Diagrammatic analysis of tetraquark production in B decays

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Outline

- Introduction on tetraquark production in B decays
- Introduction on topological diagrammatic approach
- Successful applications of Topological diagrammatic approach
  - Predictions on charm CP violation
  - Discovery channels of double-charm baryons
- Diagrammatic analysis of tetraquark production in B decays
  - Hidden-charm tetraquarks
  - Open-charm tetraquarks
- Summary

Exotic states observed in B decays

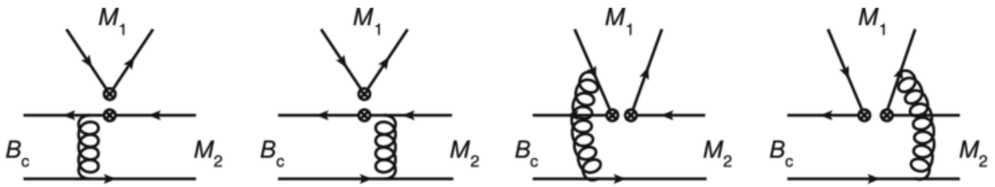
- Productions are very important to explore the nature of exotic states, complementary to their masses and decays.
- B decays are a good place for the production of exotic states.

$\Lambda_b \to J/\psi p K$	$P_c(4312)/P_c(4440)/P_c(4457)$	$B^+ \to D_s^+ \pi^+ D^-$	$T_{c\bar{s}0}(2900)^{++}$
$\Xi_b \to J/\psi \Lambda K$	$P_{cs}(4459)$	$B^0 \to D_s^+ \pi^- \bar{D}^0$	$T_{c\bar{s}0}(2900)^0$
$B_s \to J/\psi p \bar{p}$	$P_c(4337)$	$B^+ \to D^- K^+ D^+$	$X_0(2900)/X_1(2900)$
$B \to J/\psi \Lambda \bar{p}$	$P_{cs}(4338)$	$B^+ \to D^0 \bar{D}^{*0} K^+$	$X(3872)$
$B^0 \to J/\psi \pi^\mp K^\pm$	$Z_c(4200)$	$B^+ \to D_s^+ D_s^- K^+$	$X(3960)$
$B^+ \to J/\psi \omega K^+$	$X(3915)$	$B^+ \to D_s^+ \pi^0 \bar{D}^0$	$D_{s0}(2317)$
$B^+ \to J/\psi \phi K^+$	X(4140)/$Z_{cs}(4000)$, etc	$B^+ \to D_s^{*+} \pi^0 \bar{D}^0$	$D_{s1}(2460)$
$B^0 \to \psi' \pi^\mp K^\pm$	$Z_c(4430)$	$\Lambda_b \to D p \pi$	$\Lambda_c(2940)$
$B^0 \to \chi_{c1} \pi^\mp K^\pm$	$Z_c(4051)/Z_c(4248)$	...	...

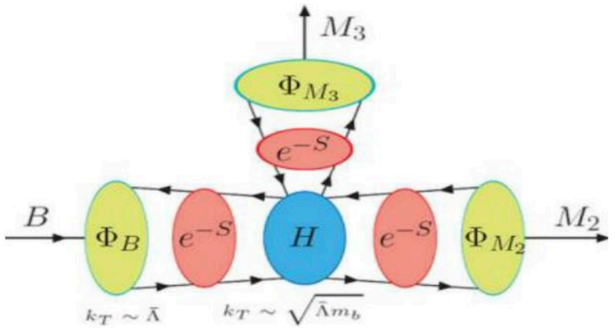
- Question: Does exist general theoretical method to study decays of B into tetraquarks, which can help us get more information about tetraquarks?

Theoretical methods for hadronic weak decays

- QCD-factorization methods are most popular: QCDF, PQCD, SCET.
- They works for energetic final states. First-principle and very predictive.
- Successful for predictions on CPV of B decays.



factorization

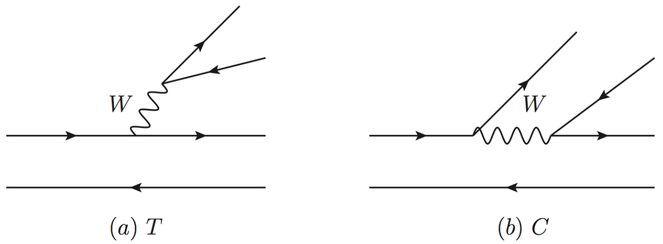


- However, tetraquarks are usually heavy. Final states in B decays are not energetic enough. No factorization ansatz works.
- Topological diagrammatic approach is helpful to study decays of B into tetraquark.

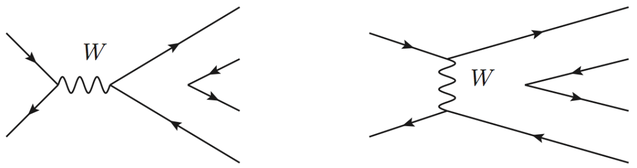
Topological diagrams

- Decaying amplitudes are classified according to the **weak flavour flows**
- **All the strong interaction effects** are included. Non-perturbative contributions are all considered.

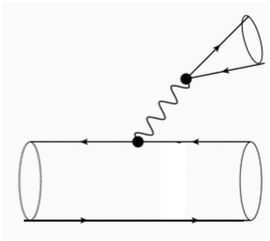
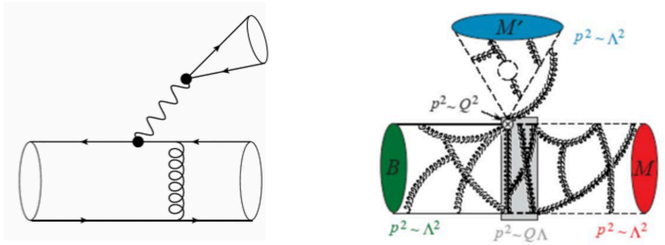
[Chau,'86; Chau,Cheng,'87]



