\jmath] (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) | % | - | - |
| $B_s^0 X$ | [k] (1.59 ± 0.13) | % | - | - |
| $B_c^+ X$ | | searched for | - | - |
| $\Lambda_c^+ X$ | | (1.54 ± 0.33) | % | - |
| $\Xi_c^0 X$ | | seen | - | - |
| $\Xi_b^- X$ | | seen | - | - |
| b -baryon X | [k] (1.38 ± 0.22) | % | - | - |
| anomalous $\gamma +$ hadrons | [\jmath] < 3.2 | $\times 10^{-3}$ | CL=95% | - |
| $e^+ e^- \gamma$ | [\jmath] < 5.2 | $\times 10^{-4}$ | CL=95% | 45594 |
| $\mu^+ \mu^- \gamma$ | [\jmath] < 5.6 | $\times 10^{-4}$ | CL=95% | 45594 |
| $\tau^+ \tau^- \gamma$ | [\jmath] < 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 [\jmath] < 7.5 | $\times 10^{-7}$ | CL=95% | 45594 |
| $e^\pm \tau^\mp$ | LF [\jmath] < 9.8 | $\times 10^{-6}$ | CL=95% | 45576 |
| $\mu^\pm \tau^\mp$ | LF [\jmath] < 1.2 | $\times 10^{-5}$ | CL=95% | 45576 |
| $p e$ | 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 $m = 125.10 \pm 0.14$ GeV

Full width $\Gamma < 0.013$ GeV, CL = 95% (assumes equal on-shell and off-shell effective couplings)

H^0 Signal Strengths in Different Channels

Combined Final States = 1.13 ± 0.06

WW^* = 1.19 ± 0.12

ZZ^* = $1.20^{+0.12}_{-0.11}$

$\gamma\gamma$ = $1.11^{+0.10}_{-0.09}$

$c\bar{c}$ Final State < 110, CL = 95%

$b\bar{b}$ = 1.04 ± 0.13

$\mu^+\mu^-$ = 0.6 ± 0.8

$\tau^+\tau^-$ = $1.15^{+0.16}_{-0.15}$

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

top Yukawa coupling < 1.7, CL = 95%

$t\bar{t}H^0$ Production = 1.28 ± 0.20

H^0 Production Cross Section in $p\bar{p}$ Collisions at $\sqrt{s} = 13$ TeV = 59 ± 5 pb

| H^0 DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|-------------------------------------|--------------------------------|-----------------------|----------------|
| e^+e^- | $<3.6 \times 10^{-4}$ | 95% | 62550 |
| $J/\psi\gamma$ | $<3.5 \times 10^{-4}$ | 95% | 62511 |
| $J/\psi J/\psi$ | $<1.8 \times 10^{-3}$ | 95% | 62473 |
| $\psi(2S)\gamma$ | $<2.0 \times 10^{-3}$ | 95% | 62495 |
| $\Upsilon(1S)\gamma$ | $<4.9 \times 10^{-4}$ | 95% | 62192 |
| $\Upsilon(2S)\gamma$ | $<5.9 \times 10^{-4}$ | 95% | 62148 |
| $\Upsilon(3S)\gamma$ | $<5.7 \times 10^{-4}$ | 95% | 62121 |
| $\Upsilon(nS)\Upsilon(mS)$ | $<1.4 \times 10^{-3}$ | 95% | - |
| $\rho(770)\gamma$ | $<8.8 \times 10^{-4}$ | 95% | 62547 |
| $\phi(1020)\gamma$ | $<4.8 \times 10^{-4}$ | 95% | 62546 |
| $e\mu$ | LF | $<6.1 \times 10^{-5}$ | 95% |
| $e\tau$ | LF | $<4.7 \times 10^{-3}$ | 95% |
| $\mu\tau$ | LF | $<2.5 \times 10^{-3}$ | 95% |
| γ invisible | | $<4.6 \%$ | 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% | $(\tan\beta = 10)$ |
| $m > 863$ GeV, CL = 95% | $(\tan\beta = 20)$ |
| $m > 1157$ GeV, CL = 95% | $(\tan\beta = 30)$ |
| $m > 1341$ GeV, CL = 95% | $(\tan\beta = 40)$ |
| $m > 1496$ GeV, CL = 95% | $(\tan\beta = 50)$ |
| $m > 1613$ GeV, CL = 95% | $(\tan\beta = 60)$ |

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

Mass limits for $m_{H^\pm} < m(\text{top})$

$m > 155$ GeV, CL = 95%

Mass limits for $m_{H^\pm} > m(\text{top})$

| | |
|--------------------------|--------------------|
| $m > 181$ 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 $m > 5200$ 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 $m > 4.500 \times 10^3$ 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) _{χ} (with $g_\chi = e/\cos\theta_W$)
Mass $m > 4.100 \times 10^3$ GeV, CL = 95% ($p\bar{p}$ direct search)
- Z_ψ of E_6 \rightarrow SO(10) \times U(1) _{ψ} (with $g_\psi = e/\cos\theta_W$)
Mass $m > 3900$ GeV, CL = 95% ($p\bar{p}$ direct search)
- Z_η of E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1) _{η} (with $g_\eta = e/\cos\theta_W$)
Mass $m > 3.900 \times 10^3$ GeV, CL = 95% ($p\bar{p}$ direct search)

Scalar Leptoquarks

- $m > 1050$ GeV, CL = 95% (1st gen., pair prod., $B(\tau t)=1$)
 $m > 1755$ GeV, CL = 95% (1st gen., single prod., $B(\tau b)=1$)
 $m > 1420$ GeV, CL = 95% (2nd gen., pair prod., $B(\mu t)=1$)
 $m > 660$ GeV, CL = 95% (2nd gen., single prod., $B(\mu q)=1$)
 $m > 900$ GeV, CL = 95% (3rd gen., pair prod., $B(e q)=1$)
 $m > 740$ GeV, CL = 95% (3rd gen., single prod., $B(e q)=1$)
- (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 $m > 6100$ 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] 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.