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Studies of hadronic B decays to final states containing open charm mesons at LHCb

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The LHCb experiment is a general purpose forward spectrometer operating at the Large Hadron Collider, optimized for the study of B and D hadrons. LHCb recorded 1.0 fb^{-1} of integrated luminosity during 2011 data taking, collecting unprecedented large samples of B decays to final states involving charmed mesons. These decays offer several complementary measurements of CP violation and CKM matrix parameters, and serve as a laboratory for testing effective theories of hadron decays. We present a selection of new world leading results in these types of decays, including first observations of new modes, world best branching ratio measurements and studies of resonant substructures.

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1. The LHCb experiment: a flavour physics detector

The LHCb experiment at the CERN Large Hadron Collider (LHC) in Geneva (Switzerland) is a single arm spectrometer designed for research in the heavy flavour sector of particle physics, aiming at studying processes involving b or c quarks. The LHC collisions produce all types of B-hadrons ($B^{\pm}$, B^0, B_s^0, $B_c^{\pm}$, b-baryons). The LHCb detector [1] is very well suited for the study of heavy flavoured hadronic decays, thanks to its efficient vertex locator, RICH particle identification subdetectors and hadronic trigger. B decays to open charm, *i.e.* of the type $B \to DX$, are important components of the LHCb physics program, as they can be used to make a precise measurement of the CKM angle γ using tree-level decays, and also to check the CKM mechanism consistency [2].

This document presents new preliminary measurements performed by LHCb with 2011 data at 7 TeV center-of-mass energy on three particular channels of B decays to open charm purely hadronic final states.

2. $B^0 \to DK^{*0}$

The $B^0 \to DK^{*0}$ channel[1] is sensitive to the CKM weak phase γ, as it occurs through the interference of $b \to u$ and $b \to c$ diagrams. Both diagrams are colour suppressed, which enhances the interference and the sensitivity to γ. Furthermore, this channel is self-tagging, as the flavour of the B meson at the time of its decay can be known by the charge of the K coming from the K^{*0}. Three different methods exist for the extraction of γ, depending on the decay mode of the D meson: the GLW method [3, 4] for $D \to K^+K^-$, the ADS method [5, 6] for $D \to K^-\pi^+$ and the GGSZ method [7] for multi-body D decays.

This analysis [8] is based on a 1 fb^{-1} data sample collected by LHCb in 2011. The D modes in study are the singly Cabibbo suppressed $D \to K^+K^-$ and the Cabibbo favoured $D \to K^+\pi^-$. It uses a cut based selection on kinematics, vertex fit quality and particle identification variables ($DLL_{K-\pi}$). Background from charmless B decays and contibutions from $B^0 \to D_{(s)}^- h^+$ decays are removed, while other backgrounds are modeled in the fit to the B invariant mass.

The fit to the invariant mass for both $D \to K^+K^-$ and $D \to K^+\pi^-$ is shown in Fig. 1; the number of events reconstructed for the signal components are listed in Table 1. The two plots on the top correspond to the favoured $D \to K^+\pi^-$, where no CP asymmetry is expected between the number of events reconstructed as $\overline{B}^0$ (left) and B^0 (right). This asymmetry is measured[2] to be

$$\mathscr{A}_d^{\text{fav}} = \frac{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) - \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})} = -0.08 \pm 0.08 \pm 0.01 \tag{2.1}$$

where the first uncertainty is statistical and the second systematic. The plots on the bottom correspond to $D \to K^+K^-$: they show the first observation of a $B^0 \to DK^{*0}$ decay in this mode with a 5.1 σ significance (B^0 and $\overline{B}^0$ combined). The corresponding asymmetry is measured to be

$$\mathscr{A}_d^{KK} = \frac{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) - \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})} = -0.47^{+0.24}_{-0.25} \pm 0.02. \tag{2.2}$$

[1] Inclusion of charge conjugate modes is implied throughout this document unless specified otherwise.
[2] These are preliminary results.

