Dirac Seesaw-like Mechanism in a Semi Left-Right Symmetry Model (or a CP-Mirror Model)

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Contributed Talk at Nutheme Institute
13 - 22 Sept. 2010, TH-Div. CERN

Many observations have confirmed: NEUTRINO OSCILLATES. → Neutrino (flavours) are mixing and Neutrino do have mass (but very tiny mass)

- The Favourite Explanation: Seesaw mechanism.
- The usual seesaw mechanism: using Majorana neutrino (lepton number violation).
- Is neutrino a DIRAC or a MAJORANA particle?
- Decisive test: Neutrinoless double beta decay (no positive result yet)

Why (not) Dirac Mass?

- Majorana Neutrino $\rightarrow \Delta l = 2 \rightarrow$ Leptogenesis $\rightarrow$ Baryogenesis [Fukugita and Yanagida, 1986] .
- But small Dirac neutrino mass $\rightarrow$ neutrinogenesis $\rightarrow$ Baryogenesis [K. Dick, et. al., Phys. Rev. Lett. **84**, 4039 (2000)] .
- The possibility that Neutrino is just a Dirac particle should be considered
- Standard Model (SM) $\rightarrow$ unnaturally tiny Yukawa coupling $<\sim \mathcal{O}(10^{-11})$.

Dirac Seesaw

- Dirac seesaw? There are many papers about Dirac seesaw (The first one: Roncadelli and Wyler [Phys. Lett. B **133**, 325 (1983)])
- The usual problem in Dirac Seesaw model: to make the seesaw mechanism only applies to neutrino. For the case of Majorana seesaw it is not a problem, since only neutrino which is (considered as) Majorana particle.
- Thus for Dirac seesaw, one usually add another global gauge group plus new scalar particle(s) that only coupled to the neutrino.

Mirror Particle, L - R Symmetry

- SM is parity asymmetry. It would be nice, from aesthetical point of view, if nature is L-R symmetry.
- Besides the usual L-R symmetry, where fermions are doublets of the left and right SU(2) gauge group, there is another kind of symmetry, the Mirror symmetry [R. Foot and R. R. Volkas, Phys. Rev. D 52, 6595 (1995); R. Foot, Int. J. Mod. Phys. D 13, 2161 (2004).]
- In mirror symmetry, we have a copy of the SM particles with the opposite chirality (thus L-R symmetry).
- Ideas about the possibility of light sterile neutrinos, have led some people to think that the sterile neutrino is just the mirror counterpart of the neutrino [(3+3)-model etc].

Mirror Particle, L - R Symmetry

- It has been realized also that in a Mirror-models, one can have a (type-I) Dirac seesaw using the singlet neutrino and mirror neutrino.
- Additional global gauge is usually assumed to prevent the mixing between singlet fermions and the mirror fermions. Indeed there is a paper where they let this happen and as consequence, all fermions gain masses through Dirac seesaw mechanism [de Almeida, F. M. L., Jr.; Coutinho, Y. A.; Simes, J. A. Martins; Ramalho, A. J.; Pinto, L. Ribeiro; Wulck, S.; Do Vale, M. A. B, Phys. Rev. D 81, 053005 (2010)].
- It would be nice if we have a mirror model with a Dirac seesaw for neutrino mass but without mixing of the other fermions and without assuming additional global gauge that prevent the particle-mirror particle mixing.

The Model, Semi L-R symmetry (CP-Mirror)

- The model is based on the gauge group $SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$ with $Q = T_{3L} + T_{3R} + \frac{Y'}{2}$.
- Consider instead of the usual mirror, we have a mirror particles with $Y' \to -Y'$, or it is basically a CP - Mirror symmetry of the particles.
- Such CP - Mirror has been considered before in the past by [C. H. Albright and J. Oliensis, Phys. Rev. D33, 2602 (1986); J. Oliensis and C. H. Albright, Phys. Lett. B160, 121 (1985)] (somehow they refer it as mirror particle (L-R symmetry) only. But their particle-mirror particle content are doublets of the L-R gauge groups, thus it is not the mirror of the SM particles.

