Evasion of helicity selection rule in some charmonium decays

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Based on PRD81, 014017(2010)

(for 3rd FCPPL, Lyon, April, 2010)

Outline

- **Introduction to the helicity selection rule**
- **Evasion of the selection rule via charmed hadron loops**
  - $\chi_{c1} \to VV$, $\chi_{c2} \to VP$
  - η_c, χ_{c0}, $h_c \to \bar{B}B$ ($\bar{p}p$, $\bar{\Lambda}\Lambda$, $\bar{\Sigma}\Sigma$, $\bar{\Xi}\Xi$)
- **Summary**

Helicity Selection Rule

According to the perturbative method of QCD, V.L. Chernyark et al. have ever obtained the asymptotic behavior for some exclusive processes, e.g.

$$BR_{J_{c\bar{c}}(\lambda)\to h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)^{|\lambda_1+\lambda_2|+2}$$

Phys. Rept. 112, 173 (1984)

The leading order will contribute when $\lambda_1+\lambda_2=0$, while the helicity configurations that do not satisfy this relation will be suppressed.

Helicity Selection Rule

An alternative description of this selection rule with the quantum number named "naturalness"

$$\sigma \equiv P(-1)^J$$

The selection rule requires that

$$\sigma^{initial} = \sigma_1\sigma_2$$

Take the process J/ψ→VP as an example $(\sigma^{initial} \neq \sigma_1\sigma_2)$

$$\mathcal{M}_{J/\psi(\lambda_\psi)\to V(\lambda_V)P(\lambda_P)} \propto \epsilon_{\mu\nu\alpha\beta} p^\mu_\psi \epsilon^\nu_\psi(p_\psi,\lambda_\psi) p^\alpha_V \epsilon^{*\beta}_V(p_V,\lambda_V)$$

In the rest frame of initial state, if λ_V=0, ε_V can be approximately expressed as a linear combination of the final state momenta. Then the contraction of the Lorentz indices will result in a vanishing amplitude.

S and P-wave Charmonium Decays

	PP	PV	VV
η_c	-	$(\surd)$	ϵ
J/ψ	$(\surd)$	ϵ	$(\surd)$
χ_{c0}	$\surd$	-	$\surd$
χ_{c1}	-	$(\surd)$	ϵ
χ_{c2}	$\surd$	(ϵ)	$\surd$

Inconsistent with exp.

Zhao et al. 0812.4902

Zhang et al. PRL102, 172001

which we will discuss in this talk.

