Modulus Mediation and lepton flavor violation in supersymmetric seesaw

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Introduction

- Supersymmetry (SUSY) is an attractive candidate for physics beyond the SM
- Lepton flavor violation is known as a sensitive probe of SUSY
- Seesaw mechanism induces LFV due to renormalization running by neutrino Yukawa coupling.
- We estimate the branching ratio of μ→e,γ including the effect of threshold correction in modulus mediation

Supersymmetry

Symmetry exchanges bosonic and fermionic fields

$$\text{fermion } \psi(x) \leftrightarrow \text{scalar (sfermon) } \phi(x)$$
$$\text{gauge boson } V_\mu(x) \leftrightarrow \text{fermion (gaugino) } \lambda(x)$$

Equal Mass

Relation among dimensionless couplings

No radiative correction in superpotential couplings (perturbative)

⇒ stable big hierarchy

Planck ⇔ Electroweak

Soft SUSY Breaking

Break SUSY by mass splitting (dimension-less couplings are intact)

Partners are heavy !

Squark, slepton mass — Gaugino mass

$$-\mathcal{L}_{Soft} = m_{ij}^2\,\phi_i^*\phi_j + \frac{1}{2}M_a\overline{\lambda^a}\lambda^a + \left[+\frac{1}{2}B_{\mu\,ij}\phi^i\phi^j + \frac{1}{3!}Y^A_{ijk}\phi^i\phi^j\phi^k + \text{h.c.}\right]$$

"Holomorphic" squark, slepton couplings

No new divergence, does not spoil the hierarchy

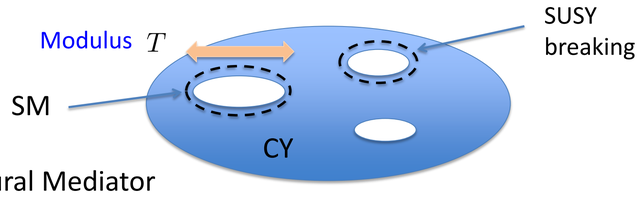
Superstring and Modulus Fields

Consistent theory of quantum gravity

Defined in 10-dimension

Compactified on 6-dimensional Calabi-Yau manifold

Moduli : parameterizes the size of the cycle in CY (+dilaton)



Natural Mediator

Modulus Mediation [1-3]

Modular weight $c_i = 1 - n_i$

4D Kinetic terms

$$\int d^4x\left(-\frac{1}{4}T F^{\mu\nu}F_{\mu\nu}\right) \quad \int d^4x (T+T^\dagger)^{c_i}(D^\mu\phi(x))^\dagger D_\mu\phi(x)$$

~ Volume where the field lives

$$\frac{1}{g_a^2} = Re\,T$$

Holomorphic couplings (not renormalized)

Canonical couplings

$$M_{ij} = \frac{\mu_{ij}}{(T+T^\dagger)^{c_i/2}(T+T^\dagger)^{c_j/2}}$$

$$Y_{ijk} = \frac{\lambda_{ijk}}{(T+T^\dagger)^{c_i/2}(T+T^\dagger)^{c_j/2}(T+T^\dagger)^{c_k/2}}$$

Neglecting flavor mixing,

$$B_{\mu_{ij}} = B_{ij}\,M_{ij} \qquad Y^A{}_{ijk} = A_{ijk}\,Y_{ijk}$$

Using Supergravity formula,

$$M_a = F^T\partial_T \ln(Re\,T) = \frac{F^T}{T+T^\dagger} \equiv M_0$$
$$B_{ij} = -(F^C\partial_C + F^T\partial_T)\ln\frac{C\,\mu_{ij}}{(T+T^\dagger)^{c_i+c_j}} = -\frac{F^C}{C} + (c_i+c_j)M_0$$
$$A_{ijk} = -F^T\partial_T \ln\frac{\lambda_{ijk}}{(T+T^\dagger)^{c_i+c_j+c_k}} = (c_i+c_j+c_k)\,M_0$$
$$m_i^2 = -F^T\,F^{T*}\,\partial_T\,\partial_{T^*}\,\ln(T+T^\dagger)^{c_i} = c_i\,|M_0|^2$$

