CP VIOLATION IN THE B SYSTEM WITH THE LHCb EXPERIMENT*

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During 2011, LHCb has collected an integrated luminosity of 1.1 fb^{-1}, giving rise to a large variety of measurements. Amongst these, measurements of CP violation in B decays play a central role. Three highlights are presented in this paper. The evidence for $b \to u$ transitions in $B^{\pm} \to DK^{\pm}$ is obtained, confirming recent BELLE results. The first evidence for direct CP violation in the B_s^0 system is presented and CP violation is observed in the B^0 system, using respectively $B_s^0 \to K^-\pi^+$ and $B^0 \to K^+\pi^-$ decays. An unambiguous world leading measurement of the mixing phase ϕ_s of the B_s^0 system is obtained by looking at $b \to c\bar{c}s$ transitions.

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1. The LHCb detector

The LHCb detector [1] is a single arm spectrometer designed to accurately measure decay products of B and D mesons for precision measurements at the LHC. In the following, an overview of the variety of CP violation measurements in B decays provided by LHCb at the very beginning of 2012 is presented. Results not related to CP violation in the B decays can be found in other contributions [2,3,4]. The commissioning of the detector and the performance reached with the current data is summarized in [5]. Key ingredients for the analyses presented in the following are the ability to trigger on and to disentangle different modes owing to dedicated ring-imaging Cherenkov detectors. Some channels of interest additionally require good tagging capabilities and excellent proper time resolution that are detailed elsewhere [6].

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The data sample used for the analyses presented here ranges from 36 pb^{-1} to 0.4 fb^{-1}. Three different categories of analyses are distinguished with respect to the studied final states. Results from B decays to open charm are first detailed, followed by charmless B decays and finally B decays to charmonium.

2. B decays to open charm

2.1. General strategy

B decays to open charm final states allow a theoretically clean extraction of the Cabibbo–Kobayashi–Maskawa (CKM) angle $\gamma = \phi_3$, see for instance [7] for a recent review. At present, this angle is constrained with a combined precision of 10° by direct measurements while the standard model prediction is accurate at few degrees [8,9].

The strategy is to exploit the γ-sensitive interference between $b \to u$ and $b \to c$ transitions that occur in the $B \to DX$ tree level decays[1]. Since there is no contribution from penguin diagrams, these measurements provide a standard model benchmark for further comparison with global CKM fits.

Two classes of such B decays can be distinguished depending on the need or not for a time dependent analysis. Self-tagged decays like $B^\pm \to DK^\pm$ or $B^0 \to DK^{*0}$, where the flavour of the final state $K^\pm$ or K^{*0} determines the flavour of the B, allow time independent extractions of γ while $B_s^0 \to D_s^- K^+$ and $B^0 \to D^-\pi^+$ require a time dependent analysis.

2.2. Evidence for $b \to u$ transitions in $B^\pm \to DK^\pm$ decays

One of the most promising channels is $B^\pm \to DK^\pm$, where the D can be reconstructed in many different decay modes, common to the D^0 and the $\bar{D}^0$. As shown in Fig. 1, clear signals of 147 ± 15 and 48 ± 11 candidates are respectively obtained for the suppressed $B^\pm \to (K^\mp\pi^\pm)_D\pi^\pm$ and $B^\pm \to (K^\mp\pi^\pm)_D K^\pm$ modes with 340 pb^{-1}. These yields are simultaneously fitted together with the favoured modes to extract CP-violating observables [10]

$$R_{\mathrm{ADS}}^{B^\pm\to DK^\pm} = (1.66 \pm 0.39 \pm 0.24) \times 10^{-2}\,, \tag{1a}$$
$$A_{\mathrm{ADS}}^{B^\pm\to(K^\mp\pi^\pm)_D K^\pm} = -0.39 \pm 0.17 \pm 0.02\,, \tag{1b}$$
$$R_{\mathrm{ADS}}^{B^\pm\to D\pi^\pm} = (4.13 \pm 0.41 \pm 0.40) \times 10^{-3}\,, \tag{1c}$$
$$A_{\mathrm{ADS}}^{B^\pm\to(K^\mp\pi^\pm)_D \pi^\pm} = 0.09 \pm 0.10 \pm 0.01\,, \tag{1d}$$

[1] D represents either a D^0 or a $\bar{D}^0$ meson.

where $R_{\rm ADS}$ and $A_{\rm ADS}$ are respectively defined, in the case of $B^\pm \to DK^\pm$, as

$$R_{\rm ADS} = \frac{\mathcal{B}\left(B^- \to (K^\pm\pi^\mp)_D\, K^-\right) + \mathcal{B}\left(B^+ \to (K^\mp\pi^\pm)_D K^+\right)}{\mathcal{B}\left(B^- \to (K^\mp\pi^\pm)_D\, K^-\right) + \mathcal{B}\left(B^+ \to (K^\pm\pi^\mp)_D K^+\right)}\,, \quad \text{(2a)}$$

$$A_{\rm ADS} = \frac{\mathcal{B}\left(B^- \to (K^\pm\pi^\mp)_D\, K^-\right) - \mathcal{B}\left(B^+ \to (K^\mp\pi^\pm)_D K^+\right)}{\mathcal{B}\left(B^- \to (K^\pm\pi^\mp)_D\, K^-\right) + \mathcal{B}\left(B^+ \to (K^\mp\pi^\pm)_D K^+\right)}\,. \quad \text{(2b)}$$

