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Large Charmless Yield in B Decays and Inclusive B Decay Puzzles

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Abstract

In recent studies of inclusive B decays, it has been suggested that either B mesons decay much more copiously to final states with no open charm than currently assumed, or $B(D^0 \to K^-\pi^+)$ has to be reduced significantly. In this study, we have taken the experimental $B(D^0 \to K^-\pi^+)$ at its face value and estimated $B(b \to$ no open charm$)$ using complementary methods: one accounts for the c quark in $b \to c$ transitions, the other accounts for the $\bar{c}$ quark in $b \to c\bar{c}s$ transitions. Through cancellation of errors, the average gives our best estimate of $B(b \to$ no open charm$)$, and the difference measures the consistency. The results of the methods are consistent with each other, strongly suggesting a much enhanced $B(b \to$ no open charm$)$. Based on the observation, we propose that a sizable fraction of the $b \to c\bar{c}s$ transitions could be seen as charmless $b \to s$ processes. This mechanism has generally been overlooked and, once accepted, requires no New Physics to explain the existing experimental data. We then briefly discuss implications on the baryon production governed by $b \to c\bar{c}s$ processes, rare hadronic B decays and CP violation studies.

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I. INTRODUCTION

It has been known for several years that the accurately measured $B(\overline{B} \to X\ell^-\overline{\nu})$ is smaller than theoretical estimates [1, 2, 3, 4, 5, 6, 7, 8] and that it indicates a sizable enhancement in non-leptonic B decay rates. The complete next-to-leading-log calculation of the ratio $\Gamma(b \to c\overline{u}d')/\Gamma(b \to ce\overline{\nu})$ has been performed with finite charm mass[3]:

$$r_{ud} \equiv \frac{\Gamma(b \to c\overline{u}d')}{\Gamma(b \to ce\overline{\nu})} = 4.0 \pm 0.4 \ . \tag{1.1}$$

Throughout this note, we define $d' \equiv V_{ud}d + V_{us}s$ and $s' \equiv V_{cs}s + V_{cd}d$. This theoretical estimate is considered reliable and indicates that the non-leptonic enhancement occurs in the $b \to c\overline{c}s'$ processes[3, 4, 5, 6, 7, 8]. Such a large rate for $b \to c\overline{c}s'$, however, predicts a charm multiplicity (c or $\overline{c}$ quarks) per B meson decay of $n_c = 1.30 \pm 0.05$ [8, 4], which disagrees with present measurements [9, 10]

$$n_c = 1.10 \pm 0.06 \ .$$

With the help of newly available experimental data, this note systematically identifies the source of the charm deficit to be the final states with neither open c nor open $\overline{c}$ [the branching fraction denoted by $B(b \to$ no open charm$)$]. It then gives a plausible mechanism within the framework of the standard model without invoking new physics[11].

In section II, we estimate $B(b \to$ no open charm$)$ in three ways: method A focuses on the c quark in $b \to c$ transitions, and method B focuses on the $\overline{c}$ quark in $W \to \overline{c}s'$ transitions. Averaging over methods A and B reduces experimental errors significantly and is denoted as our third method (Method C). Method C gives our best estimate of $B(b \to$ no open charm$)$, while differences among the various methods checks the self consistency of the analysis. We find that the experimental data are self consistent and that $B(b \to$ no open charm$)$ is significantly larger than traditional estimates. In section III, we put forward the hypothesis that a large component of low mass $c\overline{c}$ pairs are seen as light hadrons and not as open charm [12] based on a straightforward Dalitz plot analysis and simple quark-hadron duality.

Section IV discusses the relationship among (wrong) charm and charmless yields in $\overline{B}$ decays and $B(D^0 \to K^-\pi^+)$. Conclusions and their implications can be found in the last section.

II. THREE WAYS OF ESTIMATING $B(b \to$ no open charm$)$

In the following, we distinguish flavor-specific branching fractions–$B(\overline{B} \to TX)$ and $B(\overline{B} \to \overline{T}X)$–from the flavor-blind yield per B decay

$$Y_T \equiv B(\overline{B} \to TX) + B(\overline{B} \to \overline{T}X) \; ,$$

where $\overline{B}$ represents B^- or $\overline{B}^0$. The branching fractions quoted by experiments are the average number of particle T per B decay (weighted over charged and neutral B productions). When the particle T is a flavor-specific charmed hadron, however, it is safe to assume that the average number of particle per decay is the same as the branching fraction.

