Testing Bulk Matter RS Model through Rare Decays of Smuon and Scharm

Toshifumi Yamada

KEK

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Introduction

- Origin of Yukawa coupling hierarchy in SM ?
- "5D RS spacetime with matter fields in the bulk"

Weaknesses :

i. Severe constraints on KK scale :

e.g. K^0-$\bar{K}^0$ mixing ➡ 1st KK gluon mass > 21 TeV

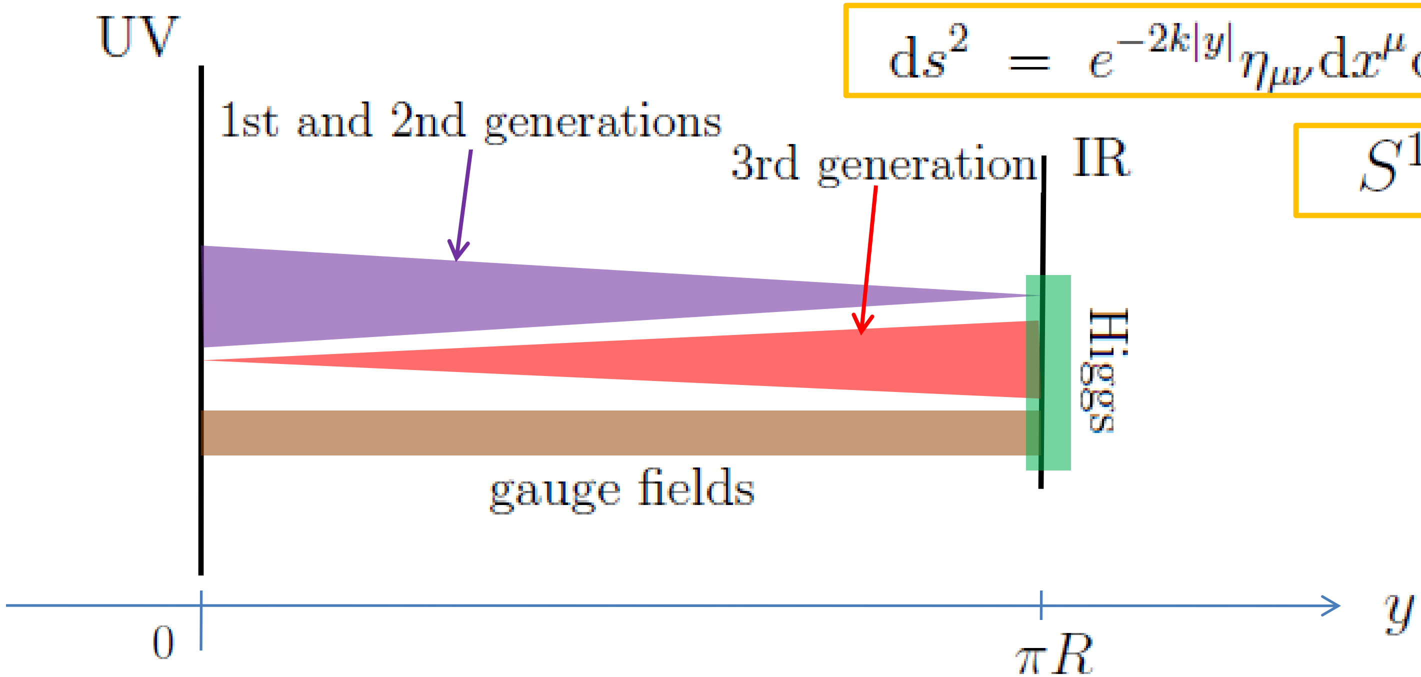
ii. KK scale need not be $\sim$ TeV to explain the Yukawa hierarchy.

- How can we confirm bulk matter RS model if **KK is far above TeV** scale?

➡ If **SUSY particles** are accessible at colliders, we can do that by studying their **rare decays**.

Setup

Bulk Matter RS Model



$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

$$S^1/Z_2$$

- **Geometrical overlap** between bulk matters and IR-localized Higgs is given by

$$\sqrt{\frac{1-2c_i}{2\{1-e^{-(1-2c_i)kR\pi}\}}}\sqrt{\frac{1-2c_j}{2\{1-e^{-(1-2c_j)kR\pi}\}}}$$

(c_i : 5D Dirac mass, i, j : flavor indices)

- Can be exponentially suppressed with O(1) c_i's .

