New physics effects to the lepton polarizations in the $B \to K l^+ l^-$ decay

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Using the general, model independent form of the effective Hamiltonian, the general expressions of the longitudinal, normal, and transversal polarization asymmetries for l^- and l^+ and combinations of them for the exclusive $B \to K l^+ l^-$ decay are found. The sensitivity of lepton polarizations and their combinations on new Wilson coefficients are studied. It is found that there exist regions of Wilson coefficients for which the branching ratio coincides with the standard model result while the lepton polarizations differ substantially from the standard model prediction. Hence, studying lepton polarization in these regions of new Wilson coefficients can serve as a promising tool for establishing new physics beyond the standard model.

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I. INTRODUCTION

The two B meson factories BaBar and Belle, which have already started operation, have opened an exciting new era in studying the physics of B mesons. Both factories already presented thrilling results on CP violation [1]. The physics program of the B factories contain two main directions: detailed study of CP violation in B_d decays and precise measurement of rare flavor changing neutral current (FCNC) processes. It is well known that FCNC processes are very sensitive to new physics beyond the standard model (SM). So, the main goal of the ongoing investigations at B factories is to find inconsistencies within the SM, in particular, to find indications of new physics in the flavor and CP violating sectors [2]. New physics effects can appear in rare B meson decays in two different ways: either through new contributions to the Wilson coefficients existing in the SM, or through new structures in the effective Hamiltonian which are absent in the SM. Rare B meson decays induced by the $b \to s(d) l^+ l^-$ transition were extensively studied in the framework of the SM and its various extensions [3–19]. One of the efficient ways to establish new physics beyond the SM is the measurement of the lepton polarization [19–26]. All previous studies of the lepton polarization were limited to the SM and its minimal extensions, except in Refs. [23,26]. In Ref. [23] an analysis of the τ lepton polarization for the inclusive $b \to s \tau^+ \tau^-$ decay was presented in a model independent way, and in Ref. [26] lepton polarizations were investigated using the most general model independent Hamiltonian for the $B \to K^* l^+ l^-$ decay.

The aim of this work is to study lepton polarizations in the exclusive $B \to K l^+ l^-$ decay using the general form of the effective Hamiltonian including all possible forms of interactions. Here we will study μ and τ leptonic modes for the following two reasons. First, electron polarization is hard to measure experimentally, and second, it is well known that in the SM the normal P_N and transversal P_T polarizations are both proportional to the lepton mass and hence it might be possible to measure them, especially in the $\tau^- \tau^+$ channel.

This work is organized as follows. In Sec. II, using a general form of four-Fermi interaction, we derive general expressions for the longitudinal, transversal, and normal polarizations of leptons. In Sec. III we investigate the sensitivity of the above-mentioned polarizations to the new Wilson coefficients. At the end of this section we also present our conclusions.

II. CALCULATION OF LEPTON POLARIZATIONS

In this section we compute the lepton polarization asymmetries, using the most general, model independent form of the effective Hamiltonian. The effective Hamiltonian for the $b \to s l^+ l^-$ transition in terms of 12 model independent four-Fermi interactions can be written in the form

$$\begin{aligned}
\mathcal{H}_{eff} = \frac{G_F \alpha}{\sqrt{2}\pi} V_{ts} V_{tb}^* \Bigg\{ & C_{SL} \bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} L b \bar{l} \gamma^\mu l \\
& + C_{BR} \bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} R b \bar{l} \gamma^\mu l + C_{LL}^{tot} \bar{s}_L \gamma_\mu b_L \bar{l}_L \gamma^\mu l_L \\
& + C_{LR}^{tot} \bar{s}_L \gamma_\mu b_L \bar{l}_R \gamma^\mu l_R + C_{RL} \bar{s}_R \gamma_\mu b_R \bar{l}_L \gamma^\mu l_L \\
& + C_{RR} \bar{s}_R \gamma_\mu b_R \bar{l}_R \gamma^\mu l_R + C_{LRLR} \bar{s}_L b_R \bar{l}_L l_R \\
& + C_{RLLR} \bar{s}_R b_L \bar{l}_L l_R + C_{LRRL} \bar{s}_L b_R \bar{l}_R l_L + C_{RLRL} \bar{s}_R b_L \bar{l}_R l_L \\
& + C_T \bar{s} \sigma_{\mu\nu} b \bar{l} \sigma^{\mu\nu} l + i C_{TE} \epsilon^{\mu\nu\alpha\beta} \bar{s} \sigma_{\mu\nu} b \bar{l} \sigma_{\alpha\beta} l \Bigg\}, \qquad (1)
\end{aligned}$$

where the chiral projection operators L and R in Eq. (1) are defined as

$$L = \frac{1-\gamma_5}{2}, \quad R = \frac{1+\gamma_5}{2};$$

C_X are the coefficients of the four-Fermi interactions, and $q = p_B - p_K$ is the momentum transfer. Note that among 12 Wilson coefficients several already exist in the SM. The coefficients C_{SL} and C_{BR} correspond to $-2 m_s C_7^{eff}$ and $-2 m_b C_7^{eff}$ in the SM, respectively. The next four terms in

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Eq. (1) are vector type interactions with coefficients C_{LL}^{tot}, C_{LR}^{tot}, C_{RL}, and C_{RR}. Two of these vector interactions containing C_{LL}^{tot} and C_{LR}^{tot} also exist in the SM in the form $(C_9^{eff}-C_{10})$ and $(C_9^{eff}+C_{10})$. Therefore we can say that C_{LL}^{tot} and C_{LR}^{tot} describe the sum of the contributions from the SM and the new physics, and they can be written as

$$C_{LL}^{tot}=C_9^{eff}-C_{10}+C_{LL},$$

$$C_{LR}^{tot}=C_9^{eff}+C_{10}+C_{LR}.$$

The terms with coefficients C_{LRLR}, C_{RLLR}, C_{LRRL}, and C_{RLRL} describe scalar-type interactions. The last two terms, with the coefficients C_T and C_{TE}, obviously describe tensor-type interactions.

Exclusive $B\to Kl^+l^-$ decay is described by the matrix element of an effective Hamiltonian over B and K meson states, which can be parametrized in terms of form factors. It follows from Eq. (1) that in order to calculate the amplitude of the $B\to Kl^+l^-$ decay, the following matrix elements are needed:

$$\langle K|\bar{s}\gamma_\mu b|B\rangle,$$

$$\langle K|\bar{s}i\sigma_{\mu\nu}q^\nu b|B\rangle,$$

$$\langle K|\bar{s}b|B\rangle,$$

$$\langle K|\bar{s}\sigma_{\mu\nu}b|B\rangle.$$

These matrix elements are defined as

$$\langle K(p_K)|\bar{s}\gamma_\mu b|B(p_B)\rangle=f_+\left[(p_B+p_K)_\mu-\frac{m_B^2-m_K^2}{q^2}q_\mu\right]+f_0\frac{m_B^2-m_K^2}{q^2}q_\mu, \qquad (2)$$

with $f_+(0)=f_0(0)$:

$$\langle K(p_K)|\bar{s}\sigma_{\mu\nu}b|B(p_B)\rangle=-i\frac{f_T}{m_B+m_K}[(p_B+p_K)_\mu q_\nu-q_\mu(p_B+p_K)_\nu]. \qquad (3)$$

