

# Probing new physics in electroweak penguins through $B_d$ and $B_s$ decays

Lars Hofer<sup>1,2</sup>, Dominik Scherer<sup>2</sup>, and Leonardo Vernazza<sup>3,4</sup>

<sup>1</sup> Institut für Theoretische Teilchenphysik, Karlsruhe Institute of Technology, D-76128  
Karlsruhe, Germany

<sup>2</sup> Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074  
Würzburg, Germany

<sup>3</sup> Institut für Physik (THEP), Johannes Gutenberg-Universität, D-55099 Mainz, Germany

E-mail: lars.hofer@physik.uni-wuerzburg.de, dominik@particle.uni-karlsruhe.de,  
vernazza@uni-mainz.de

**Abstract.** An enhanced electroweak penguin amplitude due to the presence of unknown new physics can explain the discrepancies found between theory and experiment in the  $B \rightarrow \pi K$  decays, in particular in  $A_{\text{CP}}(B^- \rightarrow \pi^0 K^-) - A_{\text{CP}}(\bar{B}^0 \rightarrow \pi^+ K^-)$ , but the current precision of the theoretical and experimental results does not allow to draw a firm conclusion. We argue that the  $\bar{B}_s \rightarrow \phi \rho^0$  and  $\bar{B}_s \rightarrow \phi \pi^0$  decays offer an additional tool to investigate this possibility. These purely isospin-violating decays are dominated by electroweak penguins and we show that in presence of a new physics contribution their branching ratio can be enhanced by about an order of magnitude, without violating any constraints from other hadronic  $B$  decays. This makes them very interesting modes for LHCb and future  $B$  factories. In [1] we have performed both a model-independent analysis and a study within realistic New Physics models such as a modified- $Z^0$ -penguin scenario, a model with an additional  $Z'$  boson and the MSSM. In this article we summarise the most important results of our study.

## 1. Introduction

The four  $B \rightarrow \pi K$  decays have been very useful in testing flavour structure and CP violation in the Standard Model (SM) since the late 1990s. These decays have a small branching ratio,  $\mathcal{O}(10^{-6})$ , and are sensitive to New Physics (NP) contributions. In the past years some discrepancies between  $B \rightarrow \pi K$  measurements and SM predictions have occurred, provoking speculations on a “ $B \rightarrow \pi K$  puzzle”. To date, the measurements of the branching fractions have fluctuated towards the SM predictions, the latter still suffering from large hadronic uncertainties, and only the following difference of CP asymmetries shows an unexpected behavior [2]:

$$\Delta A_{\text{CP}} \equiv A_{\text{CP}}(B^- \rightarrow \pi^0 K^-) - A_{\text{CP}}(\bar{B}^0 \rightarrow \pi^+ K^-) \stackrel{\text{SM}}{=} 1.9_{-4.8}^{+5.8} \% \stackrel{\text{exp.}}{=} (14.8 \pm 2.8) \%. \quad (1)$$

The theory result, derived within the framework of QCD factorisation (QCDF) [4], and the experimental result, taken from [3], differ by  $2.5\sigma$ . This result suggests a violation of the isospin symmetry beyond the amount expected in the SM. It can be interpreted as a hint of a NP electroweak (EW) penguin amplitude, or alternatively as an enhanced low-energy hadronic

<sup>4</sup> Alexander-von-Humboldt fellow.

effect which the theory is not able to catch. Present data do not allow to distinguish between these two possibilities.

Our aim is to show that the question can be partially addressed exploiting the large variety of non-leptonic  $B$  decays into two charmless mesons. For this purpose, in [1] we have studied the *purely* isospin-violating decays  $\bar{B}_s \rightarrow \phi\rho^0$  and  $\bar{B}_s \rightarrow \phi\pi^0$ , which are dominated by EW penguins, and we have shown that if NP in this sector exists at a level where it can explain the  $\Delta A_{\text{CP}}$  puzzle, it could be clearly visible in these purely isospin-violating decays. We present here a summary of the results, referring to [1] for a more detailed discussion.

## 2. Isospin violation in $B \rightarrow \pi K$ and $B_s \rightarrow \phi\rho^0$ , $B_s \rightarrow \phi\pi^0$ decays

The  $B \rightarrow \pi K$  decays are dominated by the isospin-conserving QCD penguin amplitude. Nevertheless, they receive small contributions from the tree and the EW penguin amplitude, which are isospin-violating. Combining measurements of the four different decay modes  $B^- \rightarrow \pi^- \bar{K}^0$ ,  $B^- \rightarrow \pi^0 K^-$ ,  $\bar{B}^0 \rightarrow \pi^+ K^-$  and  $\bar{B}^0 \rightarrow \pi^0 \bar{K}^0$ , it is possible to construct observables in which the leading contribution from the QCD penguin drops out, so that they are sensitive to isospin violation and therefore to a possible new contribution with the structure of the EW penguins.

