Time & Date: 10h00, 7th May, 2019 End-Semester Examination

PH4204: High Energy Physics

Duration: 150 minutes Weight: 30%

Instructions: Solve all ten problems. Any kind of notes or books are not allowed. Use of phone or other electronic device (like calculator) is forbidden.

1. **Kinematics:** Using the properties of two-body phase space argue that in the decay of muon, $\mu^- \to e^- +\text{missing}$, there has to be at least two missing neutrino to explain the observed *continuous energy distribution* of the electron. 3

2. **Weak Current:** The charged pion π^+ is a spin-0 particle that decays into $f^+\nu_f$ final state via a current $[\bar{u}(\nu_f)\gamma^\alpha(a+b\gamma^5)v(f^+)]$ for $f=e,\ \mu$. Write down the matrix-element for the decay. What observable indicates that the current is vectorial and not $[\bar{u}(\nu_f)(a+b\gamma^5)v(f^+)]$. Explain. 3

3. **Case study of Color:** The spin $3/2$ baryon Δ^{++} is made of three u quarks and it is a member of flavor 10-plet, i.e. flavor part of the wave function is symmetric. Also, the $|3/2,+3/2\rangle$ spin state requires all the u quaks to be spin-up, i.e. $|u_\uparrow u_\uparrow u_\uparrow\rangle$, or symmetric. Thus, the total space-flavor-spin part of the wave function is symmetric. How do we reconcile with this apperant violation of Fermi statistics? 3

4. **Strangeness:** The Λ baryon and K meson are produced together via strong interactions but they live longer and decay weakly. How would you explain this phenomenon using the properties of strong and weak interactions ? 3

5. **Wicks Theorem:** The scalar field $\phi(x)$ is given by

$$\phi(x) = \int \frac{d^3p}{(2\pi)^3}\frac{1}{\sqrt{2E_p}}\, a_p e^{-ix.p} + h.c. = \phi^+ + \phi^-, \quad \text{with } \phi^+|0\rangle = 0$$

Define *field contraction* and *normal ordering of operators*. State the Wick's theorem in terms of *field contraction* and *normal ordering of operators*. Explicitly show it for $\langle 0|\mathcal{T}\{\phi(x)\ \phi(y)\}|0\rangle$. 3

6. **Diagrammatics:** For a Lagrangian $\mathcal{L} = \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4$, the two point greens function is given by

$$\langle\Omega|\mathcal{T}\{\phi(x)\ \phi(y)\}|\Omega\rangle = \lim_{T\to(1-i\epsilon)\infty} \frac{\langle 0|\mathcal{T}\left\{\phi(x)\ \phi(y)\exp\left[-i\int_{-T}^{T} dtH_I\right]\right\}|0\rangle}{\langle 0|\mathcal{T}\left\{\exp\left[-i\int_{-T}^{T} dtH_I\right]\right\}|0\rangle}$$

Diagrammatically write the numerator and denominator upto one loop and show the final result after cancellations. 3

7. **Scalar QED:** Consider a charged scalar Φ with charge Q coupled to a photon through gauge interaction. Write down the gauge transformations for Φ and the full Lagrangian assuming mass m for the scalar. 3

8. **Symmetry breaking:** If we replace the Higgs doublet in the SM with a triplet with Hypercharge $+1$, which component of the triplet should get a VEV to generate the mass of $W^{\pm}$ and B leaving W_3 massless. Show some steps of calculations. 3

9. **Graph theory and Feynman diagrams :** Consider the following Lagrangian

$$\mathcal{L} = \frac{1}{2}(\partial_\mu\phi_1)(\partial^\mu\phi_1) - \frac{m_1^2}{2}\phi_1^2 - \frac{\lambda_1}{4!}\phi_1^4 + \frac{1}{2}(\partial_\mu\phi_2)(\partial^\mu\phi_2) - \frac{m_2^2}{2}\phi_2^2 - \frac{\lambda_2}{4!}\phi_2^4 - \frac{\alpha}{12}(\phi_1^3\phi_2^2 + \phi_1^2\phi_2^3)$$

Using graph theory, find out the minimum number of loops that a bubble diagram will have for the above Lagrangian. 3

10. **Feynman Rules:** Consider the Lagrangian of problem 9. Write down the momentum space Feynman rules for the matrix elements for the said Lagrangian. 3