PROCEEDINGS OF SCIENCE

Probing the minimal $U(1)_X$ model at future electron-positron colliders via the fermion pair-production channel

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The minimal $U(1)_X$ extension of the Standard Model (SM) is a well-motivated new physics scenario, where the anomaly cancellation requirement dictates the new neutral gauge boson (Z') couplings with the SM fermions in terms of two scalar charges (x_H and x_Φ). In this paper, we investigate the SM charged fermion pair production mechanism for different values of these scalar charges in the $U(1)_X$ scenario at future electron-positron colliders, i.e. $e^+e^- \to f\bar{f}$. Comparing the bounds from the LHC (dilepoton and dijet) and LEP-II, we study the angular distributions, forward-backward ($\mathcal{A}_{\rm FB}$), left-right ($\mathcal{A}_{\rm LR}$) and left-right forward-backward ($\mathcal{A}_{\rm LR,FB}$) asymmetries of the $f\bar{f}$ final states which can show substantial deviations from the SM results, even for a multi-TeV Z'. This provides a powerful complementary way to probe the heavy Z' parameter space beyond the direct reach of the Large Hadron Collider (LHC), as well as an effective way to determine the $U(1)_X$ charges.

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1. Introduction

In this proceeding we investigate a general but minimal $U(1)_X$ extension of the SM where in addition to the SM particles, three generations of right handed neutrinos and a $U(1)_X$ Higgs field-singlet under the SM gauge group- are included. The $U(1)_X$ charge assignment for the fermions in this scenario is generation independent which makes the model free from all gauge and gravitational anomalies. Reproducing the Yukawa structure of the SM we find that the $U(1)_X$ symmetry can be identified as the linear combination of the $U(1)_Y$ in SM and the $U(1)_{B-L}$ gauge groups [1].

We investigate the production of the charged fermions of the SM at the e^-e^+ collider from the Z' mediated process under the $U(1)_X$ model and test different observables including the forward-backward asymmetry ($\mathcal{A}_{FB}$), left-right asymmetry ($\mathcal{A}_{LR}$) and forward-backward left-right asymmetry ($\mathcal{A}_{LR,FB}$). However, in the $U(1)_X$ scenario the interesting features are evolved from the general charge assignment of the particles after the anomaly cancellations. We study the $e^-e^+ \to f\overline{f}$ process at the 250 GeV and 500 GeV colliders. A detailed study have been made in [2] for different center of mass energies under a general U(1) sceanrio.

There is another interesting scenario in the $U(1)_X$ model where we consider the $e^-e^+ \to e^-e^+$ process mediated by the photon, Z and Z' bosons involving the s and t channel processes which is known as the Bhabha scattering.The model including the decay modes of the Z', relative couplings and the constraints on the $U(1)_X$ gauge coupling have been discussed in [1–4].

In this model we find that the left handed and right handed fermions are differently coupled with the Z'. The Z' is originated due the U(1) extension and its mass is originated from after the $U(1)_X$ breaking. The $U(1)_X$ breaking is also responsible for the generation of the Majorana neutrino mass induced by the seesaw mechanism. The detailed heavy neutrinos searches have been performed in [5–12].

From [2] we consider $x_H = -2, -1, 1, 2$ with two benchmark choices for the Z' mass which satisfy the bounds from LHC (dilepton and dijet) and LEP-II. The limits on g' for $M_{Z'} = 7.5$ TeV due to different x_H fixing x_Φ at 1 can be considered as 0.9, 0.9, 0.6, 0.4 respectively after the strongest LEP-II limits at the high Z' mass. In this analysis we consider a benchmark of $g' = 0.4$ for $M_{Z'} = 7.5$ TeV for $x_H = -2, -1, 1, 2$ for the purpose of studying the observables.

We discuss some of the results in Sec. 2. Finally we conclude the proceeding in Sec. 3.

