CLEO 06-10

Branching Fraction for the Doubly-Cabibbo-Suppressed Decay $D^+ \to K^+\pi^0$ *

S. A. Dytman,[1] W. Love,[1] V. Savinov,[1] O. Aquines,[2] Z. Li,[2] A. Lopez,[2] S. Mehrabyan,[2] H. Mendez,[2] J. Ramirez,[2] G. S. Huang,[3] D. H. Miller,[3] V. Pavlunin,[3] B. Sanghi,[3] I. P. J. Shipsey,[3] B. Xin,[3] G. S. Adams,[4] M. Anderson,[4] J. P. Cummings,[4] I. Danko,[4] J. Napolitano,[4] Q. He,[5] J. Insler,[5] H. Muramatsu,[5] C. S. Park,[5] E. H. Thorndike,[5] F. Yang,[5] T. E. Coan,[6] Y. S. Gao,[6] F. Liu,[6] M. Artuso,[7] S. Blusk,[7] J. Butt,[7] J. Li,[7] N. Menaa,[7] R. Mountain,[7] S. Nisar,[7] K. Randrianarivony,[7] R. Redjimi,[7] R. Sia,[7] T. Skwarnicki,[7] S. Stone,[7] J. C. Wang,[7] K. Zhang,[7] S. E. Csorna,[8] G. Bonvicini,[9] D. Cinabro,[9] M. Dubrovin,[9] A. Lincoln,[9] D. M. Asner,[10] K. W. Edwards,[10] R. A. Briere,[11] I. Brock,[11] J. Chen,[11] T. Ferguson,[11] G. Tatishvili,[11] H. Vogel,[11] M. E. Watkins,[11] J. L. Rosner,[12] N. E. Adam,[13] J. P. Alexander,[13] K. Berkelman,[13] D. G. Cassel,[13] J. E. Duboscq,[13] K. M. Ecklund,[13] R. Ehrlich,[13] L. Fields,[13] L. Gibbons,[13] R. Gray,[13] S. W. Gray,[13] D. L. Hartill,[13] B. K. Heltsley,[13] D. Hertz,[13] C. D. Jones,[13] J. Kandaswamy,[13] D. L. Kreinick,[13] V. E. Kuznetsov,[13] H. Mahlke-Krüger,[13] P. U. E. Onyisi,[13] J. R. Patterson,[13] D. Peterson,[13] J. Pivarski,[13] D. Riley,[13] A. Ryd,[13] A. J. Sadoff,[13] H. Schwarthoff,[13] X. Shi,[13] S. Stroiney,[13] W. M. Sun,[13] T. Wilksen,[13] M. Weinberger,[13] S. B. Athar,[14] R. Patel,[14] V. Potlia,[14] J. Yelton,[14] P. Rubin,[15] C. Cawlfield,[16] B. I. Eisenstein,[16] I. Karliner,[16] D. Kim,[16] N. Lowrey,[16] P. Naik,[16] C. Sedlack,[16] M. Selen,[16] E. J. White,[16] J. Wiss,[16] M. R. Shepherd,[17] D. Besson,[18] T. K. Pedlar,[19] D. Cronin-Hennessy,[20] K. Y. Gao,[20] D. T. Gong,[20] J. Hietala,[20] Y. Kubota,[20] T. Klein,[20] B. W. Lang,[20] R. Poling,[20] A. W. Scott,[20] A. Smith,[20] P. Zweber,[20] S. Dobbs,[21] Z. Metreveli,[21] K. K. Seth,[21] A. Tomaradze,[21] J. Ernst,[22] and H. Severini[23]

(CLEO Collaboration)

[1]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[2]*University of Puerto Rico, Mayaguez, Puerto Rico 00681*
[3]*Purdue University, West Lafayette, Indiana 47907*
[4]*Rensselaer Polytechnic Institute, Troy, New York 12180*
[5]*University of Rochester, Rochester, New York 14627*
[6]*Southern Methodist University, Dallas, Texas 75275*
[7]*Syracuse University, Syracuse, New York 13244*
[8]*Vanderbilt University, Nashville, Tennessee 37235*
[9]*Wayne State University, Detroit, Michigan 48202*
[10]*Carleton University, Ottawa, Ontario, Canada K1S 5B6*
[11]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[12]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637*
[13]*Cornell University, Ithaca, New York 14853*
[14]*University of Florida, Gainesville, Florida 32611*
[15]*George Mason University, Fairfax, Virginia 22030*
[16]*University of Illinois, Urbana-Champaign, Illinois 61801*
[17]*Indiana University, Bloomington, Indiana 47405*
[18]*University of Kansas, Lawrence, Kansas 66045*
[19]*Luther College, Decorah, Iowa 52101*
[20]*University of Minnesota, Minneapolis, Minnesota 55455*

