Semi-leptonic B decays to tensor mesons

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Introduction

- The light P-wave tensor mesons with $J^P = 2^+$ form a $^3P_2$ nonet, which involves the iso-vector mesons $a_2(1320)$, iso-doublet states $K_2^*(1430)$ and two iso-siglet $f_2(1270)$ and $f_2'(1525)$.
- The charmed tensor mesons are $D_2^*(2460)$ and $D_{s2}^*(2573)$. In 1989, the nutral and charged $D_2^*(2460)$ was firstly observed by TPS and ARGUS collaborations in $D\pi$ invariant mass distribution. In 1994, $D_{s2}^*(2573)$ was found by CLEO collaboration in the D^0K^+ invariant mass spectrum.
- The semi-leptonic $B \to T\ell\nu_\ell$ decays play an important role not only in understanding the dynamic mechanisims of weak decay, but also studing the properties of tensor mesons.

Introduction

At the end of the twentieth century, Jaus put forward the covariant light-front quark model (CLFQM). The CLFQM has some unique advantages:

- The light-front wave functions descrbing the hadron through quark and gluon degrees of freedom can preserve a Lorentz invariant formalism.
- The final state meson at $q^2 = 0$ is usually relativistic. The CLFQM with relativistic effects involved is suitable to study hadronic transition form factors.

The CLFQM general calculation procedure

The CLFQM general calculation procedure

The Bauer-Stech-Wirble (BSW) form factors for the $B \to T$ transitions are defined as follows,

$$\langle T(p'', \varepsilon)| \ V_\mu \ |B(p')\rangle = -i\frac{2}{m_B + m_T}\epsilon_{\mu\nu\alpha\beta}\, e^{*\nu} p'^{\alpha} p''^{\beta}\, V^{BT}(q^2), \quad (1)$$

$$\begin{aligned}\langle T(p'', \varepsilon)| \ A_\mu \ |B(p')\rangle &= 2m_T\frac{e^*\cdot q}{q^2}q_\mu A_0^{BT}(q^2) + (m_B + m_T)\left[e^*_\mu - \frac{e^*\cdot q}{q^2}q_\mu\right]A_1^{BT}(q^2) \\ &\quad -\frac{e^*\cdot q}{m_B + m_V}\left[P_\mu - \frac{m_B^2 - m_T^2}{q^2}q_\mu\right]A_2^{BT}(q^2)\ , \quad (2)\end{aligned}$$

where $P = P' + P''$, $q = P' - P''$, ϵ'' is the polarization vector. The four-momentum of the initial (final) meson is $P' = p_1' + p_2$ $(P'' = p_1'' + p_2)$.

The CLFQM general calculation procedure

In the Isgur-Scora-Grinstein-Wise (ISGW) model, the general expression for the $B \to T$ transitions is parametrized as

$$\begin{aligned} \langle T(p'', \varepsilon)| \ (V - A)_\mu \ |B(p')\rangle &= ih(q^2)\epsilon_{\mu\nu\rho\sigma}\varepsilon^{*\nu^\alpha} p'_\alpha P^\rho q^\sigma - k(q^2)\varepsilon^*_{\mu\nu}p'^\nu \\ &\quad -b_+(q^2)\varepsilon^*_{\alpha\beta}p'^\alpha p'^\beta P - b_-(q^2)\varepsilon^*_{\alpha\beta}p'^\alpha p'^\beta q \end{aligned} \quad (3)$$

The relations between these two different sets of form factors are

$$V^{BT}(q^2) = m_B(m_B + m_T)h(q^2), \quad (4)$$

$$A_1^{BT}(q^2) = \frac{m_B}{m_B + m_T}k(q^2), \quad (5)$$

$$A_2^{BT}(q^2) = -m_B(m_B + m_T)b_+(q^2), \quad (6)$$

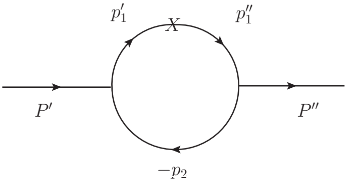
$$A_0^{BT}(q^2) = \frac{m_B}{2m_T}[k(q^2) + (m_B^2 - m_T^2)b_+(q^2) + q^2 b_-(q^2)]. \quad (7)$$

