B Physics in the LHC Era: Selected Topics

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Abstract

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B Physics in the LHC Era: Selected Topics

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We have just entered a new round in the testing of the flavour sector of the Standard Model through high-precision measurements of \( B \)-meson decays. A particularly exciting aspect is the exploration of the \( B_s \)-meson system at LHCb. We focus on two particularly promising probes of new physics which may give us first solid evidence for New Physics at the LHC: the strongly suppressed rare decay \( B^0_s \to \mu^+\mu^- \) and CP-violating effects in the \( B^0_s \to J/\psi\phi \) channel. We discuss recent theoretical developments related to these measurements and shall also sketch other highlights of the \( B \)-physics programme in the LHC era.

1. WHERE DO WE STAND?

In the last decade, we have obtained many valuable new insights into flavour physics and CP violation through the interplay between theory and the data from the \( B \) factories and the Tevatron. The lessons from the data collected so far is that the Cabibbo–Kobayashi–Maskawa (CKM) matrix is the dominant source of flavour and CP violation. New effects could not yet be established, although there are potential signals which are still not conclusive.

The implications for the structure of New Physics (NP) is that we may actually have to deal with a large characteristic NP scale \( \Lambda_{NP} \), i.e. a scale that is not just \( \sim \) TeV, or/and that symmetries prevent large NP effects in flavour-changing neutral-current (FCNC) processes, where the most prominent example is “minimal flavour violation” (MFV). It should be emphasized that MFV is still far from being experimentally established, and that there are various non-MFV scenarios with room for sizable NP effects. Prominent examples are supersymmetry, models with a 4th generation, warped extra dimensions, or \( Z' \) models. Nevertheless, we have to be prepared to deal with smallish NP effects in flavour probes.

The key problem in the use of quark-flavour physics as a probe of NP is related to the impact of strong interactions, leading to process-dependent, non-perturbative “hadronic” parameters in the corresponding calculations. A closer look shows that the \( B \)-meson system is actually a particularly promising probe: we have simplifications thanks to the large \( b \)-quark mass \( m_b \sim 5 \text{ GeV} \gg \Lambda_{QCD} \), there are strategies to determine hadronic parameters from data with the help of flavour-symmetry arguments, and there are tests of SM relations that could be spoiled by NP. There are two attractive ways for NP to manifest itself in \( B \) decays: contributions at the decay amplitude level to rare (FCNC) processes, and through contributions to \( B^0_q \to \bar{B}^0_q \) mixing (\( q \in \{d,s\} \)).

In the following discussion, we shall focus on two topics: in Section 2, we have a closer look at the rare decay \( B^0_s \to \mu^+\mu^- \), with a focus on a new strategy for the branching ratio measurement proposed in Ref. [1], while we focus in Section 3 on the CP violation in \( B^0_s \to J/\psi\phi \), having in particular a critical look at the picture emerging in the Standard Model (SM) [2]. In Section 4 we sketch other interesting \( B \) decays, and give a brief outlook in Section 5.

2. SEARCH FOR NP IN \( B^0_s \to \mu^+\mu^- \)

The decay \( B^0_s \to \mu^+\mu^- \) originates from \( Z \) penguins and box diagrams in the SM, and the corresponding low-energy effective Hamiltonian takes the following form [3]:

\[
H_{\text{eff}} = - \frac{G_F}{\sqrt{2}} \left[ \frac{\alpha}{2\pi\sin^2\Theta_W} \right] \times V^*_{tb} V_{ts} \eta Y_{\epsilon}(x_t)(\bar{b}s)(\bar{\mu}\mu)_{V-A}, \tag{1}
\]
where $\alpha$ is the QED coupling, $\Theta_W$ is the Weinberg angle, $\eta_\gamma$ describes short-distance QCD corrections, and $Y_\nu(x_t = m_\nu^2/M_W^2)$ is an “Inami–Lim function”. Concerning the hadronic sector, only $\langle 0| (b s)_{V-A}| B_s^0 \rangle$, i.e. the $B_s$ decay constant $f_{B_s}$, enters so that the $B_s^0 \rightarrow \mu^+ \mu^-$ channel belongs to the cleanest rare $B$ decays. Using the data for the mass difference $\Delta M_s$ to trade $f_{B_s}$ into the bag parameter $\hat{M}_s$ yields

