Decays of doubly charmed meson molecules

R. Molina[1], H. Nagahiro[2] and A. Hosaka[2]

[1]Research Center for Nuclear Physics (RCNP), Mihogaoka 10-1, Ibaraki 567-0047, Japan [2]Department of Physics, Nara Women's University, Nara 630-8506, Japan

Contents

The XYZ states

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state	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	e^+e^- (ISR), J/ψ decay
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi, \gamma J/\psi$	$B \to KX(3872)$, $p\bar{p}$
$X(3875)$	3875.5 ± 1.5	$3.0^{+2.1}_{-1.7}$		$D^0\bar{D}^0\pi^0$	$B \to KX(3875)$
$Z(3940)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma$
$X(3940)$	3942 ± 9	37 ± 17	J^{P+}	$D\bar{D}*$	$e^+e^- \to J/\psi X(3940)$
$Y(3940)$	3943 ± 17	87 ± 34	J^{P+}	$\omega J/\psi$	$B \to KY(3940)$
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$X(4160)$	4156 ± 29	139^{+113}_{-65}	J^{P+}	$D^*\bar{D}*$	$e^+e^- \to J/\psi X(4160)$
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to KZ^\pm(4430)$
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
Y_b	$\sim 10,870$	?	1^{--}	$\pi^+\pi^- \Upsilon(nS)$	e^+e^-

Table: A summary of the properties of the candidate XYZ mesons discussed in the text. For simplicity, the quoted errors are quadratic sums of statistical and systematic uncertainties.

Hidden gauge Lagrangian Bando,Kugo,Yamawaki

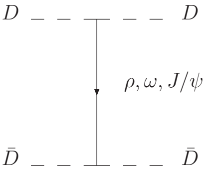
$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III} \qquad (1)$$

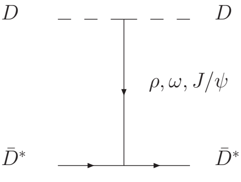
$$\mathcal{L}^{(2)} = \frac{1}{4} f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \qquad (2)$$

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2} M_V^2 \langle [V_\mu - \frac{i}{g}\Gamma_\mu]^2 \rangle$$

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu \,, \qquad U = e^{i\sqrt{2}P/f}, \qquad g = m_V/2f \qquad (3)$$

P P and P V interaction





$$\mathcal{L}_{\mathbf{PPV}} = -\mathbf{ig}\langle \mathbf{V}^\mu [\mathbf{P}, \partial_\mu \mathbf{P}] \rangle$$

$$\mathcal{L}_{\mathbf{3V}} = \mathbf{ig}\langle \mathbf{V}^\mu [\mathbf{V}^\nu, \partial_\mu \mathbf{V}_\nu] \rangle$$

Vector-vector scattering Bando,Kugo,Yamawaki

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu} V^{\mu\nu}\rangle$$

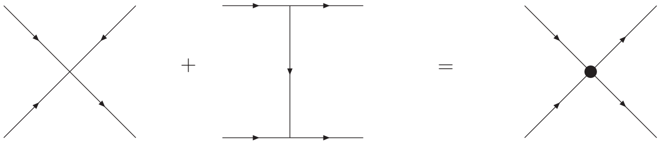
$$\mathcal{L}_{III}^{(3V)} = ig\langle(\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu\rangle$$

$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2}\langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu\rangle$$

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu]$$

$$g = \frac{M_V}{2f}$$

$$V_\mu = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu$$



(a) (b) (c)

The XYZ and doubly charm mesons

- The vector-exchange diagram (b) dominates the interaction
- In the sectors *charm* $= 2$; *strangeness* $= 0, 1$, only the potential from this diagram survives

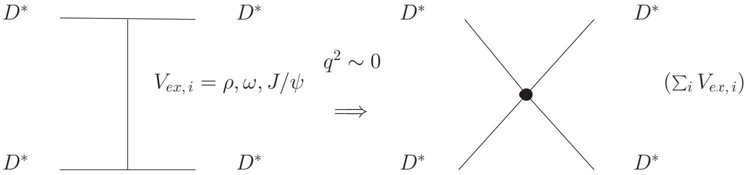


Figure: Point-like vector-vector interaction for $D^* D^* \to D^* D^*$.