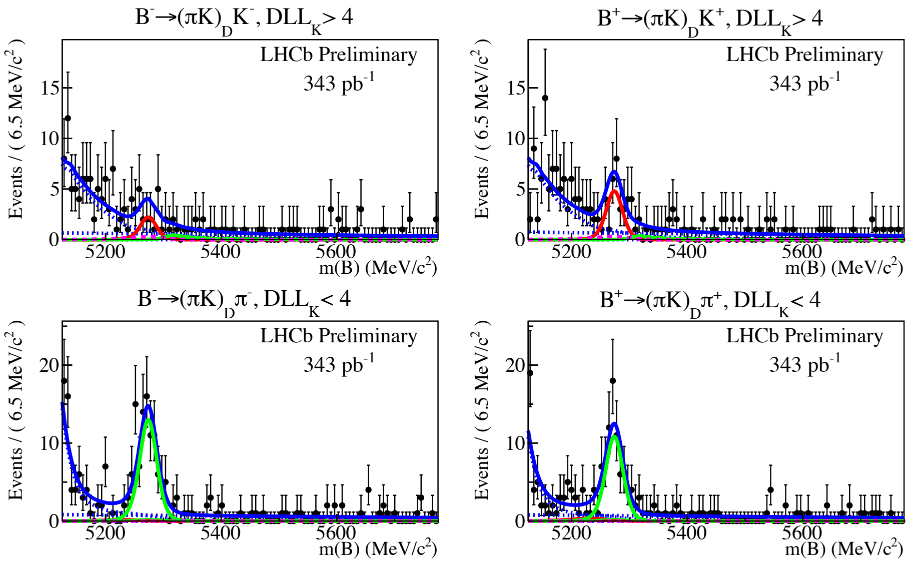

Fig. 1. Suppressed $B^\pm \to (K^\mp\pi^\pm)_D K^\pm$ (top) and $B^\pm \to (K^\mp\pi^\pm)_D \pi^\pm$ (bottom) candidates. The solid dark/red curves correspond to $B^\pm \to DK^\pm$ and the solid light/green curve is $B^\pm \to D\pi^\pm$, see [10] for details.

This result is not only in good agreement but also compete with previous measurements performed at B factories, as summarized for instance in [11]. Including systematic uncertainties, the 4σ evidence of a non-vanishing $R_{\rm ADS}^{B^\pm\to DK^\pm}$ is obtained. Systematic uncertainties are dominated by the knowledge of particle identification efficiencies and the modeling of the low mass region, where typically partially reconstructed $B \to DKX$ backgrounds lie. These uncertainties partially cancel in the extraction of the direct CP asymmetry $A_{\rm ADS}^{B^\pm\to(K^\mp\pi^\pm)_D K^\pm}$. In addition to the previous systematic uncertainties, kaon interaction and charmless background asymmetries contribute at the sub-percent level to the total uncertainty. Further improvements are thus expected with statistically larger data samples, allowing the first observation of $b \to u$ transitions in $B^\pm \to DK^\pm$ using the whole 2011 dataset.

2.3. Complementarity of other D decays

Since a similar analysis to the one already performed with $D^0 \to K^\mp\pi^\pm$ can be conducted with $D^0 \to K^\mp\pi^\pm\pi^+\pi^-$, this mode is also looked for. The number of observed favoured $B^\pm \to (K^\pm\pi^\mp\pi^+\pi^-)_D K^\pm$ candidates is found to be approximately two times less than for $D^0 \to K^\mp\pi^\pm$ with 36 pb^{-1} of 2010 data [12].

A complementary constraint on the angle γ can be obtained with the CP-eigenstate $D^0 \to K^+K^-$ decay mode, for which approximately 40 events are observed in 36 pb^{-1}. A statistically limited extraction of $R_{\mathrm{CP}+}^{B^\pm \to DK^\pm} = 1.48 \pm 0.31 \pm 0.12$ is thus performed with this data sample [12]. This result is in agreement with other measurements [11], but with larger uncertainties. However, the integrated luminosity used for this analysis is approximately 30 times smaller than the full 2011 data sample, and will thus be competitive once updated.

Complementary constraints are obtained via Dalitz measurements of $D^0 \to K_{\mathrm{S}}^0\pi^+\pi^-$, also studied at LHCb. The $B^\pm \to \left(K_{\mathrm{S}}^0\pi^+\pi^-\right)_D \pi^\pm$ mode is clearly observed with 95 ± 14 events using 36 pb^{-1} [12]. This represents approximately one eights of the statistics available for $D^0 \to K^+K^-$, the yield reduction being mainly due to the loss of trigger and reconstruction efficiencies due to the K_{S}^0 lifetime.

