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Lepton nonuniversality in exclusive $b \to s\ell\ell$ decays

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The LHCb measurements of certain ratios of decay modes testing lepton flavor nonuniversality might open an exciting world of new physics beyond the standard model. The latest LHCb measurements of R_{K^*} offer some new insight beyond the previous measurement of R_K. We work out the present significance for nonuniversality, and argue that claims of 5σ deviations from the standard model based on all present $b \to s\ell^+\ell^-$ data including the ratios are misleading and are at present still based on guesstimates of hadronic power corrections in the $b \to s\ell^+\ell^-$ angular observables. We demonstrate that only a small part of the luminosity of 50 fb^{-1} foreseen to be accumulated by the LHCb will be needed to offer soon a definite answer to the present question of whether we see a very small glimpse of lepton flavor nonuniversal new physics or not. We also present new predictions for other ratios based on our analysis of the present measurements of the ratios $R_{K^{(*)}}$ and analyze if they are able to differentiate between various new physics options within the effective field theory at present or in the near future.

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I. INTRODUCTION

The ratio $R_{K^*} \equiv \Gamma(B \to K^*\mu^+\mu^-)/\Gamma(B \to K^*e^+e^-)$ has been recently measured by the LHCb collaboration in two bins of the dilepton mass [1] reporting deviations of 2.2–2.4 and $2.4 - 2.5\sigma$ from the standard model (SM) respectively,

$$R_{K^*}([0.045, 1.1]\ \mathrm{GeV}^2) = 0.660^{+0.110}_{-0.070} \pm 0.024,$$
$$R_{K^*}([1.1, 6.0]\ \mathrm{GeV}^2) = 0.685^{+0.113}_{-0.069} \pm 0.047, \tag{1}$$

where the first errors are statistical and the second systematic. This measurement establishes another hint for lepton flavor nonuniversality besides the previously measured ratio $R_K \equiv \Gamma(B^+ \to K^+\mu^+\mu^-)/\Gamma(B^+ \to K^+e^+e^-)$ [2], which represents a 2.6σ deviation from the SM prediction

$$R_K([1, 6]\ \mathrm{GeV}^2) = 0.745^{+0.090}_{-0.074} \pm 0.036. \tag{2}$$

These observables are theoretically clean because hadronic uncertainties cancel out in the ratios [3]. One could think that electromagnetic corrections, in particular, logarithmically enhanced QED corrections, might play a role in these observables in a lepton nonuniversal way. However, these corrections of the form $\alpha\log^2(m_b/m_\ell)$ were calculated in the inclusive case and were shown to be rather well simulated by the PHOTOS Monte Carlo which is also used by the LHCb collaboration [4,5]. More recently, these corrections were directly estimated in the exclusive case [6] confirming this conclusion. Our SM predictions for these three observables based on SuperIso v3.7 [7,8] are the following:

$$R_{K^*}([0.045, 1.1]) = 0.906 \pm 0.022,$$
$$R_{K^*}([1.1, 6]) = 0.997 \pm 0.01,$$
$$R_K([1, 6]) = 1.000 \pm 0.01. \tag{3}$$

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We have taken over the analysis of QED corrections from Ref. [6]. The larger error in the very low bin is due to larger QED corrections, 2%, and due to the input parameters, 1%. The latter error is dominated by form factor uncertainties which do not fully cancel out.[1] Presently, the statistical errors of the experimental measurements are the dominating ones in all three observables.

We confirm the SM deviations claimed by the LHCb collaboration for each of the three measurements. We obtain 2.3σ (R_{K^*} low), 2.5σ (R_{K^*} central), and 2.6σ (R_K central), respectively. By combining the three measurements we arrive at a SM deviation of 3.6σ.

Beyond these theoretically clean flavor observables there are many other SM deviations in the present $b \to s\ell\ell$ data, in particular, in the angular observables of the $B \to K^*\mu\mu$ decays [13] and in the branching ratios of the $B_s \to \phi\mu\mu$ decay [14]. However, as emphasized in our previous analyses [15–19], all these observables are affected by unknown (nonfactorizable) power corrections which can only be guesstimated at present. In contrast to the claim in Ref. [9] this issue is *not* resolved but makes it rather difficult or even impossible to separate new physics (NP) effects from such potentially large hadronic power corrections within these exclusive angular observables and branching ratios. As a consequence, the significance of these deviations depends on the assumptions made within such a guesstimate of the unknown power corrections. This is of course also true if these observables are combined with the theoretically clean ratios R_K and R_{K^*} within a global analysis of all $b \to s\ell\ell$ data. In this sense, claims that such global analyses indicate a large deviation from the SM above the 5σ level are misleading as long as the precise assumptions made on the nonfactorizable power corrections are not clearly indicated. Hence a real estimate of the nonfactorizable power corrections is highly desirable to disentangle NP effects from hadronic uncertainties in the angular observables (see Sec. IV).

However, the present tensions in R_K on the one side and in the angular observables in $B \to K^*\mu\mu$ and branching ratios in $B_s \to \phi\mu\mu$ on the other side can be explained by a similar NP contribution C_9 to the semileptonic operator as was demonstrated in various global analyses (see for example [16,17,20,21]). We analyze this question including the measurements of R_{K^*} in the following. Such a coherent picture—if found—is an exciting and strong result which indicates that the NP interpretation is a valid option for the explanation of the tensions in the angular observables, but it should not be misinterpreted as a proof for the NP option at present. But such a feature also implies that a confirmation of the deviations in the ratios would indirectly confirm the NP interpretation of the anomalies in the angular observables in $B \to K^*\mu\mu$.

These findings suggest a separate analysis of the theoretically clean ratios R_K and R_{K^*} and similar ratios of this kind testing lepton universality, which we present in the following—based on our previous analyses in Refs. [16,17] (see Sec. II). Only in a second step, we compare our findings with a global fit to all the $b \to s\ell\ell$ data excluding the ratios (Sec. III).

Moreover, we analyze the prospects of the LHCb collaboration to give a definite answer to the question of whether the present deviations from the SM predictions represent a very small glimpse of lepton flavor nonuniversal new physics or not (Sec. V).

We see that the present deviations within the three ratios can be explained by NP contributions to six different Wilson coefficients. We analyze predictions of many other ratios which are sensitive to possible lepton flavor nonuniversal new physics in order to examine the possibility of distinguishing between the different new physics options (Sec. VI).

