Connecting $b \to s\mu\bar{\mu}$ anomalies to enhanced rare nonleptonic B_s decays in Z' model

PoS(ICHEP2018)124

Gaber Faisel
Department of Physics, Faculty of Arts and Sciences, Süleyman Demirel University, Isparta 32260, Turkey
E-mail: gaberfaisel@sdu.edu.tr

Jusak Tandean[*†]
Department of Physics, National Taiwan University, Taipei 106, Taiwan
Physics Division, National Center for Theoretical Sciences, Hsinchu 300, Taiwan
E-mail: jtandean@yahoo.com

The anomalous results of several recent $b \to s\mu^+\mu^-$ measurements could be initial evidence of new physics beyond the standard model in $b \to s$ transitions. Supposing this to be the case, we consider a scenario in which a heavy Z' boson is responsible for the anomalies. We further assume that its interactions also influence the rare nonleptonic decays of the B_s meson which tend to be dominated by electroweak-penguin contributions and are purely isospin-violating. Most of these B_s decay modes are not yet observed, and their rates are expected to be relatively small in the standard model. Taking into account various constraints, we find that the Z' effects can enhance the rates of some of the decays, particularly $\bar{B}_s \to \eta\pi^0, \phi\pi^0$, by up to an order of magnitude above their standard-model predictions. This Z' scenario is therefore potentially testable in upcoming experiments at LHCb.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

[*]Speaker.
[†]Research supported by Taiwan MOE Academic Excellence Program (Grant No. 105R891505).

The latest data on various $b \to s\mu^+\mu^-$ transitions have revealed intriguing deviations [1] from the expectations of the standard model (SM). These anomalies may be harbingers of physics beyond the SM, although their statistical significance is still insufficient for drawing a firm conclusion. Model-independent theoretical analyses have in fact pointed out that new physics (NP) could explain them [2]. This would suggest that they might be empirically confirmed in the near future to have originated from beyond the SM. Thus, it seems timely to explore what if the same NP could have appreciable effects on some other $b \to s$ processes.

Here we present the results of our recent study [3] entertaining such a possibility in a scenario where a nonstandard electrically neutral and uncolored spin-one particle, the Z' boson, is responsible for the $b \to s\mu^+\mu^-$ anomalies. Specifically, we investigate the potential implications for the nonleptonic decays $\bar{B}_s \to (\eta, \eta', \phi)(\pi^0, \rho^0)$, which are purely isospin-violating and most of which are not yet observed [4]. In the SM, their amplitudes proceed from $b \to s$ four-quark operators $O^u_{1,2}$ and $O_{7,8,9,10}$ derived from charmless tree and electroweak-penguin diagrams, respectively. In contrast, QCD-penguin operators, $O_{3,4,5,6}$, which conserve isospin, do not affect these processes. Since the impact of $O^u_{1,2}$ on them is suppressed by a factor $|V_{us}V_{ub}|/|V_{ts}V_{tb}| \sim 0.02$ involving Cabibbo-Kobayashi-Maskawa (CKM) matrix elements, their amplitudes tend to be dominated by the electroweak-penguin contributions [5]. Consequently, their rates in the SM are estimated to be comparatively small [5, 6, 7, 8, 9, 10], which motivated earlier works suggesting that one or more of these decays might be sensitive to NP signals [11].

In many models beyond the SM, new ingredients may modify the Wilson coefficients C_i of O_i and/or give rise to extra operators $\tilde{O}_i$, which are the chirality-flipped counterparts of O_i. (The expressions for $O_{1,2,\cdots,10}$ can be found in, *e.g.*, [10].) A flavor-violating Z' boson may contribute at tree level to part or all of the penguin sector, depending on the details of Z' properties.

