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Analyses of $D^+ \to K^0_S K^+$ and $D^+ \to K^0_S \pi^+$

CLEO Collaboration

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Abstract

Using data collected with the CLEO II detector at the Cornell Electron Storage Ring, we present new measurements of the branching fractions for $D^+ \to K_S K^+$ and $D^+ \to K_S \pi^+$. These results are combined with other recent CLEO measurements to extract the ratios of isospin amplitudes and phase shifts in the $D \to KK$ and $D \to K\pi$ channels.

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INTRODUCTION

CLEO has previously reported measurements of the branching fractions $D^+ \to \pi^+\pi^0$, $D^0 \to \pi^+\pi^-$, and $D^0 \to \pi^0\pi^0$ and used them to extract the difference of phase shifts between the two isospin amplitudes [1]. In a simple model of final-state interactions (FSI) in which FSIs are elastic (i.e. $\pi\pi$ stays as $\pi\pi$) and simply rotate the isospin amplitudes by a phase without affecting the magnitudes, a nonzero phase shift difference is indicative of final-state interactions [2]. Here we report the corresponding results for $D \to KK$ and $D \to K\pi$ using CLEO measurements. Measurements of the two D^+ branching fractions necessary for the analysis are described in this paper; details on the four D^0 measurements may be found elsewhere [3] [4] [5].

The ratio $B(D^+ \to K_S K^+)/B(D^+ \to K_S \pi^+)$ is substantially larger than the naive value of $\tan^2\theta_C$ due to destructive interference in the denominator. Namely, $D^+ \to \bar{K}^0\pi^+$ occurs through either color-favored (external W emission) or color-suppressed (internal W emission) spectator diagrams, and the two interfere destructively, and there is no similar effect in the numerator. This interference in D^+ decays does not occur in D^0 decays and is believed to be responsible for the D^+/D^0 lifetime difference [6].

BRANCHING FRACTION MEASUREMENTS

The CLEO II detector is designed to precisely measure photons and charged particles with high efficiency; a detailed description may be found elsewhere [7]. This analysis is based on 3.12 fb^{-1} of data collected at the $\Upsilon(4S)$ resonance and 1.72 fb^{-1} at just below the $\Upsilon(4S)$. Hadronic events are first selected by requiring at least three charged tracks, total detected energy of at least 0.15 $E_{c.m.}$, and a primary vertex within 5 cm in the direction along the beampipe from the interaction point.

Candidate K_S are detected only in the $K_S \to \pi^+\pi^-$ mode. They are reconstructed by combining pairs of oppositely charged tracks, each with an impact parameter in $r - \phi$ (with respect to the primary vertex) of at least four times the measurement uncertainty. The track pair must also pass a χ^2 cut based on the the distance in z between the two tracks at their $r - \phi$ intersection point. $M(\pi^+\pi^-)$ must be within 15 MeV of the known K_S mass.

Charged pion and kaon candidates must pass standard CLEO primary-vertex consistency requirements and minimum track-quality requirements. In order to reduce background from charged pions, we also require that K^+ candidates have a specific ionization (dE/dx) consistent with its expected value. In the $D^+ \to K^-\pi^+\pi^+$ channel we require that the K^+ candidate have a dE/dx value within 3σ of that expected for a kaon. Tighter cuts are applied on the K^+ candidates in the $D^+ \to K_S K^+$ mode because of a large background from $D^+ \to K_S\pi^+$ decays. The measured dE/dx must be within 2σ of that expected for a kaon and also at least 0.25σ lower than that expected for a pion.

We then reconstruct D^+ candidates from the K_S, K^+, and π^+ candidates satisfying the above cuts, in the signal modes $D^+ \to K_S K^+$ and $D^+ \to K_S\pi^+$, and the normalization mode $D^+ \to K^-\pi^+\pi^+$. In the $D^+ \to K_S\pi^+$ mode, we observe a large background from low-momentum tracks in asymmetric decays, in which the K_S is produced in the same direction as the D^+. We therefore impose an additional cut of $\cos(\theta_{K_S}) < 0.8$, where θ_{K_S} is the angle between the K_S in the D^+ rest frame and the D^+ direction in the laboratory frame. This cut is also applied in the $D^+ \to K_S K^+$ mode for consistency.

