On probing Higgs couplings in $H \to Ze^+e^-$ and $e^+e^- \to ZH$

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First slide

The discovery of the Higgs $m_H \simeq 125.7$ GeV by CMS and ATLAS at the LHC is a striking success of the contemporary fundamental physics. This discovery not only confirmed the so-called Higgs mechanism for the EW symmetry breaking, but also opened a new possibility to perform a precise test of the SM. Using all of the available data, with a total luminosity of 25 fb^{-1} from the pp collisions with energies of $\sqrt{s} = 7$ and 8 TeV runs at the LHC, such properties of the Higgs boson as a spin, parity, mass, and the couplings to other SM particles, has been further investigated. So far there are no indications of major deviations from the Higgs boson properties which are predicted by the SM. However, the total decay width of the SM Higgs (Γ_t) being around 4 MeV is not expected to be directly observable at the LHC by virtue of the fact that Γ_t is several orders of magnitude smaller than the experimental mass resolution.

Second slide

The HL-LHC is a major upgrade of the LHC to deliver an integrated luminosity of 3000 fb^{-1}. It is planned that the precision on the Higgs couplings will be improved from at present several tens of percent to about 10%. The future e^+e^- linear collider (ILC) can further enhance the accuracy bringing it up to 1%.

However, the SM cannot be considered as a complete theory, since it does not explain gravity, nonbaryonic cold dark matter, dark energy, the baryon asymmetry of the Universe, neutrino masses and mixings, $(g-2)_\mu$-anomaly, and hierarchy problem. The recently observed the lepton flavor violating Higgs decay

$$H \to \tau^- \mu^+$$

is beyond the scope of the SM too. So, the SM appears to be a good effective field theory at the least up to the energies probed by the first run of LHC.

Third slide

Some of the simplest extensions of the SM are those that add new neutral gauge boson which could arise from a variety of contexts, ranging from simple extra $U(1)$ gauge symmetries, left-right models (LRM's), 3-3-1 models and so on. These models fall into two rather broad categories depending on whether or not they arise in a GUT scenario.

We shall centre on the two most popular GUT scenarios, namely, the LRM's and models coming from E_6 grand unification (ER5M's). The purpose of our work is to consider the Higgs decay

$$H \to Z + f + \overline{f} \tag{1}$$

and the associated Higgs production with Z boson at the e^+e^- annihilation

$$e^+ + e^- \to Z + H \tag{2}$$

in the context of these SM extensions.

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The LRM, based on the low-energy gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, can arise from an $SO(10)$ or E_6 GUT. Here quarks and leptons enter both into the left- and right-handed doublets

$$q^i_L(\frac{1}{2}, 0, \frac{1}{3}), \qquad q^i_R(0, \frac{1}{2}, \frac{1}{3}), \qquad l^a_L(\frac{1}{2}, 0, -1), \qquad l^a_R(0, \frac{1}{2}, -1)$$

where in brackets the values of S^W_L, S^W_R and $B-L$ are given. The Higgs sector includes one bi-doublet $\Phi\left(\frac{1}{2}, \frac{1^*}{2}, 0\right)$ and two triplets $\Delta_L(1,0,2)$, $\Delta_R(0,1,2)$ The symmetry breaking is triggered by the following VEVs

$$< \Phi >= \begin{pmatrix} k_1/\sqrt{2} & 0 \\ 0 & k_2/\sqrt{2} \end{pmatrix}, \qquad < \Delta_{L,R} >= \begin{pmatrix} 0 & 0 \\ v_{L,R}/\sqrt{2} & 0 \end{pmatrix}.$$

$$v_L << \text{max}(k_1, k_2) << v_R.$$

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After the SSB we have 14 physical Higgs bosons: four doubly-charged scalars $\Delta_{1,2}^{(\pm\pm)}$, four singly-charged scalars $\tilde{\delta}^{(\pm)}$ and $h^{(\pm)}$, four neutral scalars $S_{1,2,3,4}$, and two neutral pseudoscalars $P_{1,2}$ (S_1 is an analog of the SM Higgs). The needed Lagrangians are as follows (O. Boyarkin, *Advanced Particles Physics, Volume II* New York, 2011)