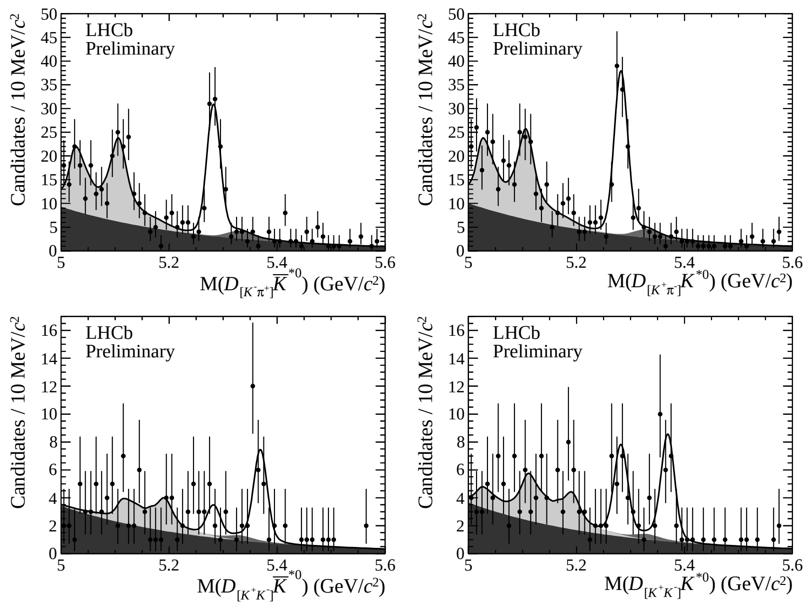

Figure 1: Invariant mass distributions of $D_{[K^-\pi^+]}\overline{K}^{*0}$ (*top left*), $D_{[K^+\pi^-]}K^{*0}$ (*top right*), $D_{[K^+K^-]}\overline{K}^{*0}$ (*bottom left*) and $D_{[K^+K^-]}K^{*0}$ (*bottom right*) candidates. The $D\overline{K}^{*0}$ distribution corresponds to $\overline{B}^0$ and B^0_s decays, the DK^{*0} distribution to B^0 and $\overline{B}^0_s$ decays. The black line represents the result of the fit, the dark grey area is the combinatorial background component, the medium grey is the cross-feed from $D\rho^0$ decays and the light grey area is the background component from D^*K^* partially reconstructed decays.

Mode	N($\overline{B}^0$)	N(B^0)	N($\overline{B}^0_s$)	N(B^0_s)
$B^0 \to D(K^+\pi^-)K^{*0}$	94 ± 11	108^{+12}_{-11}	-	-
$B^0 \to D(K^+K^-)K^{*0}$	7 ± 4	20^{+6}_{-5}	24^{+6}_{-5}	22^{+6}_{-5}

Table 1: Number of signal B events from the fit to the invariant mass for the $B^0 \to DK^{*0}$ decays candidates.

The ratio of partial widths between the GLW mode and the favoured mode is also measured, as well as the CP asymmetry of the B_s decay to the same final state,

$$\mathscr{R}_d^{KK} = \frac{\Gamma(\overline{B}^0 \to D_{[K^+K^-]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+K^-]}K^{*0})}{\Gamma(\overline{B}^0 \to D_{[K^-\pi^+]}\overline{K}^{*0}) + \Gamma(B^0 \to D_{[K^+\pi^-]}K^{*0})} = 1.42^{+0.41}_{-0.35} \pm 0.07, \tag{2.3}$$

$$\mathscr{A}_s^{KK} = \frac{\Gamma(\overline{B}^0_s \to D_{[K^+K^-]}K^{*0}) - \Gamma(B^0_s \to D_{[K^+K^-]}\overline{K}^{*0})}{\Gamma(\overline{B}^0_s \to D_{[K^+K^-]}K^{*0}) + \Gamma(B^0_s \to D_{[K^+K^-]}\overline{K}^{*0})} = 0.04 \pm 0.17 \pm 0.01. \tag{2.4}$$

The B_s CP asymmetry is zero as expected.

