Section Exercises: 06/04/13 – Good problems for experimentalists

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PHYS 125: Elementary Particle Physics April 2, 2014

Exercise 1. At an e^+e^- collider operating at $\sqrt{s} = 10\,\text{GeV}$, you observe a final state of an e^+, a μ^-, a large amount of missing momentum (that is, momentum that appears not to be conserved after all detectable particles have been reconstructed). Propose a process that may have occurred and draw its Feynman diagram.

Exercise 2. What were the first major discoveries/objectives at each of the following colliders? What initial particles were collided? Why? For each collider, draw a Feynman diagram for a process that produces the target particle(s).

(a) SPEAR (1974-2004)

(b) SPS (1981-1984)

(c) Tevatron (1987-2011)

(d) LHC (2009-Present)

Exercise 3. The vertex factor for a Higgs boson coupling to two fermions is

$$-i\frac{m_f c^2}{v} \tag{1}$$

where m_f is the mass of the fermion and v is a constant.

(a) At $m_h \approx 125\,\text{GeV}$, what would you expect to be the two most likely lowest-order fermionic decay modes of the Higgs boson? Estimate the ratio of the branching fractions of the two decay modes.

(b) Draw the leading order Feynman diagram for production of a Higgs boson at the LHC, followed by a subsequent decay to two photons ($pp \to h \to \gamma\gamma$). Again, you may ignore bosonic Higgs couplings.

Exercise 4. This problem is designed to give you a an idea of how an experimentalist might test fundamental predictions of the Standard Model while simultaneously searching for "new physics." Imagine at an e^+e^- collider you perform a dedicated study of all observable decays of the $Z-$boson.

(a) You independently measure the full width (decay rate) of the the Z, Γ_Z, and the partial widths (decay rates) of Z decays to charged lepton and hadron final states, $\Gamma(l^+l^-)$ and $\Gamma(\text{had})$, obtaining the values

$$\Gamma_Z = 2.4952\,\text{GeV} \qquad \Gamma(l^+l^-) = 83.984\,\text{MeV} \qquad \Gamma(\text{had}) = 1744.4\,\text{MeV} \tag{2}$$

We wish to this obtain decay rate for $Z \to \nu\bar{\nu}$ decays to neutrinos. We can't measure this directly, since we can't fully reconstruct the 4-momenta of the neutrinos. Nevertheless, we can calculate the decay rate to an "invisible" final state, Γ_{inv}. Find an expression for Γ_{inv} in terms of the directly-measures quantities and calculate its numerical value.

(b) Here's a little theoretical background: in the Standard Model, the decay rate of the Z to two fermions is

$$\Gamma(Z \to f\bar{f}) = \frac{g^2}{48\pi\cos^2\theta_W}(c_V^2 + c_A^2)M_Z \tag{3}$$

where, for neutrinos, $c_V = c_A = \frac{1}{2}$ and, for charged leptons, $c_V = -0.04$ and $c_A = -\frac{1}{2}$. Using this information, calculate the theoretical ratio of the branching fraction of the Z to a $\nu\bar{\nu}$ final state to that of a l^+l^- final state,

$$R_{SM} = \frac{\Gamma(Z \to \nu\bar{\nu})}{\Gamma(Z \to l^+l^-)} \tag{4}$$

(c) Combining this theoretic value with the measured values from part (a), you can actually calculate the number of neutrino flavors, N_ν, as observed in the data. Calculate N_ν. Have you found any "new physics?"