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To cite this article: M. A. Hernández-Ruiz and A. Gutiérrez-Rodríguez 2017 *J. Phys.: Conf. Ser.* **888** 012222

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Bounds on electromagnetic dipole moments of the tau-neutrino in a $U(1)_{B-L}$ model

M. A. Hernández-Ruiz

Unidad Académica de Ciencias Químicas, Universidad Autónoma de Zacatecas,
Apartado Postal 585, Zacatecas, Zacatecas 98060, México.

E-mail: mahernan@uaz.edu.mx

A. Gutiérrez-Rodríguez

Facultad de Física, Universidad Autónoma de Zacatecas,
Apartado Postal C-580, Zacatecas, Zacatecas 98060, México.

E-mail: alexgu@fisica.uaz.edu.mx

Abstract. We study the anomalous magnetic and electric dipole moments of the tau-neutrino through the process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ at the Z' -pole in the framework of $U(1)_{B-L}$ model. For the parameters of the $U(1)_{B-L}$ model we consider the mixing angle θ' , the coupling constant g'_1 and the heavy gauge boson mass $M_{Z_{B-L}}$. We find that our bounds are of the same order of magnitude as those obtained in other extensions of the standard model.

1. Introduction

The $B-L$ (baryon number minus lepton number) symmetry plays an important role in various physics scenarios beyond the Standard Model, for example, the gauge $U(1)_{B-L}$ symmetry group is contained in a GUT described by a $SO(10)$ group. The $B-L$ model [1] is attractive due to its relatively simple theoretical structure, and the crucial test of the model is the detection of the new heavy neutral (Z') gauge boson. The analysis of precision electroweak measurements indicates that the new Z' gauge boson should be heavier than about 1.2 TeV. On the other hand, recent bounds from the LHC indicate that the Z' gauge boson should be heavier than about 2 TeV [2, 3], while future LHC runs at 13-14 TeV could increase the Z' mass bounds to higher values, or may be lucky and find evidence for its presence. Further studies of the Z' properties will require a new linear collider.

Our aim in the present work is to analyze the reaction $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ in the framework of a $U(1)_{B-L}$ model. We study the indirect effects of extra gauge bosons in the cross sections of the process $e^+e^- \rightarrow \nu_\tau\bar{\nu}_\tau\gamma$ at high energy linear e^+e^- colliders; namely, International Linear Collider (ILC) [4] and Compact Linear Collider (CLIC) [5]. In addition to the limits from hadron colliders, an improvement on the sensitivity of the physical observables will be reached at future e^+e^- linear collider. Finally, we discuss how accurately the $U(1)_{B-L}$ model parameters will be measurable at the ILC and CLIC.



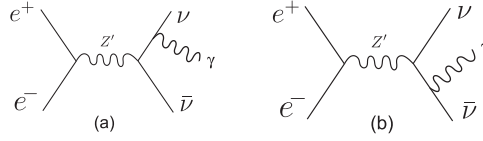


Figure 1. The Feynman diagrams contributing to the process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ in the $U(1)_{B-L}$ model.

2. Cross section of the process $e^+e^- \rightarrow \nu_\tau \bar{\nu}_\tau \gamma$ in the $U(1)_{B-L}$ model

We calculate the cross section via the process $e^+e^- \rightarrow \nu_\tau \bar{\nu}_\tau \gamma$ in the context of the $U(1)_{B-L}$ model at future high-energy and high luminosity linear electron-positron colliders, such as the ILC and CLIC. The Feynman diagrams contributing to the process are shown in Figure 1. The expressions for the total cross section of the process for the different contributions, can be written in the following form Eq. (1).

$$\sigma(e^+e^- \rightarrow \nu\bar{\nu}\gamma) = \int \frac{\alpha^2(\mu_{\nu_\tau}^2 + d_{\nu_\tau}^2)}{48\pi} \cdot \left[\frac{(g_V^e)_{B-L}^2 + (g_A^e)_{B-L}^2}{\sin^2\theta_w(1 - \sin^2\theta_w)} \right] \cdot \left[\frac{((g_V^\nu)_{B-L}^2 + (g_A^\nu)_{B-L}^2)(s - 2\sqrt{s}E_\gamma) + (g_V^\nu)_{B-L}^2 E_\gamma^2 \sin^2\theta_\gamma}{(s - M_{Z'}^2)^2 + M_{Z'}^2 \Gamma_{Z'}^2} \right] E_\gamma dE_\gamma d\cos\theta_\gamma, \quad (1)$$

where

$$\begin{aligned} (g_V^f)_{B-L} &= -T_3^f \sin\theta_{B-L} - 2Q_f \sin^2\theta_w \sin\theta_{B-L} + \frac{2g_1'}{g} \cos\theta_w \cos\theta_{B-L}, \\ (g_A^f)_{B-L} &= -T_3^f \sin\theta_{B-L}, \end{aligned} \quad (2)$$

$$T_3^f = T_3^e = -\frac{1}{2}, \quad T_3^\nu = T_3^\nu = -\frac{1}{2}, \quad Q_f = Q_e = -1, \quad (3)$$

$g = e/\sin\theta_w$ and θ_{B-L} is the $Z - Z'$ mixing angle. The current bound on this parameter is $|\theta_{B-L}| \leq 10^{-3}$ [6]. In the decoupling limit, that is to say, when $g_1' = 0$ and $\theta_{B-L} = 0$ the couplings of the standard model (SM) are recovered.

