BSM Models With The Triplet Extended Scalar Sector

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Motivation

Models with the triplet extended scalar sector:

1. naturally explain the smallness of the neutrino mass,
2. can indicate a dark matter candidate,
3. can give a solution to the baryogenesis puzzle.

The ρ parameter constraint

The basic constraint which is imposed on the models with the triplets is the experimental value of the ρ parameter:

$$\rho = \frac{m_W^2}{m_Z^2 cos^2\theta_W} \approx 1.$$

This condition is automatically fulfilled for the arbitrary number of doublets and the triplets with zero *vevs*. For the triplets with non-zero *vevs* to avoid the large corrections to ρ we can:

1. establish the very small triplet *vevs*,
2. maintain the custodial symmetry $SU(2)_C$ of the scalar potential.

Yukawa couplings

The type II seesaw mechanism arises in the Higgs-lepton-lepton coupling in the model with one triplet $\Delta(Y=2)$:

$$\mathcal{L}_Y = ih_{ij}(\Psi_{iL}^T C\tau_2 \Delta \Psi_{jL}) + h.c.,$$

where Ψ_L stands for the standard doublet of the left-handed field. The stationary conditions for the scalar potential indicate that:

$$(M_\nu)_{ij} = v_\Delta (Y_\Delta)_{ij}$$
$$\approx \frac{\sqrt{2}\mu M_\Delta v^2}{2M_\Delta^2 + v^2(\lambda_4 - \lambda_5)}(Y_\Delta)_{ij}.$$

Taking into account the data from the oscillation experiments Y_Δ can be estimated as:

$$Y_\Delta = \frac{10^{-2}}{v_\Delta}\,\mathrm{eV} \times \mathcal{O}(1)_{3\times 3},$$

where $\mathcal{O}$ is determined by the masses and mixing parameters.
The big value of M_Δ implies that the neutrino masses are naturally very small:

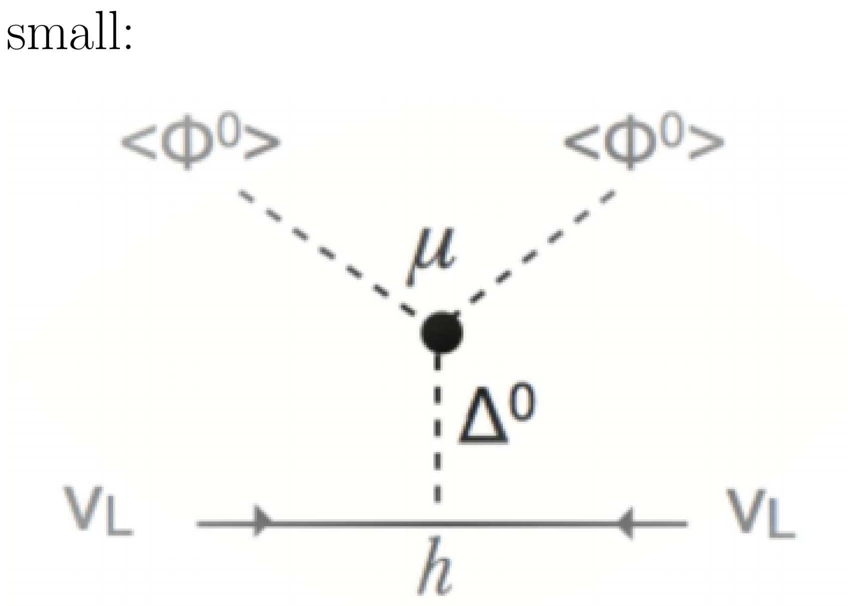

Figure : Type II see-saw mechanism

The exemplary models

Employing the convention $Q = T_3 + \frac{Y}{2}$, we distinguish 3 basic models (the quantum numbers T_3 and Y are denoted in the brackets, respectively):

The Doublet Triplet Model ($Y=0$)

- One doublet $\mathbf{\Phi}$ and one triplet ξ in the scalar potential:

$$\mathbf{\Phi}^{(1/2,1)} = \begin{pmatrix}\Phi^+ \\ \Phi_0\end{pmatrix}, \quad \xi^{(1,0)} = \left(\xi^+, \xi_0, \xi^-\right)$$