The CLFQM general calculation procedure

The decay amplitude at the lowest order for the general $P \to T$ transition can be written as

$$\mathcal{A}^{PT} = -i^3 \frac{N_c}{(2\pi)^4} \int d^4 p_1' \frac{H_P'(iH_T'')}{N_1' N_1'' N_2} S_\mu^{PT}, \tag{8}$$

where $N_1^{\prime(\prime\prime)} = p_1^{\prime(\prime\prime)2} - m_1^{\prime(\prime\prime)2}$ and $N_2 = p_2^2 - m_2^2$ arise from the quark propagators.



The CLFQM general calculation procedure

The expression of trace S_μ^{PT} can be derived using the Lorentz contraction,

$$\begin{aligned} S_\mu^{PT} &= \mathrm{Tr}[(\not p_1'' + m_1'')\gamma^\mu\gamma_5(\not p_1' + m_1')\gamma_5(-\not p_2 + m_2)] \\ &= 2p'_{1\mu}[M'^2 + M''^2 - q^2 - 2N_2 - (m_1' - m_2)^2 - (m_1'' + m_2)^2 + (m_1' + m_1'')^2] \\ &+ q_\mu[q^2 - 2M'^2 + N_1' - N_1'' + 2N_2 + 2(m_1' - m_2)^2 - (m_1' + m_1'')^2] \\ &+ P_\mu[q^2 - N_1' - N_1'' - (m_1' + m_1'')^2]. \end{aligned} \tag{9}$$

The explicit forms of H_P' and H_T'' used in this work are given by

$$H_P' = (M'^2 - M_0'^2)\sqrt{\frac{x_1 x_2}{N_c}}\frac{1}{\sqrt{2}\widetilde{M}_0'}\varphi', \tag{10}$$

$$H_T'' = (M''^2 - M_0''^2)\sqrt{\frac{x_1 x_2}{N_c}}\frac{1}{\sqrt{2}\widetilde{M}_0''}\varphi_p''. \tag{11}$$

Here φ' and φ''_p are the light-front wave function for s-wave (initial state) and p-wave (final state) mesons, respectively, which are adopted in the phenomenological Gaussian-type forms,

$$\varphi' = \varphi'(x_2, p'_\perp) = 4\left(\frac{\pi}{\beta^2}\right)^{\frac{3}{4}} \sqrt{\frac{dp'_z}{dx_2}}\exp(-\frac{p'^2_z + p'^2_\perp}{2\beta'^2}), \quad (12)$$

$$\varphi''_p = \varphi''_p(x_2, p''_\perp) = \sqrt{\frac{2}{\beta^2}}\varphi', \quad \frac{dp'_z}{dx_2} = \frac{e'_1 e_2}{x_1 x_2 M'_0}, \quad (13)$$

where the shape parameter β can be fixed by fitting the corresponding decay constant.

Input parameters:

- The constituent quark masses(GeV): $m_b = 4.8, m_c = 1.4,\ m_s = 0.37,$

  $m_{u,d} = 0.25.$

- The masses of the initial and the final mesons(GeV): $m_B = 5.28,$

  $m_{B_s} = 5.37,\ m_{a_2(1320)} = 1.32,\ m_{f_2(1270)} = 1.27,$

  $m_{D_2^*(2460)} = 2.46,\ m_{D_{s2}^*(2573)} = 2.57,\ m_{K_2^*(1430)} = 1.43.$

- The CKM matrix element:

  $V_{cb} = (41.1 \pm 1.2) \times 10^{-3}, V_{ub} = (3.82 \pm 0.2) \times 10^{-3}.$

