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On the Necessity of Recalibrating Heavy Flavor Decays and its Impact on Apparent Puzzles in High Energy Physics

Isard Dunietz

Internet: dunietz@fnth15.fnal.gov

Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510

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Abstract

It is demonstrated that charm is systematically undercounted in various experiments. Via a process of elimination, $B(D^0 \to K^-\pi^+)$ is identified as the culprit. It calibrates essentially all charmed meson production and decay properties, and thus is central to the physics of heavy flavors. We predict it to decrease significantly below currently accepted values. We suggest several novel methods for precise measurements of $B(D^0 \to K^-\pi^+)$. The $B(\Lambda_c \to pK^-\pi^+)$, on the other hand, calibrates heavy-flavored baryons. Its world average relies heavily on a model of baryon production in B decays, which would be invalidated if $\overline{B} \to D^{(*)}\ \overset{(-)}{N}\ X$ processes were found to be significant. A Dalitz-plot analysis explains naturally the soft inclusive Λ_c momentum spectrum in $\overline{B}$ decays, and predicts sizable $\overline{B} \to D^{(*)}\ \overset{(-)}{N}\ X$ processes. Consistently carrying through these modifications to charmed meson and baryon yields has the potential to resolve the heavy-flavor puzzles at Z^0-factories [R_c, R_b], the number of charm per B-decay puzzle, and the semi-leptonic B decay puzzles. We emphasize that state of the art theoretical calculations are consistent with precise experimental measurements regarding $B(\overline{B} \to X\ell\bar{\nu})$. Recent CLEO measurements are interpreted as newly available cross-checks that any inclusive theoretical investigation must satisfy. Another topic of this report concerns the $b \to c + \overline{D}^{(*)}\overline{K}$ transitions, which were predicted to be sizable and subsequently confirmed by CLEO. This report discusses the underlying dynamics of those processes and quantifies the necessary modifications in existing semileptonic analyses due to the ignored $b \to \overline{D} \to \ell^-$ background. The determination of the average, time-integrated $B - \overline{B}$ mixing parameter $\overline{\chi}$ at higher energy colliders is more subtle than currently realized. All existing dilepton analyses that determine $B(b \to \ell^-)$ must modify their removal of $B - \overline{B}$ mixing effects. Several implications on the physics of heavy flavors are mentioned.

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I. INTRODUCTION

One of the purposes of this paper is to demonstrate that there is a systematic undercounting of charm in various experiments. Whereas the number of primary charm at Z^0 factories (R_c) is accurately predicted to be 17.2%, experiment observes only $(15.98 \pm 0.69)\%$ [1–4]. Historically, the number of charmed hadrons per B decay (n_c) was measured to be smaller than expectations [5], and the sum over all exclusive semileptonic B decay BR's is significantly less than the inclusive $B(B \to X\ell\nu)$ measurements [6]. A common thread in all of these cases is charm counting which heavily depends on the value of the branching fraction for $D^0 \to K^-\pi^+$.

The value of $B(D^0 \to K^-\pi^+)$ calibrates much that is known in charm and beauty decays, and is believed to be known to better than $\pm$ 5% accuracy. The experiment CLEO [7] measures

$$B(D^0 \to K^-\pi^+) = (3.91 \pm 0.19)\% ,$$

and the 1994 Particle Data Group [8] cites a world average of

$$B(D^0 \to K^-\pi^+) = (4.01 \pm 0.14)\% .$$

These values have been used to calibrate not only most other D^0 decay modes, but D^+ decay modes as well [9], via

$$r_+ = \frac{B(D^+ \to K^-\pi^+\pi^+)}{B(D^0 \to K^-\pi^+)} .$$

The calibration mode for the D_s, namely $B(D_s \to \phi\pi)$, has also been recently tied to $B(D^0 \to K^-\pi^+)$ in a model independent fashion [10].

Historically n_c has been obtained by combining all charmed hadron yields in B decays, including the inclusive production of weakly decaying charmed baryons. The present central values for Ξ_c and Λ_c yields which are used to calculate the baryon component of n_c [11] are comparable at roughly 5%. The latter is measured rather well, whereas the Ξ_c measurement has large uncertainty. The CLEO collaboration has demonstrated that the right-sign $\ell^+\Lambda_c$

correlations dominate over the wrong-sign $\ell^- \Lambda_c$ case [15] (where the lepton comes from the semileptonic decay of one B and the Λ_c originates from the other B in an $\Upsilon(4S)$ event). As a result, the inclusive Ξ_c production in B decays cannot, in fact, be as large as that of the Λ_c. [Throughout this report, CP violation is neglected and for each process its CP-conjugated relative is implied.]

Because Λ_c production in B decays is measured with greater accuracy than that of the Ξ_c, we correlate the weakly decaying charmed baryon ($baryon_c$) production in B decays to that measured for the Λ_c (see Appendix). In the process, we find that the current measured central value for the Ξ_c yield in B decays is too high. We also propose to not use the 1994 PDG value [8] of $B(\Lambda_c \to pK^-\pi^+) = (4.4 \pm 0.6)\%$, because it relies heavily on a flawed model of baryon production in B decays. We instead follow the more satisfactory approach outlined in Ref. [16], where $B(\Lambda_c \to pK^-\pi^+) = (6.0 \pm 1.5)\%$ is obtained by assuming equal inclusive semileptonic widths for D and Λ_c decays. These two effects reduce the $baryon_c$ production in B decays significantly and yield $n_c = 1.10 \pm 0.06$ when one uses the value $B(D^0 \to K^-\pi^+) = (3.91 \pm 0.19)\%$. This is appreciably lower than current n_c estimates [11].

The CLEO [17] experiment recently confirmed our prediction [18] for significant wrong-charm production ($\overline{B} \to \overline{D}X$) in B decays and has therefore completed the mapping of the $b \to \bar{c}$ transitions. This opens up an alternate, indirect method for the determination of n_c which is far less sensitive to either $B(\overset{(-)}{B} \to baryon_c X)$ or $B(D^0 \to K^-\pi^+)$. This method yields a value of 1.19 ± 0.03, which differs from the direct measurement.

Since inclusive charm production in B decays is dominated by the inclusive D yields, we will entertain the possibility that the current accepted value for $B(D^0 \to K^-\pi^+)$ could be wrong. [We consider $B(D^0 \to K^-\pi^+)$ instead of the absolute branching fractions for D_s and Λ_c, because the latter play a smaller role in the determination of n_c and would therefore have to be altered beyond reasonable extremes to have the same result. In addition, the Standard Model allows a sufficiently accurate estimate for hidden charmonia production in B decays and for charmless B decays. We are thus naturally led to focus on the $B(D^0 \to K^-\pi^+)$ (see Eqs. (2.21)-(2.22)).] Since the two determinations for n_c must agree, we equate them and

solve for $B(D^0 \to K^-\pi^+)$ to obtain the precise result $B(D^0 \to K^-\pi^+) = (3.50 \pm 0.21)\%$, which is significantly smaller than the currently accepted value. This reduced value will be seen to solve the R_c puzzle and to mitigate the semileptonic B decay problem mentioned above.

If correct, a reduced value for $B(D^0 \to K^-\pi^+)$ would have implications for the whole field of heavy flavor decays including the discrepancy between theory and experiment regarding R_b. A downward shift in the value for $B(D^0 \to K^-\pi^+)$ could imply that current experimental analyses of R_b are underestimating their tag rate for $Z \to c\bar{c}$. Because $D^0 \to K^-\pi^+$ calibrates almost all charmed meson branching fractions, a reduced value would necessarily imply that a proper accounting has yet to be carried out for a significant fraction of D^0 decays. The modes which have been miscounted or simply missed would likely involve higher track multiplicities, since such decays are more vulnerable to detector inefficiencies, particle misidentification, and the presence of neutral daughters [19]. On the other hand, the higher multiplicities would also mean that these decays would more easily be tagged as B's. We have studied this and other sources that have the potential to remove the R_b discrepancy between the Standard Model and experiment [20]. There are, of course, many additional implications, some of which we will touch upon in the conclusion.

Because the precise knowledge of the value of $B(D^0 \to K^-\pi^+)$ is so central to these issues, we encourage a widespread effort to remeasure it, and suggest several novel methods for doing so. It is noteworthy that the most recent determination of $B(D^0 \to K^-\pi^+)$, as obtained by ARGUS [12], is compatible with our findings,

$$B(D^0 \to K^-\pi^+) = (3.41 \pm 0.12 \pm 0.28)\% \; .$$

The second topic of this note concerns $\overline{B} \to D\overline{D}\ \overline{K}X$ processes. Because they have been generally overlooked in published experimental analyses, it is of some consequence that we predicted, in a variety of ways, that they are sizable [18]. CLEO [17] confirmed our prediction and has found that the inclusive wrong-charm yield is about 10%,

$$B(\overline{B} \to \overline{D}X) \approx 10\% \; .$$

Since this comprises a large fraction of all B decays, we will discuss the underlying dynamics to help enable a more careful probing of these transitions. We then shift gears and discuss necessary modifications to published results for B decays, which have not considered the $\overline{B} \to D\overline{D}\ \overline{K}X$ background. In the interest of brevity we will give a detailed discussion only for measurements of the semileptonic decays of B hadrons.

We point out that current measurements [21] of $\overline{B} \to D^{**}(X)\ell\bar{\nu}$ have to carefully assess the impact of the $b \to c\ \overline{D}\ \overline{K}X$ background, where one of the charmed hadrons delivers the charged lepton via its semileptonic decay.

The inclusive, single lepton spectrum determines $B(\overline{B} \to X\ell\nu)$. CLEO subtracted leptons via $\overline{B} \to (\Lambda_c, D_s^-) \to \ell$ transitions [22,23]. The shapes of the primary ($\overline{B} \to \ell^-$) and secondary ($\overline{B} \to D \to \ell^+$) spectra were taken from various models. The overall normalizations for the primary and secondary spectra were obtained from a fit to data. It was found that the ACCMM model [24] fits the data well, whereas the ISGW model [25,26] does not. By letting the $\overline{B} \to D^{**}\ell\bar{\nu}$ component float in the ISGW model, CLEO [22] could get a much better fit, albeit with a very large value for the ratio;

$$\frac{B(\overline{B} \to D^{**}\ell\bar{\nu})}{B(\overline{B} \to X\ell\bar{\nu})} = 0.23 \pm 0.01\ \pm 0.05\ .$$

CLEO denotes the modified ISGW model by ISGW**. All current analyses assume that inclusive D production in $\overline{B}$ decays is mediated by $b \to c$ transitions. The leptons generated from these D decays have the opposite charge of the primary leptons. We now know that wrong-charm production in $\overline{B}$ decays is a significant source of soft $\overline{D}$'s [17]. The soft $\overline{D}$ gives rise to a soft lepton with the same charge as the primary lepton. Of the two sources of secondary leptons ($b \to D \to \ell^+$ and $b \to \overline{D} \to \ell^-$) the latter must be subtracted from the primary component measured from charge correlations [27,23,22,28]. This subtraction is lacking in all existing analyses. The secondary lepton yield $\overline{B} \to \overset{(-)}{D} \to \ell$ from single inclusive lepton fits is enhanced relative to the $\overline{B} \to D \to \ell^+$ yield obtained from dilepton analyses. We estimate the enhancement due to $B(\overline{B} \to \overline{D} \to e^-)$ to be about 1%. This systematic enhancement is indicated in Table 4.7 of Ref. [22].

Once backgrounds have been treated correctly, the inclusive single lepton analysis at $\Upsilon(4S)$ factories [22] determines the correct primary lepton spectrum since the method is insensitive to the charge of the lepton. In contrast, the published dilepton methods measure the primary lepton spectrum for which the soft $\overline{B} \to \overline{D} \to \ell^-$ background contribution still must be removed.

Several analyses at the Z^0 resonance take the primary lepton spectrum from $\Upsilon(4S)$ factories as input. Those analyses ought to be updated, because they rely on older CLEO data [29] with a softer primary lepton spectrum,

$$\frac{B(\overline{B} \to D^{**}\ell\bar{\nu})}{B(\overline{B} \to X\ell\bar{\nu})} = 0.32 \pm 0.05 \ ,$$

than recent CLEO results [22]. All inclusive $B(b \to \ell^-)$ measurements at the Z^0 that rely on the primary spectral shape from $\Upsilon(4S)$ factories will thus change.

The charge correlation method of ALEPH does not rely upon the spectral shape from lower energy measurements. The basic idea for this analysis originates from the "model independent" dilepton analysis of ARGUS [27], which was improved by CLEO [22,23]. In such analyses, the primary and secondary components are "model independently" extracted via charge correlations. However, the analyses of ARGUS, CLEO and ALEPH must be modified in two respects. First, because the $b \to \overline{D} \to \ell^-$ background has not yet been subtracted, the primary component is deceptively enhanced. Second, the removal of $B^0 - \overline{B}^0$ mixing effects is more subtle than currently realized.

Because most model dependence is indeed absent, we will be able to quantify our expectations. The threshold machines operating at $\Upsilon(4S)$ require a momentum cut $p > 0.6$ GeV/c for the signal electron. Fortunately, this cut removes most of the soft $\overline{B} \to \overline{D} \to e^-$ background and drastically reduces the modification required for the correct removal of $B_d - \overline{B}_d$ mixing effects. Experiments at the Z^0 resonance are less fortunate. In this case, the large boost imparted to the primary B hadrons causes the background leptons to contribute more significantly. As a consequence, the model independent measurement of $B(b \to \ell^-)$ at the Z^0 resonance will need to be shifted downward, alleviating the puzzle of why the inclu-

sive semileptonic BR of B hadrons at Z^0 factories is significantly larger than at its $\Upsilon(4S)$ counterpart [30,31].

The model independent extraction of $B(b \to \ell^-)$ [28] is not the only observable that is affected by a modification of the $B - \overline{B}$ mixing effects. The published measurements [32] of the average, time integrated, mixing parameter $\overline{\chi}$ at higher energy facilities must also be modified. Whereas existing analyses have implicitly assumed the same average mixing parameter $\overline{\chi}$ for the primary and secondary lepton components, we will demonstrate that the two components experience different average $B - \overline{B}$ mixing effects. Consequently, those extractions [1,28] of $B(b \to \ell^-)$ that involve the average mixing parameter $\overline{\chi}$ must be adjusted.

We hope to motivate our experimental colleagues to remeasure the quantities of interest, since they alone can correctly assess all of the uncertainties. We are eager to learn the outcome of their studies.

This report is organized as follows:

Section II determines $B(D^0 \to K^-\pi^+)$ by equating the results for two complementary methods of determining n_c. The resultant value of $B(D^0 \to K^-\pi^+)$ is lower than the current accepted values. Consequences of the theory of inclusive B decays are mentioned.

Section III interprets the low R_c measurements as another indication of a smaller than expected value for $B(D^0 \to K^-\pi^+)$.

Section IV discusses the underlying dynamics of $\overline{B} \to D\overline{D}\ \overline{K}X$ processes.

Section V reviews semileptonic B decays. It first discusses the structure of single, inclusive lepton data samples followed by dilepton samples. Modifications resulting from the hitherto neglected $b \to \overline{D} \to \ell^-$ background, and the correct removal of $B^0 - \overline{B}^0$ mixing effects are presented in great detail. Exclusive semileptonic B decays are then classified. Combining all classes of these decays again illustrates the need for a lower value of $B(D^0 \to K^-\pi^+)$. Instead of using inconclusive experimental $B(\overline{B} \to D^{**}(X)\ell\bar{\nu})$, we suggest, for now, to use a Bjorken-Isgur-Wise sumrule [33], which "model independently" relates the combined semileptonic BR into charmed p wave states to the Isgur-Wise slope

parameter, ρ^2.

