TWO-BODY MODES OF CHARM

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A RESEARCH BEGUN MANY YEARS AGO WITH

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CONTINUED WITH

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STILL GOING ON

1) CHALLENGING ASPECTS OF CHARM DECAYS

2) THE ROLE OF FINAL STATE INTERACTIONS

3) CONCLUSIONS

CHARMED MESON WEAK DECAYS HAVE PROPOSED SEVERAL CHALLENGES TO THEIR THEORETICAL UNDERSTANDING, STARTING FROM THE EXPERIMENTAL FACT

$$\tau(D^+) \gg \tau(D_s^+) \gtrsim \tau(D^0)$$

IN PARTICULAR

$$\tau(D^+) = 2.4\ \tau(D^0)$$

WHILE THE SPECTATOR MODEL

$$c\ (\bar{q}) \rightarrow s\, u\, \bar{d}\ (\bar{q})$$

IMPLIES EQUAL VALUES FOR THEIR LIFETIMES

ALSO IN THE FOUR QUARK APPROXIMATION WITH THE CKM MATRIX GIVEN BY

$$\begin{pmatrix} \cos\vartheta_c & \sin\vartheta_c & 0 \\ -\sin\vartheta_c & \cos\vartheta_c & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

WHICH IS GOOD FOR CHARM DECAYS (EXCLUDING CP VIOLATING ASYMMETRIES)

THE CABIBBO ALLOWED $\Delta S = \Delta C$ NON-LEPTONIC HAMILTONIAN $H_{\Delta S = \Delta C}$

THE CABIBBO FIRST FORBIDDEN $\frac{1}{\sqrt{2}} H_{\Delta S = 0}$ AND THE DOUBLY FORBIDDEN $H_{\Delta S = -\Delta C}$ FORM A U-SPIN TRIPLET, WHICH IMPLIES MANY SU(3) RELATIONSHIPS FOR D DECAYS (REMEMBER THAT D^0 IS A U-SINGLET AND D_s^+ AND D^+ FORM A U-DOUBLET), WHICH IN SOME CASES ARE STRONGLY CONTRADDICTED BY EXPERIMENT:

$$Br(D^0 \to K^+K^-) = Br(D^0 \to \pi^+\pi^-)$$

EXP. .425 ± .016 VERSUS .152 ± .009

$$Br(D^0 \to K^0\bar{K}^0) = 0$$

EXP .065 ± .018

DUE TO THE LARGER SCALE INVOLVED CHARM DECAYS ARE MORE RELIABLE THAN STRANGE PARTICLES DECAYS TO TEST THE SHORT-RANGE QCD CORRECTIONS TO THE BARE HAMILTONIAN, WHICH BRING THE CABIBBO ALLOWED $H_{\Delta s = \Delta c}$ INTO

$$\frac{G_F}{\sqrt{2}} \left(K_1 \bar{s}_L \gamma_\mu c_L \bar{u}_L \gamma^\mu d_L + K_2 \bar{u}_L \gamma_\mu c_L \bar{s}_L \gamma^\mu d_L \right) + \dots$$

WITH $K_1 = 1.347 \quad K_2 = -.628$

A TABLE WITH THE EXPERIMENTAL BRENCHING RATIOS FOR THE CABIBBO ALLOWED NON-LEPTONIC DECAYS INTO PP, PV AND VV FINAL STATES IS A GOOD STARTING POINT

D^+		D^0		D_s^+	
$K^S \pi^+$	$1.45 \pm .13$	$K^- \pi^+$	$3.83 \pm .09$	$K^+ K^S$	$1.8 \pm .55$
		$K^S \pi^0$	$1.05 \pm .105$	$\pi^+ \eta$	$1.7 \pm .5$
		$K^S \eta$	$.35 \pm .05$	$\pi^+ \eta'$	3.9 ± 1
		$K^S \eta'$	$.85 \pm .13$		
PP_{TOT}	$2.90 \pm .26$		$8.33 \pm .66$		9.2 ± 2.6
$\bar{K}^{*0} \pi^+$	$1.92 \pm .19$	$\bar{K}^{*0} \pi^0$	$3.1 \pm .4$	$\rho^+ \eta$	10.8 ± 3.1
$K^S \rho^+$	3.3 ± 1.25	$\rho^0 K^S$	$.605 \pm .085$	$\rho^+ \eta'$	10.1 ± 2.8
		$K^{*-} \pi^+$	$5 \pm .4$	$\pi^+ \varphi$	$3.6 \pm .9$
		$K^- \rho^+$	$10.8 \pm .9$	$K^+ \bar{K}^{*0}$	$3.3 \pm .9$
		$\bar{K}^{*0} \eta$	$1.9 \pm .5$	$K^S K^{*+}$	$2.15 \pm .7$
		$\bar{K}^{*0} \eta'$	$< .06$	$\pi^+ \rho^0$	$< .05$
		$K^S \omega$	$1.05 \pm .2$	$\pi^+ \omega$	$.28 \pm .11$
		$K^S \varphi$	$.43 \pm .05$		
PV_{TOT}	8.5 ± 2.7		24.76 ± 2.62		32.4 ± 9.2
$\bar{K}^{*0} \rho^+$	4.8 ± 1.8	$K^{*-} \rho^+$	6.1 ± 2.4	$K^{*+} \bar{K}^{*0}$	5.8 ± 2.5
		$\bar{K}^{*0} \rho^0$	$1.46 \pm .32$	$\rho^+ \varphi$	6.2 ± 2.3
		$\bar{K}^{*0} \omega$	$1.1 \pm .4$		
VV_{TOT}	4.8 ± 1.8		8.7 ± 3.1		12 ± 4.8
$(PP+PV+VV)_{TOT}$	16.2 ± 3.9		41.8 ± 6.4		53.6 ± 16.6