Geometrical Overlap

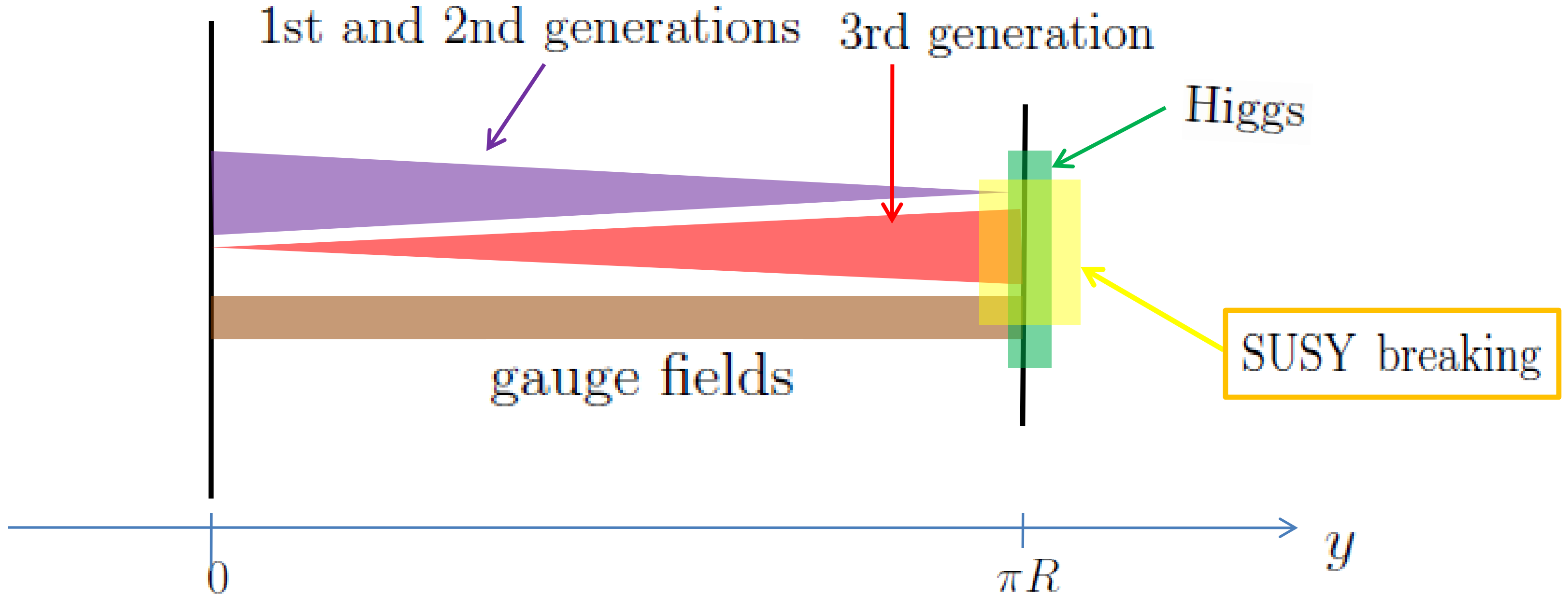
- Determine the geometrical overlap factors so that they explain the Yukawa hierarchy.
  Define $\alpha_i \equiv \sqrt{\frac{1-2c_i}{2\{1-e^{-(1-2c_i)kR\pi}\}}}$ for SU(2) doublet quark Q_i,
  $\beta_i, \gamma_i, \delta_i, \epsilon_i$ resp. for U_i, D_i, L_i, E_i.
- From the data on SM fermion mass, CKM matrix and neutrino oscillations, the **orders** of $\alpha_i, \beta_i, \gamma_i, \delta_i, \epsilon_i$ are fixed as :

$$\alpha_1 \sim \lambda^3, \quad \alpha_2 \sim \lambda^2, \quad \alpha_2 \sim 1 \; ; \; \beta_1 \sim \lambda^{-3}\frac{m_u}{v}, \quad \beta_2 \sim \lambda^{-2}\frac{m_c}{v}, \quad \beta_3 \;\sim\; 1 \; ; \quad \ldots$$

$$3\delta_1 \sim \delta_2 \sim \delta_3 \; ; \; \epsilon_1 \sim \delta_1^{-1}\frac{m_e}{v}\tan\beta, \quad \epsilon_2 \sim \delta_2^{-1}\frac{m_\mu}{v}\tan\beta, \quad \epsilon_3 \sim \delta_3^{-1}\frac{m_\tau}{v}\tan\beta \; ;$$

Note : Absolute scale of δ_3's is a free parameter because we do not know the seesaw scale.

