Probing the minimal $U(1)_X$ model at future e^-e^+ colliders via the fermion pair-production channel

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Based on: 2104.10902

A. Model

(1) Particle content

	SM	$\mathrm{U}(1)_X$
q_L^i	$\mathbf{3}\otimes\mathbf{2}\otimes\frac{1}{6}$	$x'_q=\frac{1}{6}x_H+\frac{1}{3}x_\Phi$
u_R^i	$\mathbf{3}\otimes\mathbf{1}\otimes\frac{2}{3}$	$x'_u=\frac{2}{3}x_H+\frac{1}{3}x_\Phi$
d_R^i	$\mathbf{3}\otimes\mathbf{1}\otimes\text{-}\frac{1}{3}$	$x'_d=-\frac{1}{3}x_H+\frac{1}{3}x_\Phi$
ℓ_L^i	$\mathbf{1}\otimes\mathbf{2}\otimes\text{-}\frac{1}{2}$	$x'_\ell=-\frac{1}{2}x_H-x_\Phi$
e_R^i	$\mathbf{1}\otimes\mathbf{1}\otimes\text{-}1$	$x'_e=-x_H-x_\Phi$
N_R^i	$\mathbf{1}\otimes\mathbf{1}\otimes\text{-}0$	$x'_\nu=-x_\Phi$
H	$\mathbf{1}\otimes\mathbf{2}\otimes\text{-}\frac{1}{2}$	$\text{-}\frac{1}{2}x_H$
Φ	$\mathbf{1}\otimes\mathbf{1}\otimes\mathbf{0}$	$2x_\Phi$

(2) Anomaly cancellation conditions

$$\begin{aligned}
\mathrm{U}(1)_X\otimes[\mathrm{SU}(3)_c]^2 &: & 2x'_q-x'_u-x'_d &= 0,\\
\mathrm{U}(1)_X\otimes[\mathrm{SU}(2)_L]^2 &: & 3x'_q+x'_\ell &= 0,\\
\mathrm{U}(1)_X\otimes[\mathrm{U}(1)_Y]^2 &: & x'_q-8x'_u-2x'_d+3x'_\ell-6x'_e &= 0,\\
[\mathrm{U}(1)_X]^2\otimes\mathrm{U}(1)_Y &: & x'^2_q-2x'^2_u+x'^2_d-x'^2_\ell+x'^2_e &= 0,\\
[\mathrm{U}(1)_X]^3 &: & 6x'^3_q-3x'^3_u-3x'^3_d+2x'^3_\ell-x'^3_\nu-x'^3_e &= 0,\\
\mathrm{U}(1)_X\otimes[\mathrm{grav.}]^2 &: & 6x'_q-3x'_u-3x'_d+2x'_\ell-x'_\nu-x'_e &= 0.
\end{aligned}\tag{1}$$

(i) $\mathrm{U}(1)_X$ symmetry breaking and EWSB generate the light neutrino mass through the seesaw mechanism which can satisfy the neutrino oscillation data.

(ii) Followed by that a neutral gauge boson Z' is originated with a mass of $M_{Z'}=2v_\Phi g'$ where v_Φ is the $\mathrm{U}(1)_X$ VEV and g' is the $\mathrm{U}(1)_X$ coupling. We consider $x_\Phi=1$.

(iii) The couplings between the Z' and the left handed fermions are different from the couplings of their corresponding right handed counterparts.

- **Such differences will be observed when charged fermion pair production will be studied. We consider the electron-positron e^-e^+ colliders to study such processes.**

(iv) Apart from the fermion pair production processes such a model can study a variety of phenomenological aspects including heavy neutrinos, Higgs (SM, BSM, vacuum stability), Dark Matter, etc.

(v) This model has a very interesting property. Fixing $x_\Phi=1$ and varying x_H can show a unique behavior. For example $x_H=-2$ switches off the interaction between f_L and Z'. Similarly $x_H=-1$ switches off the interaction between e_R and Z'. For $x_H=-0.5$ and $x_H=1$ there is no interaction of u_R and d_R with Z' respectively. Here $x_H=0$ reduces to the B$-$L case.

