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

T. M. Aliev *, M. K. Çakmak , A. Özpineci †, M. Savcı ‡

Physics Department, Middle East Technical University

06531 Ankara, Turkey

Abstract

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 $B \to K \ell^+ \ell^-$ 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.

PACS numbers: 12.60.–i, 13.20.–v, 13.25.Hw

*e-mail: taliev@metu.edu.tr

†e-mail: altugoz@metu.edu.tr

‡e-mail: savci@metu.edu.tr

1 Introduction

The two B meson factories BaBar and Belle , which have already started operation, open an exciting new era in studying physics of B mesons. Both factories have 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 the new physics beyond the Standard Model (SM). So, main goal of the investigations undergoing at B factories is to find inconsistencies within the SM, in particular find indications for new physics in the flavor and CP violating sector [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 the new structures in the effective Hamiltonian which are absent in the SM. Rare B meson decays induced by $b \to s(d)\ell^+\ell^-$ transition has been extensively studied in framework of the SM and its various extensions [3]–[19]. One of the efficient ways in establishing new physics beyond the SM is the measurement of the lepton polarization [19]–[26]. All previous studies for the lepton polarization have been limited to SM and its minimal extensions, except the works [23, 26]. In [23] the analysis of the τ lepton polarization for the inclusive $b \to s\tau^+\tau^-$ decay was presented in a model independent way and in [26] lepton polarizations are investigated using the most general model independent Hamiltonian for the $B \to K^*\ell^+\ell^-$ decay.

The aim of this work is studying lepton polarizations in the exclusive $B \to K\ell^+\ell^-$ decay using the general form of the effective Hamiltonian including all possible form of interactions. Here we will study μ and τ leptonic modes because of the following two reasons. Firstly, the electron polarization is hard to measure experimentally, and secondly, 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 their measurements might be possible especially in the $\tau^-\tau^+$ channel.

The work is organized as follows. In section 2, using a general form of four–Fermi interaction we derive the general expressions for the longitudinal, transversal and normal polarizations of leptons. In section 3 we investigate the sensitivity of the above–mentioned polarizations to the new Wilson coefficients. At the end of this section we also present our conclusion.

2 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 $b \to s\ell^+\ell^-$ transition in terms of twelve model independent four–Fermi interactions can be written in the following form:

$$\begin{aligned}
\mathcal{H}_{eff} &= \frac{G_F\alpha}{\sqrt{2}\pi} V_{ts}V_{tb}^\ast \Bigg\{ C_{SL}\, \bar{s} i\sigma_{\mu\nu}\frac{q^\nu}{q^2}\, L\, b\, \bar{\ell}\gamma^\mu\ell + C_{BR}\, \bar{s} i\sigma_{\mu\nu}\frac{q^\nu}{q^2}\, R\, b\, \bar{\ell}\gamma^\mu\ell \\
&+ C_{LL}^{tot}\, \bar{s}_L\gamma_\mu b_L\, \bar{\ell}_L\gamma^\mu\ell_L + C_{LR}^{tot}\, \bar{s}_L\gamma_\mu b_L\, \bar{\ell}_R\gamma^\mu\ell_R + C_{RL}\, \bar{s}_R\gamma_\mu b_R\, \bar{\ell}_L\gamma^\mu\ell_L \\
&+ C_{RR}\, \bar{s}_R\gamma_\mu b_R\, \bar{\ell}_R\gamma^\mu\ell_R + C_{LRLR}\, \bar{s}_L b_R\, \bar{\ell}_L\ell_R + C_{RLLR}\, \bar{s}_R b_L\, \bar{\ell}_L\ell_R \qquad (1)
\end{aligned}$$

$$+C_{LRRL}\,\bar{s}_L b_R\,\bar{\ell}_R \ell_L + C_{RLRL}\,\bar{s}_R b_L\,\bar{\ell}_R \ell_L + C_T\,\bar{s}\sigma_{\mu\nu} b\,\bar{\ell}\sigma^{\mu\nu}\ell$$
$$\left. +iC_{TE}\,\epsilon^{\mu\nu\alpha\beta}\bar{s}\sigma_{\mu\nu} b\,\bar{\ell}\sigma_{\alpha\beta}\ell \right\} ,$$

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

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

and C_X are the coefficients of the four–Fermi interactions and $q = p_B - p_K$ is the momentum transfer. Note that among twelve Wilson coefficients several already exist in the SM. The coefficients C_{SL} and C_{BR} correspond to $-2m_s C_7^{eff}$ and $-2m_b C_7^{eff}$ in the SM, respectively. The next four terms in Eq. (1) are the 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} do exist in the SM as well 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 SM and the new physics and they can be written as

$$\begin{aligned} C_{LL}^{tot} &= C_9^{eff} - C_{10} + C_{LL} , \\ C_{LR}^{tot} &= C_9^{eff} + C_{10} + C_{LR} , \end{aligned}$$

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

Exclusive $B \to K \ell^+ \ell^-$ decay is described by the matrix element of 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 $B \to K \ell^+ \ell^-$ decay, the following matrix elements are needed

$$\begin{aligned} &\langle K \left| \bar{s}\gamma_\mu b \right| B \rangle , \\ &\langle K \left| \bar{s} i\sigma_{\mu\nu} q^\nu b \right| B \rangle , \\ &\langle K \left| \bar{s} b \right| B \rangle , \\ &\langle K \left| \bar{s}\sigma_{\mu\nu} b \right| B \rangle . \end{aligned}$$

These matrix elements are defined as follows:

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

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

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

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

$$\begin{aligned} \langle K(p_K) \left| \bar{s} b \right| B(p_B) \rangle &= f_0\, \frac{m_B^2 - m_K^2}{m_b - m_s} , &(4) \\ \langle K(p_K) \left| \bar{s} i\sigma_{\mu\nu} q^\nu b \right| B(p_B) \rangle &= \frac{f_T}{m_B + m_K} \Big[(p_B + p_K)_\mu q^2 - q_\mu (m_B^2 - m_K^2) \Big] . &(5) \end{aligned}$$

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

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

The auxiliary functions above are defined as

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

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. Using Eq. (6) we next calculate the final lepton polarizations for the $B \to K\ell^+\ell^-$ decay. For this purpose we define the following orthogonal unit vectors, $S_L^{-\mu}$ in the rest frame of ℓ^- and $S_L^{+\mu}$ in the rest frame of ℓ^+, for the polarization of the leptons along the longitudinal (L), transversal (T) and normal (N) directions:

$$\begin{aligned}
S_L^{-\mu} &\equiv (0, \vec{e}_L^{\,-}) = \left(0, \frac{\vec{p}_-}{|\vec{p}_-|}\right) , \\
S_N^{-\mu} &\equiv (0, \vec{e}_N^{\,-}) = \left(0, \frac{\vec{p}_K \times \vec{p}_-}{|\vec{p}_K \times \vec{p}_-|}\right) , \\
S_T^{-\mu} &\equiv (0, \vec{e}_T^{\,-}) = \left(0, \vec{e}_N^{\,-} \times \vec{e}_L^{\,-}\right) , \qquad (8)
\end{aligned}$$

$$
\begin{aligned}
S_L^{+\mu} &\equiv (0, \vec{e}_L^{\,+}) = \left(0, \frac{\vec{p}_+}{|\vec{p}_+|}\right) ~, \\
S_N^{+\mu} &\equiv (0, \vec{e}_N^{\,+}) = \left(0, \frac{\vec{p}_K \times \vec{p}_+}{|\vec{p}_K \times \vec{p}_+|}\right) ~, \\
S_T^{+\mu} &\equiv (0, \vec{e}_T^{\,+}) = \left(0, \vec{e}_N^{\,+} \times \vec{e}_L^{\,+}\right) ~,
\end{aligned}
$$

