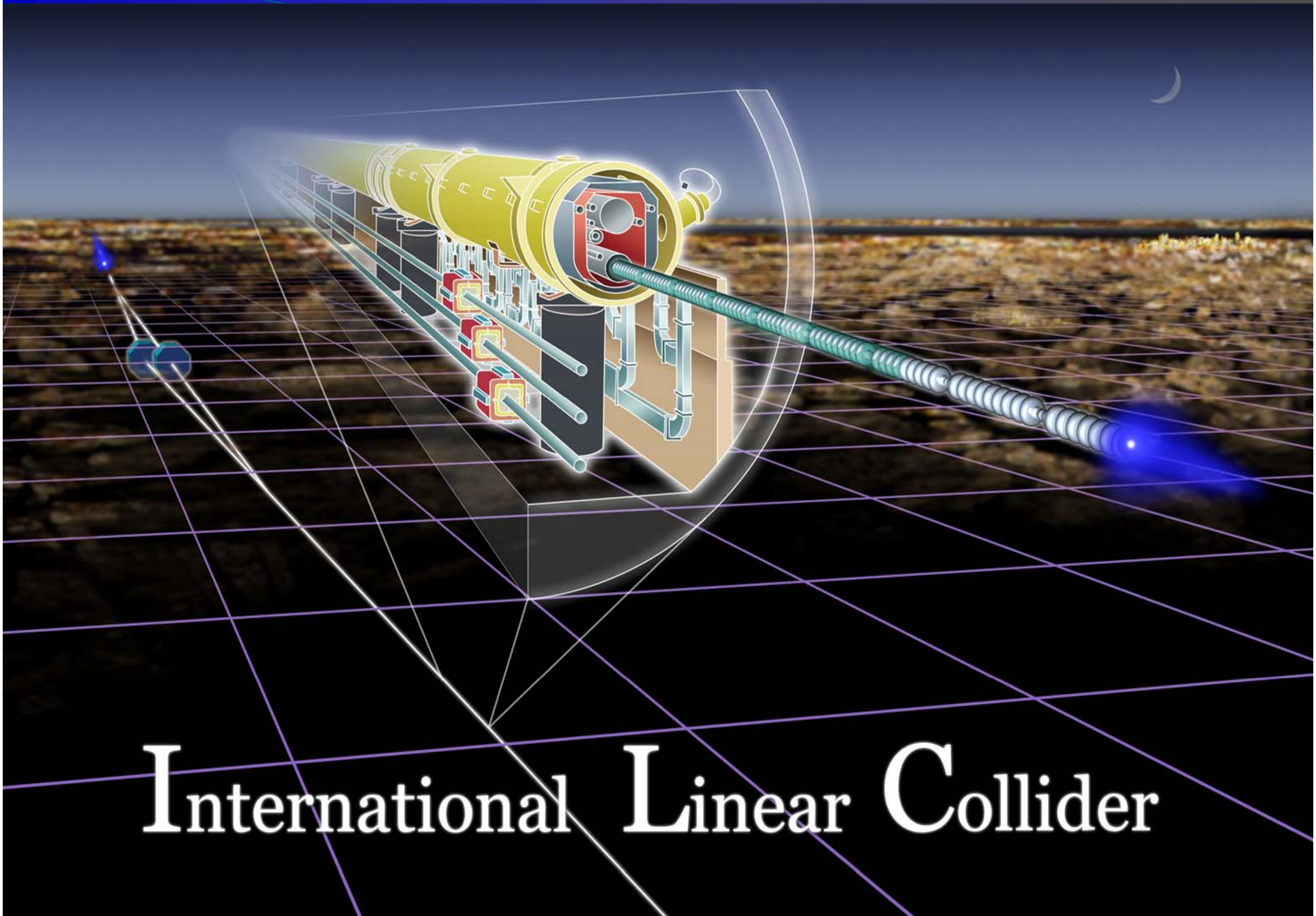
International Linear Collider

Testing extended Higgs models by resonance effects at the ILC

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Abstract

We analyze the standard model generalizations that include the extended Higgs sector. We investigate the processes at near future colliders possible to distinguish among these models, in particular, the resonance Moller scattering at the International Linear Collider (ILC). We demonstrate that the effects of triplet component or singlet doubly charged Higgs in the parity asymmetry in Moller scattering are the opposite. We show that the models with singlet doubly charged Higgs can be easily tested at the ILC.

