Charmless b-hadron decays

Giulio Dujany

on behalf of the LHCb collaboration

13-19/08/2017 XIIIe Rencontres du Vietnam
Overview

1 Introduction

2 Observation of the $B_s^0 \rightarrow p\bar{\Lambda}K^-$ decay [Phys. Rev. Lett. 119, 041802 (2017)]

3 Observation of the $B_{(s)}^0 \rightarrow pp\phi\phi$ decays [arXiv:1704.08497, Accepted by PRD]

4 First observation of the $B^0 \rightarrow p\bar{p}$ decay

5 Update of the branching fraction measurements of the $B_{(s)}^0 \rightarrow K_s^0\phi\phi$ decays [arXiv:1707.01665, Submitted to JHEP]

6 Conclusions
**Baryonic B decays – motivations**

- Many baryonic $B$ decays still to be studied / observed
- Multi-body final state tend to have larger BF that 2-body ones

\[
\mathcal{B}(B^0 \to \Lambda_c^- \rho \pi^+ \pi^-) \sim 10^{-3} \gg \mathcal{B}(B^0 \to \Lambda_c^- \rho \pi^0) \sim 10^{-4} \\
\gg \mathcal{B}(B^0 \to \Lambda_c^- \rho) \sim 10^{-5} \\
\mathcal{B}(B^0 \to p\bar{p}K^0) \sim 10^{-6} \gg \mathcal{B}(B^0 \to p\bar{p}) \sim 10^{-8}
\]

- Threshold enhancement in baryon-antibaryon systems observed in many decay modes (see eg. [Eur. Phys. J. C74 (2014) 3026])

Threshold enhancement observed for the first time by Belle in $B^\pm \to p\bar{p}K^\pm$

Baryonic $B$ decays – short history

**B factories**

- Observation and study of many $B^0$ and $B^+$ baryonic decays, both with charm in the final state and charmless
- Observed threshold enhancement in baryon-antibaryon invariant mass of several decays

**LHCb**

- **2013**: First observation of 2-body charmless baryonic mode $B^+ \to p \bar{\Lambda}(1520)$ and first evidence of CP violation in a baryonic $B$ decay seen in $B^+ \to ppK^+$ [Phys. Rev. Lett. 113, 141801 (2014)]
- **2013**: First evidence of the very suppressed $B^0 \to pp$ [J. High Energy Phys. 10 (2013) 005]
- **2014**: First observation of a baryonic $B_c^+$ decay ($B_c^+ \to J/\psi pp\pi^+$) [Phys. Rev. Lett. 113, 152003 (2014)]
Some aspects common to the following analyses

**Dataset**
LHCb Run I dataset (3 fb$^{-1}$)

**Selection strategy**
- Trigger + loose preselection
- Multivariate classifier (BDT or neural network) against combinatorial background
- Particle identification criteria on charged hadrons (each candidate only in one final state sample)
- Remove explicitly charm mesons, baryons and charmonia ($D^0, \Lambda_c, J/\psi, \ldots$) with a veto on the concerned mass window
Observation of the $B_s^0 \rightarrow p\bar{\Lambda}K^-$ decay

[Phys. Rev. Lett. 119, 041802 (2017)]
**Analysis strategy**

- **Goal:** Observe first $B_s^0$ baryonic decay
  - Look for three-body decay as larger BF expected than 2-body
- **Signal:** $B_s^0 \rightarrow p \bar{\Lambda} K^-$
- **Normalisation mode:** $B^0 \rightarrow p \bar{\Lambda} \pi^-$

\[
\frac{\mathcal{B}_{\text{sgn}}}{\mathcal{B}_{\text{norm}}} = \frac{f_d}{f_s} \frac{N_{\text{sgn}}}{N_{\text{norm}}} \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sgn}}}
\]

- **Categories:** different years and reconstruction categories


**[JINST 10 (2015) P02007]**
Perform a simultaneous fit to signal \( B_s^0 \to p \bar{\Lambda}K^- \) and normalisation mode \( B^0 \to p \bar{\Lambda}\pi^- \) for all categories

- Share shape parameters
- Constrain cross-feed background from different final states

Backgrounds considered: combinatorial, \( B_s^0 \to p \Sigma K^- \), \( B^0 \to p \Sigma\pi^- \)

Observe \( B_s^0 \to p \bar{\Lambda}K^- \) with statistical significance \( > 15 \sigma \)
\((234 \pm 29 \) signal candidates from the fit to all the categories\)
Results