The matrix elements $\langle K(p_K)|\bar{s}i\sigma_{\mu\nu}q^\nu b|B(p_B)\rangle$ and $\langle K|\bar{s}b|B\rangle$ can be calculated by contracting both sides of Eqs. (2) and (3) with q^μ, and using the equation of motion we obtain

$$\langle K(p_K)|\bar{s}b|B(p_B)\rangle=f_0\frac{m_B^2-m_K^2}{m_b-m_s}, \qquad (4)$$

$$\langle K(p_K)|\bar{s}i\sigma_{\mu\nu}q^\nu b|B(p_B)\rangle=\frac{f_T}{m_B+m_K}[(p_B+p_K)_\mu q^2-q_\mu(m_B^2-m_K^2)]. \qquad (5)$$

Taking Eqs. (1)–(4) into account, the matrix element of the $B\to Kl^+l^-$ decay can be written as

$$\begin{aligned}\mathcal{M}(B\to Kl^+l^-)&=\frac{G_F\alpha}{4\sqrt{2}\pi}V_{tb}V_{ts}^*\{\bar{l}\gamma^\mu l[A(p_B+p_K)_\mu+Bq_\mu]\\&+\bar{l}\gamma^\mu\gamma_5 l[C(p_B+p_K)_\mu+Dq_\mu]+\bar{l}lQ+\bar{l}\gamma_5 lN\\&+4\bar{l}\sigma^{\mu\nu}l(-iG)[(p_B+p_K)_\mu q_\nu-(p_B+p_K)_\nu q_\mu]\\&+4\bar{l}\sigma^{\alpha\beta}l\epsilon_{\mu\nu\alpha\beta}H[(p_B+p_K)_\mu q_\nu-(p_B+p_K)_\nu q_\mu]\}.\end{aligned} \qquad (6)$$

The auxiliary functions above are defined as

$$\begin{aligned}A&=(C_{LL}^{tot}+C_{LR}^{tot}+C_{RL}+C_{RR})f_++2(C_{BR}+C_{SL})\frac{f_T}{m_B+m_K},\\B&=(C_{LL}^{tot}+C_{LR}^{tot}+C_{RL}+C_{RR})f_--2(C_{BR}+C_{SL})\\&\quad\times\frac{f_T}{(m_B+m_K)q^2}(m_B^2-m_K^2),\\C&=(C_{LR}^{tot}+C_{RR}-C_{LL}^{tot}-C_{RL})f_+,\\D&=(C_{LR}^{tot}+C_{RR}-C_{LL}^{tot}-C_{RL})f_-,\\Q&=f_0\frac{m_B^2-m_K^2}{m_b-m_s}(C_{LRLR}+C_{RLLR}+C_{LRRL}+C_{RLRL}),\\N&=f_0\frac{m_B^2-m_K^2}{m_b-m_s}(C_{LRLR}+C_{RLLR}-C_{LRRL}-C_{RLRL}),\\G&=\frac{C_T}{m_B+m_K}f_T,\\H&=\frac{C_{TE}}{m_B+m_K}f_T,\end{aligned} \qquad (7)$$

where

$$f_-=(f_0-f_+)\frac{m_B^2-m_K^2}{q^2}.$$

It follows immediately from Eq. (6) that the difference from the SM is due to the last four terms only, namely, scalar- and tensor-type interactions. In other words, the SM result for the matrix element of the $B\to Kl^+l^-$ decay can be obtained from Eq. (6) by making the following replacement: $Q=N=G=H=0$; in the expressions for A, B, C, and D [see Eq. (7)] we take $C_{LL}=C_{LR}=C_{RL}=C_{RR}=0$. Using Eq. (6) we next calculate the final lepton polarizations for the $B\to Kl^+l^-$ decay. For this purpose we define the orthogonal unit vector $S_L^{-\mu}$ in the rest frame of l^-, and the unit $S_L^{+\mu}$ in the rest frame of l^+, for the polarization of leptons along the longitudinal (L), transversal (T), and normal (N) directions:

$$S_L^{-\mu}\equiv(0,\vec{e}_L^{\,-})=\left(0,\frac{\vec{p}_-}{|\vec{p}_-|}\right),$$

$$S_N^{-\mu}\equiv(0,\vec{e}_N^{\,-})=\left(0,\frac{\vec{p}_K\times\vec{p}_-}{|\vec{p}_K\times\vec{p}_-|}\right),$$

$$S_T^{-\mu}\equiv(0,\vec{e}_T^{\,-})=(0,\vec{e}_N^{\,-}\times\vec{e}_L^{\,-}),$$

$$S_L^{+\mu}\equiv(0,\vec{e}_L^{\,+})=\left(0,\frac{\vec{p}_+}{|\vec{p}_+|}\right),$$

$$S_N^{+\mu}\equiv(0,\vec{e}_N^{\,+})=\left(0,\frac{\vec{p}_K\times\vec{p}_+}{|\vec{p}_K\times\vec{p}_+|}\right),$$

$$S_T^{+\mu}\equiv(0,\vec{e}_T^{\,+})=(0,\vec{e}_N^{\,+}\times\vec{e}_L^{\,+}), \tag{8}$$

where $\vec{p}_\mp$ and $\vec{p}_K$ are the three momenta of $l^\mp$ and K meson in the center of mass (c.m.) frame of the l^+l^- system, respectively. The longitudinal unit vectors S_L^- and S_L^+ are boosted to the c.m. frame of l^+l^- by Lorentz transformations,

$$S_{L,CM}^{-\mu}=\left(\frac{|\vec{p}_-|}{m_l},\frac{E_l\vec{p}_-}{m_l|\vec{p}_-|}\right),$$

$$S_{L,CM}^{+\mu}=\left(\frac{|\vec{p}_-|}{m_l},-\frac{E_l\vec{p}_-}{m_l|\vec{p}_-|}\right), \tag{9}$$

while vectors $\vec{S}_N$ and $\vec{S}_T$ are not changed by the boost.

The differential decay rate of the $B\to Kl^+l^-$ decay for any spin direction $\vec{n}^{(\mp)}$ of the $l^{(\mp)}$, where $\vec{n}^{(\mp)}$ is the unit vector in the $l^{(\mp)}$ rest frame, can be written as

$$\frac{d\Gamma(\vec{n}^{(\mp)})}{dq^2}=\frac{1}{2}\left(\frac{d\Gamma}{dq^2}\right)_0[1+(P_L^{(\mp)}\vec{e}_L^{(\mp)}+P_N^{(\mp)}\vec{e}_N^{(\mp)}+P_T^{(\mp)}\vec{e}_T^{(\mp)})\cdot\vec{n}^{(\mp)}], \tag{10}$$

where $(d\Gamma/dq^2)_0$ corresponds to the unpolarized differential decay rate, and P_L, P_N, and P_T represent the longitudinal, normal, and transversal polarizations, respectively. The expression for the unpolarized differential decay rate in Eq. (10) is

$$\left(\frac{d\Gamma}{dq^2}\right)_0=\frac{G_F^2\alpha^2}{2^{14}\pi^5 m_B}|V_{tb}V_{ts}^*|^2\lambda^{1/2}(1,r,s)v\Delta, \tag{11}$$

