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# Heavy Mesons to Charmed Tetraquark Decays


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# Introduction

- In 2020, LHCb reported the observation of a charmed tetraquark $T^*_{cs0}\,(2870)^0$ in $B^- \rightarrow\; D^- T^*_{cs0}\,(2870)^0, T^*_{cs0}\,(2870)^0 \rightarrow D^+\,K^-$ decay
- The minimal quark content for $T^*_{cs0}\,(2870)^0$ : $cs\bar{u}\bar{d}$
- In 2022, two more charmed tetraquarks, namely $T^*_{c\bar{s}0}(2900)^0$ and $T^*_{c\bar{s}0}(2900)^{++}$, are reported by LHCb in $\bar{B}^0\;\rightarrow\; D^0\;\, D_s^- \pi^+$ and $B^- \rightarrow\; D^+\,D_s^-\;\pi^-$ decays.
- They have quark contents, $cd\bar{s}\bar{u}$ and $cu\bar{d}\bar{s}$.
- These three states are flavor exotic states (FES).

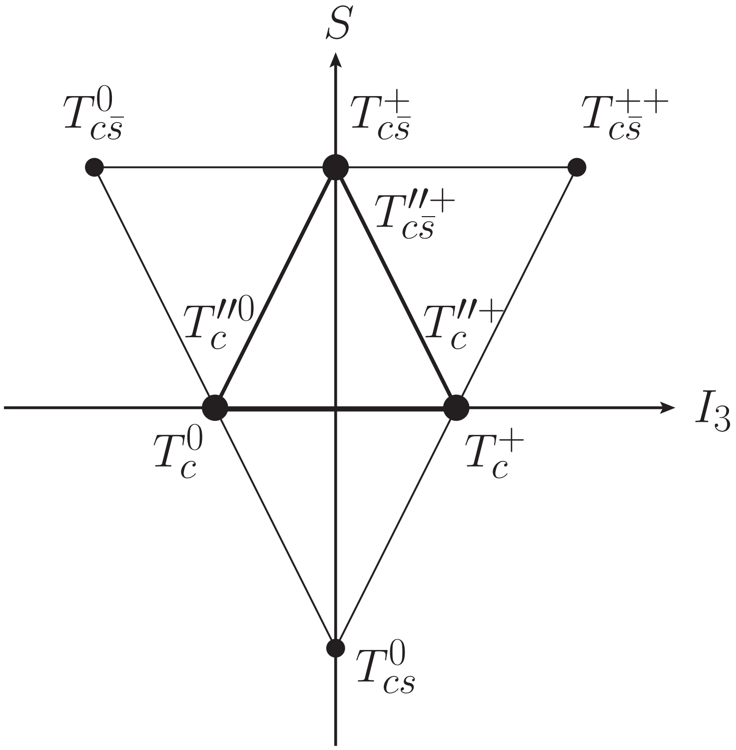
# Introduction

- We will study the decays of heavy mesons to these charmed tetraquark states ($T$ ).
- As a direct calculation of the decay amplitudes is too complicated, we will make use of a topological amplitude approach, which has been applied to many heavy meson decays (including pentaquark final states)
- A study along this line was done in 2022 by Qin, Qiu and Yu (QQY).

# Introduction

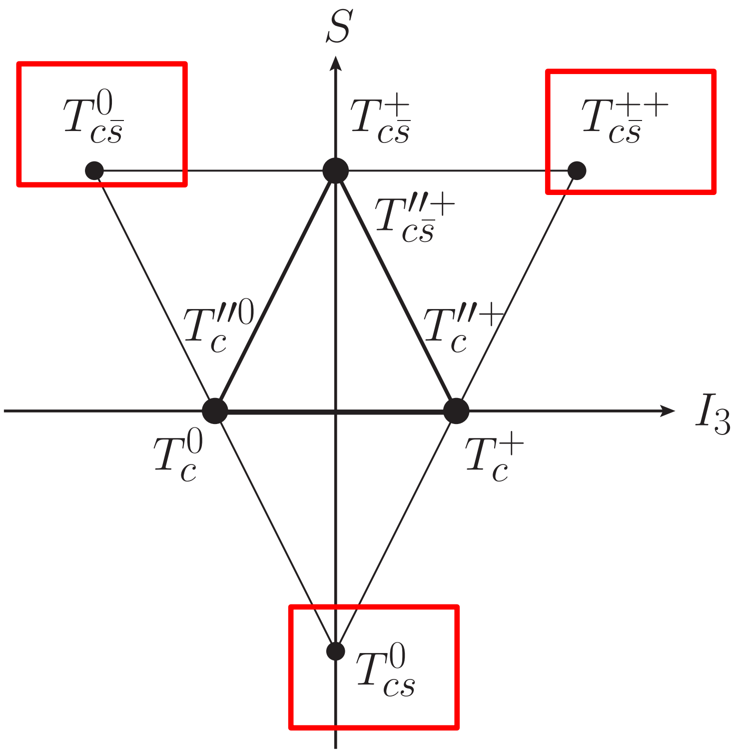
- We will consider two scenarios, where $T = T_{cq[\bar{q}'\,\bar{q}'']}$ (antisym. antiquarks) or $T = T_{cq\{\bar{q}'\,\bar{q}''\}}$ (sym. antiquarks)
- We will first obtain the $T \to DP$ and $DS$ strong decay amplitudes by decomposing them into several TA
- Weak decay amplitudes of $\overline{B} \to D\,\overline{T}$, $\overline{D}\,T$ and $\overline{B} \to TP$, $TS$ decays will also be decomposed topologically.
- In addition, $B_c^- \to T\overline{T}$ decays will also be discussed.
- Using these results, modes with an unambiguous exotic interpretation in flavor will be highlighted.

# Scenario I $(T = T_{cq[\bar{q}'\bar{q}'']})$




- $[\bar{q}'\bar{q}'']$ (antisym.) is a **3**
- $\mathbf{3} \otimes \mathbf{3} = \mathbf{6} \oplus \bar{\mathbf{3}}$
- Isotriplet,
  isodoublet,
  singet in **6** (traceless)
- Four flavor exotic states
- Three for $T^*_{c\bar{s}0}(2900)^0$, $T^*_{c\bar{s}0}(2900)^{++}$ and $T^*_{cs0}(2870)^0$
- The other one is new

# Scenario I（$T = T_{cq[\bar{q}'\,\bar{q}'']}$）

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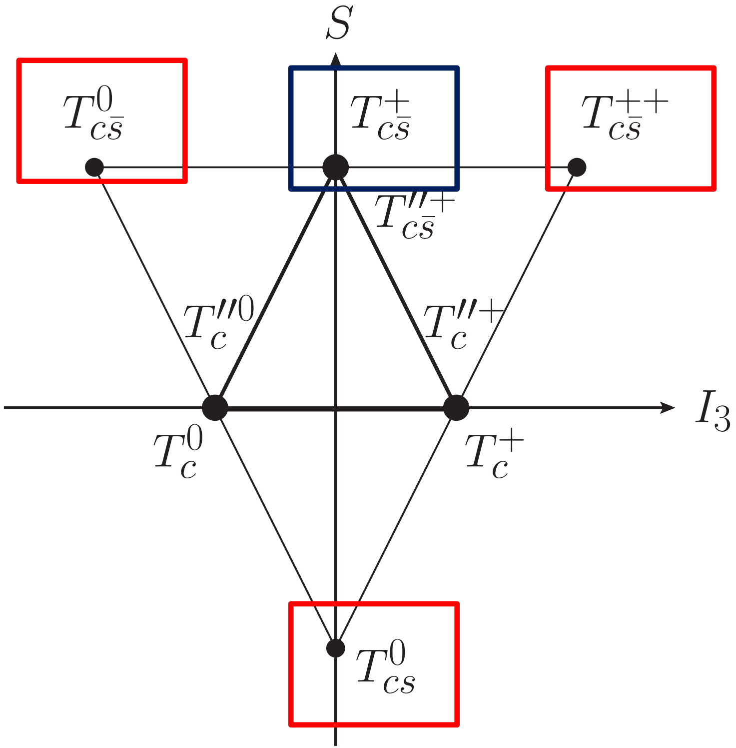


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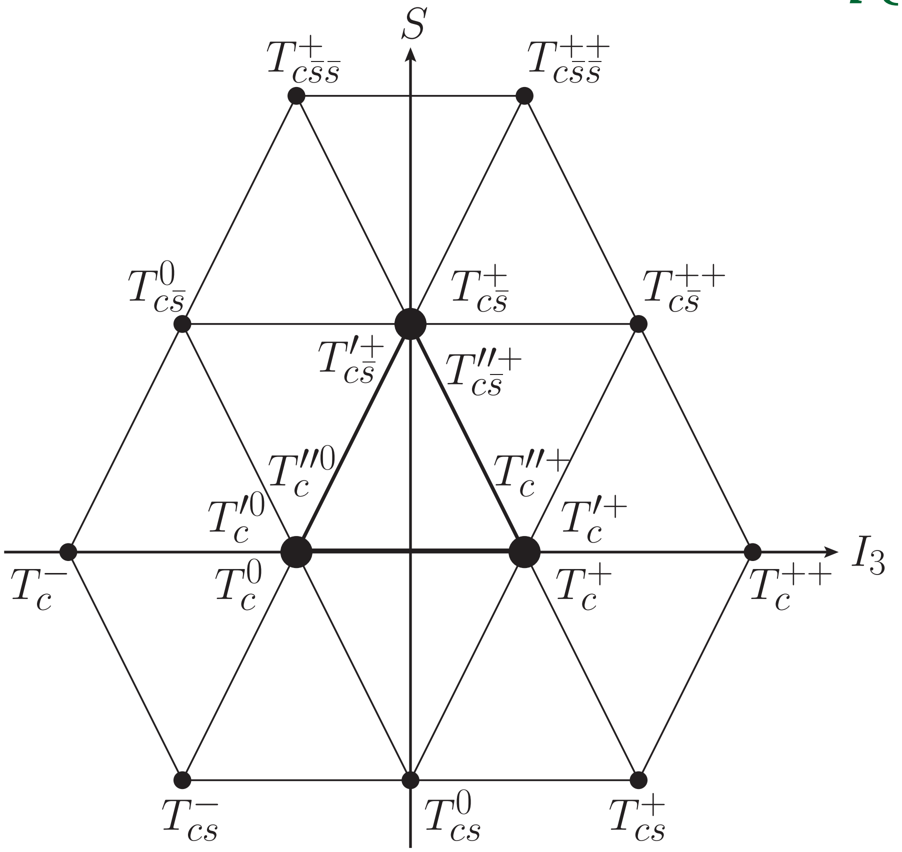
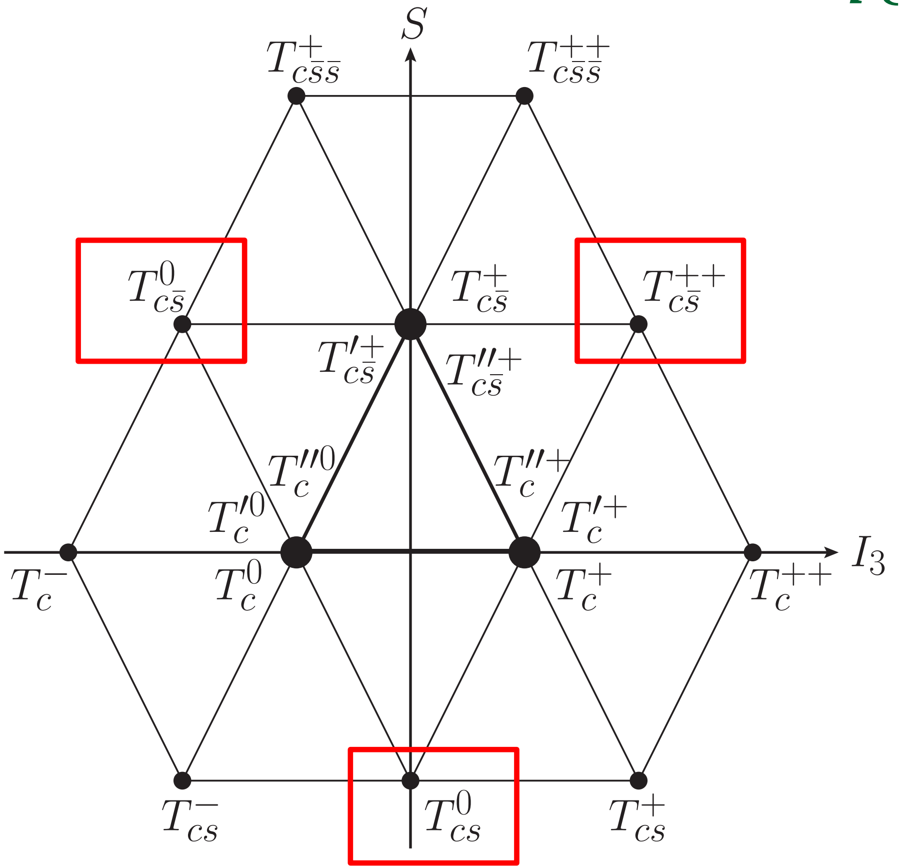
# Scenario II ($T = T_{cq\{\bar{q}'\,\bar{q}''\}}$)




- $\{\bar{q}'\,\bar{q}''\}$ (sym.) is a $\mathbf{6}$
- $\mathbf{3} \otimes \mathbf{6} = \overline{15} \oplus \mathbf{\bar{3}}$
- Isodoublet, isotriplet, isosinglet, iso-quartet, isodoublet, isotripet in $\overline{\mathbf{15}}$ (traceless)
- Twelve flavor exotic states (FES)
- Three FES have not been discussed

# Scenario II ($T = T_{cq\{\bar{q}'\,\bar{q}''\}}$)




- $\{\bar{q}'\,\bar{q}''\}$ (sym.) is a $\mathbf{6}$
- $\mathbf{3} \otimes \mathbf{6} = \overline{15} \oplus \mathbf{3}$
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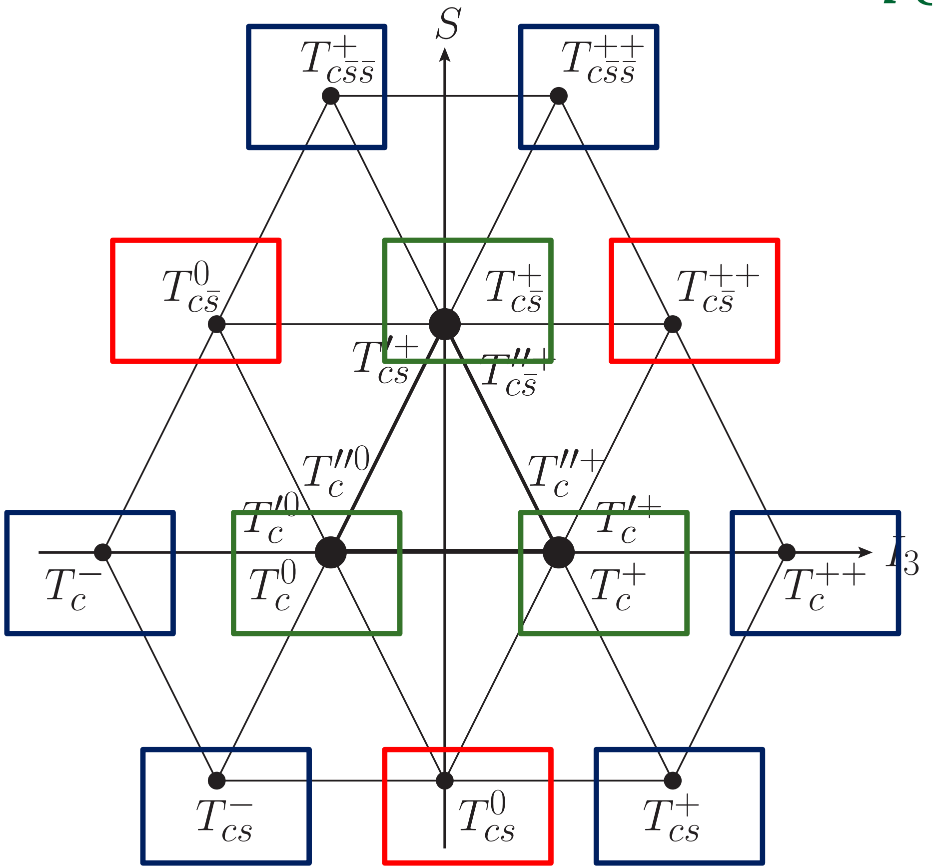


- $\{\bar{q}'\,\bar{q}''\}$ (sym.) is a $\mathbf{6}$
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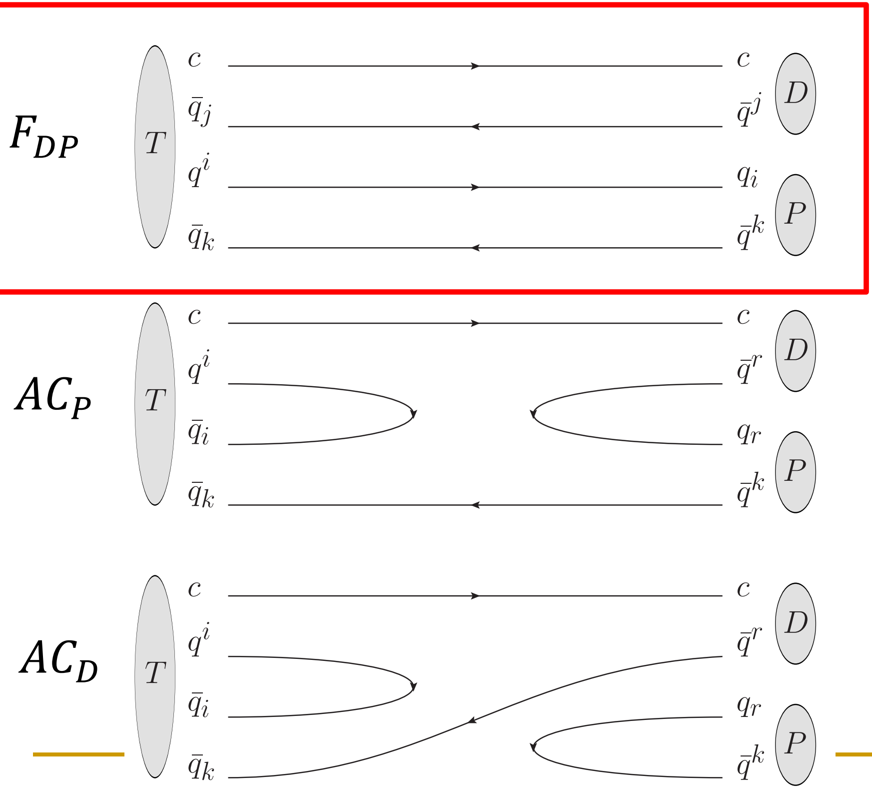
# $T \to DP$ decays