$B \to T$ transition form factors

Input parameters:

- The shape parameters fitted by the decay constants:

$$\beta_B = 0.555^{+0.060}_{-0.060}, \beta_{B_s} = 0.626^{+0.045}_{-0.045}, \beta_{a_2} = 0.312^{+0.006}_{-0.006},$$

$$\beta_{f_2} = 0.312^{+0.006}_{-0.006}, \beta_{f_2'} = 0.348^{+0.006}_{-0.006}, \beta_{K_2^*} = 0.313^{+0.010}_{-0.010},$$

$$\beta_{D_2^*} = 0.429^{+0.013}_{-0.013}, \beta_{D_{s2}^*} = 0.530^{+0.019}_{-0.019}.$$

- Mean life $(10^{-12}s)$:

$$\tau_{B^0} = (1.519 \pm 0.004), \tau_{B_s^0} = (1.520 \pm 0.005), \tau_{B^\pm} = (1.638 \pm 0.004).$$

$B \to T$ transition form factors

- All the calculations are carried out within the $q^+ = 0$ reference frame, where the form factors can only be obtained at spacelike momentum transfers $q^2 = -q_\perp^2 \leq 0$,
- The parameterized form factors are extrapolated from the space-like region to the time-like region by using

$$F\left(q^2\right) = \frac{F(0)}{\left(1 - q^2/m^2\right)\left[1 - a\left(q^2/m^2\right) + b\left(q^2/m^2\right)^2\right]}. \tag{14}$$

- $F(q^2)$ denotes different form factors, such as $V(q^2)$, $A_0(q^2)$, $A_1(q^2)$, $A_2(q^2)$.

$B \to T$ transition form factors

- The $B \to T$ transition form factors obtained within the CLFQM. The uncertainties mainly arise from the decay constants of the initial and final state mesons.

Transition	Reference	V	A_0	A_1	A_2	Transition	Reference	V	A_0	A_1	A_2
$B \to a_2$	This work	$0.25^{+0.02}_{-0.01}$	$0.21^{+0.03}_{-0.03}$	$0.19^{+0.02}_{-0.01}$	$0.17^{+0.01}_{-0.01}$	$B \to K_2^*$	This work	$0.27^{+0.02}_{-0.02}$	$0.22^{+0.04}_{-0.04}$	$0.21^{+0.03}_{-0.02}$	$0.19^{+0.01}_{-0.01}$
	LFQM'22	0.24	0.21	0.19	0.17		LFQM'22	0.28	0.24	0.22	0.20
	CLFQM'11	0.28	0.24	0.21	0.19		CLFQM'11	0.28	0.25	0.21	0.19
	PQCD'11	0.18	0.18	0.11	0.06		PQCD'11	0.21	0.18	0.13	0.08
	LCSR'21	0.27	0.27	0.19	0.14		LCSR'21	0.25	0.29	0.18	0.10
	LCSR'11	0.18	0.21	0.14	0.09		LCSR'11	0.16	0.25	0.14	0.05
	LCSR'19	0.18	0.30	0.16	0.07		LCSR'19	0.22	0.30	0.19	0.11
	QCDSR'16	0.13	0.26	0.11	0.09		ISGW2'10	$-$	-0.17	-0.38	-0.53
	ISGW2'10	0.32	0.20	0.16	0.14		LFQM'04	0.28	0.26	-0.01	-0.21
$B \to f_2$	This work	$0.24^{+0.02}_{-0.02}$	$0.22^{+0.03}_{-0.04}$	$0.19^{+0.02}_{-0.02}$	$0.17^{+0.01}_{-0.01}$	$B \to D_2^*$	This work	$0.72^{+0.05}_{-0.05}$	$0.69^{+0.07}_{-0.06}$	$0.64^{+0.05}_{-0.05}$	$0.54^{+0.03}_{-0.02}$
	PQCD'11	0.12	0.13	0.08	0.04		LFQM'22	0.75	0.64	0.63	0.58
	LCSR'16	0.30	0.22	0.17	0.11						
	LCSR'21	0.18	0.18	0.14	0.11						
	LCSR'11	0.18	0.20	0.14	0.10						
	LCSR'19	0.11	0.20	0.10	0.04						
	QCDSR'16	0.12	0.24	0.10	0.09						
	ISGW2'10	0.32	0.20	0.16	0.14						

