Hadronic D^0, D^+, and D_S^0 Decays

M. ARTUSO on behalf of the CLEO-c Collaboration
Department of Physics, Syracuse University,
Syracuse, NY 13244

Hadronic decays of the charmed mesons D^0, D^+, and D_S^0 offer unique opportunities to probe non-perturbative strong dynamics. In this report we summarize recent CLEO-c results, and we compare them with predictions from phenomenological models. Finally, we discuss their impact on our knowledge of light quark spectroscopy.

1 Introduction

Hadronic charm decays are driven by the complex interplay between short distance and long distance dynamics, which introduces a variety of complex phases resultin in enhancements and suppressions through interference effects. In these proceedings we will summarize recent CLEO-c hadronic D^0,D^+, and D_S^0 decays, based on the full CLEO-c data set,[1] with 818 pb^{-1} at the $\psi(3770)$ center-of-mass energy, and 586 pb^{-1} at $\sqrt{\mathrm{s}}$=4.170 GeV(unless otherwise noted). They correspond to 3×10^6 $D^0\bar{D}^0$ pairs, and 5.3×10^5 $D_S^{\pm}D_S^{\star\mp}$pairs.

2 Charm decays to two pseudoscalars

Cleo-c has recently published an extensive set of measurements of branching fractions of hadronic D^0, D^+, and D_S^0 into two pseudoscalars. Bhattacharya and Rosner [2] have proposed a diagrammatic approach to analyze these modes in the framework of flavor $SU(3)$. The decay amplitudes are expressed in terms of topological quark flow diagrams: each diagram represents an amplitude which accounts for weak and strong interaction effects, to all orders, including long distance effects. The key amplitudes include a color-favored tree (T), a color-suppressed tree (C), an exchange (E) and an annihilation (A). The role of the annihilation term, especially in D_S^0 decays, is very interesting as it provides information relevant to annihilation effects in charmless semileptonic decays.

Table 1 compares the results from the best fit to the quark flow diagram formalism in the case of the Cabibbo favored and the singly Cabibbo suppressed decays. The experimental information is sufficient to use the Cabibbo favored (CF) decays to fit for the quark flow diagram amplitudes, their relative phases, and the octet-singlet mixing angle θ_η, which they determine to be 11.7°. This value of θ_η is used to predict singly-Cabibbo-suppressed (CS) and doubly-Cabibbo-suppressed (DCS) decays. This approach does not work very well for singly Cabibbo suppressed decays, for example it overestimates $\mathcal{B}(D^0 \to \pi^+\pi^-)$ and underestimates $\mathcal{B}(D^0 \to K^+K^-)$.

Table 1: Comparison between CLEO-c data and theoretical predictions from Bhattacharya and Rosner. The theoretical predictions quoted are derived with their favorite singlet-octect mixing angle $\theta_\eta = 11.7^\circ$ ($\phi_1 = 45^\circ - \frac{\phi_2}{2}$, and $\phi_2 = 19.5^\circ$).

