Leptogenesis, fermion masses and mixings in a SUSY SU(5) GUT with D_4 flavor symmetry

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Outline

I- Introduction and Motivations

II- Fermion masses and mixings in a flavored SUSY SU(5) GUT

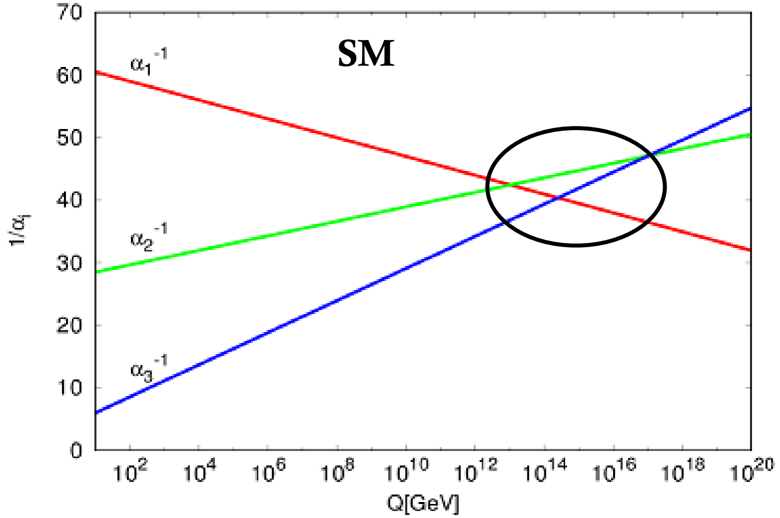
III- Leptogenesis

IV- Phenomenological implications

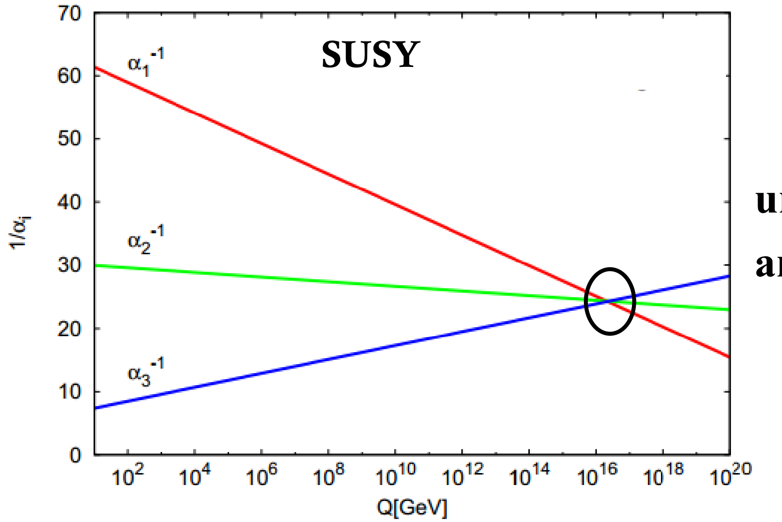
V- Summary and conclusion

I- Introduction and Motivations

Grand Unified Theories (GUTs) are well motivated extensions of the SM that can address several of its open questions.



possible unification at a high scale



unification around 10^{16} GeV

H. Georgi and S. Glashow proposed the unification of the SM gauge group into a simple group $SU(5)$

Each family in $\bar{5}$+10 of SU(5)

$$\bar{5} = \begin{pmatrix} d^c \\ d^c \\ d^c \\ \hline e^- \\ -\nu_e \end{pmatrix}$$

SU(3) Gluons

$SU(2)_L \times U(1)_Y$ $W^\pm, Z^0, \gamma$

$$10 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & u^c & u^c & u & d \\ -u^c & 0 & u^c & u & d \\ -u^c & -u^c & 0 & u & d \\ -u & -u & -u & 0 & e^c \\ -d & -d & -d & -e^c & 0 \end{pmatrix}$$

SU(3)

I- Introduction and Motivations

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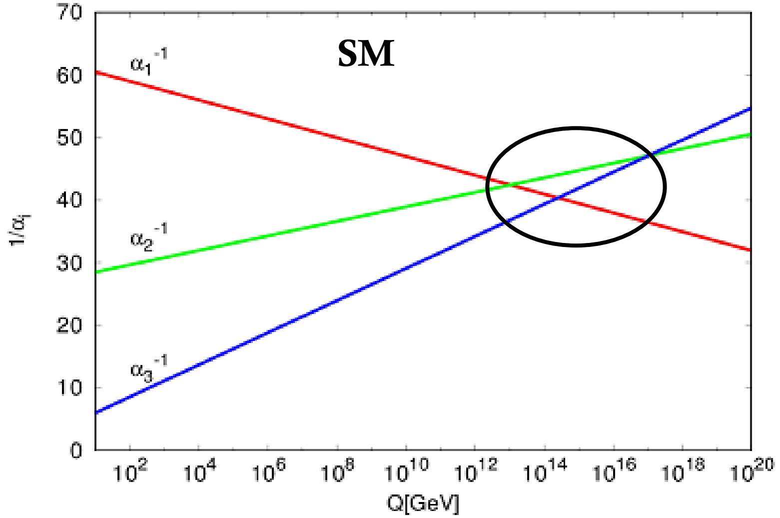