$(a)\ T$ $(b)\ C$



$(c)\ A$ $(d)\ E$

Topological diagrams	Feynman diagrams
	
No Feynman rules, cannot directly calculated, but extracted from data	Have Feynman rules, can be directly calculated

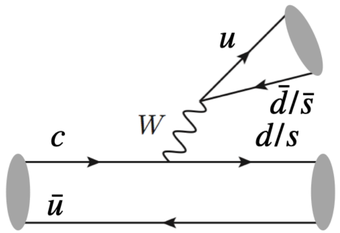
Successful prediction on charm CPV

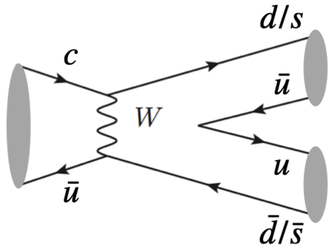
Meson	Mode	Representation	$\mathcal{B}_{\rm exp}$ (%)	$\mathcal{B}_{\rm fit}$ (%)
D^0	$K^-\pi^+$	$V_{cs}^*V_{ud}(T+E)$	3.91 ± 0.08	3.91 ± 0.17
	$\bar{K}^0\pi^0$	$\frac{1}{\sqrt{2}}V_{cs}^*V_{ud}(C-E)$	2.38 ± 0.09	2.36 ± 0.08
	$\bar{K}^0\eta$	$V_{cs}^*V_{ud}[\frac{1}{\sqrt{2}}(C+E)\cos\phi - E\sin\phi]$	0.96 ± 0.06	0.98 ± 0.05
	$\bar{K}^0\eta'$	$V_{cs}^*V_{ud}[\frac{1}{\sqrt{2}}(C+E)\sin\phi + E\cos\phi]$	1.90 ± 0.11	1.91 ± 0.09
D^+	$\bar{K}^0\pi^+$	$V_{cs}^*V_{ud}(T+C)$	3.07 ± 0.10	3.08 ± 0.36
D_s^+	$\bar{K}^0K^+$	$V_{cs}^*V_{ud}(C+A)$	2.98 ± 0.17	2.97 ± 0.32
	$\pi^+\pi^0$	0	<0.037	0
	$\pi^+\eta$	$V_{cs}^*V_{ud}(\sqrt{2}A\cos\phi - T\sin\phi)$	1.84 ± 0.15	1.82 ± 0.32
	$\pi^+\eta'$	$V_{cs}^*V_{ud}(\sqrt{2}A\sin\phi + T\cos\phi)$	3.95 ± 0.34	3.82 ± 0.36

$$T = 3.14 \pm 0.06, \qquad C = (2.61 \pm 0.08)e^{-i(152\pm1)^\circ},$$
$$E = (1.53^{+0.07}_{-0.08})e^{i(122\pm2)^\circ}, \qquad A = (0.39^{+0.13}_{-0.09})e^{i(31^{+20}_{-33})^\circ}$$

Cheng, Chiang,'10

Tree

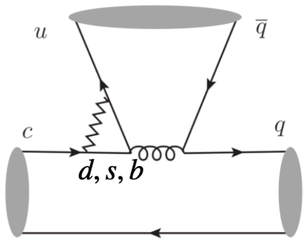


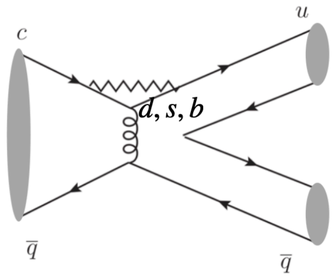


Tree diagrams are determined by data of branching fractions

Understand the dynamics at 1GeV

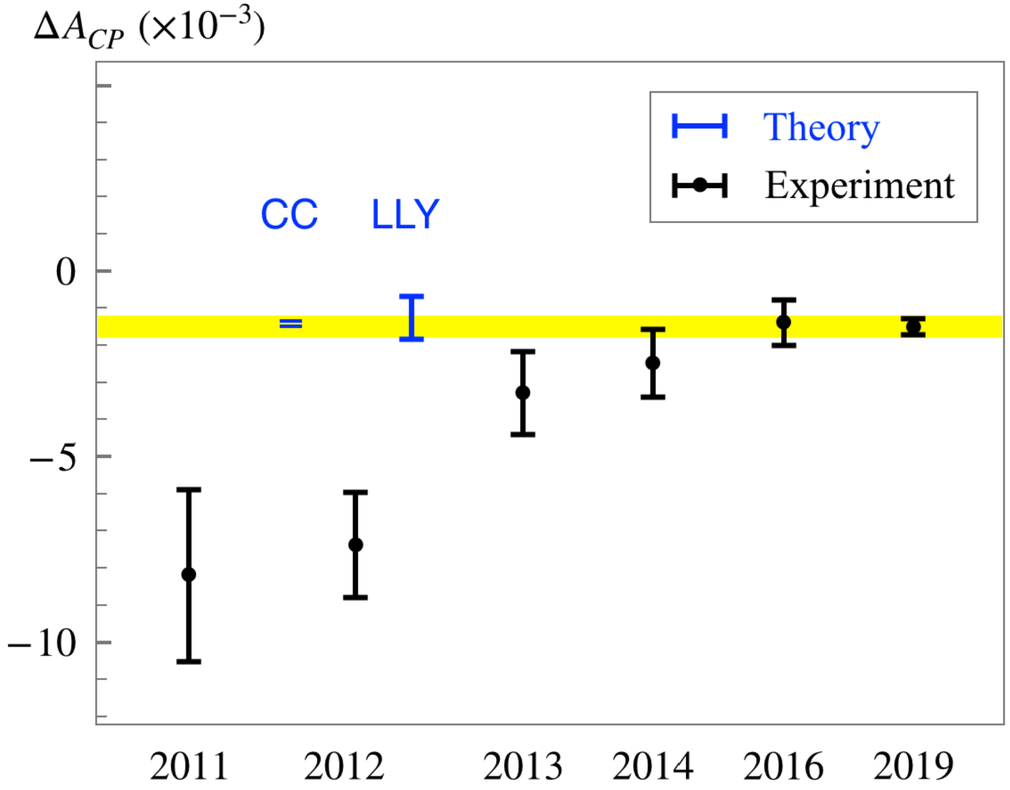
Penguin





Relate the penguins to the trees, with the known dynamics at 1GeV

Successful prediction on charm CPV



Saur, **FSY**, Sci.Bull.2020

$$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

Th: the only predictions of O(10^{-3})

