Fermi National Accelerator Laboratory

FERMILAB-Pub-94/272-E

E687

Branching Ratios of the Decays $D^0 \rightarrow \overline{K}^0 K^0$ and $D^0 \rightarrow K^0_s K^0_s K^0_s$

P. L. Frabetti, et. al
The E687 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

August 1994

Submitted to *Physics Letters B*

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

Branching ratios of the decays $D^0 \to \overline{K^0}K^0$ and $D^0 \to K^0_s K^0_s K^0_s$

P. L. Frabetti

Dip. di Fisica dell'Università and INFN - Bologna, I-40126 Bologna, Italy

H. W. K. Cheung*, J. P. Cumalat, C. Dallapiccola†, J. F. Ginkel, S. V. Greene,
W. E. Johns, M. S. Nehring

University of Colorado, Boulder, CO 80309

J. N. Butler, S. Cihangir, I. Gaines, P. H. Garbincius, L. Garren, S. A. Gourlay,
D. J. Harding, P. Kasper, A. Kreymer, P. Lebrun, S. Shukla

Fermilab, Batavia, IL 60510

S. Bianco, F. L. Fabbri, S. Sarwar, A. Zallo

Laboratori Nazionali di Frascati dell'INFN, I-00044 Frascati, Italy

R. Culbertson, R. W. Gardner, R. Greene, J. Wiss

University of Illinois at Urbana-Champaign, Urbana, IL 61801

G. Alimonti, G. Bellini, B. Caccianiga, L. Cinquini‡, M. Di Corato, M. Giammarchi,
P. Inzani, F. Leveraro, S. Malvezzi§, D. Menasce, E. Meroni, L. Moroni, D. Pedrini,
L. Perasso, A. Sala, S. Sala, D. Torretta*, M. Vittone*

Dip. di Fisica dell'Università and INFN - Milano, I-20133 Milan, Italy

D. Buchholz, D. Claes, B. Gobbi, B. O'Reilly

Northwestern University, Evanston, IL 60208

J. M. Bishop, N. M. Cason, C. J. Kennedy**, G. N. Kim, T. F. Lin, D. L. Puseljic,
R. C. Ruchti, W. D. Shephard, J. A. Swiatek, Z. Y. Wu

University of Notre Dame, Notre Dame, IN 46556

V. Arena, G. Boca, C. Castoldi, G. Gianini, S. P. Ratti, C. Riccardi, P. Vitulo
Dip. di Fisica Nucleare e Teorica dell'Università and INFN - Pavia, I-27100 Pavia, Italy.

A. Lopez
University of Puerto Rico at Mayaguez, Puerto Rico

G. P. Grim, V. S. Paolone, P. M. Yager
University of California-Davis, Davis, CA 95616

J. R. Wilson
University of South Carolina, Columbia, SC 29208

P. D. Sheldon
Vanderbilt University, Nashville, TN 37235

F. Davenport
University of North Carolina-Asheville, Asheville, NC 28804

G.R. Blackett, M. Pisharody, T. Handler
University of Tennessee, Knoxville, TN 37996

B. G. Cheon, J. S. Kang, K. Y. Kim
Korea University, Seoul 136-701, Korea

(E687 Collaboration)

Abstract

The branching ratios of $D^0 \rightarrow \overline{K^0}K^0$ and $D^0 \rightarrow K^0_sK^0_sK^0_s$ relative to $D^0 \rightarrow \overline{K^0}\pi^+\pi^-$ are reported. The data were accumulated in the 1990-1991 fixed target running period of the Fermilab high energy photoproduction experiment E687. $\Gamma(D^0 \rightarrow \overline{K^0}K^0)/\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)$ is measured to be 0.039 ± 0.013 ± 0.013 and $\Gamma(D^0 \rightarrow K_s^0K_s^0K_s^0)/\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)$ is measured to be 0.035 ± 0.012 ± 0.006. We also measure $\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)/\Gamma(D^0 \rightarrow K^-\pi^+)$ to be 1.61 ± 0.10 ± 0.15.

