SPONTANEOUS CP VIOLATION IN THE LEFT–RIGHT–SYMMETRIC MODEL

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We investigate the pattern of CP violation in K^0–$\bar{K^0}$, B_d^0–$\bar{B_d^0}$ and B_s^0–$\bar{B_s^0}$ mixing in a symmetrical $\mathrm{SU(2)_L}\times\mathrm{SU(2)_R}\times\mathrm{U(1)}$ model with spontaneous CP violation. Performing a careful analysis of all relevant restrictions on the model's parameters from ΔM_K, ΔM_{B_d}, ΔM_{B_s}, ϵ_K, the sign of ϵ'/ϵ and the mixing-induced CP asymmetry in $B_d \to J/\psi K_S$, we find that the mass of the right-handed charged gauge-boson, M_2, is restricted to be in the range 2.75 to 13 TeV, and that the mass of the flavour-changing neutral-Higgs bosons, M_H, must be between 10.2 to 14.6 TeV. We also find that the model, although still compatible with present experimental data, cannot accomodate the SM prediction of large CP violation in $B_d \to J/\psi K_S$, but, on the other hand, predicts a large CP-asymmetry of $\mathcal{O}(40\%)$ in $B_s \to J/\psi\phi$. These specific predictions make it possible to submit the model to a scrupulous test at B factories and hadron colliders.

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1 Introduction

In this talk I report on a recent investigation [1,2] of a non-standard mechanism of CP violation in an attractive extension of the Standard Model (SM), the spontaneously broken left–right–symmetric model.[3] Available data on the mass differences and the measured amount of CP violation in the K and B system seriously constrain the model's parameter space. Even if current theoretical uncertainties persist in the K system, the expected experimental progress in B physics [4] will soon bring conclusive tests of the model in the form of precise values of the CP violating asymmetries in the decays $B_d \to J/\psi K_S$ and $B_s \to J/\psi\phi$, which we predict to sizeably deviate from their SM expectations.

It is well known that CP is a natural symmetry of pure gauge theories with massless fermions. Consequently, CP violation actually probes the least known sector of unified theories, namely the scalar and Yukawa couplings. The current development of dedicated accelerators to probe CP violation in the B system prompts studies of possible departures from the SM. Left–right (LR) symmetric models based on the extended gauge group $\mathrm{SU(2)_L \times SU(2)_R \times U(1)}$ offer the advantage of a well-defined, and actually quite constraining context, largely testable experimentally, while presenting a structure significantly different from the SM. Whereas in general LR models CP violation can come from several sources, we consider here a restricted model which exhibits the aesthetically attractive feature of *spontaneous* CP violation. This means that the Lagrangian exhibits manifest CP symmetry, which at low energies is broken by "misaligned" phases of the symmetry-breaking vacuum expectation value (VEV). In this model, spontaneous breakdown is the *only* source of CP violation. Under this hypothesis, Ecker and Grimus have shown [5] that, except for an exceptional case (which will not be considered here), the Yukawa couplings can be parametrized in terms of two real symmetrical matrices. As a consequence, all CP-violating phases of the model can be be calculated exactly, as they are related to a unique phase (denoted α below) which affects the $\mathrm{SU(2)_L \times SU(2)_R}$ breaking VEV. This point is important, as it links baryogenesis, and in particular the sign of the matter–antimatter asymmetry, to low-energy CP violation.[6]

In practice, the above-defined "Spontaneously Broken Left–Right model" (SB–LR) adds a very economical *four* parameters to the SM: 2 boson masses and 2 parameters describing the VEV that breaks $\mathrm{SU(2)_L \times SU(2)_R}$. Despite being an *extension* of the SM, the SB–LR is in some sense *more restrictive* than the SM itself. Indeed, while the SM is a subset of general LR obtained by sending the R-sector masses to infinity, a similar procedure applied to the SB–LR yields additional constraints since the CKM phase δ is no longer independent, but predicted within the model. To be specific, we find that in the SB–LR δ is too small, $|\delta| < 0.25$ or $|\delta - \pi| < 0.25$, whereas a recent global fit[7] yields $\delta = 1.0 \pm 0.2$. Hence the SM limit of the SB–LR is inconsistent by 3.5σ with current experiments. This has the important consequence that the SB–LR is actually testable, and distinct from the SM: experimental bounds cannot be indefinitely evaded by simply sending the R-sector to infinite masses: scalars and vectors in the range (2–20) TeV are definitely needed.

