

Data-driven analyses and model-independent fits for present $b \rightarrow s\ell\ell$ results

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We present a critical assessment of the present B anomalies in the exclusive $b \rightarrow s\ell\ell$ mode based on the QCD factorization (QCdf) approach. In particular, we analyze the impact of different local form factor calculations and of the largest bin in the low- q^2 region. We also present a model-independent analysis of the new results of the LHCb and CMS experiments on the $B \rightarrow K^*\mu^+\mu^-$ angular observables. In addition, we update the global fit by including all $b \rightarrow s$ observables incorporating the new data from CMS and the LHCb. In these analyses, we use 10% or higher guesstimates of the nonfactorizable power corrections as additional uncertainties, serving as a placeholder for robust estimates of these contributions. Updating earlier results, we also analyze the combined LHCb and CMS data on the $B \rightarrow K^*\mu^+\mu^-$ angular observables using data-driven approaches to find indications of whether these tensions between the QCdf predictions and the present data are due to underestimated subleading hadronic contributions or due to new physics effects.

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I. INTRODUCTION

Since LHCb collaboration recently found the theoretically clean ratios, namely, R_K and R_{K^*} —which test lepton universality—to be standard model (SM)-like [1], the focus is back on the longstanding tensions in the angular observables and branching ratios of exclusive $b \rightarrow s$ observables [2–10], which have very recently been confirmed again by CMS [11] and the LHCb [12]. However, the theoretical description of these exclusive decays within the QCD factorization (QCdf) approach [13,14] is incomplete because nonfactorizable power corrections cannot be

calculated in general, in other words, there is no exact SM prediction within this approach. Therefore, it is not possible to decide whether the tensions are due to these unknown power corrections or due to new physics (NP) effects.

A possible solution to the problem was that the previously measured deviations in the theoretically clean ratios R_K and R_{K^*} [15,16] were shown to be consistent with the deviations in the angular observables and branching ratios. In this way, the discovery of new physics in the ratios would also have indirectly confirmed the new physics interpretation of the deviations in the angular observables and branching ratios. In the present post- $R_{K^{(*)}}$ era, one must look for other solutions.

There are estimates on the power corrections based on analyticity and the z expansion beyond the QCdf approach, which leads to rather small values for these contributions [17–20]. But there are also claims that not all contributions are included in these analyses, like rescattering effects of intermediate hadrons [21]. A complete analysis of all the effects due to the anomalous thresholds does not exist yet [22]. Moreover, the leading term in the computation in [19] is proportional to the local form factors (as is the leading

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term in QCDf). Therefore, updating local form factor predictions would also lead to a reevaluation of these nonlocal contributions. There is also the claim [see Ref. [23], below Eq. (2.26)] that, for example, in case of the vacuum-to- B three-particle matrix elements with the gluon and the light spectator quark, the dominant region is the one in which the two fields are aligned in different light cone directions [24]. Thus, a local light cone expansion of matrix elements with fields aligned in one light cone direction—as used in Refs. [17–19]—might not lead to the complete result (see also [27,28]).

The tensions in the exclusive $b \rightarrow s$ decays can also be verified by measurements of the corresponding inclusive decays, as was shown in Refs. [29,30]. Such measurements are feasible at the BELLE-II experiment [31], and may also be possible at the LHCb experiment, particularly in the high- q^2 region [29,32].

In principle, the new concept of refactorization within the effective field theory [33–35] can also lead to a solution by establishing factorization at the subleading level for such complicated decays in the long run. Then, the nonfactorizable power corrections would be calculable in the QCDf approach.

Meanwhile, it is possible to work out a model-independent analysis of all $b \rightarrow s$ observables, updating previous analyses [36–43] and using a guesstimate of 10% and also higher percentages for the uncertainty due to the nonfactorizable power corrections [44]. This serves as a placeholder for a robust estimate of these contributions. Furthermore, we also consider all observables in the high- q^2 region, where the operator product expansion and heavy quark effective theory provide the theoretical description [45–47]. But quark-hadron duality violations could, in principle, introduce larger uncertainties. These observables in the high- q^2 region have less sensitivity to the NP Wilson coefficients. There have been other groups presenting similar model-independent analyses [21,48–50].

We might also tackle the problem using data-driven approaches in order to get indications about the nature of the tensions. In the last years, we have presented various types of data-driven approaches [41,51–54]. In the second part of the paper, we update them and get a combined picture. More recently, data-driven analyses were also presented in Refs [49,55,56].

The paper is organized as follows. Section II compares the recent CMS measurements [11] of $B \rightarrow K^* \mu^+ \mu^-$ angular observables with the corresponding LHCb results from 2020 [7] and 2025 [12], discussing form factor choices, the treatment of the low- q^2 region, and the use of $P_i^{(\prime)}$ versus S_i observables. Section III presents updated global fits to all $b \rightarrow s \ell \ell$ data, examining the impact of the largest low- q^2 bins and varying assumptions on form factor choices and nonfactorizable power corrections. Section IV adopts a data-driven approach to contrast NP and hadronic fits, tests helicity and q^2 independence, and assesses the

statistical preference between the different fits. Section V summarizes our conclusions.

II. COMPARISON OF CMS AND LHCb RESULTS

We compare the new measurements of angular observables in the $B \rightarrow K^* \mu^+ \mu^-$ decay by CMS collaboration [11] with the corresponding ones by LHCb collaboration [7,12]. The recent CMS measurement of the $B \rightarrow K^* \mu^+ \mu^-$ angular observables is provided only for the $P_i^{(\prime)}$ basis [57,58]. Therefore, for a more coherent comparison, we also use the $P_i^{(\prime)}$ observables for the LHCb measurements (unlike in our previous work [41,42,59], where we used the S_i observables [60]). We discuss the consequences of this choice below.

For the $B \rightarrow K^*$ form factors, we use the results from Ref. [61], denoted by “GRvDV23,” as the default in our analysis, which is based on a combined fit to lattice QCD data [62,63] and light cone sum rule (LCSR) calculations [18,64] with B -meson distribution amplitudes. We also compare these predictions with those based on the “BSZ15” form factors from Ref. [65], which we used in our previous work. Those are based on a combined fit to the same lattice results [62,63] and a LCSR calculation with K^* -meson distribution amplitudes.

While the local hadronic matrix elements are described by form factors, the nonlocal, nonfactorizable contributions are more involved. These are computed at leading order in Λ/E_{K^*} and Λ/m_b within the QCDf framework [13,14]. However, power corrections beyond this leading order are not calculable in this approach. Although several efforts have been made to estimate these contributions, they remain not fully under control [17–19,66–68].

For our SM predictions, we make a heuristic estimate of these power corrections by assigning a 10% uncertainty at the amplitude level to the leading-order nonfactorizable QCDf terms. We also consider larger guesstimates of 50% and 100% in the global fit, including other modes (see Sec. III).

Additionally, since the QCDf framework is only valid in the low- q^2 region below the charm threshold, $q^2 < 4m_c^2 \approx 7 \text{ GeV}^2$ [13,14], the predictions for the largest low- q^2 bins (i.e., [6, 8] for LHCb and [6, 8.68] for CMS) should be treated with greater caution because the validity of the QCDf approach is not guaranteed in this region. Therefore, for our default dataset in this paper—unless otherwise stated—we include the low- q^2 region below the J/ψ resonance, excluding the largest low- q^2 bins, and we also consider the high- q^2 region above the $\psi(2S)$ resonance. However, in the global fit we will analyze the impact of the largest low- q^2 bins (see Sec. III).

A. Theory predictions vs measurements

In order to illustrate the consistency of the CMS and LHCb data on the various observables within the $B \rightarrow K^* \mu^+ \mu^-$ decay, we show the measurements and the SM guesstimates for each observable separately in Fig. 1.

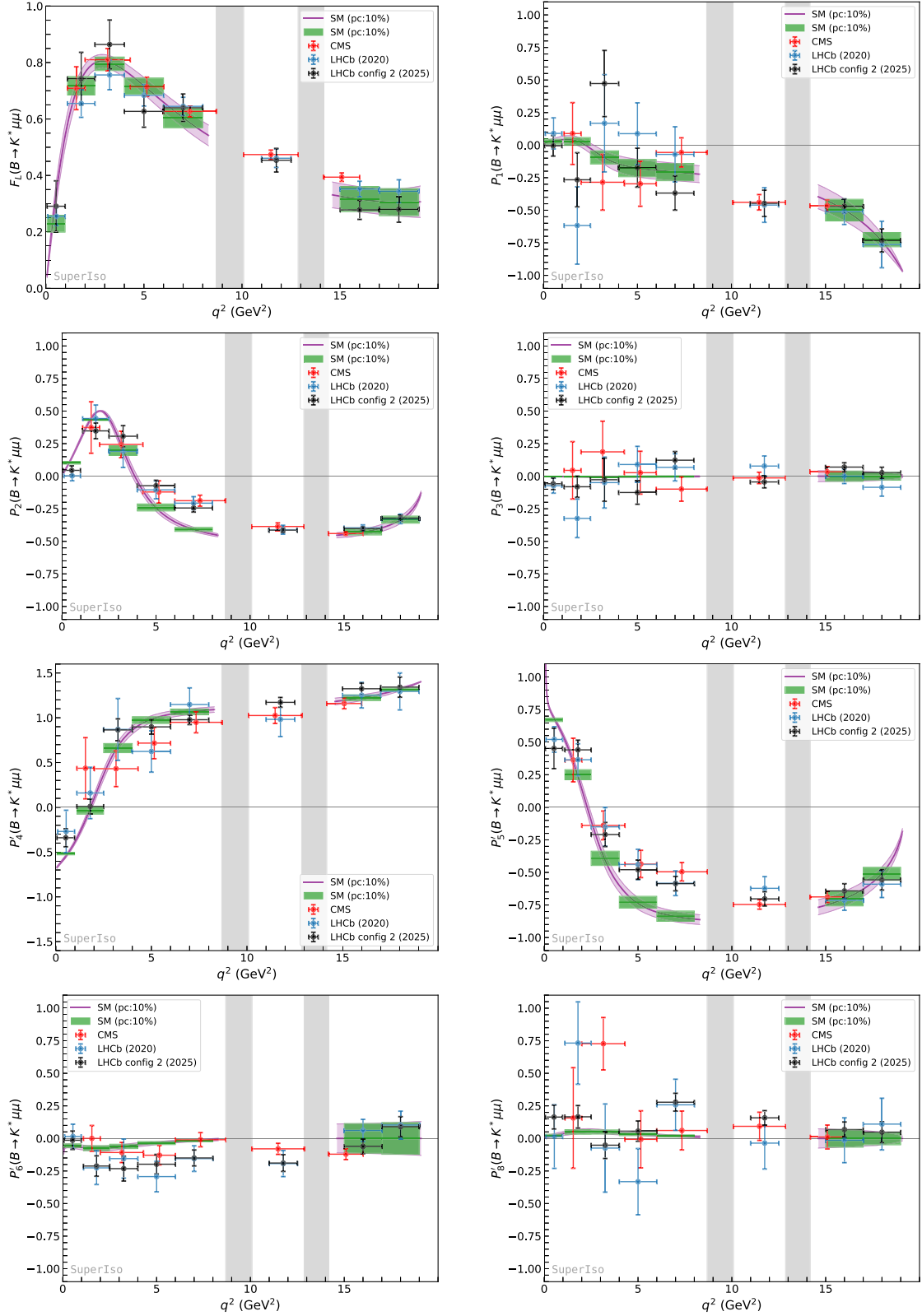


FIG. 1. $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ angular observables with SM predictions using GRvDV23 form factors and assuming 10% power corrections. The data points correspond to the CMS measurement [11] and the LHCb results from 2020 [7] and 2025 [12].

The CMS results correspond to the 140 fb^{-1} dataset [11], while for the LHCb we consider both the 2020 measurement based on 4.7 fb^{-1} [7] and the recent 2025 update with 8.4 fb^{-1} data [12]. We first compare the CMS data with the LHCb 2020 results, and then separately with the updated LHCb 2025 results to illustrate the evolution in precision and consistency between the experiments. We consider the SM predictions using GRvDV23-FF with

TABLE I. Comparison of NP fit to the $P_i^{(\prime)}$ angular observables for $B \rightarrow K^* \mu^+ \mu^-$ with the LHCb and CMS data, excluding the $[6, 8]$ and $[6, 8.68]$ GeV^2 bins, respectively. The results assume 10% power corrections. The upper panel shows the CMS results, while the middle pannel shows the LHCb measurements from 2020 and the lower pannel shows the LHCb measurements from 2025.

