Probing Flavor Structure in Supersymmetric Theories

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I. Introduction

- The recent results on the mixing-induced asymmetries of B → φ K and B → ή K are:

Belle

$$\begin{cases} S_{\varphi K} = 0.44 \pm 0.27 \pm 0.05 \\ S_{\eta' K} = 0.62 \pm 0.12 \pm 0.04 \end{cases}$$

BaBar

$$\begin{cases} S_{\varphi K} = 0.50 \pm 0.25 ^{+0.07}_{-0.04} \\ S_{\eta' K} = 0.30 \pm 0.14 \pm 0.02 \end{cases}$$

- The direct CP violation in $B^0 \to K^- \pi^+$ and $B^- \to K^- \pi^0$:

$A^{CP}_{K^- \pi^+} = -0.113 \pm 0.019$ $4.2\,\sigma$ deviation from zero

$A^{CP}_{K^- \pi^0} = 0.04 \pm 0.04.$ is quite small

- These observations are considered as signals to new physics.

- To accommodate the CP asymmetries of B decays, SUSY models with flavor non-universal soft breaking terms are favored.
- The squark mixings are classified as

  i) LL and RR mixings given by $(\delta^{u,d}_{LL})_{ij}$ and $(\delta^{u,d}_{RR})_{ij}$.

  ii) LR and RL mixings given by $(\delta^{u,d}_{LR})_{ij}$ and $(\delta^{u,d}_{RL})_{ij}$.
- Constraints are more stringent on the LR (RL) mass insertions than the LL (RR) mass insertions.
- MIs between 1st & 2nd generations are severely constrained more than MIs between 1st or 2nd & 3rd generations.
- This gives the hope that SUSY contributions to the B-system.

II. Squark Mixing: LL versus LR

- The EDM constraints severely restrict the LL and RR mass insertions:

$$(\delta^d_{LR})_{22eff} \approx (\delta^d_{LR})_{22} + (\delta^d_{LL})_{23} (\delta^d_{LR})_{33} (\delta^d_{RR})_{32}$$

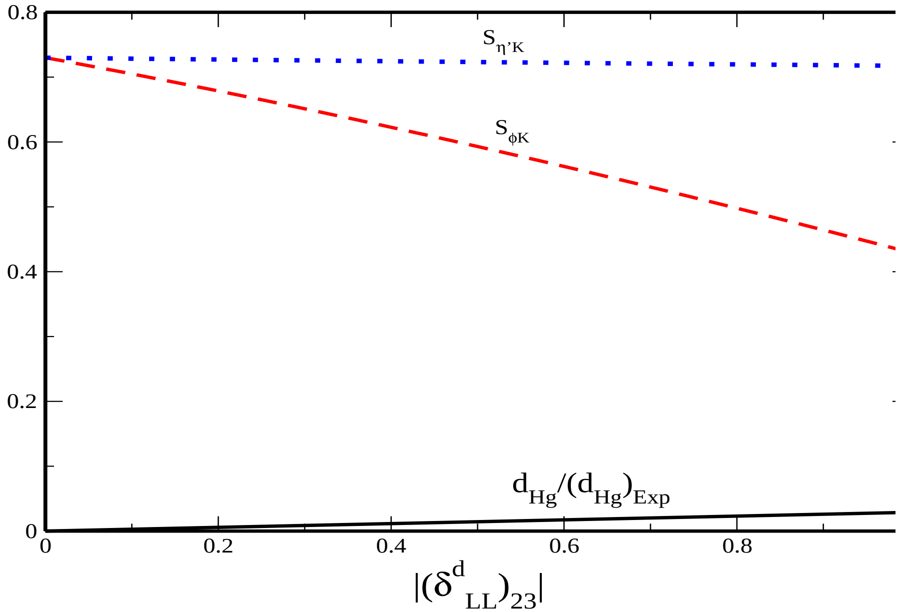
$$\approx 10^{-2} (\delta^d_{LL})_{23} (\delta^d_{RR})_{32} \quad \text{(for neg. } (\delta^d_{LR})_{22}\text{).}$$

