Particle Physics: Problem Sheet 2

More on QED, Accelerators & Detectors, Quark & Leptons

1. Please make sure you have done questions 10 and 11 on last week's question sheet.

2. Draw the lowest order Feynman diagrams for our favourite process: $e^+e^- \to \mu^+\mu^-$. Discuss the corresponding Matrix element, $\mathcal{M}(e^+e^- \to \mu^+\mu^-)$.

   A similar process can be used to create pairs of quarks, $e^+e^- \to \mathrm{q\bar{q}}$. Discuss the corresponding Matrix element for this process, $\mathcal{M}(e^+e^- \to \mathrm{q\bar{q}})$.

   What can you say about the ratio of the cross sections,
   $$\frac{\sigma(e^+e^- \to \mathrm{q\bar{q}})}{\sigma(e^+e^- \to \mu^+\mu^-)}?$$

   Please note: this is not the whole answer to the problem! We'll look more at this process in the coming weeks.

3. Draw the lowest and second order Feynman diagrams for electron-muon scattering $e^-\mu^- \to e^-\mu^-$. Discuss the corresponding matrix element, $\mathcal{M}$, and cross section for the lowest order. Estimate the contribution of the second order diagrams to the cross section.

4. Some of what we have learned about QED is applicable to the weak force. The weak force can be propagated by the $W^{\pm}$-boson with mass $m_W = 80$ GeV/c^2. For example, nuclear beta decay can be described as $\mathrm{d} \to \mathrm{u}W^-$, followed by the decay of the W^- into $e^-\bar{\nu}_e$.

   Estimate the maximum range of the weak force propagated by the W-boson.

   What does the Yukawa potential look like for exchange of a W-boson? The coupling of the W-boson, is written as g_W.

5. In a synchrotron accelerator, why do charged particles loose energy? The energy loss per turn is:
   $$\Delta E = \frac{q^2\beta^3\gamma^4}{3\epsilon_0\rho}$$
   The LEP and LHC synchrotrons were built in the same tunnel ($\rho_{\mathrm{LEP}} = \rho_{\mathrm{LHC}} = 4300$ m). At LEP the energy of the electrons was $E_e = 45.2$ GeV; at LHC the energy of the protons will be $E_p = 7000$ GeV. What is the ratio of the energy loss at LEP and LHC?

6. Describe (briefly) how an electron, a charged pion and a muon appear in a typical collider detector.

7. Cosmic ray muons are produced at the top of the atmosphere. As they travel through matter, muons loose energy to ionisation. The energy loss for muons can be described by $dE/dx \approx 2.0$ MeVg^{-1}cm^2.

   How much energy does a muon with three-momentum, $p_\mu = 5$ GeV/c lose by ionisation before reaching sea level?

   Hint: the total energy loss, $\Delta E = dE/dx \times x$, where x is the thickness of the atmosphere in g/cm^2. The mass thickness of the atmosphere can be inferred from the pressure at sea level, $P = 1$ atm $= 10^5$ kgm^{-1}s^{-2}, by assuming the density to be constant.

8. What quantum numbers are associated with leptons? Are they conserved in strong, weak and electromagnetic interactions?

9. What quantum numbers are associated with quarks? Are they conserved in strong, weak and electromagnetic interactions?

10. What are the charge, isospin, strangeness and baryon quantum numbers for the $\bar{\mathrm{u}}$, $\bar{\mathrm{d}}$ and $\bar{\mathrm{s}}$ quarks? What are the quantum numbers of the lambda anti-baryon, $\bar{\Lambda}^0$, and of the antiproton, $\bar{p}$? Make sure you understand these in terms of quark content!