Massachusetts Institute of Technology

Department of Physics

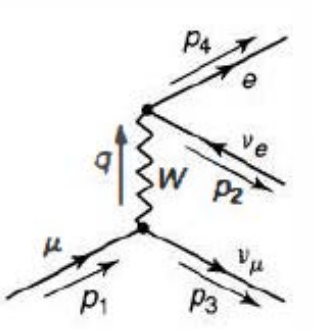
Course: 8.701 — Introduction to Nuclear and Particle Physics
Term: Fall 2020
Instructor: Markus Klute

Problem Set 4

handed out October 21st, 2020

Problem 1: Muon decay [20 points]

Consider the decay $\mu \to e\nu_\mu\bar{\nu}_e$.

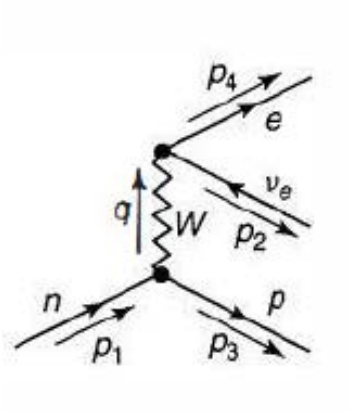


$$\tau = \frac{192\pi^3\hbar^7}{G_F^2 m_\mu^5 c^4}$$

Describe the necessary steps to calculate the lifetime of the μ as given in the formula above and highlight assumptions you might make in the calculation. [Bonus: you have all tools at hand to carry out the full calculation. Challenge yourself!]

Problem 2: Neutron decay [20 points]

Consider the decay of a neutron $n \to pe\nu_e$.



Compare this decay with the decay of the μ. Highlight the differences between the two processes and compare the expected electron energy spectra.

Problem 3: CKM Matrix [20 points]

The purpose of this exercise is review properties of unitary matrices. How many independent real parameters are there in a general 3×3 unitary matrix? How about $n \times n$?. [Hint: It helps to know that any unitary matrix (U) can be written in the form $U = e^{iH}$, wher H is a hermitian matrix. So an equivalent question is, how many independent real parameters are there in the general hermitian matrix.] How many independent real parameters are there in a general 3×3 (real) orthogonal matrix? How about $n \times n$?

Problem 4: Neutrino generations [20 points]

The LEP collider operated initially at $\sqrt{s} = m_Z$ to produce the Z boson at the Z pole. The measurement of the cross section allows the estimate of the number of *active* neutrino generations. Explain how this information can be derived without the detection of Z boson decays to neutrinos.

Problem 5: Deep inelastic scattering [20 points]

The HERA collider at DESY allowed the study of collisions of 27.5 GeV electrons on 820 GeV proton beams. Calculate the kinematic variables Q^2 ,x, and y in terms of the scattered $3^\circ < \theta'_e < 177^\circ$ calculate the kinematic region (x_{min}, x_{max}) and (Q_{min}, Q_{max}) covered by HERA.

8.701 Introduction to Nuclear and Particle Physics
Fall 2020