SUSY 2013

Two-loop Renormalization Factors of Dimension-six Proton Decay Operators in the Supersymmetric Standard Models

Based on

J. Hisano, D. K, N. Nagata Phys. Lett. B716 (2012) 406-412

J. Hisano, D. K, Y. Muramatsu, N. Nagata Phys. Lett. B724 (2013) 283-287

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1. Introduction

Grand Unified Theories (GUTs)

SU(5) GUTs

$$SU(5) \supset SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

The SM gauge groups are embedded into SU(5) group.

Attractive features

- Explain charge quantization.
- Unify three interactions.
- Predict the gauge coupling unification ← The gauge coupling unification is realized in the SUSY SU(5) GUT.

Tests of GUTs

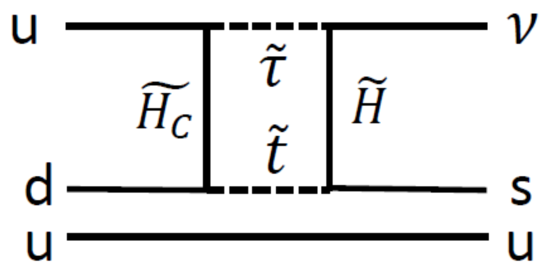
- Predict proton decay.

To verify the theories, the experiments have been searching for the proton decay signals.

Proton decay

Proton decay is induced by two different processes in the SUSY SU(5) GUT.

The colored- Higgs exchange process



The main decay mode $p \to K^+ + \overline{\nu}$

Experimental limits: $\tau(p \to K^+\overline{\nu}) > 4.0 \times 10^{33}$ years

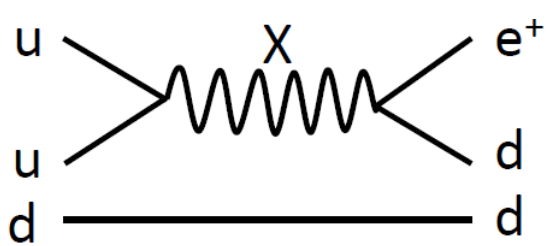
Prediction: too short lifetime $\sim 10^{30}$ years

The minimal SUSY SU(5) GUT is excluded since this process predicts too short lifetime.

T. Goto T. Nihei, Phys. Rev. Lett. 38, 1440

➡ We assume this process is suppressed by a certain symmetry.

The X-gauge boson exchange process



$$\tau(p \to e^+\pi^0) \sim \frac{M_X^4}{\alpha_5^2}$$

The main decay mode $p \to e^+ + \pi^0$

Experimental limit $\tau(p \to e^+\pi^0) > 1.29 \times 10^{34}$ years

Prediction: Longer lifetime $\sim 10^{35}$ years

We concentrate on this decay process.

➡ If the unified gauge coupling constant increases proton lifetime decreases.

2. Proton decay in the MSSM with vector-like matters

The MSSM with extra matters

motivation

- Higgs mass

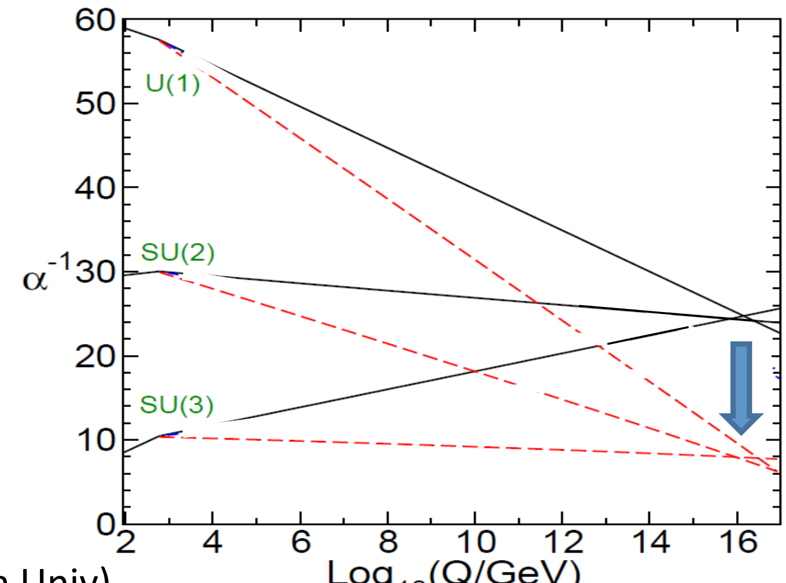
  the 126 GeV Higgs boson can be explained with extra matters since they help to increase the Higgs boson mass with radiative corrections.

