Exercises for Theoretical Particle Physics I

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Sheet 5

The Z-boson is an unstable particle with mass $m_Z \approx 91.19$ GeV. It can decay into quarks, charged leptons and neutrinos. This means that the Z-resonance has a finite width Γ_Z, which has been measured at great precision at LEP and, more recently, at the LHC. Γ_Z is an important observable because it is not only sensitive to various SM parameters, but also imposes a lower bound on the masses of particles in a fourth generation (or other weakly charged particles). If these were lighter than $m_Z/2$, the decay into them would contribute to Γ_Z.

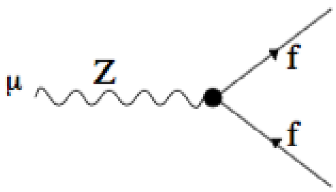
Problem 1: Matrix elements for Z-decay **5 point**

Calculate the matrix elements for Z-boson decays into up quarks, down quarks, charged leptons and neutrinos.

Problem 2: Z-decay width **5 points**

Use the results to compute the contributions to the Z-width from decay into up and down type quarks, charged leptons and neutrinos. Neglect the top quarks and assume, for simplicity, that all quarks are massless. Compare the results to the observed contributions to Γ_Z into hadrons ($\Gamma_Z \approx 1744.4$ GeV), charged leptons ($\Gamma_Z \approx 84.0$ GeV) and the "invisible Z width" ($\Gamma_Z \approx 499.0$ GeV). How important are quark masses and hadronization?

Some useful formulae: The vertex of the Z-boson with the fermions is given by



$$i\frac{g_2}{2\cos\theta_W}\gamma_\mu(v_f - a_f\gamma_5)$$

with $v_f = T_3^f - 2Q_F\sin^2\theta_{\mathrm{W}}$ and $a_f = T_3^f$. Here Q_f and T_3^f denote the charge and the third component of the weak isospin of the left-handed fermion f_{L}, respectively, while θ_{W} is the Weinberg angle with the value $\sin^2\theta_{\mathrm{W}} \approx 0.23$. The charges are:

	ν_L^e	e_L^-	e_R^-	u_L	d_L	u_R	d_R
Q	0	-1	-1	$2/3$	$-1/3$	$2/3$	$-1/3$
T_3	$1/2$	$-1/2$	0	$1/2$	$-1/2$	0	0
Y	-1	-1	-2	$1/3$	$1/3$	$4/3$	$-2/3$

For the polarization sum with a gauge boson of mass m the following formula is useful:

$$\sum_{\epsilon^\mu q_\mu = 0} \epsilon^\mu \epsilon^{\nu *} = -\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{m^2} \right) .$$