Minimal *SU*(4) models
&
B-meson anomalies

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together with

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Lepton Flavor group

$$\mathcal{L}_{\text{Y}-\text{lept}}^{\text{SM}} = \bar{L} Y_l e_R \Phi$$

Sensu lato:

$$U(3)_{L_L} \times U(3)_{e_R}$$

$L \to \mathcal{U} \bullet L$
$e_R \to \mathcal{U}' \bullet e_R$

$Y_l \stackrel{!}{=} 0$

$m_l \stackrel{!}{=} 0$

~~SM~~

FLAVOR PHYSICS
refers here!

$\bigcap \quad \mathcal{U}' = \mathcal{U}$

Sensu mezzostricto:

$$U(3)_{\text{LF}}$$

FLAVOR VIOLATION
refers there!

$\bigcap \, \mathcal{U} = \text{diag}(e^{i\alpha}, e^{i\beta}, e^{i\gamma})$

$\bigcap \det \mathcal{U} = 1$

Lepton Flavor Universality:

Sensu stricto:

$$U(1)_e \times U(1)_\mu \times U(1)_\tau$$

$\not\supset$
$\not\subset$

$$SU(3)_{\text{LFU}} \quad Y_l \stackrel{!}{=} \mathbb{1} y$$

$m_e \stackrel{!}{=} m_\mu \stackrel{!}{=} m_\tau$

~~SM~~

✓ SM
~~ν oscillations~~
✓ all other experiments

$\bigcap \, \mathcal{U} = e^{i\alpha} \mathbb{1}$

Lepton number:

$$U(1)_{\text{L}}$$

✓ SM
✓ SM $\oplus$ Dirac ν_R
✓ all experiments

✓ SM @ $E \gg \Delta m_l$
~~B-meson decays~~

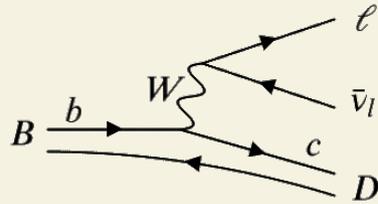# LFUV in *B*-meson decays

(Cf. today morning talks for details)

Charged current anomaly

$$R_{D^{(*)}} = \frac{\mathrm{BR}(B \to D^{(*)}\tau\bar{\nu})}{\mathrm{BR}(B \to D^{(*)}l\bar{\nu})}$$

$$R_{D^{(*)}}^{\mathrm{exp}} > R_{D^{(*)}}^{\mathrm{exp2019}} \gtrsim R_{D^{(*)}}^{\mathrm{SM}}$$

$R_D^{\mathrm{SM}} = 0.299 \pm 0.003$

$R_{D^*}^{\mathrm{SM}} = 0.258 \pm 0.005$

Pre-Moriond2019 average:

$R_D = 0.407 \pm 0.039 \pm 0.024$

$R_{D^*} = 0.306 \pm 0.013 \pm 0.007$

LHCb: [1904.08794]

$R_D = 0.307 \pm 0.037 \pm 0.016$

$R_{D^*} = 0.283 \pm 0.018 \pm 0.014$

Gone?

Neutral current anomaly

$$R_{K^{(*)}} = \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)}$$

$$R_{K^{(*)}}^{\mathrm{exp}} < R_{K^{(*)}}^{\mathrm{SM}} = 1$$

Pre-Moriond2019:

$R_K^{\mathrm{exp}} = 0.745^{+0.090}_{-0,074} \pm 0.036$

$R_{K^*}^{\mathrm{exp}} = 0.685^{+0.113}_{-0.069} \pm 0.047$

LHCb: [1903.09252]

$R_K = 0.846^{+\,0.060\,+\,0.016}_{-\,0.054\,-\,0.014}$

Support from various b-s-μ-μ probes

- angular obs. in B → K*μμ (P_5')