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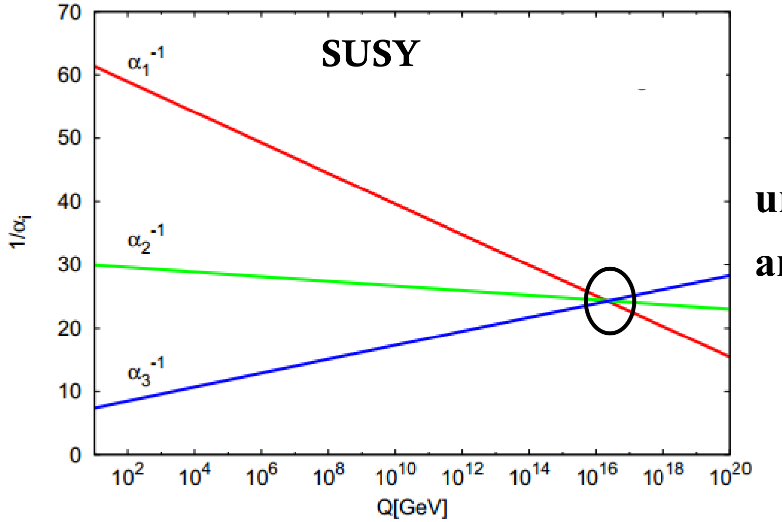


unification around 10^{16} GeV

H. Georgi and S. Glashow proposed the unification of the SM gauge group into a simple group *SU*(5)

Each family in $\bar{5}$+10 of SU(5)

$$\bar{5} = \begin{pmatrix} d^c \\ d^c \\ d^c \\ \hline e^- \\ -\nu_e \end{pmatrix} \quad \begin{matrix} X \\ \\ Y \end{matrix} \Bigg\} \; \boxed{\text{Leptoquarks}}$$

$$10 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & u^c & u^c & u & d \\ -u^c & 0 & u^c & u & d \\ -u^c & -u^c & 0 & u & d \\ -u & -u & -u & 0 & e^c \\ -d & -d & -d & -e^c & 0 \end{pmatrix}$$

$SU(5) \to 5^2 - 1 = 24$ **Gauge bosons,** $\quad 24 \to (8,1)_0 + (1,3)_0 + (1,1)_0 + (3,2)_{5/3} + (\bar{3},2)_{-5/3} \quad \begin{pmatrix} X \\ Y \end{pmatrix} \quad \begin{pmatrix} \bar{X} \\ \bar{Y} \end{pmatrix}$

The current bounds on the processes leading to proton decay are derived by the SuperKamiokande experiment as

$\tau_p(p \to e^+\pi^0) > 2,4 \times 10^{34}$ years (Non-SUSY GUTs)

$\tau_p(p \to K^+\overline{\nu}) > 6,6 \times 10^{33}$ years (SUSY GUTs)

→ Already constrain the construction of many GUT models

The minimal SU(5) and SUSY SU(5) are excluded

proton decay suppressed

- Fast proton decay
- *d* and *e* have same mass matrices up to transpose $Y_d = Y_e^T$

(Higher dimensional Higgs fields)

$m_d = m_e, \qquad m_s = m_\mu, \qquad m_b = m_\tau$

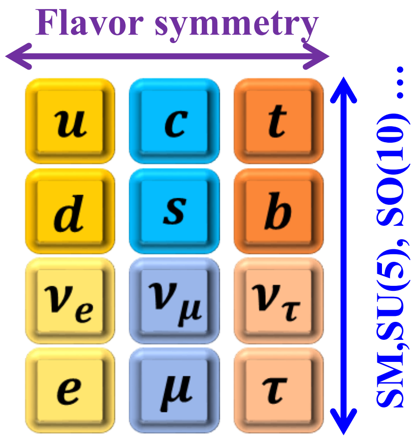
- Can't explain the presence of neutrino masses

→ Extensions of the minimal model, can solve these drawbacks.

By extending the field content of SU(5): seesaw mechanism

$N_i^c \in 1^i$ (Type I seesaw) $\qquad \Delta \in 15$ (Type II seesaw)

To describe neutrino mixing a flavor symmetry is needed



I- Introduction and Motivations

Before 2012, the oscillation data were consistent the well-known Tri-bimaximal (TBM) mixing pattern.

$$U_{TBM} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -1/\sqrt{6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -1/\sqrt{6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix} \quad \theta_{12} = 35.3^\circ,\ \theta_{23} = 45^\circ,\ \theta_{13} = 0$$

Harrison, Perkins, Scott (2002)

$$m^\nu = \begin{pmatrix} a & b & b \\ b & a+c & b-c \\ b & b-c & a+c \end{pmatrix}$$

$\mu - \tau$ symmetry : $\nu_\mu \leftrightarrow \nu_\tau$ + Magic symmetry

	$\theta_{12}/^\circ$	$\theta_{23}/^\circ$	$\theta_{13}/^\circ$
NH (best-fit$^{+3\sigma}_{-3\sigma}$)	$33.44^{+2.42}_{-2.17}$	$49.2^{+2.5}_{-9.1}$	$8.57^{+0.36}_{-0.37}$
IH (best-fit$^{+3\sigma}_{-3\sigma}$)	$33.45^{+2.42}_{-2.18}$	$49.3^{+2.5}_{-9.0}$	$8.60^{+0.36}_{-0.36}$

NuFIT 5.0 (2020), www.nu-fit.org, JHEP 09 (2020) 178 [arXiv:2007.14792]

The observation of nonzero θ_{13}
The octant of θ_{23}
} **exclude the TBM pattern**

TBM can be used as a good first approximation for the observed neutrino mixing angles

