



The Rescattering Mechanism and Doubly Heavy Baryon Decays

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Outline

- Introduction
- Framework of the rescattering mechanism
- Results of doubly heavy baryon decays
- Some discussions on the rescattering mechanism
- Summary



Introduction



The story begin with charm decays. On theoretical side,

- Small energy released, perturbative methods unreliable
- SU(3) analysis, the light front quark model, QCD sum rules, ...
- Plenty of data for charm meson decays – Topological approach

Chau,'86; Chau,Cheng,'87; Bhattacharya, Rosner, '08; Cheng, Chiang,10';

See Prof. Geng & Prof. Yu's talks

Li, Lu, FSY, '12; Geng --



Introduction

What can we do in doubly charm baryon decays?

- SU(3) analysis: Ji Xu '17; Qi-An Zhang '18
- Calculation of form factors: Zhen-Xing Zhao & Yu-Ji Shi '17-
- Calculation of BRs
 - No experimental data – TA loses its power
 - Models are needed – The rescattering mechanism

R.H. Li, C.D. Lu, W. Wang, F.S. Yu, Z.T. Zou, PLB767(2017)232
F.S. Yu, H.Y. Jiang, R.H. Li, C.D. Lu, W. Wang, Z.X. Zhao, CPC42(2018)no.5,051001
L.J. Jiang, B. He, R.H. Li, EPJC78(2018)no.11,961



The rescattering mechanism

➤ D meson decays:

Xue-Qian Li, Bing-Song Zou, Phys.Lett. B399 (1997)297-302;
You-Shan Dai, Dong-Sheng Du, Xue-Qian Li, Zheng-Tao Wei, Bing-Song Zou,
Phys.Rev. D60 (1999) 014014;
Medina Ablikim, Dong-Sheng Du, Mao-Zhi Yang, Phys.Lett.B 536 (2002) 34-42

➤ B meson decays:

Hai-Yang Cheng, Chun-Kiang Chua, Amarjit Soni, Phys.Rev.D 71, 014030(2005)

➤ Baryon decays:

Fu-Sheng Yu, Hua-Yu Jiang, Run-Hui Li, Cai-Dian Lü, Wei Wang, Zhen-Xing Zhao,
Chin.Phys. C42 (2018), 051001



Framework



For a decay $B \rightarrow i$, there is

$$\begin{aligned}\langle i; \text{out} | Q | B; \text{in} \rangle^* &= \sum_j \langle i; \text{out} | j; \text{in} \rangle \langle j; \text{out} | Q | B; \text{in} \rangle \\ &= \sum_j S_{ji}^* \langle j; \text{out} | Q | B; \text{in} \rangle.\end{aligned}$$

With $S = 1 + iT$, one has

$$2 \operatorname{Abs} \langle i; \text{out} | Q | B; \text{in} \rangle = \sum_j T_{ji}^* \langle j; \text{out} | Q | B; \text{in} \rangle.$$

PRD 71,014030



Framework



More specifically, for a two body weak decay

$$\begin{aligned} \text{Abs } M(p_B \rightarrow p_1 p_2) &= \frac{1}{2} \sum_j \left(\prod_{k=1}^j \int \frac{d^3 \vec{q}_k}{(2\pi)^3 2E_k} \right) (2\pi)^4 \delta^4(p_1 + p_2 - \sum_{k=1}^j q_k) \\ &\times M(p_B \rightarrow \{q_k\}) T^*(p_1 p_2 \rightarrow \{q_k\}). \end{aligned}$$

Weak decay at short distance. Strong interactions at long distance.

The dispersive part can be calculated by

$$\text{Dis } A(m_B^2) = \frac{1}{\pi} \int_s^\infty \frac{\text{Abs } A(s')}{s' - m_B^2} ds'$$

PRD 71,014030

Framework

The rescattering part $T^*(p_1 p_2 \rightarrow \{q_k\})$ calculated with the chiral Lagrangian at the hadron level

$$\mathcal{L}_{eff} = \mathcal{L}_{\pi hh} + \mathcal{L}_{\rho hh} + \mathcal{L}_{\pi BB} + \mathcal{L}_{\rho BB} + \mathcal{L}_{\rho\pi\pi} + \mathcal{L}_{\rho\rho\rho} + \mathcal{L}_{\rho DD} + \mathcal{L}_{\pi D^* D} + \mathcal{L}_{\rho D^* D^*},$$

$$\mathcal{L}_{\pi hh} = g_{\pi B_6 B_6} Tr[\bar{B}_6 i \gamma_5 \Pi B_6] + g_{\pi B_3 B_{\bar{3}}} Tr[\bar{B}_{\bar{3}} i \gamma_5 \Pi B_{\bar{3}}] + \{g_{\pi B_6 B_3} Tr[\bar{B}_6 i \gamma_5 \Pi B_{\bar{3}}] + h.c.\},$$

$$\mathcal{L}_{\rho hh} = f_{1\rho B_6 B_6} Tr[\bar{B}_6 \gamma_\mu V^\mu B_6] + \frac{f_{2\rho B_6 B_6}}{2m_6} Tr[\bar{B}_6 \sigma_{\mu\nu} \partial^\mu V^\nu B_6]$$

$$+ f_{1\rho B_{\bar{3}} B_3} Tr[\bar{B}_{\bar{3}} \gamma_\mu V^\mu B_{\bar{3}}] + \frac{f_{2\rho B_{\bar{3}} B_{\bar{3}}}}{2m_{\bar{3}}} Tr[\bar{B}_{\bar{3}} \sigma_{\mu\nu} \partial^\mu V^\nu B_{\bar{3}}]$$

$$+ \{f_{1\rho B_6 B_{\bar{3}}} Tr[\bar{B}_6 \gamma_\mu V^\mu B_{\bar{3}}] + \frac{f_{2\rho B_6 B_{\bar{3}}}}{m_6 + m_{\bar{3}}} Tr[\bar{B}_6 \sigma_{\mu\nu} \partial^\mu V^\nu B_{\bar{3}}] + h.c.\},$$

$$\mathcal{L}_{\pi BB} = g_{\pi BB} Tr[\bar{B} i \gamma_5 \Pi B],$$

$$\mathcal{L}_{\rho BB} = f_{1\rho BB} Tr[\bar{B} \gamma_\mu V^\mu B] + \frac{f_{2\rho BB}}{2m_B} Tr[\bar{B} \sigma_{\mu\nu} \partial^\mu V^\nu B],$$

$$\mathcal{L}_{\rho\pi\pi} = \frac{ig_{\rho\pi\pi}}{\sqrt{2}} Tr[V^\mu [\Pi, \partial_\mu \Pi]],$$

$$\mathcal{L}_{\rho\rho\rho} = \frac{ig_{\rho\rho\rho}}{\sqrt{2}} Tr[(\partial_\nu V_\mu - \partial_\mu V_\nu) V^\mu V^\nu] = \frac{ig_{\rho\rho\rho}}{\sqrt{2}} Tr[(\partial_\nu V_\mu V^\mu - V^\mu \partial_\nu V_\mu) V^\nu],$$

$$\mathcal{L}_{\rho DD} = -ig_{\rho DD} (D_i \partial_\mu D^{j\dagger} - \partial_\mu D_i D^{j\dagger})(V^\mu)_j^i,$$

$$\mathcal{L}_{\pi D^* D} = -g_{\pi D^* D} (D^i \partial^\mu \Pi_{ij} D_\mu^{*j\dagger} + D_\mu^{*i} \partial^\mu \Pi_{ij} D^{j\dagger}),$$

$$\mathcal{L}_{\rho D^* D^*} = ig_{\rho D^* D^*} (D_i^{*\nu} \partial_\mu D_\nu^{*j\dagger} - \partial_\mu D_i^{*\nu} D_\nu^{*j\dagger})(V^\mu)_j^i + 4if_{\rho D^* D^*} D_{i\mu}^{*\dagger} (\partial^\mu V^\nu - \partial^\nu V^\mu)_j^i D_\nu^{*j}.$$

$$\Pi = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix},$$

$$B_6 = \begin{pmatrix} \Sigma_c^{++} & \frac{1}{\sqrt{2}}\Sigma_c^+ & \frac{1}{\sqrt{2}}\Xi_c'^+ \\ \frac{1}{\sqrt{2}}\Sigma_c^+ & \Sigma_c^0 & \frac{1}{\sqrt{2}}\Xi_c'^0 \\ \frac{1}{\sqrt{2}}\Xi_c'^+ & \frac{1}{\sqrt{2}}\Xi_c'^0 & \Omega_c \end{pmatrix},$$

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

$$B_{\bar{3}} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix},$$

$$B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}.$$



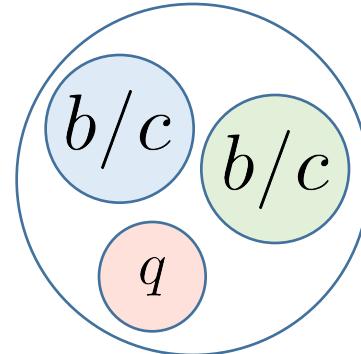
Doubly heavy baryon decays



Doubly heavy baryons (spin-1/2 triplets)

\mathcal{B}_{cc} : Ξ_{cc}^{++} , Ξ_{cc}^+ , Ω_{cc}

\mathcal{B}_{bc} : Ξ_{bc}^+ , Ξ_{bc}^0 , Ω_{bc}



Doubly heavy baryon weak decays under the rescattering mechanism in progress or finished

$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c P$: H.Y. Jiang, F.S. Yu

$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$: L.J. Jiang, B. He, R.H. Li, '18

$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c D$: J.J. Hou, B. He, Y.R. Wang, R.H. Li

