ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physics Letters B 634 (2006) 403–407
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Probing photon helicity in radiative B decays via charmonium resonance interference

Mathias Knecht, Thomas Schietinger *

Laboratory for High-Energy Physics, Ecole Polytechnique Fédérale, CH-1015 Lausanne, Switzerland

Received 14 December 2005; received in revised form 31 January 2006; accepted 2 February 2006

Available online 9 February 2006

Editor: G.F. Giudice

Abstract

We investigate a new method to probe the helicity of the photon emitted in the $b \to s\gamma$ transition. The method relies on the observation of interference effects between two resonance contributions, $B \to K^*(K\gamma)\gamma$ and $B \to \eta_c(\gamma\gamma)K$ or $B \to \chi_{c0}(\gamma\gamma)K$ to the same final state $K\gamma\gamma$. Decays of the type $B \to K_{\text{res}}(K\gamma)\gamma$ dominate the $B \to K\gamma\gamma$ yield throughout most of the phase space, and may be accessible at current B meson facilities already.

PACS: 11.30.Er; 13.20.He; 13.25.Hw; 13.88.+e

Keywords: Quark masses and SM parameters; B-physics; CP violation

1. Introduction

Flavor-changing neutral currents are an important testing ground for the Standard Model (SM) of elementary particles. The quark transition $b \to s\gamma$ has played an outstanding role in this respect by providing direct experimental evidence for the penguin diagram process, which is expected to be particularly sensitive to contributions from physics beyond the SM. Recent measurements of the $b \to s\gamma$ rate [1], however, agree very well with theoretical predictions [2], leaving little hope for observing hints of new physics via the decay rate only. Consequently, recent efforts have focused on finding additional observable degrees of freedom related to $b \to s\gamma$, such as CP asymmetries or the helicity of the emitted photon, in order to subject the SM to ever more stringent tests. In a similar vein, the decay $B \to X_s\gamma\gamma$ and its exclusive manifestation $B \to K\gamma\gamma$ have been studied in this context [3–5]. In analogy to $b \to sl^+l^-$, the diphoton invariant mass spectrum and forward–backward asymmetries have been suggested as probes for new physics beyond the SM [6].

In this Letter, we point out the significance of contributions to the $K\gamma\gamma$ final state that occur via radiatively decaying kaon resonances: $B \to K_{\text{res}}\gamma$, with K_{res} being any kaon resonance, such as $K^*(892)$ or higher, that can decay to $K\gamma$. We will further show how these decays may be used to extract information on the helicity of the emitted photon in the $b \to s\gamma$ amplitude at future high-statistics B-meson facilities.

It was first noted by Atwood, Gronau, and Soni [7] that the photon helicity in $b \to s\gamma$ carries information on the underlying interaction. While the SM amplitude for $b \to s\gamma$ results in a predominantly left-handed photon (right-handed for $\bar{b} \to \bar{s}\gamma$), there are extensions of the SM that could alter the helicity of the photon without affecting much the rate of the decay. Thus several methods for an indirect determination of the photon helicity in radiative B decays have been devised: (1) study of the *interference between $b \to s\gamma$ and $\bar{b} \to \bar{s}\gamma$*, made possible by the phenomenon of B^0–$\bar{B}^0$ mixing [7]; (2) analysis of the *decay photon by means of its conversion to e^+e^-* [8] (see also [9] for the case of off-shell photons); (3) analysis of the *recoil system arising from the hadronization of the s-quark* in $b \to s\gamma$ [10]; (4) use of a *polarized initial state*, i.e., b-baryon decay,

* Corresponding author.
E-mail address: thomas.schietinger@cern.ch (T. Schietinger).

0370-2693 © 2006 Elsevier B.V. Open access under CC BY license.
doi:10.1016/j.physletb.2006.02.004

to infer the photon polarization from angular correlations with the final state [11,12]. Yet another way to analyze the decay photon is provided by the interference with another photon in a well-known state arising from the *same decay*. For example, $B \to K^*(K\gamma)\gamma$ can interfere with $B \to Kc\bar{c}(\gamma\gamma)$, where $c\bar{c}$ is a charmonium state such as η_c or χ_{c0}.

