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Measurements of the relative branching fractions of the $B^+ \to p\bar{p}K^+$ decay channel including charmonium contributions

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Abstract. The study of the $B^+ \to p\bar{p}K^+$ decay channel at LHCb offers great opportunities to study different aspects of the Standard Model and possibly Beyond Standard Model physics. In particular it can be interesting not only for the possibility to measure CP asymmetry but also to study possible intermediate resonances. The ratios of the branching fractions of the $B^+ \to p\bar{p}K^+$ decay channel, of the charmless component with $M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$ and of the charmonium contribution η_c relative to the J/ψ are presented.

1 Introduction

The current knowledge on the $B^+ \to p\bar{p}K^+$ decay is based on the measurements performed at the B-factories[1,2]. Thanks to the high statistics available in the next years at LHCb, due to the large $b\bar{b}$ production cross section, $\sigma_{b\bar{b}} = (284 \pm 20 \pm 49)\mu$b [3] at a centre of mass energy of $\sqrt{s} = 7\,\mathrm{TeV}$, more precise measurements can be performed and possibly new physics can be revealed.
LHCb is a singla arm forward spectrometer optimised to perform precise CP violation measurements and rare decays study in the heavy flavour sector.
Three-body baryonic B decays are expected to proceed predominantly via $b \to s$ penguin diagrams or doubly Cabibbo suppressed tree diagrams [4] and as such new heavy virtual particles can give measurable departures from Standard Model expectations. The baryon-antibaryon pair can also be produced by a pair of gluons in OZI suppressed penguin diagrams, where gluonic resonances could be formed. The three Feynman diagrams are shown in Fig. 1. The interference between the penguin diagram

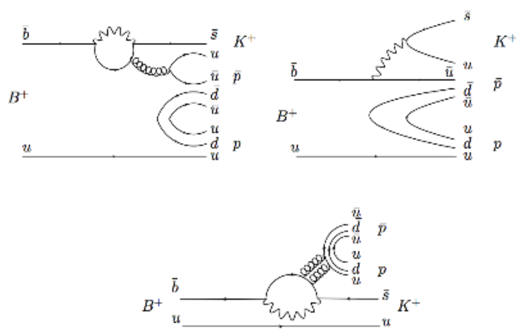

Fig. 1. Feynman Diagrams: penguin (top left), doubly Cabibbo suppressed tree (top right), OZI suppressed penguin (bottom).

and the doubly CKM suppressed tree diagram can lead to a direct CP asymmetry.

Moreover, three-body baryonic decays offer a clean environment to study intermediate states, as charmonium states, excited Λ baryons and exotic states (glueballs [5], baryonium, pentaquarks). In fact, the $p\bar{p}$ final state can be produced through a resonant intermediate state, a $c\bar{c}$ state or through an unknown exotic state. At LHCb, beyond the study of well known charmonium states, it can be interesting to observe charmonium-like states such as $X(3872)$ or new intermediate states in order to study their nature and properties.
Another interesting feature observed both at the BaBar and Belle detectors in three body baryonic B decays is the low mass $m_{p\bar{p}}$ enhancement. Several explanations have been proposed. A study of the distribution of events in the Dalitz plot can explain the origin of this mass enhancement. [6].
A preliminary study of this mode based on the sample of events collected by the LHCb detector in the 2010 data taking period is presented. The branching ratios of $B^+ \to p\bar{p}K^+$, of the charmless component in the range $M_{p\bar{p}} < 2.85\,\mathrm{GeV/c^2}$ and of the $B^\pm \to \eta_c K^\pm$ decay channel with $\eta_c \to p\bar{p}$ relative to the product of branching fractions $\mathcal{B}_{J/\psi} = \mathcal{B}(B^\pm \to J/\psi K^\pm) \times \mathcal{B}(J/\psi \to p\bar{p})$, which is well known [7], have been measured.
The measurement relies only on the ratios of events, N(mode), and efficiencies, ϵ_{mode}, with respect to the reference mode:

$$\frac{\mathcal{B}(\mathrm{mode})}{\mathcal{B}(J/\psi)} = \frac{N(\mathrm{mode})}{N(J/\psi)} \times \frac{\epsilon_{J/\psi}}{\epsilon_{\mathrm{mode}}} \qquad (1)$$

where $N(J/\psi) = N_{B^+\to J/\psi(\to p\bar{p})K^+}$ and $\epsilon_{J/\psi} = \epsilon_{B^+\to J/\psi(\to p\bar{p})K^+}$

2 Study of the $B^+ \to p\bar{p}K^+$ selection

Since the $b\bar{b}$ cross section is approximately 1% of the total inelastic cross section and the interesting channel branching ratios are of the order of $\mathcal{B} \sim 10^{-5}$-10^{-6}, it is extremely important to design a selection with a high rejection of the background. The selection strategy is based on a preselection with very loose selection criteria. A multivariate analysis using the “Boosted Decision Tree” algorithm of the

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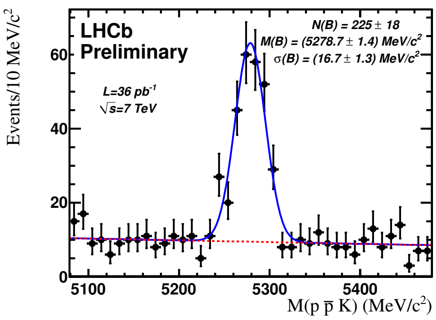

Fig. 2. Mass distribution of all selected $B^+ \to p\bar{p}K^+$ events. The continuous line show the fit result, the dashed line shows the fitted background component.

