Signature of new physics in $B \to \phi\pi$ decay

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A R T I C L E I N F O

A B S T R A C T

We investigate the effect of an extra fourth quark generation and FCNC mediated Z and Z' bosons on the rare decay mode $B^- \to \phi\pi^-$. In the Standard Model, this mode receives only $b \to d$ penguin contributions and therefore, highly suppressed with branching ratio $\sim 5 \times 10^{-9}$. This in turn makes this mode a very sensitive probe for new physics. We find that due to the above mentioned new physics contributions there is a significant enhancement in its branching ratio. Furthermore, the direct CP violation parameter which is identically zero in the SM is found to be quite significant. If this mode will be observed in the upcoming LHCb experiment, it will not only provide a clear signal of new physics but also can be used to constrain the new physics parameter space.

The B decay modes provide valuable insights to critically test the Standard Model (SM) and to look for the possible existence of physics beyond the SM. One way of searching for new physics (NP) is by studying the rare decay modes which are induced by flavor changing neutral current (FCNC) transitions. In the SM, such rare decays arise at the one-loop level and thus the study of the same will provide us an excellent testing ground for NP.

Over the years, there has been profound interest in the search for physics beyond the SM. The observed discrepancy between the measured $S_{\phi K_S}$ and $S_{\psi K_S}$ [1] already gave an indication of the possible existence of NP in the $B \to \phi K_S$ decay amplitude and this has, in one way, motivated many to carry out intensive search for NP. Although the presence of NP in the b-sector is not yet firmly established, but there exist several smoking gun signals [2] which will be verified in the upcoming LHCb experiment or super B factories. Therefore, it is interesting to examine as many different rare decay channels as possible to have an indication of new physics.

In this Letter, we would like to explore the effect of the extra fourth generation of quarks and FCNC mediated Z (Z') boson(s) in the rare decay mode $B^- \to \phi\pi^-$, which is a pure penguin induced process, mediated by the quark level transition $b \to d\bar{s}s$. The interesting feature of this process is that it is dominated by the electroweak penguin contributions as the QCD penguins are OZI suppressed, and therefore expected to be highly suppressed in the SM. It, therefore, serves as a suitable place to search for new

physics. At present only the upper limit of its branching ratio is known [3]

$$\text{Br}(B^- \to \phi\pi^-) < 0.24 \times 10^{-6}. \tag{1}$$

This decay mode has been analyzed both in the SM [4] and in various extensions of it [5] where it has been found that in some of these new physics models the branching ratio can be enhanced significantly from its corresponding SM value.

In order to discuss the effect of fourth quark generation and FCNC mediated Z (Z') boson, we would first like to present the SM result using the QCD factorization [6]. As the decay mode $B^- \to \phi\pi^-$ proceeds through the quark level transition $b \to d\bar{s}s$ and is a pure penguin induced process occurring at the one loop level, the relevant effective Hamiltonian describing this process is given by

$$\mathcal{H}_{\text{eff}}^{\text{SM}} = \frac{G_F}{\sqrt{2}} V_{pb} V_{pd}^* \sum_{i=3}^{10} C_i(\mu) O_i, \tag{2}$$

where $p = u, c$, $C_i(\mu)$'s are the Wilson coefficients evaluated at the b-quark mass scale and O_i's are the QCD and electroweak penguin operators.

In QCD factorization [6], the decay amplitude can be represented in the form

$$A\big(B^-(p_B) \to \phi(\epsilon, p_1)\pi^-(p_2)\big)$$
$$= -i\frac{G_F}{\sqrt{2}} 2m_\phi f_\phi(\epsilon^* \cdot p_B) F_+^{B\pi}(0) \sum_{p=u,c} \lambda_p \left(\alpha_3^p - \frac{1}{2}\alpha_{3,\text{EW}}^p\right), \tag{3}$$

where $\lambda_p = V_{pb}V_{pd}^*$, the QCD coefficients $\alpha_{3(3,\text{EW})}^p$ are related to the Wilson coefficients as defined in [6] and $F_+^{B\pi}$ is the form factor describing $B \to \pi$ transition. It should be noted that the QCD

