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Study of b-hadron properties with semileptonic decays

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With large branching fractions and controllable theoretical uncertainties, semileptonic B decays are excellent tools for measuring b-hadron properties as well as testing QCD calculations. The large samples of B^0_s mesons and b-baryons uniquely available at LHCb extend the experimental reach into this sector, allowing differential decay rates of these hadrons to be probed for the first time. The observation and study of $B^+ \to p\overline{p}\mu^+\nu_\mu$ decays offer the opportunity to investigate hadronic meson-to-baryon-pair transitions. The most recent measurements of b-hadron properties using semileptonic b-hadron decays are presented.

40th International Conference on High Energy physics - ICHEP2020
July 28 - August 6, 2020
Prague, Czech Republic (virtual meeting)

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PoS(ICHEP2020)415

1. Introduction

The LHCb detector [1, 2] is an ideal testing ground for studying the properties of b-hadrons. Its trigger system is designed for the displaced signature of their decays and a large amount of b-hadrons are produced, including B_s^0, B_c^+ and Λ_b^0 hadrons[1]. Studying them using semileptonic decays takes advantage of their generally large branching fractions. Also, the uncertainties on theoretical predictions are well understood as the transition involves only one hadronic current, which can be parametrised by form factors. In the following, measurements performed using (parts of the) data collected by LHCb at centre-of-mass energies $\sqrt{s}$ of 7, 8 and 13 TeV are summarized.

2. Measurement of b-hadron fractions in 13 TeV pp collisions

The B_s^0 and Λ_b^0 hadron production fractions are measured relative to the sum of the B^- and $\overline{B}^0$ meson production fractions using data corresponding to an integrated luminosity of 1.67 fb^{-1} recorded at 13 TeV in 2016 [3]. This measurement extends the previous measurement of the same quantities performed at $\sqrt{s}$ =7 TeV [4]. Knowledge of the relative production fractions is a requirement for measuring absolute branching fractions of decays of these hadrons. The measurement is performed in bins of the transverse momentum p_{T} and the pseudorapidity η of the hadron. The b-hadron yields are determined using inclusive $H_b \to H_c \mu \nu$ ($H_c = D_s^+, \Lambda_c^+, D^0, D^+$) decays. The yields are then corrected by the corresponding branching fractions and selection efficiencies. The measured relative production fraction as a function of the transverse momentum of the hadron is shown in Fig. 1, where a strong dependence on the transverse momentum is seen for the Λ_b^0 hadron and a light dependence for the B_s^0 hadron. No dependence on the pseudorapidity is observed. Integrating over the fiducial volume of $4 < p_{\mathrm{T}} < 25$ GeV, $2 < \eta < 5$, the fractions are

$$\frac{f_s}{f_u + f_d} = 0.122 \pm 0.006(stat. + syst.),$$

$$\frac{f_{\Lambda_b^0}}{f_u + f_d} = 0.259 \pm 0.018(stat. + syst.),$$

where the statistical and systematic uncertainties are combined.

3. Measurement of the B_c^- meson production fraction in 7 and 13 TeV pp collisions

Similar to the previous section, the B_c^- meson production fraction is measured using data collected at centre-of-mass energies of 7 and 13 TeV [5]. The B_c^- meson is reconstructed in the $B_c^- \to J/\psi\, \mu^- \overline{\nu}_\mu$ decay. Its yield is determined by fitting the corrected mass m_{corr} defined as

$$m_{corr} = \sqrt{m^2_{J/\psi\, \mu^-} + p_\perp^2} + p_\perp,$$

where $p_\perp$ is the magnitude of the ($J/\psi\, \mu^-$) momentum component transverse to the flight direction of the B_c^- meson. The measurement relies on the theoretical prediction of $\mathcal{B}\,(B_c^- \to J/\psi\, \mu^- \overline{\nu}_\mu)$. The average value of the theory predictions of $\mathcal{B}(B_c^- \to J/\psi\, \mu^- \overline{\nu}_\mu) = 1.95\% \pm 0.46\%$ is used.

