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Probing New Physics with q^2 distributions in $\bar{B} \to D^{(*)}\tau\bar{\nu}$

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Recent studies for the decays $\bar{B} \to D^{(*)}\tau\bar{\nu}$ at the BaBar, Belle, and LHCb experiments still show the significant deviation from the Standard Model predictions. Several new physics interactions can accommodate the deviation in the results of the ratios of $\mathscr{B}(\bar{B} \to D^{(*)}\tau\bar{\nu})$ divided by $\mathscr{B}(\bar{B} \to D^{(*)}\ell\bar{\nu})$. In our study, we show that some of these interactions are disfavored by the current data of the q^2 distributions given by BaBar and the q^2 distributions have a sufficient potential to extract an evidence for new physics at the SuperKEK/Belle II experiment.

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1. Introduction

For the observables of $\bar{B} \to D^{(*)}\tau\bar{\nu}$, the ratios of the branching fractions, defined as

$$R(D^{(*)}) \equiv \frac{\mathscr{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathscr{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}\,, \tag{1.1}$$

have been introduced in order to reduce theoretical uncertainties and separate the issue for the determination of $|V_{cb}|$ from the new physics study. The Standard Model (SM) predicts those observables as

$$R(D)^{\rm SM} = 0.305 \pm 0.012\,, \quad R(D^*)^{\rm SM} = 0.252 \pm 0.004\,. \tag{1.2}$$

The experimental results have been published by the BaBar[1] and Belle[2] collaborations. Comparing the combined experimental results with the SM predictions, we can see the significant deviation more than $3\,\sigma$ as shown in Fig. 1. Indeed, the latest experimental results have been reported by the Belle and LHCb collaborations at the conference "Flavor Physics & CP Violation 2015" [3, 4] and we show the deviation in Fig. 1.

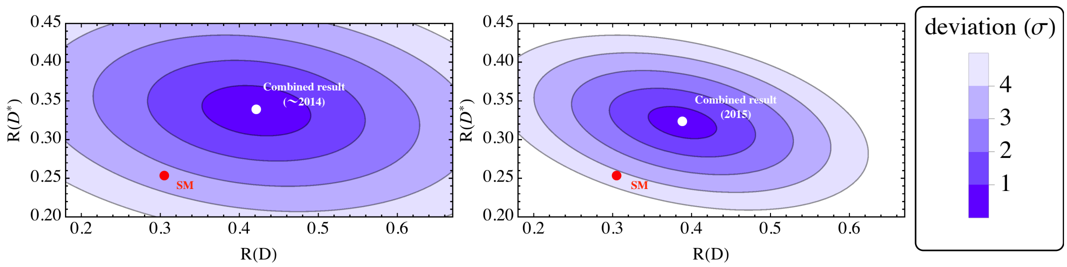

Figure 1: Standard deviations between the SM prediction and the experimental results from Refs. [1, 2] (left) and Refs. [1, 3, 4] (right).

2. Analysis with current data

In our previous work[5], we show that several new physics scenarios can explain the current experimental results (central values) of $R(D^{(*)})$ with the amount of those contributions to be

$$\begin{array}{lll} C_{V_1} = 0.16\;(0.12), & C_{X\neq V_1} = 0\,, & (V_1\text{-scenario}) \\ C_{V_2} = 0.60i\;(0.53i), & C_{X\neq V_2} = 0\,, & (V_2\text{-scenario}) \\ C_{S_2} = -1.75\;(-1.67), & C_{X\neq S_2} = 0\,, & (S_2\text{-scenario}) \\ C_T = 0.33+0.06i\;(0.27+0.15i), & C_{X\neq T} = 0\,, & (T\text{-scenario}) \\ C_{\rm LQ_1} = -0.17+0.80i\;(-0.12+0.70i), & C_{X\neq S_2,T} = 0\,, & (\text{LQ}_1\text{-scenario}) \\ C_{\rm LQ_2} = 0.34\;(0.25), & C_{X\neq S_2,T} = 0\,, & (\text{LQ}_2\text{-scenario}) \end{array} \tag{2.1}$$

where C_X denotes the Wilson coefficient for each new physics scenario defined in Ref. [5] and the value in the bracket presents the latest result obtained by using the latest combined experimental data from Refs. [1, 3, 4].

