Fermi National Accelerator Laboratory

FERMILAB-CONF-96/387-T

Puzzles in Heavy Flavor Physics *

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We show that there exists a discrepancy in two complementary determinations of $B(\overline{B} \to DX)$. Either inclusive B decays are not understood or $B(D^0 \to K^-\pi^+)$ has to be reduced from currently accepted values. Since $B(D^0 \to K^-\pi^+)$ calibrates most charmed hadron yields, a reduced value affects some measurements of R_c. We then examine the charm background in measurements of R_b and suggest how systematic errors in the charm decay multiplicity might resolve the discrepancy in R_b.

1. The $B(\overline{B} \to DX)$ Puzzle

Recent experimental results allowed us to extract $B(\overline{B} \to DX)$ [governed by $b \to c$ transitions] in two complementary ways, which disagree. Here D denotes D^0 and D^+ mesons. While measurements of the inclusive D yield in B decays [1],

$$Y_D \equiv B(\overline{B} \to DX) + B(\overline{B} \to \overline{D}X) = (0.883 \pm 0.038) \left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] ,(1)$$

had been performed already many years ago, the wrong-charm yield $B(\overline{B} \to \overline{D}X)$ has been measured only very recently. The latter measurement was motivated by the prediction that $B(\overline{B} \to \overline{D}D\overline{K}X)$ is large [2] and should not be overlooked as was customary in experimental analyses. CLEO [3] and ALEPH [4] confirmed the prediction and allowed the direct determination of $B(\overline{B} \to DX)$,

$$B(\overline{B} \to DX) = (0.80 \pm 0.04) \left[\frac{3.91\%}{B(D^0 \to K^-\pi^+)}\right] \quad CLEO , \quad (2)$$

$$B(\overline{B} \to DX) < 0.75 \pm 0.05 \quad ALEPH . \quad (3)$$

The inequality results from the fact that ALEPH [4] reported a sizable $B(\overline{B} \to D\overline{D}X) = (12.8 \pm 2.7 \pm 2.6)\%$ which does not include the $\overline{B} \to D^+D^-X$ possibility. That possibility is non-negligible as seen from the ALEPH [4] measurement $B(\overline{B} \to D^{*+}D^-X + D^{*-}D^+X) = (2.6 \pm 1.3 \pm 0.6)\%$ or from a recent DELPHI report [5].

The second method uses

$$B(b \to c) = 1 - B(b \to \text{ no } c) , \quad (4)$$

and extracts $B(\overline{B} \to DX)$ via

$$\begin{aligned} B(\overline{B} \to DX) &= 1 - B(b \to \text{ no charm}) \\ -B(\overline{B} \to D_s^+X) &- B(\overline{B} \to \text{baryon}_c X) \\ -B(\overline{B} \to (c\bar{c})X) . & \quad (5) \end{aligned}$$

We used available measurements wherever possible and predictions elsewhere to obtain [6,7]

$$B(\overline{B} \to DX) = 0.89 \pm 0.02 . \quad (6)$$

The disagreement between the two methods means that either

(a) inclusive B decays are not understood, or

(b) $B(D^0 \to K^-\pi^+)$ must have to be revised downward significantly, because it calibrates almost all charm yields.

*This work was supported in part by the Department of Energy, Contract No. DE-AC02-76CH03000.

Under the assumption that the mismatch is entirely due to $B(D^0 \to K^-\pi^+)$, we obtain from CLEO data alone,

$$B(D^0 \to K^-\pi^+) = (3.50 \pm 0.21)\% . \qquad (7)$$

If instead ALEPH's result for $B(\overline{B} \to D\overline{D}X)$ is used, the disagreement is resolved for an even smaller $B(D^0 \to K^-\pi^+)$. [Note that $B(\overline{B} \to D\overline{D}X)$ is inversely proportional to the square of $B(D^0 \to K^-\pi^+)$.]

2. Critique of Small $B(D^0 \to K^-\pi^+)$

The most precise measurements of $B(D^0 \to K^-\pi^+)$ are

$$B(D^0 \to K^-\pi^+) =$$

$$\left\{ \begin{array}{ll} (3.90 \pm 0.09 \pm 0.12)\% & ALEPH\ \ 1996 \\ (3.91 \pm 0.08 \pm 0.17)\% & CLEO\ \ 1993 \\ (3.41 \pm 0.12 \pm 0.28)\% & ARGUS\ \ 1994 \end{array} \right\} . (8)$$

Taken at face value, this would indicate that our conclusion [Eq. (7)] is incorrect.

All three measurements involve the soft charged pion (π_s^+) in $D^{*+} \to D^0\pi_s^+$ decays and determine $B(D^0 \to K^-\pi^+)$ via

$$B(D^0 \to K^-\pi^+) = \frac{N[\pi_s^+(K^-\pi^+)_{D^0}]}{N[\pi_s^+]} . \qquad (9)$$

We wonder however whether the signal shape of π_s^+ is well understood. The tails of the distribution of the signal shapes are difficult to model correctly in Monte Carlo simulations and one has to know how the inclusive signal shape changes with D^0 decay mode. If an overzealous subtraction of background occurred, then the true number of π_s^+ is larger than measured,

$$N[\pi_s^+|_{\rm true}] > N[\pi_s^+|_{\rm measured}] , \qquad (10)$$

and the true $B(D^0 \to K^-\pi^+)$ is reduced.

