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Rare B meson decays to baryonic final states

Pablo Baladrón Rodríguez[a,*]

[a] *Instituto Galego de Física de Altas Enerxías,*
Xaquín Díaz de Rábago s/n, Santiago de Compostela, Galiza

[b] *Física Nuclear e de Partículas, Universidade de Santiago de Compostela,*
Xaquín Díaz de Rábago s/n, Santiago de Compostela, Galiza

E-mail: pablo.baladron.rodriguez@cern.ch

Nowadays only few measurements are available for B-meson decays to baryonic final states. However these decays are very interesting for several reasons. On the one hand these modes receive relevant contributions from penguin topologies and are hence sensitive to new physics beyond the Standard Model. On the other hand, residual QCD effects may mimic new physics and the models used to deal with these contributions will greatly benefit from additional measurements. In this presentation the results of the most recent searches of baryonic B-meson decays at LHCb are presented.

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1. Motivation

There is an unexpected hierarchy in B-meson decays with and without $p\bar{p}$-pairs in the final state [1]. While purely mesonic 2-body decays have greater branching fractions than the 4-body case, the branching fractions of 4-body decays with a $p\bar{p}$-pair in the final state are about the same order of magnitude with respect to $B^0 \to p\bar{p}$ decay. This effect can be explained as a threshold enhancement effect on the $p\bar{p}$-pair mass. Pronounced enhancements near threshold were first reported in B decays to the $p\bar{p}K^{\pm}$ final state by the Belle Collaboration [2].

The purely baryonic 2-body decay $B^0 \to p\bar{p}$ was observed by the LHCb Collaboration for the first time [3] using Run1 data with an integrated luminosity of $3\,\text{fb}^{-1}$, the branching fraction is measured to be

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.25 \pm 0.27 \pm 0.18) \times 10^{-8}\,. \tag{1}$$

No signal of $B^0_s \to p\bar{p}$ was found and the first upper limit was set:

$$\mathcal{B}(B^0_s \to p\bar{p}) < 1.5 \times 10^{-8} \quad \text{at} \quad 90\,\% \quad \text{CL.} \tag{2}$$

The $B^0 \to p\bar{p}p\bar{p}$ decay was studied by the BaBar collaboration and determined the branching fraction [4] to be

$$\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) < 2.0 \times 10^{-7} \quad \text{at} \quad 90\,\% \quad \text{CL.} \tag{3}$$

No search for the B^0_s mode has been performed.

New measurements of purely baryonic B decays would provide new insight in the understanding of the unexpected hierarchy of branching fractions involving $p\bar{p}$-pairs.

1.1 Theory Landscape

On the theory side, different effects play a role in the understanding of the dynamics of baryonic B decays, non-perturbative strong interactions combine with short-distance weak decays to produce final states that display non-trivial patterns.

The threshold enhancement observed in the multi-body decays could be explained as non-perturbative QCD contributions. In this scenario, the main idea is that low-energy $p\bar{p}$-pairs are favoured in the phase space of the B-meson decay. There are different possible explanations such as a resonance before threshold, final state interactions, baryon form factors, etc. [6].

The contribution of the W-exchange and penguin-annihilation diagrams could have big impacts on the 2-body purely baryonic decays. If they are suppressed, the yield of $B^0_s \to p\bar{p}$ decay could be vanishingly small [5], otherwise, it could have a branching fraction up to $\mathcal{O}(10^{-8})$ [1]. Measuring the rare $B^0_s \to p\bar{p}$ decay could help us to understand the role of higher order Feynman diagrams contributing to these weak processes.

2. Search for the rare hadronic decay $B^0_s \to p\bar{p}$

The previous result on the $B^0_{(s)} \to p\bar{p}$ decays was obtained by LHCb [3], a similar strategy is used to analyse the full Run2 data with an integrated luminosity of $6\,\text{fb}^{-1}$. The branching fraction is obtained using the $B^0 \to K\pi$ as control channel:

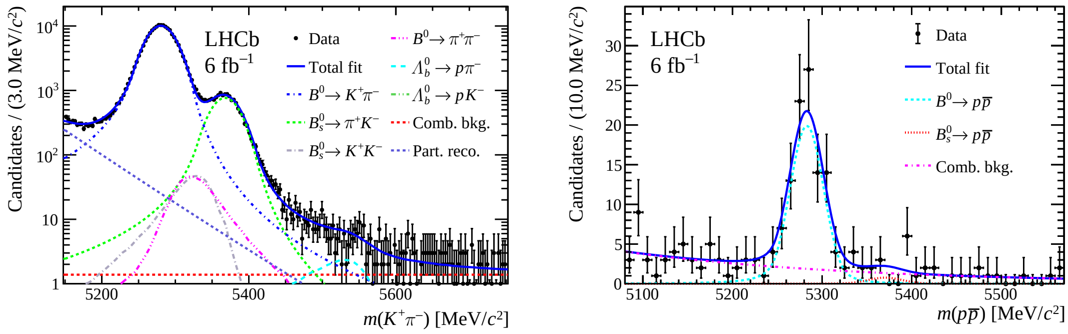

Figure 1: Mass fits on $B^0_{(s)} \to p\bar{p}$ analysis. The left plot shows the mass fit to the normalization channel. There are several contributions besides the signal, such as: the particle miss-identifications, partially reconstructed decays, the B_s^0 signal and the continuum background. In the right plot, the mass fit to the signal channel is shown. There are only 3 contributions, the 2 signals and the continuum background.

$$\mathcal{B}(B^0_{(s)} \to p\bar{p}) = \frac{N(B^0_{(s)} \to p\bar{p})}{N(B^0 \to K^+\pi^-)} \times \frac{\varepsilon_{B^0 \to K^+\pi^-}}{\varepsilon_{B^0_{(s)} \to p\bar{p}}} \times \mathcal{B}(B^0 \to K^+\pi^-) \times \frac{f_d}{f_{d(s)}} . \tag{4}$$

This analysis is performed blinded in the signal region. The yields are obtained from a fit to the invariant mass for the signal and control channels. The efficiencies are determined from simulated samples. The branching fraction input of $B^0 \to K\pi$ is taken from the Particle Data Group [7]. The hadronization fraction for the B_s^0 mode is $f_s/f_d = 0.2539 \pm 0.0079$. The branching fraction is measured as a ratio with respect to the control channel in order to cancel out most of the possible systematic uncertainties.

The selection is performed in 3 steps: a set of cuts are used to ensure a good quality of the tracks, a PID selection is performed and finally a Boost Decision Tree on topological variables is used to remove the continuum background. The mass fit is performed after the selection, as shown in Fig. 1, where the yields are determined to be $N(B^0 \to K^+\pi^-) = 179890 \pm 350$ for the control mode and $N(B^0 \to p\bar{p}) = 98 \pm 11$ and $N(B_s^0 \to p\bar{p}) = 4 \pm 5$ for the signal channels.

Finally, the branching fraction is determined to be:

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.15 \pm 0.05 \pm 0.04) \times 10^{-8}. \tag{5}$$

Using a χ^2 combination with Run 1 result yields

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.27 \pm 0.13 \pm 0.05 \pm 0.03) \times 10^{-8}; \tag{6}$$

where the first uncertainty is statistical, the second is systematic and the third is due to the uncertainty on the external branching fraction of the normalization channel.

For the B_s^0 mode, as the significance of the signal from the mass fit is below 1σ level, an upper limit is given. It is improved by a factor 4 compared with the Run 1 result. The likelihood scan is shown in Fig. 2 and leads to limit:

$$\mathcal{B}(B_s^0 \to p\bar{p}) < 4.4(5.1) \times 10^{-9} \quad \text{at} \quad 90\,\%(95\,\%) \quad \text{CL}. \tag{7}$$

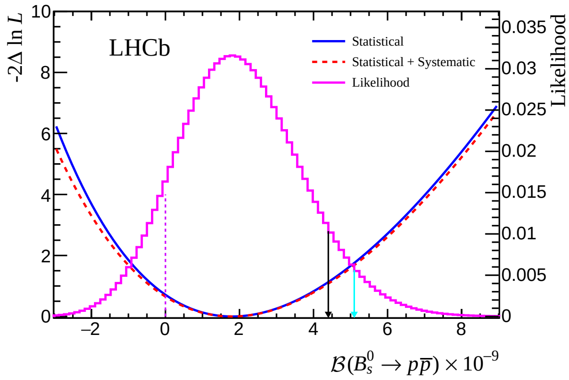

Figure 2: Likelihood scan to obtain the $B_s^0 \to p\bar{p}$ upper limits.

