Z_L associated pair production of charged Higgs bosons in the littlest Higgs model at e^+e^- colliders

Ayşe Çağıl

Middle East Technical University, Ankara, TURKEY; email:e110635@metu.edu.tr

Introduction: One of the unsolved problems of the Standard Model(SM) is the hierarchy problem. The little Higgs models[1, 2, 3, 4] are introduced to solve the hierarchy problem by stabilizing the Higgs mass by a collective symmetry breaking mechanism due to the cancelation of divergent loops by appearance of new particles as a consequence of extra symmetries. In this work, the production of single and doubly charged Higgs bosons associated with standard model gauge boson Z_L and lepton flavor violation in these processes in e^+e^- colliders in the context of Littlest Higgs model are examined.

Standard Model and the Hierarchy Problem: According to electroweak precision observables, the vacuum expectation value of Higgs field is $v \sim 250GeV$. And light Higgs boson mass in SM: $M_H \leq 245GeV$ with 95% c.l.. However, the Higgs mass gets quadratic divergences:

$$\delta_{\mu^2}(t-quark) \sim -\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim -(2\text{ TeV})^2, \quad \delta_{\mu^2}(gaugeloops) \sim \frac{9}{64\pi^2}g^2\Lambda^2 \sim (700\text{ GeV})^2,$$
$$\delta_{\mu^2}(selfloops) \sim \frac{1}{16\pi^2}\lambda^2\Lambda^2 \sim (500\text{ GeV})^2. \quad (1)$$

These loops in figure 1 can not cancel at SM cut off, $\Lambda \sim 1TeV$. So, new physics canceling these contributions required at TeV scale.

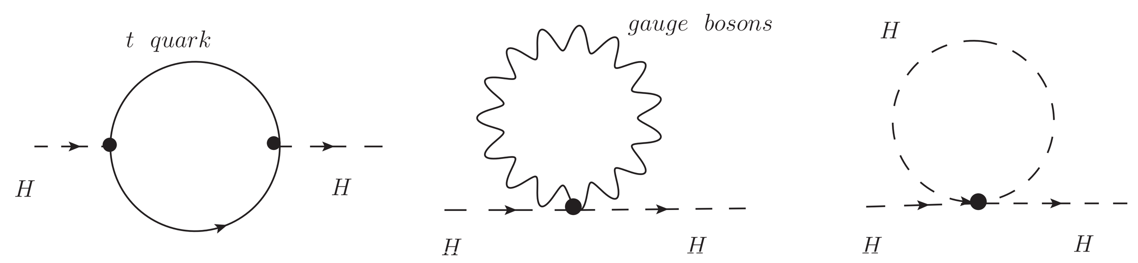

Figure 1: *The loop diagrams resulting quadratic divergences in Higgs mass in SM.*

The Littlest Higgs Model: The Littlest Higgs Model[1] is proposed by N. Arkani-Hamed, A.G. Cohen, E. Katz, and A.E. Nelson. It is the most economical Little Higgs model(reviewed in [6, 5]. In this model:

- global symmetry $SU(5)$ broken to $SO(5)$ by condansation of vacuum (Σ_0) at $\Lambda \sim 4\pi f$ ($f = 4\pi v$ is the TeV scale symmetry breaking parameter). This results 14 exact NGBs, which can be written in represantation:$\eta(1)$, $w(3)$,$h(2)$ and $\phi(3)$.
- $SU(5)$ is weakly gauged $\Rightarrow (SU(2)\otimes U(1))^2$.
- Condensation of vacuum breaks: $(SU(2)\otimes U(1))^2 \longrightarrow SU(2)\otimes U(1)_Y$ of SM. η and w are eaten by gauge bosons, giving them mass, h and ϕ remains physical.
- Then the usual electroweak symmetry breaking occurs at $v \sim 250GeV$: $SU(2)\otimes U(1)_Y \longrightarrow U(1)_Y$.
- Final particle spectrum of gauge bosons:
  - SM gauge bosons: the photon A_L, Z_L, $W_L^{\pm}$
  - New gauge bosons: heavy photon A_H, Z_H, $W_H^{\pm}$. (cancels the divergences of gauge boson loops)
- The final spectrum of scalars:
  - SM Higgs boson: H.
  - New scalars: ϕ^0, ϕ^P, $\phi^{\pm}$, $\phi^{\pm\pm}$ all degenerate in mass: $M_\phi \approx \frac{\sqrt{2}M_H f}{v}$. (cancels the divergences of higgs self loops)
- a new quark like fermion introduced: T quark, with charge:2/3. (cancels the divergences of top quark loop)
- Parameters $f/s/s'$ are not restricted by the model. (f:symmetry breaking scale, s/s' are the mixing angles of the gauge groups.) These parameters are constrained by electroweak observables[7].
- In this work; fermions have both $U(1)_1$ and $U(1)_2$ charges.