Mode	$\mathcal{B}$ (%) (CLEO-c) [1]	Representation	Predicted $\mathcal{B}$ (%) [2]	
$D^0 \to K^-\pi^+$	3.906 ± 0.077	T+E	3.891	
$D^0 \to \bar{K}^0\pi^0$	2.38 ± 0.085	(C-E)/$\sqrt{2}$	2.380	
$D^0 \to \bar{K}^0\eta$	0.962 ± 0.060	$\frac{\mathrm{C}}{\sqrt{2}}\sin(\theta_\eta+\phi_1) - \frac{\sqrt{3}\mathrm{E}}{\sqrt{2}}\cos(\theta_\eta+2\phi_1)$	0.962	
$D^0 \to \bar{K}^0\eta'$	1.900 ± 0.108	$-\frac{\mathrm{C}}{\sqrt{2}}\cos(\theta_\eta+\phi_1) - \frac{\sqrt{3}\mathrm{E}}{\sqrt{2}}\sin(\theta_\eta+2\phi_1)$	1.900	
$D^+ \to \bar{K}^0\pi^+$	3.074 ± 0.097	C+T	3.074	
$D^0_S \to \bar{K}^0K^+$	2.98 ± 0.17	C+A	2.980	
$D^0_S \to \pi^+\eta$	1.84 ± 0.15	$\mathrm{T}\cos(\theta_\eta+\phi_1) - \sqrt{2}\mathrm{A}\sin(\theta_\eta+\phi_1)$	1.840	
$D^0_S \to \pi^+\eta'$	3.95 ± 0.34	$\mathrm{T}\sin(\theta_\eta+\phi_1) + \sqrt{2}\mathrm{A}\cos(\theta_\eta+\phi_1)$	3.950	
			$\lvert T'\rvert > \lvert C'\rvert$	$\lvert T'\rvert < \lvert C'\rvert$
$D^0 \to \pi^-\pi^+$	0.145 ± 0.005	-(T$'$ +E$'$)	0.224	0.224
$D^0 \to \pi^0\pi^0$	0.081 ± 0.005	-(C$'$ - E$'$)/$\sqrt{2}$	0.135	0.136
$D^0 \to K^-K^+$	0.407 ± 0.010	(T$'$ +E$'$)	0.193	0.192
$D^0 \to K^0\bar{K}^0$	0.032 ± 0.002	0	0	
$D^+ \to \pi^0\pi^+$	0.0118 ± 0.006	-(T$'$ +C$'$)/$\sqrt{2}$	0.089	0.088
$D^+ \to K^+\bar{K}^0$	0.612 ± 0.022	(T$'$ - A$'$)	0.615	0.073
$D^0_S \to \pi^+K^0$	0.252 ± 0.027	-(T$'$ -A$'$)	0.308	0.037
$D^0_S \to \pi^0K^+$	0.062 ± 0.023	-(C$'$ +A$'$)/$\sqrt{2}$	0.085	0.086

3 $K^0\bar{K}^0$ Interference

The decay rates for $D^0 \to K_S\pi^0$ and $D^0 \to K_L\pi^0$ are not the same because of the interference between the CF component $D^0 \to \bar{K}^0\pi^0$ and the DCS $D^0 \to \bar{K}^0\pi^0$ which has a positive sign fo the decay $D^0 \to K_S\pi^0$ and a negative sign when the K_S is replaced by K_L. The amplitudes $D^0 \to \bar{K}^0\pi^0$ and $D^0 \to \bar{K}^0\pi^0$ are related by U-spin (interchange of u and s quark). Thus, assuming U-spin symmetry, $A(D^0 \to K^0\pi^0) = \tan^2\theta_c \times A(D^0 \to \bar{K}^0\pi^0)$ and the decay rate asymmetry is given by:

$$R(D^0) \equiv \frac{\Gamma(D^0 \to K_S\pi^0) - \Gamma(D^0 \to K_L\pi^0)}{\Gamma(D^0 \to K_S\pi^0) + \Gamma(D^0 \to K_L\pi^0)} = 2\tan^2\theta_c = 0.109 \quad (1)$$

CLEO-c, using a partial sample of 281 pb^{-1}, measures $R(D^0)$ exploiting kinematic constraints to reconstruct the K_L in the final state with a missing mass square technique [3] and obtains:

$$R(D^0)_{exp} = 0.108 \pm 0.025 \pm 0.024, \quad (2)$$

which is in excellent agreement with the expectations based on U-spin symmetry. The theoretical treatment of a similar asymmetry $R(D^+)$ in D^+ decays is more complex; the diagrammatic approach [2] predicts

$$R(D^+) = -0.005 \pm 0.013, \quad (3)$$

in excellent agreement with

$$R(D^+) = 0.022 \pm 0.016 \pm 0.018. \quad (4)$$

4 D^0_S decays with ω in the final state and weak annihilation

D^0_S decays are important to shed light on the poorly known weak annihilation effects which influence the extraction of $|V_{ub}|$ from inclusive charmless semileptonic B decays.[4, 5] Hadronic D^0_S decays present interesting puzzles concerning weak annihilation effects.[6, 7] Decays including ω in the final state are expected to be mediated predominantly by the annihilation diagram $c\bar{s} \to u\bar{d}$. G-parity of a J=0 $u\bar{d}$ quark-antiquark pair suggests that only D^0_S decays including an odd number of πs are allowed. This is contradicted by the observation of $D^0_S \to \omega\pi$ and the

Table 2: Summary of the CLEO-c data on exclusive and inclusive decays $D_S^0 \to \omega X$. The sum of the measured exclusive branching fraction is (5.4±1.0)%

