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Electroweak penguin decays at LHCb

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Rare $b \to s\mu^+\mu^-$ decays are flavour changing neutral current processes that are forbidden at the lowest perturbative order in the Standard Model. As a consequence, new particles in SM extensions can significantly affect the branching fractions of these decays and their angular distributions. The LHCb experiment is ideally suited for the analysis of these decays due to its high trigger efficiency, as well as excellent tracking and particle identification performance. Recent results from the LHCb experiment in the area of $b \to s\mu^+\mu^-$ decays are presented and their interpretation is discussed.

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1. Introduction

Decays involving flavour-changing neutral-current transitions can provide powerful tests of the Standard Model of particle physics (SM). Such processes can be sensitive to the existence of new particles with TeV-scale masses, which can interfere with the SM contribution to the decay. Several interesting tensions have appeared between the data and SM predictions in the LHC Run 1 data set: the rate of exclusive processes involving $b \to s\mu^+\mu^-$ quark-level transitions appears to be systematically below the corresponding predictions [1, 2, 3]; and the observed angular distribution of the $B^0 \to K^{*0}\mu^+\mu^-$ decay appears to be inconsistent with SM predictions [4]. A global analysis, of the full set of measurements, indicates that a better description of the data can be achieved my modifying the vector coupling strength (or simultaneously modifying the vector and axial-vector strength) of the decay [5]. The best-fit point in these global analyses is close to five standard deviations from the SM point. It is important that the nature of the discrepancies is understood. Two complementary measurements are presented in these proceedings, a study of the angular distribution of the $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decay and a measurement of the rate of the $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ decay.

2. Angular distribution of the $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decay

The $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decay has three important phenomenological differences with respect to the $B^0 \to K^{*0}\mu^+\mu^-$ decay: it involves a baryon-to-baryon transition rather than a meson-to-meson transition; the Λ decays weakly, leading to new hadron-side observables; and the Λ_b^0 can be produced polarised, leading to a much larger number of angular observables [6]. The angular distribution of the decay can be described by five angles, polar and azimuthal angles specifying the decay of the Λ baryon and the dimuon systems, θ_b, ϕ_b, θ_l and ϕ_l and the angle θ used to define the transverse polarisation of the Λ_b^0 baryon.

The LHCb collaboration has performed a first measurement of the full angular distribution of the $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decay using a dataset corresponding to $5\,\text{fb}^{-1}$ of integrated luminosity. Due to the large number of terms required to describe the decay, the observables are extracted by carrying out a moment analysis of the angular distribution. The distribution of $\cos\theta_b$ and $\cos\theta_l$ for selected candidates in the LHCb dataset is shown in Fig. 1. From $\cos\theta_b$ and $\cos\theta_l$, it is possible to measure the lepton-side, hadron-side and joint forward-backward asymmetries [7]

$$\begin{aligned} A^l_{\text{FB}} &= -0.39 \pm 0.04\,(\text{stat}) \pm 0.01\,(\text{syst})\ , \\ A^h_{\text{FB}} &= -0.30 \pm 0.05\,(\text{stat}) \pm 0.02\,(\text{syst})\ , \\ A^{lh}_{\text{FB}} &= +0.25 \pm 0.04\,(\text{stat}) \pm 0.01\,(\text{syst})\ . \end{aligned}$$

These measurements are all consistent with SM predictions [6]. The largest discrepancy is in the mixed asymmetry, A^{lh}_{FB}, at the level of 2.5 standard deviations. The measurements are also consistent with the current best-fit point of the various global analyses.

3. Branching fraction of the $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ decay

In the SM, the rate of processes involving $b \to d\mu^+\mu^-$ transitions is suppressed with respect to processes involving $b \to s\mu^+\mu^-$ due to the hierarchy of the Cabibbo-Kobayahsi-Maskawa quark

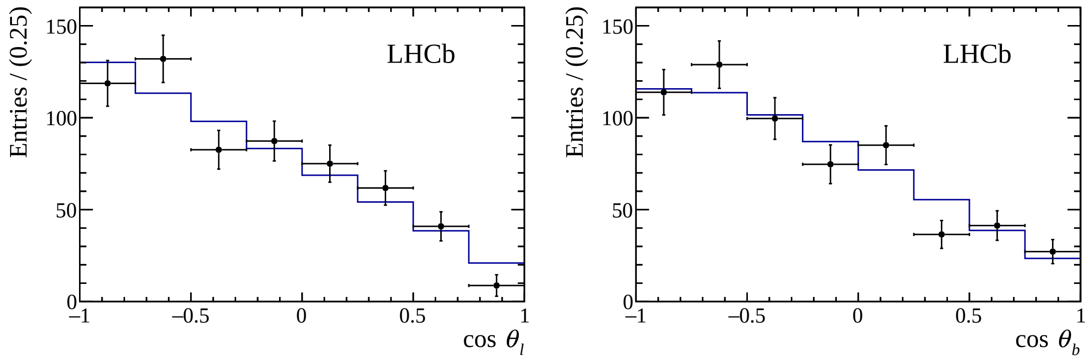

Figure 1: Angular distribution of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decays in the dataset collected by the LHCb collaboration between 2011 and 2016. The line indicates the result of the moment analysis, corrected for the non-uniform angular efficiency of the candidate reconstruction and selection.

