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Towards establishing New Physics in $B^0 \to K^{*0}\ell^+\ell^-$ decays

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Rare semileptonic $b \to s\ell^+\ell^-$ transitions provide some of the most promising framework to search for New Physics effects. Recent analyses of these decays have indicated an anomalous pattern in measurements of angular distributions of the decay $B^0 \to K^{*0}\mu^+\mu^-$ and in lepton-flavour-universality observables. We propose a novel approach to independently and complementary clarify the nature of these effects by performing a simultaneous amplitude analysis of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^0 \to K^{*0}e^+e^-$decays. This method allows the direct determination of the difference of the Wilson Coefficients C_9 and C_{10} between electrons and muons, which are found to be insensitive to both local and non-local hadronic contributions. We show that considering the current preferred New Physics scenario a first observation of LFU breaking in a single measurement is possible with LHCb Run-II dataset. The potential for a claim of New Physics analysing $B^0 \to K^{*0}\mu^+\mu^-$ decays alone is also examined and prospects for disentangling New Physics effects from non-local hadronic contributions are investigated.

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1. Introduction

An anomalous behaviour in angular and branching fraction analyses of the decay channel $B^0 \to K^{*0}\mu^+\mu^-$ has been recently reported [1, 2]. Several models have been suggested in order to interpret these results as New Physics (NP) signatures. Nonetheless, the vector-like nature of this pattern could be also explained by non-perturbative QCD contributions from $b \to sc\bar{c}$ operators that are able to either mimic or camouflage NP effects [3]. In addition, measurements of Lepton Flavour Universality (LFU) such as R_K [4] and R_{K^*} [5], which benefit from small theoretical uncertainties, deviate from their SM predictions and, despite individually not statistically significant, create a consistent pattern in $b \to s\ell^+\ell^-$ global analyses. In the following, prospects to disentangle NP effects from non-perturbative QCD contributions and to unambiguously establishing if these deviations have a common nature are presented exploiting the full set of observables through an unbinned amplitude fit to the decay rate.

2. Preliminaries

A model independent description of b decays is usually achieved within the framework of an effective field theory. The weak Lagrangian can be parametrised in terms of effective operators, $\mathscr{O}_i$, which include non-calculable long-distance effects, and the corresponding couplings, C_i, known as Wilson coefficients (WC), which can be modified by the presence of NP, *i.e.* $C_i = C_i^{\text{SM}} + C_i^{\text{NP}}$.

The differential decay rate for $B^0 \to K^{*0}\ell^+\ell^-$ decays is fully described by four kinematic variables; the di-lepton squared invariant mass, q^2, and the three angles $\vec{\Omega} = (\cos\theta_\ell, \cos\theta_K, \phi)$. It is convenient to explicitly write the dependence of the decay width on the WCs in terms of transversity amplitudes

$$A_\lambda^{L,R} = N_\lambda \left\{ (C_9 \mp C_{10}) F_\lambda(q^2) + \frac{2m_b M_B}{q^2} \left[C_7 F_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b} H_\lambda(q^2) \right] \right\}, \tag{2.1}$$

where $\lambda = \perp, \|, 0$ refers to the polarisation of the K^{*0} meson, the indices L and R denote the chirality of the lepton current, N_λ is a normalisation factor and $F_\lambda^{(T)}(q^2)$ and $H_\lambda(q^2)$ are referred to "local" and "non-local" hadronic matrix elements, respectively. The $F_\lambda^{(T)}(q^2)$ are form factors, while $H_\lambda(q^2)$ encode the aforementioned non-factorisable hadronic contributions. The non-local hadronic functions H_λ can be expressed in terms of a "conformal " variable z and Taylor-expanded around $z = 0$, resulting in an analytical expansion curtailed at a given order z^K [7].

