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A Talk on



A Predictive Neutrino Texture in Light of the JUNO Results



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Introduction

Chapter I: The Standard Model

- The Standard Model (SM).

$$\mathcal{L}_{\text{Yukawa}} = -Y_d^{ij}\,\bar{Q}_L^i\,d_R^j\,\Phi - Y_u^{ij}\,\bar{Q}_L^i\,u_R^j\,\tilde{\Phi} - Y_l^{ij}\,\bar{L}_L^i\,l_R^j\,\Phi + \text{h.c.}$$

$$M_d = \frac{Y_d v}{\sqrt{2}}, \quad M_u = \frac{Y_u v}{\sqrt{2}}, \quad M_l = \frac{Y_l v}{\sqrt{2}}.$$

- No right handed neutrino in SM.
- Neutrinos remain Massless.

Chapter I: Neutrino Mixing

- Neutrino mixing

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \tag{1}$$

  - $U \rightarrow 3 \times 3$ unitary matrix.
  - $U \rightarrow$ parametization $\rightarrow (\theta_{12}, \theta_{13}, \theta_{23})$ and $(\delta, \alpha, \beta, \phi_1, \phi_2, \phi_3)$.
  - $U \rightarrow$ Pontecorvo–Maki–Nakagawa–Sakata (PMNS) matrix.

Z. Maki, M. Nakagawa, S. Sakata, Remarks on the unified model of elementary particles, Prog. Theor. Phys. 28 (1962) 870–880.

Chapter I: Standard Parametrization

$$U = P_\phi . \begin{bmatrix} c_{12}c_{13} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - c_{12}s_{13}s_{s23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{bmatrix} . P_M$$

$$P_\phi = \begin{pmatrix} e^{i\phi_1} & 0 & 0 \\ 0 & e^{i\phi_2} & 0 \\ 0 & 0 & e^{i\phi_3} \end{pmatrix}, \qquad P_M = \begin{pmatrix} e^{i\alpha} & 0 & 0 \\ 0 & e^{i\beta} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij} \text{ and } s_{ij} = \sin\theta_{ij}.$$

Chapter I: Present Data

Parameters	bfp $\pm 1\,\sigma$	$3\,\sigma$ range
$\theta_{12}/^\circ$	$33.76^{+0.42}_{-0.41}$	32.54 - 35.03
$\theta_{23}/^\circ$	$43.27^{+1.0}_{-0.82}$	41.11 - 50.02
$\theta_{13}/^\circ$	$8.62^{+0.11}_{-0.11}$	8.27 - 8.95
$\delta_{CP}/^\circ$	207^{+23}_{-20}	114 - 405
$\frac{\Delta m^2_{21}}{10^{-5}\,eV^2}$	$7.537^{+0.094}_{-0.10}$	7.236 - 7.823
$\frac{\lvert\Delta m^2_{31}\rvert}{10^{-3}\,eV^2}$	$2.521^{+0.026}_{-0.018}$	2.454 - 2.592

Table: $3\,\nu$ oscillation parameters obtained from NuFIT 6.1 global analysis of neutrino data in normal ordering.

Collaboration NuFIT 6.1 (2025) http://www.nu-fit.org available at http://www.nu-fit.org

Chapter I: Neutrino Oscillation

- Neutrino Oscillation.

$$P_{\nu_e \to \nu_\mu} = \sin^2(2\,\theta)\,\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right), \tag{2}$$

$\Delta m^2_{21} = m^2_2 - m^2_1$
$\theta \to$ mixing angle
$L \to$ distance between source and detector
$E \to$ the energy of the neutrinos.

- The neutrino oscillation $\to$ non-zero mass of neutrino
- Beyond Standard Model $\to$ Seesaw Mechanism

B. Pontecorvo, Mesonium and anti-mesonium, Sov. Phys. JETP 6 (1957) 429.

Chapter III : Seesaw Mechanism

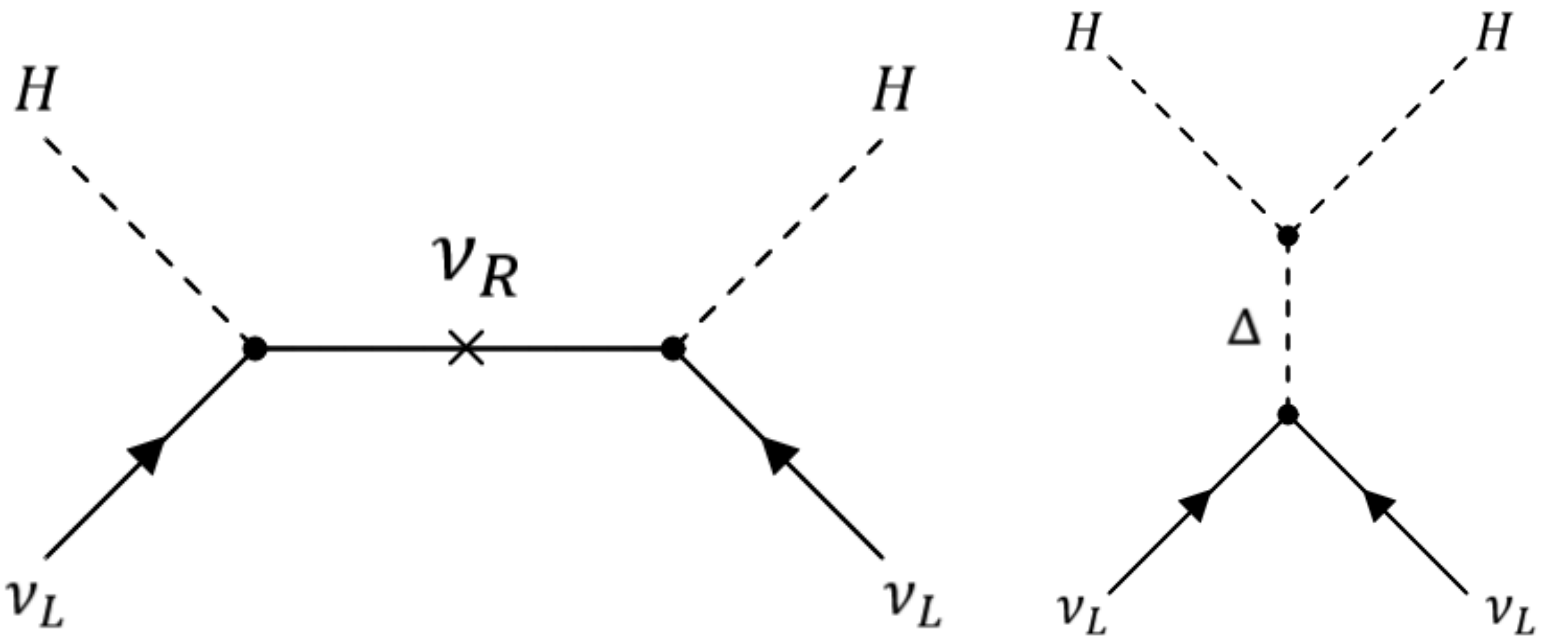


Figure: (a) Type-I seesaw Mechanism, (b) Type-II seesaw Mechanism.

Neutrino Mass Matrix: $M_\nu = -M_D M_R^{-1} M_D^T + M^{II}$

Chapter I: Neutrino Mass Matrix

- Majorana Neutrino Mass Matrix

$$M_\nu = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{12} & m_{22} & m_{23} \\ m_{13} & m_{23} & m_{33} \end{pmatrix}$$

