Forward-backward asymmetry of $B \to K_J l^+ l^-$ decays in SM and new physics models

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We report on our studies of $B \to K_J l^+ l^-$ in the standard model and several new physics variations, with K_J denoting a kaonic resoanance. In terms of helicity amplitudes, we derive a compact form for the full angular distributions, and use them to calculate the branching ratios, forward-backward asymmetries and polarizations. We have updated the constraints on effective Wilson coefficients and/or free parameters in these new physics scenarios by making use of the $B \to K^* l^+ l^-$ and $b \to s l^+ l^-$ experimental data. Their impact on $B \to K_J^* l^+ l^-$ is subsequently explored and in particular the zero-crossing point for forward-backward asymmetry in new physics scenarios can sizably deviate from the standard model.

1 Introduction

Flavor changing neutral currents are forbidden at tree level in the standard model (SM). Such rare B-decays into dileptons are precision probes of the SM and provide constraints on new physics beyond the standard model [1]. Important semileptonic modes in terms of experimental accessibility and theory control are those into K_J [2,3,4,5,6], in which K_J can be K^*, $K_1(1270), K_1(1410)$, $K^*(1410), K_0^*(1430), K_2^*(1430), K^*(1680), K_3^*(1780)$ and $K_4^*(2045)$. These decays exhibit a rich phenomenology through the angular analysis of subsequent decays of K_J, through which the forward-backward asymmetry (FBA) can be extracted. As opposed to the branching ratios which suffer from large hadronic uncertainties, the FBA is theoretically clean and sensitive to NP. Therefore it is one of the major goals of LHCb to precisely explore FBA as a hunt for new physics signals [7].

2 Form factor relations

The $B \to K_J^*$ form factors are nonperturbative in nature and the application of QCD theory to them mostly resorts to the Lattice QCD simulations, which has large limitation at the current stage. An important observation is that, in the heavy quark limit $m_b \to \infty$ and the large energy limit $E \to \infty$, interactions of the heavy and light systems can be expanded in small ratios Λ_{QCD}/E and Λ_{QCD}/m_B. At the leading power in $1/m_b$, the large energy symmetry is obtained and such symmetry greatly simplifies the heavy-to-light transition [8].

As a concrete application, the current $\bar{s}\Gamma b$ in QCD can be matched onto the current $\bar{s}_n \Gamma b_v$ constructed in terms of the fields in the low-energy effective theory. Here v denotes the velocity of the heavy meson and n is a light-like vector along the K_J^* moving direction. This procedure constrains the independent Lorentz structures and reduces the seven independent hadronic form

Table 1: $B \to K_J^*$ form factors derived from the large recoil symmetry.

K_J^*	$\xi_{\|\|}$	$\xi_\perp$
$K^*(1410)$	0.22 ± 0.03	0.28 ± 0.04
$K_0^*(1430)$	0.22 ± 0.03	–
$K_2^*(1430)$	0.22 ± 0.03	0.28 ± 0.04
$K^*(1680)$	0.18 ± 0.03	0.24 ± 0.05
$K_3^*(1780)$	0.16 ± 0.03	0.23 ± 0.05
$K_4^*(2045)$	0.13 ± 0.03	0.19 ± 0.05

factors for each $B \to K_J^*$ ($J \geq 1$) type to two universal functions $\xi_\perp$ and $\xi_{||}$. Explicitly, we have

$$\begin{aligned}
A_0^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv A_0^{K_J^*,\mathrm{eff}} \simeq (1-\frac{m_{K_J^*}^2}{m_B E})\xi_{||}^{K_J^*}(q^2) + \frac{m_{K_J^*}}{m_B}\xi_\perp^{K_J^*}(q^2),\\
A_1^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv A_1^{K_J^*,\mathrm{eff}} \simeq \frac{2E}{m_B+m_{K_J^*}}\xi_\perp^{K_J^*}(q^2),\\
A_2^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv A_2^{K_J^*,\mathrm{eff}} \simeq (1+\frac{m_{K_J^*}}{m_B})[\xi_\perp^{K_J^*}(q^2) - \frac{m_{K_J^*}}{E}\xi_{||}^{K_J^*}(q^2)],\\
V^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv V^{K_J^*,\mathrm{eff}} \simeq (1+\frac{m_{K_J^*}}{m_B})\xi_\perp^{K_J^*}(q^2),\\
T_1^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv T_1^{K_J^*,\mathrm{eff}} \simeq \xi_\perp^{K_J^*}(q^2),\\
T_2^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv T_2^{K_J^*,\mathrm{eff}} \simeq (1-\frac{q^2}{m_B^2-m_{K_J^*}^2})\xi_\perp^{K_J^*}(q^2),\\
T_3^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} &\equiv T_3^{K_J^*,\mathrm{eff}} \simeq \xi_\perp^{K_J^*}(q^2) - (1-\frac{m_{K_J^*}^2}{m_B^2})\frac{m_{K_J^*}}{E}\xi_{||}^{K_J^*}(q^2).
\end{aligned} \tag{1}$$