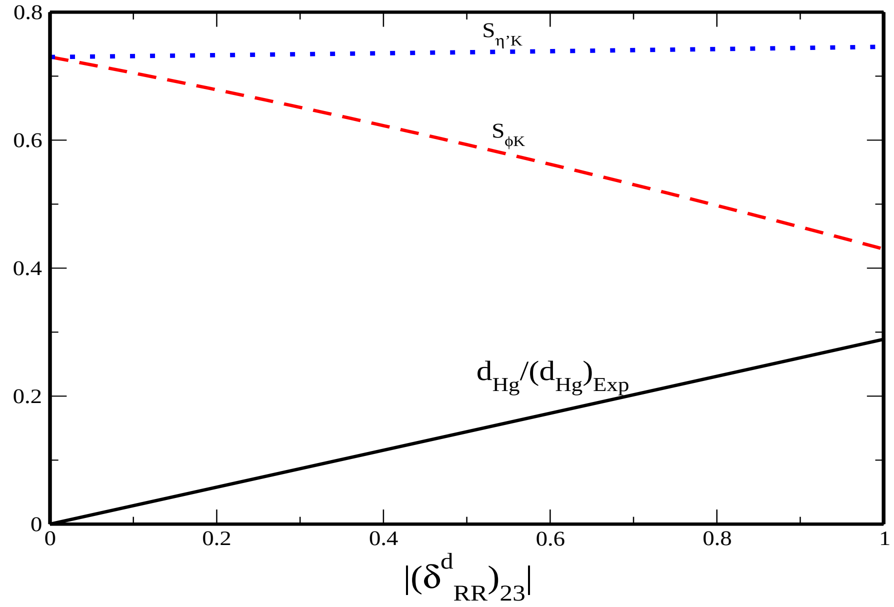
- From Hg EDM: $Im(\delta^d_{LR})_{22} < 5.6 \times 10^{-6}$.
- The SUSY contributions to the decay amplitudes B → φ K and ή K:

$$R_\varphi = -0.14\, e^{-i0.1} (\delta^d_{LL})_{23} - 127\, e^{-i0.08} (\delta^d_{LR})_{23} + (L \leftrightarrow R),$$

$$R_{ή} = -0.07\, e^{-i0.24} (\delta^d_{LL})_{23} - 64\, (\delta^d_{LR})_{23} - (L \leftrightarrow R) .$$

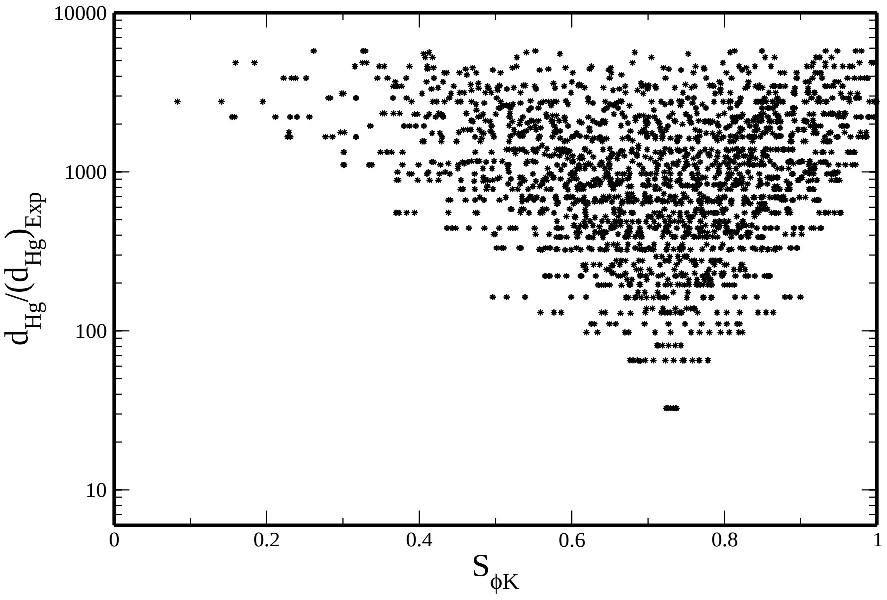
- The CP asymmetries $S_{\varphi K}$ and $S_{\acute{\eta} K}$ can not be accommodated