$1TeV \leq f \leq 2TeV$	$0.75 \leq s \leq 0.99$	$0.6 \leq s' \leq 0.75$
$2TeV \leq f \leq 3TeV$	$0.6 \leq s \leq 0.99$	$0.6 \leq s' \leq 0.8$
$3TeV \leq f \leq 4TeV$	$0.4 \leq s \leq 0.99$	$0.6 \leq s' \leq 0.85$
$f \geq 4TeV$	$0.15 \leq s \leq 0.99$	$0.4 \leq s' \leq 0.9$

Table 1: *The limits on LstH model parameters $f/s/s'$[7].*

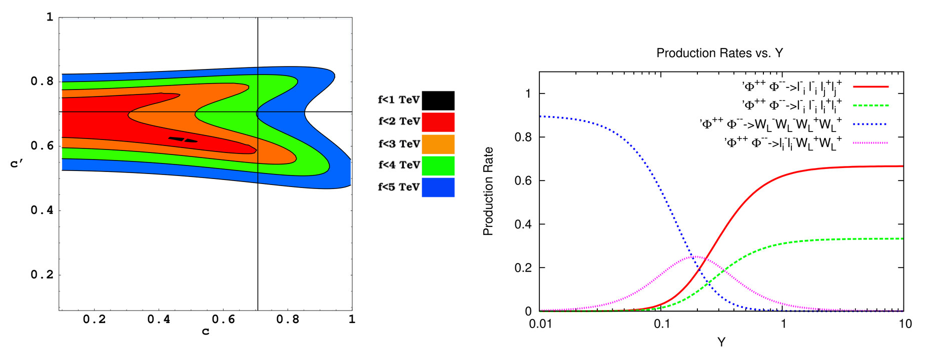

Figure 2: *The allowed values of s/s' for various values of f[7](left), and Production rates vs. Yukawa coupling Y of the final states for the single and doubly charged couples (right).*

Lepton Flavor Violation in LstH Model: for light fermions, a Majorano type mass term can be implemented in yukawa lagrangian, which results in lepton flavor violation by unit two, such as:

$$\mathcal{L}_{LFV} = iY_{ij}L_i^T\,\phi\,C^{-1}L_j + \text{h.c.}, \quad (2)$$

where L_i are the lepton doublets $\left(l\ \ \nu_l\right)$, and Y_{ij} is the yukawa coupling with $Y_{ii} = Y$ and $Y_{ij(i\neq j)} = Y'$. The values of yukawa couplings Y and Y' are restricted by the current constraints on the neutrino masses, given as; $M_{ij} = Y_{ij}v' \simeq 10^{-10}GeV$[8]. This term in the lagrangian allows scalar decays such as: $\phi^- \to l_i\nu_i(l_i\nu_j)$ and $\phi^{--} \to l_il_i(l_il_j)$ violating lepton number.

Calculations: are done numerically, by squaring the amplitudes and integrating over the momentum space. The feynman rules for the LstH model are given in [6].

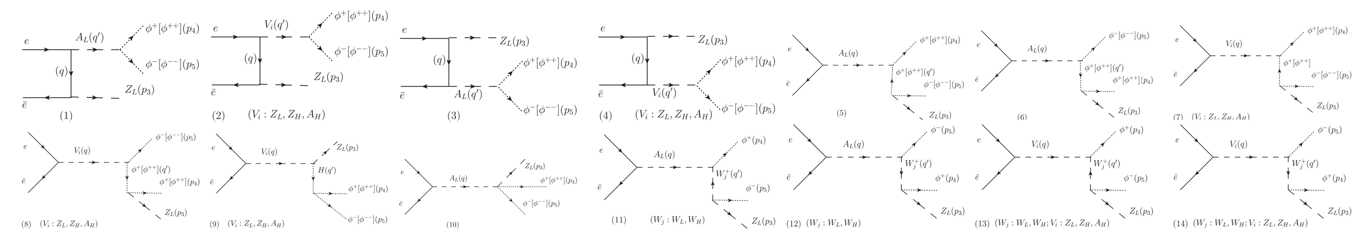

Figure 3: *Feynman diagrams contributing to $e^+e^- \to Z_L\phi^+\phi^-$ and $e^+e^- \to Z_L\phi^{++}\phi^{--}$ in LstH model. The last four diagrams only contribute to the single charged scalars.*

Results: In this work we have analyzed the production of doubly and single charged scalars associated with Z_L and also the final lepton flavor violating signals via processes: $e^+e^- \to \phi^+\phi^-Z_L$ and $e^+e^- \to \phi^{++}\phi^{--}Z_L$.

s/s'	$\sigma_{Z_L\phi^+\phi^-}$	$\sigma_{Z_L\phi^{++}\phi^{--}}$
0.8/0.6	0.042	0.48
0.8/0.7	0.031	0.44
0.95/0.6	0.043	0.78

