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Deconstructed Neutrinos

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Standard Model

Gauge bosons

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

Three families of fermions

$$\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}, \quad e_R, \quad \begin{pmatrix} u_L \\ d_L \end{pmatrix}^{r,b,g}, \quad u_R^{r,b,g}, \quad d_R^{r,b,g}$$

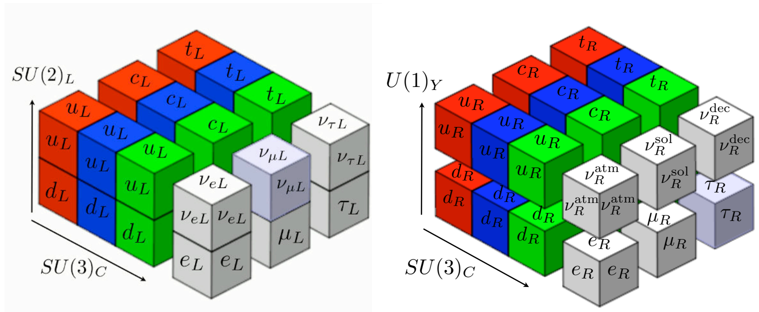
$$\begin{pmatrix} \nu_{\mu L} \\ \mu_L \end{pmatrix}, \quad \mu_R, \quad \begin{pmatrix} c_L \\ s_L \end{pmatrix}^{r,b,g}, \quad c_R^{r,b,g}, \quad s_R^{r,b,g}$$

$$\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}, \quad \tau_R, \quad \begin{pmatrix} t_L \\ b_L \end{pmatrix}^{r,b,g}, \quad t_R^{r,b,g}, \quad b_R^{r,b,g}$$

Hypercharges

$$Y = -\frac{1}{2}, \quad -1, \quad \frac{1}{6}, \quad \frac{2}{3}, \quad -\frac{1}{3}$$