$\overline{B}$ meson decays can be classified as $b \to cl\overline{\nu}(l = e, \mu, \tau)$, $c\overline{u}d'$, $c\bar{c}s'$, $u\bar{c}s'$, and no charm, where 'no charm' indicates that there is no c nor $\bar{c}$ quark in the final state at quark level and includes $b \to ul\overline{\nu}$, $u\overline{u}d'$, and charmless $b \to s'$ transitions. Then, accounting for the weakly decaying charmed hadrons originating from the c quark in the $b \to c$ transitions, we obtain

$$\begin{aligned} B(b \to \text{no open charm}) &= 1 - B(b \to u\bar{c}s') \\ &- B(\overline{B} \to DX) - B(\overline{B} \to D_s^+X) - B(\overline{B} \to N_cX) \qquad \text{(method A)} \end{aligned} \tag{2.1}$$

where D represents D^0 or D^+, N_c is any of the weakly decaying charmed baryons (namely, Λ_c, Ξ_c or Ω_c) and

$$B(b \to \text{no open charm}) \equiv B(b \to \text{no charm}) + B(\overline{B} \to (c\bar{c})X) \tag{2.2}$$

with $(c\bar{c})$ being charmonia not seen as $D\overline{D}X$. The branching fraction $B(b \to u\bar{c}s')$ is small, and estimated to be

$$B(b \to u\bar{c}s') = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \eta \; r_{ud} \; B(b \to ce\overline{\nu}) = 0.0035 \pm 0.0018 \; ,$$

where $\eta \approx 1.3$ accounts for the larger QCD corrections in $W^- \to \bar{c}s'$ transitions [4] versus $W \to ud'$ ones [3].

The experimental inputs used in (2.1) are given in Tables I - III. Table I shows the flavor-blind number of each particle type per B decay (Y_T) and Table III shows the flavor-specific content of each yield. Together, they provide flavor-specific branching fractions needed in (2.1). We have used consistent values for the key branching fractions of charm decays. The updated values are summarized in Table II. A few comments are in order.

Refs. [9, 10] tried to solve the charm deficit problem and related issues by reducing $B(D^0 \to K^-\pi^+)$ sizably below the current world average. However, a recent precise measurement by ALEPH [13], $B(D^0 \to K^-\pi^+) = 0.0390 \pm 0.0009 \pm 0.0012$, agrees with the previous measurements. This may indicate that inclusive B decays are not well understood [14], and caused us to carefully reassess every input into the puzzle.

In this note we will proceed by trusting the experimental value of $B(D^0 \to K^-\pi^+)$ and use the new world average after the Warsaw '96 Conference of [15]

$$B(D^0 \to K^-\pi^+) = 0.0388 \pm 0.0010 \ . \tag{2.3}$$

Both $B(D^+ \to K^-\pi^+\pi^+)$ and $B(D_s^+ \to \phi\pi^+)$ are measured model-independently relating them to $B(D^0 \to K^-\pi^+)$, and the measured ratios are given in Table II.

Using the values in Tables I – III, the flavor-specific D (D^0 or D^+) branching fraction is found to be

$$B(\overline{B} \to \overline{D}X) = Y_D \times \frac{r_D}{1+r_D} = 0.085 \pm 0.025 \ . \qquad \text{(CLEO)}$$

The same quantity can be inferred from the ALEPH measurement of $\overline{B} \to D\overline{D}X$[16]:

$$B(\overline{B} \to D^0\overline{D}^0X, D^0D^-X, D^+\overline{D}^0X) = 0.128 \pm 0.027 \pm 0.026 \ .$$

In order to obtain $B(\overline{B} \to \overline{D}X)$, we need to add $B(\overline{B} \to D^+D^-X)$ and $B(\overline{B} \to D_s^+\overline{D}X)$ ($\overline{B} \to N_c\ \overline{N}\ \overline{D}X_s$ is kinematically forbidden and $\overline{B} \to N_c\ \overline{N}\ \overline{D}X$ is negligible). The total D^+D^-X production can be evaluated from ALEPH's measurements [16] by assuming

factorization and isopin symmetry[9] to be $1 \pm 0.4\%$, where we have assigned a conservative error since the assumption of factorization may not hold. Our estimate for D_s^+ production in $b \to c\bar{c}s$ processes is small.* Correcting for the key charm decay branching fractions adopted in this note, we then obtain

$$B(\overline{B} \to \overline{D}X) = 0.145 \pm 0.037 \quad (\text{ALEPH}) . \tag{2.4}$$

The CLEO and ALEPH results are consistent with each other within two sigma. The agreement is encouraging since they have been measured using completely different methods. As shown in Table III, the flavor-specific D_s^+ production in $\overline{B}$ decays has been measured to be small by CLEO [17]. That conclusion has been confirmed by ALEPH[16].

The estimation of $B(\overline{B} \to N_c X)$ requires data on Ξ_c and Ω_c as well as those on Λ_c given in Tables I - III. There exists an unpublished measurement on Ξ_c production [18] while the Ω_c production has not been detected. The Ξ_c rates were measured in their non-leptonic modes which were normalized to the semileptonic decay of Ξ_c. The semileptonic Ξ_c and Λ_c decay rates were assumed equal. Voloshin recently pointed out, however, that the ratio of semileptonic rate of Ξ_c over that of Λ_c may be enhanced up to a factor of two by Pauli interference effects[19].