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coefficients contributing to $B^- \to \phi\pi^-$ are independent of $p = u, c$ (i.e., the virtual particles in the loop). Therefore, one can also represent the above amplitude using CKM unitarity $\lambda_u + \lambda_c + \lambda_t = 0$, as

$$A(B^- \to \phi\pi^-) = i\frac{G_F}{\sqrt{2}}2m_\phi f_\phi(\epsilon^* \cdot p_B)F_+^{B\pi}(0)\lambda_t\left(\alpha_3 - \frac{1}{2}\alpha_{3,\mathrm{EW}}\right), \tag{4}$$

where we have now omitted the superscripts on α's. The above amplitude can be simplified by replacing $2m_\phi\epsilon^* \cdot p_B \to m_B^2$. The branching ratio thus can be obtained using the formula

$$\mathrm{Br}(B^- \to \phi\pi^-) = \frac{\tau_B}{16\pi m_B}\left|A(B^- \to \phi\pi^-)\right|^2, \tag{5}$$

where τ_B is the lifetime of B^- meson. Another possible observable in this decay mode is the direct CP violation parameter, defined as

$$A_{\mathrm{CP}} = \frac{\Gamma(B^+ \to \phi\pi^+) - \Gamma(B^- \to \phi\pi^-)}{\Gamma(B^+ \to \phi\pi^+) + \Gamma(B^- \to \phi\pi^-)}. \tag{6}$$

In order to have non-zero direct CP violation, it is necessary that the corresponding decay amplitude should contain at least two interfering contributions with different strong and weak phases. Since in the SM, this decay mode does not have two such different contributions in its amplitude, the direct CP violation turns out to be identically zero.

For the numerical evaluation, we use the input parameters as given in the S4 scenario of QCD factorization approach [6]. The particle masses and lifetime of the B meson are taken from [7]. The value of the form factor at zero recoil is taken as $F_+^{B\pi}(0) = 0.28$. The value of the CKM matrix elements used are [7], $|V_{ub}| = 3.96 \times 10^{-3}$, $|V_{ud}| = 0.97383$, $|V_{cb}| = 42.21 \times 10^{-3}$, $|V_{cd}| = 0.2271$ and γ the phase associated with V_{ub} as 70°. With these values as input parameters, the branching ratio obtained in the SM is

$$\mathrm{Br}^{\mathrm{SM}}(B^- \to \phi\pi^-) = 4.45 \times 10^{-9}, \tag{7}$$

which is quite below the experimental upper limit as given in Eq. (1).

Now, in the presence of NP, the transition amplitude (4) receives additional contribution and can be symbolically represented as

$$A^{\mathrm{T}}(B^- \to \phi\pi^-) = A^{\mathrm{SM}} + A^{\mathrm{NP}} = A^{\mathrm{SM}}\left(1 + re^{i\delta}e^{-i(\beta-\phi)}\right), \tag{8}$$

where β is the weak phase of the SM amplitude i.e., we have used $V_{td} = |V_{td}|e^{-i\beta}$ with value $\beta = 0.375$, ϕ is the weak phase associated with the NP amplitude and δ is the relative strong phase between these two amplitudes. It should be noted that the strong phases are generated by the final state interactions (FSI) and at the quark level they arise through absorptive parts of the perturbative penguin diagrams. Furthermore, r denotes the magnitude of the ratio of NP to SM amplitude. Thus, we obtain the CP averaged branching ratio $\langle\mathrm{Br}\rangle \equiv [\mathrm{Br}(B^- \to \phi\pi^-) + \mathrm{Br}(B^+ \to \phi\pi^+)]/2$, including the new physics contribution as

$$\langle\mathrm{Br}\rangle = \mathrm{Br}^{\mathrm{SM}}\left(1 + r^2 + 2r\cos(\beta-\phi)\cos\delta\right), \tag{9}$$

where $\mathrm{Br}^{\mathrm{SM}}$ is the SM branching ratio. It can be seen from the above equation that if r is sizable, the branching ratio could be significantly enhanced from its SM value in the presence of new physics. The direct CP violation parameter (6) in the presence of NP becomes

$$A_{\mathrm{CP}} = \frac{2r\sin\delta\sin(\phi-\beta)}{1 + r^2 + 2r\cos\delta\cos(\phi-\beta)}. \tag{10}$$

We now consider the effect of a sequential fourth generation of quarks [8]. This model is an extension of the SM with the addition of a fourth quark generation. It retains all the features of the SM

Table 1

Values of the new Wilson coefficients at m_b scale where C_i^{new} represents $C_i^{t'}$ for the fourth quark generation model and $\tilde{C}_i$ for the FCNC mediated Z boson model. The phase $\phi' = (\phi - \beta)$ is the relative weak phase between the NP and SM amplitudes

