The role of $D^*_{(s)}$ and their contributions in $B_{(s)} \to D_{(s)} hh'$ decays

Jian Chai (HNU)

arXiv:2102.04691

March 27, 2021

Overview

1. Motivation
2. Framework
3. Numerics
4. Summary

Motivation

BWT

- The measurements of significant derivations from the simple phase-space model in the channels $B_{(s)} \to D_{(s)} hh'$ at B factories and LHC.
- Dalitz plot analysis from the LHCb collaboration give a rather large fit result of the virtual contribution from D_s^{*-} in the $B_s \to D^0 K^- \pi^+$ decays.

BWT

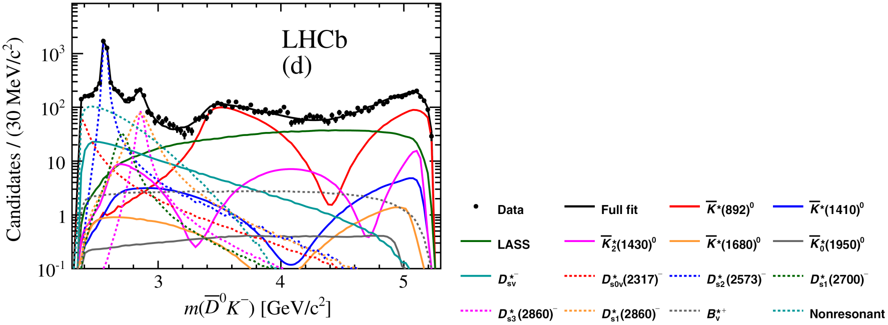

Figure 1: experiment

R. Aaij *et al.* (LHCb,2014)

These measurements motivate a systemic study of the BWT effect from $D^*_{(s)}$ in the three-body $B_{(s)} \to D_{(s)} hh'$ decays.

Framework

Framework

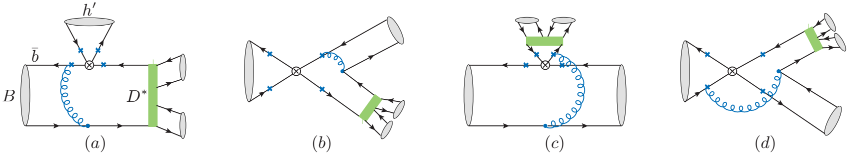

Figure 2: $B_{(s)} \to D^*_{(s)} h' \to D_{(s)} h h'$, $h = (\pi, K)$, $h' = (\pi, K)$.

Framework

The kinematics under the rest frame of B meson,

$$p_1 = \frac{m_B}{\sqrt{2}}(1, 1, 0_{\rm T}) \qquad k_1 = \left(0, x_1\frac{m_B}{\sqrt{2}}, k_{1\rm T}\right)$$
$$p_R = \frac{m_B}{\sqrt{2}}(1, \zeta, 0_{\rm T}) \qquad k_R = \left(x_R\frac{m_B}{\sqrt{2}}, 0, k_{R\rm T}\right),$$
$$p_3 = \frac{m_B}{\sqrt{2}}(0, 1-\zeta, 0_{\rm T}) \quad k_3 = \left(0, x_3(1-\zeta)\frac{m_B}{\sqrt{2}}, k_{3\rm T}\right). \qquad (1)$$

three-body decay treated as a quasi-two-body decaying process,

$$\mathcal{A}\left(B_{(s)} \to Rh' \to D_{(s)}hh'\right) \equiv \left\langle \left[D_{(s)}h\right]_R h' \middle| \mathcal{H}_{eff} \middle| B_{(s)} \right\rangle$$
$$\approx \left\langle D_{(s)}h \middle| R \right\rangle \frac{1}{\left[m_R^2 - s - im_R\Gamma_R(s)\right]} \left\langle Rh' \middle| \mathcal{H}_{eff} \middle| B_{(s)} \right\rangle. \qquad (2)$$

W. F. Wang, H. n. Li, W. Wang and C. D. Lü,(2015)

Framework

The P-wave $D\pi$ system distribution amplitude

$$\Phi^{\mathrm{P}}_{D_{(s)}h} = \frac{1}{\sqrt{2N_c}} \not{\epsilon}_L \left(\not{p}_R + \sqrt{s}\right) \phi_{D_{(s)}h}(x, b, s), \tag{3}$$