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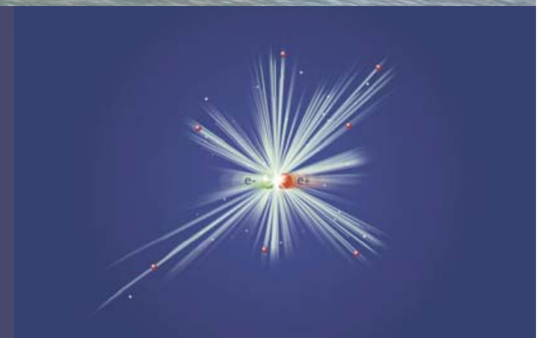

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Extended Higgs Models

Some opened points in particle physics:

- Small neutrino masses ν
- Electroweak symmetry breaking
- Baryon asymmetry in the Universe
- Dark matter
- Particle masses hierarchy

Some models to clarify the points, in particular, small observable neutrino masses, include:

Sterile neutrinos

- GUTs
- Extra dimensions
- Other new physics

Extended Higgs sector

- Charge singlet & additional doublet (Zee)
- Singly & doubly charged singlets (Zee-Babu)
- Doubly charged singlets and/or triplets

Triplet and singlet doubly charged Higgs

Complex Higgs triplet with Y = -2

$$T = \begin{pmatrix} T^0 & \frac{T^-}{\sqrt{2}} \\ \frac{T^-}{\sqrt{2}} & T^{--} \end{pmatrix}$$

$$\mathcal{L}_L = g_{ij} \overline{L^c_{iL}} T^\dagger L_{jL} + \text{H.c.}, \quad i, j = e, \mu, \tau$$

$$\Gamma_T = 3\left[\Gamma_L(\ell_i^\pm \ell_i^\pm) + \Gamma_L(\ell_i^\pm \ell_j^\pm)_{i\neq j}\right] + \Gamma_L(W^\pm W^\pm) + \Gamma_L(W^\pm P^\pm) + \Gamma_L(W^\pm W^\pm T_a^0),$$

$$M_{T^{\pm\pm}} > 136 \text{ GeV} \qquad v_T \leq 4.41 \text{ GeV} \qquad m_\nu \sim g_{ij} v_T \lesssim 0.1 \text{ eV} .$$

Doubly charged singlet Higgs with Y = 4

$$\mathcal{L}_R = Y_{ij} \overline{\ell^c_{iR}} \ell_{jR} \Psi + \text{H.c.}, \qquad \Gamma_\Psi = 3\left[\Gamma_R(\ell_i^\pm \ell_i^\pm) + \Gamma_R(\ell_i^\pm \ell_j^\pm)_{i\neq j}\right],$$

$$Y_{ij} \lesssim 1$$

CGN model

In these models the complex triplet and singlet doubly charged Higgs bosons are included simultaneously. The bosons mix to each other to form the mass eigenstates $P_{1,2}$:

$$\begin{pmatrix} P_1^{\pm\pm} \\ P_2^{\pm\pm} \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} T^{\pm\pm} \\ \Psi^{\pm\pm} \end{pmatrix} .$$

Therefore, the lepton-scalar interactions can be written as

$$\begin{aligned} \mathcal{L}_{LM} &= g_{ij}\overline{\ell^c_{Li}}\ell_{Lj}(\cos\delta P_1 - \sin\delta P_2) + \text{H.c.}, \\ \mathcal{L}_{RM} &= Y_{ij}\overline{\ell^c_{Ri}}\ell_{Rj}(\sin\delta P_1 + \cos\delta P_2) + \text{H.c.} \end{aligned}$$

The lighter massive state P_1 has following interactions and permitted decay channels

$$\frac{g^2}{\sqrt{2}} v_T c_\delta W^+_\mu W^+_\nu P_1^{--} + \text{H.c.}, \qquad Y_{ij} s_\delta P_1^{--} \overline{\ell^c_{iR}} \ell_{jR} + \text{H.c.}$$

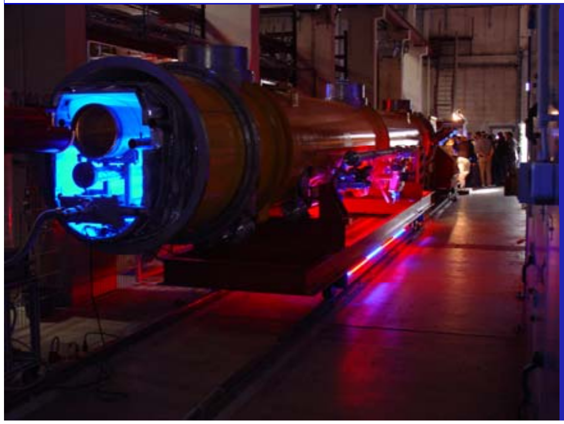
$$P_1^{\pm\pm} \to \ell^\pm_{iR}\ell^\pm_{jR}, P_1^{\pm\pm} \to W^\pm W^\pm, P_1^{\pm\pm} \to W^\pm P^\pm \text{and} P_1^{\pm\pm} \to W^\pm W^\pm T^0_a$$

