Eur. Phys. J. C (2022) 82:768
https://doi.org/10.1140/epjc/s10052-022-10728-9

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

Phenomenology analysis of $\bar{B}^* \to V\tau^-\bar{\nu}_\tau$ decays in and beyond the Standard Model

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Received: 1 April 2022 / Accepted: 18 August 2022

Abstract Motivated by the persistent anomalies reported in the $b \to c\tau\bar{\nu}$ data, we investigate the semileptonic decays $\bar{B}^* \to V\tau^-\bar{\nu}_\tau (V = D^*_{u,d,s}, J/\psi)$, within the Standard Model and beyond. The relevant transition form factors, being calculated in the covariant light-front quark model, is the main source of theoretical uncertainties. Using various best-fit solutions for the new operator Wilson coefficients, we report numerical results on various observables related to the processes $\bar{B}^* \to V\tau^-\bar{\nu}_\tau$, such as the branching ratios, the

1 Introduction

The searching for physics beyond the Standard Model (SM) has been one major part of particle physics research in high energy physics. In the flavor sector the lepton flavor universal is a key property of the SM gauge interactions. Evidence for violation of the property would be a clear sign of new physics (NP) beyond the SM. In the searching of NP, the second and third generation quarks and leptons are very important

报告人：钱建英

2023年10月29日

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1. J.P. Lees et al. [**BaBar**], *Evidence for an excess of* $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ *decays*. Phys. Rev. Lett. 109, 101802 (**2012**).arXiv:1205.5442 [hep-ex]
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3. R. Aaij et al. [**LHCb**], *Measurement of the ratio of branching fractions* $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$ Phys. Rev. Lett. 115(11), 111803(2015). [Erratum: Phys. Rev. Lett. 115(15), 159901 (**2015**)].arXiv:1506.08614 [hep-ex]
4. M. Huschle et al. [**Belle Collaboration**], *Measurement of the branching ratio of* $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$ *relative to* $\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$ *decays with hadronic tagging at Belle*. Phys. Rev. D 92(7), 072014(**2015**). arXiv:1507.03233 [hep-ex]
5. S. Hirose et al. [**Belle**], *Measurement of the* τ *lepton polarization and* $R(D^*)$ *in the decay* $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$. Phys. Rev. Lett. 118(21), 211801 (**2017**).arXiv:1612.00529 [hep-ex]
6. R. Aaij et al. [**LHCb**], *Measurement of the ratio of the* $B^0 \to D^{*-}\tau^+\nu_\tau$ *and* $B^0 \to D^{*-}\mu^+\nu_\mu$ *branching fractions using three-prong* τ *-lepton decays*. Phys. Rev. Lett. 120(17), 171802 (**2018**).arXiv:1708.08856 [hep-ex]
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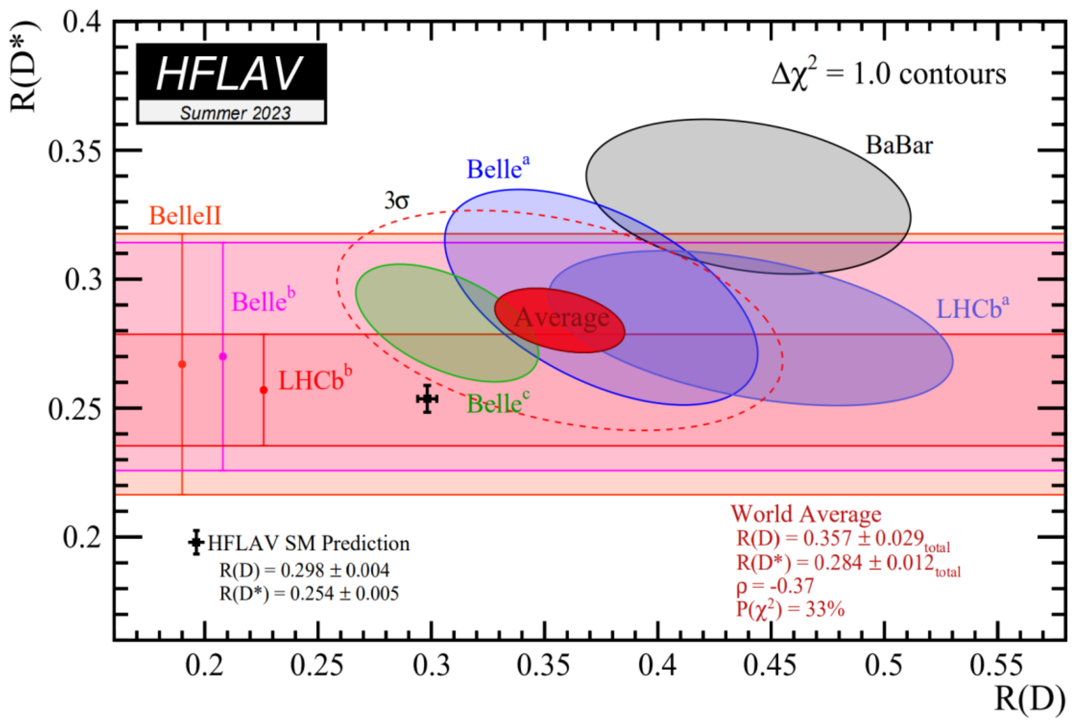
9. G. Caria et al. [**Belle**], *Measurement of* $R(D)$ *and* $R(D^*)$ *with a semileptonic tagging method*, Phys. Rev. Lett. 124(16), 161803 (**2020**).arXiv:1910.05864 [hep-ex]

一、研究背景 $\mathcal{R}(D^{(*)})$

HFLAV Collaboration, Online update for averages of RD and RD∗ for **Summer 2023** at https://hflav-eos.web.cern.ch/hflav-eos/semi/summer23/r_dtaunu/summer2023_preliminary_new.pdf



- $R(D)$ and $R(D^*)$ exceed the SM predictions given above, by **2.0σ** and **2.2σ** respectively.
- Considering the $R(D)$ - $R(D^*)$ correlation of -0.40, the resulting combined χ^2 is 14.2 for 2 degree of freedom, corresponding to a p-value of 0.82 x 10^{-3}. The difference with the SM predictions reported above, corresponds to about **3.34σ**.

