

Challenges for New Physics in the Flavour Sector

ANDREAS CRIVELLIN¹

*CERN Theory Division,
CH-1211 Geneva 23,
SWITZERLAND*

In these proceedings I present a personal perspective of the challenges for new physics (NP) searches in the flavour sector. Since the CKM mechanism of flavour violation has been established to a very high precision, we know that physics beyond the Standard Model can only contribute sub-dominantly. Therefore, any realistic model of physics beyond the Standard Model (SM) must respect the stringent constraints from flavour observables like $b \rightarrow s\gamma$, $B_s \rightarrow \mu^+\mu^-$, $\Delta F = 2$ processes etc., in a first step. In a second step, it is interesting to ask the question if some deviations from the SM predictions (like the anomalous magnetic moment of the muon or recently observed discrepancies in tauonic B decays or $B \rightarrow K^*\mu^+\mu^-$) can be explained by a model of NP without violating bounds from other observables.

PRESENTED AT

Flavor Physics and CP Violation (FPCP-2014),
Marseille, France,
May 26-30 2014

¹Work supported by a Marie Curie Intra-European Fellowship of the European Community's 7th Framework Programme under contract number (PIEF-GA-2012-326948).

1 Introduction

The CKM mechanism of flavour violation has been established by the B factories BELLE and BABAR and received further confirmation by the LHCb experiment. Global fits to the CKM matrix [1, 2] show that there is in general a very good agreement between the different observables and that new physics (NP) contributions can only be of the order of 10% (see Fig. 1): The global CKM fit includes the tree-level determinations of the CKM elements V_{us} , V_{cb} and V_{ub} as well as information from $K - \bar{K}$, $B_s - \bar{B}_s$ and $B_d - \bar{B}_d$ mixing. In addition, also the measurements of processes not included in the CKM fit like $B_{s,d} \rightarrow \mu^+ \mu^-$ and $b \rightarrow s, d \gamma$ agree very well with the Standard Model (SM) predictions.

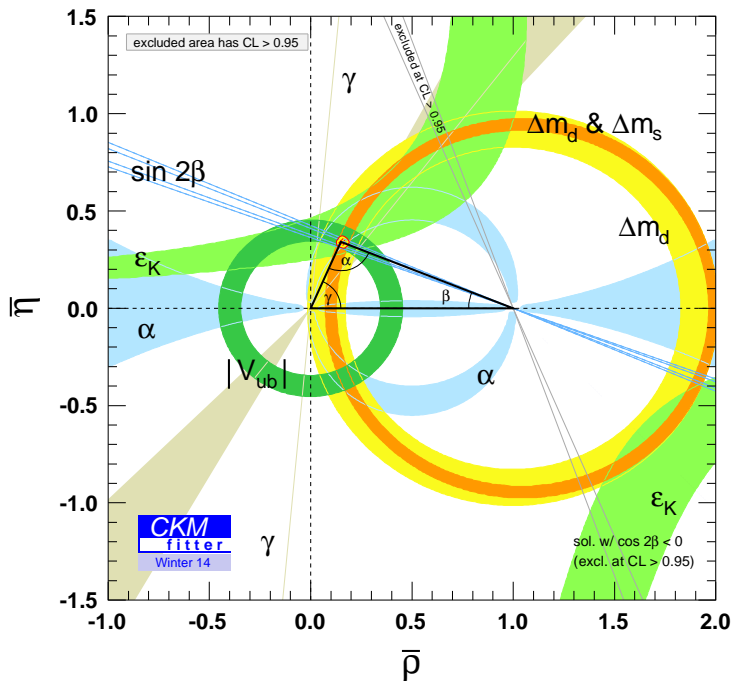


Figure 1: Global fit to the CKM matrix performed by the CKMfitter collaboration [3] shown in the $\bar{\rho}-\bar{\eta}$ plane defined as $\bar{\rho} + i\bar{\eta} = -\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}$. One can see that the allowed regions from the different observables overlap in a small region, leaving limited space for NP contributions. For a similar analysis of the UTfit collaboration see [4].

Therefore, the challenges for NP in the flavour sector are the following: In a first step, any model of NP must respect the stringent constraints from flavour observables. In a second step one can examine if the model under consideration can explain

deviations from the SM without violating bounds from other observables. It is interesting to note that in general it is rather difficult to construct a model which satisfies the stringent constraints from FCNC processes while still being capable of explaining some deviations. While step one can be fulfilled by assuming some symmetry or alignment with the SM, suppressing flavour effects, step 2 often requires a rather generic flavour structure leading in many cases to tensions.

Among the many flavour observables which are in very good agreement with the SM predictions we will consider:

- $\Delta F = 2$ processes: $B_s - \bar{B}_s$, $B_d - \bar{B}_d$, $K - \bar{K}$ and $D - \bar{D}$ mixing.
- Radiative B meson decays: $b \rightarrow s\gamma$ and $b \rightarrow d\gamma$.
- Neutral meson decays to muon pairs: $B_s \rightarrow \mu^+\mu^-$, $B_d \rightarrow \mu^+\mu^-$, $K_L \rightarrow \mu^+\mu^-$ and $D \rightarrow \mu^+\mu^-$.
- Lepton flavour violating observables: $\ell_i \rightarrow \ell_f\gamma$, $\mu \rightarrow e$ conversion and $\ell_i \rightarrow \ell_f\ell_j\ell_j$.

The stringent bounds from these observables must be respected by any reasonable NP model. Many possibilities how to ensure that NP models satisfy these bounds have been proposed, among them minimal flavour violation is probably the one most often used in the literature [5].

On the other hand, there are some observables in which some tensions with the SM have been observed, among them:

- Tauonic B decays: $B \rightarrow \tau\nu$, $B \rightarrow D\tau\nu$ and $B \rightarrow D^*\tau\nu$.
- $B \rightarrow K^*\mu^+\mu^-$ and $\text{Br}[B \rightarrow K\mu^+\mu^-]/\text{Br}[B \rightarrow Ke^+e^-]$.

Here we want to address the question which model of NP is capable to explain these deviations from the SM.

There are also tensions among the different determinations of V_{ub} and V_{cb} from different inclusive and exclusive processes (see for example [6, 7] for a review). However, it is essentially ruled out that the current data for V_{cb} can be explained by NP contributions and also in the case of V_{ub}^* it is rather likely that the differences are due to underestimated errors in the theory predictions [8]. Therefore, we do not consider these discrepancies in the following.

*For V_{ub} it is still possible that a right-handed W couplings (as proposed in [9]) could explain the differences between the inclusive and exclusive determinations[10]

1.1 The 2HDM and the MSSM in the decoupling limit

In the next section we will discuss several decays putting stringent constraints on physics beyond the SM and Sec. 3 discusses some observables in which deviations for the SM predictions have been observed. We will illustrate the impact of these observables on some selected NP models. As a specific example we consider a 2HDM [11] (for a review see for example [12]) with generic Yukawa structure (which is the decoupling limit of the MSSM). Here we introduce a second Higgs doublet and obtain four additional physical Higgs particles (in the case of a CP conserving Higgs potential): the neutral CP-even Higgs H^0 , a neutral CP-odd Higgs A^0 and the two charged Higgses H^\pm . In addition, if we allow for a generic flavour structure we have the non-holomorphic couplings which couple up (down) quarks to the down (up) type Higgs doublet. Following the notation of Ref. [13]

$$\begin{aligned}
\mathcal{L}^{eff} = & \bar{u}_{fL} V_{fj} \left(\frac{m_{d_i}}{v_d} \delta_{ij} H_d^{2*} - \epsilon_{ji}^d (H_u^1 + \tan(\beta) H_d^{2*}) \right) d_{iR} \\
& + \bar{d}_{fL} V_{jf}^* \left(\frac{m_{u_j}}{v_u} \delta_{ij} H_u^{1*} - \epsilon_{ji}^u (H_d^2 + \cot(\beta) H_u^{1*}) \right) u_{iR} \\
& - \bar{d}_{fL} \left(\frac{m_{d_i}}{v_d} \delta_{fi} H_d^{1*} + \epsilon_{fi}^d (H_u^2 - \tan(\beta) H_d^{1*}) \right) d_{iR} \\
& - \bar{u}_{fL} \left(\frac{m_{u_i}}{v_u} \delta_{fi} H_u^{2*} + \epsilon_{fi}^u (H_d^1 - \cot(\beta) H_u^{2*}) \right) u_{iR} + h.c.
\end{aligned} \tag{1}$$

Here ϵ_{ij}^q parametrizes completely flavour-changing neutral currents. In the MSSM at tree-level $\epsilon_{ij}^q = 0$ (which corresponds to the 2HDM of type II) and flavour changing neutral Higgs couplings are absent. However, these couplings are generated at the loop level [14]. The resulting expressions are non-decoupling and depend only on the ratios of SUSY parameters (for a complete one-loop analysis see [15] and for the 2-loop SQCD corrections see [16][†]). Since the dependence is only on the ratio of SUSY masses, these effects are non-decoupling and even allow for the possibility that the light fermion masses arise entirely from ϵ_{ij}^f [18].

2 Selected flavour-processes and their constraints on new physics

In this section we review some selected flavour observables and highlight their impact on models of NP, i.e. how they constrain physics beyond the SM.

[†]In the flavour-conserving case the 2-loop corrections were calculated in Ref. [17]

2.1 $\Delta F = 2$ processes

$\Delta F = 2$ processes are still one of the most constraining processes for NP (see for example [19] for a model-independent analysis and [20] for an overview on $B_q - \overline{B}_q$ and $K - \overline{K}$ mixing) since they scale like δ^2/Λ^2 while the other flavour observables scale like δ/Λ^2 . Here δ stands for a generic flavour violating parameter and Λ is the scale of NP. Especially the constraints from $K - \overline{K}$ and $D - \overline{D}$ mixing are very stringent and Kaon mixing puts extremely stringent constraints on CP violating NP.

The current situation concerning the experimental and theoretical values is the following: For $K - \overline{K}$ mixing the SM prediction was calculated at NLO in Ref. [21, 22] and (for the relevant charm contributions) at NNLO in Ref. [23].

$$|\epsilon_K|_{\text{SM}} = 1.81(28) \times 10^3, \quad \Delta M_K^{\text{SD SM}} = 3.1(1.2) \times 10^{15} \text{ GeV}. \quad (2)$$

Here $\Delta M_K^{\text{SD SM}}$ only contains the calculable short distance SM contribution. This has to be compared to the experimental value [6]

$$|\epsilon_K|_{\text{exp}} = (2.228 \pm 0.011) \times 10^3, \quad \Delta M_K^{\text{exp}} = 3.48 \pm 0.06 \times 10^{-15} \text{ GeV}. \quad (3)$$

Concerning the SM predictions for $B_s - \overline{B}_s$ and $B_d - \overline{B}_d$ mixing (calculated in Ref. [21]) the latest numerical update [24] gives

$$\Delta M_d^{\text{SM}} = 0.502 \text{ ps}^{-1}, \quad \phi_d^{\text{SM}} = (-10.1_{-6.3}^{+3.7}) \times 10^{-2}. \quad (4)$$

$$\Delta M_s^{\text{SM}} = 17.24 \text{ ps}^{-1}, \quad \phi_s^{\text{SM}} = (7.4_{-3.2}^{+0.8}) \times 10^{-3}. \quad (5)$$

This is in very good agreement with the experimental values from LHCb [25] and CDF [26] as well with the HFAG average for $B_d - \overline{B}_d$ mixing. In general, one can parametrize the NP contribution to $B_q - \overline{B}_q$ mixing as

$$C_{B_q} e^{2i\phi_{B_q}} = |\Delta_q| e^{i\phi_q^\Delta} = \frac{\langle B_q | H_{\text{eff}} | \overline{B}_q \rangle}{\langle B_q | H_{\text{eff}}^{\text{SM}} | \overline{B}_q \rangle}, \quad (6)$$

where the first notation is used by the UTfit collaboration and the second one by CKMfitter. The experimental information for CP violating quantities and the mass differences are correlated and one obtains the allowed regions in the plane shown in Fig. 2.