With RHNs



Higgs **EWSB**

$$H = \begin{pmatrix} h^+ \\ h^0 \end{pmatrix}$$

$$\frac{1}{2}$$

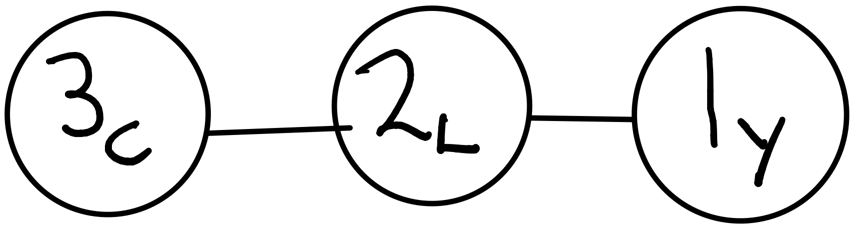
$$\langle h^0 \rangle = v/\sqrt{2}$$

$$SU(2)_L \times U(1)_Y \to U(1)_Q$$

$$Q = T_{3L} + Y$$

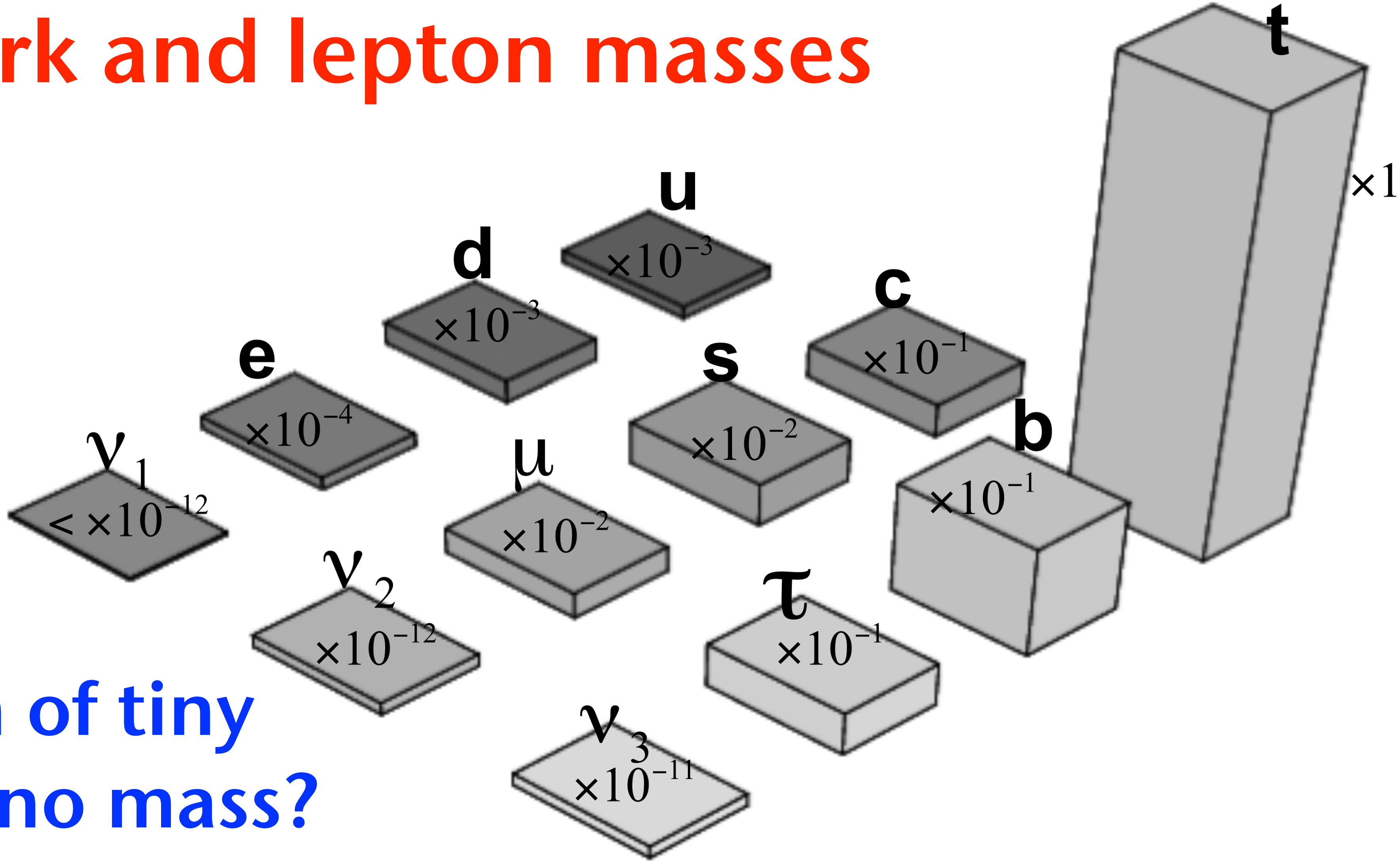
Standard Model

Quick summary

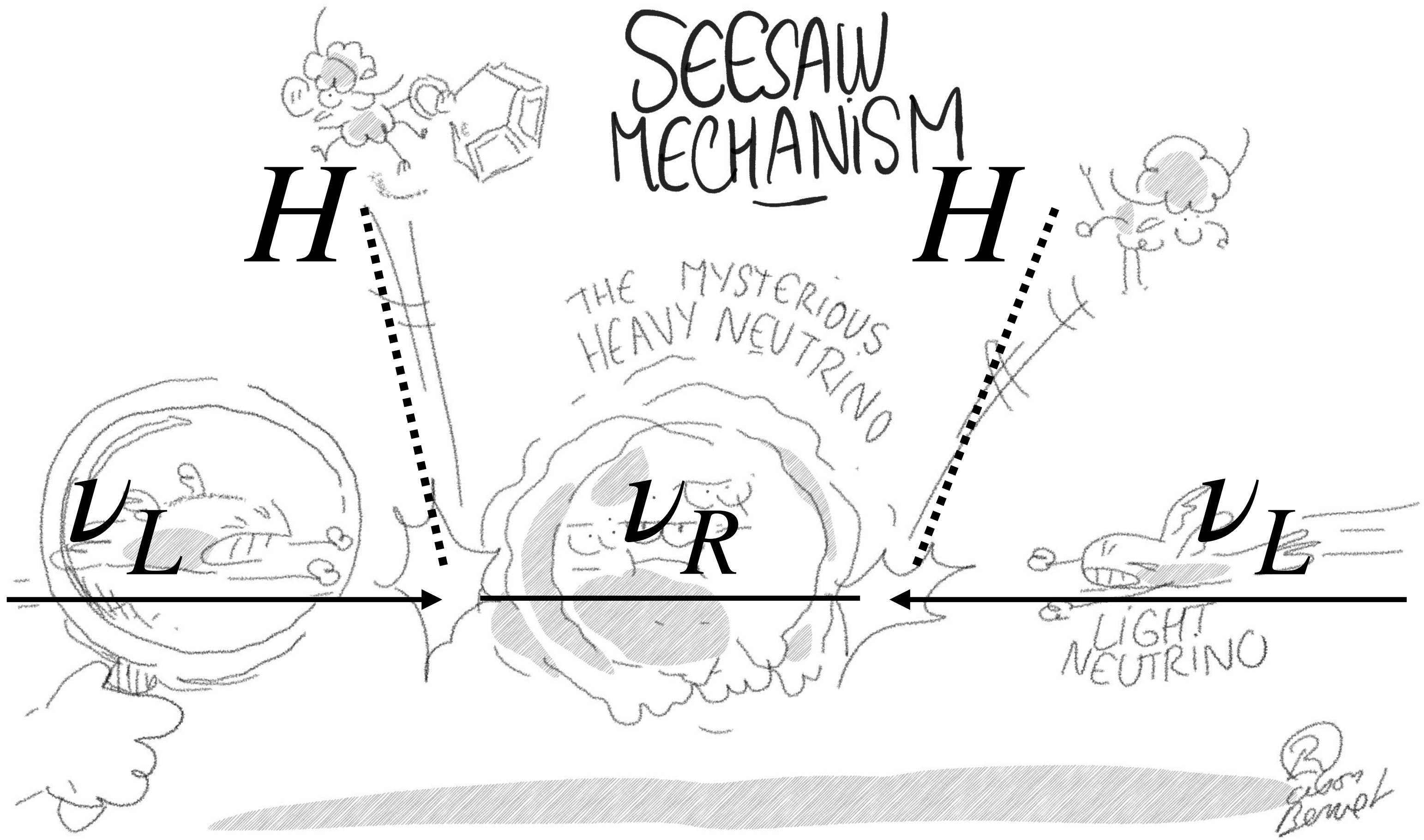


3 families,
Higgs

Quark and lepton masses

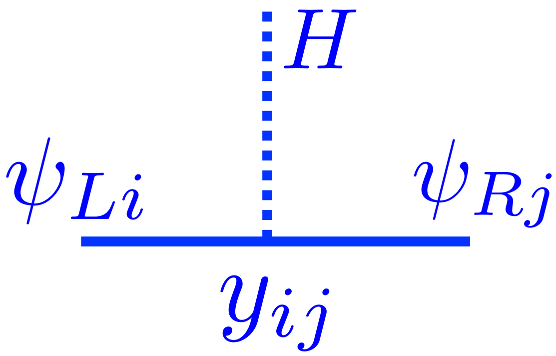


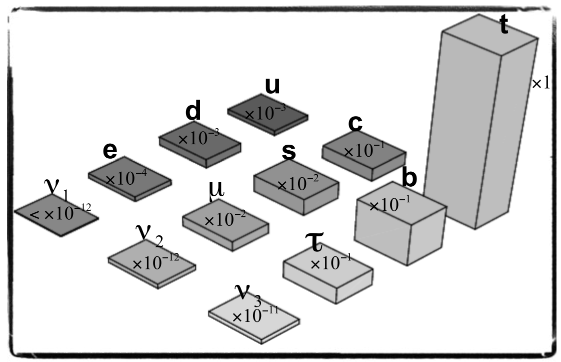
Origin of tiny neutrino mass?


