Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B Proceedings Supplement 00 (2012) 1–6

Nuclear Physics B Proceedings Supplement

# Exclusive $b \to s\,\ell^+\ell^-$ decays

Christoph Bobeth

*Excellence Cluster Universe*
*Technische Universität München*
*D-85748 Garching, Germany*

**Abstract**

The experimental progress on flavor-changing neutral current decays governed by $b \to s\,\ell^+\ell^-$ transitions has grown enormously due to the latest results of BaBar, Belle, CDF and LHCb. Especially the exclusive modes $B \to K^{(*)}\ell^+\ell^-$, which have the largest rates, provide a variety of observables which constrain non-standard interactions that would affect them beyond the Standard Model. The theoretical treatment, based on expansions in $\Lambda_{\rm QCD}/m_b$, focuses on low- and high dilepton invariant mass regions. Notably, form factor symmetries guided the identification of optimized observables in both regions which have small form factor dependences and sensitivity to new physics. Current experimental results of rates and lepton forward-backward asymmetries allow for first global analysis of $b \to s\,\ell^+\ell^-$ decays in combination with $b \to s\gamma$ and $B_s \to \mu^+\mu^-$. These analyses are now ready to be applied to include high-statistics results from LHCb and Super-Flavor factories within the next years and to profit from optimized observables.

*Keywords:*

## 1. Introduction

In the past, the experimental program of quark flavor physics addressed primarily the exploration of CP-violation in the $B$-system and the tightly related picture of quark flavor mixing in the Standard Model (SM) represented by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix. However, the ever increasing luminosity allows, nowadays, the exploration of flavor-changing neutral current (FCNC) decays of $b$-hadrons, which are loop-suppressed in the SM and therefore have an enhanced sensitivity to non-standard virtual contributions. These test the SM at the loop-level and constitute indirect searches for non-standard effects. Consequently, precise experimental measurements are needed and a good control is required over theoretical uncertainties.

The class of FCNC decays mediated by $b \to s\,\ell^+\ell^-$ ($\ell = e, \mu, \tau$) is a phenomenologically rich sub-class with branching fractions of $\sim \mathcal{O}(10^{-6})$ (in the SM), compared to $b \to d\,\ell^+\ell^-$ decays, which are CKM-suppressed by $|V_{td}/V_{ts}|^2 \sim \mathcal{O}(10^{-2})$. It comprises inclusive and exclusive semi-leptonic decays $B_{u,d} \to (X_s, K, K^*)\,\ell^+\ell^-$, $B_s \to (f_0, \phi)\,\ell^+\ell^-$, $\Lambda_b \to \Lambda\,\ell^+\ell^-$ as well as the purely leptonic $B_s \to \ell^+\ell^-$ decay. Further channels with excited $K^*$ and $\Lambda_b$ have been discussed in the literature. Within the last few years four experimental collaborations analyzed some of these channels with number of events in the range of 150 to 250 for BaBar [1], Belle [2] and CDF [3, 4] and about 1000 events at LHCb [5, 6]. The results based on the final data set have been released this year by BaBar and announced this summer by CDF, whereas Belle's results are based on a partial data set. By now LHCb dominates statistically, adding about 2 fb$^{-1}$ of data this year, 2012, and possibly another 4 fb$^{-1}$ by the year 2018 before the shut-down of the planned upgrade. The Super-Flavor factories Belle II [7] and SuperB [8] will be able to collect about 10000 – 15000 events [9] after the year 2020.

Theoretical predictions of $b \to s\,\ell^+\ell^-$ decays are obtained using the effective theory of $\Delta B = 1$ decays of the electroweak interaction of the SM. It provides the universal starting point for the calculation of observables of inclusive and exclusive decays. The short-distance information at the electroweak scale $\mu \sim M_W$ of the order of the mass of the $W$-boson are contained in effective coupling constants $C_i$ (Wilson coefficients) whereas flavor-changing interactions of $b \to s$ are described by one $b \to s\gamma$ operator $\mathcal{O}_7$ and two $b \to s\,\ell^+\ell^-$ operators $\mathcal{O}_{9,10}$. Due to operator mixing, additional 4-quark operators have to be included, which are the current-current operators $\mathcal{O}^{u,c}_{1,2}$, the QCD-penguin operators $\mathcal{O}_{3,4,5,6}$ and the chromo-magnetic dipole operator $\mathcal{O}_8$. The effective Hamiltonian reads [10, 11]

