PHY213 - KT II
Exercise Sheet 5

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Exercise 1: $e^+e^- \to \gamma/Z \to \mu^+\mu^-$ Cross Section

The differential cross section for the process $e^+e^- \to \gamma/Z \to \mu^+\mu^-$ can be simplified as

$$\frac{d\sigma}{dcos\theta} = \mathcal{F}(s)\left[A(1+\cos^2\theta) + 2B\cos\theta\right] \tag{1}$$

where $\mathcal{F}(s)$ encapsulates the dependence of the cross section on the CoM energy, while A and B are functions of the left and right couplings of the fermions such that

$$\begin{aligned} A &= ({c_L^e}^2 + {c_R^e}^2)({c_L^\mu}^2 + {c_R^\mu}^2) \\ B &= ({c_L^e}^2 - {c_R^e}^2)({c_L^\mu}^2 - {c_R^\mu}^2) \end{aligned} \tag{2}$$

After having set the correct pythia options in order to

- Activate the desired process
- Deactivate any subprocess which is not the hard one
- Set the beams to be e^+e^- and their CoM energy to be the m_Z

Loop inside the particles in each event and, using the matplotlib libraries, plot the distributions of p_Z, p_T and the rapidity η of the outgoing fermions.

Exercise 2: The forward-backward asymmetry, A_{FB}

If we define

$$\sigma_F = \int_0^1 d(cos\theta)\frac{d\sigma}{dcos\theta} \quad \text{and} \quad \sigma_B \int_{-1}^0 d(cos\theta)\frac{d\sigma}{dcos\theta} \tag{3}$$

The forward-backward asymmetry A_{FB} can be defined as

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \tag{4}$$

When plugging the cross section of equation (1) we obtain an expression for A_{FB} which is:

$$A_{FB} = \frac{16}{3\pi}A_e A_\mu \tag{5}$$

With

$$A_f = \frac{{c_L^f}^2 - {c_R^f}^2}{{c_L^f}^2 + {c_R^f}^2} = \frac{2c_V^f c_A^f}{{c_V^f}^2 + {c_A^f}^2}$$

a) Set the process to be $e^+e^- \rightarrow Z \rightarrow \mu^+\mu^-$ and rerun 10^6 events, compare the number of events ending in the forward/backward region and compute the forward backward asymmetry

b) Repeat the same exercise with half the energy available at the CoM ($s = m_Z/2$)

c) Repeat the same exercise of the previous point enabling only the exchage of a photon, do you notice any difference?

Exercise 3: Weinberg mixing angle

Using equation (5) and the fact that

$$\frac{c_V}{c_A} = 1 - 4|Q_f| sin^2\theta_W$$

Where Q_f is the charge of the fermion f, to estimate the $sin^2\theta_W$ using the computed forward-backward asymmetry value.