Right-handed currents in rare exclusive 
\[ B \to (K, K^*)\nu\bar{\nu} \] 
decays

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Abstract

The effects of possible right-handed weak hadronic currents in rare exclusive semileptonic decays \( B \to (K, K^*)\nu\bar{\nu} \) are investigated using a lattice-constrained dispersion quark model for the calculation of the relevant mesonic form factors. The results obtained for the branching ratios and the missing energy spectra are presented and the sensitivity of various observables to long-distance physics is investigated. It is shown that the asymmetry of transversely polarized \( K^*_T \) mesons as well as the \( K/K^*_T \) production ratio are only slightly sensitive to long-distance contributions and mostly governed by the relative strength and phase of right-handed currents. In particular, within the Standard Model the production of right-handed \( K^*_T \) mesons turns out to be largely suppressed with respect to left-handed ones, thanks to the smallness of the final to initial meson mass ratio. Therefore, the measurement of produced right-handed \( K^*_T \) mesons in rare \( B \to K^*\nu\bar{\nu} \) decays offers a very interesting tool to investigate right-handed weak hadronic currents.

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Weak decays induced by Flavor Changing Neutral Currents (FCNC) are widely recognized as a powerful tool to make stringent test of the Standard Model (SM) as well as to probe possible New Physics (NP) \[1\]. Our understanding of FCNC in terms of the SM and its possible extensions is expected to be improved by the foreseen advent of new accelerators and \(B\)-factories, which will allow to investigate rare \(B\)-meson decays induced by the \(b \to s\) (and \(b \to d\)) transitions. Besides many interesting processes, like, e.g., the \(B_s - B_s\) mixing and the rare \(B\)-meson decays induced by the \(b \to s\gamma\) and \(b \to s\ell^+\ell^-\) processes, the rare semileptonic decay \(b \to s\nu \bar{\nu}\) plays a peculiar role. Indeed, within the SM the process \(b \to s\nu \bar{\nu}\) is governed by the following effective weak Hamiltonian (cf. Refs. \[2, 3, 4\])

\[
\mathcal{H}_{\text{eff}}^{(SM)}(b \to s\nu \bar{\nu}) = \frac{G_F}{\sqrt{2}} \frac{\alpha_{em}}{2\pi \sin^2 \theta_W} V_{tb} V_{ts}^* X(x_t) \, O_L(b \to s\nu \bar{\nu}) \\
\equiv c_L^{(SM)} \, O_L(b \to s\nu \bar{\nu}) \tag{1}
\]

where \(O_L(b \to s\nu \bar{\nu}) \equiv (\bar{s}\gamma_{\mu}(1 - \gamma_5)b) \, (\bar{\nu}\gamma^\mu(1 - \gamma_5)\nu)\). The operator \(O_L\) is obtained from \(Z\)-penguin and \(W\)-box diagrams with a dominating top-quark intermediate state. In Eq. \(1\) \(G_F\) is the Fermi constant, \(\alpha_{em}\) the fine structure constant, \(\theta_W\) the Weinberg angle, \(V_{tb}\) the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements and \(x_t \equiv (m_t/m_W)^2\); finally, the function \(X(x_t)\) is obtained after integrating out the heavy particles and includes \(O(\alpha_s)\) corrections (see Refs. \[3, 4\] for its explicit expression).

The appealing feature of Eq. \(1\) relies in the presence of a single operator governing the transition \(b \to s\nu \bar{\nu}\). In this way the main theoretical uncertainties are concentrated in the value of only one Wilson coefficient, \(c_L^{(SM)}\). As it is well known, in case of other processes, like those driven by the \(b \to s\gamma\) and \(b \to s\ell^+\ell^-\) transitions, several operators should be included in the effective weak \(SM\) Hamiltonian, so that the corresponding set of Wilson coefficients (with their theoretical uncertainties) act coherently in determining the values of many observables, like the branching ratios, the differential decay rates, lepton asymmetries, etc. Moreover, the \(SM\) operator \(O_L\) does not contain long-distance contributions generated by four-quark operators, which are usually present in the low-energy weak Hamiltonian and affect both the \(b \to s\ell^+\ell^-\) and (to a much less extent) the \(b \to s\gamma\) processes.