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(\mathcal{H}^{(t)}_{\rm eff} + \hat{\lambda}_u \mathcal{H}^{(u)}_{\rm eff}\right) + \text{h.c.}, \quad (1)$$

containing a top- and an up-quark part

$$\begin{aligned} \mathcal{H}^{(t)}_{\rm eff} &= C_1 \mathcal{O}^c_1 + C_2 \mathcal{O}^c_2 + \sum_{3\le i} C_i \mathcal{O}_i, \\ \mathcal{H}^{(u)}_{\rm eff} &= C_1 (\mathcal{O}^c_1 - \mathcal{O}^u_1) + C_2 (\mathcal{O}^c_2 - \mathcal{O}^u_2) \end{aligned} \quad (2)$$

with $\hat{\lambda}_u = V_{ub} V_{us}^* / V_{tb} V_{ts}^*$. The Wilson coefficients are renormalized in the $\overline{\rm MS}$-scheme and evaluated at the renormalisation scale $\mu \sim m_b$ of the order of the $b$-quark mass. They have been calculated in the SM up to the next-to-next-to-leading order (NNLO) in QCD. At higher order in the electromagnetic coupling QED-penguin operators have also been considered for the inclusive decay [12, 13]. Within extensions of the SM, new contributions arise $C_i \to C_i^{\rm SM} + C_i^{\rm NP}$ and additional $(\bar{s} \ldots b)(\bar{\ell} \ldots \ell)$ operators can contribute which have zero or negligible Wilson coefficients in the SM. For example, right-handed currents give rise to chirality-flipped $\mathcal{O}_{7',9',10'}$ obtained by the interchange $P_L \leftrightarrow P_R$. Scalar and pseudo-scalar operators $\mathcal{O}_{S,S',P,P'}$ can have enhanced contributions from neutral Higgs-penguin or box-type diagrams, where the latter also give rise to tensor operators $\mathcal{O}_{T,T5}$. There are also non-standard scenarios which give rise to FCNC's at tree-level, such as LeptoQuark's or extensions with non-unitary quark mixing matrices. CP violation is suppressed in the SM in $b \to s$ transitions due to the smallness of $\text{Im}[\hat{\lambda}_u]$ which is doubly Cabibbo-suppressed.

The Wilson coefficients of the loop-induced $b \to s\gamma$ and $b \to s\,\ell^+\ell^-$ SM operators $\mathcal{O}_{7,9,10}$ – and potentially non-standard operators $\mathcal{O}_i$ with $i = 7', 9', 10', S, S', P, P', T, T5$ – are of great interest for indirect searches of signatures beyond the SM. They constitute the numerically leading contribution for large parts in the kinematic region of the dilepton invariant mass $q^2$ in most of the observables. However, when $q^2$ approaches production thresholds of $q\bar{q}$-resonances, 4-quark operators $b \to s\,q\bar{q}$ induce an additional interfering amplitude $b \to s\,(q\bar{q}) \to s\,\ell^+\ell^-$ which involves nonperturbative dynamics that are theoretically not well under control. Especially the current-current operators $\mathcal{O}^q_{1,2}$ with $q = c$ give rise to large peaking backgrounds $b \to s\,J/\psi$ and $b \to s\,\psi'$ with branching fractions of $\mathcal{O}(10^2)$ larger than the ones from $\mathcal{O}_{7,9,10}$ and are vetoed in the experimental analysis. Analogous contributions for $q = u$ are suppressed by $\hat{\lambda}_u$ whereas QCD-penguin operators have tiny Wilson coefficients.

Exclusive decays are currently available with high-statistics for the two most prominent decays $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}(\to K^+\pi^-)\,\ell^+\ell^-$. In comparison, the current experimental precision of inclusive decays does not provide such stringent constraints as exclusive decays and so future measurements at Super-Flavor factories must be awaited. In view of this, the theoretical status will be discussed only for exclusive decays in the following.

## 2. Exclusive decays

Two distinct theoretical methods have been applied in order to calculate observables of exclusive decays $B \to M\,\ell^+\ell^-$, where $M$ denotes light mesons $K$, $K^*$, for the two regions of dilepton invariant mass below and above the two narrow $c\bar{c}$-resonances $J/\psi$ and $\psi'$. These methods are based on the different kinematical limits of large hadronic recoil (of $M$) at low-$q^2$ and the high-$q^2$ transfer to the lepton-pair which allow for expansions in $\lambda \equiv \Lambda_{\rm QCD}/m_b$.

At low-$q^2$, contributions due to $b \to s\,q\bar{q}$ ($q = u, d, s, c$) 4-quark operators and the $b \to s\,gluon$ operator $\mathcal{O}_8$ are treated within QCD factorization (QCDF) [14, 15] using the large energy limit of the recoiling meson $M$. It allows to include NLO corrections in the strong coupling $\alpha_s$ and effects of spectator-quark scattering which are hard in this kinematic regime. The amplitudes factorize schematically into perturbatively calculable quantities $C$ and $T$ and nonperturbative objects, form factors $\xi$ and meson-distribution amplitudes $\phi_{B,M}$,

$$A \sim C\,\xi + \phi_B \otimes T \otimes \phi_M + \mathcal{O}(\lambda) \quad (3)$$

