PROCEEDINGS OF SCIENCE

B decays to charmonia at LHCb

Ivan Polyakov[∗†]
Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
E-mail: polyakov@itep.ru

The recent results from the analyses of B decays into final states containing charmonia resonances at the LHCb detector are presented. The analyses use the data sample collected in 2011, which corresponds to an integrated luminosity up to $1.0\,\mathrm{fb}^{-1}$.

LHC on the March - IHEP-LHC,
20-22 November 2012
Institute for High Energy Physics, Protvino,Moscow region, Russia

∗Speaker.
†on behalf of the LHCb collaboration

PoS(IHEP-LHC)015

1. Introduction

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. LHCb's efficient dimuon trigger, excellent decay time resolution and separation of muons, kaons and pions allows to perform studies of B mesons decaying to charmonia with high precision. During 2011 a total luminosity of $1.0\,\mathrm{fb}^{-1}$ was collected at $\sqrt{s} = 7$ TeV.

Decays of B mesons to final states containing a charmonium resonance such as a J/ψ or $\psi(2S)$ offer a powerful way of studying electroweak transitions. Such decays probe charmonium properties and play a role in the study of *CP* violation and mixing in the neutral B system [2].

Different analyses based on an integrated luminosity of $0.37 - 1.0\,\mathrm{fb}^{-1}$ are presented here: measurement of relative branching fractions and *CP* asymmetries of B decays to $\psi(2S)$ and J/ψ mesons, analysis of resonant components in $B^0_s \to J/\psi\,\pi^+\pi^-$, measurement of $B^0 \to J/\psi\,K^0_{\mathrm{S}}$ decay branching fraction and $B^0_s \to J/\psi\,\bar{K}^{*0}$ decay branching fraction and angular amplitudes, first evidence for the $B^0 \to J/\psi\,\omega$ and measurement of branching fractions of $B^0_s \to J/\psi\,\eta^{(\prime)}$ decays.

2. Relative branching fractions and *CP* asymmetries of B decays to $\psi(2S)$ and J/ψ mesons

The relative branching fractions of B^+, B^0 and B^0_s mesons into J/ψ and $\psi(2S)$ mesons have previously been studied by both the CDF and D0 collaborations [3–5]. Since the current experimental results for the study of *CP* violation in B^0_s mixing using the $B^0_s \to J/\psi\,\phi$ decay [6] are statistically limited, it is important to establish other channels where this analysis can be done. One such channel is the $B^0_s \to \psi(2S)\phi$ decay. The relative rates of B mesons decay into J/ψ and $\psi(2S)$ mesons are measured for the $B^+ \to \psi K^+$, $B^0 \to \psi K^{*0}$ and $B^0_s \to \psi\phi$ decay modes, where ψ represents J/ψ or $\psi(2S)$. The mass distribution for selected $B^0_s \to \psi K^+K^-$ candidates is shown in Fig. 1. The observed yields are corrected on total efficiencies estimated using simulation [7]. The key feature of the analysis is subtraction of non-resonant contribution from $B^0 \to \psi K^+\pi^-$ and $B^0_s \to \psi K^+K^-$ decays using *sPlot* technique [8]. Since the selection criteria for J/ψ and $\psi(2S)$ modes are identical, most uncertainties cancel in the ratio. Full details of this analysis are given in Ref. [9]. The measured relative rates are

$$\frac{\mathscr{B}(B^+\to\psi(2S)K^+)}{\mathscr{B}(B^+\to J/\psi K^+)} = 0.594 \pm 0.006\,(\mathrm{stat}) \pm 0.016\,(\mathrm{syst}) \pm 0.015(\mathscr{B})\,,$$
$$\frac{\mathscr{B}(B^0\to\psi(2S)K^{*0})}{\mathscr{B}(B^0\to J/\psi K^{*0})} = 0.476 \pm 0.014\,(\mathrm{stat}) \pm 0.010\,(\mathrm{syst}) \pm 0.012(\mathscr{B})\,,$$
$$\frac{\mathscr{B}(B^\pm\to\psi(2S)\phi)}{\mathscr{B}(B^\pm\to J/\psi\,\phi)} = 0.489 \pm 0.026\,(\mathrm{stat}) \pm 0.021\,(\mathrm{syst}) \pm 0.012(\mathscr{B})\,,$$

where the third uncertainty is related to knowledge of the ratio of $J/\psi \to \mu^+\mu^-$ and $\psi(2S) \to \mu^+\mu^-$ branching fractions. The results are compatible with, but more precise than, the previous measurements [3, 6]. A comparison with the previous measurements is shown in Fig. 3.