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

$$
\begin{aligned}
S_{L,CM}^{-\mu} &= \left(\frac{|\vec{p}_-|}{m_\ell}, \frac{E_\ell\, \vec{p}_-}{m_\ell\, |\vec{p}_-|}\right) ~, \\
S_{L,CM}^{+\mu} &= \left(\frac{|\vec{p}_-|}{m_\ell}, -\frac{E_\ell\, \vec{p}_-}{m_\ell\, |\vec{p}_-|}\right) ~,
\end{aligned} \tag{9}
$$

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

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

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

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

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

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 $v = \sqrt{1 - 4m_\ell^2/q^2}$ is the lepton velocity. The explicit form of Δ is

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

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 $\ell^{(\mp)}$ 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, T–even, while P_N is P–even, T–odd and CP–odd. calculations lead to the following results for the longitudinal, transversal and normal polarization of the $\ell^{(\mp)}$:

$$P_L^{(\mp)} = \frac{4m_B^2 v}{\Delta}\Bigg\{ \pm \frac{4}{3}\lambda m_B^2 \,\text{Re}(AC^*) \mp \frac{64}{3}\lambda m_B^2 m_\ell \,\text{Re}(CG^*) - \frac{64}{3}\lambda m_B^2 m_\ell \,\text{Re}(AH^*)$$

$$-4m_\ell(1-r)\,\text{Re}(CQ^*) + \frac{256}{3}\lambda m_B^4 s \,\text{Re}(GH^*) - 4m_\ell s \,\text{Re}(DQ^*) - 2\,\text{Re}(NQ^*)\Bigg\}\ , \quad (12)$$

$$P_T^{(\mp)} = \frac{\pi m_B^3 \sqrt{s\lambda}}{\Delta}\Bigg\{ \pm \frac{4}{s} m_\ell (1-r)\,\text{Re}(AC^*) \mp \frac{64}{s}(1-r) m_\ell^2 \,\text{Re}(CG^*) \quad (13)$$

$$\pm 4m_\ell \,\text{Re}(AD^*) \mp 64 m_\ell^2 \,\text{Re}(DG^*) \pm 2\,\text{Re}(AN^*) \mp 32 m_\ell \,\text{Re}(GN^*) + 2v^2 \,\text{Re}(CQ^*)\Bigg\}\ ,$$

$$P_N^{(\mp)} = \frac{m_B^3 v \sqrt{s\lambda}}{\Delta}\Bigg\{4m_\ell \,\text{Im}(CD^*) + 2\,\text{Im}(CN^*) \mp 2\,\text{Im}(AQ^*) \pm 32 m_\ell \,\text{Im}(CG^*)\Bigg\} \quad (14)$$

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

From Eq. (13) we observe that at 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, experimentally measured value of $P_{L,T}^{(\mp)}$ for the $B \to K\mu^+\mu^-$ can give a very promising hint in looking new physics beyond SM. About normal polarization we can comment as follows. One can see from Eq. (14) the difference between P_N^- and P_N^+ (for which SM predicts $P_N^- = -P_N^+$) is again due to the existence of the scalar and tensor interactions. Incidentally, w e should note that a similar situation takes place for the lepton polarizations in the $B \to K^*\ell^+\ell^-$ decay [26]. It follows from this discussion that a measurement of the lepton polarization of each lepton and combined analysis of lepton and antilepton polarizations $P_L^- + P_L^+$, $P_T^- - P_T^+$ and $P_N^- + P_N^+$ can give very useful information to constraint or to discover new physics beyond SM, which are all zero in the SM in the limit of massless leptons. Therefore if in experiments nonzero value of the above mentioned combined lepton asymmetries were observed, this can be considered as an discovery of the new physics beyond SM.

3 Numerical analysis

First of all we introduce the values of the input parameters used in the present work: $|V_{tb}V_{ts}^*| = 0.0385$, $\alpha^{-1} = 129$, $G_F = 1.17 \times 10^{-5}\ GeV^{-2}$, $\Gamma_B = 4.22 \times 10^{-13}\ GeV$, $C_9^{eff} = 4.344$, $C_{10} = -4.669$. It is well known that the Wilson coefficient C_9^{eff} receives short as well as long distance contributions coming 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 $\mathcal{B}(B \to X_s\gamma$ fixes 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 [27] (see also [28, 29]). The q^2 dependence of the form factors can be represented in terms of three parameters as

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

where the values of parameters $F(0)$, c_1, c_2 and c_3 for the $B \to K$ decay are listed in Table 1.

	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

Table 1: Central values of the parameters for the parametrization (15) of the $B \to K$ decay form factors.

From the expressions of 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 integration over q^2 in the allowed kinematical region, so that the lepton polarizations are averaged. The averaged lepton polarizations are defined as

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

We present our results in a series figures. Note that in all figures we presented the value of C_7^{eff} is chosen to have its SM value, i.e., $C_7^{eff} = -0.313$. Figs. (1) and (2) depict the dependence of the averaged longitudinal polarization $\left\langle P_L^- \right\rangle$ of ℓ^- and the combination $\left\langle P_L^- + P_L^+ \right\rangle$ on new Wilson coefficients, at $C_7^{eff} = -0.313$ for $B \to K\mu^+\mu^-$ decay. From these figures we see that $\left\langle P_L^- \right\rangle$ 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 $\left\langle P_L^- + P_L^+ \right\rangle$ 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 is always negative (positive). Therefore determination of the sign of $\left\langle P_L^- + P_L^+ \right\rangle$ can be useful in discriminating the type of the interaction. From Fig. (2) we see that

$\left\langle P_L^- + P_L^+ \right\rangle = 0$ 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 $\left\langle P_L^- + P_L^+ \right\rangle$ is smaller. Figs. (3) and (4) are the same as Figs.(1) and (2) but for the $B \to K\tau^+\tau^-$ decay. In this case the difference of the dependence of the longitudinal polarization $\left\langle P_L^- \right\rangle$ on new Wilson coefficients from the muon case is as follows: In the muon case $\left\langle P_L^- \right\rangle$ is negative for all values of the new Wilson coefficients while for the tau case $\left\langle P_L^- \right\rangle$ can receive both values, for example for $C_T < 1$, $\left\langle P_L^- \right\rangle$ is positive, and for $C_T > 1$, $\left\langle P_L^- \right\rangle$ 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 C_{TE} are negative (positive), $\left\langle P_L^- + P_L^+ \right\rangle$ is negative (positive). Absolutely similar situation takes place for $C_7^{eff} > 0$. For these reasons determination of the sign and of course magnitude of $\left\langle P_L^- + P_L^+ \right\rangle$ can give promising information about new physics.