where $\lambda(1,r,s)=1+r^2+s^2-2r-2s-2rs$, $s=q^2/m_B^2$, $r=m_K^2/m_B^2$, and $v=\sqrt{1-4m_l^2/q^2}$ is the lepton velocity. The explicit form of Δ is

$$\begin{aligned}\Delta={}&-128\lambda m_B^4 m_l\,\mathrm{Re}(AG^*)+32m_B^2m_l^2(1-r)\,\mathrm{Re}(CD^*)\\&+16m_B^2m_l(1-r)\mathrm{Re}(CN^*)+16m_B^2m_l^2s|D|^2+4m_B^2s|N|^2\\&+16m_B^2m_ls\mathrm{Re}(DN^*)+\frac{1024}{3}\lambda m_B^6sv^2|H|^2\\&+4m_B^2sv^2|Q|^2+\frac{4}{3}\lambda m_B^4s(3-v^2)|A|^2\\&+\frac{256}{3}\lambda m_B^6s(3-v^2)|G|^2\\&+\frac{4}{3}m_B^4s\{2\lambda-(1-v^2)[2\lambda-3(1-r)^2]\}|C|^2.\end{aligned}$$

The polarizations P_L, P_N, and P_T are defined as

$$P_i^{(\mp)}(q^2)=\frac{\dfrac{d\Gamma}{dq^2}(\vec{n}^{(\mp)}=\vec{e}_i^{\,(\mp)})-\dfrac{d\Gamma}{dq^2}(\vec{n}^{(\mp)}=-\vec{e}_i^{\,(\mp)})}{\dfrac{d\Gamma}{dq^2}(\vec{n}^{(\mp)}=\vec{e}_i^{\,(\mp)})+\dfrac{d\Gamma}{dq^2}(\vec{n}^{(\mp)}=-\vec{e}_i^{\,(\mp)})},$$

where $P^{(\mp)}$ represents the charged lepton $l^{(\mp)}$ polarization asymmetry for $i=L,N,T$, i.e., P_L and P_T are the longitudinal and transversal asymmetries in the decay plane, respectively, and P_N is the normal component to both of them. With respect to the direction of the lepton polarization, P_L and P_T are P odd and T even, while P_N is P even, T odd, and CP odd. Calculations lead to the following results for longitudinal, transversal, and normal polarizations of the $l^{(\mp)}$:

$$\begin{aligned}P_L^{(\mp)}={}&\frac{4m_B^2v}{\Delta}\Big\{\pm\frac{4}{3}\lambda m_B^2\,\mathrm{Re}(AC^*)\mp\frac{64}{3}\lambda m_B^2m_l\,\mathrm{Re}(CG^*)\\&-\frac{64}{3}\lambda m_B^2m_l\,\mathrm{Re}(AH^*)-4m_l(1-r)\,\mathrm{Re}(CQ^*)\\&+\frac{256}{3}\lambda m_B^4s\,\mathrm{Re}(GH^*)-4m_ls\,\mathrm{Re}(DQ^*)\\&-2\,\mathrm{Re}(NQ^*)\Big\},\end{aligned} \tag{12}$$

$$\begin{aligned}P_T^{(\mp)}={}&\frac{\pi m_B^3\sqrt{s\lambda}}{\Delta}\Big\{\pm\frac{4}{s}m_l(1-r)\,\mathrm{Re}(AC^*)\\&\mp\frac{64}{s}(1-r)m_l^2\,\mathrm{Re}(CG^*)\pm4m_l\,\mathrm{Re}(AD^*)\\&\mp64m_l^2\,\mathrm{Re}(DG^*)\pm2\,\mathrm{Re}(AN^*)\mp32m_l\,\mathrm{Re}(GN^*)\\&+2v^2\,\mathrm{Re}(CQ^*)\Big\},\end{aligned} \tag{13}$$

$$P_N^{(\mp)} = \frac{m_B^3 v \sqrt{s\lambda}}{\Delta}\{4m_l \ \mathrm{Im}(CD^*) + 2 \ \mathrm{Im}(CN^*) \mp 2 \ \mathrm{Im}(AQ^*) \pm 32 m_l \ \mathrm{Im}(CG^*)\}. \quad (14)$$

From these expressions we can make the following conclusion. Contributions from the SM to P_L^- and P_L^+ are exactly the same but with the opposite sign. However, contributions to P_L^- and P_L^+ coming from new interactions can have the same sign or opposite signs. This can be useful in looking for new physics.

From Eq. (13) we observe that at the zero lepton mass limit, contributions coming from scalar interactions survive. Similarly, terms coming from scalar and tensor interactions survive in the massless lepton limit for $P_L^{(\mp)}$. Therefore, the experimentally measured value of $P_{L,T}^{(\mp)}$ for $B \to K\mu^+\mu^-$ can give a very promising hint when looking for new physics beyond the SM. About normal polarization we can comment as follows. In the present work we assume that all form factors and all new Wilson coefficients are real. Under this condition the functions C, D, N, and G are real in the SM and beyond it, and only the function A has an imaginary part coming from C_9^{eff}. Therefore, the term $\mp$ Im (AQ^*) makes a contribution to both $P_N^{\mp}$, and for this reason $P_N^- = P_N^+ = 0$ in the SM and $P_N^- + P_N^+ = 0$ beyond it, under the above-mentioned condition. It follows from Eq. (14) that the difference between P_N^- and P_N^+ is due to the existence of scalar interaction. Incidentally, we should note that a similar situation takes place for lepton polarizations in the $B \to K^* l^+ l^-$ decay [26]. It follows from this discussion that a measurement of the lepton polarization of each lepton, and a combined analysis of lepton and antilepton polarizations $P_L^- + P_L^+$ and $P_T^- - P_T^+$, can provide very useful information to constrain or discover new physics beyond the SM; the polarizations are all zero in the SM in the limit of massless leptons. Therefore if in experiments of nonzero value of the above mentioned combined lepton asymmetries was observed, this can be considered the discovery of new physics beyond that of the SM.

III. NUMERICAL ANALYSIS

First we introduce the values of the input parameters used in the present work: $|V_{tb}V_{ts}^*| = 0.0385$, $\alpha^{-1} = 129$, $G_F = 1.17 \times 10^{-5}$ GeV^{-2}, $\Gamma_B = 4.22 \times 10^{-13}$ GeV, $C_9^{eff} = 4.344$, and $C_{10} = -4.669$. It is well known that the Wilson coefficient C_9^{eff} receives short as well as long distance contributions from the real $\bar{c}c$ intermediate states, i.e., with the J/ψ family, but in this work we consider only short distance contributions. Experimental data on $\mathcal{B}(B \to X_s\gamma)$ fix only the modulo of C_7^{eff}. For this reason, throughout our analysis we have considered both possibilities, i.e., $C_7^{eff} = \mp 0.313$, where the upper sign corresponds to the SM prediction.

For the values of the form factors, we have used the results of Ref. [27] (also see Refs. [28,29]). The q^2 dependence of the form factors can be represented in terms of three parameters as

TABLE I. Central values of the parameters for the parametrization [Eq. (15)] of the $B \to K$ decay form factors.

	f_+	f_0	f_T
$F(0)$	0.319	0.319	0.355
c_1	1.465	0.633	1.478
c_2	0.372	-0.095	0.373
c_3	0.782	0.591	0.700

$$F(s) = F(0)\exp(c_1 s + c_2 s^2 + c_3 s^3), \quad (15)$$

where the values of parameters $F(0)$, c_1, c_2, and c_3 for the $B \to K$ decay are listed in Table I.

