Exclusive $B \rightarrow K^{*\star}\gamma$ Decays in the QCD LCSR approach

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Abstract

We predict contributions of higher $K$-resonances to the radiative rare decays $b \rightarrow s\gamma$, in the framework of the QCD sum rules on the light cone (LCSR). Our calculations are restricted to the leading twist-two operators for $K^+(892)$ and to the asymptotic wave function for the other $K^{*\star}$-mesons. Using experimental data on the semileptonic $\tau \rightarrow K^{*\star}\nu_\tau$ decays, we extract the corresponding decay constants for vector and axial-vector $K^{*\star}$-mesons. We present results for the corresponding branching ratios and compare them with the existing theoretical predictions.

1 Introduction

The study of radiative decays based on the flavour-changing neutral $b \rightarrow (s,d) + \gamma$ current transition is of crucial importance for testing the flavour sector of the Standard Model and probing for new physics. In the standard model, the short distance contribution to rare B-decays is dominated by the top quark, and long distance contributions by form factors. Precise measurements of these transition will not only provide a good estimate of the top quark mass and the CKM matrix elements $V_{td}$, $V_{ts}$, $V_{tb}$, but also of the hadronic properties of $B$-mesons, namely form factors which in turn would provide a good knowledge of the corresponding dynamics and more hint for the non-perturbative regime of QCD.

Experimental measurements of exclusive $B \rightarrow K^*\gamma$ branching ratios have been reported by the BABAR, CLEO and BELLE Collaborations, with the results:

$$10^5 \text{Br}(B^0 \rightarrow \bar{K}^{*0}\gamma) = \begin{cases} 4.23 \pm 0.40 \pm 0.22 \text{[1]} \\ 4.55^{+0.72}_{-0.68} \pm 0.34 \text{[2]} \\ 4.96 \pm 0.67 \pm 0.45 \text{[3]} \end{cases}$$

and also of the inclusive rate [2–4]:

$$10^4 \text{Br}(B \rightarrow X_s\gamma) = (3.22 \pm 0.40)$$

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However, the first observation of the rare $B$-decay to the orbitally excited strange mesons has been reported by CLEO \[2\], and recently by BELLE \[3\]:

$$10^5 \text{Br}(B \to K_2^*(1430)\gamma) = \left\{ (1.66^{+0.59}_{-0.53} \pm 0.13) \quad [2] \right\}$$

These important experimental measurements provide a crucial challenge to the theory. Whereas many theoretical approaches have been employed to predict the exclusive $B \to K^*(892)\gamma$ decay rate, less attention has been devoted to rare radiative $B$-decays to excited strange mesons \[5–8\]. Most of these theoretical approaches rely on non-relativistic quark models \[5, 6\], HQET \[7\] and relativistic model \[8\]. However there is a large spread between different results, due to different treatments of the long distance effects.

In this talk we present the results of \[9\], where a systematic analysis of the electromagnetic penguin form factor $F_{K^*}(0)$ governing the exclusive rare $B$-decays to orbitally excited $K^*$-mesons was performed in the framework of the QCD sum rules on the light cone \[10\].

### 2 General framework

At the quark level, the rare semileptonic decay $b \to s\gamma$ can be described in terms of the effective Hamiltonian obtained by integrating out the top quark and $W^\pm$ bosons:

$$H_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{ts} V_{tb} \sum_{i=1}^{8} C_i(\mu) O_i(\mu).$$

where $V_{ij}$ are the corresponding CKM matrix elements and $G_F$ is the Fermi coupling constant. Following the notation and the convention of ref. \[11\], regarding the operator basis, one can test the model dependence of the form factors for the exclusive decay in the ratio of the exclusive-to-inclusive radiative decay branching ratio:

$$R_{K^{**}} \equiv \frac{\text{BR}(B \to K^{**}\gamma)}{\text{BR}(B \to X_s\gamma)} \simeq F_1^{K^{**}}(0)^2 \zeta(m_s, m_b, m_{K^{**}}, ..)$$

where $\zeta(m_s, m_b, m_{K^{**}}, ..)$ is a kinematic function which can be found in \[9\]. With this normalization, one eliminates the uncertainties from the CKM matrix elements and the short distance contribution. Thus, we are left in (2) with unknown form factors $F_1^F(0)$, which we will derive using QCD sum rules on the light cone.

The starting point of our sum rule is to consider the correlation function

$$i \int dx \ e^{iqx} \times <K^{**}(p, \epsilon)|T \{ \bar{\psi}(x)\sigma_{\mu\nu}(\sigma_{\mu\nu}\gamma_5)q^\nu b(x)\bar{b}(0)i\gamma_5\psi(0) \}|0>$$

Hereafter we use $\psi$ as a generic notation for the field of the light quark. The hadronic representation of (3) is obtained by inserting a complete set of states including the $B$-meson ground state, higher resonances and the non-resonant states with $B$-meson quantum numbers. After writing down the dispersion relation in $(p + q)^2$, we can separate the contribution of the $B$-meson as the pole contribution.