where $\otimes$ implies a convolution over the respective momentum fractions. Notably, the large energy symmetry relations for heavy-to-light form factors allow to reduce seven $B \to V$ form factors to two universal $\xi_{\perp,\parallel}$ and the three $B \to P$ form factors to one $\xi_P$ [16] which are valid up to order $\lambda$ corrections and constitute the first part of lacking terms in Eq. (3). The $\alpha_s$ corrections to the form factor relations have been calculated [17] and included in $C$ and $T$, and even $(\alpha_s)^2$ corrections are available [18]. For example the three $K^*$-transversity amplitudes in $B \to K^* \ell^+ \ell^-$ decays have a simple form at leading order in $\lambda$ and $\alpha_s$ [19]

$$A^{L,R}_{\perp,\parallel} \sim \pm C^{L,R}_{\perp} \times \xi_\perp + \mathcal{O}(\alpha_s, \lambda), \quad (4)$$

$$A^{L,R}_{0} \sim \quad C^{L,R}_{\parallel} \times \xi_\parallel + \mathcal{O}(\alpha_s, \lambda), \quad (5)$$

where the two short-distance coefficients are a linear combination of $C_{7,9,10}$

$$C^{L,R}_{\perp} = (C_9 \mp C_{10}) + \frac{2 m_b M_B}{q^2} C_7, \quad (6)$$

$$C^{L,R}_{\parallel} = (C_9 \mp C_{10}) + \frac{2 m_b}{M_B} C_7. \quad (7)$$

Besides the form factor symmetries, a second source of lacking sub-leading corrections in $\lambda$ are due to the expansions of the amplitude itself. They also involve divergent contributions of distribution amplitudes $\phi_M$ at the sub-leading order in $\lambda$ which introduce a model-dependence. This affects especially the isospin-asymmetry which arises due to differences in spectator interactions [20, 15]. Additionally, soft-gluon effects from $c\bar{c}$-resonances due to current-current operators $\mathcal{O}^c_{1,2}$ have been calculated within a non-local OPE [21] for the tails at $q^2$ below the resonances. They can change the rate up to $(10-20)\%$ for $q^2$ values of interest $\sim 6$ GeV$^2$, rising further for values even closer to the resonances.

At high-$q^2$, a local operator product expansion (OPE) can be applied to the contributions of 4-quark operators due to the hard momentum $\Lambda_{\rm QCD} \ll q^2 \sim m_b^2$ [22, 23] which is passing through the $q\bar{q}$-resonance. Now the $K^*$-transversity amplitudes depend only on one coefficient $C^{L,R}$ [24]

$$A^{L,R}_{i} \sim C^{L,R} \times f_i + C_7 \times \mathcal{O}(\lambda) + \mathcal{O}(\lambda^2), \quad (8)$$

$$C^{L,R} = (C_9 \mp C_{10}) + \kappa \frac{2\, m_b^2}{q^2} C_7. \quad (9)$$

The well-known Isgur-Wise form factor relations [25], improved by the inclusion of QCD corrections $\kappa$ [22], can be used to eliminate the three tensor form factors by the vector and axial-vector form factors. The corresponding linear combinations are denoted by $f_i$ $(i = 0, \perp, \parallel)$ [24]. Due to the local OPE $B \to M$ form factors arise as the only nonperturbative objects, which are at the lowest order (dimension 3) the usual QCD form factors [22, 23]. The use of the form factor relations introduces an uncertainties of order $\lambda$ which is $\propto C_7$. However, since the numerically leading term is dominated by $|C^{\rm SM}_{9,10}| \sim 4.2$ in comparison to $|C^{\rm SM}_7| \sim 0.3$ (in the SM), an additional numerical suppression of $|C_7/C_{9,10}| \sim 0.1$ arises. In the OPE dimension four terms are absent such that sub-leading contributions to the amplitude are suppressed by $\lambda^2$. At higher orders in the OPE new form factors of the higher dimensional operators enter. All such form factors can be calculated at high-$q^2$ in principle on the lattice due to the low recoil of $M$. The NLO $\alpha_s$ corrections to the dimension three term are known as well [26, 27] and lead to small renormalisation scale dependences. Finally, duality violating contributions to the OPE have been estimated based on a model and found to be of a few percent at the level of the rate when integrating over sufficiently large $q^2$-bins [23].

The main uncertainties in predictions of exclusive decays are due to form factors and lacking sub-leading contributions in the power expansions in $\lambda$. At high-$q^2$ sub-leading contributions are calculable and their omission less problematic due to the stronger suppression compared to the low-$q^2$ region, as can be seen when comparing Eq. (8) and Eq. (4). Moreover, the corresponding form factors of higher-dimensional operators can be calculated in principle on the lattice. At low-$q^2$, no approach is known to the arising divergences in convolutions of distribution amplitudes at sub-leading order in QCDF, which introduces a model-dependence and results in a larger theoretical uncertainty in this region.