$$-L_{NC}^{LRM} = \overline{\psi}_f \gamma_\mu (g_{V_f}^{(1)} - g_{A_f}^{(1)}\gamma_5) Z_1^\mu \psi_f + \overline{\psi}_f \gamma_\mu (g_{V_f}^{(2)} - g_{A_f}^{(2)}\gamma_5) Z_2^\mu \psi_f ,$$

$$L_{S_1 Z_n Z_k} = g_{S_1 Z_n Z_k} S_1(x) Z_n^\mu(x) Z_{k\mu}(x),$$

where

$$g_{Vf}^{(1)} = \frac{1}{2}\left\{ e c_\phi c_W^{-1} s_W^{-1} \left[S_3^W(f_L) - 2Q(f) s_W^2 \right] + \right.$$

$$\left. + \frac{e s_\phi c_W^{-1}}{\sqrt{e^{-2} g_R^2 c_W^2 - 1}} \left[e^{-2} g_R^2 c_W^2 S_3^W(f_R) + S_3^W(f_L) - 2Q(f) \right] \right\},$$

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$$g_{Af}^{(1)} = \frac{1}{2}\left\{ec_\phi c_W^{-1} s_W^{-1} S_3^W(f_L) - \frac{es_\phi c_W^{-1}}{\sqrt{e^{-2}g_R^2 c_W^2 - 1}}\left[e^{-2}g_R^2 c_W^2 S_3^W(f_R) - \right.\right.$$

$$\left.\left. - S_3^W(f_L)\right]\right\}, \qquad g_{Vf}^{(2)} = g_{Vf}^{(1)}\left(\phi \to \phi + \frac{\pi}{2}\right), \; g_{Af}^{(2)} = g_{Af}^{(1)}\left(\phi \to \phi + \frac{\pi}{2}\right),$$

$$g_{S_1 Z_1 Z_1} = -\frac{g_L^2(k_-^2 c_\theta + 2k_1 k_2 s_\theta)}{2\sqrt{2}c_W^2 k_+}(c_\Phi - \sqrt{c_W^2 - s_W^2}s_\Phi)^2,$$

$$g_{S_1 Z_1 Z_2} = \frac{g_L^2(k_-^2 c_\theta + 2k_1 k_2 s_\theta)}{\sqrt{2}c_W^2 k_+}[2c_W^2 c_\Phi s_\Phi + \sqrt{c_W^2 - s_W^2}(c_\Phi^2 - s_\Phi^2)],$$

$$g_{S_1 Z_2 Z_2} = -\frac{g_L^2(k_-^2 c_\theta + 2k_1 k_2 s_\theta)}{2\sqrt{2}c_W^2 k_+}(\sqrt{c_W^2 - s_W^2}c_\Phi + s_\Phi)^2,$$

$$s_W = \sin\theta_W, \; k_\pm = \sqrt{k_1^2 \pm k_2^2}.$$

Seventh slide

We shall deal with the simplest E_6-based low-energy group, $SU(2)_L \times U(1)_Y \times U(1)_{Y'}$ resulting from compactification of 10-dimensional $E_8 \times E_8'$ superstring theory to four dimensions. The matter fields occur in three supersymmetric chiral multiplets, each transforming according to the quantum numbers of the fundamental **27** of E_6. In each multiplet there are five colorless neutral superfields: one is usually assigned nonzero lepton number, while two, $H_1^{(a)}$ and $H_2^{(a)}$ belong to doublets of the residual $SU(2)$, and the remaining two, $N_1^{(a)}$ and $N_2^{(a)}$, are singlets under $SU(2)$. Breaking $SU(2)_L \times U(1)_Y \times U(1)_{Y'}$ to $U(1)_{em}$ is realized when only the neutral components of the third-family Higgs fields $N_1^{(3)}$, $N_2^{(3)}$ and $H_1^{(3)}$ acquire VEV's (v_1, v_2 and n). After SSB we have: one neutral pseudoscalar H_3^0, three neutral scalars H_α^0 ($\alpha = 2, deg, Z'$), and two singly-charged scalars $H^\pm$ (the neutral scalar degenerate with H_3^0 and $H^\pm$ is denoted by H_{deg}^0 and that degenerate with Z' by $H_{Z'}^0$).

