Charmonia Production in $W \to (c\bar{c})D_s^{(*)}$ Decays

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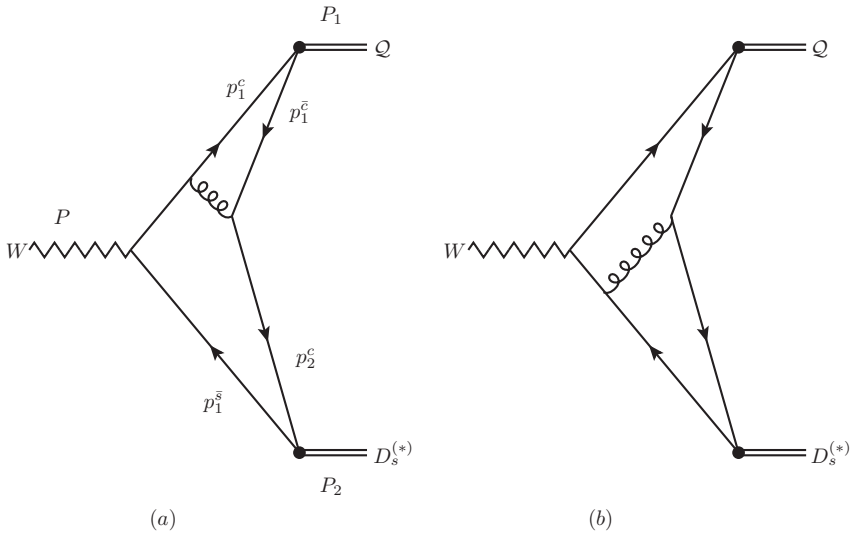
Introduction

- $(c\bar{c})$ — Elementary particles in different regimes
- NRQCD, LC
- e^+e^--annihilation — V
- hadronic reactions — V
- $(b\bar{})$-decays — V
- Z decays — V
- W decays — ???

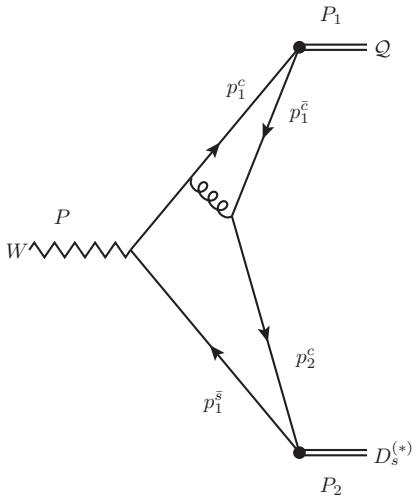
Diagrams

CS

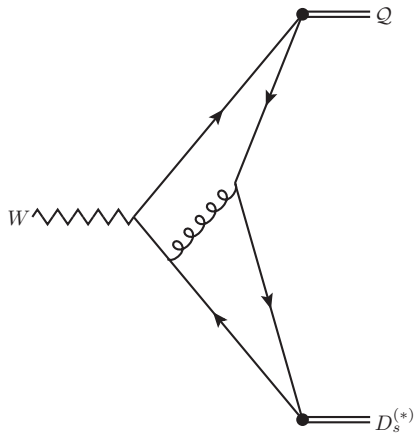


Diagrams

CS

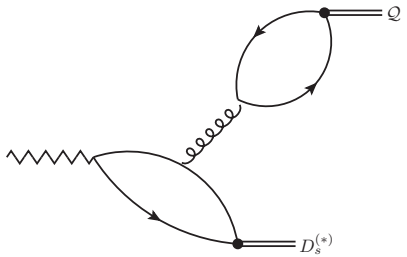


(a)

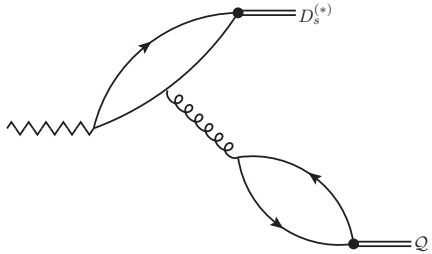


(b)