CC: topological approach + QCDF — H.Y.Cheng, C.W.Chiang, 2012

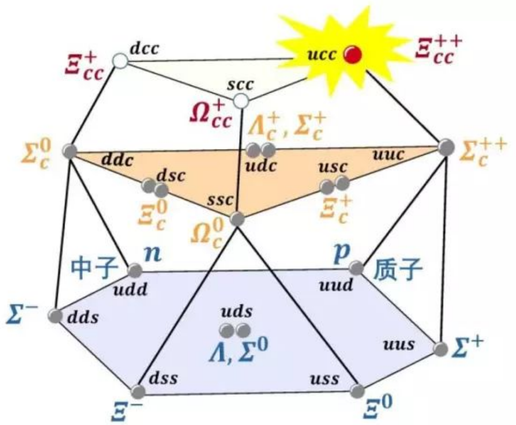
LLY: factorization-assisted topology (FAT) — H.n.Li, C.D.Lu, F.S.Yu, 2012

Exp: LHCb, PRL122, 211803 (2019)

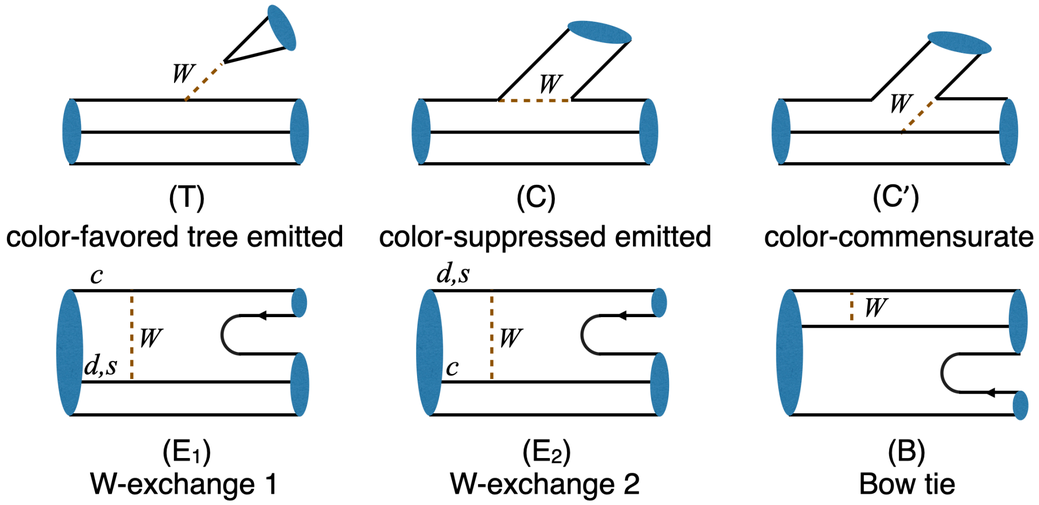
Topological diagrammatic approach successfully predicted the charm CPV !!!

Successful prediction on Ξ_{cc} discovery channel

- What decaying channel to search for double-charm baryons is an important problem before 2017.
- Predictions are required for largest branching fraction.



- Topological diagrammatic approach may help.
- Less data can be used to estimate the order of magnitude of the branching fractions



FSY, Sci.China.PMA, 2020

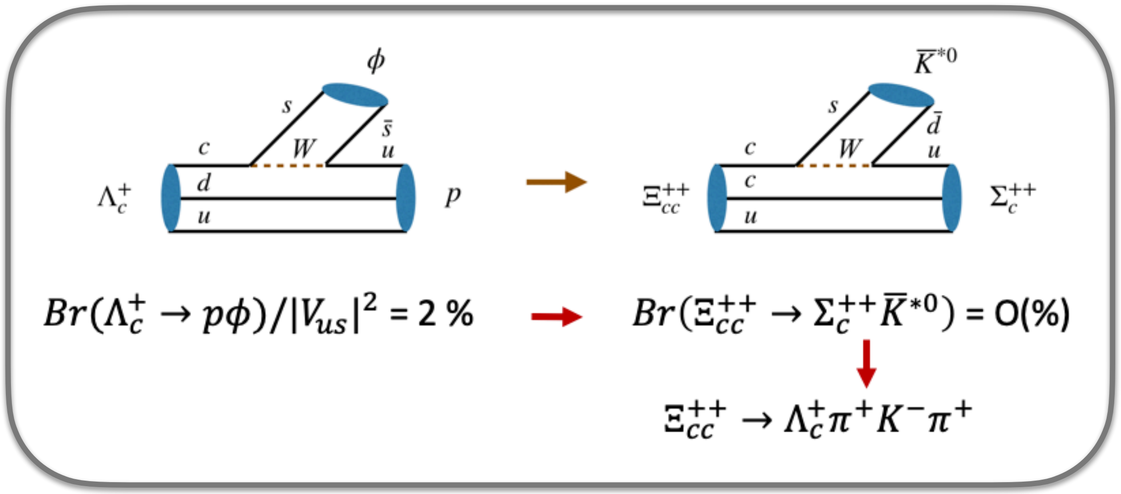
Relations between topological diagrams

- Hierarchy of topological diagrams in heavy quark expansion

SCET: |C/T|~|C'/T|~|E/T|~O($\Lambda_{\rm QCD}/m_Q$) Leibovich, Ligeti, Stewart, Wise, 2004

charm decay: |C/T|~|C'/T|~|E/T|~O($\Lambda_{\rm QCD}/m_c$)~1

- BESIII measurements on Λ_c^+ decays are very helpful BESIII, 2016



$\Lambda_c^+ \to$

Modes	Representation	$\mathcal{B}_{\rm exp}$
$p\overline{K}^0$	$\lambda_{sd}(C+E)$	$(3.04 \pm 0.17)\%$
$\Lambda^0\pi^+$	$\lambda_{sd}(T-C'+B-E)/\sqrt{2}$	$(1.24 \pm 0.08)\%$
$\Delta^{++}K^-$	$\lambda_{sd}E$	$(1.18 \pm 0.27)\%$