Thus, in this note, we choose to use a model calculation to relate $B(\overline{B} \to N_c X)$ to the measurements on Λ_c [9, 10]. The assumptions of the model are: (1) in charmed baryon production governed by the $b \to c\bar{q}q'$ transition, the two quarks cq' end up in a single (excited) charmed baryon, (2) excited Ξ_c will end up as Ξ_c and excited Λ_c (or Σ_c) will end up as Λ_c, and (3) the ratio of $s\bar{s}$ pair creation to $u\bar{u}$ or $d\bar{d}$ pair creation is universal. The

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* The total D_s^+ production in tagged $\overline{B}$ decays is $Y_{D_s} f_{D_s} = 2 \pm 1\%$ (Table I – III), which informs about the probability $P(b \to c \to D_s^+)$. Since about 10% of all B's decay as $b \to c + \overline{D}X_s$, and the formation of D_s^+ from the c quark entails phase-space suppression [due to the existence of the two charmed mesons and two extra strange quarks in the final state], we estimate that $B(\overline{B} \to D_s^+ \overline{D}X)$ not to exceed significantly the permille level.

estimate for $B(\overline{B} \to \overline{N}_c X)$ is listed in Table IV. The predicted Ξ_c production is found to be much smaller than the measurement, and when any of the assumptions are relaxed toward more realistic ones, the prediction becomes even smaller. There exists another modification which impacts in a minor way on Eq. (2.1). Refs. [9, 10] claim that one must reassess the currently accepted value of $B(\Lambda_c \to pK^-\pi^+) = 0.044 \pm 0.006$ because it has been based on a flawed model for $\overline{B} \to \overline{N}_c X$. The model is invalidated if sizable $\overline{B} \to D^{(*)} \overset{(-)}{N} X$ are observed, which we predicted from simple Dalitz plot arguments. Refs. [9, 10] thus argue to use [20]

$$B(\Lambda_c \to pK^-\pi^+) = 0.060 \pm 0.015 \ . \tag{2.5}$$

We now turn to the second way of estimating $B(b \to \text{no open charm})$ which is to account for the $\bar{c}$ quark in $b \to c\bar{c}s'$, $u\bar{c}s'$ transitions. Noting that, apart from charmonia, the $\bar{c}$ quark should hadronize to $\overline{D}$, D_s^-, or $\overline{N}_c$, we obtain

$$\begin{aligned} &B(b \to \text{no open charm}) \\ &\quad = R - B(\overline{B} \to \overline{D}X) - B(\overline{B} \to D_s^- X) - B(\overline{B} \to \overline{N}_c X) \qquad \text{(method B)} \ , \end{aligned} \tag{2.6}$$

with

$$\begin{aligned} R &\equiv B(b \to \text{no charm}) + B(b \to c\bar{c}s') + B(b \to u\bar{c}s') \\ &= 1 - B(b \to c(e,\mu,\tau)\overline{\nu}) - B(b \to c\overline{u}d') \\ &= 1 - B(b \to ce\overline{\nu})\,(2 + r_\tau + r_{ud}) \end{aligned} \tag{2.7}$$

where r_{ud} given by (1.1) and

$$r_\tau \equiv \frac{\Gamma(b \to c\tau\overline{\nu})}{\Gamma(b \to ce\overline{\nu})} = 0.22 \pm 0.02[21]$$

are calculated theoretically.

For the semileptonic branching ratio, we take the value

$$B(B \to Xe\overline{\nu}) = 0.1049 \pm 0.0046[22] \ . \tag{2.8}$$

from experiment.† We then find

$$R = 0.35 \pm 0.05 \,. \tag{2.9}$$

This result changes only minimally to

$$R = 0.36 \pm 0.05 \quad \text{(includes differences in } B^- \text{ and } \overline{B}_d) \,, \tag{2.10}$$

once differences in the B^- and $\overline{B}_d$ rates governed by $b \to c\bar{u}d$ have been conservatively incorporated [23, 24]. That is to be expected because Pauli interference and W annihilation are $O(1/m_b^3)$ effects and thus numerically small. Our prediction (2.10) for R combines the most accurate information available from both theory and experiment.

Using the experimental values from Table I - III, we obtain for methods A and B,

$$B(b \to \text{no open charm}) = 0.15 \pm 0.05 \text{ (A)} \,, \quad 0.17 \pm 0.06 \text{ (B)} \qquad \text{(CLEO)} \tag{2.11}$$

$$0.21 \pm 0.06 \text{ (A)} \,, \quad 0.11 \pm 0.07 \text{ (B)} \qquad \text{(ALEPH\&CLEO)}. \tag{2.12}$$

In (2.12), we have used $B(\overline{B} \to \overline{D}X)$ given by (2.4) and

$$B(\overline{B} \to DX) = Y_D - B(\overline{B} \to \overline{D}X)$$

with all other inputs (including Y_D) being identical to those of (2.11).

