Lepton Polarization Asymmetry in $B \to \ell^+\ell^-$ decay Beyond the Standard Model

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Abstract

The lepton polarization asymmetry in the $B \to \ell^+\ell^-$ decay, when one of the leptons is polarized, is investigated using the most general form of the effective Hamiltonian. The sensitivity of the asymmetry to the new Wilson coefficients is studied.Moreover, correlations between the lepton polarization asymmetry and the branching ratio is studied. It is observed that, there are not exist such regions of new Wilson coefficients, which the value of branching ratio coincides with SM result while the lepton polarization does not, i.e new physics effects can be established by studying lepton polarization only.

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1 Introduction

The study of rare B-decays is one of the most important research areas in particle physics. These decays induced by flavor changing neutral currents (FCNC) and provide a promising ground for testing the structure of weak interactions. These decays are forbidden in the standard model(SM) at tree level and for this reason represent " very good laboratory " for checking predictions of the SM at loop level. Moreover, these decays are very sensitive to the new physics beyond the SM, since loop with new particles can give considerable contribution to SM result. The new physics effects in rare decays can appear in two different ways, namely modification of Wilson coefficients existing is SM or through new operators with new Wilson coefficients which absent in SM.

The rare pure leptonic $B_q \to \ell^+\ell^-(q = d, s$ and $\ell = e, \mu, \tau$)decays are very good probes to test new physics beyond the standard model , mainly to reveal the Higgs sector[1-3].

In aim of the present work is , investigation of the lepton polarization as a tool for establishing new physics beyond the SM, using the most general form of effective Hamiltonian. More precisely our goal is following: Can we find such a regions of new Wilson coefficients for which lepton polarization differ from SM prediction, while branching ratio coincides with SM result. Note that lepton polarization for $B_q \to \ell^+\ell^-$ decay is studied in [4].

The paper is organized as follows: In Section 2 , we present the theoretical expression for the decay widths and lepton polarizations. Section 3 is devoted to numerical analysis and conclusion.

2 Double-Lepton polarization Asymmetry

In this section we obtained the expression for decay width and lepton polarization asymmetry, using the more general model independent form of 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 following form [5, 6]

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

Where L and R in (1) are

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

and C_x are the coefficients of the fourFermi interactions and $q=p_2+p_1$ is the momentum transfer. Among twelve Wilson coefficients some of them are already exist in the SM. For example, the coefficients C_{SL} and C_{BR} in penguin operators correspond to $-2m_sC_7^{eff}$ and $-2m_bC_7^{eff}$ 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 $C_{LRLR}, C_{RLLR}, C_{LRRL}$ andC_{RLRL} describe the scalar type interactions. The last two terms with the coefficients C_T and C_{TE}, obviously, describe the tensor type interactions. The amplitude of exclusive $B\to\ell^+\ell^-$ decay is obtained by sandwiching of effective Hamiltonian between meson and vacuum states. It follows from Eq. (1) that in order to calculate the amplitude of the $B\to\ell^+\ell^-$ decay, following matrix elements are needed:

$$\begin{aligned}\langle 0|\overline{s}\,\gamma_\mu\gamma_5\,b|B\rangle &= -if_{Bs}p_\mu\,,\\ \langle 0|\overline{s}\,\gamma_5\,b|B\rangle &= if_{Bs}\frac{m_{Bs}^2}{m_b+m_s}\,,\end{aligned}\tag{2}$$

All remaining matrix elements $\langle 0|\overline{s}\,\Gamma_i\,b|B\rangle$, where is one of the Dirac matrices $I\ ,\gamma_\mu\ ,\sigma_{\alpha\beta}$ are equal zero.