$\mathcal{B}_{bc} \rightarrow \mathcal{B}_b P$: Prof. Z.J. Xiao

$\mathcal{B}_{bc} \rightarrow \mathcal{B}_b V$: B. He, J.J. Hou, R.H. Li

$$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$$

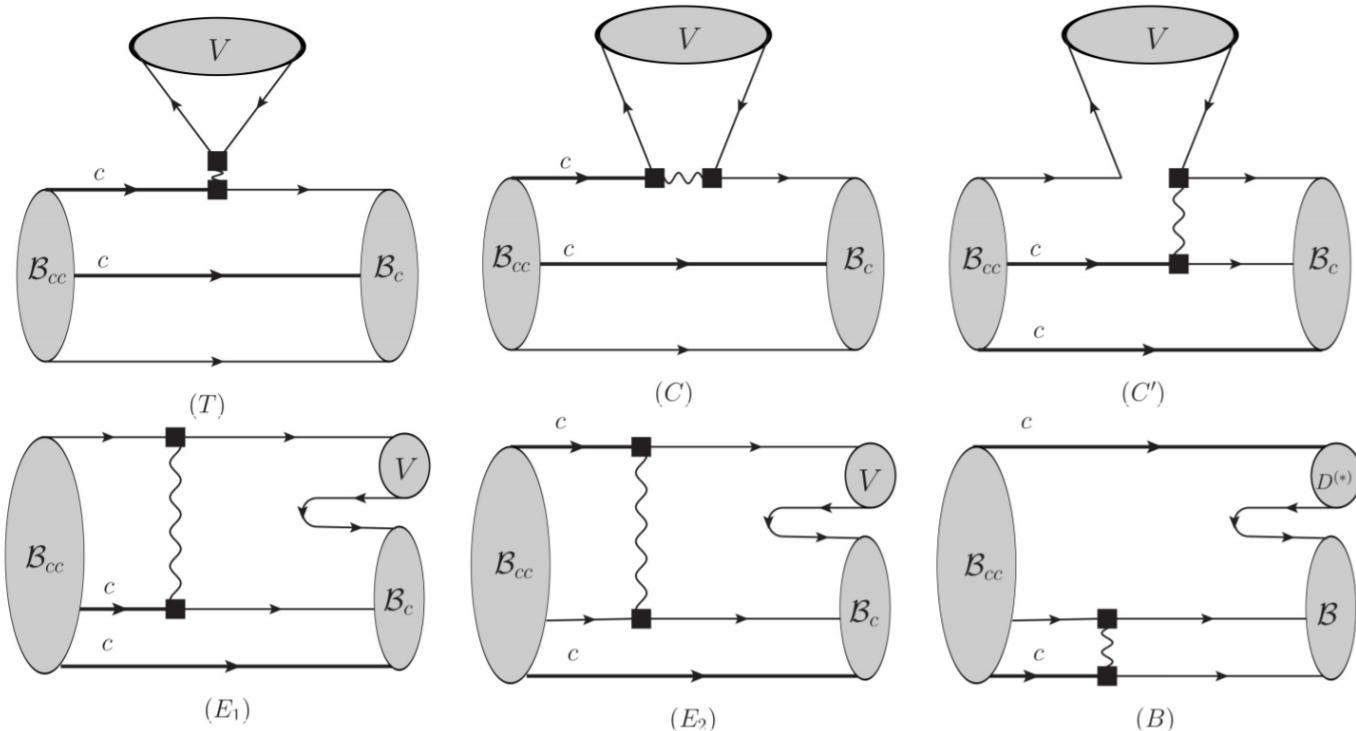
L.J. Jiang, B. He, R.H. Li, EPJC 78(2018)no.11,961

$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$:Topological contributions

The tree level low energy effective Hamiltonian:

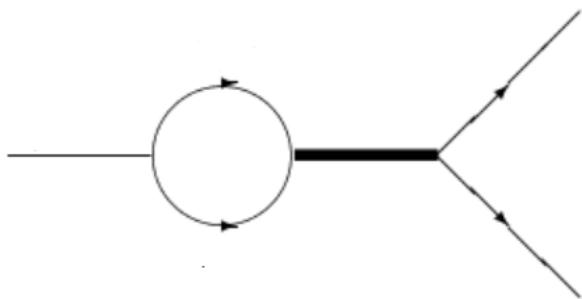
$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} V_{cq}^* V_{uD} [C_1(\mu) O_1^q(\mu) + C_2(\mu) O_2^q(\mu)] + \text{h.c.}$$

Topological contributions for $\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$ decays:

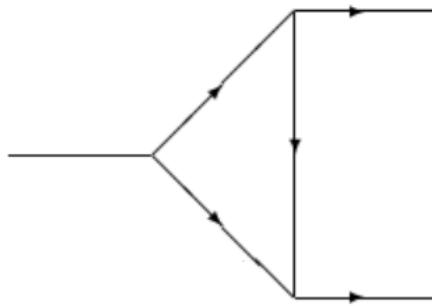


$$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$$

Diagrams in the rescattering mechanism



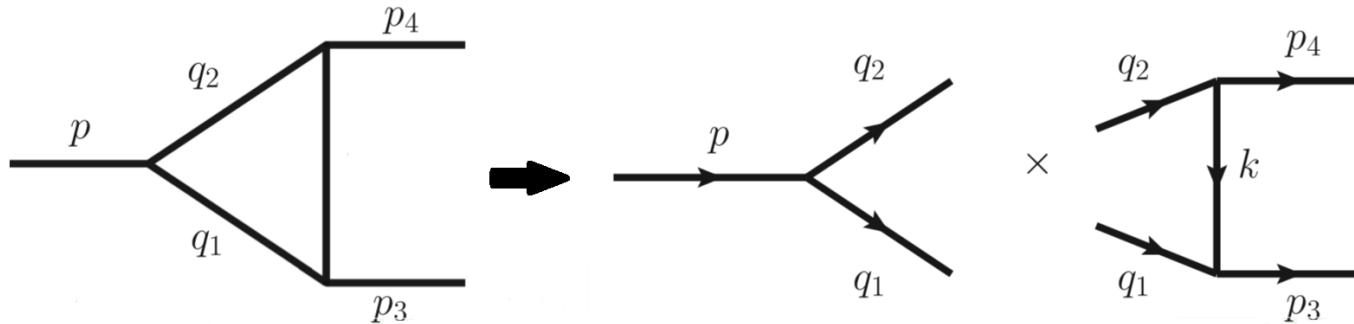
Its contribution depends on whether there exists a resonance particle with nearby mass to the mother particle.



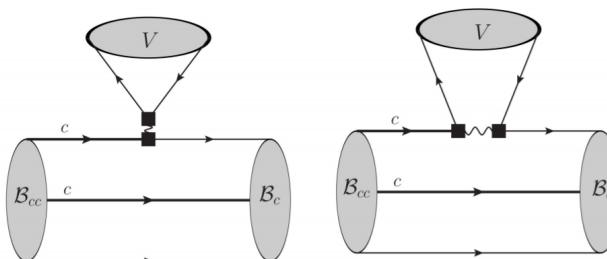
Can be calculated directly or by the optical theorem. In the optical theorem method, a phenomenological factor is associated with the exchanged particle.

$$\mathcal{B}_{cc} \rightarrow \mathcal{B}_c V$$

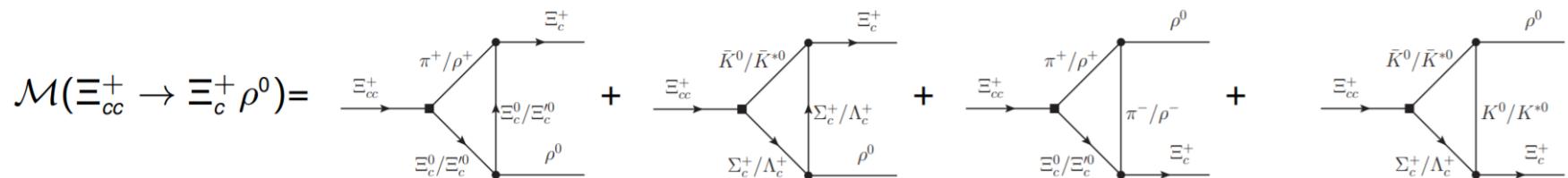
Absorptive part of the amplitude is calculated with the optical theorem.



Emission contribution dominates at short distance, which is calculated with factorization approach.



An example:



$\Xi_{cc}^{++} \rightarrow \mathcal{B}_c V$: BRs

Channels	$\mathcal{BR}(\%)$	Contributions	CKM	Channels	$\mathcal{BR}(\%)$	Contributions	CKM
$\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} \bar{K}^{*0}$	$5.40^{+5.59}_{-3.66}$	C_{SD}, C	CF	$\Xi_{cc}^{++} \rightarrow \Xi_c^+ \rho^+$	$15.98^{+5.33}_{-3.35}$	T_{SD}, T, C'	CF
$\Xi_{cc}^{++} \rightarrow \Xi_c' \rho^+$	$16.54^{+1.25}_{-0.72}$	T_{SD}, T, C'	CF	$\Xi_{cc}^{++} \rightarrow \Sigma_c^+ \rho^+$	$1.05^{+0.08}_{-0.06}$	T_{SD}, T, C'	SCS
$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ \rho^+$	$0.95^{+0.04}_{-0.03}$	T_{SD}, T, C'	SCS	$\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} \rho^0$	$0.45^{+0.51}_{-0.31}$	C_{SD}, C	SCS
$\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} \omega$	$0.14^{+0.10}_{-0.09}$	C_{SD}, C	SCS	$\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} \phi$	$0.09^{+0.08}_{-0.06}$	C_{SD}, C	SCS
$\Xi_{cc}^{++} \rightarrow \Xi_c^+ K^{*+}$	$0.59^{+0.16}_{-0.09}$	T_{SD}, T, C'	SCS	$\Xi_{cc}^{++} \rightarrow \Xi_c' K^{*+}$	$0.80^{+0.10}_{-0.05}$	T_{SD}, T, C'	SCS
$\Xi_{cc}^{++} \rightarrow \Sigma_c^+ K^{*+}$	$0.06^{+0.00}_{-0.01}$	T_{SD}, T, C'	DCS	$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^{*+}$	$0.05^{+0.00}_{-0.00}$	T_{SD}, T, C'	DCS
$\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} K^{*0}$	$0.02^{+0.02}_{-0.01}$	C_{SD}, C	DCS				

- T topology is the dominating contribution; Not so sensitive to long distance contributions.
- C topology is estimated roughly to be about 30% of T; sensitive to the long distance contributions.
- Considering the detection efficiency, $\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} \bar{K}^{*0}$ is chosen as reference of the discovery channel [CPC42,051001].

