Results from LHCb in charmless baryonic B meson decays

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A review of the latest analyses from the LHCb experiment on charmless baryonic B-meson decays is presented. Emphasis is given on the first observation of a baryonic decay of the B_s^0 meson, namely the decay mode $B_s^0 \to p\overline{\Lambda}K^-$. Decays of B mesons to final states containing baryons are now observed for all B-meson species.

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1. Introduction

The decays of B mesons to final states containing baryons have unique characteristics not found in similar decays involving mesons only. For a start, the inclusive branching fraction for baryonic B decays, is rather large, roughly 7.5% of the B total width [1]. The inclusive measurement was obtained from a study of the branching fractions of B mesons to the p, Λ and Ξ^- baryons accounting for various correlations, yielding an approximately equal rate of protons and neutrons. The hierarchy of baryonic B decays is unusual in that many-body final states tend to have a larger branching fraction than 3- and 2-body final states. Last but not least, most baryonic decays show a pronounced enhancement at threshold in the baryon-antibaryon invariant mass. The theoretical description is a challenge and experimental information is scarce, hence needed to provide input to the various phenomenology models available.

The latest studies from the LHCb experiment [2, 3] on charmless baryonic B-meson decays are here presented. All analyses are based on a pp collision data sample collected in 2011 and 2012 at centre-of-mass energies of 7 and 8 TeV, respectively, corresponding to a total integrated luminosity of 3 fb^{-1}. The inclusion of charge-conjugate processes is implied throughout these proceedings.

2. First observation of a baryonic B_s^0 decay

Baryonic B decays have been observed for all species except the B_s^0 meson. Since two-body baryonic B decays are suppressed with respect to decays to multi-body final states [4, 5], the three-body decay $B_s^0 \to p\overline{\Lambda}K^-$ is a good candidate for a search for baryonic B_s^0 decays. The branching fraction has been predicted to be of the order of 10^{-6} [6], the same as for its similar mode $B^0 \to p\overline{\Lambda}\pi^-$. The current experimental situation on the family of $B_{(s)}^0 \to p\overline{\Lambda}h^-$ decays ($h = \pi, K$) and related modes such as $B_{(s)}^0 \to p\overline{\Sigma}^0h^-$, with $\Sigma^0 \to \Lambda\gamma$, is rather poor: the $B^0 \to p\overline{\Lambda}\pi^-$ decay has been studied by the BaBar [7] and Belle [8] collaborations; the Belle collaboration also reported the 90% confidence level upper limits $\mathscr{B}(B^0 \to p\overline{\Lambda}K^-) < 8.2 \times 10^{-7}$ and $\mathscr{B}(B^0 \to p\overline{\Sigma}^0\pi^-) < 3.8 \times 10^{-6}$ [9].

The LHCb analysis measures the branching fraction of the signal decay $B_s^0 \to p\overline{\Lambda}K^-$ relative to that of the normalisation mode $B^0 \to p\overline{\Lambda}\pi^-$ [10]. The $\Lambda \to p\pi^-$ decays are reconstructed in two different categories: the first consists of Λ hadrons that decay early enough for the daughter particles to be reconstructed in the vertex detector, and the second contains those that decay later such that track segments cannot be reconstructed in the vertex detector. These categories are referred to as *long* and *downstream*, respectively. Both $B_s^0 \to p\overline{\Lambda}K^-$ and $B^0 \to p\overline{\Lambda}\pi^-$ candidates are selected in a similar way throught the selection chain. After the hardware and software stages of the trigger, multilayer perceptrons are utilised to effectively separate signals from combinatorial background. Particle identification requirements separate the candidates in either the $p\overline{\Lambda}\pi^-$ or the $p\overline{\Lambda}K^-$ spectra. Background can arise from misidentified decays to the other signal final state; from b-hadron decays where one or more decay products are misidentified, such as decays with K_S^0 mesons misidentified as Λ baryons; and partially reconstructed backgrounds in which one or more particles from the decay of the b hadron are not associated with the signal candidate, such as decays with a Σ^0 baryon. Extensive background studies are performed with simulation samples.

