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Form factors in $\bar{B}^0 \to \pi^+\pi^0\ell\bar{\nu}_\ell$ from QCD light-cone sum rules

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Abstract

The form factors of the semileptonic $B \to \pi\pi\ell\bar{\nu}$ decay are calculated from QCD light-cone sum rules with the distribution amplitudes of dipion states. This method is valid in the kinematical region, where the hadronic dipion state has a small invariant mass and simultaneously a large recoil. The derivation of the sum rules is complicated by the presence of an additional variable related to the angle between the two pions. In particular, we realize that not all invariant amplitudes in the underlying correlation function can be used, some of them generating kinematical singularities in the dispersion relation. The two sum rules that are free from these ambiguities are obtained in the leading twist-2 approximation, predicting the $\bar{B}^0 \to \pi^+\pi^0$ form factors $F_\perp$ and $F_\parallel$ of the vector and axial $b \to u$ current, respectively. We calculate these form factors at the momentum transfers $0 < q^2 \lesssim 12$ GeV^2 and at the dipion mass close to the threshold $4m_\pi^2$. The sum rule results indicate that the contributions of the higher partial waves to the form factors are suppressed with respect to the lowest P-wave contribution and that the latter is not completely saturated by the ρ-meson term.

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1. Introduction

The current tendency in the studies of the flavour-changing decays of heavy hadrons is to enlarge the set of exclusive processes used for the determination of the fundamental CKM parameters. Probing different exclusive $b \to u$ processes may, in particular, help in the $|V_{ub}|$ determination. The interval of this CKM parameter obtained from the measurements of the $B \to \pi \ell \bar{\nu}_\ell$ decay, combined with the $B \to \pi$ form factors from lattice QCD or from the QCD light-cone sum rules (LCSR), deviates from the results obtained in the inclusive $B \to X_u \ell \bar{\nu}_\ell$ decay studies (see, e.g., the review [1] and references therein).

Alternative exclusive $b \to u$ processes are being actively investigated, among them the $B \to \pi\pi \ell \bar{\nu}_\ell$ decay, where the ρ-meson contribution is prominent. The semileptonic B-decay mode with the two-pion (*dipion*) final state is not only important for the $|V_{ub}|$ determination, but also has a rich set of observables (see e.g., Ref. [2]) which can be used for nontrivial tests of Standard Model. The $B \to \pi\pi \ell \bar{\nu}_\ell$ decay has already been measured, but mainly its resonant, $B \to \rho \ell \bar{\nu}_\ell$ part (see e.g., the BaBar [3] and Belle [4] Collaborations data). Significantly more detailed data on the $B \to \pi\pi \ell \bar{\nu}_\ell$ observables are expected from the Belle-2 experiment in future.

The dynamics of the $B \to \pi\pi \ell \bar{\nu}_\ell$ decay is governed by general $B \to 2\pi$ form factors, hence the calculation of these form factors is becoming the next big task for the practitioners of QCD-based methods. As discussed in Ref. [2] in detail, various non-lattice methods, from heavy-meson chiral perturbation theory to the soft-collinear effective theory are applicable, depending on the region of the Dalitz plot formed by the invariant masses of the lepton pair and dipion.

In this paper, we use the method of LCSRs [5] to calculate the $B \to 2\pi$ form factors relevant for the $\bar{B}^0 \to \pi^+ \pi^0 \ell^- \bar{\nu}_\ell$ decay. We shall confine ourselves with the charged dipion (isovector) final state, and postpone the case of the neutral (isoscalar) state with related scalar resonances for the future work. The approach we use is applicable in the region of small and intermediate lepton-pair masses, restricting simultaneously the dipion invariant mass by the $\lesssim 1$ GeV region, so that a large hadronic recoil takes place with two energetic and almost collinear pions in the B-meson rest frame.

The technique we use has many similarities with the LCSRs obtained for $B \to \pi$ form factors, but employs a different and more complicated nonperturbative input: the light-cone distribution amplitudes (DAs) of the dipion state. These universal objects have been introduced in Refs. [6, 7] to encode the hadronization of the quark-pair in the $\gamma\gamma^* \to 2\pi$ process at large momentum transfer. The properties of dipion DAs were worked out in details in Refs. [8,9]. In a different context, two-meson wave functions in hard exclusive processes were discussed earlier in Ref. [10].

In this paper we aim at the following goals. First, we demonstrate how the method works, deriving the LCSRs for the two of the $B \to \pi\pi$ form factors in the leading twist-2 approximation. The sum rules predict these form factors at large recoil and small mass of the dipion state. Second, based on this calculation, we investigate the role of higher partial waves in the $B \to \pi\pi$ form factors and assess the impact of the contributions beyond the ρ-meson in the lowest P-wave. In what follows, the derivation of LCSRs for $B \to \pi\pi$ form factors is presented in Sect. 2. In Sect. 3 we compare our predictions with the $B \to \rho$ form factors. In Sect. 4 using the available information on the chiral-odd dipion DA, we calculate the form factors numerically. Our conclusions are presented in Sect. 5. The Appendices contain some details (A) on the decay kinematics and (B) on the dipion DAs.