This paper reports new measurements of the branching ratios of $D^0 \rightarrow \overline{K^0}K^0$ and $D^0 \rightarrow K^0_sK^0_sK^0_s$. Simple spectator diagrams do not contribute to either of these decay modes, and thus they can provide information on the importance of other processes [1] [2]. The decay $D^0 \rightarrow K^0_sK^0_sK^0_s$ is Cabibbo allowed, and could result from W-exchange or final-state interactions. For the decay $D^0 \rightarrow \overline{K^0}K^0$ there are two W-exchange diagrams which cancel almost exactly due to the Glashow-Iliopoulos-Maiani (GIM) mechanism, and thus the decay occurs primarily through final-state interactions.

The data for this analysis were collected in 1990 and 1991 in Fermilab wideband photoproduction experiment E687. A photon beam of mean energy $\sim$ 220 GeV strikes a beryllium target. Immediately downstream of the target is a high resolution microvertex detector consisting of 12 planes of silicon microstrips arranged in three views. Further downstream are two analyzing magnets of opposite polarity, and five stations of multiwire proportional chambers (MWPC's). There are three MWPC stations between the two magnets and two stations downstream of the second magnet. Three gas Čerenkov counters provide particle identification. A more detailed description of the E687 detector and analysis methods can be found in reference [3].

For the decay modes described in this paper, the K^0_s candidates are identified by the decay $K^0_s \rightarrow \pi^+\pi^-$ with both pion tracks reaching at least three MWPC planes. Figure 1 shows the $\pi^+\pi^-$ invariant mass plots, from a small sample of the full data set, for each of the reconstruction cases used in this analysis. Figure 1a shows the invariant mass for K^0_s candidates which decay downstream of the first MWPC station; in figure 1b both tracks reach all five MWPC's; in figure 1c one track reaches all five MWPC's while the other reaches only the first three; in figure 1d the K^0_s candidates decay upstream of the microvertex detector with both tracks linked between the microvertex detector and at least three MWPC's (candidates with unlinked tracks reaching only the first three MWPC stations are rejected due to the fact that they contribute large backgrounds). All K^0_s candidates are required to have an invariant mass within 2 σ of the known mass (with the error on the mass measurement calculated on an event by event basis) and momentum greater than 6 GeV/c.

The decay channel $D^0 \rightarrow \overline{K^0}\pi^+\pi^-$ is used for our normalization in order to provide a large statistical sample and reduce systematic errors due to K^0_s reconstruction efficiency. The $D^0 \rightarrow \overline{K^0}\pi^+\pi^-$ signal is extracted through the decay chain $D^{*+} \rightarrow D^0\pi^+$, with $D^0 \rightarrow K^0_s\pi^+\pi^-$ and $K^0_s \rightarrow \pi^+\pi^-$. (Charge conjugate states are implied throughout this paper). The two D^0 daughter pions are required to be inconsistent with a Čerenkov hypothesis of an electron, kaon or proton. A candidate driven vertexing algorithm [3] is used to identify the primary and secondary vertices of the decay. The significance of detachment of the vertices, or ℓ/σ_ℓ, is defined as the distance (ℓ) between the two vertices divided by the error (σ_ℓ) on ℓ. Figure 2 shows the $K^0_s\pi^+\pi^-$ invariant mass distribution with the requirements that ℓ/σ_ℓ be greater than 4 and the mass difference, $D^{*+} - D^0$, be within ± 1.8 MeV/c^2 of the mass difference value of 145.8 MeV/c^2 which is observed in both data and Monte Carlo. The mass distribution is fitted with a polynomial background function plus a Gaussian, with the width fixed to the Monte Carlo value, and has a yield of 856 ± 35 events.

