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Probing the Majorana nature of the neutrino with neutrinoless double beta decay

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Abstract. Neutrinoless double beta decay ($0\nu\beta\beta$) is the only experiment that could probe the Majorana nature of the neutrino. Here we study the theoretical implications of $0\nu\beta\beta$ for models yielding tri-bimaximal lepton mixing like A_4 and S_4.

1. Introduction

Neutrinoless double beta decay ($0\nu\beta\beta$) is the only experiment that can probe the Majorana Nature of the neutrino. $0\nu\beta\beta$ is a $\Delta L = 2$ lepton number violating decay that can occur if the neutrino is a Majorana particle. For an introduction see for instance [1]. The generic effective Majorana mass term can be write as

$$\mathcal{L}_{d5} = \frac{\lambda^\nu_{ij}}{\Lambda} L_i\phi L_j\phi, \tag{1}$$

where ϕ is the standard model higgs doublet and Λ is an effective scale. When ϕ takes a vev $\langle\phi\rangle = v$, the operator in eq. (1) gives the Majorana mass term $m^\nu_{ij} = \lambda^\nu_{ij} v^2/\Lambda$. In general m^ν is an arbitrary 3 by 3 symmetric complex matrix. It has been observed [2] that neutrino data are in very good agreement with zero a rector angle $\sin\theta_{13} = 0$, maximal atmospheric angle $\sin^2\theta_{23} = 1/2$ and large but not maximal solar angle $\sin^2\theta_{12} = 1/3$. A Leptonic mixing mixing matrix with such a values is called tri-bimaximal (TBM). The most generic neutrino mass matrix yielding to TBM mixing is invariant under exchanged the second family with the third family ($\mu \leftrightarrow \tau$ symmetry) and the sum of the elements each row of m_ν is constant, namely $\sum_j m^\nu_{1j} = \sum_j m^\nu_{2j} = \sum_j m^\nu_{3j}$. We call a neutrino mass matrix of such type tri-bimaximal form mass matrix.

We can extend the standard model by means of a flavor symmetry G_f that yields a tri-bimaximal form mass matrix. Examples are the group of even permutation of four objects A_4 [3, 4] or the group of all the permutation of four objects S_4 [5, 6]. We observe that A_4 is the smallest non-Abelian group with a triplet representation allowing to arrange in one multiplet the three families. For now on we focus on A_4 flavor symmetry. We assume three Higgs doublets transforming as a triplet $(\phi_1, \phi_2, \phi_3) \sim 3$ and the lepton doublets L_e, L_μ, L_τ, transforming as a triplet of A_4. The most generic A_4 invariant dimension five operators are given as

$$\mathcal{L}_{5d} = \frac{c_1}{\Lambda}(L_i\phi)_1(L_j\phi)_1 + \frac{c_2}{\Lambda}(L_i\phi)_{1'}(L_j\phi)_{1''} + \frac{c_3}{\Lambda}(L_i\phi)_3(L_j\phi)_3 +$$

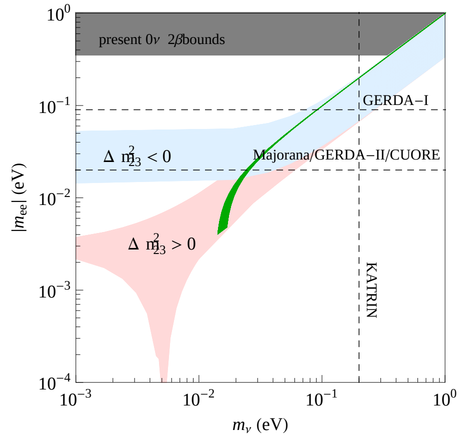

Figure 1. Allowed range of m_{ee} as a function of the lightest neutrino mass for A_4 based model.