Data support hierarchy relations

Successful prediction on Ξ_{cc} discovery channel

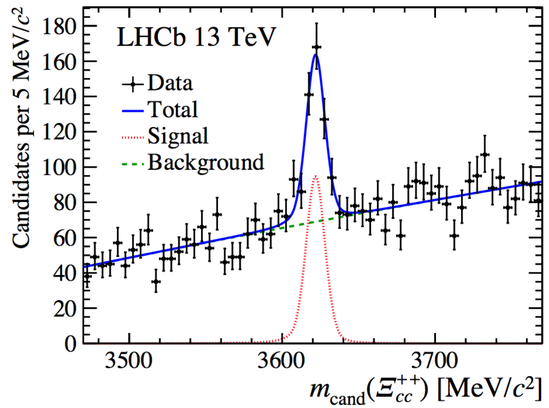
Modes		Br(first)($\times 10^{-3}$)	Br(final)($\times 10^{-3}$)	Representation
$p(D^+/D^0\pi^+)$	😀	8.	0.2	Ccm Vcd Vud
$p(D_s^+/D^0K^+)$		0.4	0.01	Ccm Vcd Vus
$(pK^-\pi^+/\Sigma^+)(D^+/D^0\pi^+)$	😀	80.	2.	Ccm Vcs Vud
$(pK^-\pi^+/\Sigma^+)(D_s^+/D^0K^+)$		3.	0.1	Ccm Vcs Vus
$(\Lambda_c^+\pi^+)(\pi^+\pi^-)$		3.	0.2	-(Ct Vcd Vud)
$(\Lambda_c^+\pi^+)(K^+\pi^-)$		0.2	0.008	Ct Vcd Vus
$(\Lambda_c^+\pi^+)(K^-\pi^+)$	😀	50.	3.	Ct Vcs Vud
$(\Lambda_c^+\pi^+)(K^+K^-)$		2.	0.08	Ct Vcs Vus
$\Lambda_c^+\pi^+$	😀	30.	1.	Ccb Vcd Vud + T Vcd Vud
$\Lambda_c^+K^+$		1.	0.06	Ccb Vcd Vus + T Vcd Vus
$(\Lambda_c^+\pi^+K^-/\Xi_c^+)\pi^+$	😀	400.	20.	Ccb Vcs Vud + T Vcs Vud
$(\Lambda_c^+\pi^+K^-/\Xi_c^+)K^+$		20.	0.9	Ccb Vcs Vus + T Vcs Vus

- discovery channels: Br=O($10^{-3\sim-4}$)

$$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$$

34

LHCb, 2017.07

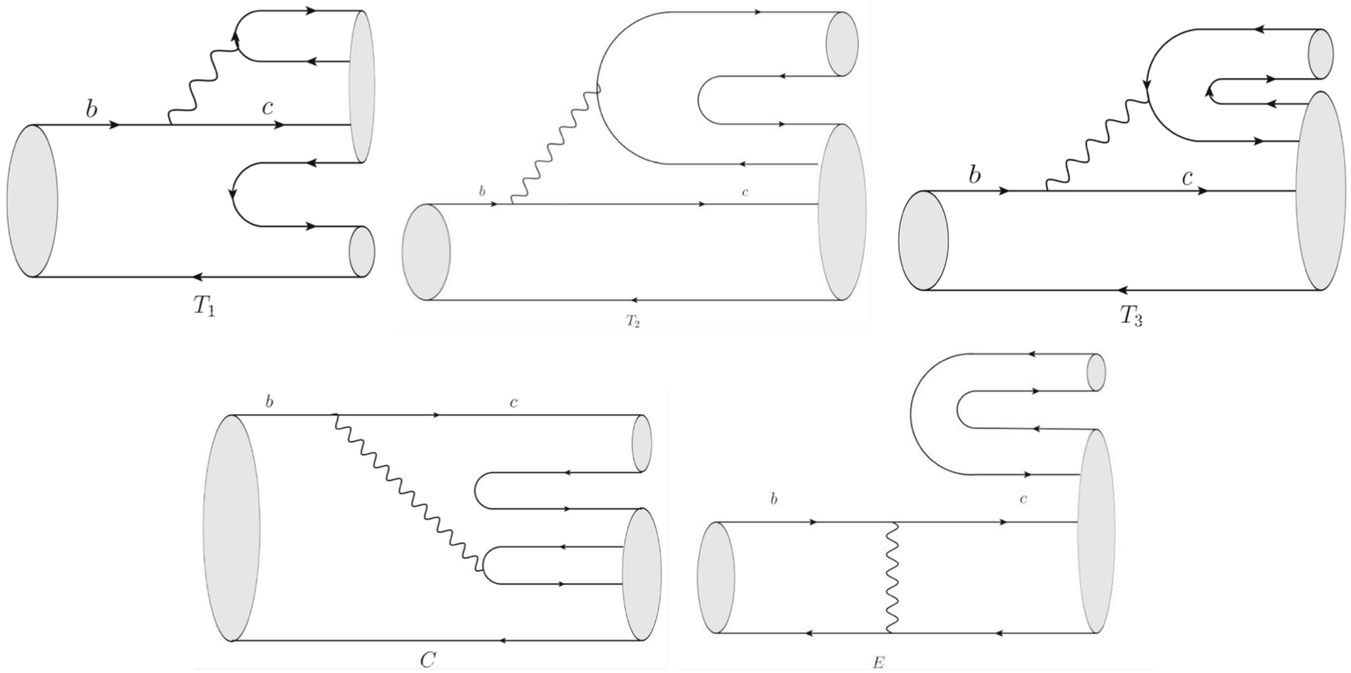


$$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$$

Talk at LHCb in 2016.12

[**FSY**, Jiang, Li, Lu, Wang, Zhao, '17]

Topological diagrams of decays of B into tetraquarks



[Qin, Qiu, **FSY**, ’23]

- No explicit values of decay amplitudes are given. But provide relations between decay channels.
- Processes with identical topological diagrams share analogous branching fractions.

