Semileptonic $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay in the Leptophobic $Z'$ Model

B. B. Şirvanlı
Gazi University, Faculty of Arts and Science, Department of Physics
06100, Teknikokullar Ankara, Turkey

March 26, 2022

Abstract

We study the exclusive flavor changing neutral current process $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ in the leptophobic $Z'$ model, where charged leptons do not couple to the extra $Z'$ boson. The branching ratio, as well as, the longitudinal, transversal and normal polarizations are calculated. It has been shown that all these physical observables are very sensitive to the existence of new physics beyond the standard model and their experimental measurements can give valuable information about it.

PACS number(s): 12.60.–i, 13.20.–v, 13.20.He
1 Introduction

Flavor-changing neutral current (FCNC) processes present as stringest tests of the Standard Model (SM) as well as looking for new physics beyond the SM. In SM, FCNC processes take place only at the loop level and therefore these decays are suppressed and for this reason experimentally their measurement is difficult. Recently, B factory experiments such as Belle and BaBar have measured FCNC decays due to the $b \to s \ell^+ \ell^-$ transition at inclusive and exclusive level [1,2,3,4]. Theoretically, the $b \to s \ell \ell$ transition is described by the effective Hamiltonian and the FCNC’s are represented by QCD penguin and electroweak penguin (EW) operators. The EW operators appear in the photon and Z mediated diagrams. Although it is experimentally very difficult to measure, $B \to X \nu \bar{\nu}$ decay is an extremely good and "pure" channel to study Z mediated EW penguin contribution within the SM and its beyond [5,6,7,8,9].

Another exclusive decay which is described at inclusive level by the $b \to s \ell^+ \ell^-$ transition is the baryonic $\Lambda_b \to \Lambda \ell \ell$ decay. Unlike the mesonic decays, the baryonic decay could maintain the helicity structure of the effective Hamiltonian for the $b \to s$ transition [10].

In this work, we study the $\Lambda_b \to \Lambda \nu \bar{\nu}$ decay in the leptophobic $Z'$ Model, as a possible candidate of new physics in the EW penguin sector. The leptophobic $Z'$ gauge bosons appear naturally in Grand Unified Theories and string inspired $E_6$ models. Here we would like to note that a similar mesonic $B \to K(K^*) \nu \bar{\nu}$ decay and $\Delta m_{B_s}$ mass difference of $B_s$ meson in the context of leptophobic $Z'$ model are studied in [11] and [12], respectively. In section 2, we briefly consider the leptophobic model based on $E_6$ model. In section 3, we present the analytical expressions for the branching ratio and the longitudinal, transverse and normal polarizations of $\Lambda_b$ baryon, as well as polarization of $\Lambda_b$. In Section 4, we give numerical analysis and our concluding remarks.

2 Theoretical background on leptophobic $Z'$ model

In this section we briefly review the leptophobic $Z'$ model. From GUT or string-inspired point of view, the $E_6$ model [13] is a very natural extension of the SM. In this model $U(1)'$ gauge group remains after the symmetry breaking of the $E_6$ group. We assume that the $E_6$ group is broken through the following way $E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi \to SU(2)_L \times U(1) \times U(1)'$, where $U(1)'$ is a linear combination of two additional $U(1)$ gauge groups with $Q' = Q_\psi \cos \theta - Q_\chi \sin \theta$, where $\theta$ is the mixing angle. When all couplings are GUT normalized, the interaction, Lagrangian of fermions with $Z'$ gauge boson can be written as

$$\mathcal{L}_{int} = -\lambda \frac{g_2}{\cos \theta_w} \sqrt{\frac{5}{3} \sin^2 \theta_w} \bar{\psi} \gamma_\mu \left( Q' + \sqrt{\frac{3}{5}} \delta Y_{SM} \right) \psi Z'_\mu, \quad (1)$$

