

### Exclusive and Inclusive Decays of $B$ Mesons into $D_s$ Mesons

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We have studied the production of  $D_s$  mesons in the decays of  $B$  mesons at the  $\Upsilon(4S)$  resonance. We report on the first observation of exclusive  $B$ -meson decays  $B \rightarrow D_s^- D^{*+}$ ,  $B \rightarrow D_s^- D^+$ , and  $B \rightarrow D_s^- D^0$ . We also present a new measurement of the branching ratio and the momentum spectrum for the inclusive decay  $B \rightarrow D_s X$ .

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Exclusive decay modes of  $B$  mesons provide a testing ground for the predictions of the theoretical models of heavy-flavor decays. A special class of  $B$ -meson decay modes is the exclusive double-charm decays which can arise from the decay chain  $b \rightarrow cW^- \rightarrow c(\bar{c}s)$ . Previous studies of the inclusive  $D_s$  production in  $B$  decays have provided indirect evidence for the presence of such decays through the observation of a peak in the momentum spectrum of  $D_s$  mesons.<sup>1</sup> In this Letter, we report on a direct observation of exclusive decays  $B \rightarrow D_s D$ , where  $D$  represents either  $D^0$ ,  $D^+$ , or  $D^{*+}$ . We also report on an improved measurement of the branching ratio and the momentum spectrum for the inclusive decay  $B \rightarrow D_s X$ . The decay  $\bar{B}^0 \rightarrow D_s^- \pi^+$  could result from the  $b \rightarrow u$  coupling and the decay  $\bar{B}^0 \rightarrow D_s^+ K^-$  from the  $W$ -exchange process. We will present upper limits for the branching ratios of these two modes. Throughout this paper charge-conjugate modes are implied.

The data used for this study were collected with the upgraded CLEO detector in the 10-GeV energy region at the Cornell Electron Storage Ring (CESR). The CLEO detector and our event-selection criteria have been described in detail elsewhere.<sup>2</sup> The main modification to the detector has been the installation of a new drift-chamber system with 64 layers of tracking. This improvement results in a momentum resolution given by  $(\delta p/p)^2 = (0.23\%p)^2 + (0.7\%)^2$ , with  $p$  expressed in GeV/c. An rms resolution of 6.5% in the measurement of the specific ionization is obtained.<sup>3</sup> The data consist of 212 pb<sup>-1</sup> at the  $\Upsilon(4S)$ , and 101 pb<sup>-1</sup> at an energy below the  $B\bar{B}$  threshold. The  $\Upsilon(4S)$  data contain 242000  $B\bar{B}$  events.

The decay mode  $D_s^- \rightarrow \phi \pi^-$  was used to measure the inclusive  $D_s^-$  yield from  $B$ -meson decays. The reconstruction procedure for this and other  $D_s$  decay modes in the CLEO detector are described in detail elsewhere.<sup>4</sup>

Briefly,  $\phi$ -meson candidates are identified in the mode  $\phi \rightarrow K^- K^+$  and are combined with the remaining charged tracks in the event to form  $\phi\pi$  combinations. We require the measurements of the specific ionization ( $dE/dx$ ) of charged tracks in the drift chamber to be within 3 standard deviations of the expected value for their mass assignment in the track combination. We also exploit the characteristic angular distribution of the decay  $D_s^- \rightarrow \phi\pi$  to suppress combinatorial backgrounds.<sup>1,4</sup> The  $\phi\pi$  invariant-mass distribution is shown in Fig. 1 for data taken at the  $\Upsilon(4S)$ . Also shown are data for the nonresonant  $e^-e^+$  annihilation scaled to account for the luminosity and the energy dependence of the cross section. A clear peak at the  $D_s^-$  mass is evident in the  $\Upsilon(4S)$  data. The mass and the width of the signal are consistent with those expected from the Monte Carlo simulation of the detector.