In Figs. (5) and (6) the dependence of the average transversal polarization $\left\langle P_T^- \right\rangle$ and the combination $\left\langle P_T^- - P_T^+ \right\rangle$ on the new Wilson coefficients are presented for the $B \to K\mu^+\mu^-$ decay, respectively. We observe from Fig. (5) that the average transversal polarization is strongly dependent only on C_{LRRL} and C_{RLRL} and quite weakly to remaining Wilson coefficients. It is also interesting to note that for the negative (positive) values of these scalar coefficients $\left\langle P_T^- \right\rangle$ is negative (positive). For the $\left\langle P_T^- - P_T^+ \right\rangle$ case, there appears strong dependence on all four scalar interactions with coefficients C_{LRRL}, C_{RLLR}, C_{LRLR}, 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 $\left\langle P_T^- - P_T^+ \right\rangle$ 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}. Remembering that in SM, in massless lepton case $\left\langle P_T^- \right\rangle \approx 0$ and $\left\langle P_T^- - P_T^+ \right\rangle \approx 0$. Therefore determination of the signs and magnitudes of $\left\langle P_T^- \right\rangle$ and $\left\langle P_T^- - P_T^+ \right\rangle$ can give quite a 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 $\left\langle P_T^- \right\rangle$ and $\left\langle P_T^- - P_T^+ \right\rangle$ are similar as in the previous case.

As is obvious from Figs. (7) and (8), $\left\langle P_T^- \right\rangle$ and $\left\langle P_T^- - P_T^+ \right\rangle$ show stronger dependence only on C_T for the $B \to K\tau^+\tau^-$ decay. Again $\left\langle P_T^- \right\rangle$ and $\left\langle P_T^- - P_T^+ \right\rangle$ change sign at $C_T \approx -1$. As has already been noted, determination of the sign and magnitude of $\left\langle P_T^- \right\rangle$ and $\left\langle P_T^- - P_T^+ \right\rangle$ are useful hints in looking for new physics.

Note that for simplicity all new Wilson coefficients in this work are assumed to be real. Under this condition $\left\langle P_N^- \right\rangle$ and $\left\langle P_N^- + P_N^+ \right\rangle$ have non-vanishing values coming from the imaginary part of SM, i.e., from C_9^{eff}. From Figs. (9) and (10) we see that $\left\langle P_N^- \right\rangle$ and $\left\langle P_N^- + P_N^+ \right\rangle$ are strongly dependent on all scalar type interactions for the $B \to K\mu^+\mu^-$ decay. Similar behavior takes place for the $B \to K\tau^+\tau^-$ decay as well. The change in sign and magnitude of both $\left\langle P_N^- \right\rangle$ and $\left\langle P_N^- + P_N^+ \right\rangle$ that are observed in these figures is an indication of the fact that an experimental verification of them can give unambiguous information about new physics.

In the present work we analyze the possibility of pinning down new physics beyond SM by studying lepton polarizations only. It follows from Eq. (11) that the branching ratio of the $B \to K \ell^+ \ell^-$ decay depends also on the new Wilson coefficients and hence we expect that it can give information about new physics. In this connection there follows the 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 lepton polarizations would not? In order to answer this question, we present in Figs. (11)–(14) 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 $10^{-7} \le \mathcal{B}(B \to K \tau^+ \tau^-) \le 5 \times 10^{-7}$. 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 the pair of Figs. (3), (11); (7), (13) and (8), (14), that if C_T lies in the region $-2 \le C_T \le 0$, the above–mentioned condition, i.e., 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 in search of new physics. Note that in all figures intersection point of all curves correspond to the SM case. This analysis allows us to conclude that there exists certain regions of new Wilson coefficients for which 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., $\langle P_L \rangle \simeq -0.9$, $\langle P_T \rangle \simeq 0.6$ 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 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 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.

References

[1] B. Aubert *et al.*, BaBar Collaboration, preprint: hep–ex/0102030 (2001);
A. Abashian *et al.*, BELLE Collaboration, preprint: hep–ex/0102018 (2001).

[2] Y. Grossman, preprint: hep-ph/0012216 (2000).

[3] T. Goto, Y. Okada, Y. Shimizu and M. Tanaka, *Phys. Rev.* **D55** (1997) 4273;
T. Goto, Y. Okada, Y. Shimizu and M. Tanaka, *Phys. Rev.* **D58**(1998) 094006.

[4] J. L. Hewett and J. D. Wells, *Phys. Rev.* **D55** (1997) 5549.

[5] Y. Grossman, Z. Ligeti and E. Nardi, *Phys. Rev.* **D55** (1997) 2768.

[6] T. G. Rizzo, *Phys. Rev.* **D58** (1998) 114014.

[7] E. Lunghi, A. Masiero, I. Scimemi and L. Silvestini, *Nucl. Phys.* **B568** (2000) 120.

[8] W. -S. Hou, R. S. Willey and A. Soni, *Phys. Rev. Lett.* **58** (1987) 1608.

[9] N. G. Deshpande and J. Trampetic, *Phys. Rev. Lett.* **60** (1988) 2583.

[10] C. S. Lim, T. Morozumi and A. I. Sanda, *Phys. Lett.* **B218** (1989) 343.

[11] B. Grinstein, M. J. Savage and M. B. Wise, *Nucl. Phys.* **B319** (1989) 271.

[12] W. Jaus and D. Wyler, *Phys. Rev.* **D41** (1990) 3405.

[13] P. J. O'Donnell and H. K. Tung, *Phys. Rev.* **D43** (1991) 2067.

[14] A. Ali, T. Mannel and T. Morozumi, *Phys. Lett.* **B273** (1991) 505.

[15] C. Greub, A. Ioannissian and D. Wyler, *Phys. Lett.* **B346** (1995) 145.

[16] G. Burdman, *Phys. Rev.* **D52** (1995) 6400.

[17] A. J. Buras and M. Münz, *Phys. Rev.* **D52** (1995) 186.

[18] N. G. Deshpande, X. -G. He and J. Trampetic, *Phys. Lett.* **B367** (1996) 362.

[19] T. M. Aliev, M. Savcı, *Phys. Lett.* **B452** (1999) 318;
T. M. Aliev, A. Özpineci, H. Koru and M. Savcı, *Phys. Lett.* **B410** (1997) 216;
T. M. Aliev, C. S. Kim and Y. G. Kim, *Phys. Rev.* **D62** (2000) 014026.

[20] Y. G. Kim, P. Ko and J. S. Lee, *Nucl. Phys.* **B544** (1999) 64.

[21] J. L. Hewett, *Phys. Rev.* **D53** (1996) 4964.

[22] F. Krüger and L. M. Sehgal, *Phys. Lett.* **B380** (1996) 199.

[23] S. Fukae, C. S. Kim and T. Yoshikawa, *Phys. Rev.* **D61** (2000) 074015.

[24] T. M. Aliev, M. Savcı, *Phys. Lett.* **B481** (2000) 275.

[25] Qi–Shu Yan, Chao–Shang Huang, Liao Wei, Shou–Hua Zhu, *Phys. Rev.* **D62** (2000) 094023.

[26] T. M. Aliev, K. Çakmak, M. Savcı, preprint: hep–ph/0009133 (2000).

[27] A. Ali, P. Ball, L. T. Handoko and G. Hiller, *Phys. Rev.* **D61** (2000) 074024.