Photon pairs arising from η_c ($J^P = 0^-$) decay are known to be in an exact state of perpendicular polarization [13], i.e., a state with photon spin orientation given by $\mathbf{k}_1 \cdot [\boldsymbol{\epsilon}_1(\mathbf{k}_1) \times \boldsymbol{\epsilon}_2(\mathbf{k}_2)]$, where $\boldsymbol{\epsilon}_1$ and $\boldsymbol{\epsilon}_2$ ($\mathbf{k}_1$ and $\mathbf{k}_2$) are the transverse polarization (momentum) vectors of the two photons. Similarly, photons from χ_{c0} ($J^P = 0^+$) decay are in a state of parallel polarization ($\boldsymbol{\epsilon}_1 \cdot \boldsymbol{\epsilon}_2$). Thus we may use η_c and χ_{c0} as probes to analyze the polarization state of the photons from $B \to K^*(K\gamma)\gamma$, since photons from η_c (χ_{c0}) will only interfere with the perpendicular (parallel) polarization component.

2. $B \to K^*(K\gamma)\gamma$ amplitude

The SM amplitude for $B \to K^*(K\gamma)\gamma$ as given in Ref. [4] is based on a description of $b \to s\gamma$ in the framework of a leading-order effective Hamiltonian,

$$\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* C_7 O_7, \tag{1}$$

with G_F the Fermi constant, C_7 the Wilson coefficient of the local operator $O_7 = (em_b)/(16\pi^2)\bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$, e the electric charge, m_b the mass of the b-quark, $F^{\mu\nu}$ the electromagnetic field tensor and $\sigma_{\mu\nu} = \frac{i}{2}(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$. V_{tb} and V_{ts} are the usual Cabibbo–Kobayashi–Maskawa matrix elements. The full amplitude is then given as $\mathcal{M}_{K^*} = [T^{\mu\nu}(k_1,k_2) + T^{\nu\mu}(k_2,k_1)]\epsilon_\mu^*(k_1)\epsilon_\nu^*(k_2)$ with

$$\begin{aligned} T^{\mu\nu}(k_1,k_2) = {} & \frac{em_b gF}{16\pi^2} \\ & \times 4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* C_7 \epsilon^{\alpha\nu\gamma\delta} k_{2\alpha}(p_B - k_1)_\gamma k_{1\beta'} \\ & \times \frac{g_{\delta\sigma'} - \frac{(p_B-k_1)_\delta (p_B-k_1)_{\sigma'}}{m_{K^*}^2}}{(p_B-k_1)^2 - m_{K^*}^2 + i m_{K^*}\Gamma_{K^*}} \\ & \times \big[i\epsilon^{\mu\beta'\sigma'\tau'}(p_B - k_1)_{\tau'} \\ & - \big(g^{\mu\sigma'}(p_B-k_1)^{\beta'} - g^{\beta'\sigma'}(p_B-k_1)^{\mu}\big)\big], \end{aligned} \tag{2}$$

where k_i are the 4-vectors $(E, \mathbf{p})$ of the photons, and p_B, p_K the 4-vectors of the B and K mesons. The constants g and F are related to the coupling strengths for $K^* \to K\gamma$ and $B \to K^*\gamma$, respectively, and are different for neutral (B^0) and charged decays (B^+).

