# Inclusive $B$-meson decays into charm

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We have measured the $B$-meson decay fractions into $D^0$, $D^+$, and $D^{*+}$ mesons to be $0.39\pm0.05\pm0.04$, $0.17\pm0.04\pm0.04$, and $0.22\pm0.04^{+0.07}_{-0.04}$, respectively, if we use the $D^0\to K^-\pi^+$ and $D^+\to K^-\pi^+\pi^+$ branching ratios determined by the Mark III Collaboration. These results suggest that $B$ decay to noncharm final states is substantial. We also find that $B$ decay to spin-1 $D^*$ mesons dominates over direct decay to spin-0 $D$ mesons and that the ratio $(D^0+D^{*0})/(D^++D^{*+})$ is consistent with unity.

## I. INTRODUCTION

An important question in the standard model of electroweak interactions concerns the rate of $b$-quark decay into the $u$ quark versus the $c$ quark.[1] This question has been investigated by using the spectrum of leptons from semileptonic $B$ decays.[2] Recent analyses have given limits on $(b\to u)/(b\to c)$ of less than 10% at 90% confidence level,[3] but extraction of this limit is not unique because of theoretical uncertainties in the nature of the final hadronic system in such decays. Nevertheless, all models presently available yield comparably low limits.[4] Alternatively, the $b\to c$ fraction may be directly determined by measuring the $B$-meson decay rate into charmed particles.

We report here on new inclusive measurements[5,6] of $B$ decay into $D^0$, $D^+$, and $D^{*+}$ mesons. Here, and throughout this paper, charge-conjugate modes are implied. The data were acquired with the CLEO detector at the Cornell Electron Storage Ring (CESR). The CLEO detector[7] and recent improvements[8] have been described elsewhere. The results reported in this paper rely on charged-particle momentum measurements in the central tracking chambers and particle identification from time-of-flight measurements and from energy-loss ($dE/dx$) measurements.

The data sample used in our analysis comes from two distinct running periods. Between the two periods our charged-particle-tracking and particle-identification capabilities were improved.[8] The first data sample (I) consists of an accumulated luminosity of 40 $\mathrm{pb}^{-1}$ at the $\Upsilon(4S)$ resonance and 17 $\mathrm{pb}^{-1}$ of continuum $e^+e^-$ data at an energy just below $B\bar{B}$ threshold. The second data sample (II), with the improved detector, contains 78 $\mathrm{pb}^{-1}$ at the $\Upsilon(4S)$ and 36 $\mathrm{pb}^{-1}$ of continuum data. Since the $\Upsilon(4S)$ decays exclusively into $B\bar{B}$ pairs,[9] the total data sample contains approximately 260 000 $B$ mesons.

All events under consideration pass our hadronic event-selection criteria.[10] For the $D^0$ and $D^+$ channels the background from continuum events under the $\Upsilon(4S)$ peak is large. To reduce this background we require that the Fox-Wolfram event-shape parameter[11] $R_2$ be less than 0.3. This requirement selects "spherical" events as opposed to "jetlike" events. We lose about 25% of the $B\bar{B}$ events while rejecting about 60% of the continuum events. We use the particle-identification capabilities of the detector to further reduce the background by requiring that $K^{\pm}$ track candidates with momenta below 900 MeV/$c$ have observed flight times and $dE/dx$ consistent with the kaon hypothesis.

## II. CHARM-MESON DETECTION

### A. $D^0$ search

We search for the $D^0$ by observing its decay into $K^-\pi^+$. In order to reduce the combinatorial background we impose an additional criterion. The $D^0$ momentum vector in the laboratory frame defines a direction in the $D^0$ rest frame. We define $\theta^*$ as the angle between this direction and the kaon in the $D^0$ rest frame. Since the $D^0$ is a spin-0 particle, the distribution of $\cos\theta^*$ is uniform, but background processes are observed to peak near $\cos\theta^* = \pm 1$. Therefore, we restrict the range of $\cos\theta^*$ for $D^0$ candidates.[12]

The $K^-\pi^+$ invariant-mass distributions are shown in Fig. 1(a) for $\Upsilon(4S)$ data and for continuum data scaled up by the ratio of integrated luminosities and corrected for the energy dependence of the total cross section. Only data from sample II are shown in this plot. (The data from sample I are given in Ref. 5.) We require the $D^0$ candidate momenta to be less than 2.5 GeV/$c$, the upper limit for $B$-meson decay at the $\Upsilon(4S)$. A clear peak is observed in the data from the $\Upsilon(4S)$, indicative of the signal from $B$ decay. Partitioning our data into momentum bins, we extract the number of $D^0$ candidates by fitting the invariant-mass distributions to a polynomial background plus a function representing the $D^0$ signal. The $D^0$ signal function is obtained from a Monte Carlo simulation of the decay $D^0 \to K^-\pi^+$ in the detector.[13]

The numbers of $D^0$ events from the fit in each momentum interval, from both the $\Upsilon(4S)$ and continuum, are

TABLE I. Numbers of $D^0$, $D^+$, and $D^{*+}$ events.