where $\lambda = \frac{g'_o}{g_o}$ is the ratio of gauge couplings $\delta = -\tan \chi / \lambda$ [14]. In the general case fermion–$Z'$ gauge boson couplings contain two arbitrary free parameters $\tan \theta$ and $\delta$ [15]. From Eq.(1), it follows that the $Z'$ gauge boson can be leptophobic when $Q' + \sqrt{\frac{3}{5}} \delta Y_{SM} = 0$ for the lepton doublet and $e^c$, simultaneously. In the conventional embedding, the $Z'$ boson can be made leptophobic with $\delta = -1/3$ and $\tan \theta = \sqrt{\frac{5}{3}}$. In the Leptophobic $Z'$ model, FCNC’s can arise through the mixing between SM fermions and exotic fermions. In principle, the mixing of the left handed
fermions can lead to the large Z-mediated FCNC’s. In order to forbid this large Z-mediated FCNC’s, we consider the case when mixing take place only between the right-handed fermions. So, the mixing between right-handed ordinary and exotic fermions can induce the FCNC’s when their Z’ charges are different [16]. In the Leptophobic Z’ model, the Lagrangian for \( b \to q(q = s, d) \) transition containing FCNC at tree level can be written as

\[
\mathcal{L}^{Z'} = -\frac{g_2}{2 \cos \theta_w} U_{qb}^{Z'} q_R \gamma^\mu b_R Z'_\mu .
\]  

Using upper experimental bounds on branching ratio for the \( B \to K \nu \bar{\nu} \) [17] and \( B \to \pi \nu \bar{\nu} \) [18] in [11] for model parameters \( U_{sb}^{Z'} \) and \( U_{db}^{Z'} \) following bounds are obtained: \( |U_{sb}^{Z'}| \leq 0.29 \) and \( |U_{db}^{Z'}| \leq 0.61 \). Analysis of \( \Delta m_{B_s} \) leads to the more stringent bound for the \( U_{sb}^{Z'} \) [12]: \( |U_{sb}^{Z'}| \leq 0.036 \) at \( m_{Z'} = 700 GeV \) and \( |U_{db}^{Z'}| \leq 0.051 \) at \( m_{Z'} = 1 TeV \). These constraints on \( U_{qb}^{Z'} \) we will use in our numerical calculations.

3 Matrix Elements for the \( \Lambda_b \to \Lambda \nu \bar{\nu} \) Decay

The \( \Lambda_b \to \Lambda \nu \bar{\nu} \) decay at quark level is described by \( b \to s \nu \bar{\nu} \) transition. In the SM, effective Hamiltonian responsible for the \( b \to s \nu \bar{\nu} \) transition is given by

\[
\mathcal{H}^{SM}_{eff} = \frac{G_F \alpha}{2 \pi \sqrt{2}} V_{tb} V_{ts} C_{10} \bar{s} \gamma_\mu (1 - \gamma_5) b \nu \bar{\nu}(1 - \gamma_5) \nu ,
\]

where \( G_F \) and \( \alpha \) are the Fermi and fine structure constant respectively, \( V_{tb} \) and \( V_{ts} \) are elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, \( C_{10} \) is the Wilson coefficient whose explicit form can be found in [17,18,19]. As we have already mentioned, in the leptophobic model, \( U(1)' \) charge is zero for all the ordinary left and right handed lepton fields within the SM. However, 27 representation of \( E_b \) contain new right handed neutrino which is absent in SM and it can give additional contribution to the processes due to the \( b \to s \nu \bar{\nu} \) transition. Then the effective Hamiltonian describing \( b \to s \nu_R \bar{\nu}_R \) transition can be written as

\[
\mathcal{H}^{new}_{eff} = \frac{\pi \alpha}{\sin^2 \frac{2 \theta_w M_{Z'}}{2}} U_{sb}^{Z'} Q_{\nu_R} \bar{s} \gamma_\mu (1 + \gamma_5) b \nu \bar{\nu}(1 + \gamma_5) \nu ,
\]

where \( Q_{\nu_R}^{Z'} = \frac{1}{2} x \sqrt{\frac{2 \sin^2 \theta_w}{3}} \). \( U_{qb}^{Z'} \) and \( x \) are model dependent parameters and we take \( x = 1 \) for simplicity. Having effective Hamiltonian for \( b \to s \nu \bar{\nu} \) transition, our next problem is the derivation of the decay amplitude for the \( \Lambda_b \to \Lambda \nu \bar{\nu} \) decay, which can be obtained by calculating the matrix element of the effective Hamiltonian for \( b \to s \nu \bar{\nu} \) transition between initial \( \Lambda_b \) and final \( \Lambda \) baryon states. It follows that the matrix elements \( \langle \Lambda | \bar{s} \gamma_\mu (1 + \gamma_5) b | \Lambda_b \rangle \) are needed for calculating the decay amplitude for the \( \Lambda_b \to \Lambda \nu \bar{\nu} \) decay. These matrix elements parametrized in terms of the form factors are as follows ([20],[21])

