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Search of the heavy neutral Higgs boson H of the $U(1)_{B-L}$ model at the future multi-TeV $\mu^+\mu^-$ collider

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The possible detection of a heavy neutral Higgs boson H predicted by the $U(1)_{B-L}$ model at the future multi-TeV muon collider for the center-of-mass energies of $\sqrt{s} = 3, 6, 10, 30, 50$ TeV with integrated luminosities of $\mathcal{L}_{\rm con} = 1, 2, 3, 4, 10$ ab^{-1} and $\sqrt{s} = 30, 50$ TeV, $\mathcal{L}_{\rm opt} = 90, 250$ ab^{-1}, are investigated. The following production and decay channels of the heavy Higgs boson through the Vector Boson Fusion (VBF) are considered: $\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp$ with the subsequent decay of the Higgs boson H to pairs of $W^\pm W^\mp$ bosons. We show that promising signals with good statistical significances can be obtained in di-vector bosons channel, with $\nu_\mu\bar{\nu}_\mu\nu_l l^\pm\bar{\nu}_l l^\mp$ final states.

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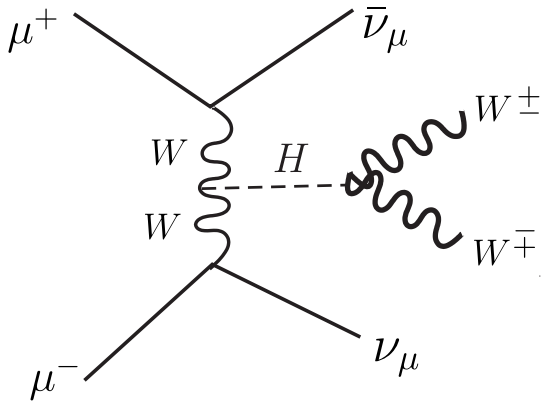

Figure 1: Schematic Feynman diagram for neutral heavy Higgs boson H production through the process $\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp$ at the future $\mu^+\mu^-$ collider.

1. Introduction

The proposed 1-100 TeV center-of-mass energies muon collider [1–7] provides outstanding discovery potential and can complement the physics program of the Large Hadron Collider (LHC). Based on the $B-L$ model, which is based on the gauge symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$, we estudy the production and decay of the boson H predicted by the $B-L$ model, via the following production and decay channel of the heavy Higgs boson H through the Vector Boson Fusion (VBF) $\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp$, see the Feynman diagram in Fig. 1.

2. Heavy Higgs boson H production and decay at the future multi-TeV muon collider

In $\mu^+\mu^-$ colliders, at tree level, heavy Higgs boson production is predominantly driven by Vector Boson Fusion (VBF) processes via $\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp$. For the B-L scenario considered here, the Feynman diagram is show in Fig. 1.

$$\sigma(\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H) = \frac{G_F^3 M_W^4}{4\sqrt{2}\pi^3}\left[\left(1+\frac{M_H^2}{s}\right)\ln\left(\frac{s}{M_H^2}\right) - 2\left(1-\frac{M_H^2}{s}\right)\right]\sin^2\alpha, \tag{1}$$

where s is the center-of-mass energy and $\sin\alpha$ is the sin of the mixing angle between $h-H$. As the H decay width Γ_H is much smaller than its mass, $\Gamma_H/M_H \ll 1$, the narrow-width approximation can be used, and the total cross-section of the signal can be approximated as

$$\sigma^{B-L}_{Tot}\left(\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp\right) \simeq \sigma\left(\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H\right) \times BR\left(H \to W^\pm W^\mp\right),$$

with the Branching Ratio $BR(H \to W^\pm W^\mp) = \Gamma(H \to WW)/\Gamma_{\text{Tot}}$ of the new Higgs boson H. Where $\Gamma(H \to WW)$ denotes the partial decay width into the particles in the final state of the considered process, and Γ_{Tot} is the total decay width of the unstable particle.

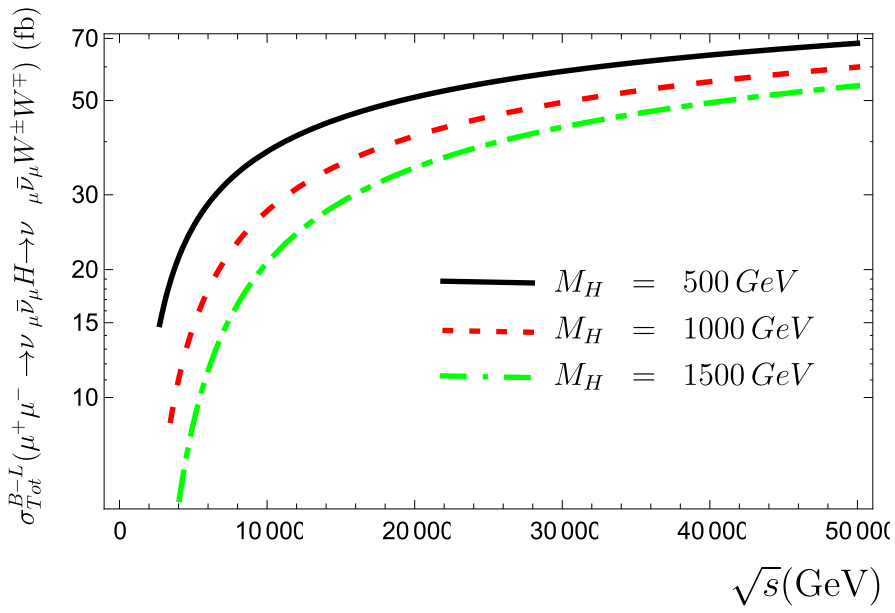

Figure 2: The cross-section of the process $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu H \to \nu_\mu \bar{\nu}_\mu W^\pm W^\mp$ as a function of $\sqrt{s}$.

