A REANALYSIS OF CHARMED D MESON BRANCHING FRACTIONS*

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ABSTRACT

We report a new determination of charmed D meson absolute hadronic branching fractions based on complete reconstruction of $D\bar{D}$ events at the $\psi(3770)$. Two backgrounds, Cabibbo suppressed and multi-π^0 D decays, are addressed in detail. Removal of these backgrounds reduces the values of our previously reported hadronic branching fractions by (21 - 24)%, leaving their ratios essentially unchanged. The new values are unable to account fully for a reported deficit of charm production in B meson decay.

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The purpose of this report is to correct our (MarkIII) previously published values[1] for the absolute hadronic branching fractions of the charmed D meson. We have discovered backgrounds arising from real $D\bar{D}$ pairs which produce a peak in the fitted mass distribution and were therefore not removed by the background subtraction performed in the original analysis. These backgrounds can be effectively removed by the addition of a simple kinematic cut, which results in a (21 - 24)% reduction in the absolute D meson hadronic branching fractions, leaving the relative values essentially unchanged. As a result of this experience, we have gained a new respect for the subtleties of nature and a heightened appreciation for the difficulty of obtaining reliable results from high energy experiments. We hope that by exposing carefully and openly our mistakes in the previous analysis, we will encourage other groups to act similarly in the future.

The new analysis uses the same data sample (9.56 pb^{-1}), particle identification, and kinematic fitting technique[2] employed in the previous work.[1] Briefly, the exclusive production of D^+D^- and $D^0\bar{D}^0$ at the $\psi(3770)$ allows the isolation of two classes of events: *single tags*, in which only one D of a pair is reconstructed, and *double tags* in which both D mesons are reconstructed through kinematic fitting of the reaction $e^+e^- \to X\bar{X} \to$ final state, with the mass constraint $M_X = M_{\bar{X}}$. By comparing the number of observed single and double tag events, individual branching fractions are determined independent of the production cross section. The single tags, having significantly smaller statistical errors, essentially fix the relative branching fractions, while the double tags largely determine their absolute value.

The single and double tag samples include the modes $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$ and $D^+ \to \bar{K}^0\pi^+$, $K^-\pi^+\pi^+$, $\bar{K}^0\pi^+\pi^0$, $\bar{K}^0\pi^+\pi^+\pi^-$. These samples differ from the original only by the addition of $D^+ \to \bar{K}^0\pi^+\pi^+\pi^-$ and the elimination of $D^+ \to K^-\pi^+\pi^+\pi^0$, which suffered from a poor signal to background ratio. The focus of the reanalysis is the determination of those backgrounds in the double tag sample which are not accounted for in the previous procedure of simply subtracting the observed number of events in the low-mass sideband region ($1.83 \leq M_X \leq 1.85$ GeV/c^2). Backgrounds escaping this subtraction must arise exclusively from sources having fitted values of $M_X \approx M_D$. Extensive Monte Carlo studies of the kinematic fitting procedure for double tagging indicate that the leading source of background after the sideband subtraction is true $D\bar{D}$ pairs in which the decay products of one D are correctly identified, and those of the second are not.[3] An incorrectly assigned D

decay can arise either from (i) a *single* particle being misidentified (*e.g.* $\pi^{\pm} \rightleftharpoons K^{\pm}$) or ($ii$) the loss of a *single* low energy π^0 (*e.g.* $K^-\pi^+\pi^0 \rightarrow K^-\pi^+$). Other event topologies (*e.g.* missing neutrinos as in $K^-e^+\nu \rightarrow K^-\pi^+$) have been studied and have been found to produce negligible backgrounds in the double tag sample.

Background (i) arises from Cabibbo suppressed channels having the correct D momentum, but incorrect energy after $\pi^{\pm} \rightleftharpoons K^{\pm}$ interchange. Background (ii) comes predominantly from higher multiplicity Cabibbo allowed channels containing π^0's, where one soft π^0 is lost; the larger measurement errors for photons allow such losses to occur while still satisfying the χ^2 requirement of the kinematic fit. The M_X distributions from Monte Carlo simulations for both (a) the signal ($K^-\pi^+$ *vs.* $K^+\pi^-$) and (b) the background ($K^-\pi^+$*vs.* (K^+K^- or $\pi^+\pi^-$ or $K^+\pi^-\pi^0$)), as shown in Figure 1, demonstrate that these backgrounds produce a peak whose mass and width are similar to those of a true signal. Indeed, I think we can say that we have better peaks in our background than most people have in their signal.

