NEW PHYSICS IN CP-VIOLATING OBSERVABLES FOR BEAUTY

J.Bernabéu

Department of Theoretical Physics and IFIC,
University of Valencia and CSIC

Abstract

After the present establishment of CP-Violation in B_d-physics, consistency tests of unitarity in the Standard Model and the search of new phenomena are compulsory. I illustrate the way to look for T-violation, without contamination of absorptive parts, in correlated decays in B-factories. B_s-mixing and penguin-mediated B_s-decays are of prime importance in hadronic machines to look for new physics.

1 Introduction

As exemplified by the presentations of this 2002 edition of the "Beauty" Conference, CP violation is currently the focus of a great deal of attention. The results of the B-factories [1] measure $\sin(2\beta)$, where β is the CP-phase between the top and charm sides of the (bd) unitarity triangle [2]. To within the experimental sensitivity, the CKM mechanism [3] of the standard theory is verified. In this description, all the CP-violating observables depend on a unique phase in the quark mixing matrix. Any inconsistency between two independent determinations of the CP-phase is an indication for new physics. Two main reasons for the search of new physics in CP-violating observables are:

i) The dynamic generation of the baryonic asymmetry in the Universe requires CP-violation, and its magnitude in the standard model looks insufficient.

ii) Essentially all extensions of the standard model introduce new sectors with additional sources of CP-phases.

The examples that I will consider here to search for new physics are based on the following attitude: the decays dominated by standard model diagrams at tree level with W-exchange allow the extraction of $|V_{ub}|$, $|V_{us}|$ and $|V_{cb}|$. On the contrary, new physics will be apparent in processes which, for the standard model, are described by loop diagrams, like $B_d - \overline{B}_d$ and $B_s - \overline{B}_s$ mixing or penguin amplitudes. In so doing, I will cover cases which are appropriate for B-factories, as well as others which need hadronic machines.

In Section 2 I discuss coherent correlated decays of B_d's in order to build (besides CP-odd asymmetries) T-odd and CPT-odd observables. Section 3 is devoted to temporal asymmetries which need absorptive parts and are a signal of a non-vanishing $\Delta\Gamma$ in B_d decays. In Section 4 I discuss B_s-mixing. The decays $B_s \to J/\psi\phi$ and $B \to \phi K_S$ are presented in Section 5 as ways to search for new physics. Some conclusions are drawn in Section 6.

2 Genuine Asymmetries from Entangled States

In a B-factory operating at the $\Upsilon(4S)$ peak, correlated pairs of neutral B-mesons are produced. This permits the performance of either a flavour tag or a CP tag. To $O(\lambda^3)$, where λ is the Wolfenstein parameter [4] in the quark mixing matrix, the determination of the single B-state is possible and unambiguous [5]. Any final configuration (X,Y), where X,Y are decay channels which are either flavour or CP conserving, corresponds to a single particle mesonic transition. The intensity for the final configuration

$$I(X, Y, \Delta t) \equiv \frac{1}{2} \int_{\Delta t}^{\infty} dt' \, |(X, Y)|^2 \tag{1}$$

is thus proportional to the time dependent probability for the meson transition.

The case (l^+, l^+) associated with the $\overline{B}^o \to B^o$ transition is shown in Figure 1.

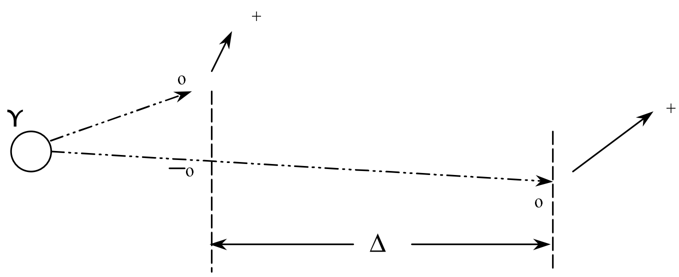

Figure 1: The flavour tag of $\overline{B}^o$ and its decay as B^o after a time Δt.