II. COMBINED ANALYSIS OF THE $R_K^{(*)}$ RATIOS

The tensions of the measurements of these three ratios with the SM predictions can be explained in a model-independent way by modified Wilson coefficients ($C_i = C_i^{\rm SM} + \delta C_i$), where δC_i can be due to some NP effects. First we consider the impact of NP in one Wilson coefficient at a time, where all other Wilson coefficients are kept to their SM values. Assuming such a scenario to be the correct description of the three ratios, the SM value for the Wilson coefficient C_i (corresponding to $\delta C_i = 0$) is in a specific tension with the best fit value ($\mathrm{Pull_{SM}}$). In Table I we give SM pulls of the various one-operator

[1] In our case the error due to the input parameters (dominantly due to form factors) is much smaller than the one quoted in Refs. [6,9]. We think in the case of Ref. [9] this is due to the difference that we use the full form factor calculation presented in Ref. [10] while the authors of Ref. [9] use the results [11,12] which are based on another LCSR method. This method has much larger uncertainties somehow by construction. We have further analyzed the dependence of the theory error of R_{K^*} in the very low bin on the form factor error. We tripled the error given in the LCSR calculation of Ref. [10] and found a 1.3% error due to the form factor (and other input parameters only) in the prediction of R_{K^*} in the low bin. In any case this feature will become relevant only in the future when the statistical error is reduced. We state that we use a Monte Carlo analysis where all the input parameters as well as the involved scales and form factors are varied randomly, taking into account all the correlations.

hypotheses.[2] We see that NP in C_9^e, C_9^μ, C_{10}^e, or C_{10}^μ are favored by the $R_{K^{(*)}}$ ratios with a significance of $3.6-4.0\sigma$. NP contributions in primed operators have no significant effect in a better description of the data. Among the chiral Wilson coefficients, we find four with a SM pull around $3.9-4.1\sigma$, namely C_{LL}^μ, C_{LL}^e, C_{LR}^e, and C_{RR}^e. The two latter ones, however, lead to a very large NP shift in the Wilson coefficient. We do not consider them in the following. Thus, there are six favored NP one-operator hypotheses to account for the deviations in the measured ratios $R_{K^{(*)}}$.

We present in addition fits based on some two-operator hypotheses (see Fig. 1 below). Our results are in agreement with the recent fit results presented in Refs. [9,23–27].

III. COMPARISON WITH THE GLOBAL FIT EXCLUDING R_K AND R_{K^*}

We redo the same exercise for all available $b\to s\ell\ell$ data without the three $R_K^{(*)}$ ratios (for a list of the used observables, see Appendix A of Ref. [17]). The SM pulls are given in Table II. We assume 10% nonfactorizable power corrections. The implementation of these corrections is done in the same way as in our previous analysis by multiplying the hadronic terms in the QCD factorization (QCDf) formula [28,29] which remain after putting the Wilson coefficients $C_{7,9,10}^{(\prime)}$ to 0 (see Sec. IIIB of Ref. [17]). Note that this part of the leading amplitude represents in many cases not more than one third of the complete leading QCDf amplitude, so in these cases the nonfactorizable power corrections represent a 3%–4% correction to the complete amplitude only.

Comparing the two cases, given in Tables I and II, one can make some interesting observations that among the one-operator hypotheses, the C_9^μ solutions are favored with SM pulls of 3.6 and 4.4σ in the two separate fits respectively but C_9^e is much less favored in the fit to all $b\to s\ell\ell$ observables without the ratios. The reason for this is that there is essentially only the branching ratio of the inclusive decay $B\to X_s e^+e^-$ in the electron sector within this new fit using all $b\to s\ell\ell$ observables except R_K and R_{K^*}, and it has a much smaller deviation from the SM than the large number of muonic channels. Primed operators have a very small SM pull in both cases; but more importantly the C_{10}-like solutions do not play a role in the global fit excluding the ratios in contrast to the $R_{K^{(*)}}$ analysis; also the chiral one-operator hypothesis C_{LL}^μ has less significance in comparison with the $R_{K^{(*)}}$ case. Thus, the NP analyses of the two sets of observables are less coherent than often stated. But if we consider two-operator NP hypotheses (see Fig. 1) (C_9^μ, C_9^e) and (C_{10}^μ, C_9^μ)

TABLE I. Best fit values in the one-operator fits (where only one Wilson coefficient is varied at a time) considering *only* the observables $R_{K^*[0.045,1.1]}$, $R_{K^*[1.1,6]}$, and $R_{K[1,6]}$. The δC_i in the fits are normalized to their SM values according to $\Delta C_i^{(\prime)}\equiv \delta C_i^{(\prime)}/C_i^{\rm SM}$ with $C_9^{\rm SM}=4.20$ and $C_{10}^{\rm SM}=-4.01$, and in the lower half of the table the normalization is always with $C_9^{\rm SM}$. When two numbers are mentioned for a given ΔC_i, they correspond to two possible minima.

	Best fit value	$\chi^2_{\rm min}$	Pull$_{\rm SM}$
ΔC_9	−0.48	18.3	0.3σ
$\Delta C_9'$	+0.78	18.1	0.6σ
ΔC_{10}	−1.02	18.2	0.5σ
$\Delta C_{10}'$	+1.18	17.9	0.7σ
ΔC_9^μ	−0.35	5.1	3.6σ
ΔC_9^e	+0.37	3.5	3.9σ
ΔC_{10}^μ	−1.66 −0.34	2.7	4.0σ
ΔC_{10}^e	−2.36 +0.35	2.2	4.0σ
$\Delta C_9^\mu=-\Delta C_{10}^\mu$ $(\Delta C_{\rm LL}^\mu)$	−0.16	3.4	3.9σ
$\Delta C_9^e=-\Delta C_{10}^e$ $(\Delta C_{\rm LL}^e)$	+0.19	2.8	4.0σ
$\Delta C_9^{\mu\prime}=-\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RL}^\mu)$	−0.01	18.3	0.4σ
$\Delta C_9^{e\prime}=-\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RL}^e)$	+0.01	18.3	0.4σ
$\Delta C_9^\mu=+\Delta C_{10}^\mu$ $(\Delta C_{\rm LR}^\mu)$	+0.09	17.5	1.0σ
$\Delta C_9^e=+\Delta C_{10}^e$ $(\Delta C_{\rm LR}^e)$	−0.55	1.4	4.1σ
$\Delta C_9^{\mu\prime}=+\Delta C_{10}^{\mu\prime}$ $(\Delta C_{\rm RR}^\mu)$	−0.01	18.4	0.2σ
$\Delta C_9^{e\prime}=+\Delta C_{10}^{e\prime}$ $(\Delta C_{\rm RR}^e)$	+0.61	2.0	4.1σ

[2]Regarding the notations, we recall that in Ref. [22] the semileptonic operators $\mathcal{O}_9^{(\prime)}$ and $\mathcal{O}_{10}^{(\prime)}$ within the electroweak Hamiltonian were singled out as the only operators which can explain the deviation in the ratio R_K,

$$\begin{aligned}\mathcal{O}_9^{(\prime)\ell}&=(\alpha_{\rm em}/4\pi)(\bar s\gamma_\mu P_{L(R)}b)(\bar\ell\gamma^\mu\ell),\\ \mathcal{O}_{10}^{(\prime)\ell}&=(\alpha_{\rm em}/4\pi)(\bar s\gamma_\mu P_{L(R)}b)(\bar\ell\gamma^\mu\gamma_5\ell).\end{aligned}\tag{4}$$