The decay distribution in the plane of the two photon energies (Dalitz plot) is shown in Fig. 1. It exhibits the typical $(1 + \cos^2\theta)$ shape along the resonance lines, as expected for the decay of a pseudoscalar particle into a pseudoscalar and two vectors via an intermediate vector resonance state. It also features a non-negligible fraction of decays in the central region of the Dalitz plot, outside the two resonance lines. This region is populated by decays receiving contributions from *both* amplitudes, $B \to K^*\gamma \to (K\gamma')\gamma$ and $B \to K^*\gamma' \to (K\gamma)\gamma'$. Despite the suppression from the Breit–Wigner resonance shape the effect of this interference amplitude results in a substantial enhancement of the over-all branching fraction of the decay. Indeed, from the distribution of events we find that $\mathcal{B}(B \to K^*(K\gamma)\gamma) \approx 3.85\mathcal{B}(B \to K^*\gamma)\mathcal{B}(K^* \to K\gamma)$. Combining this estimate with recent experimental data on $B \to K^*\gamma$ [14] and $K^* \to K\gamma$ [15] we obtain branching fractions of (3.54 ± 0.35) for B^0 and (1.54 ± 0.15) for B^+ in units of 10^{-7}, well accessible with the next generation of B factories [16] and perhaps also at hadron colliders [17] if backgrounds can be controlled.

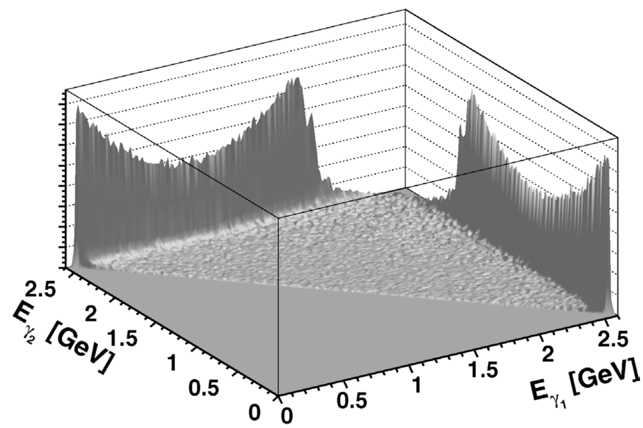

Fig. 1. Decay distribution for $B \to K^*\gamma \to K\gamma\gamma$ in the plane of the two photon energies (Dalitz plot).

3. Other contributions to $B \to K\gamma\gamma$

Other transitions yielding the $K\gamma\gamma$ final state include a non-resonant (short-distance) contribution, $b \to s\gamma$ contributions via higher kaon resonances decaying to $K\gamma$, contributions from $\eta(\gamma\gamma)K$ and $\eta'(\gamma\gamma)K$, as well as the analog contributions from charmonium resonances (η_c and χ_c states).

The non-resonant contribution is negligible with respect to the K^* contribution everywhere in phase space. Our evaluation of the amplitude given in [4] confirms the small non-resonant branching fraction of order 10^{-9} first reported by Hiller and Safir [5] in contradiction to the value given in [4]. Choudhury et al. have recently acknowledged a numerical error in their computations and published updated values [18] in accordance with [5].

The contributions from higher kaon resonances decaying to $K\gamma$ are difficult to assess with current experimental information. Recent measurements of $B \to K_1(1270)\gamma$ and $K_2^*(1430)\gamma$ [19] and corresponding radiative width determinations for these resonances [20] indicate that the effective $K\gamma\gamma$ branching fractions from these higher resonances are in the same range as for $K^*(892)$. Since a number of other kaon resonances may contribute to this final state, the overall $B \to K\gamma\gamma$ branching fraction due to kaon resonances could be an order of magnitude larger than our estimate for K^* only, bringing it to a level that may be accessible at currently running B factories. In view of the coarse experimental information available we leave these contributions to future investigations and assume here that

Table 1
Branching fractions for the cascade decays $B \to K(c\bar{c}) \to K\gamma\gamma$, where $(c\bar{c}) = \eta_c, \eta_c(2S), \chi_{c0}, \chi_{c2}$, as far as they have been measured [15,21]

Resonance	$\mathcal{B}_{(c\bar{c})\to\gamma\gamma}$ (10^{-4})	$\mathcal{B}_{B^0}\mathcal{B}_{(c\bar{c})}$ (10^{-7})	$\mathcal{B}_{B^+}\mathcal{B}_{(c\bar{c})}$ (10^{-7})
$\eta_c(2986)$	4.3 ± 1.5	5.2 ± 2.5	3.9 ± 1.8
$\chi_{c0}(3415)$	2.6 ± 0.5	< 1.3	0.8 ± 0.2
$\chi_{c2}(3556)$	2.46 ± 0.23	< 0.10	< 0.07
$\eta_c(2S)(3638)$	–	–	–

their effects can be subtracted or isolated for the purpose of this study.

