Interpretation of $D_{sJ}^{*}(2317)$ and $D_{sJ}(2460)$

OUTLINE

Spectroscopy of mesons containing a single heavy quark

Experimental evidences of charmed states

Evaluation of strong and radiative widths

Predictions in the beauty sector

Based on a work in collaboration with P. Colangelo (Bari)

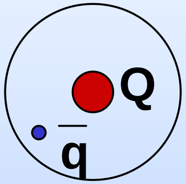
Rossella Ferrandes
Bari University

Torino IFAE, 14 April 2004

Hadrons containing a single heavy quark Q

In the infinite heavy quark mass limit, the heavy quark spin S_Q and the light degrees of freedom angular momentum S_l decouple

↓



$Q\bar{q}$ mesons are classified in doublets labeled by S_l^P:

$$L=0 \quad s_l^P=\frac{1}{2}^- \quad \begin{cases} J^P=0^- & D^0,\ D^+,\ D_s \\ J^P=1^- & D^{*0},\ D^{*+},\ D_s^* \end{cases}$$

$$L=1 \quad \begin{cases} s_l^P=\frac{1}{2}^+ & \begin{cases} J^P=0^+ & D_0^{*0},\ D_0^{*+},\ D_s^* \\ J^P=1^+ & D'^0_1,\ D'^+_1,\ D'_{s1} \end{cases} \\ s_l^P=\frac{3}{2}^+ & \begin{cases} J^P=1^+ & D_1^0,\ D_1^+,\ D_{s1} \\ J^P=2^+ & D_2^{*0},\ D_2^{*+},\ D_{s2}^* \end{cases} \end{cases}$$

$$\left(\begin{array}{l} J = S_l + S_Q \\ S_l = S_q + L \end{array} \right)$$

States differing for the heavy quark spin orientation are degenerate in mass.