Angular observables $P_i^{(\prime)}$ (CMS)			
$\chi_{\text{SM}}^2 = 39.0$			
	Best fit (b.f.) value	χ_{min}^2	Pull _{SM}
δC_9	-0.56 ± 0.20	32.7	2.5σ
δC_{10}	-0.80 ± 0.50	36.6	1.6σ
δC_{LL}	-0.56 ± 0.24	34.6	2.1σ
δC_{LR}	-0.39 ± 0.14	33.2	2.4σ
δC_{RL}	0.00 ± 0.13	34.4	2.1σ
δC_{RR}	0.28 ± 0.25	37.7	1.1σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.55 \pm 0.25$ $\delta C_{10} = 0.00 \pm 0.50$	32.7	2.0σ
Angular observables $P_i^{(\prime)}$ (LHCb 2020)			
$\chi_{\text{SM}}^2 = 64.3$			
	Best fit (b.f.) value	χ_{min}^2	Pull _{SM}
δC_9	-0.66 ± 0.21	56.7	2.8σ
δC_{10}	-0.70 ± 0.50	62.1	1.5σ
δC_{LL}	-0.55 ± 0.24	60.1	2.1σ
δC_{LR}	-0.49 ± 0.17	57.2	2.7σ
δC_{RL}	0.00 ± 0.17	63.5	0.9σ
δC_{RR}	0.14 ± 0.27	64.1	0.5σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.63 \pm 0.24$ $\delta C_{10} = -0.10 \pm 0.50$	56.6	2.3σ
Angular observables $P_i^{(\prime)}$ (LHCb 2025)			
$\chi_{\text{SM}}^2 = 103.3$			
	Best fit (b.f.) value	χ_{min}^2	Pull _{SM}
δC_9	-0.89 ± 0.14	74.2	5.4σ
δC_{10}	-1.02 ± 0.30	91.5	3.4σ
δC_{LL}	-0.71 ± 0.17	90.8	3.5σ
δC_{LR}	-0.62 ± 0.11	76.1	5.2σ
δC_{RL}	0.00 ± 0.13	93.6	3.1σ
δC_{RR}	0.26 ± 0.17	100.7	1.6σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.84 \pm 0.17$ $\delta C_{10} = -0.17 \pm 0.30$	73.9	5.1σ

10% power corrections both for the low- and high- q^2 bins. It is interesting that most observables are compatible with the QCDf predictions, including a 10% guesstimate for the nonfactorizable power corrections, but the individual deviations, for example in the observables P_2 and P'_5 , are consistently reproduced by both CMS and LHCb datasets.

B. Comparison with one- or two-parameter NP fits

In Table I and Fig. 2 we compare the NP fit to the $P_i^{(\prime)}$ angular observables of $B \rightarrow K^* \mu^+ \mu^-$ using the CMS measurement [11] and both the earlier and updated LHCb results [7,12]. The one-parameter NP fits show excellent consistency between the CMS measurement and the LHCb 2020 result, which had comparable uncertainties.

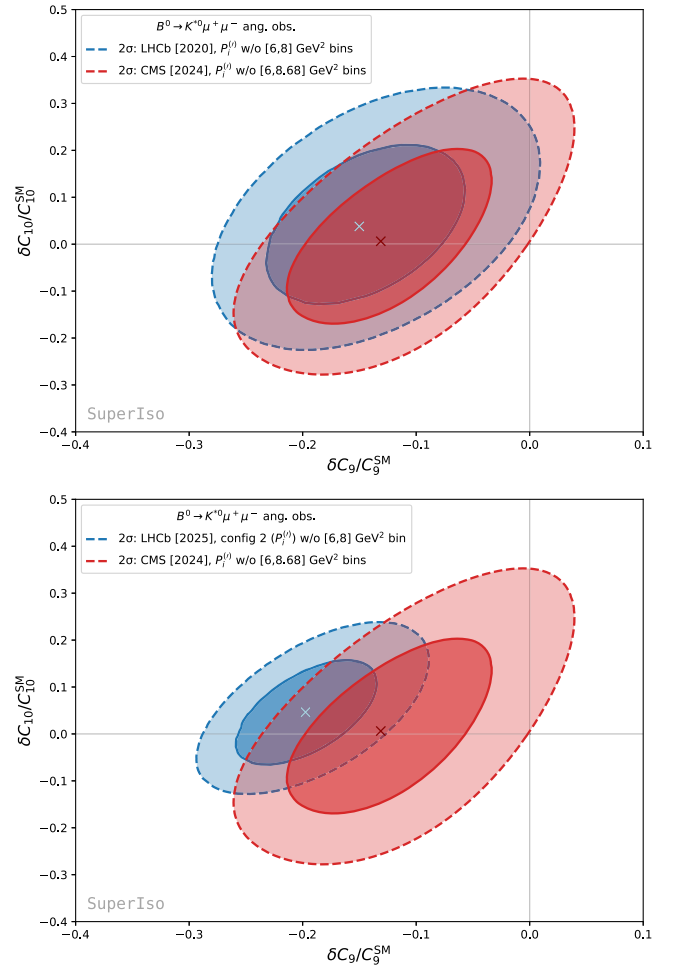


FIG. 2. The 1 and 2 σ confidence level (CL) of the $\{C_9, C_{10}\}$ fit to angular $B \rightarrow K^* \mu^+ \mu^-$ observables (without $[6, 8]$ and $[6., 8.68]$ GeV^2 bins), using the measurements from CMS [11] and, separately, two different LHCb results. The upper panel uses the earlier LHCb 2020 data [7], while the lower panel uses the updated LHCb 2025 result [12]. The fits lead to Pull_{SM} of 2.0σ for CMS and 2.3 and 5.1σ for LHCb 2020 and 2025 data, respectively.

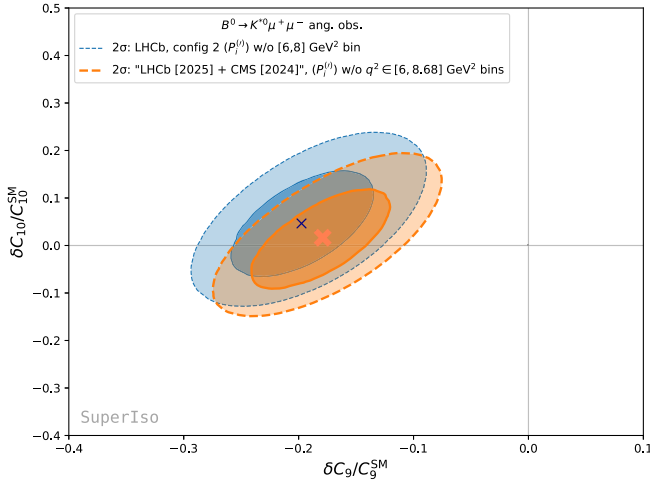


FIG. 3. The 1σ and 2σ CL regions for the $\{C_9, C_{10}\}$ fit to angular observables in $B \rightarrow K^*\mu^+\mu^-$, when a fit to the LHCb measurements [7] with and without CMS data [11] (excluding the $q^2 \in [6, 8.68]$ GeV ^{2} bins in both cases) is made, with Pull_{SM} of 5.1 and 4.9σ , respectively.

In contrast, the very recent LHCb results, with their reduced uncertainties, yield higher tensions. It can also be seen that the two-parameter NP fits are compatible with each other at the 1-sigma level. The NP significances are 2.0σ for CMS and 2.3 and 5.1σ for the 2020 and 2025 LHCb results, respectively. This is a confirmation of the previous LHCb measurements, reaffirming the discrepancy with the QCDf predictions (with the 10% guesstimate on nonfactorizable power corrections). In the rest of this paper, we will only consider the updated 2025 LHCb data [69].

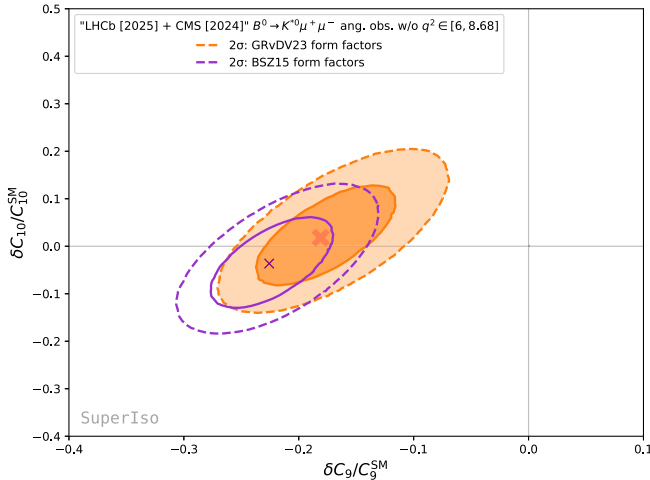


FIG. 4. The 1σ and 2σ confidence level regions for the $\{C_9, C_{10}\}$ fit to angular observables in $B \rightarrow K^*\mu^+\mu^-$, when in the combined LHCb and CMS fit two different sets of form factors, GRvDV23-FF (orange region) and BSZ15-FF (purple contours), are used, resulting in Pull_{SM} of 4.9 and 6.1σ , respectively.

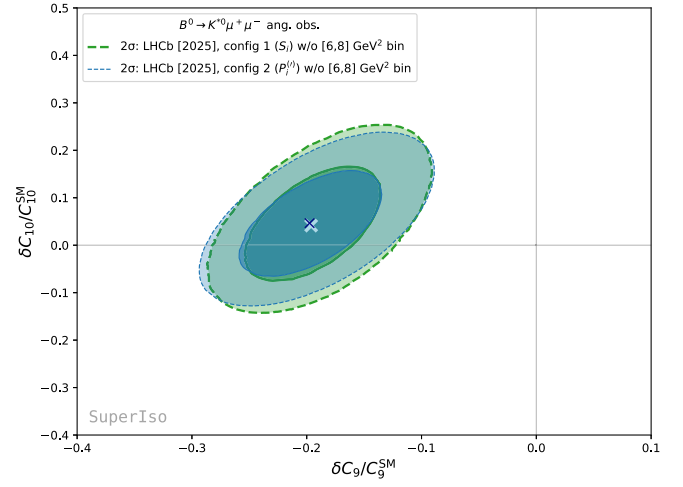


FIG. 5. The 1 and 2σ CL of the $\{C_9, C_{10}\}$ fit to angular $B \rightarrow K^*\mu^+\mu^-$ observables, using the $P_i^{(f)}$ and S_i measurements from the LHCb [7], excluding the $[6, 8]$ GeV ^{2} bins, resulting in Pull_{SM} of 5.1 and 4.8σ , respectively.

The impact of adding the CMS data to the LHCb data is shown explicitly in Fig. 3, where the two-parameter NP fit to the LHC measurements with and without CMS data is shown. The NP significance decreases slightly from 5.1 to 4.9σ . This reduction arises because the CMS data prefer a smaller NP contribution to δC_9 than suggested by the updated LHCb measurements.

We note that the choice of local form factors has a major impact, even on the angular observables' fit. Figure 4 shows the two-parameter fit to the combined CMS and LHCb data when LCSR with B -meson amplitudes (GRvDV23) or with K^* -meson amplitudes (BSZ15) are considered for the theoretical prediction. In both cases, the LCSR results are combined with the same lattice results (see above for the references). The NP significance is in the former case 4.9σ , in the latter 6.1σ . The authors of Ref. [19] observe a similar pattern with the older experimental results.

Finally, we test, using the LHCb data, whether the choice of the normalized $P_i^{(f)}$ observables (config. 2) instead of the S_i observables (config. 1) makes a difference. Figure 5 shows that the best-fit points coincide perfectly, and both configurations yield very similar Pull_{SM} values, with config. 2 giving 5.1σ and config. 1 giving 4.8σ .

III. GLOBAL FITS

In this section, we consider global fits including all $b \rightarrow s\ell\ell$ observables. We also explore the impact of the highest low- q^2 bins we have left out in the previous section because the validity of the QCDf approach in these highest low- q^2 bins is questionable. Thus, we consider two datasets in our global fit: one including these bins (containing 263 observables), and one excluding them (with 230 observables). The full list of observables for both datasets is

TABLE II. Comparison of NP fit excluding (top) or including (bottom) the LHCb [6, 8] and CMS [6, 8.68] GeV^2 bins.

All observables excluding $q^2 \in [6, 8.68]$ GeV ² bins			
$\chi^2_{\text{SM}} = 329.3$			
	Best fit (b.f.) value	χ^2_{min}	Pull _{SM}
δC_7	-0.01 ± 0.01	328.0	1.1σ
δC_{Q_1}	-0.02 ± 0.06	329.3	0.0σ
δC_{Q_2}	0.00 ± 0.01	329.3	0.0σ
δC_9	-0.69 ± 0.12	302.6	5.2σ
δC_{10}	-0.19 ± 0.12	326.9	1.5σ
δC_{LL}	-0.31 ± 0.13	323.0	2.5σ
δC_{LR}	-0.34 ± 0.08	312.7	4.1σ
δC_{RL}	0.00 ± 0.08	326.1	1.8σ
δC_{RR}	0.11 ± 0.11	328.3	1.0σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.69 \pm 0.12$	302.6	4.8σ
	$\delta C_{10} = -0.01 \pm 0.13$		
All observables including $q^2 \in [6, 8.68]$ GeV ² bins			
$\chi^2_{\text{SM}} = 431.7$			
	Best fit (b.f.) value	χ^2_{min}	Pull _{SM}
δC_7	-0.02 ± 0.01	429.3	1.5σ
δC_{Q_1}	-0.02 ± 0.05	431.7	0.0σ
δC_{Q_2}	0.00 ± 0.01	431.7	0.0σ
δC_9	-0.92 ± 0.10	377.6	7.4σ
δC_{10}	-0.32 ± 0.12	424.3	2.7σ
δC_{LL}	-0.35 ± 0.13	424.0	2.8σ
δC_{LR}	-0.47 ± 0.07	394.6	6.1σ
δC_{RL}	0.00 ± 0.09	428.1	1.9σ
δC_{RR}	0.07 ± 0.11	431.4	0.5σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.89 \pm 0.11$	377.4	7.1σ
	$\delta C_{10} = -0.05 \pm 0.13$		

provided as Supplemental Material and also given in Appendix A. These can be used with SuperIso [70–73] to obtain their SM or NP predictions.