2. Results

In this model we find that for $x_\Phi = 1$ and $x_H = -2$ there is no interaction between Z' and the left handed fermions. Also for the same x_Φ but $x_H = -1$ there is no interaction between Z' and the right handed electron. The B−L case case be realized form $x_H = 0$ and $x_\Phi = 1$. There is no interaction between the right handed up type quark and Z' for $x_H = -0.5$ and no interaction between the Z' and right handed down type quark for $x_H = 1$ and $x_\Phi = 1$. For $x_H = 2$ and $x_\Phi = 1$ all the interactions hold. The production cross sections for the $e^-e^+ \to \mu^+\mu^-$ and $e^-e^+ \to e^+e^-$ processes have been shown in Fig. 2 and the processes included the Z, γ and Z' mediated channels and the corresponding interferences. We see a peak at the Z' mass. The sharpness of the peak will depend on the $U(1)_X$ coupling, g', however, at the e^-e^+ collider an order one coupling could be realized due to the presence of the s channel and t channel processes mediated by Z, γ and Z'.

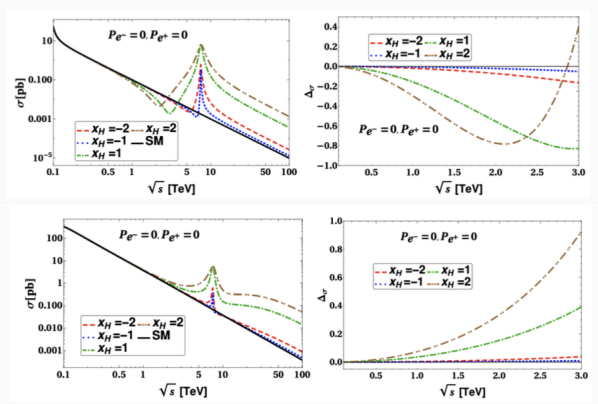

Figure 1: Fermion pair production from the electron positron collider as a function of $\sqrt{s}$ for $M_{Z'} = 7.5$ TeV. The muon pair production cross section has been shown in the upper panel and the Bhabha scattering has been shown in the lower panel.

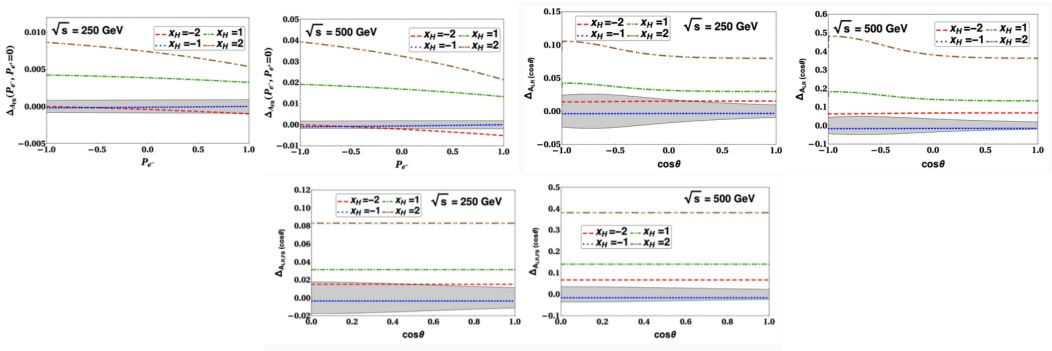

Figure 2: The FB (first two from top left), LR (first two from top right) and LR-FB (bottom panel) asymmetries for $M_{Z'} = 7.5$ TeV considering muon pair production channel.

The deviation in the FB asymmetry can be 3.8% at 500 GeV electron positron collider at $x_H = 2$. The deviation in the LR asymmetry can be 10% at 250 GeV collider for $x_H = 2$. The deviation in the LR-FB asymmetry can be 8.2% at 250 GeV collider for $x_H = 2$. For the Bhabha scattering the deviation in differential scattering cross section can reach up to 2.3% for $x_H = 2$ and $M_{Z'} = 7.5$ TeV at 500 GeV. The deviation in the LR asymmetry can be $(1-2)$% for 250 GeV collider, $(2.3-4.3)$% for 500 GeV and $(12-13)$% for 1 TeV collider.