- B$_s$ → μμ

LF[U]V in LeptoQuark interactions

$$\mathcal{L}_{\mathrm{LQ-int}} = \begin{pmatrix} \bar{d} & \bar{s} & \bar{b} \end{pmatrix} \begin{pmatrix} y_{de} & y_{d\mu} & y_{d\tau} \\ y_{se} & y_{s\mu} & y_{s\tau} \\ y_{be} & y_{b\mu} & y_{b\tau} \end{pmatrix} \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix} LQ^{+2/3}$$
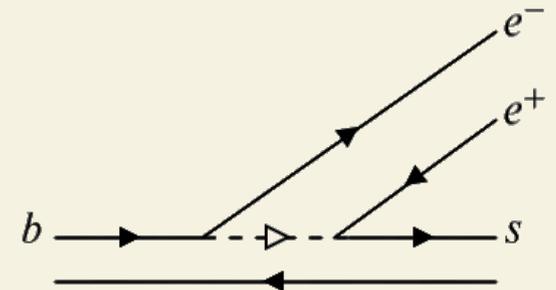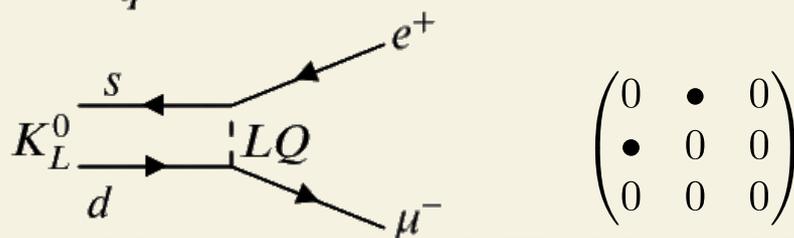
Lepton Flavor violation

⬍

(At least) two nonzero columns

$$\begin{pmatrix} 0 & 0 & 0 \\ \bullet & \bullet & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\begin{pmatrix} 0 & \bullet & 0 \\ \bullet & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Lepton Flavor Universality violation

⬍

Two (or more) columns differ
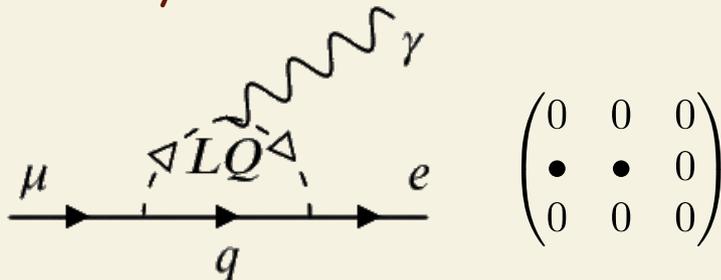
$$\begin{pmatrix} 0 & 0 & 0 \\ \bullet & 0 & 0 \\ \bullet & 0 & 0 \end{pmatrix}$$

Minimal *SU(4)* model(s)

A. D. Smirnov   (et al.)

- The Minimal quark - lepton symmetry model and the limit on Z' mass
  Phys. Lett. B346 (1995) 297-302   arXiv: hep-ph/9503239
- Phys. Lett. B431 (1998) 119-126   arXiv: hep-ph/9805339
- Mod. Phys. Lett. A20 (2005) 3003-3012   arXiv: 0511149
- Mod. Phys. Lett. A23 (2008) 2907-2913   arXiv: 0807.4486
- Mod. Phys. Lett. A24 (2009) 1199-1207   arXiv: 0902.2931
- Mod. Phys. Lett. A31 (2016) 39, 1650224   arXiv: 1610.08409

