Theoretical Particle Physics: Flavor Physics Assignment

Due 03/13/07

1. Count the number of flavor parameters for the SM lepton sector, both via explicit counting and via symmetry argument.

2. Repeat the counting for a two generation lepton sector but with the assumption that the neutrinos are Majorana particles. Do not include new states. Assume higher dim' operators, write the higher dimensional operator including the Lorentz and gauge indices.

3. Assuming one generation Majorana neutrino model, are there any other possible higher dimension operators that induce masses, explain (again no extra states beyond the SM ones).

4. Is there an enhance sym' when $m_b = m_s = m_d$? List the flavor parameters, in that case.

5. Consider a 4 generation extension of the SM
   (i) List the flavor parameters both in the quark and lepton sectors.
   (ii) Is this model allowed by data?

6. GIM mechanism: The diagram below (Fig. 1) leads to the rare decay of $K_{L,S} \to \mu\mu$ (or any other two same-flavor leptons). Here we only are only interested in the hard part (the short distance contributions) of flavor structure of the leading contributions. Calculate the diagram using $R_\xi = 1$ gauge (this implies that the gauge bosons propagators have a simple form, $1/(k^2 - M^2_{W,Z})$, note that since the couplings of the would be eaten Higgs fields, which are present in this gauge to the fermions are proportional to their Yukawa and therefore very small so they can be neglected). The calculation amounts to treating the quark and lepton as an external fields and only doing the internal momentum, $k^\mu$, integral in the large momenta limit. The result can be parameterized as the coefficient of the operator $(\bar{s}d_L)[\bar{l}(g^L_Z P_L + g^R_Z P_R)l]$ ($g^{L,R}_Z$ and $P_{L,R}$ are the left and right $Z$ couplings and projection operators respectively). All you need to do is to (i) show that the log divergent term vanishes and (ii) that the leading contribution is proportional to combination of CKM entries and up type quark masses (manifestation of the GIM mechanism).

7. Use similar heuristic arguments to estimate the BR for $t \to cZ$. No explicit calculation is required in this case. The dominant top decay mode is a weak decay mediated by $V_{tb}$, $t \to bW$ (it's actually enhanced by the top Yukawa but you can ignore this effect in your power couting). Count a loop factor as roughly $1/16\pi^2$ and $V_{cb} \sim \lambda^2$ where $\lambda \sim 0.22$. (hint: use the GIM mechanism to find extra suppression factors)

8. Match the above operators that you got to a higher dimensional one in an effective theory of minimal flavor violation.

9. Prove Eq. (55) in the notes.

10. Prove Eq. (64) in the notes.

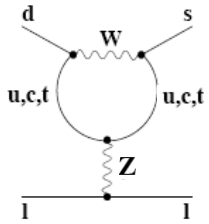


Figure 1: A SM diagram that lead to the rare flavor changing NC process $K_{L,S} \to \mu\mu$