Number of $D^0$ events

| $P$ (GeV/$c$) | Efficiency (%) (I) | Efficiency (%) (II) | on $\Upsilon(4S)$ (I) | on $\Upsilon(4S)$ (II) | Continuum (I) | Continuum (II) | Continuum fitted[a] | $10^3 B(B\to D^0X)B(D^0\to K\pi)$ |
|---|---|---|---|---|---|---|---|---|
| 0.0–0.5 | 53±2 | 58±2 | 198±59 | 291±59 | 126±64 | 76±62 | 43±8 | 1.58±0.03 |
| 0.5–1.0 | 47±1 | 59±1 | 335±146 | 1034±144 | 0±151 | 134±145 | 148±12 | 4.80±0.72 |
| 1.0–1.5 | 45±1 | 52±1 | 820±168 | 1416±156 | 0±169 | 35±146 | 273±23 | 7.10±0.79 |
| 1.5–2.0 | 46±1 | 43±1 | 933±142 | 1096±130 | 244±136 | 160±118 | 420±48 | 5.30±0.68 |
| 2.0–2.5 | 41±1 | 42±1 | 426±100 | 711±93 | 263±111 | 341±96 | 554±61 | 2.05±0.52 |
| 2.5–3.0 | | 42±1 | | | | 423±53[b] | 638±70 | |

Number of $D^+$ events[c]

| $P$ (GeV/$c$) | Efficiency (%) | on $\Upsilon(4S)$ | Continuum | Continuum fitted | $10^3 B(B\to D^+X)B(D^+\to K\pi\pi)$ |
|---|---|---|---|---|---|
| 0.0–0.5 | 39±3 | 430±187 | −153±164 | 7±2 | 2.4±1.0 |
| 0.5–1.0 | 39±1 | 1151±359 | 263±318 | 25±5 | 6.3±2.0 |
| 1.0–1.5 | 38±1 | 955±347 | −270±315 | 50±11 | 5.0±1.9 |
| 1.5–2.0 | 39±1 | 918±246 | 230±241 | 81±15 | 4.7±1.4 |
| 2.0–2.5 | 37±2 | 443±162 | 352±179 | 118±20 | 1.8±0.9 |
| 2.5–3.0 | 37±2 | | 147±28[b] | 151±27 | |

Number of $D^{*+}$ events

| $P$ (GeV/$c$) | Efficiency (%) (I) | Efficiency (%) (II) | on $\Upsilon(4S)$ (I) | on $\Upsilon(4S)$ (II) | Continuum (I) | Continuum (II) | $10^3 B(B\to D^{*+}X)B(D^{*+}\to D^0\pi)B(D^0\to K\pi)$ |
|---|---|---|---|---|---|---|---|
| 1.0–1.5 | 7.5±0.6 | 9.8±0.6 | 340±113 | 573±160 | 87±101 | 86±63 | 2.7±0.6 |
| 1.5–2.0 | 17.1±0.7 | 20.0±0.7 | 271±60 | 436±56 | 33±52 | 93±47 | 1.8±0.4 |
| 2.0–2.5 | 23.3±0.9 | 27.8±1.1 | 205±40 | 322±40 | 146±48 | 187±47 | 0.7±0.3 |

[a]The fitted continuum uses only sample II. The results have been scaled by a factor of 1.47 to account for the luminosity in sample I.
[b]Both continuum and on $\Upsilon(4S)$ data are used. (I) and (II) refer to the different data samples described in the text.
[c]Only data sample II is used.