The possibility to calculate the correlator (3) in the region of large space-like momenta $(p + q)^2 < 0$ is based on the expansion of the $T$-product of the currents in (3) near the light-cone $x^2 = 0$ which is expressed through matrix elements of non-local operators, sandwiched in between the
Table 1: Central values of the pseudoscalar, vector, scalar and axial vector $K^{**}$-meson decay constants (in MeV) and the corresponding form factors.

| $K^*(892)$ | $K^*_1(1270)$ | $K_1(1400)$ | $K^*(1410)$ | $K^*_0(1430)$ | $K_1(1650)$ | $K^*(1680)$ |
|------------|--------------|-------------|-------------|---------------|-------------|-------------|
| $J^P$ | 1$^-$ | 1$^+$ | 1$^+$ | 1$^-$ | 0$^+$ | 1$^+$ | 1$^-$ |
| $f_i$ | $210$ | $122$ | $91$ | $86$ | $79$ | $86$ | $86$ |
| $F_{K^{**}}(0)$ | $0.32_{-0.06}^{+0.06}$ | $0.14_{-0.03}^{+0.03}$ | $0.098_{-0.02}^{+0.02}$ | $0.094_{-0.02}^{+0.02}$ | $0.091_{-0.02}^{+0.02}$ | $0.091_{-0.02}^{+0.02}$ |

Table 2: Comparison of our results for the ratio $R_F[\%]$ with previous works.

| Meson | ref. [3] | ref. [7] | ref. [6] | ref. [5] | ref. [8] |
|-------|----------|----------|----------|----------|----------|
| $K^*$ | 10.0$^{+1.0}_{-1.0}$ | 16.8 ± 6.4 | 3.5 − 12.2 | 4.5 | 15$^{±3}$ |
| $K^*(1430)$ | | | | | forb. |
| $K_1(1270)$ | 2.0$^{+0.8}_{-0.4}$ | 4.3$^{+1.6}_{-0.9}$ | 4.5 − 10.1 | forb./6.0 | 1.5$^{±0.5}$ |
| $K_1(1400)$ | 0.9$^{+0.4}_{−0.4}$ | 2.1$^{+0.9}_{−0.9}$ | 6.0 − 13.0 | forb./6.0 | 2.6$^{±0.6}$ |
| $K_{2}^*(1430)$ | 5.0$^{+2.0}_{−2.0}$ | 6.2$^{+2.9}_{−2.9}$ | 17.3 − 37.1 | 6.0 | 5.7$^{±1.2}$ |
| $K^*(1680)$ | 0.7$^{+0.3}_{−0.3}$ | 0.5$^{+0.2}_{−0.2}$ | 1.0 − 1.5 | 0.9 | |
| $K_2(1580)$ | | 1.7$^{±0.4}_{−0.4}$ | 4.5 − 6.4 | 4.4 | |
| $K(1460)$ | | | | | forb. |
| $K^*(1410)$ | 0.8$^{+0.4}_{−0.4}$ | 4.1$^{+0.6}_{−0.6}$ | 7.2 − 10.6 | 7.3 | |
| $K^*_0(1950)$ | | | | | forb. |
| $K_1(1650)$ | 0.8$^{+0.3}_{−0.3}$ | 1.7$^{±0.6}_{−0.6}$ | not given | not given | |

vacuum and the meson state. These matrix elements define the light-cone meson wave functions. We restricted our calculations to the leading twist-2 operator for the $K^*(892)$, as in [2], and to the asymptotic wave function for the other $K^{**}$-mesons. The latter choice is simply based on the fact that using QCD sum rules, it is impossible to get rid of the lower-lying states contributions from these higher resonances.

However, nothing is known about the corresponding $K^{**}$-decay constants, and one has to predict them. For that, we have used recent data [3] on semileptonic $\tau \to (K^{**})\nu_\tau$ decays [1] to obtain them [3]. We present in table [3] the corresponding decay constants. For $K_2^*(1430)$, we have constrained the corresponding decay constant with the recent data [3] on $B \to K_2^*(1430)\gamma$.

Following the basic steps of the QCD sum rules on the light-cone, as described above, and using the experimental $K^{**}$-decay constants, we show in table [3] the corresponding form factors. Finally, in table [2] we compare our results for the ratio $R_{K^{**}}[\%]$ with previous works [3][8].

### 3 Summary

Motivated by the first observation of the radiative decay $B \to K_2^*(1430)\gamma$, we have investigated rare radiative $B$ decays to orbitally excited $K^{**}$-mesons. First, we have presented an alternative method of calculating the transition form factors and related decays using the QCD sum rules on the light-cone. For that, We have extracted the unknown $K^{**}$-decay constants using the recent

These quantities contribute to the transition rates for pseudoscalar, vector, scalar and axial vector emission.
data on semileptonic $\tau \to K^{*}\nu_\tau$ decays.

For $K_2^*(1430)$, we have constrained the corresponding decay constant with the recent data on $B \to K_2^*(1430)\gamma$. We find that if $f_{K_2^*(1430)} = (140 - 180)$ MeV, a substantial fraction (3.0 - 7.0)% of the inclusive $b \to s\gamma$ branching ratio goes into the $K_2^*(1430)$ channel, in a good agreement with recent CLEO data. Our prediction for the $B \to K^*(892)\gamma$ branching fraction yields to (6.0 - 14.0)% also in good agreement with the experimental data.

In order to make comparison of our results with previous calculations, we have tabulated our results together with results of [5], [6], [7] and [8] in table 2. As far as decays into higher $K$-resonances are concerned, our results are in general in much better agreement with [7] than [5] and [6], apart from the $K^*(1410)$-channel where the difference is more significant. Finally, it should be noticed that the theoretical uncertainties in our light-cone sum rules are the wave functions and the decay constants of the $K^{**}$-mesons. The accuracy of our calculation can be substantially improved by taking into account the wave functions of twist-3 and twist-4 for the $B \to K^*(892)\gamma$ decay, and going beyond the asymptotic form for the other decay modes. To reduce the uncertainties on the $K^{**}$-mesons decay constants, one can determine them independently using QCD sum rules for the two-point correlator of the corresponding currents.

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