L.J. Jiang, B. He, R.H. Li, EPJC 78(2018)no.11,961

$$\Xi_{cc}^+ \rightarrow \mathcal{B}_c V$$

Channels	Γ/GeV	CKM	Channels	Γ/GeV	CKM
$\Xi_{cc}^+ \rightarrow \Sigma_c^+ \bar{K}^{*0}$	$(8.42^{+8.87}_{-5.74}) * 10^{-14}$	CF	$\Xi_{cc}^+ \rightarrow \Lambda_c^+ \bar{K}^{*0}$	$(7.06^{+7.68}_{-4.86}) * 10^{-14}$	CF
$\Xi_{cc}^+ \rightarrow \Xi_c^0 \rho^+$	$(3.83^{+0.47}_{-0.37}) * 10^{-13}$	CF	$\Xi_{cc}^+ \rightarrow \Xi_c^{'0} \rho^+$	$(4.77^{+0.31}_{-0.24}) * 10^{-13}$	CF
$\Xi_{cc}^+ \rightarrow \Xi_c^+ \rho^0$	$(1.82^{+1.85}_{-1.22}) * 10^{-13}$	CF	$\Xi_{cc}^+ \rightarrow \Xi_c^{'+} \rho^0$	$(6.13^{+6.23}_{-4.14}) * 10^{-14}$	CF
$\Xi_{cc}^+ \rightarrow \Xi_c^+ \omega$	$(1.63^{+1.87}_{-1.14}) * 10^{-14}$	CF	$\Xi_{cc}^+ \rightarrow \Xi_c^{'+} \omega$	$(2.47^{+2.71}_{-1.70}) * 10^{-15}$	CF
$\Xi_{cc}^+ \rightarrow \Sigma_c^{++} K^{*-}$	$(7.38^{+7.83}_{-5.02}) * 10^{-10}$	CF	$\Xi_{cc}^+ \rightarrow \Xi_c^+ \phi$	$(5.12^{+5.59}_{-3.52}) * 10^{-15}$	CF
$\Xi_{cc}^+ \rightarrow \Xi_c^{'+} \phi$	$(9.90^{+10.24}_{-6.72}) * 10^{-17}$	CF	$\Xi_{cc}^+ \rightarrow \Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$	$* 10^{-14}$	CF
$\Xi_{cc}^+ \rightarrow \Sigma_c^+ \rho^0$	$(1.31^{+1.50}_{-0.91}) * 10^{-14}$	SCS	$\Xi_{cc}^+ \rightarrow \Lambda_c^+ \rho^0$	$(3.36^{+3.33}_{-2.35}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow \Sigma_c^+ \omega$	$(2.21^{+2.37}_{-1.52}) * 10^{-15}$	SCS	$\Xi_{cc}^+ \rightarrow \Lambda_c^+ \omega$	$(1.01^{+1.12}_{-0.70}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow \Sigma_c^0 \rho^+$	$(6.01^{+0.57}_{-0.43}) * 10^{-14}$	SCS	$\Xi_{cc}^+ \rightarrow \Sigma_c^+ \phi$	$(1.54^{+1.40}_{-1.01}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow \Lambda_c^+ \phi$	$(2.61^{+2.67}_{-1.76}) * 10^{-15}$	SCS	$\Xi_{cc}^+ \rightarrow \Xi_c^0 K^{*+}$	$(1.30^{+0.00}_{-0.00}) * 10^{-14}$	SCS
$\Xi_{cc}^+ \rightarrow \Xi_c^{'0} K^{*+}$	$(2.19^{+0.19}_{-0.10}) * 10^{-14}$	SCS	$\Xi_{cc}^+ \rightarrow \Xi_c^+ K^{*0}$	$(1.00^{+0.86}_{-0.64}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow \Xi_c^{'+} K^{*0}$	$(1.53^{+1.47}_{-1.01}) * 10^{-15}$	SCS	$\Xi_{cc}^+ \rightarrow \Sigma_c^{++} \rho^-$	$(9.08^{+9.39}_{-6.14}) * 10^{-17}$	SCS
$\Xi_{cc}^+ \rightarrow \Sigma_c^+ K^{*0}$	$(4.87^{+5.02}_{-3.29}) * 10^{-16}$	DCS	$\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^{*0}$	$(2.54^{+2.86}_{-1.76}) * 10^{-16}$	DCS
$\Xi_{cc}^+ \rightarrow \Sigma_c^0 K^{*+}$	$(2.88^{+0.00}_{-0.00}) * 10^{-15}$	DCS			

H.Y. Cheng, PRD98,113005

Estimated with $\tau_{\Xi_{cc}^+} = 45 fs$, $\mathcal{BR}(\Xi_{cc}^+ \rightarrow \Xi_c^0 \rho^+) \in [2.4\%, 2.9\%]$, $\mathcal{BR}(\Xi_{cc}^+ \rightarrow \Xi_c^{'0} \rho^+) \in [3.1\%, 3.5\%]$, $\mathcal{BR}(\Xi_{cc}^+ \rightarrow \Xi_c^+ \rho^0) \in [0.4\%, 2.5\%]$.

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$$\Omega_{cc} \rightarrow \mathcal{B}_c V$$

Channels	Γ/GeV	CKM	Channels	Γ/GeV	CKM
$\Omega_{cc}^+ \rightarrow \Xi_c^+ \bar{K}^{*0}$	$(1.38^{+1.49}_{-0.95}) * 10^{-13}$	CF	$\Omega_{cc}^+ \rightarrow \Xi_c' + \bar{K}^{*0}$	$(2.64^{+2.72}_{-1.79}) * 10^{-13}$	CF
$\Omega_{cc}^+ \rightarrow \Omega_c^0 \rho^+$	$(8.75^{+0.00}_{-0.00}) * 10^{-13}$	CF	$\Omega_{cc}^+ \rightarrow \Sigma_c^+ \bar{K}^{*0}$	$(1.35^{+1.53}_{-0.96}) * 10^{-15}$	SCS
$\Omega_{cc}^+ \rightarrow \Lambda_c^+ \bar{K}^{*0}$	$(1.00^{+1.16}_{-0.70}) * 10^{-15}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi_c^+ \rho^0$	$(4.28^{+4.78}_{-2.96}) * 10^{-14}$	SCS
$\Omega_{cc}^+ \rightarrow \Xi_c' + \rho^0$	$(8.58^{+9.88}_{-5.98}) * 10^{-14}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi_c^+ \omega$	$(8.22^{+9.60}_{-5.77}) * 10^{-15}$	SCS
$\Omega_{cc}^+ \rightarrow \Xi_c' + \omega$	$(6.09^{+6.52}_{-4.18}) * 10^{-15}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi_c^0 \rho^+$	$(2.87^{+0.69}_{-0.49}) * 10^{-14}$	SCS
$\Omega_{cc}^+ \rightarrow \Xi_c' 0 \rho^+$	$(2.85^{+0.19}_{-0.14}) * 10^{-14}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi_c^+ K^- \pi^+$	$(1.86^{+1.74}_{-1.23}) * 10^{-15}$	SCS
$\Omega_{cc}^+ \rightarrow \Xi_c' + \phi$	$(9.45^{+8.84}_{-6.23}) * 10^{-15}$	SCS	$\Omega_{cc}^+ \rightarrow \Sigma_c^+ \bar{\Lambda}_c^0$	$(4.18^{+0.02}_{-0.01}) * 10^{-14}$	SCS
$\Omega_{cc}^+ \rightarrow \Sigma_c^{++} K^{*-}$	$(1.63^{+2.06}_{-1.16}) * 10^{-17}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi_c' + K^{*0}$	$(4.77^{+5.07}_{-3.26}) * 10^{-16}$	DCS
$\Omega_{cc}^+ \rightarrow \Sigma_c^+ \phi$	$(8.45^{+9.15}_{-5.81}) * 10^{-17}$	DCS	$\Omega_{cc}^+ \rightarrow \Lambda_c^+ \phi$	$(4.25^{+4.64}_{-2.93}) * 10^{-17}$	DCS
$\Omega_{cc}^+ \rightarrow \Xi_c^0 K^{*+}$	$(1.00^{+0.01}_{-0.00}) * 10^{-15}$	DCS	$\Omega_{cc}^+ \rightarrow \Xi_c' 0 K^{*+}$	$(1.12^{+1.22}_{-0.77}) * 10^{-16}$	DCS
$\Omega_{cc}^+ \rightarrow \Xi_c^+ K^{*0}$	$(6.24^{+6.49}_{-4.23}) * 10^{-16}$	DCS	$\Omega_{cc}^+ \rightarrow \Sigma_c^{++} \rho^-$	$(1.20^{+1.38}_{-0.84}) * 10^{-17}$	DCS
$\Omega_{cc}^+ \rightarrow \Sigma_c^+ \rho^0$	$(4.27^{+4.87}_{-2.98}) * 10^{-17}$	DCS	$\Omega_{cc}^+ \rightarrow \Lambda_c^+ \rho^0$	$(4.10^{+4.74}_{-2.87}) * 10^{-17}$	DCS
$\Omega_{cc}^+ \rightarrow \Sigma_c^+ \omega$	$(1.74^{+2.05}_{-1.23}) * 10^{-17}$	DCS	$\Omega_{cc}^+ \rightarrow \Lambda_c^+ \omega$	$(1.76^{+2.23}_{-1.27}) * 10^{-17}$	DCS
$\Omega_{cc}^+ \rightarrow \Sigma_c^0 \rho^+$	$(1.39^{+1.62}_{-0.97}) * 10^{-16}$	DCS			

H.Y. Cheng, PRD98,113005

Estimated with $\tau_{\Omega_{cc}^+} = 75 fs$, $\mathcal{BR}(\Omega_{cc}^+ \rightarrow \Xi_c^+ \bar{K}^{*0}) \in [0.5\%, 3.3\%]$, $\mathcal{BR}(\Omega_{cc}^+ \rightarrow \Xi_c' + \bar{K}^{*0}) \in [1.0\%, 6.1\%]$, $\mathcal{BR}(\Omega_{cc}^+ \rightarrow \Omega_c^0 \rho^+) \approx 10.0\%$.