Wilson coefficients	4-generation ($m_{t'} = 400$ GeV)	Z boson model ($\kappa = \frac{|U_{bd}|}{|V_{tb}V_{td}^*|}$)	Z' model ($\xi_{L,R} = |\xi_{L,R}|e^{i\phi'}$)
$C_3^{\mathrm{new}}(m_b)$	0.0195	$0.19\kappa e^{i\phi'}$	$0.05\xi_L - 0.01\xi_R$
$C_4^{\mathrm{new}}(m_b)$	−0.0373	$-0.066\kappa e^{i\phi'}$	$-0.14\xi_L + 0.008\xi_R$
$C_5^{\mathrm{new}}(m_b)$	0.0101	$0.009\kappa e^{i\phi'}$	$0.029\xi_L + 0.017\xi_R$
$C_6^{\mathrm{new}}(m_b)$	−0.0435	$-0.031\kappa e^{i\phi'}$	$-0.162\xi_L + 0.01\xi_R$
$C_7^{\mathrm{new}}(m_b)$	0.0044	$0.145\kappa e^{i\phi'}$	$0.036\xi_L - 3.65\xi_R$
$C_8^{\mathrm{new}}(m_b)$	0.002	$0.053\kappa e^{i\phi'}$	$0.01\xi_L - 1.33\xi_R$
$C_9^{\mathrm{new}}(m_b)$	−0.029	$-0.566\kappa e^{i\phi'}$	$-4.41\xi_L + 0.04\xi_R$
$C_{10}^{\mathrm{new}}(m_b)$	0.0062	$0.127\kappa e^{i\phi'}$	$0.99\xi_L - 0.005\xi_R$

except that it brings into existence the new members denoted by (t', b'). The fourth up-type quark (t') like u, c, t quarks contributes in the $b \to d$ transition at the loop level and hence will modify the SM result. The effect of fourth generation of quarks in various B decays are extensively studied in the literature [9,10].

Due to the additional fourth generation, there will be mixing among the new b' quark and the three down type quarks of the SM and the resulting mixing matrix will be a 4×4 matrix. Accordingly the unitarity condition becomes $\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$ and thus the effective Hamiltonian modifies as

$$\mathcal{H}_{\mathrm{eff}} = -\frac{G_F}{\sqrt{2}}\left[V_{tb}V_{td}^*\sum C_iO_i + V_{t'b}V_{t'd}^*\sum C_i^{t'}O_i\right], \tag{11}$$

where $C_i^{t'}$ are the new Wilson coefficients arising due to the t' quark in the loop. The values of these Wilson coefficients at the M_W scale can be obtained from the corresponding contributions from the t quark by replacing the mass of t quark in the Inami Lim functions [11] by t' mass (here we neglect the RG evolution of these coefficients from t' mass scale to the weak scale M_W). These values can then be evolved to the m_b scale using renormalization group (RG) equation [12], as

$$\vec{C}_i(m_b) = U_5(m_b, M_W, \alpha)\vec{C}(M_W), \tag{12}$$

where $\vec{C}$ is the 10×1 column vector of the Wilson coefficients and U_5 is the five flavor 10×10 evolution matrix. The explicit forms of $\vec{C}(M_W)$ and $U_5(m_b, M_W, \alpha)$ are given in [12]. In Table 1, we present the values of these new Wilson coefficients at m_b scale for a representative set of values for $m_{t'} = 400$ GeV.

After obtaining the values of the new Wilson coefficients at the b quark mass scale, one can directly write the decay amplitude analogous to (4), due to the fourth generation quarks as

$$A^{\mathrm{NP}} = \frac{G_F}{\sqrt{2}}2m_\phi f_\phi(\epsilon^* \cdot p_B)F_+^{B\pi}(0)\lambda_{t'}\left(\alpha_3' - \frac{1}{2}\alpha_{3,\mathrm{EW}}'\right), \tag{13}$$

where $\alpha_{3(3,\mathrm{EW})}'$'s are the new contributions arising from the t' quark contribution. We parameterize the new CKM elements as $\lambda_{t'} = r_d e^{i\phi}$, where ϕ is the new weak phase associated with $\lambda_{t'}'$. Furthermore, since the unitarity condition has now become modified the elements of the 3×3 upper submatrix of the 4×4 quark mixing matrix will be different from the corresponding values of SM CKM matrix elements. Since V_{tb} and V_{td} are not precisely known (i.e., not directly extracted from the experimental data, but fitted using the unitarity constraint) we will use the lower limits from [7] i.e., $|V_{tb}| = 0.78$ and $|V_{td}| = 7.4 \times 10^{-3}$.