Strong decays

$$\Gamma \sim |\bar{p}|^{2L+1}$$

$$(0^+)_{\frac{1}{2}^+} \to (0^-)_{\frac{1}{2}^-} 0^-$$

$$(1^+)_{\frac{1}{2}^+} \to (1^-)_{\frac{1}{2}^-} 0^-$$

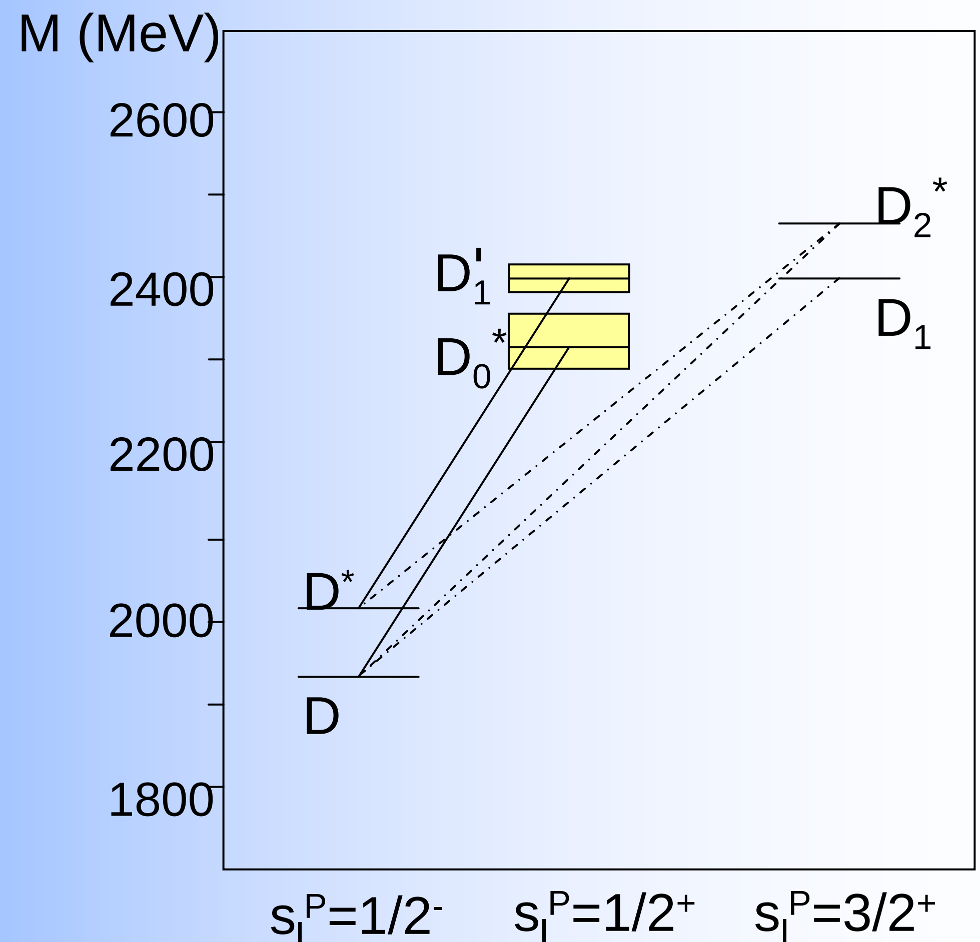
s-wave decays

$$(1^+)_{\frac{3}{2}^+} \to (1^-)_{\frac{1}{2}^-} 0^-$$

$$(2^+)_{\frac{3}{2}^+} \to (0^-)_{\frac{1}{2}^-} 0^-$$

$$(2^+)_{\frac{3}{2}^+} \to (1^-)_{\frac{1}{2}^-} 0^-$$

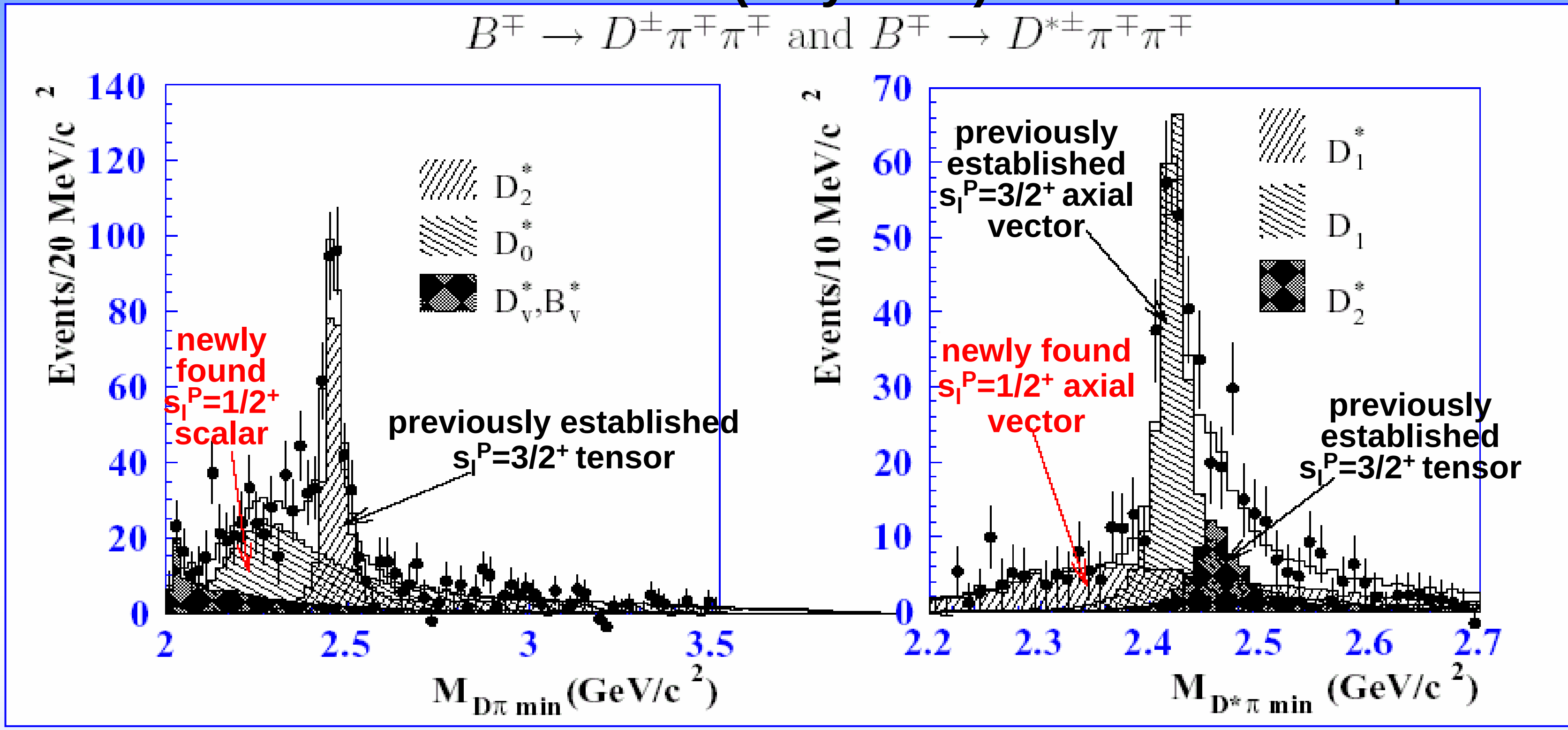
d-wave decays



EXPERIMENTAL OBSERVATIONS OF STATES CONTAINING A CHARM QUARK

Belle (July 2003)

arXiv:hep ex/0307021



	M [MeV/c²]	Γ [MeV/c²]
D_0^*	2308 ± 17 ± 15 ± 28	276 ± 21 ± 18 ± 60
$D_1'^0$	2427 ± 26 ± 20 ± 15	384 $^{+107}_{-75}$ ± 24 ± 70
D_1^0	2421.4 ± 1.5 ± 0.4 ± 0.8	23.7 ± 2.7 ± 0.2 ± 4.0
D_2^{*0}	2461.6 ± 2.1 ± 0.5 ± 3.3	45.6 ± 4.4 ± 6.5 ± 1.6

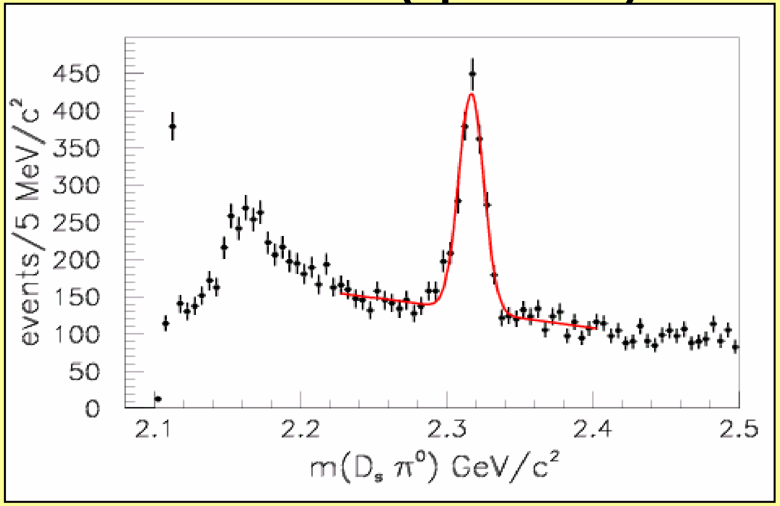
Broad states

Recently confirmed by FOCUS PL**B** 586,11 (2004)

Discovery of narrow resonance $D_{sJ}^*(2317)$ in the $D_s\pi^0$ system

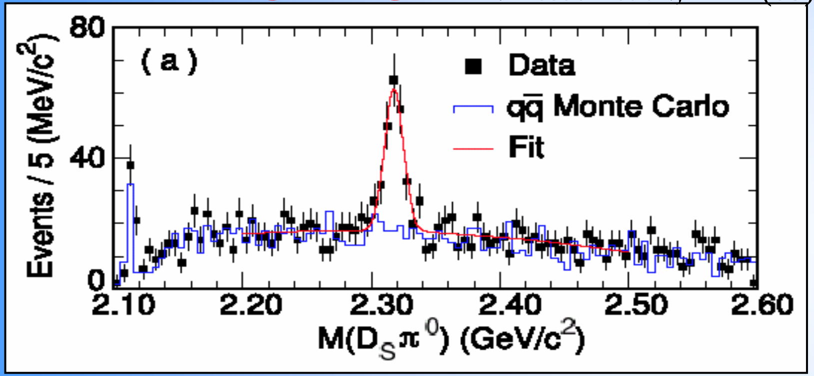
B. Aubert et al., PRL (03)

BaBar (april 2003)



CLEO

D. Besson et al., PRD (03)

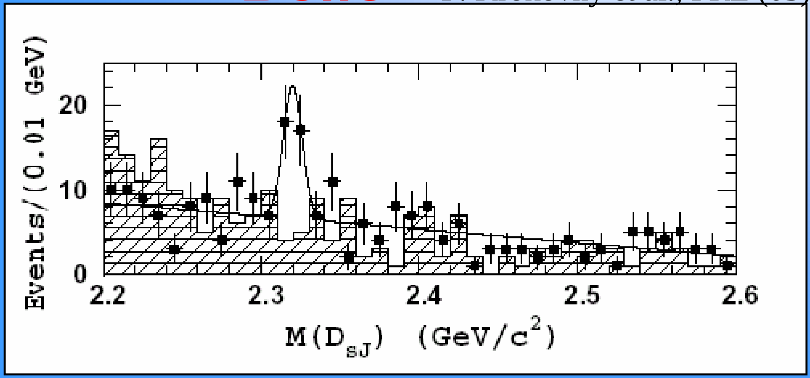


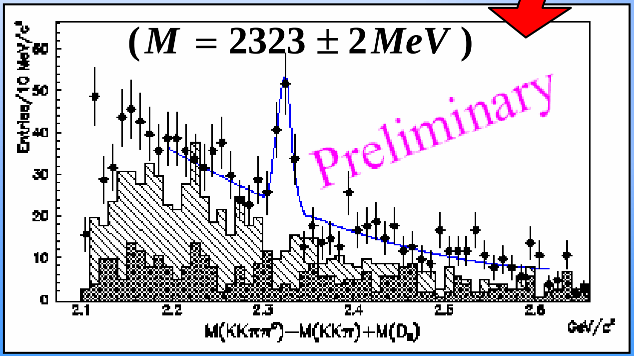
	mass (MeV/c^2)	width (MeV/c^2)
BaBar	$2317.3 \pm 0.4 \pm 0.8$	<10
Belle	$2317.2 \pm 0.5 \pm 0.9$	<4.6
CLEO	$2318.5 \pm 1.2 \pm 1.1$	<7

