PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 55, Nos 1 & 2
July & August 2000
pp. 265–270

New physics effects from B meson decays

ANIRBAN KUNDU
Department of Physics, Jadavpur University, Calcutta 700 032, India

Abstract. In this talk, we point out some of the present and future possible signatures of physics beyond the Standard Model from B-meson decays, taking R-parity conserving and violating supersymmetry as illustrative examples. An expanded version is available on hep-ph archive.

Keywords. B-decays; supersymmetry; new physics.

PACS Nos 13.20.He; 13.25.Hw; 12.60.-i

1. Introduction

It has long been established that the B-meson system (both charged and neutral) may be the ideal place to look for indirect effects of physics, both CP-conserving and CP-violating, beyond the Standard Model (BSM) [1]. However, before one proceeds, one must remember that the theoretical uncertainties are still significant, and will probably remain so in the near future [2], which makes it *extremely* difficult to find the signature of BSM physics if that is more than one order of magnitude smaller than the SM contribution.

Fortunately, there are cases when the BSM signal may be equally (or more) large as the SM one, and can be easily distinguished. There are two major ways to proceed.

First, one can look for CP-asymmetries, both direct and mixing-induced, and see whether they tally with the SM predictions. Such investigations involve the measurement of the angles as well as the sides of the unitarity triangle (UT). Here, one may face a number of different situations, some of which are:

(i) The three angles of the UT do not sum up to π.
(ii) The angles do sum up to π, but the sides are not in the proper ratio.
(iii) CP-asymmetries measured from different modes, which should yield the same angle in SM, give different results. For example, $J/\psi K_S$ and ϕK_S modes may produce different CP asymmetries (both should give the same angle β in SM), and one may find nonzero CP-asymmetries in $b \to c$ decay modes of B_s (which, in SM, should not give any significant CP-asymmetry).
(iv) One can observe sizable asymmetries in leptonic, semileptonic and radiative B-decays too.

Secondly, one can concentrate on CP-conserving observables. A good place is the branching ratios (BR) of rare modes. CLEO already has some interesting signals [3] which are listed in table 1; there may be more in near future. Another excellent channel is to look for forbidden modes in the SM (like $B^+ \to K^+K^+\pi^-$ [4]) where even a single event may signal BSM physics. OPAL has looked for such signals and placed limits on BSM couplings [5].

Anyway, we should realize that quantification of BSM physics is something we must approach with caution; qualitative signals are what we can hope to observe quickly. Of course, if BSM physics is indicated from other experiments, then the B-system can be used to complement and quantify that.

In the SM, the quark-level subprocesses that are important to determine the angles of the UT are shown in table 2, which is mainly taken from [6]. It is helpful to remember that $B^0 - \bar{B}^0$ mixing measures 2β, $b \to u$ measures 2γ, presence of both simultaneously measures 2α (assuming the UT closes), and $B_s - \bar{B}_s$ mixing and $b \to c$ decay are CP-conserving to a very good extent. Some of such CP-conserving modes are also shown; a nonzero CP-asymmetry in them (say, in $B_s \to J/\psi\phi$) would be an encouraging signal for BSM physics.

Table 1. Branching ratios ($\times 10^6$) of the ηK and $\eta' K$ modes. The experimental results are at 90% CL.

Mode	Theoretical BR	Experiment
$B^+ \to \eta' K^+$	7–41	$80^{+10}_{-9} \pm 8$
$B^0 \to \eta' K^0$	9–33	$88^{+18}_{-16} \pm 9$
$B^+ \to \eta K^{*+}$	0.03–9	$27.3^{+9.6}_{-8.2} \pm 5.0$
$B^0 \to \eta K^{*0}$	0.05–3	$13.8^{+5.5}_{-4.4} \pm 1.7$

Table 2. Quark-level subprocesses for B-decays. P and V denote pseudoscalar and vector mesons respectively.

