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Absolute Branching Fractions of Cabibbo-Suppressed $D \to K\bar{K}$ Decays

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Abstract

Using 281 pb^{-1} of data collected with the CLEO-c detector at the $\psi(3770)$ resonance, we have studied Cabibbo-suppressed decays of D mesons to final states with two kaons. We present results for the absolute branching fractions of the modes $D^0 \to K^+K^-$, $D^0 \to K^0_S K^0_S$, and $D^+ \to K^+K^0_S$. We measure $\mathcal{B}(D^0 \to K^+K^-) = (4.08 \pm 0.08 \pm 0.09) \times 10^{-3}$, $\mathcal{B}(D^0 \to K^0_S K^0_S) = (1.46 \pm 0.32 \pm 0.09) \times 10^{-4}$, and $\mathcal{B}(D^+ \to K^+K^0_S) = (3.14 \pm 0.09 \pm 0.08) \times 10^{-3}$. We also determine the ratio $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to \pi^+\pi^-) = 2.89 \pm 0.05 \pm 0.06$. For each measurement, the first uncertainty is statistical and the second uncertainty is systematic.

Detailed studies of the decay of charmed mesons provide an opportunity to probe the interplay between the strong and weak force, such as examining the contributions of W-exchange diagrams and final state interactions [1]. In particular, the branching ratio $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to \pi^+\pi^-)$ exposes large SU(3) flavor symmetry breaking effects. To first order one would expect a branching ratio close to unity, but the most recent studies show the ratio to be $2.760 \pm 0.040 \pm 0.034$ [2]. The direct weak decay $D^0 \to K^0\bar{K}^0$ is expected to occur primarily via two W-exchange diagrams, which in a four-quark model under SU(3) is expected to be zero due to destructive interference [3]. Hence, substantial contributions to the rate for $D^0 \to K^0\bar{K}^0$ are expected from rescattering in such channels as $D^0 \to K^{*+}K^{*-}$, $D^0 \to \pi^+\pi^-$, and $D^0 \to \rho^+\rho^-$ [4–6]. Theoretical estimates of SU(3)-breaking effects give branching fractions ranging from a few parts in 10^4 [5] up to 0.3% [4]. Here we study the decay mode $D^0 \to K^0_S K^0_S$, whose branching fraction should be half that of $D^0 \to K^0\bar{K}^0$. Note that the decay mode $D^0 \to K^0_S K^0_L$ is forbidden by CP conservation. Understanding SU(3) flavor symmetry breaking is important in attempting to quantify Standard Model contributions to $D^0 - \bar{D}^0$ mixing [7]. The decay mode $D^+ \to K^+K^0_S$ is useful for the estimation of SU(3)-violating effects in the D meson system [8]. Thus, a precise measurement of the absolute branching fraction of $D \to K\bar{K}$ modes will test our current understanding of the Standard Model.

We use a 281 pb^{-1} data sample of e^+e^- collisions at a center-of-mass energy of approximately 3770 MeV produced at the Cornell Electron Storage Ring (CESR) and recorded with the CLEO-c detector. The CLEO-c detector is a general purpose solenoidal detector that includes a tracking system for measuring momenta and specific ionization (dE/dx) of charged particles, a Ring Imaging Cherenkov detector (RICH) for particle identification, and a CsI calorimeter for detection of photons. The details of the CLEO-c detector have been described elsewhere [9–11].

We are interested in events of the type $e^+e^- \to \psi(3770) \to D\bar{D}$. The D mesons have energy equal to the beam energy since the $\psi(3770)$ resonance is below the kinematic threshold for $D\bar{D}\pi$ production. After selecting candidate particles that may be the daughters of a D meson decay, we define the following two variables, $\Delta E \equiv \sum_i E_i - E_{\mathrm{beam}}$ and $M_{\mathrm{BC}} \equiv \sqrt{E^2_{\mathrm{beam}} - |\sum_i \mathbf{p}_i|^2}$, where E_i and $\mathbf{p}_i$ are the energies and momenta respectively of the D meson daughters and E_{beam} is the beam energy. If the event is reconstructed correctly, ΔE should be consistent with zero and the beam constrained mass M_{BC} should be consistent with the mass of the D meson.