\[
\langle \Lambda | \bar{s} \gamma_\mu b | \Lambda_b \rangle = \bar{u}_\Lambda \left[ f_1 \gamma_\mu + i f_2 \sigma_{\mu \nu} q^\nu + f_3 q_\mu \right] u_{\Lambda_b} ,
\]
\[ \langle \Lambda | \bar{s} \gamma_\mu \gamma_5 b | \Lambda_b \rangle = \bar{u}_\Lambda \left[ g_1 \gamma_\mu \gamma_5 + i g_2 \sigma_\mu \nu q' \gamma_5 + g_3 q_\mu \gamma_5 \right] u_{\Lambda_b} \]  

(6)

where \( q = p_{\Lambda_b} - p_\Lambda \) is the momentum transfer and \( f_i \) and \( g_i \) (\( i = 1, 2, 3 \)) are the form factors. Note that form factors \( f_3 \) and \( g_3 \) do not give contribution to the considered decay since neutrinos are massless. Using Eqs. (3)-(4)-(6) and (7) for the decay amplitude of the \( \Lambda_b \rightarrow \Lambda \nu \bar{\nu} \) decay in leptonophobic model, we have

\[ \mathcal{M} = \frac{\alpha G_F}{\sqrt{2}} V_{tb} V_{ts}^* C_{10} \left\{ \bar{\nu} \gamma_\mu (1 - \gamma_5) \nu \times \bar{u}_\Lambda \left[ A_1 \gamma_\mu (1 + \gamma_5) + B_1 \gamma_\mu (1 - \gamma_5) \right] u_{\Lambda_b} 
+ i \sigma_\mu \nu q' A_2 (1 + \gamma_5) + B_2 (1 - \gamma_5) \right\} u_{\Lambda_b} + C_{RR} \bar{\nu} \gamma_\mu (1 + \gamma_5) \nu \times \bar{u}_\Lambda \left[ B_1 \gamma_\mu (1 + \gamma_5) + A_1 \gamma_\mu (1 - \gamma_5) \right] u_{\Lambda_b} + i \sigma_\mu \nu q' B_2 (1 + \gamma_5) + A_2 (1 - \gamma_5) \right\} u_{\Lambda_b} \right\}, \]  

(7)

where \( C_{RR} = \frac{\pi Q_{U} Z'}{\alpha \bar{v} V_{ts}^* C_{10} m_{\Lambda_b}^2} \). It is shown in [21] that when HQET is applied the number of independent form factors are reduced to two (\( F_1 \) and \( F_2 \)), irrelevant of the Dirac structure of the corresponding operators, i.e.,

\[ \langle \Lambda(p_\Lambda) | \bar{s} \Gamma b | \Lambda(p_{\Lambda_b}) \rangle = \bar{u}_\Lambda \left[ F_1 (q^2) + g^2 F_2 (q^2) \right] \Gamma u_{\Lambda_b}, \]  

where \( \Gamma \) is an arbitrary Dirac matrix and \( \nu^\mu = p^\mu / m_{\Lambda_b} \) is the four velocity of \( \Lambda_b \). Using this result we get

\[ f_1 = g_1 = F_1 + \sqrt{r} F_2, \]

\[ f_2 = g_2 = \frac{F_2}{m_{\Lambda_b}}, \]  

(8)

where \( r = m_{\Lambda}^2 / m_{\Lambda_b}^2 \).

Our next problem is the calculation of \( \Lambda \) baryon polarizations using the matrix element in Eq.(7). In the rest frame of \( \Lambda \), the unit vectors along the longitudinal, normal and transversal components of \( \Lambda \) are chosen as

\[ s^\mu_L = (0, \bar{e}_L) = \left( 0, \frac{\vec{p}_\Lambda}{|\vec{p}_\Lambda|} \right), \]

\[ s^\mu_T = (0, \bar{e}_T) = \left( 0, \frac{\bar{e}_L \times \vec{\xi}_{\Lambda_b}}{|\bar{e}_L \times \vec{\xi}_{\Lambda_b}|} \right), \]

\[ s^\mu_N = (0, \bar{e}_N) = (0, \bar{e}_L \times \bar{e}_T). \]  

