Studies of open heavy flavour production at LHCb

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The data collected by LHCb in 2010 have been used to study the production of beauty hadrons in pp collisions at $\sqrt{s} = 7$ TeV. Differential cross-sections are measured and compared with theoretical predictions. Results are also shown on relative fractions of B_s and Λ_b production.

1 Introduction

The LHCb is one of the four LHC experiments which started data-taking in 2010 at a centre-of-mass energy of 7 TeV. The LHCb detector [1] is a forward spectrometer dedicated to measure CP violating and rare decays of hadrons containing b and c quarks. Knowledge of the b yield is critical in ascertaining the sensitivity of experiments that aim to measure fundamental parameters of interest involving, for example, CP violation. It is useful for normalising backgrounds for measurements of higher mass objects that decay into $b\overline{b}$, such as the Higgs boson. The first data taken with the LHCb detector allows for the measurements of the production cross-section for the average of b- and $\overline{b}$-flavoured hadrons in pp collisions which also can be compared to QCD predictions. The LHCb detector explores a unique kinematic region. It detects b hadrons produced in a cone centered around the beam axis covering a region of pseudo-rapidity η, ranging approximately between 2 and 5, and with transverse momenta ranging from 0 to about 15 GeV. The $b\overline{b}$ quark production cross-section is related with the fragmentation fractions which are needed to determine any B_s^0 branching ratio at the LHC. The fragmentation fractions f_u, f_d, f_s and f_Λ describe the probability that a b quark will fragment into a B_q meson (where $q = u, d, s$), or Λ_b baryon, respectively. The measurement of branching ratio of the rare decay $B_s^0 \to \mu^+\mu^-$ is the prime example where knowledge on ratio of f_s/f_d is crucial to reach the highest sensitivity in the search for New Physics [2].

2 The b-flavoured hadrons cross-section measurements

Two independent data samples are used to measure the cross-section for $b\overline{b}$ quark production and the results are subsequently combined (Figure 1). The decay channel $b \to D^0\mu^-\overline{\nu}X$ is used, as it has a large branching fraction of $(6.84 \pm 0.35)\%$, and is advantageous from the point of view of signal to background. For the earliest period of data taking the number of colliding bunches was sufficiently low that the high-level trigger could process all crossing and accept events when at least one track was reconstructed in either the VELO [1] or the tracking stations. This data set, called as "microbias", has an integrated luminosity $\mathcal{L} = 2.9$ nb^{-1}. The second sample, referred to as "triggered", uses triggers designed to select a single muon. Here $\mathcal{L} = 12.2$ nb^{-1}. The cross-section to produce b-flavoured hadrons is measured to be $\sigma(b\bar{b}X) = (75.3 \pm 5.4 \pm 13.0)$ μb in the pseudo-rapidity interval $2 < \eta < 6$ over the entire range of p_T assuming the LEP fraction for fragmentation into b-flavoured hadrons [3]. The measured cross-section is consistent with theoretical predictions. For extrapolation to the full η region using PYTHIA 6.4 total $b\bar{b}$ cross-section of $\sigma(b\bar{b}X) = (284 \pm 20 \pm 49)$ μb based on LEP fragmentation results; using the Tevatron fragmentation fractions the result increases by 19 %.

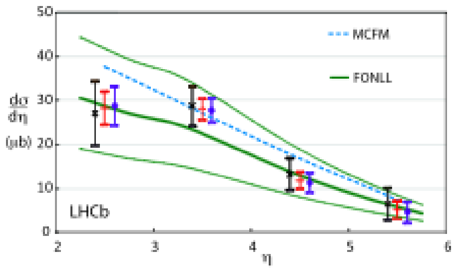

Figure 1: The $\sigma(pp \to b\bar{b}X)$ as a function of η for the microbias ($\times$) and triggered ($\bullet$) samples, shown displaced from the bin center and the average (+). The data are shown as points with statistics error bars only, the MCFM [4] prediction as a dashed line, and the FONLL [5] prediction as a thick solid line. The thin upper and lower lines indicate the theoretical uncertainties on the FONLL prediction.