Section VI discusses the possibility of novel precision measurements of $B(D^0 \to K^-\pi^+)$ from semileptonic B decays. (Other new measurements were advertised in earlier sections.)

Section VII explains why we prefer $B(\Lambda_c \to pK^-\pi^+) = (6.0 \pm 1.5)\%$ over the smaller world average $(4.4 \pm 0.6)\%$.

Section VIII discusses some of the consequences of a smaller than currently accepted value for $B(D^0 \to K^-\pi^+)$. It also discusses several implications of significant $b \to c + \overline{D}^{(*)}\overline{K}$ transitions.

We believe that the adjustments to published, experimentally extracted quantities suggested in this report are reasonable estimates of what is required for a consistent picture of heavy flavor decays. Nevertheless, we emphasize the fact that the most accurate values and their systematic uncertainties can only be obtained by the various experiments involved in these measurements by means of the analysis of new data or reanalysis of existing data. We are eager to learn from our experimental colleagues what results are obtained after the effects discussed in this note have been taken into account.

II. $B(D^0 \to K^-\pi^+)$ FROM N_C

The number of charmed hadrons per B decay is defined by

$$n_c \equiv Y_D + Y_{D_s} + Y_{baryon_c} + 2B(\overline{B} \to (c\bar{c})X) \,, \tag{2.1}$$

where the inclusive production of an arbitrary hadron T is defined as

$$Y_T \equiv B(\overline{B} \to TX) + B(\overline{B} \to \overline{T}X) \,. \tag{2.2}$$

Here all weakly decaying, singly charmed baryon species $(\Lambda_c, \Xi_c^{+,0}, \Omega_c)$ are denoted collectively by $baryon_c$ while $(c\bar{c})$ denotes charmonia not seen as open charm. Table I summarizes relevant CLEO measurements. Note that the inclusive D^+ yield in B decays involves $B(D^+ \to K^-\pi^+\pi^+)$, which in turn is calibrated by $D^0 \to K^-\pi^+$ [9],

$$\frac{B(D^+ \to K^-\pi^+\pi^+)}{B(D^0 \to K^-\pi^+)} = 2.35 \pm 0.23 \ . \tag{2.3}$$

We can thus write

$$\begin{aligned} Y_{D^+} &= (0.235 \pm 0.017)\ \frac{9.3}{3.91(2.35 \pm 0.23)}\ \left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] = \\ &= (0.238 \pm 0.029)\ \left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] \ . \end{aligned} \tag{2.4}$$

The inclusive D yield in $\overline{B}$ decays,

$$Y_D \equiv Y_{D^0} + Y_{D^+} \ , \tag{2.5}$$

can then be expressed as shown in Table I. The measurement of inclusive Ξ_c production in B decays has large uncertainty because it suffers from a low number of candidate events and a large uncertainty in the branching fraction used for its calibration. In the Appendix, we therefore correlate both Ξ_c and Ω_c production in tagged and untagged B decays to Y_{Λ_c} and

$$r_{\Lambda_c} \equiv \frac{B(\overline{B} \to \overline{\Lambda}_c X)}{B(\overline{B} \to \Lambda_c X)} \ . \tag{2.6}$$

We neglect $b \to u$ transitions and use the Cabibbo suppression factor, $\theta^2 = (0.22)^2$, for charmed baryon production in $b \to c\bar{u}s(b \to c\bar{c}d)$ versus $b \to c\bar{u}d'(b \to c\bar{c}s')$. [The prime indicates that the corresponding Cabibbo suppressed mode is included.] The Appendix also parametrizes $s\bar{s}$ fragmentation from the vacuum, and predicts

$$\frac{Y_{\Xi_c}}{Y_{\Lambda_c}} = 0.38 \pm 0.10 \ , \tag{2.7}$$

$$\frac{Y_{baryon_c}}{Y_{\Lambda_c}} = 1.41 \pm 0.12 \ , \tag{2.8}$$

$$\frac{B(\overline{B} \to baryon_c X)}{Y_{\Lambda_c}} = 1.22 \pm 0.07 \ , \tag{2.9}$$

$$\frac{B(\overline{B} \to \overline{baryon_c}\ X)}{Y_{\Lambda_c}} = 0.20 \pm 0.10 \ . \tag{2.10}$$

We probably overestimate Ξ_c production in $\overline{B}$ decay, because our unsophisticated predictions do not include the fact that the V-A interactions tend to create highly excited Ξ_c baryons in $\overline{B}$ decays (see the Appendix). The quark flavor of an initially highly excited Ξ_c baryon is generally not retained by its weakly decaying offspring. Nevertheless, the true value for $Y_{baryon_c}/Y_{\Lambda_c}$ must lie in the range

$$1 < \frac{Y_{baryon_c}}{Y_{\Lambda_c}} < 1.41 \pm 0.12 \, . \tag{2.11}$$

Variation over this range has negligible effect upon the accurate extraction of n_c, and so, for now, we use the values Eqs. (2.7) - (2.10), and hope to return with a more realistic modelling of charmed as well as uncharmed baryon production in B decays in a future report. Thus n_c becomes:

$$\begin{aligned} n_c = (0.883 \pm 0.038) \left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] + (0.1211 \pm 0.0096) \left[\frac{3.5\%}{B(D_s \to \phi\pi)}\right] + \\ + (0.042 \pm 0.008) \left[\frac{6\%}{B(\Lambda_c \to pK^-\pi^+)}\right] + 2B(\overline{B} \to (c\bar{c})X) \, . \end{aligned} \tag{2.12}$$

Inserting the necessary absolute branching ratios (BR) for charm decays (see Table II) and estimating [18]

$$B(\overline{B} \to (c\bar{c})X) = 0.026 \pm 0.004 \, , \tag{2.13}$$

one would obtain

$$n_c = 1.10 \pm 0.06 \quad , \tag{2.14}$$

which is below the currently accepted value [11].

Most recently, CLEO completed the direct measurement of $B(b \to c\bar{c}s')$ which allows an alternative extraction of n_c via the expression [18],

$$\tilde{n}_c = 1 - B(b \to \text{ no charm}) + B(b \to c\bar{c}s') \, . \tag{2.15}$$

This alternative extraction of n_c is far less sensitive to miscalibrations of absolute branching ratios of charmed hadron decays. For $B(b \to$no charm) we use [18],

$$B(b \to \text{ no charm}) = (0.25 \pm 0.10)\ (0.1049 \pm 0.0046) =$$
$$= 0.026 \pm 0.010 \tag{2.16}$$

The inclusive wrong-charm B decay yield is [34,35,18,36]

$$B(b \to c\bar{c}s') \approx B(\overline{B} \to \overline{D}X) + B(\overline{B} \to D_s^- X) +$$
$$+ B(\overline{B} \to \overline{baryon}_c\, X) + B(\overline{B} \to (c\bar{c})X)\ . \tag{2.17}$$

From Tables I and III, Eq. (2.17) and our charmed baryon model, we find

$$B(b \to c\bar{c}s') = (0.085 \pm 0.025)\ \frac{3.91\%}{B(D^0 \to K^-\pi^+)} +$$
$$+ (0.100 \pm 0.012)\ \left[\frac{3.5\%}{B(D_s \to \phi\pi)}\right] + (0.0059 \pm 0.0031)\ \left[\frac{6\%}{B(\Lambda_c \to pK^-\pi^+)}\right] +$$
$$+ B(\overline{B} \to (c\bar{c})X)\ . \tag{2.18}$$

With the absolute charm branching values from Table II we obtain

$$B(b \to c\bar{c}s') = 0.22 \pm 0.03\ , \tag{2.19}$$

$$\tilde{n}_c = 1.19 \pm 0.03\ . \tag{2.20}$$

Since n_c and $\tilde{n}_c$ must be equal, the apparent discrepancy between them (compare Eqs. (2.14) with (2.20)) indicates to us a possible miscalibration of absolute BR's of charmed hadron decays. We hypothesize that the problem is limited to $B(D^0 \to K^-\pi^+)$ (see Section I) and propose an accurate method for determining this quantity as follows. By treating $B(D^0 \to K^-\pi^+)$ as an unknown and equating n_c with $\tilde{n}_c$, one gets

$$B(\overline{B} \to DX) = 1 - B(\overline{B} \to \text{ no charm}) - B(\overline{B} \to D_s^+ X) +$$
$$- B(\overline{B} \to baryon_c X) - B(\overline{B} \to (c\bar{c})X)\ . \tag{2.21}$$

Eq. (2.21) expresses the trivial fact that [36]

$$B(b \to c) \approx 1 - B(b \to \text{no charm})\ ,$$

and yields

$$B(D^0 \to K^-\pi^+) = \frac{3.91\% \cdot \left[B\left(\overline{B} \to DX\right)\right]|_{\text{for } B(D^0\to K^-\pi^+)=3.91\%}}{1 - B(\overline{B} \to \text{no charm}) - B(\overline{B} \to D_s^+ X) - B(\overline{B} \to baryon_c X) - B(\overline{B} \to (c\bar{c})X)} . \tag{2.22}$$

Inserting the current CLEO data

$$B(\overline{B} \to DX) = (0.798 \pm 0.042)\left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] , \tag{2.23}$$

$$B(\overline{B} \to D_s^+ X) = (0.021 \pm 0.010)\left[\frac{3.5\%}{B(D_s \to \phi\pi)}\right] , \tag{2.24}$$

$$B(\overline{B} \to baryon_c X) = (0.0365 \pm 0.0065)\left[\frac{6\%}{B(\Lambda_c \to pK^-\pi^+)}\right] , \tag{2.25}$$

and Eqs. (2.13) and (2.16) we obtain

$$B(D^0 \to K^-\pi^+) = (3.50 \pm 0.21)\% . \tag{2.26}$$

This in turn yields

$$B(b \to c\bar{c}s') = 0.227 \pm 0.035 , \tag{2.27}$$

$$n_c = \tilde{n}_c = 1.20 \pm 0.04 . \tag{2.28}$$

Once the model independent measurement invented by CLEO for [10]

$$\frac{B(D_s \to \phi\pi)}{B(D^0 \to K^-\pi^+)}$$

becomes accurate enough, we suggest that it be used to determine $B(D^0 \to K^-\pi^+)$ from Eq. (2.21) by combining both the D and D_s^+ yields in tagged $\overline{B}$ decays.

Comparison of the Theory of Inclusive B Decays with Experimental Results

The direct $B(b \to c\bar{c}s')$ measurement is now known to be compatible with theoretical predictions (0.24 ± 0.051 in on-shell scheme and 0.30 ± 0.044 in $\overline{MS}$ scheme) [37,38], which have larger uncertainties. Furthermore, we are finally in a situation to confront the theoretical calculation of 4.0 ± 0.4 [39] for

$$r_{ud} \equiv \frac{\Gamma(b \to c\bar{u}d')}{\Gamma(b \to ce\bar{\nu})} , \tag{2.29}$$

which served as a necessary input for a number of our predictions [18]. With accurate measurements of $B(b \to c\bar{c}s')$ and $B(\overline{B} \to Xe\bar{\nu})$, r_{ud} is determined by [34,35,18],

$$r_{ud}\Big|_{exp} = \frac{1 - B(b \to c\bar{c}s')}{B(\overline{B} \to Xe\bar{\nu})} - (2 + r_\tau + r_{q'}) . \tag{2.30}$$

We use [40,41]

$$r_\tau \equiv \frac{\Gamma(b \to c\tau\bar{\nu})}{\Gamma(b \to ce\bar{\nu})} = 0.25 , \tag{2.31}$$

$$B(\overline{B} \to X\ell\bar{\nu}) = (10.49 \pm 0.46)\% \ (CLEO \ II), \tag{2.32}$$

and we have chosen [18]

$$r_{q'} \equiv \frac{\Gamma(b \to \text{ no charm})}{\Gamma(b \to ce\bar{\nu})} = 0.25 \pm 0.10 , \tag{2.33}$$

to obtain

$$r_{ud}\Big|_{exp} = 4.86 \pm 0.47 . \tag{2.34}$$

If the discrepancy between the measured and theoretically predicted values of r_{ud} persist, it will indicate either large higher order QCD corrections [42] or important nonperturbative effects at $\mathcal{O}(1/m_b^3)$ [43,44] or both.

We favor the explanation due to non-perturbative effects at $\mathcal{O}(1/m_b^3)$. The reason goes as follows. There are no $\mathcal{O}(1/m_b^3)$ corrections of the Pauli-interference and Weak-annihilation type for $\overline{B}$ decays governed by $b \to c\bar{c}s$ transitions. Thus, comparing theory and experiment

for $B(b \to c\bar{c}s')$ indicates whether higher order QCD corrections are important for $b \to c\bar{c}s'$ transitions, under the assumption of local duality. Because theory and experiment are compatible for $B(b \to c\bar{c}s')$ (with theory tending to give slightly larger values), we speculate that $\mathcal{O}(1/m_b^3)$ effects rather than higher order QCD corrections enhance the $b \to c\bar{u}d'$ rate.

We conclude that there is no problem between the precisely measured $B(\overline{B} \to X\ell\bar{\nu})$ and the state of the art theoretical investigations [43]. In fact, CLEO's recent measurements provide theorists with several consistency checks. A successful theoretical calculation must not only agree with the precisely measured $B(\overline{B} \to X\ell\bar{\nu})$, but with the following accurately-known quantities as well:

$$B(b \to c\bar{c}s') = 0.227 \pm 0.035, \text{ and} \tag{2.35}$$

$$r_{ud} = 4.86 \pm 0.47 \, . \tag{2.36}$$

III. THE LOW R_C MEASUREMENT

Whereas theory predicts

$$R_c \equiv \frac{\Gamma(Z^0 \to c\bar{c})}{\Gamma(Z^0 \to \text{ hadrons})} = 0.172 \, , \tag{3.1}$$

LEP/SLC have measured it 2 σ below this value at [2]

$$R_c|_{exp} = 0.1598 \pm 0.0069 \, . \tag{3.2}$$

One must, however, distinguish among the various R_c measurements. The measurements which fully reconstruct primary D^{*+}'s are inversely proportional to $B(D^0 \to K^-\pi^+)$

$$R_c(DELPHI\ D^*) = 0.148 \pm 0.007 \pm 0.011 \text{ [45]}, \tag{3.3}$$

$$R_c(OPAL\ D^*) = 0.1555 \pm 0.0196 \text{ [46]}, \tag{3.4}$$

with a world average of

$$R_c(D^*) = 0.150 \pm 0.011 \ . \tag{3.5}$$

Unfortunately OPAL and DELPHI have not explicitly presented the uncertainty due to $B(D^0 \to K^-\pi^+)$ in their R_c measurements which would allow $B(D^0 \to K^-\pi^+)$ to be determined straightforwardly. In the absence of such information, we will be conservative and retain the full uncertainty in R_c to obtain

$$17.2 = (15.0 \pm 1.1)\left[\frac{3.84\%}{B(D^0 \to K^-\pi^+)}\right] \ . \tag{3.6}$$

This yields

$$B(D^0 \to K^-\pi^+) = (3.35 \pm 0.25)\% \ , \tag{3.7}$$

which is compatible with our extracted value of $B(D^0 \to K^-\pi^+)$ from n_c (see Eq. (2.26)).

DELPHI also measured R_c via an inclusive double tag method, where only the daughter pions of the energetic $D^{*\pm}$ have been reconstructed. This method does not involve $B(D^0 \to K^-\pi^+)$ and the result, albeit with large uncertainty, [2]

$$R_c(\pi^+\pi^-) = 0.171^{+0.014}_{-0.012} \pm 0.015 \tag{3.8}$$

agrees with theory without modification.

