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The see-saw mechanism predictions within the SU(5) framework

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THE SEE-SAW MECHANISM PREDICTIONS WITHIN THE *SU*(5) FRAMEWORK

Ilja Doršner

ICTP 07
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•I.D. and Irina Mocioiu, in preparation.

•I.D. and Pavel Fileviez Pérez, **hep-ph/0612216**, **hep-ph/0606062**.

•I.D., P.F.P. and German Rodrigo **hep-ph/0607208**; I.D., P.F.P. and Ricardo Gonzalez Felipe, **hep-ph/0512068;** I.D. and P.F.P., **hep-ph/0504276**.

OUTLINE OF THE PRESENTATION

- **FERMION MASSES IN $SU(5)$**
- **PROTON DECAY**
- **UNIFICATION**
- **SIMPLE $SU(5)$ MODELS AND THEIR PREDICTIONS**
- **CONCLUSIONS**

FERMION MASSES…

NEUTRINO MASSES

The <u>S</u>tandard <u>M</u>odel (SM) content requires higher-dimensional operators† ($d > 4$) to accommodate massive neutrinos. The lowest order¤ one is the so-called $d = 5$ operator.

$$\mathcal{L} \sim \frac{\mathcal{O}}{\Lambda^{d-4}} \quad \overset{\dim(\mathcal{O})=d}{\Longrightarrow} \quad Y_{ab}\frac{L_a L_b \Psi_D \Psi_D}{\Lambda} \quad \overset{\nu\ \text{mass}}{\Longrightarrow} \quad (m_\nu)_{ab} = Y_{ab}\frac{\langle \Psi_D \rangle^2}{\Lambda}$$

$$L_a = \underbrace{(\mathbf{1}, \mathbf{2}, -1/2)_a}_{(SU(3), SU(2), U(1))} \qquad \Psi_D = (\mathbf{1}, \mathbf{2}, 1/2) \qquad L = \begin{pmatrix} \nu \\ e \end{pmatrix} \quad \Psi_D = \begin{pmatrix} \Psi^1 + \imath \Psi^2 \\ \Psi^3 + \imath \Psi^4 \end{pmatrix}$$

$$m_\nu \sim 10^{-1}\,\text{eV}, \qquad Y_{ab} \sim 1, \qquad \langle \Psi_D \rangle \sim 10^2\,\text{GeV} \qquad \Rightarrow \Lambda \leq 10^{14}\,\text{GeV}$$

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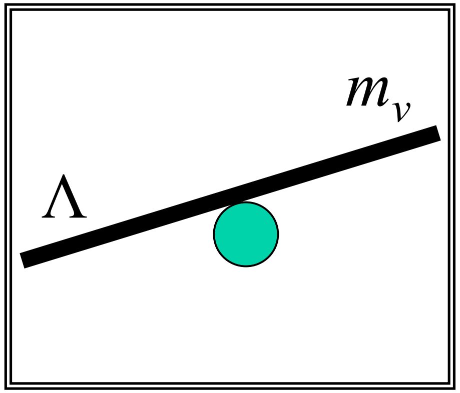
† S. Weinberg (1979).

SEESAW MECHANISM

(Why are the m_ν elements so small?)



•TYPE I■: fermion(s) — $(\mathbf{1},\mathbf{1},0)$

•TYPE II†: scalar — $(\mathbf{1},\mathbf{3},1)$

•TYPE III‡: fermion(s) — $(\mathbf{1},\mathbf{3},0)$

The SM transformation properties

■ P. Minkowski (1977); T. Yanagida (1979); M. Gell-Mann, P. Ramond and R. Slansky (1979); R.N. Mohapatra and G. Senjanović (1980).

† G. Lazarides, Q. Shafi and C. Wetterich (1981); R.N. Mohapatra and G. Senjanović (1981).

‡ R. Foot, H. Lew, X.G. He and G.C. Joshi (1989); E. Ma (1998).

SEESAW MECHANISM IN *SU*(5)

			SM	*SU*(5)
•TYPE I:	fermion(s)	—	(**1**,**1**,0)	**1**, **24**‡
•TYPE II:	scalar	—	(**1**,**3**,1)	**15**†
•TYPE III:	fermion(s)	—	(**1**,**3**,0)	**24**‡

† I.D. and P.F.P. (2005); I.D., P.F.P. and G. Rodrigo (2006); I.D., P. F.P. and R. Gonzalez Felipe (2006); F.R. Joaquim, A. Rossi (2006); I.D. and I. Mocioiu, in preparation.

‡ B. Bajc and G. Senjanović (2006); I.D. and P.F.P. (2006), B. Bajc, M. Nemevšek and G. Senjanović (2007), P.F.P. (2007).

CHARGED FERMION MASSES IN *SU*(5)

$$\overline{\mathbf{5}}_a = (\mathbf{1}, \mathbf{2}, -1/2)_a + (\overline{\mathbf{3}}, \mathbf{1}, 1/3)_a$$

$$L_a \equiv (\mathbf{1}, \mathbf{2}, -1/2)_a$$
$$d_a^C \equiv (\overline{\mathbf{3}}, \mathbf{1}, 1/3)_a$$

$$(\overline{\mathbf{5}}_i)_a = \begin{pmatrix} d_1^C \\ d_2^C \\ d_3^C \\ \nu \\ e \end{pmatrix}_a$$

$$\mathbf{10}_a = (\mathbf{1}, \mathbf{1}, 1)_a + (\mathbf{3}, \mathbf{2}, 1/6)_a + (\overline{\mathbf{3}}, \mathbf{1}, -2/3)_a$$

$$e_a^C \equiv (\mathbf{1}, \mathbf{1}, 1)_a$$
$$Q_a \equiv (\mathbf{3}, \mathbf{2}, 1/6)_a$$
$$u_a^C \equiv (\overline{\mathbf{3}}, \mathbf{1}, -2/3)_a$$

$$(\mathbf{10}^{ij})_a = \begin{pmatrix} 0 & u_3^C & -u_2^C & -u^1 & -d^1 \\ -u_3^C & 0 & u_1^C & -u^2 & -d^2 \\ u_2^C & -u_1^C & 0 & -u^3 & -d^3 \\ u^1 & u^2 & u^3 & 0 & -e^C \\ d^1 & d^2 & d^3 & e^C & 0 \end{pmatrix}_a$$

$$\mathbf{10} \times \mathbf{10} = \overline{\mathbf{5}} \oplus \overline{\mathbf{45}} \oplus \overline{\mathbf{50}}$$

$$\mathbf{10} \times \overline{\mathbf{5}} = \mathbf{5} \oplus \mathbf{45}$$

H. Georgi and S.L. Glashow (1974).

FERMION MASSES IN *SU*(5)

Up quark masses:

$$\mathbf{10} \times \mathbf{10} = \overline{\mathbf{5}} \oplus \overline{\mathbf{45}} \oplus \overline{\mathbf{50}}$$

Down quark and charged lepton masses:

$$\mathbf{10} \times \overline{\mathbf{5}} = \mathbf{5} \oplus \mathbf{45}$$

$$\mathbf{5}_H = \Psi = (\Psi_D,\ \Psi_T) = \underline{(\mathbf{1}, \mathbf{2}, 1/2)} + (\mathbf{3}, \mathbf{1}, -1/3)$$

$$\mathbf{45}_H = \Delta = (\Delta_1, \Delta_2, \Delta_3, \Delta_4, \Delta_5, \Delta_6, \Delta_7) = (\mathbf{8}, \mathbf{2}, 1/2) + (\overline{\mathbf{6}}, \mathbf{1}, -1/3) + (\mathbf{3}, \mathbf{3}, -1/3) + (\overline{\mathbf{3}}, \mathbf{2}, -7/6) + (\mathbf{3}, \mathbf{1}, -1/3) + (\overline{\mathbf{3}}, \mathbf{1}, 4/3) + \underline{(\mathbf{1}, \mathbf{2}, 1/2)}$$

Neutrino masses:

$$\overline{\mathbf{5}} \times \overline{\mathbf{5}} = \overline{\mathbf{10}} \oplus \overline{\mathbf{15}}$$

$$\mathbf{15}_H = \Phi = (\Phi_a,\ \Phi_b,\ \Phi_c) = \underline{(\mathbf{1}, \mathbf{3}, 1)} + (\mathbf{3}, \mathbf{2}, 1/6) + (\mathbf{6}, \mathbf{1}, -2/3)$$