- Importance of Correlations
  - Texture Zeroes
  - Hybrid Textures

Phenomenology

The Proposed Texture

- The Proposed Texture

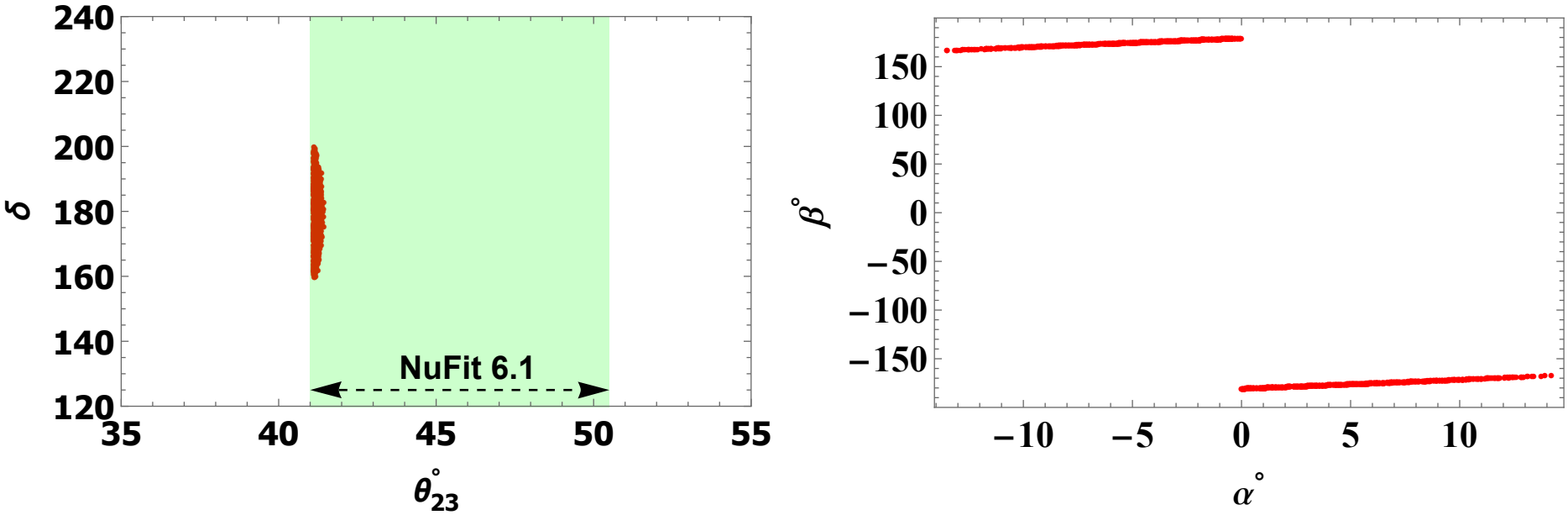
$$M_\nu = \begin{bmatrix} a & b & g \\ b & h & -2b \\ g & -2b & -2b \end{bmatrix}, \tag{3}$$

- Diagonalization $\rightarrow M_\nu^{\text{diag}} = U^T M_\nu U$

$$M_\nu^{\text{diag}} = \begin{bmatrix} m_1 e^{-2i\alpha} & 0 & 0 \\ 0 & m_2 e^{-2i\beta} & 0 \\ 0 & 0 & m_3 \end{bmatrix}$$

$$\alpha = -\frac{1}{2}\,\text{Arg}\,[M_{\nu_{11}}^{\text{diag}}], \quad \beta = -\frac{1}{2}\,\text{Arg}\,[M_{\nu_{22}}^{\text{diag}}].$$

Chapter III : Predictions



(a) (b)

Figure: The correlation plots between (a) θ_{23} vs δ, (b) α vs β.

Chapter III : Predictions

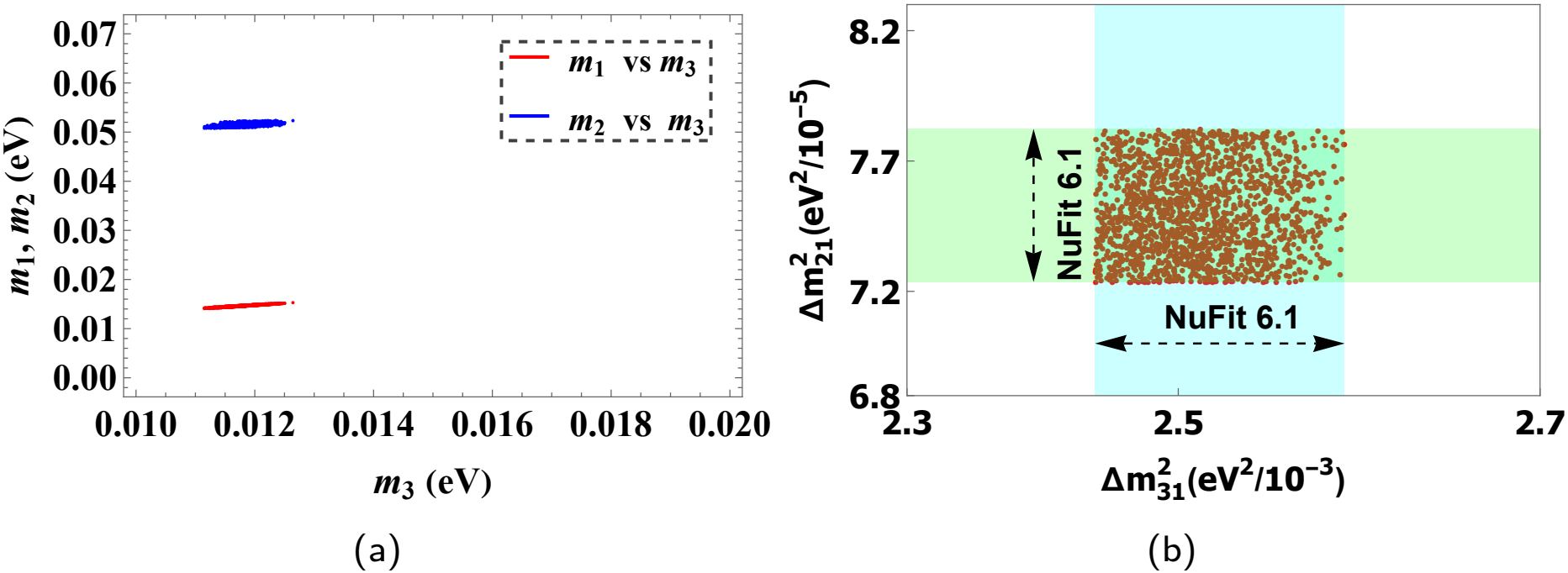


Figure: The correlation plots between (a) m_1 and m_2 vs m_3, (b) Δm^2_{21} vs Δm^2_{31}.

Chapter III : Predictions

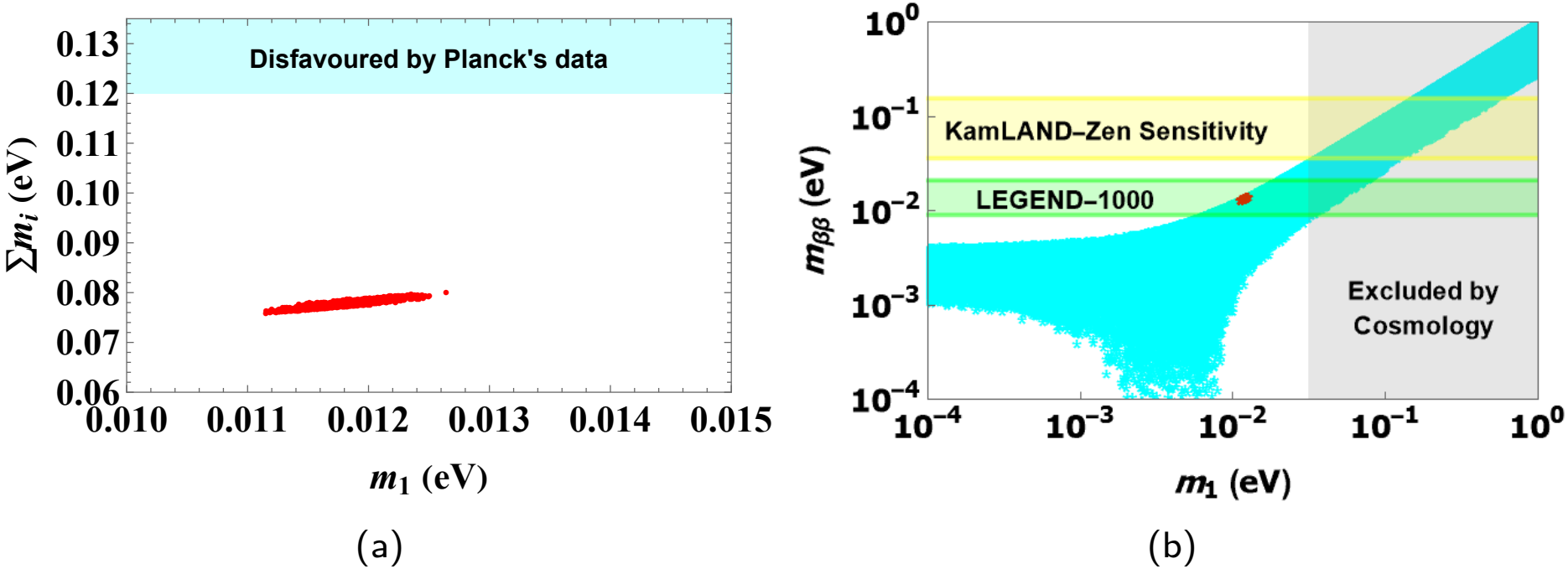


Figure: The correlation plots between (a) $\sum m_i$ vs m_1, (b) The effective Majorana neutrino mass $m_{\beta\beta}$ vs m_1.

Chapter III : The Texture Parameters

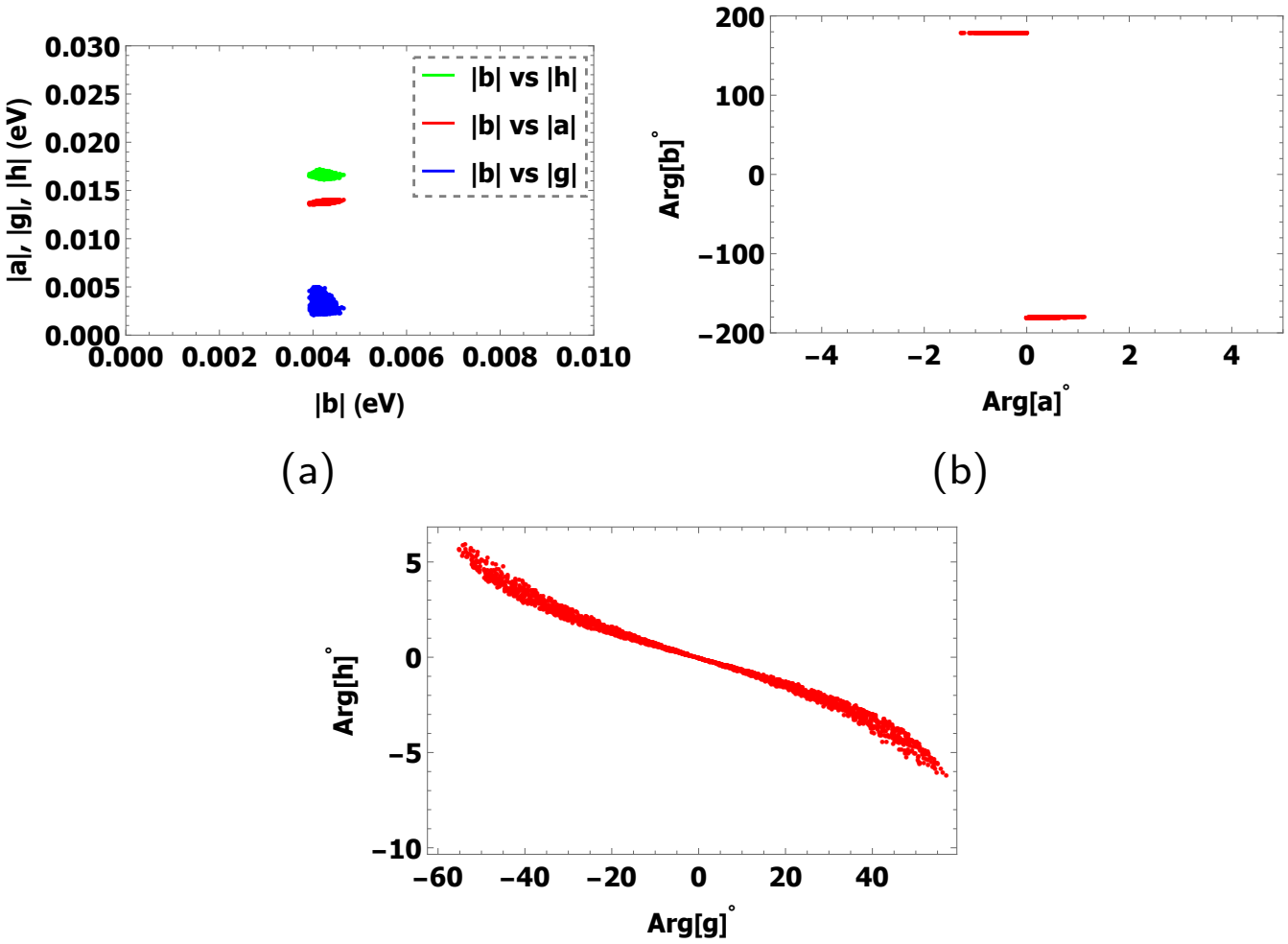


Figure: The texture parameters.

Chapter III : The Physical Parameters

Parameters	Minimum Value	Maximum Value
$\theta_{23}/^\circ$	41.43	41.11
$\delta/^\circ$	199.96	160.01
$\alpha/^\circ$	-13.49	14.19
$\beta/^\circ$	-180	180
m_1/eV	0.011	0.012
m_2/eV	0.014	0.015
m_3/eV	0.050	0.052

Table: Shows the maximum and minimum values of θ_{23}, δ, α, β, m_1, m_2 and m_3 predicted from the proposed texture.

Chapter III : The Texture Parameters

Parameters	Minimum Value	Maximum Value
$\|a\|$/eV	0.0039	0.0046
$\|b\|$/eV	0.014	0.014
$\|g\|$/eV	0.002	0.005
$\|h\|$/eV	0.016	0.017
Arg $[a]/^\circ$	-1.28	1.12
Arg $[b]/^\circ$	-180	180
Arg $[g]/^\circ$	-55.10	57.01
Arg $[h]/^\circ$	-6.17	5.98

Table: Shows the maximum and minimum values of $|a|$, $|b|$, $|g|$, $|h|$, Arg $[a]$, Arg $[b]$, Arg $[g]$ and Arg $[h]$.

Symmetry Realization

Chapter III : Field Content

Field	$SU(2)_L$	$U(1)_Y$	A_4	Z_{10}	Z_7	Z_3
D_{l_L}	2	-1	3	0	-2	ω^2
l_R	1	$(-2,-2,-2)$	$(1,1',1'')$	$(1,4,7)$	$(4,4,4)$	(ω,ω,ω)
ν_{l_R}	1	$(0,0,0)$	$(1,1',1'')$	$(0,4,3)$	$(6,6,6)$	$(1,1,1)$
H	2	1	3	0	1	ω
Δ	3	-2	3	0	3	ω
χ	1	0	1	6	0	1
ψ	1	0	1	7	0	1
ξ	1	0	1	1	0	ω
η	1	0	$1'$	2	2	1
κ	1	0	1	6	2	1
ρ	1	0	1	4	2	1

Table: Transformation properties of fields under $A_4 \times Z_{10} \times Z_7 \times Z_3$.

Chapter III : Yukawa Lagrangian

Yukawa Lagrangian

$$-\mathcal{L}_Y = \frac{y_e}{\Lambda^9}(\bar{D}_{l_L} H)_1 e_R \xi^9 + \frac{y_\mu}{\Lambda^6}(\bar{D}_{l_L} H)_{1''} \mu_R \xi^6 + \frac{y_\tau}{\Lambda^3}(\bar{D}_{l_L} H)_{1'} \tau_R \xi^3 + y_1(\bar{D}_{l_L} \tilde{H})_1 \nu_{eR}$$
$$+ \frac{y_2}{\Lambda}(\bar{D}_{l_L} \tilde{H})_{1''} \nu_{\mu_R} \chi + \frac{y_3}{\Lambda}(\bar{D}_{l_L} \tilde{H})_{1'} \nu_{\tau_R} \psi + \frac{y_a}{2}(\bar{\nu}^c_{\tau_R} \nu_{\tau_R})_1 \rho + \frac{y_b}{2}[(\bar{\nu}^c_{e_R} \nu_{\mu_R}) + \bar{\nu}^c_{\mu_R}$$
$$(\nu_{e_R})]_1 \kappa + \frac{y_c}{2}(\bar{\nu}^c_{\mu_R} \nu_{\mu_R})_{1''} \eta + \frac{y_T}{2}(\bar{D}_{l_L} D^c_{l_L})_{3_s} i\sigma_2 \Delta + h.c.,$$

Vacuum Alignments

$\langle H \rangle_0 = v_H(1,1,1)^T$, $\langle \Delta \rangle_0 = v_\Delta(0,1,1)^T$, $\langle \chi \rangle_0 = v_\chi$, $\langle \psi \rangle_0 = v_\psi$, $\langle \xi \rangle_0 = v_\xi$, $\langle \eta \rangle_0 = v_\eta$, $\langle \kappa \rangle_0 = v_\kappa$ and $\langle \rho \rangle_0 = v_\rho$