Currently, the form factors are known mainly from light-cone sum rule (LCSR) calculations which are restricted to low-$q^2$ [28, 29, 21]. At high-$q^2$ form factors have been calculated for $B \to K$ on the lattice in the quenched approximation [30, 31, 32], whereas only preliminary unquenched results for $B \to K^{(*)}$ are reported without final error estimates [33, 34]. Thus, all predictions at high-$q^2$ rely on extrapolations of the LCSR form factor results from the low-$q^2$. Unquenched lattice results should become available in the close future for $B \to K$ and $B \to K^*$.

## 3. Optimized Observables

Both decays, $B^+ \to K^+ \ell^+ \ell^-$ and $B^0 \to K^{*0}(\to K^+\pi^-)\ell^+\ell^-$, allow to measure several observables in their angular distributions. For the 3-body final state in $B^+ \to K^+ \ell^+ \ell^-$ this is the angle $\theta_\ell$ between the $\ell^-$ momentum and the direction of flight of the meson $M$ in the $(\ell^+\ell^-)$ center of mass (CMS) frame. In the 4-body final state $B^0 \to K^{*0}(\to K^+\pi^-)\ell^+\ell^-$ two additional angles exist. These are an analogous angle $\theta_K$ between the Kaon momentum and the $K^*$ momentum in the $(K\pi)$ CMS frame and the angle $\phi$ spanned by the two decay planes of the $(\ell^+\ell^-)$ and $(K\pi)$ systems. The intermediate $K^*$ is assumed to be on-shell, such that the $(K\pi)$ invariant mass is fixed to the mass of the $K^*$ and the narrow width approximation is used frequently. Recent works addressed the issue of additional scalar resonances [35], including also a finite width for the $K^*$, finding a non-negligible impact at low-$q^2$ depending on the observable and the value of $q^2$. Moreover the problem of S-wave contributions can be avoided when using so-called "folded" angular distributions [36].

Currently, for $B^+ \to K^+\ell^+\ell^-$ the branching ratio, $Br$, the lepton forward-backward asymmetry, $A_{\rm FB}$, and the isospin asymmetry, $A_I$, have been measured in $q^2$-bins covered by the theoretical methods described above, whereas for $B^0 \to K^{*0}\ell^+\ell^-$ these are $Br$, $A_{\rm FB}$, $A_I$, the longitudinal $K^*$ polarization fraction, $F_L$, and further observables in the $\phi$-distribution by LHCb and CDF: $S_{3,9}$ and $A_T^{(2)}$, $A_{im}$.

In $B^+ \to K^+\ell^+\ell^-$ the angular distribution w.r.t. $\cos\theta_\ell$ allows to measure the lepton $A_{\rm FB}$ and the observable $F_H$ [37, 38]. The first is very sensitive to scalar and tensor $(\bar{s}\ldots b)(\bar{\ell}\ldots\ell)$ operators which are absent in the SM and similarly for $F_H$ [37]. In the presence of chirality-flipped operators $\mathcal{O}_{7',9',10',S',P'}$ the combination $(C_i + C_{i'})$ enters all observables, contrary to $B_s \to \ell^+\ell^-$ which depends on $(C_i - C_{i'})$ (for $i = 10, S, P$) and $B \to K^*\ell^+\ell^-$, depending on both (for $i = 7, 9, 10$).

The structure of the $K^*$-transversity amplitudes (4) and (8) have phenomenological interesting consequences for the 4-body final state in $B \to K^*(\to K\pi)\,\ell^+\ell^-$ decays. Its angular analysis offers a large number of angular observables $J_i(q^2)$ $(i = 1s, \ldots 9)$ [39], such that 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 scenarios beyond. These "optimized observables" at low-$q^2$ are $A_T^{(2,3,4,5,{\rm re},{\rm im})}$ and $P_{4,5,6}$ [19, 40, 41, 42, 43, 44] whereas at high-$q^2$ $H_T^{(2,3,4,5)}$ [24]. Further observables have been identified in the presence of scalar operators at low-$q^2$ [43]. Additionally, at high-$q^2$ also combinations are known which do not depend on the short-distance couplings (mostly in the SM operator basis) [24] and allow to probe the form factor shapes with data [45, 46]. CP asymmetric combinations with reduced hadronic uncertainties have also been found at low-$q^2$ [19, 40, 41, 42] and high-$q^2$ [47]. The sensitivity to $B_s$-mixing parameters $\phi_s$ and $\Delta\Gamma_s$ in time-integrated CP asymmetries of $B_s \to \phi(\to K^+K^-)\,\ell^+\ell^-$ turns out to be small [47, 48]. The $J_i(q^2)$ normalised to the decay rate and the associated CP-asymmetries have also been studied model-independently and model-dependently in great detail [48, 49]. At the moment no experimental measurements are available for the optimized observables, except for $A_T^{(2)}$ from CDF [3].

## 4. Global analysis

Current global analysis of radiative, semi-leptonic and leptonic decays combine available data for inclusive $B \to X_s(\gamma,\, \ell^+\ell^-)$ and exclusive $B \to K\ell^+\ell^-$, $B \to K^*(\gamma,\, \ell^+\ell^-)$, $B_s \to \mu^+\mu^-$ modes. There are model-independent studies which determine the constraints on the Wilson coefficients for varying sets of operators or model-dependent studies which derive bounds on the parameters of extensions of the SM.

