There are 7 problems on the following two pages. Do all of them. Total points = 60.

Please take note of the following:

When comparing to experimental data (here or in future assignments) please refer to the Particle Data Group listings (on the web at http://pdg.lbl.gov). If you are having trouble, please come to see me; we could also go over this quickly in class, if need be. I suspect that most of you will probably have questions when doing this assignment. Please feel free to come ask me, or send me an email. We can also arrange to use a tutorial timeslot on Fridays to do some exercises, if anyone would like to do that.

In the case of problems taken from the text, the problem numbers refer to the Second, Revised Edition. If you are working from an older edition (all blue cover) note that there are some differences. In that case, please make sure to get the problems from the new text (which presumably most of your classmates will have).

For problems in relativistic kinematics, it is wise to practice by doing as many problems as possible. There are a variety of such problems at the end of chapter 3 of the text, many of them with the answer provided (but not the solution). In particular 3.15, 3.16, 3.19 and 3.21 are typical of the kind of problems I have assigned in the past or which have appeared on midterms or exams.

Please note that the final question is on material that we will not cover until the lecture on Sep.30, two days prior to the assignment due date. This problem is quite straightforward and should be easy (and quick) for you to do following the lecture. So the timing should not be a problem (and the relevant material should be fresh in your minds).

The quark content of most of the hadrons referred to in these problems can be found on page xiv of the text. If not, have a look at the PDG web pages referred to above. [The ϕ referred to in problem 1k) is not included on page xiv of the text. This is an $s\bar{s}$ meson: it is a little hard to locate in the PDG listings since it appears in the meson summary tables under the heading “Light unflavored” since it has zero net strangeness.].

1. For each process listed below, state whether it is possible or not possible according to the Standard Model, at lowest order (e.g. two vertices associated with the interaction that is responsible for the decay). For allowed processes, state via which interaction the process (dominantly) proceeds. Otherwise, cite at least one conservation law that prevents it. Feel free to comment on whether the process can proceed through a higher-order diagram, but this is not required. For allowed decay and scattering processes draw one possible lowest-order Feynman diagram (except for the scattering processes involving only hadrons in the initial and final state; diagrams for these are rather messy and rarely drawn). Note that the charges of the proton (p) and neutron (n) are conventionally not explicitly written, nor is that of the photon (γ). Note that I sometimes make mistakes in writing these expressions: you should give the answer according to what is written for the reaction, even if you think there's a typo. [18 points]

   a) $D^+ \to \bar{K}^0 e^+ \nu_e$
   b) $\mu^- \nu_\mu \to \tau^- \nu_\tau$
   c) $e^+e^- \to K^+ K^{*-} \pi^+ \pi^- \pi^0$
   d) $e^+e^- \to \nu_\mu \bar{\nu}_\mu$
   e) $\Sigma^0 \to \Lambda^0 \gamma$
   f) $\tau^- \to \mu^- \gamma$
   g) $e^+e^- \to \gamma\gamma$
   h) $D_s^+ \to \phi \pi^+ \pi^+ \pi^-$
   i) $p\bar{p} \to K^- K^0 \pi^+ \pi^+ \pi^- \pi^0$
   j) $pp \to p\bar{n} \pi^+ \pi^+ \pi^+ \pi^- \pi^-$
   k) $\phi \to K^+ K^-$
   l) $e^- \bar{\nu}_e \to \mu^- \bar{\nu}_\mu$
   m) $\Lambda_c^+ \to p K^- \pi^+$
   n) $B^0 \to \pi^- \tau^+ \nu_\tau$

   Where hadrons are involved, you will likely need to look up the quark content, which can be found online in the Particle Data Group (PDG) listings. Most are also provided in text, on the pages following the preface (or on the endpapers of the older edition).

2. For the processes listed below, list the possible final states and draw all of the lowest order Feynman diagrams for all contributions. [8 points]

   a) $e^+\tau^-$ scattering
   b) $\nu_\mu \nu_\tau$ scattering
   c) $\nu_e \bar{\nu}_u$ scattering
   d) $e\gamma$ scattering

3. Griffiths Problem 2.5: In the lectures we drew our examples (for hadrons) from states made up only of u, d, and s quarks (though I've drawn some others). One can also make mesons and baryons using other quarks as well (c and b). The decays of some of these states are investigated in this problem. Note that top quarks (t) do not form hadrons, for reasons given briefly in section 1.9 of the text. You will hopefully have a better understanding of the reason for this after we have discussed particle decays and lifetimes in more detail. [6 points]

4. Consider a beam of π^- mesons impinging on a proton target. What is the threshold beam energy for the production of a K^- meson, assuming the interaction is mediated solely by the strong interaction? If we account for other possible interactions would the threshold energy go up, down or remain the same? How would the production rate be affected? [8 points]

5. Consider the decay in flight of a neutral π meson of total energy E_π into two photons, $\pi^0 \to \gamma\gamma$. If the two photons have energies E_1 and E_2 in the lab frame, what is the opening angle between them? [6 points]

6. Assume that some experiment is performed to search for a hypothetical exotic particle X, produced (strongly) in proton-proton collisions via the reaction pp $\to$ XK^+K^+. Answer the following questions [8 points]:

   a) What are the values of electric charge, strangeness and baryon number for the particle X ? How many quarks would it need to contain?

   b) Assume some theoretical calculation for the mass of X predicts $M_X = 2150$ MeV/c^2. What would be the minimum incident proton beam energy required to produce the state, in a fixed target experiment in which the target proton is at rest?

   c) If this mass prediction were correct, what decays modes would be expected for X? Give an order of magnitude guess at its lifetime.

7. Suppose that you have a system composed of two spin-3/2 particles, with no relative orbital angular momentum. Answer the following questions: [6 points]

   a) If you were told that the total spin of the system is > 0 and that a measurement of S_z for either of the spin-3/2 particles would yield all possible values with equal probability, what would you conclude about the spin state of the system?
   b) If you were instead told that the spin state of the system is $|1,+1\rangle$, with what probability would measurements of the S_z for each of the two spin-3/2 particles yield the same value?

   Note that a) and b) are both are a little oddly constructed just to make them different from the ones in the text (problems 4.12, 4.13 and 4.14, which you may also want to attempt – not for the assignment, however).