Low-scale Gaugino Mediation in Warped Spacetime

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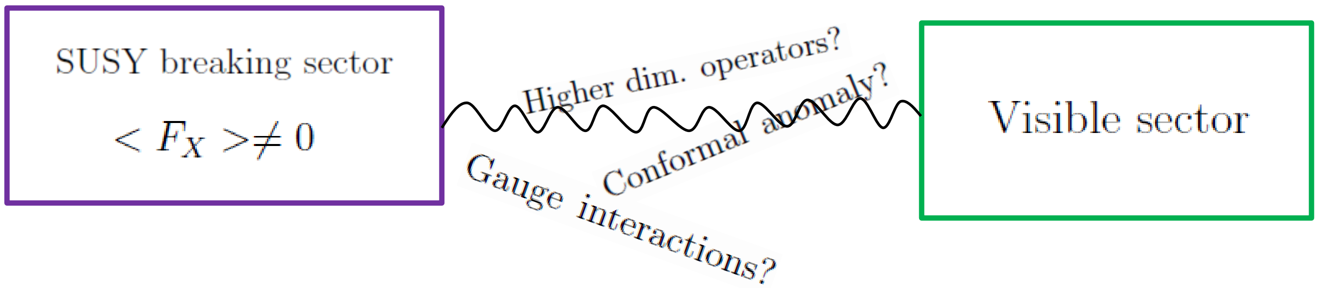
SUSY Breaking Mediation

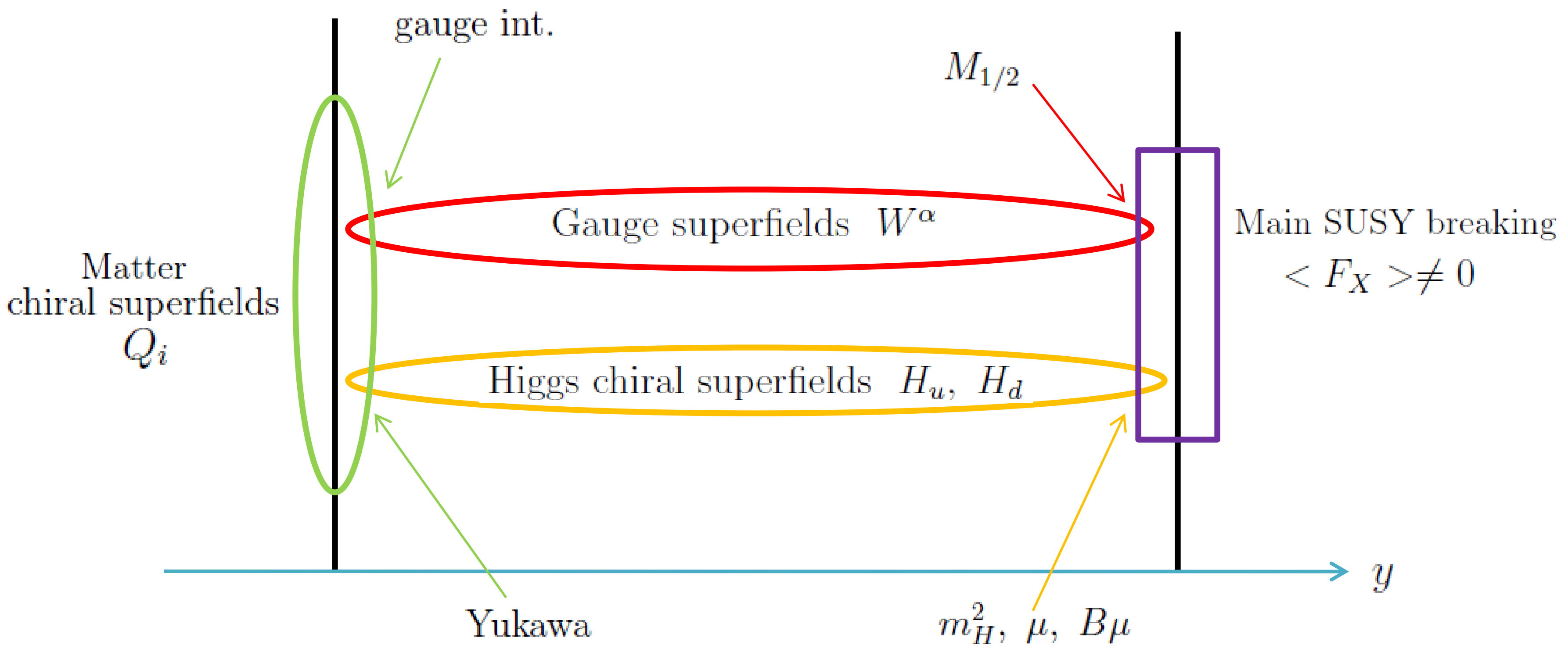
- What is the mechanism for SUSY breaking mediation in MSSM?