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The third-family Higgs bosons will have trilinear tree-level couplings to vector-boson pairs and their Yukawa couplings to fermions of all generations will be tied to the fermion masses. In contrast, the Higgs fields of the first and second families by definition do not have VEV's and they possess only quartic couplings to vector-boson pairs, and their Yukawa couplings to fermions of their own and other generations cannot be very large. Therefore, only the Higgs bosons associated with the third-generation **27** multiplet of E_6 participate in the electroweak symmetry breaking. The Lagrangians of the H_2^0 being an analog of the SM Higgs with the fermions and neutral gauge bosons have the form

$$-L_{NC}^{E_6} = \sum_f \{ \overline{\psi}_f \gamma_\mu (g_{V_f} - g_{A_f}\gamma_5) Z^\mu \psi_f + + \overline{\psi}_f \gamma_\mu (g'_{V_f} - g'_{A_f}\gamma_5) Z'^\mu \psi_f ,$$

$$L_{NGB}^{E_6} = g_{H_2^0 ZZ} H_2^0(x) Z_\mu(x) Z^\mu(x) + g_{H_2^0 ZZ'} H_2^0(x) Z_\mu(x) Z'^\mu(x),$$

where

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$$g'_{V_l} = -g'_{V_d} = \frac{ec_\beta}{c_W}\sqrt{\frac{5}{30}}, \qquad g'_{A_l} = g'_{A_d} = \frac{e}{2c_W}\sqrt{\frac{5}{3}}\left[\frac{c_\beta}{\sqrt{10}} + \frac{s_\beta}{\sqrt{6}}\right],$$

$$g'_{V_\nu} = g'_{A_\nu} = \frac{e}{2c_W}\sqrt{\frac{5}{3}}\left[\frac{3c_\beta}{\sqrt{40}} + \frac{s_\beta}{\sqrt{24}}\right], \qquad g'_{V_u} = \frac{e}{2c_W}\sqrt{\frac{5}{3}}\left[-\frac{c_\beta}{\sqrt{10}} + \frac{s_\beta}{\sqrt{6}}\right],$$

$$g_{H_2^0 ZZ} = \frac{em_Z}{s_W c_W}, \qquad g_{H_2^0 ZZ'} = \frac{em_Z}{3c_W}(c_\beta^2 - 4s_\beta^2), \qquad \tan\beta = \frac{v_2}{v_1},$$

and $g_{H_2^0 ZZ}$ and $g_{H_2^0 ZZ'}$ are given in the limit of large n and small neutral gauge boson mixing. β is treated as a free parameter and its particular values correspond to special models. The more popular models are: the χ model ($\beta = 0$), the ψ model ($\beta = \pi/2$), the η model ($\beta = \pi - \arctan\sqrt{5/3}$, the inert model ($-\beta = \arctan\sqrt{3/5}$), the neutral N model ($\beta = \arctan\sqrt{15}$), the secluded sector model ($\beta = \arctan\sqrt{15}/9$).

Tenth slide

The Higgs decay modes into gauge bosons, with one of them being off-shell are important. In this three-body decay, although suppressed by an additional power of the electroweak coupling squared compared to the dominant $H \to b\bar{b}$ case and by the virtuality of the intermediate vector boson state, there is a compensation since in the SM the Higgs couplings to gauge bosons Z and W bosons are proportional to their masses and as a result much larger than the Higgs Yukawa coupling to b quarks. However, the similar proportionality does not always happen in the SM extensions. For example, in the LRM the $W_1 W_1 S_1$ coupling is proportional to m_{W_1}, while the $Z_1 Z_1 S_1$ does not.

At first, we shall speak about the LRM. In the second order of the perturbation theory this decay proceeds through the diagrams in Fig.1 with one real and one virtual neutral gauge bosons.