Subtracting the continuum component and fitting the resulting mass spectrum to a Gaussian representing the signal and a polynomial background shape we find a total of  $257 \pm 41$   $D_s$  mesons from  $B\bar{B}$  events in our data sample. By fitting the mass spectra corresponding to momentum bins we determine the momentum distribution of the  $D_s$  mesons. The  $D_s$  detection efficiency is determined by using a Monte Carlo procedure which includes the effects of geometrical acceptance, tracking, the kinematic requirements, and particle-identification efficiencies. The particle-identification efficiencies are determined using samples of  $\pi$ 's,  $K$ 's, and  $p$ 's from kinematically identified  $K_S$ ,  $\phi$ , and  $\Lambda$  decays. The efficiency corrected momentum distribution of  $D_s^-$  mesons from  $B$  decay is shown in Fig. 2. Integrating this distribution and dividing by the number of  $B$  mesons in the data sample, we determine  $B(B \rightarrow D_s X) B(D_s \rightarrow \phi\pi) = (3.06 \pm 0.47) \times 10^{-3}$ . This result is consistent with previous measurements.<sup>1</sup>

In order to determine the inclusive branching ratio

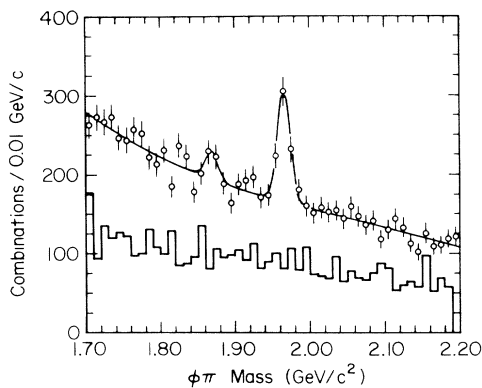


FIG. 1. The  $\phi\pi$  mass spectrum for  $0.0 < P_{\phi\pi} < 2.5$  GeV/c from  $\Upsilon(4S)$  (circles) data and nonresonant  $e^+e^-$  annihilation collisions (solid histogram). The smooth curve shows a polynomial background and fits to a  $D_s$  peak as well as a peak from the rare decay  $D^+ \rightarrow \phi\pi^+$ .

$B(B \rightarrow D_s X)$  we need the absolute branching ratio for the decay  $D_s^- \rightarrow \phi\pi^-$ . Since this has not yet been measured, throughout this paper we use the estimated  $B(D_s^- \rightarrow \phi\pi^-) = 2\%$ , which was obtained using arguments based on the measured charm-hadron cross sections in nonresonant  $e^+e^-$  annihilation in the 10-GeV energy region.<sup>4</sup> This gives  $B(B \rightarrow D_s X) = (15.3 \pm 2.3)\%$ .

In the  $B$ -meson rest frame, a two-body decay such as  $B \rightarrow D_s D$  yields a monochromatic momentum spectrum for the  $D_s$  meson. At the  $\Upsilon(4S)$ , however,  $B$  mesons are produced with a momentum of about 0.3 GeV/c, which results in a small Doppler broadening of the momentum spectra. The observed hard spectrum (Fig. 2) clearly indicates the presence of two-body modes. We fitted the spectrum to a linear combination of functions representing the two-body double-charm decay modes  $B^- \rightarrow D_s D$ ,  $B^- \rightarrow D_s D^*$ ,  $B^- \rightarrow D_s^* D$ , and  $B^- \rightarrow D_s^* D^*$  and a possible three-body process such as  $B \rightarrow D_s D\pi$ . The relative contribution of two-body modes ( $B \rightarrow D_s D$ )/( $B \rightarrow D_s X$ ) is determined to be  $(56 \pm 10)\%$ .<sup>5</sup>

While this inclusive analysis provides the combined rate for the two-body double-charm decays, the determination of the branching ratios for the various modes requires the reconstruction of each decay process. Here we have searched for the modes  $B^- \rightarrow D_s^- D^0$ ,  $\bar{B}^0 \rightarrow D_s^- D^{*+}$ , and  $\bar{B}^0 \rightarrow D_s^- D^+$ . Because of the poor resolution and low efficiency of photon identification in the CLEO-I detector, the reconstruction of modes involving  $D_s^{*-}$  mesons is not feasible. In order to enhance our reconstruction efficiency, we use most of the known decay modes of the charmed mesons which result in final states containing only charged particles. These are  $D_s \rightarrow \phi\pi^-$ ,  $K^{*0}K^-$ ,  $K^0K^-$ ,  $K^{*-}K^0$ , and  $K^{*-}K^{*0}$ ,

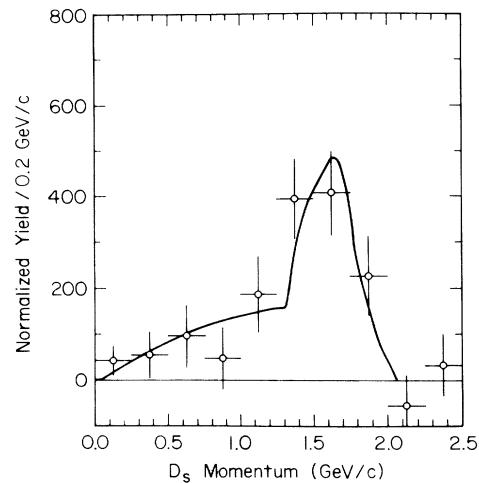


FIG. 2. The momentum distribution of  $D_s$  mesons from  $B$  decays. The curve is the fit by a linear combination of functions representing the two-body decays  $B \rightarrow D_s D$  and the three-body process  $B \rightarrow D_s D\pi$ .