Unless otherwise stated, we use the following form factor inputs for the exclusive semileptonic decays involving $B \rightarrow V$ and $B \rightarrow P$ transitions: for the $B \rightarrow K$ form factors, we adopt the combined fit to light cone sum rule and lattice QCD results from Ref. [64] (GKvD18), consistent with our previous analyses [41,42,59]. The LCSR calculation is based on B -meson distribution amplitudes, while the lattice input is taken from Ref. [74]. In Appendix B 1, we again illustrate the impact of alternative form factor inputs on the SM prediction for Branching Ratio (BR) $\text{BR}(B \rightarrow K\mu^+\mu^-)$, as done in the last section for the angular observables in the $B \rightarrow K^*\ell^+\ell^-$ mode. For $B \rightarrow K^*$ and $B_s \rightarrow \phi$, we use the form factors provided in Ref. [61] (GRvDV23), which are based on a combined fit to lattice QCD data [62,63] and light cone sum rule

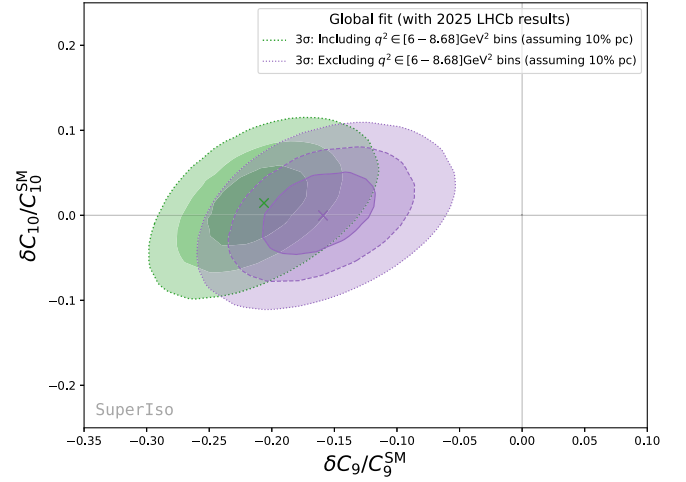


FIG. 6. Two-dimensional fit of $\{C_9, C_{10}\}$ to all observables with (green) or without (purple) $q^2 \in [6, 8.68] \text{ GeV}^2$ bins with Pull_{SM} of 4.8 and 7.1 σ , respectively. These values are obtained assuming a 10% guesstimate for the power corrections.

calculations [18,64] with B -meson distribution amplitudes. This represents an update to our earlier work, in which we used the BSZ15 results [65] with light-meson distribution amplitudes combined with the same lattice data [62,63]. In Appendix B 2 we show the impact of the different choices in the case of the observables P_2 and P'_5 for the $B \rightarrow K^*\mu^+\mu^-$ decay, while Appendix B 3 illustrates their effect on $\text{BR}(B_s \rightarrow \phi\mu^+\mu^-)$.

Our current choice ensures a consistent treatment across decay modes using form factors derived from LCSR calculations with B -meson distribution amplitudes.

In Table II the results of one-parameter NP fits without (top) and with the highest bins above 6 GeV^2 (bottom) are shown. The NP Wilson coefficients δC_7 and δC_{10} get strongly constrained by the radiative penguin decays $b \rightarrow s\gamma$ and the $B_s \rightarrow \mu^+\mu^-$ decay, respectively. The NP significance in the one-parameter fits to the Wilson coefficients δC_9 and also δC_{LR} changes dramatically when the highest low- q^2 bins are included—they change from 5.2 σ to 7.4 σ and from 4.1 σ to 6.1 σ , respectively [75].

We emphasize again that these values are obtained assuming a 10% guesstimate for the power corrections and with the mentioned choices of form factors. The impact of δC_9 on key $b \rightarrow s\ell\ell$ observables is further illustrated in Appendix C.

Analogously, the NP significance in the two-parameter fits, shown in Fig. 6, changes from 4.8 σ to 7.1 σ . One can speculate that this drastic increase in NP significance is due to the fact that these high bins in the low- q^2 bins just below the resonances are not well described by the QCDF approach. This circumstance makes it very difficult to establish a conclusion regarding new physics based on these results in the largest low- q^2 bins within this framework.

TABLE III. NP fits to all $b \rightarrow s\ell\ell$ observables excluding $q^2 \in [6, 8.68]$ GeV² bins when using GRvDV23 form factors [61] for $B \rightarrow K^*$, $B_s \rightarrow \phi$, and GKvD18 form factors [64] for $B \rightarrow K$, assuming 10%, 50%, and 100% power corrections from top to bottom, respectively.

All observables except $q^2 \in [6, 8.68]$ GeV ²			
10% pc ($\chi^2_{\text{SM}} = 329.3$)			
	Best fit (b.f.) value	χ^2_{min}	Pull _{SM}
δC_9	-0.69 ± 0.12	302.6	5.2σ
δC_{10}	-0.19 ± 0.12	326.9	1.5σ
δC_{LL}	-0.31 ± 0.13	323.0	2.5σ
δC_{LR}	-0.34 ± 0.08	312.7	4.1σ
δC_{RL}	0.00 ± 0.08	326.1	1.8σ
δC_{RR}	0.11 ± 0.11	328.3	1.0σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.69 \pm 0.12$ $\delta C_{10} = -0.01 \pm 0.13$	302.6	4.8σ
All observables except $q^2 \in [6, 8.68]$ GeV ²			
50% pc ($\chi^2_{\text{SM}} = 304.0$)			
	Best fit (b.f.) value	χ^2_{min}	Pull _{SM}
δC_9	-0.64 ± 0.17	293.8	3.2σ
δC_{10}	-0.03 ± 0.14	304.0	0.0σ
δC_{LL}	-0.19 ± 0.13	301.8	1.5σ
δC_{LR}	-0.23 ± 0.11	300.2	1.9σ
δC_{RL}	0.00 ± 0.08	302.7	1.1σ
δC_{RR}	0.07 ± 0.13	303.7	0.5σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.64 \pm 0.17$ $\delta C_{10} = 0.01 \pm 0.14$	293.8	2.7σ
All observables except $q^2 \in [6, 8.68]$ GeV ²			
100% pc ($\chi^2_{\text{SM}} = 291.4$)			
	Best fit (b.f.) value	χ^2_{min}	Pull _{SM}
δC_9	-0.56 ± 0.20	286.0	2.3σ
δC_{10}	0.05 ± 0.16	291.3	0.3σ
δC_{LL}	-0.17 ± 0.13	289.7	1.3σ
δC_{LR}	-0.14 ± 0.14	290.5	0.9σ
δC_{RL}	0.00 ± 0.08	290.4	1.0σ
δC_{RR}	0.02 ± 0.15	291.4	0.0σ
$\{\delta C_9, \delta C_{10}\}$	$\delta C_9 = -0.57 \pm 0.21$ $\delta C_{10} = 0.03 \pm 0.15$	286.0	1.8σ

TABLE IV. Four operator NP fit excluding the LHCb [6, 8] and CMS [6, 8.68] GeV² bins assuming 10% power corrections.

All observables excluding $q^2 \in [6, 8.68]$ GeV ² bins with $\chi^2_{\text{SM}} = 329.3$			
$(\chi^2_{\text{min}} = 291.7; \text{Pull}_{\text{SM}} = 5.3\sigma)$			
δC_7	δC_8	δC_9	δC_{10}
0.06 ± 0.02	-0.74 ± 0.22	-0.86 ± 0.15	0.06 ± 0.14

For the nonfactorizable power corrections in the $B \rightarrow K^{(*)}\ell\ell$ and $B_s \rightarrow \phi\ell\ell$ decays, we have always assumed a 10% uncertainty to the leading-order nonfactorizable QCDf amplitude as the default value in our model-independent analyses in the past. Here, we analyze how much an increase in the guesstimate of the nonlocal power corrections (by increasing it from 10% to 50% and 100%) affects the NP significance in the global fit. As noted in Sec. I, these guesstimates serve only as a placeholder until solid and robust estimates of these power corrections are available.

The results are given in Table III and clearly indicate that 100% nonfactorizable power corrections compared to the leading nonfactorizable QCDf amplitude are needed, on average, to get the one-parameter fit to the NP Wilson coefficient δC_9 down to 2.3σ . Such large contributions are not currently expected in view of the analysis in Ref. [19], which predicts a very small nonlocal contribution. If there are corrections or additional contributions, it is not expected that they will induce an order-of-magnitude change. However, the result demonstrates that the deviation between data and QCDf predictions is rather significant.

Finally, we extend our analysis beyond the one- and two-dimensional fits presented in Table II by allowing NP contributions in all relevant Wilson coefficients. Since there is no theoretical justification for restricting NP to only a few operators, we perform multidimensional fits in which potentially the coefficients $C_{7,8,9,10}$ and the scalar and pseudoscalar couplings C_{Q_1} and C_{Q_2} , as well as their chirality-flipped counterparts, can be varied simultaneously. We give the fit results (excluding the $q^2 \in [6, 8.68]$ GeV² bins) with four, six, and also all universal Wilson coefficients in Tables IV–VI. It is noteworthy that the SM pull remains sizeable at 4.2σ even in the

TABLE V. Six operator NP fit excluding the LHCb [6, 8] and CMS [6, 8.68] GeV² bins assuming 10% power corrections.

All observables excluding $q^2 \in [6, 8.68]$ bins with $\chi^2_{\text{SM}} = 329.3$					
$(\chi^2_{\text{min}} = 291.1; \text{Pull}_{\text{SM}} = 4.9\sigma)$					
δC_7	δC_8	δC_9	δC_{10}	δC_{Q_1}	δC_{Q_2}
0.06 ± 0.02	-0.74 ± 0.22	-0.85 ± 0.16	0.04 ± 0.19	-0.13 ± 0.06	0.06 ± 0.08

TABLE VI. Twelve operator NP fit excluding the LHCb [6, 8] and CMS [6, 8.68] GeV² bins assuming 10% power corrections.

All observables excluding $q^2 \in [6, 8.68]$ GeV ² bins with $\chi^2_{\text{SM}} = 329.3$			
$(\chi^2_{\text{min}} = 286.8; \text{Pull}_{\text{SM}} = 4.2\sigma)$			
δC_7	$\delta C'_7$	δC_8	$\delta C'_8$
0.06 ± 0.02	0.00 ± 0.01	-0.78 ± 0.22	0.50 ± 0.50
δC_9	$\delta C'_9$	δC_{10}	$\delta C'_{10}$
-0.88 ± 0.16	-0.26 ± 0.20	0.09 ± 0.19	-0.03 ± 0.14
δC_{Q_1}	$\delta C'_{Q_1}$	δC_{Q_2}	$\delta C'_{Q_2}$
-0.12 ± 0.09	0.01 ± 0.10	0.40 ± 0.09	0.34 ± 0.09

TABLE VII. Pull_{SM} of 1-, 2-, 4-, 6-, and 12-dimensional fits. The last row also includes the chirality-flipped counterparts of the Wilson coefficients. In the last column the significance of improvement of the fit compared to the scenario of the previous row is given.

All observables excluding $q^2 \in [6, 8.68]$ bins				
Set of WC	Parameters	χ^2_{min}	Pull _{SM}	Improvement
SM	0	329.3	...	...
C_9	1	302.6	5.2 σ	5.2 σ
C_9, C_{10}	2	302.6	4.8 σ	0.0 σ
C_7, C_8, C_9, C_{10}	4	291.7	5.3 σ	2.9 σ
$C_7, C_8, C_9, C_{10}, C_{Q_1}, C_{Q_2}$	6	291.1	4.9 σ	0.3 σ
All WC (including primed)	12	286.8	4.2 σ	0.5 σ

12-dimensional fit of Table VI. Because all these NP fits are nested, the various NP hypotheses can be compared by the Wilks' test [76] (for more details about Wilks' theorem, see Sec. IV). Table VII provides a statistical comparison of the multidimensional fits with respect to the SM prediction and to each other. The "Improvement" column reports the gain in fit quality relative to the NP scenario (of the previous row) with a smaller set of Wilson coefficients, evaluated using Wilks' theorem.

IV. DATA-DRIVEN ANALYSES

In this section, we update our data-driven analyses presented in Refs. [41,51,53,54] in view of the new CMS and LHCb data. These analyses contributed to the question of whether the large deviations from QCDf predictions in the angular observables of the decay $B \rightarrow K^* \ell \ell$ represent a sign for new physics beyond the standard model or a consequence of underestimated hadronic power corrections. We present a direct comparison of two global fits to the data in the low- q^2 region based on the two different assumptions. We already know [51] that the new physics fit can be embedded into the general hadronic fit and, therefore, it is not and will not be possible to disprove

the hadronic hypothesis in favor of the NP one within this analysis with the set of observables considered in the present study. On the other hand, NP can hide within hadronic contributions and new observables like inclusive modes, confirming that the NP option can rule out the hadronic hypothesis.