The yields of the signal and background candidates in the eight subsamples are determined using a simultaneous unbinned extended maximum likelihood fit. The eight subsamples correspond to the 2011 and 2012 data-taking periods, the two Λ reconstruction categories, and the two $p\overline{\Lambda}\pi^-$ and $p\overline{\Lambda}K^-$ final states.
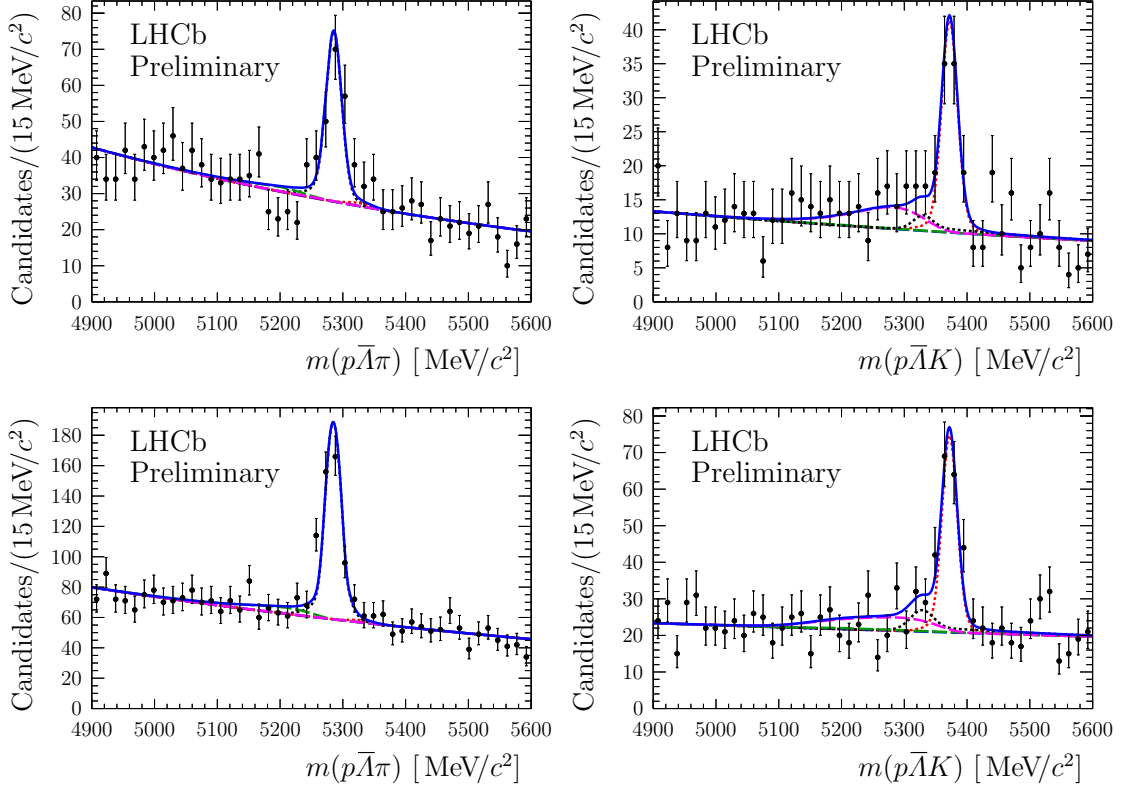

Figure 1: Results of the fit for the 2012 data sample reconstructed under (left) the $p\overline{\Lambda}\pi^-$ invariant mass hypothesis and (right) the $p\overline{\Lambda}K^-$ invariant mass hypothesis for (top) the long sample and (bottom) the downstream sample. The black points represent the data, the solid blue curve the complete fit model, the black (red) dotted curve the $B^0 \to p\overline{\Lambda}\pi^-$ ($B^0_s \to p\overline{\Lambda}K^-$) contribution, and the green (magenta) dashed curve the contribution from $B^0 \to p\overline{\Sigma}^0\pi^-$ ($B^0_s \to p\overline{\Sigma}^0 K^-$) decays.

Figure 1 presents the fit to the $p\overline{\Lambda}h^-$ invariant mass distributions for the 2012 subsamples. Prominent $B^0 \to p\overline{\Lambda}\pi^-$ and $B^0_s \to p\overline{\Lambda}K^-$ signals are observed. The total signal yields $N(B^0 \to p\overline{\Lambda}\pi^-) = 521 \pm 32$ and $N(B^0_s \to p\overline{\Lambda}K^-) = 260 \pm 21$, where the uncertainties are statistical only. The $B^0_s \to p\overline{\Lambda}K^-$ decay is observed with a statistical significance above 15 standard deviations, estimated from the change in log-likelihood between fits with and without the $B^0_s \to p\overline{\Lambda}K^-$ signal component [11]. It is the first observation of a baryonic B^0_s decay.

