

## TEXTURE 5 ZERO LEPTON MASS MATRICES

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**Abstract—** Assuming Majorana nature of neutrinos, texture five zero lepton mass matrices where  $M_I$  to be texture 3 zero or  $M_{\nu D}$  to be texture 2 zero or vice versa have been investigated in detail, taking into account both Fritzsche like as well as non Fritzsche like cases. These matrices have been checked for their compatibility with the latest neutrino oscillation data for Normal hierarchy (NH) and Inverted Hierarchy (IH) of Majorana neutrinos. Several phenomenological quantities such as neutrinoless double beta decay  $\langle m_{ee} \rangle$ , Jarlskog's rephasing invariant parameter in the leptonic sector  $J_l$  and the corresponding Dirac like CP violating phase  $\delta_l$  have been calculated for the viable case, which is essential for the model selection and can be measured by future experiments.

**Index Terms—**Fermion mass matrices, Majorana neutrinos, Mixing angles, Normal hierarchy, Inverted hierarchy

### I. INTRODUCTION

Fermion masses and mixings is one of the most challenging and outstanding problems in the present day high energy physics which the Standard Model (SM) cannot explain. Tremendous efforts have been put in both by experimentalists and theoreticians to unravel the physics beyond the SM. On the experimental side, the observation of nonzero masses of neutrinos has provided a signal to go beyond SM. In the current scenario, the neutrino oscillation experiments MINOS [1], Daya Bay [2], Double Chooz [3], RENO [4] concludes very precise non zero and relatively large value of reactor mixing angle  $\theta_{13}$  which gives us the hint that quarks and leptons melt into each other at very high energies. The results from long baseline accelerator neutrino experiments T2K [5] and NovA [6] explain nearly maximal mixing angle  $\theta_{23} \geq 45^\circ$  and Dirac CP violating phase  $\delta_l \sim 270^\circ$  along with the preference for the normal ordering (NO) of neutrino masses. The atmospheric neutrino experiment at Super-Kamiokande [5] also supports the results of long baseline accelerator experiments. Further, a statistical analysis of the cosmological data [7] gives the value of neutrino less double beta decay  $\langle m_{ee} \rangle$  which is less than 16meV. The discovery of Higgs Boson in 2012 by the ATLAS and CMS collaborations [8] completes the SM without giving any clue for the physics beyond SM. The current experimental scenario lag behind to explain the neutrino parameters like the octant of  $\theta_{23}$ , the nature of neutrinos whether they are Dirac or Majorana and also the possible ordering Normal hierarchy (NH)  $m_{\nu 1} < m_{\nu 2} < m_{\nu 3}$  or Inverted hierarchy (IH)  $m_{\nu 1} < m_{\nu 3} < m_{\nu 2}$  of neutrino masses.

On the other side, by theoreticians several ideas have proposed in the literature [9-11] which reduces the number of free parameters in the SM. However, these parameters are

completely arbitrary in SM and no relationship amongst them is provided, therefore explaining the origin of fermion masses and mixings remains one of the important goals in particle physics. Since the flavor structure of SM is dictated by the fermion mass matrices, therefore a successful choice of mass matrix helps us to suggest an appropriate dynamical model for explaining the fermion mass spectrum. In the present work, we are considering the "bottom up approach" wherein one tries to find the phenomenological fermion mass matrices which are in tune with the low energy data and can serve as guiding stone for developing more ambitious theories.

In this context, several ansatzes e.g., texture zeros, seesaw mechanism, radiative mechanism, flavor symmetries, extra dimensions [12-16] have been made to formulate phenomenological mass matrices compatible with an experimental data. One of the successful approaches is the "texture zero" approach initiated by Fritzsche [12]. A particular texture structure is said to be texture  $n$  zero, if it has  $n$  number of non trivial zeros, for example, if the sum of the number of diagonal zeros and half the number of symmetrically placed off diagonal zeros is  $n$ . It means that the corresponding matrix elements are sufficiently suppressed in comparison with their neighboring counterparts. Textures are imposed by some underlying symmetries to allow us to derive some predictions which can be compared with experimental data. In this context, as an important approach, mass matrices have been considered wherein specific elements are exactly zero; such matrices are referred as "texture specific mass matrices".