- 3 topological amplitudes (TA)
- Subscripts denote mesons receiving light (anti) quark of T
- F: fall apart
- AC: annihilation-creation
- Only one contributes to flavor exotic states (traceless)
- Highly related

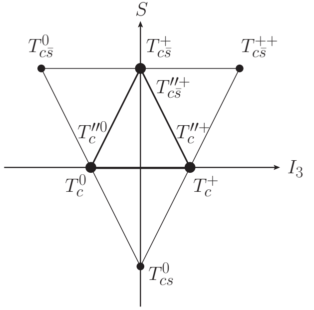



TABLE III: $T \to DP$ decay amplitudes in scenario I, with $T = T_{cq[\bar q'\bar q'']}$.

| # | Mode | $A(T \to DP)$ | Mode | $A(T \to DP)$ |
|---|---|---|---|---|
| 1* | $T^{++}_{c\bar s} \to D^+ K^+$ | $F_{DP}$ | $T^{++}_{c\bar s} \to D^+_s \pi^+$ | $-F_{DP}$ |
| 2* | $T^{+}_{c\bar s} \to D^0 K^+$ | $\frac{1}{\sqrt{2}} F_{DP}$ | $T^{+}_{c\bar s} \to D^+ K^0$ | $-\frac{1}{\sqrt{2}} F_{DP}$ |
| | $T^{+}_{c\bar s} \to D^+_s \pi^0$ | $F_{DP}$ | | |
| 3* | $T^{0}_{c\bar s} \to D^0 K^0$ | $F_{DP}$ | $T^{0}_{c\bar s} \to D^+_s \pi^-$ | $-F_{DP}$ |
| 4* | $T^{0}_{cs} \to D^0 \overline{K}^0$ | $F_{DP}$ | $T^{0}_{cs} \to D^+ K^-$ | $-F_{DP}$ |
| 5 | $T^{+}_{c} \to D^0 \pi^+$ | $\frac{1}{\sqrt{2}} F_{DP}$ | $T^{+}_{c} \to D^+ \pi^0$ | $-\frac{1}{2} F_{DP}$ |
| | $T^{+}_{c} \to D^+_s \overline{K}^0$ | $-\frac{1}{\sqrt{2}} F_{DP}$ | $T^{+}_{cu\bar u\bar d} \to D^+ \eta$ | $-\frac{c_{\phi'} + \sqrt{2} s_{\phi'}}{2} F_{DP}$ |
| | $T^{+}_{c} \to D^+ \eta'$ | $\frac{\sqrt{2} c_{\phi'} - s_{\phi'}}{2} F_{DP}$ | | |
| 6 | $T^{0}_{c} \to D^0 \pi^0$ | $-\frac{1}{2} F_{DP}$ | $T^{0}_{c} \to D^+ \pi^-$ | $-\frac{F_{DP}}{\sqrt{2}}$ |
| | $T^{0}_{c} \to D^+_s K^-$ | $\frac{1}{\sqrt{2}} F_{DP}$ | $T^{0}_{cd\bar u\bar d} \to D^+ \eta$ | $\frac{c_{\phi'} + \sqrt{2} s_{\phi'}}{2} F_{DP}$ |
| | $T^{0}_{c} \to D^+ \eta'$ | $-\frac{\sqrt{2} c_{\phi'} - s_{\phi'}}{2} F_{DP}$ | | |

- Amp. of states *T* in **6** are highly related
- All FES modes are highly related $(DP \sim \overline{3} \otimes 8 = \overline{15} \oplus 6 \oplus \overline{3})$

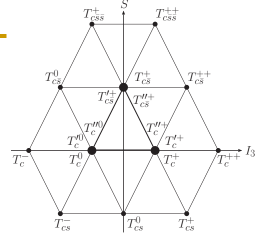


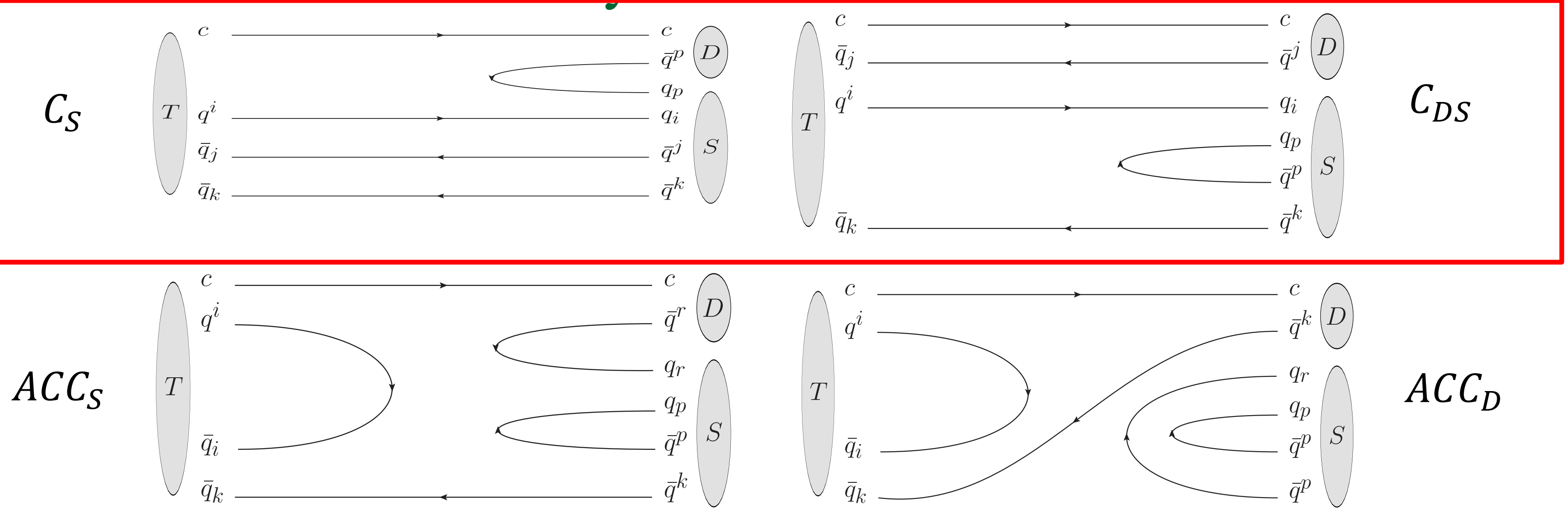
TABLE IV: $T \to DP$ decay amplitudes in scenario II, with $T = T_{cq\{\bar q' \bar q''\}}$.

| # | Mode | $A(T \to DP)$ | Mode | $A(T \to DP)$ |
|---|---|---|---|---|
| $1'^*$ | $T_{c\bar s}^{++} \to D^+K^+$ | $F_{DP}$ | $T_{c\bar s}^{++} \to D_s^+\pi^+$ | $F_{DP}$ |
| $2'^*$ | $T_{c\bar s}^{+} \to D^0K^+$ | $\frac{1}{\sqrt{2}}F_{DP}$ | $T_{c\bar s}^{+} \to D^+K^0$ | $-\frac{1}{\sqrt{2}}F_{DP}$ |
| | $T_{c\bar s}^{+} \to D_s^+\pi^0$ | $F_{DP}$ | | |
| $3'^*$ | $T_{c\bar s}^{0} \to D^0K^0$ | $F_{DP}$ | $T_{c\bar s}^{0} \to D_s^+\pi^-$ | $F_{DP}$ |
| $4'^*$ | $T_{cs}^{+} \to D^+\overline{K}^0$ | $\sqrt{2}F_{DP}$ | | |
| $5'^*$ | $T_{cs}^{0} \to D^0\overline{K}^0$ | $F_{DP}$ | $T_{cs}^{0} \to D^+K^-$ | $F_{DP}$ |
| $6'^*$ | $T_{cs}^{-} \to D^0K^-$ | $\sqrt{2}F_{DP}$ | | |
| $7'^*$ | $T_{c\bar s\bar s}^{++} \to D_s^+K^+$ | $\sqrt{2}F_{DP}$ | | |
| $8'^*$ | $T_{c\bar s\bar s}^{+} \to D_s^+K^0$ | $\sqrt{2}F_{DP}$ | | |
| $9'^*$ | $T_{c}^{++} \to D^+\pi^+$ | $\sqrt{2}F_{DP}$ | | |
| $10'^*$ | $T_{c}^{+} \to D^0\pi^+$ | $\sqrt{\frac{2}{3}}F_{DP}$ | $T_{c}^{+} \to D^+\pi^0$ | $\frac{2}{\sqrt{3}}F_{DP}$ |
| $11'^*$ | $T_{c}^{0} \to D^0\pi^0$ | $\frac{2}{\sqrt{3}}F_{DP}$ | $T_{c}^{0} \to D^+\pi^-$ | $-\sqrt{\frac{2}{3}}F_{DP}$ |
| $12'^*$ | $T_{c}^{-} \to D^0\pi^-$ | $\sqrt{2}F_{DP}$ | | |
| $13'$ | $T_{c}'^{+} \to D^0\pi^+$ | $\frac{1}{2\sqrt{3}}F_{DP}$ | $T_{c}'^{+} \to D^+\pi^0$ | $-\frac{1}{2\sqrt{6}}F_{DP}$ |
| | $T_{c}'^{+} \to D^+\eta$ | $\frac{\sqrt{6}}{4}(c_{\phi'} + \sqrt{2}s_{\phi'})F_{DP}$ | $T_{c}'^{+} \to D^+\eta'$ | $\frac{\sqrt{6}}{4}(s_{\phi'} - \sqrt{2}c_{\phi'})F_{DP}$ |
| | $T_{c}'^{+} \to D_s^+\overline{K}^0$ | $-\frac{\sqrt{3}}{2}F_{DP}$ | | |
| $14'$ | $T_{c}'^{0} \to D^0\pi^0$ | $\frac{1}{2\sqrt{6}}F_{DP}$ | $T_{c}'^{0} \to D^0\eta$ | $\frac{\sqrt{6}}{4}(c_{\phi'} + \sqrt{2}s_{\phi'})F_{DP}$ |
| | $T_{c}'^{0} \to D^0\eta'$ | $\frac{\sqrt{6}}{4}(s_{\phi'} - \sqrt{2}c_{\phi'})F_{DP}$ | $T_{c}'^{0} \to D^+\pi^-$ | $\frac{1}{2\sqrt{3}}F_{DP}$ |
| | $T_{c}'^{0} \to D_s^+K^-$ | $-\frac{\sqrt{3}}{2}F_{DP}$ | | |
| $15'$ | $T_{c\bar s}'^{+} \to D^0K^+$ | $\frac{1}{2}F_{DP}$ | $T_{c\bar s}'^{+} \to D^+K^0$ | $\frac{1}{2}F_{DP}$ |
| | $T_{c\bar s}'^{+} \to D_s^+\eta$ | $\frac{1}{\sqrt{2}}(c_{\phi'} + \sqrt{2}s_{\phi'})F_{DP}$ | $T_{c\bar s}'^{+} \to D_s^+\eta'$ | $\frac{1}{\sqrt{2}}(s_{\phi'} - \sqrt{2}c_{\phi'})F_{DP}$ |

- Amp. of states $T$ in $\overline{\mathbf{15}}$ /FES are highly related

$$(DP \sim \bar{\mathbf{3}} \otimes \mathbf{8} = \overline{\mathbf{15}} \oplus \mathbf{6} \oplus \bar{\mathbf{3}})$$

# $T \to DS$ decays




- 4 (3) TA in scenario I (II), only 2 (1) contribute to FES
- Only one combination, $\boldsymbol{DS} \sim \bar{\mathbf{3}} \otimes \mathbf{8} = \overline{\mathbf{15}} \oplus \mathbf{6} \oplus \bar{\mathbf{3}}$

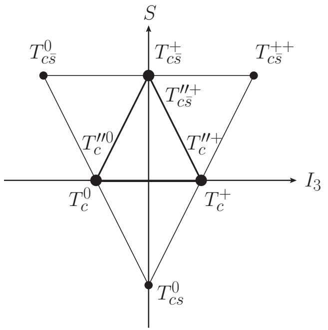


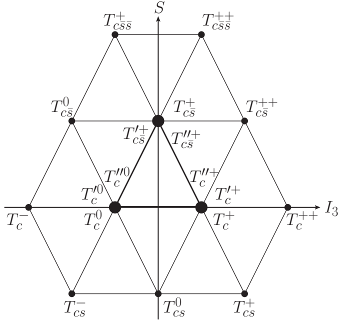

TABLE V: $T \to DS$ decay amplitudes in scenario I, with $T = T_{cq[\bar{q}'\bar{q}'']}$.

| # | Mode | $A(T \to DS)$ | Mode | $A(T \to DS)$ |
|---|---|---|---|---|
| 1* | $T^{++}_{c\bar{s}} \to D^+\kappa^+$ | $2C_S + C_{DS}$ | $T^{++}_{c\bar{s}} \to D^+_s a^+_0$ | $-(2C_S + C_{DS})$ |
| 2* | $T^+_{c\bar{s}} \to D^0\overline{\kappa}^+$ | $\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ | $T^+_{c\bar{s}} \to D^+\kappa^0$ | $-\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ |
| | $T^+_{c\bar{s}} \to D^+_s a^0_0$ | $-2(C_S + C_{DS})$ | | |
| 3* | $T^0_{c\bar{s}} \to D^0\kappa^0$ | $2C_S + C_{DS}$ | $T^0_{c\bar{s}} \to D^+_s a^-_0$ | $-(2C_S + C_{DS})$ |
| 4* | $T^0_{cs} \to D^0\overline{\kappa}^0$ | $2C_S + C_{DS}$ | $T^0_{cs} \to D^+\kappa^-$ | $-(2C_S + C_{DS})$ |
| 5 | $T^+_c \to D^0 a^+_0$ | $\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ | $T^+_c \to D^+ a^0_0$ | $-\frac{1}{2}(2C_S + C_{DS})$ |
| | $T^+_c \to D^+_s\overline{\kappa}^0$ | $-\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ | $T^+_c \to D^+\sigma$ | $\frac{1}{2}(\sqrt{2}c_\phi + s_\phi)(2C_S + C_{DS})$ |
| | $T^+_c \to D^+ f_0$ | $-\frac{1}{2}(c_\phi - \sqrt{2}s_\phi)(2C_S + C_{DS})$ | | |
| 6 | $T^0_c \to D^0 a^0_0$ | $-\frac{1}{2}(2C_S + C_{DS})$ | $T^0_c \to D^+ a^-_0$ | $-\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ |
| | $T^0_c \to D^+_s\kappa^-$ | $\frac{1}{\sqrt{2}}(2C_S + C_{DS})$ | $T^0_c \to D^+\sigma$ | $-\frac{1}{2}(\sqrt{2}c_\phi + s_\phi)(2C_S + C_{DS})$ |
| | $T^0_c \to D^+ f_0$ | $\frac{1}{2}(c_\phi - \sqrt{2}s_\phi)(2C_S + C_{DS})$ | | |

- Amp. of states in **6 / FES** are highly related (one comb.)

