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Studies of b-hadron decays to final states containing charmonia at LHCb

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The LHCb experiment is a forward arm spectrometer designed to make high precision measurements of b-hadron decays at the LHC.
The efficient muon trigger allows to perform studies of B mesons decaying to charmonia with high precision. An overview of the analyses of the LHCb experiment concerning B decays to final states containing charmonia is given.

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1. Introduction

Charmonium states are often exploited in studies of CP violation in the b sector because of their clean experimental signature and because of the many final states containing charmonia accessible to both B mesons and their anti-particles $\bar{B}$.

One of the difficulties in determining parameters of the CKM formalism from CP asymmetries is the contribution to the final state from higher order processes (*penguin* topologies). Such contributions are expected to become the dominant source of uncertainty once sufficient statistics will be collected, but they are difficult to predict theoretically. Relying on U-spin symmetry, the penguin contribution in B_s^0 decays can be easily related to the contribution in B^0 decays. The $B_s^0 \to J/\psi K_S^0$ effective lifetime measurement, presented here, is a first step toward a measurement of the penguin contribution to B_s^0 decays.

Large size and high purity $b \to c\bar{c}$ samples selected relying on the clear $(c\bar{c}) \to \mu^+\mu^-$ experimental signature allow to study relatively rare decays, as $B^0_{(s)} \to J/\psi f_1(1285)$, and to draw conclusions about the spectroscopy of light states.

Finally, at the LHC, the average flight distance of a B meson is much larger than the uncertainties. Exploiting this feature it is possible to strongly suppress the combinatorial background and to study relatively rare decays of charmonium states produced in $b \to c\bar{c}$ transitions. Three notable examples are reported here. First, the branching fraction measurement $\mathscr{B}(B^+ \to (c\bar{c})K^+ \to p\bar{p}K^+)$ decays $\big($with $(c\bar{c})$ being a J/ψ, $\psi(2S)$, χ_{c0}, h_c, η_c, $X(3872)$, or $X(3915)$ meson$\big)$, which can be combined with previous measurements of $\mathscr{B}(B^+ \to (c\bar{c})K^+)$ to obtain the branching fraction of $(c\bar{c}) \to p\bar{p}$ decays. Second, the first observation of both the $B^+ \to \psi(4160)K^+$ decay, and the subsequent $\psi(4160) \to \mu^+\mu^-$ decay. Third, the observation of the $B_s^0 \to \chi_{c1}\phi$ decay, and a study of $B^0 \to \chi_{c1,2}K^{*0}$ decays.

2. The LHCb detector

The LHCb detector [1] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the pp interaction region, a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations of silicon-strip detectors and straw drift tubes placed downstream. The combined tracking system provides a momentum measurement with relative uncertainty that varies from 0.4% at 5 GeV/c to 0.6% at 100 GeV/c, and impact parameter resolution of 20 μm for tracks with large transverse momentum. Different types of charged hadrons are distinguished by information from two ring-imaging Cherenkov detectors [2]. Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers [3]. The trigger [4] consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction.

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3. Effective lifetime measurement in $B^0_s \to J/\psi K^0_S$

Measuring the $B^0 \to J/\psi K^0_S$ mode allows the determination of the $B^0 - \bar{B}^0$ mixing phase ϕ_d. The average composed by the Heavy Flavour Averaging Group (HFAG) is $\sin\phi_d = 0.682 \pm 0.019$ [5] and is dominated by the results of Belle and Babar. Among the phases constrained by the unitarity triangle, ϕ_d is the most precisely measured, and an improvement could help to resolve a possible small tensions with other measurements constraining the unitarity triangle. However, it is impossible to achieve a precision below the percent level without an accurate knowledge of the double Cabibbo-suppressed higher order perturbative corrections, originating from penguin topologies, which can't be accurately predicted.

The $B^0_s \to J/\psi K^0_S$ decay is related to the $B^0 \to J/\psi K^0_S$ decay through the interchange of all the d and s quarks (U-spin symmetry). Moreover, the $B^0_s \to J/\psi K^0_S$ penguin topologies are not CKM suppressed relative to the tree diagram. As discussed in detail in [6], it is thus important to characterize the $B^0_s \to J/\psi K^0_S$ decay mode, measuring in particular the branching fraction and effective lifetime, defined as $\tau^{\mathrm{eff}}_{J/\psi K^0_S} \equiv \frac{\int_0^\infty t\langle\Gamma(B_s(t)\to J/\psi K^0_S)\rangle \mathrm{d}t}{\int_0^\infty \langle\Gamma(B_s(t)\to J/\psi K^0_S)\rangle \mathrm{d}t}$, where $\langle\Gamma(B_s(t) \to J/\psi K^0_S)\rangle = \Gamma(B^0_s(t) \to J/\psi K^0_S) + \Gamma(\bar{B}^0_s(t) \to J/\psi K^0_S) = R_H e^{-\Gamma_H t} + R_L e^{-\Gamma_L t}$ is the untagged decay time distribution, under the assumption that CP violation in $B^0_s - \bar{B}^0_s$ mixing can be neglected.