3. Conclusion

We consider a general $U(1)_X$ scenario to study the fermion pair production at the electron positron collider at a variety of center of mass energies. Using the bounds on the $U(1)_X$ coupling and the observables we study the pair production of the muons, bottom quarks and top quarks at the electron positron colliders. We study the differential and integrated scattering cross sections, forward-backward asymmetry, left-right asymmetry and forward-backward left-right asymmetry

with their respective deviations. We find significant deviations from the SM results can be observed at the electron positron collider in the near future. We also study the Bhabha scattering for the electron positron final state calculating the integrated and differential scattering cross sections. We have found the significant deviations at the electron positron colliders with different center of mass energies which can be tested in the near future.

References

[1] A. Das, S. Oda, N. Okada, and D.-s. Takahashi, *Classically conformal U(1)' extended standard model, electroweak vacuum stability, and LHC Run-2 bounds*, *Phys. Rev. D* **93** (2016), no. 11 115038, [arXiv:1605.01157].

[2] A. Das, P. S. B. Dev, Y. Hosotani, and S. Mandal, *Probing the minimal $U(1)_X$ model at future electron-positron colliders via the fermion pair-production channel*, arXiv:2104.10902.

[3] A. Das, N. Okada, and N. Papapietro, *Electroweak vacuum stability in classically conformal B-L extension of the Standard Model*, *Eur. Phys. J. C* **77** (2017), no. 2 122, [arXiv:1509.01466].

[4] A. Das, S. Goswami, K. N. Vishnudath, and T. Nomura, *Constraining a general U(1)' inverse seesaw model from vacuum stability, dark matter and collider*, *Phys. Rev. D* **101** (2020), no. 5 055026, [arXiv:1905.00201].

[5] A. Das, N. Okada, and D. Raut, *Enhanced pair production of heavy Majorana neutrinos at the LHC*, *Phys. Rev. D* **97** (2018), no. 11 115023, [arXiv:1710.03377].

[6] A. Das, N. Okada, and D. Raut, *Heavy Majorana neutrino pair productions at the LHC in minimal U(1) extended Standard Model*, *Eur. Phys. J. C* **78** (2018), no. 9 696, [arXiv:1711.09896].

[7] A. Das, P. S. B. Dev, and N. Okada, *Long-lived TeV-scale right-handed neutrino production at the LHC in gauged $U(1)_X$ model*, *Phys. Lett. B* **799** (2019) 135052, [arXiv:1906.04132].

[8] C.-W. Chiang, G. Cottin, A. Das, and S. Mandal, *Displaced heavy neutrinos from Z decays at the LHC*, *JHEP* **12** (2019) 070, [arXiv:1908.09838].

[9] A. Das, P. Konar, and S. Majhi, *Production of Heavy neutrino in next-to-leading order QCD at the LHC and beyond*, *JHEP* **06** (2016) 019, [arXiv:1604.00608].

[10] A. Das, P. S. Bhupal Dev, and N. Okada, *Direct bounds on electroweak scale pseudo-Dirac neutrinos from $\sqrt{s}$ = 8 TeV LHC data*, *Phys. Lett. B* **735** (2014) 364–370, [arXiv:1405.0177].

[11] A. Das and N. Okada, *Improved bounds on the heavy neutrino productions at the LHC*, *Phys. Rev. D* **93** (2016), no. 3 033003, [arXiv:1510.04790].

[12] A. Das, Y. Gao, and T. Kamon, *Heavy neutrino search via semileptonic Higgs decay at the LHC*, *Eur. Phys. J. C* **79** (2019), no. 5 424, [arXiv:1704.00881].