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- the ratio $\mathcal{R}(J/\psi)$ of the decay $B_c \to J/\psi\ell\bar{\nu}$ has been measured by the LHCb collaboration and it shows about **1.8σ** discrepancy with SM results.

$P_\tau^{D^*}$ and $F_L^{D^*}$

1. S. Hirose et al. [**Belle**], *Measurement of the τ lepton polarization and $R(D^*)$ in the decay $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$*. Phys. Rev. Lett. 118(21), 211801 (**2017**).arXiv:1612.00529 [hep-ex]
2. **Belle collaboration**, *Measurement of the D^{*-} polarization in the decay $B^0 \to D^{*-}\tau^+\nu_\tau$*, talk given at the 10th International Workshop on the CKM Unitarity Triangle (CKM2018), September 17-21,Heidelberg, Germany (2018), arXiv:1903.03102 [hep-ex]

$$P_\tau^{D^*} = \frac{\Gamma(\lambda_\tau = \frac{1}{2}) - \Gamma(\lambda_\tau = -\frac{1}{2})}{\Gamma(\lambda_\tau = \frac{1}{2}) + \Gamma(\lambda_\tau = -\frac{1}{2})},$$

$$F_L^{D^*} = \frac{\Gamma(\lambda_{D^*} = 0)}{\Gamma(\lambda_{D^*} = 1) + \Gamma(\lambda_{D^*} = 0) + \Gamma(\lambda_{D^*} = -1)},$$

- While $P_\tau^{D^*}$ is reconstructed from the hadronic decays of the τ and is still statistically limited,
- the reported measurement of $F_L^{D^*}$ rather precise and disagrees with the SM prediction with a signifcance of 1.7σ.

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一、研究背景

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8. M. Bauer, M. Neubert, *One* ***Leptoquark*** *to Rule Them All: A Minimal Explanation for* $R_{D^{(*)}}$, R_K *and* $(g-2)_\mu$. Phys. Rev. Lett. 116(14), 141802 (2016).arXiv:1511.01900 [hep-ph]

二、研究内容

考虑新物理贡献时，通过$b \to c\ell\bar{\nu}$过程发生的$\bar{B}^{*} \to V\tau^{-}\bar{\nu}_{\tau}$衰变的低能有效拉氏量为：

$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}V_{cb}\Big\{(1+V_L)\bar{l}_L\gamma_\mu\nu_L\bar{c}_L\gamma^\mu b_L + V_R\bar{l}_L\gamma_\mu\nu_L\bar{c}_R\gamma^\mu b_R + S_L\bar{l}_R\nu_L\bar{c}_R b_L + S_R\bar{l}_R\nu_L\bar{c}_L b_R\Big\} + {\rm h.c.},$$

$\bar{B}^{*} \to V\tau^{-}\bar{\nu}_{\tau}$过程的振幅为

$$M(\bar{B}^{*} \to Vl\bar{\nu}_l) = \frac{G_F}{\sqrt{2}}V_{cb}\sum_k C_k\langle V|\bar{c}\Gamma^k b\rangle\,\bar{u}_\ell\,\Gamma_k\,\nu_\nu$$

$$|M(\bar{B}^{*} \to V\ell\bar{\nu}_\ell)|^2 = \frac{G_F^2}{2}|V_{cb}|^2\sum_{ij}C_{i,j}(L_{\mu\nu}^{ij}H^{\mu\nu,ij})$$

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强子螺旋度振幅

$$H^{V_L, V_R}_{\lambda_{W^*}\lambda_{B^*}\lambda_V}(q^2) = \langle V(p_V, \lambda_V)|\bar{c}\gamma_\mu(1 \pm \gamma_5)b|\bar{B}^*(p_{B^*}, \lambda_{B^*})\rangle\bar{\epsilon}^{*\mu}(\lambda_{W^*})$$

$$\begin{aligned}&\langle V(\epsilon_2, p_V)|\bar{c}\gamma_\mu b|\bar{B}^*(\epsilon_1, p_{B^*})\rangle\\ &= (\epsilon_1\cdot\epsilon_2^*)\left[-P_\mu V_1(q^2) + q_\mu V_2(q^2)\right]\\ &\quad+\frac{(\epsilon_1\cdot q)(\epsilon_2^*\cdot q)}{m_{B^*}^2 - m_V^2}\left[P_\mu V_3(q^2) - q_\mu V_4(q^2)\right]\\ &\quad-(\epsilon_1\cdot q)\epsilon_{2\mu}^* V_5(q^2) + (\epsilon_2^*\cdot q)\epsilon_{1\mu} V_6(q^2),\end{aligned}$$

$$\begin{aligned}&\langle V(\epsilon_2, p_V)|\bar{c}\gamma_5\gamma_\mu b|\bar{B}^*(\epsilon_1, p_{B^*})\rangle\\ &= -i\varepsilon_{\mu\nu\alpha\beta}\epsilon_1^\alpha\epsilon_2^{*\beta}\left[P^\nu A_1(q^2) - q^\nu A_2(q^2)\right]\\ &\quad-\frac{i\epsilon_2^*\cdot q}{m_{B^*}^2 - m_V^2}\varepsilon_{\mu\nu\alpha\beta}\epsilon_1^\nu P^\alpha q^\beta A_3(q^2)\\ &\quad+\frac{i\epsilon_1\cdot q}{m_{B^*}^2 - m_V^2}\varepsilon_{\mu\nu\alpha\beta}\epsilon_2^{*\nu} P^\alpha q^\beta A_4(q^2)\end{aligned}$$