Resonance Moller scattering at ILC

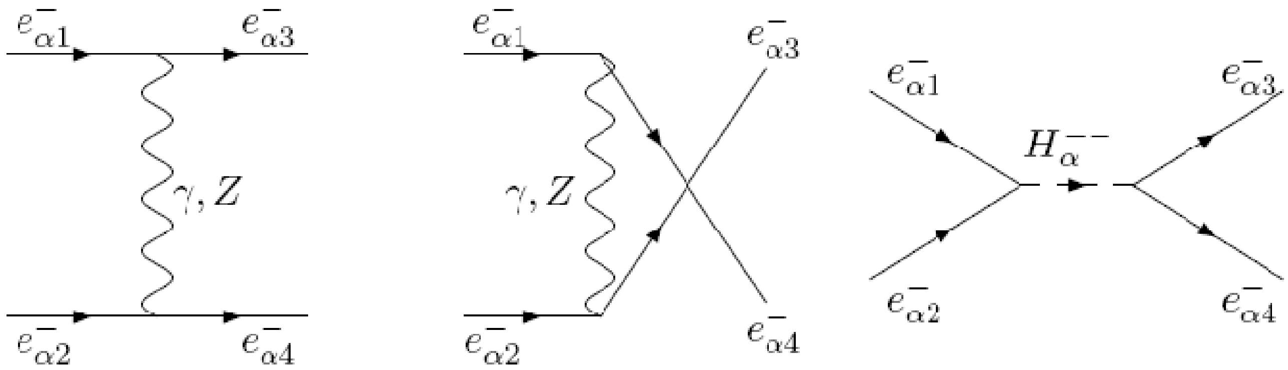
It is possible to distinguish the models with the doubly charged Higgs bosons $H^{\pm\pm}$ from the triplet (singlet) by studying the Möller scattering of $e^-e^- \to e^-e^-$ at a linear e^-e^- collider. With polarized initial electron beams, one can define the parity violating left-right asymmetry (LRA) by

$$A_P = \frac{\frac{d\sigma_{LL}}{d\cos\theta} - \frac{d\sigma_{RR}}{d\cos\theta}}{\frac{d\sigma_{LL}}{d\cos\theta} + \frac{d\sigma_{RR}}{d\cos\theta}} ,$$

where LL and RR denote the initial e^-e^- polarizations and θ is the angle between the initial and final ee beams. As the asymmetry can be measured with high accuracy in the process, it provides an excellent opportunity to probe the effects from new physics. In particular, the LRA is sensitive to the doubly charged Higgs bosons of $H^{\pm\pm}$ at their mass poles.



Feynman diagrams of the Möller scattering for the contributions from γ, Z and the doubly charged Higgs bosons H_α^{--} ($\alpha = L,\, R$) at tree level:



The parity violating LRA can now be rewritten as

$$A_P = \frac{\sum_{spin} |M_L|^2 - \sum_{spin} |M_R|^2}{\sum_{spin} |M_L|^2 + \sum_{spin} |M_R|^2},$$

$$\sum_{spin} |M_\alpha|^2 = \sum_{spin} |M_\alpha|^2_{SM} + \sum_{spin} |M_{H\alpha}|^2 .$$

The SM contributions are

$$\sum_{spin} |M_\alpha|^2_{SM} = \sum_{spin} |M_{\gamma\alpha}|^2 + \sum_{spin} |M_{Z\alpha}|^2 + \left(\sum_{spin} M_{\gamma\alpha} M^\dagger_{Z\alpha} + \sum_{spin} M_{Z\alpha} M^\dagger_{\gamma\alpha} \right),$$

$$\sum_{spin} |M_{\gamma\alpha}|^2 = \left[2e^2 \frac{s(t+u)}{tu} \right]^2, \qquad \sum_{spin} |M_{Z\alpha}|^2 = \left[2C_\alpha \frac{s(\tilde{t}+\tilde{u})}{\tilde{t}\tilde{u}} \right]^2,$$

$$\sum_{spin} M_{\gamma\alpha} M^\dagger_{Z\alpha} = \sum_{spin} M_{Z\alpha} M^\dagger_{\gamma\alpha} = 4e^2 C_\alpha s^2 \left[\frac{1}{t\tilde{t}} + \frac{1}{t\tilde{u}} + \frac{1}{u\tilde{t}} + \frac{1}{u\tilde{u}} \right],$$

$$C_L = \frac{g(1-2\sin^2\theta_W)}{2\cos\theta_W}, \quad C_R = \frac{g\sin^2\theta_W}{\cos\theta_W}, \qquad \tilde{a} = a - M_Z^2, \;\; a = t, u.$$