A two-dimensional data model for the invariant mass of the $J/\psi K^0_s$ combination and the B^0_s decay time is used to determine [7] the effective lifetime, from a sample corresponding to an integrated luminosity of 1.0 fb^{-1}: $\tau^{\mathrm{eff}}_{J/\psi K^0_S} = 1.75 \pm 0.12(\mathrm{stat}) \pm 0.07(\mathrm{syst})\,\mathrm{ps}$. The branching fraction $\mathscr{B}(B^0_s \to J/\psi K^0_S)$ has been measured to be $(1.97 \pm 0.023) \times 10^{-5}$. Where the uncertainty includes both statistical and systematic sources.

4. First observation of $B^0_{(s)} \to J/\psi f_1(1285)$ decays

Decays of B^0_s and B^0 mesons into $J/\psi \pi^+\pi^-\pi^+\pi^-$ final states, produced in pp collisions, have been investigated [8] using data corresponding to an integrated luminosity of 3 fb^{-1}. $B^0_{(s)} \to J/\psi f_1(1285)$ with $f_1(1285) \to \pi^+\pi^-\pi^+\pi^-$ decays have been seen for the first time, and the branching fractions relative to $B_{(s)} \to J/\psi\pi^+\pi^-$ have been measured to be $(3.82 \pm 0.52^{+0.29}_{0.32})\%$ and $(2.32 \pm 0.54 \pm 0.11)\%$ for B^0_s and B^0 respectively.

The ratio of these branching fraction $\mathscr{B}(B^0 \to J/\psi f_1(1285))/\mathscr{B}(B^0_s \to J/\psi f_1(1285)) = 1.14\%$ differs by 3.3 standard deviation from the tetraquark interpretation (1.14%) including the systematic uncertainty.

Using these branching fractions, the $f_1(1285)$ mixing angle between strange and non-strange components of its wave function in the $q\bar{q}$ structure model has been determined to be $\pm(24.0^{+3.1+0.6}_{-2.6-0.8})^\circ$, where the two uncertainties are due to statistical and systematic sources, respectively.

5. Branching fraction of $B^+ \to p\bar{p}K^+$ decays

The branching fractions of the decay $B^+ \to p\bar{p}K^+$ for different intermediate states have been measured [9] using data corresponding to an integrated luminosity of 1.0 fb^{-1}. The total branching fraction, its charmless component ($M_{p\bar{p}} < 2.85\mathrm{GeV}/c^2$) and the branching fractions via the resonant

$c\bar{c}$ states η_c and $\psi(2S)$ relative to the decay via a J/ψ intermediate state are

$$\frac{\mathcal{B}(B^+\to p\bar{p}K^+)_{total}}{\mathcal{B}(B^+\to J/\psi K^+\to p\bar{p}K^+)} = 4.91\pm 0.19\pm 0.14\ ;\ \frac{\mathcal{B}(B^+\to p\bar{p}K^+)_{charmless}}{\mathcal{B}(B^+\to J/\psi K^+\to p\bar{p}K^+)} = 2.02\pm 0.10\pm 0.08;$$

$$\frac{\mathcal{B}(B^+\to \eta_c(1S)K^+\to p\bar{p}K^+)}{\mathcal{B}(B^+\to J/\psi K^+\to p\bar{p}K^+)} = 0.578\pm 0.035\pm 0.027;$$

$$\frac{\mathcal{B}(B^+\to \psi(2S)\to K^+ p\bar{p}K^+)}{\mathcal{B}(B^+\to J/\psi K^+\to p\bar{p}K^+)} = 0.080\pm 0.012\pm 0.009$$

where the two values for the uncertainties are due to statistical and systematic sources, respectively.

An upper limit on the ratio $\frac{\mathcal{B}(B^+\to X(3872)K^+\to p\bar{p}K^+)}{\mathcal{B}^+\to J/\psi K^+\to p\bar{p}K^+)} < 0.017$ has been obtained, from which a limit of

$$\frac{\mathcal{B}(X(3872)\to p\bar{p})}{\mathcal{B}(X(3872)\to J/\psi\pi^+\pi^-)} < 2.0\times 10^{-3}$$

was derived.

6. First observation of $B^+\to\psi(4160)K^+$ and $\psi(4160)\to\mu^+\mu^-$

A sample corresponding to an integrated luminosity of 3.0 fb^{-1} has been used to study [10] the dimuon spectrum of $B^+\to K^+\mu^+\mu^-$ decays in the kinematic region where the kaon has a low recoil against the dimuon system. A structure consistent with interference between the $B^+\to K^+\mu^+\mu^-$ decay and a resonance has been observed with a statistical significance exceeding six standard deviations. The mean and width of the resonance have been measured to be 4191^{+9}_{-8} MeV/c^2, and 65^{+22}_{-16} MeV/c^2, respectively, where the uncertainties include statistical and systematic contributions. These measurements are compatible with the properties of the $\psi(4160)$ meson. This was interpreted as the first observation of both the decay $B^+\to\psi(4160)K^+$ and the subsequent decay $\psi(4160)\to\mu^+\mu^-$.