mixing matrix. Exclusive $b \to d\mu^+\mu^-$ decays are therefore exceedingly rare, with branching fractions of $\mathcal{O}(10^{-8})$. So far, only the decays $B^+ \to \pi^+\mu^+\mu^-$ [8] and $\Lambda_b^0 \to p\pi^-\mu^+\mu^-$ [9] have been observed. Evidence for the decay $B^0 \to \pi^+\pi^-\mu^+\mu^-$, in the region around the $\rho(770)$ resonance, has also been reported in by the LHCb collaboration in Ref. [10].

A first measurement of the branching fraction of the $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ decay is reported in Ref. [11], based on a data set corresponding to approximately $5\,\text{fb}^{-1}$ of integrated luminosity collected between 2011 and 2016. A signal selection is carried out using a neural network classifier and the resulting analysis is performed in bins of the classifier response. This binning improves the statistical separation of the rare signal from the different experimental backgrounds. Figure 2 shows the reconstructed $K^-\pi^+\mu^+\mu^-$ mass of the selected $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ candidates in the three highest bins of each data-taking period. The main experimental challenge is in understanding the background from $B^0 \to K^{*0}\mu^+\mu^-$ decays, which due to the experimental resolution can contribute at masses above the known B^0 mass.

The number of $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ decays is determined by performing a simultaneous fit to the $K^-\pi^+\mu^+\mu^-$ mass distribution of the candidates in the bins of neural network response. An excess over the background only hypothesis is found at the level of 3.4 standard deviations [11]. This corresponds to a best fit branching fraction of

$$\mathcal{B}(B_s^0 \to \overline{K}^{*0}\mu^+\mu^-) = [2.9 \pm 1.0\,(\text{stat}) \pm 0.2(\text{syst}) \pm 0.3(\text{norm})] \times 10^{-8} ,$$

where the first uncertainty is statical, the second systematic and the third due to the use of $B^0 \to J/\psi K^{*0}$ as a normalisation channel. The systematic uncertainty comprises contributions due to the modelling of the $B^0 \to K^{*0}\mu^+\mu^-$ line-shape and due to our knowledge of the relative efficiency between the $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ decays. The normalisation uncertainty includes the uncertainty on the $B^0 \to J/\psi K^{*0}$ and the $J/\psi \to \mu^+\mu^-$ branching fractions and the uncertainty on the relative production of B_s^0 and B^0 mesons in pp collisions. The resulting branching fraction is consistent with SM predictions [12].

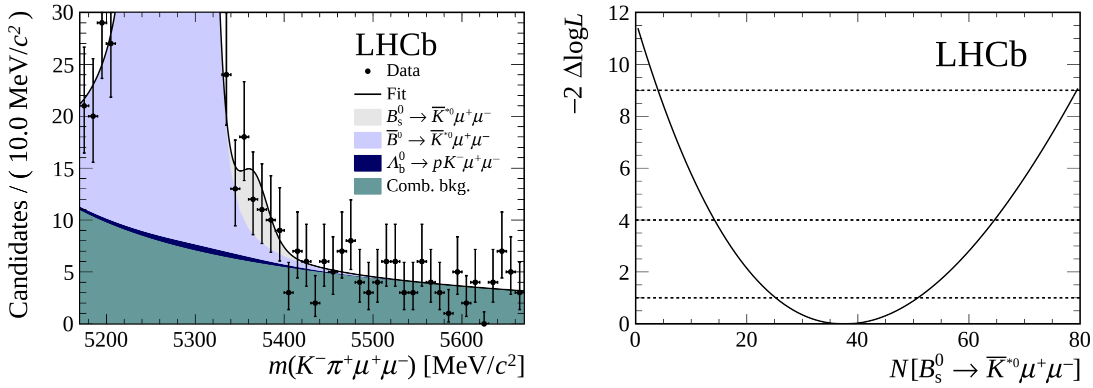

Figure 2: Reconstructed $K^-\pi^+\mu^+\mu^-$ mass of selected $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ candidates in the LHCb data set (left) and change in log-likelihood in the fit to the data as a function of the $B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$ yield (right).

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