In order to study the effect of the fourth generation, we need to know the values of the new parameters $(m_{t'}, r_d, \phi)$. Based on an integrated luminosity of 2.3 fb^{-1} CDF Collaboration [13] gives the lower bound on $m_{t'}$ as $m_{t'} > 284$ GeV. Recently it has been shown that the observed pattern of deviations in the CP symmetries of B system can be explained in the fourth quark generation model
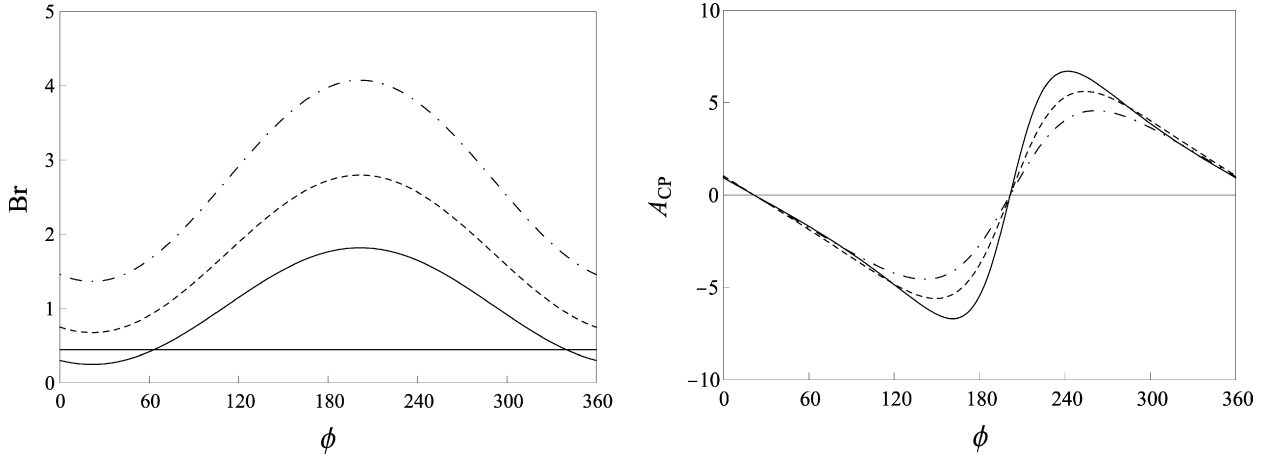
Fig. 1. Variation of CP averaged branching ratio (9) (in units of 10^{-8}) (left panel) and direct CP asymmetry (10) (in %) (right panel) with the new weak phase ϕ, where the solid, dashed and dot-dashed lines correspond to $m_{t'} = 400$, 600 and 800 GeV, respectively. The horizontal line in the left panel represents the SM value.

if $m_{t'} > 700$ GeV [14]. Therefore, in our analysis we consider three representative values for $m_{t'} = 400$, 600 and 800 GeV. The value of r_d can be obtained from the measured mass difference ΔM_{B_d} of $B^0 - \bar{B}^0$ system and the corresponding expression for ΔM_{B_d} in the presence of fourth quark generation can be found in Ref. [10]. Thus, we obtain the values r_d for different $m_{t'}$, consistent with the unitarity condition of 4×4 matrix as: $r_d \sim -3.8 \times 10^{-3}$ ($m_{t'} = 400$ GeV), $r_d \sim -2.7 \times 10^{-3}$ ($m_{t'} = 600$ GeV) and $r_d \sim -2.1 \times 10^{-3}$ ($m_{t'} = 800$ GeV). Using these values, in Fig. 1 we show the variation of the branching ratio (left panel) and the direct CP asymmetry (right panel) with the new weak phase ϕ for three different values of $m_{t'}$. From the figure one can see that the branching ratio is significantly enhanced from its SM value and this enhancement is more pronounced for large $m_{t'}$. It should also be noted that non-zero direct CP violation in this mode could be possible in the presence of an additional generation of quarks.

Now we consider another extension of the SM, where the fermion sector is enlarged by an extra down type singlet quark. Isosinglet quarks appear in many extensions of the SM like the low energy limit of the E_6 GUT models [15]. The mixing of this singlet type down quark with the three SM down type quarks provides a framework to study the deviations of the unitarity constraint of the 3×3 CKM matrix. The mixing also induces tree level flavor changing neutral currents, which can thus substantially modify the SM results. In this model the Z mediated FCNC interaction is given by [16]

$$\mathcal{L} = \frac{g}{2 \cos \theta_W} [\bar{d}_{L\alpha} U_{\alpha\beta} \gamma^\mu d_{L\beta}] Z_\mu, \tag{14}$$

with

$$U_{\alpha\beta} = \sum_{i=u,c,t} V_{\alpha i}^\dagger V_{i\beta} = \delta_{\alpha\beta} - V_{4\alpha}^* V_{4\beta}, \tag{15}$$

where α, β are generation indices and U is the neutral current mixing matrix for the down quark sector. The non-vanishing component of $U_{\alpha\beta}$ will lead to the presence of FCNC transitions at the tree level. The implications of the FCNC mediated Z boson effect has been extensively studied in the context of b physics [17–19].