Mode	$\mathcal{B}$ (%) (CLEO-c) [9, 10]
$D_S^0 \to \pi^+\omega$	0.21 ± 0.09 ±0.01
$D_S^0 \to \pi^+\pi^0\omega$	2.78 ± 0.65 ±0.25
$D_S^0 \to \pi^+\pi^+\pi^-\omega$	1.58 ± 0.45 ±0.09
$D_S^0 \to \pi^+\eta\omega$	0.85 ± 0.54 ±0.06
	$<$ 2.3 (90% CL)
$D_S^0 \to K^+\omega$	$<$ 0.24 (90% CL)
$D_S^0 \to K^+\pi^0\omega$	$<$ 0.82 (90% CL)
$D_S^0 \to K^+\pi^+\pi^-\omega$	$<$ 0.54 (90% CL)
$D_S^0 \to K^+\eta\omega$	$<$ 0.79 (90% CL)
$D_S^0 \to \pi^0 K^+$	0.062 ± 0.023
$D_S^0 \to \omega X$	6.1 ±1.4

non-observation of $D_S^0 \to \rho\pi$. [8] Table 2 summarizes the CLEO-c measurements of inclusive and exclusive D_S^0 decays including ω in the final state. These data show that the measured branching fractions account for the inclusive rate, but the interplay between annihilation and rescattering makes a simple model based on annihilation and G-parity conservation inadequate to describe these decays.

5 The Dalitz Decay $D_S^0 \to K^+K^-\pi^+$

The kinematics of the 3-body decay $D \to ABC$ is fully described in terms of the invariant masses M_{AB}^2 and M_{BC}^2 of two pair of final state mesons. The "Dalitz analysis" of these decays, involving the measurement of the differential distribution $d\Gamma/dM_{AB}^2 M_{BC}^2$ provides an impressive wealth of information relevant to D and B meson dynamics, as well as light meson spectroscopy, in particular the poorly known scalar meson sector. I will illustrate this point with the Dalitz analysis of $D_S^0 \to K^+K^-\pi^+$.

An example, recently studied by CLEO-c,[11] is the decay $D_S^0 \to K^+K^-\pi^+$. Table 3 gives the the relevant isobar model fit parameters. This study is based on 12K $D_S^0 \to K^+K^-\pi^+$ decays, to be compared with the pioneering E687 [12] analysis based on 701 events. CLEO-c confirms the strength of the dominant s-wave component ($f_0(890)$). The best fit to the CLEO-c data is achieved by adding another scalar mesons, the $f_0(1370)$.[13] This meson is strongly overlapping with the broad $f_0(600)$ and the narrow $f_0(1500)$. Its mass and width[8] have large uncertainties due to the small fraction of these decays into two π or K. The CLEO-c fit with floating resonance parameters gives $M_{f_0(1370)} = (1315 \pm 34)$ MeV/c^2, and $\Gamma_{f_0(1370)} = 276 \pm 39$ MeV/c^2, where the quoted errors are statistical only. CLEO-c obtains a reasonably good fit, χ^2/d.o.f $= 178/117$, using these resonances.

6 Conclusions

This report gives a quick snapshot of some of the many important contributions towards our understanding of fundamental interactions provided by CLEO-c studies of hadronic charm decays. Excellent reviews [14, 15] offer a broader picture of the experimental and theoretical landscape.

Acknowledgments

This work was supported by the US National Science Foundation. I would like to thank the organizers for a lovely conference with spirited discussions, great physics, and wonderful skiing opportunities, and my CLEO collaborators for all the years of shared fun and discoveries.

Table 3: Summary of the six resonance model (Model A) fit to the $D_S^0 \to K^+K^-\pi^+$ Dalitz plot. Fit parameters are shown with their statistical and systematic uncertainty respectively. The "δMean" and "RMS" account for variation of the fit parameters in the systematic cross checks as discussed in the text. The "Total" is a quadratic sum of "δMean" and "RMS" and after rounding is the systematic uncertainty given in the second column. The results of the E687 Model are also shown for comparison.