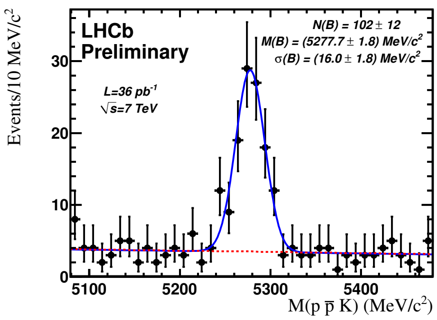

Fig. 3. Mass distribution of the selected $B^+ \to p\bar{p}K^+$ events for $M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$. The continuous line shows the fit result, the dashed line shows the fitted background component.

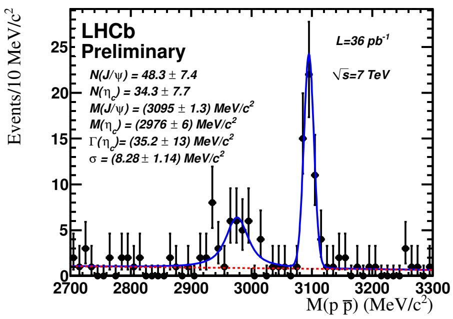

Fig. 4. Mass distribution of $p\bar{p}$ in the J/ψ-η_c range for events having $|M(p\bar{p}K) - M(B)| < 50\,\mathrm{MeV/c}^2$. The solid line shows the result of the fit, the dashed line corresponds to the fitted background contribution.

TMVA package [8] is used to optimise the selection efficiency. The variables used in the selection procedure exploit kinematic and topological characteristics of b-hadron decays. Three charged particles in the final state with large transverse momenta are required. The three final state particles have to come from the same displaced secondary vertex requiring a good vertex fit and a significant distance between the two vertices. Moreover it is required a small maximum distance of closest approach between the tracks and non zero impact parameters. And the momenta direction of the three daughters has to be compatible with the flight direction of the B. Furthermore the particle identification information, provided by two RICH detectors in LHCb, is a fundamental ingredient of the selection in order to identify correctly protons and kaons candidates. A signal efficiency of more than 70% with respect to preselected events has been obtained using the BDT algorithm with a signal to background ratio of $S/B \sim 1$.

3 Signal Extraction

The number of $B^+ \to p\bar{p}K^+$ signal events are extracted from an unbinned maximum likelihood fit to the $M_{p\bar{p}K}$ invariant mass distribution of the selected events (Fig. 2). The fit procedure has been applied also on the subsample of events having $M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$ to extract the number of events in the charmless region (Fig. 3). The signal probability density function has been parametrized with a Gaussian function while for the background a linear function has been used.
For the $B^+ \to J/\psi(\to p\bar{p})K^+$ and $B^+ \to \eta_c(\to p\bar{p})K^+$, the yield has been extracted with a fit to the $M_{p\bar{p}}$ distribution for the B events having $M_{p\bar{p}K}$ invariant mass compatible within 2.5σ with the known B^+ mass (Fig. 4). Since the J/ψ meson has a natural width much smaller than the detector resolution while the natural width of the η_c is not negligible, the J/ψ has been parametrized with a Gaussian function while for the η_c the convolution of a Breit-Wigner with a Gaussian function with the same resolution of the J/ψ has been used.

4 Estimation of efficiencies

The calculation of the branching fractions based on Eq. 1 requires the determination of the ratio of the efficiency for each considered channel (all the events, events with $M_{p\bar{p}} < 2.85\,\mathrm{GeV}/c^2$ and η_c events) with respect to the J/ψ: $\epsilon_{\mathrm{mode}}/\epsilon_{J/\psi}$.
The overall efficiency ratios, product of reconstruction, trigger and event selection efficiency as a function of $M_{p\bar{p}}$ invariant mass have been calculated using simulated events in order to correct for varying efficiency over the $M_{p\bar{p}}$ range. The ratios with their uncertainties are reported in Tab. 1.