Because of the new interactions the effective Hamiltonian describing $b \to d\bar{s}s$ process is given as [18],

$$\mathcal{H}_{\text{eff}}^Z = -\frac{G_F}{\sqrt{2}} V_{tb} V_{td}^* [\tilde{C}_3 O_3 + \tilde{C}_7 O_7 + \tilde{C}_9 O_9], \tag{16}$$

where the four-quark operators O_3, O_7 and O_9 have the same structure as the SM QCD and electroweak penguin operators and the new Wilson coefficients $\tilde{C}_i$'s at the M_Z scale are given by

$$\tilde{C}_3(M_Z) = \frac{1}{6} \frac{U_{bd}}{V_{tb} V_{td}^*},$$

$$\tilde{C}_7(M_Z) = \frac{2}{3} \frac{U_{bd}}{V_{tb} V_{td}^*} \sin^2 \theta_W,$$

$$\tilde{C}_9(M_Z) = -\frac{2}{3} \frac{U_{bd}}{V_{tb} V_{td}^*} (1 - \sin^2 \theta_W). \tag{17}$$

These new Wilson coefficients will be evolved from the M_Z scale to the m_b scale using renormalization group equation [12] as described earlier. Because of the RG evolution these three Wilson coefficients generate new set of Wilson coefficients $\tilde{C}_i$ ($i = 3, \ldots, 10$) at the low energy regime (i.e., at the m_b scale) as presented in Table 1. Thus, one can write the new amplitude due to the tree level FCNC mediated Z boson effect in a straightforward manner from Eq. (4) by replacing $\alpha_{3(3,\text{EW})}$ by $\tilde{\alpha}_{3(3,\text{EW})}$, where $\tilde{\alpha}$'s are related to the new Wilson coefficients $\tilde{C}_i(m_b)$'s. In order to see the effect of this FCNC mediated Z boson effect we have to know the value of the parameter $Z - b - d$ coupling parameter which can be explicitly written as $U_{bd} = |U_{bd}| e^{i\phi}$ and the allowed range of $|U_{bd}|$ is found to be $(2 \times 10^{-4} \leqslant |U_{bd}| \leqslant 1.2 \times 10^{-3})$ [19]. In Fig. 2, we present the variation of the CP averaged branching ratio (9) with $|U_{bd}|$ and ϕ (left panel) and the direct CP asymmetry parameter A_{CP} with ϕ (right panel), where we have used $\sin^2 \theta_W = 0.231$. From Fig. 2 it can be seen that the branching ratio could be significantly enhanced and large CP violation could be possible in this model.

