PRAMANA — journal of physics © Indian Academy of Sciences Vol. 76, No. 5 May 2011 pp. 699–705

Working group summary: Neutrinos and beyond Standard Model

ANJAN S JOSHIPURA[1,*], SOUROV ROY[2] and S UMA SANKAR[3]
[1]Physical Research Laboratory, Navarangpura, Ahmedabad 380 009, India
[2]Department of Theoretical Physics, Indian Association for the Cultivation of Science, 2A & 2B Raja S.C. Mullick Road, Kolkata 700 032, India
[3]Department of Physics, Indian Institute of Technology Bombay, Mumbai 400 076, India
*Corresponding author. E-mail: anjan@prl.res.in

Members: Rathin Adhikari, C S Aulakh, K S Babu, Debashish Borah, Biswajoy Brahmachari, Mamta Dahiya, Sukh Dev, H Zeen Devi, Sukanta Dutta, Deeptimoy Ghosh, Rohini Godbole, Srihari Gopalakrishna, Srubabati Goswami, Shivani Gupta, Thomas Hambye, Xiao-Gang He, R Islam, Anjan Joshipura, Subrata Khan, M Kumar, Sanjeev Kumar, Y Y Keum, Manfred Lindner, Swapan Majee, Debashis Majumdar, Sasmita Misra, Manimala Mitra, Subhendra Mohanty, Sudhanwa Patra, Sushant Raut, Amitava Raychaudhuri, Saurabh Rindani, D P Roy, Probir Roy, Sourov Roy, Narendra Sahu, Rui Santos, Anjishnu Sarkar, Utpal Sarkar, P Sharma, N Nimai Singh, Santosh K Singh, S Uma Sankar, Rishikesh Vaidya, Sudhir Vempati and Surender Verma

Abstract. This is the report of the working group on neutrinos and beyond the Standard Model in WHEPP-XI.

Keywords. Beyond Standard Model; neutrino.

PACS Nos 12.60.-i; 12.15.Ff; 12.60.Jv; 14.60.Pq; 14.60.St

1. Resonant leptogenesis and 4-zero Yukawa textures

K S Babu, Srubabati Goswami

In the context of type-I see-saw with three left and three right-handed neutrinos, Majorana mass matrices motivated by simple $U(1)$ flavour symmetries can have two degenerate eigenvalues. Consequently, this can induce resonant leptogenesis. It was proposed to study the possible textures in m_{D} which can allow this. It is already known that Yukawa matrices with five zeros and some particular forms of M_{R} are not consistent with low-energy phenomenology. But for m_{D} with four zeros it may be possible to explain neutrino oscillation phenomenology and get resonant leptogenesis. Further work in this will be pursued.

2. Textures in extended see-saw models

S Khan, S Roy, U Sarkar, A Raychaudhuri, S Goswami and B Brahmachari

The main idea behind extended see-saw models is that one can add an arbitrary number of gauge singlet leptons to the Standard Model (SM). In these cases the Lagrangian responsible for generating the neutrino mass can be written as

$$\mathcal{L} = Y_\nu \bar{\nu}_{\rm L} \nu_{\rm R} \phi + M_N \bar{S} \nu_{\rm R} + \frac{1}{2} \bar{S} \mu S^c.$$

After spontaneous symmtery breaking the ϕ field acquires a vacuum expectation value and $Y_\nu v = m_{\rm D}$ gives rise to the Dirac mass term of the neutrinos. Assigning lepton numbers $+1$ to the $\nu_{\rm L}$ field, -1 to the $\nu_{\rm R}$ field and $+1$ to the S field one can see that the last term containing μ violates lepton number by two units and hence gives rise to a Majorana mass term. Here μ is a complex symmetric matrix. The matrices $m_{\rm D}$ and $M_{\rm R}$ have Dirac character and hence can be completely general. μ can be naturally small. The above Lagrangian gives rise to the following mass matrix (in the basis $(\nu_{\rm L}, \nu_{\rm R}, S)$),

$$\begin{pmatrix} 0 & m_{\rm D} & 0 \\ m_{\rm D}^T & 0 & M_{\rm R}^T \\ 0 & M_{\rm R} & \mu \end{pmatrix}.$$

In the limit $M_{\rm R} > m_{\rm D} \gg \mu$, the light neutrino mass matrix is given as

$$m_\nu = m_{\rm D} M_{\rm R}^{-1} \mu M_{\rm R}^{T^{-1}} m_{\rm D}^T \equiv Q \mu Q^{-1},$$

where $Q = m_{\rm D} M_{\rm R}^{-1}$. In these models the smallness of the neutrino masses can be related to the smallness of the parameter μ. For $\mu \sim$ KeV one can get $m_\nu \sim 0.1$ eV with $M_{\rm R} \sim$ TeV.