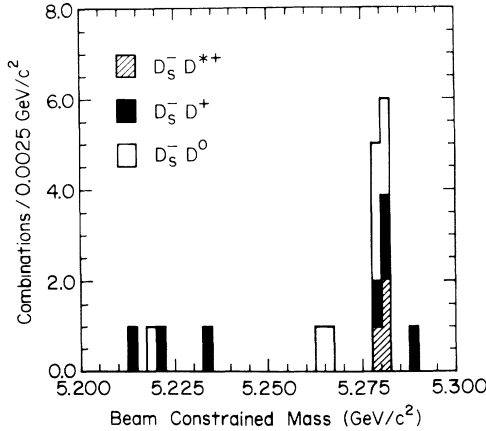


FIG. 3. The distribution of the beam-constrained mass for  $B \rightarrow D_s D$  candidates.

$D^0 \rightarrow K^- \pi^+$ ,  $K^- \pi^+ \pi^+ \pi^-$ , and  $K^0 \pi^+ \pi^+$ ;  $D^+ \rightarrow K^- \pi^+ \pi^+$ ,  $K^0 \pi^+$ , and  $K^0 \pi^+ \pi^- \pi^+$ ; and  $D^{*+} \rightarrow D^0 \pi^+$ . Invariant masses of the  $D$  candidates were required to be within 2 standard deviations ( $2 \times 20$  MeV) of the known masses of the mesons.  $B$  candidates were found by forming  $D_s D$  combinations having flavor and sign consistent with the decay chain  $b \rightarrow c(\bar{c}s)$ . Since  $B$  mesons are produced as pairs in the process  $e^+ e^- \rightarrow \Upsilon(4S) \rightarrow \bar{B}B$ , we require that the reconstructed energy of the  $B$  candidates be within 3 standard deviations of the beam energy. From Monte Carlo studies, we determine the rms resolution of the difference between the reconstructed energy of  $B$  candidates and the beam energy to be about 25 MeV. This requirement also suppresses the “feed-down” background from the decay modes with a missing  $\pi^0$  or  $\gamma$ , such as  $\bar{B}^0 \rightarrow D_s^{*-} D^{*+}$ , where  $D_s^{*-} \rightarrow D_s^- \gamma$  or  $D^{*+} \rightarrow D^+ \pi^0$ .

We compute the beam-constrained invariant mass  $M_B$  of the  $B$  candidates from  $M_B^2 = E_{\text{beam}}^2 - \mathbf{p}_B^2$ , where  $E_{\text{beam}}$  is the beam energy and  $\mathbf{p}_B$  is the vector sum of the momenta of tracks forming the  $B$  candidate. The resolution of the beam-constrained mass, which is dominated by the spread of the beam energy, is estimated from Monte Carlo studies to be about 2.6 MeV. The mass distribution of the  $B$  candidates is shown in Fig. 3. A cluster of

11 events is evident around the  $B$ -meson mass at 5.28 GeV. Assuming a flat background, we estimate 0.2 background event in the observed signal, by using the mass region  $5.200 < M_B < 5.265$  GeV. The reconstruction efficiency for each mode of  $B$  decay can be expressed as  $\epsilon_B = \sum_{ij} B_i B_j \epsilon_{ij}$ , where the sum is over all charmed-meson decay modes used in the search, and  $B_i$ ,  $B_j$ , and  $\epsilon_{ij}$  are the corresponding branching ratios and the reconstruction efficiencies, respectively.