二、研究内容

$$\frac{d^2\Gamma^{\lambda_\ell=1/2}}{dq^2 d\cos\theta_l} = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|}{256\pi^3 m_{B^*}^2}\frac{1}{3}q^2\left(1-\frac{m_\ell^2}{q^2}\right)^2\frac{m_\ell^2}{q^2}\Big\{(|1+V_L|^2+|V_R|^2)\times\Big[\sin^2\theta_l(H_{+0+}^2+H_{+-0}^2+H_{-0-}^2+H_{-+0}^2)$$

$$+2(H_{t++}-\cos\theta_l\,H_{0++})^2+2(H_{t--}-\cos\theta_l\,H_{0--})^2\;+2(H_{t00}-\cos\theta_l\,H_{000})^2\Big]+4Re[(1+V_L)V_R^*]\times\Big[\sin^2\theta_l(H_{+0+}H_{-0-}+H_{+-0}H_{-+0})$$

$$+(H_{t00}-\cos\theta_l\,H_{000})^2+2(H_{t++}-\cos\theta_l\,H_{0++})\times(H_{t--}-\cos\theta_l\,H_{0--})\Big]+\frac{2q^2}{m_\ell^2}\Big[(|S_L|^2+|S_R|^2)$$

$$\times(H_{00}^2+H_{++}^2+H_{--}^2)+2Re[S_L S_R^*](H_{00}^2+2H_{++}H_{--})\Big]$$

$$+\frac{2\sqrt{q^2}}{m_\ell}2Re[(1+V_L)S_L^*+V_R S_R^*]\Big[H_{00}(H_{t00}-H_{000}\cos\theta_l)$$

$$+H_{++}(H_{t++}-H_{0++}\cos\theta_l)+H_{--}(H_{t--}-H_{0--}\cos\theta_l)\Big]$$

$$+\frac{2\sqrt{q^2}}{m_\ell}2Re[(1+V_L)S_R^*+V_R S_L^*]\Big[H_{00}(H_{t00}-H_{000}\cos\theta_l)$$

$$+H_{--}(H_{t++}-H_{0++}\cos\theta_l)+H_{++}(H_{t--}-H_{0--}\cos\theta_l)\Big]\Big\},$$

二、研究内容

$$\frac{d^2\Gamma^{\lambda_\ell=-1/2}}{dq^2 d\cos\theta_l} = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|}{256\pi^3 m_{B^*}^2}\frac{1}{3}q^2\left(1-\frac{m_\ell^2}{q^2}\right)^2 \Big\{\Big[\big[|1+V_L|^2(1-\cos\theta_l)^2 +|V_R|^2(1+\cos\theta_l)^2\big](H_{+0+}^2+H_{+-0}^2) +\big[|1+V_L|^2(1+\cos\theta_l)^2+|V_R|^2(1-\cos\theta_l)^2\big] \times(H_{-0-}^2+H_{-+0}^2)+\left(|1+V_L|^2+|V_R|^2\right)2\sin\theta_\ell^2 \times\left(H_{000}^2+H_{0++}^2+H_{0--}^2\right)+4Re[(1+V_L)V_R^*] \times\Big[(1+\cos\theta_l^2)\left(H_{+0+}H_{-0-}+H_{+-0}H_{-+0}\right) +\sin^2\theta_l(H_{000}^2+2H_{0++}H_{0--})\Big]\Big\}, \quad (7)$$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|}{288\pi^3 m_{B^*}^2}q^2\left(1-\frac{m_\ell^2}{q^2}\right)^2\Big\{(|1+V_L|^2+|V_R|^2)\Big[\frac{3m_\ell^2}{2q^2} \times(H_{t++}^2+H_{t--}^2+H_{t00}^2)+(1+\frac{m_\ell^2}{2q^2})(H_{+0+}^2+H_{+-0}^2+H_{-0-}^2 +H_{-+0}^2+H_{000}^2+H_{0--}^2+H_{0++}^2)\Big]+2Re[(1+V_L)V_R^*]\Big[\frac{3m_\ell^2}{2q^2} \times(H_{t00}^2+2H_{t++}H_{t--})+\left(1+\frac{m_\ell^2}{2q^2}\right)\left(H_{000}^2+2H_{+0+}H_{-0-} +2H_{+-0}H_{-+0}+2H_{0++}H_{0--}\right)\Big]+\frac{3}{2}(|S_L|^2+|S_R|^2) \times\left(H_{00}^2+H_{++}^2+H_{--}^2\right)+3Re[S_LS_R^*](H_{00}^2+2H_{++}H_{--}) +\frac{3m_\ell}{\sqrt{q^2}}\left(Re[(1+V_L)S_L^*]+Re[V_RS_R^*]\right)\left(H_{00}H_{t00}+H_{++}H_{t++} +H_{--}H_{t--}\right)+\frac{3m_\ell}{\sqrt{q^2}}\left(Re[(1+V_L)S_R^*]+Re[V_RS_L^*]\right) \times\left(H_{00}H_{t00}+H_{++}H_{t--}+H_{--}H_{t++}\right)\Big\}. \quad (8)$$

${}^{d\Gamma}/_{dq^2}$, Γ, $R_V^{*(L)}$, A_{FB}^l, P_l ,F_L^{*V} ,F_T^{*V}等物理可观测量。

三、研究方法　形状因子

Q. Chang, X.L. Wang, J. Zhu, X.N. Li, *Study of $b \to c$ induced $\bar{B}^* \to V\ell\bar{\nu}_\ell$ decays*, Adv. High Energy Phys. 2020, 3079670 (2020). arXiv:2003.08600 [hep-ph]