We require that every D^+ candidate also be a product of the decay $D^{*+} \to D^+\pi^0$. The π^0 is produced near the kinematic limit and therefore provides a clean tag for the D^+. Pairs of electromagnetic showers detected by CLEO's CsI(Tl) crystal calorimeter are combined to form π^0 candidates, which must have the correct π^0 mass to within 2.5σ of the experimentally observed $M(\gamma\gamma)$ peak. Both daughter photons must be detected in the "barrel" region of the detector, have energies of at least 30 MeV, and deposit most of their energy in a compact group of crystals [8].

Since D^{*+} fragmentation is relatively hard [9] and combinatoric background comes mostly from low-momentum tracks, we impose a cut of $x \equiv p(D^{*+})/p(D^{*+}_{max}) > 0.55$. For each event we calculate ΔM, the difference between the masses of the $D^+\pi^0$ combination and the D^+ candidate. We require ΔM to be within about 2.5 MeV (3σ), of the known mass difference.

Events in which a random slow π^0 is added to a correctly reconstructed D^+ will contribute to the peak in $M(D^+)$, but will not peak in the ΔM distribution. In order to remove this background, we perform a sideband subtraction in ΔM. The invariant-mass distributions for all events passing the cuts is shown in Figure 1.

The reconstruction efficiencies for the signal and normalization modes were estimated using a GEANT-based simulation of the CLEO II detector. Furthermore, to study the backgrounds in $M(D^+)$ for each mode we ran a full Monte Carlo simulation that included all particle decay processes except for the signal mode. We find that the backgrounds are smooth in all three D^+ modes, and may be safely parametrized using a quadratic polynomial, with the exceptions of the high and low mass regions of $M(K_S K^+)$ and the low mass region of $M(K_S\pi^+)$.

The invariant mass plot of $M(K_S K^+)$ includes a significant reflection peak from $D^+ \to K_S\pi^+$ events, in which the π^+ is misidentified as a kaon. The shape of this background was obtained by generating $D^+ \to K_S\pi^+$ Monte Carlo events, then running them through the detector simulation and the $K_S K^+$ reconstruction code. The normalization of this background component was allowed to float in the fit of the $M(K_S K^+)$ spectrum. The background in the low mass region is from non-signal D^+ and D^0 modes in which a pion is misidentified as a kaon and a different pion is undetected. To avoid fitting to this we exclude the mass region from 1.67 to 1.795 GeV. The overall background is parametrized by a quadratic polynomial that is simultaneously fit, up to a floating scale factor, to the Monte Carlo background shape. The signal is fit with a sum of two Gaussians with the same means. The ratios of the widths and areas of the two gaussians is obtained from signal Monte Carlo, and the overall width is allowed to float. Using this fit procedure for the $M(K_S K^+)$ invariant mass spectrum, we find a signal yield of 78.9 ± 12.8 events at the D^+ mass. The reconstruction efficiency, ϵ, which includes the $K_S \to \pi^+\pi^-$ branching fraction, is $(2.69 \pm 0.09)\%$.

The invariant mass plot of $M(K_S\pi^+)$ includes a reflection in the low mass region from $D^+ \to K_S K^+$, where the K^+ is misidentified as a pion. Study of this background shows that it is sufficiently small and far away from the signal that it is safe to exclude the region between 1.67 and 1.80 GeV from the fits. Doing so, and using the same fitting procedure as above, we observe 471 ± 26 events with $\epsilon = (3.63 \pm 0.10)\%$.

In the normalization mode of $D^+ \to K^-\pi^+\pi^+$ we find 5457 ± 110 events with $\epsilon = (7.05 \pm 0.11)\%$.