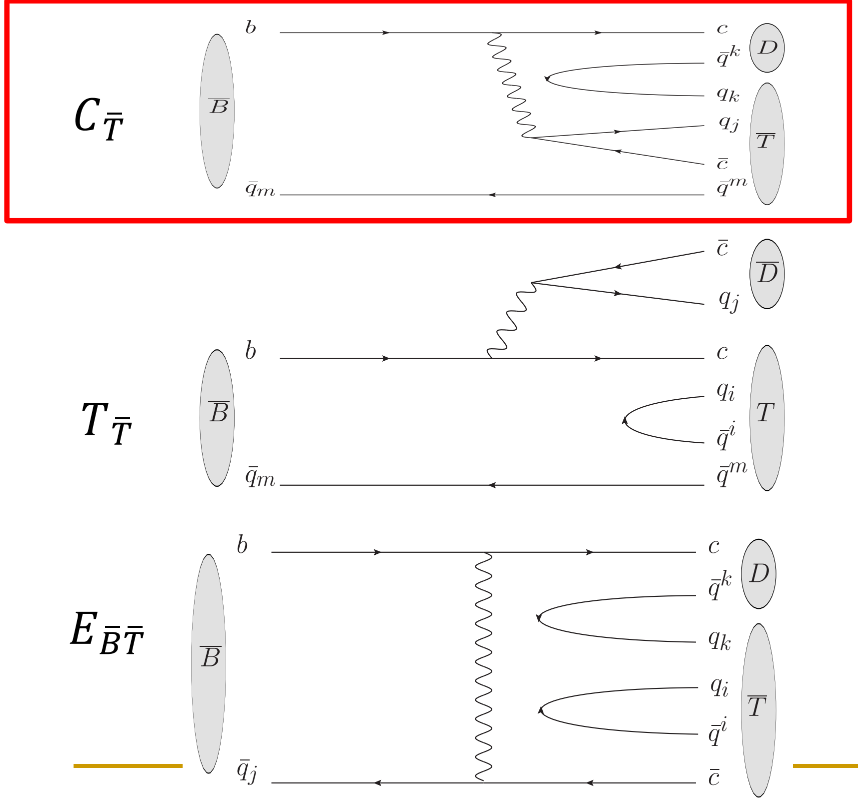
TABLE VI: $T \to DS$ decay amplitudes in scenario II, with $T = T_{cq\{\bar q'\bar q''\}}$.

| # | Mode | $A(T \to DS)$ | Mode | $A(T \to DS)$ |
|---|---|---|---|---|
| $1'^*$ | $T_{c\bar s}^{++} \to D^+\kappa^+$ | $C_{DS}$ | $T_{c\bar s}^{++} \to D_s^+ a_0^+$ | $C_{DS}$ |
| $2'^*$ | $T_{c\bar s}^{+} \to D^0\kappa^+$ | $\frac{1}{\sqrt2}C_{DS}$ | $T_{c\bar s}^{+} \to D^+\kappa^0$ | $-\frac{1}{\sqrt2}C_{DS}$ |
| | $T_{c\bar s}^{+} \to D_s^+ a_0^0$ | $C_{DS}$ | | |
| $3'^*$ | $T_{c\bar s}^{0} \to D^0\kappa^0$ | $C_{DS}$ | $T_{c\bar s}^{0} \to D_s^+ a_0^-$ | $C_{DS}$ |
| $4'^*$ | $T_{cs}^{+} \to D^+\overline{\kappa}^0$ | $\sqrt2 C_{DS}$ | | |
| $5'^*$ | $T_{cs}^{0} \to D^0\overline{\kappa}^0$ | $C_{DS}$ | $T_{cs}^{0} \to D^+\kappa^-$ | $C_{DS}$ |
| $6'^*$ | $T_{cs}^{-} \to D^0\kappa^-$ | $\sqrt2 C_{DS}$ | | |
| $7'^*$ | $T_{c\bar s\bar s}^{++} \to D_s^+\kappa^+$ | $\sqrt2 C_{DS}$ | | |
| $8'^*$ | $T_{c\bar s\bar s}^{+} \to D_s^+\kappa^0$ | $\sqrt2 C_{DS}$ | | |
| $9'^*$ | $T_{c}^{++} \to D^+ a_0^+$ | $\sqrt2 C_{DS}$ | | |
| $10'^*$ | $T_{c}^{+} \to D^0 a_0^+$ | $\sqrt{\frac{2}{3}}C_{DS}$ | $T_{c}^{+} \to D^+ a_0^0$ | $\frac{2}{\sqrt3}C_{DS}$ |
| $11'^*$ | $T_{c}^{0} \to D^0 a_0^0$ | $\frac{2}{\sqrt3}C_{DS}$ | $T_{c}^{0} \to D^+ a_0^-$ | $-\sqrt{\frac{2}{3}}C_{DS}$ |
| $12'^*$ | $T_{c}^{-} \to D^0 a_0^-$ | $\sqrt2 C_{DS}$ | | |
| $13'$ | $T_{c}'^{+} \to D^0 a_0^+$ | $\frac{1}{2\sqrt3}C_{DS}$ | $T_{c}'^{+} \to D^+ a_0^0$ | $-\frac{1}{2\sqrt6}C_{DS}$ |
| | $T_{c}'^{+} \to D^+\sigma$ | $-\frac{\sqrt6}{4}(\sqrt2 c_\phi + s_\phi)C_{DS}$ | $T_{c}'^{+} \to D^+ f_0$ | $-\frac{\sqrt6}{4}(\sqrt2 s_\phi - c_\phi)C_{DS}$ |
| | $T_{c}'^{+} \to D_s^+\overline{\kappa}^0$ | $-\frac{\sqrt3}{2}C_{DS}$ | | |
| $14'$ | $T_{c}'^{0} \to D^0 a_0^0$ | $\frac{1}{2\sqrt6}C_{DS}$ | $T_{c}'^{0} \to D^+ a_0^-$ | $\frac{1}{2\sqrt3}C_{DS}$ |
| | $T_{c}'^{0} \to D^+\sigma$ | $-\frac{\sqrt6}{4}(\sqrt2 c_\phi + s_\phi)C_{DS}$ | $T_{c}'^{0} \to D^+ f_0$ | $-\frac{\sqrt6}{4}(\sqrt2 s_\phi - c_\phi)C_{DS}$ |
| | $T_{c}'^{0} \to D_s^+\kappa^-$ | $-\frac{\sqrt3}{2}C_{DS}$ | | |
| $15'$ | $T_{c\bar s}'^{+} \to D^0\kappa^+$ | $\frac{1}{2}C_{DS}$ | $T_{c\bar s}'^{+} \to D^+\kappa^0$ | $\frac{1}{2}C_{DS}$ |
| | $T_{c\bar s}'^{+} \to D_s^+\sigma$ | $-\frac{1}{\sqrt2}(\sqrt2 c_\phi + s_\phi)C_{DS}$ | $T_{c\bar s}'^{+} \to D_s^+ f_0$ | $-\frac{1}{\sqrt2}(\sqrt2 s_\phi - c_\phi)C_{DS}$ |



- Amp. of $T$ in $\overline{\mathbf{15}}$ /FES are highly related

# $\overline{B} \to D\,\overline{T}$ decays

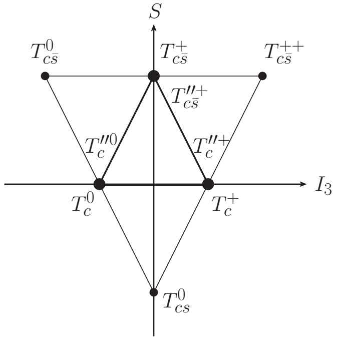



- Three topological amplitudes
- Subscripts denote mesons receiving $c\bar{s}(\bar{d})$ from $W \to c\bar{q}$
- *C*, *T*, *E*: Internal W, External W, Exchange diagrams
- Only one contributes to FES (traceless)
- Amp. Of modes with FES are highly related

TABLE VII: $\overline{B}_q \to D\overline{T}_{\bar c\bar q[q'q'']}$ decay amplitudes in $\Delta S = -1$ and $\Delta S = 0$ transitions in scenario I.

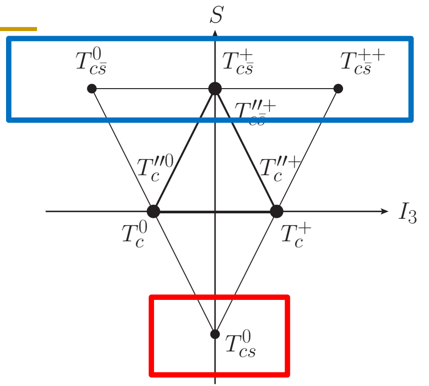
| # | Mode | $A(\overline{B}_q \to D\overline{T}_{\bar c\bar q[q'q'']})$ | # | Mode | $A(\overline{B}_q \to D\overline{T}_{\bar c\bar q[q'q'']})$ |
|---|---|---|---|---|---|
| $\bar{1}^*$ | $B^- \to D^+\overline{T}^{--}_{\bar cs}$ | $-C_{\overline{T}}$ | $\bar{2}^*$ | $B^- \to D^0\overline{T}^{-}_{\bar cs}$ | $-\frac{1}{\sqrt{2}}C_{\overline{T}}$ |
| $\bar{2}^*$ | $\overline{B}^0 \to D^+\overline{T}^{-}_{\bar cs}$ | $\frac{1}{\sqrt{2}}C_{\overline{T}}$ | $\bar{3}^*$ | $\overline{B}^0 \to D^0\overline{T}^{0}_{\bar cs}$ | $-C_{\overline{T}}$ |
| $\bar{5}$ | $\overline{B}^0_s \to D^+\overline{T}^{-}_{\bar c}$ | $-\frac{1}{\sqrt{2}}C_{\overline{T}}$ | $\bar{6}$ | $\overline{B}^0_s \to D^0\overline{T}^{0}_{\bar c}$ | $\frac{1}{\sqrt{2}}C_{\overline{T}}$ |
| $\bar{7}$ | $\overline{B}^0_s \to D^+\overline{T}''^{-}_{\bar c}$ | $\frac{1}{\sqrt{2}}(C_{\overline{T}} + 2E_{\overline{T}\overline{B}})$ | $\bar{8}$ | $\overline{B}^0_s \to D^0\overline{T}''^{0}_{\bar c}$ | $\frac{1}{\sqrt{2}}(C_{\overline{T}} + 2E_{\overline{T}\overline{B}})$ |
| $\bar{9}$ | $B^- \to D^0\overline{T}''^{-}_{\bar cs}$ | $-\frac{1}{\sqrt{2}}(C_{\overline{T}} + 2T_{\overline{T}})$ | $\bar{9}$ | $\overline{B}^0 \to D^+\overline{T}''^{-}_{\bar cs}$ | $-\frac{1}{\sqrt{2}}(C_{\overline{T}} + 2T_{\overline{T}})$ |
| $\bar{9}$ | $\overline{B}^0_s \to D^+_s\overline{T}''^{-}_{\bar cs}$ | $\sqrt{2}(-T_{\overline{T}} + E_{\overline{T}\overline{B}})$ | | | |

| # | Mode | $A'(\overline{B}_q \to D\overline{T}_{\bar c\bar q[q'q'']})$ | # | Mode | $A'(\overline{B}_q \to D\overline{T}_{\bar c\bar q\{q'q''\}})$ |
|---|---|---|---|---|---|
| $\bar{1}^*$ | $B^- \to D^+_s\overline{T}^{--}_{\bar cs}$ | $C'_{\overline{T}}$ | $\bar{2}^*$ | $\overline{B}^0 \to D^+_s\overline{T}^{-}_{\bar cs}$ | $-\frac{C'_{\overline{T}}}{\sqrt{2}}$ |
| $\bar{4}^*$ | $\overline{B}^0_s \to D^0\overline{T}^{0}_{\bar cs}$ | $-C'_{\overline{T}}$ | | | |
| $\bar{5}$ | $B^- \to D^0\overline{T}^{-}_{\bar c}$ | $-\frac{1}{\sqrt{2}}C'_{\overline{T}}$ | $\bar{5}$ | $\overline{B}^0_s \to D^+_s\overline{T}^{-1}_{\bar c}$ | $\frac{1}{\sqrt{2}}C'_{\overline{T}}$ |
| $\bar{6}$ | $\overline{B}^0 \to D^0\overline{T}^{0}_{\bar c}$ | $-\frac{1}{\sqrt{2}}C'_{\overline{T}}$ | | | |
| $\bar{7}$ | $B^- \to D^0\overline{T}''^{-}_{\bar c}$ | $-\frac{1}{\sqrt{2}}(C'_{\overline{T}} + 2T'_{\overline{T}})$ | $\bar{7}$ | $\overline{B}^0 \to D^+\overline{T}''^{-}_{\bar c}$ | $\sqrt{2}(E'_{\overline{T}\overline{B}} - T'_{\overline{T}})$ |
| $\bar{7}$ | $\overline{B}^0_s \to D^+_s\overline{T}''^{-}_{\bar c}$ | $-\frac{1}{\sqrt{2}}(C'_{\overline{T}} + 2T'_{\overline{T}})$ | $\bar{8}$ | $\overline{B}^0 \to D^0\overline{T}''^{0}_{\bar c}$ | $\frac{1}{\sqrt{2}}(C'_{\overline{T}} + 2E'_{\overline{T}\overline{B}})$ |
| $\bar{9}$ | $\overline{B}^0 \to D^+_s\overline{T}''^{-}_{\bar cs}$ | $\frac{1}{\sqrt{2}}(C'_{\overline{T}} + 2E'_{\overline{T}\overline{B}})$ | | | |




- Modes with states in **6** / FES are highly related

# Relations on rates

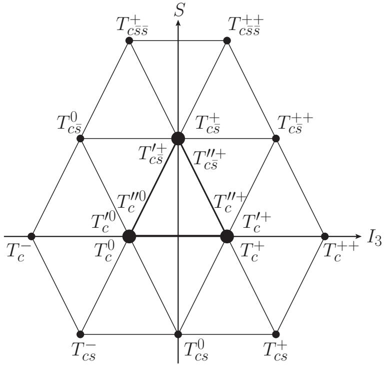



$$\begin{aligned}\Gamma(B^- \to D^+ \overline{T}^{--}_{\bar c s}) &= \Gamma(\overline{B}^0 \to D^0 \overline{T}^0_{\bar c s}) = 2\Gamma(\overline{B}^0 \to D^+ \overline{T}^-_{\bar c s}) = 2\Gamma(B^- \to D^0 \overline{T}^-_{\bar c s}) \\ &= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D_s^+ \overline{T}^{--}_{\bar c s}) = 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D_s^+ \overline{T}^-_{\bar c s}) \\ &= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0_s \to D^0 \overline{T}^0_{\bar c \bar s}).\end{aligned}$$

- All four FES are involved (2 LHCb modes)
- But need $\Delta S = -1$ and $\Delta S = 0$ transitions

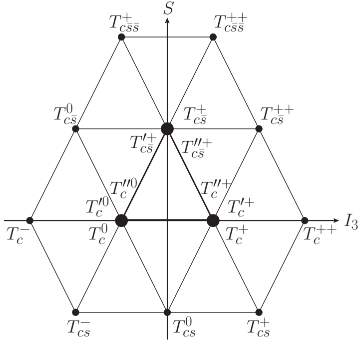
TABLE VIII: $\overline{B}_q \to D\overline{T}_{\bar{c}\bar{q}\{q'q''\}}$ decay amplitudes in $\Delta S = -1$ and 0 transitions in scenario II.

| # | Mode | $A(\overline{B}_q \to D\overline{T}_{\bar{c}\bar{q}[q'q'']})$ | # | Mode | $A(\overline{B}_q \to D\overline{T}_{\bar{c}\bar{q}\{q'q''\}})$ |
|---|---|---|---|---|---|
| $\bar{1}'^*$ | $B^- \to D^+\overline{T}_{\bar{c}s}^{--}$ | $C_{\bar{T}}$ | $\bar{2}'^*$ | $B^- \to D^0\overline{T}_{\bar{c}s}^{-}$ | $\frac{1}{\sqrt{2}}C_{\bar{T}}$ |
| $\bar{2}'^*$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}s}^{-}$ | $-\frac{1}{\sqrt{2}}C_{\bar{T}}$ | $\bar{3}'^*$ | $\overline{B}^0 \to D^0\overline{T}_{\bar{c}s}^{0}$ | $C_{\bar{T}}$ |
| $\bar{7}'^*$ | $B^- \to D_s^+\overline{T}_{\bar{c}ss}^{--}$ | $\sqrt{2}C_{\bar{T}}$ | $\bar{8}'^*$ | $\overline{B}^0 \to D_s^+\overline{T}_{\bar{c}ss}^{-}$ | $\sqrt{2}C_{\bar{T}}$ |
| $13'$ | $\overline{B}_s^0 \to D^+\overline{T}_{\bar{c}}^{\prime -1}$ | $-\frac{\sqrt{3}}{2}C_{\bar{T}}$ | $14'$ | $\overline{B}_s^0 \to D^0\overline{T}_{\bar{c}}^{\prime 0}$ | $-\frac{\sqrt{3}}{2}C_{\bar{T}}$ |
| $\overline{15}'$ | $B^- \to D^0\overline{T}_{\bar{c}s}^{\prime -}$ | $\frac{1}{2}C_{\bar{T}}$ | $\overline{15}'$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}s}^{\prime -}$ | $\frac{1}{2}C_{\bar{T}}$ |
| $\overline{15}'$ | $\overline{B}_s^0 \to D_s^+\overline{T}_{\bar{c}s}^{\prime -}$ | $-C_{\bar{T}}$ | | | |
| $\overline{16}'$ | $\overline{B}_s^0 \to D^+\overline{T}_{\bar{c}}^{\prime\prime -}$ | $\frac{1}{2}(C_{\bar{T}} + 4E_{\bar{T}\bar{B}})$ | $\overline{17}'$ | $\overline{B}_s^0 \to D^0\overline{T}_{\bar{c}}^{\prime\prime 0}$ | $\frac{1}{2}(C_{\bar{T}} + 4E_{\bar{T}\bar{B}})$ |
| $\overline{18}'$ | $B^- \to D^0\overline{T}_{\bar{c}s}^{\prime\prime -}$ | $\frac{1}{2}(4T_{\bar{T}} + C_{\bar{T}})$ | $\overline{18}'$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}s}^{\prime\prime -}$ | $\frac{1}{2}(4T_{\bar{T}} + C_{\bar{T}})$ |
| $\overline{18}'$ | $\overline{B}_s^0 \to D_s^+\overline{T}_{\bar{c}s}^{\prime\prime -}$ | $2T_{\bar{T}} + C_{\bar{T}} + 2E_{\bar{T}\bar{B}}$ | | | |
| # | Mode | $A'(\overline{B}_q \to D\overline{T}_{\bar{c}\bar{q}[q'q'']})$ | # | Mode | $A'(\overline{B}_q \to D\overline{T}_{\bar{c}\bar{q}\{q'q''\}})$ |
| $\bar{1}'^*$ | $B^- \to D_s^+\overline{T}_{\bar{c}s}^{--}$ | $C'_{\bar{T}}$ | $\bar{2}'^*$ | $\overline{B}^0 \to D_s^+\overline{T}_{\bar{c}s}^{-}$ | $-\frac{1}{\sqrt{2}}C'_{\bar{T}}$ |
| $\bar{4}'^*$ | $\overline{B}_s^0 \to D^+\overline{T}_{\bar{c}\bar{s}}^{-}$ | $\sqrt{2}C'_{\bar{T}}$ | $\bar{5}'^*$ | $\overline{B}_s^0 \to D^0\overline{T}_{\bar{c}\bar{s}}^{0}$ | $C'_{\bar{T}}$ |
| $\bar{9}'^*$ | $B^- \to D^+\overline{T}_{\bar{c}}^{--}$ | $\sqrt{2}C'_{\bar{T}}$ | $\overline{10}'^*$ | $B^- \to D^0\overline{T}_{\bar{c}}^{-}$ | $\sqrt{\frac{2}{3}}C'_{\bar{T}}$ |
| $\overline{10}'^*$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}}^{-}$ | $-\sqrt{\frac{2}{3}}C'_{\bar{T}}$ | $\overline{11}'^*$ | $\overline{B}^0 \to D^0\overline{T}_{\bar{c}}^{0}$ | $-\sqrt{\frac{2}{3}}C'_{\bar{T}}$ |
| $\overline{13}'$ | $B^- \to D^0\overline{T}_{\bar{c}}^{\prime -}$ | $\frac{1}{2\sqrt{3}}C'_{\bar{T}}$ | $\overline{13}'$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}}^{\prime -}$ | $\frac{1}{\sqrt{3}}C'_{\bar{T}}$ |
| $\overline{13}'$ | $\overline{B}_s^0 \to D_s^+\overline{T}_{\bar{c}}^{\prime -}$ | $-\frac{\sqrt{3}}{2}C'_{\bar{T}}$ | $\overline{14}'$ | $\overline{B}_s^0 \to D^0\overline{T}_{\bar{c}}^{\prime 0}$ | $\frac{1}{2\sqrt{3}}C'_{\bar{T}}$ |
| $\overline{15}'$ | $\overline{B}^0 \to D_s^+\overline{T}_{\bar{c}s}^{\prime -}$ | $\frac{1}{2}C'_{\bar{T}}$ | | | |
| $\overline{16}'$ | $B^- \to D^0\overline{T}_{\bar{c}}^{\prime\prime -}$ | $\frac{1}{2}(4T'_{\bar{T}} + C'_{\bar{T}})$ | $\overline{16}'$ | $\overline{B}^0 \to D^+\overline{T}_{\bar{c}}^{\prime\prime -}$ | $2T'_{\bar{T}} + C'_{\bar{T}} + 2E'_{\bar{T}\bar{B}}$ |
| $\overline{16}'$ | $\overline{B}_s^0 \to D_s^+\overline{T}_{\bar{c}}^{\prime\prime 0}$ | $\frac{1}{2}(4T'_{\bar{T}} + C'_{\bar{T}})$ | $\overline{17}'$ | $\overline{B}^0 \to D^0\overline{T}_{\bar{c}}^{\prime\prime 0}$ | $\frac{1}{2}(C'_{\bar{T}} + 4E'_{\bar{T}\bar{B}})$ |
| $\overline{18}'$ | $\overline{B}^0 \to D_s^+\overline{T}_{\bar{c}s}^{\prime\prime -}$ | $\frac{1}{2}(C'_{\bar{T}} + 4E'_{\bar{T}\bar{B}})$ | | | |



