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Recent results from b-baryon decays at LHCb

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Abstract. Recent measurements of b-baryon decays using $3\,\mathrm{fb}^{-1}$ proton-proton collision data collected by the LHCb experiment are presented. Measurements of the branching fractions of $\Lambda_b^0 \to J/\psi\, p\pi^-$, $\Lambda_b^0 \to \Lambda_c^+ D_s^-$, $\Lambda_b^0 \to \Lambda_c^+ D^-$ and $\Lambda_b^0 \to \Lambda_c^+\pi^-$ decays have been made, as well as precise measurements of the mass and lifetime of the Ξ_b^0 baryon. In addition, the p_T and η dependence of the ratio of Λ_b^0 to B^0 production fractions has been measured.

1. Introduction

Physics involving b-baryons is still a relatively unexplored field in particle physics, but is of particular interest since baryons have a non-zero spin, and so would allow us to probe the helicity structure of the Heavy Quark Expansion Hamiltonian. In order to achieve this, precise measurements of branching fractions, lifetimes and masses of b-baryons are needed. In addition to this, one can look for *CP* asymmetries in b-baryon decays, which can arise due to interference between tree and loop diagrams in these decays. There studies would be relatively easy to carry out, since conservation of baryon number provides a natural method to tag decays; however, no *CP* asymmetries have yet been observed in any baryon decays.

This note presents a selection of recent results involving b-baryon decays, and precise measurements of the Ξ_b^0 baryon. Unless otherwise stated, results are obtained using a sample of $3\,\mathrm{fb}^{-1}$ proton-proton collision data collected in 2011 and 2012 by the LHCb experiment.

2. Observation of the $\Lambda_b^0 \to J/\psi\, p\pi^-$ decay.

This section presents the search for the $\Lambda_b^0 \to J/\psi\, p\pi^-$ decay using the $\Lambda_b^0 \to J/\psi\, pK^-$ decay as a control channel (except for *CP* measurements, charge conjugation is implied throughout). Full details of the results can be found in Ref. [1]. The selection consists of a loose kinematic constraint, followed by particle identification (PID) requirements, which make use of the LHCb detector to separate protons, pions and kaons. Finally, to achieve the optimal separation between signal and background, a multivariate selection is applied, namely a Neural Net (NN). After the selection is applied, an unbinned maximum likelihood fit is performed to the $J/\psi\, ph$ invariant mass distribution, and 2102 ± 61 $\Lambda_b^0 \to J/\psi\, p\pi^-$ candidates are found. This is the first observation of this decay, with a significance of $> 30\sigma$. Using the ratio of yields of signal to control channel, corrected by the ratio of selection efficiencies, η, the ratio of branching fractions is calculated to be

$$\frac{\mathcal{B}(\Lambda_b^0 \to J/\psi\, p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\, pK^-)} = \frac{N(\Lambda_b^0 \to J/\psi\, p\pi^-)}{N(\Lambda_b^0 \to J/\psi\, pK^-)} \times \frac{\eta(\Lambda_b^0 \to J/\psi\, pK^-)}{\eta(\Lambda_b^0 \to J/\psi\, p\pi^-)} = 0.0824 \pm 0.0025\,(\mathrm{stat}) \pm 0.0042\,(\mathrm{syst})$$

where the first uncertainty is statistical, and the second is systematic.

From these extracted yields, we can measure the raw asymmetry for each decay,

$$\mathcal{A}^{\rm raw}(\Lambda_{\rm b}^0 \to {\rm J/\psi\, p}\pi^-) = (+7.9 \pm 2.2)\%$$
$$\mathcal{A}^{\rm raw}(\Lambda_{\rm b}^0 \to {\rm J/\psi\, pK}^-) = (+1.1 \pm 0.7)\%,$$

where the uncertainties are entirely statistical and

$$\mathcal{A}^{\rm raw} = \frac{N(\Lambda_{\rm b}^0) - N(\overline{\Lambda}_{\rm b}^0)}{N(\Lambda_{\rm b}^0) + N(\overline{\Lambda}_{\rm b}^0)}. \tag{1}$$

