GUT Scale Threshold Effect on Proton Decay

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in collaboration with J.Hisano Y.Omura: arXiv:1503.08561

Background & Motivation

Supersymmetric Grand Unified Theories (SUSY GUTs)

- Promising models solving problems in the standard model
- Proton decay is a signature of GUTs

Hyper-Kamiokande (10yrs project) sensitivity on proton lifetime

- τ (p -> π + e^+) > 1.0×10^{35} yrs
- τ (p -> K^+ + ν) > 2.5×10^{34} yrs

Important issue

Quantum correction to the $\not{B}$ operators

- ☑ Long-range RGE (2-loop) Arafune, Nihei (1994)
- ☑ Short-range RGE (2-loop) Hisano, Kobayashi, Nagata, Muramatsu (2013)
- ☐ Threshold Correction @GUT scale ⬅ THIS WORK!

⋮

Threshold correction:
GUT mass spectrum dependent -> Minimal setup & its extension

Another motivation

Vector-like Extension of MSSM Martin (2009)

* Adding $5+\overline{5}$, $10+\overline{10}$ matters
* Explaining Higgs mass
* Large gauge coupling @ GUT scale

Proton decay can be affected due to large coupling!

Minimal SUSY SU(5) GUT

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Matter Sector

$$\phi_\alpha(\mathbf{5}^*) = \begin{pmatrix} D_a^C \\ \epsilon_{rs} L^s \end{pmatrix}$$

$$\psi^{\alpha\beta}(\mathbf{10}) = \begin{pmatrix} \epsilon^{abc} U_c^C & Q^{ar} \\ -Q^{sa} & \epsilon^{sr} E^c \end{pmatrix}$$

Higgs Sector

$${}^tH(\mathbf{5}) = (\underline{H_C},\ \underline{H_C},\ \underline{H_C},\ H_u^+,\ H_u^0)$$

$${}^t\overline{H}(\mathbf{5}^*) = (\underline{\overline{H}_C},\ \underline{\overline{H}_C},\ \underline{\overline{H}_C},\ \overline{H}_d^-,\ -\overline{H}_d^0)$$

Color-triplet Higgs

Adjoint Higgs

$$\Sigma = \begin{pmatrix} \Sigma_8 & \Sigma_{X^\dagger} \\ \Sigma_X & \Sigma_3 \end{pmatrix} + \frac{1}{\sqrt{2}}\frac{1}{\sqrt{30}} \begin{pmatrix} 2 & 0 \\ 0 & -3 \end{pmatrix} \Sigma_{24}$$

Gauge Sector

$$V(\mathbf{24}) = \begin{pmatrix} G - \frac{2}{\sqrt{30}}B & \underline{X^\dagger} \\ \underline{X} & W + \frac{3}{\sqrt{30}}B \end{pmatrix}$$

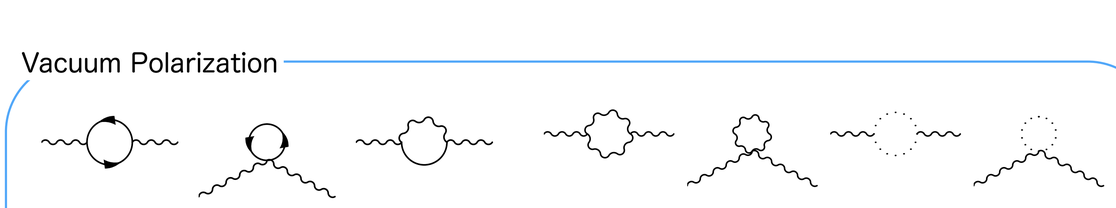
B, W, and G : MSSM gauge multiplets

X, $X^\dagger$ give rise to B# violating interaction

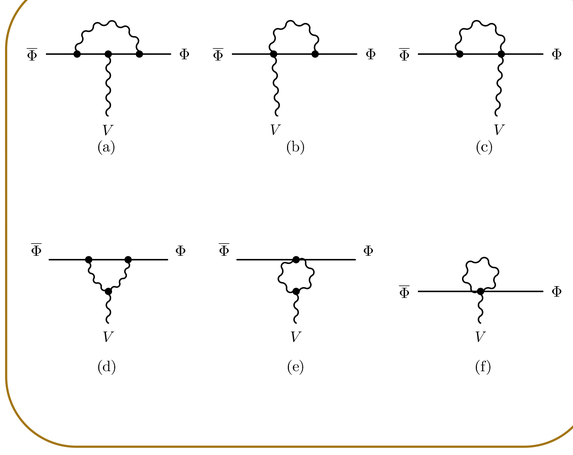
Procedure

- To match the amplitudes of proton decay process in Full and EFTs
- The one-loop (supergraph) diagrams in Full theory are given by:

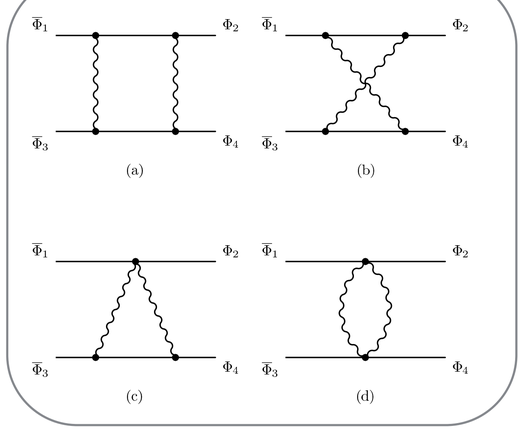
Vacuum Polarization



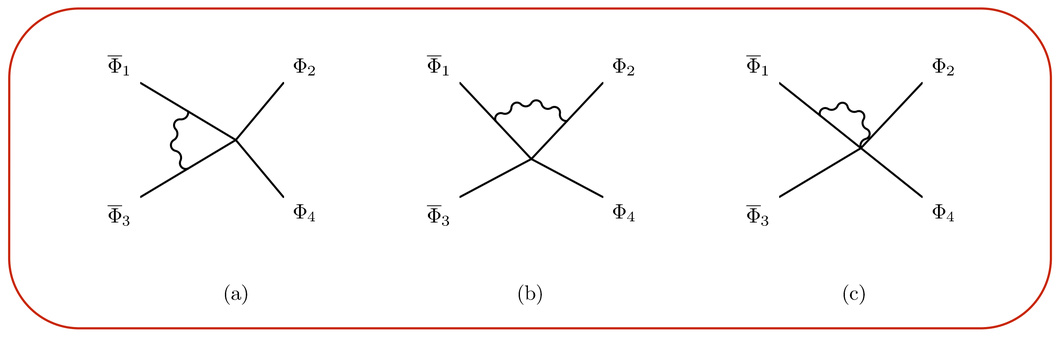
Vertex Corrections



Box Corrections



- The one-loop (supergraph) diagrams in EFTs are given by:



Results

In order to compare to the previous work…
we define the ratio of the decay rate:

$$(\mathrm{Ratio}) = \frac{\Gamma(p \to \pi^0 + e^+)|_{\mathrm{w}}}{\Gamma(p \to \pi^0 + e^+)|_{\mathrm{w/o}}}$$

w/ and w/o denote the decay rate with and without threshold corrections (with 2-loop RGEs of Wilson coefficients).

In the minimal SUSY SU(5) GUT,

$$(\mathrm{Ratio}) = 0.948$$

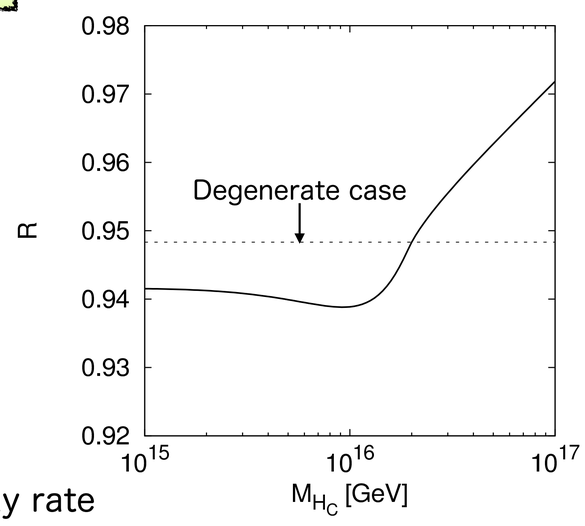
Setups:
M_{SUSY} = 1TeV
Matching scale: 2×10^{16}GeV
Masses of GUT particles: 2×10^{16}GeV

Threshold effect -> Proton lives a little bit longer

GUT mass spectrum (M_{HC}) dependence

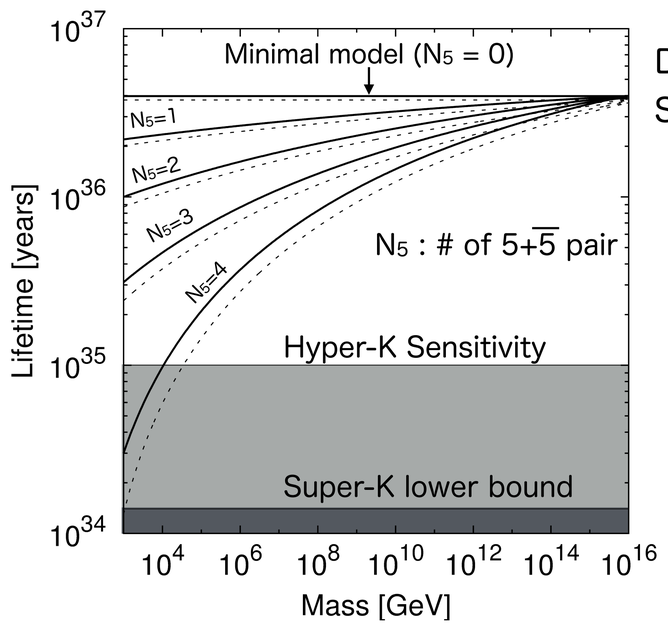
Color-triplet Higgs mass: M_{HC}

Parameter setups:
Other GUT particle mass: 2×10^{16}GeV



Heavy color-triplet Higgs
=> slightly enhance the proton decay rate
(shorten the lifetime) due to the vacuum polarization of X-boson

Extra vector-like matter scenarios



Dotted: w/o threshold correction
Solid: w/ threshold correction

Summary

- Derive the threshold correction of proton decay process @ M_{GUT}
- In the minimal SUSY SU(5): proton lives a bit longer (about 5%)
- GUT mass hierarchy leads a short lifetime (X lighter than H_C case)
- Extra vector-like matters: proton lives longer (more than 10%)