This makes the model testable in various ways. Nonunitary mixing between light and heavy particles can be large and in the measurable range of future neutrino factories. Lepton flavour violating processes as well as signature of the TeV scale right-handed neutrinos can be studied at LHC. The minimal model consistent with the low energy phenomenology consists of two right-handed neutrinos and two gauge singlets. Models with lesser number of right-handed neutrinos or singlets give zero masses in the $(\nu_{\rm R}, S)$ sector, which is not allowed by phenomenology. In the limit $\mu \gg M_{\rm R}$ also the above expression for m_ν is valid. These are usually called the double see-saw scheme.

Recently, another variant of the above mass matrix was proposed in the context of $SO(10)$ grand unified theory (GUT).

$$\begin{pmatrix} 0 & m_{\rm D} & M_{\rm L} \\ m_{\rm D}^T & 0 & M_{\rm R}^T \\ M_{\rm L} & M_{\rm R} & 0 \end{pmatrix}.$$

The corresponding light neutrino mass matrix can be written as

$$m_\nu = m_{\rm D} (M_{\rm L} M_{\rm R}^{-1})^T + M_{\rm L} {M_{\rm R}}^{-1} m_{\rm D}^T.$$

This was termed as linear see-saw since the light neutrino masses depend on single power of $m_{\rm D}$ unlike in canonical or inverse see-saw. It was proposed to study the allowed textures of $m_{\rm D}$ and $M_{\rm R}$ and μ in the minimal inverse see-saw scheme.

3. Inverse see-saw realization of four-zero texture

Probir Roy, S Dev, S Kumar, S Verma and S Gupta

There is a correspondence between type-I see-saw and inverse see-saw. When the Dirac mass matrix $m_{\rm D}$ for type-I see-saw is replaced by $M_{\rm D}(M_{\rm R}^T)^{-1}$ where $M_{\rm D}$ and $M_{\rm R}$ are Dirac and right-handed neutrino mass matrices appearing in the inverse see-saw and the right-handed neutrino mass matrix $m_{\rm R}^{-1}$ appearing in type-I see-saw is replaced by the scalar mass matrix μ appearing in inverse see-saw, type-I see-saw relation transforms into inverse see-saw relation.

This correspondence can be used to realize a form of $m_{\rm D}$ having four texture zeros and mu–tau symmetry

$$m_{\rm D} = \begin{pmatrix} a & c & c \\ 0 & b & 0 \\ 0 & 0 & b \end{pmatrix}$$

in inverse see-saw by solving the matrix equation

$$M_{\rm D}(M_{\rm R}^T)^{-1} = m_{\rm D}.$$

Two solutions have been listed below. When $M_{\rm D}$ and $M_{\rm R}$ given below are substituted in the expression for $m_{\rm D}$, we obtain an $m_{\rm D}$ with four texture zeros and mu–tau symmetry. Such an $m_{\rm D}$ is of phenomenological interest because it is one of the two allowed textures in [1]. So, finding $M_{\rm D}$ and $M_{\rm R}$ corresponding to $m_{\rm D}$ will give us a realization of the above texture in inverse see-saw. The inverse see-saw realization of other solution of ref. [1] can also be done.

Our aim was to derive textures of $M_{\rm D}$ and $M_{\rm R}$ which give $m_{\rm D}$ of the required symmetry. Two such possible textures have been listed below:

$$M_{\rm D} = \begin{pmatrix} A & C & C \\ 0 & B & 0 \\ 0 & 0 & B \end{pmatrix}, \quad M_{\rm R} = \begin{pmatrix} x & 0 & 0 \\ 0 & y & 0 \\ 0 & 0 & y \end{pmatrix}$$

and

$$M_{\rm D} = \begin{pmatrix} A & 0 & 0 \\ 0 & B & 0 \\ 0 & 0 & B \end{pmatrix}, \quad M_{\rm R} = \begin{pmatrix} x & 0 & 0 \\ x & z & 0 \\ x & 0 & z \end{pmatrix}.$$

We have chosen these two solutions because of their simplicity. Others such as textures can be obtained by solving the relevant equation. Further, one may invoke family symmetries to realize such textures of $M_{\rm D}$ and $M_{\rm R}$.

