Measurements of Absolute Hadronic Branching Fractions of D Mesons

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Abstract. Using e^+e^- collisions recorded at the $\psi(3770)$ resonance with the CLEO-c detector at the Cornell Electron Storage Ring, we determine absolute hadronic branching fractions of charged and neutral D mesons. Among measurements for both Cabibbo-favored and Cabibbo-suppressed modes, we obtain reference branching fractions $\mathscr{B}(D^0 \to K^-\pi^+) = (3.91 \pm 0.08 \pm 0.09)\%$ and $\mathscr{B}(D^+ \to K^-\pi^+\pi^+) = (9.5 \pm 0.2 \pm 0.3)\%$, where the uncertainties are statistical and systematic, respectively. Using a determination of the integrated luminosity, we also extract the $e^+e^- \to D\bar{D}$ cross sections.

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Absolute measurements of hadronic charm meson branching fractions play a central role in the study of the weak interaction because they serve to normalize many D and B meson branching fractions, from which CKM matrix elements are determined. At CLEO-c, we have measured several charge-averaged branching fractions listed in Tables 1 and 2. Two of these modes, $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$, are particularly important because essentially all other D^0 and D^+ branching fractions have been determined from ratios to one of these branching fractions. Our data sample was produced in e^+e^- collisions on the $\psi(3770)$ resonance at the Cornell Electron Storage Ring and collected with the CLEO-c detector.

For the results in Table 1, based on 55.8 pb^{-1} of integrated luminosity, we employ a double tagging technique pioneered by MARK III [1, 2], which obviates the need for knowledge of the luminosity or the $e^+e^- \to D\bar{D}$ production cross section. A single reconstructed D or $\bar{D}$ (called single tag or ST) tags the event as either $D^0\bar{D}^0$ or D^+D^-. Double tag (DT) events have both the D and $\bar{D}$ reconstructed. The measured ST and DT yields are assumed to be $N_i = \varepsilon_i \mathscr{B}_i N_{D\bar{D}}$ and $N_{ij} = \varepsilon_{ij} \mathscr{B}_i \mathscr{B}_j N_{D\bar{D}}$, ε_i and ε_{ij} are ST and DT efficiencies, $\mathscr{B}_i$ is the branching fraction for mode i (assuming no D^0-$\bar{D}^0$ mixing or CP violation) and $N_{D\bar{D}}$ is the number of produced $D\bar{D}$ pairs. Thus, we can extract the $\mathscr{B}_i$ and $N_{D\bar{D}}$, simultaneously for D^0 and D^+, with a least-squares procedure described in Ref. [3]. We identify D candidates by their beam-constrained mass, $M \equiv \sqrt{E^2_{\rm beam} - \mathbf{p}^2_D}$, and by $\Delta E \equiv E_D - E_{\rm beam}$. The $\mathscr{B}_i$ and $N_{D\bar{D}}$ statistical uncertainties are dominated by those of the DT yields, which we find to be 2484 ± 51 for D^0 and 1650 ± 42 for D^+.

The results of the data fit are shown in Table 1. The χ^2 of the fit is 28.1 for 52 degrees of freedom, corresponding to a confidence level of 99.7%. All nine branching fractions have comparable precision to the current PDG averages. We do not explicitly reconstruct FSR photons, but because FSR is simulated in the samples used to calculate efficiencies, our branching fractions are inclusive of photons radiated from the final state particles. If

TABLE 1. Fitted branching fractions and $D\bar{D}$ pair yields, along with the fractional FSR corrections and comparisons to the Particle Data Group [5] fit results. Uncertainties are statistical and systematic, respectively.