The experimental data of binned q^2 distributions are available in Ref. [1] and hence we have performed the p-value fit to the Wilson coefficient for each scenario. The result is shown in Table 1. You can see that the scalar and tensor scenarios, which can accommodate the deviation in $R(D^{(*)})$, are disfavored by the observed q^2 distribution of $\bar{B} \to D\tau\bar{\nu}$ and $\bar{B} \to D^*\tau\bar{\nu}$, respectively *only by using the current BaBar data.*

model	$\bar{B} \to D\tau\bar{\nu}$	$\bar{B} \to D^*\tau\bar{\nu}$	$\bar{B} \to (D+D^*)\tau\bar{\nu}$
SM	54%	65%	67%
V_1	54%	65%	67%
V_2	54%	65%	67%
S_2	0.02%	37%	0.1%
T	58%	0.1%	1.0%
LQ$_1$	13%	58%	25%
LQ$_2$	21%	72%	42%

Table 1: p values for the fit of the BaBar data of $d\mathscr{B}/dq^2$ with various models.

3. Discriminative potential at SuperKEK/Belle II

It is expected that the future SuperKEK/Belle II will improve the analysis for $\bar{B} \to D^{(*)}\tau\bar{\nu}$ thanks to larger amount of signal events. To extract maximum potential at the SuperKEK/Belle II, we introduce new observables for q^2 distributions defined as

$$R_D(q^2) \equiv \frac{d\mathscr{B}(\bar{B} \to D\tau\bar{\nu})/dq^2}{d\mathscr{B}(\bar{B} \to D\ell\bar{\nu})/dq^2} \frac{\lambda_D(q^2)}{(m_B^2 - m_D^2)^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}, \tag{3.1}$$

$$R_{D^*}(q^2) \equiv \frac{d\mathscr{B}(\bar{B} \to D^*\tau\bar{\nu})/dq^2}{d\mathscr{B}(\bar{B} \to D^*\ell\bar{\nu})/dq^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}, \tag{3.2}$$

where additional purely kinematic factors are given as in Ref. [5]. With use of $R_{D^{(*)}}(q^2)$, we have evaluated the luminosity required at the SuperKEK/Belle II to discriminate the simulated data with the new physics scenarios at 99.9% confidence level (CL), where the simulated data is generated by assuming the new physics contribution fixed as in Eq. (2.1).

In Table 2, we show the result of our simulation. The values in the brackets are the ones from the simulated data generated by using the Wilson coefficients in the brackets of Eq. (2.1). As seen in the table, some of new physics scenarios can be already tested by analyzing the present data of q^2 distributions. It is also found that the q^2 distributions are very useful to test SM, V_1, V_2, S_2, and T scenarios with lower luminosity costs, around $5\,\mathrm{ab}^{-1}$ expect for $V_{1,2}$-like data. To test the two LQ scenarios, we expect that higher integrated luminosity of $O(10)\,\mathrm{ab}^{-1}$ is required at the SuperKEK/Belle II. Comparison with integrated observables $R(D^{(*)})$ can be seen in Ref. [5].

4. Conclusion

Recent improvements for the analysis in $\bar{B} \to D^{(*)}\tau\bar{\nu}$ at the BaBar, Belle, and LHCb experiments still imply the deviation from the SM. To identify and, at the same time, distinguish the new physics effects from the others, it is useful to study the q^2 distributions. The discriminative

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$\mathscr{L}$ [ab^{-1}]		model						
		SM	V_1	V_2	S_2	T	LQ$_1$	LQ$_2$
"data"	V_1	1.17 (1.85)	–	10^3 (10^3)	0.50 (0.70)	0.90 (1.28)	4.14 (6,51)	2.86 (5.20)
	V_2	1.14 (1.79)	10^3 (10^3)	–	0.51 (0.72)	0.91 (1.31)	4.21 (6.67)	3.37 (6.84)
	S_2	0.56 (0.74)	0.56 (0.78)	0.54 (0.74)	–	0.38 (0.53)	1.31 (1.66)	0.73 (1.00)
	T	0.60 (0.85)	0.68 (1.00)	0.70 (1.05)	0.32 (0.45)	–	0.62 (0.93)	0.55 (0.84)
	LQ$_1$	1.01 (1.59)	4.82 (7.20)	4.65 (7.06)	1.51 (1.92)	0.80 (1.16)	–	5.91 (12.5)
	LQ$_2$	1.02 (1.65)	3.42 (5.60)	3.99 (7.31)	1.04 (1.28)	0.65 (1.00)	5.93 (12.6)	–

Table 2: Required luminosity to distinguish various simulated "data" and new physics scenarios at 99.9% CL, with assuming the best fitted value of the Wilson coefficient for generation of the simulated events.

potential at the SuperKEK/Belle II has been estimated from the simulated analysis based on the current experimental situation on $R(D^{(*)})$. The result suggests that various new physics scenarios can be tested up to at $10\,\mathrm{ab}^{-1}$ analyzing the q^2 distributions of the decays. Other distributions and asymmetries are also helpful to investigate new physics in $\bar{B} \to D^{(*)}\tau\bar{\nu}$ [6].

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