We consider genuine asymmetries for CP, T and CPT operations, in the sense that a non-vanishing value is a proof of the violation of the symmetry. Two cases are of particular interest:

i) **Flavour-to-flavour transitions**

The final configuration denoted by (l, l), with flavour definite (for example, semileptonic) decays detected on both sides of the detector, corresponds to flavour-to-flavour transitions at the meson level. The equivalence is shown in Table 1. The first two processes in the Table are conjugated under CP and also under T.

The corresponding Kabir asymmetry [6], to linear order in the CPT violating parameter δ of the meson mixing, is given by

$$A(l^+, l^+) \simeq \frac{4\frac{\mathrm{Re}(\varepsilon)}{1+|\varepsilon|^2}}{1 + 4\frac{\mathrm{Re}(\varepsilon)}{1+|\varepsilon|^2}} \tag{2}$$

where ε is the rephasing invariant [7] CP-odd, T-odd parameter in the neutral meson mixing. The asymmetry (2) does not depend on time. However, in the exact limit $\Delta\Gamma = 0$, $\mathrm{Re}(\varepsilon)$ also vanishes and A will be zero. For the B_d

Table 1: Flavour-to-flavour transitions

(X, Y)	Meson Transition
(l^+, l^+)	$\overline{B}^o \to B^o$
	CP, T
(l^-, l^-)	$B^o \to \overline{B}^o \hookleftarrow$
(l^+, l^-)	$\overline{B}^o \to \overline{B}^o$
	CP, CPT
(l^-, l^+)	$B^o \to B^o \hookleftarrow$

system, experimental limits on $\mathrm{Re}(\varepsilon)$ are of few parts in a thousand [8, 9]. A second asymmetry arises from the last two processes in Table 1, related by a CP or a CPT operation.

$$A(l^+, l^-) \simeq -2 \frac{\mathrm{Re}\left(\frac{\delta}{1-\varepsilon^2}\right) \sinh \frac{\Delta\Gamma \Delta t}{2} - \mathrm{Im}\left(\frac{\delta}{1-\varepsilon^2}\right) \sin\left(\Delta m \Delta t\right)}{\cosh \frac{\Delta\Gamma\Delta t}{2} + \cos\left(\Delta m \Delta t\right)} \quad (3)$$

which is an odd function of Δt. This asymmetry also vanishes with $\Delta\Gamma = 0$,

because then $\mathrm{Im}(\delta) = 0$ as well. Present limits on $\mathrm{Im}(\delta)$ are at the level of few percent [8].

One discovers the weakness of these asymmetries to look for T-, and CPT-violation in the B_d-system. The reason is that one needs both the violation of the symmetry and $\Delta\Gamma \neq 0$.

ii) **CP-to-flavour transitions**

Alternative asymmetries can be constructed making use of the CP eigenstates, which can be identified in this system by means of a CP tag. If the first decay product, X, is a CP eigenstate produced along the CP-conserving direction [5], the decay is free of CP violation. If Y is a flavour definite channel, then the mesonic transition corresponding to the configuration (X,Y) is of the type CP-to-flavour.

In Table 2 we show the mesonic transitions, with their related final configurations, connected by genuine symmetry transformations to $B_+ \to B^o$.

Comparing the intensities of the four processes, we may construct three genuine asymmetries, namely A(CP), A(T) and A(CPT) [10]:

$$A(CP) = -2 \frac{\mathrm{Im}(\varepsilon)}{1 + |\varepsilon|^2} \sin(\Delta m \Delta t) + \frac{1 - |\varepsilon|^2}{1 + |\varepsilon|^2} \frac{2\mathrm{Re}(\delta)}{1 + |\varepsilon|^2} \sin^2\left(\frac{\Delta m \Delta t}{2}\right) \quad (4)$$

Table 2: Transitions connected to $(J/\psi K_S, l^+)$

(X,Y)	Transition	Transformation
$(J/\psi K_S, l^-)$	$B_+ \to \overline{B}^o$	CP
$(l^-, J/\psi K_L)$	$B^o \to B_+$	T
$(l^+, J/\psi K_L)$	$\overline{B}^o \to B_+$	CPT

