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DECAYS OF *B* MESON, SUPERSYMMETRY AND POLARIZATION

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In present work we discuss the usage of the set of *B* meson decays for testing Standard Model and its supersymmetric extensions. We select here the group of *B* decay modes, which are sensitive to new physics effects and collect some crucial data on branching ratios, showing the lack of correspondence for several orders of magnitude between supersymmetric model and Standard Model results, thus giving an undisputable evidence for supersymmetric extensions. Also the role of *B* meson system in confirmation of the factorization hypothesis is reflected here.
KEYWORDS : *B* meson, tests of Standard Model, supersymmetric extensions, branching ratios of *B* decays, polarization in *B* decays, factorization hypothesis.

Nowadays considerable theoretical attention has been focused on *B* meson system in scope of using it for testing Standard Model of elementary particles (plus Standard Model predictions at loop level) and various Standard Model extensions, especially two Higgs doublet model and Minimal Supersymmetric extension of the Standard Model. Much work was done on both nonleptonic and leptonic decays,

$$B \to X\gamma, B \to Xl^+l^-, B \to \gamma\gamma, B \to l^+l^-, B \to \gamma l^+l^-,$$

but the last one are now in more rapt heed because of there relative cleanliness and sensitivity to new physics beyond the Standard Model [1]. These rare *B* decays with the new momentum, which are induced by the flavor changing neutral current, are expected to be observed on future *B* meson factories and fixed target machines, which likely to measure branching fractions as low as 10^{-8}.

TESTS OF STANDARD MODEL EXTENSIONS

The calculations of the branching ratios of flavor changing neutral current processes are sensitive to new physics beyond Standard Model. They are calculated in the Minimal Supersymmetric extension of the Standard Model in the set of works, but nothing spectacularly different from Standard Model happens to the theoretical predictions, except sizable changes that can occur for some regions of the parameter space in the Minimal Supersymmetric extension of the Standard Model. In addition, the *B* decay processes can be also used in more precise determination of the Cabibbo-Kobayashi-Maskawa matrix elements, in extracting information about some hadronic parameters, such as the leptonic decay constants f_{B_s} and f_{B_d}, which are yet poorly known [2], and certainly in searching for new sources of CP violation, but we won't discuss it here.

Pure and radiative leptonic *B* decays in the frame of Standard Model

In Standard Model it is difficult to determine decay constants from pure leptonic decays of heavy pseudoscalar mesons into light lepton pairs because they are helicity suppressed and their branching ratio are of the order of 10^{-9} for $B_s \to \mu^+\mu^-$, and 10^{-14} for $B_s \to e^+e^-$. For B_d the situation is even worse due to the smaller Cabibbo-Kobayashi-Maskawa angle. And although the process $B_s \to \tau^+\tau^-$ is free from helicity suppression and its branching ratio is around $8\cdot 10^{-7}$ in the Standard Model, it is likely to be compatible with the decays into lepton pairs only when its efficiency is better than 10^{-2} [3], and thus this decay can be measured in future *B*-factories with high enough efficiency.

If a photon is emitted in addition to the lepton pair, then the mechanism of helicity suppression will not hold any longer and larger branching ratios are expected. Indeed, in [4] it was shown that the branching ratio for $B_s \to e^+e^-\gamma$ is approximately $2.35\cdot 10^{-9}$. In $B_s \to \tau^+\tau^-\gamma$ decay the contribution of the diagrams, where photon is radiated from the final τ-leptons, cannot be neglected, since the mass of the τ-lepton is not so much smaller than that of the *B* meson. And when only short (short and long together) distance contributions are taken into account, the Standard Model branching ratio is found as $9.54\cdot 10^{-9}$ $(1.52\cdot 10^{-8})$, for the value of the cut $\delta=0.01$ imposed on the photon energy [5].

In the constituent quark model the branching ratios for $B_s \to \mu^+\mu^-\gamma$ turn out to be around $5\cdot 10^{-9}$ and for $B_d \to \mu^+\mu^-\gamma$ around $6\cdot 10^{-10}$ [6].

Studies within the light-front model in Standard Model give for the decays $B_{s(d)} \to l^+l^-\gamma(l=e,\mu,\tau)$ the following values respectively: *7.1·10^{-9}(1.5·10^{-10}), 8.3·10^{-9}(1.8·10^{-10}), 1.6·10^{-8}(6.2·10^{-10})* [7].