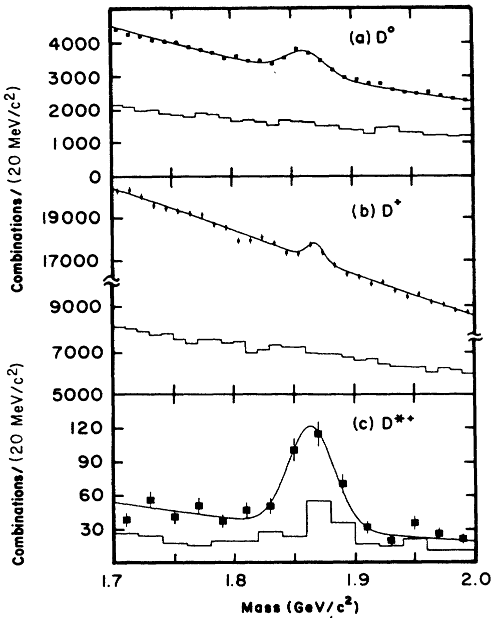


FIG. 1. Invariant-mass plots for $D$-candidate momenta below 2.5 GeV/$c$. $\Upsilon(4S)$ data are shown by solid points, while the scaled continuum data are shown by histograms. The solid lines are fits to the data with a Monte Carlo–based signal shape plus background polynomial. (a) $K^-\pi^+$ mass spectrum, $R_2<0.3$; (b) $K^-\pi^+\pi^+$ mass spectrum, $R_2<0.3$; (c) $K^-\pi^+$ mass spectrum cut on $K\pi\pi$-$K\pi$ mass difference, no $R_2$ cut. (See text for definition of $R_2$ cut.)

given in Table I. In order to reduce the sensitivity from statistical fluctuations in the continuum $D^0$ signal, we fit the continuum momentum spectrum to a smooth function.[14] The $D^0$ detection efficiencies, estimated by Monte Carlo simulation, are also given in Table I. They include the effects of hadronic event-selection, particle-identification, kinematics, tracking, solid-angle, and event-shape criteria. Subtracting the continuum component yields the $D^0$ momentum spectrum shown in Fig. 3. The integral of this spectrum gives the product branching fraction[15,16]

$$B(B\to D^0X)B(D^0\to K^-\pi^+)=0.0210\pm0.0015\pm0.0021.$$

The continuum and $B$-meson contributions to $D^0$ production can best be shown by removing the $R_2$ cut. In Fig. 2 we present the distribution $d\sigma/dx$ without the $R_2$ cut, where $x$ is the ratio of the $D$ momentum to the maximum possible $D$ momentum from continuum production.[17] The contribution from $B$ decays is evident at low $x$.

### B. $D^+$ search

We search for $D^+$ by detecting its decay into $K^-\pi^+\pi^+$. The $K\pi\pi$ invariant-mass distribution, for combinations with momentum less than 2.5 GeV/$c$, is shown in Fig. 1(b). In this analysis only data sample (II) was used since the improved particle identification was required to reduce the substantial combinatorial background. The results are given in Table I. The $D^+$ detection efficiencies are determined using a Monte Carlo procedure. Subtracting the continuum contribution yields the $D^+$ momentum spectrum from $B$ decay shown in Fig. 3. We find a product branching ratio[15]

$$B(B\to D^+X)B(D^+\to K^-\pi^+\pi^+)=0.019\pm0.004\pm0.002\ .$$

As in the $D^0$ case, the non-$R_2$-cut $d\sigma/dx$ distribution, presented in Fig. 4, shows a clear excess from $B$ decay at low $x$.

### C. $D^{*+}$ search

We search for $D^{*+}$ through its decay into $D^0\pi^+$ with the $D^0$ subsequently decaying into $K^-\pi^+$. We require the $K\pi\pi$-$K\pi$ mass difference to be within $\pm1.5$ MeV of

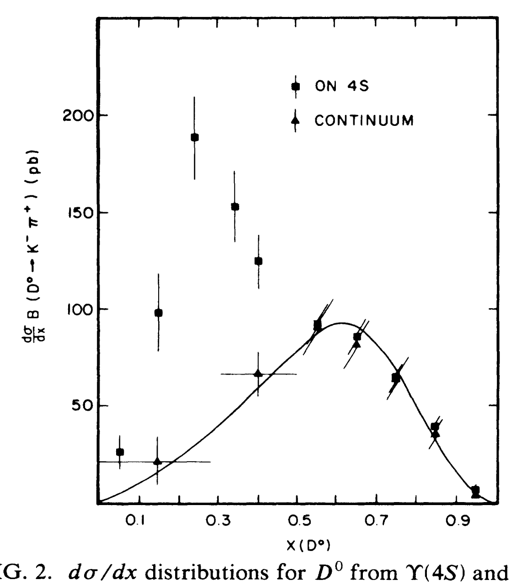


FIG. 2. $d\sigma/dx$ distributions for $D^0$ from $\Upsilon(4S)$ and continuum data. The curve is a Peterson function with $\epsilon=0.24$, normalized to the continuum data. The $R_2$ cut was not used.