For the matrix element of $B\to\ell^+\ell^-$ decay we get

$$M=if_B\frac{G_F\alpha}{2\sqrt{2}\pi}V_{ts}V_{tb}^*\Big[C_{PV}\,\overline{\ell}\,\gamma^5\ell\;+\;C_{PS}\,\overline{\ell}\,\ell\Big]\tag{3}$$

where pseudovector coefficient C_{PV} and pseudoscalar coefficient C_{PS} are as following:

$$\begin{aligned}C_{PV}&=m_\ell(C_{LL}^{tot}-C_{LR}^{tot}-C_{RL}+C_{RR})+\frac{m_B^2}{2(m_b+m_s)}(C_{LRLR}-C_{RLLR}-C_{LRRL}+C_{RLRL})\,,\\ C_{PS}&=\frac{m_B^2}{2(m_b+m_s)}(C_{LRLR}-C_{RLLR}+C_{LRRL}-C_{RLRL})\,,\end{aligned}\tag{4}$$

After some calculation we get following expression for the un polarized $B\to\ell^+\ell^-$ decay width

$$\Gamma_0 = f_B^2\frac{1}{16\,\pi\,m_B}\left|\frac{G_F\alpha}{2\sqrt{2}\pi}V_{tb}\,V_{ts}^*\right|^2\Big\{2\,C_{PV}^2\,m_B^2+2\,C_{PS}^2\,m_B^2\,\upsilon^2\Big\}\upsilon\tag{5}$$

where $\upsilon = \sqrt{1 \; - \; m_\ell^2/m_B^2}$ is the final lepton velocity.

Now let get expression for the lepton polarization. In the rest frame of final leptons one can define only one direction. Therefore the unit vectors of each lepton polarization can defined as

$$s^\mu = (0, \; \overrightarrow{e}_L^{\mp}) = (0, \; \mp\frac{\overrightarrow{p}_-}{|\overrightarrow{p}_-|}) \tag{6}$$

where is the tree momentum of ℓ^- and subscript L means longitudinal polarization. Boosting these unit vectors to the dilepton center of mass frame by using Lorentz transformation we get

$$s^\mu_{\ell^\mp} = (\frac{|\overrightarrow{p}_-|}{m_\ell}, \; \mp\frac{E_\ell \overrightarrow{p}_-}{m_\ell |\overrightarrow{p}_-|}) \tag{7}$$

$$\tag{8}$$

where E_ℓ is the lepton energy.

The decay width of the $B \to \ell^+\ell^-$ decay can written in following form

$$\Gamma \; = \; \frac{1}{2} \; \Gamma_0 \; \{1 \; + \; P_L^\mp \; \overrightarrow{e}_L^\mp \; . \overrightarrow{n}^\mp\} \tag{9}$$

$$\tag{10}$$

where P_L is longitudinal lepton polarization asymmetry. It define as follows:

$$P_L^\mp \;\; = \;\; \frac{\Gamma(\overrightarrow{n}^\mp \;\; = \;\; \overrightarrow{e}_L^\mp) \; - \; \Gamma(\overrightarrow{n}^\mp \;\; = \;\; -\overrightarrow{e}_L^\mp)}{\Gamma(\overrightarrow{n}^\mp \;\; = \;\; \overrightarrow{e}_L^\mp) \; + \; \Gamma(\overrightarrow{n}^\mp \;\; = \;\; -\overrightarrow{e}_L^\mp)} \tag{11}$$

The explicit expression of longitudinal polarization asymmetry is:

$$P_L^\mp \;\; = \;\; \frac{2 \; Re(C_{PV} \; C_{PS}^*) \; \upsilon}{C_{PS}^2 \; \upsilon^2 \; + \; C_{PV}^2} \tag{12}$$

From this expression it is obvious that in SM lepton polarization asymmetry $P_L^\mp \;\; = \;\; 0$ since in SM $C_{PS} \;\; = \;\; 0$ (see eq. (4)).

3 Numerical analysis

. In this section, we study the dependency of P_L on new Wilson coefficients. In the present work all new Wilson coefficients are taken to be real. Here we would like to made following remark. Recent experimental results on the B meson decay into two pseudoscalar meson indicated that Wilson coefficient C_{10} can has large phase[7]. Therefore in principal appear new source for CP violating effects. We will discuss this possibility elsewhere. In performing numerical analysis we will vary the new Wilson coefficients describing the scalar interactions, in the range $-4 \leq |C_{ii}| \leq 4$. The experimental result on branching ratio of $B \to K(k^*)\ell^+\ell^-$ [8, 9]

and the bound on branching ratio of the $B \to \ell^+\ell^-$ [10] decay suggest that this is the right order of magnitude for scalar interaction.