For $D - \overline{D}$ mixing the SM calculation for the mass difference is not reliable but it is sensible to assume that NP does not generate more than the total observed value. In addition the CP-violating phase in the SM is very small [27] resulting in stringent bounds on NP derived from recent experimental data [28].

Therefore, $\Delta F = 2$ processes put stringent constraints on physics beyond the SM. Especially combining $D - \overline{D}$ and $K - \overline{K}$ mixing is very powerful due to $SU(2)_L$ relations for NP [29]. As an example of how $\Delta F = 2$ processes constrain models of

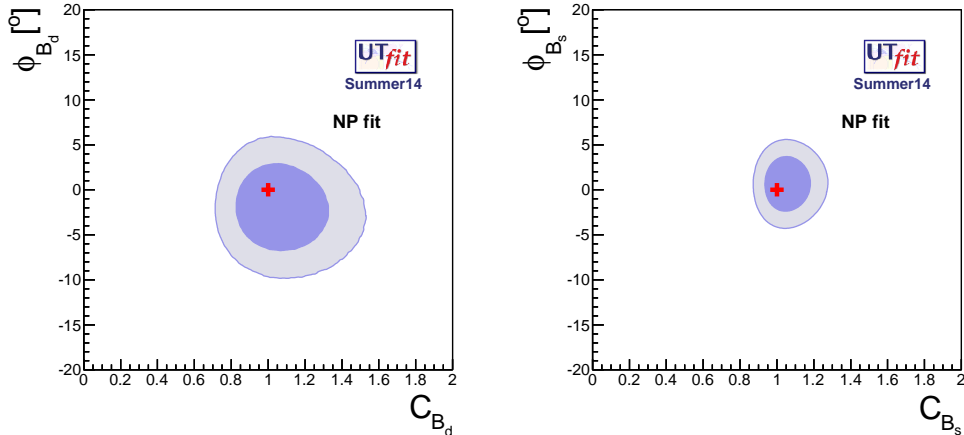


Figure 2: Analysis of NP in $B_q - \bar{B}_q$ mixing of the UTfit collaboration [4]. For a similar analysis of the CKMfitter collaboration see [3]. The SM point (red cross) corresponds to $C_{B_q} = 1$ and $\phi_{B_q} = 0$.

NP we consider the MSSM. Here the mass splitting between the first two generation of left-handed squarks is limited by $K - \bar{K}$ and $D - \bar{D}$ mixing [30]. However, due to cancellations among the different contributions (gluino, chargino and neutralino) it has been shown that the mass splitting can still be sizable [31] (right plot of Fig. 3). A mass splitting among the first two generations has interesting consequences for LHC searches [32].

2.2 $B_q \rightarrow \mu^+ \mu^-$

Thanks to LHCb and CMS [33] we know the branching ratio for $B_q \rightarrow \mu^+ \mu^-$ now rather precisely and also the SM prediction has been improved recently [34]:

$$\text{Br}[B_s \rightarrow \mu^+ \mu^-]_{\text{exp}} = (2.9 \pm 0.7) \times 10^{-9}, \quad \text{Br}[B_s \rightarrow \mu\mu]_{SM} = (3.65 \pm 0.23) \times 10^{-9}. \quad (7)$$

$$\text{Br}[B_d \rightarrow \mu^+ \mu^-]_{\text{exp}} < 7.4 \times 10^{-9}, \quad \text{Br}[B_d \rightarrow \mu\mu]_{SM} = (3.6_{-1.4}^{+1.6}) \times 10^{-10}, \quad (8)$$

$$(9)$$

Due to the good agreement with the SM we can place stringent bounds on models of NP, especially if the NP model possesses scalar currents [35].

As an example we consider again the 2HDM of type III. In the middle plot of Fig. 3 we show the constraints on the parameter $\epsilon_{23,32}^d$ which generate $B_s \rightarrow \mu^+ \mu^-$ via a tree-level Higgs exchange. While the experimental bounds on $B_d \rightarrow \mu^+ \mu^-$

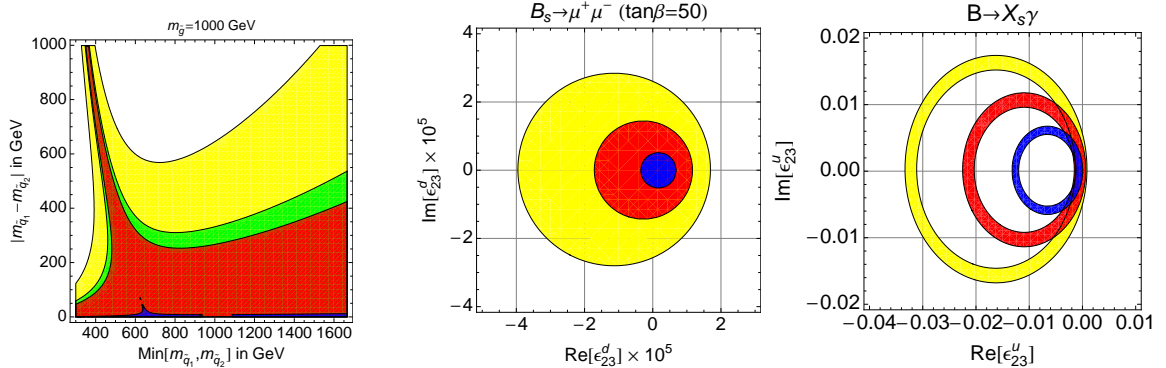


Figure 3: Left: Allowed mass splitting between the first two generations of left-handed squarks for different gluino masses for $M_2 = (\alpha_2/\alpha_s)m_{\tilde{g}} \cong 0.35$ taken from Ref [31]. Yellow (lightest) corresponds to the maximally allowed mass splitting assuming an intermediate alignment of $m_{\tilde{q}}^2$ with $Y_u^\dagger Y_u$ and $Y_d^\dagger Y_d$. The green (red) region is the allowed range assuming an diagonal up (down) squark mass matrix. The blue (darkest) area is the minimal region allowed in which the off-diagonal element carries a maximal phase. Middle: Allowed regions in the complex ϵ_{23}^d -plane from $B_s \rightarrow \mu^+ \mu^-$ for $\tan\beta = 50$ and $m_H = 700$ GeV (yellow), $m_H = 500$ GeV (red) and $m_H = 300$ GeV (blue). Note that the allowed regions for ϵ_{32}^d -plane are not full circles because in this case a suppression of $\mathcal{B}[B_s \rightarrow \mu^+ \mu^-]$ below the experimental lower bound is possible. Right: Allowed regions for ϵ_{23}^u from $B \rightarrow X_s \gamma$, obtained by adding the 2σ experimental error and theoretical uncertainty linear for $\tan\beta = 50$ and $m_H = 700$ GeV (yellow), $m_H = 500$ GeV (red) and $m_H = 300$ GeV (blue). The middle and the right plot are taken from Ref. [13].

are still weaker compared to the SM prediction but LHCb will further improve the experimental limit in the future. Also here stringent limits on $\epsilon_{13,31}^d$ can be obtained. Concerning $K_L \rightarrow \mu^+ \mu^-$ the SM prediction is limited by hadronic uncertainties related to photon rescattering which complicates the extraction on bounds on NP [36]. For $D \rightarrow \mu^+ \mu^-$ the SM prediction is not reliable but it is again sensible to assume that not more than the entire decay rate is generated by NP. Therefore, we can derive in an analogous way stringent constraints on $\epsilon_{12,21}^{u,d}$ as well. In summary, neutral meson decays to muons constrain all flavour-changing elements ϵ_{ij}^d and $\epsilon_{12,21}^u$ stringently.

2.3 $b \rightarrow q\gamma$

Concerning the radiative B decays $b \rightarrow s\gamma$ and $b \rightarrow d\gamma$ the current experimental values [37] and theoretical predictions are given by:

$$\text{Br}[b \rightarrow s\gamma]_{\text{exp}} = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4}, \quad (10)$$

$$\text{Br}[b \rightarrow s\gamma]_{SM} = (3.15 \pm 0.22) \times 10^{-4}, \quad (11)$$

$$\text{Br}[b \rightarrow d\gamma]_{\text{exp}} = (1.41 \pm 0.57) \times 10^{-5}, \quad (12)$$

$$\text{Br}[b \rightarrow d\gamma]_{SM} = 1.54_{-0.31}^{+0.26} \times 10^{-5}. \quad (13)$$

Again, we observe a good agreement between theory predictions[‡] and experiment.

$b \rightarrow s\gamma$ has been used extensively to constrain models of NP, especially the MSSM and the 2HDM of type II [42]. In fact, $b \rightarrow s\gamma$ still gives the best lower bound of 380 GeV [43] on the charged Higgs mass in the 2HDM of type II for low or moderate values of $\tan\beta$ (see Fig. 6).

$b \rightarrow s\gamma$ can for example also be used to put bounds on ϵ_{23}^u originating from charged Higgs loop contributions. The results are shown in the right plot of Fig. 3. Similar constraints apply for ϵ_{13}^u from $b \rightarrow d\gamma$.

2.4 Lepton flavour violation

Flavor-changing neutral current processes are strongly suppressed in the Standard Model (SM) and therefore sensitive even to small new physics (NP) contributions. Lepton flavor violation (LFV) is an especially promising probe of NP since in the SM with massive neutrinos all flavor-violating effects in the charged lepton sector are proportional to tiny neutrino masses.[§] For instance, the decay rates of heavy charged leptons into lighter ones are suppressed at least by m_ν^4/m_W^4 , where m_ν (m_W) is the neutrino (W -boson) mass. This leads to branching ratios of the order of 10^{-50} , which are thus by far too small to be measurable in any foreseeable experiment. Therefore, any evidence of charged LFV would be a clear signal of physics beyond the SM.

Table 1 shows the current experimental status of search for LFV decays.

LFV processes have been studied in great detail in many extensions of the SM. For example, in the MSSM non-vanishing rates for LFV processes are generated by flavor non-diagonal SUSY-breaking terms [51]. Extending the MSSM with right-handed neutrinos by the seesaw mechanism gives rise to LFV [52], as well as allowing for

[‡]The SM prediction for $b \rightarrow d\gamma$ is taken from [38] (based on the calculation of Ref. [39]) while the value for $b \rightarrow s\gamma$ is taken from Ref. [40]. For the experimental value of $b \rightarrow s\gamma$ we used the average of [41].