	A_1	A_2	A_3	A_4	V_1	V_2	V_3	V_4	V_5	V_6
$\bar{B}^* \to D^*$										
$F(0)$	$0.66^{+0.01}_{-0.01}$	$0.36^{+0.00}_{-0.00}$	$0.07^{+0.00}_{-0.00}$	$0.08^{+0.00}_{-0.00}$	$0.67^{+0.01}_{-0.01}$	$0.36^{+0.00}_{-0.00}$	$0.13^{+0.00}_{-0.00}$	$0.00^{+0.00}_{-0.00}$	$1.17^{+0.01}_{-0.01}$	$0.48^{+0.01}_{-0.01}$
a	$1.31^{+0.02}_{-0.02}$	$1.32^{+0.02}_{-0.02}$	$1.79^{+0.02}_{-0.02}$	$1.81^{+0.02}_{-0.02}$	$1.30^{+0.02}_{-0.02}$	$1.32^{+0.02}_{-0.02}$	$1.72^{+0.02}_{-0.02}$	$-0.09^{+0.45}_{-0.40}$	$1.30^{+0.02}_{-0.02}$	$1.29^{+0.02}_{-0.02}$
b	$0.42^{+0.02}_{-0.02}$	$0.42^{+0.02}_{-0.02}$	$1.10^{+0.03}_{-0.03}$	$1.15^{+0.04}_{-0.04}$	$0.43^{+0.02}_{-0.02}$	$0.42^{+0.02}_{-0.02}$	$1.01^{+0.03}_{-0.04}$	$1.27^{+0.38}_{-0.28}$	$0.41^{+0.02}_{-0.02}$	$0.40^{+0.02}_{-0.02}$
$\bar{B}_s^* \to D_s^*$										
$F(0)$	$0.65^{+0.01}_{-0.01}$	$0.38^{+0.01}_{-0.01}$	$0.10^{+0.00}_{-0.00}$	$0.09^{+0.00}_{-0.00}$	$0.66^{+0.01}_{-0.01}$	$0.38^{+0.01}_{-0.01}$	$0.15^{+0.00}_{-0.00}$	$-0.02^{+0.00}_{-0.00}$	$1.19^{+0.02}_{-0.02}$	$0.53^{+0.01}_{-0.01}$
a	$1.42^{+0.03}_{-0.04}$	$1.47^{+0.03}_{-0.03}$	$1.89^{+0.03}_{-0.03}$	$1.88^{+0.02}_{-0.03}$	$1.43^{+0.03}_{-0.04}$	$1.48^{+0.03}_{-0.03}$	$1.79^{+0.03}_{-0.03}$	$2.22^{+0.04}_{-0.03}$	$1.41^{+0.03}_{-0.03}$	$1.35^{+0.04}_{-0.04}$
b	$0.64^{+0.04}_{-0.05}$	$0.67^{+0.04}_{-0.04}$	$1.33^{+0.05}_{-0.06}$	$1.36^{+0.09}_{-0.07}$	$0.64^{+0.04}_{-0.05}$	$0.67^{+0.04}_{-0.05}$	$1.20^{+0.06}_{-0.06}$	$1.92^{+0.08}_{-0.12}$	$0.61^{+0.04}_{-0.05}$	$0.56^{+0.04}_{-0.05}$
$\bar{B}_c^* \to J/\psi$										
$F(0)$	$0.55^{+0.01}_{-0.01}$	$0.35^{+0.00}_{-0.00}$	$0.14^{+0.00}_{-0.00}$	$0.15^{+0.01}_{-0.01}$	$0.57^{+0.01}_{-0.01}$	$0.35^{+0.00}_{-0.00}$	$0.21^{+0.00}_{-0.01}$	$-0.01^{+0.01}_{-0.01}$	$1.19^{+0.02}_{-0.02}$	$0.64^{+0.01}_{-0.01}$
a	$2.48^{+0.07}_{-0.07}$	$2.65^{+0.08}_{-0.08}$	$2.88^{+0.09}_{-0.09}$	$2.88^{+0.08}_{-0.08}$	$2.48^{+0.07}_{-0.07}$	$2.56^{+0.08}_{-0.08}$	$2.75^{+0.08}_{-0.09}$	$3.58^{+0.17}_{-0.12}$	$2.42^{+0.07}_{-0.07}$	$2.32^{+0.06}_{-0.06}$
b	$2.71^{+0.20}_{-0.22}$	$2.87^{+0.23}_{-0.26}$	$3.88^{+0.31}_{-0.34}$	$3.90^{+0.30}_{-0.33}$	$2.73^{+0.20}_{-0.22}$	$2.88^{+0.23}_{-0.26}$	$3.51^{+0.29}_{-0.32}$	$6.37^{+0.23}_{-0.13}$	$2.54^{+0.20}_{-0.22}$	$2.33^{+0.17}_{-0.19}$

三、研究方法

A. Ray, S. Sahoo, R. Mohanta, *Model independent analysis of $B^* \to P\ell\bar{\nu}_\ell$ decay processes*. Eur. Phys. J. C 79(8), 670 (2019).arXiv:1907.13586 [hep-ph]

Eur. Phys. J. C (2019) 79:670
https://doi.org/10.1140/epjc/s10052-019-7183-8

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Regular Article - Theoretical Physics

Model independent analysis of $B^* \to P\ell\bar{\nu}_\ell$ decay processes

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Received: 16 April 2019 / Accepted: 31 July 2019 / Published online: 9 August 2019

Abstract Very compelling deviations in the recently observed lepton nonuniversality observables ($R_{D^{(*)}}$, $R_{K^{(*)}}$, $R_{J/\psi}$) of semileptonic B meson decays from their Standard Model predictions hint towards the presence of some kind of new physics beyond it. In this regard, we investigate the effect of new physics in the semileptonic $\bar{B}^*_{d(s)} \to P\ell\bar{\nu}_\ell$ decay processes, where $P = D, \pi(D_s, K)$, in a model independent way. We consider the presence of additional vector and scalar type interactions and constrain the corresponding new couplings by fitting $\text{Br}(B^+_u \to \tau^+\nu_\tau)$, $\text{Br}(B \to \pi\tau\bar{\nu}_\tau)$, $\text{Br}(B^+_c \to \tau^+\nu_\tau)$, R^l_π, $R_{D^{(*)}}$ and $R_{J/\psi}$ data. Using the constrained new parameters, we estimate the branching ratios, forward–backward asymmetry, lepton-spin asymmetry and lepton non-universality observables of $\bar{B}^*_{d,s} \to P\tau\bar{\nu}_\tau$ processes. We find that the branching ratios of these decay modes are sizeable and deviate significantly (for vector-type couplings) from their corresponding standard model values, which are expected to be within the reach of Run III of Large Hadron Collider experiment.

with $R_D - R_{D^*}$ correlation of -0.38, indicate $\sim 3.08\sigma$ discrepancy with their corresponding Standard Model (SM) predictions

$$R_D^{\rm SM} = 0.299 \pm 0.003, \quad R_{D^*}^{\rm SM} = 0.258 \pm 0.005. \qquad (2)$$

The recently measured $R_{J/\psi} = \text{Br}(B_c \to J/\psi\tau\bar{\nu}_\tau)/\text{Br}(B_c \to J/\psi l\bar{\nu}_l) = 0.71 \pm 0.17 \pm 0.184$ parameter by LHCb Collaboration [11] is in the same line and has nearly 2σ deviation from its SM value $R_{J/\psi} = 0.289 \pm 0.01$ [12,13]. Similarly, in the semileptonic $B \to K^{(*)}\ell\ell$ decay processes, mediated by the neutral current transition $b \to s\ell\ell$, 2.6σ and $(2.2-2.4)\sigma$ deviations have been observed in the measured values of $R_K = \text{Br}(B^+ \to K^+\mu^+\mu^-)/\text{Br}(B^+ \to K^+e^+e^-)$ [14] and $R_{K^*} = \text{Br}(\bar{B}^0 \to \bar{K}^*\mu^+\mu^-)/\text{Br}(\bar{B}^0 \to \bar{K}^*e^+e^-)$ [15] with values

$$R_K|_{q^2\in[1,6]\,\text{GeV}^2} = 0.745^{+0.090}_{-0.074} \pm 0.036,$$
$$R_{K^*}|_{q^2\in[0.045,1.1]\,\text{GeV}^2} = 0.66^{+0.11}_{-0.07} \pm 0.03,$$
$$R_{K^*}|_{q^2\in[1.1,6]\,\text{GeV}^2} = 0.69^{+0.11}_{-0.07} \pm 0.05, \qquad (3)$$

