Relation between neutrino sector and proton decay in flipped SU(5) unification

Helena Kolešová

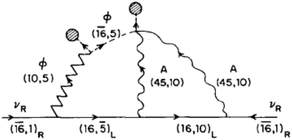
Faculty of Nuclear Sciences and Physical Engineering, CTU in Prague

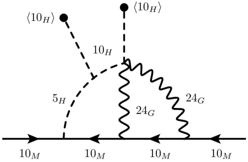
Institute of Particle and Nuclear Physics, FMP CU

Joint work with Michal Malinský (IPNP) and Carolina Arbeláez Rodriguez (University of Valencia)


Outline

1. Witten's mechanism (=loop generation of RH neutrino masses) in SO(10) unification

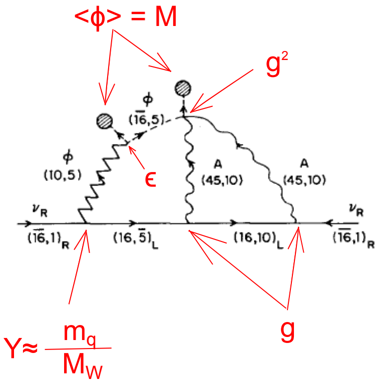




2. Witten's mechanism in non-SUSY flipped SU(5) unification
3. Interplay between neutrino sector and proton decay predictions
4. Witten's mechanism in SUSY: Qualitatively the same conclusions are valid if split SUSY considered!

Witten's mechanism

- Edward Witten: Neutrino Masses in the Minimal O(10) Theory, Phys. Lett. B91, 81 (1980)



We can then estimate a right-handed neutrino mass

$$m_{\nu_R} = (m_q/M_W)\epsilon(\alpha/\pi)^2 M . \qquad (3)$$

...

Thus, from (4), $m_{\nu_L} = m_q^2/m_{\nu_R}$, so, using our previous estimate for m_{ν_R}, we find

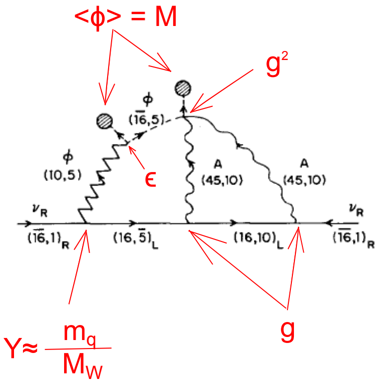
$$m_{\nu_L} = m_q\,[\epsilon(\alpha/\pi)^2]^{-1} M_W/M . \qquad (5)$$

With our previous numbers, $M = 10^{15}$ GeV and $\epsilon = 1/10$, this means that for each generation $m_{\nu_L} = 10^{-7}\, m_q$.

For the electron neutrino, this means $m_\nu \approx 1$ eV, while for the muon neutrino $m_{\nu_\mu} = 10^{-7} m_c \approx 100$ eV and for the τ neutrino $m_{\nu_\tau} = 10^{-7} m_t$ and might be 1–10 keV, depending on the t quark mass.

Witten's mechanism

- Edward Witten: Neutrino Masses in the Minimal O(10) Theory, Phys. Lett. B91, 81 (1980)



We can then estimate a right-handed neutrino mass

$$m_{\nu\mathrm{R}} = (m_\mathrm{q}/M_\mathrm{W})\epsilon(\alpha/\pi)^2 M \,. \qquad (3)$$

...

Thus, from (4), $m_{\nu\mathrm{L}} = m_\mathrm{q}^2/m_{\nu\mathrm{R}}$, so, using our previous estimate for $m_{\nu\mathrm{R}}$, we find

$$m_{\nu\mathrm{L}} = m_\mathrm{q}\,[\epsilon(\alpha/\pi)^2]^{-1} M_\mathrm{W}/M \,. \qquad (5)$$

With our previous numbers, $M = 10^{15}$ GeV and $\epsilon = 1/10$, this means that for each generation $m_{\nu\mathrm{L}} = 10^{-7}\, m_\mathrm{q}$.

For the electron neutrino, this means $m_\nu \approx 1$ eV, while for the muon neutrino $m_{\nu_\mu} = 10^{-7} m_\mathrm{c} \approx 100$ eV and for the τ neutrino $m_{\nu_\tau} = 10^{-7} m_\mathrm{t}$ and might be 1–10 keV, depending on the t quark mass.

- Precise measurements of $\sin\theta_W \Rightarrow$ gauge coupling unification for non-SUSY models only if $M \sim 10^{13}$ GeV (intermediate scale) $\Rightarrow m_{\nu_L}$ too big.

Witten's mechanism in the flipped SU(5) unification

flipped SU(5) [De Rújula, Georgi, Glashow (1980)], [Barr (1982)], [Derendinger, Kim, Nanopoulos (1984)]

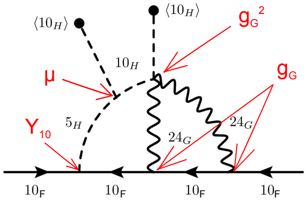
- based on gauge group $SU(5) \times U(1)_X \Rightarrow$ no constraints from gauge unification
- SM hypercharge $Y = \frac{1}{5}(X - T_{24}) \Rightarrow$

$$1_F^{X=+5} = e^c, \quad \bar{5}_F^{X=-3} = \begin{pmatrix} u_1^c \\ u_2^c \\ u_3^c \\ e \\ -\nu \end{pmatrix}, \quad 10_F^{X=+1} = \begin{pmatrix} 0 & d_3^c & -d_2^c & u_1 & d_1 \\ -d_3^c & 0 & d_1^c & u_2 & d_2 \\ d_2^c & -d_1^c & 0 & u_3 & d_3 \\ -u_1 & -u_2 & -u_3 & 0 & \nu^c \\ -d_1 & -d_2 & -d_3 & -\nu^c & 0 \end{pmatrix}$$

- $SU(5) \times U(1)_X \xrightarrow{\langle 10_H^{X=+1} \rangle \sim 10^{16}\text{ GeV}}$ SM, SM Higgs $\in 5_H^{X=-2}$

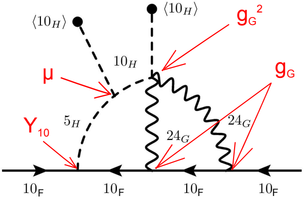
$$\mathcal{L} \ni Y_{10} 10_F 10_F 5_H + Y_{\bar{5}} 10_F \bar{5}_F 5_H^* + Y_1 \bar{5}_F 1_F 5_H + h.c. \quad \Rightarrow \quad M_\nu^D = M_u^T$$

$$M_{\nu_R} = \left(\frac{1}{16\pi^2}\right)^2 g_G^4 \, Y_{10} \, \mu \frac{\langle 10_H \rangle^2}{M_G^2} \times \mathcal{O}(1)$$



Witten's mechanism in the flipped SU(5) unification

$$M_{\nu_R} = \left(\frac{1}{16\pi^2}\right)^2 g_G^4\, Y_{10}\, \mu \frac{\langle 10_H \rangle^2}{M_G^2} \times \mathcal{O}(1)$$



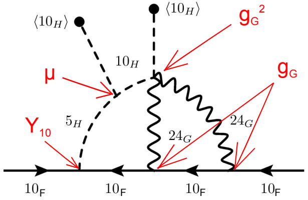
- $M_G \approx g_G \langle 10_H \rangle$ (VB mass), $\mu \leq \lambda \langle 10_H \rangle$ (non-tachyonic spectrum).

Perturbativity of couplings $\Rightarrow$

$$\boxed{\max_{i,j \in \{1,2,3\}} |(M_{\nu_R})_{ij}| \leq \frac{\alpha_G}{16\pi^2} M_G \times \mathcal{O}(1)}$$

Witten's mechanism in the flipped SU(5) unification

$$M_{\nu_R} = \left(\frac{1}{16\pi^2}\right)^2 g_G^4\, Y_{10}\, \mu \frac{\langle 10_H \rangle^2}{M_G^2} \times \mathcal{O}(1)$$



- $M_G \approx g_G \langle 10_H \rangle$ (VB mass), $\mu \leq \lambda \langle 10_H \rangle$ (non-tachyonic spectrum).