[§]For a review we refer to [44].

Process	Experimental bound
$\text{Br} [\tau \rightarrow \mu \gamma]$	4.4×10^{-8} [45, 46]
$\text{Br} [\tau \rightarrow e \gamma]$	3.3×10^{-8} [45]
$\text{Br} [\mu \rightarrow e \gamma]$	5.7×10^{-13} [47]
$\text{Br} [\tau^- \rightarrow \mu^- \mu^+ \mu^-]$	2.1×10^{-8} [48]
$\text{Br} [\tau^- \rightarrow e^- e^+ e^-]$	2.7×10^{-8} [48]
$\text{Br} [\tau^- \rightarrow e^- \mu^+ \mu^-]$	2.7×10^{-8} [48]
$\text{Br} [\tau^- \rightarrow \mu^- e^+ \mu^-]$	1.7×10^{-8} [48]
$\text{Br} [\mu^- \rightarrow e^- e^+ e^-]$	1.0×10^{-12} [49]
$\text{Br}_{\text{Au}} [\mu \rightarrow e]$	7.0×10^{-13} [50]

Table 1: Experimental upper limits on the branching ratios of LFV decays.

R -parity violation [53]. The Littlest Higgs Model with T -parity [54], 2HDMs with generic flavor structures [55], and models with an extended fermion sector [56] have sources of LFV as well. In order to make NP scenarios consistent with the non-observation of LFV processes in nature, the assumption of Minimal Flavor Violation has been extended to the lepton sector, see e.g. [57]. LFV decays have been studied in a model-independent way in [58].

Let us consider $\mu \rightarrow e$ conversion in some more detail since it has very promising experimental prospect [59] and is especially suited to test Higgs mediated flavour violation since it does not necessarily involve couplings to light leptons as $\mu \rightarrow e \gamma$ [60]. In Fig. 4 we show the constraints on ϵ_{12}^ℓ in the 2HDM from $\mu \rightarrow e$ conversion.

3 Deviations from the SM

3.1 Tauonic B decays

Tauonic B -meson decays are an excellent probe of new physics: they test lepton flavor universality satisfied in the SM and are sensitive to new particles which couple proportionally to the mass of the involved particles (e.g. Higgs bosons) due to the heavy τ lepton involved. Recently, the BABAR collaboration performed an analysis of the semileptonic B decays $B \rightarrow D \tau \nu$ and $B \rightarrow D^* \tau \nu$ using the full available data set [62]. They find for the ratios

$$\mathcal{R}(D^{(*)}) = \mathcal{B}(B \rightarrow D^{(*)} \tau \nu) / \mathcal{B}(B \rightarrow D^{(*)} \ell \nu), \quad (14)$$

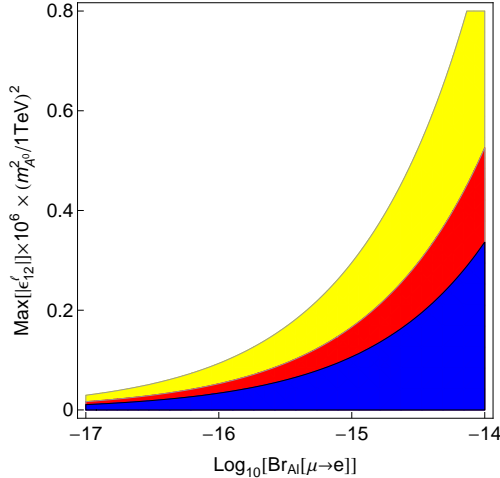


Figure 4: Allowed regions for $\epsilon'_{12} \equiv \epsilon'_{e\mu}$ as a function of the upper limit on $\mu \rightarrow e$ conversion in aluminum [60]. The blue, red, and yellow regions correspond to $\tan \beta = 50, 40, 30$, respectively (the regions are superimposed with more stringent limits for larger $\tan \beta$). Note the simple quadratic scaling of the constraints on the heavy Higgs mass. For the numerical evaluation we used the improved predictions of the nucleon-quark couplings of Ref. [61].

the following results:

$$\mathcal{R}(D) = 0.440 \pm 0.058 \pm 0.042, \quad \mathcal{R}(D^*) = 0.332 \pm 0.024 \pm 0.018. \quad (15)$$

Here the first error is statistical and the second one is systematic. Comparing these measurements to the SM predictions [63] (using the form factors of Refs [64, 41, 6])

$$\mathcal{R}_{\text{SM}}(D) = 0.297 \pm 0.017, \quad \mathcal{R}_{\text{SM}}(D^*) = 0.252 \pm 0.003, \quad (16)$$

we see that there is a discrepancy of 2.2σ for $\mathcal{R}(D)$ and 2.7σ for $\mathcal{R}(D^*)$ and combining them gives a 3.4σ deviation from the SM [62]. This evidence for new physics in B -meson decays to taus is further supported by the measurement of $\mathcal{B}[B \rightarrow \tau\nu] = (1.15 \pm 0.23) \times 10^{-4}$ which disagrees with by 1.6σ higher than the SM prediction using V_{ub} from a global fit of the CKM matrix [1].

The generic effect of NP including differential distributions has been studied in [65]. Many NP explanations of this anomaly have been proposed [66]. A natural possibility to explain these enhancements compared to the SM prediction is a charged scalar particle which couples proportionally to the masses of the fermions involved in the interaction: a charged Higgs boson. A charged Higgs affects $B \rightarrow \tau\nu$ [69], $B \rightarrow D\tau\nu$ and $B \rightarrow D^*\tau\nu$ [70]. In a 2HDM of type II (with MSSM like Higgs potential) the only free additional parameters are $\tan \beta = v_u/v_d$ (the ratio of the

two vacuum expectation values) and the charged Higgs mass m_{H^\pm} (the heavy CP even Higgs mass m_{H^0} and the CP odd Higgs mass m_{A^0} can be expressed in terms of the charged Higgs mass and differ only by electroweak corrections). In this setup the charged Higgs contribution to $B \rightarrow \tau\nu$ interferes necessarily destructively with the SM contribution[69]. Thus, an enhancement of $\mathcal{B}[B \rightarrow \tau\nu]$ is only possible if the absolute value of the charged Higgs contribution is bigger than two times the SM one. Furthermore, a 2HDM of type II cannot explain $\mathcal{R}(\mathcal{D})$ and $\mathcal{R}(\mathcal{D}^*)$ simultaneously [62].

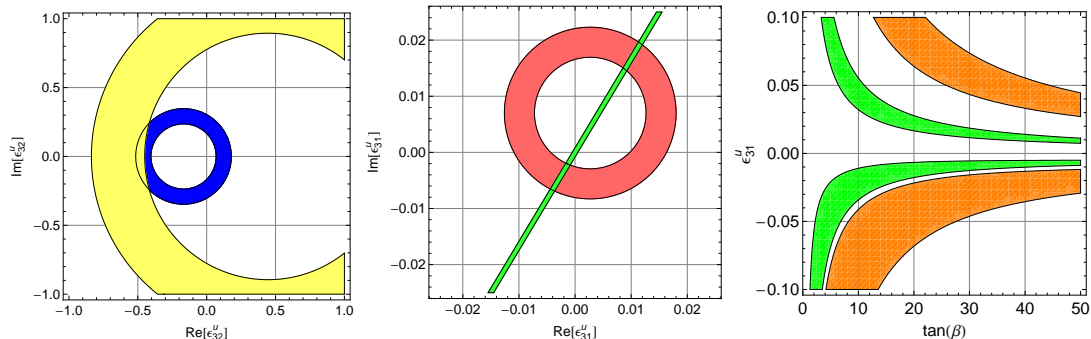


Figure 5: Left: Allowed regions in the complex ϵ_{32}^u -plane from $\mathcal{R}(\mathcal{D})$ (blue) and $\mathcal{R}(\mathcal{D}^*)$ (yellow) for $\tan\beta = 50$ and $m_H = 500$ GeV. Middle: Allowed regions in the complex ϵ_{31}^u -plane from $B \rightarrow \tau\nu$. Right: Allowed regions in the $\tan\beta$ - ϵ_{31}^u plane from $B \rightarrow \tau\nu$ for real values of ϵ_{31}^u and $m_H = 400$ GeV (green), $m_H = 800$ GeV (orange). The scaling of the allowed region for ϵ_{32}^u with $\tan\beta$ and m_H is the same as for ϵ_{31}^u . ϵ_{32}^u and ϵ_{31}^u are given at the matching scale m_H .

As we found before, all ϵ_{ij}^d and $\epsilon_{13,23}^u$ are stringently constrained from FCNC processes in the down sector and only ϵ_{31}^u (ϵ_{32}^u) significantly effects $B \rightarrow \tau\nu$ ($\mathcal{R}(\mathcal{D})$ and $\mathcal{R}(\mathcal{D}^*)$) without any suppression by small CKM elements. Furthermore, since flavor-changing $t \rightarrow u$ (or $t \rightarrow c$) transitions are not constrained with sufficient accuracy, we can only constrain these elements from charged Higgs-induced FCNCs in the down sector. However, since in this case an up (charm) quark always propagates inside the loop, the contribution is suppressed by the small Yukawa couplings of the up-down-Higgs (charm-strange-Higgs) vertex involved in the corresponding diagrams. Thus, the constraints from FCNC processes are weak, and $\epsilon_{32,31}^u$ can be sizable. Indeed, it turns out that by using $\epsilon_{32,31}^u$ we can explain $\mathcal{R}(\mathcal{D}^*)$ and $\mathcal{R}(\mathcal{D})$ simultaneously [71]. In Fig. 5 we see the allowed region in the complex ϵ_{32}^u -plane, which gives the correct values for $\mathcal{R}(\mathcal{D})$ and $\mathcal{R}(\mathcal{D}^*)$ within the 1σ uncertainties for $\tan\beta = 50$ and $M_H = 500$ GeV. Similarly, $B \rightarrow \tau\nu$ can be explained by using ϵ_{31}^u .

3.2 $B \rightarrow K^* \mu^+ \mu^-$ and $B \rightarrow K \mu^+ \mu^-$ vs $B \rightarrow K e^+ e^-$

The decays $B \rightarrow K^* \ell^+ \ell^-$ and $B \rightarrow K \ell^+ \ell^-$ (with $\ell = e, \mu$) have been studied extensively in the SM (including also non-standard operator structures) [72].

While the forward-backward asymmetry in $B \rightarrow K^* \mu^+ \mu^-$ agrees with the SM predictions [73], deviations from the SM predictions have been observed by LHCb in angular observables [74], mainly in the observable called P'_5 . While it is still possible that this anomaly could originate from hadronic uncertainties or power corrections [75], it is still interesting to examine if and how NP can explain this anomaly. In a model independent approach, the deviations from the SM can be explained by rather large contributions to the Wilson coefficient C_9 [76, 78]. Concerning concrete models of NP properly the most natural expectation is a flavour changing Z or Z' coupling [79] while explaining the central value of the anomaly in the MSSM is not possible without violating bounds from other observables [78, 80] which is also true for models with extra dimensions [81].