4. Lepton flavour violating decays

S Uma Sankar, N Sahu, S Raut, Mamta Dahiya, S Patra, R Islam, R Vaidya, S Dutta, M Kumar, D Ghosh, N Nimai Singh and Y Y Keum

The most general expression for the radiative decay $l_1 \to l_2\gamma$ was calculated in ref. [2]. It was proposed to do a similar calculation for $l_1 \to l_2 l_3 \bar{l}_3$. Assuming that these decays can be observed in the near future, one determines the flavour structure of the new physics which leads to these decays. Two benchmark assumptions which can be made are (a) new physics does not distinguish between flavours and (b) new physics couplings are proportional to fermion masses.

An additional intriguing suggestion, made by K S Babu, is to study the inter-relationship between lepton flavour violation and quark flavour violation. However, this problem has to be defined carefully.

5. SUSY Inert doublet model with ν mass, leptogenesis and dark matter

S Patra, X G He and U Sarkar

We postulate a novel extension of the minimal supersymmetric Standard Model (MSSM) with right-handed (RH) Majorana neutrino and two extra Higgs doublets (H_3, H_4) to accommodate smallness of light neutrino mass. Imposing an extra Z_2 symmetry in which all SM particles are even, N_R, H_4 are odd, whereas H_3 is even. Neutrino mass will get zero contribution at tree level. It is generated at the one-loop level even for TeV scale mass of right-handed neutrino. Leptogenesis is possible via decay of (s)neutrino by out-of-equilibrium decay. The extra Higgs, H_4, is a candidate for dark matter in this model. It is also interesting to study various phenomenologies of extra Higgs field.

6. Type-III see-saw model with unusual triplet fermions

A S Joshipura, S Goswami, N Sahu, S Patra, S Khan, S Rindani, S Majee, A Sarkar, B Brahmachari, M Mitra, S Dev, H Zeen Devi, K Patel, P Sharma, R Vaidya, R Godbole, D Ghosh, D Borah, S K Singh, K S Babu and Xiao-Gang He

Neutrinos can obtain their masses by mixing with either an $SU(2)$-singlet or an $SU(2)$-triplet fermion. The see-saw mechanism generated through mixing with a triplet fermion is termed as the 'type-III' see-saw. One possible choice considered in the literature so far is to assume that the extra triplet fermion has hypercharge zero. This choice has an advantage that the nonsupersymmetric $SU(5)$, containing such a fermion as a part of the adjoint representation, can lead to the gauge coupling unification. The triplet fermion with nonzero hypercharge arises naturally in the supersymmetric type-II models of neutrino mass generation. We discuss the feasibility of using the hypercharged triplet fermions to obtain the neutrino masses. In the process, some of the obstacles in doing so were identified and our aim is to obtain a future workable solution.

Consider SM with additional triplet fermion Δ with hypercharge 1. The leptonic doublet L and the Higgs doublet H_d carry hypercharge $-1/2$. One also needs to introduce additional triplet fermion $\bar{\Delta}$ with hypercharge -1 to cancel anomalies. This allows the following renormalizable couplings:

$$\lambda L \Delta H_d + M \Delta \bar{\Delta} + \text{h.c.}$$

and leads to the following mass matrix in the basis (ν, Δ^0, $\bar{\Delta}^0$),

$$\begin{pmatrix} 0 & \lambda\langle H_d\rangle & 0 \\ \lambda\langle H_d\rangle & 0 & M \\ 0 & M & 0 \end{pmatrix}.$$

This matrix conserves lepton number and leads to massless neutrinos. Neutrino mass can be induced by adding a small entry along the diagonal.

Nonzero 11-element corresponds to adding type-II contribution. 22- or 33-element can be induced by invoking additional fields. One possibility considered is to add spin 2-scalar η with hypercharge -2. It has a neutral component which leads to the 33 entry and would generate neutrino mass. The coupling $\Delta\Delta\eta$ can be made invariant under the lepton number symmetry by assinging the lepton number 2 to η. This gets broken spontaneously when its neutral component obtains a VEV. But this generates a majoron which would run into problem with the invisible Z width. Various ways of avoiding this majoron or making it invisible were discussed and it was felt that it is not straightforward to do so. New ideas are needed to solve this problem. Such a model contains a doubly charged fermion and may have definitive signatures which also would be looked for in the future work. In addition, supersymmetric generalization of this scheme would practically have all the mechanisms of neutrino mass generations proposed so far built into it and would be interesting to study.

7. Flavour effects in leptogenesis in fermion triplet models

Manimala Mitra, Sudhanwa Patra and Diptimay Ghosh

We add a fermion triplet to Standard Model and study neutrino mass and leptogenesis, including flavour effects which can lower the bound on mass of fermion triplet which is potentialy an interesting topic to study.