CO



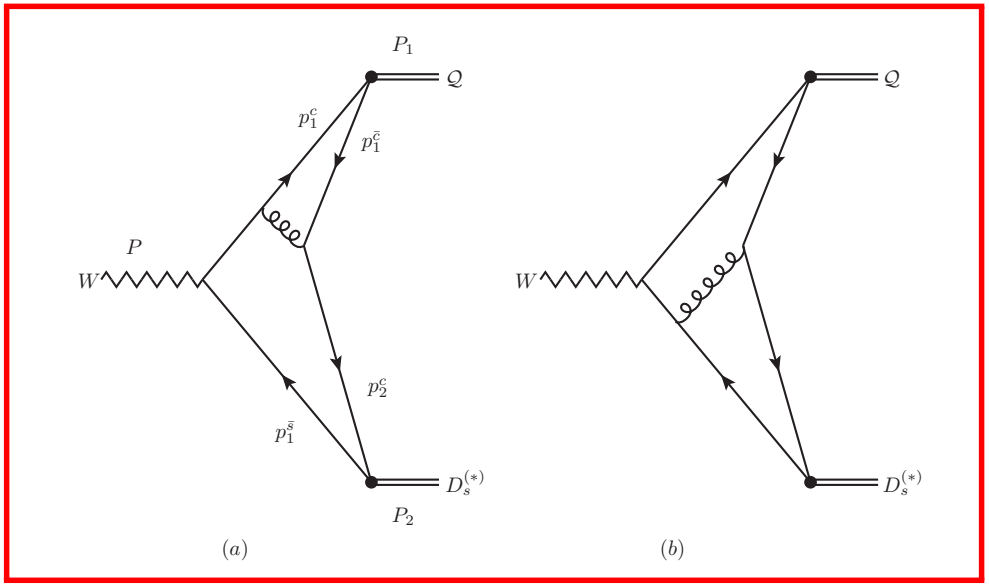
(a)



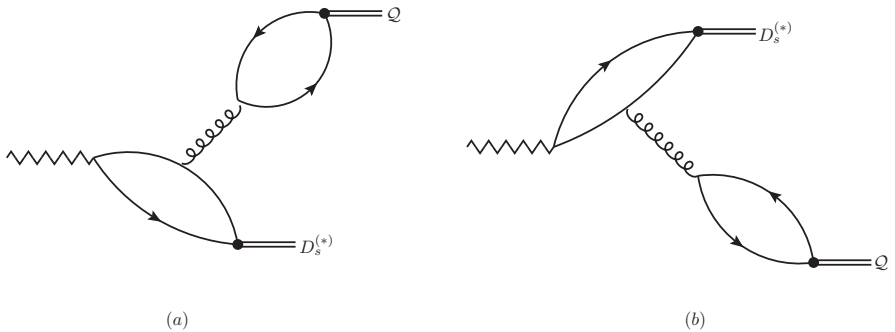
(b)

Diagrams

CS



CO



NRQCD

$$\mathcal{Q} : p_c = p_{\bar{c}} = \frac{P}{2}, \qquad D_s^{(*)} : p_{c,s} = \frac{m_{c,s}}{M} P$$

$$\Pi \sim F_{\mathcal{Q}} \hat{\Gamma} \left(\hat{P} + M \right) \delta_{ij}$$

$$\Gamma_{\mathrm{NRQCD}} \left(W \to \mathcal{Q} D_s^{(*)} \right) = \frac{16\pi\alpha_s^2 \lambda g_W^2}{243} \left(\frac{m_c + m_s}{m_c} \right)^2 \frac{F_{\mathcal{Q}}^2 F_{D_s^{(*)}}^2}{M_W^3} C_{\mathcal{Q}D_s^{(*)}},$$

$$r_{c,s} = \frac{m_{c,s}}{M_W}$$

$$C_{\eta_c D_s} = \left(\frac{1}{1 - (r_c - r_s)^2} \right)^3 \left[1 + r_c^2 + 6 r_c r_s + r_s^2 - 65 r_c^4 - 108 r_c^3 r_s - 54 r_c^2 r_s^2 - 12 r_c r_s^3 - r_s^4 - \left(15 r_c^3 + 23 r_c^2 r_s + 9 r_c r_s^2 + r_s^3 \right)^2 \right] \approx 1,$$