In Table I, we summarize the exclusive measurements and the theoretical predictions<sup>6</sup> of the branching ratios for the two-body double-charm decays. In calculating the branching ratios, we have assumed an equal production ratio for  $B^0 \bar{B}^0$  and  $B^- B^+$  pairs at the  $\Upsilon(4S)$  resonance. The exclusive branching ratios make up about 40% of the inclusive branching ratio, consistent with the results of the fit to the  $D_s$  momentum spectrum. The sum of exclusive modes appears to be larger than the summed theoretical predictions. However, it should be noted that this apparent discrepancy vanishes if one uses  $B(D_s^- \rightarrow \phi \pi^-) = 4\%$ , which is consistent with the current experimental bound on the  $D_s$  branching ratios.<sup>4</sup>

Using a similar technique we have also searched for the decays  $\bar{B}^0 \rightarrow D_s^- \pi^+$  and  $\bar{B}^0 \rightarrow D_s^- K^+$ . Since much of the background to these processes is from continuum jetlike events, we require  $|\cos \theta_s| < 0.8$ , where  $\theta_s$  is the angle between the direction of the  $D_s^-$  meson and the sphericity axis of all tracks in the event excluding those in the  $B$  candidate. We find no evidence for these decays and set upper limits on the branching ratios  $\bar{B}^0 \rightarrow D_s^- \pi^+ < 0.13\%$  and  $\bar{B}^0 \rightarrow D_s^- K^+ < 0.13\%$  at 90% confidence level.

The detection efficiency for double-charm decays is handicapped by the small branching ratios of the  $D_s$  and  $D$  mesons into easily detectable modes. For the processes  $\bar{B}^0 \rightarrow D_s^- D^{*+}$  and  $\bar{B}^0 \rightarrow D_s^{*-} D^{*+}$ , where  $D^{*+} \rightarrow D^0 \pi^+$ , a method which exploits the kinematics characteristics of the decays can be used to avoid explicit reconstruction of the  $D^0$  meson. This technique has been described in detail in an earlier publication<sup>7</sup> of the measurement of the branching ratio for the decay  $B \rightarrow D^{*+} \pi^-$ . Briefly, it involves identification of events where a  $\phi \pi^-$  combination and a soft pion from the decay  $D^{*+} \rightarrow D^0 \pi^+$  are present. Using the measured momen-

TABLE I. Branching ratios for two-body  $B \rightarrow D_s$  decays. Here we have used  $B(D_s^- \rightarrow \phi \pi^-) = 2\%$ .

Decay mode	Efficiency (%)	Events	Branching ratio (%)	Theoretical prediction (%)
$\bar{B}^0 \rightarrow D^{*+} D_s^-$	0.05	3	$2.4 \pm 1.4$	0.40–0.67
$\bar{B}^0 \rightarrow D^+ D_s^-$	0.10	3	$1.2 \pm 0.7$	0.90
$B^- \rightarrow D^0 D_s^-$	0.07	5	$2.9 \pm 1.3$	0.8–1.0
$\bar{B}^0 \rightarrow \pi^+ D_s^-$	0.90	< 3	< 0.13 at 90% C.L.	$0.35  V_{ub}/V_{cb} ^2$
$\bar{B}^0 \rightarrow K^- D_s^+$	0.90	< 3	< 0.13 at 90% C.L.	...

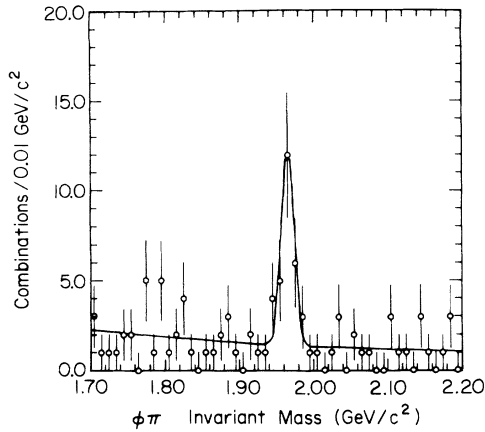


FIG. 4. The  $\phi\pi$  invariant-mass distribution for the mass cut  $5.275 \text{ GeV} < M'_B < E_{\text{beam}}$ .

ta of the  $\phi\pi^-$  combination and of the soft  $\pi^+$  we calculate an approximate beam-constrained mass  $M'_B$  for the  $\bar{B}^0$  candidates from

$$(M'_B)^2 = E_{\text{beam}}^2 - (\mathbf{p}_{\phi\pi} + \mathbf{p}_{D^0} + \mathbf{p}_{\pi})^2.$$