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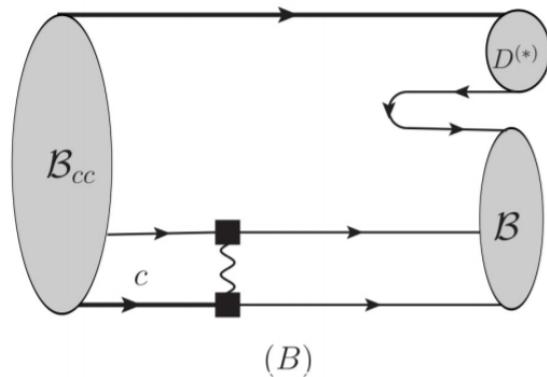
$$\mathcal{B}_{cc} \rightarrow \mathcal{B}D$$

- Why this process?
- Because we can.



J.J. Hou, B. He, Y.R. Wang, R.H. Li in preparation

Pure bow tie contribution.



(B)

J.J. Hou, B. He, Y.R. Wang, R.H. Li in preparation

$\mathcal{B}_{cc} \rightarrow \mathcal{B}D$

$$\Xi_{cc}^{++} \rightarrow \mathcal{B}D$$

Channels	$\mathcal{BR}(10^{-3})$	CKM	Channels	$\mathcal{BR}(10^{-3})$	CKM
$\Xi_{cc}^{++} \rightarrow \Sigma^+ D^+$	$2.98^{+3.16}_{-2.02}$	CF	$\Xi_{cc}^{++} \rightarrow \Sigma^+ D^{*+}$	$16.06^{+17.28}_{-10.50}$	CF
$\Xi_{cc}^{++} \rightarrow \Sigma^+ D_s^+$	$0.17^{+0.18}_{-0.12}$	SCS	$\Xi_{cc}^{++} \rightarrow \Sigma^+ D_s^{*+}$	$2.68^{+2.64}_{-1.71}$	SCS
$\Xi_{cc}^{++} \rightarrow p D^+$	$0.16^{+0.18}_{-0.11}$	SCS	$\Xi_{cc}^{++} \rightarrow p D^{*+}$	$2.96^{+3.38}_{-2.06}$	SCS
$\Xi_{cc}^{++} \rightarrow p D_s^+$	$0.01^{+0.02}_{-0.00}$	DCS	$\Xi_{cc}^{++} \rightarrow p D_s^{*+}$	$0.11^{+0.13}_{-0.07}$	DCS

$$\Xi_{cc}^+ \rightarrow \mathcal{B}D$$

Channels	Γ/GeV	CKM	Channels	Γ/GeV	CKM
$\Xi_{cc}^+ \rightarrow \Sigma^0 D^+$	$(5.93^{+6.31}_{-4.05}) * 10^{-15}$	CF	$\Xi_{cc}^+ \rightarrow \Lambda D^{*+}$	$(1.82^{+2.03}_{-1.26}) * 10^{-13}$	CF
$\Xi_{cc}^+ \rightarrow \Lambda D^+$	$(5.84^{+6.16}_{-3.08}) * 10^{-15}$	CF	$\Xi_{cc}^+ \rightarrow \Sigma^0 D^{*+}$	$(2.17^{+2.45}_{-1.51}) * 10^{-13}$	CF
$\Xi_{cc}^+ \rightarrow \Sigma^+ D^0$	$(1.23^{+1.24}_{-0.77}) * 10^{-15}$	CF	$\Xi_{cc}^+ \rightarrow \Sigma^+ D^{*0}$	$(6.77^{+7.37}_{-4.46}) * 10^{-14}$	CF
$\Xi_{cc}^+ \rightarrow \Xi^0 D_s^+$	$(4.52^{+5.22}_{-3.49}) * 10^{-16}$	CF	$\Xi_{cc}^+ \rightarrow \Xi^0 D_s^{*+}$	$(2.52^{+2.23}_{-1.48}) * 10^{-14}$	CF
$\Xi_{cc}^+ \rightarrow p D^0$	$(1.85^{+2.02}_{-1.27}) * 10^{-15}$	SCS	$\Xi_{cc}^+ \rightarrow \Sigma^0 D_s^{*+}$	$(1.15^{+1.41}_{-0.85}) * 10^{-14}$	SCS
$\Xi_{cc}^+ \rightarrow \Lambda D_s^+$	$(3.00^{+2.93}_{-2.00}) * 10^{-16}$	SCS	$\Xi_{cc}^+ \rightarrow \Lambda D_s^{*+}$	$(1.58^{+1.73}_{-1.09}) * 10^{-14}$	SCS
$\Xi_{cc}^+ \rightarrow n D^+$	$(1.59^{+1.87}_{-1.13}) * 10^{-16}$	SCS	$\Xi_{cc}^+ \rightarrow n D^{*+}$	$(1.04^{+1.41}_{-0.87}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow \Sigma^0 D_s^+$	$(2.85^{+2.72}_{-1.78}) * 10^{-16}$	SCS	$\Xi_{cc}^+ \rightarrow p D^{*0}$	$(9.46^{+10.20}_{-6.49}) * 10^{-15}$	SCS
$\Xi_{cc}^+ \rightarrow n D_s^+$	$(3.26^{+3.88}_{-2.41}) * 10^{-17}$	DCS	$\Xi_{cc}^+ \rightarrow n D_s^{*+}$	$(1.47^{+1.57}_{-1.00}) * 10^{-16}$	DCS

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$\Omega_{cc} \rightarrow \mathcal{B}D$

Channels	Γ/GeV	$\sim 0.21\%$	Channels	Γ/GeV	$\sim 0.57\%$
$\Omega_{cc}^+ \rightarrow \Xi^0 D^+$	$(1.88^{+1.97}_{-1.25}) * 10^{-14}$	CR	$\Omega_{cc}^+ \rightarrow \Xi^0 D^{*+}$	$(4.99^{+4.05}_{-2.62}) * 10^{-14}$	CR
$\Omega_{cc}^+ \rightarrow \Sigma^+ D^0$	$(1.76^{+1.71}_{-1.07}) * 10^{-15}$	SCS	$\Omega_{cc}^+ \rightarrow \Sigma^0 D^{*+}$	$(1.80^{+2.14}_{-1.27}) * 10^{-14}$	$\sim 0.21\%$
$\Omega_{cc}^+ \rightarrow \Lambda D^+$	$(1.75^{+1.98}_{-1.21}) * 10^{-15}$	SCS	$\Omega_{cc}^+ \rightarrow \Lambda D^{*+}$	$(7.65^{+8.69}_{-5.32}) * 10^{-15}$	SCS
$\Omega_{cc}^+ \rightarrow \Xi^0 D_s^+$	$(9.93^{+10.87}_{-6.84}) * 10^{-16}$	SCS	$\Omega_{cc}^+ \rightarrow \Xi^0 D_s^{*+}$	$(4.26^{+4.06}_{-2.81}) * 10^{-16}$	SCS
$\Omega_{cc}^+ \rightarrow \Sigma^0 D^+$	$(2.37^{+2.14}_{-1.20}) * 10^{-16}$	SCS	$\Omega_{cc}^+ \rightarrow \Sigma^+ D^{*0}$	$(6.91^{+6.24}_{-4.15}) * 10^{-15}$	SCS
$\Omega_{cc}^+ \rightarrow \Sigma^0 D_s^+$	$(1.17^{+10.93}_{-6.57}) * 10^{-16}$	DCS	$\Omega_{cc}^+ \rightarrow \Sigma^0 D_s^{*+}$	$(1.68^{+1.92}_{-1.18}) * 10^{-16}$	DCS
$\Omega_{cc}^+ \rightarrow p D^0$	$(1.74^{+2.05}_{-1.23}) * 10^{-17}$	DCS	$\Omega_{cc}^+ \rightarrow p D^{*0}$	$(3.83^{+4.85}_{-2.74}) * 10^{-16}$	DCS
$\Omega_{cc}^+ \rightarrow n D^+$	$(4.32^{+5.56}_{-3.30}) * 10^{-17}$	DCS	$\Omega_{cc}^+ \rightarrow \Lambda D_s^{*+}$	$(1.06^{+1.27}_{-0.75}) * 10^{-16}$	DCS
$\Omega_{cc}^+ \rightarrow \Lambda D_s^+$	$(7.00^{+7.87}_{-4.85}) * 10^{-18}$	DCS	$\Omega_{cc}^+ \rightarrow n D^{*+}$	$(2.74^{+3.29}_{-2.09}) * 10^{-17}$	DCS

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$$\mathcal{B}_{bc} \rightarrow \mathcal{B}_b V$$

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$$\Xi_{bc}^+ \rightarrow \mathcal{B}_b V$$