In order to account for lepton nonuniversality, one considers separate electron and muon semileptonic operators, $\ell=\mu, e$. The corresponding Wilson coefficients are denoted as $C_{9,10}^{(\prime)e}$ and $C_{9,10}^{(\prime)\mu}$ respectively which are equal in the SM or in models with lepton universality. Under the assumption that there are left-handed leptons only—which represents an attractive option in model building beyond the SM—one finds the following relations between the Wilson coefficients:

$$\delta C_{LL}^\ell\equiv\delta C_9^\ell=-\delta C_{10}^\ell,\qquad \delta C_{RL}^\ell\equiv\delta C_9^{\prime\ell}=-\delta C_{10}^{\prime\ell}.\tag{5}$$

Here we introduced the quantities C_{XY}^ℓ where ℓ is again the flavor index, X denotes the chirality of the quark current and Y of the lepton current. Assuming right-handed leptons only, one gets the following relations:

$$\delta C_{RR}^\ell\equiv\delta C_9^{\prime\ell}=+\delta C_{10}^{\prime\ell},\qquad \delta C_{LR}^\ell\equiv\delta C_9^\ell=+\delta C_{10}^\ell.\tag{6}$$

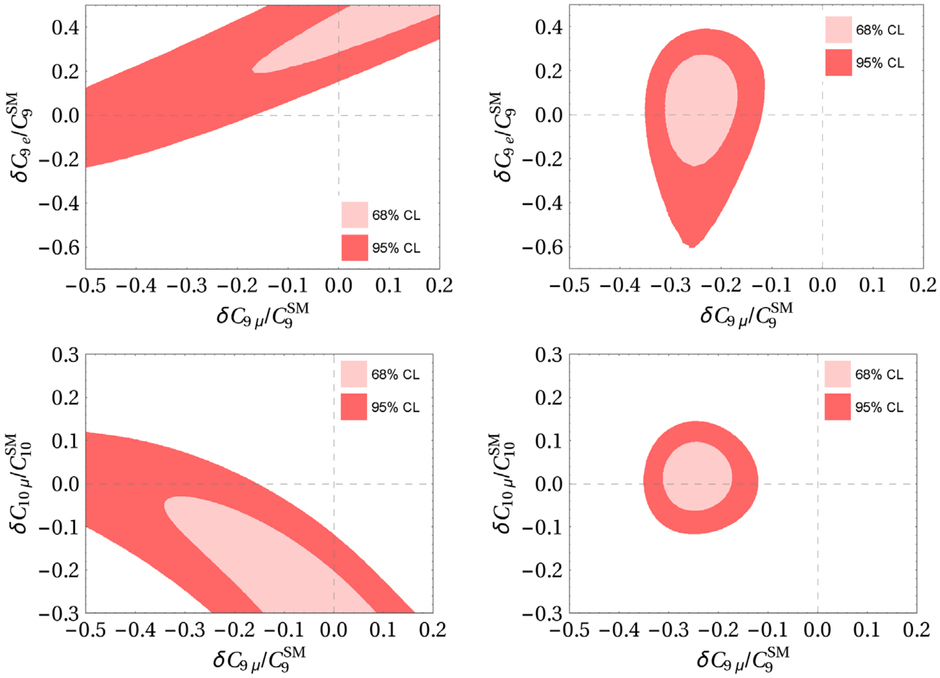

FIG. 1. Global fit results with present data, using only R_K and R_K^* (left), using all observables except R_K and R_K^* (under the assumption of 10% nonfactorizable power corrections) (right).

one finds that the two sets are compatible at least at the 2σ level.[3]

In this context we emphasize that the present high significance of NP effects in C_{10}^{μ} within the analysis of the ratios is not only due to the measurement on the very low bin of R_{K^*}. Removing this bin, $\mathrm{Pull}_{\mathrm{SM}}$ for C_{10}^{μ} gets only slightly reduced from t4.0σ in Table I (where this bin is included) to 3.7σ with the best fit points of ΔC_{10}^{μ} changing negligibly from -0.34 (-1.66) to -0.31 (-1.69).

IV. NONFACTORIZABLE POWER CORRECTIONS

Until now we worked out the global fit of all the $b \to s\ell\ell$ data under the assumption that the nonfactorizable power corrections do not exceed 10%. But this is only a guesstimate at present. It was already demonstrated by several groups [19,30] that the anomalies in the $b \to s\ell\ell$ data (without the $R_{K^{(*)}}$ ratios) can be *fully* explained by large nonfactorizable power corrections: The unknown nonfactorizable power corrections are just fitted to the data using an ansatz with 18 real parameters. This fit to the data needs very large nonfactorizable power corrections in the critical bins—up to 50% or more relative to the leading QCDf amplitude. Clearly, the existence of such large power corrections cannot be ruled out in principle and the situation stays undecided if the anomalies in this set of

TABLE II. Best fit values in the one-operator fit considering all observables (under the assumption of 10% factorizable power corrections) except R_K and R_{K^*}. Normalization is as in Table I.

	Best fit value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\mathrm{SM}}$
ΔC_9	-0.24	70.5	4.1σ
$\Delta C_9'$	-0.02	87.4	0.3σ
ΔC_{10}	-0.02	87.3	0.4σ
$\Delta C_{10}'$	$+0.03$	87.0	0.7σ
ΔC_9^{μ}	-0.25	68.2	4.4σ
ΔC_9^{e}	$+0.18$	86.2	1.2σ
ΔC_{10}^{μ}	-0.05	86.8	0.8σ
ΔC_{10}^{e}	-2.14 $+0.14$	86.3	1.1σ
$\Delta C_9^{\mu} = -\Delta C_{10}^{\mu}$ ($\Delta C_{\rm LL}^{\mu}$)	-0.10	79.4	2.8σ
$\Delta C_9^{e} = -\Delta C_{10}^{e}$ ($\Delta C_{\rm LL}^{e}$)	$+0.08$	86.3	1.1σ
$\Delta C_9^{\mu\prime} = -\Delta C_{10}^{\mu\prime}$ ($\Delta C_{\rm RL}^{\mu}$)	-0.01	87.3	0.4σ
$\Delta C_9^{e\prime} = -\Delta C_{10}^{e\prime}$ ($\Delta C_{\rm RL}^{e}$)	-0.01	87.0	0.7σ
$\Delta C_9^{\mu} = +\Delta C_{10}^{\mu}$ ($\Delta C_{\rm LR}^{\mu}$)	-0.12	79.5	2.8σ
$\Delta C_9^{e} = +\Delta C_{10}^{e}$ ($\Delta C_{\rm LR}^{e}$)	$+0.50$	85.8	1.3σ
	-1.12	86.7	0.9σ
$\Delta C_9^{\mu\prime} = +\Delta C_{10}^{\mu\prime}$ ($\Delta C_{\rm RR}^{\mu}$)	$+0.03$	87.1	0.6σ
$\Delta C_9^{e\prime} = +\Delta C_{10}^{e\prime}$ ($\Delta C_{\rm RR}^{e}$)	-0.54	86.3	1.1σ

[3]The branching ratio $\mathrm{BR}(B_s \to \mu^+\mu^-)$ is a theoretically rather clean observable. There is good agreement between the SM prediction and the current experimental measurement of $\mathrm{BR}(B_s \to \mu^+\mu^-)$. It is well known that this observable constrains C_{10} and one might expect that the fit to the ratios changes if this observable is included. However, as was shown in Tables II and III of Ref. [23], the significance for the various NP options within the one-operator hypotheses changes only very mildly when including $\mathrm{BR}(B_s \to \mu^+\mu^-)$ (see also Table IV below).

