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B_s decays: CP asymmetries in left-right models with spontaneous CP violation

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Abstract

We present the contributions of new CP phases in CP asymmetries of two-body neutral B_s decays coming from a left-right model with spontaneous CP violation. Large deviations from the Standard Model predictions can be accommodated in a natural way by this type of models. The new physics effects on the mixing, width difference and decays are analysed. In particular, we show how the measurement of the angle γ in electroweak penguin-dominated processes can be largely affected.

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I. INTRODUCTION

CP violation in B decays and its measurement using CP asymmetries is one of the major targets of B factories and of B experiments at hadron facilities. The Standard Model (SM) has specific predictions on the size as well as on the pattern of CP violation in $B_{d,s}$ meson decays. Since these predictions can be tested in these experiments, deviations from them would signal New Physics (NP). This justifies the big effort that is being done both on the experimental and on the theoretical side.

Moreover, on the theoretical side, certain CP-violating asymmetries in neutral B decays are particularly clean, i.e., free from hadronic uncertainties or with controlled ones using complementary tools such as isospin analysis or other symmetries. In the context of the SM they would allow for a clean extraction of the CKM phases, while if NP is at work they would be quite sensitive. Clear signals of NP can be detected by measuring asymmetries that are predicted to be zero in the SM or by comparing two asymmetries that measure the same angle in the SM but that are differently affected by NP.

In the SM the $B_{d,s}$ systems have been extensively studied [1]. There are also a number of studies of the NP effects in B_d decays [2]. However, the B_s system has received somewhat less attention from the NP point of view [3]. Very fast oscillations of the B_s system require outstanding experimental sensitivity (not yet achieved) to measure time-dependent asymmetries. However, due to the large width difference $\Delta\Gamma^{(s)}$, the B_s system offers new possibilities for testing NP which do not exist in the B_d system.

In this talk we will present an example of how NP can affect the CP asymmetries in two-body B_s^0 decays [4] using a specific model: a left–right-symmetric model (LRSM) with spontaneous CP violation [5]. This model has, concerning CP violation, two very interesting features. On the one hand, it is a natural extension to CP of the idea of parity as a spontaneously broken symmetry, with no need for the Higgs sector to be enlarged. On the other hand, due to the new phases that appear in the model, the LRSM with spontaneous CP violation is able to accommodate in a natural way large deviations from the SM predictions, if they are seen in future experiments.

II. THE MODEL: LRSM WITH SPONTANEOUS CP VIOLATION

This model is a gauge extension of the SM based on the gauge group: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ [5]. It contains, in addition to the standard gauge bosons, an extra W'^{\pm} and Z' . The two charged gauge bosons mix with a mixing angle ξ^{\pm} .

The fermionic sector is organized in $SU(2)$ left and right doublets with respect to the corresponding gauge group. The Higgs sector contains a bidoublet ϕ that gives masses to the extra gauge bosons and two triplets (Δ_R and Δ_L), one of them with a large v_R vacuum

expectation value coupling primarily to the W_R and the other that is included to preserve the left–right symmetry. The choice of this scalar sector also allows us to give a natural explanation of the smallness of the neutrino masses.

The gauge-symmetry breaking proceeds in two stages. In a first stage, the neutral component of Δ_R acquires a vev v_R and breaks the symmetry group to $SU(2)_L \times U(1)_Y$, breaking also the parity symmetry. In a second stage the vev’s of the bidoublet ϕ

$$\langle \phi \rangle = \begin{pmatrix} \frac{k_1}{\sqrt{2}} & 0 \\ 0 & \frac{k_2}{\sqrt{2}} \end{pmatrix}, \quad (1)$$

completely break the gauge group down to $U(1)_Q$. If one allows for the possibility of the vev’s having phases, it is easy to see, using all the freedom in redefining fields, that we have the choice of two phases at will. For instance, we can take $k_2 = |k_2|e^{i\alpha}$ and $v_R = |v_R|e^{in}$, breaking CP spontaneously. The phase α will be the relevant one when dealing with CP violation in the quark sector. Also the neutral component of Δ_L acquires a vev v_L .

Finally, in order to discuss the CP-violation effects, it is useful to show explicitly the charged-current lagrangian in the quark mass eigenstate basis given by $\mathcal{L}_{CC} = g/\sqrt{2}(W_L^{\dagger\mu}\bar{u}_L K_L \gamma_\mu d_L + W_R^{\dagger\mu}\bar{u}_R K_R \gamma_\mu d_R) + h.c.$, where the left and right CKM matrices (K_L and K_R respectively) are related by $K_L = K_R^*$. The details of the implications in the phase structure of the model of the previous relation between CKM matrices can be found in [6].