The non-SM ones due to the doubly charged Higgs bosons are

$$\sum_{spin} |M_{H\alpha}|^2 = |Y_{\alpha ee}|^4 \frac{s^2}{(s-M^2_{H_\alpha})^2 + M^2_{H_\alpha}\Gamma^2_{H_\alpha}}.$$

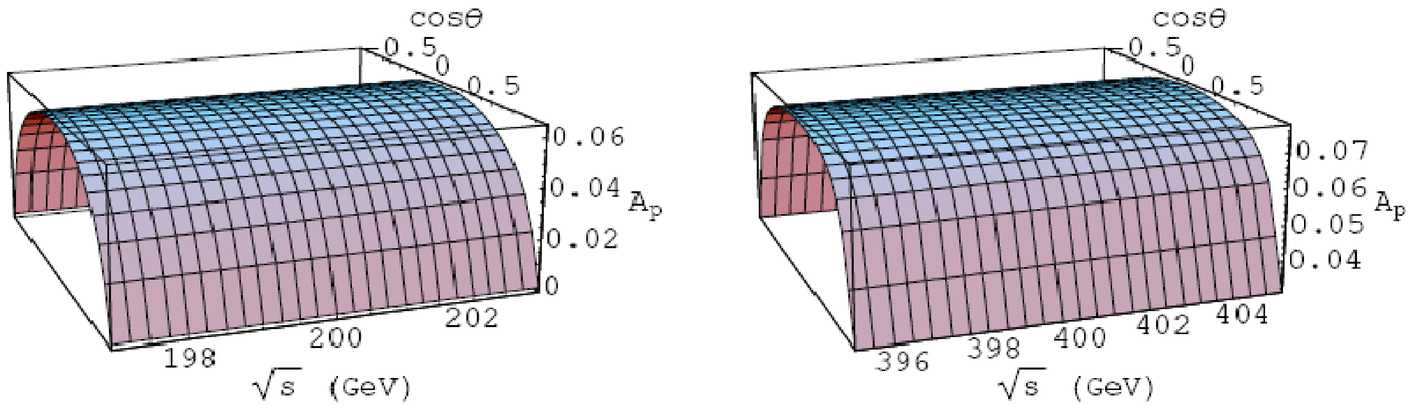


FIG. 1: The asymmetry A_P vs. $\cos\theta$ for the energies around $\sqrt{s} = 200$ (*left*) and 400 GeV (*right*) in the SM.

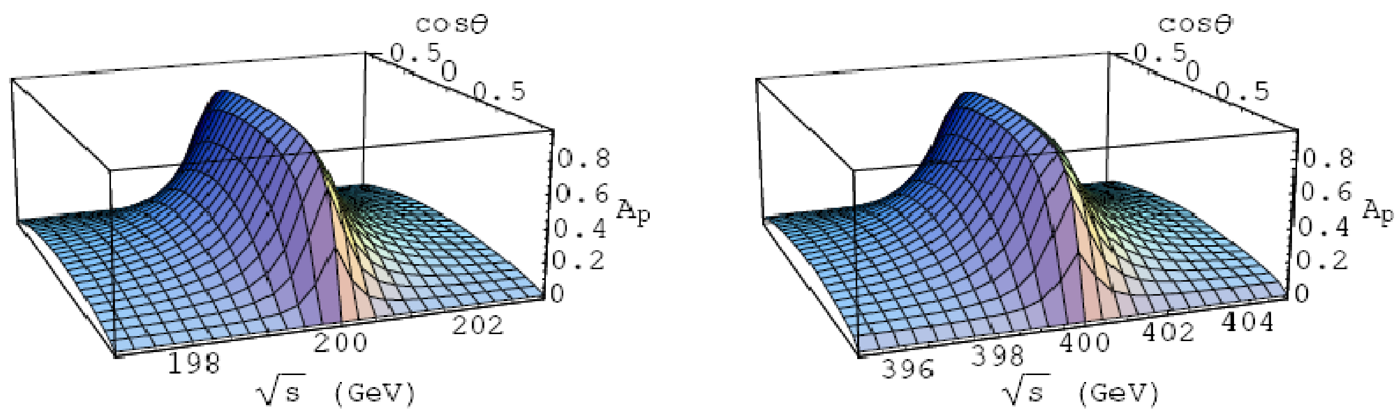


FIG. 2: The asymmetry A_P vs. $\cos\theta$ for the resonance energies around $M_T = 200$ (*left*) and 400 GeV (*right*) with the triplet Higgs boson. $|Y_{Lee}| = 0.1$.