In this section, the fit includes the branching ratio of $B^{(+,0)} \rightarrow K^{*(+,0)} \gamma$ (to get reasonable bounds on δC_7), branching ratio and angular observables of $B^{(+,0)} \rightarrow K^{*(+,0)} \mu^+ \mu^-$, and angular observables of $B^0 \rightarrow K^{*0} e^+ e^-$, all restricted to the low- q^2 region (either including or excluding the bin above 6 GeV²). The full list of observables is provided as Supplemental Material.

Finally, we note that within the data-driven approach, we do not add any guesstimate of nonfactorizable power corrections to the known QCDf prediction. The pull is calculated with respect to this *plain* QCDf prediction.

A. Theoretical framework

Already in Ref. [77], it was shown that the deviation in the low- q^2 region from the QCDf prediction can be fitted by hadronic power corrections. For this purpose, one has to derive the most general ansatz for the nonfactorizable power corrections. We recall that the $b \rightarrow s \ell \ell$ transitions are described by an effective Hamiltonian that can be divided into hadronic and semileptonic components. In case of the decay $B \rightarrow K^* \mu^+ \mu^-$, the semileptonic part is the dominant contribution and is described by seven independent form factors $\tilde{S}, \tilde{V}_\lambda, \tilde{T}_\lambda$, with helicities $\lambda = \pm 1, 0$ [78,79]. Then the decay $B \rightarrow V \bar{\ell} \ell$, where V is a vector meson, is described by the following eight helicity amplitudes:

$$H_V(\lambda) = -iN' \left\{ C_9^{\text{eff}} \tilde{V}_\lambda - C'_9 \tilde{V}_{-\lambda} + \frac{m_B^2}{q^2} \left[\frac{2\hat{m}_b}{m_B} (C_7^{\text{eff}} \tilde{T}_\lambda - C'_7 \tilde{T}_{-\lambda}) - 16\pi^2 \mathcal{N}_\lambda \right] \right\}, \quad (1)$$

$$H_A(\lambda) = -iN' (C_{10} \tilde{V}_\lambda - C'_{10} \tilde{V}_{-\lambda}), \quad (2)$$

$$H_P = iN' \left\{ (C_{Q_2} - C'_{Q_2}) + \frac{2m_\ell \hat{m}_b}{q^2} \left(1 + \frac{m_s}{m_b} \right) (C_{10} - C'_{10}) \right\} \tilde{S}, \quad (3)$$

$$H_S = iN' (C_{Q_1} - C'_{Q_1}) \tilde{S}. \quad (4)$$

At this level, it is manifest that the new physics contributions can be mimicked by hadronic ones [78,79]. The effective part of C_9^{eff} , i.e., $C_9 + Y(q^2)$, as well as the nonfactorizable contribution, $\mathcal{N}_\lambda(q^2)$, arise from the hadronic part of the Hamiltonian, via the emission of a photon that subsequently turns into a lepton pair. Due to the

vectorial coupling of the photon to the lepton pair, the contributions from the hadronic effective Hamiltonian appear in the vectorial helicity amplitude $[H_V(\lambda)]$. A similar effect occurs with the short-distance contribution of C_9 (and C_7), resulting in an ambiguity when separating the NP effects of δC_9 (and δC_7) from the nonfactorizable hadronic contributions.

Thus, $\mathcal{N}_\lambda(q^2)$ corresponds to the leading nonfactorizable contribution calculable in QCDf, plus some unknown nonfactorizable power corrections, which we denote as h_λ . The most general ansatz for the unknown h_λ terms respecting the analyticity of the amplitude (up to higher-order terms in q^2) is given by (see Refs [78,79])

$$h_\pm(q^2) = h_\pm^{(0)} + \frac{q^2}{1 \text{ GeV}^2} h_\pm^{(1)} + \frac{q^4}{1 \text{ GeV}^4} h_\pm^{(2)}, \quad (5)$$

$$h_0(q^2) = \sqrt{q^2} \times \left(h_0^{(0)} + \frac{q^2}{1 \text{ GeV}^2} h_0^{(1)} + \frac{q^4}{1 \text{ GeV}^4} h_0^{(2)} \right). \quad (6)$$

The extra $\sqrt{q^2}$ in the longitudinal amplitude assures that the longitudinal amplitude vanishes when the intermediate γ becomes on-shell.

B. Hadronic 18 parameter fit to helicity-dependent parametrization

Thus, $\mathcal{N}_\lambda(q^2)$ corresponds to the leading nonfactorizable contribution calculable in QCDf, plus some unknown nonfactorizable power corrections, which we denote as h_λ . The most general ansatz for the unknown h_λ terms respecting the analyticity of the amplitude (up to higher-order terms in q^2) is given by (see Refs [78,79])

$$h_\pm(q^2) = h_\pm^{(0)} + \frac{q^2}{1 \text{ GeV}^2} h_\pm^{(1)} + \frac{q^4}{1 \text{ GeV}^4} h_\pm^{(2)}, \quad (7)$$

$$h_0(q^2) = \sqrt{q^2} \times \left(h_0^{(0)} + \frac{q^2}{1 \text{ GeV}^2} h_0^{(1)} + \frac{q^4}{1 \text{ GeV}^4} h_0^{(2)} \right). \quad (8)$$

In the previous section, we have made guesstimates of the unknown nonfactorizable power corrections. We assumed them to be 10% of the leading-order nonfactorizable contribution, which is calculable in QCDf. However, it is also possible to make just a fit to the data for these power corrections—using the most general parametrization with 18 parameters [51–54,77,80]. The results of this fit are summarized in Table VIII, with a detailed illustration of its impact on some of the observables given in Appendix D.

One finds that half of the fitted parameters in such a fit are still consistent with zero. However, this is a large change to our previous corresponding analysis [54] where almost all parameters were compatible with zero within the 1σ range. Also, the pull compared with the QCDf prediction increases from 4.7σ to 9.2σ (in the case where bins up to 8.68 GeV^2 are included). When we leave out the

TABLE VIII. Hadronic power correction fit to $B \rightarrow K^* \gamma / \ell \ell$ observables for low- q^2 bins, with complex power corrections up to q^4 terms (18 free parameters).

$B \rightarrow K^* \gamma / \ell \ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins		
$(\chi^2_{\text{QCDf}} = 158.8, \chi^2_{\text{min}} = 94.9; \text{Pull}_{\text{QCDf}} = 5.0\sigma)$		
	Real	Imaginary
$h_+^{(0)}$	$(0.0 \pm 5.0) \times 10^{-5}$	$(1.1 \pm 0.8) \times 10^{-4}$
$h_+^{(1)}$	$(-2.0 \pm 8.0) \times 10^{-5}$	$(-7.0 \pm 12.0) \times 10^{-5}$
$h_+^{(2)}$	$(1.7 \pm 2.0) \times 10^{-5}$	$(0.0 \pm 2.6) \times 10^{-5}$
$h_-^{(0)}$	$(-1.0 \pm 0.6) \times 10^{-4}$	$(-2.5 \pm 1.4) \times 10^{-4}$
$h_-^{(1)}$	$(5.0 \pm 6.0) \times 10^{-5}$	$(3.7 \pm 1.4) \times 10^{-4}$
$h_-^{(2)}$	$(7.0 \pm 12.0) \times 10^{-6}$	$(-8.5 \pm 3.2) \times 10^{-5}$
$h_0^{(0)}$	$(6.0 \pm 12.0) \times 10^{-5}$	$(3.7 \pm 1.6) \times 10^{-4}$
$h_0^{(1)}$	$(8.0 \pm 10.0) \times 10^{-5}$	$(-1.1 \pm 1.5) \times 10^{-4}$
$h_0^{(2)}$	$(-4.0 \pm 17.0) \times 10^{-6}$	$(-1.3 \pm 2.5) \times 10^{-5}$
$B \rightarrow K^* \gamma / \ell \ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins		
$(\chi^2_{\text{QCDf}} = 269.8, \chi^2_{\text{min}} = 133.6; \text{Pull}_{\text{QCDf}} = 9.2\sigma)$		
	Real	Imaginary
$h_+^{(0)}$	$(-2.0 \pm 4.0) \times 10^{-5}$	$(6.0 \pm 7.0) \times 10^{-5}$
$h_+^{(1)}$	$(4.0 \pm 7.0) \times 10^{-5}$	$(1.0 \pm 8.0) \times 10^{-5}$
$h_+^{(2)}$	$(-6.0 \pm 13.0) \times 10^{-6}$	$(-1.3 \pm 1.6) \times 10^{-5}$
$h_-^{(0)}$	$(-7.0 \pm 5.0) \times 10^{-5}$	$(-7.0 \pm 13.0) \times 10^{-5}$
$h_-^{(1)}$	$(1.0 \pm 4.0) \times 10^{-5}$	$(9.0 \pm 12.0) \times 10^{-5}$
$h_-^{(2)}$	$(1.5 \pm 0.5) \times 10^{-5}$	$(-9.0 \pm 26.0) \times 10^{-6}$
$h_0^{(0)}$	$(9.0 \pm 10.0) \times 10^{-5}$	$(3.8 \pm 1.3) \times 10^{-4}$
$h_0^{(1)}$	$(8.0 \pm 6.0) \times 10^{-5}$	$(-1.6 \pm 0.9) \times 10^{-4}$
$h_0^{(2)}$	$(-9.0 \pm 7.0) \times 10^{-6}$	$(1.0 \pm 1.1) \times 10^{-5}$

problematic bins above 6 GeV^2 , one finds a pull of 4.7σ . And because there are still rather large uncertainties, one may expect that such a hadronic fit will improve further in the future. Indeed, we have shown in a previous analysis [54] that assuming the present central value, the significance compared with the QCDf prediction will increase dramatically within the first and second LHCb upgrades.

C. New physics fits

We can now fit the same experimental data from CMS and the LHCb to the complex or real NP Wilson coefficients δC_7 and δC_9 or only to the complex or real NP Wilson coefficients δC_9 , as given in Tables IX–XI. If we take the low- q^2 bins beyond 6 GeV^2 into account, we can

TABLE IX. Two operator NP fits for complex δC_7 and δC_9 with four parameters considering $B \rightarrow K^*\gamma/\ell\ell$ observables for low- q^2 bins.

$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 158.8 \chi^2_{\text{min}} = 113.4; \text{Pull}_{\text{QCDf}} = 5.9\sigma)$	
Best-fit value	
δC_7	$(0.09 \pm 0.03) + i(-0.20 \pm 0.03)$
δC_9	$(-1.65 \pm 0.26) + i(1.90 \pm 0.50)$
$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 269.8 \chi^2_{\text{min}} = 163.6; \text{Pull}_{\text{QCDf}} = 9.7\sigma)$	
Best-fit value	
δC_7	$(0.11 \pm 0.02) + i(-0.22 \pm 0.02)$
δC_9	$(-1.87 \pm 0.19) + i(2.10 \pm 0.40)$

compare the pulls with those of our earlier analysis in Ref. [54], which shows that the pulls have increased dramatically: in the case of the fit to the complex δC_9 from 5.8σ to 9.3σ , and in the case of the real coefficient from 6.0σ to 8.8σ . If we omit the low- q^2 bins beyond 6 GeV^2 for the reasons discussed in Sec. II, we find 5.6σ , which is compatible with the result of the one-parameter fit to δC_9 in Sec. II.

The imaginary parts in NP fits to a complex NP Wilson coefficient δC_9 are very large. But these results have to be taken with caution, because there are no strongly constraining CP -violating observables measured with high precision yet, therefore, only CP -averaged observables are considered in this analysis.

D. Test of helicity independence of NP fit

The independent NP fits with a complex C_9 in each helicity amplitude separately represent a null test of the NP hypothesis. This can be done via [52–54]

TABLE X. One operator NP fits for complex δC_9 with two parameters considering $B \rightarrow K^*\gamma/\ell\ell$ observables for low- q^2 bins.

$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 158.8 \chi^2_{\text{min}} = 122.6; \text{Pull}_{\text{QCDf}} = 5.7\sigma)$	
Best-fit value	
δC_9	$(-0.69 \pm 0.16) + i(-1.90 \pm 0.50)$
$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 269.8 \chi^2_{\text{min}} = 177.9; \text{Pull}_{\text{QCDf}} = 9.3\sigma)$	
Best-fit value	
δC_9	$(-0.84 \pm 0.15) + i(2.22 \pm 0.32)$

TABLE XI. One operator NP fits for complex δC_9 with two parameters considering $B \rightarrow K^*\gamma/\ell\ell$ observables for low- q^2 bins.

$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 158.8 \chi^2_{\text{min}} = 127.7; \text{Pull}_{\text{QCDf}} = 5.6\sigma)$	
Best-fit value	
δC_9	-0.82 ± 0.13
$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 269.8 \chi^2_{\text{min}} = 193.1; \text{Pull}_{\text{QCDf}} = 8.8\sigma)$	
Best-fit value	
δC_9	-1.13 ± 0.10

$$h_\lambda(q^2) = -\frac{\tilde{V}_\lambda(q^2)}{16\pi^2} \frac{q^2}{m_B^2} \Delta C_9^{\lambda, \text{PC}}, \quad (9)$$

with $\Delta C_9^{\lambda, \text{PC}}$ being three complex (six real) q^2 -independent parameters. This can be regarded as a minimalist description of hadronic power corrections, in which ruling out the NP hypothesis requires no extra q^2 term, and where it suffices if the fits to the three helicities are incompatible with each other.