In selecting events, charged tracks are required to satisfy criteria based on the track quality [12]. They must also be consistent with coming from the interaction point in three dimensions. Pions and kaons are identified by consistency with the expected dE/dx and, when available, RICH information. We also require that $|\Delta E|$ be less than 20 MeV. Other selection criteria are mode dependent as described below. Charge-conjugate modes are implied throughout.

In selecting events for the mode $D^0 \to K^+K^-$, we veto events that contain leptons, e.g. cosmic rays and Bhabha events, and furthermore require $\cos\theta > -0.9$ for K^- and $\cos\theta < 0.9$ for K^+, where θ is the angle between the e^+ direction and the kaon momentum direction. The $\cos\theta$ criterion is useful to further suppress radiative Bhabha background events that have the same energy loss at about 800 MeV as the kaons in $D^0 \to K^+K^-$.

In selecting events for the mode $D^+ \to K^+K^0_S$, we require the K^0_S candidate invariant mass to be within 12 MeV/c^2, or roughly 4.5σ, of the known K^0_S invariant mass [13] and require the K^0_S candidate to have a flight distance significance (L/σ_L) greater than two in

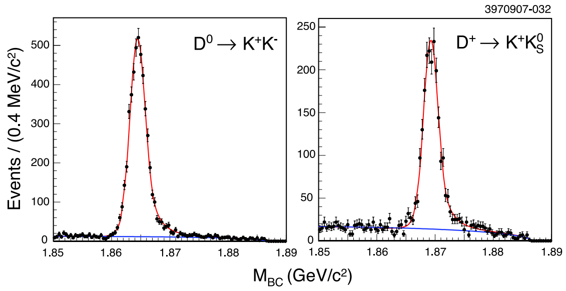

FIG. 1: $M_{\rm BC}$ plots for data, left to right: $D^0 \to K^+K^-$ and $D^+ \to K^+K^0_S$.

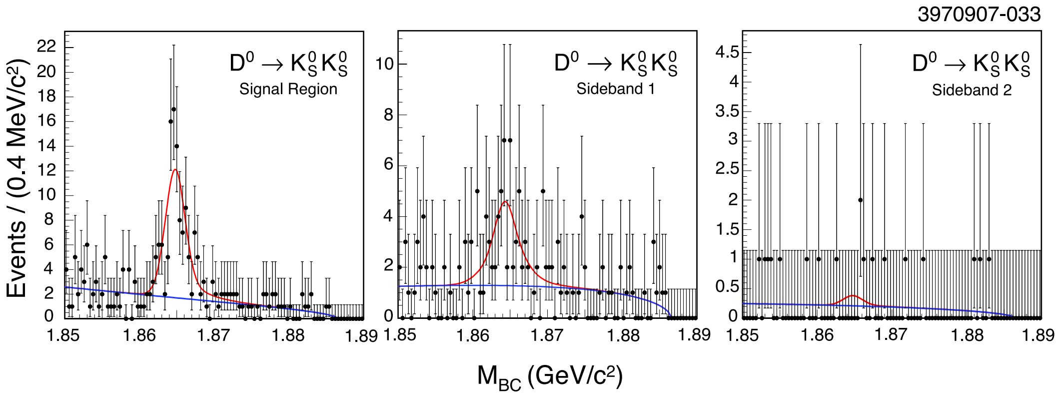

FIG. 2: $D^0 \to K^0_S K^0_S$ plots for data, left to right: $M_{\rm BC}$ fits for the signal region for $D^0 \to K^0_S K^0_S$, sideband region 1 for $D^0 \to K^0_S K^0_S$ and sideband region 2 for $D^0 \to K^0_S K^0_S$.

order to separate true K^0_S particles from pairs of pions produced at the interaction point.

The mode $D^0 \to K^0_S K^0_S$ has significant backgrounds, mostly from the mode $D^0 \to K^0_S \pi^+\pi^-$ where the π^+ and the π^- have an invariant mass consistent with the K^0_S mass. Therefore, similar to our analysis of the mode $D^+ \to K^+K^0_S$, we require the flight distance significance for each of the K^0_S candidates to be greater than two. Furthermore, we perform a background subtraction where we take the region $|M_{\pi^+\pi^-} - M_{K^0_S}| < 7.5$ MeV$/c^2$ to be our signal region and take the region $20 > |M_{\pi^+\pi^-} - M_{K^0_S}| > 9$ MeV$/c^2$ to be our background region, where $M_{\pi^+\pi^-}$ is the reconstructed K^0_S candidate invariant mass and $M_{K^0_S}$ is the known K^0_S invariant mass [13]. This will be described in detail later.