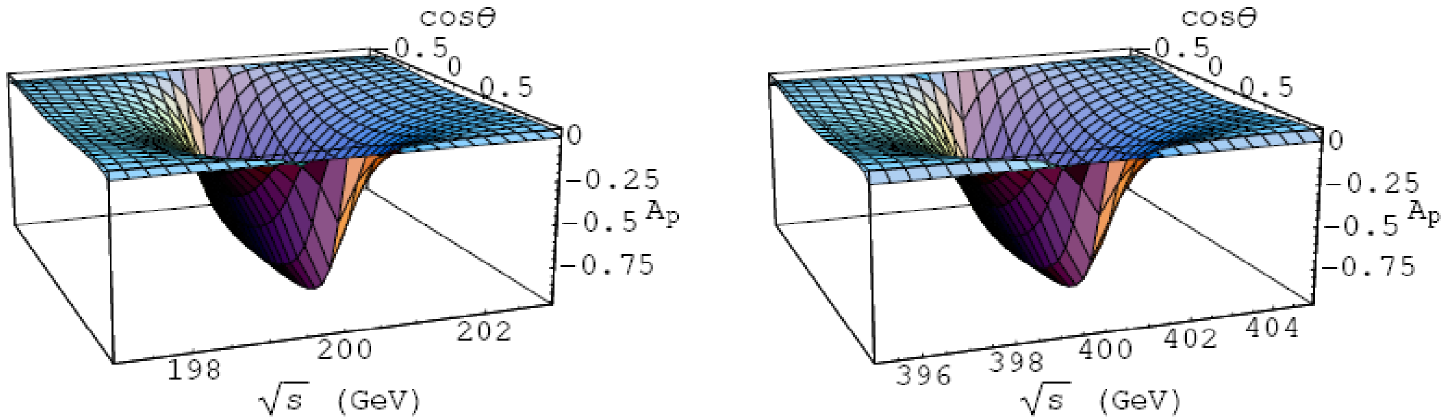


FIG. 3: The asymmetry A_P vs. $\cos\theta$ for the resonance energies around $M_\Psi = 200$ (*left*) and 400 GeV (*right*) with the singlet doubly charged Higgs boson. $|Y_{Ree}| = 0.1$.

TABLE I: The values of $\Gamma_{H\alpha}$ for the various values of $M_{H\alpha}$.

$\lvert Y_{\alpha ee}\rvert$	$M_{H\alpha}$, GeV	Γ_T, GeV	Γ_Ψ, GeV
0.1	200	0.359	0.358
0.1	400	0.736	0.716
0.05	200	0.091	0.090
0.005	200	0.0020	0.00090
0.002	200	0.0012	0.00014

Since the doubly charged Higgs T and Ψ couple to the different helicity states of the electron, the effects lead to the opposite sign of A_P. The strong dependence of these effects on the values of $Y_{\alpha ee}$ is shown for the resonance point of $\sqrt{s} = M_{H\alpha} = 200$ GeV in Figs. 4 and 5 and the near one of $\sqrt{s} = 202$ GeV in Figs. 6 and 7.

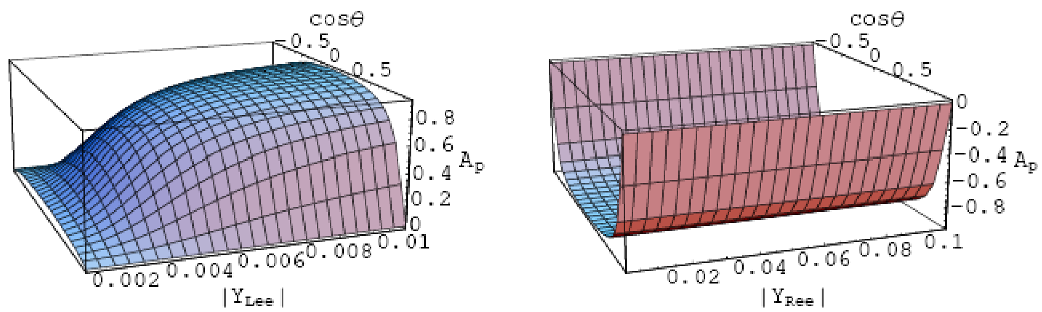


FIG. 4: A_p vs. $\cos\theta$, $|Y_{\alpha ee}|$ in the resonance point $\sqrt{s} = M_{H\alpha} = 200$ GeV with the doubly charged Higgs bosons from the triplet (*left*) and singlet (*right*) scalars.