(9)

The longitudinal component of the \( \Lambda \) baryon polarization is boosted to the center of mass frame of the neutrino–antineutrino pair by Lorentz transformation, yielding

\[ \langle s^\mu_L \rangle_{CM} = \left( \frac{|\vec{p}_\Lambda|}{m_\Lambda}, \frac{E_\Lambda \vec{p}_\Lambda}{m_\Lambda |\vec{p}_\Lambda|} \right). \]  

(10)
where $E_\Lambda$ and $m_\Lambda$ are the energy and mass of the $\Lambda$ baryon in the CM frame of neutrino–antineutrino pair. The remaining two unit vectors $s_T^\mu$ and $s_N^\mu$ are unchanged under Lorentz transformation.

After integration over neutrino and antineutrino momentum the differential decay rate of the $\Lambda_b \rightarrow \Lambda\nu\bar{\nu}$ decay for any spin direction $\xi$ along the $\Lambda$ baryon can be written as (in the rest frame of $\Lambda_b$)

$$d\Gamma = \frac{1}{4} d\Gamma^0 \left[ 1 + \frac{I_1}{I_0} \hat{e}_L \cdot \hat{\xi}_{\Lambda b} \right] \left[ 1 + \bar{P}_\Lambda \cdot \hat{\xi}_{\Lambda} \right].$$  \hspace{1cm} (11)

$$\bar{P}_\Lambda = \frac{1}{1 + \frac{I_1}{I_0} \hat{e}_L \cdot \hat{\xi}_{\Lambda b}} \left[ \left( \frac{I_2}{I_0} + \frac{I_3}{I_0} \hat{\xi}_{\Lambda b} \right) \hat{e}_L + \frac{I_4}{I_0} \hat{e}_N + \frac{I_5}{I_0} \hat{e}_T \right]$$ \hspace{1cm} (12)

$$d\Gamma^0 = \frac{3G_F^2 \alpha_{em}^2 |V_{tb}V_{ts}^*|^2 |C_{10}|^2}{32.32.4\pi^7 m_\Lambda} |\mathbf{p}_\Lambda| I_0 dE_\Lambda d\Omega_\Lambda$$ \hspace{1cm} (13)

The functions $I_i$ in Eq.(13) have following expressions:

$$I_0 = \frac{32}{3} \pi \left\{ (q^2 p_\Lambda \cdot p_{\Lambda b} + 2 p_\Lambda \cdot q p_{\Lambda b} \cdot q)(|A_1|^2 + |B_1|^2 + |C_{RR}|^2(|B_1|^2 + |A_1|^2)) + (q^2 p_\Lambda \cdot p_{\Lambda b} - 4 p_\Lambda \cdot q p_{\Lambda b} \cdot q)q^2(|A_2|^2 + |B_2|^2 + |C_{RR}|^2(|B_2|^2 + |A_2|^2)) + 6m_\Lambda q^2 p_{\Lambda b} \cdot q \left[ Re[A_1 A_2^*] + Re[B_1 B_2^*] + |C_{RR}|^2 Re[B_1 B_2^*] + |C_{RR}|^2 Re[A_1 A_2^*] \right] - 6m_\Lambda q^2 p_{\Lambda b} \cdot q \left[ Re[A_2 B_1^*] + Re[A_1 B_2^*] + |C_{RR}|^2 Re[B_2 A_1^*] + |C_{RR}|^2 Re[B_1 A_2^*] \right] - 6m_\Lambda q^2 p_{\Lambda b} \cdot q \left[ Re[A_1 B_1^*] + q^2 Re[A_2 B_2^*] + |C_{RR}|^2 Re[B_1 A_1^*] \right] + |C_{RR}|^2 q^2 Re[B_2 A_2^*] \right\}$$ \hspace{1cm} (14)