The Cabibbo-suppressed decay $B^+ \to \psi\pi^+$ proceeds via a $\bar{b} \to \bar{c}c\bar{d}$ quark transition. In contrast to the $B^+ \to \psi K^+$ decay the tree and penguin contributions have different phases and *CP* asymmetries at the per mille level may occur [10]. An additional asymmetry may be generated, at the percent level, from long-distance rescattering, particularly from decays that have the same

PoS(IHEP-LHC)015

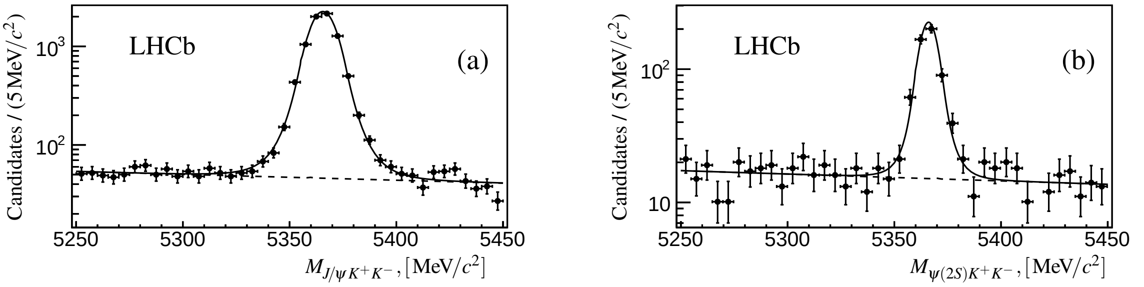

Figure 1: Invariant mass distribution: (a) $B_s^0 \to J/\psi K^+K^-$ and (b) $B_s^0 \to \psi(2S)K^+K^-$. The total fitted function (solid) and the combinatorial background (dashed) are shown.

quark content (D^0D^-, $D^{*-}D^0$ ...) [11]. Any asymmetry larger than this would be of significant interest. In the analysis the *CP* asymmetries $A^{\psi\pi}$ and charge-averaged ratios of branching fractions $R^\psi = \mathscr{B}(B^\pm \to \psi\pi^\pm)/\mathscr{B}(B^\pm \to \psi K^\pm)$ are measured. The $B^\pm \to J/\psi K^\pm$ acts as a control mode in the asymmetry analysis because it is well measured and no *CP* violation is observed [6]. The $B^+ \to \psi(2S)h^+$ candidate invariant mass distributions are shown in Fig. 2. The ratios R^ψ and *CP* asymmetries are extracted from the observed yields by taking account of instrumental effects and production asymmetries. The identification efficiency and detection and identification asymmetry of kaons and pions are measured on data using sample of $D^{*+} \to D^0\pi^+$, $D^0 \to K^+\pi^-$ decays. The production asymmetry, which describes different rates with which B^+ and B^- hadronize out of the pp collisions, has been estimated using $B^+ \to J/\psi K^+$ decays. The measured ratios of branching fractions are

$$R^{J/\psi} = (3.83 \pm 0.11\,(\text{stat}) \pm 0.07\,(\text{syst})) \times 10^{-2} \,,$$
$$R^{\psi(2S)} = (3.95 \pm 0.40\,(\text{stat}) \pm 0.12\,(\text{syst})) \times 10^{-2} \,.$$

The resulting $R^{\psi(2S)}$ is compatible with the Belle measurement [12], while $R^{J/\psi}$ is 3.2σ lower than the world average at that time, $(5.2 \pm 0.4) \times 10^{-2}$ [6]. A comparison with the previous measure-

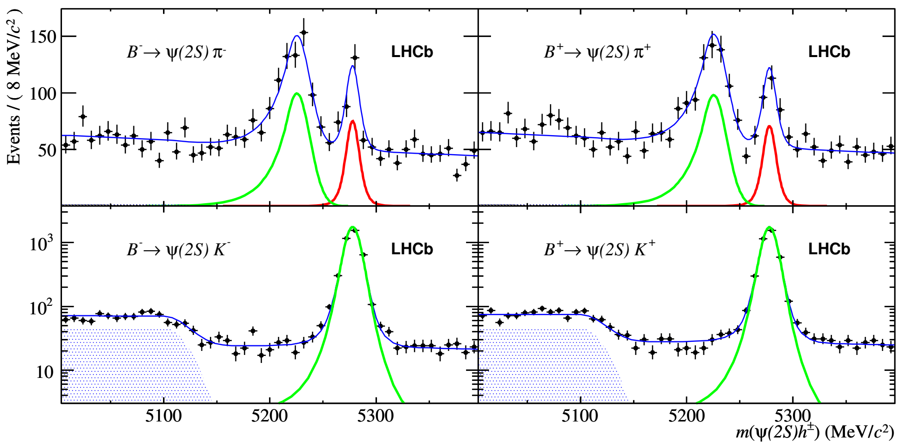

Figure 2: Distributions of $B^\pm \to \psi(2S)h^\pm$ invariant mass, overlain by the total PDF (thin line) which represents a sum of correctly reconstructed decay, misidentified events, partially reconstructed decays and combinatorial background. The dark (red) curve shows the $B^+ \to \psi(2S)\pi^+$ component, the light (green) curve represents $B^+ \to \psi(2S)K^+$.

ments is shown in Fig. 3. The measured *CP* asymmetries,

$$
\begin{aligned}
A_{CP}^{J/\psi\pi} &= 0.005 \pm 0.027\,(\text{stat}) \pm 0.011\,(\text{syst})\,, \\
A_{CP}^{\psi(2S)\pi} &= 0.048 \pm 0.090\,(\text{stat}) \pm 0.011\,(\text{syst})\,, \\
A_{CP}^{\psi(2S)K} &= 0.024 \pm 0.014\,(\text{stat}) \pm 0.008\,(\text{syst})\,,
\end{aligned}
$$

have comparable or better precision than the previous results, and no evidence of *CP* violation is seen. Full details of the analysis are presented in Ref. [13].

