IL NUOVO CIMENTO **40 C** (2017) 39
DOI 10.1393/ncc/i2017-17039-0

Colloquia: IFAE 2016

Measurement of B^0, B_s^0, B^+ and Λ_b^0 production asymmetries in 7 and 8 TeV pp collisions at LHCb

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received 17 October 2016

Summary. — Using a data sample corresponding to an integrated luminosity of $3.0\,\mathrm{fb}^{-1}$, collected by LHCb in pp collisions at centre-of-mass energies of 7 and 8 TeV, the B^+, B^0, B_s^0 and Λ_b^0 production asymmetries are measured using $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to D_s^- \pi^+$ decays. The measurements are performed as a function of the transverse momentum (p_T) and rapidity (y) of the b hadrons and then finally integrated in the ranges $2 < p_T < 30\,\mathrm{GeV}/c$ and $2.1 < y < 4.5$. No evidence of production asymmetry is found within the current experimental uncertainties.

1. – Introduction

The production rates of b and $\overline{b}$ hadrons in pp collisions at the LHC are not expected to be strictly identical. In fact, a $\overline{b}$ quark produced in pp interaction could combine with a u or d valence quark from the remnants of the colliding protons to form a meson, whereas the same is impossible for a b quark. For this reason, one could expect a slight excess in the production of B^+ and B^0 mesons with respect to B^- and $\overline{B}^0$ mesons, giving rise to an asymmetry that must be compensated by other b meson and baryon species.

The production asymmetries of b hadrons are defined as

$$A_{\mathrm{P}} = \frac{\sigma(h_{\overline{b}}) - \sigma(h_b)}{\sigma(h_{\overline{b}}) + \sigma(h_b)}, \tag{1}$$

where $\sigma(h_{\overline{b}})$ ($\sigma(h_b)$) stands for the production cross-section of the hadron containing the $\overline{b}$ (b) quark. The LHCb Collaboration already measured the B^0 and B_s^0 production asymmetries using an integrated luminosity of 1 fb^{-1} collected at the centre-of-mass energy of 7 TeV [1].

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The measurement of the b-hadrons production asymmetries is of fundamental importance in order to perform CP violation measurements, since the physical CP asymmetry needs to be disentagled from other spurious sources.

As the production asymmetries could be function of the kinematics of the b hadrons [2-4], measurements are done as a function of p_T and y and then integrated within the LHCb acceptance.

2. – Analysis

2·1. B^+ *production asymmetry.* – In order to measure the B^+ production asymmetry, first we perform invariant-mass fits to the B^+ invariant-mass spectra in order to measure the so-called raw asymmetry, defined as

$$A_{\mathrm{RAW}}(B^+) = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)}. \tag{2}$$

To first order, this quantity is equal to the sum of various terms, notably including the production asymmetry:

$$A_{\mathrm{RAW}}(B^+) \simeq A_{\mathrm{P}}(B^+) + A_{\mathrm{D}}(K^+) + A_{\mathrm{CP}}(B^+ \to J/\psi K^+), \tag{3}$$

where $A_{\mathrm{D}}(K^+)$ is the kaon detection asymmetry and $A_{\mathrm{CP}}(B^+ \to J/\psi K^+)$ is the physical asymmetry of the decay. The former quantity is measured by means of $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to \bar{K}^0\pi^+$ decays, while the latter is taken as external input from the PDG [5].

Once one corrects for these two quantities, the B^+ production asymmetry is obtained by subtracting them from the measured raw asymmetry.

2·2. B^0 *and* B^0_s *production asymmetries.* – In order to obtain the production asymmetries of the neutral b mesons, two-dimensional simultaneous invariant-mass and decay time fits need to be performed. The production asymmetry is then obtained as the amplitude of the oscillatory term in the time-dependent decay rate asymmetry:

$$A(t) \simeq \frac{\mathcal{R}(B(t) \to f) - \mathcal{R}(B(t) \to \overline{f})}{\mathcal{R}(B(t) \to f) + \mathcal{R}(B(t) \to \overline{f})} = A_{\mathrm{CP}}(f) + A_{\mathrm{D}}(f) + A_{\mathrm{P}} \frac{\cos(\Delta m_{d(s)} t)}{\cosh(\Delta\Gamma_{d(s)} t/2)}, \tag{4}$$

where $B(t)$ indicates the $B^0_{(s)}$ oscillating flavour eigenstate, $A_{\mathrm{CP}}(f)$ is the physical asymmetry of the decay and $A_{\mathrm{D}}(f)$ is the detection asymmetry of the final state.

