

**Fall Quarter 2009**  
**UCSD Physics 214 & UCSB Physics 225**  
**Final Exam**

**Exam is due on Friday, December 4th, 2009, at 10am in my office.**

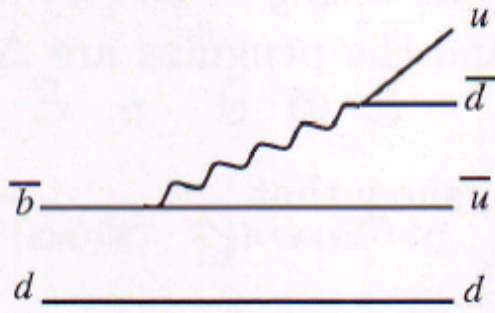
*This is an open book exam in the sense that you are welcome to use any of the references listed or linked in on the course web site, including Halzen & Martin. You will need a computer to do some of the work. You will need to look some things up in the particle data book, and may do so either online or on paper.*

*You are not allowed to use solution sets from a previous year's class, as many of the problems are similar to problems from previous years.*

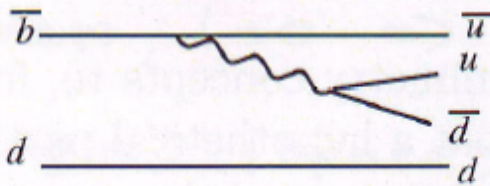
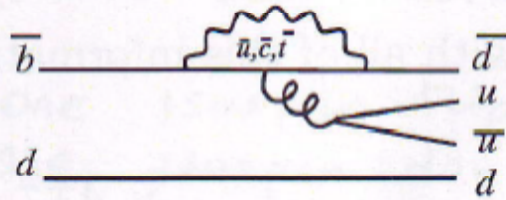
1. **26 Points:** As mentioned in class, I want you to do a crude evaluation of an analysis. The analysis we'll do is to search for two processes:  $W^+W^+W^-$  (and charge conjugate) as well as  $t\bar{t}W^+$  (as well as charge conjugate). We will pretend to search for these processes at the LHC with 14TeV proton-proton center of mass in the final state of two same sign dileptons (electron or muon), i.e. the final states  $ee$ ,  $mumu$ ,  $emu$ . What I want you to calculate is the amount of integrated luminosity needed to find a signal of 10 events. I want you to calculate this separately for each of the two processes. Let me walk you through this one step at a time.
  - a. Let's start with an efficiency estimate. Take a look at the WW production PAS Note EWK-09-002 that our group produced. This is linked in at the course website for your convenience. What is the probability to observe two leptons (e or mu) in a WW event?
  - b. In both processes of interest, you have three Ws in the final state. Is there a factor from combinatorics that you should worry about when estimating the expected yield of same sign dileptons from the 3 W final state?
  - c. Verify that you can reproduce the cross section calculation for  $W^+W^-$  using comphep. (Hint: Make sure you calculate each of the relevant processes, and add them up properly. I got 74pb at 14TeV. The PAS note claims 74pb at 10TeV. The numerical agreement is accidental because the PAS note is NLO, whereas comphep is LO. If you have trouble installing comphep, ask me for help.) A gzipped tar archive is linked in at the course web site. Here's what you do to install it:

- (a) wget  
<http://physics.ucsd.edu/students/courses/fall2009/physics214/finalExamComphep.tgz>
  - (b) tar -xvzf finalExamComphep.tgz
  - (c) cd comphep-4.4.3
  - (d) ./configure
  - (e) make
  - (f) make setup WDIR=/data/tmp/fkw/wkdir (you of course need to pick a working directory of your own here.)
  - (g) cd /data/tmp/fkw/wkdir
  - (h) ./comphep &
  - (i) At this point, follow the instructions given in class on Monday Nov.30th. You'll want to use the structure function 12 (cteq611)
- d. Now calculate the cross sections for  $WWW$  and  $t\bar{t}W$  using comphep. (Hint: Remember to add charge conjugates, as well as parton-parton subprocesses).
    - (a) As an aside. Explain the difference in  $W^+W^+W^-$  and  $W^+W^-W^-$  cross sections.
  - e. At this point you have all the pieces together to estimate the integrated luminosity required to observe 10 events in the same sign dilepton final state. Go ahead and estimate it for each of the two processes.
  - f. As an afterthought, read the PAS note again. There is one requirement that is made there (in addition to the opposite sign leptons requirement) which does not make any sense for a  $WWW$  or  $t\bar{t}W$  analysis because it would kill the signal. What is it? How might one use something like it to distinguish  $WWW$  from  $t\bar{t}W$  ?
2. **10 points:** Consider  $J^P = 1^-$  mesons with zero strangeness that can be built from u,d, and s quarks and anti-quarks.
    - a. What are the flavor wave functions of  $\rho^+-0$ ,  $\omega$ , and  $\phi$  ?
    - b. What is the color wave function ?
    - c. What is the spin wave function for  $J_z=0$  ?
  3. **8 points:** Consider the process  $e^+e^- \rightarrow \text{Upsilon}(4S) \rightarrow B^+B^-$ . The  $\text{Upsilon}(4S)$  is a  $b\bar{b}$  bound state with quantum numbers  $J^{PC} = 1^-$ . What is the angular distribution of the B-mesons in the center of mass? Explain your reasoning.
  4. **10 points:** Let A, B, C be pseudoscalar mesons. Let D be a vector meson (NOT an axial vector meson). Which of the following decays if any is allowed if parity is conserved? Explain your reasoning.
    - a.  $A \rightarrow BC$
    - b.  $D \rightarrow BC$
    - c.  $D \rightarrow BC$  if B and C are identical particles.
  5. **10 points:** Consider the  $\Omega^-$  ( $S=-3, I=0$ ) hyperon. First write down the obvious strong interaction decays that you might expect, given its quantum numbers. Then check its lifetime and decay modes in the particle data book. Did you find the strong interaction decays you expected? If not, why not? What's the interaction responsible for its decay? Why?

