CP asymmetry of $B \rightarrow K\pi$ in SUSY models with non-universal A-terms

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Introduction

- The puzzle of the CP asymmetries in $B \to K\pi$ decays have created a lot of interest and several research work have been done to explain the experimental data.

Decay channel	$BR \times 10^{-6}$	A_{CP}
$K^+\pi^-$	19.4 ± 0.6	-0.097 ± 0.012
$K^+\pi^0$	12.9 ± 0.6	0.05 ± 0.025
$K^0\pi^+$	23.1 ± 1.0	0.009 ± 0.025
$K^0\pi^0$	9.9 ± 0.6	-0.12 ± 0.11

The latest world average of the branching ratio and CP asymmetry results.

- The difference between $A^{CP}(K^+\pi^-)$ and $A^{CP}(K^+\pi^0)$ is about 3.2 σ, which is quite difficult to be accommodated within the SM. This can be a hint for new physics.

$B \to K\pi$ CP symmetry in the SM

- **The effective Hamiltonian of $\Delta B = 1$ transition is given by**

$$H_{\text{eff}}^{\Delta B=1} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p \left(C_1 Q_1^p + C_2 Q_2^p + \sum_{i=3}^{10} C_i Q_i + C_{7\gamma} Q_{7\gamma} + C_{8g} Q_{8g} \right) + h.c.,$$

- **$\lambda_p = V_{pb} V^*_{ps}$, C_i= are the Wilson coefficients and Q_i= are the relevant operators.**
- **The hadronic matrix elements of operators is the source of uncertainty in calculating the decay amplitudes.**
- **In the SM the amplitudes of $B \to K\pi$ can be approximately written as**

$$\begin{aligned}
A_{\bar{B}^0 \to \pi^+ K^-} &\simeq (a_1 + b_1\ i)\ C_1 + (a_2 + b_2\ i)\ C_4, \\
A_{\bar{B}^0 \to \pi^0 K^0} &\simeq -\frac{1}{\sqrt{2}} (a_2 + b_2\ i)\ C_4, \\
A_{B^- \to \pi^0 K^-} &\simeq \frac{1}{\sqrt{2}} (a_1 + b_1\ i)\ C_1 + \frac{1}{\sqrt{2}} (a_2 + b_2\ i)\ C_4 \\
A_{B^- \to \pi^- K^0} &\simeq (a_2 + b_2\ i)\ C_4.
\end{aligned}$$

- **The SM predictions for the direct CP asymmetries of $B \to K\pi$ at $\gamma=\pi/3$.**

CP asymmetry	$\rho_{A,H}=0$	$\rho_{A,H}=1$ & $\phi_{A,H}\sim 1(-1)$	$\rho_{A,H}=3$ & $\phi_{A,H}\sim 1(-1)$
$A^{CP}_{\bar{K}^0\pi^-}$	0.007	0.0086 (0.005)	0.0078 (0.001)
$A^{CP}_{K^-\pi^0}$	0.029	0.063 (-0.006)	0.185 (-0.15)
$A^{CP}_{K^-\pi^+}$	0.0044	0.057 (-0.049)	0.194 (-0.19)
$A^{CP}_{\bar{K}^0\pi^0}$	-0.02	-0.013 (-0.025)	-0.019 (-0.002)

- **$A_{CP}(K^0\pi^+)$ & $A_{CP}(K^0\pi^0)$ are very small even with large values of ρ.**
- **$A^{CP}_{K^-\pi^+}$ can be of order the experimental result.**
- **However, in this case, $A^{CP}_{K^-\pi^0}$ is also enhanced and becomes one order of magnitude larger than its experimental value.**
- **More accurate experimental data is necessary.**
- **within the SM the current experimental measurements can not be accommodated even if one considers large hadronic uncertainties.**