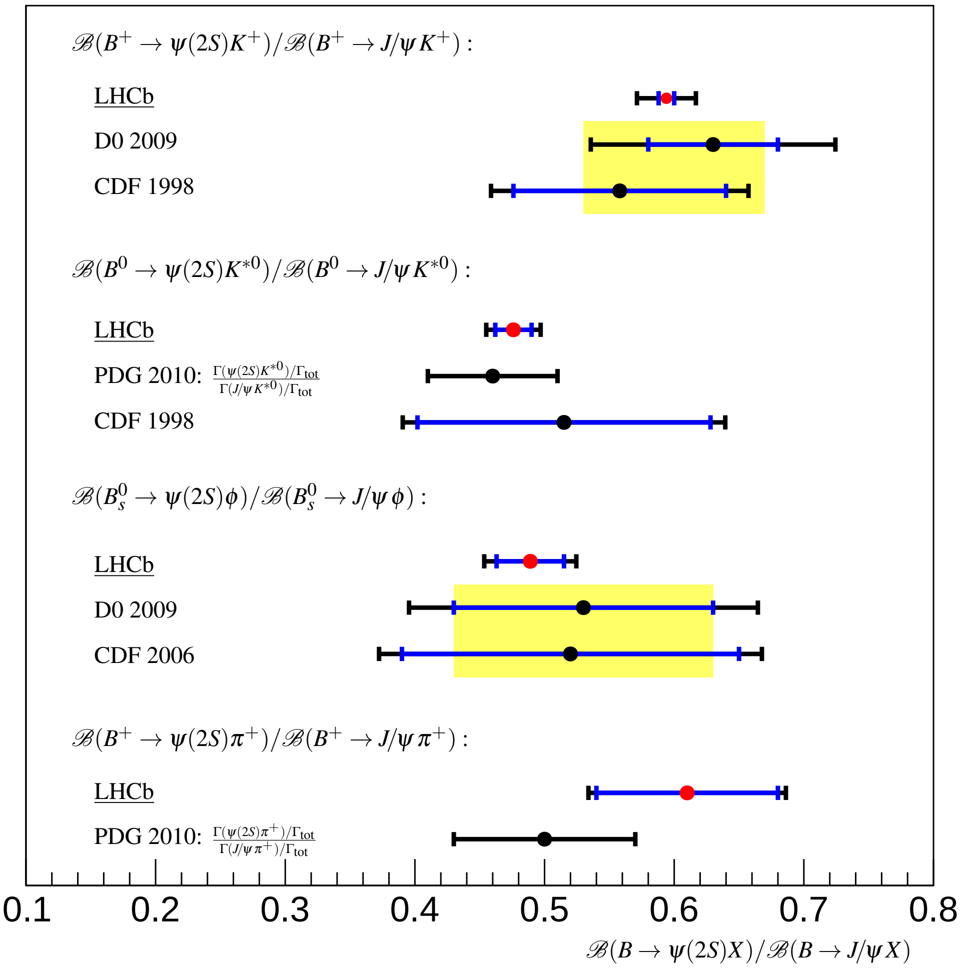

Figure 3: Comparison of the obtained results with measurements from previous experiments: $\mathcal{B}(B^+ \to \psi(2S)K^+)/\mathcal{B}(B^+ \to J/\psi K^+)$, $\mathcal{B}(B^0 \to \psi(2S)K^{*0})/\mathcal{B}(B^0 \to J/\psi K^{*0})$, $\mathcal{B}(B_s^0 \to \psi(2S)\phi)/\mathcal{B}(B_s^0 \to J/\psi\phi)$ and $\mathcal{B}(B^+ \to \psi(2S)\pi^+)/\mathcal{B}(B^+ \to J/\psi\pi^+)$. The blue error bars represent statistical uncertainties, while the black represent total uncertainties. The shaded regions represent the PDG averages.

3. Resonant structure of $B_s^0 \to J/\psi\pi^+\pi^-$ decay

The decay $B_s^0 \to J/\psi f_0(980)$, first observed by LHCb [14], has been used to measure the *CP*-violating phase ϕ_s [15], in complement to measurements from $B_s^0 \to J/\psi\phi$ [16–18]. It is possible that a larger $\pi^+\pi^-$ mass range could also be used for such studies. Therefore, to fully exploit the $J/\psi\pi^+\pi^-$ final state for measuring *CP* violation, it is important to determine its resonant and *CP* content. Full details of this analysis are given in Ref. [19]. In the so-called modified Dalitz-plot analysis the $m^2_{J/\psi\pi^+}$, $m^2_{\pi^+\pi^-}$ and the J/ψ helicity angle $\Theta_{J/\psi}$ distributions are used to study the resonant and non-resonant structures. No resonant structure is observed in $m^2_{J/\psi\pi^+}$ while there is very clear structure in $m^2_{\pi^+\pi^-}$, which is illustrated in Fig 4. The largest component is the $f_0(980)$ resonance ($\sim 70\%$), followed by the $f_0(1370)$ ($\sim 21\%$) and a nonresonant component ($\sim 8\%$). There is also a *D*-wave contribution from the $f_2(1270)$, which accounts for around 0.5% of the helicity 0 rate. The mixed-*CP* $A_{2\pm1}$ amplitude is $(0.2\pm0.7)\%$ of the total and the contribution from $\rho(770)^0$ is less than 1.5% at 95% CL. It is possible therefore to conclude that the decay is dominantly *CP*-odd, > 0.977 at 95% confidence level. Thus, the whole mass range can be used for *CP* violation studies. In addition, the first measurement of $\mathscr{B}(B_s^0 \to J/\psi\pi^+\pi^-)$ relative to $\mathscr{B}(B_s^0 \to J/\psi\phi)$ of $(19.79\pm0.47\pm0.52)\%$ is done.