$$\frac{\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)}{\Delta M_s} = 4.4 \times 10^{-10} \frac{\tau_{B_s} Y^2(\nu)}{B_s S(\nu)}, \quad (2)$$

which holds in MFV models, and gives for the SM

$$\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.6 \pm 0.4) \times 10^{-9}, \quad (3)$$

where the error is fully dominated by $\hat{M}_s$ coming from lattice QCD [4]. As is well known, this branching ratio may be significantly enhanced through NP (see Ref. [4] and references therein). The present 95% C.L. upper bounds from CDF and DØ are still about one order of magnitude above the SM prediction in (3) and read as $4.3 \times 10^{-8}$ [5] and $5.1 \times 10^{-8}$ [6], respectively.

The measurement of $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$ at LHCb will rely on normalization channels such as $B_s^+ \rightarrow J/\psi K^+$, $B_s^0 \rightarrow K^+ \pi^-$ and/or $B_s^0 \rightarrow J/\psi K_s$. Therefore, $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)$ will be measured using these decays for the determination of $f_{d}/f_{s}$ (4)

$$\text{BR}(B_s \rightarrow \mu^+ \mu^-) = \text{BR}(B_q \rightarrow X) \frac{f_a}{f_s} \frac{\epsilon_X}{\epsilon_{\mu\mu}} \frac{N_{\mu\mu}}{N_X}, \quad (4)$$

where the $\epsilon$ are total detector efficiencies and the $N$ denote the observed numbers of events. The $f_q$ are fragmentation functions, which describe the probability that a $b$ quark fragments in a $B_q$ ($q \in \{u, d, s\}$). A closer look shows that $f_d/f_s$ is actually the major source of uncertainty, limiting the ability to detect a 5$\sigma$ deviation from the SM at LHCb to $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) > 11 \times 10^{-9}$ (assuming an uncertainty of 13% for $f_d/f_s$) [7].

Since the determinations of $f_d/f_s$ are not sufficient to meet the high precision at LHCb, a new strategy to measure this quantity at LHCb was proposed in Ref. [8]. The starting point is

$$\frac{N_d}{N_s} = \frac{f_s}{f_d} \frac{\epsilon(B_s \rightarrow X_1)}{\epsilon(B_d \rightarrow X_2)} \frac{\text{BR}(B_s \rightarrow X_1)}{\text{BR}(B_d \rightarrow X_2)}; \quad (5)$$

knowing the ratio of the branching ratios, we could obviously extract $f_d/f_s$ experimentally. In order to implement this feature in practice, the $B_s \rightarrow X_1$ and $B_d \rightarrow X_2$ decays have to satisfy the following requirements:

- the ratio of their branching ratios must be easy to measure at LHCb;
- the decays must be robust with respect to the impact of NP contributions;
- the ratio of their BRs must be theoretically well understood within the SM.

These requirements guide us to the $B_s^0 \rightarrow D^+ K^-$ and $B_s^0 \rightarrow D_s^+ \pi^-$ channels, which receive only contributions from colour-allowed tree-diagram-like topologies, as can be seen in Fig. 1. Their hadronic amplitudes are related to each other by the $U$-spin symmetry of strong interactions, and the decays are known as prime examples of decays where “factorization” is expected to hold:

$$A(B_s^0 \rightarrow D_s^+ \pi^-) = \frac{G_F}{\sqrt{2}} V_{qs} V_{cb}$$

$$\times a_1(D_s P) f_P F_0^{(q)}(m_P^2)(m_{B_s}^2 - m_{D_s}^2). \quad (6)$$

This feature could be put on a rigorous theoretical basis in the heavy-quark limit [8-9]. In QCD factorization, $a_1$ is found as a quasi-universal quantity $|a_1| \approx 1.05$ with very small process-dependent “non-factorizable” corrections [8].