$$I_1 = \frac{32}{3I_0} \pi p_\Lambda \left\{ (-m_{\Lambda b})(q^2 - 2 p_\Lambda \cdot q)(|A_1|^2 - |B_1|^2) + |C_{RR}|^2(|B_1|^2 - |A_1|^2)) + m_\Lambda q^2 (q^2 + 4 p_\Lambda \cdot q)(|A_2|^2 - |B_2|^2) + |C_{RR}|^2(|B_2|^2 - |A_2|^2)) + 6m_\Lambda m_\Lambda q^2 \left[ Re[A_1 A_2^*] - Re[B_1 B_2^*] + |C_{RR}|^2 Re[B_1 B_2^*] - |C_{RR}|^2 Re[A_1 A_2^*] \right] + 2q^2 (p_{\Lambda b} \cdot p_\Lambda + p_{\Lambda b} \cdot q) \left[ Re[A_1 B_2^*] - Re[A_2 B_1^*] - |C_{RR}|^2 Re[B_2 A_1^*] \right] + |C_{RR}|^2 Re[B_1 A_1^*] \right\}$$ \hspace{1cm} (15)
\[ I_2 = \frac{32}{3I_0} \pi p_{\lambda} m_{\lambda} \left\{ 2m_{\lambda} p_{\lambda} (|A_1|^2 + |B_1|^2) + (q^2 + p_{\lambda_b} \cdot q)(|A_1|^2 - |B_1|^2) \right. \\
+ 2q^2 (3m_{\lambda_b} + p_{\lambda}) \left[ \text{Re}[A_2B_1^*] + |C_{RR}|^2 \text{Re}[B_2^*A_1^*] \right] \\
- 2q^2 (3m_{\lambda_b} - p_{\lambda}) \left[ \text{Re}[A_1B_2^*] + |C_{RR}|^2 \text{Re}[B_1^*A_2^*] \right] \\
- \frac{2}{m_{\lambda}} p_{\lambda} q^4 \left[ \text{Re}[A_2B_2^*] + |C_{RR}|^2 \text{Re}[B_2^*A_2^*] \right] \\
+ \frac{2}{m_{\lambda}} q^2 (m_{\lambda} p_{\lambda} + p_{\lambda_b} \cdot p_{\lambda} + p_{\lambda} \cdot q) \left[ \text{Re}[B_1B_2^*] + |C_{RR}|^2 \text{Re}[A_1A_2^*] \right] \\
+ \frac{2}{m_{\lambda}} q^2 (m_{\lambda} p_{\lambda} - p_{\lambda_b} \cdot p_{\lambda} + p_{\lambda} \cdot q) \left[ \text{Re}[A_1A_2^*] + |C_{RR}|^2 \text{Re}[B_1B_2^*] \right] \\
+ \frac{2p_{\lambda}}{m_{\lambda}} (q^2 - 2p_{\lambda_b} \cdot p_{\lambda} + 2p_{\lambda} \cdot q - 2p_{\lambda_b} \cdot q) \left[ \text{Re}[A_1B_1^*] + |C_{RR}|^2 \text{Re}[B_1^*A_1^*] \right] \\
+ |C_{RR}|^2 (2m_{\lambda} p_{\lambda} - q^2 - 2p_{\lambda_b} \cdot q) \left[ |E_1|^2 + |D_1|^2 \right] \\
- q^2 (4m_{\lambda} p_{\lambda} + q^2 - 4p_{\lambda_b} \cdot q) \left[ |A_2|^2 + |B_2|^2 \right] \\
- q^2 |C_{RR}|^2 (4m_{\lambda} p_{\lambda} + q^2 - 4p_{\lambda_b} \cdot q) \left[ |D_2|^2 + |E_2|^2 \right] \right\} \] (16)