$B\to K\pi$ in the SUSY models

- **In QCDF scheme, the SUSY contribution to the decay amplitudes of $B\to K\pi$ are given by**

$$
\begin{aligned}
A_{B^-\to\pi^-\overline{K}^0} &= \lambda_c A_{\pi\bar{K}} P\left[e^{i\theta_P} + r_A e^{i\delta_A} e^{-i\gamma}\right] \\
\sqrt{2}A_{B^-\to\pi^0K^-} &= \lambda_c A_{\pi\bar{K}} P[e^{i\theta_P} + \left(r_A e^{i\delta_A} + r_C e^{i\delta_C}\right) e^{-i\gamma} + r_{EW} e^{i\theta_{EW}} e^{i\delta_{EW}}] \\
-\sqrt{2}A_{\overline{B}^0\to\pi^0\overline{K}^0} &= \lambda_c A_{\pi\overline{K}} P\Big[e^{i\theta_P} + \left(r_A e^{i\delta_A} + r_T e^{i\delta_T} - r_C e^{i\theta_C} e^{i\delta_C}\right) e^{-i\gamma} + r^C_{EW} e^{i\theta^C_{EW}} e^{i\delta^C_{EW}} \\
&\quad - r_{EW} e^{i\theta_{EW}} e^{i\delta_{EW}}\Big].
\end{aligned}
$$

- **T, C, A, P, EW. EW^C represent a tree, a color suppressed tree, an annihilation, QCD penguin, electroweak penguin, and suppressed electroweak penguin diagrams.**

$$
\begin{aligned}
P e^{i\theta_P} e^{i\delta_P} &= \alpha_4^c - \frac{1}{2}\alpha^c_{4,EW} + \beta_3^c + \beta^c_{3,EW}, \\
r_{EW} e^{i\theta_{EW}} e^{i\delta_{EW}} &= \left[\frac{3}{2}(R_{K\pi}\alpha^c_{3,EW} + \alpha^c_{4,EW})\right]/P, \\
r^C_{EW} e^{i\theta^C_{EW}} e^{i\delta^C_{EW}} &= \left[\frac{3}{2}(\alpha^c_{4,EW} - \beta^c_{3,EW})\right]/P.
\end{aligned}
$$

- **For** $m_{\tilde{g}} = 500$ GeV, $m_{\tilde{q}} = 500$ GeV,

  $m_{\tilde{t}_R} = 150$ GeV, $M_2 = 200$ GeV, $\mu = 400$ GeV and $\tan\beta = 10$,

- **The SUSY contribution to r_{EW} and r^C_{EW}, in MIA, are given by**

$$r_{EW}^{SUSY} \simeq r_{EW}^{SM}\left[1 + 0.053\tan\beta(\delta^u_{LL})_{32} - 2.78(\delta^d_{LR})_{23} + 1.11(\delta^u_{LR})_{32}\right].$$

$$(r^C_{EW})^{SUSY} \simeq (r^C_{EW})^{SM}\left[1 + 0.134\tan\beta(\delta^u_{LL})_{32} + 26.4(\delta^d_{LR})_{23} + 1.62(\delta^u_{LR})_{32}\right].$$

- **$(r^C_{EM})^{SM} \sim 0.01$ and $(r_{EW})^{SM} \sim 0.1$.**

- **$b \to s\,\gamma$ severely constrain the MIs: $(\delta^d_{LR})_{23}$ and $(\delta^u_{LL})_{32}$.**

- **The MI $(\delta^u_{LR})_{32}$ is unconstrained and can be of order one.**

- **Thus, $(r^C_{EW})^{SUSY} \sim (r^C_{EM})^{SM} \sim O(10^{-2})$ & the CP asymmetries are given by**

$$
\begin{aligned}
A_{CP}(K^+\pi^-) &\simeq -2r_T \sin\delta_T \sin(\theta_P+\gamma),\\
A_{CP}(K^0\pi^+) &\simeq -2r_A \sin\delta_A \sin(\theta_P+\gamma),\\
A_{CP}(K^0\pi^0) &\simeq 2r_{EW} \sin\delta_{EW} \sin(\theta_P-\theta_{EW}),\\
A_{CP}(K^+\pi^0) &\simeq -2r_T \sin\delta_T \sin(\theta_P+\gamma) - 2r_{EW} \sin\delta_{EW} \sin(\theta_P-\theta_{EW}),
\end{aligned}
$$

