PROCEEDINGS OF SCIENCE

Rare b-hadron decays at LHCb

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Rare b-hadron decays are suppressed or forbidden processes in the Standard Model, such as flavour-changing neutral current and lepton and baryon number violation. New particles in Standard Model extensions could give significant contributions to the same final state, modifying branching fractions and angular distributions. Consequently, rare decays are particularly sensitive probes for new physics. These proceedings summarize the latest results from the LHCb experiment on rare b-hadron decays, excluding $b \to sll$ transitions.

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1. Introduction

Suppressed decays of heavy-flavoured hadrons provide a wide range of opportunities to test the Standard Model (SM) expectations and search for new physics (NP). These proceedings present four recent results on rare decays from LHCb, focusing on b-hadron decays, excluding $b \to sll$ transitions. A dataset of 9 fb^{-1} integrated luminosity, taken during the LHC Run 1 and Run 2, between 2011 and 2018, was used.

The LHCb experiment [1] is a detector measuring proton-proton collisions at the Large Hadron Collider [2] in the forward pseudorapidity range of $2 < \eta < 5$. The LHCb detector during Run 1 and Run 2 consists of a high precision vertex detector, a dipole magnet, one silicon tracker upstream and three large-area trackers (silicon and straw-tubes) downstream, two RICH detectors, a calorimeter system, and five layers of muon chambers.

2. Results

2.1 Search for the baryon- and lepton-number violating decays $B^0_{(s)} \to p\mu^-$

The matter-antimatter asymmetry of the universe could be explained by Baryon Number Violation (BNV) [3] processes. Various extensions of the SM include BNV processes, such as Grand Unified Theory (GUT) models [4]. These GUT models usually require two hypothetical gauge bosons, X and Y, that couple quarks to leptons and lead to both BNV and Lepton Number Violation (LNV). LHCb has made the first search for the BNV and LNV process $B^0_{(s)} \to p\mu^-$ [5].

Two normalisation channels are used, $B^0 \to J/\psi K^+$ and $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$. The $B^0_{(s)} \to p\mu^-$ candidates with $p\mu^-$ pair invariant mass in the range [5067, 5667] MeV/c^2 are selected. A multilayer perceptron (MLP) is used to discriminate the combinatorial background. The $J/\psi K^+$ invariant-mass distribution for the $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ normalization channel is shown in Figure 1 (left) for Run 2 data. The analysis is performed in different MLP bins. Figure 1 (right) shows the $p\mu^-$ invariant-mass distribution for signal event candidates in the $0.25 \le \mathrm{MLP} \le 0.40$ region for Run 2 data. The same distributions are studied in Run 1 and every MLP region.

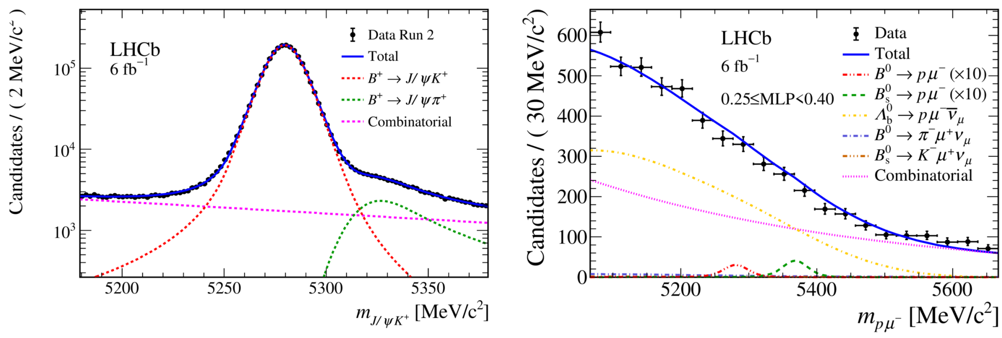

Figure 1: Invariant-mass distribution of $J/\psi K^+$ for the normalization channel (left), and $p\mu^-$ of signal channel in the $0.25 \le \mathrm{MLP} \le 0.40$ region (right).

The branching fractions ($\mathcal{B}$) of the signal decays are determined using an unbinned extended maximum-likelihood fit to the $p\mu^-$ mass distributions, performed simultaneously on all the data.

With the inclusion of systematic effects, the Confidence Level (CL) intervals as a function of the $\mathcal{B}$ are shown in Figure 2. No excesses are observed and an upper limit (UL) on the $\mathcal{B}$ is set at 90% (95%) CL for each decay:

$$\mathcal{B}(B^0 \to p\mu^-) < 2.6\ (3.1) \times 10^{-9}, \tag{1}$$

$$\mathcal{B}(B_s^0 \to p\mu^-) < 12.1\ (14.0) \times 10^{-9}. \tag{2}$$

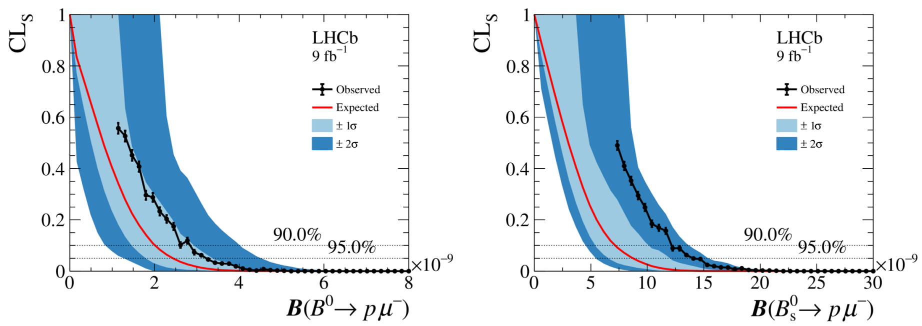

Figure 2: Results from the CLs scan used to obtain the limit on the branching fractions.