SEESAW MECHANISM
H
H
THE MYSTERIOUS HEAVY NEUTRINO
ν_L
ν_R
ν_L
LIGHT NEUTRINO

Yukawa couplings

$$y_{ij} H \overline{\psi}_{Li} \psi_{Rj}$$





Suggests third family Yukawas dominate

Deconstructed gauge theories

Basic idea is to have a separate SM gauge group for each fermion family $SM_1 x SM_2 x SM_3$ broken to SM by new Higgs

The SM Higgs doublet is assigned to third family SM group then at leading order only have third family masses

Suppressed first and second family masses and mixing arise from non-renormalisable operators involving new Higgs

In general can apply this to SU(3), SU(2) or U(1) independently

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Deconstructed Hypercharge: Tri-hypercharge

Field	$SU(3)_c$	$SU(2)_L$	$U(1)_{Y_1}$	$U(1)_{Y_2}$	$U(1)_{Y_3}$
Q_1	$\mathbf{3}$	$\mathbf{2}$	$1/6$	0	0
u_1^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	$-2/3$	0	0
d_1^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	$1/3$	0	0
L_1	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	0	0
e_1^c	$\mathbf{1}$	$\mathbf{1}$	1	0	0
Q_2	$\mathbf{3}$	$\mathbf{2}$	0	$1/6$	0
u_2^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	0	$-2/3$	0
d_2^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	0	$1/3$	0
L_2	$\mathbf{1}$	$\mathbf{2}$	0	$-1/2$	0
e_2^c	$\mathbf{1}$	$\mathbf{1}$	0	1	0
Q_3	$\mathbf{3}$	$\mathbf{2}$	0	0	$1/6$
u_3^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	0	0	$-2/3$
d_3^c	$\overline{\mathbf{3}}$	$\mathbf{1}$	0	0	$1/3$
L_3	$\mathbf{1}$	$\mathbf{2}$	0	0	$-1/2$
e_3^c	$\mathbf{1}$	$\mathbf{1}$	0	0	1

A separate gauged weak hypercharge for each fermion family broken to SM hypercharge $Y = Y_1 + Y_2 + Y_3$

Higgs doublet carries third family hypercharge Y_3

$$H(\mathbf{1},\mathbf{2})_{(0,0,-\frac{1}{2})}$$

Allows only third family Yukawa couplings

$$y_t Q_3 \tilde{H} u_3^c + y_b Q_3 H d_3^c + y_\tau L_3 H e_3^c$$

To explain top-bottom mass hierarchy use

$$H_u(\mathbf{1},\mathbf{2})_{(0,0,\frac{1}{2})}, \qquad H_d(\mathbf{1},\mathbf{2})_{(0,0,-\frac{1}{2})}$$

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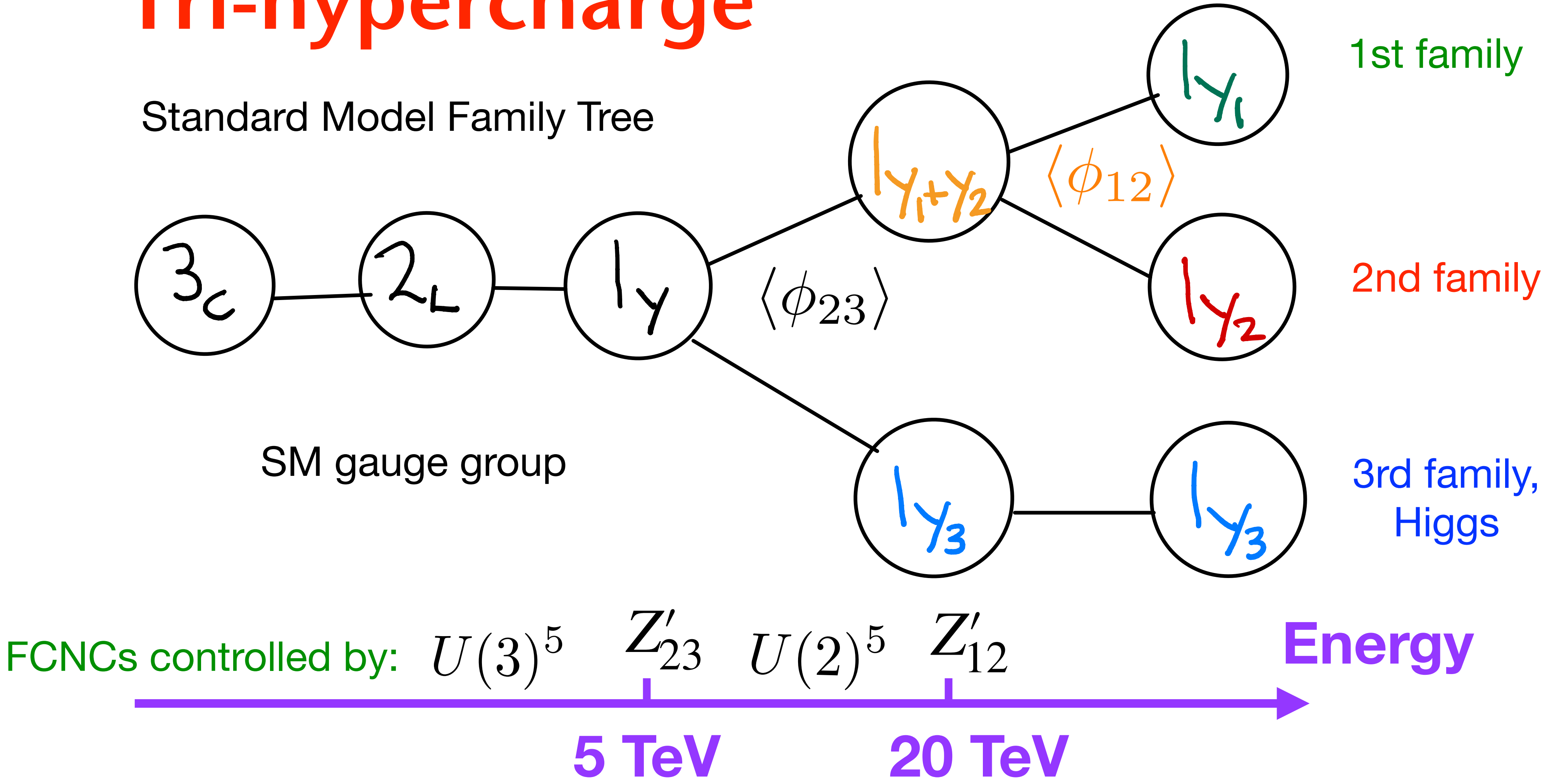
Tri-hypercharge