Topological diagrams of decays of B into tetraquarks

- Processes with identical topological diagrams share analogous branching fractions, regardless of what spins and flavor SU(3) representations of the final states.

Meson	Mode	Amplitudes	$\mathcal{B}_{\rm exp}(\times 10^{-5})$	$\mathcal{B}_{\rm FAT}(\times 10^{-5})$
$\overline{B}^0$		$V_{cb}V_{ud}^*$		
	$D_s^+ K^-$	E	3.45 ± 0.32	$3.0^{+0.4}_{-0.2} \pm 0.0 \pm 0.3$
	$D_s^{*+} K^-$	E	2.19 ± 0.30	$2.2^{+0.3}_{-0.1} \pm 0.0 \pm 0.3$
	$D_s^+ K^{*-}$	E	3.5 ± 1.0	$3.8^{+0.5}_{-0.2} \pm 0.0 \pm 0.6$
$\overline{B}^0$		$V_{cb}V_{us}^*$		
	$D^0 \overline{K}^0$	C	5.2 ± 0.7	$4.0 \pm 0.0 \pm 1.0 \pm 0.0$
	$D^{*0} \overline{K}^0$	C	3.6 ± 1.2	$4.5^{+0.2}_{-0.3} \pm 0.9 \pm 0.5$
	$D^0 \overline{K}^{*0}$	C	4.2 ± 0.6	$3.7 \pm 0.2 \pm 0.7 \pm 0.2$
Meson	Mode	Amplitudes	$\mathcal{B}_{\rm exp}(\times 10^{-3})$	$\mathcal{B}_{\rm FAT}(\times 10^{-3})$
$\overline{B}_s^0$		$V_{cb}V_{ud}^*$		
	$D_s^+ \pi^-$	T	3.04 ± 0.23	$3.02 \pm 0.00 \pm 0.6 \pm 0.01$
	$D_s^{*+} \pi^-$	T	2.0 ± 0.5	$2.71 \pm 0.00 \pm 0.54 \pm 0.01$
	$D_s^+ \rho^-$	T	7.0 ± 1.5	$7.86 \pm 0.00 \pm 1.57 \pm 0.79$

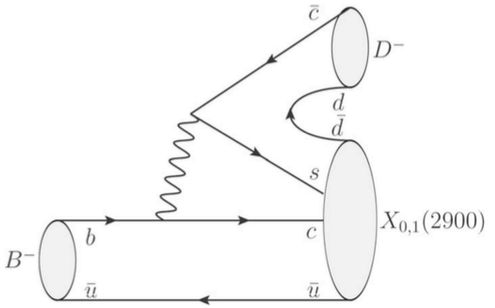
$\propto \chi^E e^{i\phi^E}$

$\propto \chi^C e^{i\phi^C}$

factorization

[Zhou, Wei, Qin, Li, **FSY**, Lu, ’15]

	$Br_{\rm exp}$
$B^- \to D^- X_0(2900)^0$	$(1.23 \pm 0.41) \times 10^{-5}$
$B^- \to D^- X_1(2900)^0$	$(6.73 \pm 2.26) \times 10^{-5}$



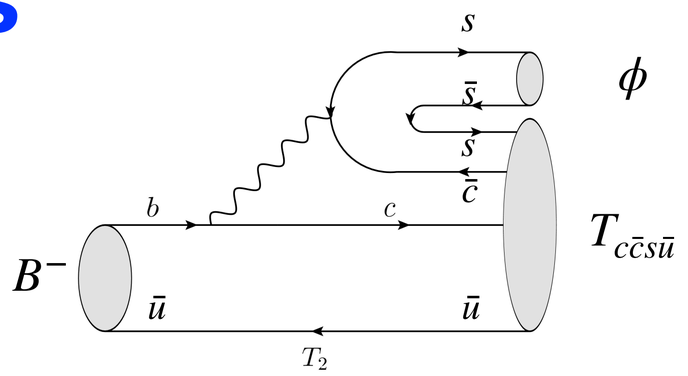
T_3

[Chen, Han, Lu, Wang, **FSY**, ’20]

