Scalar Mediated Proton Decays in SO(10) Models

Saurabh K. Shukla

Theoretical Physics Division, Physical Research Laboratory & Indian Institute of Technology, Gandhinagar

saurabhks@prl.res.in

Based on *"Anatomy of scalar mediated proton decays in $SO(10)$ models"*; DOI: https://doi.org/10.1007/jhep08(2022)042

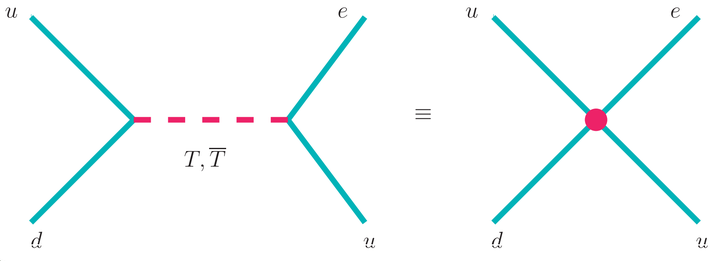
Abstract

Any grand unified model is plagued with particles capable of inducing proton decay. Identifying all potential scalar proton decay mediators stemming from different irreducible representations of SO(10), we show their coupling with the Standard Model fermions, tree-level contributions of the effective strength of $B-L$ conserving ($D=6$), and $B-L$ violating ($D=7$) operators to proton decay width expression. Through the computed branching ratio of various decay modes of proton in a realistic SO(10) model based on 10_H and $\overline{126}_H$, we enumerate distinct features of scalar mediated proton decay including bound on the mass of the proton decay mediators.

Couplings in SO(10)

- Scalar spectrum of $SO(10)$ consists of 10_H, $\overline{126}_H$ and 120_H which are comprised of 60 scalars with distinct SM charges[1].

$$
\begin{aligned}
-\mathcal{L}_{\mathcal{Y}} &= 16_A\,(H_{AB}10_H + G_{AB}120_H \\
&\quad + F_{AB}\overline{126}_H)\,16_B \\
-\mathcal{L}_Y^{\mathbf{10}/5} &\supset i2\sqrt{2}\,H_{AB}\Big(u_{\gamma A}^{CT}\,C^{-1}\,e_B^C \\
&\quad - \frac{1}{2}\epsilon_{\alpha\beta\gamma}\,\epsilon_{ab}\,q_A^{\alpha a\,T}\,C^{-1}\,q_B^{\beta b}\Big)T^{\gamma} \\
-\mathcal{L}_Y^{\overline{\mathbf{126}}/50} &\supset -i\frac{2}{3\sqrt{5}}\,F_{AB}\Big(u_{\gamma A}^{CT}\,C^{-1}\,e_B^C \\
&\quad + \frac{1}{2}\epsilon_{\alpha\beta\gamma}\,\epsilon_{ab}\,q_A^{\alpha aT}\,C^{-1}\,q_B^{\beta b}\Big)T_2^{\gamma} \\
-\mathcal{L}_Y^{\mathbf{120}/\overline{5}} &\supset -i\frac{2}{\sqrt{3}}\,G_{AB}\Big(\epsilon^{\alpha\beta\gamma}u_{\alpha A}^{CT}\,C^{-1}\,d_{\beta B}^C \\
&\quad - \epsilon_{ab}\,q_A^{\gamma aT}\,C^{-1}\,l_B^b\Big)\,\overline{T}_{1\gamma}
\end{aligned}
$$



D=6 Effective Operators

- Intergrating out scalars, proton decay operators are obtained.
- Baryon decays into anti-lepton and meson.

