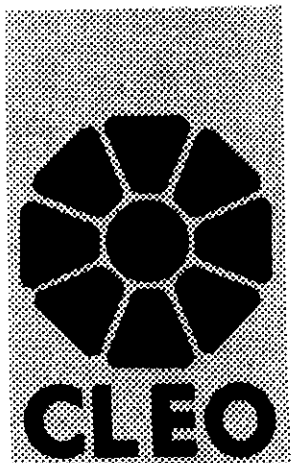

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UNUSUAL DECAY MODES OF D^0 AND D^+ MESONS

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Unusual decay modes of D^0 and D^+ mesons

The CLEO Collaboration

R. Ammar,[1] P. Baringer,[1] D. Coppage,[1] R. Davis,[1] P. Haas,[1] M. Kelly,[1] N. Kwak,[1] Ha Lam,[1] S. Ro.[1] Y. Kubota,[2] J.K. Nelson,[2] D. Perticone,[2] R. Poling,[2] S. Schrenk,[2] G. Crawford,[3] R. Fulton,[3] T. Jensen,[3] D.R. Johnson,[3] H. Kagan,[3] R. Kass,[3] R. Malchow,[3] F. Morrow,[3] J. Whitmore,[3] P. Wilson,[3] D. Bortoletto,[4] D. Brown,[4] J. Dominick,[4] R.L. McIlwain,[4] D.H. Miller,[4] M. Modesitt,[4] C.R. Ng,[4] S.F. Schaffner,[4] E.I. Shibata,[4] I.P.J. Shipsey,[4] M. Battle,[5] H. Kroha,[5] K. Sparks,[5] E.H. Thorndike,[5] C.-H. Wang,[5] M.S. Alam,[6] I.J. Kim,[6] W.C. Li,[6] B. Nemati,[6] V. Romero,[6] C.R. Sun,[6] P.-N. Wang,[6] M.M. Zoeller,[6] M. Goldberg,[7] T. Haupt,[7] N. Horwitz,[7] V. Jain,[7] Rosemary Kennett[7] M.D. Mestayer,[7] G.C. Moneti,[7] Y. Rozen,[7] P. Rubin,[7] T. Skwarnicki,[7] S. Stone,[7] M. Thusalidas,[7] W.-M. Yao,[7] G. Zhu,[7] A.V. Barnes,[8] J. Bartelt,[8] S.E. Csorna,[8] T. Letson,[8] J. Alexander,[9] M. Artuso,[9] C. Bebek,[9] K. Berkelman,[9] D. Besson,[9] T. Browder,[9] D.G. Cassel,[9] E. Cheu,[9] D.M. Coffman,[9] P.S. Drell,[9] R. Ehrlich,[9] R.S. Galik,[9] M. Garcia-Sciveres,[9] B. Geiser,[9] B. Gittelman,[9] S.W. Gray,[9] D.L. Hartill,[9] B.K. Heltsley,[9] K. Honscheid,[9] J. Kandaswamy,[9] N. Katayama,[9] D.L. Kreinick,[9] J.D. Lewis,[9] G.S. Ludwig,[9] J. Masui,[9] J. Mevissen,[9] N.B. Mistry,[9] S. Nandi,[9] E. Nordberg,[9] C. O'Grady,[9] J. R. Patterson,[9] D. Peterson,[9] M. Pisharody,[9] D. Riley,[9] M. Sapper,[9] M. Selen,[9] A. Silverman,[9] H. Worden,[9] M. Worris,[9] A. J. Sadoff[10] P. Avery,[11] A. Freyberger,[11] J. Rodriguez,[11] J. Yelton,[11] S. Henderson,[12] K. Kinoshita,[12] F. Pipkin,[12] M. Procario,[12] M. Saulnier,[12] R. Wilson,[12] J. Wolinski,[12] and D. Xiao.[12]

1. *University of Kansas, Lawrence, Kansas 66045*
2. *University of Minnesota, Minneapolis, Minnesota 55455*
3. *Ohio State University, Columbus, Ohio, 43210*
4. *Purdue University, West Lafayette, Indiana 47907*
5. *University of Rochester, Rochester, New York 14627*
6. *State University of New York at Albany, Albany, New York 12222*
7. *Syracuse University, Syracuse, New York 13244*
8. *Vanderbilt University, Nashville, Tennessee 37235*
9. *Cornell University, Ithaca, New York 14853*
10. *Ithaca College, Ithaca, New York 14850*
11. *University of Florida, Gainesville, Florida 32611*
12. *Harvard University, Cambridge, Massachusetts 02138*