[21]*Northwestern University, Evanston, Illinois 60208*
[22]*State University of New York at Albany, Albany, New York 12222*
[23]*University of Oklahoma, Norman, Oklahoma 73019*

(Dated: July 25, 2006)

Abstract

We present a measurement of the branching fraction for the doubly-Cabibbo-suppressed decay $D^+ \to K^+\pi^0$, using 281 pb^{-1} of data accumulated with the CLEO-c detector on the $\psi(3770)$ resonance. We find $\mathcal{B}\left(D^+ \to K^+\pi^0\right) = (2.25 \pm 0.36 \pm 0.15 \pm 0.07) \times 10^{-4}$, where the first uncertainty is statistical, the second is systematic, and the last error is due to the uncertainty in the reference mode. The results presented in this document are preliminary.

---

[*] Submitted to the 33rd International Conference on High Energy Physics, July 26 - August 2, 2006, Moscow

The Cabibbo-favored hadronic decays of the c quark proceed through $c \to sW_V^+$, $W_V^+ \to u\overline{d}$. The doubly-suppressed decays proceed through $c \to dW_V^+$, $W_V^+ \to u\overline{s}$, and are expected to be suppressed by a factor $|(V_{cd}V_{us})/(V_{cs}V_{ud})|^2 \approx 2.5 \times 10^{-3}$. We have measured the branching fraction for the doubly-Cabibbo-suppressed decay $D^+ \to K^+\pi^0$ (charge conjugate mode $D^- \to K^-\pi^0$ implied also, except where noted).

For this measurement we have used a sample of 281 $\mathrm{pb}^{-1} e^+e^- \to \psi(3770)$ events, produced with the CESR-c storage ring and detected with the CLEO-c detector. The data sample contains about 0.8×10^6 D^+D^- events (our target sample), one million $D^0\overline{D}^0$ events, five million $e^+e^- \to u\overline{u}$, $d\overline{d}$, or $s\overline{s}$ continuum events, one million $e^+e^- \to \tau^+\tau^-$ events, one million $e^+e^- \to \gamma\psi'$ radiative return events (sources of background), as well as Bhabha events, μ-pair events, $\gamma\gamma$ events (useful for luminosity determination and resolution studies).

The CLEO-c detector is a general purpose solenoidal detector which includes a tracking system for measuring momenta and specific ionization (dE/dx) of charged particles, a Ring Imaging Cherenkov detector (RICH) to aid in particle identification, and a CsI calorimeter for detection of electromagnetic showers. The CLEO-c detector is described in detail elsewhere [1–4].

The resonance $\psi(3770)$ is below the threshold for $D\overline{D}\pi$ production, and so the events of interest, $e^+e^- \to \psi(3770) \to D\overline{D}$, have D mesons with energy equal to the beam energy, and a unique momentum. Having picked the particles being considered to make up a D meson, following Mark III [5] we define the two variables:

$$\Delta E \equiv \sum_i E_i - E_{\mathrm{beam}} \quad , \tag{1}$$

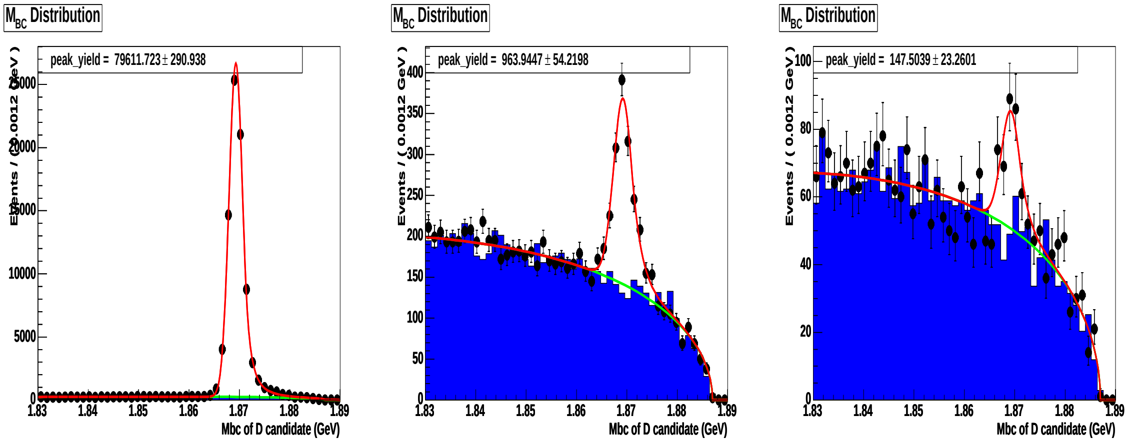
and

$$M_{\mathrm{bc}} \equiv \sqrt{E_{\mathrm{beam}}^2 - |\sum_i \vec{P}_i|^2} \quad , \tag{2}$$

where E_i, $\vec{P}_i$ are the energy and momentum of each particle making up the D meson. For a correct combination of particles, ΔE will be consistent with zero, and the beam-constrained mass M_{bc} will be consistent with the D mass.