From the expressions for the lepton polarizations we see that they all depend on q^2 and the new Wilson coefficients. It may be experimentally difficult to study the dependence of the the polarizations of each lepton on both quantities. Therefore, we eliminate the dependence of the lepton polarizations on q^2, by performing as integration over q^2 in the allowed kinematical region, so that the lepton polarizations are averaged. The averaged lepton polarizations are defined as

$$\langle P_i \rangle = \frac{\displaystyle\int_{4m_l^2}^{(m_b - m_K)^2} P_i \frac{d\mathcal{B}}{dq^2} dq^2}{\displaystyle\int_{4m_l^2}^{(m_b - m_K)^2} \frac{d\mathcal{B}}{dq^2} dq^2}. \quad (16)$$

We present our results in a series of figures. Note that in all figures we presented the value of C_7^{eff} is chosen to have its SM value, i.e., $C_7^{eff} = -0.313$. Figures 1 and 2 depict the dependence of the averaged longitudinal polarization $\langle P_L^- \rangle$ of l^- and the combination $\langle P_L^- + P_L^+ \rangle$ on new Wilson coefficients, at $C_7^{eff} = -0.313$ for $B \to K\mu^+\mu^-$ decay. From these figures we see that $\langle P_L^- \rangle$ is sensitive to the existence of all new interactions except to vector and scalar interactions with coefficients C_{LL}, C_{RL} and C_{RLLR}, C_{LRLR}, respectively, while the combined average $\langle P_L^- + P_L^+ \rangle$ is sensitive to scalar-type interactions only. It is interesting that contributions from C_{RLLR}, C_{LRLR} (C_{LRRL}, C_{RLRL}) to the combined asymmetry are always negative (positive). Therefore, a determination of the sign of $\langle P_L^- + P_L^+ \rangle$ can be useful in discriminating the type of the interaction. From Fig. 2 we see that $\langle P_L^- + P_L^+ \rangle = 0$ at $C_X = 0$, which confirms the SM result, as expected. For the other choice of C_7^{eff}, i.e., $C_7^{eff} = 0.313$, the situation is similar to the previous case, but the magnitude of $\langle P_L^- + P_L^+ \rangle$ is smaller. Figures 3 and 4 are the same as Figs. 1 and 2, but for $B \to K\tau^+\tau^-$ decay. In this case the difference of the dependence of the longitudinal polarization $\langle P_L^- \rangle$ on new Wilson coefficients from the muon case is as follows: In the muon case $\langle P_L^- \rangle$ is negative for all values of the new Wilson coefficients, while for the τ case $\langle P_L^- \rangle$ can receive both values; for example for $C_T < -1$, $\langle P_L^- \rangle$ is positive, and for $C_T > -1$, $\langle P_L^- \rangle$ is negative.

It is obvious from Fig. 4 that if the values of the new Wilson coefficients C_{LRRL}, C_{LRLR}, C_{RLLR}, C_{RLRL}, and

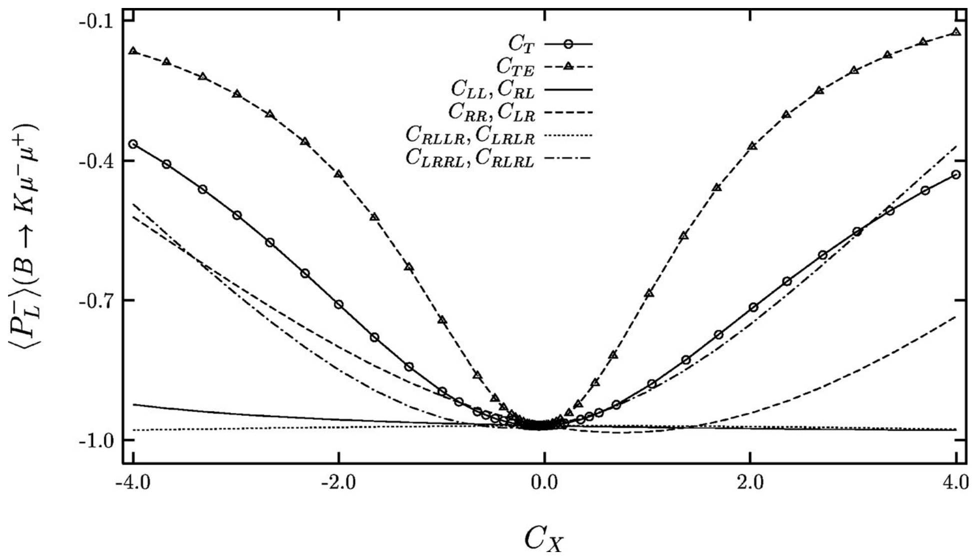

FIG. 1. The dependence of the average longitudinal polarization asymmetry $\langle P_L^- \rangle$ of a muon on the new Wilson coefficients.

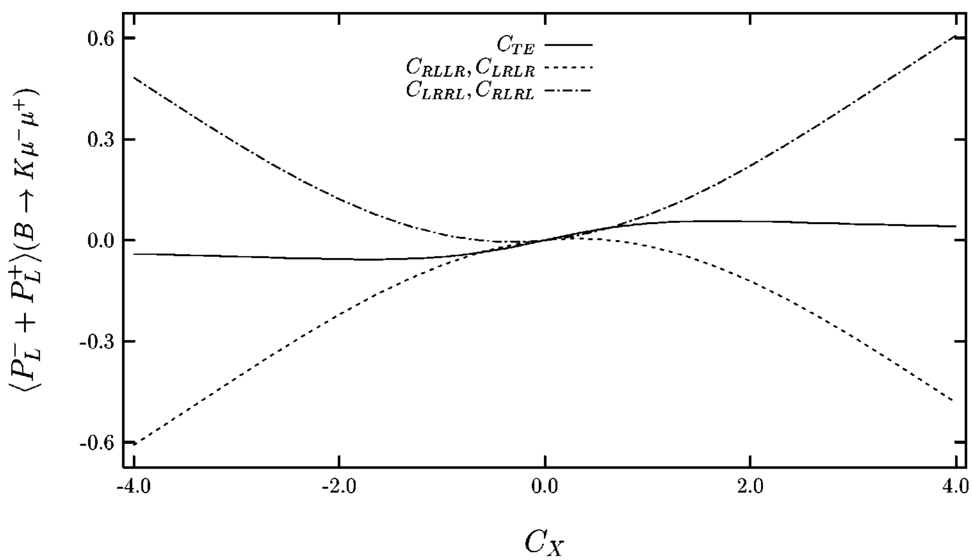

FIG. 2. The dependence of the combined average longitudinal polarization asymmetry $\langle P_L^- + P_L^+ \rangle$ of l^- and l^+ on the new Wilson coefficients for the $B \to K \mu^- \mu^+$ decay.

