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Constraints on new physics in MFV models: A model-independent analysis of $\Delta F = 1$ processes

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Abstract

We analyse the constraints on dimension-six $\Delta F = 1$ effective operators in models respecting the MFV hypothesis, both in the one-Higgs doublet case and in the two-Higgs doublet scenario with large $\tan\beta$. The constraints are derived mainly from the $b \to s$ inclusive observables measured at the B factories. The implications of these bounds in view of improved measurements in exclusive and inclusive observables in $b \to s\ell^+\ell^-$ and $s \to d\nu\bar{\nu}$ transitions are discussed.

1. Introduction

The Standard Model (SM) can be viewed as the renormalizable part of an effective field theory, valid up to some still undetermined cut-off scale Λ above the electroweak scale, $(\sqrt{2}G_F)^{-1/2} \approx 250$ GeV. Theoretical arguments based on a natural solution of the hierarchy problem suggest that Λ should not exceed a few TeV. This expectation leads to a paradox when combined with the absence of significant deviations from the SM in loop-induced flavour-violating observables, potentially sensitive to very high energy scales. An effective solution to this problem is provided by the so-called hypothesis of Minimal Flavour Violation [1], namely

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Table 1
Main observables used to determine bounds on the MFV dimension-six operators. The SM predictions are updated according to the most recent determinations of the SM input values (see Section 4).

Observable	Experiment	SM prediction
$\mathcal{B}(B \to X_s \gamma)_{[E_\gamma > 1.6\ \mathrm{GeV}]}$	$(3.52 \pm 0.24) \times 10^{-4}$ [10]	$(3.13 \pm 0.23) \times 10^{-4}$ [11–13]
$\mathcal{B}(B \to X_s \ell^+\ell^-)_{[q^2 \in [0.04, 1.0]\ \mathrm{GeV}^2]}$	$(0.6 \pm 0.5) \times 10^{-6}$	$(0.8 \pm 0.2) \times 10^{-6}$
$\mathcal{B}(B \to X_s \ell^+\ell^-)_{[q^2 \in [1.0, 6.0]\ \mathrm{GeV}^2]}$	$(1.6 \pm 0.5) \times 10^{-6}$ [14,15]*	$(1.6 \pm 0.1) \times 10^{-6}$ [16–23]
$\mathcal{B}(B \to X_s \ell^+\ell^-)_{[q^2 > 14.4\ \mathrm{GeV}^2]}$	$(4.4 \pm 1.3) \times 10^{-7}$	$(2.4 \pm 0.8) \times 10^{-7}$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$< 5.8 \times 10^{-8}$ (95% C.L.) [24]	$(4.1 \pm 0.8) \times 10^{-9}$ [25,26]
$\bar{A}_{\mathrm{FB}}(B \to K^*\ell^+\ell^-)_{[q^2 < 6.25\ \mathrm{GeV}^2]}$	$0.24^{+0.19}_{-0.24}$	-0.01 ± 0.02
$\bar{A}_{\mathrm{FB}}(B \to K^*\ell^+\ell^-)_{[q^2 > 10.24\ \mathrm{GeV}^2]}$	$0.76^{+0.53}_{-0.34}$ [27]	0.20 ± 0.08 [28–31]
$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$	$(14.7^{+13.0}_{-8.9}) \times 10^{-11}$ [32]	$(8.6 \pm 0.9) \times 10^{-11}$ [33–37]

* Here we quote naïve averages of the values obtained by the experiments and with symmetrized errors.

by the assumption that the SM Yukawa couplings are the only relevant breaking sources of the $SU(3)^5$ flavour symmetry [2] of the low-energy effective theory.[1]

This symmetry and symmetry-breaking ansatz is realised in various explicit extensions of the SM, such as supersymmetric models (see e.g. Refs. [5,6] and [7]) or models with extra dimensions (see e.g. Ref. [8]). However, its main virtue is the possibility to perform a general analysis of new-physics effects in low-energy observables independently of the ultraviolet completion of the model. As shown in Ref. [1], the MFV hypothesis allows to build a rather predictive effective theory in terms of SM and Higgs fields. The predictions on flavour-violating observables derived within this effective theory are powerful tests of the underlying flavour structure of the model: if falsified, these tests would unambiguously signal the presence of new symmetry-breaking terms.

The observables most relevant to test the MFV hypothesis and, within this framework, to constrain the structure of the effective theory are $\Delta F = 2$ and $\Delta F = 1$ flavour-changing neutral-current (FCNC) processes. An updated analysis of the $\Delta F = 2$ sector, or the meson–antimeson mixing amplitudes, has been presented recently in Ref. [9]. The goal of this work is a complete analysis of the $\Delta F = 1$ sector, or the rare-decay amplitudes.

Using the currently available measurements of $\Delta F = 1$ FCNC processes from $b \to s$ and $s \to d$ transitions (see Table 1) we derive updated bounds on the effective scale of new physics within MFV models. We consider in particular both the scenario of one effective Higgs doublet and the case of two Higgs doublets and large $\tan\beta$, where we are free to change the relative normalization of the two Yukawa couplings and to decouple the breaking of $U(1)_{\mathrm{PQ}}$ and $SU(3)^5$ global symmetries [1].

Having derived the bounds on the effective operators from the observables listed in Table 1, we derive a series of predictions for exclusive and inclusive observables in $b \to s\ell^+\ell^-$ and $s \to d\nu\bar{\nu}$ transitions which have not been measured so far with high accuracy. On the one hand, these predictions indicate where to look for large new physics effects in the flavour sector, even under the pessimistic hypothesis of MFV. On the other hand, some of these predictions could provide, in the future, a proof of the MFV hypothesis: a set of deviations from the SM exhibiting the correlation predicted by this symmetry structure.

[1] For earlier/alternative definitions of the MFV hypothesis see Refs. [3,4].