7. First observation of $B^0_s\to\chi_{c1}\phi$ decay and study of $B^0\to\chi_{c1,2}K^{*0}$ decays.

Analysing a dataset corresponding to an integrated luminosity of 1.0 fb^{-1}, the $B^0_s\to\chi_{c1}\phi$ decay has been observed [11], and studies on $B^0\to\chi_{c1,2}K^{*0}$ decays were performed.

The following ratios of branching fractions have been measured

$$\frac{\mathcal{B}(B^0_s\to\chi_{c1}\phi)}{\mathcal{B}(B^0_s\to J/\psi\phi)} = (18.9\pm 1.8(\text{stat})\pm 1.3(\text{syst})\pm 0.8(\mathcal{B}))\times 10^{-2}$$

$$\frac{\mathcal{B}(B^0\to\chi_{c1}K^{*0})}{\mathcal{B}(B^0\to J/\psi K^{*0})} = (19.8\pm 1.1(\text{stat})\pm 1.2(\text{syst})\pm 0.9(\mathcal{B}))\times 10^{-2}$$

$$\frac{\mathcal{B}(B^0\to\chi_{c2}K^{*0})}{\mathcal{B}(B^0\to\chi_{c1}K^{*0})} = (17.1\pm 5.0(\text{stat})\pm 1.7(\text{syst})\pm 1.1(\mathcal{B}))\times 10^{-2}$$

where the third uncertainty is due to the limited knowledge on the branching fraction of $\chi_c\to J/\psi\gamma$ modes.

8. Outlook

Charmonia in the final states of b decays offer clear signature for several studies at LHCb, reported here only very partially. All the analyses described are limited by the statistical uncertainties. Among the topics not covered, it is worth to mention the studies of the B_c^+ meson, whose observed decays often include a charmonium state in the final state. Our knowledge of the heaviest ground-state meson in the Standard Model will benefit from the increased statistics expected in the next years. LHCb has collected so far data corresponding to an integrated luminosity of 3.0 fb^{-1}. Other 5 fb^{-1} are expected before the Long Shutdown 2, and 50 fb^{-1} after the upgrade. At its restart in 2015, the center-of-mass energy at the LHC will increase from 8 to 14 TeV, roughly doubling the $b\bar{b}$ production cross-section.

References

[1] LHCb Collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, *JINST* **8** (2008) S08005

[2] M. Adinolfi *et al.*, *Performance of the LHCb RICH detector at the LHC*, *EPJ* **C73** (2013) 2431 [arXiv:1211.6759]

[3] A. A. Alves Jr. *et al.*, *Performance of the LHCb muon system*, *JINST* **8** (2013) P04022, [arXiv:1211.1346]

[4] R. Aaij *et al.*, *The LHCb trigger and its performance in 2011*, JINST **8** (2013) P04022, [arXiv:1211.3055]

[5] Heavy Flavor Averaging Group, Y. Amhis *et al.*, *Averages of b-hadron, c-hadron, and τ-lepton properties as if early 2012*, arXiv:1207.1158

[6] K. De Bruyn, R. Fleisher, and P. Koppenburg, *Extracting γ and penguin topologies through CP violation in $B_s^0 \to J/\psi K_S^0$*, *EPJ* **C70** (2010) 1025, [arXiv:1010.0089]

[7] LHCb Collaboration, R. Aaij *et al.*, *Measurement of the effective $B_s^0 \to J/\psi K_s^0$ lifetime*, *Nucl. Phys.* **B873** (2013) 275 [arXiv:1304.4500]

[8] LHCb Collaboration, R. Aaij *et al.*, *Observation of $\bar{B}^0_{(s)} \to J/\psi f_1(1285)$ decays and measurement of the $f_1(1285)$ mixing angle* LHCB-PAPER-2013-055 [arXiv:1310.2145]

[9] LHCb Collaboration, R. Aaij *et al.*, *Measurement of the branching fractions of $B^+ \to p\bar{p}K^+$ decays*, *EPJ* **C73** (2013) 2462 [arXiv:1303.7133]

[10] LHCb Collaboration, R. Aaij *et al.*, *Observation of a Resonance in $B^+ \to K^+\mu^+\mu^-$ decays at low recoil*, *PRL* **111** (2013) 112003, [arXiv:1307.7595]

[11] LHCb Collaboration, R. Aaij *et al.*, *Observation of $B_s^0 \to \chi_{c1}\phi$ decay and study of $B^0 \to \chi_{c1,2}K^{*0}$ decays*, *Nucl. Phys.* **B874** (2013) 663 [arXiv:1305.6511]