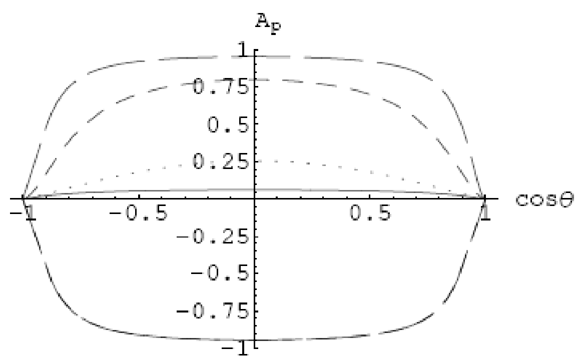


FIG. 5: A_p vs. $\cos\theta$ in the resonance point $\sqrt{s} = M_{H\alpha} = 200$ GeV in the SM (solid line), the model with the doubly charged Higgs boson from the triplet (lines upper the solid one) or the singlet (coincided lines below the solid one), where the doted, short-dashed and long-dashed lines represent $|Y_{\alpha ee}| = 0.002$, 0.005 and 0.1, respectively.

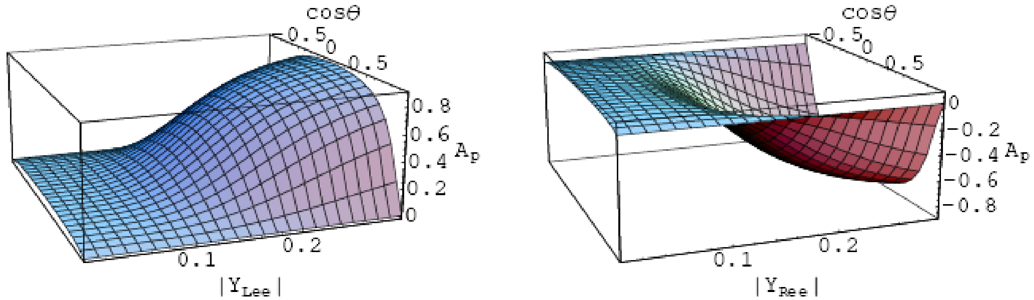


FIG. 6: A_p vs. $\cos\theta$, $|Y_{\alpha ee}|$ for the energy $\sqrt{s} = 202$ GeV close to $M_{H\alpha}$=200 GeV with the doubly charged Higgs bosons from the triplet (*left*) and singlet (*right*) scalars.

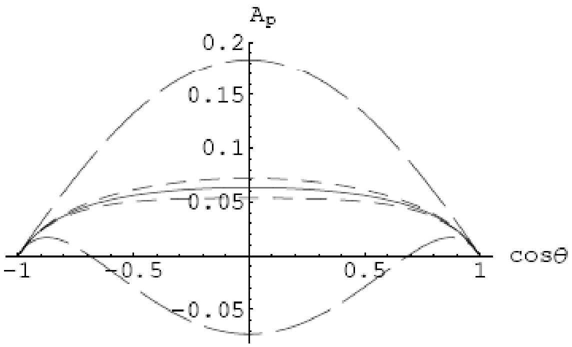


FIG. 7: A_p vs. $\cos\theta$ for the energy $\sqrt{s} = 202$ GeV close to $M_{H\alpha} = 200$ GeV in the SM (solid line) and the model with the doubly charged Higgs boson from the triplet (lines upper the solid one) or the singlet (lines below the solid one), where the short-dashed (long-dashed) line stands for $|Y_{\alpha ee}| = 0.05$ (0.1).

By taking into account the strong bounds on the couplings $g_{ij} \sim Y_{Lij}$, one can conclude that there is no chance to observe the LRA for the triplet scalar in the near future. On the other hand, the constraints on the interaction for the singlet scalar are much relax, providing a good chance to detect the effects at the ILC.

As shown in Figs. 8 and 9, the deviations from the SM are smaller in the CGN model comparing to the case with only the singlet scalar. However, they can be observed at the ILC. We have taken $|Y_{ee}| = 0.2$ and the small (large) mixing as $\sin\delta = 0.1$ (0.5).