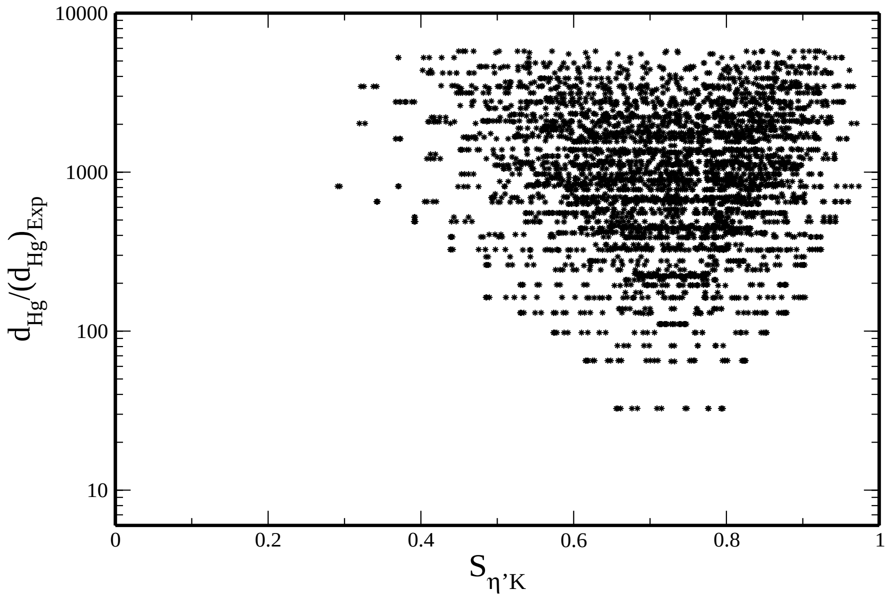




- Combining the effects of LL and RR MIs, we can fit the exp. data of SφK and SήK.

- However, the Hg EDM exceeds with many order of magnitudes its exp. Bound.





- Thus, SUSY models with dominant LR and RL may be the most favorite scenario.

- However, it is difficult to arrange for $(\delta^d_{LR})_{23} \approx O(10^{-2})$ whilst $(\delta^d_{LR})_{12}$ remains small:

From ΔM_K and έ/ε: Re $(\delta^d_{LR})_{12} < O(10^{-4})$ &
Im $(\delta^d_{LR})_{12} < O(10^{-5})$.

- The MI $(\delta^d_{LR})_{ij}$ are given by

$$(\delta^d_{LR})_{ij} \approx [V^{d+}_L \,.\, (Y^d A^d) .\, V^d_R]_{ij} \,.$$

- The factorizable A-term is an example of a specific texture to satisfy this hierarchy between $(\delta^d_{LR})_{12}$ and $(\delta^d_{LR})_{23}$.

- With intermediate/large tanβ, an effective $(\delta^d_{LR})_{23}$ can be obtained: $(\delta^d_{LR})_{23\ eff} = (\delta^d_{LR})_{23} + (\delta^d_{LL})_{23} (\delta^d_{LR})_{33}$

- For negligible $(\delta^d_{LR})_{23}$, we find

$$(\delta^d_{LR})_{23\ eff} \approx (\delta^d_{LL})_{23} \frac{m_b}{\tilde{m}} \tan\beta$$

- Thus if $(\delta^d_{LL})_{23} \approx 10^{-2}$, we get $(\delta^d_{LR})_{23\,\mathrm{eff}} \approx O(10^{-2} - 10^{-3})$.
- These contributions are considered as LL (or RR).
- The main effect is still due to the Wilson coefficient C_{8g} of the chromomagnetic operator.
- Although $(\delta^d_{LL})_{23} \approx 10^{-2}$ is not enough to explain the CP asymmetries of B-decays.
- Still it can induce an effective LR mixing that accounts for these results.