Unusual Decay Modes of D^0 and D^+ Mesons

Abstract:

CLEO has measured decay modes of the D^0 and D^+ into final states consisting of $K^{\pm}$'s, $\pi^{\pm}$'s, K^0's and $\overline{K}^0$'s, using data taken with the CLEO detector at the Cornell Electron Storage Rings. We report new results on the decays of D^0's into $4\pi^{\pm}$, $K^-K^+\pi^-\pi^+$, $\overline{K}^0K^+K^-$, $\overline{K}^0K^+\pi^-$, $K^0K^-\pi^+$ and $\overline{K}^0\phi$ together with some of their resonant substructure. We also present the first observation of the decay $D^+ \to \overline{K}^0K^0K^+$ and give limits on the doubly-Cabibbo suppressed decays of the D^0 into $K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$.

Introduction

Since the discovery of charmed mesons in 1976 [1] there have been many measurements of their decay properties. Measurements of the relative lifetimes and semi-leptonic branching fractions of the D^0 and D^+ immediately lead to the conclusion that the simple spectator model of charmed meson decay is inadequate. More detailed measurements of exclusive decay modes of the D^0 and D^+ have helped estimate the contributions of W-exchange diagrams and final state interactions to their decays. The measurements of the D^0 branching fractions have almost reached the point where all the decays are accounted for, but the measurements of the D^+ are not so well advanced. This paper reports new measurements of the decay rates of several unusual decay modes of the D^0 together with one of the D^+. These rates are measured relative to those of well known decay modes. All the decay modes reported here involve final states with no photons; other decay modes involving photonic final states have been reported elsewhere.[2]

The data used for this study were taken by the CLEO detector operating at the Cornell Electron Storage Ring. The data sample used comprises 466 pb^{-1} in the Υ energy range, including data taken at the $\Upsilon(3S)$, $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances. The trajectories of charged particles produced in the collisions were measured using a set of three concentric drift chambers inside a 1 Tesla magnetic field produced by a 1 meter radius solenoid. The innermost of these three was a three layer "straw tube" vertex detector with a position resolution of 70 μ in the $r-\phi$ plane. The middle detector was a 10 layer high resolution drift chamber with a position resolution of 90 μ in the $r-\phi$ plane. The main drift chamber comprised 51 layers each with a position resolution of 110 μ. Measurement of the along-the-beam coordinate of the charged particles was obtained by a combination of stereo layers in the main drift chamber together with cathode strips. The tracking system had a momentum resolution given by: $(dp/p)^2 = (0.23\%p)^2 + (0.7\%)^2$, where p is in GeV/c. The CLEO method of selecting hadronic events has been explained elsewhere.[3] Protons, kaons and pions were identified by

: required to have a large x_p, where x_p is defined
to its maximum possible momentum, in order to
a few modes that are not background limited the
x_p are listed in table I for all modes investigated.
are produced directly, i.e. they are not the decay
er sets out only to measure the relative branching
ıechanism is not relevant. Now we describe the
y mode studied.

ple Feynmann diagrams leading to this final state
ode the D^0 mass band was defined to be 1.84-
ground subtraction were 1.805-1.83 GeV/c^2 and
were required to have $x_p > 0.5$. Decays of the
nstructed as $\pi^+\pi^-\pi^+\pi^-$ populate regions below
subtracted mass difference plot is shown in figure
$^+\pi^-$'s. Those π's that are part of reconstructed
er there remain some D^0 decays into $K^0_s\pi^+\pi^-$
ed vertex. Defining D^0 candidates as those with
mass difference of $0.1435 - 0.1475$ MeV/c^2, a
nbinations in these candidates is shown in figure
rea of 84 events. This number is consistent with
$^0_s\pi^+\pi^-$. These are thus subtracted from the 4π
345 ± 50. This decay mode is then compared
$\rightarrow K^-\pi^+\pi^-\pi^+$ analyzed in a similar way. The
ned by Monte-Carlo simulation to be 1.15. This

