CP asymmetries and branching ratios of $B \to K\pi$ in supersymmetric models

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Summary

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Introduction

- **The recent result (LP05) of $B \to J/\psi K_S$ CP asymmetry is:** $S_{J/\psi K_s} = \sin 2\beta = 0.685 \pm 0.032$, **in agreement with the SM.**

- **The most recent measurements for the CP asymmetry of $B \to \phi K_S$ are**

  $S_{\phi K_s} = 0.44 \pm 0.27 \pm 0.05$ **(Belle) : compatible with the SM** $\sin 2\beta$

  $S_{\phi K_s} = 0.50 \pm 0.25^{+0.07}_{-0.04}$ **(BaBar) : also compatible with the SM prediction**

  i.e., **the average** $S_{\phi K_s} = 0.47 \pm 0.19.$ **displays a** $< 1\sigma$ **deviation** $S_{J/\psi K_s}$.

- **The measurment of the CP asymmetry of $B \to \eta' K_S$ leads to** $S_{\eta' K_s} = 0.30 \pm 0.14 \pm 0.02$ **(BaBar)** $S_{\eta' K_s} = 0.62 \pm 0.12 \pm 0.04$ **(Belle)** *i.e.*, **the average** $S_{\eta' K_s} = 0.48 \pm 0.09.$ **displays a** 2.5σ **discrepancy.**

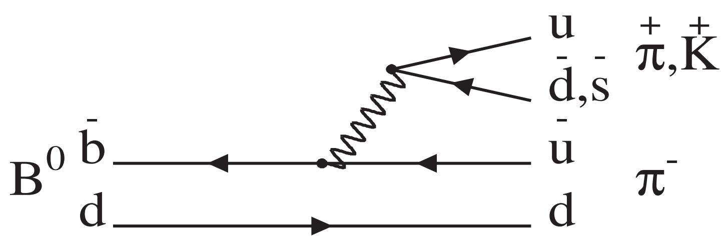
- **New Physcis must have new sources of flavour and CP violation to explain the discrepancy between the CP asymmetries** $S_{J/\psi K_s}$, $S_{\eta' K_s}$ **and** $S_{\phi K_s}$.

- **The latest experimental measurements for the four branching ratios and the four CP asymmetries of $B \to K\pi$ are:**

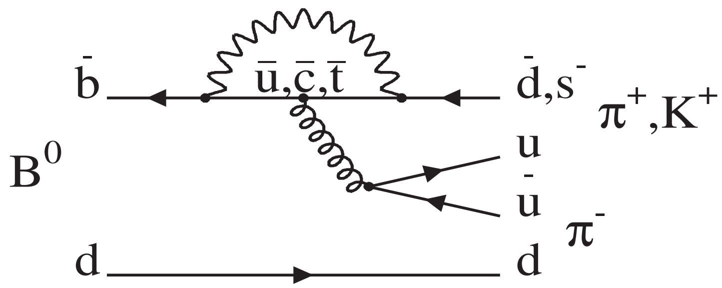
Decay channel	**BR** $\times 10^6$	A_{CP}	S_f
$\bar{K}^0\pi^-$	24.1 ± 1.3	-0.02 ± 0.034	$-$
$K^-\pi^0$	12.1 ± 0.8	0.04 ± 0.04	$-$
$K^-\pi^+$	18.2 ± 0.8	-0.113 ± 0.019	$-$
$\bar{K}^0\pi^0$	11.5 ± 1.0	-0.09 ± 0.14	0.34 ± 0.28

- **The direct CP $A^{CP}_{K^-\pi^+} = -0.113 \pm 0.019$ corresponds to a 4.2σ deviation from zero.**

- The $A^{CP}_{K^-\pi^0}$ is quite small. Why $A^{CP}_{K^-\pi^0} \neq A^{CP}_{K^-\pi^+}$



tree ($\phi_w = \phi_3$)



penguin ($\phi_w = 0$)

- From these results, the ratios R_c, R_n and R of $B \to K\pi$ decays are given by

$$\begin{aligned} R_c &= 2\left[\frac{BR(B^+ \to K^+\pi^0) + BR(B^- \to K^-\pi^0)}{BR(B^+ \to K^0\pi^+) + BR(B^- \to \bar{K}^0\pi^-)}\right] = 1.00 \pm 0.08, \\ R_n &= \frac{1}{2}\left[\frac{BR(B^0 \to K^+\pi^-) + BR(\bar{B}^0 \to K^-\pi^+)}{BR(B^0 \to K^0\pi^0) + BR(\bar{B}^0 \to \bar{K}^0\pi^0)}\right] = 0.79 \pm 0.08. \end{aligned}$$

- In the SM the R_c and R_n ratios are approximately equal. The experimental results indicate to 2.4σ deviation from the SM prediction.

- These inconsistencies between the $A^{CP}_{K\pi}$ and the $R_c - R_n$ measurements and the SM results are known as $K\pi$ puzzles.

$B \to K\pi$ in the Standard Model

- The effective Hamiltonian of $\Delta B = 1$ transition governing these processes is

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

$\lambda_p = V_{pb} V_{ps}^*$, C_i are the Wilson coefficients and Q_i are the relevant operators.

- The SM Wilson coefficients of $b \to s$ transition are given by

$$\begin{array}{lllll} C_1^{SM} \simeq 1.077, & C_2^{SM} \simeq -0.175, & C_3^{SM} \simeq 0.012, & C_4^{SM} \simeq -0.33, & C_5^{SM} \simeq 0.0095, \\ C_6^{SM} \simeq -0.039, & C_7^{SM} \simeq 0.0001, & C_8^{SM} \simeq 0.0004, & C_9^{SM} \simeq -0.01, & C_{10}^{SM} \simeq 0.0019, \\ C_{7\gamma}^{SM} \simeq -0.315, & C_{8g}^{SM} \simeq -0.149. & & & \end{array}$$

- The calculation of the decay amplitudes involves the evaluation of the hadronic matrix elements of operators which is the most uncertain part.

- **Adopting the QCD factorization the amplitudes of $B \to K\pi$ are given by (for $\gamma = \pi/3$, and $\rho_{A,H}$ and $\phi_{A,H}$ are of order one)**

$$\begin{aligned}
A_{\bar{B}^0\to\pi^+K^-}\times 10^8 &\simeq (1.05-0.02\ i)C_1+(0.24+0.07\ i)C_2+(3.1+14.5\ i)C_3\\
&+ (4.9+37.7\ i)C_4-(2.9-13.1\ i)C_5+(5.5-43.7\ i)C_6\\
&+ (1.7+10.4\ i)C_7+(5.8+36.5\ i)C_8+(2.8+12.7\ i)C_9\\
&+ (0.6+35.5\ i)C_{10}-(0.0006+0.04\ i)C_{7\gamma}^{eff}-(0.04+2.5\ i)C_{8g}^{eff},
\end{aligned}$$

$$\begin{aligned}
A_{\bar{B}^0\to\pi^0K^0}\times 10^8 &\simeq (-0.14+0.3\ i)C_1+(0.4+0.2\ i)C_2-(2.2+10.5\ i)C_3\\
&- (3.5+26.7\ i)C_4+(2.1-9.3\ i)C_5+(3.9-30.9\ i)C_6\\
&- (1.7+37.02\ i)C_7-(1.9+1.7\ i)C_8+(1.3+46.6\ i)C_9\\
&+ (2.2+28.8\ i)C_{10}-(0.0002+0.01\ i)C_{7\gamma}^{eff}+(0.03+1.8\ i)C_{8g}^{eff},
\end{aligned}$$

$$\begin{aligned}
A_{B^-\to\pi^0K^-}\times 10^8 &\simeq (0.9+0.06\ i)C_1+(0.6+0.3\ i)C_2+(2.2+10.5\ i)C_3\\
&+ (3.5+26.7\ i)C_4-(2.1-9.3\ i)C_5-(3.9-30.9\ i)C_6\\
&- (2.7+32.4\ i)C_7-(5.4-17.8\ i)C_8+(1.9+51.6\ i)C_9\\
&+ (2.4+42.8\ i)C_{10}-(0.0004+0.03\ i)C_{7\gamma}^{eff}-(0.03+1.8\ i)C_{8g}^{eff},
\end{aligned}$$

$$\begin{aligned}
A_{B^-\to\pi^-K^0}\times 10^8 &\simeq (0.4-0.4\ i)C_1-(0.00004-0.02\ i)C_2+(3.1+14.9\ i)C_3\\
&+ (4.9+37.7\ i)C_4-(2.9-13.1\ i)C_5+(5.5-43.7\ i)C_6\\
&- (3.2+3.8\ i)C_7-(10.8+13.8\ i)C_8-(1.9+5.7\ i)C_9\\
&- (0.3+19.7\ i)C_{10}+(0.0003+0.02\ i)C_{7\gamma}^{eff}-(0.04+2.5\ i)C_{8g}^{eff}.
\end{aligned}$$

- In the SM, the dominant contribution to the $B \to K\pi$ amplitudes is due to the QCD penguin operator Q_4.

