Particle Physics: Problem Sheet 4

QCD, gluons, partons

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

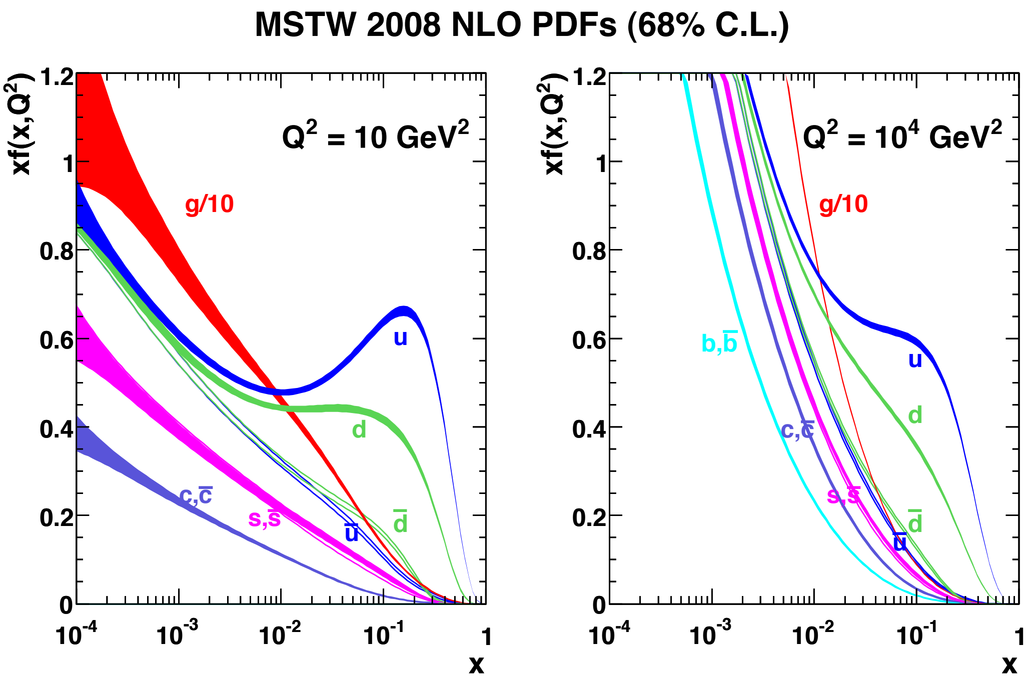
3. The ϕ meson decays via the strong force as follows:

$\phi \to K^+K^-$	49%
$\phi \to K^0\bar{K}^0$	34%
$\phi \to \pi^+\pi^-\pi^0$	17%

   What is the amount of kinetic energy produced in the decay, for these decays (also know as the Q-value of the decay).

   Draw Feynman diagrams of the above decays and explain why the decays to kaons is favoured despite the low Q-value?
   Hint: You have to consider the colour charge of the gluons.

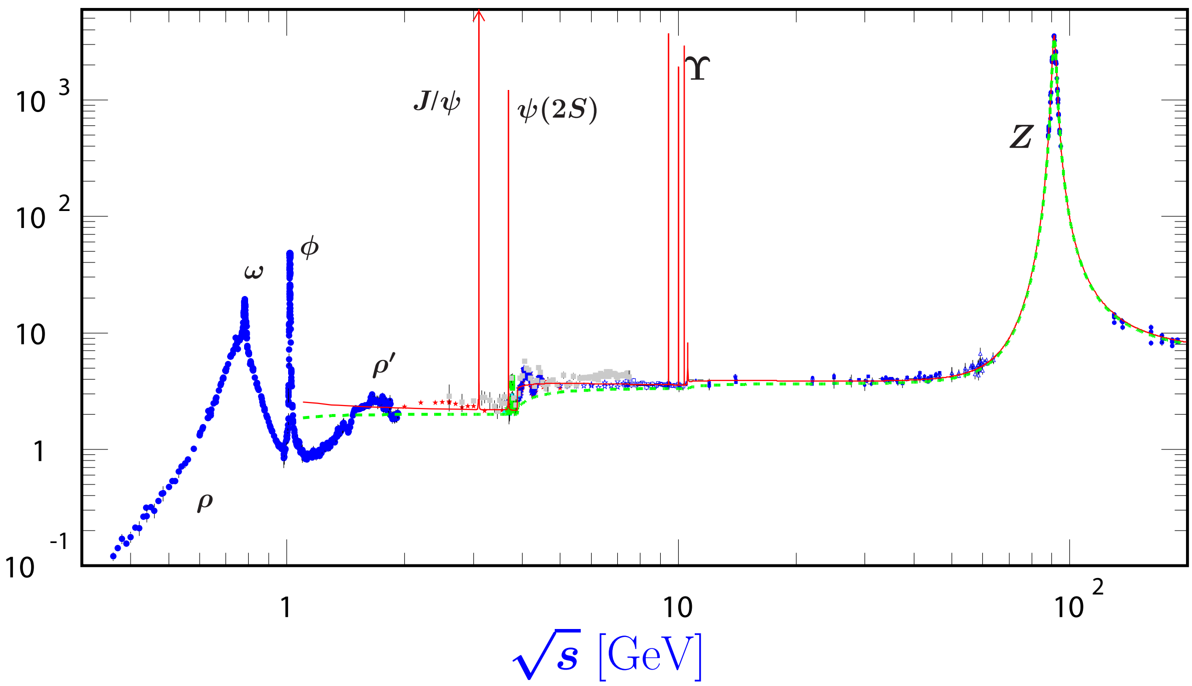
4. What is meant by colour confinement?



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. The above plot shows the measured value of cross section ratio, R, defined as:

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

as a function of the centre of momentum energy, $\sqrt{s}$. The jumps at $\sqrt{s} \sim 3$ GeV and ~ 10 GeV are due to the production of extra quarks. In the range:

- $2 < \sqrt{s}/\text{GeV} < 4$, when u, d and s quarks can be produced, $R \sim 2$.
- $4 < \sqrt{s}/\text{GeV} < 10$, u, d, s and c quarks can be produced , $R \sim 3.3$
- $10 < \sqrt{s}/\text{GeV} < 30$, u, d, s, c and b quarks can be produced, $R \sim 3.7$
- (For $\sqrt{s} > 30$ GeV weak force processes also take place, we won't therefore consider this here.)

Can you explain the observed values of R? Remember that $e^+e^- \to \mathrm{q\bar{q}}$ should include all possible $\mathrm{q\bar{q}}$ final states that can be produced for a given $\sqrt{s}$.