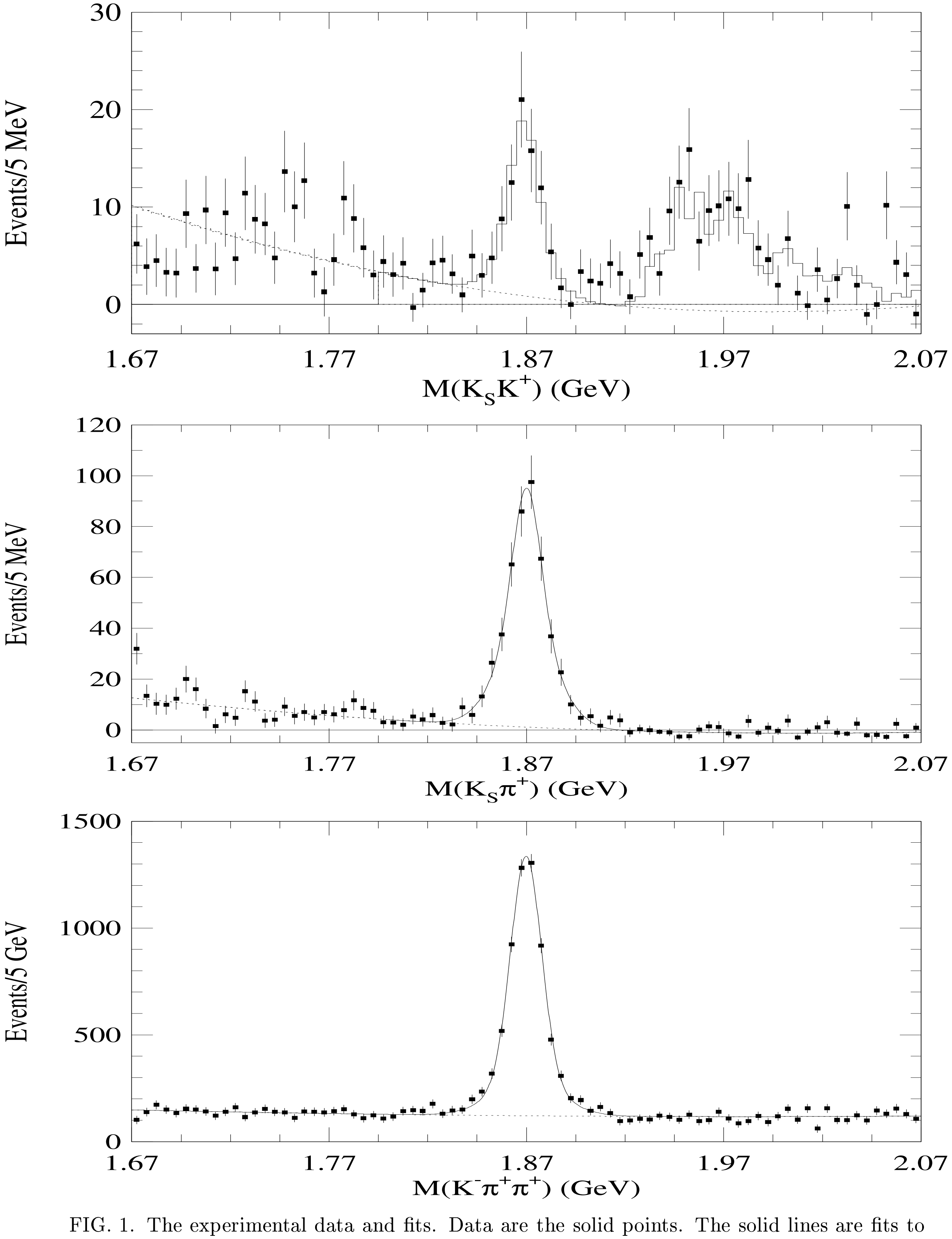

FIG. 1. The experimental data and fits. Data are the solid points. The solid lines are fits to the data; dashed lines under the signal are the background component of the fit. Top: $M(K_S K^+)$. Middle: $M(K_S \pi^+)$. Bottom: $M(K^- \pi^+ \pi^+)$.