number is greater than unity because of the lower efficiency of assigning a kaon the correct identity compared to the analogous pion efficiency as well as the greater likelihood of a kaon decaying in flight compared with a pion. The final result is that the ratio of decay rates $B(D^0 \to \pi^+\pi^-\pi^+\pi^-)/B(D^0 \to K^-\pi^+\pi^-\pi^+) = 0.102 \pm 0.013$ (see table 1.) This number is considerably larger than the 1990 world average,[4] in particular it appears to be inconsistent with the number obtained by the ACCMOR collaboration.[5] However it is very similar to the recent value obtained by the E-691 collaboration .[6] An invariant mass plot of all $\pi^+\pi^-$ pairs within the $D^0 \to \pi^+\pi^-\pi^+\pi^-$ candidates shows a clear ρ^0 peak, with an area of 447 ± 72 events (figure 2c). By also fitting the $\pi^+\pi^-$ peak in $K^0_s\pi^+\pi^-$ events where the K^0_s has been identified, we can estimate that 17 ± 4 of the 447 events come from this source. Thus there are $1.25 \pm 0.25 \pm 0.25\rho$'s per $\pi^+\pi^-\pi^+\pi^-$ decay, where the systematic error quoted is an estimate of the uncertainty in the fitting procedure. There can be contributions to this mode from $D^0 \to \rho^0\rho^0$, $D^0 \to a_1^-\pi^+$ and $D^0 \to a_1^+\pi^-$, where $a_1 \to \rho\pi$ and $\rho^0 \to \pi^+\pi^-$, but the data are not sufficient to disentangle this resonant sub-structure. Nonetheless, our result implies that the $\pi^+\pi^-\pi^+\pi^-$ are not produced through pure phase space.

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

This decay mode is also Cabibbo suppressed; typical diagrams are shown in figure 1(b and c). The analysis proceeds in a similar way to that of $D^0 \to \pi^+\pi^-\pi^+\pi^-$. There is a more restrictive requirement on the D^0 mass (see table 1) because of the narrower signal in this mode, and the x_p cut is lowered to 0.4 to obtain more statistical precision. There is a further requirement on the dE/dx information of the two tracks designated K's. The sum of the squares of the deviations of the measured dE/dx from the expected dE/dx is required to be less than 4 for these two tracks in order to reduce pion background. Combinations that have a $\pi^+\pi^-$ mass consistent with the K^0_s mass are excluded from this analysis; this cut results in only a small lowering of the efficiency. The background subtracted mass difference plot is shown in

figure 3a and the fit gives a total yield in this mode of 97 ± 27 $D^0 \to K^+K^-\pi^+\pi^-$ events. This yields a ratio of branching fractions $B(K^+K^-\pi^+\pi^-)/B(K^-\pi^+\pi^-\pi^+)$ of 0.031 ± 0.010 (see table 1.)

Taking those combinations with a mass difference of .1435-.1475 GeV/c^2, the background subtracted K^+K^- invariant mass is plotted for the candidates. There is a clear ϕ signal (figure 3b). Furthermore, figure 3c shows the invariant mass of the $\pi^+\pi^-$ pair for those decays that have a K^+K^- mass consistent with a ϕ. The mass spectrum is consistent with being entirely due to ρ's and is fit to a ρ shape with phase space suppression taken into account. It is clear from this plot that any contribution to this mode from non-resonant $\phi\pi^+\pi^-$ is small as Monte-Carlo modelling predicts that $\pi^+\pi^-$ invariant mass plot for such events peaks at around 0.5 GeV/c^2. This fit yields a $\phi\rho$ signal of 34.5 ± 8.6 events, where the statistical uncertainty includes the possibility of $\phi\pi^+\pi^-$ non-resonant decays. This corresponds to a branching fraction of $0.19 \pm .05\%$ into this mode. A signal in $D^0 \to \phi\pi^+\pi^-$ has previously been by the ACCMOR collaboration ,[7] and E-691 [6] have recently published an upper limit of 0.15% in this mode. Neither of these experiments has the statistics necessary to separate $\phi\rho$ from $\phi\pi^+\pi^-$(non-resonant). Another possible substructure in the $D^0 \to K^+K^-\pi^+\pi^-$ events is $D^0 \to K^{*0}\overline{K}^{*0}$. This mode is particularly interesting as not only can it not occur through simple spectator decay diagrams, but furthermore the W-exchange diagram (figure 1c) is GIM suppressed. Thus evidence of this mode would be a strong indication of importance of final state interactions. This is explained in more detail in our previous letter detailing the observation of $D^0 \to K^0\overline{K}^0$.[8] To search for this mode, we define $K^{*0}(\overline{K}^{*0})$'s as those $K^-\pi^+(K^+\pi^-)$ combinations with an invariant mass within $40 MeV/c^2$ of the K^{*0} mass. A small number of these combinations are also in the $\phi\rho$ sample defined above. The background subtracted $D^{*+} - D^0$ mass difference plot is shown in figure 3d. Although there appears to be some enhancement in the in the D^{*+} region, the fit does not yield a statistically significant signal, and we prefer to quote an upper limit for this mode.