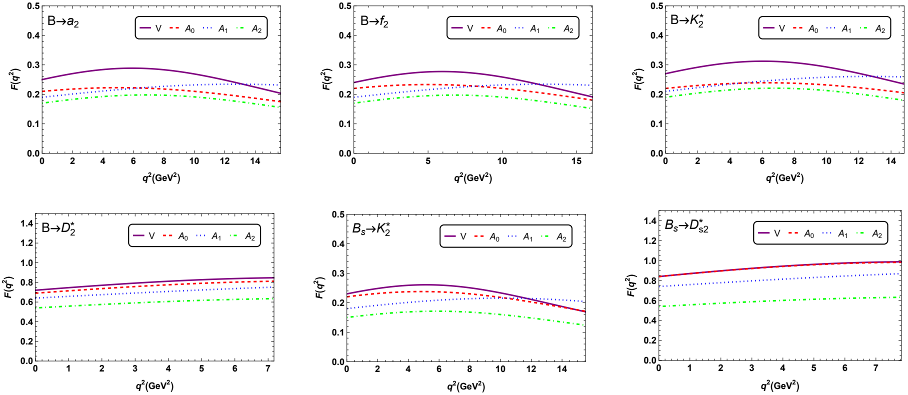
$B \to T$ transition form factors

- The $B \to T$ transition form factors obtained within the CLFQM. The uncertainties mainly arise from the decay constants of the initial and final state mesons.

Transitions	Reference	V	A_0	A_1	A_2	Transitions	Reference	V	A_0	A_1	A_2
$B_s \to K_2^*$	This work	$0.23^{+0.02}_{-0.02}$	$0.22^{+0.04}_{-0.03}$	$0.18^{+0.02}_{-0.01}$	$0.16^{+0.01}_{-0.01}$	$B_s \to f_2'$	This work	$0.31^{+0.02}_{-0.01}$	$0.31^{+0.04}_{-0.01}$	$0.25^{+0.02}_{-0.04}$	$0.21^{+0.01}_{-0.01}$
	LFQM'22	0.23	0.18	0.17	0.16		LFQM'22	0.32	0.26	0.24	0.22
	PQCD'11	0.18	0.15	0.11	0.07		PQCD'11	0.20	0.16	0.12	0.09
	LCSR'21	0.25	0.29	0.18	0.10		LCSR'21	0.25	0.32	0.18	0.08
	LCSR'11	0.15	0.22	0.12	0.05		LCSR'11	0.15	0.25	0.13	0.03
	QCDSR'16	0.13	0.23	0.10	0.05		ISGW2'95	–	−0.26	−0.45	−0.59
	ISGW2'10	–	−0.27	−0.39	−0.47						
$B_s \to D_{s2}^*$	This work	$0.84^{+0.05}_{-0.03}$	$0.84^{+0.06}_{-0.03}$	$0.74^{+0.04}_{-0.02}$	$0.57^{+0.02}_{-0.01}$						
	LFQM'22	0.95	0.76	0.74	0.66						
	CLFQM'25	0.81	0.69	0.68	0.67						

$B \to T$ transition form factors

图: The q^2-dependence of the $B_{(s)} \to a_2, f_2, K_2^*, D_2^*, D_{s2}^*$ transtion form factors.