The distributions of the baryon-antibaryon system mass, $m(p\overline{\Lambda})$, are obtained with the *sPlot* technique [12], see Fig. 2. They show the well-known pronounced enhancement at threshold first suggested in Ref. [13]. A threshold enhancement in baryonic B^0_s decays is observed for the first time.
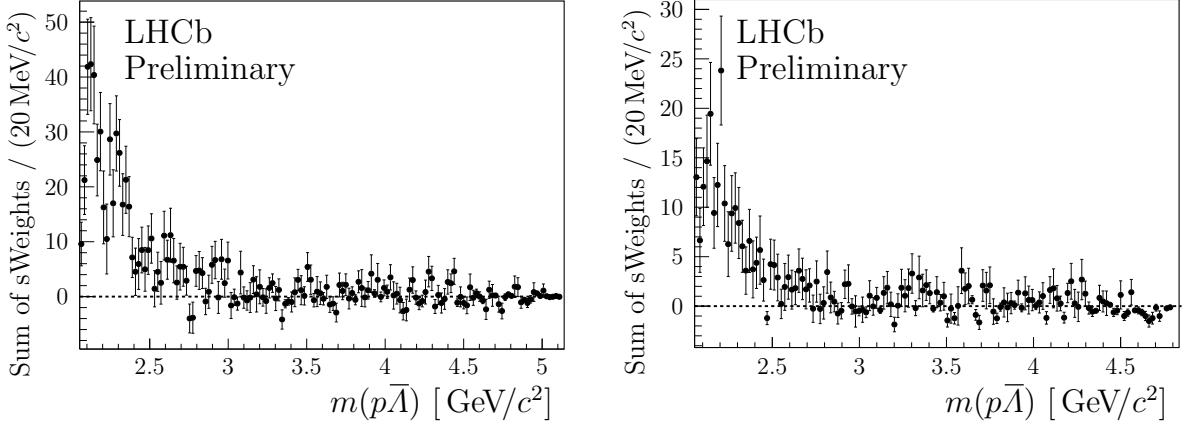
Figure 2: Invariant mass distributions of $m(p\overline{\Lambda})$ for (left) the $B^0 \to p\overline{\Lambda}\pi^-$ and (right) the $B_s^0 \to p\overline{\Lambda}K^-$ decay mode. The background subtraction is performed using the *sPlot* technique. The distributions are not corrected for efficiency.

The branching fraction of the $B_s^0 \to p\overline{\Lambda}K^-$ decay is measured to be [10]

$$\mathscr{B}(B_s^0 \to p\overline{\Lambda}K^- + \bar{B}_s^0 \to \overline{p}\Lambda K^-) = \left[5.48^{+0.82}_{-0.80} \pm 0.60 \pm 0.51(\mathscr{B}) \pm 0.32(f_s/f_d)\right] \times 10^{-6},$$

where the first uncertainty is statistical and the second systematic, the third uncertainty accounts for the experimental uncertainty on the branching fraction of the $B^0 \to p\overline{\Lambda}\pi^-$ decay used for normalisation, and the fourth uncertainty relates to the knowledge of f_s/f_d. This branching fraction measurement is not corrected for a possible bias due to the finite width difference of the B_s^0 system [14]. The dominant source of systematic uncertainty comes from the poor knowledge of other baryonic B decays representing backgrounds to the signals, which implies a challenging description of the spectra and non-negligible uncertainties on the fit model components and their characteristics.

Decays of B mesons to final states containing baryons are now observed for all B-meson species. The results provide valuable information towards a better understanding of the dynamics of baryonic B decays. In particular, further studies of the B_s^0 decays are welcome. So far, their phenonenology has focused on two-body final states [4, 15] and charmed baryonic decays [16].

3. First evidence for $B^+ \to p\overline{\Lambda}$

The BaBar and Belle experiments have made numerous searches and observations of baryonic B decays [17]. But only recently did the LHCb collaboration report the first observation of a two-body charmless baryonic B^+ decay and the first evidence for a similar B^0 decay, namely $B^+ \to p\overline{\Lambda}(1520)$ [18] and $B^0 \to p\overline{p}$ [19]. No other such type of decay has been observed, as B decays to two-body baryonic final states are suppressed, with branching fractions typically one to two orders of magnitude lower than similar baryonic decays to multibody final states.