In order to confirm our understanding of the K^0_s reconstruction efficiency, we first measure the branching ratio $\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)/\Gamma(D^0 \rightarrow K^-\pi^+)$. The $D^0 \rightarrow K^-\pi^+$ signal, with the D^* tag and $\ell/\sigma_\ell > 8$, has a yield of 957 ± 37 events (figure 3). The Monte Carlo determined efficiencies for $D^0 \rightarrow K^0_s\pi^+\pi^-$ and $D^0 \rightarrow K^-\pi^+$ (including the branching ratio of $K^0_s \rightarrow \pi^+\pi^-$) are $\varepsilon_{K^0_s\pi^+\pi^-} = 0.0122$ and $\varepsilon_{K^-\pi^+} = 0.0110$. After correcting both yields for their efficiencies, and multiplying by 2 in order to express the branching ratio in terms of $\overline{K^0}$, we find $\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)/\Gamma(D^0 \rightarrow K^-\pi^+)$ to be $1.61 \pm 0.10 \pm 0.15$. The second error is the systematic error, due primarily to uncertainties in the ℓ/σ_ℓ efficiency and the K^0_s reconstruction efficiency. Our measurement is consistent with the world average value [4] of $\Gamma(D^0 \rightarrow \overline{K^0}\pi^+\pi^-)/\Gamma(D^0 \rightarrow K^-\pi^+) = 1.49 \pm 0.12$.

The $D^0 \rightarrow K^0_sK^0_sK^0_s$ decay mode has been reported by two experiments [5] [6]. As before, we reconstruct $D^{*+} \rightarrow D^0\pi^+$ and $K^0_s \rightarrow \pi^+\pi^-$. Because only a small fraction of the K^0_s candidates decay upstream of the microvertex detector there is no vertexing requirement for this mode. Figure 4 shows the $K^0_sK^0_sK^0_s$ mass distribution with the requirement that the

$D^{*+} - D^0$ mass difference be within ± 1.8 MeV/c^2 of the observed mass difference. The mass distribution is fitted with a polynomial background function plus a Gaussian, with the width fixed to the Monte Carlo value. The yield from this fit is 10.1 ± 3.4 events. After correcting for the Monte Carlo determined efficiencies ($\varepsilon_{K^0_sK^0_sK^0_s} = 0.00207$) we measure $\Gamma(D^0 \to K^0_sK^0_sK^0_s)/\Gamma(D^0 \to \overline{K^0}\pi^+\pi^-)$ to be $0.035 \pm 0.012 \pm 0.006$.

The systematic error is due primarily to the uncertainties in the K^0_s reconstruction efficiency and the fitting method. We note that when the yields are taken from the D^{*+} - D^0 mass difference instead of the D^0 mass plot, the branching ratio is consistent within the errors.

The Cabibbo suppressed mode $D^0 \to \overline{K^0}K^0$ is not well established. Recently, two groups have reported observations of $D^0 \to \overline{K^0}K^0$ [7] [8], and three groups have reported upper limits [5] [9] [10]. For our analysis the same D^* and K^0_s mass requirements as above are used. A high statistics Monte Carlo study was performed in order to determine the possible background for the $K^0_sK^0_s$ mode from $D^0 \to K^0_s\pi^+\pi^-$. Calculating the invariant mass of the $K^0_s\pi^+\pi^-$ Monte Carlo sample as $K^0_sK^0_s$, and normalizing the number of reconstructed Monte Carlo $K^0_s\pi^+\pi^-$ events to the number in data, indicates that approximately 1.4 background events are expected in the $K^0_sK^0_s$ signal. Instead of subtracting this background from the signal, we require a separation between the K^0_s and the D^0 vertices. Because the D^0 daughter pions from $K^0_s\pi^+\pi^-$ events pass through the microvertex detector, we perform our standard vertexing algorithm. Thus for all events with at least one pion passing through the microvertex detector, we require that the separation between the D^0 vertex and the K^0_s vertex be greater than 0.5 cm. In the Monte Carlo study this requirement removed all background from $K^0_s\pi^+\pi^-$ with a 0.5% loss of $K^0_sK^0_s$ signal. Figure 5 shows the mass distribution, with a yield of 19.8 ± 6.8 events. The efficiency for $D^0 \to K^0_sK^0_s$ is $\varepsilon_{K^0_sK^0_s} = 0.00715$. After correcting for efficiencies and multiplying by a factor of 2 (because D^0 can decay to either $K^0_sK^0_s$ or $K^0_LK^0_L$), $\Gamma(D^0 \to \overline{K^0}K^0)/\Gamma(D^0 \to \overline{K^0}\pi^+\pi^-)$ is measured to be $0.039 \pm 0.013 \pm 0.013$ where the systematic uncertainty is primarily due to the K^0_s reconstruction efficiency and the fitting procedure.