\[ I_3 = \frac{64\pi}{3I_0} \left\{ \frac{E_{\lambda}}{m_{\lambda}} q^4 p_{\lambda} p_{\lambda_b} \left( \text{Re}[A_2B_2^*] - |C_{RR}|^2 (\text{Re}[B_1A_2^*] - \text{Re}[B_2A_2^*]) \right) \\
- m_{\lambda_b} q^2 p_{\lambda} \cdot q \left[ \text{Re}[A_1A_2^*] + \text{Re}[B_1B_2^*] - |C_{RR}|^2 (\text{Re}[B_1B_2^*] + \text{Re}[A_1A_2^*]) \right] \right\} \\
+ m_{\lambda} q^2 p_{\lambda_b} \cdot q \left[ \text{Re}[A_2B_1^*] + \text{Re}[A_1B_2^*] + |C_{RR}|^2 (\text{Re}[B_2A_1^*] + \text{Re}[B_1A_2^*]) \right] \\
+ |C_{RR}|^2 (p_{\lambda_b} \cdot q p_{\lambda} \cdot q \text{Re}[B_1A_2^*] - (q^2 p_{\lambda_b} \cdot p_{\lambda} - 2p_{\lambda_b} \cdot q p_{\lambda} \cdot q) \text{Re}[A_1B_1^*] \right) \\
+ \frac{m_{\lambda}}{m_{\lambda_b}} q^2 \left[ m_{\lambda_b} q^2 \left( \text{Re}[A_1A_2^*] + \text{Re}[B_1B_2^*] + |C_{RR}|^2 (\text{Re}[B_1B_2^*] + \text{Re}[A_1A_2^*]) \right) \\
+ m_{\lambda} q^2 \left( \text{Re}[A_2B_1^*] + \text{Re}[A_1B_2^*] + |C_{RR}|^2 (\text{Re}[B_2A_1^*] + \text{Re}[B_1A_2^*]) \right) \right\} \] (17)

\[ I_4 = \frac{16\pi}{3I_0} \left\{ -m_{\lambda} m_{\lambda_b} q^2 \left( |A_1|^2 + |B_1|^2 \right) + q^2 (|A_2|^2 + |B_2|^2) + |C_{RR}|^2 (|B_1|^2 + |A_1|^2) \right. \\
+ |C_{RR}|^2 q^2 (|B_2|^2 + |A_2|^2) \right) + 2q^4 p_{\lambda} \cdot p_{\lambda_b} \left[ \text{Re}[A_2B_2^*] + |C_{RR}|^2 \text{Re}[B_2A_2^*] \right] \\
+ |C_{RR}|^2 q^2 (|B_2|^2 + |A_2|^2) \right\} \]
Here the kinematics and the relationships for the form factors are given as follows

\[ q^2 = m_{\Lambda_b}^2 + m_\Lambda^2 - 2m_{\Lambda_b}E_\Lambda \]
\[ p_\Lambda \cdot p_{\Lambda_b} = m_{\Lambda_b}E_\Lambda \]
\[ p_{\Lambda_b} \cdot q = m_{\Lambda_b}^2 - m_{\Lambda_b}E_\Lambda \]
\[ p_\Lambda \cdot q = m_{\Lambda_b}E_\Lambda - m_\Lambda^2 \] (20)

and

\[ A_1 = (f_1 - g_1) \]
\[ A_2 = (f_2 - g_2) \]
\[ B_1 = (f_1 + g_1) \]
\[ B_2 = (f_2 + g_2) \] (21)

4 Numerical analysis and discussion

In this section, we present our numerical analysis on the branching ratio and \( P_L, P_N, P_T \) polarizations of \( \Lambda \) baryon. The value of input parameters, we use in our calculations are

\[ m_{\Lambda_b} = 5.62 \, GeV, \quad m_\Lambda = 1.116 \, GeV, \]
\[ f_B = 0.2 \, GeV, \quad |V_{tb}V_{ts}^*| = 0.04, \quad \alpha^{-1} = 137, \]
\[ |C_{10}^\nu| = 4.6, \quad G_F = 1.17 \times 10^{-5} \, GeV^{-2}, \quad \tau_{\Lambda_b} = 1.24 \times 10^{-12} \, s, \]
\[ |U_{sb}^{Z'}| \leq 0.29, \quad |U_{d\bar{b}}^{Z'}| \leq 0.61. \] (22)

We have assumed that all the neutrinos are massless. From the expressions of branching ratio and \( \Lambda \) baryon polarizations it follows that the form factors are the main input parameters. The exact calculation for the all form factors which appear in \( \Lambda_b \rightarrow \Lambda \) transition does not exist at present.
Table 1: Form factors for $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay in a three parameters fit.

|   | $F(0)$ | $a_F$   | $b_F$   |
|---|---------|---------|---------|
| $F_1$ | 0.462   | -0.0182 | -0.000176 |
| $F_2$ | -0.077  | -0.0685 | 0.00146  |

For the form factors, we will use results from QCD sum rules method in corporation with heavy quark effective theory [23,24]. The $q^2$ dependence of the two form factors are given as follows:

$$F(q^2) = \frac{F(0)}{1 + a_F(q^2/m_{\Lambda_b}^2) + b_F(q^2/m_{\Lambda_b}^2)^2}. \tag{23}$$

The values of the form factors parameters are given listed in Table 1.