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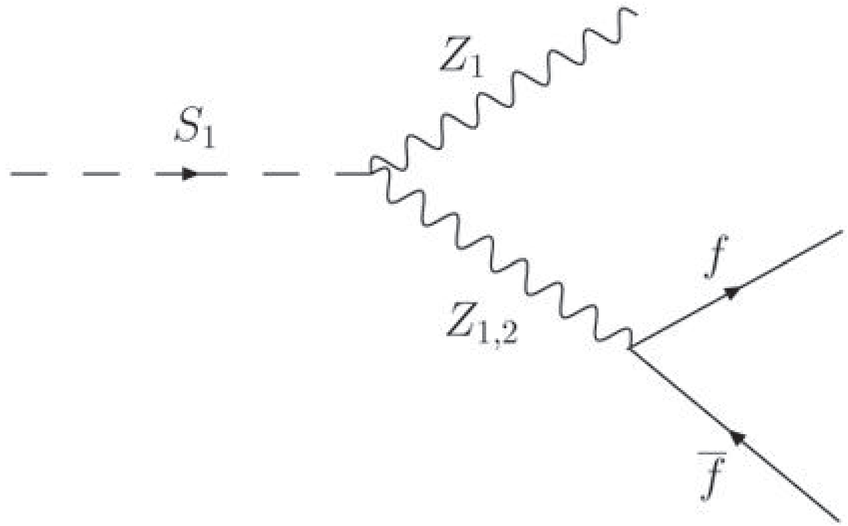

Figure 1: The Feynman diagrams for $S_1 \to Z_1 \overline{f} f$.

Neglecting the fermion masses and summing over polarization of the final particles, for the partial decay width we get

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$$\Gamma^{LRM} = \Gamma(S_1 \to Z_1 Z_1^*) + \Gamma(S_1 \to Z_1 Z_2^*),$$

$$\Gamma(S_1 \to Z_1 Z_1^*) = \frac{g^2_{S_1 Z_1 Z_1} m_{S_1} [(g^{(1)}_{V_f})^2 + (g^{(1)}_{A_f})^2]}{48\pi^3 m^2_{Z_1}} f(\epsilon),$$

$$\Gamma(S_1 \to Z_1 Z_2^*) = \frac{g_{S_1 Z_1 Z_1} g_{S_1 Z_1 Z_2} m_{S_1} [g^{(1)}_{V_f} g^{(2)}_{V_f} + g^{(1)}_{A_f} g^{(2)}_{A_f}]}{24\pi^3 m^2_{Z_1} \eta} F(\epsilon),$$

$$f(\epsilon) = \frac{3(1 - 8\epsilon^2 + 20\epsilon^4)}{\sqrt{4\epsilon^2 - 1}} \arccos\left(\frac{3\epsilon^2 - 1}{2\epsilon^3}\right) - (1-\epsilon^2)\left(\frac{47\epsilon^2}{2} - \frac{13}{2} + \frac{1}{\epsilon^2}\right) -$$

$$-3(1 - 6\epsilon^2 + 4\epsilon^4) \ln \epsilon,$$

$$F(\epsilon) = \sqrt{4\epsilon^2 - 1}(4\epsilon^2 - 12\epsilon^4 - 1) \arccos\left(\frac{3\epsilon^2 - 1}{2\epsilon^3}\right) + (1-\epsilon^2)\left(\frac{11}{6} - \frac{61\epsilon^2}{6} +\right.$$

$$\left. + \frac{19\epsilon^4}{3}\right) + (6\epsilon^2 - 36\epsilon^4 - 1) \ln \epsilon, \qquad \epsilon = \frac{m_{Z_1}}{m_{S_1}}, \quad \eta = \frac{m^2_{Z_2} - m^2_{Z_1}}{m^2_{S_1}}.$$

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Summing over all fermions we get

$$\Gamma^{LRM}(S_1 \to Z_1 \sum f\overline{f}) \simeq \frac{g_L^6 (k_-^2 c_\theta + 2k_1 k_2 s_\theta)^2 m_{S_1}}{4096\pi^3 c_W^6 k_+^2 m_{Z_1}^2} \Big[f(\epsilon)\Big(7 - \frac{40}{3} s_W^2 + + \frac{160}{9} s_W^4\Big) - \frac{2F(\epsilon)}{\eta}\Big(\frac{320}{9} s_W^4 - \frac{38}{3} s_W^2\Big)\Big].$$

The first term in the square bracket significantly exceeds the second one: e.g., at $m_{Z_2} = 1.5$ TeV ($m_{Z_2} = 2$ TeV) their ratio is 1.5×10^{-3} (0.8×10^{-3}).