Under the only assumption of purely left-handed neutrinos (possible neutrino mass effects are expected to be negligible \[5\]) \(NP\) effects in the \(b \to s\nu \bar{\nu}\) transitions can be a modification of the \(SM\) value of the coefficient \(c_L\) and/or the introduction of a new right-handed (RH) operator, viz.

\[
\mathcal{H}_{\text{eff}}(b \to s\nu \bar{\nu}) = c_L \, O_L(b \to s\nu \bar{\nu}) + c_R \, O_R(b \to s\nu \bar{\nu}) \tag{2}
\]

where \(O_R(b \to s\nu \bar{\nu}) \equiv (\bar{s}\gamma_{\mu}(1 + \gamma_5)b) \, (\bar{\nu}\gamma^\mu(1 - \gamma_5)\nu)\) and the values of the coefficients \(c_L\) and \(c_R\) depend on the specific \(NP\) model. In what follows, we will make use of two parameters, \(\epsilon\) and \(\eta\), defined as

\[
\epsilon^2 \equiv \frac{|c_L|^2 + |c_R|^2}{|c_L^{(SM)}|^2}, \quad \eta \equiv -\frac{\text{Re}(c_L c_R^*)}{|c_L|^2 + |c_R|^2} \tag{3}
\]

\(^a\)It turns out that the main uncertainty on \(c_L^{(SM)}\) is the uncertainty on the top-quark mass and on the product \(|V_{tb}V_{ts}|\) of \(CKM\) matrix elements \[3\], being the radiative \(QCD\) corrections substantially small \[3\].
which are clearly connected to the relative strength and phase of RH currents with respect to left-handed (LH) ones.

From the theoretical point of view the inclusive $B \to X_s \nu \bar{\nu}$ decay is a particularly clean process for investigating possible NP effects, because the non-perturbative $1/m_b^2$ corrections to the free-quark result are known to be small [3]. This is valid not only for the branching ratio, but also for the differential decay rate, except for the regions close to the kinematical end-point, where the spectrum has to be smeared out to get reliable results. The free-quark prediction for the missing-energy spectrum of the $B \to X_s \nu \bar{\nu}$ decay can be read off from, e.g., Ref. [4]. While the differential decay rate is directly proportional to $c^2$, its dependence upon $\eta$ is due to interference effects between the LH and RH currents. However, since the final to initial quark mass ratio, $m_s/m_b$, is quite small, the shape of the missing energy spectrum is only slightly affected by the value of $\eta$ (cf. Ref. [5]). Therefore, a full determination of the coefficients $c_L$ and $c_R$ requires at least to consider also decay processes other than the inclusive $B \to X_s \nu \bar{\nu}$ one. It is the aim of this letter to show that the effects of possible RH currents can be investigated in rare exclusive semileptonic decays $B \to (K,K^*)\nu \bar{\nu}$ and to this end a lattice-constrained dispersion quark model, recently developed in Ref. [6], is used to evaluate the relevant mesonic form factors. It will be shown that the asymmetry of transversely polarized $K_T^*$ mesons as well as the $K/K^*$ production ratio are only slightly affected by the model dependence of the form factors and remarkably sensitive both to $\epsilon$ and $\eta$, i.e. to the relative strength and phase of RH currents. In particular, within the SM the production of RH $K_T^*$ mesons turns out to be largely suppressed with respect to LH ones, thanks to the smallness of the final to initial meson mass ratio and, therefore, the measurement of produced $RH K_T^*$ mesons in rare $B \to K^* \nu \bar{\nu}$ decays offers a very interesting tool to investigate RH weak hadronic currents.