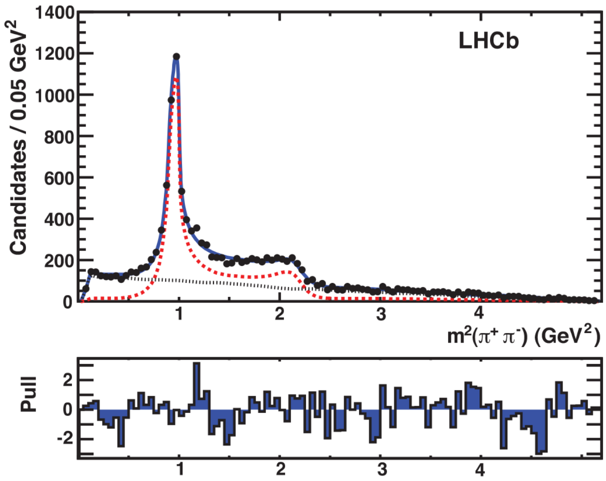

Figure 4: Di-pion invariant mass squared, $m^2_{\pi^+\pi^-}$, distribution of $B_s^0 \to J/\psi\pi^+\pi^-$ candidates in data with the projections of the Dalitz-plot fit superimposed. The signal fit is shown with a (red) dashed line, the background with a (black) dotted line, and the (blue) solid line represents the total.

4. Branching fraction of $B_s^0 \to J/\psi K_S^0$ decay

The decay $B^0 \to J/\psi K_S^0$ has been used for the measurement of the *CP*-violating phase ϕ_d by the *B* factories [20, 21]. To improve the existing measurements and determine possible small deviations from the SM value a knowledge of penguin diagram corrections becomes mandatory. The $B_s^0 \to J/\psi K_S^0$ decay is the most promising candidate to extract the parameters related to the penguin contribution [22]. The measurement of its branching fraction is an important first step. In the selection of $B_s^0 \to J/\psi K_S^0$ candidates a neural network (NN) classifier [23] was used. The NN was trained entirely on data using $B^0 \to J/\psi K^0_S$ decay for signal and mass sidebands for background. The selection is separated for pions that both have hits in the vertex detector (long K^0_S candidate) or not (downstream K^0_S candidate). The selected $J/\psi K^0_S$ candidates are shown in the Fig. 5. The $B^0 \to J/\psi K^0_S$ decay is used as a control channel. The $B^0_s \to J/\psi K^0_S$ branching fraction is measured to be $(1.83 \pm 0.21\,(\text{stat}) \pm 0.10\,(\text{syst}) \pm 0.14\,(f_s/f_d) \pm 0.07\,(\mathscr{B}(B^0 \to J/\psi K^0_S))) \times 10^{-5}$ which is compatible, but more precise than previous measurement [24]. The analysis is described in detail in Ref. [25].

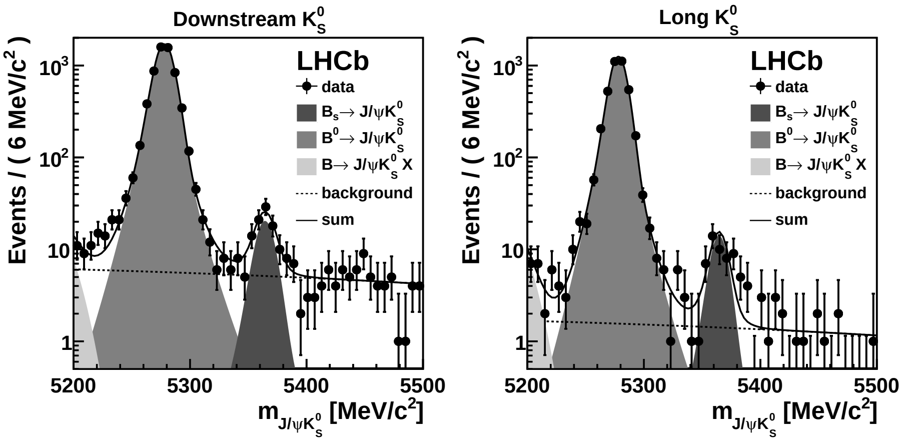

Figure 5: Full $J/\psi K^0_S$ sample after the optimal NN cut has been applied with downstream K^0_S to the left and long K^0_S to the right.

