Fall Quarter 2009
UCSD Physics 214 & UCSB Physics 225
Homework 6

This Homework assignment covers chapter 5 & 6 in Halzen & Marten.

1. H&M problem 5.4
2. H&M problem 5.6
3. H&M problem 5.13
4. H&M problem 5.14
5. H&M problem 5.15
6. All of the above are exercises to remind you of the Dirac formalism. The following problem on the other hand is real physics.

As mentioned in class, in the $e^+e^- \to q\bar{q}$ process there are contributions from annhilations of the incoming electron-positron pair into a photon and into a Z-boson. The latter is a weak process. You will see weak interactions next quarter. Nevertheless, if you are given the Feynman rules for Z-exchange processes, you should be already able to calculate the full cross-section.

Consider $e^+e^- \to b\bar{b}$. The first-order electroweak matrix element for this process is given by Halzen and Martin, equation 13.57. (Actually equation 13.57 is for $e^+e^- \to \mu^+\mu^-$, but as pointed out in the text the calculation for a $q\bar{q}$ final state is very similar).

(i) Start from equation 13.57, and make sure you understand how to get from there to equation 13.60. Make also sure that you understand the definition of the angle θ. Is it the angle between the e^- and the μ^- or between the e^- and the μ^+?

(ii) Modify equation 13.60 appropriately for $b\bar{b}$ final states. Then, plot the total cross-section for $e^+e^- \to b\bar{b}$ for center-of-mass energies between 20 and 150 GeV (Use a computer, use a log scale, and sensible

units, e.g. nbarn or μbarn). On the same graph, also plot the purely QED cross-section. (The vector and axial couplings, c_V and c_A of fermions are given in Table 13.2). Use $\sin^2\theta_W = 0.23$, and look up-the values of the mass and width of the Z in the particle data-book.

(iii) Calculate the forward-backward asymmetry A_{FB} (see equation 13.65) as a function of the center-of-mass energy. Plot it in the interval 20-150 GeV. The first measurement of this asymmetry was performed at the Petra storage ring in Hamburg, Germany in 1984 at a center-of mass energy of 34.6 GeV (W. Bartel *et al.*, Phys. Lett. **B146**, 437 1984). They found $A_{FB} = -22.8 \pm 6.5\%$. As you have calculated, this asymmetry depends on c_V and c_A, which are different for up-type and down-type quarks (see Table 13.2). This measurement showed that the b-quark was a down-type quark.