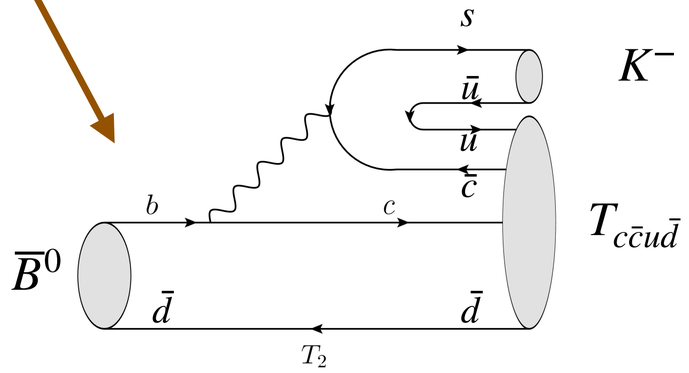
B decays into hidden-charm tetraquarks

Modes	Topological amplitudes	Experimental processes	Experimental processes
$B^- \to T_{c\bar{c}s\bar{u}}\phi$	$T_2\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D_s^{(*)-}\phi$	$B^- \to J/\psi K^-\phi$ [29]
$\overline{B}^0 \to T_{c\bar{c}s\bar{d}}\phi$	$T_2\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}D_s^{(*)-}\phi$	$\overline{B}^0 \to J/\psi \overline{K}^{(*)0}\phi$
$\overline{B}^0 \to T_{c\bar{c}u\bar{d}}K^-$	$T_2\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}\overline{D}^{(*)0}K^-$	$\overline{B}^0 \to J/\psi\pi^+K^-$ [24]
$B^- \to T_{c\bar{c}d\bar{u}}\overline{K}^{(*)0}$	$T_2\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D^{(*)-}\overline{K}^{(*)0}$	$B^- \to J/\psi\pi^-\overline{K}^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}d\bar{s}}\overline{K}^{(*)0}$	$(T_2+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D_s^{(*)+}D^{(*)-}\overline{K}^{(*)0}$	$\overline{B}_s^0 \to J/\psi K^0\overline{K}^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}u\bar{s}}K^-$	$(T_2+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\overline{D}^{(*)0}K^-$	$\overline{B}_s^0 \to J/\psi K^+K^-$
$\overline{B}_s^0 \to T_{c\bar{c}u\bar{d}}\pi^-$	$E\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)+}\overline{D}^{(*)0}\pi^-$	$\overline{B}_s^0 \to J/\psi\pi^+\pi^-$
$\overline{B}_s^0 \to T_{c\bar{c}d\bar{u}}\pi^+$	$E\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)0}D^{(*)-}\pi^+$	$\overline{B}_s^0 \to J/\psi\pi^-\pi^+$
$\overline{B}^0 \to T_{c\bar{c}s\bar{u}}\pi^+$	$T_1\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)0}D_s^{(*)-}\pi^+$	$\overline{B}^0 \to J/\psi K^-\pi^+$
$B^- \to T_{c\bar{c}s\bar{d}}\pi^-$	$T_1\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)+}D_s^{(*)-}\pi^-$	$B^- \to J/\psi\overline{K}^0\pi^-$
$B^- \to T_{c\bar{c}s\bar{u}}\pi^0$	$\frac{1}{\sqrt{2}}T_1\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D_s^{(*)-}\pi^0$	$B^- \to J/\psi K^-\pi^0$
$\overline{B}^0 \to T_{c\bar{c}s\bar{d}}\pi^0$	$\frac{1}{\sqrt{2}}T_1\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}D_s^{(*)-}\pi^0$	$\overline{B}^0 \to J/\psi\overline{K}^0\pi^0$
$\overline{B}_s^0 \to T_{c\bar{c}s\bar{d}}K^{(*)0}$	$(T_1+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)+}D_s^{(*)-}K^{(*)0}$	$\overline{B}_s^0 \to J/\psi\overline{K}^0K^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}s\bar{u}}K^+$	$(T_1+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)0}D_s^{(*)-}K^+$	$\overline{B}_s^0 \to J/\psi K^-K^+$

[Qin, Qiu, **FSY**, '23]



$Z_{cs}(4000)^-$, LHCb 2021



$Z_c(4200)^+$, Belle 2014

B decays into hidden-charm tetraquarks

Modes	Topological amplitudes	Experimental processes	Experimental processes
$B^- \to T_{c\bar{c}s\bar{u}}\phi$	$T_2\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D_s^{(*)-}\phi$	$B^- \to J/\psi K^-\phi$ [29]
$\overline{B}^0 \to T_{c\bar{c}s\bar{d}}\phi$	$T_2\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}D_s^{(*)-}\phi$	$\overline{B}^0 \to J/\psi \overline{K}^{(*)0}\phi$
$\overline{B}^0 \to T_{c\bar{c}u\bar{d}}K^-$	$T_2\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}\overline{D}^{(*)0}K^-$	$\overline{B}^0 \to J/\psi\pi^+K^-$ [24]
$B^- \to T_{c\bar{c}d\bar{u}}\overline{K}^{(*)0}$	$T_2\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D^{(*)-}\overline{K}^{(*)0}$	$B^- \to J/\psi\pi^-\overline{K}^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}d\bar{s}}\overline{K}^{(*)0}$	$(T_2+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D_s^{(*)+}D^{(*)-}\overline{K}^{(*)0}$	$\overline{B}_s^0 \to J/\psi K^0\overline{K}^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}u\bar{s}}K^-$	$(T_2+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\overline{D}^{(*)0}K^-$	$\overline{B}_s^0 \to J/\psi K^+K^-$
$\overline{B}_s^0 \to T_{c\bar{c}u\bar{d}}\pi^-$	$E\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)+}\overline{D}^{(*)0}\pi^-$	$\overline{B}_s^0 \to J/\psi\pi^+\pi^-$
$\overline{B}_s^0 \to T_{c\bar{c}d\bar{u}}\pi^+$	$E\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)0}D^{(*)-}\pi^+$	$\overline{B}_s^0 \to J/\psi\pi^-\pi^+$
$\overline{B}^0 \to T_{c\bar{c}s\bar{u}}\pi^+$	$T_1\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)0}D_s^{(*)-}\pi^+$	$\overline{B}^0 \to J/\psi K^-\pi^+$
$B^- \to T_{c\bar{c}s\bar{d}}\pi^-$	$T_1\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)+}D_s^{(*)-}\pi^-$	$B^- \to J/\psi\overline{K}^0\pi^-$
$B^- \to T_{c\bar{c}s\bar{u}}\pi^0$	$\frac{1}{\sqrt{2}}T_1\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}D_s^{(*)-}\pi^0$	$B^- \to J/\psi K^-\pi^0$
$\overline{B}^0 \to T_{c\bar{c}s\bar{d}}\pi^0$	$\frac{1}{\sqrt{2}}T_1\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}D_s^{(*)-}\pi^0$	$\overline{B}^0 \to J/\psi\overline{K}^0\pi^0$
$\overline{B}_s^0 \to T_{c\bar{c}s\bar{d}}K^{(*)0}$	$(T_1+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)+}D_s^{(*)-}K^{(*)0}$	$\overline{B}_s^0 \to J/\psi\overline{K}^0K^{(*)0}$
$\overline{B}_s^0 \to T_{c\bar{c}s\bar{u}}K^+$	$(T_1+E)\ V_{cb}V_{cs}^*$	$\overline{B}_s^0 \to D^{(*)0}D_s^{(*)-}K^+$	$\overline{B}_s^0 \to J/\psi K^-K^+$