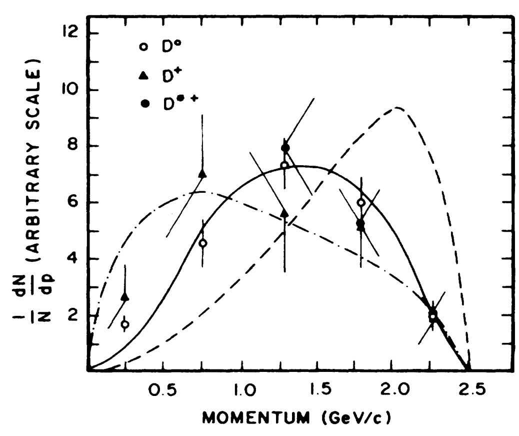


FIG. 3. $D^0$ (○), $D^+$ (▲), and $D^{*+}$ (●) momentum spectrum from $B$ decay. The dashed curve is the expectation from semileptonic $B$ decay and the other curves show predictions of different $B$ decay models (see text). The data sets and the models have been normalized to each other.

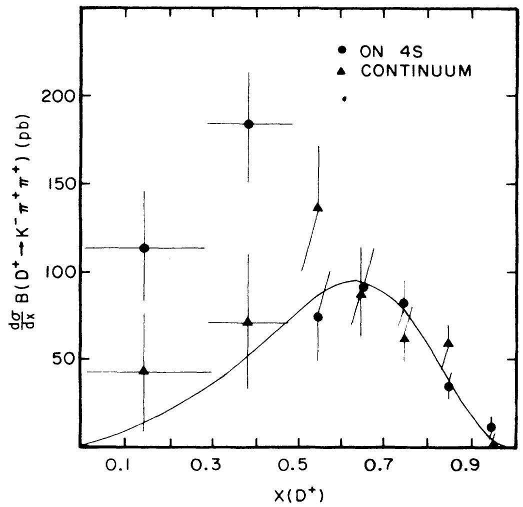


FIG. 4. $d\sigma/dx$ distributions for $D^+$ from $\Upsilon(4S)$ and continuum data. The curve is a Peterson function with $\epsilon=0.19$, normalized to the continuum data. The $R_2$ cut was not used.

the known $D^{*+}$-$D^0$ mass difference of 145.4 MeV. The resulting $K^-\pi^+$ invariant-mass distribution is shown in Fig. 1(c). (Only the data from sample II are shown; the data from sample I are given in Ref. 6.) We also require $\cos\theta^* > -0.8$ to reduce background, and only look for $D^{*+}$ candidates with momenta above 1 GeV/$c$, since the $D^{*+}$ detection efficiency is negligible below this value. The $R_2$ cut was not used because of the cleanliness of the $D^{*+}$ signal. The corrected numbers of $D^{*+}$ events from the $\Upsilon(4S)$ and scaled continuum are given as a function of momentum in Table I. The efficiency-corrected $D^{*+}$ momentum distribution is shown in Fig. 3. We obtain a product branching fraction[15]

$$B(B\to D^{*+}X)B(D^{*+}\to\pi^+D^0)B(D^0\to K^-\pi^+) = 0.0073\pm0.0012\pm0.0007\ ,$$

where the shape of the $D^0$ momentum spectrum is used to estimate the number of low-momentum $D^{*+}$ events.

## III. $D$ MOMENTUM SPECTRUM

The $D^0$, $D^+$, and $D^{*+}$ momentum spectra give information on the decay processes of the $B$ meson. We compare the data to three possible models. The first is a pure $V-A$ semileptonic decay of the $B$ meson, in which $b\to cW^-$ is followed by the decay of the virtual $W^-$ into $l^-\bar{\nu}$. The resulting momentum spectrum, which is peaked toward the maximum allowed momentum, is shown as the dashed curve in Fig. 3.

The second model of $B$-meson decay has $b\to cW^-$, with the virtual $W^-$ decaying into the appropriate mixture of quark-antiquark pairs and lepton-antineutrino pairs. When the $W^-$ decays into a quark-antiquark pair, the two quarks combine randomly with the $c$ and spectator quarks to form final-state hadrons which are distributed according to phase space. The resulting $D$ momentum spectrum is shown as the dot-dashed curve in Fig. 3.