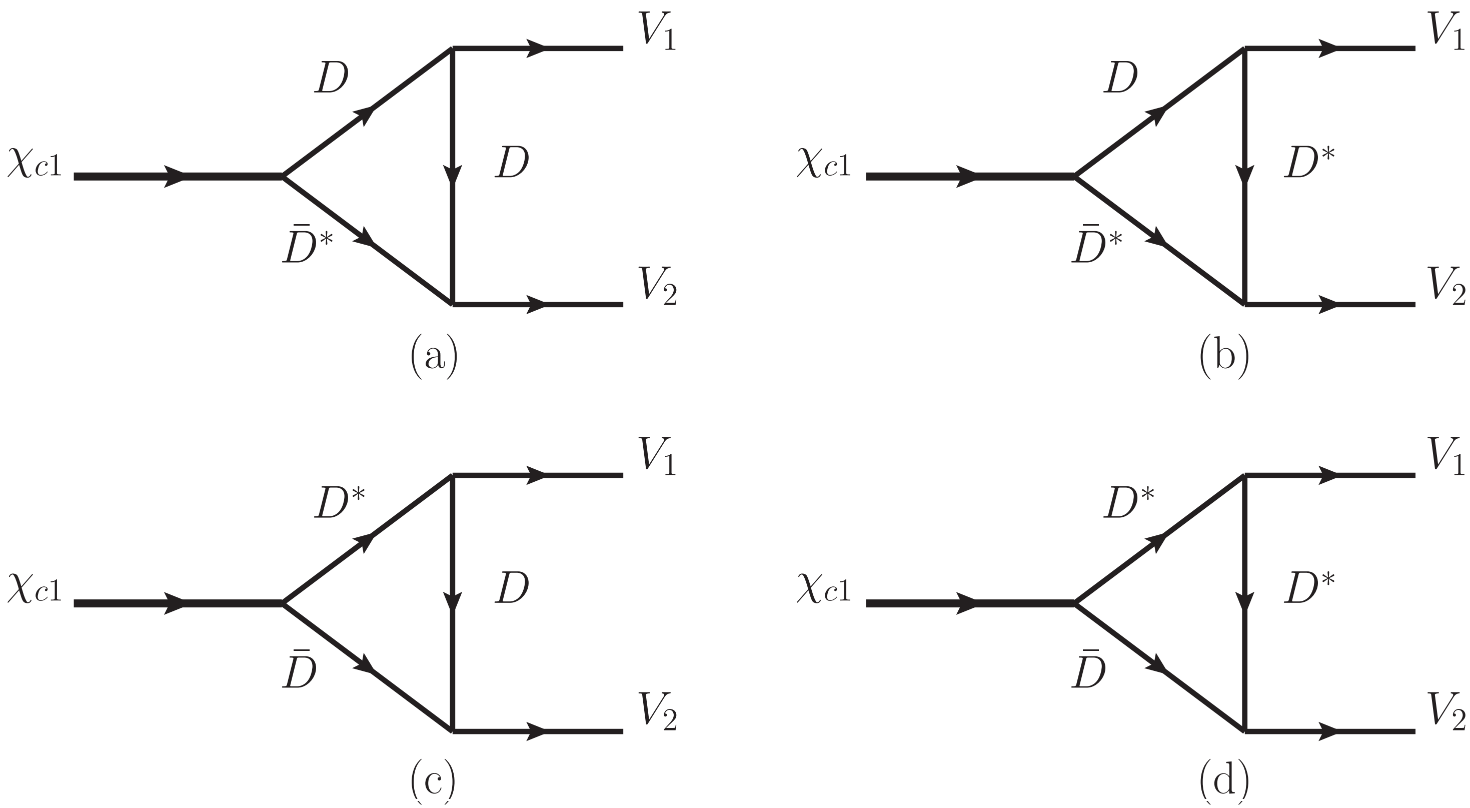
T. Feldmann & P. Kroll

PRD62, 074006 (2000)

$$BR(\chi_{c1} \to K^{*0}\bar{K}^{*0}) = (1.6 \pm 0.4) \times 10^{-3}$$ **PDG**

Long-distance Contribution

Charmed meson loops mechanism for $\chi_{c1} \to VV$



The Model

An effective Lagrangian based on heavy quark symmetry and chiral symmetry is adopted in this model. Some relevant Lagrangians are

Colangelo et al. PRD69, 054023

$$\mathcal{L}_1 = i g_1 Tr[P^{\mu}_{c\bar{c}} \bar{H}_{2i} \gamma_\mu \bar{H}_{1i}] + h.c.$$

$$\mathcal{L}_2 = i g_2 Tr[R_{c\bar{c}} \bar{H}_{2i} \gamma^\mu \overleftrightarrow{\partial}_\mu \bar{H}_{1i}] + h.c.$$

P-wave

$$P^{\mu}_{c\bar{c}} = \left(\frac{1+\not{v}}{2}\right)\left(\chi^{\mu\alpha}_{c2}\gamma_\alpha + \frac{1}{\sqrt{2}}\epsilon^{\mu\nu\alpha\beta} v_\alpha \gamma_\beta \chi_{c1\nu} + \frac{1}{\sqrt{3}}(\gamma^\mu - v^\mu)\chi_{c0} + h^\mu_c \gamma_5\right)\left(\frac{1-\not{v}}{2}\right)$$

$$R_{c\bar{c}} = \left(\frac{1+\not{v}}{2}\right)(\psi^\mu \gamma_\mu - \eta_c \gamma_5)\left(\frac{1-\not{v}}{2}\right)$$

S-wave

$$H_{1i} = \left(\frac{1+\not{v}}{2}\right)[\mathcal{D}^{*\mu}_i \gamma_\mu - \mathcal{D}_i \gamma_5]$$

$$H_{2i} = [\bar{\mathcal{D}}^{*\mu}_i \gamma_\mu - \bar{\mathcal{D}}_i \gamma_5]\left(\frac{1-\not{v}}{2}\right)$$

(D^0, D^+, D^+_s)

The Model

With the effective lagrangian method the rescattering amplitudes are expressed as

$$\mathcal{M}_{1a} = 2ig_{DD^*\chi_{c1}}g_{DDV}f_{D^*DV}\epsilon_{\lambda}^{\chi_{c1}}\epsilon_1^{*\sigma}\epsilon_2^{*\tau}\int\frac{d^4q}{(2\pi)^4}$$
$$\times\ (q_{1\sigma}+q_\sigma)\epsilon_{\mu\tau\alpha\beta}p_2^{\mu}(q^{\alpha}-q_2^{\alpha})\frac{g^{\lambda\beta}-q_2^{\lambda}q_2^{\beta}/m_{D^*}^2}{D_aD_1D_2}\mathcal{F}(q^2)$$

$$\mathcal{M}_{1b} = 2ig_{DD^*\chi_{c1}}g_{DDV}f_{D^*DV}\epsilon_{\lambda}^{\chi_{c1}}\epsilon_1^{*\sigma}\epsilon_2^{*\tau}\int\frac{d^4q}{(2\pi)^4}$$
$$\times\ \epsilon_{\mu\sigma\alpha\beta}p_1^{\mu}(q_1^{\alpha}+q^{\alpha})\left[g_{D^*D^*V}(q_{2\tau}-q_\tau)g_{\gamma\delta}+4f_{D^*D^*V}(p_{2\delta}g_{\tau\gamma}-p_{2\gamma}g_{\delta\tau})\right]$$
$$\times\ (g^{\beta\gamma}-q^{\beta}q^{\gamma}/m_{D^*}^2)(g^{\lambda\delta}-q_2^{\lambda}q_2^{\delta}/m_{D^*}^2)\times\frac{1}{D_bD_1D_2}\mathcal{F}(q^2)$$