Now we are ready to perform numerical calculations. The values of input parameters which we have used in our numerical analysis are:

$f_{Bs} = 0.245$ Gev [11], $m_B = 5.279.2 \pm\ 1.8$ Mev, $m_\mu = 105.7$ Gev, $m_\tau = 1777$ Mev, $\alpha = \frac{1}{129}$

The values of these parameters taken from [12].

In Fig. 1 we present the dependence of longitudinal polarization of the lepton on Wilson coefficients of scalar interactions C_{LRLR}, C_{RLLR}, C_{LRRL} and C_{RLRL} for $B \to \mu^+\mu^-$decay. It should be noted that zero value of Wilson coefficients for scalar interactions corresponds to the standard model, case.

From this figure we see that contributions coming from C_{RLRL} and C_{LRLR} also, C_{LRRL} and C_{RLLR} are equal in magnitude but differ with sign. The similar circumstance take place for $B \to \tau^+\tau^-$decay (see Fig. 2). Therefore measurement the magnitude and sign of the lepton polarization can give unambiguous information about nature of scalar interaction.

Obviously, if new physics beyond the SM exist, their effects can be appears in branching ratio, besides the lepton polarization. It is well known that the measurement of the branching ratio is more easy, that the lepton polarization. For this reason, it is more convenient and easy to study to study the branching ratio than the polarization, for establishing new physics beyond the standard model.

In this connection we could like to discuss following problem: Can be establish new physics only by measuring lepton polarization. In other world, do exist such a regions of new Wilson coefficients, for which branching ratio coincides with the SM prediction, while lepton polarization do not. In order to answer this question, we study the correlations of single lepton polarization and branching ratio (see Fig. 3 and Fig. 4).

From Figs. 3 and 4 we see that there are not exist such for regions of Wilson coefficients for which branching ratios coincides with the SM result, while lepton polarization do not.

In summary, we present analysis for the longitudinal lepton polarization using the most general form of the effective Hamiltonian. We found that measurement of lepton polarization can provide us essential information about nature of scalar interaction. Moreover, we obtained that there are not exist such regions for the new Wilson coefficients, for which the only measurement of the lepton polarization gives invaluable information in looking for new physics beyond the SM.

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Figure Captions

Fig. (1) The dependence of longitudinal polarization asymmetry P_L on new Wilson coefficients responsible for scalar interactions for the $B \to \mu^+\mu^-$ decay. Here the solid, dashed, doted and small dashed lines corresponds to C_{LRLR}, C_{RLLR},C_{RLRL} and C_{LRRL}, respectively.

Fig. (2) The same as **Fig. (1)**, but for the $B \to \tau^+\tau^-$ decay.

Fig. (3) Parametric plot of the correlation between longitudinal lepton polarization asymmetry and branching ratio for the $B \to \mu^+\mu^-$ decay. The vertical line corresponds to SM result for branching ratio. In this figure, solid line corresponds to the Wilson coefficients C_{LRLR} and C_{RLRL} , and dashed line C_{LRRL} and C_{RLLR}, respectively.

Fig. (4) The same as **Fig. (3)**, but for the $B \to \tau^+\tau^-$ decay.

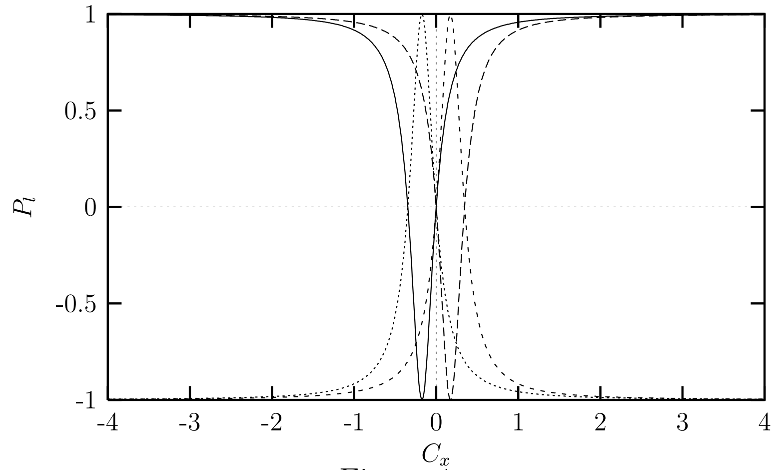

Figure 1:

