Exam PPP

April 8, 2019

- Put your name and student number on each answer sheet.
- Answer all questions short and to the point, but complete; write legible.
- Final point grade = total number of points/10.

1. **The ϕ-meson factory (25 points)**
   DAϕNE is an electron-positron collider at Frascati, Italy. The experiment is designed to abundantly produce ϕ mesons via the process $e^+ + e^- \rightarrow \phi$. The ϕ mesons are produced at rest in the laboratory frame. The ϕ particle is a vector meson, hence, with spin-parity of $J^{PC} = 1^{--}$ and you may assume that their quark contents is $s\bar{s}$. The mass of the ϕ meson is 1020 MeV/c^2.

   a) Draw the dominant Feynman diagram of the production process of the ϕ meson.

   b) What are the possible spin (S) and orbital angular momenta (L) of the combined $s\bar{s}$ system? Motivate your answer.

   c) The ϕ meson can decay into a pair of K^+K^- or in the final state composed of $\pi^+\pi^-\pi^0$. The kaon (K) and pion (π) are both pseudoscalar mesons with spin-parity $J^P = 0^-$. The mass of the kaon (pion) is 494 MeV (139 MeV). Sketch the dominant Feynman diagrams of the *strong* decay modes $\phi \rightarrow K^+K^-$ and $\phi \rightarrow \pi^+\pi^-\pi^0$.

   d) The branching fraction of the decay $\phi \rightarrow K^+K^-$ is about 50%, whereas the branching fraction of the $\phi \rightarrow \pi^+\pi^-\pi^0$ decay is only 15%. What could be the reason why the K^+K^- mode is more favorable than the $\pi^+\pi^-\pi^0$ process? Motivate your answer. Note that the strong coupling constant α_S is less than one at the energy scale of the ϕ meson.

   e) Calculate the maximum energy that one of the pions in the decay $\phi \rightarrow \pi^+\pi^-\pi^0$ can have. You can take the ϕ meson at rest and you may assume that all three pions have the same mass of 139 MeV.

2. **Quantum Chromodynamics and Isospin (25 points)**
The strong interaction is described by the theory of *Quantum Chromodynamics* (QCD). The continuous symmetry group (Lie algebra) that forms the basis of QCD is SU(3) in which quarks carry a *color* quantum number, i.e. $q = (r, g, b)$. The mediator of the strong interaction is the gluon, which carries a color-anticolor label, or more technical, it corresponds to the "8" representation of SU(3).

a) Discuss an experimental historical evidence that has led to the notion of color.

b) What does *color confinement* imply and how does it relate to the fact that one only observes integer-charged hadrons.

c) What is the origin of color confinement? How do we presently understand this phenomena? Motivate your answer.

d) *Isospin* invariance is considered a reasonable SU(2) symmetry and it is often used to label hadrons and to understand their properties. What is *isospin* and how does it relate to the properties of QCD? What are the reasons why isospin is not an exact symmetry (in contrast to SU(3)-color)?

e) Use isospin invariance to estimate the relative partial decay rates of the isospin-3/2 Δ resonance decaying into a nucleon and pion:

$$\frac{\Gamma(\Delta \to p + \pi^-)}{\Gamma(\Delta \to n + \pi^0)}. \tag{1}$$

The nucleon (p, n) has an isospin of 1/2 and the pion (π^-, π^0, π^+) has an isospin of 1. You may consult Fig. 1 at the end of this exam form.