There is also a lepton method for measuring R_c, but it has very large systematic uncertainties, and there are R_c measurements from both OPAL and DELPHI from direct charm counting [2,4]. The extraction of $B(D^0 \to K^-\pi^+)$ from the latter is less direct than from the fully reconstructed D^{*+} data samples, because additional charmed hadrons are involved. We illustrate what is involved with the data sample published recently by OPAL [4],

$$R_c(\text{charm counting}) = 0.167 \pm 0.011\ (stat) \pm 0.011\ (sys) \pm 0.005\ (br) \ . \tag{3.9}$$

OPAL measured

$$\begin{aligned}
R_c\ f(c \to D^0)\ B(D^0 \to K^-\pi^+) &= (0.389 \pm 0.037)\% \ , \\
R_c\ f(c \to D^+)\ B(D^+ \to K^-\pi^+\pi^+) &= (0.358 \pm 0.055)\% \ , \\
R_c\ f(c \to D_s^+)\ B(D_s^+ \to \phi\pi^+) &= (0.056 \pm 0.017)\% \ , \\
R_c\ f(c \to \Lambda_c^+)\ B(\Lambda_c^+ \to pK^-\pi^+) &= (0.041 \pm 0.020)\% \ .
\end{aligned} \tag{3.10}$$

It then summed these fractions using the reference branching fractions from the preliminary 1996 PDG:

$$B(D^0 \to K^-\pi^+) = (3.84 \pm 0.13)\% \,,$$
$$B(D^+ \to K^-\pi^+\pi^+) = (9.1 \pm 0.6)\% \,,$$
$$B(D_s^+ \to \phi\pi^+) = (3.5 \pm 0.4)\% \,,$$
$$B(\Lambda_c \to pK^-\pi^+) = (4.4 \pm 0.6)\% \,. \tag{3.11}$$

OPAL assumed that the undetected primary Ξ_c and Ω_c production is $(15 \pm 5)\%$ of the primary Λ_c production, and thus obtained Eq. (3.9).

We want to modify this treatment in several respects. First, we wish to solve for $B(D^0 \to K^-\pi^+)$ assuming the standard model value for $R_c = 0.172$. Second, as Section VII explains, a more satisfactory estimate for $B(\Lambda_c \to pK^-\pi^+)$ is $(6.0 \pm 1.5)\%$, rather than $(4.4 \pm 0.6)\%$. This causes the primary production fraction of Λ_c to decrease. We then correlate the inclusive primary production fraction of $baryon_c$ to that of Λ_c via

$$f(c \to baryon_c) = f(c \to \Lambda_c) \,/\, (1-p)^2 \,, \tag{3.12}$$

where p models the production fraction of $s\bar{s}$ fragmentation relative to $f\bar{f}$ from the vacuum, where $f = u, d$ or s [47]. A value of $B(D^0 \to K^-\pi^+)$ is thus obtained via

$$B(D^0 \to K^-\pi^+) = \frac{(0.389 \pm 0.037) + \frac{0.358 \pm 0.055}{r_+}}{R_c - \frac{(0.056 \pm 0.017)\%}{B(D_s \to \phi\pi^+)} - \frac{(0.041 \pm 0.020)\%}{(1-p)^2 B(\Lambda_c \to pK^-\pi^+)}} \;\%. \tag{3.13}$$

Inserting,

$$r_+ = 2.35 \pm 0.23, R_c = 17.2\%, B(D_s \to \phi\pi^+) = (3.5 \pm 0.4)\% \,, \tag{3.14}$$

$$\text{and } B(\Lambda_c \to pK^-\pi^+) = (6.0 \pm 1.5)\%, \tag{3.15}$$

we obtain

$$B(D^0 \to K^-\pi^+) = (3.67 \pm 0.42)\% \,. \tag{3.16}$$

This is again compatible with our other $B(D^0 \to K^-\pi^+)$ determinations. We have thus shown that a reduction in the value of $B(D^0 \to K^-\pi^+)$ eliminates the discrepancy between theory and experiment regarding R_c.

IV. ANATOMY OF $\overline{B} \to D\overline{D}\,\overline{K}X$ PROCESSES

Since CLEO II has proven the prediction [18] that a sizable fraction of all B decays are governed by $\overline{B} \to D\overline{D}\,\overline{K}X$, it is imperative to classify these processes. This section serves then the dual purpose of aiding experimentalists in finding and classifying the $\overline{B} \to D\overline{D}\,\overline{K}X$ processes and discusses how to properly take them into account in other B decay analyses, such as semileptonic B decays, where they represent a background.

Current [semileptonic] analyses have not accounted for $\overline{B} \to D\overline{D}\,\overline{K}X$ backgrounds, and therefore need to be modified, as discussed in the next section. This section focusses on the more global properties of the $\overline{B} \to D\overline{D}\,\overline{K}X$ transitions.

Isospin symmetry is a powerful tool for these processes because the underlying $b \to c\bar{c}s$ quark transition has $I = 0$. A sizable [probably majority] fraction of all $\overline{B} \to D\overline{D}\,\overline{K}X$ decays will be of the exclusive form $\overline{B} \to D^{(*)}\overline{D}^{(*)}\overline{K}$ [48],

$$\begin{aligned} B^- \to\ & D^{(*)+}\, D^{(*)-}\, K^- \,, \\ & D^{(*)0}\, \overline{D}^{(*)0}\, K^- \,, \\ & D^{(*)0}\, D^{(*)-}\, \overline{K}^0 \,, \end{aligned} \tag{4.1}$$

$$\begin{aligned} \overline{B}_d \to\ & D^{(*)+}\, D^{(*)-}\, \overline{K}^0 \,, \\ & D^{(*)+}\, \overline{D}^{(*)0}\, K^- \,, \\ & D^{(*)0}\, \overline{D}^{(*)0}\, \overline{K}^0 \,. \end{aligned} \tag{4.2}$$

Isospin symmetry alone demands that [49,50]

$$\Gamma(B^- \to D^{(*)+}\, D^{(*)-}\, K^-) = \Gamma(\overline{B}_d \to D^{(*)0}\, \overline{D}^{(*)0}\, \overline{K}^0) \,, \tag{4.3}$$

$$\Gamma(B^- \to D^{(*)0}\, \overline{D}^{(*)0}\, K^-) = \Gamma(\overline{B}_d \to D^{(*)+}\, D^{(*)-}\, \overline{K}^0) \,, \tag{4.4}$$

$$\Gamma(B^- \to D^{(*)0}\, D^{(*)-}\, \overline{K}^0) = \Gamma(\overline{B}_d \to D^{(*)+}\, \overline{D}^{(*)0}\, K^-) \,. \tag{4.5}$$

Color transparency arguments [51] predict that the isospin of $\overline{D}^{(*)}\overline{K}$ is essentially zero [50]

$$B(b \to c + (\overline{D}^{(*)}\overline{K})_{I=0}) \gg B(b \to c + (\overline{D}^{(*)}\overline{K})_{I=1}) \tag{4.6}$$

This could also be demonstrated by observing that the virtual $W \to \bar{c}s$ decay gives rise to an isospin and color singlet. The isospin singlet, $I_{\bar{c}s} = 0$, hadronizes independent of what the rest of the system does under the factorization assumption [52], thus corroborating Eq. (4.6). It then follows that [50]

$$\Gamma(B^- \to D^{(*)+}\, D^{(*)-}\, K^-) = \Gamma(\overline{B}_d \to D^{(*)0}\, \overline{D}^{(*)0}\, \overline{K}^0) = 0\,, \tag{4.7}$$

and for the remaining processes,

$$\begin{aligned} &\Gamma(B^- \to D^{(*)0}\, \overline{D}^{(*)0}\, K^-) = \Gamma(B^- \to D^{(*)0}\, D^{(*)-}\, \overline{K}^0) = \\ &= \Gamma(\overline{B}_d \to D^{(*)+}\, D^{(*)-}\, \overline{K}^0) = \Gamma(\overline{B}_d \to D^{(*)+}\, \overline{D}^{(*)0}\, K^-)\,. \end{aligned} \tag{4.8}$$

Of the 24 potentially different rates represented in Eqs. (4.1)-(4.2), we have thus reduced the problem to 4 (as yet) unrelated, reduced matrix elements,

$$\overline{B} \to D^{(*)}\, \overline{D}^{(*)}\, \overline{K}\,. \tag{4.9}$$

To go further, we complete the implications of the factorization assumption, wherein the [relative] D and D^* production is described by the $\overline{B} \to D^{(*)}$ form factors [53,54]. To probe the hadronization of $\bar{c}s$ into $\overline{D}^{(*)}\overline{K}$, one may contemplate the matrix element

$$< \overline{D}^{(*)}\overline{K}|\bar{s}\gamma_\mu(1-\gamma_5)c|0 > \ . \tag{4.10}$$

This presents a formidable, but *academic*, theoretical problem. The dominant hadronization processes will be $\bar{c}s \to D_s^{(*)-}$ and $\bar{c}s \to D_s^{r-} \to \overline{D}^{(*)}\overline{K}X$, where D_s^{r-} denotes all $\bar{c}s$ resonances beyond the D_s^- and D_s^{*-}. The following matrix elements are thus of great importance

$$< D_s^{r-}|\bar{s}\gamma_\mu(1-\gamma_5)c|0 >\,, \tag{4.11}$$

and are being analyzed at present [55]. Because of the V-A nature of the current, the final D_s resonances cannot have spin 2 or higher. Spinless p wave resonances are suppressed, as

can be seen by taking the limit $m_s \to m_c$ in which case the matrix element [Eq. (4.11)] vanishes. We expect the radially excited s wave D_s resonances, 0^- and 1^-, to be significant contributors, because their decay constants are found to be very large in preliminary lattice studies [56].

Whereas the $b \to c + \overline{D}^{(*)}\overline{K}$ processes were the highlight of this section, in the next section they will be viewed as a background in semileptonic B decays.

V. SEMILEPTONIC B DECAYS

Semileptonic decays are one of the most studied aspects of B hadrons [21]. These must be reevaluated since roughly 10% of all B's decay via $\overline{B} \to D\overline{D}\,\overline{K}X$ [18] which introduce a $\overline{B} \to \overline{D} \to \ell^-$ background that has not previously been considered. We will discuss inclusive decays first, followed by a detailed accounting of their various exclusive components.

A. Inclusive Semileptonic B Decays

Inclusive semileptonic measurements include the single lepton analyses and the so-called "model independent" dilepton analyses [21,30,22]. The lepton spectrum in these analyses is made up of the following components: primary leptons from ($b \to c\ell\nu$), secondary [or cascade] leptons from ($b \to cX, c \to s\ell\nu$), and leptons from primary charm decays ($c \to s\ell\nu$). Because $|V_{ub}/V_{cb}| \approx 0.1$, the $b \to u\ell\nu$ transition is highly suppressed.

One of the well known features of the V-A interactions is that, in the respective restframes of the decaying heavy flavors, the charged lepton spectrum for $b \to q\ell^-\bar{\nu}$ transitions is hard, whereas that of the $c \to q'\ell^+\nu$ transitions, is soft. Together with the fact that $M_b > M_c$, it follows that the primary leptons ($b \to q\ell^-$) will be harder [in momentum p at $\Upsilon(4S)$ factories, in p as well as $p_{T,rel}$ at higher energy colliders] than the secondary leptons ($b \to c \to \ell^+, b \to \bar{c} \to \ell^-$). In the laboratory frame the secondary charm has a boost that must be taken into account and the B mesons are not strictly at rest in the center of mass frame of an $\Upsilon(4S)$.

Figure 2 of Ref. [23] shows the inclusive lepton spectra at the $\Upsilon(4S)$. That Figure demonstrates that essentially only primary leptons satisfy the $p > 1.5$ GeV/c cut, whereas both secondary and primary leptons contribute at lower momenta.

1. Single Inclusive Lepton Analysis at the $\Upsilon(4S)$

In many of the single lepton analyses, the shape of the cascade lepton momentum spectrum is obtained by convoluting the measured $\overline{B} \to DX$ momentum distribution with that of the $D \to \ell X$. Secondary leptons from cascading D_s, Λ_c, and J/ψ decays $(\overline{B} \to (\Lambda_c, D_s^-, J/\psi) \to \ell)$ are treated as background and are subtracted. Since no charge correlations are performed in the analysis, it is immaterial whether the regular D (i.e., D^0 and D^+) charmed hadrons are created through $b \to c$ and/or $b \to \bar{c}$ transitions. The normalizations of the various lepton components are extracted from a fit to the inclusive lepton data sample. Ultimately, significant model dependence persists in the determination of the inclusive primary $B(\overline{B} \to X\ell^-\bar{\nu})$ as Table IV demonstrates.

It is therefore important to note that ARGUS invented a "model independent" dilepton method, which extracts the inclusive yields of the primary and secondary components separately. CLEO improved upon this method by introducing the more optimal Wang diagonal cut [22,23]. ALEPH tailored the dilepton analysis to the Z^0 environment. However, as mentioned above, the dilepton analyses are flawed in two respects. First, the background from $\overline{B} \to \overline{D} \to \ell^-$ transitions was not taken into account. Second, the removal of $B - \overline{B}$ mixing effects is more subtle than has been assumed. The next subsection describes how to incorporate these two effects and attempts to quantify the subsequent modifications.

2. Model Independent Dilepton Analysis

We now take issue with the so-called "model independent" dilepton method invented by ARGUS [27], and improved by CLEO [22,23]. First, the dilepton analysis has to be corrected for the neglected $\overline{B} \to \overline{D} \to e^-$ background. The current procedure takes the lepton from

the decay of the wrong-charmed hadron ($\overline{B} \to \overline{D} \to e^-$) to be primary, thereby deceptively increasing the primary component. Second, the current modelling of $B^0 - \overline{B}^0$ mixing effects is flawed in that it implicitly assumes that

$$B(\overline{B}_d \to D \to e^+X) = B(B^- \to D \to e^+X).$$

The correct removal of $B^0 - \overline{B}^0$ mixing effects is discussed in Ref. [57]. It is straightforward once we recognize that

$$B(\overline{B}_d \to D \to e^+X) > B(B^- \to D \to e^+X).$$

Before we begin a more detailed discussion of these modifications, we will briefly review the current dilepton analyses.

Strict cuts on the first lepton guarantee it to be primary ($b \to \ell^-$). This is the lepton used in the "tag" of one B in the event. No momentum restrictions are placed on the second lepton, which in the case of ARGUS and CLEO is an $e^\pm$. Angular correlations, however, are used to ensure that the second lepton comes from the other B in the event. The unlike-sign and like-sign lepton momentum spectra are expressed in terms of the primary ($B(b)$), and cascade ($B(c)$), branching fractions [27,22,23].

$$\frac{dN_{\pm\mp}}{dp} \sim \epsilon(p)\left(\frac{dB(b)}{dp}(1-\chi) + \frac{dB(c)}{dp}\chi\right), \tag{5.1}$$

$$\frac{dN_{\pm\pm}}{dp} \sim \frac{dB(b)}{dp}\chi + \frac{dB(c)}{dp}(1-\chi). \tag{5.2}$$

Here $\epsilon(p)$ is the momentum dependent efficiency of a cut that removes unlike-sign dileptons originating from a single B decay and χ parameterizes $B^0 - \overline{B}^0$ mixing. The primary and secondary electron spectra were obtained by solving these two equations. It is claimed that there is no model dependence for the measured momentum spectrum $\frac{dB(B\to Xe\nu)}{dp}$, where $P > 0.6$ GeV/c [23]. Refs. [22,23] have subtracted backgrounds coming from inclusive charmed baryon and D_s production in B decays.

a. The $\overline{B} \to \overline{D} \to \ell^-$ Background

The background from $\overline{B} \to \overline{D} \to \ell^-$ transitions however, was not taken into account. To clarify this criticism note that if there were no mixing ($\chi = 0$), the $\overline{B} \to \overline{D} \to \ell^-$ transitions would feed into the unlike-sign dilepton data sample. The "model independent" analysis is therefore more complicated than currently believed, but nevertheless possible once one differentiates between the conventional $b \to c \to e^+$, and the additional $b \to \bar{c} \to e^-$, secondary lepton sources.

