Name: **Group:**

Problem sheet 10 – Physics V – WS 2006/2007

Due: January 11/12, 2007

Problem 10.1: Hadron production in e^+e^- annihilations (30 points)

The production channels $e^+e^- \to f\bar{f}$ have been studied extensively at the PETRA collider at DESY up to centre-of-mass energies of 22 GeV. (Note: $f/\bar{f}$ stands for any kind of fermion / antifermion.)

a) Give a list of all possible production channels (at the level of quarks and leptons) at this energy and draw the Feynman disagram for one of these channels. Which channel cannot be described by the annihilation diagram alone and why?

b) The total cross section for muon pair production is given (in leading order) by

$$\sigma_{\mathrm{tot},\,\mu^+\mu^-} = \frac{4\pi}{3}\,\frac{\alpha^2}{s}$$

What is the corresponding cross section for up quarks and bottom quarks, respectively, in the quark parton model including leading order QCD corrections?

c) Why are QCD corrections relevant but not higher order QED corrections?

d) Give the formula for the expected ratio $R = N(e^+e^- \to \mathrm{hadrons})/N(e^+e^- \to \mathrm{muons})$ at $\sqrt{s} = 22$ GeV? Calculate it including the QCD correction in order α_s. Use $\alpha_s(m_Z^2) = 0.118$ to calculate α_s for the PETRA energy.

Problem 10.2: Z production at hadron colliders (40 points)

In 1983, the Z boson was discovered at the CERN $p\bar{p}$ collider at a centre-of-mass energy of $\sqrt{s} = 540$ GeV by its decay into lepton pairs.

a) Draw the Feynman diagrams for Z production by quark-antiquark annihilation and decay into muons.

b) The mass of the Z is 91 GeV. What is the condition for the quark/antiquark momentum fractions x_1 and x_2 to produce a Z particle?

c) Which type of quarks (valence or sea quarks) will dominate production at the CERN $p\bar{p}$ collider? Use the table of parton densities below / on the next page to estimate the fraction of up, down, and sea quarks which are able to contribute to Z production assuming symmetric production ($x_1 = x_2$). Keep in mind that the Z production cross section has the same resonance shape in the parton centre-of-mass system as in $e^+e^- \to Z$.

d) Would a pp collider with the same $\sqrt{s}$ perform just as well?

e) At the LHC we expect a huge production rate for Z bosons at the centre-of-mass energy of $\sqrt{s} = 14$ TeV in pp collisions. Which type of quarks (valence or sea quarks) will dominate at that centre-of-mass energy? (Have a look at the table of parton densities again.)

Problem 10.3: QCD and parton model (30 points)

For each of the following statements, quote at least one experimental measurement demonstrating that the statement is true:

a) The nucleon is made of point-like constituents.
b) Quarks have spin 1/2.
c) Quarks exist with three different colour charges.
d) Quarks carry fractional electrical charges.
e) In addition to quarks, there are gluons in the nucleon.
f) Gluons have spin 1.

x	Δx	$x\,u(x)$	$x\,d(x)$	$x\,q_s(x)$
0.005	0.010	0.771	0.714	0.634
0.015	0.010	0.644	0.549	0.408
0.030	0.020	0.624	0.485	0.291
0.060	0.040	0.641	0.435	0.187
0.100	0.040	0.659	0.390	0.117
0.160	0.080	0.640	0.323	0.062
0.250	0.100	0.539	0.225	0.024
0.350	0.100	0.386	0.136	0.007
0.450	0.100	0.238	0.072	0.002
0.550	0.100	0.124	0.032	0.000
0.700	0.200	0.030	0.006	0.000
$\sum_i \Delta x_i$	$x_i f(x_i)$	0.264	0.129	0.037

Table 1: Momentum distributions of quarks in the proton. The column $x\,q_s(x)$ gives the average distribution of sea quarks, assuming $q_s(x) = s(x) = \bar{s}(x) = \bar{u}(x) = \bar{d}(x)$. The term $x\,u(x) = x\,u_v(x) + x\,q_s(x)$ contains valence and sea quarks.