University of Toronto PHY357S

Problem Set 3

due <u>Wednesday</u>, 20 March 2002

(Late penalty is 10% per day, and no problem set is accepted after March 22.)

Each problem is of equal weight, but **not all problems may be marked**.

These problems are primarily based on Chapters 1-9 of Martin and Shaw and on the lectures up to March 11; Appendices A, B and E and the inside back cover of M&S may also be helpful.

1) Use the data shown in Martin & Shaw Figure 7.14 to set an upper limit on the charge radius of charm quarks. (The solid line in the figure is the prediction assuming all quarks are point fermions.) Any reasonable criterion for setting the upper limit will be accepted. Assume a dipole form factor for the size of the quarks.

2) Assume that the momentum distributions of valence u quarks in the proton and valence $\bar{d}$ quarks in the antiproton have the forms:

$$F_u(x) = x\,u(x) = a_1(1-x)^3,$$

$$F_{\bar{d}}(x) = x\,\bar{d}(x) = a_2(1-x)^3,$$

where x is the Bjorken *scaling variable* (fractional momentum of nucleon carried by a quark.

a) If the quarks account in total for half the nucleon momentum, find a_1 and a_2. (Neglect the existence of sea quarks; gluons carry the other half of the nucleon momentum.)

b) Write down the resonant cross section (as a function of $\hat{s}$) $\sigma_{u\bar{d}\to W^+}(\hat{s})$ for $u\bar{d}\to W^+$ production, where $\hat{s}$ is the c.o.m. energy of the $u\bar{d}$ collision. Assume the quarks and antiquarks are inside a proton or antiproton. *Remember that quarks come in different colours and the W boson is colourless*.

c) By considering all possible decays of the W boson (*e.g.* Martin & Shaw Figs. 8.10 & 8.20), estimate the branching ratio for $W^+\to u\,\bar{d}$.

d) What is the value, σ_{peak}, of the $u\bar{d}\to W$ cross-section at the peak of the resonance?

e) Make a "narrow width" approximation that the $u\bar{d}\to W$ resonance is a delta function. (*i.e. For a resonance of mass M and width Γ,* $\sigma(s) \sim \delta\left(1 - s/M^2\right)\sigma_{peak}\,\Gamma/M$.) Integrate the cross-section over the quark distributions of part (a) to calculate the cross-section for $p\bar{p}\to W^+ +$ *anything*. *(This part has some very tedious integration. Don't forget that* $\int_{x-\varepsilon}^{x+\varepsilon}\delta(x)\,dx = 1$.*)*

f) Estimate the total cross sections for $\sigma_{p\bar{p}\to W^+}$ at

i) the UA1 experiment at CERN ($\sqrt{s}$ =0.54 TeV in 1982),

ii) the CDF experiment at Fermilab ($\sqrt{s}$ =2TeV in 2002), and

3) There is very weak evidence from CERN for a boson with a mass around 115GeV.

a) Such a Higgs would be similar in mass to the Z^0. Estimate the branching ratios of such a Higgs into each possible type of quark-antiquark or lepton-antilepton pair, and compare these to the branching ratios of the Z^0. *i.e.* Write down a table with the branching ratios into each possible pair for both the Higgs and the Z^0.

b) Use dimensional arguments to make a rough estimate of the total decay width of a 115 GeV Higgs boson and compare it to the total decay width of the Z^0.