Model independent analysis of the angular observables in $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^{*+}\mu^+\mu^-$ [*]

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We analyze the results recently presented on the $B^+ \to K^{*+}\mu^+\mu^-$ angular observables by the LHCb Collaboration, which show indications for new physics beyond the Standard Model. Within a model-independent analysis, we compare the fit results with the corresponding results for the angular observables in $B^0 \to K^{*0}\mu^+\mu^-$.

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Following the latest update of the angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ [1] in March 2020, the LHCb collaboration has very recently presented a new angular analysis in the $B^+ \to K^{*+}\mu^+\mu^-$ decay [2]. In particular, for the first time, the observable P_5' is measured outside the B^0 meson system. Both analyses show some tensions with the Standard Model (SM) predictions. It is very suggestive to compare the tensions in these two modes using model-independent methods in order to check their consistency.

In Table I, we compare one-operator fits using the two sets of angular observables. As in our previous analyses, we assume 10% uncertainty for the power corrections (see Refs. [3,4] for more details). Clearly, the SM pull in the B^0 mode is significantly larger due to much smaller experimental errors, which are, on average, about a factor of 5 smaller than in the B^+ mode.

The second major difference is that the best fit values differ in all cases, preferring larger new physics (NP) contributions in the B^+ mode. For δC_7 and δC_{10}^μ, one must keep in mind that the constraints of $\bar{B} \to X_s\gamma$ and $B_{s,d} \to \mu^+\mu^-$ are not taken into account in the $B^{+,0} \to K^{*+,0}\mu^+\mu^-$-specific fits of Tables I–III, but, of course, they are considered in the global fits of Tables IV and V. In the case of δC_{10}^μ, negative values are preferred, while we know that the ratios $R_{K^{(*)}}$, indicating flavor nonuniversality, ask for positive NP contributions. For the δC_9^μ case, we find in the recent B^+ mode a best fit value, which is larger by a factor of 2 as compared to the one in the B^0 mode.

However, regarding NP significance, the hierarchy among the various one-parameter fits is the same in both modes. It is again the coefficient C_9^μ that is favored by both sets of data. This consistency is also manifested when we fit for the chiral Wilson coefficients, given in Table II. Thus, at the level of the one-operator fits, the two sets guide us to the same NP patterns.

In Table III, we directly compare the NP significance that we obtain for C_9^μ with the NP significance LHCb quotes in their analysis of the B^0 mode. The drastic difference, 5.4σ versus 3.3σ, reflects the fact that LHCb uses the Flavio package [5], while in the present analysis, SuperIso [6] is used. SuperIso and Flavio use the same set of form factors and similar input parameters, but there are differences in the parameterization of the power corrections. In SuperIso, we consider 10% on top of the leading order nonlocal effects (known from QCDf calculations), motivated by the fact that it is only higher powers of these contributions that are to be accounted for, while in Flavio, the additional power correction uncertainty is considered on both factorizable and nonfactorizable pieces (multiplied by $C_7^{\rm eff}$ or $C_9^{\rm eff}$), which inflates the errors artificially.[1]

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[1] In SuperIso, the error estimation for the power corrections is implemented (as described in Ref. [4] within the full form factor approach) by multiplying the hadronic terms which remain after putting $C_{7,9,10}$ to zero by the q^2-dependent factor $(1 + b_i e^{\theta_i} + c_i(q^2/6\ \mathrm{GeV}^2)e^{\phi_i})$. In Flavio, $C_7^{\rm eff}$ (or $C_9^{\rm eff}$) is multiplied by a similar q^2-dependent factor (see Refs. [7,8]).

TABLE I. One-operator fits to only $B^0 \to K^{*0}\mu^+\mu^-$ observables in the upper table and to only $B^+ \to K^{*+}\mu^+\mu^-$ observables in the lower table, considering 10% power corrections for both cases.

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables ($\chi^2_{\rm SM} = 81.86$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_7	-0.11 ± 0.02	61.4	4.5σ
δC_9^μ	-1.03 ± 0.15	52.8	5.4σ
δC_{10}^μ	-1.20 ± 0.50	75.0	2.6σ

$B^+ \to K^{*+}\mu^+\mu^-$ angular observables ($\chi^2_{\rm SM} = 58.52$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_7	-0.27 ± 0.09	49.4	3.0σ
δC_9^μ	-2.06 ± 0.34	43.3	3.9σ
δC_{10}^μ	-4.70 ± 2.10	51.4	2.7σ

TABLE II. One-operator fits in the chiral basis using only $B^0 \to K^{*0}\mu^+\mu^-$ observables in the upper table and only $B^+ \to K^{*+}\mu^+\mu^-$ observables in the lower table, considering 10% power corrections for both cases.