The systematic errors are summarized in Table I. A study of the particle ID cuts, based on a clean sample of kaons from the decay chain $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$, shows that the efficiency of particle ID cuts on the data differs from that of Monte Carlo. We measure the efficiency as a function of kaon momentum for both data and Monte Carlo, then find an overall efficiency by integrating this over the K^+ momentum distribution in Monte Carlo $D^+ \to K_S K^+$ events. We find $\epsilon_{MC}(K_S K^+)/\epsilon_{data}(K_S K^+) = 1.100 \pm 0.030$, so a correction factor of 1.10 is applied to the efficiency-adjusted yield of $D^+ \to K_S K^+$. From a similar study on the secondary-veefinder K_S cuts, we find correction factors of 1.030 ± 0.014 for the $D^+ \to K_S\pi^+$ efficiency-adjusted yield and 1.036 ± 0.011 for the $D^+ \to K_S K^+$ efficiency-adjusted yield.

The $K^-\pi^+\pi^+$ systematic error is due to differences between Monte Carlo and data in the Dalitz plot distribution of $D^+ \to K^-\pi^+\pi^+$ events. The systematic error for fitting procedure was obtained by varying the method of obtaining the Monte Carlo background shape, and also changing the fit window and bin sizes. The systematic error for Monte Carlo tracking efficiency is small because we measure ratios of branching fractions, and all decay modes have a final state of three charged tracks.

Systematic bias	$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K_S\pi^+)}$	$\frac{B(D^+ \to K_S\pi^+)}{B(D^+ \to K^-\pi^+\pi^+)}$	$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K^-\pi^+\pi^+)}$
K^+ particle ID	4.0%	1.0%	4.0%
K_S detection efficiency	1.5%	2.0%	2.0%
$K^-\pi^+\pi^+$ Dalitz plot	0.0%	3.5%	3.5%
π^0 cuts	1.2%	1.2%	1.2%
Sideband determination	2.7%	2.7%	2.7%
Fitting Procedure	4.0%	1.5%	5.5%
Signal shape	2.8%	2.8%	2.8%
Tracking efficiency	1.0%	1.0%	1.0%
TOTAL	7.2%	6.1%	8.9%

TABLE I. Systematic error summary. For each ratio measurement, we list the contributions to the systematic error in terms of a percentage of the measurement.

The final results after accounting for systematic errors are:

$$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K_S\pi^+)} = 0.250 \pm 0.044[stat] \pm 0.018[syst] \tag{1}$$

$$\frac{B(D^+ \to K_S K^+)}{B(D^+ \to K^-\pi^+\pi^+)} = 0.0432 \pm 0.0072[stat] \pm 0.0039[syst] \tag{2}$$

$$\frac{B(D^+ \to K_S\pi^+)}{B(D^+ \to K^-\pi^+\pi^+)} = 0.173 \pm 0.012[stat] \pm 0.011[syst] \tag{3}$$

To find absolute branching fractions, results (2) and (3) are combined with the CLEO measurements of $B(D^+ \to K^-\pi^+\pi^+) = (2.35 \pm 0.16 \pm 0.16) B(D^0 \to K^-\pi^+)$ [10] and $B(D^0 \to K^-\pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$ [5] [11] to obtain

$$B(D^+ \to K_S K^+) = (0.397 \pm 0.067[stat] \pm 0.035[syst] \pm 0.043[norm])\%$$

$$B(D^+ \to K_S \pi^+) = (1.59 \pm 0.11[stat] \pm 0.10[syst] \pm 0.17[norm])\%$$

The third error is due to uncertainty in the normalization branching fraction.

When converting these measurements to branching fractions involving $\bar{K}^0$, we must consider interference between doubly Cabbibo suppressed and favored modes [12]. The decay $D^+ \to K_S\pi^+$ may be produced by the Cabbibo-favored $D^+ \to \bar{K}^0\pi^+$ and the doubly-suppressed $D^+ \to K^0\pi^+$. The amplitudes interfere with a magnitude of roughly $2\tan^2(\theta_C)\cos(\delta)$, so we assign an 10% uncertainty in $B(D^+ \to \bar{K}^0\pi^+)$ due to the unknown phase δ. There is no such interference in $D^+ \to \bar{K}^0 K^+$.

$$B(D^+ \to \bar{K}^0 K^+) = (0.793 \pm 0.133[stat] \pm 0.071[syst] \pm 0.085[norm])\%$$

$$B(D^+ \to \bar{K}^0 \pi^+) = (3.18 \pm 0.21[stat] \pm 0.19[syst] \pm 0.34[norm] \pm 0.32[DCSD])\%$$

Using isospin invariance and CLEO semileptonic D decay results [13], we can indirectly deduce a value for $B(D^+ \to K^0\pi^+)$ of $(4.34 \pm 0.98)\%$. Our result is lower but consistent.

