Heavy Quark Hadronic Weak Decays from CLEO-II

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ABSTRACT

We present preliminary results from the CLEO-II collaboration on a variety of hadronic final states of mesons containing heavy quarks. In particular, the pattern of 2-body B decays is now decisively different that of D and K decays; perhaps a consequence will be that \( \tau_B^- < \tau_K^- \). We have observed ‘wrong-sign’ \( D^0 \rightarrow K^+\pi^- \) decays, which are probably due to a doubly Cabibbo-suppressed transition.

Introduction

We present preliminary results on the decays of mesons containing \( b \) and \( c \) quarks to a variety of hadronic final states. The data sample for these analyses is typically \( 1 - 1.8 \text{ fb}^{-1} \) accumulated by the CLEO-II detector, 2/3 of which is on the \( \Upsilon(4S) \), and 1/3 of which is in the continuum just below that resonance.

Of primary importance are the high statistics measurements of the decays of B-mesons to two body final states. The evidence is now that the description of decays to two body final states for D and K mesons does not pertain for B’s.

We present results on inclusive measurements of D and \( J/\psi \) mesons in B decays. Also, results on Cabibbo-suppressed decays of D mesons, the observation of the wrong-sign decay \( D^0 \rightarrow K^+\pi^- \), and precision measurement of absolute branching ratios for the \( D^0 \) and \( D^+ \) are presented.

Two Body Decays of B’s

Consider the generic Cabibbo-favored decay of a flavored pseudoscalar meson with one light quark, \( M \), to two pseudoscalars. The neutral pseudoscalar, \( M^0 \), can decay either to a charged final state \(-+\) or a neutral final state \((00)\); the charged pseudoscalar, \( M^+ \), decays to a mixed charge final state, \( 0+ \); consider \( \Gamma(M^0 \rightarrow -+)/\Gamma(M^+ \rightarrow 0+) \). In the kaon system, due to the \( \Delta I=1/2 \) rule:

\[
\Gamma(K^0 \rightarrow \pi^+\pi^-)/\Gamma(K^- \rightarrow \pi^-\pi^0) \approx 225
\]

In the D system, where the relative enhancement of the amplitude that produces the smallest change in isospin is not as prominent,

\[
\Gamma(D^0 \rightarrow K^-\pi^+)/\Gamma(D^+ \rightarrow K^0\pi^+) \approx 3.6
\]

However, the results we present here indicate, assuming \( \tau_B^- = \tau_K^- \), and that the \( \Upsilon(4S) \) decays equally to \( B^+B^- \)

\[
\Gamma(B^0 \rightarrow D^+\pi^-)/\Gamma(B^- \rightarrow D^0\pi^-) \approx 0.6 \pm 0.1
\]

decisively less than unity. Because the ratio \( \Gamma(-+)/\Gamma(0+) \) is near to unity, the spectator quark processes shown in Fig. 1 rather than processes with more complicated light quark interactions in the final state, presumably dominate the two-body decay amplitudes for the B system. Because \( \Gamma(-+)/\Gamma(0+) < 1 \), the two amplitudes for \( B^- \) decay that lead to identical final states add constructively.

Figure 1: Spectator Diagrams for Two-Body B Decay: (a) External, which under the assumption of factorization can be related to an exclusive semileptonic amplitude, and (b) Internal, which can suffer color suppression. For the \( B^- \), the two amplitudes add constructively, according the results presented here.

The reconstructed D decay modes are shown in Table 1. Two variables, the beam constrained mass, \( M_B^2 = E_{\text{beam}}^2 - (\sum p_i)^2 \), and the energy difference with the beam,
Table 1: Charm Decay Modes and Branching Ratios used in the B reconstructions.

| Mode               | B Assumed | Source |
|--------------------|-----------|--------|
| $D^0 \to K^-\pi^+$ | (3.91 ± 0.10)% | CLEO-II |
| $D^0 \to K^-\pi^+\pi^0$ | (12.1 ± 1.1)% | PDG |
| $D^0 \to K^-\pi^+\pi^-$ | (8.0 ± 0.5)% | PDG |
| $D^+ \to K^-\pi^+\pi^+$ | (10.0 ± 1.4)% | CLEO-II |
| $D^{*+} \to D^0\pi^+$ | (67.9 ± 2.3)% | CLEO-II |
| $D^{*0} \to D^0\pi^0$ | (62.5 ± 4.2)% | CLEO-II |