The CP-odd asymmetry, contains both T-violating and CPT-violating contributions, which are, respectively, odd and even functions of Δt. This asymmetry corresponds to the "gold plate" decay [11] and has been measured recently [1]. The result is interpreted in terms of the standard model $\sin(2\beta)$ with neither CPT-violation nor $\Delta\Gamma$ [12]. One finds [7]

$$-\frac{2\mathrm{Im}(\varepsilon)}{1+|\varepsilon|^2} = \sin(2\beta) \tag{5}$$

The two T- and CPT-violating terms in Eq. (4) can be separated out by constructing other asymmetries

$$A(T) = -2\frac{\mathrm{Im}(\varepsilon)}{1+|\varepsilon|^2}\sin(\Delta m\Delta t)\left[1 - \frac{1-|\varepsilon|^2}{1+|\varepsilon|^2}\frac{2\mathrm{Re}(\delta)}{1+|\varepsilon|^2}\sin^2\left(\frac{\Delta m\Delta t}{2}\right)\right] \tag{6}$$

the T-asymmetry needs $\varepsilon \neq 0$ and turns out to be purely odd in Δt in the limit we are considering.

$$A(CPT) = \frac{1-|\varepsilon|^2}{1+|\varepsilon|^2}\frac{2\mathrm{Re}(\delta)}{1+|\varepsilon|^2}\frac{\sin^2\left(\frac{\Delta m\Delta t}{2}\right)}{1-2\frac{\mathrm{Im}(\varepsilon)}{1+|\varepsilon|^2}\sin(\Delta m\Delta t)} \tag{7}$$

is the CPT asymmetry. It needs $\delta \neq 0$ and includes both even and odd time dependences.

The expressions (4), (6) and (7) correspond to the limit $\Delta\Gamma = 0$, but, being genuine observables, a possible absorptive part could not induce by itself a non-vanishing asymmetry.

3 $\Delta\Gamma$ and Non-genuine Asymmetry

The construction of the quantities described above requires to tag both B_+ and B_- states, and thus the reconstruction of both $B \to J/\psi K_S$ and

Table 3: Final configurations with only $J/\psi K_S$

(X,Y)	Transition	Transformation
$(J/\psi K_S, l^+)$	$B_+ \to B^o$	CP
$(l^+, J/\psi K_S)$	$\overline{B}^o \to B_-$	Δt
$(l^-, J/\psi K_S)$	$B^o \to B_-$	$CP\Delta t$

$B \to J/\psi K_L$ decays. One can consider non-genuine asymmetries from $B \to J/\psi K_S$ only: they involve [10] the discrete transformation, denoted by Δt, consisting in the exchange in the order of appearance of decay products X and Y, which cannot be associated with any fundamental symmetry.

Table 3 shows the different transitions we may study from such final states. Besides the genuine CP asymmetry, there are two new quantities that can be constructed from the comparison between $(J/\psi K_S, l^+)$ and the processes in the Table 3.

In the exact limit $\Delta\Gamma = 0$, Δt and T operations, although different (compare the second lines of Tables 2 and 3), are found to become equivalent, so that the temporal asymmetries satisfy $A(\Delta t) = A(T)$ and $A(CP\Delta t) = A(CPT)$.

The asymmetries $A(\Delta t)$ and $A(CP\Delta t)$ are non-genuine, so that the presence of $\Delta\Gamma \neq 0$ may induce non-vanishing values for them, even in the absence of true T or CPT violation. These effects can be calculated and are thus controllable. This reasoning leads to an interesting suggestion: **there are linear terms in $\Delta\Gamma$ inducing a non-vanishing asymmetry $\mathbf{A(CP\Delta t)}$**. This last asymmetry is particularly clean, under the reasonable assumption that $A(CPT) = 0$. Explicit calculations [10] show that, even in the limit of perfect symmetry, i.e., $\varepsilon = 0$ besides $\delta = 0$, one finds a non-vanishing $(CP\Delta t)$-asymmetry, given by

$$A(l^-, J/\psi K_S) = \frac{\Delta\Gamma\Delta t}{2}; \quad \varepsilon = \delta = 0 \tag{8}$$