Semi-leptonic decays $B \to T\ell\nu_\ell$

Semi-leptonic Decays $B \to T\ell\nu_\ell$

The partial decay widths of the semi-leptonic decays $B \to T\ell\nu_\ell$

$$\frac{d\Gamma}{dq^2} = \sum_{i=L,\pm} \frac{d\Gamma_i}{dq^2}, \tag{15}$$

$$\frac{d\Gamma_{L,\pm}}{dq^2} = \frac{|G_F V_{CKM}|^2 \sqrt{\lambda_T}}{256 m_B^3 \pi^3 q^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 (X_L, X_\pm), \tag{16}$$

where $\lambda_T = \lambda(m_B^2, m_T^2, q^2) = (m_B^2 - m_T^2 - q^2)^2 - 4m_T^2 q^2$, and $X_L, X_\pm$ are defined as

$$X_L = \frac{\lambda_T}{9m_T^2 m_B^2}\Big[(2q^2 + m_\ell^2)h_0^2(q^2) + 3\lambda_T m_\ell^2 A_0^2(q^2)\Big], \tag{17}$$

$$X_\pm = \frac{2q^2}{3}(2q^2 + m_\ell^2)\frac{\lambda_T}{8m_T^2 m_B^2}\left[(m_B + m_T)A_1(q^2) \mp \frac{\sqrt{\lambda_T}}{m_B + m_T} V(q^2)\right]^2, \tag{18}$$

$$h_0(q^2) = \frac{1}{2m_T}\left[(m_B^2 - m_T^2 - q^2)(m_B + m_T)A_1(q^2) - \frac{\lambda_T}{m_B + m_T} A_2(q^2)\right]. \tag{19}$$

Semi-leptonic decays $B \to T\ell\nu_\ell$

One can define the partial forward-backward asymmetry $\mathcal{A}_{FB}$ of the lepton,

$$\frac{d\mathcal{A}_{FB}}{dq^2} = \frac{1}{X_L + X_+ + X_-}\Bigg(\frac{\lambda_T}{6m_T^2 m_B^2} 2m_\ell^2 \sqrt{\lambda_T} h_0(q^2) A_0(q^2) - \frac{\lambda_T}{8m_T^2 m_B^2} 4q^4 \sqrt{\lambda_T} A_1(q^2) V(q^2) \Bigg), \tag{20}$$

The longitudinal polarization fraction is defined as

$$f_L = \frac{\Gamma_L}{\Gamma_L + \Gamma_+ + \Gamma_-}. \tag{21}$$

Semi-leptonic decays $B \to T\ell\nu_\ell$

- The branching ratios (10^{-5}) of the semi-leptonic decays $B \to (a_2, f_2, K_2^*)\ell\nu_\ell$.