R. Molina, T. Branz and E. Oset, Phys. Rev. D **82**, 014010 (2010)

$$V_{ij} = -\frac{g^2}{m^2_{V_{ex}}} C_{ij}(s-l) \quad \text{for} \quad J=0,2\,,$$
$$V_{ij} = \frac{g^2}{m^2_{V_{ex}}} C_{ij}(s-l) \quad \text{for} \quad J=1\,,$$

where $l=u$ in the t-channel and t in the u-channel, and $V_{ex} = \rho, \omega, J/\psi$.

The $SU(4)$ structure of the Lagrangian allows us to take into account all possible channels by a single interaction term. The SU(4) flavour symmetry is broken:

1) Masses are taken from the PDG. The strength of the potential increases with s: Stronger potential for D^*.

2) The exchange of heavy particles, f. ex. J/ψ is supressed.

3) Different coupling constants "g" are taken, "g_h^2" for $V_h V_h \to V_h V_h$, "$g_h g_l$" for $V_h V_h \to V_l V_l$, and "g_l^2" for $V_l V_l \to V_l V_l$, with $g_h = g_{D^*} = m_{D^*}/(2f_D)$, or $g_l = m_\rho/(2f_\pi)$, with $f_D = 206/\sqrt{2}$ MeV and $f_\pi = 93$ MeV.

The XYZ states and doubly charm mesons

- Bethe Salpeter equation:

$$T = (\hat{1} - VG)^{-1} V \ . \tag{4}$$

- The potencial V here is a 10×10 matrix in $I = 0$: $D^* \bar{D}^*$, $D^*_s \bar{D}^*_s$, $K^* \bar{K}^*$, $\rho\rho$, $\omega\omega$, $\phi\phi$, $J/\psi J/\psi$, $\omega J/\psi$, $\phi J/\psi$, $\omega\phi$. In $I = 1$, V is a 6×6: $D^* \bar{D}^*$, $K^* \bar{K}^*$, $\rho\rho$, $\rho\omega$, $\rho J\psi$, $\rho\phi$
- *charm* $= 2$; *strangeness* $= 0$: $D^* D^*$, *strangeness* $= 1$: $D^* D^*_s$
- G is a diagonal matrix with

$$G_i(P) = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{q^2 - m_1^2 + i\epsilon} \frac{1}{(P-q)^2 - m_2^2 + i\epsilon} \ , \tag{5}$$

$G_i(P)$ is a function of $\alpha(\mu)$ in dimensional regularization or $q_{\max}$ with cutoff.

XYZ and doubly charm mesons

To investigate the effect of the SU(4) $''g = \frac{m_V}{2f}''$ breaking, we have performed the calculation by using two parameter sets:

1) SU(4) symmetric coupling, $g_l = m_\rho/(2f_\pi)$ and $\alpha_h = -1.4$ ($\mu = 1500$ MeV) in all channels

2) SU(4) breaking for couplings, we use g_h^2 or $g_l g_h$, being $g_h = m_{D^*}/(2f_D)$ for heavy particles, and $\alpha_h = -1.27$.

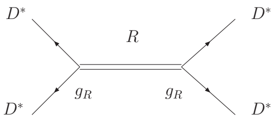
$C; S$	I,J	M_R		channel	$\|g_R\|$		g_W		PDG
		(g_l)	(g_h)		(g_l)	(g_h)	(g_l)	(g_h)	
0; 0	0, 0	3936	3950	$D^*\bar{D}^*$	18700	18000	18050	17200	Y(3940)
	0, 1	3940	3955	$D^*\bar{D}^*$	18260	17200	17800	16900	"X(3940)"
	0, 2	3921	3922	$D^*\bar{D}^*$	20600	21000	18800	18800	Z(3930)
	0, 2	4174	4160	$D_s^*\bar{D}_s^*$	20400	19500	16700	17700	X(4160)
	1, 2	3970	3924	$D^*\bar{D}^*$	20500	20560	15800	18700	"Z_c(3945)"
2; 0	0, 1	3968	3942	D^*D^*	16800	19500	15900	17800	"R_c(3970)"
2; 1	1/2, 1	4100	4070	$D_s^*D^*$	13400	17700	13100	16400	"S_c(4100)"

