Supersymmetric origin of a low $a_{J/\psi}$ CP asymmetry

A. Masiero and M. Piai
SISSA – ISAS, Via Beirut 4, I-34013 Trieste, Italy
and INFN, Sezione di Trieste, Trieste, Italy

O. Vives
Departament de Física Teòrica and IFIC, Universitat de València–CSIC, E-46100 Burjassot, Spain
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We show that general minimal supersymmetric extensions of the standard model (MSSM) allow for a CP asymmetry in $B\rightarrow J/\psi K_S$ well below the SM expectations with dominant supersymmetric contributions to ε_K and ε'/ε. Indeed, we provide an explicit example of an MSSM with nonuniversal soft breaking terms fully consistent with the low results of this asymmetry recently announced by BaBar and Belle Collaborations.

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The strong implications of the presence of generic supersymmetric (SUSY) soft-breaking terms in flavor changing neutral current (FCNC) and CP violation phenomena were readily realized in the early 1980s with the beginning of the SUSY phenomenological studies. The need of an analogue of the Glashow-Iliopoulos-Maiani mechanism in the scalar sector to suppress too large SUSY contributions to K^0-$\bar{K}^0$ mixing was emphasized [1] and this showed the large potentiality of looking for SUSY signals in FCNC and CP violation experiments. Still, the existence of a single experimental measure of CP violation in nature, namely, indirect CP violation in kaon mixing ε_K, made it impossible to distinguish between a pure Cabibbo-Kobayashi-Maskawa (CKM) origin of CP violation or a large supersymmetric (or more generally new physics) contribution. The actual possibility of disentangling these two options arises with the comparison of different CP violating processes. Especially, the CP asymmetries in B^0 decays to be measured in the B factories and the improvement of electric dipole moment constraints can play a very important role in accomplishing this objective.

Recently, the arrival of the first results of B^0 CP asymmetries from B factories has caused a lot of excitement in the high energy physics community:

$$a_{J/\psi}=\begin{cases} 0.12\pm0.37\pm0.09 & \text{(BaBar [2])}\\ 0.45^{+0.43+0.07}_{-0.44-0.09} & \text{(Belle [3])}\\ 0.79^{+0.41}_{-0.44} & \text{(CDF [4]).}\end{cases} \tag{1}$$

As it is clear from Eq. (1), the errors are still too large to draw any firm conclusion. In any case, the BaBar and Belle results seem to indicate a lower value than the standard model (SM) expectations corresponding to $0.59\leqslant\sin(2\beta)\leqslant0.82$. Several works in the literature discussed the possible implications of this small CP asymmetry [5,6] and pointed out two possibilities. A small asymmetry can be due to a large new physics contribution in the B system and/or to a new contribution in the kaon system, modifying the usual determination of the unitarity triangle.

In a recent paper [6], two of us proved that, in generic minimal supersymmetric extensions of the standard models (MSSMs), it is more natural to expect large SUSY contributions to FCNC and CP-violating observables in the kaon rather then in the B system, unless additional flavor structures thoroughly different from the fermionic couplings are present in the sfermionic sector.[1] In this work we bring those considerations to their consequences for $a_{J/\psi}$: we show that in nonuniversal MSSM it is realistic to reproduce the CP violation in the kaon system through SUSY effects, while being left with a small $a_{J/\psi}$ in the B system. Indeed the role of the CKM phase could be confined to the SM fit of the charmless semileptonic B decays and B^0_d-$\bar{B}^0_d$ mixing, while dominantly attributing to SUSY the K CP violation (ε_K and ε'/ε). In this case the CKM phase can be quite small, hence leading to a low $a_{J/\psi}$ CP asymmetry.

Although these results are quite general [6,8–10], to make our point more explicit we prefer to discuss a concrete example based on type-I [11] string theory and, just for the sake of clearness, we take a real CKM matrix.

We use the model defined in [10] where soft scalar masses for quark doublets and the Higgs fields are all universal at $M_{\rm GUT}$,

$$m^2_{Q_i}=m^2_{3/2}(1-\tfrac{3}{2}\cos^2\theta(1-\Theta^2_1)), \tag{2}$$

while the soft scalar masses for quark singlets are nonuniversal

$$m^2_{D_i}=m^2_{3/2}(1-3\cos^2\theta\Theta^2_i), \tag{3}$$

in terms of θ and Θ_i which are goldstino angles with the constraint, $\Sigma\Theta^2_i=1$, and $m_{3/2}$ the gravitino mass.[2]

In this basis of diagonal sfermion masses, the Yukawa matrices are not diagonal and they can be written as $v_1 Y_d$

[1] Still, even in the absence of additional flavor structures, SUSY loops can modify the SM contributions proportional to CKM elements. However, these changes are relatively small in a grand unified theory (GUT) defined MSSM once we take into account all the relevant constraints [7].

[2] The complementary situation with nonuniversal doublets and universal singlets or the complete nonuniversal picture are also perfectly possible. In the literature, the case where large flavor-independent soft phases may give a dominant contribution to CP violation has been discussed in [12].