- The mass eigenstates: $h^\pm, h^0, k^0$,
- The ρ parameter:

$$\rho = 1 + \frac{2v_\xi^2}{v_\Phi^2} > 0$$

The Doublet Triplet Model ($Y=\pm 2$)

- One doublet $\mathbf{\Phi}$ and one triplet $\mathbf{\Delta}$ in the scalar potential:

$$\mathbf{\Phi}^{(1/2,1)} = \begin{pmatrix}\Phi^+ \\ \Phi_0\end{pmatrix}, \quad \mathbf{\Delta}^{(1,2)} = \begin{pmatrix}\frac{\Delta^+}{\sqrt{2}} & \Delta^{++} \\ \Delta^0 & -\frac{\Delta^+}{\sqrt{2}}\end{pmatrix},$$

- The mass eigenstates: $h^{\pm\pm}, h^\pm, h^0, H^0, A^0$,
- The ρ parameter:

$$\rho = 1 - \frac{2v_\Delta^2}{v_\Phi^2 + 4v_\Delta^2} < 0$$

The Georgi Machacek Model

- One bidoublet $\mathbf{\Phi}$, two isospin-triplets ξ and χ in the scalar potential:

$$\mathbf{\Phi}^{(1/2,0)} = \begin{pmatrix}\Phi^0 & \Phi^+ \\ \Phi^- & \Phi^0\end{pmatrix}, \quad \chi^{(1,2)} = \begin{pmatrix}\chi^{++} \\ \chi^+ \\ \chi^0\end{pmatrix}, \quad \xi^{(1,0)} = \begin{pmatrix}\xi^+ \\ \xi^0 \\ \xi^-\end{pmatrix}$$

- The mass eigenstates: $H_5^{\pm\pm}, H_5^\pm, H_5^0, H_3^\pm, H_3^0, H_1^0, h_1^0$,
- The ρ parameter:

$$\rho = \frac{v_\Phi^2 + 4v_{\chi^2} + 4v_\xi^2}{v_\Phi^2 + 8v_\chi^2} \overset{v_\chi = v_\xi}{=} 1$$

The potential of the Doublet-Triplet Model ($Y=\pm 2$)

The most general potential of the Doublet-Triplet Model can be written as:

$$V(\Phi,\Delta) = m^2(\Phi^\dagger\Phi) + M_\Delta^2 Tr(\Delta^\dagger\Delta) + [\mu\Phi^T i\tau_2\Delta^\dagger\Phi + h.c.] +$$
$$\lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2[Tr(\Delta^\dagger\Delta)]^2 + \lambda_3 Tr[(\Delta^\dagger\Delta)^2] + \lambda_4(\Phi^\dagger\Phi)Tr(\Delta^\dagger\Delta) + \lambda_5\Phi^\dagger\Delta\Delta^\dagger\Phi.$$

This potential is subjected to the several constraints. It must :

1. Be **positive** (the conditions are imposed on the value of lepton-number violating term μ),
2. Be **bounded from below**,
3. Fulfil the requirements coming from the tree-level **unitarity** condition of the S-matrix, the **perturbativity** and the experimental measurements of the ρ parameter, m_h, α_{EM} and m_t (top quark mass).