To begin with, let us denote by $P_B$ and $P_{K(K^*)}$ the four-momentum of the initial and final mesons and define $q = P_B - P_{K(K^*)}$ as the four-momentum of the $\nu \bar{\nu}$ pair and $x \equiv E_{\text{miss}}/M_B$ the missing energy fraction, which is related to the squared four-momentum transfer $q^2$ by: $q^2 = M_B^2 \left[ 2x - 1 + r_{K(K^*)}^2 \right]$, where $r_{K(K^*)} \equiv M_{K(K^*)}/M_B$ with $M_B$ and $M_{K(K^*)}$ being the initial and final meson masses. The missing energy spectrum for the decay $B \to K \nu \bar{\nu}$ can be written as (cf. Refs. [4][5])

$$\frac{dBr}{dx}(B \to K \nu \bar{\nu}) = 3 Br_0 \left| \frac{c_L + c_R}{c_L^{\text{SM}}} \right|^2 \left[ (1-x)^2 - r_{K}^2 \right]^{3/2} |F_1(q^2)|^2$$

(4)

where the factor 3 arises from the sum over the three neutrino generations and

$$Br_0 \equiv c_L^{\text{SM}} \left| \frac{M_B^2 \tau_B}{6\pi^3} \right| = \frac{G_F^2 M_B^2}{(4\pi)^3} \frac{4\alpha_{em}^2}{3\pi^2\sin^4(\theta_W)} \frac{X^2(x_i)}{V_{tb} V_{ts}^*} \tau_B$$

(5)

with $\tau_B$ being the $B$-meson lifetime. In Eq. (3) the mesonic form factor $F_1(q^2)$ is obtained from the covariant decomposition of the hadronic transition $B \to K$ driven by the vector current $\bar{s}\gamma_\mu b$, viz.

$$\langle K|\bar{s}\gamma_\mu b |B \rangle = (P_B + P_K)_{\mu} F_1(q^2) + q_{\mu} \left[ F_0(q^2) - F_1(q^2) \right] \frac{M_B^2 - M_K^2}{q^2}$$

(6)
with $F_0(q^2) = F_1(q^2) = 0$. As for the $B \to K^*_h \nu \bar{\nu}$ decay, the missing energy spectrum corresponding to a definite polarization $h = (0, \pm 1)$ of the final $K^*$ meson is given by \[8\]

$$
\frac{dBr}{dx}(B \to K^*_{h=0} \nu \bar{\nu}) = \frac{3}{4} Br_0 \left| \frac{c_L - c_R}{c_L^{(SM)}} \right|^2 \frac{1}{r_{K*}^2 (1 + r_{K*})^2} \sqrt{(1 - x)^2 - r_{K*}^2} \cdot (1 + r_{K*})^2 (1 - x - r_{K*}^2) A_1(q^2) - 2[(1 - x)^2 - r_{K*}^2] A_2(q^2) \right|^2 \quad (7)
$$

$$
\frac{dBr}{dx}(B \to K^*_{h=\pm 1} \nu \bar{\nu}) = \frac{3}{4} Br_0 \sqrt{(1 - x)^2 - r_{K*}^2} \left( \frac{2x - 1 + r_{K*}^2}{(1 + r_{K*})^2} \right)^2 \left| \frac{c_L - c_R}{c_L^{(SM)}} \right|^2 (1 + r_{K*})^2 A_1(q^2) \right|^2 \quad (8)
$$

where the mesonic form factors $V(q^2)$, $A_1(q^2)$ and $A_2(q^2)$ appear in the covariant decomposition of the hadronic matrix elements of the $B \to K^*$ transition generated by the $V - A$ current $\bar{s} \gamma_{\mu}(1 - \gamma_5)b$, viz.

$$
\langle K^*_h | \bar{s} \gamma_{\mu}(1 - \gamma_5)b | B \rangle = \epsilon_{\mu \nu \alpha \beta} e^{\nu \alpha}(h) P_B^\alpha P_K^\beta K_{M_B + M_{K*}} - i \left\{ \epsilon_{\mu}(h)(M_B + M_{K*}) A_1(q^2) - [e^\nu(h) \cdot q] (P_B + P_{K*})_\mu \frac{A_2(q^2)}{M_B + M_{K*}} - [e^\nu(h) \cdot q]_\mu \frac{2M_{K*}}{q^2} [A_3(q^2) - A_0(q^2)] \right\} \quad (9)
$$

where $\epsilon(h)$ is the polarization four-vector of the $K^*$-meson and $A_3(q^2) \equiv [(M_B + M_{K*}) A_1(q^2) - (M_B - M_{K*}) A_2(q^2)]/2M_{K*}$.