3. Searches for the rare hadronic decays $B^0 \to p\bar{p}p\bar{p}$ and $B_s^0 \to p\bar{p}p\bar{p}$

The main goal of this analysis is the first observation of a purely baryonic B-meson four-body decay. The strategy of this analysis [9] is to perform a branching fraction measurement with the full LHCb Run 1 and Run 2 data with an integrated luminosity of $9\,\text{fb}^{-1}$. A simultaneous fit to the normalization and signal channels is performed. The efficiencies are obtained separately from simulation and re-weighted to data of the normalization modes. This analysis is also performed blinded in the signal region.

The branching fraction is finally obtained as follows (note that labels between parenthesis refers to the B_s^0 mode):

$$\mathcal{B}(B^0_{(s)} \to p\bar{p}p\bar{p}) = \frac{N(B^0_{(s)} \to p\bar{p}p\bar{p})}{N(B^0_{(s)} \to J/\psi\, K^{*0}(\phi))} \times \frac{\varepsilon_{B^0_{(s)} \to J/\psi\, K^{*0}(\phi)}}{\varepsilon_{B^0_{(s)} \to p\bar{p}p\bar{p}}} \times \mathcal{B}_{vis}(B^0_{(s)} \to J/\psi\, K^{*0}(\phi)), \tag{8}$$

where the branching fraction is measured as a ratio with respect to the control channel in order to cancel out most of the possible systematic uncertainties.

There are 2 different selection categories, *tight* and *very tight*. In the second case, very tight cuts are applied to the PID. The *very tight* selection is used to study the B_s^0-meson as it is supposed to be further suppressed than the B^0 mode. The χ^2_{IP} of the $B^0_{(s)}$ meson with respect to the origin vertex and the aforementioned PID are the most important variables in the selection. The yields for the signal channels are obtained from the fits to the invariant mass projections, as shown in Fig.3. The results are: $N(B^0 \to p\bar{p}p\bar{p}) = 48 \pm 8$ with a significance $S > 9\sigma$ and $N(B_s^0 \to p\bar{p}p\bar{p}) = 7.1 \pm 2.9$ with $S = 4\sigma$. In Fig.4 and Fig.5 the 3D fits to the normalization channels are shown.

The results obtained for the branching fractions are

$$\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (2.2 \pm 0.4 \pm 0.1 \pm 0.1) \times 10^{-8} \tag{9}$$

and

$$\mathcal{B}(B_s^0 \to p\bar{p}p\bar{p}) = (2.3 \pm 1.0 \pm 0.2 \pm 0.1) \times 10^{-8}\,; \tag{10}$$

where the first uncertainty is statistical, the second is systematic and the third is due to the uncertainty on the external branching fraction of the normalization channel.

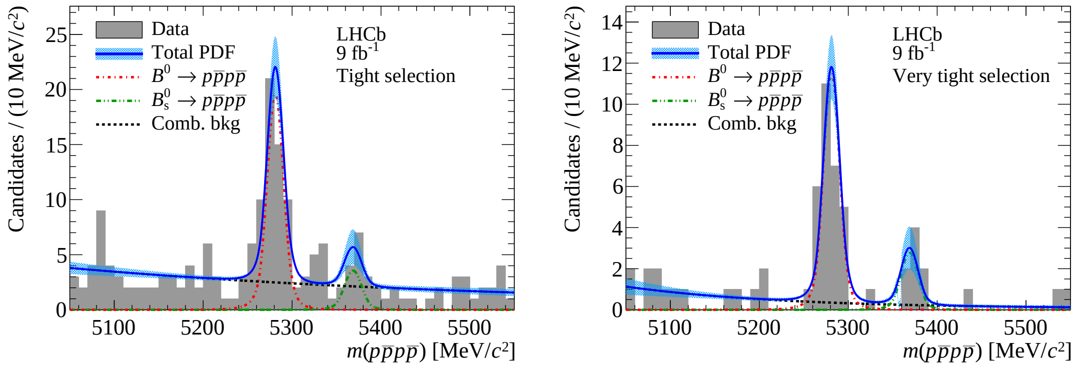

Figure 3: Mass fits on $B^0_{(s)} \to p\bar{p}p\bar{p}$ analysis. There are only 3 contributions, the 2 signals and the continuum background. *Tight* (left) and *very tight* (right) categories are used for B^0 and B^0_s modes respectively.

