

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

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

□ Scalars

$$\mathbf{24}_H: \quad \text{SU}(5) \rightarrow \text{SU}(3)_C \times \text{SU}(2)_L \times \text{U}(1)_Y$$

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

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)

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

Georgi-Jarlskog model

$$\square \bar{\mathbf{5}}_{F_i} + \mathbf{10}_{F_i} + \mathbf{24}_H + \mathbf{5}_H + \mathbf{45}_H$$

$$\square \mathbf{5}_H : Y_e = Y_d^T, \quad \mathbf{45}_H : Y_e = -3Y_d^T$$

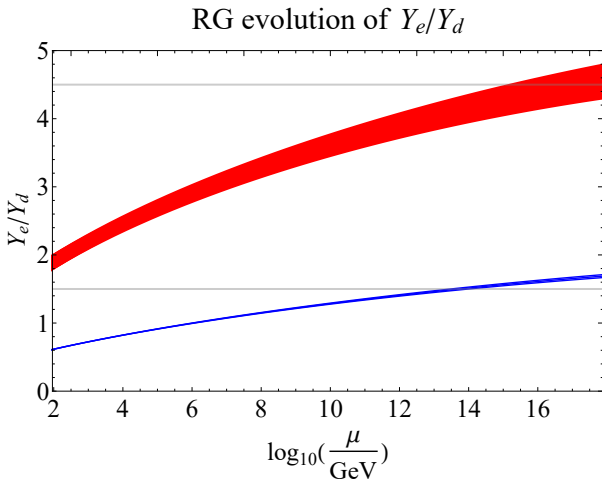
□ Different Yukawa entries are generated from different Higgses:

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

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

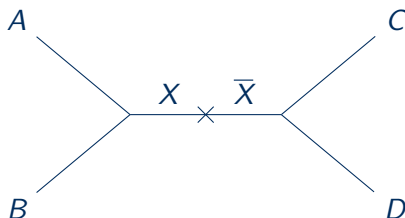
Georgi, Jarlskog (1979)

RG running of Yukawa ratios



Non-renormalizable operators

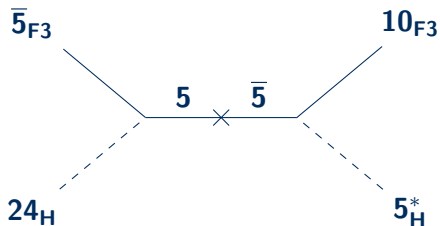
- Diagrams of the form



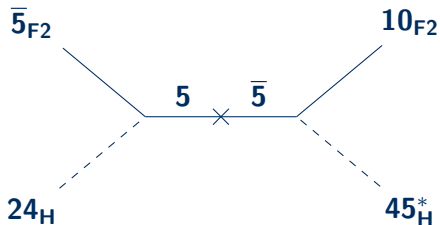
- $A, B, C, D \longleftrightarrow \mathbf{\bar{5}_{Fi}}, \mathbf{10_{Fi}}$, Higgs with EW vev,
Higgs with GUT vev
- $X, \bar{X} \longleftrightarrow$ heavy messenger fields
- Clebsch-Gordan coefficient \Rightarrow Yukawa ratio

Antusch, Spinrath (2009)

Example


 \Rightarrow

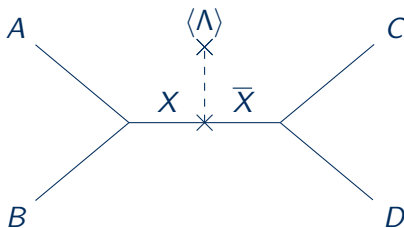
$$\frac{y_\tau}{y_b} = -\frac{3}{2}$$


 \Rightarrow

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

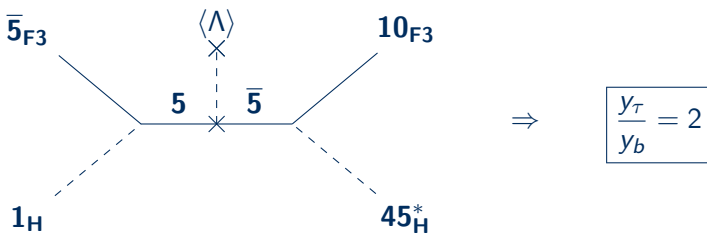
Non-renormalizable operators

- Messenger mass generated from GUT vev, i.e. mass term of the form $\bar{X}\langle\Lambda\rangle X$



Antusch, King, Spinrath (2013)

Example



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

$\bar{5}_{F_i} + 10_{F_i} + 1_{F_i} + 24_H + 5_H + 45_H$

See-saw type I

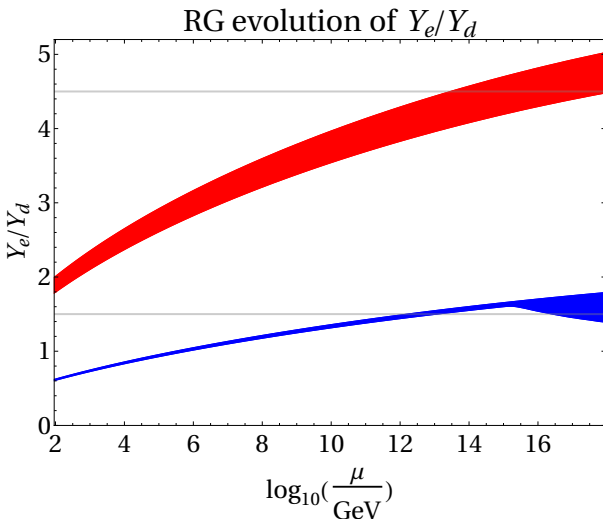
Gauge coupling unification

Doršner, Perez (2006)

Yukawa ratios

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

RG running of Yukawa ratios



Toy models

□ model 1

$$\square Y_u \sim \begin{pmatrix} * & * & 0 \\ * & * & * \\ 0 & * & * \end{pmatrix}, \quad Y_d \sim \begin{pmatrix} 0 & * & 0 \\ * & * & 0 \\ 0 & 0 & * \end{pmatrix}$$

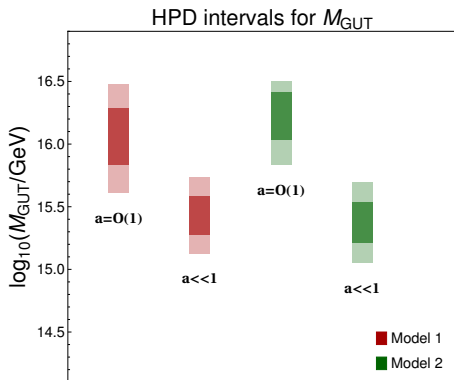
$$\square Y_e = \begin{pmatrix} 0 & 1 & 0 \\ \frac{3}{2} & \frac{9}{2} & 0 \\ 0 & 0 & \frac{3}{2} \end{pmatrix} \cdot Y_d^T$$

□ model 2

$$\square Y_u \sim \begin{pmatrix} * & * & * \\ * & * & * \\ * & * & * \end{pmatrix}, \quad Y_d \sim \begin{pmatrix} * & 0 & 0 \\ 0 & * & 0 \\ 0 & 0 & * \end{pmatrix}$$

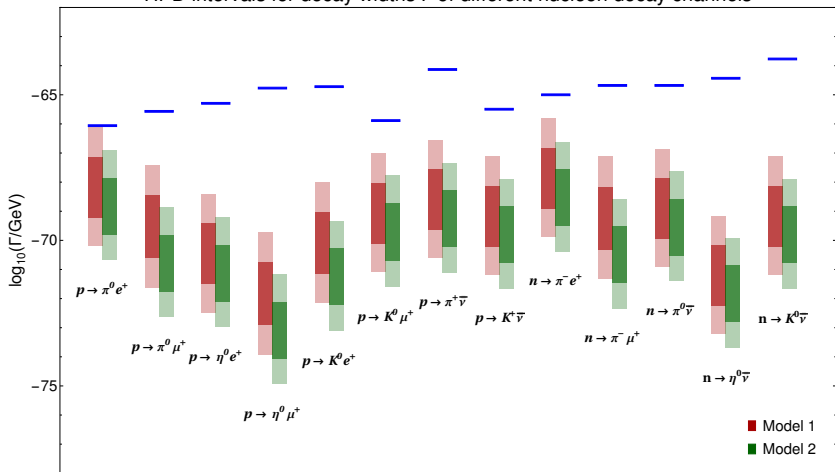
$$\square Y_e = \begin{pmatrix} \frac{4}{9} & 0 & 0 \\ 0 & \frac{9}{2} & 0 \\ 0 & 0 & \frac{3}{2} \end{pmatrix} \cdot Y_d^T$$

GUT scale



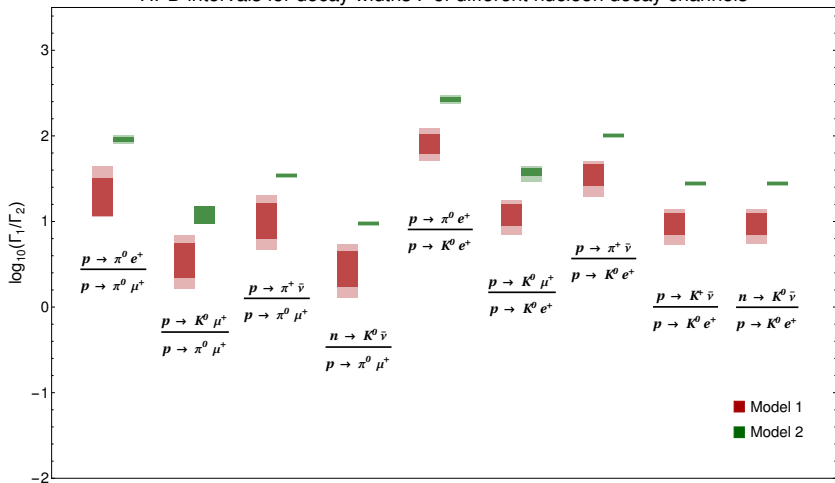
Nucleon decay rates

HPD intervals for decay widths Γ of different nucleon decay channels



Branching ratios

HPD intervals for decay widths Γ of different nucleon decay channels



GUT scenario 2 with predicted Yukawa ratios

□ $\bar{5}_{F_i} + 10_{F_i} + 24_H + 5_H + 45_H + 15_H$

□ See-saw type II

Doršner, Perez (2005)

□ Gauge coupling unification

Doršner, Perez (2008)

□ Yukawa ratios

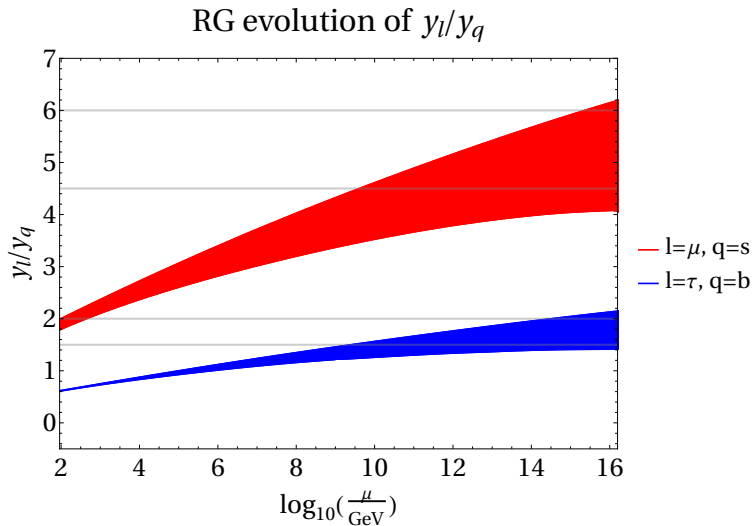
$$y_\tau/y_b = 3/2, \quad y_\mu/y_s = 9/2$$

model 1

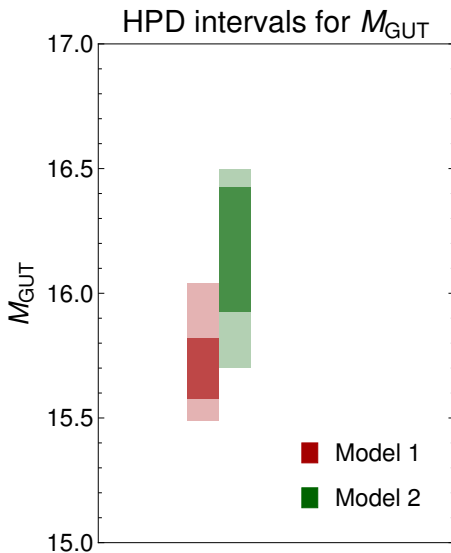
$$y_\tau/y_b = 2, \quad y_\mu/y_s = 6$$

model 2

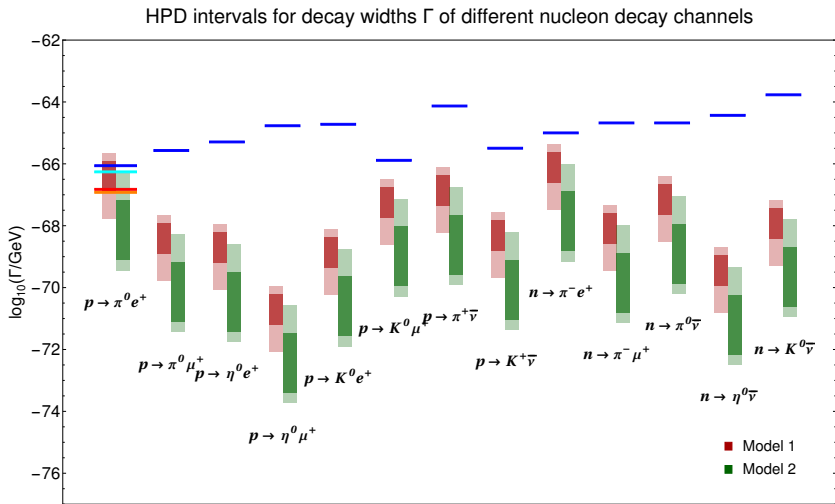
RG running of Yukawa ratios



GUT scale

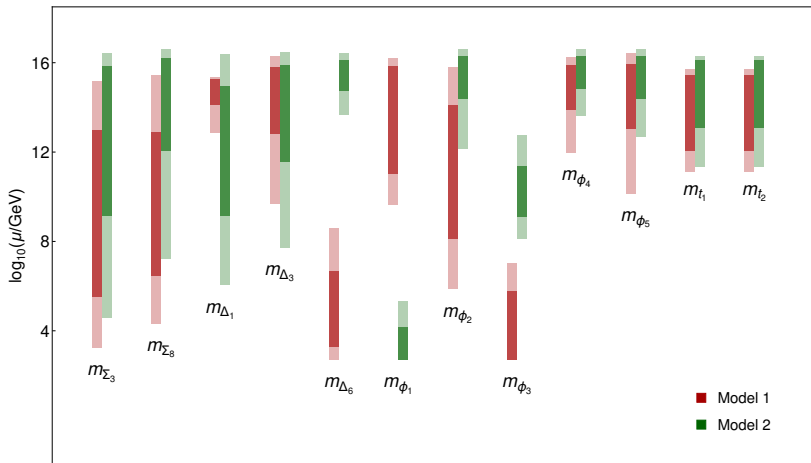


Nucleon decay widths



Scalar masses

HPD intervals for added scalar field masses



■ Model 1
■ Model 2

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.