The errors in methods A and B are of course highly correlated. For example, when r_D (see Table III) fluctuates upward, the value given by A will increase while that given by B will decrease. The best estimate of $B(b \to \text{no open charm})$ can be obtained if we take the average of the two methods where the errors due to flavor-specific fractions (Table III) cancel out:

$$\begin{aligned} B(b \to \text{no open charm}) &= 0.5\,(1 + R - B(b \to u\bar{c}s') - Y_D - Y_{D_s} - Y_{N_c}) \qquad \text{(method C)} \\ &= 0.16 \pm 0.04 \,. \qquad \text{(CLEO)} \end{aligned} \tag{2.13}$$

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† Several published values for $B(b \to \ell^- X)$ at Z^0 factories are likely to decrease significantly, as pointed out recently [9].

where the error correlations are properly taken into account. If we take the difference of the two methods, then it will check the self consistency of the analysis and the data:

$$B(b \to \text{no open charm})\ (\mathrm{A}) - B(b \to \text{no open charm})\ (\mathrm{B})$$

$$= -0.02 \pm 0.08 \qquad (\mathrm{CLEO}) \tag{2.14}$$

$$0.10 \pm 0.10 \qquad (\mathrm{ALEPH\&CLEO}). \tag{2.15}$$

The CLEO data are clearly self consistent, but the ALEPH data also is not inconsistent. The consistency puts some constraint on the allowed value of $B(D^0 \to K^-\pi^+)$. Fig. 1 shows the estimates of $B(b \to \text{no open charm})$ as functions of $B(D^0 \to K^-\pi^+)$ using CLEO data. The experimental value of $B(D^0 \to K^-\pi^+)$ is well within the allowed region. In fact, consistency between methods A and B gives

$$B(D^0 \to K^-\pi^+) = 4.0 \pm 0.5\% \ .$$

III. $B(b \to$ no open charm$)$ AND DALITZ PLOT OF $b \to c\bar{c}s$

We now discuss what to expect for $B(b \to \text{no open charm})$ defined by (2.2). $B(b \to \text{no charm})$ has two charmless contributions: $b \to u$ and $b \to s'$. Because of the small measured $|V_{ub}/V_{cb}| = 0.08 \pm 0.02$ the $b \to u$ transitions are not large ($\sim 1\%$). It has been argued that charmless $b \to s'$ transitions are small due to the small Wilson coefficients of $b \to s'$ penguin operators leading to a small branching ratio for $B(b \to s' + ng,\ s' + q\bar{q})$[25]. Traditional estimates yield [8]

$$B(b \to \text{no charm}) = 0.026 \pm 0.010 \quad (\text{traditional guess}). \tag{3.1}$$

We later challenge this small estimate and point to a generally overlooked mechanism that could increase $B(b \to s')$ manyfold within the Standard Model.

Charmonia ($c\bar{c}$) production in B decays has been observed with an inclusive branching fraction of 0.0176 ± 0.0016[18]. Within the factorization approximation, the ($c\bar{c}$) are produced with color suppressed coefficients. Ref. [8] estimated

$$B(\overline{B} \to (c\bar{c})X) = 0.026 \pm 0.004 \quad \text{(traditional guess)} \tag{3.2}$$

by using experimental measurements for J/ψ, ψ', χ_{c1}, and χ_{c2}. The estimate used published calculations for decay constants of η_c, η_c' and related their yield to that of J/ψ assuming factorization and the same color suppressed coefficient a_2. However, a_2 should in reality be process-dependent, and more significantly, it is well known that factorization cannot be justified for color-suppressed modes [26]. The measured χ_{c2} production in B decays, if confirmed, serves as experimental proof. The estimate Eq. (3.2) assumed $1.2B(b \to \chi_{c2}X)$ for nonfactorizable $(c\bar{c})$ production other than χ_{c2}.[‡] Adding up the traditional estimates, we obtain

$$B(b \to \text{no open charm}) = 0.052 \pm 0.011 \quad \text{(traditional guess)}. \tag{3.3}$$

The traditional estimate (3.3) falls far below 0.16 ± 0.04. Though estimate (3.2) is unreliable, we do not expect the true $(c\bar{c})$ production to be large enough to explain the bulk of the discrepancy. What could be the source of such a large enhancement of $B(b \to$ no open charm)? Here we put forward a hypothesis that the enhancement is caused by annihilation of the $c\bar{c}$ pair in $b \to c\bar{c}s'$ transitions [12]. This hypothesis does not modify any of the analysis in the previous section except that it fixes the discrepancy between the measurement and prediction for $B(b \to$ no open charm). We now argue that such a process is indeed plausible. Figure 2 shows the $b \to c\bar{c}s$ Dalitz plot resulting from the $(V-A) \times (V-A)$ matrix element, where the initial and final spins were averaged and summed. The invariant $c\bar{c}$ mass configuration below open charm threshold is seen to be densely populated,[§]

$$\frac{\Gamma(b \to c\bar{c}s, m_{\bar{c}c} < 2m_D)}{\Gamma(b \to c\bar{c}s)} = 0.68^{+0.16}_{-0.25} \,. \tag{3.4}$$

[‡] Eq. (3.2) is clearly unreliable and one should search for not only η_c in B decays [18] but also for other $(c\bar{c})$, such as $\eta_c', \chi_{c0}, h_c, {}^1D_2, {}^3D_2$.