[1]charge conjugation is implied throughout this document

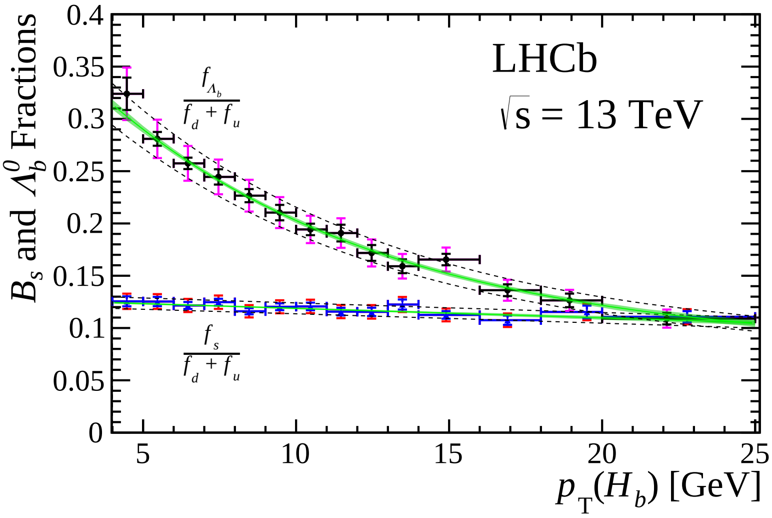

Figure 1: The ratios $f_s/(f_u + f_d)$ and $f_{\Lambda^0_b}/(f_u + f_d)$ in bins of $p_{\mathrm{T}}(H_b)$ [3]

No strong dependence on η is found for the relative B_c^- production fraction, but a decrease of the production fraction with the transverse momentum of the B_c^- hadron is observed, as shown in Fig. 2 The average relative production fraction in the fiducial volume is determined to be

$$\frac{f_c}{f_u + f_d} = (3.63 \pm 0.08(stat.) \pm 0.12(syst.) \pm 0.86(ext.)) \cdot 10^{-3} \text{ for 7 TeV,}$$
$$\frac{f_c}{f_u + f_d} = (3.78 \pm 0.04(stat.) \pm 0.15(syst.) \pm 0.89(ext.)) \cdot 10^{-3} \text{ for 13 TeV,}$$

where the first uncertainty is statistical, the second systematic and the third due to the uncertainty on the prediction of $\mathcal{B}\,(B_c^- \to J/\psi\,\mu^-\overline{\nu}_\mu)$.

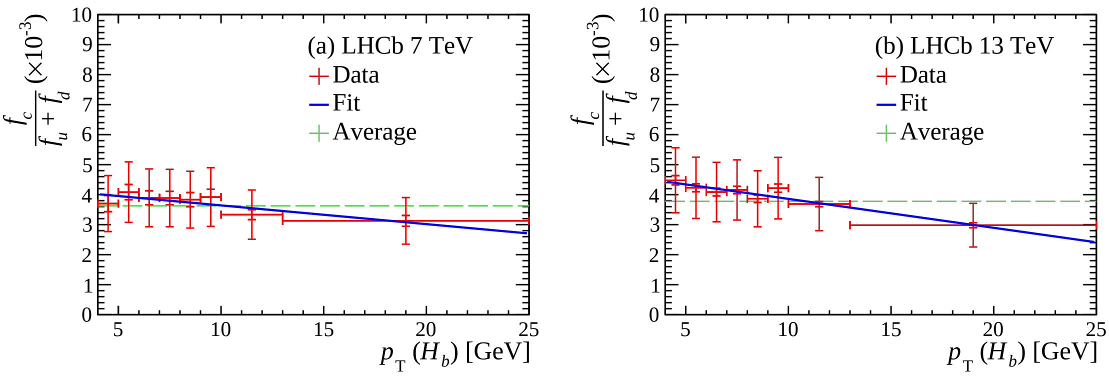

Figure 2: Ratio $f_c/(f_u + f_d)$ as a function of $p_{\mathrm{T}}(H_b)$ in 7 TeV (left) and 13 TeV (right) data [5].

