Neutrino masses and the decays of triplet Higgs in the Littlest Higgs scenario

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Plan of the talk

- Introduction
- Neutrino masses in Littlest Higgs model
- Decays of the triplet Higgs
- Some observations

Littlet Higgs (LtH) Model

Consider a global symmetry breaking, $SU(5) \longrightarrow SO(5)$ at a scale $\Lambda \sim 4\pi f \approx$ 10 TeV.
14 Goldstone bosons (GBs) are released.

$$\Sigma_0 = \begin{pmatrix} & & \mathbf{1}_{2\times 2} \\ & 1 & \\ \mathbf{1}_{2\times 2} & & \end{pmatrix} . \qquad (1)$$

Consider a local gauge subgroup, $[SU(2) \otimes U(1)]^2$ of $SU(5)$.

$$[SU(2) \otimes U(1)]^2 \longrightarrow SU(2)_L \otimes U(1)_Y .$$

Remaining 10 GBs can be parameterised by nonlinear sigma field,

$$\Sigma = e^{i\Pi/f}\Sigma_0 e^{i\Pi^T/f}, \tag{2}$$

$$\Pi = \begin{pmatrix} & \frac{h^\dagger}{\sqrt{2}} & \phi^\dagger \\ \frac{h^*}{\sqrt{2}} & & \frac{h}{\sqrt{2}} \\ \phi & \frac{h^T}{\sqrt{2}} & \end{pmatrix}, \tag{3}$$

where

$$h = (h^+, h^0), \quad \phi = -i \begin{pmatrix} \phi^{++} & \frac{\phi^+}{\sqrt{2}} \\ \frac{\phi^+}{\sqrt{2}} & \phi^0 \end{pmatrix}. \tag{4}$$

$$\mathcal{L}_\Sigma = \frac{f^2}{8} Tr|D_\mu \Sigma|^2, \tag{5}$$

where

$$D_\mu \Sigma = \partial_\mu \Sigma - i \sum_{j=1,2} [g_j w^a_{j\mu}(Q^a_j \Sigma + \Sigma Q^{aT}_j) + g'_j B_{j\mu}(Y_j \Sigma + \Sigma Y^T_j)], \tag{6}$$

Introduce a heavy vector-like quark pair $(\tilde{t}, \tilde{t}^c)$.

$$\mathcal{L}_t = \frac{\lambda_1}{2} f \epsilon_{ijk} \epsilon_{xy} \chi_i \Sigma_{jx} \Sigma_{ky} u^c_3 + \lambda_2 f \tilde{t}\tilde{t}^c + h.c. \tag{7}$$

where $\chi_i = (b_3, t_3, \tilde{t})$, u^c_3 is an SU(2) singlet.

Coleman-Weinberg potential is

$$V_{CW} = \lambda_{\phi^2} Tr(\phi^\dagger \phi) + i\lambda_{h\phi h} f (h\phi^\dagger h^T - h^* \phi h^\dagger) \\ -\mu^2 hh^\dagger + \lambda_{h^4}(hh^\dagger)^2. \quad (8)$$

Electroweak symmetry breaking is triggered if $\mu^2 > 0$.

$$\langle h^0 \rangle = \frac{v}{\sqrt{2}}, \quad \langle \phi^0 \rangle = v'.$$

Minimisation conditions of the potential gives

$$v^2 = \frac{\mu^2}{\lambda_{h^4} - \frac{\lambda_{h\phi h}^2}{\lambda_{\phi^2}}}, \quad v' = \frac{\lambda_{h\phi h} v^2}{2\lambda_{\phi^2} f}. \quad (9)$$

Neutrino masses in LtH model

Current experimental bounds on the light neutrino mass is 0.3 eV.
Let us introduce right-handed neutrinos (N_R) in to the model. Then we can write Dirac mass terms of the form

$$y_{ij}^D \, \overline{L}_{Li} \, H N_{Rj} + h.c. \tag{10}$$

and also Majorana mass terms

$$M_{ij} N_{Ri}^T C^{-1} N_{Rj} + h.c., \tag{11}$$

i, j being flavour indices.
By see-saw mechanism light neutrino masses $\sim (y^D v)^2/M$.