In the whole accessible kinematical decay region we have calculated the relevant mesonic form factors $F_1(q^2)$, $V(q^2)$, $A_1(q^2)$ and $A_2(q^2)$, appearing in Eqs. \(10\) and \(11\), adopting a dispersion formulation of the relativistic quark model \[11\]. For the explicit evaluation of the form factors one needs to specify the quark model parameters such as the constituent quark masses and the meson wave functions. In Ref. \[10\] we performed calculations of the mesonic form factors adopting different model wave functions, in particular: the simple Gaussian ansatz of the ISGW2 model \[11\] and the variational solution \[12\] of the effective $q\bar{q}$ semi-relativistic Hamiltonian of Godfrey and Isgur (GI) \[13\]. These two models differ both in the shape of the meson wave functions, particularly at high internal momenta, and in the values of the quark masses (see Ref. \[10\] for details). The results of our calculations showed that the mesonic form factors for heavy-to-light transitions are sensitive both to the high-momentum tail of the meson wave function and to the values adopted for the quark masses (see also Ref. \[14\]). In order to obtain more reliable predictions for the form factors, we have required \[11\] the quark model parameters to be adjusted in such a way that the calculated form factors at high $q^2$ are compatible with recent available lattice QCD results \[13,14\]. We found that the best agreement with the high-$q^2$ lattice data can be obtained adopting the quark masses and wave functions of
the GI model with a switch-offed one-gluon exchange, which will be denoted hereafter as to the GI – OGE quark model.

Recently, in the whole range of accessible values of $q^2$ a lattice-constrained parametrization for the $B \to K^*$ form factors has been developed [17], based on the Stech’s parametrization of the form factors obtained within the constituent quark picture [13], on the Heavy Quark Symmetry (HQS) scaling relations near $q^2 = M_B^2 - M_{K^*(L)}^2$ and on a single-pole behavior of $A_1(q^2)$ suggested by the heavy-quark mass dependence at $q^2 = 0$ expected from the QCD sum rules (see Ref. [17] for details). The parameters of the single-pole fit to the form factor $A_1(q^2)$ were found from the least-$\chi^2$ fit to the lattice QCD simulations [13, 16] in a limited region at high values of $q^2$. Such a parametrization, though still phenomenological, is also consistent with the dispersive bounds of Ref. [19] and therefore it obeys all known theoretical constraints. The comparison of the mesonic form factors relevant in rare $B \to (K, K^*)\nu\bar{\nu}$ decays, obtained in our GI – OGE relativistic quark model, with the parametrization of Ref. [17] is shown in Fig. 1. It can clearly be seen that the two sets of form factors agree each other within $\sim 10\%$, except near the zero-recoil point. We want to stress that both sets of form factors satisfy all known rigorous theoretical constraints in the whole kinematical accessible region. Therefore, we expect that the difference between the two sets of form factors provide a typical present-day theoretical uncertainty of our knowledge of long-distance effects in the mesonic channels. Consequently, in order to investigate the sensitivity of the missing-energy spectra and branching ratios of rare $B \to (K, K^*)\nu\bar{\nu}$ decays to the specific $q^2$-behavior of the relevant form factors, we have run calculations of Eqs. (4) and (7-8) adopting the two sets of mesonic form factors shown in Fig. 1. We have also adopted the following values: $\tau_B = (1.57 \pm 0.04) \, ps$ [21], $M_B = 5.279 \, GeV$ [21], $\sin(\theta_{W}) = 0.2315$ [21] and $|V_{tb}V_{ts}^{*}| = 0.038 \pm 0.005 (0.041 \pm 0.005)$ in case of our GI – OGE form factors (parametrization of Ref. [17]). Finally, at $m_t = 176 \, GeV$ one gets $X(x_t) = 2.02$, yielding $Br_0 = (5.3 \pm 1.4) \times 10^{-4}$ (see Eq. (9)), which implies a present-day theoretical uncertainty of $\sim 25\%$ in rare $b \rightarrow s\nu\bar{\nu}$ decay rates.