The phenomenologically introduced form factor reads

$$\mathcal{F}(q^2)=\prod_i\left(\frac{m_i^2-\Lambda_i^2}{q_i^2-\Lambda_i^2}\right)$$

← **model dependent**

where $\Lambda_i = m_i + \alpha\Lambda_{QCD}$

Numerical Result for $\chi_{c1}\to VV$

BR ($\times 10^{-4}$)	$K^{*0}\bar{K}^{*0}$	$\rho\rho$	$\omega\omega$	$\phi\phi$
Exp. data	16 ± 4	—	—	—
Meson loop	$12\sim 20$	$26\sim 54$	$8.7\sim 18$	$2.7\sim 4.6$
SU(3)($R=1$)	16.0	26.8	8.8	6.8
SU(3)($R=0.838$)	16.0	32.0	10.6	4.0

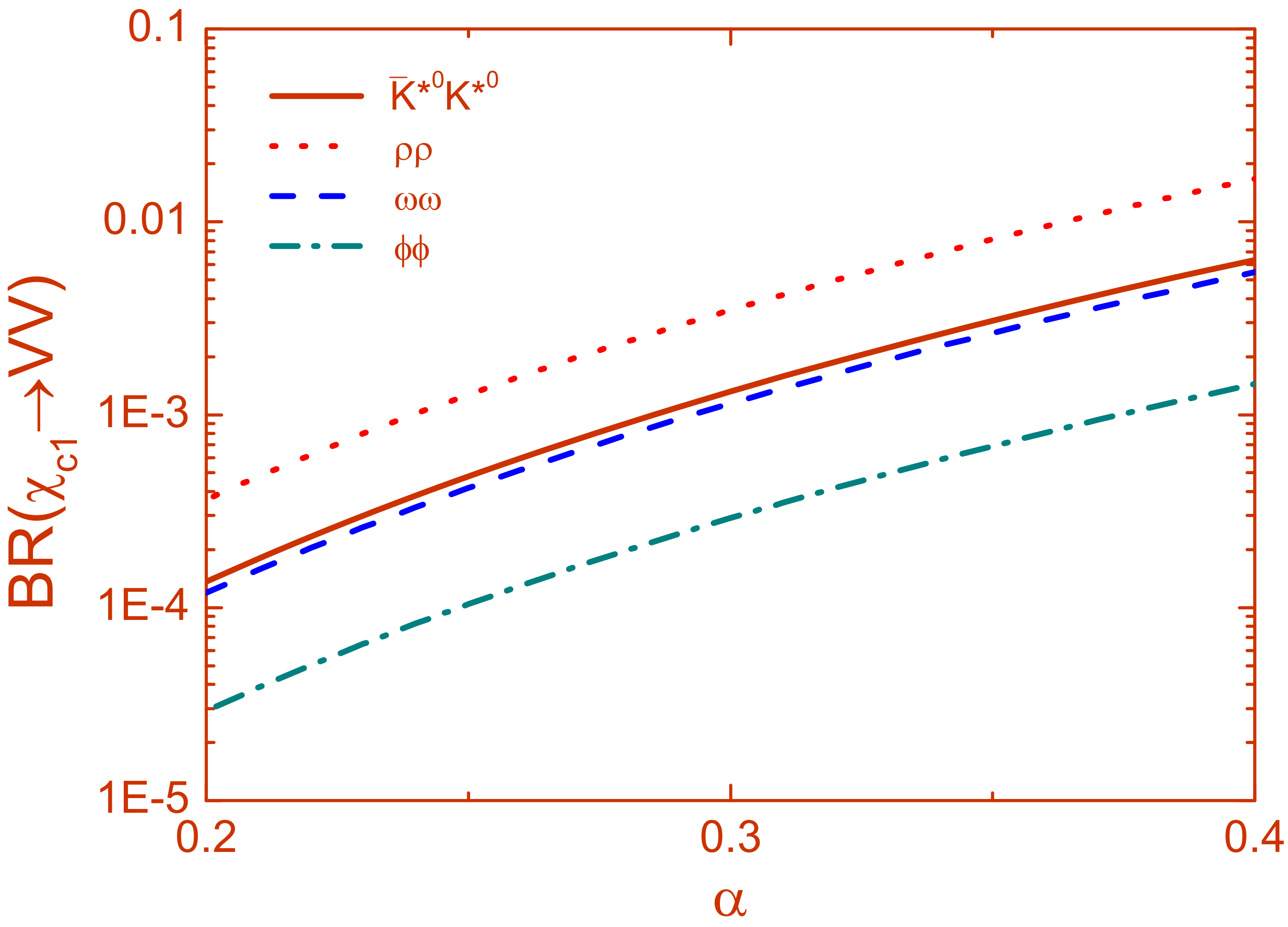
← α=0.3~ 0.33

The results of a simple parameterization method based on SU(3) falvour symmetry are also presented in the table, where