Combining these results with previous CLEO measurements [1] [3], we calculate two ratios sensitive to SU(3)-breaking:

$$\left|\frac{V_{cs}}{V_{cd}}\right|^2 \frac{B(D^+ \to \pi^0\pi^+)}{B(D^+ \to K_S\pi^+)} = 2.69 \pm 0.94$$

and

$$\frac{B(D^0 \to K^+K^- + \bar{K}^0K^0)}{B(D^0 \to \pi^+\pi^- + \pi^0\pi^0)} = 2.46 \pm^{0.36}_{0.29}$$

where the sums over states in the second ratio make it invariant under elastic FSI phase rotations [14]. Both ratios are significantly higher than 1, the expected value in the SU(3) symmetry limit. The model of Buccella *et al.* [15] obtains ratios of 3.06 and 2.00 respectively, in agreement with the data.

ISOSPIN ANALYSIS

The isospin amplitudes for $D \to KK$ can be written as

$$A^{+-} = \frac{1}{\sqrt{2}}(A_1 + A_0)$$

$$A^{00} = \frac{1}{\sqrt{2}}(A_1 - A_0)$$

$$A^{+0} = \sqrt{2}A_1$$

where $A^{+-} \equiv \langle K^+K^-|H|D^0\rangle$, $A^{00} \equiv \langle K^0\bar{K}^0|H|D^0\rangle$, and $A^{+0} \equiv \langle K^+\bar{K}^0|H|D^+\rangle$. In writing these equations we have assumed that H_I, the isospin-changing component of the Hamiltonian, is the same for all decay processes. In $D \to KK$, $H_I = |\frac{1}{2} + \frac{1}{2} >$ for all processes except for two weak annihilation diagrams – namely, the W-exchange, $s\bar{s}$-popping diagram of $D^0 \to \bar{K}^0K^0$ and the D^+ annihilation diagram of $D^+ \to \bar{K}^0K^+$. Therefore in writing the isospin decomposition above we have assumed that that these processes may be neglected.

Likewise, for $D \to K\pi$,

$$A^{+-} = \sqrt{\frac{1}{3}}A_{\frac{3}{2}} + \sqrt{\frac{2}{3}}A_{\frac{1}{2}}$$

$$A^{00} = \sqrt{\frac{2}{3}}A_{\frac{3}{2}} - \sqrt{\frac{1}{3}}A_{\frac{1}{2}}$$

$$A^{+0} = \sqrt{3}A_{\frac{3}{2}}$$

In the Cabbibo-favored $D \to K\pi$ system, $H_I = |1 + 1 >$ for all Standard Model decay processes.

From these equations one can write the ratio of isospin amplitudes and the isospin phase shift angle in terms of measured branching fractions:

$$\left|\frac{A_1}{A_0}\right|^2 = \frac{\Gamma^{+0}}{2\Gamma^{+-} + 2\Gamma^{00} - \Gamma^{+0}} \tag{4}$$

$$\cos(\delta_{KK}) = \frac{\Gamma^{+-} - \Gamma^{00}}{\sqrt{\Gamma^{+0}}\sqrt{2\Gamma^{+-} + 2\Gamma^{00} - \Gamma^{+0}}} \tag{5}$$

for $D \to KK$, where $\delta_{KK} \equiv \arg(A_1/A_0)$, and

$$\left|\frac{A_{\frac{3}{2}}}{A_{\frac{1}{2}}}\right|^2 = \frac{\Gamma^{+0}}{3\Gamma^{+-} + 3\Gamma^{00} - \Gamma^{+0}} \tag{6}$$

$$\cos(\delta_{K\pi}) = \frac{3\Gamma^{+-} - 6\Gamma^{00} + \Gamma^{+0}}{2\sqrt{2}\sqrt{\Gamma^{+0}}\sqrt{3\Gamma^{+-} + 3\Gamma^{00} - \Gamma^{+0}}} \tag{7}$$

for $D \to K\pi$, where $\delta_{K\pi} \equiv \arg(A_{\frac{3}{2}}/A_{\frac{1}{2}})$.