No	Quark level	Type	Meson level	Remarks
1	$b \to d\bar{u}u$	P_1P_2	$\bar{B}^0 \to \pi^+\pi^-$	α (penguin pollution)
2	$b \to d\bar{c}c$	P_1P_2	$\bar{B}^0 \to D^+D^-$	β (clean)
3	$b \to d\bar{c}c$	PV	$\bar{B}^0 \to J/\psi\pi^0$	β (penguin pollution)
4	$b \to d\bar{c}c$	PV	$\bar{B}_s \to J/\psi K_S$	$\lambda^2\eta$ (very clean)
5	$b \to s\bar{u}u$	P_1P_2	$\bar{B}^0 \to \pi^0 K_S$	α, γ (not so clean)
6	$b \to s\bar{u}u$	P_1P_2	$\bar{B}_s \to K^+K^-$	γ (clean)
7	$b \to s\bar{c}c$	P_1P_2	$\bar{B}_s \to D_s^+D_s^-$	$\lambda^2\eta$ (very clean)
8	$b \to s\bar{c}c$	PV	$\bar{B}^0 \to J/\psi K_S$	β (gold-plated)
9	$b \to s\bar{c}c$	V_1V_2	$\bar{B}_s \to J/\psi\phi$	CP-conserving
10	$b \to d\bar{s}s$	P_1P_2	$\bar{B}^0 \to K^0\bar{K}^0$	QCD penguin dominates
11	$b \to d\bar{s}s$	PV	$\bar{B}^0 \to \pi^0\phi$	EW penguin dominates
12	$b \to s\bar{s}s$	PV	$\bar{B}^0 \to K_S\phi$	β (clean)
13	$b \to s\bar{d}d$	P_1P_2	$\bar{B}_s \to K^0\bar{K}^0$	QCD penguin
14a	$b \to u\bar{c}s$	P_1P_2	$B^- \to \bar{D}^0K^-$	DK triangles
14b	$b \to c\bar{u}s$	P_1P_2	$B^- \to D^0K^-$	measure γ

2. Possible new physics

In this section, we first briefly review a couple of non-SUSY extensions of the SM, and the results are taken mainly from [7]. Then we discuss two versions of SUSY.

2.1 *Four generations*

With four quark generations, the CKM matrix is 4×4, with three independent phases. This makes UT a quadrangle, and the asymmetries measured by different processes will be different from their SM predictions: for example, the asymmetry measured in $B^0 - \bar{B}^0$ mixing is not only 2β but some $2(\beta + \theta_d)$ due to the t' mediated box.

With four generations, α, β and γ will not sum up to π. Also, $b \to d\gamma$ and $b \to d\ell^+\ell^-$ may be enhanced compared to their SM values depending on the magnitudes of V_{td} and $V_{t'd}$ [8]. CP asymmetry in $B \to J/\psi K_S$ is negative for almost half of the parameter space, and almost 40% of the parameter space predicts the magnitude of CP asymmetry in $B_s \to J/\psi\ \phi$ to be more than 0.2 (the SM asymmetry is almost zero) [9].

2.2 *Multi-Higgs doublet with no FCNC*

In such models, the CP-asymmetries are almost identical to that of the SM, since the CKM matrix still has the same structure, and $H^+\bar{u}_i d_j$ couplings have the same phase as that of the SM. There may be a significant change in the total amplitude of $B^0 - \bar{B}^0$ mixing due to the H^+ box diagrams, which will in turn affect the value of V_{td}.

An interesting signal in this model may be the $B^0 \to \ell^+\ell^-$ rates, which, for some particular choice of the parameter space, can be much higher than the SM ones.

We do not discuss the spontaneous CP-violation scenario, since only spontaneous CP-violation would mean a real CKM matrix, which is ruled out from the $K_L - K_S$ mass difference and the CDF measurement of $\sin 2\beta$.

2.3 *Supersymmetry with R-parity conservation*

The minimal SUSY and its R-parity conserving variants are interesting mainly for the CP-violating observables; any CP-conserving observable like the BRs must have two SUSY particles in the loop and is thereby suppressed in general.

