R-Symmetric Flipped SU(5)

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1. Introduction

SU(5) unification and doublet-triplet splitting problem

- Minimal SUSY SU(5) GUT
- MSSM Higgs: embedded in 5 and $\bar{5}$ in SU(5) theory
  - $H = \begin{pmatrix} \zeta_u \\ H_u \end{pmatrix}$, $\bar{H} = \begin{pmatrix} \bar{\zeta}_d \\ H_d \end{pmatrix}$

$\zeta_u, \bar{\zeta}_d$: colored Higgs —> need to be heavy

H_u, H_d : MSSM Higgs —> need to be light

- Superpotential $W \supset \lambda(H\Phi\bar{H} + MH\bar{H})$
  - $< \Phi > = \mathrm{diag}(b, b, b, -\frac{3}{2}b, -\frac{3}{2}b)$
  - $W_{\mathrm{eff}} = \lambda(b + M)\zeta_u\bar{\zeta}_d + \lambda(-\frac{3}{2}b + M)H_uH_d$

Heavy Light

- Missing partner mechanism
- **The SU(5) model require huge representations.**

[R. N. Mohapatra in Proceeding, Summer School in Particle Physics: Trieste, Italy, June 21-July 9, 1999]

Flipped SU(5)

- **SU(5)xU(1)** gauge theory

[Barr 1982, Derendinger, Kim, Nanopoulos 1984, Antoniadis, Ellis, Hagelin, Nanopoulos 1987, Barr 1989.]

- Three generations of MSSM matter fields and **right-handed neutrinos**
- $Y = \frac{1}{\sqrt{15}} T_{24} + \sqrt{\frac{8}{5}} Q_X$
- $F_i = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & d^c_{i3} & -d^c_{i2} & u^1_i & d^1_i \\ -d^c_{i3} & 0 & d^c_{i1} & u^2_i & d^2_i \\ d^c_{i2} & -d^c_{i1} & 0 & u^3_i & d^3_i \\ -u^1_i & -u^2_i & -u^3_i & 0 & \nu^c_i \\ -d^1_i & -d^2_i & -d^3_i & -\nu^c_i & 0 \end{pmatrix}, \quad \bar{f}_i = \begin{pmatrix} u^c_{i1} \\ u^c_{i2} \\ u^c_{i3} \\ e_i \\ -\nu_i \end{pmatrix}, \quad l^c_i = \left(e^c_i\right)$

Outline

- 1. Introduction
- 2. R-symmetric flipped SU(5)
- 3. Proton decay
- 4. Conclusion

2. R-symmetric flipped SU(5)

2.1 Model

R-symmetric flipped SU(5)

[K. Hamaguchi, S. Hor and N. Nagata, JHEP 11 (2020) 140]

- SU(5)xU(1) gauge theory
- **MSSM Higgs reside in h and $\bar{h}$**
- **Global U(1)R symmetry** (The superpotential has the U(1)R charge +2)
- Additional singlet field S
- **H and $\bar{H}$ break the SU(5)xU(1)** down to the SM gauge group

Fields	Components	SU(5)	U(1)	$\mathrm{U}(1)_R$
F_i	$d_i^c,\ Q_i,\ \nu_i^c$	$\mathbf{10}$	$+1$	$17/36$
$\bar{f}_i$	$u_i^c,\ L_i$	$\bar{\mathbf{5}}$	-3	$17/36$
ℓ_i^c	e_i^c	$\mathbf{1}$	$+5$	$17/36$
H	$d_H^c,\ Q_H,\ \nu_H^c$	$\mathbf{10}$	$+1$	$1/36$
$\bar{H}$	$d_{\bar{H}}^c,\ Q_{\bar{H}},\ \nu_{\bar{H}}^c$	$\overline{\mathbf{10}}$	-1	$17/36$
h	$D,\ H_d$	$\mathbf{5}$	-2	$19/18$
$\bar{h}$	$\bar{D},\ H_u$	$\bar{\mathbf{5}}$	$+2$	$19/18$
S	S	$\mathbf{1}$	0	$1/9$

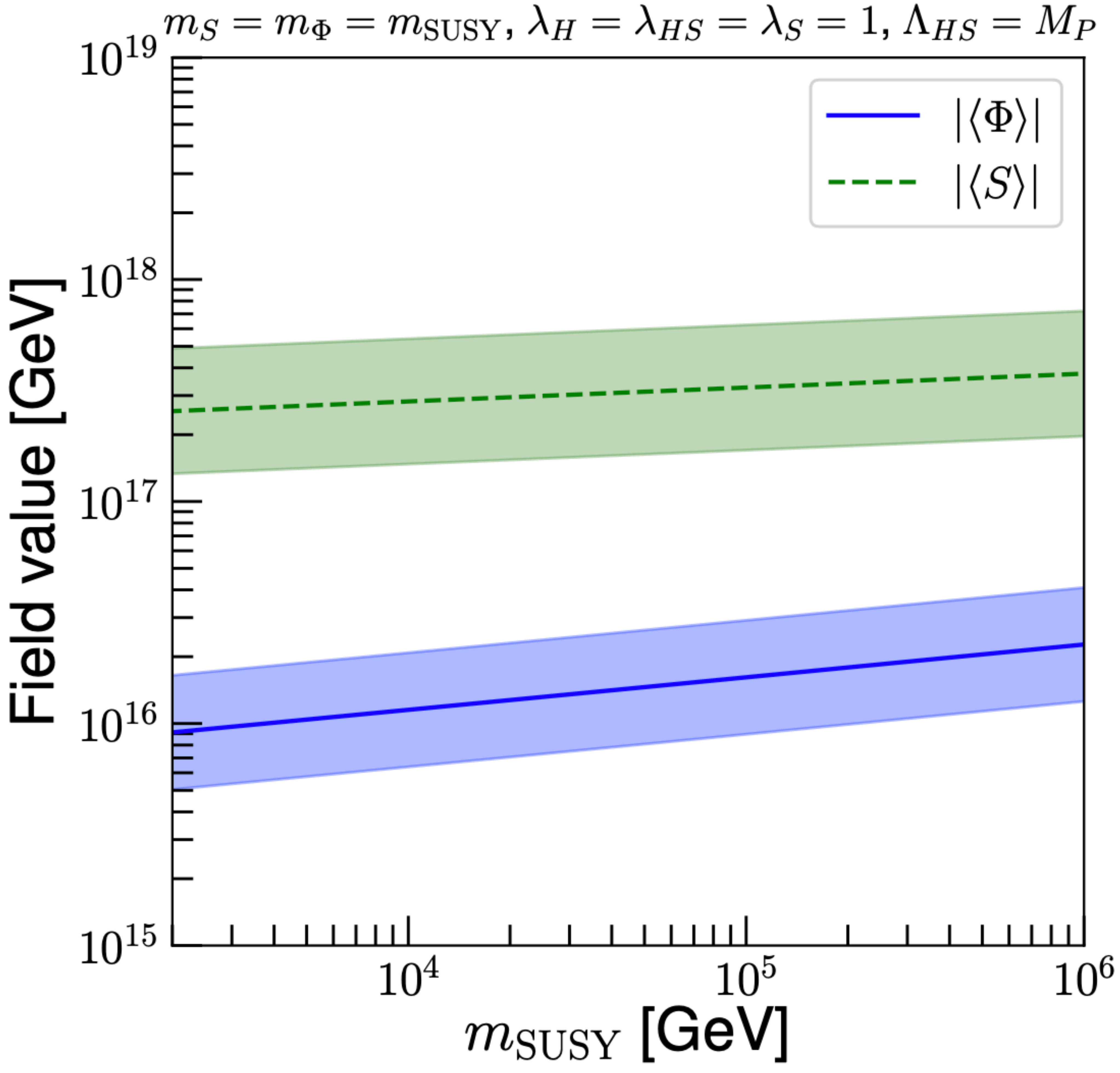
The field content and the charge assignments in our model.
The U(1) charges are given in inits of $1/\sqrt{40}$

- Superpotential $W = W_{\text{Yukawa}} + W_{\text{DT}} + W_{\text{neutrino}} + W_{HS} \cdots$,
  - $W_{\text{Yukawa}} = \frac{1}{4}\lambda_1^{ij}\epsilon_{\alpha\beta\gamma\delta\epsilon}F_i^{\alpha\beta}F_j^{\gamma\delta}h^\epsilon + \sqrt{2}\lambda_2^{ij}F_i^{\alpha\beta}\bar{f}_{j\alpha}\bar{h}_\beta + \lambda_3^{ij}\bar{f}_{i\alpha}\ell_j^c h^\alpha$,
  - $W_{\text{DT}} = \frac{\lambda_4}{4\Lambda_{\text{DT}}^8}\epsilon_{\alpha\beta\gamma\delta\epsilon}S^8 H^{\alpha\beta}H^{\gamma\delta}h^\epsilon + \frac{1}{4}\lambda_5\epsilon^{\alpha\beta\gamma\delta\epsilon}\bar{H}_{\alpha\beta}\bar{H}_{\gamma\delta}\bar{h}_\epsilon$,
  - $W_{\text{neutrino}} = \frac{c_{ij}}{2\Lambda_N^2}S(F_i^{\alpha\beta}\bar{H}_{\alpha\beta})(F_j^{\gamma\delta}\bar{H}_{\gamma\delta})$,
  - $W_{HS} = \frac{\lambda_H}{4\Lambda_{HS}^5}(H^{\alpha\beta}\bar{H}_{\alpha\beta})^4 + \frac{\lambda_{HS}}{18\Lambda_{HS}^{10}}(H^{\alpha\beta}\bar{H}_{\alpha\beta})^2 S^9 + \frac{\lambda_S}{18\Lambda_{HS}^{15}}S^{18}$,
- Unwanted $H\bar{H}$ and $h\bar{h}$ terms are both **forbidden** by the **U(1)R** symmetry.
- Right-handed neutrino masses: **non-renormalizable operator**
- U(1)R symmetry highly **restricts possible forms of operators in** W_{HS}.

2.2 Symmetry breaking and mass spectrum

The scalar potential

- The potential minimum at which ν^c_{H}, $\nu^c_{\bar{H}}$ and S develop VEVs.
  - D-flat direction
    $\langle \nu^c_H \rangle = \langle \nu^c_{\bar{H}} \rangle = \Phi \equiv |\Phi| e^{i\theta}$
  - Φ breaks the SU(5)xU(1) into the SM gauge group.
  - $m^2_\Phi \equiv m^2_H + m^2_{\bar{H}}$
- $|\langle \Phi \rangle| \simeq 10^{16}$ GeV
- $|\langle S \rangle| \simeq$ a few $\times\, 10^{17}$ GeV



Doublet-triplet splitting

- **Doublet-triplet splitting problem is solved** by the **Missing partner mechanism.**
- $W_{\rm DT} = \frac{\lambda_4}{4\Lambda_{\rm DT}^8}\epsilon_{\alpha\beta\gamma\delta\epsilon}S^8 H^{\alpha\beta}H^{\gamma\delta}h^{\epsilon} + \frac{1}{4}\lambda_5\epsilon^{\alpha\beta\gamma\delta\epsilon}\bar{H}_{\alpha\beta}\bar{H}_{\gamma\delta}\bar{h}_{\epsilon}\ ,$
- $10_{+1} \to (\bar{3},1)_{-5/3} + (3,2)_{-5/6} + (1,1)_0$
- $5_{-2} \to (3,1)_{+5/3} + (1,2)_{+5/2}$

- $M_{H_C} = \lambda_4 |\langle\Phi\rangle| \left(\frac{\langle S\rangle}{\Lambda_{\rm DT}}\right)^8$ **Light color-triplet Higgs**

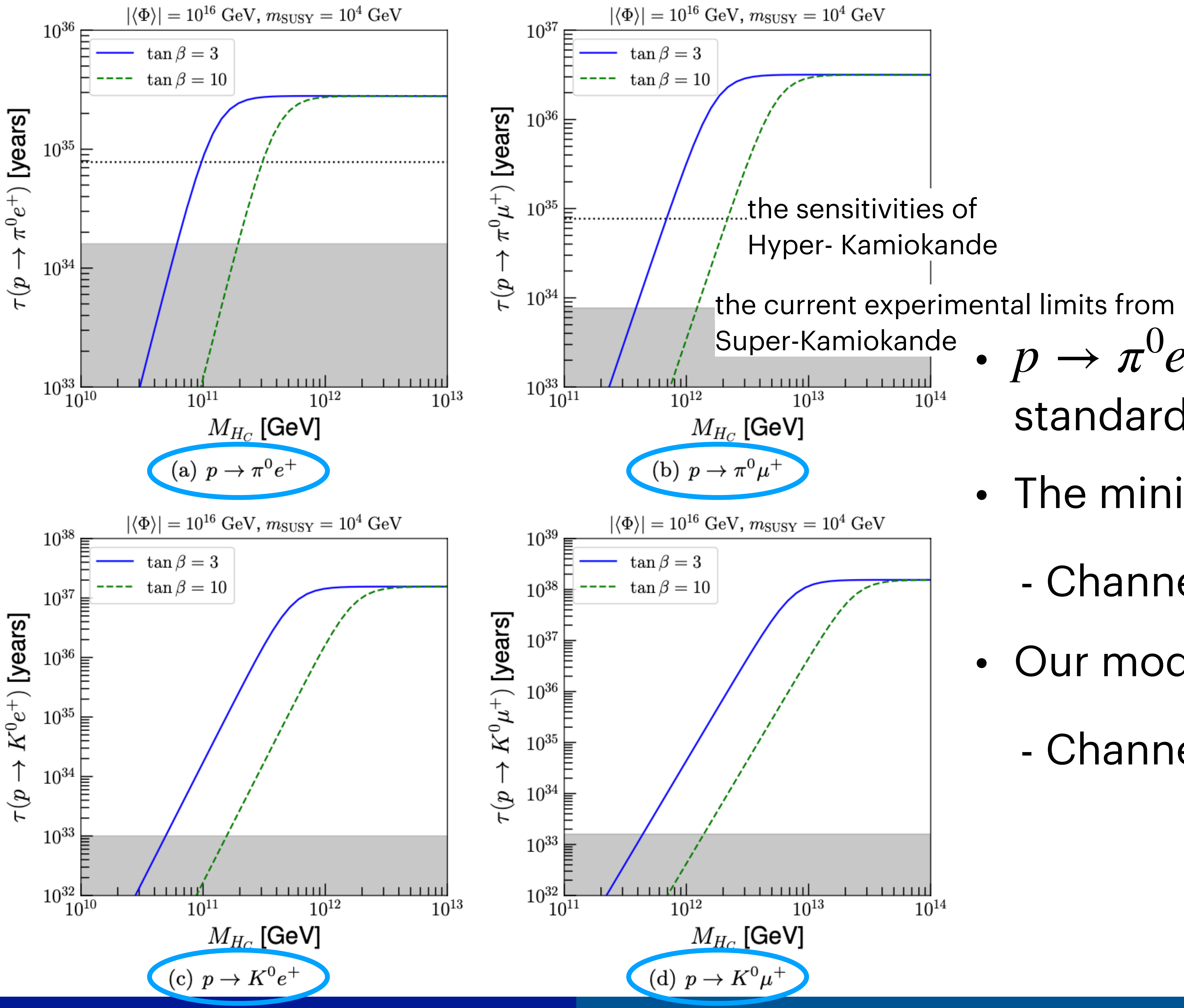
$$\simeq \lambda_4 \times 7\times 10^{11} \times \left(\frac{|\langle\Phi\rangle|}{10^{16}\ \mathrm{GeV}}\right)\left(\frac{\langle S\rangle}{3\times 10^{17}\ \mathrm{GeV}}\right)^8\left(\frac{\Lambda_{\rm DT}}{10^{18}\ \mathrm{GeV}}\right)^{-8}\ \mathrm{GeV}\ ,$$