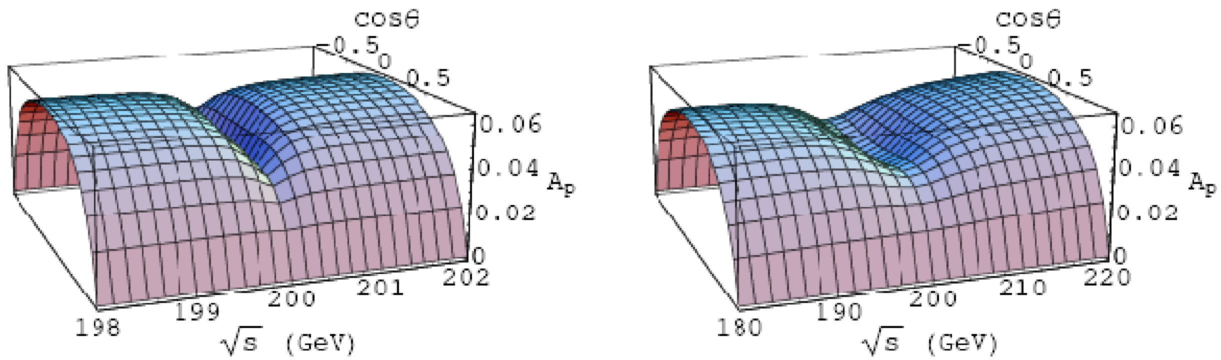


FIG. 8: A_P in the general model at the resonance point of 200 GeV with small mixing (*left*) and large mixing (*right*) angles.

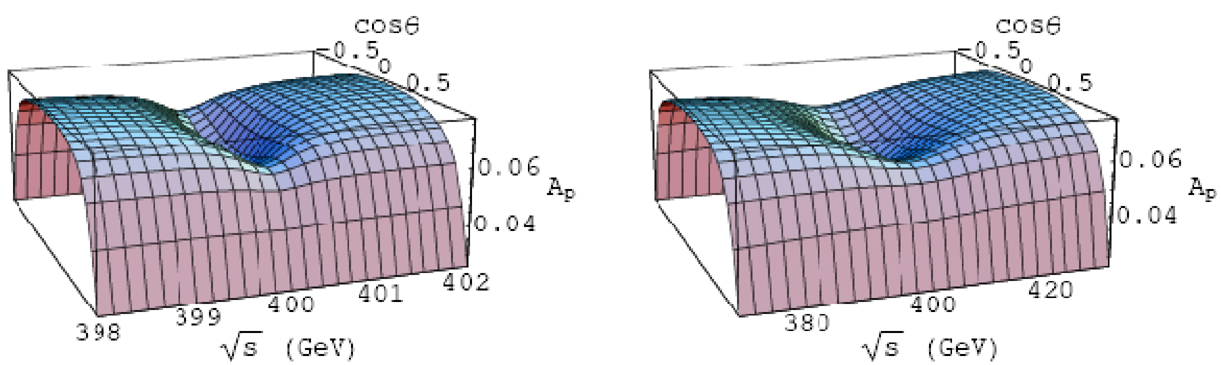


FIG. 9: Legend is the same as Fig. 9 but at the resonance point of 400 GeV.

In Fig. 10 (11) we show the deviation from the SM with the large and small mixing angles in the resonance energy region for the doubly charged Higgs scalar mass being equal to 200 (400) GeV. The deviations in the small mixing are much less than those in the large mixing. This may help to clarify the mixing between the doubly charged scalars.

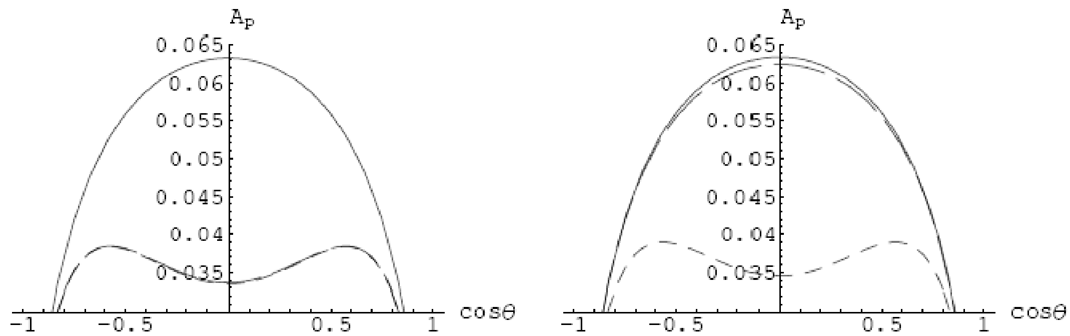


FIG. 10: A_P in the general model at the resonance point of 200 GeV (*left*) and around the resonance point of 201 GeV (*right*), where the solid, long-dash and short-dash lines represent the SM, the small mixing and the large mixing, respectively.