SUSY Bulk Matter RS Model



- Gravity mediation for 1st and 2nd generation matter fields is geometrically suppressed. ➡ 5D sequestering
- Introduce 0 to several "messenger" fields.

➡ Hybrid of <u>gravity mediation</u> (on IR brane), <u>gaugino mediation</u> and (optional) <u>gauge mediation</u>.

Two Scales of Soft Terms

- Gravity mediation contributions on IR brane
  Gaugino mediation contributions

  (Gaugino masses arise from contact terms, then their RG effects give rise to matter soft masses)

➡ The mass scale of soft terms :

F-term SUSY breaking

$$\sim \frac{|<F>|}{M_5 e^{-kR\pi}} \equiv M_X$$

- Gauge mediation contributions

➡ The mass scale of soft terms :

typical messenger mass

$$\sim \frac{1}{16\pi^2}\frac{|<F>|}{M_{mess}} \equiv M_G$$

Sparticle Mass Spectrum

Flavor-Violating Soft Terms

- Gravity mediation violates flavor.
  Geometrical overlap between matters and IR brane controls the **flavor structure** of its contributions.

➡ Matter soft mass and A-terms from grav. med. are expressed in terms of $\alpha_i, \beta_i, \gamma_i, \delta_i, \epsilon_i$:

$$(m_Q^2) \sim \alpha_i \alpha_j M_X^2, \quad (m_U^2) \sim \beta_i \beta_j M_X^2, \quad (m_D^2) \sim \gamma_i \gamma_j M_X^2,$$
$$(m_L^2) \sim \delta_i \delta_j M_X^2, \quad (m_E^2) \sim \epsilon_i \epsilon_j M_X^2;$$
$$(A_u)_{ij} \sim \beta_i \alpha_j M_X, \quad (A_d)_{ij} \sim \gamma_i \alpha_j M_X, \quad (A_e)_{ij} \sim \epsilon_i \delta_j M_X$$

- Gaugino med. and gauge med. only generate flavor-universal terms.

➡ **Grav. med. contributions are detectable thru flavor-violating soft terms.**

Gravity Mediation vs. MFV

- Unfortunately, RG of Yukawa couplings also generate flavor-violating soft terms. (Minimal Flavor Violation)
- Compare the predictions of “grav.med. in bulk matter RS model” with those of MFV.

Orders of MFV effects

up-type quark Yukawa

- In Y_u-diagonal flavor basis, MFV effects on $(m_U^2)_{ij},\ (A_u)_{ij}$ are given by :

$$(m_U^2)_{ij} \sim \beta_i(\alpha_i)^2(\alpha_j)^2\beta_j \max\{M_X, M_G\}^2,$$
$$(A_u)_{ij} \sim \beta_i(\beta_i)^2\alpha_j\, M_X$$

$(m_D^2)_{ij},\ (A_d)_{ij}$ in Y_d -diagonal basis:

$$(m_D^2)_{ij} \sim \gamma_i(\alpha_i)^2(\alpha_j)^2\gamma_j \max\{M_X, M_G\}^2$$
$$(A_d)_{ij} \sim \gamma_i(\gamma_i)^2\alpha_j\, M_X$$

$(m_E^2)_{ij},\ (A_e)_{ij}$ in Y_e -diagonal basis, if singlet neutrinos exist:

$$(m_E^2)_{ij} \sim \epsilon_i(\delta_i)^2(\delta_j)^2\epsilon_j \max\{M_X, M_G\}^2,\quad (A_e)_{ij} \sim \epsilon_i(\epsilon_i)^2\delta_j\, M_X$$

⇒ If $M_X \gtrsim M_G$, grav. med. induces **larger amount of flavor violation than MFV** for

$$(m_U^2)_{ij},\ (m_D^2)_{ij},\ (m_E^2)_{ij},\ (A_u)_{ij},\ (A_d)_{ij},\ (A_e)_{ij} \quad (i=1,2)$$

in their natural bases.

Experimental Test

- The model predicts that flavor-violating soft terms :

$$(m_U^2)_{ij},\ (m_D^2)_{ij},\ (m_E^2)_{ij},\ (A_u)_{ij},\ (A_d)_{ij},\ (A_e)_{ij} \quad (i=1,2)$$

are much larger than MFV effects if $M_X \gtrsim M_G$.