8. Fourth generation in SM4 and beyond

Rohini Godbole, Shrihari Gopalkrishna, Sourov Roy, Rui Santos, Sudhir Vempati and Utpal Sarkar

Choose a model where a fourth generation appears. We have decided to choose SM4, MSSM4 and RS models. In each model there can be new contributions to the production cross-section and to the (charged/neutral current) decay modes of the t' and the b'. In each model we find how the Tevatron bounds on the production and the decay constrain both masses as a function of the parameters of the model. We shall consider cases with and without hierarchy between t' and b' masses. Usual bounds on the parameter space assume chiral fermions only and we shall extend it to vector-like fermions.

Next we include precision physics constraints. In SM4 they imply a mass difference of the order or below 50 GeV. Is it true for other models? How are precision observables affected? Finally we include B-physics constraints. It will further constrain the CKM elements as a function of the mass of the fourth generation particles. With all the contraints in place, we discuss the phenomenology of the proposed models at the LHC in the allowed parameter space. We shall later extend this study to the lepton sector.

9. Four generations and neutrino masses

A Joshipura, M Mitra, S Patra, S Roy, S Vempati, R Godbole and R Santos

The fourth generation neutrino should have mass $m_{\nu_\tau} > 45$ GeV. The question is whether it is possible to generate both light neutrino masses for the first three generations while the fourth generation has a heavy mass of $\mathcal{O}(45)$ GeV.

Three possible mechanisms have been put forward. In the first mechanism, fourth generation neutrino attains a Dirac mass of the required order. This can be implemented by incorporating a 'singular' right-handed neutrino mass matrix within the ordinary see-saw mechanism extended to four generations. In this case, the massless right-handed neutrino pairs up with the fourth generation right-handed neutrino forming a Dirac particle of the order of the weak scale. The remaining three light neutrinos get their masses via see-saw mechanism.

In the second mechanism, a type-II see-saw mechanism is incorporated within a double see-saw. Here the fourth generation left-handed neutrino attains a Majorana mass of the order of the weak scale due to the see-saw effect of a heavy additional singlet which has been included in the model. An additional discrete symmetry is typically used to distinguish the first three generations with the fourth generation in this case. The scalar potential in both nonsupersymmetric as well as supersymmetric version of the theory is being explored. These mechanisms would be explored in more detail and details of the mixing patterns will be obtained. Cosmological implications of the stable neutrino of the weak scale also need to be explored.

In the third mechanism, a Higgs triplet (Δ) and a right-handed neutrino (N_{R}) are added. Discrete symmetry Z_n needs to be imposed. The neutrino mass matrix is

$$M_\nu = \begin{pmatrix} 0 & y_\nu^4 v_\Delta & 0 \\ {y^4}_\nu^T v_\Delta & 0 & y_\nu^a v_u \\ 0 & {y_\nu^a}^T v_u & M_{\mathrm{R}} \end{pmatrix}.$$

Fourth generation neutrino mass

$$m_{\nu_4} = -m_a M_{\mathrm{R}}^{-1} m_a^T,$$

where $m_a = y_\nu^a v_u$. The light neutrino masses:

$$m_{\mathrm{light}_\nu} = -m_{\mathrm{D}} m_{\nu_4}^{-1} m_{\mathrm{D}}^T,$$

where $m_{\mathrm{D}} = y_\nu^4 v_\Delta$, involves a double see-saw and one of the neutrinos will get mass.

10. Four generations and fine-tuning

M Mitra, S Vempati, S Roy and R Vaidya

We address the question of fine-tuning constraints within the class of four generational MSSMs. The additional heavy fermions in the MSSM4 would contribute to the light Higgs mass through their large Yukawa couplings thus leading to a heavier light Higgs mass. One question thus posed was to quantify the reduction in fine-tuning in terms of

Barbieri–Giudice fine-tuning parameters and demonstrate that MSSM4 has less fine-tuning compared to MSSM3. In terms of a specific high-scale framework for MSSM4, one can work with general gauge mediation boundary conditions at a scale close to 100 TeV. These fine-tuning parameters within this framework will be computed and will be compared with mSUGRA conditions.

11. Fourth generation neutrino as dark matter

Utpal Sarkar, Anjan Joshipura and Subhendra Mohanty

The fourth generation fermions could be accommodated in the Standard Model, if the fourth generation neutrinos are pseudo-Dirac particles. It is possible that the fourth generation Dirac neutrinos could account for the dark matter of the Universe naturally in conjunction with a lepton asymmetry of the Universe after the electroweak phase transition. A realistic four-generation model was discussed which can have leptogenesis. Such a model can give rise to the required amount of lepton asymmetry and dark matter to solve both the problems simultaneously.

References

[1] B Adhikary, A Ghosal and P Roy, *J. High Energy Phys.* **0910**, 040 (2009)
[2] L Lavoura, hep-ph/0302221