- Vector leptoquark mass limits and branching ratios of K_L^0, B^0, $B_s \to l_i^+ l_j^-$ decays
  with account of fermion mixing...
  Mod. Phys. Lett. A33 (2018) 1850019   arXiv: 1801.02895

vanilla version

P. Fileviez Pérez, M. B. Wise

- Low-scale quark-lepton unification
  Phys. Rev. D88 (2013) 057703   arXiv: 1307.6213

inverse seesaw

T. Faber, W. Porod, M. Hudec, M. Malinský, H. Kolešová, F. Staub

- A unified LQ model confronted with lepton non-universality in B-meson decays
  Phys. Lett. B 787 (2018) 159-166   arXiv: 1808.05511
- Collider phenomenology of a unified LQ model   arXiv: 1812.07592

Minimal *SU(4)* model(s)

- ## SU(4)_C x SU(2)_L x U(1)_R

$$\mathrm{A}_\mu^{\mathrm{SU}(4)} = \begin{pmatrix} G_\mu + \frac{\mathbb{1}}{\sqrt{12}} A_\mu^{15} & U_{1\mu} \\ U_{1\mu}^\dagger & \frac{-3}{\sqrt{12}} A_\mu^{15} \end{pmatrix}$$

  Quark-Lepton unification

  natural LeptoQuark environment

$$F_{(4,2,0)} = \begin{pmatrix} Q \\ L \end{pmatrix}$$

$$f_{u\,(4,1,+1/2)}^c = \begin{pmatrix} u_R{}^c & \nu_R{}^c \end{pmatrix}$$

$$f_{d\,(4,1,+1/2)}^c = \begin{pmatrix} d_R{}^c & e_R{}^c \end{pmatrix}$$

- ## No extra charged fermions

  mandatory: ν_R

  optional: extra singlet → inverse seesaw

$$N_{(1,1,0)}$$

- ## Minimal scalar sector

  Cascade SSB

  Independent fermion masses

$$\chi_{(4,1,+1/2)} = \begin{pmatrix} \bar{S}_{1\,(3,1,+2/3)}^\dagger \\ \chi^0{}_{(1,1,0)} \end{pmatrix}$$

$$H_{(1,2,+1/2)}$$

$$\Phi_{(15,2,+1/2)} = \begin{pmatrix} G_{(8,2,+1/2)} + \frac{H_2}{\sqrt{12}} & R_{2\,(3,2,+7/6)} \\ \tilde{R}_{2\,(\bar{3},2,-1/6)}^\dagger & \frac{-3}{\sqrt{12}} H_{2\,(1,2,+1/2)} \end{pmatrix}$$

LeptoQuarks in the model

- vector $U_1 \sim$ (3, 1, +2/3)

  - Unitary interaction matrix → LFV inevitable → m_{U1} > 60 TeV

    [1801.02895]

- scalar $\overline{S}_1 \sim$ (3, 1, +2/3)

  - Goldstone boson eaten by U_1

- scalar $\widetilde{R}_2 \sim$ (3, 2, -1/6)

  - Unable to accommodate R(K*)   [1704.05438]

- scalar $R_2 \sim$ (3, 2, +7/6)

  - able to accommodate R(K) & R(K*)   [1704.05438]

  - also used to explain R(D) & R(D*)   [1806.05689]