Suggested supersymmetric flavor model

- As an example, we consider the following SUSY model:

$$M_1 = M_2 = M_3 = M_{1/2}$$
$$A^u = A^d = A_0$$
$$M_U^2 = M_D^2 = m_0^2$$
$$m_{H1}^2 = m_{H2}^2 = m_0^2$$

- The masses of the squark doublets are given by

$$M_Q^{\ 2} = \begin{pmatrix} m_0^2 & & \\ & m_0^2 & \\ & & a^2 m_0^2 \end{pmatrix}$$

tan β=15, $m_0 = M_{1/2} = A_0 = 250 \ \longrightarrow \ a \leq 5$

- The Yukawa textures play an important rule in the CP and flavour supersymmetric results.

$$Y^{u}=1/v \sin\beta \, \mathrm{diag}(m_u, m_c, m_t)$$

$$Y^{d}=1/v\sin\beta \, V^{+}_{CKM} \, . \, \mathrm{diag}(m_d, m_s, m_b) \, . \, V_{CKM}$$

- Although, it is hierarchical texture, it lads to a good mixing between the second and third generations.
- The LL down MIs are given by:

$$(\delta^{d}_{LL})_{ij} = 1/m_q^2 \, [V_L^{d+} \, (M^d)^2_{LL} \, V^d_L]_{ij}$$

With $a=5 \rightarrow (\delta^{d}_{LL})_{23} \sim 0.08 \, e^{0.4\, I}$

- Thus, one gets: $(\delta^{d}_{LR})_{23eff} \sim O\,(10^{-2}\text{-}10^{-3})$.

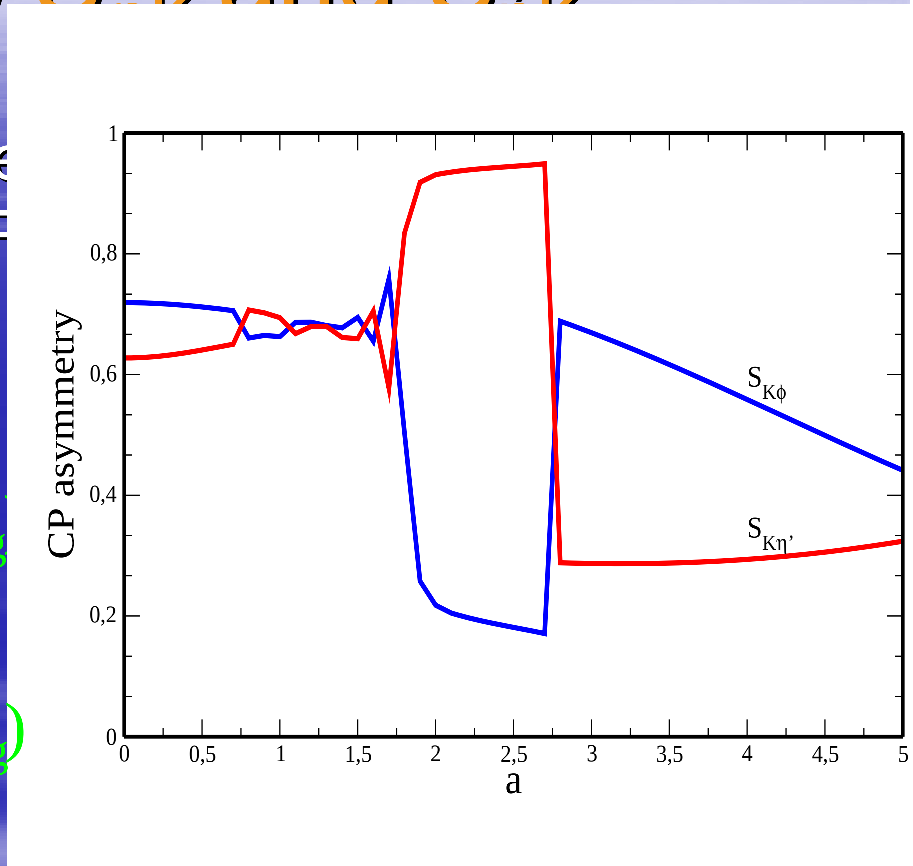
- The corresponding single LR MI is negligible due to the degeneracy of the A-terms.

Contribution to S... and S...