Table 2 Values of the observables used in the fitting

Observables	Experimental value	SM prediction
R_D	$0.340 \pm 0.027 \pm 0.013$	0.299 ± 0.003
R_{D^*}	$0.295 \pm 0.011 \pm 0.008$	0.258 ± 0.005
$R_{J/\psi}$	0.71 ± 0.251	0.289 ± 0.01
$\text{Br}(B_c \to \tau\nu)$	$< 30\%$	$(3.6 \pm 0.14) \times 10^{-2}$
R^l_π	0.699 ± 0.156	0.583 ± 0.055
$\text{Br}(B_u \to \tau\nu)$	$(1.09 \pm 0.24) \times 10^{-4}$	$(8.48 \pm 0.5) \times 10^{-5}$
$\text{Br}(B^0 \to \pi^+\tau\nu)$	$< 2.5 \times 10^{-4}$	$(9.40 \pm 0.75) \times 10^{-5}$

$$R^l_\pi = \frac{\tau_{B^0}}{\tau_{B^-}}(\text{Br}(B^- \to \tau^-\bar{\nu}_\tau)/\text{Br}(B^0 \to \pi^+ l^-\bar{\nu}_l))$$

Decay modes	New coefficients	Best-fit
$b \to c\tau\bar{\nu}_\tau$	$(\text{Re}[V_L], \text{Im}[V_L])$	$(-1.233, 1.045)$
	$(\text{Re}[V_R], \text{Im}[V_R])$	$(-0.0034, -0.3783)$
	$(\text{Re}[S_L], \text{Im}[S_L])$	$(0.097, 0)$
	$(\text{Re}[S_R], \text{Im}[S_R])$	$(-0.695, -0.777)$
$b \to u\tau\bar{\nu}_\tau$	$(\text{Re}[V_L], \text{Im}[V_L])$	$(-0.915, 1.108)$
	$(\text{Re}[V_R], \text{Im}[V_R])$	$(-0.116, 0)$
	$(\text{Re}[S_L], \text{Im}[S_L])$	$(-0.024, 0)$
	$(\text{Re}[S_R], \text{Im}[S_R])$	$(-0.439, 0.005)$

三、研究方法

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R. Dutta, *Exploring R_D, R_{D^*} and $R_{J/\psi}$ anomalies.* arXiv:1710.00351 [hep-ph]

Exploring R_D, R_{D^*} and $R_{J/\psi}$ anomalies

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Deviations from the standard model predictions have been reported in various observables concerned with the lepton flavor universality. At present, the deviation of the measured values of R_D and R_{D^*} from the standard model expectation is exceeded by 2.3σ and 3.4σ, respectively. Very recently LHCb has measured the ratio of branching ratio $R_{J/\Psi} = \mathcal{B}(B_c \to J/\Psi\tau\nu)/\mathcal{B}(B_c \to J/\Psi\, l\,\nu)$, where $l \in (e, \mu)$, to be $0.71 \pm 0.17 \pm 0.18$ which is at more than 2σ away from the standard model prediction. We investigate the anomalies in R_D, R_{D^*}, and $R_{J/\psi}$ using a model independent framework with minimal number of new physics couplings. We find various new physics models that can explain these anomalies within 1σ.

PACS numbers: 14.40.Nd, 13.20.He, 13.20.-v

I. INTRODUCTION

Lepton flavor universality violation has been the center of attention due to the long standing anomalies that persisted in the ratio of branching ratios R_D and R_{D^*}, where

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}l\nu)}, \qquad l \in (e, \mu). \tag{1}$$

Unlike the individual branching ratio of these decay modes, R_D and R_{D^*} do not suffer from the uncertainties coming from the Cabbibo-Kobayashi-Mashakawa (CKM) matrix elements and the meson to meson form factors. The dependency on the CKM matrix elements exactly cancels in these ratios. Similarly, the uncertainties due to the form factors also largely cancel in these ratios and a clean prediction of R_D and R_{D^*} can be made within the standard model (SM). Hence, any deviation from the SM prediction would clearly indicate the presence of new physics (NP). At present, combining the results of R_D and R_{D^*} measured by various experiments such as BABAR [1, 2], BELLE [3–5], and LHCb [6, 7], i.e, $R_D = 0.407 \pm 0.039 \pm 0.024$ and $R_{D^*} = 0.304 \pm 0.013 \pm 0.007$ exceed the SM predictions by 2.3σ and 3.4σ, respectively. Again, including the $R_D - R_{D^*}$ correlation, the discrepancy with SM prediction [8–12] currently stands at about 4.1σ [13]. Recently, LHCb [14, 15] has measured the value of the ratio of branching ratio

- We include a total of three measurements for the evaluation of χ^2, namely, R_D, R_{D^*} **and** $R_{J/\psi}$. We have not included $P_\tau^{D^*}$ in our fit as the error associated with it is rather large.