In LtH model $M \simeq \Lambda \simeq 10$TeV. Then in order this mass to be consistent with observations $y_{ij}^D \sim 10^{-5}$.

But

$$y_\tau^D \sim 0.01.$$

This is inconsistent. One can have a lepton violating dimension-5 operator of the form

$$Y_5 \frac{(LH)^2}{\Lambda}. \qquad (12)$$

The mass from this operator $\sim \frac{Y_5 v^2}{\Lambda}$. Again because $\Lambda \simeq 10$ TeV, $Y_5 \sim 10^{-10}$. There is no physics to explain the smallness of this parameter.

$$\mathcal{L}_L = iY_{ij}L_i^T\phi C^{-1}L_j + h.c. \tag{13}$$

where i, j are family indices. $\mathcal{L}_L$ is invariant under electroweak gauge group.
We have seen that adding $\mathcal{L}_L$ to the LtH model lagrangian does not effect heirarchy problem. Tree level majorana neutrino mass is

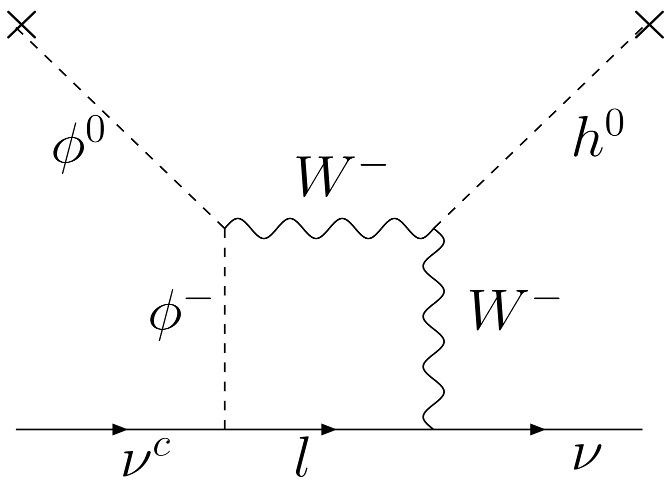
$$\mathcal{M}_{ij} \;=\; Y_{ij}v'. \tag{14}$$

Neutrinos have mass 10^{-10} GeV.

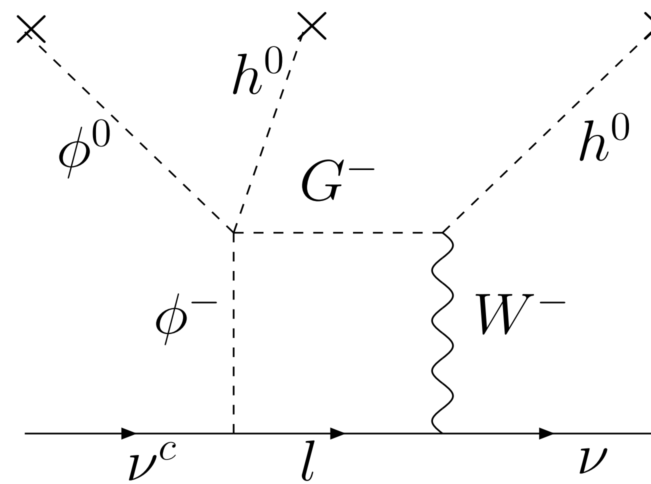
1. $Y_{ij} \sim 10^{-10}$, $v' \sim 1GeV$
2. $Y_{ij} \sim 1$, $v' \sim 10^{-10}GeV$

Case(2) is better.

