Transverse polarization asymmetry of $B \to \rho\tau^+\tau^-$ decay in non-universal Z' model

P. Nayek[1] and S. Sahoo[2]
Department of Physics, National Institute of Technology,
Durgapur-713209, West Bengal, India
[1]*E-mail: mom.nayek@gmail.com* [2]*E-mail: sukadevsahoo@yahoo.com*

Introduction

Exclusive B decays based on $b \to s(d)$ transition provide useful information about the various parameters in the standard model (SM) and have received special attention. Although there exists a lot of precise results on $b \to sl^+l^-$ induced processes, there is lack of sufficient data for $b \to dl^+l^-$ induced decays. From experimental evidences it is found that the semileptonic B decays having quark level transition $b \to d$ are more challenging than $b \to s$ because of small branching ratio $\mathcal{O}(10^{-8})$ and large CP asymmetry. It is also found that the leading order contribution for $b \to d$ transition is smaller compared to that of the transition $b \to s$. B meson decays induced by $b \to d$ flavour changing neutral current (FCNC) transitions play a significant role to study the quark-flavour sector of the SM and also to search new physics (NP). To the best of our knowledge, the decay mode $B \to \rho\tau^+\tau^-$ has not been studied experimentally so far. In this work, we study the transverse polarization asymmetry $P_T(\hat{s})$ theoretically of the decay mode $B \to \rho\tau^+\tau^-$ which proceeds via $b \to d$ transition at the quark level in non-universal Z' model. Non-universal Z' model is one of the most important theoretically constructed NP model beyond the SM [1-4].

Standard model contribution

In the SM, the effective Hamiltonian for the transition $b \to dl^+l^-$ is expressed as [5]

$$H_{eff} = -\frac{4G_F\alpha}{\sqrt{2}} V_{tb}V_{td}^* [\sum_{i=1}^{10} C_i O_i - \lambda_u\{C_1|O_1^u - O_1| + C_2|O_2^u - O_2|\}], \quad (1)$$

where $\lambda_u = \frac{V_{ub}V_{ud}^*}{V_{tb}V_{td}^*}$. O_1 and O_2 are the current operators, $O_3 \ldots\ldots O_6$ are QCD penguin operators and O_9, O_{10} are semileptonic electroweak penguin operators, G_F is Fermi coupling constant. Now from eqn. (1) the QCD corrected matrix element can be written as

$$\mathcal{M} = \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{td}^* \left\{-2C_7^{eff}\frac{m_b}{q^2}\left(\bar{d}i\sigma_{\mu\upsilon}q^\upsilon P_R b\right) \times \left(\bar{l}\gamma^\mu l\right) + C_9^{eff}\left(\bar{d}\gamma_\mu P_L b\right)\left(\bar{l}\gamma^\mu l\right) + C_{10}\left(\bar{d}\gamma_\mu P_L b\right)\left(\bar{l}\gamma^\mu\gamma^5 l\right)\right\}, \quad (2)$$

where $C_7^{eff} = -0.315$, $C_{10} = -4.642$ and $C_9^{SM} = 4.227$. Now the matrix element of the decay $B \to \rho l^+l^-$ in terms of form factors can be represented as follows [6]

$$\mathcal{M}^{B\to\rho} = \left[i \in_{\mu\nu\alpha\beta} \epsilon^{\nu^*} p_B^\beta q^\beta A + \epsilon_\mu^* B + (\epsilon^* q)(p_B)_\mu C\right]\left(\bar{l}\gamma^\mu l\right) + \left[i \in_{\mu\nu\alpha\beta} \epsilon^{\nu^*} p_B^\alpha q^\beta D + \epsilon_\mu^* E + (\epsilon^* q)(p_B)_\mu F\right]\left(\bar{l}\gamma^\mu l\right) + H(\epsilon^* q)\left(\bar{l}\gamma_5 l\right). \quad (3)$$

In the above expression A, B, C, D, E, F and H are taken from [6] and they are represented in terms of form factors given in [7]. Now from the above matrix element the transverse polarization asymmetry $P_T(\hat{s})$ can be written as

$$P_T = \lambda^{1/2}\left(1, \hat{s}, \hat{m}_\rho{}^2\right)\sqrt{\hat{s}}\hat{m}_l\pi\left[-4Re(A^*B) + \frac{1}{4\hat{m}_\rho{}^2\hat{s}}\left\{2\left(2\left(1-\hat{m}_\rho{}^2-\hat{s}\right)Re(B^*E) + m_B{}^2\right)\lambda\left(1, \hat{s}, \hat{m}_\rho{}^2\right)Re(C^*E)\right\}\right]. \quad (4)$$