[§] The masses were taken as $m_b = 4.8 \pm 0.2$ GeV, $m_b - m_c = 3.4$ GeV and $m_s = 0.2$ GeV.

This indicates that a significant fraction of $b \to c\bar{c}s$ processes ends up with invariant $c\bar{c}$ masses below the $2m_D$ threshold. The QCD corrected operator responsible for the $b \to c\bar{c}s$ transition can be written as [neglecting the small conventional penguin contributions]

$$2c_2(\bar{s}T^a b)_{V-A}(\bar{c}T^a c)_{V-A} + (c_1 + \frac{c_2}{N_c})(\bar{s}b)_{V-A}(\bar{c}c)_{V-A} \ . \tag{3.5}$$

The estimate for the coefficient of the color-singlet term $(c_1 + c_2/N_c)$ ranges from 0.10 to 0.25[26] and is much smaller than $c_2 \approx 1.1$. This indicates that the $c\bar{c}$ quark pair is dominantly in a color-octet state which can annihilate into a single gluon. Thus a significant fraction of $c\bar{c}$ below open charm threshold $(2m_D)$ may be seen as light hadrons [12]! New Physics scenarios as discussed in Ref. [11] are not required. Work in progress will be able to quantify the probability that such low invariant mass $\bar{c}c$ configurations are actually seen as light hadrons, and the probability that such configurations hadronize as open charm, producing $\bar{c}s$ resonances [8, 9].** The cs configuration gives rise to charmed baryon production in $b \to c\bar{c}s$ transitions, which is known to be strongly suppressed [29, 9, 10]. The cs configuration can thus be safely neglected to the level of accuracy that we aim at.

IV. SYSTEMATICS AND CORRELATIONS AMONG OBSERVABLES

What could have possibly gone wrong with our analysis? Could CLEO have badly mismeasured the coefficient (0.876 ± 0.037) of Y_D (i.e., apart from $B(D^0 \to K^-\pi^+)$, see Table I)? In order for the best estimate of $B(b \to \text{no open charm})$ (method C) to come down to the 5% level, Y_D needs to increase by about 20%. That appears unlikely since then the charm multiplicity in B decays as measured by CLEO should be significantly different from

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** When one assumes color-allowed factorization and sums over all exclusive D_s^{**} resonances that can be formed from a virtual W, one calculates a $B(\overline{B} \to \overline{D}X)$ which is larger than measured [27, 28]. This is consistent with our hypothesis that a significant fraction of low mass $\bar{c}c$ pairs are seen as light hadrons, thereby depleting D_s^{**} resonance production.

recent ALEPH [30] and OPAL [31] measurements which are given in Table V.[††] It shows that all measurements are consistent. Also, method A is more sensitive to the change in Y_D than method B, and increasing Y_D by 20% results in a 2-sigma discrepancy between the two methods evaluated at the nominal value of $B(D^0 \to K^-\pi^+)$.

In contrast, the size of the wrong-sign charm yield $B(\overline{B} \to \overline{D}X)$ is still confused. The method currently employed by CLEO uses angular correlations between a high energy lepton and a D meson to separate the cases where the D-lepton pair comes from the same $\overline{B}$ meson or different $\overline{B}$ mesons. At low D momenta, however, the angular correlation is smeared out and it is difficult to distinguish the two cases. The ALEPH measurement fully reconstructs both charmed mesons from a single B thus avoiding such systematics, but suffers from low statistics.

Methods A, B, and C quantify tight correlations among r_D, $B(b \to$ no open charm) and $B(D^0 \to K^-\pi^+)$. If the true value of r_D is around 0.1, then our hypothesis of $c\bar{c}$ annihilation requires no experimental measurements to be outside their quoted errors (see Figure 1). [We dismissed though the unpublished Ξ_c data, and adopted $B(\Lambda_c \to pK\pi)$ which is slightly larger than generally accepted. Even if we were to double the charmed baryon yield in B meson decays, however, the result $B(b \to$ no open charm$) = 0.14 \pm 0.04$ via method C would still be significantly larger than the traditional estimate.]