$=K^{D_L\dagger}\cdot M_d\cdot K^{D_R}$ and $v_2 Y_u=K^{U_L\dagger}\cdot M_u\cdot K^{U_R}$, with $K^{U_L\dagger}\cdot K^{D_L}=K_{\rm CKM}$. For definiteness we take the Yukawa matrices to be Hermitian such that $K^{D_R}=K^{D_L}$ and $K^{U_R}=K^{U_L}$. Moreover, as announced in the Introduction, we take $K_{\rm CKM}$ to be completely real. These matrices, K^{D_L} and K^{U_L}, are completely unknown unitary matrices, nevertheless, as discussed in [6,13], given the smallness of CKM mixings, it is natural to expect that Yukawa matrices are strongly hierarchical. Then we may take as a typical situation the case where the mixings in both K^{D_L} and K^{U_L} are of the same order as the mixings in $K_{\rm CKM}$. Notice that, in general, these matrices can have a different structure, however, a Cabibbo-like mixing between the first two generations is required to reproduce the CKM matrix, and this is indeed the key ingredient in our discussion. This feature will be shared by any other texture and, as shown in [6] other mixings have a smaller effect. In any case, given that now $K^{D(U)_L}$ measures the flavor misalignment among $d(u)_L-\tilde{Q}_L$ and we have already used the rephasing invariance of the quarks to make $K_{\rm CKM}$ real, it is evident that we can expect new observable (unremovable) phases in the quark-squark mixings [14], and in particular in the first two generation sector, i.e.,

$$K^{D_L}=\begin{pmatrix} 1-\lambda^2/2 & \lambda e^{i\alpha} & A\rho\lambda^3 e^{i\beta} \\ -\lambda e^{-i\alpha} & 1-\lambda^2/2 & A\lambda^2 e^{i\gamma} \\ A\lambda^3(e^{-i(\alpha+\gamma)}-\rho e^{-i\beta}) & -A\lambda^2 e^{-i\gamma} & 1 \end{pmatrix} \tag{4}$$

to $\mathcal{O}(\lambda^4)$ and A, ρ the usual parameters in the Wolfenstein parametrization (with $\eta=0$) with both them being $\mathcal{O}(1)$.

Following Ref. [6] it is straightforward to estimate the right-right (RR) mass insertion (MI) as

$$(\delta^d_R)_{ij}=\frac{1}{m^2_{\tilde{q}}}\big((m^2_{\tilde{D}_2}-m^2_{\tilde{D}_1})K^{D_L}_{i2}K^{D_L}_{j2}{}^* + (m^2_{\tilde{D}_3}-m^2_{\tilde{D}_1})K^{D_L}_{i3}K^{D_L}_{j3}{}^*\big). \tag{5}$$

However, due to the gluino dominance in the squark eigenstates at M_W we can say that $m^2_{\tilde{q}}(M_W)\approx 6m^2_{\tilde{g}}(M_{\rm GUT})$. In this model [10], the gluino mass at $M_{\rm GUT}$ is given by $m^2_{\tilde{g}}=3m^2_{3/2}\sin^2\theta$. Replacing these values in Eq. (5) this means, for the kaon system,

$$(\delta^d_R)_{12}\simeq\frac{\cos^2\theta(\Theta_1^2-\Theta_2^2)}{6\sin^2\theta}K^{D_L}_{12}K^{D_L}_{22}{}^* + \frac{\cos^2\theta(\Theta_1^2-\Theta_3^2)}{6\sin^2\theta}K^{D_L}_{13}K^{D_L}_{23}{}^* \simeq\frac{\cos^2\theta(\Theta_1^2-\Theta_2^2)}{6\sin^2\theta}\lambda e^{i\alpha}. \tag{6}$$

This value has to be compared with the MI bounds required to saturate ε_K [15], that in this case are, $\mathrm{Im}(\delta^d_R)^{\rm bound}_{12}\leqslant 0.0032$. Taking $\theta\simeq 0.7$ as in [10] we get

$$(\delta^d_R)_{12}\simeq 0.035(\Theta_1^2-\Theta_2^2)\sin\alpha\lesssim 0.0032. \tag{7}$$

Hence, it is clear that we can easily saturate ε_K without fine tuning. Similarly, it is already well known [6,10,13,16] that these models can analogously saturate ε'/ε. In summary, we have explicitly shown that a generic MSSM can fully saturate the observed CP violation in the kaon system.

Now we turn to the CP asymmetries in the B system. Once more, with Eq. (5) we have

$$\begin{aligned}(\delta^d_R)_{13}&\simeq\frac{\cos^2\theta(\Theta_2^2-\Theta_1^2)}{6\sin^2\theta}K^{D_L}_{12}K^{D_L}_{32}{}^* + \frac{\cos^2\theta(\Theta_3^2-\Theta_1^2)}{6\sin^2\theta}K^{D_L}_{13}K^{D_L}_{33}{}^*\\ &\simeq A\lambda^3\frac{\cos^2\theta}{6\sin^2\theta}\big(-(\Theta_2^2-\Theta_1^2)e^{i(\alpha+\gamma)}+(\Theta_3^2-\Theta_1^2)\\ &\quad\times(e^{-i(\alpha+\gamma)}-\rho e^{-i\beta})\big)\\ &\lesssim 10^{-3},\end{aligned} \tag{8}$$

to be compared with the MI bound $(\delta^d_R)^{\rm bound}_{13}\leqslant 0.098$ required to saturate the B^0 mass difference. Something similar can be done in this case for the left-right (LR) sector [6]. This implies that the SUSY contribution to $a_{J/\psi}$ is necessarily very small. Hence, due to the absence of any phase in the CKM mixing matrix, the conclusion is that the CP asymmetry in the $B\to J/\psi K_S$ decays will be very small in this extreme (nonrealistic) situation with real CKM. It is very interesting to check the consequences of this picture in other observables, as for instance rare kaon decays [17,18]. Clearly this extreme situation should be modified with the inclusion of an additional phase in the CKM matrix, in any case, shifting significantly the usual fit of the unitarity triangle.

In conclusion, we showed that general MSSM schemes allow for a significantly small $a_{J/\psi}$ CP asymmetry (in agreement with the present B factories central values), with the observed CP violation in the kaon system largely due to new SUSY phases.

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