2.4. Additional results with other H_b^0 decays

Other decays of b hadrons are also sensitive to γ. With 36 pb^{-1}, the first observation of the $B_s^0 \to \bar{D}^0\bar{K}^{*0}$ decay mode is performed by reconstructing $D^0 \to K^\mp\pi^\pm$ and $K^{*0} \to K^+\pi^-$. Its branching fraction is measured relatively to $\bar{B}^0 \to D^0\rho^0$ to be $\frac{\mathcal{B}\left(\bar{B}^0 \to D^0 K^{*0}\right)}{\mathcal{B}\left(\bar{B}^0 \to D^0\rho^0\right)} = 1.48 \pm 0.34 \pm 0.15 \pm 0.12$ [13]. This mode has the same final state as the γ-sensitive $B^0 \to DK^{*0}$ decay, and is thus a first step towards measurement of CP-violating observables in $B^0 \to DK^{*0}$. This mode contributes also as a partially reconstructed background in the $B^\pm \to DK^\pm$ study, for which the low mass fit model enters as one of the dominant systematic uncertainties. The knowledge of the size of this background contribution is thus impacting the $B^\pm \to DK^\pm$ measurement.

The favoured $B^\pm \to DK^\pm\pi^+\pi^-$ mode is also observed for the first time with 36 pb^{-1} and found to represent approximately one fourth of the statistics in $B^\pm \to DK^\pm$ mode [14].

Similarly the $\Lambda_b \to D^0pK^-$ is observed for the first time with approximately 100 candidates in 330 pb^{-1} [15].

2.5. Prospects for time dependent measurements

$B_s^0 \to D_s^- K^+$ and $B^0 \to D^- \pi^+$ decays can be used to further constrain the angle γ by measuring the angle $\gamma + \phi_{\text{mixing}}$, where ϕ_{mixing} denotes the mixing angle, either ϕ_s or -2β in B_s^0 or B^0 decays, respectively. Details on the technique and original references can be found in [16].

On the way to these measurements, a determination of $f_s/f_d = 0.253 \pm 0.017 \pm 0.017 \pm 0.020$ has been performed with 36 pb^{-1}, using the similar decay modes $B_s^0 \to D_s^- \pi^+$, $B^0 \to D^- K^+$ and $B^0 \to D^- \pi^+$ [17, 18]. The branching fractions of $B_s^0 \to D_s^- K^+$ and $B_s^0 \to D_s^- \pi^+$ are then measured with 340 pb^{-1} [19, 20].

$B_s^0 \to D_s^- \pi^+$ is also used, together with $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$, to assert LHCb capabilities for tagged time dependent measurements. In particular, a competitive measurement of $\Delta m_s = 17.63 \pm 0.11 \pm 0.02$ ps^{-1} is performed with only 36 pb^{-1} [21].

Additional modes with higher multiplicities, like $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ could also be used in the future to further increase the sensitivity to γ. As the first step, $B^0 \to D^- K^+ \pi^+ \pi^-$ is observed for the first time with 36 pb^{-1} [14].

3. Hadronic charmless B decays

3.1. General strategy

A complementary way to extract γ, sensitive to New Physics effects, consists in measuring CP violation in charmless B decays, where generally many contributions from different diagram topologies must be considered. Thus the extraction of the weak phases is more complicated than in the open charm case. On the other hand, the presence of dominant loop contributions makes this extraction sensitive to New Physics, and can thus be compared with standard model benchmark measurements. For instance, the $B \to hh'$ decays are key channels at LHCb to develop this strategy [16]. On a longer term, tagged time dependent analyses are targeted to maximally exploit the information contained in these decays.

3.2. First evidence for CP violation in the B_s^0 system

Searches for direct CP violation in the flavour specific $B^0 \to K^+ \pi^-$ decays are performed with 320 pb^{-1}. Small corrections to the raw CP asymmetries, clearly visible in Fig. 2, are introduced to account for detection and production asymmetries. Detection asymmetries, induced by different reconstruction efficiencies and by different cross sections in the interactions of oppositely charged particles with the detector material, are determined by means of large samples of two-body D meson decays. The former contribution amounts to about 0.2% and is further cancelled owing to the ability to flip the magnetic field in LHCb. The latter is dominated by the kaon detection asymmetry and amounts to 1%. The production asymmetry of B^0 mesons is estimated using $B^0 \to J/\psi K^{*0}$ decays, assuming no CP violation. This asymmetry is further diluted by the mixing of the B^0 mesons and the shape of the proper time acceptance. Owing to the fast B_s^0 oscillations, the possible presence of a B_s^0 production asymmetry plays no role. The total correction from these polluting asymmetries amounts to $1.0 \pm 0.2\%$ and $-0.7 \pm 0.6\%$ respectively in the B_s^0 and B^0 cases.

