Nonperturbative effects in exclusive reactions $B \rightarrow K^{(*)}ll$ are discussed. Form factors which describe the main long-distance contribution to the meson transition amplitude are calculated within the dispersion formulation of the quark model: namely, the form factors in the decay region are expressed as relativistic double spectral representations through the wave functions of the initial and final mesons. The dilepton forward–backward asymmetry and the lepton polarization turn out to be largely independent of the particular choice of the quark model parameters and can be predicted with high accuracy. At the same time, these asymmetries are sensitive to the short–distance structure of the theory and might be used as a test of the Standard Model and probe of new physics.

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Rare decays of $B$ mesons induced by the flavour–changing neutral current (FCNC) transition $b \to s,d$ provide an important probe of the Standard Model (SM) and its extensions. These decays are forbidden at the tree level and occur in the lowest order through one–loop diagrams and thus open a possibility to probe at comparatively low energies the structure of the theory at high mass scales which shows through virtual particles in the loops. Thus deviations from the SM might be observed in FCNC decays long before a direct observation of the new particles. On the other hand, measurements of the FCNC processes provide bounds on the numerical values of the parameters of the models beyond the Standard Model (SM).

In order to reliably separate the short–distance effects which contain the information on the short-distance structure of the theory, nonperturbative long–distance contributions which enter the amplitudes of the exclusive rare $B$ decays should be known with sufficient accuracy. Theoretical study of these contributions encounters the problem of describing the hadron structure and this gives the main uncertainty in predictions for exclusive rare decays.

A strategy of the analysis of exclusive semileptonic $B$ decays looks as following: It is convenient to describe the $b \to s$ transition within the framework of the low–energy effective theory. Integrating out the heavy degrees of freedom one arrives at the effective Hamiltonian at the matching scale $\mu \simeq M_W$ which has the form 1)

$$ H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^\ast \sum_i C_i(\mu) O_i(\mu). \tag{1} $$

$O_i$ are the basis operators and it is the set of the the Wilson coefficients that $C_i(\mu)$ encodes all information on short–distance physics.

Next, it is necessary to go down to the hadronic scale relevant to the meson transition $\mu \simeq m_b$ in order to avoid large logarithms in the meson transition amplitudes. The QCD evolution of the Wilson coefficients from $\mu = M_W$ to $\mu = m_b$ is given by the matrix of the anomalous dimensions of the the basis operators $O_i$ 2). The 4–quark operators from the basis $O_i$ generate the long–distance contribution to the quark transition $b \to sl^+l^−$ which is mainly due to the $J/\psi$ and ψ′ resonances in the dilepton channel. The effective Hamiltonian for the transition $b \to sl^+l^−$ with a built–in long–distance contribution reads 3)

$$ H_{\text{eff}}(b \to sl^+l^−) = \frac{G_F \alpha_s}{\sqrt{2} 2\pi} V_{ts}^\ast V_{tb} \left[ \frac{-2\bar{m}_b}{q^2} C_7(m_b)(\bar{s}\sigma_{\mu\nu}q^\nu(1 + \gamma_5)b)(\bar{l}\gamma^\mu l) \right. $$

$$ + C_9^{\text{eff}}(m_b, q^2)(\bar{s}\gamma_\mu(1 - \gamma_5)b)(\bar{l}\gamma^\mu l) + C_{10}(m_b)(\bar{s}\gamma_\mu(1 - \gamma_5)b)(\bar{l}\gamma^\mu\gamma_5 l) \right] $$

where $C_9^{\text{eff}}(m_b, q^2)$ involves the effects of $\psi$ and $\psi'$. The amplitude of the reaction $B \to K(\ast)l^+l^−$ is given by the meson matrix element of the operator eq.(3). Long–distance dynamical effects related to meson formation are contained in relativistic–invariant form factors which appear in Lorentz covariant expansion of the meson amplitudes of bilinear quark currents $\bar{b}\Gamma$’s from the effective Hamiltonian (2).

Various nonperturbative theoretical approaches have been used for calculating the form factors of rare semileptonic $B \to K(\ast)l^+l^−$ decays: light–cone quark model 4), constituent quark picture 5), heavy–quark symmetry (HQS) relations 6,7), QCD Sum Rules (SR) 8,9).

The results of these nonperturbative considerations yield quite uncertain predictions for branching ratios of these decays in the SM 3,4,7–10) which hamper isolation of short–distance effects from exclusive rare $B$ decays.

We have studied the transition form factors within a dispersion formulation of the quark model (QM) 11). This formulation is based on representing the form factors as double spectral
representations in the channels of the initial and final $q\bar{q}$ pairs through the wave functions of the initial and final mesons. We start with the region $q^2 < 0$ where the double spectral densities of the form factors can be calculated from the Feynman graphs. The form factors at $q^2 > 0$ relevant to the decay processes are obtained by performing the analytical continuation in $q^2$. This procedure yields the appearance of an anomalous contribution which rises with $q^2$ and completely determines the form factor at the zero recoil point. Thus the dispersion formulation of the QM allows a direct calculation of the form factors at $q^2 > 0$ through the wave functions of the initial and final mesons once a proper spectral representation at spacelike $q$ is constructed.

However, it should be taken into account that the dispersion approach calculates only double spectral density but does not determine possible subtraction terms. To specify such terms we refer to the ideas of the HQ expansion: namely, we require the structure of the $1/m_Q$ expansion of the QM form factors in the case of meson transition induced by the heavy quark transition to be consistent with the structure of meson transition amplitudes obtained within the Heavy Quark Effective Theory (HQET). This comparison shows that no subtractions are necessary for the transition between pseudoscalar mesons, whereas some of the form factors related to the pseudoscalar-to-vector meson transition require subtractions. This is mainly explained by problems with constructing a purely $S$-wave vector state in relativistic theory.