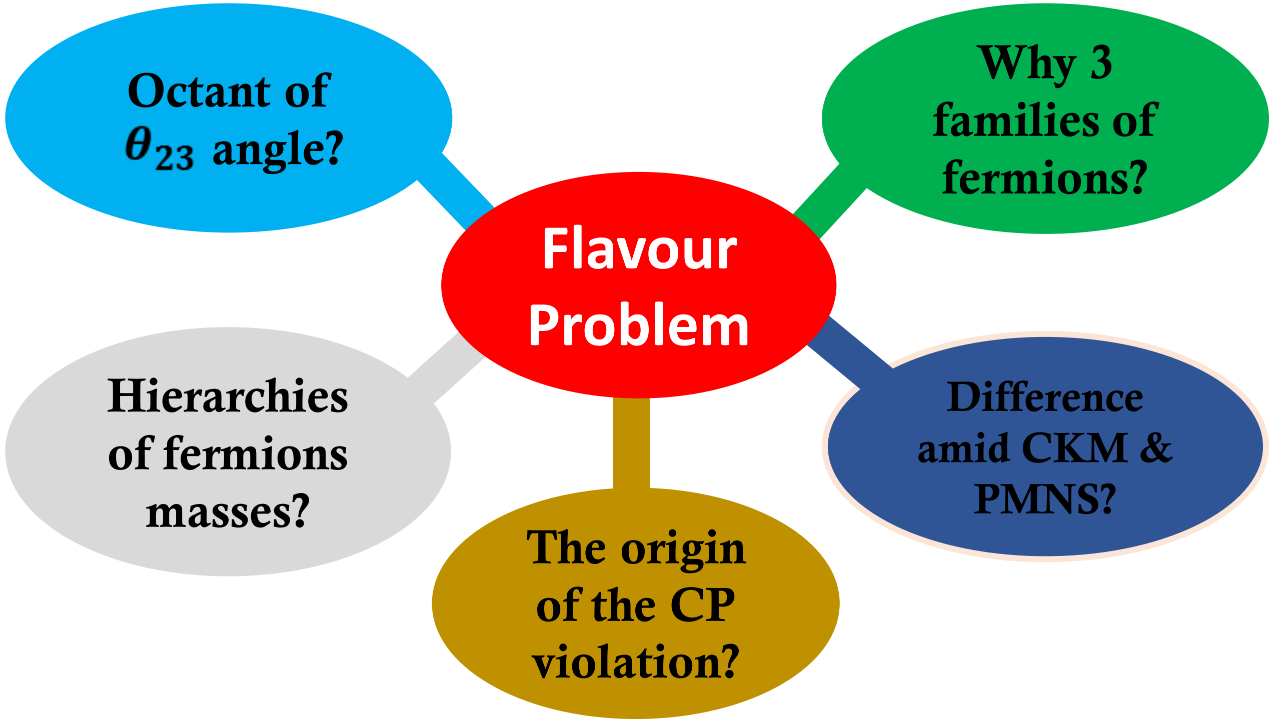
Corrections to m^ν : $\boxed{m^\nu \to m^\nu + \delta m^\nu \longrightarrow U_\nu \to U_{TBM} + \delta U_\nu}$

Trimaximal mixing is a good candidate for the neutrino mixing, and it is consistent with current observations.

I- Introduction and Motivations

Discrete non-Abelian symmetries such as S_3, S_4, A_4, D_4 … are nice candidates to realize these mixings.

These symmetries possess non-singlet representations that can be assigned to connect the three families of fermions, and they are directly motivated by large mixing angles measured by neutrino oscillation data.



These structures could be explained by flavor (family) symmetries,

- Assign charges under a flavor symmetry.
- To make the Lagrangian invariant, we need to add Higgs-like fields ‘flavons’.
- The structure of the flavon VEVs leads to the desired fermion mass matrices.

II- Fermion masses and mixings in a flavored SUSY SU(5) GUT

Some basics on D_4 family symmetry

The dihedral group D_4 is a finite non-Abelian group of order four and it consists of eight elements.

It is generated by two non-commuting generators a reflection *t* and a 45 rotation *s*.

D_4 has five irreducible representations denoted as $\mathbf{1}_{+,+}, \mathbf{1}_{+,-}, \mathbf{1}_{-,+}, \mathbf{1}_{-,-}$ $\boldsymbol{and}$ $\mathbf{2}_{0,0}$

Trivial singlet

An interesting feature of D_4 is that the product of two doublets contains only singlets:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}_{2_{0,0}} \otimes \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}_{2_{0,0}} = (x_1 y_2 + x_2 y_1)_{1_{+,+}} \oplus (x_1 y_1 + x_2 y_2)_{1_{+,-}} \oplus (x_1 y_2 - x_2 y_1)_{1_{-,+}} \oplus (x_1 y_1 - x_2 y_2)_{1_{-,-}}$$

The tensor products among the singlet representations can be expressed as

$$1_{d,e} \otimes 1_{f,g} = 1_{df,eg} \qquad with \qquad d,e,f,g = \pm$$

For more details on D_4, see *H. Ishimori et al, arXiv:1003.3552*

The SU(5)×D_4 representations and U(1) charges of the matter, RH neutrinos and Higgs superfields

	T_1	T_2	T_3	F_1	$F_{2,3}$	N_1^c	$N_{3,2}^c$	H_5	$H_{\bar{5}}$	$H_{\overline{45}}$	H_{24}
SU(5)	10_1	10_2	10_3	$\bar{5}_1$	$\bar{5}_{2,3}$	1_1^ν	$1_{2,3}^\nu$	5_{H_u}	$\bar{5}_{H_d}$	$\overline{45}_H$	24_H
D_4	$1_{+,-}$	$1_{+,-}$	$1_{+,+}$	$1_{+,+}$	$2_{0,0}$	$1_{+,+}$	$2_{0,0}$	$1_{+,+}$	$1_{+,-}$	$1_{+,+}$	$1_{+,+}$
U(1)	6	12	4	13	13	−5	−5	−8	4	−16	0

Type I Seesaw

Ratios of Yukawa couplings

D_4×U(1) charges of flavons used in the d-quark sector

Flavons	ϕ	φ	Ω	Φ
D_4	$1_{+,-}$	$1_{+,-}$	$2_{0,0}$	$2_{0,0}$
U(1)	−9	−14	−21	−9

The effective superpotential for the d-quarks and charged leptons

$$W_{e,d} = \frac{y_{11}^d}{\langle H_{24}\rangle^2} T_1 F_1 \varphi \phi H_{\bar{5}} + \frac{y_{12}^d}{\langle H_{24}\rangle^2} T_1 F_{2,3} \varphi \Phi H_{\bar{5}} + \frac{y_{22}^d}{\Lambda^2} T_2 F_{2,3} \Phi H_{24} H_{\overline{45}} + \frac{y_{33}^d}{\Lambda} T_3 F_{2,3} \Omega H_{\bar{5}}$$

The flavon fields and the 24-Higgs fiels H_{24} develops its VEV along the direction

$$\langle\varphi\rangle = v_\varphi, \langle\phi\rangle = v_\phi, \langle\Phi\rangle = (v_\Phi, 0)T, \langle\Omega\rangle = (0, v_\Omega)T \qquad \langle (H_{24})_b^a \rangle = diag(1,1,1,-3/2,-3/2)v_{24}$$

$$\langle (H_{\overline{45}})_i^{i5} \rangle = v_{45} \quad \text{for } i=1,2,3 \qquad \langle (H_{\overline{45}})_4^{45} \rangle = -3v_{45}$$