So, there are two possibilities. The first is: this partial width is measured with the high precision and it coincides with the SM prediction. However, even then the LRM could not be ruled out provided that the coupling constant $g_{S_1 Z_1 Z_1}$ is equal to its SM value ($em_Z/(c_W s_W)$). Then comparing $\Gamma^{LRM}(S_1 \to Z_1 \sum f\overline{f})$ with the experimantal result and taking into consideration

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$$m_{Z_1} \simeq \frac{g_L^2}{2}(k_+^2 + 4v_L^2),$$

we come to the result

$$k_+^2 + 4v_L^2 \simeq \frac{(k_-^2 c_\theta + 2k_1 k_2 s_\theta)^2}{c_W^2 k_+^2}. \qquad (3)$$

From (3) it follows

$$k_2 \preceq 0.25 k_1.$$

The second possibility speculates that the measured partial decay width differs from the value the SM predicts. In this case, having evaluated the coupling constant $g_{S_1 Z_1 Z_1}$ from the Higgs decay under investigation, we could achieve good agreement between the LRM and experiment.

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Thus, there exist ambiguity connected with the coupling constant defining interaction between neutral gauge boson and the SM Higgs. To keep this ambiguity as small as possible, and to display deviations from the SM prediction, we introduce the following quantities

$$\Delta_{\pm} = \Lambda_{\pm}^{SM} - \Lambda_{\pm}^{LRM},$$

where

$$\Lambda_{\pm}^{SM} = \frac{\Gamma_{\pm}^{SM}}{\Gamma_{+}^{SM} + \Gamma_{-}^{SM}}, \qquad \Lambda_{\pm}^{LRM} = \frac{\Gamma_{\pm}^{LRM}}{\Gamma_{+}^{LRM} + \Gamma_{-}^{LRM}},$$

$\Gamma_{+}^{SM}(\Gamma_{-}^{SM})$ is the SM expression for the total width of the decay $H \to Ze^{-}e^{+}$ in the case of left- (right-) polarized electrons.

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With the help of $\Delta_\pm$ we can find the number of the left- or right-polarized electrons pointing to deviation from the SM

$$N_\pm = \sigma(gg \to H) \times \mathcal{L} \times \mathrm{Br}(H \to Ze^-e^+) \times \Delta_\pm,$$

where $\sigma(gg \to H)$ is the Higgs boson production total cross section via gluon+gluon fusion, and $\mathcal{L}$ is the collider integrated luminosity. Setting $\sqrt{s} = 14$ TeV and $\mathcal{L} = 3000$ fb^{-1} we get

$$N_+^{LRM} \simeq \begin{cases} 103 \text{ events}, & \text{when } m_{Z_2} = 1.5 \text{ TeV}, \\ 58 \text{ events}, & \text{when } m_{Z_2} = 2 \text{ TeV}, \\ 15 \text{ events}, & \text{when } m_{Z_2} = 4 \text{ TeV}. \end{cases}$$

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To obtain the expression for the decay of the Higgs being an analog of the SM Higgs in the ER5M's, we should make in the LRM partial decay width the following replacements

$$g_{S_1Z_1Z_1} \to g_{H_2^0ZZ}, \qquad g_{S_1Z_1Z_2} \to g_{H_2^0ZZ'}, \qquad g^{(1)}_{V_f} \to g_{V_f},$$

$$g^{(1)}_{A_f} \to g_{A_f}, \qquad g^{(2)}_{V_f} \to g'_{V_f}, \qquad g^{(2)}_{A_f} \to g'_{A_f}.$$

Analysis shows that $N_+^{E_6}$ has the maximum value for the case of the η-model. Calculations result in

$$N_+^{\eta} \simeq \begin{cases} 74 \text{ events}, & \text{when } m_{Z_2} = 1.5 \text{ TeV}, \\ 42 \text{ events}, & \text{when } m_{Z_2} = 2 \text{ TeV}, \\ 11 \text{ events}, & \text{when } m_{Z_2} = 4 \text{ TeV}. \end{cases}$$

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Now we consider the Higgsstrahlung process $e^+e^- \to HZ$ that should be measured with precision at a high-energy e^+e^- collider such as the ILC and should provide a clean way to extract Higgs couplings. To be specific, we sample the LRM.