The LCDA at leading twist

$$\phi_{D_{(s)}h} = \frac{F_{D_{(s)}h}(s)}{2\sqrt{2N_c}} 6x(1-x)\left[1 + a_{D_{(s)}h}(1-2x)\right] \exp\left[-\frac{\omega^2_{D_{(s)}h} b^2}{2}\right]. \tag{4}$$

T. Kurimoto, H. n. Li and A. I. Sanda,(2003)

Framework

$F_{D_{(s)}h}(s)$ form factor

$$F_{D_{(s)}h}(s) \equiv \frac{s\bar{p}_R^{\mu}\langle D_{(s)}h|\bar{c}\gamma_\mu(1-\gamma_5)q|0\rangle}{\left[s^2-2s\left(m_{D_{(s)}}^2+m_h^2\right)+\left(m_{D_{(s)}}^2-m_h^2\right)^2\right]} = \frac{\sqrt{s}f_R g_{RD_{(s)}h}}{\left[m_R^2-s-im_R\Gamma_R(s)\right]} \quad (5)$$

The energy dependent width

$$\Gamma_R(s)=\Gamma_R^{\rm tot}\left(\frac{q(s)}{q_R}\right)^3\left(\frac{m_R}{\sqrt{s}}\right)\left(\frac{1+\left[q_R\,{\rm r_{BW}}\right]^2}{1+\left[q(s)\,{\rm r_{BW}}\right]^2}\right), \quad (6)$$

$$q(s)=\tfrac{1}{2\sqrt{s}}\sqrt{\left[s-(m_{D_{(s)}}+m_h)^2\right]\left[s-(m_{D_{(s)}}-m_h)^2\right]}.$$

Framework

The strong coupling $g_{RD_{(s)}h} \equiv \langle D_{(s)}h|R\rangle$.

$$\frac{g_{D^*D\pi(K)}\, f_\pi}{2\sqrt{m_D^* m_D}} = \frac{g_{D_s^*DK}\, f_K}{2\sqrt{m_{D_s}^* m_D}} = g \tag{7}$$

- $g_{D^*D^0\pi^+} = 16.92 \pm 0.13 \pm 0.14$ BaBar (2013)
  $g_{D_s^*DK} = 14.6 \pm 0.06 \pm 0.07$, $g_{D^*D_sK} = 14.6 \pm 0.10 \pm 0.13$.
- $g_{D_s^*DK} = 14.6 \pm 1.7$, $g_{D^*D_sK} = 14.7 \pm 1.7$ CLEO collaboration
- $g_{D_s^*DK} = 15.2$, $g_{D^*D_sK} = 15.2$ quark model.

Numerics

Numerical Results

Table 1: The pQCD predictions for quasi-two-body decays $B^0 \to D^*_{(s)} h' \to Dhh'$.