Reference	This work	PQCD	QCDSR	LCSR	RQM
$B^+ \to a_2^0 e^+\nu_e$	$9.25^{+0.02+1.11+1.67}_{-0.02-2.91-0.59}$	–	–	5.60	–
$B^+ \to a_2^0 \mu^+\nu_\mu$	$9.22^{+0.02+1.11+1.66}_{-0.02-2.90-0.57}$	–	–	5.50	–
$B^+ \to a_2^0 \tau^+\nu_\tau$	$2.15^{+0.01+0.30+0.34}_{-0.01-0.61-0.36}$	–	–	1.10	–
$B^0 \to a_2^- e^+\nu_e$	$8.56^{+0.02+1.03+1.55}_{-0.02-2.70-0.55}$	11.60	8.20	10.30	12.70
$B^0 \to a_2^- \mu^+\nu_\mu$	$8.54^{+0.02+1.03+1.54}_{-0.02-2.69-0.53}$	11.60	8.20	10.20	12.70
$B^0 \to a_2^- \tau^+\nu_\tau$	$2.00^{+0.01+0.28+0.31}_{-0.01-0.56-0.33}$	4.10	5.10	2.00	2.80
$B^+ \to f_2^0 e^+\nu_e$	$12.44^{+0.03+3.10+2.20}_{-0.03-4.70-1.05}$	6.90	7.70	6.00	–
$B^+ \to f_2^0 \mu^+\nu_\mu$	$12.38^{+0.03+3.08+2.19}_{-0.03-4.67-1.05}$	6.90	7.70	6.00	–
$B^+ \to f_2^0 \tau^+\nu_\tau$	$2.88^{+0.01+0.66+0.45}_{-0.01-0.93-0.24}$	2.50	5.30	1.20	–
$B^0 \to f_2^- e^+\nu_e$	$11.54^{+0.03+2.89+2.02}_{-0.03-4.34-0.99}$	–	–	–	–
$B^0 \to f_2^- \mu^+\nu_\mu$	$11.47^{+0.03+2.85+2.03}_{-0.03-4.33-0.97}$	–	–	–	–
$B^0 \to f_2^- \tau^+\nu_\tau$	$2.67^{+0.01+0.62+0.42}_{-0.01-0.86-0.23}$	–	–	–	–
$B_s^0 \to K_2^{*-} e^+\nu_e$	$7.90^{+0.03+0.90+2.45}_{-0.03-1.29-0.82}$	7.30	6.50	9.60	13.30
$B_s^0 \to K_2^{*-} \mu^+\nu_\mu$	$7.87^{+0.03+0.90+2.43}_{-0.03-1.27-0.82}$	7.30	6.50	9.50	13.30
$B_s^0 \to K_2^{*-} \tau^+\nu_\tau$	$1.77^{+0.01+0.23+0.46}_{-0.01-0.23-0.21}$	2.50	3.50	1.70	3.60

- The branching ratios (10^{-3}) of the semi-leptonic decays $B_{(s)} \to D^*_{(s)2}\ell\nu_\ell$.

Reference	This work	RQM	BT	GI	ISGW	OPAL
$B^+ \to D_2^{*0} e^+\nu_e$	$7.08^{+0.02+1.17+0.03}_{-0.02-1.26-0.48}$	–	$4.50 \sim 8.00$	7.00	7.70	8.80
$B^+ \to D_2^{*0} \mu^+\nu_\mu$	$7.02^{+0.02+1.16+0.03}_{-0.02-1.25-0.47}$	–	$4.50 \sim 8.00$	7.00	7.70	8.80
$B^+ \to D_2^{*0} \tau^+\nu_\tau$	$0.42^{+0.00+0.05+0.06}_{-0.00-0.02-0.01}$	–	–	–	–	–
$B^0 \to D_2^{*-} e^+\nu_e$	$6.56^{+0.02+1.08+0.02}_{-0.02-1.17-0.44}$	–	$4.50 \sim 8.00$	–	–	–
$B^0 \to D_2^{*-} \mu^+\nu_\mu$	$6.50^{+0.02+1.07+0.03}_{-0.02-1.16-0.44}$	–	$4.50 \sim 8.00$	–	–	–
$B^0 \to D_2^{*-} \tau^+\nu_\tau$	$0.34^{+0.00+0.06+0.01}_{-0.00-0.06-0.02}$	–	–	–	–	–
$B_s^0 \to D_{s2}^{*-} e^+\nu_e$	$8.20^{+0.03+0.37+0.47}_{-0.03-0.46-0.28}$	6.70	7.5	–	–	–
$B_s^0 \to D_{s2}^{*-} \mu^+\nu_\mu$	$8.20^{+0.03+0.98+0.43}_{-0.06-0.42-0.31}$	6.70	–	–	–	–
$B_s^0 \to D_{s2}^{*-} \tau^+\nu_\tau$	$0.42^{+0.00+0.05+0.06}_{-0.00-0.03-0.01}$	0.29	–	–	–	–