3. $B^0_{(s)} \to \overline{D}^0 K^+K^-$

The $B^0_{(s)} \to \overline{D}^0 K^+K^-$ decays, which can occur via a W-exchange diagram or a color-suppressed tree diagram, have never been previously observed. This analysis [9], based on 575 pb^{-1} of the 2011 LHCb data set, presents a measurement of their branching fraction normalised to the favoured

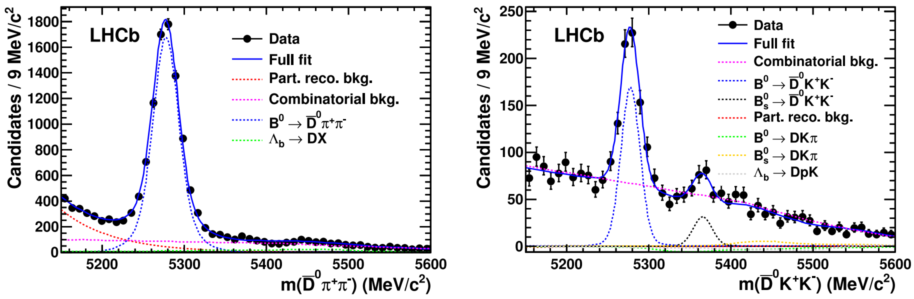

Figure 2: Fits to the B invariant mass distributions for $\overline{D}^0\pi^+\pi-$ (left) and $\overline{D}^0K^+K^-$ (right).

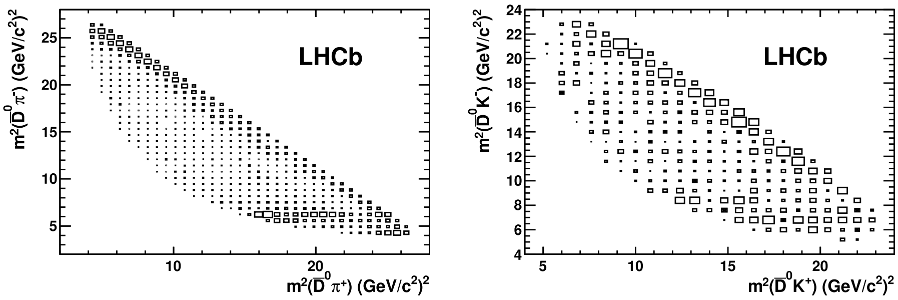

Figure 3: Dalitz plot distributions for $B^0 \to \overline{D}^0\pi^+\pi^-$ (*left*), showing contributions from $\rho^0(770)$ and $f_2(1270)$ (upper diagonal edge) and from $D_2^{*-}(2460)$ (horizontal band), and $B^0 \to \overline{D}^0K^+K^-$ (*right*), where a possible contribution from $D_{s2}^{*-}(2573)$ and an enhancement of events at low K^+K^- invariant mass (upper diagonal edge) are visible.

N($B^0 \to \overline{D}^0\pi^+\pi^-$)	N($B^0 \to \overline{D}^0K^+K^-$)	N($B_s^0 \to \overline{D}^0K^+K^-$)
8060 ± 150	558 ± 49	104 ± 29

Table 2: Number of signal B events from the fit to the invariant mass for the $B^0_{(s)} \to \overline{D}^0K^+K^-$ mode.

$B^0 \to \overline{D}^0\pi^+\pi^-$. The selection is optimised using a neural network. Contributions from D^{*-} decays are vetoed, while charmless peaking background is subtracted to the fitted yields.