Coefficients	Best fit value	R_D
SM		0.334
V_L	−2.11	0.398
V_R	−0.09	0.276
S_L	−1.51	0.365
S_R	0.31	0.427
$\widetilde{V}_L$	0.48	0.398
$\widetilde{V}_R$	0.48	0.398
$\widetilde{S}_L$	0.73	0.432
$\widetilde{S}_R$	0.73	0.432
T_L	−0.08	0.309
$\widetilde{T}_L$	0.27	0.352

三、研究方法

S. Sahoo, R. Mohanta, *Investigating the role of new physics in $b \to c\,\tau\bar{\upsilon}_\tau$ transitions*. arXiv:1910.09269 [hep-ph]

Investigating the role of new physics in $b \to c\tau\bar{\nu}_\tau$ transitions

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Abstract

In recent times, the charged-current mediated semileptonic $b \to c\tau\bar{\nu}_\tau$ processes have attracted a lot of attention after the observation of lepton non-universality ratios, $R_{D^{(*)}}$, $R_{J/\psi}$ and the measurements on D^* and τ longitudinal polarization fractions in $\bar{B} \to D^*\tau\bar{\nu}_\tau$ processes. We present a model-independent analysis of $\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau$, $B_s \to D_s^{(*)}\tau\bar{\nu}_\tau$, $B_c^+ \to (\eta_c, J/\psi)\tau^+\nu_\tau$, $\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau$ and $\bar{B} \to D^{**}\tau\bar{\nu}_\tau$ (where $D^{**} = \{D_0^*, D_1^*, D_1, D_2^*\}$ are the four lightest excited charm mesons) processes involving $b \to c\tau\bar{\nu}$ quark level transitions by considering the most general effective Lagrangian in the presence of new physics. We perform a global fit to various set of new coefficients, including the measurements on $R_{D^{(*)}}$, $R_{J/\psi}$ and the upper limit on $\mathrm{Br}(B_c^+ \to \tau^+\bar{\nu}_\tau)$. We then show the implications of constrained new couplings on the branching fractions, lepton non-universality ratios and various angular observables of these decay modes in four different bins of q^2.

Cases	New Wilson coefficients	Best-fit values	$\chi^2_{\rm min}$/d.o.f	Pull
Case A	V_L	-2.07	0.767	2.982
	V_R	-0.0434	2.91	1.57
	S_L	0.097	2.81	1.663
	S_R	-1.443	3.319	1.112
	T	-0.0263	1.6	2.527
Case B	$(\mathrm{Re}[V_L], \mathrm{Im}[V_L])$	$(-1.233, 1.045)$	1.151	2.982
	$(\mathrm{Re}[V_R], \mathrm{Im}[V_R])$	$(-0.0034, -0.3783)$	1.145	2.984
	$(\mathrm{Re}[S_L], \mathrm{Im}[S_L])$	$(0.97, 0)$	4.213	1.663
	$(\mathrm{Re}[S_R], \mathrm{Im}[S_R])$	$(-0.695, -0.777)$	2.175	2.616
	$(\mathrm{Re}[T], \mathrm{Im}[T])$	$(0.0886, -0.17)$	1.416	2.892
Case C	(V_L, V_R)	$(0.0694, -0.0026)$	1.147	2.983
	(V_L, S_L)	$(0.0714, -0.0063)$	1.147	2.983
	(V_L, S_R)	$(0.0724, -0.0086)$	1.145	2.984
	(V_L, T)	$(-0.194, 0.3913)$	2.42	2.52
	(V_R, S_L)	$(-0.09, 0.1726)$	1.167	2.976
	(V_R, S_R)	$(-0.072, 0.154)$	1.15	2.96
	(V_R, T)	$(0.091, -0.0519)$	1.02	3.02
	(S_L, S_R)	$(-1.04, -0.449)$	2.72	2.4
	(S_L, T)	$(-1.25, 0.303)$	1.989	2.686
	(S_R, T)	$(-1.1875, 0.352)$	2.23	2.596

NP scenarios 分为三类

- **Case *A*:** consider **one real** Wilson coefficient V_L , V_R , S_L and S_R at a time,

  $V_L = -2.11$,

  $V_R = -0.09$,

  $S_L = -1.51$ and

  $S_R = 0.31$.

  We marked them as BMP1, BMP2, BMP3 and BMP4, respectively.

- **Case *B*:** consider **one complex** Wilson coefficient V_L , V_R , S_L and S_R at a time,

  $(Re[V_L], Im[V_L]) = (-1.233, 1.045)$,

  $(Re[V_R], Im[V_R]) = (-0.0034, -0.3783)$,

  $(Re[S_L], Im[S_L]) = (0.097, 0)$ and

  $(Re[S_R], Im[S_R]) = (-0.695, -0.777)$.

  We marked them as BMP5, BMP6, BMP7 and BMP8, respectively

- **Case C**: consider various combinations of **two real** Wilson coefficients at a time, namely