Semi-leptonic decays $B \to T\ell\nu_\ell$

- For the decays $B \to (a_2, f_2, K_2^*)\ell\nu_\ell$ induced by the $b \to u$ transition, their branching ratios lie in the range $10^{-5} \sim 10^{-4}$. While the branching ratios of the decays $B_{(s)} \to D^*_{(s)2}\ell\nu_\ell$ can reach $10^{-4} \sim 10^{-3}$.
- Due to phase space constraints, the branching ratios of the decays $B \to T\tau\nu_\tau$ are estimated to be $1/5 \sim 1/20$ of those the corresponding decays $B \to T\ell'\nu_{\ell'}$ with $\ell' = e, \mu$.
- The branching ratios of most considered decays are consistent with the results from other approaches, such as the PQCD, QCDSRs, LCSRs and RQM.
- All the branching ratios of these considered decays are larger than 10^{-5}, indicating promising prospects for measuring these processes in ongoing Belle II and LHCb experiments.

- The forward-backward asymmetries $\mathcal{A}_{FB}$ for the decays $B \to T\ell\nu_\ell$.

Decay modes	$B^0 \to a_2^- e^+\nu_e$	$B^0 \to a_2^- \mu^+\nu_\mu$	$B^0 \to a_2^- \tau^+\nu_\tau$
This work	-0.204	-0.202	0.012
PQCD	-0.186	-0.202	0.031
Decay modes	$B^0 \to f_2^- e^+\nu_e$	$B^0 \to f_2^- \mu^+\nu_\mu$	$B^0 \to f_2^- \tau^+\nu_\tau$
This work	-0.180	-0.178	0.027
PQCD	-0.175	-0.175	0.048
Decay modes	$B^0 \to D_2^{*-} e^+\nu_e$	$B^0 \to D_2^{*-} \mu^+\nu_\mu$	$B^0 \to D_2^{*-} \tau^+\nu_\tau$
This work	-0.146	-0.143	0.117
Decay modes	$B_s^0 \to K_2^{*-} e^+\nu_e$	$B_s^0 \to K_2^{*-} \mu^+\nu_\mu$	$B_s^0 \to K_2^{*-} \tau^+\nu_\tau$
This work	-0.183	-0.182	0.045
PQCD	-0.221	-0.221	-0.024
Decay modes	$B_s^0 \to D_{s2}^{*-} e^+\nu_e$	$B_s^0 \to D_{s2}^{*-} \mu^+\nu_\mu$	$B_s^0 \to D_{s2}^{*-} \tau^+\nu_\tau$
This work	-0.139	-0.135	0.126
NRQM	-0.14	-0.12	0.06

Semi-leptonic decays $B \to T\ell\nu_\ell$

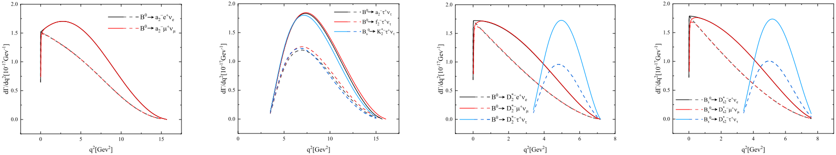
- The longitudinal polarization fractions f_L (%) for the decays $B \to T\ell\nu_\ell$.