So far, this interesting feature did not have any practical application. However, we can actually use these decays for the determination of $f_d/f_s$.
at LHCb. On the one hand, we have
\[
\frac{\text{BR}(B_s^0 \rightarrow D_s^+\pi^-)}{\text{BR}(B_d^0 \rightarrow D^+K^-)} \sim \frac{\tau_{B_s}}{\tau_{B_d}} \left( \frac{V_{us}}{V_{u_s}} \right)^2 \times \left( \frac{f_s}{f_K} \right)^2 \frac{F_0^{(s)}(m_{\pi}^2)}{F_0^{(d)}(m_{K}^2)} \left[ \frac{a_1(D_s\pi)}{a_1(D_dK)} \right]^2,
\]
while the ratio of the number of signal events observed in the experiment is given by
\[
\frac{N_{D_s\pi}}{N_{D_dK}} = \frac{f_s}{f_d} \frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}} \frac{\text{BR}(B_s^0 \rightarrow D_s^+\pi^-)}{\text{BR}(B_d^0 \rightarrow D^+K^-)}.
\]
Consequently, we obtain
\[
\frac{f_s}{f_d} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[ \frac{N_{D_s\pi}}{N_{D_dK}} \frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}} \right]^{1/2},
\]
with
\[
N_a = \left| \frac{a_1(D_s\pi)}{a_1(D_dK)} \right|^2, \quad N_F = \left| \frac{F_0^{(s)}(m_{\pi}^2)}{F_0^{(d)}(m_{K}^2)} \right|^2.
\]

The $B_s^0 \rightarrow D_s^+\pi^-$ and $B_d^0 \rightarrow D^+K^-$ decays can be exclusively reconstructed with the help of the $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^+ \rightarrow K^+\pi^+\pi^+$ transitions, respectively. Since both channels are selected with an identical flavour final state containing the four charged hadrons $KK\pi\pi$, the uncertainty on $\epsilon_{D_s\pi}/\epsilon_{D_dK}$ is small. Using a toy Monte Carlo simulation to generate a 0.2 fb$^{-1}$ sample yields about 5500 $B_s^0 \rightarrow D_s^+\pi^-$ and 1100 $B_d^0 \rightarrow D^+K^-$ events, resulting in an error of 7.5% for $r \equiv (\epsilon_{D_s\pi}N_{D_dK})/(\epsilon_{D_dK}N_{D_s\pi})$. Here the dominant uncertainty comes from $\text{BR}(D_s \rightarrow K^+K^-\pi^+) = (5.50 \pm 0.28)\%$. Extrapolating to 1 fb$^{-1}$, which corresponds to the end of 2011, the statistical uncertainty becomes essentially negligible so that the total uncertainty is reduced to $\Delta r \sim 5.6\%$.

Concerning the theoretical uncertainties, we have to deal with non-factorizable $U$-spin-breaking effects, which are described by
\[
N_a \approx 1 + 2\Re(a_1^{\text{NF}}(D_s\pi) - a_1^{\text{NF}}(D_dK)).
\]
Here $a_1^{\text{NF}}$ is associated with non-universal, i.e. process-dependent, non-factorizable contributions, which cannot be calculated reliably. However, they arise as power corrections to the heavy-quark limit, i.e. they are suppressed by at least one power of $\Lambda_{\text{QCD}}/m_b$, and are – in the decays at hand – numerically expected at the few percent level \[8\]. Moreover, since we are only sensitive to an $SU(3)$-breaking difference, 1 – $N_a$ is conservatively expected to be at most a few percent. In this context, it is important to emphasize that we can also experimentally test factorization, as discussed in detail in Ref. \[1\].

