Eigenvector parametrisation, reactor mixing angle, and hybrid seesaw

Ivo de Medeiros Varzielas

University of Basel

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Outline

Eigenvector parametrisation

D. Aristizabal Sierra, IdMV, E. Houet, 1302.6499 (PRD)

$$\boldsymbol{m_\nu} = \sum_{i=1}^{3} m_{\nu_i} \, \boldsymbol{v_i} \otimes \boldsymbol{v_i} \, . \tag{1}$$

Expand around TBM

$$\boldsymbol{v_i} = \boldsymbol{v_i}^{\text{TBM}} + \boldsymbol{\varepsilon_i} \,, \tag{2}$$

For $\delta = 0$ case

$$\boldsymbol{\varepsilon_1} = \begin{pmatrix} \epsilon_{12}/\sqrt{2} \\ \epsilon_{12}/\sqrt{2} - (\epsilon_{13} + \epsilon_{23})/\sqrt{3} \\ \epsilon_{12}/\sqrt{2} + (\epsilon_{13} + \epsilon_{23})/\sqrt{3} \end{pmatrix} , \tag{3}$$

$$\boldsymbol{\varepsilon_2} = \begin{pmatrix} -\epsilon_{12} \\ \epsilon_{12}/2 - \epsilon_{13}/\sqrt{6} + \sqrt{2}\epsilon_{23}/\sqrt{3} \\ \epsilon_{12}/2 + \epsilon_{13}/\sqrt{6} - \sqrt{2}\epsilon_{23}/\sqrt{3} \end{pmatrix} , \tag{4}$$

$$\boldsymbol{\varepsilon_3} = \begin{pmatrix} -\epsilon_{13} \\ \epsilon_{23} \\ \epsilon_{23} \end{pmatrix} . \tag{5}$$

Small deviations from TBM

$$\sin\theta_{12} = \frac{1}{\sqrt{3}} - \epsilon_{12}\,,$$
$$\sin\theta_{23} = \frac{1}{\sqrt{2}} - \epsilon_{23}\,,$$
$$\sin\theta_{13} = \epsilon_{13}\,.$$

$$\epsilon_{12} \subset [-0.0309, 0.0577]\,,$$
$$\epsilon_{23} \subset [-0.117, 0.107]\,,$$
$$\epsilon_{13} \subset [0.130, 0.181]\,.$$

Deviation vectors

$$\boldsymbol{m_\nu} = \sum_{i=1}^{3} m_{\nu_i} \left[\left(\boldsymbol{v_i}^{\text{TBM}} \otimes \boldsymbol{v_i}^{\text{TBM}} \right) + \boldsymbol{\mathcal{V}_i} \right] , \tag{6}$$

with

$$\boldsymbol{\mathcal{V}_i} = \left[\left(\boldsymbol{v_i}^{\text{TBM}} \otimes \boldsymbol{\varepsilon_i} \right) + \left(\boldsymbol{\varepsilon_i} \otimes \boldsymbol{v_i}^{\text{TBM}} \right) + \left(\boldsymbol{\varepsilon_i} \otimes \boldsymbol{\varepsilon_i} \right) \right] . \tag{7}$$

Appealing case

$$\boldsymbol{m}_{\nu}^{(\boldsymbol{A})} = \sum_i m_{\nu_i} \boldsymbol{v_i}^{\text{TBM}} \otimes \boldsymbol{v_i}^{\text{TBM}} \,,$$
$$\boldsymbol{m}_{\nu}^{(\boldsymbol{B})} = \sum_i m_{\nu_i} \boldsymbol{\mathcal{V}_i} \,. \tag{8}$$

The A_4 framework

$$\frac{x}{\Lambda^2}\{L\,L\}\,\xi\,H_u\,H_u \quad \overset{\text{SB}}{\rightarrow} \quad m_\nu = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

Plus contribution with aligned triplet $\phi_\nu \propto (1,1,1)$ and diagonal charged leptons from $\phi_l \propto (1,0,0)$.

Simplest hybrid case (in A_4 framework)

D. Aristizabal Sierra, IdMV, 1404.2529

Add A_4 singlet ξ'' or ξ' (triplet needs VEV alignment).
Single insertion undesirable. If

$$\mathcal{O}_5 = \frac{z}{\Lambda^2}\{L\,L\}'\,\xi''\,H_u\,H_u\ , \qquad \mathcal{O}_5 = \frac{z}{\Lambda^2}\{L\,L\}''\,\xi'\,H_u\,H_u\ , \qquad (9)$$

Then the extra singlet appears in type I.

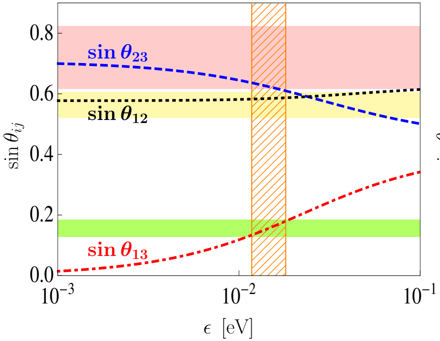
Two insertions

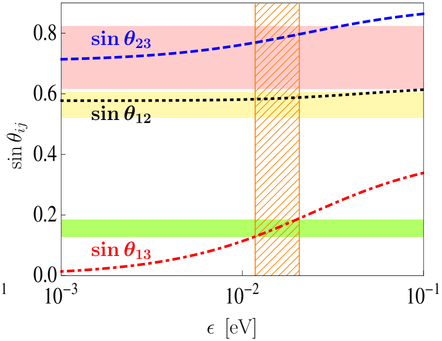
$$\mathcal{O}_6 = \frac{z}{\Lambda^3} \{L\,L\}'\,\xi'\xi'\,H_u\,H_u \quad \stackrel{\text{SB}}{\rightarrow} \quad \delta m_\nu = \delta m^{33}_{12} = \epsilon \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} ,$$

$$\mathcal{O}_6 = \frac{z}{\Lambda^3} \{L\,L\}''\,\xi''\xi''\,H_u\,H_u \quad \stackrel{\text{SB}}{\rightarrow} \quad \delta m_\nu = \delta m^{22}_{13} = \epsilon \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix} .$$