[28] T. M. Aliev, A. Özpineci, M. Savcı, H. Koru, *Phys. Lett.* **B400** (1997) 194.

[29] V. M. Belyaev, A. Khodjamirian, R. Rückl, *Z. Phys.* **C60** (1993) 349.

[30] P. Ball, *JHEP* **9809** (1998) 005.

Figure captions

Fig. (1) The dependence of the average longitudinal polarization asymmetry $\left\langle P_L^- \right\rangle$ of muon on the new Wilson coefficients.

Fig. (2) The dependence of the combined average longitudinal polarization asymmetry $\left\langle P_L^- + P_L^+ \right\rangle$ 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 in Fig. (2), but for the $B \to K \tau^- \tau^+$ decay.

Fig. (5) The same as in Fig. (1), but for the average transversal polarization asymmetry $\left\langle P_T^- \right\rangle$ of muon.

Fig. (6) The same as in Fig. (2), but for the transversal polarization asymmetry $\left\langle P_T^- - P_T^+ \right\rangle$.

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

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

Fig. (9) The dependence of the average normal asymmetry $\left\langle P_N^- \right\rangle$ of muon on the new Wilson coefficients.

Fig. (10) The dependence of the combined average normal polarization asymmetry $\left\langle P_N^- + P_N^+ \right\rangle$ on the new Wilson coefficients for the $B \to K \mu^- \mu^+$ 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 $\left\langle P_L^- \right\rangle$ 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 in the Fig. (11), but for the combined average longitudinal lepton polarization asymmetry $\left\langle P_L^- + P_L^+ \right\rangle$.

Fig. (13) The same as in Fig. (11), but for the average transversal lepton polarization asymmetry $\left\langle P_T^- \right\rangle$.

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

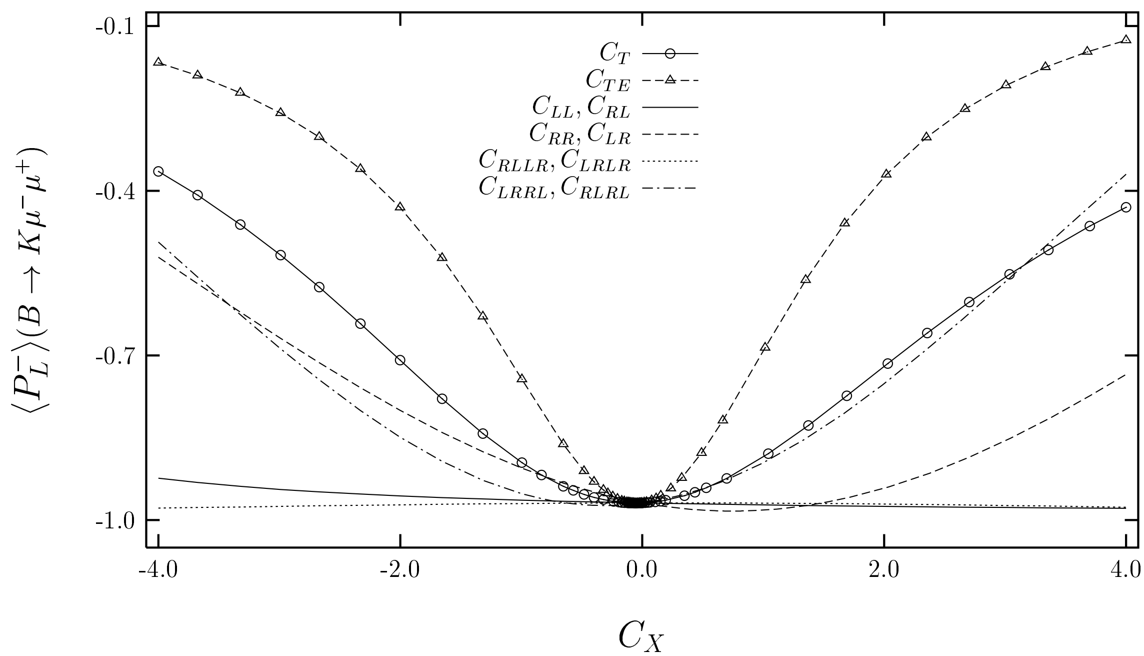

Figure 1:

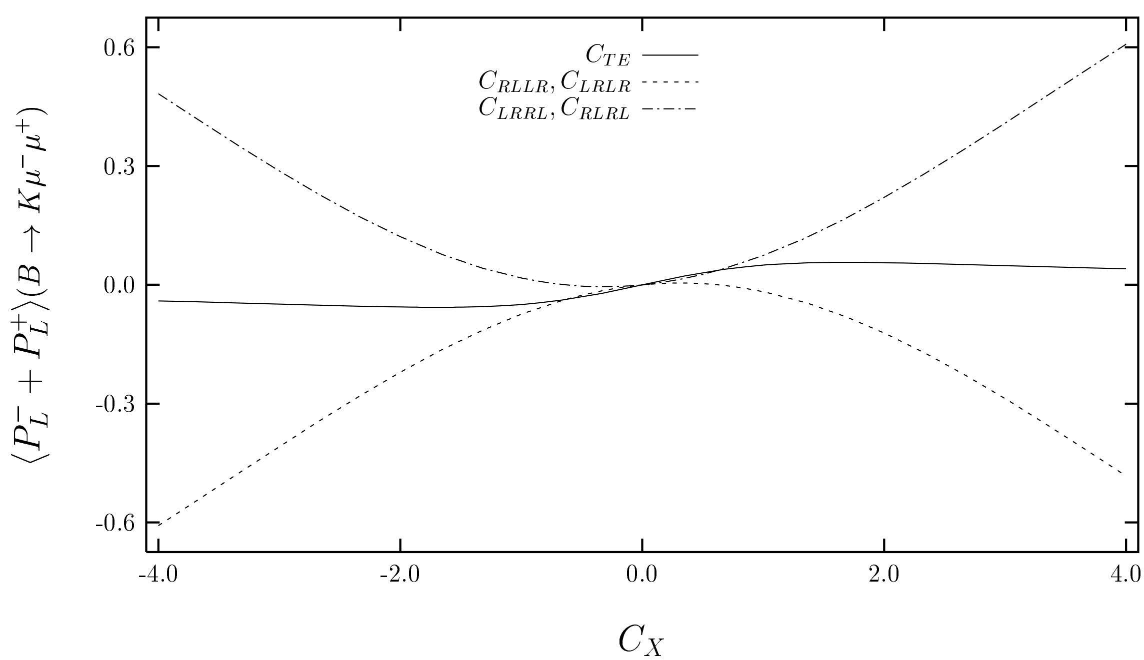

Figure 2:

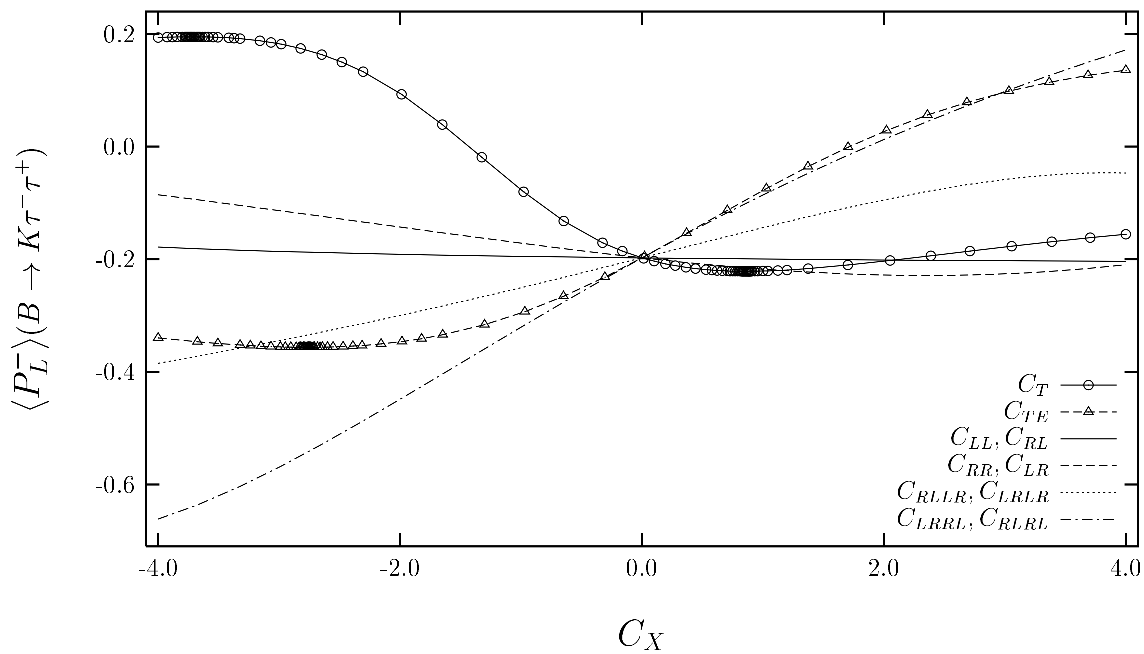

Figure 3:

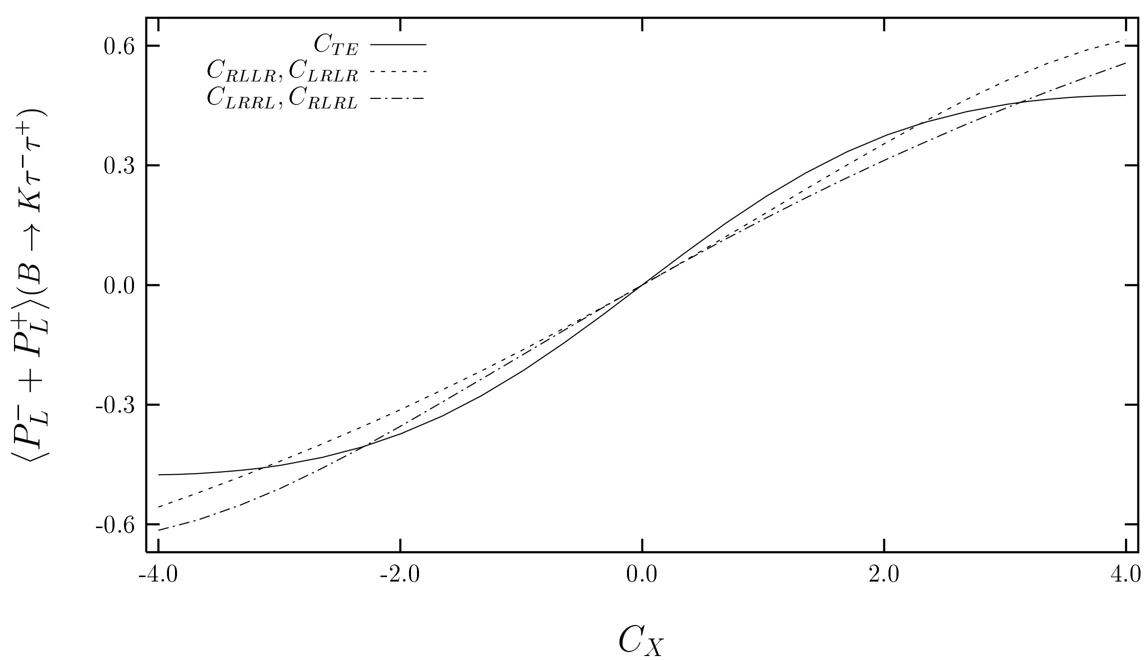

Figure 4:

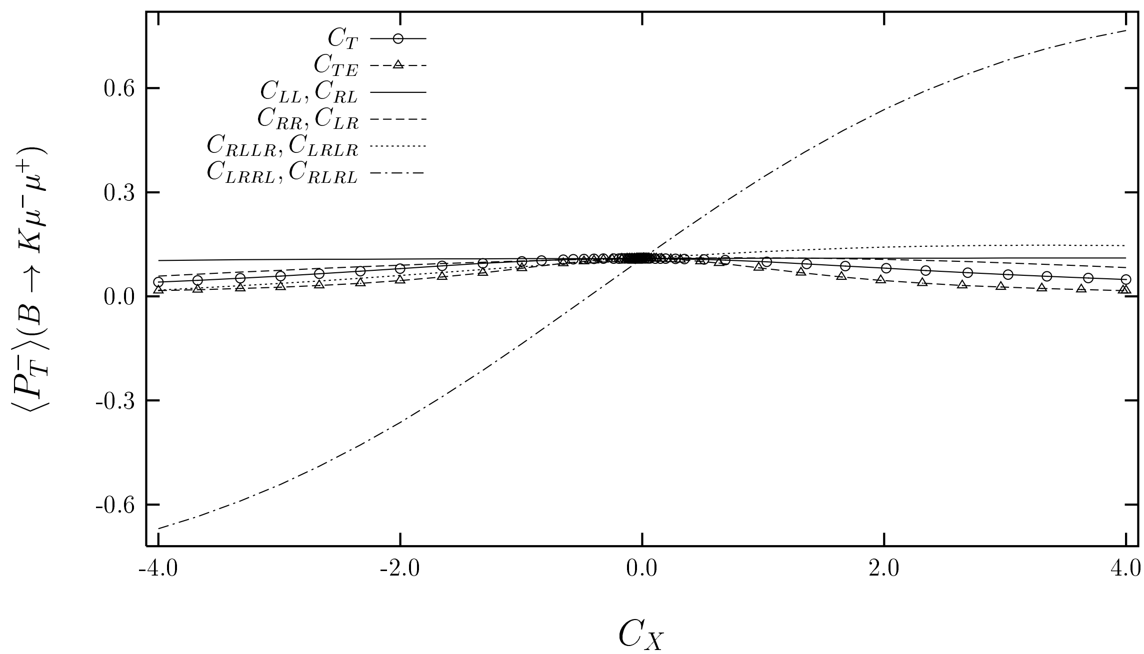

Figure 5:

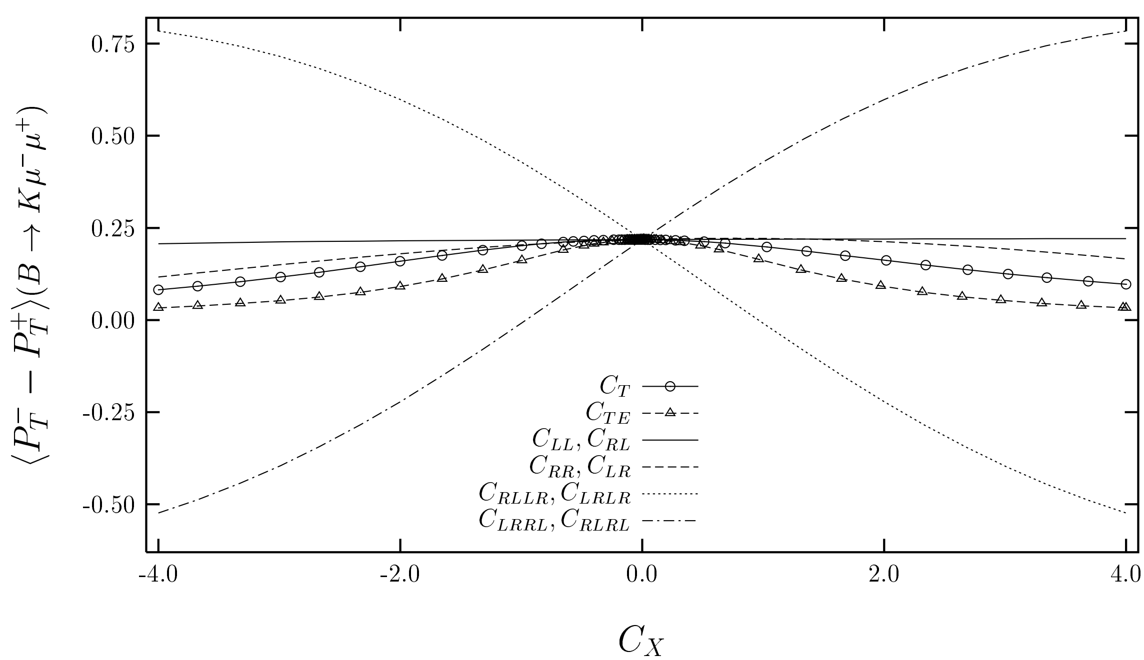

Figure 6:

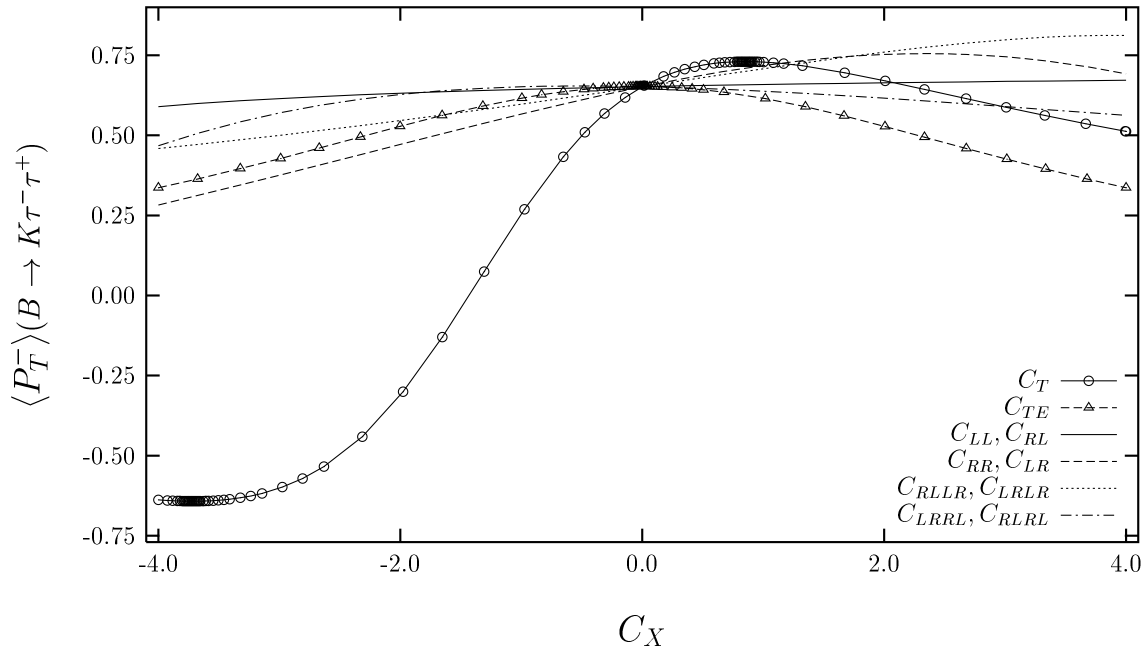

Figure 7:

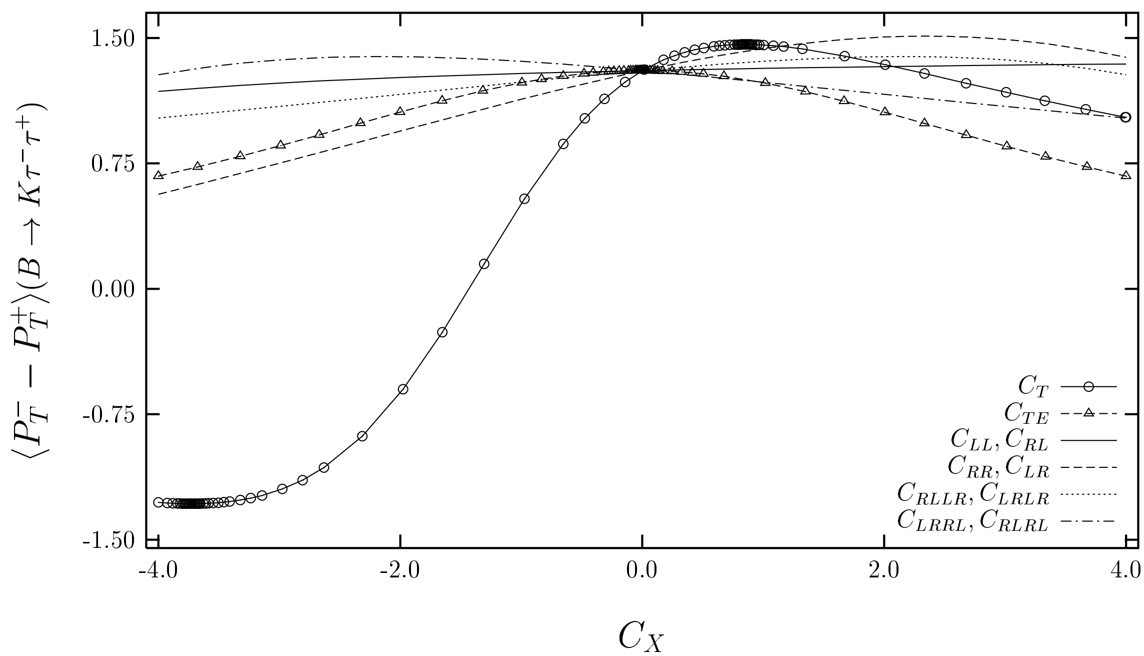

Figure 8:

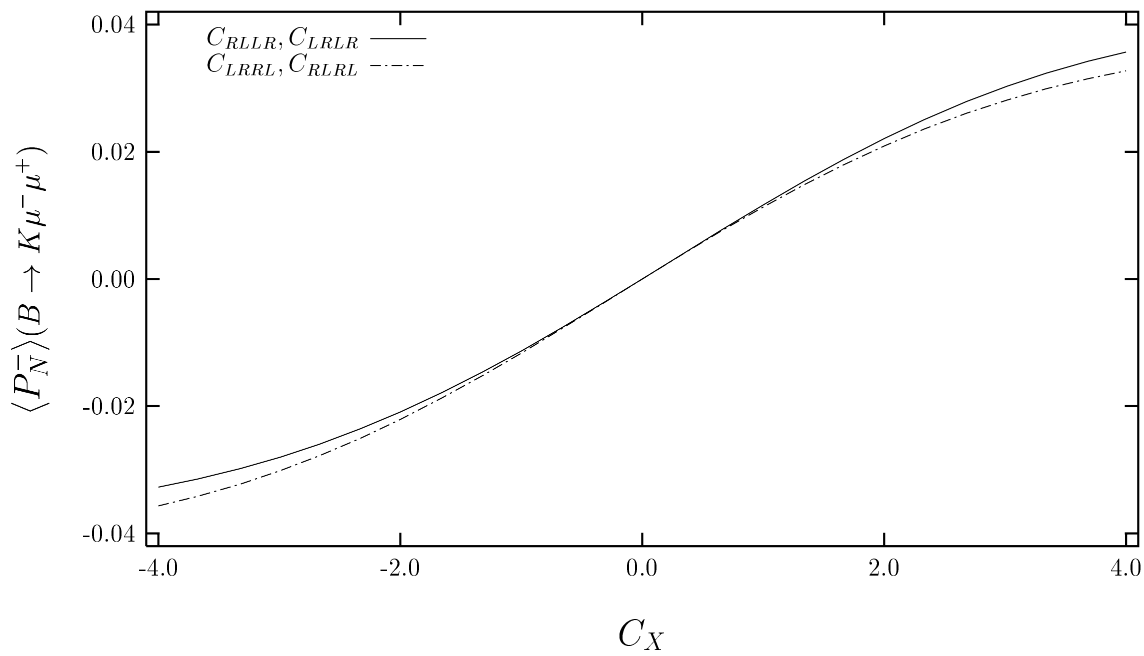

Figure 9:

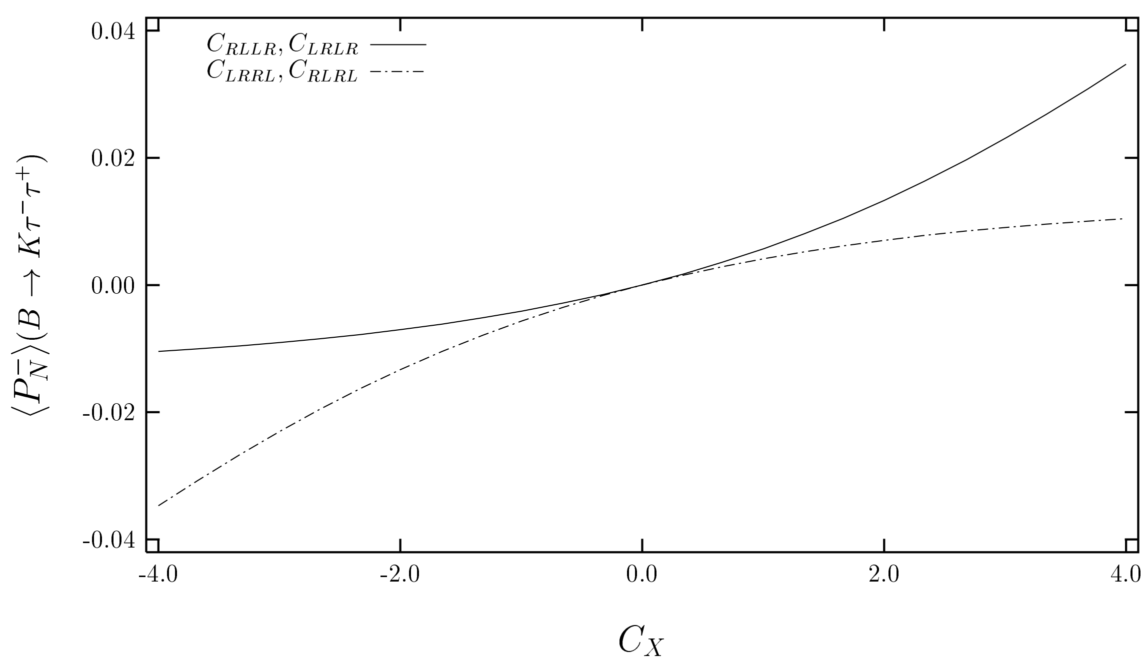

Figure 10:

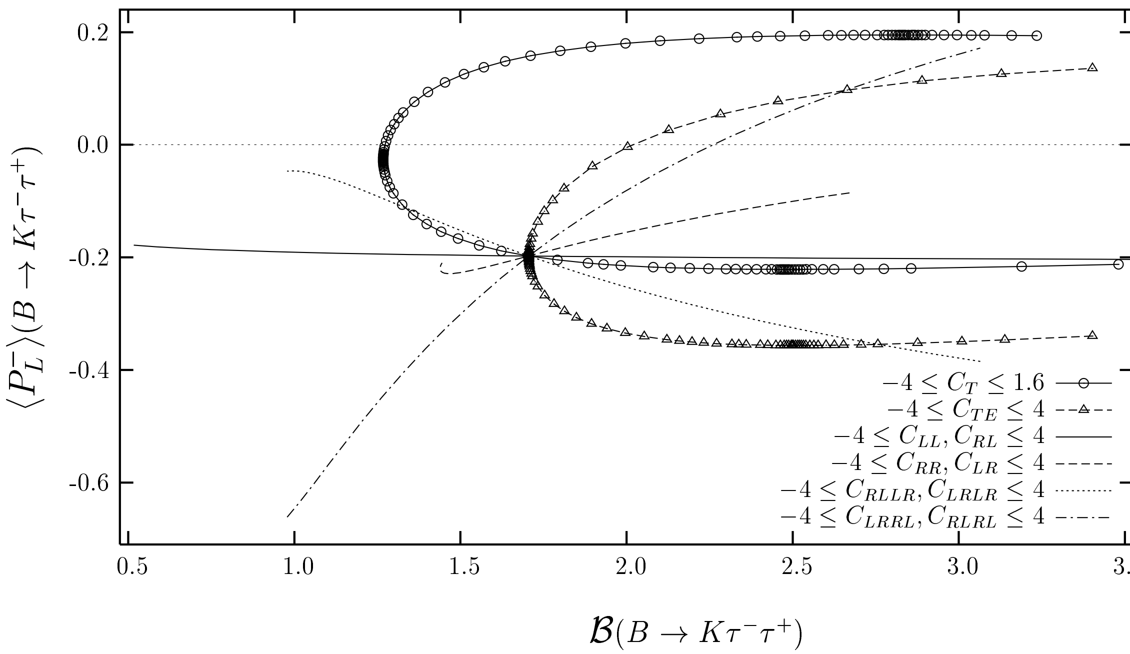

Figure 11:

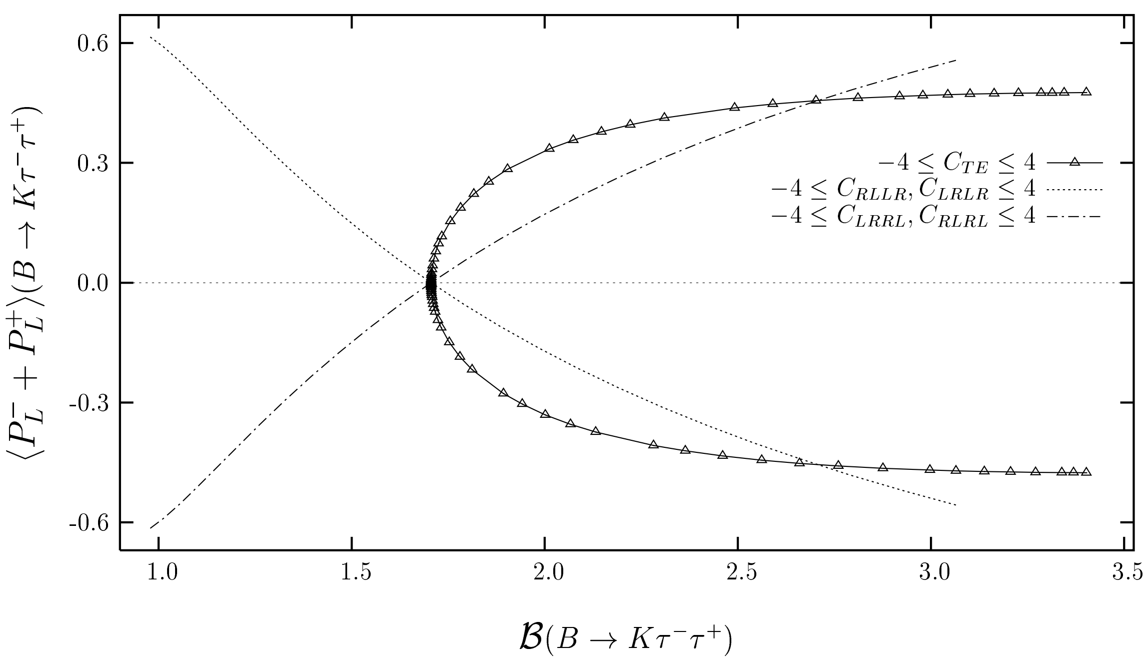

Figure 12:

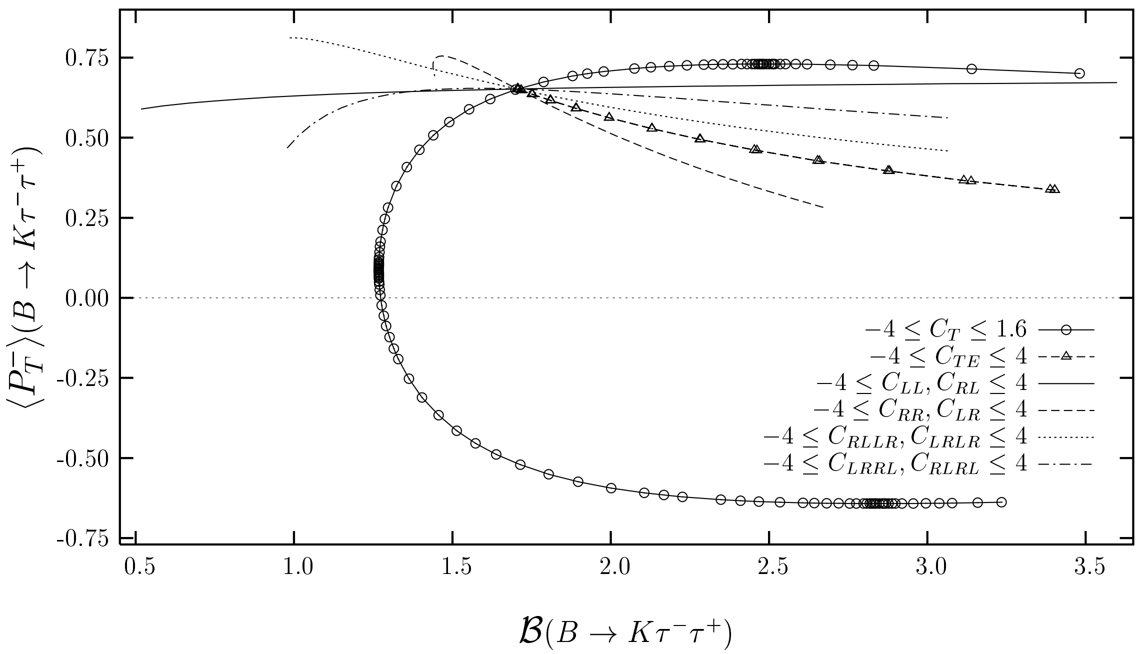

Figure 13:

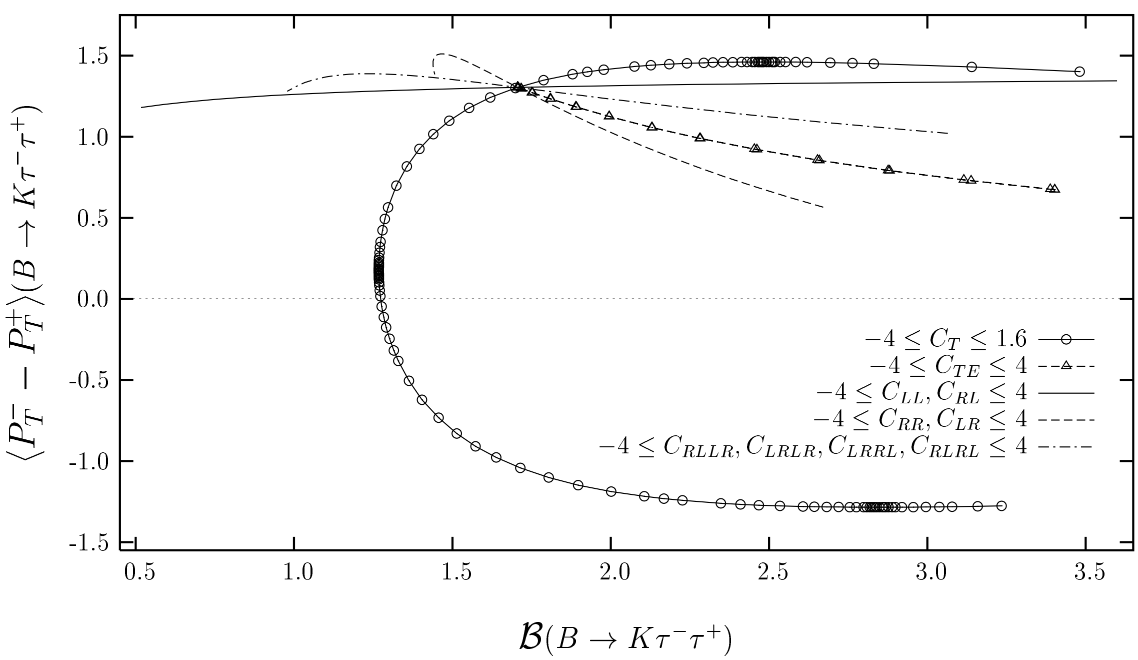

Figure 14: