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On the model dependence of measured B_s-meson branching fractions

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ABSTRACT

The measurement of B_s-meson branching fractions is a fundamental tool to probe physics beyond the Standard Model. Every measurement of untagged time-integrated B_s-meson branching fractions is model-dependent due to the time dependence of the experimental efficiency and the large lifetime difference between the two B_s mass eigenstates. In recent measurements, this effect is bundled in the systematics. We reappraise the potential numerical impact of this effect – we find it to be close to 10% in real-life examples where new physics is a correction to dominantly Standard-Model dynamics. We therefore suggest that this model dependence be made explicit, i.e. that B_s branching-fraction measurements be presented in a two-dimensional plane with the parameter that encodes the model dependence. We show that ignoring this effect can lead to over-constraining the couplings of new-physics models. In particular, we note that the effect also applies when setting upper limits on non-observed B_s decay modes, such as those forbidden within the Standard Model.

1. Introduction

The branching fractions of B_s mesons belong to the most sensitive probes of physics beyond the Standard Model (SM) in low-energy, high-intensity experiments. Their precise measurement is of prime importance to establish possible new physics or else to constrain models beyond the SM. However, the comparison between measurements and theory predictions of B_s-meson branching fractions presents some subtleties due to the sizeable lifetime difference $\Delta\Gamma_s$ between the two mass eigenstates of the $B_s^0 - \bar{B}_s^0$ system [1]. First of all, in the absence of flavour tagging the measured branching fraction will be the average of the B_s^0 and $\bar{B}_s^0$ branching fractions, due to their fast mixing. Secondly, since the theoretically calculated branching fraction is usually defined as the CP average between the flavour eigenstates *before any oscillation*, a $\Delta\Gamma_s$-dependent correction is required for it to be compared to the experimental values [1,2]. Both effects are proportional to a model- and channel-dependent factor known as $\mathcal{A}^f_{\Delta\Gamma}$ (f denotes the final state). So, in general, the comparison between measurements and theoretical predictions involves an assumption about this factor.

A third model-dependent bias is introduced by the non-perfect time acceptance of real experiments, again because of the sizeable lifetime difference $\Delta\Gamma_s$. This effect is discussed in [3], where it is quantified as a 1–3% correction.[1] In experimental measurements this effect was first appreciated in Ref. [6] (see also Ref. [4]), and in recent results this model-dependent correction is accounted for in the systematic error.

Aim of the present paper is twofold: *(i)* we reappraise the relevance of this effect with respect to existing literature, as we find an O(7%) correction in a realistic example. We accordingly advocate that experiments report explicitly the correlation of the result with the value of the model-dependent parameter ($\mathcal{A}^f_{\Delta\Gamma}$, or any other parameter correlated with it), even when the effect is smaller than the statistical uncertainty; *(ii)* we emphasise that this effect has implications when setting bounds on new-physics couplings, especially in decay modes where new physics is not a correction, but the bulk of the dynamics. In such cases, not properly tracking this effect may even lead to constraints that qualitatively depart from the dynamics actually at play, as we discuss in a specific example related to present-day anomalies in flavour data.

We begin by shortly reviewing the basic observation in Ref. [1]. One starts from the time-dependent untagged decay rate for a B_s into a final state f, defined as [7]

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[1] The effect is also mentioned in [1] (see sec. V). In the specific context of the $B_s \to \mu^+\mu^-$ measurement [4], this effect was subsequently developed in Ref. [5] and by one of the authors.

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$$\begin{aligned}\langle\Gamma(B_s(t)\to f)\rangle &\equiv \Gamma(B_s^0(t)\to f)+\Gamma(\bar{B}_s^0(t)\to f)\\ &= R_H^f e^{-\Gamma_H t}+R_L^f e^{-\Gamma_L t}=\\ &=(R_H^f+R_L^f)e^{-\Gamma_s t}\left[\cosh\left(\frac{y_s t}{\tau_{B_s}}\right)+\mathcal{A}_{\Delta\Gamma}^f\sinh\left(\frac{y_s t}{\tau_{B_s}}\right)\right], \end{aligned}\tag{1}$$

where, in standard notation [8], $\Gamma_s = 1/\tau_{B_s}$ is the average between the widths, Γ_H and Γ_L, of the two mass eigenstates in the B_s system. The parameter $y_s = \frac{\Gamma_L-\Gamma_H}{2\Gamma_s} = \frac{\Delta\Gamma_s}{2\Gamma_s}$ quantifies the generic size of effects due to the B_s-system width difference, $y_s = 0.061(4)$ [9]. Finally $\mathcal{A}_{\Delta\Gamma}^f = \frac{R_H^f-R_L^f}{R_H^f+R_L^f}$ depends on the final state and is related to the underlying dynamics, hence being model-dependent. The time-integrated branching ratio is then obtained by integrating eq. (1):

$$\begin{aligned}\mathcal{B}_{\rm ave}(B_s\to f) &= \frac{1}{2}\int_0^\infty \langle\Gamma(B_s(t)\to f)\rangle dt\\ &=(R_H^f+R_L^f)\frac{\tau_{B_s}}{2}\left[\frac{1+\mathcal{A}_{\Delta\Gamma}^f y_s}{1-y_s^2}\right].\end{aligned}\tag{2}$$

As noted in Ref. [1], this is different from the theoretical branching fraction, which is usually calculated as CP-averaged at time zero:

$$\mathcal{B}_{\rm th}(B_s\to f)\equiv\frac{\tau_{B_s}}{2}\langle\Gamma(B_s(t)\to f)\rangle|_{t=0}\,,\tag{3}$$

so that even with a perfect experiment, a model-dependent correction is needed to compare with the time-integrated branching fraction, $\mathcal{B}_{\rm ave}$:

$$\mathcal{B}_{\rm th}(B_s\to f)=\left(\frac{1-y_s^2}{1+\mathcal{A}_{\Delta\Gamma}^f y_s}\right)\mathcal{B}_{\rm ave}(B_s\to f)\,.\tag{4}$$

2. Time-dependent efficiencies

However, experiments are not perfect. In particular, the integral of the rate over the meson proper time is sampled according to a time-dependent efficiency. Hence, the experimentally measured branching fraction is actually

$$\mathcal{B}_{\rm exp}(B_s\to f)=\frac{N_{\rm obs}}{N\varepsilon_{\rm exp}}=\frac{1}{2\varepsilon_{\rm exp}}\int_0^\infty\varepsilon(t)\langle\Gamma(B_s(t)\to f)\rangle dt\tag{5}$$

where $\varepsilon(t)$ is the time-dependent efficiency of the apparatus, $\varepsilon_{\rm exp}$ is the time-averaged efficiency with which the observed yield, $N_{\rm obs}$, is corrected, and N is the total number of mesons produced to which the experiment normalises.

Unless $\varepsilon(t)$ is perfectly constant, the apparatus efficiency introduces an extra dependence on $\mathcal{A}_{\Delta\Gamma}^f$, and the latter makes the measurement of eq. (5) model dependent. This dependence cannot be factorised and accounted for as in eq. (4) as it rests on the explicit functional form of the efficiency. Intuitively, the rates of the two physical eigenstates will not be sampled uniformly, and this will distort the more the physical decay distribution, the more the two lifetimes differ. As a consequence, the measured admixture is not as given by the r.h.s. of eq. (2), and the dependence on $\mathcal{A}_{\Delta\Gamma}^f$ in the relation between the calculated and the measured branching fraction is not as simple as given in eq. (4).

This bias could be simply corrected for if $\mathcal{A}_{\Delta\Gamma}^f$ could be univocally fixed for each given decay channel f. However $\mathcal{A}_{\Delta\Gamma}^f$ depends on the short-distance structure of the decay, hence it is in general different in models of new physics with respect to the SM. For example, within the SM for the $B_s\to\mu^+\mu^-$ decay one has $\mathcal{A}_{\Delta\Gamma}^{\mu\mu}=+1$, i.e. that the decay occurs mostly through the heavier B_s eigenstate ($R_L=0$) [10]. This assumes negligible CP violation in mixing and in the interference between decays with and without mixing – an assumption that turns out to be robust. However, the $B_s\to\mu^+\mu^-$ decay could receive contributions beyond the SM from semileptonic scalar and pseudoscalar couplings, whose current bounds do not actually exclude any $\mathcal{A}_{\Delta\Gamma}^{\mu\mu}$ value in the whole range $[-1,+1]$ [10,11].

One clear way to expose the measurements' dependence on the value of $\mathcal{A}_{\Delta\Gamma}^f$, and the ensuing model dependence would be to present measurements as a function of the assumed value for $\mathcal{A}_{\Delta\Gamma}^f$. Of course, such practice is not always necessary. Notably, if the mixture of the heavy and light eigenstates is known for a given final state, the effect can be properly accounted for in the experimental efficiency. For example, $\mathcal{A}_{\Delta\Gamma}^f=0$ for flavour-specific decays. Furthermore, this effect is diluted or absent in decay rates where the SM contribution is precisely known and dominant. This effect can instead be prominent in rare decays, whose branching fractions can receive large contributions from new physics. We now illustrate such effect with a concrete example (see also [3]).

While the functional form of the time-dependent efficiency can be non-trivial, to estimate the size of the bias one may assume a simple step function $\varepsilon(t)=\theta(t-t_0)$, i.e. $\varepsilon=0$ for $t<t_0$ and $\varepsilon=1$ elsewhere. With this function one gets

$$\begin{aligned}\frac{1}{2}\int_0^\infty\varepsilon(t)\langle\Gamma(B_s(t)\to f)\rangle dt &= (R_H^f+R_L^f)\frac{\tau_{B_s}}{2}\frac{e^{-\Gamma_s t_0}}{1-y_s^2}\\ &\times\left[\cosh(\Gamma_s y_s t_0)(1+\mathcal{A}_{\Delta\Gamma}^f y_s)+\sinh(\Gamma_s y_s t_0)(y_s+\mathcal{A}_{\Delta\Gamma}^f)\right],\end{aligned}\tag{6}$$

which clearly reduces to eq. (2) for $t_0=0$. One can accordingly define the bias δ with respect to the branching ratio obtained with constant efficiency as the function

$$\begin{aligned}\delta(\mathcal{A}_{\Delta\Gamma}^f,y_s,\varepsilon_{\rm exp}) &\equiv \frac{\mathcal{B}_{\rm exp}(B_s\to f)}{\mathcal{B}_{\rm ave}(B_s\to f)}\\ &=\frac{e^{-\Gamma_s t_0}}{\varepsilon_{\rm exp}}\left(\cosh(\Gamma_s y_s t_0)+\sinh(\Gamma_s y_s t_0)\frac{y_s+\mathcal{A}_{\Delta\Gamma}^f}{1+\mathcal{A}_{\Delta\Gamma}^f y_s}\right),\end{aligned}$$

where the efficiency correction appears explicitly as in eq. (5). This efficiency is estimated by making a definite assumption about $\mathcal{A}_{\Delta\Gamma}^f$, namely as

$$\varepsilon_{\rm exp}(\mathcal{A}_{\rm a})=\frac{\int_0^\infty\varepsilon(t)\langle\Gamma_{\rm a}(B_s(t)\to f\rangle dt}{\int_0^\infty\langle\Gamma_{\rm a}(B_s(t)\to f\rangle dt}\tag{7}$$

where $\Gamma_{\rm a}$ is the time-dependent width under the assumption $\mathcal{A}_{\Delta\Gamma}^f=\mathcal{A}_{\rm a}$. Here we posit that the experimenter can estimate $\varepsilon(t)$ with good accuracy from auxiliary measurements, typically from control channels, or else from Monte Carlo simulations. The bias will be therefore a function of $\mathcal{A}_{\rm a}$:

$$\delta(\mathcal{A}_{\Delta\Gamma}^f,y_s,\mathcal{A}_{\rm a})=\frac{\cosh(\Gamma_s y_s t_0)+\sinh(\Gamma_s y_s t_0)\frac{y_s+\mathcal{A}_{\Delta\Gamma}^f}{1+\mathcal{A}_{\Delta\Gamma}^f y_s}}{\cosh(\Gamma_s y_s t_0)+\sinh(\Gamma_s y_s t_0)\frac{y_s+\mathcal{A}_{\rm a}}{1+\mathcal{A}_{\rm a} y_s}}\tag{8}$$

which is by construction equal to 1 when the assumed value $\mathcal{A}_{\rm a}$ for $\mathcal{A}_{\Delta\Gamma}^f$ coincides with the physical one. Hence in practice $\varepsilon_{\rm exp}$ has to be calculated for each value of $\mathcal{A}_{\rm a}$, so that for the same experimental event yield the branching fraction can be properly estimated for an assumed model. We illustrate the numerical impact of the bias δ in Fig. 1. Here δ is shown as a function of

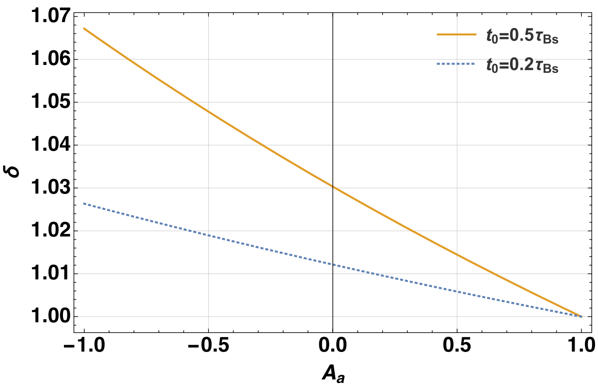

Fig. 1. The bias δ as a function of the assumed value for $\mathcal{A}^f_{\Delta\Gamma}$, $\mathcal{A}_a$, for a decay with $\mathcal{A}^f_{\Delta\Gamma} = 1$. The efficiency function is modelled as a step function $\theta(t - t_0)$, with two realistic t_0 values.

$\mathcal{A}_a$, under the hypothesis that the physical $\mathcal{A}^f_{\Delta\Gamma} = 1$, and for two realistic values of t_0. In this example the bias amounts to overestimating the measured branching fraction with respect to the real one: as soon as the assumed value of $\mathcal{A}^f_{\Delta\Gamma}$, $\mathcal{A}_a$, departs from the physical value, the bias δ is larger than 1. This is as expected. In fact, with the considered efficiency function, estimating $\varepsilon_{\rm exp}$ with $\mathcal{A}_a < +1$ means that one is undersampling the heavy eigenstate, the only one actually contributing if the physical $\mathcal{A}^f_{\Delta\Gamma} = +1$. As a consequence, $\varepsilon_{\rm exp}$ in eq. (5) is smaller than the correct value that one would obtain for the physical $\mathcal{A}^f_{\Delta\Gamma} = +1$. As the figure shows, for values as low as $t_0 = 0.5\tau_{B_s}$ the bias can be as large as $\sim 7\%$.

Conversely, if one assumes that the inefficiency is for high proper-time values, $\varepsilon(t) = \theta(t_0 - t)$, then the bias will be in the opposite direction. In general, in real experiments one can expect inefficiencies both at low and at high proper-time values, so that the convolution with the expected time distribution will be performed by means of Monte Carlo simulations.

3. Current status

In the majority of recent B_s branching fraction measurements, the effect of the possible model dependence generated by a time-dependent efficiency has been treated as a systematic uncertainty, e.g. see Refs. [12–15]. On the other hand, only in very few examples is the effect treated as full-fledged dependence – which is what we advocate. An example of such treatment is the latest LHCb measurement of $\mathcal{B}(B_s \to \mu^+\mu^-)$ [16], where the branching fraction is quoted for the SM assumption ($\mathcal{A}^f_{\Delta\Gamma} = 1$), and corrections for $\mathcal{A}^f_{\Delta\Gamma} = \{0, -1\}$ are reported. The size of the variation is respectively $+4.6\%$ ($\mathcal{A}^f_{\Delta\Gamma} = 0$) and $+10.9\%$ ($\mathcal{A}^f_{\Delta\Gamma} = -1$). This is displayed in Fig. 2 where the three values are shown in the two-dimensional plane of branching fraction and $\mathcal{A}^f_{\Delta\Gamma}$, together with the SM prediction [17]. We also note that Ref. [16] reports a measurement of the $B_s \to \mu^+\mu^-$ effective lifetime ($\tau_{\mu\mu}$) [10,18,19], which is in turn directly sensitive to $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$ itself. Therefore the two observables could already be represented in a two-dimensional plane, although the current $\tau_{\mu\mu}$ measurement would translate into $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = 8 \pm 11$, whose central value lies in the non-physical region but with large uncertainty. An illustrative example of such a correlated measurement is again in Fig. 2. In particular, the lines labelled "future contours" represent 1- and 2-σ contours assuming the current central value of the branching fraction with $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = 1$, and a tenfold smaller uncertainties with respect to the LHCb measurement [16].

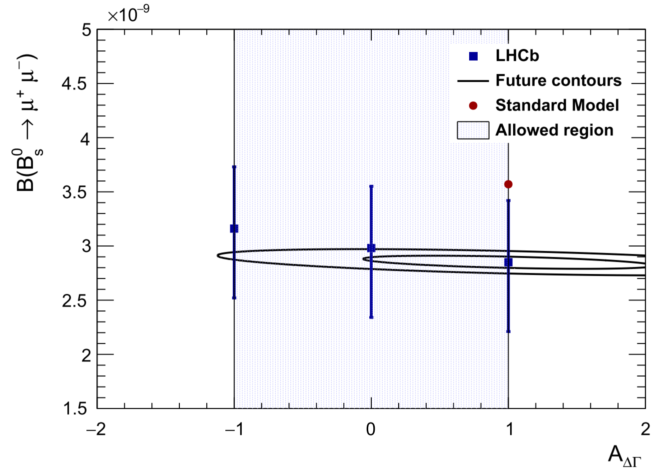

Fig. 2. LHCb measurement of the $B_s \to \mu^+\mu^-$ branching fraction vs. $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$ (blue squares) [16]. The respective SM predictions are also reported (red circle). Black ellipses show 1- and 2-σ contours of a possible future measurement of the two observables simultaneously (see text). (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

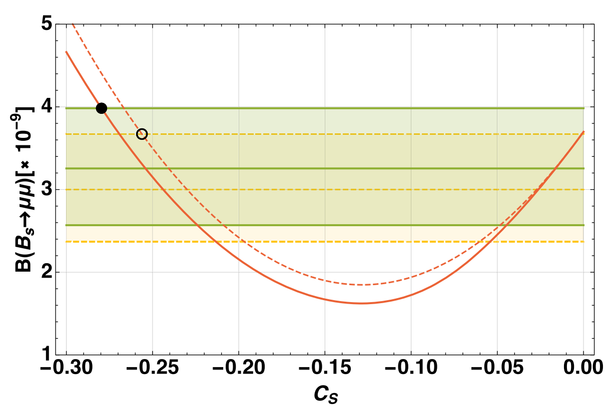

Fig. 3. Red lines: theory predictions as a function of a scalar Wilson-coefficient shift $C_S = -C_P$, for $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1$ (dashed) and respectively $\mathcal{A}_{\Delta\Gamma}(C_S)$ (solid). Horizontal bands: experimental ranges for $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1$ (yellow dashed), and respectively $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}(\bar{C}_S)$, where $\bar{C}_S$ corresponds to the filled dot in the figure. See text for more details.

4. Biases on the Wilson coefficients

Neglecting the discussed variation can lead to an over-constraining of the theory parameter space, notably in models with sizeable scalar or pseudo-scalar contributions (with arbitrary phases), as illustrated by the following example. Let us consider a shift to the Wilson coefficients $C_{S,P}$ of the operators

$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,, \tag{9}$$

that can give sizeable contributions to the $B_s \to \mu^+\mu^-$ rate. Let us assume they fulfil the constraint $C_S = -C_P$, as generally expected for new physics above the electroweak symmetry-breaking scale [20]. The $\mathcal{B}(B_s \to \mu^+\mu^-)$ prediction as a function of C_S, and corrected by the factor $(1 + \mathcal{A}^f_{\Delta\Gamma}\, y_s)/(1 - y_s^2)$ (see eq. (4)), is displayed in Fig. 3 for two choices of $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$. The first choice is $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1$, shown as a red dashed curve. The latest LHCb measurement corresponding to this value of $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$ is shown as a yellow dashed horizontal band. The upper line of this band and the red dashed curve intersect at $C_S \simeq -0.25$ which may be taken as a 1σ bound on C_S. However, $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = \mathcal{A}^{\mu\mu}_{\Delta\Gamma}(C_S)$ [10]: the theory prediction corrected for this dependence, again through the $(1 + \mathcal{A}^f_{\Delta\Gamma}(C_S)\, y_s)/(1 - y_s^2)$ factor, is displayed as a solid red curve. Concurrently, also the experimental measurement is a function of $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$ as we have discussed. In the figure we show as a solid green band the measurement for $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = -0.56$, which corresponds to $C_S \simeq -0.28$, the value at which the theory prediction and the experimental central value $+1\sigma$ intersect. It is this C_S value that should be taken as the correct 1σ bound on C_S. We see that the difference between the two bounds, obtained respectively for $\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = +1$ and the correct $\mathcal{A}^{\mu\mu}_{\Delta\Gamma}$, is of O(10%).

Of course, the size of the effect just described will depend on the relative importance of scalar operators in the process being constrained. While intuitively the size $\lesssim$ O(10%) of the experimental bias – concretely, the variation of the branching-ratio measurement with $\mathcal{A}^f_{\Delta\Gamma}$ – is expected to provide an upper bound on the size of the corresponding bias on Wilson coefficients, we would like to put forward an example where the latter bias turns out to be larger. This example is relevant in view of the existing discrepancies in flavour physics, and underlines the necessity of precisely tracking the theory that is being constrained (hence assumed), as soon as the measured $\mathcal{A}^f_{\Delta\Gamma}$ in a given decay mode $B_s \to f$ should differ from the assumed one. This in turn highlights the importance of effective-lifetime measurements, pointed out in [10,18,19], that are a probe of $\mathcal{A}^f_{\Delta\Gamma}$. Let us consider the effective-theory description emerging from present-day discrepancies in $b \to s\mu\mu$ data, in particular by the lepton universality violation (LUV) tests R_K and R_{K^*} measurements [21,22]. Among the preferred explanations in terms of shifts to the Wilson coefficients of the $b \to s$ effective Hamiltonian, an important one is the scenario with opposite contributions to the operators $\mathcal{O}_9 \propto (\bar{s}\gamma_L^\alpha b)\,(\bar{\mu}\gamma_\alpha \mu)$ and $\mathcal{O}_{10} \propto (\bar{s}\gamma_L^\alpha b)\,(\bar{\mu}\gamma_\alpha\gamma^5 \mu)$. In particular a shift $\delta C_9^\mu = -\delta C_{10}^\mu \simeq -13\%|C_{10}^{\rm SM}| \approx -0.5$ to the $C^\mu_{9(10),{\rm SM}}$ Wilson coefficients is preferred [23,24]. The structure resulting from such shifts, $(\bar{s}\gamma_L^\alpha b)\,(\bar{\mu}\gamma_{\alpha L}\mu)$, has a $(V - A) \times (V - A)$ form and as such is very suggestive from the point of view of the ultraviolet dynamics, e.g. it can be straightforwardly rewritten in terms of $SU(2)_L$-invariant fields [20,25]. Since the effective scale of such structure lies typically above the electroweak scale, the fermion fields involved will in general not be aligned with the mass basis. Hence, below the electroweak symmetry-breaking scale, such structure, introduced to account for LUV, will also generate lepton flavour violating dynamics, whose size is related to the *measured* amount of LUV [26]. From this argument, the analogous $(V - A) \times (V - A)$ operator $(\bar{s}\gamma_L^\alpha b)\,(\bar{\ell}\gamma_{\alpha L}\ell')$ would contribute to processes such as $B_s \to \ell^-\ell'^+$, if a similar structure with the appropriate flavour indices is also favoured to explain LUV. Such argument does not forbid contributions from scalar operators of comparable size. Actually, constraints on scalar contributions (for recent analyses see [27,28]) are substantially weakened to the extent that a shift to C_{10} is at play, as we discuss next.[2] In any of the $B_s \to \ell^-\ell'^+$ decays, contributions from the Wilson coefficients of the operators

$$\begin{aligned}
\mathcal{O}_9^{\ell\ell'} &\equiv \tfrac{e^2}{16\pi^2}(\bar{s}\gamma_L^\alpha b)\,(\bar{\ell}\gamma_\alpha\ell')\,, \qquad & \mathcal{O}_{10}^{\ell\ell'} &\equiv \tfrac{e^2}{16\pi^2}(\bar{s}\gamma_L^\alpha b)\,(\bar{\ell}\gamma_\alpha\gamma_5\ell')\,,\\
\mathcal{O}_S^{\ell\ell'} &\equiv m_b\tfrac{e^2}{16\pi^2}(\bar{s}P_R b)\,(\bar{\ell}\ell')\,, \qquad & \mathcal{O}_P^{\ell\ell'} &\equiv m_b\tfrac{e^2}{16\pi^2}(\bar{s}P_R b)\,(\bar{\ell}\gamma_5\ell')\,,
\end{aligned} \tag{10}$$

are of the form (see e.g. [29])

$$\mathcal{B}(B_s \to \ell_1^+\ell_2^-) \propto (1 - \hat{m}^2)|F_P + \hat{M}C_{10}|^2 + (1 - \hat{M}^2)|F_S - \hat{m}C_9|^2\,, \tag{11}$$

where $\hat{m} \equiv \hat{m}_{\ell_2} - \hat{m}_{\ell_1}$, $\hat{M} \equiv \hat{m}_{\ell_1} + \hat{m}_{\ell_2}$, with hats denoting that the given mass is normalized by M_{B_s}, and where $F_{S,P} \approx M_{B_s}C_{S,P}$. A sizeable departure in $\mathcal{A}^f_{\Delta\Gamma}$ from unity would signal accordingly sizeable contributions from $C_{S,P}$. In particular, C_P could partly cancel (depending on its phase, which is unconstrained) the contribution from C_{10} so that the measured signal would actually be due to C_S dominantly, and this is the Wilson coefficient that the measurement would constrain in reality. In these circumstances, if one insisted with the assumption $\mathcal{A}^f_{\Delta\Gamma} = +1$, one would, instead, interpret the branching-ratio measurement as a constraint to C_{10}, under the hypothesis that scalar contributions are negligible. So, the combination of Wilson coefficients that is actually constrained by a $B_s \to f$ decay measurement needs be carefully tracked as soon as $\mathcal{A}^f_{\Delta\Gamma}$ is measured and departs from unity.[3]

In short, it will be important to present future experimental measurements in a two-dimensional plane of the branching fraction and either $\mathcal{A}^f_{\Delta\Gamma}$ or another observables correlated with it, such as the effective lifetime. A quite useful example is Ref. [30], where the limit is quoted for $\mathcal{A}^f_{\Delta\Gamma} = \{-1, 1\}$, thus allowing a handy extrapolation to any scenario with shifts to the operators in the second line of eq. (10).

5. Other considerations

It is clear that if time information is available and the statistics are sufficient to perform a time-dependent analysis, the effect described in this paper is no longer present as the time-dependent efficiency can be convoluted with the correct time distribution. Secondly, this effect is even more relevant when combining different experimental measurements, as different apparatuses can have a different time-dependent efficiency and thus a different dependence on $\mathcal{A}^f_{\Delta\Gamma}$. In third place, since this effect depends experimentally on the apparatus efficiency *and not on the yield*, it is also present when setting limits on branching fractions; for example, it does apply to limits on channels forbidden in the SM and, as we argued, it may be a large effect there.

Finally, we note that this effect was presented here for the case of B_s mesons but in fact it is more general. The measurement of a branching fraction of a meson that oscillates is model dependent if

1. the experiment is realistic, i.e. $\varepsilon(t)$ is not constant over the whole proper-time range;
2. the final state f is available to both mass eigenstates;
3. the difference in lifetime between the mass eigenstates is not negligible with respect to the meson average lifetime.

In practice the last condition is realized only for B_s mesons so far. In fact, while for B_s mesons $\Delta\Gamma_s$ is sizeable compared to Γ_s, this is not true for B_d or D^0 mesons. In the other relevant case of K^0 mesons, the difference in lifetimes between K_S and K_L is so large that branching fractions are directly reported for the two mass eigenstates rather than for the flavour ones. If one had to report branching fractions for the K^0 and $\bar{K}^0$ the effect here described would be maximal.

[2] Sensitivity of rare decays to scalar operators is warranted by the fact that the fermion mass necessary to perform the chiral flip may actually be a large mass, at variance with the SM case. Sizeable scalar contributions are accordingly ubiquitous as soon as the bosonic sector is enlarged with respect to the sheer SM content.

[3] We emphasise that our argument holds for LU and lepton-flavour conserving decays alike.

6. Summary

Every measurement of a B_s untagged time-integrated branching fraction is model dependent due to the time dependence of the experimental efficiency [1,3]. We show with two real-life examples that this dependence can be as large as O(10%), and argue that it needs be properly tracked. We accordingly suggest that B_s branching-fraction measurements be presented in a two-dimensional plane with the parameter $\mathcal{A}^f_{\Delta\Gamma}$ or another observable correlated with it, even in the case the latter would not be yet measurable. We also argue that theoretical predictions within a given model should be compared with the measured value of the branching fraction corresponding to the $\mathcal{A}^f_{\Delta\Gamma}$ value calculated assuming the same model. These practices should also be carried out for upper limits on the branching fraction of non-observed channels, notably those forbidden in the SM, where new physics is dominant, rather than just a correction. Ignoring this effect may lead to over-constraining new-physics couplings, or even to constraints that qualitatively depart from the dynamics actually at play.

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