Queen Mary & Westfield College
Royal Holloway UoL
University College

Intercollegiate Postgraduate Course in Elementary Particle Physics

Paper 2: Thursday, 20 March 1997

Attempt THREE *questions - One from each section*

Time allowed for the Examination: 3 hours

Section A: LEP Physics
Section B: Deep Inelastic Scattering
Section C: Experimental Techniques in High Energy Physics

Section A: LEP Physics

Question 1.

(i)(a) The Weizsäcker-Williams distribution of initial state radiation (ISR) has the form:

$$\frac{d^2\sigma}{dz dp_T^2} = \frac{\alpha}{\pi} \frac{1}{p_T^2} \frac{1+z^2}{1-z} \sigma_0 \left(s\sqrt{z}\right)$$

Describe the meaning of the various terms in this equation and draw the Feynman diagrams relevant to this process. [3]
(b) A threshold cross section consists of a sharp rising step at energy E_0 and either side of the step the cross section is constant. Discuss qualitatively the effect of ISR on the form of the observed cross section. [2]
(ii) Draw the three Feynman diagrams giving rise to W-pair production at LEP2 and sketch the form of the cross section as a function of $\sqrt{s}$. Indicate qualitatively how the cross section would vary when:
(a) The mass of the W increases ,
(b) The width of the W increases. [4]
(iii) Write down the three main event topologies (ie number of jets, leptons etc.) for W-pair events. Calculate approximately their relative abundances and rate each channel as to its usefulness in measuring the mass of the W. [5]
(iv) Draw the two Feynman diagrams responsible for standard model Higgs production at LEP2. Indicate which one is dominant for lower higgs masses and hence provide a “rule of thumb” as to the maximum higgs mass detectable for a given value of $\sqrt{s}$. [3]
(v) Given that you are searching for a higgs boson events with purely hadronic final states, discuss *briefly* how you would achieve the following:
(a) Optimise the mass resolution of the higgs boson,
(b) Reduce the background from W-pair events. [3]

Question 2.

(a) The total cross-section for $e^+e^- \to$ hadrons is shown in the diagram, as a function of centre of mass energy, together with the $\mu^+\mu^-$ and $\gamma\gamma$ final state cross-sections. Explain the shape of the curves, and say which parameters determine the position and height of the various features.

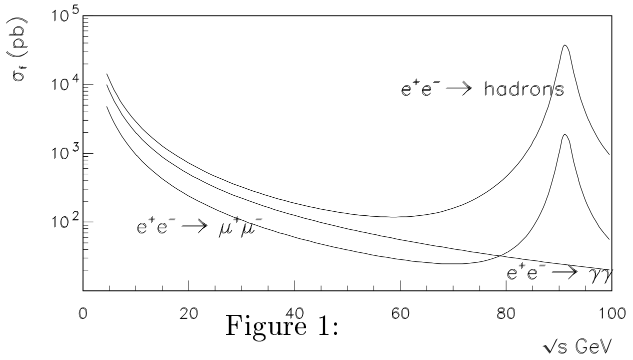

Figure 1:

(b) Explain what is meant by a partial width. What experimental quantities have been measured to establish values for the partial widths $\Gamma_{ee}, \Gamma_{\mu\mu}, \Gamma_{\tau\tau}$ and Γ_{hadrons}?

(c) Explain how the LEP and SLC experiments have measured the number of light neutrino flavours. Why could PEP/PETRA/TRISTAN not make this measurement?

(d) Define forward-backward asymmetry experimentally and explain the Standard Model theoretical expression,

$$A^f_{\text{FB}} = 3\frac{v_e a_e v_f a_f}{(v_e^2 + a_e^2)(v_f^2 + a_f^2)}$$

Briefly relate the theory to the experiment.

Section B: Deep Inelastic Scattering

Question 3.

(i) 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.

(ii) Explain what is meant by scaling in deep inelastic processes.

(iii) The cross section for electron - muon scattering is given by

$$\frac{d\sigma}{d\hat{t}} = \frac{2\pi\alpha^2}{\hat{t}^2}\left[\frac{\hat{s}^2+\hat{u}^2}{\hat{s}^2}\right]$$

where $\hat{s}$, $\hat{t}$ and $\hat{u}$ are the usual Mandelstam variables for e^- μ^- scattering and α is the fine structure constant.

The cross section for DIS with single photon exchange is given by

$$\frac{d^2\sigma}{dtdu} = \frac{2\pi\alpha^2}{t^2s^2(s+u)}\left[(s+u)^2 2xF_1(x) - 2usF_2(x)\right]$$

where s, t and u are the usual Mandelstam variables for DIS, and $F_1(x)$ and $F_2(x)$ are the Bjorken Structure Functions. By comparing the above show that

$$2xF_1(x) = F_2(x) = \sum_i q_i^2 x_i f_i(x_i).$$

in the quark parton model where q_i is the fractional charge of a quark carrying x_i of the proton four momentum with probablility $f(x_i)$.

(iv) Show that

$$\int F_2^{ep}(x)dx = \frac{4}{9}\epsilon_u + \frac{1}{9}\epsilon_d \text{ and } \int F_2^{en}(x)dx = \frac{1}{9}\epsilon_u + \frac{4}{9}\epsilon_d$$

where $\epsilon_u = \int_0^1 x(u(x)+\overline{u}(x))dx$ and $u(x), \overline{u}(x)$ are the up quark and antiquark momentum fraction distribution functions. You may assume that $u(x)$ in the proton is the same as $d(x)$ ie the down quark distribution in the neutron.

(v) If $\int_0^1 F_2^{ep}(x)dx = 0.18$ and $\int_0^1 F_2^{en}(x)dx = 0.12$ what fraction of the nucleon momentum is carried by the gluons?

(vi) If a spin zero leptoquark or squark of mass M, be resonantly produced at HERA what would be the x and y distributions of such events?

Section C: Experimental Techniques in High Energy Physics

Question 4.
Explain what features of silicon material make it particularly appropriate for use in charged particle tracking instrumentation in colliding beam experiments.

Give a schematic layout of a silicon detector sysytem as currently used within a LEP experiment.

Derive the *semiconductor equation*, $\mathrm{np} = \mathrm{n}_i^2$, and explain what is meant by the term *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 and the consequences these effects will have on the operation of future silicon tracker systems at LHC.

Question 5.
Discuss the processes involved in the production of

(a) an electromagnetic shower by a high energy electron,

(b) a hadronic shower by a high energy charged pion.

Describe , with the aid of sketches as appropriate, the structure of a typical calorimeter of each type when it is part of a detector at a colliding beam machine. Give indications of typical dimensions involved.

State which is closer to the interaction point and explain why.

State which normally has the better energy resolution and explain why.

Question 6.
Describe and sketch a cylindrical Jet Chamber and a cylindrical TPC similar to those used in the OPAL and Aleph experiments. Give two advantages of each device over the other and explain briefly how these advantages arise from the basic operating principles of drift chambers.

The quantity $\omega\tau$ is important to the performance of both kinds of chamber. What parameters of the system affect the size of it? Why is it desirable to make it small for Jet Chambers and large for TPCs?

Question 7.
(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.

(d) Summarise the advantages of using standard buses for data acquisition and triggering. Mention any disadvantages that may arise in adopting such an approach.