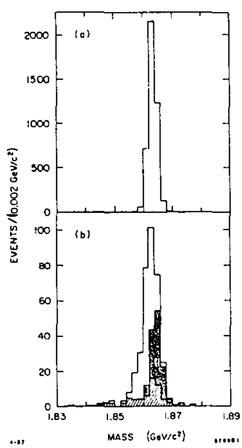

Fig 1. M_X from fits to $K^-\pi^+$ *vs.* $K^+\pi^-$ from Monte Carlo simulations of
(a) $K^-\pi^+$ *vs.* $K^+\pi^-$,
(b) $K^-\pi^+$ *vs.* (K^+K^- or $\pi^+\pi^-$(shaded) or $K^+\pi^-\pi^0$ (dotted)).

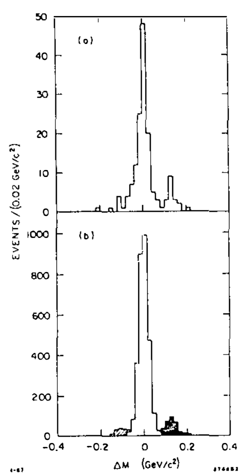

Fig 2. ΔM for (a) the original data, and (b) Monte Carlo simulations of:
(i) the signal ($K^-\pi^+$ *vs.*$K^+\pi^-$), and
(ii) the backgrounds ($K^-\pi^+$ *vs.* $\pi^-\pi^+$ (shaded), and $K^+\pi^-\pi^0$(darkened), and K^-K^+(dotted)).

While both backgrounds can be suppressed by lowering the χ^2 cut, this procedure would result in a substantial reduction in detection efficiency for some final states. Therefore, we have chosen to keep the previous χ^2 cut, but impose an additional kinematic selection on the *individual* D mesons composing a double tag. For each D candidate the unfitted invariant mass (M_{inv}) is compared with the mass evaluated using the beam energy constraint (M_{bc}).[4] Distributions of the difference $\Delta M \equiv M_{bc} - M_{inv}$, are shown in Figure 2 for the $K^-\pi^+$ mode of the original analysis and for Monte Carlo simulations of the signal ($K^-\pi^+$) and the dominant backgrounds ($K^-\pi^+, \pi^-\pi^+$, and $K^-\pi^+\pi^0$). Requiring $|\Delta M| \leq 60$ MeV/c^2 for all modes containing only charged particles, removes essentially all the background with a loss of efficiency of $\leq 5\%$ for each mode. For modes containing π^0's, the cut is widened to $-120 \leq \Delta M \leq 100$ MeV/c^2, eliminating 90% of the background with a loss of efficiency of $\leq 30\%$ for each mode. The fraction of signal events ($f_{\Delta M}$) remaining after the ΔM cut for each final state is given in Table I.

To verify that the ΔM requirement provides sufficient background rejection *regardless of the source*, Monte Carlo simulations of all contributing topologies were generated and compared with the data. While measurements of the branching fractions of many Cabibbo suppressed decays[5] and of several modes containing a single π^0 have already been made,[1] no data has heretofore been available on decays with two or more π^0's. Examination of the double tags containing candidates for $D^0 \to K^-\pi^+\pi^0$ indicates, however, the presence of an additional π^0 in a subset of events that survive the kinematic fit but fail the ΔM cut. These events which form the largest background to $K^-\pi^+\pi^0$ in the previous analysis, arise from the multi-π^0 decay, $D^0 \to K^-\pi^+\pi^0\pi^0$. This channel is measured with 7% efficiency in fully reconstructed $D^0\bar{D}^0$ events along with $K^+\pi^-$. The fitted mass distribution (M_X) for these events is shown in Figure 3 indicating a signal of 24 ± 5 events.