Threshold Correction (New)

Submitted to PRL

Superpotential could have non-perturbative corrections

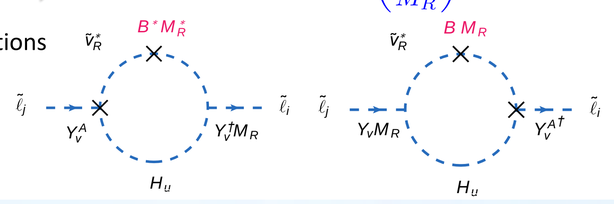
⇒ origin of intermediate scale in superstring [9-14]

$$M_R = \Lambda\exp\left(-\frac{b}{g_0^2}\right) = \Lambda\exp(-bT)$$

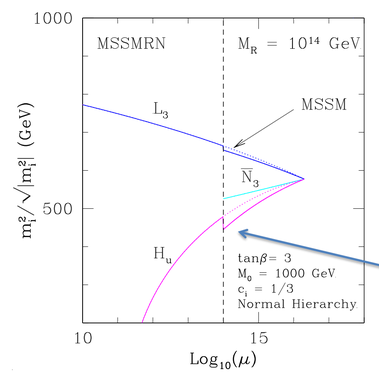
Modulus dependence ⇒ $\delta B = -F^T\partial\ln M_R = 2\ln\left(\frac{\Lambda}{M_R}\right)M_0 >> M_0$

Finite corrections

$$\delta m_{\tilde\ell}^2 =$$



Exact cancellation with RG running at one-loop for $\Lambda = M_S$ and $c_i + c_j + c_k = 1$

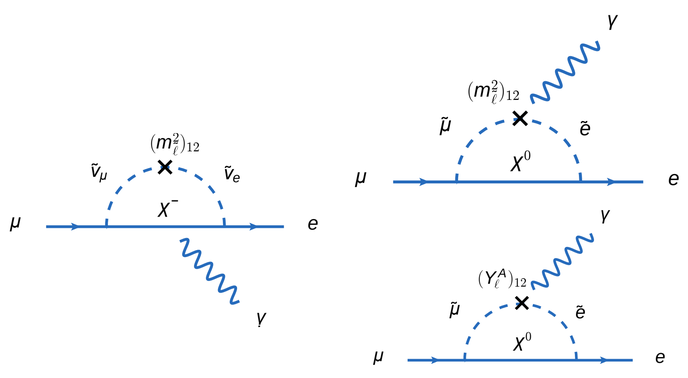


Threshold correction δm_i^2

Scaling property of RG solutions ⇔ anomaly mediation

BR(μ→e, γ)

One-loop diagram induces μ→e, γ at electroweak scale



SUSY Breaking and Flavor Violation

Soft SUSY breaking generally does not preserve flavor

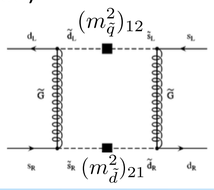
Quark lepton mass ⇔ SUSY breaking

$$Y_{u\,ij},\quad Y_{d\,ij},\quad Y_{e\,ij} \qquad m_{\tilde q\,ij}^2,\ m_{\tilde u\,ij}^2,\ m_{\tilde d\,ij}^2,\ m_{\tilde\ell\,ij}^2,\ m_{\tilde e\,ij}^2,\ Y_u^A{}_{ij},\ Y_d^A{}_{ij}$$

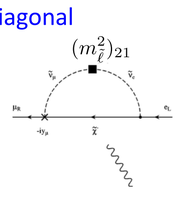
Diagonal (up to CKM) — irrelevant, per se