The result of the unbinned likelihood fit to the B invariant mass is shown in Fig. 2; the fitted signal yields are shown in Table 2. The first observation of the $B^0 \to \overline{D}^0K^+K^-$ mode at 5.8 σ significance and evidence of the $B_s^0 \to \overline{D}^0K^+K^-$ mode at 3.8 σ significance are presented. The measurement of the branching fraction for both decays is performed,

$$\frac{\mathscr{B}(B^0 \to \overline{D}^0K^+K^-)}{\mathscr{B}(B^0 \to \overline{D}^0\pi^+\pi^-)} = 0.056 \pm 0.011 \pm 0.007, \tag{3.1}$$

$$\frac{\mathscr{B}(B_s^0 \to \overline{D}^0K^+K^-)}{\mathscr{B}(B^0 \to \overline{D}^0K^+K^-)} = 0.90 \pm 0.27 \pm 0.20, \tag{3.2}$$

where the first uncertainty is statistical and the second systematic. Using the value of

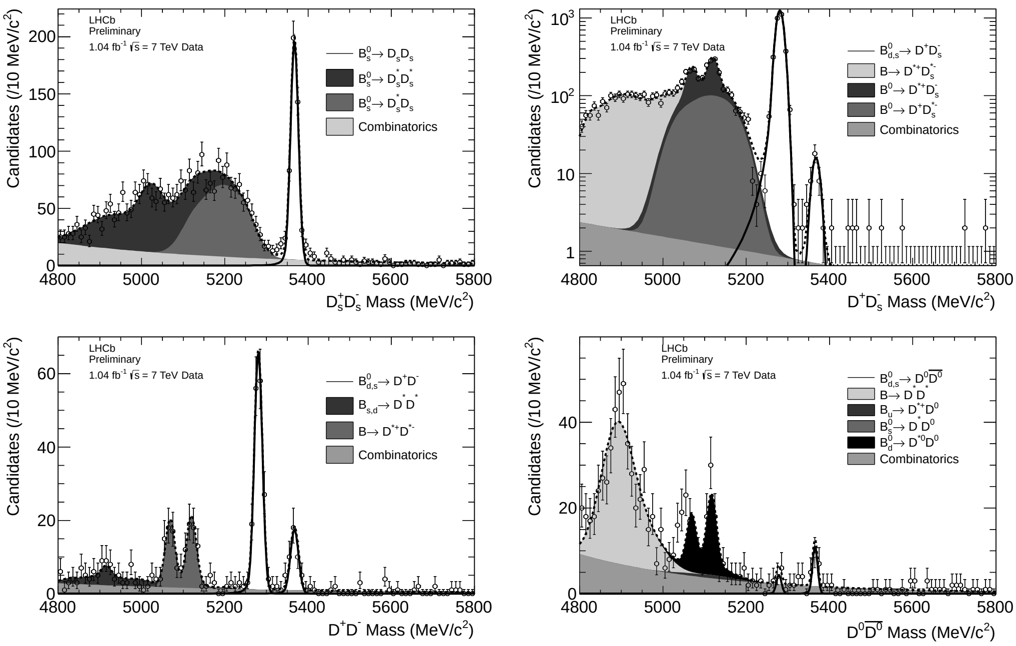

Figure 4: Invariant mass distributions for decays of the type $\overline{B}_s^0 \to D\overline{D}'$.

$\mathscr{B}(B^0 \to \overline{D}^0\pi^+\pi^-)$, the absolute branching fraction for the B^0 mode is computed,

$$\mathscr{B}(B^0 \to \overline{D}^0 K^+K^-) = (4.7 \pm 0.9 \pm 0.6 \pm 0.5) \times 10^{-5}, \tag{3.3}$$

where the third uncertainty arises from the knowledge on $\mathscr{B}(B^0 \to \overline{D}^0\pi^+\pi^-)$.

Fig. 3 shows the Dalitz plots of these decays, where substructures can be seen as discussed in the figure caption.