Table 2: Two body decay modes of the $B^0$. The top error is statistical, on the inner bottom is intrinsic systematic error, and on the outer bottom is the extrinsic systematic error from, for example, errors in D branching ratios.

| Mode               | #    | $B$ (%) |
|--------------------|------|---------|
| $D^+\pi^-$         | 76±10 | 0.22±0.03 ±0.02±0.03 |
| $D^{*+}\pi^-$      | 73±10 | 0.27±0.04 ±0.02±0.031 |
| $D^+\rho^-$        | 86±11 | 0.62±0.08 ±0.08±0.09 |
| $D^{*+}\rho^-$     | 52±8  | 0.74±0.11 ±0.13±0.03 |

Table 3: Two body decay modes of the $B^-$. The error notation is the same as the previous table.

| Mode               | #  | $B$ (%) |
|--------------------|----|---------|
| $D^0\pi^-$         | 302±22 | 0.47±0.03 ±0.05±0.02 |
| $D^0\rho^-$        | 93±12  | 0.50±0.06 ±0.07±0.04 |
| $D^0\pi^-$         | 248±22 | 1.07±0.10 ±0.16±0.04 |
| $D^0\rho^-$        | 92±12  | 1.41±0.19 ±0.13±0.11 |

Table 4: Limits on decays of the type $B^0 \to 00$, which can proceed via the internal spectator amplitude of Fig. 1(b). In addition to $f_{+-} = f_{00}$, $\tau_{B^-} = \tau_{B^0}$ is assumed for all extractions of the BSW parameters $a_1$ and $a_2$.

| $B^0 \to B\% (90\% C.L.) | \gamma(00) | \% BSW (%) |
|---------------------------|------------|-------------|
| $D^0\pi^0$                | 0.03       | 14          |
| $D^0\rho^0$               | 0.06       | 22          |
| $D^0\pi^0$                | 0.08       | 13          |
| $D^0\rho^0$               | 0.17       | 23          |

One can see in all cases that $B(B^- \to 0^-) > B(B^0 \to 0^-)$. The two body decay data can be described by the phenomenology of Bauer, Stech, and Wirbel (BSW)[1], where the external spectator in Fig. 1(a) is associated with the coefficient $a_1$, and the internal spectator in Fig. 1(b) is as-
imply that we obtain increased sensitivity to the interference term; second, we can measure the modes produced by the internal spectator diagram where the W hadronizes as a $\tau$'s rather than $\tau_d$, such as $B^0 \rightarrow J/\psi K_S^*$. For the first method, define:

$$R_1 = \frac{B(B^0 \rightarrow D^+ \pi^-)}{B(B^0 \rightarrow D^0 \pi^-)} = \frac{1}{(1 + 1.23a_2/a_1)^2} \quad (4)$$

$$R_2 = \frac{B(B^0 \rightarrow D^+ \pi^-)}{B(B^0 \rightarrow D^0 \pi^-)} = \frac{1}{(1 + 1.29a_2/a_1)^2} \quad (5)$$

$$R_3 = \frac{B(B^0 \rightarrow D^+ \rho^0)}{B(B^0 \rightarrow D^0 \rho^0)} = \frac{1}{(1 + 0.66a_2/a_1)^2} \quad (6)$$

$$R_4 = \frac{B(B^0 \rightarrow D^+ \rho^0)}{B(B^0 \rightarrow D^0 \rho^0)} \approx \frac{1}{(1 + 1.5a_2/a_1)^2} \quad (7)$$

With these definitions, we find the results given in Table 6, which indicate $a_2/a_1 \approx 0.24$. Note the relative sign is positive, in contradiction to the destructive interference obtained in the BSW analysis of the analogous charm decays.

| Ratio $a_2/a_1$ | $a_2/a_1$ | CLEO-II |
|-----------------|-----------------|---------|
| $R_1$           | 2.0             | 0.59    | 0.56 ± 0.09 ± 0.11 |
| $R_2$           | 2.1             | 0.58    | 0.64 ± 0.06 ± 0.05 |
| $R_3$           | 1.4             | 0.74    | 0.69 ± 0.11 ± 0.12 |
| $R_4$           | 1.3             | 0.54    | 0.63 ± 0.07 ± 0.05 |

Table 6: Estimation of $a_2$ by interference in $B^- \rightarrow 0-$-decays.

When the W hadronizes as a $\tau$'s, the internal spectator can produce the decays $B \rightarrow J/\psi K$. The decays of the $B^0$ of this type produce CP eigenstates, and are expected to be useful in the measurement of CP violation in the $B^0$-$\bar{B}^0$ system, in particular to extract $\sin 2\beta$. The CLEO-II signals in these modes, where the $J/\psi \rightarrow \ell^+\ell^-$, are shown in Fig. 7. The numbers for extraction of $a_2$ are shown in Table 7, and yield $|a_2| = 0.25 ± 0.013 ± 0.006 ± 0.02$, in agreement with the determination from interference.

| $B^0 \rightarrow B$ (%) | BSW (%) | B (%) | $B^- \rightarrow$ |
|-------------------------|---------|-------|--------------------|
| $J/\psi K_S^*$ | 1.82 | 0.11 ± 0.02 | 0.74 ± 0.04 |
| $J/\psi K^*$ | 2.93 | 0.21 ± 0.06 | 1.09 ± 0.04 |

Table 7: Measurement of $|a_2|$ by rate of $B \rightarrow J/\psi K$ decays.

To conclude this discussion of the two body decays of the $B$: given that a number of branching ratios for the $B^-$ are greater than those for the $B^0$, one can wonder whether the oft-quoted prediction that $\tau_{B^-} > \tau_{B^0}$ really has a solid foundation. One can see that differences between exclusive $B^- \rightarrow 0-$ and $B^0 \rightarrow +-$ partial rates where the W

![Figure 3: Beam constrained mass ($M_B$) distributions for (a) $B^0 \rightarrow D^0\pi^0$ decays; (b) $B^0 \rightarrow D^{*0}\pi^0$ decays; (c) $B^0 \rightarrow D^0\rho^0$ decays; and (d) $B^0 \rightarrow D^{*0}\rho^0$ decays. The solid curves show just the background shape, the dotted curves the 90% CL upper limit.](image-url)
hadronizes as $\pi d$, will wash out in the inclusive decay rate: partial widths when the W hadronizes as $\tau s$ or couples to leptons are surely the same between $B^-$ and $B^0$. What is hard to see is how the remaining decay rates, predominantly high multiplicity decays where the W hadronizes $\pi d$, could push the inclusive $B^0$ decay rate higher than the $B^-$.  

**Inclusive measurements of $D'$s and $J/\psi$'s**

We have recently made new measurements of the inclusive branching ratios of $B$ mesons to various openly charmed and hidden charmed mesons. The statistics involved in these measurements is much better than earlier results: for example, about 1500 events are used to measure $B \rightarrow J/\psi X$. These measurements are summarized in Table 8. Whether the excess of $D^{*0}$ relative to $D^{*+}$ is due to isospin breaking in the decay sequence of excited $D'$s, $f_+ \neq f_0$, or $\tau_{B^-} < \tau_{B^0}$ remains to be seen.

### $D\pi\pi$

The CsI calorimeter of CLEO-II has allowed the observation of the decay modes $D^{+} \rightarrow \pi^{+}\pi^{0}$ and $D^{0} \rightarrow 2\pi^{0}$. The $D^{+} \rightarrow \pi^{+}\pi^{0}$ signal is shown in Fig. 5. CLEO-II results on all three $\pi\pi$ decay modes are given in Table 3.

One can see from Table 3 and the D lifetimes that $\Gamma(\pi^{+})/\Gamma(\pi^{0}) = 1.19 \pm 0.26$, which is rather low for the D system. Before concluding that this process is spectator driven, however, note $\Gamma(\pi^{0})/\Gamma(\pi^{+}) = 0.63 \pm 0.12$, which is similar to the K system, so an isospin analysis is appropriate. The result of such an analysis is that the ratio of

**Wrong Sign Decays of the $D^{0}$**

We have observed a signal from tagged $D^{0}$'s decaying to $K^{+}\pi^{-}$. We tag the $D^{0}$ with the charge of the soft pion from $D^{*+}(D^{*+}) \rightarrow D^{0}\pi^{+}(D^{0}\pi^{-})$. The $K^{+}\pi^{-}$ could either result from the doubly Cabibbo-suppressed decay of the $D^{0}$, or from $D^{0} \rightarrow D^{0}$ mixing, followed by Cabibbo-allowed decay of the $D^{0}$.

### Table 8: Results on inclusive branching ratios. The second systematic error, when given, reflects the extrinsic systematic from propagation of errors on branching ratios used in reconstruction.

$$
\Delta I = 2 \rightarrow \Delta I = 0 \text{ amplitudes, } |A_2/A_0| = 0.72 \pm 0.13 \pm 0.11, \\
\text{which is far greater than the K system, while } \delta_2 - \delta_0 = 82^\circ \pm 8^\circ \pm 5^\circ, \text{ a large phase shift.}$$
Table 9: Results on D → 2π branching ratios

| D → | B (%) |
|-----|-------|
| π−π+ | 0.136 ± 0.012 ± 0.012 |
| π0π0 | 0.086 ± 0.016 ± 0.015 |
| π0π+ | 0.24 ± 0.05 ± 0.05 |

The basic quantities of the analysis are the mass of the putative K+π− system, mK+π−, and the mass difference computed by addition of the soft pion to this system, δm. Backgrounds from K/π misidentification will tend to peak in δm, but mK+π− will not peak at mD0; in fact, any mK+π− that reconstructs near mD0 under the hypothesis that a misidentification occurred is cut. Backgrounds from random slow pion tags will tend not to peak in δm.

The distribution of δm for D0 → K+π− candidates is shown in Fig. 6(a). For this figure, hard K/π separation cuts have been made. A signal region is defined in δm, and the projection of this signal region on the mK+π− axis is shown in Fig. 6(c). Sidebands in δm are projected onto the mK+π− axis and shown in Fig. 6(d); little peaking is evident. The difference between (c) and (d) is the signal, shown if Fig. 6(b), and is 14.9 events on an expected background of 0.9, a rather significant result.

\[
R = \frac{\Gamma(D^0(\rightarrow K^-\pi^+))}{\Gamma(D^0(\rightarrow K^-\pi^+))} = [0.77 \pm 0.25 \pm 0.25]\% \quad (8)
\]

\[
(2.92 \pm 0.95 \pm 0.95) \tan^4 \theta_c \quad (9)
\]

where θc is the Cabibbo angle.

Absolute D0 and D+ Branching Ratios

CLEO-II has also used the soft pions D+ decays to provide the normalization in new, precise measurements of the absolute branching ratios for D0 → K−π+ and D+ → K−π+π+. The possibility of soft pion tags from \( \Sigma^0 \rightarrow \pi^-\Xi_c^- \) has been excluded in a Monte Carlo independent way. The result for the D0, where the tags are only π+ from the D+, is:

\[
B(D^0 \rightarrow K^-\pi^+) = (3.912 \pm 0.082 \pm 0.17)\% \quad (10)
\]

The largest contribution to the systematic error results from uncertainty in track reconstruction efficiency.

For the D+ decay, the soft π0 from the D+ must be used, which brings in background from D+0 → D0π0. The analysis is specially designed to suppress systematic uncertainty from the D+ branching ratios. The result is:

\[
B(D^+ \rightarrow K^-\pi^+\pi^+) = (10.0 \pm 0.5 \pm 0.7 \pm 1.4)\% \quad (11)
\]

The second systematic error results only from uncertainty on the relative efficiency of soft π0 to soft π+ reconstruction.

Conclusions

CLEO-II’s large data sample has been exploited to further understanding of a number of hadronic weak decays of heavy mesons. There is clear evidence that a number of two body branching ratios for the B− are larger than the analogous branching ratios for the \( \overline{B}^0 \). It remains to be seen whether \( \tau_{B^-} > \tau_{\overline{B}^0} \).

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References

[1] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C 29, (1985) 637; ibid 34, (1987) 103; ibid 42, (1989) 671.