FERMION MASSES IN *SU*(5)

(type II seesaw)

$$\mathcal{L} = (Y_1)_{ab}\ (\mathbf{10}^{\alpha\beta})_a(\overline{\mathbf{5}}_\alpha)_b\mathbf{5}^*_{H\beta} + (Y_2)_{ab}\ (\mathbf{10}^{\alpha\beta})_a(\overline{\mathbf{5}}_\delta)_b\mathbf{45}^{*\delta}_{H\alpha\beta}$$

$$+ (Y_3)_{ab}\ (\overline{\mathbf{5}}_\alpha)_a(\overline{\mathbf{5}}_\beta)_b\mathbf{15}^{\alpha\beta}_H$$

$$+ \epsilon_{\alpha\beta\gamma\delta\epsilon}\left[(Y_4)_{ab}\ (\mathbf{10}^{\alpha\beta})_a(\mathbf{10}^{\gamma\delta})_b\mathbf{5}^\epsilon_H + (Y_5)_{ab}\ (\mathbf{10}^{\alpha\beta})_a(\mathbf{10}^{\zeta\gamma})_b\mathbf{45}^{\delta\epsilon}_{H\zeta}\right] + \cdots$$

$M_D = \left(Y_1^T\ v_5^*\ +\ 2\ Y_2^T\ v_{45}^*\right)/\sqrt{2}$	$D_C^T\ M_D\ D = M_D^{\rm diag}$
$M_E = (Y_1\ v_5^*\ - 6\ Y_2\ v_{45}^*)/\sqrt{2}$	$E_C^T\ M_E\ E = M_E^{\rm diag}$
$M_N = Y_3\ v_{15}$	$N^T\ M_N\ N = M_N^{\rm diag}$
$M_U = \left[4\ (Y_4^T + Y_4)\ v_5\ -\ 8\ (Y_5^T - Y_5)\ v_{45}\right]/\sqrt{2}$	$U_C^T\ M_U\ U = M_U^{\rm diag}$

$$\langle \mathbf{5}_H \rangle = v_5/\sqrt{2} \qquad \langle \mathbf{15}_H \rangle = v_{15}$$

$$\langle \mathbf{45}_H \rangle_1^{15} = \langle \mathbf{45}_H \rangle_2^{25} = \langle \mathbf{45}_H \rangle_3^{35} = v_{45}/\sqrt{2}, \quad \sum_{i=1}^3 \langle \mathbf{45}_H \rangle_i^{i5} = -\langle \mathbf{45}_H \rangle_4^{45}$$

SU(5) SYMMETRY BREAKING

$$\mathbf{24}_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_{GUT}=M_{(X,Y)}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\bar{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$M_{GUT} \sim 10^{14-17}$ GeV

SU(5): $\langle \Sigma_{24} \rangle = \frac{v}{\sqrt{30}} \begin{pmatrix} 2 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & -3 & 0 \\ 0 & 0 & 0 & 0 & -3 \end{pmatrix} \Rightarrow SU(3) \times SU(2) \times U(1)$

α_{GUT}

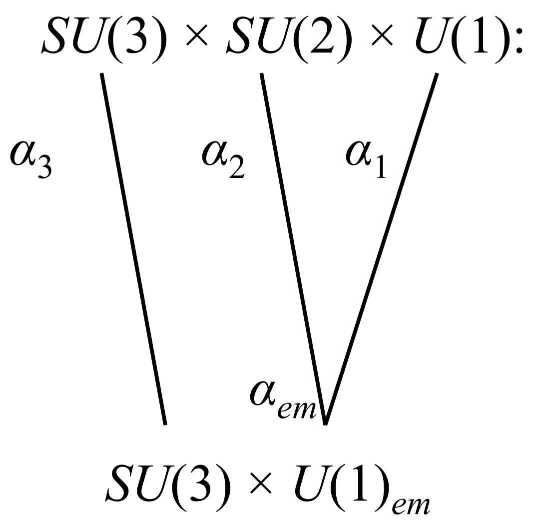
α_3 α_2 α_1

10^2 GeV

SU(3) × *SU*(2) × *U*(1):

$$\langle \Sigma_3 \rangle = v'$$
$$\langle \mathbf{5}_H \rangle = v_5/\sqrt{2} \Rightarrow SU(3) \times U(1)_{em}$$
$$\langle \mathbf{15}_H \rangle = v_{15}$$
$$\langle \mathbf{45}_H \rangle_1^{15} = \langle \mathbf{45}_H \rangle_2^{25} = \langle \mathbf{45}_H \rangle_3^{35} = v_{45}/\sqrt{2}$$

$SU(3) \times SU(2) \times U(1)$ SYMMETRY BREAKING[‡]



$$\langle \mathbf{5}_H \rangle = v_5/\sqrt{2}$$

$$\langle \Sigma_3 \rangle = v'$$

$$\langle \mathbf{15}_H \rangle = v_{15}$$

$$\langle \mathbf{45}_H \rangle_1^{15} = \langle \mathbf{45}_H \rangle_2^{25} = \langle \mathbf{45}_H \rangle_3^{35} = v_{45}/\sqrt{2}$$

⇓

$$\rho = \frac{M_W^2}{M_Z^2 \cos^2 \theta_W}$$

$$\rho = \frac{v_5^2 + v_{45}^2 + 4v_{15}^2 + 4v'^2}{v_5^2 + v_{45}^2 + 8v_{15}^2}$$

[‡] I.D. and I. Mocioiu, in preparation; H. Georgi and M. Machacek (1985); M.S. Chanowitz and M. Golden (1985).

CHARGED FERMION MASSES

(non-renormalizable terms with $\mathbf{5}_H$ and $\Sigma \equiv \mathbf{24}_H$•)