narrow width

Belle

P. Krokovny et al., PRL (03)



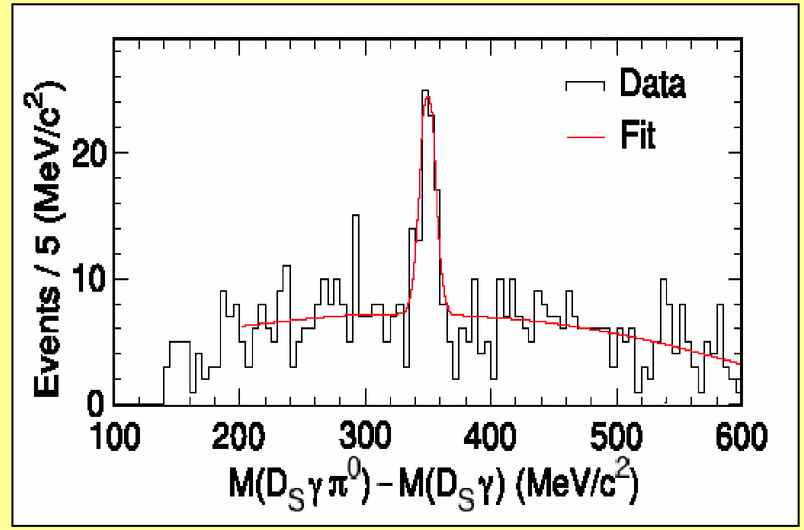


Recently confirmed by FOCUS

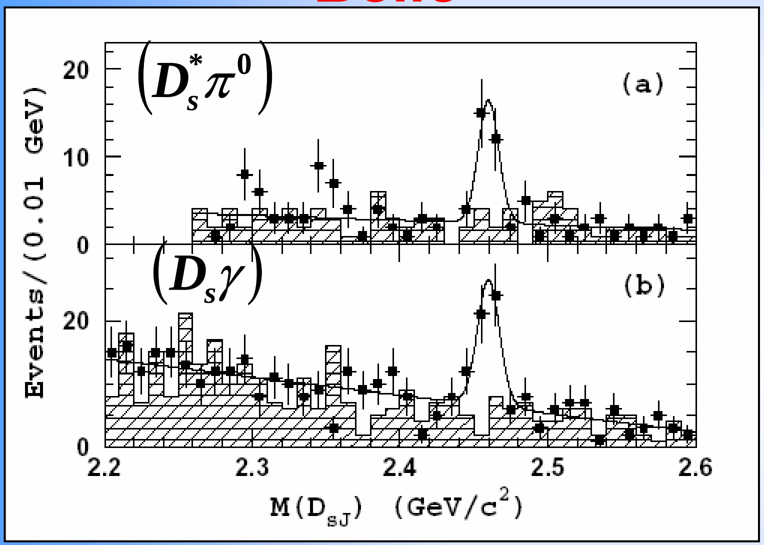
E. W. Vaandering, XXXIX Rencontres de Moriond (04)

Discovery of narrow resonance $D_{sJ}'(2460)$ in the $D_s^* \pi^0$ system

CLEO (may 2003)

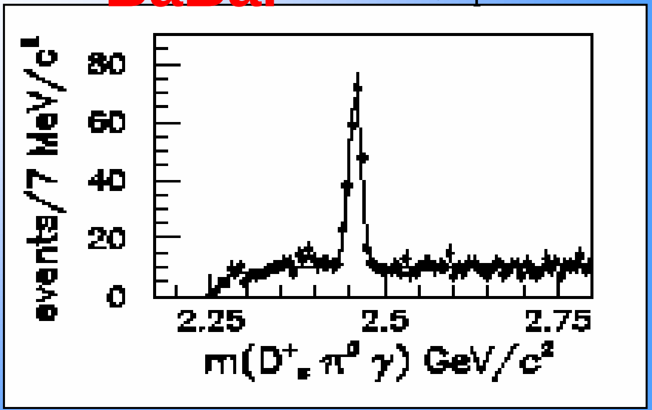


Belle



BaBar

arXiv:hep-ex/0310050



	mass (MeV/c^2)	width (MeV/c^2)
BaBar	$2458.0 \pm 1.0 \pm 1.0$	<10
Belle	$2456.5 \pm 1.3 \pm 1.3$	<5.5
CLEO	$2463.6 \pm 1.7 \pm 1.2$	<7

narrow width

widths

meson	width (MeV)
D_0^{*0}	$276 \pm 21 \pm 18 \pm 60$ (Belle)[21]
$D_{sJ}^*(2317)$	< 10 (BaBar) < 4.6 (Belle)[15] < 7 (CLEO)
$D_1^{\prime 0}$	$384^{+107}_{-75} \pm 24 \pm 70$ (Belle)[21]
$D_{sJ}^*(2460)$	< 10 (BaBar) < 5.5 (Belle)[15] < 7 (CLEO)
D_1^0	$23.7 \pm 2.7 \pm 0.2 \pm 4.0$ (Belle)[21] $18.9^{+4.6}_{-3.5}$ (PDG)
$D_{s1}(2536)$	< 2.3 (PDG)
D_2^{*0}	$45.6 \pm 4.4 \pm 6.5 \pm 1.6$ (Belle)[21] $38.7 \pm 5.3 \pm 2.9$ (FOCUS) 23 ± 5 (PDG)
D_2^{*+}	$34.1 \pm 6.5 \pm 4.2$ (FOCUS) 25^{+8}_{-7} (PDG)
$D_{sJ}^*(2573)$	15^{+5}_{-4} (PDG)

ratios

	Belle	CLEO
$\frac{\Gamma(D_{s0}^* \to D_s^* \gamma)}{\Gamma(D_{s0}^* \to D_s \pi^0)}$	$(\star)$ < 0.9 < 0.18	< 0.059
$\frac{\Gamma(D_{s1}' \to D_s \gamma)}{\Gamma(D_{s1}' \to D_s^* \pi^0)}$	$(\star)$ 0.38 ± 0.19 $0.55 \pm 0.13 \pm 0.08$	< 0.49
$\frac{\Gamma(D_{s1}' \to D_s^* \gamma)}{\Gamma(D_{s1}' \to D_s^* \pi^0)}$	$(\star)$ < 0.4 < 0.31	< 0.16
$\frac{\Gamma(D_{s1}' \to D_s^* \gamma)}{\Gamma(D_{s1}' \to D_s \gamma)}$	$(\star)$ < 1.1	