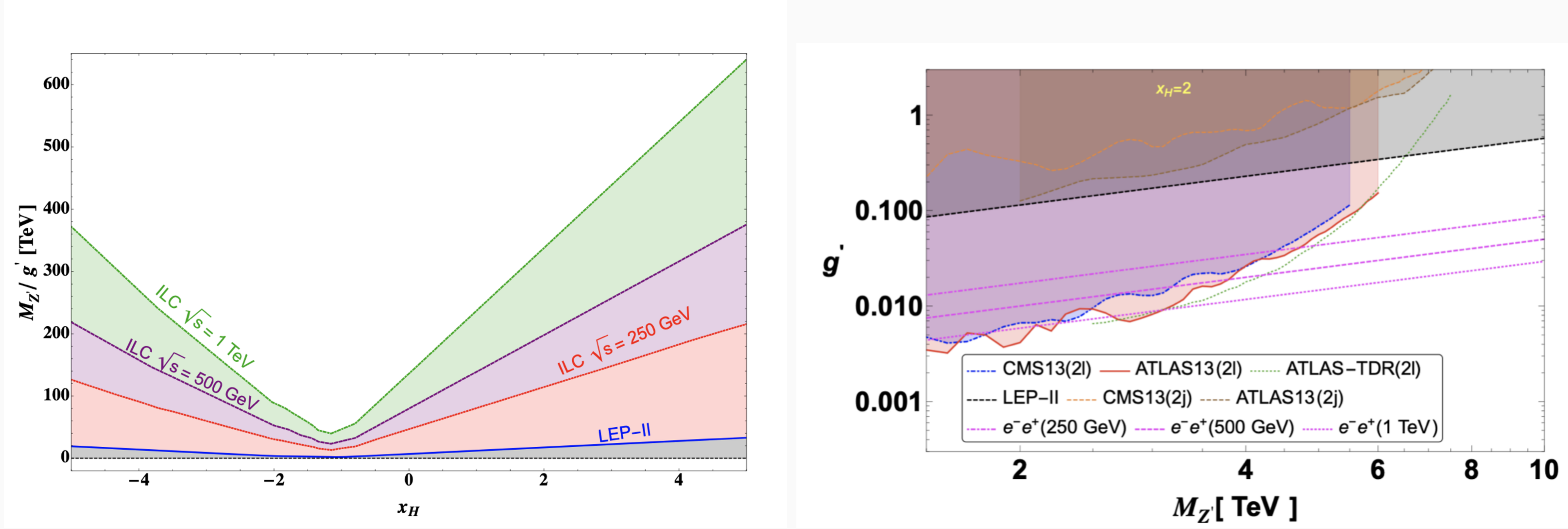
(4) Fermion pair production: $e^-e^+\to f\bar{f}$ includes inference between γ, Z and Z' and $f=e$ case is the Bhabha scattering. We consider here $f=\mu$ case only which includes the s-channel processes whereas the Bhabha scattering will include both of the s and t channel processes and the corresponding interferences.

B. Constraints on the $\mathrm{U}(1)_X$ couplings

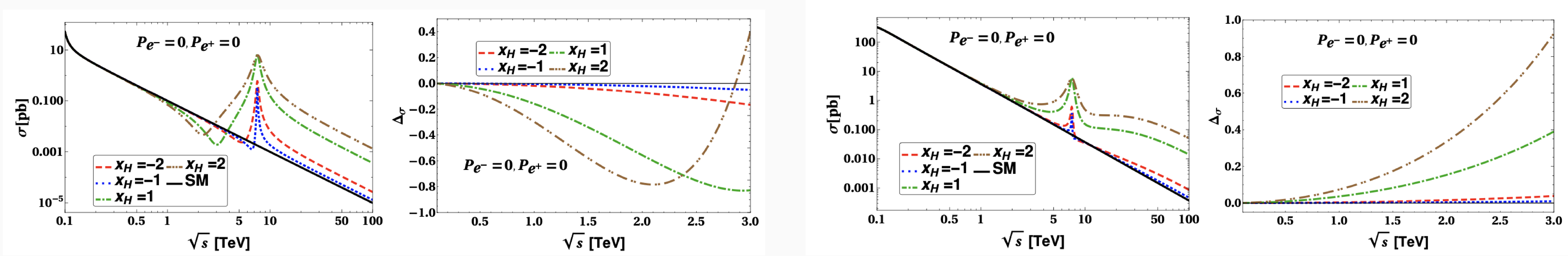
LHC: dilepton, dijet channels from CMS and ATLAS using Sequential Standard Model, LEP-II, Prospective ILC 250, 500, 1000. The master equation to estimate the bounds on the $\mathrm{U}(1)_X$ coupling $g'=\sqrt{\frac{g^2_{\mathrm{Model}}\,\sigma_{\mathrm{LHC}}}{\sigma_{\mathrm{Model}}}}$. We consider g'=0.4 and $M_{Z'}=7.5$ allowed by the constraints. See 2104.10902