Table 1: decay branching ratios of $\Xi_{bc}^+ \rightarrow \mathcal{B}_b V$

Channels	$\mathcal{BR}(\%)$	Contributions	CKM	Channels	$\mathcal{BR}(\%)$	Contributions	CKM
$\Xi_b^{'+} \rho^+$	$10.922^{+1.578}_{-1.466}$	T_{SD}, T, C'	CF	$\Xi_b^0 \rho^+$	$7.838^{+0.629}_{-0.366}$	T_{SD}, T, C'	CF
$\Sigma_b^+ \bar{K}^{*0}$	$3.854^{+4.098}_{-2.632}$	C_{SD}, C	CF	$\Lambda_b^0 \rho^+$	$0.620^{+0.017}_{-0.012}$	T_{SD}, T, C'	SCS
$\Sigma_b^0 \rho^+$	$0.536^{+0.043}_{-0.027}$	T_{SD}, T, C'	SCS	$\Sigma_b^+ \rho^0$	$0.444^{+0.504}_{-0.310}$	C_{SD}, C, C'	SCS
$\Xi_b^{'+} K^{*+}$	$0.379^{+0.049}_{-0.027}$	T_{SD}, T, C'	SCS	$\Xi_b^0 K^{*+}$	$0.359^{+0.064}_{-0.038}$	T_{SD}, T, C'	SCS
$\Sigma_b^+ \phi$	$0.064^{+0.056}_{-0.042}$	C_{SD}, C	SCS	$\Sigma_b^+ \omega$	$0.057^{+0.063}_{-0.039}$	C_{SD}, C, C'	SCS
$\Lambda_b^0 K^{*+}$	$0.032^{+0.003}_{-0.001}$	T_{SD}, T, C'	DCS	$\Sigma_b^0 K^{*+}$	$0.029^{+0.003}_{-0.002}$	T_{SD}, T, C'	DCS
$\Sigma_b^+ K^{*0}$	$0.012^{+0.014}_{-0.008}$	C_{SD}, C	DCS				

Calculated with $\tau_{\Xi_{bc}^+} = 240$ fs . [PRD98,113004(2018)]

B. He, J.J. Hou, R.H. Li, in preparation

$\Xi_{bc}^0 \rightarrow \mathcal{B}_b V$

Table 1: decay branching ratios of $\Xi_{bc}^0 \rightarrow \mathcal{B}_b V$

Channels	$\mathcal{BR}(\%)$	Contributions	CKM	Channels	$\mathcal{BR}(\%)$	Contributions	CKM
$\Xi_b^- \rho^+$	$7.736^{+0.464}_{-0.354}$	T_{SD}, T, E_1	CF	$\Xi_b^- \rho^+$	$7.200^{+0.400}_{-0.306}$	T_{SD}, T, E_1	CF
$\Lambda_b^0 \bar{K}^{*0}$	$1.688^{+1.886}_{-1.168}$	C_{SD}, C, E_2	CF	$\Sigma_b^0 \bar{K}^{*0}$	$1.282^{+1.423}_{-0.885}$	C_{SD}, C, E_2	CF
$\Sigma_b^- \rho^+$	$1.101^{+0.148}_{-0.106}$	T_{SD}, T, E_1	SCS	$\Xi_b^0 \rho^0$	$0.457^{+0.469}_{-0.308}$	C', E_1	CF
$\Xi_b^0 \rho^0$	$0.382^{+0.392}_{-0.259}$	C', E_1	CF	$\Sigma_b^0 \rho^0$	$0.334^{+0.373}_{-0.231}$	C_{SD}, C', C, E_1, E_2	SCS
$\Xi_b^- K^{*+}$	$0.324^{+0.016}_{-0.007}$	T_{SD}, T, E_1	SCS	$\Lambda_b^0 \rho^0$	$0.165^{+0.199}_{-0.117}$	C_{SD}, C', C, E_1, E_2	SCS
$\Omega_b^- K^{*+}$	$0.081^{+0.074}_{-0.053}$	E_1	CF	$\Lambda_b^0 \phi$	$0.051^{+0.053}_{-0.034}$	C_{SD}, C	SCS
$\Sigma_b^- K^{*+}$	$0.049^{+0.000}_{-0.000}$	T_{SD}, T	DCS	$\Sigma_b^0 \phi$	$0.028^{+0.025}_{-0.027}$	C_{SD}, C	SCS
$\Xi_b^0 \phi$	$0.026^{+0.029}_{-0.018}$	E_2	CF	$\Sigma_b^+ K^{*-}$	$0.023^{+0.024}_{-0.015}$	E_2	CF
$\Lambda_b^0 \omega$	$0.015^{+0.017}_{-0.010}$	C_{SD}, C', C, E_1, E_2	SCS	$\Sigma_b^0 \omega$	$0.015^{+0.015}_{-0.010}$	C_{SD}, C', C, E_1, E_2	SCS
$\Xi_b^0 K^{*0}$	$0.014^{+0.014}_{-0.009}$	C', E_2	SCS	$\Xi_b^0 K^{*0}$	$0.014^{+0.013}_{-0.009}$	C', E_2	SCS
$\Xi_b^0 \omega$	$0.007^{+0.008}_{-0.005}$	C', E_1	CF	$\Xi_b^0 \omega$	$0.006^{+0.006}_{-0.004}$	C', E_1	CF
$\Lambda_b^0 K^{*0}$	$0.005^{+0.006}_{-0.003}$	C_{SD}, C', C	DCS	$\Sigma_b^0 K^{*0}$	$0.004^{+0.004}_{-0.003}$	C_{SD}, C', C	DCS
$\Sigma_b^+ \rho^-$	$0.001^{+0.000}_{-0.001}$	E_2	SCS				

Calculated with $\tau_{\Xi_{bc}^0} = 220$ fs . [PRD98,113004(2018)]

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$$\Omega_{bc} \rightarrow \mathcal{B}_b V$$

Table 1: decay branching ratios of $\Omega_{bc}^0 \rightarrow \mathcal{B}_b V$

Channels	$\mathcal{BR}(\%)$	Contributions	CKM	Channels	$\mathcal{BR}(\%)$	Contributions	CKM
$\Omega_b^- \rho^+$	$9.168^{+0.002}_{-0.003}$	T_{SD}, T	CF	$\Xi_b' \bar{K}^{*0}$	$1.417^{+1.363}_{-0.942}$	C_{SD}, C, C'	CF
$\Xi_b^0 \bar{K}^{*0}$	$0.894^{+0.941}_{-0.611}$	C_{SD}, C, C'	CF	$\Xi_b^- \rho^+$	$0.351^{+0.040}_{-0.031}$	T_{SD}, T, E_1	SCS
$\Xi_b' \rho^+$	$0.345^{+0.032}_{-0.023}$	T_{SD}, T, E_1	SCS	$\Omega_b^- K^{*+}$	$0.330^{+0.006}_{-0.001}$	T_{SD}, T, E_1	SCS
$\Xi_b^0 \rho^0$	$0.092^{+0.103}_{-0.064}$	C_{SD}, C, E_1	SCS	$\Xi_b' \rho^0$	$0.077^{+0.084}_{-0.053}$	C_{SD}, C, E_1	SCS
$\Lambda_b^0 \bar{K}^{*0}$	$0.020^{+0.022}_{-0.014}$	C', E_2	SCS	$\Sigma_b^0 \bar{K}^{*0}$	$0.020^{+0.022}_{-0.014}$	C', E_2	SCS
$\Xi_b' K^{*+}$	$0.016^{+0.001}_{-0.001}$	T_{SD}, T, E_1	DCS	$\Xi_b^- K^{*+}$	$0.014^{+0.000}_{-0.000}$	T_{SD}, T, E_1	DCS
$\Xi_b^0 \phi$	$0.009^{+0.007}_{-0.006}$	C_{SD}, C, C', E_2	SCS	$\Xi_b' \phi$	$0.005^{+0.003}_{-0.003}$	C_{SD}, C, C', E_2	SCS
$\Xi_b^0 \omega$	$0.004^{+0.004}_{-0.003}$	C_{SD}, C, E_1	SCS	$\Xi_b' \omega$	$0.003^{+0.003}_{-0.002}$	C_{SD}, C, E_1	SCS
$\Xi_b^0 K^{*0}$	$0.003^{+0.002}_{-0.002}$	C_{SD}, C, E_2	DCS	$\Xi_b' K^{*0}$	$0.002^{+0.003}_{-0.001}$	C_{SD}, C, E_2	DCS
$\Sigma_b^+ K^{*-}$	$0.002^{+0.002}_{-0.001}$	E_2	SCS	$\Sigma_b^0 \rho^0$	$0.002^{+0.010}_{-0.002}$	E_1, E_2	DCS
$\Lambda_b^0 \omega$	$0.002^{+0.001}_{-0.002}$	E_1, E_2	DCS	$\Sigma_b^0 \omega$	$0.002^{+0.001}_{-0.002}$	E_1, E_2	DCS
$\Lambda_b^0 \phi$	$0.001^{+0.001}_{-0.001}$	C'	DCS	$\Sigma_b^0 \phi$	$0.001^{+0.001}_{-0.001}$	C'	DCS
$\Sigma_b^- \rho^+$	$0.001^{+0.002}_{-0.001}$	E_1	DCS	$\Lambda_b^0 \rho^0$	$0.001^{+0.002}_{-0.001}$	E_1, E_2	DCS

Calculated with $\tau_{\Omega_{bc}} = 180$ fs . [PRD98,113004(2018)]

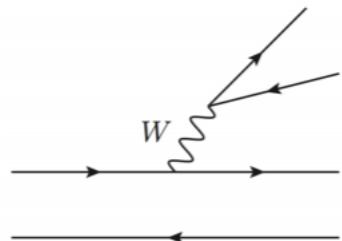
B. He, J.J. Hou, R.H. Li, in preparation

- Isospin triangle relationship
- Relations between triangle diagrams and the topological diagrams

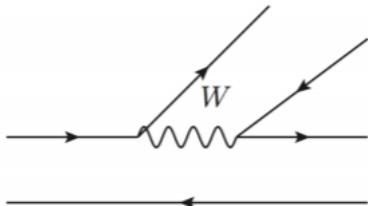
H.Y. Jiang, R.H. Li, F.S. Yu



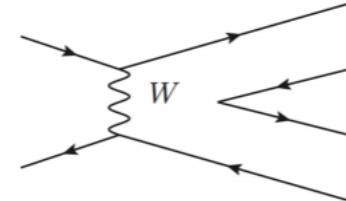
Topological diagrams in $B \rightarrow D\pi$