5. Branching fraction and angular amplitudes of $B^0_s \to J/\psi \bar{K}^{*0}$ decay

Similarly to the measurement of *CP* violation in $B^0 \to J/\psi K^0_S$ decay, the penguin contributions could affect the measured asymmetries in $B^0_s \to J/\psi \phi$. It has been suggested that the penguin effects can be controlled by means of an analysis of the angular distribution of $B^0_s \to J/\psi \bar{K}^{*0}$ [26]. In this analysis the branching fraction of the $B^0_s \to J/\psi \bar{K}^{*0}$ decay is determined with measurement of its angular properties and non-resonant $K\pi$ contribution. Full details of the analysis are presented in Ref. [27]. For the branching fraction measurement the $B^0 \to J/\psi K^{*0}$ decay is used as a normalization channel. To determine K^{*0} polarization fractions and non-resonant $K\pi$ S-wave contribution a simultaneous fit were performed for B^0_s mass and three angular distributions. The $K\pi$ invariant mass distributions for $B^0 \to J/\psi K\pi$ and $B^0_s \to J/\psi K\pi$ decays are shown in Fig. 6. The first measurement of polarization fractions gives $f_L = 0.50 \pm 0.08 \pm 0.02$ and $f_{||} = 0.19^{+0.10}_{-0.08} \pm 0.02$. The determined S-wave contribution is $|A_s|^2 = 0.07^{+0.15}_{-0.07}$ in a $\pm 40\,\text{MeV}/c^2$ window around the K^{*0} mass. The $B^0_s \to J/\psi \bar{K}^{*0}$ branching fraction was measured to be $(4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$ which is compatible to the CDF result [24]. It is also similar to naive quark spectator model prediction of $|V_{cd}|^2/|V_{cs}|^2 \times \mathscr{B}(B^0 \to J/\psi K^{*0}) = (6.5 \pm 1.0) \times 10^{-5}$, although it is closer to the estimation of $2 \times \mathscr{B}(B^0 \to J/\psi \rho^0) = (4.6 \pm 0.4) \times 10^{-5}$ [26].

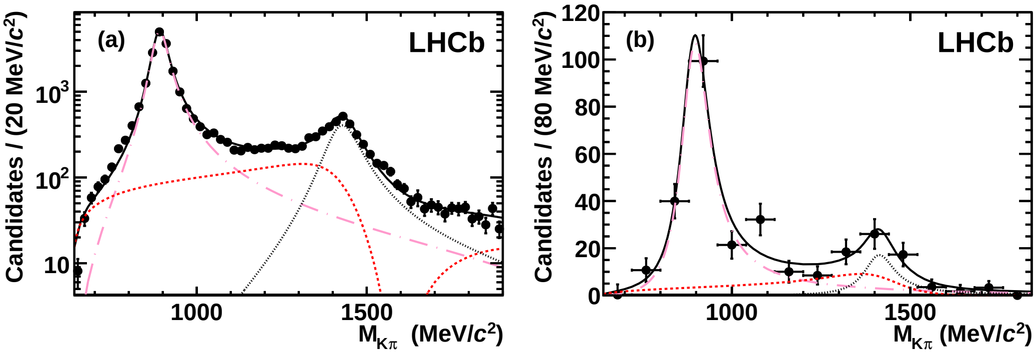

Figure 6: Fit to the $K\pi$ mass spectrum for (a) $B^0 \to J/\psi K\pi$ events and (b) $B^0_s \to J/\psi K\pi$ events. The pink dashed-dotted line represents the P-wave, the red short-dashed line the S-wave and the black dotted line is the $K_2^*(1430)$. The black solid line is their sum.

6. First evidence for the $B^0 \to J/\psi\,\omega$ and branching fractions of $B^0_s \to J/\psi\,\eta^{(\prime)}$ decays

Decays of B mesons into a J/ψ and a light meson are dominated by color-suppressed tree diagrams involving $\bar{b} \to \bar{c}c\bar{s}$ and $\bar{b} \to \bar{c}c\bar{d}$ transitions [28]. Measurements of branching fractions can help to shed lights on the hadronic interactions. The $B^0_s \to J/\psi\,\eta$ and $B^0_s \to J/\psi\,\eta'$ decays can be used for *CP* violation studies in the future [29] and the measurement of their branching ratios allow to estimate gluonic component in the η' meson [30]. These decays were previously studied by Belle [31] while the $B^0 \to J/\psi\,\omega$ has not been previously observed. In this analysis the branching ratios of $B^0 \to J/\psi\,\omega$ and $B^0_s \to J/\psi\,\eta^{(\prime)}$ decays are measured relative to $\mathscr{B}(B^0 \to J/\psi\,\rho^0)$ and the ratio $\dfrac{\mathscr{B}(B^0_s \to J/\psi\,\eta')}{\mathscr{B}(B^0_s \to J/\psi\,\eta)}$ is determined. The detailed description of the analysis is presented in Ref. [32].

The light meson candidates are reconstructed in $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$, $\eta' \to \rho^0\gamma$, $\eta' \to \eta\pi^+\pi^-$ and $\omega \to \pi^+\pi^-\pi^0$ final states. The invariant mass distribution of $J/\psi\,\omega$ candidates is shown in Fig. 7, where a B^0 signal is seen with statistical significance of 5.0 standard devia-

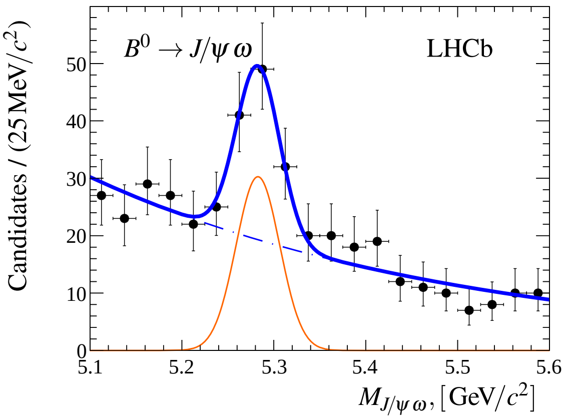

Figure 7: Invariant mass distribution for selected $B^0 \to J/\psi\,\omega$ candidates. The thick solid blue line is the total fit function, the blue dashed line shows the background contribution and the orange thin line is the signal component of the fit function.