The cross-section to produce b-flavoured hadrons also was determined from the measurements of double-differential cross-section for J/ψ from b in the various (y, p_T) bins [6] which are shown in Figure 2. The analysis is based on a data sample corresponding to the $\mathcal{L} = 5.2$ pb^{-1}. The measured cross-section for the production of J/ψ from b integrated over the fiducial region $p_T \in [0; 14]$ GeV and $y \in [2.0; 4.5]$ is $\sigma(J/\psi\, from\, b) = 1.14 \pm 0.01 \pm 0.16$ μb, where the first uncertainty is statistical and the second systematic. Using this measurement and the LHCb Monte Carlo simulation based on PYTHIA 6.4, the cross-section to produce b-flavoured hadrons extrapolated to the full polar angle range is $\sigma(b\bar{b}X) = (288 \pm 4 \pm 48)$ μb. This result is in excellent agreement with $\sigma(b\bar{b}X) = (284 \pm 20 \pm 49)$ μb obtained from b decays into $D^0\mu^-\bar{\nu}X$.

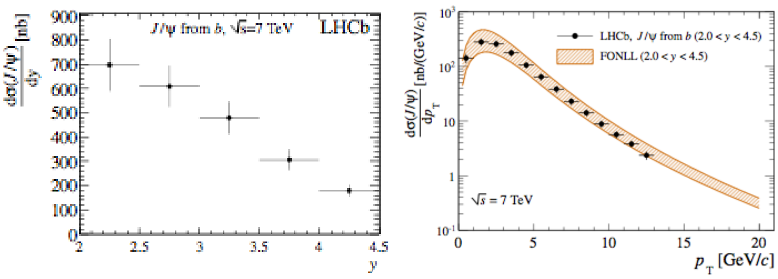

Figure 2: Left: Differential production cross-section as a function of y integrated over p_T, for unpolarised J/ψ from b. The errors are the quadratic sums of the statistical and systematic uncertainties. **Right:** Comparison of the LHCb results for the differential J/ψ from b production for unpolarised J/ψ (circles with error bars) with J/ψ from b production as predicted by FONLL (hatched orange uncertainty band).

3 Fragmentation fraction measurements

Knowledge of the fragmentation fractions allows to relate theoretical predictions of the $b\overline{b}$ quark production cross-section, derived from perturbative QCD, to the observed hadrons. It suffices to measure the ratio of B_s production to either B^- or $\overline{B}^0$ production to perform precise absolute B_s branching fraction measurements. The first data taken with the LHCb detector allows for the measurements of two ratios of fragmentation fractions: strange B meson to light B meson production $[f_s/(f_u + f_d)]$ and Λ_b baryon to light B meson production $[f_{\Lambda_b}/(f_u + f_d)]$, where $f_q \equiv \mathcal{B}(b \to B_q)$ and $f_{\Lambda_b} \equiv \mathcal{B}(b \to \Lambda_b)$ [7]. The results are shown in Figure 3 as a function of the charmed hadron-muon system transverse momentum p_T and of the b-hadron pseudo-rapidity η. This analysis follows previous analysis of $b \to D^0\mu^-\overline{\nu}X$ [3]. Charmed hadrons and muons are combined to form a partially reconstructed b-hadron by requiring that they come from a common vertex. Details of the event selection are described in [7]. Perturbative QCD calculations lead to expect the ratios $[f_s/(f_u + f_d)]$ and $[f_{\Lambda_b}/(f_u + f_d)]$ to be fairly independent of the pseudo-rapidity η, while a possible dependence upon the b-hadron transverse momentum p_T is not ruled out, especially for the ratios involving baryon species. The measured ratio $[f_s/(f_u + f_d)]$ is fairly constant over the whole $\eta - p_T$ domain. By fitting all the data to a single constant, we obtain $[f_s/(f_u + f_d)] = 0.134 \pm 0.004^{+0.011}_{-0.010}$ in the interval $\eta = (2, 5)$, where the first error is statistical and the second is systematic. The corresponding ratio $[f_{\Lambda_b}/(f_u + f_d)]$ is found to be dependent upon the transverse momentum of the charm hadron-μ pair. Assuming the linear dependence, we get $[f_{\Lambda_b}/(f_u + f_d)] = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T(\text{GeV})]$, where the errors on the absolute scale are statistical, systematic and absolute scale uncertainty due to the error in $\mathcal{B}(\Lambda_c \to pK\pi)$ respectively. No η dependence is found.