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables ($\chi^2_{\rm SM} = 81.86$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
$\delta C^\mu_{\rm LL}$ ($\delta C_9^\mu = -\delta C_{10}^\mu$)	-0.93 ± 0.17	63.8	4.3σ
$\delta C^\mu_{\rm LR}$ ($\delta C_9^\mu = +\delta C_{10}^\mu$)	-0.76 ± 0.13	56.3	5.1σ
$\delta C^\mu_{\rm RL}$ ($\delta C_9^{\mu\prime} = -\delta C_{10}^{\mu\prime}$)	-0.35 ± 0.16	77.1	2.2σ
$\delta C^\mu_{\rm RR}$ ($\delta C_9^{\mu\prime} = +\delta C_{10}^{\mu\prime}$)	0.51 ± 0.26	77.8	2.0σ

$B^+ \to K^{*+}\mu^+\mu^-$ angular observables ($\chi^2_{\rm SM} = 58.52$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
$\delta C^\mu_{\rm LL}$ ($\delta C_9^\mu = -\delta C_{10}^\mu$)	-1.80 ± 0.40	51.0	2.8σ
$\delta C^\mu_{\rm LR}$ ($\delta C_9^\mu = +\delta C_{10}^\mu$)	-1.70 ± 0.40	43.6	3.9σ
$\delta C^\mu_{\rm RL}$ ($\delta C_9^{\mu\prime} = -\delta C_{10}^{\mu\prime}$)	-1.40 ± 0.50	48.1	3.2σ
$\delta C^\mu_{\rm RR}$ ($\delta C_9^{\mu\prime} = +\delta C_{10}^{\mu\prime}$)	1.00 ± 0.80	56.9	1.3σ

Hence, even with similarly assumed percentages, the two parameterizations lead to the different NP significances. The different assumptions about the power corrections have no impact in the B^+ mode because the large experimental uncertainties dominate in this mode. Furthermore, in view of the recent theoretical analyses [9–11], the assumptions on power corrections in SuperIso seem to be more realistic.

In the global fit to all relevant $b \to s$ observables, including the recent B^+ mode, the hierarchy of the favored one-dimensional NP scenarios has remained the same with δC_9^μ as the most favored scenario. In Table IV, we present the full one-operator fit results using the complete set of $b \to s$ observables described in Ref. [12] and the new $B^+ \to K^{*+}\mu^+\mu^-$ angular observables.

TABLE III. One-dimensional fit to C_9^μ by SuperIso and LHCb, considering the angular observables of either the $B^0 \to K^{*0}\mu^+\mu^-$ decay or the $B^+ \to K^{*+}\mu^+\mu^-$ decay (the best fit value for the B^0 mode when excluding the $[6,8]$ GeV^2 bin and the error on the best fit value for the B^+ mode was not given by LHCb).

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables				
	Excluding $[6,8]$ GeV^2 bin		Including $[6,8]$ GeV^2 bin	
δC_9^μ	best fit value	$\mathrm{Pull}_{\rm SM}$	best fit value	$\mathrm{Pull}_{\rm SM}$
SuperIso	-0.86 ± 0.19	3.8σ	-1.05 ± 0.15	5.4σ
LHCb	$\cdots$	2.7σ	-0.99 ± 0.25	3.3σ

$B^+ \to K^{*+}\mu^+\mu^-$ angular observables		
	Excluding $[6,8]$ GeV^2 bin	
δC_9^μ	best fit value	$\mathrm{Pull}_{\rm SM}$
SuperIso	-1.80 ± 0.40	2.9σ
LHCb	-1.90	3.1σ

TABLE IV. One-operator fits to all observables, assuming 10% error for the power corrections.

All observables ($\chi^2_{\rm SM} = 215.1$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_7	-0.03 ± 0.01	207.3	2.8σ
δC_9	-1.01 ± 0.13	177.4	6.1σ
δC_9^e	0.84 ± 0.26	203.4	3.4σ
δC_9^μ	-0.99 ± 0.12	165.9	7.0σ
δC_{10}	0.16 ± 0.21	214.5	0.8σ
δC_{10}^e	-0.79 ± 0.23	202.1	3.6σ
δC_{10}^μ	0.50 ± 0.17	205.1	3.2σ