2·3. Λ^0_b *production asymmetry.* – Once the b mesons production asymmetries are measured, one can obtain $A_{\mathrm{P}}(\Lambda^0_b)$ by means of the relation

$$A_{\mathrm{P}}(\Lambda^0_b) = -\left[\frac{f_u}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^+) + \frac{f_d}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^0) + \frac{f_s}{f_{\Lambda^0_b}} A_{\mathrm{P}}(B^0_s)\right], \tag{5}$$

where the f_h, with $h = u,\ d,\ s$ or Λ^0_b, are the hadronization fractions. Equation (5) holds under the assumption that b and $\overline{b}$ quarks are produced only in pairs and neglecting the other species. These hypotheses are well confirmed by theory and existing experimental data, and any deviation from them is treated a systematic uncertainty.

3. – Results

The B^+, B^0, B^0_s and Λ^0_b production asymmetries are measured in the ranges $2 < p_T < 30\,\mathrm{GeV}/c$ and $2.1 < y < 4.5$ and their values are found to be

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\begin{aligned}
A_\mathrm{P}(B^0)_{\sqrt{s}=7\,\mathrm{TeV}} &= (0.20 \pm 0.88(\mathrm{stat.}) \pm 0.11(\mathrm{syst.}))\%,\\
A_\mathrm{P}(B^0)_{\sqrt{s}=8\,\mathrm{TeV}} &= (-1.49 \pm 0.55(\mathrm{stat.}) \pm 0.12(\mathrm{syst.}))\%,\\
A_\mathrm{P}(B^0_s)_{\sqrt{s}=7\,\mathrm{TeV}} &= (-1.11 \pm 2.88(\mathrm{stat.}) \pm 0.50(\mathrm{syst.}))\%,\\
A_\mathrm{P}(B^0_s)_{\sqrt{s}=8\,\mathrm{TeV}} &= (1.78 \pm 1.96(\mathrm{stat.}) \pm 0.53(\mathrm{syst.}))\%,\\
A_\mathrm{P}(B^+)_{\sqrt{s}=7\,\mathrm{TeV}} &= (-0.46 \pm 0.24(\mathrm{stat.}) \pm 0.17(\mathrm{uncorr.\ syst.}) \pm 0.60(\mathrm{corr.\ syst.}))\%,\\
A_\mathrm{P}(B^+)_{\sqrt{s}=8\,\mathrm{TeV}} &= (-0.80 \pm 0.15(\mathrm{stat.}) \pm 0.12(\mathrm{uncorr.\ syst.}) \pm 0.60(\mathrm{corr.\ syst.}))\%,\\
A_\mathrm{P}(\Lambda^0_b)_{\sqrt{s}=7\,\mathrm{TeV}} &= (0.96 \pm 2.44(\mathrm{stat.}) \pm 1.50(\mathrm{uncorr.\ syst.}) \pm 0.57(\mathrm{corr.\ syst.}))\%,\\
A_\mathrm{P}(\Lambda^0_b)_{\sqrt{s}=8\,\mathrm{TeV}} &= (3.51 \pm 1.59(\mathrm{stat.}) \pm 0.73(\mathrm{uncorr.\ syst.}) \pm 0.57(\mathrm{corr.\ syst.}))\%.
\end{aligned}
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The correlated systematic uncertainty on the $A_\mathrm{P}(B^+)$ measurement is due to the external input, $A_{CP}(B^+ \to J/\psi K^+)$, that is subtracted from every kinematic bin on which the integration is performed in order to obtain the final integrated values reported above. The uncorrelated systematic uncertainty (the only one present in the B^0 and B^0_s modes) is due to inaccuracies in the shapes of every component contributing to the fit model and (only for the neutral mesons) to inaccuracies in the decay time resolution and acceptance functions. Finally, the correlated and uncorrelated systematic contributions are propagated separately in order to obtain the respective uncertainties on the Λ^0_b production asymmetry measurement.

No evidence of production asymmetry is found within the current precision. A paper is in preparation, and until publication these results have to be considered as LHCb-unofficial.

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