However, if these three independent determinations of ΔC_9^λ are highly consistent with each other, then the NP description is strongly favored. And while it is not possible in principle to rule out the hadronic explanation in that case, it is extremely unlikely that the power corrections for all different helicities would conspire to imitate the new physics description.

The results of the six-parameter hadronic fit are given in Table XII. As can be seen, the results are not conclusive yet. The compatibility of the three complex numbers has not improved compared to our previous result in Ref. [54]. The large uncertainties in the case of $\Delta C_9^{+, \text{PC}}$ can be explained by the fact that the power corrections of $H_V(\lambda = +)$ are predicted to be smaller than those of $H_V(\lambda = -)$ by a factor of m_B/Λ [78,79]. We have shown in Ref. [54] that with the two LHCb upgrades, we can expect a much clearer picture showing preference either for the NP or hadronic interpretation.

E. Test of q^2 independence of NP fit

Yet another test to differentiate between the hadronic and the NP interpretation is the analysis of the q^2 dependence. In Ref. [77], the authors claimed that a nonzero q^4 term in the hadronic fit ansatz is incompatible with the NP interpretation of the B anomalies, as it could not be understood as a shift to the Wilson coefficients. However, this argument misses the fact that such a q^4 term could also be produced by the q^2 dependence of the

TABLE XII. Hadronic power correction fits for the three helicities ($\lambda = \pm, 0$) in the form of complex $\Delta C_9^{\lambda, \text{PC}}$, considering $B \rightarrow K^* \gamma / \ell \ell$ observables for low- q^2 bins.

$B \rightarrow K^* \gamma / \ell \ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 158.8 \chi^2_{\text{min}} = 108.9; \text{Pull}_{\text{QCDf}} = 5.8\sigma)$	
Best-fit value	
$\Delta C_9^{+, \text{PC}}$	$(3.00 \pm 5.00) + i(-10.00 \pm 5.00)$
$\Delta C_9^{-, \text{PC}}$	$(-0.79 \pm 0.18) + i(-0.89 \pm 0.27)$
$\Delta C_9^{0, \text{PC}}$	$(-0.59 \pm 0.33) + i(-0.96 \pm 0.34)$
$B \rightarrow K^* \gamma / \ell \ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins	
$(\chi^2_{\text{QCDf}} = 269.8 \chi^2_{\text{min}} = 160.0; \text{Pull}_{\text{QCDf}} = 9.5\sigma)$	
Best-fit value	
$\Delta C_9^{+, \text{PC}}$	$(1.00 \pm 4.00) + i(-0.50 \pm 3.20)$
$\Delta C_9^{-, \text{PC}}$	$(-1.11 \pm 0.13) + i(-1.21 \pm 0.28)$
$\Delta C_9^{0, \text{PC}}$	$(-0.72 \pm 0.28) + i(-0.69 \pm 0.33)$

helicity form factors, which multiply the NP Wilson coefficients [51]. In Ref. [55], this problem is circumvented by the determination of the Wilson coefficients in a bin-by-bin fit (using a specific estimate of the nonlocal contribution from the $c\bar{c}$ loops based on Refs [66,67]). Of course, this NP fit includes the assumption that possible NP contributions affect only single Wilson coefficients. The same authors have recently updated their analysis in Ref. [49]. They found that the bin-by-bin analysis of the three channels $B \rightarrow K^{(*)} / \phi \mu^+ \mu^-$ with all independent C_9 fits are compatible with the best-fit value of the global fit at the 2σ level. It is worth noting that in their bin-by-bin fit combining all $b \rightarrow s \ell \ell$ modes, they find the largest deviation from the best-fit point of the global fit in the 6–8 GeV^2 bin. More recently, another group has presented a similar analysis including an estimate of the effects induced by the charmonium resonances via a dispersive method in order to subtract the dominant hadronic q^2 -dependent contribution [56].

We have done this exercise using the LHCb and CMS data on $B \rightarrow K^* \mu^+ \mu^-$ in the low- q^2 region, without taking into account any hadronic contributions beyond the plain QCDf predictions, see Fig. 7. With the new LHCb data, we get a similar degree of consistency in the bin-by-bin determinations, although we have considered plain QCDf. This fact indicates that this test is far from being conclusive yet: comparing with the overall fit to C_9 up to 6 GeV^2 (orange) or up to 8.68 GeV^2 , where we used the combined LHCb and CMS data, we consider both config. 2 [full-size $P_i^{(\ell)}$ bins] and config. 6 (half-size S_i bins) for the LHCb data. One finds excellent agreement for LHCb with the full-size bins, while the half-size bins yield somewhat

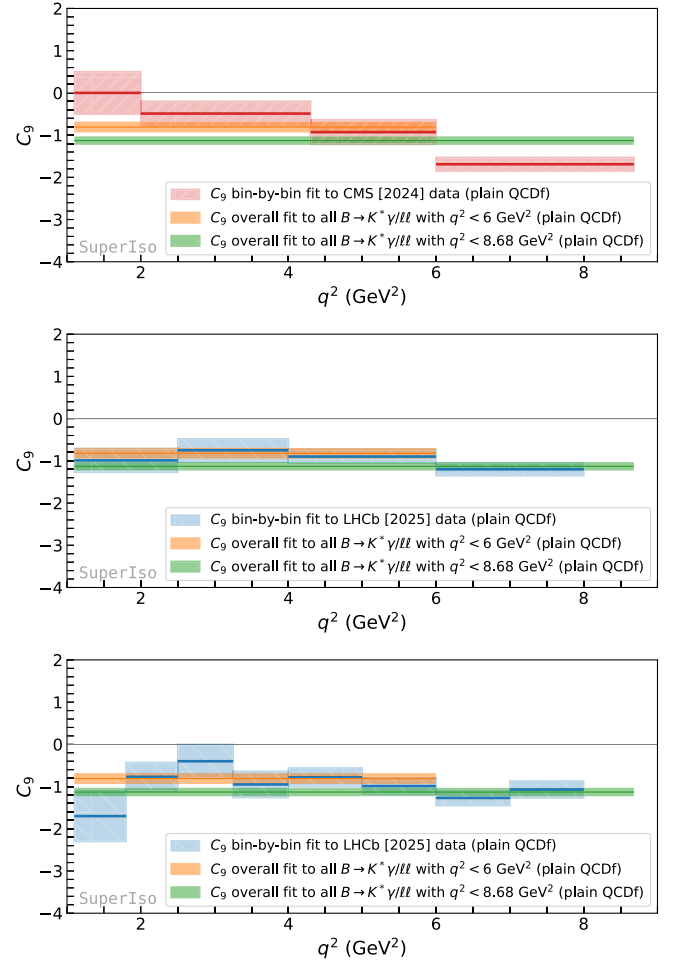


FIG. 7. Bin-by-bin fit to C_9 for CMS (top), LHCb config. 2 (middle), and LHCb config. 6 (bottom) results—compared with combined fit up to 6 GeV^2 (orange) or up to 8.68 GeV^2 (green). For the LHCb data, config. 2 corresponds to $P_i^{(\ell)}$ observables with full-size bins, and config. 6 to S_i observables with half-size bins. The results assume plain QCDf, without power corrections.

larger fitted regions due to their higher experimental uncertainties. Still, both configurations are compatible at about the 1σ level, whereas the CMS data show larger deviations (see Fig. 7).

Finally, we note that if these separate bin-by-bin determinations of the NP Wilson coefficients are highly inconsistent with each other, the NP interpretation can be ruled out, while strictly speaking, it is not possible to prove the NP interpretation in this way. However, at the point where one can prove the consistency of the individual determinations for smaller and smaller bins, it becomes rather unlikely that hadronic corrections can generate such a specific q^2 dependence.

F. Wilks' test

Finally, we use Wilks' test to analyze the various interpretations of the deviation. This test includes all the

various data-driven tests we discussed in this section and compares the various hypotheses with a precise statistical method [51]. The Wilks' test allows for this direct comparison of the various hypotheses because the NP fits can be considered as scenarios embedded within the hadronic fits. Thus, the different hypotheses can be compared using likelihood ratio tests. As these are nested hypotheses, the p values can be determined by applying Wilks' theorem [76]. Here, the difference in χ^2 between two hypotheses is itself a χ^2 distribution with a number of degrees of freedom corresponding to the difference in the number of parameters. The p value, therefore, indicates the significance of the newly added parameters. We then translate the p values into Gaussian single parameter significances using the relation $\sigma = \sqrt{2}\text{Erf}^{-1}(1 - p)$. We note that Wilks' theorem

is only valid under the assumption of Gaussian distributed uncertainties.

Therefore, as long as our various NP and hadronic fits are nested, we can compare them using Wilks' test. For example, the fit to real NP Wilson coefficients can be compared to the fit to the corresponding complex ones. A NP scenario can then be regarded as a nested scenario with respect to the hadronic fit.

From the upper panel in Table XIII, when the largest low- q^2 bins are not included, we find significances of $5.0 - 5.9\sigma$ when comparing the various NP and hadronic descriptions of the data with the plain QCDf prediction. The number in the second row and the last column indicates that adding 17 hadronic parameters to the real NP δC_9 fit does improve the description of the data with a significance

TABLE XIII. Improvement of the fits to $B \rightarrow K^*\gamma/\ell\ell$ observables for low- q^2 bins for the hadronic fit and the scenarios with real and complex NP contributions to Wilson coefficients C_7 and C_9 compared to the plain QCDf hypothesis and compared to each other.

$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 6 \text{ GeV}^2$ bins										
No. of free	1	2	2	4	3	6	6	9	12	18
Parameters	(Real) δC_9	(Real) $\delta C_7, \delta C_9$	(Comp.) δC_9	(Comp.) $\delta C_7, \delta C_9$	(Real) $\Delta C_9^{\lambda, \text{PC}}$	(Comp.) $\Delta C_9^{\lambda, \text{PC}}$	(Real) $h_{+,-,0}^{(0,1)}$	(Real) $h_{+,-,0}^{(0,1,2)}$	(Comp.) $h_{+,-,0}^{(0,1)}$	(Comp.) $h_{+,-,0}^{(0,1,2)}$
0 (plain QCDf)	5.6	5.4	5.7	5.9	5.0	5.8	5.2	5.0	5.4	5.0
1 (Real δC_9)	...	1.3	2.3	3.0	0.5	3.1	2.0	2.0	2.7	2.5
2 (Real $\delta C_7, \delta C_9$)	...	...	...	3.1	...	...	1.9	1.9	2.7	2.5
2 (Comp. δC_9)	...	...	...	2.6	...	2.6	...	...	2.3	2.1
4 (Comp. $\delta C_7, \delta C_9$)	...	...	...	...	...	...	...	...	...	1.3
3 (Real $\Delta C_9^{\lambda, \text{PC}}$)	...	...	...	...	...	3.5	2.4	2.2	3.0	2.7
6 (Comp. $\Delta C_9^{\lambda, \text{PC}}$)	...	...	...	...	...	...	...	...	1.0	1.0
6 (Real $h_{+,-,0}^{(0,1)}$)	...	...	...	...	...	...	...	1.2	2.3	2.0
9 (Real $h_{+,-,0}^{(0,1,2)}$)	...	...	...	...	...	...	...	...	...	2.0
12 (Comp. $h_{+,-,0}^{(0,1)}$)	...	...	...	...	...	...	...	...	...	1.0

$B \rightarrow K^*\gamma/\ell\ell$ observables: $q^2 \leq 8.68 \text{ GeV}^2$ bins										
No. of free	1	2	2	4	3	6	6	9	12	18
Parameters	(Real) δC_9	(Real) $\delta C_7, \delta C_9$	(Comp.) δC_9	(Comp.) $\delta C_7, \delta C_9$	(Real) $\Delta C_9^{\lambda, \text{PC}}$	(Comp.) $\Delta C_9^{\lambda, \text{PC}}$	(Real) $h_{+,-,0}^{(0,1)}$	(Real) $h_{+,-,0}^{(0,1,2)}$	(Comp.) $h_{+,-,0}^{(0,1)}$	(Comp.) $h_{+,-,0}^{(0,1,2)}$
0 (plain QCDf)	8.8	8.6	9.3	9.7	8.6	9.5	8.8	9.0	9.1	9.2
1 (Real δC_9)	...	1.4	3.9	4.8	1.9	4.6	3.1	3.9	4.3	4.8
2 (Real $\delta C_7, \delta C_9$)	...	...	...	4.9	...	...	3.1	3.9	4.3	4.8
2 (Comp. δC_9)	...	...	...	3.4	...	3.2	...	...	3.0	3.7
4 (Comp. $\delta C_7, \delta C_9$)	...	...	...	...	...	...	...	...	...	2.7
3 (Real $\Delta C_9^{\lambda, \text{PC}}$)	...	...	...	...	...	4.6	2.9	3.7	4.1	4.7
6 (Comp. $\Delta C_9^{\lambda, \text{PC}}$)	...	...	...	...	...	...	...	...	1.3	2.6
6 (Real $h_{+,-,0}^{(0,1)}$)	...	...	...	...	...	...	...	2.8	3.3	4.0
9 (Real $h_{+,-,0}^{(0,1,2)}$)	...	...	...	...	...	...	...	...	...	3.3
12 (Comp. $h_{+,-,0}^{(0,1)}$)	...	...	...	...	...	...	...	...	...	2.7

of 2.5σ . The table shows the comparative statistical preferences of various hypotheses: any preference among various models does not exceed 2.7σ , which indicates that the situation with the present data is still not conclusive. There is no real change to our previous analysis in Ref. [54]. The high significance—in the cases where a complex Wilson coefficient C_9 is involved—is again a consequence of the lack of CP -violating observables measured with high precision.