- We must have almost flavor blind and CP-preserving soft masses.
  We also have to derive μ term and $B\mu$ term with the same order.

Gaugino Mediation Framework

Z. Chacko, M. A. Luty, A. E. Nelson and E. Ponton (2000)
M. Schmaltz and W. Skiba (2000)



- **Gauge** and **Higgs** superfields couple to SUSY breaking at **Tree Level**.
- **Matter sparticles** get soft mass **radiatively** below KK scale.

Features of Gaugino Mediation

- SUSY breaking sector and Matter are separated.

  ➡ **No contact terms** ➡ **No large FCNC**

- μ and $B\mu$ arise from Giudice-Masiero mechanism.

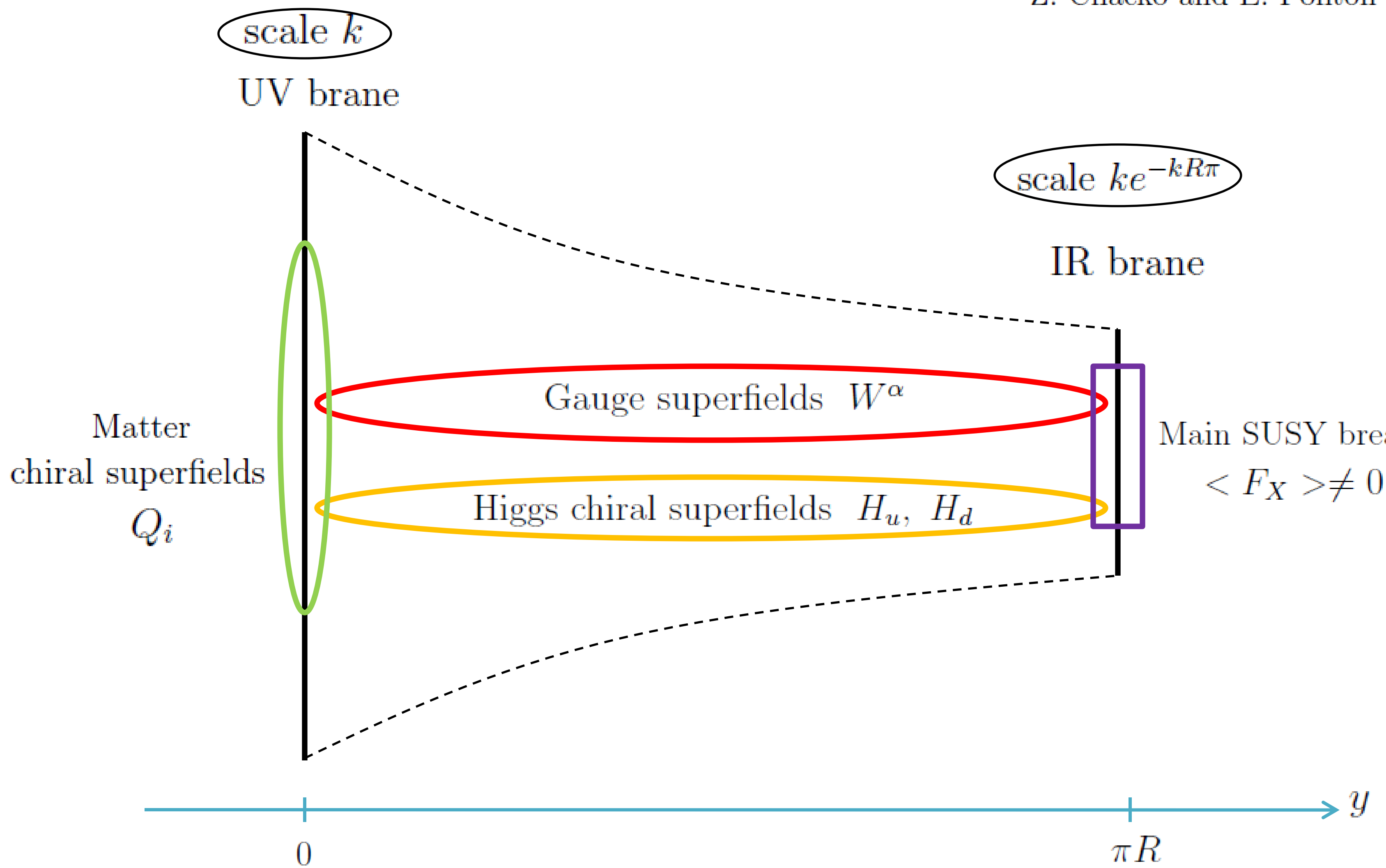
  ➡ **We have** $\boxed{\mu^2 \sim B\mu}$.