- However the QCD penguin preserves the isospin. It gives the same contribution to all the decay modes.

- In the SM the amplitudes of $B \to K\pi$ can be approximately written as

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

Thus, the parameters R_c and R_n are given by

$$R_c = R_n = \frac{|(a_1 + b_1\ i)\ C_1 + (a_2 + b_2\ i)\ C_4|^2}{|(a_2 + b_2\ i)\ C_4|^2} \gtrsim 1$$

which is consistent with the result, using the full set of the Wilson coefficients.

Branching ratio	$\rho_{A,H} = 0$	$\rho_{A,H} = 1$ & $\phi_{A,H} \sim 1$	$\rho_{A,H} = 3$ & $\phi_{A,H} \sim 1$
$BR_{\bar{K}^0\pi^-} \times 10^6$	31.06	33.35	43.92
$BR_{K^-\pi^0} \times 10^6$	**17.31**	**18.45**	**23.36**
$BR_{K^-\pi^+} \times 10^6$	**25.87**	**27.98**	**39.55**
$BR_{\bar{K}^0\pi^0} \times 10^6$	**11.41**	**12.47**	**18.66**
R_n	**1.13**	**1.12**	**1.059**
R_c	**1.11**	**1.106**	**1.063**

The SM predictions for the branching ratios of $B \to K\pi$ with $\gamma = \pi/3$

- **Large values of $\rho_{A,H}$ enhance the branching ratios and eventually they exceed the experimental limits.**
- **The SM results for $BR(B^- \to \bar{K}^0\pi^-)$ & $BR(\bar{B}^0 \to \bar{K}^0\pi^0)$ are larger than the experiment measurements, while the results for $BR(B^- \to K^-\pi^0)$ & $BR(\bar{B}^0 \to K^-\pi^+)$ are consistent with their experimental values.**
- **The parameters R_c and R_n exhibit this deviation from the SM prediction in a clear way.**

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)

The SM predictions for the direct CP asymmetries of $B \to \pi K$ with $\gamma = \pi/3$

- Due to the sensitivity of the CP asymmetry on the strong phase ϕ_A, we consider both cases of $\phi_A = \mathcal{O}(\pm 1)$.
- $A^{CP}_{K^-\pi^0}$ & $A^{CP}_{K^-\pi^+}$ are sensitive to the sign ϕ_A, whilst $A^{CP}_{K^0\pi^-}$ & $A^{CP}_{K^0\pi^0}$ are insensitive.
- $A^{CP}_{K^0\pi^-}$ and $A^{CP}_{K^0\pi^0}$ are very small even with large values of ρ_A.
- large ρ_A enhances $A^{CP}_{K^-\pi^0}$ and $A^{CP}_{K^-\pi^+}$.
- $A^{CP}_{K^-\pi^+}$ can be of order the experimental result. BUT $A^{CP}_{K^-\pi^0}$ is also enhanced in the same way and it becomes one order of magnitude larger than its experimental value.

- **Another useful way of parameterizing the decay amplitudes is by factorizing the dominant penguin amplitude P**

$$Pe^{i\delta_P} = \alpha_4^c - \frac{1}{2}\alpha_{4,EW}^c + \beta_3^c + \beta_{3,EW}^c$$

$$\begin{aligned}
Thus \quad A_{B^-\to\pi^-\overline{K}^0} &= \lambda_c A_{\pi\overline{K}} P\left[1 + r_A e^{i\delta_A} e^{-i\gamma}\right], \\
\sqrt{2}A_{B^-\to\pi^0 K^-} &= \lambda_c A_{\pi\overline{K}} P\left[1 + \left(r_A e^{i\delta_A} + r_C e^{i\delta}\right) e^{-i\gamma} + r_{EW} e^{i\delta_{EW}}\right], \\
A_{\overline{B}^0\to\pi^+ K^-} &= \lambda_c A_{\pi\overline{K}} P\left[1 + \left(r_A e^{i\delta_A} + r_T e^{i\delta_T}\right) e^{-i\gamma} + r_{EW}^C e^{i\delta_{EW}^C}\right], \\
-\sqrt{2}A_{\overline{B}^0\to\pi^0\overline{K}^0} &= \lambda_c A_{\pi\overline{K}} P\left[1 + \left(r_A e^{i\delta_A} + r_T e^{i\delta_T} - r_C e^{i\delta_C}\right) e^{-i\gamma} + r_{EW}^C e^{i\delta_{EW}^C} - r_{EW} e^{i\delta_{EW}}\right],
\end{aligned}$$

where

$$\begin{aligned}
r_A e^{i\delta_A} &= \epsilon_{KM}[\beta_2 + \alpha_4^u - \frac{1}{2}\alpha_{4,EW}^u + \beta_3^u + \beta_{3,EW}^u]/P, \\
r_T e^{i\delta_T} &= \epsilon_{KM}[\alpha_1 + \frac{3}{2}\alpha_{4,EW}^u - \frac{3}{2}\beta_{3,EW}^u - \beta_2)]/P, \\
r_C e^{i\delta_P} &= \epsilon_{KM}[\alpha_1 + R_{K\pi}\alpha_2 + \frac{3}{2}(R_{K\pi}\alpha_{3,EW}^u + \alpha_{4,EW}^u)]/P, \\
r_{EW} e^{i\delta_{EW}} &= [\frac{3}{2}(R_{K\pi}\alpha_{3,EW}^c + \alpha_{4,EW}^c)]/P, \qquad r_{EW}^C e^{i\delta_{EW}^C} = [\frac{3}{2}(\alpha_{4,EW}^c - \beta_{3,EW}^c)]/P.
\end{aligned}$$

r_T, r_C **measure the relative size of tree and QCD penguin conts.** r_{EW}, r_{EW}^C **measure the relative size of the electroweak and QCD conts.**

- **In this case we have**

$$(Pe^{i\delta_P})_{\rm SM} = -0.11e^{0.051i}, \qquad (r_A e^{i\delta_A})_{\rm SM} = 0.019e^{0.26i},$$
$$(r_C e^{i\delta_C})_{\rm SM} = 0.186e^{2.9i}, \qquad (r_T e^{i\delta_T})_{\rm SM} = 0.191e^{2.9i},$$
$$(r_{EW} e^{i\delta_{EW}})_{\rm SM} = 0.13e^{-0.2i}, \qquad (r_{EW}^C e^{i\delta_{EW}^C})_{\rm SM} = 0.012e^{-2.5i}.$$

- **The parameters R_c and R_n can be expressed by the following approximated expressions**

$$R_c \simeq 1 + 2r_C \cos\delta_C \cos\gamma + 2r_{EW}\cos\delta_{EW},$$

$$R_n \simeq \frac{1 + 2r_T \cos\delta_T \cos\gamma}{1 + 2r_T \cos\delta_T \cos\gamma - 2r_C \cos\delta_C \cos\gamma - 2r_{EW}\cos\delta_{EW}}$$

which confirms our previous conclusion that in the SM $R_n \sim R_c \gtrsim 1$. Explicitly,

$$R_c = 1.08(1.45), \qquad R_n = 1.13(1.6)$$

for $\gamma = \pi/3(2\pi/3)$, which is quite close to the full result.

$B \to K\pi$ SUSY Models

- The SUSY contributions to the $b \to s$ transition could be dominated by the gluino or the chargino exchanged diagrams.

- Chromomagnetic penguin (Q_{8g}) dominates both contributions. $B \to K\pi$ is sensitive to the isospin violating interactions: the electromagnetic penguin ($Q_{7\gamma}$) and photon- and Z-penguins contributions to Q_7 and Q_9.

$$C_{7\gamma}^{\tilde{g}}(M_S) = \frac{8\alpha_s\pi}{9\sqrt{2}G_F m_{\tilde{q}}^2}\left[(\delta_{LL}^d)_{23}M_3(x) + (\delta_{LR}^d)_{23}\frac{m_{\tilde{g}}}{m_b}M_1(x)\right],$$

$$C_{8g}^{\tilde{g}}(M_S) = \frac{\alpha_s\pi}{\sqrt{2}G_F m_{\tilde{q}}^2}[(\delta_{LL}^d)_{23}\left(\frac{1}{3}M_3(x) + 3M_4(x)\right) + (\delta_{LR}^d)_{23}\frac{m_{\tilde{g}}}{m_b}\left(\frac{1}{3}M_3(x) + 3M_2(x)\right)],$$

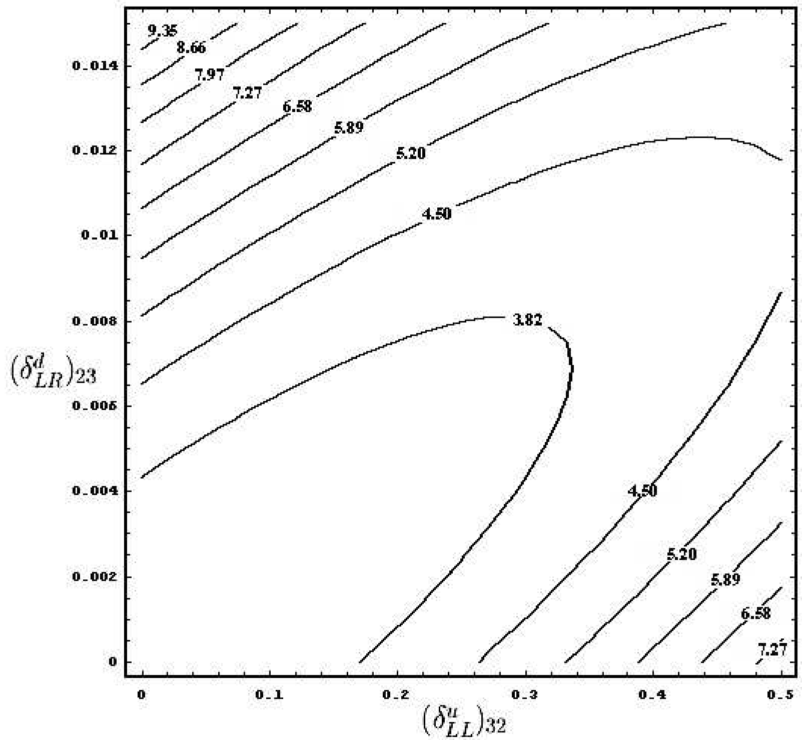
$$C_7^{\chi}(M_S) = \frac{\alpha}{6\pi}(4C_\chi + D_\chi), \qquad C_9^{\chi}(M_S) = \frac{\alpha}{6\pi}\left(4(1 - \frac{1}{\sin^2\theta_W})C_\chi + D_\chi\right),$$

$$C_{7\gamma}^{\chi} = M_\gamma, \qquad C_{8g}^{\chi} = M_g.$$

The functions $F \equiv C_\chi, D_\chi, M^\gamma, M^g$ are given by

$$F_\chi = [\,(\delta_{LL}^u)_{32} + \lambda(\delta_{LL}^u)_{31}\,]R_F^{LL} + [\,(\delta_{RL}^u)_{32} + \lambda(\delta_{RL}^u)_{31}\,]\,Y_t\,R_F^{RL}.$$

constraints from $BR(B \to X_s\gamma)$



Contour plot for $BR(b \to s\gamma) \times 10^4$ as function of $(\delta^d_{LR})_{23}$ and $(\delta^u_{LL})_{32}$.

In generic SUSY models, both gluino and chargino contributions to $b \to s\gamma$ are large and cancelation of order $20 - 50\%$ can take place.

SUSY solution to the $R_c - R_n$ Puzzle

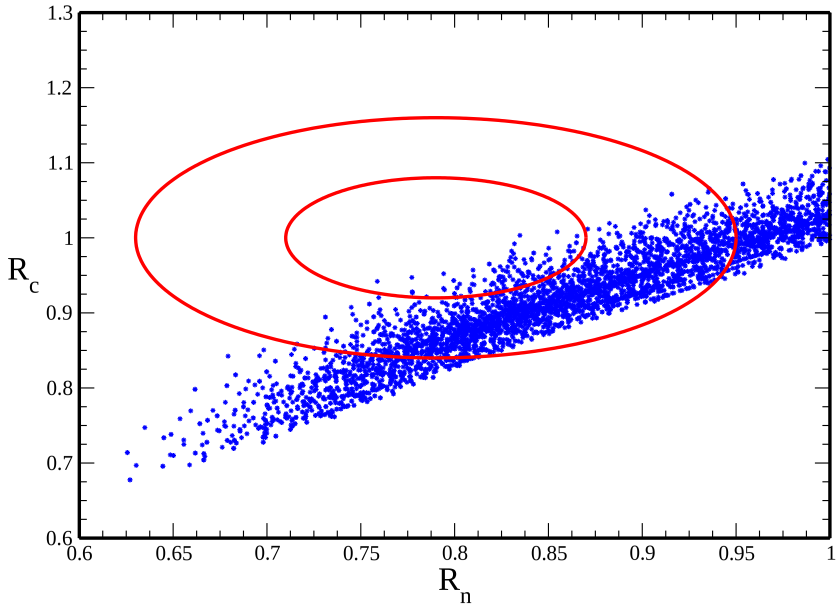
- **There are three possible sources of large SUSY contribution to $B \to K\pi$**
  1. **Gluino mass enhanced $O_{7\gamma}$ and O_{8g} which depend on $(\delta^d_{LR})_{23}$ and $(\delta^d_{RL})_{23}$.**
  2. **Chargino mass enhanced $O_{7\gamma}$ and O_{8g} which depend on $\tan\beta(\delta^u_{LL})_{23}$.**
  3. **Right handed stop mass enhanced Z penguin which depends on $(\delta^u_{RL})_{32}$.**

- **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 $\tan\beta = 10$**

$$
\begin{aligned}
A_{\bar{B}^0\to\pi^0\bar{K}^0} \times 10^7 &\simeq -9.82 \left[(\delta^d_{LR})_{23} + (\delta^d_{RL})_{23}\right] + 0.036\ (\delta^u_{LL})_{32} - 0.02\ (\delta^u_{RL})_{32},\\
A_{\bar{B}^0\to\pi^+K^-} \times 10^7 &\simeq 14.04 \left[(\delta^d_{LR})_{23} + (\delta^d_{RL})_{23}\right] + 0.06\ (\delta^u_{LL})_{32} - 0.001\ (\delta^u_{RL})_{32},\\
A_{B^-\to\pi^0K^-} \times 10^7 &\simeq 9.9 \left[(\delta^d_{LR})_{23} + (\delta^d_{RL})_{23}\right] - 0.04\ (\delta^u_{LL})_{32} + 0.024\ (\delta^u_{RL})_{32},\\
A_{B^-\to\pi^-\bar{K}^0} \times 10^7 &\simeq 13.89 \left[(\delta^d_{LR})_{23} + (\delta^d_{RL})_{23}\right] + 0.05\ (\delta^u_{LL})_{32} - 0.006\ (\delta^u_{RL})_{32}.
\end{aligned}
$$

$i)$ **The effect of $(\delta^u_{RL})_{32}$ is not negligible for $A_{\bar{B}^0\to\pi^0\bar{K}^0}$ and $A_{B^-\to\pi^0K^-}$.**

$ii)$ **A possible distractive interference between $(\delta^d_{LR})_{23}$ and $(\delta^u_{LL})_{32}$ in these two processes.**



$R_c - R_n$ **correlation for** $|(\delta^u_{LR})_{32}| \simeq 1$, $|(\delta^d_{LR})_{23}| \in [0.001, 0.01]$ **and** $|(\delta^u_{LL})_{32}| \in [0.1, 1]$.

- **The results of R_n & R_c at 2σ can be accommodated by the SUSY contributions.**

- **The results at 1σ can be only obtained by a smaller region of parameter space.**

- **The values of R_c is predicted to be less than one for the most of the parameter space. It will be nice accordance with SUSY results if the experimental result of R_c goes down.**

- To understand the impact of the SUSY on the correlation between R_n and R_c, we extend our previous parametrization as follows:

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

The parameters P, r_{EW}, r^C_{EW} are now defined as

$$
\begin{aligned}
P e^{i\theta_P} e^{i\delta_P} &= \alpha^c_4 - \frac{1}{2} \alpha^c_{4,EW} + \beta^c_3 + \beta^c_{3,EW}, \\
r_{EW} e^{i\theta_{EW}} e^{i\delta_{EW}} &= \left[\frac{3}{2} (R_{K\pi} \alpha^c_{3,EW} + \alpha^c_{4,EW}) \right] / P, \\
r^C_{EW} e^{i\theta^C_{EW}} e^{i\delta^C_{EW}} &= \left[\frac{3}{2} (\alpha^c_{4,EW} - \beta^c_{3,EW}) \right] / P.
\end{aligned}
$$

- To simplify these formula, same strong phase for SM and SUSY are assumed.

- **This leads to the following:**

$$\begin{aligned} P e^{i\delta_P} e^{i\theta_P} &= P^{\mathrm{SM}} e^{i\delta_P}(1 + k e^{i\theta'_P}) \\ r_{EW} e^{i\delta_{EW}} e^{i\theta_{EW}} &= (r_{EW})^{\mathrm{SM}} e^{i\delta_{EW}}(1 + l e^{i\theta'_{EW}}) \\ r^C_{EW} e^{i\delta^C_{EW}} e^{i\theta^C_{EW}} &= (r^C_{EW})^{\mathrm{SM}} e^{i\delta^C_{EW}}(1 + m e^{i\theta^{C'}_{EW}}). \end{aligned}$$

For the SUSY parameters that we onsidere

$$\begin{aligned} k e^{i\theta_P} &= -0.0019 \tan\beta(\delta^u_{LL})_{32} - 35.0(\delta^d_{LR})_{23} + 0.061(\delta^u_{LR})_{32} \\ l e^{i\theta_q} &= 0.0528 \tan\beta(\delta^u_{LL})_{32} - 2.78(\delta^d_{LR})_{23} + 1.11(\delta^u_{LR})_{32} \\ m e^{i\theta_{qC}} &= 0.134 \tan\beta(\delta^u_{LL})_{32} + 26.4(\delta^d_{LR})_{23} + 1.62(\delta^u_{LR})_{32} \end{aligned}$$

Assuming

1. **the strong phases are negligible, i.e.,** $\delta_P, \delta_A, \delta_C, \delta_{EW}, \delta^C_{EW}$ **are all zero.**
2. **the annihilation tree contribution is negligible, i.e.** $r_A \simeq 0$
3. **the color suppressed tree contribution is negligible, i.e.** $r_C e^{i\delta_C} \sim r_T e^{i\delta_T}$**.**

$$\begin{aligned} R_c &\simeq 1 + r_T^2 - 2r_T \cos(\gamma+\theta_P) + 2r_{EW}\cos(\theta_P - \theta_{EW}) - 2r_T r_{EW}\cos(\gamma+\theta_{EW}) \\ R_c - R_n &\simeq 2r_T r_{EW}\cos(\gamma + 2\theta_P - \theta_{EW}) - 2r_T r^C_{EW}\cos(\gamma + 2\theta_{EW} - \theta^C_{EW}) \end{aligned}$$

- $R_c - R_n \gtrsim 0.2 \to r_T r_{EW} > 0.1$ or $r_{EW} > 0.5$ and r_T^{SM}, i.e. for $k = 0$, one needs $l \gtrsim 2$.

- For a single MI $(\delta^u_{LL})_{32}, (\delta^d_{LR})_{23}$ or $(\delta^u_{LR})_{32}$ to $\{k, l, m\}$; the maximum value of $\{k, l, m\}$:

$$\begin{aligned} \{k,l,m\} &= \{0.061, 1.11, 1.62\}, \\ \{k,l,m\} &= \{0.18, 0.014, 0.13\}, \\ \{k,l,m\} &= \{0.0019, 0.053, 0.13\}. \end{aligned}$$

  Thus it is extremely difficult to have $R_c - R_n \gtrsim 0.2$.

- Simult. contributions from $(\delta^d_{LR})_{23}$ & $(\delta^u_{LR})_{32}$ lead to: $\{k, l, m\} = \{0.24, 1.12, 1.48\}$.

  Again, the experimental data are not reproduced very well.

- Finally, with the three non-zero MIs. a relaxation of the constraints on $|\tan\beta \times (\delta^u_{LL})_{32}|$ and $|(\delta^d_{LR})_{23}|$ from $b \to s\gamma$, is expected due to cancelation their contributions.

- Under this circumstance, we observe much larger $R_c - R_n$ for various combination of the phases in this scenario.

SUSY contributions to the CP asymmetry of $B \to K\pi$

- The time dependent CP asymmetry for $B \to K\pi$ is given by

$$A_{K\pi}(t) = A_{K\pi} \cos(\Delta M_{B_d} t) + S_{K\pi} \sin(\Delta M_{B_d})t$$

- Using the previous parametrization of the amplitudes of $B \to K\pi$, we find:

$$\begin{aligned}
A^{CP}_{K^-\pi^+} &\simeq 2r_T \sin\delta_T \sin(\theta_P + \gamma) + 2r^C_{EW} \sin\delta^C_{EW} \sin(\theta_P - \theta^c_{EW}), \\
A^{CP}_{K^0\pi^-} &\simeq 2r_A \sin\delta_A \sin(\theta_P + \gamma), \\
A^{CP}_{K^0\pi^0} &\simeq 2r^C_{EW} \sin\delta^C_{EW} \sin(\theta_P - \theta^C_{EW}) - 2r_{EW} \sin\delta_{EW} \sin(\theta_P - \theta_{EW}), \\
A^{CP}_{K^-\pi^0} &\simeq 2r_T \sin\delta_T \sin(\theta_P + \gamma) - 2r_{EW} \sin\delta_{EW} \sin(\theta_P - \theta_{EW}).
\end{aligned}$$

- If we ignore the strong phases, then the direct CP asymmetries would vanish

  The leading conts. to $A^{CP}_{K\pi}$ are given by the linear terms of r_i, unlike $R_c - R_n$.