The major uncertainty affecting \[9\] is hence the form-factor ratio $N_F$, where $U$-spin-breaking corrections arise from $d$ and $s$ spectator-quark effects. Unfortunately, the $B_s \rightarrow D_s$ form factors have so far received only small theoretical attention. In Ref. \[10\], such effects were explored using heavy-meson chiral perturbation theory, while QCD sum-rule techniques were applied in Ref. \[11\]. The numerical value given in the latter paper yields $N_F = 1.3 \pm 0.1$. If we assume $N_F > 1$ (as the radius of the $B_s^0$ is smaller than that of the $B_d^0$), we obtain the following lower bound
\[
\text{BR}(B_s^0 \rightarrow \mu^+\mu^-) > \text{BR}(B_s^0 \rightarrow \mu^+\mu^-)_0, \quad \text{assumes } N_F = 1,
\]
which offers an interesting probe for NP. In order to match experiment, it is sufficient to calculate the $U$-spin-breaking corrections to $F_0^{(s)}(m_{\pi}^2)/F_0^{(d)}(m_{K}^2)$ with non-perturbative methods, such as lattice QCD, at the level of 20%, which should be feasible soon.

In Fig. 2, we illustrate the NP discovery potential of the $B_s^0 \rightarrow \mu^+\mu^-$ channel at LHCb resulting
from the strategy proposed in Ref. [1]. Here we show the smallest value of $\text{BR}(B_s^0 \to \mu^+ \mu^-)$ that allows the detection of a 5σ deviation from the SM as a function of the luminosity at LHCb (at the nominal beam energy of 14 TeV). The figure on the left-hand side shows the low-luminosity regime, whereas the one on the right-hand side illustrates the asymptotic behaviour. The plot on the right-hand shows that we obtain a NP discovery potential about twice as large as the present LHCb expectation [7] (upper horizontal line) enabling a possible discovery of NP down to $\text{BR}(B_s^0 \to \mu^+ \mu^-) > 6 \times 10^{-9}$ (lower horizontal line). In addition to the increased sensitivity in the regime of low branching ratios, even for large values close to the current CDF exclusion limit the significance of a possible NP discovery would be increased. Thanks to the decrease of the systematical uncertainty, LHCb will be able to fully exploit the statistical improvement, taking full advantage of the accumulated LHCb data up to 10 fb$^{-1}$, which corresponds to five years of nominal LHCb data taking. The value of $f_d/f_s$ is not only crucial for the measurement of $\text{BR}(B_s^0 \to \mu^+ \mu^-)$ but enters the measurement of any $B_s$ branching ratio at LHCb.

3. SEARCH FOR NP IN $B_s^0 \to J/\psi\phi$

The $B_s^0 \to J/\psi\phi$ channel is the $B_s$-meson counterpart of the $B_d^0 \to J/\psi K_S$ decay. NP may well manifest itself in CP-violating phenomena in $B_s^0 \to J/\psi\phi$ through contributions to $B_s^0$-$\bar{B}_s^0$ mixing, yielding a mixing phase $\phi_s$ different from the doubly Cabibbo-suppressed SM value $\phi_s^{SM} \approx -2^\circ$; since the final state of $B_s^0 \to J/\psi\phi$ is an admixture of CP-even and CP-odd eigenstates, a time-dependent angular analysis is required to search for NP effects [12]. The most recent compilation of the corresponding results by the CDF and DØ collaborations can be found in Refs. [13] and [14], respectively. Unfortunately, the situation is not conclusive, though the CDF and DØ analyses are consistent with each other. While CDF finds $\phi_s \in [-59.6^\circ, -2.29^\circ] \sim -30^\circ \vee [-177.6^\circ, -123.8^\circ] \sim -150^\circ$ (68% C.L.), DØ gives a best fit value around $\phi_s \sim -45^\circ$, taking also information from the dimuon charge asymmetry and the measured $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ branching ratio into account.

