Flavorspin

A Novel Reparameterization of the Flavor Puzzle

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BASED ON:

ARXIV:1502.04140 (JB, D. HERNÁNDEZ); IN PREPARATION (JB, P. COLOMA, D. HERNÁNDEZ)

Motivation

$$\mathcal{L}_{Yuk} \supset -\overline{Q_L} Y_U U_R \widetilde{H} - \overline{Q_L} Y_D D_R H - \overline{L_L} Y_L E_R H + h.c.$$

Fermion masses are hierarchical ($m_u \ll m_c \ll m_t$, etc.)

Quark mixing angles are small

Two leptonic mixing angles are large

Where is this all coming from?

Flavorspin

Flavor physics governed by a *symmetry*: $SU(2)_V$

Fermions $(Q_L, L_L, U_R, D_R, E_R, N_R)$ — **3**

Yukawa couplings— **5** $\oplus$ **3** $\oplus$ **1** (*real*)

$$Y_U = e^{i\eta_5} Y_5 + e^{i\eta_3} Y_3 + y\,\mathbb{I}$$
$$Y_D = \alpha\left(e^{i\zeta_5} Y_5 + e^{i\zeta_3} \beta_3 Y_3 + \beta_d y\,\mathbb{I}\right)$$

CP violation does not come from Y_5, Y_3*!*

Quark Sector – CP Conservation

Set all phases in Y_U, Y_D to zero.

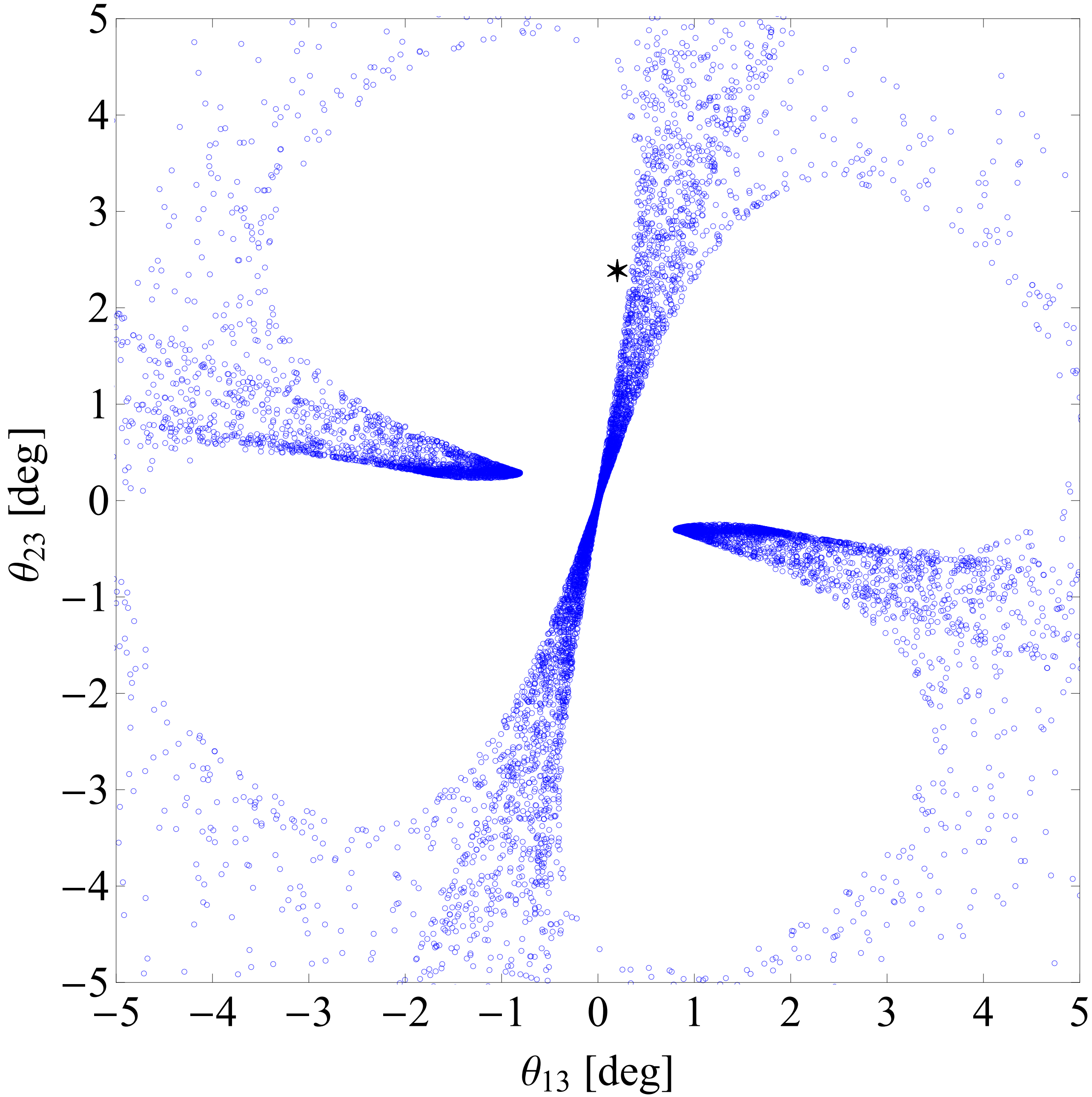
Counting parameters – choose a basis for Y_5, Y_3:

$$Y_5 = \begin{pmatrix} a & 0 & 0 \\ 0 & b & 0 \\ 0 & 0 & -a-b \end{pmatrix}, \quad Y_3 = \begin{pmatrix} 0 & X & Y \\ -X & 0 & Z \\ -Y & -Z & 0 \end{pmatrix}$$

Solve for $\{a, b, y, X, Y, Z, \alpha, \beta_3, \beta_d\}$ in terms of $\{m_u, m_c, m_t, m_d, m_s, m_b, \theta_{12}, \theta_{13}, \theta_{23}\}$.

Quark Sector
CP Conservation

Parameter	Value
$m_t(160.0\ \text{GeV})$	160.0 GeV
$m_c(1.275\ \text{GeV})$	1.275 GeV
$m_u(2\ \text{GeV})$	0.0023 GeV
$m_b(4.180\ \text{GeV})$	4.180 GeV
$m_s(2\ \text{GeV})$	0.095 GeV
$m_d(2\ \text{GeV})$	0.0048 GeV
θ_{12}	13.04º

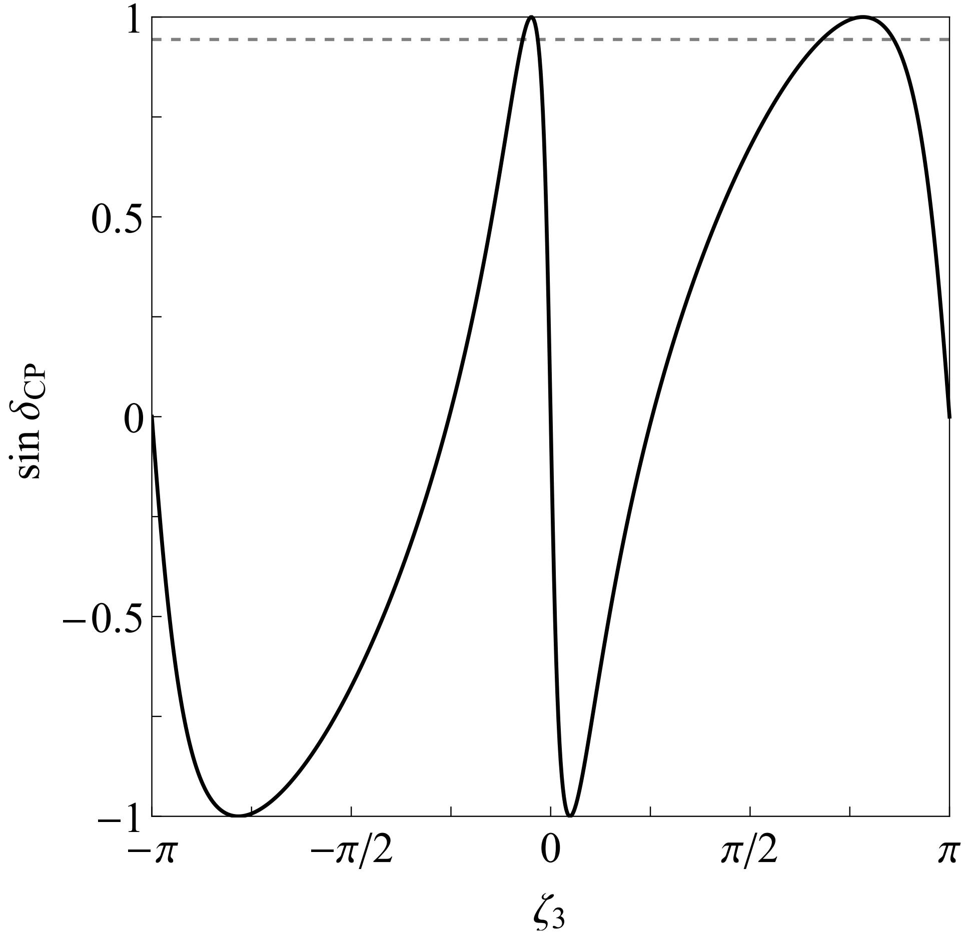


Quark Sector — CP Violation

Allow for phases to be nonzero – only ζ_3 is acceptable.

$$Y_U = Y_5 + Y_3 + y\,\mathbb{I}$$
$$Y_D = \alpha\left(Y_5 + e^{i\zeta_3}\beta_3 Y_3 + \beta_d y\,\mathbb{I}\right)$$

Modifications to mixing angles are small, but large δ_{CP}!



Leptons

The central question:

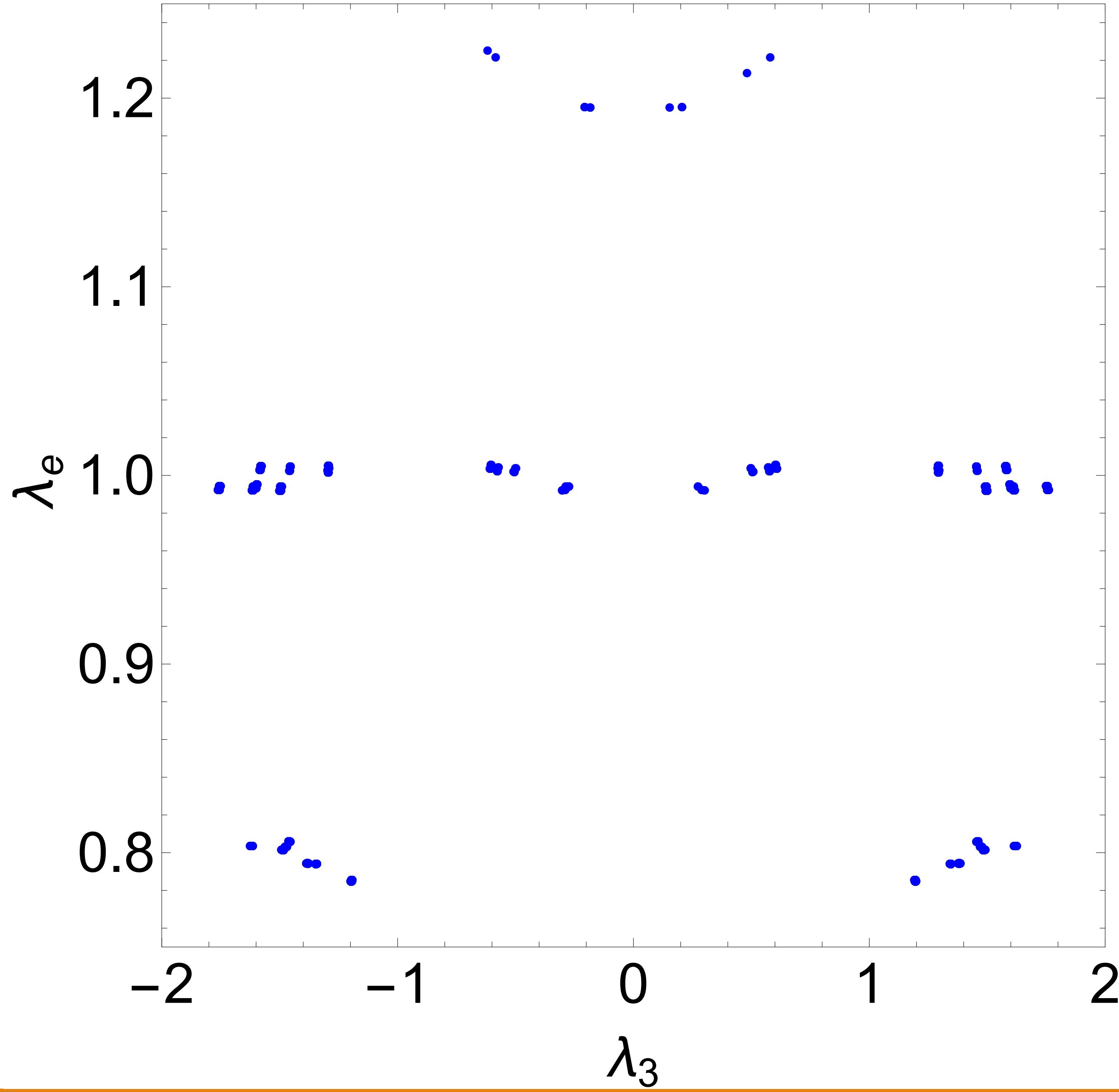
Can we use *the same* Y_5, Y_3 to describe the observed masses/mixing angles in leptonic sector?

Charged Leptons

$$\mathcal{L}_{Yuk} \supset -\overline{L_L} Y_L E_R H + h.c.$$

$$Y_L = \alpha_L (Y_5 + \lambda_3 Y_3 + \lambda_e y \, \mathbb{I})$$

Determine $\alpha_L, \lambda_3, \lambda_e$ for *each* quark solution.



Neutrino Masses

How to introduce neutrino masses?

1. Type-II Seesaw: $\mathcal{L}_{Yuk} \supset -\frac{v^2}{2\Lambda} \cdot \left\{ \overline{\nu_L^c} Y_\nu^{(II)} \nu_L + h.c. \right\}$
2. Pure Dirac Mass: $\mathcal{L}_{Yuk} \supset -\frac{v}{\sqrt{2}} \cdot \{ \overline{\nu_L} Y_\nu N_R + h.c. \}$
3. Type-I Seesaw: $\mathcal{L}_{Yuk} \supset -\frac{v^2}{2\Lambda} \cdot \left\{ \overline{\nu_L^c} Y_\nu Y_\nu^T \nu_L + h.c. \right\}$

Neutrino Masses

Available Information — $\Delta m_{12}^2, \Delta m_{13}^2$

- Type-II is solvable: $Y_\nu^{(II)} = \alpha_\nu (Y_5 + \rho_\nu y\, \mathbb{I})$
- Dirac, Type-I are under-constrained; need lowest mass as input to be solvable.

$$Y_\nu = \alpha_\nu (Y_5 + \rho_3 Y_3 + \rho_\nu y\, \mathbb{I})$$

Inverted hierarchy is strongly disfavored!

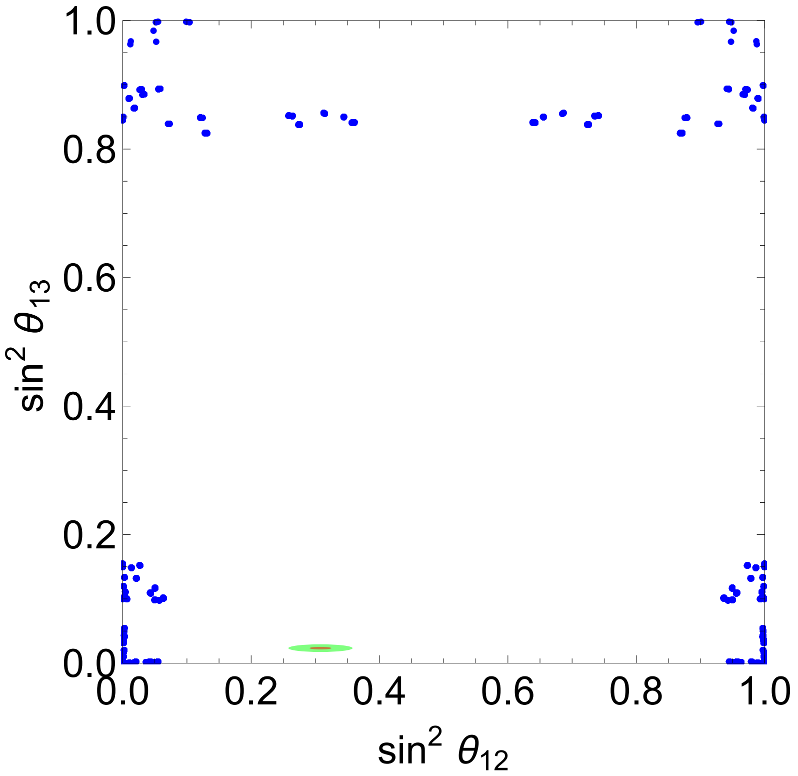
Leptonic Mixing

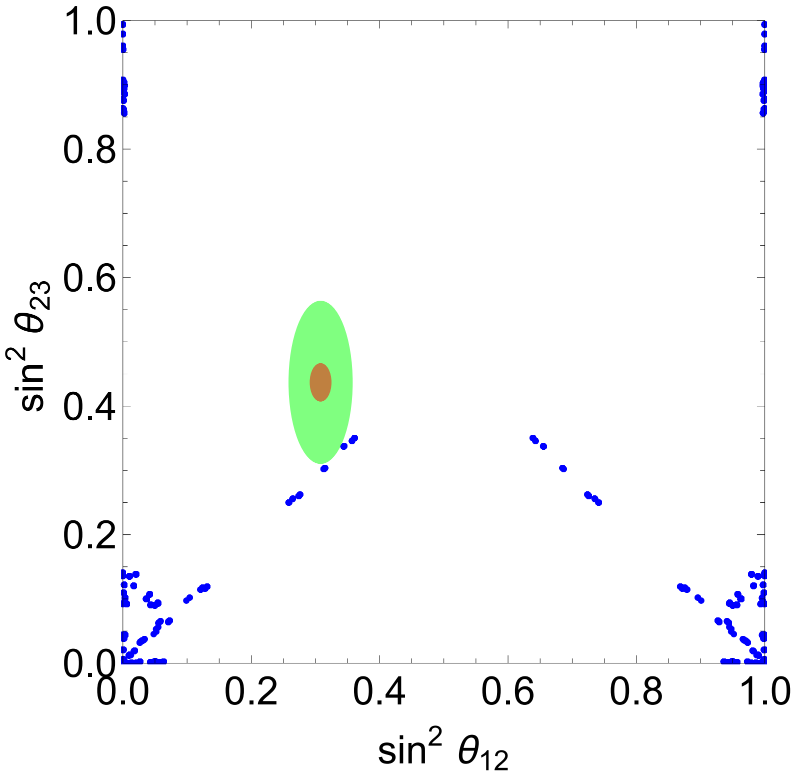
The real litmus test:

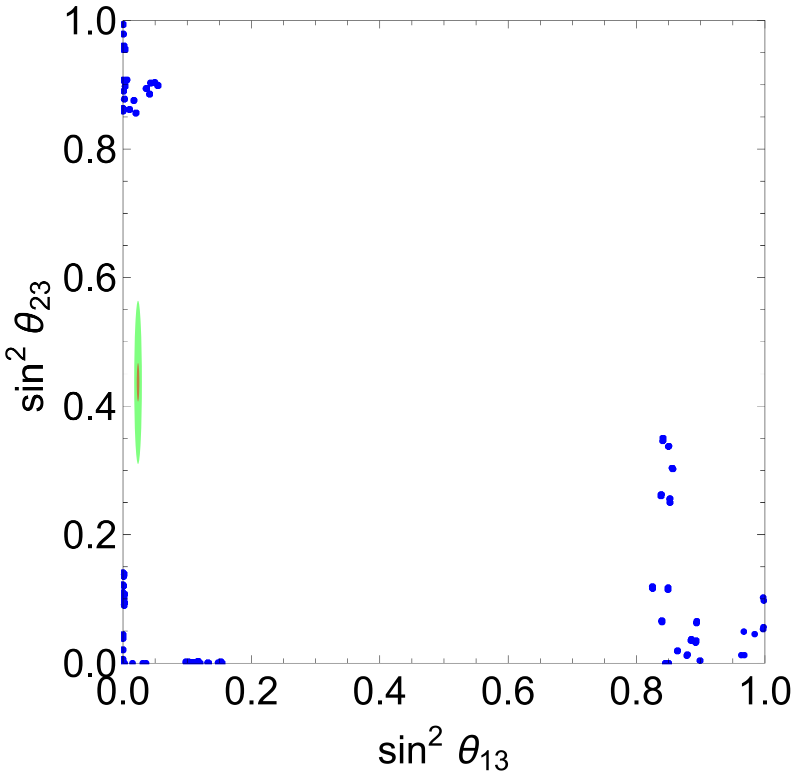
Can the solutions found reproduce the leptonic mixing angles and U_{PMNS}?