Yukawa matrices of the down-type quarks and charged leptons expressed as

$$Y_d = \begin{pmatrix} \frac{y_{11}^d v_\varphi v_\phi}{v_{24}^2} & \frac{y_{12}^d v_\varphi v_\Phi}{v_{24}^2} & 0 \\ 0 & \frac{y_{22}^d v_{24} v_\phi}{\Lambda^2} & 0 \\ 0 & 0 & \frac{y_{33}^d v_\Omega}{\Lambda} \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{pmatrix}$$

$$Y_e = \begin{pmatrix} \frac{4}{9}\frac{y_{11}^d v_\phi}{v_{24}^2} & 0 & 0 \\ \frac{4}{9}\frac{y_{12}^d v_\phi v_\Phi}{v_{24}^2} & \frac{9}{2}\frac{y_{22}^d v_{24} v_\Phi}{\Lambda^2} & 0 \\ 0 & 0 & \frac{y_{33}^d v_\Omega}{\Lambda} \end{pmatrix} = \begin{pmatrix} \frac{4}{9} b_{11} & 0 & 0 \\ \frac{4}{9} b_{12} & \frac{9}{2} b_{22} & 0 \\ 0 & 0 & b_{33} \end{pmatrix}$$

$\boldsymbol{Y_d}$ and $\boldsymbol{Y_e}$ Yukawa matrices lead to diagonal Yukawa couplings

$$y_d = b_{11}, \quad y_s = b_{22}, \quad y_b = b_{33}$$
$$y_e = (4/9) b_{11}, \quad y_\mu = (9/2) b_{22}, \quad y_\tau = b_{33}$$

Ratios of these couplings are given by

$$\frac{y_e}{y_d} = \frac{4}{9}, \quad \frac{y_\mu}{y_s} = \frac{9}{2}, \quad \frac{y_\tau}{y_b} = 1$$

$$\frac{y_\mu}{y_s}\frac{y_d}{y_e} = 10,12$$

Double ratio at the GUT scale independent of the threshold corrections

$$\frac{y_\mu}{y_s}\frac{y_d}{y_e} \approx 10{,}7^{+1{,}8}_{-0{,}8}$$

S. Antusch and V. Maurer, *JHEP* 11 (2013) 115

The SU(5)×D_4 representations and U(1) charges of the matter, RH neutrinos and Higgs superfields

	T_1	T_2	T_3	F_1	$F_{2,3}$	N_1^c	$N_{3,2}^c$	H_5	$H_{\bar{5}}$	$H_{\overline{45}}$	H_{24}
SU(5)	10_1	10_2	10_3	$\bar{5}_1$	$\bar{5}_{2,3}$	1_1^ν	$1_{2,3}^\nu$	5_{H_u}	$\bar{5}_{H_d}$	$\overline{45}_H$	24_H
D_4	$1_{+,-}$	$1_{+,-}$	$1_{+,+}$	$1_{+,+}$	$2_{0,0}$	$1_{+,+}$	$2_{0,0}$	$1_{+,+}$	$1_{+,-}$	$1_{+,+}$	$1_{+,+}$
U(1)	6	12	4	13	13	-5	-5	-8	4	-16	0

D_4×U(1) charges of the flavons used in the up quark sector

Flavons	ρ_1	ρ_2	ρ_3	F	Γ
D_4	$1_{+,+}$	$1_{+,-}$	$1_{-,-}$	$2_{0,0}$	$2_{0,0}$
U(1)	10	10	10	10	10

The invariant effective superpotential for the up quarks

$$W_\nu = \boxed{\lambda_1 N_1^c F_1 H_5 + \lambda_2 N_{3,2}^c F_{2,3} H_5} + \boxed{\lambda_3 N_1^c N_1^c \rho_1 + \lambda_4 N_{3,2}^c N_{3,2}^c \rho_1 + \lambda_5 N_1^c N_{3,2}^c F + \lambda_6 N_1^c N_{3,2}^c \Gamma + \lambda_7 N_{3,2}^c N_{3,2}^c \rho_2 + \lambda_8 N_{3,2}^c N_{3,2}^c \rho_3}$$

Flavons get their VEVs as:

$$\langle \rho_i \rangle = \upsilon_{\rho_i}, \quad \langle \Gamma \rangle = (0, \upsilon_\Gamma)^T, \quad \langle F \rangle = (\upsilon_F, \upsilon_F)^T$$

Dirac mass matrix

$$m_D = \upsilon_u \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_2 \end{pmatrix}$$

Majorana mass matrix

$$m_M = \begin{pmatrix} \lambda_3 \upsilon_{\rho_1} & \lambda_5 \upsilon_F & \lambda_5 \upsilon_F + \lambda_6 \upsilon_\Gamma \\ \lambda_5 \upsilon_F & \lambda_7 \upsilon_{\rho_2} - \lambda_8 \upsilon_{\rho_3} & 2\lambda_4 \upsilon_{\rho_1} \\ \lambda_5 \upsilon_F + \lambda_6 \upsilon_\Gamma & 2\lambda_4 \upsilon_{\rho_1} & \lambda_7 \upsilon_{\rho_2} + \lambda_8 \upsilon_{\rho_3} \end{pmatrix}$$

To simplify the parametrization of the total neutrino mass matrix we parametrize the Majorana mass matrix as follows

$$a = \frac{\lambda_3 v_{\rho_1}}{M_R}, \quad b = \frac{\lambda_5 v_F}{M_R}, \quad \text{and} \quad k = \frac{\lambda_6 v_\Gamma}{M_R}$$

The usual canonical seesaw formula $\boldsymbol{m_\nu = m_D M_R^{-1} m_D^T}$ yields the total neutrino mass matrix

$$m_\nu = \frac{m_0}{P}\begin{pmatrix} -(a+b)^2 & (a+b)(b+k) & b^2-k^2-b(k-a) \\ (a+b)(b+k) & -(b+k)^2 & -a^2-ab+b^2+kb \\ b^2-k^2-b(k-a) & -a^2-ab+b^2+kb & ak-b^2 \end{pmatrix}$$

Magic symmetry

$$\sum_{i=1}^{3}(m_\nu)_{ij} = \sum_{j=1}^{3}(m_\nu)_{ij} = m_2$$

where $\quad m_0 = \frac{(\lambda_1 v_u)^2}{M_R}$ and $\quad P = (a+2b+k)(ak-a^2+b^2-k^2)$

$$U_{TM_2} = \begin{pmatrix} \sqrt{\frac{2}{3}}\cos\theta & \frac{1}{\sqrt{3}} & \sqrt{\frac{2}{3}}\sin\theta e^{-i\sigma} \\ -\frac{\cos\theta}{\sqrt{6}} - \frac{\sin\theta}{\sqrt{2}}e^{i\sigma} & \frac{1}{\sqrt{3}} & \frac{\cos\theta}{\sqrt{2}} - \frac{\sin\theta}{\sqrt{6}}e^{-i\sigma} \\ -\frac{\cos\theta}{\sqrt{6}} + \frac{\sin\theta}{\sqrt{2}}e^{i\sigma} & \frac{1}{\sqrt{3}} & -\frac{\cos\theta}{\sqrt{2}} - \frac{\sin\theta}{\sqrt{6}}e^{-i\sigma} \end{pmatrix}$$

$\boldsymbol{\theta \to 0}$ corresponds to Tribimaximal mixing

$\boldsymbol{\sigma}$ is related to the Dirac CP phase $\boldsymbol{\delta_{CP}}$

$U_\nu = U_{TM_2} U_P \quad$ where $\quad U_P = diag\left(1, e^{i\frac{\alpha_{21}}{2}}, e^{i\frac{\alpha_{31}}{2}}\right)$

$$\boldsymbol{U_{TM_2}^\dagger m_\nu U_{TM_2} = diag(|m_1|, |m_2|, |m_3|)}$$

Assuming that the parameters a and b are real while $\mathbf{k}$ is complex; $\mathbf{k} = |\mathbf{k}|\, e^{i\phi_k}$

The diagonalization of m_ν using the U_{TM2} leads to the following eigenvalues

$$|m_1| = \frac{m_0}{\sqrt{(a-b)^2 - |k|(a-b)cos\phi_k + (|k|^2/4)}} \quad , \quad |m_2| = \frac{m_0}{\sqrt{(a+2b)^2 + 2|k|(a+2b)cos\phi_k + (|k|^2)}}$$

$$|m_3| = \frac{m_0}{\sqrt{(a+b)^2 - |k|(a+b)cos\phi_k + (|k|^2/4)}}$$

Under the conditions

$$tan2\theta = \frac{\sqrt{3}|k|\sqrt{b^2cos^2\phi_k + a^2sin^2\phi_k}}{2ab - b|k|cos\phi_k}$$

$$tan\sigma = \frac{-a}{b} tan\phi_k$$

Regarding the mixing, they may be expressed in the case of Trimaximal mixing as a function of θ and σ

$\sin^2\theta_{13} = \frac{2}{3}\sin^2\theta$	$\sin^2\theta_{12} = \frac{1}{3 - 2\sin^2\theta}$	$\sin^2\theta_{23} = \frac{1}{2} - \frac{3\sin 2\theta}{2\sqrt{3}(3 - 2\sin^2\theta)}\cos\sigma$

A relationship between the arbitrary phase σ and the Dirac phase δ_{CP} can be obtained by means of the Jarlskog invariant parameter

$$J_{CP} = Im(U_{e1}U^*_{\mu 1}U_{\mu 2}U^*_{e2})$$

$$J_{CP} = \frac{1}{8}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}\cos\theta_{13}\sin\delta_{CP}$$

$$J_{CP}|_{TM_2} = (1/6\sqrt{3})\sin 2\theta\sin\sigma$$

$$\Rightarrow \sin 2\theta_{23} = (\sin\sigma/\sin\delta_{CP})$$

III- Leptogenesis

Why is the Universe filled with matter when the standard model of cosmology predicts a Universe born with equal parts of matter and anti-matter?

The observed baryon asymmetry must have been generated dynamically $\longrightarrow$ Baryogenesis.

The excess of baryons over anti-baryons is given by (Planck 2018)

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6{,}13 \pm 0{,}04) \times 10^{-10} \qquad Y_B = \frac{n_B - n_{\bar{B}}}{s} = (8{,}72 \pm 0{,}08) \times 10^{-11}$$

A matter-antimatter asymmetry can be dynamically generated in an expanding universe if the particle interactions and the cosmological evolution satisfy Sakharov's conditions

- **Baryon number violation**
- ***C* and *CP* violation**
- **Deviation from thermal equilibrium**

While the Standard Model contains all the ingredients of baryogenesis, it fails to generate the observed asymmetry.

III- Leptogenesis

Leptogenesis provide a unified solution of a) BAU, b) nature of neutrinos, and c) smallness of their masses

$$W_\nu = \lambda_1 N_1^c F_1 H_5 + \lambda_2 N_{3,2}^c F_{2,3} H_5 + \underbrace{\lambda_3 N_1^c N_1^c \rho_1 + \lambda_4 N_{3,2}^c N_{3,2}^c \rho_1 + \lambda_5 N_1^c N_{3,2}^c F + \lambda_6 N_1^c N_{3,2}^c \Gamma + \lambda_7 N_{3,2}^c N_{3,2}^c \rho_2 + \lambda_8 N_{3,2}^c N_{3,2}^c \rho_3}$$

violate L by two units → neutrino are Majorana in nature

The seesaw formula leads to $m_i = (\lambda_1 \upsilon_u)^2 / M_i$ ➡ Active neutrino masses are suppressed by the masses of RH neutrinos

In order to meet the requirements of a successful Leptogenesis that produces the experimental values of Y_B, we add a correction to the leading order Dirac

$$\delta W_D = \frac{\lambda_9}{\Lambda} N_{3,2}^c F_{23} H_5 \omega \qquad \textbf{where} \qquad \omega \sim (D_4, U(1)) \sim (1_{+,-}, 0) \qquad \textbf{and} \qquad \lambda_9 = |\lambda_9| e^{i\phi_\omega}$$

When the flavon field acquires its VEV as $\langle \boldsymbol{\omega} \rangle = \boldsymbol{\upsilon_\omega}$, we get the total Yukawa mass matrix

$$\boxed{\mathcal{Y}_D = Y_D + \delta Y_D = \frac{m_D}{\upsilon_u} + \delta Y_D = \lambda_1 \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \kappa e^{i\phi_\omega} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}} \qquad \textbf{where} \qquad \kappa = \frac{|\lambda_9| \upsilon_\omega}{\Lambda}$$

III- Leptogenesis

The magnitude of $B-L$ asymmetry generated by N_3 can be parameterized as

$$Y_{B-L} = -2\varepsilon_{N_3} Y_{N_3}^{eq} \eta_{33}$$

$$\varepsilon_{N_3} = \frac{1}{8\pi} \sum_{j=1,2} \frac{Im\left[\left(\mathcal{Y}_\nu \mathcal{Y}_\nu^\dagger\right)_{j3}^2\right]}{\left(\mathcal{Y}_\nu \mathcal{Y}_\nu^\dagger\right)_{33}} f\left(\frac{M_j}{M_3}\right)$$

the *CP* violating parameter

the neutrino Yukawa coupling matrix

n_{N_3}/s

the efficiency factor

RHN masses < 10^{14}GeV

G.F. Giudice, et al, *Nucl. Phys. B* **685** (2004) 89

$$\eta_{33} \approx \left(\frac{3{,}3 \times 10^{-3} eV}{\tilde{m}_3} + \left(\frac{\tilde{m}_3}{0{,}55 \times 10^{-3} eV}\right)^{1{,}16}\right)^{-1}$$

$$\tilde{m}_3 = v_u^2 \frac{\left(\mathcal{Y}_\nu \mathcal{Y}_\nu^\dagger\right)_{33}}{M_3}$$

The *CP* asymmetry parameter ε_{N_3} corresponding to the lightest RH neutrino N_3 is given approximately by

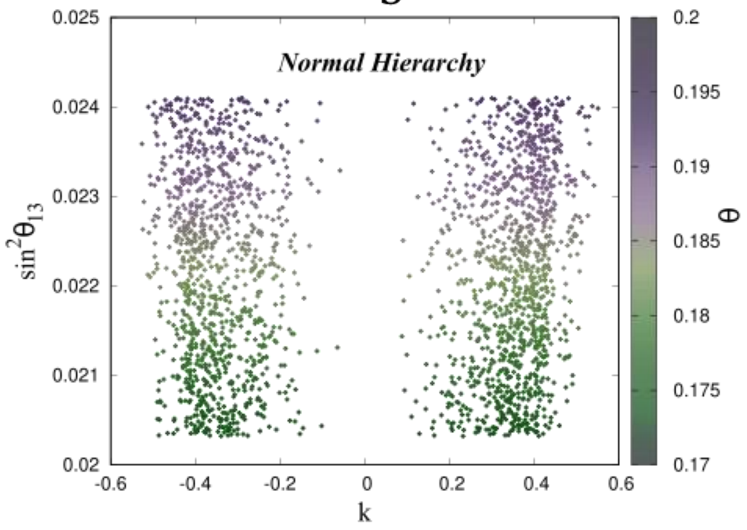
$$\varepsilon_{N_3} \simeq \frac{\kappa^2}{9\pi} \cos^2\phi_\omega \left[2\sin^2(2\theta)\sin^2\left(\sigma - \frac{\alpha_{31}}{2}\right) f\left(\frac{\tilde{m}_1}{\tilde{m}_3}\right) + \sin^2\theta \sin^2\left(\sigma + \frac{(\alpha_{21} - \alpha_{31})}{2}\right) f\left(\frac{\tilde{m}_2}{\tilde{m}_3}\right)\right]$$

The amount of the baryon asymmetry generated in the present model is given by

$$Y_B \approx \left(\frac{8N_f + 4N_H}{22N_f + 13N_H}\right) Y_{B-L} \Longrightarrow \boldsymbol{Y_B \approx -1{,}266 \times 10^{-3} \varepsilon_{N_3} \eta_{33}}$$

IV- Phenomenological implications

$$\sin^2\theta_{13} = \frac{2}{3}\sin^2\theta$$

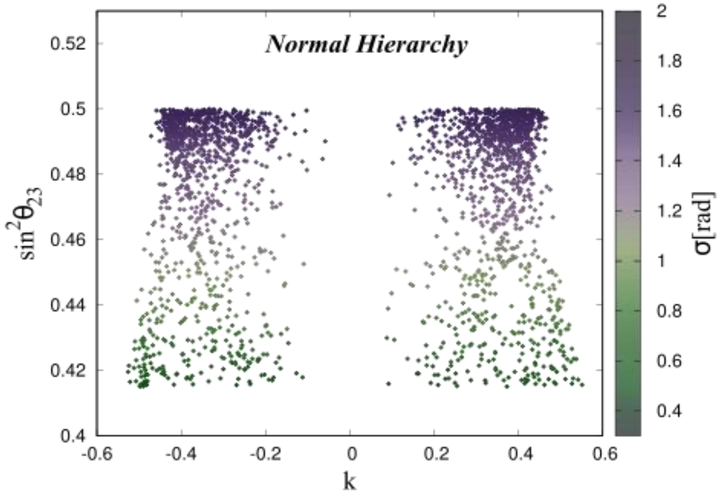


$\Delta m^2_{31} > 0$ → **The model predicts normal hierarchy**

For IH, we find 0.398 < θ <0.579 which implies that both $\sin^2\theta_{13}$ and $\sin^2\theta_{12}$ fall far outside their experimental range → **IH excluded**