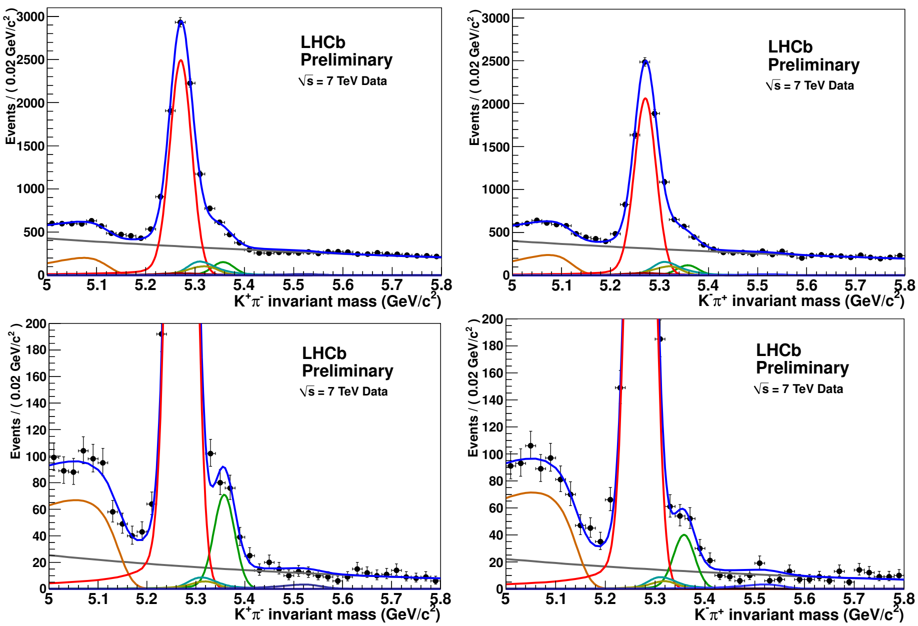

Fig. 2. The $K^+\pi^-$ (left) and $K^-\pi^+$ (right) invariant mass spectra optimized for the B^0 asymmetry measurement (top), and for the B_s^0 asymmetry measurement (bottom). The main components of the fit model are $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$, $B_s^0 \to K^-\pi^+$, combinatorial background, 3-body partially reconstructed decays [22].

B_s^0 and B^0 CP-violating asymmetries are thus determined to be [22]

$$A_{\rm CP}^{B_s^0 \to K\pi} = \frac{\mathcal{B}\left(\bar{B}^0 \to K^+\pi^-\right) - \mathcal{B}\left(B_s^0 \to K^-\pi^+\right)}{\mathcal{B}\left(\bar{B}^0 \to K^+\pi^-\right) + \mathcal{B}\left(B_s^0 \to K^-\pi^+\right)} = 0.27 \ \pm 0.08 \ \pm 0.02 \ , \tag{3a}$$

$$A_{\mathrm{CP}}^{B^0\to K\pi} = \frac{\mathcal{B}\left(\bar{B}^0 \to K^-\pi^+\right) - \mathcal{B}\left(B^0 \to K^+\pi^-\right)}{\mathcal{B}\left(\bar{B}^0 \to K^-\pi^+\right) + \mathcal{B}\left(B^0 \to K^+\pi^-\right)} = -0.088 \pm 0.011 \pm 0.008\,. \tag{3b}$$

For the first time, an evidence of CP violation in the B_s^0 system is obtained and for the first time at an hadron collider a direct CP asymmetry is observed with more than 5σ. The dominating systematic uncertainties are linked to the modeling of the B invariant mass in the B_s^0 case and to the polluting asymmetries in the B^0 case and will be reduced with larger integrated luminosities. These results are in agreement and competitive with previous measurements made at B factories and by CDF, see for instance [23].

3.3. Additional LHCb results in $B \to hh'$ decays

With 320 pb^{-1}, $B^0 \to K^+K^-$ and $B_s^0 \to \pi^+\pi^-$ decay modes, dominated by exchange and penguin annihilation diagrams, are searched for. The first observation for $B_s^0 \to \pi^+\pi^-$ is thus performed and its branching fraction measured to be $\mathcal{B}\left(B_s^0 \to \pi^+\pi^-\right) = (0.98^{+0.23}_{-0.19} \pm 0.11) \times 10^{-6}$, while the $B^0 \to K^+K^-$ branching fraction is found equal to $\mathcal{B}\left(B^0 \to K^+K^-\right) = (0.13^{+0.06}_{-0.05} \pm 0.07) \times 10^{-6}$. These observations are in good agreement with previous results on these branching fractions. These measurements allow to assert the size of the pollution coming from these diagrams in the extraction of the CP violating observables.