The raw asymmetry is related to the *CP* asymmetry, $\mathcal{A}^{CP}$, via the equation

$$\mathcal{A}^{\rm raw} = \mathcal{A}^{CP} + \mathcal{A}^{\rm prod}(\Lambda_{\rm b}^0) - \mathcal{A}^{\rm det}(\pi/{\rm K}) + \mathcal{A}^{\rm det}({\rm p}), \tag{2}$$

where $\mathcal{A}^{\rm prod}$ is the asymmetry in production of $\Lambda_{\rm b}^0$ and $\overline{\Lambda}_{\rm b}^0$, and $\mathcal{A}^{\rm det}$ is the detection asymmetry. Since $\mathcal{A}^{\rm prod}$ ($\Lambda_{\rm b}^0$) and $\mathcal{A}^{\rm det}$ (p) have not been well measured, we measure the difference in $\mathcal{A}^{CP}$ between theJ/ψ pπ^- and J/ψ pK$^-$ decays, defined as

$$\Delta\mathcal{A}^{CP} = \mathcal{A}^{CP}({\rm J/\psi\, p}\pi^-) - \mathcal{A}^{CP}({\rm J/\psi\, pK}^-) = \mathcal{A}^{\rm raw}({\rm J/\psi\, p}\pi^-) - \mathcal{A}^{\rm raw}({\rm J/\psi\, pK}^-) + \mathcal{A}^{\rm det}(\pi) - \mathcal{A}^{\rm det}({\rm K}).$$

The difference in detection asymmetries, $\mathcal{A}^{\rm det}$ (π) - $\mathcal{A}^{\rm det}$ (K), is measured using $\overline{\rm B}^0 \to {\rm J/\psi}\, \overline{\rm K}^{*0}$ decays and is found to be -0.0110 ± 0.0033 [2]. The difference in *CP* asymmetries is found to be $\Delta\mathcal{A}^{CP} = (+5.7 \pm 2.3\,({\rm stat}) \pm 1.2\,({\rm syst}))\%$, which is consistent with no *CP* violation at the level of 2.2σ.

3. $\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}^-$ and $\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}_{\rm s}^-$ decays.

This section presents for search for $\Lambda_{\rm b}^0$ baryons decaying into pairs of charm hadrons with $\Lambda_{\rm c}^+$ D$^-$ and $\Lambda_{\rm c}^+$ D$_{\rm s}^-$ final states, as described in Ref. [3]. The charm hadron resonances are reconstructed through the ${\rm D}^+ \to {\rm K}^-\pi^+\pi^+$, ${\rm D}_{\rm s}^+ \to {\rm K}^-{\rm K}^+\pi^+$ and $\Lambda_{\rm c}^+ \to {\rm pK}^-\pi^+$ decays, and a Boosted Decision Tree (BDT) is used to reduce the combinatoric background. Both decays are observed for the first time, with 4633 ± 69 $\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}_{\rm s}^-$ candidates and 262 ± 19 $\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}^-$ candidates. The efficiency corrected yields are used to calculate the ratio of branching fractions:

$$\frac{\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}^-)}{\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}_{\rm s}^-)} = 0.042 \pm 0.003\,({\rm stat}) \pm 0.003\,({\rm syst}),$$

where the first uncertainty is statistical, and the second is systematic. In order to obtain the absolute branching fractions for these decays, the high statistics $\overline{\rm B}^0 \to {\rm D}^+{\rm D}_{\rm s}^-$ decay is used, along with the ratio of $\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+\pi)$ to $\mathcal{B}(\overline{\rm B}^0 \to {\rm D}^+\pi^-)$. By taking the double ratio of branching fractions, all dependence on the ratio of production fractions and charm hadron branching fractions is removed. The double ratio has been measured to be

$$\left[\frac{\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}_{\rm s}^-)}{\mathcal{B}(\overline{\rm B}^0 \to {\rm D}^+ {\rm D}_{\rm s}^-)}\right] / \left[\frac{\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ \pi^-)}{\mathcal{B}(\overline{\rm B}^0 \to {\rm D}^+ \pi^-)}\right] = 0.96 \pm 0.02\,({\rm stat}) \pm 0.06\,({\rm syst}).$$

From this the absolute branching fractions are found to be $\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}_{\rm s}^-) = (1.1 \pm 0.1) \times 10^{-2}$ and $\mathcal{B}(\Lambda_{\rm b}^0 \to \Lambda_{\rm c}^+ {\rm D}^-) = (4.7 \pm 0.6) \times 10^{-4}$.

From the unbinned maximum likelihood fit to the invariant mass distributions of the $\Lambda_{\rm c}^+$ D$_{\rm s}^+$ and D$^+$ D$_{\rm s}^-$, the difference between the mass of the $\Lambda_{\rm b}^0$ baryon and B^0 meson is measured

$$m(\Lambda_{\rm b}^0) - m({\rm B}^0) = 339.72 \pm 0.24\,({\rm stat}) \pm 0.18\,({\rm syst})\,{\rm MeV}/c^2.$$

Using the known mass of the B^0 meson, and taking an average with the $\Lambda_{\rm b}^0$ baryon mass measured previously by LHCb [4], the mass of the $\Lambda_{\rm b}^0$ baryon is measured to be $m(\Lambda_{\rm b}^0) = 5619.36 \pm 0.26\,{\rm MeV}/c^2$.

