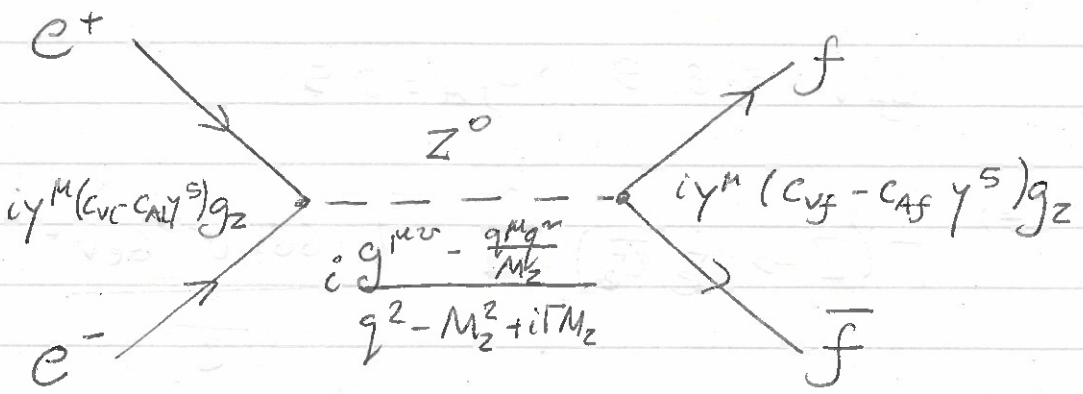
Ant.

Advanced Particle Physics 2017 Q.5

i



where y is the gamma matrix

c_{Vl}, c_{Vf} are the vector coupling strengths

c_{Al}, c_{Af} are " axial vector " "

$g^{\mu\nu}$ is the metric

q^μ is the 4-momentum

M_Z is the mass of the Z boson.

ii

$$\Gamma = \frac{\langle |M|^2 \rangle \rho}{2\hat{s}} \quad [a] \qquad , \qquad M_Z = \frac{g_W^2}{\cos^2\theta_W} \quad [c]$$

Phase factor $\rho = \frac{1}{8\pi}$ [b] , COM energy $= \sqrt{s} = M_Z$ [d]

(a) (b) $\frac{G_F}{\sqrt{2}} = \frac{g_W^2}{8M_W^2}$ [e]

$$\Rightarrow \Gamma(Z \to f\bar{f}) = \frac{1}{2\hat{s}} \frac{g_W^2 M_Z^2}{3\cos^2\theta_W} \frac{1}{8\pi} \left(c_{fV}^2 + c_{fA}^2\right)$$

(d) =>

$$= \frac{g_W^2}{8M_W^2} \frac{1}{6\pi} \frac{M_W^2 M_Z^2}{M_Z^2 \cos^2\theta_W} \left(c_{fV}^2 + c_{fA}^2\right)$$

(e), (c) =>

$$= \frac{G_F}{\sqrt{2}} \frac{1}{6\pi} M_Z^3 \left(c_{fV}^2 + c_{fA}^2\right)$$

ANSWERS CHECKED AGAINST PARTICLE DATA GROUP pdg.lbl.gov

$f = \nu_e \qquad \bar{f} = \bar{\nu}_e$

$C_{fV} = 0.5 \;, \; C_{fA} = 0.5$

$$\Rightarrow \Gamma(Z \to \nu_e \bar{\nu}_e) = \frac{1.166\times10^{-5}\,\text{GeV}^{-2}}{\sqrt{2}} \frac{91.19^3}{6\pi} \times \left(\frac{1}{2}^2 + \frac{1}{2}\right)$$

$$= 0.166 \text{ GeV}$$

iii

Decay mode	Partial width. ~~Branching ratio~~ (GeV)
	[PDG 0.499]
$Z \to \nu_{e,\mu,\tau}\bar{\nu}_{e,\mu,\tau}$	$3 \times 0.166 = 0.498$
	[PDG 0.252] 0.24975
$Z \to \ell^+\ell^-$	$3 \times 0.0834 = 0.250$ / 0.25019
[Checked vs. PDG PDG: 499.0 MeV]	
$Z \to u\bar{u}$ $c\bar{c}$ $\bar{u}\bar{c}$ $c\bar{u}$	Colours ↓ $3 \times 2 \times 0.0951$ = ~~0.381~~ ~~0.28541~~ ~~0.38054~~ 0.571
	[PDG: $\frac{0.166}{3}$] [PDG: 0.332]
$Z \to d\bar{d}$ ~~$d\bar{s}$~~ ~~$d\bar{b}$~~ ~~$s\bar{d}$~~ ~~$s\bar{s}$~~ ~~$s\bar{b}$~~ ~~$b\bar{d}$~~ ~~$b\bar{s}$~~ $b\bar{b}$ $s\bar{s}$	Colour ↓ $3 \times 3 \times 0.1226$ = ~~0.7356~~ ~~0.73577~~ 1.103
	[PDG: $\frac{0.223}{3}$] [PDG: 0.669]

Here we have not included decays to top quarks since m_t is large

iv Visible partial width $= \Gamma(\text{Leptons}) + \Gamma(\text{Hadrons})$

$= 1.93$ GeV $= 3.62$ GeV

Total width $= 4.12$ GeV

? The partial widths & total width used to measure

Comparison between $W^{\pm}$ and Z decays

W and Z have similar masses

Branching ratios for hadronic v. similar

[PDG: $B(Z \to \text{hadrons}) = 0.669$, $B(W^{+} \to \text{hadrons}) = 0.674$]

Branching ratios for leptonic modes differ.

[PDG: $B(Z \to \text{leptons}) = 0.101$

$B(W^{\pm} \to \text{charged lepton + neutrino}) = 3 \times 0.1086 = 0.32$]

ptc.

v $\frac{\Gamma(Z \to \text{Leptons})}{\Gamma(Z \to \text{Hadrons})} = 0.224$

$\Gamma_{TOTAL} = 2.42\,GeV$

$\frac{\Gamma(Z \to \text{Leptons})}{\Gamma_{TOTAL}} = 0.103$

[PDG: 0.101]

$\frac{\Gamma(Z \to \text{Hadrons})}{\Gamma_{TOTAL}} = 0.692$

[PDG: 69.9%]

$\frac{\Gamma(Z \to \text{Charmed})}{\Gamma_{TOTAL}} = \frac{0.0951 \times 3}{2.42} = 11.8\%$

[PDG: 12.0%] $= 0.089$

$\frac{\Gamma(Z \to \text{bottom})}{\Gamma_{TOTAL}} = \frac{0.1226 \times 3}{2.42}$

$= 0.051$

[PDG: 12 %]

≈ 0.153

vi Distinguishing between decays of the Z boson

$Z \to e^- e^+$ will produce electron showers in detectors such as silicon strip detectors, bubble chambers or scintillation counters.

Use a magnetic field to find momentum via the radius of curvature, and distinguish e^- & e^+ from dir^n.

Electrons are more strongly interacting than muons as a result of lower mass.

$Z \to \mu^- \mu^+$ use the same principle as from $e^+ e^-$ but as a result of lower interaction strength use muon calorimeters

$Z \to$ hadrons will produce hadronic showers. Will pass through electron calorimeters.

Invisible decays can be inferred from conservation of momentum - check angles of outgoing particles.