Very recently, LHCb measured the ratio $R_K = \text{Br}[B \rightarrow K \mu^+ \mu^-] / \text{Br}[B \rightarrow K e^+ e^-]$ [74] and found significant deviations from the SM prediction $R_K^{\text{SM}} = 1.0003 \pm 0.0001$:

$$R_K^{\text{LHCb}} = 0.745_{-0.074}^{+0.090} \pm 0.036. \quad (17)$$

A possible explanation would be NP contributing to $B \rightarrow K \mu^+ \mu^-$ but not to $B \rightarrow K e^+ e^-$ involving C_9 with muons only [83] which also give welcome NP effects in $B \rightarrow K^* \mu^+ \mu^-$.

4 Conclusions

In these proceedings I presented a personal perspective of the challenges for NP physics in the flavour sector. We reviewed the stringent constraints on physics beyond the SM imposed by flavour observables which must be respected by any viable model of NP. As an example, the combined flavour constraints on the 2HDM of type II are shown in Fig. 6. In case deviations from the SM are observed, it is interesting to examine which model of NP is capable of explaining such deviations without violating bounds from other observables. As examples we considered tauonic B decays, $B \rightarrow K^* \ell^+ \ell^-$ and R_K . While a rather natural explanation for $B \rightarrow (D^{(*)} \tau \nu)$ is a charged Higgs contribution in a 2HDM with flavour-changing couplings involving the top quark, $B \rightarrow K^* \ell^+ \ell^-$ and R_K can most naturally be explained by a Z' boson.

ACKNOWLEDGEMENTS

I thank the organizers for the invitation and the possibility to present these results. I also thank Ulrich Nierste for useful discussions and proofreading. This work is

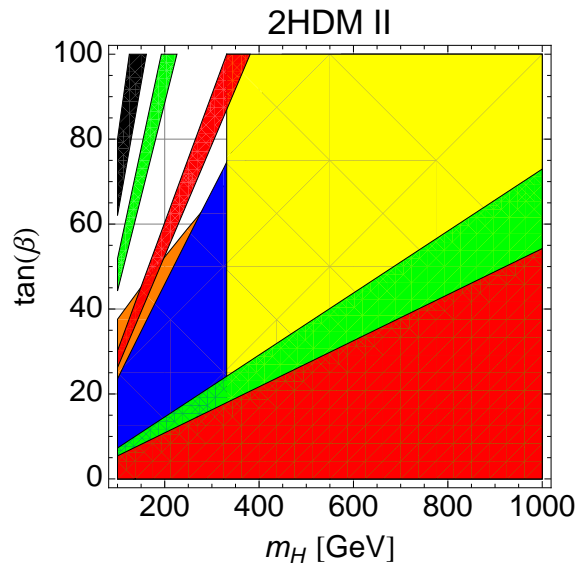


Figure 6: Updated constraints on the 2HDM of type II parameter space [13]. The regions compatible with experiment are shown (the regions are superimposed on each other): $b \rightarrow s\gamma$ (yellow), $B \rightarrow D\tau\nu$ (green), $B \rightarrow \tau\nu$ (red), $B_s \rightarrow \mu^+\mu^-$ (orange), $K \rightarrow \mu\nu/\pi \rightarrow \mu\nu$ (blue) and $B \rightarrow D^*\tau\nu$ (black). Note that no region in parameter space is compatible with all processes. Explaining $B \rightarrow D^*\tau\nu$ would require very small Higgs masses and large values of $\tan\beta$ which is not compatible with the other observables. To obtain this plot, we added the theoretical uncertainty linearly on top of the 2σ experimental error.

supported by a Marie Curie Intra-European Fellowship of the European Community's 7th Framework Programme under contract number (PIEF-GA-2012-326948).

References

- [1] J. Charles *et al.* [CKMfitter Group Collaboration], “CP violation and the CKM matrix: Assessing the impact of the asymmetric B factories,” *Eur. Phys. J. C* **41** (2005) 1 [hep-ph/0406184].
- [2] M. Bona *et al.* [UTfit Collaboration], “The 2004 UTfit collaboration report on the status of the unitarity triangle in the standard model,” *JHEP* **0507** (2005) 028 [hep-ph/0501199].
- [3] Homepage of the CKMfitter collaboration: <http://ckmfitter.in2p3.fr>.
- [4] Homepage of the UTfit collaboration: <http://www.utfit.org/UTfit>.

- [5] R. S. Chivukula, H. Georgi and L. Randall, “A Composite Technicolor Standard Model of Quarks,” Nucl. Phys. B **292** (1987) 93.
G. D’Ambrosio, G. F. Giudice, G. Isidori and A. Strumia, “Minimal flavor violation: An Effective field theory approach,” Nucl. Phys. B **645** (2002) 155 [hep-ph/0207036].
- [6] J. Beringer *et al.* [Particle Data Group Collaboration], “Review of Particle Physics (RPP),” Phys. Rev. D **86** (2012) 010001.
- [7] G. Ricciardi, “Determination of the CKM matrix elements $|V_{xb}|$,” Mod. Phys. Lett. A **28** (2013) 1330016 [arXiv:1305.2844 [hep-ph]].
G. Ricciardi, “Progress on semi-leptonic $B_{(s)}$ decays,” Mod. Phys. Lett. A **29** (2014) 1430019 [arXiv:1403.7750 [hep-ph]].
- [8] A. Crivellin and S. Pokorski, “Can the differences in the determinations of V_{ub} and V_{cb} be explained by New Physics?,” arXiv:1407.1320 [hep-ph].
- [9] C. H. Chen and S. h. Nam, “Left-right mixing on leptonic and semileptonic $b \rightarrow u$ decays,” Phys. Lett. B **666** (2008) 462 [arXiv:0807.0896 [hep-ph]].
A. Crivellin, “Effects of right-handed charged currents on the determinations of $|V_{ub}|$ and $|V_{cb}|$,” Phys. Rev. D **81** (2010) 031301 [arXiv:0907.2461 [hep-ph]].
A. J. Buras, K. Gemmler and G. Isidori, “Quark flavour mixing with right-handed currents: an effective theory approach,” Nucl. Phys. B **843** (2011) 107 [arXiv:1007.1993 [hep-ph]].
- [10] F. U. Bernlochner, Z. Ligeti and S. Turczyk, “New ways to search for right-handed current in $B \rightarrow \rho \ell \nu$ decay,” arXiv:1408.2516 [hep-ph].
- [11] T. D. Lee, “A Theory of Spontaneous T Violation,” Phys. Rev. D **8** (1973) 1226.
- [12] G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, “Theory and phenomenology of two-Higgs-doublet models,” Phys. Rept. **516** (2012) 1 [arXiv:1106.0034 [hep-ph]].
- [13] A. Crivellin, A. Kokulu and C. Greub, “Flavor-phenomenology of two-Higgs-doublet models with generic Yukawa structure,” Phys. Rev. D **87** (2013) 9, 094031 [arXiv:1303.5877 [hep-ph]].
- [14] T. Banks, “Supersymmetry and the Quark Mass Matrix,” Nucl. Phys. B **303** (1988) 172.
L. J. Hall, R. Rattazzi and U. Sarid, “The Top quark mass in supersymmetric SO(10) unification,” Phys. Rev. D **50** (1994) 7048 [hep-ph/9306309, hep-ph/9306309].

- C. Hamzaoui, M. Pospelov and M. Toharia, “Higgs mediated FCNC in supersymmetric models with large $\tan\beta$,” Phys. Rev. D **59** (1999) 095005 [hep-ph/9807350].
- K. S. Babu and C. F. Kolda, “Higgs mediated $B^0 \rightarrow \mu^+\mu^-$ in minimal supersymmetry,” Phys. Rev. Lett. **84** (2000) 228 [hep-ph/9909476].
- M. S. Carena, M. Olechowski, S. Pokorski and C. E. M. Wagner, “Electroweak symmetry breaking and bottom - top Yukawa unification,” Nucl. Phys. B **426** (1994) 269 [hep-ph/9402253].
- R. Hempfling, “Yukawa coupling unification with supersymmetric threshold corrections,” Phys. Rev. D **49** (1994) 6168.
- T. Blazek, S. Raby and S. Pokorski, “Finite supersymmetric threshold corrections to CKM matrix elements in the large $\tan\beta$ regime,” Phys. Rev. D **52** (1995) 4151 [hep-ph/9504364].
- M. S. Carena, D. Garcia, U. Nierste and C. E. M. Wagner, “Effective Lagrangian for the $\bar{t}bH^+$ interaction in the MSSM and charged Higgs phenomenology,” Nucl. Phys. B **577** (2000) 88 [hep-ph/9912516].
- G. Isidori and A. Retico, “ $B_{s,d} \rightarrow \ell^+\ell^-$ and $K_L \rightarrow \ell^+\ell^-$ in SUSY models with nonminimal sources of flavor mixing,” JHEP **0209** (2002) 063 [hep-ph/0208159].
- A. J. Buras, P. H. Chankowski, J. Rosiek and L. Slawianowska, “ $\Delta M_{d,s}, B^0d, s \rightarrow \mu^+\mu^-$ and $B \rightarrow X_s\gamma$ in supersymmetry at large $\tan\beta$,” Nucl. Phys. B **659** (2003) 3 [hep-ph/0210145].
- L. Hofer, U. Nierste and D. Scherer, “Resummation of $\tan\beta$ -enhanced supersymmetric loop corrections beyond the decoupling limit,” JHEP **0910** (2009) 081 [arXiv:0907.5408 [hep-ph]].
- [15] A. Crivellin, “Effective Higgs Vertices in the generic MSSM,” Phys. Rev. D **83** (2011) 056001 [arXiv:1012.4840 [hep-ph]].
- A. Crivellin, L. Hofer and J. Rosiek, “Complete resummation of chirally-enhanced loop-effects in the MSSM with non-minimal sources of flavor-violation,” JHEP **1107** (2011) 017 [arXiv:1103.4272 [hep-ph]].
- [16] A. Crivellin and C. Greub, “Two-loop SQCD corrections to Higgs-quark-quark couplings in the generic MSSM,” arXiv:1210.7453 [hep-ph].
- [17] D. Noth and M. Spira, “Supersymmetric Higgs Yukawa Couplings to Bottom Quarks at next-to-next-to-leading Order,” JHEP **1106** (2011) 084 [arXiv:1001.1935 [hep-ph]].
- A. Bauer, L. Mihaila and J. Salomon, “Matching coefficients for α_s and $m(b)$ to $O(\alpha_s^2)$ in the MSSM,” JHEP **0902** (2009) 037 [arXiv:0810.5101 [hep-ph]].
- A. Bednyakov, A. Onishchenko, V. Velizhanin and O. Veretin, “Two loop $O(\alpha_s^2)$