D **Decay Mode**	**Fitted** $\mathscr{B}$ **(%)**	**PDG** $\mathscr{B}$ **(%)**	Δ_{FSR}
$K^-\pi^+$	$3.91 \pm 0.08 \pm 0.09$	3.80 ± 0.09	-2.0%
$K^-\pi^+\pi^0$	$14.9 \pm 0.3 \pm 0.5$	13.0 ± 0.8	-0.8%
$K^-\pi^+\pi^+\pi^-$	$8.3 \pm 0.2 \pm 0.3$	7.46 ± 0.31	-1.7%
$K^-\pi^+\pi^+$	$9.5 \pm 0.2 \pm 0.3$	9.2 ± 0.6	-2.2%
$K^-\pi^+\pi^+\pi^0$	$6.0 \pm 0.2 \pm 0.2$	6.5 ± 1.1	-0.6%
$K^0_S\pi^+$	$1.55 \pm 0.05 \pm 0.06$	1.41 ± 0.10	-1.8%
$K^0_S\pi^+\pi^0$	$7.2 \pm 0.2 \pm 0.4$	4.9 ± 1.5	-0.8%
$K^0_S\pi^+\pi^+\pi^-$	$3.2 \pm 0.1 \pm 0.2$	3.6 ± 0.5	-1.4%
$K^+K^-\pi^+$	$0.97 \pm 0.04 \pm 0.04$	0.89 ± 0.08	-0.9%
$D\bar{D}$ **Yield**	**Fitted Value**		Δ_{FSR}
$N_{D^0\bar{D}^0}$	$(2.01 \pm 0.04 \pm 0.02) \times 10^5$		-0.2%
$N_{D^+D^-}$	$(1.56 \pm 0.04 \pm 0.01) \times 10^5$		-0.2%

no FSR were included in the simulations, then all the branching fractions would change by Δ_{FSR} in Table 1.

We obtain the $e^+e^- \to D\bar{D}$ cross sections by scaling $N_{D^0\bar{D}^0}$ and $N_{D^+D^-}$ by the luminosity, $\mathscr{L} = (55.8 \pm 0.6)$ pb^{-1}. Thus, at $E_{\text{cm}} = 3773$ MeV, we find peak cross sections of $\sigma(e^+e^- \to D^0\bar{D}^0) = (3.60 \pm 0.07^{+0.07}_{-0.05})$ nb, $\sigma(e^+e^- \to D^+D^-) = (2.79 \pm 0.07^{+0.10}_{-0.04})$ nb, $\sigma(e^+e^- \to D\bar{D}) = (6.39 \pm 0.10^{+0.17}_{-0.08})$ nb, and $\sigma(e^+e^- \to D^+D^-)/\sigma(e^+e^- \to D^0\bar{D}^0) = 0.776 \pm 0.024^{+0.014}_{-0.006}$, where the uncertainties are statistical and systematic, respectively. The systematic uncertainties include uncertainties on $N_{D^0\bar{D}^0}$, $N_{D^+D^-}$, and $\mathscr{L}$, as well as the effect of E_{cm} variations with respect to the peak. Our measured cross sections are in good agreement with BES [4] and higher than those of MARK III [2].

For the Cabibbo-suppressed branching fractions in Table 2, based on 281 pb^{-1} of integrated luminosity, we measure ST yields only and determine branching ratios with respect to the reference modes $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$. Backgrounds from Cabibbo-favored decays with $K^0_S \to \pi^+\pi^-$ are suppressed with a veto on the $\pi^+\pi^-$ invariant mass. Six of the modes in Table 2 are observed for the first time, and we obtain absolute branching fractions by combining the PDG average [5] and our results in Table 1 for the reference modes. For the three $D \to \pi\pi$ modes, we also find the ratio of the $\Delta I = 3/2$ to $\Delta I = 1/2$ isospin amplitudes to be $A_2/A_0 = 0.420 \pm 0.014(\text{stat.}) \pm 0.010(\text{syst.})$ and the relative strong phase to be $\delta_I = (86.4 \pm 2.8 \pm 3.3)^\circ$, which indicates a substantial contribution from final state interactions.

Using the 281 pb^{-1} sample, we also search for an asymmetry between $\mathscr{B}(D^+ \to K^0_S\pi^+)$ and $\mathscr{B}(D^+ \to K^0_L\pi^+)$, which can arise from interference among competing amplitudes [7]. We reconstruct the neutral kaon inclusively by fully-reconstructing the D^-, finding the π^+ daughter of the D^+, and computing the missing mass of the event, which peaks at the neutral kaon mass for both $K^0_S\pi^+$ and $K^0_L\pi^+$ signal de-

TABLE 2. Ratios of branching fractions to the reference branching fractions $\mathscr{R}_0 \equiv \mathscr{B}(D^0 \to K^-\pi^+)$ and $\mathscr{R}_+ \equiv \mathscr{B}(D^+ \to K^-\pi^+\pi^+)$, along with comparisions to the Particle Data Group [5] fit results. Uncertainties arise from statistics, experimental systematic effects, $\mathscr{R}_{0/+}$, and quantum correlations (D^0 modes only) [6]. For the relative branching fractions, the $\mathscr{R}_{0/+}$ uncertainty is omitted.