The branching fractions are calculated using $\mathcal{B} = Y/2\epsilon N_{D\bar{D}}$, where Y is the measured signal yield, ϵ is the efficiency obtained from Monte Carlo simulations, and $N_{D\bar{D}}$ is the produced number of $D\bar{D}$ pairs (charged or neutral depending on the decay mode) in our data sample. We use $N_{D\bar{D}}$ from Ref. [12].

To determine the measured yields, we perform an unbinned maximum likelihood fit to a signal shape and one background component to extract signal yields from the $M_{\rm BC}$ distributions. The signal shape includes the effects of beam energy spread, initial state radiation, the line shape of the $\psi(3770)$, and reconstruction resolution [12]. The background is described by an ARGUS function [14], which models combinatorial contributions. We have validated our analysis procedure by studying simulated $D\bar{D}$ events in a sample 40 times the size of our

TABLE I: Efficiencies and yields with their statistical uncertainties. The yield for $D^0 \to K^0_S K^0_S$ is the yield after background subtraction.

Mode	Efficiency (%)	Yield
$D^0 \to K^+K^-$	56.47 ± 0.33	4746 ± 74
$D^0 \to K^0_S K^0_S$	22.75 ± 0.22	68 ± 15
$D^+ \to K^+ K^0_S$	38.29 ± 0.28	1971 ± 51

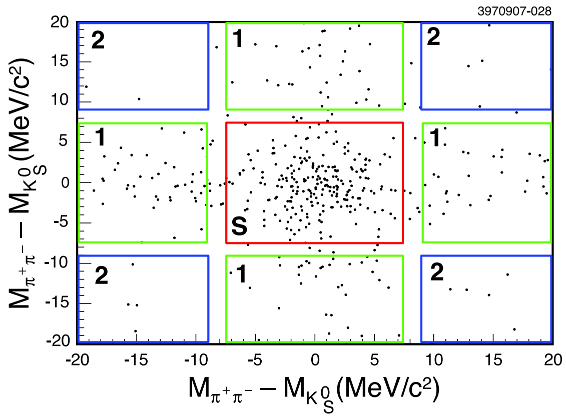

FIG. 3: $(M_{\pi^+\pi^-} - M_{K^0_S})$ vs. $(M_{\pi^+\pi^-} - M_{K^0_S})$ for $D^0 \to K^0_S K^0_S$ candidates. The region labeled 'S' is the signal region, the regions labeled '1' are the sideband 1 region, and the regions labeled '2' are the sideband 2 region.

data set and we reproduce the input branching fractions to within statistical uncertainties. Our fits to the data are shown in Figs. 1 and 2, and our efficiencies, along with the fitted yields, are given in Table I.

The scatter plot for the two K^0_S candidate invariant masses in data in the region $|M_{\pi^+\pi^-} - M_{K^0_S}| < 20$ MeV/c^2 is shown in Fig. 3, where $M_{\pi^+\pi^-}$ is the reconstructed K^0_S candidate invariant mass and $M_{K^0_S}$ is the known K^0_S invariant mass [13]. The order of the two K^0_S candidates is essentially random as it is determined by the order the tracks were found in the event. We expect the bulk of the signal to be in the central (signal) region which we define to be $|M_{\pi^+\pi^-} - M_{K^0_S}| < 7.5$ MeV/c^2 for the two K^0_S candidates. In order to account for $D^0 \to K^0_S \pi^+\pi^-$ and other background events entering into the signal region of $D^0 \to K^0_S K^0_S$, we perform a background subtraction. We then take the four sideband regions where one K^0_S candidate has $20 > |M_{\pi^+\pi^-} - M_{K^0_S}| > 9$ MeV/c^2 and the other K^0_S candidate has $|M_{\pi^+\pi^-} - M_{K^0_S}| < 7.5$ MeV/c^2. We call this region sideband 1. Finally we take the four corner regions where both K^0_S candidates satisfy $20 > |M_{\pi^+\pi^-} - M_{K^0_S}| > 9$ MeV/c^2. We call this region sideband 2. The number of candidate events in each region is determined by a fit to the $M_{\rm BC}$ distribution of the D meson candidates and are found to be $S = 95 \pm 13$, $S_1 = 40 \pm 11$, and $S_2 = 2 \pm 3$ for the signal region, sideband 1, and sideband 2 respectively. We let r_1 denote the ratio of the area in the signal region to the sideband region 1 and r_2 denote the ratio of the area in the signal region to the sideband region 2. Then the total