Therefore, any prediction on the branching ratios in the framework of the above mentioned approaches is strongly model dependent, so, to draw full picture: if $B_{s(d)} \to l^+l^-\gamma(l=e,\mu,\tau)$ processes are investigated in a model independent way, namely, within the framework of the light cone Quantum Chromodynamics sum rules method, the results are [8]:

$$Br\left(B_s \to e^+e^-\gamma\right)=2.35\cdot 10^{-9}, Br\left(B_s \to \mu^+\mu^-\gamma\right)=1.9\cdot 10^{-9},$$
$$Br\left(B_d \to e^+e^-\gamma\right)=1.5\cdot 10^{-10}, Br\left(B_d \to \mu^+\mu^-\gamma\right)=1.2\cdot 10^{-10}.$$

_B_ decays in various Standard Model extensions

Now turn to the investigation of new physics effects in *B* meson decays using the Minimal Supersymmetric extension of the Standard Model and two Higgs doublet models. We will now list the most important results that have occurred in recent years on topic that we are discussing here.

Dileptonic pure decays of B_s meson into channels of e^+e^- and $\mu^+\mu^-$ are suppressed in the Quantum Chromodynamics corrected Standard Model due to the vector and axial nature of the coupling to lepton bilinears. Therefore, in supersymmetric theories with large *tanβ*, contributions to the amplitude arising out of exchange of neutral Higgs Bosons considerably enhances the decay of B_s into l^+l^-. In some region of parameter space, the enhancement is more than two orders of magnitude, bringing it well within experimental possibilities in the near future [9].

The processes $B \to X_s l^+l^-$ and $B_s \to l^+l^-\gamma$ have been already examined in the Minimal Supersymmetric extension of the Standard Model with large *tanβ*. Taking into account the gluino-loop and neutralino-loop effects, it was found that for a large *tanβ* the neutral Higgs exchanging diagrams could enhance $Br\left(B \to X_s\tau^+\tau^-\right)$ by a factor of 5 and $Br\left(B_s \to \tau^+\tau^-\gamma\right)$ by a couple of orders in some part of supersymmetric parameter space allowed by current experiments such as $b \to s\gamma$, $B_s \to K^{(*)}l^+l^-$ and $B_s \to l^+l^-$ [10]. The forward-backward asymmetry and the distributions of the differential branching ratios are also found to differ significantly from the Standard Model results. Such enhanced branching ratios reach the level of 10^{-5} and thus might be observable in the new generation of *B* experiments.

In [11] the exclusive $B \to l^+l^-\gamma$ decay is investigated using the general two Higgs doublet model (model III) including the neutral Higgs boson effects with an emphasis on possible CP-violating effects. Authors analyze the dependencies of the forward-backward asymmetry of the lepton pair, CP-violating asymmetry in forward-backward asymmetry, and they observe that physical quantities, which describes these asymmetries, are sensitive to the model parameters and neutral Higgs boson effects are quite sizable for some values of the coupling $\bar{\xi}^D_{N,\tau\tau}$. As for effects of the Minimal Supersymmetric extension of the Standard Model on various kinematical distributions in the radiative dileptonic decay $B_s \to l^+l^-\gamma$, they can be found in [12]. The forward-backward asymmetry of the lepton pair, and the various polarization asymmetries of both final state leptons and polarization effects of the final state photon are studied there.

The dependence of the differential branching ratio on the photon energy and the branching ratio on the two Higgs doublet model parameters, $m_{H^\pm}$ and *tanβ* in $B \to \tau^+\tau^-\gamma$ decay is investigated in [13]. There is an enhancement in the predictions of the two Higgs doublet model compared to the Standard Model case. It was also observed that contributions of neutral Higgs bosons to the decay are sizable when *β* is large.

Branching fractions of $B_{s,d} \to l^+l^-$ in the type-II two-Higgs-doublet model with large *tanβ* are computed in [14]. The parameters of the neutral Higgs sector of the two Higgs doublet model cancel in the result, so that the branching fractions depend only on the charged Higgs mass and *tanβ*. For large values of *tanβ* and a charged Higgs mass above the bound from $b \to s\gamma$, authors find that the branching fractions can be enhanced by up to an order of magnitude or suppressed by up to a factor of two compared to the Standard Model result.