The determination of confidence or probability regions varies in all analysis. Simple approaches determine allowed regions of parameter space by combining $n \cdot \sigma$ $(n = 1, 2, 3)$ experimental and theoretical errors [50, 32]. Others calculate $\chi^2$ values by combining experimental and theoretical errors following the $R$-fit scheme [47, 38] or different definitions [51, 52, 53, 54]. A third approach includes parameters associated with theoretical uncertainties as nuisance parameters in the fit [46]. Once more precise data are available, the more sophisticated methods should be used and experimental correlations among observables have to be included as well, a task requiring a close collaboration between experimental and theory sides. The first dedicated software tools have been developed for exclusive $b \to s\,\ell^+\ell^-$ decays [55] and existing flavor-decay tools extended [56, 57].

In the context of model-independent analysis, the simplest scenario assumes new physics in $C_{7,9,10}$ which is real, i.e. involves the same CP-violation as in the SM. The combined fit of inclusive and/or exclusive decay data allows for two solutions, one around the SM and a second obtained by a simultaneous sign-flip of all three Wilson coefficients compared to the SM signs. The goodness of the fit indicates a good fit and the data provides also additional information on nuisance parameters [46]. The solution with only $C_7$ flipped is now excluded [46, 51], mainly due to the measurements of $A_{\rm FB}$. Here the high-$q^2$ region plays currently a crucial role. Overall, the SM is in good agreement with the data, in part due to the large theory uncertainties of the observables $Br$ and $F_L$, and furthermore large deviations are still not excluded.

More general scenarios have been analyzed too, including chirality-flipped Wilson coefficients [50, 51, 58, 53, 54] assuming them to be real or complex. The measurement of the optimized observables will be important in order to efficiently constrain these scenarios which currently still allow for large deviations from SM predictions, especially in optimized observables and CP asymmetries.

In the framework of the minimal supersymmetric SM (MSSM) the $b \to s\,\ell^+\ell^-$ transitions provide constraints on flavor-changing left-right mixing in the up-squark-sector $(\delta^u_{23})_{LR}$, which in turn place constraints on top-quark FCNC decays $t \to c\gamma$, $t \to cg$ and $t \to cZ$ [59]. The interplay of $B_s \to \mu^+\mu^-$ at large $\tan\beta$ and angular observables in $B \to K^*\ell^+\ell^-$ at moderate $\tan\beta$ has been investigated in constrained scenarios such as the CMSSM and NUHM [60]. LeptoQuark interactions, which induce scalar and pseudo-scalar operators $\mathcal{O}_{S,S',P,P'}$, have been constraint with recent data from $B \to (X_s, K)\,\ell^+\ell^-$, and $B_s \to \mu^+\mu^-$ [61].

Currently the SM describes the measured observables, but in the future higher experimental statistics and form factor predictions from lattice calculations will allow to test it more stringently, especially with optimized observables. This will allow to derive stronger constraints on new physics scenarios which will be complementary to other particle physics sectors.

**Acknowledgments** I am indebted to the organizers of the *BEACH-2012* conference for the opportunity to present a talk and the kind hospitality in Wichita. I thank Frederik Beaujean, Gudrun Hiller, Danny van Dyk and Christian Wacker for our fruitful collaborations.

## References

[1] J. Lees, et al., Measurement of Branching Fractions and Rate Asymmetries in the Rare Decays $B \to K^{(*)}l^+l^-$, Phys.Rev. D86 (2012) 032012. arXiv:1204.3933, doi:10.1103/PhysRevD.86.032012.

[2] J.-T. Wei, et al., Measurement of the Differential Branching Fraction and Forward-Backword Asymmetry for $B \to K^{(*)}l^+l^-$, Phys.Rev.Lett. 103 (2009) 171801. arXiv:0904.0770, doi:10.1103/PhysRevLett.103.171801.

[3] T. Aaltonen, et al., Observation of the Baryonic Flavor-Changing Neutral Current Decay $\Lambda_b \to \Lambda\mu^+\mu^-$, Phys.Rev.Lett. 107 (2011) 201802. arXiv:1107.3753, doi:10.1103/PhysRevLett.107.201802.

[4] T. Aaltonen, et al., Measurements of the Angular Distributions in the Decays $B \to K^{(*)}\mu^+\mu^-$ at CDF, Phys.Rev.Lett. 108 (2012) 081807. arXiv:1108.0695, doi:10.1103/PhysRevLett.108.081807.

[5] R. Aaij, et al., Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$, Phys.Rev.Lett. 108 (2012) 181806. arXiv:1112.3515, doi:10.1103/PhysRevLett.108.181806.

[6] R. Aaij, et al., Measurement of the isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$ decays, JHEP 1207 (2012) 133. arXiv:1205.3422, doi:10.1007/JHEP07(2012)133.

