1 FCNC in the lepton sector

1. Consider the SM leptons with the dimension six operator:

$$\mathcal{L} = -\frac{\lambda'}{\Lambda^2} H^\dagger H \bar{L} H e \tag{1}$$

   Derive the condition to generate FCNC Higgs couplings after EWSB.

2. Show why one spurion of the leptonic flavor group, $SU(3)^2$, is not enough to generate lepton flavor-changing couplings.

3. Find the predictions of models with Natural Flavor Conservation (NFC) for $\mu_{\tau^+\tau^-}$, $X_{\mu^+\mu^-}$ and $X_{\tau\mu}$.

4. Estimate the ratio $(|Y^h_{e\mu}|^2+|Y^h_{\mu e}|^2)/(|Y^h_{\mu\tau}|^2+|Y^h_{\tau\mu}|^2)$ in the FN framework. The upper bound on $\mathrm{BR}(\mu \to e\gamma)$ requires $\sqrt{|Y^h_{e\mu}|^2 + |Y^h_{\mu e}|^2} \leq 1.2 \times 10^{-6}$. Estimate the corresponding upper bound on $\mathrm{BR}(h \to \tau\mu)$ in the FN framework

2 VLQ mixing with SM fermions

In class we derived the effective operators generated by integrating out heavy vector-like B, B^c quarks.

1. The number of different VLQ representations that can couple to the SM quarks is rather small. Find these representations.

2. Another way to analyse a model of VLQ is to study the mixing of the new fields with SM quarks. Consider $D \sim (3,2)_{1/6}$ and $D^c \sim (\bar{3},\bar{2})_{-1/6}$, and write the most general renormalizable Lagrangian terms which involve D, D^c and SM fields. How many physical parameters are in the model?

3. In the following we assume that D, D^c couples only to third generation quarks. After EWSB D and D^c mix with the SM fields. Find θ_L and θ_R in terms of the Lagrangian parameters. Direct searches for D, D^c dictate that $M_D \gg v$ should hold. Write the leading terms for the mixing angles in v/M_D expansion.

4. Are there any FCNC in the model? Base your answer on symmetry arguments.

5. Find the Higgs and gauge bosons couplings to quarks. What are the modifications with respect to the SM predictions?

6. Consider the CKM 3×3 matrix for the light quarks. Is it still Unitary?

7. Discuss the experimental constraints on the model (no explicit calculation is required). Estimate the resulting limit on $M_D/|\lambda_3|$.