The Z' Boson of the Minimal $B - L$ Model as a Higgs Boson Factory

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We study the Higgs boson production in the minimal $B - L$ model at the future linear colliders ILC and CLIC, with the reactions $e^+e^- \to (Z, Z') \to Zh$. We evaluate the total cross section of Zh considering the complete set of Feynman diagrams at tree level.

1 Introduction

The existence of a heavy neutral (Z') vector boson is a feature of many extensions of the Standard Model (SM). In particular, one (or more) additional $U(1)'$ gauge group provides one of the simplest extensions of the SM. Additional Z' gauge bosons appear in Grand Unified Theories (GUTs) [1], Superstring Theories [2], Left-Right Symmetric Models (LRSM) [3] and in other models such as models of composite gauge bosons [4]. In particular, it is possible to study some phenomenological features associated with this extra neutral gauge boson by considering a minimal $B - L$ (baryon number minus lepton number) model.

The $B - L$ symmetry plays an important role in various physics scenarios beyond the SM: Firstly, the gauge $U(1)_{(B-L)}$ symmetry group is contained in a GUT described by a $SO(10)$ group [5]. Secondly, the scale of the $B-L$ symmetry breaking is related to the mass scale of the heavy right-handed Majorana neutrino mass terms providing the well-known see-saw mechanism [6] to explain light left-handed neutrino masses. Thirdly, the $B - L$ symmetry and the scale of its breaking are tightly conneted to the baryogenesis mechanism through leptogenesis [7] via sphaleron interactions preserving $B - L$.

The minimal $B - L$ model [8] is attractive due to its relatively simple theory structure, and the crucial test of the model is the detection of the new heavy neutral (Z') gauge boson. Analyses of precision electroweak measurements indicate that the new Z' gauge boson should be heavier than about 1.2 TeV [9]. On the other hand, recent bounds from the LHC indicate that the Z' gauge boson should be heavier than about 2 TeV [10], while future LHC runs at 13 TeV could increase the Z' mass bounds to higher values, or we may be lucky and find evidence for its presence. Further studies of the Z' properties will require a new linear collider [11], which will also allow us to perform precision studies of the Higgs sector. Detailed discussions on the minimal $B - L$ model can be found in the literature [8, 12].

It is possible to search for the Higgs boson from this model using the process of Higgstralung, a mechanism similar to the one used to search for the SM Higgs boson. However, the existence of a new heavy gauge bosons could also provide new Higgs production mechanisms, which could probe its non-standard origin. In this work, we are analyzing how the Z' gauge boson of the minimal $U_{(B-L)}$ model could be used as a factory of Higgs bosons.

Our aim in the present work is to analyze the Higgs production cross section from processes like $e^+e^- \to (Z, Z') \to Zh$ in the framework of the minimal $B - L$ model.

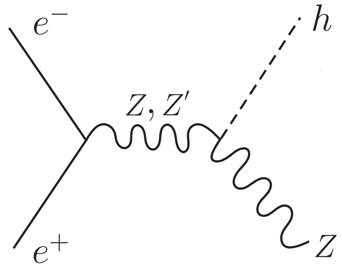

Figure 1: Feynman diagram for the process $e^+e^- \to Zh$ in the minimal $U(1)_{(B-L)}$ model.

2 The Total Cross section of the Process $e^+ + e^- \to Zh$

In this section, we calculated the Higgs production cross section via the process $e^+e^- \to Zh$ in the context of the minimal $U_{(B-L)}$ model at a future high-energy and high-luminosity linear electron-positron colliders, such as the ILC or CLIC.

The contributing Feynman diagram is shown in figure 1. The expression for the respective cross section in the context of the minimal $U(1)_{(B-L)}$ model is given by

$$\begin{aligned}\sigma(e^+e^- \to Zh) &= \frac{\pi\alpha^2[(g_V^e)^2 + (g_A^e)^2]}{48 s x_W^2 (1-x_W)(1-m_Z^2/s)^2}\sqrt{\lambda}[\lambda + 12 m_Z^2/s] \\ &+ \frac{[f(\theta')\cos\beta - g(\theta')\sin\beta]^2[(g_V^{'e})^2 + (g_A^{'e})^2]}{384\pi s(1-x_W)(1-m_{Z'}^2/s)^2}\sqrt{\lambda'}[\lambda' + 12 m_{Z'}^2/s] \\ &+ \frac{\alpha[f(\theta')\cos\beta - g(\theta')\sin\beta][g_V^e g_V^{'e} + g_A^e g_A^{'e}]}{24 s x_W (1-x_W)(1-m_Z^2/s)(1-m_{Z'}^2/s)}\sqrt{\lambda}[\lambda + 12 m_Z^2/s], \qquad (1)\end{aligned}$$