Spin-parity assignment for $D_{sJ}^*(2317)$

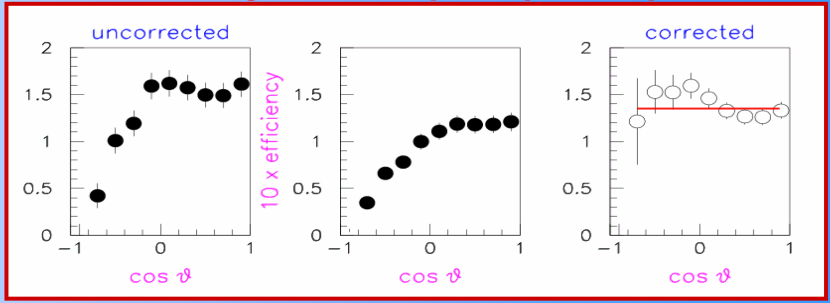
observation of $D_s\pi^0$ decay → natural spin-parity: 0^+, 1^-, 2^+...

$D_s\gamma$ decay not observed → 1^- assignment not favoured

BaBar angular analysis consistent with J=0

These arguments support $J^P=0^+$ assignment

angular analysis (BaBar)



Spin-parity assignment for $D_{sJ}(2460)$

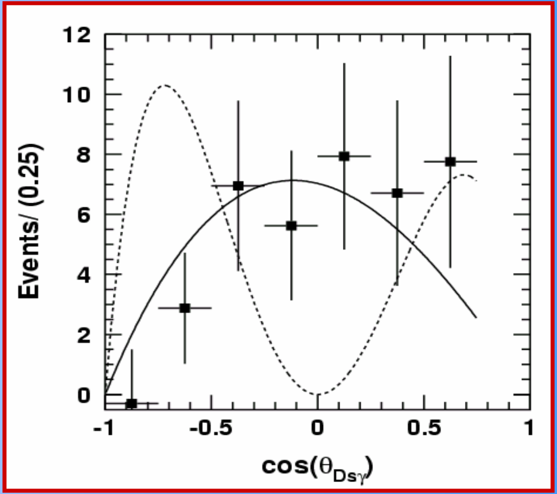
observation of $D_s^*\pi^0$ decay → spin-parity: 0^-, 1^+, 2^-...

observation of $D_s\gamma$ decay → J=0 assignment ruled out

Belle angular analysis consistent with J=1

These arguments support $J^P=1^+$ assignment

helicity distribution (Belle)



INTERPRETATIONS

For $s_l^P = 1/2^+$ strange states potential models typically predict masses larger than the experimental values, above the DK and D*K thresholds

So $s_l^P = 1/2^+$ states were expected to have large widths

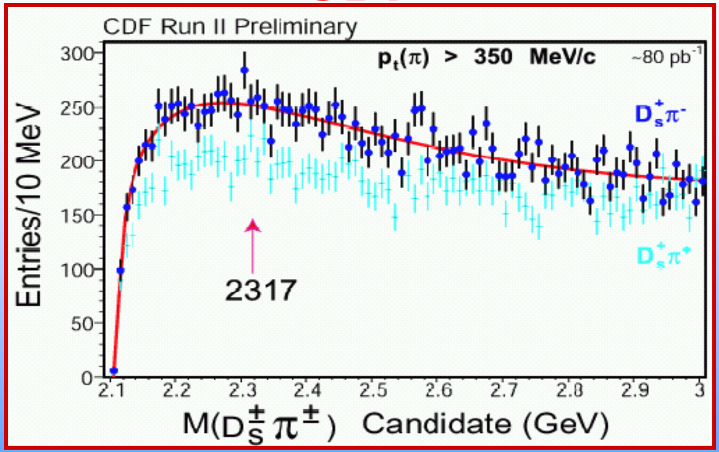
In the canonical interpretation as $c\bar{s}$ states, the experimental resonances are narrow because of isospin violation.

Different interpretations:

- 4-quark state (H. Y. Cheng et al. 03)
- DK molecule (Barnes, Close, Lipkin 03)
- $D_s\pi$ atom (Szczepaniak 03)
- …

CDF looks for isospin partners in $D_s^+\pi^-$ and $D_s^+\pi^+$ systems.

CDF



To identify the experimental resonances with $c\bar{q}$ states of $S_l^P=1/2^+$ doublet we must

- calculate strong widths
- calculate radiative widths

obtaining

- for non strange states:
  large widths $(\sim 100\ MeV)$

- for strange states:
  - width < experimental resolution
  - $\frac{\Gamma_{e.m.}}{\Gamma_{strong}}$ according to experimental values

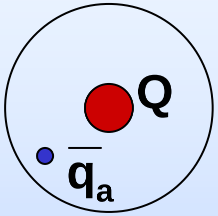
Effective lagrangian describing interactions between heavy mesons and pseudoscalar light mesons

based on
- heavy quark spin-flavour symmetry
- chiral symmetry for light mesons

$$H_a = \frac{1+\not{v}}{2}\left[P_{a\mu}\gamma^{\mu} - P_a\gamma_5\right]$$

$$S_a = \frac{1+\not{v}}{2}\left[P^{\mu}_{1a}\gamma_{\mu}\gamma_5 - P_{0a}\right]$$

$$T^{\mu}_a = \frac{1+\not{v}}{2}\left[D^{\mu\nu}_{2a}\gamma_{\nu} - \sqrt{\frac{3}{2}}D_{1a\nu}\gamma_5\left(g^{\mu\nu} - \frac{1}{3}\gamma^{\nu}(\gamma^{\mu} - v^{\mu})\right)\right]$$



$$\xi = \exp\left[\frac{i\pi_a T^a}{f}\right] \qquad A_{\mu} = \frac{1}{2}\left(\xi^{+}\partial_{\mu}\xi - \xi\partial_{\mu}\xi^{+}\right)$$

$$\pi_a T^a = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^{+} & K^{+} \\ \pi^{-} & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & K^0 \\ K^{-} & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

$$L_{eff} = igTr\left\{\overline{H}_a H_b \gamma_{\mu}\gamma_5 A^{\mu}_{ba}\right\} + \quad \Longleftrightarrow \quad \left(\frac{1}{2}^{-}\right) \rightarrow \left(\frac{1}{2}^{-}\right) + 0^{-}$$

