# Experimental Quantum Physics (Part III) – Exam

December 4, 2015

## 1 Virtual Particles

1. What are virtual particles, and which of the properties can in general be different from real particles? (*2 points*)

2. Give examples (minimum 2) of properties. which are the same between real and virtual particles. (*2 points*)

3. Explain the role of virtual photons as force carriers of the EM interaction and illustrate it with an example Feynman diagram. (*2 points*)

## 2 Scattering Kinematics

Study the scattering of a proton with $E_{\text{lab}}$ off a proton at rest.

1. Give the rapidities and the four-momenta of the two colliding protons for $E_{\text{lab}} = 200\,\text{GeV}$. (*2 points*)

2. Give an expression for $\sqrt{s}$ as a function of $E_{\text{lab}}$. Calculate the value for $E_{\text{lab}} = 200\,\text{GeV}$. (*2 points*)

3. Calculate the four-momenta of the protons in the CM system. (*1 point*)

## 3 Two-Body Decay

Study the decay $X \rightarrow e^+ + e^-$.

1. Give a formula for the calculation of the mass $m_X$ of the parent particle as a function of the four-momenta of the decay products. (*2 points*)

2. Simplify the formula for $m_X \gg m_e$ to obtain a function of the energies and the opening angle. (*2 points*)

# 4  Feynman Diagrams

1. Which of the diagrams shown in Fig. 1 correspond to possible physical processes? For those that do not, give arguments why. (*3 points*)
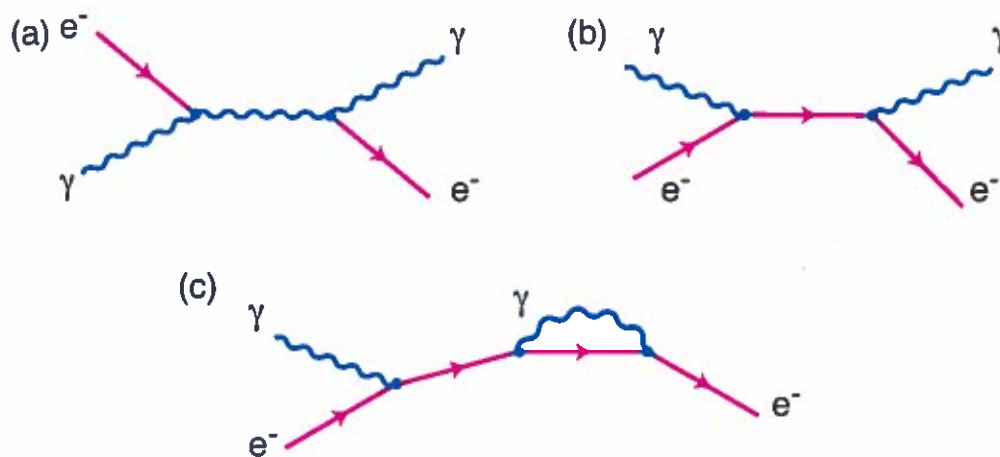


Figure 1: Feynman diagrams of hypothetical processes.

2. What are the simplest Feynman diagrams for the reactions:

   (a) $e^+ + e^- \rightarrow e^+ + e^- + \gamma$.
   (b) $e^+ + e^- \rightarrow e^+ + e^- + \gamma + \gamma$.
   (c) $\gamma + \gamma \rightarrow e^+ + e^-$.

   Discuss the relative cross sections of the processes in terms of powers of $\alpha$. For reaction (b) there are four non-trivially different diagram of the lowest order - try to list them all. (*4 points*)