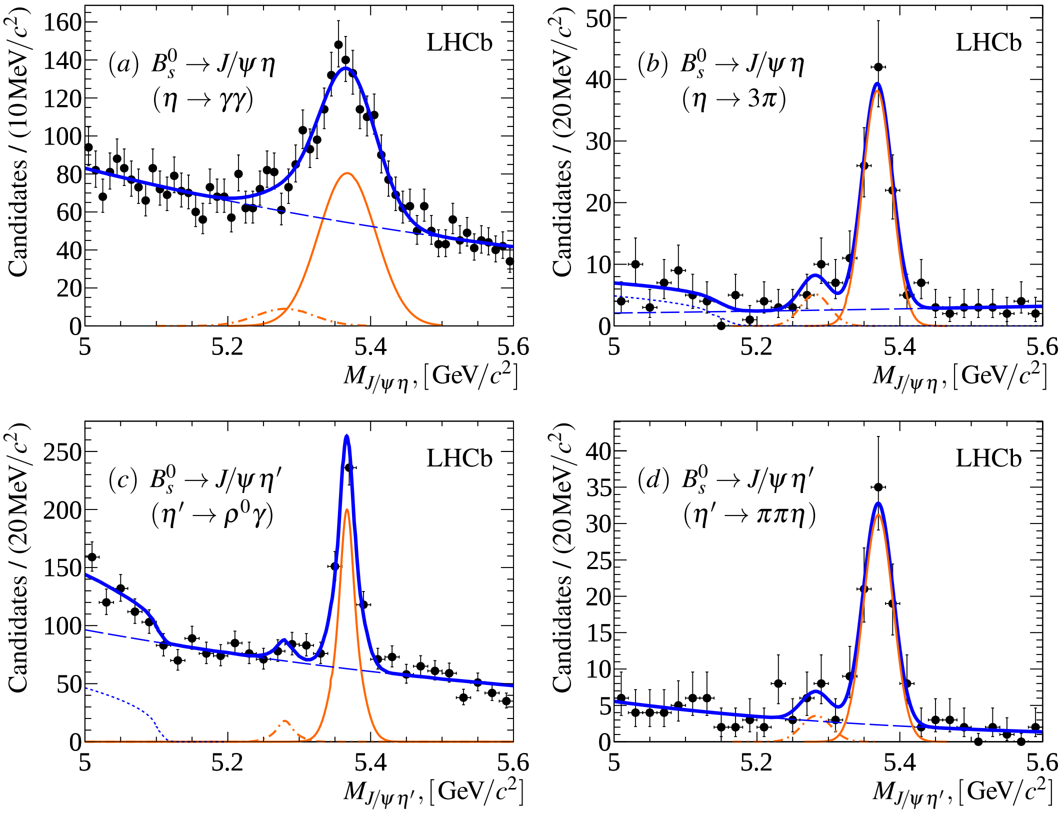

Figure 8: Invariant mass distributions for selected $B_s^0 \to J/\psi\,\eta^{(\prime)}$ candidates: (a) $B_s^0 \to J/\psi\,\eta\ (\eta \to \gamma\gamma)$, (b) $B_s^0 \to J/\psi\,\eta\ (\eta \to \pi^+\pi^-\pi^0)$, (c) $B_s^0 \to J/\psi\,\eta'\ (\eta' \to \rho^0\gamma,\ \rho^0 \to \pi^+\pi^-)$ and (d) $B_s^0 \to J/\psi\,\eta'\ (\eta' \to \pi^+\pi^-\eta)$. The thin solid orange lines show the signal B_s^0 contributions and the orange dot-dashed lines correspond to the B^0 contributions. The blue dashed lines show the combinatorial background contributions and the dotted blue lines show the partially reconstructed background components. The total fit functions are drawn as solid blue lines.

tions. The invariant mass spectra for $B_s^0 \to J/\psi\,\eta^{(\prime)}$ candidates are shown in Fig. 8. The $B^0 \to J/\psi\,\rho^0(\rho^0 \to \pi^+\pi^-)$ decay is used as a normalization channel, to study its dipion mass distribution the *sPlot* technique [8] is used. The resulting $\pi^+\pi^-$ invariant mass spectrum from $B^0 \to J/\psi\,\pi^+\pi^-$ decays is shown in Fig 9. The distribution is fitted with the sum of several components: P-wave component describing ρ^0, a D-wave describing the enhancement at 1260 MeV/c^2 and S-wave contribution expected from $f_0(500)$. The final ratios are determined using an averaging procedure and are