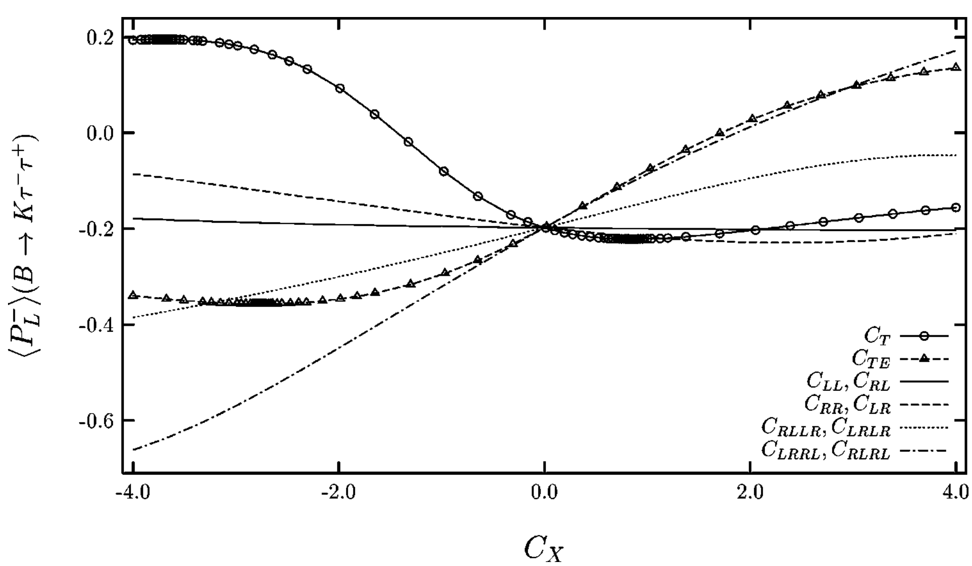

FIG. 3. The same as in Fig. 1, but for the $B \to K \tau^- \tau^+$ decay.

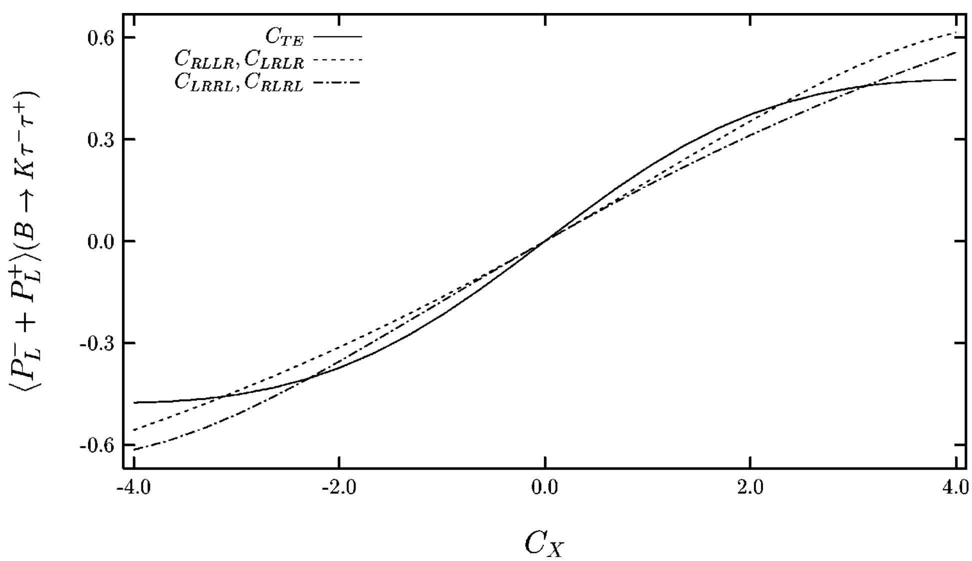

FIG. 4. The same as Fig. 2, but for the $B \to K\tau^-\tau^+$ decay.

C_{TE} are negative (positive), $\langle P_L^- + P_L^+ \rangle$ is negative (positive). A similar situation takes place for $C_7^{eff} > 0$. For these reasons a determination of the sign and of course magnitude of $\langle P_L^- + P_L^+ \rangle$ can give promising information about new physics.

In Figs. 5 and 6 the dependence of the average transversal polarization $\langle P_T^- \rangle$ and the combination $\langle P_T^- - P_T^+ \rangle$ on the new Wilson coefficients are presented for the $B \to K\mu^+\mu^-$ decay, respectively. From Fig. 5 we observe that the average transversal polarization is strongly dependent only on C_{LRRL} and C_{RLRL}, and quite weakly dependent on the remaining Wilson coefficients. It is also interesting to note that for the negative (positive) values of these scalar coefficients $\langle P_T^- \rangle$ is negative (positive). For the $\langle P_T^- - P_T^+ \rangle$ case, there appears to be strong dependence on all four scalar interactions with coefficients C_{LRRL}, C_{RLLR}, C_{LRLR}, and C_{RLRL}. The behavior of this combined average transversal polarization is identical for the coefficients C_{LRLR}, C_{RLLR} and C_{LRRL}, C_{RLRL} in pairs, so that four lines responsible for these interactions appear only to be two. Moreover $\langle P_T^- - P_T^+ \rangle$ is negative (positive) for the negative (positive) values of the new Wilson coefficients C_{LRRL} and C_{RLRL}, and positive (negative) for the coefficients C_{LRLR} and C_{RLLR}. Remember that in the SM, in the massless lepton case, $\langle P_T^- \rangle \approx 0$ and $\langle P_T^- - P_T^+ \rangle \approx 0$. Therefore, a determination of the signs and magnitudes of $\langle P_T^- \rangle$ and $\langle P_T^- - P_T^+ \rangle$ can give provide useful information about the existence of new physics. For the choice of $C_7^{eff} = 0.313$, apart from the minor differences in their magnitudes, the behaviors of $\langle P_T^- \rangle$ and $\langle P_T^- - P_T^+ \rangle$ are similar to what they were in the previous case.

As is obvious from Figs. 7 and 8, $\langle P_T^- \rangle$ and $\langle P_T^- - P_T^+ \rangle$ show stronger dependences only on C_T for the $B \to K\tau^+\tau^-$ decay. Again $\langle P_T^- \rangle$ and $\langle P_T^- - P_T^+ \rangle$ change sign at $C_T \approx -1$. As already noted, a determination of the sign and magnitude of $\langle P_T^- \rangle$ and $\langle P_T^- - P_T^+ \rangle$ provides useful hints when looking for new physics.