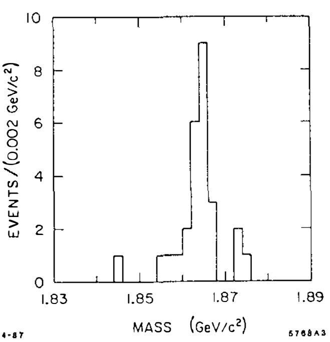

Fig 3. M_X for $K^+\pi^- vs.\ K^-\pi^+\pi^0\pi^0$

To further check our understanding of the identification and rejection of these backgrounds, a study of the absolute number of signal events removed by the ΔM cut is presented in Table I. The loss of 176 ± 21 signal events from the original sample by the ΔM cut compares well with that predicted (168 ± 13) from Monte Carlo simulation of D background sources for all measured modes, and suggests that all

Table I. Signal Events Removed by the ΔM Cut

Double Tag Combination			$f_{\Delta M}$	Predicted Loss	Observed Loss
$K^-\pi^+$	vs.	$K^+\pi^-$	0.95	6±2	11±4
$K^-\pi^+$	vs.	$K^+\pi^-\pi^0$	0.66	48±6	50±8
$K^-\pi^+$	vs.	$K^+\pi^-\pi^-\pi^+$	0.92	11±2	13±5
$K^-\pi^+\pi^0$	vs.	$K^+\pi^-\pi^0$	0.51	49±9	34±14
$K^-\pi^+\pi^0$	vs.	$K^+\pi^-\pi^-\pi^+$	0.67	40±6	53±10
$K^-\pi^+\pi^+\pi^-$	vs.	$K^+\pi^-\pi^-\pi^+$	0.91	2±1	1±3
$K^-\pi^+\pi^+$	vs.	$K^0\pi^-$	0.93	2±1	2±1
$K^-\pi^+\pi^+$	vs.	$K^+\pi^-\pi^-$	0.94	4±1	8±3
$K^-\pi^+\pi^+$	vs.	$K^0\pi^-\pi^0$	0.72	6±2	4±4

significant backgrounds are now accounted for.

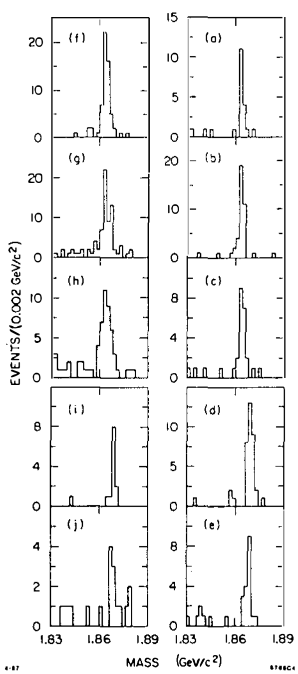

Fig 4. M_X for (a)$K\pi$ *vs.* $K\pi$, (b)$K\pi$ *vs.* $K\pi\pi\pi$, (c)$K\pi\pi\pi$ *vs.* $K\pi\pi\pi$, (d)$K\pi$ *vs.* $K\pi\pi^0$, (e)$K\pi\pi\pi$ *vs.* $K\pi\pi^0$, (f)$K\pi\pi^0$ *vs.* $K\pi\pi^0$, (g)$K\pi\pi$ *vs.* $K\pi\pi$, (h)$K\pi\pi$ *vs.* $K^0\pi\pi^0$, (i)$K\pi\pi$ *vs.* $K^0\pi$, (j)$K\pi\pi$ *vs.* $K^0\pi\pi\pi$.

The fitted M_X distributions are shown in Figure 4 after the ΔM cut. The sideband subtraction is performed as in the previous work, and combined with the single tags to perform independent fits to the D^0 and D^+ samples.[1] A χ^2 of 3.5 for 5 and 1.8 for 3 degrees of freedom are obtained for the D^0 and D^+ fits, respectively.

The values of the branching fractions obtained from the D^0 and D^+ fits are given in Table II (a). The systematic errors are calculated by propagating individual uncertainties (acceptance modeling, resonant substructure, and background subtractions) through the fit and adding in quadrature an error estimate of $\pm 7\%(\pm 2\%)$ for each $D^0(D^+)$ mode to account for uncertainties in the efficiency of the ΔM cut. The cross-sections,

$$\sigma_{D^0} = (5.8 \pm 0.5 \pm 0.6)\ nb, \quad \text{and}$$

$$\sigma_{D^+} = (4.2 \pm 0.6 \pm 0.3)\ nb$$

Table II. D^0 , D^+ Branching Fractions

Decay Mode	Branching Fraction(%)
(a) Results of Global Fits	
$D^0 \to K^-\pi^+$	$4.2 \pm 0.4 \pm 0.4$
$D^0 \to K^-\pi^+\pi^-\pi^+$	$9.1 \pm 0.8 \pm 0.8$
$D^0 \to K^-\pi^+\pi^0$	$13.3 \pm 1.2 \pm 1.3$
$D^+ \to K^-\pi^+\pi^+$	$9.1 \pm 1.3 \pm 0.4$
$D^+ \to \bar{K}^0\pi^+$	$3.2 \pm 0.5 \pm 0.2$
$D^+ \to \bar{K}^0\pi^+\pi^0$	$10.2 \pm 2.5 \pm 1.6$
$D^+ \to \bar{K}^0\pi^+\pi^-\pi^+$	$6.6 \pm 1.5 \pm 0.5$
(b) New Double Tag Measurement	
$D^0 \to K^-\pi^+\pi^0\pi^0$	$14.9 \pm 3.7 \pm 3.0$
(c) Corrected Values for Previous Mark III Measurements	
$D^0 \to K^-K^+$	$0.51 \pm 0.09 \pm 0.06$
$D^0 \to \pi^-\pi^+$	$0.14 \pm 0.04 \pm 0.03$
$D^0 \to \bar{K}^0\phi$	$0.86^{+0.50+0.31}_{-0.41-0.18}$
$D^0 \to \bar{K}^0K^+K^-_{non-res}$	$0.85^{+0.27+0.20}_{-0.24-0.18}$
$D^0 \to \bar{K}^0K^0$	≤ 0.46 at 90 % C.L.
$D^0 \to \mu^+e^-$	≤ 0.012 at 90 % C.L.
$D^+ \to K^+\bar{K}^0$	$1.01 \pm 0.32 \pm 0.18$
$D^+ \to \pi^+\pi^-\pi^+$	$0.38 \pm 0.15 \pm 0.09$
$D^+ \to K^-K^+\pi^+_{non-res}$	$0.54 \pm 0.25 \pm 0.09$
$D^+ \to \phi\pi^+$	$0.77 \pm 0.22 \pm 0.11$
$D^+ \to K^+\bar{K}^{*0}$	$0.44 \pm 0.20 \pm 0.10$

are obtained from the fitted number of produced events ($27700 \pm 2400 \pm 2600$ $D^0\bar{D}^0$ and $20300 \pm 2900 \pm 1100$ D^+D^-) and the integrated luminosity.[6] Using these new values, the signal for the new channel $D^0 \to K^-\pi^+\pi^0\pi^0$ is converted to a branching fraction in Table II (b), and previous Mark III results[5][7][8] are corrected and summarized in Table II (c).

The values of the hadronic branching fractions given in Table II are smaller than our original determinations by (21 - 24)% but remain substantially larger than earlier measurements employing $\sigma_{\psi(3770)}$ normalization.[9][10] Our new values also have implications for experimental studies of charm production mechanisms and the production and decay of all heavier flavors. For example, the existence of a large deficit in charm from B meson decay was first suggested by the CLEO group based on their inclusive measurement[11][12] of $B(B_{u,d} \to D^0$ or $D^+) = 0.56 \pm 0.06 \pm 0.06$. Using the corrected D hadronic branching fractions, this result becomes $0.70 \pm 0.08 \pm 0.07$, which still differs significantly from the expectation of one D meson per B decay.[12][13] Recent results from ARGUS,[12] similarly corrected give $B(B_{u,d} \to D^0$ or $D^+) = 0.96 \pm 0.14 \pm 0.13$. The average[14] of these results is $0.74 \pm 0.08 \pm 0.07$, where the first(second) error represents the statistical(systematic) errors from the combination of the measurements of the three experiments. We therefore conclude that our new values are not able to account for a reported deficit of charm production in B meson decay.

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3. The presence of at least one correctly identified D meson in the event is sufficient to influence the equal mass hypothesis in the kinematic fit, weakening the rejection power of the fit to backgrounds. Decays with two or more erroneous assignments are adequately rejected.
4. In channels that contain π^0's, a 1C fit to the π^0 mass is first performed on the two photons. Fits with $\chi^2 \leq 4$ and fitted photon energies ≥ 40 MeV/c^2 are retained.
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6. The ratio $\frac{\sigma_{D^0}}{\sigma_{D^+}}$ is $1.36 \pm 0.23 \pm 0.14$, is close to $1.34^{+0.17}_{-0.20} \pm 0.11$ from ref.[1].
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14. The average is calculated from the product branching fractions (*e.g.* $B(B \to D^0 + X)B(D^0 \to K^-\pi^+)$) which are measured directly by CLEO and by ARGUS.