The experimental prospects for the analysis of $B_s^0 \to J/\psi\phi$ at LHCb are very promising. With 2 fb$^{-1}$, an experimental uncertainty of $\sigma(\phi_s)_{\text{exp}} \sim 1^\circ$ can be achieved, which could be reached at an LHCb upgrade with an integrated luminosity of 100 fb$^{-1}$ to $\sigma(\phi_s)_{\exp} \sim 0.2^\circ$.

So far, the SM penguin effects were fully neglected in the analysis of the CP violation in the $B_s^0 \to J/\psi\phi$ channel:

$$\xi_{f(\psi\phi)} \propto e^{-i\phi_s} [1 - 2i \lambda^2 a_f e^{i\theta_f} \sin \gamma + O(\lambda^4)],$$  \hspace{1cm} (13)

where $a_f e^{i\theta_f}$ describes the ratio of penguin to tree contributions for a given final-state configuration $(J/\psi\phi)f$. In Ref. [2], a detailed discussion of their impact was given, proposing also a strategy to control these penguin effects through data. The penguin contributions modify the expression for the mixing-induced CP violation $\hat{A}_{M}^f$ as follows:

$$\eta_f \hat{A}_{M}^f / \sqrt{1 - (\hat{A}_{M}^f)^2} = \sin(\phi_s + \Delta\phi_s^f),$$  \hspace{1cm} (14)

where $\eta_f$ is the CP eigenvalue of the final-state configuration, $\hat{A}_{M}^f$ is a direct CP asymmetry (which can be measured), and $\Delta\phi_s^f$ is a hadronic phase shift caused by the penguin contributions, which can be expressed in terms of $a_f$ and $\theta_f$ as given in Ref. [2]. It should be stressed that $\Delta\phi_s^f$ does not depend on the value of $\phi_s$ itself. In Fig. 3, we show the resulting dependence of $\Delta\phi_s^f$...
on the penguin parameter $a_f$ for various values of $\theta_f$. We observe that $\Delta \phi'_f$ is of the same size as $\phi'_s^{SM}$ for $a_f \sim 0.4$. As far as the direct CP asymmetry is concerned, we have $-0.05 \lesssim \hat{A}^{s}_f \lesssim +0.05$ for $a_f \lesssim 1$ and values of $|\theta_f - 180^\circ|$ as large as $40^\circ$ [2]. As we expect $\cos \theta_f < 0$, the shift of $\phi_s$ is expected to be negative as well, i.e. it would interfere constructively with $\phi'_s^{SM}$. These features are fully supported by a recent analysis of the $B^0_s \rightarrow J/\psi \pi^0$ channel [15] (see also Ref. [16]).

Consequently, it is important to get a handle on the penguin effects in the $B^0_s \rightarrow J/\psi \phi$ decay. This can be done by means of the $B^0_s \rightarrow J/\psi \bar{K}^{*0}$ mode, which has the following SM amplitude:

$$A(B^0_s \rightarrow (J/\psi \bar{K}^{*0})_f) \propto 1 - a'_f e^{i \theta'_f} e^{i \gamma}.$$  

(15)

It should be stressed that the penguin term is here not doubly Cabibbo-suppressed. If we use the $SU(3)$ flavour symmetry and neglect penguin annihilation and exchange amplitudes (which can be probed through $B^0_d \rightarrow J/\psi \phi$), we have $a_f = a'_f$ and $\theta_f = \theta'_f$. In the summer of 2010, CDF has announced the observation of the $B^0_s \rightarrow J/\psi \bar{K}^{*0}$ mode, with a branching ratio at the $8 \times 10^{-5}$ level [17]. Moreover, also the $B^0_s \rightarrow J/\psi K_S$ decay was observed, which allows us to control the penguin effects discussed above in the measurement of $\sin 2 \beta$ through $B^0_d \rightarrow J/\psi K_S$ [15,19].