  Perturbativity of couplings $\Rightarrow$ $$\max_{i,j\in\{1,2,3\}} |(M_{\nu_R})_{ij}| \leq \frac{\alpha_G}{16\pi^2} M_G \times \mathcal{O}(1)$$

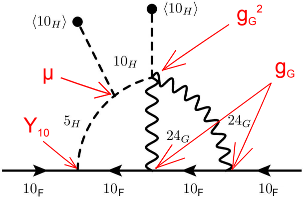
- Seesaw mechanism:

  $$M_{\nu_L} = -M_\nu^D (M_{\nu_R})^{-1} (M_\nu^D)^T \quad \Rightarrow \quad M_{\nu_R} = -D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u$$

  ($D_{u/\nu}$ – diagonal mass matrices for up-type quarks/light neutrinos
  U_ν – unitary matrix such that $M_{\nu_L} = U_\nu^T D_\nu U_\nu$)

Witten's mechanism in the flipped SU(5) unification

$$M_{\nu_R} = \left(\tfrac{1}{16\pi^2}\right)^2 g_G^4 \, Y_{10} \, \mu \frac{\langle 10_H \rangle^2}{M_G^2} \times \mathcal{O}(1)$$



- $M_G \approx g_G \langle 10_H \rangle$ (VB mass), $\mu \leq \lambda \langle 10_H \rangle$ (non-tachyonic spectrum).

  Perturbativity of couplings $\Rightarrow$ $$\max_{i,j \in \{1,2,3\}} |(M_{\nu_R})_{ij}| \leq \frac{\alpha_G}{16\pi^2} M_G \times \mathcal{O}(1)$$

- Seesaw mechanism:

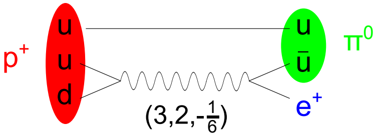
  $$M_{\nu_L} = -M_\nu^D (M_{\nu_R})^{-1} (M_\nu^D)^T \quad \Rightarrow \quad M_{\nu_R} = -D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u$$

  ($D_{u/\nu}$ – diagonal mass matrices for up-type quarks/light neutrinos
  U_ν – unitary matrix such that $M_{\nu_L} = U_\nu^T D_\nu U_\nu$)

$\Rightarrow$ **constraint on U_ν (dependent on light neutrino masses!)**

GUT = Theories of Proton Decay

- In the simplest flipped $SU(5)$ scenarios (with down quark mass matrix symmetric):



$$\Gamma(p \to K^+\overline{\nu}) = 0$$

$$\Gamma(p \to \pi^+\overline{\nu}) = C_1 \left(\frac{g_G}{M_G}\right)^4$$

$$\frac{\Gamma(p \to \pi^0 e^+_\alpha)}{\Gamma(p \to \pi^+\overline{\nu})} = \frac{1}{2}|(V_{CKM})_{11}|^2|(V_{PMNS}U_\nu)_{\alpha 1}|^2$$

$$\frac{\Gamma(p \to \eta e^+_\alpha)}{\Gamma(p \to \pi^+\overline{\nu})} = \frac{C_2}{C_1}|(V_{CKM})_{11}|^2|(V_{PMNS}U_\nu)_{\alpha 1}|^2$$

$$\frac{\Gamma(p \to K^0 e^+_\alpha)}{\Gamma(p \to \pi^+\overline{\nu})} = \frac{C_3}{C_1}|(V_{CKM})_{12}|^2|(V_{PMNS}U_\nu)_{\alpha 1}|^2$$

- C_i - calculable factors, U_ν constrained in our model!
- Lower bound on proton lifetime determined experimentally: e.g. $\tau(p \to \pi^0 + e^+) > 8.2 \times 10^{33}\, y$ [Super-Kamiokande Collaboration (2012)]

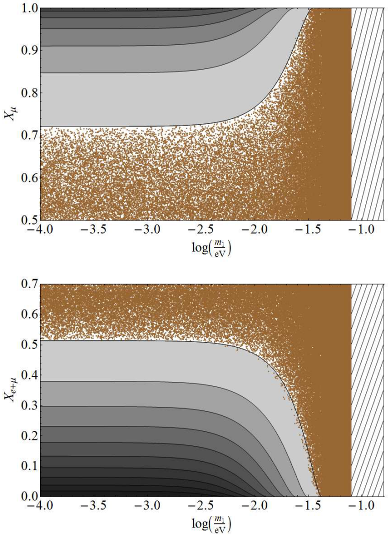
Results

- $|(V_{PMNS}U_\nu)_{\alpha 1}|^2$ computed if constraints on U_ν applied and the mass of the lightest neutrino m_1 varied from 10^{-4} eV to 0.08 eV.