While the contributions from η and η' are sizable, giving effective branching fractions of up to 1.5×10^{-6}, they result in photons of relatively low energy. This will render the observation of interference effects with the $B \to K^*(K\gamma)\gamma$ amplitude experimentally difficult. We will therefore focus on the more promising charmonium resonances occurring at higher energies. Table 1 summarizes the relevant experimental data for these resonances. Among the charmonium resonances, only η_c and χ_{c0} are known both to decay into two photons and to be produced in B decays with an associated kaon, so that we will restrict our analysis to these two resonances.

To model the amplitudes $\mathcal{M}_{\eta_c,\chi_{c0}}$ for the B decays to $\eta_c(\gamma\gamma)K$ and $\chi_{c0}(\gamma\gamma)K$ we use a general Breit–Wigner ansatz along the lines described in Ref. [5]. Thus we neglect variations in the amplitudes beyond the Breit–Wigner form. For $B \to \eta_c K$ we follow the factorization approach employed in Ref. [4]. The full amplitude for $B \to K\gamma\gamma$, including the three resonance contributions, is then given by

$$\mathcal{M}_{\text{tot}} = \mathcal{M}_{K^*} + \xi_{\eta_c}\mathcal{M}_{\eta_c} + \xi_{\chi_{c0}}\mathcal{M}_{\chi_{c0}}, \tag{3}$$

where $\xi_{\eta_c,\chi_{c0}} = \pm 1$ denote unknown relative interference signs. Note that in this simplified approach, the relative strong phases between the decay processes are assumed to be real. While there are good reasons to question this assumption, we nevertheless choose to study the relevant observables first in this approximation in order to investigate and illustrate the potential of the method *in principle.* In Section 5 we will consider the case with arbitrary relative strong phases.

4. Interference terms and asymmetries

To study the role of the interference terms as photon polarization analyzers, we generalize the SM amplitude for $B \to K^*(K\gamma)\gamma$ to include an amplitude for the emission of a right-handed photon from the b-quark. Following Ref. [12], we add a right-handed component to the operator O_7 from Eq. (1), i.e., $C_7 O_7 \to C_7 O_7 + C_7' O_7'$, with $O_7' = \frac{e m_b}{16\pi^2}\bar{s}_R \sigma_{\mu\nu} b_L F^{\mu\nu}$, describing the emission of a right-handed photon. In this picture, the probability f_R for the emission of a right-handed photon from the b-quark is given by the corresponding Wilson coefficient, $f_R = |C_7'|^2/(|C_7|^2 + |C_7'|^2)$. The naive SM estimate for this fraction is $f_R \approx 0.1\%$ based on $C_7'/C_7 \approx m_s/m_b$ from the chiral structure of the W-boson couplings to quarks [7]. A recent study including other operators that contribute to $b \to s\gamma_R$ finds that f_R may be as large as 1% within the SM [22]. In the following we assume the Wilson coefficients to be real, i.e., we do not consider additional sources of CP violation beyond the SM.

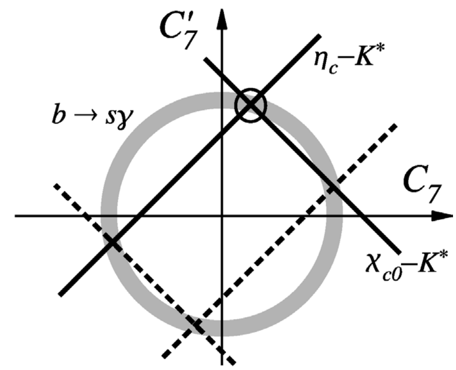

Fig. 2. Schematic illustration of the constraints in the C_7–C_7' plane obtained from a spectrum measurement of $B \to K\gamma\gamma$ (under the assumption of negligibly small strong phases). The gray circle depicts the region allowed from inclusive $b \to s\gamma$ measurements, the solid diagonal lines represent the solutions corresponding to the η_c–K^* and χ_{c0}–K^* interferences, with dashed lines indicating mirror solutions in the case where the interference signs are unknown.