- Gauge mediation

  the gauge mediation mechanism contains the vector-like matter as the SUSY-breaking messenger.

- etc.

It is found that the gauge coupling unification is still preserved if the particles form the SU(5) multiplets.

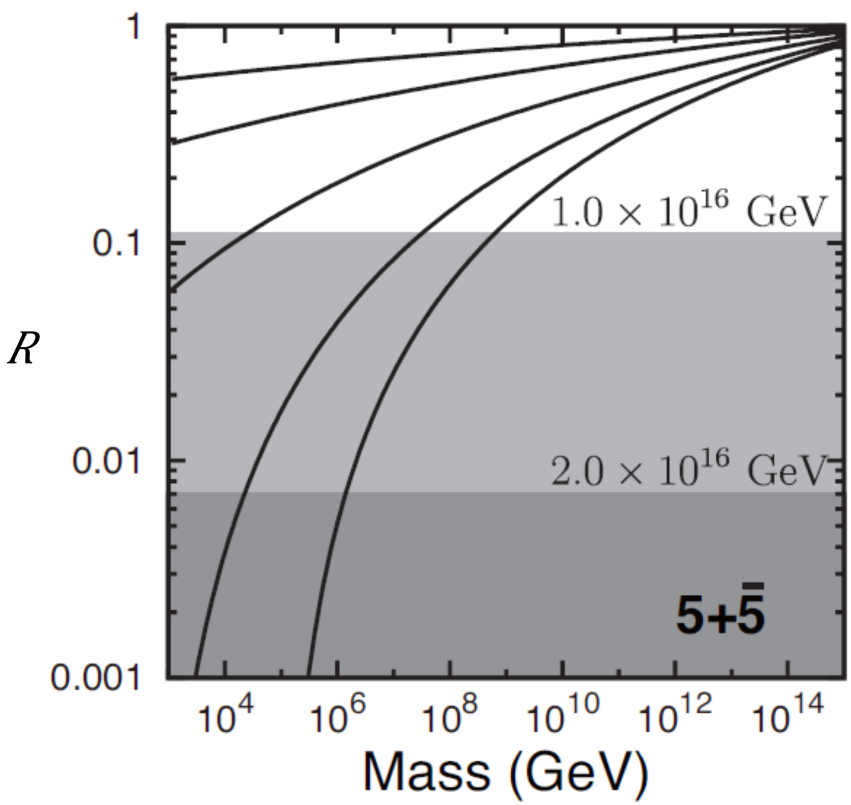


S. Martin Phys.Rev.D81:035004

Proton lifetime in the MSSM with vector-like matters

$$R \equiv \frac{\tau(p \to e^+\pi^0)|_{\rm w/}}{\tau(p \to e^+\pi^0)|_{\rm w/o}}$$

The ratio of the proton lifetime with vector-like matters to that without vector-like matters



Each solid line corresponds to the number of $5+\bar{5}$ multiplets $n_5 = 1, 2, \ldots, 5$ from top to bottom

Light (dark) shaded region is excluded by the current experimental limits in the case of $M_X = 1.0 \times 10^{16}$ GeV ($M_X = 2.0 \times 10^{16}$ GeV)

Proton lifetime is significantly reduced if the number of vector-like matters increases and their masses are set to be lower.

J. Hisano, D. K, N. Nagata Phys. Lett. B 716 (2012) 406-412

3. Renormalization factors

Renormalization factors

Effective Lagrangian for proton decay

$$\mathcal{L}_{\text{eff}} = -\frac{g_5^2}{M_X^2} e^{i\varphi_u} \epsilon_{\alpha\beta\gamma} \left[A_R^{(1)} \left(\overline{d_R^{\mathcal{C}}}^{\alpha} u_R^{\beta} \right) \left(\overline{e_L^{\mathcal{C}}} u_L^{\gamma} \right) + (1 + |V_{ud}|^2) A_R^{(2)} \left(\overline{d_L^{\mathcal{C}}}^{\alpha} u_L^{\beta} \right) \left(\overline{e_R^{\mathcal{C}}} u_R^{\gamma} \right) \right]$$

$$A_R^{(I)} = A_L \cdot A_S^{(I)} \qquad I=1, 2$$

A_L : long-distance factor

$A_S^{(I)}$: short-distance factor

In the previous calculation for proton decay

A_L was computed at two-loop order T. Nihei and J. Arafune, Prog. Theor. Phys. 93, 665

$A_S^{(I)}$ was computed at one-loop order C. Munoz, Phys Lett. B 177, 55

The unified gauge coupling constant increases
if there exist extra particles in the intermediate scale.

⇒ The two-loop effects may be more significant in such cases.

We evaluate the short-distance factor at two-loop level.

Effective Kähler potential

Effective operator for proton decay in the SUSY SU(5) GUT

$$\mathcal{O}^{(1)} = \int d^4\theta\, e^{-\frac{2}{3}g_Y V_1} \overline{U}^\dagger e^{2g_3 V_3} Q \overline{D}^\dagger L$$

$$\mathcal{O}^{(2)} = \int d^4\theta\, e^{\frac{2}{3}g_Y V_1} e^{-2g_3 V_3} \overline{U}^\dagger Q \overline{E}^\dagger Q$$

Since they are D-terms, they receive the quantum corrections.

The quantum corrections can be taken into account by means of the effective Kähler potential.

A supergraph computation of the effective Kähler potential at two loops for general SUSY theories described by arbitrary Kähler potential.

S. Groot Nibbelink, T. S. Nyawelo ; JHEP 0601 (2006) 034

By using the results, we evaluate short-distance renormalization factor at two –loop level.

To obtain the renormalization factors for the higher-dimensional effective operators, we consider the following Kähler potential.

$$K = \bar{\phi}_a \phi^a + C\mathcal{O} + C\mathcal{O}^\dagger$$

$\mathcal{C}$: Wilson coefficient of the operator $\mathcal{O}$

Short-distance factors for the MSSM without vector-like matter

Short-distance factor

$$A_S^{(I)} \equiv \frac{C^{(I)}(M_{\rm SUSY})}{C^{(I)}(M_{\rm GUT})} \,, \qquad (I=1,2) \qquad \begin{array}{r} M_{\rm SUSY} = 1.0\times 10^{3}\ {\rm GeV} \\ M_{\rm GUT} = 2.0\times 10^{16}\ {\rm GeV} \end{array}$$