$$
\begin{aligned}
\mathcal{L}_{\text{eff}} &= y\,\epsilon^{\alpha\beta\gamma}\,\overline{(d_{\beta BR})^C}\,u_{\alpha AR}\,\overline{(u_{\gamma DL})^C}\,e_{CL} \\
&\quad + y\,\epsilon^{\alpha\beta\gamma}\,\overline{(d_{\beta BR})^C}\,u_{\alpha AR}\,\overline{(d_{\gamma DL})^C}\,\nu_{CL} \\
h &= 8\left(\frac{s_T^2}{M_T^2} + \frac{c_T^2}{M_{\overline{T}}^2}\right) \\
&\quad \left(U_{u^C}^T H U_{d^C}\right)_{AB}\left(U_e^\dagger H^\dagger U_u^*\right)_{CD} \\
f &= \frac{2}{15M_{\overline{T}}^2}\left(U_{u^C}^T F U_{d^C}\right)_{AB}\left(U_\nu^\dagger F^\dagger U_d^*\right)_{CD} \\
g &= \frac{4}{3}\left(\frac{1}{M_{\overline{T}_1}^2} - \frac{c_T^2}{M_{\overline{T}_2}^2} - \frac{s_T^2}{M_T^2}\right) \\
&\quad \left(U_{u^C}^T G U_{d^C}\right)_{AB}\left(U_e^\dagger G^\dagger U_u^*\right)_{CD},
\end{aligned}
$$

Proton Decay Width

$$
\Gamma[p\to\overline{\nu}\pi^+] = \frac{(m_p^2 - m_{\pi^\pm}^2)^2}{32\,\pi\,m_p^3 f_\pi^2}A^2\left(1+\tilde{D}+\tilde{F}\right)^2
$$

$$
\sum_{i=1}^{3}\alpha\,y^*[u_1^C, d_1^C, \nu_i, d_1]\Big| + \beta\,y'[u_1, d_1, \nu_i, d_1]\Big|^2
$$

D=7 Effective Operators

- $B-L$ violation happens when $\sigma(1,1,0)$ acquires a vev.
- Baryon decays into lepton and meson.

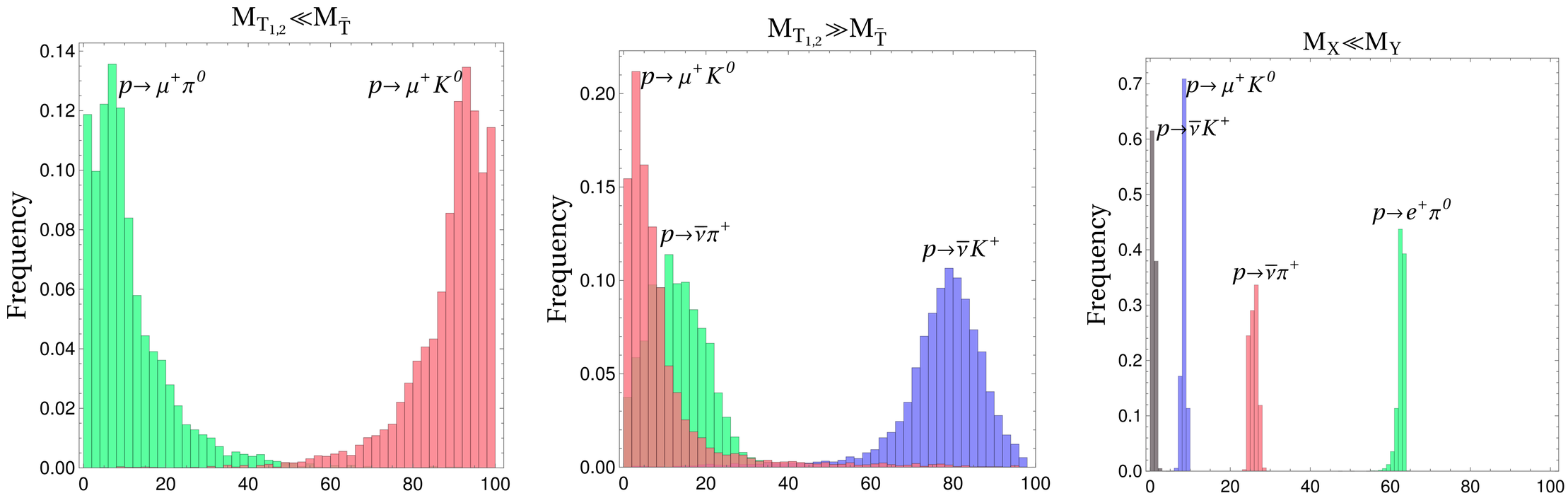
$$
\begin{aligned}
&\sigma\,D^a\,T^\alpha\,\overline{\Delta}_{\alpha a} \quad , \quad \sigma\,\overline{D}_a\,\overline{T}_\alpha\,\Delta^{\alpha a} \\
&\sigma\,D^a\,\Theta_{\alpha\beta}\,\overline{\Omega}_a^{\alpha\beta} \quad , \quad \sigma\,\overline{D}_a\,\overline{\Theta}^{\alpha\beta}\,\Omega_{\alpha\beta}^a\,;
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{L}_{\text{eff}} &= \tilde{y}\epsilon^{\alpha\beta\gamma}\,\overline{(d_{\beta BR})^C}\,u_{\alpha AR}\,\overline{d_{\gamma DR}}\,\nu_{CL} \\
\tilde{f} &= -\frac{4\lambda v_\sigma v_{\overline{D}}}{15M_\Delta^2 M_{\overline{T}}^2} \\
&\quad \left(U_{u^C}^T F U_{d^C}\right)_{AB}\left(U_\nu^T F U_{d^C}\right)_{CD}
\end{aligned}
$$