Sensitivity studies for a direct determination of the WCs C_9 and C_{10} from data are performed. Within this framework, prior theoretical knowledge on form factors [8] is included in the fit by introducing Gaussian constraints on the relative (nuisance) parameters. Furthermore, branching ratio measurements are incorporated in the amplitude analysis by performing an extended maximum likelihood fit and extracting the signal yields in the q^2 region of interest.

3. Diagnosing New Physics in $B^0 \to K^{*0}\mu^+\mu^-$ decays

A novel theory-experimental approach is proposed to disentangle NP effects from non perturbative QCD contributions in $B^0 \to K^{*0}\mu^+\mu^-$ decays [9]. The amplitude fit is extended to

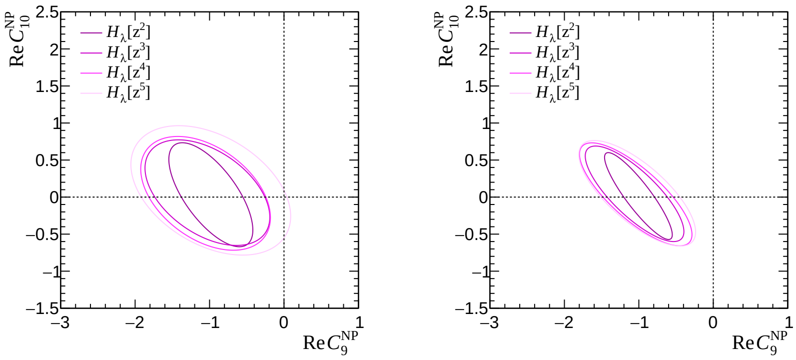

Figure 1: Two-dimensional sensitivity scans for the pair of Wilson coefficients C_9 and C_{10} for different non-local hadronic parametrisation models $H_\lambda[z^2,...,z^5]$. The contours correspond to 3σ statistical uncertainty bands evaluated for NP models with $C_9^{\rm NP} = -1$, with the expected statistics after LHCb Run-II (left) and LHCb Upgrade (right) and for the analysis of two q^2 regions, [1.1, 8] GeV^2 and [11, 12.5] GeV^2 [9].

include the state-of-the-art knowledge on the non-local hadronic matrix elements. This consists of theoretical calculations at negative q^2 [7] and experimental measurements of hadronic decays $B^0 \to K^{*0}J/\psi$ and $B^0 \to K^{*0}\psi(2S)$ [7]. The model dependence introduced by the truncation of the series $H_\lambda(z)$ is studied with pseudoexperiments, where the order of the expansion is varied between $z^2,...,z^5$. Figure 1 shows the fit results for ensembles produced with the expected statistics at LHCb Run-II and Upgrade. The uncertainty on the WCs is found to mildly increase for order of the non-local hadronic parametrisation between z^3 and z^5 proving a small model dependence in the determination of the WCs. Furthermore, a quantitative determination of the systematic uncertainties associated to the non-local hadronic contributions is for the first time possible.

4. Lepton Flavour Universality test in $B^0 \to K^{*0}\ell^+\ell^-$ decays

The amplitude fit can be extended to perform a simultaneous analysis of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^0 \to K^{*0}e^+e^-$ decays as test of LFU [10]. Within this assumption, all the hadronic effects (know to be lepton universal) are in common between the two modes and, therefore, all the corresponding parameters are shared in the fit, while only the WCs are treated separately for the two channels. It is natural to define the difference of WCs, *i.e.* $\Delta C_i = C_i^{(\mu)} - C_i^{(e)}$. Fig. 2 shows the sensitivity the proposed parameters ΔC_9 and ΔC_{10}, which are found to be strongly independent on the parametrisation of the non-local hadronic matrix elements. Furthermore, ΔC_9 and ΔC_{10} are found to be independent also on form factors uncertainties and result in a clean and powerful test of LFU that, thanks to the inclusiveness of the approach, surpasses the sensitivity of previous measurements.