2.2 Search for the rare hadronic decay $B_s^0 \to p\bar{p}$

Theoretical estimations disagree about the order of magnitude of $\mathcal{B}(B_s^0 \to p\bar{p})$ [6, 7]. Experimental results are needed to understand the contributions to this decay. LHCb has searched for the $B_s^0 \to p\bar{p}$ process [8]. The $B^0 \to K^+\pi^-$ decay is used as normalisation channel. Its mass distribution is shown in Figure 3 (left). A tight particle identification selection, to reduce background from misidentified hadrons, is applied and a boosted decision tree is used to reduce combinatorial background. The final $p\bar{p}$ invariant-mass distribution is shown in Figure 3 (right), for signal candidates.

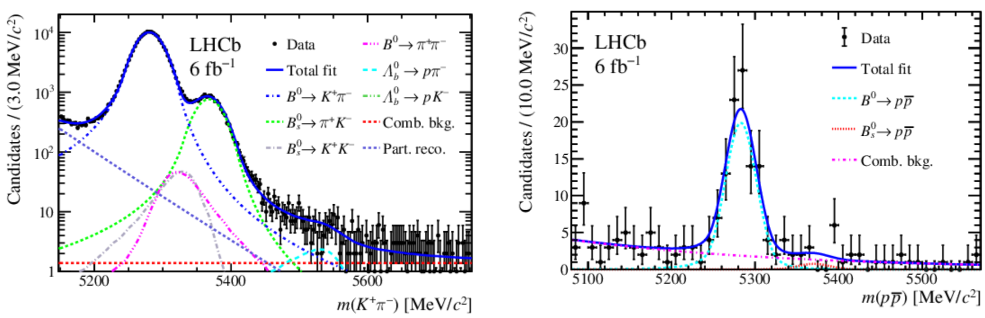

Figure 3: Invariant-mass distribution of $K^+\pi^-$ for the normalization channel (left), and $p\bar{p}$ of signal channel (right), for Run 2 data.

No evidence of the $B_s^0 \to p\bar{p}$ decay is found. Using the likelihood distribution shown in Fig. 4, the decay $\mathcal{B}$ UL at 90% (95%) CL is set at:

$$\mathcal{B}(B_s^0 \to p\bar{p}) < 4.4\ (5.1) \times 10^{-9}. \tag{3}$$

This best UL supersedes and improves the previous limit [9] by approximately a factor of four.

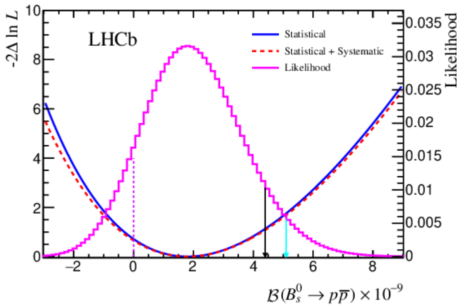

Figure 4: Negative logarithm of the profile likelihoods and the corresponding likelihood.

2.3 Searches for $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

Decays of B_s^0 and B^0 mesons into four muons are highly suppressed in the SM, with their $\mathcal{B}$ estimated to be at the order of 10^{-12} and 10^{-10}, respectively. A potential NP contribution could modify this value. In Ref. [10], LHCb has searched for these processes. The $B^0 \to J/\psi(\to \mu^+\mu^-)\phi(\to \mu^+\mu^-)$ decay chain is used as normalization channel. Figure 5 shows the four-muon invariant mass for the B^0 (left), and B_s^0 (right), candidates.

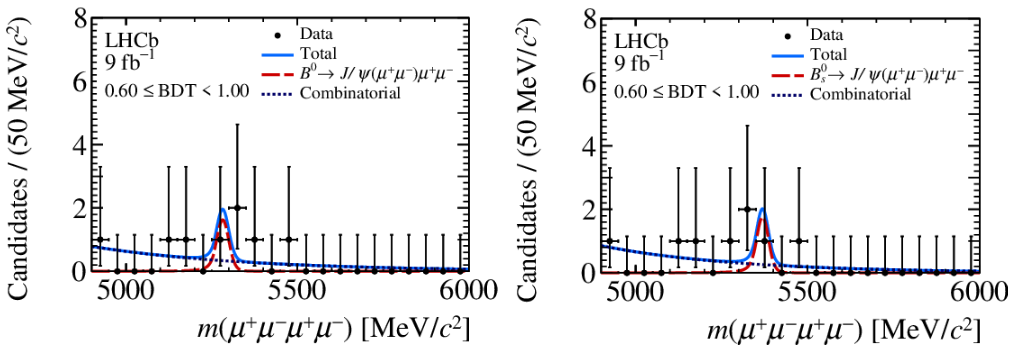

Figure 5: Four-muon invariant-mass distribution for B^0 (left), and B_s^0 (right) candidates.