Decay modes	$\mathcal{B}/\mathcal{B}_v$	Results	Units
$B^0 \to D^{*-}\pi^+ \to \bar{D}^0\pi^-\pi^+$	$\mathcal{B}$	$1.69^{+0.57+0.15+0.13+0.07+0.04}_{-0.52-0.15-0.11-0.05-0.02}$	10^{-3}
$\to D^-\pi^0\pi^+$	$\mathcal{B}$	$7.79^{+3.70+0.70+0.58+0.33+0.25}_{-2.34-0.67-0.69-0.23-0.13}$	10^{-4}
$\to D_s^- K^0\pi^+$	$\mathcal{B}_v$	$1.25^{+0.62+0.11+0.10+0.05+0.02}_{-0.38-0.11-0.09-0.04-0.04}$	10^{-5}
$B^0 \to D^{*+}\pi^- \to D^0\pi^+\pi^-$	$\mathcal{B}$	$1.01^{+0.39+0.09+0.00+0.04+0.02}_{-0.25-0.08-0.00-0.03-0.01}$	10^{-6}
$\to D^+\pi^0\pi^-$	$\mathcal{B}$	$4.64^{+1.72+0.41+0.03+0.18+0.01}_{-1.22-0.40-0.00-0.13-0.02}$	10^{-7}
$\to D_s^+\bar{K}^0\pi^-$	$\mathcal{B}_v$	$1.64^{+0.59+0.15+0.00+0.06+0.00}_{-0.42-0.14-0.00-0.04-0.00}$	10^{-8}
$B^0 \to D^{*-}K^+ \to \bar{D}^0\pi^-K^+$	$\mathcal{B}$	$1.38^{+0.64+0.16+0.04+0.06+0.04}_{-0.42-0.09-0.10-0.04-0.03}$	10^{-4}
$\to D^-\pi^0K^+$	$\mathcal{B}$	$6.39^{+2.78+0.57+0.56+0.27+0.05}_{-2.13-0.56-0.52-0.19-0.28}$	10^{-5}
$\to D_s^-K^0K^+$	$\mathcal{B}_v$	$1.02^{+0.48+0.10+0.09+0.04+0.03}_{-0.31-0.09-0.08-0.03-0.02}$	10^{-6}
$B^0 \to \bar{D}^{*0}\pi^0 \to \bar{D}^0\pi^0\pi^0$	$\mathcal{B}$	$1.05^{+0.45+0.10+0.02+0.05+0.03}_{-0.27-0.09-0.00-0.03-0.02}$	10^{-4}
$\to D^-\pi^+\pi^0$	$\mathcal{B}_v$	$1.02^{+0.37+0.10+0.02+0.04+0.01}_{-0.27-0.09-0.02-0.03-0.01}$	10^{-5}
$\to D_s^-K^+\pi^0$	$\mathcal{B}_v$	$2.39^{+0.94+0.23+0.00+0.11+0.02}_{-0.66-0.22-0.02-0.07-0.03}$	10^{-6}
$B^0 \to D^{*0}K^0 \to D^0\pi^0K^0$	$\mathcal{B}$	$9.49^{+2.57+0.85+0.40+0.38+0.19}_{-1.76-0.81-0.46-0.27-0.14}$	10^{-7}
$\to D^+\pi^-K^0$	$\mathcal{B}_v$	$6.32^{+2.50+0.58+0.15+0.26+0.02}_{-1.69-0.54-0.15-0.17-0.05}$	10^{-8}
$\to D_s^+K^-K^0$	$\mathcal{B}_v$	$9.89^{+2.65+0.90+0.42+0.40+0.21}_{-2.05-0.90-0.47-0.28-0.15}$	10^{-9}
$B^0 \to \bar{D}^{*0}K^0 \to \bar{D}^0\pi^0K^0$	$\mathcal{B}$	$1.66^{+0.88+0.15+0.04+0.07+0.01}_{-0.45-0.14-0.05-0.03-0.02}$	10^{-5}
$\to D^-\pi^+K^0$	$\mathcal{B}_v$	$1.55^{+0.62+0.14+0.00+0.07+0.03}_{-0.43-0.13-0.00-0.05-0.03}$	10^{-6}
$\to D_s^-K^+K^0$	$\mathcal{B}_v$	$3.46^{+1.36+0.31+0.00+0.15+0.03}_{-0.94-0.30-0.00-0.10-0.03}$	10^{-7}

Numerical Results

Table 2: The same as table 1, the quasi-two-body decays $B^+ \to D^*_{(s)} h' \to D h h'$.