Experimental constraints on the SB–LR, mainly from the K system, have been thoroughly investigated in the late 80's.[8] Since then, many SM parameters, in particular the CKM angles and the top quark mass, have been measured much more accurately, and also theory has progressed, as exact relations for the CP-violating phases in the quark mixing-matrices have been derived,[9] which supersede the previously used small-phase approximation [10] that breaks down for b decays due to the large top-quark mass. The perspective of finding non-standard CP violation in the B system at the B factories, the Tevatron and the LHC has prompted us to undertake a new comprehensive analysis of restrictions on the SB–LR from available experimental data. The main results can be summarized as follows:

- the role of the Higgs bosons, neglected in most analyses, is crucial;
- the decoupling limit of the model, where the extra boson masses M_2 and M_H are sent to infinity, is experimentally excluded, which implies *upper bounds* on M_2 and M_H;
- neglecting uncertainties of quark masses and CKM angles, the SB–LR favours opposite signs of the CP-violating observables $\mathrm{Re}\,\epsilon$ and $a_{\mathrm{CP}}(B_d \to J/\psi K_S)$, which are both expected to be positive in the SM; hence, the model cannot accommodate both the experimentally measured ϵ and the SM expectation $a_{\mathrm{CP}}^{\mathrm{SM}}(B_d \to J/\psi K_S) \approx 0.75$ and is excluded if a_{CP} will be measured close to its SM expectation;
- the CP asymmetry in $B_s \to J/\psi\phi$, which is negligible in the SM, can be as large as 35% in SB–LR.

2 The Left-Right-Symmetric Model with Spontaneous CP Violation

Before discussing its predictions for CP-violating phenomena, let us explain very shortly the essential features of the SB–LR. As already mentioned, it is based on the gauge group $\mathrm{SU(2)_L}\times\mathrm{SU(2)_R}\times\mathrm{U(1)}$, which cascades down to the unbroken electromagnetic subgroup $\mathrm{U(1)_{em}}$ through the following simple symmetry-breaking pattern:

$$\underbrace{\underbrace{\mathrm{SU(2)_R}\times\mathrm{SU(2)_L}}_{\mathrm{SU(2)_L}}\times\mathrm{U(1)}}_{\mathrm{U(1)_{em}}}$$

The scalar sector is highly model-dependent; for the generation of quark masses, there has to be at least one scalar bidoublet Φ, i.e. a doublet under both SU(2), which, by spontaneous breakdown of $\mathrm{SU(2)_R}\times\mathrm{SU(2)_L}$, acquires the VEV

$$\langle\Phi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} v & 0 \\ 0 & we^{i\alpha}\end{pmatrix}. \tag{1}$$

Here, v and w are real and the phase α is the (only) source of CP violation in the model. The particle content of Φ corresponds to four particles, one analogue of the SM Higgs, two flavour-changing neutral Higgs bosons, and one flavour-changing charged Higgs. The masses of these new Higgs particles can be assumed to be degenerate to good accuracy; they will be denoted by M_H below.

LR symmetry implies that the left-handed quark sector of the SM gets complemented by a right-handed one, with quark mixing matrices V_L and V_R, respectively, and $|V_\mathrm{L}| = |V_\mathrm{R}|$ (but $V_\mathrm{L} \neq V_\mathrm{R}$ due to different complex phases!). In the standard Maiani convention, V_L contains one, V_R five complex phases, which depend on the three generalized Cabibbo-type angles ("CKM angles"), the quark masses, and the VEV (1). The presence of such a large number of weak phases, calculable in terms of only one non-SM variable,[a] is a feature that makes the investigation of CP-violating phenomena in the SB–LR very interesting. The left- and right-handed charged gauge-bosons W_L and W_R mix with each other; the mass eigenstates are denoted by W_1 and W_2. The mixing angle ζ, obtained as