The simple result (8) is modified under the realistic $\varepsilon \neq 0$ situation. One has, if only $\delta = 0$, the result

$$A(l^-, J/\psi K_S) = \frac{1}{1 - \frac{2\mathrm{Im}(\varepsilon)}{1+|\varepsilon|^2}\sin(\Delta m \Delta t)} \tag{9}$$

$$\left\{ \frac{\Delta\Gamma\Delta t}{2} \frac{1-|\varepsilon|^2}{1+|\varepsilon|^2} + \frac{4\mathrm{Re}(\varepsilon)}{1+|\varepsilon|^2} \sin^2\left(\frac{\Delta m \Delta t}{2}\right) - \frac{2\mathrm{Im}(\varepsilon)}{1+|\varepsilon|^2} \frac{2\mathrm{Re}(\varepsilon)}{1+|\varepsilon|^2} \sin(\Delta m \Delta t) \right\}$$

The three terms of Eq. (9) contain different Δt-dependences, so that a good time resolution will allow the determination of the parameters. Taking into account that $\mathrm{Re}(\varepsilon) = x\Delta\Gamma$, all of the three terms are linear in $\Delta\Gamma$. We conclude that the comparison between the channels $(l^-, J/\psi K_S)$ and $(J/\psi K_S, l^+)$ is a good method to obtain information on $\Delta\Gamma$, due to the absence of any non-vanishing difference when $\Delta\Gamma = 0$.

4 B_s Mixing

B^o and $\bar{B}^o$ are not mass eigenstates, so that their oscillation frequency is governed by their mass-difference. The measurement by the UA1 collaboration [13] of a large value of ΔM_d was historically the first indication of the heavy top quark mass. This is so because of non-decoupling effects of the heavy-mass exchange in the Box Diagram. For $B_s - mixing$, it is shown in Figure 2.

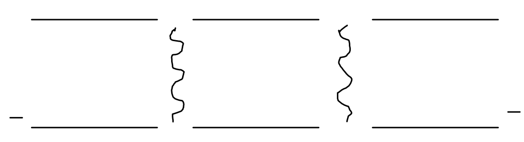

Figure 2: Box Diagram responsible of the neutral meson mixing

To avoid many hadronic uncertainties, it is interesting to consider the ratio between ΔM_s and ΔM_d, given by [14]

$$\frac{\Delta M_s}{\Delta M_d} = \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{M_{Bd}}{M_{Bs}} \xi^2 \tag{10}$$

where $\xi^2 \equiv \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}}$ is the flavour-SU(3) breaking parameter in terms of the meson decay constants and the bag factors. $B_{B_q} = 1$ if one uses a vacuum saturation of the hadronic matrix element. The great advantage of Eq. (10) is that, in the ratio, different systematics in the evaluation of the matrix element tends to cancel out. However, unlike $\Delta M_d = 0.479(12)\ ps^{-1}$, which is measured with a good precision [15], the determination of ΔM_s is an experimental challenge due to the rapid oscillation of the $B_s - system$. At present [15], $\Delta M_s > 13.1 ps^{-1}$, with 95% C.L., but this bound already provides a strong constraint on $|V_{td}|$. The use of QCD spectral sum rules leads to [14].

$$\xi \simeq 1.18 \pm 0.03 \to \Delta M_s \simeq 18.6(2.1)\text{ps}^{-1} \tag{11}$$

in agreement with the present experimental lower bound and within the reach of the proposed experiments.

Ali and London [16] have examined the situation for SUSY theories with minimal flavour violation. In this class of models, the SUSY contributions to ΔM_d and ΔM_s can both be described by a single common parameter f.

$$\Delta M_d = \Delta M_d(SM)[1 + f] \tag{12}$$
$$\Delta M_s = \Delta M_s(SM)[1 + f] \tag{13}$$

The parameter f is positive definite, so that the SUSY contributions add constructively to the SM contributions in the entire allowed supersymmetric parameter space. The size of f depends, in general, on the parameters of the SUSY model. They conclude that, if M_s is measured to be near its lower limit, SUSY with large f is disfavoured.

With respect to the values of the CP phases α, β and γ of the unitarity triangle, the key observation is that a measurement of β will not distinguish among the various values of f, i.e., β is rather independent of f. If one wants to distinguish among the various SUSY models, it will be necessary to measure γ and/or α independently.