To accurately account for the background due to $\overline{B} \to \overline{D} \to \ell^-$, one has to study the $D - \ell^\pm$ and $D^* - \ell^\pm$ correlations, where the $D^{(*)}$ and lepton have different B parents. In such a study, one must

(a) remove $B_d - \overline{B}_d$ mixing effects, and

(b) determine the probability that a wrong-sign charm ($\overline{D}$) is seen as a $\overline{D}^0$ as opposed to a D^- [since their semileptonic branching fractions differ].

Let us explain what is involved in our case. Denote by $D^{(*)}$ the sum of the charged $D^{(*)+}$ and neutral $D^{(*)0}$. The inclusive wrong-charm rate is predicted to satisfy,

$$\Gamma(B^- \to \overline{D}^{(*)} X) = \Gamma(\overline{B}_d \to \overline{D}^{(*)} X) \,, \tag{5.3}$$

whereas the right-charm rate satisfies

$$\Gamma(B^- \to D^{(*)} X) \approx \Gamma(\overline{B}_d \to D^{(*)} X) \,. \tag{5.4}$$

While the color allowed and color suppressed B decay amplitudes interfere for the B^-, they do not for the neutral $\overline{B}_d$. Given the inclusive nature of the processes under consideration, it is expected that the above approximation will be still valid. Since the charged and neutral B lifetimes are approximately equal [58,59],

$$B(B^- \to \overline{D}^{(*)} X) \approx B(\overline{B}_d \to \overline{D}^{(*)} X) \,, \tag{5.5}$$

$$B(B^- \to D^{(*)} X) \approx B(\overline{B}_d \to D^{(*)} X) \,, \tag{5.6}$$

the $B_d - \overline{B}_d$ mixing removal is now straightforward from measurements of the $\ell^{\pm} - D$ and $\ell^{\pm} - \overline{D}^{(*)}$ correlations, separately [57] (where the hard primary lepton comes from one B and the charmed hadron from the other B in the process).

With mixing successfully removed, one has the separate inclusive BR's into wrong-charmed $\overline{D}$ and $\overline{D}^*$, for an unmixed $\overline{B}$. Isospin symmetry tells us that the wrong-charm $\overline{D}^*$'s are seen in equal fractions as D^{*-} and $\overline{D}^{*o}$, which is also true for the wrong-charmed $\overline{D}$'s that do not originate from $\overline{D}^*$'s !

Note that the procedure just described ignores (a) kinematic threshold effects where $\bar{c}s \to D_s^{**-}$ in the neighborhood of the $\overline{D}^{(*)}\overline{K}$ mass, and (b) the Cabibbo suppressed transition $W \to \bar{c}d \to D^{(*,**)-}$. These small effects can be incorporated if desired. The relative fractions of the wrong-charmed mesons hadronizing into D^- and $\overline{D}^0$ can therefore be experimentally determined to allow the accurate modelling of the $\overline{B} \to \overline{D} \to \ell^-$ background.

If all other backgrounds were modelled correctly, the subtraction of the $\overline{B} \to \overline{D} \to \ell^-$ background would decrease the semileptonic BR of B mesons since, as discussed above, the various analyses have taken the lepton from the decay of the wrong- charmed hadron ($\overline{B} \to \overline{D} \to \ell^-$) to be primary which incorrectly increased the primary component. We suspect however that CLEO has oversubtracted some of the other $b \to \bar{c}s \to e^-$ backgrounds. It may therefore be worthwhile to quantify our expectations.

An elaborate account of the "model independent" inclusive semileptonic $B(\overline{B} \to X\ell\bar{\nu})$ measurement can be found in Roy Wang's thesis [22] and in Ref. [23]. Since the predominant representative of the $\bar{c}s$ background (in $b \to c\bar{c}s$ transitions) is D_s^-, we needed to understand it and therefore obtained the following central value parameterization [60]:

$$\int_{0.6\,\mathrm{GeV/c}}^{2.6\,\mathrm{GeV/c}} dp_e \ \frac{dB}{dp_e}(\overline{B} \to Xe\bar{\nu}) = [9.85 + 0.434\,(1-w)]\,\% \ . \tag{5.7}$$

Here w denotes the actual $b \to \bar{c}s \to e^-$ background in units of the original D_s background used by Wang in his thesis,

$$w(s) \equiv \frac{s \cdot B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D\overline{D}\,\overline{K}X} + B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X}}{B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X\ [\mathrm{Wang}]}} \ . \tag{5.8}$$

The quantity $s = 0.2 \pm 0.1$ is a correction factor, which takes into account the fact that the diagonal cut invented by Wang [22] suppresses the $B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D\overline{D}\,\overline{K}X}$ background more than that of the $B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X}$, on account of its softer lepton spectrum. In general [61]

$$
\begin{aligned}
& B(b \to \bar{c}s \to \ell^-)|_{\overline{B} \to D\overline{D}\,\overline{K}X} = \\
&= \frac{1}{2}\,\frac{B(\overline{B} \to \overline{D}X)}{(1+r)}\,B(\overline{D}^0 \to \ell^- X)\Big\{1 + r + B\left(D^{*-} \to \overline{D}^0\pi^-\right) + \\
&+ \frac{B(D^- \to \ell^- X)}{B(\overline{D}^0 \to \ell^- X)}\,\left[r + B\left(D^{*-} \to D^- X^0\right)\right]\Big\} \approx \\
&\approx \frac{1}{2}\,\frac{B(\overline{B} \to \overline{D}X)}{(1+r)}\,B(\overline{D}^0 \to \ell^- X)\Big\{1 + r + B(D^{*-} \to \overline{D}^0\pi^-) + \\
&+ \frac{\tau(D^+)}{\tau(D^0)}\,\left[r + B\left(D^{*-} \to D^- X^0\right)\right]\Big\}\,. \qquad (5.9)
\end{aligned}
$$

The last approximation is excellent and assumes the same inclusive semileptonic rates for D^- and $\overline{D}^0$. The observable r denotes

$$
r \equiv \frac{B(\overline{B} \to X + \overline{D}_{dir})}{B(\overline{B} \to X + \overline{D}^*)}\,, \qquad (5.10)
$$

where $\overline{D}_{dir}$ denotes wrong-charm $\overline{D}$ without $\overline{D}^*$ parentage. As demonstrated above, r can be experimentally determined from $\ell^\pm - D$ and $\ell^\pm - D^*$ correlations. Whereas the D_s background in Wang's thesis was taken to be [22,60],

$$
B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X\,[\mathrm{Wang}]} = B(\overline{B} \to D_s^- X)B(D_s^- \to Xe^-\bar{\nu}) = 0.1181 \times 0.0793 = 9.36 \times 10^{-3}\,, \qquad (5.11)
$$

we use a smaller inclusive semielectronic D_s BR,

$$
\begin{aligned}
B(D_s^- \to Xe^-\bar{\nu}) &= \frac{\Gamma(D_s^- \to Xe^-\bar{\nu})}{\Gamma(\overline{D}^0 \to Xe^-\bar{\nu})}\,\frac{\tau(D_s)}{\tau(D^0)}\,B(\overline{D}^0 \to Xe^-\bar{\nu}) \approx \\
&\approx B(\overline{D}^0 \to Xe^-\bar{\nu}) = (6.64 \pm 0.18 \pm 0.29)\%\,. \qquad (5.12)
\end{aligned}
$$

The reason is that while the lifetime ratio is measured as [8],

$$
\frac{\tau(D_s)}{\tau(D^0)} = 1.12 \pm 0.05 \qquad (5.13)
$$

ISGW2 [26] predicts a substantial decrease in the inclusive semielectronic D_s rate versus that of the D^0, because of the restricted phase space of $D_s \to \eta' e^- \bar{\nu}$.

The portion of the inclusive D_s yield in B decays that contributes to the background is [62]

$$B(\overline{B} \to D_s^- X) = 0.100 \pm 0.017 \,, \tag{5.14}$$

so that we obtain

$$B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X} = B(\overline{B} \to D_s^- X) B(D_s^- \to X e^- \bar{\nu}) \approx 6.64 \times 10^{-3} \,. \tag{5.15}$$

Table V estimates $B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D\overline{D}\,\overline{K}X}$ and w, as a function of r. It uses the recent CLEO measurement [63],

$$B(\overline{D}^0 \to X e^- \bar{\nu}) = (6.64 \pm 0.18 \pm 0.29)\ \% \,,$$

and takes the D^+/D^0 lifetime ratio and $B(D^{*-} \to \overline{D}^0 \pi^-)$ from the 1994 particle data group [8]. Our guess for the "actual" $b \to \bar{c}s \to e^-$ background is roughly as large as that of the original D_s^- background employed in the published CLEO II analysis [23] and in Wang's thesis [22]. It is relatively insensitive to the precise value chosen for r, as seen in Table V. For $w = 0.9$, the primary lepton BR between $0.6 \le p_e \le 2.6$ GeV/c is [see Eq. (5.7)],

$$B(\overline{B} \to X e^- \bar{\nu}, p_e \ge 0.6 \text{ GeV/c}) = 9.89\% \,. \tag{5.16}$$

The undetected primary fraction is estimated to be [23],

$$\frac{B(\overline{B} \to X e^- \bar{\nu},\ p_e < 0.6 \text{ GeV/c})}{B(\overline{B} \to X e^- \bar{\nu})} = (6.1 \pm 0.5)\% \,. \tag{5.17}$$

We therefore interpret the published CLEO II data [23,22] to mean

$$B(\overline{B} \to X e^- \bar{\nu}) = (10.5 \pm 0.5)\% \,, \tag{5.18}$$

which is in excellent agreement with the published CLEO II result

$$B(\overline{B} \to X e^- \bar{\nu}) = (10.49 \pm 0.46)\% \,. \tag{5.19}$$

We found that the impact of the $\overline{B} \to \overline{D} \to e^-$ background is much reduced on account of its soft momentum spectrum, which causes it to be efficiently removed by the Wang cut [22]. Because CLEO has probably oversubtracted the $\overline{B} \to D_s^- \to e^-$ background, not much changed in overall normalization when we added the $\overline{B} \to \overline{D} \to e^-$ background to our $\overline{B} \to D_s^- \to e^-$ estimate. However, we predict the $b \to \bar{c}s \to e^-$ background to be softer than that which they used, resulting in a stiffer primary lepton spectrum than currently measured by CLEO [22,23].

Clearly, other backgrounds must be modified. For instance, the "e from same B background" listed in Table 4.5 of Wang's thesis is predicted to increase because of an expected increase in the exclusive $B(\overline{B} \to D^{(*)}\ell\bar{\nu})$ which in turn is due to an expected decrease in $B(D^0 \to K^-\pi^+)$.

We encourage CLEO to carry out the necessary modifications. We have seen that the $\overline{B} \to \overline{D} \to e^-$ background is much reduced for the present analyses at symmetric $\Upsilon(4S)$ factories, primarily because of a fortuitous momentum cut $p_e > 0.6$ GeV/c. At asymmetric $\Upsilon(4S)$ factories and for Z^0 factories similar reductions do not occur and so this background will contribute significantly and must be carefully subtracted. It is partially responsible for the apparent larger $B(b \to X\ell\bar{\nu})$ at Z^0 factories compared to $\Upsilon(4S)$ machines, see Section V.A.3 below.

Before moving on to Z^0 factories, we will next discuss possible flaws in the treatment $B^0 - \overline{B}^0$ mixing effects by ARGUS and CLEO.

b. Removal of $B^0 - \overline{B}^0$ Mixing Effects

We believe that the removal of $B^0 - \overline{B}^0$ mixing effects is not correctly performed in experimental analyses. CLEO [64], for instance, has removed mixing from their observed $\Lambda - \ell^\pm$ data sample by adding and subtracting a constant. ARGUS [65] has implicitly assumed equal inclusive baryon production fractions from B_d and B^+ decays separately. The same implicit assumption was made by CLEO when $B(\overline{B} \to \overline{\Lambda}_c X)/B(\overline{B} \to \Lambda_c X) = 0.20 \pm 0.14$ was determined from $\ell^\pm\Lambda_c$ correlations [15]. The quoted error does not include

the following systematic uncertainty. Suppose that only charged B's produce $\overset{(-)}{\Lambda}_c$ baryons. Then the $\ell^{\pm}\Lambda_c$ correlations should clearly not be corrected for $B^0 - \overline{B}^0$ mixing effects. On the other hand, if only neutral B's produce $\overset{(-)}{\Lambda}_c$, then $B^0 - \overline{B}^0$ mixing effects are maximal and must be removed.

Ref. [57] discusses how to properly take into account otherwise confusing $B^0 - \overline{B}^0$ mixing effects. We will briefly summarize the procedure here. The charged and neutral B meson lifetimes and production rates are currently found to be approximately equivalent and will be assumed to be identical. (It is a straightforward exercise to incorporate inequalities if such are observed.) Suppose that one wishes to determine $B(B \to TX)$ and $B(\overline{B} \to TX)$, where T denotes any flavor specific partially reconstructed final state. $N_{\ell^{\pm}T}$ denotes the produced number of $T - \ell^{\pm}$ correlations, where T and primary $\ell^{\pm}$ originate from different B mesons,

$$N_{\ell^+T} \sim B(B^- \to TX) + (1 - 2\chi)B(\overline{B}_d \to TX) + 2\chi\ B(B_d \to TX)\ . \tag{5.20}$$

$$N_{\ell^-T} \sim B(B^+ \to TX) + (1 - 2\chi)B(B_d \to TX) + 2\chi\ B(\overline{B}_d \to TX)\ . \tag{5.21}$$

The above two equations hold for each momentum bin of T, separately. For the dilepton analyses, $T = e^-$ and the primary component satisfies

$$B(B^- \to TX) = B(\overline{B}_d \to TX) = B(\overline{B} \to Xe^-\bar{\nu}) \equiv B(b) \tag{5.22}$$

If the secondary component would have satisfied

$$B(\overline{B}_d \to \overline{T}X) = B(B^- \to \overline{T}X) = B(\overline{B} \to Xe^+\nu)\ , \tag{5.23}$$

then we would recover Eqs. (5.1)-(5.2), and the removal of $B_d - \overline{B}_d$ mixing effects would not have to be modified. The predominant source of e^+ in $\overline{B}$ decays originates via the decay chain $\overline{B} \to D \to e^+$. We thus predict that

$$c \equiv \frac{B(\overline{B}_d \to e^+X)}{B(B^- \to e^+X)} > 1\ , \tag{5.24}$$

because

$$B(D^+ \to e^+X)/B(D^0 \to e^+X) \approx \tau(D^+)/\tau(D^0) = 2.55\ . \tag{5.25}$$

The dilepton analysis requires the following modifications (where the momentum dependence of the signal $T = e^-$ is implicit):

$$N_{\ell+T} \sim 2[(1-\chi)B(b) + \chi c\ B(c)]\ , \tag{5.26}$$

$$N_{\ell-T} \sim (1 + c - 2c\chi)B(c) + 2\chi B(b)\ . \tag{5.27}$$

$B(b)$ denotes the primary lepton spectrum in B decays, and $B(c)$ denotes the secondary lepton spectrum from charged B decays [66],

$$B(c) \equiv B(B^- \to D \to e^+)\ .$$

Note that the original dilepton analyses are recovered for $c = 1$. However, for the estimated value of $c \approx 1.76$ [67] the result is to decrease the published CLEO II value of

$$B(\overline{B} \to Xe^-\bar{\nu}) = (10.49 \pm 0.46)\% \tag{5.28}$$

to [60]

$$B(\overline{B} \to Xe^-\bar{\nu}) = (10.4 \pm 0.5)\%\ , \tag{5.29}$$

which is our estimate for this effect.