Contribution from FCNC mediated Z' boson

Now we discuss the effect of FCNC mediated Z' boson on the transverse polarization asymmetry of the semileptonic decay channel $B \to \rho\tau^+\tau^-$. In non-universal Z' model, FCNC transition for $b \to dl^+l^-$ process can occur at the tree level due to the presence of non-diagonal chiral coupling matrix. The detail analysis of this model is discussed in [2]. The contributions of Z' boson on the current operators, semileptonic electroweak penguin operators and QCD penguin operators remain same as that of the SM. By neglecting $Z - Z'$ mixing and considering the couplings of only right handed quarks with Z' are diagonal [8, 9], we can write the new modified Z' part of effective Hamiltonian for the transition $b \to dl^+l^-$ as

$$H_{eff}^{Z'} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{td}^* \left[\Lambda_{db}\, C_9^{Z'} O_9 + \Lambda_{db}\, C_{10}^{Z'} O_{10}\right] \quad (5)$$

where, $$\Lambda_{db} = \frac{4\pi e^{-i\varphi_{db}}}{\alpha V_{tb} V_{td}^*}, \quad (6)$$

$B_{db}^L = |B_{db}^L| e^{-i\varphi_{db}}$ indicates the off-diagonal left handed couplings of quark sector with Z' boson and φ_{db} is the new weak phase. Now the total contributions on Wilson coefficients C_9 and C_{10} can be written as

$$C_9^{Total} = C_9^{eff} + \Lambda_{db}\, C_9^{Z'} \quad (8)$$

$$C_{10}^{Total} = C_{10} + \Lambda_{db}\, C_{10}^{Z'}. \quad (9)$$

Results and Discussions

The values of coupling parameter $|B_{db}|$ and the weak phase φ_{db} are taken from [10, 11] and encapsulated in Table-1 for two different scenarios S_1 and S_2. The numerical values of all input parameters are taken from [6, 12].

Table-1. Numerical values of Z' coupling parameters and weak phase

Scenarios	$B_{db} \times 10^{-3}$	φ_{db} in Degree
S_1	0.16 ± 0.08	-33 ± 45
S_2	0.12 ± 0.03	-23 ± 21

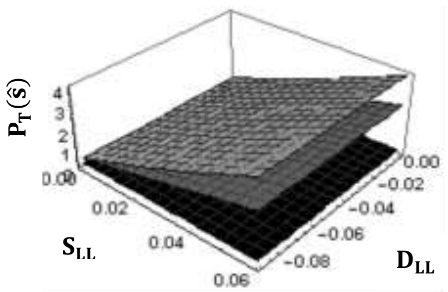

Fig. 1. The dependence of $P_T(\hat{s})$ on coupling parameters S_{LL} and D_{LL} for $B \to \rho\tau^+\tau^-$ in SM (black plate), scenario-1 (dark gray plate) and scenario-2 (light gray plate).

In Fig. 1 we find that for $\hat{s} = 0.7$, $P_T(\hat{s})$ increases with the increase of coupling parameters S_{LL} and D_{LL} in $B \to \rho\tau^+\tau^-$ decay. This variation is significantly large for S_2 than S_1. This deviation of $P_T(\hat{s})$ from the SM value provides a clue for NP.

Acknowledgments

P. Nayek and S. Sahoo would like to thank SERB, DST, Govt. of India for financial support through grant no. EMR/2015/000817.

Reference

1. A. Leike, Phys. Rep. **317**, 143 (1999).
2. P. Langacker and M. Plümacher, Phys. Rev. D **62**, 013006 (2000).
3. S. Sahoo, Indian J. Phys. **80**, 191 (2006).
4. P. Langacker, *Rev. Mod. Phys.*, **81**, 1199 (2009) [arXiv:0801.1345 [hep-ph]].
5. G. Buchalla, A. Buras and M. Lautenbacher, Rev. Mod. Phys. **68**, 1125 (1996) [arXiv: hep-ph/9512380].
6. S. Rai Choudhury and N. Gaur, Phys. Rev. D **66**, 094015 (2002).
7. P. Coleangelo, F. De. Fazio, P. Santorelli and E. Scrimieri phys. Rev. D **53**, 3672 (1996).
8. A. Arhrib, K. Chung, C-W. Chiang and T-C. Yuan, Phys. Rev. D **73**, 075015 (2006) [arXiv: hep-ph/0602175].
9. K. Cheung et al., Phys. Lett. B **652**, 285 (2007) [arXiv: hep-ph/0604223].
10. Q. Chang, X. Q. Li and Y. D. Yang, JHEP **1002**, 082 (2010) [arXiv:0907.4408].
11. Q. Chang and Y. D. Yang, Nucl. Phys. B **852**, 539 (2011) [arXiv: 1010.3181].
12. C. Patrignani et al. (Particle Data Group), Chin. Phys. C **40**, 100001 (2016).