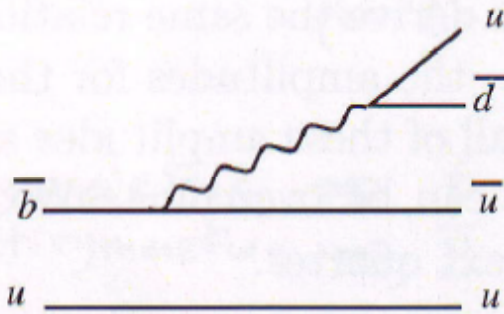
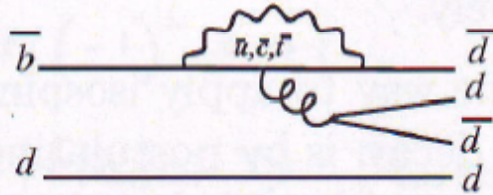
6. **8 points:** Let's assume you observed the reaction  $e^- \text{ proton} \rightarrow \text{electron neutrino} + \Gamma + \Gamma + X^{++}$ , where  $X^{++}$  refers to the double charged remnants of the inelastic collision with the proton, and  $\Gamma$  refers to some lepton flavor. (Hint: Draw the appropriate second order weak interaction diagram and explain it.)
- What's the significance of this observation if  $\Gamma = \text{electron}$  ?
  - Does your conclusion change when  $\Gamma = \text{muon}$  ?
7. **8 points:**  $W^-$  bosons can be produced in  $pp$  or  $p\bar{p}$  collisions via the parton process  $\bar{u} + d \rightarrow W^-$ . This is a charged weak interaction process, and only left-handed fermions and right-handed anti-fermions contribute.
- Sketch the expected polarization of the  $W^-$  with respect to the direction of motion of the  $\bar{u}$  and  $d$  quarks.
  - Make qualitative comments about the difference, if any, in the  $W^-$  polarization at the CERN SppbarS ( $p\bar{p}$  at 630 GeV center of mass), Tevatron ( $p\bar{p}$  at 2 TeV), and LHC ( $pp$  at 14 TeV).
  - How does your discussion change if the LHC was colliding  $p \bar{p}$  instead of  $pp$ ?
8. **20 points:** Isospin arguments can in some cases be used to relate amplitudes from weak processes, despite the fact that weak interactions violate isospin. In these cases, the flavor symmetry arguments relate the hadronization of final state quarks into hadrons, which conserves isospin. A very important example is the weak decay of B mesons into two pions.
- Write down the Isospin decomposition of the two pion final state. Why is  $I=1$  forbidden in this case? You are thus left with only two transition amplitudes  $\Delta I=1/2$  and  $3/2$ .
  - The figure below shows the two kinds of Feynman diagrams. The ones on the left are called "tree diagram" the ones on the right are called "penguin diagram".
    - Explain why tree diagrams are an admixture of  $\Delta I=1/2$  and  $3/2$  while the penguin diagram is pure  $\Delta I=1/2$ .
    - Why is there no penguin diagram for  $B^+ \rightarrow \pi^+ \pi^0$  ?
  - Armed with all of this information, show the amplitude relationship:
 
$$\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}$$
 Where the charge superscript refers to the charges of the final state pions.



$$B^0 \rightarrow \pi^+ \pi^-$$



$$B^0 \rightarrow \pi^0 \pi^0$$



$$B^+ \rightarrow \pi^+ \pi^0$$