Table: Masses and couplings to the most important channel in MeV.

$$\frac{g_W^2}{4\pi} = 4(m_1 + m_2)^2\sqrt{\frac{2B}{\mu}}[1 + O(\frac{\sqrt{2\mu B}}{\beta})]$$

And also doubly charm mesons! R. Molina, T. Branz and E. Oset, PRD 82, 014010 (2010)

Couplings (g_a) of the doubly charm mesons to $D^* D^*_{(s)}$



$$T \simeq \frac{[g_R \frac{1}{2}(\epsilon_1^i \epsilon_2^j - \epsilon_1^j \epsilon_2^i)][g_R \frac{1}{2}(\epsilon_1^i \epsilon_2^j - \epsilon_2^j \epsilon_2^i)]}{s - s_p}$$

C, S	*Name*	$I[J^P]$	Channel	$\sqrt{s}_{\rm pole}$ (MeV)	$g_{\rm R}[MeV]$
2; 0	R_{cc}	$0[1^+]$	$D^* D^*$	3970	16800
2; 1	S_{cc}	$1/2[1^+]$	$D^* D^*_s$	4100	13400

- Note we use the same value of $\alpha_H = -1.3 - (-1.4)$ to reproduce the Y(3940), X(4160) and R_{cc}'s!

Decays of double charm states to $D_{(s)} D^*_{(s)}$

R_{cc} has isospin $I = 0$ and S_{cc} ($S = 1$) $I = \frac{1}{2}$:

- $|D^* D^*, I = 0, I_3 = 0\rangle$

$$= \frac{1}{\sqrt{2}}(-D^{*+}(q, \epsilon_1) D^{*0}(P - q, \epsilon_2) + D^{*0}(q, \epsilon_1) D^{*+}(P - q, \epsilon_2)) \quad (6)$$

- $|D^* D^*_s, I = \frac{1}{2}, I_3 = -\frac{1}{2}\rangle = -D^{*0}(q, \epsilon_1) D_s^{*+}(P - q, \epsilon_2)$
- $|D^* D^*_s, I = \frac{1}{2}, I_3 = \frac{1}{2}\rangle = D^{*+}(q, \epsilon_1) D_s^{*+}(P - q, \epsilon_2)$

$$\text{Isospin multiplets}: \begin{pmatrix} D^{*+} \\ -D^{*0} \end{pmatrix}, \quad D_s^{*+} \quad (7)$$

R_{cc}^{+} S_{cc}^{+} S_{cc}^{++}

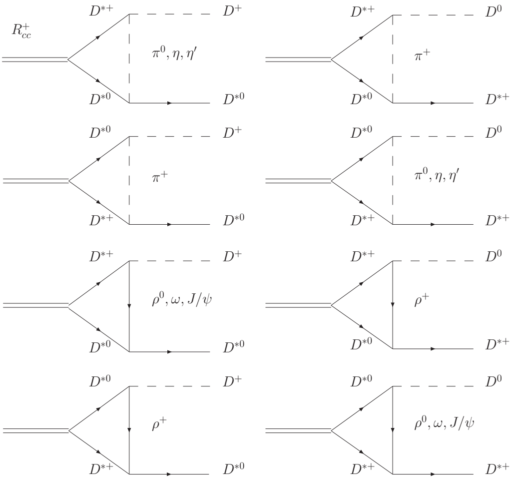


Figure: Feynmann diagrams evaluated in the decay $R_{cc} \to DD^*$.

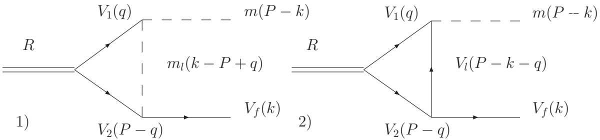


Figure: PPV and 3V Feynmann diagrams for the evaluation of the $R_{cc} \to DD^*_{(s)}$ decay width.