- MSSM corrections to the pole masses of heavy quarks,” *Eur. Phys. J. C* **29** (2003) 87 [hep-ph/0210258].
- [18] A. B. Lahanas and D. Wyler, “Radiative Fermion Masses and Supersymmetry,” *Phys. Lett. B* **122** (1983) 258.
 E. Ma, “Radiative Quark and Lepton Masses Through Soft Supersymmetry Breaking,” *Phys. Rev. D* **39** (1989) 1922.
 N. V. Krasnikov, “The $m(d) / m(e)$ ratio in a supersymmetric SU(5) model with radiative fermion masses of the first generation through soft supersymmetry breaking,” *Phys. Lett. B* **302** (1993) 59.
 N. Arkani-Hamed, H. C. Cheng and L. J. Hall, “A Supersymmetric theory of flavor with radiative fermion masses,” *Phys. Rev. D* **54** (1996) 2242 [hep-ph/9601262].
 F. Borzumati, G. R. Farrar, N. Polonsky and S. D. Thomas, “Soft Yukawa couplings in supersymmetric theories,” *Nucl. Phys. B* **555** (1999) 53 [hep-ph/9902443].
 J. Ferrandis and N. Haba, “Supersymmetry breaking as the origin of flavor,” *Phys. Rev. D* **70** (2004) 055003 [hep-ph/0404077].
 A. Crivellin, J. Girrbach and U. Nierste, “Yukawa coupling and anomalous magnetic moment of the muon: an update for the LHC era,” *Phys. Rev. D* **83** (2011) 055009 [arXiv:1010.4485 [hep-ph]].
 A. Crivellin and U. Nierste, “Supersymmetric renormalisation of the CKM matrix and new constraints on the squark mass matrices,” *Phys. Rev. D* **79** (2009) 035018 [arXiv:0810.1613 [hep-ph]].
 A. Crivellin, “CKM Elements from Squark Gluino Loops,” arXiv:0905.3130 [hep-ph].
 A. Crivellin, L. Hofer, U. Nierste and D. Scherer, “Phenomenological consequences of radiative flavor violation in the MSSM,” *Phys. Rev. D* **84** (2011) 035030 [arXiv:1105.2818 [hep-ph]].
 A. Crivellin, L. Hofer and U. Nierste, “The MSSM with a Softly Broken $U(2)^3$ Flavor Symmetry,” *PoS EPS -HEP2011* (2011) 145 [arXiv:1111.0246 [hep-ph]].
- [19] M. Bona *et al.* [UTfit Collaboration], “Model-independent constraints on $\Delta F = 2$ operators and the scale of new physics,” *JHEP* **0803** (2008) 049 [arXiv:0707.0636 [hep-ph]].
- [20] A. Lenz, U. Nierste, J. Charles, S. Descotes-Genon, A. Jantsch, C. Kaufhold, H. Lacker and S. Monteil *et al.*, “Anatomy of New Physics in $B - \bar{B}$ mixing,” *Phys. Rev. D* **83** (2011) 036004 [arXiv:1008.1593 [hep-ph]].

- [21] A. J. Buras, M. Jamin and P. H. Weisz, “Leading and Next-to-leading QCD Corrections to ϵ Parameter and $B^0 - \bar{B}^0$ Mixing in the Presence of a Heavy Top Quark,” Nucl. Phys. B **347** (1990) 491.
- [22] S. Herrlich and U. Nierste, “Enhancement of the $K_L - K_S$ mass difference by short distance QCD corrections beyond leading logarithms,” Nucl. Phys. B **419** (1994) 292 [hep-ph/9310311].
S. Herrlich and U. Nierste, “The Complete $|\Delta S| = 2$ - Hamiltonian in the next-to-leading order,” Nucl. Phys. B **476** (1996) 27 [hep-ph/9604330].
- [23] J. Brod and M. Gorbahn, “ ϵ_K at Next-to-Next-to-Leading Order: The Charm-Top-Quark Contribution,” Phys. Rev. D **82** (2010) 094026 [arXiv:1007.0684 [hep-ph]].
J. Brod and M. Gorbahn, “Next-to-Next-to-Leading-Order Charm-Quark Contribution to the CP Violation Parameter ϵ_K and ΔM_K ,” Phys. Rev. Lett. **108** (2012) 121801 [arXiv:1108.2036 [hep-ph]].
- [24] A. Lenz and U. Nierste, “Theoretical update of $B_s - \bar{B}_s$ mixing,” JHEP **0706** (2007) 072 [hep-ph/0612167].
A. Lenz and U. Nierste, “Numerical Updates of Lifetimes and Mixing Parameters of B Mesons,” arXiv:1102.4274 [hep-ph].
- [25] R. Aaij *et al.* [LHCb Collaboration], “Precision measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency with the decay $B_s^0 \rightarrow D_s^- \pi^+$,” New J. Phys. **15** (2013) 053021 [arXiv:1304.4741 [hep-ex]].
R. Aaij *et al.* [LHCb Collaboration], “Measurement of the CP-violating phase ϕ_s in $\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-$ decays,” Phys. Lett. B **736** (2014) 186 [arXiv:1405.4140 [hep-ex]].
- [26] A. Abulencia *et al.* [CDF Collaboration], “Observation of B0(s) - anti-B0(s) Oscillations,” Phys. Rev. Lett. **97** (2006) 242003 [hep-ex/0609040].
- [27] M. Bobrowski, A. Lenz, J. Riedl and J. Rohrwild, “How Large Can the SM Contribution to CP Violation in $D^0 - \bar{D}^0$ Mixing Be?,” JHEP **1003** (2010) 009 [arXiv:1002.4794 [hep-ph]].
- [28] A. J. Bevan *et al.* [UTfit Collaboration], “The UTfit collaboration average of D meson mixing data: Winter 2014,” JHEP **1403** (2014) 123 [arXiv:1402.1664 [hep-ph]].
- [29] K. Blum, Y. Grossman, Y. Nir and G. Perez, “Combining K0 - anti-K0 mixing and D0 - anti-D0 mixing to constrain the flavor structure of new physics,” Phys. Rev. Lett. **102** (2009) 211802 [arXiv:0903.2118 [hep-ph]].

- [30] Y. Nir and N. Seiberg, “Should squarks be degenerate?,” *Phys. Lett. B* **309** (1993) 337 [hep-ph/9304307].
 Y. Nir and G. Raz, “Quark squark alignment revisited,” *Phys. Rev. D* **66** (2002) 035007 [hep-ph/0206064].
- [31] A. Crivellin and M. Davidkov, “Do squarks have to be degenerate? Constraining the mass splitting with Kaon and D mixing,” *Phys. Rev. D* **81** (2010) 095004 [arXiv:1002.2653 [hep-ph]].
- [32] R. Mahbubani, M. Papucci, G. Perez, J. T. Ruderman and A. Weiler, “Light Nondegenerate Squarks at the LHC,” *Phys. Rev. Lett.* **110** (2013) 15, 151804 [arXiv:1212.3328 [hep-ph]].
- [33] RAaij *et al.* [LHCb Collaboration], “First Evidence for the Decay $B_s^0 \rightarrow \mu^+\mu^-$,” *Phys. Rev. Lett.* **110** (2013) 021801 [arXiv:1211.2674 [hep-ex]].
 S. Chatrchyan *et al.* [CMS Collaboration], “Measurement of the $B_s^0 \rightarrow \mu^+\mu^-$ branching fraction and search for $B^0 \rightarrow \mu^+\mu^-$ with the CMS Experiment,” *Phys. Rev. Lett.* **111** (2013) 101804 [arXiv:1307.5025 [hep-ex]].
 R. Aaij *et al.* [LHCb Collaboration], “Measurement of the $B_s^0 \rightarrow \mu^+\mu^-$ branching fraction and search for $B^0 \rightarrow \mu^+\mu^-$ decays at the LHCb experiment,” *Phys. Rev. Lett.* **111** (2013) 101805 [arXiv:1307.5024 [hep-ex]].
 CMS and LHCb Collaborations [CMS and LHCb Collaboration], “Combination of results on the rare decays $B_{(s)}^0 \rightarrow \mu^+\mu^-$ from the CMS and LHCb experiments,” CMS-PAS-BPH-13-007.
- [34] C. Bobeth, M. Gorbahn, T. Hermann, M. Misiak, E. Stamou and M. Steinhauser, “ $B_{s,d} \rightarrow l^+l^-$ in the Standard Model with Reduced Theoretical Uncertainty,” *Phys. Rev. Lett.* **112** (2014) 101801 [arXiv:1311.0903 [hep-ph]].
- [35] K. S. Babu and C. F. Kolda, “Higgs mediated $B^0 \rightarrow \mu^+\mu^-$ in minimal supersymmetry,” *Phys. Rev. Lett.* **84** (2000) 228 [hep-ph/9909476].
 H. E. Logan and U. Nierste, “ $B(s, d) \rightarrow \ell^+\ell^-$ in a two Higgs doublet model,” *Nucl. Phys. B* **586** (2000) 39 [hep-ph/0004139].
 A. Dedes, H. K. Dreiner and U. Nierste, “Correlation of $B_s \rightarrow \mu^+\mu^-$ and $(g-2) (\mu)$ in minimal supergravity,” *Phys. Rev. Lett.* **87** (2001) 251804 [hep-ph/0108037].
 A. Dedes, J. Rosiek and P. Tanedo, “Complete One-Loop MSSM Predictions for $B \rightarrow \ell\ell'$ at the Tevatron and LHC,” *Phys. Rev. D* **79** (2009) 055006 [arXiv:0812.4320 [hep-ph]].
 A. J. Buras, M. V. Carlucci, S. Gori and G. Isidori, “Higgs-mediated FCNCs: Natural Flavour Conservation vs. Minimal Flavour Violation,” *JHEP* **1010** (2010) 009 [arXiv:1005.5310 [hep-ph]].
 W. Altmannshofer and D. M. Straub, “Cornering New Physics in $b \rightarrow s$ Transitions,” *JHEP* **1208** (2012) 121 [arXiv:1206.0273 [hep-ph]].