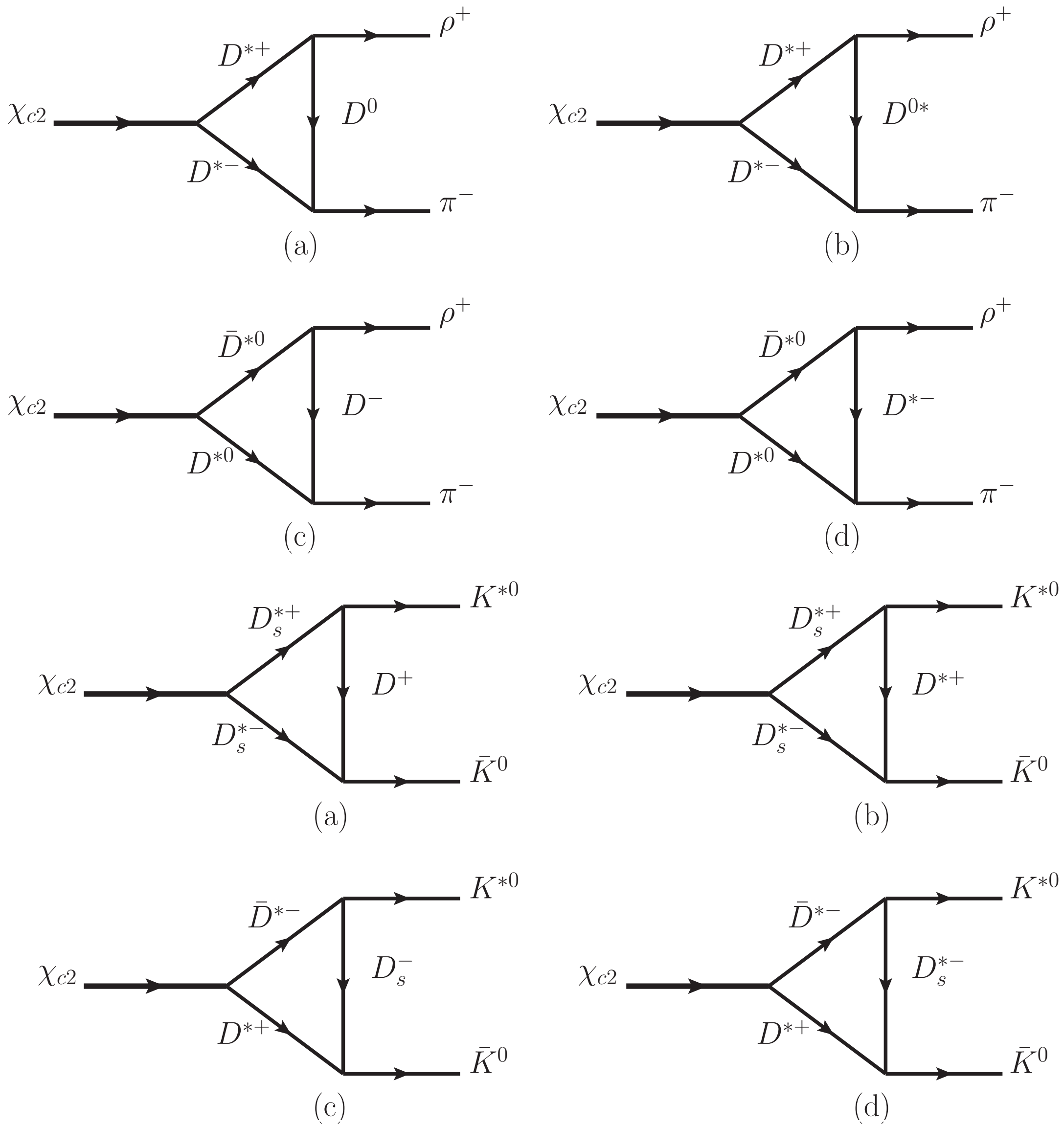
$$R\equiv \langle (q\bar{s})_{V_1}(s\bar{q})_{V_2}|\hat{H}|\chi_{c1}\rangle/\langle (q\bar{q})_{V_1}(q\bar{q})_{V_2}|\hat{H}|\chi_{c1}\rangle$$