$$m_G^2 + 2m_{\hat{H}}^2 \sin^2 \beta = \frac{3}{2}(m_{R_2}^2 + m_{\tilde{R}_2}^2)$$
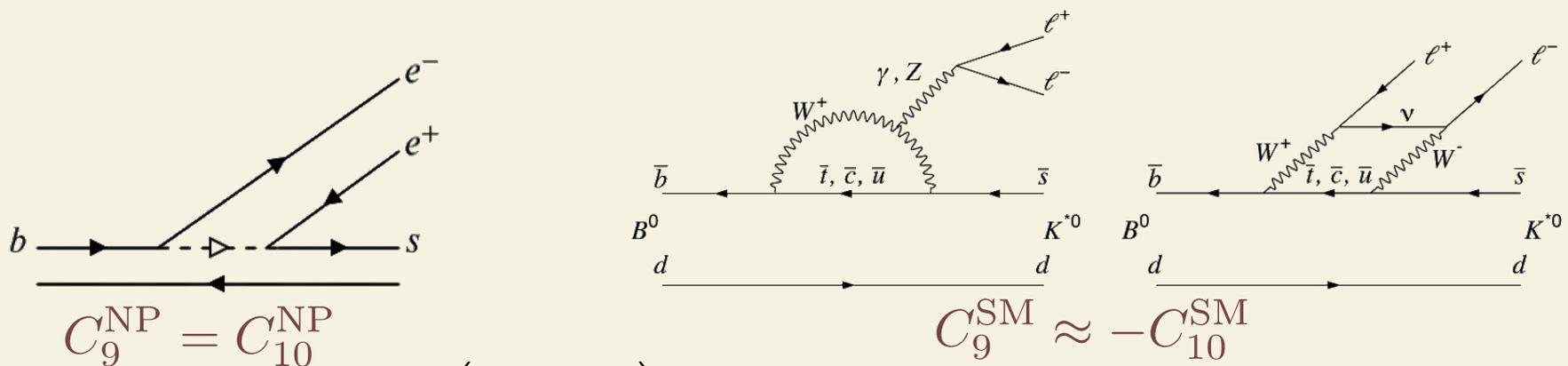
The R_2 LeptoQuark & R(K$^{(*)}$) anomaly

$$R_2 = \begin{bmatrix} R^{5/3} \\ R^{2/3} \end{bmatrix} \sim \left(3, 2, +\frac{7}{6}\right)$$

$$R_{K^{(*)}} = \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)} \lesssim 1$$

$$\mathcal{L}_{\mathrm{R_2}} = \left(R^{2/3}\overline{d_L} + R^{5/3}\overline{u_L}\,V_{\mathrm{CKM}}\right) Y_4\, e_R + \overline{u_R}\,Y_2\left(\nu_L\,R^{2/3} + e_L\,R^{5/3}\right) + \mathrm{h.c.}$$

Different chiralities than weak interactions

→ sums incoherently with SM contributions

→ can improve R(K) iff coupling to electrons

$$C_9^{\mathrm{NP}} = C_{10}^{\mathrm{NP}}$$

$$C_9^{\mathrm{SM}} \approx -C_{10}^{\mathrm{SM}}$$

Ideal case: $\quad Y_4 = \begin{pmatrix} 0 & 0 & 0 \\ \bullet & 0 & 0 \\ \bullet & 0 & 0 \end{pmatrix} \quad \longrightarrow \quad R_K \approx \frac{|C^{\mathrm{SM}}|^2}{|C^{\mathrm{SM}}|^2 + |C_{ee}^{\mathrm{NP}}|^2}$

Constraints on the R_2 LQ interaction from extended gauge symmetry

The relevant Yukawa matrix must satisfy
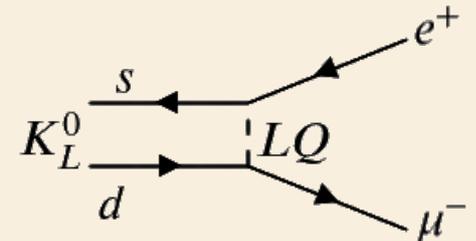
$$Y_4 = \frac{U\hat{M}_d - \hat{M}_l V}{\sqrt{2/3}\, v_{\text{ew}} \cos\beta} \propto \begin{array}{c} \\ d_L \\ s_L \\ b_L \end{array} \begin{pmatrix} u_{de}m_d - v_{de}m_e & u_{d\mu}m_d - v_{d\mu}m_\mu & u_{d\tau}m_d - v_{d\tau}m_\tau \\ u_{se}m_s - v_{se}m_e & u_{s\mu}m_s - v_{s\mu}m_\mu & u_{s\tau}m_s - v_{s\tau}m_\tau \\ u_{be}m_b - v_{be}m_e & u_{b\mu}m_b - v_{b\mu}m_\mu & u_{b\tau}m_b - v_{b\tau}m_\tau \end{pmatrix}$$

