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Towards global analysis of $b \to s\ell^+\ell^-$ decays

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Flavour changing neutral current decays mediated by $b \to s\ell^+\ell^-$ were under experimental investigation at B-factories and the Tevatron during the last decade and the final analysis are expected soon. Moreover, new data has been released this summer and more is currently taken at the LHC mainly by LHCb. The theoretical methods for both inclusive and exclusive decays have been also refined and a global analysis of these decays becomes more and more feasible. First analysis of combined $b \to s\ell^+\ell^-$ data towards a global analysis provide constraints on the involved short distance couplings. Recently, specially designed observables, which can be determined in the angular distribution of $B \to K^*(\to K\pi)\,\ell^+\ell^-$, became of particular interest since they are subject of reduced hadronic uncertainties and currently their potential role in a global analysis is under investigation.

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Flavour physics constitutes a substantial and important part of the standard model (SM) phenomenology. Especially B-physics at the 1st generation B-factories and the Tevatron played a major role during the last decade. One of the main aims was – and still is – to measure and test the picture of quark-flavour mixing and CP violation in the SM, represented by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix. Great effort was put into the determination of the CKM parameters with the help of elaborated strategies developed by the CKMfitter and UTfit groups. The constant improvement of experiment and theory led to a steadily increasing precision of the involved parameters. Currently, this physics program is continued at the LHC mainly by LHCb and in the future around 2015 at the 2nd generation B-factories with Belle II and SuperB.

Flavour changing neutral current (FCNC) decays mediated by $b \to s\,\ell^+\ell^-$ are not of primary importance for the determination of CKM parameters. In the SM they are absent at tree-level, having branching fractions of $\mathscr{O}(10^{-6})$ and being sensitive to contributions beyond the SM (BSM) at the electroweak scale or even higher, depending on the BSM scenario. They constitute indirect probes of virtual contributions of new physics which requires a certain degree of experimental and theoretical precision to test the SM or to be able to claim deviations. The experiments Belle [1], CDF [2] and LHCb [3] started to accumulate enough $b \to s\,\ell^+\ell^-$ events in order to begin first studies. Especially, LHCb will provide at least a factor five more data with 2 fb^{-1} until the end of next year for exclusive final states such as $B^+ \to K^+\,\mu^+\mu^-$ and $B^0 \to K^{*0}(\to K^+\pi^-)\,\mu^+\mu^-$. In view of the experimental progress it is desirable to develop strategies towards a global fit of $b \to s\,\ell^+\ell^-$ and related FCNC decays similar to the ones existing for the CKM matrix.

Theoretical predictions of $b \to s\,\ell^+\ell^-$ decays focus on regions of the dilepton invariant mass q^2 below and above the two narrow $c\bar{c}$-resonances J/ψ and ψ', which are frequently denoted as low- and high-q^2 region, respectively. In the SM, the numerically dominant contributions in both q^2-regions are due to loop-induced FCNC operators, usually denoted as $\mathscr{O}_{9,10} \sim [\bar{s}\,\gamma^\mu P_L\, b][\bar{\ell}\,\gamma_\mu(1,\gamma_5)\,\ell]$ for $b \to s\,\ell^+\ell^-$ and the electric dipole operator $\mathscr{O}_7 \sim m_b[\bar{s}\,\sigma^{\mu\nu}P_R\, b]F_{\mu\nu}$ for $b \to s\gamma$. At low-q^2, contributions due to $b \to s\,\bar{q}q$ ($q = u,d,s,c,b$) 4-quark operators are treated within QCD factorization [4] based on the large recoil limit and soft-gluon effects from $c\bar{c}$-resonances can be included following [5]. At high-q^2, a local expansion can be applied for these operators due to the hard momentum $\Lambda_{\rm QCD} \ll q^2 \sim m_b^2$ of the order of the b-quark mass [6, 7]. The main uncertainties in predictions of exclusive decays $B \to K^*\gamma$, $B \to K^{(*)}\ell^+\ell^-$, but also others like $B_s \to \phi\,\ell^+\ell^-$, $\Lambda_b \to \Lambda\,\ell^+\ell^-$, stem from form factors and lacking sub-leading contributions in the power expansions in $\Lambda_{\rm QCD}/m_b$.

The particular kinematical limits of large and low recoil of the hadronic system $K^{(*)}$ allow to reduce the number of form factors with the help of form factor relations at lowest order in the above mentioned power expansions. In combination with the angular analysis of the 4-body final state in $B \to K^*(\to K\pi)\,\ell^+\ell^-$, which offers a large number of angular observables $J_i(q^2)$ ($i = 1s,\,1c,\,2s,\,2c,\,3,\ldots 9$) [8], suitable combinations of $J_i(q^2)$ could be identified which exhibit a reduced hadronic uncertainty and enhanced sensitivity to short-distance couplings of the SM and BSM scenarios. At low-q^2 there are $A_T^{(2,3,4,5,\rm re,im)}$ [9] whereas at high-q^2 $H_T^{(2,3,4,5)}$ [10]. Additionally, at high-q^2 also combinations are known which do not depend on the short-distance couplings [10] and allow to probe the form factor shapes with data. CP asymmetric combinations with reduced hadronic uncertainties have been also found at low-q^2 [9] and high-q^2 [11]. The sensitivity to B_s-mixing parameters ϕ_s and $\Delta\Gamma_s$ in time-integrated CP asymmetries of $B_s \to \phi(\to K^+K^-)\,\ell^+\ell^-$ turns out to be small [11]. The $J_i(q^2)$ normalised to the decay rate and the

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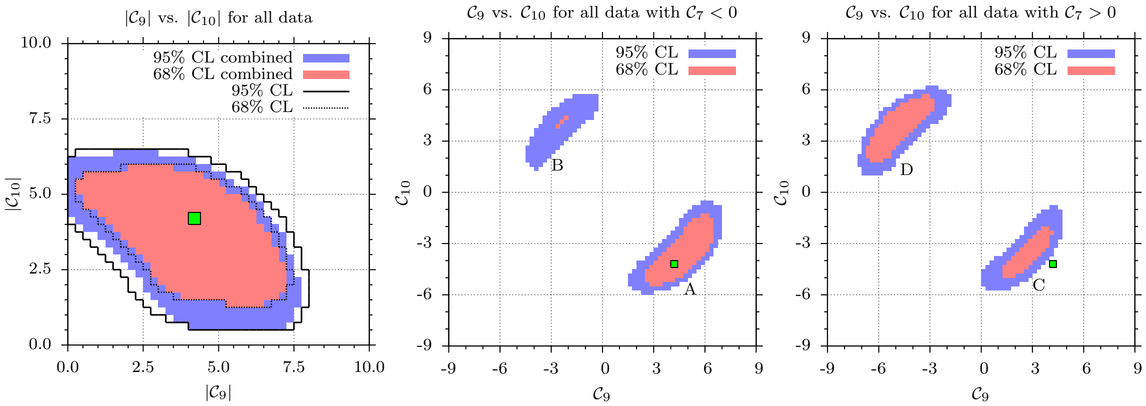

Figure 1: Constraints on $|C_9|$ and $|C_{10}|$ for complex $C_{7,9,10}$ [left] and real $C_{9,10}$ with $C_7 = C_7^{\rm SM}$ [middle] as well as $C_7 = -C_7^{\rm SM}$ [right] using low- and high-q^2 constraints from $B \to K^{(*)}\ell^+\ell^-$ [14] which updates the results of [10, 11]. The black contours in the left plot are obtained by discarding $B \to K\,\ell^+\ell^-$ data and the (green) square denotes the SM point. All observables used in [10, 11, 14] are implemented in the public package [15].

associated CP-asymmetries have been also studied model-independently and model-dependently in great detail [12].