	Normal Hierarchy Best fit $(+3\sigma \to -3\sigma)$	Inverted Hierarchy Best fit $(+3\sigma \to -3\sigma)$
$\sin^2\theta_{13}$	$0.02219(0.02032 \to 0.02410)$	$0.02238(0.02052 \to 0.02428)$
$\sin^2\theta_{12}$	$0.304(0.269 \to 0.343)$	$0.304(0.269 \to 0.343)$
$\sin^2\theta_{23}$	$0.573(0.415 \to 0.616)$	$0.575(0.419 \to 0.617)$
$\Delta m^2_{21}/10^{-5}$	$7.42(6.82 \to 8.04)$	$7.42(6.82 \to 8.04)$
$\Delta m^2_{3l}/10^{-3}$	$2.517(2.435 \to 2.598)$	$-2.498(-2.581 \to -2.414)$
δ°_{CP}	$197(120 \to 369)$	$282(193 \to 352)$

NuFIT 5.0 (2020), www.nu-fit.org, JHEP 09 (2020) 178 [arXiv:2007.14792]



$\sin^2\theta_{23} < 0{,}5$ → **The model predicts lower octan**

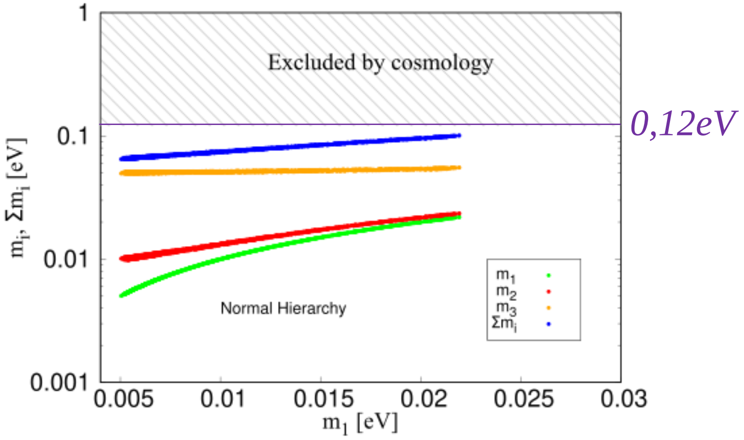
$0.57565 \lesssim \sigma \lesssim 1.57073$

$\sin 2\theta_{23} = (\sin\sigma/\sin\delta_{CP})$ → **CP violation**

IV- Phenomenological implications

Neutrino masses from non-oscillatory experiments

Cosmology

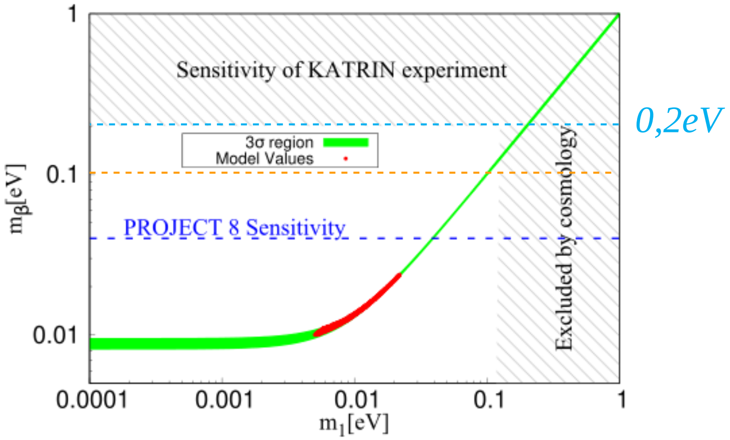


$$\sum_i m_i = m_1 + m_2 + m_3$$

$$0.06475 \lesssim \sum_i m_i\,[eV] \lesssim 0.10092$$

The lower value of Σm_i may be achieved in the upcoming experiments such as CORE targeting a bound on Σm_i around 0.062eV.

Direct limits

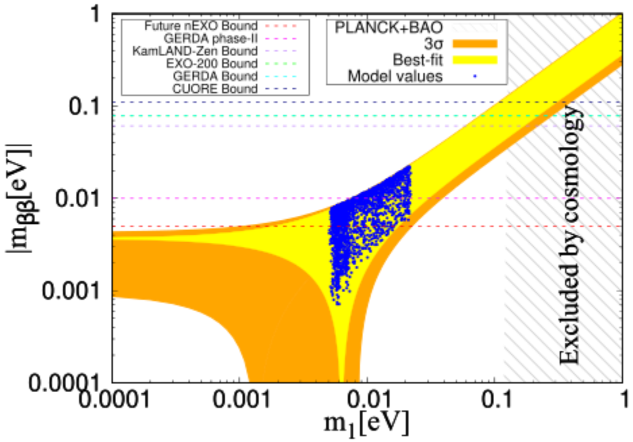


$$m_\beta = \left(\sum_i |U_{ei}|^2 m_i^2\right)^{1/2}$$

$$0.010015 \lesssim m_\beta\ [eV] \lesssim 0.023765$$

The values in this interval are too small when compared to the anticipated future -decay experiments sensitivities such as KATRIN, HOLMES, and Project 8.

0νββ decays

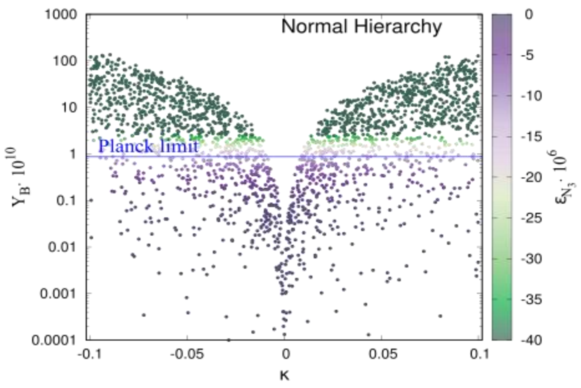


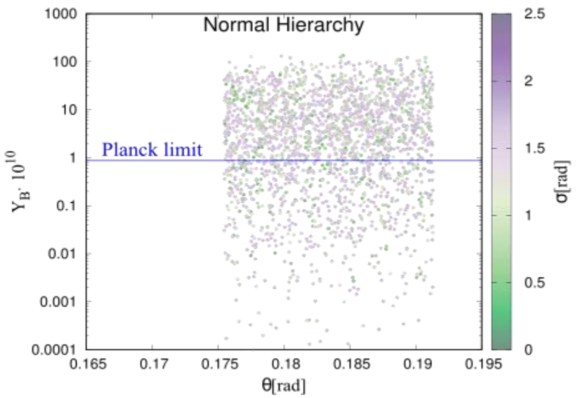
$$|m_{\beta\beta}| = \left|\sum_i U_{ei}^2 m_i\right|$$