An independent analysis of $B_s^0 \to K^+K^-$ decays is also performed to measure its effective lifetime that is sensitive to CP violation and to potential effects of New Physics. It is performed both through an absolute lifetime measurement by estimating a per event acceptance function (see Fig. 3, left),

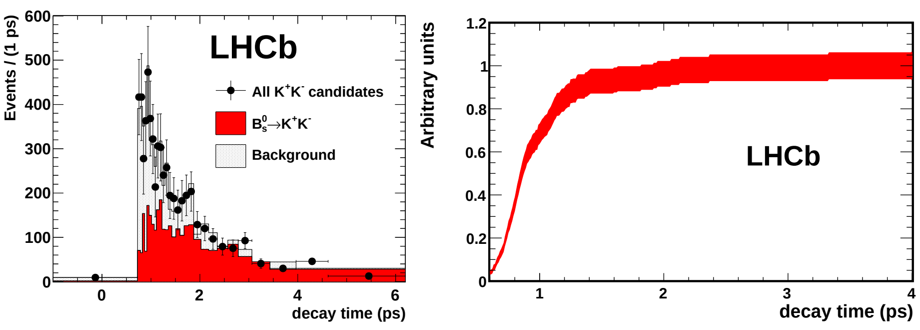

Fig. 3. Proper time distribution of the $B_s^0 \to K^+K^-$ candidates used in the relative lifetime measurement (left) and average decay-time acceptance function for signal events used for the absolute lifetime measurement, where the error band is an estimate of the statistical uncertainty (right) [24].

and through a measurement relative to the $B^0 \to K^+\pi^-$ lifetime[2] (see Fig. 3, right) that assumes similar acceptance functions for both modes. The result $\tau_{KK} = 1.440 \pm 0.096 \pm 0.008 \pm 0.003$ ps [24], obtained with 36 pb^{-1}, is in good agreement with the standard model prediction $\tau_{KK} = 1.390 \pm 0.032$ [25].

3.4. LHCb prospects for three body decays

With 36 pb^{-1}, LHCb performs competitive measurements of ratio of branching fractions for charged B decays in three charmless charged hadrons [26]

$$\frac{\mathcal{B}\left(B^\pm \to K^\pm K^+ K^-\right)}{\mathcal{B}\left(B^\pm \to K^\pm \pi^+\pi^-\right)} = 0.52 \pm 0.03 \pm 0.01\,, \tag{4a}$$

$$\frac{\mathcal{B}\left(B^\pm \to K^\pm p\bar{p}\right)}{\mathcal{B}\left(B^\pm \to K^\pm \pi^+\pi^-\right)} = 0.19 \pm 0.02 \pm 0.02\,. \tag{4b}$$

The $B^\pm \to K^\pm p\bar{p}$ mode is reconstructed without any veto on charmonium resonances. An independent analysis is performed with the same data sample. The measurement of the branching fraction for this decay mode relative to charmonium intermediate resonance gives [27]

$$\frac{\mathcal{B}\left(B^\pm \to K^\pm p\bar{p}\right)}{\mathcal{B}\left(B^\pm \to J/\psi K^\pm\right)\mathcal{B}\left(J/\psi \to p\bar{p}\right)} = 4.6 \pm 0.6 \pm 0.5\,. \tag{5}$$

These results are in fair agreement with the existing world averages. The next step will consist in a measurement of time-integrated CP asymmetries, sensitivity to time dependent CP asymmetries will come with even larger integrated luminosities.

3.5. LHCb results and prospects for decays in four body final states

Four charged body decays can be reconstructed in quasi-two body approaches that allow to have additional lever arms against the larger combinatorial background. In particular, the first observation of $B_s^0 \to K^{*0}\bar{K}^{*0}$ is performed with 36 pb^{-1}. This allows not only to extract the branching fraction for this decay mode, $\mathcal{B}\left(B_s^0 \to K^{*0}\bar{K}^{*0}\right) = (2.81 \pm 0.46 \pm 0.45 \pm 0.34) \times 10^{-5}$, but also to measure the longitudinal polarization, $f_{\rm L} = 0.31 \pm 0.12 \pm 0.04$ [28]. This latter measurement is quite different from the one performed with $B^0 \to K^{*0}\bar{K}^{*0}$ despite these two decays are U-spin related. However, the former is consistent with expectations.

[2] The effective lifetime in the B^0 system equals the B^0 lifetime thanks to the vanishing lifetime difference of CP-eigenstates in the B^0 system.

Triple product asymmetries are also measured in the $B_s^0 \to \phi\phi$ decay. These asymmetries, sensitive to CP-violation under the assumption that CPT is conserved, are measured with 340 pb^{-1}, see Fig. 4, [29]

$$A_U = \frac{N(U<0) - N(U>0)}{N(U<0) + N(U>0)} = -0.064 \pm 0.057 \pm 0.014 \tag{6a}$$

$$A_V = \frac{N(V<0) - N(V>0)}{N(V<0) + N(V>0)} = -0.070 \pm 0.057 \pm 0.014, \tag{6b}$$

where $U = \frac{1}{2}\sin(2\Phi)$, $V = \sin(\varepsilon\Phi)$ and $\varepsilon = \mathrm{sign}(\cos\theta_1 \cos\theta_2)$, Φ being the angle between the decay planes of the two ϕ mesons and $\cos\theta_{1,2}$ the helicity angles in the two ϕ meson decays. This result is in agreement with a previous existing CDF measurement. On the longer term, this channel may also be used for the determination of the mixing phase in the B_s^0 system ϕ_s.