In addition to $D^+ \to K^+\pi^0$, we have studied the singly-Cabibbo-suppressed decay $D^+ \to \pi^+\pi^0$, as a higher rate decay possessing many of the features of $D^+ \to K^+\pi^0$, and the Cabibbo-favored decay $D^+ \to K^-\pi^+\pi^+$, as a high rate, clean mode used for normalization. We distinguish between $K^\pm$ and $\pi^\pm$ using information from the RICH, and dE/dx information from the central drift chamber. We detect π^0's via $\pi^0 \to \gamma\gamma$, detecting the γ rays in the CsI calorimeter. We require that the calorimeter clusters be above 30 MeV, have a lateral distribution consistent with that from γ rays, and not be matched to charged tracks. We require that the $\gamma\gamma$ invariant mass be within 3 standard deviations of the π^0 mass.

We select candidate combinations that have ΔE between -40 MeV and $+35$ MeV, for $K^+\pi^0$ and $\pi^+\pi^0$, and between -20 MeV and $+20$ MeV for $K^-\pi^+\pi^+$. These are roughly 3 standard deviations requirements, based on Monte Carlo studies. The asymmetric cut for $K^+\pi^0$ and $\pi^+\pi^0$ is due to a low-side tail on π^0 energies, and the wider window due to poorer energy resolution. To study background, we select combinations with ΔE between -100 and -50 MeV, and between $+45$ and $+100$ MeV ($+50$ and $+100$ MeV for $K^-\pi^+\pi^+$). On the rare occasion when an event contains more than one $K^+\pi^0$ combination that passes our ΔE requirement, we choose the combination with ΔE value closest to zero. Multiple candidates per event for $\pi^+\pi^0$ and for $K^-\pi^+\pi^+$ are removed by the same procedure. Thus, we allow only one candidate per event per decay mode per D charge.



$D^+ \to K^-\pi^+\pi^+$ $D^+ \to \pi^+\pi^0$ $D^+ \to K^+\pi^0$

FIG. 1: $M_{\rm bc}$ distributions of $D^+ \to K^-\pi^+\pi^+$, $D^+ \to \pi^+\pi^0$ and $D^+ \to K^+\pi^0$. The points are obtained by selecting the ΔE signal region, the shaded histogram is from the ΔE sidebands, and the line is the fit described in the text.

The $M_{\rm bc}$ distributions for candidate combinations are shown in Fig. 1. The normalization mode $D^+ \to K^-\pi^+\pi^+$ is essentially background free. The $D^+ \to \pi^+\pi^0$ mode background is well described by the distribution obtained from the ΔE sideband, as is that for the $D^+ \to K^+\pi^0$ mode. There is a clear peak in $D^+ \to K^+\pi^0$.

We perform an unbinned maximum likelihood fit to extract signal yields from the $M_{\rm bc}$ distributions. For the background, we use an ARGUS function [6], with shape parameter determined from the ΔE sideband $M_{\rm bc}$ plot. For the signal, we use a Crystal Ball line shape [7], which is a Gaussian with a high-side tail. As Monte Carlo studies show that $D^+ \to K^+\pi^0$ and $D^+ \to \pi^+\pi^0$ have the same signal shapes, we have determined the line shape parameters (Gaussian peak location, Gaussian width, point at which high-side tail begins) from the $D^+ \to \pi^+\pi^0$ $M_{\rm bc}$ distribution, and used them in the fit to the $D^+ \to K^+\pi^0$ $M_{\rm bc}$ distribution. We have varied the shape of the high-side tail, as part of the systematic error study.

TABLE I: The MC efficiencies, fit yields and branching fractions. A correction has been applied to the branching fraction for π^0-finding efficiency (see below). Only statistical uncertainties are included.

Mode	ϵ (%)	Yield	$\mathcal{B}$ (%)
$D^+ \to K^-\pi^+\pi^+$	54.91 ± 0.17	79612 ± 290	Input
$D^+ \to \pi^+\pi^0$	50.16 ± 0.16	963 ± 54	0.1311 ± 0.0074
$D^+ \to K^+\pi^0$	44.53 ± 0.15	147 ± 23	0.0225 ± 0.0036

Results of the fits are shown in Table *I*. Also given in Table *I* is the detection efficiency for each mode, and the branching fractions obtained for $D^+ \to \pi^+\pi^0$ and $D^+ \to K^+\pi^0$.