- A. Arbey, M. Battaglia, F. Mahmoudi and D. Martinez Santos, “Supersymmetry confronts $B_s \rightarrow \mu^+\mu^-$: Present and future status,” *Phys. Rev. D* **87** (2013) 035026 [arXiv:1212.4887 [hep-ph]].
- W. Altmannshofer, M. Carena, N. R. Shah and F. Yu, “Indirect Probes of the MSSM after the Higgs Discovery,” *JHEP* **1301** (2013) 160 [arXiv:1211.1976 [hep-ph]].
- W. Altmannshofer, “The B_s^+ and B_d^+ Decays: Standard Model and Beyond,” *PoS Beauty* **2013** (2013) 024 [arXiv:1306.0022 [hep-ph]].
- X. Q. Li, J. Lu and A. Pich, “ $B_{s,d}^0 \rightarrow \ell^+\ell^-$ Decays in the Aligned Two-Higgs-Doublet Model,” *JHEP* **1406** (2014) 022 [arXiv:1404.5865 [hep-ph]].
- [36] G. Isidori and R. Unterdorfer, “On the short distance constraints from $K_{L,S} \rightarrow \mu^+\mu^-$,” *JHEP* **0401** (2004) 009 [hep-ph/0311084].
- [37] S. Chen *et al.* [CLEO Collaboration], “Branching fraction and photon energy spectrum for $b \rightarrow s\gamma$,” *Phys. Rev. Lett.* **87** (2001) 251807 [hep-ex/0108032].
- K. Abe *et al.* [Belle Collaboration], “A Measurement of the branching fraction for the inclusive $B \rightarrow X_s\gamma$ decays with BELLE,” *Phys. Lett. B* **511** (2001) 151 [hep-ex/0103042].
- A. Limosani *et al.* [Belle Collaboration], “Measurement of Inclusive Radiative B-meson Decays with a Photon Energy Threshold of 1.7-GeV,” *Phys. Rev. Lett.* **103** (2009) 241801 [arXiv:0907.1384 [hep-ex]].
- J. P. Lees *et al.* [BaBar Collaboration], “Exclusive Measurements of $b \rightarrow s\gamma$ Transition Rate and Photon Energy Spectrum,” *Phys. Rev. D* **86** (2012) 052012 [arXiv:1207.2520 [hep-ex]].
- J. P. Lees *et al.* [BaBar Collaboration], “Measurement of $B(B \rightarrow X_s\gamma)$, the $B \rightarrow X_s\gamma$ photon energy spectrum, and the direct CP asymmetry in $B \rightarrow X_{s+d}\gamma$ decays,” *Phys. Rev. D* **86** (2012) 112008 [arXiv:1207.5772 [hep-ex]].
- B. Aubert *et al.* [BaBar Collaboration], “Measurement of the $B \rightarrow X_s\gamma$ branching fraction and photon energy spectrum using the recoil method,” *Phys. Rev. D* **77** (2008) 051103 [arXiv:0711.4889 [hep-ex]].
- P. del Amo Sanchez *et al.* [BaBar Collaboration], “Study of $B \rightarrow X\gamma$ decays and determination of $|V_{td}/V_{ts}|$,” *Phys. Rev. D* **82** (2010) 051101 [arXiv:1005.4087 [hep-ex]].
- [38] A. Crivellin and L. Mercolli, *Phys. Rev. D* **84** (2011) 114005 [arXiv:1106.5499 [hep-ph]].
- [39] A. Ali and C. Greub, “Rare decays $B \rightarrow X_d\gamma$ in the standard model,” *Phys. Lett. B* **287** (1992) 191.
- A. Ali, H. Asatrian and C. Greub, “Inclusive decay rate for $B \rightarrow X_d + \gamma$ in next-to-leading logarithmic order and CP asymmetry in the standard model,”

- Phys. Lett. B **429** (1998) 87 [hep-ph/9803314].
T. Hurth, E. Lunghi and W. Porod, “Untagged $B \rightarrow X_{s+d}$ gamma CP asymmetry as a probe for new physics,” Nucl. Phys. B **704** (2005) 56 [hep-ph/0312260].
- [40] M. Misiak, H. M. Asatrian, K. Bieri, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia and P. Gambino *et al.*, “Estimate of $B \rightarrow X_s \gamma$ at $O(\alpha_s^2)$,” Phys. Rev. Lett. **98** (2007) 022002 [hep-ph/0609232].
- [41] Y. Amhis *et al.* [Heavy Flavor Averaging Group Collaboration], “Averages of B-Hadron, C-Hadron, and tau-lepton properties as of early 2012,” arXiv:1207.1158 [hep-ex].
- [42] S. Bertolini, F. Borzumati, A. Masiero and G. Ridolfi, “Effects of supergravity induced electroweak breaking on rare B decays and mixings,” Nucl. Phys. B **353** (1991) 591.
F. Borzumati, C. Greub, T. Hurth and D. Wyler, “Gluino contribution to radiative B decays: Organization of QCD corrections and leading order results,” Phys. Rev. D **62** (2000) 075005 [hep-ph/9911245].
M. Ciuchini, G. Degrassi, P. Gambino and G. F. Giudice, “Next-to-leading QCD corrections to $B \rightarrow X_s \gamma$: Standard model and two Higgs doublet model,” Nucl. Phys. B **527** (1998) 21 [hep-ph/9710335].
M. Ciuchini, G. Degrassi, P. Gambino and G. F. Giudice, “Next-to-leading QCD corrections to $B \rightarrow X_s \gamma$ in supersymmetry,” Nucl. Phys. B **534** (1998) 3 [hep-ph/9806308].
F. Borzumati and C. Greub, “2HDMs predictions for $B \rightarrow X_s \gamma$ in NLO QCD,” Phys. Rev. D **58** (1998) 074004 [hep-ph/9802391].
M. S. Carena, D. Garcia, U. Nierste and C. E. M. Wagner, “ $b \rightarrow s \gamma$ and supersymmetry with large $\tan \beta$,” Phys. Lett. B **499** (2001) 141 [hep-ph/0010003].
G. Degrassi, P. Gambino and G. F. Giudice, “ $B \rightarrow X_s \gamma$ in supersymmetry: Large contributions beyond the leading order,” JHEP **0012** (2000) 009 [hep-ph/0009337].
T. Besmer, C. Greub and T. Hurth, “Bounds on supersymmetric flavor violating parameters from $B \rightarrow X_s \gamma$,” Nucl. Phys. B **609** (2001) 359 [hep-ph/0105292].
J. Foster, K. i. Okumura and L. Roszkowski, “New Higgs effects in B-physics in supersymmetry with general flavour mixing,” Phys. Lett. B **609** (2005) 102 [hep-ph/0410323].
A. Crivellin and U. Nierste, “Chirally enhanced corrections to FCNC processes in the generic MSSM,” Phys. Rev. D **81** (2010) 095007 [arXiv:0908.4404 [hep-ph]].
- [43] T. Hermann, M. Misiak and M. Steinhauser, “ $\overline{B} \rightarrow X_s \gamma$ in the Two Higgs Doublet Model up to Next-to-Next-to-Leading Order in QCD,” JHEP **1211** (2012) 036 [arXiv:1208.2788 [hep-ph]].

- [44] M. Raidal, A. van der Schaaf, I. Bigi, M. L. Mangano, Y. K. Semertzidis, S. Abel, S. Albino and S. Antusch *et al.*, “Flavour physics of leptons and dipole moments,” *Eur. Phys. J. C* **57** (2008) 13 [arXiv:0801.1826 [hep-ph]].
Y. Kuno and Y. Okada, “Muon decay and physics beyond the standard model,” *Rev. Mod. Phys.* **73** (2001) 151 [hep-ph/9909265].
- [45] B. Aubert *et al.* [BaBar Collaboration], “Searches for Lepton Flavor Violation in the Decays $\tau \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$,” *Phys. Rev. Lett.* **104** (2010) 021802 [arXiv:0908.2381 [hep-ex]].
- [46] K. Hayasaka *et al.* [Belle Collaboration], “New search for $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ decays at Belle,” *Phys. Lett. B* **666** (2008) 16 [arXiv:0705.0650 [hep-ex]].
- [47] J. Adam *et al.* [MEG Collaboration], “New constraint on the existence of the $\mu^+ \rightarrow e^+\gamma$ decay,” *Phys. Rev. Lett.* **110** (2013) 20, 201801 [arXiv:1303.0754 [hep-ex]].
- [48] K. Hayasaka, K. Inami, Y. Miyazaki, K. Arinstein, V. Aulchenko, T. Aushev, A. M. Bakich and A. Bay *et al.*, “Search for Lepton Flavor Violating Tau Decays into Three Leptons with 719 Million Produced Tau+Tau- Pairs,” *Phys. Lett. B* **687** (2010) 139 [arXiv:1001.3221 [hep-ex]].
- [49] U. Bellgardt *et al.* [SINDRUM Collaboration], “Search for the Decay $\mu^+ \rightarrow e^+e^+e^-$,” *Nucl. Phys. B* **299** (1988) 1.
- [50] W. H. Bertl *et al.* [SINDRUM II Collaboration], “A Search for muon to electron conversion in muonic gold,” *Eur. Phys. J. C* **47** (2006) 337.
- [51] F. Borzumati and A. Masiero, “Large Muon and electron Number Violations in Supergravity Theories,” *Phys. Rev. Lett.* **57** (1986) 961.
A. Brignole and A. Rossi, “Anatomy and phenomenology of mu-tau lepton flavor violation in the MSSM,” *Nucl. Phys. B* **701** (2004) 3 [hep-ph/0404211].
P. Paradisi, “Constraints on SUSY lepton flavor violation by rare processes,” *JHEP* **0510** (2005) 006 [hep-ph/0505046].
P. Paradisi, “Higgs-mediated $e \rightarrow \mu$ transitions in II Higgs doublet model and supersymmetry,” *JHEP* **0608** (2006) 047 [hep-ph/0601100].
W. Altmannshofer, A. J. Buras, S. Gori, P. Paradisi and D. M. Straub, “Anatomy and Phenomenology of FCNC and CPV Effects in SUSY Theories,” *Nucl. Phys.*

- B **830** (2010) 17 [arXiv:0909.1333 [hep-ph]].
 J. Girrbach, S. Mertens, U. Nierste and S. Wiesenfeldt, “Lepton flavour violation in the MSSM,” JHEP **1005** (2010) 026 [arXiv:0910.2663 [hep-ph]].
- [52] A. Ilakovac and A. Pilaftsis, “Flavor violating charged lepton decays in seesaw-type models,” Nucl. Phys. B **437** (1995) 491 [hep-ph/9403398].
 J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, “Lepton flavor violation via right-handed neutrino Yukawa couplings in supersymmetric standard model,” Phys. Rev. D **53** (1996) 2442 [hep-ph/9510309].
 J. Hisano and K. Tobe, “Neutrino masses, muon $g-2$, and lepton flavor violation in the supersymmetric seesaw model,” Phys. Lett. B **510** (2001) 197 [hep-ph/0102315].
 K. S. Babu and C. Kolda, “Higgs mediated $\tau \rightarrow 3\mu$ in the supersymmetric seesaw model,” Phys. Rev. Lett. **89** (2002) 241802 [hep-ph/0206310].
 A. Masiero, S. K. Vempati and O. Vives, “Massive neutrinos and flavor violation,” New J. Phys. **6** (2004) 202 [hep-ph/0407325].
 S. Antusch, E. Arganda, M. J. Herrero and A. M. Teixeira, “Impact of $\theta(13)$ on lepton flavour violating processes within SUSY seesaw,” JHEP **0611** (2006) 090 [hep-ph/0607263].
 A. Dedes, H. E. Haber and J. Rosiek, “Seesaw mechanism in the sneutrino sector and its consequences,” JHEP **0711** (2007) 059 [arXiv:0707.3718 [hep-ph]].
 A. Ilakovac, A. Pilaftsis and L. Popov, “Charged lepton flavor violation in supersymmetric low-scale seesaw models,” Phys. Rev. D **87** (2013) 5, 053014 [arXiv:1212.5939 [hep-ph]].
 A. Ilakovac, A. Pilaftsis and L. Popov, “Lepton Dipole Moments in Supersymmetric Low-Scale Seesaw Models,” Phys. Rev. D **89** (2014) 015001 [arXiv:1308.3633 [hep-ph]].
- [53] A. de Gouvea, S. Lola and K. Tobe, “Lepton flavor violation in supersymmetric models with trilinear R-parity violation,” Phys. Rev. D **63** (2001) 035004 [hep-ph/0008085].
 A. Abada, S. Davidson and M. Losada, “Neutrino masses and mixings in the MSSM with soft bilinear R(p) violation,” Phys. Rev. D **65** (2002) 075010 [hep-ph/0111332].
 A. Dedes, S. Rimmer and J. Rosiek, “Neutrino masses in the lepton number violating MSSM,” JHEP **0608** (2006) 005 [hep-ph/0603225].
 A. Abada, M. E. Krauss, W. Porod, F. Staub, A. Vicente and C. Weiland, “Lepton flavor violation in low-scale seesaw models: SUSY and non-SUSY contributions,” arXiv:1408.0138 [hep-ph].
- [54] M. Blanke, A. J. Buras, B. Duling, A. Poschenrieder and C. Tarantino, “Charged Lepton Flavour Violation and $(g-2)(\mu)$ in the Littlest Higgs Model with T-