Table 2: *The total cross sections in fb, for $f = 1TeV$.*

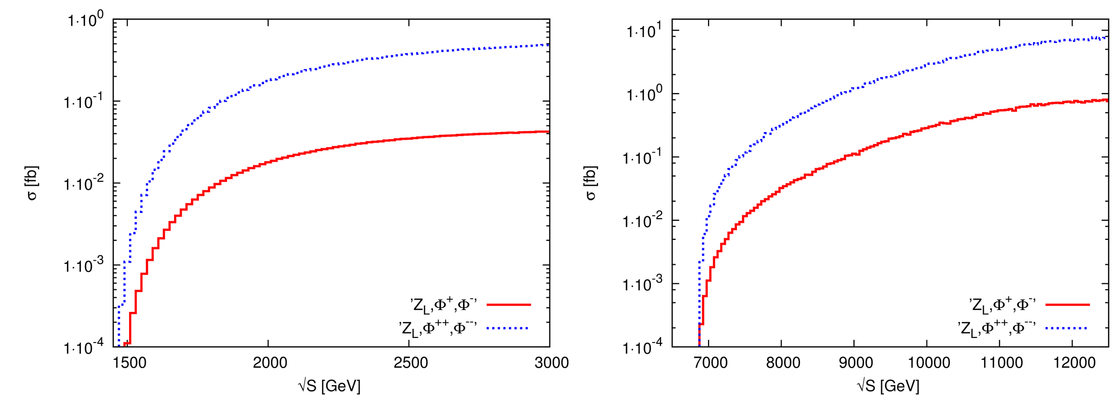

Figure 4: *The cross section vs $\sqrt{s}$ graphs for $f = 1TeV$, $s/s' = 0.8/0.7$(left), and for $f = 5TeV$, $s/s' = 0.6/0.4$(right).*

For an e^+e^- collider with a luminosity of $100fb^{-1}$:

- the single charged final state $\phi^+\phi^-Z_L$
  - for $f = 1TeV$, $s/s' = 08/07$, the total cross section is $0.04fb$ at $\sqrt{s} = 3TeV$.
  - this will give 4 production events per year, NOT REMARKABLE.
  - only if $f = 5TeV$, $s/s' = 06/04$, the cross section is $0.9fb$, giving 90 event per year for $\sqrt{s} \sim 10TeV$, out of the reach of CLIC.
- the doubly charged final state $\phi^{++}\phi^{--}Z_L$
  - for $f = 1TeV$, $s/s' = 08/07$, the total cross section is $0.4 \sim 0.8fb$ at $\sqrt{s} = 3TeV$
  - $40 \sim 80$ production events per year, REMARKABLE.
  - if Yukawa coupling is high $Y \sim 1$, 50 signals violating lepton number, such as: $l_il_il_i^+l_j^+$, free from SM backgrounds.
  - for $Y \sim 0.2$, semileptonic final states, such as $l_il_iW_L^+W_L^+$ can be observed.
  - for higher f values, $f = 5TeV$, $s/s' = 06/04$, the cross section reaches to $8fb$ resulting 800 production events, but at energies $\sqrt{s} \sim 10TeV$.

Conclusion: It is found that at an e^+e^- collider of $\sqrt{s} \geq 2TeV$ with a luminosity of $100fb^{-1}$, the Z_L associated production of charged scalars will be in the reach, being the single charged pair is quite challenging due to low production rates, and the production of doubly charged scalar pair more promising for the electroweak allowed parameters at $f = 1TeV$. The final states will contain lepton flavor violating signals if the value of yukawa coupling Y is close to unity. For larger values of f the mixing angles s/s' are less constrained, e.g. for $f = 5TeV$ and $s/s' = 0.6/0.4$, the production rates increases allowing remarkable final lepton number violating events for $0.1 \leq Y \leq 1$, but for these set of parameters the center of mass energy of the colliders should be increased.

References

[1] N. Arkani-Hamed, A.G. Cohen, E. Katz, and A.E. Nelson, JHEP**0207**(2002)034, `arXiv:hep-ph/0206021`.
[2] N. Arkani-Hamed *et al.*, JHEP**0208**(2002)021, `arXiv:hep-ph/0206020`.
[3] M. Schmaltz, Nucl.Phys.Proc.Suppl.**117**(2003),`arXiv:hep-ph/0210415`.
[4] D.E.Kaplan and M. Schmaltz, JHEP**0310**(2003)039, `arXiv:hep-ph/0302049`.
[5] M. Perelstein, Prog.Part.Nucl.Phys.**58**(2007)247-291, `arXiv:hep-ph/0512128`.
[6] T. Han, H. E. Logan, B. McElrath and L-T. Wang, Phys.Rev. **D67**(2003)095004, `arXiv:hep-ph/0301040`.
[7] C. Csaki, J. Hubisz, G. D. Kribs, P. Meade and J. Terning, Phys.Rev. **D68** (2003) 035009 , `arXiv:hep-ph/0303236`.
[8] T. Han, H.E. Logan, B. Mukhopadhyaya and R. Srikanth, Phys.Rev. **D72** (2005) 053007 , `arXiv:hep-ph/0505260`.