In the case of B to scalar meson transition, the large energy limit gives

$$\frac{m_B}{m_B+m_{K_0^*}}F_T(q^2) = F_1(q^2) = \frac{m_B}{2E}F_0(q^2) = \xi^{K_0^*}(q^2). \tag{2}$$

The results for $\xi_{||}^{K_J^*}$ and $\xi_\perp^{K_J^*}$ obtained from the Bauer-Stech-Wirbel (BSW) model [9] in Ref. [10] are used in our work and we collect these results in Tab. 1. For the $B \to K_0^*$ transition, it is plausible to employ $\xi^{B\to K_0^*} = \xi_{||}^{B\to K_2^*}$ since both K_0^* and K_2^* are p-wave states.

In addition, we have employed the perturbative QCD approach to directly compute these form factors [11,12,13] and find many agreements with the large recoil symmetries, for instance the PQCD results for $B \to K_2^*$ transition are shown in Table 2 (See Ref. [5] for a more detailed comparison).

3 New physics contributions

We choose several kinds of new physics models, such as family non-universal Z' model, Supersymmetric model and vector-like quark model. All of them can induce extra contributions to the branching ratios, polarizations and forward-backward asymmetry parameters, through the effective operators O_9 and/or O_{10}. Via modifying the Wilson coefficients C_9 and C_{10}, these

Table 2: $B \to K_2^*$ form factors at $q^2 = 0$ in the ISGW2 model, the covariant light-front quark model and the light-cone QCD sum rules and perturbative QCD approach.

	ISGW2	CLFQM	LCSR	LEET+BSW	PQCD
$V^{BK_2^*}$	0.38	0.29	0.16 ± 0.02	0.21 ± 0.03	$0.21^{+0.06}_{-0.05}$
$A_0^{BK_2^*}$	0.27	0.23	0.25 ± 0.04	0.15 ± 0.02	$0.18^{+0.05}_{-0.04}$
$A_1^{BK_2^*}$	0.24	0.22	0.14 ± 0.02	0.14 ± 0.02	$0.13^{+0.04}_{-0.03}$
$A_2^{BK_2^*}$	0.22	0.21	0.05 ± 0.02	0.14 ± 0.02	$0.08^{+0.03}_{-0.02}$
$T_1^{BK_2^*}$		0.28	0.14 ± 0.02	0.16 ± 0.02	$0.17^{+0.05}_{-0.04}$
$T_3^{BK_2^*}$		-0.25	$0.01^{+0.02}_{-0.01}$	0.10 ± 0.02	$0.14^{+0.05}_{-0.03}$

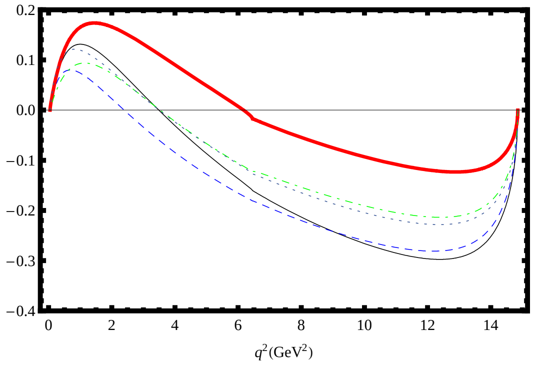

Figure 1: Impacts of the NP contributions on normalized forward-backward asymmetry of $B \to K_2^* l^+ l^-$. Black (solid) line denotes the SM result, while the dashed (blue) and thick (red) lines correspond to the modification of C_9. Dot-dashed (green) and dotted lines are obtained by modifying C_{10}.

contributions affect the observables in $B \to K^* l^+ l^-$ as well and the comparison of theory with data derive the constraints on C_9 and C_{10}.