D **Decay Mode**	$\mathscr{B}/\mathscr{R}_{0/+}$ **(%)**	$\mathscr{B}$ **(10^{-3})**	**PDG** $\mathscr{B}$ **(10^{-3})**
$\pi^+\pi^-$	$3.62 \pm 0.10 \pm 0.07 \pm 0.04$	$1.39 \pm 0.04 \pm 0.04 \pm 0.03 \pm 0.01$	1.38 ± 0.05
$\pi^0\pi^0$	$2.05 \pm 0.13 \pm 0.16 \pm 0.02$	$0.79 \pm 0.05 \pm 0.06 \pm 0.01 \pm 0.01$	0.84 ± 0.22
$\pi^+\pi^-\pi^0$	$34.4 \pm 0.5 \pm 1.2 \pm 0.3$	$13.2 \pm 0.2 \pm 0.5 \pm 0.2 \pm 0.1$	11 ± 4
$\pi^+\pi^+\pi^-\pi^-$	$19.1 \pm 0.4 \pm 0.6 \pm 0.2$	$7.3 \pm 0.1 \pm 0.3 \pm 0.1 \pm 0.1$	7.3 ± 0.5
$\pi^+\pi^-\pi^0\pi^0$	$25.8 \pm 1.5 \pm 1.8 \pm 0.3$	$9.9 \pm 0.6 \pm 0.7 \pm 0.2 \pm 0.1$	
$\pi^+\pi^+\pi^-\pi^-\pi^0$	$10.7 \pm 1.2 \pm 0.5 \pm 0.1$	$4.1 \pm 0.5 \pm 0.2 \pm 0.1 \pm 0.0$	
$\omega\pi^+\pi^-$	$4.1 \pm 1.2 \pm 0.4 \pm 0.0$	$1.7 \pm 0.5 \pm 0.2 \pm 0.0 \pm 0.0$	
$\eta\pi^0$	$1.47 \pm 0.34 \pm 0.11 \pm 0.01$	$0.62 \pm 0.14 \pm 0.05 \pm 0.01 \pm 0.01$	
$\pi^0\pi^0\pi^0$	—	< 0.35 (90% C.L.)	
$\omega\pi^0$	—	< 0.26 (90% C.L.)	
$\eta\pi^+\pi^-$	—	< 1.9 (90% C.L.)	
$\pi^+\pi^0$	$1.33 \pm 0.07 \pm 0.06$	$1.25 \pm 0.06 \pm 0.07 \pm 0.04$	1.33 ± 0.22
$\pi^+\pi^+\pi^-$	$3.52 \pm 0.11 \pm 0.12$	$3.35 \pm 0.10 \pm 0.16 \pm 0.12$	3.1 ± 0.4
$\pi^+\pi^0\pi^0$	$5.0 \pm 0.3 \pm 0.3$	$4.8 \pm 0.3 \pm 0.3 \pm 0.2$	
$\pi^+\pi^+\pi^-\pi^0$	$12.4 \pm 0.5 \pm 0.6$	$11.6 \pm 0.4 \pm 0.6 \pm 0.4$	
$\pi^+\pi^+\pi^+\pi^-\pi^-$	$1.73 \pm 0.20 \pm 0.17$	$1.60 \pm 0.18 \pm 0.16 \pm 0.06$	1.73 ± 0.23
$\eta\pi^+$	$3.81 \pm 0.26 \pm 0.21$	$3.61 \pm 0.25 \pm 0.23 \pm 0.12$	3.0 ± 0.6
$\omega\pi^+$	—	< 0.34 (90% C.L.)	

cays. The dominant background comes from $D^+ \to \eta\pi^+$, which partially overlaps with $K^0\pi^+$ in missing mass. We find a branching fraction asymmetry of $[\mathscr{B}(K_L^0\pi^+) - \mathscr{B}(K_S^0\pi^+)]/[\mathscr{B}(K_L^0\pi^+) + \mathscr{B}(K_S^0\pi^+)] = -0.01 \pm 0.04 \pm 0.07$, which is consistent with the prediction of $\mathscr{O}(10\%)$ [7].

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