The present experimental upper bound on the inclusive branching ratio $Br(B \rightarrow X_s\nu\bar{\nu})$, determined by the ALEPH collaboration ($Br(B \rightarrow X_s\nu\bar{\nu}) < 7.7 \cdot 10^{-4}$ [22]), turns out to be about an order of magnitude larger than the typical $SM$ prediction ($Br_{(SM)}(B \rightarrow X_s\nu\bar{\nu}) \approx 4 \div 5 \cdot 10^{-5}$ [3, 8]). Thus, till now the inclusive $B \rightarrow X_s\nu\bar{\nu}$ decay constrains weakly the range of values of the relative strength factor $\epsilon^2$, namely: $\epsilon^2 \lesssim 15 \cdot Br(B \rightarrow X_s\nu\bar{\nu})/(7.7 \cdot 10^{-4})$ and, in general, the admixture of possible RH currents in $b \rightarrow s$ transitions is not yet constrained too much, leaving the possibility of a sizable strength with unknown relative phase (see, e.g., [23]). Since the present $SM$ uncertainty on rare $b \rightarrow s\nu\bar{\nu}$ decay rates is about $25\%$, we have simply considered a relative strength factor $\epsilon^2$ equal to $1.25$ (i.e., a $25\%$ enhancement with respect to the $SM$ value $\epsilon^2_{(SM)} = 1$) and varied the parameter $\eta$ in its allowable range. Note that the value $\epsilon^2 = 1$ can be realized not only within the $SM$ framework, but possibly also in NP scenarios; however, for sake of simplicity, in what follows we will assume $\epsilon_L = \epsilon_L^{(SM)}$. Our results obtained for the branching ratios $Br(B \rightarrow K\nu\bar{\nu})$, $Br(B \rightarrow K^*_L\nu\bar{\nu})$ and $Br(B \rightarrow K^*_T\nu\bar{\nu})$ (where $K^*_L$ and $K^*_T$ stand for longitudinally and transversely polarized $K^*$-mesons, respectively), are reported in Fig. 2(a) and clearly show that the production of longitudinally polarized $K^*_L$-

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\textsuperscript{b}The values adopted for $|V_{tb}V_{ts}^{*}|$ for the two sets of form factors have been determined in Ref. [6] by the request of reproducing the CLEO result [24] on the rare exclusive $B \rightarrow K^*\gamma$ decay within the $SM$ basis.
mesons is remarkably sensitive to the detailed $q^2$-behavior of the mesonic form factors, while our predictions for both $K^\pm_T$- and $K$-meson production are only slightly model-dependent. Note that, contrary to what happens in case of the inclusive $B \to X_s \nu\bar{\nu}$ process, the exclusive branching ratios $Br[B \to (K, K^*)\nu\bar{\nu}]$ are much more sensitive to the value of the parameter $\eta$, i.e. to the relative phase of $RH$ currents with respect to $LH$ ones, even when a quite small enhancement factor $\epsilon^2 - 1$ is considered. Our predictions for the ratio $R_{K/K^*_T}$ of produced $K$- to $K^*_T$-mesons as well as the transverse asymmetry $A_T$, defined as

$$
R_{K/K^*_T} \equiv \frac{Br(B \to K\nu\bar{\nu})}{Br(B \to K^*_{h=-1}\nu\bar{\nu}) + Br(B \to K^*_{h=+1}\nu\bar{\nu})}
$$

$$
A_T \equiv \frac{Br(B \to K^*_{h=-1}\nu\bar{\nu}) - Br(B \to K^*_{h=+1}\nu\bar{\nu})}{Br(B \to K^*_{h=-1}\nu\bar{\nu}) + Br(B \to K^*_{h=+1}\nu\bar{\nu})}
$$

(10)

are shown in Fig. 2(b). It can be seen that the transverse asymmetry $A_T$ is only marginally affected by the model-dependence of the mesonic form factors, while the ratio $R_{K/K^*_T}$ is more sensitive to their specific $q^2$-behavior, particularly at negative values of $\eta$. It should be pointed out however that both $A_T$ and (to a much larger extent) $R_{K/K^*_T}$ are remarkably affected by the value of $\eta$. The advantage of such a large sensitivity should be taken into account when comparing inclusive versus exclusive decay modes, the latter being affected by the general problem of the model dependence of the form factors.