In contrast, in the lower table (when the largest low- q^2 bins are included) we can read off from the first row that the various hadronic and NP scenarios offer a better description of the data than the plain QCDf prediction, with a significance larger than 8.6σ . Compared to our previous results [54], this is a large increase of significance, where only $5 - 6\sigma$ were previously found. More importantly, one realizes that the description of the data improves with a large significance of 3.9σ when going from the NP scenario of one real δC_9 to a hadronic fit with more than nine parameters. This is an important change compared to our previous analysis in Ref [54], where one found only a change of 1.5σ in this case. This is not unexpected, as the largest low- q^2 bins extend into a region where the QCDf approach is not considered very reliable. In the LHCb binning, the highest low- q^2 bin ($[6, 8] \text{ GeV}^2$) was already included in our previous results. However, in the present analysis we also include the CMS result, whose largest low- q^2 bin ($[6, 8.68] \text{ GeV}^2$) extends even further, approaching the tail of the J/ψ resonance and moving deeper into the region where the QCDf treatment becomes increasingly questionable. Therefore, it is difficult to establish a preference for the NP or the hadronic hypothesis based on these largest low- q^2 bins.

In any case, we have worked out projections of the present data for the two upgrade stages of the LHCb experiment in Ref. [54]. Assuming that future experimental data correspond to the present best-fit point of the NP fit to a real δC_9 , one finds in both future upgrade scenarios—where we expect highly reduced uncertainties—large pulls, which strongly favors the NP hypothesis—in spite of the fact that because the NP model is nested in the hadronic models we cannot disprove the hadronic option in favor of the NP one.

In the other extreme future scenario, we assume the present best-fit points of the 18-parameter hadronic fit, then of course the hadronic fit shows a large improvement in the description of the experimental data compared with the plain QCDf prediction or the NP fits. In that case, the Wilks' test shows a clear preference for the hadronic hypothesis. Thus, also in the case of this comprehensive Wilks' test, we can expect that the two LHCb upgrades will provide a clear picture.

V. SUMMARY

In this manuscript, we have presented a critical assessment of the present B anomalies based on the QCDf approach.

First, we have shown that the new CMS measurements of the angular observables of the $B \rightarrow K^* \mu^+ \mu^-$ are compatible with the corresponding LHCb measurements at the 1σ level. The updated 2025 LHCb data are in agreement with the previous LHCb results and also with the recent CMS data, but exhibit even larger tensions due to their smaller experimental uncertainties.

We also have shown in several examples that using different sets of local form factors based on LCSR and lattice calculations leads to notable changes in the NP significance. These large changes require further analysis. One explanation could be that the uncertainties in the form factor calculations have been underestimated so far—already stated in Ref. [51].

We find a NP significance of 5.2σ in the one-parameter fit to the Wilson coefficient δC_9 in our global fit to all $b \rightarrow s \ell \ell$ data assuming a 10% guesstimate for the unknown power corrections to the QCDf prediction, and adopting the mentioned choice of form factors. This result corresponds to the global fit excluding the $q^2 \in [6, 8.68] \text{ GeV}^2$ region, where QCDf is not expected to be valid. We have shown that a 100% guesstimate for the unknown power corrections is needed to reduce the NP significance to 2.3σ . This test demonstrates that there is still a significant deviation between data and QCDf predictions, which has to be understood.

Within the data-driven approach, we have updated our earlier analyses in light of the new CMS and LHCb data, performing a comprehensive comparison between NP fits and general hadronic fits to the low- q^2 region. We have tested the helicity and q^2 independence of the NP description and found that present uncertainties are still too large for decisive conclusions. However, in the case of q^2 independence, the LHCb and CMS results indicate a slightly different picture, with the latter showing a greater inclination toward a q^2 dependence. A global comparison using Wilks' test (possible due to the nesting of the NP scenario into the hadronic one) confirms that, with present data, there is no strong statistical preference between NP and hadronic scenarios once the largest low- q^2 bins are excluded, whereas including them yields a preference for the hadronic fit—though this interpretation is complicated by the reduced reliability of QCDf in this region. Future LHCb and CMS upgrades should, however, provide much stronger discrimination between NP and hadronic scenarios.

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DATA AVAILABILITY

The data that support the findings of this article are openly available.

APPENDIX A: LIST OF ALL OBSERVABLES

In this appendix, we provide the list of observables used in the global fit when including the $q^2 \in [6, 8.68]$ GeV² bins,

resulting in a total of 263 observables (see Supplemental Material `set_AllConfig2.in` [81]). For the set with 230 observables (`set_AllConfig2_wo68.in` [81]), the $q^2 \in [6, 8.68]$ GeV² bins are excluded.

For the fits to angular observables only, discussed in Sec. II, we use subsets of the observables listed in Tables XIV–XVI, as given in `set_LHCbConfig2_AngObs_wo68.in` [81], `set_CMS_AngObs_wo68.in` [81], and `set_CMS_LHCbConfig2_AngObs_wo_68.in` [81]. For the fit to the S_i observables, we replace the $P_i^{(\gamma)}$ observables of config. 2 (192–263 in Table XVI) with the corresponding S_i observables of config. 1 (`set_LHCbConfig1_AngObs_wo68.in` [81]).

For the hadronic fits presented in Sec. IV, we employ the observables listed in `set_HadronicFit_below6.in` [81] and `set_HadronicFit_below8.in` [81].

TABLE XIV. Observables used in the global fit.

No.	Observable	Ref.
1	AI_BKstargamma	[82]
2	BR_BXsgamma	[82]
3	BRntag_Bsmumu	[83]
4	BRntag_Bsee	[84]
5	BR_BXsmumu_1_6	[85]
6	BR_BXsmumu_14.2_22	[85]
7	BR_BXsee_1_6	[85]
8	BR_BXsee_14.2_22	[85]
9	BR_B0Kstar0gamma	[83]
10	BR_BKstargamma	[83]
11	dGamma/dq2_BKstarmumu_1.1_6	[3]
12	dGamma/dq2_BKstarmumu_15_19	[3]
13	R-1_B0Kstar0ll_0.1_1.1	[1]
14	R-1_B0Kstar0ll_1.1_6	[1]
15	R-1_B0Kstar0ll_0.045_1.1_Belle	[86]
16	R-1_B0Kstar0ll_1.1_6_Belle	[86]
17	R-1_B0Kstar0ll_15_19_Belle	[86]
18	dGamma/dq2_B0K0mumu_1.1_6	[3]
19	dGamma/dq2_B0K0mumu_15_22	[3]
20	dGamma/dq2_BKmmumu_1.1_6	[3]
21	FH_BKmmumu_1.1_6	[87]
22	dGamma/dq2_BKmmumu_15_22	[3]
23	FH_BKmmumu_15_22	[87]
24	R-1_BK1l_0.1_1.1	[3]
25	R-1_BK1l_1.1_6	[3]
26	dGamma/dq2_Bsphimumu_0.1_0.98	[10]
27	FL_Bsphimumu_0.1_0.98	[9]
28	S3_Bsphimumu_0.1_0.98	[9]
29	S4_Bsphimumu_0.1_0.98	[9]
30	S7_Bsphimumu_0.1_0.98	[9]
31	dGamma/dq2_Bsphimumu_1.1_2.5	[10]
32	dGamma/dq2_Bsphimumu_2.5_4	[10]
33	FL_Bsphimumu_1.1_4	[9]
34	S3_Bsphimumu_1.1_4	[9]
35	S4_Bsphimumu_1.1_4	[9]

(Table continued)

TABLE XIV. (Continued)

No.	Observable	Ref.
36	S7_Bsphimumu_1.1_4	[9]
37	dGamma/dq2_Bsphimumu_4_6	[10]
38	FL_Bsphimumu_4_6	[9]
39	S3_Bsphimumu_4_6	[9]
40	S4_Bsphimumu_4_6	[9]
41	S7_Bsphimumu_4_6	[9]
42	dGamma/dq2_Bsphimumu_6_8	[10]
43	FL_Bsphimumu_6_8	[9]
44	S3_Bsphimumu_6_8	[9]
45	S4_Bsphimumu_6_8	[9]
46	S7_Bsphimumu_6_8	[9]
47	dGamma/dq2_Bsphimumu_15_19	[10]
48	FL_Bsphimumu_15_18.9	[9]
49	S3_Bsphimumu_15_18.9	[9]
50	S4_Bsphimumu_15_18.9	[9]
51	S7_Bsphimumu_15_18.9	[9]
52	dGamma/dq2_LambdabLambdamumu_15_20	[4]
53	ALFB_LambdabLambdamumu_15_20	[88]
54	AhFB_LambdabLambdamumu_15_20	[88]
55	AlhFB_LambdabLambdamumu_15_20	[88]
56	FL_LambdabLambdamumu_15_20	[4]
57	FL_BKstarmumu_0.1_0.98	[7]
58	AFB_BKstarmumu_0.1_0.98	[7]
59	S3_BKstarmumu_0.1_0.98	[7]
60	S4_BKstarmumu_0.1_0.98	[7]
61	S5_BKstarmumu_0.1_0.98	[7]
62	S7_BKstarmumu_0.1_0.98	[7]
63	S8_BKstarmumu_0.1_0.98	[7]
64	S9_BKstarmumu_0.1_0.98	[7]
65	FL_BKstarmumu_1.1_2.5	[7]
66	AFB_BKstarmumu_1.1_2.5	[7]
67	S3_BKstarmumu_1.1_2.5	[7]
68	S4_BKstarmumu_1.1_2.5	[7]
69	S5_BKstarmumu_1.1_2.5	[7]
70	S7_BKstarmumu_1.1_2.5	[7]

TABLE XV. Continued from Table XIV.

No.	Observable	Ref.
71	S8_BKstarmumu_1.1_2.5	[7]
72	S9_BKstarmumu_1.1_2.5	[7]
73	FL_BKstarmumu_2.5_4	[7]
74	AFB_BKstarmumu_2.5_4	[7]
75	S3_BKstarmumu_2.5_4	[7]
76	S4_BKstarmumu_2.5_4	[7]
77	S5_BKstarmumu_2.5_4	[7]
78	S7_BKstarmumu_2.5_4	[7]
79	S8_BKstarmumu_2.5_4	[7]
80	S9_BKstarmumu_2.5_4	[7]
81	FL_BKstarmumu_4_6	[7]
82	AFB_BKstarmumu_4_6	[7]
83	S3_BKstarmumu_4_6	[7]
84	S4_BKstarmumu_4_6	[7]
85	S5_BKstarmumu_4_6	[7]
86	S7_BKstarmumu_4_6	[7]
87	S8_BKstarmumu_4_6	[7]
88	S9_BKstarmumu_4_6	[7]
89	FL_BKstarmumu_6_8	[7]
90	AFB_BKstarmumu_6_8	[7]
91	S3_BKstarmumu_6_8	[7]
92	S4_BKstarmumu_6_8	[7]
93	S5_BKstarmumu_6_8	[7]
94	S7_BKstarmumu_6_8	[7]
95	S8_BKstarmumu_6_8	[7]
96	S9_BKstarmumu_6_8	[7]
97	FL_BKstarmumu_15_17	[7]
98	AFB_BKstarmumu_15_17	[7]
99	S3_BKstarmumu_15_17	[7]
100	S4_BKstarmumu_15_17	[7]
101	S5_BKstarmumu_15_17	[7]
102	S7_BKstarmumu_15_17	[7]
103	S8_BKstarmumu_15_17	[7]
104	S9_BKstarmumu_15_17	[7]
105	FL_BKstarmumu_17_19	[7]
106	AFB_BKstarmumu_17_19	[7]
107	S3_BKstarmumu_17_19	[7]
108	S4_BKstarmumu_17_19	[7]
109	S5_BKstarmumu_17_19	[7]
110	S7_BKstarmumu_17_19	[7]
111	S8_BKstarmumu_17_19	[7]
112	S9_BKstarmumu_17_19	[7]
113	R-1_BKstar11_0.045_6	[89]
114	R-1_BOK011_1.1_6	[89]
115	R-1_BK11_1_6_Belle	[90]
116	FH_BKmumu_1_6_CMS	[91]
117	dGamma/dq2_BOKstar0ee_0.0009_1	[92]
118	FL_BOKstar0ee_0.0008_0.257	[93]
119	ATRe_BOKstar0ee_0.0008_0.257	[93]
120	AT2_BOKstar0ee_0.0008_0.257	[93]
121	dGamma/dq2_BKmumu_0.1_0.98_CMS	[94]
122	dGamma/dq2_BKmumu_1.1_2_CMS	[94]
123	dGamma/dq2_BKmumu_2_3_CMS	[94]
124	dGamma/dq2_BKmumu_3_4_CMS	[94]
125	dGamma/dq2_BKmumu_4_5_CMS	[94]

(Table continued)

TABLE XV. (Continued)