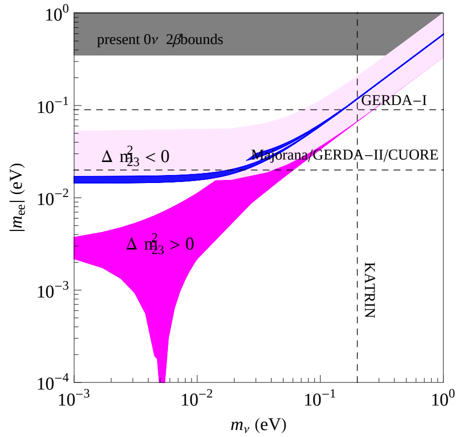

Figure 2. Allowed range of m_{ee} as a function of the lightest neutrino mass for S_4 based model.

$$+ \frac{c_4}{\Lambda}(L_iL_j)_1(\phi\phi)_1 + \frac{c_5}{\Lambda}(L_iL_j)_{1'}(\phi\phi)_{1''} + \frac{c_5'}{\Lambda}(L_iL_j)_{1''}(\phi\phi)_{1'} + \frac{c_6}{\Lambda}(L_iL_j)_3(\phi\phi)_3. \quad (2)$$

The resulting neutrino mass matrix is of tri-bimaximal form if and only if $c_5 = c_5' = 0$. Such a condition can naturally be explained by adding Higgs doublets or flavons carrying extra Abelian symmetries, see for instance [4].

Differently the most generic S_4 invariant dimension five operators

$$\begin{aligned}\mathcal{L}_{5d} &= \frac{\lambda_1}{\Lambda}(L_i\phi)_1(L_j\phi)_1 + \frac{\lambda_2}{\Lambda}(L_i\phi)_2(L_j\phi)_2 + \frac{\lambda_3}{\Lambda}(L_i\phi)_{3_1}(L_j\phi)_{3_1} + \frac{\lambda_3'}{\Lambda}(L_i\phi)_{3_2}(L_j\phi)_{3_2} + \\ &+ \frac{\lambda_4}{\Lambda}(L_iL_j)_1(\phi\phi)_1 + \frac{\lambda_5}{\Lambda}(L_iL_j)_2(\phi\phi)_2 + \frac{\lambda_6}{\Lambda}(L_iL_j)_{3_1}(\phi\phi)_{3_1}, \quad (3)\end{aligned}$$

give neutrino mass matrix of tri-bimaximal form. In S_4 we do not need to introduce extra scalars or add symmetries in order to have tri-bimaximal in the neutrino sector. The resulting neutrino mass matrix is diagonalized by the tri-bimaximal matrix.

Now we study the theoretical implications for $0\nu\beta\beta$ in models based on the two flavor groups A_4 and S_4. The allowed ranges of m_{ee} as a function of the lightest neutrino are presented in Figures (1) and (2). The two bands correspond to the normal hierarchy and the inverse hierarchy with $\sin^2\theta_{12} = 1/3$, $\sin^2\theta_{23} = 1/2$, $\sin^2\theta_{13} = 0$ (tri-bimaximal). We call this bands the *tri-bimaximal region* for $0\nu\beta\beta$.

In order to simplify the discussion and to show the difference between A_4 and S_4 based models, we assume $c_1 = c_2 = c_3 = 0$ and $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_3' = 0$. This could be the case if the dimension five operators arise from type-II seesaw mechanism only. We have already said that A_4 gives tri-bimaximal mixing if $c_5 = c_5' = 0$.

If $\lambda_5 = 0$ A_4 and S_4 are phenomenologically equivalent since the operators proportional to c_4 and c_6 correspond to the operators proportional to λ_4 and λ_6 respectively.

If $\lambda_5 \neq 0$, then A_4 and S_4 are not phenomenologically equivalent. For instance the S_4 allowed range for m_{ee} is the full tri-bimaximal region. When $\lambda_4 = 0$ the allowed m_{ee} ranges for A_4 and S_4 are given respectively in Figures (1) and (2).