5 Evaluation of systematics

Since the final state for the considered modes and the reference one is the same, most of the systematic uncertainties cancel.
Possible systematic uncertainties have been considered on the event yield determination and on the efficiency ratios.
The systematic uncertainty on the event yield extraction is estimated using different fit ranges, different parametrisation for signal and background. Half of the largest difference in the central value obtained with different fit configurations is taken as systematic uncertainty on the number of signal events. The event yields for each mode and the corresponding systematic uncertainties are listed in Tab. 1.
The uncertainty on the efficiency ratios described in Section 4 is considered as a systematic uncertainty.
Most data-simulation discrepancies are independent from the Dalitz plot variables and cancel in the ratio. In some cases, in particular for particle identification, the discrepancies are larger for low momentum tracks. A conservative 10% systematic uncertainty due to momentum depen-

dent data-simulation discrepancy on the efficiency ratios has been assumed for the total $\mathcal{B}(B^+ \to p\bar{p}K^+)$ and for the charmless $\mathcal{B}(B^+ \to p\bar{p}K^+)_{M_{p\bar{p}}<2.85\,\mathrm{GeV}/c^2}$ branching ratios.

6 Branching ratio measurements

Using the number of events extracted for each considered mode and the corresponding ratios of efficiencies with respect to the $B^+ \to J/\psi(\to p\bar{p})K^+$ the preliminary measurements of ratios of branching fractions have been extracted and are reported in Tab. 2.

Table 1. Yields of $B^+ \to p\bar{p}K^+$ events in each mode, ratio of efficiencies of each mode with respect to the $B^+ \to J/\psi(\to p\bar{p})K^+$.

Mode	Yield ± stat ± syst	$\epsilon/\epsilon_{J/\psi}$
J/ψ	48 ± 7 ± 2	1
ALL	225 ± 18 ± 5	1.01 ± 0.10
$M_{p\bar{p}} < 2.85\,\mathrm{GeV/c^2}$	102 ± 12 ± 2	0.96 ± 0.10
η_c	34 ± 8 ± 3	0.994 ± 0.003

Table 2. Ratios of branching fractions with statistical and systematic uncertainties for the different modes considered.

Mode	$\mathcal{B}$ ratio LHCb
J/ψ	1
ALL	4.6 ± 0.6 ± 0.5
$M_{p\bar{p}} < 2.85\,\mathrm{GeV/c^2}$	2.21 ± 0.41 ± 0.24
η_c	0.71 ± 0.20 ± 0.07

7 Conclusions and perspectives with the full 2011 data set

The preliminary measurements of the ratios of branching fractions for the $B^+ \to p\bar{p}K^+$ decays have been reported. From the measured ratios, using the known values of the $\mathcal{B}(B^+ \to J/\psi K^+)$ and $\mathcal{B}(J/\psi \to p\bar{p})$ the corresponding branching fractions have been derived and reported in Tab. 3.

Table 3. Derived LHCb preliminary branching ratios with statistical error, systematic uncertainty and the uncertainty on the knowledge of the $\mathcal{B}(B^+ \to J/\psi(\to p\bar{p})K^+)$. All values are in units 10^{-6}.

Mode	LHCb $\mathcal{B}$ (preliminary)
ALL	10.2 ± 1.4 ± 1.1 ± 0.5
$M_{p\bar{p}} < 2.85\,\mathrm{GeV/c^2}$	4.87 ± 0.91 ± 0.54 ± 0.22
η_c	1.57 ± 0.43 ± 0.15 ± 0.07

Table 4. Branching ratios measured at the B-factories. All values are in units 10^{-6}.

Mode	BaBar [1]	Belle [2]
ALL	-	$10.76^{+0.36}_{-0.33} \pm 0.70$
$M_{p\bar{p}} < 2.85\,\mathrm{GeV/c^2}$	5.3 ± 0.4 ± 0.3	$5.0^{+0.24}_{-0.22} \pm 0.32$
η_c	$1.8^{+0.3}_{-0.2} \pm 0.2$	$1.42 \pm 0.11^{+0.16}_{-0.20}$

The results are compatible with the average values reported in the PDG and measured at the B-factories as reported in Tab. 4, even with the limited statistics used in this analysis.

The current systematic uncertainty is largely of statistical origin, so both statistic and systematic uncertainties will decrease as soon as the available statistics increase.

In 2011 LHCb has collected more than 1 fb^{-1}. The large available statistics collected in 2011 is a factor almost 10 more with respect to the statistics collected at the B-factories. The most accurate available measurements have been performed by the BaBar and Belle Collaborations using about 1000 fully reconstructed exclusive decays. An improvement on the precision of the branching fractions is expected in particular for $\mathcal{B}(B^\pm \to \eta_c K^\pm) \times \mathcal{B}(\eta_c \to p\bar{p})$. Moreover the study of more rare charmonium contributions will be possible, such as $\eta_c(2S)$ and $X(3872)$, observing or putting an upper limit on $\mathcal{B}(B^+ \to c\bar{c}K^+) \times \mathcal{B}(c\bar{c} \to p\bar{p}) \sim 10^{-7}$.

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