In the case where CP is conserved, the answer appears to be ***no!***

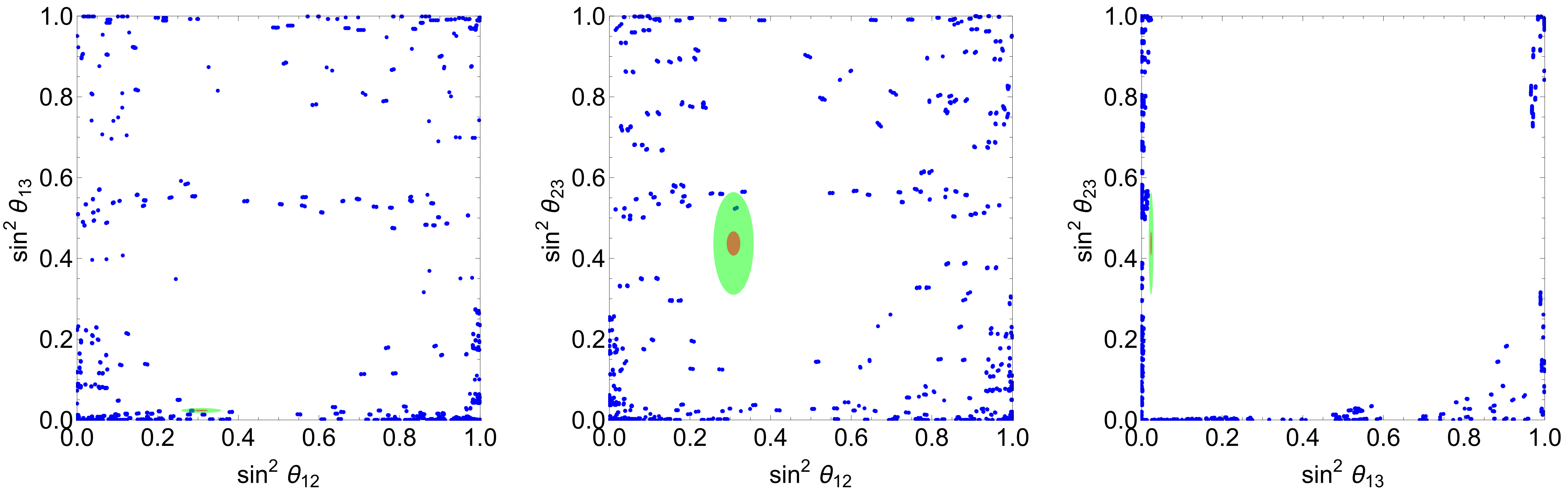
Type-II Seesaw



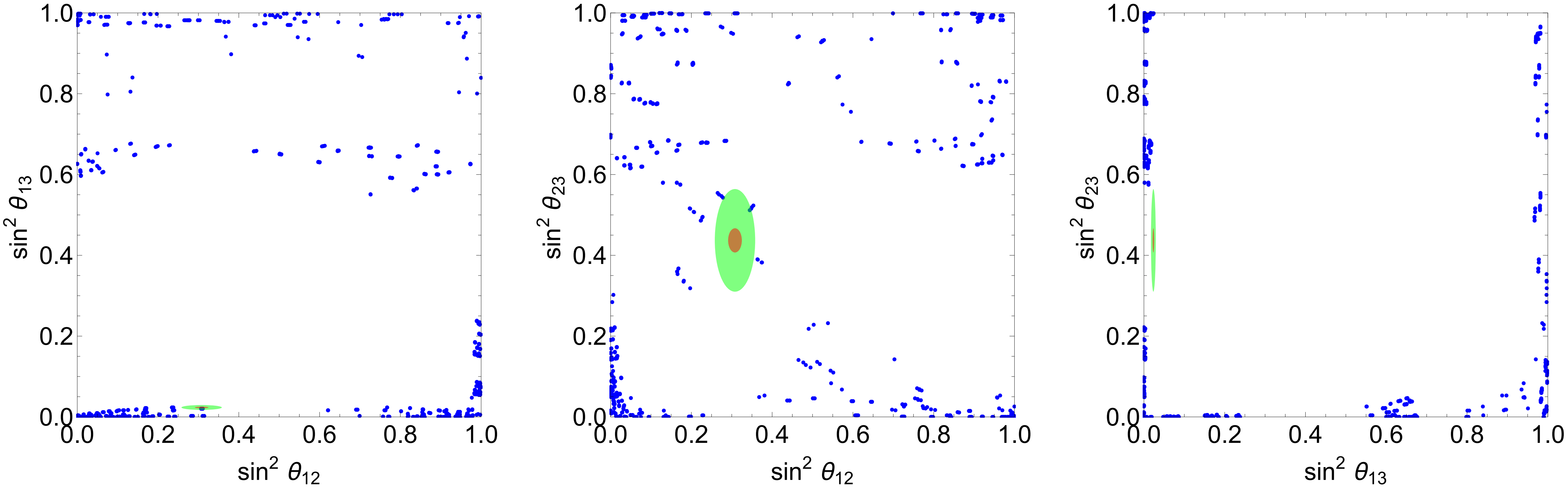




Pure Dirac with
$m_1 = 0.05\ eV$



Type-I Seesaw with $m_1 = 0.05\ eV$



Neutrinos — CP Violation

CP violation may be a crucial part of the story…

Type-II Seesaw is highly disfavored!

$$Y_\nu^{(II)} = \alpha_\nu\left(Y_5 + e^{i\varepsilon}\rho_\nu y\,\mathbb{I}\right)$$

Analyses of Dirac and Type-I ongoing, but seem to favor Type-I…

$$Y_\nu = \alpha_\nu\left(Y_5 + e^{i\varepsilon}\rho_3 Y_3 + \rho_\nu y\,\mathbb{I}\right)$$

Prospects – What's Next?

- Phenomenology
  - Flavor-Changing Neutral Currents: $b \to s\gamma, \mu \to e\gamma, \ldots$
  - Minimal Flavor Violation

$$\mathcal{L}_{(d>4)} \supset \frac{c}{\Lambda^{d-4}}(Y_5 + c_3 Y_3 + c_1 \mathbb{I})^{\alpha\beta} Q_{\alpha\beta}^{(d)}$$

$$\text{e.g., } Q_{\alpha\beta}^{(d)} \to \overline{L_L^\alpha} \sigma^{\mu\nu} E_R^\beta \cdot H F_{\mu\nu} \qquad (d = 6)$$

- Constructing Models – Gauging, UV Completion…

Conclusions

- Flavorspin imposes order on the chaos.
- Predictive for the leptons.
  - Inverted hierarchy, Type-II Seesaw are disfavored.
- Analysis with CP violation still ongoing…