$K\pi$ and $S_{\phi K}$ Anomaly and New Physics Search in the Zprim Model

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Anomaly in $B \to K\pi$

It is an anomaly in $B \to K\pi$ branching ratios:

$$
R_c \equiv 2 \frac{\text{BR}(B^+ \to \pi^0 K^+) + \text{BR}(B^- \to \pi^0 K^-)}{\text{BR}(B^+ \to \pi^+ K^0) + \text{BR}(B^- \to \pi^- K^0)} = 1.00 \pm 0.08 ,
$$

(1)

$$
R_n \equiv \frac{1}{2} \frac{\text{BR}(B^0 \to \pi^- K^+) + \text{BR}(\bar{B}^0 \to \pi^+ K^-)}{\text{BR}(B^0 \to \pi^0 K^0) + \text{BR}(\bar{B}^0 \to \pi^0 K^0)} = 0.79 \pm 0.08 ,
$$

(2)

- In SM, $R_c \simeq R_n \simeq 1$, but experimental data showes 1.9 $\sigma$ deviation from zero. $R_c > 1$ and $R_n < 1$ is a consistent pattern by separate BaBar, Belle and CLEO data.

- The $B^\pm \to K^\pm \pi^0$ and $B^0 \to K^0\pi^0$ has color-allowed EWP contribution. NP(New Physics) which enhances the EWP may explain $B \to K\pi$ and $\phi K_s$ data.
$B \rightarrow K\pi$ Decays

\[ A(B^+ \rightarrow \pi^+ K^0) = -P', \]
\[ \sqrt{2}A(B^+ \rightarrow \pi^0 K^+) = P' \left[ 1 - (e^{i\gamma} - qe^{i\phi}) r_c e^{i\delta_c} \right], \]
\[ A(B_0^0 \rightarrow \pi^- K^+) = P' \left[ 1 - re^{i\delta} e^{i\gamma} \right], \]
\[ \sqrt{2}A(B_0^0 \rightarrow \pi^0 K^0) = -P' \left[ 1 + \rho_n e^{i\theta_n} e^{i\gamma} - qe^{i\phi} r_c e^{i\delta_c} \right], \]

with \( P' \equiv A\lambda^2(P'_t - P'_c). \)

We follow Buras et al.'s approach\[PRL92,101804(2004)\]

- Assume no manifest NP effect in (QCD-penguin sensitive) \( B \rightarrow \pi\pi \).
- Assume SU(3) flavor symmetry.
- Then \( B \rightarrow \pi\pi \) data provide the \( B \rightarrow K\pi \) hadronic parameters except EWP parameters (\( q \) and \( \phi \)).

\[ r = 0.11^{+0.07}_{-0.05}, \quad \delta = +(42^{+23}_{-19})^\circ, \]
\[ \rho_n = 0.13^{+0.07}_{-0.05}, \quad \theta_n = -(29^{+21}_{-26})^\circ, \]
\[ r_c = 0.20^{+0.09}_{-0.07}, \quad \delta_c = +(2^{+23}_{-18})^\circ. \]
Only EWP sector is assumed to have a manifest NP effect.

- **Necessary EWP Enhancement**

EWP sector of $B \rightarrow K \pi$ are parameterized by $q$ and $\phi$:

$$qe^{i\phi} \equiv \frac{P_{EW}'}{T' + C'}$$

$$\simeq -\frac{3}{2} \frac{1}{\lambda |V_{ub}/V_{cb}|} \left[ \frac{c_9(m_b) + c_{10}(m_b)}{c_1(m_b)\xi + c_2(m_b)} \right] ,$$

with

$$\xi \equiv \frac{\sqrt{2} \langle K^0\pi^0 | O_1(m_b) | B^0 \rangle + \langle K^+\pi^- | O_1(m_b) | B^0 \rangle}{\sqrt{2} \langle K^0\pi^0 | O_2(m_b) | B^0 \rangle + \langle K^+\pi^- | O_1(m_b) | B^0 \rangle}$$

(8)

$\xi = 1$ in our SU(3) flavour symmetry limit. Then SM prediction of EWP parameters are $\{q, \phi\}_{SM} = \{0.75, 0^o\}$. 
Zprim Model

Two-fold solutions are found to satisfy $B \to K\pi$ data, $R_c$ and $R_n$:

\[(A) \{ q, \phi \} = \{ 1.06, -89^\circ \} \]
\[(B) \{ q, \phi \} = \{ 2.50, 86^\circ \} \]

We need an enhanced magnitude and new phase in EWP sector. Next, we will explore if the flavor-changing $Z'$ model can provide them.

We simplify our $Z'$ model by assuming:

- Only left-handed coupling like SM weak interaction,
- No RG running effect between $M_{Z'}$ and $M_W$ scale.
- Negligible $Z'$ effect on QCD penguin ($\delta c_3 = 0$) so that NP is manifest only in the EWP sector.

(The most general $Z'$ model has many undetermined parameters. Our simplifications provides a way to introduce the $Z'$ effect minimally to explain $B \to \pi K$ decay)
Figure 1: A $Z'$-mediated FCNC Feynman diagram contributing to the $B^0 \to \pi^0 K^0$ decay.

\[ \mathcal{H}_{eff}^{Z'} = \frac{2G_F}{\sqrt{2}} \left( \frac{g_2 M_Z}{g_1 M_{Z'}} \right)^2 B_{sb}^{L*} (\bar{b}s)_{V-A} \sum_q (B_{qq}^{L} (\bar{q}q)_{V-A} + B_{qq}^{R} (\bar{q}q)_{V+A}) + h.c. , \]

QCD penguin: \[ O_{3}^{(q)} = (\bar{b}s)_{V-A} (\bar{q}q)_{V-A} \]

EW penguin: \[ O_{9}^{(q)} = \frac{3}{2} e_q (\bar{b}s)_{V-A} (\bar{q}q)_{V-A} \]

\[ \Delta C_3(M_W) = 0; \]
\[ \Delta C_9(M_W) = \frac{4}{V_{tb}V_{ts}} \left( \frac{g_2 M_Z}{g_1 M_{Z'}} \right)^2 B_{sb}^L B_{dd}^L \]  

(11)

Now \( Z' \) effect can be given as an additional of \( \Delta C_9 \).

\[ \mathcal{H}_{\text{eff}}^{Z'} = \frac{G_F}{\sqrt{2}} V_{tb}^* V_{ts} \sum_q \Delta C_9 O_9^{(q)} + \text{h.c.} \]  

(12)

with

\[ \Delta C_9(M_W) = 4 \left| \frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}} \right| \xi^{LL} e^{-i\phi_L} \]  

(13)

written in terms of 2 real independent parameters.

\[ \xi^{LL} = \left( \frac{g_2 M_Z}{g_1 M_{Z'}} \right)^2 \left| \frac{B_{sb}^L B_{dd}^L}{V_{tb}^* V_{ts}} \right| \quad \text{and} \quad \phi_L \equiv \text{Arg}[B_{sb}^L] \]
Solution of $K\pi$ Anomaly in Zprim Model

EWP parameters $q$ and $\phi$ in terms of $Z^i$ parameters $\xi^{LL}$ and $\phi_L$:

\[
q e^{i\phi} \approx -\frac{3}{2\lambda} \frac{1}{|V_{ub}/V_{cb}|} \left[ \frac{c_9(m_b) + c_{10}(m_b)}{c_1(m_b)\tilde{\xi} + c_2(m_b)} \right],
\]
\[
\approx 0.75(1 + 410 \xi^{LL} e^{-i\phi_L}) \quad (14)
\]

The $Z^i$ solutions are found to be:

(A) $\{\xi^{LL}, \phi_L\} = \{0.0042, 124.6^o\}$

(B) $\{\xi^{LL}, \phi_L\} = \{0.0083, -103.0^o\}$

Flavor-changing $Z^i$ can provide the necessary EWP enhancement to explain $B \rightarrow K\pi$ data.
Figure 2: Contours of $Z'$ solutions to $B \to K\pi$ puzzle
Predictions on the other EWP-sensitive $K\pi$ and $K\phi$ observables

By using PQCD formulas for $B \to \phi K_s$ decay;

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Sol. A</th>
<th>Sol. B</th>
<th>Exp. Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{CP}(\pi^0 K^\pm)$</td>
<td>−0.03</td>
<td>0.02</td>
<td>0.04 ± 0.04</td>
</tr>
<tr>
<td>$A_{CP}(\pi K_s)$</td>
<td>−0.10</td>
<td>−0.14</td>
<td>0.00 ± 0.14</td>
</tr>
<tr>
<td>$S_{CP}(\pi K_s)$</td>
<td>0.40</td>
<td>0.86</td>
<td>0.34$^{+0.27}_{-0.29}$</td>
</tr>
<tr>
<td>$R$</td>
<td>0.943</td>
<td>0.943</td>
<td>0.91 ± 0.07</td>
</tr>
<tr>
<td>$A_{CP}(\pi^\pm K^\pm)$</td>
<td>−0.14</td>
<td>−0.14</td>
<td>−0.13 ± 0.02</td>
</tr>
<tr>
<td>$A_{CP}(\pi^\pm K^0)$</td>
<td>0.0</td>
<td>0.0</td>
<td>−0.02 ± 0.03</td>
</tr>
<tr>
<td>$C_{\phi K_s}$</td>
<td>−0.92%</td>
<td>1.88%</td>
<td>−0.04 ± 0.17[CL = 0.81]</td>
</tr>
<tr>
<td>$S_{\phi K_s}$</td>
<td>0.738</td>
<td>0.744</td>
<td>0.34 ± 0.20[CL = 0.30]</td>
</tr>
</tbody>
</table>

Table 1:

\[ R \equiv \frac{\text{BR}(B^0 \to \pi^- K^+) + \text{BR}(\overline{B}^0 \to \pi^+ K^-)}{\text{BR}(B^+ \to \pi^+ K^0) + \text{BR}(B^- \to \pi^- K^0)} \frac{\tau_{B^+}}{\tau_{B^0_d}} \]

\[ = 0.91 \pm 0.07 \]

(15)

where $\tau_{B^+}/\tau_{B^0_d} = 1.086 \pm 0.017$ was used.
Remarks:

- We reviewed the $B \rightarrow K\pi$ puzzle in a view of NP indications in EWP sector.
- It turns out a flavor-changing $Z'$ model can provide the magnitude and phase in EWP sector and explain $B \rightarrow K\pi$ data even with limitations of left-handed coupling only.
- It is hard to explain both $K\pi$ and $\phi K_s$ anomaly simultaneously within simplified $Z'$ model.