3. Inclusive Lepton Analyses at Higher Energy Colliders

At energies above the $\Upsilon(4S)$ it is also possible to determine the inclusive semileptonic BR of B hadrons. The difference with $\Upsilon(4S)$ factories is that there are now more B species being produced. At Z^0 factories, the production fractions [denoted by p_i] are approximately

$$\overline{B}_d : B^- : \overline{B}_s : \Lambda_b \approx 0.4 : 0.4 : 0.12 : 0.08\ . \tag{5.30}$$

Thus the inclusive semileptonic BR measurements are a weighted sum over all produced weakly decaying B hadron species. Measurements at the Z^0 resonance are comparable in accuracy to those at the $\Upsilon(4S)$. A recent LEP/SLC review determined the primary component to be [1]

$$B(b \to \ell^-) = (11.11 \pm 0.23)\% \; . \tag{5.31}$$

This is significantly larger than the $\Upsilon(4S)$ measurements and appears puzzling at first sight, especially since one would expect the smaller Λ_b lifetime to result in a smaller BR relative to that measured at $\Upsilon(4S)$ [30,31]. If no lifetime cuts are imposed upon the collected semileptonic data sample, then

$$\begin{aligned} B(b \to \ell^-) = p_d \frac{\Gamma(\overline{B}_d \to X\ell^-\bar{\nu})}{\Gamma(B_d)} + p_u \frac{\Gamma(B^- \to X\ell^-\bar{\nu})}{\Gamma(B^-)} + \\ + \frac{p_s}{2}\left(\frac{\Gamma(\overline{B}_s \to X\ell^-\bar{\nu})}{\Gamma(B_s^H)} + \frac{\Gamma(\overline{B}_s \to X\ell^-\bar{\nu})}{\Gamma(B_s^L)}\right) + p_{\Lambda_b} \frac{\Gamma(\Lambda_b \to X\ell^-\bar{\nu})}{\Gamma(\Lambda_b)} \; . \end{aligned} \tag{5.32}$$

Note that the heavy and light B_s mesons could have a sizable width difference [68,44]. The average B_s width is however predicted to be $\Gamma(B_d)$ to excellent accuracy [58,43,44],

$$\frac{\Gamma(B_s^H) + \Gamma(B_s^L)}{2} = \Gamma(B_d)\; [1 + \mathcal{O}(1\%)] \; . \tag{5.33}$$

In addition, contrary to the widely held belief that $\tau(B^-)/\tau(B_d)$ is larger than one [58], it has been found that theory could accommodate shorter lived B^- than $\overline{B}_d$ [43,44].

Great care is exercised by the LEP/SLC experiments to guarantee an unbiased B data sample for use in the extraction of $B(b \to \ell)$. Experimentalists are aware that the extraction will be biased towards larger $B(b \to \ell)$ values if a lifetime cut is employed in the hemisphere of the signal lepton tag. The longer lived B species have larger inclusive semileptonic BR under the assumption that the semileptonic decay width is the same for all B flavored hadrons. Lifetime cuts are effective in highly enriching the B data sample and suppressing the $Z \to c\bar{c} \to \ell$ background.

For this reason the ALEPH collaboration prepares a pure B sample by means of requirements applied to the collection of tracks belonging to one hemisphere in the event, and

extracts $B(b \to \ell)$ and $B(b \to c \to \ell)$ from signals in the opposite hemisphere. This is referred to as the single lepton and same side dilepton method [28]. The ALEPH values [28] for $B(b \to \ell)$ from this method and also the single lepton and opposite side dilepton method need to be updated, since they both rely on an older measured momentum spectrum of $b \to \ell$ at threshold machines (CLEO) [29]. In particular, a new CLEO measurement has become available [22] which shows a stiffer primary lepton momentum spectrum than was seen in earlier CLEO results [29]. In addition, the extraction of the primary $b \to \ell$ spectrum from dilepton analyses at threshold machines has yet to remove the $\overline{B} \to \overline{D} \to \ell^-$ component. The correct extraction of the primary momentum spectrum is best performed by CLEO, and therefore we will not attempt to quantify the changes for $B(b \to \ell)$ at Z^0 factories for the above two methods.

On the other hand, ALEPH employs the charge correlation method to determine $B(b \to \ell)$ with no dependence on spectra obtained from lower energy data [28]. This allows us to be more quantitative, especially because the extraction of $B(b \to \ell^-)$ depends strongly on the correct modelling of the $b \to \bar{c}s \to \ell^-$ background. The ALEPH collaboration recently reported a preliminary result using this method [28],

$$B(b \to \ell^-) = (11.01 \pm 0.38)\% \tag{5.34}$$

with the $b \to \bar{c}s \to \ell^-$ background modelled by

$$B(b \to \bar{c}s \to \ell^-) = (1.440 \pm 0.288)\% \; . \tag{5.35}$$

At $\Upsilon(4S)$ factories the opposite sign dilepton data sample has a large contribution from single B decays. The CLEO collaboration efficiently suppresses that background by the diagonal cut invented by Wang [22]. The cut has the desirable feature of reducing the sensitivity of $B(\overline{B} \to Xe^-\bar{\nu})$ to the precise value of $B(b \to \bar{c}s \to e^-)$. The central value behaves quantitatively as follows [see Eqs. (5.7)-(5.8) and (5.17)].

$$\begin{aligned} B(\overline{B} \to Xe^-\bar{\nu}) = 0.1095 &- 0.494 \; B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D_s^- X} + \\ &- 0.494 \cdot s \; B(b \to \bar{c}s \to e^-)|_{\overline{B} \to D\overline{D}\,\overline{K}X} \; , \end{aligned} \tag{5.36}$$

where s is defined just below Eq. (5.8). In contrast, at the Z^0 resonance the two B hadrons generally decay in opposite hemispheres so that no such cut is required. In addition, the leptons experience a significant boost. We therefore expect a larger sensitivity to the $b \to \bar{c}s \to \ell^-$ background, and indeed, evidence for this is found in the preliminary analysis of ALEPH [69]

$$B(b \to \ell^-) = 0.1179 - 0.54 \cdot B(b \to \bar{c}s \to \ell^-) \,. \tag{5.37}$$

Since the J/ψ and ψ' backgrounds already have been explicitly subtracted by ALEPH, what remains is

$$\begin{aligned} B(b \to \bar{c}s \to \ell^-) = {} & B(\overline{B} \to D_s^- X) B(D_s^- \to \ell^- X) + \\ & + B(\overline{B} \to \overline{D} X)\; B(\overline{D} \to \ell^- X) + B(\overline{B} \to \overline{\Lambda}_c X)\; B(\overline{\Lambda}_c \to \ell^- X) \,. \end{aligned} \tag{5.38}$$

The actual values for $B(D_s^- \to \ell^- X)$ differ for $\Upsilon(4S)$ and Z^0 analyses. The latter experiments record a larger fraction of the leptons in the decay chain

$$\begin{array}{l} \overline{B} \to X D_s^- [\to \tau^- \bar{\nu}] \\ \qquad\qquad\quad \hookrightarrow \ell^- \nu \bar{\nu} \end{array} \tag{5.39}$$

than is true for the former experiments, because of the large boost of the B hadrons. Whereas CLEO/ARGUS used only $e^\pm$ as signal leptons, the LEP/SLC uses both $e^\pm$ and $\mu^\pm$. [ALEPH assumes the same background BR for electrons and muons [28]. We caution that the process $B(D_s^- \to \mu^- \bar{\nu}) \approx 1\%$ enhances the $b \to \bar{c}s \to \mu^-$ background over that of the $b \to \bar{c}s \to e^-$.] To make our point more forcefully, we oversimplify and almost ignore process (5.39) for CLEO/ARGUS while taking it fully into account for Z^0 factories. The D_s's from $\overline{B} \to D_s^- X$ then satisfy :

$$\begin{aligned} B(D_s^- \to \ell^- X)|_{Z^0} = {} & B(D_s^- \to e^- X)|_{\Upsilon(4S)} + \\ & + B(D_s^- \to \ell^- \bar{\nu}) + B(D_s^- \to \tau^- \bar{\nu})\; B(\tau^- \to \ell^- \nu \bar{\nu}) \approx \\ & \approx 6.64 \times 10^{-2} + 0.0091 + 0.091 \times 0.18 = 0.092 \,. \end{aligned} \tag{5.40}$$

Here the values are for the case of a muon. The background is then estimated as

$$B(b \to \bar{c}s \to \mu^-) = 0.10 \times 0.092 + 0.01 + 1.6 \times 10^{-4} \approx 0.02 \,. \tag{5.41}$$

This larger background reduces the primary lepton BR of ALEPH to

$$B(b \to \ell^-) = (10.7 \pm 0.4)\% \,. \tag{5.42}$$

Clearly, the correct acceptances and efficiencies for each relevant process must be obtained by the various Z^0 experiments. One of the main points of this subsection is that now that CLEO has completed the mapping out of the $b \to c + \bar{c}s$ processes, we recommend the use of the measured BR's and momentum spectra of the wrong-charm $b \to \bar{c}$ transitions for a correct modelling of the $b \to \bar{c}s \to \ell^-$ background at the Z^0. The removal of $B^0 - \overline{B}^0$ mixing effects is more subtle than currently performed by ALEPH.

The secondary lepton component experiences different (probably larger) $B - \overline{B}$ mixing effects than the primary lepton component (see Section V.A.2.b). The recent charge correlation method presented by ALEPH did not take into account different mixing effects of primary and secondary leptons. This is not the only analysis that has to be modified for such effects. All published reports [32], which determine the average (time integrated) mixing parameter $\overline{\chi}$ from dilepton analyses, must be modified, because they implicitly assumed the same average mixing effects for the primary and secondary lepton components. This impacts measurements of $B(b \to \ell^-)$ that involve $\overline{\chi}$.

We hope to have motivated experimentalists to reanalyze their data so as to find out the cause of the apparent puzzle of a significantly larger inclusive semileptonic BR of B hadrons at the Z^0 resonance than at the $\Upsilon(4S)$.

B. Exclusive Semileptonic B Decays

Table VI catalogues the various exclusive semileptonic processes. Class 1 consists of the exclusive $\overline{B} \to D^* \ell^- \bar{\nu}$ processes. The most accurate measurement of such a process, where D^{*+}'s are fully reconstructed, was performed by CLEO [70,21]

$$B(\overline{B}^0 \to D^{*+}\ell^-\nu) = (4.49 \pm 0.50)\% \,, \tag{5.43}$$

whereas that for the charged B decay has a larger error [21],

$$B(B^- \to D^{*o}\ell^-\bar{\nu}) = (5.34 \pm 0.80)\% \,. \tag{5.44}$$

The last two equations used the 1994 PDG values for BR's of the weakly decaying charm decays [21]. We will be conservative and keep the full error and factor out $B(D^0 \to K^-\pi^+)$ explicitly (see Table VI). Most recently CLEO [71] reported accurate measurements for exclusive $\overline{B}^0 \to D^+$ transitions via the missing mass and neutrino reconstruction techniques, respectively,

$$\begin{aligned} B(\overline{B}^0 \to D^+\ell^-\overline{\nu})\ B(D^+ \to K^-\pi^+\pi^+) &= 0.00159 \pm 0.00029 \ , \\ &= 0.00172 \pm 0.00036 \quad . \end{aligned} \tag{5.45}$$

The exclusive $B^- \to D^0$ BR measurement of CLEO has a larger error, namely,

$$B(B^- \to D^0\ell^-\overline{\nu}) = (1.95 \pm 0.55)\% \quad [6] \,. \tag{5.46}$$

Since the experimental situation regarding p wave states is controversial (ARGUS [72] and OPAL [73] claim to see most of the remainder as p wave excitations, whereas ALEPH [74] and CLEO [6,75] do not) and since current experiments cannot observe semileptonic B decays with broad charmed p waves, we resort to a model independent sum rule [33]. This sum rule obtains the sum over all (both narrow and broad) charmed p wave semileptonic BR's, $\overline{B} \to D^{**}\ell\nu$ from the slope ρ^2 of the Isgur-Wise function which parameterizes the $\overline{B} \to D^{(*)}\ell\nu$ process,

$$\frac{B(\overline{B} \to D^{**}\ell\nu)}{B(\overline{B} \to X_c\ell\nu)} \approx \frac{\left(\rho^2 - \frac{1}{4}\right)}{0.5}\ (0.08 \pm 0.04) \,. \tag{5.47}$$

Current slope values yield that about 10% of the inclusive semileptonic decays are $D^{**}\ell\bar{\nu}$ [76], a value consistent with calculations of various models [26,77].

One may argue that present data rule out such a small p wave contribution [72,73], but none of the existing analyses have removed the $\overline{B} \to D\overline{D}\ \overline{K}X$ background. ARGUS [72]

claimed to have measured

$$B(\overline{B} \to D^{**}\ell\nu) = (2.7 \pm 0.5 \pm 0.5)\% \ ,$$

by applying the missing mass technique to their $\overline{B} \to D^{*}\ell^{-}X$ data sample [72]. But the shape of their missing mass spectrum indicates [at least to us] a sizeable $\overline{B} \to D\overline{D}^{*}\overline{K}X, D^{*}\overline{D}\ \overline{K}X$ component where one of the charms decayed semileptonically. To buttress their claim, ARGUS searched for additional π^{-}'s, which they then correlated with the D^{*+}, to form a peak. While the additional π^{-} has some discriminating power, there could still be sizable backgrounds such as

$$\begin{aligned} \overline{B} &\to D^{*+}D^{*-}\overline{K}X \\ &\qquad \hookrightarrow \pi^{-}\overline{D}^{0}[\to \ell^{-}X] \end{aligned} \tag{5.48}$$

Note that we have assumed that no π^{-}/K^{-} misidentification has been made. To the extent that this is not true, more background sources become important.

The LEP measurements can use significantly displaced vertices to isolate their $\overline{B} \to D^{**}\ell^{-}\bar{\nu}$ signal. If only loose particle identification cuts have been applied, then the primary (or secondary) kaon in $\overline{B} \to D^{(*)}\overline{D}^{(*)}\overline{K}X$ could have been combined with the $D^{(*)}$ to form a fake signal. Another potential problem occurs if a sizable fraction of the background is seen as

$$\overline{B} \to D^{**}\overline{D}[\to \ell^{-}KX]\overline{K}X = D^{**}\ell^{-}X \ .$$

This background is removable, for instance, on account of the two additional kaons it generates, via differences in $D^{**}\ell^{-}$ correlations, or by means of momentum or relative transverse momentum spectrum of the lepton. Because experiments have to sort out what exactly has been measured, we suggest for now the use of the Bjorken-Isgur-Wise sum rule.

Model calculations find negligible semileptonic BR's with excited charm resonances beyond the p wave states [77,26]. Because also the truly "non resonant" $[D^{(*)}n\pi\ell\bar{\nu}, D_s\overline{K}X\ell\bar{\nu}]$ component is predicted to be small [78,79,77,80] [at the (5-10)% level of the inclusive semileptonic BR], it appears that the sum over all exclusive semileptonic modes does not saturate

the inclusive semileptonic BR (see Table VI). To see the excess clearly, choose the recent CLEO value

$$B(D^0 \to K^-\pi^+) = (3.91 \pm 0.19)\% \,, \tag{5.49}$$

and use classes $1^+, 2-5$ of Table VI. The combined BR is

$$BR(1^+) + BR(2-5) = (8.2 \pm 0.9)\% \tag{5.50}$$

and falls significantly below the inclusive measurements. [If the more poorly measured $B(\overline{B} \to D^{*\circ}\ell^-\bar{\nu})$ is used, one obtains from Table VI,

$$BR(1^0) + BR(2-5) = (9.1 \pm 1.1)\% \,.] \tag{5.51}$$

The $\Upsilon(4S)$ experiments have an additional experimental handle which could shed light upon this issue [81].

We note that the shortfall is solved by sufficiently reducing the value of $B(D^0 \to K^-\pi^+)$. Table VI furnishes the BR's for the equation [82]

$$BR(1^+) + BR(2-5) = BR(t)\ [BR(1^0) + BR(2-5) = BR(t)]. \tag{5.52}$$

The above equation is solved for the following value

$$B(D^0 \to K^-\pi^+) = (2.9 \pm 0.4)\%\ [(3.3 \pm 0.5)\%]. \tag{5.53}$$

There is no reason yet to be concerned about the smallish $B(D^0 \to K^-\pi^+)$ value, because the coefficient of $(\rho^2 - 1/4)$ for the p wave BR (Class 3 of Table VI) could have been underestimated, and so could the nonresonant BR (Class 5 of Table VI). The accurate measurements of $B(\overline{B} \to D^*\ell\overline{\nu})$ and $B(\overline{B} \to D\ell\overline{\nu})$ allow CLEO to perform consistency checks with the inclusive data samples. This enables CLEO to probe the fraction of the time semileptonic decays are not seen as $\overline{B} \to D^{(*)}\ell\overline{\nu}$. Future theoretical investigations would then be useful in estimating how to partition that remainder into Classes 3 and 5 of Table VI.

There appears to exist weighty evidence from the low values of R_c, n_c and sum over exclusive semileptonic BR's of B decays that $B(D^0 \to K^-\pi^+)$ ought to be lower than presently estimated. The precise determination of $B(D^0 \to K^-\pi^+)$ is of paramount importance, because this mode calibrates much that is known in heavy flavor (both charm and beauty) decays. As indicated above, it is of significance in ascertaining whether there is a Standard Model reason for the apparent discrepancy between theory and experiment regarding R_b. The next section thus suggests several methods that accurately measure $B(D^0 \to K^-\pi^+)$ from correlations with the primary lepton data sample from B decays. One of them uses the fact that

$$B(\overline{B} \to D^+\ell^- X) + B(\overline{B} \to D^0\ell^- X) + B(\overline{B} \to D_s^+\ell^- X) \approx B(\overline{B} \to X_c\ell^-)\,. \qquad (5.54)$$

This method does not involve soft π^+ detection efficiencies [from $D^{*+} \to \pi^+ D^0$ decays], and is thus complementary to the existing determinations of $B(D^0 \to K^-\pi^+)$ [8].

VI. MEASURING $B(D^0 \to K^-\pi^+)$ FROM $\overline{B} \to X_C\ell\nu$ PROCESSES

Our suggestion that a sizable fraction of all B decays are seen as $\overline{B} \to D\overline{D}\ \overline{K}X$ [18] has recently been proven by CLEO from $\ell^\pm - D$ correlations [17]. A severe momentum cut ($p > 1.5$ GeV/c) guarantees the lepton to be primary, and angular correlations between $\ell - D$ allow us to measure separately the two cases in which [83]:

(a) the lepton originates from one B and the D originates from the other B in the event, and

(b) both the lepton and the D come from a single B decay.

Whereas case (a) probes our suggestion, case (b) is important in its own right because it provides an accurate method for determining $B(D^0 \to K^-\pi^+)$:

The number of $\overline{B} \to D^0\ell^-, D^+\ell^-, D_s^+\ell^-, \Lambda_c^+\ell^-$ must equal the number of ℓ^- produced from $b \to c\ell^-$ processes. Here all leptons satisfy a high momentum cut of say $p > 1.5$ GeV/c.

Backgrounds from the continuum and from $b \to u\ell^-$ transitions have been subtracted. Good vertexing would allow further suppression of the backgrounds relative to the $b \to c\ell^-$ signal. The semileptonic decay $\overline{B} \to D_s^+ \overline{K} X \ell\nu$ has not yet been observed, and stringent upper limits exist [62]. While it is expected to occur with a small few permille BR to start with, it will be even less important fractionally for the high end lepton momentum region advocated here. This process is currently being estimated [80]. The process $\overline{B} \to \Lambda_c^+ \overline{N} X \ell^- \bar{\nu}$ is expected to be utterly negligible at the current level of accuracy. Denote the produced number of events $(f\ell^-)$ from $\overline{B} \to X_c \ell^- \bar{\nu}$ transitions by $N[f\ell^-]$. Then

$$\frac{N[D^0\ell^-] + N[D^+\ell^-] + N[D_s^+\ell^-] + N[\Lambda_c^+\ell^-]}{N[c\,\ell^-]} = 1\,, \tag{6.1}$$

where $N[c\,\ell^-]$ denotes the produced number of $b \to c\ell^-$ processes. Define further,

$$L\,[(f)_H] \equiv \frac{N\,[(f)_H\,\ell^-]}{N[c\,\ell^-]}\,, \tag{6.2}$$

$$r_+ \equiv \frac{B(D^+ \to K^-\pi^+\pi^+)}{B(D^0 \to K^-\pi^+)}\,, \quad r_s \equiv \frac{B(D_s^+ \to \phi\pi^+)}{B(D^0 \to K^-\pi^+)}\,. \tag{6.3}$$

The desired BR is then

$$B(D^0 \to K^-\pi^+) = \frac{L[(K^-\pi^+)_{D^0}] + L[(K^-\pi^+\pi^+)_{D^+}]\,/\,r_+ + L[(\phi\pi^+)_{D_s}]/\,r_s}{1 - L[(pK^-\pi^+)_{\Lambda_c}]\,\frac{1}{B(\Lambda_c \to pK^-\pi^+)}}\,. \tag{6.4}$$

$B(D^0 \to K^-\pi^+)$ is measured by determining the quantities on the right hand side of the above equation, where, for instance, $L[(K^-\pi^+)_{D^0}]$ denotes the fraction of $\overline{B} \to (K^-\pi^+)_{D^0}\ X\ \ell^-\bar{\nu}$ events relative to $\overline{B} \to X_c\ell^-\bar{\nu}$ events [84].

For now the use of 1 for the denominator is a useful approximation, and the $D_s^+\ell^-/(c\ell^-)$ fraction could either be taken from theory [80] or from experiment once it is observed. Since the $D^+\ell^-/(c\,\ell^-)$ fraction will be substantially smaller than $D^0\ell^-/(c\,\ell^-)$ [because of isospin violating D^* decays], the ratio of BR's r_+ need not be known to the same degree of accuracy that is pursued for $B(D^0 \to K^-\pi^+)$. Still, Menary suggested that it may be feasible to determine r_+ to 2% accuracy from the $\Upsilon(4S)$ continuum [85]. To augment statistical data, we suggest the use of all available final states of charmed hadron decays, because the ratios of BR's to the calibrating modes are well known.

With straightforward modifications, higher energy experiments (such as Z^0 factories) may wish to study the feasibility of determining $B(D^0 \to K^-\pi^+)$ from an analogous analysis. This determination of $B(D^0 \to K^-\pi^+)$ is complementary to the present measurements of $B(D^0 \to K^-\pi^+)$, in that it does not require the observation of the soft π^+ from $D^{*+} \to \pi^+ D^0$ decays.

The process $\overline{B}_d \to D^{*+}\ell^-\bar{\nu}$ allows a second method for determining $B(D^0 \to K^-\pi^+)$ [86]. Here one infers the existence of a D^{*+} from its soft π^+ daughter. CLEO [87] could extract $B(D^0 \to K^-\pi^+)$ by measuring the fraction of the time where the $\pi^+\ell^-$ sample involves an additional $(K^-\pi^+)_{D^0}$, which gives the D^{*+} peak when combined with the soft π^+.

Hadron facilities (such as the CDF collaboration), Z^0 factories and asymmetric B factories could suppress backgrounds by requiring the $\pi^+\ell^-$ sample to form a detached vertex. Once this sample is correlated with a fully reconstructed D^0, which together with the soft π^+ forms the D^{*+}, $B(D^0 \to K^-\pi^+)$ can be extracted. In an analogous spirit, the mode $\overline{B}_d \to D^{*+}\pi^-$ could be also used [87].

We hope to have convinced the reader of the importance of the $D^0 \to K^-\pi^+$ BR, and the need for additional high precision measurements.

VII. HEAVY BARYON PRODUCTION AND DECAY

The calibrating mode of heavy baryon decays is $\Lambda_c \to pK^-\pi^+$. While the world average is [8]

$$B(\Lambda_c \to pK^-\pi^+) = (4.4 \pm 0.6)\% \,, \tag{7.1}$$

this section argues to use instead [16]

$$B(\Lambda_c \to pK^-\pi^+) = (6.0 \pm 1.5)\% \,. \tag{7.2}$$

The world average is dominated by baryon production analyses in B decays [64,65] which assumed that almost always a weakly decaying charmed baryon is involved. The assumption

is invalidated by the observation of significant $\overline{B}$ decays into a charmed meson and a nucleon and/or anti-nucleon,

$$\overline{B} \to D^{(*)} N X, D^{(*)} \overline{N} X \; . \tag{7.3}$$

A straightforward Dalitz-plot analysis predicts that a sizable fraction of all baryon producing $\overline{B}$ decays is likely to be of that form (see the Appendix). The $b \to c + W$ transition, where the virtual W hadronizes as a baryon-antibaryon pair plus perhaps additional debris, provides another source for $\overline{B} \to D^{(*)} N X, D^{(*)} \overline{N} X$ processes. Flavor correlations within the $\overline{B} \to D^{(*)} \overset{(-)}{N} X$ processes allow to distinguish between the two production mechanisms.

An extension of the $\ell^+ D^{(*)}$ correlations presented recently by CLEO [17], may yield the first observation of such processes. A positively charged high momentum lepton and a $D^{(*)}$ meson must originate from two different B's in the $\Upsilon(4S)$ event. An additional nucleon or antinucleon should be searched in that data sample. A positive signal would then most likely demonstrate the existence of the processes given in Eq. (7.3), or very unlikely baryon production in semileptonic $\overline{B}$-decays [88]. The existence of angular correlations between the $\overset{(-)}{N}$ and $D^{(*)}$ would then prove that both particles originate from the same B [89]. If such correlations are found to be sizable (which we predict), the 1994 and 1996 PDG world average for $B(\Lambda_c \to p K^- \pi^+)$ must be abandoned in favor of [16]

$$B(\Lambda_c \to p K^- \pi^+) = (6.0 \pm 1.5)\% \; .$$

One consequence would be that current measurements overestimate heavy baryon production.

VIII. IMPLICATIONS AND CONCLUSIONS

When we try to make sense of the combined experimental evidence reviewed here, we conclude that the absolute BR of charmed hadrons must be reevaluated. This note considered the evidence from the (a) n_c values in B decays, (b) R_c measurements at the Z^0

resonance, and (c) the combined exclusive semileptonic B decay BR's versus the inclusive semileptonic BR. We identified $D^0 \to K^-\pi^+$ as the main culprit and expect that its BR will decrease from the presently accepted value. Some of the consequences of this are that

(a) a sizable fraction of D^0 decays may still have to be accounted for;

(b) $B(\overline{B} \to D^{(*)}\ell\bar{\nu})$ will increase, causing its derived $|V_{cb}|$ to increase;

(c) $B(\overline{B} \to \overset{(-)}{D^0} X)$ and $B(\overline{B} \to D^{\pm}X)$ will increase;

(d) $B(D_s \to \phi\pi^+)$ would decrease, because of its recent "model independent" extraction which relates $B(D_s \to \phi\pi^+) \sim B(D^0 \to K^-\pi^+)$ [10]; and thus

(e) $B(\overline{B} \to D_s^{\pm}X)$ would increase.

The $\overline{B} \to D\overline{D}\ \overline{K}X$ processes were neglected in all existing experimental analyses. But CLEO has demonstrated that they have a sizable BR [18], with some of the following consequences:

(a) the current understanding of primary and secondary lepton spectra in B decays has to be modified;

(b) $B(\overline{B} \to X_c\ell\bar{\nu})$ will have to be modified;

(c) the exclusive B^- and $\overline{B}_d$ lifetime determinations from $\overline{B} \to D^{(*)}X\ell^-\bar{\nu}$ data samples will have to be modified; and

(d) the traditional belief that $\overline{B} \to D^{(*)}X\ell^-\bar{\nu}$ processes unambiguously tag their parent B flavor at time of decay is not true, because of the following background

$$\begin{array}{l} \overline{B} \to D\overline{D}\ \overline{K}X = \ell^+\overline{D} \quad . \\ \qquad\quad \hookrightarrow \ell^+ \end{array}$$

The discovery and accurate modeling of B flavor tags is crucial for $B_q^0 - \overline{B}_q^0$ mixing ($q = d$ or s) and CP violation studies. Thus we note that the $\overline{B} \to D\overline{D}\ \overline{K}X$ background is removable from the semileptonic $\overline{B} \to DX\ell^-\bar{\nu}$ processes on several accounts:

1. softer lepton spectrum (in p and $p_{T,r\ell}$);

2. different $D^{(*)} - \ell$ correlations; and

3. the two additional kaons generated in background events: Primary kaon from the $b \to c\bar{c}s$ transition, and secondary kaon from semileptonic charm decay ($c \to s\ell^+\nu$ or $\bar{c} \to \bar{s}\ell^-\bar{\nu}$).

While this background can be accurately taken into account and is easily removable, none of the present experiments have done so. We are eager to learn what will change in the published measurements, once the effects in this note have been included.

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X. APPENDIX: (CHARMED) BARYON PRODUCTION IN B DECAYS

The accurate accounting of inclusive charm yields in B decays requires a consistent description of charmed baryon production which is lacking in the existing literature. Two years ago we hypothesized that the soft inclusive momentum spectrum of inclusive Λ_c production indicates that $b \to c\bar{c}s$ is the dominant source of Λ_c's in B decays [90]. Our hypothesis predicted (i) large wrong-sign $\ell^- \Lambda_c$ correlations, where the lepton comes from the semileptonic decay of one B and the Λ_c from the other B in an $\Upsilon(4S)$ event; and (ii) large Ξ_c production in B decays, which at the time had not been observed and was believed to be greatly suppressed [64]. Within two months, CLEO observed the first evidence of Ξ_c production in B decays (see Table I), but proved that the right-sign $\ell^+ \Lambda_c$ correlations are dominant (see Table III) [15]. Removing $B^0 - \overline{B}^0$ mixing effects as outlined in Ref. [57], CLEO measured [15]

$$r_{\Lambda_c} \equiv \frac{B(\overline{B} \to \overline{\Lambda}_c X)}{B(\overline{B} \to \Lambda_c X)} = 0.20 \pm 0.14 \ , \tag{10.1}$$

where the error does not include a possible systematic uncertainty emphasized in [57] and mentioned in Section V.A.2.b above.

Because the CLEO measurements of inclusive Ξ_c production in B decays involve large uncertainties and their central values appeared to us to be too high, this appendix correlates the Ξ_c and Ω_c production in tagged $\overset{(-)}{B}$ decays to that of the Λ_c which has been measured with greater accuracy. We neglect $b \to u$ transitions and use the Cabibbo suppression factor $\theta^2 = (0.22)^2$ for charmed baryon production in $b \to c\bar{u}s (b \to c\bar{c}d)$ versus $b \to c\bar{u}d' (b \to c\bar{c}s')$ transitions. The parameter $p = 0.15 \pm 0.05$ models $s\bar{s}$ fragmentation relative to $f\bar{f}$ fragmentation from the vacuum, where $f = u, d$ or s. The large numerical value for p was chosen on purpose. It is used to demonstrate that even large values of p yield a significant reduction in Ξ_c production in $\overline{B}$ decays.

Denote by $C_{\bar{u}d}$ the fraction of $\overline{B}$ decays to weakly decaying charmed baryons which come from $b \to c\bar{u}d$, and define $C_{\bar{c}s}, C_{\bar{c}d}, C_{\bar{u}s}$ analogously. Because our model allows for

substantial charmless-baryon charmless-anti-baryon production in B decays, $C_{\bar{u}d}$ is smaller or at most equal to $B_{\bar{u}d}$ defined in Ref. [90]. Similar comments hold for the analogous C and B quantities. The simplest version of the model predicts

$$B(\overline{B} \to \Lambda_c X) = (1-p)(C_{\bar{u}d} + C_{\bar{c}d}) \tag{10.2}$$

$$B(\overline{B} \to \overline{\Lambda}_c X) = (1-p)(C_{\bar{c}s} + C_{\bar{c}d}) \tag{10.3}$$

$$B(\overline{B} \to \Xi_c X) = p\, C_{\bar{u}d} + (1-p)\, C_{\bar{u}s} + (1-p)\, C_{\bar{c}s} + p\, C_{\bar{c}d} \tag{10.4}$$

$$B(\overline{B} \to \overline{\Xi}_c X) = p\,(C_{\bar{c}s} + C_{\bar{c}d}) \tag{10.5}$$

$$B(\overline{B} \to \Omega_c X) = p(C_{\bar{u}s} + C_{\bar{c}s}) \tag{10.6}$$

$$B(\overline{B} \to \overline{\Omega}_c X) = 0 \tag{10.7}$$

The Cabibbo structure

$$C_{\bar{c}d}/(C_{\bar{c}d} + C_{\bar{c}s}) = C_{\bar{c}d}/C_{\bar{c}s'} = \theta^2 \tag{10.8}$$

$$C_{\bar{u}s}/(C_{\bar{u}s} + C_{\bar{u}d}) = C_{\bar{u}s}/C_{\bar{u}d'} = \theta^2 \tag{10.9}$$

allows one to express the six observables listed on the left hand sides of Eqs. (10.2)-(10.7) in terms of the two unknowns $C_{\bar{u}d}$ and $C_{\bar{c}s}$. These are obtained, in turn, from the two measurements involving inclusive Λ_c production in B decays, namel Y_{Λ_c} and r_{Λ_c}, as follows :

$$\frac{C_{\bar{u}d}}{Y_{\Lambda_c}} = \frac{(1+\lambda^2-\lambda^2 r_{\Lambda_c})}{(1-p)(1+\lambda^2)(1+r_{\Lambda_c})}\,, \tag{10.10}$$

$$\frac{C_{\bar{c}s}}{C_{\bar{u}d}} = \frac{r_{\Lambda_c}}{1+\lambda^2(1-r_{\Lambda_c})}\,, \tag{10.11}$$

where

$$\lambda^2 = \frac{\theta^2}{|V_{cs}|^2} = \frac{\theta^2}{\left(1 - \frac{1}{2}\theta^2\right)^2} \,. \tag{10.12}$$

The inclusive $\overset{(-)}{\Xi}_c, \overset{(-)}{\Omega}_c$ yields in $\overline{B}$ decays are thus correlated to inclusive $\overset{(-)}{\Lambda}_c$ production,

$$\frac{B(\overline{B} \to \Lambda_c X)}{Y_{\Lambda_c}} = \frac{1}{1 + r_{\Lambda_c}} \,, \tag{10.13}$$

$$\frac{B(\overline{B} \to \overline{\Lambda}_c X)}{Y_{\Lambda_c}} = \frac{r_{\Lambda_c}}{1 + r_{\Lambda_c}} \,, \tag{10.14}$$

$$\frac{B(\overline{B} \to \Xi_c X)}{Y_{\Lambda_c}} = \frac{C_{\bar{u}d}}{Y_{\Lambda_c}} \left\{ p + (1-p)\lambda^2 + \frac{C_{\bar{c}s}}{C_{\bar{u}d}}(1 - p + p\lambda^2) \right\} \,, \tag{10.15}$$

$$\frac{B(\overline{B} \to \overline{\Xi}_c X)}{Y_{\Lambda_c}} = \frac{C_{\bar{u}d}}{Y_{\Lambda_c}} \frac{C_{\bar{c}s}}{C_{\bar{u}d}} \, p(1 + \lambda^2) \,, \tag{10.16}$$

$$\frac{B(\overline{B} \to \Omega_c X)}{Y_{\Lambda_c}} = p \frac{C_{\bar{u}d}}{Y_{\Lambda_c}} \left(\lambda^2 + \frac{C_{\bar{c}s}}{C_{\bar{u}d}} \right) \,, \tag{10.17}$$

$$B(\overline{B} \to \overline{\Omega}_c X) = 0 \,. \tag{10.18}$$

We have taken p to be a universal quantity and have assumed that the initially produced charmed baryon retains its charm [and when applicable, its strange] quantum number[s] through to its weakly decaying offspring. That is not justified. We typically expect the initially produced charmed baryons (via $b \to c$) to be highly excited, while this is not expected of their pair produced antibaryons (via $b \to \bar{u}$ or $b \to \bar{c}$) [91]. That scenario explains naturally the puzzling soft momentum spectrum of the inclusive Λ_c yield in $\overline{B}$ decays [92]. That a sizable fraction of these highly excited charmed baryons could break up into a charmed meson, a charmless baryon and additional debris is irrelevant to our discussion which focusses on weakly decaying charmed baryon production in B decays [93]. In contrast, it is important to note that $\Xi_c^r \to \Lambda_c \overline{K} X$ could occur significantly [where the superscript r denotes excited resonances], and can be tested by observing $\Lambda_c \overline{\Lambda}$ correlations from single $\overline{B}$ decays. This introduces an additional mechanism for Λ_c production in $\overline{B}$ decays, which may help explain the small measured value of r_{Λ_c}. It also decreases the naive estimate for weakly decaying Ξ_c production. Because our predictions have not incorporated such effects, they should be viewed strictly as upper limits for Ξ_c production in $\overline{B}$ decays.

TABLES

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

T	$Y_T \equiv B(\overline{B} \to TX) + B(\overline{B} \to \overline{T}X)$	Reference
D^0	$(0.645 \pm 0.025) \left[\frac{3.91\%}{B(D^0 \to K^- \pi^+)}\right]$	[94]
D^+	$(0.235 \pm 0.017) \left[\frac{9.3\%}{B(D^+ \to K^- \pi^+ \pi^+)}\right]$	[94]
D	$(0.883 \pm 0.038) \left[\frac{3.91\%}{B(D^0 \to K^- \pi^+)}\right]$	
D_s	$(0.1211 \pm 0.0096) \left[\frac{3.5\%}{B(D_s \to \phi\pi)}\right]$	[95]
Λ_c	$(0.030 \pm 0.005) \left[\frac{6\%}{B(\Lambda_c \to pK^- \pi^+)}\right]$	[92]
Ξ_c^+	0.020 ± 0.007	[14]
Ξ_c^0	0.028 ± 0.012	[14]

TABLE II. Absolute Branching Ratios of Key Charm Decays as used by CLEO

Mode	BR [in %]	Reference
$D^0 \to K^- \pi^+$	3.91 ± 0.19	[7]
$D_s \to \phi\pi$	3.5 ± 0.4	[8]
$\Lambda_c \to pK^- \pi^+$	6.0 ± 1.5	[16]

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	[15]
$r_D \equiv \frac{B(\overline{B} \to \overline{D} X)}{B(\overline{B} \to D X)}$	0.107 ± 0.034	[17]
$f_{D_s} \equiv \frac{B(\overline{B} \to D_s^+ X)}{Y_{D_s}}$	0.172 ± 0.083	[62]

TABLE IV. Inclusive Semileptonic BR for Various Models from Ref. [22]

Model	Ref.	$B(\overline{B} \to X\ell\nu)$ [%]
ACCMM	[24]	$10.56 \pm 0.04 \pm 0.22$
ISGW	[25]	$10.26 \pm 0.03 \pm 0.22$
ISGW**	[22]	$10.96 \pm 0.07 \pm 0.22$

TABLE V. The $b \to \bar{c}s \to e^-$ background assumes $B(\overline{B} \to \overline{D}X) = 10\%$, $B(\overline{D}^0 \to Xe^-\bar{\nu}) = 6.64\%$, $\tau(D^+)/\tau(D^0) = 2.55$, and $B(D^{*-} \to \overline{D}^0\pi^-) = 68.1\%$. The quantities r and $w(s)$ are defined in the text.

r	$B(b \to \bar{c}s \to e^-)\vert_{\overline{B}\to D\overline{D}\,\overline{K}X}(\times 10^{-3})$	$w(s = 0.2)$
0	8.28	0.89
1/6	8.78	0.90
1/3	9.16	0.91
1	10.0	0.92

TABLE VI. Classification of Semileptonic B decays

Class	Process	Branching Ratio (in %)	Remark
1^+	$\overline{B}^0 \to D^{*+}\ell^-\nu$	$(4.49 \pm 0.50)\ \left[\frac{4.01\%}{B(D^0\to K^-\pi^+)}\right]$	Ref. [21,70]
1^0	$B^- \to D^{*o}\ell^-\nu$	$(5.34 \pm 0.80)\ \left[\frac{4.01\%}{B(D^0\to K^-\pi^+)}\right]$	Ref. [21]
2	$\overline{B}^0 \to D^+\ell\nu$	$(1.69 \pm 0.36)\ \left[\frac{4.01\%}{B(D^0\to K^-\pi^+)}\right]$	missing mass technique of Ref. [71]
3	$\overline{B} \to D^{**}\ell\nu$	$\frac{(\rho^2-\frac{1}{4})}{0.5}\ (0.8 \pm 0.4)$	D^{**} denotes the narrow and broad p wave states, BR reflects Bjorken-Isgur-Wise sum rule [33]
4	$\overline{B} \to D^{r'}\ell\nu$	0.1 - 0.2	$D^{r'}$ denotes all resonances beyond the p wave states [77,26].
5	$\overline{B} \to [X_c]_{non-res}\ell\nu$	0.5 - 1.0	Nonresonant BR [26,77–80]
$1^+ + 2 - 5$	Σ exclusives	8.2 ± 0.9	with $B(D^0 \to K^-\pi^+) = (3.91 \pm 0.19)\%$
$1^0 + 2 - 5$	Σ exclusives	9.1 ± 1.1	with $B(D^0 \to K^-\pi^+) = (3.91 \pm 0.19)\%$
t	$\overline{B} \to X\ell\nu$	10.49 ± 0.46	Published inclusive semileptonic BR from "model independent" dilepton analysis [23]

REFERENCES

[1] D. Abbaneo et al. (The LEP electroweak working group and the SLD Heavy Flavor Group), A Combination of Preliminary LEP and SLD Electroweak Measurements and Constraints on the Standard Model, LEPEWWG/96-01, SLD Physics Note 47.

[2] E. Graziani (Delphi Collaboration), talk given at Fermilab, May 9, 1996.

[3] D. Charlton (OPAL collaboration), talk presented at the University of Chicago, October 1995; P. Antilogus et al. (LEP electroweak working group), CERN preprint, CERN-PPE/95-172.

[4] G. Alexander et al. (Opal Collaboration), CERN Report, CERN-PPE/96-51, April 1996.

[5] T.E. Browder, K. Honscheid, and S. Playfer, in *B decays*, edited by S. Stone, 2nd edition (World Scientific, Singapore, 1994), p. 158.

[6] J.P. Alexander et al. (CLEO collaboration), CLEO conference report, CLEO CONF 95-30.

[7] D.S. Akerib et al. (CLEO collaboration), Phys. Rev. Lett. **71**, 3070 (1993) measures $B(D^0 \to K^-\pi^+(\gamma)) = (3.95 \pm 0.19)\%$. But because the detected $D^0 \to K^-\pi^+$ decays have an effective cutoff on the radiative photons, CLEO uses for them $(3.91 \pm 0.19)\%$.

[8] Particle Data Group, L. Montanet et al., Phys. Rev. **D50**, 1173 (1994).

[9] R. Balest et al. (CLEO Collaboration), Phys. Rev. Lett. **72**, 2328 (1994).

[10] M. Artuso et al. (CLEO Collaboration), Cornell report, CLNS-95-1387, Jan. 1996.

[11] T.E. Browder, K. Honscheid and D. Pedrini [University of Hawaii report, UH-511-848-96, to appear in the 1996 Annual Review of Nuclear and Particle Science] obtain from CLEO data the larger value

$$n_c = 1.18 \pm 0.06 \quad ,$$

for a number of reasons. First of all they have combined the CLEO [7], ARGUS [12] and ALEPH [13] measurements to obtain

$$B(D^0 \to K^- \pi^+) = (3.76 \pm 0.15)\% \, .$$

They then used the much larger measured inclusive Ξ_c yield in B decays [where an error that propagates through the semileptonic Ξ_c BR's has not yet been corrected, see Ref. [14]]. They also used a factor of two larger Y_{Λ_c} than our central estimate [because they used older CLEO 1.5 data and a smaller $B(\Lambda_c \to pK\pi)$]. Finally, they have used a somewhat smaller measured $B(\overline{B} \to (c\bar{c})X)$.

[12] H. Albrecht et al. (ARGUS collaboration), Phys. Lett. **B340**, 125 (1994).

[13] D. Decamp et al. (ALEPH collaboration), Phys. Lett. **B266**, 218 (1991).

[14] We thank Vivek Jain for providing us with a corrected update of the Ξ_c production fractions in B decays as measured by CLEO.

[15] D. Cinabro et al. (CLEO Collaboration), Cornell report, CLEO CONF 94-8, 1994.

[16] T. Bergfeld et al. (CLEO Collaboration), Phys. Lett. **B323**, 219 (1994).

[17] Y. Kwon (CLEO Collaboration), seminar presented at Moriond, March 1996.

[18] G. Buchalla, I. Dunietz, and H. Yamamoto, Phys. Lett. **B364**, 188 (1995).

[19] We thank Jeff Appel for pointing this fact out to us.

[20] I. Dunietz, J. Incandela, R. Snider, K. Tesima, and I. Watanabe, Fermilab report, FERMILAB-PUB-96/26-T, in progress.

[21] J.D. Richman and P.R. Burchat, Rev. Mod. Phys. **67**, 893 (1995).

[22] R. Wang (CLEO collaboration), Ph. D. Thesis, University of Minnesota report, Dec. 1994.

[23] B. Barish et al. (CLEO collaboration), Phys. Rev. Lett. **76**, 1570 (1996).

[24] G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani, G. Martinelli, Nucl. Phys. **B208**, 365 (1982).

[25] N. Isgur, D. Scora, B. Grinstein, and M.B. Wise, Phys. Rev. **D39**, 799 (1989).

[26] D. Scora and N. Isgur, Phys. Rev. **D52**, 2783 (1995).

[27] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. **B318**, 397 (1993).

[28] ALEPH Collaboration, Contribution to the IECHEP, EPS-HEP Brussels, July-August 1995, EPS95 Ref. eps0404.

[29] S. Henderson (CLEO Collaboration), Phys. Rev. **D45**, 2212 (1992).

[30] T.E. Browder and K. Honscheid, Prog. Part. Nucl. Phys. **35**, 81 (1995).

[31] M. Neubert, CERN report, CERN-TH-96-055 [hep-ph/9604412], April 1996.

[32] C. Albajar et al. (UA1 Collaboration), Phys. Lett. **B262**, 171 (1991); F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. **67**, 3351 (1991); K. Johns et al. (D0 Collaboration), Proceedings of the 5th International Symposium on Heavy Flavor Physics, Montreal, Canada, July 1993; D. Decamp et al. (ALEPH Collaboration), Phys. Lett. **B258**, 236 (1991); B. Adeva et al. (L3 Collaboration), Phys. Lett. **B288**, 395 (1992); P. Abreu et al. (DELPHI Collaboration), Phys. Lett. **B301**, 145 (1993); P.D. Acton et al. (OPAL Collaboration), Phys. Lett. **B276**, 379 (1992); D. Buskulic et al. (ALEPH Collaboration), Z. Phys. **C62**, 179 (1994); CDF collaboration, CONTRIBUTED PAPER TO THE XVII INTL. SYMP. ON LEPTON-PHOTON INTERACTIONS, BEIJING, CHINA, AUGUST 1995, FERMILAB-CONF-95/230-E; I. Dunietz, Fermilab report, FERMILAB-PUB-94-163-T [hep-ph/9409355], Sep. 1994, unpublished.

[33] J.D. Bjorken, invited talk given at Les Rencontre de la Valle d'Aoste, La Thuile, Italy, March 18-24, 1990; N. Isgur and M.B. Wise, Phys. Rev. **D43**, 819 (1991); J.D. Bjorken, I. Dunietz, and J. Taron, Nucl. Phys. **B371**, 111 (1992).

[34] A.F. Falk, M.B. Wise, and I. Dunietz, Phys. Rev. **D51**, 1183 (1995).

[35] I. Dunietz, Phys. Rev. **D52**, 3048 (1995).

[36] The $b \to u\bar{c}s'$ transitions were neglected at present. They can be straightforwardly incorporated in future high precision measurements.

[37] E. Bagan, P. Ball, V.M. Braun, P. Gosdzinsky, Phys. Lett. **B342**, 362 (1995); [Erratum to appear in Phys. Lett. **B**]; E. Bagan, P. Ball, B. Fiol, P. Gosdzinsky, Phys. Lett. **B351**, 546 (1995).

[38] M.B. Voloshin, Phys. Rev. **D51**, 3948 (1995).

[39] E. Bagan, P. Ball, V.M. Braun, P. Gosdzinsky, Nucl. Phys. **B432**, 3 (1994).

[40] D. Buskulic et al. (ALEPH Collaboration), Phys. Lett. **B343**, 444 (1995).

[41] A.F. Falk, Z. Ligeti, M. Neubert, Y. Nir, Phys. Lett. **B326**, 145 (1994).

[42] M. Beneke and G. Buchalla, private communication. Arguments for large higher order QCD corrections in $b \to c\bar{c}s'$ transitions are given in M.B. Voloshin, TPI-MINN-96-1-T [hep-ph/9602256], Feb. 1996; and M. Lu, M. Luke, M.J. Savage, B.H. Smith, University of Toronto report, UTPT-96-07 [hep-ph/9605406], May 1996.

[43] M. Neubert and C.T. Sachrajda, CERN report, CERN-TH-96-19 [hep-ph/9603202], March 1996.

[44] M. Beneke, G. Buchalla, and I. Dunietz, SLAC report, SLAC-PUB-7165 [hep-ph/9605259], May 1996.

[45] D. Bloch et al. (DELPHI Collaboration), DELPHI report, DELPHI 96-30 PHYS 604, April 1996.

[46] T. Behnke (OPAL Collaboration), private communication.

[47] We choose here $p = 0.10 \pm 0.05$ as motivated by the measured primary production fraction of D_s mesons versus $D + D_s$ mesons. The larger p used in the Appendix is meant to demonstrate that even then Y_{Ξ_c}/Y_{Λ_c} is much smaller than currently believed.

[48] All the arguments in this Section hold when the primary $\overline{K}$ is replaced by $\overline{K^*}$. However, primary $\overline{K^*}$ may not be copiously produced as briefly mentioned in footnote 2 of Ref. [18].

[49] H.J. Lipkin and A.I. Sanda, Phys. Lett. **201B**, 541 (1988).

[50] I. Dunietz, Seminar given at CLEO, June 1995.

[51] J.D. Bjorken, Nucl. Phys. **B** (Proc. Suppl.) **11** (1989) 325; **SLAC-PUB-5389** (1990), published in Proc. of the SLAC Summer Institute 1990, p. 167.

[52] D. Fakirov and B. Stech, Nucl. Phys. **B133** (1978) 315; L.L. Chau, Phys. Rep. **B95** (1983) 1; M. Bauer, B. Stech and M. Wirbel, Z. Phys. **C34** (1987) 103.

[53] For a review see, for instance, M. Neubert, Phys. Rep. **245**, 259 (1994).

[54] To model the inclusive $\overline{B} \to X_c + \overline{D}^{(*)}\overline{K}$ processes, we recommend to model the $\overline{B} \to X_c$ transition via the underlying $V - A$ quark current $b \to c$, as was done in a different context by W.F. Palmer and B. Stech, Phys. Rev. **D48**, 4174 (1993).

[55] S. Veseli and I. Dunietz, work in progress.

[56] E. Eichten, private communication.

[57] I. Dunietz, Fermilab report, FERMILAB-PUB-94-163-T [hep-ph/9409355], Sep. 1994, unpublished.

[58] I. Bigi, B. Blok, M. Shifman, N. Uraltsev and A. Vainshtein, in *B Decays*, edited by S. Stone, 2nd edition (World Scientific, Singapore, 1994), p. 132.

[59] M.-H. Schune, talk given at Moriond, March 1996.

[60] We thank Roy Wang for many useful discussions.

[61] Because the Cabibbo suppressed transition $b \to c\bar{c}d$ is below the presently available sensitivity, this subsection ignores it for simplicity. It is possible to take it into account in future high precision measurements.

[62] X. Fu et al. (CLEO collaboration), CLEO report, CLEO CONF 95-11.

[63] Y. Kubota et al. (CLEO collaboration), CLEO report, CLEO 95-18.

[64] G. Crawford et al. (CLEO collaboration), Phys. Rev. **D45**, 752 (1992).

[65] H. Albrecht et al., (ARGUS Collaboration) Z. Phys. **C56**, 1 (1992).

[66] Where we understand that the small fraction of e^+ from right-charm $\overline{B} \to (D_s^+,\ baryon_c) \to e^+$ has been subtracted from the raw data.

[67] To estimate c, we note the following:

$$B(\overline{B}_d \to e^+X) = B(\overline{B}_d \to DX)B(D^0 \to e^+X)\,[z_o + (1-z_o)\,\tau]\ ,$$

$$B(B^- \to e^+X) = B(B^- \to DX)B(D^0 \to e^+X)\,[p_o + (1-p_o)\,\tau]\ ,$$

where D denotes the combined regular charm D^0 and D^+, and

$$z_o \equiv \frac{B(\overline{B}_d \to D^0X)}{B(\overline{B}_d \to DX)}\ ,\quad p_o \equiv \frac{B(B^- \to D^0X)}{B(B^- \to DX)}\ ,$$

$$\tau \equiv \frac{B(D^+ \to e^+X)}{B(D^0 \to e^+X)} \approx \frac{\tau_{D^+}}{\tau_{D^0}} = 2.55\ .$$

The parameter c is thus given by

$$c = \frac{B(\overline{B}_d \to DX)}{B(B^- \to DX)}\ \frac{[z_o + (1-z_o)\,\tau]}{[p_o + (1-p_o)\,\tau]}\ .$$

Our unsophisticated estimate chooses $B(\overline{B}_d \to DX)/B(B^- \to DX) \approx 1$, and can be refined by a careful investigation of the $\mathcal{O}(1/m_b^3)$ effects to the $b \to c\bar{u}d$ transitions. Information on the z_o and p_o parameters is contained in the measurements [17] of

$$B(\overline{B} \to D^0\ell^-X) \text{ and } B(\overline{B} \to D^+\ell^-X)$$

and applying the factorization assumption. We are intrigued by what CLEO obtains for z_o and p_o via this method. We employed a cruder method, where we assumed factorization and that the $b \to c$ transition predominantly gives rise to the lowest lying s wave states D and D^*. [By observing $B(B^- \to D_1(2420)^0\pi^-) \approx 0.16$ %, CLEO demonstrated that our estimate has to be refined. Our estimate has to be modified in more than one way.] So our crude model predicts $p_o \approx 1$. As for z_o, we take the ratio $\Gamma(\overline{B}_d \to D^{*+}X)/\Gamma(\overline{B}_d \to D^+_{dir}X)$ to be equal to 3, motivated by $\Gamma(\overline{B} \to D^*\ell\bar{\nu})/\Gamma(\overline{B} \to D\ell\bar{\nu}) \approx 3$. We thus obtain $z_o = 0.51$, which yields $c = 1.76$.

[68] J.S. Hagelin, Nucl. Phys. **B193** (1981) 123; E. Franco, M. Lusignoli and A. Pugliese, *ibid* **B194** (1982) 403; L.L Chau, W.-Y. Keung and M. D. Tran, Phys. Rev. **D27** (1983) 2145; L.L Chau, Phys. Rep. **95** (1983) 1; A.J. Buras, W. Slominski and H. Steger, Nucl. Phys. **B245** (1984) 369; M.B. Voloshin, N.G. Uraltsev, V.A. Khoze and M.A. Shifman, Yad. Fiz. **46** (1987) 181 [Sov. J. Nucl. Phys. **46** (1987) 112]; A. Datta, E.A. Paschos and U. Türke, Phys. Lett. **B196** (1987) 382; M. Lusignoli, Z. Phys. **C41** (1989) 645; R. Aleksan, A. Le Yaouanc, L. Oliver, O. Pène and Y.-C. Raynal, Phys. Lett. **B316** (1993) 567; I. Bigi, B. Blok, M. Shifman, N. Uraltsev and A. Vainshtein, in *B Decays*, edited by S. Stone, 2nd edition (World Scientific, Singapore, 1994), p. 132 and references therein.

[69] R. Tenchini (ALEPH Collaboration), private communication.

[70] B. Barish et al. (CLEO Collaboration), Phys. Rev. **D51**, 1014 (1995).

[71] R. Kutschke (CLEO Collaboration), private communication.

[72] H. Albrecht (ARGUS Collaboration), Z. Phys. **C57**, 533 (1993).

[73] R. Akers et al. (OPAL Collaboration), Z. Phys. **C69**, 57 (1995).

[74] D. Buskulic et al. (ALEPH Collaboration), Phys. Lett. **B345**, 103 (1994)

[75] A. Bellerive (CLEO collaboration), talk presented at the APS meeting, Indianapolis, Indiana, May 1996.

[76] N. Isgur, private communication.

[77] S. Veseli and M.G. Olsson, MADPH-96-924 [hep-ph/9601307], Jan. 1996.

[78] T.-M. Yan, H.-Y. Cheng, C.-Y. Cheung, G.-L. Lin, Y.C. Lin, and H.-L. Yu, Phys. Rev. **D46**, 1148 (1992).

[79] J.L. Goity and W. Roberts, Phys. Rev. **D51**, 3459 (1995).

[80] D. Atwood, I. Dunietz, J.L. Goity and W. Roberts, in preparation.

[81] Evidently any additional experimental information regarding this puzzle is desirable. To that effect, consider that one B is known to be charged. At an $\Upsilon(4S)$ experiment, the other B is then also charged and becomes the focus of our study. If this other B is seen to decay semileptonically as

$$B^- \to D^+ X^- \ell^- \bar{\nu} \,,$$

then this proves either higher resonance [beyond $D^{(*)}$] or nonresonant charm production in semileptonic B decay. P. Drell informed us that B. Gittelman independently suggested this idea and found that, at present, CLEO is statistics limited and is unable to perform those measurements.

[82] The contribution due to the tiny $B(b \to u\ell\overline{\nu})$ must be subtracted from $BR(t)$. Because it is significantly smaller than the error on $BR(t)$ we neglect it in the following.

[83] P.L. Tipton (CLEO Collaboration), Ph. D. Thesis, University of Rochester report, UR 984, 1987; M.S. Alam (CLEO collaboration), Phys. Rev. Lett. **58**, 1814 (1987).

[84] This idea is being independently pursued by the CLEO Collaboration. Y. Kwon and E. Thorndike, private communication.

[85] S. Menary, CBX95-88, September, 1995, unpublished.

[86] H. Albrecht et al. (ARGUS Collaboration), Phys. Lett. **B324**, 249 (1994).

[87] H. Yamamoto, private communication for the CLEO collaboration.

[88] We thank H. Yamamoto for a discussion on this point.

[89] We thank E. Thorndike for a discussion on this point.

[90] I. Dunietz, P.S. Cooper, A.F. Falk, and M.B. Wise, Phys. Rev. Lett. **73**, 1075 (1994).

[91] Consider the $b \to cd\bar{u}$ transition governed by the $V - A$ interaction. The invariant mass of the cd peaks at the highest possible values as seen in a Dalitz plot [18]. Thus we expect the charmed baryons initially produced via $b \to c$ to be highly excited. In contrast, the $V - A$ nature of the interaction favors smaller energies for the $\bar{u}$ antiquark in the restframe of the decaying b. Since the spectator antiquark $\bar{q}$ of the $\overline{B}(\equiv b\bar{q})$ meson involves only a modest Fermi momentum, the invariant mass of the $\bar{u}\bar{q}$ system is also expected to be modest.

[92] M.M. Zoeller (CLEO collaboration), Ph. D. Thesis, submitted to the State University of New York, Albany, 1994.

[93] The tight upper limit [64],

$$B(\overline{B} \to D^{*+} p\bar{p}X) < 0.4\% \text{ (90\% C.L.)} ,$$

is not a problem for our scenario, because of flavor correlations. The dominant charmed baryon producing process is governed by $b \to cd\bar{u}$, and gives rise to highly excited baryons with flavor cdq, where $q = u$ or d. Strong decays of this highly excited baryon can yield a $D^{(*)+}$, which is normally not correlated with a proton, but rather

$$[cdq]^r \to D^{(*)+} [ddq] = D^{(*)+}(n, \Delta^{0,-}, ...) .$$

This naturally explains why no $D^{(*)+}p$ correlations from a single $\overline{B}$ decay have been seen. In contrast, we predict larger $D^{(*)0}p$ correlations from single $\overline{B}$ decays, via

$$[cdq]^r \to D^{(*)0} pX .$$

Searches for these could be performed.

[94] H. Yamamoto (CLEO collaboration), private communication.

[95] D. Gibaut et al. (CLEO Collaboration), Phys. Rev. **D53**, 4734 (1996).