- Modes with $T$ in $\overline{\mathbf{15}}$ /FES are highly related
- 4 modes have been considered by QQY

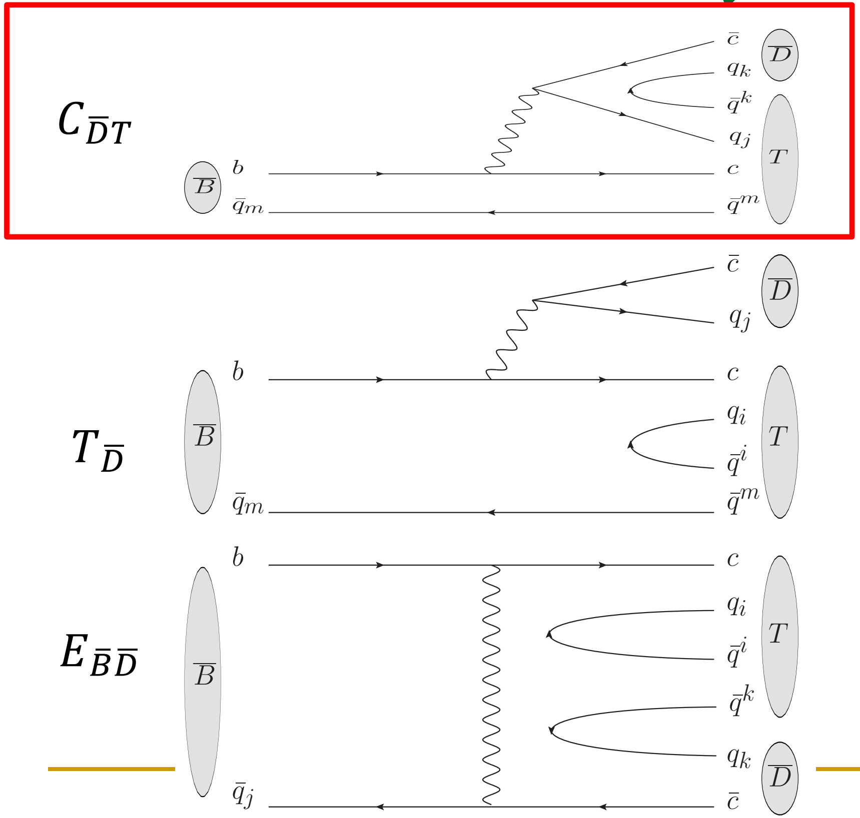
# Relations on rates




$$
\begin{aligned}
2\Gamma(B^- \to D^+ \overline{T}_{\bar{c}s}^{\,--}) &= 4\Gamma(B^- \to D^0 \overline{T}_{\bar{c}s}^{\,-}) = 4\Gamma(\overline{B}^0 \to D^+ \overline{T}_{\bar{c}s}^{\,-}) = 2\Gamma(\overline{B}^0 \to D^0 \overline{T}_{\bar{c}s}^{\,0}) \\
&= \Gamma(B^- \to D_s^+ \overline{T}_{\bar{c}ss}^{\,--}) = \Gamma(\overline{B}^0 \to D_s^+ \overline{T}_{\bar{c}ss}^{\,-}) \\
&= 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D_s^+ \overline{T}_{\bar{c}s}^{\,--}) = 4\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D_s^+ \overline{T}_{\bar{c}s}^{\,-}) \\
&= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to D^+ \overline{T}_{\bar{c}\bar{s}}^{\,-}) = 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to D^0 \overline{T}_{\bar{c}\bar{s}}^{\,0}) \\
&= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D^+ \overline{T}_{\bar{c}}^{\,--}) = 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D^0 \overline{T}_{\bar{c}}^{\,-}) \\
&= 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D^+ \overline{T}_{\bar{c}}^{\,-}) = 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D^0 \overline{T}_{\bar{c}}^{\,0}).
\end{aligned}
$$

- 14 decay modes of 9 FES are highly related
- If not observed pose tension on scenario II

# $\overline{B} \rightarrow \overline{D}T$ decays

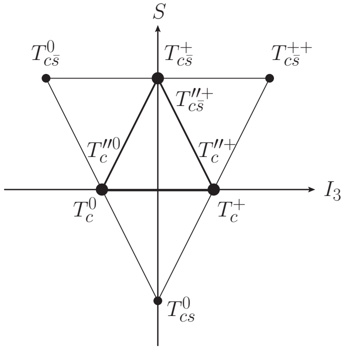



- Three TA
- Subscripts denote mesons receiving $c\bar{s}(\bar{d})$ from $W \rightarrow c\bar{q}$
- *C*, *T*, *E*: Internal W, External W, Exchange diagrams
- Only one contributes to FES (traceless)
- Highly related
- ~~$T^{++}$~~ charge conservation.

TABLE IX: $\overline{B}_q \to \overline{D}T_{cq[\bar q'\bar q'']}$ decay amplitudes in $\Delta S = -1$ and $\Delta S = 0$ transitions in scenario I.

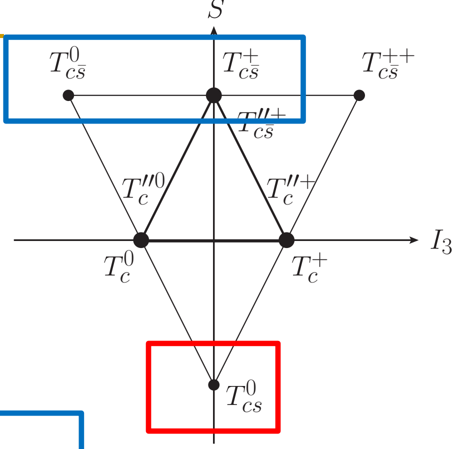
| # | Mode | $A(\overline{B}_q \to \overline{D}T_{cq[\bar q'\bar q'']})$ | # | Mode | $A(\overline{B}_q \to \overline{D}T_{cq[\bar q'\bar q'']})$ |
|---|---|---|---|---|---|
| 4* | $B^- \to D^- T^0_{cs}$ | $C_{\bar D T}$ | 4* | $\overline{B}^0 \to \overline{D}^0 T^0_{cs}$ | $-C_{\bar D T}$ |
| 5 | $\overline{B}^0 \to D^-_s T^+_c$ | $\frac{C_{\bar D T}}{\sqrt{2}}$ | 5 | $\overline{B}^0_s \to D^- T^+_c$ | $-\frac{1}{\sqrt{2}}C_{\bar D T}$ |
| 6 | $B^- \to D^-_s T^0_c$ | $-\frac{1}{\sqrt{2}}C_{\bar D T}$ | 6 | $\overline{B}^0_s \to \overline{D}^0 T^0_c$ | $\frac{1}{\sqrt{2}}C_{\bar D T}$ |
| 7 | $\overline{B}^0 \to D^-_s T''^+_c$ | $-\frac{1}{\sqrt{2}}(2T_{\bar D} + C_{\bar D T})$ | 7 | $\overline{B}^0_s \to D^- T''^+_c$ | $\frac{1}{\sqrt{2}}(C_{\bar D T} + 2E_{\bar D \bar B})$ |
| 8 | $B^- \to D^-_s T''^0_c$ | $-\frac{1}{\sqrt{2}}(2T_{\bar D} + C_{\bar D T})$ | 8 | $\overline{B}^0_s \to \overline{D}^0 T''^0_c$ | $\frac{1}{\sqrt{2}}(C_{\bar D T} + 2E_{\bar D \bar B})$ |
| 9 | $\overline{B}^0_s \to D^-_s T''^+_{c\bar s}$ | $-\sqrt{2}(T_{\bar D} - E_{\bar D \bar B})$ | | | |

| # | Mode | $A'(\overline{B}_q \to \overline{D}T_{cq[\bar q'\bar q'']})$ | # | Mode | $A'(\overline{B}_q \to \overline{D}T_{cq[\bar q'\bar q'']})$ |
|---|---|---|---|---|---|
| 2* | $\overline{B}^0 \to D^-_s T^+_{c\bar s}$ | $-\frac{1}{\sqrt{2}}C'_{\bar D T}$ | 2* | $\overline{B}^0_s \to D^- T^+_{c\bar s}$ | $\frac{1}{\sqrt{2}}C'_{\bar D T}$ |
| 3* | $B^- \to D^-_s T^0_{c\bar s}$ | $C'_{\bar D T}$ | 3* | $\overline{B}^0_s \to \overline{D}^0 T^0_{c\bar s}$ | $-C'_{\bar D T}$ |
| 6 | $B^- \to D^- T^0_c$ | $\frac{1}{\sqrt{2}}C'_{\bar D T}$ | 6 | $\overline{B}^0 \to \overline{D}^0 T^0_c$ | $-\frac{1}{\sqrt{2}}C'_{\bar D T}$ |
| 7 | $\overline{B}^0 \to D^- T''^+_c$ | $-\sqrt{2}(T'_{\bar D} - E'_{\bar D \bar B})$ | 8 | $B^- \to D^- T''^0_c$ | $-\frac{1}{\sqrt{2}}(2T'_{\bar D} + C'_{\bar D T})$ |
| 8 | $\overline{B}^0 \to \overline{D}^0 T''^0_c$ | $\frac{1}{\sqrt{2}}(C'_{\bar D T} + 2E'_{\bar D \bar B})$ | | | |
| 9 | $\overline{B}^0 \to D^-_s T''^+_{c\bar s}$ | $\frac{1}{\sqrt{2}}(C'_{\bar D T} + 2E'_{\bar D \bar B})$ | 9 | $\overline{B}^0_s \to D^- T''^+_{c\bar s}$ | $-\frac{1}{\sqrt{2}}(2T'_{\bar D} + C'_{\bar D T})$ |




- Modes with states in **6**/FES are highly related.

# Relations on rates




$$\Gamma(B^- \to D^- T^0_{cs}) = \Gamma(\overline{B}^0 \to \overline{D}^0 T^0_{cs}) = \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D_s^- T^0_{c\bar{s}})$$

$$= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to \overline{D}^0 T^0_{c\bar{s}}) = 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D_s^- T^+_{c\bar{s}})$$

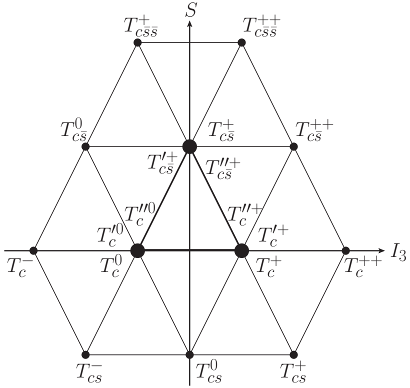
$$= 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to D^- T^+_{c\bar{s}}).$$

- Three FES are involved
- Only one mode is observed so far

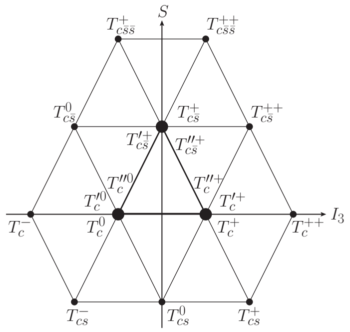
TABLE X: $\overline{B}_q \to \overline{D}T_{cq\{\bar q'\bar q''\}}$ decay amplitudes in $\Delta S = -1$ and $\Delta S = 0$ transitions in scenerio II.

| # | Mode | $A(\overline{B}_q \to \overline{D}T_{cq\{\bar q'\bar q''\}})$ | # | Mode | $A(\overline{B}_q \to \overline{D}T_{cq\{\bar q'\bar q''\}})$ |
|---|---|---|---|---|---|
| 4′* | $\overline{B}^0 \to D^- T^+_{cs}$ | $\sqrt{2}C_{\bar{D}T}$ | 5′* | $B^- \to D^- T^0_{cs}$ | $C_{\bar{D}T}$ |
| 5′* | $\overline{B}^0 \to \overline{D}^0 T^0_{cs}$ | $C_{\bar{D}T}$ | 6′* | $B^- \to \overline{D}^0 T^-_{cs}$ | $\sqrt{2}C_{\bar{D}T}$ |
| 13′ | $\overline{B}^0 \to D_s^- T'^+_c$ | $-\frac{\sqrt{3}}{2}C_{\bar{D}T}$ | 13′ | $\overline{B}^0_s \to D^- T'^+_c$ | $-\frac{\sqrt{3}}{2}C_{\bar{D}T}$ |
| 14′ | $B^- \to D_s^- T'^0_c$ | $-\frac{\sqrt{3}}{2}C_{\bar{D}T}$ | 14′ | $\overline{B}^0_s \to \overline{D}^0 T'^0_c$ | $-\frac{\sqrt{3}}{2}C_{\bar{D}T}$ |
| 15′ | $\overline{B}^0_s \to D_s^- T'^+_{c\bar s}$ | $-C_{\bar{D}T}$ | | | |
| 16′ | $\overline{B}^0 \to D_s^- T''^+_c$ | $\frac{1}{2}(4T_{\bar{D}} + C_{\bar{D}T})$ | 16′ | $\overline{B}^0_s \to D^- T''^+_c$ | $\frac{1}{2}(C_{\bar{D}T} + 4E_{\bar{D}\bar{B}})$ |
| 17′ | $B^- \to D_s^- T''^0_c$ | $\frac{1}{2}(4T_{\bar{D}} + C_{\bar{D}T})$ | 17′ | $\overline{B}^0_s \to \overline{D}^0 T''^0_c$ | $\frac{1}{2}(C_{\bar{D}T} + 4E_{\bar{D}\bar{B}})$ |
| 18′ | $\overline{B}^0_s \to D_s^- T''^+_{c\bar s}$ | $2T_{\bar{D}} + C_{\bar{D}T} + 2E_{\bar{D}\bar{B}}$ | | | |

| # | Mode | $A'(\overline{B}_q \to \overline{D}T_{cq\{\bar q'\bar q''\}})$ | # | Mode | $A'(\overline{B}_q \to \overline{D}T_{cq\{\bar q'\bar q''\}})$ |
|---|---|---|---|---|---|
| 2′* | $\overline{B}^0 \to D_s^- T^+_{c\bar s}$ | $-\frac{C'_{\bar{D}T}}{\sqrt{2}}$ | 2′* | $\overline{B}^0_s \to D^- T^+_{c\bar s}$ | $-\frac{C'_{\bar{D}T}}{\sqrt{2}}$ |
| 3′* | $B^- \to D_s^- T^0_{c\bar s}$ | $C'_{\bar{D}T}$ | 3′* | $\overline{B}^0_s \to \overline{D}^0 T^0_{c\bar s}$ | $C'_{\bar{D}T}$ |
| 8′* | $\overline{B}^0_s \to D_s^- T^+_{c\bar s\bar s}$ | $\sqrt{2}C'_{\bar{D}T}$ | | | |
| 10′* | $\overline{B}^0 \to D^- T^+_c$ | $-\sqrt{\frac{2}{3}}C'_{\bar{D}T}$ | 11′* | $B^- \to D^- T^0_c$ | $-\sqrt{\frac{2}{3}}C'_{\bar{D}T}$ |
| 11′* | $\overline{B}^0 \to \overline{D}^0 T^0_c$ | $-\sqrt{\frac{2}{3}}C'_{\bar{D}T}$ | 12′* | $B^- \to \overline{D}^0 T^-_c$ | $\sqrt{2}C'_{\bar{D}T}$ |
| 13′ | $\overline{B}^0 \to D^- T'^+_c$ | $\frac{1}{\sqrt{3}}C'_{\bar{D}T}$ | 14′ | $B^- \to D^- T'^0_c$ | $\frac{1}{2\sqrt{3}}C'_{\bar{D}T}$ |
| 14′ | $\overline{B}^0 \to \overline{D}^0 T'^0_c$ | $\frac{1}{2\sqrt{3}}C'_{\bar{D}T}$ | | | |
| 15′ | $\overline{B}^0 \to D_s^- T'^+_{c\bar s}$ | $\frac{1}{2}C'_{\bar{D}T}$ | 15′ | $\overline{B}^0_s \to D^- T^+_{c\bar s}$ | $\frac{1}{2}C'_{\bar{D}T}$ |
| 16′ | $\overline{B}^0 \to D^- T''^+_c$ | $2T'_{\bar{D}} + C'_{\bar{D}T} + 2E'_{\bar{D}\bar{B}}$ | 17′ | $B^- \to D^- T''^0_c$ | $\frac{1}{2}(4T'_{\bar{D}} + C'_{\bar{D}T})$ |
| 17′ | $\overline{B}^0 \to \overline{D}^0 T''^0_c$ | $\frac{1}{2}(C'_{\bar{D}T} + 4E'_{\bar{D}\bar{B}})$ | | | |
| 18′ | $\overline{B}^0 \to D_s^- T''^+_{c\bar s}$ | $\frac{1}{2}(C'_{D.5} + 4E'_{\bar{D}\bar{B}})$ | 18′ | $\overline{B}^0_s \to D^- T''^+_{c\bar s}$ | $\frac{1}{2}(4T'_{\bar{D}} + C'_{\bar{D}T})$ |




