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The Standard Model of Particle Physics - SoSe 2010 Assignment 5

Due May 27

1 e^+e - B-factories

B-factories are electron-positron storage rings which are operated at a center-of-mass energy of the colliding e^+e^- system of 10.58 GeV. At this energy it is possible that the photon fluctuates into an $\Upsilon(4S)$ which is a resonant $b\bar{b}$ state with $J^{PC} = 1^{--}$. The cross section to produce the Υ is about 1 nb and adds to the standard QED cross section to produce fermion pairs. The Υ decays nearly entirely to pairs of $B\bar{B}$ mesons.

a) It is planned to build a Super-B factory at KEK in Japan. For the instantaneous luminosity of this machine a value of $L = 10^{34}\text{cm}^{-2}s^{-1}$ is aimed for. Estimate the annual yield of $B\bar{B}$ pairs if the machine is operated for 10^7 seconds per year.

b) An important background for the analysis of B mesons are hadrons from the standard QED production of light quark pairs (no b-quarks). What is the cross section to produced these hadronic „continuum“ events? For comparison, how large is the muon pair production cross section at this energy?

2 Tau-Decays

Tau leptons can decay to leptons and hadrons and therefore present an excellent system for studying properties of weak and strong interactions. Note, that the lightest charmed hadron (D meson) has a mass of 1.865 GeV and is thus heavier than the Tau.

a) Draw the Feynman graphs for the possible lowest order τ decays to leptons and quarks (no QCD contributions like gluon bremsstrahlung, final state quarks can be considered as free particles). Add the coupling strengths described by the CKM matrix elements $V_{ud} \approx \cos\theta_C$ and $V_{us} \approx \sin\theta_C$ to the quark vertices in each graph. For the Cabibbo angle one finds $\theta_C \approx 0.22$.

b) Neglecting the mass of the decay products, estimate the τ-branching fractions to electron, muon and hadrons.

Hint: If masses are neglected and the number of final state partons is the same, what can you conclude on the phase space factors? How do the quark contributions with their different coupling strength in a) add to the total hadronic decay width of the tau? Do not forget the different color charges.

c) Find an equation which relates the partial width $\Gamma(\tau^- \to e^-\bar{\nu_e}\nu_\tau)$ to the muon lifetime.

Hint: Use the Sargent rule which states that for the weak decay of a particle of mass M into 3 particles of negligible mass the (partial) decay width is $\Gamma \propto M^5$. In this way $\Gamma(\mu^- \to^- \bar{\nu}_e \nu_\mu)$ can be related to $\Gamma(\tau^- \to^- \bar{\nu}_e \nu_\tau)$.

d) Express the τ-lifetime as a function of the partial decay width $\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$. Use the result of c) and the muon lifetime to estimate the τ-lifetime. Compare your results with the experimental value listed by the PDG.