See also
IdMV, D. Pidt, 1211.5370 (JHEP)

Mixing angles





Dangerous operators

Adding field content easily destroys alignment through e.g.

$$\xi' \{\phi_l^0 \phi_l\}'' \to \eta_N^{(1+a)} \xi' \{\phi_l^0 \phi_l\}'' , \quad (10)$$

$$\xi' \{\phi_\nu^0 \phi_l\}'' \to \eta_N^{-3(1+a)} \xi' \{\phi_\nu^0 \phi_l\}'' , \quad (11)$$

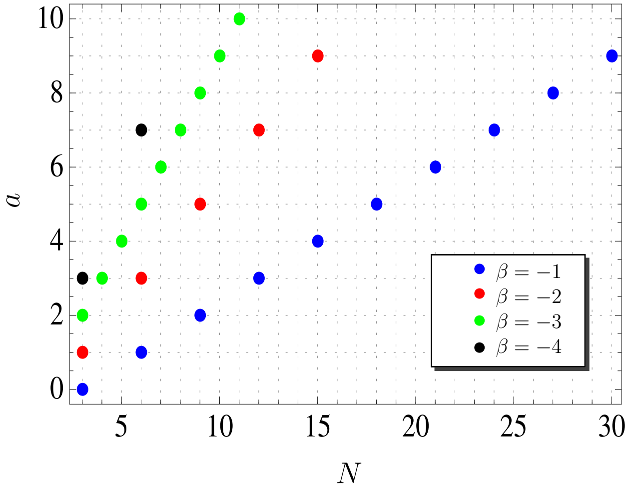
$$\xi' \{\phi_l^0 \phi_\nu\}'' \to \eta_N^{3(1+a)} \xi' \{\phi_l^0 \phi_\nu\}'' . \quad (12)$$

$\eta_N \equiv e^{i2\pi/N}$. Thus, these terms will be allowed if

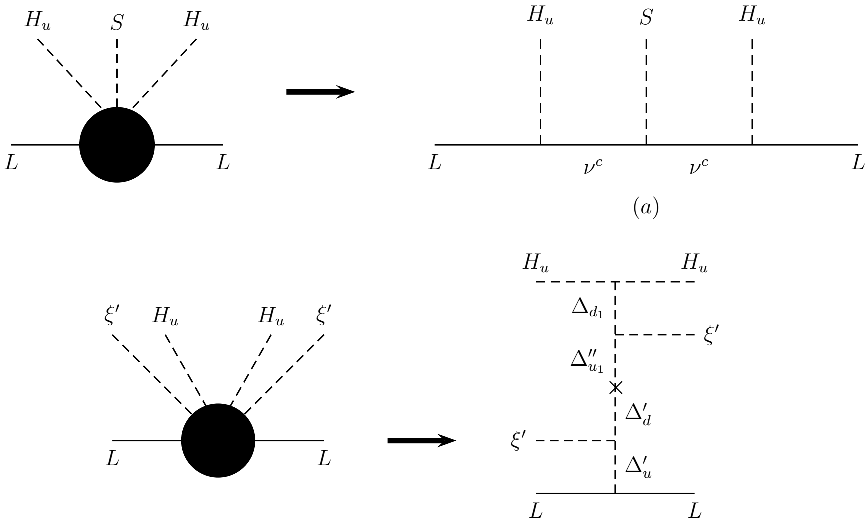
$$1 + a = N\alpha , \qquad -3(1+a) = N\beta , \qquad 3(1+a) = N\gamma , \quad (13)$$

Solutions found

Plot with charges Z_N that (don't) work

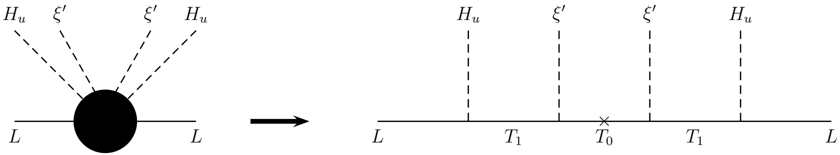


Type I + II



H_u
S
H_u
L
L
H_u
S
H_u
L
ν^c
ν^c
L
(a)
ξ'
H_u
H_u
ξ'
L
L
H_u
H_u
Δ_{d_1}
ξ'
Δ''_{u_1}
Δ'_d
ξ'
Δ'_u
L
L

Type I + III



Other works on mixing within hybrid seesaw

On type I+II:

W. Rodejohann, hep-ph/0403236 (PRD)
M. Lindner, W. Rodejohann, hep-ph/0703171 (JHEP)
A. Adulpravitchai, R. Takahashi, 1107.3829 (JHEP)
D. Borah, 1307.2426 (NPB)

Hybrid seesaw

Conclusions

- Useful parametrization
- All angles in the 3 sigma ranges at same time
- Examples for type I+II and also I+ III hybrid seesaw