- Modes with $T$ in $\overline{\mathbf{15}}$ /FES are highly related
- 4 modes have been considered by QQY




# Relations on rates

$$
\begin{aligned}
\Gamma(\overline{B}^0 \to D^- T_{cs}^+) &= 2\Gamma(B^- \to D^- T_{cs}^0) = 2\Gamma(\overline{B}^0 \to \overline{D}^0 T_{cs}^0) = \Gamma(B^- \to \overline{D}^0 T_{cs}^-) \\
&= 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D_s^- T_{c\bar{s}}^0) = 2\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to \overline{D}^0 T_{c\bar{s}}^0) \\
&= 4\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D_s^- T_{c\bar{s}}^+) = 4\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to D^- T_{c\bar{s}}^+) \\
&= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}_s^0 \to D_s^- T_{c\bar{s}\bar{s}}^+) = 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to D^- T_c^+) \\
&= 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to D^- T_c^0) = 3\left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(\overline{B}^0 \to \overline{D}^0 T_c^0) \\
&= \left|\frac{V_{cs}}{V_{cd}}\right|^2 \Gamma(B^- \to \overline{D}^0 T_c^-).
\end{aligned}
$$

- 13 decay modes of 9 FES are highly related
- If not observed, pose tension to scenario II

# Participation of the three $T$

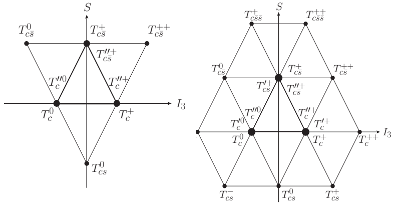


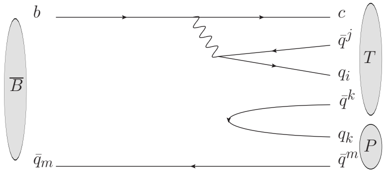
TABLE XI: Participation of $T^*_{c\bar{s}0}(2900)^{++}$, $T^*_{c\bar{s}0}(2900)^0$ and $T^*_{cs0}(2870)^0$ in $\overline{B} \to D\overline{T}$ and $\overline{B} \to \overline{D}T$ decays in $\Delta S = -1$ and $\Delta S = 0$ transitions. TA stands for topological amplitude.

| Decays | $T^*_{c\bar{s}0}(2900)^{++}$ | $T^*_{c\bar{s}0}(2900)^0$ | $T^*_{cs0}(2870)^0$ | TA involved |
|---|---|---|---|---|
| $\overline{B} \to D\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | X | $C_{\overline{T}}$ |
| $\overline{B} \to \overline{D}T$, $\Delta S = -1$ | X | X | ✓ | $C_{\overline{D}T}$ |
| $\overline{B} \to D\overline{T}$, $\Delta S = 0$ | ✓ | X | ✓ | $C'_{\overline{T}}$ |
| $\overline{B} \to \overline{D}T$, $\Delta S = 0$ | X | ✓ | X | $C'_{\overline{D}T}$ |

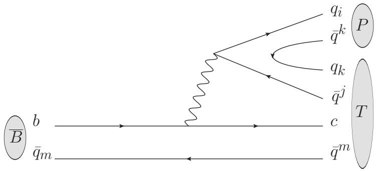
- Observed in $\Delta S = -1$ transitions
- Need $\Delta S = -1$ and $\Delta S = 0$ transitions to check if they are in the same multiplet.

# $\overline{B} \to TP$ decays

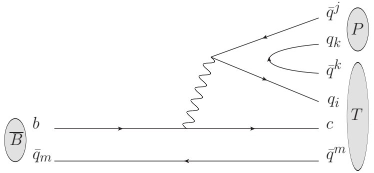
$C_T$



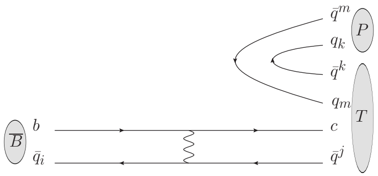
$C_{PT,1}$

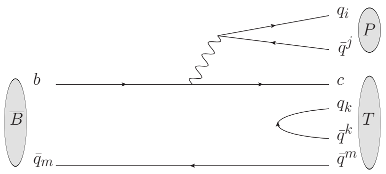


$C_{TP}$

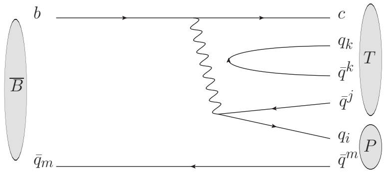


$E_{\bar{B}T}$

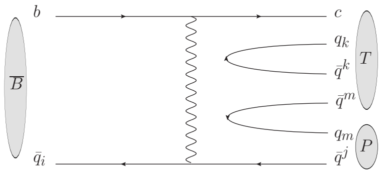




$T_P$



$C_{PT,2}$



$E_{\bar{B}P}$

- Seven TA, only four contribute to FES
- Three (four) indep. combinations for FES in scenario I (II)
- In scenario I

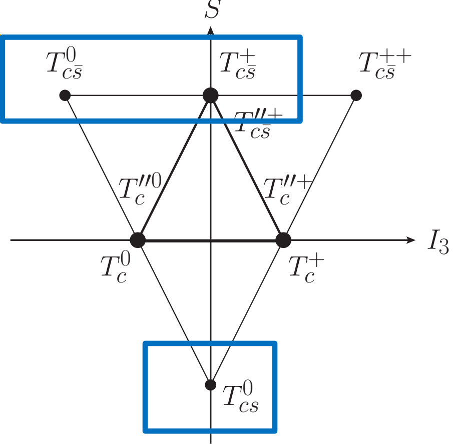
$$\boldsymbol{\overline{B}\,O \sim \overline{3} \otimes 8 = \overline{15} \oplus 6 \oplus \overline{3}}$$

$$\boldsymbol{TP \sim 6 \otimes 8 = 24 \oplus \overline{15} \oplus 6 \oplus \overline{3}}$$

TABLE XII: $\overline{B}_q \to T_{cq'[\bar q''\bar q''']}P$ decay amplitudes in $\Delta S = 0$ and $-1$ transitions in scenario I.

| # | Mode | $A(\overline{B}_q \to T_{cq[\bar q'\bar q'']}P)$ | # | Mode | $A(\overline{B}_q \to T_{cq[\bar q'\bar q'']}P)$ |
|---|---|---|---|---|---|
| 2* | $\overline{B}^0 \to T^+_{c\bar s}K^-$ | $-\frac{1}{\sqrt2}(C_{TP} - E_{\bar BT})$ | 2* | $\overline{B}^0_s \to T^+_{c\bar s}\pi^-$ | $\frac{1}{\sqrt2}(C_{TP} - C_{PT,1})$ |
| 3* | $B^- \to T^0_{c\bar s}K^-$ | $C_T + C_{TP}$ | 3* | $\overline{B}^0 \to T^0_{c\bar s}\overline{K}^0$ | $C_T + E_{\bar BT}$ |
| 3* | $\overline{B}^0_s \to T^0_{c\bar s}\pi^0$ | $-\frac{1}{\sqrt2}(C_{TP} - C_{PT,1})$ | 3* | $\overline{B}^0_s \to T^0_{c\bar s}\eta$ | $-\frac{c_{\phi'}}{\sqrt2}(C_{TP} + C_{PT,1}) - s_{\phi'}C_T$ |
| 3* | $\overline{B}^0_s \to T^0_{c\bar s}\eta'$ | $-\frac{s_{\phi'}}{\sqrt2}(C_{TP} + C_{PT,1}) + c_{\phi'}C_T$ | 4* | $\overline{B}^0 \to T^0_{cs}K^0$ | $-C_{PT,1} + E_{\bar BT}$ |
| 5 | $\overline{B}^0 \to T^+_c\pi^-$ | $-\frac{1}{\sqrt2}(C_{PT,1} - E_{\bar BT})$ | 6 | $B^- \to T^0_c\pi^-$ | $\frac{1}{\sqrt2}(C_T + C_{TP})$ |
| 6 | $\overline{B}^0 \to T^0_c\pi^0$ | $\frac12(-C_T - C_{TP} + C_{PT,1} - E_{\bar BT})$ | 6 | $\overline{B}^0 \to T^0_c\eta$ | $\frac{c_{\phi'}}{2}(C_T - C_{TP} - C_{PT,1} + E_{\bar BT}) + \frac{s_{\phi'}}{\sqrt2}E_{\bar BT}$ |
| 6 | $\overline{B}^0_s \to T^0_cK^0$ | $\frac{1}{\sqrt2}(C_T + C_{PT,1})$ | 6 | $\overline{B}^0 \to T^0_c\eta'$ | $\frac{s_{\phi'}}{2}(C_T - C_{TP} - C_{PT,1} + E_{\bar BT}) - \frac{c_{\phi'}}{\sqrt2}E_{\bar BT}$ |
| 7 | $\overline{B}^0 \to T''^+_c\pi^-$ | $-\frac{1}{\sqrt2}(2T_P + C_{PT,1} - E_{\bar BT} + 2E_{\bar BP})$ | 8 | $B^- \to T''^0_c\pi^-$ | $-\frac{1}{\sqrt2}(2T_P + C_T + C_{TP} + 2C_{PT,2})$ |
| 8 | $\overline{B}^0 \to T''^0_c\eta$ | $\frac{c_{\phi'}}{2}(-C_T + C_{TP} + C_{PT,1} - 2C_{PT,2}$ $-E_{\bar BT} - 2E_{\bar BP}) + \frac{s_{\phi'}}{\sqrt2}E_{\bar BT}$ | 8 | $\overline{B}^0 \to T''^0_c\eta'$ | $\frac{s_{\phi'}}{2}(-C_T + C_{TP} + C_{PT,1} - 2C_{PT,2}$ $-E_{\bar BT} - 2E_{\bar BP}) - \frac{c_{\phi'}}{\sqrt2}E_{\bar BT}$ |
| 8 | $\overline{B}^0 \to T''^0_c\pi^0$ | $\frac12(C_T + C_{TP} - C_{PT,1} + 2C_{PT,2}$ $+E_{\bar BT} - 2E_{\bar BP})$ | 8 | $\overline{B}^0_s \to T''^0_cK^0$ | $-\frac{1}{\sqrt2}(C_T - C_{PT,1} + 2C_{PT,2})$ |
| 9 | $\overline{B}^0 \to T''^+_{c\bar s}K^-$ | $\frac{1}{\sqrt2}(C_{TP} + E_{\bar BT} - 2E_{\bar BP})$ | 9 | $\overline{B}^0_s \to T''^+_{c\bar s}\pi^-$ | $-\frac{1}{\sqrt2}(2T_P + C_{TP} + C_{PT,1})$ |

| # | Mode | $A'(\overline{B}_q \to T_{cq[\bar q'\bar q'']}P)$ | # | Mode | $A'(\overline{B}_q \to T_{cq[\bar q'\bar q'']}P)$ |
|---|---|---|---|---|---|
| 2* | $\overline{B}^0_s \to T^+_{c\bar s}K^-$ | $-\frac{1}{\sqrt2}(C'_{PT,1} - E'_{\bar BT})$ | 3* | $\overline{B}^0_s \to T^0_{c\bar s}\overline{K}^0$ | $-C'_{PT,1} + E'_{\bar BT}$ |
| 4* | $B^- \to T^0_{cs}\pi^-$ | $C'_T + C'_{TP}$ | 4* | $\overline{B}^0 \to T^0_{cs}\pi^0$ | $-\frac{1}{\sqrt2}(C'_T + C'_{TP})$ |
| 4* | $\overline{B}^0 \to T^0_{cs}\eta$ | $\frac{c_{\phi'}}{\sqrt2}(C'_T - C'_{TP}) + s_{\phi'}C'_{PT,1}$ | 4* | $\overline{B}^0 \to T^0_{cs}\eta'$ | $\frac{s_{\phi'}}{\sqrt2}(C'_T - C'_{TP}) - c_{\phi'}C'_{PT,1}$ |
| 4* | $\overline{B}^0_s \to T^0_{cs}K^0$ | $C'_T + E'_{\bar BT}$ | 5 | $\overline{B}^0 \to T^+_cK^-$ | $\frac{1}{\sqrt2}(C'_{TP} - C'_{PT,1})$ |
| 5 | $\overline{B}^0_s \to T^+_c\pi^-$ | $-\frac{1}{\sqrt2}(C'_{TP} - E'_{\bar BT})$ | 6 | $B^- \to T^0_cK^-$ | $-\frac{1}{\sqrt2}(C'_T + C'_{TP})$ |
| 6 | $\overline{B}^0 \to T^0_c\overline{K}^0$ | $-\frac{1}{\sqrt2}(C'_T + C'_{PT,1})$ | 6 | $\overline{B}^0_s \to T^0_c\pi^0$ | $\frac12(C'_{TP} - E'_{\bar BT})$ |
| 6 | $\overline{B}^0_s \to T^0_c\eta$ | $\frac{c_{\phi'}}{2}(C'_{TP} + E'_{\bar BT})$ $+\frac{s_{\phi'}}{\sqrt2}(C'_T - C'_{PT,1} + E'_{\bar BT})$ | 6 | $\overline{B}^0_s \to T^0_c\eta'$ | $\frac{s_{\phi'}}{2}(C'_{TP} + E'_{\bar BT})$ $-\frac{c_{\phi'}}{\sqrt2}(C'_T - C'_{PT,1} + E'_{\bar BT})$ |
| 7 | $\overline{B}^0 \to T''^+_cK^-$ | $-\frac{1}{\sqrt2}(2T'_P + C'_{TP} + C'_{PT,1})$ | 7 | $\overline{B}_s{}^0 \to T''^+_c\pi^-$ | $\frac{1}{\sqrt2}(C'_{TP} + E'_{\bar BT} - 2E'_{\bar BP})$ |
| 8 | $B^- \to T''^0_cK^-$ | $-\frac{1}{\sqrt2}(2T'_P + C'_T + C'_{TP} + 2C'_{PT,2})$ | 8 | $\overline{B}^0 \to T''^0_c\overline{K}^0$ | $-\frac{1}{\sqrt2}(C'_T - C'_{PT,1} + 2C'_{PT,2})$ |
| 8 | $\overline{B}^0_s \to T''^0_c\eta$ | $\frac{c_{\phi'}}{2}(C'_T - E'_{\bar BT} - 2E'_{\bar BP})$ $+\frac{s_{\phi'}}{\sqrt2}(C'_T - C'_{PT,1} + 2C'_{PT,2} + E'_{\bar BT})$ | 8 | $\overline{B}^0_s \to T''^0_c\eta'$ | $\frac{s_{\phi'}}{2}(C'_T - E'_{\bar BT} - 2E'_{\bar BP})$ $-\frac{c_{\phi'}}{\sqrt2}(C'_T - C'_{PT,1} + 2C'_{PT,2} + E'_{\bar BT})$ |
| 8 | $\overline{B}^0_s \to T''^0_c\pi^0$ | $\frac12(C'_{TP} + E'_{\bar BT} - 2E'_{\bar BP})$ | 9 | $\overline{B}^0_s \to T''^+_{c\bar s}K^-$ | $-\frac{1}{\sqrt2}(2T'_P + C'_{PT,1} - E'_{\bar BT} + 2E'_{\bar BP})$ |




- 15 modes with 3 FES
- ~~$T^{++}$~~ charge conservation

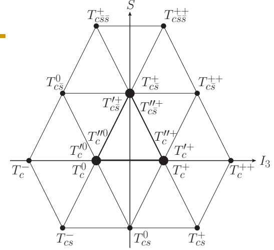


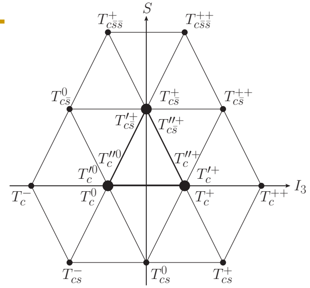
TABLE XIII: $\overline{B}_q \to T_{cq'\{\bar{q}''\bar{q}'''\}} P$ decay amplitudes in $\Delta S = 0$ transitions in scenario II.

| # | Mode | $A(\overline{B}_q \to T_{cq\{\bar{q}'\bar{q}''\}} P)$ |
|---|---|---|
| $2'*$ | $\overline{B}^0 \to T^+_{c\bar{s}} K^-$ | $-\frac{1}{\sqrt{2}}(C_{TP} - E_{\bar{B}T})$ |
| $2'*$ | $\overline{B}^0_s \to T^+_{c\bar{s}} \pi^-$ | $-\frac{1}{\sqrt{2}}(C_{TP} - C_{PT,1})$ |
| $3'*$ | $B^- \to T^0_{c\bar{s}} K^-$ | $C_T + C_{TP}$ |
| $3'*$ | $\overline{B}^0_s \to T^0_{c\bar{s}} \pi^0$ | $\frac{1}{\sqrt{2}}(C_{TP} - C_{PT,1})$ |
| $3'*$ | $\overline{B}^0_s \to T^0_{c\bar{s}} \eta$ | $-s_{\phi'} C_T + \frac{c_{\phi'}}{\sqrt{2}}(C_{PT,1} + C_{TP})$ |
| $3'*$ | $\overline{B}^0_s \to T^0_{c\bar{s}} \eta'$ | $c_{\phi'} C_T + \frac{s_{\phi'}}{\sqrt{2}}(C_{PT,1} + C_{TP})$ |
| $3'*$ | $\overline{B}^0 \to T^0_{c\bar{s}} \overline{K}^0$ | $C_T + E_{\bar{B}T}$ |
| $5'*$ | $\overline{B}^0 \to T^0_{cs} K^0$ | $C_{PT,1} + E_{\bar{B}T}$ |
| $6'*$ | $B^- \to T^-_{cs} K^0$ | $\sqrt{2} C_{PT,1}$ |
| $6'*$ | $\overline{B}^0 \to T^-_{cs} K^+$ | $\sqrt{2} E_{\bar{B}T}$ |
| $8'*$ | $\overline{B}^0_s \to T^+_{c\bar{s}\bar{s}} K^-$ | $\sqrt{2} C_{TP}$ |
| $10'*$ | $\overline{B}^0 \to T^+_c \pi^-$ | $\sqrt{\frac{2}{3}}(-C_{TP} + C_{PT,1} + E_{\bar{B}T})$ |
| $11'*$ | $B^- \to T^0_c \pi^-$ | $-\sqrt{\frac{2}{3}}(C_T + C_{TP} - C_{PT,1})$ |
| $11'*$ | $\overline{B}^0 \to T^0_c \pi^0$ | $\frac{1}{\sqrt{3}}(C_T - C_{PT} + C_{PT,1} + 2E_{\bar{B}T})$ |
| $11'*$ | $\overline{B}^0 \to T^0_c \eta$ | $-\frac{c_{\phi'}}{\sqrt{3}}(C_T + C_{TP} + C_{PT,1})$ |
| $11'*$ | $\overline{B}^0 \to T^0_c \eta'$ | $-\frac{s_{\phi'}}{\sqrt{3}}(C_T + C_{TP} + C_{PT,1})$ |
| $11'*$ | $\overline{B}^0_s \to T^0_c K^0$ | $-\sqrt{\frac{2}{3}} C_T$ |
| $12'*$ | $B^- \to T^-_c \pi^0$ | $C_T + C_{TP} - C_{PT,1}$ |
| $12'*$ | $B^- \to T^-_c \eta$ | $c_{\phi'}(C_T + C_{TP} + C_{PT,1})$ |
| $12'*$ | $B^- \to T^-_c \eta'$ | $s_{\phi'}(C_T + C_{TP} + C_{PT,1})$ |
| $12'*$ | $\overline{B}^0 \to T^-_c \pi^+$ | $\sqrt{2}(C_T + E_{\bar{B}T})$ |
| $12'*$ | $\overline{B}^0_s \to T^-_c K^+$ | $\sqrt{2} C_T$ |

- 22 FES modes (10 modes were given in QQY)
- 4 indep. combinations
- Many relations

TABLE XIV: $\overline{B}_q \to T_{cq'\{\bar q''\bar q'''\}}P$ decay amplitudes in $\Delta S = -1$ transitions in scenario II.

| # | Mode | $A'(\overline{B}_q \to T_{cq\{\bar q'\bar q''\}}P)$ |
|---|---|---|
| $2'^*$ | $\overline{B}{}^0_s \to T^+_{c\bar s}K^-$ | $\frac{1}{\sqrt{2}}(C'_{PT,1}+E'_{\bar BT})$ |
| $3'^*$ | $\overline{B}{}^0_s \to T^0_{c\bar s}\overline{K}{}^0$ | $C'_{PT,1}+E'_{\bar BT}$ |
| $4'^*$ | $\overline{B}{}^0 \to T^+_{cs}\pi^-$ | $\sqrt{2}C'_{TP}$ |
| $5'^*$ | $B^- \to T^0_{cs}\pi^-$ | $C'_T+C'_{TP}$ |
| $5'^*$ | $\overline{B}{}^0 \to T^0_{cs}\pi^0$ | $\frac{1}{\sqrt{2}}(-C'_T+C'_{TP})$ |
| $5'^*$ | $\overline{B}{}^0 \to T^0_{cs}\eta$ | $\frac{c_{\phi'}}{\sqrt{2}}(C'_T+C'_{TP})-s_{\phi'}C'_{PT,1}$ |
| $5'^*$ | $\overline{B}{}^0 \to T^0_{cs}\eta'$ | $\frac{s_{\phi'}}{\sqrt{2}}(C'_T+C'_{TP})+c_{\phi'}C'_{PT,1}$ |
| $5'^*$ | $\overline{B}{}^0_s \to T^0_{cs}K^0$ | $C'_T+E'_{\bar BT}$ |
| $6'^*$ | $B^- \to T^-_{cs}\pi^0$ | $C'_T+C'_{TP}$ |
| $6'^*$ | $B^- \to T^-_{cs}\eta$ | $c_{\phi'}(C'_T+C'_{TP})-\sqrt{2}s_{\phi'}C'_{PT,1}$ |
| $6'^*$ | $B^- \to T^-_{cs}\eta'$ | $s_{\phi'}(C'_T+C'_{TP})+\sqrt{2}c_{\phi'}C'_{PT,1}$ |
| $6'^*$ | $\overline{B}{}^0 \to T^-_{cs}\pi^+$ | $\sqrt{2}C'_T$ |
| $6'^*$ | $\overline{B}{}^0 \to T^-_{cs}K^+$ | $\sqrt{2}(C'_T+E'_{\bar BT})$ |
| $10'^*$ | $\overline{B}{}^0 \to T^+_c K^-$ | $\sqrt{\frac{2}{3}}C'_{PT,1}$ |
| $10'^*$ | $\overline{B}{}^0_s \to T^+_c\pi^-$ | $\sqrt{\frac{2}{3}}E'_{\bar BT}$ |
| $11'^*$ | $B^- \to T^0_c K^-$ | $\sqrt{\frac{2}{3}}C'_{PT,1}$ |
| $11'^*$ | $\overline{B}{}^0 \to T^0_c\overline{K}{}^0$ | $-\sqrt{\frac{2}{3}}C'_{PT,1}$ |
| $11'^*$ | $\overline{B}{}^0_s \to T^0_c\pi^0$ | $\frac{2}{\sqrt{3}}E'_{\bar BT}$ |
| $12'^*$ | $B^- \to T^-_c\overline{K}{}^0$ | $\sqrt{2}C'_{PT,1}$ |
| $12'^*$ | $\overline{B}{}^0_s \to T^-_c\pi^+$ | $\sqrt{2}E'_{\bar BT}$ |

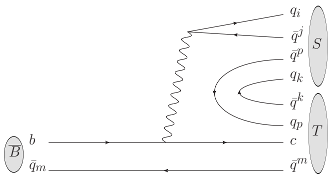


- 20 FES modes
- 4 indep. comb.
- Many relations

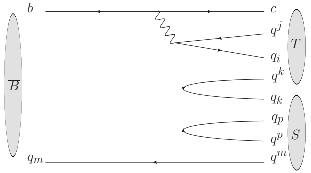
$$\bar{\mathbf{3}}\otimes\mathbf{8}=\overline{\mathbf{15}}\oplus\mathbf{6}\oplus\mathbf{3}\qquad \overline{\mathbf{15}}\otimes\mathbf{8}=\overline{\mathbf{42}}\oplus\mathbf{24}\oplus\overline{\mathbf{15}}'\oplus\overline{\mathbf{15}}\oplus\overline{\mathbf{15}}\oplus\mathbf{6}\oplus\bar{\mathbf{3}}$$

# $\overline{B} \to TS$ decays

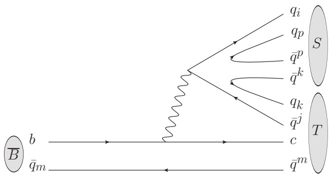
$C_S$



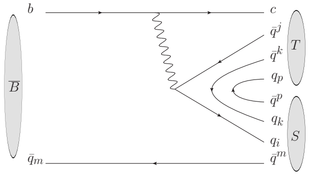

$C_T$



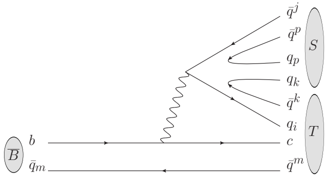

$C_{ST,1}$



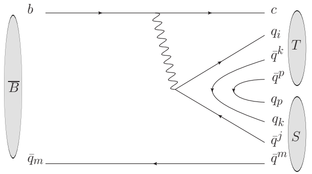

$C_{ST,2}$



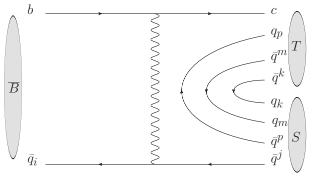

$C_{TS,1}$



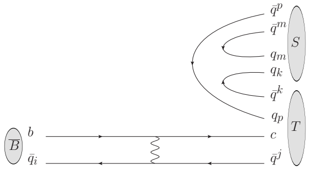

$C_{TS,2}$

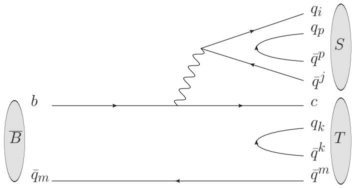



$E_{\bar{B}S,1}$

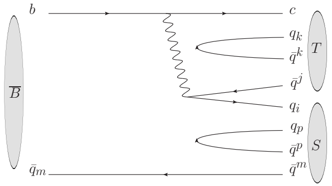



$E_{\bar{B}T}$

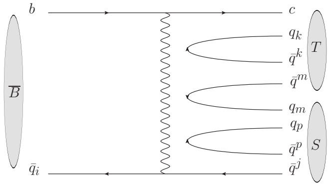



$T_S$




$C_{ST,3}$




$E_{\bar{B}S,2}$

# $\overline{B} \to TS$ decays

- Eleven(nine) TA in scenario I (II)
- Only eight(seven) contribute to FES
- Three(four) combinations for FES with $S = a_0, \kappa$

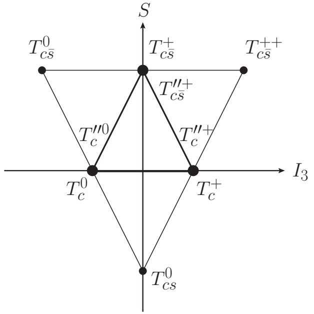
$$\overline{B}\,O \sim \overline{3} \otimes 8 = \overline{15} \oplus 6 \oplus \overline{3}$$

$$TS \sim 6 \otimes 8 = 24 \oplus \overline{15} \oplus 6 \oplus \overline{3}$$

$$TS \sim \overline{15} \otimes 8 = \overline{42} \oplus 24 \oplus \overline{15}' \oplus \overline{15} \oplus \overline{15} \oplus 6 \oplus \overline{3}$$

TABLE XV: $\overline{B}_q \to T_{cq'[\bar q''\bar q''']}S$ decay amplitudes in $\Delta S = 0$ transitions in scenario I.

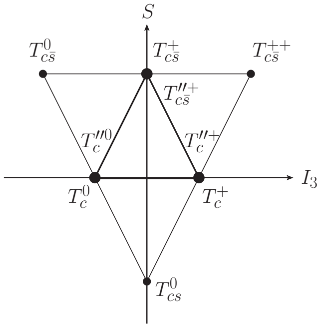
| # | Mode | $A(\overline{B}_q \to T_{cq[\bar q'\bar q'']}S)$ |
|---|---|---|
| 2* | $\overline{B}^0 \to T^+_{c\bar s}\kappa^-$ | $\frac{1}{\sqrt{2}}(C_S + C_{ST,2} - C_{TS,1} - 2C_{TS,2} + 2E_{\bar BS,1} + E_{\bar BT})$ |
| 2* | $\overline{B}^0_s \to T^+_{c\bar s}a_0^-$ | $-\frac{1}{\sqrt{2}}(C_{ST,1} + C_{ST,2} - C_{TS,1} - 2C_{TS,2})$ |
| 3* | $B^- \to T^0_{c\bar s}\kappa^-$ | $C_T - C_S - C_{ST,2} + C_{TS,1}$ |
| 3* | $\overline{B}^0 \to T^0_{c\bar s}\overline{\kappa}^0$ | $C_T - 2C_{TS,2} + 2E_{\bar BS,1} + E_{\bar BT}$ |
| 3* | $\overline{B}^0_s \to T^0_{c\bar s}a^0_0$ | $\frac{1}{\sqrt{2}}(C_{ST,1} + C_{ST,2} - C_{TS,1} - 2C_{TS,2})$ |
| 3* | $\overline{B}^0_s \to T^0_{c\bar s}f_0$ | $-\frac{c_\phi}{\sqrt{2}}(2C_T - C_{ST,1} - C_{ST,2} - C_{TS,1} - 2C_{TS,2})$ $-s_\phi(C_S - C_{ST,1} - C_{TS,1})$ |
| 3* | $\overline{B}^0_s \to T^0_{c\bar s}\sigma$ | $\frac{s_\phi}{\sqrt{2}}(2C_T - C_{ST,1} - C_{ST,2} - C_{TS,1} - 2C_{TS,2})$ $-c_\phi(C_S - C_{ST,1} - C_{TS,1})$ |
| 4* | $\overline{B}^0 \to T^0_{cs}\kappa^0$ | $C_S - C_{ST,1} + 2E_{\bar BS,1} + E_{\bar BT}$ |
| 5 | $\overline{B}^0 \to T^+_c a_0^-$ | $\frac{1}{\sqrt{2}}(C_S - C_{ST,1} + 2E_{\bar BS,1} + E_{\bar BT})$ |
| 6 | $B^- \to T^0_c a_0^-$ | $-\frac{1}{\sqrt{2}}(C_S - C_T + C_{ST,2} - C_{TS,1})$ |
| 6 | $\overline{B}^0 \to T^0_c a^0_0$ | $-\frac{1}{2}(C_T - C_{ST,1} - C_{ST,2} + C_{TS,1} + 2E_{\bar BS,1} + E_{\bar BT})$ |
| 6 | $\overline{B}^0 \to T^0_c f_0$ | $-\frac{c_\phi}{2}(C_T - C_{ST,1} - C_{ST,2} - C_{TS,1} - 2E_{\bar BS,1} - E_{\bar BT})$ $-\frac{s_\phi}{\sqrt{2}}(C_S + C_T - C_{ST,1} - C_{TS,1} - 2C_{TS,2} + 2E_{\bar BS,2} + E_{\bar BT})$ |
| 6 | $\overline{B}^0 \to T^0_c\sigma$ | $\frac{s_\phi}{2}(C_T - C_{ST,1} - C_{ST,2} - C_{TS,1} - 2E_{\bar BS,1} - E_{\bar BT})$ $-\frac{c_\phi}{\sqrt{2}}(C_S + C_T - C_{ST,1} - C_{TS,1} - 2C_{TS,2} + 2E_{\bar BS,2} + E_{\bar BT})$ |
| 6 | $\overline{B}^0_s \to T^0_c\kappa^0$ | $\frac{1}{\sqrt{2}}(C_T - C_S + C_{ST,1} - 2C_{TS,2})$ |




- 3 indep. comb.
- Many relations

TABLE XVI: $\overline{B}_q \to T_{cq'[\bar{q}''\bar{q}''']}S$ decay amplitudes in $\Delta S = -1$ transition in scenario I.

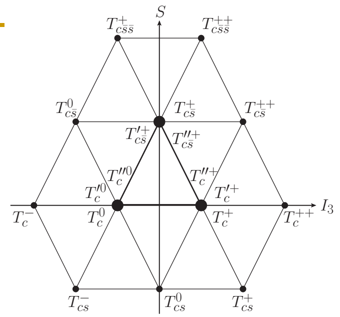
| # | Mode | $A'(\overline{B}_q \to T_{cq[\bar{q}'\bar{q}'']}S)$ |
|---|---|---|
| 2* | $\overline{B}{}^0_s \to T^+_{c\bar{s}}\kappa^-$ | $\frac{1}{\sqrt{2}}(C'_S - C'_{ST,1} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ |
| 3* | $\overline{B}{}^0_s \to T^0_{c\bar{s}}\overline{\kappa}^0$ | $C'_S - C'_{ST,1} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T}$ |
| 4* | $B^- \to T^0_{cs}a^-$ | $C'_T - C'_S - C'_{ST,2} + C'_{TS,1}$ |
| 4* | $\overline{B}{}^0 \to T^0_{cs}a^0_0$ | $-\frac{1}{\sqrt{2}}(C'_T - C'_S - C'_{ST,2} + C'_{TS,1})$ |
| 4* | $\overline{B}{}^0 \to T^0_{cs}f_0$ | $-\frac{c_\phi}{\sqrt{2}}(C'_T + C'_S - 2C'_{ST,1} - C'_{ST,2} - C'_{TS,1})$ $-s_\phi(C'_T - C'_{TS,1} - 2C'_{TS,2})$ |
| 4* | $\overline{B}{}^0 \to T^0_{cs}\sigma$ | $\frac{s_\phi}{\sqrt{2}}(C'_T + C'_S - 2C'_{ST,1} - C'_{ST,2} - C'_{TS,1})$ $-c_\phi(C'_T - C'_{TS,1} - 2C'_{TS,2})$ |
| 4* | $\overline{B}{}^0_s \to T^0_{cs}\kappa^0$ | $C'_T - 2C'_{TS,2} + 2E'_{\bar{B}S,2} + E'_{\bar{B}T}$ |
| 5 | $\overline{B}{}^0 \to T^+_c\kappa^-$ | $-\frac{1}{\sqrt{2}}(C'_{ST,1} + C'_{ST,2} - C'_{TS,1} - 2C'_{TS,2})$ |
| 5 | $\overline{B}{}^0_s \to T^+_c a^-$ | $\frac{1}{\sqrt{2}}(C'_S + C'_{ST,2} - C'_{TS,1} - 2C'_{TS,2} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ |
| 6 | $B^- \to T^0_c\kappa^-$ | $\frac{1}{\sqrt{2}}(C'_S - C'_T + C'_{ST,2} - C'_{TS,1})$ |
| 6 | $\overline{B}{}^0 \to T^0_c\overline{\kappa}^0$ | $\frac{1}{\sqrt{2}}(C'_S - C'_T - C'_{ST,1} + 2C'_{TS,2})$ |
| 6 | $\overline{B}{}^0_s \to T^0_c a^0_0$ | $-\frac{1}{2}(C'_S + C'_{ST,2} - C'_{TS,1} - 2C'_{TS,2} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ |
| 6 | $\overline{B}{}^0_s \to T^0_c f_0$ | $\frac{c_\phi}{2}(C'_S + 2C'_T - 2C'_{ST,1} - C'_{ST,2} - C'_{TS,1} - 2C'_{TS,2} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ $-\frac{s_\phi}{\sqrt{2}}(C'_{TS,1} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ |
| 6 | $\overline{B}{}^0_s \to T^0_c\sigma$ | $-\frac{s_\phi}{2}(C'_S + 2C'_T - 2C'_{ST,1} - C'_{ST,2} - C'_{TS,1} - 2C'_{TS,2} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ $-\frac{c_\phi}{\sqrt{2}}(C'_{TS,1} + 2E'_{\bar{B}S,1} + E'_{\bar{B}T})$ |




- 3 indep. comb.
- Many relations

TABLE XVII: $\overline{B}_q \to T_{cq'\{\bar q''\bar q'''\}}S$ decay amplitudes in $\Delta S = 0$ transitions in scenario II.