$$t_{RVV} = \frac{I\, g_R}{2}(\epsilon_1^i \epsilon_2^j - \epsilon_1^j \epsilon_2^i) \tag{8}$$

$$\mathcal{L}_{3V} = ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu) V^\nu)\rangle \Longrightarrow$$
$$t_{V_3} = V_3 g\{(2k+q-P)^\mu \epsilon_{(l)\,\nu}\epsilon_{2\,\mu}\epsilon^\nu_{(f)} - (k+P-q)^\mu \epsilon_{2\,\nu}\epsilon_{(l)\,\mu}\epsilon^\nu_{(f)} + (2(P-q)-k)_\mu \epsilon_{(l)\,\nu}\epsilon^\mu_{(f)}\epsilon^\nu_2\} \tag{9}$$

$$\mathcal{L}_{VVP} = \frac{G'}{\sqrt{2}}\epsilon^{\mu\nu\alpha\beta}\langle \partial_\mu V_\nu \partial_\alpha V_\alpha P\rangle \Longrightarrow t_{VVP} = AG'\epsilon^{\alpha\beta\gamma\delta}(P-q)_\alpha \epsilon_{2\,\beta} k_\gamma \epsilon_{(f)\,\delta}\,, \tag{10}$$

$$\mathcal{L}_{PPV} = -ig\langle V^\mu [P, \partial_\mu P]\rangle \Longrightarrow t_{PPV} = g\, P_V \epsilon_1^\mu (2(P-k)-q)_\mu\,. \tag{11}$$

Decays of double charm states to $D_{(s)}D^*_{(s)}$

$$-it^{ij} = -\frac{1}{2}AIV_3 g_R G' g \int \frac{d^4q}{(2\pi)^4} \frac{q_\alpha (P-k)_\gamma}{(q^2-m_1^2)((P-q)^2-m_2^2)((k+q-P)^2-M_l^2)}$$
$$\times\{\epsilon_{(f)\,\delta}((2k+q-P)^j \epsilon^{\alpha i\gamma\delta} - (2k+q-P)^i \epsilon^{\alpha j\gamma\delta}$$
$$-(k+P)_\delta(\epsilon^{\alpha i\gamma\delta}\epsilon^j_{(f)} - \epsilon^{\alpha j\gamma\delta}\epsilon^i_{(f)})$$
$$+(2(P-q)-k)_\mu \epsilon^\mu_{(f)}(\epsilon^{\alpha i\gamma j} - \epsilon^{\alpha j\gamma i})\} \qquad (12)$$

- The integral is logarithmically divergent.
- We take a Feynmann parametrization for the convergent part:

$$\frac{1}{abc} = 2\int_0^1 dx \int_0^x dy \frac{1}{(a+(b-a)x+(c-b)y)^3}$$

$$a = q^2 - m_1^2; \quad b = (P-q)^2 - m_2^2; \quad c = (P-q-k)^2 - M_l^2 \ .$$

With a change of variable $q' = q - px + ky$.

- The second term is proportional to $k_\gamma P_\delta P_\alpha \epsilon^{\alpha i\gamma\delta}$ or $k_\gamma P_\delta k_\alpha \epsilon^{\alpha i\gamma\delta}$
$-2\int_0^1 dx \int_0^x dy \int \frac{d^4q}{(2\pi)^4} \frac{(q'+px-ky)_\alpha}{(q'^2+s(M_l))^3} 2k_\gamma P_\delta(\epsilon^{\alpha i\gamma\delta}\epsilon^j_f - \epsilon^{\alpha j\gamma\delta}\epsilon^i_f) = 0$

Decays of double charm states to $D_{(s)}D^*_{(s)}$

- First and third terms:

$$\int \frac{d^4q}{(2\pi)^4} \frac{q_\alpha(2k+q-P)_j}{(q^2-m_1^2)((P-q)^2-m_2^2)((k+q-P)^2-M_l^2)} = i(aP_\alpha P_j + bP_\alpha k_j + ck_\alpha P_j + dk_\alpha k_j + eg_{\alpha j}) \quad (13)$$

$$\int \frac{d^4q}{(2\pi)^4} \frac{q_\alpha(2(P-q)-k)_\mu}{(q^2-m_1^2)((P-q)^2-m_2^2)((k+q-P)^2-M_l^2)} = i(AP_\alpha P_\mu + BP_\alpha k_\mu + Ck_\alpha P_\mu + Dk_\alpha k_\mu + Eg_{\alpha\mu}) \quad (14)$$