- Since r_A is quite small $\left(r_A^{SM} \simeq \mathcal{O}(0.01)\right)$, the CP asymmetry of $B^\pm \to K^0\pi^\pm$ is very small, consistently with the experimental measurements.

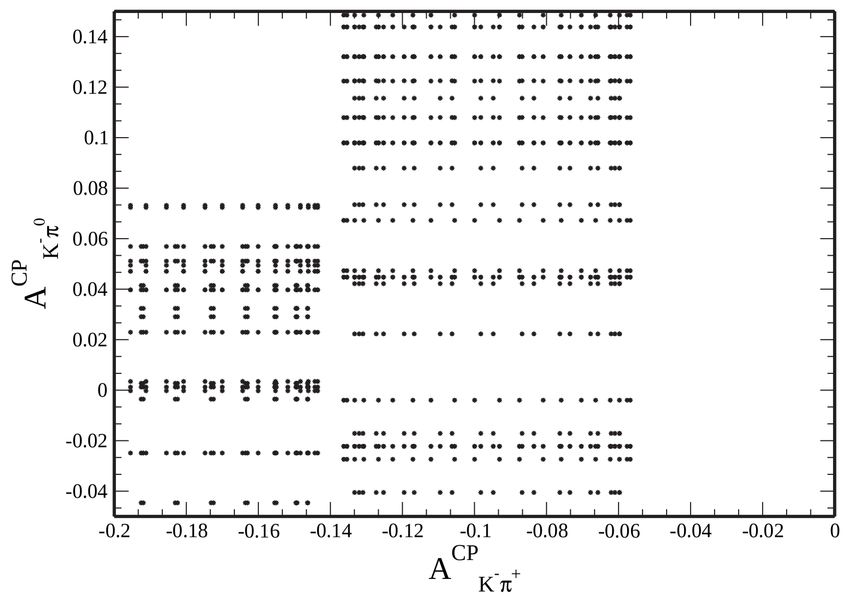
- In the SM, $r_A, r_{EW}^C << r_T, r_{EW}$ & $\theta_P = 0$, thus

$$A^{CP}_{K^-\pi^0} \gtrsim A^{CP}_{K^-\pi^+} \gtrsim A^{CP}_{K^0\pi^0} > A^{CP}_{K^0\pi^-}.$$

- Large r_{EW}^C and non-vanishing value of θ_P are favored to obtain $A^{CP}_{K^-\pi^+} > A^{CP}_{K^-\pi^0}$.

- With large value of θ_P, the CP asymmetry results can be accommodated with moderate values of the electroweak penguin parameter r_{EW}^C.

- Models neglected the QCD penguin contributions require r_{EW}^C of order one.



CP asy. of $B \to K^-\pi^+$ versus CP asy. of $B \to K^-\pi^0$ for $\{k, l, m\} = \{0.18, 0.014, 0.13\}$.

- $A^{CP}_{K^-\pi^+} \in [-0.075, -0.151]$ **and** $A^{CP}_{K^-\pi^0} \in [-0.04, 0.12]$, **in the exper. range with one MI in dominant gluino models. This is contrary to the** $R_c - R_n$ **results.**

$$(\delta^d_{LR})_{23} \simeq 0.005 e^{i\pi/3} \Rightarrow \{k, l, m\} = \{0.18, 0.014, 0.13\}$$

In this case, r_T **is reduced from** $r_T^{SM} \simeq 0.2$ **to** $r_T \simeq 0.12$ **, while** r_{EW} **and** r^C_{EW} **remain the same as in the SM.**

Conclusions

- We analyzed the SUSY contributions to the CP asy. and BR of the $B \to K\pi$ decays in a model independent way.
- In the SM, the $R_c - R_n$ puzzle can not be resolved. $A^{CP}_{K^0\pi^-}$ and $A^{CP}_{K^0\pi^0}$ are very small. $A^{CP}_{K^0\pi^0} \sim A^{CP}_{K^-\pi^+}$ can be large. This is inconsistent with the recent measurements.
- The Z & the *em* penguins enhance the contr. of the electroweak penguin to $B \to K\pi$ play a crucial role but not enough to solve the $R_c - R_n$ puzzle.
- A combination of gluino & chargino is necessary to account for R_c & R_n with $b \to s\gamma$ constraints.
- A large gluino contribution is essential to explain the CP asymmetry results.
- Unlike the $R_c - R_n$, $A^{CP}_{K\pi}$ can be saturated by a single mass insertion $(\delta^d_{LR})_{23}$.