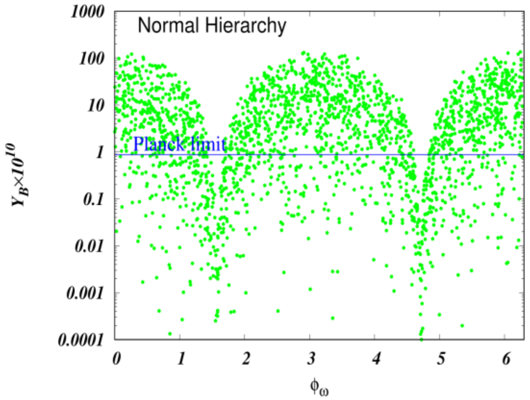
$$0.000715 \lesssim |m_{\beta\beta}|\,[eV] \lesssim 0.022028$$

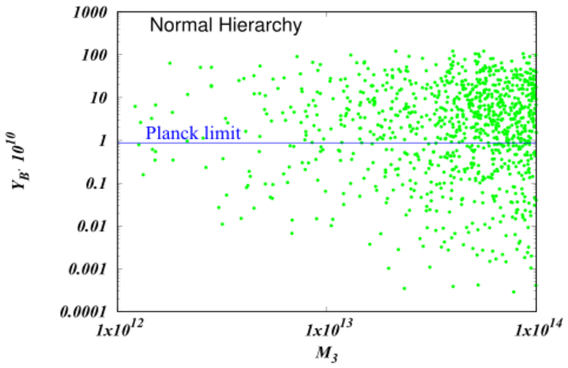
These values are far from the current sensitivities, while the next-generation experiments such as GERDA Phase II, CUPID, nEXO and SNO+-II will cover the obtained range.

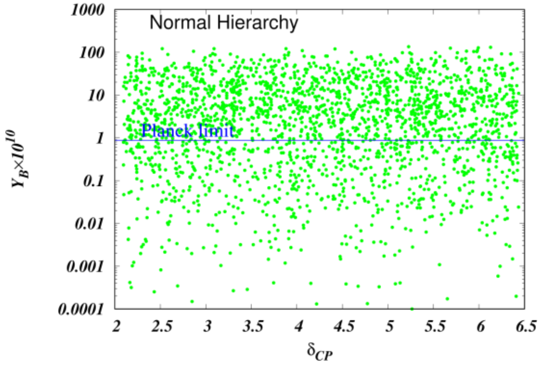
IV- Phenomenological implications

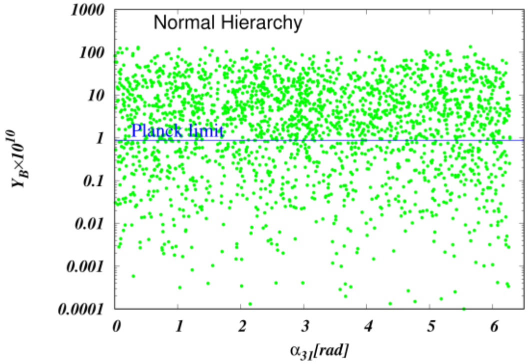


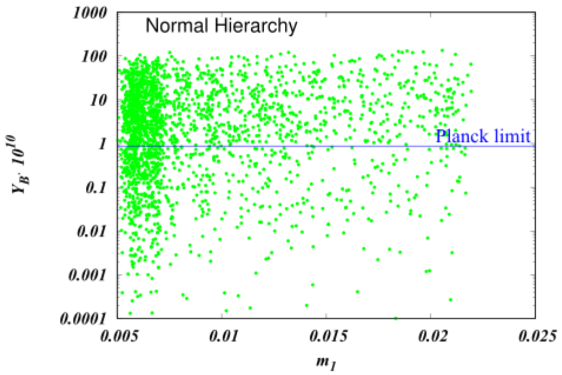


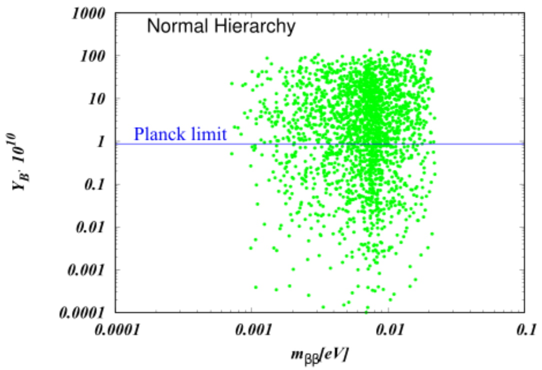


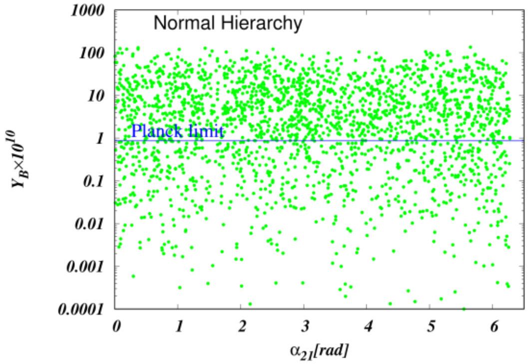












V – Summary and conclusion

- The minimal SU(5) and SUSY SU(5) can't explain the presence of neutrino masses and must be necessarily extended.

- SU(5) GUT with a Discrete Family Symmetry very predictive framework

- A flavor symmetry with Trimaximal mixing lead to interesting predictions.

- Heavy right handed neutrinos can be the common origin of neutrino masses and baryons in the universe.

- The observation of L violation and of CPV in the lepton sector (neutrino oscillations and/or ($0\beta\beta\nu$ -decay) would be a **indication, even if not a proof,** of Leptogenesis as the explanation for the observed baryon asymmetry of the Universe.

Thanks for your

ATTENTION