The decay amplitudes can be written in terms topological amplitudes  $r_i$  which are normalised to the dominant QCD penguin contribution. Introducing as well a NP EW penguin amplitude, such that

$$r_{\text{EW}} \rightarrow r_{\text{EW}} + \tilde{r}_{\text{EW}} e^{-i\delta}, \quad r_{\text{EW}}^{\text{C}} \rightarrow r_{\text{EW}}^{\text{C}} + \tilde{r}_{\text{EW}}^{\text{C}} e^{-i\delta}, \quad r_{\text{EW}}^{\text{A}} \rightarrow r_{\text{EW}}^{\text{A}} + \tilde{r}_{\text{EW}}^{\text{A}} e^{-i\delta}, \quad (2)$$

one obtains

$$\Delta A_{\text{CP}} \simeq -2 \text{Im}(r_{\text{C}}) \sin \gamma + 2 \text{Im}(\tilde{r}_{\text{EW}} + \tilde{r}_{\text{EW}}^{\text{A}}) \sin \delta. \quad (3)$$

Here  $r_{\text{EW}}$ ,  $r_{\text{EW}}^{\text{(C,A)}}$  represent respectively the SM colour-allowed, colour-suppressed and annihilation electroweak penguin amplitudes, while the  $\tilde{r}_{\text{EW}}^i$  are the corresponding NP contributions. It is clear from (3) that a large  $\Delta A_{\text{CP}}$  can be obtained both through enhanced low-energy effects in  $\text{Im}(r_{\text{C}})$ , as well as by means of a NP contribution. An  $\text{Im}(r_{\text{C}})$  large enough to solve the  $\Delta A_{\text{CP}}$  discrepancy, however, would break QCDF, so that within this framework a NP solution is favoured. Although one can construct many other observables which are sensitive to isospin violation, the colour-allowed EW penguin contribution and the colour-suppressed tree contribution cannot be disentangled within the  $B \rightarrow \pi K$  decays alone since they enter the amplitudes exclusively in the combination

$$r_{\text{EW}} - r_{\text{C}} e^{-i\gamma}. \quad (4)$$

Our proposal is now to get a more complete picture by considering as well the decays

$$\boxed{\bar{B}_s \rightarrow \phi\rho^0 \quad \text{and} \quad \bar{B}_s \rightarrow \phi\pi^0.}$$

These decays are purely isospin-violating and their structure in the SM is very simple. Even though we are facing the same type of EW penguin vs colour-suppressed tree amplitude pollution as in the  $B \rightarrow \pi K$  decays, various elements suggest that the analysis of these decays may be interesting:

- these decays are dominated by the EW penguin amplitude such that a NP effect coming from a new EW penguin amplitude should have more spectacular effects in these decays than in the QCD penguin dominated  $B \rightarrow \pi K$ : A new EW amplitude of the same order as the SM one can enhance the branching ratios by about an order of magnitude.

