

# Electroweak Penguin Hunting Through $B \rightarrow \pi\pi, \pi K$ and Rare $K$ and $B$ Decays

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The  $B \rightarrow \pi K$  decays with significant electroweak penguin contributions show a puzzling pattern. We explore this “ $B \rightarrow \pi K$  puzzle” through a systematic strategy. The starting point, which is essentially unaffected by electroweak penguins, is the determination of the angle  $\gamma$  of the unitarity triangle through the CP-violating  $B_d^0 \rightarrow \pi^+ \pi^-$ ,  $B_d^0 \rightarrow \pi^- K^+$  asymmetries, yielding  $\gamma = (73.9^{+5.8}_{-6.5})^\circ$ , and the extraction of hadronic parameters through the measured  $B \rightarrow \pi\pi$  branching ratios. Using arguments related to the  $SU(3)$  flavour symmetry, we convert the hadronic  $B \rightarrow \pi\pi$  parameters into their  $B \rightarrow \pi K$  counterparts, allowing us to predict the  $B \rightarrow \pi K$  observables in the Standard Model. We find agreement with the data for those quantities that are only marginally affected by electroweak penguins, while this is not the case for the observables with sizeable electroweak penguin contributions. Since we may also perform a couple of internal consistency checks of our working assumptions, which are nicely satisfied for the current data, and find a small sensitivity of our results to large non-factorizable  $SU(3)$ -breaking corrections, the “ $B \rightarrow \pi K$ ” puzzle may be due to new physics in the electroweak penguin sector. We show that it can indeed be resolved through such a kind of new physics with a large CP-violating phase. Further insights into the electroweak penguins are provided by the  $B^+ \rightarrow \pi^0 K^+$  and  $B_d^0 \rightarrow \pi^0 K_S$  CP asymmetries, and in particular through correlations with various rare  $K$  and  $B$  decays.

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## 1. Introduction

Since the observation of the decay  $B_d^0 \rightarrow \pi^0 K^0$  by the CLEO collaboration in 2000 with a remarkably prominent rate, we are faced with a possible discrepancy with the picture of the Standard Model (SM). This “ $B \rightarrow \pi K$  puzzle” is still present in the most recent  $B$ -factory data, and has recently received a lot of attention. In [1], where also a comprehensive list of the relevant literature can be found, we developed a strategy to explore this exciting topic in a systematic manner. The starting point is an analysis of the  $B \rightarrow \pi\pi$  system, where the data can be accommodated in the SM through large non-factorizable effects. In particular, the  $B \rightarrow \pi\pi$  decays allow us to extract a set of hadronic parameters with the help of the isospin symmetry of strong interactions. Using then the  $SU(3)$  flavour symmetry and neglecting certain exchange and penguin annihilation topologies, we can convert the hadronic  $B \rightarrow \pi\pi$  parameters in their  $B \rightarrow \pi K$  counterparts, allowing us to predict all  $B \rightarrow \pi K$  observables in the SM. We find agreement for those decays that are only marginally affected by (colour-suppressed) electroweak (EW) penguins. On the other hand, the SM predictions of the  $B \rightarrow \pi K$  observables which are significantly affected by (colour-allowed) EW penguins do not agree with the data, thereby reflecting the  $B \rightarrow \pi K$  puzzle. Moreover, we can perform internal consistency checks of our working assumptions, which work well within the current uncertainties, and find that our results are very stable under large non-factorizable  $SU(3)$ -breaking corrections. In view of these features, new physics (NP) in the EW penguin sector may be at the origin of the  $B \rightarrow \pi K$  puzzle. In fact, it can be resolved through a modification of the EW penguin parameters, involving in particular a large CP-violating NP phase that vanishes in the SM. The implications of this kind of NP on rare  $K$  and  $B$  decays are then investigated in the final step of our strategy.

The numerical results presented below refer to our very recent analysis [2]. A somewhat surprising development of this summer is a new world average for  $(\sin 2\beta)_{\psi K_S}$ , which went down by about  $1\sigma$ . The picture in the  $\bar{\rho}-\bar{\eta}$  plane with the fits of the unitarity triangle (UT) is now no longer “perfect”, which may indicate NP in  $B_d^0-\bar{B}_d^0$  mixing. Consequently, we use the CP asymmetries of the  $B_d^0 \rightarrow \pi^+\pi^-$ ,  $B_d^0 \rightarrow \pi^-K^+$  system to determine the “true” value of the UT angle  $\gamma$ , yielding

$$\gamma = (73.9_{-6.5}^{+5.8})^\circ, \quad (1.1)$$

and use it as an input for our  $B \rightarrow \pi\pi, \pi K$  analysis. If we complement (1.1) with  $|V_{ub}/V_{cb}|$  (semi-lept.  $B$  decays), we may also extract the “true” value of  $\beta$ . We obtain  $\beta = (25.8 \pm 1.3)^\circ$ , which would correspond to a NP phase  $\phi_d^{\text{NP}} = -(8.2 \pm 3.5)^\circ$  in  $B_d^0-\bar{B}_d^0$  mixing, in accordance with [3].

## 2. The $B \rightarrow \pi\pi$ System

The starting point of our  $B \rightarrow \pi\pi$  study is given by the following ratios:

$$R_{+-}^{\pi\pi} \equiv 2 \left[ \frac{\text{BR}(B^+ \rightarrow \pi^+\pi^0) + \text{BR}(B^- \rightarrow \pi^-\pi^0)}{\text{BR}(B_d^0 \rightarrow \pi^+\pi^-) + \text{BR}(\bar{B}_d^0 \rightarrow \pi^+\pi^-)} \right] = F_1(d, \theta, x, \Delta; \gamma) \stackrel{\text{exp}}{=} 2.04 \pm 0.28 \quad (2.1)$$

$$R_{00}^{\pi\pi} \equiv 2 \left[ \frac{\text{BR}(B_d^0 \rightarrow \pi^0\pi^0) + \text{BR}(\bar{B}_d^0 \rightarrow \pi^0\pi^0)}{\text{BR}(B_d^0 \rightarrow \pi^+\pi^-) + \text{BR}(\bar{B}_d^0 \rightarrow \pi^+\pi^-)} \right] = F_2(d, \theta, x, \Delta; \gamma) \stackrel{\text{exp}}{=} 0.58 \pm 0.13. \quad (2.2)$$

Here we have used the isospin symmetry of strong interactions to express these observables in terms of  $\gamma$  and the hadronic parameters  $de^{i\theta}$ ,  $xe^{i\Delta}$  that were introduced in [1], and have also given

the current experimental numbers. Moreover, we have the CP asymmetries

$$\mathcal{A}_{\text{CP}}^{\text{dir}}(B_d \rightarrow \pi^+ \pi^-) = G_1(d, \theta; \gamma) \stackrel{\text{exp}}{=} -0.37 \pm 0.10 \quad (2.3)$$

$$\mathcal{A}_{\text{CP}}^{\text{mix}}(B_d \rightarrow \pi^+ \pi^-) = G_2(d, \theta; \gamma, \phi_d) \stackrel{\text{exp}}{=} +0.50 \pm 0.12 \quad (2.4)$$

at our disposal, where  $\phi_d \stackrel{\text{exp}}{=} (43.4_{-2.4}^{+2.6})^\circ$  is the  $B_d^0 - \bar{B}_d^0$  mixing phase; its numerical value follows from the data for CP violation in  $B_d \rightarrow J/\psi K_S$ . If we use the value of  $\gamma$  in (1.1), we are in a position to determine the hadronic parameters characterizing the  $B \rightarrow \pi\pi$  system, with the following results:

$$d = 0.52_{-0.09}^{+0.09}, \quad \theta = (146_{-7.2}^{+7.0})^\circ, \quad x = 0.96_{-0.14}^{+0.13}, \quad \Delta = -(53_{-26}^{+18})^\circ. \quad (2.5)$$

These numbers, which exhibit large non-factorizable effects, are in excellent agreement with our previous analysis [4]. Let us stress that we have also included EW penguin effects in (2.5) through the isospin symmetry, although these topologies have a minor impact on the  $B \rightarrow \pi\pi$  decays.

Finally, we may predict the CP asymmetries of the decay  $B_d \rightarrow \pi^0 \pi^0$ , where we obtain

$$\mathcal{A}_{\text{CP}}^{\text{dir}}(B_d \rightarrow \pi^0 \pi^0) = -0.30_{-0.26}^{+0.48} \stackrel{\text{exp}}{=} -0.28_{-0.39}^{+0.40}, \quad \mathcal{A}_{\text{CP}}^{\text{mix}}(B_d \rightarrow \pi^0 \pi^0) = -0.87_{-0.19}^{+0.29}. \quad (2.6)$$

Here we have also included the experimental value for the direct CP asymmetry [5]. Although no stringent test of our predictions is currently provided, the indicated agreement is very encouraging.

### 3. The $B \rightarrow \pi K$ System

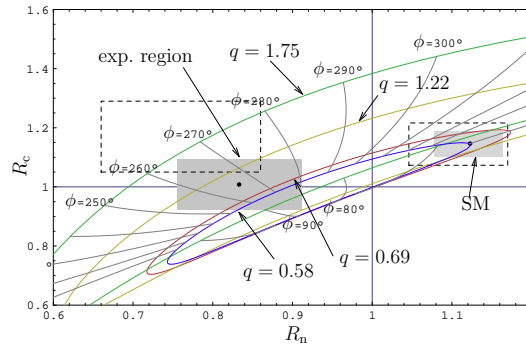
If we use now the  $SU(3)$  flavour symmetry and neglect exchange and penguin annihilation topologies, we can convert the hadronic parameters in (2.5) into their  $B \rightarrow \pi K$  counterparts, allowing us to predict the  $B \rightarrow \pi K$  observables in the SM. Moreover, a couple of internal consistency checks of these working assumptions can be performed, which are nicely fulfilled by the current data, and the sensitivity of our SM predictions on large non-factorizable  $SU(3)$ -breaking effects turns out to be surprisingly small [2]. Consequently, no anomaly is indicated in this sector.

In the case of the  $B_d^0 \rightarrow \pi^- K^+$ ,  $B^+ \rightarrow \pi^+ K^0$  system, where EW penguins have a minor impact, we obtain a SM picture in accordance with the data. In order to analyse the decays  $B^+ \rightarrow \pi^0 K^+$  and  $B_d^0 \rightarrow \pi^0 K^0$ , which are significantly affected by EW penguins, it is useful to introduce

$$R_c \equiv 2 \left[ \frac{\text{BR}(B^+ \rightarrow \pi^0 K^+) + \text{BR}(B^- \rightarrow \pi^0 K^-)}{\text{BR}(B^+ \rightarrow \pi^+ K^0) + \text{BR}(B^- \rightarrow \pi^- \bar{K}^0)} \right] \stackrel{\text{exp}}{=} 1.01 \pm 0.09 \quad (3.1)$$

$$R_n \equiv \frac{1}{2} \left[ \frac{\text{BR}(B_d^0 \rightarrow \pi^- K^+) + \text{BR}(\bar{B}_d^0 \rightarrow \pi^+ K^-)}{\text{BR}(B_d^0 \rightarrow \pi^0 K^0) + \text{BR}(\bar{B}_d^0 \rightarrow \pi^0 \bar{K}^0)} \right] \stackrel{\text{exp}}{=} 0.83 \pm 0.08. \quad (3.2)$$

The EW penguin effects are described by a parameter  $q$ , which measures the strength of the EW penguins with respect to tree-diagram-like topologies, and a CP-violating phase  $\phi$ . In the SM, this phase vanishes, and  $q$  can be calculated with the help of the  $SU(3)$  flavour symmetry, yielding a value of 0.58. The situation can transparently be discussed in the  $R_n - R_c$  plane, as shown in Fig. 1: the shaded areas indicate our SM prediction and the experimental range, the lines show the theory predictions for the central values of the hadronic parameters and various values of  $q$  with  $\phi \in [0^\circ, 360^\circ]$ ; the dashed rectangles represent the SM predictions and experimental ranges



**Figure 1:** The situation in the  $R_n$ – $R_c$  plane, as discussed in the text.

at the time of our original analysis [1]. Although the central values of  $R_n$  and  $R_c$  have slightly moved towards each other, the puzzle is as prominent as ever. The experimental region can now be reached without an enhancement of  $q$ , but a large CP-violating phase  $\phi$  of the order of  $-90^\circ$  is still required, although  $\phi \sim +90^\circ$  can also bring us rather close to the experimental range of  $R_n$  and  $R_c$ .

We may also predict the CP-violating asymmetries of the  $B^\pm \rightarrow \pi^0 K^\pm$  and  $B_d \rightarrow \pi^0 K_S$  decays both in the SM and in our NP scenario. In particular the mixing-induced CP asymmetry of the latter decay has recently received a lot of attention, as the current  $B$ -factory data yield a value of  $-0.38 \pm 0.26$  for  $\Delta S \equiv (\sin 2\beta)_{\pi^0 K_S} - (\sin 2\beta)_{\psi K_S}$ . We predict this difference to be *positive* in the SM, and in the ballpark of 0.10–0.15 [2]. Interestingly, the best values for  $(q, \phi)$  that are implied by  $R_{n,c}$  make the disagreement of  $\Delta S$  with the data even larger than in the SM. However, also values of  $(q, \phi)$  can be found for which  $\Delta S$  could be smaller than in the SM or even reverse the sign [2].

#### 4. Rare $K$ and $B$ Decays

An important feature of our strategy is a connection between the  $B \rightarrow \pi\pi, \pi K$  modes and rare decays of the kind  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ ,  $K_L \rightarrow \pi^0 \nu \bar{\nu}$ ,  $K_L \rightarrow \pi^0 \ell^+ \ell^-$ ,  $B \rightarrow X_s \nu \bar{\nu}$  and  $B_{s,d} \rightarrow \mu^+ \mu^-$ . If we assume that the dominant NP contributions enter through the  $Z^0$ -penguin function  $C$  and make the renormalization-group evolution from scales  $\mathcal{O}(M_W, m_t)$  down to  $\mathcal{O}(m_b)$ , we can directly explore the interplay of the modified EW penguin sector with these rare decays, which shows that we may encounter sizeable effects, in particular in the  $K \rightarrow \pi \nu \bar{\nu}$  system. In [2], we point out that the most recent  $B$ -factory constraints for rare decays have interesting new implications, and discuss a few future scenarios. We look forward to confronting our strategy with more accurate data!

#### References

- [1] A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, Phys. Rev. Lett. **92** (2004) 101804 [arXiv:hep-ph/0312259]; Nucl. Phys. B **697** (2004) 133 [arXiv:hep-ph/0402112].
- [2] A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, to appear.
- [3] M. Bona *et al.* [UTfit Collaboration], arXiv:hep-ph/0509219.
- [4] A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, Acta Phys. Polon. B **36** (2005) 2015 [arXiv:hep-ph/0410407].
- [5] Heavy Flavour Averaging Group: <http://www.slac.stanford.edu/xorg/hfag/>.