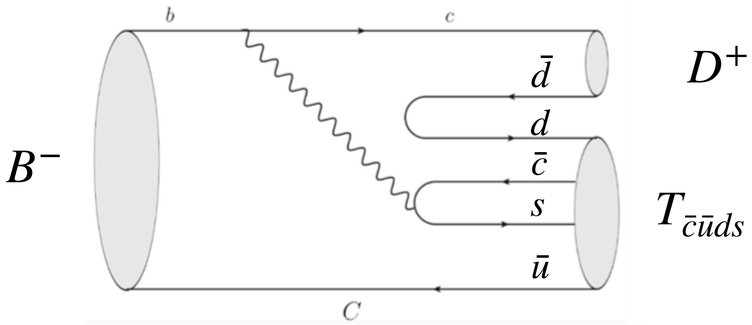
[Qin, Qiu, **FSY**, '23]

- Suggest to search for all the processes with T_2 diagrams.
- It is helpful to explore the nature of observed $Z_{cs}(4000)$ and $Z_c(4200)$.
- It might be used to distinguish whether the exotic states are resonances or non-resonant kinematic effects.

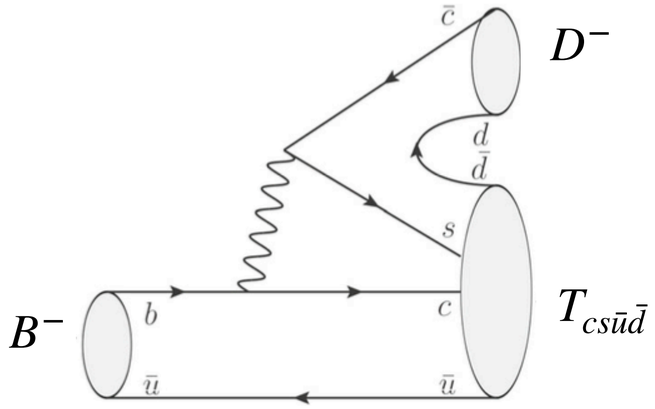
$\overline{B}^0 \to T_{c\bar{c}u\bar{d}}K^-$ *v.s.* $B^- \to T_{c\bar{c}d\bar{u}}\overline{K}^{*0}$

B decays into open-charm tetraquarks

Modes	Topological amplitudes	Experimental processes	Experimental processes
$B^- \to T_{\bar{c}\bar{u}ds} D^{(*)+}$	$C\ V_{cb}V_{cs}^*$	$B^- \to D_s^{(*)-}\pi^- D^{(*)+}$ [32,33]	$B^- \to D^{(*)-}K^- D^{(*)+}$
$\overline{B}^0 \to T_{\bar{c}\bar{d}us} D^{(*)0}$	$C\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D_s^{(*)-}\pi^+ D^{(*)0}$ [32,33]	$\overline{B}^0 \to \overline{D}^{(*)0}\overline{K}^0 D^{(*)0}$
$B^- \to T_{\bar{c}\bar{u}ss} D_s^{(*)+}$	$\sqrt{2}C\ V_{cb}V_{cs}^*$	$B^- \to D_s^{(*)-}K^- D_s^{(*)+}$	
$\overline{B}^0 \to T_{\bar{c}\bar{d}ss} D_s^{(*)+}$	$\sqrt{2}C\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D_s^{(*)-}\overline{K}^0 D_s^{(*)+}$	
$B^- \to T_{cs\bar{u}\bar{d}} D^{(*)-}$	$T_3\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)+}K^- D^{(*)-}$ [30]	$B^- \to D^{(*)0}\overline{K}^0 D^{(*)-}$
$\overline{B}^0 \to T_{cs\bar{u}\bar{d}} \overline{D}^{(*)0}$	$T_3\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}K^- \overline{D}^{(*)0}$	$\overline{B}^0 \to D^{(*)0}\overline{K}^0 \overline{D}^{(*)0}$
$B^- \to T_{cs\bar{u}\bar{u}} \overline{D}^{(*)0}$	$\sqrt{2}T_3\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}K^- \overline{D}^{(*)0}$	
$\overline{B}^0 \to T_{cs\bar{d}\bar{d}} D^{(*)-}$	$\sqrt{2}T_3\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}\overline{K}^0 D^{(*)-}$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{s}}\pi^0$	$\frac{1}{\sqrt{2}}(T_3 - T_2)\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\pi^-\pi^0$	$\overline{B}_s^0 \to D^{(*)0}K^0\pi^0$
$\overline{B}_s^0 \to T_{cd\bar{s}\bar{s}}K^-$	$\sqrt{2}T_3\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}K^0K^-$	
$B^- \to T_{cd\bar{u}\bar{s}}K^-$	$(T_1 + T_3)\ V_{cb}V_{ud}^*$	$B^- \to D_s^{(*)+}\pi^-K^-$	$B^- \to D^{(*)0}K^0K^-$
$B^- \to T_{cd\bar{u}\bar{u}}\pi^0$	$(T_1 + T_3 - T_2)\ V_{cb}V_{ud}^*$	$B^- \to D^{(*)0}\pi^-\pi^0$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{u}}K^+$	$\sqrt{2}T_1\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D^{(*)0}\pi^-K^+$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{s}}\phi$	$T_1\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\pi^-\phi$	$\overline{B}_s^0 \to D^{(*)0}K^0\phi$
$\overline{B}^0 \to T_{cd\bar{u}\bar{s}}\overline{K}^{(*)0}$	$(E + T_1)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D_s^{(*)+}\pi^-\overline{K}^{(*)0}$	$\overline{B}^0 \to D^{(*)0}K^0\overline{K}^{(*)0}$
$\overline{B}^0 \to T_{cd\bar{u}\bar{u}}\pi^+$	$\sqrt{2}(E + T_1)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)0}\pi^-\pi^+$	
$B^- \to T_{cs\bar{u}\bar{u}}K^{(*)0}$	$\sqrt{2}T_2\ V_{cb}V_{ud}^*$	$B^- \to D^{(*)0}K^-K^{(*)0}$	
$\overline{B}^0 \to T_{cs\bar{u}\bar{d}}K^{(*)0}$	$(E + T_2)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)+}K^-K^{(*)0}$	$\overline{B}^0 \to D^{(*)0}\overline{K}^0K^{(*)0}$
$\overline{B}^0 \to T_{cs\bar{u}\bar{u}}K^+$	$\sqrt{2}\ E\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)0}K^-K^+$	