In conclusion, we report new measurements of branching ratios involving the decays $D^0 \rightarrow K_s^0 K_s^0 K_s^0$ and $D^0 \rightarrow \overline{K^0} K^0$. Table I summarizes the existing measurements for these two decay modes. We have included the branching ratio of $\Gamma(D^0 \rightarrow \overline{K^0} K^0)/\Gamma(D^0 \rightarrow K^+ K^-)$, assuming the world average [4] for the branching ratio of $\Gamma(D^0 \rightarrow \overline{K^0} \pi^+ \pi^-)/\Gamma(D^0 \rightarrow K^+ K^-)$, in order to allow for comparison with all previous measurements.

We wish to acknowledge the assistance of the staffs of the Fermi National Accelerator Laboratory, the INFN of Italy, and the physics departments of the collaborating institutions. This research was supported in part by the National Science Foundation, the U.S. Department of Energy, the Italian Istituto Nazionale di Fisica Nucleare and Ministero dell'Università e della Ricerca Scientifica e Tecnologica, and the Korean Science and Engineering Foundation.

REFERENCES

[*] Now at Fermilab, Batavia, IL 60510.

[†] Now at Univ. of Maryland, College Park, MD 20742.

[‡] Now at Univ. of Colorado, Boulder, CO 80309.

[§] Now at Dip. di Fisica Nucleare e Teorica dell'Università and INFN - Pavia, I-27100 Pavia, Italy.

[**] Now at Yale Univ., New Haven, CT 06511.

[1] X. -Y. Pham, Phys. Lett. B **193**, 331 (1987)

[2] H. J. Lipkin, Phys. Rev. Lett. **44**, 710 (1980)

[3] P. L. Frabetti *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **320**, 519 (1992).

[4] Particle Data Group, K. Hikasa *et al.*, *Review of particle properties*, Phys. Rev. D **45**, 1 (1992).

[5] H. Albrecht *et al.*, Z. Phys. C **46**, 9 (1990)

[6] R. Ammar *et al.*, Phys. Rev. D **44**, 3383 (1991).

[7] J. P. Cumalat *et al.*,Phys. Lett. B **210**, 253 (1988)

[8] J. Alexander *et al.*,Phys. Rev. Lett. **65**, 1184 (1990)

[9] J. Adler *et al.*, Phys. Rev. Lett. **60**, 89 (1988)

[10] J. C. Anjos *et al.*, Phys Rev. D Rapid Comm. **46** R1 (1992)

TABLES

TABLE I. Branching ratios, or 90 % confidence level limits

Measurement	$\frac{\Gamma(D^0\to\overline{K^0}K^0)}{\Gamma(D^0\to K^+K^-)}$	$\frac{\Gamma(D^0\to\overline{K^0}K^0)}{\Gamma(D^0\to\overline{K^0}\pi^+\pi^-)}$	$\frac{\Gamma(D^0\to K^0_s K^0_s K^0_s)}{\Gamma(D^0\to\overline{K^0}\pi^+\pi^-)}$
ARGUS [5]	< 0.24	< 0.016	$0.017 \pm 0.007 \pm 0.005$
CLEO [6,8]		$0.021^{+0.011+0.002}_{-0.008-0.002}$	0.016 ± 0.005
E400 [7]	0.24 ± 0.16		
E691 [10]	< 0.27		
E687	$0.51 \pm 0.18 \pm 0.19$ [1]	$0.039 \pm 0.013 \pm 0.013$	$0.035 \pm 0.012 \pm 0.006$

---

[1] based on $\frac{\Gamma(D^0\to\overline{K^0}K^0)}{\Gamma(D^0\to\overline{K^0}\pi^+\pi^-)}$ and the world average value [4] for $\frac{\Gamma(D^0\to\overline{K^0}\pi^+\pi^-)}{\Gamma(D^0\to K^+K^-)}$.

