PHY493/803 Spring 2025, Intro to Elementary Particle Physics

Homework 4 - Due Date 24th of March 2025

Please clearly state any assumptions, show all your work, number the equations, and indicate logical connections between the lines.

1. (10 pts + 10 pts)

   a) A 50-mCi source emits 5-MeV alpha particles and is suspended between the plates of a large gas ionization chamber. If the emitted alpha particles lose all their energy in the chamber, calculate the current measured at the output. Assume that the average energy to create an electron-ion pair in the gas is 30 eV and that the charge collection efficiency is 89%.

      i. How many alphas per second?
      ii. How many electrons-ion pairs are produced per alpha?
      iii. What is the total charge of the electrons produced?
      iv. What is the current, taking the collection efficiency into account?

   b) When a 5-MeV alpha particle is stopped in the gas ionization chamber, the voltage at the detector output undergoes a step change of 2 mV. Assume that the average energy to create an electron-ion pair in the gas is 30 eV and that the charge collection efficiency is 89% (like in part a). Calculate the capacitance of the chamber, assuming that the time constant of the chamber and electronics is long compared to the duration of charge deposition by the alpha particles.

2. (10pts + 10pts)

   a) A linear accelerator, consisting of a series of drift tubes, operates with a frequency, f, of 30 MHz and accelerates particles to a velocity v_i. What is the length of the following drift tube? Assume that the particle will travel the full length of the drift tube as the voltage swings from positive to negative (i.e. ½ period).

   b) If the particles above are ^{16}O ions and are accelerated to a momentum of 80 MeV, what is the length of the chamber?

3. Feynman Diagrams (10 pts + 10 pts)

   (a) Sketch the lowest level Feynman diagram for Delbruck scattering: $\gamma + \gamma \rightarrow \gamma + \gamma$. (Griffiths 2.2)

   (b) Draw possible Feynman diagrams for the following decay. Note it involves multiple forces. (Griffiths 2.8a)

$$\mu^- \rightarrow e^- + e^- + e^+ + \nu_\mu + \bar{\nu}_e$$

4. (10 pts + 10 pts) **{Required for PHY803 students only. +20 pts extra credit for PHY493 students.}**

Two particles with masses m_1 and m_2 and equal momenta travel between two scintillation detectors (i.e. passing through one, then traveling through the gap in between, then passing through the other). The detectors are separated by a distance L. The time at which each particle passes through each scintillation detector is measured, thus measuring their times of passage through the gap. The difference in the times measured by the two detectors for a given particle is a measure of its "time-of-flight" for the distance of the gap L.

a) Show that the differences between the two particles' times-of-flight decreases like $|\vec{p}|^{-2}$ for sufficiently large values of momentum. The expression $\sqrt{1+a} \approx 1 + a/2$ may be useful here.

b) Compute the minimum separation between scintillation detectors necessary to distinguish whether a particle is a π^+ or a K^+ if its momentum is 3 GeV/c and the time-of-flight can be measured with an accuracy of 200 ps, i.e. the time difference has to be at least 200 ps. Use $m(\pi^+) = 139.6$ MeV/c^2 and $m(K^+) = 493.7$ MeV/c^2.