It can be easily checked (starting from Eqs. (9) and (11)) that the ratio $R_{K/K^*_T}$ is independent of $\epsilon$, while the asymmetry $A_T$ depends both on $\eta$ and $d$. Our predictions for the $SM$ values of $R_{K/K^*_T}$ and $A_T$ are $0.76 \pm 0.04$ (see Fig. 2(b) at $\eta = 0$) and $0.93 \pm 0.02$, respectively, where the quoted uncertainties correspond to the variation obtained using the two sets of mesonic form factors adopted in this work. The $SM$ value of $A_T$ indicates a dominance of produced $LH$ ($h = -1$) $K^*_T$-mesons with respect to $RH$ ($h = +1$) ones. This fact is clearly illustrated in Fig. 3, where our predictions for the missing-energy spectra of longitudinally and transversely polarized $K^*$-mesons, obtained within the $SM$ framework, are reported. The main outcome can be summarised as follows: i) the energy spectrum of longitudinally polarized $K^*_L$-mesons is largely affected by the model-dependence of the mesonic form factors, while the opposite feature is exhibited by the production of transversely polarized $K^*_T$-mesons, and ii) $RH$ $K^*_T$-mesons are less abundant than $LH$ ones within the $SM$ in a wide range of values of $x$, except near the zero-recoil point (corresponding to $x = x_{max} = 1 - r_{K^*}$). We have reached the same conclusions also after having carried out the calculations of the transverse asymmetry $A_T$ using other sets of form factors, like those obtained within the two $QCD$ sum rule versions of Refs. [8] and [23], or the form factors fulfilling the $HQS$ relations at leading-order in the inverse heavy-quark mass (see Refs. [26, 10]). As for the latter case, it is well known that in the heavy-quark limit ($HQL$) all the relevant form factors are related to a single universal function, the Isgur-Wise form factor. Moreover, in the $HQL$ the (differential) transverse asymmetry $A_T(x)$ is independent of the Isgur-Wise function and within the $SM$ it simply reduces to a kinematical

\footnote{Note also that both $R_{K/K^*_T}$ and $A_T$ are clearly independent of $|V_{tb}V_{ts}^*|$ and the top-quark mass.}
function, viz:

\[ A_T(x) \equiv \frac{dBr(B \to K_{h=\pm 1}^* \bar{\nu} \nu)}{dBr(B \to K_{h=\pm 1}^* \bar{\nu} \nu)/dx} - \frac{dBr(B \to K_{h=\pm 1}^* \bar{\nu} \nu)}{dBr(B \to K_{h=\pm 1}^* \bar{\nu} \nu)/dx} \rightarrow \text{HQL} \left( \frac{\sqrt{\omega^2 - 1}}{\omega} \right) \]  

(11)