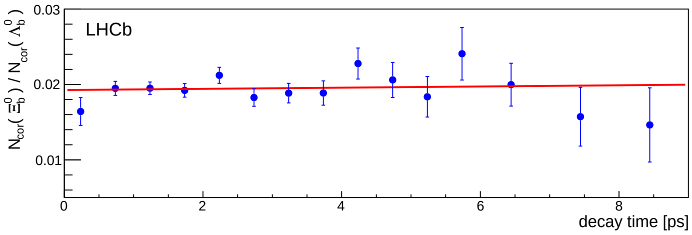

Figure 1. Efficiency corrected yield as a function of decay time, fit with an exponential.

4. Mass and lifetime measurements of the Ξ_b^0 baryon

This section presents precision measurements of the Ξ_b^0 baryon. Full details can be found in Ref. [5]. The Ξ_b^0 baryon is measured using the $\Xi_b^0 \to \Xi_c^+\pi^-$ decay, with the $\Lambda_b^0 \to \Lambda_c^+\pi^-$ decay used as a control channel. Both charm baryons are reconstructed through decays to $pK^-\pi^+$ final state, and a BDT is used to obtain a clean sample of 3775 ± 71 Ξ_b^0 candidates and $(180.8 \pm 0.5) \times 10^3$ Λ_b^0 candidates. An unbinned maximum likelihood fit to the invariant mass distributions is used to extract the difference in mass of the Ξ_b^0 and Λ_b^0 baryons, which is measured to be

$$m(\Xi_b^0) - m(\Lambda_b^0) = 172.44 \pm 0.39\,(\text{stat}) \pm 0.17\,(\text{syst})\,\text{MeV}/c^2.$$

Using the mass of the Λ_b^0 baryon measured in Section 3, the mass of the Ξ_b^0 baryon is measured to be $m(\Xi_b^0) = 5791.80 \pm 0.39\,(\text{stat}) \pm 0.17\,(\text{syst}) \pm 0.26(\Lambda_b^0)\,\text{MeV}/c^2$, which is a vast improvement on previous measurements. In addition, the first measurement of the lifetime of the Ξ_b^0 is made by plotting the efficiency corrected ratio of Ξ_b^0 to Λ_b^0 yields as a function of decay time, shown in Figure 1. This is then fit with with an exponential of the the form $e^{-\beta t}$ where

$$\beta = \frac{1}{\tau(\Xi_b^0)} - \frac{1}{\tau(\Lambda_b^0)}. \tag{3}$$

From the fit we find $\beta = (0.40 \pm 1.21) \times 10^{-2}\,\text{ps}^{-1}$, corresponding to the ratio of Ξ_b^0 to Λ_b^0 lifetimes:

$$\frac{\tau(\Xi_b^0)}{\tau(\Lambda_b^0)} = \frac{1}{1 - \beta\tau(\Lambda_b^0)} = 1.006 \pm 0.018\,(\text{stat}) \pm 0.010\,(\text{syst}).$$

Using the value of $\tau(\Lambda_b^0)$ measured in Ref. [6], the lifetime of the Ξ_b^0 baryon is measured for the first time to be $\tau(\Xi_b^0) = 1.477 \pm 0.026\,(\text{stat}) \pm 0.014\,(\text{syst}) \pm 0.013(\Lambda_b^0)\,\text{ps}$.

5. Λ_b^0 production and $\Lambda_b^0 \to \Lambda_c^+\pi^-$ branching fraction measurements.

This section presents the measurement of Λ_b^0 production fractions, $f_{\Lambda_b^0}/f_d$, using a sample of proton-proton collision data at $\sqrt{s}$ =7 TeV corresponding to an integrated luminosity of 1 fb^{-1}. Full details can be found in Ref. [7]. It has been known for some time that the production of Λ_b^0 baryons depends on the transverse momentum, p_T, of the system. Measurements made by LEP [8] were inconsistent with those made by CDF [9], and the p_T dependence was explicitly measured by LHCb using semileptonic Λ_b^0 decays [10]. This analysis is an update of this measurement using the hadronic $\Lambda_b^0 \to \Lambda_c^+\pi^-$ and $\overline{B}^0 \to D^+\pi^-$ decays, and the production fractions are measured as a function of p_T and pseudorapidity, η. The ratio of Λ_b^0 to B^0 production fractions is then given by