The third model of $B$-meson decay also has $b\to cW^-$. In this case, when the $W^-$ produces a quark-antiquark pair, the two quarks hadronize independently of the $c$ and spectator quarks. The $c$ and spectator quarks form either a $D$ or a $D^*$ meson. The resulting $D$ momentum spectrum is shown as the solid curve in Fig. 3. It gives the best fit to the data of the three models we have considered.

## IV. THE $B$-TO-CHARM FRACTION

### A. Numerical evaluation

Recently, the Mark III group has measured a new set of branching ratios for $D$-meson decay.[18] Specifically, they find $B(D^0\to K^-\pi^+)=(5.6\pm0.4\pm0.3)\%$ and $B(D^+\to K^-\pi^+\pi^+)=(11.6\pm1.4\pm0.7)\%$. These values differ markedly from previous measurements which had, for example, $B(D^0\to K^-\pi^+)=(3.0\pm0.6)\%$ (Ref. 19). Using the Mark III branching ratios, we find

$$B(B\to D^0X)=0.39\pm0.05\pm0.04\ ,$$

$$B(B\to D^+X)=0.17\pm0.04\pm0.04\ ,$$

$$B(B\to D^{*+}X)B(D^{*+}\to D^0\pi^+)=0.13\pm0.02\pm0.012\ .$$

The first error is the combined statistical and systematic error in our measurements and the second is the combined statistical and systematic uncertainty in the $D$ branching fractions. These measured $B$-to-$D$ branching fractions are summarized in Table II. In addition, using $B(D^{*+}\to D^0\pi^+)=0.60^{+0.08}_{-0.15}$ (Ref. 20), we obtain

$$B(B\to D^{*+}X)=0.22\pm0.044^{+0.07}_{-0.04}\ .$$

We have checked our measurements of $B(B\to D^0X)$ by observing the decay $D^0\to\bar{K}^0\pi^+\pi^-$. Using $B(D^0\to\bar{K}^0\pi^+\pi^-)=(8.7\pm1.2)\%$ from Mark III, we find $B(B\to D^0X)=0.45\pm0.14\pm0.10$, which is in good agreement with our more precise measurement using the $K^-\pi^+$ mode.

Since all $D^*$'s decay to $D^0$ or $D^+$, the summed rate

$$B(B\to D^0X)+B(B\to D^+X)=0.56\pm0.06\pm0.06$$

represents the total decay fraction of $B$ to $D$ mesons. Other charmed particles available for $B$ decays are $F$ mesons and charmed baryons.[21,22] The $B$ decay rate to charmed baryons is bounded by previous measurements on inclusive $\Lambda^0$ and proton production in $B$ decay to be

TABLE II. Charmed-particle fractions from $B$ decay.

| Particle | Fraction |
|---|---|
| $D^0$ | $0.39\pm0.05\pm0.04$ |
| $D^+$ | $0.17\pm0.04\pm0.04$ |
| $F^-$ | $\sim0.15$ |
| Charmed baryons | $<0.1$ |
| Sum | $\lesssim0.81$ |
| Expected | 1.15 |

less than 0.1 charmed baryon per $B$ decay.[23] We have recently published the first observation of $F$ production in $B$ decay.[24] This result indicates that $F$ production in $B$ decay can be entirely attributed to the process $b \to cW^-$, $W^- \to \bar{c}s$, which is estimated to be 15% of the $B$ decays.[25] The estimated $B$-to-charm fractions are summarized in Table II.

### B. Implications of result

The spectator model of $B$-meson decay predicts a total yield of 1.15 charmed particles per $B$ decay if $b \to u$ is negligible.[25] The additional 0.15 charm per $B$ results from the phase-space-suppressed process $b \to cW^-$, $W^- \to \bar{c}s$. The sum of the measured and estimated charmed fractions (Table II), however, falls short of this value.

In the spectator model of $B$ decay these results would indicate a substantial branching fraction of the $b$ quark to the $u$ quark ($\sim 35\%$), in contradiction to limits obtained from semileptonic $B$ decay. Although the $b \to u$ limits depend on a model of the semileptonic decays of the $B$ meson, no model investigated thus far would allow the $b \to u$ fraction indicted by the results given in Table II (Ref. 3). However, contributions from nonspectator effects might be present. Final-state-interaction or annihilation diagrams could change the relative amount of $b \to u$ in hadronic decays relative to semileptonic decays. Another possibility is large contributions from "penguin" diagrams giving charmless final states. Although penguin effects are expected to be small, they cannot presently be excluded by experiment.[26] It is also possible that $b \to u$ transitions include a substantial rate into hadronic final states not predicted by current models of $B$ semileptonic decay, thus invalidating the upper limits based on the lepton momentum spectrum.[27] Another possibility is that the $\Upsilon(4S)$ does not decay entirely into $B\bar{B}$ (Ref. 28); although we have no evidence for this,[9] we cannot exclude a small contribution from such decays which would raise the apparent $B$-to-charm fraction. Finally, it is possible that the $D$ branching ratios measured by the Mark III group are too large. We note that using the previous values for the $D$ branching fractions[19] yields larger $D^0$ and $D^+$ fractions in $B$ decay.