CLEO has now measured the six branching fractions necessary to calculate the amplitude ratios and phase shifts in $D \to KK$ and $D \to K\pi$. The measurements are summarized in Table II.

We convert these measurements to absolute branching fractions using the CLEO measurement $B(D^+ \to K^-\pi^+\pi^+) = (2.35 \pm 0.16 \pm 0.16)B(D^0 \to K^-\pi^+)$ [10] and the PDG fit

Ref	Signal Mode	Normalization Mode	Measurement (%)
[3]	$D^0 \to K^-K^+$	$D^0 \to K^-\pi^+$	$11.6 \pm 0.7 \pm 0.7$
[3]	$D^0 \to \bar{K}^0K^0$	$D^0 \to \bar{K}^0\pi^+\pi^-$	$1.01 \pm 0.22 \pm 0.16$
This work	$D^+ \to \bar{K}^0K^+$	$D^+ \to K^-\pi^+\pi^+$	$8.63 \pm 1.45 \pm 0.77$
[5]	$D^0 \to K^-\pi^+$	(absolute)	$3.91 \pm 0.08 \pm 0.17$
[4]	$D^0 \to \bar{K}^0\pi^0$	$D^0 \to \bar{K}^0\pi^+\pi^-$	$44.0 \pm 2.0 \pm 5.0 \pm 4.4$
This work	$D^+ \to \bar{K}^0\pi^+$	$D^+ \to K^-\pi^+\pi^+$	$34.6 \pm 2.3 \pm 2.1 \pm 3.5$

TABLE II. CLEO measurements for the six $D \to KK$ and $D \to K\pi$ modes. Errors listed are statistical, systematic, and from DCSD interference, respectively.

Measurement	$D \to KK$	$D \to K\pi$	$D \to \pi\pi$
$\frac{\Gamma^{+-}}{\Gamma_{D^+}}$	$(0.116 \pm 0.010)\mathsf{B}$	$(1.000 \pm 0.000)\mathsf{B}$	$0.140 \pm 0.016\%$
$\frac{\Gamma^{00}}{\Gamma_{D^0}}$	$(0.014 \pm 0.004)\mathsf{B}$	$(0.620 \pm 0.126)\mathsf{B}$	$0.088 \pm 0.023\%$
$\frac{\Gamma^{+0}}{\Gamma_{D^0}}$	$(0.203 \pm 0.043)\mathsf{B}$	$(0.812 \pm 0.135)\mathsf{B}$	$0.255 \pm 0.073\%$
$\left\lvert\frac{A_h}{A_l}\right\rvert$	$\left\lvert\frac{A_1}{A_0}\right\rvert = 0.66^{0.12}_{0.11}$	$\left\lvert\frac{A_{\frac{3}{2}}}{A_{\frac{1}{2}}}\right\rvert = 0.26 \pm 0.03$	$\left\lvert\frac{A_2}{A_0}\right\rvert = 0.72 \pm 0.17$
$\cos\delta$	$0.85^{0.09}_{0.07}$	$-0.12^{0.23}_{0.21}$	0.14 ± 0.16

TABLE III. Isospin analysis inputs and results. $\mathsf{B} \equiv B(D^0 \to K^-\pi^+)$. All entries in the $D \to \pi\pi$ column are taken from reference [1].

result $B(D^0 \to \bar{K}^0\pi^+\pi^-) = (1.41 \pm 0.11)B(D^0 \to K^-\pi^+)$ [9]. By writing the six $D \to KK$ and $D \to K\pi$ branching fractions relative to $B(D^0 \to K^-\pi^+)$, we avoid additional statistical error from uncertainty in $B(D^0 \to K^-\pi^+)$. Substituting into Equations (4)-(7), we obtain the results in Table III. For comparison, we list the corresponding results for the $D \to \pi\pi$ system [1].