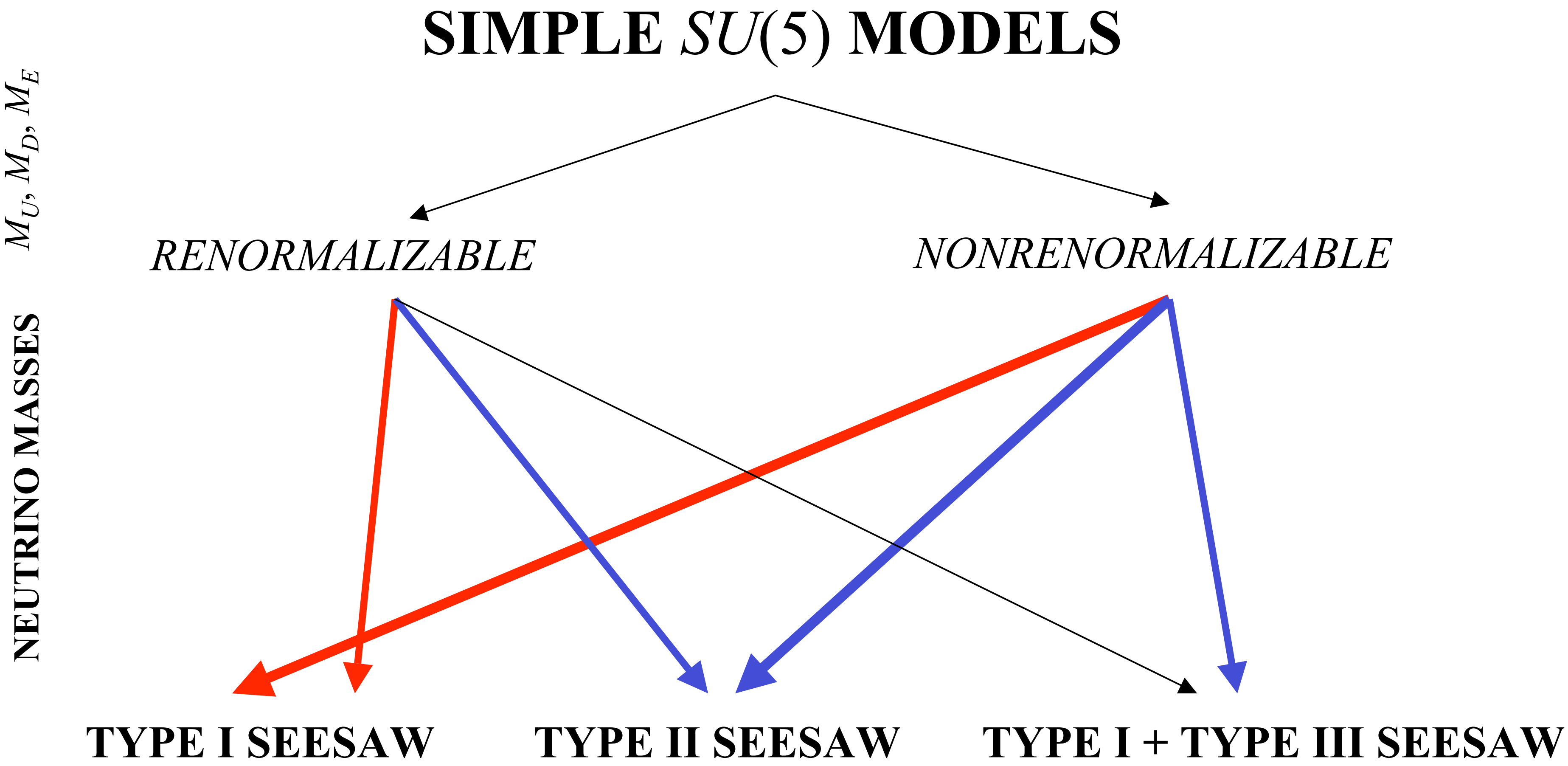
$$\mathcal{L} = (G_0)_{ab}\,(\mathbf{10}^{\alpha\beta})_a(\overline{\mathbf{5}}_\beta)_b\mathbf{5}^*_{H\alpha} + (G_1)_{ab}\,\mathbf{5}^*_{H\alpha}\frac{\Sigma^\alpha{}_\beta}{\Lambda}(\mathbf{10}^{\beta\gamma})_a(\overline{\mathbf{5}}_\gamma)_b + (G_2)_{ab}\,\mathbf{5}^*_{H\alpha}(\mathbf{10}^{\alpha\beta})_a\frac{\Sigma^\gamma{}_\beta}{\Lambda}(\overline{\mathbf{5}}_\gamma)_b$$

$$+\ \epsilon_{\alpha\beta\gamma\delta\epsilon}\left[(F_0)_{ab}\,(\mathbf{10}^{\alpha\beta})_a(\mathbf{10}^{\gamma\delta})_b\mathbf{5}^\epsilon_H + \left((F_1)_{ab}\,(\mathbf{10}^{\alpha\beta})_a(\mathbf{10}^{\gamma\delta})_b\mathbf{5}^\zeta_H + (F_2)_{ab}\,(\mathbf{10}^{\alpha\beta})_a(\mathbf{10}^{\gamma\zeta})_b\mathbf{5}^\delta_H\right)\frac{\Sigma^\epsilon{}_\zeta}{\Lambda}\right]$$

$$Y_D = -G_0^T + 3\,r\,G_1^T - 2\,r\,G_2^T + \cdots$$
$$Y_E = -G_0 + 3\,r\,G_1 + 3\,r\,G_2 + \cdots$$
$$Y_U = 4\,(F_0^T + F_0) - 12\,r\,(F_1^T + F_1) - 2\,r\,(4F_2^T - F_2) + \cdots$$

$$r = \frac{v}{\sqrt{30}\Lambda} \qquad M_{GUT} \equiv M_{(X,Y)} = \frac{\sqrt{5\pi\alpha_{GUT}}}{3}v \;\Rightarrow\; r = \frac{M_{GUT}}{\Lambda}\frac{1}{\sqrt{50\pi\alpha_{GUT}}}$$

•J.R. Ellis and M.K. Gaillard (1979).


SIMPLE $SU(5)$ MODELS
M_U, M_D, M_E
NEUTRINO MASSES
RENORMALIZABLE
NONRENORMALIZABLE
TYPE I SEESAW
TYPE II SEESAW
TYPE I + TYPE III SEESAW

PROTON DECAY IN *SU*(5)

(vector gauge boson *d*=6 contributions†)

$$O_1 = k^2\ \epsilon_{ijk}\ \epsilon_{\alpha\beta}\ \overline{u^C_{ia}}\ \gamma^\mu\ Q_{j\alpha a}\ \overline{e^C_b}\ \gamma_\mu\ Q_{k\beta b}$$

$$O_2 = k^2\ \epsilon_{ijk}\ \epsilon_{\alpha\beta}\ \overline{u^C_{ia}}\ \gamma^\mu\ Q_{j\alpha a}\ \overline{d^C_{kb}}\ \gamma_\mu\ L_{\beta b}$$

$$k^2 = 2\pi\alpha_{GUT} M^{-2}_{(X,Y)}$$

$$\Gamma(p \to \pi^0 e^+_\beta) = \frac{C(p,\pi)}{2} A_1^2 \left[A^2_{SR} \left| V_1^{11} V_3^{1\beta} \right|^2 + A^2_{SL} \left| V_1^{11} V_2^{\beta 1} + (\overbrace{V_1 K_1 V_{CKM} K_2}^{V_1 V_{UD}})^{11} (V_2 K_2^* V^\dagger_{CKM} K_1^*)^{\beta 1} \right|^2 \right]$$

$$\Gamma(p \to K^0 e^+_\beta) = C(p,K) A_2^2 \left[A^2_{SR} \left| V_1^{11} V_3^{2\beta} \right|^2 + A^2_{SL} \left| V_1^{11} V_2^{\beta 2} + (V_1 K_1 V_{CKM} K_2)^{12} (V_2 K_2^* V^\dagger_{CKM} K_1^*)^{\beta 1} \right|^2 \right]$$

$$V_1 = U_C^\dagger U \qquad V_2 = E_C^\dagger D \qquad V_3 = D_C^\dagger E \qquad V_{UD} = U^\dagger D = K_1 V_{CKM} K_2$$

$$C(a,b) = \frac{(m_a^2 - m_b^2)^2}{8\pi m_a^3 f_\pi^2}\ A_L^2\ |\alpha|^2\ k^4$$

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† P.F.P. hep-ph/0403286 ; I.D. and P.F.P. hep-ph/0409095.

PROTON DECAY

$$G_F = 1.16637(1) \times 10^{-5}\,\mathrm{GeV}^{-2}$$

$$k^2 = 2\pi\alpha_{GUT} M_{(X,Y)}^{-2}$$

$$\alpha_{GUT} = 1/36 \qquad M_{GUT} = 10^{15.5}\,\mathrm{GeV}$$

$$\Downarrow$$

$$k^2 \simeq 2 \times 10^{-32}\,\mathrm{GeV}^{-2}$$

PROTON DECAY IN $SU(5)$

(vector gauge boson d=6 contributions)

$$U_C = U \qquad D_C = E \qquad E_C = D$$

$$\Gamma(p \to \pi^0 e^+) = \frac{C(p,\pi)}{2} A_1^2 \left[A_{SR}^2 + A_{SL}^2 (1 + V_{ud}^2)^2\right]$$

$$\tau^{\text{exp.}}(p \to \pi^0 e^+) > 4.4 \times 10^{33}\,\text{years}$$

$$\tau^{\text{tho.}}(p \to \pi^0 e^+) = 1.0 \times 10^{32} \alpha_{GUT}^{-2} \left(\frac{M_{GUT}}{10^{16}\,\text{GeV}}\right)^4 \text{years}$$

$$M_{GUT} > 2.6 \times 10^{16} \sqrt{\alpha_{GUT}}\,\text{GeV}$$

$A_1 = 1 + D + F,\ A_2 = 1 + \frac{m_p}{m_B}(D - F),\ m_p = 938.3\,\text{MeV},\ D = 0.81,\ F = 0.44,\ m_B = 1150\,\text{MeV},$
$f_\pi = 139\,\text{MeV},\ A_L = 1.25,\ \alpha = 0.015\,\text{GeV}^3,\ |V_{ud}| = 0.97377,\ |V_{ub}| = 3.96 \times 10^{-3},\ A_{SL} = A_{SR} = 2.5$