THE TOTAL BRENCHING RATIO IS SMALLER FOR D^+ THAN FOR D^0 AND D_s^+ AND THE DIFFERENCE FOR THE INDIVIDUAL RATES IS STILL LARGER, SINCE THE TOTAL RATE IS SMALLER FOR D^+.

AS SOON AS THE EVIDENCE FOR $\tau(D^+) >> \tau(D^0)$ WAS KNOWN, THAT FACT WAS RELATED TO A DESTRUCTIVE INTERFERENCE BETWEEN THE $\bar{d}$ SPECTATOR AND THE $\bar{d}$ CREATED BY THE NON-LEPTONIC C DECAY AMPLITUDE

$$D^+ \equiv c(\bar{d}) \rightarrow s\, u\, \bar{d}\, (\bar{d})$$

INDEED FOR THE FINAL STATE $\bar{K}^0\pi^+$ THERE IS AN INTERFERENCE FOR THE FACTORIZED CONTRIBUTIONS COMING FROM THE TWO TERMS OF THE EFFECTIVE WEAK HAMILTONIAN

$$A(D^+ \to \bar{K}^0 \pi^+) = \frac{G_F}{\sqrt{2}}$$

$$\left[(K_1 + \xi K_2) \langle \bar{K}^0 | \bar{s} \gamma_\mu c | D^+ \rangle \langle \pi^+ | \bar{u} \gamma^\mu \gamma_5 d | 0 \rangle + (K_2 + \xi K_1) \langle \pi^+ | \bar{u} \gamma_\mu c | D^+ \rangle \langle \bar{K}^0 | \bar{s} \gamma^\mu \gamma_5 d | 0 \rangle \right]$$

IN THE SU(3) LIMIT

$$\sim \frac{G_F}{\sqrt{2}} (K_1 + K_2)(1 + \xi)$$

AND THE RELATIONSHIP

$$A(D^+ \to \bar{K}^0 \pi^+) = A(D^0 \to K^- \pi^+) + \sqrt{2} A(D^0 \to \bar{K}^0 \pi^0)$$

FOLLOWS FROM SU(2)

WITH THE VALUE $\xi = 0$ FOUND BY THE FIT SU(3) WOULD IMPLY

$$\frac{Br(D^+ \to \bar{K}^0 \pi^+)}{Br(D^0 \to \bar{K} \pi)} = \frac{\tau(D^+)}{\tau(D^0)} \frac{(K_1 + K_2)^2}{K_1^2 + \frac{1}{2} K_2^2} \sim .6$$

TO BE COMPARED WITH THE EXPERIMENTAL VALUE .35 WHICH WILL BE OBTAINED FROM THE LARGER DESTRUCTIVE INTERFERENCE COMING FROM SU(3) BREAKING ($\frac{f_K}{f_\pi} > 1 \ldots$)

SIMILAR CONSIDERATIONS APPLY TO PV FINAL STATES WITH A DESTRUCTIVE INTERFERENCE BETWEEN THE VECTOR-VECTOR AND AXIAL-AXIAL FACTORIZED CONTRIBUTIONS

$$A(D^+ \to \bar{K}^0 \rho^+) = \frac{G_F}{\sqrt{2}}$$

$$[K_1 <\bar{K}^0 | \bar{s}\gamma_\mu c | D^+><\rho^+ | \bar{u}\gamma^\mu d | 0>$$

$$+ K_2 <\rho^+ | \bar{u}\gamma_\mu \gamma_5 c | D^+><\bar{K}^0 | \bar{s}\gamma_\mu \gamma_5 d | 0>$$