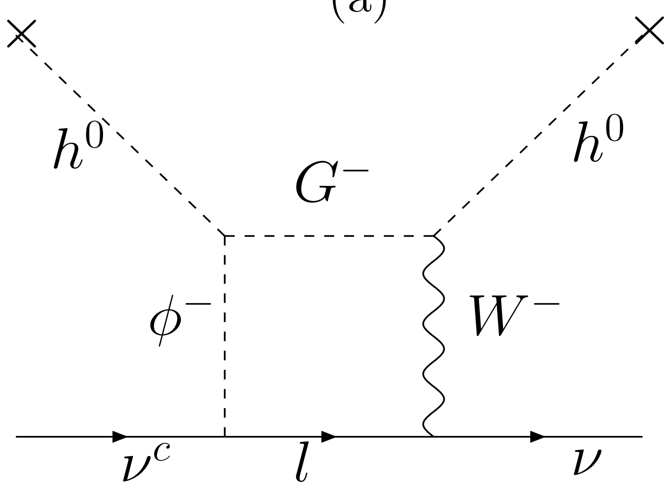
Radiative contributions:



(a)



(b)



(c)

Neutrino mass from Figure 1(a) is

$$\mathcal{M}_{ij} \approx (Y_{ij} v') \frac{g^4 \; v^2}{32\sqrt{2}\pi^2 m_\phi^2}. \tag{15}$$

The mass term from Figure 1(b) is

$$\mathcal{M}_{ij} \approx (Y_{ij} v') \frac{g^2 v^2}{24\sqrt{2}\pi^2 f^2}. \tag{16}$$

The contribution from Figure 1(c) is

$$\mathcal{M}_{ij} \approx (Y_{ij} v') \frac{g^2}{32\sqrt{2}\pi^2}. \tag{17}$$

W. Kilian and J. Reuter (03) and J. Lee (05) considered

$$\mathcal{L}_{LFV} = z_{\alpha\beta}\epsilon^{ij}\epsilon^{kj}f(\bar{l_i^c})^{\alpha}\Sigma^*_{jk}(l_l)^{\beta} + h.c. \tag{18}$$

where $\alpha, \beta = 1, 2, 3$ are flavour indices and $i, j = 1, 2$ are $SU(5)$ indices. This respects $[SU(2) \otimes U(1)]^2$. The above lagrangian yield neutrino mass matrix,

$$[m_\nu]_{\alpha\beta} = 2z_{\alpha\beta}\left(v' + \frac{v^2}{4f}\right). \tag{19}$$

The problem with this approach is $z_{\alpha\beta} \sim 10^{-10}$.

Decays of the triplet states

The possible decays of the triplet states are

$$\begin{array}{rcl} \phi^{++} & \rightarrow & \ell_i^+ \ell_j^+, \quad W^+ W^+, \\ \phi^{+} & \rightarrow & \ell_i^+ \bar{\nu}_{\ell_j}, \quad t\bar{b}, \quad T\bar{b}, \quad W^+ Z, \quad W^+ h, \\ \phi^{s} & \rightarrow & \nu_i \nu_j, \quad \bar{\nu}_i \bar{\nu}_j, \quad t\bar{t}, \quad b\bar{b}, \quad t\bar{T} + \bar{t}T, \quad ZZ, \quad hh, \\ \phi^{p} & \rightarrow & \nu_i \nu_j, \quad \bar{\nu}_i \bar{\nu}_j, \quad t\bar{t}, \quad b\bar{b}, \quad t\bar{T} + \bar{t}T, \quad Zh. \end{array} \tag{20}$$

We have taken $Yv' \sim 10^{-10}$ GeV.
We consider the degeneracy of triplet states.
ϕ^s and ϕ^p are defined by