III. CP ASYMMETRIES IN THE $B_{D/S}$ SYSTEM

The time-dependent CP asymmetry for the decays that were tagged as pure B_q^0 or \bar{B}_q^0 into a common CP eigenstate defined by

$$a_{CP}^{(q)}(t) \equiv \frac{\Gamma(B_q^0(t) \rightarrow f) - \Gamma(\bar{B}_q^0(t) \rightarrow f)}{\Gamma(B_q^0(t) \rightarrow f) + \Gamma(\bar{B}_q^0(t) \rightarrow f)}, \quad (2)$$

is given explicitly by

$$a_{CP}^{(q)}(t) = -\frac{(|\lambda^{(q)}|^2 - 1) \cos(\Delta M^{(q)}t) - 2\text{Im}\lambda^{(q)}\sin(\Delta M^{(q)}t)}{(1 + |\lambda^{(q)}|^2)\cosh(\frac{1}{2}\Delta\Gamma^{(q)}t) - 2\text{Re}\lambda^{(q)}\sinh(\frac{1}{2}\Delta\Gamma^{(q)}t)}, \quad (3)$$

where

$$\lambda^{(q)} = \left(\sqrt{\frac{M_{12}^{(q)*} - \frac{i}{2}\Gamma_{12}^{(q)*}}{M_{12}^{(q)} - \frac{i}{2}\Gamma_{12}^{(q)}}} \right) \frac{\bar{A}_q}{A_q} \sim e^{-2i\phi_M^q} \frac{\bar{A}_q}{A_q}, \quad (4)$$

with $\Gamma_{12}^{(q)}$ and $M_{12}^{(q)}$ being the off-diagonal terms of the B_0 – \bar{B}_0 mixing matrix, ϕ_M^q the weak mixing phase and $\Delta\Gamma^{(q)} = \Gamma_H^{(q)} - \Gamma_L^{(q)}$ and $\Delta M^{(q)} = M_H^{(q)} - M_L^{(q)}$ are the differences in decay rates and masses between the physical eigenstates, respectively. In the previous expression

CPT and $|\Gamma_{12}^{(q)}| \ll |M_{12}^{(q)}|$ have been assumed. Concerning the width differences while $\Delta\Gamma^{(d)}$ is very small in the SM, $\Delta\Gamma^{(s)}$ is expected to be large providing us with another observable, which could be measured using for instance the untagged B_s rates $\Gamma(B_q^0 \rightarrow f) + \Gamma(\bar{B}_q^0 \rightarrow f)$.

IV. NEW PHYSICS EFFECTS

Finally we will show how the LRSM affects the CP asymmetries described above. It will give contributions to $\Delta M^{(q)}$, $\Delta\Gamma^{(q)}$, ϕ_M^q and \bar{A}_q/A_q [4,7].

In order to compute the new contributions to $\Delta M^{(q)} = 2|M_{12}^{(q)}|$ and $\Delta\Gamma^{(q)} = 2|\Gamma_{12}^{(q)}| |\cos(2\xi)|$ [8] with $2\xi = \arg(-M_{12}^{(q)}\Gamma_{12}^{(q)*})$ one needs to compute the dispersive and absorptive parts of the box diagrams depicted in [9]. While $M_{12}^{(q)}$ gets a significant contribution from the diagrams with an exchange of one W'^{\pm} and one W^{\pm} or associated Goldstone boson, $\Gamma_{12}^{(q)}$ is practically keep untouched, since the new contribution is strongly suppressed by $\beta = M_{W'}^2/M_W^2$. However, ξ that enters $\Delta\Gamma^{(q)}$ and also the weak mixing phase $\phi_M \rightarrow \phi_M^{SM} + 2\xi$, can range between 0 and π depending on the values of $\alpha, M_{W'}$ and the mass M_H of the two neutral flavour-changing Higgs-bosons whose masses are taken to be equal. This implies that the weak mixing phase can also range between these values so that the asymmetry can accommodate large deviations from the SM relation. Concerning $\Delta\Gamma^{(s)}$, since in the SM $\cos(2\xi) \sim 1$ the overall effect of the LRSM can only be to reduce $\Delta\Gamma^{(s)}$. Indeed if a drastic reduction is observed experimentally it could be explained quite naturally by this model [4].