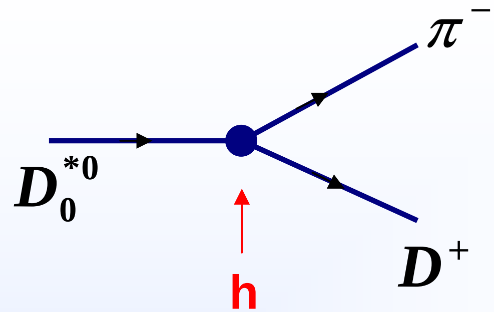
$$+ ihTr\left\{S_b \gamma_{\mu}\gamma_5 A^{\mu}_{ba}\overline{H}_a\right\} + h.c. + \quad \Longleftrightarrow \quad \left(\frac{1}{2}^{+}\right) \rightarrow \left(\frac{1}{2}^{-}\right) + 0^{-}$$

$$+ i\frac{h'}{\Lambda_{\chi}}Tr\left\{T^{\mu}_b \gamma_{\lambda}\gamma_5 (D_{\mu}A^{\lambda})_{ba}\overline{H}_a\right\} + h.c. + \quad \Longleftrightarrow \quad \left(\frac{3}{2}^{+}\right) \rightarrow \left(\frac{1}{2}^{-}\right) + 0^{-}$$

$$+ \ldots$$

Strong decays

Non strange states



$$D_0^{*0} \to D^+\pi^-$$

$$L_{eff} = ihTr\left\{S_1\gamma_\mu\gamma_5 A_{12}^\mu \overline{H}_2\right\}$$

$$|h| = 0.6 \pm 0.2$$ **(QCD sum rules)**

P. Colangelo et al., PRD (95)

$$\Gamma_{teor}\left(D_0^{*0} \to D^+\pi^-\right) = (200 \pm 40)MeV$$

Considering also $D^0\pi^0$ decay

$$\Gamma_{teor}\left(D_0^{*0}\right) = (300 \pm 60)MeV$$

Experimentally:

$$\Gamma_{sper}\left(D_0^{*0}\right) = (276 \pm 21 \pm 18 \pm 60)MeV$$

Analogously for the axial state:

$$\Gamma_{teor}\left(D'^0_1\right) = (264 \pm 45)MeV$$

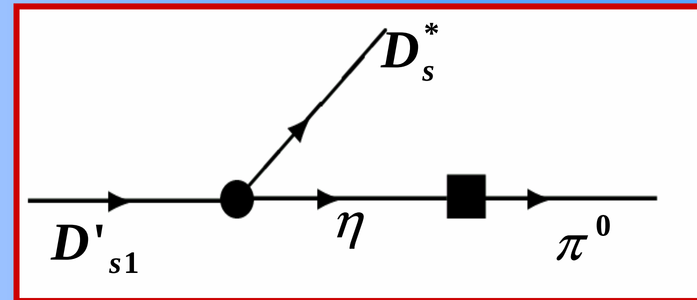
$$\Gamma_{sper}\left(D'^0_1\right) = (384\ ^{+107}_{-75} \pm 24 \pm 70)MeV$$

$$\left[\frac{\Gamma\left(D'^0_1\right)}{\Gamma\left(D_0^{*0}\right)}\right]_{teor} = 0.9 \pm 0.3 \qquad \left[\frac{\Gamma\left(D'^0_1\right)}{\Gamma\left(D_0^{*0}\right)}\right]_{sper} = 1.4 \pm 0.5$$

Strange states

$$D^*_{s0} \to D_s \pi^0$$
$$D'_{s1} \to D^*_s \pi^0$$

Isospin violating decays



$$L_{eff} = \frac{f^2}{8} Tr\{\partial^\mu \Sigma^+ \partial_\mu \Sigma\} + \underline{vTr\{M^+\Sigma + M\Sigma^+\}} + \ldots$$

$\pi^0 - \eta$ **mixing**

$$\langle \pi^0 | \eta \rangle = -\frac{4v}{f^2} \frac{m_u - m_d}{\sqrt{3}}$$

$$\Sigma = \exp\left[\frac{2i\pi_a T^a}{f}\right]$$

$$\Gamma(D'_{s1} \to D^*_s \pi^0) = \frac{1}{16\pi} \frac{h^2}{f^2} \frac{M_{D^*_s}}{M_{D'_{s1}}} \left(m^2_{\pi^0} + |\vec{q}|^2\right) |\vec{q}| \left(\frac{m_u - m_d}{\frac{m_u + m_d}{2} - m_s} \right)^2 \frac{1}{3}\left(2 + \frac{\left(M^2_{D'_{s1}} + M^2_{D^*_s} - m^2_{\pi^0}\right)^2}{4 M^2_{D'_{s1}} M^2_{D^*_s}}\right)$$

$$\Gamma_{teor}(D'_{s1} \to D^*_s \pi^0) = (7 \pm 1) KeV$$

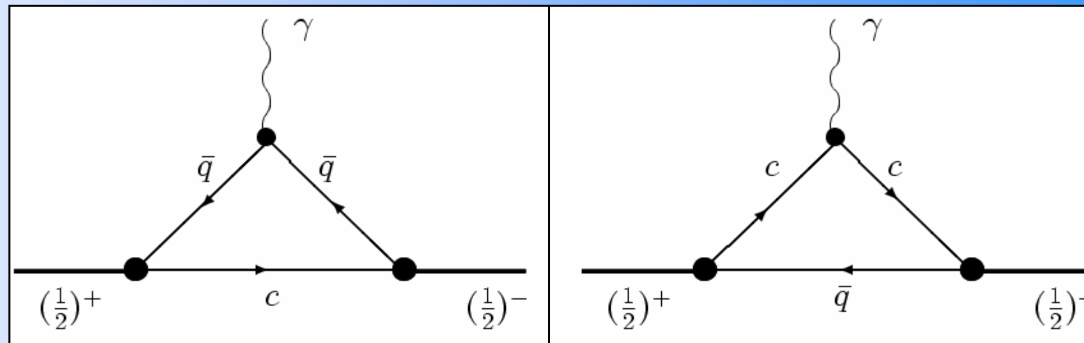
$$\frac{1}{43.7}$$

Gasser and Leutwyler, NPB (1985)

Analogously for the scalar state:

$$\Gamma_{teor}(D^*_{s0} \to D_s \pi^0) = (7 \pm 1) KeV$$

Radiative decays

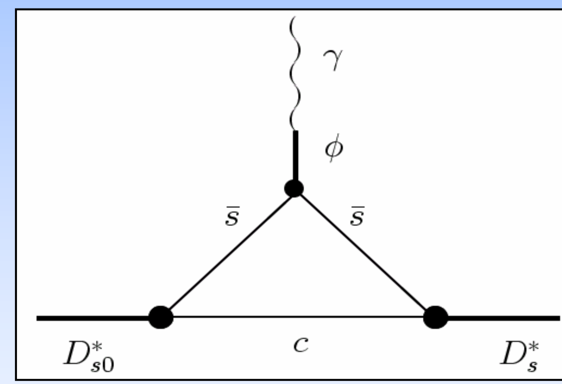


suppressed as $1/m_c$

$$\left\langle \left(\frac{1}{2}^-\right) \middle| \bar{q}\gamma^\mu q \middle| \left(\frac{1}{2}^+\right) \right\rangle \cong$$

$$\cong \left\langle \left(\frac{1}{2}^-\right) V(\eta^{(\lambda)}) \middle| \left(\frac{1}{2}^+\right) \right\rangle \frac{i}{q^2 - m_V^2} \left\langle 0 \middle| \bar{q}\gamma^\mu q \middle| V(\eta^{(\lambda)}) \right\rangle$$