Taking account of the symmetry properties of the amplitude (2) it is straightforward to incorporate the emission of a right-handed photon by adding a parity-inverted term proportional to C_7'. Evaluation of the full amplitude then shows explicitly that the η_c–K^* interference term is proportional to $(C_7 - C_7')$ while the χ_{c0}–K^* interference term is proportional to $(C_7 + C_7')$. These interference terms are accessible to experiment: they manifest themselves as enhancements or reductions in the diphoton mass spectrum of $B \to K\gamma\gamma$ decays near the resonance peaks, depending on the signs involved. The Wilson coefficients C_7 and C_7' may thus be cleanly extracted from the observed diphoton mass spectrum, if the signs of the interference terms are known (and relative strong phases are negligible, see Section 5). Unfortunately, neither of the two interference signs is known model-independently today, such that, even under the assumption of negligibly small strong phases, only values for $|C_7 - C_7'|$ and $|C_7 + C_7'|$ could be derived from a measured spectrum, leading to a four-fold ambiguity in the solution for (C_7, C_7'), see Fig. 2. In spite of the four-fold ambiguity, a measurement of these interference terms may still represent a valuable test of the SM. Recall that the overall normalization $|C_7|^2 + |C_7'|^2$ is given by the inclusive $b \to s\gamma$ rate and hence already known from experiment. In Fig. 3 we show diphoton mass spectra for various values of $c_7^{(\prime)} = C_7^{(\prime)}/\sqrt{C_7^2 + C_7'^2}$ for B^- decay, with positive interference signs assumed throughout.

Experimentally, the interference terms are most readily isolated by means of asymmetries. An observable that is particularly convenient to extract the η_c interference is the charge asymmetry A_C, defined as

$$A_C(m_{\gamma\gamma}) = \frac{d\Gamma^-/dm_{\gamma\gamma} - d\Gamma^+/dm_{\gamma\gamma}}{d\Gamma^-/dm_{\gamma\gamma} + d\Gamma^+/dm_{\gamma\gamma}}, \tag{4}$$

with $\Gamma^\pm = \Gamma(B^\pm \to K^\pm\gamma\gamma)$. An analog asymmetry may be defined for neutral B decays, where experimental difficulties

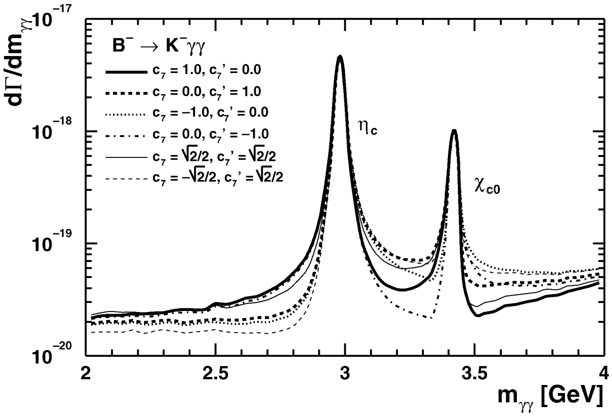

Fig. 3. Diphoton mass spectra for $B^- \to K^-\gamma\gamma$ for various values of the normalized Wilson coefficients c_7 and c_7'.

arise from flavor tagging, compensated in part by the larger statistics available. Here we only consider the charged decay. In Fig. 4(a) we show the expected A_C for various combinations of c_7 and c_7'. It exhibits the typical shape of a Breit–Wigner interference around the position of the η_c resonance, with a distortion at higher energies due to the presence of the χ_{c0} resonance, which forces the charge asymmetry to zero in its vicinity. The value of the maximum asymmetry below the η_c peak is a direct measure of $(c_7 - c_7')$, we find $A_C^{\max} \approx (0.37 \pm 0.02)(c_7 - c_7')$ for positive interference sign. The error is dominated by the uncertainty in the η_c branching fraction, see Table 1.