\mathcal{T}



\mathcal{C}



\mathcal{E}

$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = \mathcal{T} + \mathcal{E}$$

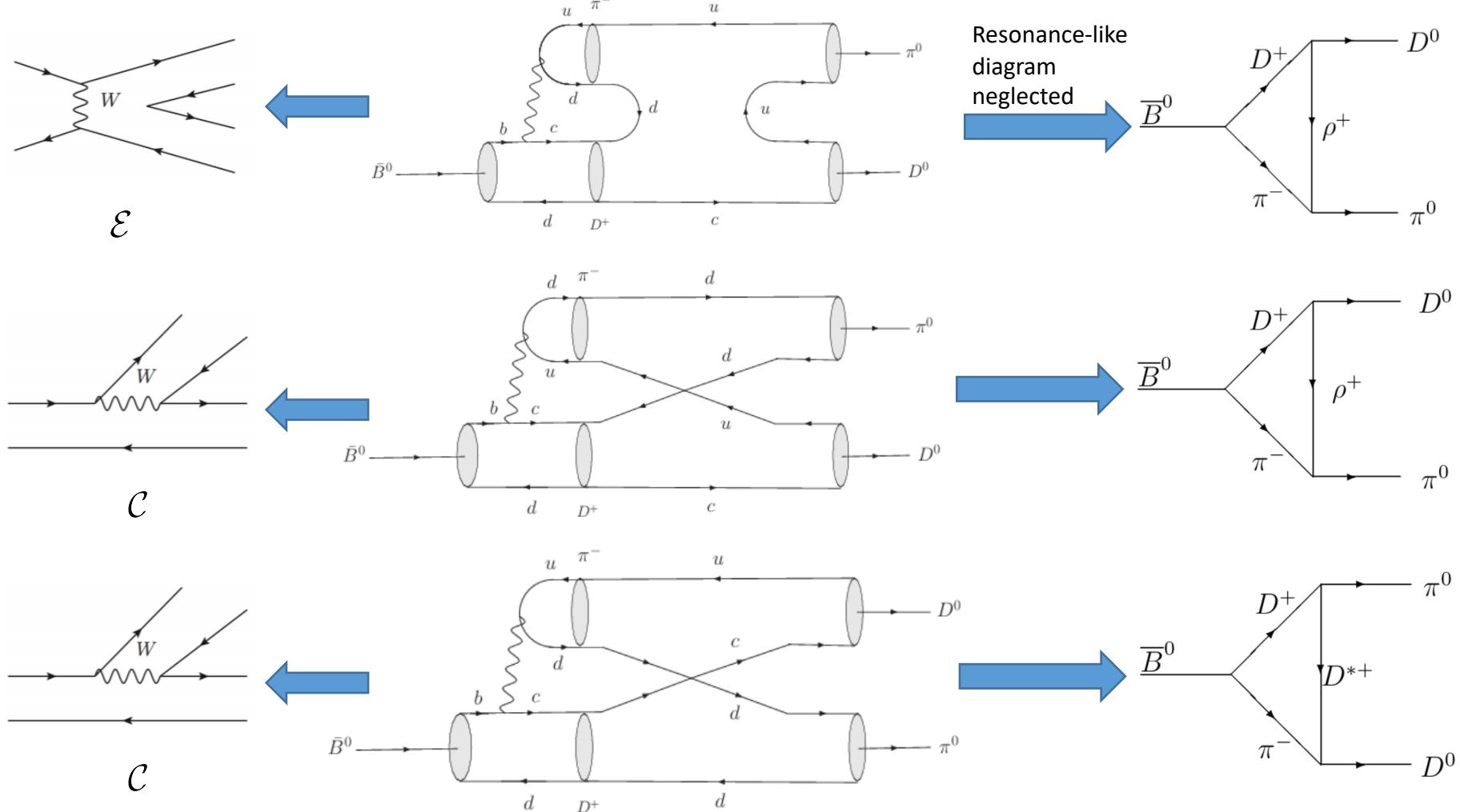
$$A(B^- \rightarrow D^0 \pi^-) = \mathcal{T} + \mathcal{C}$$

$$A(\bar{B}^0 \rightarrow D^0 \pi^0) = \frac{1}{\sqrt{2}}(-\mathcal{C} + \mathcal{E})$$

$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = \sqrt{2}A(\bar{B}^0 \rightarrow D^0 \pi^0) + A(B^- \rightarrow D^0 \pi^-)$$



Quark diagram approach ($\bar{B}^0 \rightarrow D^0\pi^0$)



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Quark diagram approach ($B \rightarrow D\pi$)

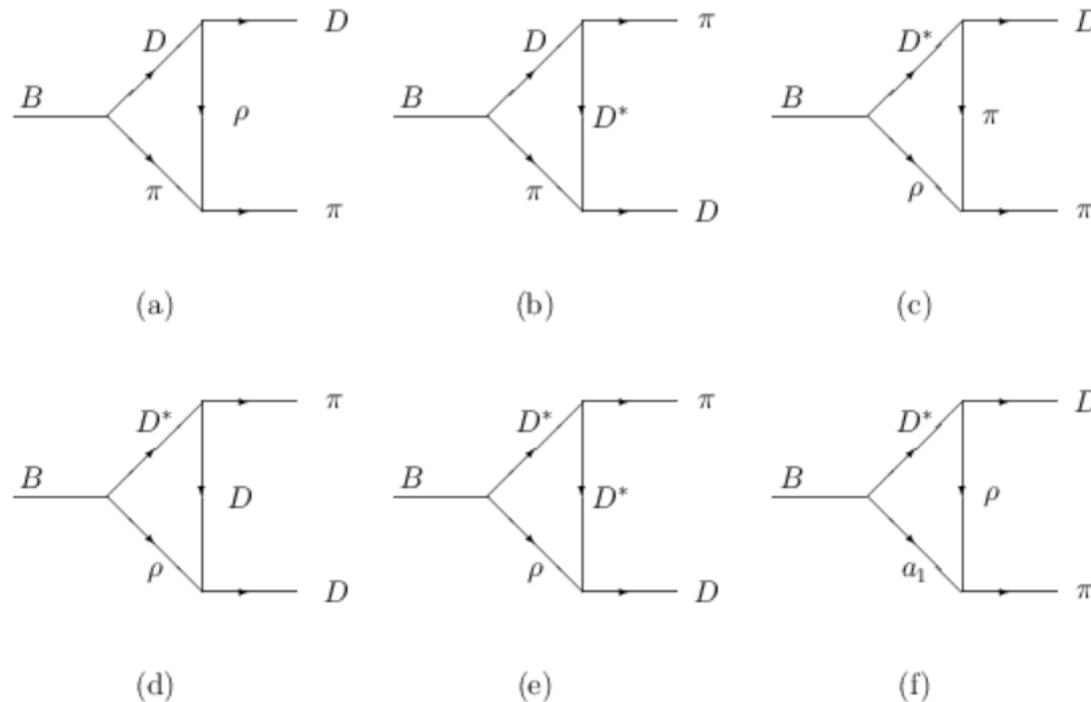


FIG. 4: Long-distance t -channel rescattering contributions to $B \rightarrow D\pi$.

$$\mathcal{T} = \mathcal{T}_{SD},$$

$$\mathcal{C} = \mathcal{C}_{SD} + iAbs(4a + 4b + 4c + 4d + 4e + 4f),$$

$$\mathcal{E} = \mathcal{E}_{SD} + iAbs(4a + 4c + 4f).$$

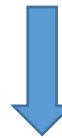
Quark diagram approach ($B \rightarrow D\pi$)

$$A(\overline{B}^0 \rightarrow D^+ \pi^-) = \mathcal{T} + \mathcal{E}$$

$$A(B^- \rightarrow D^0 \pi^-) = \mathcal{T} + \mathcal{C}$$

$$A(\overline{B}^0 \rightarrow D^0 \pi^0) = \frac{1}{\sqrt{2}}(-\mathcal{C} + \mathcal{E})$$

Different actually



$$A(\overline{B}^0 \rightarrow D^+ \pi^-) = \mathcal{T}_{SD} + \mathcal{E}_{SD} + i\mathcal{A}bs(4a + 4c + 4f),$$

