PHYS 575, HW #9

Due: 4/29/20

1. **CKM angles (15 points).** Larkoski problem 12.5. Note that what he calls θ_C is what Schwartz calls θ_{12}. *Hint: this should be a 2-line calculation; don't compute the full squared matrix element and phase space integral!*

2. **Indirect evidence for the top quark (30 points).** Peskin problem 18.2. (Much of the progress in understanding the Standard Model from the 1970's on consisted of predicting the existence of additional particles based on the properties of observed particles. We saw in class that unitarity constraints on longitudinal gauge boson scattering predicted something like the Higgs boson; in this problem you will see how decays of b quarks predict the necessity of the top quark to complete the SU(2) doublet.)

3. e^+e^- **annihilation at the** Z **pole (30 points).** Peskin problem 17.2. For part (a), compute the amplitude in eq. (17.56) using the P_L and P_R projectors in the matrix element with 4-component Dirac spinors; once you've done this you can just quote the results from (8.47) and (8.48) without derivation.

4. Z **decays (35 points).**

   (a) Calculate the partial width of the Z boson into a single pair of massless neutrinos from the same generation (the "invisible width"), and check that you obtain the numerical result of Peskin (17.45). This shows how the measurement of the lineshape of the Z resonance is a powerful consistency check on the Standard Model.

   (b) By inserting left- and right-handed projectors, or by using explicit left- or right-handed spinors, calculate the polarization fraction of down quarks produced in $Z \to d\bar{d}$ (in other words, the partial width into left-handed down quarks, minus the partial width into right-handed down quarks, divided by the total width into both spins). Show that you obtain the expression in Peskin (17.36). Plug in numerical values and check that you get the value given in Peskin (17.35). Note how close this value is to 1! This is just a coincidence, yet it is very convenient for measuring parity-violating couplings of the Z to neutrons, for example, since neutrons are mostly down quarks.

(c) *Without* doing a full calculation from scratch, estimate $\Gamma_{Z\to\tau^+\tau^-}/\Gamma_{Z\to e^+e^-}$, including the effects of the τ mass on both the amplitude and the final-state phase space. In other words, this ratio is $1+\epsilon$ and you want to estimate ϵ. Compare your estimate to the PDG; do you get the right order of magnitude?

5. **Higgs boson production at LEP (30 points).** Schwartz problem 29.1. The total integrated luminosity at LEP was 536 pb^{-1}. This problem completes the argument of Larkoski Ch. 13.1; you can follow the derivation in Larkoski as long as you provide derivations for the steps he skips. (Unfortunately, given its center of mass energy, LEP was only sensitive to Higgs bosons lighter than 115 GeV; they just missed the Higgs at 125 GeV!)

6. **Higgs decays (40 points).**

   (a) Peskin problem 21.1.

   (b) Peskin problem 21.2 (a)-(g). You can use the explicit polarization vectors suggested in the problem or the sum over massive vector polarizations we discussed in class, whichever you prefer.

7. **CP violation in B mesons (20 points).** Peskin problem 19.1.