Partice Physics: Problem Sheet 4

QCD, gluons, partons and the weak force

1. At very high beam momenta, $p \sim 100$ GeV/c, the total cross sections for $\pi^+ p$ and pp scattering is dominated by the exchange of a gluon between quarks inside the pions and protons.

   (a) Draw a Feynman diagram for pp and $\pi^+ p$ scattering.

   (b) Use the number of possible diagrams to calculate the ratio of cross sections $\sigma(\pi^+ p)/\sigma(pp)$. **Hint**: every (different) diagram you can draw is equally likely.

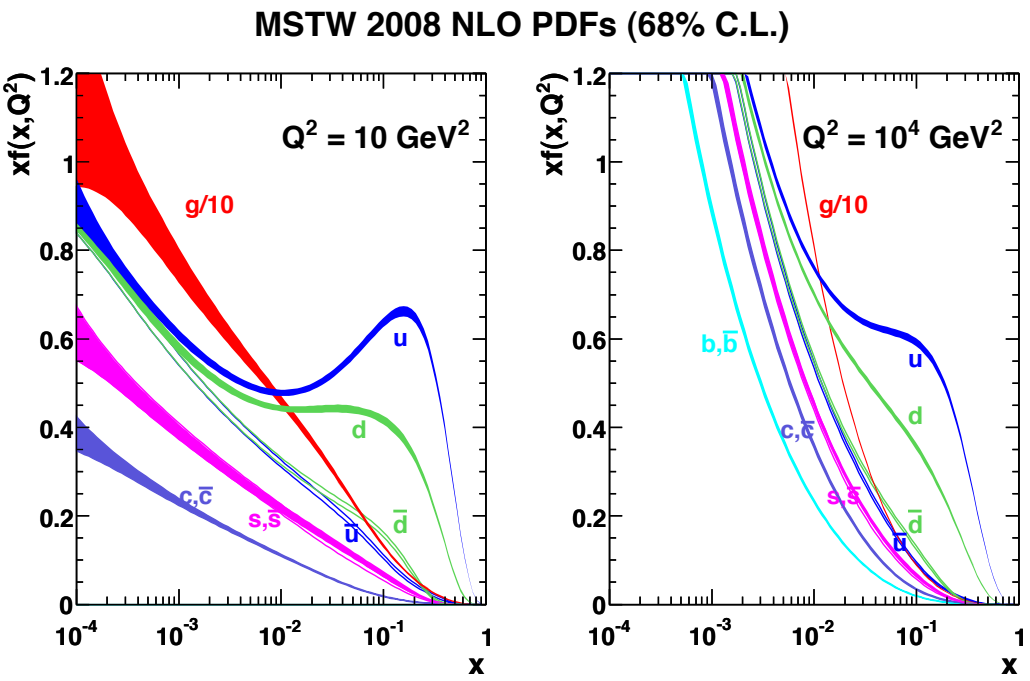
2. The J/ψ meson was discovered through its electromagnetic decays into e^+e^- and $\mu^+\mu^-$. However, the J/ψ decays mainly through strong interactions such as: $J/\psi \to \pi^+\pi^-\pi^0$.

   Parity, π is a conserved quantum number in quantum numbers. The parity of J/ψ meson is $\pi(J/\psi) = -1$ and the parity of a gluon is $\pi(\mathrm{g}) = -1$. Recall (from nuclear part of the course), that parity is multiplicative quantum number, i.e. you need to multiply the parity of each of the particles to get the overall parity of the state.

   By considering the conservation of parity and **colour quantum numbers**, draw the Feynman diagram for the decay $J/\psi \to \pi^+\pi^-\pi^0$. Hence explain why, although most of the decays of J/ψ are due to the strong force, it has a relatively long lifetime.

3. Draw a Feynman diagram for the process $p\pi^+ \to \Delta^{++} \to p\pi^+$.

4. What is meant by colour confinement?



5. The above figure on the right shows the (predicted) parton distribution function for the proton at momentum transfer (boson momentum) of $Q^2 = 10^4$ GeV^2, which is roughly appropriate for proton-proton collisions at the LHC.

   (a) At this value of Q^2, what is the most commonly found parton in the proton?

   (b) The "hard scatter" is the term used for the collision of two partons. In one particular collision event at the LHC, a gluon with $x = 0.1$ collides with an up quark with $x = 0.2$. What is the effective collsion energy of this event, $\sqrt{\hat{s}}$?

6. Calculate the value of the cross section ratio, R:

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

   in the range $4 < E_{CM}/\text{GeV} < 10$, when u, d, s and c quarks can be produced. Compare these values, as best you can, to the values on the plot in lecture 6.

   By considering the centre of mass energy which they are produced, what is the quark content of the $\psi(2S)$ and Υ states shown in the plot?

   What is the peak at $E_{CM} \approx 90$ GeV?

7. Write down all possible decay modes of the W^- boson into quarks and leptons. What is the strength of each of these vertices?

8. By drawing the lowest order Feynman diagrams, show that both charged ($W^\pm$ exchange) and neutral current (Z^0 exchange) contribute to neutrino electron scattering: $\nu_e + e^- \to \nu_e + e^-$.

9. Draw the lowest order Feynman diagram for the decay of a tau into an electron and into a muon: $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$, respectively.

   Calculate the matrix element for each of these decays. How does this relate to the Fermi constant:

$$G_F = \frac{\sqrt{2}\, g_w^2}{8\, m_W^2} \ ?$$