PROTON DECAY IN *SU*(5)

(vector gauge boson *d*=6 contributions[†])

$$\Gamma(p \to \pi^0 e^+_\beta) = \frac{C(p,\pi)}{2} A_1^2 \left[A_{SR}^2 \left| V_1^{11} V_3^{1\beta} \right|^2 + A_{SL}^2 \left| V_1^{11} V_2^{\beta 1} + (\overbrace{V_1 K_1 V_{CKM} K_2}^{V_1 V_{UD}})^{11} (V_2 K_2^* V_{CKM}^\dagger K_1^*)^{\beta 1} \right|^2 \right]$$

$$\Gamma(p \to K^0 e^+_\beta) = C(p,K) A_2^2 \left[A_{SR}^2 \left| V_1^{11} V_3^{2\beta} \right|^2 + A_{SL}^2 \left| V_1^{11} V_2^{\beta 2} + (V_1 K_1 V_{CKM} K_2)^{12} (V_2 K_2^* V_{CKM}^\dagger K_1^*)^{\beta 1} \right|^2 \right]$$

$$V_1 = \begin{pmatrix} 0 & \star & \star \\ \star & \star & \star \\ \star & \star & \star \end{pmatrix} \qquad V_1 V_{UD} = \begin{pmatrix} 0 & 0 & e^{i\phi} \\ \star & \star & 0 \\ \star & \star & 0 \end{pmatrix}$$

$$(V_1)^\dagger V_1 V_{UD} \sim V_{CKM} = \begin{pmatrix} \star & \star & 0 \\ \star & \star & \star \\ \star & \star & \star \end{pmatrix} \qquad \Rightarrow V_{ub} = 0$$

[†] S. Nandi, A. Stern and E.C.G. Sudarshan (1982).

PROTON DECAY IN GUTS

(vector gauge boson *d*=6 contributions[‡])

$$(V_1 V_{UD})^{1\alpha} = 0; \qquad V_2^{\alpha\beta} = 0 \qquad V_3^{\alpha\beta} = 0 \qquad (\alpha = 1 \text{ or } \beta = 1)$$

$$\Gamma(p \to K^0 \mu^+) = C(p, K) A_2^2 \left[A_{SR}^2 + A_{SL}^2 \right] |V_{ub}|^2$$

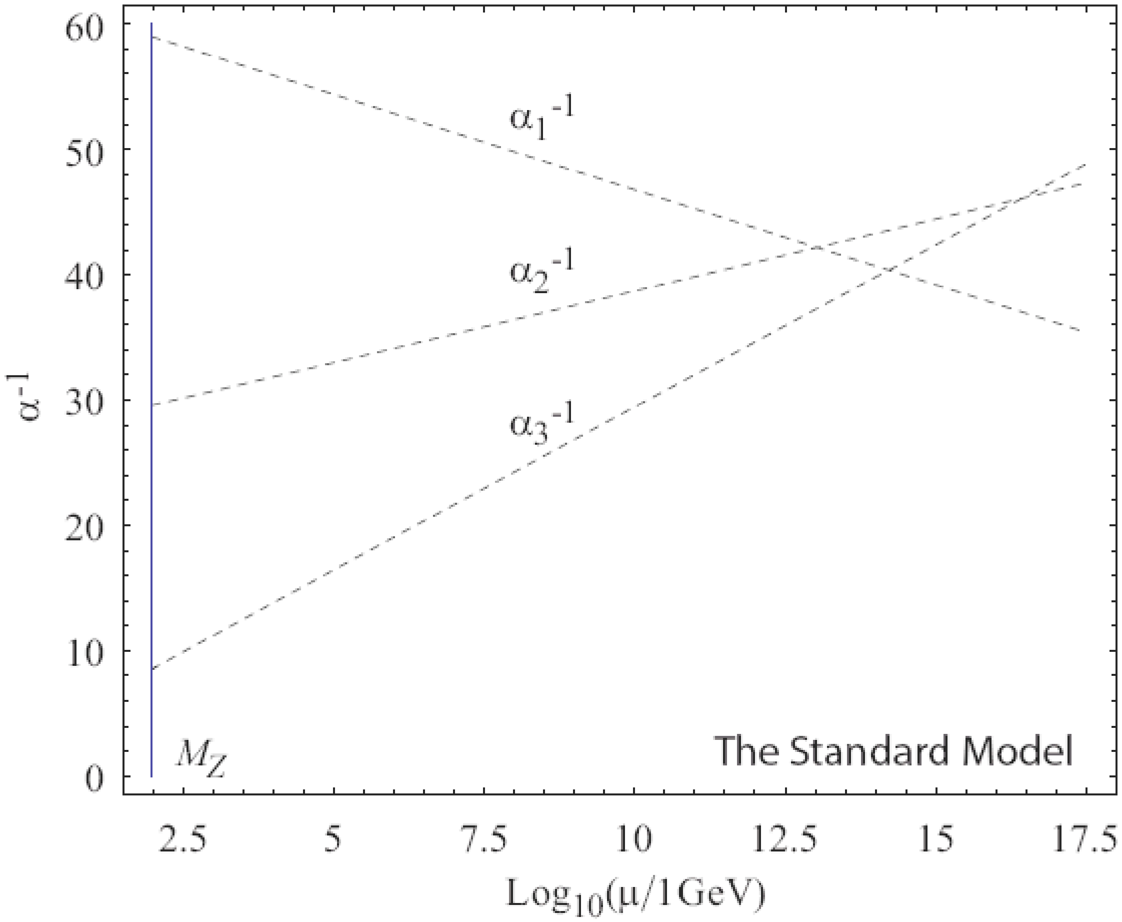
$$\tau^{\text{exp.}} > 4.4 \times 10^{33} \text{ years}$$

$$\tau^{\text{tho.}} = 2.3 \times 10^{38} \alpha_{GUT}^{-2} \left(\frac{M_{GUT}}{10^{16}\,\text{GeV}} \right)^4 \text{ years}$$

$$M_{GUT} > 9.9 \times 10^{14} \sqrt{\alpha_{GUT}}\,\text{GeV}$$

[‡] I.D. and P. F.P., "**How long could we live?**" *Phys. Lett. B* **625** (2005).

UNIFICATION OF GAUGE COUPLINGS IN THE SM



DATA: PDG 2006

UNIFICATION OF GAUGE COUPLINGS

$$\frac{B_{23}}{B_{12}} = \frac{5}{8}\frac{\sin^2\theta_W(M_Z) - \alpha_{em}(M_Z)/\alpha_s(M_Z)}{3/8 - \sin^2\theta_W(M_Z)} = 0.716 \pm 0.005$$

$$\ln\frac{M_{GUT}}{M_Z} = \frac{16\pi}{5}\frac{3/8 - \sin^2\theta_W(M_Z)}{\alpha_{em}(M_Z)\ B_{12}} = \frac{184.9 \pm 0.2}{B_{12}}$$

$$B_{ij} = B_i - B_j, \qquad B_i = \sum_I b_{iI}\, r_I, \qquad r_I = \frac{\ln M_{GUT}/M_I}{\ln M_{GUT}/M_Z}, \qquad (0 \le r_I \le 1)$$

$$B_1^{\mathrm{SM}} = 40/10 + 1/10 \qquad B_2^{\mathrm{SM}} = -20/6 + 1/6 \qquad B_3^{\mathrm{SM}} = -7$$

$$B_{23}^{\mathrm{SM}}/B_{12}^{\mathrm{SM}} = 0.53$$

Georgi-Glashow $SU(5)$[‡]

The Georgi-Glashow GUT content

HIGGS SECTOR:

$$\mathbf{24}_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_V = M_{GUT}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$$\mathbf{5}_H = \Psi = (\Psi_D,\ \Psi_T) = (\mathbf{1},\mathbf{2},1/2) + (\mathbf{3},\mathbf{1},-1/3)$$

MATTER SECTOR:

$$\mathbf{10}_a = (\mathbf{1},\mathbf{1},1) + (\mathbf{3},\mathbf{2},1/6) + (\overline{\mathbf{3}},\mathbf{1},-2/3)$$

$$\overline{\mathbf{5}}_a = (\mathbf{1},\mathbf{2},-1/2) + (\overline{\mathbf{3}},\mathbf{1},1/3)$$

GG model is ruled out by low-energy experiments.