- **Within the SM ($\theta_P= \theta_{EW}=0$, $r_T\sim0.2$ and $r_{EW}\sim0.1$), one finds: $A_{CP}(K^+\pi^-)= A_{CP}(K^+\pi^0)$**
- **In SM, $A_{CP}(K^0\pi^0)$ is predicted to be ~ zero. This may contradict the exp. results: $A_{CP}(K^0\pi^0) \sim -0.12 \pm 0.11$.**
- **$A_{CP}(K^0\pi^+)$ is consistent with the SM since $r_A\sim O(0.01)$.**
- **SUSY CP violating phases θ_P and θ_{EW} play important role in accommodating the observed measurements.**

SUSY models with non-universal A-term

- **Motivated by string/brane inspired models, we parameterize the trilinear matrices $Y^A_{(u,d)}$ as $(YA)_{ij} = A_{ij} Y_{ij}$, where A_{ij} is given by**

$$A^u = A^d = \tilde{m}_0 \begin{pmatrix} x & y & z \\ x & y & z \\ x & y & z \end{pmatrix} ,$$

- **The entries x, y and z are complex and of order one. We also assume universal soft scalar mass m_0 and universal gaugino mass $M_{1/2}$.**

- **This "factorizable" A-term implies that $Y^A = Y.A$. In the super-CKM basis it is given by $Y^A = Y_{diag}.(U.A.V)$. Hence MI's are given by:**

$$(\delta^q_{LR})_{ij} = \frac{m^q_i}{\tilde{m}^2_q} (U.A^q.V)_{ij} ,$$

- **It is now clear that the mass insertion $(\delta^u_{LR})_{11} \sim m_u/m_0 \sim O(10^6)$, which is consistent with the stringent EDM constraint.**

- **In SUSY models with non-universal *A*-terms, it is possible to have large effects in CP violation observable, and in particular in ϵ'/ϵ.**

- **Furthermore, the mass insertion $(\delta^u_{LR})_{32}$, which is relevant for the CP asymmetry of $B \to K\pi$, is given by $(\delta^u_{LR})_{32} \sim m_t/m_0 \sim O(0.1)$.**

- **In SUSY models with non-universal *A*-terms, the relevant Wilson coefficients due to the gluino exchange (in MIA) are as follows:**

$$C_{7\gamma}^{\tilde{g}} \simeq \frac{8\alpha_S\pi}{9\sqrt{2}G_F m_{\tilde{q}}^2}\frac{m_{\tilde{g}}}{m_b}\left[\left(\delta^d_{LR}\right)_{23} + \left(\delta^d_{RL}\right)_{23}\right] M_1(x),$$

$$C_{8g}^{\tilde{g}} \simeq \frac{8\alpha_S\pi}{9\sqrt{2}G_F m_{\tilde{q}}^2}\frac{m_{\tilde{g}}}{m_b}\left[\left(\delta^d_{LR}\right)_{23} + \left(\delta^d_{RL}\right)_{23}\right]\left(\frac{1}{3}M_1(x) + 3M_2(x)\right).$$

- **While the Wilson coefficients due to chargino exchange are given by:**

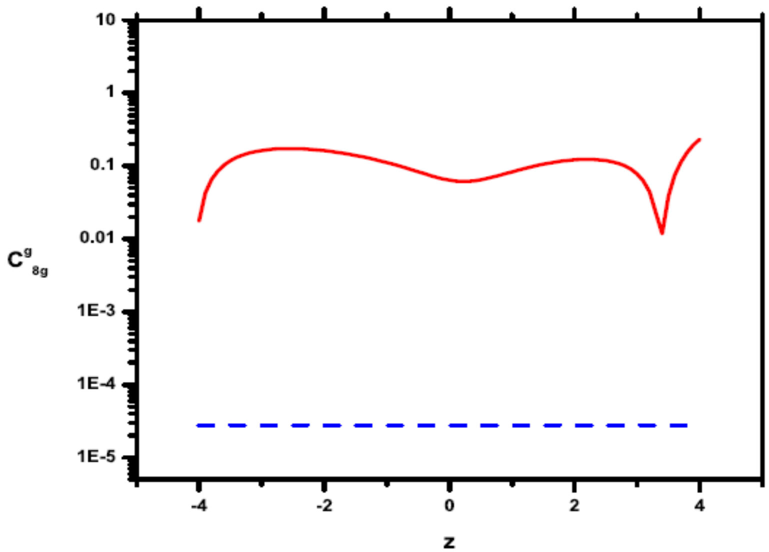
$$C_7^{\chi} \simeq \frac{\alpha}{4\pi}Y_t\left[(\delta^u_{RL})_{32} + \lambda\,(\delta^u_{RL})_{31}\right](4R_C + R_D),$$