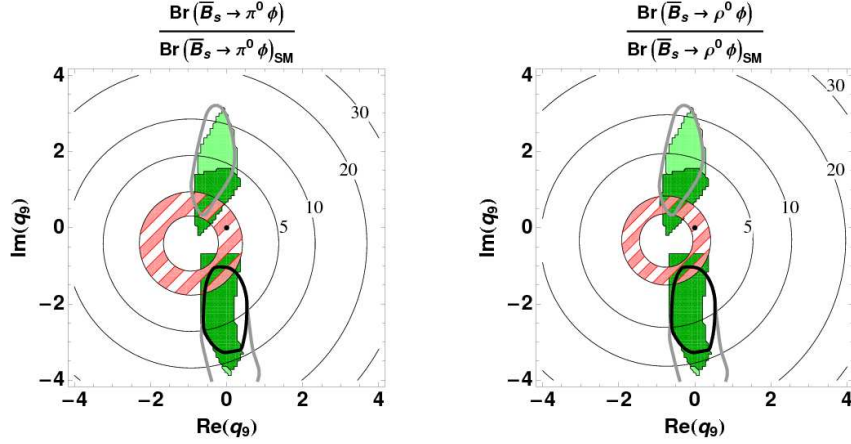


Figure 1: Enhancement factors of the  $\bar{B}_s \rightarrow \phi\rho^0, \phi\pi^0$  branching ratios with respect to their SM values. The black dot represents the SM result while the red striped region shows the theoretical uncertainty in the SM. The dark green area is the region allowed by the  $2\sigma$  constraints from  $\bar{B} \rightarrow \pi K^{(*)}, \rho K^{(*)}, \phi K^{(*)}$  and  $\bar{B}_s \rightarrow \phi\phi, \bar{K}K$  decays; for comparison, the light green area represents the area allowed by constraints from isospin-sensitive observables only, considering only  $\bar{B} \rightarrow \pi K, \pi K^{(*)}, \rho K$  decays. The solid black line represents the  $1\sigma$  CL of the fit with  $S_{CP}(\bar{B}^0 \rightarrow \pi\bar{K}^0)$ , while the solid grey line represents the  $1\sigma$  CL of the fit without it. Here the scenario  $q_9 \neq 0$  is shown.

- the nature of these  $B_s$  decays is different from the  $B \rightarrow \pi K$  decays, the first being  $PV, VV$  decays, respectively, while the latter are  $PP$  decays. The non-perturbative low-energy QCD dynamics is expected not to be correlated among the two classes of decays, and the exact relation cannot be determined within QCDF. Phenomenological comparison with other decays such as  $B \rightarrow \pi\pi, B \rightarrow \pi\rho, B \rightarrow \rho\rho$  suggests a decreasing of non-perturbative effects when vector mesons appear in the final state. A NP contribution is instead of high-energy origin, and its effects can be reliably studied within perturbation theory, allowing for a correlation among the  $B \rightarrow \pi K$  and the  $B_s$  decays of interest.

### 3. Model-independent analysis

We first perform a model-independent analysis. We parameterise NP in EW penguins by adding corresponding terms  $C_{7,9}^{(\prime)\text{NP}}$  to the Wilson coefficients of the effective weak Hamiltonian,

$$C_{7,9}^{(\prime)\text{NP}}(m_W) = C_9^{\text{LO}}(m_W) q_{7,9}^{(\prime)}, \quad q_{7,9}^{(\prime)} = |q_{7,9}^{(\prime)}| e^{i\phi_{7,9}^{(\prime)}}. \quad (5)$$

Here  $C_9^{\text{LO}}$  denotes the leading-order SM coefficient, the primed operators are obtained from the SM  $Q_{7,9}$  by flipping the chiralities of the quark fields. The purpose is to perform a  $\chi^2$ -fit in order to determine the NP parameters in such a way that they describe better  $B \rightarrow \pi K$  data. In particular we look for a solution of the  $\Delta A_{CP}$  discrepancy. Further hadronic decays like  $B \rightarrow \rho K, \pi K^*, \rho K^*$  are used to impose additional constraints at the  $2\sigma$  level. The result of the fit is used to study the decays  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  and quantify a potential enhancement of their branching fractions. Such an analysis, correlating different hadronic decay modes, is only possible if hadronic matrix elements are calculated from first principles like in the framework of QCDF. A method based on flavour symmetries, as it has been used in most studies of  $B \rightarrow \pi K$  decays so far, could not achieve this. In particular, the decays  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  are not related to any other decay via  $SU(3)_F$  so their branching fractions cannot be predicted in this way.

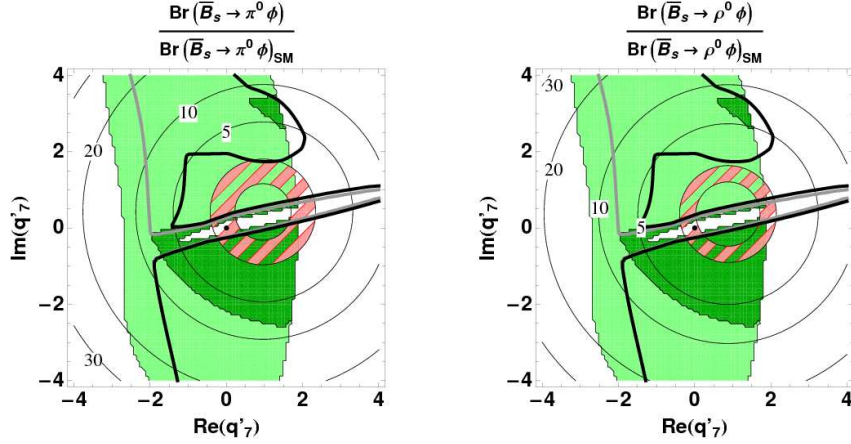


Figure 2: Enhancement factors of the  $\bar{B}_s \rightarrow \phi\rho^0, \phi\pi^0$  branching ratios with respect to their SM values. The meaning of the contours and regions is the same as in fig. 1. Here the scenario  $q'_7 \neq 0$  is displayed. The  $1\sigma$  region of the fit is the region to the right of the black (grey) curve.