[7] T. Aushev, W. Bartel, A. Bondar, J. Brodzicka, T. Browder, et al., Physics at Super B FactoryarXiv:1002.5012.

[8] B. O'Leary, et al., SuperB Progress Reports – PhysicsarXiv:1008.1541.

[9] A. J. Bevan, The Physics of Heavy Flavours at SuperB, J.Phys.G G39 (2012) 023001. arXiv:1110.3901, doi:10.1088/0954-3899/39/2/023001.

[10] K. G. Chetyrkin, M. Misiak, M. Munz, Weak radiative B meson decay beyond leading logarithms, Phys.Lett. B400 (1997) 206–219. arXiv:hep-ph/9612313, doi:10.1016/S0370-2693(97)00324-9.

[11] C. Bobeth, M. Misiak, J. Urban, Photonic penguins at two loops and $m_t$ dependence of $BR[B \to X_s\ell^+\ell^-]$, Nucl.Phys. B574 (2000) 291–330. arXiv:hep-ph/9910220, doi:10.1016/S0550-3213(00)00007-9.

[12] C. Bobeth, P. Gambino, M. Gorbahn, U. Haisch, Complete NNLO QCD analysis of $B \to X_s\ell^+\ell^-$ and higher order electroweak effects, JHEP 0404 (2004) 071. arXiv:hep-ph/0312090, doi:10.1088/1126-6708/2004/04/071.

[13] T. Huber, E. Lunghi, M. Misiak, D. Wyler, Electromagnetic logarithms in $B \to X_s\ell^+\ell^-$, Nucl.Phys. B740 (2006) 105–137. arXiv:hep-ph/0512066, doi:10.1016/j.nuclphysb.2006.01.037.

[14] M. Beneke, T. Feldmann, D. Seidel, Systematic approach to exclusive $B \to V\ell^+\ell^-$, $V\gamma$ decays, Nucl.Phys. B612 (2001) 25–58. arXiv:hep-ph/0106067, doi:10.1016/S0550-3213(01)00366-2.

[15] M. Beneke, T. Feldmann, D. Seidel, Exclusive radiative and electroweak $b \to d$ and $b \to s$ penguin decays at NLO, Eur.Phys.J. C41 (2005) 173–188. arXiv:hep-ph/0412400, doi:10.1140/epjc/s2005-02181-5.

[16] J. Charles, A. Le Yaouanc, L. Oliver, O. Pene, J. Raynal, Heavy to light form-factors in the heavy mass to large energy limit of QCD, Phys.Rev. D60 (1999) 014001. arXiv:hep-ph/9812358, doi:10.1103/PhysRevD.60.014001.

[17] M. Beneke, T. Feldmann, Symmetry breaking corrections to heavy to light $B$ meson form-factors at large recoil, Nucl.Phys. B592 (2001) 3–34. arXiv:hep-ph/0008255, doi:10.1016/S0550-3213(00)00585-X.

[18] G. Bell, M. Beneke, T. Huber, X.-Q. Li, Heavy-to-light currents at NNLO in SCET and semi-inclusive $B \to X_s\ell^+\ell^-$ decay, Nucl.Phys. B843 (2011) 143–176. arXiv:1007.3758, doi:10.1016/j.nuclphysb.2010.09.022.

[19] F. Kruger, J. Matias, Probing new physics via the transverse amplitudes of $B^0 \to K^{*0}(\to K^-\pi^+)\ell^+\ell^-$ at large recoil, Phys.Rev. D71 (2005) 094009. arXiv:hep-ph/0502060, doi:10.1103/PhysRevD.71.094009.

[20] T. Feldmann, J. Matias, Forward backward and isospin asymmetry for $B \to K^*\ell^+\ell^-$ decay in the standard model and in supersymmetry, JHEP 0301 (2003) 074. arXiv:hep-ph/0212158.

[21] A. Khodjamirian, T. Mannel, A. Pivovarov, Y.-M. Wang, Charm-loop effect in $B \to K^{(*)}\ell^+\ell^-$ and $B \to K^*\gamma$, JHEP 1009 (2010) 089. arXiv:1006.4945, doi:10.1007/JHEP09(2010)089.

[22] B. Grinstein, D. Pirjol, Exclusive rare $B \to K^*\ell^+\ell^-$ - decays at low recoil: Controlling the long-distance effects, Phys.Rev. D70 (2004) 114005. arXiv:hep-ph/0404250, doi:10.1103/PhysRevD.70.114005.

[23] M. Beylich, G. Buchalla, T. Feldmann, Theory of $B \to K^{(*)}\ell^+\ell^-$ decays at high $q^2$: OPE and quark-hadron duality, Eur.Phys.J. C71 (2011) 1635. arXiv:1101.5118, doi:10.1140/epjc/s10052-011-1635-0.

