CHARM PRODUCTION IN B MESON DECAYS

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ABSTRACT

We present new preliminary results from CLEO of inclusive branching fractions $\mathcal{B}(B \to D^0 X) = (63.8 \pm 1.1 \pm 2.0 \pm 1.7)\%$, and $\mathcal{B}(B \to D_s^+ X) = (11.8 \pm 0.4 \pm 0.9 \pm 2.9)\%$, and of the exclusive two-body decays $B \to D_s^{+(*)} \bar{D}^{(*)}$. These results are used to extract the D_s^+ decay constant f_{D_s} and the total charm production rate in B meson decays.

1. Introduction

Most B mesons decay via either the external or color-suppressed internal spectator diagram into charmed mesons or charmed baryons. Due to the large phase space available in these decays many exclusive final states are formed. The calculation of rates into final states is model-dependent whereas an attempt has been made to calculate the rates into inclusive final states based on QCD.[1–3] Thus it is important to measure inclusive decay rates into charmed particles. In this talk we present new results from CLEO on the inclusive decays $B \to D^0 X$ and $B \to D_s^+ X$ (charge-conjugate states are always implied), respectively. We also present measurements of the exclusive branchings of the two-body decays where the W fragments into $\bar{c}s$ quark pair, $B \to D_s^{+(*)} \bar{D}^{(*)}$. These results are used to extract the D_s^+ meson decay constant f_{D_s} by applying factorization in B meson decays. The new measurements of inclusive branching fractions are combined with other measurements from CLEO and ARGUS to obtain a total charm production rate from B mesons.

2. New CLEO Results

2.1. Measurement of $B \to D^0 X$ Decays

The data sample consists of 2020 pb^{-1} and 960 pb^{-1} of e^+e^- annihilations taken at CESR with the CLEO II detector[4] at the $\Upsilon(4S)$ resonance and in the nearby continuum, respectively. The $\Upsilon(4S)$ data correspond to about 2.15 million $B\bar{B}$ events.

Hadronic events are selected based on measured charged and neutral energy, at least three charged tracks and an event vertex consistent with the nominal interaction point. To suppress events from continuum production it is required that $R_2 < 0.5$ where R_2, the ratio of the second to the zeroth Fox-Wolfram moment,[5] exploits the different event shapes of "spherical" $B\bar{B}$ events as opposed to "jetty" continuum events.

The $D^0 \to K^-\pi^+$ channel is used. Each track candidate has to be consistent with originating from the event vertex. We also require that the specific ionization loss (dE/dx) is consistent with the K or π hypothesis. The $K^-\pi^+$ invariant mass distribution is used to extract the yield in the following way. First, the data is subdivided in 20 bins in reduced momentum x where $x = p_{D^0}/p_{\max}$. The continuum production which is estimated by the continuum data, scaled for luminosity and energy differences, is subtracted for each bin. The subtracted distribution is then fitted in each x-bin to a double Gaussian signal and background contributions. The combinatorial background is parameterized with a 2nd order Chebyshev polynomial. Additional sources of background are due to switched particle mass assignments from the decay $D^0 \to K^-\pi^+$ itself and from the Cabibbo suppressed decays $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$, which peak underneath or near the signal region, respectively. The shape and normalization of these backgrounds is determined with D^0 decays stemming from $D^{*+} \to D^0\pi^+$ where the charge of the slow π uniquely identifies the mass assignments of the D^0 daughters. The efficiency is determined by Monte Carlo simulations. The signal shape parameters and the efficiency have been smoothed as a function of x. The raw yield is 61050 reconstructed $D^0 \to K^-\pi^+$ decays. In Fig. 1 we show the obtained D^0 momentum spectrum corrected for efficiency.

By summing all bins with $0 < x < 0.5$ we obtain a branching fraction $\mathcal{B}(B \to D^0X) = (63.8 \pm 1.1 \pm 2.0 \pm 1.7)\%$ where the first error is statistical, and the second error accounts for the systematic uncertainties which have been estimated by varying the R_2 cut and redoing the analysis by a single fit to the integral $(0 < x < 0.5)$ $K^-\pi^+$ mass distribution. The systematic error also comprises contributions which arise when signal shape parameters are changed within their errors and from the total number of B meson pairs. The third error is due to the branching ratio of $D^0 \to K^-\pi^+$.[6] We combine this result with earlier measurements of ARGUS and CLEO (Table 1) which have been rescaled to the new CLEO result[6] of $\mathcal{B}(D^0 \to K^-\pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$ and obtain a new world average of $\mathcal{B}(B \to D^0X) = (62.1 \pm 2.6)\%$.