$\Rightarrow$ Global upper/lower limits on

$$X_\mu \equiv \frac{\Gamma(p \to \pi^0 \mu^+)}{\frac{1}{2}\Gamma(p \to \pi^+ \overline{\nu})|(V_{CKM})_{11}|^2}$$

$$X_{e+\mu} \equiv \frac{\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)}{\frac{1}{2}\Gamma(p \to \pi^+ \overline{\nu})|(V_{CKM})_{11}|^2}$$



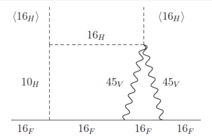
- Brown dots = points consistent with constraints on U_ν,
  full lines = analytically computed bounds of the regions with consistent points
- The model parameterized by the multiplicative constant in the expression for the loop-generated RH neutrino mass $\Rightarrow$ different curves.
- Absolute scale: $\Gamma^{-1}(p \to \pi^+ \overline{\nu}) \sim 10^{39} y$

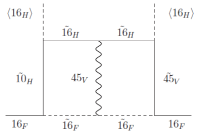
Witten's mechanism in SUSY SO(10)

- ☺ Gauge unification works for SUSY SO(10) without intermediate scale ⇒ VEV entering the Witten's loop of order $M_G \sim 10^{16}$ GeV ⇒ realistic neutrino masses
- ☹ Soft SUSY breaking @TeV ⇒ Witten's loop compensated by superpartner contributions (non-renormalization theorem)

B. Bajc and G. Senjanović, Phys. Lett. B 610 (2005) 80

- Implementation of Witten's mechanism in maximally split SUSY SO(10) model
- Gauginos and higgsinos @ TeV ⇒ ☺ remains
- Sfermions @ GUT scale ⇒ ☹ solved
- Loop contributions to charged fermion masses ⇒ possible cure for wrong mass relations like $M_d = M_l$ for down-type quark and charged lepton mass matrices



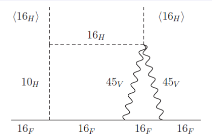


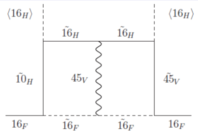
Witten's mechanism in SUSY SO(10)

- ☺ Gauge unification works for SUSY SO(10) without intermediate scale ⇒ VEV entering the Witten's loop of order $M_G \sim 10^{16}$ GeV ⇒ realistic neutrino masses
- ☹ Soft SUSY breaking @TeV ⇒ Witten's loop compensated by superpartner contributions (non-renormalization theorem)

B. Bajc and G. Senjanović, Phys. Lett. B 610 (2005) 80

- Implementation of Witten's mechanism in maximally split SUSY SO(10) model
- Gauginos and higgsinos @ TeV ⇒ ☺ remains
- Sfermions @ GUT scale ⇒ ☹ solved
- Loop contributions to charged fermion masses ⇒ possible cure for wrong mass relations like $M_d = M_l$ for down-type quark and charged lepton mass matrices





Qualitatively no change if our model considered in the split SUSY context!

Conclusion

- Viable model based on $SU(5) \times U(1)$ gauge group ("flipped SU(5)") constructed
- To generate Majorana masses of RH neutrinos no new fields added – generated via Witten's mechanism $\Rightarrow$ "minimal" setting
- Predictions on potentially measurable quantities (all proton decay partial widths) calculable
- N.B.: Alternative option for generating RH neutrino masses in flipped SU(5) model: adding 50_H scalar representation. No correlation between neutrino sector and proton decay in this case!
- Our results are valid qualitatively in the split SUSY context as well
- For further details see C. A. Rodríguez, H. Kolešová, and M. Malinský, Phys.Rev. D89 (2014) 055003, arXiv:1309.6743 [hep-ph]

Conclusion

- Viable model based on $SU(5) \times U(1)$ gauge group ("flipped SU(5)") constructed
- To generate Majorana masses of RH neutrinos no new fields added – generated via Witten's mechanism $\Rightarrow$ "minimal" setting
- Predictions on potentially measurable quantities (all proton decay partial widths) calculable
- N.B.: Alternative option for generating RH neutrino masses in flipped SU(5) model: adding 50_H scalar representation. No correlation between neutrino sector and proton decay in this case!
- Our results are valid qualitatively in the split SUSY context as well
- For further details see C. A. Rodríguez, H. Kolešová, and M. Malinský, Phys.Rev. D89 (2014) 055003, arXiv:1309.6743 [hep-ph]

Thank you for your attention!