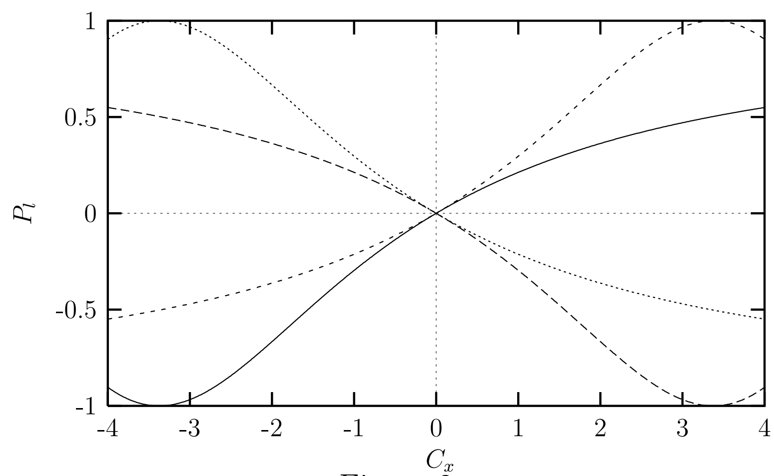

Figure 2:

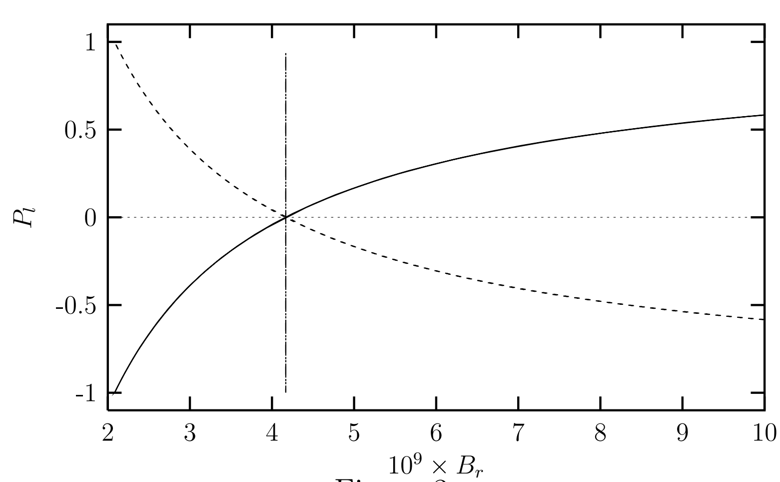

Figure 3:

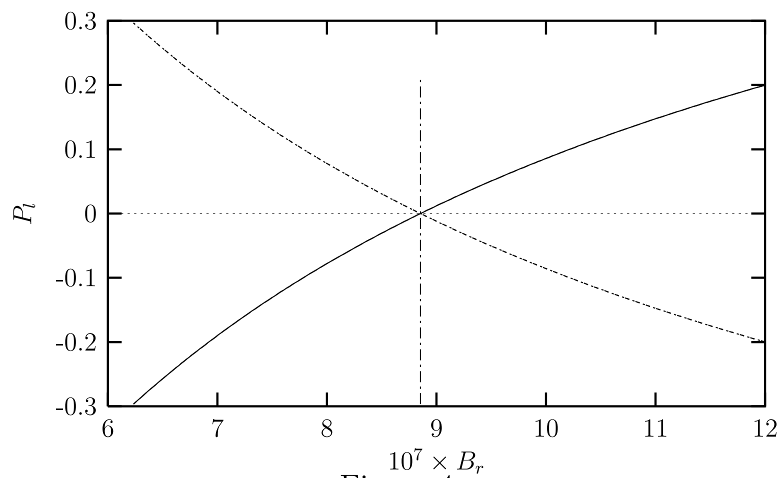

Figure 4: