**362L Homework Set #1** **Jan. 25, 2019**

["H & G" refers to our textbook. This assignment is due in about one week: to be specific, it is due in class on **Feb. 4.** Show a *complete solution* to each question; for example, if you need to use relativistic kinematics, the first time you need a certain result, derive it from the basic concepts (as in Sec. 2.7 in the text), explaining things in your words. Many of the questions are quite simple and straightforward. Work on one problem part per day and you will finish the assignment in plenty of time. DO NOT try to do it all at the last minute.]

(1) (a) Problem 1.8 in H & G.

(b) Problem 1.9 in H & G.

(c) One of the first things you probably learned about the photon in your first-ever sequence of physics courses is that a photon emitted by a charge oscillated at frequency $\nu$ has kinetic energy $K = h\nu$, and momentum $p = h\nu/c$. What is $p^\mu p_\mu$ for a photon? Could physics ever involve a photon with a different value than that? Under what circumstances?

(d) In class we showed a "slide" (linked on the webpage as "cross sections") which at the bottom showed p + p collisions at 450 GeV beam energy and claimed that for fixed-target collisions only 29 GeV of energy is actually available in the center-of-momentum system. Verify that.

(2) (a) Problem 2.24 in H & G.

(b) Problem 2.28 in H & G.

(3) At the LHC suppose the luminosity is $10^{34}$ cm$^{-2}$sec$^{-1}$. (a) Suppose the total cross section for some process is 80 mb. How many such processes occur per second? (b) If the cross section for a rare process that is supposed to produce a new particle X is estimated at $10^{-15}$ b, how many X particles could be seen in a full year of operation?

(4) (a) Draw the simplest Feynman diagram that describes Delbrück scattering, which is $\gamma + \gamma \rightarrow \gamma + \gamma$ (elastic) scattering.

(b) The "Feynman diagrams" are part of a way to understand a perturbation series expansion of the amplitude for a process. For two electrons interacting electromagnetically, a "first order" diagram involves 1 virtual photon. Give some examples of "second order" diagrams that involve 2 virtual photons. Draw at least four different diagrams, that look quite different to the casual eye.

(c) Here are two Feynman diagrams for the same process in QED. What is the process?