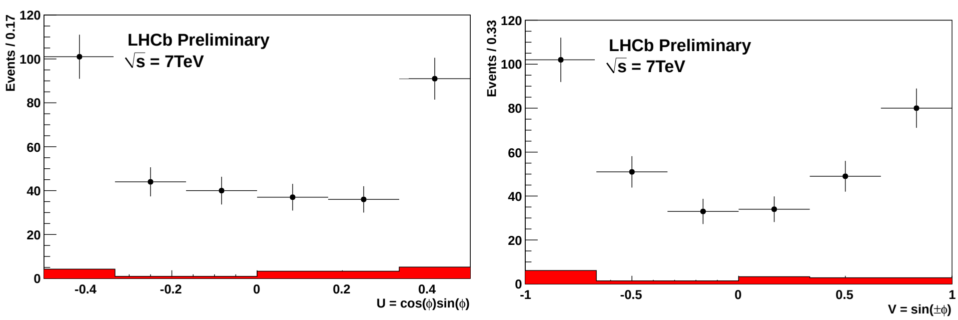

Fig. 4. Distributions of the U (left) and V (right) observables for the $B_s^0 \to \phi\phi$ data in the mass range $5286.6 < m(B_s^0) < 5446$ MeV. The distribution for the background is taken from the mass sidebands and shown in black/red [29].

4. B decays to final state with charmonium

4.1. General strategy

CP-violation in the interference between the mixing and the decay is precisely predicted to be $\phi_s^{\mathrm{SM}} = -2\beta_s = -0.0363 \pm 0.0017$ rad within the standard model. This quantity can be experimentally measured via tree-level dominated $b \to c\bar{c}s$ transitions, for which the vanishing phase is robust against New Physics contributions. Measuring the phase of the interference of these diagrams with the diagram involved in the mixing allows to extract the weak mixing phase. This method is similar to the one developed at B factories to precisely determine the mixing phase β in the B^0 system.

4.2. Measurement of ϕ_s in $B_s^0 \to J/\psi\phi$

A clean $B_s^0 \to J/\psi\phi$ sample of about 8500 events is obtained with 370 pb^{-1}, allowing the extraction of the mixing phase ϕ_s, the average B_s^0 decay width Γ_s and the decay width difference of mass eigenstates $\Delta\Gamma_s$. Involving two vector mesons as intermediate resonances an angular analysis is required in addition to the proper time measurement. Background and three signal components that correspond to the two P-wave amplitudes and an S-wave amplitude are simultaneously fitted, see Fig. 5. One of the two ambiguous solutions [30] related by the transformation $(\phi_s, \Delta\Gamma_s) \to (\pi - \phi_s, -\Delta\Gamma_s)$

$$\phi_s = 0.15 \pm 0.18 \pm 0.06\,\mathrm{rad}\,, \tag{7a}$$
$$\Gamma_s = 0.657 \pm 0.009 \pm 0.008\,\mathrm{ps}^{-1}\,, \tag{7b}$$
$$\Delta\Gamma_s = 0.123 \pm 0.029 \pm 0.011\,\mathrm{ps}^{-1} \tag{7c}$$

is in good agreement with the standard model prediction, see Fig. 6. This result shows for the first time the evidence for a non-vanishing decay width difference of the two B^0 mass eigenstates, in good agreement with the standard model prediction $\Delta\Gamma_s^{\mathrm{SM}} = 0.082 \pm 0.021\,\mathrm{ps}^{-1}$.

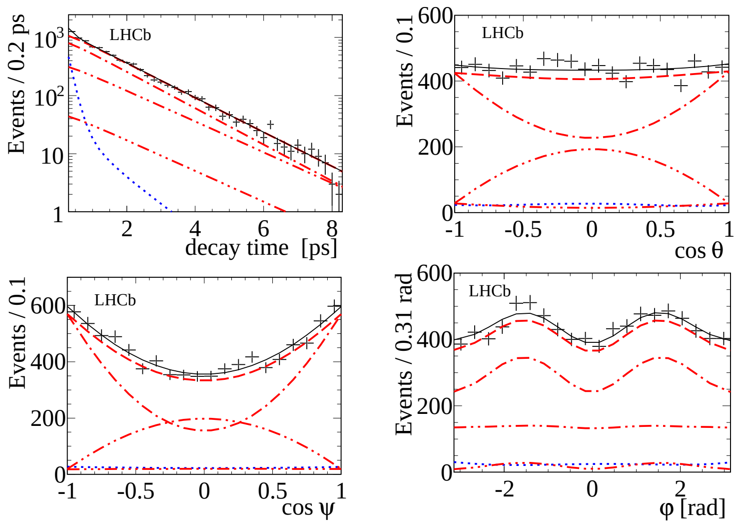

Fig. 5. Projections for the decay time and transversity angle distributions. The dashed/red, dotted/blue and solid/black lines represent the fitted contributions from signal, background and their sum. The remaining curves correspond to the CP-even P-wave (dash-single dotted/red), the CP-odd P-wave (dash-double dotted/red) and the S-wave (dash-triple dotted/red) signal components [30].