where

$$\begin{aligned}\lambda &= (1 - x_Z - x_h)^2 - 4x_Z x_h, & \lambda' &= (1 - x_{Z'} - x_h)^2 - 4x_{Z'} x_h, \\ f(\theta') &= \sin 2\theta'\left(\frac{4m_Z^2}{v^2} - g_1^2\right) + \frac{4g_1 m_Z}{v}\cos 2\theta', & g(\theta') &= \frac{4v'}{v} g_1^2 \sin 2\theta', \\ g_V^e &= \frac{1}{2}\cos\theta' + 2x_W\cos\theta' + \frac{2g_1'}{g}\cos\theta_W \sin\theta', & g_A^e &= \frac{1}{2}\cos\theta', \\ g_V^{'e} &= -\frac{1}{2}\sin\theta' + 2x_W\sin\theta' + \frac{2g_1'}{g}\cos\theta_W\cos\theta', & g_A^{'e} &= -\frac{1}{2}\sin\theta',\end{aligned}$$

with $x_Z = m_Z^2/s$, $x_{Z'} = m_{Z'}^2/s$, $x_h = m_h^2/s$, $x_W = \sin^2\theta_W$, $\beta = \frac{\pi}{9}$, $v = 246$ GeV, $v' = 2000$ GeV.

The first term of equation 1 corresponds to the cross section from the process with the exchange of a Z boson, while the second and third term comes from the contribution of the minimal $U(1)_{(B-L)}$ model and of the interference respectively. The SM expression for the cross section of the reaction $e^+e^- \to Zh$ can be obtained when the mixing angle and the coupling constant are decoupled in the limited $\theta' = 0$ and $g'_1 = 0$. In this case the terms that depend on θ' and g'_1 in equation 1 are zero and the total expression is reduced to the one given in ref. [13] for the SM.

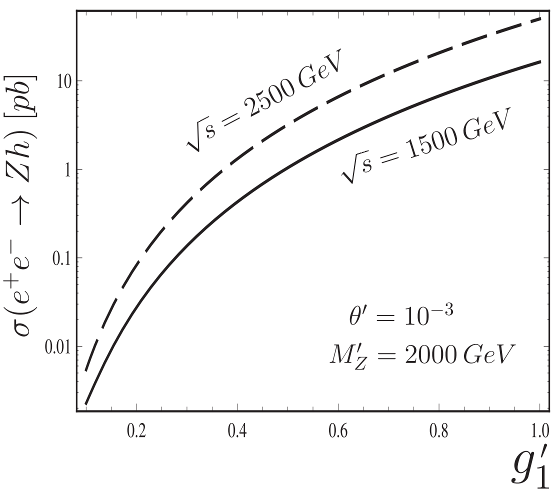

Figure 2: The total cross section for the process $e^+e^- \to Zh$ as a function of the coupling constant g'_1.

3 Results and Conclusions

Using the numerical values $\alpha = 1/128$, $x_W = \sin^2\theta_W = 0.2314$, $m_Z = 91.18$ GeV, $M_h = 125$ GeV, and $\Gamma_Z = 2.49$ GeV, we obtain the cross section $\sigma = \sigma(\sqrt{s}, m_{Z'}, \theta', g'_1)$.

We plot the total cross section of the reaction $e^+e^- \to Zh$ in figure 2 as a function of the coupling constant g'_1 for $m_{Z'} = 2000$ GeV and $\sqrt{s} = 1500, 2500$ GeV. We observed that the total cross section increases as g'_1 increases.

In conclusion, we have analyzed the total cross section of the reaction $e^+e^- \to Zh$ in the context of the minimal $U(1)_{(B-L)}$ model with an additional heavy gauge boson at the high energies expected at the ILC and CLIC colliders. We observed an increase in the total cross section when g'_1, the free parameter of the $U(1)_{(B-L)}$, increases.

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