Particle and CP-mirror particle contents

$$l_L = \begin{pmatrix} \nu_1^0 \\ e^- \end{pmatrix} (\mathbf{2},1,\text{-}1); \quad \nu_{1R}\ (1,1,0); \quad e_R^-\ (1,1,\text{-}2) \tag{1}$$

$$L_R = \begin{pmatrix} e^+ \\ \nu_2^0 \end{pmatrix} (1,\mathbf{2},1); \quad \nu_{2L}\ (1,1,0); \quad e_L^+\ (1,1,2) \tag{2}$$

$$q_L = \begin{pmatrix} u^{2/3} \\ d^{-1/3} \end{pmatrix} (\mathbf{2},1,1/3); \quad u_R^{2/3}\ (1,1,4/3); \quad d_R^{-1/3}\ (1,1,\text{-}2/3) \tag{3}$$

$$Q_R = \begin{pmatrix} d^{1/3} \\ u^{-2/3} \end{pmatrix} (1,\mathbf{2},\text{-}1/3); \quad u_L^{-2/3}\ (1,1,\text{-}4/3); \quad d_L^{1/3}\ (1,1,2/3) \tag{4}$$

The particle and CP-mirror particle assignment, each of the set, is chiral-anomaly free (just like in SM).

The Higgs scalars

The model equipped with the two Higgs doublets χ_L (**2**,1,1) and its CP-mirror χ_R (1,**2**,-1) together with their rotated counter part $\tilde{\chi}_L$ (**2**,1,-1) and $\tilde{\chi}_R$ (**2**,1,1), plus one singlet neutral Higgs scalar S (1,1,0). The VEV for these Higgs upon spontaneous symmetry breaking (SSB) are

$$\langle \chi_L \rangle = \begin{pmatrix} 0 \\ v_L \end{pmatrix}; \qquad \langle \chi_R \rangle = \begin{pmatrix} v_R \\ 0 \end{pmatrix}, \qquad \langle S \rangle = v \tag{5}$$

The existence of S is necessary to make $v_R > v_L$ (A bidoublet can also furnish this job but it will mix the W_L and W_R.

Higgs potential

A general Higgs potential invariant under the gauge

$$\begin{aligned} V &= -\mu_1^2|S|^2 + \lambda_1|S|^4 - \mu_2^2(\chi_L^\dagger\chi_L + \chi_R^\dagger\chi_R) + \lambda_2((\chi_L^\dagger\chi_L)^2 + (\chi_R^\dagger\chi_R)^2) \\ &+ \lambda_3\chi_L^\dagger\chi_L\chi_R^\dagger\chi_R + \epsilon(\chi_L^\dagger\chi_L + \chi_R^\dagger\chi_R)|S|^2 \\ &+ \delta(S(\chi_L^\dagger\chi_L - \chi_R^\dagger\chi_R) + \text{h.c.}) \end{aligned} \tag{6}$$

where I have assumed that under the CP-mirror

$$S \leftrightarrow -S$$

(thus it is semi L-R symmetry).
This is necessary in order to have a different (and non zero) VEV for v_L and v_R.

The Yukawa couplings

The Lagrangian that is relevant for fermion mass generation is

$$
\begin{aligned}
\mathcal{L} &= G_{eij}\bar{l}_{L,i}\chi_L e_{jR} + G_{Eij}\bar{L}_{R,i}\chi_R E_{jL} + G_{\nu_1 ij}\bar{l}_{L,i}\tilde{\chi}_L \nu_{1jR} + G_{\nu_2 ij}\bar{L}_{R,i}\tilde{\chi}_R \nu_{2jL} \\
&+ G_{dij}\bar{q}_{L,i}\chi_L d_{jR} + G_{Dij}\bar{Q}_{R,i}\chi_R D_{jL} + G_{uij}\bar{q}_{L,i}\tilde{\chi}_L u_{jR} + G_{Uij}\bar{Q}_{R,i}\tilde{\chi}_R U_{jL} \\
&+ M_{ij}\bar{\nu}_{1iR}\nu_{2jL} + \text{h.c.} \qquad (7)
\end{aligned}
$$

where the G's are the Yukawa couplings, and i, j are the generation index. Note that because the different Y' assignment between the particle and the mirror, there is no mixing between them except for the case of the singlet neutrinos which both have $Y' = 0$ (and M_{ij} as the couplings).