The CP violating asymmetry in $B \to X_d l^+l^-$ were considered in [15]. Also there the calculation is made for branching ratio in general two Higgs doublet model with extra phase angle in the charged-Higgs-fermion coupling.

As regards $B \to X_s\mu^+\mu^-$ processes, in supersymmetric models the large supersymmetric contributions to it come from the Feynman diagrams which consist of exchanging neutral Higgs bosons and the chargino-stop loop and are proportional to $m_b m_\mu \tan^3\beta / m_h^2$ when *tanβ* is large and the mass of the lightest neutral Higgs boson m_h is not too large (say, less than *150 GeV*). Numerical results show that the branching ratios of $B \to X_S \mu^+\mu^-$ can be enhanced by more than *100%* compared to the Standard Model and the backward-forward asymmetry of lepton is significantly different from that in Standard Model when $tan\beta \geq 30$ [16].

Decay rate asymmetry in the inclusive decay $B \to X_S \gamma$, assuming the supersymmetric Standard Model based on *N = 1* supergravity, is discussed in [17]. This decay rate is predicted there to be much larger than by Standard Model (the Standard Model prediction is less than 0.01) in a wide region of the parameter space allowed by experiments and compatible with them. It happens due to the new interactions for the b quark which appear in supersymmetric Standard Model and which sizably induce processes of flavor-changing neutral current and of CP violation. Its magnitude can be maximally around *0.1*, which will be well accessible at *B* factories. Thus supersymmetry here may be revealed.

As for nonleptonic *B* decays, such as $B \to \phi K$ and $B \to \phi K^*$, which involve $b \to s\bar{s}s$ transitions, they are forbidden to first order in the Standard Model, but proceed by second order loop diagrams (penguin and box diagrams), which lead to the flavor changing neutral current transition $b \to s$. These processes provide information on the Cabibbo-Kobayashi-Maskawa matrix elements V_{ts} and are sensitive to physics beyond the Standard Model such as *R*-parity violating Supersymmetry contributions to $b \to s\bar{s}s$ [18]. They can also be used to perform independent measurements of the CP-violating parameter $\sin 2\varphi_1$ [19].

To illustrate indisputable discrepancy between Standard Model and its extensions predictions have a look on Fig.1 and Fig.2 [20]:

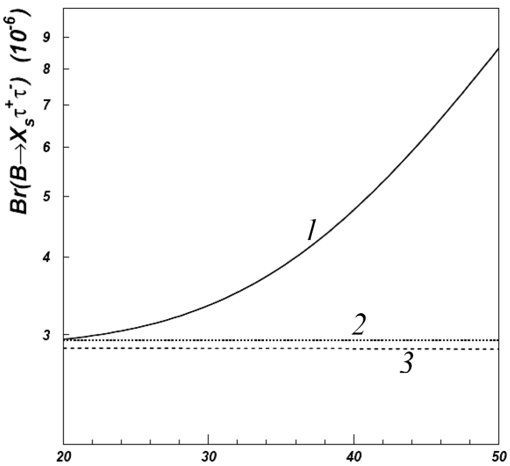

Fig.1. Branching ratio of $B \to X_s \tau^+\tau^-$ versus $\tan\beta$.

1. The Minimal Supersymmetric Standard Model prediction with the contributions of the gluino and neutralinos.
2. The Standard Model prediction
3. The Minimal Supersymmetric Standard Model prediction without the contributions of the gluino and neutralinos.

(The parameter space is specified as $m_A = 899 GeV$, the masses of the sparticles are dependent on the value of $\tan\beta$)

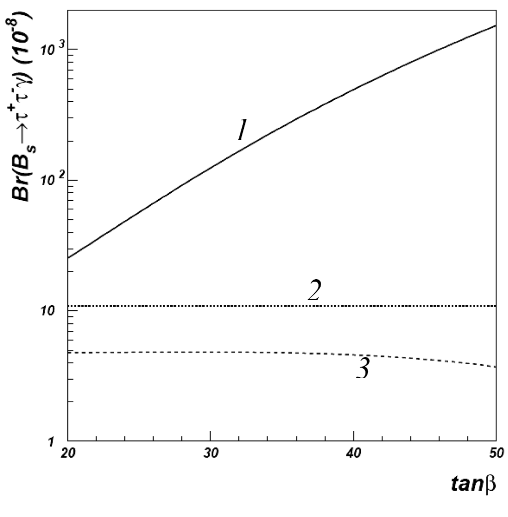

Fig.2. The same as Fig.1, but for $B_s \to \tau^+\tau^-\gamma$.