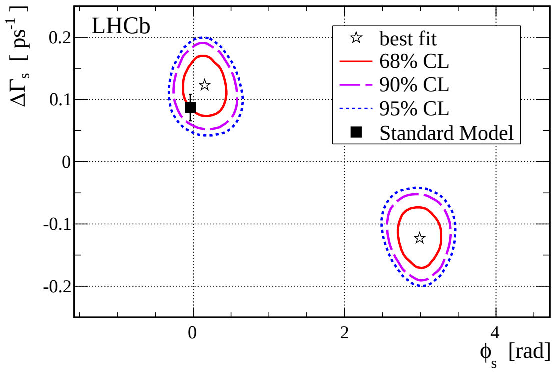

Fig. 6. Likelihood confidence regions in the $\Delta\Gamma_s - \phi_s$ plane. The black square and error bar correspond to the Standard Model prediction [30].

4.3. Resolving the ambiguity in ϕ_s

Taking advantage of the fact that the strong phase difference of the S-wave relative to the P-wave is expected to decrease with an increasing K^+K^- invariant mass[3], the two previous ambiguities can be resolved. Indeed, the sign of this strong phase difference changes depending on the choice of the one or the other ambiguity. It is found with 370 pb^{-1} that the decreasing strong phase difference is the solution with ϕ_s close to zero rather than π, see Fig. 7 [31].

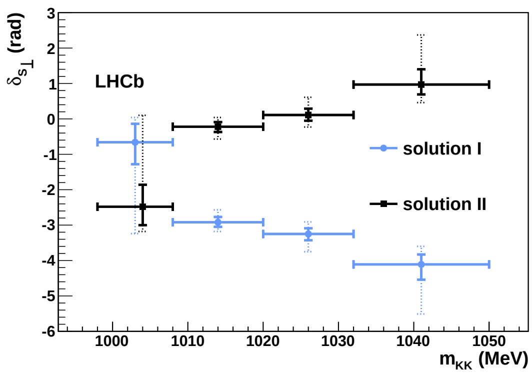

Fig. 7. Measured phase differences between S-wave and perpendicular P-wave amplitudes for the two solutions (in light grey/blue) the solution with ϕ_s close to zero). The asymmetric error bars correspond to $\Delta \ln \mathcal{L} = -0.5$ (solid) and $\Delta \ln \mathcal{L} = -2$ (dotted) [31].

[3] The P-wave Breit–Wigner phase increases rapidly with $m_{K^+K^-}$ while the S-wave Flatté phase varies slowly with $m_{K^+K^-}$.

4.4. Additional constraints and prospects on ϕ_s

Additional charmonium decay modes can be used to further constrain measurements of the mixing phase. Since $f_0(980)$ is a spin-0 resonance, an angular analysis of the $B_s^0 \to J/\psi f_0(980)$ decay mode is not required to extract the mixing phase. However, this mode is potentially polluted by other $\pi^+\pi^-$ contributions. In particular, pollution of spin-2 resonances is found to be negligible as shown in Fig. 8. Using the previous measurement for Γ_s and $\Delta\Gamma_s$, $\phi_s = -0.44 \pm 0.44 \pm 0.02$ rad is obtained with 410 pb^{-1} [32]. The combination of the two measurements, $\phi_s = 0.03 \pm 0.16 \pm 0.07$ rad, is performed by fitting simultaneously $B_s^0 \to J/\psi f_0(980)$ and $B_s^0 \to J/\psi\phi$ [33].

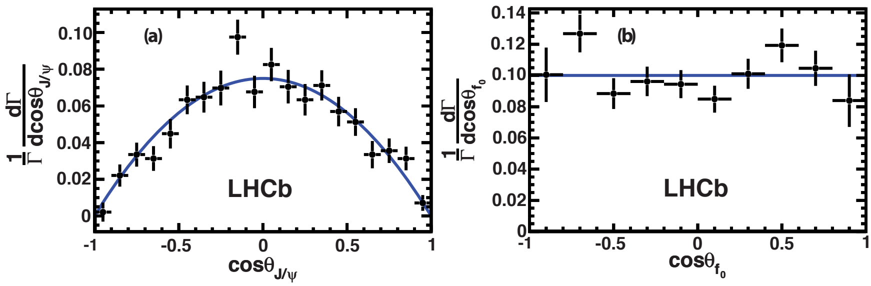

Fig. 8. Efficiency corrected, background subtracted helicity angle distributions in the $\pi^+\pi^-$ mass region within ± 90 MeV of the $f_0(980)$ mass of 980 MeV and within ± 20 MeV of the B_s^0 mass for J/ψ (left) and $f_0(980)$ (right). The solid lines show the expectations for a spin-0 object [32].

