

# Particle Physics - Problem Sheet 3

## Discussion Questions

- D1 The quark confinement mechanism is one of the most difficult problems in particle physics, and is listed under “Yang-Mills Theory” as one of 7 mathematical problems of the new millennium.  
<http://www.claymath.org/millennium>

What is the evidence that quarks and gluons are confined?

What are the differences between QED & QCD that might explain confinement of colour, but not of electric charge?

How are the following models related to the problem?

- (a) A QCD potential
  - (b) The colour flux-tube model
  - (c) A “relativistic superconductor” model of “chromomagnetism” (Aitchison & Hey P.292-296)
- D2 (a) Describe the possible parton-parton scattering processes in proton-proton collisions at the LHC.
- (b) What are the differences between proton-proton and antiproton-proton collisions?
- (c) How are heavy quark pairs  $b\bar{b}$  and  $t\bar{t}$  produced?

## Standard Questions

- S1 (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  $d(x)$ . If  $u(x) = 2d(x)$ , 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,  $\bar{u}(x)$ ,  $\bar{d}(x)$ ,  $\bar{s}(x)$  at low  $x$ ? If the contribution of the valence quarks can be neglected at very small  $x$ , what is the ratio of the neutron to proton form factors as  $x \rightarrow 0$ ?
- S2 (a) Discuss why there are 8 (and not 9) gluon colour-anticolour states.
- (b) What are the possible gluon exchanges between the quark and antiquark in a meson which has a color wavefunction:

$$\psi = \frac{1}{\sqrt{3}}(r\bar{r} + g\bar{g} + b\bar{b})$$

- (c) Show that the sum of the meson color factors is  $-4/3$ .

S3 (a) Determine the value of

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

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

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

S4 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?

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

S5 Draw a diagram for production of a pair of heavy quarks (c, b, t) at a hadron collider. Draw a diagram for a single top quark at a hadron collider. Which process is more common?

S6 Decide whether each of the following decays is the result of a strong, electromagnetic or weak decay:

$$\begin{array}{lll} \rho^0 \rightarrow \pi^+\pi^- & K^{*+} \rightarrow K^0\pi^+ & \eta \rightarrow \pi^+\pi^- \\ \eta \rightarrow \gamma\gamma & \Sigma_0 \rightarrow \Lambda\gamma & \Sigma^+ \rightarrow n\pi^+ \end{array}$$