Numerical results

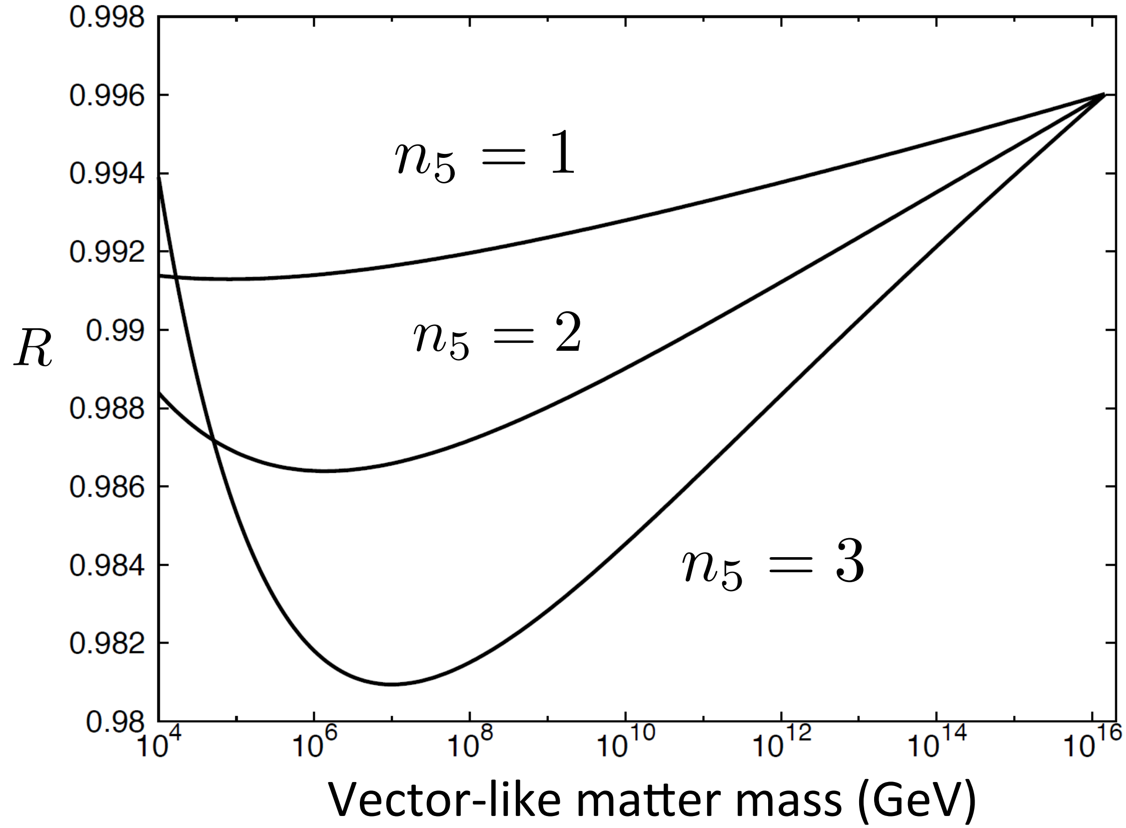
$$A_S^{(1)}(\text{1-loop}) = 1.960 \qquad A_S^{(1)}(\text{2-loop}) = 1.962$$
$$A_S^{(2)}(\text{1-loop}) = 2.059 \qquad A_S^{(2)}(\text{2-loop}) = 2.053$$

The two-loop contributions hardly change the renormalization factors evaluated at one-loop level.

Short –distance factor for the MSSM with vector-like matter

$$R = \frac{(A_S^{(1)})^2 + (A_S^{(2)})^2(1+|V_{ud}|^2)^2|_{2-\mathrm{loop}}}{(A_S^{(1)})^2 + (A_S^{(2)})^2(1+|V_{ud}|^2)^2|_{1-\mathrm{loop}}}$$