Contrary to these SUSY models, in which the ratio $\Delta M_s/\Delta M_d$ remains that of the Standard Model, Left-Right-Symmetric Models with Spontaneous CP Violation modify ΔM_s and ΔM_d with different phases relative to the SM contribution. One has [17]

$$\frac{\Delta M_s}{\Delta M_d} = \frac{\Delta M_s(SM)}{\Delta M_d(SM)} \left| \frac{1 + \kappa e^{i\sigma_s}}{1 + \kappa e^{i\sigma_d}} \right| \tag{14}$$

As a consequence, the ratio is modified with respect to the SM. In Ref. [18], an analysis of the joint constraints imposed by ΔM_K and ΔM_B is performed, with the conclusion that the Left-Right Model favours opposite signs of ϵ_K and $\sin(2\beta)$ and it would be disfavoured for $\sin(2\beta) > 0.1$. A test of the $B_s - mixing$ would be crucial in this context.

5 Two Decays: $B_s \to J/\psi\phi$, $B_d \to \phi K_S$

The general argument of considering CP-Violation in $B_s - mixing$ as a prime candidate for New Physics is well defined. In $B_d \to J/\psi K_S$, the SM amplitudes of mixing (dominated by the virtual top quark) $V_{bt}V_{td}^* \sim \lambda^3$ and decay $V_{bc}V_{cd}^* \sim \lambda^3$ define a relative phase β of the order of one, because the corresponding unitarity triangle satisfies the scales of figure 3.

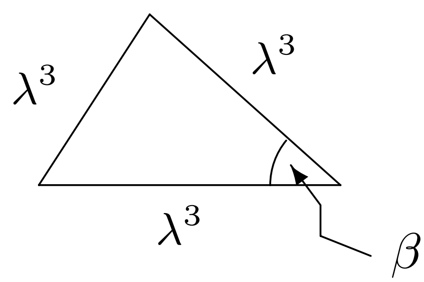

Figure 3: The (bd) unitarity triangle.

Contrary to this standard β, the SM amplitudes for $B_s \to J/\psi\phi$ satisfy that $V_{bt}V_{ts}^* \sim \lambda^2$, $V_{bc}V_{cs}^* \sim \lambda^2$, so that the corresponding unitarity triangle is shown in figure 4 and the relative phase χ is tiny, of the order of λ^2. It does not take much New Physics to change the tiny standard χ!

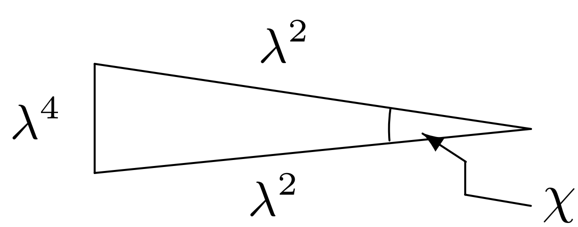

Figure 4: The (bs) unitarity triangle.

In hadronic machines, substantial number of $B_s \to J/\psi\phi$ events are expected. The decay process is described by three Lorentz invariant terms, two

CP-even terms and one CP-odd term. The joint angular distibution with $J/\psi \to l^+l^-$ and $\phi \to K^+K^-$ has been described in Ref. [19], with the aim of separating out the definite CP eigenstates and thus recovering a CP asymmetry free of cancellations.

Following the argument of the Introduction, candidates for New Physics are processes which, in the SM, are described by either mixing or penguin amplitudes in the decay. In Left-Right models, the gluonic penguin contribution to $b \to s\bar{s}s$ transition is enhanced by m_t/m_b due to the presence of right-handed currents. This may overcome the suppression due to small left-right mixing angle. Two new phases [20] in the $B \to \phi K_S$ decay amplitude may therefore modify the time dependent CP asymmetry in this decay mode by O(1). This scenario implies also large CP asymmetry in the decay $B_s \to \phi\phi$ which can be tested in hadronic machines.