(columns labeled e_R, μ_R, τ_R)

Freedom: U, V = arbitrary unitary matrices; $\cos\beta$; m_{LQ}

Special case: Low-energy *SO(10)* → *U = V*   LFV inevitable

$$\begin{array}{c} \\ d_L \\ s_L \\ b_L \end{array} \begin{pmatrix} u_{de}(m_d - m_e) & u_{d\mu}(m_d - m_\mu) & u_{d\tau}(m_d - m_\tau) \\ u_{se}(m_s - m_e) & u_{s\mu}(m_s - m_\mu) & u_{s\tau}(m_s - m_\tau) \\ u_{be}(m_b - m_e) & u_{b\mu}(m_b - m_\mu) & u_{b\tau}(m_b - m_\tau) \end{pmatrix}$$

(columns labeled e_R, μ_R, τ_R)

K_L^0 → $e^+ \mu^-$ via LQ (s, d lines)

model with $R_K = 0.8$ EXCLUDED

Only working scenario:

$$Y_4 = \sqrt{\frac{3}{2}} \frac{1}{v_{\text{s}} \cos\beta} \begin{pmatrix} 0 & 0 & m_\tau \sin\phi \\ m_s/\sqrt{2} & 0 & m_\tau \cos\phi \\ m_b/\sqrt{2} & 0 & -m_b/\sqrt{2} \end{pmatrix}$$

NO muon flavor violation

Summary of Results

	Vanilla minimal model	Minimal model + inverse seesaw - SO(10)	Minimal model + inverse seesaw
$R(D^{(*)})$	✗	✗	✗
$R(K^{(*)})$	✗	✗	✓ • $1 \times 10^{-8} < \tau \to e\,\gamma < 3 \times 10^{-8}$ discovery@BelleII • $\tau \to eee, \tau \to e\mu\mu$ @BelleII • $\tau \to e\pi\pi$ possible @BelleII • 2/3 LQ decaying to $be^+ : b\tau^+ : j\tau^+ = 1 : 1 : 1.17$ @pp-colliders
b-s-μ-μ	✗	✗	✗

Thank you

Matěj Hudec

Scalar potential

$$V = \mu_H^2 |H|^2 + \mu_\chi^2 |\chi|^2 + \mu_\Phi^2 \mathrm{Tr}(|\Phi|^2) + \lambda_1 |H|^2 |\chi|^2 + \lambda_2 |H|^2 \mathrm{Tr}(|\Phi|^2) + \lambda_3 |\chi|^2 \mathrm{Tr}(|\Phi|^2)$$

$$+ (\lambda_4 H_i^\dagger \chi^\dagger \Phi^i \chi + \mathrm{h.c.}) + \lambda_5 H_i^\dagger \mathrm{Tr}(\Phi_j^\dagger \Phi^i) H^j + \lambda_6 \chi^\dagger \Phi^i \Phi_i^\dagger \chi + \lambda_7 |H|^4 + \lambda_8 |\chi|^4 + \lambda_9 \mathrm{Tr}(|\Phi|^4)$$

$$+ \lambda_{10}(\mathrm{Tr}|\Phi|^2)^2 + \left(\lambda_{11} H_i^\dagger \, \mathrm{Tr}(\Phi^i \, \Phi^j) H_j^\dagger + \lambda_{12} H_i^\dagger \, \mathrm{Tr}(\Phi^i \, \Phi^j \, \Phi_j^\dagger) + \lambda_{13} H_i^\dagger \, \mathrm{Tr}(\Phi^i \, \Phi_j^\dagger \, \Phi^j) + \mathrm{h.c.} \right)$$