Decay modes		$\mathcal{B}/\mathcal{B}_v$	Results	Units
$B^+ \to D^{*+}\pi^0$	$\to D^0\pi^+\pi^0$	$\mathcal{B}$	$5.81^{+1.45+0.52+0.03+0.23+0.05}_{-1.20-0.50-0.05-0.16-0.02}$	10^{-7}
	$\to D^+\pi^0\pi^0$	$\mathcal{B}$	$2.65^{+0.70+0.24+0.00+0.10+0.01}_{-0.46-0.23-0.03-0.07-0.00}$	10^{-7}
	$\to D_s^+\bar{K}^0\pi^0$	$\mathcal{B}_v$	$9.04^{+3.04+0.89+0.03+0.36+0.01}_{-2.26-0.79-0.01-0.25-0.01}$	10^{-9}
$B^+ \to \bar{D}^{*0}\pi^+$	$\to \bar{D}^0\pi^0\pi^+$	$\mathcal{B}$	$3.22^{+1.30+0.29+0.09+0.13+0.05}_{-0.94-0.28-0.22-0.09-0.03}$	10^{-3}
	$\to D^-\pi^+\pi^+$	$\mathcal{B}_v$	$2.33^{+0.98+0.21+0.13+0.10+0.04}_{-0.72-0.20-0.16-0.07-0.05}$	10^{-4}
	$\to D_s^-K^+\pi^+$	$\mathcal{B}_v$	$3.52^{+1.54+0.32+0.17+0.15+0.06}_{-1.03-0.30-0.17-0.10-0.07}$	10^{-5}
$B^+ \to \bar{D}^{*0}K^+$	$\to \bar{D}^0\pi^0K^+$	$\mathcal{B}$	$2.46^{+1.18+0.14+0.16+0.10+0.09}_{-0.69-0.28-0.10-0.07-0.01}$	10^{-4}
	$\to D^-\pi^+K^+$	$\mathcal{B}_v$	$1.80^{+0.84+0.16+0.11+0.07+0.03}_{-0.54-0.15-0.10-0.05-0.04}$	10^{-5}
	$\to D_s^-K^+K^+$	$\mathcal{B}_v$	$2.63^{+1.18+0.24+0.13+0.11+0.04}_{-0.79-0.23-0.13-0.08-0.05}$	10^{-6}
$B^+ \to D^{*0}K^+$	$\to D^0\pi^0K^+$	$\mathcal{B}$	$1.00^{+0.28+0.05+0.01+0.04+0.02}_{-0.30-0.11-0.02-0.03-0.01}$	10^{-6}
	$\to D^+\pi^-K^+$	$\mathcal{B}_v$	$5.92^{+2.23+0.53+0.12+0.24+0.05}_{-1.53-0.51-0.08-0.16-0.04}$	10^{-8}
	$\to D_s^+K^-K^+$	$\mathcal{B}_v$	$1.10^{+0.42+0.12+0.01+0.04+0.00}_{-0.31-0.11-0.02-0.03-0.00}$	10^{-8}

Numerical Results

Table 3: The same as table 1, the quasi-two-body decays $B_s^0 \to D^*_{(s)} h' \to D h h'$.

Decay modes	$\mathcal{B}/\mathcal{B}_v$	Results	Units
$B_s^0 \to D_s^{*-}\pi^+ \to \bar{D}^0 K^- \pi^+$	$\mathcal{B}_v$	$1.90^{+0.94+0.28+0.16+0.08+0.14}_{-0.59-0.26-0.14-0.06-0.15}$	10^{-5}
$\to D^- \bar{K}^0 \pi^+$	$\mathcal{B}_v$	$1.83^{+0.94+0.27+0.15+0.08+0.14}_{-0.57-0.25-0.13-0.06-0.14}$	10^{-5}
— — —	—	— — —	—
$B_s^0 \to D_s^{*-} K^+ \to \bar{D}^0 K^- K^+$	$\mathcal{B}_v$	$1.28^{+0.66+0.19+0.10+0.06+0.10}_{-0.42-0.17-0.09-0.04-0.10}$	10^{-6}
$\to D^- \bar{K}^0 K^+$	$\mathcal{B}_v$	$1.23^{+0.66+0.18+0.09+0.05+0.09}_{-0.40-0.17-0.09-0.04-0.10}$	10^{-6}
— — —	—	— — —	—
$B_s^0 \to D^{*-}\pi^+ \to \bar{D}^0 \pi^- \pi^+$	$\mathcal{B}$	$8.61^{+0.76+0.77+0.84+0.37+0.19}_{-0.84-0.74-0.97-0.26-0.21}$	10^{-7}
$\to D^- \pi^0 \pi^+$	$\mathcal{B}$	$3.82^{+0.70+0.34+0.36+0.16+0.06}_{-0.23-0.33-0.29-0.12-0.08}$	10^{-7}
$\to D_s^- K^0 \pi^+$	$\mathcal{B}_v$	$5.50^{+0.44+0.49+0.82+0.24+0.13}_{-0.48-0.47-0.73-0.17-0.13}$	10^{-9}
$B_s^0 \to D^{*+} K^- \to D^0 \pi^+ K^-$	$\mathcal{B}$	$1.13^{+0.46+0.10+0.00+0.04+0.00}_{-0.31-0.10-0.00-0.03-0.00}$	10^{-6}
$\to D^+ \pi^0 K^-$	$\mathcal{B}$	$5.14^{+2.10+0.46+0.01+0.20+0.00}_{-1.41-0.44-0.00-0.14-0.00}$	10^{-7}
$\to D_s^+ \bar{K}^0 K^-$	$\mathcal{B}_v$	$1.67^{+0.68+0.15+0.00+0.06+0.00}_{-0.46-0.14-0.00-0.04-0.00}$	10^{-8}
$B_s^0 \to \bar{D}^{*0}\pi^0 \to \bar{D}^0 \pi^0 \pi^0$	$\mathcal{B}$	$4.16^{+0.24+0.37+0.50+0.18+0.07}_{-0.44-0.36-0.41-0.13-0.16}$	10^{-7}
$\to D^- \pi^+ \pi^0$	$\mathcal{B}_v$	$2.36^{+0.25+0.21+0.28+0.10+0.05}_{-0.21-0.20-0.27-0.07-0.06}$	10^{-8}
$\to D_s^- K^+ \pi^0$	$\mathcal{B}_v$	$2.75^{+0.23+0.25+0.41+0.12+0.06}_{-0.24-0.24-0.37-0.08-0.01}$	10^{-9}
$B_s^0 \to \bar{D}^{*0} \bar{K}^0 \to \bar{D}^0 \pi^0 \bar{K}^0$	$\mathcal{B}$	$1.71^{+0.73+0.15+0.04+0.07+0.02}_{-0.56-0.15-0.04-0.05-0.08}$	10^{-4}
$\to D^- \pi^+ \bar{K}^0$	$\mathcal{B}_v$	$1.59^{+0.75+0.14+0.01+0.07+0.01}_{-0.50-0.14-0.00-0.05-0.02}$	10^{-5}
$\to D_s^- K^+ \bar{K}^0$	$\mathcal{B}_v$	$3.82^{+1.79+0.34+0.01+0.16+0.03}_{-1.18-0.33-0.00-0.12-0.04}$	10^{-6}

