# Particle Physics - Problem Sheet 5

## Discussion Questions

D1 (a) Draw a Feynman diagram illustrating Deep Inelastic Scattering (DIS) $e^-p \to e^-X$.

Four variables are defined to describe DIS:

$$x \equiv \frac{Q^2}{2p_2 \cdot q} \qquad Q^2 \equiv -q^2 = (p_1 - p_3)^2 > 0 \qquad \nu \equiv \frac{p_2 \cdot q}{M_p} \qquad y \equiv \frac{p_2 \cdot q}{p_2 \cdot p_1}$$

  (b) Show that $0 < x \leq 1$. What does $x$ represent?

  (c) Working in the proton rest frame, calculate a value for $y$ and show that $0 \leq y \leq 1$. What does $y$ represent?

D2 (a) Draw the two main Feynman diagrams that contribute to the process $B^0 \to J/\psi \, K_S^0$ (one diagram is a so-called "penguin diagram"). What elements of the CKM matrix is this process sensitive to?

  *Look up the quark content of each of the mesons - you are not expected to know this on the top of your head! "$J/\psi$" is a single meson.*

  (b) In November 2012, the LHCb collaboration at CERN observed the decay of the $B_S$ meson into $\mu^+\mu^-$ for the first time with a branching ratio of $3.2^{+1.5}_{-1.2} \times 10^{-9}$. Draw a Feynman diagram for this decay. What elements of the CKM matrix is this process sensitive to?

## Standard Questions

S1 (a) Determine the value of

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

for CM energies, $\sqrt{s}$, of 2 GeV, 5 GeV, and 30 GeV.

  (b) What is the angular distribution of the jets produced by $e^+e^- \to$ hadrons?

S2 (a) Write down the deep inelastic form factors $F_2(x)$ for electron-proton and electron-neutron scattering in terms of the valence quark parton density functions, u$(x)$ and d$(x)$. With the assumption that u$(x) = $ 2d$(x)$, what is the ratio of these form factors for large $x$?

  (b) What is the effect on the form factors of the addition of the sea quark distributions, $\bar{\text{u}}(x), \bar{\text{d}}(x), \bar{\text{s}}(x)$ at low $x$? If the contribution of the valence quarks can be neglected at very small $x$, what is then the ratio of the neutron to proton form factors?

S3 The $\Delta^{++}$, $\Delta^-$ and $\Omega^-$ are members of the baryon decuplet.

(a) Give the valence quark flavours and spins of these states.

(b) Why is the existence of these baryons evidence for an antisymmetric color wavefunction?

$$\frac{1}{\sqrt{6}}[rgb - rbg + gbr - grb + brg - bgr]$$