3. Results and Conclusion

We have studied the production and decay of the heavy Higgs boson H predicted by the extension $U(1)_{B-L}$ of the SM through the VBF process $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu H \to \nu_\mu \bar{\nu}_\mu W^\pm W^\mp$, the cross-section of the process as a function of the center-of-mass energy $\sqrt{s}$ of the future muon collider is shown in Fig. 2, for this figure we choose the values for the heavy Higgs boson mass of $M_H = 500, 1000, 1500$ GeV.

As part of the analysis, we present the contours of the cross-section in the plane $(\cos\alpha, M_H)$. Contours plot for the total cross-section $\sigma_{Tot}^{B-L} = \sigma_{Tot}^{B-L}\left(\sqrt{s}, M_H, \cos\alpha\right)$ of the process $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu H \to \nu_\mu \bar{\nu}_\mu W^\pm W^\mp$ is show in Fig. 3. The contours are for $\sigma_{Tot}^{B-L} = 90, 120, 150, 180, 250$ fb and $\sqrt{s} = 6$ TeV.

In conclusion, we have studied the production and decay of the heavy Higgs boson H predicted by the extension $U(1)_{B-L}$ of the SM. Our results show that the production of the heavy Higgs boson through the VBF-W process is a good mechanism for studying this particle in the context of the $U(1)_{B-L}$ model and for the energies and luminosities of the future muon collider. Our results yield $N_{\text{con}} = 593, 701$ for the expected number of events with conservative energies and luminosities, while the optimistic case yields $N_{\text{opt}} = 65, 436, 722$. All these results strongly motivate the development of a future muon collider as a Higgs boson factory.

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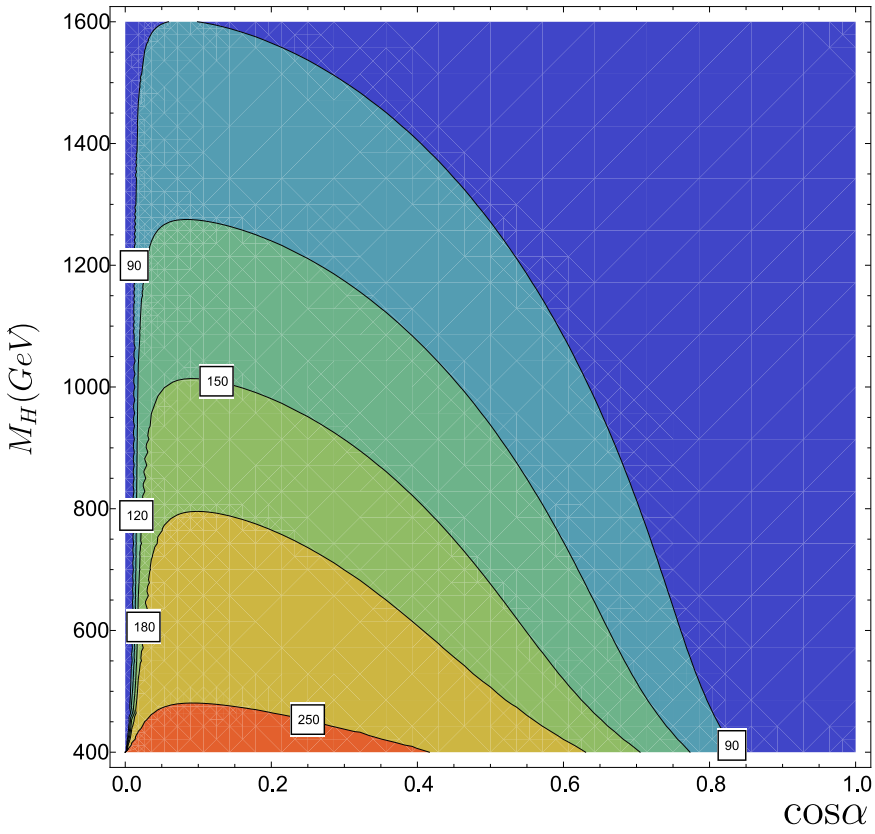

Figure 3: Contours plot for the total cross-section $\sigma_{Tot}^{B-L} = \sigma_{Tot}^{B-L}(\sqrt{s}, M_H, \cos\alpha)$ of the process $\mu^+\mu^- \to \nu_\mu\bar{\nu}_\mu H \to \nu_\mu\bar{\nu}_\mu W^\pm W^\mp$.

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