PROCEEDINGS OF SCIENCE

An overview of $b \to s\mu^+\mu^-$ decays at LHCb

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Rare B decays at LHCb, such as those mediated via $b \to s\mu^+\mu^-$ transitions, offer sensitivity to heavy New Physics particles. Over the last decade, a pattern of coherent tensions between observables measured in $b \to s\mu^+\mu^-$ transitions and their Standard Model predictions have emerged. An overview of the recent measurements by LHCb in $b \to s\mu^+\mu^-$ transitions are summarised in these proceedings, highlighting the tensions observed in both branching fraction measurements and angular analyses. Furthermore, the future prospects for the field are outlined.

The European Physical Society Conference on High Energy Physics - EPS-HEP 2023 -
20-25 August 2023
Universität Hamburg, Hamburg, Germany

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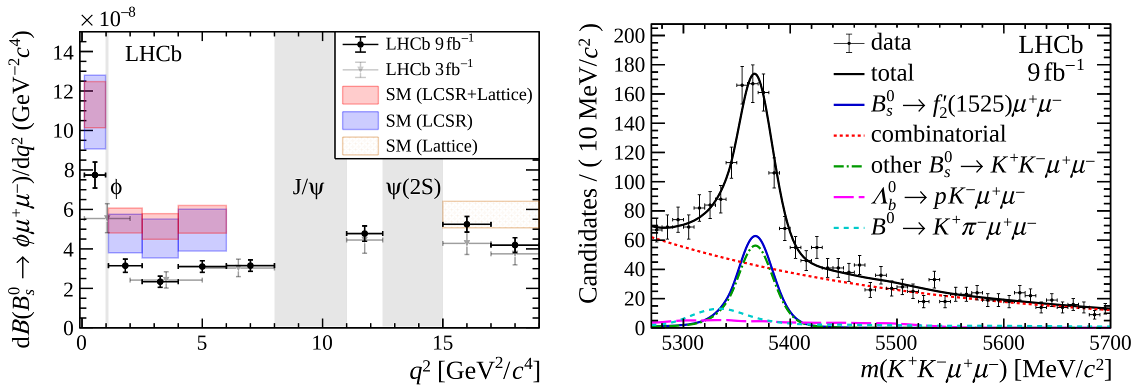
PoS(EPS-HEP2023)351

1. Introduction

Physics processes mediated by $b \to s\ell^+\ell^-$ quark-level transitions are flavour changing neutral currents (FCNC), that are largely suppressed and in fact forbidden at tree-level in the Standard Model. Therefore, they constitute excellent probes for possible New Physics contributions, that could enhance or suppress decay rates, modify angular distributions or introduce new sources for CP violation. These FCNC transitions have been extensively studied in mesonic and baryonic decay modes in the past years and these proceedings present the state of the art of the LHCb measurements of such decays involving muons in the final state. The presented measurement are based on data collected with the LHCb detector [1] located at CERN. It is highly suited for this type of decays, being a forward spectrometer with a high acceptance for the many b hadrons produced by the LHC, good particle identification and trigger performance on displaced tracks and excellent tracking efficiency. As a result most of the presented measurements are leading the experimental precision in the flavour field.

2. Mesonic $b \to s\mu^+\mu^-$ transitions

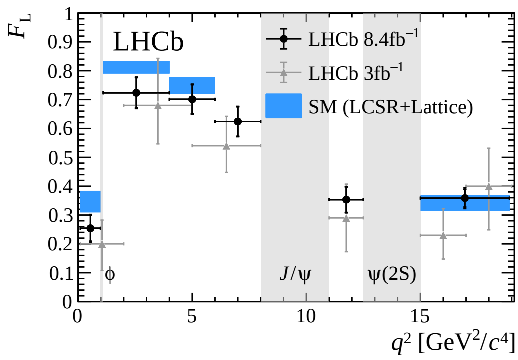
In mesonic $b \to s\mu^+\mu^-$ transitions, LHCb recently measured the differential branching fraction of $B^0_s \to \phi\mu^+\mu^-$ [2] as a function of the dilepton invariant mass squared, $q^2 = m^2(\mu^+\mu^-)$, with the full Run 1 and 2 dataset. The left plot of figure 1 shows, that the branching fraction appears to be lower than the Standard Model predictions obtained with lattice QCD. While in the central q^2 region, ranging from 1.1 to 6.0 GeV^2/c^4, there are in general discrepancies, the largest one goes up to $\sim 3.6\sigma$. This observation is consistent with previous measurements of other differential decay rates [3, 4]. However, the size of these discrepancies largely depends on the theory uncertainties, which are dominated by the so-called form factors. Here different groups obtain different estimations on the uncertainty and therefore the size of the tension is under discussion. In addition, LHCb published the first branching fraction measurement of the decay $B^0_s \to f_2'\mu^+\mu^-$ [2]. It is the first measurement of a $b \to s\mu^+\mu^-$ transitions from a B^0_s meson to a spin-2 meson with a significance of 9σ. The B^0_s invariant mass distribution is shown in the right plot of figure 1.