As far as the  $B \rightarrow \pi K$  decays are concerned, the new contributions to the EW penguin amplitudes are given by

$$\begin{aligned}
\sum_{i=7,9,7',9'} \tilde{r}_{\text{EW},i} e^{-i\delta_i} &= (q_7 - q'_7) [(-0.12)_{-0.05}^{+0.04} + (-0.02)_{-0.02}^{+0.07} i] + \\
&\quad (q_9 - q'_9) [0.12_{-0.04}^{+0.05} + 0.02_{-0.07}^{+0.02} i], \\
\sum_{i=7,9,7',9'} \tilde{r}_{\text{EW},i}^{\text{C}} e^{-i\delta_i} &= (q_7 - q'_7) [0.10_{-0.02}^{+0.03} + 0.01_{-0.06}^{+0.01} i] + \\
&\quad (q_9 - q'_9) [0.04_{-0.03}^{+0.02} + (-0.005)_{-0.026}^{+0.016} i], \\
\sum_{i=7,9,7',9'} \tilde{r}_{\text{EW},i}^{\text{A}} e^{-i\delta_i} &= (q_7 - q'_7) [0.03_{-0.07}^{+0.04} + (-0.06)_{-0.01}^{+0.12} i] + \\
&\quad (q_9 - q'_9) [0.007_{-0.010}^{+0.003} + (-0.006)_{-0.003}^{+0.012} i]. \tag{6}
\end{aligned}$$

From these expressions one draws e.g. the following conclusions:

- parity-symmetric models with  $q_7 = q'_7$  and  $q_9 = q'_9$  do not contribute to  $B \rightarrow \pi K$  at all. Therefore such a scenario cannot solve the  $\Delta A_{\text{CP}}$  discrepancy.
- The contributions  $\tilde{r}_{\text{EW},7^{(\prime)}}$  and  $\tilde{r}_{\text{EW},9^{(\prime)}}$  tend to cancel each other. Hence in the scenarios with  $q_7 = q_9$  and  $q'_7 = q'_9$  only a negligible new colour-allowed EW penguin contribution is generated.
- Whereas  $\text{Re}(\tilde{r}_{\text{EW},9^{(\prime)}}^{\text{C}})$  features the typical colour-suppression with respect to  $\text{Re}(\tilde{r}_{\text{EW},9^{(\prime)}})$ , this pattern is not obeyed by the  $q_7^{(\prime)}$  terms.
- The annihilation coefficient  $\tilde{r}_{\text{EW},7^{(\prime)}}^{\text{A}}$  develops a large imaginary part. In scenarios with non-vanishing  $q_7^{(\prime)}$  this term gives the dominant contribution to  $\Delta A_{\text{CP}}$ .

From eq. (3) we see that the  $\Delta A_{\text{CP}}$  discrepancy can be solved either through  $\tilde{r}_{\text{EW}}$  or through  $\tilde{r}_{\text{EW}}^{\text{A}}$ . Except for parity-symmetric models, any scenario with at least one of  $q_{7,9}^{(\prime)}$  different from zero can achieve such a solution. The minimal  $|q|$ -value needed to reduce the  $\Delta A_{\text{CP}}$  tension below the  $1\sigma$  level varies among different scenarios. One finds e.g.  $|q_7| \gtrsim 0.3$  for a model with

only  $q_7 \neq 0$ ,  $|q_9| \gtrsim 0.8$  for a model with only  $q_9 \neq 0$  and  $|q_7| = |q_9| \gtrsim 0.4$  for a model with  $q_7 = q_9$  and the primed coefficients being zero. The fact that in the  $q_7 = q_9$  case only a small NP contribution is needed, in spite of the absence of  $\tilde{r}_{EW}$ , demonstrates the importance of the annihilation term  $\tilde{r}_{EW}^A$ . Finally, we like to stress that the solution of the  $\Delta A_{CP}$  discrepancy via a minimal  $|q|$ -value requires the adjustment of the phase  $\phi$  to a certain value. Realistic scenarios avoiding such a fine-tuning have larger  $|q|$ -values, typically  $|q| \sim 1$ .