and $R\simeq f_\pi/f_K$

Model-dependence on α



$\chi_{c2} \to$ VP

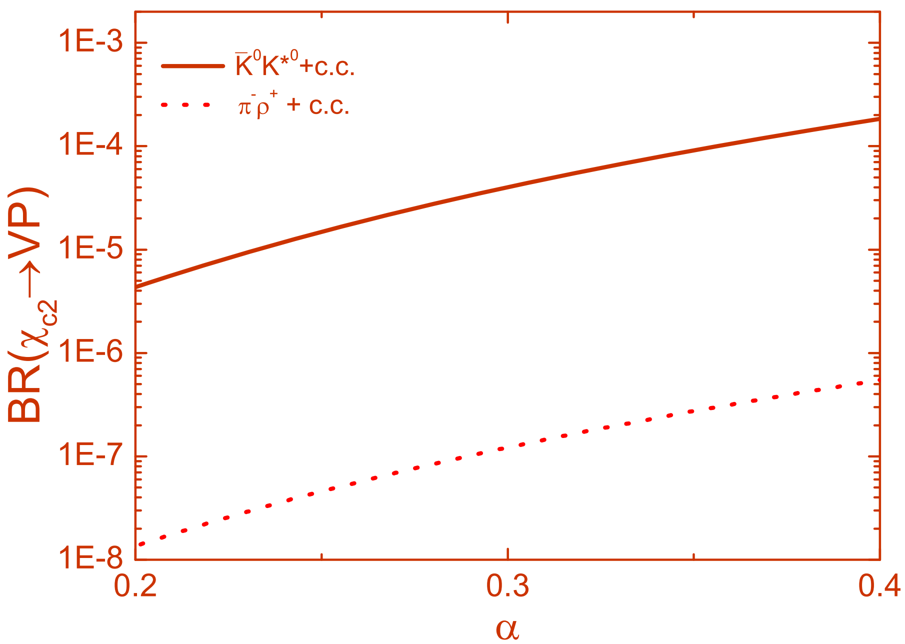


Further suppressed by approximate G-parity or isospin/U-spin conservation. Decay to neutral VP is forbidden by C-parity conservation.

$\chi_{c2} \to VP$

BR($\times 10^{-5}$)	$K^{*0}\bar{K}^0 + c.c.$	$K^{*+}K^- + c.c.$	$\rho^+\pi^- + c.c.$
Meson loop	$4.0 \sim 6.7$	$4.0 \sim 6.7$	$(1.2 \sim 2.0) \times 10^{-2}$
Exp. data	—	—	—

α=0.3~ 0.33



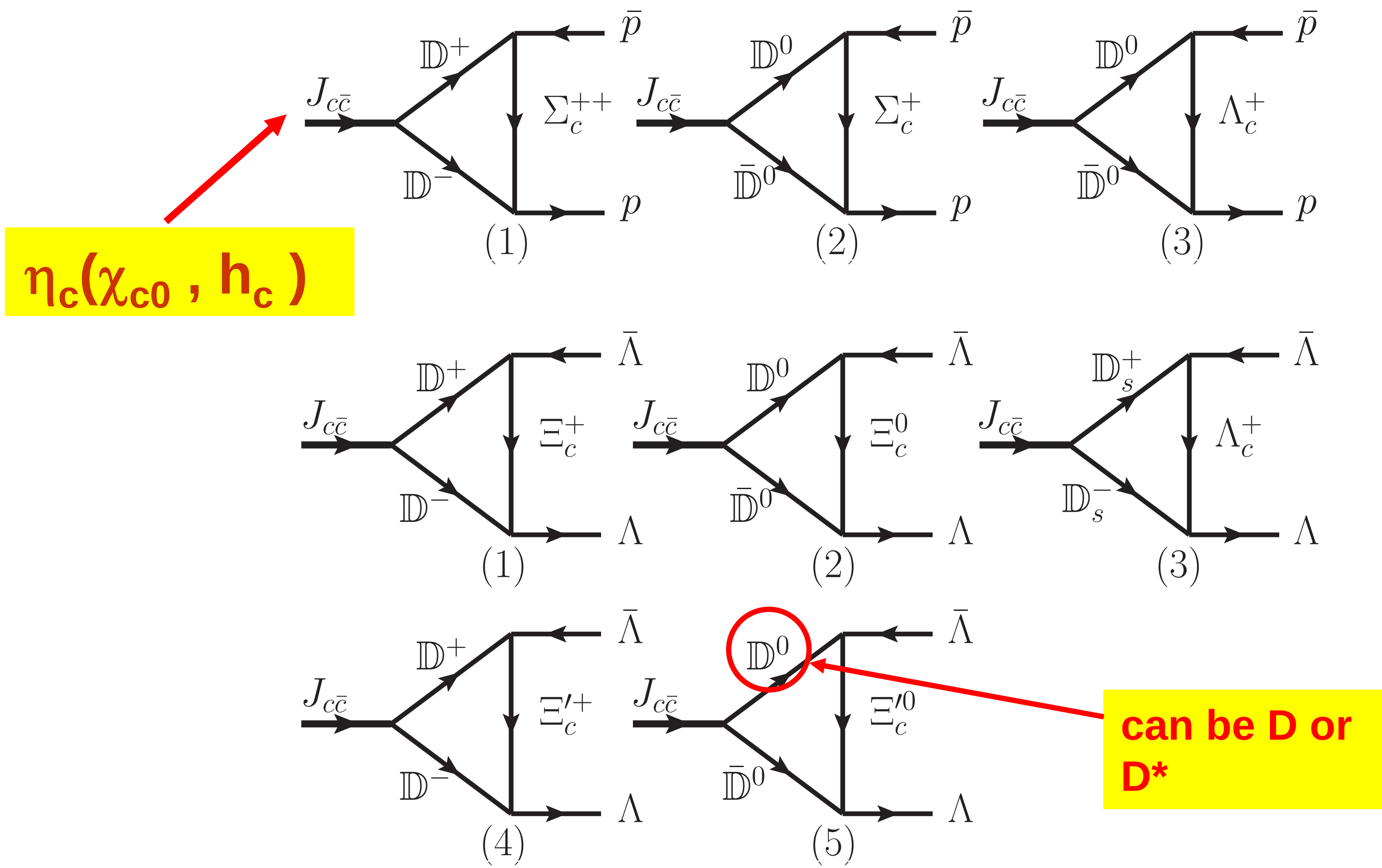
Brief summary

- The long-distance rescattering effects can give sizeable contributions to the prpcesses $\chi_{c1} \to VV$ and $\chi_{c2} \to VP$, which are supposed to be suppressed according to the helicity selection rule.
- With the parameter α constrained by the measured BR($\chi_{c1} \to \bar{K}^{*0} K^{*0}$), BR($\chi_{c1} \to VV$) are predicted to be at least at the order of 10^{-4}, and BR($\chi_{c2} \to \bar{K}^{*0} K + c.c.$) is at the order of 10^{-5} that may be detectable.