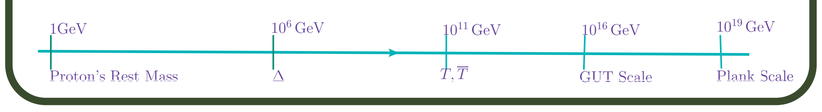
Nucleon Decay Mediators

SM Charges	Notation	$B-L$	$\mathbf{10}_H$	$\overline{\mathbf{126}}_H$	$\mathbf{120}_H$
$(3,1,-1/3)$	T^α	$-2/3$	1	2	2
$(\overline{3},1,1/3)$	$\overline{T}_\alpha$	$2/3$	1	1	2
$(3,1,2/3)$	$\Theta_{\alpha\beta}$	$-2/3$	0	1	1
$(\overline{3},1,-2/3)$	$\overline{\Theta}^{\alpha\beta}$	$2/3$	0	0	1
$(3,1,-4/3)$	$\mathcal{T}^\alpha$	$-2/3$	0	1	1
$(\overline{3},1,4/3)$	$\overline{\mathcal{T}}_\alpha$	$2/3$	0	0	1
$(3,2,1/6)$	$\Delta^{\alpha a}$	$4/3$	0	1	1
$(\overline{3},2,-1/6)$	$\overline{\Delta}_{\alpha a}$	$-4/3$	0	1	1
$(3,2,7/6)$	$\Omega^a_{\alpha\beta}$	$4/3$	0	1	1
$(\overline{3},2,-7/6)$	$\overline{\Omega}_a^{\alpha\beta}$	$-4/3$	0	1	1
$(3,3,-1/3)$	$\mathbb{T}_b^{a\alpha}$	$-2/3$	0	0	1
$(\overline{3},3,1/3)$	$\overline{\mathbb{T}}_{b\alpha}^a$	$2/3$	0	1	1

Results



Scale



Reference

[1] Ketan M. Patel and Saurabh K. Shukla. Anatomy of scalar mediated proton decays in SO(10) models. *JHEP*, 08:042, 2022.

Conclusions

- The $d=6$ operators which can induce B and L non-conserving (but $B-L$ conserving) baryon decays arise from only three pairs of color triplet fields: $T(3,1,-\frac{1}{3})$, $\mathcal{T}(3,1,-\frac{4}{3})$, $\mathbb{T}(3,3,-\frac{1}{3})$ and their conjugates.
- In the models with $\mathbf{10}_H$ and/or $\overline{\mathbf{126}}_H$, only T and $\overline{T}$ mediate the proton decay with M_T and $M_{\overline{T}} > 10^{11}$ GeV.
- The $B-L$ non-conserving nucleon decays, which arise through $d=7$ operators at the leading order, can be mediated in general by $\Theta(3,1,\frac{2}{3})$, $\Delta(3,2,\frac{1}{6})$, $\Omega(3,2,\frac{7}{6})$ and their conjugate partners. In the models without $\mathbf{120}_H$, only Δ can induce such decays with a lower bound of 10^6 GeV .
- Proton dominantly decays into $\overline{\nu}\,K^+$ or $\mu^+\,K^0$ for lighter $\overline{T}$ or T, respectively. Moreover, $\text{BR}[p\to\mu^+\pi^0] \gg \text{BR}[p\to e^+\pi^0]$.