Fermion mass

All fermions besides the neutrino will get masses through similar mechanism like in the SM. The same also for the mirror fermions. The mirror fermions will be very massive due to its coupling to χ_R. For the case of neutrino, for one generation case, the above Lagrangian will lead to the following mass matrix, upon SSB

$$\begin{array}{c} \\ \bar{\nu}_{1L} \\ \bar{\nu}_{1R} \\ \bar{\nu}_{2L} \\ \bar{\nu}_{2R} \end{array} \begin{array}{c} \begin{array}{cccc} \nu_{1L} & \nu_{1R} & \nu_{2L} & \nu_{2R} \end{array} \\ \begin{pmatrix} 0 & m_1 & 0 & 0 \\ m_1 & 0 & M & 0 \\ 0 & M & 0 & m_2 \\ 0 & 0 & m_2 & 0 \end{pmatrix} \end{array}$$

where $m_1 = G_{\nu_1} v_L$, $m_2 = G_{\nu_2} v_R$, and $M = M_{11}$. Assuming that M is very large $M >> m_2 > m_1$, the above mass matrix will lead to a type I seesaw mechanism.

Upon diagonalizing, we have one small mass and one large mass for the neutrinos

$$m_{\nu N}^2 = \frac{1}{2}(m_1^2 + m_2^2 + M^2)\left[1 \pm (1 - 4\frac{m_1^2 m_2^2}{(m_1^2 + m_2^2 + M^2)^2})^{1/2})\right] \tag{8}$$

or approximately

$$m_\nu \approx \frac{m_1 m_2}{M}; \quad m_N \approx M \tag{9}$$

and the new mass eigenstates

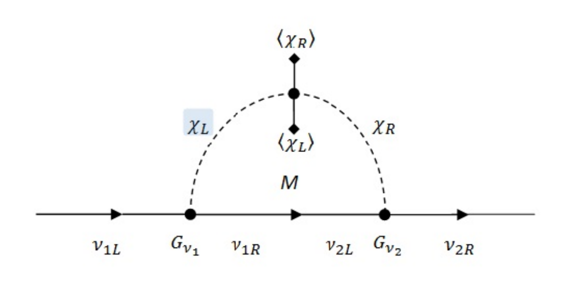
$$\nu \approx \nu_{1L} + \nu_{2R} - \frac{m_1}{M}\nu_{2L} - \frac{m_2}{M}\nu_{1R} \tag{10}$$

$$N \approx \nu_{2L} + \nu_{1R} + \frac{m_1}{M}\nu_{1L} + \frac{m_2}{M}\nu_{2R} \tag{11}$$

The light neutrino is dominated by the doublet neutrino, while the heavy neutrino is dominated by the singlet neutrino.

Radiative correction

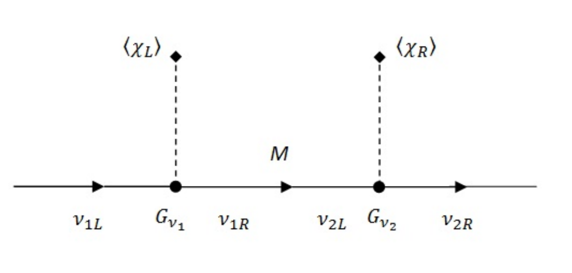
Since the mass of the light neutrino is so small, we have to check the correction to this mass. The leading order correction comes from the following diagram



$$\delta m_\nu \approx \frac{\lambda_3}{(4\pi)^2}\frac{m_1 m_2}{M} < m_\nu \qquad (12)$$

Generalization to three generations

For three generation case, one has to diagonalize a 12 by 12 matrix. In the first approximation, the mass of the light neutrino comes from the following diagram



Thus we have for the flavour mass matrix of the light neutrino

$$M_\nu \approx M_1 M^{-1} M_2 \qquad (13)$$

where $(M_1)_{ij} = G_{\nu_1 ij} v_L$, $(M_2)_{ij} = G_{\nu_2 ij} v_R$ and $(M)_{ij} = M_{ij}$

Order of magnitude calculation

For the one generation case,

$$m_\nu \approx \frac{m_1 m_2}{M}; \tag{14}$$

Assume that m_1 is at the order of the electron mass ($\approx 10^{-3}$ GeV), and m_2 is at the order of the electron-mirror mass. In order to have neutrino mass at the order of less than eV, we have to have

$$\frac{m_2}{M} < 10^{-6} \tag{15}$$

Thus in the mirror world, the mirror-electron is lighter than the heavy neutrino. If $m_2 \approx 10^3$ GeV, then $M \approx 10^9$ GeV.

No Conclusion Yet

THANK YOU