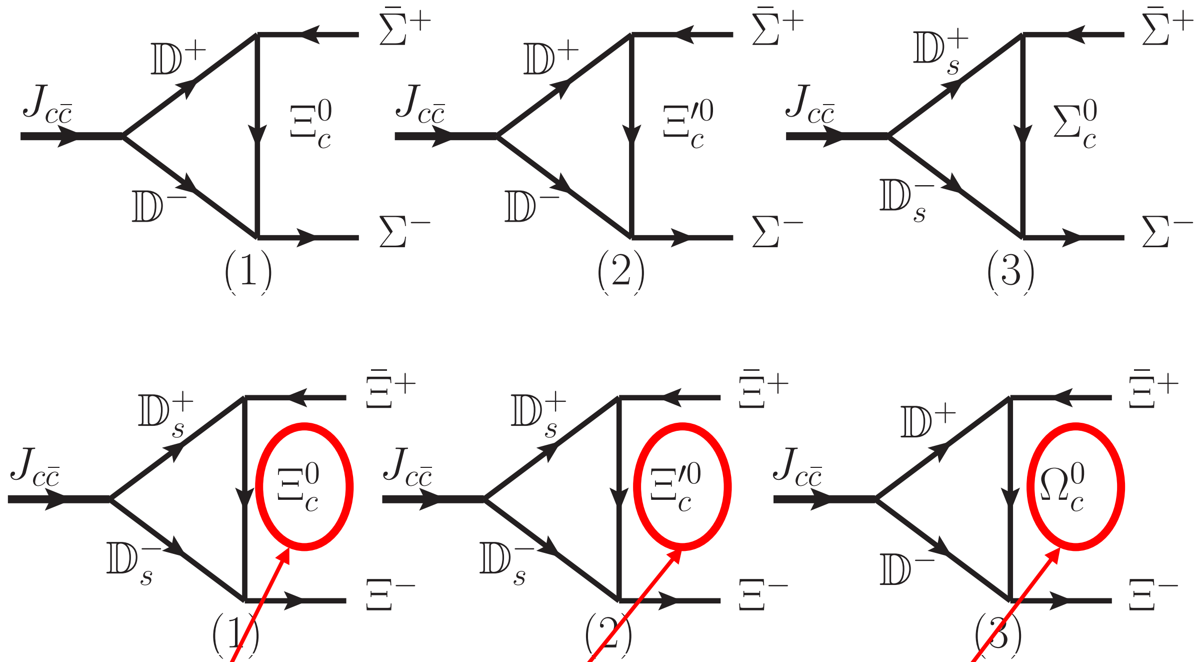
$\eta_c(\chi_{c0}, h_c) \to \bar{B}B$

- $\bar{B}B$ represents the $J^P=1/2^+$ octet baryon-antibaryon pairs
- These processes also violate the helicity selection rule
- Some attempts have been made to understand this contradiction
  - quark-diquark model M. Anselmino et al.
  - quark mass correction F. Murgia; M. Anselmino et al.
  - mixing with glueball M. Anselmino et al.
  - quark pair creation model R.G. Ping et al.

Model of Charmed Hadron Loops



Model of Charmed Hadron Loops



Exchange of the ground states $J^P=1/2^+$ charmed baryons are considered

Amplitude

We take the transition amplitude of $\eta_c \to \bar{B}B$ via the charmed hadron loops as an example