IN CONCLUSION THE SMALLER RATES FOR D^+ CABIBBO ALLOWED NON-LEPTONIC DECAYS ARE EXPLAINED BY THE DESTRUCTIVE INTERFERENCE ADVOCATED FOR THE 2 $\bar{d}$ IN THE FINAL STATE, WHICH FOLLOWS FROM THE NEGATIVE SIGN OF K_2 PREDICTED BY QCD CORRECTIONS AND BY THE ASSUMPTION

$$\xi\left(\frac{1}{N_c}\right) = 0$$

THE AMPLITUDES FOR

$D^0 \to PP$

EVALUATED IN THE FACTORIZATION APPROXIMATION, INCLUDING THE ANNIHILATION TERM

$$\frac{G_F}{\sqrt{2}} K_2 < 0 | \bar{u} \gamma_\mu \gamma_5 c | D^0 > < \bar{K} \pi (\eta, \eta') | \bar{s} \gamma^\mu d | 0 >$$

WHICH WOULD VANISH IN THE LIMIT OF SU(3) SYMMETRY WOULD GIVE DISASTREOUS PREDICTIONS, WERE NOT FOR THE FINAL STATE INTERACTION INDUCED BY THE 0^+ RESONANCE $K^{0^+}(1950)$

$D^0 \to$	Br (N.R.)	Exp.	Br. (R.)
$K_S^- \pi^+$	5.05	$3.83 \pm .09$	3.84
$K_S \pi^0$	.35	$1.05 \pm .105$	.67
$K_L \pi^0$	.23		.53
$K_S \eta$	.20	$.35 \pm .05$	.45
$K_S \eta'$	.48	$.855 \pm .13$	1.09

A I = 1 0^+ RESONANCE IS RELEVANT FOR THE

$F^+ \to PP$ AMPLITUDES

$D_s^+ \to$	Br (N.R.)	Exp.	Br (R.)
$K^+ K^S$	1.24	1.8 ± .55	2.13
$K^+ K^L$	1.60		1.85
$\pi^+ \eta$	4.93	1.7 ± .5	1.01
$\pi^+ \eta'$	2.83	3.9 ± 1	3.4

FOR PV FINAL STATES WE NEED ALSO A FINAL STATE INTERACTION IN THE 27 SU(3) CHANNEL, FOR WHICH WE ASSUME A DIFFERENT PHASE AT THE D AND D_s^+ MASS AND FIND VALUES NOT SO DIFFERENT

$D^+ \to$	Br (N.R)	Exp.	Br (R.)
$\bar{K}^{*0}\pi^+$	.035	1.9±.19	2.07
$\rho^+ K^S$	6.295	3.3±1.25	5.10
$\rho^+ K^L$	6.411		5.13
$D^0 \to$			
$\bar{K}^{*0}\pi^0$	1.84	3.1±.4	3.64
$\rho^0 K^S$	.98	.605±.085	.45
$\rho^0 K^L$	.90		.33
$K^{*-}\pi^+$	1.94	5±.4	4.89
$\rho^+ K^-$	17.30	10.8±.9	10.7
$\bar{K}^{*0}\eta$	1.46	1.9±.5	.34
$\bar{K}^{*0}\eta'$	.002	<.06	.003
ωK^S	.22	1.05±.2	1.20
φK^S	.06	.43±.05	.30
$D_s^+ \to$			
$\rho^+\eta$	9.01	10.8±3.1	7.75
$\rho^+\eta'$	2.48	10.1±2.8	2.40
$\varphi\pi^+$	4.42	3.6±.9	3.74
$\bar{K}^{*0}K^+$	3.83	3.3±.9	4.80
$K^{*+}K^S$	.80	2.15±.7	1.58
$\rho^0\pi^+$	.035	<.05	.03
$\omega\pi^+$	.035	.28±.11	.19

FOR THE CABIBBO FORBIDDEN DECAYS OF THE CHARGED D'S NO NEW PARAMETER IS NEEDED SINCE THE FINAL STATES FOR D^+ CABIBBO FORBIDDEN DECAYS ARE THE SAME OF F^+ CABIBBO ALLOWED AND F^+ CABIBBO FORBIDDEN HAVE THE OPPOSITE HYPERCHARGE THAN THE D^+ CABIBBO ALLOWED

$D^+ \to$	Br (N.R.)	EXP.	Br (R.)
$\pi^+ \pi^0$	.19	.25±.07	.19
$\pi^+ \eta$	.04	.30±.06	.15
$\pi^+ \eta'$	.30	.5±.1	.5
$K^+ \bar{K}^0$	1.35	.74±.1	.64
D_s^+			
$K^+ \pi^0$	.20		.07
$K^+ \eta$	.005		.14
$K^+ \eta'$	~0		.27
$K^0 \pi^+$	1.08	<.49	.46