On the other hand, Figure 3 shows the hypothetical case of $r_D = 0.20 \pm 0.03$. The lines would cross at $B(b \to$ no open charm$) = 0.06$ and $B(D^0 \to K^-\pi^+) = 0.032$. It demonstrates that increasing the wrong charm yield makes $B(b \to$ no open charm) more consistent with the traditional estimate. The charm deficit would disappear due to the lower value of $B(D^0 \to K^-\pi^+)$. Thus if r_D is known to be around 0.2 with certainty, then one suspect would be a mismeasured $B(D^0 \to K^-\pi^+)$.

[††] The combined yields of D, D_s, Λ_c in b-hadron decays at Z^0 and $\Upsilon(4S)$ factories are expected to agree within existing experimental errors.

If we trust the current world average $B(D^0 \to K^-\pi^+) = 0.0388 \pm 0.0010$, then equating methods A and B leads to

$$r_D = 0.12 \pm 0.05, \tag{4.1}$$

which is not very constraining. Because accurate measurements of r_D are important, we urge our experimental colleagues to accurately measure r_D with all available methods. For instance, Z^0 factories could select a highly enriched b-data sample, employ optimized flavor-tagging, and measure the right and wrong sign D yields in flavor-tagged b-decays [8]. After the removal of neutral $B-\overline{B}$ mixing effects, $B(b \to \overline{D}X)$ and $B(\overline{B} \to \overline{D}X)$ can be extracted.

V. SUMMARY AND DISCUSSION

Newly available data allowed us to demonstrate that either $B(b \to$ no open charm) is much larger than generally accepted, or $B(D^0 \to K^-\pi^+)$, which calibrates charm meson yields, needs to be reduced significantly from presently accepted values[9, 10, 14]. The recent precise measurement of $B(D^0 \to K^-\pi^+)$ by the ALEPH collaboration agrees with previous measurements and suggests that the problem lies in an underestimation of $B(b \to$ no open charm), which we have estimated using complementary methods. Indeed a Dalitz plot analysis reveals that in $b \to c\bar{c}s'$ transitions the low mass $\bar{c}c$ pairs could be seen appreciably as light hadrons. The $\bar{c}c$ pair favors to be in a color-octet configuration which may readily transform itself to light hadrons. Thus $B(b \to$ no open charm) could be much larger than generally accepted within the Standard Model. New Physics scenarios as suggested in Ref. [11] are not required. In fact, while New Physics scenarios involve very energetic kaons, the proposed mechanism here mostly involves softer kaons. Using the methods of estimating $B(b \to$ no open charm), we were also able to formulate consistency checks in B-decays that eliminated entirely the dependence on $B(b \to$ no open charm). The checks may prove useful in future experimental investigations of heavy flavor decays.

A large $B(b \to$ no open charm) could well be the final missing piece in the puzzle of the small charm multiplicity in B decays and small $B(\overline{B} \to X\ell\overline{\nu})$. The proposed mechanism

of color-octet annihilation of low invariant $\bar{c}c$ masses could explain the low observed ratio of[29]

$$B(\overline{B} \to \overline{N}_c X)/B(\overline{B} \to N_c X),$$

because the numerator is governed essentially by $b \to c\bar{c}s'$ transitions, where $c\bar{c}$ pairs may annihilate significantly before hadronizing thereby reducing the baryon yield, whereas the denominator is dominated by $b \to c\bar{u}d'$ processes and $c\bar{u}$ cannot annihilate because of flavor conservation. The mechanism of color-octet $c\bar{c}$ annihilation is also consistent with the observation of a significant surplus of K^- in inclusive $\overline{B}$ decays beyond conventional sources and the large K-flavor correlation with B-flavor at time of decay[32, 18].

One way to measure $B(b \to \text{no open charm})$ could use a vertex detector which searches in a b-enriched sample for a secondary vertex and vetoes on tertiary vertices from open charm. In addition, one could then search for a kaon attached to the secondary vertex. That kaon is not as highly energetic as the kaons produced in New Physics scenarios. This technique requires the B mesons to be moving; a similar technique, however, may be applicable for CLEO using only charm vertices.

If our predictions are confirmed, then many studies of rare B decays and CP violation will have to be re-evaluated. Through long-distance effects, amplitudes governed by $b \to d$ (s) transitions could have much larger contributions governed by the CKM combination $V_{cb}V_{cd}^*$ $(V_{cb}V_{cs}^*)$ than previously assumed. This realization favors the $\overline{B} \to K^-\pi^+$ interpretation over the $\overline{B} \to \pi^-\pi^+$ one. Further, the penguin amplitude in $b \to d$ processes may be enhanced such that direct CP violation may become observable either inclusively or exclusively, as in $B \to \pi\rho, \pi\omega, \pi a_1, 3\pi, B^0 \to \pi^+\pi^-$. Also we expect $\overline{B} \to \eta'\overline{K}$ to be enhanced. Many CP studies with such rare decay modes and similar ones will have to be rethought, if our findings are confirmed.

