Queen Mary & Westfield College
Royal Holloway UoL
University College

Intercollegiate Postgraduate Course in Elementary Particle Physics

Paper 2: Wednesday, 8 April 1998

Time allowed for the Examination: 3 hours

Attempt **one** question from **section A** and **two** questions from **section B**.

Section A: Electroweak Interactions part 2
Section B: Experimental Techniques

Section A : Electroweak Interactions part 2

Question 1

1. Define, in terms of the usual four vectors, the scaling variables x and y for deep inelastic lepton - nucleon scattering (DIS). Give simple interpretations of the variables x and y in terms of the parton model and the lepton parton CM frame.

2. Explain what is meant by scaling in deep inelastic processes.

3. For Q^2 much smaller than M_W^2 the neutrino deep inelastic cross section is given by

$$\frac{d^2\sigma^{\nu\overline{\nu}}}{dxdy} = \frac{G_F^2}{2\pi} s \left[F_2 \frac{(1+(1-y)^2)}{2} \pm xF_3 \frac{(1-(1-y)^2)}{2} \right]$$

where s is the square of the CMS energy, F_2 and F_3 are the structure functions, and G_F is the Fermi constant. (In this question the Cabibbo angle is ignored).

If the ν quark and ν antiquark cross sections are given by

$$\frac{d\sigma^{\nu}}{d\Omega} = \frac{G_F^2}{4\pi^2}\hat{s} \text{ and } \frac{d\sigma^{\nu}}{d\Omega} = \frac{G_F^2}{4\pi^2}\hat{s}(1+cos\theta)^2$$

where $\hat{s}$ and θ are respectively the square of the CM energy and the scattering angle in the lepton quark CM frame, show that

$$F_2^{\nu} = 2x(Q(x) + \overline{Q(x)}) \text{ and } xF_3^{\nu} = 2x(Q(x) - \overline{Q(x)})$$

here $Q(x)$ and $\overline{Q(x)}$ are the appropriate quark probability distributions within the nucleon.

4. Recalling that for the deep inelastic scattering of electrons, $F_2 = \sum_i xq_i^2 Q_i(x)$ where q_i is the fractional quark charge, and the sum is over all quarks and anti quarks in the nucleon, show that

$$F_2^{\nu N} = \frac{18}{5} F_2^{eN}$$

if strange and heavier quarks are neglected and N represents the nucleon average of neutron and proton.

5. Draw and label the Feynman diagrams of two processes that lead to scaling violations.

6. Write down the matrix element for the QCD Compton process.

Question 2

1. Show that the action of γ^5 on a spinor is the same as that of the helicity operator in the massless limit. You may assume without proof that the lower components of a spinor is given by $\sigma.p/(E+M)$ times the upper components and that in the Dirac - Pauli representation γ^5 is given by

$$\begin{pmatrix} 0 & I \\ I & 0 \end{pmatrix}$$

2. Starting from the charged weak current expressed in the form

$$J^{+\mu} = \frac{g_w}{\sqrt{2}} \overline{u_\nu} \gamma^\mu \frac{1}{2}(1-\gamma^5) u_e$$

show that the weak charged current may be written as

$$J^{+\mu} = \frac{g_w}{\sqrt{2}} \overline{\lambda_l} \gamma^\mu \tau^+ \lambda_l$$

where λ_l are lepton left-handed weak isospin doublets, and τ^+ is the weak isospin raising operator.

Show that g_w is related to the Fermi constant G_F by

$$\frac{G_F}{\sqrt{2}} = \frac{g_w^2}{8M_w^2}$$

3. Explain what is meant by weak hypercharge Y where $Y = 2Q - 2T^3$.
4. Starting from the interaction term

$$g_w J^{\mu 3} W_\mu^3 + \frac{g^{'}}{2} J_Y^\mu B_\mu$$

and making the massless W^3 and B fields superpositions of the photon and Z^0 fields obtain the form of the neutral current coupling.

Section B : Experimental Techniques

Question 3

The Binomial and Poisson probability distributions are

$$P(n) = \frac{N!}{n!(N-n)!}\, p^n (1-p)^{N-n}, \qquad P(n) = \frac{\lambda^n}{n!}\, e^{-\lambda}$$

respectively. Explain the meanings of the symbols in these equations. **2 marks**

An HEP experiment runs for several years and a histogram is made of the distribution of the number of reconstructed charged tracks per event, where all the events recorded by the experiment are included in the plot. Consider a single bin in this histogram, for example, the number of events where exactly 5 tracks are observed, N_5.

- Consider the (thought-experiment) case in which the whole experiment is repeated multiple times, where a repeat is defined to be that the experiment is rerun until the integrated luminosity taken is exactly the same as in the original experiment. Explain which probability distribution would be expected to describe the distribution of values of N_5 which would result from the multiple experiments. State or derive the mean and variance of this distribution. **4 marks**

  If 100 events were observed with exactly 5 charged tracks in the original experiment (i.e. $N_5 = 100$), then give an estimate of the unknown parameter of this distribution and hence an estimate of the error on N_5 **3 marks**

- Consider a second case in which the whole experiment is repeated multiple times, where a repeat is now defined to be that the experiment is rerun until the total number of events recorded is exactly the same as in the original experiment. Explain which probability distribution would be now expected to describe the distribution of values of N_5. State or derive the mean and variance of this distribution. **4 marks**

  Again, if 100 events were observed with exactly 5 charged tracks in the original experiment, then give an estimate of the unknown parameter of this distribution, and hence an estimate of the error on N_5, for the two cases where

  - a) the total number of events is 10000 and
  - b) the total number of events is 101

  4 marks

Comment on any differences or similarities between these results. Carefully state under what conditions these different ways of estimating the error would give approximately the same value. **3 marks**

Question 4

By means of a schematic diagram, show the arrangement of sub-detectors in a typical (or actual) detector at a colliding beam machine.

Discuss carefully how particles of different type can be identified in this detector.

Describe fully a typical electromagnetic or hadronic calorimeter, including the physical principles on which it is based, its construction and its performance.

Question 5

Explain what properties of silicon make it particularly appropriate for use in precision tracking of charged particles, and outline the instrumentation in which it is used currently at colliding beam experiments.

Derive the *semiconductor equation*, $\mathrm{np} = \mathrm{n}_i^2$, and explain the meaning of *depletion layer* when applied to a biassed device.

Silicon devices are normally n-type, and suffer radition damage when subjected to the influence of scattered particles from high energy hadron colliders. Discuss briefly the sources of the damage processes in the silicon and comment on how these effects can be overcome in the operation of future silicon tracker systems at LHC.

Question 6

(a) Most high energy physics experiments adopt a multi-level approach to data acquisition and triggering. Explain carefully what this means? What are the functions that are typically carried out within a level and what are the characteristics of different levels in terms of the type of computation they carry out and the technology they use for processing?

(b) Show how arrays of scintillation counters can be used together with a coincidence matrix to select charged particles produced in the region of a hydrogen target by an incident beam of protons.

(c) Distinguish between analogue and digital signals and explain the importance of analogue to digital and digital to analogue converters in particle physics experiments. Explain with diagrams how an analogue to digital converter can be interfaced to a microprocessor and how data can be transferred to the memory of the processor. Show how direct memory access (DMA) can be used to obtain very high performance.