$$\frac{f_{\Lambda_b^0}}{f_d}(X) = \frac{\mathcal{B}(B^0 \to D^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)}\frac{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} \times \frac{N_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)\epsilon_{B^0\to D^+\pi^-}(X)}{N_{B^0\to D^+\pi^-}(X)\epsilon_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)} \tag{4}$$

$$\equiv S \times \frac{N_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)\epsilon_{B^0\to D^+\pi^-}(X)}{N_{B^0\to D^+\pi^-}(X)\epsilon_{\Lambda_b^0\to\Lambda_c^+\pi^-}(X)} \tag{5}$$

$$\equiv S \times R(X).$$

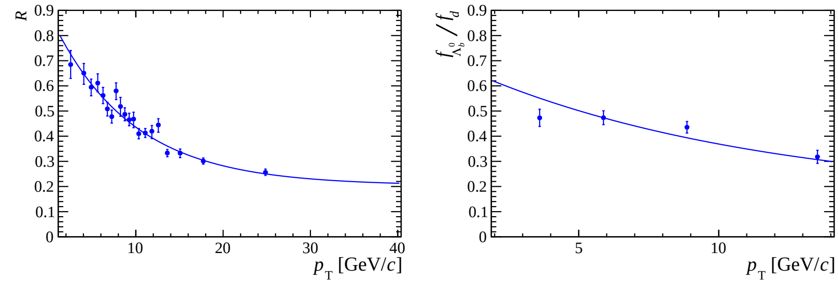

Figure 2. a) Efficiency corrected ratio of yields as a function of p_{T}, fit with an exponential function. b) Ratio of production fractions as a function of p_{T} from [10], fit with the parameters from the fit in a)

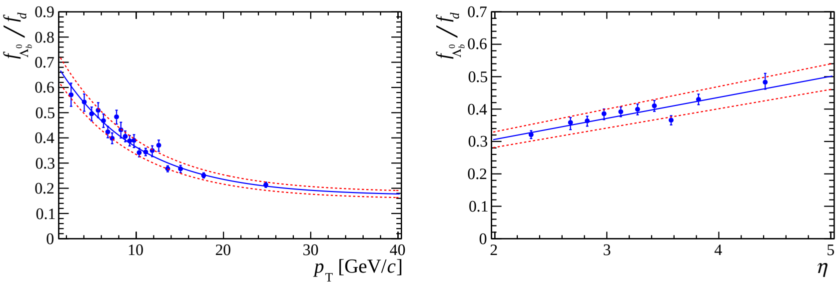

Figure 3. Ratio of production fractions as a function of a) p_{T}, fit with an exponential function, and b) as a function of η, fit with a linear function. The bands indicate the uncertainties from the semileptonic measurement.

The efficiency corrected ratio of yields, $\mathrm{R}(p_{\mathrm{T}})$, is plotted as a function of p_{T} in Figure 2a), and fit with an exponential function. The parameters of the exponential are then fixed, and the same fit is performed to the ratio $f_{\Lambda_b^0}/f_{\mathrm{d}}$ measured in the semileptonic decay, allowing the normalisation to float. This is shown in Figure 2b). From S, the branching fraction of the $\Lambda_b^0 \to \Lambda_c^+\pi^-$ decay is extracted, and found to be $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-) = (4.46 \pm 0.36) \times 10^{-3}$. This is the most precise measurement of a branching fraction of a Λ_b^0 decay measured to date.

Figure 3a) shows the ratio of efficiency corrected yields multiplied by the scale factor, S. This corresponds to a measurement of the p_{T} dependence of the ratio of production fractions, and the dependence is fit with an exponential function. Figure 3b) shows $f_{\Lambda_b^0}/f_{\mathrm{d}}$ as a function of η, which is fit with a linear function.

6. Summary

In summary, many new measurements of b-baryon decays performed by the LHCb experiment have been presented, including the branching fractions of $\Lambda_b^0 \to J/\psi\, p\pi^-$, $\Lambda_b^0 \to \Lambda_c^+ D_s^-$, $\Lambda_b^0 \to \Lambda_c^+ D^-$ and $\Lambda_b^0 \to \Lambda_c^+\pi^-$ decays. Precise measurements of the mass and lifetime of the Ξ_b^0 baryon have been made, and the p_{T} and η dependence of the ratio of Λ_b^0 to B^0 production fractions has been measured. The programme of analyses at LHCb involving baryons is extensive, and more results can be expected in the near future.

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