### C. $D^0$ rate in semileptonic $B$ decay

The situation can be clarified by studying the $D$ yield in semileptonic $B$ decays. We search for $D^0$ via the $K^-\pi^+$ decay as the above analysis. We also require that an identified lepton of momentum greater than 1.4 GeV/$c$ be present in the event,[29] and that the charge of the lepton and the candidate kaon be the same. The latter requirement discriminates between $D^0$, from the same $B$ decay, and $\bar{D}^0$ from the other $B$ decay. If $B^0 \to \bar{B}^0$ mixing is present this technique will overestimate the $D^0$ number.[30] We find $0.35 \pm 0.09$ $D^0$ per semileptonic $B$ decay,[31] a number which is almost the same as in the average $B$ decay.

Unfortunately, we cannot measure a rate for $D^+$ in semileptonic $B$ decay because of large background and limited statistics, but we do see a signal for $D^{*+}$. We find $0.2 \pm 0.1$ $D^{*+}$ per semileptonic $B$ decay. The presence of $D^*$'s in semileptonic $B$ decays suggests that the $D^+$ rate is lower than the $D^0$ rate. (See the Appendix.) Thus, the $D$ rate in semileptonic $B$ decay, as in normal $B$ decay, is low. In the absence of $b \to u$, we expect to have one $D$ per semileptonic $B$ decay.[32] Penguin diagrams or other nonspectator effects do not contribute to semileptonic decay and therefore cannot explain the low $D$ rate in semileptonic decay.

## V. CONTINUUM CHARM PRODUCTION

In order to check the consistency of these results, we have also measured the continuum production of $D^0$ and $D^+$. The total hadronic continuum cross section at 10.6-GeV center-of-mass energy is $3.33 \pm 0.05 \pm 0.21$ nb (Ref. 33), before applying radiative corrections. Assuming that charm accounts for $\frac{4}{10}$ of the total cross section gives a charm contribution of $2 \times 0.4 \times 3.33 = 2.67$ nb. (The factor of two includes both the charm and anticharm quarks.) The measured $D^0$ and $D^+$ momentum distributions from continuum annihilation, shown in Figs. 2 and 4, have been fit to a Peterson fragmentation function.[34] Using these fits we obtain

$$\sigma(D^0)B(D^0 \to K^-\pi^+) = 0.046 \pm 0.002 \pm 0.004 \text{ nb} ,$$

$$\sigma(D^+)B(D^+ \to K^-\pi^+\pi^+) = 0.047 \pm 0.006 \pm 0.004 \text{ nb} .$$

Using the Mark III branching ratios, we find

$$\sigma(D^0) = 0.82 \pm 0.08 \pm 0.07 \text{ nb} ,$$

$$\sigma(D^+) = 0.40 \pm 0.05 \pm 0.05 \text{ nb} ,$$

where the first error is our statistical and systematic error added in quadrature and the second error is due to the quoted uncertainties in the $D$ branching fractions. Thus, $D^0 + D^+$ production accounts for $(46 \pm 6 \pm 4)\%$ of the total charm cross section. We note that the High Resolution Spectrometer (HRS) group[35] finds similar results at $\sqrt{s} = 29$ GeV (Ref. 36).

In order to account for the remainder of the total charm cross section, $F$-meson and/or charmed-baryon production must be large. Since the branching ratios of $F$ mesons and charmed baryons have not yet been accurately measured, there is insufficient information to exclude this possibility. We note, however, that an $F$ production cross section of 150 pb derived from our measurement of $F$ continuum production cross section,[24] assuming $B(F^+ \to \phi\pi^+) = 0.04$, and a charmed baryon production rate of 0.2 per charm quark,[37] are not sufficient to account for the non-$D$ part of the charm cross section. Use of the $D$ branching ratios of Schindler *et al.*[19] would increase the $D$ fraction to $(86 \pm 11)\%$.