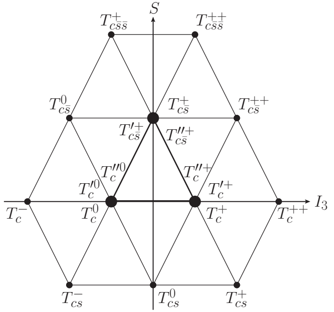
| # | Mode | $A(\overline{B}_q \to T_{cq\{\bar q'\bar q''\}}S)$ |
|---|---|---|
| $2'^*$ | $\overline{B}^0 \to T^+_{c\bar s}\kappa^-$ | $\frac{1}{\sqrt{2}}(C_S + C_{ST,2} - C_{TS,1} + E_{\bar BT})$ |
| $2'^*$ | $\overline{B}^0_s \to T^+_{c\bar s}a_0^-$ | $\frac{1}{\sqrt{2}}(C_{ST,1} - C_{ST,2} - C_{TS,1})$ |
| $3'^*$ | $B^- \to T^0_{c\bar s}\kappa^-$ | $C_T - C_S - C_{ST,2} + C_{TS,1}$ |
| $3'^*$ | $\overline{B}^0 \to T^0_{c\bar s}\overline{\kappa}^0$ | $C_T + E_{\bar BT}$ |
| $3'^*$ | $\overline{B}^0_s \to T^0_{c\bar s}a_0^0$ | $-\frac{1}{\sqrt{2}}(C_{ST,1} - C_{ST,2} - C_{TS,1})$ |
| $3'^*$ | $\overline{B}^0_s \to T^0_{c\bar s}f_0$ | $-\frac{c_{\phi'}}{\sqrt{2}}(2C_T + C_{ST,1} - C_{ST,2} + C_{TS,1}) + s_{\phi'}(C_S - C_{ST,1} - C_{TS,1})$ |
| $3'^*$ | $\overline{B}^0_s \to T^0_{c\bar s}\sigma$ | $\frac{s_{\phi'}}{\sqrt{2}}(2C_T + C_{ST,1} - C_{ST,2} + C_{TS,1}) + c_{\phi'}(C_S - C_{ST,1} - C_{TS,1})$ |
| $5'^*$ | $\overline{B}^0 \to T^0_{cs}\kappa^0$ | $-C_S + C_{ST,1} + E_{\bar BT}$ |
| $6'^*$ | $B^- \to T^-_{cs}\kappa^0$ | $-\sqrt{2}(C_S - C_{ST,1} + C_{ST,2})$ |
| $6'^*$ | $\overline{B}^0 \to T^-_{cs}\kappa^+$ | $\sqrt{2}(C_{ST,2} + E_{\bar BT})$ |
| $8'^*$ | $\overline{B}^0_s \to T^+_{c\bar s\bar s}\kappa^-$ | $-\sqrt{2}(C_S - C_{TS,1})$ |
| $10'^*$ | $\overline{B}^0 \to T^+_c a_0^-$ | $\sqrt{\frac{2}{3}}(C_{ST,1} - C_{TS,1} + E_{\bar BT})$ |
| $11'^*$ | $B^- \to T^0_c a_0^-$ | $-\sqrt{\frac{2}{3}}(C_T - C_{ST,1} + C_{TS,1})$ |
| $11'^*$ | $\overline{B}^0 \to T^0_c a_0^0$ | $\frac{1}{\sqrt{3}}(C_T + C_{ST,1} - C_{TS,1} + 2E_{\bar BT})$ |
| $11'^*$ | $\overline{B}^0 \to T^0_c f_0$ | $\frac{c_\phi}{\sqrt{3}}(C_T + C_{ST,1} + C_{TS,1}) + \sqrt{\frac{2}{3}}s_\phi(C_T - C_S + C_{ST,1} - C_{ST,2} + C_{TS,1})$ |
| $11'^*$ | $\overline{B}^0 \to T^0_c\sigma$ | $-\frac{s_\phi}{\sqrt{3}}(C_T + C_{ST,1} + C_{TS,1}) + \sqrt{\frac{2}{3}}c_\phi(C_T - C_S + C_{ST,1} - C_{ST,2} + C_{TS,1})$ |
| $11'^*$ | $\overline{B}^0_s \to T^0_c\kappa^0$ | $-\sqrt{\frac{2}{3}}(C_T - C_{ST,2})$ |
| $12'^*$ | $B^- \to T^-_c a_0^0$ | $C_T - C_{ST,1} + C_{TS,1}$ |
| $12'^*$ | $B^- \to T^-_c f_0$ | $-c_{\phi'}(C_T + C_{ST,1} + C_{TS,1}) - \sqrt{2}s_\phi(C_T - C_S + C_{ST,1} - C_{ST,2} + C_{TS,1})$ |
| $12'^*$ | $B^- \to T^-_c\sigma$ | $s_{\phi'}(C_T + C_{ST,1} + C_{TS,1}) - \sqrt{2}c_\phi C_T - C_S + C_{ST,1} - C_{ST,2} + C_{TS,1})$ |
| $12'^*$ | $\overline{B}^0 \to T^-_c a_0^+$ | $\sqrt{2}(C_T + E_{\bar BT})$ |
| $12'^*$ | $\overline{B}^0_s \to T^-_c\kappa^+$ | $\sqrt{2}(C_T - C_{ST,2})$ |




- 4 indep. comb.
- Many relations

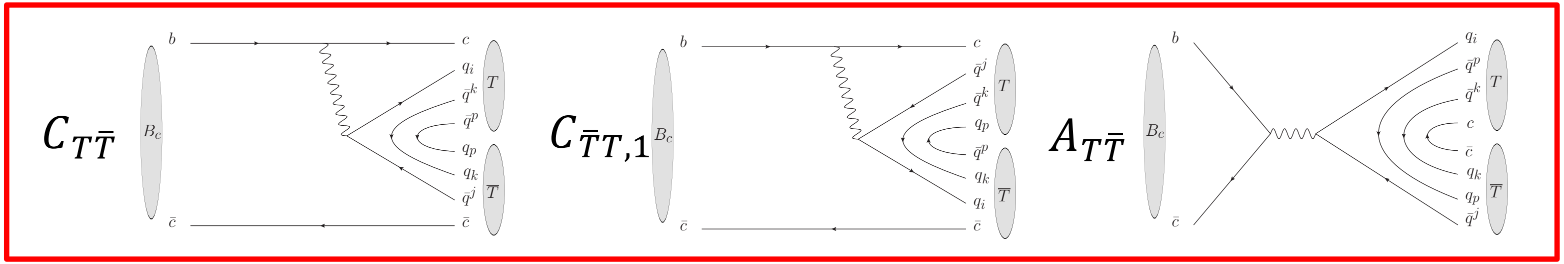
TABLE XVIII: $\overline{B}_q \to T_{cq'\{\bar q''\bar q'''\}}S$ decay amplitudes in $\Delta S = -1$ transition in scenario II.

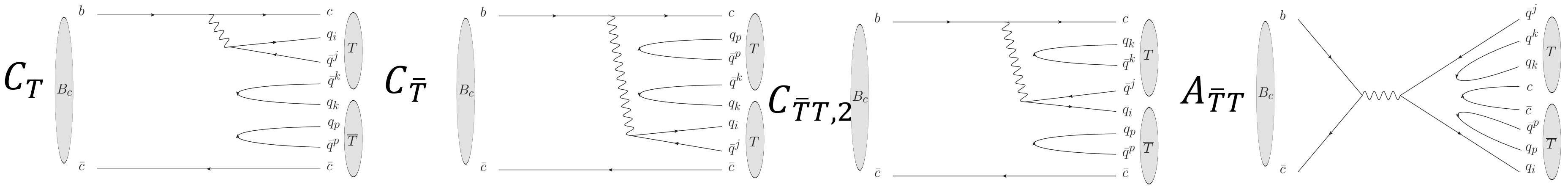
| # | Mode | $A'(\overline{B}_q \to T_{cq\{\bar q'\bar q''\}}S)$ |
| --- | --- | --- |
| $2'^*$ | $\overline{B}^0_s \to T^+_{c\bar s}\kappa^-$ | $-\frac{1}{\sqrt{2}}(C'_S - C'_{ST,1} - E'_{\bar BT})$ |
| $3'^*$ | $\overline{B}^0_s \to T^0_{c\bar s}\overline{\kappa}^0$ | $-C'_S + C'_{ST,1} + E'_{\bar BT}$ |
| $4'^*$ | $\overline{B}^0 \to T^+_{cs}a^-$ | $-\sqrt{2}(C'_S - C'_{TS,1})$ |
| $5'^*$ | $B^- \to T^0_{cs}a^-$ | $C'_T - C'_S - C'_{ST,2} + C'_{TS,1}$ |
| $5'^*$ | $\overline{B}^0 \to T^0_{cs}a^0_0$ | $-\frac{1}{\sqrt{2}}(C'_T + C'_S - C'_{ST,2} - C'_{TS,1})$ |
| $5'^*$ | $\overline{B}^0 \to T^0_{cs}f_0$ | $-\frac{c_\phi}{\sqrt{2}}(C'_T - C'_S + 2C'_{ST,1} - C'_{ST,2} + C'_{TS,1}) - s_\phi(C'_T + C'_{TS,1})$ |
| $5'^*$ | $\overline{B}^0 \to T^0_{cs}\sigma$ | $\frac{s_\phi}{\sqrt{2}}(C'_T - C'_S + 2C'_{ST,1} - C'_{ST,2} + C'_{TS,1}) - c_\phi(C'_T + C'_{TS,1})$ |
| $5'^*$ | $\overline{B}^0_s \to T^0_{cs}\kappa^0$ | $C'_T + E'_{\bar BT}$ |
| $6'^*$ | $B^- \to T^-_{cs}a^0_0$ | $C'_T - C'_S - C'_{ST,2} + C'_{TS,1}$ |
| $6'^*$ | $B^- \to T^-_{cs}f_0$ | $-c_\phi(C'_T - C'_S + 2C'_{ST,1} - C'_{ST,2} + C'_{TS,1}) - \sqrt{2}s_\phi(C'_T + C'_{TS,1})$ |
| $6'^*$ | $B^- \to T^-_{cs}\sigma$ | $s_\phi(C'_T - C'_S + 2C'_{ST,1} - C'_{ST,2} + C'_{TS,1}) - \sqrt{2}c_\phi(C'_T + C'_{TS,1})$ |
| $6'^*$ | $\overline{B}^0 \to T^-_{cs}a^+$ | $\sqrt{2}(C'_T - C'_{ST,2})$ |
| $6'^*$ | $\overline{B}^0_s \to T^-_{cs}\kappa^+$ | $\sqrt{2}(C'_T + E'_{\bar BT})$ |
| $10'^*$ | $\overline{B}^0 \to T^+_c\kappa^-$ | $-\sqrt{\frac{2}{3}}(C'_S - C'_{ST,1} + C'_{ST,2})$ |
| $10'^*$ | $\overline{B}^0_s \to T^+_c a^-$ | $\sqrt{\frac{2}{3}}(C'_{ST,2} + E'_{\bar BT})$ |
| $11'^*$ | $B^- \to T^0_c\kappa^-$ | $-\sqrt{\frac{2}{3}}(C'_S - C'_{ST,1} + C'_{ST,2})$ |
| $11'^*$ | $\overline{B}^0 \to T^0_c\overline{\kappa}^0$ | $\sqrt{\frac{2}{3}}(C'_S - C'_{ST,1} + C'_{ST,2})$ |
| $11'^*$ | $\overline{B}^0_s \to T^0_c a^0_0$ | $\frac{2}{\sqrt{3}}(C'_{ST,2} + E'_{\bar BT})$ |
| $12'^*$ | $B^- \to T^-_c\overline{\kappa}^0$ | $-\sqrt{2}(C'_S - C'_{ST,1} + C'_{ST,2})$ |
| $12'^*$ | $\overline{B}^0_s \to T^-_c a^+$ | $\sqrt{2}(C'_{ST,2} + E'_{\bar BT})$ |




- 4 indep. comb.
- Many relations

# $B_c^- \to T\bar{T}$ decays

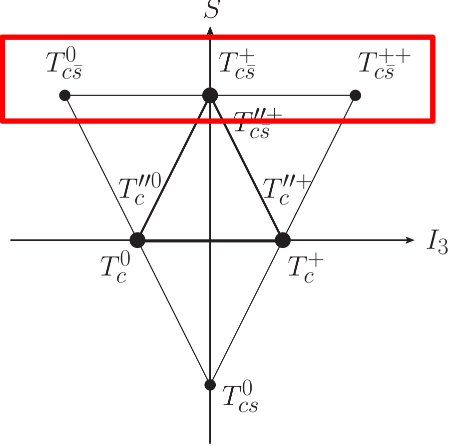



- Seven TA, only three contribute to full FES
- Only one (two) independent combinations for FES in scenario I  (II)

TABLE XIX: $B_c^- \to T\overline{T}$ decay amplitudes with $T = T_{cq[\bar q'\bar q'']}$ in $\Delta S = 0$ and $\Delta S = -1$ transitions in scenario I.

| # | Mode | $A(B_c^- \to T\overline{T})$ |
|---|---|---|
| $(2^*, \bar 1^*)$ | $B_c^- \to T^+_{c\bar s}\overline{T}^{--}_{\bar c s}$ | $\frac{1}{\sqrt2}(C_{\bar T T,1} + 2C_{T\bar T} + 2A_{T\bar T})$ |
| $(3^*, \bar 2^*)$ | $B_c^- \to T^0_{c\bar s}\overline{T}^{-}_{\bar c s}$ | $-\frac{1}{\sqrt2}(C_{\bar T T,1} + 2C_{T\bar T} + 2A_{T\bar T})$ |
| $(6, \bar 5)$ | $B_c^- \to T^0_{c}\overline{T}^{-}_{\bar c}$ | $-\frac{1}{2}(C_{\bar T T,1} + 2C_{T\bar T} + 2A_{T\bar T})$ |
| $(3^*, \bar 9)$ | $B_c^- \to T^0_{c\bar s}\overline{T}''^{-}_{\bar c s}$ | $-\frac{1}{\sqrt2}(2C_T - C_{\bar T T,1} + 2C_{T\bar T} + 2A_{T\bar T})$ |
| $(6, \bar 7)$ | $B_c^- \to T^0_{c}\overline{T}''^{-}_{\bar c}$ | $-\frac{1}{2}(2C_T - C_{\bar T T,1} + 2C_{T\bar T} + 2A_{\bar T T})$ |
| $(8, \bar 5)$ | $B_c^- \to T''^0_{c}\overline{T}^{-}_{\bar c}$ | $\frac{1}{2}(2C_{\bar T} - C_{\bar T T,1} + 2C_{T\bar T} + 2A_{\bar T T})$ |
| $(9, \bar 1^*)$ | $B_c^- \to T''^+_{c\bar s}\overline{T}^{--}_{\bar c s}$ | $-\frac{1}{\sqrt2}(2C_{\bar T} - C_{\bar T T,1} + 2C_{T\bar T} + 2A_{T\bar T})$ |
| $(8, \bar 7)$ | $B_c^- \to T''^0_{c}\overline{T}''^{-}_{\bar c}$ | $\frac{1}{2}(2C_T + 2C_{\bar T} + C_{\bar T T,1} + 4C_{\bar T T,2} + 2C_{T\bar T} + 4A_{\bar T T} + 2A_{T\bar T})$ |
| # | Mode | $A'(B_c^- \to T\overline{T})$ |
| $(4^*, \bar 5)$ | $B_c^- \to T^0_{cs}\overline{T}^{-}_{\bar c}$ | $-\frac{1}{\sqrt2}(C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(5, \bar 1^*)$ | $B_c^- \to T^+_{c}\overline{T}^{--}_{\bar c s}$ | $-\frac{1}{\sqrt2}(C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(6, \bar 2^*)$ | $B_c^- \to T^0_{c}\overline{T}^{-}_{\bar c s}$ | $\frac{1}{2}(C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(4^*, \bar 7)$ | $B_c^- \to T^0_{cs}\overline{T}''^{-}_{\bar c}$ | $-\frac{1}{\sqrt2}(C'_T - C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(6, \bar 9)$ | $B_c^- \to T^0_{c}\overline{T}''^{-}_{\bar c s}$ | $\frac{1}{2}(2C'_T - C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(8, \bar 2^*)$ | $B_c^- \to T''^0_{c}\overline{T}^{-}_{\bar c s}$ | $\frac{1}{2}(2C'_{\bar T} - C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(7, \bar 1^*)$ | $B_c^- \to T''^+_{c}\overline{T}^{--}_{\bar c s}$ | $\frac{1}{\sqrt2}(2C'_{\bar T} - C'_{\bar T T,1} + 2C'_{T\bar T} + 2A'_{T\bar T})$ |
| $(8, \bar 9)$ | $B_c^- \to T''^0_{c}\overline{T}''^{-}_{\bar c s}$ | $\frac{1}{2}(2C'_T + 2C'_{\bar T} + C'_{\bar T T,1} + 4C'_{\bar T T,2} + 2C'_{T\bar T} + 4A'_{\bar T T} + 2A'_{T\bar T})$ |



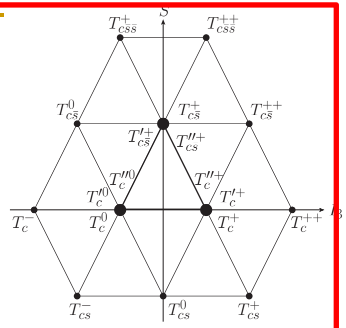

- One comb.
- $T^{++}$ OK

$$B_c\, O \sim 1 \otimes 8 = 8$$

$$T\,\overline{T} \sim 6 \otimes \overline{6} = 27 \oplus 8 \oplus 1$$

TABLE XX: $B_c^- \to T\overline{T}$ decay amplitudes with $T = T_{cq\{\bar{q}'\bar{q}''\}}$ in $\Delta S = 0$ transition.