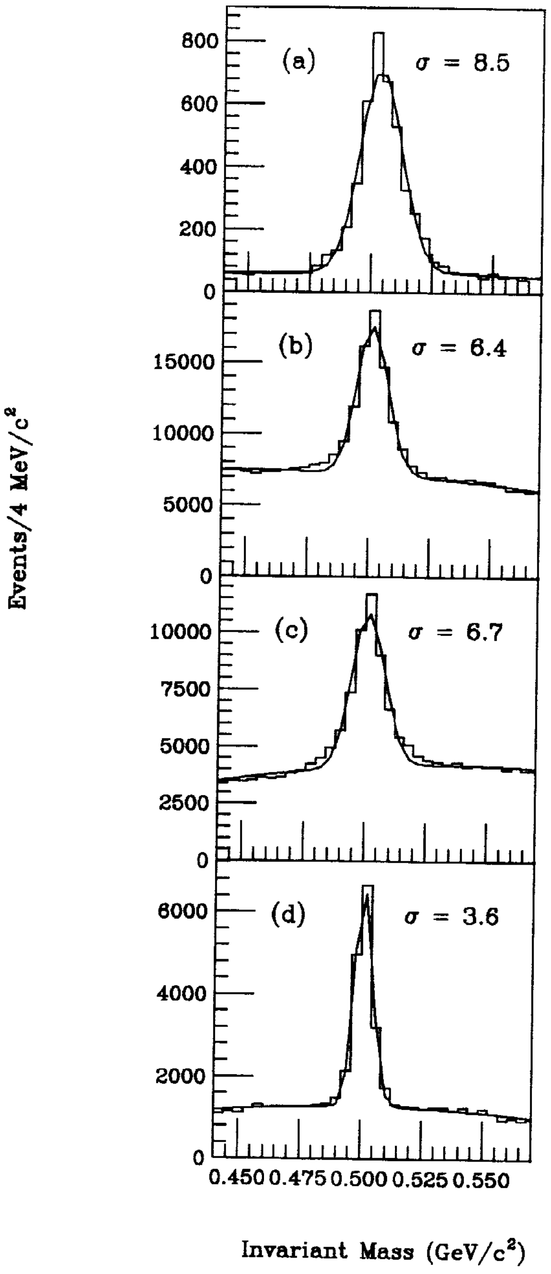

FIG. 1. $\pi^+\pi^-$ invariant mass plots and widths, in MeV/c^2, for four event categories:

a) both tracks are downstream of the first MWPC station;

b) both tracks reach all five MWPC planes;

c) one track reaches five MWPC's, one reaches the first three;

d) both tracks have linked microvertex and MWPC tracks.

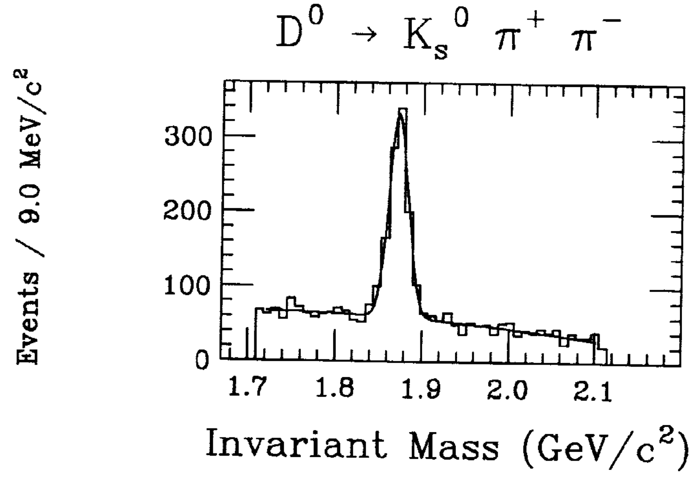

FIG. 2. Invariant mass distribution and fit for $D^0 \to K_s{}^0 \pi^+ \pi^-$ with D^* tag and $1/\sigma > 4$.