As a result, we arrive at the form factors with the following properties: for the transition induced by the heavy-to-heavy quark transition they satisfy not only the leading-order Isgur–Wise relations but also subleading $O(1/m_Q)$ relations of the HQET provided the wave functions of heavy mesons are localized near the $q\bar{q}$ threshold with the width of order $\Lambda_{QCD}$. For the meson decay induced by the heavy-to-light quark transition the QM form factors satisfy the leading-order relations between the form factors of the vector and tensor currents.

The numerical analysis of the transition form factors for various sets of the QM parameters performed in exhibits a strong dependence of the form factors and decay rates on a choice of such parameters. This yields considerable errors in the QM predictions for the decay rates (see Table 1).

| Ref. | Decay | QM | HQS | SR | Exp. |
|------|-------|-----|-----|----|------|
|      | $B \to K^\ast \gamma$ | $(3.9 \pm 1.7) \times 10^{-5}$ | $(4.9 \pm 2.0) \times 10^{-5}$ | - | $(4.2 \pm 1.0) \times 10^{-5}$ [17] |
|      | $B \to K^{\pm} \ell^\mp$ | $(4.2 \pm 0.9) \times 10^{-7}$ | $(4.0 \pm 1.5) \times 10^{-7}$ | $2 \times 10^{-7}$ | $< 0.9 \times 10^{-5}$ [18] |
|      | $B \to K^{*} e^+ e^-$ | $(1.4 \pm 0.5) \times 10^{-6}$ | $(2.3 \pm 0.9) \times 10^{-6}$ | $0.7 \times 10^{-6}$ | $< 1.6 \times 10^{-6}$ [18] |
|      | $B \to K^{*} \mu^+ \mu^-$ | $(1.0 \pm 0.4) \times 10^{-6}$ | $(1.5 \pm 0.6) \times 10^{-6}$ | $0.7 \times 10^{-6}$ | $< 2.5 \times 10^{-6}$ [19] |

Fortunately, the dependence of the asymmetries on the QM parameters is negligible and the forward-backward asymmetry as well as lepton polarization asymmetry are predicted with high accuracy in largely model-independent way.

At the same time the asymmetries in the nonresonance regions are sensitive to the values of the Wilson coefficients and thus can be used as a test of the SM and a probe of new physics. Fig.1 shows asymmetries obtained within the SM and MSSM for various regions of the MSSM parameter space.

Notice that obtaining more accurate predictions for the exclusive distributions is also necessary in particular for the extraction of $V_{tb}$. To this end one needs a relevant choice of the
Figure 1: Forward–backward asymmetry in $B \to K^*\mu^+\mu^–$. (a) in the SM: total – solid, non-resonance – dashed. (b) in the MSSM for various values of $R_7 = C_7(M_W)_{SM}/C_7(M_W)_{MSSM}$: upper solid line – $R_7 = 1.2$, lower solid line – $R_7 = 0.4$; upper dashed line – $R_7 = -2.4$, lower dashed line – $R_7 = -4.2$. The regions between the solid and dashed lines, respectively correspond to the allowed regions of the MSSM parameter space $^{20}$. Because of a weak sensitivity of $A_{FB}$ to $C_9$ and $C_{10}$, the latter are equated to their SM values.

QM parameters. Further analysis of the semileptonic decays and new more accurate data on exclusive radiative decay $B \to K^*\gamma$ will be very helpful.

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[1] B.Grinstein, M.B.Wise and M.J.Savage, Nucl.Phys. B319 (1989) 271.
[2] A.Buras and M.Münz, Phys.Rev. D52 (1995) 186.
[3] A. Ali, preprint DESY 96-106.
[4] W.Jaus and D.Wyler, Phys. Rev. D41 (1990) 3405.
[5] B.Stech, Phys.Lett. B354(1995)447 and hep-ph/9608297.
[6] G.Burdman, Phys.Rev. D52 (1995) 6400.
[7] W. Roberts, Phys.Rev. D54 (1996) 863.
[8] P.Colangelo, F.De Fazio, P.Santorelli and E.Scrimieri, Phys.Rev. D53 (1996) 3672.
[9] T.M. Aliiev, A.Ozpineci and M.Savci, hep-ph/9612480 and hep-ph/9702209.
[10] C.Q.Geng and C.P.Kao, Phys.Rev. D54 (1996) 5636.
[11] D. Melikhov, Phys.Rev. D53 (1996) 2460; Phys.Lett. B380 (1996) 363, B394 (1997) 385.
[12] D.Melikhov, N.Nikitin, hep-ph/9609503.
[13] N.Isgur and M.B. Wise, Phys.Lett. B232 (1989) 113; B237 (1990) 527.
[14] M. Luke, Phys. Lett. B252 (1990) 447.
[15] N.Isgur and M.B.Wise, Phys.Rev. D42 (1990) 2388.
[16] D.Melikhov, N.Nikitin, and S.Simula, hep-ph/9704266.
[17] CLEO collaboration (R.Ammar et al), CLEO CONF 96-05 (1996).
[18] T. Skwarnicki, hep-ph/9512399.
[19] CDF collaboration (T.Speer et al.), FERMILAB CONF-96/320-E (1996).
[20] P.Cho, M.Misiak, and D.Wyler, Phys.Rev.D54 (1996) 3329.