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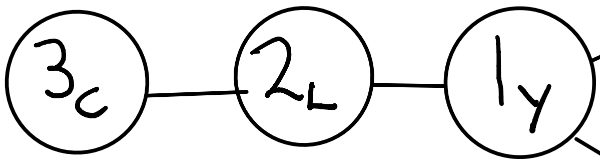
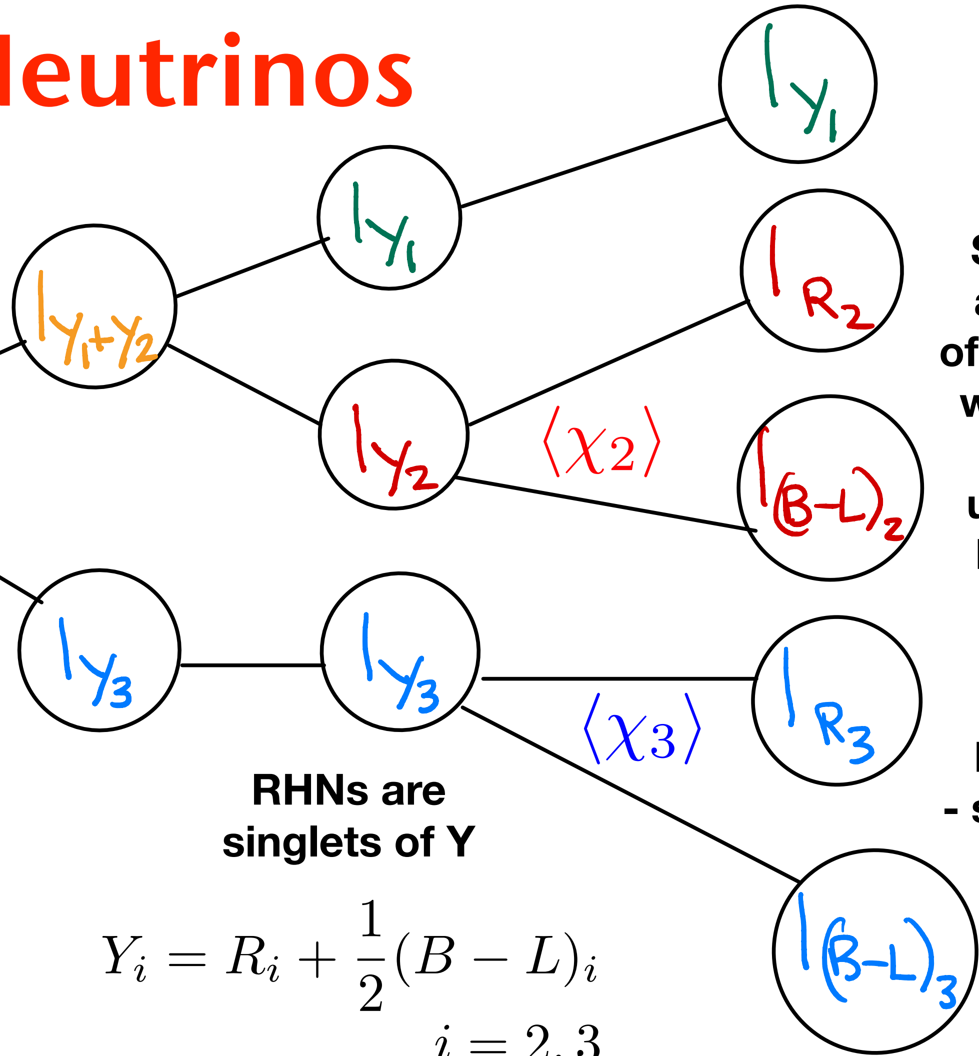
Deconstructed Neutrinos

Standard Model
Extended Family Tree





SM gauge group is the
tip of a very big iceberg

RHNs are singlets of Y

$$Y_i = R_i + \frac{1}{2}(B-L)_i$$
$$i = 2, 3$$

Since RHNs are singlets of hypercharge we introduce R and B-L under which RHNs carry charges (avoids anarchy in RHN sector - see backups)

Field	$U(1)_{Y_1}$	$U(1)_{R_2} \times U(1)_{(B-L)_2/2}$	$U(1)_{R_3} \times U(1)_{(B-L)_3/2}$
ℓ_1	$-\frac{1}{2}$	$(0,0)$	$(0,0)$
ℓ_2	0	$(0,-\frac{1}{2})$	$(0,0)$
ℓ_3	0	$(0,0)$	$(0,-\frac{1}{2})$
e_1^c	1	$(0,0)$	$(0,0)$
e_2^c	0	$(\frac{1}{2},\frac{1}{2})$	$(0,0)$
e_3^c	0	$(0,0)$	$(\frac{1}{2},\frac{1}{2})$
ν_2^c	0	$(-\frac{1}{2},\frac{1}{2})$	$(0,0)$
ν_3^c	0	$(0,0)$	$(-\frac{1}{2},\frac{1}{2})$
$H_{u,d}$	0	$(0,0)$	$(\pm\frac{1}{2},0)$
χ_2	0	$(1,-1)$	$(0,0)$
χ_3	0	$(0,0)$	$(1,-1)$
ϕ_{12}^R	$\frac{1}{2}$	$(-\frac{1}{2},0)$	$(0,0)$
ϕ_{12}^L	$\frac{1}{2}$	$(0,-\frac{1}{2})$	$(0,0)$
ϕ_{23}^R	0	$(\frac{1}{2},0)$	$(-\frac{1}{2},0)$
ϕ_{23}^L	0	$(0,\frac{1}{2})$	$(0,-\frac{1}{2})$