In addition, our work indicates that complete next-to-leading-log calculations and estimates of long-distance effects are required to reliably compute the $B_s - \overline{B}_s$ width difference [24] and the inclusive, mixing-induced CP violating effects in B_d decays governed by

$b \to u\bar{u}d, c\bar{c}d$ transitions [33]. Superb vertex detectors would still be able to isolate the inclusive $b \to u\bar{u}d$ transitions but the signal of singly detached vertices may involve a larger background than previously appreciated.

VI. ACKNOWLEDGEMENTS

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FIGURES

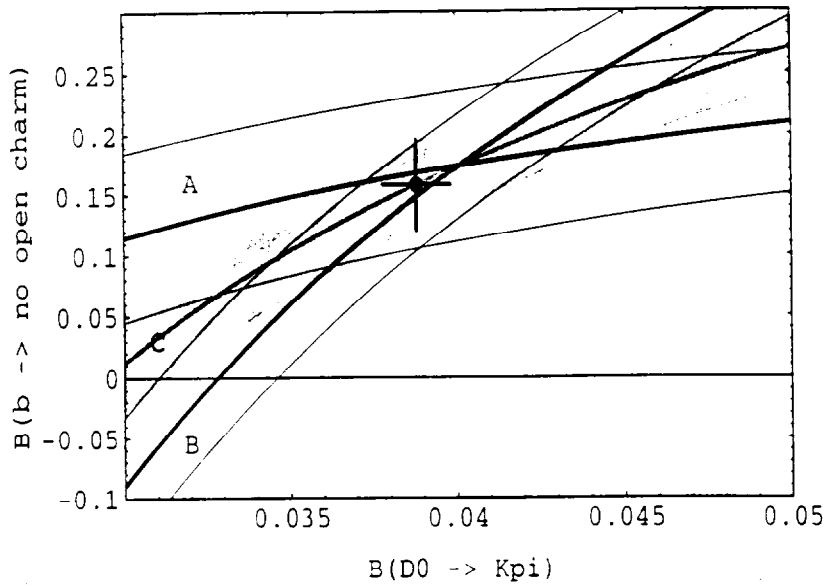

FIG. 1. Methods (labeled A, B, C: see text for detail) of estimating $B(b \to \text{no open charm})$ are plotted against $B(D^0 \to K^-\pi^+)$ together with bands corresponding to one standard deviation using CLEO data. The point with error bars shows the world average of $B(D^0 \to K^-\pi^+)$ and the best estimate of $B(b \to \text{no open charm})$ via method C.

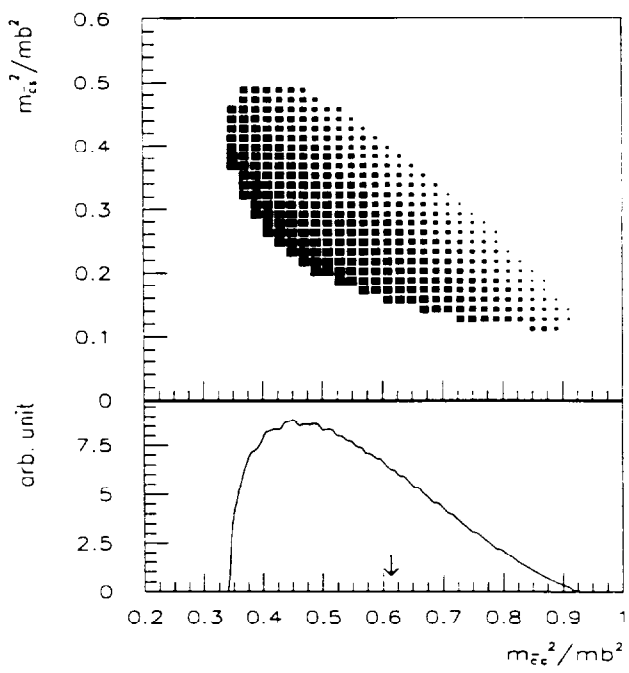

FIG. 2. Dalitz plot of the $b \to c\bar{c}s$ transition. Projection onto the axis of $m^2_{c\bar{c}}$ is also shown. The $D\overline{D}$ threshold is indicated by an arrow.