No.	Observable	Ref.
126	dGamma/dq2_BKmumu_5_6_CMS	[94]
127	dGamma/dq2_BKmumu_6_7_CMS	[94]
128	dGamma/dq2_BKmumu_7_8_CMS	[94]
129	dGamma/dq2_BKmumu_14.82_16_CMS	[94]
130	dGamma/dq2_BKmumu_16_17_CMS	[94]
131	dGamma/dq2_BKmumu_17_18_CMS	[94]
132	dGamma/dq2_BKmumu_18_19.24_CMS	[94]
133	dGamma/dq2_BKmumu_19.24_22.9_CMS	[94]
134	R-1_BK11_1.1_6_CMS	[94]
135	FL_BOKstar0mumu_1.1_2_CMS	[11]
136	P1_BOKstar0mumu_1.1_2_CMS	[11]
137	P2_BOKstar0mumu_1.1_2_CMS	[11]
138	P3_BOKstar0mumu_1.1_2_CMS	[11]
139	P4prime_BOKstar0mumu_1.1_2_CMS	[11]
140	P5prime_BOKstar0mumu_1.1_2_CMS	[11]
141	P6prime_BOKstar0mumu_1.1_2_CMS	[11]
142	P8prime_BOKstar0mumu_1.1_2_CMS	[11]
143	FL_BOKstar0mumu_2_4.3_CMS	[11]
144	P1_BOKstar0mumu_2_4.3_CMS	[11]
145	P2_BOKstar0mumu_2_4.3_CMS	[11]
146	P3_BOKstar0mumu_2_4.3_CMS	[11]
147	P4prime_BOKstar0mumu_2_4.3_CMS	[11]
148	P5prime_BOKstar0mumu_2_4.3_CMS	[11]
149	P6prime_BOKstar0mumu_2_4.3_CMS	[11]
150	P8prime_BOKstar0mumu_2_4.3_CMS	[11]
151	FL_BOKstar0mumu_4.3_6_CMS	[11]
152	P1_BOKstar0mumu_4.3_6_CMS	[11]
153	P2_BOKstar0mumu_4.3_6_CMS	[11]
154	P3_BOKstar0mumu_4.3_6_CMS	[11]
155	P4prime_BOKstar0mumu_4.3_6_CMS	[11]
156	P5prime_BOKstar0mumu_4.3_6_CMS	[11]
157	P6prime_BOKstar0mumu_4.3_6_CMS	[11]
158	P8prime_BOKstar0mumu_4.3_6_CMS	[11]
159	FL_BOKstar0mumu_6_8.68_CMS	[11]
160	P1_BOKstar0mumu_6_8.68_CMS	[11]
161	P2_BOKstar0mumu_6_8.68_CMS	[11]
162	P3_BOKstar0mumu_6_8.68_CMS	[11]
163	P4prime_BOKstar0mumu_6_8.68_CMS	[11]
164	P5prime_BOKstar0mumu_6_8.68_CMS	[11]
165	P6prime_BOKstar0mumu_6_8.68_CMS	[11]
166	P8prime_BOKstar0mumu_6_8.68_CMS	[11]
167	FL_BOKstar0mumu_14.18_16_CMS	[11]
168	P1_BOKstar0mumu_14.18_16_CMS	[11]
169	P2_BOKstar0mumu_14.18_16_CMS	[11]
170	P3_BOKstar0mumu_14.18_16_CMS	[11]
171	P4prime_BOKstar0mumu_14.18_16_CMS	[11]
172	P5prime_BOKstar0mumu_14.18_16_CMS	[11]
173	P6prime_BOKstar0mumu_14.18_16_CMS	[11]
174	P8prime_BOKstar0mumu_14.18_16_CMS	[11]
175	dGamma/dq2_Bsphiee_0.1_1.1	[95]
176	dGamma/dq2_Bsphiee_1.1_6	[95]
177	dGamma/dq2_Bsphiee_15_19	[95]
178	R-1_Bsphil1_0.1_1.1	[95]
179	R-1_Bsphil1_1.1_6	[95]
180	R-1_Bsphil1_15_19	[95]

TABLE XVI. Continued from Table XV.

No.	Observable	Ref.
181	FL_Bsphiee_0.0009_0.2615	[96]
182	AT2_Bsphiee_0.0009_0.2615	[96]
183	AT2_B0Kstar0ee_0.0008_1.12_Belle	[97]
184	FL_B0Kstar0ee_1.1_6	[98]
185	P1_B0Kstar0ee_1.1_6	[98]
186	P2_B0Kstar0ee_1.1_6	[98]
187	P3_B0Kstar0ee_1.1_6	[98]
188	P4prime_B0Kstar0ee_1.1_6	[98]
189	P5prime_B0Kstar0ee_1.1_6	[98]
190	P6prime_B0Kstar0ee_1.1_6	[98]
191	P8prime_B0Kstar0ee_1.1_6	[98]
192	FL_B0Kstar0mumu_0.06_0.98	[12]
193	S2s_B0Kstar0mumu_0.06_0.98	[12]
194	S1c_B0Kstar0mumu_0.06_0.98	[12]
195	P1_B0Kstar0mumu_0.06_0.98	[12]
196	P2_B0Kstar0mumu_0.06_0.98	[12]
197	P3_B0Kstar0mumu_0.06_0.98	[12]
198	P4prime_B0Kstar0mumu_0.06_0.98	[12]
199	P5prime_B0Kstar0mumu_0.06_0.98	[12]
200	P6prime_B0Kstar0mumu_0.06_0.98	[12]
201	P8prime_B0Kstar0mumu_0.06_0.98	[12]
202	S6c_B0Kstar0mumu_0.06_0.98	[12]
203	dGamma/dq2_B0Kstar0mumu_0.06_0.98	[12]
204	FL_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
205	S1c_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
206	P1_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
207	P2_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
208	P3_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
209	P4prime_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
210	P5prime_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
211	P6prime_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
212	P8prime_B0Kstar0mumu_1.1_2.5_LHCb2025c2	[12]
213	dGamma/dq2_B0Kstar0mumu_1.1_2.5	[12]
214	FL_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
215	S1c_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
216	P1_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
217	P2_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
218	P3_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
219	P4prime_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
220	P5prime_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
221	P6prime_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
222	P8prime_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
223	dGamma/dq2_B0Kstar0mumu_2.5_4.0_LHCb2025c2	[12]
224	FL_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
225	S1c_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
226	P1_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
227	P2_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
228	P3_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
229	P4prime_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
230	P5prime_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
231	P6prime_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
232	P8prime_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
233	dGamma/dq2_B0Kstar0mumu_4.0_6.0_LHCb2025c2	[12]
234	FL_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
235	S1c_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
236	P1_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]

(Table continued)

TABLE XVI. (Continued)

No.	Observable	Ref.
237	P2_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
238	P3_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
239	P4prime_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
240	P5prime_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
241	P6prime_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
242	P8prime_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
243	dGamma/dq2_B0Kstar0mumu_6.0_8.0_LHCb2025c2	[12]
244	FL_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
245	S1c_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
246	P1_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
247	P2_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
248	P3_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
249	P4prime_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
250	P5prime_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
251	P6prime_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
252	P8prime_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
253	dGamma/dq2_B0Kstar0mumu_15.0_17.0_LHCb2025c2	[12]
254	FL_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
255	S1c_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
256	P1_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
257	P2_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
258	P3_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
259	P4prime_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
260	P5prime_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
261	P6prime_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
262	P8prime_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]
263	dGamma/dq2_B0Kstar0mumu_17.0_19.0_LHCb2025c2	[12]

APPENDIX B: IMPACT OF THE CHOICE OF FORM FACTORS ON TENSIONS

1. $BR(B \rightarrow K\mu^+\mu^-)$ with different form factors

In Fig. 8, we illustrate the impact of different form factor choices on the standard model prediction for the branching ratio of $B \rightarrow K\mu^+\mu^-$. We compare the results obtained using four different sets of form factors.

Using the weighted average of the LHCb [87] and CMS [94] measurements in the $[1.1, 6.0]$ GeV^2 bin only, we find that the level of tension with the SM prediction varies significantly depending on the form factor input—ranging from 1.7σ to more than 4σ —as noted in the list below and as illustrated in Fig. 8:

- (i) *GKvD18*: the combined LCSR (based on B -meson distribution amplitudes) and lattice QCD result from Ref. [64], using lattice input from Ref. [74] (1.7σ).
- (ii) *GRvDV23*: the combined fit of Ref. [61], based on LCSR calculations from Ref. [64] and lattice QCD results from Refs. [74,99,100] (4.1σ).
- (iii) *HPQCD22*: the lattice QCD result from Ref. [100], valid across the entire physical q^2 range (3.6σ).
- (iv) *KR17*: the results of Ref. [101] calculated via LCSR with kaon distribution amplitude, applicable only for the low- q^2 region (3.4σ).

This comparison highlights the sensitivity of the branching ratio prediction to the choice of hadronic form factors.

We emphasize again that we consider here one single bin in this comparison. The differences would be larger if all observables were taken into account. We also note that the results of Ref. [100], denoted HPQCD22 in the list above, were also used in Ref. [61] in the low- q^2 region. One can

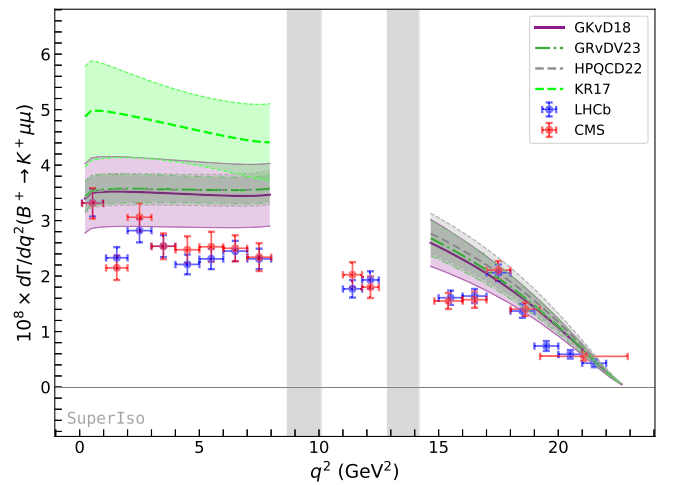


FIG. 8. Theoretical prediction for $BR(B^+ \rightarrow K^+\mu^+\mu^-)$ with different choices of $B \rightarrow K$ form factors. Notice that the dash-dotted dark green line indicating GRvDV23 almost coincides with the dashed gray line, which corresponds to HPQCD22. The experimental results are from the LHCb [87] and CMS [94].

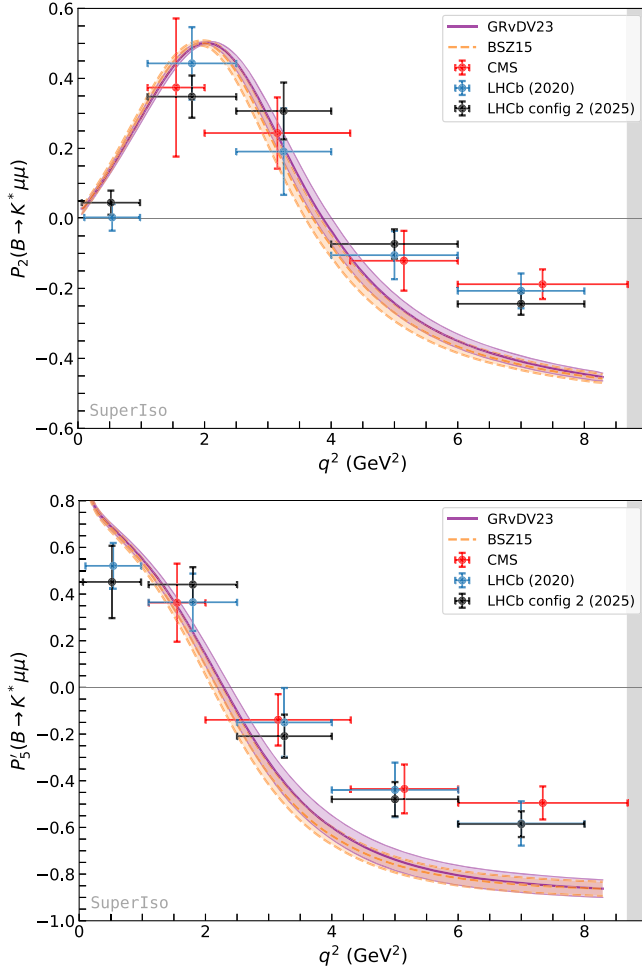


FIG. 9. Theoretical prediction for $P_2, P_5'(B^0 \rightarrow K^{*0}\mu^+\mu^-)$ with two different choices of $B \rightarrow K^*$ form factors. The experimental results are from LHCb [7] and CMS [11]. The data points correspond to the CMS measurement [11] and the LHCb results from 2020 [7] and 2025 [12].

see in Fig. 8 that this lattice result dominates the result of Ref. [61], denoted GRvDV23 in the low- q^2 region.