$$\phi^0 = \phi^s + i\phi^p.$$

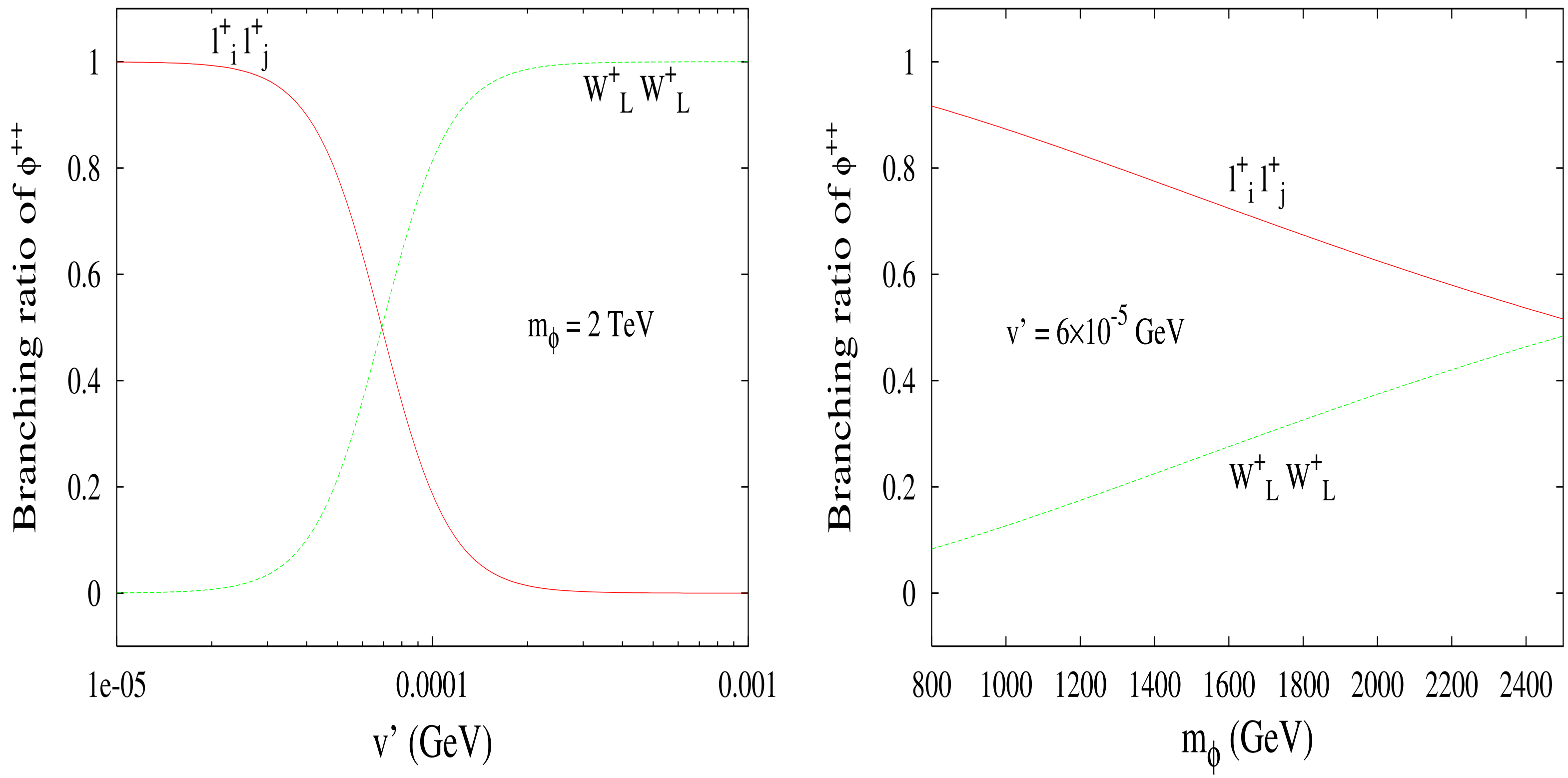


Figure 2: Branching ratios of ϕ^{++} (a) versus the triplet vev for $Yv' = 10^{-10}$ GeV and $m_\phi = 2$ TeV and (b) versus m_ϕ for $v' = 6 \times 10^{-5}$ GeV.