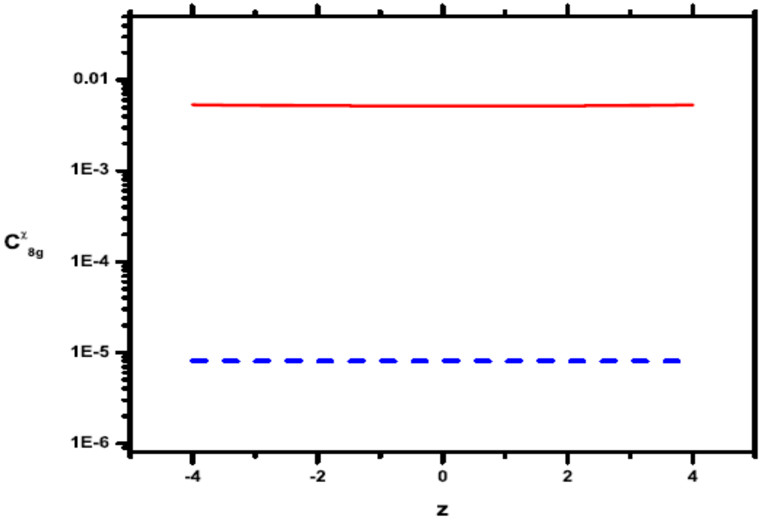
$$C_9^{\chi} \simeq \frac{\alpha}{4\pi}Y_t\left[(\delta^u_{RL})_{32} + \lambda\,(\delta^u_{RL})_{31}\right]\left(4(1 - \frac{1}{4\sin^2\theta_W}R_C + R_D\right),$$

$$C_{7\gamma}^{\chi} \simeq Y_t\left[(\delta^u_{RL})_{32} + \lambda\,(\delta^u_{RL})_{31}\right] R_{M_\gamma},$$

$$C_{8g}^{\chi} \simeq Y_t\left[(\delta^u_{RL})_{32} + \lambda\,(\delta^u_{RL})_{31}\right] R_{M_g}.$$

- The gluino and chargino contributions to C_{8g} as function of A_0 in MIA (solid line) and mass eignestate (dashed line).





- The Wilson coefficients are two order of magnitude larger in mass eigenstate than MIA.

- MIA is not an accurate approximation in B-sector.

- **The SUSY contribution to decay amplitudes are given by**

$$10^6 \times A^{SUSY}_{K^0\pi^-} = (0.8+0.8i)C_7 + (0.4+1.2i)C_9 + 0.006iC_{7\gamma} + 0.7iC_{8g}$$

$$10^6 \times A^{SUSY}_{K^-\pi^+} = (0.4+2.6i)C_7 + (0.6+2.9i)C_9 + 0.012iC_{7\gamma} + 0.7iC_{8g}$$

$$10^6 \times A^{SUSY}_{K^0\pi^0} = (0.3+9.6i)C_7 + (0.1+12.1i)C_9 + 0.004iC_{7\gamma} + 0.5iC_{8g}$$

$$10^6 \times A^{SUSY}_{K^0\pi^-} = (0.5+8.3i)C_7 + (0.3+13.2i)C_9 + 0.008iC_{7\gamma} + 0.51iC_{8g}$$

- **Let us assume the following parametrization for the SM and SUSY amplitudes:**

$$A^{SM} = |A^{SM}|e^{i(\theta_{SM}+\delta_{SM})} \qquad A^{SUSY} = |A^{SUSY}|e^{i(\theta_{SUSY}+\delta_{SUSY})},$$

$$\bar{A}^{SM} = |A^{SM}|e^{i(-\theta_{SM}+\delta_{SM})} \qquad \bar{A}^{SUSY} = |A^{SUSY}|e^{i(-\theta_{SUSY}+\delta_{SUSY})},$$