We adopt a least χ^2-fit method and make use of the experimental data on $B \to K^* l^+ l^-$. Embedded in the vector-like quark model, the free two parameters, real part and imaginary part of the FCNC coupling λ_{sb}, are found as

$$\mathrm{Re}\lambda_{sb} = (0.07 \pm 0.04) \times 10^{-3}, \quad \mathrm{Im}\lambda_{sb} = (0.09 \pm 0.23) \times 10^{-3}, \tag{3}$$

from which we obtain $|\lambda_{sb}| < 0.3 \times 10^{-3}$ but the phase is less constrained again. The corresponding constraint on Wilson coefficients are

$$|\Delta C_9| = |C_9 - C_9^{SM}| < 0.2, \quad |\Delta C_{10}| = |C_{10} - C_{10}^{SM}| < 2.8. \tag{4}$$

Turning to family nonuniveral Z' model in which the coupling between Z' and a lepton pair is unknown, the two Wilson coefficients, C_9 and C_{10}, can be chosen as independent parameters. Assuming ΔC_9 and ΔC_{10} as real, we find

$$\Delta C_9 = 0.88 \pm 0.75, \quad \Delta C_{10} = 0.01 \pm 0.69. \tag{5}$$

Removal of the above assumption leads to

$$\Delta C_9 = -0.81 \pm 1.22 + (3.05 \pm 0.92)i, \quad \Delta C_{10} = 1.00 \pm 1.28 + (-3.16 \pm 0.94)i. \tag{6}$$

For illustration, we choose $\Delta C_9 = 3e^{i\pi/4, i3\pi/4}$ and $\Delta C_{10} = 3e^{i\pi/4, i3\pi/4}$ as the reference points and give the plots of FBAs in Fig. 1. The black (solid) line denotes the SM result, while the dashed (blue) and thick (red) lines correspond to the modification of C_9. The dot-dashed (green) and dotted lines are obtained by modifying C_{10}. From the figure for A_{FB}, we can see that the zero-crossing point s_0 can be sizably changed, which can be tested on the future collider or can be further constrained.

4 Summary

Heavy flavor physics has entered a precision era as large samples of flavor physics data have been brought to us from B factories and the LHC. As a result, we are able to reach a multitude of observables from exclusive $b \to sl^+l^-$ processes, which allow to map out the structure of the underlying physics.

In this talk we have concentrated on the $B \to K_1(K_0^*, K_2^*, K_3^*, K_4^*)l^+l^-$ in the standard model. Their branching ratios are predicted to have the order 10^{-6} or 10^{-7} which are large enough for observation of these processes. Using the experimental data on $B \to K^*l^+l^-$, we have also presented an update of the constraints on new physics parameters in two specific scenarios and elaborated on the impact on $B \to K_Jl^+l^-$. We expect more and more results from the LHCb quite soon, which may lead to success of the justification of new physics degree of freedoms from flavor physics.

Acknowledgments

We are very grateful to M.Jamil Aslam, Run-Hui Li and Yu-Ming Wang for collaboration. This work is partly supported by the National Science Foundation of China under the Grant No.11075168.

References

1. A. Ali, P. Ball, L. T. Handoko and G. Hiller, Phys. Rev. D **61** (2000) 074024 [hep-ph/9910221].
2. M.Jamil Aslam, Cai-Dian Lu, Yu-Ming Wang, Phys. Rev. D79 (2009) 074007 e-Print: arXiv:0902.0432 [hep-ph]
3. Run-Hui Li, Cai-Dian Lu, Wei Wang, Phys. Rev. D79 (2009) 094024 e-Print: arXiv:0902.3291 [hep-ph]
4. Run-Hui Li, Cai-Dian Lu, Wei Wang, Phys. Rev. D83 (2011) 034034 e-Print: arXiv:1012.2129 [hep-ph]
5. Cai-Dian Lu, Wei Wang, Phys. Rev. D85 (2012) 034014, e-Print: arXiv:1111.1513 [hep-ph]
6. Cheng-Wei Chiang, Run-Hui Li, Cai-Dian Lu, Chin. Phys. C36 (2012) 14-24 e-Print: arXiv:0911.2399 [hep-ph]
7. RAaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **108** (2012) 181806 [arXiv:1112.3515 [hep-ex]].
8. J. Charles, A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Rev. D **60**, 014001 (1999) [hep-ph/9812358].
9. M. Wirbel, B. Stech, M. Bauer, Z. Phys. **C29**, 637 (1985).
10. H. Hatanaka and K. C. Yang, Phys. Rev. D **79**, 114008 (2009) [arXiv:0903.1917 [hep-ph]]; Eur. Phys. J. C **67**, 149 (2010) [arXiv:0907.1496 [hep-ph]].
11. R. -H. Li, C. -D. Lu, W. Wang and X. -X. Wang, Phys. Rev. D **79** (2009) 014013 [arXiv:0811.2648 [hep-ph]].
12. R. -H. Li, C. -D. Lu and W. Wang, Phys. Rev. D **79** (2009) 034014 [arXiv:0901.0307 [hep-ph]].
13. W. Wang, Phys. Rev. D **83** (2011) 014008 [arXiv:1008.5326 [hep-ph]].