VMD (Vector Meson Dominance)



$$L = i\mu Tr\left\{ \overline{S}_a H_b \sigma^{\lambda\nu} F_{\lambda\nu}(\rho)_{ba} \right\} + h.c.$$

$$\mu = -0.1 GeV^{-1}$$

Casalbuoni et al., Phys. Rept. (1997)

$$\Gamma(D'_{s1} \to D_s\gamma) = (3.3 \pm 0.6) KeV$$

$$\Gamma(D'_{s1} \to D^*_s\gamma) = 1.5 KeV$$

$$\Gamma(D^*_{s0} \to D^*_s\gamma) = (0.85 \pm 0.05) KeV$$

Summary of the results:

P. Colangelo et al., PL**B** (03)
P. Colangelo, R.F., in preparation

meson	experimental width (MeV)	evaluated width (MeV)
D_0^{*0}	$276 \pm 21 \pm 18 \pm 60$ (Belle)	300 ± 60
$D_{sJ}^*(2317)$	< 10 (BaBar) < 4.6 (Belle) < 7 (CLEO)	$(8 \pm 1) \times 10^{-3}$
$D_1^{\prime 0}$	$384^{+107}_{-75} \pm 24 \pm 70$ (Belle)	264 ± 45
$D_{sJ}^{\prime}(2460)$	< 10 (BaBar) < 5.5 (Belle) < 7 (CLEO)	$(12 \pm 1) \times 10^{-3}$

	Belle	CLEO	teoria
$\frac{\Gamma(D_{s0}^* \to D_s^* \gamma)}{\Gamma(D_{s0}^* \to D_s \pi^0)}$	($\star$) < 0.9 < 0.18	< 0.059	0.1
$\frac{\Gamma(D_{s1}^{\prime} \to D_s \gamma)}{\Gamma(D_{s1}^{\prime} \to D_s^* \pi^0)}$	($\star$) 0.38 ± 0.19 $0.55 \pm 0.13 \pm 0.08$	< 0.49	0.5
$\frac{\Gamma(D_{s1}^{\prime} \to D_s^* \gamma)}{\Gamma(D_{s1}^{\prime} \to D_s^* \pi^0)}$	($\star$) < 0.4 < 0.31	< 0.16	0.2
$\frac{\Gamma(D_{s1}^{\prime} \to D_s^* \gamma)}{\Gamma(D_{s1}^{\prime} \to D_s \gamma)}$	($\star$) < 1.1		0.4

Overall agreement with experiments supports our interpretation

Predictions for beauty mesons belonging to 1/2+ doublet

$$m_M = m_Q + \overline{\Lambda} + \frac{\Delta m_M^2}{2m_Q} + \ldots \qquad \Delta m_M^2 = -\lambda_1 + d_M \lambda_2$$

$\frac{1}{2}^-$ $$m_M = m_Q + \overline{\Lambda} - \frac{\lambda_1}{2m_Q} + d_M \frac{\lambda_2}{2m_Q}$$

M=P, V

kinetic energy — chromomagnetic interaction

$\frac{1}{2}^+$ $$m_M^* = m_Q + \overline{\Lambda}' - \frac{\lambda_1'}{2m_Q} + d_M \frac{\lambda_2'}{2m_Q}$$

M=S, A

$$S_Q \cdot S_l = \frac{1}{2}\left(J^2 - S_Q^2 - S_l^2\right) \Rightarrow d_{P,S} = -3, \quad d_{V,A} = 1$$

$$\tilde{m}^* = \frac{m_S + 3m_A}{4} = m_Q + \overline{\Lambda}' - \frac{\lambda'_1}{2m_Q}$$

← centre of mass of the doublet

$$\tilde{m}^*_{[b]} - \tilde{m}_{[b]} = \overline{\Lambda}' - \overline{\Lambda} - \frac{\lambda'_1 - \lambda_1}{2m_b}$$

$$\tilde{m}^*_{[c]} - \tilde{m}_{[c]} = \overline{\Lambda}' - \overline{\Lambda} - \frac{\lambda'_1 - \lambda_1}{2m_c}$$

$$\left(\frac{\lambda'_1 - \lambda_1}{2m_Q} \cong 0\right)$$

$$\tilde{m}^*_{[b]} = \tilde{m}_{[b]} + \tilde{m}^*_{[c]} - \tilde{m}_{[c]}$$

$$\tilde{m}^*_{[b]} = \tilde{m}_{[b]} + \tilde{m}^*_{[c]} - \tilde{m}_{[c]}$$

$$m(B'_{s1}) - m(B^*_{s0}) \cong \frac{m_c}{m_b}\left[m(D'_{s1}) - m(D^*_{s0})\right]$$

$\rightarrow$ $m(B^*_{s0}) = 5721\ MeV$

$m(B'_{s1}) = 5762\ MeV$

Analogously for non strange states: $\rightarrow$ $m(B^{*0}_0) = 5710\ MeV$

$m(B'^0_1) = 5744\ MeV$

$$m(B) + m(K) = 5.73\,GeV$$

$$m(B^*) + m(K) = 5.82\,GeV$$

$B^*_{s0} \not\rightarrow BK$

$B'_{s1} \not\rightarrow B^* K$

meson	mass (MeV/c²)	width (MeV/c²)
B_0^{*0}	5710	330 ± 24
B^*_{s0}	5721	$(10.5 \pm 0.5) \times 10^{-3}$
$B_1'^0$	5744	204 ± 14
B'_{s1}	5762	$(11 \pm 0.5) \times 10^{-3}$

$$\frac{\Gamma(B^*_{s0} \to B^*_s \gamma)}{\Gamma(B^*_{s0} \to B_s \pi^0)} = 0.4$$

$$\frac{\Gamma(B'_{s1} \to B_s \gamma)}{\Gamma(B'_{s1} \to B^*_s \pi^0)} = 0.3$$

$$\frac{\Gamma(B'_{s1} \to B^*_s \gamma)}{\Gamma(B'_{s1} \to B^*_s \pi^0)} = 0.3$$

$$\frac{\Gamma(B'_{s1} \to B^*_s \gamma)}{\Gamma(B'_{s1} \to B_s \gamma)} = 1$$

CONCLUSIONS

Charm sector

Strange states:

- **widths << experimental resolution**
- **strong widths ~ radiative widths**
- $\dfrac{\Gamma_{e.m.}}{\Gamma_{strong}}$ **according to experimental values**

Non strange states:

- **widths consistent with experimental measurements (~100 MeV)**

→ **Experimental measurements consistent with canonical interpretation**

Beauty sector

- **Predictions of masses and widths for beauty mesons belonging to $1/2^+$ doublet**

