Particle Physics, Autumn 2014 CMI

Problem set 5: Due by Monday Dec 1, 2014

1. ⟨**2**⟩ Find the threshold π^+ beam energy for production of the $\Delta(1232)$ resonance in collisions with a stationary proton target (threshold in the sense that the final state contains only the Δ and no other particles).

2. ⟨**3**⟩ Find the threshold charged pion beam energy for production of Λ^0 strange baryons in association with neutral kaons in collisions with a stationary proton target. Compare the threshold pion beam energy with the mass difference between final state particles and target particle. Why is the threshold energy required larger than this difference? Write the reaction. $m_\Lambda = 1116$ MeV.

3. ⟨**3**⟩ What is the center of momentum energy in head-on collisions of 9 GeV (total energy) electrons with 3.1 GeV (total energy) positrons at an asymmetric collider? Answer using Mandelstam variable. With this CM energy, which heavy quark-anti-quark bound state could be produced and studied at the BaBar experiment?

4. ⟨**4**⟩ Draw quark-level Feynman diagrams for (a) $B^0 - \bar{B}^0$ mixing and (b) $\bar{K}^0 \to \pi^+\pi^-$ decay. Mention why they must proceed via weak interactions.

5. ⟨**5**⟩ What did C Cowan and F Reines discover in 1956? Where (geographic name and near what device) was the experiment done? What was the reaction and what was simultaneously detected? Whose 1930 hypothesis on what did they confirm?

6. ⟨**3**⟩ The (design) CM energy in symmetric pp collisions (7 TeV on 7 TeV) at the LHC is 14 TeV, which is also the invariant mass of the final state. Estimate the beam energy (in TeV) required to produce a final state with the same invariant mass as before, but via collisions of a proton beam with a fixed target of protons.

7. ⟨**5**⟩ Find an explicit 2×2 matrix representation of the Fermionic canonical anti-commutation relations for one degree freedom, $a^2 = a^{\dagger 2} = 0, aa^\dagger + a^\dagger a = I$. Evaluate the number operator $N = a^\dagger a$ in this representation and find its eigenvalues and eigenvectors. Say what your representation describes physically. Can your a and $a^\dagger$ each be diagonalized? Why/why not?

8. ⟨**3**⟩ Around 1948, who accurately measured the magnetic moment of the electron and showed that it departs from the prediction of the Dirac equation? What is the value predicted by the Dirac equation? With whom did he share a Nobel prize, and in which year? What was his co-recipient recognized for?

9. ⟨**5**⟩ Suppose we have a state of a system of two spin one particles. The total spin of the state is one of $s = 0, 1, 2$. How does the wave function of the system behave under exchange of the spins of the two particles? Express the answer in terms of s. Write down the highest spin projection states for each value of s and examine how it behaves under exchange.

10. ⟨**4**⟩ Suppose $\vec{\epsilon}_1, \vec{\epsilon}_2, \mathbf{k}/k$ form an orthonormal system of vectors (polarization directions and propagation direction). (a) Show that the transverse projection operator may be expressed as a sum over polarizations: $\delta_{ij} - \frac{k_i k_j}{k^2} = \sum_{\lambda=1,2} (\epsilon_\lambda)_i (\epsilon_\lambda)_j$. Here k_i are the components of the wave vector $\mathbf{k}$ and $k = |\mathbf{k}|$. (b) Show that the sum over polarizations $\sum_\lambda |\vec{\epsilon}_\lambda \cdot \mathbf{r}|^2 = |\mathbf{r}|^2 \sin^2\theta$ where θ is the angle between the 'dipole moment' vector $\mathbf{r}$ and $\mathbf{k}$.

11. ⟨**2**⟩ What did Bruno Touschek propose and build in the early 1960s, and where?