$$\zeta = \frac{2|vw|}{|v|^2+|w|^2}\left(\frac{M_1}{M_2}\right)^2, \tag{2}$$

is rather small: as the ratio $|v|/|w|$ is smaller than 1,[b] one has $\zeta < (M_1/M_2)^2 \sim 10^{-3}$ (assuming M_2 in the TeV range as indicated by the experimental absence of right-handed weak currents). There are, however, arguments according to which a small ratio $|v|/|w| \sim \mathcal{O}(m_b/m_t)$ would naturally explain the observed smallness of the CKM angles;[11] in this case, $\zeta \sim 10^{-5}$. An experimental bound on ζ can in principle be obtained from the upper bound on the electromagnetic dipole moment of the neutron, which is induced by L–R mixing; existing theoretical calculations are, however, very sensitive to the precise values of only poorly known nucleon matrix elements;[12c] the present status of an experimental bound on ζ is thus not quite clear, although large values of $\zeta \sim 10^{-4}$ appear to be disfavoured.

The fact that the SB–LR has no perceptible impact on SM tree-level amplitudes (no experimental indication of right-handed weak interactions or large flavour-changing neutral currents!) implies that the new boson masses must be in the TeV range. The SB–LR effects thus manifest themselves mostly in

- W_L–W_R mixing in top-dominated penguin diagrams, enhanced by large quark-mass terms from spin-flips, $\zeta \to \zeta\, m_t/m_b$ (similar for penguins with charged-Higgs particles);

- SM amplitudes that are forbidden or heavily suppressed (e.g. electromagnetic dipole moment of the neutron);

[a] I.e. the variable β introduced in the next section; note also that there is a 64-fold discrete ambiguity of the phases due to the *signs* of the quark masses, which are physical in LR models.

[b] Which can always be achieved by a redefinition of the Higgs bidoublet $\Phi \to \sigma_2\Phi^*\sigma_2$.

[c] In addition, the Higgs contributions to the dipole moment are usually not included.

- mixing of neutral K and B mesons, where the suppression factor $(M_1/M_2)^2$ is partially compensated by large Wilson-coefficients or hadronic matrix-elements (chiral enhancement in K mixing), and to which the flavour-changing Higgs bosons contribute at tree level.

The SB–LR does, however, *not* significantly modify the decay amplitudes of the "gold-plated" decay mode $B_d \to J/\psi K_S$ or the decay $B_s \to J/\psi\phi$:[d] these decays are dominated by one single CKM amplitude ($b \to ccs$) with contributions from colour-suppressed tree and penguin-topologies with internal c or t quarks. The "gold-plated" mode $B_d \to J/\psi K_S$ is the standard example for a special type of decays of a neutral B meson into a CP-eigenstate, whose time-dependent CP-asymmetry takes a particularly simple form and allows the direct extraction of a weak CKM phase without hadronic uncertainties:

$$\mathcal{A}_{\rm CP}(B_d \to J/\psi K_S) = \frac{\Gamma(t) - \overline{\Gamma}(t)}{\Gamma(t) + \overline{\Gamma}(t)} = \sin\phi_{\rm weak}\, \sin\Delta M_d t, \tag{3}$$

where $\overline{\Gamma}(t)$ denotes the decay-rate of $\bar{B}_d^0(t) \to J/\psi K_S$ and ΔM_d is the mass-difference in the B_d^0–$\bar{B}_d^0$ system. The LR contribution to the tree-topology is given by W_L–W_R mixing, W_R or neutral-Higgs exchange and suppressed by $\sim (M_1/M_2)^2 \sim 10^{-3}$ or more with respect to the SM contribution. As for the penguins, internal W_R or charged-Higgs exchange are suppressed by the same order of magnitude as for the tree-topology, and the only potentially relevant contribution comes from W_L–W_R mixing: the corresponding top-penguin topology is enhanced by a spin-flip factor $\sim \zeta m_t/m_b$, which is at most 5% in the most unfavourable case $|v|/|w| = 1$ and in the range of permille for the preferred value $|v|/|w| \sim \mathcal{O}(m_b/m_t)$. Consequently, the SB–LR contributions to the amplitudes of the "gold-plated" B decays are small and do neither scratch the lustre of the golden plates nor yield sizeable direct CP violation:[e] the main impact of the model on these decays is from B–$\overline{\rm B}$ mixing and modifies the extracted value of the weak phase $\phi_{\rm weak}$. Sizeable LR-effects on amplitudes are, however, to be expected in theoretically less "clean" channels like $B_d \to \pi\pi$ and $b \to s\gamma$.

