Exercises for "Phenomenology of Particle Physics II"

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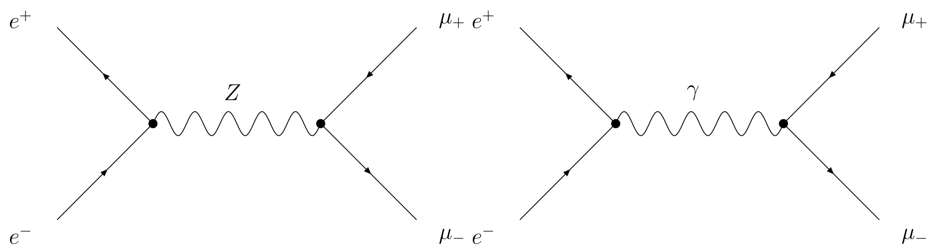
http://www.itp.phys.ethz.ch/education/lectures_fs09/PPPII

Exercise 6 $e^+e^- \to \mu^+\mu^-$ with the Z-boson

In the electroweak standard model, the following two diagrams contribute to $e^+e^- \to \mu^+\mu^-$ at tree level:



Calculate the cross section and the forward-backward asymmetry for this process for $m_\mu^2 \ll s$. Take into account the fact that the Z-boson is unstable, therefore $p^2 - M_Z^2 \to p^2 - M_Z^2 + iM_Z\Gamma_Z$ in the propagator of the Z-boson.
Proceed as follows:

- Decompose both amplitudes using the projectors P_R and P_L for both fermions, such that the matrix element is a sum of four non-interfering contributions
- Write the differential cross section $\frac{d\sigma}{d\Omega}$ as
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\alpha^2}{4s}\left[A_0\left(1+\cos^2\Theta\right) + A_1\cos\theta\right].$$
- Show that the forward-backward asymmetry is given by
$$A = \frac{F-B}{F+B} = \frac{3A_1}{8A_0}, \qquad F = \int_{\cos\theta=0}^{\cos\theta=1} \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\mathrm{d}\Omega, \qquad B = \int_{\cos\theta=-1}^{\cos\theta=0} \frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\mathrm{d}\Omega$$

The QED results for the polarized differential cross sections are
$$\frac{\mathrm{d}\sigma^{\mathrm{QED}}}{\mathrm{d}\Omega}(e_L^+e_R^- \to \mu_L^+\mu_R^-) = \frac{\mathrm{d}\sigma^{\mathrm{QED}}}{\mathrm{d}\Omega}(e_R^+e_L^- \to \mu_R^+\mu_L^-) = \frac{\alpha^2}{4s}\left(1+\cos\Theta\right)^2$$
$$\frac{\mathrm{d}\sigma^{\mathrm{QED}}}{\mathrm{d}\Omega}(e_L^+e_R^- \to \mu_R^+\mu_L^-) = \frac{\mathrm{d}\sigma^{\mathrm{QED}}}{\mathrm{d}\Omega}(e_R^+e_L^- \to \mu_L^+\mu_R^-) = \frac{\alpha^2}{4s}\left(1-\cos\Theta\right)^2.$$