$b \to s\ell\ell$ observables originate from new physics or from large hadronic power corrections.

There are methods offered in Refs. [12,31] (see also Refs. [32,33]) which may allow one to replace the present guesstimates of the nonfactorizable power corrections by real estimates of these hadronic effects. Obviously, such estimates are highly desirable to disentangle NP effects from hadronic uncertainties in the angular observables. More recently, a slightly different approach was proposed in which the nonfactorizable corrections are estimated using the analyticity structure of the corresponding amplitudes [34]. But also new experimental data on these angular observables might help to disentangle nonfactorizable power corrections from new physics effects within the angular observables. If the electron modes of the angular observables are measured and do not show any deviation, then this is a clear hint for the NP option. This is of course equivalent to a clear NP signal within the corresponding theoretically clean R ratios as already discussed in the introduction.

In addition, we mention that underestimated uncertainties in the form factor determination can also at least partially account for the tensions in the global analysis of all the present $b \to s$ data (excluding the three ratios) as we have shown in Ref. [17].

If we now combine the two sets of observables—assuming 10% nonfactorizable power corrections as this is often used as the standard choice in global analyses—we find a SM pull of 5.7σ for the one-operator NP hypothesis C_9^μ. However, NP claims based on this result are misleading. As explained, the significance of the SM pull of such a combined fit also depends directly on the guesstimates of the nonfactorizable power corrections. These findings prevent us from making further combined fits with the theoretically clean ratios and the rest of the $b \to s\ell\ell$ data.

V. FUTURE PROSPECTS

The LHCb detector will be upgraded and is expected to collect a total integrated luminosity of 50 fb^{-1}. A second upgrade at a high-luminosity LHC will allow for a full data set of up to 300 fb^{-1}. Due to the expected luminosity of 300 fb^{-1}, of 50 fb^{-1}, and in the near future of 12 fb^{-1} the statistical error will be decreased by a factor 10, 4, and 2, respectively.[4]

For the three luminosity cases we consider three upgrade scenarios in which the current central values are assumed to remain and in which the systematic error is either unchanged or reduced by a factor of 2 or 3. In all cases we consider two (extreme) options regarding the error correlations, namely that the three R_K and R_{K^*} bins/observables have no correlation or 50% correlation between each of the three measurements.

[4]The 12 fb^{-1} is an effective luminosity, corresponding to 1 fb^{-1} at 7 TeV, 2 fb^{-1} at 8 TeV and 5 fb^{-1} at 13 TeV.

The results for these future scenarios are given in Table III. Here we show the one-operator NP hypothesis ΔC_9^μ as an exemplary mode. It is obvious from the SM pulls that—within the scenario in which the central values are assumed to remain—only a small part of the 50 fb^{-1} is needed to establish NP in the $R_{K^{(*)}}$ ratios even in the pessimistic case that the systematic errors are not reduced by then at all.

In addition we have found that the SM pulls for the six favored one-operator NP hypotheses are all very similar in each of the upgrade scenarios. This feature can also be read off from the analytical dependence of the ratios on the NP Wilson coefficients (see Ref. [25]). This indicates that also in future scenarios based on much larger data sets there is no differentiation between the NP hypotheses possible. This motivates the search for other ratios in the next section which are sensitive for lepton nonuniversality *and* serve this purpose.

If in addition to R_K and R_{K^*} we add the prospected measurement for the rather clean $\mathrm{BR}(B_s \to \mu^+\mu^-)$ observable into the fit, we still find that the different favored NP scenarios cannot be differentiated. In Table IV we give $\mathrm{Pull}_{\mathrm{SM}}$ for NP in ΔC_9^μ, ΔC_{10}^μ or ΔC_{LL}^μ considering the prospects for the LHCb upgrade of the R_K and R_K^* ratios assuming the current central values remain and compare it with the case when $\mathrm{BR}(B_s \to \mu^+\mu^-)$ is also included. For the statistical errors of R_K and R_{K^*} ratios we consider the most optimistic scenario of Table III where they are 1/3 of their current values without any correlations and for $\mathrm{BR}(B_s \to \mu^+\mu^-)$ we assume 5% theoretical uncertainty with (combined statistical and systematic) experimental errors to be 0.38×10^{-9}, 0.32×10^{-9}, 0.26×10^{-9} for the LHCb results with 12, 50 and 300^{-1} luminosity combined with the prospected ATLAS and CMS measurements. The $\mathrm{Pull}_{\mathrm{SM}}$ remains the same for the ΔC_9^μ scenario for the R_K and R_{K^*} fit prospects whether $\mathrm{BR}(B_s \to \mu^+\mu^-)$ is included or not as the latter observable is insensitive to C_9 (the fit was redone for ΔC_9^μ as a validation test). But also the ΔC_{10}^μ and ΔC_{LL}^μ change only very mildly when the prospected measurement for the rather clean $\mathrm{BR}(B_s \to \mu^+\mu^-)$ observable is added to the fit.

We also consider the set of $b \to s\ell\ell$ observables, which is complementary to R_K and R_K^*. We again assume that their

TABLE III. $\mathrm{Pull}_{\mathrm{SM}}$ for the fit to ΔC_9^μ based on the ratios R_K and R_{K^*} for the LHCb upgrade scenarios with 12,50 and 300 fb^{-1} luminosity collected, assuming current central values remain. For each of the upgraded luminosities the systematic error (denoted by "Syst." in the table) is considered to either remain unchanged or be reduced by a factor of 2 or 3. In each scenario the three R_K and R_{K^*} bins/observables are assumed to have no correlation (50% correlation between each of the three measurements).

	Syst.	Syst./2	Syst./3
ΔC_9^μ	$\mathrm{Pull}_{\mathrm{SM}}$	$\mathrm{Pull}_{\mathrm{SM}}$	$\mathrm{Pull}_{\mathrm{SM}}$
12 fb^{-1}	$6.1\sigma(4.3\sigma)$	$7.2\sigma(5.2\sigma)$	$7.4\sigma(5.5\sigma)$
50 fb^{-1}	$8.2\sigma(5.7\sigma)$	$11.6\sigma(8.7\sigma)$	$12.9\sigma(9.9\sigma)$
300 fb^{-1}	$9.4\sigma(6.5\sigma)$	$15.6\sigma(12.3\sigma)$	$19.5\sigma(16.1\sigma)$

TABLE IV. Predictions of $\mathrm{Pull}_{\mathrm{SM}}$ for the fit to ΔC_9^μ, ΔC_{10}^μ and ΔC_{LL}^μ based on the ratios R_K and R_{K^*} [and also $\mathrm{BR}(B_s \to \mu^+\mu^-)$] for the LHCb upgrade scenarios with 12,50 and 300 fb^{-1} luminosity collected, assuming current central values remain. For R_K and R_{K^*} in each of the upgraded luminosities we have assumed the optimistic scenario where systematic errors are reduced by a factor 3 with no correlation among the errors. For $\mathrm{BR}(B_s \to \mu^+\mu^-)$ we have considered the absolute experimental error to be 3.8×10^{-10}, 3.2×10^{-10}, 2.6×10^{-10} from the prospected LHCb results with 12, 50 and 300^{-1} luminosity as well as the prospected ATLAS and CMS results.

LHCb luminosity	$\mathrm{Pull}_{\mathrm{SM}}$ with R_K and R_K^*[$+\mathrm{BR}(B_s\to\mu^+\mu^-)$] prospects		
	12 fb^{-1}	50 fb^{-1}	300 fb^{-1}
C_9^μ	$7.4\sigma[7.4\sigma]$	$12.9\sigma[12.9\sigma]$	$19.5\sigma[19.5\sigma]$
C_{10}^μ	$8.1\sigma[7.6\sigma]$	$13.9\sigma[13.5\sigma]$	$20.8\sigma[20.6\sigma]$
C_{LL}^μ	$7.9\sigma[7.8\sigma]$	$13.6\sigma[13.6\sigma]$	$20.5\sigma[20.4\sigma]$

central values remain. Future prospects are given for two operator fits in Fig. 2. Under this assumption it seems possible that the LHCb collaboration will be able to establish new physics within the angular observables even in the pessimistic case that there will be no theoretical progress on nonfactorizable power corrections.

VI. PREDICTIONS FOR OTHER RATIOS BASED ON THE PRESENT MEASUREMENTS OF R_K AND R_{K^*}

Finally, we make predictions for other ratios within the $b \to s\ell\ell$ transitions which could test lepton universality. In Ref. [17] we made predictions based on the global fit of all $b \to s\ell\ell$ observables with R_K considering two Wilson coefficients C_9^μ and C_9^e. We found that in most cases the SM point is outside the 2σ region of our indirect predictions reflecting the deviation in R_K. Here we base our predictions on the measurements of R_K and R_{K^*}, assuming NP in one operator only. We consider the six one-operator hypotheses which were favored in our fit to the present data; see Table V.

The predictions of the ratios are also given for the future 12 fb^{-1} upgrade in Table VI, assuming the central values of the three observables $R_K^{(*)}$ remain at their current values (considering the statistical error is reduced by a factor of 2 and the systematic error remains, while no correlation among the uncertainties is assumed).

From the numbers in the last four rows of Table V one can read off that the ratios of decay rates considered in our analysis do not help in differentiating between the six NP models. The 2σ ranges are almost equal for all six NP options in these four cases. This will most probably not change in the future when LHCb will have collected 12 fb^{-1} as one can see in our results presented in Table VI). This feature is expected when one crosschecks the analytical formulas of the decay rates (it can also be directly seen from Appendix D of Ref. [17]).

In contrast, the ratios of the angular observables of $B \to K^*\ell\ell$ in the low-q^2, namely F_L, A_{FB}, and the three angular observables S_3,S_4, S_5 are able to differentiate between the six new physics options. For example the predictions of the 2σ regions for these observables within the C_9^μ and the C_{10}^μ NP models are not overlapping in any of the cases (see the first five rows of Table V). And the differentiating power increases significantly with the 12 fb^{-1} data set of LHCb (see Table VI).

However, the corresponding angular observables in the high-q^2 region have almost no differentiating power (see rows 7–12 in Table V). This is expected from the well-known effect that the dependence on the Wilson coefficients and, thus, also the NP sensitivity, in general, is rather weak for observables in the high-q^2 region.

Some of the angular observables have zero crossings in which case it would be better to use lepton flavor differences instead of ratios [35]. Moreover, an alternative set of observables would be the ratios and/or differences of the well-known P_i observables [36] which are free from form factor dependences to first order. Predictions for all these observables are given in Tables VII and VIII in the appendix. Further observables have been introduced where weighted differences of the angular observables are constructed [37].

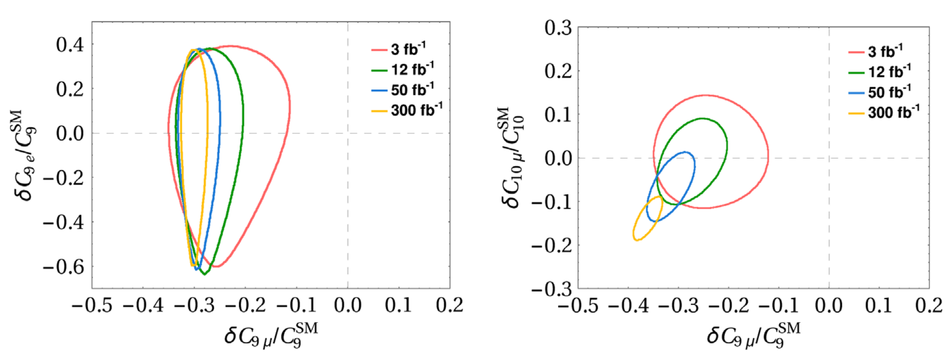

FIG. 2. Global fit results for $\delta C_9^e - \delta C_9^\mu$ and $\delta C_9 - \delta C_{10}$, using all $b \to s\bar{\ell}\ell$ observables (under the assumption of 10% factorizable power corrections) besides R_K and R_{K^*} are shown with a red solid line (at 2σ level). Future LHCb prospects of the fit (at 2σ level), assuming the current central values remain, are shown with green, blue and yellow (from right to left) lines corresponding to 12, 50 and 300 fb^{-1} luminosity, respectively, with the 2σ regions shrinking from right towards left.

TABLE V. Predictions of ratios of observables with muons in the final state to electrons in the final state at 95% confidence level, considering one-operator fits obtained using the 3 fb^{-1} data for $R_{K^{(*)}}$. The observables $R_{F_L}, R_{A_{FB}}, R_{S_{3,4,5}}$ correspond to ratios of F_L, $A_{FB}, S_{3,4,5}$ of the $B \to K^* \bar{\ell}\ell$ decay, respectively. The observables $R_{K^{(*)}}$ and R_ϕ correspond to the ratios of the branching fractions of $B \to K^{(*)}\bar{\ell}\ell$ and $B_s \to \phi\bar{\ell}\ell$, respectively. The superscripts denote the q^2 bins.

	Predictions for 3 fb^{-1} luminosity					
Observable	C_9^μ	C_9^e	C_{10}^μ	C_{10}^e	C_{LL}^μ	C_{LL}^e
$R_{F_L}^{[1.1,6.0]}$	[0.714, 0.940]	[0.905, 0.946]	[0.996, 1.059]	[0.995, 1.023]	[0.901, 0.967]	[0.959, 0.970]
$R_{A_{FB}}^{[1.1,6.0]}$	[4.054, 19.162]	[−0.462, −0.138]	[0.697, 0.933]	[0.954, 1.099]	[2.515, 7.503]	[−1.520, −0.212]
$R_{S_3}^{[1.1,6.0]}$	[0.890, 0.932]	[0.768, 0.919]	[0.230, 0.838]	[0.714, 0.873]	[0.485, 0.879]	[0.741, 0.895]
$R_{S_4}^{[1.1,6.0]}$	[0.971, 1.152]	[0.822, 0.950]	[0.161, 0.822]	[0.695, 0.862]	[0.570, 0.892]	[0.755, 0.903]
$R_{S_5}^{[1.1,6.0]}$	[−1.450, 0.637]	[0.591, 0.758]	[0.753, 1.008]	[1.031, 1.188]	[0.293, 0.833]	[0.653, 0.858]
$R_{F_L}^{[15,19]}$	[0.999, 0.998]	[0.998, 0.998]	[0.997, 0.998]	[0.998, 0.998]	[0.998, 0.998]	[0.998, 0.998]
$R_{A_{FB}}^{[15,19]}$	[0.331, 0.964]	[0.994, 1.093]	[0.729, 1.003]	[1.027, 1.169]	[0.989, 0.997]	[0.994, 0.998]
$R_{S_3}^{[15,19]}$	[0.996, 0.998]	[0.998, 0.999]	[0.999, 1.001]	[0.999, 1.000]	[0.999, 1.000]	[0.998, 0.999]
$R_{S_4}^{[15,19]}$	[0.998, 0.999]	[0.998, 0.998]	[0.998, 0.998]	[0.998, 0.999]	[0.998, 0.999]	[0.998, 0.998]
$R_{S_5}^{[15,19]}$	[0.330, 0.964]	[0.994, 1.092]	[0.729, 1.003]	[1.027, 1.169]	[0.989, 0.997]	[0.994, 0.997]
$R_{K^*}^{[15,19]}$	[0.572, 0.867]	[0.520, 0.841]	[0.529, 0.844]	[0.530, 0.838]	[0.523, 0.847]	[0.525, 0.839]
$R_K^{[15,19]}$	[0.527, 0.869]	[0.534, 0.846]	[0.610, 0.873]	[0.532, 0.908]	[0.561, 0.863]	[0.554, 0.855]
$R_\phi^{[1.1,6.0]}$	[0.740, 0.897]	[0.561, 0.867]	[0.517, 0.838]	[0.476, 0.883]	[0.576, 0.860]	[0.543, 0.849]
$R_\phi^{[15,19]}$	[0.575, 0.867]	[0.520, 0.841]	[0.526, 0.843]	[0.481, 0.887]	[0.521, 0.847]	[0.524, 0.839]

TABLE VI. Predictions of ratios of observables with muons in the final state to electrons in the final state at 95% confidence level, considering one-operator fits obtained by assuming the central values of $R_{K^{(*)}}$ with 12 fb^{-1} luminosity remain the same as the current 3 fb^{-1} data. In a few cases, the 12 fb^{-1} predictions are not fully within the 3 fb^{-1} prediction ranges which is due to a change in the position of the minimum. For the definition of the observables see the caption of Table V.

	Predictions assuming 12 fb^{-1} luminosity					
Observable	C_9^μ	C_9^e	C_{10}^μ	C_{10}^e	C_{LL}^μ	C_{LL}^e
$R_{F_L}^{[1.1,6.0]}$	[0.785, 0.913]	[0.909, 0.933]	[1.005, 1.042]	[1.001, 1.018]	[0.920, 0.958]	[0.960, 0.966]
$R_{A_{FB}}^{[1.1,6.0]}$	[6.048, 14.819]	[−0.288, −0.153]	[0.816, 0.928]	[0.974, 1.061]	[3.338, 6.312]	[−0.684, −0.256]
$R_{S_3}^{[1.1,6.0]}$	[0.858, 0.904]	[0.795, 0.886]	[0.399, 0.753]	[0.738, 0.832]	[0.586, 0.819]	[0.766, 0.858]
$R_{S_4}^{[1.1,6.0]}$	[0.970, 1.051]	[0.848, 0.926]	[0.344, 0.730]	[0.719, 0.818]	[0.650, 0.841]	[0.780, 0.868]
$R_{S_5}^{[1.1,6.0]}$	[−0.787, 0.394]	[0.603, 0.697]	[0.881, 1.002]	[1.053, 1.146]	[0.425, 0.746]	[0.685, 0.806]
$R_{F_L}^{[15,19]}$	[0.999, 0.999]	[0.998, 0.998]	[0.997, 0.998]	[0.998, 0.998]	[0.998, 0.998]	[0.998, 0.998]
$R_{A_{FB}}^{[15,19]}$	[0.616, 0.927]	[1.002, 1.061]	[0.860, 0.994]	[1.046, 1.131]	[0.992, 0.996]	[0.995, 0.997]
$R_{S_3}^{[15,19]}$	[0.997, 0.998]	[0.998, 0.998]	[0.999, 1.000]	[0.999, 1.000]	[0.999, 1.000]	[0.999, 0.999]
$R_{S_4}^{[15,19]}$	[0.998, 0.999]	[0.998, 0.998]	[0.998, 0.998]	[0.998, 0.999]	[0.998, 0.998]	[0.998, 0.998]
$R_{S_5}^{[15,19]}$	[0.615, 0.927]	[1.002, 1.061]	[0.860, 0.994]	[1.046, 1.131]	[0.991, 0.996]	[0.994, 0.997]
$R_{K^*}^{[15,19]}$	[0.621, 0.803]	[0.577, 0.771]	[0.589, 0.778]	[0.586, 0.770]	[0.585, 0.780]	[0.582, 0.771]
$R_K^{[15,19]}$	[0.597, 0.802]	[0.590, 0.778]	[0.659, 0.818]	[0.632, 0.805]	[0.620, 0.802]	[0.609, 0.791]
$R_\phi^{[1.1,6.0]}$	[0.748, 0.852]	[0.620, 0.805]	[0.578, 0.770]	[0.578, 0.764]	[0.629, 0.800]	[0.600, 0.784]
$R_\phi^{[15,19]}$	[0.623, 0.803]	[0.577, 0.771]	[0.586, 0.776]	[0.583, 0.769]	[0.584, 0.779]	[0.581, 0.770]

VII. CONCLUSIONS

The future measurements of the theoretically clean ratios $R_{K^{(*)}}$ and similar observables which are sensitive to lepton flavor nonuniversality have the potential to unambiguously establish lepton nonuniversal new physics in the near future. We have demonstrated that this may be possible already with the 12 fb^{-1} data set of LHCb. We have also shown that more such theoretically clean ratios are needed to differentiate between the six NP hypotheses favored by the present data. We have singled out the ratios of the angular observables of the $B \to K^* \ell\ell$ decay in the low q^2 region to have the largest differentiating power in this respect. Such a finding of lepton flavor nonuniversal new physics may also indirectly establish the new physics explanation of the present anomalies in the angular observables in $B \to K^* \mu\mu$ decays and in the branching ratios of $B_s \to \phi\mu\mu$ if there is a coherent NP picture of both sets of observables.

APPENDIX: PREDICTIONS FOR FURTHER OBSERVABLES SENSITIVE TO LEPTON FLAVOR VIOLATION

TABLE VII. Predictions of ratios and differences of observables with muons in the final state to electrons in the final state at 95% confidence level, considering one-operator fits obtained using the 3 fb^{-1} data for $R_{K^{(*)}}$. The observables $D_{S_{3,4,5}} = S^{\mu}_{3,4,5} - S^{e}_{3,4,5}$, $D_{A_{FB}} = A^{\mu}_{FB} - A^{e}_{FB}$, $D_{F_L} = Q_{F_L} = F^{\mu}_L - F^{e}_L$ and $Q_{1,2,4,5} = P^{(\prime)\mu}_{1,2,4,5} - P^{(\prime)e}_{1,2,4,5}$ and $R_{P_i} = P^{(\prime)\mu}_{1,2,4,5}/P^{(\prime)e}_{1,2,4,5}$ all correspond to the $B \to K^* \ell\ell$ decay. The observables $R_{K^{(*)}}$, R_{X_s} and R_ϕ correspond to the ratios of the branching fractions of $B \to K^{(*)}\bar{\ell}\ell$, $B \to X_s\bar{\ell}\ell$ and $B_s \to \phi\bar{\ell}\ell$, respectively. The superscripts denote the q^2 bins.

	Predictions for 3 fb^{-1} luminosity					
Observable	C_9^{μ}	C_9^{e}	C_{10}^{μ}	C_{10}^{e}	C_{LL}^{μ}	C_{LL}^{e}
$D_{F_L}^{[1.1,6.0]}$	$[-0.046, -0.218]$	$[-0.078, -0.043]$	$[-0.003, 0.045]$	$[-0.004, 0.017]$	$[-0.076, -0.025]$	$[-0.032, -0.023]$
$D_{A_{FB}}^{[1.1,6.0]}$	$[-0.247, -0.041]$	$[-0.104, -0.040]$	$[0.001, 0.004]$	$[-0.001, 0.001]$	$[-0.088, -0.021]$	$[-0.072, -0.021]$
$D_{S_3}^{[1.1,6.0]}$	$[0.001, 0.001]$	$[0.001, 0.003]$	$[0.002, 0.009]$	$[0.002, 0.005]$	$[0.001, 0.006]$	$[0.001, 0.004]$
$D_{S_4}^{[1.1,6.0]}$	$[-0.004, 0.019]$	$[-0.027, -0.007]$	$[-0.106, -0.023]$	$[-0.055, -0.020]$	$[-0.055, -0.014]$	$[-0.041, -0.014]$
$D_{S_5}^{[1.1,6.0]}$	$[0.059, 0.401]$	$[0.052, 0.113]$	$[-0.001, 0.040]$	$[-0.026, -0.005]$	$[0.027, 0.116]$	$[0.027, 0.087]$
$D_{F_L}^{[15,19]}$	$[-0.001, -0.000]$	$[-0.001, -0.001]$	$[-0.001, -0.001]$	$[-0.001, -0.001]$	$[-0.001, -0.001]$	$[-0.001, -0.001]$
$D_{A_{FB}}^{[15,19]}$	$[-0.254, -0.014]$	$[-0.002, 0.032]$	$[-0.103, 0.001]$	$[0.010, 0.055]$	$[-0.004, -0.001]$	$[-0.002, -0.001]$
$D_{S_3}^{[15,19]}$	$[0.000, 0.001]$	$[0.000, 0.000]$	$[-0.000, 0.000]$	$[-0.000, 0.000]$	$[0.000, 0.000]$	$[0.000, 0.000]$
$D_{S_4}^{[15,19]}$	$[-0.001, -0.000]$	$[-0.001, -0.001]$	$[-0.001, -0.001]$	$[-0.001, -0.000]$	$[-0.001, -0.000]$	$[-0.001, -0.000]$
$D_{S_5}^{[15,19]}$	$[0.010, 0.191]$	$[-0.024, 0.002]$	$[-0.001, 0.077]$	$[-0.041, -0.007]$	$[0.001, 0.003]$	$[0.001, 0.002]$
$R_{P_2}^{[1.1,6.0]}$	$[3.653, 10.426]$	$[-0.416, -0.103]$	$[0.983, 1.009]$	$[1.019, 1.272]$	$[2.461, 6.105]$	$[-1.499, -0.201]$
$R_{P_1}^{[1.1,6.0]}$	$[0.484, 0.840]$	$[0.575, 0.827]$	$[0.325, 0.906]$	$[0.826, 0.933]$	$[0.395, 0.860]$	$[0.702, 0.882]$
$R_{P_4}^{[1.1,6.0]}$	$[0.951, 1.006]$	$[0.747, 0.927]$	$[0.186, 0.857]$	$[0.739, 0.894]$	$[0.541, 0.898]$	$[0.750, 0.910]$
$R_{P_5}^{[1.1,6.0]}$	$[-1.266, 0.624]$	$[0.537, 0.740]$	$[0.869, 1.050]$	$[1.068, 1.263]$	$[0.278, 0.838]$	$[0.649, 0.865]$
$R_{P_2}^{[15,19]}$	$[0.331, 0.966]$	$[0.996, 1.095]$	$[0.732, 1.006]$	$[1.029, 1.171]$	$[0.991, 0.999]$	$[0.996, 1.000]$
$R_{P_1}^{[15,19]}$	$[0.997, 1.000]$	$[1.000, 1.001]$	$[1.001, 1.005]$	$[1.001, 1.003]$	$[1.001, 1.002]$	$[1.001, 1.001]$
$R_{P_4}^{[15,19]}$	$[0.999, 1.000]$	$[1.000, 1.000]$	$[1.000, 1.001]$	$[1.000, 1.001]$	$[1.000, 1.000]$	$[1.000, 1.000]$
$R_{P_5}^{[15,19]}$	$[0.330, 0.966]$	$[0.996, 1.094]$	$[0.732, 1.006]$	$[1.029, 1.171]$	$[0.991, 0.999]$	$[0.996, 0.999]$
$Q_2^{[1.1,6.0]}$	$[0.102, 0.361]$	$[0.123, 0.387]$	$[-0.001, 0.000]$	$[0.001, 0.008]$	$[0.056, 0.196]$	$[0.060, 0.216]$
$Q_1^{[1.1,6.0]}$	$[0.016, 0.050]$	$[0.021, 0.073]$	$[0.009, 0.066]$	$[0.007, 0.021]$	$[0.014, 0.059]$	$[0.013, 0.042]$
$Q_4^{[1.1,6.0]}$	$[-0.029, 0.003]$	$[-0.204, -0.048]$	$[-0.486, -0.086]$	$[-0.213, -0.072]$	$[-0.274, -0.061]$	$[-0.201, -0.060]$
$Q_5^{[1.1,6.0]}$	$[0.145, 0.872]$	$[0.138, 0.338]$	$[-0.019, 0.051]$	$[-0.082, -0.025]$	$[0.062, 0.278]$	$[0.061, 0.212]$
$Q_2^{[15,19]}$	$[0.013, 0.254]$	$[-0.033, 0.001]$	$[-0.002, 0.102]$	$[-0.056, -0.011]$	$[0.000, 0.003]$	$[0.000, 0.002]$
$Q_1^{[15,19]}$	$[0.000, 0.002]$	$[-0.000, -0.000]$	$[-0.003, -0.001]$	$[-0.002, -0.001]$	$[-0.001, -0.000]$	$[-0.001, -0.000]$
$Q_4^{[15,19]}$	$[-0.001, -0.000]$	$[0.000, 0.000]$	$[0.000, 0.001]$	$[0.000, 0.001]$	$[0.000, 0.000]$	$[0.000, 0.000]$
$Q_5^{[15,19]}$	$[0.021, 0.405]$	$[-0.052, 0.002]$	$[-0.003, 0.162]$	$[-0.088, -0.017]$	$[0.000, 0.005]$	$[0.000, 0.003]$