↓

$b\bar{s}$ states could be discovered analyzing LEP data

L	s_l^P	j^P	$c\bar{q}$ mesons	$\bar{b}q$ mesons
0	$\frac{1}{2}^-$	0^-	D^0, D^+, D_s^+	B^0, B^+, B_s^0
0	$\frac{1}{2}^-$	1^-	D^{*0}, D^{*+}, D_s^{*+}	B^{*0}, B^{*+}, B_s^{*0}
1	$\frac{1}{2}^+$	0^+	$D_0^{*0}, D_0^{*+}, D_{s0}^{*+}$	$B_0^{*0}, B_0^{*+}, B_{s0}^{*0}$
1	$\frac{1}{2}^+$	1^+	$D_1'^0, D_1'^+, D_{s1}'^+$	$B_1'^0, B_1'^+, B_{s1}'^0$
1	$\frac{3}{2}^+$	1^+	D_1^0, D_1^+, D_{s1}^+	B_1^0, B_1^+, B_{s1}^0
1	$\frac{3}{2}^+$	2^+	$D_2^{*0}, D_2^{*+}, D_{s2}^{*+}$	$B_2^{*0}, B_2^{*+}, B_{s2}^{*0}$

$$m\left(D^{*+}\right) - m\left(D^{+}\right) = 141\ MeV$$
$$m\left(D^{*0}\right) - m\left(D^{0}\right) = 142\ MeV$$
$$m\left(D_s^{*+}\right) - m\left(D_s^{+}\right) = 144\ MeV$$
$$m\left(B^{*0}\right) - m\left(B^{0}\right) = 46\ MeV$$
$$m\left(B_s^{*}\right) - m\left(B_s\right) = 47\ MeV$$

← **Mesons belonging to $s_l^P = \frac{1}{2}^-$ doublet**

Analogous situation for $\frac{1}{2}^+$ and $\frac{3}{2}^+$ doublets

experimental masses

$mesone\ c\bar{q}$	$massa\ (MeV)$	$mesone\ \bar{b}q$	$massa\ (MeV)$
D^+	1869.3 ± 0.5	B^+	5279.0 ± 0.5
D^0	1864.5 ± 0.5	B^0	5279.4 ± 0.5
D_s^+	1968.5 ± 0.6	B_s^0	5369.6 ± 2.4
D^{*+}	2010.0 ± 0.5	B^*	5325.0 ± 0.6
D^{*0}	2006.7 ± 0.5		
D_s^{*+}	2112.4 ± 0.7	B_s^*	5416.6 ± 3.5
D_0^{*0}	$(\star)\ 2308 \pm 17 \pm 15 \pm 28$		
$D_{sJ}^*(2317)$	$(\star\star)\ 2317.3 \pm 0.4 \pm 0.8$ $(\star)\ 2317.2 \pm 0.5 \pm 0.9$ $(\bullet)\ 2318.5 \pm 1.2 \pm 1.1$		
$D_1'^0$	$(\star)\ 2427 \pm 26 \pm 20 \pm 15$		
$D'_{sJ}(2460)$	$(\star\star)\ 2458.0 \pm 1.0 \pm 1.0$ $(\star)\ 2456.5 \pm 1.3 \pm 1.3$ $(\bullet)\ 2463.6 \pm 1.7 \pm 1.2$		
D_1^0	2422.2 ± 1.8 $(\star)\ 2421 \pm 1.5 \pm 0.4 \pm 0.8$		
$D'_{s1}(2536)$	$2535.35 \pm 0.34 \pm 0.5$		
D_2^{*+}	2459 ± 4 $(\bullet\bullet)\ 2467.6 \pm 1.5 \pm 0.76$		
D_2^{*0}	2458.9 ± 2.0 $(\star)\ 2462 \pm 2.1 \pm 0.5 \pm 3.3$ $(\bullet\bullet)\ 2464.5 \pm 1.1 \pm 1.9$		
$D'_{sJ}(2573)$	2572.4 ± 1.5		

large states

narrow states

$s_l^P = \frac{1}{2}^-$

$s_l^P = \frac{1}{2}^+$

$s_l^P = \frac{3}{2}^+$

Masse dei mesoni con un quark pesante charm o beauty. Con $(\star)$ sono indicati i valori misurati da Belle, con $(\star\star)$ quelli misurati da BaBar, con $(\bullet)$ sono indicati i valori di CLEO, e con $(\bullet\bullet)$ quelli di FOCUS; tutti gli altri valori sono quelli riportati sul PDG .

decay	$\mathcal{B}$, 10^{-4}
$B \to \overline{D} D_{sJ}^{*}(2317)$ $[D_s \pi^0]$	$8.5^{+2.1}_{-1.9} \pm 2.6$
$B \to \overline{D} D_{sJ}^{*}(2317)$ $[D_s^* \gamma]$	$2.5^{+2.0}_{-1.8}$ (< 7.5)
$B \to \overline{D} D'_{sJ}(2460)$ $[D_s^* \pi^0]$	$17.8^{+4.5}_{-3.9} \pm 5.3$
$B \to \overline{D} D'_{sJ}(2460)$ $[D_s \gamma]$	$6.7^{+1.3}_{-1.2} \pm 2.0$
$B \to \overline{D} D'_{sJ}(2460)$ $[D_s^* \gamma]$	$2.7^{+1.8}_{-1.5}$ (< 7.3)
$B \to \overline{D} D'_{sJ}(2460)$ $[D_s \pi^+ \pi^-]$	< 1.6
$B \to \overline{D} D'_{sJ}(2460)$ $[D_s \pi^0]$	< 1.8

$D_0^{*0} \to D^+\pi^-$

$$\Gamma_1 = \frac{1}{2\pi}\frac{h^2}{f^2}\frac{M_{D^+}}{M_{D_0^{*0}}}\left(m_{\pi^+}^2 + |\bar{q}|^2\right)|\bar{q}|$$

$$\Gamma_2 = \frac{1}{2\pi}\frac{h^2}{f^2}\frac{1}{M_{D_0^{*0}} M_{D^+}}(p\cdot q)^2|\bar{q}|$$

$D'^0_1 \to D^{*+}\pi^-$

$$\Gamma_1 = \frac{1}{2\pi}\frac{h^2}{f^2}\frac{M_{D^{*+}}}{M_{D'^0_1}}\left(m_{\pi^+}^2 + |\bar{q}|^2\right)|\bar{q}|\frac{1}{3}\left(2+\frac{\left(M_{D'^0_1}^2 + M_{D^{*+}}^2 - m_{\pi^+}^2\right)^2}{4M_{D'^0_1}^2 M_{D^{*+}}^2}\right)$$

$$\Gamma_2 = \frac{1}{2\pi}\frac{h^2}{f^2}\frac{1}{M_{D'^0_1} M_{D^{*+}}}(p\cdot q)^2|\bar{q}|\frac{1}{3}\left(2+\frac{\left(M_{D'^0_1}^2 + M_{D^{*+}}^2 - m_{\pi^+}^2\right)^2}{4M_{D'^0_1}^2 M_{D^{*+}}^2}\right)$$

