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Relative rates of B meson decays into $\psi(2S)$ and J/ψ mesons

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We report on a study of the relative rates of B meson decays into $\psi(2S)$ and J/ψ mesons using 1.3 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV recorded by the D0 detector operating at the Fermilab Tevatron Collider. We observe the channels $B_s^0 \to \psi(2S)\phi$, $B_s^0 \to J/\psi\phi$, $B^\pm \to \psi(2S)K^\pm$, and $B^\pm \to J/\psi K^\pm$ and

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we measure the relative branching fractions for these channels to be $\frac{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = 0.53 \pm 0.10(\text{stat}) \pm 0.07(\text{syst}) \pm 0.06(\mathcal{B})$, $\frac{\mathcal{B}(B^\pm \to \psi(2S)K^\pm)}{\mathcal{B}(B^\pm \to J/\psi K^\pm)} = 0.63 \pm 0.05(\text{stat}) \pm 0.03(\text{syst}) \pm 0.07(\mathcal{B})$, where the final error corresponds to the uncertainty in the J/ψ and $\psi(2S)$ branching ratio into two muons.

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B meson decays into final states containing charmonium play a crucial role in the study of CP violation and the precise measurement of neutral B meson mixing parameters [1]. For CP violation in B_s mixing, $B_s \to J/\psi\phi$ decays are being used to measure the width difference between the mass eigenstates and the CP violating relative phase difference between the off diagonal elements Γ_{12} and M_{12} describing the mixing of neutral B mesons [2,3]. Since the current experimental results are limited by statistics, it is important to establish new channels like the decay $B_s^0 \to \psi(2S)\phi$ where these studies can be performed.

The study of B meson decays into several charmonium states can also be used to constrain the long-distance parameters associated with color octet production which are important for the understanding of both mixing induced and direct CP violation [4]. While these modes have been precisely measured in B^+ and B^0 decays [5], an extension of these studies into the B_s^0 system provides an important test of quark-hadron duality.

In this paper, we report measurements of B meson decays into charmonium using the channels $B^+ \to J/\psi K^+$, $B^+ \to \psi(2S)K^+$, $B_s^0 \to J/\psi\phi$, and $B_s^0 \to \psi(2S)\phi$. Charge conjugation is implied throughout. The J/ψ and $\psi(2S)$ mesons are reconstructed in the dimuon channel and the ϕ is reconstructed in the K^+K^- channel. The study uses a data sample of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV corresponding to an integrated luminosity of approximately 1.3 fb^{-1} recorded by the D0 detector operating at the Fermilab Tevatron Collider. Similar studies have recently been reported by the CDF collaboration [6].

D0 is a general purpose detector described in detail in Ref. [7]. Charged particles are reconstructed using a silicon vertex tracker and a scintillating fiber tracker located inside a superconducting solenoidal coil that provides a magnetic field of approximately 2 T. The tracking volume is surrounded by a LAr-U calorimeter. Muons are reconstructed using a spectrometer consisting of magnetized iron toroids and three superlayers of proportional tubes and plastic trigger scintillators located outside the calorimeter. Only data recorded by dimuon triggers were used for this analysis.

The selection requirements are determined using simulated samples for the four decay modes. The PYTHIA [8] Monte Carlo (MC) generator is used to model $b\bar{b}$ production and fragmentation, followed by EVTGEN [9] to simulate the kinematics of B-meson decay. The detector response is simulated using a GEANT [10] based MC. Simulated events are processed through the same reconstruction code as used for the data. The dimuon trigger is modeled using a detailed simulation program incorporating all aspects of the trigger logic. The trigger simulation is verified using a data sample collected with single muon triggers. Backgrounds are modeled using data in the mass sideband regions around the candidate B meson.

Muon candidates are required to have track segments reconstructed in at least two out of the three muon system superlayers and to be associated with a track reconstructed with hits in both the silicon and fiber trackers. We require that the muon transverse momentum, p_T, is greater than 2 GeV$/c$. The charmonium system is formed by combining two oppositely charged muon candidates that are associated with the same track jet [11] and form a well-reconstructed vertex with $\chi^2/\text{DOF} < 16$. We require the dimuon p_T to be greater than 4 GeV$/c$. The invariant mass of the dimuon system is required to be within 250 MeV$/c^2$ of the nominal charmonium state mass [5], since the invariant mass resolution is about ≈ 75 MeV$/c^2$. We then redetermine the muon momenta with a mass constraint imposed when forming the B meson candidate.