For the  $q_7$ -only and the  $q_9$ -only scenarios, the result of the fit to  $B \rightarrow \pi K$  data and the consequences for the  $B_s$  decays of interest are shown in figs. 1,2. For details about the fit and the observables used we refer to [1]. We find that the  $B \rightarrow \pi K$  and related decays set quite strong constraints on the parameter space, especially in scenarios where  $q_9 \neq 0$  or  $q'_9 \neq 0$ . This basically rules out the possibility of having  $|q_i| \gtrsim 5$ , i.e. NP corrections cannot be much larger than the EW penguins of the SM. The SM point is always excluded at the  $2\sigma$  level as a direct consequence of the  $\Delta A_{CP}$  data. According to the sign pattern in eq. (6), the  $B \rightarrow \pi K$  fits of the primed and unprimed scenarios in figs. 1,2 are related to each other through rotation by  $180^\circ$ . The fit works best in the  $q_9^{(\prime)}$  scenario where the best fit point is given by

$$|\hat{q}_9^{(\prime)}| = 1.9 \quad \hat{\phi}_9^{(\prime)} = -100^\circ (+180^\circ). \quad (7)$$

This parameter point yields a full agreement of all the  $B \rightarrow \pi K$  observables with the experimental mean values. In the  $q_7^{(\prime)} = q_9^{(\prime)}$  case a plateau of  $\chi^2 = 0$  points arises due to the large theoretical errors. It turns out that the  $B \rightarrow \pi K$  observables are not very sensitive to the  $q_7^{(\prime)}$ -only scenarios and so the fit does not work well here.

From figs. 1,2 the enhancement  $\text{Br}^{\text{SM+NP}}/\text{Br}^{\text{SM}}$  of the  $B_s$  branching fractions can be read off with respect to the different constraint- and fit-regions. In most scenarios an enhancement of an order of magnitude or more is possible, especially in those involving  $q_7^{(\prime)} \neq 0$ . The fact that large parts of the allowed regions do not overlap with the SM uncertainty regions is encouraging. It means that, if such NP is realised in nature, it could be possible to probe it easily.

Exceptions are  $\bar{B}_s \rightarrow \phi\pi$  for  $q_7^{(\prime)} = q_9^{(\prime)}$  and  $\bar{B}_s \rightarrow \phi_L\rho_L$  (with the subscript  $L$  denoting longitudinally polarised vector-mesons) for parity-symmetric models, where no enhancement is expected. Furthermore, effects in the  $q'_9$  and the  $q'_7 = q'_9$  scenarios are limited by the small allowed region resulting from the  $B \rightarrow \pi K$  fit. Largest effects occur as expected in the scenarios which are least constrained by  $B \rightarrow \pi K$ , i.e. the single  $q_7^{(\prime)}$  and the parity-symmetric models. Especially in these cases a  $\bar{B}_s \rightarrow \phi\pi$  measurement would complement  $B \rightarrow \pi K$  data and, while the parity-symmetric models lack the motivation via the  $\Delta A_{CP}$  discrepancy, the  $q'_7$  setting resolves it with ease. Moreover, we like to stress that  $B \rightarrow \pi K$  data alone cannot distinguish among opposite-parity scenarios because such scenarios generate equal results for the  $B \rightarrow \pi K$  observables (for  $180^\circ$ -rotated parameter points). Therefore an analysis of  $B \rightarrow \pi K$  should for example be supported by the analysis of a  $PV$  decay, suggesting  $\bar{B}_s \rightarrow \phi\pi^0$  as an ideal candidate.

#### 4. Analysis of specific NP models

The results of the previous section raise the question: which concrete models for NP can provide a large new EW penguin amplitude without being excluded by present data? In this section we provide a survey of results obtained analysing a set of well-motivated NP models, referring to [1] for more details. The main difference with respect to the model-independent analysis is the possibility of adding constraints from other flavour processes beyond the hadronic  $B$  modes, e.g. the semileptonic decay  $\bar{B} \rightarrow X_s e^+ e^-$ , the radiative decay  $\bar{B} \rightarrow X_s \gamma$  and  $B_s$ - $\bar{B}_s$  mixing. These processes usually yield tight constraints on new flavour structures and it has to be investigated if the effects in  $B \rightarrow \pi K$  and  $\bar{B}_s \rightarrow \phi\rho^0, \phi\pi^0$  survive these constraints.

