Hadronic $B$ Decay

T. E. Browder
Physics Department, University of Hawaii at Manoa,
Honolulu, HI, 96822, USA

We review recent experimental results from CLEO and LEP experiments on hadronic decays of hadrons containing $b$ quarks. We discuss charm counting and the semileptonic branching fraction in $B$ decays and the color suppressed amplitude in $B$ decay.

1 Charm counting and the semileptonic branching fraction

A complete picture of inclusive $B$ decay is beginning to emerge from recent measurements by CLEO II and the LEP experiments. These measurements can be used to address the question of whether the hadronic decay of the $B$ meson is compatible with its semileptonic branching fraction.

Three facts emerge from the experimental examination of inclusive $B$ decay at the $\Upsilon(4S)$:

$$n_c = 1.10 \pm 0.05$$

where $n_c$ is the number of charm quarks produced per $B$ decay from recent CLEO II result and using $B(D^0 \to K^-\pi^+) = (3.91 \pm 0.08 \pm 0.17\%)$.

$$B(B \to X\ell\nu) = 10.23 \pm 0.39\%.$$  (2)

This value is the average of the CLEO and ARGUS model independent measurements using dileptons. We note that the value used by the LEP Electroweak Working Group for $B(b \to X\ell\nu) = 11.16 \pm 0.20\%$ is only marginally consistent with the $\Upsilon(4S)$ results.

The third quantity, $B(b \to c\bar{c}s)$, is calculated from the inclusive $B \to D_s$, $B \to (c\bar{c})X$, and $B \to \Xi_c$ branching fractions, and is

$$B(b \to c\bar{c}s) = 14.0 \pm 2.8\%.$$  (3)

The above value is determined assuming no contribution from $B \to D$ decays, an assumption which can be checked using data and is discussed in further detail below.

In the parton model, it is difficult to accommodate a low semileptonic branching fraction unless the hadronic width of the $B$ meson is increased. The explanations for the semileptonic branching fraction which have been proposed can be distinguished by expressing the hadronic width of the $B$ meson
in terms of three components:

\[ \Gamma_{\text{hadronic}}(b) = \Gamma(b \to c\bar{c}s) + \Gamma(b \to c\bar{u}d) + \Gamma(b \to s g). \]

If the semileptonic branching fraction is to be reduced to the observed level, then one of the components must be enhanced.

A large number of explanations for the low semileptonic branching fraction and charm yield have been proposed in the last few years. These explanations can be logically classified as follows:

1. An enhancement of \( b \to c\bar{c}s \) due to large QCD corrections or the breakdown of local duality. A variety of possible experimental signatures have been suggested.

2. An enhancement of \( b \to c\bar{u}d \) due to non-perturbative effects.

3. An enhancement of \( b \to s g \) or \( b \to d g \) from New Physics.

4. The cocktail solution: For example, if both the \( b \to c\bar{c}s \) and the \( b \to c\bar{u}d \) mechanisms are increased, this could suffice to explain the inclusive observations.
5. There might also be a systematic experimental problem in the determination of either $n_c$, \( B(b \to c\bar{c}s) \), or \( B(B \to X\ell\nu) \).

Inclusive charm particle-lepton correlations can be used to probe the $B$ decay mechanism and give further insight into this problem. The correlation of the lepton charge and the charm particle flavor distinguishes between different production mechanisms. High momentum leptons, $p_\ell > 1.4$ GeV, are used to tag the flavor of the $B$. The angular correlation between the meson and the lepton is then employed to select events in which the tagging lepton and meson are from different $B$s. When the lepton and meson originate from the same $B$ meson they tend to be back to back, whereas when the meson and leptons come from different $B$ mesons they are uncorrelated. After this separation is performed, wrong sign charge correlations from $B^+\bar{B}$ mixing must be subtracted. Since the mixing rate is well measured, this correction is straightforward and has little uncertainty.