4. Observation of the semileptonic decay $B^+ \to p\overline{p}\mu^+\nu_\mu$

The Belle collaboration reported evidence for the $B^+ \to p\overline{p}\mu^+\nu_\mu$ decay [6]. The first observation of this decay is made using data recorded at LHCb corresponding to integrated luminosities of 1 fb^{-1}, 2 fb^{-1} and 1.7 fb^{-1} at centre-of-mass energies of 7, 8 and 13 TeV respectively [7]. The signal yield is extracted by fitting the corrected mass

$$m_{corr} = \sqrt{m^2_{p\overline{p}\mu} + p^2_{\perp}} + p_{\perp}$$

in bins of the $p\overline{p}$ invariant mass and the corresponding branching fraction is measured relative to the $B^+ \to J/\psi\,(\to \mu^+\mu^-)K^+$ branching fraction.

The overall branching fraction is determined to be

$$\mathcal{B}(B^+ \to p\overline{p}\mu^+\nu_\mu) = (5.27^{+0.23}_{-0.24}(stat.) \pm 0.21(syst.) \pm 0.15(ext.)) \times 10^{-6},$$

where the first uncertainty is statistical, the second systematic and the third due to the uncertainty on the $B^+ \to J/\psi\,(\to \mu^+\mu^-)K^+$ branching fraction. The measured value is found to be lower than the theory prediction from perturbative QCD [8]. The measured branching fraction in bins of the $p\overline{p}$ invariant mass is shown in Fig. 3. Also shown is the theoretical prediction scaled to the measured value. The observed shape of the differential branching fraction is consistent with the theory expectation and an enhancement of the branching fraction at the $p\overline{p}$ threshold is seen.

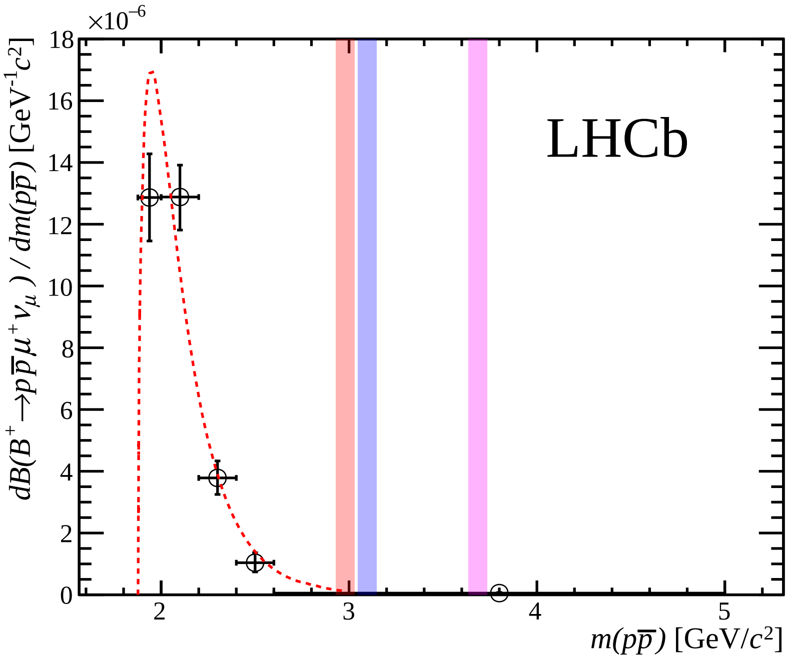

Figure 3: Differential branching fraction of the $B^+ \to p\overline{p}\mu^+\nu_\mu$ decay as a function of the $p\overline{p}$ invariant mass. The red dashed line shows the prediction from perturbative QCD normalised to the observed branching fraction. The $\eta_c \to p\overline{p}$, $J/\psi \to p\overline{p}$ and $\psi(2S) \to p\overline{p}$ regions, which are vetoed in the measurement, are shown as red, blue and pink bands, respectively [7].