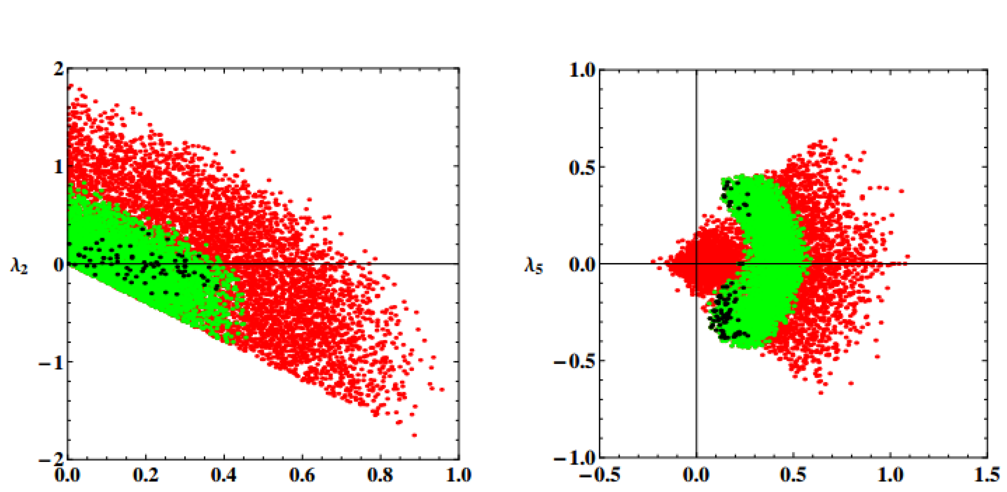

Figure : The admissible parameter space for 200 GeV $\leq M_\Delta \leq$ 1 TeV , 0.01 GeV $\leq v_\Delta \leq$ 5 GeV [1]

Some basic processes

The Doublet-Triplet model ($Y=\pm 2$) points to the existence of the doubly-charged Higgs bosons. They can be produced in the **s** and **t** channel of the process: $e + e- \to H^{++}H^{--}$:

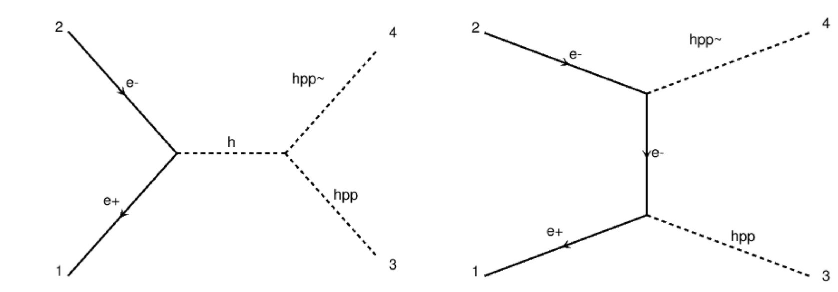

Figure : H^{++} and H^{--} production via s and t-channel, respectively

or in the process featuring Majorana neutrinos:

$$e^+e^- \to W^{+*}W^{-*} \to H^{++}H^{--}\nu_e\nu_e :$$

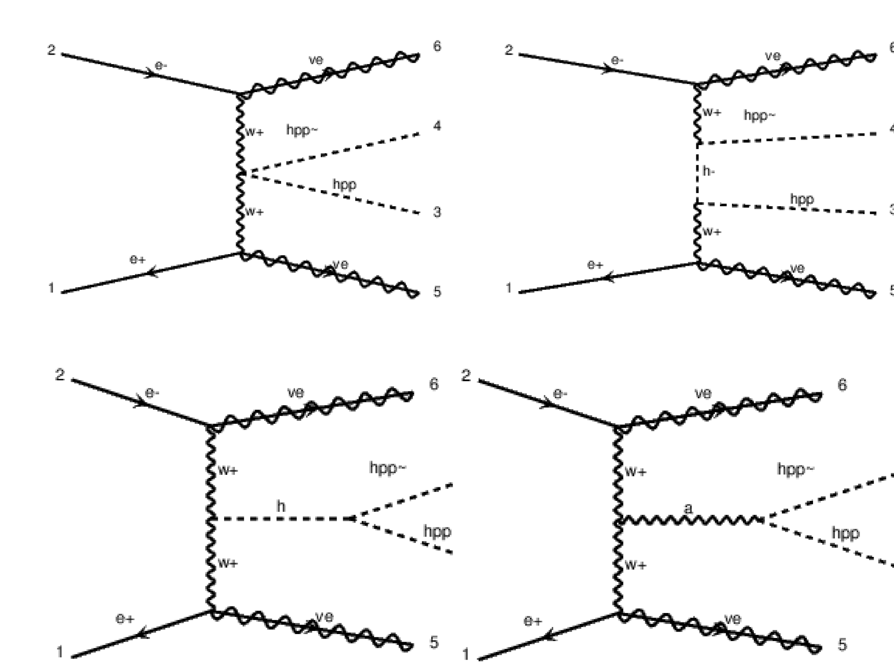

Figure : H^{++} and H^{--} production via WW fusion process

References

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