- Parity: A Clear Distinction from Supersymmetry,” JHEP **0705** (2007) 013 [hep-ph/0702136].
- [55] S. Kanemura, K. Matsuda, T. Ota, T. Shindou, E. Takasugi and K. Tsumura, “Search for lepton flavor violation in the Higgs boson decay at a linear collider,” Phys. Lett. B **599** (2004) 83 [hep-ph/0406316].
S. Kanemura, T. Ota and K. Tsumura, “Lepton flavor violation in Higgs boson decays under the rare tau decay results,” Phys. Rev. D **73** (2006) 016006 [hep-ph/0505191].
P. Paradisi, “Higgs-mediated $\tau \rightarrow \mu$ and $\tau \rightarrow e$ transitions in II Higgs doublet model and supersymmetry,” JHEP **0602** (2006) 050 [hep-ph/0508054].
- [56] A. J. Buras, C. Grojean, S. Pokorski and R. Ziegler, “FCNC Effects in a Minimal Theory of Fermion Masses,” JHEP **1108** (2011) 028 [arXiv:1105.3725 [hep-ph]].
- [57] V. Cirigliano, B. Grinstein, G. Isidori and M. B. Wise, “Minimal flavor violation in the lepton sector,” Nucl. Phys. B **728** (2005) 121 [hep-ph/0507001]. E. Nikolidakis and C. Smith, “Minimal Flavor Violation, Seesaw, and R-parity,” Phys. Rev. D **77** (2008) 015021 [arXiv:0710.3129 [hep-ph]].
- [58] M. Raidal and A. Santamaria, “Muon electron conversion in nuclei versus $\mu \rightarrow e\gamma$: An Effective field theory point of view,” Phys. Lett. B **421** (1998) 250 [hep-ph/9710389].
V. Cirigliano, R. Kitano, Y. Okada and P. Tuzon, “On the model discriminating power of $\mu \rightarrow e$ conversion in nuclei,” Phys. Rev. D **80** (2009) 013002 [arXiv:0904.0957 [hep-ph]]. B. M. Dassinger, T. Feldmann, T. Mannel and S. Turczyk, “Model-independent analysis of lepton flavour violating tau decays,” JHEP **0710** (2007) 039 [arXiv:0707.0988 [hep-ph]].
A. Crivellin, S. Najjari and J. Rosiek, “Lepton Flavor Violation in the Standard Model with general Dimension-Six Operators,” JHEP **1404** (2014) 167 [arXiv:1312.0634 [hep-ph]].
A. Celis, V. Cirigliano and E. Passemar, “The model-discriminating power of lepton flavor violating tau decays,” Phys. Rev. D **89** (2014) 095014 [arXiv:1403.5781 [hep-ph]].
- [59] R. K. Kutschke, “The Mu2e Experiment at Fermilab,” arXiv:1112.0242 [hep-ex].
Y. G. Cui *et al.* [COMET Collaboration], “Conceptual design report for experimental search for lepton flavor violating $\mu^- \rightarrow e^-$ conversion at sensitivity of $10^{**}(-16)$ with a slow-extracted bunched proton beam (COMET),” KEK-2009-10.
R. M. Carey *et al.* [Mu2e Collaboration], “Proposal to search for $\mu^- N \rightarrow e^- N$ with a single event sensitivity below 10^{-16} ,” FERMILAB-PROPOSAL-0973.

- [60] A. Crivellin, M. Hoferichter and M. Procura, “Improved predictions for $\mu \rightarrow e$ conversion in nuclei and Higgs-induced lepton flavor violation,” *Phys. Rev. D* **89** (2014) 093024 [arXiv:1404.7134 [hep-ph]].
- [61] A. Crivellin, M. Hoferichter and M. Procura, “Accurate evaluation of hadronic uncertainties in spin-independent WIMP-nucleon scattering: Disentangling two- and three-flavor effects,” *Phys. Rev. D* **89** (2014) 054021 [arXiv:1312.4951 [hep-ph]].
- [62] J. P. Lees *et al.* [BaBar Collaboration], “Evidence for an excess of $\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau$ decays,” *Phys. Rev. Lett.* **109** (2012) 101802 [arXiv:1205.5442 [hep-ex]].
- [63] J. G. Korner and G. A. Schuler, “Exclusive Semileptonic Decays of Bottom Mesons in the Spectator Quark Model,” *Z. Phys. C* **38** (1988) 511 [Erratum-ibid. C **41** (1989) 690].
J. G. Korner and G. A. Schuler, “Exclusive Semileptonic Heavy Meson Decays Including Lepton Mass Effects,” *Z. Phys. C* **46** (1990) 93.
- [64] W. Dungen *et al.* [Belle Collaboration], “Measurement of the form factors of the decay $B0 \rightarrow D^{*-}\ell^+\nu$ and determination of the CKM matrix element $|V_{cb}|$,” *Phys. Rev. D* **82** (2010) 112007 [arXiv:1010.5620 [hep-ex]].
- [65] J. F. Kamenik and F. Mescia, “ $B \rightarrow D\tau\nu$ Branching Ratios: Opportunity for Lattice QCD and Hadron Colliders,” *Phys. Rev. D* **78** (2008) 014003 [arXiv:0802.3790 [hep-ph]].
U. Nierste, S. Trine and S. Westhoff, “Charged-Higgs effects in a new $B \rightarrow D\tau\nu$ differential decay distribution,” *Phys. Rev. D* **78** (2008) 015006 [arXiv:0801.4938 [hep-ph]].
S. Fajfer, J. F. Kamenik and I. Nisandzic, “On the $B \rightarrow D^*\tau\bar{\nu}_\tau$ Sensitivity to New Physics,” *Phys. Rev. D* **85** (2012) 094025 [arXiv:1203.2654 [hep-ph]].
Y. Sakaki and H. Tanaka, “Constraints on the charged scalar effects using the forward-backward asymmetry on $B \rightarrow D^{(*)}\tau\nu_\tau$,” *Phys. Rev. D* **87** (2013) 5, 054002 [arXiv:1205.4908 [hep-ph]].
- [66] S. Fajfer, J. F. Kamenik, I. Nisandzic and J. Zupan, “Implications of Lepton Flavor Universality Violations in B Decays,” *Phys. Rev. Lett.* **109** (2012) 161801 [arXiv:1206.1872 [hep-ph]].
A. Datta, M. Duraishamy and D. Ghosh, “Diagnosing New Physics in $b \rightarrow c\tau\nu_\tau$ decays in the light of the recent BaBar result,” *Phys. Rev. D* **86** (2012) 034027 [arXiv:1206.3760 [hep-ph]].
P. Biancofiore, P. Colangelo and F. De Fazio, “Rare semileptonic $B \rightarrow K^*\ell^+\ell^-$ decays in RS_c model,” *Phys. Rev. D* **89** (2014) 095018 [arXiv:1403.2944 [hep-ph]].

- X. Q. Li, Y. D. Yang and X. B. Yuan, “Exclusive radiative B-meson decays within minimal flavour violating 2HDMs,” *Phys. Rev. D* **89** (2014) 054024 [arXiv:1311.2786 [hep-ph]].
- [67] G. Faisel, “Charged Higgs contribution to $\bar{B}_s \rightarrow \phi\pi^0$ and $\bar{B}_s \rightarrow \phi\rho^0$,” *Phys. Lett. B* **731** (2014) 279 [arXiv:1311.0740 [hep-ph]].
- [68] M. Atoui, V. Mornas, D. Beirevic and F. Sanfilippo, “ $B_s \rightarrow D_s\ell\nu_\ell$ near zero recoil in and beyond the Standard Model,” *Eur. Phys. J. C* **74** (2014) 2861 [arXiv:1310.5238 [hep-lat]].
 Y. Sakaki, M. Tanaka, A. Tayduganov and R. Watanabe, “Testing leptoquark models in $\bar{B} \rightarrow D^{(*)}\tau\bar{\nu}$,” *Phys. Rev. D* **88** (2013) 9, 094012 [arXiv:1309.0301 [hep-ph]].
 A. Celis, “Effects of a charged Higgs boson in $B \rightarrow D^{(*)}\tau\nu$ decays,” *PoS EPS -HEP2013* (2013) 334 [arXiv:1308.6779 [hep-ph]].
- [69] W. S. Hou, “Enhanced charged Higgs boson effects in $B^- \rightarrow \tau\nu, \mu\nu$ and $b \rightarrow \tau\nu + X$,” *Phys. Rev. D* **48** (1993) 2342. A. G. Akeroyd and S. Recksiegel, “The Effect of H^\pm on $B^\pm \rightarrow \tau^\pm\nu_\tau$ and $B^\pm \rightarrow \mu^\pm\mu\nu$,” *J. Phys. G* **29** (2003) 2311 [hep-ph/0306037].
- [70] M. Tanaka, “Charged Higgs effects on exclusive semitauonic B decays,” *Z. Phys. C* **67** (1995) 321 [hep-ph/9411405].
 T. Miki, T. Miura and M. Tanaka, “Effects of charged Higgs boson and QCD corrections in $B \rightarrow D\tau\nu_\tau$,” hep-ph/0210051.
- [71] A. Crivellin, C. Greub and A. Kokulu, “Explaining $B \rightarrow D\tau\nu$, $B \rightarrow D^*\tau\nu$ and $B \rightarrow \tau\nu$ in a 2HDM of type III,” *Phys. Rev. D* **86** (2012) 054014 [arXiv:1206.2634 [hep-ph]].
- [72] A. Ali, P. Ball, L. T. Handoko and G. Hiller, “A Comparative study of the decays $B \rightarrow (K, K^*)\ell^+\ell^-$ in standard model and supersymmetric theories,” *Phys. Rev. D* **61** (2000) 074024 [hep-ph/9910221].
 M. Beneke, T. Feldmann and D. Seidel, “Systematic approach to exclusive $B \rightarrow V\ell^+\ell^-, V\gamma$ decays,” *Nucl. Phys. B* **612** (2001) 25 [hep-ph/0106067].
 A. Ali, G. Kramer and G. h. Zhu, “ $B \rightarrow K^+\ell^+\ell^-$ decay in soft-collinear effective theory,” *Eur. Phys. J. C* **47** (2006) 625 [hep-ph/0601034].
 C. Bobeth, G. Hiller and G. Piranishvili, “Angular distributions of $B \rightarrow K\bar{\ell}\ell$ decays,” *JHEP* **0712** (2007) 040 [arXiv:0709.4174 [hep-ph]].
 C. Bobeth, G. Hiller and G. Piranishvili, “CP Asymmetries in $\bar{B} \rightarrow \bar{K}^*(\rightarrow \bar{K}\pi)\bar{\ell}\ell$ and Untagged $\bar{B}_s, B_s \rightarrow \phi(\rightarrow K^+K^-)\bar{\ell}\ell$ Decays at NLO,” *JHEP* **0807**