In our Z' scenario of interest, the pertinent nonstandard interactions are described by [3]

$$\begin{aligned}\mathscr{L}_{Z'} \supset & -\left[\bar{s}\gamma^\kappa\left(\Delta^{sb}_L P_L + \Delta^{sb}_R P_R\right) b\, Z'_\kappa \,+\, \text{H.c.}\right] - \Delta^{\mu\mu}_V\, \bar{\mu}\gamma^\kappa \mu\, Z'_\kappa \\ & - \left[\bar{u}\gamma^\kappa\left(\Delta^{uu}_L P_L + \Delta^{uu}_R P_R\right) u + \bar{d}\gamma^\kappa\left(\Delta^{dd}_L P_L + \Delta^{dd}_R P_R\right) d\right] Z'_\kappa\,, \end{aligned} \tag{1}$$

where the constants $\Delta^{sb}_{L,R}$ are generally complex, while $\Delta^{\mu\mu}_V$ and $\Delta^{uu,dd}_{L,R}$ are real due to the Hermiticity of $\mathscr{L}_{Z'}$, and $P_{L,R} = (1 \mp \gamma_5)/2$. We assume that any other possible Z' couplings to SM fermions are negligible and that the Z' does not mix with SM gauge bosons but is not necessarily a gauge boson. Also, for simplicity we focus on the case in which $\Delta^{sb}_{L,R} = \rho_{L,R} V^*_{ts} V_{tb}$ with real $\rho_{L,R}$.

These Z' parameters are subject to a number of restrictions. Obviously, the products $\Delta^{sb}_{L,R}\Delta^{\mu\mu}_V$ must have values consistent with the observed $b \to s\mu^+\mu^-$ anomalies. Since $\Delta^{sb}_{L,R}$ influence B_s-$\bar{B}_s$ mixing at tree level, restraints implied by its data are to be satisfied as well. Interestingly, together these two conditions translate into the requirement [3] $\Delta^{sb}_L \sim 10\Delta^{sb}_R$ and so $\rho_L \sim 10\rho_R$. Also germane is the fact that $\bar{B}_s \to \phi\rho^0$ has been seen with a branching fraction of $(2.7 \pm 0.8) \times 10^{-7}$ [4], which is compatible with its SM estimates albeit with sizable errors [6, 7, 8] and hence leads to limitations on some of the Z' couplings. In addition, they have to respect the bounds inferred from collider measurements.

In numerical work, for definiteness we take $\rho_R = 0.1\,\rho_L$ and the Z' mass to be $m_{Z'} = 1\,\text{TeV}$. Adopting the framework of soft-collinear effective theory (SCET) [8, 9, 10], we then compute the SM and Z' contributions to each decay mode. Combining them, we write resulting amplitudes $\mathscr{A}$, in units of 10^{-9} GeV, as [3]

$$\begin{aligned}
\mathscr{A}_{\bar{B}_s\to\eta\pi^0} &\simeq 1.67+0.47i+1.1(3.96-0.08i)(\delta_L-\delta_R)\rho_L\,, \\
\mathscr{A}_{\bar{B}_s\to\eta'\pi^0} &\simeq 0.48-2.48i-1.1(1.90-0.04i)(\delta_L-\delta_R)\rho_L\,, \\
\mathscr{A}_{\bar{B}_s\to\phi\pi^0} &\simeq -2.88-1.69i-0.9(7.85-0.15i)(\delta_L-\delta_R)\rho_L\,, \\
\mathscr{A}_{\bar{B}_s\to\eta\rho^0} &\simeq 2.56+0.77i+1.1(6.32-0.12i)(\delta_L+\delta_R)\rho_L\,, \\
\mathscr{A}_{\bar{B}_s\to\eta'\rho^0} &\simeq 0.78-4.12i-1.1(3.03-0.06i)(\delta_L+\delta_R)\rho_L\,, \\
\mathscr{A}_{\bar{B}_s\to\phi\rho^0} &\simeq -6.53-1.47i-0.9(15.3-0.3i)(\delta_L+\delta_R)\rho_L\,,
\end{aligned} \tag{2}$$

where $\delta_{L,R} = \Delta^{uu}_{L,R} - \Delta^{dd}_{L,R}$.