3 Phenomenological Analysis

As mentioned above, the main impact of the SB–LR on channels with available experiemental data is to modify the SM pattern of neutral K and B meson mixing. The relevant quantity to be calculated is the matrix-element

$$\langle M^0 \mid \mathcal{H}_{\rm eff}^{|\Delta F|=2} \mid \bar{M}^0 \rangle = 2 m_M M_{12}$$

with the effective weak Hamiltonian $\mathcal{H}_{\rm eff}^{|\Delta F|=2}$. Experimental observables which restrict SB–LR contributions to $M_{12}^{B,K}$ are

$$\Delta M_{B,K} = 2\left|M_{12}^{B,K}\right|, \quad \epsilon_K \approx \frac{1}{2\sqrt{2}}\, e^{i\pi/4}\, \sin(\arg M_{12}^K), \quad a_{\rm CP}(B_d \to J/\psi K_S) = \sin(\arg M_{12}^{B_d}). \tag{4}$$

In addition, we also consider constraints posed by the smallness of direct CP violation in the K system encoded in the value of ϵ'/ϵ, but in view of the theoretical uncertainties associated with this observable [13] we only require the *sign* of ϵ'/ϵ to be correctly reproduced. $|M_{12}^K|$ is affected by long-distance QCD uncertainties which are also present in the SM, so that in our analysis, instead of attempting a full calculation of that quantity, we impose the reasonable requirement that SB–LR effects be smaller than the experimental mass difference: $2|M_{12}^{K,SB-LR}| < \Delta M_K$. The quantities $\arg M_{12}^K$ and M_{12}^B, on the other hand, are short-distance dominated and can be reliably calculated in the SB–LR. For the technicalities I refer to Ref. [1]; here I only specify the set of SM input parameters,[f]

$$\begin{aligned}
\overline{m}_t(\overline{m}_t) &= 170\,{\rm GeV}, & \overline{m}_b(\overline{m}_b) &= 4.25\,{\rm GeV},\\
\overline{m}_c(\overline{m}_c) &= 1.33\,{\rm GeV}, & \overline{m}_s(2\,{\rm GeV}) &= 110\,{\rm MeV},\\
m_s/m_d &= 20.1, & m_u/m_d &= 0.56,\\
|V_{us}| = 0.2219, &\quad |V_{ub}| = 0.004, & |V_{cb}| &= 0.04,
\end{aligned} \tag{5}$$

[d] Recall that, in the SM and using the standard "generalized Wolfenstein parametrization" of the CKM matrix, the amplitudes of these decays carry only small or zero weak phases and the CP-violating asymmetry is essentially given by the B–$\overline{\rm B}$ mixing-phase.

[e] Which would show up as terms in $\cos\Delta M_d t$ in (3).

[f] Note that we do not take into account uncertainties associated with these parameters.

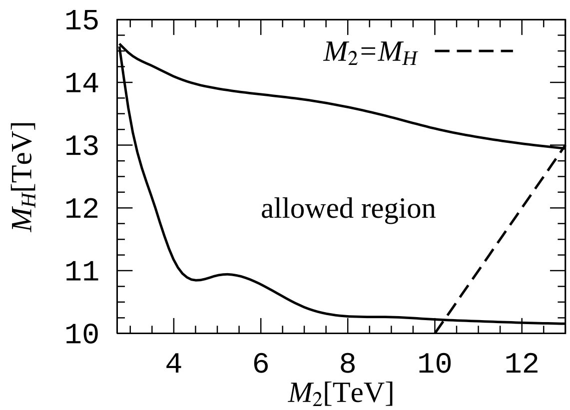

Figure 1: Allowed region in (M_2, M_H).

