Yukawa Ratios and Nucleon Decay Fingerprints in SU(5) GUTs

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Based on: - Nucl.Phys.B 976, 115719 (Stefan Antusch, Kevin Hinze)
- arXiv:2205.01120 (Stefan Antusch, Kevin Hinze, Shaikh Saad)

Georgi-Glashow model

- Fermions

$$\overline{\mathbf{5}}_{\mathbf{F}} = \begin{pmatrix} d_1^c \\ d_2^c \\ d_3^c \\ e \\ -\nu \end{pmatrix} , \quad \mathbf{10}_{\mathbf{F}} = \begin{pmatrix} 0 & u_3^c & -u_2^c & u_1 & d_1 \\ -u_3^c & 0 & u_1^c & u_2 & d_2 \\ u_2^c & -u_1^c & 0 & u_3 & d_3 \\ -u_1 & -u_2 & -u_3 & 0 & e^c \\ -d_1 & -d_2 & -d_3 & -e^c & 0 \end{pmatrix} .$$

- Scalars

$$\mathbf{24}_H : \quad \mathrm{SU}(5) \to \mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$$
$$\mathbf{5}_H : \quad \mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \to \mathrm{SU}(3)_C \times \mathrm{U}(1)_{em}$$

Georgi, Glashow (1974)

Georgi-Glashow model

- No gauge coupling unification
  - Introduce intermediate-scale particles

- Massless neutrinos
  - $n \times 1_F$: see-saw type I
  - $1 \times 15_H$: see-saw type II

    Doršner, Perez (2005)
  - $1 \times 24_F$: hybrid see-saw type III + I

    Bajc, Senjanović (2007); Perez (2007)
  - Loop-level

    Perez, Murgui (2016); Saad (2019); Doršner, Saad (2019)

- $Y_e = Y_d^T \quad \Rightarrow \quad \boxed{y_\tau / y_b = 1\,, \;\; y_\mu / y_s = 1\,, \;\; y_e / y_d = 1}$
  - Linear combination of different (non-)renormalizable operators
  - Single operator dominance

Georgi-Jarlskog model

- $\overline{\mathbf{5}}_{\mathbf{Fi}} + \mathbf{10}_{\mathbf{Fi}} + \mathbf{24}_{\mathbf{H}} + \mathbf{5}_{\mathbf{H}} + \mathbf{45}_{\mathbf{H}}$

- $\mathbf{5}_{\mathbf{H}} : Y_e = Y_d^T \,, \qquad \mathbf{45}_{\mathbf{H}} : Y_e = -3Y_d^T$

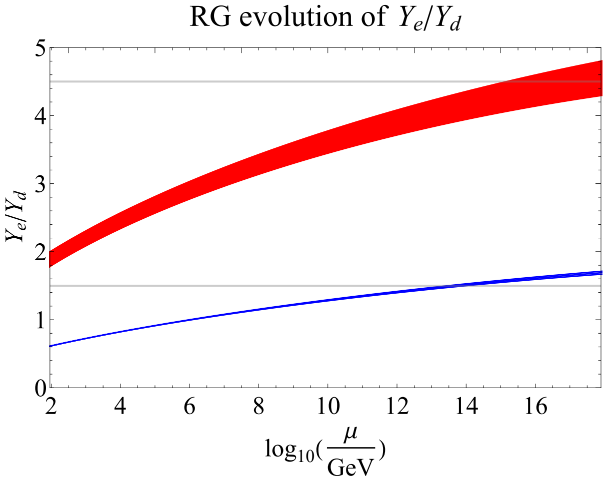
- Different Yukawa entries are gerenated from different Higgses:

$$Y_d = \begin{pmatrix} 0 & B & 0 \\ A & C & 0 \\ 0 & 0 & D \end{pmatrix}, \quad Y_e^T = \begin{pmatrix} 0 & B & 0 \\ A & -3C & 0 \\ 0 & 0 & D \end{pmatrix}$$

$$\Rightarrow \quad \boxed{\frac{y_\tau}{y_b} = 1, \quad \frac{y_\mu}{y_s} = -3, \quad \frac{y_e}{y_d} = -\frac{1}{3}}$$

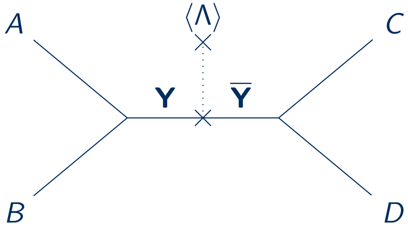
Georgi, Jarlskog (1979)

