Partice Physics: Problem Sheet 5

Electroweak and LHC Physics

1. Draw a quark level diagram for the weak decay $K^+ \to \pi^+\pi^0$.

2. Estimate the total decay width, Γ_Z, and the lifetime of the Z^0 boson using:

   - The measurement of the total hadronic width:
     $\Gamma(Z \to \text{hadrons}) = 1744.4$ MeV
   - The measurement of the width into charged leptons:
     $\Gamma(Z \to \ell^+\ell^-) = 84.0$ MeV. $(\ell \equiv \{e, \mu, \tau\})$.
   - The prediction for the width into one flavour of neutrino:
     $\Gamma(Z \to \nu\bar{\nu}) = 167.0$ MeV.

   Compare with the observed resonance width, $\Gamma_Z = 2495.2 \pm 2.3$ MeV.

   What are the branching ratios of each of the decay modes?

3. The key predications of electroweak theory is that the couplings and the masses of the bosons are related as:

$$e = g_W \sin\theta_W \qquad m_Z^2 = m_W^2/\cos^2\theta_W$$

   At high energies, the measured values of the electromagnetic coupling constant, the "weak mixing angle" and the Z-boson mass are $\alpha_{\text{EM}}(\underline{\underline{q}}^2 = m_Z^2) = 1/128$, $\sin^2\theta_W(\underline{\underline{q}}^2 = m_Z^2) = 0.23120$ and $m_Z = 91.188$ GeV/c^2.

   Calculate the weak coupling constant, α_W, and predicted mass of the W-boson in the electroweak model, and compare this to the measured mass of $m_W = 80.413$ GeV/c^2.

4. **Higgs at the LHC**

   At LHC the Higgs boson, H can be produced in association with a W or Z boson, e.g. $pp \to WH, pp \to ZH$.

   (a) Draw the Feynman diagram for this process. (Select the correct one from page 10 of lecture 10.) What partons are involved in the hard scatter?

   (b) What is the minimum effective collision energy, $\sqrt{\hat{s}}$ needed to create a real Higgs boson of mass, $m_H = 120$ GeV/c^2 in association with a Z boson. What are typical values of Feynman-x for this value of $\sqrt{\hat{s}}$?

   (c) Looking at the Higgs branching ratio plot on Lecture 10, page 7, what is the most likely decays of a Higgs boson with $m_H = 120$ GeV/c^2?

   (d) What are the possible final states for the process $pp \to ZH$ where $m_H = 120$ GeV/c^2? What would this look like in the ATLAS detector?

5. **Feynman diagrams practise**
   In each of the following decays try to draw a quark level Feynman diagram and determine which interaction is responsible. The quark content of $D^{\star+}$ is $c\bar{d}$; the quark content of K^{*0} is $\bar{s}d$. The others are given on the particle properties sheet.

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

   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. Quark and lepton flavours are conserved at each vertex for the strong and electromagnetic processes, the weak charged current is flavour changing. Always draw the simplest possible diagrams.

   Do your answers agree with the observed lifetimes?