2.2. Measurement of $B \to D_s^+X$ Decays

The $D_s^+ \to \phi\pi^+, \phi \to K^+K^-$ decay channel is chosen. The event and track selection has been described in the preceding section. Here we require $R_2 < 0.35$. The invariant mass of the K^+K^- pairs has to be within 10 MeV of the ϕ mass and we make angular cuts using the spin-parity structure of the decay. As in the $B \to D^0X$ analysis we divide the data sample in x bins and fit the $\phi\pi^+$ invariant mass distribution in each bin to a Gaussian signal and polynomial background shape. To increase the statistical precision of the continuum subtraction we fit the continuum data before subtraction. The raw yield of reconstructed D_s^+ mesons from B decay is 1978 ± 78 events. The detector efficiency as a function of x is determined with Monte Carlo simulations. We plot the obtained D_s^+ momentum spectrum, corrected for efficiency, in Fig. 2.

Combining all bins with $x < 0.5$ we obtain $\mathcal{B}(B \to D_s^+X) = (11.81 \pm 0.43 \pm 0.94 \pm 2.9)\%$ where the first error is statistical and the second is the systematic error dominated by the uncertainty in the tracking efficiency. The third error is due to $\mathcal{B}(D_s^+ \to \phi\pi^+) = (3.7 \pm 0.9)\%$[7] which is not directly measured and has a large uncertainty. Previous CLEO and ARGUS measurements for $\mathcal{B}(B \to D_s^+X)$ are given in Table 1. The new world average is $\mathcal{B}(B \to D_s^+X) = (10.0 \pm 2.5)\%$.

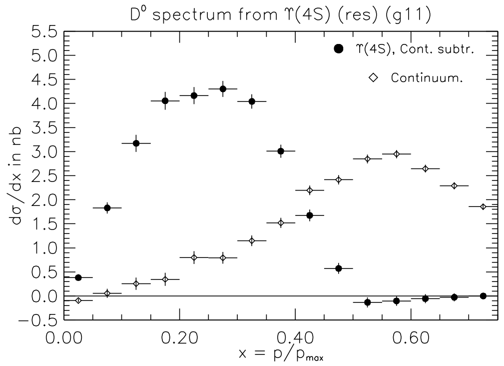

Fig. 1. The continuum-subtracted, efficiency-corrected yield of D^0 mesons versus x.

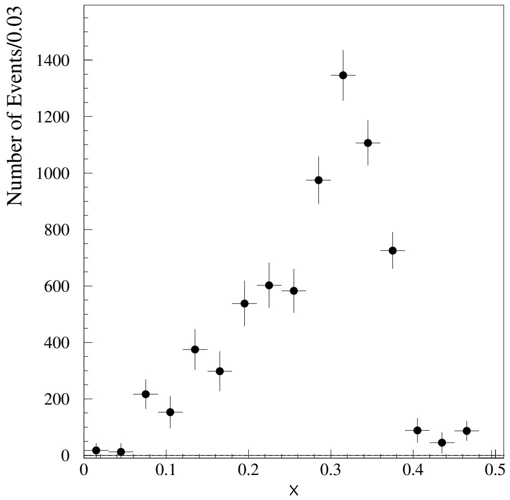

Fig. 2. The continuum-subtracted, efficiency-corrected yield of D_s^+ mesons versus x.

Table 1. Branching fractions $\mathcal{B}(B \to D^0 X)$ and $\mathcal{B}(B \to D_s^+ X)$.

Experiment	$\mathcal{B}(B \to D^0 X)[\%]$	$\mathcal{B}(B \to D_s^+ X)[\%] \frac{3.7\%}{\mathcal{B}(D_s^+ \to \phi\pi^+)}$
CLEO (preliminary)	63.8 ± 1.1 ± 2.0 ± 1.7	11.81 ± 0.43 ± 0.94
ARGUS[8]	49.6 ± 3.8 ± 6.4 ± 2.4	7.89 ± 1.05 ± 0.84
CLEO[8]	59.6 ± 3.1 ± 3.6 ± 2.9	8.27 ± 1.24 ± 0.81
ARGUS (87)[8]		11.4 ± 3.2
CLEO (86)[8]		10.3 ± 2.7
New world average	62.1 ± 2.6	10.0 ± 0.7 ± 2.4

