Answer TWO questions.

The numbers in square brackets in the right-hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

You may assume the following data:

Quark name	Approx.Mass ('bound')	Q	S	C	$\tilde{B}$	T
d	0.3 GeV	-1/3	0	0	0	0
u	0.3 GeV	2/3	0	0	0	0
s	0.5 GeV	-1/3	-1	0	0	0
c	1.3 GeV	2/3	0	1	0	0
b	4.5 GeV	-1/3	0	0	-1	0
t	180 GeV	2/3	0	0	0	1

Quark quantum numbers

Quark compositions:

$\pi^+ = u\bar{d}, \Lambda = uds, K^- = s\bar{u}$

∇^2 in spherical polars:

$$\nabla^2 = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2(\frac{\partial}{\partial r})) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta(\frac{\partial}{\partial\theta})) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2}$$

Constants:

$\hbar = 6.582 \times 10^{-25}$ GeV s.
$c = 2.998 \times 10^8$ m s^{-1}.

[Part marks]

1. Sketch the cross section $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ for e^+e^- centre of mass energies in the range 10GeV $< \sqrt{s} <$ 110 GeV, indicating the reasons for the main features. Briefly state what you expect to happen in the range between 10 GeV and 0 GeV. [3]

   Draw the leading order Feynman diagrams for the following processes and briefly outline how such events might be identified in a LEP detector. (e^-e^+ collisions took place at LEP at $\sqrt{s} \approx 90$ GeV.)

   $$e^+e^- \rightarrow e^+e^-$$ [6]

   $$e^+e^- \rightarrow \mu^+\mu^-$$ [4]

   $$e^+e^- \rightarrow b\bar{b}$$ [4]

   How is the cross section $\sigma(e^+e^- \rightarrow$ neutrinos) obtained from LEP data? [3]

2. A force is mediated by boson of mass M. Using the Klein-Gordon equation, obtain an equation satisfied by the potential due to a fixed source of these bosons. [3]

Show that $\psi = -K\dfrac{e^{-r/R}}{r}$, the Yukawa potential, is a solution of this equation for a spherically symmetric source where r is the distance from the source and K is a constant. What is R in terms of the mass of the boson? What is the physical significance of R?. [3]

The weak force is due to W, Z exchange, mass $\approx$ 100 GeV. Give the range in metres. [1]

Given that the gluon is massless, what feature of the strong force is responsible for the fact that it has a finite range. Give an approximate expression for the range and briefly justify this expression. [4]

By drawing quark diagrams for the following processes, argue whether they proceed via the strong, electromagnetic or weak interactions, or whether they are completely forbidden. [10]

$$p + p \rightarrow p + n + \pi^+$$
$$\pi^0 \rightarrow \gamma + \gamma$$
$$K^- + n \rightarrow \Lambda + \pi^-$$
$$p + n \rightarrow \pi^+ + \pi^0$$
$$p + K^- \rightarrow p + \pi^0 + \pi^-$$

3. For a two-body scattering $A + B \rightarrow C + D$, the Mandelstam variables are given by:

$$\begin{aligned} s &= (p_A + p_B)^2 \\ t &= (p_A - p_C)^2 \\ u &= (p_A - p_D)^2 \end{aligned}$$

where p_A is the four-momentum of particle A, and so on. Show that $s + t + u = m_A^2 + m_B^2 + m_C^2 + m_D^2$ [2]

Draw a diagram for **neutral-current** deep inelastic electron proton scattering $e^- + p \rightarrow e^- + X$, where X is a hadronic system. What is the invariant mass of the exchanged boson in terms of the Mandelstam variables? [4]

In the quark parton model the cross section for deep inelastic scattering may be written

$$\frac{d\sigma}{dx dQ^2} = \mathcal{A}(x, Q^2) \times F_2(x, Q^2)$$

where x is the fraction of the proton's momentum carried by the struck parton and $Q^2 = -t$. $\mathcal{A}$ is a factor depending upon the kinematics of the e^+q scattering and $F_2(x, Q^2)$ parameterises the distribution of quarks inside the proton.

What is the expected Q^2 dependence of F_2 in this model? Say briefly why this is so, discussing the relationship between Q^2 and distance. [3]

Draw a diagram for **charged-current** deep inelastic electron proton scattering $e^- + p \rightarrow \nu_e +$ hadrons. Say which of the two cross sections (neutral or charged current) you expect to be dominant at

(a) $Q^2 = 50$ GeV^2

(b) $Q^2 = 50000$ GeV^2,

and explain why. [4]

At HERA, 820 GeV protons are in head-on collisions with 27.5 GeV electrons. Both charged- and neutral-current processes are observed, as well as large background from $p + A$ processes where A is the nucleus of an atom of residual gas in the beampipe. Suggest two trigger cuts (or sets of cuts) based upon measurements of the total energy and momentum in an event, one to accept neutral-current events, the other to accept charged-current events. In each case state clearly why $p + A$ events would fail the trigger. [6]

For which of the two classes of deep inelastic scattering event would you expect the final (offline) x and Q^2 resolution to be better? Why? [1]

PHYS4441/1997 **END OF PAPER**