- **where $\delta_{SM(SUSY)}$ is the CP conserving phase, while γ and θ are the SM and SUSY CP violating phases respectively.**

- **The direct CP asymmetry of B→Kπ decay is defined as**

$$A^{CP}(K^-\pi^+) = \frac{|A(\bar{B}^0 \to K^-\pi^+)|^2 - |A(B^0 \to K^+\pi^-)|^2}{|A(\bar{B}^0 \to K^-\pi^+)|^2 + |A(B^0 \to K^+\pi^-)|^2},$$

- **Using the above parameterization one finds**

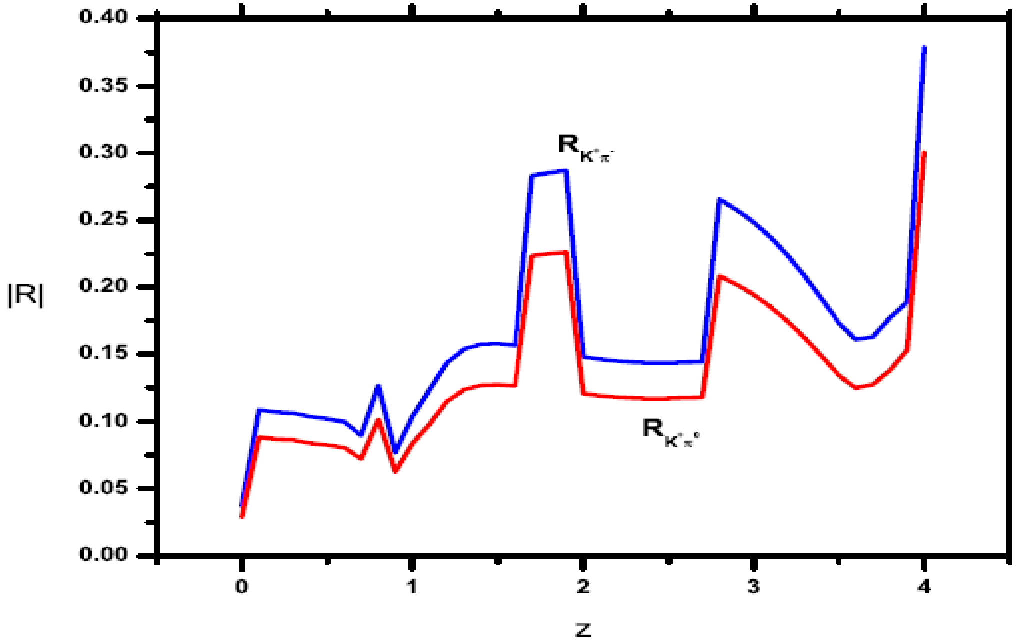
$$A^{CP} = \frac{2R\sin(\delta_{SM} - \delta_{SUSY})\sin(\theta_{SM} - \theta_{SUSY})}{1 + R^2 + 2R\cos(\delta_{SM} - \delta_{SUSY})\cos(\theta_{SM} - \theta_{SUSY})},$$

- **where R is defined by $R = |A_{SUSY} = A_{SM}|$ and the CP phases are given by:**

$$\theta_{SM} = \frac{1}{2}\arg(A_{SM} - \bar{A}_{SM}) \qquad \delta_{SM} = \frac{1}{2}\arg(A_{SM} + \bar{A}_{SM}),$$