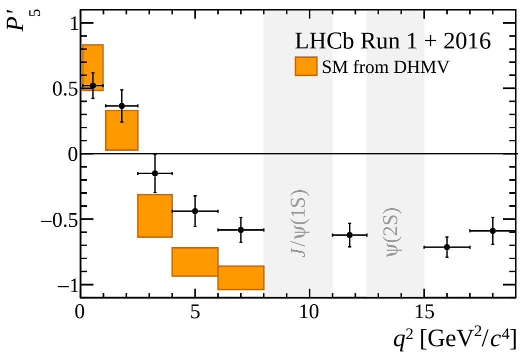
(a) $B^0_s \to \phi\mu^+\mu^-$ **(b)** $B^0_s \to f_2'\mu^+\mu^-$

Figure 1: Differential branching fractions extracted as a function of the di-muon invariant mass squared, (q^2), and the mass peak for the decay $B^0_s \to f_2'\mu^+\mu^-$ [2].

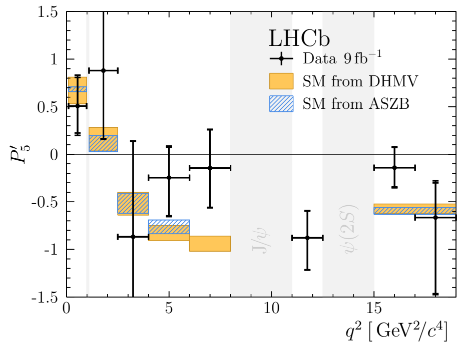
The measurements of FCNCs can be interpreted in terms of Wilson coefficients from model independent effective field theories to extract constraints for new physics models. Especially the measurements of angular distributions are suited to disentangle these different Wilson coefficients, due to the large number of parameters that describe the angular distribution. The decay rate of processes such as $B_s^0 \to \phi\mu^+\mu^-$ can be fully described by three angles: $\cos(\theta_l)$, $\cos(\theta_K)$ and ϕ, as defined in Ref. [5]. This angular analysis is performed with a fully flavour symmetric final state, leading to a smaller number of accessible angular coefficients. Figure 2 shows the fraction of longitudinal polarised hadrons, F_L, for the $B_s^0 \to \phi\mu^+\mu^-$ decay being in agreement with the Standard Model prediction. Another benefit of angular analyses is that they give access to observables, where the aforementioned form factor uncertainties cancel at leading order. The P_5' observable is one such optimised observable, which is not accessible for decays with flavour-symmetric fianl states, and is shown in Figure 2 for the decays $B^0 \to K^{*0}\mu^+\mu^-$ [6] (using 4.7 fb^{-1} of integrated luminosity) and $B^+ \to K^{*+}\mu^+\mu^-$ [7] (using the full Run 1+2 dataset). Notably, the measurement of the $B^+ \to K^{*+}\mu^+\mu^-$ decay is the first analysis of a full set of P-wave observables. A local tension of $2.4-2.7\sigma$ with respect to the Standard Model prediction is observed, depending on the q^2 intervals and the description of hadronic uncertainties. While these tensions persist in several decay modes, there is a long standing debate in the theory community whether these discrepancies can be explained by non-pertubative QCD contributions from charm-loops.



(a) $B_s^0 \to \phi\mu^+\mu^-$



(b) $B^0 \to K^{*0}\mu^+\mu^-$

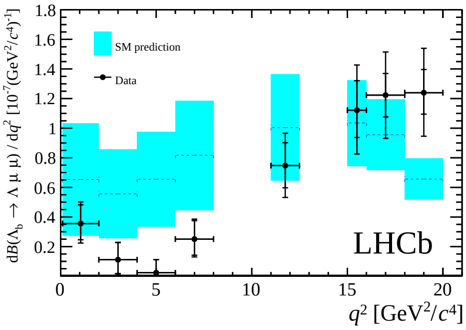


(c) $B^+ \to K^{*+}\mu^+\mu^-$

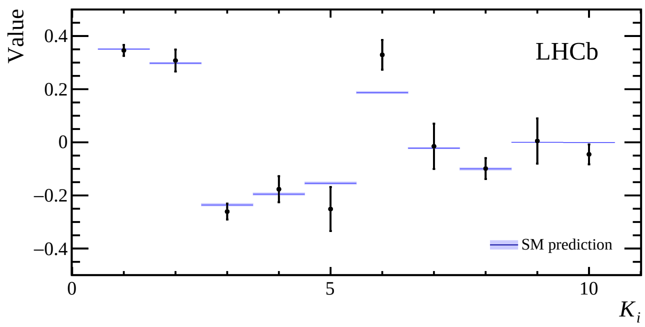
Figure 2: Angular observables measured by the LHCb collaboration [5–7] and the respective Standard Model predictions for different decays, in bins of the di-lepton invariant mass squared.