Log. divergent term:

$$\int \frac{d^4q}{(2\pi)^4} \frac{q_\alpha q_\mu}{(q^2-m_1^2)((P-q)^2-m_2^2)((k+q-P)^2-M_l^2)} = i(A_1P_\alpha P_\mu + B_1P_\alpha k_\mu + C_1k_\alpha P_\mu + D_1k_\alpha k_\mu + E_1g_{\alpha\mu})$$

- For $\alpha = 0; \mu = 0$, $i(A_1P_0^2 + B_1P_0k_0 + C_1k_0P_0 + E_1)$
- For $\alpha = 0; \mu = 3$, $i(B_1P_0k_3)$, $\alpha = 3; \mu = 0$, $i(C_1P_3k_0)$
- For $\alpha = 3; \mu = 3$, $i(-E_1)$

$B_1 = C_1; D_1k^\mu\epsilon_\mu = 0$; $P_j = 0$ (z axes in the direction of $\vec{k}$)

Decays of double charm states to $D_{(s)}D^*_{(s)}$

Perform integral in q^0 and use a cutoff in momenta $q_{\rm max} = 750$ MeV to get the dynamically generated states $R_c(3970)$ and $S_c(4100)$ MeV

$$b = \frac{1}{16\pi^2}\int_0^1 dx \int_0^x dy \frac{(2-y)x}{s(M_l)+i\epsilon} \qquad d = \frac{1}{16\pi^2}\int_0^1 dx \int_0^x dy \frac{(y-2)y}{s(M_l)+i\epsilon} \qquad e = E_1(M_l) \tag{15}$$

$$A = \frac{1}{P_0^2}\{\frac{2i}{(2\pi)^3} f_1(P,k,M_l) + \frac{1}{8\pi^2}\int_0^1 dx \int_0^x dy \frac{k_3^2 y^2 + k_0^2 y^2 - 2P_0 k_0 xy + xP_0^2}{s(M_l)+i\epsilon}\}$$

$$C = \frac{1}{8\pi^2}\int_0^1 dx \int_0^x dy \frac{(x-1)y}{s(M_l)+i\epsilon} \qquad E = -2E_1(M_l)$$

$$E_1 = \frac{i}{(2\pi)^3} f(P,k,M_l) + \frac{k_3^2}{16\pi^2}\int_0^1 dx \int_0^x dy \frac{y^2}{s(M_l)+i\epsilon}\ . \tag{16}$$

$$f(P,k,M_l) = \int \frac{dq^0\, d\cos\theta\, dq q^4 \cos^2\theta}{(q^2-m_1^2+i\epsilon)((P-q)^2-m_2^2+i\epsilon)((k+q-P)^2-M_l^2+i\epsilon)}$$

$$f_1(P,k,M_l) = \int \frac{dq^0\, d\cos\theta\, dq q^2 (q_0^2 + q^2\cos^2\theta)}{(q^2-m_1^2+i\epsilon)((P-q)^2-m_2^2+i\epsilon)((k+q-P)^2-M_l^2+i\epsilon)} \tag{17}$$

Decays of double charm states to $D_{(s)}D^*_{(s)}$

Amplitud including pseudoscalar and vector meson exchange

$$t_1^{ij} = \quad g g_X G' \epsilon_{(f)\,\delta}\{\mathcal{H} P_\alpha k_\gamma (k^i \epsilon^{\alpha j\gamma\delta} - k^j \epsilon^{\alpha i\gamma\delta}) + (\mathcal{I} k_\gamma + \mathcal{J} P_\gamma)\epsilon^{ij\gamma\delta} + \mathcal{F} P_\gamma k_\alpha P^\delta \epsilon^{ij\gamma\alpha}\} \tag{18}$$

$\mathcal{H} = (\sum_{\rm diag}(C_V H - \frac{1}{2} C_P \tilde{B}))$, $\mathcal{I} = (\sum_{\rm diag}(3e(M_l)C_V - e(m_l)C_P))$, $\mathcal{J} = -\sum_{\rm diag} 3e(M_l)C_V$,
$\mathcal{F} = (\sum_{\rm diag} C_V F)$, and $C_V = AIV_3$, $C_P = AIP_V$. $H = (b+d)/2$, $\tilde{B} = \frac{1}{16\pi^2}\int_0^1 dx \int_0^x dy \frac{(x-1)(2-y)}{s(m_l)+i\epsilon}$

$$\Gamma_{R_{cc}\to DD^*_{(s)}} = \frac{1}{2J+1}\frac{|\vec{k}|\sum_\delta |t_1|^2}{8\pi M^2_{R_{cc}}} \,. \tag{19}$$

with

$$\sum_\delta |t_1|^2 = g^2 g_X^2 G'^2 (r_1|\vec{k}|^4 + r_2|\vec{k}|^2 + r_3) \tag{20}$$

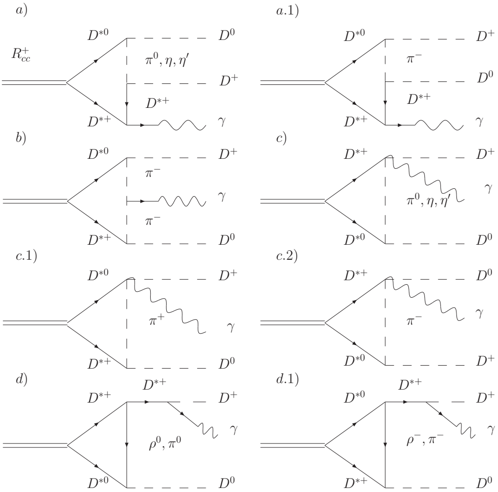


Figure: diagrams for the $R_{cc}^+ \to D^0 D^+ \gamma$ decay through one loop.

Decays into $DD^*\gamma$

$$\Gamma = \frac{1}{64 M_X \pi^3 (2J+1)} \int_{E_{1\,\min}}^{E_{1\,\max}} dE_1 \int_{E_{\gamma\,\min}}^{E_{\gamma\,\max}} dE_\gamma\, \theta(1-\cos^2\theta) \sum_{\lambda_{\rm in},\lambda_{\rm fn}} |t_2|^2$$

being $\cos\theta$ the angle between p_1 and k.

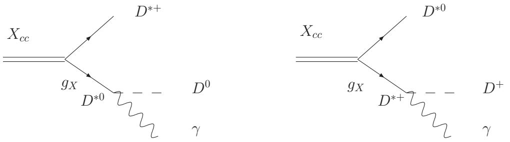


Figure: Decay of the doubly charm states into $D^* D_{(s)}\gamma$

$$\Gamma = \frac{1}{32\, M_R \pi^3} \int \frac{\tilde{p}_2 p_1}{\sqrt{s}} \frac{1}{2J+1} \sum_\delta |t_3|^2 dM_{D\gamma} \qquad (21)$$

$$\sum |t_3|^2 = -\frac{C'^2 I^2 g_R^2 G'^2 e^2}{\ldots} \left(\frac{M_{D\gamma}^2 - m_D^2}{\ldots} \right)^2 \qquad (22)$$

Results

State	*Channel i*	Γ^i [MeV]	*Channel j*	Γ^i_j [MeV]	$\Gamma_{\rm tot}$ [MeV]
$R^+_{cc}(3970)$	$D^0 D^{*+}$	22 ± 6	$D^0(D^+\pi^0)$	7 ± 2	44 ± 12
			$D^0(D^0\pi^+)$	15 ± 4	
			$D^0(D^+\gamma)$	0.4 ± 0.2	
	$D^+ D^{*0}$	22 ± 6	$D^+(D^0\pi^0)$	14 ± 4	
			$D^+(D^0\gamma)$	8 ± 2	
	$D^0 D^+ \gamma$	$(2 \pm 1) \times 10^{-3}$			
	$D^{*0} D^+ \gamma$	$(0.03 \pm 0.01) \times 10^{-3}$			
	$D^{*+} D^0 \gamma$	$(0.5 \pm 0.2) \times 10^{-3}$			

Table: Total and partial decay widths of the different decay modes of the doubly charm states.

Results

State	*Channel i*	Γ^i [MeV]	*Channel j*	Γ^i_j [MeV]	$\Gamma_{\rm tot}$ [MeV]
$S_{cc}^{+}(4100)$	$D^0 D_s^{*+}$	12 ± 4	$D^0(D_s^+\gamma)$	11 ± 4	24 ± 8
	$D_s^+ D^{*0}$	12 ± 4	$D_s^+(D^0\pi^0)$	7 ± 2	
			$D_s^+(D^0\gamma)$	5 ± 2	
	$D^0 D_s^+\gamma$	$(2 \pm 1) \times 10^{-3}$			
	$D^{*0} D_s^+\gamma$	$(0.3 \pm 0.1) \times 10^{-3}$			
	$D_s^{*+} D^0\gamma$	$(4 \pm 1) \times 10^{-3}$			
$S_{cc}^{++}(4100)$	$D^+ D_s^{*+}$	12 ± 4	$D^+(D_s^+\gamma)$	11 ± 4	24 ± 8
	$D_s^+ D^{*+}$	12 ± 4	$D_s^+(D^+\pi^0)$	4 ± 1	
			$D_s^+(D^0\pi^+)$	8 ± 3	
			$D_s^+(D^+\gamma)$	0.2 ± 0.1	
	$D^+ D_s^+\gamma$	$(1.3 \pm 0.1) \times 10^{-4}$			
	$D^{*+} D_s^+\gamma$	$(0.3 \pm 0.1) \times 10^{-3}$			
	$D_s^{*+} D^+\gamma$	$(0.3 \pm 0.1) \times 10^{-3}$			

Table: Total and partial decay widths of the different decay modes of the doubly charm states.

Results

State	*Intermediate meson*	Γ_k [MeV]
$R_{cc}^{+}(3970)$	ρ	15.2
$(D^{*0}D^{+})$	π	7.2
$(\Gamma = 22\,\mathrm{MeV})$	ω	1.7
	J/ψ	0.6
	η	0.14
	η_c	0.07
	η'	0.018
	$\rho + \pi$	30.0
	$\rho + \omega$	7.0
	$\pi + \omega$	6.0

Table: Decay width obtained for the channel DD^* and one meson exchanged.

State	*Intermediate meson*	Γ_k [MeV]
$S_{cc}^{+(+)}(4100)$	K^*	15.0
$(D^{*0(+)}D_s^{+})$	K	4.3
$(\Gamma = 12\,\mathrm{MeV})$	J/ψ	1.7
	η	0.4
	η'	0.2
	η_c	0.19
	$K^* + K$	24.9
	$K^* + J/\psi$	9.8
	$J/\psi + K$	4.2

Table: Decay width obtained for the channel DD_s^* and one meson exchanged.

Conclusions

1. The double charm mesons are dynamically generated by the $D^* D^*$ and $D^* D_s^*$ interaction
2. They are rather narrow: widths around $30 - 55$ and $15 - 35$ MeV respectively
3. They decay in DD^* and DD_s^* becoming $DD_{(s)}\pi$ and $DD_{(s)}\gamma$
4. Hopefully, will be able to observe in JPARC or LHCb

The hidden gauge formalism

Starting from a nonlinear sigma model based on

$G/H = SU(2)_L \otimes SU(2)_R / SU(2)_V$: Bando,Kugo,Yamawaki

$$L = (f_\pi^2/4)\mathrm{Tr}(\partial_\mu U \partial^\mu U^\dagger) \; , \qquad U(x) = \exp[2i\pi(x)/f_\pi] \tag{24}$$

and introduce new variables ξ_L, ξ_R and the field V_μ:

$$U(x) \equiv \xi_L^\dagger(x)\xi_R(x) \; , \; V_\mu = (1/2i)(\partial_\mu \xi_L \cdot \xi_L^\dagger + \partial_\mu \xi_R \cdot \xi_R^\dagger) \tag{25}$$

Any linear combination $L = L_A + aL_V$ of the invariants:

$$L_V = -\frac{f_\pi^2}{4} Tr(D_\mu \xi_L \cdot \xi_L^\dagger + D_\mu \xi_R \cdot \xi_R^\dagger)^2 \quad L_A = -\frac{f_\pi^2}{4} Tr(D_\mu \xi_L \cdot \xi_L^\dagger - D_\mu \xi_R \cdot \xi_R^\dagger)^2$$

is equivalent to the original one. A kinetic term is added, $-(1/4g^2)(V_{\mu\nu})^2$, and choosing $a = 2$ it is obtained

- 1)$m_\rho^2 = 2g_{\rho\pi\pi}^2 f_\pi^2$ (KSFR relation)
- 2)ρ dominance of the electromagnetic form factor of pions $(gV_\mu(\pi \times \partial^\mu \pi))$

And, fixing the gauge $\xi_L^\dagger = \xi_R \equiv \xi$ the Lagrangian becomes in the Weinberg's Lagrangian (nonlinear realization of the chiral symmetry)

Radiative decays of the XYZ

	T. Branz			Present work		
state	$D^*\bar{D}^*$		$D_s^*\bar{D}_s^*$	$D^*\bar{D}^*$		$D_s^*\bar{D}_s^*$
J^{PC}	0^{++}	2^{++}	2^{++}	0^{++}	2^{++}	2^{++}
$\Gamma_{\gamma\gamma}$ [KeV]	0.33	0.27	0.50	0.031	0.059	0.25
$\Gamma_{\omega J/\psi}$ [MeV]	5.47	7.48		1.52	8.66	12.02
$\Gamma_{\gamma\gamma}\mathcal{B}(X \to \omega J/\psi)$ [eV]	54.7	69.6		1.46	17.6	
$\Gamma_{\gamma\gamma}^{\rm exp}\mathcal{B}(X \to \omega J/\psi)$ [eV]	61	18		61	18	

Table: Comparison with the work of T. Branz and the experiment. To evaluate the branching ratios we have used the experimental central

3. To compensate with the large experimental value of the coupling constant, $g^{\mathrm{exp}}_{D^* D\pi} = 8.95$ (CLEO) (6.3 for us) we use different form factors in the $D^* D\pi$ vertex (Model B):

- Model A:

$$F_1(q^2) = \frac{\Lambda_b^2 - m_\pi^2}{\Lambda_b^2 - q^2}, \tag{26}$$

Titov, Kampfer EPJA7, PRC65

with $\Lambda_b = 1.4, 1.5$ GeV and $g = M_\rho / 2 f_\pi$.

- Model B:

$$F_2(q^2) = e^{q^2/\Lambda^2}\ , \tag{27}$$

Navarra, Nielsen, Bracco PRD65 (2002)

with $\Lambda = 1, 1.2$ GeV and $g_D = g^{\mathrm{exp}}_{D^* D\pi} = 8.95$ (experimental value)

Heavy quark spin symmetry?

In our model we can build the matrices for $I = 0, J = 0$: $T^{(0)}$ with $T^{(0)}_{11} = t(D\bar{D} \to D\bar{D})$, $T^{(0)}_{12} = t(D\bar{D} \to D^*\bar{D}^*)$ and $T^{(0)}_{22} = t(D^*\bar{D}^* \to D^*\bar{D}^*)$,

$$\begin{pmatrix} -\frac{2g^2}{m_\rho^2}(s-u) & \text{int. pseudos.} \\ \text{int. pseudos.} & -\frac{2g^2}{m_\rho^2}(s-u) \end{pmatrix} \tag{28}$$

where $t(D^*(q_1)\bar{D}^*(q_2) \to D(q_3)\bar{D}(q_4)) \sim \frac{g^2}{q^2-m_\pi^2}\epsilon_1^\mu q_{3\mu}\epsilon_2^\nu q_{4\nu}$.
Close to the threshold, $\epsilon_1^\mu q_{3\mu} \sim -\epsilon_1^i q_3^i$, and in the c.m. frame,

$$t(D^*\bar{D}^* \to D\bar{D}) \sim \frac{g^2 q_{3,z}^2}{m_D^2 - m_{D^*}^2 - m_\pi^2} \sim \frac{g^2(m_{D^*}^2 - m_D^2)}{m_D^2 - m_{D^*}^2 - m_\pi^2} \sim g^2 \tag{29}$$

There's a cancellation between the box and the contact term and our potential for $\rho(\omega,\phi)$ exchange corresponds to $C_{0b} = 0$ of the HHChPT Lagrangian