‡ Georgi and Glashow (1974)

Doršner-Fileviez Pérez $SU(5)$[‡]

HIGGS SECTOR:

$$24_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_V = M_{GUT}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$$5_H = \Psi = (\Psi_D,\ \Psi_T) = (\mathbf{1},\mathbf{2},1/2) + (\mathbf{3},\mathbf{1},-1/3)$$

MATTER SECTOR:

$$10_a = (\mathbf{1},\mathbf{1},1) + (\mathbf{3},\mathbf{2},1/6) + (\overline{\mathbf{3}},\mathbf{1},-2/3)$$

$a = 1,2,3$

$$\overline{5}_a = (\mathbf{1},\mathbf{2},-1/2) + (\overline{\mathbf{3}},\mathbf{1},1/3)$$

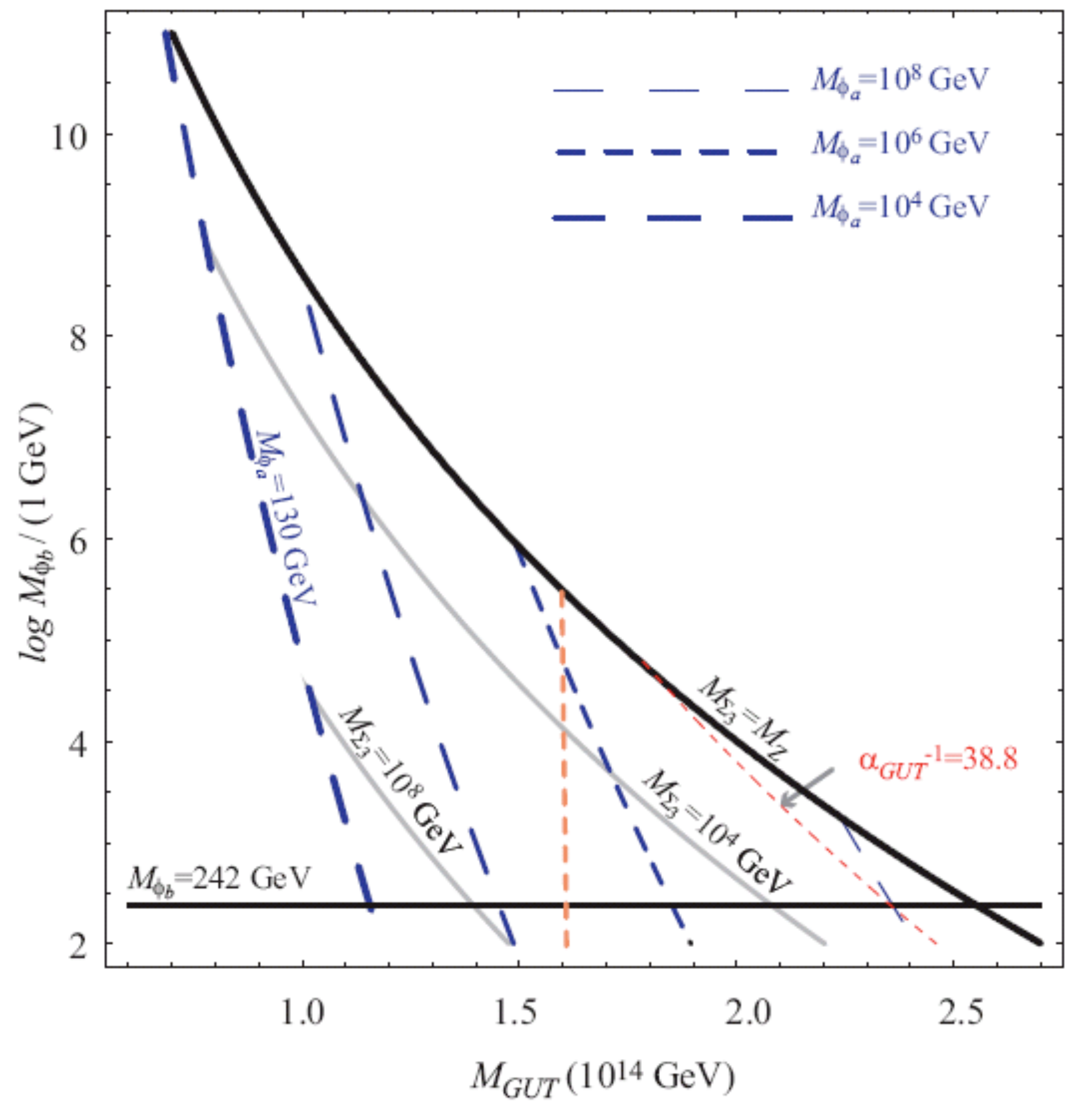
The Georgi-Glashow GUT content

EXTRA SCALAR:

$$15_H = \Phi = (\underline{\Phi_a},\ \Phi_b,\ \Phi_c) = \underline{(\mathbf{1},\mathbf{3},1)} + (\mathbf{3},\mathbf{2},1/6) + (\mathbf{6},\mathbf{1},-2/3)$$

The Doršner-Fileviez Pérez $SU(5)$[‡] content

‡ I.D. and P.F.P., hep-ph/0504276; I.D., P.F.P. and R.G. Felipe hep-ph/0512068; I.D., P.F.P. and G. Rodrigo hep-ph/0607208.



PREDICTIONS:

i) Light leptoquarks Φ_b.

ii) Light Σ_3 scalar.

iii) $\max(\tau_p^{\text{tho.}}) \sim 10\ \tau_p^{\text{exp.}}$.

	SM	Ψ_T	Σ_8	Σ_3	Φ_a	Φ_b	Φ_c
ΔB_{23}	$\frac{11}{3}+\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{3}{6}$	$\frac{2}{6}$	$\frac{4}{6}$	$\frac{1}{6}$	$-\frac{5}{6}$
ΔB_{12}	$\frac{22}{3}-\frac{1}{15}$	$\frac{1}{15}$	0	$-\frac{5}{15}$	$-\frac{1}{15}$	$-\frac{7}{15}$	$\frac{8}{15}$

Georgi-Jarlskog *SU*(5)[‡]

HIGGS SECTOR:

$$\mathbf{24}_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_V=M_{GUT}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$$\mathbf{5}_H = \Psi = (\Psi_D,\ \Psi_T) = (\mathbf{1},\mathbf{2},1/2) + (\mathbf{3},\mathbf{1},-1/3)$$

MATTER SECTOR:

$$\mathbf{10}_a = (\mathbf{1},\mathbf{1},1) + (\mathbf{3},\mathbf{2},1/6) + (\overline{\mathbf{3}},\mathbf{1},-2/3)$$

$a = 1,2,3$

$$\overline{\mathbf{5}}_a = (\mathbf{1},\mathbf{2},-1/2) + (\overline{\mathbf{3}},\mathbf{1},1/3)$$