- First observation of a baryonic $B_s^0$ decay!
- Branching fraction measured to be

$$\mathcal{B}(B_s^0 \to p\bar{\Lambda}K^-) + \mathcal{B}(B_s^0 \to p\Lambda K^+) = [5.46 \pm 0.61{\text{(stat)}} \pm 0.57{\text{(syst)}}$$
$$\pm 0.50(\mathcal{B}_{\text{norm}}) \pm 0.32(f_s/f_d)] \times 10^{-6}$$

- Observed threshold enhancement in $p\bar{p}$ mass spectra (efficiency corrected and background subtracted)
Observation of the $B^0_{(s)} \rightarrow p\bar{p}h^+h'^-$ decays

[arXiv:1704.08497, Accepted by PRD]
Goal: Observe and measure BF of charmless $B^{0}_{(s)} \rightarrow p\bar{p}h^{+}h'^{-}$ modes
- Only known $\mathcal{B}(B^{0} \rightarrow p\bar{p}K^{*0}) = (1.24^{+0.28}_{-0.25}) \times 10^{-6}$ (BaBar and Belle)

Signal: $B^{0}_{(s)} \rightarrow p\bar{p}h^{+}h'^{-}$ ($h' = K$ or $\pi$)

Normalisation mode: $B^{0} \rightarrow (J/\psi \rightarrow p\bar{p})(K^{*0} \rightarrow K^{+}\pi^{-})$, same selection as signal except charm vetoes

Simultaneous fit to invariant mass of 3 final states

3-D fit in $m(p\bar{p}K^{\pm}\pi^{\mp})$, $m(p\bar{p})$ and $m(K^{\pm}\pi^{\mp})$ for normalisation mode
Simultaneous signal fits

\[ n_{B}^{p\bar{p}K^+K^-} = 68 \pm 17 \]
\[ n_{B_s}^{p\bar{p}K^+K^-} = 635 \pm 32 \]
\[ n_{B}^{p\bar{p}K^+\pi^\mp} = 4155 \pm 83 \]
\[ n_{B_s}^{p\bar{p}K^+\pi^\mp} = 246 \pm 39 \]
\[ n_{B}^{p\bar{p}\pi^+\pi^-} = 902 \pm 35 \]
\[ n_{B_s}^{p\bar{p}\pi^+\pi^-} = 39 \pm 16 \]

First strong evidence
First observations
**Substructures in** $m(h^+h'^-)$

$B^0_s \rightarrow p\bar{p}K^+K^-$

- Efficiency-corrected and background-subtracted
- Vector mesons visible ($\phi(1020), K^*(892)^0, \rho^0(770)$)

$B^0 \rightarrow p\bar{p}K^\pm\pi^\mp$

$B^0 \rightarrow p\bar{p}\pi^+\pi^-$
Threshold enhancement in $m(p\bar{p})$

$B^0_s \rightarrow p\bar{p}K^+K^-$

- Efficiency-corrected and background-subtracted
- Clear threshold enhancement

$B^0 \rightarrow p\bar{p}K^\pm\pi^\mp$

$B^0 \rightarrow p\bar{p}\pi^+\pi^-$
### Results

[arXiv:1704.08497, Accepted by PRD]

- **3 first observations and a strong evidence**

<table>
<thead>
<tr>
<th>Decay channel</th>
<th>Significance [$\sigma$]</th>
<th>Branching fraction / $10^{-6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow p\bar{p}K^+K^-$</td>
<td>4.1</td>
<td>$0.113 \pm 0.028 \pm 0.011 \pm 0.008$</td>
</tr>
<tr>
<td>$B^0 \rightarrow p\bar{p}K^{\pm}\pi^{\mp}$</td>
<td>$&gt; 25$</td>
<td>$5.9 \pm 0.3 \pm 0.3 \pm 0.4$</td>
</tr>
<tr>
<td>$B^0 \rightarrow p\bar{p}\pi^+\pi^-$</td>
<td>$&gt; 25$</td>
<td>$2.7 \pm 0.1 \pm 0.1 \pm 0.2$</td>
</tr>
<tr>
<td>$B^0_s \rightarrow p\bar{p}K^+K^-$</td>
<td>$&gt; 25$</td>
<td>$4.2 \pm 0.3 \pm 0.2 \pm 0.3 \pm 0.2$</td>
</tr>
<tr>
<td>$B^0_s \rightarrow p\bar{p}K^{\pm}\pi^{\mp}$</td>
<td>6.5</td>
<td>$1.30 \pm 0.21 \pm 0.11 \pm 0.09 \pm 0.08$</td>
</tr>
<tr>
<td>$B^0_s \rightarrow p\bar{p}\pi^+\pi^-$</td>
<td>2.6</td>
<td>$0.41 \pm 0.17 \pm 0.04 \pm 0.03 \pm 0.02$</td>
</tr>
</tbody>
</table>