The first observation of $B_s^0 \to J/\psi f_2'(1525)$ (in K^+K^- final state), and the measurement of its branching fraction relative to $B_s^0 \to J/\psi\phi$

$$\frac{\mathcal{B}\left(B_s^0 \to J/\psi f_2'(1525)\right)}{\mathcal{B}\left(B_s^0 \to J/\psi\phi\right)} = (26.4 \pm 2.7 \pm 2.4)\% \tag{8}$$

is obtained with 160 pb^{-1} [34]. It is, however, a more complicated channel for the extraction of ϕ_s since it involves a spin-2 resonance instead of a spin-1.

A measurement of the $B_s^0 \to \psi(2S)\phi$ branching fraction relative to $B_s^0 \to J/\psi\phi$ is also performed with 36 pb^{-1} [35]. The obtained result, $\frac{\mathcal{B}\left(B_s^0\to\psi(2S)\phi\right)}{\mathcal{B}(B_s^0\to J/\psi\phi)} = 0.68 \pm 0.10 \pm 0.09 \pm 0.07$, shows that it could substantially contribute to further improvements in the determination of ϕ_s.

Finally, the $B_s^0 \to J/\psi\bar{K}^{*0}$ branching fraction $\mathcal{B}\left(B_s^0 \to J/\psi\bar{K}^{*0}\right) = (3.5^{+1.1}_{-1.0} \pm 0.9) \times 10^{-5}$ is measured with 36 pb^{-1} [36]. This will give, with larger statistics, insights to control the size of polluting penguin contributions in $B_s^0 \to J/\psi\phi$.

4.5. Prospects for the decay mode $B^0_{d,s} \to J/\psi K^0_{\rm S}$

CP-violation in $B^0 \to J/\psi K^0_{\rm S}$ is already extremely well determined by B factories, see for instance [37]. With 36 pb^{-1}, LHCb measured $S_{J/\psi K^0_{\rm S}} = 0.53^{+0.28}_{-0.29} \pm 0.05$ [38]. With 100 times more statistics (three times more than what was collected by LHCb in 2011), it may well allow to have a measurement competitive with present world leading determinations.

To go further, it will be necessary to constrain both the amplitude and the phase of the penguin contribution in $B^0 \to J/\psi K^0_{\rm S}$. This can be done thanks to the study of $B^0_s \to J/\psi K^0_{\rm S}$, under SU(3) assumption. Its branching fraction is measured with 380 pb^{-1} relatively to $B^0 \to J/\psi K^0_{\rm S}$: $\frac{\mathcal{B}\left(B^0_s \to J/\psi K^0_{\rm S}\right)}{\mathcal{B}\left(B^0 \to J/\psi K^0_{\rm S}\right)} = 0.0378 \pm 0.0058 \pm 0.0020 \pm 0.0030$ [39].

5. Conclusion

During 2011 LHCb has collected an integrated luminosity of 1.1 fb^{-1}, clearing the way to the measurements of several decay modes of charm and beauty hadrons. Among the large variety of measurements performed by the Collaboration, CP violation measurements in the B system are key observables. Three different categories of measurements have been presented here.

The evidence for $b \to u$ transitions in $B^\pm \to DK^\pm$ is obtained, confirming beginning of 2011 results from BELLE. This analysis is performed by reconstructing the final state $D^0 \to K^\mp\pi^\pm$, while other D decay modes are also under study at LHCb and will increase the sensitivity on tree-level determinations of the CKM angle γ. Additional, similar B decay modes are also scrutinized at LHCb, and will potentially add significant information in the extraction of γ. Time dependent γ measurements are studied as well, and first intermediate physics results are obtained.

Charmless B decays also allow for the determination of weak phases, but with contributions from loop diagrams, so that the measurement is sensitive to New Physics effects. The first evidence for direct CP violation in the B^0_s system is obtained and CP violation is observed in the B^0 system, using respectively $B^0_s \to K^-\pi^+$ and $B^0 \to K^+\pi^-$ decays. Other measurements involving two body decay modes are performed to complete the picture of $B \to hh'$ decays. First intermediate measurements are performed with three body charged B decays and studies devoted to measurement of triple product asymmetries or longitudinal polarization measurements are performed with four body decays modes.

LHCb performs a world leading measurement of the mixing phase in the B^0_s system, by looking at $b \to c\bar{c}s$ transitions. Both $B^0_s \to J/\psi\phi$ and $B^0_s \to J/\psi f_0(980)$ decay modes provide an interesting constraint on ϕ_s and allow, for the first time, to determine the sign of the decay width difference in the B_s^0 system. These measurements may be enriched in the future by additional ϕ_s-sensitive decay modes, and the pollution from penguin diagrams may be well under control thanks to decay modes already seen at LHCb. Given the excellent results of B factories on the B^0 mixing phase, a competitive measurement at LHCb would require larger integrated luminosities than the one collected in 2011.

All these results are very promising for the 2012 data taking and show that the knowledge of the CP violation in the B system is already improving thanks to measurements performed at LHCb.

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