The Model

Setup

We studied gaugino mediation in **warped spacetime**.

Z. Chacko and E. Ponton (2003)



How does Warped Spacetime work?

Thanks to warped geometry,

Explained later.

- Cutoff can be low without inconsistency.

  ⟹ **"SUSY fine-tuning problem"** is solved.

- Gravitino is the LSP.

  ⟹ **"Stau LSP problem"** is solved.

SUSY Fine-tuning Problem

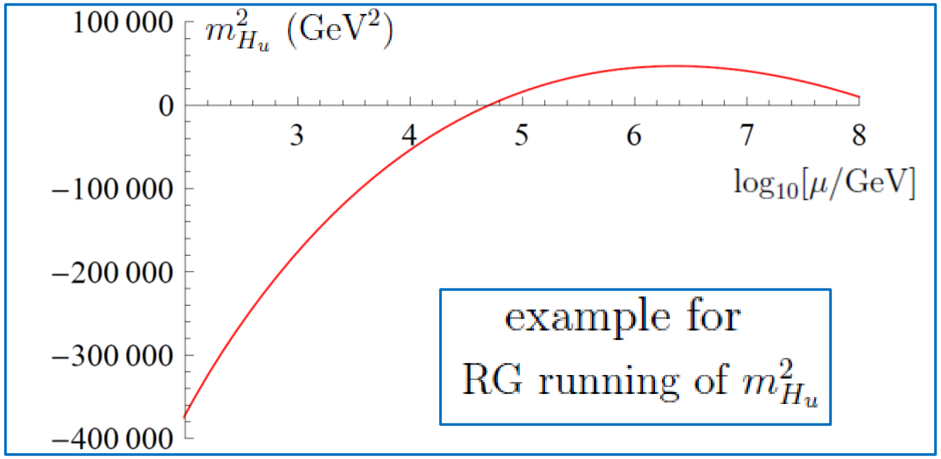
R. Harnik, G. D. Kribs, D. T. Larson and H. Murayama (2004)

"SUSY fine-tuning problem"

EWSB imposes $\frac{1}{2}M_Z^2[M_s] \simeq -m_{H_u}^2[M_s] - \mu^2[M_s]$ for large $\tan\beta$

@ SUSY breaking scale M_s .

On the other hand, $m_{H_u}^2$ gets **large RG contribution** while running from MSSM cutoff scale Λ_{cutoff} to SUSY breaking scale M_s .



To avoid fine-tuning, cutoff scale Λ_{cutoff} must be **Low**.

Actually, $\Lambda_{cutoff} \lesssim 10^4$ TeV is required to avoid fine-tuning. → To be seen later.