The decay $B^+ \to p\overline{\Lambda}$ has been searched for by the CLEO [20] and Belle [21] collaborations. The most stringent experimental upper limit on its branching fraction is 3.2×10^{-7} at 90% confidence level, determined by the Belle collaboration. The LHCb collaboration performed a search

for this rare decay mode $B^+ \to p\overline{\Lambda}$ using the topologically identical $B^+ \to K^0_S \pi^+$ decay as normalisation channel in the determination of the branching fraction, to suppress common systematic uncertainties [22].

In the analysis, the candidates are selected in a similar way throught the selection chain for both the $B^+ \to p\overline{\Lambda}$ signal decay and the normalisation channel $B^+ \to K^0_S \pi^+$. After the hardware and software stages of the trigger, multilayer perceptrons are utilised to effectively separate signals from backgrounds. Possible sources of non-combinatorial background to the $p\overline{\Lambda}$ and $K^0_S \pi^+$ spectra are investigated using simulation samples. The peaking background from $B^+ \to p\overline{p}\pi^+$ decays in the $p\overline{\Lambda}$ spectrum is found to be insignificant after selection. The currently unobserved $B^+ \to p\overline{\Sigma}^0$ decay is treated as a source of systematic uncertainty.
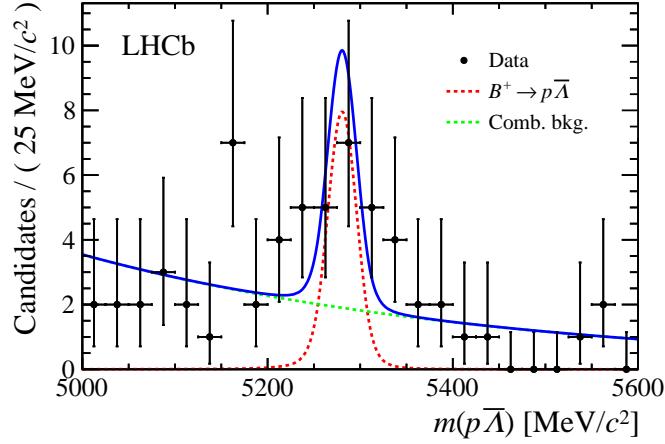

Figure 3: Invariant mass distribution of $p\overline{\Lambda}$ candidates after full selection. The result of the fit to the data (blue, solid) is shown together with each fit model component, namely the $B^+ \to p\overline{\Lambda}$ signal and the combinatorial background.

The yields of the signal and background candidates in both the signal and normalisation samples are determined using unbinned extended maximum likelihood fits to the invariant mass spectra. The fit to the $p\overline{\Lambda}$ invariant mass distribution is presented in Fig. 3. An excess of $B^+ \to p\overline{\Lambda}$ candidates with respect to background expectations is found, corresponding to a signal yield of $N(B^+ \to p\overline{\Lambda}) = 13.0^{+5.1}_{-4.3}$, where the uncertainties, obtained from a profile likelihood scan, are statistical only. The statistical significance of the $B^+ \to p\overline{\Lambda}$ signal, of 4.1 standard deviations, is determined with a large set of samples simulated assuming the presence of background only. Inclusion of systematic uncertainties affecting the signal yield gives only a marginal change in the signal significance.

The $B^+ \to p\overline{\Lambda}$ branching fraction is measured to be

$$\mathscr{B}(B^+ \to p\overline{\Lambda}) = (2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-7},$$

where the first uncertainty is statistical and the second systematic. The main sources of systematic uncertainty arise from the description of the fit model in the $p\overline{\Lambda}$ invariant mass and from uncertainties on the tracking efficiencies, which do not completely cancel given the nature of the final states of the signal and the normalisation channel.

The measured branching fraction is compatible with the theoretical predictions in Refs. [15, 23] but is in tension with calculations based on QCD sum rules [24] and calculations based on factorisation with the hypothesis of the violation of partial conservation of the axial-vector current at the GeV scale [4].

References

[1] ARGUS, H. Albrecht *et al.*, *Measurement of inclusive B meson decays into baryons*, Z. Phys. **C42** (1989) 519.

[2] LHCb collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, JINST **3** (2008) S08005.

[3] LHCb collaboration, R. Aaij *et al.*, *LHCb detector performance*, Int. J. Mod. Phys. **A30** (2015) 1530022, `arXiv:1412.6352`.

[4] Y. K. Hsiao and C. Q. Geng, *Violation of partial conservation of the axial-vector current and two-body baryonic B and D_s decays*, Phys. Rev. **D91** (2015) 077501, `arXiv:1407.7639`.