3. Results and Conclusion

We evaluate the total cross section of the process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ in the context of the $B - L$ model at next generation linear e^+e^- colliders such as the ILC and CLIC. Using the following values for numerical computation: $\sin^2\theta_W = 0.23126 \pm 0.00022$, $M_Z = 91.1876 \pm 0.0021$ GeV, $\Gamma_Z = 2.4952 \pm 0.0023$ GeV, and considering the most recent limit from LEP: $\frac{M_{Z'}}{g_1'} \geq 7$ TeV. In Figure 2 we present the total cross section as a function of g_1' and μ_{ν_τ} . In our numerical computation, we consider \sqrt{s} , $M_{Z'}$ and g_1' as free parameters. In Figure 3, we show the total differential cross section as a function of E_γ and $\cos\theta_\gamma$, finally in figure 4, we show the total differential cross section as a function of E_γ and μ_{ν_τ} .

In conclusion, we find that the future linear e^+e^- colliders experiments such as the ILC and CLIC could test the $B - L$ model it would be possible to perform precision measurements of the Z' gauge boson, as well as of the parameters of the model θ_{B-L} and g_1' , complementing other studies on the $B - L$ model. The limits for the tau-neutrino magnetic in the context the $U(1)_{B-L}$ model compare favorably with the limits obtained by the L3 Collaboration, and complement previous studies on the dipole moments. On the other hand, it seems that in order to improve these limits it might be necessary to study direct CP-violating effects. The SM expression for

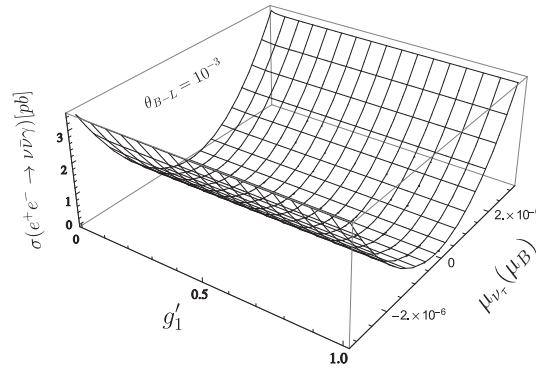


Figure 2. The total cross section for $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ as a function of the collision energy g'_1 and $\mu_{\nu\tau}$.

the cross section of the reaction $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ can be obtained in the decoupling limit, that is to say, when $\theta_{B-L} = 0$ and $g'_1 = 0$, in this case the terms that depend on θ_{B-L} and g'_1 are zero and Eq. (1) is reduced to the expression given for the standard model. In addition, the analytical and numerical results for the total cross section have never been reported in the literature.

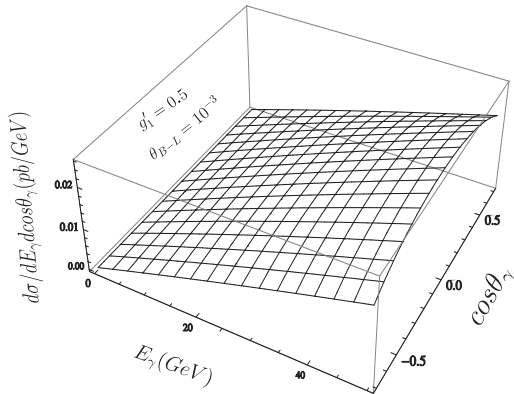


Figure 3. The total differential cross section for $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ as a function of E_γ and $\cos\theta_\gamma$ for $g'_1 = 0.5$ and $\theta_{B-L} = 10^{-3}$.

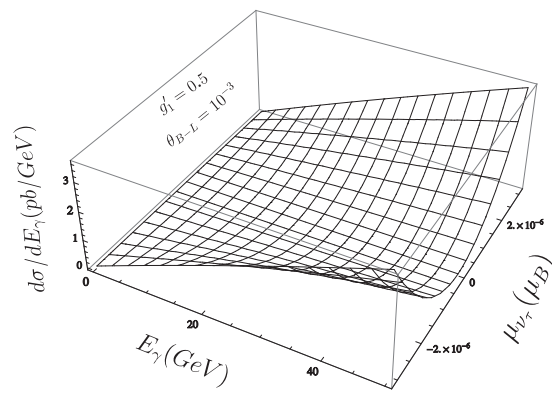


Figure 4. The differential cross section for $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ as a function of E_γ and $\mu_{\nu\tau}$ with $g'_1 = 0.5$ and $\theta_{B-L} = 10^{-3}$.

Acknowledgments

The authors acknowledges support from Universidad Autónoma de Zacatecas (UAZ), México and Consejo Nacional de Ciencia y Tecnología (CONACyT-SNI).

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