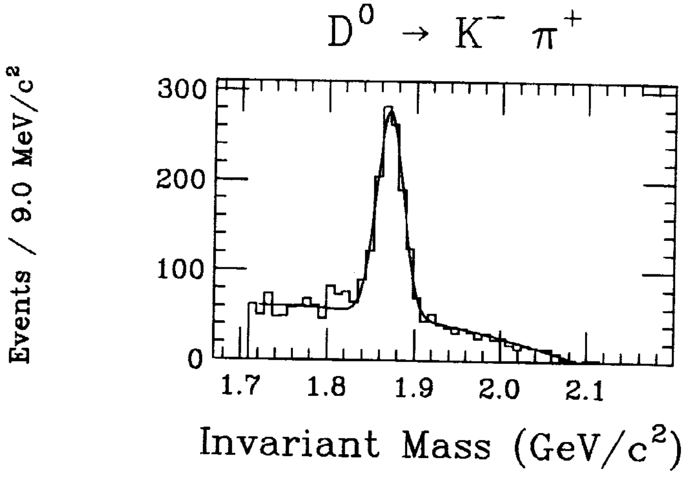

FIG. 3. Invariant mass distribution and fit for $D^0 \to K^- \pi^+$ with D^* tag and $1/\sigma > 8$.

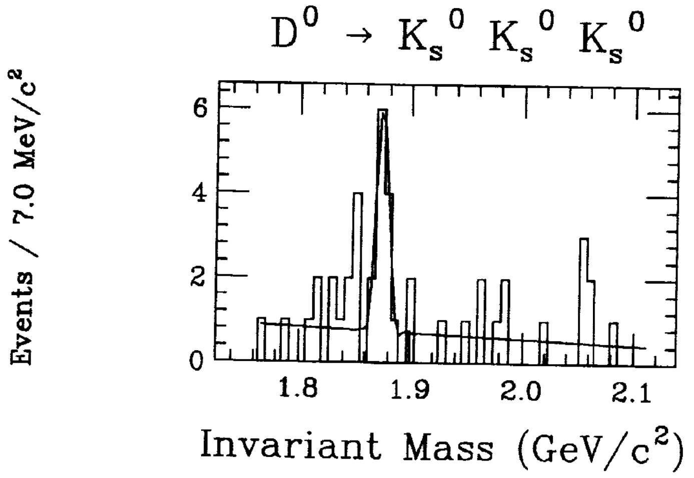

FIG. 4. Invariant mass distribution and fit for $D^0 \to K_s{}^0 K_s{}^0 K_s{}^0$ with D^* tag.

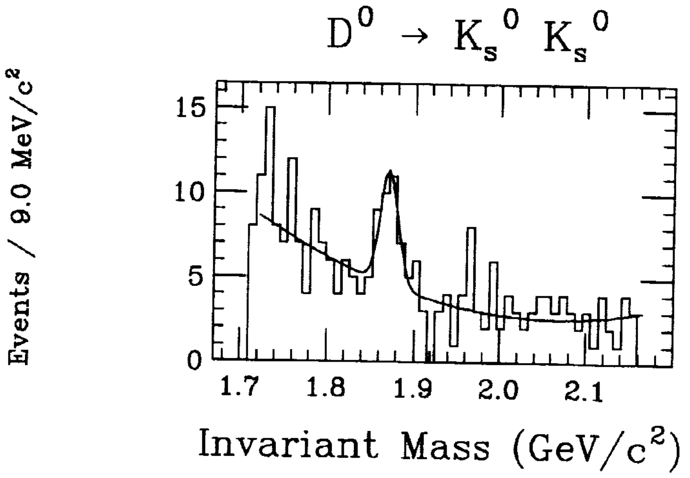

FIG. 5. Invariant mass distribution and fit for $D^0 \to K_s{}^0 K_s{}^0$ with D^* tag.