$\ldots$

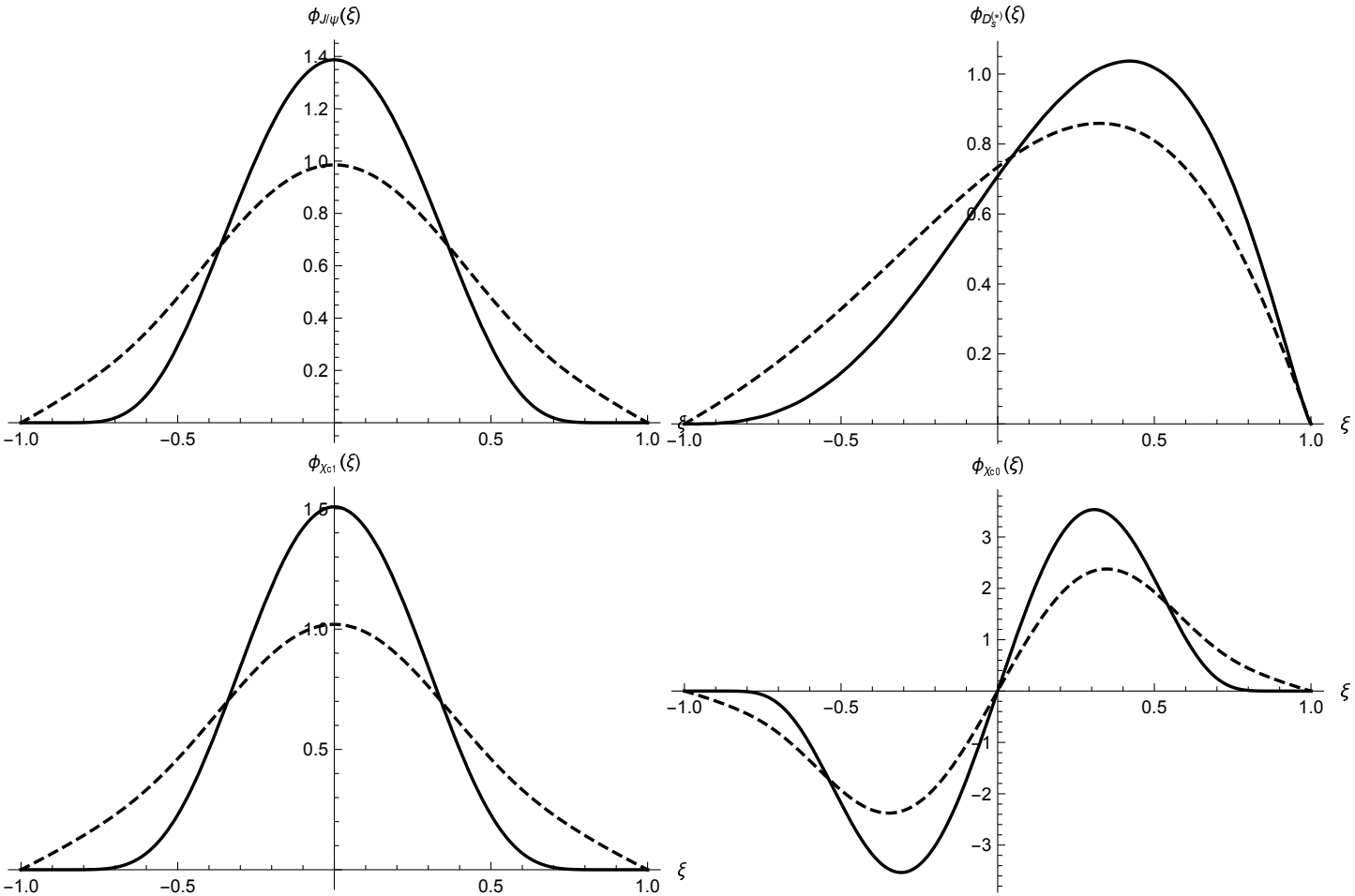
$$p_c = xP, \qquad p_{\bar{c}} = (1-x)P$$