$$
\begin{aligned}
\frac{\mathcal{B}(B^0 \to J/\psi\,\omega)}{\mathcal{B}(B^0 \to J/\psi\,\rho^0)} &= 0.89 \pm 0.19\,(\mathrm{stat})^{+0.07}_{-0.13}\,(\mathrm{syst})\ , \\
\frac{\mathcal{B}(B_s^0 \to J/\psi\,\eta')}{\mathcal{B}(B_s^0 \to J/\psi\,\eta)} &= 0.90 \pm 0.09\,(\mathrm{stat})^{+0.06}_{-0.02}\,(\mathrm{syst})\ , \\
\frac{\mathcal{B}(B_s^0 \to J/\psi\,\eta)}{\mathcal{B}(B^0 \to J/\psi\,\rho^0)} &= 14.0 \pm 1.2\,(\mathrm{stat})^{+1.1}_{-1.5}\,(\mathrm{syst})^{+1.1}_{-1.0}\left(\tfrac{f_d}{f_s}\right)\ , \\
\frac{\mathcal{B}(B_s^0 \to J/\psi\,\eta')}{\mathcal{B}(B^0 \to J/\psi\,\rho^0)} &= 12.7 \pm 1.1\,(\mathrm{stat})^{+0.5}_{-1.3}\,(\mathrm{syst})^{+1.0}_{-0.9}\left(\tfrac{f_d}{f_s}\right).
\end{aligned}
$$

where the third uncertainty is related to a knowledge of b-quark factorization factors. The first measurement of $B^0 \to J/\psi\,\omega$ branching fraction is done. The determined ratio of $B_s^0 \to J/\psi\,\eta'$ and $B_s^0 \to J/\psi\,\eta$ branching fractions is compatible, but more precise, than the previous Belle measurement [31].

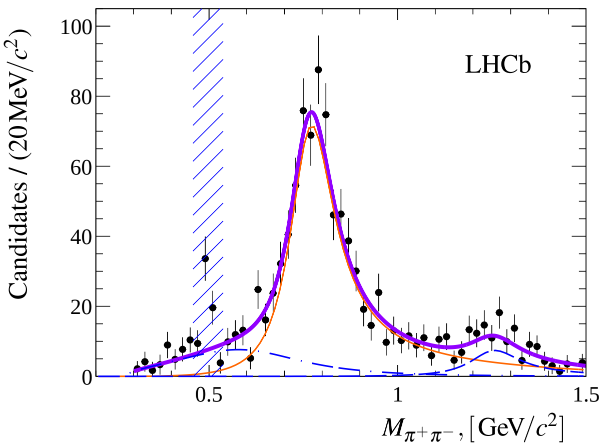

Figure 9: Background-subtracted $\pi^+\pi^-$ invariant mass distribution from $B^0 \to J/\psi\,\pi^+\pi^-$ decays. A violet solid line denotes the total fit function, the solid orange line shows the ρ^0 signal contribution and the blue dashed line shows the $f_2(1270)$ contribution. The blue dot-dashed line shows the contribution from the $f_0(500)$. The region $\pm 40\,\mathrm{MeV}/c^2$ around the K_S^0 mass represented by the blue-dashed box is excluded from the fit.

7. Summary

This contribution has reviewed studies of B meson decays to final states containing charmonium resonances. A large variety of different decays are being studied in order to probe charmonium properties, QCD effects and provide input for *CP* violation measurements. The analysis were based on 0.37-1.0 fb^{-1} of 2011 data collected at $\sqrt{s} = 7\,\mathrm{TeV}$. During 2011 and 2012 LHCb has collected around 3.0 fb^{-1}. The analysis of these data will produce even more exciting results in this field.

References

[1] A. A. Alves, Jr. *et al.* [LHCb Collaboration], *The LHCb Detector at the LHC*, *JINST* **3**, S08005 (2008)

[2] I.I.Y. Bigi, A.I. Sanda, *Notes on the observability of CP violations in B decays*, *Nucl. Phys. B* **193**, 85 (1981)

[3] F. Abe *et al.* [CDF collaboration], *Observation of $B^+ \to \psi(2S)K^+$ and $B^0 \to \psi(2S)K^{*0}$ decays and measurements of B-meson branching fractions into J/ψ and $\psi(2S)$ final states*, *Phys. Rev.* **D58** 072001 (1998)

[4] A. Abulencia *et al.* [CDF collaboration], *Observation of $B_s^0 \to \psi(2S)\phi$ and measurement of ratio of branching fractions $\mathscr{B}(B_s^0 \to \psi(2S)\phi)/\mathscr{B}(B_s^0 \to J/\psi\,\phi)$*, *Phys. Rev. Lett.* **96** 231801 (2006)

[5] V. Abazov *et al.* [D0 collaboration], *Relative rates of B meson decays into $\psi(2S)$ and J/ψ mesons*, *Phys. Rev.* **D79** 111102(R) (2009)

[6] K. Nakamura *et al.* [Particle Data Group], *J. Phys. Rev.* **G37**, 075021 (2010)

[7] M. Clementic *et al.* [LHCb collaboration], *The LHCb simulation application, Gauss: design, evolution and experience*, *J. of Phys. : Conf. Ser.* **331**, (2011) 032023.