- **Measure the orders of these terms** to test bulk matter RS model.
- In our model, LSP is gravitino, and NLSP is charged slepton and long-lived, so that it is **possible to reconstruct the masses** of all SUSY matter particles.

SUSY Particles of Interest

- **2nd generation, SU(2) singlet** sparticles give the best channels to test the model;

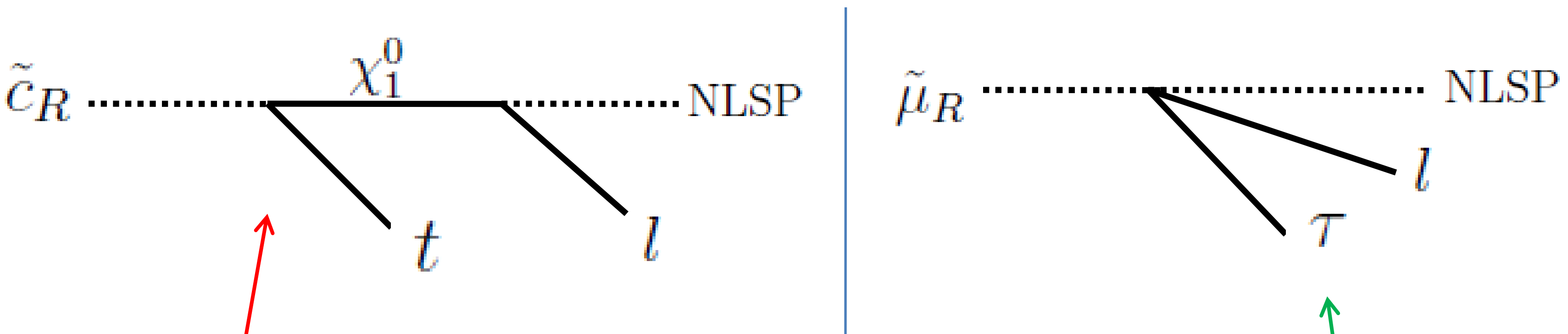
i. Large mixings between 2nd and 3rd generations.

ii. Much larger mixings among SU(2) singlet sparticles than MFV.

iii. Doublet-singlet mixings for 2nd gen. sparticles are small, hence doublet and singlet sparticles separately form mass eigenstates.

Rare Decay Events

- $\tilde{c}_R$ and $\tilde{\mu}_R$ mainly decay into $c\ \chi_1^0$ and $\mu + \text{lepton(s)} + \text{NLSP}$ resp. They can be identified by their reconstructed masses.
- Focus on the following rare decay events :



- Their rates are predicted to be :

$$\begin{cases} Br(\tilde{c}_R \ \rightarrow \ t\ \chi_1^0) \ \sim \ (\beta_2\beta_3)^2 \ \sim \ 1/300 \\ Br(\tilde{\mu}_R \ \rightarrow \ \tau + \ldots) \ \sim \ (\epsilon_2\epsilon_3)^2 \ \sim \ 3\cdot 10^{-11}\ (\delta_3)^{-4}\ \tan^4\beta \end{cases}$$

when $M_X \sim M_G$.

- The scale of δ_3 can be obtained by measuring the rate of MFV-dominant event: $Br(\tilde{\mu}_L \ \rightarrow \ \tau + \ldots) \ \sim \ (\delta_2\delta_3)^2 \ \sim \ (\delta_3)^4$

In Other Scenarios

- If $M_X << M_G$, impossible to test the model because MFV effects surpass grav. med. effects.
- If $M_X < M_G$, $Br(\tilde{c}_R \rightarrow t\ \chi_1^0)$ and $Br(\tilde{\mu}_R \rightarrow \tau + ...)$ are smaller, but the model can be tested through their ratio.
- If there is no 5D structure but grav. med. effects are sizeable, we will observe

$$Br(\tilde{\mu}_R \rightarrow \tau + ...) \sim Br(\tilde{\mu}_R \rightarrow e + ...)$$.

Conclusions

- Discussed the test of bulk matter RS model in case KK scale is far above TeV.
- Flavor-violating soft terms reflect the 5D structure of bulk matter RS model.
- Distinguishable from MFV effects.
- To test bulk matter RS model at colliders, measure the rates of rare decays in which $\tilde{c}_R$ and $\tilde{\mu}_R$ resp. decay into SM t and τ .