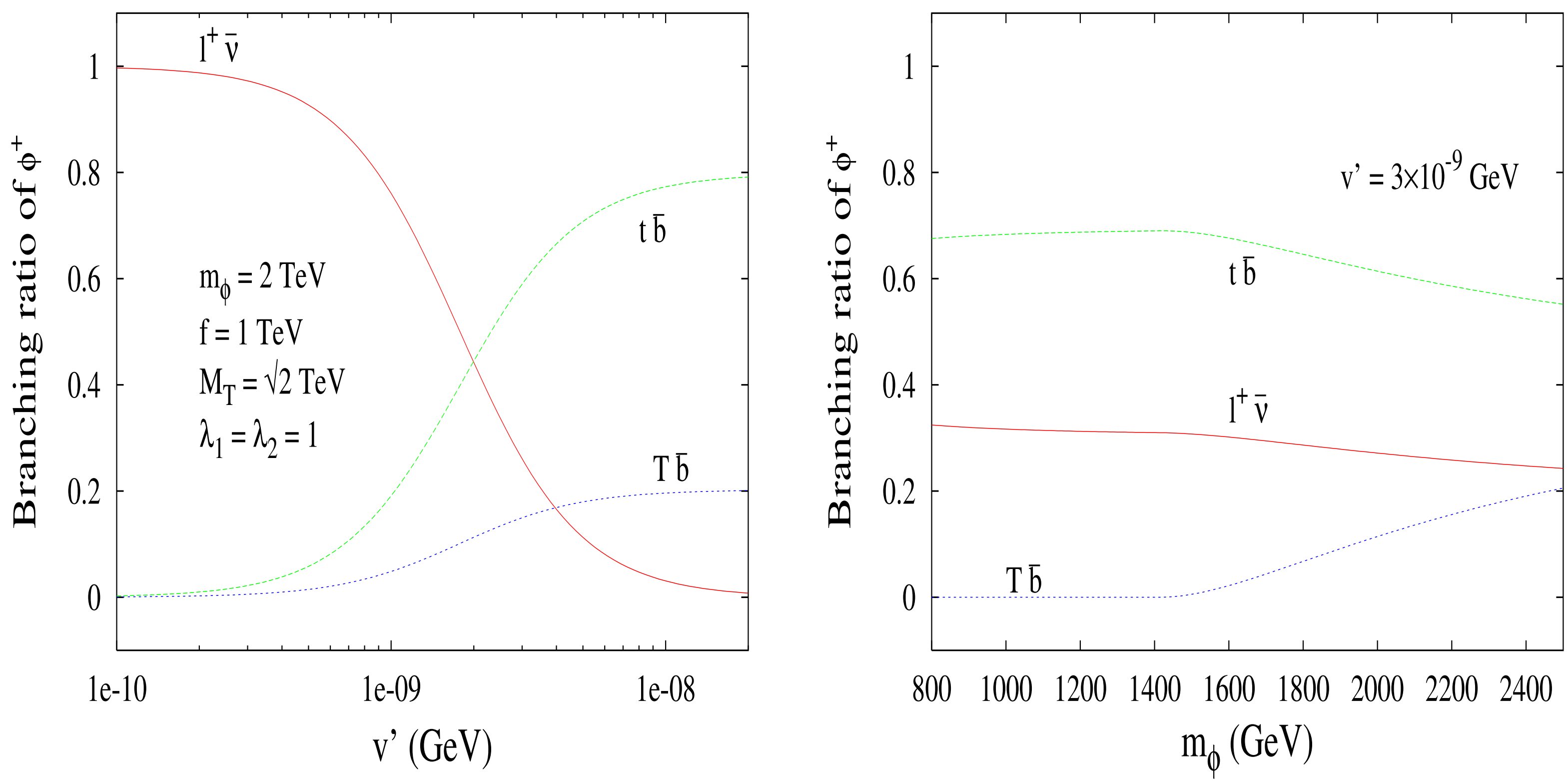


Figure 3: Branching ratio of ϕ^+ (a) versus the triplet vev for $Yv' = 10^{-10}$ GeV and $m_\phi = 2$ TeV and (b) versus m_ϕ for $v' = 3 \times 10^{-9}$ GeV.