## VI. OTHER RESULTS

Finally, the measurements of the yields of $D^0$, $D^+$, and $D^{*+}$ in $B$ decay may be combined to find (1) the ratio of neutral to charged $D$ production in $B$ decay, $(D^0 + D^{*0})/(D^+ + D^{*+})$ (denoted by $\gamma$), and (2) the ratio of direct decays of the $B$ to spin-0 $D$ mesons ($D_{\text{direct}}$) to that into spin-1 $D^*$ mesons. To find $\gamma$, we make the assumption that

$$\frac{D^{+}_{\rm direct}/B}{D^{*+}/B}=\frac{D^{0}_{\rm direct}/B}{D^{*0}/B} ,$$

and with some algebra (see the Appendix) find

$$\gamma=0.85\pm0.19\pm0.08 .$$

Two mechanisms may produce unequal numbers of neutral and charged $D$ mesons (i.e., $\gamma\neq1$). First, the $\Upsilon(4S)$ may decay to unequal numbers of neutral and charged $B$ mesons. If $B$'s decay according to a simple spectator model, in which the $c\bar{q}$ system always forms just a $D$ or $D^*$ meson, then neutral (charged) $B$'s will make charged (neutral) $D$ mesons. Second, even if equal numbers of neutral and charged $B$'s are produced, nonspectator effects (such as $W$ exchange, which can contribute only in neutral $B$ decay) may produce different numbers of neutral and charged $D$'s. Both mechanisms tend to increase the net neutral $D$ production relative to charged $D$ production, giving $\gamma\geq1$.

Using our measured value for $\gamma$, we find (see the Appendix)

$$D_{\rm direct}/(D_{\rm direct}+D^*)=0.28\pm0.14^{+0.18}_{-0.11} .$$

It should be noted that if the value of $\gamma$ is increased, $D_{\rm direct}/(D_{\rm direct}+D^*)$ becomes smaller. Current theoretical models predict[38] more $D^*$ than $D_{\rm direct}$.

## VII. CONCLUSIONS

In conclusion, we have measured the branching fractions and momentum spectra for $B$ to $D^0$, $D^+$, and $D^{*+}$. The momentum spectra are consistent with a simple spectator model of $B$ decay. The production of $D^*$ mesons is more copious than the direct production of $D^0$ and $D^+$ in $B$ decay. Using the most recent values for $D$ branching fractions obtained by the Mark III Collaboration yields a $B$-to-charm rate which is inconsistent with a small $b\rightarrow u$ coupling. This conclusion is in contradiction with analyses of the lepton momentum spectrum in semileptonic $B$ decay. The use of the Mark III branching fractions would also indicate that only about one-half of the charm production in continuum $e^+e^-$ annihilation results in $D^0$ or $D^+$ mesons.

## ACKNOWLEDGMENTS

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## APPENDIX: EQUATIONS RELATING $D^0$, $D^+$, AND $D^{*+}$ YIELDS

We make the following definitions:

$$\alpha\equiv B(D^{*+}\rightarrow D^0\pi^+) , \tag{A1}$$

$$\gamma\equiv\frac{D^{0}_{\rm direct}/B+D^{*0}/B}{D^{+}_{\rm direct}/B+D^{*+}/B} . \tag{A2}$$

[Note that $B(D^{*0}\rightarrow D^0X)=1.0$.] We use our measured product branching ratio and the Mark III Collaboration measurement of $B(D^0\rightarrow K^-\pi^+)$ to find $\alpha B(B\rightarrow D^{*+}X)=0.13\pm0.02\pm0.01$, which we denote as $(\alpha D^{*+})/B$. We assume that

$$\frac{D^{+}_{\rm direct}/B}{D^{*+}/B}=\frac{D^{0}_{\rm direct}/B}{D^{*0}/B} , \tag{A3}$$

so that

$$\gamma=\frac{D^{*0}/B}{D^{*+}/B} . \tag{A4}$$

Equations (A5) and (A6) relate the measured quantities to $D^{+}_{\rm direct}$ and $D^{0}_{\rm direct}$:

$$\begin{aligned} D^{+}_{\rm direct}/B&=D^+/B-D^{+}_{{\rm from}\ D^{*+}}/B\\ &=D^+/B-\frac{1-\alpha}{\alpha}(\alpha D^{*+})/B , \end{aligned} \tag{A5}$$

$$\begin{aligned} D^{0}_{\rm direct}/B&=D^0/B-D^{0}_{{\rm from}\ D^{*+}}/B-D^{0}_{{\rm from}\ D^{*0}}/B\\ &=D^0/B-(\alpha D^{*+})/B-D^{*0}/B\\ &=D^0/B-\left[1+\frac{\gamma}{\alpha}\right](\alpha D^{*+})/B . \end{aligned} \tag{A6}$$

Using Eqs. (A3) and (A4),

$$\gamma=\frac{D^0/B-(\alpha D^{*+})/B}{D^+/B+(\alpha D^{*+})/B} , \tag{A7}$$

giving $\gamma=0.85\pm0.19\pm0.08$.