- (2008) 106 [arXiv:0805.2525 [hep-ph]].
- W. Altmannshofer, P. Ball, A. Bharucha, A. J. Buras, D. M. Straub and M. Wick, “Symmetries and Asymmetries of $B \rightarrow K^* \mu^+ \mu^-$ Decays in the Standard Model and Beyond,” JHEP **0901** (2009) 019 [arXiv:0811.1214 [hep-ph]].
- C. Bobeth, G. Hiller and D. van Dyk, “The Benefits of $\overline{B} \rightarrow \overline{K}^* l^+ l^-$ Decays at Low Recoil,” JHEP **1007** (2010) 098 [arXiv:1006.5013 [hep-ph]].
- A. K. Alok, A. Datta, A. Dighe, M. Duraissamy, D. Ghosh and D. London, “New Physics in $b \rightarrow s \mu^+ \mu^-$: CP-Conserving Observables,” JHEP **1111** (2011) 121 [arXiv:1008.2367 [hep-ph]].
- A. K. Alok, A. Datta, A. Dighe, M. Duraissamy, D. Ghosh and D. London, “New Physics in $b \rightarrow s \mu^+ \mu^-$: CP-Violating Observables,” JHEP **1111** (2011) 122 [arXiv:1103.5344 [hep-ph]].
- S. Descotes-Genon, D. Ghosh, J. Matias and M. Ramon, “Exploring New Physics in the C7-C7’ plane,” JHEP **1106** (2011) 099 [arXiv:1104.3342 [hep-ph]].
- C. Bobeth, G. Hiller and D. van Dyk, “More Benefits of Semileptonic Rare B Decays at Low Recoil: CP Violation,” JHEP **1107** (2011) 067 [arXiv:1105.0376 [hep-ph]].
- D. Becirevic and E. Schneider, “On transverse asymmetries in $B \rightarrow K^* l^+ l^-$,” Nucl. Phys. B **854** (2012) 321 [arXiv:1106.3283 [hep-ph]].
- C. Bobeth, G. Hiller, D. van Dyk and C. Wacker, “The Decay $B \rightarrow K l^+ l^-$ at Low Hadronic Recoil and Model-Independent Delta B = 1 Constraints,” JHEP **1201** (2012) 107 [arXiv:1111.2558 [hep-ph]].
- J. Matias, F. Mescia, M. Ramon and J. Virto, “Complete Anatomy of $\overline{B}_d \rightarrow \overline{K}^{*0} (\rightarrow K \pi) l^+ l^-$ and its angular distribution,” JHEP **1204** (2012) 104 [arXiv:1202.4266 [hep-ph]].
- F. Beaujean, C. Bobeth, D. van Dyk and C. Wacker, “Bayesian Fit of Exclusive $b \rightarrow s \overline{l} l$ Decays: The Standard Model Operator Basis,” JHEP **1208** (2012) 030 [arXiv:1205.1838 [hep-ph]].
- C. Bobeth, G. Hiller and D. van Dyk, “General Analysis of $\overline{B} \rightarrow \overline{K}^{(*)} l^+ l^-$ Decays at Low Recoil,” Phys. Rev. D **87** (2013) 034016 [arXiv:1212.2321 [hep-ph]].
- S. Descotes-Genon, J. Matias, M. Ramon and J. Virto, “Implications from clean observables for the binned analysis of $B \rightarrow K^* \mu^+ \mu^-$ at large recoil,” JHEP **1301** (2013) 048 [arXiv:1207.2753 [hep-ph]].
- S. Descotes-Genon, T. Hurth, J. Matias and J. Virto, “Optimizing the basis of $B \rightarrow K^* l^+ l^-$ observables in the full kinematic range,” JHEP **1305** (2013) 137 [arXiv:1303.5794 [hep-ph]].
- [73] J.-T. Wei *et al.* [BELLE Collaboration], “Measurement of the Differential Branching Fraction and Forward-Backward Asymmetry for $B \rightarrow K^{(*)} l^+ l^-$,” Phys. Rev. Lett. **103** (2009) 171801 [arXiv:0904.0770 [hep-ex]].
- J. P. Lees *et al.* [BaBar Collaboration], “Measurement of Branching Fractions

- and Rate Asymmetries in the Rare Decays $B \rightarrow K^{(*)}\ell^+\ell^-$,” Phys. Rev. D **86** (2012) 032012 [arXiv:1204.3933 [hep-ex]]. // T. Aaltonen *et al.* [CDF Collaboration], “Measurements of the Angular Distributions in the Decays $B \rightarrow K^{(*)}\mu^+\mu^-$ at CDF,” Phys. Rev. Lett. **108** (2012) 081807 [arXiv:1108.0695 [hep-ex]].
- R. Aaij *et al.* [LHCb Collaboration], “Differential branching fraction and angular analysis of the decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$,” JHEP **1308** (2013) 131 [arXiv:1304.6325, arXiv:1304.6325 [hep-ex]].
- [74] R. Aaij *et al.* [LHCb Collaboration], “Measurement of Form-Factor-Independent Observables in the Decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$,” Phys. Rev. Lett. **111** (2013) 19, 191801 [arXiv:1308.1707 [hep-ex]].
- [75] A. Khodjamirian, T. Mannel, A. A. Pivovarov and Y.-M. Wang, “Charm-loop effect in $B \rightarrow K^{(*)}\ell^+\ell^-$ and $B \rightarrow K^*\gamma$,” JHEP **1009** (2010) 089 [arXiv:1006.4945 [hep-ph]].
- M. Beylich, G. Buchalla and T. Feldmann, “Theory of $B \rightarrow K^{(*)}\ell^+\ell^-$ decays at high q^2 : OPE and quark-hadron duality,” Eur. Phys. J. C **71** (2011) 1635 [arXiv:1101.5118 [hep-ph]].
- D. Becirevic and A. Tayduganov, “Impact of $B \rightarrow K_0^*\ell^+\ell^-$ on the New Physics search in $B \rightarrow K^*\ell^+\ell^-$ decay,” Nucl. Phys. B **868** (2013) 368 [arXiv:1207.4004 [hep-ph]].
- J. Matias, “On the S-wave pollution of $B \rightarrow K^*\ell^+\ell^-$ observables,” Phys. Rev. D **86** (2012) 094024 [arXiv:1209.1525 [hep-ph]].
- S. Jäger and J. Martin Camalich, “On $B \rightarrow V\ell\ell$ at small dilepton invariant mass, power corrections, and new physics,” JHEP **1305** (2013) 043 [arXiv:1212.2263 [hep-ph]].
- F. Beaujean, C. Bobeth and D. van Dyk, “Comprehensive Bayesian analysis of rare (semi)leptonic and radiative B decays,” Eur. Phys. J. C **74** (2014) 2897 [arXiv:1310.2478 [hep-ph]].
- J. Lyon and R. Zwicky, “Resonances gone topsy turvy - the charm of QCD or new physics in $b \rightarrow s\ell^+\ell^-$?,” arXiv:1406.0566 [hep-ph].
- S. Descotes-Genon, L. Hofer, J. Matias and J. Virto, “On the impact of power corrections in the prediction of $B \rightarrow K^*\mu^+\mu^-$ observables,” arXiv:1407.8526 [hep-ph].
- [76] S. Descotes-Genon, J. Matias and J. Virto, “Understanding the $B \rightarrow K^*\mu^+\mu^-$ Anomaly,” Phys. Rev. D **88** (2013) 7, 074002 [arXiv:1307.5683 [hep-ph]].
- 5
- [77] A. Datta, M. Duraisamy and D. Ghosh, “Explaining the $B \rightarrow K^*\mu^+\mu^-$ data with scalar interactions,” Phys. Rev. D **89** (2014) 071501 [arXiv:1310.1937 [hep-ph]].
- T. Hurth and F. Mahmoudi, “On the LHCb anomaly in $B \rightarrow K^*\ell^+\ell^-$,” JHEP **1404** (2014) 097 [arXiv:1312.5267 [hep-ph]].

- [78] W. Altmannshofer and D. M. Straub, “New physics in $B \rightarrow K^* \mu \mu$?,” *Eur. Phys. J. C* **73** (2013) 2646 [arXiv:1308.1501 [hep-ph]].
- [79] R. Gauld, F. Goertz and U. Haisch, “An explicit Z' -boson explanation of the $B \rightarrow K^* \mu^+ \mu^-$ anomaly,” *JHEP* **1401** (2014) 069 [arXiv:1310.1082 [hep-ph]].
R. Gauld, F. Goertz and U. Haisch, “On minimal Z' explanations of the $B \rightarrow K^* \mu^+ \mu^-$ anomaly,” *Phys. Rev. D* **89** (2014) 015005 [arXiv:1308.1959 [hep-ph]].
A. J. Buras, F. De Fazio and J. Girrbach, “331 models facing new $b \rightarrow s \mu^+ \mu^-$ data,” *JHEP* **1402** (2014) 112 [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
W. Altmannshofer, S. Gori, M. Pospelov and I. Yavin, “Dressing $L_\mu - L_\tau$ in Color,” *Phys. Rev. D* **89**, 095033 (2014) [arXiv:1403.1269 [hep-ph]].
A. J. Buras, F. De Fazio and J. Girrbach-Noe, “ Z - Z' mixing and Z -mediated FCNCs in $SU(3)_C \times SU(3)_L \times U(1)_X$ models,” *JHEP* **1408** (2014) 039 [arXiv:1405.3850 [hep-ph]].
- [80] F. Mahmoudi, S. Neshatpour and J. Virto, “ $B \rightarrow K^* \mu^+ \mu^-$ optimised observables in the MSSM,” *Eur. Phys. J. C* **74** (2014) 2927 [arXiv:1401.2145 [hep-ph]].
- [81] P. Biancofiore, P. Colangelo and F. De Fazio, “Rare semileptonic $B \rightarrow K^* \ell^+ \ell^-$ decays in RS_c model,” *Phys. Rev. D* **89** (2014) 095018 [arXiv:1403.2944 [hep-ph]].
- [82] R. Aaij *et al.* [LHCb Collaboration], “Test of lepton universality using $B^+ \rightarrow K^+ \ell^+ \ell^-$ decays,” arXiv:1406.6482 [hep-ex].
- [83] R. Alonso, B. Grinstein and J. M. Camalich, “ $SU(2) \times U(1)$ gauge invariance and the shape of new physics in rare B decays,” arXiv:1407.7044 [hep-ph].
G. Hiller and M. Schmaltz, “ R_K and future $b \rightarrow s \ell \ell$ BSM opportunities,” arXiv:1408.1627 [hep-ph].
D. Ghosh, M. Nardecchia and S. A. Renner, “Hint of Lepton Flavour Non-Universality in B Meson Decays,” arXiv:1408.4097 [hep-ph].