In particular, in Figure (1) we see that A_4 is compatible only with normal hierarchy. The A_4 case has a lower bound with $m_{ee} > 3 \cdot 10^{-3}$, see [7]. In Figure (2) we see that S_4 is compatible only with inverse hierarchy.

[8] and [9] have studied $0\nu\beta\beta$ implications assuming respectively type-I and inverse/linear seesaw mechanisms with A_4 flavor symmetry. An effective neutrino mass model with S_4 flavor symmetry has been studied in [10]. In [11] a model with type-I seesaw with S_4 flavor symmetry has been studied.

Note that for values of the lightest mass bigger than 10^{-1} eV, namely when neutrino are quasi degenerate, A_4 and S_4 allowed ranges are well separated. Therefore it could be in principle possible to distinguish A_4 from S_4 in the quasi degenerate region.

In case of inverse hierarchy there is a lower limit for m_{ee}. In [1] the dependence of such a limit as a function of the solar angle has been studied. However, in case of normal hierarchy in general there is no lower limit. If $m_{\nu_1} = m_{ee} = 0$ we have that the lower limit depends from the values of the solar and reactor angles,

$$\sin^2\theta_{12}\cos^2\theta_{13}e^{i\alpha}\sqrt{\Delta m^2_{12}} + \sin^2\theta_{13}e^{i\beta}\sqrt{\Delta m^2_{13}} = 0. \tag{4}$$

This equation gives a relation between the solar and the reactor angles and the allowed region is represented in Figure (3) with the blue band. The small red region is the range allowed by the data at $3\,\sigma$ and compatible with $m_{\nu_1} = m_{ee} = 0$, namely eq. (4).

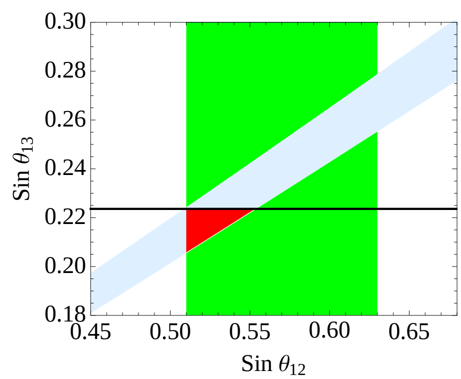

Figure 3. Relation between solar and reactor angles for normal hierarchy when $m_{\nu_1} = m_{ee} = 0$.

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References

[1] M. Hirsch, arXiv:hep-ph/0609146.
[2] P. F. Harrison, D. H. Perkins and W. G. Scott, Phys. Lett. B **530**, 167 (2002) [arXiv:hep-ph/0202074].
[3] K. S. Babu, E. Ma and J. W. F. Valle, Phys. Lett. B **552**, 207 (2003) [arXiv:hep-ph/0206292];
[4] G. Altarelli and F. Feruglio, Nucl. Phys. B **720**, 64 (2005) [arXiv:hep-ph/0504165].
[5] C. S. Lam, Phys. Rev. Lett. **101**, 121602 (2008) [arXiv:0804.2622 [hep-ph]].
[6] F. Bazzocchi and S. Morisi, arXiv:0811.0345 [hep-ph].
[7] G. Altarelli, arXiv:0711.0161 [hep-ph].
[8] M. Hirsch, S. Morisi and J. W. F. Valle, Phys. Rev. D **78**, 093007 (2008) [arXiv:0804.1521 [hep-ph]].

[9] M. Hirsch, S. Morisi and J. W. F. Valle, Phys. Lett. B **679**, 454 (2009) [arXiv:0905.3056 [hep-ph]].
[10] F. Bazzocchi, L. Merlo and S. Morisi, Nucl. Phys. B **816**, 204 (2009) [arXiv:0901.2086 [hep-ph]].
[11] F. Bazzocchi, L. Merlo and S. Morisi, Phys. Rev. D **80**, 053003 (2009) [arXiv:0902.2849 [hep-ph]].