The q^2-binning for several observables measured by Belle [1], CDF [2] and LHCb [3] falls into the low- and high-q^2 regions which are accessible by theoretical methods and allows to preform first fits of the short-distance couplings $C_{9,10}$. The constraining potential of the combination of both q^2-regions has been demonstrated using Belle and CDF $B \to K^*\ell^+\ell^-$ data from 2010 [10]. For this purpose, the integrated branching ratio, the lepton forward-backward asymmetry $A_{\rm FB}$ and the longitudinal K^*-polarisation fraction F_L in the bins $q^2 \in [1,6]$, $[14.18, 16.0]$ and $[> 16.0]$ GeV^2 has been studied for a SM operator basis scenario with real $C_{9,10}$ and $C_7 = \pm C_7^{\rm SM}$. In the lack of QCD-Lattice predictions, the fits rely on extrapolations of form factors from the low- to the high-q^2 region. The according results for a scenario of complex $C_{7,9,10}$, i.e. accounting also for CP violation beyond the SM, can be found in [11]. The study [13] included only data from the low-q^2 region, but supplemented with inclusive and exclusive $b \to s\,\gamma$ observables for the SM scenario with real $C_{7,9,10}$ and its extension including the chirality-flipped operators $\mathcal{O}_{7',9',10'}$. Especially, the transversity observable $A_T^{(2)}$ was studied which is particularly sensitive to $C_{7,7'}$, showing, that large deviations from the SM prediction are still allowed.

During this summer CDF (6.8 fb^{-1}) released updated results for several exclusive $b \to s\,\ell^+\ell^-$ decays [2] and moreover, LHCb (309 pb^{-1}) presented the first results of $B \to K^*\ell^+\ell^-$ [3]. Figure 1 shows the allowed ranges of $|C_{10}|$ vs $|C_9|$ for complex and real $C_{7,9,10}$ taking into account the new data from 2011 as well as the branching ratio of $B \to K\,\ell^+\ell^-$ [14] and updating [10, 11]. The upper bound on $|C_{10}|$ implies an upper bound on $Br(B_s \to \mu^+\mu^-) \lesssim 1 \times 10^{-8}$ [11] whereas the upper bound on $|C_9|$ can be translated into a lower bound on the position of the zero-crossing of the $A_{\rm FB}$ in $B \to K^*\ell^+\ell^-$ [14] in this scenario.

In the absence of strong direct $b \to s\,\tau^+\tau^-$ constraints, a global fit of $b \to s\,\ell^+\ell^-$ data combined with $b \to s\,\gamma$ proved also useful to provide indirect constraints due to operator mixing on $b \to s\,\tau^+\tau^-$ operators. A model-independent study of absorptive BSM contributions to Γ_{12}^s in B_s-mixing due to

$b \to s\tau^+\tau^-$ showed that they do not exceed 40% deviation from the SM prediction [16].

This summer CDF has presented the first measurement of the transversity observable $A_T^{(2)}$ and the observable $A_{im} \sim J_9/(d\Gamma/dq^2)$ [2] which appear in the single-differential angular distribution w.r.t. the angle ϕ in $B \to K^*(\to K\pi)\ell^+\ell^-$. This completes the other two previously measured single-differential distribution w.r.t. to $\cos\theta_\ell$ and $\cos\theta_{K^*}$ which allowed to determine $A_{\rm FB}$ and F_L. As already emphasized, especially LHCb will collect larger data sets, hopefully enabling the full angular analysis w.r.t. all 3 angles and a smaller q^2-binning. The measurement of the angular observables J_i and the specially designed observables $A_T^{(2,3,4,5,{\rm re},{\rm im})}$ and $H_T^{(2,3,4,5)}$ with reduced hadronic uncertainties would be a welcome input of a global analysis of $b \to s\ell^+\ell^-$. On the theoretical side, especially form factor predictions at high-q^2 are not fully available yet [17] and moreover a better understanding of the sub-leading corrections in the power expansion can help to improve the confidence in the uncertainty estimates.

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