In literature, texture specific mass matrices have received a good deal of attention. In quark sector, analysis has been carried out for both Fritzsche like as well as non Fritzsche like texture 5 zero mass matrices [17]. In leptonic sector, most of the analyses have done in flavor basis [18] whereas in non flavor basis a large number of possibilities have not yet been investigated [19]. Further, analysis has been carried out for Fritzsche type [20] but non-Fritzsche like cases have not been discussed in detail. Therefore, this would require a very careful scrutiny of all possible texture 5 zero fermion mass matrices to find a viable structure compatible with the current oscillation data.

The purpose of the present work is to investigate both the possibilities ( $M_I$  is texture 2 zero and  $M_{\nu D}$  is texture 3 zero or vice versa) for texture 5 zero hermitian mass matrices for normal and inverted hierarchy of Majorana neutrinos and check their compatibility with latest data pertaining to neutrino mixing matrix. For this, to preserve the parallelism between quarks and leptons only those neutrino mass matrices have been considered which are consistent with the

requirement of non zero and distinct neutrino masses. It would also be a desirable exercise to calculate phenomenological quantities such as neutrinoless double beta decay  $\langle m_{ee} \rangle$ , Jarlskog's rephasing invariant parameter in the leptonic sector  $J_1$  and the corresponding Dirac like CP violating phase  $\delta_1$  have been calculated for the viable cases.

## II. LEPTON MASS MATRICES AND PMNS MATRIX

To begin with, we present the hermitian texture 2 zero Fritzsche type lepton mass matrices, e.g;

$$M_l = \begin{pmatrix} 0 & A_l & 0 \\ A_l^* & D_l & B_l \\ 0 & B_l^* & C_l \end{pmatrix}, \quad M_{\nu D} = \begin{pmatrix} 0 & A_{\nu D} & 0 \\ A_{\nu D}^* & D_{\nu D} & B_{\nu D} \\ 0 & B_{\nu D}^* & C_{\nu D} \end{pmatrix}; \quad (1)$$

$M_l$  and  $M_{\nu D}$  respectively corresponding to Dirac like charged lepton and neutrino mass matrices. Texture 5 zero can be obtained by taking either  $D_l = 0$  or  $D_{\nu D} = 0$  thereby, giving rise to two possible cases of texture 5 zero matrices, referred to as texture 5 zero  $D_l = 0$  case pertaining to  $M_l$  texture 3 zero type and  $M_{\nu D}$  texture 2 zero type and texture 5 zero  $D_{\nu D} = 0$  case pertaining to  $M_l$  texture 2 zero type and  $M_{\nu D}$  texture 3 zero type.

In the absence of any theoretical justification for Fritzsche like mass matrices, it becomes essential from the phenomenological point of view to include non Fritzsche like mass matrices. These can be obtained by distributing nonzero elements in the possible 9 slots available keeping in mind the hermiticity of matrix. For analysis, adopting quark-lepton symmetry [21] we have considered only those patterns which lead to non zero and distinct mass eigenvalues. Using this, we obtain 12 possible patterns for texture 3 zero and 15 patterns for texture 2 zero. These patterns are further classified into distinct classes depending on the diagonalisation equations they satisfied as discussed in our previous paper [22]. Class I and II correspond to texture 3 zero while Class III, IV, V, VI to be texture 2 zero as discussed in Table I. Class VI is ruled out due to the decoupling of one of the generation of texture 2 zero fermion mass matrices. The patterns in Table I labeled as a, b, c, d, e, f are the permutations of elements to be zero in the mass matrix.