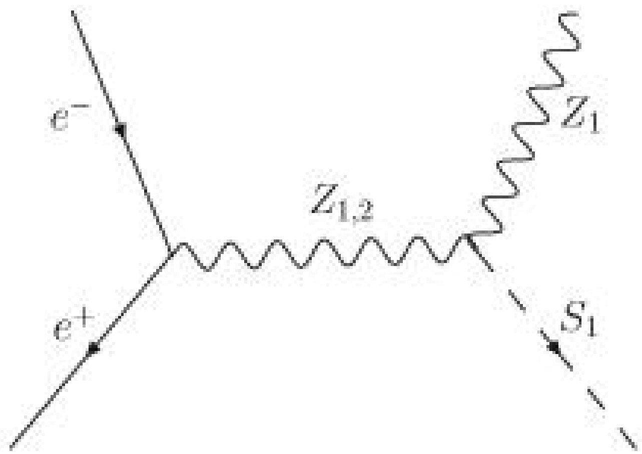

Figure 2: The Feynman diagrams for $e^+e^- \to HZ$.

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At e^+e^- collider the Higgsstrahlung process is dominant for moderate values of the ratio $m_H/\sqrt{s}$. At high energies it falls off according to the scaling law s^{-1}. When $\sqrt{s} = m_{Z_2}$ there is the resonance peak whose high crucially depends on the ratio $r = g_{S_1Z_1Z_2}/g_{S_1Z_1Z_1}$ and the total decay width of Z_2 boson. Since in the LRM $r = -2\sqrt{c_W^2 - s_W^2}$, the resonance effect will be important.

If $g_{S_1Z_1Z_1}$ takes the SM value, then we may directly compare the SM cross section with the LRM one. In this case we have

$$\sigma^{LRM} = \sigma^{SM} - \Delta\sigma,$$

where

$$\Delta\sigma = f(s, m_{Z_1}, m_{Z_2}, \Gamma_{Z_1}, \Gamma_{Z_2}).$$

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Calculations show that in the case under consideration contributions coming from $\Delta\sigma$ are sizable

$$\left.\frac{\Delta\sigma}{\sigma^{SM}}\right|_{\sqrt{s}=0.5\ TeV} = \begin{cases} 0.032, & \text{when } m_{Z_2} = 4 \text{ TeV} \\ 0.0051, & \text{when } m_{Z_2} = 10 \text{ TeV}, \end{cases}$$

and

$$\left.\frac{\Delta\sigma}{\sigma^{SM}}\right|_{\sqrt{s}=1\ TeV} = \begin{cases} 0.135, & \text{when } m_{Z_2} = 4 \text{ TeV} \\ 0.021, & \text{when } m_{Z_2} = 10 \text{ TeV}. \end{cases}$$

Once it will prove that the coupling constant $g_{S_1Z_1Z_1}$ does not equal to the SM value, then we have to examine the case of the polarized electron-positron beams. With this object in mind the following quantities are introduced

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$$\lambda_{\pm}^{SM} = \frac{\sigma_{\pm}^{SM}}{\sigma_{+}^{SM} + \sigma_{-}^{SM}}, \quad \lambda_{\pm}^{LRM} = \frac{\sigma_{\pm}^{LRM}}{\sigma_{+}^{LRM} + \sigma_{-}^{LRM}}, \quad \delta_{\pm}^{LRM} = \lambda_{\pm}^{SM} - \lambda_{\pm}^{LRM},$$

where σ_{+}^{SM} (σ_{-}^{SM}) is the SM cross section for the left- (right-) polarized electrons. Then we have

$$\delta_{+}^{LRM}(s)\Big|_{\sqrt{s}=0.5\ TeV} \simeq \begin{cases} -0.016, & \text{when } m_{Z_2} = 2 \text{ TeV}, \\ -0.004, & \text{when } m_{Z_2} = 4 \text{ TeV}, \\ -0.0006, & \text{when } m_{Z_2} = 10 \text{ TeV}, \end{cases}$$

and

$$\delta_{+}^{LRM}(s)\Big|_{\sqrt{s}=1\ TeV} \simeq \begin{cases} -0.403, & \text{when } m_{Z_2} = 1.5 \text{ TeV}, \\ -0.113, & \text{when } m_{Z_2} = 2 \text{ TeV}, \\ -0.016, & \text{when } m_{Z_2} = 4 \text{ TeV}, \\ -0.0023, & \text{when } m_{Z_2} = 10 \text{ TeV}. \end{cases}$$