Parameter	Model A	δMean	RMS	Total	E687 Model
$m_{K^*(892)}$	894.9±0.5±0.7	0.088	0.654	0.660	895.8±0.5
$\Gamma_{K^*(892)}$	45.7±1.1±0.5	0.148	0.499	0.520	44.2±1.0
$a_{K_0^*(1430)}$ (a.u.)	1.51±0.11±0.09	-0.024	0.089	0.092	1.76±0.12
$\phi_{K_0^*(1430)}$ ($^\circ$)	146±8±8	-0.623	8.442	8.465	145±8
$a_{f_0(980)}$ (a.u.)	4.72±0.18±0.17	-0.029	0.167	0.170	3.67±0.13
$\phi_{f_0(980)}$ ($^\circ$)	157±3±4	-0.343	4.036	4.051	156±3
$a_{\phi(1020)}$ (a.u.)	1.13±0.02±0.02	0.004	0.017	0.018	1.15±0.02
$\phi_{\phi(1020)}$ ($^\circ$)	–8±4±4	0.081	3.850	3.851	–15±4
$a_{f_0(1370)}$ (a.u.)	1.15±0.09±0.06	-0.003	0.063	0.063	
$\phi_{f_0(1370)}$ ($^\circ$)	53±5±6	-0.536	5.820	5.845	
$a_{f_0(1710)}$ (a.u.)	1.11±0.07±0.10	-0.004	0.098	0.098	1.27±0.07
$\phi_{f_0(1710)}$ ($^\circ$)	89±5±5	0.195	4.916	4.920	102±4
FF[$K^*(892)$] (%)	47.4±1.5±0.4	0.016	0.357	0.4	48.2±1.2
FF[$K_0^*(1430)$] (%)	3.9±0.5±0.5	0.036	0.460	0.5	5.3±0.7
FF[$f_0(980)$] (%)	28.2±1.9±1.8	0.096	1.792	1.8	16.8±1.1
FF[$\phi(1020)$] (%)	42.2±1.6±0.3	0.018	0.277	0.3	42.7±1.3
FF[$f_0(1370)$] (%)	4.3±0.6±0.5	0.044	0.488	0.5	
FF[$f_0(1710)$] (%)	3.4±0.5±0.3	0.044	0.311	0.3	4.4±0.4
$\sum_R$ FF$_R$ (%)	129.5±4.4±2.0	0.020	1.981	2.0	117.3±2.2
χ^2/ν	178/117				278/119

References

1. H. Mendez *et al.* [CLEO Collaboration], Phys. Rev. D **81** (2010) 052013 [arXiv:0906.3198 [hep-ex]].
2. B. Bhattacharya and J. L. Rosner, Phys. Rev. D **81**, 014026 (2010) [arXiv:0911.2812 [hep-ph]].
3. Q. He *et al.*CLEO Collaboration], Phys. Rev. Lett. {**100**,091801 (2008).
4. M. B. Voloshin, Mod. Phys. Lett. A **17** (2002) 245 [arXiv:hep-ph/0202028].
5. Z. Ligeti, M. Luke and A. V. Manohar, arXiv:1003.1351 [hep-ph].
6. M. Gronau and J. L. Rosner, Phys. Rev. D **79**, 074022 (2009) [arXiv:0903.2287 [hep-ph]].
7. F. E. Close and H. J. Lipkin, Phys. Lett. B **551** (2003) 337 [arXiv:hep-ph/0208217].
8. C. Amsler *et al.* [Particle Data Group], Phys. Lett. B **667** (2008) 1.
9. J. Y. Ge *et al.* [CLEO Collaboration], Phys. Rev. D **80** (2009) 051102 [arXiv:0906.2138 [hep-ex]].
10. S. Dobbs *et al.*[CLEO Collaboration], Phys. Rev. D **76**, 112001 (2007).
11. R. E. Mitchell *et al.* [CLEO Collaboration], Phys. Rev. D **79** (2009) 072008 [arXiv:0903.1301 [hep-ex]].
12. P. L. Frabetti *et al.* [E687 Collaboration], Phys. Lett. B **351**, 591 (1995).
13. S. Spanier, N. A. Tornqvist and C. Amsler, Phys. Lett. B **667** (2008) 1.
14. M. Artuso, B. Meadows and A. A. Petrov, Ann. Rev. Nucl. Part. Sci. **58**, 249 (2008) [arXiv:0802.2934 [hep-ph]].
15. A. Ryd and A. A. Petrov, arXiv:0910.1265 [hep-ph].