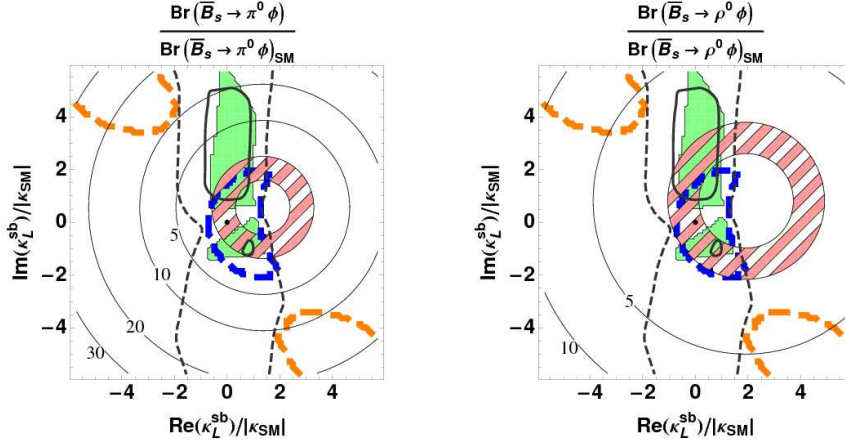


Figure 3: Enhancement factor for the  $\bar{B}_s \rightarrow \phi\rho^0, \phi\pi^0$  branching ratios with respect to their SM values in the modified- $Z^0$ -penguin scenario. The green area represents the region allowed by the  $2\sigma$  constraints from all the considered hadronic decays, while the area inside the dashed blue line represents the region allowed by the  $2\sigma$  constraint from semi-leptonic decays. The areas inside the dashed orange line represent the parameter values for which the modified- $Z^0$ -penguin would explain the  $B_s$ - $\bar{B}_s$  mixing phase

#### 4.1. The modified $Z^0$ -penguin scenario

The simplest class of models with large new contributions to EW penguins comprises models with a modified  $Z\bar{s}b$  coupling. Such a FCNC coupling can either be generated by integrating out new heavy particles, e.g. in supersymmetric models or fourth-generation models, or it can exist at tree-level in more exotic scenarios like models with non-sequential quarks.

The model is described in terms of two parameters,  $\kappa_{L,R}^{sb}$ , which parameterise the effective coupling of the  $Z^0$  to left- and right-handed quarks, respectively. A scenario with only  $\kappa_L^{sb} \neq 0$  scenario shares its most important features with the  $q_9$ -only setup of the model-independent study, while the case with only  $\kappa_R^{sb} \neq 0$  is similar to the  $q_7$ -only case. This expectation is confirmed by the graphs in fig. 3. We only note that we get a  $180^\circ$  rotation due to the signs of  $\delta C_9$  and  $C_7'$ . The main difference is that we now face additional constraints from semileptonic decays and  $B_s$ - $\bar{B}_s$  mixing. The allowed region for the former is given by the interior of the blue dashed curve, the allowed region for the latter by the orange areas outside the zone preferred by the  $B \rightarrow \pi K$  fit. We see that the  $\Delta_s$  anomaly of  $B_s$ - $\bar{B}_s$  mixing cannot be resolved in a modified  $Z$  scenario when fulfilling at the same time the semileptonic constraints. However, in models with loop-induced modified  $Z$  couplings the  $Z$  exchange contribution to  $B_s$ - $\bar{B}_s$  mixing has to be regarded as a subleading effect and therefore the corresponding constraint does not apply in this case. Focussing on the semileptonic constraints, we find that they are compatible with the  $1\sigma$  region of the  $B \rightarrow \pi K$  fit for all three cases, but draw the FCNC couplings  $\kappa_{L,R}^{sb}$  to very small values. As a consequence, we expect no significant effects in  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$ .

#### 4.2. Models with an additional $U(1)'$ gauge symmetry

The presence of a heavy  $Z'$  boson associated with an additional  $U(1)'$  gauge symmetry is a well-motivated extension of the SM. This additional symmetry has not been invented to solve a particular problem of the SM, but rather occurs as a byproduct in many models like e.g. Grand Unified Theories, various models of dynamical symmetry breaking and Little-Higgs models.

The case of interest, in which the flavour effect is assumed to contribute mainly to the