$$+ \lambda_{14} \chi^\dagger |\Phi|^2 \chi + \lambda_{15} \mathrm{Tr}(\Phi_i^\dagger \, \Phi^j \, \Phi_j^\dagger \, \Phi^i) + \lambda_{16} \mathrm{Tr}(\Phi_i^\dagger \, \Phi^j) \, \mathrm{Tr}(\Phi_j^\dagger \, \Phi^i) + \lambda_{17} \mathrm{Tr}(\Phi_i^\dagger \, \Phi_j^\dagger) \, \mathrm{Tr}(\Phi^i \, \Phi^j)$$

$$+ \lambda_{18} \mathrm{Tr}(\Phi_i^\dagger \, \Phi_j^\dagger \, \Phi^i \, \Phi^j) + \lambda_{19} \mathrm{Tr}(\Phi_i^\dagger \, \Phi_j^\dagger \, \Phi^j \, \Phi^i)$$

$$\Downarrow$$

$$m_G^2 = \left(\frac{\sqrt{3}\lambda_4}{4} \tan\beta - \frac{3}{8}(\lambda_6 + \lambda_{14}) \right) v_\chi^2 \,,$$

$$m_{R_2}^2 = \left(\frac{\sqrt{3}\lambda_4}{4} \tan\beta + \frac{\lambda_{14} - 3\lambda_6}{8} \right) v_\chi^2 \,,$$

$$m_{\tilde{R}_2}^2 = \left(\frac{\sqrt{3}\lambda_4}{4} \tan\beta + \frac{\lambda_6 - 3\lambda_{14}}{8} \right) v_\chi^2 \,,$$

$$m_{\hat{H}}^2 = \frac{\sqrt{3}\lambda_4}{2\sin(2\beta)} v_\chi^2 \,,$$

$$\Downarrow$$

$$m_G^2 + 2 m_{\hat{H}}^2 \sin^2\beta = \frac{3}{2}(m_{R_2}^2 + m_{\tilde{R}_2}^2)$$

Some more eqns

Fermions	Scalars
$F_{(4,2,0)} = \begin{pmatrix} Q \\ L \end{pmatrix}$	$\chi_{(4,1,+1/2)} = \begin{pmatrix} \bar{S}^\dagger_{1\,(3,1,+2/3)} \\ \chi^0_{\,(1,1,0)} \end{pmatrix}$
$f^c_{u\,(\bar{4},1,-1/2)} = \begin{pmatrix} u^c & \nu^c \end{pmatrix}$	$H_{(1,2,+1/2)}$
$f^c_{d\,(\bar{4},1,+1/2)} = \begin{pmatrix} d^c & e^c \end{pmatrix}$	$\Phi_{(15,2,+1/2)} = \begin{pmatrix} G_{(8,2,+1/2)} + \frac{\mathbb{1}}{\sqrt{12}} H_2 & R_{2\,(3,2,+7/6)} \\ \tilde{R}^\dagger_{2\,(\bar{3},2,-1/6)} & \frac{-3}{\sqrt{12}} H_{2\,(1,2,+1/2)} \end{pmatrix}$
$N_{(1,1,0)}$	

$$-\mathcal{L}_Y = f^c_u Y_1 H F + f^c_u Y_2 \Phi F + f^c_d Y_3 H^\dagger F + f^c_d Y_4 \Phi^\dagger F + f^c_u Y_5 \chi N + \frac{1}{2} N \mu N + \text{h.c.}$$