C. Results

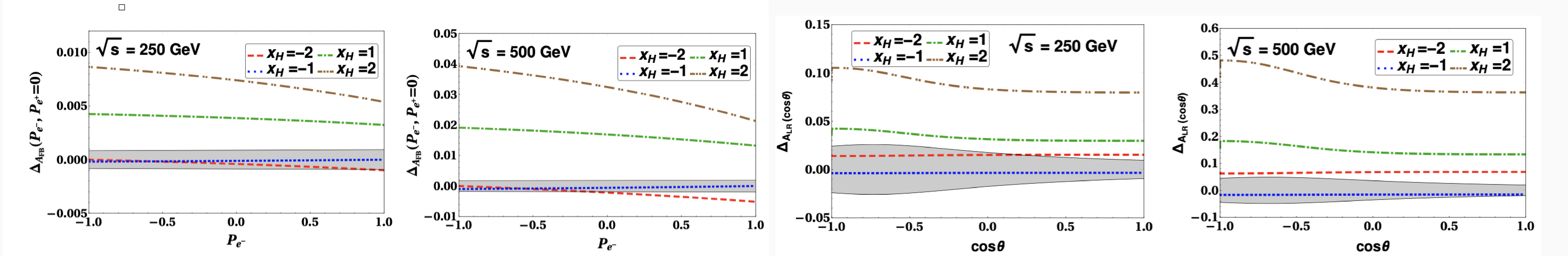
Constraints on the $\mathrm{U}(1)_X$ breaking scale from the LEP-II (1302.3415) and prospective ILC250, ILC500 and ILC1000 (1908.11299) considering $M_{Z'}>\sqrt{s}$ with respect to x_H (left panel) and fixed $x_H=2$ (right panel) respectively. Using these bounds we estimate the asymmetries.

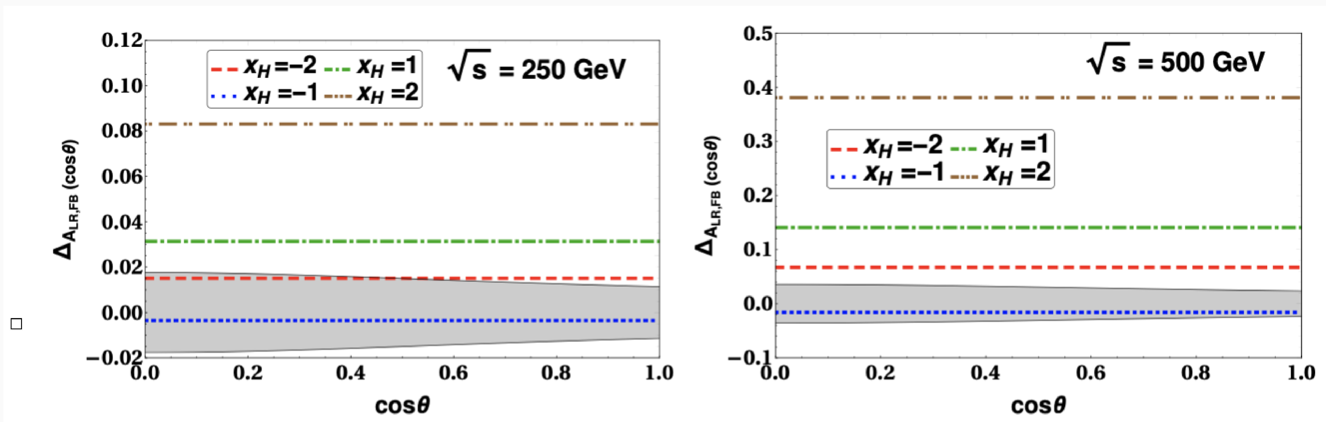


Total cross section and the deviation for $e^+e^-\to\mu^+\mu^-$ (first and second) and $e^+e^-\to e^+e^-$ (third and fourth) processes respectively for different x_H as a function of $\sqrt{s}$ for different polarizations of the electron and positron at $\sqrt{s}=250$ GeV and $\sqrt{s}=500$ GeV.



We also study the Forward-Backward (top, left first and second figures), Left-Right (top right third and fourth figues)and Left-Right-Forward-Backward (bottom) asymmetries for different x_H for 250 GeV and 500 GeV center of mass energies.





D. Conclusion

FB asymmetry vary 4%, LR asymmetry reaches up to 50% and LE-FB can reach up to 40% depending on the center of mass energies, x_H and $\cos\theta$.Integrated asymmetries, Bhabha scattering and detailed analyses for different benchmark scenarios are shown in 2104.10902.

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