Considering  $M_l$  to be texture 3 zero (12 patterns) or  $M_{\nu D}$  to be texture 2 zero type (12 patterns) lead to 144 combinations. Similarly, if  $M_l$  to be texture 2 zero or  $M_{\nu D}$  to be texture 3 zero type, again we get 144 combinations which in total leads to 288 combinations for two possible cases of texture 5 zero mass matrices. These combinations have been investigated for both normal hierarchy and inverted hierarchy of mass matrices. The lepton mass matrices have been diagonalised by bi-unitary transformation, e.g.,

$$M_{\nu D}^{diag} = U_{\nu L}^\dagger M_{\nu D} U_{\nu D} = \text{Diag}(m_1, m_2, m_3); \quad (2)$$

where  $U_{\nu D}$  and  $U_{\nu L}$  are unitary matrices and  $M^{diag}$  is a diagonal matrix. The corresponding mixing matrix obtained, known as Pontecorvo-Maki-Nakagawa-Sakata (PMNS) or lepton mixing matrix  $V_{PMNS}$ , is given as

$$V_{PMNS} = V_{\nu L}^\dagger V_{\nu D}; \quad (3)$$

where  $V_{\nu L}^\dagger$  and  $V_{\nu D}$  correspond to the diagonalization transformations of lepton and neutrino mass matrices respectively. The  $V_{PMNS}$  expresses the relationship between the neutrino mass eigenstates and the flavor eigenstates, e.g.,

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} V_{e1} & V_{e2} & V_{e3} \\ V_{\mu1} & V_{\mu2} & V_{\mu3} \\ V_{\tau1} & V_{\tau2} & V_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}; \quad (4)$$

Where  $\nu_e, \nu_\mu, \nu_\tau$  are the flavor eigenstates and  $\nu_1, \nu_2, \nu_3$  are the mass eigenstates and the  $3 \times 3$  mixing matrix is leptonic mixing matrix. For Majorana neutrinos, the neutrino mass matrix  $M_\nu$  is given by seesaw mechanism [23], for example,

$$M_\nu = -M_{\nu D}^T (M_R)^{-1} M_{\nu D} \quad (5)$$

where  $M_{\nu D}$  and  $M_R$  are respectively, the Dirac neutrino mass matrix and the right handed Majorana mass matrix. In the absence any guidelines regarding right handed Majorana mass matrix  $M_R$ , we would keep its structure as simple as possible to reduce the number of parameters. Following Fukugita et. al [24], we take  $M_R = m_R I$ , where  $I$  is unitary matrix and  $m_R$  denotes a large mass.

Apart from mixing angles, we have also calculated the Jarlskog's rephasing invariant in the leptonic sector  $J_1$  and Dirac like CP violating phase  $\delta_1$  and effective neutrino mass  $\langle m_{ee} \rangle$  related to neutrinoless double beta decay  $\beta\beta_{0\nu}$ . The parameter  $J_1$  has been calculated by using an expression

$$J_1 = \text{Im}[V_{23} V_{33}^* V_{22} V_{32}^*]; \quad (6)$$

where  $U_{23}, U_{33}, U_{22}, U_{32}$  are the elements of mixing matrix. The Dirac like CP violating phase  $\delta_1$  can be determined from

$$J_1 = S_{12} S_{13} S_{23} C_{12} C_{23} C_{13} \sin \delta_1. \quad (7)$$

The effective Majorana mass to be measured in  $\beta\beta_{0\nu}$  decay experiment is given as

$$\langle m_{ee} \rangle = |m_{\nu 1} V_{11}^2 + m_{\nu 2} V_{12}^2 + m_{\nu 3} V_{13}^2|. \quad (8)$$

## III. CURRENT STATUS OF NEUTRINO MASSES AND MIXINGS

While carrying out an analysis regarding the compatibility of neutrino mass matrices with the recent data, one needs to keep in mind the experimental constraints imposed by the relationship between mass matrices and their corresponding mixing matrices. To facilitate our discussion in this regard, we present the status of relevant data in the lepton sector. The  $3\sigma$  confidence level ranges of the neutrino oscillation parameters obtained in a latest global three neutrino oscillation analysis carried out by Gonzalez-Garcia et al. [25] have been presented in the Table II. The data reveals that the hierarchy of neutrino masses and their absolute values are not known much.