In Figs. 9 and 10 we present the dependence of averaged normal asymmetry $\langle P_N^- \rangle$ for the $B \to K\mu^+\mu^-$ and $B \to K\tau^+\tau^-$ decays, respectively. From these figures we see that $\langle P_N^- \rangle$ is strongly dependent on all scalar-type interac-

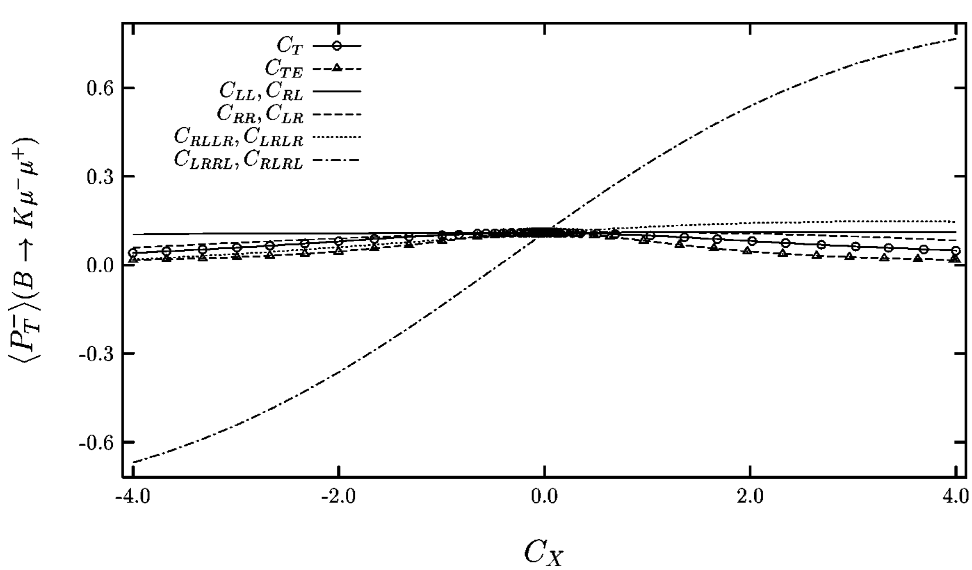

FIG. 5. The same as Fig. 1, but for the average transversal polarization asymmetry $\langle P_T^- \rangle$ of a muon.

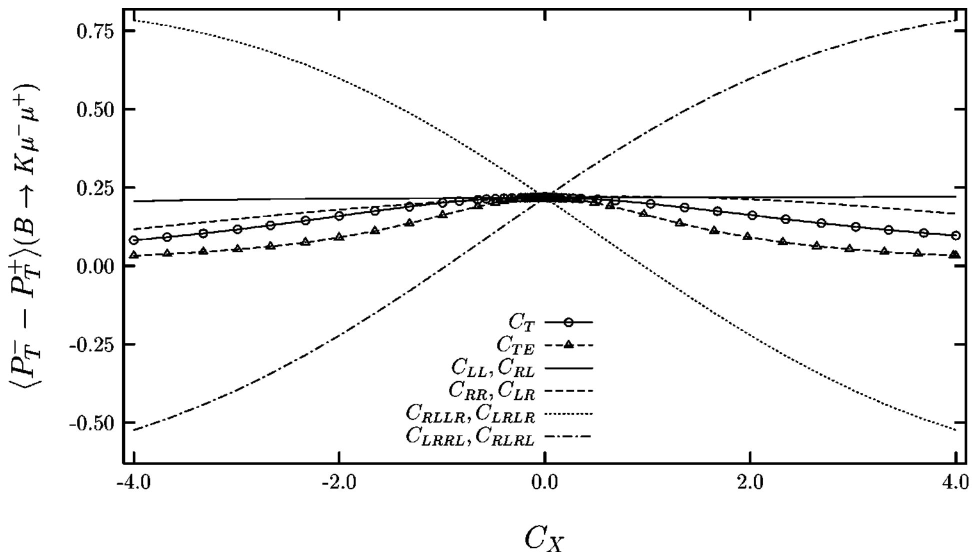

FIG. 6. The same as Fig. 2, but for the transversal polarization asymmetry $\langle P_T^- - P_T^+\rangle$.

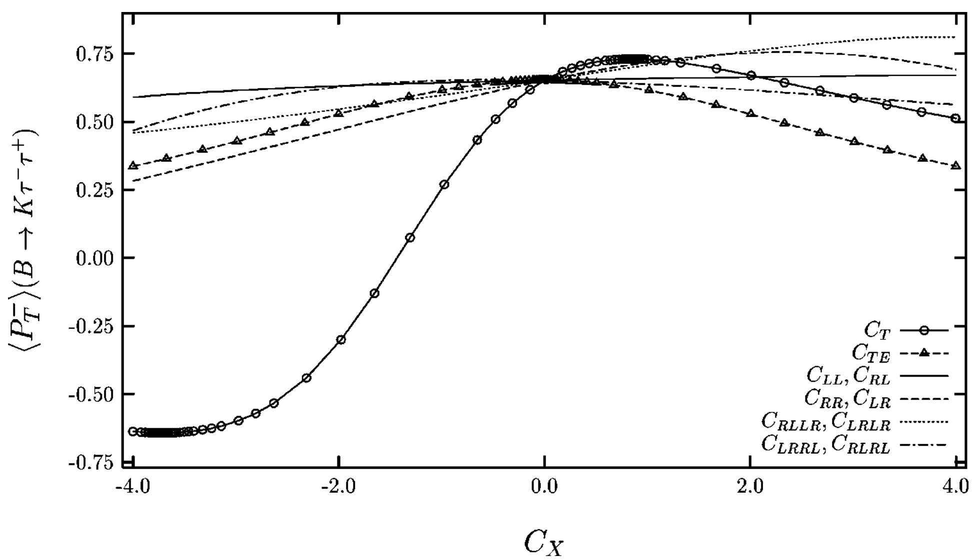

FIG. 7. The same as Fig. 5, but for the $B \to K\tau^-\tau^+$ decay.

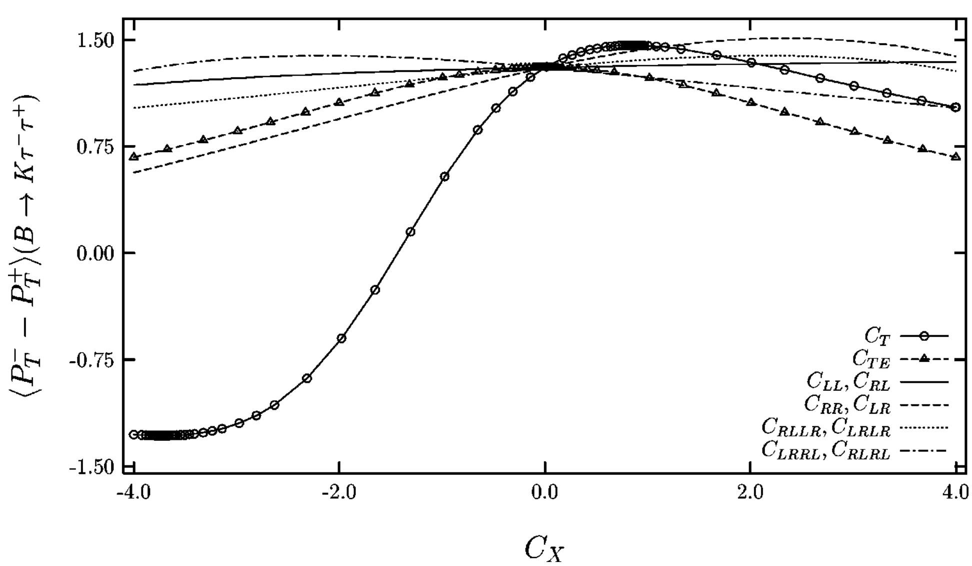

FIG. 8. The same as Fig. 6, but for the $B \to K\tau^-\tau^+$ decay.