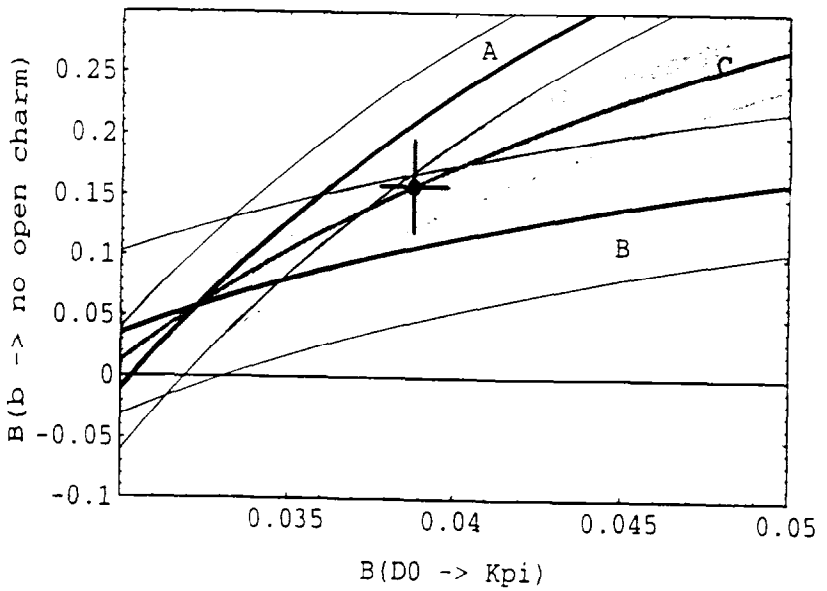

FIG. 3. Same as Figure 1, except for the value of r_D which is hypothetically taken to be 0.20 ± 0.03.

TABLES

TABLE I. Inclusive Charmed Hadron Production in B Meson Decays as Measured by CLEO

T	$Y_T \equiv B(\overline{B} \to TX) + B(\overline{B} \to \overline{T}X)$	Reference
D	$(0.876 \pm 0.037)\left[\frac{0.0388}{B(D^0 \to K^-\pi^+)}\right]$	[34]
D_s	$(0.1177 \pm 0.0093)\left[\frac{0.036}{B(D_s \to \phi\pi)}\right]$	[17]
Λ_c	$(0.030 \pm 0.005)\left[\frac{0.06}{B(\Lambda_c \to pK^-\pi^+)}\right]$	[29]

TABLE II. Absolute Branching Ratios of Key Charm Decays as Used in this Note

Quantity	Value	Comment
$B(D^0 \to K^-\pi^+)$	0.0388 ± 0.0010	World Average [15]
$r_+ \equiv \frac{B(D^+ \to K^-\pi^+\pi^+)}{B(D^0 \to K^-\pi^+)}$	2.35 ± 0.23	CLEO [35]
$r_s \equiv \frac{B(D_s \to \phi\pi)}{B(D^0 \to K^-\pi^+)}$	0.92 ± 0.23	CLEO [36]
$B(\Lambda_c \to pK^-\pi^+)$	0.060 ± 0.015	CLEO [20]

TABLE III. Inclusive Charmed Hadron Production in Tagged B Decays as Measured by CLEO

Observable	Value	Reference
$r_{\Lambda_c} \equiv \frac{B(\overline{B} \to \overline{\Lambda}_c X)}{B(\overline{B} \to \Lambda_c X)}$	0.20 ± 0.14	[29]
$r_D \equiv \frac{B(\overline{B} \to \overline{D}X)}{B(\overline{B} \to DX)}$	0.107 ± 0.034	[37]
$f_{D_s} \equiv \frac{B(\overline{B} \to D_s^+ X)}{Y_{D_s}}$	0.172 ± 0.083	[17]

TABLE IV. Charmed Baryon [$N_c \equiv \Lambda_c, \Xi_c, \Omega_c$] Production in B Meson Decay as Predicted In Refs. [9,10].

Quantity	Value
$B(\overline{B} \to N_c X)$	$(0.0365 \pm 0.0065) \left[\frac{0.06}{B(\Lambda_c \to pK^- \pi^+)}\right]$
$B(\overline{B} \to \overline{N}_c X)$	$(0.0059 \pm 0.0038) \left[\frac{0.06}{B(\Lambda_c \to pK^- \pi^+)}\right]$
Y_{N_c}	$(0.0424 \pm 0.0082) \left[\frac{0.06}{B(\Lambda_c \to pK^- \pi^+)}\right]$

TABLE V. Charm Multiplicity in B Meson Decays at $\Upsilon(4S)$, $Y_T \equiv B(\overline{B} \to TX) + B(\overline{B} \to \overline{T}X)$, and in b-Hadron Decays at Z^0, $Y_T \equiv B(b \to TX) + B(b \to \overline{T}X)$

Quantity	CLEO [34]	ALEPH [30]	OPAL [31]
$(Y_D + Y_{D_s}) \frac{B(D^0 \to K^- \pi^+)}{0.0388}$	0.99 ± 0.04	1.01 ± 0.05	0.93 ± 0.06
$Y_{\Lambda_c} \frac{B(\Lambda_c \to pK^- \pi^+)}{0.06}$	0.030 ± 0.005	0.08 ± 0.01	0.09 ± 0.02
$Y_D + Y_{D_s} + Y_{\Lambda_c}$	1.02 ± 0.05	1.09 ± 0.07	1.02 ± 0.08

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