Scalar extensions of SM

$\Psi(Y)_L^{3B}$	$\overline{\nu_R}\,(0)_{-1}^0$	$\overline{e_R}\,(-1)_{-1}^0$	$L^j\,(-\frac{1}{2})_1^0$	$\overline{d_{R\beta}}\,(\frac{1}{3})_0^{-1}$	$\overline{u_{R\beta}}\,(-\frac{2}{3})_0^{-1}$	$Q^{j\beta}\,(\frac{1}{6})_0^1$
$Q^{i\alpha}\,(\frac{1}{6})_0^1$	$\tilde{R}_{2\alpha i}^\dagger\,(-\frac{1}{6})$	$R_{2\alpha i}^\dagger\,(-\frac{7}{6})$	$S_{1\alpha}\varepsilon_{ij}\,(\frac{1}{3})$ $S_{3\,\alpha ij}$	$H_i^\dagger\delta_\alpha^\beta\,(-\frac{1}{2})$ $G^{\dagger\,\beta}_{\alpha j}$	$H^j\varepsilon_{ij}\delta_\alpha^\beta\,(\frac{1}{2})$ $X_\alpha^{j\beta}\varepsilon_{ij}$	$S_1^{\dagger\,\gamma}\varepsilon_{\alpha\beta\gamma}\,\varepsilon_{ij}$ $\chi_{\alpha\beta}\,\varepsilon_{ij}$ $S_{3\,ij}^{\dagger\,\gamma}\,\varepsilon_{\alpha\beta\gamma}\,(-\frac{1}{3})$ $X_{\alpha\beta ij}$
$\overline{u_{R\alpha}}\,(-\frac{2}{3})_0^{-1}$	$\bar{S}_1^{\dagger\,\alpha}\,(\frac{2}{3})$	$S_1^{\dagger\,\alpha}\,(-\frac{1}{3})$	$R_2^{\,\alpha i}\,\varepsilon_{ij}\,(\frac{7}{6})$	$S_{1\gamma}\,\varepsilon^{\alpha\beta\gamma}\,(\frac{1}{3})$ $\chi^{\dagger\alpha\beta}$	$\tilde{S}_{1\gamma}\,\varepsilon^{\alpha\beta\gamma}\,(\frac{4}{3})$ $\chi^{\dagger\alpha\beta}$	
$\overline{d_{R\alpha}}\,(\frac{1}{3})_0^{-1}$	$S_1^{\dagger\,\alpha}\,(-\frac{1}{3})$	$\tilde{S}_1^\dagger\,(-\frac{4}{3})$	$\tilde{R}_2^{\,\alpha i}\,\varepsilon_{ij}\,(\frac{1}{6})$	$\chi_\gamma^\dagger\,\varepsilon^{\alpha\beta\gamma}\,(-\frac{2}{3})$ $\chi^{\dagger\alpha\beta}$		
$L^i\,(-\frac{1}{2})_1^0$	$H^j\,\varepsilon_{ij}\,(\frac{1}{2})$	$H_i^\dagger\,(-\frac{1}{2})$	$\varphi\,\varepsilon_{ij}\,(1)$ Δ_{ij}			
$\overline{e_R}\,(-1)_{-1}^0$	$\varphi^\dagger\,(-1)$	$\varphi^\dagger\,(-2)$				
$\overline{\nu_R}\,(0)_{-1}^0$	$\varphi\,(0)$					

