The SUSY flavor problem

Recall, the MSSM is defined by

- Gauge symmetry $SU(3)_c \times SU(2)_L \times U(1)_Y$
- Matter content (= chiral superfields):

  $\{Q, u^c, d^c, L, e^c\}_{3\text{-families}} \oplus \{H_u, H_d\}$
- Matter parity ($\leftrightarrow$ R parity)
- $W_{MSSM} = u^c Y_u Q H_u + d^c Y_d Q H_d + e^c Y_e L H_d + \mu H_u H_d$
- $\mathcal{L}^{MSSM}_{soft} \longrightarrow$ that "lift" in mass all "superpartners"

Let's give a closer look to the mass terms for the squarks:

$$\sum_{i,j} (\tilde{m}^2_d)_{ij}\, \tilde{d}^+_i \tilde{d}_j \qquad \tilde{m}^2_d = \left(\begin{array}{c|c} (\tilde{m}_Q)_{ij} & (a_d^+)_{ij} v_d \\ \hline (a_d)_{ij} v_d & (\tilde{m}_d)_{ij} \end{array}\right)$$

$\uparrow$ 6x6 matrix $\qquad\qquad$ $\uparrow$ 3x3 blocks

$$(\tilde{d}^+_{L_1}, \tilde{d}^+_{L_2}, \tilde{d}^+_{L_3}, \tilde{d}^+_{R_1}, \tilde{d}^+_{R_2}, \tilde{d}^+_{R_3}) \equiv \tilde{d}^+_i$$

This is often indicated also as

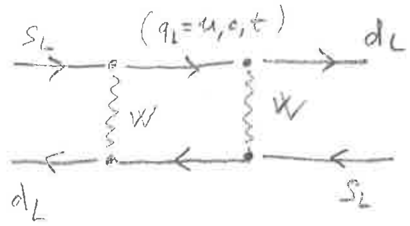
$$\tilde{m}^2_d = \left(\begin{array}{c|c} \tilde{m}^2_{LL} & \tilde{m}^2_{LR} \\ \hline \tilde{m}^{2\,+}_{LR} & \tilde{m}^2_{RR} \end{array}\right)$$

The large number of free parameters in $\mathcal{L}_{soft}$ are all hidden/encoded in these squark/slepton mass matrices

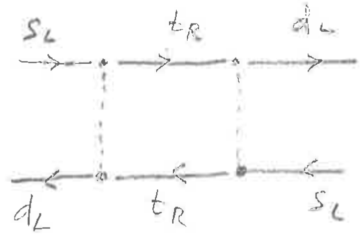
If these mass matrices are "generic" (i.e. all $m^2_{ij} \sim O(m^2_{soft})$) we have a serious problem with flavor observables.

Let's consider for instance $K-\bar{K}$ mixing

Within the SM



$\Longleftrightarrow$



GIM mechanism, top-quark contribution dominates

$$A_{SM} \sim \frac{1}{16\pi^2} \frac{g^4}{m_W^4} m_t^2 (V_{ts}^* V_{td})^2 (\bar{s}_L \gamma^\mu d_L)^2$$

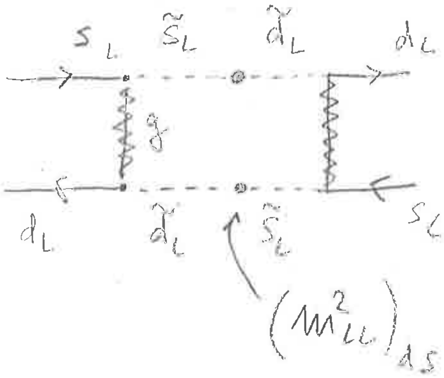
flavor-changing amplitudes are controlled by the Yukawa interaction

$$A_{SM}^{Yukawa} \sim \frac{1}{16\pi^2} \frac{1}{m_t^2} y_t^4 (V_{ts}^* V_{td})^2 (\bar{s}_L \gamma^\mu d_L)$$

Easy to check that

$$A_{SM} \xrightarrow[m_t \gg m_W]{} A_{SM}^{Yukawa}$$

In the MSSM we have new contributions that are not due to the Yukawa interactions:



$$\to \quad A_{SUSY}^{gluino} \sim \frac{g_s^4}{16\pi^2} \frac{1}{m^2_{soft}} \left[\frac{(m^2_{LL})_{ds}}{(\tilde{m}_d^2)} \right]^2 (\bar{s}_L \gamma^\mu d_L)^2$$

$(\delta_{LL})^2_{ds}$ $=$ $\left[\frac{(m^2_{LL})_{ds}}{(\tilde{m}_d^2)} \right]^2$

average down-type squark mass

$$\frac{A^{\text{gluino}}_{\text{SUSY}}}{A^{\text{Yukawa}}_{\text{SM}}} \sim \underbrace{\left(\frac{g_s}{y_t}\right)^4}_{O(1)} \left(\frac{m_t^2}{\tilde{m}^2_{\text{soft}}}\right) * \left(\frac{(\delta_{LL})_{ds}}{V^*_{ts} V_{td}}\right)^2$$

$$|V^*_{ts} V_{td}| \sim 10^{-4}$$

$$\sim \left(\frac{1\ \text{TeV}}{\tilde{m}^2_{\text{soft}}}\right)^2 * \left[\frac{(\delta_{LL})_{ds}}{10^{-3}}\right]^2$$

Since we do not observe deviations from the SM in $K-\bar{K}$ mixing we must impose

$$\tilde{m}^2_{\text{soft}} \gtrsim 10^3\ \text{TeV} * |(\delta_{LL})_{ds}|$$

$\Rightarrow$ If we want to keep $m^2_{\text{soft}} \sim 1\text{-}10$ TeV, then $(\delta_{LL})_{ds} \equiv \dfrac{(m^2_{LL})_{ds}}{\tilde{m}_d^2}$ must be <u>very small</u>

$\Rightarrow$ <u>Squark mass matrices cannot be generic matrices in flavor space</u>

$\Downarrow$

We need a mechanism for SUSY breaking that leads to soft-breaking terms almost proportional to the identity matrix in flavor space

(so-called "flavor-blind" or "flavor-degenerate" soft-breaking terms)