- Gluino exchanges give the dominant contribution to the CP asymmetries: $S_{\varphi K}$ and $S_{\eta' K}$.

$$A(B\to\varphi K)\sim -i\frac{G_F}{\sqrt{2}}m_B^2 F_+^{B\to K} f_\varphi H_{8g}(C_{8g}+\tilde{C}_{8g}$$

$$A(B\to\eta' K)\sim -i\frac{G_F}{\sqrt{2}}m_B^2 F_+^{B\to K} f_{\eta'} H'_{8g}(C_{8g}-\tilde{C}_{8g})$$



- 1 σ constraints on $S_{\eta' K}$ leads to a lower bound on a: a ≥ 3.
- With a large a, it is quite possible to account simultaneously for the experimental results SφK and Sή K .

Contribution to $B \to K\pi$

- The direct CP asymmetries of $B \to K\pi$ are given by:

$$A^{CP}_{K^-\pi^+} \sim 2\, r_T\ \sin\delta_T\ \sin(\theta_P + \gamma) + 2 r_{EW}{}^C \sin\delta_{EW}{}^C \sin(\theta_P - \theta_{EW}{}^C),$$
$$A^{CP}_{K^-\pi^0} \sim 2\, r_T\ \sin\delta_T \sin(\theta_P + \gamma) - 2\, r_{EW} \sin\delta_{EW} \sin(\theta_P - \theta_{EW}).$$

- The parameters θ_P, $\theta_{EW}{}^C$, θ_{EW} and δ_T, δ_{EW}, $\delta_{EW}{}^C$ are the CP violating and CP conserving phases respectively.

- The parameter r_T measures the relative size of the tree and QCD penguin contributions.

- The parameter, r_{EW}, $r_{EW}{}^C$ measure the relative size of the electroweak and QCD contributions.

$$P\, e^{\theta_P} = P^{sm}\,(1 + k\, e^{\theta'_P}),$$

$$r_{EW}\, e^{\delta_{EW}}\, e^{\theta_{EW}} = r_{EW}^{sm}\, e^{\delta_{EW}}\,(1 + l\, e^{\theta'_{EW}}),\; r_{EW}^{C}\, e^{\delta_{EW}^{C}}\, e^{\theta_{EW}^{C}} = (r_{EW}^{C})^{sm}\, e^{\delta_{EW}^{C}}(1 + m\, e^{\theta'_{EW}{}^{C}}),$$

$$r_T\, e^{\delta_T} = (r_T\, e^{\delta_T})^{sm} / |1 + k\, e^{\theta'_P}|$$

- k,l,m are given by ($m_g = m_q = 500$, $M_2 = 200$, $\mu = 400$):

$k\, e^{\theta'_P} = -0.0019 \tan\beta\, (\delta^u_{LL})_{32} - 35.0\, (\delta^d_{LR})_{23} + 0.061\, (\delta^u_{LR})_{32}$

$l\, e^{\theta'_{EW}} = 0.0528 \tan\beta\, (\delta^u_{LL})_{32} - 2.78\, (\delta^d_{LR})_{23} + 1.11 (\delta^u_{LR})_{32}$

$m\, e^{\theta'_{EW}{}^{C}} = 0.134 \tan\beta\, (\delta^u_{LL})_{32} + 26.4\, (\delta^d_{LR})_{23} + 1.62\, (\delta^u_{LR})_{32}$.

a=5, $m_0 = M_{1/2} = A_0 = 250$ GeV $\rightarrow (\delta d_{LR})_{23} \sim 0.006 x e^{-2.7 i}$.

Thus: K~0.2, l~ 0.009, m ~0.16 $\rightarrow r_{EW} \sim 0.13$, $r^c_{EW} \sim 0.012$, $r_T \sim 0.16 \rightarrow A^{CP}_{K^-\pi^+} \sim -0.113$ and $A^{CP}_{K^-\pi^0} < A^{CP}_{K^-\pi^+}$

Conclusions

- We studied the possibility of probing SUSY flavor structure using K, B CP asymmetries constraints & EDM.
- One possibility: large LR and/or RL sector.
- Second possibility: large LL combined with a very small RR and also intermediate or large tan β.
- Large LR requires a specific pattern for A terms.
- Large LL seems quite natural and can be obtained by a non-universality between the squark masses.
- As an example, a SUSY model with a non-universal left squark masses is considered.
- one gets effective $(\delta^d_{LR})_{23}$ that leads to a significant SUSY contributions to the CP asymmetries of B decays.