[8] M. Pivk and F. R. Le Diberder, *sPlot: a statistical tool to unfold data distributions*, *Nucl. Instrum. Meth.* **A555** 356 (2005)

[9] R. Aaij *et al.* [LHCb collaboration], *Measurement of relative branching fractions of B decays to $\psi(2S)$ and J/ψ mesons*, *Eur. Phys. J. C* (2012) 72:2118

[10] I. Dunietz and J. M. Soares, *Phys. Rev. D* **49**, 5904 (1994)

[11] J. M. Soares, *Phys. Rev. D* **52**, 242 (1995)

[12] V. Bhardwaj *et al.* [Belle Collaboration], *Observation of $B^\pm \to \psi(2S)\pi^\pm$ and search for direct CP violation*, *Phys. Rev.* **D78**, 051104 (2008)

[13] R. Aaij *et al.* [LHCb collaboration], *Measurements of the branching fractions and CP asymmetries of $B^\pm \to J/\psi\pi^\pm$ and $B^\pm \to \psi(2S)\pi^\pm$ decays*, *Phys. Rev.* **D85**, 091105(R) (2012)

[14] R. Aaij *et al.* [LHCb collaboration], *First observation of $B_s^0 \to J/\psi f^0(980)$ decays*, *Phys. Lett.* **B698**, 115 (2011)

[15] R. Aaij *et al.* [LHCb collaboration], *Measurement of the CP violating phase ϕ_s in $B_s^0 \to J/\psi f^0(980)$*, *Phys. Lett.* **B707**, 497 (2012)

[16] R. Aaij *et al.* [LHCb collaboration], *Measurement of the CP-violating phase ϕ_s in the decay $B_s^0 \to J/\psi\phi$*, *Phys. Rev. Lett.* **108**, 101803 (2012)

[17] T. Aaltonen *et al.* [CDF collaboration], *Measurement of the CP-Violating phase β_s in $B_s^0 \to J/\psi\phi$ decays with the CDF II detector*, *Phys. Rev.* **D85**, 072002 (2012)

[18] V. M. Abazov *et al.* [D0 collaboration], *Measurement of the CP-Violating phase $\phi_s^{J/\psi\phi}$ using flavour-tagged decay $B_s^0 \to J/\psi\phi$ in $8\,fb^{-1}$ of $p\,\overline{p}$ collisons*, *Phys. Rev.* **D85**, 032006 (2012)

[19] R. Aaij *et al.* [LHCb collaboration], *Analysis of the resonant components in $B_s^0 \to J/\psi\pi^+\pi^-$*, *Phys. Rev.* **D86**, 052006 (2012)

[20] I. Adachi *et al.* [Belle collaboration], *Precise measurement of the CP violation parameter $sin2_1$ in $B^0 \to (c\overline{c})K^0$ decays*, *Phys. Rev. Lett.* **108**, 171802 (2012)

[21] B. Aubert *et al.* [BaBar collaboration], *Measurement of time-dependent CP asymmetry in $B^0 \to c\overline{c}K^*0 Decays$*, *Phys. Rev.* **D79**, 072009 (2009)

[22] R. Fleischer, *Extracting γ from $B_{s(d)} \to J/\psi K_S^0$ and $B_{d(s)} \to D^+_{d(s)}D^-_{d(s)}$*, *Eur. Phys. J.* **C10**, 299 (1999)

[23] M. Feindt and U. Kerzel, *The NeuroBayes neural network package*, *Nucl. Instrum. Meth.* **A559**, 190 (2006)

[24] T. Aaltonen *et al.* [CDF collaboration], *Observation of $B_s^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi K_S^0$ decays*, *Phys. Rev.* **D83**, 052012 (2011)

[25] R. Aaij *et al.* [LHCb collaboration], *Measurement of the $B_s^0 \to J/\psi K_S^0$ branching fraction*, *Phys. Lett.* **B713**, 172 (2012)

[26] S. Faller, R. Fleischer, and T. Mannel, *Precision physics with $B_s^0 \to J/\psi\phi$ at the LHC: the quest for new physics*, *Phys. Rev.* **D79**, 014005 (2009)

[27] R. Aaij *et al.* [LHCb collaboration], *Measurement of the $B_s^0 \to J/\psi K^{*0}$ branching fraction and angular amplitudes*, *Phys. Rev.* **D86**, 071102(R) (2012)

[28] R. Fleischer, R. Knegjens, and G. Ricciardi, *Exploring CP Violation and $\eta-\eta'$ mixing with the $B_s^0 \to J/\psi \eta^{(\prime)}$ systems*, *Eur. Phys. J.* **C71**, 1798 (2011)

[29] M. Jung, *Determining weak phases from $B \to J/\psi P$ decays*, [arXiv:1206.2050]

[30] X. Liu, H.-n. Li, and Z.-J. Xiao, *Implications on $\eta-\eta'$ — glueball mixing from $B_{d/s} \to J/\psi \eta^{(\prime)}$ decays*, *Phys. Rev.* **D86**, 011501 (2012)

[31] J. Li *et al.* [Belle collaboration], *First observations of $B_s^0 \to J/\psi \eta$ and $B_s^0 \to J/\psi \eta'$*, *Phys. Rev. Lett.* **108**, No 3, 181808 (2012)

[32] R. Aaij *et al.* [LHCb collaboration], *Evidence for the decay $B^0 \to J/\psi \omega$ and measurement of the relative branching fractions of B_s^0 meson decays to $J/\psi \eta$ and $J/\psi \eta'$*, *Nucl. Phys.* **B867**, No 3, 547-566 (2013)