All observables ($\chi^2_{\rm SM} = 215.1$)			
	best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
$\delta C^e_{\rm LL}$ ($\delta C_9^e = -\delta C_{10}^e$)	0.43 ± 0.14	202.7	3.5σ
$\delta C^\mu_{\rm LL}$ ($\delta C_9^\mu = -\delta C_{10}^\mu$)	-0.55 ± 0.10	180.7	5.9σ
$\delta C^e_{\rm LR}$ ($\delta C_9^e = +\delta C_{10}^e$)	-1.64 ± 0.29	201.1	3.7σ
$\delta C^\mu_{\rm LR}$ ($\delta C_9^\mu = +\delta C_{10}^\mu$)	-0.43 ± 0.11	203.5	3.4σ
$\delta C^e_{\rm RL}$ ($\delta C_9^{e\prime} = -\delta C_{10}^{e\prime}$)	0.07 ± 0.11	214.7	0.6σ
$\delta C^\mu_{\rm RL}$ ($\delta C_9^{\mu\prime} = -\delta C_{10}^{\mu\prime}$)	-0.08 ± 0.07	213.8	1.1σ
$\delta C^e_{\rm RR}$ ($\delta C_9^{e\prime} = +\delta C_{10}^{e\prime}$)	1.81 ± 0.30	202.0	3.6σ
$\delta C^\mu_{\rm RR}$ ($\delta C_9^{\mu\prime} = +\delta C_{10}^{\mu\prime}$)	0.14 ± 0.14	214.2	0.9σ

It is more reasonable to assume that a UV complete NP model affects several Wilson coefficients at the same time. Therefore, we consider the NP significance of a multidimensional fit using the full set of 20 Wilson coefficients. The results are given in Table V. In Ref. [12], we found that the update of the B^0 dataset changed the global fit significantly (by 0.8σ) compared to the previous global fits (see Table 8 in Ref. [3]). Surprisingly, this is also true when including the B^+ data. Adding the new data on the B^+ mode

TABLE V. Best fit values for the 20 operator fits to all observables, assuming 10% error for the power corrections. In the upper (lower) table, we have the results excluding (including $B^+ \to K^{*+}\mu^+\mu^-$ observables).

All observables (excl. $B^+ \to K^{*+}\mu^+\mu^-$) with $\chi^2_{\rm SM} = 157.5$			
($\chi^2_{\rm min} = 100.4$; $\mathrm{Pull}_{\rm SM} = 4.3\sigma$)			
δC_7		δC_8	
0.05 ± 0.03		-0.70 ± 0.40	
$\delta C_7'$		$\delta C_8'$	
-0.01 ± 0.02		-0.10 ± 0.80	
δC_9^μ	δC_9^e	δC_{10}^μ	δC_{10}^e
-1.12 ± 0.19	-6.70 ± 0.90	0.12 ± 0.23	4.00 ± 1.70
$\delta C_9'^\mu$	$\delta C_9'^e$	$\delta C_{10}'^\mu$	$\delta C_{10}'^e$
0.13 ± 0.33	1.80 ± 1.10	-0.12 ± 0.21	0.00 ± 2.00
$C_{Q_1}^\mu$	$C_{Q_1}^e$	$C_{Q_2}^\mu$	$C_{Q_2}^e$
0.04 ± 0.16	-1.40 ± 1.40	-0.08 ± 0.18	-4.30 ± 0.70
$C_{Q_1}'^\mu$	$C_{Q_1}'^e$	$C_{Q_2}'^\mu$	$C_{Q_2}'^e$
0.16 ± 0.17	-1.30 ± 1.50	-0.14 ± 0.18	-4.20 ± 0.70

All observables with $\chi^2_{\rm SM} = 215.1$			
($\chi^2_{\rm min} = 151.3$; $\mathrm{Pull}_{\rm SM} = 4.8\sigma$)			
δC_7		δC_8	
0.06 ± 0.03		-0.80 ± 0.40	
$\delta C_7'$		$\delta C_8'$	
-0.01 ± 0.02		0.00 ± 0.80	
δC_9^μ	δC_9^e	δC_{10}^μ	δC_{10}^e
-1.20 ± 0.18	-6.70 ± 1.20	0.10 ± 0.23	4.00 ± 5.00
$\delta C_9'^\mu$	$\delta C_9'^e$	$\delta C_{10}'^\mu$	$\delta C_{10}'^e$
0.07 ± 0.33	1.80 ± 1.50	-0.12 ± 0.20	0.00 ± 5.00
$C_{Q_1}^\mu$	$C_{Q_1}^e$	$C_{Q_2}^\mu$	$C_{Q_2}^e$
0.07 ± 0.10	-1.40 ± 0.90	-0.06 ± 0.13	-4.20 ± 1.50
$C_{Q_1}'^\mu$	$C_{Q_1}'^e$	$C_{Q_2}'^\mu$	$C_{Q_2}'^e$
0.19 ± 0.10	-1.30 ± 1.90	-0.13 ± 0.14	-4.20 ± 0.90

to the global fit, we find an additional increase of the NP significance by 0.5σ in spite of the comparably larger experimental error. However, as shown above, the new data on the B^+ mode leads also to a best fit value for the favored NP Wilson coefficient δC_9^μ, which is different from the best fit value of the same coefficient in the global fit by a factor of 2.

In summary, the new data add another consistent piece to the NP interpretation of the various tensions in the $b \to s$ data. Also, the recent developments on the theoretical analyses of power corrections supports the new physics interpretation.

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Correction: The title was altered incorrectly during the review process and has been fixed.