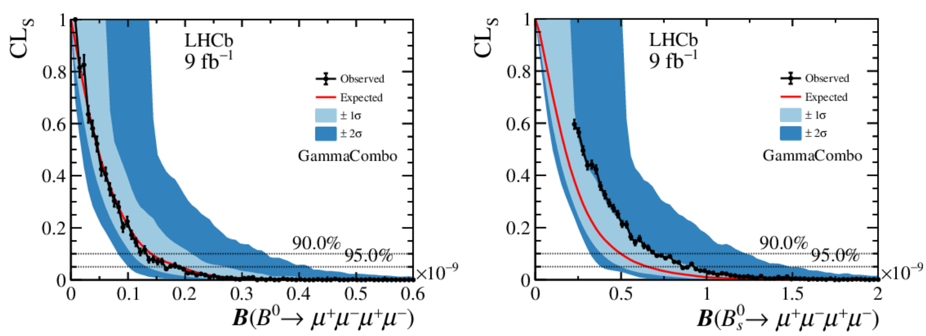

Figure 6: Confidence levels on the branching fractions of B^0 (left), and B_s^0 (right), decays to four muons.

No evidence of the $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ decays are found. From the CL distributions in Fig. 6, the ULs at 95% CL are set to:

$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 1.8 \times 10^{-10}, \tag{4}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 8.6 \times 10^{-10}. \tag{5}$$

2.4 Search for $D^*(2007)^0 \to \mu^+\mu^-$ in $B^- \to \pi^-\mu^+\mu^-$ decays

The $\mathcal{B}$ for the suppressed process $D^{*0} \to \mu^+\mu^-$ is of the order of 10^{-11}, unless there are enhancements due to NP. LHCb has searched for this decay using the $B^- \to D^{*0}\pi^-$ decay, since the displaced vertex and exclusive final state provide powerful background rejection capabilities [11].

A multivariate algorithm is used to identify secondary vertices consistent with the decay of a b hadron. The B^- candidates are formed from pairs of well-reconstructed oppositely charged tracks that are identified as muons. Figure 7 shows the dimuon (left) and B^- candidate (right) invariant-mass distributions, of selected $B^- \to D^{*0}\pi^-$ candidates.

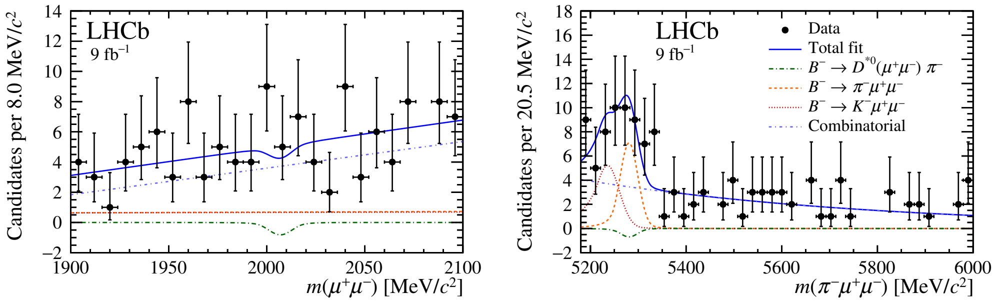

Figure 7: Invariant-mass distribution of $\mu^+\mu^-$ (left), and $\pi^-\mu^+\mu^-$ (right), for the B^- candidates.

No excess with respect to the background-only hypothesis is observed. Figure 8 shows the confidence bands at the 90% (95%) CL. The UL is determined to be:

$$\mathcal{B}(D^{*0} \to \mu^+\mu^-) < 2.6\ (3.4) \times 10^{-8}. \tag{6}$$

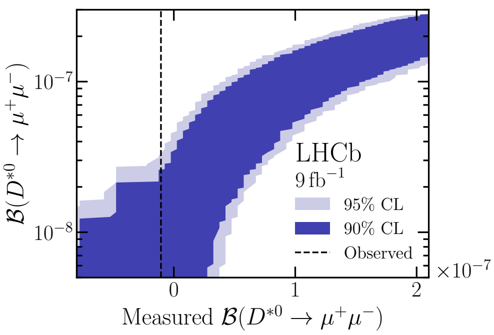

Figure 8: The CL band from pseudoexperiments. The vertical line shows the result of the data fit.

This analysis has set the first limits on the D^{*0} decay into muons.

3. Conclusions

A selection of recent results on very rare b decays from LHCb have been presented. No evidence of NP processes have been found, and limits on the branching fractions of four decays have been set.

The results presented here are mainly limited by statistical uncertainties. The LHC Run 3 is providing more statistics that, together with the LHCb upgrade [12], will give crucial results on rare decays, in order to push the limits of the SM and explore beyond.

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