In the absence of the Z' portions, (2) leads to the SM predictions for the branching fractions collected in the last column of Table 1. The two errors in each of the SCET entries are due to flavor-SU(3)-breaking effects which we assume to be 20% and due to uncertainties in the SCET parameter fits to data done in [8, 9]. For comparison, in the second and third columns we quote numbers calculated with QCD factorization (QCDF) [6] and perturbative QCD (PQCD) [7] approaches. Evidently, these different methods produce results comparable to each other, in light of the errors in the predictions. The important implication is that NP would not be easily noticeable in the decay rates unless it could enhance them by much more than a factor of 2. This possibility may be unlikely to be realized in $\bar{B}_s \to \phi\rho^0$, which has an experimental rate in line with SM expectations. Nevertheless, substantial enhancement can still occur in some of the other channels.

Including the Z' terms in the amplitudes and imposing 2σ ranges of the various empirical constraints, we scan the allowed parameter space to explore how much the decay rates can increase with respect to their SM values. We find that the enhancement factors for $\bar{B}^0_s \to \eta'\pi^0, (\eta,\eta')\rho^0$ can be at most only a few, partly because of the $\bar{B}_s \to \phi\rho^0$ requisite. On the other hand, the Z' impact on $\bar{B}^0_s \to (\eta,\phi)\pi^0$ can cause their rates to grow considerably, by up to an order of magnitude above their SM expectations, as illustrated in Fig. 1.

In conclusion, we have entertained the possibility that the anomalies manifest in the latest data on $b \to s\mu^+\mu^-$ processes arise from physics beyond the SM and that the same underlying NP also affects the rare nonleptonic decays of the $\bar{B}_s$ meson, most of which are not yet seen. Since the rates of these modes in the SM are comparatively low, one or more of them may be sensitive to NP signals. Adopting a scenario in which the NP is due to the interactions of a heavy Z' boson, we have investigated the implications for $\bar{B}^0_s \to (\eta,\eta',\phi)(\pi^0,\rho^0)$. Taking into account

Decay mode	QCDF	PQCD	SCET
$\bar{B}_s \to \eta\pi^0$	$0.05^{+0.03+0.02}_{-0.01-0.01}$	$0.05^{+0.02+0.01+0.00}_{-0.02-0.01-0.00}$	$0.025 \pm 0.010 \pm 0.003$
$\bar{B}_s \to \eta'\pi^0$	$0.04^{+0.01+0.01}_{-0.00-0.00}$	$0.11^{+0.05+0.02+0.00}_{-0.03-0.01-0.00}$	$0.052 \pm 0.021 \pm 0.015$
$\bar{B}_s \to \phi\pi^0$	$0.12^{+0.02+0.04}_{-0.01-0.02}$	$0.16^{+0.06+0.02+0}_{-0.05-0.02-0}$	$0.091 \pm 0.036 \pm 0.016$
$\bar{B}_s \to \eta\rho^0$	$0.10^{+0.02+0.02}_{-0.01-0.01}$	$0.06^{+0.03+0.01+0.00}_{-0.02-0.01-0.00}$	$0.059 \pm 0.023 \pm 0.006$
$\bar{B}_s \to \eta'\rho^0$	$0.16^{+0.06+0.03}_{-0.02-0.03}$	$0.13^{+0.06+0.02+0.00}_{-0.04-0.02-0.01}$	$0.141 \pm 0.056 \pm 0.042$
$\bar{B}_s \to \phi\rho^0$	$0.18^{+0.01+0.09}_{-0.01-0.04}$	$0.23^{+0.09+0.03+0.00}_{-0.07-0.01-0.01}$	$0.36 \pm 0.14 \pm 0.04$

Table 1: Branching fractions, in units of 10^{-6}, of $\bar{B}_s \to (\eta,\eta',\phi)(\pi^0,\rho^0)$ decays in the SM.

PoS(ICHEP2018)124

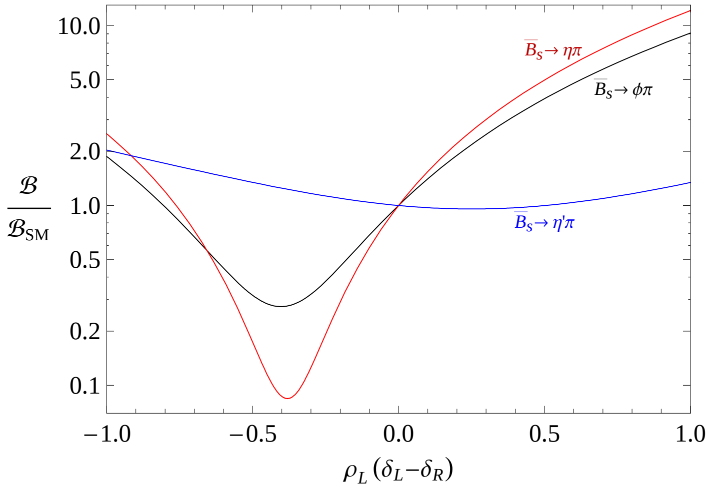

Figure 1: Calculated branching fractions of $\bar{B}_s \to (\eta, \eta', \phi)\pi^0$ (red, blue, and black curves, respectively), normalized by their corresponding SM SCET central values listed in Table 1, versus the Z' coupling product $\rho_L(\delta_L - \delta_R)$ in the case where $\rho_R = 0.1\,\rho_L$ and $m_{Z'} = 1\,\text{TeV}$.

the pertinent restrictions, we have shown that the Z' effects could amplify the rates of two of these modes, $\bar{B}^0_s \to (\eta, \phi)\pi^0$, by as much as an order of magnitude relative to their SM predictions. These decays are therefore potentially very consequential should future experiments establish that the $b \to s\mu^+\mu^-$ anomalies are really evidence of NP. For good measure, it is worth noting that two other rare nonleptonic B_s transitions, namely $\bar{B}^0_s \to (\eta, \phi)\omega$, may be similarly significant, as discussed in [12].

References

[1] I. Bediaga *et al.* [LHCb Collaboration], arXiv:1808.08865 [hep-ex].

[2] B. Capdevila *et al.*, JHEP **1801**, 093 (2018); W. Altmannshofer *et al.*, Phys. Rev. D **96**, 055008 (2017).

[3] G. Faisel and J. Tandean, JHEP **1802**, 074 (2018) [arXiv:1710.11102].

[4] M. Tanabashi et al. [Particle Data Group], Phys. Rev. D **98**, no. 3, 030001 (2018).

[5] R. Fleischer, Phys. Lett. B **332**, 419 (1994); N.G. Deshpande *et al.*, Phys. Lett. B **345**, 547 (1995).

[6] H.Y. Cheng and C.K. Chua, Phys. Rev. D **80**, 114026 (2009) [arXiv:0910.5237].

[7] A. Ali *et al.*, Phys. Rev. D **76**, 074018 (2007) [hep-ph/0703162].

[8] C. Wang, S.H. Zhou, Y. Li, and C.D. Lu, Phys. Rev. D **96**, no. 7, 073004 (2017) [arXiv:1708.04861].

[9] W. Wang, Y.M. Wang, D.S. Yang, and C.D. Lu, Phys. Rev. D **78**, 034011 (2008) [arXiv:0801.3123].

[10] A.R. Williamson and J. Zupan, Phys. Rev. D **74**, 014003 (2006); Erratum, *ibid*. **74**, 03901 (2006).

[11] J. Hua, C.S. Kim, and Y. Li, Phys. Lett. B **690**, 508 (2010); L. Hofer, D. Scherer, and L. Vernazza, JHEP **1102**, 080 (2011); G. Faisel, JHEP **1208**, 031 (2012); Phys. Lett. B **731**, 279 (2014); Eur. Phys. J. C **77**, no. 6, 380 (2017); Q. Chang, X.Q. Li, and Y.D. Yang, J. Phys. G **41**, 105002 (2014); C. Bobeth, M. Gorbahn, and S. Vickers, Eur. Phys. J. C **75**, no. 7, 340 (2015).

[12] G. Faisel and J. Tandean, arXiv:1810.11437 [hep-ph].