$\langle\chi_2\rangle$ → $U(1)_{Y_2}$

$\langle\chi_3\rangle$ → $U(1)_{Y_3}$

RHNs not singlets of R and B-L

Charged leptons

RHNs

2HDM

hyperons

Expansion parameters $\epsilon_{ij}^{R,L} = \langle \phi_{ij}^{R,L} \rangle / \Lambda_{ij}$

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$$\begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \end{pmatrix} \begin{pmatrix} a_{12}^{\nu}\epsilon_{12}^{L}\epsilon_{23}^{R} & a_{13}^{\nu}\epsilon_{12}^{L}\epsilon_{23}^{L} \\ a_{22}^{\nu}\epsilon_{23}^{R} & a_{23}^{\nu}\epsilon_{23}^{L} \\ a_{32}^{\nu}\epsilon_{23}^{L}\epsilon_{23}^{R} & a_{33}^{\nu} \end{pmatrix} \begin{pmatrix} \nu_1^c \\ \nu_2^c \end{pmatrix} H_u + \begin{pmatrix} \nu_1^c & \nu_2^c \end{pmatrix} \begin{pmatrix} \chi_2 & \epsilon_{23}^{L}\epsilon_{23}^{R}\chi_3 \\ \epsilon_{23}^{L}\epsilon_{23}^{R}\chi_3 & \chi_3 \end{pmatrix} \begin{pmatrix} \nu_1^c \\ \nu_2^c \end{pmatrix}$$

~ diagonal

hierarchical by columns

$\boldsymbol{m_e}$

$$\begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \end{pmatrix} \begin{pmatrix} a_{11}^{e}\epsilon_{12}^{R}\epsilon_{23}^{R} & a_{12}^{e}\epsilon_{12}^{L}\epsilon_{23}^{R} & a_{13}^{e}\epsilon_{12}^{L}\epsilon_{23}^{L} \\ a_{21}^{e}\epsilon_{12}^{L}\epsilon_{12}^{R}\epsilon_{23}^{R} & a_{22}^{e}\epsilon_{23}^{R} & a_{23}^{e}\epsilon_{23}^{L} \\ a_{31}^{e}\epsilon_{12}^{L}\epsilon_{12}^{R}\epsilon_{23}^{L}\epsilon_{23}^{R} & a_{32}^{e}\epsilon_{23}^{L}\epsilon_{23}^{R} & a_{33}^{e} \end{pmatrix} \begin{pmatrix} e_1^c \\ e_2^c \\ e_3^c \end{pmatrix} H_d$$

~ diagonal and hierarchical

$$m_e \sim \epsilon_{12}^{R}\epsilon_{23}^{R}\langle H_d \rangle$$

$$m_\mu \sim \epsilon_{23}^{R}\langle H_d \rangle$$

$$m_\tau \sim \langle H_d \rangle$$

$\Rightarrow$

$$\epsilon_{12}^{R} \sim \frac{m_e}{m_\mu} \simeq 0.005$$

$$\epsilon_{23}^{R} \sim \frac{m_\mu}{m_\tau} \simeq 0.06$$

$+$

$$\epsilon_{12,23}^{L} \gtrsim 0.1$$

$$\langle \chi_2 \rangle \sim 10^{13}\ \mathrm{GeV}$$

$$\langle \chi_3 \rangle \sim 10^{14}\ \mathrm{GeV}$$

$$\mathcal{O}(1)\ a\text{'s}$$

See review: S.F.K.2502.07877

Leads to sequential dominance of RHNs

$$\begin{pmatrix} a^\nu_{12}\epsilon^L_{12}\epsilon^R_{23} & a^\nu_{13}\epsilon^L_{12}\epsilon^L_{23} \\ a^\nu_{22}\epsilon^R_{23} & a^\nu_{23}\epsilon^L_{23} \\ a^\nu_{32}\epsilon^L_{23}\epsilon^R_{23} & a^\nu_{33} \end{pmatrix} \Rightarrow \begin{pmatrix} a & d \\ b & e \\ c & f \end{pmatrix} \qquad \begin{pmatrix} \chi_2 & \epsilon^L_{23}\epsilon^R_{23}\chi_3 \\ \epsilon^L_{23}\epsilon^R_{23}\chi_3 & \chi_3 \end{pmatrix} \Rightarrow \begin{pmatrix} M_{\rm sol} & 0 \\ 0 & M_{\rm atm} \end{pmatrix}$$

$$\Rightarrow \quad m^\nu \approx -m_D M_R^{-1} m_D^T = \frac{1}{M_{\rm atm}} \begin{pmatrix} d^2 & de & df \\ de & e^2 & ef \\ df & ef & f^2 \end{pmatrix} + \frac{1}{M_{\rm sol}} \begin{pmatrix} a^2 & ab & ac \\ ab & b^2 & bc \\ ac & bc & c^2 \end{pmatrix}$$

First matrix dominates

Neutrino Mixing angles

$$\tan\theta_{23} \approx \frac{|e|}{|f|} \qquad \tan\theta_{12} \approx \frac{a}{\cos\theta_{23} b - \sin\theta_{23} c} \qquad \theta_{13} \approx \frac{1}{m_3}\left[\frac{a\,(\sin\theta_{23} b + \cos\theta_{23} c)}{M_{\rm sol}} + \frac{d\sqrt{|e|^2 + |f|^2}}{M_{\rm atm}}\right]$$

Masses

$$m_3 \approx \frac{|e|^2 + |f|^2}{M_{\rm atm}} \qquad m_2 \approx \frac{a^2}{M_{\rm sol}} + \frac{(\cos\theta_{23} b - \sin\theta_{23} c)^2}{M_{\rm sol}}, \quad m_1 \approx 0.$$

In the charged lepton sector:

SD condition

$$m_e = \begin{pmatrix} a' & a & d \\ b' & b & e \\ c' & c & f \end{pmatrix}$$

$$|d|\,,|e|\,,|f| \gg |a|\,,|b|\,,|c| \gg |a'|\,,|b'|\,,|c'|$$

Similar to neutrino mixing angles

$$\tan\theta^e_{23} \simeq \frac{|e|}{|f|} \qquad \theta^e_{13} \simeq \frac{|d|}{\sqrt{|e|^2+|f|^2}}$$

$$\tan\theta^e_{12} \simeq \frac{|a|}{c^e_{23}|b|\cos(\tilde{\phi}^e_b) - s^e_{23}|c|\cos(\tilde{\phi}^e_c)}$$

