Brunel University
Queen Mary, University of London
Royal Holloway, University of London
University College London

Intercollegiate post-graduate course in High Energy Physics

Paper 3 : Current HEP Projects

Tuesday, 9 February 2016

Time allowed for Examination : 2.5 hours

Answer **ALL** questions

Books and notes may be consulted

The paper is split into the following sections each carrying 20 marks :

1. Neutrino physics
2. CP violation
3. Hadron colliders and LHC physics
4. QCD phenomenology

Please start a new piece of paper for each question

Question A : Neutrino physics

1. (a) Briefly describe a reactor neutrino experiment, which also acts as detector for neutrino-less double-beta decay searches. Mention the most important oscillation results and $0\nu2\beta$ decay results. **[2]**

   (b) What are the advantages of high-Q 2β decay isotopes? **[2]**

   (c) If the 2β decay isotope mass could be increased by a factor 10, how much the lower bound on the decay life-time could improve (assume same runtime, efficiency, energy resolution and background)? **[3]**

   (d) If both Katrin and Super-Nemo experiments measured a non-zero neutrino mass, could the measured value be significantly different? Justify your reply. **[3]**

2. (a) Describe briefly the MiniBoone experiment (beam, detector, main results). **[2]**

   (b) What are the main differences with regard to LSND? What is similar? **[2]**

   (c) In the proposal for a future short-baseline neutrino oscillation programme in the Fermilab Booster Neutrino Beam, three detectors are foreseen at L=110, 470 and 600m, with fiducial mass M=112t ,89t, 476t, respectively. Which technology these detectors will use? Motivate the choice. **[3]**

   (d) If N1 is the number of ν_μ CC events observed in the near detector, how many events are expected in the two far detectors in absence of oscillation? Assume same number of protons on target (POT) for the three detectors. (e) If 500 ν_e events are observed in the Icarus T600 detector for $\Delta m^2_{41} = 0.43$ eV^2 and $sin^2 2\theta_{e\mu} = 0.013$, what is the value of N1? Make reasonable assumptions on cross-section and detection efficiencies for ν_e and ν_μ and assume $E_\nu = 0.6$ GeV. **[3]**

[Total Marks = 20]

Question B : CP violation

1) Describe the CP discrete transformation and how the forces behave under CP. Briefly list in which meson system CP violation has been observed so far and to which type of CP violation it corresponds.

(5 marks)

2) Describe the direct CP violation, define it as function of the decay rates and derive the necessary requirement on the decay amplitudes in order to have such a violation.

(6 marks)

3) Describe the main features of the CKM matrix: number of free parameters, their meaning and briefly mention how we measure them.

(4 marks)

4) Draw the main Feynman diagrams which contribute to the $B \to DK$ decays. Note CKM matrix elements on vertices where appropriate and state which fundamental parameter can be measured through these decays.

(3 marks)

Describe one advantage and one disadvantage to be considered in the measurement of these decays.

(2 marks)

[Total Marks = 20]

Question C : Hadron colliders and LHC physics

1. In referring to a detector region, should rapidity or pseudorapidity be used, and why? **[2]**

2. Why the total energy of a particle is usually not a good variable to use in the analysis of data of a hadron collider? **[2]**

3. Two massless particles are emitted at the same azimuthal angle ϕ; the first at an angle θ with respect to the beam of 90°, the second with an angle of 45°. A Lorentz boost along the beam direction is applied, such that the first particle will be at a distance of 30° with respect to the beam. Considering that rapidity differences are conserved for a boost along z, calculate the angle of the second particle with respect to the beam after the boost. **[3]**

4. What are the main purely theoretical boundaries to the mass of the Higgs boson? **[2]**

5. Can the mass of the Higgs boson be constrained by measuring the properties of other heavy particles, and why? **[2]**

6. Assume the jet energy scale to be 3%, constant as a function of transverse momentum. If the inclusive jet cross-section has the form $Aexp(-3 * E_T)$, what is the impact of this energy scale on the cross-section measurement? **[3]**

7. How is it possible to define an asymmetry for W production, having a symmetric proton-proton collision? **[2]**

8. Describe the main issues in measuring W and Z cross-section and mass at the LHC. **[2]**

9. Explain the main phenomenological differences between R-parity conserving and R-parity violating Supersymmetry, and describe some SUSY search channels. **[2]**

[Total Marks = 20]

Question D : QCD phenomenology

(a) At lowest order the equation for the running of a coupling in quantum field theory can be written in the form

$$\frac{d\alpha}{d\ln\mu^2} = b_0\alpha^2,$$

where $\alpha = g^2/4\pi$, find the solution subject to boundary conditions $\alpha = \alpha_0$ at $\mu^2 = \mu_0^2$ for $b_0 = \pm\beta_0$, where β_0 is a positive constant. [3]
If b_0 is negative show that the solution may be rewritten as

$$\alpha(\mu^2) = \frac{1}{\beta_0\ln(\mu^2/\Lambda^2)}.[2]$$

b_0 is negative for the strong QCD coupling. Explain what happens as $\mu^2 \to \infty$ and for small μ^2, and discuss briefly what results this produces in strong interaction physics. (Assume $\beta_0 \approx 1$.) [2]

Discuss the behaviour of the coupling with μ^2 for positive b_0. This is the case for the QED coupling. Why does this imply we cannot use the Standard model for arbitrarily large μ^2? [3]

(b) At the LHC we have a pair of we have a pair of jets with transverse momentum p_T in the final state, each at zero rapidity. Draw diagrams illustrating dijet production from the different combinations of quark, antiquark and gluon initial partons. Determine the x value of the incoming partons for the interaction in terms of p_T and collider centre of mass energy $\sqrt{s}$. How does the dominant initial state for the process depend on p_T and why? [6]
Consider fixed partonic centre of mass energy of order 1 TeV. What happens to the x values for the partons if the jets are both produced at high positive rapidity? Why does this increase the fraction of jets produced from quark-gluon interactions? [2]
Strictly speaking the photon is a constituent of the proton in the same way as the gluon. Draw a Feynman diagram with an incoming photon such that a Z boson is produced in the final state in a scattering at the LHC. [2]

[Total Marks = 20]

END OF PAPER