  (V_L, V_R)=(0.0694,- 0.0026),

  (V_L, S_L)=(0.0714,-0.0063),

  (V_L, S_R)=(0.0724,- 0.0086),

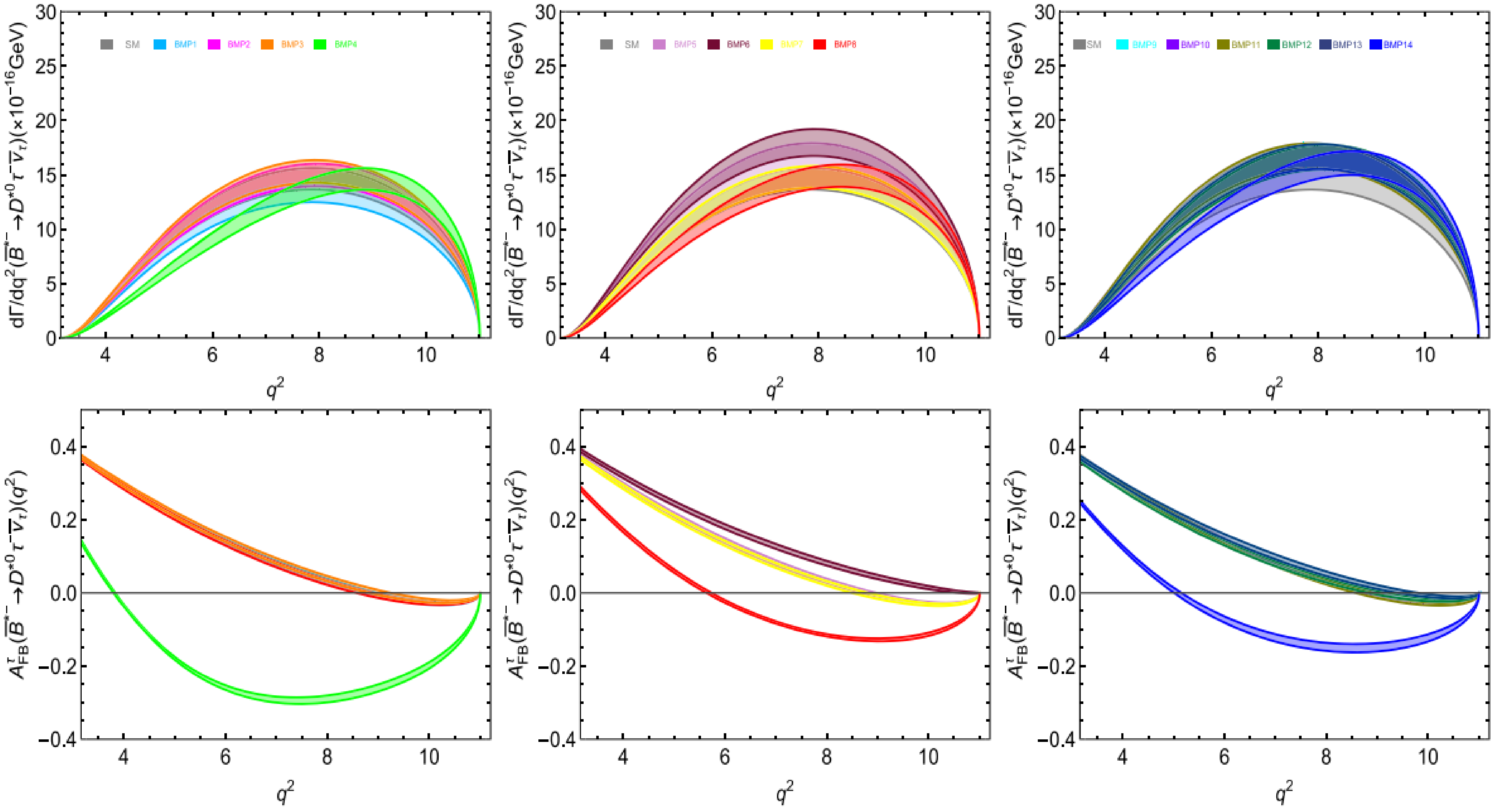
  (V_R, S_L)=(-0.09,0.1726),

  (V_R, S_R)=(-0.072, 0.154), and

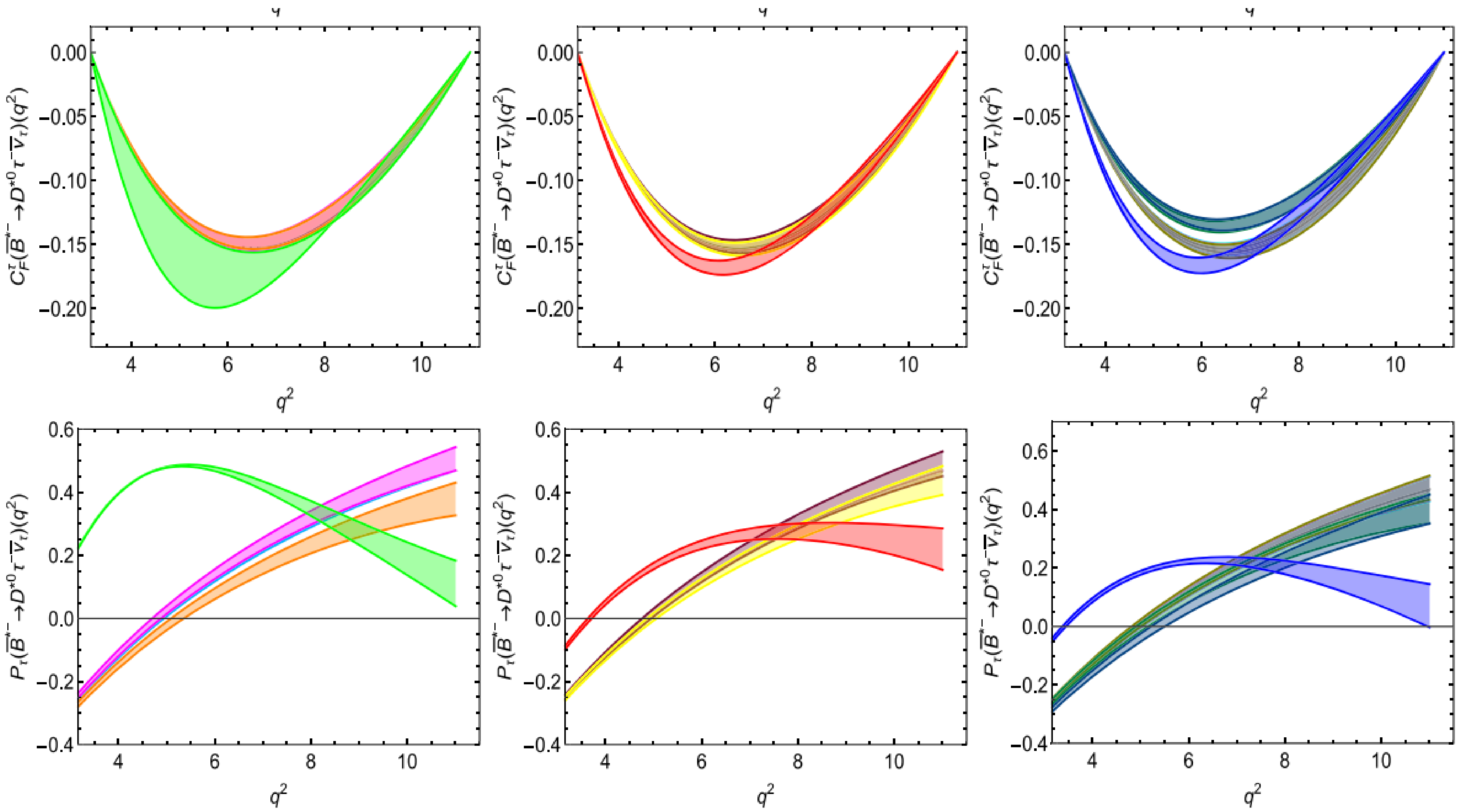
  (S_L, S_R)=(-1.04,-0.449).

  We marked them as BMP9-BMP14.