We define

$$\begin{aligned} \frac{D_{\rm direct}}{D_{\rm direct}+D^*}&\equiv\frac{D^{+}_{\rm direct}+D^{0}_{\rm direct}}{D^{+}_{\rm direct}+D^{0}_{\rm direct}+D^{*+}+D^{*0}}\\ &=1-\left[\frac{(\alpha D^{*+})/B}{D^0/B+D^+/B}\right]\left[\frac{1+\gamma}{\alpha}\right] . \end{aligned} \tag{A8}$$

Using the value of $\gamma$ given above, we find

$$D_{\rm direct}/(D_{\rm direct}+D^*)=0.28\pm0.14^{+0.18}_{-0.11} .$$

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[12]For the data sample I the cuts are $\cos\theta^* < 0.9$ for $D^0$ candidate momentum between 0.5 and 2.0 GeV/$c$ and $-0.95 < \cos\theta^* < 0.8$ between 2.0 and 2.5 GeV/$c$. For data sample II the cuts are $\cos\theta^* > -0.8$ between 1.0 and 1.5 GeV/$c$, $0.9 > \cos\theta^* > -0.75$ between 1.5 and 2.0 GeV/$c$, and $\cos\theta^* > -0.7$ between 2.0 and 2.5 GeV/$c$.

[13]The observed peak is not a pure signal. $D^0$ decays into $K^-\pi^+$ also produce a peak in the invariant-mass distribution when the outgoing particles are interpreted as $\pi^-K^+$. The particle-identification information helps to reduce, but does not eliminate, this effect. To extract the number of real $D^0$ events, we fit the distribution to a shape found by Monte Carlo simulation, representing $D^0$ decays with right and wrong mass assignments. This procedure takes into account the particle-identification capabilities of the detector.

[14]We require the continuum $D^0$ cross section to vanish at zero momentum and use the point from 2.5 to 3.0 GeV/$c$ to further constrain the fit. The fitted continuum points are also given in Table I. The errors assigned are due to systematic variations in the possible fitting functions. To extract the product branching fraction $B(B\to D^0X)B(D^0\to K^-\pi^+)$, we scale the on $\Upsilon(4S)$ data from samples I and II by their respective luminosities (40 and 78 pb$^{-1}$), take a weighted average, and then subtract the fitted continuum scaled by a factor of 1.47, since we used only sample II for the fitted continuum.

[15]The first error is statistical; the second error is our estimate of the systematic uncertainties.

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[29]This momentum cut has been chosen to eliminate leptons from $D$ decays. We estimate that less than 2% of the remaining leptons are from $D$'s or $\Psi$'s. The background from misidentified hadrons is 5%.

[30]Limits have been set on $B^0\to\overline{B}{}^0$ mixing by both the CLEO and ARGUS groups. See V. Matveev and D. Kreinick, in *Proceedings of the International Symposium on Production and Decay of Heavy Flavours*, Heidelberg, 1986, edited by K. R. Schubert and R. Waldi (DESY, Hamburg, 1986).

[31]This number does not depend on the $R_2$ cut. Systematic errors are much smaller than the quoted statistical errors. We have used the Mark III $D^0\to K^-\pi^+$ branching ratio.

[32]We do not expect a significant contribution from $F$ production in semileptonic decay, since this would require an $s\overline{s}$ pair to be created from the vacuum. Measurements of $F$ production from $B$ decay indicate that only a small fraction of the $F$ production could arise from this source. See Ref. 24.

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[36]As a check on our detection efficiencies, we have compared our observed $D^{*+}$ continuum production cross section above a value of $x=0.5$ with measurements of the ARGUS Collaboration, H. Albrect *et al.*, Phys. Lett. **150B**, 235 (1984). We find $\sigma(D^{*+})B(D^{*+}\to D^0\pi^+)B(D^0\to K^-\pi^+)$ to be $11.6\pm0.7$ pb. The ARGUS measurement, when scaled to the $\Upsilon(4S)$ en-

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