

# QCD corrections in exclusive $c \rightarrow ul^+l^-$

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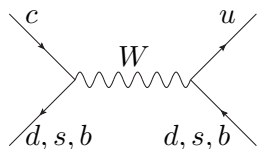
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Project 4; in collaboration with  
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December 8th, 2014



# $c \rightarrow u\gamma$ inclusive/exclusive



- Cabibbo allowed decays:  
 $D^0 \rightarrow \bar{K}^{*0}\gamma^{(*)}$ ,  $D_s^\pm \rightarrow \rho^\pm\gamma^{(*)}$
- Cabibbo suppressed decays:  
 $D^0 \rightarrow \rho^0\gamma^{(*)}$ ,  $D^0 \rightarrow \omega\gamma^{(*)}$ ,  
 $D^0 \rightarrow \phi\gamma^{(*)}$ ,  $D^\pm \rightarrow \rho^\pm\gamma^{(*)}$ ,  
 $D_s^\pm \rightarrow K^\pm\gamma^{(*)}$
- doubly Cabibbo suppressed decays:  
 $D^0 \rightarrow K^{*0}\gamma^{(*)}$ ,  $D^\pm \rightarrow K^\pm\gamma^{(*)}$

## short distance $c \rightarrow u\gamma$ at LO

$$\mathcal{L}_{\text{int}} \simeq \frac{4G_F}{\sqrt{2}} \frac{g_{em}m_c}{16\pi^2} (\bar{u}_L \sigma^{\mu\nu} c_R) F_{\mu\nu} \underbrace{\sum_{q=d,s,b} V_{cq}^* V_{uq} \left( \frac{m_q}{M_W} \right)^2}_{\sim 2 \times 10^{-7}}$$

$$|V_{cd}^* V_{ud}| \simeq |V_{cs}^* V_{us}| \simeq 0.22$$

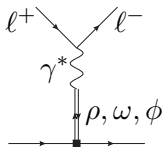
$$|V_{cb}^* V_{ub}| \simeq 10^{-4}$$

# Long distance contribution for $D^0 \rightarrow (\pi^0/\rho^0)\ell^+\ell^-$

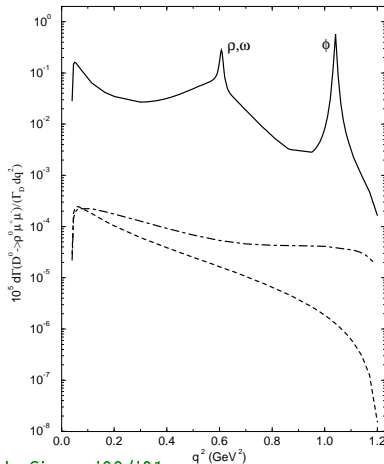
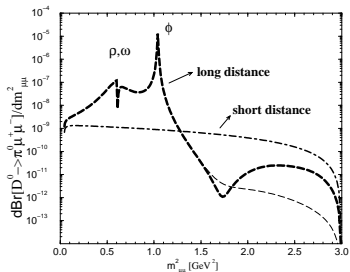
$$a_1 = 1.26, a_2 = -0.55, q_i = d, s$$

(Bauer/Stech/Wirbel '87)

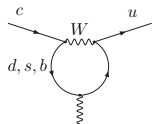
$$\mathcal{L}_{LD} = -\frac{G_F}{\sqrt{2}} V_{uq_i} V_{cq_j}^* [a_1 (\bar{u}q_i)^\mu (\bar{q}_j c)_\mu + a_2 (\bar{u}c)_\mu (\bar{q}_j q_i)^\mu]$$



- vector meson dominance
- Breit-Wigner for resonance



# Short distance contribution



- $m_d, m_s, m_b \ll M_W$
- CKM unitary: penguin operators are not generated (GIM)

## Effective Hamiltonian

$$H_{\text{eff}}(M_W > \mu > m_b) = \frac{4G_F}{\sqrt{2}} \sum_{q=d,s,b} V_{cq}^* V_{uq} [C_1(\mu)\mathcal{O}_1^q + C_2(\mu)\mathcal{O}_2^q]$$

$$H_{\text{eff}}(m_b > \mu > m_c) = \frac{4G_F}{\sqrt{2}} \sum_{q=d,s} V_{cq}^* V_{uq} [C_1(\mu)\mathcal{O}_1^q + C_2(\mu)\mathcal{O}_2^q + \sum_{i=3}^{10} C_i(\mu)\mathcal{O}_i]$$

$$\mathcal{O}_1^q = (\bar{u}_L \gamma_\mu T^a q_L)(\bar{q}_L \gamma^\mu T^a c_L),$$

$$\mathcal{O}_2^q = (\bar{u}_L \gamma_\mu q_L)(\bar{q}_L \gamma^\mu c_L)$$

$$\mathcal{O}_7 = -\frac{g_{\text{em}} m_c}{16\pi^2} (\bar{u}_L \sigma^{\mu\nu} c_R) F_{\mu\nu},$$