Those branching fractions are obtained relative to $D^+ \to K^-\pi^+\pi^+$, taking that branching fraction as $(9.40 \pm 0.30)\%$, which is obtained from a weighted average of the Particle Data Group (PDG) value [11] and the recent CLEO measurement [8]. The branching fraction for $D^+ \to \pi^+\pi^0$ is in good agreement with our previously-published branching fraction using the same data set $((0.125 \pm 0.006 \pm 0.007 \pm 0.004)\%)$ [9], is *not* independent of it, and should *not* be used in place of it.

We have considered many sources of systematic error to the $D^+ \to K^+\pi^0$ branching fraction, including: signal Monte Carlo statistics, track-finding efficiency, π^0-finding efficiency, particle identification, the ΔE requirement, final state radiation, and the uncertainty from our fitting procedure (background shape, signal shape). The only ones greater than 1/10 the statistical error are π^0-finding efficiency, background shape, and signal shape.

The Monte Carlo simulation of the calorimeter response to photons is imperfect, particularly in those angular regions where there is considerable material between the interaction point and the calorimeter. Consequently, the Monte Carlo simulation slightly overestimates the efficiency for detecting π^0's. Various data-Monte Carlo comparisons suggest a correction factor of (0.95 ± 0.04), which we apply.

The background shape is determined by a fit to the ΔE sideband data. The error on the shape parameter thus determined translates into a $\pm 4.4\%$ relative error in the $D^+ \to K^+\pi^0$ branching fraction. The signal shape is determined by a fit to the $D^+ \to \pi^+\pi^0$ signal. Uncertainty comes from the determination of Gaussian width (σ), and point at which non-Gaussian tail sets in (α). We have determined the error ellipse in the determination of these two parameters, and noted the variation in fitted $D^+ \to K^+\pi^0$ yield as one travels around this error ellipse. In that way, we obtain a systematic error of $\pm 2.6\%$, relative. Note that both the background shape uncertainty and signal shape uncertainty are really statistical errors, hence can be reliably determined and will decrease as additional data are taken.

Our final result is

$$\mathcal{B}\left(D^+ \to K^+\pi^0\right) = (2.25 \pm 0.36 \pm 0.15 \pm 0.07) \times 10^{-4}$$

where the first error is statistical, the second error is systematic, and the third error is from the uncertainty in the $D^+ \to K^-\pi^+\pi^+$ branching fraction, $(9.40 \pm 0.30)\%$, used as the normalizing mode.

Our result is in good agreement with the only other measurement of this branching fraction, Babar's recent $\mathcal{B}(D^+ \to K^+\pi^0) = (2.52 \pm 0.47 \pm 0.25 \pm 0.08) \times 10^{-4}$ [10]. It can be converted to a width, using the PDG value for the D^+ lifetime, and compared with the width for doubly-Cabibbo-suppressed D^0 decay $D^0 \to K^+\pi^-$, using the PDG value for $D^0 \to K^+\pi^-$ branching fraction and D^0 lifetime [11]. In this way we obtain

$$\frac{\Gamma(D^+ \to K^+\pi^0)}{\Gamma(D^0 \to K^+\pi^-)} = \frac{\mathcal{B}(D^+ \to K^+\pi^0) \times \tau_{D^0}}{\mathcal{B}(D^0 \to K^+\pi^-) \times \tau_{D^+}} = 0.64 \pm 0.12$$

Implications of our result are discussed in [12].

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. D. Cronin-Hennessy and A. Ryd thank the A.P. Sloan Foundation. This work was supported by the National Science Foundation, the U.S. Department of Energy, and the Natural Sciences and Engineering Research Council of Canada.

---

[1] G. Bonvicini *et al.* (CLEO Collaboration), Phys. Rev. D **70**, 112004 2004 [hep-ex/0411050].
[2] Y. Kubota *et al.* (CLEO Collaboration), Nucl. Instrum. and Meth. A **320**, 66 (1992).
[3] D. Peterson *et al.*, Nucl. Instrum. and Meth. A **478**, 142 (2002).
[4] M. Artuso *et al.*, Nucl. Instrum. and Meth. A **502**, 91 (2003).
[5] J. Adler *et al.* (Mark III Collaboration), Phys. Rev. Lett. **62**, 1821(1989).
[6] H. Albrecht *et al.* (ARGUS Collaboration), Phys. Lett B **229**, 304 (1989).
[7] T. Skwarnicki, Ph.D thesis, Institute for Nuclear Physics, Krakow, Poland, 1986.
[8] Q. He *et al.* (CLEO Collaboration), Phys. Rev. Lett. **95**, 121801 (2005).
[9] P.Rubin *et al.* (CLEO Collaboration), Phys. Rev. Lett. **96**, 081802 (2006).
[10] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **74**, 011107(R) (2006).
[11] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
[12] Q. He *et al.* (CLEO Collaboration), CLEO-CONF-06-11, contributed to ICHEP06 [arXiv:hep-ex/0607068].