Here, the magnitude of the  $D^0$  momentum is obtained from the energy-conservation relation  $E_{\text{beam}} = E_{D^0} + E_{\pi} + E_{\phi\pi}$ . The  $D^0$  direction is estimated using the constraint  $m_{D^{*+}}^2 = (E_{\text{beam}} - E_{\phi\pi})^2 - (\mathbf{p}_{D^0} + \mathbf{p}_{\pi})^2$  and by maximizing the value of  $M'_B$ . Monte Carlo studies have shown that the distribution of  $M'_B$  for the two-body decays  $\bar{B}^0 \rightarrow D_s^- D^{*+}$  and  $\bar{B}^0 \rightarrow D_s^{*-} D^{*+}$  peaks near the beam energy 5.29 GeV, while the distributions for the decays such as  $B \rightarrow D^{*+} D_s$  and  $B \rightarrow D^* D_s \pi$  are flat in the range  $5.21 < M'_B < 5.29$  GeV. Requiring  $M'_B > 5.275$  GeV results in a detection efficiency of 6% for two-body modes and an efficiency of less than 0.3% for multibody modes.<sup>8</sup> In Fig. 4, we display the distribution of the invariant mass of the  $\phi\pi$  combinations for the  $B$  candidates satisfying the above mass criterion. A clear peak at the  $D_s$  mass is evident. Fitting this spectrum we find  $22 \pm 5$  events at the  $D_s^-$  mass. In order to estimate the background to this signal we have examined the distributions for (a) wrong-sign combinations  $D_s^- \pi^-$ , (b) right-sign combinations from continuum data, (c) the mass region  $5.19 < M'_B < 5.21$  GeV, and (d) right-sign combinations for which the direction of the soft pion has been inverted. None of these distributions show any enhancement at the  $D_s^-$  mass.

Attributing the observed  $D_s^-$  signal in Fig. 4 to the sum of the decays  $\bar{B}^0 \rightarrow D_s^- D^{*+}$  and  $\bar{B}^0 \rightarrow D_s^{*-} D^{*+}$ , and correcting for the reconstruction efficiency and the

branching ratio  $B(D_s^- \rightarrow \phi\pi^-) = 2\%$ , we calculate the branching ratio

$$B(\bar{B}^0 \rightarrow D_s^- D^{*+} + \bar{B}^0 \rightarrow D_s^{*-} D^{*+}) = (7.5 \pm 2)\%.$$

This result is consistent with the results of the inclusive measurements and the exclusive reconstruction technique.

In conclusion, we have measured the branching ratio and the momentum spectrum for the inclusive decay  $B \rightarrow D_s X$ . We have searched for exclusive decays  $B \rightarrow D_s D$  and find eleven such decays in our data sample. The measured branching ratios of the exclusive modes are consistent with those inferred from the  $D_s$  momentum spectrum. We have also set upper limits on the branching ratios of the decays  $\bar{B}^0 \rightarrow D_s^+ K^-$  and  $\bar{B}^0 \rightarrow D_s^- \pi^+$ .

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<sup>1</sup>P. Haas *et al.*, Phys. Rev. Lett. **56**, 2781 (1986); H. Albrecht *et al.*, Phys. Lett. B **187**, 425 (1987).

<sup>2</sup>D. Andrews *et al.*, Nucl. Instrum. Methods Phys. Res. **211**, 47 (1983); S. Behrens *et al.*, Phys. Rev. D **31**, 2161 (1985).

<sup>3</sup>D. G. Cassel *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **252**, 325 (1986).

<sup>4</sup>W. Y. Chen *et al.*, Phys. Lett. B **226**, 192 (1989).

<sup>5</sup>If we estimate the two-body component by allowing a contribution from the process  $B \rightarrow D_s^+ K W^-$ , where  $W^-$  is the virtual  $W$  decaying into pairs of leptons and quarks and the  $D_s^+$  meson is produced from the fragmentation of the valence primary charm quark from  $b \rightarrow c$  coupling, the two-body component is reduced to 45%.

<sup>6</sup>F. Hussain and M. D. Scadron, Phys. Rev. D **30**, 1492 (1984); J. G. Korner *et al.*, University of Mainz Report No. Mz-TH/86-11 (unpublished); B. Stech, Heidelberg University Report No. HD-THEP-87-18 (unpublished).

<sup>7</sup>R. Giles *et al.*, Phys. Rev. D **30**, 2279 (1984).

<sup>8</sup>Here we have assumed  $\bar{B}^0 \rightarrow D_s^- D^{*+} : \bar{B}^0 \rightarrow D_s^{*-} D^{*+} = 1:3$ . Assuming an equal production rate for these processes leads to a detection efficiency of 7%.