This technique has been applied previously to several types of correlations of charmed hadrons and leptons. For example, the sign of $\Lambda_c$-lepton correlations distinguishes between the $b \to c\bar{u}d$ and the $b \to c\bar{c}s$ mechanisms.

It was found that the $b \to c\bar{c}s$ mechanism comprises $19\pm13\pm4\%$ of $B \to \Lambda_c$ decay\( ^2 \). This observation effectively ruled out one proposed source of additional $b \to c\bar{c}s$ decays\( ^3 \). Similarly, examination of the sign of $D_s$-lepton correlations shows that most $D_s$ mesons originate from $b \to c\bar{s}d$ rather than from $b \to c\bar{u}d$ with $s\bar{s}$ quark popping at the lower vertex. In this case, it was found that $17.2\pm7.9\pm2.6\%$ of $D_s$ mesons originate from the latter mechanism\( ^4 \). The same experimental technique has now been applied to $D$-lepton correlations.

The conventional $b \to c\bar{u}d$ mechanism which was previously assumed to be responsible for all $D$ production in $B$ decay will give $D\ell^-$ correlations. If a significant fraction of $D$ mesons arise from $b \to c\bar{c}s$ with light quark popping at the upper vertex as proposed by Buchalla, Dunietz, and Yamamoto significant wrong sign $D\ell^+$ correlations will be observed\( ^5 \).

Final results of this study have been presented by CLEO II which finds, $\Gamma(B \to D X)/\Gamma(B \to \bar{D} X) = 0.100 \pm 0.026 \pm 0.016\%$\( ^6 \). This implies a new contribution to the $b \to c\bar{c}s$ width

$$B(B \to DX) = 7.9 \pm 2.2\%$$

ALEPH finds evidence for semi-inclusive $B \to D^0\bar{D}^0 X + D^0\bar{D}^+ X$ decays with a somewhat larger branching fraction of $12.8 \pm 2.7 \pm 2.6\%$\( ^7 \). DELPHI reports the observation of $B \to D^{*+}D^{*-} X$ decays with a branching fraction of $1.0 \pm 0.2 \pm 0.3\%$\( ^8 \). Additional and quite compelling evidence that these signals are due to $B \to D^{(*)}\bar{D}^{(*)}K^{(*)}$ decays has been presented by CLEO\( ^9 \), which has
observed fully reconstructed signals in exclusive modes:

\[ B(\bar{B}^0 \to D^{+\ast} \bar{D}^0 K^-) = 0.45^{+0.25}_{-0.19} \pm 0.08\% \]
\[ B(B^- \to D^{*0} \bar{D}^0 K^-) = 0.54^{+0.33}_{-0.24} \pm 0.12\% \]
\[ B(\bar{B}^0 \to D^{+\ast} \bar{D}^{*0} K^-) = 1.30^{+0.61}_{-0.47} \pm 0.27\% \]
\[ B(B^- \to D^{*0} \bar{D}^{*0} K^-) = 1.45^{+0.78}_{-0.58} \pm 0.36\% \]

The rates observed by ALEPH and DELPHI are consistent with the rate of wrong sign $D$-lepton correlation reported by CLEO. It is possible that these channels are actually resonant modes of the form $B \to D D^{\ast\ast}$ decays, where the p-wave $D^{\ast\ast}$ or radially excited $D'_{s}$ state decays to $\bar{D}^{(*)}(\ast)\bar{D}K$. A direct search by CLEO has ruled out the possibility of narrow $B \to D_{s1} X$ decay: $B(B \to D_{s1} X) < 0.95\%$ at the 90\% confidence level.

There are other implications of these observations. A $B$ decay mechanism with a $O(10\%)$ branching fraction has been found which was not previously included in the CLEO or LEP Monte Carlo simulations of $B$ decay. This may have consequences for other analyses of particle-lepton correlations. For example, CLEO has re-examined the model independent dilepton measurement of $B(B \to X\ell\nu)$. Due to the lepton threshold of 0.6 GeV and the soft spectrum of leptons, the CLEO measurement is fortuitously unchanged. It is also important to check the size of this effect in LEP measurements of the $B$ semileptonic branching fraction using dileptons.