The determination of the penguin parameters from the observables of the angular distribution of $B^0_s \rightarrow J/\psi \bar{K}^{*0}$ is presented in Ref. [2]. Let us here just emphasize that the favoured negative sign of $\Delta \phi_s$ implies a constructive interference with $\phi'_s^{SM} \sim -2^\circ$ in (14). For values of $a'_f = 0.4$ and $\theta'_f = 220^\circ$ (consistent with the picture following from current $B^0_d \rightarrow J/\psi \pi^0$ data [15]), we get a phase shift of $\Delta \phi'_s = -1.7^\circ$, which yields $\eta_f \hat{A}^{s}_f = -6.7\%$, i.e. about twice the naive SM value. Consequently, without a control of the penguin effects, this SM effect would be misinterpreted as a 4$\sigma$ NP effect with 2 fb$^{-1}$ at LHCb, and about 20$\sigma$ at an upgrade with 100 fb$^{-1}$. Should we find large mixing-induced CP violation in $B^0_s \rightarrow J/\psi \phi$, such as $\eta_f \hat{A}^{s}_f \sim -40\%$, we would have an immediate and unambiguous signal of NP. On the other hand, should we find $\eta_f \hat{A}^{s}_f \sim -(5\ldots10)\%$, more theoretical and experimental work would be needed in order to settle the picture. Also in the case of $B^0_d \rightarrow J/\psi K_S$, we have to control the penguin effects in order to match the experimental precision at LHCb [19].

4. OTHER $B$ PHYSICS TOPICS

There is much more interesting physics left for the $B$-decay studies at LHCb. An important line of research is given by precision measurements of the angle $\gamma$ of the unitarity triangle. This quantity can be determined through pure “tree” decays on the one hand (such as $B^0_d \rightarrow D^{\mp} K^\pm$), and through decays with penguin contributions on the other hand ($B^0_s \rightarrow K^+ K^-$, $B^0_d \rightarrow \pi^+ \pi^-$ system). The central question is whether we will get values of $\gamma$ that are consistent with one another [20].

Another key topic is given by the study of rare decays, complementing the leptonic $B^0_d \rightarrow \mu^+ \mu^-$ (and its even stronger suppressed partner $B^0_s \rightarrow \mu^+ \mu^-$) channel discussed above. The semileptonic decays $B^0_s \rightarrow K^{*0} \mu^+ \mu^-$, $B^0_s \rightarrow \phi \mu^+ \mu^-$ offer another interesting probe for NP. Here the hadronic sector involves quark-current form factors, and the goal is to find and measure observables that are particularly robust with respect to the corresponding uncertainties. The prime example is the 0-crossing of the forward–backward asymmetry; other observables were recently proposed (see Ref. [21]). There are also non-leptonic rare decays that originate only from loop processes. Particularly interesting are CP-violating asymmetries in $B^0_s \rightarrow \phi \phi$ and similar modes. In order to deal with hadronic corrections, flavour symmetries offer strategies to control them through experimental data. Also here the key question is whether we will encounter discrepancies with respect to the SM picture.

Studies of charm physics offer another line of research. While FCNCs in the $B$ system are sensitive to new effects in the up sector, charm physics probes the down sector, i.e. we have $b$, $s$, $d$ quarks running in the SM loops. Such a process is $D^0-\bar{D}^0$ mixing, which is seen in the ball park of the SM. NP could be hiding there, but is obscured through long-distance QCD effects. In order to search for NP, CP-violating effects, which are tiny in the SM but may be enhanced through NP contributions,
are most promising.

Last but not least, we can also search for lepton flavour violation through $B_{d,s}^0 \to e^\pm \mu^\mp$ and $B_{d,s}^0 \to \mu^\pm \tau^\mp$ decays, which are forbidden in the SM but may arise in NP scenarios. These studies complement other searches by means of $\mu \to e\gamma$, $\tau \to \mu\gamma$ or $\tau \to \mu\mu\mu$ processes.