$T^a_{c\bar{s}0}(2900)^{++,0}$, LHCb 2022



T_3

$X_{0,1}(2900)$, LHCb 2020

B decays into open-charm tetraquarks

Modes	Topological amplitudes	Experimental processes	Experimental processes
$B^- \to T_{\bar{c}\bar{u}ds} D^{(*)+}$	$C\ V_{cb}V_{cs}^*$	$B^- \to D_s^{(*)-}\pi^- D^{(*)+}$ [32,33]	$B^- \to D^{(*)-}K^- D^{(*)+}$
$\overline{B}^0 \to T_{\bar{c}\bar{d}us} D^{(*)0}$	$C\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D_s^{(*)-}\pi^+ D^{(*)0}$ [32,33]	$\overline{B}^0 \to \overline{D}^{(*)0}\overline{K}^0 D^{(*)0}$
$B^- \to T_{\bar{c}\bar{u}ss} D_s^{(*)+}$	$\sqrt{2}C\ V_{cb}V_{cs}^*$	$B^- \to D_s^{(*)-}K^- D_s^{(*)+}$	
$\overline{B}^0 \to T_{\bar{c}\bar{d}ss} D_s^{(*)+}$	$\sqrt{2}C\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D_s^{(*)-}\overline{K}^0 D_s^{(*)+}$	
$B^- \to T_{cs\bar{u}\bar{d}} D^{(*)-}$	$T_3\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)+}K^- D^{(*)-}$ [30]	$B^- \to D^{(*)0}\overline{K}^0 D^{(*)-}$
$\overline{B}^0 \to T_{cs\bar{u}\bar{d}} \overline{D}^{(*)0}$	$T_3\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}K^- \overline{D}^{(*)0}$	$\overline{B}^0 \to D^{(*)0}\overline{K}^0 \overline{D}^{(*)0}$
$B^- \to T_{cs\bar{u}\bar{u}} \overline{D}^{(*)0}$	$\sqrt{2}T_3\ V_{cb}V_{cs}^*$	$B^- \to D^{(*)0}K^- \overline{D}^{(*)0}$	
$\overline{B}^0 \to T_{cs\bar{d}\bar{d}} D^{(*)-}$	$\sqrt{2}T_3\ V_{cb}V_{cs}^*$	$\overline{B}^0 \to D^{(*)+}\overline{K}^0 D^{(*)-}$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{s}}\pi^0$	$\frac{1}{\sqrt{2}}(T_3 - T_2)\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\pi^-\pi^0$	$\overline{B}_s^0 \to D^{(*)0}K^0\pi^0$
$\overline{B}_s^0 \to T_{cd\bar{s}\bar{s}}K^-$	$\sqrt{2}T_3\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}K^0K^-$	
$B^- \to T_{cd\bar{u}\bar{s}}K^-$	$(T_1 + T_3)\ V_{cb}V_{ud}^*$	$B^- \to D_s^{(*)+}\pi^-K^-$	$B^- \to D^{(*)0}K^0K^-$
$B^- \to T_{cd\bar{u}\bar{u}}\pi^0$	$(T_1 + T_3 - T_2)\ V_{cb}V_{ud}^*$	$B^- \to D^{(*)0}\pi^-\pi^0$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{u}}K^+$	$\sqrt{2}T_1\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D^{(*)0}\pi^-K^+$	
$\overline{B}_s^0 \to T_{cd\bar{u}\bar{s}}\phi$	$T_1\ V_{cb}V_{ud}^*$	$\overline{B}_s^0 \to D_s^{(*)+}\pi^-\phi$	$\overline{B}_s^0 \to D^{(*)0}K^0\phi$
$\overline{B}^0 \to T_{cd\bar{u}\bar{s}}\overline{K}^{(*)0}$	$(E + T_1)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D_s^{(*)+}\pi^-\overline{K}^{(*)0}$	$\overline{B}^0 \to D^{(*)0}K^0\overline{K}^{(*)0}$
$\overline{B}^0 \to T_{cd\bar{u}\bar{u}}\pi^+$	$\sqrt{2}(E + T_1)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)0}\pi^-\pi^+$	
$B^- \to T_{cs\bar{u}\bar{u}}K^{(*)0}$	$\sqrt{2}T_2\ V_{cb}V_{ud}^*$	$B^- \to D^{(*)0}K^-K^{(*)0}$	
$\overline{B}^0 \to T_{cs\bar{u}\bar{d}}K^{(*)0}$	$(E + T_2)\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)+}K^-K^{(*)0}$	$\overline{B}^0 \to D^{(*)0}\overline{K}^0K^{(*)0}$
$\overline{B}^0 \to T_{cs\bar{u}\bar{u}}K^+$	$\sqrt{2}\ E\ V_{cb}V_{ud}^*$	$\overline{B}^0 \to D^{(*)0}K^-K^+$	

- Suggest to search for all the processes with C or T_3 diagrams.
- It is helpful to explore the nature of observed $T^a_{c\bar{s}0}(2900)$ and $X_{0,1}(2900)$.
- It might be used to distinguish whether the exotic states are resonances or non-resonant kinematic effects.

Summary

- Topological diagrammatic approach has been successfully used in the phenomenological analysis in charm CPV and double-charm baryons.
- Topological diagrammatic approach is applied in the tetraquark production in B decays.
- Some relations are obtained for branching fractions between different channels.
- Experimental searches can help to distinguish the nature of exotic states for resonances or non-resonant kinematic effects.

Thank you!