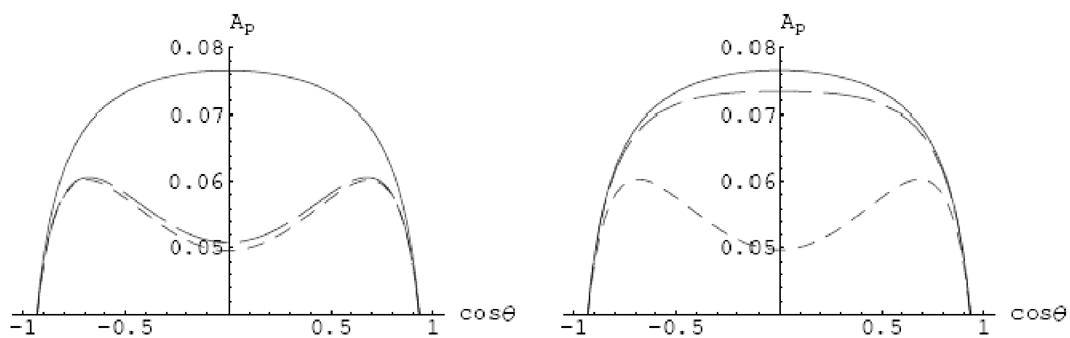


FIG. 11: Legend is the same as Fig. 11 but replacing 200 and 201 to 400 and 401 GeV, respectively.

The relative deviations of A_P from the SM values A_P^{SM}, defined by $\alpha_P = (A_P^{SM} - A_P)/A_P^{SM}$ are given in Table II for the various resonance energies $\sqrt{s}$ at the maximum points of $\cos\theta = 0$ with $M_{P_1} = 200$ and 400 GeV and $\sin\delta = 0.1$ and 0.5.

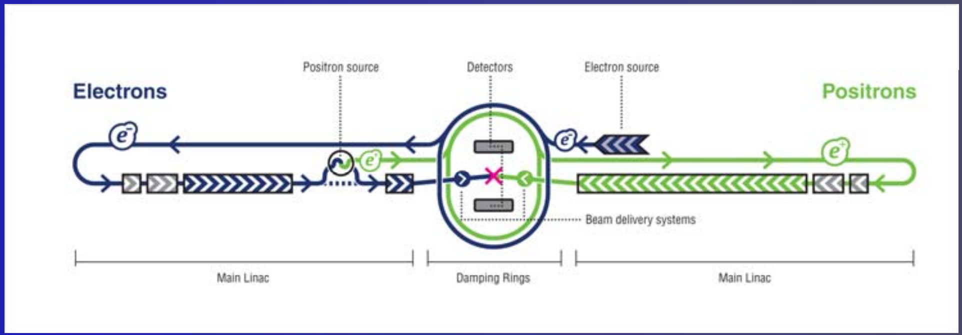
TABLE II: Relative deviations α_P of A_P at $\cos\theta = 0$ in and around the resonance energies.

M_{P_1}, GeV	$\sqrt{s}$, GeV	α_P, $\sin\delta = 0.1$	α_P, $\sin\delta = 0.5$
200	200	0.47	0.47
	200 ± 1	0.015	0.46
	200 ± 2	0.004	0.41
	200 ± 4	0.001	0.28
400	400	0.33	0.35
	400 ± 1	0.039	0.35
	400 ± 2	0.012	0.34
	400 ± 4	0.003	0.30

One can see that measuring α_P with 10% (1%) accuracy and fixing the energy with 1% accuracy or less allow to observe the resonance effects in the large (small) mixing.

Conclusion

We have investigated the contributions to the LRA of A_P from the doubly charged Higgs bosons coupled to the electrons with different chiralities in the Möller scattering. We have found that it is easy to extract the properties of the models with $H^{\pm\pm}$ interacting with e_R from the measurements of A_P around the resonance point at the ILC, whereas it is impossible to observe the effects of the models with $H^{\pm\pm}$ coupled only to e_L. The discovery has also application to understanding of the neutrino masses generation.




Thank you!