TABLE II: Measured branching fractions and PDG values [13]; the first uncertainty is statistical and the second uncertainty is systematic.

Mode	Our Result	PDG 2007
$\mathcal{B}(D^0 \to K^+K^-)$	$(4.08 \pm 0.08 \pm 0.09) \times 10^{-3}$	$(3.85 \pm 0.09) \times 10^{-3}$
$\mathcal{B}(D^0 \to K^0_S K^0_S)$	$(1.46 \pm 0.32 \pm 0.09) \times 10^{-4}$	$(3.6 \pm 0.7) \times 10^{-4}$
$\mathcal{B}(D^+ \to K^+ K^0_S)$	$(3.14 \pm 0.09 \pm 0.08) \times 10^{-3}$	$(2.95 \pm 0.19) \times 10^{-3}$

yield Y is given by $Y = S - 2r_1S_1 + r_2S_2$. Note that S_1 is the measured yield in two bands, so after rescaling S_1 with r_1, a factor of two is needed in the second term on the right hand side to account for the fact that two bands are overlapping in the signal region. The third term is added since the second term oversubtracts the uniform background, but we find that S_2 is much smaller than S and S_1. We have $r_1 = 225/660$ and $r_2 = 225/484$.

We have studied various systematic uncertainties in our analysis. These include particle identification efficiency, tracking efficiency, uncertainties in the fitting procedure, and the uncertainties due to the ΔE selection criterion. Using techniques outlined in Ref. [12], the systematic error in the absolute tracking efficiency for pions (kaons) was determined to be 0.3% (0.7%). We have also determined that our Monte Carlo simulation accurately models the identification efficiency of pions, kaons, and K^0_S to within 0.3%, 0.2%, and 1.9% respectively. To determine the systematic errors due to the fitting procedure, we varied the background shape and the momentum resolution in the fit and compared the variations in the fit yield. These have been determined to be 0.8%, 0.6%, and 4.1% for each of the modes $D^0 \to K^+K^-$, $D^+ \to K^+K^0_S$, and $D^0 \to K^0_S K^0_S$ respectively. To determine the systematic error due to the ΔE criterion, we varied the ΔE criterion and studied its effect on the yield. This has a negligible effect for the modes $D^0 \to K^+K^-$, $D^+ \to K^+K^0_S$, and for the mode $D^0 \to K^0_S K^0_S$ we assign a systematic error of 2.0%. Finally, we determined that the systematic error due to background subtraction in the mode $D^0 \to K^0_S K^0_S$ is negligible.

The measured branching fractions are summarized in Table II. We use the $D\bar{D}$ yields $N_{D^0\bar{D}^0} = (1.031 \pm 0.008 \pm 0.013) \times 10^6$ and $N_{D^+D^-} = (0.819 \pm 0.008 \pm 0.010) \times 10^6$ as measured in Ref. [12] to determine our branching fractions. We also determined the ratio of branching fractions $\mathcal{B}(D^0 \to K^+K^-)$ to $\mathcal{B}(D^0 \to \pi^+\pi^-)$, where the latter branching fraction has previously been measured using the same data sample [15], to be $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to \pi^+\pi^-) = 2.89 \pm 0.05 \pm 0.06$, consistent with the previous measured value of $\mathcal{B}(D^0 \to K^+K^-)/\mathcal{B}(D^0 \to \pi^+\pi^-) = 2.760 \pm 0.040 \pm 0.034$ [2]. The modes $D^0 \to K^+K^-$ and $D^+ \to K^+K^0_S$ are consistent with the PDG average. Finally, for the $D^0 \to K^0_S K^0_S$ mode, our errors are significantly smaller than previous measurements, while our branching fraction is about a factor of 2.4 (2.7 standard deviations) smaller [13].

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