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On the anomalies in the latest LHCb data

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Abstract

Depending on the assumptions on the power corrections to the exclusive $b \to s\ell^+\ell^-$ decays, the latest data of the LHCb Collaboration – based on the 3 fb^{-1} data set and on two different experimental analysis methods – still shows some tensions with the Standard Model predictions. We present a detailed analysis of the theoretical inputs and various global fits to all the available $b \to s\ell^+\ell^-$ data. This constitutes the first global analysis of the new data of the LHCb Collaboration based on the hypothesis that these tensions can be at least partially explained by new physics contributions. In our model-independent analysis we present one-, two-, four-, and also five-dimensional global fits in the space of Wilson coefficients to all available $b \to s\ell^+\ell^-$ data. We also compare the two different experimental LHCb analyses of the angular observables in $B \to K^*\mu^+\mu^-$. We explicitly analyse the dependence of our results on the assumptions about power corrections, but also on the errors present in the form factor calculations. Moreover, based on our new global fits we present predictions for ratios of observables which may show a sign of lepton non-universality. Their measurements would crosscheck the LHCb result on the ratio $R_K = \mathrm{BR}(B^+ \to K^+\mu^+\mu^-)/\mathrm{BR}(B^+ \to K^+e^+e^-)$ in the low-q^2 region which deviates from the SM prediction by 2.6σ.

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1. Introduction

The LHCb Collaboration has recently presented the angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay with the 3 fb^{-1} data set. They use two analysis methods. The observables are determined using an unbinned maximum likelihood fit and by the principal angular moments [1]. In addition, a new analysis on the angular observables in $B_s \to \phi\mu^+\mu^-$ has been presented [2].

These new analyses of the LHCb Collaboration have been eagerly awaited in view of the previous LHCb analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ based on the 1 fb^{-1} data set [3]. The LHCb Collaboration had announced a local discrepancy of 3.7σ from the Standard Model (SM) predictions in one bin for one of the angular observables [3]. There had been also more, yet smaller tensions with the SM predictions in other observables. This announcement was followed by a large number of theoretical analyses showing that, due to the large hadronic uncertainties in exclusive modes, it is not clear at all whether this anomaly is a first sign for new physics beyond the SM or a consequence of underestimated hadronic power corrections or just a statistical fluctuation [4–22].

In the recent analysis based on the 3 fb^{-1} data set the LHCb Collaboration now announced a 3.4σ tension with predictions based on the SM within a global fit to the complete set of CP-averaged observables [1]. They point out that this tension could be explained by contributions from physics beyond the SM or by unexpectedly large hadronic effects that are underestimated in the SM predictions.

Regarding the latter option it is important to note that there is a significant difference in the theoretical accuracy of the inclusive and exclusive $b \to s\ell^+\ell^-$ decays in the low-q^2 region. In the inclusive case, there is a theoretical description of power corrections; they can be calculated or at least *estimated* within the theoretical approach (for reviews see [23–25]).[2] In contrast, in the exclusive case there is no theoretical description of power corrections existing within the theoretical framework of QCD factorisation and SCET which is the standard theoretical framework for these exclusive decay modes in the low-q^2 region. Thus, power corrections can only be *guesstimated*. This issue makes it rather difficult or even impossible to separate new physics effects from such potentially large hadronic power corrections within these exclusive angular observables. So

[2] In the inclusive case one can show that if only the leading operator of the electroweak hamiltonian is considered, one is led to a local operator product expansion (OPE). In this case, the leading hadronic power corrections in the decay $\bar{B} \to X_s\ell^+\ell^-$ scale with $1/m_b^2$ and $1/m_b^3$ only and have already been analysed [26]. A systematic and careful analysis of hadronic power corrections including all relevant operators has been performed in the case of the decay $\bar{B} \to X_s\gamma$ [27]. Such linear power corrections can be analysed within soft-collinear effective theory (SCET). This analysis goes beyond the local OPE. An additional uncertainty of $\pm 5\%$ has been identified. The analysis in the case of $\bar{B} \to X_s\ell^+\ell^-$ is work in progress. There is no reason to expect any large deviation from the $\bar{B} \to X_s\gamma$ result. Nonfactorisable power corrections that scale with $1/m_c^2$ have first been considered in Ref. [28], but can be now included in the systematic analysis of hadronic power corrections and be calculated quite analogously to those in the decay $\bar{B} \to X_s\gamma$ [27]. Moreover, in the KS approach [29,30] one absorbs factorisable long-distance charm rescattering effects (in which the $\bar{B} \to X_s c\bar{c}$ transition can be factorised into the product of $\bar{s}b$ and $c\bar{c}$ colour-singlet currents) into the matrix element of the leading semileptonic operator O_9. Following the inclusion of nonperturbative corrections scaling with $1/m_c^2$, the KS approach avoids double-counting.

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