While carrying out analysis, the masses and mixing angles have been constrained by the data given in Table II. The lightest neutrino mass  $m_1$  for normal hierarchy (NH) and  $m_3$  for inverted hierarchy (IH), is considered to be the free parameter in our analysis while the other two masses are obtained using the following equations  $\Delta m_{12}^2 = m_{\nu 2}^2 - m_{\nu 1}^2$ ;  $\Delta m_{23}^2 = m_{\nu 3}^2 - m_{\nu 2}^2$  for normal hierarchy and  $\Delta m_{23}^2 = m_{\nu 2}^2 - m_{\nu 3}^2$  for inverted hierarchy. The explored range of lightest

neutrino mass is taken to be 0.0001-1.0 eV as our results remain unaffected even if the range is extended further. In the absence of any constraint on the phases  $\phi_1$  and  $\phi_2$ , these have been given full variation from 0 to  $2\pi$ . The element  $D_{1\nu}$  is considered to be a free parameter and it can be constrained such that diagonalizing transformations  $O_l$  and  $O_\nu$  always remain real.

IV. NUMERICAL ANALYSIS

As already discussed in section II, there are in total, 288 combinations for two possible cases of texture 5 zero lepton mass matrices corresponding to normal hierarchy of Majorana neutrino, by confronting their corresponding mixing matrix against latest neutrino oscillation data given in section III. To detail the methodology, we consider a non Fritzsche combination corresponding to the case where  $M_l$  is to be texture 3 zero and  $M_{\nu D}$  to be texture 2 zero non Fritzsche type and  $M_R$  as diagonal. For example;

$$M_l = \begin{pmatrix} 0 & A_l & B_l \\ A_l^* & 0 & 0 \\ B_l^* & 0 & C_l \end{pmatrix}; M_{\nu D} = \begin{pmatrix} C_{\nu D} & 0 & B_{\nu D} \\ 0 & 0 & A_{\nu D} \\ B_{\nu D}^* & A_{\nu D}^* & D_{\nu D} \end{pmatrix}; M_R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (9)$$

The real matrices can be diagonalized by using orthogonal transformation  $O_l$  and  $O_{\nu D}$  and elements are obtained in terms of lepton masses and neutrino masses  $m_1, m_2, m_3$  as  $m_e, m_\mu, m_\tau$  and  $m_{\nu 1}, m_{\nu 2}, m_{\nu 3}$ . The diagonalizing transformation for  $O_l$  is given as

$$\begin{pmatrix} \sqrt{\frac{m_1(m_3 - m_2)}{(m_3 - m_1)(m_1 + m_2)}} & \sqrt{\frac{m_2(m_1 + m_3)}{(m_3 + m_2)(m_1 + m_2)}} & \sqrt{\frac{m_3(m_2 - m_1)}{(m_3 - m_1)(m_3 + m_2)}} \\ \sqrt{\frac{m_2 m_3 (m_3 - m_2)}{(m_3 - m_1)(m_1 + m_2)(c_l)}} & \sqrt{\frac{m_1 m_3 (m_1 + m_3)}{(m_3 + m_2)(m_1 + m_2)(c_l)}} & \sqrt{\frac{m_1 m_2 (m_2 - m_1)}{(m_3 - m_1)(m_3 + m_2)(c_l)}} \\ \sqrt{\frac{m_1(m_2 - m_1)(m_1 + m_3)}{(m_3 - m_1)(m_1 + m_2)(c_l)}} & \sqrt{\frac{m_2(m_3 - m_2)(m_1 + m_2)}{(m_3 + m_2)(m_1 + m_2)(c_l)}} & \sqrt{\frac{m_3(m_3 - m_2)(m_3 + m_1)}{(m_3 - m_1)(m_3 + m_2)(c_l)}} \end{pmatrix}; \quad (10)$$