Thus listed above features and special nature of some modes of *B* decays can be used, in theory, to reveal new physics beyond the Standard Model as soon as new *B* factories will be put in operation.

POLARIZATION IN B DECAYS

Examination of the polarization in B meson decays into two vector mesons can be used for test of factorization hypothesis, widely used in heavy-quark physics for hadronic two-body decays, which assumes that the two hadronic currents in hadronic decays may be treated independently of each other, neglecting final-state interactions, and the validity of which has not been demonstrated by any rigorous theoretical calculation. This test was suggested by Körner and Goldstein [21]. The idea is that, under the factorization hypothesis, certain hadronic decays are analogous to similar semileptonic decays evaluated at a fixed value of the momentum transfer, $q^2 \equiv M^2_{l\overline{\nu}}$. For instance, the polarization of the D^{*+} meson in $\overline{B^0} \to D^{*+}\rho^-$ should equal that in $\overline{B^0} \to D^{*+}l^-\overline{\nu}$ at $q^2 \equiv M^2_{\rho}$. Specifically,

$$\frac{\Gamma_L}{\Gamma}\left(\overline{B^0} \to D^{*+}\rho^-\right) = \frac{\Gamma_L}{\Gamma}\left(\overline{B^0} \to D^{*+}l^-\overline{\nu}\right)_{q^2 \equiv M^2_{\rho}},$$

where Γ_L/Γ is the fraction of longitudinal polarization. Using three complex helicity amplitudes H_0, H_+, H_-, which define differential decay rate for two-particle decay, the longitudinal and transverse polarization can be defined as

$$\frac{\Gamma_L}{\Gamma} = \frac{|H_0|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2},$$

and

$$\frac{\Gamma_T}{\Gamma} = 1 - \frac{\Gamma_L}{\Gamma}.$$

In [22] new results concerning the fraction of longitudinal polarization in $\overline{B^0} \to D^{*+}\rho^-$ and $B^- \to D^{*0}\rho^-$ are presented. The first one is found to be consistent with that in $\overline{B^0} \to D^{*+}l^-\overline{\nu}$ at $q^2 \equiv M^2_{\rho}$. The longitudinal polarization in the B^- mode is similar, namely

$$\frac{\Gamma_L}{\Gamma}\left(B^- \to D^{*0}\rho^-\right) = 0.892 \pm 0.018 \pm 0.016,$$

$$\frac{\Gamma_L}{\Gamma}\left(\overline{B^0} \to D^{*+}\rho^-\right) = 0.885 \pm 0.016 \pm 0.012.$$

These results are in good agreement with the heavy quark effective theory prediction of 0.895±0.019 [23] using factorization and the measurements of the semileptonic $\overline{B^0} \to D^{*+}l^-\overline{\nu}$ form factors [24], thus indicating that the factorization approximation works well at the level of the current uncertainties at relatively low q^2.

It was possible that the factorization assumption of no final state interactions may be simplistic and inapplicable to modes of higher q^2 (than low q^2 mode $\overline{B^0} \to D^{*+}\rho^-$) such as $\overline{B^0} \to D_s^{*+}D^{*-}$. However, the measured D_s^{*+} longitudinal polarization with high q^2, $\Gamma_L/\Gamma = 0.506 \pm 0.139 \pm 0.036$ [25], is also consistent with the factorization prediction of 0.54 (Fig.3).