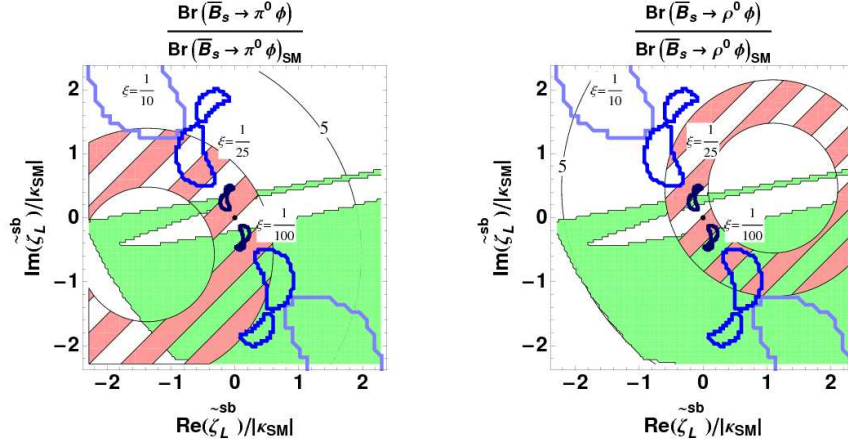


Figure 4: Enhancement factors of  $\text{Br}(\bar{B}_s \rightarrow \phi\pi^0)$  and  $\text{Br}(\bar{B}_s \rightarrow \phi\rho^0)$  for  $\tilde{\zeta}_L^{sb} \neq 0$ . The red-hatched ring corresponds to the SM uncertainty. The green area is allowed by the  $2\sigma$  constraints from all hadronic  $B$  decays while the regions inside the blue lines are compatible with the constraint from  $B_s$ - $\bar{B}_s$  mixing. From the biggest to the smallest region they stand for  $\xi = 1/10$ ,  $\xi = 1/25$  and  $\xi = 1/100$ , respectively.

electroweak penguin, can be described in terms of two parameters,  $\tilde{\zeta}_{L,R}^{sb}$ , corresponding to the properly normalised couplings of the  $Z'$ -boson to left- and right-handed quarks, respectively. The three scenarios with only  $\tilde{\zeta}_L^{sb} \neq 0$ , only  $\tilde{\zeta}_R^{sb} \neq 0$  and with  $\tilde{\zeta}_L^{sb} = \tilde{\zeta}_R^{sb} \neq 0$  exactly correspond to the  $q_7$ -only,  $q'_9$ -only and the  $q_7 = q'_9$  scenarios in our model-independent analysis, except for a normalisation factor. The exclusion regions from the  $2\sigma$  constraints and the confidence levels from the fit can be immediately read off from figs. 1 and 2, provided one rescales the axes by an appropriate normalisation factor and rotates the pictures by  $180^\circ$  to take into account a minus sign in the Wilson coefficients. In this scenario no direct constraints arise from semileptonic decays, assuming leptophobic  $Z'$  couplings. The relation to  $B_s$ - $\bar{B}_s$  mixing moreover depends on an additional parameter  $\xi \equiv \frac{g_{U(1)'}^2}{g^2} \frac{M_W^2}{M_{Z'}^2}$ , which is related to the overall strength of the  $Z'$  coupling to fermions, and to its mass. From the diagrams in fig. 4 we see that the  $B_s$ - $\bar{B}_s$  mixing constraint is in general very tight. It prohibits large effects in  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  for realistic values of the parameter  $\xi \lesssim 1/25$ , which would correspond for example to  $g_{U(1)'} \sim g$  and  $M_{Z'} \sim 400\text{GeV}$ . We find that enhancement of a factor  $\sim 5$  is possible in the  $\zeta_L^{sb}$  and  $\zeta_R^{sb}$  scenarios whereas no effect can occur in the  $\zeta_L^{sb} = \zeta_R^{sb}$ . For  $\xi = 1/100$  the constraints from  $B_s$ - $\bar{B}_s$  mixing become so strong that no effect in  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  would be detectable. A measurement of a significant enhancement would therefore set a lower limit on  $\xi$ , equivalent to an upper limit on the  $Z'$  mass.

#### 4.3. MSSM

The main contribution to the electroweak penguin in supersymmetry comes from  $Z$  penguins induced by chargino-squark loops. This scenario is equivalent to a modified  $Z^0$  penguin model with only  $\kappa_L^{sb}$  different from zero. Constraints from flavour observables and squark masses, however, strongly constrain the parameter space available. In Fig. 5 we provide a zoom of the  $\kappa_L^{sb}$  scenario with a superposition of points obtained from a scan of the MSSM parameter space. The constraints from squark and chargino masses and from  $\text{Br}(\bar{B} \rightarrow X_s\gamma)$  are taken into account. One sees that these points are not able to decrease the  $\Delta A_{\text{CP}}$  discrepancy below the  $2\sigma$  level, nor to create a large enhancement in the  $B_s$  decays branching ratio.