RG running of Yukawa ratios



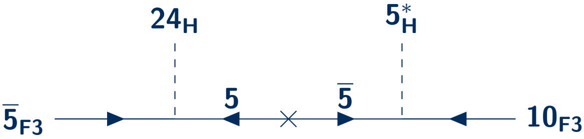
Non-renormalizable operators

- Diagrams of the form

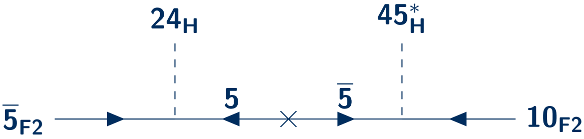


- A, B, C, D $\longleftrightarrow$ $\overline{\mathbf{5}}_{\mathbf{Fi}}$, $\mathbf{10}_{\mathbf{Fj}}$, Higgs with EW/GUT vev
- $\mathbf{Y}$, $\overline{\mathbf{Y}}$ $\longleftrightarrow$ heavy messenger fields
- $\langle\Lambda\rangle$ $\longleftrightarrow$ mass term for messenger fields
- Clebsch-Gordan coefficient $\Rightarrow$ Yukawa ratio

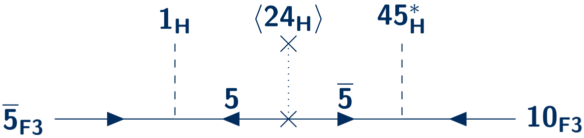
Antusch, Spinrath (2009); Antusch, King, Spinrath (2013)



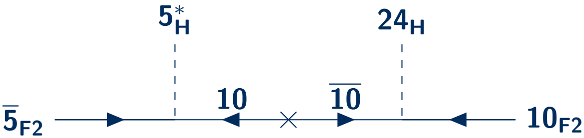
$\Rightarrow$ $\frac{y_\tau}{y_b} = -\frac{3}{2}$



$\Rightarrow$ $\frac{y_\mu}{y_s} = \frac{9}{2}$



$\Rightarrow$ $\frac{y_\tau}{y_b} = 2$



$\Rightarrow$ $\frac{y_\mu}{y_s} = 6$

Necessary conditions for Yukawa ratios

- Hierarchical Yukawa matrices

- 33- and 22- entries dominated by single GUT operator:

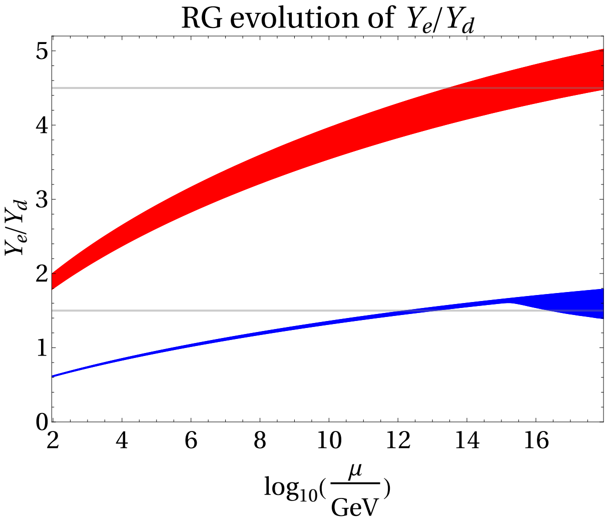
$$Y_d = \begin{pmatrix} 0 & 0 & 0 \\ 0 & y_d^2 & 0 \\ 0 & 0 & y_d^3 \end{pmatrix} + \dots , \quad Y_e^T = \begin{pmatrix} 0 & 0 & 0 \\ 0 & c_2 y_d^2 & 0 \\ 0 & 0 & c_3 y_d^3 \end{pmatrix} + \dots .$$

GUT scenario 1 with predicted Yukawa ratios

- $\overline{\mathbf{5}}_{\mathbf{Fi}} + \mathbf{10}_{\mathbf{Fi}} + \mathbf{1}_{\mathbf{Fi}} + \mathbf{24}_{\mathbf{H}} + \mathbf{5}_{\mathbf{H}} + \mathbf{45}_{\mathbf{H}}$
- See-saw type I
- Gauge coupling unification

  Doršner, Perez (2006)
- Yukawa ratios $\boxed{y_\tau / y_b = 3/2,\ y_\mu / y_s = 9/2}$

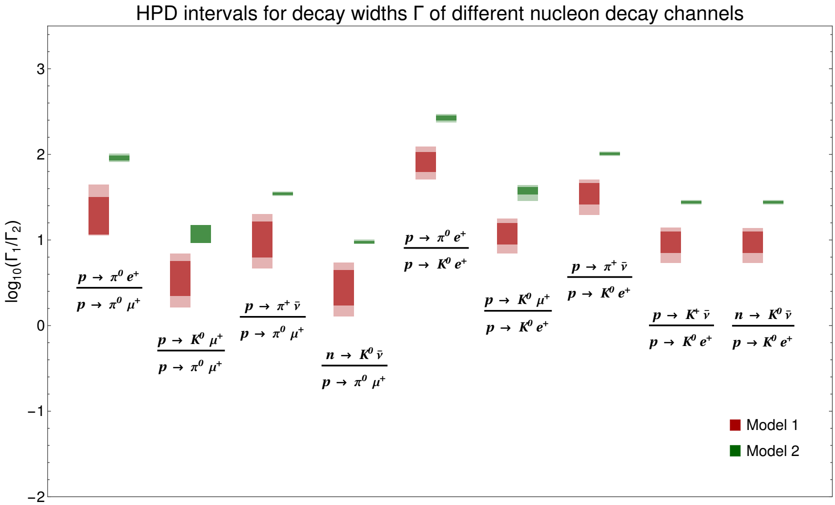
RG running of Yukawa ratios



Toy models

- model 1
  - $Y_u \sim \begin{pmatrix} y^u_{11} & y^u_{12} & 0 \\ y^u_{12} & y^u_{22} & y^u_{23} \\ 0 & y^u_{23} & y^u_{33} \end{pmatrix}, \quad Y_d \sim \begin{pmatrix} 0 & y^d_{12} & 0 \\ y^d_{21} & y^d_{22} & 0 \\ 0 & 0 & y^d_{33} \end{pmatrix}$
  - $Y_e = \begin{pmatrix} 0 & 1 \cdot y^d_{21} & 0 \\ \frac{3}{2} \cdot y^d_{12} & \frac{9}{2} \cdot y^d_{22} & 0 \\ 0 & 0 & \frac{3}{2} \cdot y^d_{33} \end{pmatrix}$
- model 2
  - $Y_u \sim \begin{pmatrix} y^u_{11} & y^u_{12} & y^u_{13} \\ y^u_{12} & y^u_{22} & y^u_{23} \\ y^u_{13} & y^u_{23} & y^u_{33} \end{pmatrix}, \quad Y_d \sim \begin{pmatrix} y^d_{11} & 0 & 0 \\ 0 & y^d_{22} & 0 \\ 0 & 0 & y^d_{33} \end{pmatrix}$
  - $Y_e = \begin{pmatrix} \frac{4}{9} \cdot y^d_{11} & 0 & 0 \\ 0 & \frac{9}{2} \cdot y^d_{22} & 0 \\ 0 & 0 & \frac{3}{2} \cdot y^d_{33} \end{pmatrix}$

Branching ratios



GUT scenario 2 with predicted Yukawa ratios

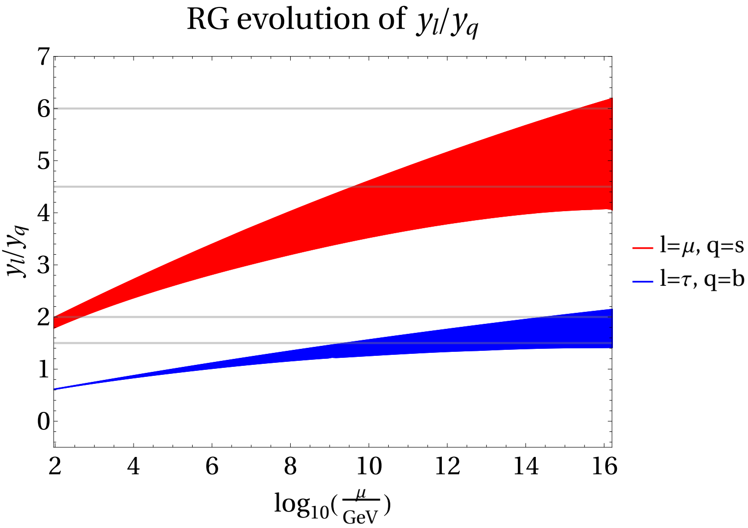
- $\mathbf{\overline{5}_{Fi} + 10_{Fi} + 24_H + 5_H + 45_H + 15_H}$
- See-saw type II

  Doršner, Perez (2005)
- Gauge coupling unification

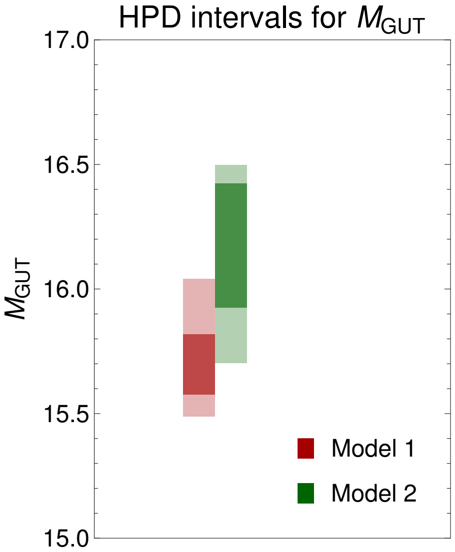
  Doršner, Perez (2008)
- Yukawa ratios

$y_\tau/y_b = 3/2,\ y_\mu/y_s = 9/2$	model 1
$y_\tau/y_b = 2,\ \ y_\mu/y_s = 6$	model 2

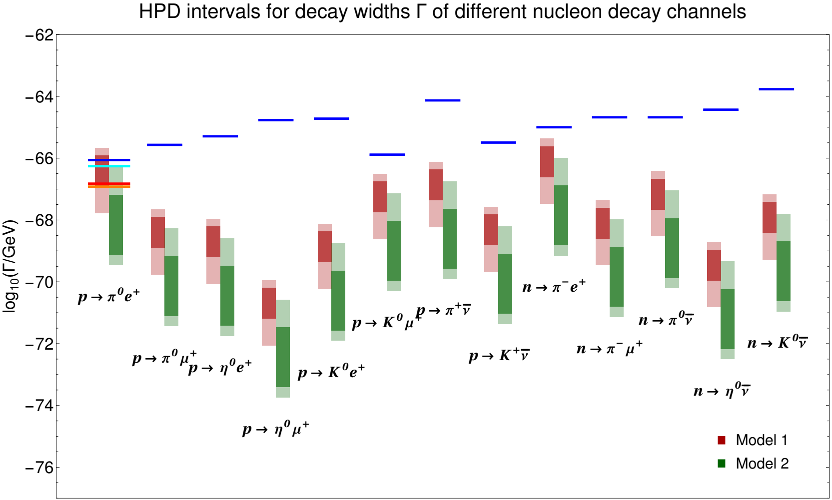
RG running of Yukawa ratios



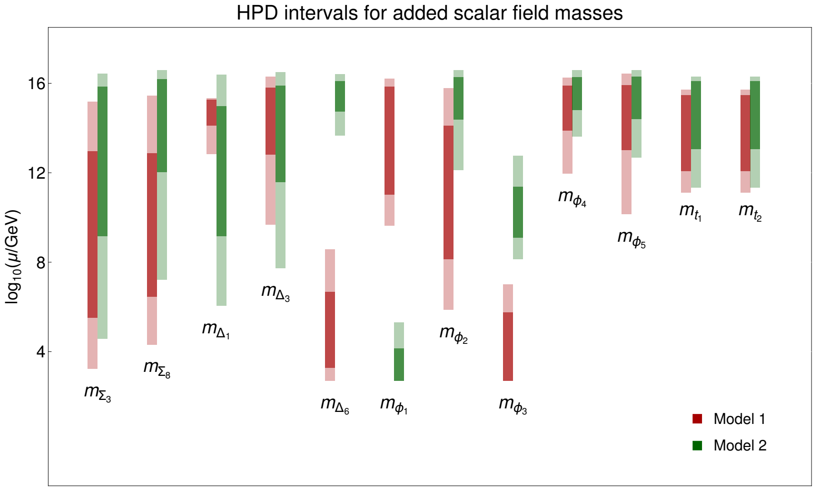
GUT scale


HPD intervals for M_{GUT}
17.0
16.5
16.0
15.5
15.0
M_{GUT}
Model 1
Model 2

Nucleon decay widths



Scalar masses

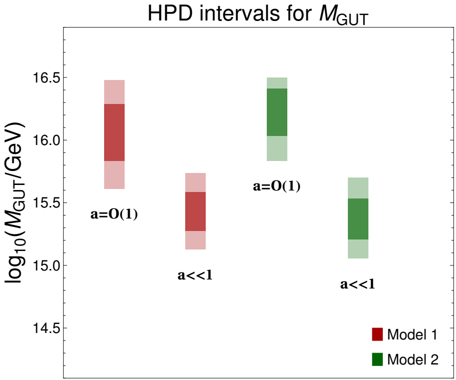


Conclusion

- Higher dimensional operators can lead to fixed GUT scale Yukawa ratios.
- The GUT scale ratios $y_\tau/y_b = 3/2$, $y_\mu/y_s = 9/2$ are viable in SU(5) GUTs with type I see-saw. On top of that in GUTs with type II see-saw the ratios $y_\tau/y_b = 2$, $y_\mu/y_s = 6$ are viable.
- GUT scenarios with different fixed Yukawa ratios predict different GUT scales and thus different nucleon decay rates.
- GUT scenarios with different fixed Yukawa ratios predict different light states.
- Branching ratios of nucleon decay channels can serve as "fingerprints" of different Yukawa textures.

Backup

GUT scale


HPD intervals for M_{GUT}
$\log_{10}(M_{GUT}/\mathrm{GeV})$
16.5
16.0
15.5
15.0
14.5
a=O(1)
a<<1
a=O(1)
a<<1
Model 1
Model 2

Nucleon decay rates