where \( \omega \) is dot product of the initial and final meson four-velocities. Therefore, starting from the zero-recoil point \( (\omega = 1) \) where \( A_T(x) = 0 \), the transverse asymmetry in the \( SM \) rapidly increases up to its maximum value \( (1 - r_{K^*})/(1 + r_{K^*}) \), reached at the maximum-recoil point \( \omega_{max} = (1 + r_{K^*}^2)/2r_{K^*} \) (corresponding to \( x = x_{min} = (1 - r_{K^*}^2)/2 \)). Since \( r_{K^*} \approx 0.03 \) one has \( A_T(x) \sim 0.9 \) in a wide range of values of \( x \). Though the final \( K^* \)-mesons are far from being considered as heavy daughters, approximate \( HQS \) relations among the form factors of the \( B \to K^* \) transition have been shown to hold within \( \approx 20\% \) accuracy \(^{[7,10]} \), so that the dominance of \( LH \) produced \( K_T^* \) mesons within the \( SM \) holds not only in the \( HQL \), but also in case of finite quark masses. To sum up, the measurement of produced \( RH \) \( K_T^* \)-mesons in rare \( B \to K^* \nu \bar{\nu} \) decays could offer a clear signature of possible \( RH \) weak hadronic currents. Finally, we have collected in Fig. 4 our predictions for the shape of the missing-energy spectra of the \( B \to K_{h=\pm 1}^* \bar{\nu} \nu \) decay, obtained for various values of \( \epsilon \) at fixed value of \( \eta \) (see Fig. 4(a)) as well as for various values of \( \eta \) at fixed \( \epsilon \) (see Fig. 4(b)). Note in particular that the production of \( LH \) \( K_T^* \)-mesons is almost independent of the value of \( \epsilon \), while the differential rate for \( RH \) ones is approximately proportional to \( (\epsilon^2 - 1) \).

In conclusion, the missing-energy spectra and branching ratios of rare exclusive semileptonic \( B \to (K, K^*) \nu \bar{\nu} \) decays have been investigated adopting a lattice-constrained dispersion quark model for the calculation of the relevant mesonic form factors. The effects of possible right-handed weak hadronic current have been considered and the sensitivity of the branching ratios and the missing energy spectra to long-distance physics has been investigated. It has been shown that the asymmetry of transversely polarized \( K_T^* \) mesons as well as the \( K/K_T^* \) production ratio are only slightly sensitive to long-distance contributions and mostly governed by the relative strength and phase of right-handed currents. In particular, within the Standard Model the production of right-handed \( K_T^* \) mesons turns out to be largely suppressed with respect to left-handed ones, thanks to the smallness of the final to initial meson mass ratio. Therefore, the measurement of produced right-handed \( K_T^* \) mesons in rare \( B \to K^* \nu \bar{\nu} \) decays offers a very interesting tool to investigate right-handed weak hadronic currents and, despite the general problem of the model dependence of the hadronic form factors, the exclusive decay modes \( B \to (K, K^*) \nu \bar{\nu} \) turn out to be more sensitive to the effects of right-handed currents with respect to the inclusive \( B \to X_s \nu \bar{\nu} \) process.

References

[1] See, e.g., S. Bertolini, F. Borzumati, A. Masiero and G. Ridolfi: Nucl. Phys. B353 (1991) 591.

[2] T. Inami and C.S. Lim: Prog. Theor. Phys. 65 (1981) 287.

[3] G. Buchalla and A.J. Buras: Nucl. Phys. B400 (1993) 225. G. Buchalla, A.J. Buras and M. Lautenbacher: Rev. Mod. Phys. 65 (1996) 1125.
[4] For a recent review see, e.g., A. Ali: Acta Physica Pol. B27 (1996) 3529 and preprint DESY 97-192, September 1997 (e-print archive hep-ph/9709507).

[5] Y. Grossman, Z. Ligeti and E. Nardi: Nucl. Phys. B465 (1996) 369.

[6] A.F. Falk, M. Luke and M.J. Savage: Phys. Rev. D53 (1996) 2491.

[7] D. Melikhov, N. Nikitin and S. Simula: preprint ISS-INFN 97/15, e-print archive hep-ph/9711362.

[8] P. Colangelo et al.: Phys. Lett. B395 (1997) 339.

[9] D. Melikhov: Phys. Rev. D53 (1996) 2460; Phys. Lett. B380 (1996) 363; Phys. Lett. B394 (1997) 385; Phys. Rev. D56 (1997) 7089.

[10] D. Melikhov, N. Nikitin and S. Simula: Phys. Lett. B410 (1997) 290.

[11] D. Scora and N. Isgur: Phys. Rev. D52 (1995) 2783.

[12] F. Cardarelli et al.: Phys. Lett. B332 (1994) 1.

[13] S. Godfrey and N. Isgur: Phys. Rev. D32 (1985) 189.

[14] I. L. Grach et al.: Phys. Lett. B385 (1996) 317; Phys. Atom. Nucl. 59 (1996) 2152. S. Simula: Phys. Lett. B373 (1996) 193.