Similarly, the diagonalizing transformation for  $O_{\nu D}$  is given as

$$\begin{pmatrix} \sqrt{\frac{m_1(m_3 + m_1 - D)(D + m_2 - m_1)}{c_{\nu D}(m_3 - m_1)(m_1 + m_2)}} & \sqrt{\frac{m_2(m_3 - m_2 - D)(D + m_2 - m_1)}{c_{\nu D}(m_3 + m_2)(m_1 + m_2)}} & \sqrt{\frac{m_3(D - m_3 + m_2)(D - m_1 - m_3)}{c_{\nu D}(m_3 - m_1)(m_3 + m_2)}} \\ \sqrt{\frac{m_2 m_3 (D - m_3 + m_2)}{c_{\nu D}(m_1 - m_3)(m_1 + m_2)}} & \sqrt{\frac{m_1 m_3 (D + m_2 - m_3)}{c_{\nu D}(m_2 + m_3)(m_1 + m_2)(q)}} & \sqrt{\frac{m_1 m_2 (D + m_2 - m_1)}{c_{\nu D}(m_3 - m_1)(m_3 + m_2)}} \\ \sqrt{\frac{m_1(D + m_2 - m_3)}{(m_1 - m_3)(m_1 + m_2)}} & \sqrt{\frac{m_2(m_1 + m_3 - D)}{(m_3 + m_2)(m_1 + m_2)}} & \sqrt{\frac{m_3(D + m_2 - m_1)}{(m_3 - m_1)(m_3 + m_2)}} \end{pmatrix}; \quad (11)$$

where  $C_l = m_e - m_\mu + m_\tau$ ,  $C_{\nu D} = m_{\nu 1} - m_{\nu 2} + m_{\nu 3} - D_{\nu D}$  and  $D_{\nu D}$  as a free parameter in texture 2 zero neutrino mass matrices. For this particular set of matrices, the phase matrix is  $(e^{-i\phi}, e^{-i\psi}, 1)$  where  $\phi = \phi_1 - \phi_\nu$  and  $\psi = \psi_1 - \psi_\nu$ . The scanned ranges of lightest neutrino masses, mixing angles and phases have been given in section III. Using the equation (3), PMNS matrix obtained is

$$\begin{bmatrix} .8148 - .8272 & .5417 - .5598 & .1489 - .1508 \\ .3034 - .3194 & .5601 - .5605 & .7642 - .7706 \\ .4623 - .4940 & .6103 - .6265 & .6192 - .6276 \end{bmatrix}; \quad (12)$$

which is in excellent agreement within the ranges given at  $3\sigma$  C.L.. The mixing angle  $\theta_{12}$  span its entire experimental range,  $\theta_{13}$  has large value,  $\theta_{23} = (49-51)^\circ$ , satisfying the condition of  $\theta_{23} > 45^\circ$ . The neutrino masses  $m_{\nu 1} = 0.0050 - 0.0079$ ,  $m_{\nu 2} = 0.0712 - 0.0895$  and  $m_{\nu 3} = 0.2707 - 0.3039$ ; are following normal hierarchy and thus ruled out degenerate scenario of neutrino

masses. The Dirac CP violating phase comes out to be  $(291-307)^\circ$ , is in good agreement with the experimental results at  $3\sigma$  C.L. The value of  $\langle m_{ee} \rangle$  and  $J_1$  come out to be  $(0.013-0.016)$  meV and  $(0.026-0.029)$  meV respectively, are in agreement with the ranges obtained in other such analyses [26].