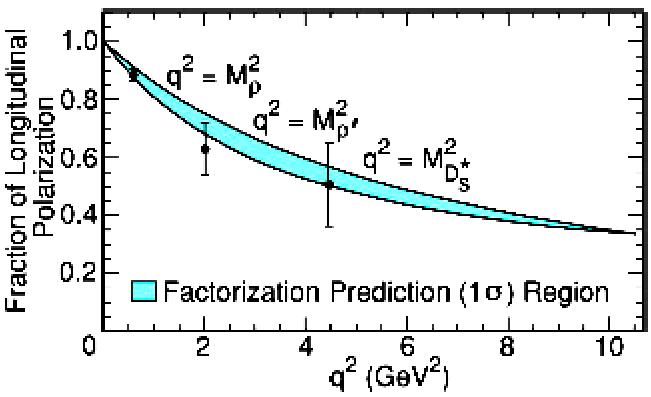

Fig. 3. The fraction of longitudinal polarization in $\overline{B^0} \to D^{*+}X$ decays as a function of $q^2 \equiv M^2_X$ (where X is a vector meson).
Shown are the current $\overline{B^0} \to D^{*+}\rho^-$ polarization measurement, and earlier measurements of $\overline{B^0} \to D^{*+}\rho'^-$ [26], and $\overline{B^0} \to D_s^{*+}D^{*-}$ [25]. The shaded region represents the prediction using factorization and heavy quark effective theory, and extrapolating from the semileptonic $\overline{B^0} \to D^{*+}l^-\overline{\nu}$ form factor results [24]. The shaded contour shows a one standard deviation variation in the theoretical prediction.

Also the longitudinal polarization in $\overline{B^0} \to D^{*+}D^{*-}$ mode is $\Gamma_L/\Gamma = 0.063 \pm 0.055 \pm 0.009$ [27], what is very close to the theoretical prediction of 6% [28], what, in addition, indicates the validity of factorization hypothesis.

As for the lepton transverse polarization in three body semileptonic heavy meson decays to pseudoscalar mesons and to vector mesons, studied in heavy quark effective limit, for example muon polarization, it can be of order 10%, while τ polarization can even approach unity. It is also shown that lepton polarization in decays to vector mesons, unlike in decays to pseudoscalars, can get contributions from left-right models. Unfortunately, lepton polarization in that case is proportional to $W_L - W_R$ mixing, and is thus small [29].

Polarization of the vector particle in semileptonic decay can be used as a measure of Cabibbo-Kobayashi-Maskawa quark-mixing matrix elements. $|V_{cb}|$ can be determined from the measurement of polarization of vector meson in $\overline{B}, \overline{B}_C \to Vl\overline{v}$ decay, where V is vector meson [30].

Polarization in B meson decay can be also used for measuring CP violation. If the *B* meson decay is strongly polarized than it is very suitable to use polarization measurements to project out the CP-even and CP-odd states statistically from the decay. So the decay $B \to \psi K^*$ is polarized with $\Gamma_L/\Gamma = 0.80 \pm 0.08 \pm 0.05$ [31] and therefore this mode will be useful for measuring CP violation. For these purposes also very suitable is $B^0 \to D^{*-}\rho^+$ mode with mentioned above polarization.

CONCLUSIONS

The study of *B* mesons continue to be one of the most productive fields in particle physics and is still full of surprises. The coming years look equally promising, because each of the asymmetric *B* factory experiments, Belle and BABAR, has accumulated data samples well over *100 fb^{-1}*. Also Run II at Fermilab has began and new results from CDF and D0 can be expected soon. These experiments promise a rich spectrum of rare and precision measurements that have the potential to affect fundamentally our understanding of the Standard Model and, at the same time, can serve for establishing new physics as Minimal Supersymmetric extension of the Standard Model or general two Higgs Doublet Model.

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РАСПАДЫ *B* МЕЗОНА, СУПЕРСИММЕТРИЯ И ПОЛЯРИЗАЦИЯ

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В настоящей работе мы обсуждаем использование ряда распадов *B* мезона для тестирования Стандартной модели и её суперсимметричных расширений. Мы выделяем здесь группу мод распада *B* мезона, которая чувствительна к эффектам, указывающим на новую физику, и собираем особо значимые данные по относительным ширинам распада, свидетельствующие о расхождениях на несколько порядков по величине между результатами Стандартной Модели и её суперсимметричных расширений, подтверждая таким образом справедливость последних. Также обсуждается роль *B* мезона в подтверждении гипотезы о факторизации.

КЛЮЧЕВЫЕ СЛОВА: *B* мезон, тесты Стандартной Модели, суперсимметричные расширения, коэффициенты ветвления, поляризация в *B* распадах, гипотеза о факторизации.