$$
\begin{aligned}
\mathcal{M}_a &= 2g_{\eta_c\mathcal{D}\mathcal{D}^*}g_{B_c\mathcal{D}B}g_{B_c\mathcal{D}^*B}\int\frac{d^4q}{(2\pi)^4}(q_{2\lambda}-q_{1\lambda})\left(-g^{\lambda\mu}+\frac{q_2^\lambda q_2^\mu}{m_{\mathcal{D}^*}^2}\right)\\
&\times\ \bar{u}(p_2)\left(\gamma_\mu+i\frac{\kappa_{B_c\mathcal{D}^*B}}{2m_N}\sigma_{\mu\nu}q_2^\nu\right)(\not{q}+m_{B_c})\gamma_5 v(p_1)\\
&\times\ \frac{1}{q^2-m_{B_c}^2}\frac{1}{q_1^2-m_{\mathcal{D}}^2}\frac{1}{q_2^2-m_{\mathcal{D}^*}^2}\mathcal{F}(q^2)\\
\mathcal{M}_b &= 2g_{\eta_c\mathcal{D}\mathcal{D}^*}g_{B_c\mathcal{D}B}g_{B_c\mathcal{D}^*B}\int\frac{d^4q}{(2\pi)^4}(q_{2\lambda}-q_{1\lambda})\left(-g^{\lambda\mu}+\frac{q_1^\lambda q_1^\mu}{m_{\mathcal{D}^*}^2}\right)\\
&\times\ \bar{u}(p_2)\gamma_5(\not{q}+m_{B_c})\left(\gamma_\mu+i\frac{\kappa_{B_c\mathcal{D}^*B}}{2m_N}\sigma_{\mu\nu}q_1^\nu\right)v(p_1)\\
&\times\ \frac{1}{q^2-m_{B_c}^2}\frac{1}{q_1^2-m_{\mathcal{D}^*}^2}\frac{1}{q_2^2-m_{\mathcal{D}}^2}\mathcal{F}(q^2)
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{M}_c &= -2ig_{\eta_c\mathcal{D}^*\mathcal{D}^*}g_{B_c\mathcal{D}^*B}^2\int\frac{d^4q}{(2\pi)^4}\epsilon^{\mu\nu\lambda\tau}p_\nu(q_{2\mu}-q_{1\mu})\\
&\times\ \bar{u}(p_2)\left(\gamma_\tau+i\frac{\kappa_{B_c\mathcal{D}^*B}}{2m_N}\sigma_{\tau\xi}q_2^\xi\right)(\not{q}+m_{B_c})\left(\gamma_\lambda+i\frac{\kappa_{B_c\mathcal{D}^*B}}{2m_N}\sigma_{\lambda\sigma}q_1^\sigma\right)v(p_1)\\
&\times\ \frac{1}{q^2-m_{B_c}^2}\frac{1}{q_1^2-m_{\mathcal{D}^*}^2}\frac{1}{q_2^2-m_{\mathcal{D}^*}^2}\mathcal{F}(q^2)
\end{aligned}
$$

Couplings

There is no much information on the couplings of a charmed baryon to a charmed meson and light baryon. If considering SU(4) symmetry, we would expect the following relations

$$[\bar{\Sigma}_c^{--} D^+ p] = [\bar{\Sigma}_c^{--} D_s^+ \Sigma^+] = -\sqrt{2}[\bar{\Xi}_c'^{0} D^+ \Sigma^-] = -\sqrt{2}[\bar{\Xi}_c'^{-} D_s^+ \Xi^0]$$
$$= -\frac{2}{\sqrt{3}}[\bar{\Xi}_c'^{-} D^+ \Lambda] = -[\bar{\Omega}_c^0 D^+ \Xi^-] = -\sqrt{2}[\bar{p} K^+ \Sigma^0],$$
$$[\bar{\Lambda}_c^- D^+ n] = [\bar{\Xi}_c^0 D^+ \Sigma^-] = -[\bar{\Xi}_c^- D_s^+ \Xi^0] = -\sqrt{6}[\bar{\Xi}_c^- D^+ \Lambda]$$
$$= \sqrt{\frac{3}{2}}[\bar{\Lambda}_c^- D_s^+ \Lambda] = -[\bar{p} K^+ \Lambda]$$

"[…]" denotes the coupling constant of the corresponding vertex

Numerical Results

$\eta_c \to \bar{B}B$

BR($\times 10^{-4}$)	$p\bar{p}$	$\Lambda\bar{\Lambda}$	$\Sigma^-\bar{\Sigma}^+$	$\Xi^-\bar{\Xi}^+$
Hadron loop	$9.0 \sim 17.0$	$6.3 \sim 12.5$	$5.05 \sim 10.0$	$4.82 \sim 9.56$
Exp.	13 ± 4	10.4 ± 3.1	$\cdots$	$\cdots$

be used to constrain the parameter α

$\chi_{c0} \to \bar{B}B$

BR($\times 10^{-4}$)	$p\bar{p}$	$\Lambda\bar{\Lambda}$	$\Sigma^-\bar{\Sigma}^+$	$\Xi^-\bar{\Xi}^+$
Hadron loop	$1.96 \sim 2.34$	$1.19 \sim 1.51$	$0.55 \sim 0.69$	$0.52 \sim 0.66$
Exp. [4]	2.15 ± 0.19	4.4 ± 1.5	$\cdots$	< 10.3
Exp. [39]	2.25 ± 0.27	4.7 ± 1.6	3.25 ± 1.14	5.14 ± 1.25

← CLEOc

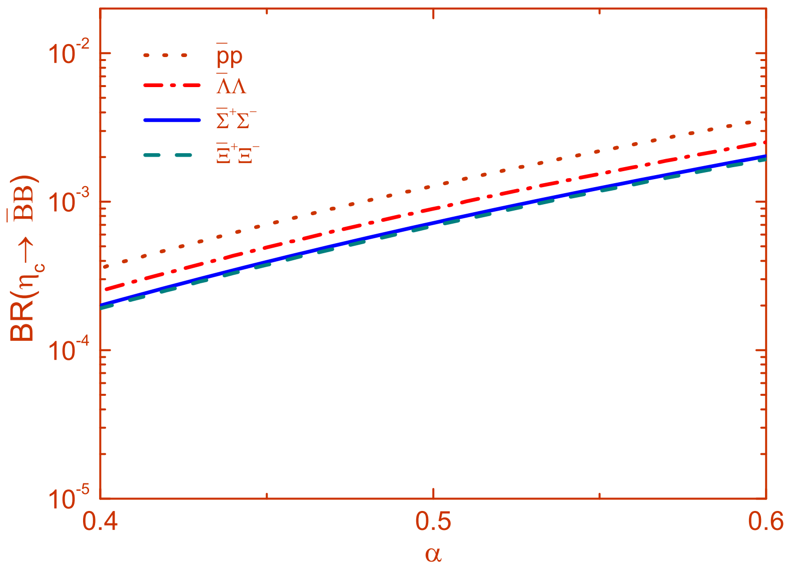
SU(3) symmetry seems to be badly broken here