Now we consider the effect due to an extra $U(1)'$ gauge boson Z'. The existence of extra Z' boson is a feature of many models addressing physics beyond the SM, e.g., models based on extended gauge groups characterized by additional $U(1)$ factors [20]. Also the new physics models which contain exotic fermions, predict the existence of additional gauge boson. Flavor mixing can be induced at the tree level in the up-type and/or down-type quark sector after diagonalizing their mass matrices. Here again as in the Z model, FCNCs due to Z' exchange can be induced by mixing among the SM quarks and the exotic quark which have different Z' quantum numbers. Here we will consider the model in which the interaction between the Z' boson and fermions are flavor nonuniversal for left handed couplings and flavor diagonal for right-handed couplings. The detailed description of the model can be found in Refs. [21,22], where it has been shown that such model can successfully explain the deviations of $S_{\phi K}$ and $S_{\eta' K}$ from $S_{\psi K}$ and also can explain the $B \to \pi K$ puzzle. The search for the extra Z' boson occupies an important place in the experimental programs of the Fermilab Tevatron and CERN LHC [23]. At such hadron colliders heavy neutral gauge bosons with mass upto around 5 TeV can be pro-
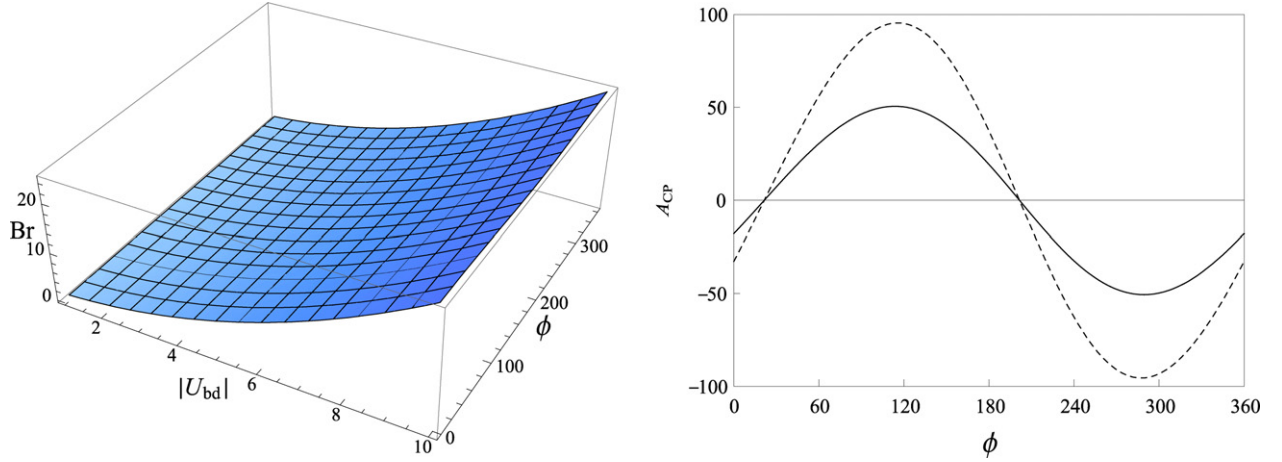
Fig. 2. Variation of the CP averaged branching ratio (in units of 10^{-8}) with $|U_{bd}|$ (in units of 10^{-4}) and the new weak phase ϕ (left panel) and the variation of direct CP asymmetry (10) (in %) with the new weak phase ϕ (right panel) where the dashed and solid lines correspond to $|U_{bd}| = 10^{-4}$ and 5×10^{-4}.
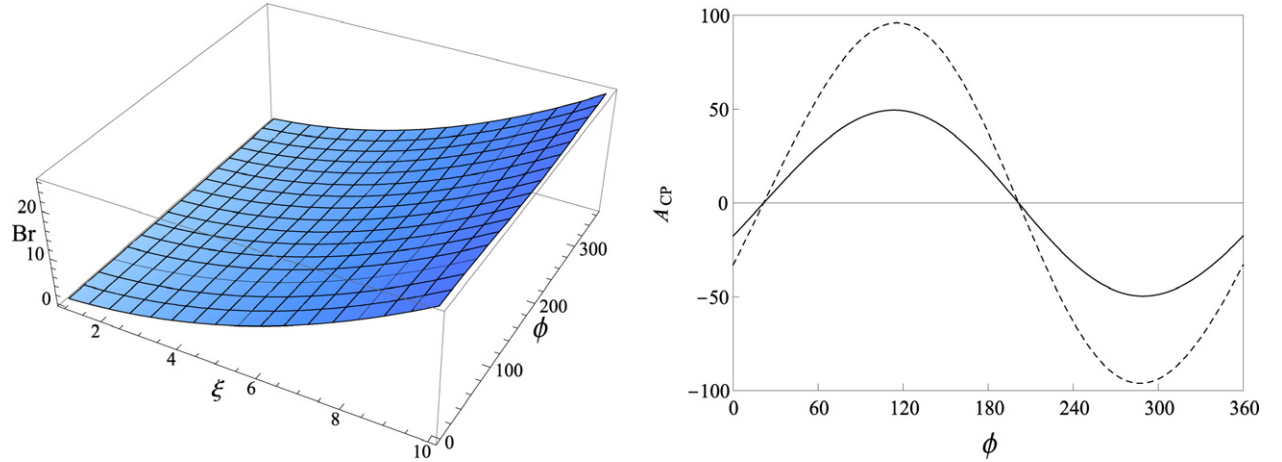

Fig. 3. Variation of the CP averaged branching ratio (in units of 10^{-8}) with ξ (in units of 10^{-3}) and the new weak phase ϕ (left panel) and the variation of direct CP asymmetry (10) (in %) with the new weak phase ϕ (right panel) where the dashed and solid lines correspond to $\xi = 10^{-3}$ and 5×10^{-3}.

duced and detected via two fermion decays $pp(p\bar{p}) \to Z' \to l^+ l^-$ ($l = e, \mu$).

The effective Hamiltonian describing the transition $b \to d\bar{s}s$ mediated by the Z' boson is given by [21]

$$\mathcal{H}_{\text{eff}}^{Z'} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{td}^* \left[\left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \frac{B_{db}^L}{V_{tb} V_{td}^*} \left(B_{ss}^L O_9 + B_{ss}^R O_7 \right) \right], \quad (18)$$

where $g_1 = e/(\sin\theta_W \cos\theta_W)$ and $B_{ij}^{L(R)}$ denote the left- (right-) handed effective Z' couplings of the quarks i and j at the weak scale. The diagonal elements are real due to the hermiticity of the effective Hamiltonian but the off diagonal elements may contain effective weak phase. Therefore, both the terms in (18) will have the same weak phase due to B_{db}^L. We can parameterize these coefficients as

$$\xi_L = \left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \left(\frac{B_{db}^L B_{ss}^L}{V_{tb} V_{td}^*} \right) = |\xi_L| e^{i\phi'},$$

$$\xi_R = \left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \left(\frac{B_{db}^L B_{ss}^R}{V_{tb} V_{td}^*} \right) = |\xi_R| e^{i\phi'}, \quad (19)$$

where $\phi' = \phi - \beta$ (ϕ is the weak phase associated with B_{db}^L).