We find that the isospin phase shift difference in $D \to KK$ is smaller than that of both $D \to K\pi$ and $D \to \pi\pi$. In a simple model in which we assume that FSI are elastic only and the FSI only change the phase of the isospin amplitudes, a nonzero phase angle is a sign of final-state interactions [2]. Our result for δ_{KK} then leaves open the possibility that elastic FSI is small. Then, the small δ_{KK} may be interpreted as evidence that $D^0 \to \bar{K}^0K^0$ has a significant amplitude even after correcting for a contribution from elastic final-state interactions.

Alternatively, one of the assumptions may be incorrect. Inelastic FSI, where $D^0 \to \bar{K}^0K^0$ is fed into from, for instance, $\bar{K}^{*0}K^{*0}$ or $\phi\phi$ [16], would complicate the analysis. Another possible complication would be large D^+ annihilation (unlikely in a factorization model [17]) or $s\bar{s}$-popping W-exchange amplitudes.

In conclusion, we have made two new measurements of $B(D^+ \to K_SK^+)$ and $B(D^+ \to K_S\pi^+)$. Our result for $B(D^+ \to \bar{K}^0K^+)/B(D^+ \to \bar{K}^0\pi^+)$ is 3.6σ higher than $\tan^2(\theta_C)$, consistent with the expectation that destructive interference suppresses the $D^+ \to \bar{K}^0\pi^+$ rate. The absolute branching fraction obtained for $B(D^+ \to \bar{K}^0\pi^+)$ is consistent with previous CLEO results in semileptonic decays. Combining these results with previous CLEO measurements of the $D^0 \to KK$ and $D^0 \to K\pi$ branching fractions, we find that the isospin phase shift difference in $D \to KK$ is consistent with zero, in contrast to the much larger phase shift differences in $D \to K\pi$ and $D \to \pi\pi$. The result for δ_{KK} rules out any model in which $D^0 \to \bar{K}^0K^0$ is generated from elastic FSI originating from spectator diagrams only.

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REFERENCES

[1] M. Selen *et al* [CLEO Collaboration], Phys. Rev. Lett. **71**, 1973 (1993).
[2] A. N. Kamal, Int. J. Mod. Phys. A **7**, 3515 (1992).
[3] D. M. Asner *et al* [CLEO Collaboration], Phys. Rev. D **54** (1996)
[4] M. Procario *et al* [CLEO Collaboration], Phys. Rev. D **48**, 4007 (1993).
[5] D. S. Akerib *et al* [CLEO Collaboration], Phys. Rev. Lett. **71**, 3070 (1993).
[6] B. Guberina *et al*, Phys. Lett. B **89**, 111 (1979).
[7] Y. Kubota *et al* [CLEO Collaboration], Nucl. Instrum. Methods Phys. Res. A **320**, 66 (1992)
[8] The energy deposited by the photon candidate in a 3x3 block of CsI crystals, normalized to the energy deposited in the 5x5 block of crystals that surrounds the 3x3 block, must be greater than a value which is a function of shower energy.
[9] Particle Data Group, R. M Barnett *et al*, Phys. Rev. D **54**, 1 (1996).
[10] R. Balest *et al* [CLEO Collaboration], Phys. Rev. Lett. **72**, 2328 (1994).
[11] We use the result quoted in Ref. [5] that does not include radiative corrections.
[12] I. I. Bigi and H. Yamamoto, Phys. Lett. B **349**, 363 (1995).
[13] A. Bean *et al* [CLEO Collaboration], Phys. Lett. B **316**, 647 (1993).
[14] I. I. Bigi in "*Heavy Quark Physics*," ed. by P. S. Drell and D. L. Rubin, AIP Conf. Proc. No. 196, N. Y. (1989).
[15] F. Buccella *et al*, Phys. Rev. D **51**, 3478 (1995).
[16] A.N. Kamal and T.N. Pham, Phys. Rev. D **50**, 1832 (1994).
[17] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34**, 103 (1987).