5. OUTLOOK

We are currently moving towards new frontiers in precision $B$ physics thanks to the start-up of the LHCb experiment. The last decade has led to various interesting results, showing – among many other insights – that the CKM matrix is the dominant source of flavour and CP violation. Potential signals of new phenomena were also seen, although the situation is still not conclusive.

Flavour physics takes part in the big scientific adventure of this decade, which is the LHC. Specific NP scenarios still leave room for sizable effects. Particularly promising channels to find first signals at LHCb (and the LHC) are $B_{d,s}^0 \to \mu^+\mu^-$ and $B_s^0 \to J/\psi\phi$.

In view of the new territory we are about to enter now, the SM phenomena have to be critically reviewed and strategies to control the corresponding hadronic uncertainties to be further developed and refined. Concerning the search for NP, the patterns in specific scenarios should be further explored. In particular correlations between different observables should play a key role in revealing the structure of NP, should we actually see footprints of physics beyond the SM. Moreover, synergies with the high-$Q^2$ physics at ATLAS and CMS should be further studied and exploited. Exciting times are ahead of us!

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REFERENCES

1. R. Fleischer, N. Serra and N. Tuning, Phys. Rev. D 82 (2010) 034038 [arXiv:1004.3982 [hep-ph]].
2. S. Faller, R. Fleischer and T. Mannel, Phys. Rev. D 79 (2009) 014005 [arXiv:0810.4248 [hep-ph]].
3. G. Buchalla and A. J. Buras, Nucl. Phys. B 548 (1999) 309 [arXiv:hep-ph/9901288].
4. A. J. Buras, PoS E PS-HEP2009 (2009) 024 [arXiv:0910.1032 [hep-ph]].
5. CDF Collaboration, CDF Public Note 9892 (2009).
6. DØ Collaboration, DO Note 5906-CONF (2009).
7. LHCb Collaboration, B. Adeva et al., LHCb-PUB-2009-029, arXiv:0912.4179v2.
8. M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Nucl. Phys. B 591 (2000) 313 [arXiv:hep-ph/0006124].
9. C. W. Bauer, D. Pirjol and I. W. Stewart, Phys. Rev. Lett. 87 (2001) 201806 (2001) arXiv:hep-ph/0107002.
10. E. E. Jenkins and M. J. Savage, Phys. Lett. B 281 (1992) 331.
11. P. Blasi, P. Colangelo, G. Nardulli and N. Paver, Phys. Rev. D 49 (1994) 238 [arXiv:hep-ph/9307290].
12. I. Dunietz, R. Fleischer and U. Nierste, Phys. Rev. D 63 (2001) 114015 [arXiv:hep-ph/0112219]; A. S. Dighe, I. Dunietz and R. Fleischer, Eur. Phys. J. C 6 (1999) 647 [arXiv:hep-ph/9804253].
13. CDF Collaboration, Public Note CDF/ANAL/BOTTOM/PUBLIC/10206 (2010); D. Tonelli, these proceedings.
14. DØ Collaboration, DØ-Note 6093-CONF (2010); R. Josik, these proceedings.
15. S. Faller, M. Jung, R. Fleischer and T. Mannel, Phys. Rev. D 79 (2009) 014030 [arXiv:0809.0842 [hep-ph]].
16. M. Ciuchini, M. Pierini and L. Silvestrini, Phys. Rev. Lett. 95 (2005) 221804 [arXiv:hep-ph/0507290].
17. CDF Collaboration, CDF Note 10240 (2010).
18. R. Fleischer, Eur. Phys. J. C 10 (1999) 299 [arXiv:hep-ph/9903455].
19. K. De Bruyn, R. Fleischer and P. Koppenburg, arXiv:1010.0089 [hep-ph].
20. V. Vagnoni, these proceedings.
21. U. Egede, these proceedings.