In order to see the effect of Z' boson, we have to know the values of the ξ_L and ξ_R or equivalently B_{db}^L and $B_{ss}^{L,R}$. Assuming only left-handed couplings are present, the bound on FCNC Z' coupling

(B_{db}^L) from $B^0 - \bar{B}^0$ mass difference has been obtained in Ref. [24] as

$$y \left| \text{Re}(B_{db}^L)^2 \right| < 5 \times 10^{-8}, \qquad y \left| \text{Im}(B_{db}^L)^2 \right| < 5 \times 10^{-8}, \quad (20)$$

where $y = (g' M_Z / g_1 M_{Z'})^2$. Generally one expects $g'/g_1 \sim 1$, if both the $U(1)$ gauge groups have the same origin from some grand unified theories, $M_Z/M_{Z'} \sim 0.1$ for a TeV scale neutral Z' boson, which yields $y \sim 10^{-2}$. However, in Ref. [24] assuming a small mixing between Z–Z' bosons the value of y is taken as $y \sim 10^{-3}$. Using $y \sim 10^{-2}$, one can obtain a more stringent bound on $|B_{db}^L| < 10^{-3}$. It has been shown in [22] that the mass difference of B_s–$\bar{B}_s$ mixing can be explained if $|B_{sb}^L| \sim |V_{tb} V_{ts}^*|$. Similarly, the CP asymmetry anomaly in $B \to \phi K, \pi K$ can be resolved if $|B_{sb}^L B_{ss}^{L,R}| \sim |V_{tb} V_{ts}^*|$. From these two relations one can obtain $|B_{ss}^L| \sim 1$. Thus, it is expected that $\xi_{L,R} \sim 10^{-3}$. However, in this analysis we vary their values within the range 0.01–0.001.

After having an idea about the magnitudes of these new coefficients which are at the M_Z scale, we now evolve them to the b scale using renormalization group equation [12]. The new Wilson coefficients at the m_b scale are presented in Table 1. Using the values of these coefficients at b scale we can analogously obtain the new contribution to the transition amplitude as done in the case of Z boson. Now using $|\xi_L| = |\xi_R| = \xi$, in Fig. 3, we show the variation of the CP averaged branching ratio with ξ and the new weak phase ϕ (left panel) and the direct CP violation with ϕ (right panel). In this case also one can have a significant enhancement

in the branching ratio for large ξ, or in other words for a lighter Z' boson. Furthermore, the observation of this mode could in turn help us to constrain the Z' mass.

In this Letter, we have studied the $B^- \to \phi\pi^-$ decay mode in the Standard Model and in some beyond the Standard Model scenarios. This is a pure penguin rare decay process and proceeds through the quark level transition $b \to d\bar{s}s$, which occurs at the one loop level and is therefore expected to be highly suppressed in the SM. The SM prediction of its branching ratio is $\sim \mathcal{O}(10^{-9})$ which is below the experimental upper limit of $\mathcal{O}(10^{-7})$. We have analysed this decay mode in the fourth quark generation model and in the FCNC mediated Z and Z' models. In the fourth quark generation model, we find that the branching ratio enhances from its SM value, with increasing $m_{t'}$ and it can have a value of $\sim \mathcal{O}(10^{-8})$. In the Z and Z' models, the branching ratio can be significantly enhanced for sizable new physics couplings $|U_{bd}|$ and ξ. In these cases it can reach up to $\mathcal{O}(10^{-7})$ level but still within the experimental upper limit. Furthermore, it is found that large direct CP violation could be possible in this decay mode in the presence of above mentioned new physics models. Thus, if this mode could be observed in the upcoming LHCb experiment it will provide a clear signal of new physics and also can be used to constrain the parameter space of various new physics models. However, it would not be possible to distinguish between these new physics models considering this mode alone.