We can now recalculate

\[ B(b \to c\bar{c}s) = 21.9 \pm 3.7\% \]

which would suggest a somewhat larger charm yield ($n_c \sim 1.22$). This supports hypothesis (1), large QCD corrections in $b \to c\bar{c}s$ BUT the charm yield $n_c$ as computed in the usual way is unchanged. Moreover, the contribution of $B \to D D K X$ decays was properly accounted for in the computation of $n_c$. This suggests that the experimental situation is still problematic.

One possibility that must be addressed is whether there could be an error in the normalization $B(D^0 \to K^- \pi^+)$ \[4\]. This branching fraction calibrates the inclusive measurements of $B \to D^0$, $B \to D^+$, and $B \to D_s$ rates as well as $n_c$. Historically, a flaw in $B(D^0 \to K^- \pi^+)$ has been the culprit in other consistency problems with charm counting. The most precise measurements of $B(D^0 \to K^- \pi^+)$ are obtained by fitting the $p_T$ spectrum of soft pions in charm jets. An examination of Table \[4\] shows that these measurements are statistically precise but systematics dominated. The Particle Data Group
Table 1: Recent Measurements of $B(D^0 \to K^- \pi^+)$

| Experiment | Measurement (%) |
|------------|-----------------|
| ALEPH      | $3.897 \pm 0.094 \pm 0.117$ |
| CLEO II    | $3.91 \pm 0.08 \pm 0.17$ |
| ARGUS      | $3.41 \pm 0.12 \pm 0.28$ |

The world average is currently dominated by the ALEPH measurement. Using $B$ decay data it is also possible to make consistency checks on the calibration branching fraction. For example, the ratio

$$\frac{B(B \to D^*\ell\nu)_{\text{partial}}}{B(B \to D^*\ell\nu)_{\text{full}}}$$

where the decay in the numerator is observed without reconstructing the $D$ decay gives a measurement of the calibration branching fraction with very different systematic effects. In CLEO data, this method gives $B(D^0 \to K^- \pi^+) = 3.81 \pm 0.15 \pm 0.16\%$. Another quantity which can be examined is

$$\frac{B(B \to DX\ell\nu)}{B(B \to X\ell\nu)}$$

which should be unity modulo small corrections for semileptonic $D_s$ and baryon production as well as for processes which do not produce charm. Applied to CLEO data, this method gives $B(D^0 \to K^- \pi^+) = 3.69 \pm 0.08 \pm 0.17\%$. Neither method is sufficiently precise yet to conclusively demonstrate that either the $D$ branching fraction scale is correct or that it has a systematic flaw.

Another possibility is enhanced $B(b \to cud)$. On the theoretical side, Bagan et al. find that at next to leading order,

$$r_{ud} = \frac{B(b \to cud)}{B(b \to c\ell\nu)} = 4.0 \pm 0.4$$

The value of $B(b \to cud)$ can be checked using measurements of inclusive $B$ decay from the $\Upsilon(4S)$ experiments:

$$B(b \to cud)_{\text{exp}} = B(B \to DX) + B(B \to \Lambda_cX)$$

$$-B(B \to D\Lambda_cX) - 2B(B \to D\bar{D}KX) - 2.25B(b \to c\ell\nu)$$

$$= (0.871 \pm 0.035) + (0.036 \pm 0.020)$$
\[ -(0.10 \pm 0.027) - 2 \times (0.079 \pm 0.022) - (0.236 \pm 0.010) \]

\[ B(b \to c\bar{d})_{\text{exp}} = 0.41 \pm 0.07 \]

In the above calculation, a small correction (0.004) has been applied to the \( B \to \Lambda_c X \) branching fraction to account for \( b \to c\bar{c}s \) production in baryonic \( B \) decay. The factor of 2.25 accounts for phase space suppression in \( b \to c\tau \nu \) decay. The experimental result is consistent with the theoretical expectation,

\[ B(b \to c\bar{d})_{\text{theory}} = 0.42 \pm 0.04 \]

However, the present experimental accuracy is not quite sufficient to completely rule out \( b \to c\bar{u}d \) as the cause of the discrepancy.

We note that ALEPH and OPAL have recently reported a value for \( n_c \) in \( Z \to b\bar{b} \) decay. ALEPH finds \( n_c^Z = 1.230 \pm 0.036 \pm 0.038 \pm 0.053 \). The rate of \( D_s \) and \( \Lambda_c \) production is significantly higher than what is observed at the \( \Upsilon(4S) \). It is not clear whether the quantity being measured is the same as \( n_c \) at the \( \Upsilon(4S) \), which would be the case if the spectator model holds and if the contribution from the other \( b \)-hadrons, \( B_s \) and \( \Lambda_b \), could be neglected. OPAL reports a somewhat lower value of \( n_c = 1.10 \pm 0.045 \pm 0.060 \pm 0.037 \) after correcting for unseen charmonium states. OPAL assumes no contribution from \( \Xi_c \) production while ALEPH includes a very large contribution from this source. The contribution of \( B \to \) baryon decays to charm counting as well as the \( \Lambda_c, \Xi_c \) branching fraction scales are still poorly measured and definitely merit further investigation.

### 2 Exclusive Hadronic Decays

Recent progress has been made on partial reconstruction of hadronic \( B \) decays. For example, the decay chain

\[ B \to D^* \pi_f, D^* \to (D)\pi_s \]

can be measured without reconstructing the \( D \) meson. In this reaction, there are five particles \((B, D^*, D, \pi_s, \pi_f)\) with five 4-momenta give 20 unknowns. The 4-momenta of the \( \pi_s, \pi_f \) are measured which gives 8 constraints. The \( B, D, D^* \) masses and beam energy are known and gives 4 constraints. Then energy-momentum conservation in the \( B \to D^* \pi_f \) and \( D^* \to D \pi_s \) decay chains gives 8 additional constraints. Thus, one can perform a \( 20 - 8 - 8 - 4 = 0 \) fit.

Two variables are used to extract the signal: \( \cos \Theta_{D^*} \), the angle between the \( p_{\pi_s} \) and \( p_B \) in the \( D^* \) rest frame, and \( \cos \theta_B \), the angle between the \( p_{\pi_f} \) and \( p_B \) in the \( B \) rest frame.
This method gives the most precise measurements of two exclusive branching fractions:

\[ B(\bar{B}^0 \to D^{*+}\pi^-) = (2.81 \pm 0.11 \pm 0.21 \pm 0.05) \times 10^{-3} \]

\[ B(B^- \to D^{*0}\pi^-) = (4.81 \pm 0.42 \pm 0.40 \pm 0.21) \times 10^{-3}. \]

The second systematic error is from the \( D^* \) branching fractions. A similar partial reconstruction analysis has been applied to the \( B^- \to D^{**}(2420)^0\pi^- \) and \( B^- \to D^{**}(2460)^0\pi^- \) decay modes. The event yields from fitting these distributions are substantial: 281±56 \( D^{**}(2420) \), 165±61 \( D^{**}(2460) \), although there are also large background subtractions. These correspond to branching fractions,

\[ B(B^- \to D_1(2420)\pi^-) = (1.17 \pm 0.24 \pm 0.16 \pm 0.03) \times 10^{-3} \]

\[ B(B^- \to D_2^*(2460)\pi^-) = (2.1 \pm 0.8 \pm 0.3 \pm 0.05) \times 10^{-3} \]

The former mode was previously observed using a similar technique by ARGUS. The latter mode is observed for the first time by CLEO. As noted by J. Gronberg and H. Nelson, the partial reconstruction technique may also be useful for observing a time dependent CP asymmetry in \( \bar{B}^0 \to D^{*+}\pi^- \).