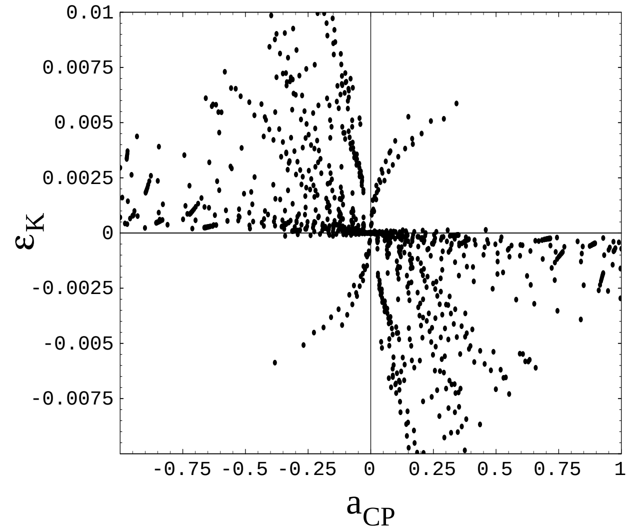

Figure 2: Allowed values of ϵ_K and $a_{\rm CP}(B_d \to J/\psi K_S)$.

and remind that M_{12} depends in addition on the SB–LR parameters M_2, M_H and, as shown in Ref. [9], the variable β defined as

$$\beta = \arctan\frac{2|wv|\sin\alpha}{|v|^2-|w|^2}\,. \tag{6}$$

The combined analysis of the experimental data on $\Delta M_{K,B_d,B_s}$, ϵ_K, the sign of ϵ'/ϵ and $a_{\rm CP}^{\rm exp}(B_d \to J/\psi K_S) = -0.79^{+0.44}_{-0.41}$ (see the talk [14]) yields the allowed region for M_2 and M_H shown in Fig. 1 and the correlations between values of $a_{\rm CP}$ and ϵ_K shown in Fig. 2. The evident preference of the SB–LR for *opposite* signs of $a_{\rm CP}$ and ϵ_K, which is in contradiction to experiment at 98% CL,[14] actually helps to resolve the 64-fold discrete ambiguity of the CKM phases mentioned in the previous section: only *one* of these 64 solutions can reproduce a positive ϵ_K compatible with the experimental result *and* $a_{\rm CP} > 0$. The resulting value of $a_{\rm CP}$ is, however, rather smallish, $a_{\rm CP} < 0.1$, and at variance with the SM expectation $a_{\rm CP}^{\rm SM} \approx 0.75$, but in agreement with the present experimental result within 2σ. I thus quote as a first specific and testable prediction of the SB–LR:

$$\boxed{a_{\rm CP}^{\rm SB-LR}(B_d \to J/\psi K_S) < 0.1 \Longleftrightarrow a_{\rm CP}^{\rm SM}(B_d \to J/\psi K_S) \approx 0.75}$$

With the parameters M_2, M_H and β being constrained, we can now predict the allowed range for mixing-induced CP violation in the B_s system. In the simple case of $b \to ccs$ dominated $B_s \to f$ transitions into a final state f that is a CP eigenstate (e.g. $f = D_s^+D_s^-$, $J/\psi\eta(')$), the CP asymmetry is completely analogous to the $B_d \to J/\psi K_S$ case:

$$a_{\rm CP}(B_s \to D_s^+D_s^-, J/\psi\eta(')) = \sin(\arg M_{12}^{B_s});$$

the corresponding correlation with $a_{\rm CP}(B_d \to J/\psi K_S)$ is plotted in Fig. 3(a). The situation is a bit more complicated for the decay $B_s \to J/\psi\phi$, as here the final state is a superposition of CP-even and odd states. The standard time-dependent CP asymmetry as defined in (3) does now contain poorly known hadronic matrix-elements. These can, in principle, be extracted by an analysis of the angular correlations between the observed decay products $(J/\psi \to)\ell^+\ell^-$ and $(\phi \to)K^+K^-$ [15]. Such an analysis requires, however, large statistics and is probably possible only at the LHC.[4]

In Fig. 3(b), we show the correlation between the B_s^0–$\overline{B_s^0}$ mass and width difference $\Delta\Gamma_s$ in the SB–LR. The reduction of $\Delta\Gamma_s$ through new-physics effects is not very effective in this case, whereas the mass difference ΔM_s may be reduced significantly. Although, at first glance, values of ΔM_s as small as $0.55\Delta M_s^{\rm SM}$ may seem to be at variance with the experimental bound $\Delta M_s > 14.3\,{\rm ps}^{-1}$ at 95% CL [16], this is actually not the case: with the hadronic parameters from [17] and $|V_{ts}| = 0.04$ with the generalized Cabibbo-angles fixed from (5), one has the theoretical prediction (see [1], e.g., for the full formula)

$$\Delta M_s^{\rm SM} = (14.5 \pm 6.3){\rm ps}^{-1}.$$

Combining this with the experimental bound, one has

$$\frac{\Delta M_s^{\rm LR}}{\Delta M_s^{\rm SM}} > \frac{14.3}{14.5 + 2 \times 6.3} = 0.53.$$