$D^+ \to$	Br (N.R.)	Exp.	Br (R.)
$\rho^0 \pi^+$	.04	.105±.039	.122
$\rho^+ \pi^0$	.74		.52
$\rho^+ \eta$	.002	<.43	.06
$\rho^+ \eta'$	.12	<.30	.12
$\omega \pi^+$	.055	<.43	.055
$\varphi \pi^+$	.46	.61±.06	.61
$K^{*+} \bar{K}^0$	1.33	3.2±1.5	1.34
$\bar{K}^{*0} K^+$	.58	.42±.05	.43
$D_s^+ \to$			
$\rho^0 K^+$	.007	<.18	.29
φK^+	.03	<.03	.01
$K^{*0} \pi^+$	1.14	.65±.28	.38

FOR CABIBBO FORBIDDEN D^0 DECAYS WE INTRODUCE TWO PARAMETERS TO DESCRIBE THE FINAL STATE INTERACTION IN THE $I=0$ CHANNELS

$D^0 \to$	Br (N.R.)	Exp.	Br (R.)
$\pi^+\pi^-$	.431	.152 ± .009	.153
K^+K^-	.567	.425 ± .016	.438
$K^0\bar{K}^0$	0	.065 ± .018	.052
$\pi^0\pi^0$	.048	.084 ± .022	.080
$\pi^0\eta$	.05		.032
$\pi^0\eta'$			.155
$\eta\eta$			.106
$\eta\eta'$			.245
$\varphi\pi^0$	.089	$<.085$	.099
$\varphi\eta$	.020	$<.17$	.056
$K^{*0}\bar{K}^0$	.011	$<.05$	.062
$\bar{K}^{*0}K^0$	.011	$<.1$	.084
$K^{*+}K^-$	.87	.35 ± .08	.44
$K^{*-}K^+$	.07	.18 ± .10	.30
$\rho^+\pi^-$			.76
$\rho^-\pi^+$			.50
$\rho^0\pi^0$			.24

THE FINAL STATE INTERACTIONS IS ABLE TO PRODUCE THE LARGE SU(3) VIOLATIONS FOUND EXPERIMENTALLY

THE FINAL STATE INTERACTION DOES NOT MODIFY THE NON-DIAGONAL MATRIX ELEMENT OF THE WIDTH OF THE D^0-$\bar{D}^0$ SYSTEM

$$\Gamma_{12} = \sum_f A^*(D^0 \to f) A(\bar{D}^0 \to f)$$

WHICH SHOULD VANISH IN THE 4-QUARK LIMIT, SHOULD ONE NEGLECT SU(3) VIOLATION

INDEED THE CONTRIBUTION TO Γ_{12} OF PP AND PV STATES GAVE

$$\Gamma_{12} \sim 1.5 \cdot 10^{-3} \, \Gamma_{D^0}$$

WITH A LARGE CANCELLATION BETWEEN THE CONTRIBUTION OF $|S|=1$ AND $S=0$ FINAL STATES

FOR VV FINAL STATES ONE MIGHT HAVE LARGER SU(3) VIOLATIONS IN THE N.R. AMPLITUDES FOR THRESHOLD EFFECTS

THIS MOTIVATES OUR PRESENT WORK TO EXTEND THE ANALYSIS TO VV, FOR WHICH ARE PRESENTED PRELIMINARY RESULTS FOR CABIBBO ALLOWED RATES

	Br (N.R.)	Exp.	Br (R.)
$D^+ \to \bar{K}^{*0} \rho^+$	2.15	2.1 ± 1.3	2.09
$D^0 \to K^{*-} \rho^+$	4.60	6.1 ± 2.4	6.4
$\to \bar{K}^{*0} \rho^0$	1.86	$1.46 \pm .32$	1.52
$\to \bar{K}^{*0} \omega$	.46	$1.1 \pm .4$	1.78
$D_s^+ \to K^{*+} \bar{K}^{*0}$	1.54	5.8 ± 2.5	.71
$\to \rho^+ \phi$	4.7	6.7 ± 2.3	6.1

CONCLUSIONS

1) COMPLETE COLOUR SCREENING ($\xi = 0$) AND FINAL STATE INTERACTION APPEAR NECESSARY TO DESCRIBE NON-LEPTONIC CHARM DECAYS

2) THE LARGE PHASES INVOLVED ARE PROMISING FOR THE RESEARCH OF CP VIOLATING ASYMMETRIES

3) THE EXTENSION TO VV IS IMPORTANT TO EVALUATE THEIR CONTRIBUTION TO

$\Gamma_{12}^{+}(D^0 - \bar{D}^0)$