New Physics can also induce modifications in the decay amplitudes [4]. Mainly, two situations can arise, depending on the type of CP asymmetry one is looking at: either there exist CP asymmetries dominated by tree-level processes whose SM contribution vanishes or is small (β') (i.e. $B_s \rightarrow \psi\phi, B_s \rightarrow \psi K_s$). All of them would be affected by the new contribution coming from the $B^0-\bar{B}^0$ mixing phase and therefore large departures from the expected zero are possible. However, notice that all of them would be modified in the same way $\beta' \rightarrow \beta' + \delta_m$, where $\delta_m = 2\xi$ stands for the new contribution to the mixing phase. Or a completely different situation occurs when the CP asymmetries are dominated by pure QCD penguin decays (such as $B_s \rightarrow \phi\phi$ or $B_s \rightarrow \bar{K}K_s$) or electroweak penguins ($B_s \rightarrow \eta\pi, B_s \rightarrow \phi\pi, \dots$). In that case, their decays may receive considerable contribution from New Physics. Moreover, since the NP contribution could be different for each process, CP asymmetries that were measuring the same angle no longer do.

In order to illustrate this second case we will analyse, as an example, the flavour-changing decay $b \rightarrow s\bar{s}s$ [4]. We will follow four steps. First, one should write the Hamiltonian due to gluon exchange describing this decay at the scale M_W : $\mathcal{H}_{eff} = -\frac{G_F\alpha_s}{\sqrt{2}\pi} V_L^{ts*} V_L^{tb} (\bar{s}[\Gamma_{\mu}^{LL} + \Gamma_{\mu}^{LR}]T^a b)(\bar{s}\gamma_{\mu}T^a s)$, where Γ_{μ}^{LL} is the SM contribution and $\Gamma_{\mu}^{LR} = 2i\frac{m_b}{q^2}\tilde{E}'_0(x)[A^{tb}\sigma_{\mu\nu}q^{\nu}P_R + A^{ts*}\sigma_{\mu\nu}q^{\nu}P_L]$ is the new contribution induced by W exchange via

the right handed current, P_L and P_R are the left and right projectors and $A_{tb} = \xi^+ m_t/m_b e^{i\sigma_1}$ and $A_{ts} = \xi^\pm m_t/m_b e^{i\sigma_2}$. This new contribution is suppressed by the mixing angle $\xi^\pm < 0.01$, but enhanced by $m_t/m_b \sim 60$ and the numerical value of $\tilde{E}'_0(x) \sim 4E'_0(x)$. This enhancement overcomes completely the suppression due to the mixing angle. Moreover two phases σ_1 and σ_2 , functions of α and the signs of the masses of the quarks, appear allowing for potential big effects in the asymmetries. The second step consists in calculating the LO QCD corrections, using an OPE to integrate out the top and calculate the Wilson coefficients C_i . In the basis used to describe this decay NP effects will enter only into the photonic and gluonic magnetic operators with the left and right structures $(C_7^\gamma, C_8^G, C_7^{\gamma'}$ and $C_8^{G'})$. The third step consists in running down the Wilson coefficients from the M_W scale to m_b . Finally, the last step is to compute the hadronic matrix elements using some approximation (we used factorization). It was found that the magnetic contributions are absorbed into penguin contributions by redefining the Wilson coefficients. One can now apply this procedure to the evaluation of processes such as $B_s \rightarrow \phi\phi$ [4]. This process is dominated by QCD penguins and it receives 30% contribution from EW penguins. Its asymmetry, which is expected to be zero in the SM, is largely affected by LRSM with spontaneous CP violation and can be as large as 0.85 depending on the values of the new phases σ_1 and σ_2 . Another example is $B_s \rightarrow \eta\rho^0$. In that case the current-current contribution is CKM-suppressed and the EW penguins dominate. This process was proposed in [10] to measure γ . While the structure of the amplitude in the SM is $A(B_s \rightarrow \eta\rho^0) = A_{CC}e^{-i\gamma} + A_{EW}$, where A_{CC} and A_{EW} are the current-current and EW penguin contributions, respectively, if NP is present an extra piece $A_{NP}e^{-i\phi}$ should be added for each new phase, where A_{NP} is the magnitude of the new contribution and ϕ its phase. Then, in the presence of NP, the asymmetry does not measure anymore $\sin\gamma$ but $\sin\gamma + z\sin\phi$ (for one extra phase), where z is defined by $z = A_{NP}/A_{CC}$. In the case of a LRSM with spontaneous CP violation [4] z can be of order 1 and the two new phases, σ_1 and σ_2 , distort completely the measurement of γ . If the extracted value of γ from a second process differs, that would signal NP.

In conclusion, we have shown that if large departures from the SM are found in the width and mass difference of the B_s^0 system they can be accommodated by a model of LRSM with spontaneous CP violation. Also important effects can be induced in the asymmetries of the decays that are predicted to be zero in the SM such as $B_s \rightarrow \phi\phi$ or in EW penguin-dominated decays such as $B_s^0 \rightarrow \eta^{(\prime)}\rho^0, \phi\rho^0$.

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