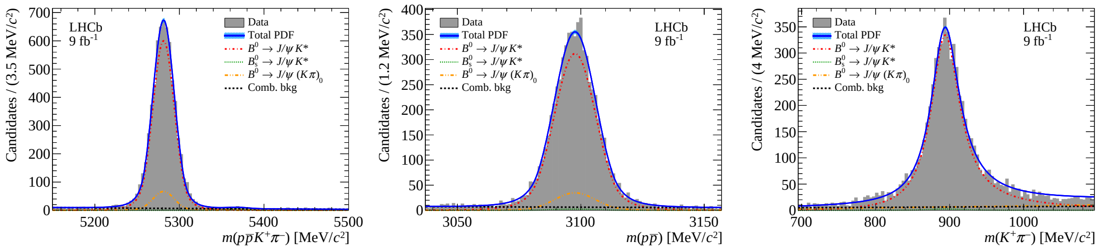

Figure 4: 3D mass fits on $B^0 \to J/\psi(p\bar{p})\, K^{*0}(K\pi)$ normalization channel.

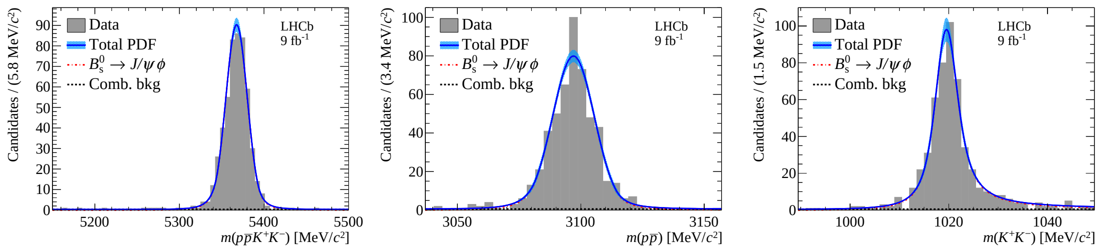

Figure 5: 3D mass fits on $B^0_s \to J/\psi(p\bar{p})\, \phi(KK)$ normalization channel.

Finally, a qualitative study was performed to explore for possible $c\bar{c}$ contributions, where the branching fractions are re-computed with a veto avoiding any $c\bar{c}$ contribution to the phase space (note that the efficiencies decrease with the $c\bar{c}$ veto and uncertainties are only statistical), resulting

$$\mathcal{B}(B^0 \to p\bar{p}p\bar{p}) = (1.6 \pm 0.4) \times 10^{-8} \tag{11}$$

and

$$\mathcal{B}(B^0_s \to p\bar{p}p\bar{p}) = (2.2 \pm 1.2) \times 10^{-8}\,. \tag{12}$$

The results are consistent with decays proceeding primarily through charmless transitions.

4. Conclusions

The precise branching fraction measurement of the $B^0 \to p\bar{p}$ and the stringent upper limit on the $B_s^0 \to p\bar{p}$ is performed by LHCb, which will allow further improvement in the extraction of both tree and penguin amplitudes of charmless two-body baryonic B decays.

A first observation of purely baryonic four-body B-meson decay has been performed. The reported branching fraction of $B^0 \to p\bar{p}p\bar{p}$ is about an order of magnitude lower than the upper limit previously reported by the BABAR Collaboration and about twice that of the $B^0 \to p\bar{p}$ decay, while the measured $B_s^0 \to p\bar{p}p\bar{p}$ is about four times the upper limit for the $B_s^0 \to p\bar{p}$ decay.

With the removal of the hardware trigger and the increase in the recorded luminosity, these analyses will greatly benefit from the LHCb Upgrade. The observation of $B_s^0 \to p\bar{p}$, confirmation for the large $B_s^0 \to p\bar{p}p\bar{p}$ branching fraction, an amplitude analysis on $B^0 \to p\bar{p}p\bar{p}$ could be performed and more baryonic modes can be studied, e.g.: $B^+ \to p\bar{\Lambda}$.

References

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