

Chargino Contributions to FCNC and C/P processes in B Decays

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Works made in collaboration with

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D. Chakraverty, E. G., K. Huitu, S. Khalil
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Summary

- The SUSY Flavour Problem
- Mass Insertion Method: Gluino + Chargino
- $K - \bar{K}$, $B - \bar{B}$ mixing, $B \rightarrow X_s \gamma$
- CP Asymmetries in B decays
 - $B \rightarrow J/\Psi K_S$
 - $B \rightarrow \Phi K_S$
- Conclusions

The Hierarchy Problem

- Two fundamental scales in nature
 - Plank Mass $M_{\text{pl}} = 10^{19} \text{ GeV}$
 - Electroweak scale $\Lambda_{\text{EW}} = \langle H \rangle = 240 \text{ GeV}$
- 17 order of magnitudes of difference !
- Difficult to maintain at quantum level
- Quadratic divergencies in Higgs sector

$$(\delta m_H^2 = \alpha \Lambda_{UV}^2 + \dots \text{ fine tuning problem})$$

- Supersymmetry solves this problem

boson $\leftrightarrow$ fermion symmetry

Supersymmetry

- Doubling the spectrum of the SM with new particles of opposite statistics

If **SUSY** exact $\Rightarrow$ $\text{mass}(\text{SM}) = \text{mass}(\text{SUSY})$

- **SUSY must be SOFTLY broken**

SUSY breaking scale Λ_{SUSY}

$$M_{\text{Plank}} < \Lambda_{\text{SUSY}} < \Lambda_{EW}$$

- In **Gravity mediated** SUSY break. models

– **Gravitino mass** $m_{3/2} \simeq \frac{\Lambda_{\text{SUSY}}^2}{M_{\text{pl}}}$ sets the scale of SUSY partners masses.

If $m_{3/2} \simeq \mathcal{O}(\text{TeV})$ then $\Lambda_{\text{SUSY}} \simeq 10^{11} \text{ GeV}$

– **EW breaking** induced by radiative corrections

- **Gauge couplings unification !**

$$\alpha_1(M_{\text{GUT}}) = \alpha_2(M_{\text{GUT}}) = \alpha_3(M_{\text{GUT}})$$

SUSY breaking mechanisms

Spont. Break. of SUSY in a hidden sector

(communicated to the observable sector
by= *gravity, gauge interactions, anomaly*)



Soft Breaking Terms of MSSM

(at Λ scale)

- Λ_F = scale of **Flavour** symmetry breaking
- Gravity mediated $\Rightarrow \Lambda \sim M_{Pl} \geq \Lambda_F$
- Gauge-mediated $\Rightarrow \Lambda \sim M_M \leq \Lambda_F$

RGE



Soft Breaking Terms of MSSM

(at EW scale)

The SUSY Flavour Problem

- The most general soft-breaking sector in MSSM contains: **106** unknown parameters (26 masses, 37 angles, 43 phases).
Dimopoulos-Sutter ('95)
- Flavour changing neutral currents (FCNC) and CP violating processes set strong constraints on the most general structure of the soft-break. sector of MSSM.
- If we want scalar partner masses $\tilde{m} < 1\text{TeV}$
 $\Rightarrow$ **the FCNC and CP constraints demand strong mass degeneracy in the flavour space among the scalars.**

Hagelin, Kelley, Tanaka, ('94)
Gabbiani, E.G., Masiero, Silvestrini ('96)

- Mass terms

$$\mathcal{L}_{\text{mass}} = \bar{q} M_q q + \tilde{q}^\dagger \tilde{m}_q^2 \tilde{q} + \text{h.c.}$$

- Gluino-interactions (λ_G)

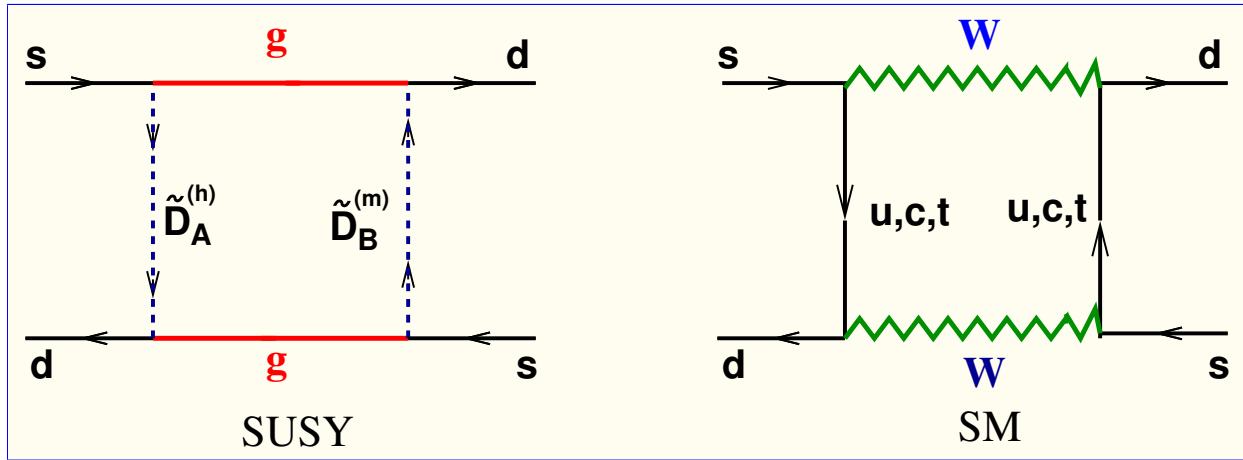
$$\mathcal{L}_{\text{gluino}} = g_s (\bar{q} \tilde{q} \lambda_G) + \text{h.c.}$$

- $q \rightarrow Uq$ and $\tilde{q} \rightarrow V\tilde{q}$ in order to diagonalize M_q and $\tilde{m}_q^2$. THEN

$$\mathcal{L}_{\text{gluino}} \rightarrow g_s (\bar{q} U^\dagger V \tilde{q} \lambda_G) + \text{h.c.}$$

- If $U^\dagger V \neq 1 \Rightarrow$ **tree-level FCNC** mediated by gluino.
- The gluino-mediated FCNC can give **LARGE EFFECTS** to the standard FCNC and CP violating processes.

Super-GIM mechanism



The usual GIM suppression is replaced by

$$\xi_{ij} = \frac{(m_{U_i}^2 - m_{U_j}^2)}{M_W^2} \rightarrow \xi_{ij} = \frac{(\tilde{m}_i^2 - \tilde{m}_j^2)}{\tilde{m}^2}$$

$$\Delta m_K \propto m_K f_K^2 \left(\frac{\alpha_s^2}{\tilde{m}^2} \right) \text{Re} \left\{ \left(\Gamma_{1i} \Gamma_{i2}^\dagger \Gamma_{1j} \Gamma_{j2}^\dagger \right) \times \xi_{ij} \right\}$$

$$\Delta m_K \propto m_K f_K^2 \left(\frac{\alpha_W^2}{M_W^2} \right) \text{Re} \left\{ \left(V_{1i} V_{i2}^\dagger V_{1j} V_{j2}^\dagger \right) \times \xi_{ij} \right\}$$

Mass Insertion Method

- It is a powerful tool in constraining SUSY models from FCNC
- The SuperCKM basis: obtained by a superfield rotation $\Rightarrow M_q$ diagonal

- The gluino vertex is diagonal in flavour:

$$\boxed{q_L^i - \tilde{q}_L^i - \lambda_G^a} \quad \boxed{q_R^i - \tilde{q}_R^i - \lambda_G^a} \quad \simeq g_s T^a$$

but NOT the squark mass matrix $\tilde{m}_{\tilde{q}}^2$

$$\tilde{m}_{\tilde{q}}^2 = \tilde{m}^2 \mathbf{1} + \Delta$$

- The squark propagator is expanded in terms of $\Delta/\tilde{m}^2$, namely 3×3 matrices:

$$(\Delta_{LL})_{ij}, (\Delta_{LR})_{ij}, (\Delta_{RL})_{ij}, (\Delta_{RR})_{ij}$$

$$\frac{i}{((k^2 - \tilde{m}^2)\mathbf{1} - \Delta)_{ab}} \simeq \frac{i\delta_{ab}}{k^2 - \tilde{m}^2} + \frac{i\Delta_{ab}}{(k^2 - \tilde{m}^2)^2}$$

GLUINO CONTRIBUTIONS TO $\Delta S = 2$



EFFECTIVE HAMILTONIAN $\Delta B_d = 2$

$$H_{\text{eff}}^{\Delta B_d=2} = \sum_{i=1}^5 C_i(\mu) Q_i(\mu) + \sum_{i=1}^3 \tilde{C}_i(\mu) \tilde{Q}_i(\mu) + \text{h.c.}$$

$$\begin{aligned} Q_1 &= \bar{d}_L^\alpha \gamma_\mu b_L^\alpha \bar{d}_L^\beta \gamma_\mu b_L^\beta & Q_2 &= \bar{d}_R^\alpha b_L^\alpha \bar{d}_R^\beta b_L^\beta \\ Q_3 &= \bar{d}_R^\alpha b_L^\beta \bar{d}_R^\beta b_L^\alpha & Q_4 &= \bar{d}_R^\alpha b_L^\alpha \bar{d}_L^\beta b_R^\beta \\ Q_5 &= \bar{d}_R^\alpha b_L^\beta \bar{d}_L^\beta b_R^\alpha \end{aligned}$$

$$\tilde{Q}_{1,2,3} = \{Q_{1,2,3}(L \leftrightarrow R)\}$$

$$C_1(M_S) = \frac{\alpha_s^2}{\tilde{m}^2} G_1(x) (\delta_{13}^d)_{LL}$$

$$C_2(M_S) = \frac{\alpha_s^2}{\tilde{m}^2} G_2(x) (\delta_{13}^d)_{RL}$$

$$C_3(M_S) = \frac{\alpha_s^2}{\tilde{m}^2} G_3(x) (\delta_{13}^d)_{RL}$$

$$C_4(M_S) = \frac{\alpha_s^2}{\tilde{m}^2} [G_4^a(x) (\delta_{13}^d)_{LL} (\delta_{13}^d)_{RR} + G_4^b(x) (\delta_{13}^d)_{LR} (\delta_{13}^d)_{RL}]$$

$$C_5(M_S) = \frac{\alpha_s^2}{\tilde{m}^2} [G_5^a(x) (\delta_{13}^d)_{LL} (\delta_{13}^d)_{RR} + G_5^b(x) (\delta_{13}^d)_{LR} (\delta_{13}^d)_{RL}]$$

$x = m_{\tilde{g}}^2 / \tilde{m}^2$

$m_{\tilde{g}}$ = Gluino mass $\tilde{m}^2$ = average squark mass

$G_i(x)$ = Loop functions

CHARGINO INTERACTIONS

Lagrangian in Super-CKM basis

$$\begin{aligned} \mathcal{L}_{d\tilde{q}\tilde{\chi}^+} = & -g \sum_{k=1}^2 \sum_{a,b=1}^3 [V_{k1} K_{ba}^* \bar{d}_L^a (\tilde{\chi}^+)^* \tilde{u}_L^b \\ & - U_{k2}^* (Y_d^{\text{diag}} \cdot K^+)_{ab} \bar{d}_R^a (\tilde{\chi}^+)^* \tilde{u}_L^b \\ & - V_{k2}^* (K \cdot Y_u^{\text{diag}})_{ab} \bar{d}_L^a (\tilde{\chi}^+)^* \tilde{u}_R^b] + \text{h.c.} \end{aligned}$$

- $Y_{u,d}^{\text{diag}}$ = Diagonal Yukawas, K = CKM matrix
- Chargino mass matrix $M_{\tilde{\chi}^+}$

$$U^* M_{\tilde{\chi}^+} V^{-1} = \text{diag}(m_{\tilde{\chi}_1^+}, m_{\tilde{\chi}_2^+})$$

$$M_{\tilde{\chi}^+} = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin \beta \\ \sqrt{2} M_W \cos \beta & \mu \end{pmatrix}$$

- M_2 soft-breaking mass of gaugino field $\tilde{W}_2$
- μ Bilinear-coupling in Superpotential $W = \mu \hat{H}_U \hat{H}_D$
- $\tan \beta = \langle H_U \rangle / \langle H_D \rangle$

CHARGINO CONTRIBUTIONS TO $\Delta S = 2$

S. Khalil, O. Lebedev PL B515 (2001) 387

- Significant contribution only to SM operator, due to the gaugino dominance of chargino interactions

$$Q_1 = \bar{s}_L^\alpha \gamma^\mu d_L^\alpha \bar{s}_L^\beta \gamma_\mu d_L^\beta$$

- Chargino contributions to other operators are suppressed by Yukawas of first generations

$$C_1^{\tilde{\chi}^\pm}(M_S) = \frac{\alpha_W}{\tilde{m}^2} \left(\sum_{a,b} K_{a2}^* (\delta_{LL}^u)_{ab} K_{b1} \right)^2 \times \text{Loop-Funct.}$$

$$\sum_{a,b} K_{a2}^* (\delta_{LL}^u)_{ab} K_{b1} = (\delta_{LL}^u)_{21} + \lambda [(\delta_{LL}^u)_{11} - (\delta_{LL}^u)_{22}] + \mathcal{O}(\lambda^2)$$

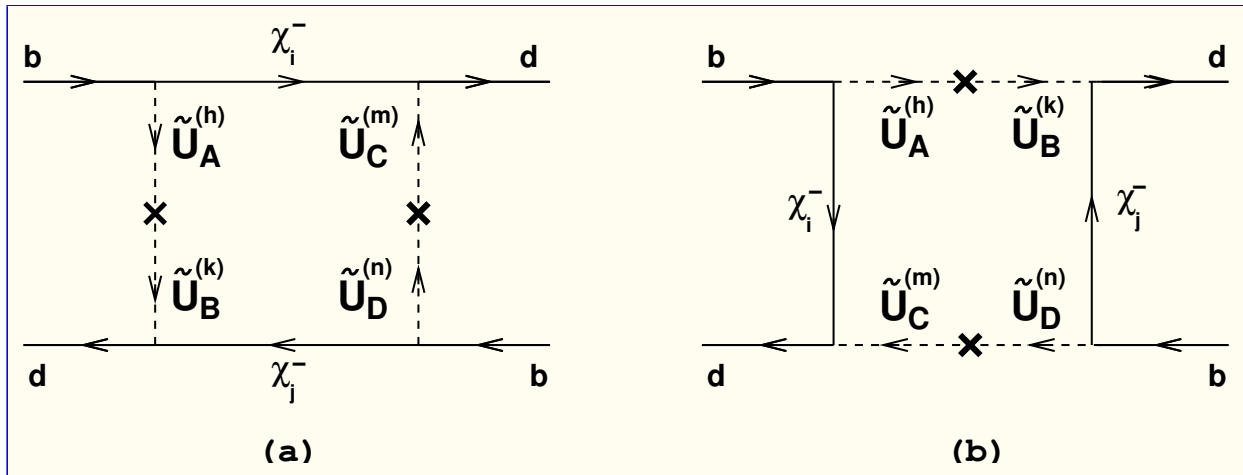
- **Flavour-conserving mass insertions $(\delta_{LL}^u)_{aa}$ contribute, unlike for the gluino case**
- **Bounds on $\sqrt{|\text{Re}[(\delta_{LL}^u)_{21}]|^2}$ from $K^0 - \bar{K}^0$ mixing**

$M_2 \setminus \tilde{m}$	300	500	700	900
150	4×10^{-2}	6×10^{-2}	8×10^{-2}	9×10^{-2}
250	7×10^{-2}	8×10^{-2}	9×10^{-2}	1.1×10^{-1}
350	9×10^{-2}	1×10^{-1}	1.1×10^{-1}	1.2×10^{-1}
450	1.2×10^{-1}	1.2×10^{-1}	1.3×10^{-1}	1.4×10^{-1}

Largely insensitive to $\tan \beta$, $\mu \simeq (200-500)$ GeV

CHARGINO CONTRIBUTIONS TO $\Delta B = 2$

E.G and S. Khalil , PRD 67:015008 (2003)



At first order in $\lambda = \sin \theta_c$

$$\begin{aligned}
 C_1^\chi(M_S) = & \frac{\alpha_W^2}{\tilde{m}^2} \{ A ((\delta_{LL}^u)_{31}^2 + 2\lambda(\delta_{LL}^u)_{31}(\delta_{LL}^u)_{32}) \\
 & + B Y_t ((\delta_{LL}^u)_{31}(\delta_{RL}^u)_{31} + \lambda(\delta_{LL}^u)_{32}(\delta_{RL}^u)_{31} + \\
 & \lambda(\delta_{LL}^u)_{31}(\delta_{RL}^u)_{32}) \\
 & + C Y_t^2 ((\delta_{RL}^u)_{31}^2 + 2\lambda(\delta_{RL}^u)_{31}(\delta_{RL}^u)_{32}) \}
 \end{aligned}$$

$$\tilde{C}_3^\chi(M_S) = \frac{\alpha_W^2}{\tilde{m}^2} Y_b^2 D ((\delta_{LL}^u)_{31}^2 + 2\lambda(\delta_{LL}^u)_{31}(\delta_{LL}^u)_{32})$$

- A, B, C, D = Loop functions $\times$ products of U and V matrices (depend on μ , M_2 , $\tan \beta$, $\tilde{m}$)

- We also consider a **light right-stop** $\tilde{m}_R^2 \ll \tilde{m}^2$

CONSTRAINTS FROM $B - \bar{B}$ mixing

- Experimental value $\Delta M_{B_d} = 0.484 \pm 0.010 \text{ (ps)}^{-1}$

$$\Delta M_{B_d} = 2 |\langle B_d^0 | H_{\text{eff}}^{\Delta B=2} | \bar{B}_d^0 \rangle|$$

- $C_i(\mu \simeq m_b)$ connected to $C_i(M_S)$ at NLO in α_s

$$C_r(\mu) = \sum_i \sum_s \left(b_i^{(r,s)} + \eta c_i^{(r,s)} \right) \eta^{a_i} C_s(M_S)$$

- at NLO we obtain (where $\eta = \alpha_s(\mu)/\alpha_s(M_S)$)

$$\begin{aligned} C_1(\mu) &= x_1(\mu) C_1(M_S), & C_2(\mu) &= x_2(\mu) C_3(M_S) \\ C_3(\mu) &= x_3(\mu) C_3(M_S) \end{aligned}$$

- Hadronic matrix elements

$$\begin{aligned} \langle B_d | Q_1 | \bar{B}_d \rangle &= \frac{1}{3} m_{B_d} f_{B_d}^2 B_1(\mu), \\ \langle B_d | Q_2 | \bar{B}_d \rangle &= -\frac{5}{24} \left(\frac{m_{B_d}}{m_b(\mu) + m_d(\mu)} \right)^2 m_{B_d} f_{B_d}^2 B_2(\mu), \\ \langle B_d | Q_3 | \bar{B}_d \rangle &= \frac{1}{24} \left(\frac{m_{B_d}}{m_b(\mu) + m_d(\mu)} \right)^2 m_{B_d} f_{B_d}^2 B_3(\mu) \end{aligned}$$

- We use Lattice QCD results for $B_i(\mu)$ factors

Upper BOUNDS on $(\delta_{AB}^u)_{ij}$ (CHARGINO)

$M_2 = \mu = 200$ GeV and $\tan \beta = 5$

$\tilde{m}$	$\sqrt{ \text{Re}[(U_{LL}^{31})^2] }$	$\sqrt{ \text{Re}[(U_{RL}^{31})^2] }$	$\sqrt{ \text{Re}[U_{LL}^{31} U_{LL}^{32}] }$
200	1.4×10^{-1}	4.7×10^{-1}	2.1×10^{-1}
400	1.8×10^{-1}	9.0×10^{-1}	2.7×10^{-1}
600	2.2×10^{-1}	1.5	3.4×10^{-1}
800	2.7×10^{-1}	2.3	4.1×10^{-1}

$\tilde{m}$	$\sqrt{ \text{Re}[U_{LL}^{31} U_{RL}^{31}] }$	$\sqrt{ \text{Re}[U_{LL}^{31} U_{RL}^{32}] }$	$\sqrt{ \text{Re}[U_{RL}^{31} U_{RL}^{32}] }$
200	1.8×10^{-1}	4.0×10^{-1}	7.1×10^{-1}
400	3.0×10^{-1}	6.3×10^{-1}	1.3
600	4.5×10^{-1}	9.5×10^{-1}	2.3
800	6.3×10^{-1}	1.3	3.5

- Upper bounds on $(LL)_{31}$ are almost insensitive to $200\text{GeV} < \mu < 500\text{GeV}$, due to dominant gaugino contribution (M_2)
- Upper bounds are less stringent for larger M_2 , due to the decoupling
- All bounds are almost insensitive to $\tan \beta$ (no leading contributions in bottom Yukawa Y_b)
- $(LL)_{32}$ and $(LL)_{32}$ are not very constrained, being proportional to λ

Upper BOUNDS on $(\delta_{AB}^d)_{ij}$ (GLUINO)

(Evaluated at $\tilde{m} = 400 \text{ GeV}$)

(Real part of [...] is taken)

M_3	$\sqrt{ (D_{LL}^{31})^2 }$	$\sqrt{ (D_{RL}^{31})^2 }$	$\sqrt{ D_{LL}^{31} D_{RR}^{31} }$	$\sqrt{ D_{LR}^{31} D_{RL}^{31} }$
200	4.6×10^{-2}	2.2×10^{-2}	8.4×10^{-3}	1.1×10^{-2}
400	1.0×10^{-1}	2.4×10^{-2}	9.6×10^{-3}	1.9×10^{-2}
600	4.8×10^{-1}	2.9×10^{-2}	1.2×10^{-2}	3.0×10^{-2}
800	2.4×10^{-1}	3.4×10^{-2}	1.4×10^{-2}	4.4×10^{-2}

- M_3 is the Gluino mass
- Upper bounds are 1-order of magnitude stronger than the Chargino ones

A light Right-Stop scenario

- In SUSY models the **Right-Stop squark** could be much lighter than other squarks
- Our results generalized to a **LIGHT Right-Stop**
- **This affects only** $C_1^\chi(M_S)$ since the Right-Stop contributions to $\tilde{C}_3^\chi(M_S)$ are of order $\mathcal{O}(\lambda^2)$
- It does not affect bounds on **LL** mass insertions
- **The effect is sizeable!**

Non-decoupling phenomena

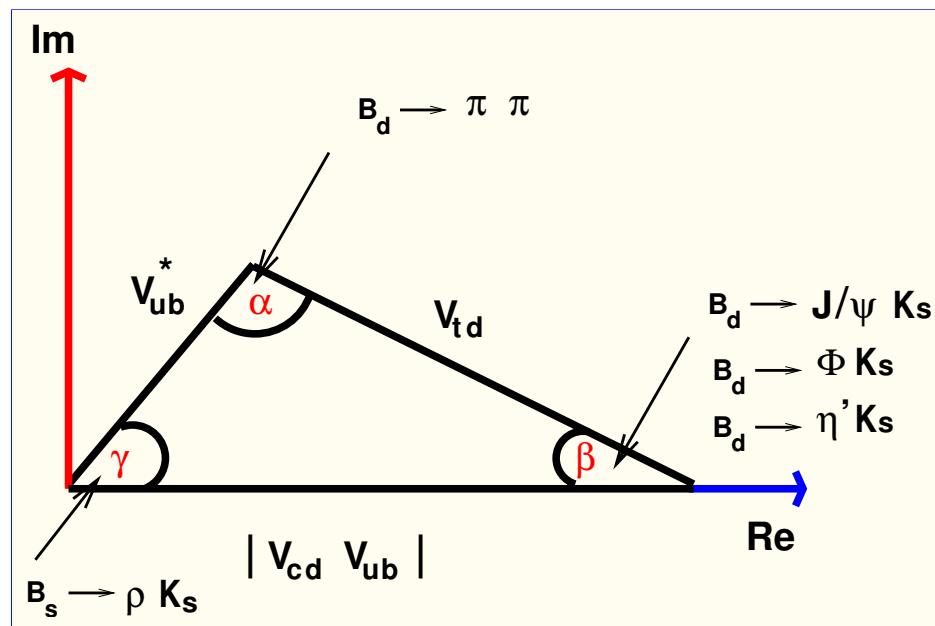
- **When 2 Right-Stops run inside BOX**
- $\tilde{m} \rightarrow \infty$, but fixed M_χ , $\tilde{m}_{\tilde{t}_R} \rightarrow$ **finite effect!**

$\tilde{m}$	$\tilde{m}_{\tilde{t}_R}$	$\sqrt{ \text{Re}[(U_{RL}^{31})^2] }$	$\sqrt{ \text{Re}[U_{LL}^{31} U_{RL}^{3i}] }$	$\sqrt{ \text{Re}[U_{RL}^{31} U_{RL}^{32}] }$
400	100	1.9×10^{-1}	$1.6(3.3) \times 10^{-1}$	2.8×10^{-1}
600	100	1.8×10^{-1}	$1.9(4.0) \times 10^{-1}$	2.6×10^{-1}
800	100	1.8×10^{-1}	$2.3(4.9) \times 10^{-1}$	2.6×10^{-1}
400	200	3.5×10^{-1}	$2.0(4.2) \times 10^{-1}$	5.2×10^{-1}
600	200	3.3×10^{-1}	$2.3(5.0) \times 10^{-1}$	4.9×10^{-1}
800	200	3.2×10^{-1}	$2.8(5.9) \times 10^{-1}$	4.8×10^{-1}

(numbers in parenthesis correspond to $i = 2$)

CP ASYMMETRIES IN B

- **B_d-Factory (BaBar & Belle) Benchmark Modes**
 - $B_d \rightarrow J/\psi K_S$
 - $B_d \rightarrow \pi^+ \pi^-$
 - $B_d \rightarrow \Phi K_S$
- **Hadron Colliders TeV-II and LHC B_s System**
- $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$



Time dependent CP Asymmetries

- The **time-dependent CP Asymmetry** of the B_d and $\bar{B}_d$ meson decay to the CP eigenstate $J/\psi K_S$ is

$$\begin{aligned} A_{\psi K_S}(t) &= \frac{\Gamma(B_d^0(t) \rightarrow \psi K_S) - \Gamma(\bar{B}_d^0(t) \rightarrow \psi K_S)}{\Gamma(B_d^0(t) \rightarrow \psi K_S) + \Gamma(\bar{B}_d^0(t) \rightarrow \psi K_S)} \\ &= A_{\psi K_S}^{\text{dir}} \cos(\Delta m_{B_d} t) - A_{\psi K_S}^{\text{mix}} \sin(\Delta m_{B_d} t) \end{aligned}$$

- The most recent measurements of the MIXING contribution (indirect CP violations) are given by

$$A_{\psi K_S}^{\text{mix}} = 0.741 \pm 0.067 \pm 0.033 \quad (\text{BaBar'02})$$

$$A_{\psi K_S}^{\text{mix}} = 0.719 \pm 0.074 \pm 0.035 \quad (\text{Belle'02})$$

- In SM $A_{\psi K_S}^{\text{mix}} = \sin 2\beta$, while the contribution of direct CP violation in SM is of order $\mathcal{O}(\lambda^3)$

- The present world average

$$\sin 2\beta = 0.734 \pm 0.054$$

- Consistent with CKM fits $0.6 < \sin 2\beta < 0.9$
- These results show that there is a large CP asymmetry in the B meson system

SUSY effects on $A_{\psi K_S}^{\text{mix}}$

- $\mathcal{M}_{12}(\mathbf{B}_d) = \langle \mathbf{B}_d^0 | \mathbf{H}_{\text{eff}}^{\Delta B=2} | \bar{\mathbf{B}}_d^0 \rangle$

$$\mathcal{M}_{12}(\mathbf{B}_d) = \mathcal{M}_{12}^{\text{SM}}(\mathbf{B}_d) + \mathcal{M}_{12}^{\tilde{g}}(\mathbf{B}_d) + \mathcal{M}_{12}^{\tilde{\chi}^+}(\mathbf{B}_d)$$

- In the presence of SUSY contributions, the CP asymmetry $\bar{\mathbf{B}}_d \rightarrow \mathbf{J}/\psi \mathbf{K}_S$ is modified

$$A_{\psi K_S}^{\text{mix}} = \sin 2\beta_{\text{eff}} = \sin (2\beta + 2\theta_d)$$

where

$$2\theta_d = \arg \left(1 + \frac{\mathcal{M}_{12}^{\text{SUSY}}(B_d)}{\mathcal{M}_{12}^{\text{SM}}(B_d)} \right)$$

- The measurement of $A_{\psi K_S}$ would not determine $\sin 2\beta$ but rather $\sin 2\beta_{\text{eff}}$
- We switch off the SM CP phase and require that SUSY contribution does not exceed $(\sin 2\beta)^{\text{EXP}}$
- This will give us conservative bounds on $\text{Im}(\delta_{AB}^u)_{ij}$

Chargino

Upper bounds on Imaginary parts of mass insertions $(\delta_{AB}^u)_{ij}$ for $M_2 = \mu = 200 \text{ GeV}$ and $\tan \beta = 5$

$\tilde{m}$	$\sqrt{ \text{Im} [(U_{LL}^{31})^2] }$	$\sqrt{ \text{Im} [(U_{RL}^{31})^2] }$	$\sqrt{ \text{Im} [U_{LL}^{31} U_{LL}^{32}] }$
200	1.6×10^{-1}	5.4×10^{-1}	2.4×10^{-1}
400	2.0×10^{-1}	1.0	3.0×10^{-1}
600	2.5×10^{-1}	1.7	3.8×10^{-1}
800	3.1×10^{-1}	2.7	4.6×10^{-1}

$\tilde{m}$	$\sqrt{ \text{Im} [U_{LL}^{31} U_{RL}^{31}] }$	$\sqrt{ \text{Im} [U_{LL}^{31} U_{RL}^{32}] }$	$\sqrt{ \text{Im} [U_{RL}^{31} U_{RL}^{32}] }$
200	2.1×10^{-1}	4.5×10^{-1}	8.0×10^{-1}
400	3.4×10^{-1}	7.2×10^{-1}	1.5
600	5.1×10^{-1}	1.1	2.5
800	7.2×10^{-1}	1.5	4.0

Gluino

Upper bounds on Imaginary parts of mass insertions $(\delta_{AB}^d)_{ij}$ evaluated at $\tilde{m} = 400 \text{ GeV}$

M_3	$\sqrt{ \text{Im} [(D_{LL}^{31})^2] }$	$\sqrt{ \text{Im} [(D_{RL}^{31})^2] }$	$\sqrt{ \text{Im} [D_{LL}^{31} D_{RR}^{31}] }$	$\sqrt{ \text{Im} [D_{LR}^{31} D_{RL}^{31}] }$
200	5.2×10^{-2}	2.5×10^{-2}	9.6×10^{-3}	1.2×10^{-2}
400	1.2×10^{-1}	2.7×10^{-2}	1.1×10^{-2}	2.2×10^{-2}
600	5.5×10^{-1}	3.3×10^{-2}	1.3×10^{-2}	3.4×10^{-2}
800	2.8×10^{-1}	3.9×10^{-2}	1.6×10^{-2}	5.0×10^{-2}

CP Asymmetry in $B \rightarrow \Phi K_S$ decay

- The decay is due to FCNC $\Delta B = 1$ transitions.
- In SM the decay is dominated by **QCD penguin contributions**. **Electro-Weak Penguins** are also sizeable
- $A(B^0 \rightarrow \Phi K_S) = \lambda_u^{(s)} A_P^u + \lambda_c^{(s)} A_P^c + \lambda_t^{(s)} A_P^t$
- **Very sensitive to New Physics**
- **In the SM we have**

$$A_{CP}^{\text{dir}}(B_d \rightarrow \Phi K_S) = 0 + \mathcal{O}(\lambda^2)$$

$$A_{CP}^{\text{mix}}(B_d \rightarrow \Phi K_S) = A_{CP}^{\text{mix}}(B_d \rightarrow J/\Psi K_S) + \mathcal{O}(\lambda^2)$$

- **Experimental Status**

$$A_{CP}^{\text{dir}}(B_d \rightarrow \Phi K_S) = \begin{cases} -0.38 \pm 0.37 \pm 0.12 & (\text{BaBar '03}) \\ +0.15 \pm 0.29 \pm 0.07 & (\text{Belle '03}), \end{cases}$$

$$A_{CP}^{\text{mix}}(B_d \rightarrow \Phi K_S) = \begin{cases} 0.45 \pm 0.43 \pm 0.07 & (\text{BaBar '03}) \\ -0.96 \pm 0.50^{+0.11}_{-0.09} & (\text{Belle '03}), \end{cases}$$

- World average $\simeq 2.7\sigma$ deviation from SM result
- **Hint for new physics ?**

G. Hiller ('02), M. Ciuchini, L. Silvestrini ('02)

SUSY contributions to $B \rightarrow \Phi K_S$ decay

Motivations

- Supersymmetry can generate new phases by Penguin diagrams
- **Gluino contribution** has been recently analyzed by several authors
Khalil, Kou ('03), Kane *et.al.* ('03), Harnik *et.al.* ('03), Ciuchini *et.al.* ('03)
- **Gluino contributions could account for the observed deviation**
- However, in many SUSY scenarios gluino is very heavy. If so, no sizeable effects due to decoupling
- Chargino is light in many SUSY scenarios. If gluino is heavy, chargino contributions could be sizeable
- Moreover, $\text{Im}(\delta_{AB}^u)_{23}$ and $\text{Im}(\delta_{AB}^u)_{13}$ are not strongly constrained by $B - \bar{B}$ mixing
- In this framework, we recently analyzed chargino contributions to $\Delta B = 1$ transitions and to CP asymmetry in $B \rightarrow \Phi K_S$ in a model independent way

CHARGINO CONTRIBUTION TO $\Delta B = 1$

$$H_{\text{eff}}^{\Delta B=1} = \sum_{i=1}^{12} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{12} \tilde{C}_i(\mu) \tilde{Q}_i(\mu) + \text{h.c.}$$

- Q_2 Tree-level SM
- $Q_3 - Q_6$ Strong penguin operators
- $Q_7 - Q_{10}$ Electroweak penguin operators
- Q_{11} Magnetic, Q_{12} Chromo-Magnetic penguin operators

Chargino contribution

- Main contribution only to SM Q_i operators
- Gluino-chargino $\Delta B = 1$ Boxes contribute to new operators, but their effects is negligible

$$\begin{aligned} F_\chi = & [(\delta_{LL}^u)_{32} + \lambda(\delta_{LL}^u)_{31}] R_F^{LL} + Y_t [(\delta_{RL}^u)_{32} + \lambda(\delta_{RL}^u)_{31}] R_F^{RL} \\ & + \mathcal{O}(\lambda^2) \end{aligned}$$

- **F=Penguins, Magnetic-penguins, Boxes**
- R_F^{LL} and R_F^{RL} are loop functions

SUSY contribution to CP ASYMMETRY

- Parametrization of SUSY and SM amplitudes

$$\left(\frac{A^{\text{SUSY}}}{A^{\text{SM}}} \right)_{\phi K_S} \equiv R_\phi e^{i\theta_\phi} e^{i\delta_{12}}$$

θ_ϕ is the SUSY CP violating phase

$\delta_{12} = \delta_{\text{SM}} - \delta_{\text{SUSY}}$ is the strong (CP cons.) phase

- The CP mixing Asymmetry

$$A_{\phi K_S}^{\text{mix}} = \frac{\sin 2\beta + 2R_\phi \cos \delta_{12} \sin(\theta_\phi + 2\beta) + R_\phi^2 \sin(2\theta_\phi + 2\beta)}{1 + 2R_\phi \cos \delta_{12} \cos \theta_\phi + R_\phi^2}$$

- The most general amplitude for $B \rightarrow \phi K_S$ process can be written as

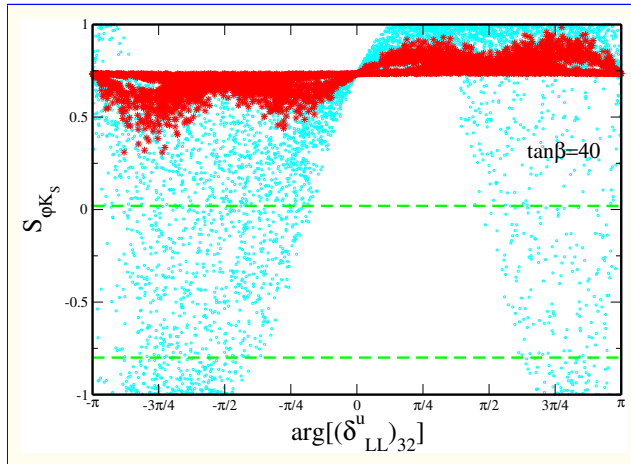
$$\overline{A}(\phi K) = -\frac{G_F}{\sqrt{2}} \sum_{i=1}^{12} \left[C_i(\mu) + \tilde{C}_i(\mu) \right] \langle \phi \bar{K}^0 | Q_i(\mu) | \bar{B}^0 \rangle$$

- We calculated $C_{i=1-10}$ at **NLO** (QCD+QED), and Chromomagnetic-operator $C_{12}(\mu)$ at **LO**
- $\langle \phi \bar{K}^0 | Q_i | \bar{B}^0 \rangle$ are calculated in the naive factorization approximation

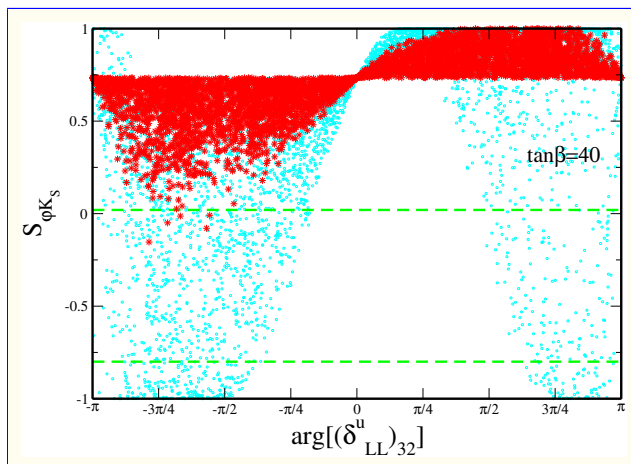
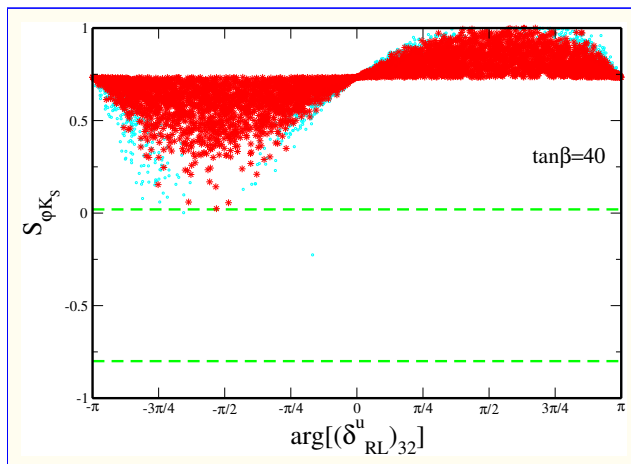
Phenomenological Analysis (Scheme)

- One mass insertion dominant with respect to the others
- Two mass insertions dominant with respect to the others, but same CP violating phase
- Therefore, there is only one SUSY CP phase that factorizes, $\theta_\phi = \arg[(\delta_{AB}^u)_{ij}]$
- We scan over all the **relevant SUSY parameters**: $\tilde{m}$, M_2 , the μ term, and $m_{\tilde{t}_R}$
- We scan over all the **relevant mass insertions**: $(\delta_{LL}^u)_{32}$ and $(\delta_{RL}^u)_{32}$
- **EXPERIMENTAL CONSTRAINTS**
 - Lightest chargino $m_\chi > 90 \text{ GeV}$
 - Heavy squarks $\tilde{m} > 300 \text{ GeV}$
 - Light right-stop $m_{\tilde{t}_R} > 150 \text{ GeV}$
 - $b \rightarrow s\gamma$ and $B - \bar{B}$ constraints

Green band = 1σ EXP region



Red = Allowed by $b \rightarrow s\gamma$



$$\text{Arg}(\delta_{LL}^u)_{32} = \text{Arg}(\delta_{RL}^u)_{32}$$

- The dominant contribution is due to the Chromomagnetic operator Q_{12}
- Allowed regions are almost insensitive to $\tan\beta$

CONCLUSIONS

- We analyzed H_{eff} for $\Delta B = 2$ and $\Delta B = 1$ transitions at first order in Mass Insertion Approximation
- Upper bounds on Real (Imaginary) parts of $(\delta_{LL}^u)_{32}$ and $(\delta_{RL}^u)_{32}$, $(\delta_{LL}^u)_{31}$ and $(\delta_{RL}^u)_{31}$ from $B - \bar{B}$ mixing ($\sin 2\beta$) are obtained.
- $\Delta B = 2$ sector mainly constrain $(\delta_{LL}^u)_{31}$ and $(\delta_{RL}^u)_{31}$
- CP Asymmetry in $A_{\text{CP}}^{\text{mix}}(B \rightarrow \Phi K_S)$ has shown 2.7σ deviation from SM predictions
- Dominant SUSY effect in $A_{\text{CP}}(B \rightarrow \Phi K_S)$ is due to Chromomagnetic operator
- Gluino and Chargino contributions to CP Asymmetry in $B \rightarrow \Phi K_S$ can provide large and negative values, but the latter suffer from $b \rightarrow s\gamma$ constraints
- Maybe too early to get excited... hadronic uncertainties not completely under control !