The relative abundances of the three decay modes $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$, $B^0 \to D^-(K^+\pi^-\pi^-)K^+$ and $B_s^0 \to D_s^-(K^+K^-\pi^-)\pi^+$ are used to determine the ratio of

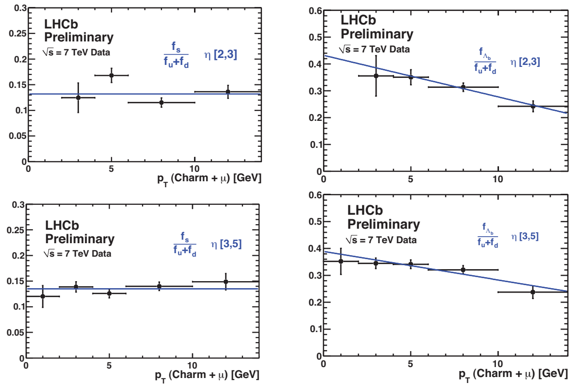

Figure 3: The ratio between $\overline{B_s^0}$ and light B meson production fractions as a function of the transverse momentum of the $D_s\mu$ pair (left) and fragmentation ratio $[f_{\Lambda_b}/(f_u+f_d)]$ dependence upon $p_T(\mu\Lambda_c)$ (right) in two bins of η. The errors shown are statistical only [7].

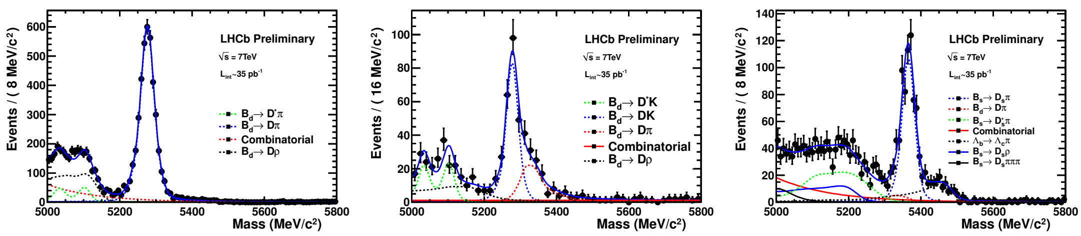

Figure 4: Results of the fits to $B^0 \to D^-\pi^+$, $B^0 \to D^-K^+$ and $B_s^0 \to D_s^-\pi^+$ candidates (left to right). The curves are as summarised in the legends and described in the text [8].

fragmentation fractions f_s/f_d. Details of event selection are described in [8]. The $B^0 \to D^-\pi^+$, $B^0 \to D^-K^+$ and $B_s^0 \to D_s^-\pi^+$ event yields are 4109 ± 75, 253 ± 21 and 670 ± 34, respectively, and the fit results are shown in Figure 4. This analysis is based on $\mathcal{L} = 35\,\text{pb}^{-1}$ of data collected using the LHCb detector during the 2010 LHC running. The theoretically cleaner extraction f_s/f_d is performed using the decays $B^0 \to D^-K^+$ and $B_s^0 \to D_s^-\pi^+$ as $f_s/f_d = 0.242 \pm 0.024 \pm 0.018 \pm 0.016$, where the first error is the statistical, the second the systematic uncertainty, and the third the theoretical uncertainty dominated by the uncertainty on the form factor ratio. The ratio f_s/f_d extracted from the modes $B^0 \to D^-\pi^+$ and $B_s^0 \to D_s^-\pi^+$ is found to be $f_s/f_d = 0.249 \pm 0.013 \pm 0.020 \pm 0.025$, where the theoretical uncertainty increases by an additional uncertainty from the W-exchange diagrams [9]. The two values for f_s/f_d can be combined into a single value, by taking all correlated uncertainties into account. The average values is $f_s/f_d = 0.245 \pm 0.017 \pm 0.018 \pm 0.018$. These values of f_s/f_d are in good agreement with the values determined at LEP and at the Tevatron.

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