[15] APE Collaboration, A. Abada et al.: Phys. Lett. B365 (1996) 275.

[16] UKQCD Collaboration, J. M. Flynn and C. T. Sachrajda, e-print archive hep-lat/9710057. J. M. Flynn et al.: Nucl. Phys. B461 (1996) 327.

[17] UKQCD Collaboration, L. Del Debbio et al, e-print archive hep-lat/9708008.

[18] B. Stech: Phys. Lett. B354 (1995) 447; Z. Phys. C75 (1997) 245.

[19] L. Lellouch: Nucl. Phys. B479 (1996) 353.

[20] T.E. Browder, K. Honscheid and D. Pedrini: Ann. Rev. Nucl. Part. Sci. 46 (1996) 395.

[21] Particle Data Group: R.M. Barnet et al: Phys. Rev. D53 (1996) 1.

[22] ALEPH Collaboration: contribution PA10-019 to the Int. Conf. on High Energy Physics, Warsaw (Poland), 25-31 July, 1996 and D. Buskulic et al.: Phys. Lett. B343 (1995) 444.

[23] T.G. Rizzo: preprint SLAC-PUB-7702, e-print archive hep-ph/9802401.

[24] CLEO Collaboration, R. Ammar et al.: Phys. Rev. Lett. 71 (1993) 674 and CLEO CONF. 96-05 (1996).

[25] T. M. Aliev et al.: Phys. Rev. D56 (1997) 4260; Phys. Lett. B400 (1997) 194.

[26] N. Isgur and M.B. Wise: Phys. Lett. B232 (1989) 113; Phys. Lett. B237 (1990) 527; Phys. Rev. D42 (1990) 2388.
Figure 1. The mesonic form factors $F_1(q^2)$, $V(q^2)$, $A_1(q^2)$ and $A_2(q^2)$ relevant in rare $B \to (K, K^*)\nu\bar{\nu}$ decays as a function of the squared four-momentum $q^2$ of the $\nu\bar{\nu}$ pair. Thin lines represent the parametrization of Ref. [17], while the thick lines correspond to the results of our lattice-constrained dispersion quark picture, based on the GI – OGE model (see text and Ref. [7]).

Figure 2. (a) Branching ratios of the rare exclusive processes $B \to K\nu\bar{\nu}$ (dot-long dashed lines), $B \to K^*_L\nu\bar{\nu}$ (dashed lines) and $B \to K^*_T\nu\bar{\nu}$ (solid lines), where $K^*_L$ ($K^*_T$) stands for longitudinally (transversely) polarized $K^*$-mesons, versus the parameter $\eta$ at $\epsilon^2 = 1.25$ (see Eq. (3)). The thin and thick lines have the same meaning as in Fig. 1. (b) The same as in (a), but for the ratio $R_{K/K^*_T}$ and the transverse asymmetry $A_T$ (see Eq. (10)).
Figure 3. Differential branching ratio of the decay process $B \to K^* \nu \bar{\nu}$ (see Eqs. (7-8)) versus the missing-energy fraction $x$, calculated within the SM framework. The dot-long dashed, dashed and solid lines correspond to final $K^*$-mesons with polarization $h = 0, +1, -1$, respectively. The thin and thick lines have the same meaning as in Fig. 1.

Figure 4. Missing-energy spectrum of transversely polarized $K_T^*$-mesons produced in rare $B \to K^* \nu \bar{\nu}$ decays, calculated using our lattice-constrained dispersion quark model. In (a) the parameter $\eta$ (Eq. (8)) is fixed at the value $\eta = 0$, while the solid, dashed, dotted and dot-long dashed lines correspond to $\epsilon^2 = 1.0, 1.05, 1.25$ and 1.55, respectively. The thin and thick lines are the results obtained in case of RH and LH final $K_T^*$-mesons. In (b) the same as in (a), but at $\epsilon^2 = 1.25$ for various values of $\eta$; the dashed, solid and dot-long dashed lines correspond to $\eta = -0.25, 0.0$ and 0.25, respectively.