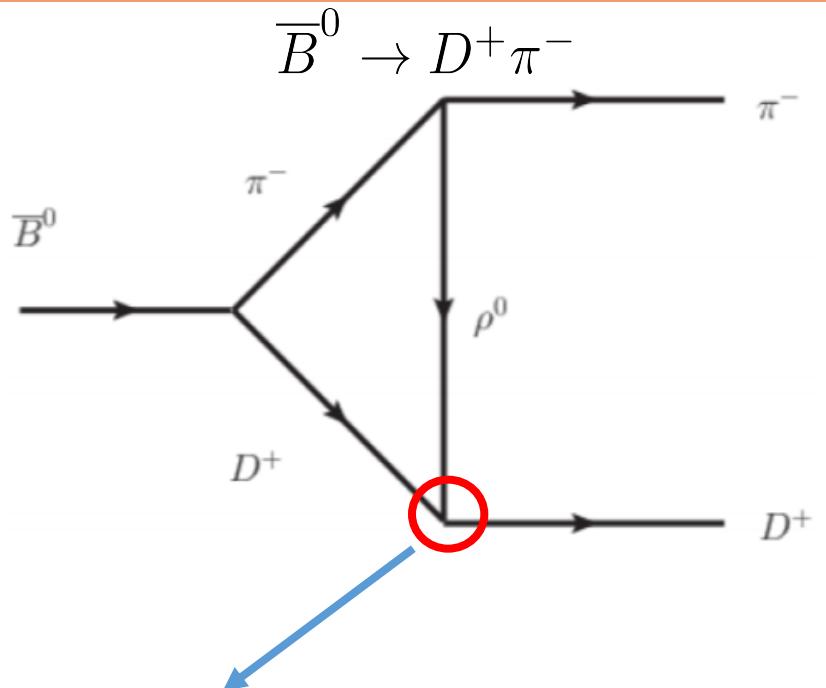
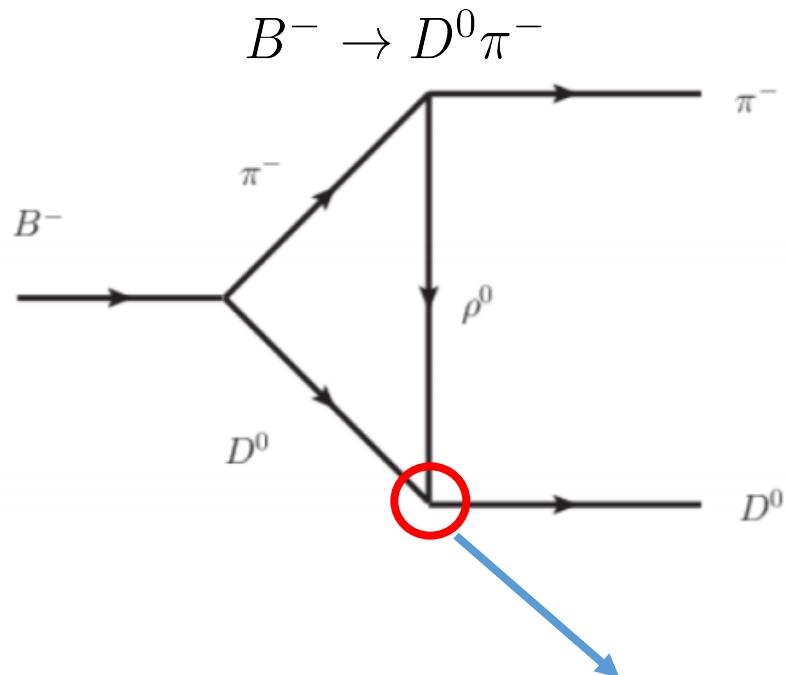
$$A(B^- \rightarrow D^0 \pi^-) = \mathcal{T}_{SD} + \mathcal{C}_{SD} + i\mathcal{A}bs(4a + 4b + 4c + 4d + 4e + 4f),$$

$$A(\overline{B}^0 \rightarrow D^0 \pi^0) = \frac{1}{\sqrt{2}}(-\mathcal{C} + \mathcal{E})_{SD} - \frac{i}{\sqrt{2}}\mathcal{A}bs(4b + 4d + 4e).$$



$$A(\overline{B}^0 \rightarrow D^+ \pi^-) = \sqrt{2}A(\overline{B}^0 \rightarrow D^0 \pi^0) + A(B^- \rightarrow D^0 \pi^-)$$

Fig. 4a for different decays



Opposite sign coupling constants in chiral Lagrangian.

$i\mathcal{A}bs~4a$

$-i\mathcal{A}bs~4a$

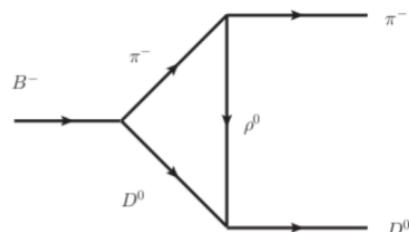
$$A(\bar{B}^0 \rightarrow D^+\pi^-) \neq \sqrt{2}A(\bar{B}^0 \rightarrow D^0\pi^0) + A(B^- \rightarrow D^0\pi^-)$$

The ITR in the rescattering mechanism

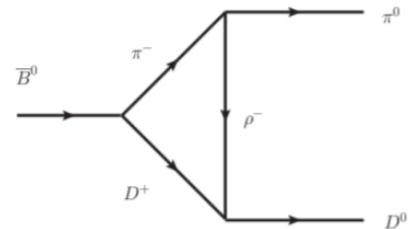
What if performing the calculation with the chiral Lagrangian in Feynman diagram way?

The ITR should be respected in different groups of contributions, respectively.
For the case with intermediate state generated in external W-emission contribution.

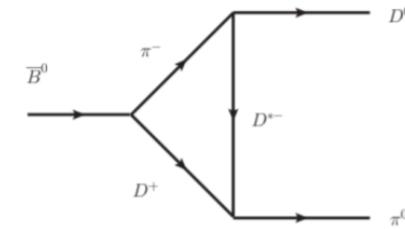
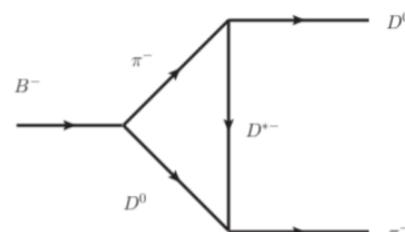
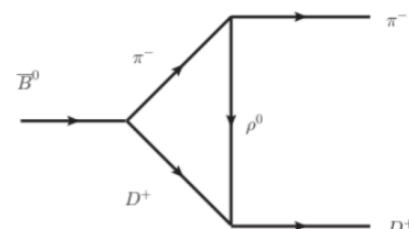
$$B^- \rightarrow D^0\pi^-$$



$$\bar{B}^0 \rightarrow D^0\pi^0$$



$$\bar{B}^0 \rightarrow D^+\pi^-$$



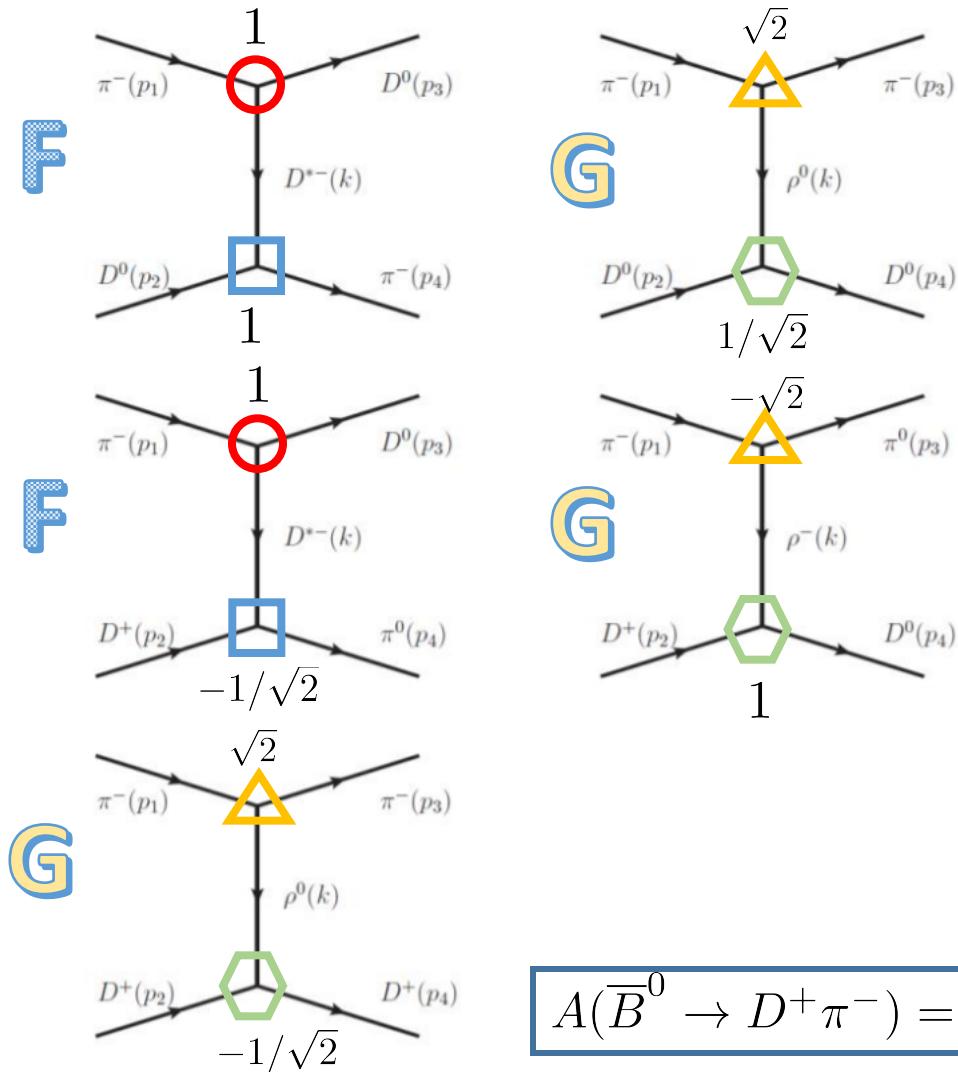
The ITR in the rescattering mechanism

The weak vertices are identical in isospin symmetry. Therefore the relation is determined by the 2-> 2 rescattering part.