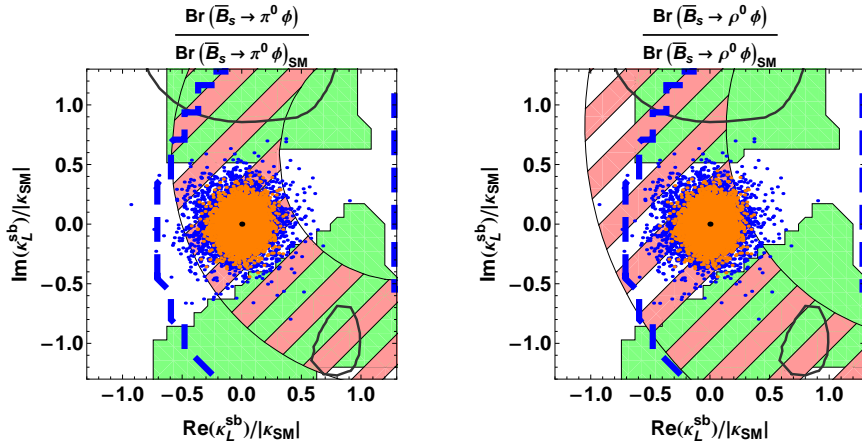


Figure 5: Zoom of the upper plots in fig. 3. On top we add the  $\kappa_L^{sb}/|\kappa_{SM}|$  values resulting from chargino-induced flavour-violating  $Z$  couplings in a parameter scan.

## 5. Conclusion

We have studied the possibility of probing isospin-violating NP in hadronic  $B$  decays. Our analysis is motivated by discrepancies found in  $B \rightarrow \pi K$  decays. In particular, the  $2.5\sigma$  discrepancy found in the observable  $\Delta A_{CP}$  can be interpreted as a sign of NP in the EW penguin sector of the theory. Since this discrepancy alone is not able to provide evidence of NP, we have proposed here to consider the decays  $\bar{B}_s \rightarrow \phi\pi^0$  and  $\bar{B}_s \rightarrow \phi\rho^0$  as well, which are extremely sensitive to EW penguins. First, we have demonstrated in a model-independent analysis that the solution of the  $B \rightarrow \pi K$  discrepancy is obtained with an additional NP contribution to the EW penguin operators  $Q_7^{(\prime)}, \dots, Q_{10}^{(\prime)}$  of the same order of magnitude as the leading SM coefficient  $C_9^{SM}$ . Then, we have studied the corresponding enhancement of the  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  branching ratios for various scenarios, taking into account constraints from other hadronic  $B$  decays. The results show that in many cases a large enhancement of about an order of magnitude is possible. Exceptions are parity-symmetric models, which have no impact on the  $VV$  decay  $\bar{B}_s \rightarrow \phi\rho^0$ , and scenarios with (approximately) equal contributions to  $C_7^{(\prime)}$  and  $C_9^{(\prime)}$ , which cancel in  $\bar{B}_s \rightarrow \phi\pi^0$ .

The last part of the analysis concerns a survey of concrete NP models such as modified  $Z^0$  penguin, a model with an additional  $U(1)'$  gauge symmetry and the MSSM. In such models additional constraints arise from the semileptonic decays  $\bar{B} \rightarrow X_s e^+ e^-$  and  $\bar{B} \rightarrow K^* l^+ l^-$  and from  $B_s$ - $\bar{B}_s$  mixing. While the solution of the  $\Delta A_{CP}$  discrepancy is in some cases still possible, like in the modified- $Z^0$ -penguin scenario or in a model with an additional  $Z'$  boson, the enhancement of the  $\bar{B}_s \rightarrow \phi\pi^0, \phi\rho^0$  decays is usually strongly constrained by either the constraint from semileptonic decays or from  $B_s$ - $\bar{B}_s$  mixing. Last, we find that the new contribution to the EW penguins in the MSSM is always marginal and cannot solve the  $\Delta A_{CP}$  discrepancy, nor create a large enhancement of the  $B_s$  decays considered here.

### Acknowledgements

L.V. would like to thank the organizers of Discrete 2010 for putting together an exciting conference in a very pleasant environment.

## References

- [1] L. Hofer, D. Scherer, L. Vernazza, JHEP **1102** (2011) 080. [arXiv:1011.6319 [hep-ph]].



- [2] M. Gronau, J. L. Rosner, Phys. Rev. **D59** (1999) 113002. [hep-ph/9809384]; S. Baek, D. London, Phys. Lett. **B653** (2007) 249-253. [hep-ph/0701181]; R. Fleischer, S. Recksiegel, F. Schwab, Eur. Phys. J. **C51** (2007) 55-61. [hep-ph/0702275 [HEP-PH]].
- [3] E. Barberio *et al.* [ Heavy Flavor Averaging Group Collaboration ], [arXiv:0808.1297 [hep-ex]].
- [4] M. Beneke, G. Buchalla, M. Neubert *et al.*, Nucl. Phys. **B606** (2001) 245-321. [hep-ph/0104110]; M. Beneke, M. Neubert, Nucl. Phys. **B675**, 333-415 (2003). [hep-ph/0308039].