$$\Pi \sim f_{\mathcal{Q}} \hat{P} \delta_{ij} \int_0^1 dx \phi(x)$$

$$\Gamma_{\mathrm{LC}}\left(W \to \mathcal{Q}D_s^{(*)}\right) = \frac{16\pi\alpha_s^2 g_W^2}{243} \frac{f_{\mathcal{Q}}^2 f_{D_s^{(*)}}^2}{M_W^3} \mathcal{I}^2_{\mathcal{Q}D_s^{(*)}}.$$

$$\mathcal{I}_{\mathcal{Q}D_s^{(*)}} = 2\int_{-1}^1 d\xi_1 d\xi_2 \frac{\phi_{\mathcal{Q}}(\xi_1)\phi_{D_s^{(*)}}(\xi_2)}{(1-\xi_1)(1+\xi_2)}.$$

LC: Amplitudes



$W \to QD_s$ Branching Fractions (10^{-12}

Q	$\mathrm{Br}_{\mathrm{NRQCD}}$	$\mathrm{Br}^{\delta}_{\mathrm{LC}}$	$\mathrm{Br}_{\mathrm{LC}}$	$\mathrm{Br}_{\mathrm{LC}}/\mathrm{Br}^{\delta}_{\mathrm{LC}}$
η_c	2.28			
J/ψ	2.1			
h_c	0.112			
χ_{c0}	0.0387			
χ_{c1}	0.226			
χ_{c2}	0.0731			

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η_c	2.28	$3. \pm 0.4$		
J/ψ	2.1	4.12 ± 0.4		
h_c	0.112	0.906 ± 0.3		
χ_{c0}	0.0387	0.302 ± 0.1		
χ_{c1}	0.226	1.81 ± 0.7		
χ_{c2}	0.0731	0.604 ± 0.2		

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η_c	2.28	$3. \pm 0.4$	$13.1 \pm 2.^{+2.7}_{-0.84}$	
J/ψ	2.1	4.12 ± 0.4	$18. \pm 2.^{+3.7}_{-1.1}$	
h_c	0.112	0.906 ± 0.3	$2.13 \pm 0.8^{+0.55}_{-0.24}$	
χ_{c0}	0.0387	0.302 ± 0.1	$0.71 \pm 0.3^{+0.18}_{-0.079}$	
χ_{c1}	0.226	1.81 ± 0.7	$7.83 \pm 3.^{+1.6}_{-0.53}$	
χ_{c2}	0.0731	0.604 ± 0.2	$1.42 \pm 0.5^{+0.37}_{-0.16}$	