Masses:

$$m_\tau \simeq \sqrt{|e|^2+|f|^2}$$

$$m_\mu \simeq \frac{|a|}{s^e_{12}}$$

$$m_e \simeq |a'|c^e_{12}\cos(\tilde{\phi}^e_{a'}) - |b'|s^e_{12}c^e_{23}\cos(\tilde{\phi}^e_{b'}) + |c'|s^e_{12}s^e_{23}\cos(\tilde{\phi}^e_{c'})$$

Lepton mixing

$$U_{\mathrm{PMNS}} = U_e U_\nu^\dagger = U_{12}^{e\dagger} U_{13}^{e\dagger} U_{23}^{e\dagger} U_{23}^{\nu} U_{13}^{\nu} U_{12}^{\nu} \,.$$

$$s_{23}\, e^{-i\delta_{23}} \approx c_{23}^e s_{23}^\nu e^{-i\delta_{23}^\nu} - c_{23}^\nu s_{23}^e e^{-i\delta_{23}^e} \,,$$

both terms are important

$$\theta_{13}\, e^{-i\delta_{13}} \approx \theta_{13}^\nu e^{-i\delta_{13}^\nu} - \theta_{13}^e (c_{23}^e c_{23}^\nu + s_{23}^e s_{23}^\nu e^{i(\delta_{23}^e - \delta_{23}^\nu)}) e^{-i\delta_{13}^e}$$
$$- \theta_{12}^e (c_{23}^e s_{23}^\nu e^{-i\delta_{23}^\nu} - c_{23}^\nu s_{23}^e e^{-i\delta_{23}^e}) e^{-i\delta_{12}^e} \,,$$

θ_{13} dominated by θ_{12}^e

$$s_{12}\, e^{-i\delta_{12}} \approx s_{12}^\nu e^{-i\delta_{12}^\nu} + \theta_{13}^e (c_{23}^e s_{23}^\nu e^{i\delta_{23}^\nu} - c_{23}^\nu s_{23}^e e^{i\delta_{23}^e}) c_{12}^\nu e^{-i\delta_{13}^e}$$
$$- \theta_{12}^e (c_{23}^e c_{23}^\nu + s_{23}^e s_{23}^\nu e^{-i(\delta_{23}^e - \delta_{23}^\nu)}) c_{12}^\nu e^{-i\delta_{12}^e} \,.$$

θ_{12} dominated by θ_{12}^ν

Predictions of the model

★ High scale seesaw, three light neutrino paradigm, leptogenesis

★ Normal neutrino mass ordering and hierarchy

$$m_3^2 \gg m_2^2 \gg m_1^2$$

★ Large atmospheric and solar angles, small reactor angle

★ Hierarchical charged lepton masses

★ Heavy Z'_{12} (~20 TeV) and Z'_{23} (~5 TeV) with observable consequences

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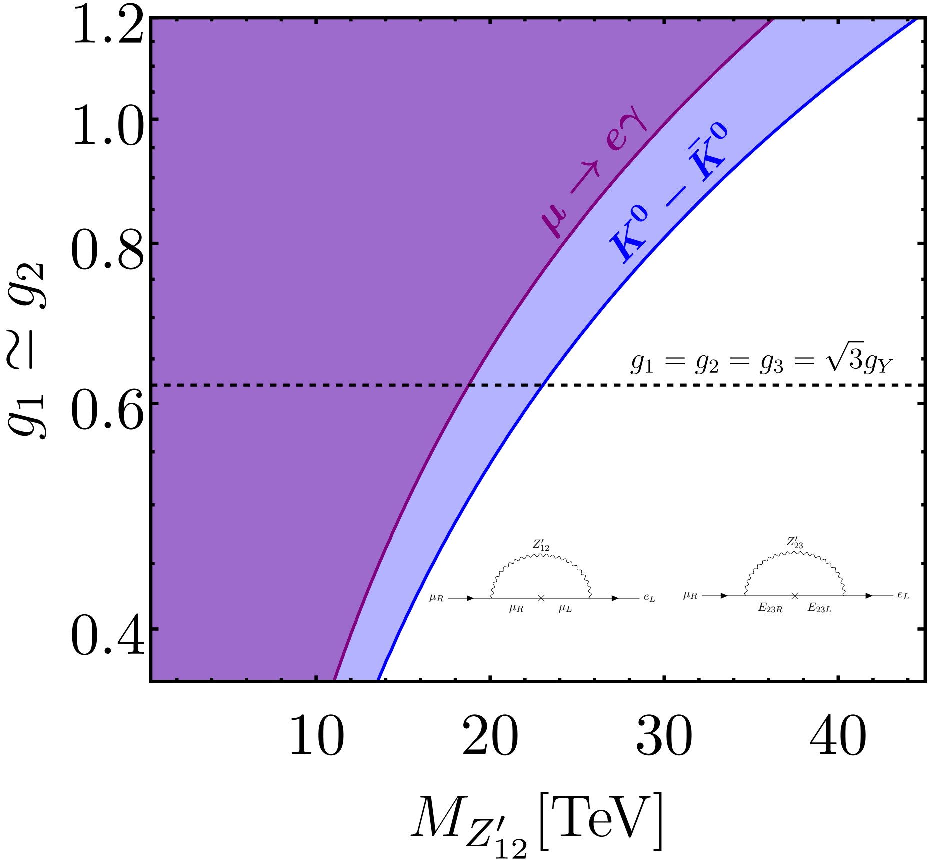
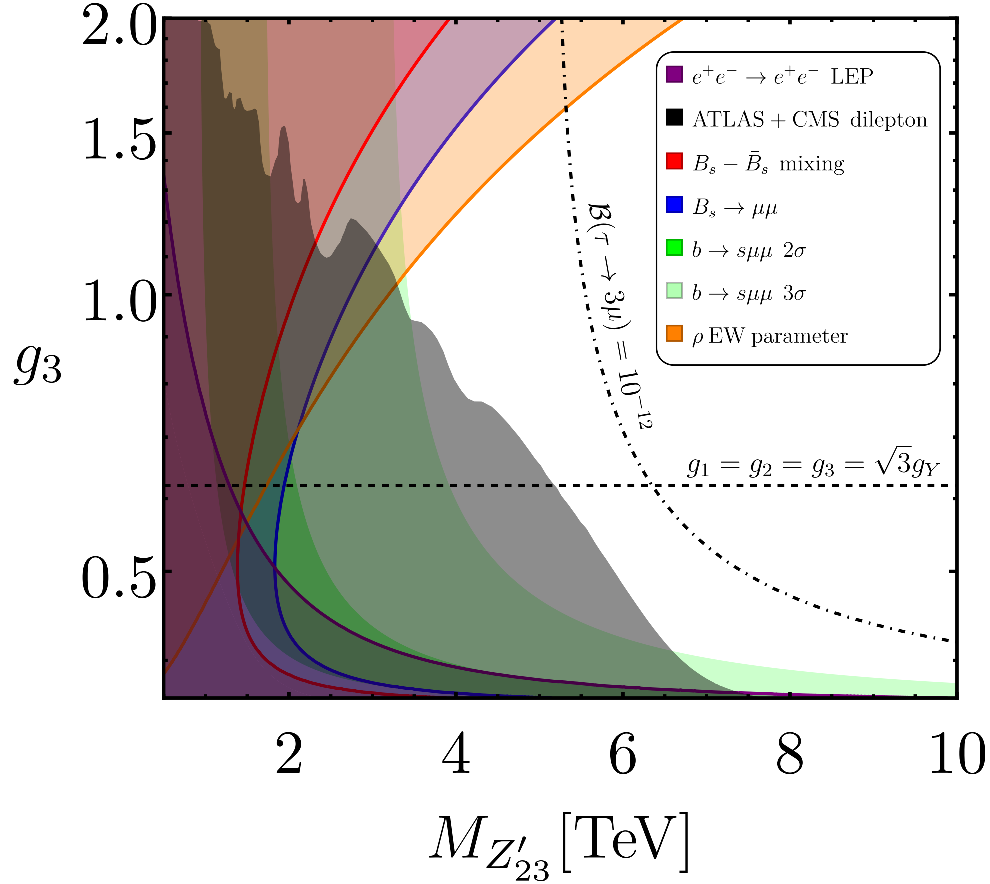
Observable consequences of Z'_{12} and Z'_{23}