A pattern of B_s mass and decay width differences like that emerging in the SB–LR would be in favour of experimental studies of the B_s decays at hadron machines, where small values of ΔM_s and large values of $\Delta\Gamma_s$ would be desirable.

Let us finally illustrate the CP-violating asymmetry of the decay $B_s \to J/\psi\,\phi$:

$$\mathcal{A}_{\rm CP}(B_s(t) \to J/\psi\,\phi) \equiv \frac{\Gamma(t) - \overline{\Gamma}(t)}{\Gamma(t) + \overline{\Gamma}(t)} = \left[\frac{1-D}{F_+(t) + DF_-(t)}\right] \sin(\Delta M_s t)\, \sin(\arg M_{12}^{B_s}), \tag{7}$$

where $\Gamma(t)$ and $\overline{\Gamma}(t)$ denote the time-dependent rates for decays of initially, i.e. at $t = 0$, present B_s^0 and $\overline{B_s^0}$ mesons into $J/\psi\,\phi$ final states, respectively. The remaining quantities are defined as

$$D \equiv \frac{|A_\perp(0)|^2}{|A_0(0)|^2 + |A_\parallel(0)|^2}\,, \tag{8}$$

and

$$F_\pm(t) \equiv \frac{1}{2}\left[\left(1 \pm \cos(\arg M_{12}^{B_s})\right) e^{+\Delta\Gamma_s t/2} + \left(1 \mp \cos(\arg M_{12}^{B_s})\right) e^{-\Delta\Gamma_s t/2}\right]. \tag{9}$$

Here $A_0(t)$, $A_\perp(t)$ and $A_\parallel(t)$ are linear polarization amplitudes that describe the CP-even and odd final-state configurations [18]. Note that we have $F_+(t) = F_-(t) = 1$ for a negligible width difference $\Delta\Gamma_s$. Obviously, the advantage of the "integrated" observable (7) is that it can be measured *without* performing an angular analysis and is thus accessible at HERA-B and Tevatron Run II. The disadvantage is of course that it also depends on the hadronic quantity D, which precludes a theoretically clean extraction of $\arg M_{12}^{B_s}$ from (7). However, this feature does not limit the power of this CP asymmetry to search for indications of new physics, which would be provided by a sizeable measured value of (7). Model calculations of D, making use of the factorization hypothesis, typically give $D = 0.1 \ldots 0.5$ [15], which is also in agreement with a recent analysis of the $B_s \to J/\psi\,\phi$ polarization amplitudes performed by the CDF collaboration [19]. A recent calculation of the relevant hadronic form factors from QCD sum rules on the light-cone [20] yields $D = 0.33$ in the factorization approximation. Consequently, the CP-odd contributions proportional to $|A_\perp(0)|^2$ may have a significant impact on (7). In Fig. 3(c), we plot this CP asymmetry as a function of t, for fixed values of $D = 0.3$, $\sin\arg M_{12}^{B_s} = -0.38$, $\Delta\Gamma_s/\Gamma_s = -0.14$ and $\Delta M_s = 14.5\,{\rm ps}^{-1}$. Although the B_s^0–$\overline{B_s^0}$ oscillations are very rapid, as can be seen in this figure, it should be possible to resolve them experimentally, for example at the LHC. The first extremal value of (7), corresponding to $\Delta M_s t = \pi/2$, is given to a very good approximation by

$$A_{\rm CP}(B_s \to J/\psi\,\phi) = \left(\frac{1-D}{1+D}\right) \sin(\arg M_{12}^{B_s}), \tag{10}$$

which would also fix the magnitude of the $B_s \to J/\psi\,\phi$ CP asymmetry (7) in the case of a negligible width difference $\Delta\Gamma_s$. In Fig. 3(d), we show the prediction of the SB–LR for (10) as a function of the hadronic parameter D. For a value of $D = 0.3$, the CP asymmetry may be as large as -25%. The dilution through the hadronic parameter D is not effective in the case of the CP-violating observables of the $B_s \to J/\psi[\to l^+l^-]\,\phi[\to K^+K^-]$ angular distribution, which allow one to probe $\sin(\arg M_{12}^{B_s})$ directly. I thus quote as a second specific and testable prediction of the SB–LR:

$$\boxed{a_{\rm CP}^{\rm SB-LR}(B_s \to J/\psi\phi) \approx -(10-40)\% \Longleftrightarrow a_{\rm CP}^{\rm SM}(B_s \to J/\psi\phi) \sim 10^{-2}}$$

4 Summary

In this talk I have presented a detailed investigation of the present status of the left–right symmetrical model with spontaneous CP violation, based on the gauge group $\mathrm{SU(2)_L \times SU(2)_R \times U(1)}$. The parameter space of this model includes the masses of the predominantly right-handed charged gauge boson, M_2, and of FC neutral and charged Higgs bosons, which we have assumed to be degenerate with a common mass M_H. Also included are the parameter β, which measures the size of the VEV of the Higgs bidoublet Φ that characterizes the spontaneous breakdown of CP symmetry, and the 64-fold discrete ambiguity of the CKM phases due to different quark mass signatures. In contrast to previous publications, in which the constraints on the model from K and B physics were treated separately, our paper[1] is the first one to consider them in a coherent way and to use the exact results for the CKM phases instead of the small phase approximation. We have concentrated on experimental constraints imposed by the mass differences $\Delta M_{K,B}$ and observables describing CP violation, i.e. ϵ_K, ϵ'/ϵ and $a_{\rm CP}(B_d \to J/\psi K_S)$. In view of the large theoretical uncertainties, we only use the sign, but not the absolute value of Re (ϵ'/ϵ) as a constraint, and we do not use the electric dipole moment of the neutron. Our main finding is that, although the K and B constraints can be met *separately* by a large range of input parameters, it is their *combination* that severely restricts the model. We find in particular that the CP violating observables ϵ_K and $a_{\rm CP}(B_d \to J/\psi K_S)$ are crucial: the sets of input parameters that pass the constraints imposed by the meson mass differences $\Delta M_{K,B}$ yield to a large majority *opposite signs* of ϵ_K and $a_{\rm CP}(B_d \to J/\psi K_S)$.

We have also performed an analysis of mixing-induced CP-violating effects in $B_s \to D_s^+ D_s^-$, $J/\psi\, \eta^{(\prime)}$, $J/\psi\, \phi$ decays and have demonstrated that the corresponding CP asymmetries may be as large as $\mathcal{O}(40\%)$, whereas the SM predicts vanishingly small values. Since the decay amplitudes of these modes are not significantly affected in the SB–LR, direct CP violation remains negligible, as in the SM. From an experimental point of view, $B_s \to J/\psi\, \phi$ is a particularly promising mode, which is very accessible at B physics experiments at hadron machines. We have proposed a simple strategy to search for indications of new physics in this transition, which does not require an angular analysis of the $J/\psi[\to l^+ l^-]$ and $\phi[\to K^+ K^-]$ decay products. In contrast to the large mixing-induced CP asymmetries in the B_s channels, the SB–LR predicts a small value for $a_{\rm CP}(B_d \to J/\psi K_{\rm S})$ below 10%. Since the B_s decays cannot be explored at the asymmetric e^+–e^- B factories operating at the $\Upsilon(4S)$ resonance, such a pattern would be in favour of hadronic B experiments. We look forward to experimental data to check whether this scenario is actually realized by Nature.

We would like to stress that our study does not claim to be exhaustive as we did not allow the most crucial SM input parameters, the CKM angles and quark masses, to float within their presently allowed ranges. Taking into account these uncertainties would certainly affect the phases of the CKM matrices and thus mainly show up in the CP violating observables, which, as we have shown, are crucial. It is therefore not to be excluded that an analysis of the input parameter uncertainties would result in increasing the viable LR parameter ranges, but we doubt that it will change the anticorrelation between the signs of ϵ_K and $a_{\rm CP}(B_d \to J/\psi K_S)$ which implies a small maximum value of $a_{\rm CP}^{\rm SB-LR}(B_d \to J/\psi K_S)$ attainable in the model.