[24] C. Bobeth, G. Hiller, D. van Dyk, The Benefits of $B \to K^*\ell^+\ell^-$ Decays at Low Recoil, JHEP 1007 (2010) 098. arXiv:1006.5013, doi:10.1007/JHEP07(2010)098.

[25] N. Isgur, M. B. Wise, Relationship between form-factors in semileptonich $B$ and $D$ decays and exclusive rare $B$ meson decays, Phys.Rev. D42 (1990) 2388–2391. doi:10.1103/PhysRevD.42.2388.

[26] D. Seidel, Analytic two loop virtual corrections to $b \to$

$d\ell^+\ell^-$, Phys.Rev. D70 (2004) 094038. arXiv:hep-ph/0403185, doi:10.1103/PhysRevD.70.094038.

[27] C. Greub, V. Pilipp, C. Schupbach, Analytic calculation of two-loop QCD corrections to $b \to s\ell^+\ell^-$ in the high $q^2$ region, JHEP 0812 (2008) 040. arXiv:0810.4077, doi:10.1088/1126-6708/2008/12/040.

[28] P. Ball, R. Zwicky, New results on $B \to \pi, K, \eta$ decay formfactors from light-cone sum rules, Phys.Rev. D71 (2005) 014015. arXiv:hep-ph/0406232, doi:10.1103/PhysRevD.71.014015.

[29] P. Ball, R. Zwicky, $B_{(d,s)} \to \rho, \omega, K^*, \phi$ decay form-factors from light-cone sum rules revisited, Phys.Rev. D71 (2005) 014029. arXiv:hep-ph/0412079, doi:10.1103/PhysRevD.71.014029.

[30] D. Becirevic, V. Lubicz, F. Mescia, An Estimate of the $B \to K^*\gamma$ form factor, Nucl.Phys. B769 (2007) 31–43. arXiv:hep-ph/0611295, doi:10.1016/j.nuclphysb.2007.01.032.

[31] A. Al-Haydari, et al., Semileptonic form factors $D \to \pi, K$ and $B \to \pi, K$ from a fine lattice, Eur.Phys.J. A43 (2010) 107–120. arXiv:0903.1664, doi:10.1140/epja/i2009-10893-3.

[32] D. Becirevic, N. Kosnik, F. Mescia, E. Schneider, Complementarity of the constraints on New Physics from $B_s \to \mu^+\mu^-$ and from $B \to K\ell^+\ell^-$ decaysarXiv:1205.5811.

[33] Z. Liu, S. Meinel, A. Hart, R. R. Horgan, E. H. Muller, et al., A Lattice calculation of $B \to K^{(*)}$ form factorsarXiv:1101.2726.

[34] R. Zhou, et al., Form Factors for $B \to K\ell^+\ell^-$ Semileptonic Decay from Three-Flavor Lattice QCD, PoS LATTICE2011 (2011) 298. arXiv:1111.0981.

[35] D. Becirevic, A. Tayduganov, Impact of $B \to K_0^*\ell^+\ell^-$ on the New Physics search in $B \to K^*\ell^+\ell^-$ decayarXiv:1207.4004.

[36] J. Matias, On the S-wave pollution of $B \to K^*\ell^+\ell^-$ observablesarXiv:1209.1525.

[37] C. Bobeth, G. Hiller, G. Piranishvili, Angular distributions of $B \to K\ell^+\ell^-$ decays, JHEP 0712 (2007) 040. arXiv:0709.4174, doi:10.1088/1126-6708/2007/12/040.

[38] C. Bobeth, G. Hiller, D. van Dyk, C. Wacker, The Decay $B \to K\ell^+\ell^-$ at Low Hadronic Recoil and Model-Independent Delta B = 1 Constraints, JHEP 1201 (2012) 107. arXiv:1111.2558, doi:10.1007/JHEP01(2012)107.

[39] F. Kruger, L. M. Sehgal, N. Sinha, R. Sinha, Angular distribution and CP asymmetries in the decays $\bar{B} \to K^-\pi^+e^-e^+$ and $\bar{B} \to \pi^-\pi^+e^-e^+$, Phys.Rev. D61 (2000) 114028. arXiv:hep-ph/9907386, doi:10.1103/PhysRevD.61.114028, 10.1103/PhysRevD.63.019901.

[40] U. Egede, T. Hurth, J. Matias, M. Ramon, W. Reece, New observables in the decay mode $B_d \to K^{*0}\ell^+\ell^-$, JHEP 0811 (2008) 032. arXiv:0807.2589, doi:10.1088/1126-6708/2008/11/032.

[41] U. Egede, T. Hurth, J. Matias, M. Ramon, W. Reece, New physics reach of the decay mode $\bar{B} \to \bar{K}^{*0}\ell^+\ell^-$, JHEP 1010 (2010) 056. arXiv:1005.0571, doi:10.1007/JHEP10(2010)056.

[42] D. Becirevic, E. Schneider, On transverse asymmetries in $B \to K^*\ell^+\ell^-$, Nucl.Phys. B854 (2012) 321–339. arXiv:1106.3283, doi:10.1016/j.nuclphysb.2011.09.004.

[43] J. Matias, F. Mescia, M. Ramon, J. Virto, Complete Anatomy of $\bar{B}_d \to \bar{K}^{*0}(\to K\pi)l^+l^-$ and its angular distribution, JHEP 1204 (2012) 104. arXiv:1202.4266, doi:10.1007/JHEP04(2012)104.

[44] D. Das, R. Sinha, New Physics Effects and Hadronic Form Factor Uncertainties in $B \to K^*\ell^+\ell^-$arXiv:1205.1438.

[45] C. Hambrock, G. Hiller, Extracting $B \to K^*$ Form Factors from DataarXiv:1204.4444.

[46] F. Beaujean, C. Bobeth, D. van Dyk, C. Wacker, Bayesian Fit of Exclusive $b \to s\bar{\ell}\ell$ Decays: The Standard Model Operator Basis, JHEP 1208 (2012) 030. arXiv:1205.1838, doi:10.1007/JHEP08(2012)030.

[47] C. Bobeth, G. Hiller, D. van Dyk, More Benefits of Semileptonic Rare $B$ Decays at Low Recoil: CP Violation, JHEP 1107 (2011) 067. arXiv:1105.0376, doi:10.1007/JHEP07(2011)067.

[48] C. Bobeth, G. Hiller, G. Piranishvili, CP Asymmetries in bar $B \to \bar{K}^*(\to \bar{K}\pi)\bar{\ell}\ell$ and Untagged $\bar{B}_s$, $B_s \to \phi(\to K^+K^-)\bar{\ell}\ell$ Decays at NLO, JHEP 0807 (2008) 106. arXiv:0805.2525, doi:10.1088/1126-6708/2008/07/106.

[49] W. Altmannshofer, P. Ball, A. Bharucha, A. J. Buras, D. M. Straub, et al., Symmetries and Asymmetries of $B \to K^*\mu^+\mu^-$ Decays in the Standard Model and Beyond, JHEP 0901 (2009) 019. arXiv:0811.1214, doi:10.1088/1126-6708/2009/01/019.

[50] S. Descotes-Genon, D. Ghosh, J. Matias, M. Ramon, Exploring New Physics in the $C_7 - C_7'$ plane, JHEP 1106 (2011) 099. arXiv:1104.3342, doi:10.1007/JHEP06(2011)099.

[51] W. Altmannshofer, P. Paradisi, D. M. Straub, Model-Independent Constraints on New Physics in $b \to s$ Transitions, JHEP 1204 (2012) 008. arXiv:1111.1257, doi:10.1007/JHEP04(2012)008.

[52] T. Hurth, F. Mahmoudi, The Minimal Flavour Violation benchmark in view of the latest LHCb data, Nucl.Phys. B865 (2012) 461–485. arXiv:1207.0688, doi:10.1016/j.nuclphysb.2012.08.004.

[53] W. Altmannshofer, D. M. Straub, Cornering New Physics in $b \to s$ Transitions, JHEP 1208 (2012) 121. arXiv:1206.0273, doi:10.1007/JHEP08(2012)121.

[54] S. Descotes-Genon, J. Matias, M. Ramon, J. Virto, Implications from clean observables for the binned analysis of $B \to K^*\ell^+\ell^-$ at large recoilarXiv:1207.2753.

[55] E. Collaboration, http://project.het.physik.tu-dortmund.de/eos/.

[56] F. Mahmoudi, SuperIso: A Program for calculating the isospin asymmetry of $B \to K^*\gamma$ in the MSSM, Comput.Phys.Commun. 178 (2008) 745–754. arXiv:0710.2067, doi:10.1016/j.cpc.2007.12.006.

[57] F. Mahmoudi, SuperIso v2.3: A Program for calculating flavor physics observables in Supersymmetry, Comput.Phys.Commun. 180 (2009) 1579–1613. arXiv:0808.3144, doi:10.1016/j.cpc.2009.02.017.

[58] D. Becirevic, E. Kou, A. Le Yaouanc, A. Tayduganov, Future prospects for the determination of the Wilson coefficient $C'_{7\gamma}$, JHEP 1208 (2012) 090. arXiv:1206.1502, doi:10.1007/JHEP08(2012)090.

[59] A. Behring, C. Gross, G. Hiller, S. Schacht, Squark Flavor Implications from $B \to K^*\ell^+\ell^-$, JHEP 1208 (2012) 152. arXiv:1205.1500, doi:10.1007/JHEP08(2012)152.

[60] F. Mahmoudi, S. Neshatpour, J. Orloff, Supersymmetric constraints from $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ observables, JHEP 1208 (2012) 092. arXiv:1205.1845, doi:10.1007/JHEP08(2012)092.

[61] N. Kosnik, Model independent constraints on leptoquarks from $b \to s\ell^+\ell^-$ processesarXiv:1206.2970.