All charged particles within the same track jet as the dimuon system are considered as kaon candidates and the kaon mass is assigned. The candidates are required to have hits in both the silicon and fiber trackers and have $p_T > 0.6$ GeV$/c$. Pairs of oppositely charged kaons with $p_T > 0.9$ GeV$/c$ are combined to form ϕ candidates. The expected invariant mass resolution for the ϕ mesons is 4 MeV$/c^2$. Therefore the pair of kaons must form a well-reconstructed vertex and have $1.008 < m(K^+K^-) < 1.032$ GeV$/c^2$.

The charmonium candidates are combined with either a kaon or ϕ candidate to form either a B^+ or a B_s^0 candidate. The B meson daughter particles are required to form a well-reconstructed vertex and have an invariant mass between 4.4 and 6.2 GeV$/c^2$.

Backgrounds from prompt charmonium production are reduced by requiring the B meson decay vertex to be displaced from the interaction point in the transverse plane by more than 4 times the error on the measured displacement for B^+ candidates and 6 times the error for B_s^0 candidates. For all candidates, the error on the displacement measurement is required to be less than 150 μm. Combinatorial backgrounds are reduced by requiring the B candidate momentum vector to be aligned with the position vector of the secondary vertex to within 26 degrees. Possible background contamination from kaons and pions misidentified as muons and other source of B meson decays which could result in a peaking background have been studied and found to be negligible.

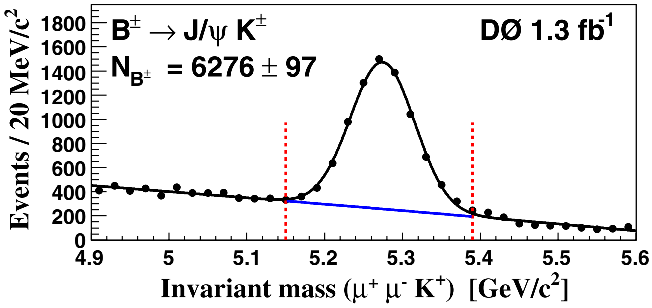

FIG. 1 (color online). $\mu^+\mu^-K^\pm$ invariant mass distribution for the $B^\pm \to J/\psi K^\pm$ data selection. The region between two dashed vertical lines represents the signal window.

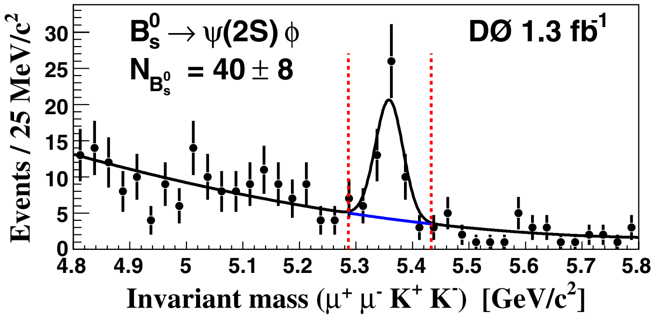

FIG. 4 (color online). $\mu^+\mu^-\phi$ invariant mass distribution for the $B_s^0 \to \psi(2S)\phi$ data selection. The region between two dashed vertical lines represents the signal window.

The resulting mass distributions of the B meson candidates are displayed in Figs. 1–4. The B meson yield is extracted from the data using a binned likelihood fit to the data assuming a Gaussian component for signal and a second-order polynominal distribution for background. The number of signal events is obtained by integrating the fit functions over the range of interest. This range is indicated by the two dashed vertical lines in Figs. 1–4 for each channel, and covers a region corresponding to $\pm 3\sigma$, where σ is the expected invariant mass resolution. We see signals in all four channels. The results of the signal yields, corrected for the background contributions, are listed in Table I.

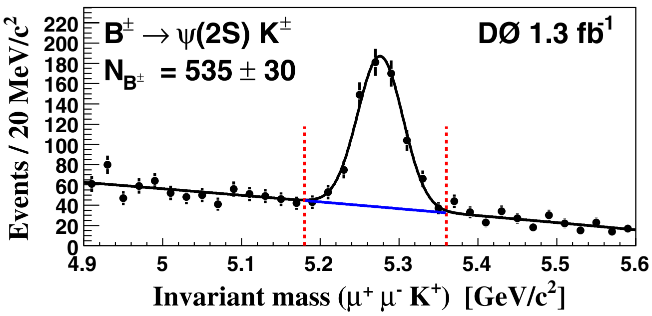

FIG. 2 (color online). $\mu^+\mu^-K^\pm$ invariant mass distribution for the $B^\pm \to \psi(2S)K^\pm$ data selection. The region between two dashed vertical lines represents the signal window.