Now, let us examine the new effects to the branching ratio of the $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay and polarization effects of the $\Lambda$ baryon in the leptophobic $Z'$ boson. In the Leptophobic $Z'$ model, there are two new parameters, namely, the effective FCNC coupling constant $|U_{sb}^{Z'}|$ and the mass for the $Z'$ boson. Although the mass of $Z'$ boson range is given $365 \text{ GeV} \leq M_{Z'} \leq 615 \text{ GeV}$ in the D0 experiment, we take $M_{Z'} = 700 \text{ GeV}$ and $|U_{sb}^{Z'}| \leq 0.29$ [22], which we will use in our calculations. In Fig. 1, we present the dependence of the differential decay branching ratio (BR), for $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay, as function of the momentum square, $q^2$. We observe from this figure that the differential branching ratio at low $q^2$ region is one order larger compared to that of the SM prediction. In Fig. 2, we show our prediction for the branching ratio as a function of the effective coupling constant $|U_{sb}|$ in the Leptophobic $Z'$ Model. We see from this figure with increasing $|U_{sb}|$, BR also increases. We see that difference between two models is clear when $|U_{sb}| \geq 0.4$. In Fig. 3, the dependence of the longitudinal polarization $P_L$ for $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay is presented. For completeness, in this figure we also present the prediction of SM for $P_L$. From this figure we see that the magnitude and sign of $P_L$ are different in these models. Therefore a measurement of the magnitude and sign of $P_L$ can provide valuable information about the new physics effects. With increasing $q^2$ the difference between two models decreases. At least up to $q^2 = 10 \text{ GeV}^2$ there is noticeable difference between these models and this can serve as a good test for discrimination of these theories. The transverse component $P_T$ of the $\Lambda$ polarization is a T-odd quantity. A nonzero value of $P_T$ could indicate CP violation. In the SM, there is no CP violating phase in the CKM element of $V_{tb}V_{ts}^*$ and since parametrization of the form factors are real, they can not induce $P_T$ in the $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay. Therefore if transverse $\Lambda$ polarization is measured in the experiments to be nonzero, it is an indication of the existence of new CP violating source and new types of interactions. The parameter $U_{sb}^{Z'}$ in leptophobic $Z'$ model, in principle, can have imaginary part and therefore it can induce CP violation. But in the considered model, there is no interference terms between SM and leptophobic $Z'$ model contributions and terms proportional to $U_{sb}^{Z'}$ involves to the branching ratio and polarization effects in the form $|U_{sb}^{Z'}|^2$. Therefore it cannot induce CP violation. Depicted in Fig. 4 is the dependence of the normal polarization $P_N$ for $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay. The difference between the two models in prediction of $P_N$ becomes considerable at $q^2 \geq 10 \text{ GeV}^2$. Therefore analysis of $P_N$ in this region can be informative for discriminating these models.
When $\Lambda$ is not polarized, summing over the $\Lambda$ spin in Eq.(11), we get

$$d\Gamma = \frac{d\Gamma^0}{2} \left( 1 + \alpha_{\Lambda_b} \hat{e}_L \cdot \hat{\xi}_{\Lambda_b} \right),$$

(24)

where $\alpha_{\Lambda_b} = \frac{I_2}{I_0}$. So, the polarization of $\Lambda_b$ is $P_{\Lambda_b} \equiv \alpha_{\Lambda_b}$. In Fig.5 we present the dependence of polarization of $\Lambda_b$ baryon $\alpha_{\Lambda_b}$ on $q^2$. We see that up to $q^2 = 13 GeV^2$ the sign of $\alpha_{\Lambda_b}$ in leptophobic model is positive and negative in SM. When $q^2 > 13 GeV^2$ situation becomes vice versa. For this reason measurement of the sign and magnitude of $\alpha_{\Lambda_b}$ at different $q^2$ can provide us essential information about existence of new physics. For unpolarized $\Lambda_b$; i.e. $\hat{\xi}_{\Lambda_b} = 0$, we have

$$\vec{P}_\Lambda = \alpha_L \hat{e}_L,$$

(25)

with $\alpha_L = \frac{I_2}{I_0}$ which leads to the result that the $\Lambda$ polarization is purely longitudinal, i.e. $P_{\Lambda} = \alpha_L$ and $P_N = P_T = 0$.