### 2.1 The sign of the color suppressed amplitude and lifetimes

The sign and magnitude of the color suppressed amplitude can be determined using several classes of decay modes in charm and bottom mesons. The numerical determination assumes factorization and uses form factors from various phenomenological models.

For \( D \) decay one uses exclusive modes such as \( D \to K\pi, D \to K\rho \) etc., and obtains

\[ a_1 = 1.10 \pm 0.03, \quad a_2 = -0.50 \pm 0.03 \]

The destructive interference observed in two body \( D^+ \) decays leads to the \( D^+ \cdot D^0 \) lifetime difference.

For \( B \) decay, one can find the magnitude of \(|a_1|\) from the branching fractions for the decay modes \( \bar{B}^0 \to D^{(s)}+\pi^- \), \( \bar{B}^0 \to D^{+(s)}\rho^- \). This gives \(|a_1| = 1.06 \pm 0.03 \pm 0.06 \). One can also extract \( |a_1| \) from measurements of branching fractions \( B \to D^{+(s)} \). The magnitude \(|a_2|\) can be determined from the branching fractions for \( B \to \psi K^{(*)} \). This yields \(|a_2| = 0.23 \pm 0.01 \pm 0.01 \).

The value of \( a_2/a_1 \) can be found by comparing \( B^- \) decays where both the external and spectator diagrams contribute to \( \bar{B}^0 \) decays where only the
external spectator decays contribute. For example, the model of Neubert et al. predicts the following ratios:

\[
R_1 = \frac{\mathcal{B}(B^- \to D^0\pi^-)}{\mathcal{B}(B^0 \to D^+\pi^-)} = (1 + 1.23a_2/a_1)^2
\]

(4)

\[
R_2 = \frac{\mathcal{B}(B^- \to D^0\rho^-)}{\mathcal{B}(B^0 \to D^+\rho^-)} = (1 + 0.66a_2/a_1)^2
\]

(5)

\[
R_3 = \frac{\mathcal{B}(B^- \to D^{*0}\pi^-)}{\mathcal{B}(B^0 \to D^{*+}\pi^-)} = (1 + 1.29a_2/a_1)^2
\]

(6)

\[
R_4 = \frac{\mathcal{B}(B^- \to D^{*0}\rho^-)}{\mathcal{B}(B^0 \to D^{*+}\rho^-)} \approx (1 + 0.75a_2/a_1)^2
\]

(7)

Improved measurements of these exclusive branching fractions with better background subtraction and additional data have recently been presented by CLEO (see Fig. 2). Using the latest branching fractions,

\[a_2/a_1 = 0.21 \pm 0.03 \pm 0.03^{+0.13}_{-0.12},\]

where the third error is a conservative estimate of the uncertainty (∼ 20%) in the relative production of $B^+$ and $B^0$ mesons at the $\Upsilon(4S)$. There are a number of additional theoretical uncertainties which could significantly modify the magnitude of $a_2/a_1$ but not its sign. For example, the ratios of some heavy-to-heavy to heavy-to-light form factors is needed (e.g. $B \to \pi/B \to D$). Comparing the value of $a_2/a_1$ determined using form factors from the model of Neubert et al. with the value obtained using form factors from the model of Deandrea et al. shows that this uncertainty is small. The effect of including the $B \to VV$ mode for which the form factors have somewhat larger theoretical uncertainties is also small. It is important to remember that the determination of $a_2/a_1$ also assumes the factorization hypothesis. The large error on the relative production of $B^+$ and $B^0$ mesons is the most significant experimental uncertainty in the determination of $a_2/a_1$.

The value of $a_2/a_1$ determined above is consistent with the ratio $|a_2|/|a_1|$ where $|a_2|$ is computed from $B \to \psi$ modes and $|a_1|$ is computed from $B^0 \to D^{(*)}\pi, D^{(*)}\rho$ modes. Although the result is surprisingly different from what is observed in hadronic charm decay (where the interference is destructive) and from what is expected in the $1/N_c$ expansion, Buras claims that the result can be accommodated in NLO QCD calculations.

If the constructive interference which is observed in these $B^+$ decays is present in all $B^+$ decays, then we expect a significant $B^+-B^0$ lifetime difference ($\tau_{B^+} < \tau_{B^0}$), of order 15 − 20%, in a direction opposite to the $D^+ - D^0$...
Figure 2: The beam constrained mass distributions of exclusive hadronic decay modes used in the determination of $a_2/a_1$. The mass plots have been continuum subtracted. The shaded histogram is a high statistics simulation of $B\bar{B}$ backgrounds.

lifetime difference. This scenario is only marginally consistent with experimental measurements of lifetimes; the world average computed by the LEP lifetime working group in August 1997 is

$$\tau_{B^+}/\tau_{B^0} = 1.07 \pm 0.04$$

It is possible that the hadronic $B^+$ decays that have been observed to date are atypical. The remaining higher multiplicity $B^+$ decays could have destructive interference or no interference. Or perhaps there is a mechanism which also enhances the $B^0$ width to compensate for the increase in the $B^+$ width and which maintains the $B^+/B^0$ lifetime ratio near unity. Such a mechanism would be relevant to the charm counting and semileptonic branching fraction problem. In either case, there will be experimental consequences in
the pattern of hadronic $B$ branching fractions. Experimentally one can compare other $B^-$ and $B^0$ decays including $D^{**}\pi^-$ and $D^{**}\rho^-$ as well decays to $D^{(*)}a_1^-, a_1^- \rightarrow \rho^0\pi^-$ and $D^{(*)}b_1^-, b_1^- \rightarrow \omega\pi^-$ to check the first possibility.

3 Conclusion

The charm counting and semileptonic $B$ branching fraction problem persists. Three possible solutions are still experimentally viable. These are (1) a systematic problem in the $D$ branching fraction, (2) an enhancement of $b \rightarrow c\bar{c}ud$ or (3) an enhancement of $b \rightarrow s g$. Any proposed solution must also satisfy the experimental constraints on $B(b \rightarrow c\bar{c} s)$ and $B(b \rightarrow c\bar{c}d)$.

The sign of $a_3/a_1$ is found to be positive in the low multiplicity hadronic $B$ decays that have been observed so far. This indicates constructive interference in hadronic $B^+$ decay. It will be interesting to see whether this pattern persists as higher multiplicity $B$ decay modes are measured.

References

1. T.E. Browder, K. Honscheid, and D. Pedrini, UH-515-848-96, OHSTPY-HEP-E-96-006, 1996 edition of Annual Reviews of Nuclear and Particle Science.
2. T.E. Browder and K. Honscheid, Progress in Nuclear and Particle Physics, Vol. 35, ed. K. Faessler, p. 81-220 (1995).
3. L. Gibbons et al. (CLEO Collaboration), Phys. Rev. D 56, 3783 (1997).
4. D. Akerib et al. (CLEO Collaboration), Phys. Rev. Lett. 71, 3070 (1993).
5. I.I. Bigi, B. Blok, M. Shifman, A. Vainshtein, Phys. Lett. B 323, 408 (1994).
6. A. Falk, M. Wise, I. Dunietz, Phys. Rev. D 51, 1183 (1995); Phys. Lett. B 73, 1075 (1995).
7. M. Buchalla, I. Dunietz, H. Yamamoto, Phys. Lett. B 364, 188 (1995).
8. E. Bagan, P. Ball, V. Braun, P. Gobzdinsky, Nucl. Phys. B 432, 3 (1994); Phys. Lett. B 342, 362 (1995) and Erratum; Phys. Lett. B 374, 363 (1996).
9. W.F. Palmer and B. Stech, Phys. Rev. D 48, 4174 (1993).
10. I. Dunietz, J. Incandela, F.D. Snider, and H. Yamamoto, [hep-ph/9612421]
    Eur. Phys. J. C1, 211 (1998).
11. A. Lenz, U. Nierste, and G. Ostermaier, [hep-ph/9706501], Phys. Rev. D 56, 7228 (1997).
12. K. Honscheid, K.R. Schubert, and R. Waldi, Z. Phys. C 63, 117 (1994).
13. M. Neubert and C.T. Sachrajda, Nucl. Phys. B 483, 339 (1997). Also see the recent review, M. Neubert, hep-ph/9801269 to appear in the Proceedings of the 1997 Jerusalem Europhysics Conference.

14. G. Altarelli, G. Martinelli, S. Petrarca, and F. Rapuano, Phys. Lett. B 382, 409 (1996).

15. I.L. Grach, I.M. Narodetskii, G. Simula, and K.A. Ter-Martirosyan, hep-ph/9603239.

16. A. L. Kagan, Phys. Rev. D 51, 6196 (1995); A. L. Kagan and J. Rathsman, hep-ph/9701304.

17. L. Roszkowski, M. Shifman, Phys. Rev. D 53, 404 (1996).

18. B. Grzadowski and W.S. Hou, Phys. Lett. B 272, 383 (1992).

19. I. Dunietz, FERMILAB-PUB-96/104-T, hep-ph/9606247.

20. R. Ammar et al. (CLEO Collaboration), Phys. Rev. D 55, 13 (1997); R. Barish et al. (CLEO Collaboration), Phys. Rev. Lett. 79, 3599 (1997).

21. X. Fu et al. (CLEO Collaboration), CLEO-CONF 95-11.

22. T.E. Coan et al. (CLEO Collaboration), CLNS-97-1516, to appear in Phys. Rev. Lett.

23. ALEPH Collaboration, ICHEP96 PA05-060

24. CLEO Collaboration, CLEO CONF 97-26.

25. R. Barate et al. (ALEPH Collaboration), Phys. Lett. B 405, 191 (1997).

26. M. Artuso et al. (CLEO Collaboration), CLNS 97/1517, submitted to Phys. Rev. Lett.

27. D. Buskulic et al. (ALEPH Collaboration), Phys. Lett. B 388, 648 (1996).

28. G. Alexander et al. (OPAL Collaboration), Z. Phys. C 72, 1 (1996).

29. DELPHI Collaboration, ICHEP96 PA01-108, DELPHI 96-97 CONF 26. DELPHI has also given a preliminary result on the rate of double charm production using inclusive vertexing, \( r_{2C} = 16.6 \pm 6\% \), with \( D_s \) present in \( 84 \pm 16\% \) of the events. See EPS 448, contributed paper for the 1997 Jerusalem EPS conference.

30. B. Blok, M. Shifman, and N. Uraltsev, Nucl. Phys. B 494, 237 (1997).

31. M. Bishai et al. (CLEO Collaboration), Cornell preprint CLNS 97/1513.

32. G. Brandenburg et al. (CLEO Collaboration), CLNS 97/1485, to appear in Phys. Rev. Lett.

33. J. Gronberg et al. (CLEO Collaboration), CLEO CONF 96-25.

34. J. Rodriguez, hep-ex/9801028, contribution to the Proceedings IInd International Conference on B Physics and CP Violation, Honolulu, HI 1997 (World Scientific).

35. A. J. Buras, Nucl. Phys. B 434, 606 (1995).

36. B. Stech, contribution to the Proceedings IInd International Conference
37. M. Neubert, hep-ph/9707368 to appear in the Proceedings of the Montpellier QCD97 Conference.
38. F. E. Close and H. J. Lipkin, \textit{Phys. Lett.} B 372, 306 (1996).