[“H & G” refers to our textbook. This assignment is due in about one week; to be specific, it is due in class on Sept 15. 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 for example in Sec. 2.7 in the text), explaining things in your own words. Most of the questions are quite simple and straightforward. Work on one problem 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 magnitude $p = h\nu/c$. What is the four-vector inner product $p^\mu p_\mu$ for a photon? Could physics ever involve a photon with a different value than that? Under what circumstances?

(2) (a) In class we showed a “slide” (linked on the webpage as “cross sections”) which at the bottom showed $p + p$ collisions at 450 GeV accelerator 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. You’ll find the formal solution that answers all such questions in the text, section 2.7. Justify it in your answer.
   (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 what integrals contribute to 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 at least to the casual eye.