Decay modes	$B^0 \to a_2^- e^+ \nu_e$	$B^0 \to a_2^- \mu^+ \nu_\mu$	$B^0 \to a_2^- \tau^+ \nu_\tau$
This work	$69.53^{+0.17+8.19+15.29}_{-0.17-25.27-6.98}$	$69.56^{+0.17+8.33+15.26}_{-0.17-25.23-6.81}$	$62.47^{+0.15+9.49+11.92}_{-0.15-20.22-2.16}$
PQCD	73.3	73.3	69.9
LCSR	71.8	71.8	59.6
Decay modes	$B^0 \to f_2^- e^+ \nu_e$	$B^0 \to f_2^- \mu^+ \nu_\mu$	$B^0 \to f_2^- \tau^+ \nu_\tau$
This work	$72.58^{+0.17+8.19+15.29}_{-0.17-25.27-6.98}$	$72.58^{+0.17+8.33+15.26}_{-0.17-25.23-6.81}$	$64.74^{+0.15+9.49+11.92}_{-0.15-20.22-2.16}$
PQCD	74.9	74.9	71.9
LCSR	68.9	68.8	56.7
Decay modes	$B^0 \to D_2^{*-} e^+ \nu_e$	$B^0 \to D_2^{*-} \mu^+ \nu_\mu$	$B^0 \to D_2^{*-} \tau^+ \nu_\tau$
This work	$70.65^{+0.17+11.89+0.33}_{-0.17-12.94-4.93}$	$70.60^{+0.17+11.88+0.36}_{-0.17-12.93-4.91}$	$55.98^{+0.14+9.37+0.63}_{-0.14-10.10-3.64}$
Decay modes	$B_s^0 \to K_2^{*-} e^+ \nu_e$	$B_s^0 \to K_2^{*-} \mu^+ \nu_\mu$	$B_s^0 \to K_2^{*-} \tau^+ \nu_\tau$
This work	$67.99^{+0.27+7.54+21.22}_{-0.27-13.83-6.55}$	$68.08^{+0.27+7.67+21.13}_{-0.27-13.74-6.62}$	$62.75^{+0.25+8.72+17.03}_{-0.25-9.78-7.18}$
PQCD	68.3	68.3	64.1
LCSR	77.6	77.5	65.8
Decay modes	$B_s^0 \to D_{s2}^{*-} e^+ \nu_e$	$B_s^0 \to D_{s2}^{*-} \mu^+ \nu_\mu$	$B_s^0 \to D_{s2}^{*-} \tau^+ \nu_\tau$
This work	$71.52^{+0.28+8.34+4.92}_{-0.28-5.12-2.21}$	$71.21^{+0.28+8.31+4.86}_{-0.28-5.06-2.22}$	$56.28^{+0.22+6.39+3.21}_{-0.22-3.51-1.54}$

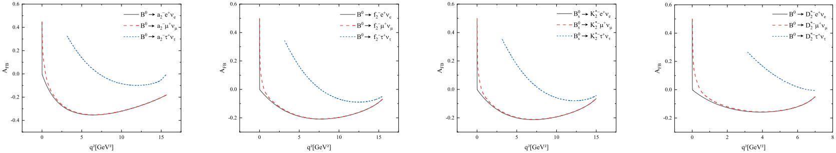
Semi-leptonic decays $B \to T\ell\nu_\ell$

- The q^2 dependence of the differential decay widths $d\Gamma/dq^2$ (solid lines) and $d\Gamma_L/dq^2$ (dashed lines) for the decays

  $B \to a_2\ell'\nu_{\ell'}$, $B_{(s)} \to (a_2, f_2, K_2^*)\tau\nu_\tau$, $B \to D_2^*\ell\nu_\ell$ and $B_s \to D_{s2}^*\ell\nu_\ell$.



- The q^2 dependence of the $\mathcal{A}_{FB}$ for the decays $B \to a_2\ell\nu_\ell$, $B \to f_2\ell\nu_\ell$, $B_s \to K_2^*\ell\nu_\ell$, $B \to D_2^*\ell\nu_\ell$.



Summary

- All the branching ratios of these decays are larger than 10^{-5}, in which the maximum value can reach up to 10^{-3}, which are likely to be detected by the present LHCb and Belle II experiments.
- The decays $B \to T\ell'\nu_{\ell'}$ are dominated by the longitudinal polarization, where the polarization fractions are close to 70%. Those of the decays $B \to T\tau\nu_\tau$ are a little smaller, where the least values coming from the decays $B_{(s)} \to D^*_{(s)2}\tau\nu_\tau$ are about 56%.
- There exists obvious disparity about the $\mathcal{A}_{FB}$ for the decays $B \to T\tau\nu_\tau$ among different theoretical predictions, which remains to be clarified with further investigation.

Thank you for your attention!