4. $\overline{B}_s^0 \to D\overline{D}'$

Decays of the type $\overline{B}_s^0 \to D\overline{D}'$ are a rich laboratory for measurements in the CKM sector. Sensitivity to the CKM angle γ can be achieved from $\overline{B}^0 \to D^+D^-$ and $\overline{B}_s^0 \to D_s^+D_s^-$ assuming U-spin symmetry [10], as well as to $\sin(2\beta)$ from penguin diagrams or the weak phase Φ_s and $\Delta\Gamma_s/\Gamma_s$. This analysis [11] presents four measurements of ratios of branching fractions between $\overline{B}_s^0 \to D\overline{D}'$ and $B^{0,+} \to D\overline{D}'$ decays.

This analysis is based on 1 fb^{-1} data sample collected by LHCb in 2011. The selection uses a Boosted Decision Tree optimised for kinematic and PID variables, trained on real data, and additional requirements on the vertex quality and the flight distance are applied.

The distributions of the fit to the B invariant mass for the different studied decays are shown in Fig. 4; the signal yields and the results for the different branching fraction ratios[3] are available in Table 3. The world most precise measurement up to date of $\overline{B}_s^0 \to D_s^+D_s^-$ with respect to $\overline{B}^0 \to D^+D_s^-$ is obtained, together with the first observations of the $\overline{B}_s^0 \to D_s^+D^-$ mode at 10.1 σ

[3] These are preliminary results.

Measurement	Result	Numerator Yield	Denominator Yield
$\frac{\mathscr{B}(\overline{B}{}_s^0 \to D_s^+ D_s^-)}{\mathscr{B}(\overline{B}{}^0 \to D^+ D_s^-)}$	$0.508 \pm 0.026 \pm 0.043$	477.0 ± 23.2	5261.9 ± 74.3
$\frac{\mathscr{B}(\overline{B}{}_s^0 \to D_s^+ D^-)}{\mathscr{B}(B^0 \to D_s^+ D^-)}$	$0.048 \pm 0.008 \pm 0.004$	37.7 ± 6.6	2936.4 ± 54.5
$\frac{\mathscr{B}(\overline{B}{}_s^0 \to D^+ D^-)}{\mathscr{B}(\overline{B}{}^0 \to D^+ D^-)}$	$1.00 \pm 0.18 \pm 0.09$	43.4 ± 7.1	161.8 ± 13.1
$\frac{\mathscr{B}(\overline{B}{}_s^0 \to D^0 \overline{D}{}^0)}{\mathscr{B}(B^- \to D^0 D_s^-)}$	$0.015 \pm 0.004 \pm 0.002$	17.2 ± 4.9	5182.0 ± 73.9

Table 3: Branching fraction ratios measurements of $B \to DD'$ decays. The first uncertainty is statistical, the second systematic. The signal yields involved are also shown.

significance, $\overline{B}{}_s^0 \to D^+D^-$ at 10.7 σ and $\overline{B}{}_s^0 \to D^0\overline{D}{}^0$ at 5.4 σ. Their branching fractions are measured with respect to favoured modes, and an indication of $\overline{B}{}^0 \to D^0\overline{D}{}^0$ at 2.1 σ significance is also seen.

5. Conclusion

The LHCb experiment is performing very well, and a lot of new results have been obtained with data collected in 2011. New measurements have been reviewed in this document, concerning B decays to purely hadronic final states containing open charm mesons: the first measurement of the CP asymmetry in the $B^0 \to D(K^+K^-)K^{*0}$ decay, the first observation of the $B^0 \to \overline{D}{}^0K^+K^-$ mode and evidence of $B_s^0 \to \overline{D}{}^0K^+K^-$, and finally first observations and the most precise branching fractions measurements for decays of the type $\overline{B}{}_s^0 \to D\overline{D}'$. These modes can be used to impove knowledge of different CKM parameters.

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