To solve the SUSY flavour problems regarding ϵ_K and dipole moment of neutron, a number of different models were proposed. Among them are: (1) heavy squarks at the TeV scale; (2) universality among right and left squark masses for different generations; (3) alignment of quark and squark mixing matrices, and (4) approximate CP-symmetry of the Lagrangian. There are a number of specific flavour models in the literature which incorporates one or more of the above features [10]. As has been pointed out, the effects on measured observables crucially depend on the exact structure of the model, and not all models in a given category have same CP-violating predictions. In table 3, which is taken from [11], we summarise the predictions of various type of models. For a detailed discussion, see [10,11].

Table 3. Prediction of different SUSY flavour models. θ_d is the phase change from the SM prediction β in $B^0-\bar{B}^0$ mixing. a denotes CP-asymmetries for the two decay channels. Taken from [11].

Model	$d_n/d_n^{\rm exp}$	θ_d	$a_{D^0\to K^-\pi^+}$	$a_{K\to\pi\nu\bar{\nu}}$
SM	$\leq 10^{-6}$	0	0	$\mathcal{O}(1)$
Exact universality	$\leq 10^{-6}$	0	0	$\approx$ SM
Approx. universality	$\geq 10^{-2}$	$\mathcal{O}(0.2)$	0	$\approx$ SM
Approx. CP	$\sim 10^{-1}$	$-\beta$	$\mathcal{O}(10^{-3})$	$\mathcal{O}(10^{-5})$
Alignment	$\geq 10^{-3}$	$\mathcal{O}(0.2)$	$\mathcal{O}(1)$	$\approx$ SM
Heavy $\tilde{q}$	$\approx 10^{-1}$	$\mathcal{O}(1)$	$\mathcal{O}(10^{-2})$	$\approx$ SM

Another interesting observable is the forward-backward lepton asymmetry (as well as the absolute BRs) in $B\to X_s\ell^+\ell^-$ where $\ell=e$ or μ [12]. For both the leptons, the SM predictions for A_{FB} is 0.23 but it can vary from 0.33 to -0.18 in SUSY models. The negative A_{FB} constitutes an interesting signal. The BRs can be enhanced by a factor of four or can be suppressed by a factor of two, which should also be measured in the B-factories.

2.4 *Supersymmetry without R-parity*

R-parity violating (RPV) SUSY has one great advantage over the non-RPV SUSY models: the new physics contributions appear in the tree-level, and hence can greatly enhance or suppress the SM contributions. Here we will discuss the popular approach, i.e., we will consider all RPV couplings to be free parameters, constrained only by various experimental data, and study its consequences on B-decays.

For $B\to M_1M_2$ decays (M is any meson in general) the relevant pair of couplings is either $\lambda'\lambda'$ or $\lambda''\lambda''$ type. For $B\to M\ell^+\ell'^-$ decays, it is $\lambda\lambda'$ and $\lambda'\lambda'$ together. For example, we can have sneutrino/squark mediated $b\to d_i\bar{d}_jd_k$ decays and selectron/squark mediated $b\to d_i\bar{u}_ju_k$ decays (i,j,k are generation indices). All B-decay modes are affected by suitable pair of RPV couplings; more specifically, all UT angles can change from their SM predictions. In SM, the decays $B\to J/\psi K_S$ and $B\to\phi K_S$ measure the same angle β; with RPV, the measured CP-asymmetries may be different, which will definitely signal new physics [13]. One can see forbidden modes like $B^+\to K^+K^+\pi^-$ originating from the SM forbidden $b\to ss\bar{d}$ decay [4]. CP-asymmetries $\sim 100\%$ in the measurement of the UT angle γ can be obtained even from B^+ decays [14]; thus, study of B^+s, alongwith B^0s and B_ss, are of paramount importance. The leptonic forward-backward asymmetries are modified too: for a pure $\lambda\lambda'$ type coupling, there is no FB asymmetry, whereas for a $\lambda'\lambda'$ type coupling, it is in the opposite direction from SM [15].