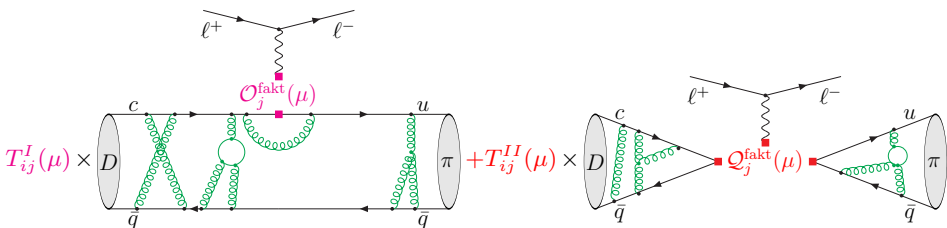
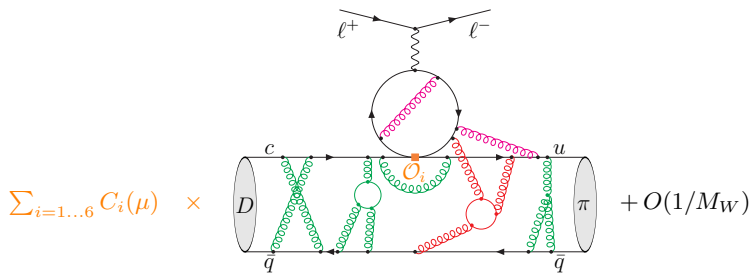
$$\mathcal{O}_8 = -\frac{g_s m_c}{16\pi^2} (\bar{u}_L \sigma^{\mu\nu} T^a c_R) G_{\mu\nu}^a,$$

$$\mathcal{O}_9 = \frac{\alpha_{\text{em}}}{4\pi} (\bar{u}_L \gamma_\mu c_L)(\bar{\ell} \gamma^\mu \ell),$$

$$\mathcal{O}_{10} = \frac{\alpha_{\text{em}}}{4\pi} (\bar{u}_L \gamma_\mu c_L)(\bar{\ell} \gamma^\mu \gamma_5 \ell)$$

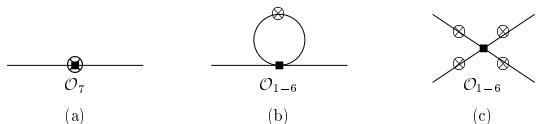
- $c \rightarrow u\gamma$ : running of  $C_7(\mu)$  to  $\mu = m_c$   
 $\rightsquigarrow$  more than order of magnitude larger than LO

# QCD factorization

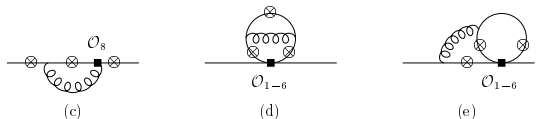
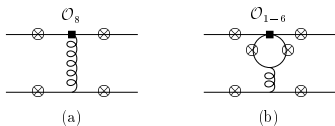


- corrections to factorization of  $O(1/M_D)$

# Diagrams



- Diag. (b):  $\rho, \omega, \phi$  resonances



- Diag. (d),(e) for  $c \rightarrow u\gamma$

$\rightsquigarrow$  more than two orders of magnitude larger than LL  
 more than four orders of magnitude larger than LO

# Wilson coefficients PRELIMINARY

Wilson coefficients at the scale  $\mu = 1.3 \text{ GeV}$

	$\bar{C}_1$	$\bar{C}_2$	$\bar{C}_3$	$\bar{C}_4$	$\bar{C}_5$	$\bar{C}_6$
LL	-0.526	1.272	0.011	-0.027	0.008	-0.032
NLL	-0.361	1.159	0.012	-0.038	0.009	-0.040
NNLL	-0.320	1.141	0.011	-0.036	0.007	-0.038
	$C_7^{\text{eff}}$	$C_8^{\text{eff}}$	$C_9$	$C_{10}$	$C_9^{\text{NNLL}}$	$C_{10}^{\text{NNLL}}$
LL	0.147	-0.060	-0.118	0	-0.379	0
NLL	0.114	-0.066	-0.225	0		

- $C_1 - C_8$ : same order of magnitude than for  $B$ -decays
- $C_9$ : order of magnitude smaller than for  $B$ -decays; convergence (?)