6 Conclusions

The prospects for an experimental study of the Flavour Problem in the next coming years are much interesting, from CP-violating observables in B-factories and hadronic machines. The (bd) Unitarity Triangle will be tested, with separate determinations of the CP-phases (α, β, γ), after the present establishment of CP-Violation in B_d -physics.

New phenomena are probably around the corner. Discoveries like T-violation in B-physics, without any contamination of absorptive parts, and sensitive limits (or spectacular surprises) for CPT-violation are expected. Temporal asymmetries in B-decays are a good method to search for linear terms in $\Delta\Gamma/\Gamma$. The intensities $I(l^-,\ J/\psi K_S)$ and $I(J/\psi K_S,\ l^+)$ are predicted to be equal under CPT invariance and $\Delta\Gamma = 0$. Linear terms in $\Delta\Gamma$ induce a non-vanishing asymmetry for this CP Δt transformation.

$B_s - mixing$ is considered to be of prime importance for the search of new physics, particularly in its CP-violating component. Extended models modify the tiny phase between the top and charm sides of the standard (bs) unitarity triangle. The non-decoupling effects of new physics can be put under control by the cancellation of hadronic matrix element uncertainties in the ratio $\Delta M_s/\Delta M_d$. The interest in a detailed analysis of $B_s \to J/\psi\phi$ is apparent in this context.

New physics in penguin-mediated decays, like $B_d \to \phi K_S$ and $B_s \to \phi\phi$, is also expected, with information complementary to that of mixing.

All in all, we can expect a beautiful future in front of us!

Acknowledgements

I would like to thak E. Alvarez, P. Ball, D. Binosi, F.Botella, J. Matias, M.Nebot and J. Papavassiliou for interesting discussions and to the Organizers of ”Beauty 2002” for their invitation to such a beautiful event in Santiago. This work has been supported by the Grant AEN-99/0692 of the Spanish Ministry of Science and Technology.

References

[1] B.Aubert et al., Phys.Rev.Lett. 86(2001) 2515;
B.Abe et al., Phys.Rev.Lett. 87(2001) 091802.

[2] L.-L.Chau, W.-Y.Keung, Phys.Rev.Lett. 53(1984) 1802.

[3] N.Cabibbo, Phys.Rev.Lett. 10(1963) 531;
M.Kobayashi, K.Maskawa, Prog.Theor.Phys. 49(1973) 652.

[4] L.Wolfenstein, Phys.Rev.Lett. 51(1983) 1945.

[5] M.C.Bañuls and J.Bernabéu, JHEP9906 (1999) 032.

[6] P.K.Kabir, The CP Puzzle, Academic Press (1968) 99.

[7] M.C.Bañuls and J.Bernabéu, Phys.Lett. B423 (1998) 151.

[8] K.Ackerstaff et al., Z.Phys. C76 (1997) 401;
F.Abe et al., Phys.Rev. D55 (1997) 2546;
J.Bartelt et al., Phys.Rev.Lett. 71(1993) 1680.

[9] B.Aubert et al., SLAC-PUB-927 (2001), hep-ex/0107059.

[10] M.C.Bañuls and J.Bernabéu, Phys.Lett. B464 (1999) 117;
M.C.Bañuls and J.Bernabéu, Nucl.Phys. B590 (2000) 19.

[11] I.I.Bigi and A.I.Sanda, Nucl.Phys. B193 (1981) 85.

[12] V.Khoze et al., Yad.Fiz. 46 (1987) 181;
A.Acuto and D.Cocolicchio, Phys.Rev. D47 (1993) 3945.

[13] C.Albajar et al., Phys.Lett. B186 (1987) 237, 247.

[14] K.Hagiwara et al., hep-ph/0205092

[15] D.E.Groom et al. (PDG), Euro.Phys. J. C15 (2000) 1

[16] A.Ali and D.London, Eur.Phys. J. C18 (2001) 665.

[17] G.Barenboim, J.Bernabéu and M.Raidal, Nucl.Phys. B511 (1998)577.

[18] P.Ball, J.-M.Frère and J.Matias, Nucl.Phys. B572 (2000) 3.

[19] I.Dunietz et al., Phys.Rev. D43 (1991) 2193.

[20] M.Raidal, hep-ph/0208091.