| # | Mode | $A(B_c^- \to T\overline{T})$ |
|---|---|---|
| $(5'^*, \overline{4}'^*)$ | $B_c^- \to T^0_{cs}\overline{T}^-_{\bar{c}\bar{s}}$ | $\sqrt{2}C_{\bar{T}T,1}$ |
| $(6'^*, \bar{5}'^*)$ | $B_c^- \to T^-_{cs}\overline{T}^0_{\bar{c}\bar{s}}$ | $\sqrt{2}C_{\bar{T}T,1}$ |
| $(8'^*, \bar{7}'^*)$ | $B_c^- \to T^+_{c\bar{s}\bar{s}}\overline{T}^{--}_{\bar{c}ss}$ | $2(C_{T\bar{T}} + A_{T\bar{T}})$ |
| $(2'^*, \bar{1}'^*)$ | $B_c^- \to T^+_{c\bar{s}}\overline{T}^{--}_{\bar{c}s}$ | $\frac{1}{\sqrt{2}}(C_{\bar{T}T,1} - 2C_{T\bar{T}} - 2A_{T\bar{T}})$ |
| $(3'^*, \bar{2}'^*)$ | $B_c^- \to T^0_{c\bar{s}}\overline{T}^-_{\bar{c}s}$ | $-\frac{1}{\sqrt{2}}(C_{\bar{T}T,1} - 2C_{T\bar{T}} - 2A_{T\bar{T}})$ |
| $(10'^*, \bar{9}'^*)$ | $B_c^- \to T^+_c\overline{T}^{--}_{\bar{c}}$ | $\frac{2}{\sqrt{3}}(C_{\bar{T}T,1} - C_{T\bar{T}} - A_{T\bar{T}})$ |
| $(11'^*, \overline{10}'^*)$ | $B_c^- \to T^0_c\overline{T}^-_{\bar{c}}$ | $\frac{4}{3}(C_{\bar{T}T,1} - C_{T\bar{T}} - A_{T\bar{T}})$ |
| $(12'^*, \overline{11}'^*)$ | $B_c^- \to T^-_c\overline{T}^0_{\bar{c}}$ | $-\frac{2}{\sqrt{3}}(C_{\bar{T}T,1} - C_{T\bar{T}} - A_{T\bar{T}})$ |
| $(3'^*, \overline{15}')$ | $B_c^- \to T^0_{c\bar{s}}\overline{T}'^-_{\bar{c}s}$ | $\frac{1}{2}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(11'^*, \overline{13}')$ | $B_c^- \to T^0_c\overline{T}'^-_{\bar{c}}$ | $-\frac{1}{3\sqrt{2}}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(12'^*, \overline{14}')$ | $B_c^- \to T^-_c\overline{T}'^0_{\bar{c}}$ | $\frac{1}{\sqrt{6}}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(13', \bar{9}'^*)$ | $B_c^- \to T^+_{cd\bar{d}\bar{d}}\overline{T}^{--}_{\bar{c}\bar{u}dd}$ | $\frac{1}{\sqrt{6}}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(14', \overline{10}'^*)$ | $B_c^- \to T'^0_c\overline{T}^-_{\bar{c}}$ | $\frac{1}{3\sqrt{2}}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(15', \bar{1}'^*)$ | $B_c^- \to T^+_{c\bar{s}}\overline{T}^{--}_{\bar{c}s}$ | $\frac{1}{2}(C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |
| $(14', \overline{13}')$ | $B_c^- \to T'^0_c\overline{T}'^-_{\bar{c}}$ | $\frac{1}{12}(13C_{\bar{T}T,1} + 2C_{T\bar{T}} + 2A_{T\bar{T}})$ |

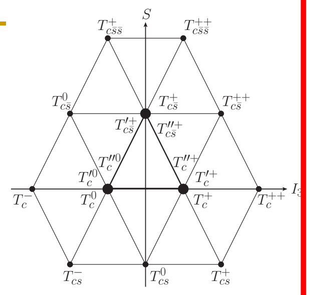



- 2 comb.
- All FES involved

$B_c\,O \sim 1 \otimes 8 = 8$

$T\overline{T} \sim \overline{15} \otimes 15$
$= 64 \oplus 35 \oplus \overline{35} \oplus 27 \oplus \overline{27} \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$

TABLE XXI: $B_c^- \to T\overline{T}$ decay amplitudes with $T = T_{cq\{\bar q'\bar q''\}}$ in $\Delta S = -1$ transition in scenario II.



| # | Mode | $A'(B_c^- \to T\overline{T})$ |
|---|---|---|
| $(2'^*, \bar 7'^*)$ | $B_c^- \to T^{+}_{c\bar s}\overline{T}^{--}_{\bar c ss}$ | $C'_{\overline{T}T,1}$ |
| $(3'^*, \bar 8'^*)$ | $B_c^- \to T^{0}_{c\bar s}\overline{T}^{-}_{\bar c ss}$ | $\sqrt{2}C'_{\overline{T}T,1}$ |
| $(10'^*, \bar 1'^*)$ | $B_c^- \to T^{+}_{c}\overline{T}^{--}_{\bar c s}$ | $\sqrt{\frac{2}{3}}C'_{\overline{T}T,1}$ |
| $(11'^*, \bar 2'^*)$ | $B_c^- \to T^{0}_{c}\overline{T}^{-}_{\bar c s}$ | $\frac{2}{\sqrt{3}}C'_{\overline{T}T,1}$ |
| $(12'^*, \bar 3'^*)$ | $B_c^- \to T^{-}_{c}\overline{T}^{0}_{\bar c s}$ | $\sqrt{2}C'_{\overline{T}T,1}$ |
| $(4'^*, \bar 9'^*)$ | $B_c^- \to T^{+}_{cs}\overline{T}^{--}_{\bar c}$ | $2(C'_{T\overline{T}} + A'_{T\overline{T}})$ |
| $(5'^*, \overline{10}'^*)$ | $B_c^- \to T^{0}_{cs}\overline{T}^{-}_{\bar c}$ | $2\sqrt{\frac{2}{3}}(C'_{T\overline{T}} + A'_{T\overline{T}})$ |
| $(6'^*, \overline{11}'^*)$ | $B_c^- \to T^{-}_{cs}\overline{T}^{0}_{\bar c}$ | $\frac{2}{\sqrt{3}}(C'_{T\overline{T}} + A_{T\overline{T}})$ |
| $(5'^*, \overline{13}')$ | $B_c^- \to T^{0}_{cs}\overline{T}'^{-}_{\bar c}$ | $-\frac{1}{2\sqrt{3}}(3C'_{\overline{T}T,1} - 2C'_{T\overline{T}} - 2A'_{T\overline{T}})$ |
| $(6'^*, \overline{14}')$ | $B_c^- \to T^{-}_{cs}\overline{T}'^{0}_{\bar c}$ | $-\frac{1}{\sqrt{6}}(3C'_{\overline{T}T,1} - 2C'_{T\overline{T}} - 2A'_{T\overline{T}})$ |
| $(14', \overline{15}')$ | $B_c^- \to T'^{0}_{c}\overline{T}'^{-}_{\bar c s}$ | $\frac{\sqrt{3}}{4}(3C'_{\overline{T}T,1} - 2C'_{T\overline{T}} - 2A'_{T\overline{T}})$ |
| $(15', \bar 7'^*)$ | $B_c^- \to T'^{+}_{c\bar s}\overline{T}^{--}_{\bar c ss}$ | $\frac{1}{\sqrt{2}}(C'_{\overline{T}T,1} - 2C'_{T\overline{T}} - 2A'_{T\overline{T}})$ |
| $(13', \bar 1'^*)$ | $B_c^- \to T'^{+}_{c}\overline{T}^{--}_{\bar c s}$ | $\frac{1}{2\sqrt{3}}(C'_{\overline{T}T,1} - 6C'_{T\overline{T}} - 6A'_{T\overline{T}})$ |
| $(14', \bar 2'^*)$ | $B_c^- \to T'^{0}_{c}\overline{T}^{-}_{\bar c s}$ | $\frac{1}{2\sqrt{6}}(C'_{\overline{T}T,1} - 6C'_{T\overline{T}} - 6A'_{T\overline{T}})$ |

- 2 comb.
- All FES involved

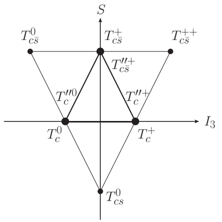


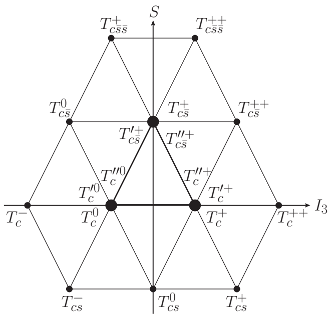
TABLE XXII: Participation of flavor exotic states in scenario I in $\overline{B} \to D\overline{T}$, $\overline{B} \to \overline{T}$, $\overline{B} \to TP$, $\overline{B} \to TS$ and $B_c^- \to T\overline{T}$ decays in $\Delta S = 0$ and $\Delta S = -1$ transitions. Those with parentheses are modes also involving non-flavor exotic states. These results and those in the Tables can be generalized with $D$ and $P$ replaced with $D^*$ and $V$, respectively.

| Decays | $T_{c\bar{s}}^{++}$ | $T_{c\bar{s}}^{+}$ | $T_{c\bar{s}}^{0}$ | $T_{cs}^{0}$ | Tables |
|---|---|---|---|---|---|
| $\overline{B} \to D\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | ✓ | X | VII |
| $\overline{B} \to D\overline{T}$, $\Delta S = 0$ | ✓ | ✓ | X | ✓ | VII |
| $\overline{B} \to \overline{D}T$, $\Delta S = -1$ | X | X | X | ✓ | IX |
| $\overline{B} \to \overline{D}T$, $\Delta S = 0$ | X | ✓ | ✓ | X | IX |
| $\overline{B} \to TP$, $\Delta S = 0$ | X | ✓ | ✓ | ✓ | XII |
| $\overline{B} \to TP$, $\Delta S = -1$ | X | ✓ | ✓ | ✓ | XII |
| $\overline{B} \to TS$, $\Delta S = 0$ | X | ✓ | ✓ | ✓ | XV |
| $\overline{B} \to TS$, $\Delta S = -1$ | X | ✓ | ✓ | ✓ | XVI |
| $B_c^- \to T\overline{T}$, $\Delta S = 0$ | ✓ | ✓ | ✓ | X | XIX |
| $B_c^- \to T\overline{T}$, $\Delta S = -1$ | (✓) | (✓) | X | (✓) | XIX |

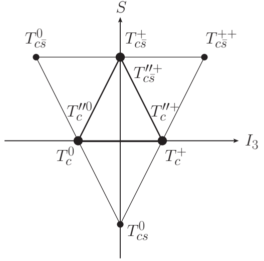
TABLE XXIII: Participation of flavor exotic states in scenario II in $\overline{B} \to D\overline{T}$, $\overline{B} \to \overline{T}$, $\overline{B} \to TP$, $\overline{B} \to TS$ and $B_c^- \to T\overline{T}$ decays in $\Delta S = 0$ and $\Delta S = -1$ transitions. These results and those in the Tables can be generalized with $D$ and $P$ replaced with $D^*$ and $V$, respectively.

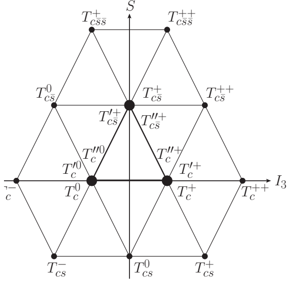
| Decays | $T_{c\bar s}^{++}$ | $T_{c\bar s}^{+}$ | $T_{c\bar s}^{0}$ | $T_{cs}^{+}$ | $T_{cs}^{0}$ | $T_{cs}^{-}$ | Tables |
|---|---|---|---|---|---|---|---|
| $\overline{B} \to D\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | ✓ | X | X | X | VIII |
| $\overline{B} \to D\overline{T}$, $\Delta S = 0$ | ✓ | ✓ | X | ✓ | ✓ | X | VIII |
| $\overline{B} \to \overline{D}T$, $\Delta S = -1$ | X | X | X | ✓ | ✓ | ✓ | X |
| $\overline{B} \to \overline{D}T$, $\Delta S = 0$ | X | ✓ | ✓ | X | X | X | X |
| $\overline{B} \to TP$, $\Delta S = 0$ | X | ✓ | ✓ | X | ✓ | ✓ | XIII |
| $\overline{B} \to TP$, $\Delta S = -1$ | X | ✓ | ✓ | ✓ | ✓ | ✓ | XIV |
| $\overline{B} \to TS$, $\Delta S = 0$ | X | ✓ | ✓ | X | ✓ | ✓ | XVII |
| $\overline{B} \to TS$, $\Delta S = -1$ | X | ✓ | ✓ | ✓ | ✓ | ✓ | XVIII |
| $B_c^- \to T\overline{T}$, $\Delta S = 0$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | XX |
| $B_c^- \to T\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | XXI |

| Decays | $T_{c\bar s\bar s}^{++}$ | $T_{c\bar s\bar s}^{+}$ | $T_{c}^{++}$ | $T_{c}^{+}$ | $T_{c}^{0}$ | $T_{c}^{-}$ | Tables |
|---|---|---|---|---|---|---|---|
| $\overline{B} \to D\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | X | X | X | X | VIII |
| $\overline{B} \to D\overline{T}$, $\Delta S = 0$ | X | X | ✓ | ✓ | ✓ | X | VIII |
| $\overline{B} \to \overline{D}T$, $\Delta S = -1$ | X | X | X | X | X | X | X |
| $\overline{B} \to \overline{D}T$, $\Delta S = 0$ | X | ✓ | X | ✓ | ✓ | ✓ | X |
| $\overline{B} \to TP$, $\Delta S = 0$ | X | ✓ | X | ✓ | ✓ | ✓ | XIII |
| $\overline{B} \to TP$, $\Delta S = -1$ | X | X | X | ✓ | ✓ | ✓ | XIV |
| $\overline{B} \to TS$, $\Delta S = 0$ | X | ✓ | X | ✓ | ✓ | ✓ | XVII |
| $\overline{B} \to TS$, $\Delta S = -1$ | X | X | X | ✓ | ✓ | ✓ | XVIII |
| $B_c^- \to T\overline{T}$, $\Delta S = 0$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | XX |
| $B_c^- \to T\overline{T}$, $\Delta S = -1$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | XXI |



# Conclusion



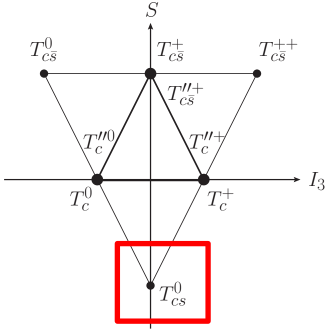


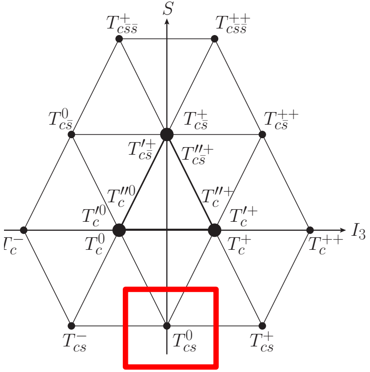
- We study the decays of heavy mesons to charmed tetraquark states using a topological amplitude approach.
- We consider two scenarios (anti-sym. & sym.)
- Identify 4+12 flavor exotic states (FES)
- The $T \to DP$ and $DS$ strong decay amplitudes are decomposed into several topological amplitudes
- Modes with FES are highly related

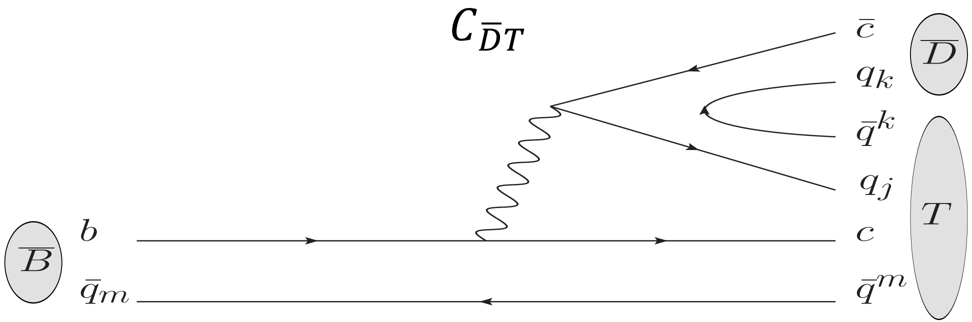
# Conclusion

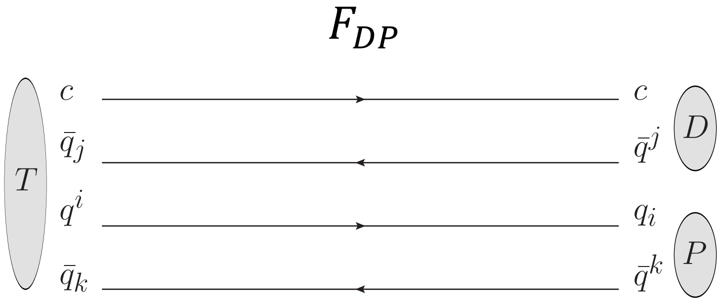
- Weak decay amplitudes of $\overline{B} \to D\,\overline{T}$, $\overline{D}\,T$ and $\overline{B} \to TP$, $TS$ decays are also decomposed topologically.
- Modes with flavor exotic states are highly related.
- Need to consider both $\Delta S = 0, -1$ transitions to test relations (FES in the same multiplet?)
- $B_c^- \to T\overline{T}$ decays are also discussed.
- Many/All FES are involved in $B_c^- \to T\overline{T}$ decays
- Modes with FES are highlighted.

- In both scenarios




$$\Gamma(B^- \to D^- T^0_{cs}, T^0_{cs} \to D^+ K^-) = \Gamma(B^- \to D^- T^0_{cs}, T^0_{cs} \to D^0 \overline{K}^0),$$

- Agree with a recent LHCb result (PRL134, 101901)