Particle Physics: Problem Sheet 4

Weak Interactions, Neutrinos, W and Z Bosons

1. Draw the lowest order Feynman diagram for electronic and muonic tau decay, $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$, respectively. Discuss the corresponding matrix elements, decay rates and branching fractions. How far will a tau lepton travel on average if it has a momentum of $p = 5$ GeV/c?

   The mass and lifetime of the tau lepton are $m_\tau = 1.777$ GeV and $\tau_\tau = 2.91 \times 10^{-13}$ s, respectively. You may neglect the mass of the electron and the muon.

2. Write down all possible decay modes of the W^- boson into quark- and lepton-pairs.

3. Show that both charged and neutral current interactions contribute to the process $\nu_e + e^- \to \nu_e + e^-$ and draw the corresponding lowest order Feynman diagrams.

4. Estimate the total decay width, Γ_Z, and the lifetime of the Z^0 boson using the measurements of $\Gamma_{q\bar{q}} = 1744.4$ MeV, $\Gamma_{l\bar{l}} = 84.0$ MeV and $\Gamma_{\nu\bar{\nu}} = 167.0$ MeV. Compare with the observed resonance width, $\Gamma_Z = 2495.2$ MeV.

5. Draw a quark level diagram for the weak decay $K^+ \to \pi^+\pi^0$. The relevant quark contents are $K^+ = (u\bar{s})$, $\pi^+ = (u\bar{d})$, and $\pi^0 = \frac{1}{\sqrt{2}}(d\bar{d} - u\bar{u})$, respectively (see also hints on question 6).

6. **Feynman diagrams**
   In each of the following decays try to draw a quark level Feynman diagram and determine which interaction is responsible.

$$\begin{aligned} \mathrm{D}^{\star+} &\longrightarrow \mathrm{D}^0\pi^+ & \qquad \Sigma^0 &\longrightarrow \Lambda\gamma \\ \mathrm{D}^+ &\longrightarrow \overline{\mathrm{K}}^0\pi^+ & \qquad \tau^- &\longrightarrow \rho^-\nu_\tau \\ \mathrm{K}^{*0} &\longrightarrow \mathrm{K}^+\pi^- & \qquad \pi^0 &\longrightarrow \gamma\gamma \end{aligned}$$

   Hints: The photon only interacts electromagnetically and the neutrino only weak. First establish the relevant quark and lepton flavour quantum numbers of the initial and final states. While quark and lepton flavours are conserved at each vertex for the strong and electromagnetic processes, the weak charged interaction is flavour changing. Always draw the simplest possible diagrams.
   Do your answers agree with the observed lifetimes?

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Use the particle data group webpages for particle properties,
e.g. lifetimes.
http://durpdg.dur.ac.uk/lbl     -> Summary Tables ...
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