The χ_{c0} interference, being CP-even, cannot be extracted in the same manner. Instead we define a charge-averaged peak asymmetry around the χ_{c0},

$$A_{\chi_{c0}}(\Delta m_{\gamma\gamma}) = \frac{d\bar{\Gamma}(m^-)/dm_{\gamma\gamma} - d\bar{\Gamma}(m^+)/dm_{\gamma\gamma}}{d\bar{\Gamma}(m^-)/dm_{\gamma\gamma} + d\bar{\Gamma}(m^+)/dm_{\gamma\gamma}}, \tag{5}$$

where $m^\pm = m_{\chi_{c0}} \pm \Delta m_{\gamma\gamma}$, and $\bar{\Gamma} = (\Gamma^+ + \Gamma^-)/2$. The expected peak asymmetry is shown in Fig. 4(b), again for various combinations of c_7 and c_7'. It is dominated by the sought-after interference effect, since the distribution of $B \to K^*(K\gamma)\gamma$ events is rather flat in that region. For values of $\Delta m_{\gamma\gamma}$ well below $m_{\chi_{c0}} - m_{\eta_c}$ (at which point $A_{\chi_{c0}} = 1$ due to the η_c peak) we find $A_{\chi_{c0}}^{\max} \approx (0.40 \pm 0.01)(c_7 + c_7')$ for positive interference sign. In this case the error mainly originates from the uncertainty in the χ_{c0} branching fraction (Table 1).

5. Uncertainty from strong phases

In our simplified approach within the factorization approximation we have neglected the effect of relative strong phases between the $B \to K^*\gamma$ and $B \to \eta_c(\chi_{c0})K$ decays. Recent evaluations for $B \to D\pi$ [23] and $B \to \pi\pi$ [24], however, indicate sizable strong phases, thus casting into doubt our initial assumption.

In the presence of strong-phases the coefficients $\xi_{\eta_c,\chi_{c0}}$ in Eq. (3) simply become $\exp(i\phi_{\eta_c,\chi_{c0}})$, where $\phi_{\eta_c,\chi_{c0}}$ denote the relative strong phases between the $B \to K^*\gamma$ and $B \to \eta_c(\chi_{c0})K$ amplitudes. The corresponding interference terms appearing in the $K\gamma\gamma$ spectrum will no longer only depend on