- $M_{\bar{H}_C} = \lambda_5 |\langle\Phi\rangle|\ ,$

3. Proton decay

- Dimension-five proton decay operators (negligible)
  - Exchange of color-triplet Higgs
- Dimension-six proton decay operators
  - Exchange of SU(5) gauge boson and the **light color-triplet Higgs**

- $\Gamma(p \to \pi^0 e^+) = \frac{m_p}{32\pi}\left(1 - \frac{m_\pi^2}{m_p^2}\right)^2 \left|V_{ud}\right|^2 \left|\left(U_\ell\right)_{11}\right|^2 \left(\langle \pi^0 | (ud)_R u_L | p \rangle_e\right)^2 \times \left[\frac{(A_1^H)^2 (A_1^R)^2}{|\langle \Phi \rangle|^4} + \frac{(A_2^R)^2}{M_{H_C}^4}\left\{y_d(M_{H_C}) y_e(M_{H_C})\right\}^2\right]$,
- $\Gamma(p \to \pi^0 \mu^+) = \frac{m_p}{32\pi}\left(1 - \frac{m_\pi^2}{m_p^2}\right)^2 \left|V_{ud}\right|^2 \left|\left(U_\ell\right)_{12}\right|^2 \left(\langle \pi^0 | (ud)_R u_L | p \rangle_\mu\right)^2 \times \left[\frac{(A_1^H)^2 (A_1^R)^2}{|\langle \Phi \rangle|^4} + \frac{(A_2^R)^2}{M_{H_C}^4}\left\{y_d(M_{H_C}) y_\mu(M_{H_C})\right\}^2\right]$,
- $\Gamma(p \to K^0 e^+) = \frac{m_p}{32\pi}\left(1 - \frac{m_K^2}{m_p^2}\right)^2 \left|V_{us}\right|^2 \left|\left(U_\ell\right)_{11}\right|^2 \left(\langle K^0 | (us)_R u_L | p \rangle_e\right)^2 \times \left[\frac{(A_1^H)^2 (A_1^R)^2}{|\langle \Phi \rangle|^4} + \frac{(A_2^R)^2}{M_{H_C}^4}\left\{y_s(M_{H_C}) y_e(M_{H_C})\right\}^2\right]$,
- $\Gamma(p \to K^0 \mu^+) = \frac{m_p}{32\pi}\left(1 - \frac{m_K^2}{m_p^2}\right)^2 \left|V_{us}\right|^2 \left|\left(U_\ell\right)_{12}\right|^2 \left(\langle K^0 | (us)_R u_L | p \rangle_\mu\right)^2 \times \left[\frac{(A_1^H)^2 (A_1^R)^2}{|\langle \Phi \rangle|^4} + \frac{(A_2^R)^2}{M_{H_C}^4}\left\{y_s(M_{H_C}) y_\mu(M_{H_C})\right\}^2\right]$,
- The color-triplet Higgs exchange process is induced by the Yukawa interactions, so its contribution tends to be more significant for the decay modes that contain the **second generations**.



- $p \to \pi^0 e^+$ is suppressed in the standard flipped SU(5) model.
- The minimal SUSY SU(5)
  - Channel $p \to K^+\bar{\nu}$ or $p \to \pi^0 e^+$
- Our model: R-symmetric flipped SU(5)
  - Channel $p \to \pi^0 \mu^+$ and $p \to K^0 \mu^+$

4. Conclusion

- We constructed a flipped SU(5) SUSY GUT model which is invariant under a global U(1)R symmetry
  - The SU(5)-breaking Higgs fields acquire a VEV in the flat direction after SUSY is broken.
  - The μ**-terms of the Higgs fields are forbidden** by the U(1)R symmetry.
  - Light color-triplet Higgs at intermediate scale
  - Missing partner mechanism
  - Right-handed neutrino masses: non-renormalizable operators
- Proton decay
  - Channel $p \to \pi^0 \mu^+$ and $p \to K^0 \mu^+$

Thank you for your attention.