$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = T = A(B^- \rightarrow D^0 \pi^-)$$

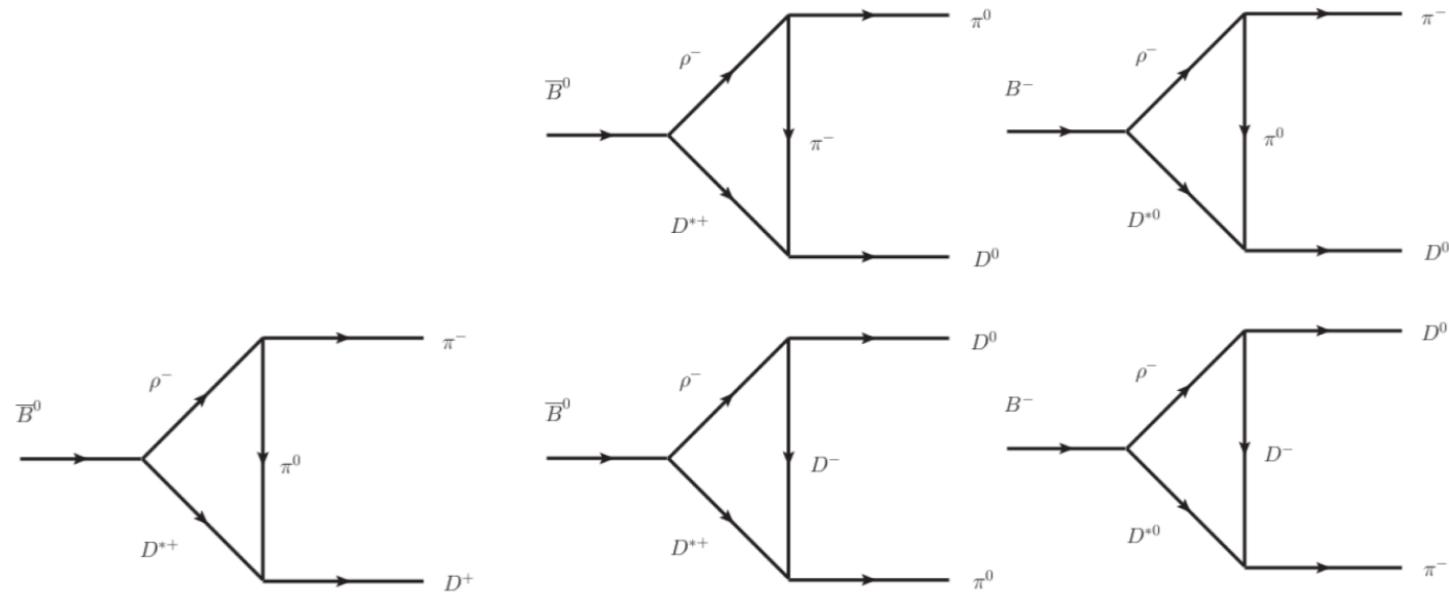
The 2->2 rescattering process in B->D pi



$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = \sqrt{2}A(\bar{B}^0 \rightarrow D^0 \pi^0) + A(B^- \rightarrow D^0 \pi^-)$$

Test ITR in other cases

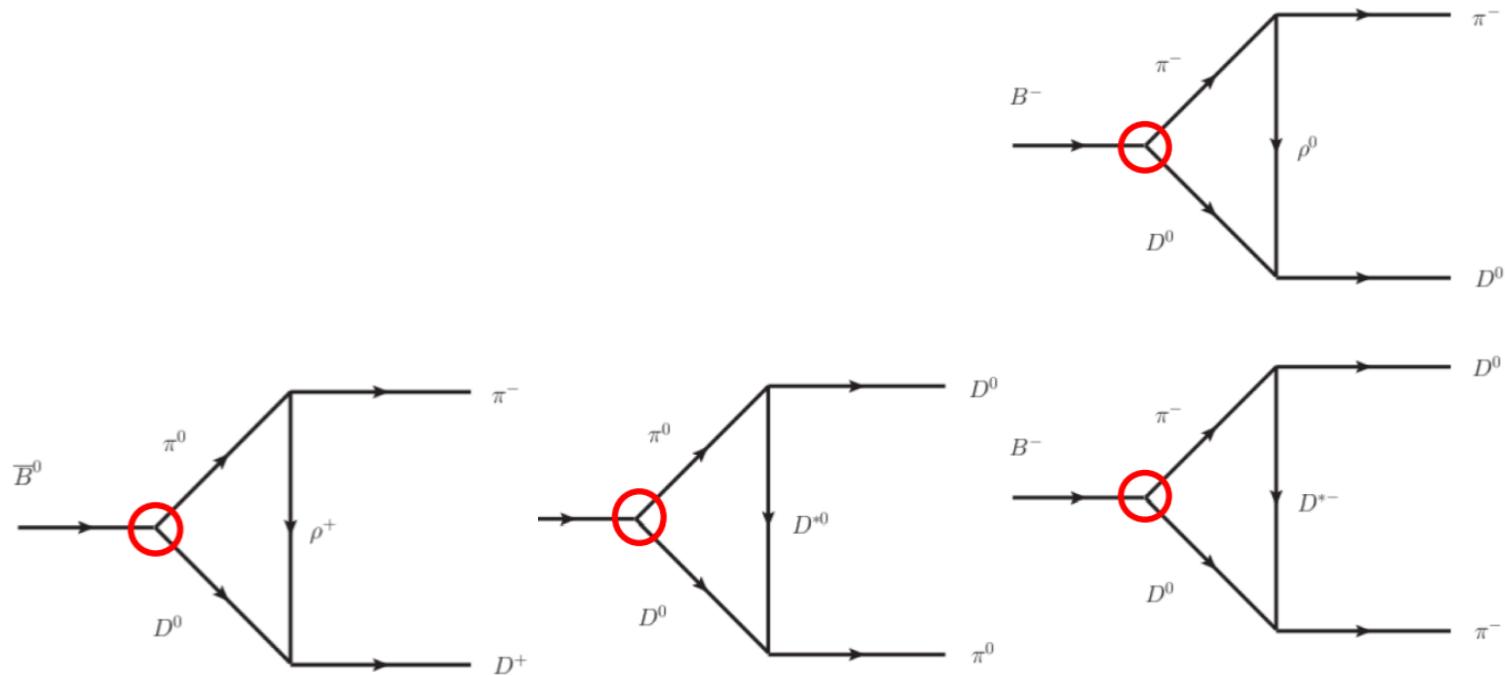
Substitute the intermediate state with excited state particles. ITR is respected.



$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = \sqrt{2}A(\bar{B}^0 \rightarrow D^0 \pi^0) + A(B^- \rightarrow D^0 \pi^-)$$

Test ITR in other cases

For the contributions with intermediate states generated in \mathcal{C} , respected.

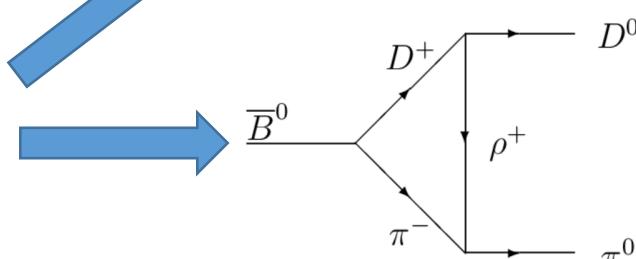
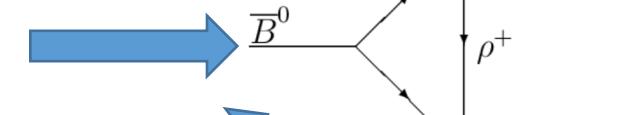
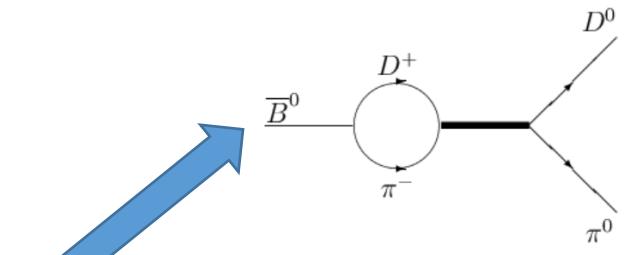
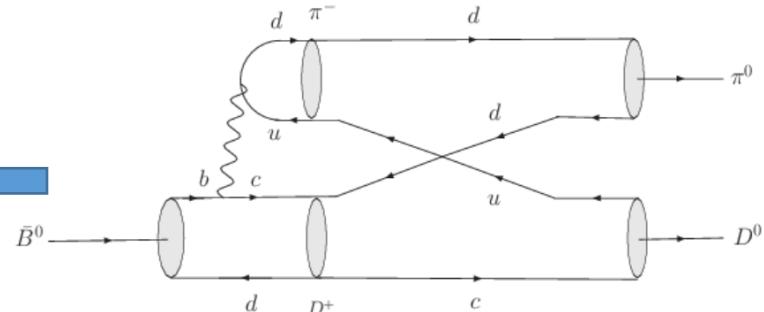
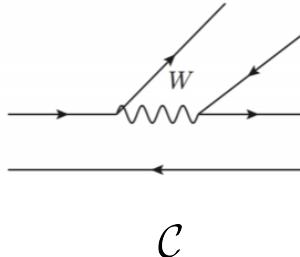
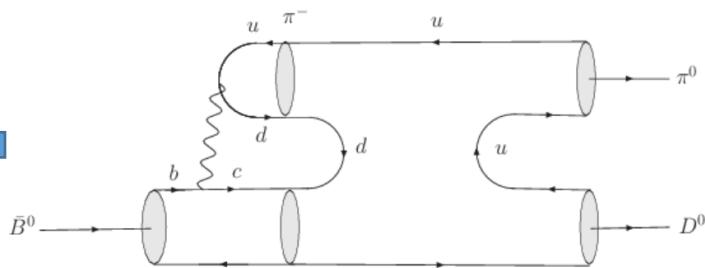
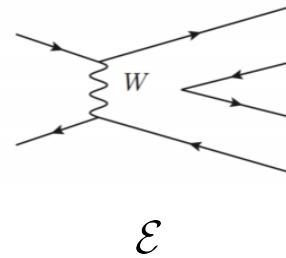


$$A(\bar{B}^0 \rightarrow D^+ \pi^-) = \sqrt{2}A(\bar{B}^0 \rightarrow D^0 \pi^0) + A(B^- \rightarrow D^0 \pi^-)$$



Quark diagram \leftrightarrow hadron level diagram

Let's look back at the relations between quark diagrams and hadron level diagrams



- The rescattering mechanism can be used to estimate charm decays.

The decays of doubly heavy baryons are being calculated

systematically. $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$ and $\Omega_{cc}^+ \rightarrow \Xi_c^+ K^- \pi^+$ may be

used as the discovery channel for Ξ_{cc}^+ and Ω_{cc}^+ .

- Performing the calculation with the chiral Lagrangian in a Feynman diagram way can respect the isospin/SU(3) relations very well.
- The quantitative relations between the quark diagrams (topological diagrams) and triangle diagrams may be not obvious and clear.