Discussion

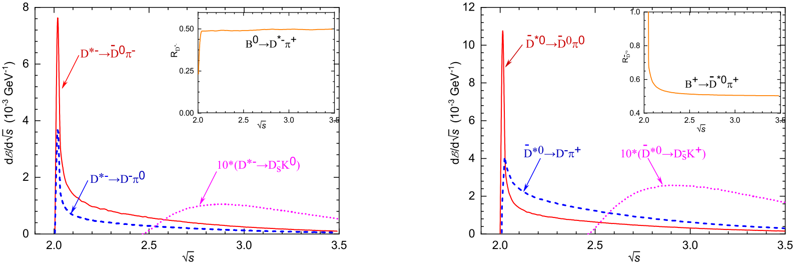

Figure 3: The differential branching ratios for the quasi-two-body $B^0 \to D^{*-}\pi^+ \to Dh\pi^+$ decays (left pannel) and $B^+ \to \bar{D}^{*0}\pi^+ \to Dh\pi^+$ (right panel). The embedded graphs denote the ratios $R_{D^*\to D\pi}$.

Discussion

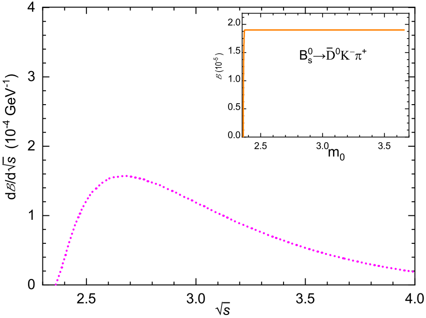

Figure 4: $B_s^0 \to D_s^{*-}\pi^+ \to \bar{D}^0 K^- \pi^+$ with the $\sqrt{s} \in [2.3, 4.0]$ GeV. The embedded graph indicates the evolution on $m_0(\bar{D}^0 K^-$ threshold value-$m_0^{eff})$.

$$\sqrt{s} > 2.359 \text{ GeV}$$
$$\Gamma_{D_s^{*-}} < 1.9 \text{ MeV}$$

$$|m^2_{D_s^{*-}} - s| \gg |m_{D_s^{*-}} \Gamma_{D_s^{*-}}(s)|$$

Quasi-two-body $\to$ Two-body

The narrow width approximation

$$\mathcal{B}(B \to D^*_{(s)}h' \to D_{(s)}hh') \approx \mathcal{B}(B \to D^*_{(s)}h') \cdot \mathcal{B}(D^*_{(s)} \to D_{(s)}h) \tag{8}$$

$$\mathcal{B}(D^{*+} \to D^0\pi^+) = 67.7\%,\ \mathcal{B}(D^{*+} \to D^+\pi^0) = 30.7\%$$
$$\text{and } \mathcal{B}(D^{*0} \to D^0\pi^0) = 64.7\%.$$

- The CKM favoured channels is shown in table 4,
- For the CKM suppressed decays,