Consider the reverse of equation (9) as  $M_l$  to be texture 2 zero and  $M_{\nu D}$  to be texture 3 zero non Fritzsche type again we have obtained the results which are in good agreement with the experimental results. Thus, the said combination is viable and produces a result quite compatible with the current neutrino oscillation data for both cases. Further, analysis has been done for the above said combination for both the cases for inverted hierarchy. For this, the lightest neutrino mass is  $m_3$  and other two masses are constrained by equation  $\Delta m_{23}^2 = m_{\nu 2}^2 - m_{\nu 3}^2$ .

Rest of all other inputs is same as considered for the normal hierarchy case. We find that the combination does not give us viable results thus ruling out inverted hierarchy for both cases.

Similarly, exhaustive analysis has been carried out for all the combinations mentioned in Table I and checks their compatibility with the latest oscillation data. The viable cases pertaining to normal hierarchy and inverted hierarchy have been presented in Table III. We find that 66 out of 288 total combinations are compatible with the oscillation data for NH and 24 combinations are compatible with the data for IH. Table III reveals that the number of viable possibilities is understandably quite large in texture 5 zero fermion mass matrices. Phenomenological quantities have been calculated for viable combinations both for NH and IH combinations. In each one of the combination mixing angle  $\theta_{12}$  and  $\theta_{13}$  are spanning the entire experimental range and angle  $\theta_{23}$  is around the maximal value. The magnitude of  $J_1$  ( $\sim 10^{-2}$ ) can reach the percentage level and might be detected in the upcoming long baseline neutrino oscillation experiments. The magnitude of effective mass  $\langle m_{ee} \rangle$  to be measured in the neutrino less double beta decay ( $\sim 10^{-3}$ ) is too small to be experimentally accessible in foreseeable experiments. The CP violating phase can be measured and is in agreement with the data [23].

V. CONCLUSIONS

To summarize, we have analysed combinations corresponding to hermitian texture five zero lepton mass matrices to check their viability against current neutrino oscillation data at  $3\sigma$  C.L.. For each of the combination of mass matrices, both cases have been considered in the analysis for example  $M_l$  to be texture 2 zero and  $M_{\nu D}$  to be texture 3 zero non Fritzsche type for normal hierarchy and inverted hierarchy of Majorana neutrinos. Large number of cases is viable for normal hierarchy as compared to inverted hierarchy. Moreover, the above mentioned viable texture combinations are found to be compatible with current data even at  $2\sigma$  level. For all the allowed cases we are able to get the ranges of effective neutrino mass and CP violating phase which lie in the sensitivity limits of the experimental data. More refined measurements of mixing angles, effective neutrino mass and CP violating phase in lepton sector can help us to locate

unique texture structure for charged leptons and neutrinos and thus they are important for building more ambitious theories.