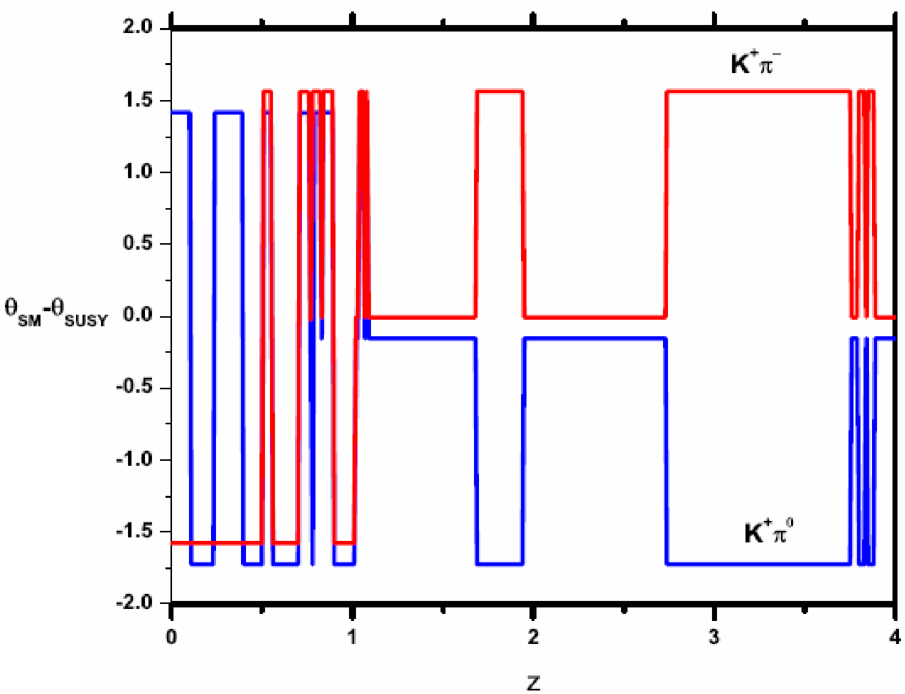
$$\theta_{SUSY} = \frac{1}{2}\arg(A_{SUSY} - \bar{A}_{SUSY}) \qquad \delta_{SUSY} = \frac{1}{2}\arg(A_{SUSY} + \bar{A}_{SUSY}).$$

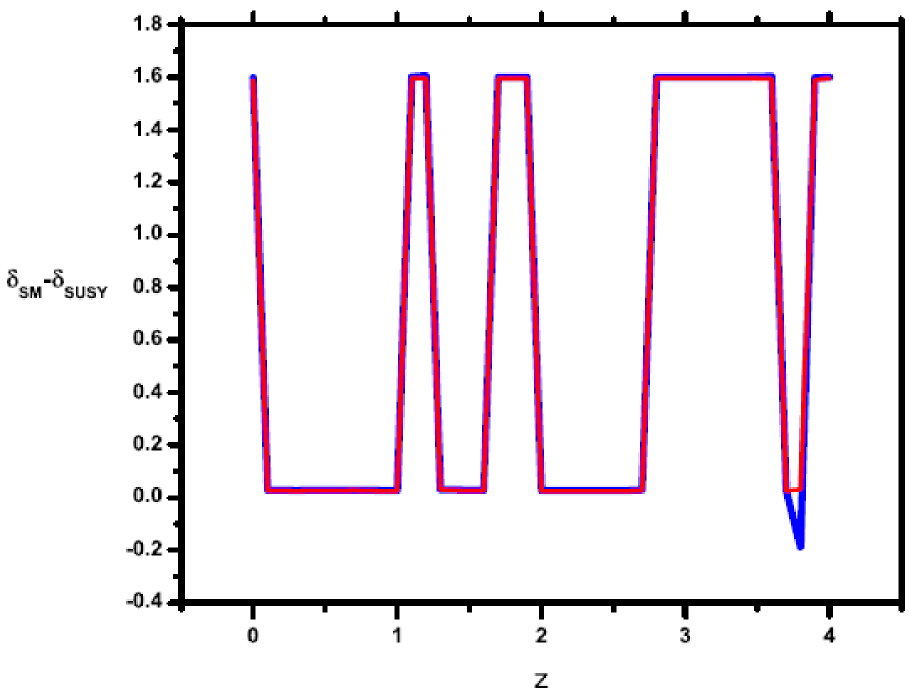
- **The free parameters in this model are: m_0, $M_{1/2}$, x, y, z, ϕ_1, ϕ_2, ϕ_3, $\tan\beta$.**
- **The important constraints are due to $b\to s\gamma$ and EDM.**