[5] H.-Y. Cheng and C.-K. Chua, *On the smallness of tree-dominated charmless two-body baryonic B decay rates*, Phys. Rev. **D91** (2015) 036003, `arXiv:1412.8272`.

[6] C. Q. Geng, Y. K. Hsiao, and E. Rodrigues, *Three-body charmless baryonic $\bar{B}_s^0$ decays*, Phys. Lett. **B 767** (2017) 205, `arXiv:1612.08133`.

[7] BaBar collaboration, B. Aubert *et al.*, *Measurement of the branching fraction and $\overline{\Lambda}$ polarization in $B^0 \rightarrow \overline{\Lambda} p\pi^-$*, Phys. Rev. **D79** (2009) 112009, `arXiv:0904.4724`.

[8] Belle collaboration, M.-Z. Wang *et al.*, *Study of $B^+ \rightarrow p\overline{\Lambda}\gamma, p\overline{\Lambda}\pi^0$ and $B^0 \rightarrow p\overline{\Lambda}\pi^-$*, Phys. Rev. **D76** (2007) 052004, `arXiv:0704.2672`.

[9] Belle collaboration, M. Z. Wang *et al.*, *Observation of $B^0 \rightarrow p\bar{\Lambda}\pi^-$*, Phys. Rev. Lett. **90** (2003) 201802, `arXiv:hep-ex/0302024`.

[10] LHCb collaboration, *First observation of a baryonic B_s^0 decay*, LHCb-CONF-2016-016.

[11] S. S. Wilks, *The large-sample distribution of the likelihood ratio for testing composite hypotheses*, Ann. Math. Stat. **9** (1938) 60.

[12] M. Pivk and F. R. Le Diberder, *sPlot: a statistical tool to unfold data distributions*, Nucl. Instrum. Meth. **A555** (2005) 356, `arXiv:physics/0402083`.

[13] W.-S. Hou and A. Soni, *Pathways to rare baryonic B decays*, Phys. Rev. Lett. **86** (2001) 4247, `arXiv:hep-ph/0008079`.

[14] K. De Bruyn *et al.*, *Branching ratio measurements of B_s decays*, Phys. Rev. **D86** (2012) 014027, `arXiv:1204.1735`.

[15] C.-K. Chua, *Charmless two-body baryonic $B_{u,d,s}$ decays revisited*, Phys. Rev. **D89** (2014) 056003, `arXiv:1312.2335`.

[16] Y. K. Hsiao and C. Q. Geng, *$f_J(2220)$ and hadronic $\bar{B}_s^0$ decays*, Eur. Phys. J. **C75** (2015) 101, `arXiv:1412.4900`.

[17] BaBar and Belle collaborations, A. J. Bevan *et al.*, *The physics of the B factories*, Eur. Phys. J. **C74** (2014) 3026, `arXiv:1406.6311`.

[18] LHCb collaboration, R. Aaij *et al.*, *Evidence for CP violation in $B^+ \rightarrow p\bar{p}K^+$ decays*, Phys. Rev. Lett. **113** (2014) 141801, `arXiv:1407.5907`.

[19] LHCb collaboration, R. Aaij *et al.*, *First evidence for the two-body charmless baryonic decay* $B^0 \to p\overline{p}$, JHEP **10** (2013) 005, `arXiv:1308.0961`.

[20] CLEO collaboration, T. E. Coan *et al.*, *Search for exclusive rare baryonic decays of B mesons*, Phys. Rev. **D59** (1999) 111101, `arXiv:hep-ex/9810043`.

[21] Belle collaboration, Y.-T. Tsai *et al.*, *Search for* $B^0 \to p\bar{p}, \Lambda\overline{\Lambda}$ *and* $B^+ \to p\overline{\Lambda}$ *at Belle*, Phys. Rev. **D75** (2007) 111101, `arXiv:hep-ex/0703048`.

[22] LHCb collaboration, R. Aaij *et al.*, *Evidence for the two-body charmless baryonic decay* $B^+ \to p\overline{\Lambda}$, `arXiv:1611.07805`, submitted to JHEP.

[23] H.-Y. Cheng and K.-C. Yang, *Charmless exclusive baryonic B decays*, Phys. Rev. **D66** (2002) 014020, `arXiv:hep-ph/0112245`.

[24] V. L. Chernyak and I. R. Zhitnitsky, *B-meson exclusive decays into baryons*, Nucl. Phys. **B345** (1990) 137.

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