Chapter III : Charged Lepton Sector

Charged Lepton Mass Matrix

$$M_l = v_H \begin{bmatrix} \frac{y_e}{\Lambda^9} v_\xi^9 & \frac{y_\mu}{\Lambda^6} v_\xi^6 & \frac{y_\tau}{\Lambda^3} v_\xi^3 \\ \frac{y_e}{\Lambda^9} v_\xi^9 & \omega \frac{y_\mu}{\Lambda^6} v_\xi^6 & \omega^2 \frac{y_\tau}{\Lambda^3} v_\xi^3 \\ \frac{y_e}{\Lambda^9} v_\xi^9 & \omega^2 \frac{y_\mu}{\Lambda^6} v_\xi^6 & \omega \frac{y_\tau}{\Lambda^3} v_\xi^3 \end{bmatrix},$$

Diagonalizing Matrices

$$U_{l_L} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \omega & \omega^2 \\ 1 & \omega^2 & \omega \end{bmatrix}, \quad U_{l_R} = diag\left[1, \quad 1, \quad 1\right].$$

Charged lepton mass hierarchy: Froggatt-Nielsen Mechanism

$$m_e : m_\mu : m_\tau = \Omega^6 y_e : \Omega^3 y_\mu : y_\tau, \text{ where, } \Omega = v_\xi/\Lambda.$$

$$m_e : m_\mu : m_\tau \approx 0.00028 : 0.0594 : 1,$$

provided $\Omega \approx 0.35$, $y_e \approx 0.15$, $y_\mu \approx 0.14$ and $y_\tau \approx 1$.

Dirac and heavy neutrino mass matrices

$$M_D = \begin{bmatrix} y_1 v_H & \frac{y_2}{\Lambda} v_H v_\chi & \frac{y_3}{\Lambda} v_H v_\psi \\ y_1 v_H & \frac{y_2}{\Lambda} \omega v_H v_\chi & \frac{y_3}{\Lambda} \omega^2 v_H v_\psi \\ y_1 v_H & \frac{y_2}{\Lambda} \omega^2 v_H v_\chi & \frac{y_3}{\Lambda} \omega v_H v_\psi \end{bmatrix}, \quad M_R = \begin{bmatrix} 0 & \frac{y_b}{2} v_\kappa & 0 \\ \frac{y_b}{2} v_\kappa & \frac{y_c}{2} v_\eta & 0 \\ 0 & 0 & \frac{y_a}{2} v_\rho \end{bmatrix}.$$

The type-II contribution

$$M^{II} = \begin{bmatrix} 0 & y_T v_\Delta & y_T v_\Delta \\ y_T v_\Delta & 0 & 0 \\ y_T v_\Delta & 0 & 0 \end{bmatrix}.$$

Neutrino Mass Matrix $M_{\nu_s} = -M_D M_R^{-1} M_D^T + M^{II}$

Flavour basis $\rightarrow M_\nu = U_{l_L}^T M_{\nu_s} U_{l_L}$

$$a = \frac{6v_H^2 y_1^2 y_c v_\eta}{y_3^2 v_\xi^2} + \frac{4y_T v_\Delta}{3},$$
$$b = \frac{y_T v_\Delta}{3},$$
$$g = \frac{y_T v_\Delta}{3} - \frac{6v_H^2 y_1 y_2 v_\chi}{\Lambda y_3 v_\xi},$$
$$h = -\frac{6v_H^2 y_3^2 v_\psi^2}{\Lambda^2 y_a v_\xi} - \frac{2y_T v_\Delta}{3}.$$

Summary and Discussion

Chapter III : Summary and Discussions

- A minimal model with four parameters.
- The texture shelters unique correlations.
- It constrains θ_{23} in the lower octant.
- It constrains three CP phases.
- Rules out IH and predict mass eigenvalues.
- Explains charged lepton mass hierarchy.

References

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- B. Pontecorvo, Mesonium and anti-mesonium, Sov. Phys. JETP 6 (1957) 429.
- Roopam Sinha, Probir Roy, and Ambar Ghosal. CP transformed mixed $\mu - \tau$ antisymmetry for neutrinos and its consequences. Phys. Rev. D, 99 (3):033009, 2019.

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Thank you