四、研究结果


SM BMP1 BMP2 BMP3 BMP4
SM BMP5 BMP6 BMP7 BMP8
SM BMP9 BMP10 BMP11 BMP12 BMP13 BMP14
$d\Gamma/dq^2(\overline{B}^{*-}\to D^{*0}\tau^-\overline{\nu}_\tau)(\times 10^{-16}\mathrm{GeV})$
$A_{FB}^{\tau}(\overline{B}^{*-}\to D^{*0}\tau^-\overline{\nu}_\tau)(q^2)$
q^2

四、研究结果


$C_F^\tau(\overline{B}^{*-} \to D^{*0}\tau^-\overline{\nu}_\tau)(q^2)$
$P_\tau(\overline{B}^{*-} \to D^{*0}\tau^-\overline{\nu}_\tau)(q^2)$
q^2
0.00
−0.05
−0.10
−0.15
−0.20
0.6
0.4
0.2
0.0
−0.2
−0.4
4
6
8
10

四、研究结果

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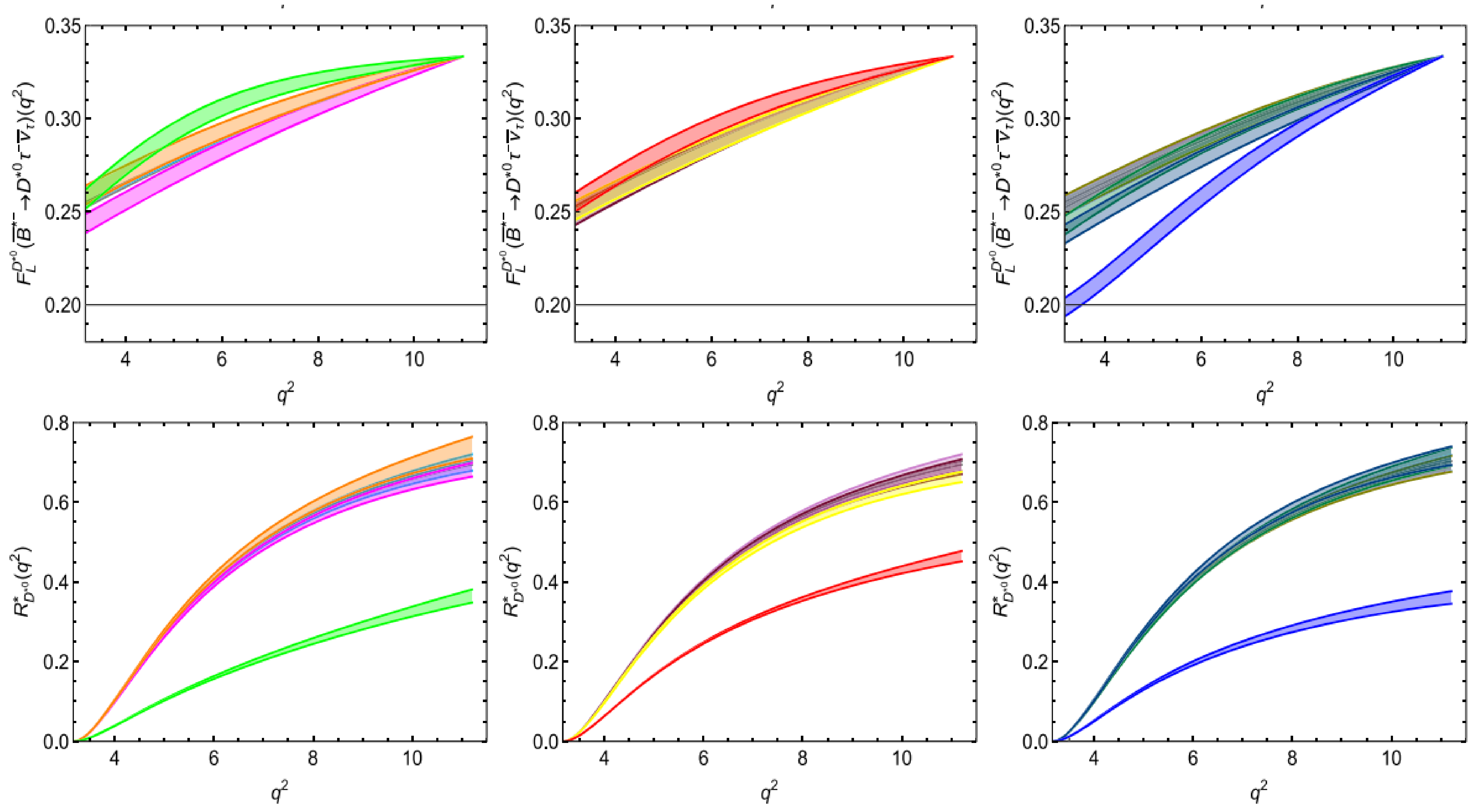

Eur. Phys. J. C (2022) 82:768
https://doi.org/10.1140/epjc/s10052-022-10728-9

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

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Phenomenology analysis of $\bar{B}^* \to V\tau^-\bar{\nu}_\tau$ de... the Standard Model

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Received: 1 April 2022 / Accepted: 18 August 2022

Abstract Motivated by the persistent anomalies reported in the $b \to c\tau\bar{\nu}$ data, we investigate the semileptonic decays $\bar{B}^* \to V\tau^-\bar{\nu}_\tau (V = D^*_{u,d,s}, J/\psi)$, within the Standard Model and beyond. The relevant transition form factors, being calculated in the covariant light-front quark model, is the main source of theoretical uncertainties. Using various best-fit solutions for the new operator Wilson coefficients, we report numerical results on various observables related to the processes $\bar{B}^* \to V\tau^-\bar{\nu}_\tau$, such as the branching ratios, the

1 Introduc...

The searchi... has been or... energy phys... is a key property of the SM gauge interactions. Evidence for violation of the property would be a clear sign of new physics (NP) beyond the SM. In the searching of NP, the second and third generation quarks and leptons are very important

- 作者使用了模型无关的方法对$\bar{B}^* \to V\tau^-\bar{\nu}_\tau$半轻衰变过程中新物理效应研究。
- 对于新物理方案选取，作者依次选取了新物理参数只有一个且为实数（case A）、新物理参数只有一个且为复数（case B）、新物理参数有两个且为实数（case C）等三种类型共14种不同的方案。
- 研究结果表明在新物理的作用下，$d\Gamma/dq^2, \Gamma, R_V^{*(L)}, A_{FB}^l, P_l, F_L^{*V}, F_T^{*V}$等物理可观测量中的新物理贡献不可忽略。

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