Homework set 3, FYTN04, Autumn 2018

Due: Friday 30 November 2018, 10.15

1. Consider a collision $A + B \to C + D$ in its center of mass frame. Calculate E_C, E_D and $p^*_C = |\mathbf{p}_C|$ as functions of the CM energy and the masses (which are assumed non-negligible).

2. Suppose a fourth family exists, with a complete set of particles including a fourth neutrino ν_4 of mass similar to the other neutrinos, and gauge interactions identical to those of the other families. What would the branching ratio be for $Z^0 \to \nu_4 \overline{\nu}_4$ and for $W^+ \to L_4^+ \nu_4$, where L_4 is the charged lepton of the family? At first consider the physical case that top and the fourth generation fermions (except the assumed neutrino) are too heavy to be produced, and later consider what would have changed if instead they had been very light.

3. Suppose we want to measure the cross section for colliding ν_μ with right-handed electrons, e_R, in order to determine $\sin^2\theta_W$.
(i) How does the cross section vary with θ_W at fixed g_w?
(ii) Estimate the cross section assuming $m_Z^2 \gg s \gg m_e^2$.
Proceed by (a) drawing any diagrams that allow the scattering to occur; (b) put in the vertex factors and propagators; (c) make suitable approximations to obtain the matrix element; (d) go from the matrix element to the cross section using the standard phase space expressions.
(iii) How does the answer to (i) change if e is fixed rather than g_w?

4. (a) Suppose in a collision two oppositely charged particles emerge into the detector with four-momenta measured to be $p_1 \simeq (46.1; 45, 0, 10)$ and $p_2 \simeq (49.2; -45, 0, 20)$ with units in GeV. How would you interpret the event?
(b) Suppose Z^0's are produced in the process $q + \overline{q} \to Z^0 + g$. What fraction of Z^0's would not appear in the detector? How could such events be recognized anyhow?

5. Estimate the relative rate of observable Z^0 to $W^\pm$ production at a hadron collider. Since the full calculation would require detailed numerical integration over parton distributions, allow the following simplifications. Assume a $p\overline{p}$ collider like the Fermilab Tevatron, and only use the u and d valence parton distributions of the proton, with $u(x) = 2d(x)$. Also assume $m_W = m_Z$ to further simplify the PDF integration. Finally, experimentally the Z is observed in the e^+e^- and $\mu^+\mu^-$ decay channels, whereas $W^\pm$ is observed in the $e\nu$ and $\mu\nu$ ones.

6. Complement the study in the lectures of the three-body phase space in muon decay. (With the neglect of electron and neutrino masses.)
(a) Calculate $\cos\theta_{qk}$.
(b) Derive the limits of the allowed triangular area of the ($q = |\mathbf{q}|, k = |\mathbf{k}|$) plane.

7. Suppose an accelerator has been constructed that provides a one TeV proton beam. Now it is necessary to decide how to utilize it. Four possibilities are:
(a) hit a fixed target,
(b) collide it with a 50 GeV electron beam to study *ep* collisions,
(c) collide it with another proton beam, also accelerated to one TeV, and
(d) collide it with an antiproton beam made from a source of $\overline{p}$'s (antiprotons are harder to obtain than protons, of course).
What is the maximum available energy for production of new particles in each case? What other considerations might be important in making a decision?