Non-diagonal

$K-\overline{K}$ mixing

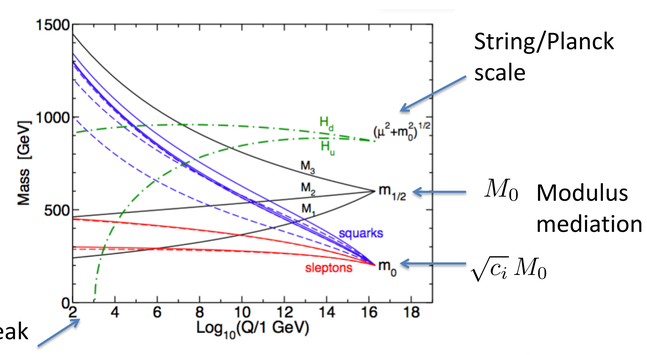


$\mu\to e,\gamma$



Renormalization Group

Soft SUSY Breaking parameters evolve by renormalization group equation



String/Planck scale

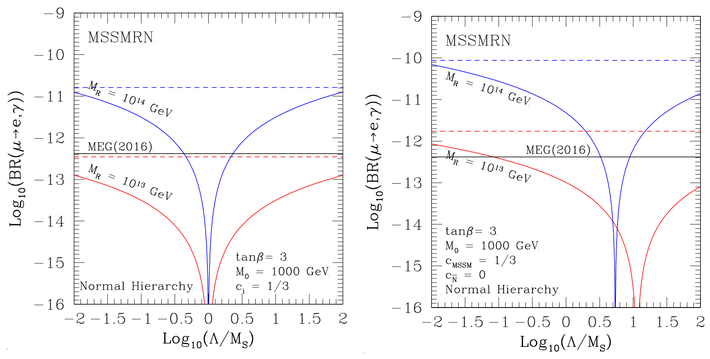
M_0 Modulus mediation

$\sqrt{c_i}\,M_0$

Electroweak scale

From "A Supersymmetry Primer" hep-ph/9709356

Results



$c_{H_u} + c_{\nu_R} + c_\ell = 1$ $\qquad$ $c_{H_u} + c_{\nu_R} + c_\ell \neq 1$

Origin of SUSY breaking

Prevent too much flavor violation

Hidden sector (SUSY breaking) ⇒ Mediator ⇒ SUSY SM

(Almost) Flavor blind interaction

CMSSM: Benchmark

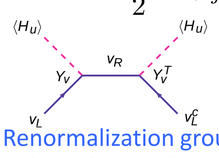
Popular scenario:

Gravity mediation (Modulus mediation)	Supergravity
Gauge mediation	SM gauge
Anomaly mediation (tachyonic slepton)	Weyl anomaly

Seesaw Mechanism and LFV

3-generation of heavy right-handed neutrinos

$$-\delta\mathcal{L} = \frac{1}{2}M_{R\,ij}\,\overline{\nu_{R\,i}^c}\,\nu_{R\,j} + \left(Y_{\nu\,ij}\,H_u\,\overline{\nu_{R\,i}}\,\ell_j + \text{h.c.}\right)$$



$$m_\nu = Y_\nu^T\,M_R^{-1}\,Y_\nu\,\langle H_u\rangle^2$$

Small neutrino mass

Renormalization group running due to neutrino Yukawa coupling induces lepton flavor violation [4-8]

$$\delta m_{\tilde\ell}^2 \simeq \frac{1}{16\pi^2}\left[m_{\tilde\ell}^2\,Y_\nu^\dagger Y_\nu + Y_\nu^\dagger Y_\nu\,m_{\tilde\ell}^2 + 2(Y_\nu^\dagger\,m_{\tilde\nu}^2\,Y_\nu + m_{H_u}^2\,Y_\nu^\dagger Y_\nu + Y_\nu^{A^\dagger}Y_\nu^A)\right]\ln\left(\frac{M_R}{M_S}\right)$$

M_S : string scale

Conclusion

- We calculated BR(μ→e,γ) in the minimal supersymmetric seesaw with modulus mediaion.
- We include threshold corrections due to the non-perturbative right-handed neutrino mass
- Exact cancellation occurs between the corrections and the RG induced LFV if Λ=M_S and the sum rule of the modular weight holds.
- Order reduction of the branching ratio is expected even for an order difference in Λ/M_S , reviving the excluded parameter space

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