Conclusions

Gauge flavour deconstruction is a successful and novel approach to the flavour problem of the Standard Model

Tri-hypercharge is the minimal example of deconstruction

Neutrinos are problematic since RHNs carry zero hypercharge and the simplest deconstruction models typically lead to small lepton mixing

If the tri-hypercharges arise from $U(1)_{\mathrm{R}}$ and $U(1)_{B-L}$ then RHNs are no longer gauge singlets and can lead to large lepton mixing via sequential dominance

Predicts the three light neutrino paradigm with a normal hierarchy

The lightest two Z' hypercharge gauge bosons provide indirect and direct tests

Back-ups

Examples:

- Tri-hypercharge: $SU(3)_c \times SU(2)_L \times U(1)_Y^3$ [Fernández Navarro, King , Vicente]
- $SU(3)_c \times SU(2)_L^3 \times U(1)_Y$ [Li, Ma, Muller, Nandi, Chiang, Deshpande, He, Jiang, Davighi...]
- $SU(3)_c^3 \times SU(2)_L \times U(1)_Y$ [Carone, Murayama]
- (Pati-Salam)^3 [Bordone, Cornella, Fuentes-Martin, Isidori, Pagès, Stefanek...]
- Grand unified models [Rajpoot, Barbieri, Dvali, Strumia, Babu, Barr, Gogoladze, Fernández Navarro, King , Vicente]
- Partial deconstruction [Muller, Nandi, Malkawi, Tait, Yuan, Lynch, Mrenna, Narain, Simmons, He, Valencia, Davighi, Stefanek...]

+ other groups
+ other authors

We shall focus on the minimal case of Tri-hypercharge

(apologies if I missed your contribution!)

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A two Higgs doublet plus two hyperon model

	$U(1)_{Y_1}$	$U(1)_{Y_2}$	$U(1)_{Y_3}$	$SU(3)_c \times SU(2)_L$
$H_3^{u,d}$	0	0	$\pm 1/2$	$(\mathbf{1},\mathbf{2})$
ϕ_{q12}	-1/6	1/6	0	$(\mathbf{1},\mathbf{1})$
ϕ_{q23}	0	-1/6	1/6	$(\mathbf{1},\mathbf{1})$

$$\frac{\langle \phi_{q12} \rangle}{\Lambda_1} \sim \frac{\langle \phi_{q23} \rangle}{\Lambda_2} \sim \lambda$$

Generates the effective Yukawa matrices in an EFT framework

$$\mathcal{L} = \begin{pmatrix} Q_1 & Q_2 & Q_3 \end{pmatrix} \begin{pmatrix} \tilde\phi_{q12}^3 \tilde\phi_{q23}^3 & \phi_{q12} \tilde\phi_{q23}^3 & \phi_{q12}\phi_{q23} \\ \tilde\phi_{q12}^4 \tilde\phi_{q23}^3 & \tilde\phi_{q23}^3 & \phi_{q23} \\ \tilde\phi_{q12}^4 \tilde\phi_{q23}^4 & \tilde\phi_{q23}^3 \tilde\phi_{q23} & 1 \end{pmatrix} \begin{pmatrix} u_1^c \\ u_2^c \\ u_3^c \end{pmatrix} H_3^u$$
$$+ \begin{pmatrix} Q_1 & Q_2 & Q_3 \end{pmatrix} \begin{pmatrix} \phi_{q12}^3 \phi_{q23}^3 & \phi_{q12} \phi_{q23}^3 & \phi_{q12}\phi_{q23} \\ \phi_{q12}^2 \phi_{q23}^3 & \phi_{q23}^3 & \phi_{q23} \\ \phi_{q12}^2 \phi_{q23}^2 & \phi_{q23}^2 & 1 \end{pmatrix} \begin{pmatrix} d_1^c \\ d_2^c \\ d_3^c \end{pmatrix} H_3^d$$
$$+ \begin{pmatrix} L_1 & L_2 & L_3 \end{pmatrix} \begin{pmatrix} \phi_{q12}^3 \phi_{q23}^3 & \tilde\phi_{q12}^3 \phi_{q23}^3 & \tilde\phi_{q12}^3 \tilde\phi_{q23}^3 \\ \phi_{q12}^6 \phi_{q23}^3 & \phi_{q23}^3 & \tilde\phi_{q23}^3 \\ \phi_{q12}^6 \phi_{q23}^6 & \phi_{q23}^6 & 1 \end{pmatrix} \begin{pmatrix} e_1^c \\ e_2^c \\ e_3^c \end{pmatrix} H_3^d + \text{h.c.}$$