Baryon & lepton numbers

	G	G_{SM}	G_{vac}	$[B-L]$	F	M	B	L, L'
Fermions								
$F_L = \begin{pmatrix} Q \\ L \end{pmatrix}$	$(4,2,0)$	$Q\ \ (3,2,{}^1/6)$ $L\ \ (1,2,-{}^1/2)$	$u\ \ (3,{}^2/3)$ $d\ \ (3,-{}^1/3)$ $\nu\ \ (1,0)$ $e\ \ (1,-1)$	$\begin{pmatrix} +{}^1/3 \\ -1 \end{pmatrix}$	$+1$	$+1$	$\begin{pmatrix} +{}^1/3 \\ 0 \end{pmatrix}$	$\begin{pmatrix} 0 \\ +1 \end{pmatrix}$
$f_u^c = (u^c\ \nu^c)$	$(\bar{4},1,-{}^1/2)$	$u^c\ (\bar{3},1,-{}^2/3)$ $\nu^c\ \ (1,1,0)$	$(\bar{3},-{}^2/3)$ $(1,0)$	$(-{}^1/3\ \ 1)$	-1	-1	$(-{}^1/3\ \ 0)$	$(0\ \ -1)$
$f_d^c = (d^c\ e^c)$	$(\bar{4},1,{}^1/2)$	$d^c\ (\bar{3},1,{}^1/3)$ $e^c\ \ (1,1,1)$	$(\bar{3},{}^1/3)$ $(1,1)$	$(-{}^1/3\ \ 1)$	-1	-1	$(-{}^1/3\ \ 0)$	$(0\ \ -1)$
N	$(1,1,0)$	$(1,1,0)$	$(1,0)$	0	$+1$	0	0	$0,+1$
Scalars								
$\chi = \begin{pmatrix} \bar{S}_1^\dagger \\ \chi^0 \end{pmatrix}$	$(4,1,{}^1/2)$	$\bar{S}_1^\dagger\ (3,1,{}^2/3)$ $\chi^0\ \ (1,1,0)$	$(3,{}^2/3)$ $(1,0)$	$\begin{pmatrix} +{}^1/3 \\ -1 \end{pmatrix}$	0	$+1$	$\begin{pmatrix} +{}^1/3 \\ 0 \end{pmatrix}$	$\begin{pmatrix} 0 \\ +1 \end{pmatrix}, \begin{pmatrix} -1 \\ 0 \end{pmatrix}$
H	$(1,2,{}^1/2)$	$(1,2,{}^1/2)$	$H_1^+\ \ (1,1)$ $H_1^0\ \ (1,0)$	0	0	0	0	0
$\Phi = \begin{pmatrix} G & R_2 \\ \tilde{R}_2^\dagger & 0 \end{pmatrix}$ $+\sqrt{2}\,T^{15}H_2$	$(15,2,{}^1/2)$	$R_2\ \ (3,2,{}^7/6)$ $\tilde{R}_2^\dagger\ (\bar{3},2,-{}^1/6)$ $G\ \ (8,2,{}^1/2)$ $H_2\ \ (1,2,{}^1/2)$	$R_2^{5/3}\ \ (3,{}^5/3)$ $R_2^{2/3}\ \ (3,{}^2/3)$ $\tilde{R}_2^{-1/3\,\dagger}\ (\bar{3},{}^1/3)$ $\tilde{R}_2^{2/3\,\dagger}\ (\bar{3},-{}^2/3)$ $G^+\ \ (8,1)$ $G^0\ \ (8,0)$ $H_2^+\ \ (1,1)$ $H_2^0\ \ (1,0)$	$\begin{pmatrix} 0 & +{}^4/3 \\ -{}^4/3 & 0 \end{pmatrix}$	0	0	$\begin{pmatrix} 0 & +{}^1/3 \\ -{}^1/3 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & -1 \\ +1 & 0 \end{pmatrix}$
Gauge Bosons								
$A_\mu = \begin{pmatrix} G_\mu & X_\mu \\ X_\mu^* & 0 \end{pmatrix}$ $+T^{15}B'_\mu$	$(15,1,0)$	$G_\mu\ \ (8,1,0)$ $X_\mu\ \ (3,1,{}^2/3)$ $B'_\mu\ \ (1,1,0)$	$(8,0)$ $(3,{}^2/3)$ $(1,0)$	$\begin{pmatrix} 0 & +{}^4/3 \\ -{}^4/3 & 0 \end{pmatrix}$	0	0	$\begin{pmatrix} 0 & +{}^1/3 \\ -{}^1/3 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 & -1 \\ +1 & 0 \end{pmatrix}$
W_μ	$(1,3,0)$	$(1,3,0)$	$W_\mu^\pm\ \ (1,\pm1)$ $W_\mu^3\ \ (1,0)$	0	0	0	0	0
B_μ	$(1,1,0)$	$(1,1,0)$	$(1,0)$	0	0	0	0	0

$$M = (\#\ \text{upper}\ SU(4)\ \text{indices}) - (\#\ \text{lower}\ SU(4)\ \text{indices})$$