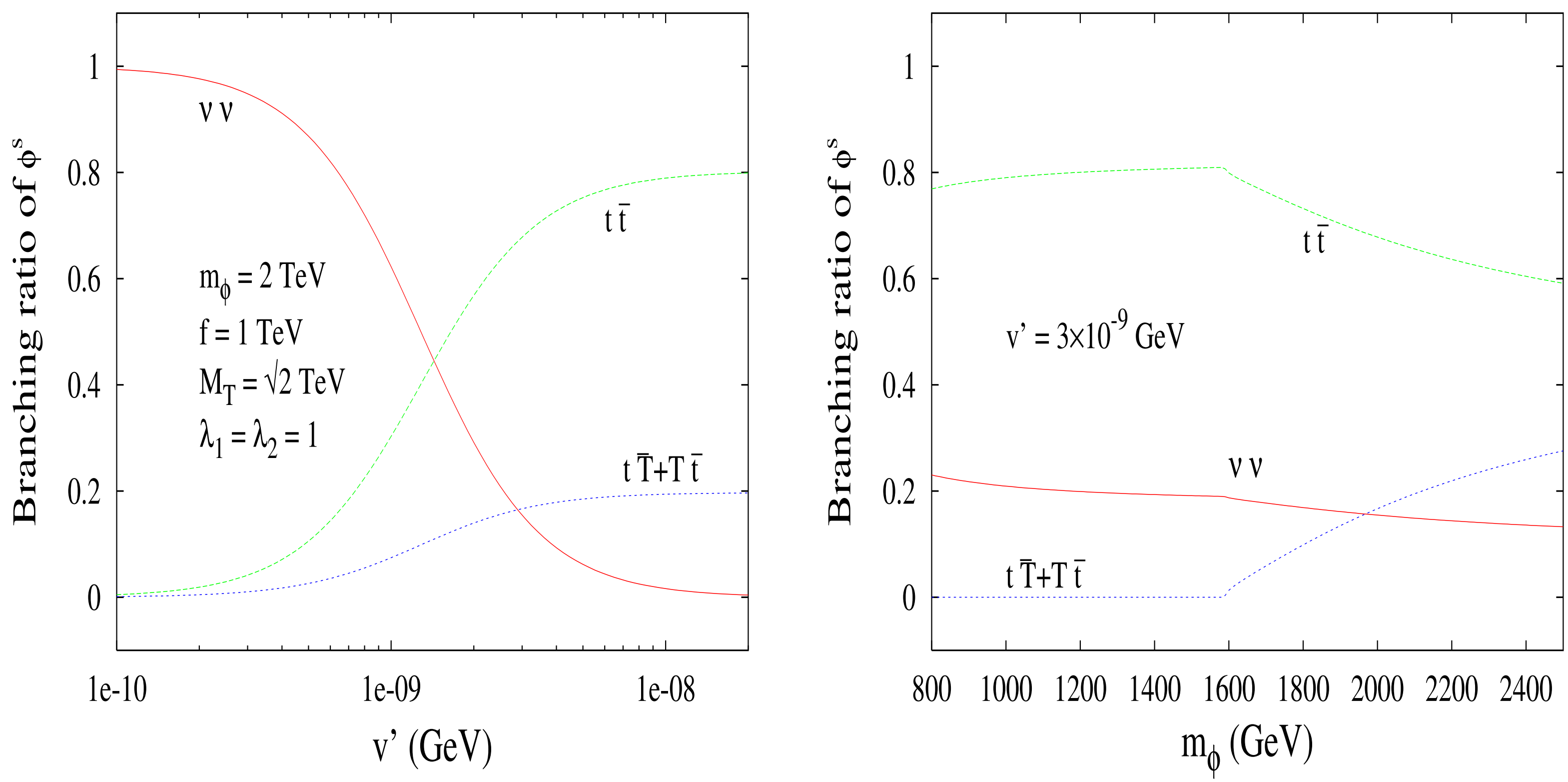


Figure 4: Branching ratios of ϕ^s (a) versus the triplet vev for $Yv' = 10^{-10}$ GeV and $m_\phi = 2$ TeV, and (b) versus m_ϕ for $v' = 3 \times 10^{-9}$ GeV.

Some observations

Decay modes like

$$\begin{aligned} \phi^+ &\rightarrow W^+Z, \quad W^+h, \\ \phi^s &\rightarrow ZZ, \quad hh, \\ \phi^p &\rightarrow \quad Zh \end{aligned} \tag{21}$$

are suppressed by v'/v.
This means that production of the SM Higgs from triplet decays will be unobservable in this scenario.

The end