5. Conclusions

In conclusion, the proposed method demonstrates that a disentanglement of NP effects from non-local hadronic contributions in $B^0 \to K^{*0}\mu^+\mu^-$ decays is possible and guarantees a model-independent determination of LFU-breaking difference of WCs. This approach not only surpasses the sensitivity of previous methods but enables a deeper understanding of the nature of NP.

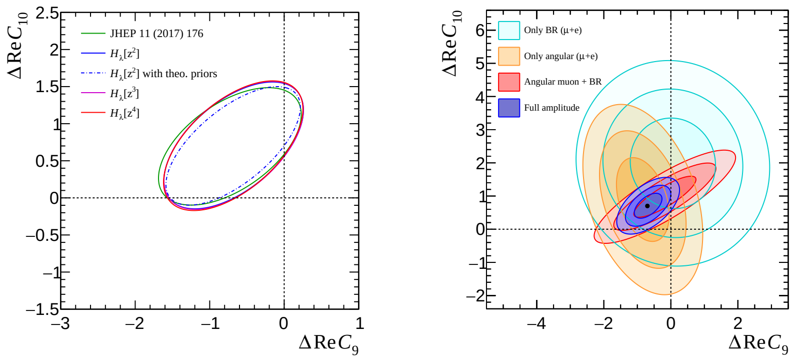

Figure 2: Left: two-dimensional sensitivity scans for the proposed parameters ΔC_9 and $\Delta C10$ for different non-local hadronic parametrisation models. The contours correspond to $3\,\sigma$ statistical uncertainty. Right: the relative contribution ($1, 2, 3\,\sigma$ contours) of each step of the analysis is shown in different colours. Both plots are evaluated for NP models with $C_9^{\rm NP} = -C_{10}^{\rm NP} = -0.7$, where NP is inserted only in the muon channel, and with the expected statistics after LHCb Run-II.

References

[1] LHCb collaboration, R. Aaij et al., *Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay using 3 fb^{-1} of integrated luminosity*, *JHEP* **02** (2016) 104 [1512.04442].

[2] LHCb collaboration, R. Aaij et al., *Measurements of the S-wave fraction in $B^0 \to K^+\pi^-\mu^+\mu^-$ decays and the $B^0 \to K^*(892)^0\mu^+\mu^-$ differential branching fraction*, *JHEP* **11** (2016) 047 [1606.04731].

[3] S. Jäger and J. Martin Camalich, *Reassessing the discovery potential of the $B \to K^*\ell^+\ell^-$ decays in the large-recoil region: SM challenges and BSM opportunities*, *Phys. Rev.* **D93** (2016) 014028 [1412.3183].

[4] LHCb collaboration, R. Aaij et al., *Test of lepton universality using $B^+ \to K^+\ell^+\ell^-$ decays*, *Phys. Rev. Lett.* **113** (2014) 151601 [1406.6482].

[5] LHCb collaboration, R. Aaij et al., *Test of lepton universality with $B^0 \to K^{*0}\ell^+\ell^-$ decays*, *JHEP* **08** (2017) 055 [1705.05802].

[6] C. Bobeth, G. Hiller and 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* **07** (2008) 106 [0805.2525].

[7] C. Bobeth, M. Chrzaszcz, D. van Dyk and J. Virto, *Long-distance effects in $B \to K^*\ell\ell$ from Analyticity*, 1707.07305.

[8] A. Bharucha, D. M. Straub and R. Zwicky, *$B \to V\ell^+\ell^-$ in the Standard Model from light-cone sum rules*, *JHEP* **08** (2016) 098 [1503.05534].

[9] M. Chrzaszcz, A. Mauri, N. Serra, R. Silva Coutinho and D. van Dyk, *Prospects for disentangling long- and short-distance effects in the decays $B \to K^*\mu^+\mu^-$*, 1805.06378.

[10] A. Mauri, N. Serra and R. Silva Coutinho, *Towards establishing Lepton Flavour Universality violation in $\bar{B} \to \bar{K}^*\ell^+\ell^-$ decays*, 1805.06401.