$h_c \to \bar{B}B$

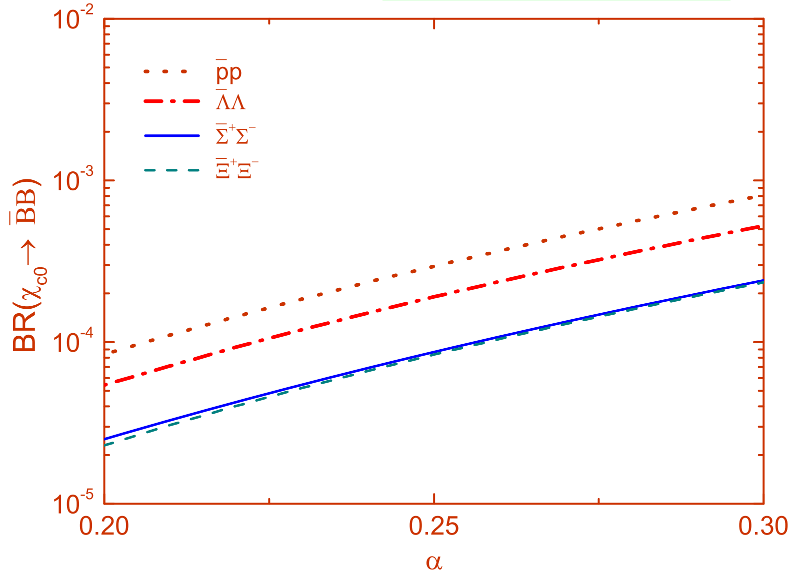
BR($\times 10^{-4}$)	$p\bar{p}$	$\Lambda\bar{\Lambda}$	$\Sigma^-\bar{\Sigma}^+$	$\Xi^-\bar{\Xi}^+$
Hadron loop	$15.2 \sim 19.3$	$5.88 \sim 7.47$	$4.56 \sim 5.80$	$5.57 \sim 7.08$
Exp.	$\cdots$	$\cdots$	$\cdots$	$\cdots$

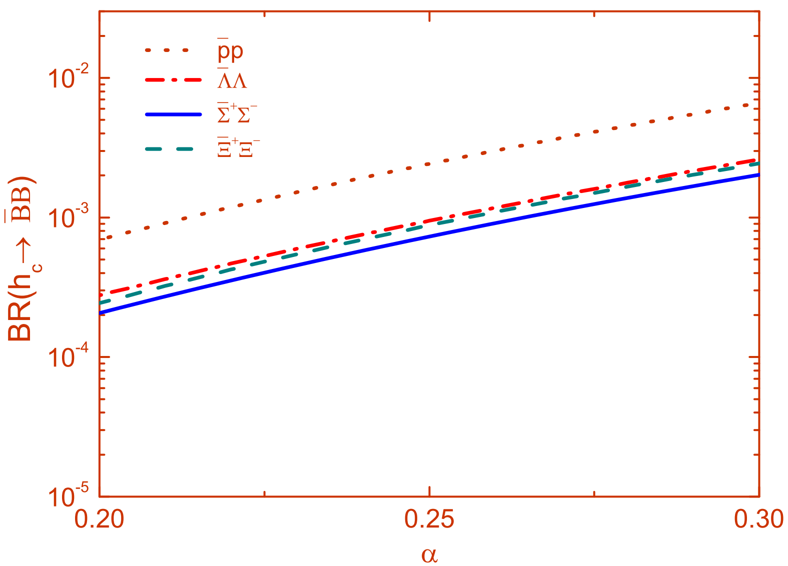
Model-dependence on α

$\eta_c \rightarrow \bar{B}B$



$\chi_{c0} \rightarrow \bar{B}B$





$h_c \rightarrow \bar{B}B$

Summary and Outlook

- We have investigated the evasion mechanism of helicity selection rule via charmed hadron loops. Within a reasonable range of the values of the parameters, the results indicate that such kind of long distance effect will give sizeable contributions to the processes considered.
- Apart from $\chi_{c1} \rightarrow VV$ and $\chi_{c2} \rightarrow VP$, the evasion mechanism is also further tested in the processes of $\eta_c(\chi_{c0}, h_c) \rightarrow B\bar{B}$.
- We expect that the BESIII experiments will provide a good opportunity for revealing the underlying mechanisms in charmonium hadronic decays, with its huge data sample.

Thanks!