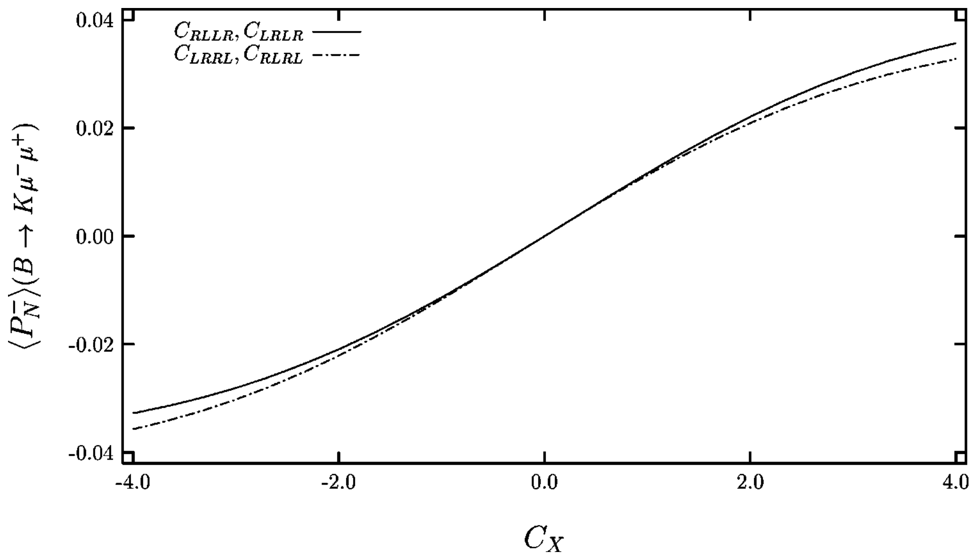

FIG. 9. The dependence of the average normal asymmetry $\langle P_N^- \rangle$ of a muon on the new Wilson coefficients.

tions for $B \to K\mu^+\mu^-$ and $B \to K\tau^+\tau^-$ decays. The changes in the sign and magnitude of $\langle P_N^- \rangle$ that are observed in these figures is an indication of the fact that an experimental verification of them can provide unambiguous information about the new physics.

In the present work we analyzed the possibility of pinning down new physics beyond that of the SM by studying lepton polarizations only. It follows from Eq. (11) that the branching ratio of the $B \to Kl^+l^-$ decay also depends on the new Wilson coefficients, and hence we expect that it can give information about the new physics. In this connection there follows a question: Can one establish new physics by studying the lepton polarizations only? In other words, are there regions of the new Wilson coefficients C_X in which the value of the branching ratio coincides with that of the SM prediction, but the value of the lepton polarization does not? In order to answer this question, in Figs. 11–14 we present the dependence of the branching ratio on the average and combined average polarizations of the leptons. In these figures the value of the branching ratio ranges between the values $10^{-7} \leqslant \mathcal{B}(B \to K\tau^+\tau^-) \leqslant 3.5\times 10^{-7}$. These figures depict that there indeed exist such regions of C_X in which the value of the branching ratio does agree with the SM result, while the lepton polarizations differ from the SM prediction. It follows from pairing of Figs. 3 and 11, 7 and 13, and 8 and 14 that if C_T lies in the region $-2 \leqslant C_T \leqslant 0$, the abovementioned condition, i.e., the mismatch of the polarizations in the standard model and the new physics, is fulfilled. On the other hand, one can immediately see from Fig. 12 that such a region for the combined average longitudinal lepton polarization does not exist, and hence it is not suitable to a search for new physics. Note that in all figures the intersection point of all curves correspond to the SM case. This analysis allows us to conclude that there exist certain regions of new Wilson coefficients for which a study of the lepton polarization itself can give promising information about new physics.

Finally, a few words about the detectibilty of the lepton polarization asymmetries at B factories or future hadron colliders are in order. As an estimation, we choose the averaged values of the longitudinal polarization of muon and transversal and normal polarizations of the τ lepton, which are approximately close to the SM prediction, i.e., $\langle P_L \rangle \simeq -0.9$,

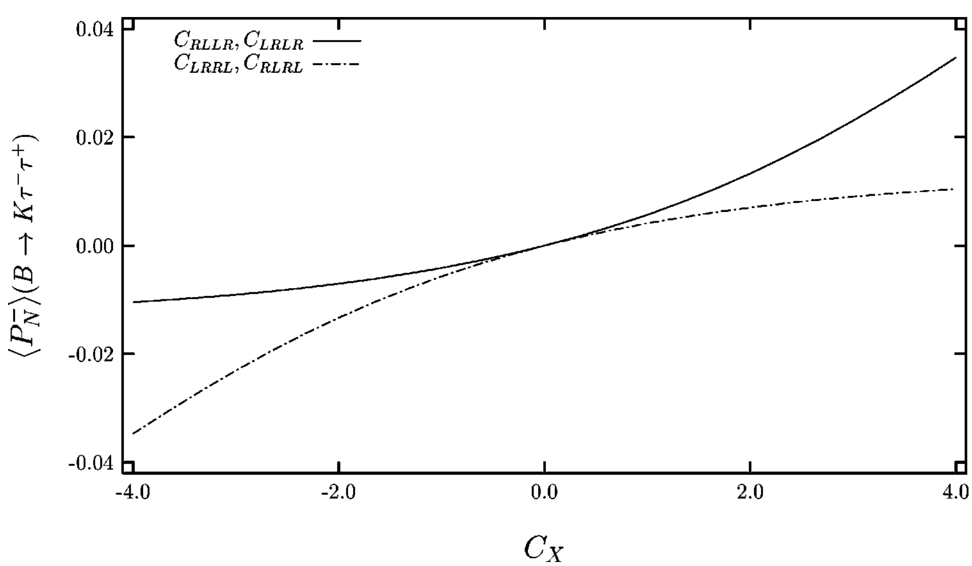

FIG. 10. The dependence of the average normal polarization asymmetry $\langle P_N^- \rangle$ on the new Wilson coefficients for the $B \to K\tau^-\tau^+$ decay.

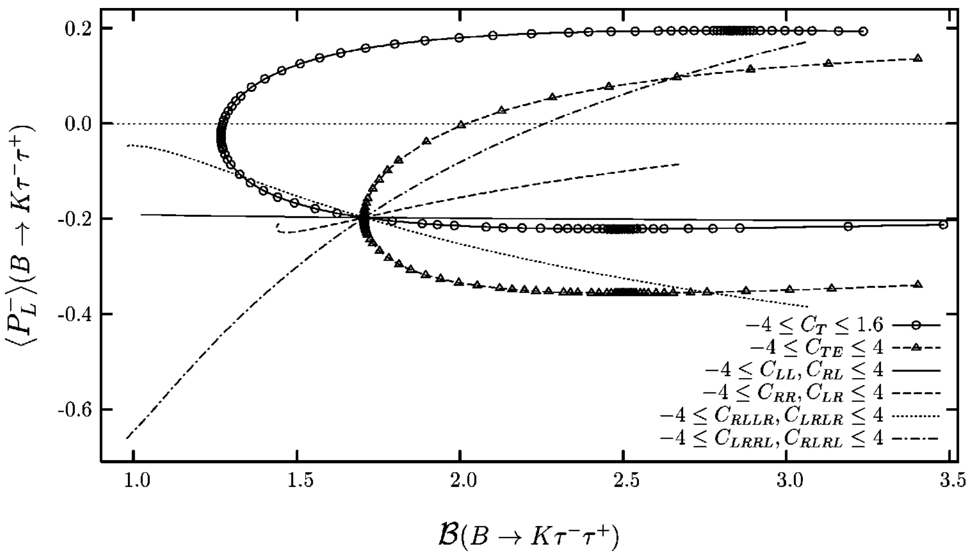

FIG. 11. Parametric plot of the correlation between the integrated branching ratio $\mathcal{B}$ (in units of 10^{-7}) and the average longitudinal lepton polarization asymmetry $\langle P_L^- \rangle$ as function of the new Wilson coefficients as indicated in the figure, for the $B \to K\tau^-\tau^+$ decay.