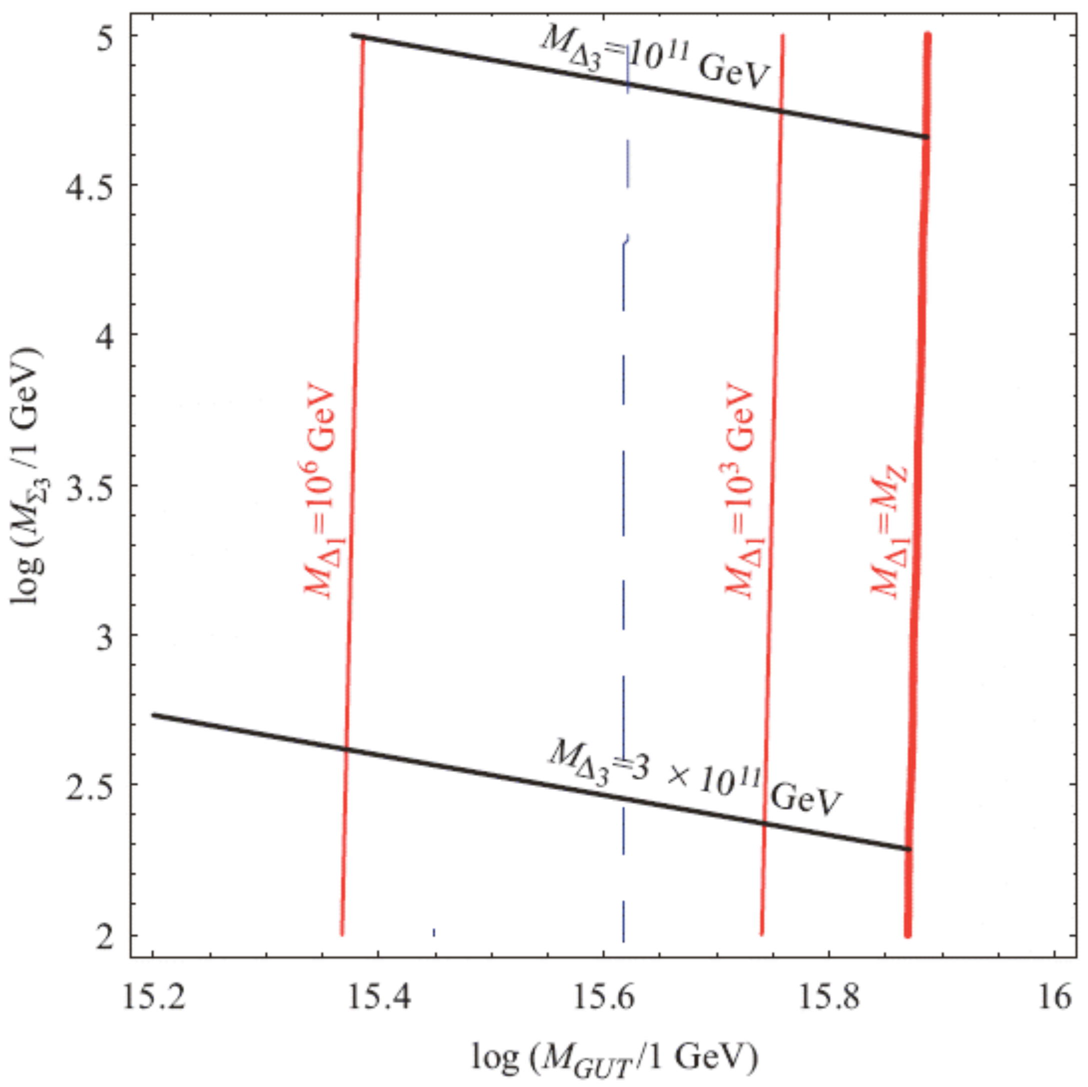
The Georgi-Glashow GUT content

The Georgi-Jarlskog *SU*(5)[‡] content

EXTRA SCALAR:

$$\mathbf{45}_H = \Delta = (\Delta_1,\Delta_2,\Delta_3,\Delta_4,\Delta_5,\Delta_6,\Delta_7) = (\mathbf{8},\mathbf{2},1/2) + (\overline{\mathbf{6}},\mathbf{1},-1/3)$$
$$+ (\mathbf{3},\mathbf{3},-1/3) + (\overline{\mathbf{3}},\mathbf{2},-7/6) + (\mathbf{3},\mathbf{1},-1/3) + (\overline{\mathbf{3}},\mathbf{1},4/3) + (\mathbf{1},\mathbf{2},1/2)$$

[‡] I.D. and P.F.P., hep-ph/0504276; I.D. and Irina Mocioiu, in preparation.



PREDICTIONS:

If certain class of d=6 proton decay operators is not suppressed then the model with the Georgi-Jarlskog particle content with the type I seesaw is ruled out!

NOTE:

$$M_{GUT} > 2.6\times 10^{16}\sqrt{\alpha_{GUT}}\ \text{GeV}$$

$$M_{\text{SCALAR}} > 10^{12}\ \text{GeV}$$

	SM	Ψ_T	Σ_8	Σ_3	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7
ΔB_{23}	$\frac{11}{3}+\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{3}{6}$	$\frac{2}{6}$	$-\frac{4}{6}$	$-\frac{5}{6}$	$\frac{9}{6}$	$\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{1}{6}$	$\frac{1}{6}$
ΔB_{12}	$\frac{22}{3}-\frac{1}{15}$	$\frac{1}{15}$	0	$-\frac{5}{15}$	$-\frac{8}{15}$	$\frac{2}{15}$	$-\frac{27}{15}$	$\frac{17}{15}$	$\frac{1}{15}$	$\frac{16}{15}$	$-\frac{1}{15}$

Bajc-Senjanović $SU(5)$[‡]

HIGGS SECTOR:

$$\mathbf{24}_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_V = M_{GUT}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$$\mathbf{5}_H = \Psi = (\Psi_D,\ \Psi_T) = (\mathbf{1},\mathbf{2},1/2) + (\mathbf{3},\mathbf{1},-1/3)$$

MATTER SECTOR:

$$\mathbf{10}_a = (\mathbf{1},\mathbf{1},1) + (\mathbf{3},\mathbf{2},1/6) + (\overline{\mathbf{3}},\mathbf{1},-2/3)$$

$a = 1,2,3$

$$\overline{\mathbf{5}}_a = (\mathbf{1},\mathbf{2},-1/2) + (\overline{\mathbf{3}},\mathbf{1},1/3)$$

The Georgi-Glashow GUT content

The Bajc-Senjanović $SU(5)$[‡] content

EXTRA MATTER:

$$\mathbf{24} = \rho = (\rho_8,\ \underline{\rho_3},\ \rho_{(3,2)},\ \rho_{(\bar{3},2)},\ \underline{\rho_{24}})$$

$$= (\mathbf{8},\mathbf{1},0) + \underline{(\mathbf{1},\mathbf{3},0)} + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + \underline{(\mathbf{1},\mathbf{1},0)}$$

‡ B. Bajc and G. Senjanović, hep-ph/0612029.

	SM	Ψ_T	Σ_8	Σ_3	ρ_8	ρ_3	$\rho_{(3,2)}$	$\rho_{(3,2)}$
ΔB_{23}	$\frac{11}{3}+\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{3}{6}$	$\frac{2}{6}$	-2	$\frac{8}{6}$	$\frac{2}{6}$	$\frac{2}{6}$
ΔB_{12}	$\frac{22}{3}-\frac{1}{15}$	$\frac{1}{15}$	0	$-\frac{5}{15}$	0	$-\frac{20}{15}$	$\frac{10}{15}$	$\frac{10}{15}$

LIGHT TRIPLETS‡

‡ B. Bajc and G. Senjanović, hep-ph/0612029; I.D. and P.F.P. hep-ph/0612216; B. Bajc M. Nemevšek and G. Senjanović, hep-ph/0703080.

Doršner-Mocioiu $SU(5)$[‡]

HIGGS SECTOR:

$$24_H = \Sigma = (\Sigma_8,\ \Sigma_3,\ \overbrace{\Sigma_{(3,2)},\ \Sigma_{(\bar{3},2)}}^{M_V = M_{GUT}},\ \Sigma_{24})$$
$$= (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{3},\mathbf{2},-5/6) + (\overline{\mathbf{3}},\mathbf{2},5/6) + (\mathbf{1},\mathbf{1},0)$$

$$5_H = \Psi = (\Psi_D,\ \Psi_T) = (\mathbf{1},\mathbf{2},1/2) + (\mathbf{3},\mathbf{1},-1/3)$$

MATTER SECTOR:

$$10_a = (\mathbf{1},\mathbf{1},1) + (\mathbf{3},\mathbf{2},1/6) + (\overline{\mathbf{3}},\mathbf{1},-2/3)$$

$a = 1,2,3$

$$\overline{5}_a = (\mathbf{1},\mathbf{2},-1/2) + (\overline{\mathbf{3}},\mathbf{1},1/3)$$

The Georgi-Glashow GUT content

EXTRA SCALARS:

$$45_H = \Delta = (\Delta_1,\Delta_2,\Delta_3,\Delta_4,\Delta_5,\Delta_6,\Delta_7) = (\mathbf{8},\mathbf{2},1/2) + (\overline{\mathbf{6}},\mathbf{1},-1/3)$$
$$+ (\mathbf{3},\mathbf{3},-1/3) + (\overline{\mathbf{3}},\mathbf{2},-7/6) + (\mathbf{3},\mathbf{1},-1/3) + (\overline{\mathbf{3}},\mathbf{1},4/3) + (\mathbf{1},\mathbf{2},1/2)$$

$$15_H = \Phi = (\Phi_a,\ \Phi_b,\ \Phi_c) = (\mathbf{1},\mathbf{3},1) + (\mathbf{3},\mathbf{2},1/6) + (\mathbf{6},\mathbf{1},-2/3)$$

The Doršner-Mocioiu $SU(5)$[‡] content

[‡] I.D. and Irina Mocioiu, in preparation.