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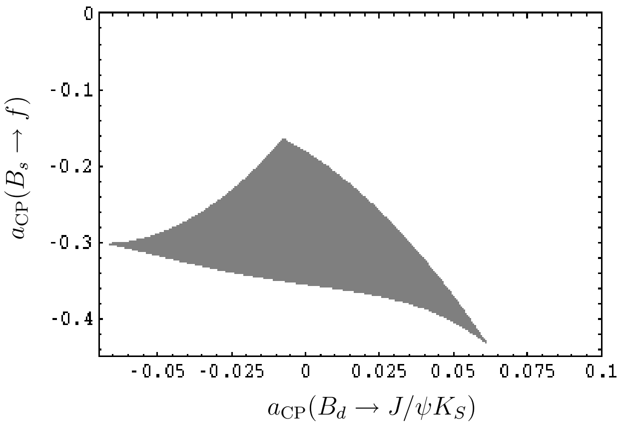
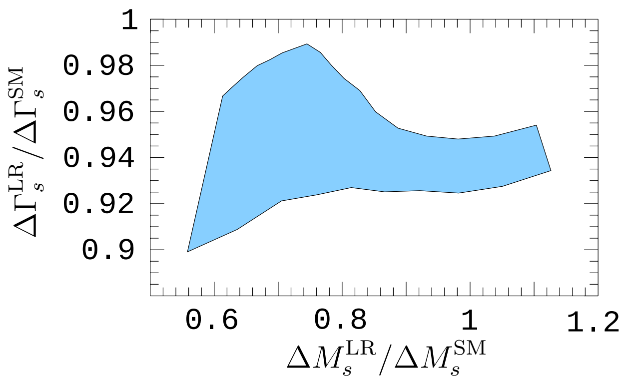
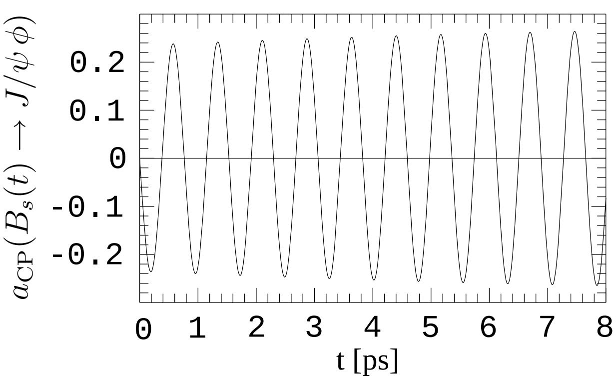


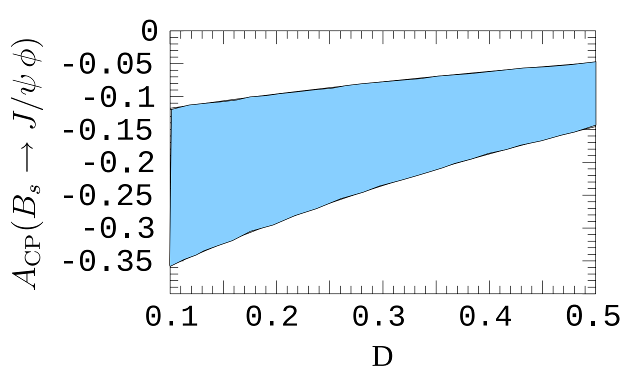
(a) Allowed values for $a_{\mathrm{CP}}(B_d \to J/\psi K_{\mathrm{S}})$ and $a_{\mathrm{CP}}(B_s \to f)$, with $f = D_s^+ D_s^-$, $J/\psi\,\eta^{(\prime)}$.



(b) Correlation between ΔM_s and $\Delta\Gamma_s$, normalized to their SM values.



(c) The time-dependent CP-asymmetry $a_{\mathrm{CP}}(B_s(t) \to J/\psi\phi)$.



(d) $A_{\mathrm{CP}}(B_s \to J/\psi\phi)$ as a function of the hadronic parameter D.

Figure 3: Predictions of the left-right symmetric model for several CP observables in B_s decays.