In conclusion, we have studied the Semileptonic $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay in the Leptophobic $Z'$ Model. We have analysed the longitudinal, transverse and normal polarization of the $\Lambda$ baryon on $q^2$ dependence. The sensitivity of the branching ratio on $|U_{q_b}^{Z'}|$ is investigated and the dependence of the polarization parameter of $\Lambda_b$ baryon on $q^2$ is also investigated. We find that all physical observables are very sensitive to the existence of new physics beyond SM.

We would like to thank T. M. Aliev and M. Savcı for useful discussions.
Figure 1: The dependence of the differential decay branching ratio (BR), for $\Lambda_b \rightarrow \Lambda \nu \bar{\nu}$ decay, as function of the momentum transfer, $q^2$.

Figure 2: Integrated branching ratio (BR) as function of the $|U_{sb}|$, effective coupling constant in the Leptophobic $Z'$ Model.
Figure 3: The dependence of the longitudinal polarization $P_L$ for $\Lambda_b \to \Lambda \nu \bar{\nu}$ decay.

Figure 4: The dependence of the normal polarization $P_N$ for $\Lambda_b \to \Lambda \nu \bar{\nu}$ decay.
Figure 5: The distribution of $\alpha_{\Lambda b}$ as a function of $q^2$. 
References

[1] K. Abe, et al., Belle Collaboration Prep, [hep-ex/0410006] (2004).

[2] B. Aubert, et al., BaBar Collaboration Prep, [hep-ex/0507005] (2005).

[3] M. Iwasaki, et al., Belle Collaboration Phys. Rev., D 72 (2005) 092005.

[4] B. Aubert, et al., BaBar Collaboration Phys. Rev. Lett., 93 (2004) 081802.

[5] Y.H. Ahn, S.K. Kang, C.S. Kim, J. Lee Phys. Rev., D 73 (2006) 093005.

[6] J.H. Jeon, C.S. Kim, J. Lee, C. Yu Phys. Lett., B 636 (2006) 270-277.

[7] C.S. Kim, C. Yu, K.Y. Lee Phys. Lett., B 636 (2006) 074014.

[8] S. Baek, J. Jeon, C.S. Kim and C. Yu prep[hep-ph/0610329] (2006).

[9] T. Fujihara, S.K. Kang, C.S. Kim, D. Kimura, T. Morozumi Phys. Rev., D 73 (2006) 074011.

[10] T. Mannel, S. Recksiegel J. Phys., G 29 (1998) 979.

[11] S. Baek, J. Jeon, C.S. Kim Phys. Lett., B 641 (2006) 183-188.

[12] S. Chang, C.S. Kim, J. Song, Prep, [hep-ph/0607313], (2006).

[13] F. Gursey, M. Serdaroglu Lett. Nuo. Cim., (1978) 21-28.

[14] T. Rizzo, Phys. Rev. D, 59 (1999) 015020.

[15] K.S. Babu, C.F. Kolda, J. March-Russell P.R.D., 54 (1996) 4635.

[16] K. Leroux, D. London Phys. Lett., B 526 (2002) 97.

[17] T.M. Aliev, C.S. Kim Phys. Rev., D 58 (1998) 013003.

[18] G. Buchalla, A.J. Buras, M.E. Lautenbacher Rev. Mod. Phys., 68 (1996) 1125.

[19] M. Misiak, J. Urban Phys. Lett., B 451 (1999) 161; G. Buchalla, A.J. Buras Nucl. Phys., B 548 (1999) 309.

[20] T.M. Aliev, A. Ozpineci, M. Savci Nucl. Phys., B 649 (2003) 1681.

[21] C.H. Chen, C.Q. Geng Phys. Rev., D 64 (2001) 074001.

[22] B. Abbott, et al., D0 Collaboration, FERMILAB-CONF-97-356-E Presented at 18th Int. Sym. on Lepton and Photon Interactions (LP 97) Hamburg, Germany, 28 Jul-1 Aug 1997.

[23] T. Mannel, W. Roberts and Z. Ryzak, Nucl. Phys., B 355 (1991) 38.

[24] C.S. Huang, M.G. Yan, Phys. Rev., D 59 (1999) 114022.