	SM	Ψ_T	Σ_8	Σ_3	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	Φ_a	Φ_b	Φ_c
ΔB_{23}	$\frac{11}{3}+\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{3}{6}$	$\frac{2}{6}$	$-\frac{4}{6}$	$-\frac{5}{6}$	$\frac{9}{6}$	$\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{1}{6}$	$\frac{1}{6}$	$\frac{4}{6}$	$\frac{1}{6}$	$-\frac{5}{6}$
ΔB_{12}	$\frac{22}{3}-\frac{1}{15}$	$\frac{1}{15}$	0	$-\frac{5}{15}$	$-\frac{8}{15}$	$\frac{2}{15}$	$-\frac{27}{15}$	$\frac{17}{15}$	$\frac{1}{15}$	$\frac{16}{15}$	$-\frac{1}{15}$	$-\frac{1}{15}$	$-\frac{7}{15}$	$\frac{8}{15}$

LIGHT SCALARS[‡]

[‡] I.D. and Irina Mocioiu, in preparation.

Let us fix the mass of *both* the scalar triplet Φ_a and fermionic triplet ρ_3 at 300 GeV in order to insure their detection at LHC and then find the maximal value of the GUT scale (or minimum of B_{12}) that one can have in both cases. This exercise yields the following:

MODEL	A_{SR}	A_{SL}	$(M_{GUT}/10^{16}\ \text{GeV})$	α_{GUT}^{-1}	$\tau^{d=6\ \text{gauge}}/\tau^{\text{exp.}}$	$\tau^{d=6\ \text{scalar}}/\tau^{\text{exp.}}$
Doršner-Mocioiu	2.8	3.0	1.4	29.4	51	1
Bajc-Senjanović	2.5	2.7	1.5	37.6	150	15000

$$A_{SL(R)} = \prod_{M_I=M_Z}^{M_I \le M_{GUT}} \left[\frac{\alpha_3(M_{I+1})}{\alpha_3(M_I)}\right]^{\frac{2}{\sum_{J=0}^{I} b_{3J}}} \left[\frac{\alpha_2(M_{I+1})}{\alpha_2(M_I)}\right]^{\frac{9}{4\sum_{J=0}^{I} b_{2J}}} \left[\frac{\alpha_1(M_{I+1})}{\alpha_1(M_I)}\right]^{\frac{23(11)}{20\sum_{J=0}^{I} b_{1J}}}$$

CONCLUSIONS

1) The simplest $SU(5)$ **models with the type I seesaw mechanism are ruled out under the** ***usual*** **assumptions.**

2) Other realistic nonSUSY $SU(5)$ **GUT theories could be tested at LHC.**

Three specific $SU(5)$ **GUT models that aim in that direction are: (i) nonrenormalizable** $SU(5)$ **with the type II seesaw, (ii) renormalizable** $SU(5)$ **with the type II seesaw, and** (iii) nonrenormalizable $SU(5)$ with the hybrid–type I + type III–seesaw scenario.

CONCLUSIONS (CONTINUED)

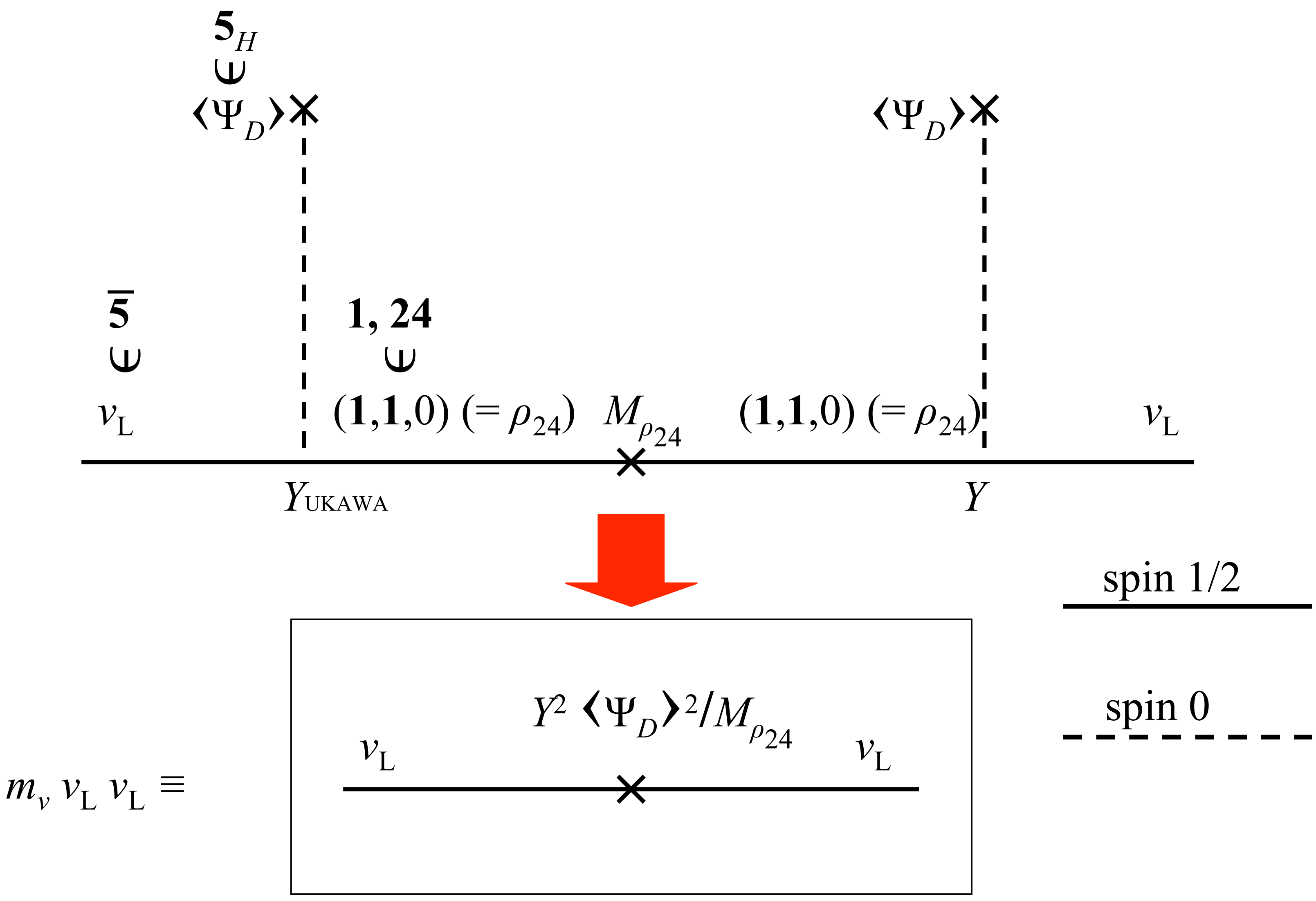
In all three cases interesting signatures include (in)direct observation of exotic light particles, enhanced rates for specific rare processes, observable proton decay and, most importantly, correlation between these processes and the parameters in the neutrino sector. Latter could also allow us to experimentally probe the underlying seesaw mechanism.

Even though these models are extremely fine tuned they are very predictive and hence verifiable as well as falsifiable.