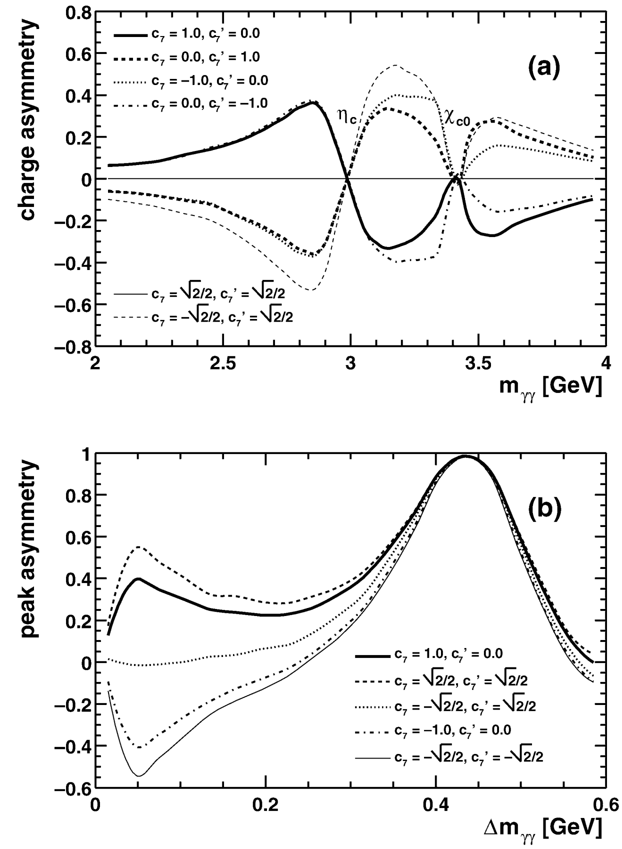

Fig. 4. (a) Charge asymmetry $A_C(m_{\gamma\gamma})$ and (b) peak asymmetry $A_{\chi_{c0}}(\Delta m_{\gamma\gamma})$ for various values of c_7 and c_7'. All interference terms are assumed to have positive sign.

$(C_7 - C_7')$ and $(C_7 + C_7')$, but rather on $\cos\phi_{\eta_c}(C_7 - C_7')$ and $\cos\phi_{\chi_{c0}}(C_7 + C_7')$. Thus the extraction of useful information on C_7 and C_7' entirely hinges on the knowledge of the relative strong phases ϕ_{η_c} and $\phi_{\chi_{c0}}$. This severely limits the applicability of the method for the time being.

Conversely, we may of course note that once the photon polarization is known from one of the other proposed methods, a measurement of the above defined asymmetries may serve to improve our understanding of the strong phases at play.

6. Experimental considerations and conclusion

Apart from the strong phase problem, the principal experimental limitation for such a measurement will be the required statistics of B decays. To arrive at a rough estimate of the required order of magnitude of B mesons, we note that some 10^3 clean $B \to K^*(K\gamma)\gamma$ decays would be necessary for a measurement distinguishing between the case of maximum asymmetry from that of zero asymmetry. Factoring in branching fractions and typical reconstruction efficiencies for radiative decays at e^+e^- B factories ($\approx 10\%$) and hadron colliders ($\approx 0.1\%$) we find that several 10^{10} (10^{12}) neutral or charged B mesons would be needed in the case of an e^+e^- (hadron) collider. These numbers are compatible with expected annual production rates at future facilities being proposed [16] or built [17]. Of course, many experimental issues remain to be addressed within the context of a specific experimental setup and as more knowledge on the amplitudes involved in $B \to K\gamma\gamma$ decay becomes available.

Our main conclusion is that contributions from kaon resonances dominate the $B \to K\gamma\gamma$ yield throughout most of the phase space and thus render the non-resonant $b \to s\gamma\gamma$ amplitude inaccessible to experiment in this final state.

Furthermore, we have investigated the possibility to utilize resonance interferences in the $K\gamma\gamma$ final state to probe the photon polarization in the $b \to s\gamma$ transition, which may reveal contributions from new physics beyond the SM. While possible in principle, the method suffers in practice from theoretical uncertainties related to the unknown strong phases present in the decays and experimentally from the formidable requirement on the statistics of B meson decays. But in the event that the relevant strong phases can be obtained from elsewhere and the required number of B decays can be collected, the method has the advantage of yielding direct information on the Wilson coefficients C_7 and C_7'.

Acknowledgements

We are indebted to Gudrun Hiller for very helpful suggestions and comments. We also thank Namit Mahajan for fruitful exchanges. For some of our calculations we have used the EvtGen software package [25]. This work was supported by the Swiss National Science Foundation under grant No. 620-066162.