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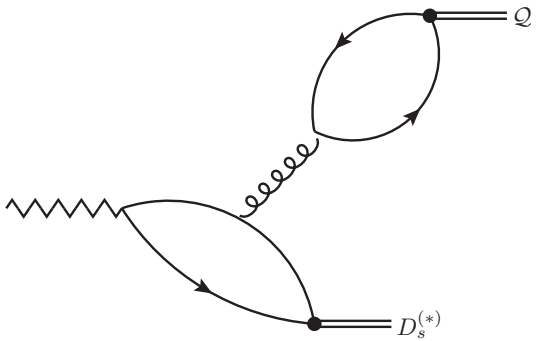
η_c	2.28	$3. \pm 0.4$	$13.1 \pm 2.^{+2.7}_{-0.84}$	$4.37^{0.9}_{-0.3}$
J/ψ	2.1	4.12 ± 0.4	$18. \pm 2.^{+3.7}_{-1.1}$	$4.37^{0.9}_{-0.3}$
h_c	0.112	0.906 ± 0.3	$2.13 \pm 0.8^{+0.55}_{-0.24}$	$2.35^{0.6}_{-0.3}$
χ_{c0}	0.0387	0.302 ± 0.1	$0.71 \pm 0.3^{+0.18}_{-0.079}$	$2.35^{0.6}_{-0.3}$
χ_{c1}	0.226	1.81 ± 0.7	$7.83 \pm 3.^{+1.6}_{-0.53}$	$4.32^{0.9}_{-0.3}$
χ_{c2}	0.0731	0.604 ± 0.2	$1.42 \pm 0.5^{+0.37}_{-0.16}$	$2.35^{0.6}_{-0.3}$

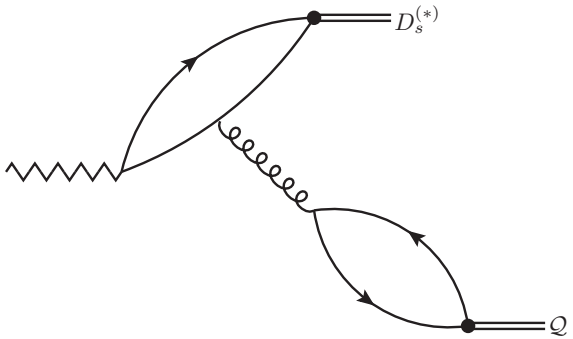
$W \to QD_s^*$ (10^{-12} Branching Fractions

Q	$\mathrm{Br}_{\mathrm{NRQCD}}$	$\mathrm{Br}_{\mathrm{LC}}^{\delta}$	$\mathrm{Br}_{\mathrm{LC}}$	$\mathrm{Br}_{\mathrm{LC}}/\mathrm{Br}_{\mathrm{LC}}^{\delta}$
η_c	3.18	3.38 ± 0.5	$14.8 \pm 2.^{+3.}_{-0.95}$	$4.37^{0.9}_{-0.3}$
J/ψ	2.97	4.64 ± 0.5	$20.3 \pm 2.^{+4.1}_{-1.3}$	$4.37^{0.9}_{-0.3}$
h_c	0.153	1.02 ± 0.4	$2.4 \pm 0.9^{+0.62}_{-0.27}$	$2.35^{0.6}_{-0.3}$
χ_{c0}	0.0664	0.341 ± 0.1	$0.8 \pm 0.3^{+0.21}_{-0.089}$	$2.35^{0.6}_{-0.3}$
χ_{c1}	0.311	2.04 ± 0.8	$8.83 \pm 3.^{+1.8}_{-0.6}$	$4.32^{0.9}_{-0.3}$
χ_{c2}	0.102	0.681 ± 0.3	$1.6 \pm 0.6^{+0.41}_{-0.18}$	$2.35^{0.6}_{-0.3}$

CO



(a)



(b)

$$\Gamma^{CO}_{\mathrm{NRQCD}} \approx \frac{\pi\alpha_s^2 g_W^2}{54}\frac{(m_c^2+m_c^2)(m_c+m_s)^2}{m_c^4 m_s^2}\frac{\tilde{F}^2_{J/\psi}\tilde{F}^2_{D_s}}{M_W}C^{CO}_{^3S_1^{[8]}D_s},$$

$$\frac{\Gamma^{CO}_{\mathrm{NRQCD}}}{\Gamma_{\mathrm{NRQCD}}} \sim \frac{M_W^2}{m_c^2}.$$

Conclusion

- $W \to \mathcal{Q}D_s^{(*)}$
- The branching fractions are small
- LC leads to some increase
- In comparison to $Z \to \mathcal{Q}_1\mathcal{Q}_2$:
  - All decays are allowed
  - Branching fractions are higher
- CO cotrtibutions are estimated

Thank you for your attention