Particle Physics: Problem Sheet 1

The Standard Model, Measuring Techniques and QED

1. List all fundamental fermions in the Standard Model.

2. Explain why the decays $\mu^- \to e^- \bar{\nu}_e \nu_\mu$ and $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ are allowed and why $\mu^+ \to e^+ \gamma$ and $\mu^+ \to e^+ e^- e^+$ are forbidden. What about $\mu^+ \to e^- \bar{\nu}_e \nu_\mu$?

3. What is 1 fm in inverse GeV? How many seconds is 1 inverse GeV?

4. Write down the typical lifetimes for particles that decay by:

   (a) The strong force

   (b) The electromagnetic force

   (c) The weak force

   By looking at the liftetimes on the Particle Properties sheet, which force is responsible for the decay of π^0, B^+, ω^0?

5. The lifetime of the η'^0 has not been measured directly. The measurement of the width of the η'^0 is 0.203 ± 0.016 MeV. What is the lifetime of the η'^0? What force is responsible for its decay?

6. What are the Centre-of-Momentum (CoM) energies of the following machines:

   LEP1: e^+e^- collider, both beams 45.6 GeV

   LHC: pp collider, both beams 7 TeV

   HERA: ep collider, $E_\mathrm{e} = 30$ GeV and $E_\mathrm{p} = 820$ GeV. If HERA were a fixed target machine what energy would the electron require to give an equivalent CoM energy?

7. The Δ^{++} particle can be produced as a resonance by aiming a pion beam onto a hydrogen target, $\pi^+ p \to \Delta^{++} \to \pi^+ p$. Calculate the energy and momentum of the pions in the Δ^{++} centre-of-mass frame.

   From the measured resonance width of $\Gamma(\Delta)$=120 MeV calculate the lifetime of the Δ^{++}.

8. At the LEP collider operating at a beam energy of 45.6 GeV the B_d^0 mesons are produced with an average energy of 32 GeV. Calculate the mean decay length of a B_d^0 meson. What is the most probable decay length?

9. The simplest vertex in QED is a fermion-fermion-photon vertex. Draw an example Feynman diagram for such a vertex. Write down *all* possible electromagnetic fermion-fermion-photon vertices.

10. Draw the lowest order Feynman diagram for electron-proton scattering $e^- p \to e^- p$. Discuss the corresponding scattering amplitude or Matrix element, $\mathcal{M}$.

    Show that the photon propagator is the origin of the $1/\sin^4(\frac{\theta}{2})$ dependence of the Rutherford cross section for $e^- p \to e^- p$ scattering.