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REFERENCES

[1] P. Adamson et al., [MINOS Collaboration], Phys. Rev. Lett. 107, 181802 (2011), arXiv:1108.0015 [hep-ex].  
 [2] F. P. An et al., [Daya Bay Collaboration], Phys. Rev. Lett. 115, (2015) 111802.  
 [3] Y. Abe et al., [Double Chooz Collaboration], JHEP 1410 (2014) 086; Erratum: ibid. 1502 (2015) 074.  
 [4] S. B. Kim et al. [RENO Collaboration], Nucl. Phys. B 908 (2016) 94.  
 [5] K. Abe et al. (T2K), Phys. Rev. D. 91, 072010 (2015), arXiv: 1502.01550 [hep-ex].  
 [6] P. Adamson et al. [NOvA Collaboration], Phys. Rev. Lett. 116 (2016) no.15, 151806.  
 [7] P.A.R. Ade et al. (Planck), 2015, arXiv : 1502.01589 [hep-ex].  
 [8] G. Aad et al. (ATLAS, CMS), Phys. Rev. Lett. 114, 191803 (2015), arXiv:1503.07589 [hep-ex].  
 [9] H. Fritzsch, Phys. Lett. B 70 (1977),436; B73 (1978),317; P. Minokowski, Phys. Lett. B 67 (1977) 421.  
 [10] S. Weinberg, Phys. Rev. D 5 (1972), 1962; C.D. Froggatt and H.B. Nielson, Nucl. Phys. B 147 (1979), 277.  
 [11] M. Randhawa and M. Gupta, Phys. Rev. D 63,097301 (2001).  
 [12] H. Fritzsch, Phys. Lett. B 70, 436 (1977); H. Fritzsch, Phys. Lett. B 73, 317 (1978).  
 [13] P. Minkowski, Phys. Lett. B 67 (1977) 421; T. Yanagida, in Proceedings of the Workshop on Unified Theory and the Baryon Number of the Universe, edited by O. Sawada and A. Sugamoto (KEK, Tsukuba, 1979), p. 95; M. Gell-Mann, P. Ramond, and R. Slansky, in Supergravity, edited by F. van Nieuwenhuizen and D. Freedman (North Holland, Amsterdam, 1979), p. 315; S.L. Glashow, in Quarks and Leptons, edited by M. L'evy et al. (Plenum, New York, 1980), p. 707; R. N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. 44 (1980), 912.  
 [14] S. Weinberg, Phys. Rev. D 5 (1972), 1962; A. Zee, Phys. Lett. B 93 (1980), 389;

[15] C.D. Froggatt and H.B. Nielsen, Nucl. Phys. B 147 (1979), 277; Y. Nir and N. Seiberg, Phys. Lett. B 309 (1993), 337; M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B 420 (1994), 468  
 [16] K.R. Dienes, E. Dudas, and T. Gherghetta, Nucl. Phys. B 557 (1999), 25; G. Dvali and A.Yu. Smirnov, Nucl. Phys. B 563 (1999), 63; N. ArkaniHamed, S. Dimopoulos, G. Dvali, J. March-Russell, Phys. Rev. D 65 (2002) 024032; A. J. Buras, C. Grojean, S. Pokorski and R. Ziegler, arXiv:1105.3725, and references therein; Z. Guo and B. Ma, JHEP 0909 (2009), 091 and references therein.  
 [17] N. Mahajan, R. Verma, M. Gupta, Int. J. Mod. Phys. A 25 (2010), 1.  
 [18] P. H. Frampton, S. L. Glashow, D. Marfatia, Phys. Lett. B 536 (2002), 79; Z. Z. Xing, Phys. Lett. B 530 (2002), 159.  
 [19] M. Randhawa, G. Ahuja, M. Gupta, Phys. Rev. D 65 (2002).  
 [20] P. Raymond, R. G. Roberts and G. G. Ross, Nucl. Phys. B 406, 19 (1993), arXiv:hep-ph/9303320.  
 [21] Michael A. Schmidt, Alexei Yu. Smirnov, Phys. Rev. D 74 (2006), 113003.  
 [22] Neelu Mahajan, Monika Randhawa, Manmohan Gupta, P.S. Gill, Prog. Theor. Exp. Phys. 2013, 083B02 (2013).  
 [23] P. Minkowski, Phys. Lett. B 7 (1977) 421; T. Yanaida in Proceedings of the Workshop on Unified Theory and the Baryon number of the Universe, edited by O. Sawada and A. Suamoto p. 95; R.N. Mohapatra and . Senjanovic, Phys. Rev. Lett. 44 (1980), 912.  
 [24] M. Fukugita, M. Tanimoto, T. Yanaida, Phys. Lett. B 562 (2003),273; M. Fukugita, Y. Shimizu, M. Tanimoto, T. Yanagida, Phys. Lett. B 716 (2012), 294.  
 [25] M.C.Gonzalez Garcia, M. Maltoni and T. Schwetz, Nucl. Phys. B 908 (2016) 199.  
 [26] Z. Z. Xing, S. Zhou, Phy. Lett. B 593 (2004), 156; S. Choubey, W. Rodejohann, P. Roy, Nucl. Phys. B 808 (2009), 272, Erratum-ibid. 818:136, 2009; H. Fritzsch, X. X. Xing, Phys. Lett. B 682 (2009), 220; S. Goswami, A. Watanabe, Phys. Rev. D 79 (2009), 033004; G. Ahuja, M. Gupta, M. Randhawa, R. Verma, Phys. Rev. D 79 (2009), 093006; M. Gupta, G. Ahuja, R. Verma, Int. J. Mod. Phys. A 24 (2009), 3462; H.Fritzsch, Z.Z.Xing, S.Zhou, J. High Energy Physics 83 (2011), 1109; H.Fritzsch, S. Zhou, hep-ph/1212.0411.