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For the ER5M's we shall work with the polarized electron-positron beams. Analysis reveals that the maximal deviation from the SM prediction occurs for the η-model. But now the value of $\delta_+^{E_6}$ is one order of magnitude less than in the LRM case. To cite an example, we have

$$\delta_+^{E_6}(s)\Big|_{\sqrt{s}=1\ TeV} \simeq \begin{cases} -0.026, & \text{when } m_{Z_2} = 1.5 \text{ TeV} \\ -0.013, & \text{when } m_{Z_2} = 2 \text{ TeV}, \\ -0.003, & \text{when } m_{Z_2} = 4 \text{ TeV}. \end{cases}$$

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At ILC one could achieve luminosity $\mathcal{L} \sim \mathcal{O}(\text{ab}^{-1})$ at $\sqrt{s} \sim \mathcal{O}(\text{TeV})$. In this range, for example, the SM cross section has the order of magnitude of $few \times 10^{-1}$ pb. Then, the number of the produced Higgs bosons which is predicted by the SM is as large as

$$n = \sigma^{SM}(e^+e^- \to ZH) \times \mathcal{L} \sim \text{few pb} \times 1\ \text{ab}^{-1} \sim \text{few} \times 10^5.$$

So, we have a good chance to establish whether deviations from the SM take place or not.

The cleanest channel for isolating the Higgsstrahlung from the background is provided by the $\mu^+\mu^-$ or e^+e^- decay mode for the Z boson and $b\bar{b}$ decay mode for H boson.

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CONCLUSIONS

Two kinds of models arising in a GUT scenario, the LRM and ER5M's, has been considered.

1. Within these models the three body decay of the Higgs being an analog of the SM Higgs (ASMH)

$$H \to Z + e^+ + e^-$$

has been investigated.

In the LRM $g_{S_1 Z_1 Z_1}$ defining interaction between the ASMH and Z_1 boson, may equal to or not equal to the SM coupling constant g_{HZZ} ($g_{S_1 Z_1 Z_1}$ contains k_1 and k_2 whose values could be fixed by the experiments only). To keep this ambiguity as small as possible, and to display deviations from the SM prediction, we investigated the case when the final electrons were left-polarized.

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Analysis demonstrated that discrepancy between predictions of the LRM and the SM could be detected for $m_{Z_2} \leq 4$ TeV. It should be noted that the experimental data give the following limits on the extra neutral gauge boson of the LRM

$$m_{Z_2} = \begin{cases} > 630 \text{ GeV}, & (p\bar{p} \text{ direct search}), \\ > 1162 \text{ GeV}, & (\text{electroaweak fit}), \end{cases}$$

while the low bounds on m_{Z_2} theoretically obtained are larger. For example, in Ref. [A. Maiezza *et al.*, Phys. Rev. D **82** (2010) 055022] this bound is ~ 4.25 TeV.

As far as the ER5M's are concerned, the maximal deviations from the SM predictions for the $H \to Ze^+e^-$ decay width hold for the η model. Detecting the polarized electrons in the final state, one could reveal discrepancy between the SM and the η model at $m_{Z'}$ values of no more than 4 TeV.

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2. The Higgsstrahlung process has been investigated too.

For the LRM two cases, $g_{S_1 Z_1 Z_1} = g_{HZZ}$ and $g_{S_1 Z_1 Z_1} \neq g_{HZZ}$, have been considered. In the former the σ^{LRM} and the σ^{SM} have been compared. When $m_{Z_2} = 4$ TeV $(10$ TeV) deviations from the SM predictions are increasing from 3% (0.5%) at $\sqrt{s} = 0.5$ Tev up to 14% (2%) at $\sqrt{s} = 1$ Tev.

For $g_{S_1 Z_1 Z_1} \neq g_{HZZ}$ we have compared the ratios of the number of events with the left-polarized electrons to the number of events with the unpolarized electrons. At $\sqrt{s} = 1$ TeV and $\mathcal{L} = 1$ ab^{-1}, deviations from the SM could be detected even for the $m_{Z_2} \simeq 10$ TeV.

Among the ER5M's the maximal deviations from the SM gives the η model. Here we have compared the ratios n_+/n_g for the SM and the η model. In that event the deviations from the SM predictions are approximately less on one order of magnitude than for the LRM.

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So that is how the things are