$\mathcal{B}(B^+ \to D^{*0}K^+) =$	$(7.8 \pm 2.2) \times 10^{-6}$	experiment
	$(1.54^{+0.45}_{-0.49}) \times 10^{-6}$	our extraction
	$(0.71^{+0.76}_{-0.53}) \times 10^{-6}$	pQCD approach
	$(11.8^{+3.5}_{-3.5}) \times 10^{-6}$	FAT approach

Quasi-two-body $\rightarrow$ Two-body

Table 4: Branching ratios of $B_{(s)} \rightarrow D^* h'$ decays obtained from quasi-two-body processes under the narrow width approximation. The previous two-body pQCD calculation and the experimental measurements are also listed for comparison.

Decay modes	pQCD (10^{-4})	This work (10^{-4})	Data (10^{-4})
$B^0 \rightarrow D^{*-}\pi^+$	$26.1^{+8.90}_{-9.50}$	$25.0^{+8.90}_{-8.10}$	27.4 ± 1.30
		$25.4^{+12.4}_{-8.20}$	
$B^0 \rightarrow D^{*-}K^+$	$2.21^{+0.82}_{-0.83}$	$2.04^{+0.98}_{-0.65}$	2.12 ± 0.15
		$2.08^{+0.94}_{-0.74}$	
$B^0 \rightarrow \bar{D}^{*0}\pi^0$	$2.30^{+0.87}_{-0.83}$	$1.62^{+0.71}_{-0.44}$	2.20 ± 0.60
$B^0 \rightarrow \bar{D}^{*0}K^0$	$0.25^{+0.10}_{-0.09}$	$0.26^{+0.14}_{-0.07}$	0.36 ± 0.12
$B^+ \rightarrow \bar{D}^{*0}\pi^+$	$51.1^{+14.7}_{-14.2}$	$49.8^{+20.7}_{-15.6}$	49.0 ± 1.70
$B^+ \rightarrow \bar{D}^{*0}K^+$	$3.94^{+1.24}_{-1.32}$	$3.80^{+1.86}_{-1.16}$	$3.97^{+0.31}_{-0.28}$
$B_s^0 \rightarrow \bar{D}^{*0}\bar{K}^0$	$4.14^{+2.01}_{-1.52}$	$2.64^{+1.15}_{-0.90}$	2.80 ± 1.10

R. H. Li, C. D. Lü and H. Zou (2008)

PDG(2020)

Results of BWT

Table 5: The comparison between pQCD predictions and available experimental measurements for some channels happened by the BWT effect.

Decay modes	$\mathcal{B}_v(10^{-5})$	$\mathcal{B}_v^{\rm cut}(10^{-5})$	Data (10^{-5})
$B^+ \to \bar{D}^{*0}\pi^+ \to D^-\pi^+\pi^+$	$23.3^{+10.1}_{-7.70}$	$19.2^{+8.80}_{-6.20}$	22.3 ± 3.20 [Belle]
			10.9 [BaBar]
			10.9 ± 2.70 [LHCb]
$B^+ \to \bar{D}^{*0}K^+ \to D^-\pi^+K^+$	$1.80^{+0.86}_{-0.57}$	$1.48^{+0.68}_{-0.47}$	0.56 ± 0.23 [LHCb]
$B_s^0 \to D_s^{*-}\pi^+ \to \bar{D}^0K^-\pi^+$	$1.90^{+1.01}_{-0.68}$		4.70 ± 4.38 [LHCb]

K. Abe *et al.* ([Belle],2004) B. Aubert *et al.* ([BaBar],2009)
R. Aaij *et al.* ([LHCb],2016,2015,2014)

Summary

Summary

$D^*_{(s)} \to D_{(s)}h'$ by u-, d- and s-quark pair configurations.

1. $D^{*\pm}$

   the u- and d-quark from the pole mass dynamics,
   the s-quark configuration from the BWT effect.

2. $\bar{D}^{*0}$ and D^{*0}

   the u-quark from the pole mass,
   the d- and s-quark from the BWT effect.
   The smallness ($<5\%$) of the BWT effect

3. D_s^*

   only happen by the BWT effect for both the u- and d-quark.
   $B_s \to D_s^{*-}\pi^+ \to \bar{D}^0 K^- \pi^+$

Under the narrow width approximation, extracting the branching ratios of two-body decays, and found it works well for the CKM-favoured channels.

Thanks for your attention!