**Table I:** Phenomenological allowed possibilities categorized into distinct classes. 12 possibilities of texture 3 zero classified into Class I and Class II and 15 possibilities of texture 2 classified into Class III, Class IV, Class V, Class VI. Patterns at positions a, b, c, d, e, f are the permutations of elements to be zero.

Class	Permutations					
	A	B	C	d	e	F
C-I	11,22,13,31	11,12,21,33	11,22,23,32	13,31,22,33	11,23,32,33	12,21,22,33
C-II	11,13,31,23	11,12,21,23, 32	13,31,22,23	12,21,13,31, 33	12,23,32, 33	12,21,13,31,22

<b>C-III</b>	11,13,31	11,12,21	22,23,32	13,31,33	23,32,33	12,21,22
<b>C-IV</b>	13,31,22	12,21,33	11,23,32	-	-	-
<b>C-V</b>	11,22	11,33	22,33	-	-	-
<b>C-VI</b>	12,21,13,31	12,21,23,32	13,31,23,32	-	-	-

**Table II:** Current status of neutrino mixing parameters

Parameter	$3\sigma$
$\Delta m_{12}^2 (10^{-5} \text{eV}^2)$ (solar)	$7.50^{+0.19}_{-0.17}$
$\Delta m_{31}^2 (10^{-5} \text{eV}^2)$ (atmospheric)	$2.457 \pm 0.047$
$\Delta m_{12}^2 / \Delta m_{31}^2$	$\sim 0.03$
$\sin^2 \theta_{12}$	$0.304^{+0.013}_{-0.012}$
$\sin^2 \theta_{23}$	$0.452^{+0.052}_{-0.028}$ (NH); $0.579^{+0.025}_{-0.037}$ (IH)
$\sin^2 \theta_{13}$	$0.0218 \pm 0.0010$ ; $0.0219^{+0.0011}_{-0.0010}$ (IH)
$\delta_l$	$306^{+39}_{-70}$

**Table III:** Viable texture 5 zeros lepton mass matrices for NH and IH

$M_l, M_{\nu D}$	NH	IH
I, III	aa, bb, cc, dd, ee, ff, ab, ba, cf, fc, de, ed	ac, ae, bc, be, ca, cd, db, df, eb, ef, fa, fd
III, I	aa, bb, cc, dd, ee, ff, ab, ba, cf, de, ed, fc	-
I, IV	da, db, ea, eb, fa, fb	-
IV, I	ad, ae, bc, bf, cc	-
I, V	aa, ab, ba, bb, cc, fc	-
V, I	aa, ab, bb, ba, cc, cf	-
II, III	aa, bb, cc, ee, ab, ba, cf, da, fa, fb	ac, ae, bb, bf, ca, ce, dc, de, eb, ef, fc, fe
III, II	aa, ba, cc, fc	-
II, IV	db, fb	-
IV, II	-	-
II, V	aa, ba, da, fc	-
V, II	-	-