References

[1] S. Chen, et al., CLEO Collaboration, Phys. Rev. Lett. 87 (2001) 251807;
P. Koppenburg, et al., Belle Collaboration, Phys. Rev. Lett. 93 (2004) 061803.
[2] See, for instance, T. Hurth, Rev. Mod. Phys. 75 (2003) 1159.
[3] L. Reina, G. Ricciardi, A. Soni, Phys. Lett. B 396 (1997) 231;
L. Reina, G. Ricciardi, A. Soni, Phys. Rev. D 56 (1997) 5805.
[4] S.R. Choudhury, G.C. Joshi, N. Mahajan, B.H.J. McKellar, Phys. Rev. D 67 (2003) 074016.
[5] G. Hiller, A.S. Safir, JHEP 0502 (2005) 011.
[6] J. Cao, Z. Xiao, G. Lu, Phys. Rev. D 64 (2001) 014012;
A. Gemintern, S. Bar-Shalom, G. Eilam, Phys. Rev. D 70 (2004) 035008.
[7] D. Atwood, M. Gronau, A. Soni, Phys. Rev. Lett. 79 (1997) 185.
[8] Y. Grossman, D. Pirjol, JHEP 0006 (2000) 029.
[9] D. Melikov, N. Nikitin, S. Simula, Phys. Lett. B 442 (1998) 381.
[10] M. Gronau, Y. Grossman, D. Pirjol, A. Ryd, Phys. Rev. Lett. 88 (2002) 051802;
M. Gronau, D. Pirjol, Phys. Rev. D 66 (2002) 054008.
[11] T. Mannel, S. Recksiegel, Acta Phys. Pol. B 28 (1997) 2489;
T. Mannel, S. Recksiegel, J. Phys. G: Nucl. Part. Phys. 24 (1998) 979.
[12] G. Hiller, A. Kagan, Phys. Rev. D 65 (2002) 074038.
[13] C.N. Yang, Phys. Rev. 77 (1950) 242.
[14] J. Alexander, et al., Heavy Flavor Averaging Group, Averages of b-hadron Properties as of Summer 2004, hep-ex/0412073, unpublished, and April 2005 web update available at http://www.slac.stanford.edu/xorg/hfag.
[15] S. Eidelman, et al., Particle Data Group, Phys. Lett. B 592 (2004) 1.
[16] S. Hashimoto, M. Hazumi, J. Haba, J.W. Flanagan, Y. Ohnishi (Eds.), Letter of Intent for KEK Super B Factory, KEK Report 2004-4 (2004);
J. Hewett, D.G. Hitlin (Eds.), The Discovery Potential of a Super B Factory, Proceedings of the 2003 SLAC Workshops, SLAC-R-709 (2004), hep-ph/0503261.
[17] R. Antunes Nobrega et al., LHCb Collaboration, LHCb Reoptimized Detector Design and Performance Technical Design Report, CERN/LHCC 2003-030.
[18] S.R. Choudhury, G.C. Joshi, N. Mahajan, B.H.J. McKellar, hep-ph/0210160 (revised version of [4] from 23 February 2005).
[19] S. Nishida, et al., Belle Collaboration, Phys. Rev. Lett. 89 (2002) 231801;
B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 70 (2004) 091105;
H. Yang, et al., Belle Collaboration, Phys. Rev. Lett. 94 (2005) 111802.
[20] S. Cihangir, et al., Fermilab–Minnesota–Rochester Collaboration, Phys. Lett. B 117 (1982) 123;
A. Alavi-Harati, et al., KTeV Collaboration, Phys. Rev. Lett. 89 (2002) 072001.
[21] K. Abe, et al., Belle Collaboration, Phys. Rev. Lett. 88 (2002) 031802;
B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 69 (2004) 071103;
B. Aubert, et al., BaBar Collaboration, Phys. Rev. Lett. 94 (2005) 171801.
[22] B. Grinstein, Y. Grossman, Z. Ligeti, D. Pirjol, Phys. Rev. D 71 (2005) 011504.
[23] S. Mantry, D. Pirjol, I.W. Stewart, Phys. Rev. D 68 (2003) 114009.
[24] See, for instance, A.J. Buras, R. Fleischer, S. Recksiegel, F. Schwab, Phys. Rev. Lett. 92 (2004) 101804.
[25] D. Lange, A. Ryd, The EvtGen event generator package, International Conference on Computing in High Energy Physics, Chicago, IL, USA, August 31–September 4, 1998.