Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 285–286 (2017) 39–44

www.elsevier.com/locate/nppp

Present Status of $b \to s\ell^+\ell^-$ Anomalies☆

Farvah Mahmoudi

Univ Lyon, Univ Lyon 1, ENS de Lyon, CNRS, Centre de Recherche Astrophysique de Lyon UMR5574, F-69230 Saint-Genis-Laval, France;

Theoretical Physics Department, CERN, CH-1211 Geneva 23, Switzerland

Tobias Hurth

PRISMA Cluster of Excellence and Institute for Physics (THEP)

Johannes Gutenberg University, D-55099 Mainz, Germany

Siavash Neshatpour

School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM)

P.O. Box 19395-5531, Tehran, Iran

Abstract

We discuss the observed deviations in $b \to s\ell^+\ell^-$ processes from the Standard Model predictions and present global fits for the New Physics description of these anomalies. We further investigate the stability of the global fits under different theoretical assumptions and suggest strategies and a number of observables to clear up the source of the anomalies.

Keywords: B-Physics, Global Fit, Lepton Flavour Universality Violation

1. Introduction

The angular observables of the $B \to K^*\mu^+\mu^-$ decay were measured in 2013 by the LHCb collaboration using 1 fb^{-1} of data [1]. While most of the measured observables agreed with their Standard Model (SM) predictions, the angular observable P_5' was in 3.7σ tension with respect to the SM prediction, in the $q^2 \in [4.30, 8.63]$ GeV^2 bin. Assuming the anomaly is not due to an underestimation of the hadronic effects or a statistical fluctuation in the experimental data, global analysis of $b \to s$ data indicated that a New Physics (NP) explanation for this anomaly is in the effective theory language a reduction of about 25% in the Wilson coefficient C_9 [2–6]. In 2014, LHCb presented experimental results for the ratio $R_K \equiv BR(B^+ \to K^+\mu^+\mu^-)/BR(B^+ \to K^+e^+e^-)$ in the $q^2 \in [1, 6]$ GeV^2 bin which was in 2.6σ tension with the SM prediction [7]. This anomaly which points toward violation of lepton flavour universality can be explained through a reduction in C_9^μ which is consistent with the NP explanation for the P_5' anomaly [8, 9]. This observable, unlike the $B \to K^*\mu^+\mu^-$ observables is theoretically very clean. Furthermore, in 2015 the LHCb collaboration measured a number of $B_s \to \phi\mu^+\mu^-$ observables where the branching ratio in the $q^2 \in [1, 6]$ GeV^2 bin is in tension with the SM prediction at 3.2σ [10], which again can be explained with a reduction in C_9 [8]. In 2015, LHCb updated the measurements of $B \to K^*\mu^+\mu^-$ observables with 3 fb^{-1} of data where the tension in P_5' (in

☆Based on the talk by F.M. at the Sixth Workshop on Theory, Phenomenology and Experiments in Flavour Physics, Capri, June 2016.

Email addresses: nazila@cern.ch (Farvah Mahmoudi), tobias.hurth@cern.ch (Tobias Hurth), neshatpour@ipm.ir (Siavash Neshatpour)

http://dx.doi.org/10.1016/j.nuclphysbps.2017.03.008

the [4, 6] and [6, 8] GeV^2 bins) remained although with slightly less significance [11]. In addition, recently the Belle experiment presented a measurement of the angular observables of $B \to K^*\ell^+\ell^-$ [12] which shows a 2σ deviation for P_5' in the $q^2 \in [4,8]$ GeV^2 bin, which supports the LHCb result.

For the exclusive decays $B_{(s)} \to K^*(\phi)\mu^+\mu^-$, where the final state meson is a vector meson, the long-distance contributions of the electromagnetic and semileptonic operators ($O_{7,9,10}$) can be described through seven independent form factors $V, A_{0,1,2}, T_{1,2,3}$. The form factors are usually considered a main source of uncertainty as non-perturbative calculations are required to estimate them. There are further hadronic effects from the four-quark and chromomagnetic operators (O_{1-6} and O_8, respectively) accompanied with the exchange of a virtual photon. The matrix elements of these operators cannot all be factorised into form factors, giving rise to non-factorisable corrections. At low q^2, in the heavy quark and large energy limit, these effects are calculable at leading order in Λ/m_b in QCD factorisation and its field-theoretical formulation of Soft-Collinear Effective Theory (SCET). However, higher powers of the non-factorisable effects are not known and until further calculations become available can only be "*guesstimated*" (a partial calculation of the power corrections for the $B \to K^*\ell^+\ell^-$ decay is available through a phenomenological description [13]).

In the low q^2 region the seven a priori independent form factors can be reduced to two soft form factors $\xi_{\perp,\|}$ [14], up to corrections of $O(\alpha_s)$ and $O(1/m_b)$, and while the former corrections have been calculated the latter remain unknown. These unknown factorisable power corrections can be guesstimated through dimensional arguments or by fitting ad hoc functions when comparing with the full form factors [15]. Reduction of the seven form factors to two soft form factors makes it possible to construct angular observables which are (soft) form factor independent at leading order [16, 17]. One set of such form factor independent observables includes the so-called optimised (P_i') observables. These observables are specially interesting in the absence of correlations among the form factor uncertainties, since otherwise there can be an overestimation of the theoretical errors.

The two theoretical strategies for $B_{(s)} \to K^*(\phi)\ell^+\ell^-$ decays are therefore using the soft form factors (soft FF) or the full form factors (full FF). In either of the approaches the significance of the anomalies is dependent on the estimated size of the power corrections. For the soft FF approach, we estimate the factorisable and non-factorisable power corrections collectively by varying the tranversity amplitudes according to

$$A_{\perp,\|,0} \to A_{\perp,\|,0} \times \left(1 + b_i e^{\theta_i} + c_i (q^2/6\ \text{GeV}^2) e^{\phi_i}\right),$$

where i stands for $\perp, \|, 0$, and with $\theta_i, \phi_i \in (-\pi, \pi)$ and $b_i \in (-0.1, +0.1)$, $(-0.2, +0.2)$, $(-0.3, +0.3)$ ranges and $c_i \in (-0.25, +0.25)$, $(-0.5, +0.5)$, $(-0.75, +0.75)$ ranges which in the following we refer to as 10, 20 and 30% error for the power corrections, respectively. In the full FF approach only the non-factorisable power corrections are relevant which we consider by multiplying the hadronic part of the tranversity amplitudes by a multiplicative factor similar to the soft FF case with $b_i \in (-0.05, +0.05), (-0.1, +0.1), (-0.2, +0.2), (-0.6, +0.6)$ and $c_i \in (-0.125, +0.125)$, $(-0.25, +0.25)$, $(-0.5, +0.5)$, $(-1.5, +1.5)$ for the 5, 10, 20 and 60% error, respectively.

2. Model-independent New Physics fits

We perform global fits using `SuperIso v3.6` [18–20] by calculating and minimising the χ^2 in which all the theoretical and experimental correlations are considered [21].

Assuming New Physics to appear only in one operator, a model independent analysis of all the relevant $b \to s$ data favours NP models with negative contributions to C_9. The best fit values for various one operator fits are given in Tab. 1, where the full FF approach with 10% power correction error has been considered for the theoretical prediction of the $B(s) \to K^*(\phi)\mu^+\mu^-$ observables.

	b.f. value	Pull_{SM}	68% C.L.	95% C.L.
$\delta C_9/C_9^{\text{SM}}$	-0.18	3.0σ	$[-0.25, -0.09]$	$[-0.30, -0.03]$
$\delta C_9'/C_9^{\text{SM}}$	$+0.03$	1.0σ	$[-0.05, +0.12]$	$[-0.11, +0.18]$
$\delta C_{10}/C_{10}^{\text{SM}}$	-0.12	1.9σ	$[-0.23, -0.02]$	$[-0.31, +0.04]$
$\delta C_9^e/C_9^{\text{SM}}$	$+0.25$	2.9σ	$[+0.11, +0.36]$	$[+0.03, +0.46]$
$\delta C_9^\mu/C_9^{\text{SM}}$	-0.21	4.2σ	$[-0.27, -0.13]$	$[-0.32, -0.08]$

Table 1: Best fit values and the corresponding 68 and 95% confidence level intervals in the one operator global fit to the $b \to s$ data. In the last two rows the fits are done when considering lepton non-universality.

As can be seen from the table, the most probable scenario is for a reduction in C_9^μ in which the SM value is in 4.2σ tension with the best fit value of C_9^μ.

It is also plausible for NP effects to appear in more than one operator. Assuming two operator fits, the results of the fits for the $\{C_9, C_{10}\}$, $\{C_9, C_9'\}$ and $\{C_9^e, C_9^\mu\}$ sets have been shown in Fig. 1 where we considered the