$val \pm stat \pm syst \pm \sigma(B) \pm \sigma(f_s/f_d)$

- **Upper limit set on $\mathcal{B}(B^0_s \rightarrow p\bar{p}\pi^+\pi^-)$**

$$\mathcal{B}(B^0_s \rightarrow p\bar{p}\pi^+\pi^-) < 6.6 \times 10^{-7} \text{ at } 90\% \text{ CL}$$
First observation of the $B^0 \rightarrow p\bar{p}$ decay

[LHCb-PAPER-2017-022, In preparation]
Motivations

- Two-body baryonic $B$ decays rather suppressed
- Not seen at the $B$ factories
- First two-body mode observed: $B^+ \rightarrow p \Lambda(1520)$ [Phys. Rev. Lett. 113, 141801 (2014)]
- First evidence of $B^0 \rightarrow p\bar{p}$ with $1 \text{ fb}^{-1}$, no $B^0_s$ signal [J. High Energy Phys. 10 (2013) 005]

$$B(B^0 \rightarrow p\bar{p}) = (1.47^{+0.62+0.35}_{-0.51-0.14}) \times 10^{-8} \quad \text{at } 68.3\% \text{ CL}$$

$$B(B^0_s \rightarrow p\bar{p}) = (2.84^{+3.57+2.00}_{-2.12-0.21}) \times 10^{-8} \quad \text{at } 90\% \text{ CL}$$

- Most recent calculations in agreement with branching fraction $O(10^{-8})$ for $B^0 \rightarrow p\bar{p}$ [Phys. Rev. D91, 077501 (2015), Phys. Rev. D 91, 036003 (2015)]
- Important to improve knowledge of these very rare decays $B^0_{(s)} \rightarrow p\bar{p}$
Analysis strategy

- **Signal:** $B^O_{(s)} \rightarrow p\bar{p}$
- **Normalisation mode:** $B^O \rightarrow K^+\pi^-$

Various sources of background considered

- $H_b \rightarrow hh', B \rightarrow hh'h''$
- Baryonic $B$ decays and many-body $\Lambda_b^0$ decays
- Semi-leptonic decays with $B^+ \rightarrow p\bar{p}l^{+}\nu$

Various sources of background considered
Results

$LHCb-PAPER-2017-022$, In preparation

\[ N(B^0 \rightarrow p\bar{p}) = 39 \pm 8 \quad \text{and} \quad N(B_s^0 \rightarrow p\bar{p}) = 2 \pm 4 \]

- First observation of $B^0 \rightarrow p\bar{p}$ at 5.3 $\sigma$

\[ \mathcal{B}(B^0 \rightarrow p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8} \]

- Use Feldman-Cousin method to set upper limit on $B_s^0 \rightarrow p\bar{p}$

\[ \mathcal{B}(B_s^0 \rightarrow p\bar{p}) < 1.5 \times 10^{-8} \quad \text{at 90\% CL} \]
Update of the branching fraction measurements of the $B^0_{(s)} \rightarrow K^0_S h^+h'^-$ decays

[arXiv:1707.01665, Submitted to JHEP]
Motivations

- Update with $3 \text{ fb}^{-1}$ of previous LHCb analysis on $1 \text{ fb}^{-1}$ [J. High Energy Phys. 10 (2013) 143]
- Search still unobserved for $B^0_S \rightarrow K^0_K K^+ K^-$
- Prepare for Dalitz-plot analysis

Family of modes with great physics potential

- Possibility to perform Dalitz-plot analysis
- Contribution to extractions of angle $\gamma$, weak phase of $B^0$ mixing
Analysis strategy

- Measure branching fraction of different $B_{(s)}^0 \rightarrow K_S^0 h^+ h'^-$ decays with respect to $B^0 \rightarrow K_S^0 \pi^+ \pi^-$
- **Categories**: different data-taking periods and $K_S^0$ decaying inside or outside the VELO
- **Selection**: Optimise selection separately for each decay mode (two different optimised selections for each final state)
- **Fit**: Simultaneous fit to 3 final states
  - Signal: $B^0$, $B_s^0$
  - Combinatorial background
  - Partially reconstructed background
  - Mis-identified backgrounds ($B^0 \rightarrow K_S^0 \pi^+ \pi^-$ and $B^0 \rightarrow K_S^0 K^+ K^-$ in $m(K_S^0 K^{\mp} \pi^\mp)$ and $B^0 \rightarrow K_S^0 K^\pm \pi^\mp$ and $B_s^0 \rightarrow K_S^0 K^\pm \pi^\mp$ in the other two)
Branching fraction ratio relative to $B^0 \to K_S^0 \pi^+ \pi^-$