3. Baryonic $b \to s\mu^+\mu^-$ transitions

In baryonic $b \to s\mu^+\mu^-$ transitions only decays of Λ_b^0 baryons have been measured so far. This is motivated by the much larger production fraction of this b baryon compared to the other weakly decaying ones [8]. Recently, two different decay modes have been studied involving the Λ_b^0 decaying to a Λ^0 or to an excited Λ resonance. While the Λ^0 decays weakly, the excited Λ resonance is a strongly decaying particle which gives rise to different challenges both for the experiment and the theoretical analysis. Whereas the weakly decaying Λ^0 final state is theoretically more accessible, experimentally it is challenging to reconstruct, due to the comparably large lifetime of the Λ^0. Here, special care needs to be taken in the reconstruction of the decay products. The strongly decaying Λ^* always decays within the LHCb acceptance, however the complex structure with a plethory of interefering resonances poses considerable challenges both for the theoretical and experiment.
For the ground state decay $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ the measurement of the differential decay rate [9] shows similar tensions in the central q^2 bins below the J/ψ resonance as the mesonic ones described earlier. However, the analysis still needs to be updated to the full Run 1+2 dataset. A more recent measurement was the angular analysis of the decay using an integrated luminosity of 5 fb^{-1} [10]. This analysis was preformed with the method of moments and enabled the extraction of the full angular basis for the first time in $b \to s\mu^+\mu^-$ transitions of Λ_b^0 decays. All angular coefficients are consistent with the Standard Model predictions. Both the differential decay rate and the angular parameters can be seen in Figure 3.



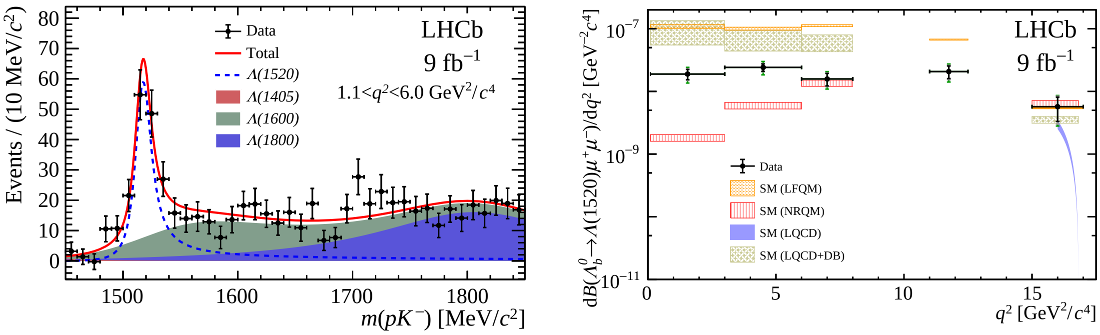
(a) Differential branching fraction



(b) Angular coefficients

Figure 3: Differential branching fraction [9] and angular coefficients [10] of the $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ decay, published by the LHCb collaboration.

The most recent publication was the first measurement of a $b \to s\mu^+\mu^-$ transition with a $\Lambda(1520) \to pK^-$ resonance [11]. The invariant mass distribution for the decay $\Lambda_b^0 \to \Lambda(1520)\mu^+\mu^-$ in the $1.1 < q^2 < 6.0$ GeV$^2/c^4$ bin and the differential decay rate can be seen in Figure 4. As there are several, disagreeing Standard Model predictions in the lower q^2 region [12–14], it is not possible to determine whether the trend of tensions with respect to the predictions also persists in these q^2 bins.



(a) Mass peak in the $1.1 < q^2 < 6.0$ GeV$^2/c^4$ bin **(b)** Differential decay rate

Figure 4: The mass peak for the decay $\Lambda_b^0 \to \Lambda(1520)\mu^+\mu^-$ and the differential branching fractions extracted as a function of the di-muon invariant mass [11]. In the right plot are also shown the SM predictions using the form factors calculated with the nonrelativistic quark model (NRQM) [12], light-front quark model (LFQM) [13], joint lattice QCD and dispersive bound (LQCD + DB) [14] and lattice QCD (LQCD) [15]. Note that the LQCD prediction is only available for q^2 above 16 GeV$^2/c^4$, and the trend instead of a rate average is shown.

4. Conclusion

LHCb has intensively studied semi-leptonic $b \to s\mu^+\mu^-$ transitions, offering valuable constraints to New Physics scenarios. However, the tensions with respect to the Standard Model predictions persist in different decay rates and angular observables. Many of the presented measurements are currently being updated with the full dataset collected and more channels are being studied. These include decay modes with electrons in the final state and additional FCNC transitions such as $b \to d\mu^+\mu^-$ decays [16, 17]. Moreover, the upgraded LHCb detector, with the removal of the hardware trigger and an upgraded tracking system is ready to profit the most from the LHC Run3-Run4 data taking periods. The new data collected will be fundamental in order to reduce the statistical uncertainty, which is the dominant source of uncertainty for the majority of the measurements presented in these proceedings. All of the aforementioned improvements will allow to reach unprecedented precision to observables in the flavour sector, allowing to further constrain potential New Physics scenarios.

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