- **The ratio R as function of the trilinear parameter z for $\tan\beta=10$, $\phi_1, \phi_2, \phi_3 \sim O(1)$, $m_0 \sim 300$ GeV, $M_{1/2} \sim 500$.**
- **In SUSY, $R_{K^+\pi^-} > R_{K^+\pi^0}$, therefore, it is natural to have $|A^{CP}_{K^+\pi^-}| > |A^{CP}_{K^+\pi^0}|$**

The CP violating and CP conserving Phases as function of the trilinear parameter z

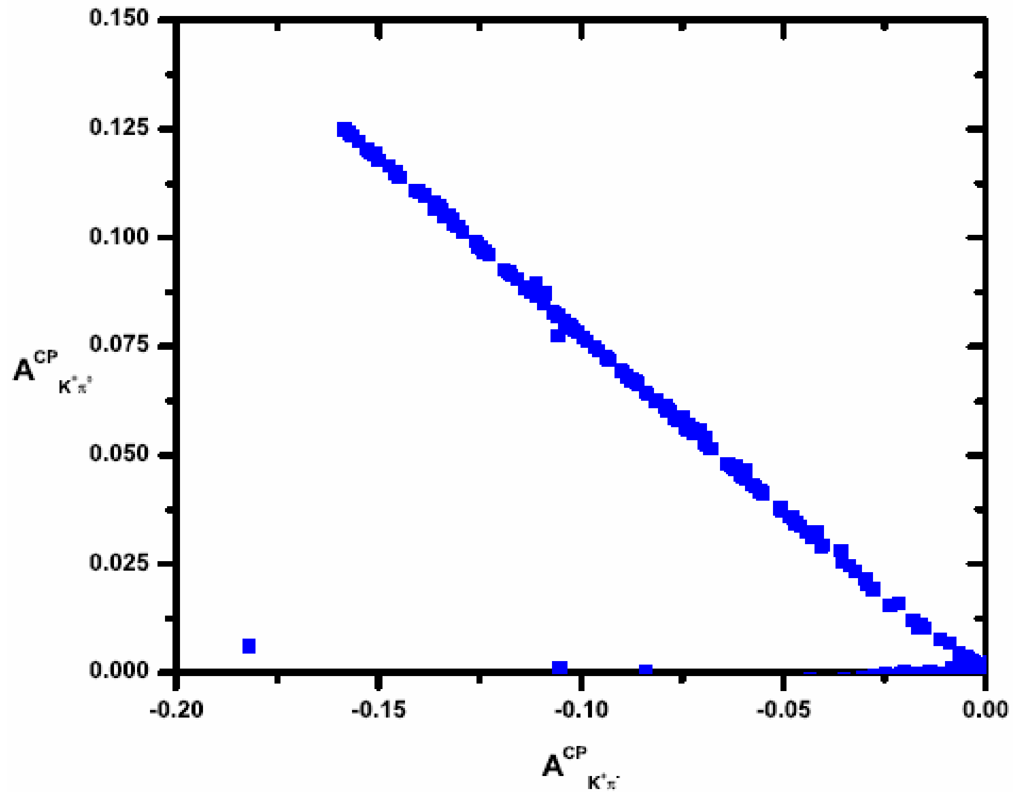




For most of the parameter space: The CP violating phases of $K^+\pi^-$ and $K^+\pi^0$ have opposite sign.

While they have equal CP conserving Phases.

Correlation between The CP asymmetries of $B \to K^+\pi^-$ and $B^+ \to K^+\pi^0$



It is quite possible in SUSY models with non-universal A-terms to obtain negative values for $A^{CP}(K+\pi-)$ with positive values for $A^{CP}(K+\pi 0)$, which was not possible in SM.

Conclusions

- **We presented an explicit example for SUSY model that can naturally accommodate the experimental results of the CP asymmetries in B→Kπ decays.**

- **This model is based on the non-universal A-terms, which are quite natural to obtain in most of SUSY breaking scenarios.**

- **we performed a comparative analysis for the results estimated within MIA and those obtained from the one loop calculation in the usual mass eigenstate.**