\[
\frac{\mathcal{B}(B^0 \to K_S^0 K^{\pm} \pi^\mp)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = 0.123 \pm 0.009 \text{ (stat)} \pm 0.015 \text{ (syst)},
\]

\[
\frac{\mathcal{B}(B^0 \to K_S^0 K^+ K^-)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = 0.549 \pm 0.018 \text{ (stat)} \pm 0.033 \text{ (syst)},
\]

\[
\frac{\mathcal{B}(B_s^0 \to K_S^0 \pi^+ \pi^-)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = 0.191 \pm 0.027 \text{ (stat)} \pm 0.031 \text{ (syst)} \pm 0.011 \text{ (}f_s/f_d\text{)},
\]

\[
\frac{\mathcal{B}(B_s^0 \to K_S^0 K^{\pm} \pi^\mp)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = 1.70 \pm 0.07 \text{ (stat)} \pm 0.11 \text{ (syst)} \pm 0.10 \text{ (}f_s/f_d\text{)},
\]

\[
\frac{\mathcal{B}(B_s^0 \to K_S^0 K^+ K^-)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = 0.026 \pm 0.011 \text{ (stat)} \pm 0.007 \text{ (syst)} \pm 0.002 \text{ (}f_s/f_d\text{)}.
\]

Use Feldman-Cousin method to set upper limit for $B_s^0 \to K_S^0 K^+ K^-$

\[
\frac{\mathcal{B}(B_s^0 \to K_S^0 K^+ K^-)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} \in [0.008 - 0.051] \text{ at 90\% C.L.}
\]
From World average (omitting LHCb previous result) [PDG]
\[ \mathcal{B}(B^0 \to K^0 \pi^+ \pi^-) = (4.96 \pm 0.20) \times 10^{-5} : \]
\[ \mathcal{B}(B^0 \to \bar{K}^0 K^\pm \pi^\mp) = (6.1 \pm 0.5 \pm 0.7 \pm 0.3) \times 10^{-6} , \]
\[ \mathcal{B}(B^0 \to K^0 K^+ K^-) = (27.2 \pm 0.9 \pm 1.6 \pm 1.1) \times 10^{-6} , \]
\[ \mathcal{B}(B_s^0 \to K^0 \pi^+ \pi^-) = (9.5 \pm 1.3 \pm 1.5 \pm 0.4) \times 10^{-6} , \]
\[ \mathcal{B}(B_s^0 \to \bar{K}^0 K^\pm \pi^\mp) = (84.3 \pm 3.5 \pm 7.4 \pm 3.4) \times 10^{-6} , \]
\[ \mathcal{B}(B_s^0 \to K^0 K^+ K^-) \in [0.4 - 2.5] \times 10^{-6} \text{ at 90% C.L.} , \]

- Compatible with previous analysis [J. High Energy Phys. 10 (2013) 143]
- Dalitz-plot analyses under way
LHCb is very active in the study of charmless \( b \)-hadron decays

In particular many results with baryonic final states

In this talk presented several recent results from the LHCb collaboration:

- First observation of baryonic \( \bar{B}_s \) decay
- First observation of 3 new \( \bar{B}^0_{(s)} \to p\bar{p}h^+h'^- \) modes and evidence of a fourth one
- First observation of the \( \bar{B}^0 \to p\bar{p} \) decay: the rarest hadronic \( B \) decay observed so far
- Updated branching fraction of \( \bar{B}^0_{(s)} \to K^0_{s}h^+h'^- \) decays

Run II is providing a lot more statistics

Expect in the near future to perform more sophisticated analyses with the newly observed decay modes (CP-violation studies, amplitude analyses, . . . )
BACKUP
Acceptance: $2 < \eta < 5$
\sim 1/4$ of produced $b\bar{b}$ pairs.

Decay time
resolution \sim 45\,fs

IP resolution \sim 20\,\mu m

Vertex resolution \sim 13\,\mu m
in $x\,y$ (25 tracks)

$\Delta p/p \sim 0.5 - 1.0\%$

$\varepsilon(\mu) \sim 97\%,$

$misID(\pi \to \mu) \sim 1 - 3\%$

$\varepsilon(K) \sim 95\%,$

$misID(\pi \to K) \sim 5\%$
Reconstructing $\Lambda$ and $K^0_s$ [Int. J. Mod. Phys. A 30 (2015) 1530022]