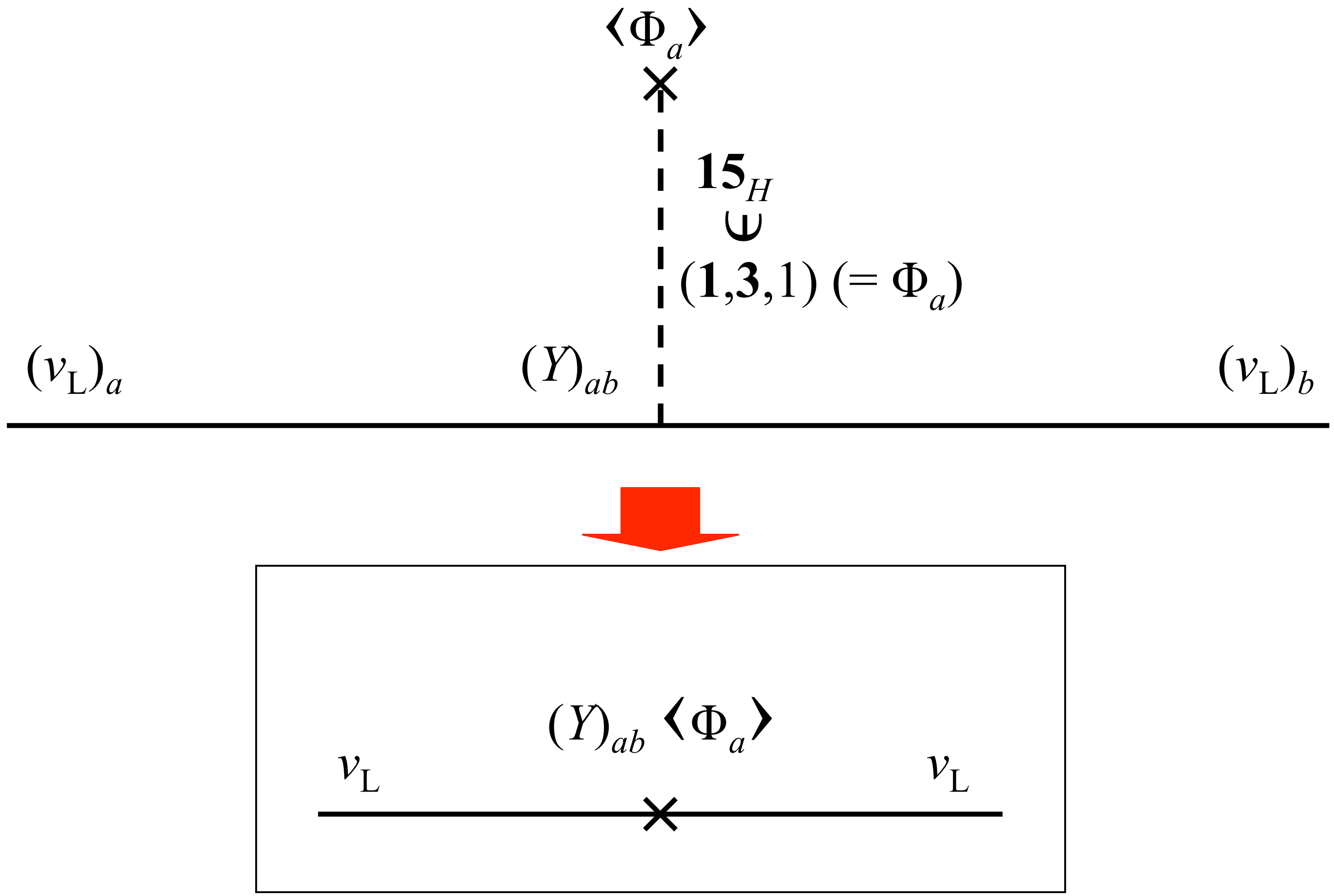
$M_{\Sigma_3} = M_Z \qquad M_{\Sigma_8} = 10^5\,\mathrm{GeV} \qquad M_{\Delta_1} = M_Z \qquad M_{\Delta_2} = 2 \times 10^{10}\,\mathrm{GeV} \qquad M_{\Delta_7} = M_Z$

$M_{\Sigma_3} = M_Z \qquad M_{\rho_8} = 1.5 \times 10^6\,\mathrm{GeV}$

TYPE I SEESAW IN $SU(5)$

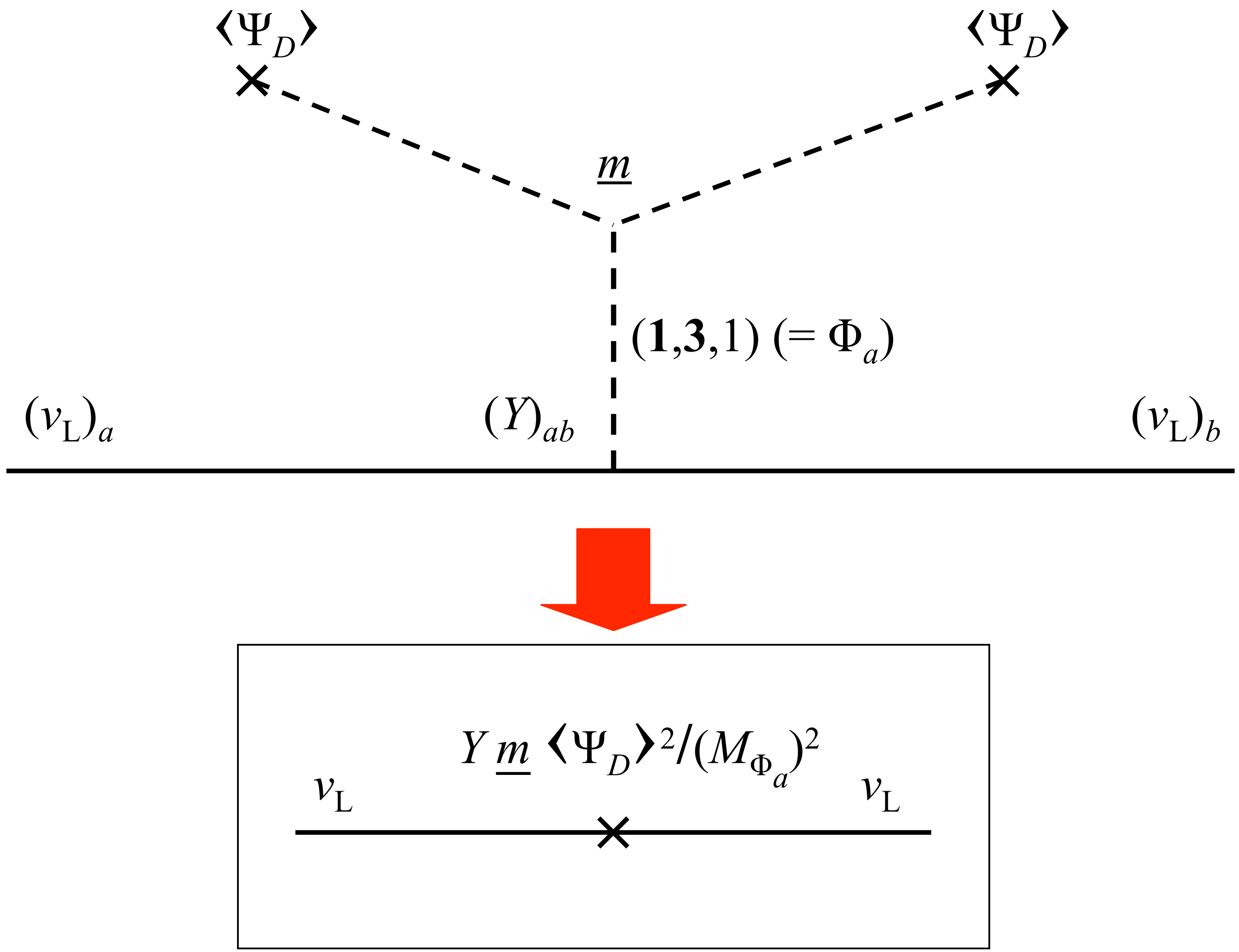


TYPE II SEESAW IN $SU(5)$†



†F. Buccella, G.B. Gelmini, A. Masiero and M. Roncadelli (1984).

TYPE II SEESAW IN $SU(5)$[†]



† I.D. and P.F.P. (2005).

TYPE III SEESAW IN $SU(5)$