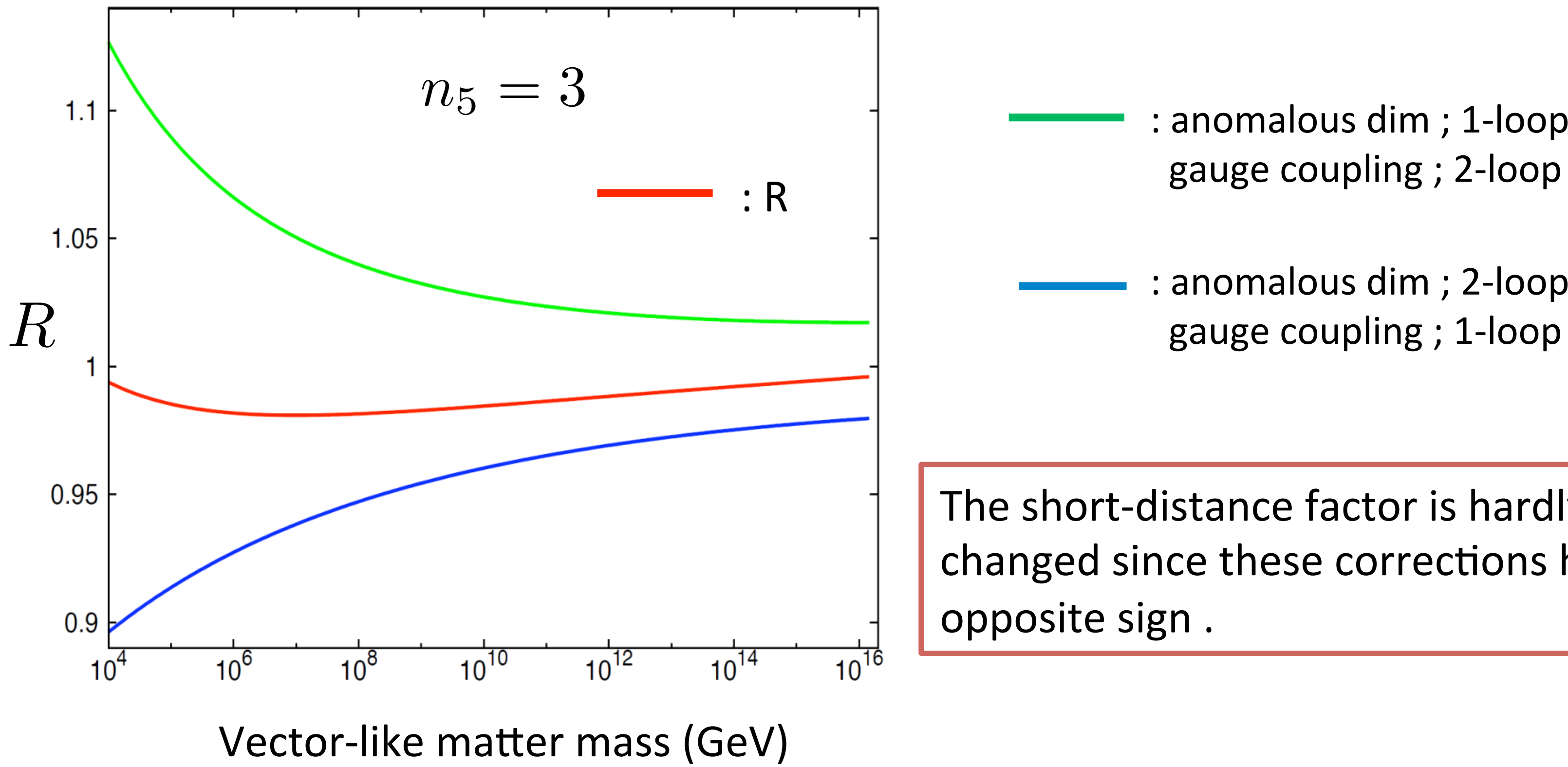
R represents the two-loop RG effect for proton decay operators .



Proton decay rate at two-loop level decreses by a few % compared with that at one-loop level since there is cancellation among two-loop corrections

Cancelation among two-loop corrections in the case of n_5=3

$$R = \frac{(A_S^{(1)})^2 + (A_S^{(2)})^2(1+|V_{ud}|^2)^2|_{2-\mathrm{loop}}}{(A_S^{(1)})^2 + (A_S^{(2)})^2(1+|V_{ud}|^2)^2|_{1-\mathrm{loop}}}$$



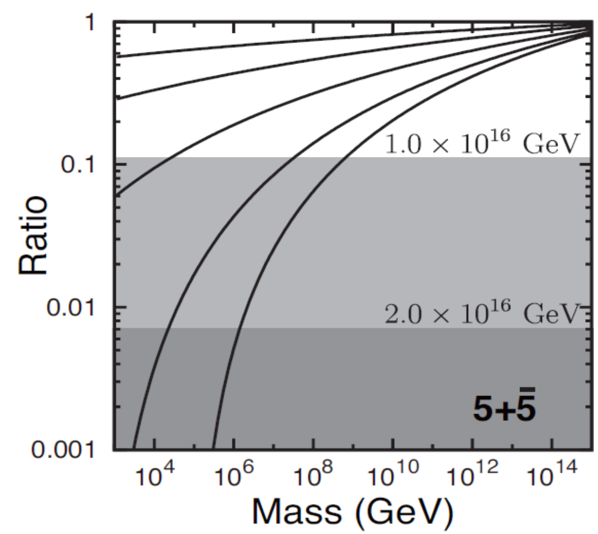
The short-distance factor is hardly changed since these corrections have opposite sign .

4. Conclusion

conclusion

- We evaluated the short-distance renormalization factors for the dimension-six proton decay operators at two-loop level with the effective Kähler potential .

- We found that the two-loop contributions hardly change the renormalization factors evaluated at one-loop level since there is a cancellation among the two-loop corrections.



- In the MSSM with vector-like matter, it is found that proton lifetime significantly reduced.
  The models with vector-like matters are constrained by proton decay.

- (To complete the two-loop calculation, we need evaluate threshold corrections)