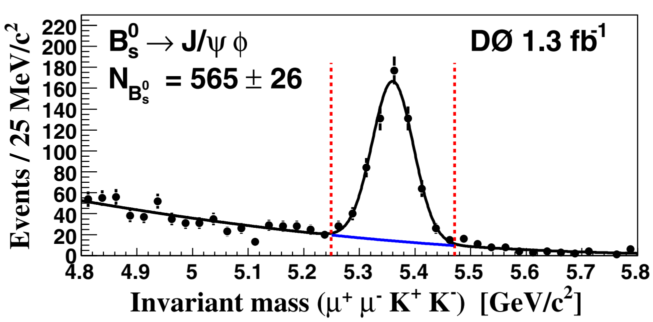

FIG. 3 (color online). $\mu^+\mu^-\phi$ invariant mass distribution for the $B_s^0 \to J/\psi\phi$ data selection. The region between two dashed vertical lines represents the signal window.

The relative yield of B meson decays into $\psi(2S)$ and J/ψ mesons is given by

$$\frac{\mathcal{B}(B \to \psi(2S)M)}{\mathcal{B}(B \to J/\psi M)} = \frac{N_{\psi(2S)M}}{N_{J/\psi M}} \cdot \frac{\epsilon_{J/\psi M}}{\epsilon_{\psi(2S)M}} \cdot \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{\mathcal{B}(\psi(2S) \to \mu^+\mu^-)}, \quad (1)$$

where B is either a B^+ or B_s^0 meson, M is either a K^+ or ϕ meson, N is the number of signal events returned from the fit, and ϵ is the reconstruction efficiency determined from MC. The measured branching fractions $\mathcal{B}(J/\psi \to \mu^+\mu^-) = (5.93 \pm 0.06) \cdot 10^{-2}$ and $\mathcal{B}(\psi(2S) \to \mu^+\mu^-) = (7.5 \pm 0.8) \cdot 10^{-3}$ are taken from Ref. [5] and combined into a ratio of branching fractions $\mathcal{B}(J/\psi \to \mu^+\mu^-)/\mathcal{B}(\psi(2S) \to \mu^+\mu^-) = 8.12 \pm 0.89$. The uncertainty on the ratio is given by the uncertainty on the single measured branching fractions assuming no correlations.

For the measurement of B meson branching fractions the sources of systematic uncertainties are (i) the branching fractions of the charmonium mesons to dimuons, (ii) systematics of the individual signal yield determinations, and (iii) the determination of the efficiencies $\epsilon_{\psi(2S)\phi}$ and $\epsilon_{J/\psi\phi}$. In the ratio many systematic uncertainties cancel, such as the integrated luminosity, b production and fragmentation, and the selection efficiencies. However, the polarization could be different for the B_s^0

TABLE I. Summary of obtained event yields from the fits as described in the text and signal efficiencies obtained from MC simulations.

Decay	Efficiency	Yield
$B^\pm \to J/\psi K^\pm$	$(1.07 \pm 0.02) \cdot 10^{-3}$	6276 ± 97
$B^\pm \to \psi(2S)K^\pm$	$(1.14 \pm 0.04) \cdot 10^{-3}$	535 ± 30
$B_s^0 \to J/\psi\phi$	$(14.4 \pm 0.7) \cdot 10^{-5}$	565 ± 26
$B_s^0 \to \psi(2S)\phi$	$(15.2 \pm 0.6) \cdot 10^{-5}$	40 ± 8

TABLE II. Relative systematic uncertainties on the ratio of branching fractions $\mathcal{B}(B^\pm \to \psi(2S)K^\pm)/\mathcal{B}(B^\pm \to J/\psi K^\pm)$ and $\mathcal{B}(B_s^0 \to \psi(2S)\phi)/\mathcal{B}(B_s^0 \to J/\psi\phi)$.

Source	Relative uncertainty [%]	
	$(J/\psi,\ \psi(2S))K^\pm$	$(J/\psi,\ \psi(2S))\phi$
$\mathcal{B}(J/\psi \to \mu\mu)$	1.7	
$\mathcal{B}(\psi(2S) \to \mu\mu)$	11	
Total $\mathcal{B}$	11	
$\epsilon_{J/\psi(K^\pm,\phi)}/\epsilon_{\psi(2S)(K^\pm,\phi)}$	4.1	7.2
Event yield $\psi(2S)$ channel	3.0	7.5
Event yield J/ψ channel	0.9	2.1
CP odd-even mixture $(J/\psi\phi)$	N.A.	8.0
Total (systematic)	5.2	13.3

decays. We use a pure CP-even state for the generated $B_s^0 \to \psi(2S)\phi$ and $B_s^0 \to J/\psi\phi$ MC.