$D_{s0}^{*} \to D_s \pi^0$

$$\Gamma_1 = \frac{1}{16\pi}\frac{h^2}{f^2}\frac{M_{D_s}}{M_{D_{s0}^*}}\left(m_{\pi^0}^2 + |\bar{q}|^2\right)|\bar{q}|\left(\frac{m_u - m_d}{\frac{m_u + m_d}{2} - m_s}\right)^2$$

$$\Gamma_1 = \frac{1}{16\pi}\frac{h^2}{f^2}\frac{1}{M_{D_{s0}^*} M_{D_s}}(p \cdot q)^2|\bar{q}|\left(\frac{m_u - m_d}{\frac{m_u + m_d}{2} - m_s}\right)^2$$

$D'_{s1} \to D_s^* \pi^0$

$$\Gamma_1 = \frac{1}{16\pi}\frac{h^2}{f^2}\frac{M_{D_s^*}}{M_{D'_{s1}}}\left(m_{\pi^0}^2 + |\bar{q}|^2\right)|\bar{q}|\left(\frac{m_u - m_d}{\frac{m_u + m_d}{2} - m_s}\right)^2 \frac{1}{3}\left(2 + \frac{\left(M_{D'_{s1}}^2 + M_{D_s^*}^2 - m_{\pi^0}^2\right)^2}{4 M_{D'_{s1}}^2 M_{D_s^*}^2}\right)$$

$$\Gamma_2 = \frac{1}{16\pi}\frac{h^2}{f^2}\frac{1}{M_{D_s^*} M_{D'_{s1}}}(p \cdot q)|\bar{q}|\left(\frac{m_u - m_d}{\frac{m_u + m_d}{2} - m_s}\right)^2 \frac{1}{3}\left(2 + \frac{\left(M_{D'_{s1}}^2 + M_{D_s^*}^2 - m_{\pi^0}^2\right)^2}{4 M_{D'_{s1}}^2 M_{D_s^*}^2}\right)$$

$D^*_{s0} \to D^*_s \gamma$

$$\Gamma_1 = 8\alpha(e_s \mu g_V)^2 \frac{M_{D^*_s}}{M^3_{D^*_{s0}}}\left(\frac{f_\phi}{m_\phi}\right)^2 |\bar{q}|(p\cdot q)^2$$

$$\Gamma_2 = 8\alpha(e_s \mu g_V)^2 \frac{1}{M_{D^*_{s0}} M_{D^*_s}}\left(\frac{f_\phi}{m_\phi}\right)^2 |\bar{q}|(p\cdot q)^2$$

$D'_{s1} \to D_s \gamma$

$$\Gamma_1 = \frac{8}{3}\alpha(e_s \mu g_V)^2 \frac{M_{D_s}}{M^3_{D'_{s1}}}\left(\frac{f_\phi}{m_\phi}\right)^2 |\bar{q}|(p\cdot q)^2$$

$$\Gamma_2 = \frac{8}{3}\alpha(e_s \mu g_V)^2 \frac{1}{M_{D_s} M_{D'_{s1}}}\left(\frac{f_\phi}{m_\phi}\right)^2 |\bar{q}|(p\cdot q)^2$$

$D'_{s1} \to D^*_s \gamma$

$$\Gamma = \frac{8}{3}\alpha(e_s \mu g_V)^2 \frac{1}{M_{D^*_s} M_{D'_{s1}}}\left(\frac{f_\phi}{m_\phi}\right)^2 |\bar{q}|(p\cdot q)^2$$

$D_0^{*0} \to D^{*0}\gamma$

$$\Gamma_1 = 4\alpha\left(e_u \mu g_V\right)^2 \frac{M_{D^{*0}}}{M^3_{D_0^{*0}}}\left(\frac{f_{\rho^0}}{m_{\rho^0}} + \frac{f_\omega}{m_\omega}\right)^2 |\bar{q}|(p\cdot q)^2$$

$$\Gamma_2 = 4\alpha\left(e_u \mu g_V\right)^2 \frac{1}{M_{D_0^{*0}} M_{D^{*0}}}\left(\frac{f_{\rho^0}}{m_{\rho^0}} + \frac{f_\omega}{m_\omega}\right)^2 |\bar{q}|(p\cdot q)^2$$

$\Gamma = (26 \pm 4)KeV$

$D'^0_1 \to D^0\gamma$

$$\Gamma_1 = \frac{4}{3}\alpha\left(e_u \mu g_V\right)^2 \frac{M_{D^0}}{M^3_{D'^0_1}}\left(\frac{f_{\rho^0}}{m_{\rho^0}} + \frac{f_\omega}{m_\omega}\right)^2 |\bar{q}|(p\cdot q)^2$$

$$\Gamma_2 = \frac{4}{3}\alpha\left(e_u \mu g_V\right)^2 \frac{1}{M_{D'^0_1} M_{D^0}}\left(\frac{f_{\rho^0}}{m_{\rho^0}} + \frac{f_\omega}{m_\omega}\right)^2 |\bar{q}|(p\cdot q)^2$$

$\Gamma = (50 \pm 13)KeV$

$D'^0_1 \to D^{*0}\gamma$

$$\Gamma = \frac{4}{3}\alpha\left(e_u \mu g_V\right)^2 \frac{1}{M_{D'^0_1} M_{D^{*0}}}\left(\frac{f_{\rho^0}}{m_{\rho^0}} + \frac{f_\omega}{m_\omega}\right)^2 |\bar{q}|(p\cdot q)^2$$

$\Gamma = 27\ KeV$

$$\left\langle \left(\frac{1}{2}^{-}\right) \middle| J^{\mu}_{em} \middle\| \left(\frac{1}{2}^{+}\right) \right\rangle = ee_q \left\langle \left(\frac{1}{2}^{-}\right) \middle| \bar{q}\gamma^{\mu} q \middle\| \left(\frac{1}{2}^{+}\right) \right\rangle + ee_c \left\langle \left(\frac{1}{2}^{-}\right) \middle| \bar{c}\gamma^{\mu} c \middle\| \left(\frac{1}{2}^{+}\right) \right\rangle$$

$$\frac{1}{m_c}$$

$$\left\langle \left(\frac{1}{2}^{-}\right) \middle| \bar{q}\gamma^{\mu} q \middle\| \left(\frac{1}{2}^{+}\right) \right\rangle \cong \sum_{V,\lambda} \left\langle \left(\frac{1}{2}^{-}\right) V\left(q, \eta^{(\lambda)}\right) \middle\| \left(\frac{1}{2}^{+}\right) \right\rangle \frac{i}{q^2 - m_V^2} \left\langle 0 \middle| \bar{q}\gamma^{\mu} q \middle| V\left(q, \eta^{(\lambda)}\right) \right\rangle$$

$$\left\langle D_s^*(p, \varepsilon)\gamma(q, \tilde{\varepsilon}) \middle| D_{s0}^*(p+q) \right\rangle \cong$$

$$\cong ee_s \sum_{\lambda} \left\langle D_s^*(p, \varepsilon)\phi\left(q, \eta^{(\lambda)}\right) \middle| D_{s0}^*(p+q) \right\rangle \frac{i}{q^2 - m_\phi^2} \left\langle 0 \middle| \bar{s}\gamma^{\mu} s \middle| \phi\left(q, \eta^{(\lambda)}\right) \right\rangle \tilde{\varepsilon}_{\mu}^{*}$$