btraction for the feedthrough into $K^{*0}\overline{K}^{*0}$ from $\phi\rho$, $K^{*0}K^-$, non-resonant). Our upper limit of 0.26%, which includes the ty due to the modelling of the phase space suppression of the wer than the signal claimed by the E-691 experiment.[6]

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

ın opportunity of observing mixing between particle and anti- his effect in both the strange and bottom sector has also been ıns of the origin of CP-violation. In general, the likelihood is nt Δ_{+-}/Γ, wher Δ_{+-} is the mass difference not between the ^{0}, but rather the CP-eigenstates D_L and D_S. Unlike the bottom an decay within its own generation; correspondingly, the mixing h smaller than the Cabibbo allowed simple $c \to s$ transition.

either mixing or doubly Cabibbo suppressed D^0 decays (DSCD) ound. The standard technique for observation of such decays is ıere the soft pion has the same charge as the K arising from the tral D. Without measuring the time-evolution of the final state iate between DCSD decays and $D^0\,\overline{D}^0$ mixing.

earch for these decays as sensistive as possible, an analysis tech- differs from that used for the other decay modes reported in this sideband subtraction technique to account for background, very l with a view to eliminating all background. $K^+\pi^-$ candidates $D^{*+} \to D^0, D^0 \to K^+\pi^-$, with the $K^+\pi^-$ mass required to be) mass. A function corresponding to the probability of the dE/dx e to a K^+ and a π^- was calculated and this probability was re- l.4. In order to further discriminate against $K^-\pi^+$ combinations,

the invariant mass of the $K^+\pi^-$ candidates, when interpreted as $K^-\pi^+$'s, were required to be more than $60MeV/c^2$ away from the D^0 mass. Lastly a very restrictive x_p requirement of 0.6 was made. Figure 4a shows the resultant mass difference plot. The fit shown is the best fit to a D^0 signal with fixed mass and width, but no statistically significant signal is observed. The 90% confidence level limit to the number of produced combinations is 4.3. In order to provide a suitable normalization, the analogous cuts were applied to obtain a signal in $D^0 \to K^-\pi^+$ (figure 4b), where a signal of 420 ± 21 is observed. Assuming the efficiencies of $K^-\pi^+$ and $K^+\pi^-$ when analyzed in this manner are identical, an upper limit on the ratio of branching fractions $B(D^0 \to K^+\pi^-)/B(D^0 \to K^-\pi^+)$ of .011 is obtained.

For the case of $K^+\pi^-\pi^+\pi^-$ a similar analysis technique was used, but with slightly more stringent mass requirements since the resolution of the D^0 mass is better. The $K^+\pi^-\pi^+\pi^-$ combination was required to be within $10MeV/c^2$ of the D^0 mass; with both possible $K^-\pi^+\pi^-\pi^+$ interpretations required to be greater than $40MeV/c^2$ of the D^0 mass. In this the probability function was constructed with the dE/dx information from all 4 tracks, with the requirement on this probability at 0.4 as before. The mass difference plot for this mode is shown in figure 4c, together with that for the decay $K^-\pi^+\pi^-\pi^+$ analyzed in the same way (figure 4d). Once again, a 90% confidence level upper limit is obtained; $B(D^0 \to K^+\pi^-\pi^+\pi^-)/B(D^0 \to K^-\pi^+\pi^-\pi^+) < .018$. The naive expectation for the ratio of the DCSD mode to the Cabibbo- allowed analogue is that it should be $tan^4\Theta_c \approx 0.002$. The data are not sufficient to test this expectation.

The Decay $D^o \to \overline{K}^o K^+ K^-$

The Cabibbo allowed decay $D^0 \to \overline{K}^0 K^+ K^-$ has been the object of considerable interest for some years. In particular, the first observations[9] of the decay chain $D^0 \to \phi\overline{K}^0$ were interpreted as firm evidence of W- exchange diagrams (figure 1d) in D decays, as a simple spectator model predicts a zero amplitude. More recent theoretical considerations have led