The relative uncertainties that enter into the calculation of the relative branching fractions are given in Table II. The uncertainty related to the measured charmonium resonance branching fractions enter both measurements and are the same for both. The uncertainties are treated as uncorrelated and give a combined uncertainty of 11% on each of the ratios of branching fractions.

The relative statistical uncertainties on the efficiencies $\epsilon_{\psi(2S)K}$ and $\epsilon_{J/\psi K}$ are 3.7% and 1.9%, respectively. They are combined into a single statistical uncertainty on the efficiency ratio assuming no correlations. To obtain and estimate the signal yield variation, the background shape and fit range for the background region are varied. This yields a variation of 3% for $B^\pm \to \psi(2S)K^\pm$ and 0.9% for $B^\pm \to J/\psi K^\pm$. The ratio of branching fractions $\mathcal{B}(B^\pm \to \psi(2S)K^\pm)/\mathcal{B}(B^\pm \to J/\psi K^\pm)$ is then $0.63 \pm 0.05(\text{stat}) \pm 0.03(\text{syst}) \pm 0.07(\mathcal{B})$.

The relative uncertainties on $\epsilon_{\psi(2S)\phi}$ and $\epsilon_{J/\psi\phi}$ are 4.5% and 5.6%, respectively. These uncertainties are combined into a single statistical uncertainty on the efficiency ratio assuming no correlations. As an estimate of the signal yield variation, the shape of the background as well as the invariant mass regions for the background estimations are changed. This gives a variation of 7.5% for the $B_s^0 \to \psi(2S)\phi$ and 2.1% for the $B_s^0 \to J/\psi\phi$ signal yield. The $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \psi(2S)\phi$ MC events are generated as pure CP-even decays with a B_s^0 lifetime of 1.44 ps [12]. To account for a possible efficiency difference related with the different lifetime of the B_s^0, the $B_s^0 \to J/\psi\phi$ MC events are weighted according to the combined world average lifetime [13]. The efficiency difference is estimated to be 8%, which is taken as an additional systematic uncertainty. The resulting ratio of branching fractions is $\mathcal{B}(B_s^0 \to \psi(2S)\phi)/\mathcal{B}(B_s^0 \to J/\psi\phi)) = 0.53 \pm 0.10(\text{stat}) \pm 0.07(\text{syst}) \pm 0.06(\mathcal{B})$.

In summary, we have presented the observation of the decay $B_s^0 \to \psi(2S)\phi$ with the decay $\psi(2S) \to \mu^+\mu^-$ at D0 and performed a measurement of the ratio of branching fractions

$$\frac{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = 0.53 \pm 0.10(\text{stat}) \pm 0.07(\text{syst}) \pm 0.06(\mathcal{B}). \quad (2)$$

In addition, a measurement of the ratio of branching fractions

$$\frac{\mathcal{B}(B^\pm \to \psi(2S)K^\pm)}{\mathcal{B}(B^\pm \to J/\psi K^\pm)} = 0.63 \pm 0.05(\text{stat}) \pm 0.03(\text{syst}) \pm 0.07(\mathcal{B}) \quad (3)$$

has been performed. These results are competitive and in good agreement with published measurements [6,14]. The combination with these measurements should result in a significant precision improvement on the measured ratios of branching fractions.

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[1] A. B. Carter and A. I. Sanda, Phys. Rev. D **23**, 1567 (1981); I. I. Bigi and A. I. Sanda, Nucl. Phys. **B193**, 85 (1981).
[2] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **100**, 161802 (2008).
[3] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **101**, 241801 (2008).
[4] M. Beneke, F. Maltoni, and I. Z. Rothstein, Phys. Rev. D **59**, 054003 (1999).
[5] C. Amsler *et al.*, Phys. Lett. B **667**, 1 (2008).
[6] A. Abulencia *et al.* (CDF Collaboration), Phys. Rev. Lett. **96**, 231801 (2006).
[7] V. M. Abazov *et al.* (D0 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **565**, 463 (2006).

[8] T. Sjöstrand *et al.*, Comput. Phys. Commun. **135**, 238 (2001).

[9] D. J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[10] R. Brun and F. Carminati, CERN Program Library Long Writeup W5013, 1993 (unpublished).

[11] All charged particles in the event are clustered into jets using the DURHAM clustering algorithm with the p_T cutoff parameter of 15 GeV/c. S. Catani *et al.*, Phys. Lett. B **269**, 432 (1991).

[12] V. M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **94**, 042001 (2005).

[13] Heavy Flavor Averaging Group (HFAG), arXiv:hep-ex/0505100.

[14] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **65**, 032001 (2002).