We have also measured all eight two-body decay modes $B \to D_s^{+(*)} \bar{D}^{(*)}$. The following decay channels are used: $D_s^{*+} \to \gamma D_s^+$, $D^{*+} \to \pi^+ D^0$, $D^{*0} \to \pi^0 D^0, D_s^+ \to \phi\pi^+, \bar{K}^0 K^+, \bar{K}^{*0} K^+, \phi\rho^+, \eta\pi^+, \eta\rho^+, D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+, D^+ \to K^-\pi^+\pi^+$ for the charmed mesons and $\pi^0 \to \gamma\gamma, \eta \to \gamma\gamma, \bar{K}^0 \to K_s \to \pi^+\pi^-, \rho^+ \to \pi^+\pi^0, \bar{K}^{*0} \to K^-\pi^+, \phi \to K^+K^-$ for the resonances. Photons have to have energies larger than 30 MeV. The summed energy of the candidate has to be within 25 MeV of the beam energy E_{beam}. In Fig. 3 we show the beam constrained mass $m_B = \sqrt{E_{\text{beam}}^2 - p_B^2}$ where p_B is the summed momentum of the candidate. The fit to a Gaussian signal plus a background shape yields 134 ± 15 signal events. The branching ratios, averaged over charged and neutral B meson decays, are given in Table 2.

3. D_s^+ Decay Constant f_{D_s}

Factorization is the assumption that hadronic two-body B decays ($B \to \bar{D}^* h^+$) can be expressed as the product of two amplitudes, one that describes $B \to \bar{D}^*$ and can be measured in the semileptonic decay $B \to \bar{D}^* \ell^+ \nu$, and another one that couples the h^+ to the virtual W^+. This assumption has been shown to be valid at the 20 % level for

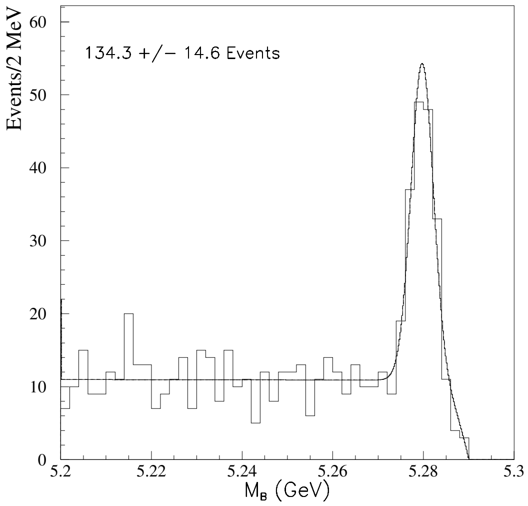

Fig. 3. The beam-constrained mass for the sum of the eight $B \to D_s^{+(*)}\bar{D}^{(*)}$ modes.

Table 2. Branching fractions $\mathcal{B}(B \to D_s^{+(*)}\bar{D}^{(*)})$.

Mode	$\mathcal{B}[\%]\frac{3.7\%}{\mathcal{B}(D_s^+\to\phi\pi^+)}$
$B \to D_s^+\bar{D}$	$1.24 \pm 0.19 \pm 0.29$
$B \to D_s^+\bar{D}^*$	$1.07 \pm 0.23 \pm 0.23$
$B \to D_s^{*+}\bar{D}$	$0.81 \pm 0.21 \pm 0.19$
$B \to D_s^{*+}\bar{D}^*$	$1.98 \pm 0.42 \pm 0.45$

light hadrons.[9] Factorization can be applied to the case where the h^+ is a $D_s^{+(*)}$. This leads to the relation

$$\frac{\Gamma(B \to \bar{D}^* D_s^{+(*)})}{\frac{d\Gamma}{dq^2}(B \to \bar{D}^*\ell^+\nu)|_{q^2=m^2_{D_s}}} = \delta 6\pi^2 \left|V_{cs}\right|^2 f^2_{D_s} \tag{1}$$

where $\delta = 0.41$ (1.0) for $D_s^{+(*)}$ and we assume $f_{D_s^*} = f_{D_s}$. Using the presented CLEO measurements for $\mathcal{B}(B \to D_s^{+(*)}\bar{D}^*)$ (Table 2) and for $\frac{d\mathcal{B}}{dq^2}(B \to \bar{D}^*\ell^+\nu)|_{q^2=m^2_{D_s}} = (5.0 \pm 0.7)\cdot 10^{-3}\ \mathrm{GeV}^{-2}$,[10] averaged over charged and neutral B mesons, we obtain

$$f_{D_s} = (280 \pm 43)\sqrt{\frac{3.7\%}{\mathcal{B}(D_s^+ \to \phi\pi^+)}}\ \mathrm{MeV} \quad . \tag{2}$$

CLEO has also observed[7] the leptonic decay mode of the D_s^+ into a muon and a neutrino which measures the decay constant f_{D_s} as

$$f_{D_s} = (344 \pm 64)\sqrt{\frac{\mathcal{B}(D_s \to \phi\pi^+)}{3.7\%}}\ \mathrm{MeV} \quad . \tag{3}$$

Equations (3) and (2) both depend on $\mathcal{B}(D_s^+ \to \phi\pi^+)$, but in an opposite manner. Solving the two equations gives

$$f_{D_s} = (310 \pm 37)\ \mathrm{MeV}, \quad \text{and} \quad \mathcal{B}(D_s \to \phi\pi^+) = (3.0 \pm 0.7)\% \quad . \tag{4}$$

This value of f_{D_s} is higher than most theoretical predictions, eg. lattice gauge calculations which give $f_{D_s} = (230 \pm 35)$ MeV.[11]

4. Total Charm Production

B meson decays proceed via $b \to c$ transitions most of the time. From the parton model we expect about 115% charm where the additional 15% arises when the W fragments as a $\bar{c}s$ quark pair. The small contributions from $b \to u$ and Penguin transitions are neglected. The various charm contributions are listed in Table 3. We use the new world averages for the D^0 and D_s^+ branching fractions, and we have averaged previous ARGUS and CLEO measurements of $\mathcal{B}(B \to D^+X)$ rescaled to $\mathcal{B}(D^+ \to K^-\pi^+\pi^+) = (9.23 \pm 0.81)\%$ which is an average of the MARK III[8] and the new CLEO measurement.[12] The charmonium production is estimated by multiplying $\mathcal{B}(B \to \psi X)$[13] by $2f$ where the factor of 2 accounts for the two charm quarks and $f = 2.0 \pm 0.5$ allows for charmonium states not decaying via a ψ. Decays into baryons mostly proceed via a Λ_c^+. We use the average of previous ARGUS and CLEO measurements.[8] Finally, we add a small contribution of $b \to c\bar{c}s$ transitions into $\Xi_c\Lambda_c^-$ baryon pairs for which CLEO has some evidence.[14] Thus we obtain a value of $(108 \pm 6)\%$ for the number of charm quarks produced in B decays and $(15.6 \pm 2.9)\%$ for the sum of all $b \to c\bar{c}s$ transitions. These measurements are in good agreement with the naive parton model prediction and do not support the larger estimates of 130%.[3]

Table 3. $b \to c$ branching fractions.

$\mathcal{B}(B \to D^0X)$	(62.1 ± 2.6) %	$\mathcal{B}(B \to \psi X)$	(1.1 ± 0.1) %
$\mathcal{B}(B \to D^+X)$	(23.9 ± 3.7) %	$\mathcal{B}(B \to \Lambda_c^+X)$	(6.4 ± 2.3) %
$\mathcal{B}(B \to D_s^+X)$	(10.0 ± 2.5) %	$\mathcal{B}(B \to \Xi_c\Lambda_c^-X)$	(1.1 ± 0.8) %
Σ(Charm)	(108 ± 6) %	$\Sigma(b \to c\bar{c}s)$	$15.6 \pm 2.9)$ %

5. Conclusions

We have presented new CLEO results on inclusive $b \to c$ decays of $\mathcal{B}(B \to D^0X) = (63.8 \pm 1.1 \pm 2.0 \pm 1.7)\%$, and $\mathcal{B}(B \to D_s^+X) = (11.8 \pm 0.4 \pm 0.9 \pm 2.9)\%$. New results of exclusive two-body decays $B \to D_s^{+(*)}\bar{D}^{(*)}$ combined with the CLEO measurement of $D_s^+ \to \mu^+\nu$ give $f_{D_s} = (310 \pm 37)$ MeV if factorization holds in B meson decays. The total charm production rate in B meson decays is $(108 \pm 6)\%$ and the $b \to c\bar{c}s$ rate is (15.6 ± 2.9) %.

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