Acknowledgements

References

[1] E. Barberio, et al., HFAG Collaboration, arXiv: 0704.3575 [hep-ex].
[2] E. Lunghi, A. Soni, JHEP 0709 (2007) 053, arXiv: 0707.0212 [hep-ph].
[3] B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 74 (2006) 011102.
[4] D. Du, H. Gong, J. Sun, D. Yang, G. Zhu, Phys. Rev. D 65 (2002) 094025;
D. Du, H. Gong, J. Sun, D. Yang, G. Zhu, Phys. Rev. D 66 (2002) 079904, Erratum;
R. Aleksan, P.-F. Giraud, V. Morenas, O. Pene, A.S. Safir, Phys. Rev. D 67 (2003) 094019;
B. Melic, Phys. Rev. D 59 (1999) 074005;
A. Ali, G. Kramer, C.D. Lu, Phys. Rev. D 58 (1998) 094009;
R. Fleischer, Phys. Lett. B 321 (1994) 259;
D.S. Du, Z.Z. Xing, Phys. Lett. B 312 (1993) 199.
[5] S. Bar-Shalom, G. Eilam, Y.D. Yang, Phys. Rev. D 67 (2003) 014007;
J.F. Cheng, C.S. Huang, Phys. Lett. B 554 (2003) 155;
A.K. Giri, R. Mohanta, Phys. Lett. B 594 (2004) 196;
A.K. Giri, R. Mohanta, Phys. Lett. B 660 (2008) 376;
J.F. Cheng, Y.N. Gao, C.S. Huang, X.H. Wu, Phys. Lett. B 647 (2007) 413.
[6] M. Beneke, M. Neubert, Nucl. Phys. B 675 (2003) 333;
M. Beneke, G. Buchalla, M. Neubert, C.T. Sachrajda, Nucl. Phys. B 606 (2001) 245.
[7] Particle Data Group, W.M. Yao, et al., J. Phys. G 33 (2006) 1.
[8] W.-S. Hou, A. Soni, H. Steger, Phys. Lett. B 192 (1987) 441;
W.-S. Hou, R.S. Willey, A. Soni, Phys. Rev. Lett. 58 (1987) 1608.
[9] W.-S. Hou, M. Nagashima, G. Raz, A. Soddu, JHEP 0609 (2006) 012;
W.-S. Hou, M. Nagashima, A. Soddu, Phys. Rev. Lett 95 (2005) 141601;
W.-S. Hou, H.-N. Li, S. Mishima, M. Nagashima, Phys. Rev. Lett. 98 (2007) 131801;
T.M. Aliev, A. Ozpineci, M. Savci, Eur. Phys. J. C 29 (2003) 265;
L. Solmaz, Phys. Rev. D 69 (2004) 015003;
T. Hasuike, T. Hattori, T. Hayashi, S. Wakaizumi, Phys. Rev. D 41 (1990) 1691.
[10] A. Arhrib, W.-S. Hou, Eur. Phys. J. C 27 (2003) 555.
[11] T. Inami, C.S. Lim, Prog. Theor. Phys. 65 (1981) 297;
T. Inami, C.S. Lim, Prog. Theor. Phys. 65 (1981) 1772, Erratum.
[12] G. Buchalla, A.J. Buras, M. Lautenbacher, Rev. Mod. Phys. 68 (1996) 1125.
[13] CDF Collaboration, http://www-cdf.fnal.gov/physics/new/top/2008/tprop/Tprime2.3/cdf9234_tprime_23_pub.pdf.
[14] A. Soni, A.K. Alok, A. Giri, R. Mohanta, S. Nandi, arXiv: 0807.1971 [hep-ph].
[15] M. Bando, T. Kugo, Prog. Theor. Phys. 101 (1999) 1313;
M. Bando, T. Kugo, K. Yoshioka, Prog. Theor. Phys. 104 (2000) 211.
[16] Y. Grossman, Y. Nir, R. Rattazzi, in: A.J. Buras, M. Lindner (Eds.), Heavy Flavours II, World Scientific, Singapore, 1998, p. 755.
[17] M. Gronau, D. London, Phys. Rev. D 55 (2000) 2845;
A.K. Giri, R. Mohanta, Phys. Rev. D 68 (2003) 014020;
A.K. Giri, R. Mohanta, Phys. Rev. D 69 (2004) 014008;
A.K. Giri, R. Mohanta, Mod. Phys. Lett. A 19 (2004) 1903;
A.K. Giri, R. Mohanta, JHEP 0411 (2004) 084;
A.K. Giri, R. Mohanta, Eur. Phys. J. C 45 (2006) 151;
R. Mohanta, Phys. Rev. D 71 (2005) 114013.
[18] D. Atwood, G. Hiller, hep-ph/0307251;
N.G. Deshpande, D.K. Ghosh, Phys. Lett. B 593 (2004) 135.
[19] G. Barenboim, F.J. Botella, O. Vives, Phys. Rev. D 64 (2001) 015007;
G. Barenboim, F.J. Botella, O. Vives, Nucl. Phys. B 613 (2001) 285.
[20] P. Langacker, M. Plümacher, Phys. Rev. D 62 (2000) 013006;
P. Langacker, hep-ph/0308033.
[21] V. Barger, C.W. Chiang, P. Langacker, H.S. Lee, Phys. Lett. B 580 (2004) 186;
V. Barger, C.W. Chiang, P. Langacker, H.S. Lee, Phys. Lett. B 598 (2004) 218.
[22] V. Barger, C.W. Chiang, J. Jiang, P. Langacker, Phys. Lett. B 596 (2004) 229.
[23] T.G. Rizzo, hep-ph/0610104;
P. Langacker, arXiv: 0801.1345 [hep-ph].
[24] C.W. Chiang, N.G. Deshpande, J. Jiang, JHEP 0608 (2006) 075.