PHASM/G 442. 2017 : Problem Sheet 4

Please return to Prof. Saakyan by 15th January 2018.

1. Draw the lowest Feynman diagrams for the decays:

$$D^0 \to K^- + \pi^+ \qquad D^0 \to K^+ + \pi^-$$

and predict the ratio

$$\frac{\Gamma\left(D^0 \to K^+ + \pi^-\right)}{\Gamma\left(D^0 \to K^- + \pi^+\right)}$$

[8]

2. Calculate the matrix element of a longitudinally polarised Z-boson decay at rest to a pair of muons, $Z \to \mu^+\mu^-$, and express it in terms of g_Z, m_Z and θ, where θ is the muon angle in the centre-of-mass frame. **[12]**

3. Top quark pair production and decay at the Tevatron proceed mostly by:

$$q\bar{q} \to t\bar{t} \to bW^+\bar{b}W^-$$

(a) Draw the corresponding lowest order Feynman diagram at quark level showing one of the W's decay hadronically and the other leptonically

(b) Identify detector systems of a typical collider detector, which can be used to reconstruct the final state particles in the Feynman diagram you have drawn.

(c) Which kinematic variable is used to identify W-bosons and top quarks in the detector?

[8]

4. (a) Describe two problems with the Standard Model that are solved by the Higgs mechanism.

(b) Draw the dominant lowest order Feynman diagrams for the two decays of the Higgs boson with the largest branching ratios.

(c) In some beyond the Standard Model theories there are Higgs-like particles, which are significantly heavier than 125 GeV. Draw the dominant lowest-order Feynman diagrams for the decay of a 200 GeV Higgs-like particle, assuming its couplings are the same as the Standard Model Higgs.

(d) One of the current goals of the LHC at CERN is the search for Higgs decays to fermions. Assuming that a Higgs at rest decays via $h \to \tau^-\tau^+$ estimate the distance travelled by the τ^- before it decays. **[12]**

5. (a) In the three-flavour treatment of neutrino oscillations the three weak eigenstates are related to the mass eigenstates by the 3×3 **unitary** PMNS matrix:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Use the unitarity condition of the PMNS matrix to write down relations between the elements U_{ei} and U^*_{ei}, as well as U_{ei} and $U^*_{\mu i}$ of the PMNS matrix where $i = 1, 2, 3$.

(b) If a pure electron neutrino beam is created at $t = 0$ write down this initial state in terms of neutrino mass eigenstates.

(c) Do the same for the neutrino state $|\psi(L)\rangle$ after travelling some distance L along the z-axis.

(d) Hence, show that the neutrino oscillation probability $P(\nu_e \to \nu_\mu)$ can be written as

$$P(\nu_e \to \nu_\mu) = \left| U_{e1}U^*_{\mu 1}e^{-i\phi_1} + U_{e2}U^*_{\mu 2}e^{-i\phi_2} + U_{e3}U^*_{\mu 3}e^{-i\phi_3} \right|^2$$

[10]