TABLE VIII. Predictions of ratios and differences of observables with muons in the final state to electrons in the final state at 95% confidence level, considering one-operator fits obtained by assuming the central values of $R_{K^{(*)}}$ with 12 fb^{-1} luminosity remain the same as the current 3 fb^{-1} data. For the definition of the observables see the caption of Table VII.

	Predictions assuming 12 fb^{-1} luminosity					
Observable	C_9^μ	C_9^e	C_{10}^μ	C_{10}^e	C_{LL}^μ	C_{LL}^e
$D_{F_L}^{[1.1,6.0]}$	[−0.164, −0.066]	[−0.075, −0.053]	[0.004, 0.032]	[0.000, 0.013]	[−0.061, −0.032]	[−0.032, −0.026]
$D_{A_{FB}}^{[1.1,6.0]}$	[−0.188, −0.069]	[−0.095, −0.056]	[0.001, 0.003]	[−0.001, 0.000]	[−0.072, −0.032]	[−0.062, −0.031]
$D_{S_3}^{[1.1,6.0]}$	[0.001, 0.002]	[0.001, 0.003]	[0.003, 0.007]	[0.002, 0.004]	[0.002, 0.005]	[0.002, 0.004]
$D_{S_4}^{[1.1,6.0]}$	[−0.004, 0.007]	[−0.023, −0.010]	[−0.083, −0.034]	[−0.049, −0.028]	[−0.044, −0.020]	[−0.035, −0.019]
$D_{S_5}^{[1.1,6.0]}$	[0.099, 0.292]	[0.071, 0.107]	[−0.000, 0.019]	[−0.021, −0.008]	[0.041, 0.094]	[0.039, 0.075]
$D_{F_L}^{[15,19]}$	[−0.001, −0.000]	[−0.001, −0.001]	[−0.001, −0.001]	[−0.001, −0.001]	[−0.001, −0.001]	[−0.001, −0.001]
$D_{A_{FB}}^{[15,19]}$	[−0.146, −0.027]	[0.001, 0.022]	[−0.053, −0.002]	[0.017, 0.044]	[−0.003, −0.001]	[−0.002, −0.001]
$D_{S_3}^{[15,19]}$	[0.000, 0.001]	[0.000, 0.000]	[−0.000, 0.000]	[−0.000, 0.000]	[0.000, 0.000]	[0.000, 0.000]
$D_{S_4}^{[15,19]}$	[−0.000, −0.000]	[−0.001, −0.001]	[−0.001, −0.001]	[−0.001, −0.000]	[−0.001, −0.000]	[−0.001, −0.001]
$D_{S_5}^{[15,19]}$	[0.021, 0.110]	[−0.016, −0.001]	[0.002, 0.040]	[−0.033, −0.012]	[0.001, 0.002]	[0.001, 0.002]
$R_{P_2}^{[1.1,6.0]}$	[5.054, 9.201]	[−0.246, −0.117]	[1.037, 1.061]	[1.060, 1.211]	[3.185, 5.402]	[−0.666, −0.243]
$R_{P_1}^{[1.1,6.0]}$	[0.532, 0.755]	[0.607, 0.758]	[0.518, 0.842]	[0.843, 0.906]	[0.501, 0.781]	[0.727, 0.835]
$R_{P_4}^{[1.1,6.0]}$	[0.928, 0.935]	[0.777, 0.887]	[0.385, 0.770]	[0.762, 0.854]	[0.626, 0.839]	[0.776, 0.871]
$R_{P_5}^{[1.1,6.0]}$	[−0.700, 0.377]	[0.553, 0.668]	[0.985, 1.057]	[1.098, 1.214]	[0.410, 0.745]	[0.681, 0.810]
$R_{P_2}^{[15,19]}$	[0.616, 0.929]	[1.004, 1.063]	[0.863, 0.996]	[1.048, 1.133]	[0.994, 0.998]	[0.997, 0.999]
$R_{P_1}^{[15,19]}$	[0.998, 1.000]	[1.000, 1.000]	[1.002, 1.004]	[1.001, 1.002]	[1.001, 1.002]	[1.001, 1.001]
$R_{P_4}^{[15,19]}$	[1.000, 1.000]	[1.000, 1.000]	[1.000, 1.001]	[1.000, 1.000]	[1.000, 1.000]	[1.000, 1.000]
$R_{P_5}^{[15,19]}$	[0.615, 0.929]	[1.004, 1.063]	[0.863, 0.996]	[1.048, 1.133]	[0.993, 0.998]	[0.996, 0.999]
$Q_2^{[1.1,6.0]}$	[0.155, 0.314]	[0.183, 0.346]	[0.001, 0.002]	[0.002, 0.006]	[0.084, 0.169]	[0.090, 0.185]
$Q_1^{[1.1,6.0]}$	[0.024, 0.046]	[0.032, 0.064]	[0.015, 0.047]	[0.010, 0.019]	[0.021, 0.049]	[0.020, 0.037]
$Q_4^{[1.1,6.0]}$	[−0.043, −0.039]	[−0.173, −0.077]	[−0.367, −0.137]	[−0.188, −0.104]	[−0.223, −0.096]	[−0.174, −0.089]
$Q_5^{[1.1,6.0]}$	[0.240, 0.654]	[0.195, 0.317]	[−0.022, 0.006]	[−0.069, −0.035]	[0.098, 0.227]	[0.092, 0.183]
$Q_2^{[15,19]}$	[0.027, 0.146]	[−0.023, −0.001]	[0.001, 0.052]	[−0.045, −0.017]	[0.001, 0.002]	[0.000, 0.001]
$Q_1^{[15,19]}$	[0.000, 0.001]	[−0.000, −0.000]	[−0.002, −0.001]	[−0.001, −0.001]	[−0.001, −0.000]	[−0.001, −0.000]
$Q_4^{[15,19]}$	[−0.000, −0.000]	[0.000, 0.000]	[0.000, 0.001]	[0.000, 0.001]	[0.000, 0.000]	[0.000, 0.000]
$Q_5^{[15,19]}$	[0.232, 0.043]	[−0.036, −0.002]	[0.002, 0.083]	[−0.071, −0.028]	[0.001, 0.004]	[0.001, 0.002]

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