Another important feature is that RPV couplings can enhance or suppress the BRs significantly. As we have seen, the CLEO data on $\eta'K$ and ηK^* are quite far away from the SM prediction. It has been shown [16] that a moderate value of the product coupling $d^R_{222}\equiv\lambda'_{i23}\lambda'_{i22}$ (each $\lambda'=0.05$–0.09, say), perfectly compatible with the experimental bounds, can enhance the BRs to their experimental value. At the same time, this product suppresses decays like $B^0 \to \phi K$; in SM, this decay is allowed only for $\xi \equiv 1/N_c^{\rm eff} < 0.23$ so that this range is in conflict with other PV modes $B^\pm \to \omega K^\pm$ and $B^\pm \to \omega\pi^\pm$. The former requires either $\xi < 0.05$ or $0.65 < \xi < 0.85$ while the latter requires $0.45 < \xi < 0.85$ [17]. With d^R_{222}, only the ϕK mode is affected; the BR goes down and the allowed range of $\xi(> 0.65)$ is in perfect accord with the other modes.

3. Conclusions

The study of B decays, both in the CP-conserving and CP-violating fronts, is important to unveil indirect effects of new physics, more so in view of the upcoming B-factories. CLEO has already given some food for thought. Among various new physics models, non-SUSY extensions of the SM mainly affect the $B^0 - \bar{B}^0$ amplitude, and, maybe, phase. The determination of V_{td} may be affected too. Different SUSY flavour models will have different signatures regarding the neutron dipole moment and asymmetries in $J/\psi K_S$ and $\pi\nu\bar{\nu}$ modes. RPV SUSY models can contribute to almost all B-decays, and can even induce some SM forbidden decays. One of the important achievements is to explain the CLEO result on $B \to \eta' K$ with RPV.

However, this is only about the observation of BSM physics, and to have a qualitative measurement, one needs to minimize the theoretical errors, which will be the biggest challenge to the theoreticians in the next few years. In short, we await some really exciting years on both theoretical and experimental fronts!

Acknowledgements

I thank Rahul Basu and other organisers of WHEPP-6 for providing a most stimulating atmosphere. Some of the material presented here is based on the work done with Debajyoti Choudhury and Bhaskar Dutta.

References

[1] See, e.g., Y Grossman and M P Worah, *Phys. Lett.* **B395**, 241 (1997)
M Gronau and D London, *Phys. Rev.* **D55**, 2845 (1997)
[2] For a discussion of such uncertainties, see, e.g., H Quinn, hep-ph/9912325
[3] CLEO collaboration: hep-ex/9908019, hep-ex/9912059
[4] K Huitu *et al*, *Phys. Rev. Lett.* **81**, 4313 (1998)
[5] OPAL collaboration: hep-ex/0002008
[6] A J Buras and R Fleischer, *Heavy flavours II* edited by A J Buras and M Lindner (World Scientific, Singapore, 1997)
[7] M Gronau and D London, in [1]
[8] W-S Hou, A Soni and H Steger, *Phys Lett.* **B192**, 441 (1987)
[9] D London, *Phys. Lett.* **B234**, 354 (1990)
[10] G Barenboim and M Raidal, *Phys. Lett.* **B457**, 109 (1999), and references therein
[11] Y Nir, hep-ph/9911321
[12] E Lunghi and I Scimemi, hep-ph/9912430

[13] D Guetta, *Phys. Rev.* **D58**, 116008 (1998)
[14] G Bhattacharyya and A Datta, *Phys. Rev. Lett.* **83**, 2300 (1999)
[15] J-H Jang, Y G Kim and J S Lee, *Phys. Lett.* **B408**, 367 (1997)
[16] D Choudhury, B Dutta and A Kundu, *Phys. Lett.* **B456**, 185 (1999)
[17] N G Deshpande, B Dutta and S Oh, hep-ph/9712445