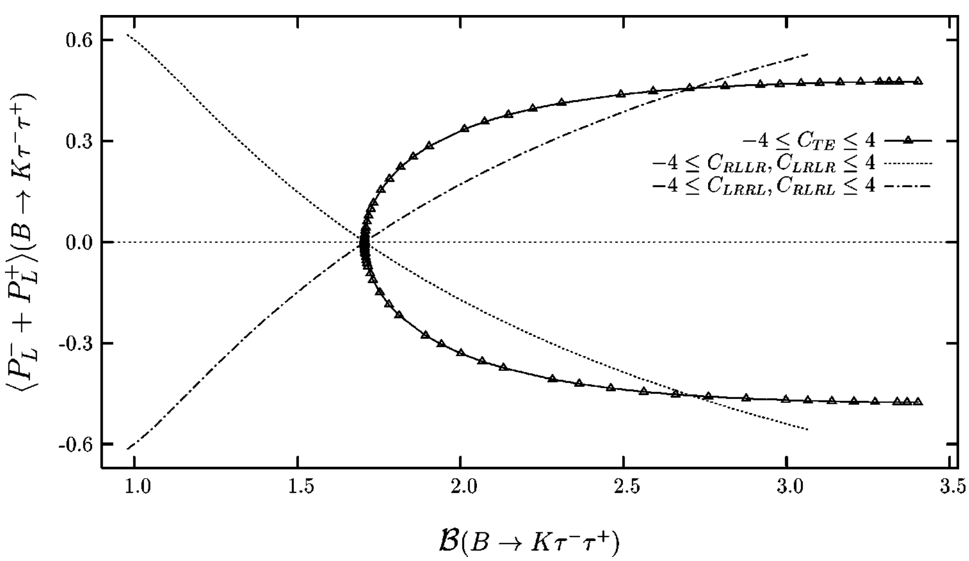

FIG. 12. The same as Fig. 11, but for the combined average longitudinal lepton polarization asymmetry $\langle P_L^- + P_L^+ \rangle$.

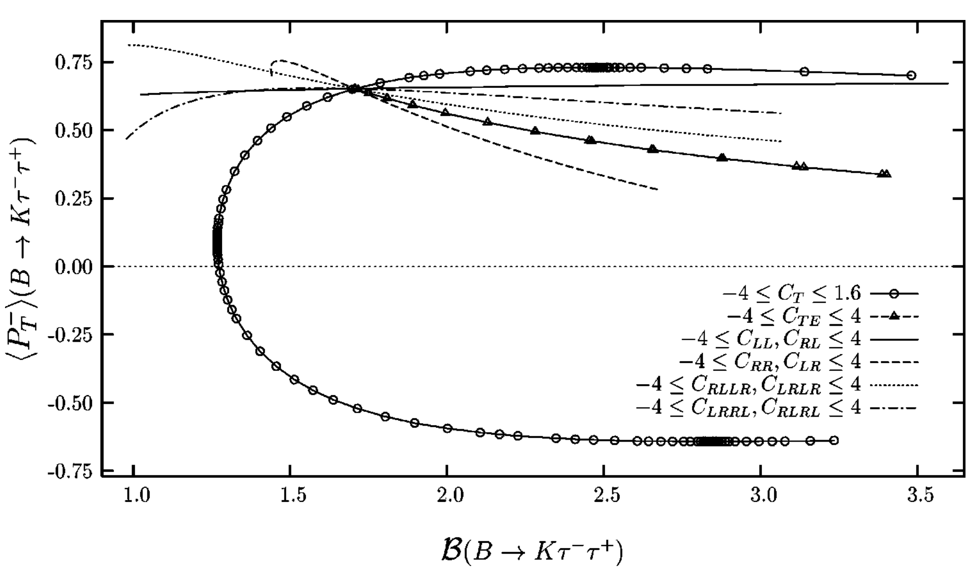

FIG. 13. The same as Fig. 11, but for the average transversal lepton polarization asymmetry $\langle P_T^- \rangle$.

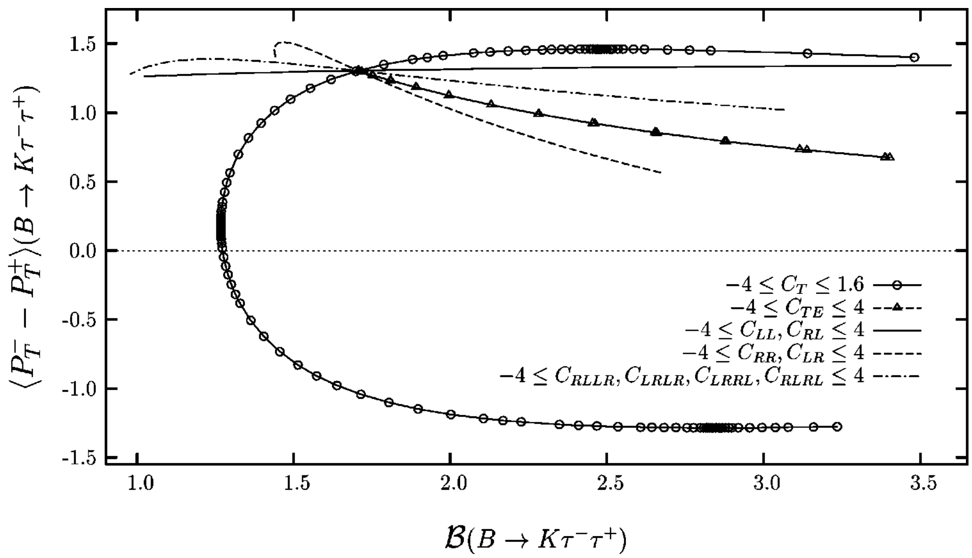

FIG. 14. The same as Fig. 13, but for the combined average transversal lepton polarization asymmetry $\langle P_T^- - P_T^+ \rangle$.

$\langle P_T \rangle \simeq 0.6$, and $\langle P_N \rangle \simeq -0.01$. Experimentally, to measure an asymmetry $\langle P_i \rangle$ of a decay with the branching ratio B at the $n\sigma$ level, the required number of events is given by the formula $N = n^2/(\mathcal{B}\langle P_i \rangle)^2$. It follows from this expression that to observe the lepton polarizations $\langle P_L \rangle$, $\langle P_T \rangle$, and $\langle P_N \rangle$ in $B \to K\tau^+\tau^-$ decay at the 1σ level, the expected number of events are $N = (1;3;10^4) \times 10^7$, respectively. On the other hand, the number of $B\bar{B}$ pairs that is expected to be produced at B factories is about $N \sim 5 \times 10^8$. A comparison of these numbers allows us to conclude that while a measurement of the normal polarization of the τ lepton is impossible, measurements of the longitudinal polarization of muon and transversal polarization of τ lepton could be accessible at B factories [30].

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