5. Measurement of the shape of the $B^0_s \to D^{*-}_s\mu^+\nu_\mu$ differential decay rate

The shape of the differential decay rate of the $B^0_s \to D^{*-}_s\mu^+\nu_\mu$ decay is measured using data corresponding to an integrated luminosity of 1.7 fb^{-1} at a centre-of-mass energy of 13 TeV [9]. The

D_s^{*-} is reconstructed in the $D_s^{*-} \to D_s^- \gamma$ final state and the D_s^- through the $D_s^- \to K^- K^+ \pi^-$ decay. The signal yield is extracted by fitting the corrected mass distribution

$$m_{corr} = \sqrt{m^2_{D_s^{*-}\mu^+} + p_\perp^2} + p_\perp$$

in bins of the hadron recoil w

$$w = \frac{p_{B_s^0}}{m_{B_s^0}} \frac{p_{D_s^{*-}}}{m_{D_s^{*-}}} = \frac{m^2_{B_s^0} + m^2_{D_s^{*-}} - q^2}{2 m_{B_s^0} m_{D_s^{*-}}},$$

where q^2 is the squared momentum transfer to the lepton system $q^2 = (p_{B_s^0} - p_{D_s^{*-}})^2$. The obtained distribution of w is unfolded to account for the resolution of w and corrected by the efficiency. The resulting w_{unf} distribution is fitted using the CLN [10] and BGL [11] form factor parametrisations, as shown in Fig. 4. The two form factor models are observed to be consistent with each other and the data. This is the first time the normalised differential decay rate of the $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ decay is measured.

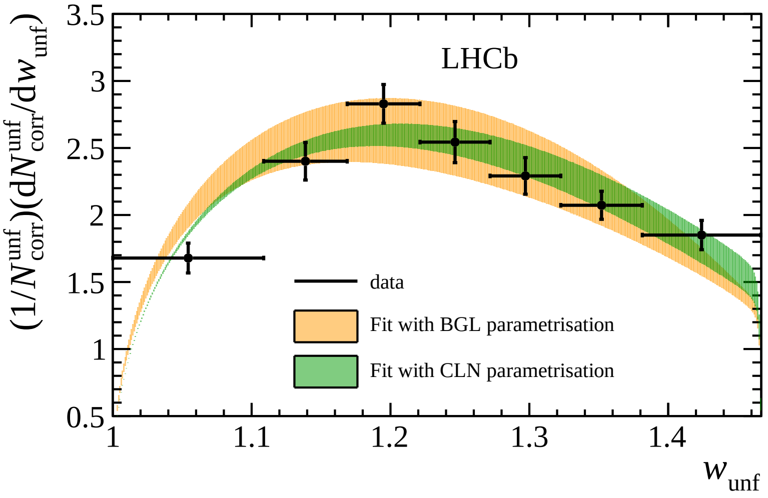

Figure 4: Unfolded normalised differential $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ decay rate with the fit results for the CLN and BGL parametrisations [9].

6. Conclusions

Using the large data sample it has recorded, the LHCb collaboration studied various b-hadron properties. Particularly, the relative production fractions of B_s^0, Λ_b^0 and B_c^- hadrons are measured. Investigation of the data sample has also led to the first observation of the Cabibbo-suppressed $B^+ \to p\overline{p}\mu^+\nu_\mu$ decay and the first-time measurement of the normalised differential decay rate of the $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$ decay. Measuring these properties provides important input for further measurements and theory predictions. The relative production fractions are required to extract absolute branching fractions. Experimental determination of form factors is a necessary input to predict relative branching fractions used in lepton universality tests. Furthermore, predictions by (perturbative) QCD can be explicitly tested.

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Acknowledgments

FR acknowledges funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No 724777 "RECEPT".

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