R_c has been measured using a variety of techniques, not all of which are sensitive to the value of $B(D^0 \to K^-\pi^+)$. Two in particular, the "exclusive D^{*+}/inclusive π^-" and "charm counting" methods, depend explicitly on $B(D^0 \to K^-\pi^+)$. The charm counting results [8,9] favor a smaller $B(D^0 \to K^-\pi^+)$ [6,7]. Measurements of R_c (excl. D^{*+}/incl. π^-) were reported in Warsaw [9],

$$R_c(\text{ALEPH}) = 0.176 \ {}^{+0.013}_{-0.012} \pm 0.011 ,$$

$$R_c(\text{DELPHI}) = 0.167 \pm 0.015 \pm 0.015 .$$

$$R_c(\text{OPAL}) = 0.182 \pm 0.011 \pm 0.015 .$$

Because the dependence on low energy data was removed,

$$R_c(\text{excl. } D^{*+}/\text{incl. } \pi^-) \sim 1/B(D^0 \to K^-\pi^+) .$$

The Standard Model predicts $R_c = 0.172$. Thus the exclusive/inclusive measurements appear to favor larger $B(D^0 \to K^-\pi^+)$. But consistently carrying through Eq. (10) could also explain the large measured R_c(excl.D^*/incl. π) values and allows a significantly reduced $B(D^0 \to K^-\pi^+)$.

Comparing semileptonic B decays where charm has been reconstructed with inclusive measurements favors smaller $B(D^0 \to K^-\pi^+)$ [6,7]. With the $B(\overline{B} \to D^{(*)}\pi X\ell\bar{\nu})$ results reported by ALEPH at Warsaw '96 [10], the new world-average [11] for $B(\overline{B} \to D^{(*)+}\ell\bar{\nu})$ [which was assumed to be dominated by measurements that fully reconstruct $D^{(*)+}$] and CLEO's [12] inclusive measurement of $(10.49 \pm 0.46)\%$, we obtain

$$B(D^0 \to K^-\pi^+) = (3.4 \pm 0.3)\% .$$

It is thus crucial to measure $B(D^0 \to K^-\pi^+)$ accurately. Such measurements can be conducted with

(a) a $\psi'' \to D\overline{D}$ threshold factory,

(b) using semileptonic B decays that generally involve charm [6],

(c) $\overline{B} \to D^{*+}\ell^-\bar{\nu}$ decays [13].

3. R_b Measurements

While the Standard Model predicts $R_b = 0.2158$, experimental measurements as recent as Moriond '96 yielded a weighted average which was about 3σ higher [14]. The most precise measurements used a lifetime tag, which weighted the significance of impact parameters of tracks. A simultaneous study of singly and doubly-tagged hemispheres allowed to experimentally extract R_b and the hemisphere b-tagging efficiency ϵ_b. In contrast, the charm contamination had to be simulated. The simulation used the Mark III measurements for multiplicities of the various charmed meson decays [15]. The Mark III results may have significantly underestimated higher charged multiplicity decay modes [16] which are more efficient in faking b-decays. Consequently, the charm background could have been significantly underestimated, potentially solving the R_b discrepancy [7]. Our speculation is consistent with the recent measurements of SLD [17] and ALEPH [18], where the lifetime tag was augmented by a vertex mass cut. That vertex mass cut $m_{\rm vertex} > m_{\rm charm}$ is designed to remove most of the charm background. As expected, the results now agree with the Standard Model,

$$R_b = \begin{cases} 0.2158 \pm 0.0009 \pm 0.0011 & \text{ALEPH} \\ 0.2149 \pm 0.0032 \pm 0.0021 & \text{SLD}\,. \end{cases}$$

Our hypothesis could be tested by plotting R_b as a function of charm contamination, for instance by varying the cut on the jet charge probability or on the vertex-mass. We predict R_b to increase as the charm contamination increases with charm modelled via current simulation packages.

4. Conclusions

Recent experimental results allowed us to demonstrate a discrepancy in inclusive B decays. Either inclusive B decays are not understood or $B(D^0 \to K^-\pi^+)$ has to be reduced sizably from currently accepted values. A critique of a smaller $B(D^0 \to K^-\pi^+)$ followed. The most precise measurements of $B(D^0 \to K^-\pi^+)$ and the R_c(excl.D^*/incl.π) measurement use the inclusive soft pion technique (from $D^{*+} \to D^0\pi^+$ decays). Perhaps the signal shape of that soft pion is not exactly understood. We thus listed several $B(D^0 \to K^-\pi^+)$ measurements that do not involve soft pions and encourage a widespread experimental effort to remeasure $B(D^0 \to K^-\pi^+)$. The R_b measurements at Moriond '96 were 3σ above the Standard Model prediction. One possible reason is that charm mimics b-decays more efficiently than indicated by Monte Carlo simulations. LEP/SLC experiments could study that possibility systematically by varying R_b as a function of charm background. ALEPH and SLD removed most of the charm background and recovered the Standard Model value for R_b consistent with our expectation.

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