$$\mathcal{L} = \begin{pmatrix} u_1 & u_2 & u_3 \end{pmatrix} \begin{pmatrix} \lambda^6 & \lambda^4 & \lambda^2 \\ \lambda^7 & \lambda^3 & \lambda \\ \lambda^9 & \lambda^5 & 1 \end{pmatrix} \begin{pmatrix} u_1^c \\ u_2^c \\ u_3^c \end{pmatrix} \frac{v_{\mathrm{SM}}}{\sqrt{2}}$$
$$+ \begin{pmatrix} d_1 & d_2 & d_3 \end{pmatrix} \begin{pmatrix} \lambda^6 & \lambda^4 & \lambda^2 \\ \lambda^5 & \lambda^3 & \lambda \\ \lambda^6 & \lambda^4 & 1 \end{pmatrix} \begin{pmatrix} d_1^c \\ d_2^c \\ d_3^c \end{pmatrix} \lambda^2 \frac{v_{\mathrm{SM}}}{\sqrt{2}}$$
$$+ \begin{pmatrix} e_1 & e_2 & e_3 \end{pmatrix} \begin{pmatrix} \lambda^6 & \lambda^6 & \lambda^6 \\ \lambda^9 & \lambda^3 & \lambda^3 \\ \lambda^{12} & \lambda^6 & 1 \end{pmatrix} \begin{pmatrix} e_1^c \\ e_2^c \\ e_3^c \end{pmatrix} \lambda^2 \frac{v_{\mathrm{SM}}}{\sqrt{2}}$$

Hierarchical charged fermion mass matrices

Good!

But…

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...what about the neutrinos?

Consider lepton model with 2 RHN singlets

Field	$U(1)_{Y_1}$	$U(1)_{Y_2}$	$U(1)_{Y_3}$
ℓ_1	$-\frac{1}{2}$	0	0
ℓ_2	0	$-\frac{1}{2}$	0
ℓ_3	0	0	$-\frac{1}{2}$
e^c_1	1	0	0
e^c_2	0	1	0
e^c_3	0	0	1
ν^c_1	0	0	0
ν^c_2	0	0	0
H_u	0	0	$\frac{1}{2}$
H_d	0	0	$-\frac{1}{2}$
ϕ_{12}	$\frac{1}{2}$	$-\frac{1}{2}$	0
ϕ_{23}	0	$\frac{1}{2}$	$-\frac{1}{2}$

RHNs are singlets

Small suppression factors

$$\epsilon^e_{12} = \langle\phi_{12}\rangle/\Lambda^e_{12}$$
$$\epsilon^e_{23} = \langle\phi_{23}\rangle/\Lambda^e_{23}$$

Mass matrices

$\boldsymbol{m_e}$

$$\begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \end{pmatrix} \begin{pmatrix} a^e_{11}\epsilon^e_{12}\epsilon^e_{23} & a^e_{12}\epsilon^e_{12}\epsilon^e_{23} & a^e_{13}\epsilon^e_{12}\epsilon^e_{23} \\ a^e_{21}(\epsilon^e_{12})^2\epsilon^e_{23} & a^e_{22}\epsilon^e_{23} & a^e_{23}\epsilon^e_{23} \\ a^e_{31}(\epsilon^e_{12})^2(\epsilon^e_{23})^2 & a^e_{32}(\epsilon^e_{23})^2 & a^e_{33} \end{pmatrix} \begin{pmatrix} e^c_1 \\ e^c_2 \\ e^c_3 \end{pmatrix} H_d$$

Order one coefficients

~ diagonal and hierarchical

$\boldsymbol{m_D}$

$$\begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \end{pmatrix} \begin{pmatrix} a^\nu_{11}\epsilon^\nu_{12}\epsilon^\nu_{23} & a^\nu_{12}\epsilon^\nu_{12}\epsilon^\nu_{23} \\ a^\nu_{21}\epsilon^\nu_{23} & a^\nu_{22}\epsilon^\nu_{23} \\ a^\nu_{31} & a^\nu_{32} \end{pmatrix} \begin{pmatrix} \nu^c_1 \\ \nu^c_2 \end{pmatrix} H_u \,.$$

$\boldsymbol{M_M}$

$$\begin{pmatrix} \nu^c_1 & \nu^c_2 \end{pmatrix} \begin{pmatrix} M_{22} & M_{23} \\ M_{32} & M_{33} \end{pmatrix} \begin{pmatrix} \nu^c_1 \\ \nu^c_2 \end{pmatrix}$$

anarchic

Hierarchical lepton masses implies small lepton mixing! 😅

Deconstructed Neutrinos (other approaches)

Non-trivial RHN hypercharges and dedicated neutrino hyperons -> "Neutrino Anarchy"

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Consider particular gauge symmetries where both hierarchical m_D and hierarchical M_M cancel in the seesaw mechanism -> "Neutrino Anarchy"

A.Greljo, G.Isidori, 2406.01696

Assign all lepton doublet the same quantum numbers and assume that anomalies are cancelled with extra fermions in the UV -> "Neutrino Anarchy"

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"Neutrino Anarchy" means neutrino mass matrix with O(1) coefficients and generically large mixing angles and denegerate neutrinos - unpredictive