2. $P_2, P_5'(B \rightarrow K^*\mu^+\mu^-)$ with different form factors

In this section, we compare the P_2 and P_5' observables of the $B \rightarrow K^*\mu^+\mu^-$ decay using two different sets of $B \rightarrow K^*$ form factors: BSZ15 and GRvDV23, as introduced in Sec. II¹. We focus on the penultimate low- q^2 bin—[4, 6] GeV^2 for LHCb and [4.3, 6] GeV^2 for CMS—and report the local tensions between the SM

¹In reproducing the $B \rightarrow K^*$ form factors from Ref. [64], we find that the ancillary file provided for the LCSR+ lattice results (BKstar_LCSR-Lattice.json) does not reproduce the uncertainties shown in Fig. 6 of the paper. Specifically, the uncertainties at high q^2 are significantly larger, suggesting either an inconsistency in the ancillary files or that the figure was generated using inputs not reflected in the provided data.

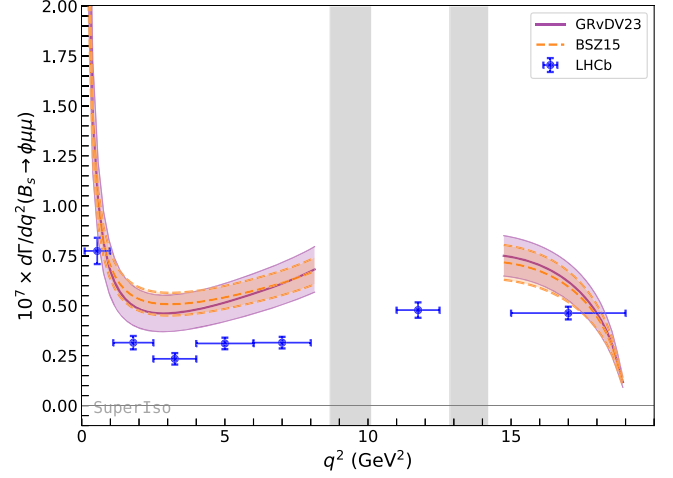


FIG. 10. Theoretical prediction for $\text{BR}(B_s \rightarrow \phi\mu^+\mu^-)$ with two different choices of $B_s \rightarrow \phi$ form factors. The experimental result is from the LHCb [10].

predictions and experimental measurements (CMS [11] and LHCb 2020 [7] and 2025 [12]) for each form factor choice. For the P_5' observable we find:

- (i) *BSZ15*: 3.4σ for LHCb 2025, 2.6σ for LHCb 2020, and 3.0σ for CMS.
- (ii) *GRvDV23*: 2.9σ for LHCb 2025, 2.3σ for LHCb 2020, and 2.7σ for CMS.

In the same bins, for the P_2 observable, we have:

- (i) *BSZ15*: 4.0σ for LHCb 2025, 2.2σ for LHCb 2020, and 1.9σ for CMS.
- (ii) *GRvDV23*: 3.3σ for LHCb 2025, 1.8σ for LHCb 2020, and 1.6σ for CMS.

The results are also shown in Fig. 9. This comparison demonstrates the sensitivity of the $B \rightarrow K^*\mu^+\mu^-$ observables to the choice of hadronic form factors, with the BSZ15 resulting in larger tensions between theoretical prediction and measurement compared to when employing the GRvDV23 form factors. The cumulative impact of these two different choices of form factors on the $B \rightarrow K^*\mu^+\mu^-$ observables can be seen in the new physics fit of Fig. 4. Note that each individual $P_i^{(\prime)}$ observable is constructed in such a way that its sensitivity to the local (soft) form factors is minimized.

3. $\text{BR}(B_s \rightarrow \phi\mu^+\mu^-)$ with different form factors

In Fig. 10, we show the $\text{BR}(B_s \rightarrow \phi\mu^+\mu^-)$ using two different sets of $B_s \rightarrow \phi$ form factors: BSZ15 and GRvDV23, as described in Sec. III, with the latter being the default set used in the global fit. Considering the LHCb measurement [10] for the [1.1, 6.0] GeV^2 bin, we find the following tensions with the SM prediction for the two different form factor choices:

- (i) *BSZ15*: 4.1σ .
- (ii) *GRvDV23*: 2.2σ .

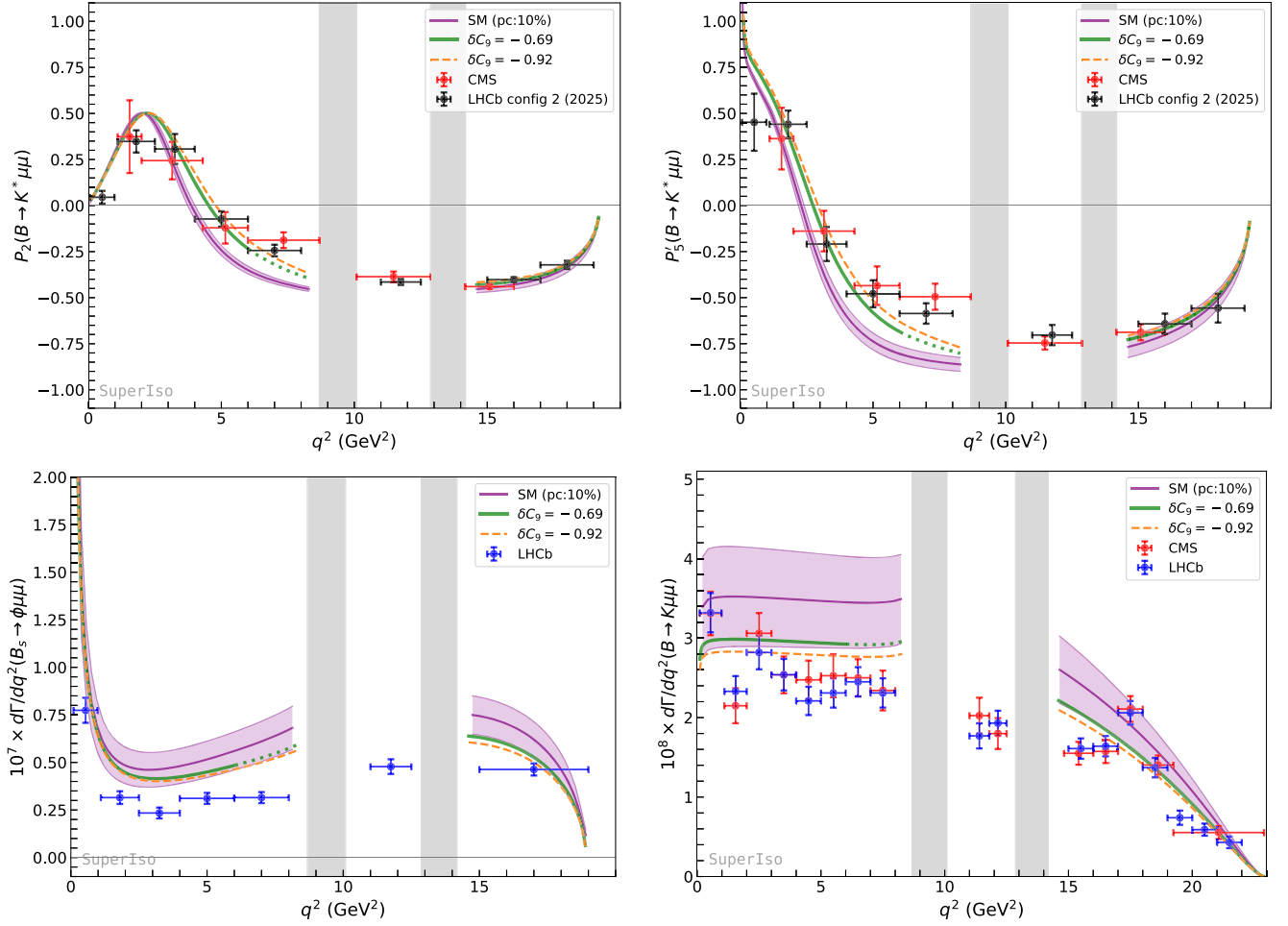


FIG. 11. Impact of $\delta C_9 = -0.69$ (green solid) and $\delta C_9 = -0.92$ (brown dashed), corresponding to the best-fit points from the top and bottom panels of Table II, respectively. The dotted green line represents the prediction of the fit with $\delta C_9 = -0.69$ in the $[6, 8.68]$ GeV^2 region, which was not included in that particular fit.

APPENDIX C: δC_9 EFFECTS ON KEY OBSERVABLES

In this section, in Fig. 11 we illustrate the effect of new physics in δC_9 on several $b \rightarrow s \ell \ell$ observables that exhibit the most pronounced tensions between SM predictions and experimental measurements.

APPENDIX D: HADRONIC FIT AT THE OBSERVABLE LEVEL

In this section, we illustrate the impact of the hadronic fit—described in Sec. IV B and summarized in Table VIII—at the level of physical observables.

Figure 12 displays the predictions for the observables BR , P_2 , and P'_5 . The left panels correspond to fits performed up to 6 GeV^2 , while the right panels show fits extended up to 8.68 GeV^2 .

A comparison between the left and right plots highlights the effect of including the largest low- q^2 bins in the fit. This demonstrates how the inclusion of additional data points influences the hadronic fit in the low- q^2 region, leading to a reduction in uncertainties. Note that in the left panels, the fits are extrapolated beyond 6 GeV^2 , as indicated by the dotted lines.

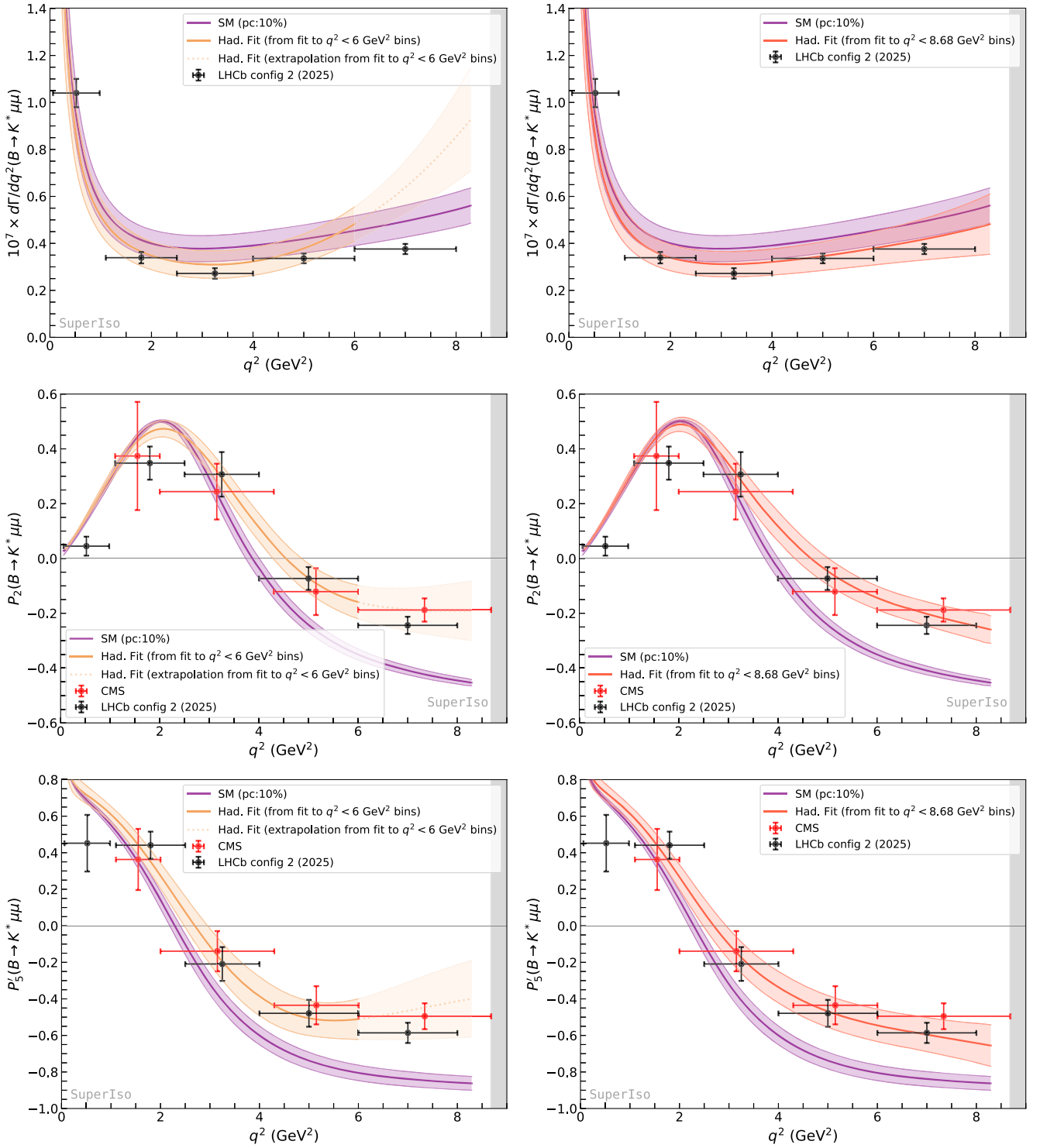


FIG. 12. Theoretical predictions of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ observables BR, P_2 , and P'_5 for our SM prediction (assuming 10% power corrections) as well as when considering the hadronic fit. On the left (right) the hadronic fit to $B \rightarrow K^* \gamma / \ell \ell$ observables with $q^2 \leq 6(8.68)$ GeV² bins has been considered as given in the top (bottom) panel of Table VIII. In the left panels, the hadronic fits are extrapolated beyond the fitted range (6 GeV²), with the extrapolated region marked by dotted lines.

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