Cutoff of Gaugino Mediation

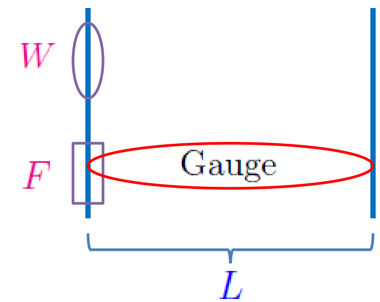
- **Cutoff** of MSSM with Gaugino mediation = **KK** scale.
- KK scale **cannot** be low in 5D **Flat** Gaugino mediation.

***Proof* :** Consider **flat** 5th dimension $-L \leq y \leq L$ on S^1/Z_2 .

M_5 : 5D Planck

W : const. superpotential on a brane

F : SUSY breaking vev on a brane



Consistency of theory on branes : $W < M_5^3$

To derive 4D Planck scale : $2LM_5^3 = M_P^2$

Zero cosmological const. : $F^\dagger F \simeq 3W^\dagger W/M_P^2$

To derive TeV scale gaugino mass : $F/M_5^2 L \sim \text{TeV}$

$$1/L \gtrsim 10^4 \text{ TeV}$$

KK scale cannot be low

- Strongly warped spacetime (KK scale = $ke^{-kR\pi}$) has **no** such problem.

From the previous two slides, …

- Low MSSM cutoff $\Lambda_{cutoff} \lesssim 10^4\ \mathrm{TeV}$ is favorable from the point of view of "SUSY fine-tuning problem".
- Cutoff of 5D flat gaugino mediation models cannot be low, $1/L \gtrsim 10^4\ \mathrm{TeV}$.

On the other hand, cutoff of gaugino mediation in warped spacetime, $ke^{-kR\pi}$, can be anywhere.

⬇

Warped geometry is desired to solve "SUSY fine-tuning problem".

Stau LSP Problem

“Stau LSP problem”

Normally, **stau is the LSP** in 5D **flat** gaugino mediation models (without GUT).

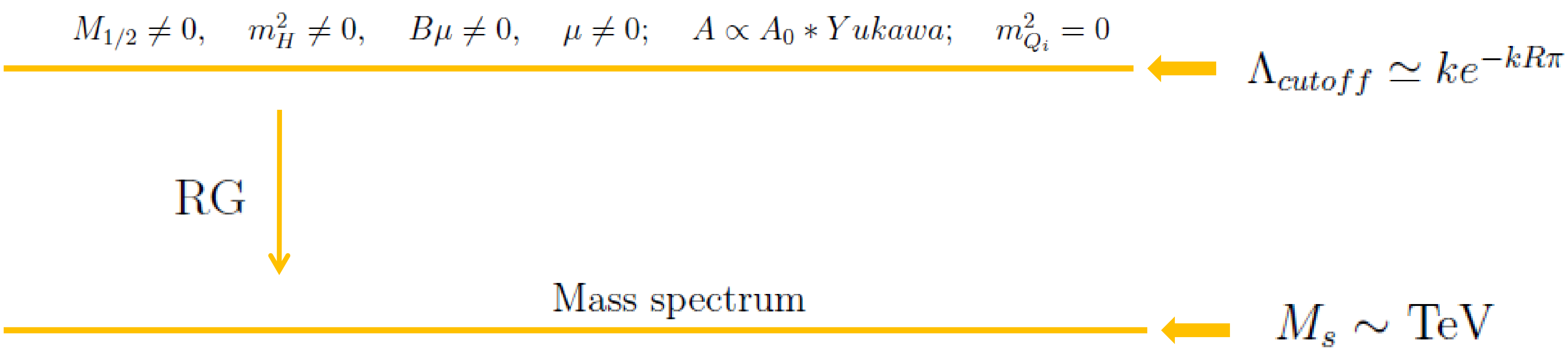
However, charged LSP is cosmologically disfavored.

- In warped spacetime, gravitino mass is suppressed by the warp factor. So **gravitino is always the LSP** and “Stau LSP problem” does not exist.

Numerical Analysis

Mass Spectrum

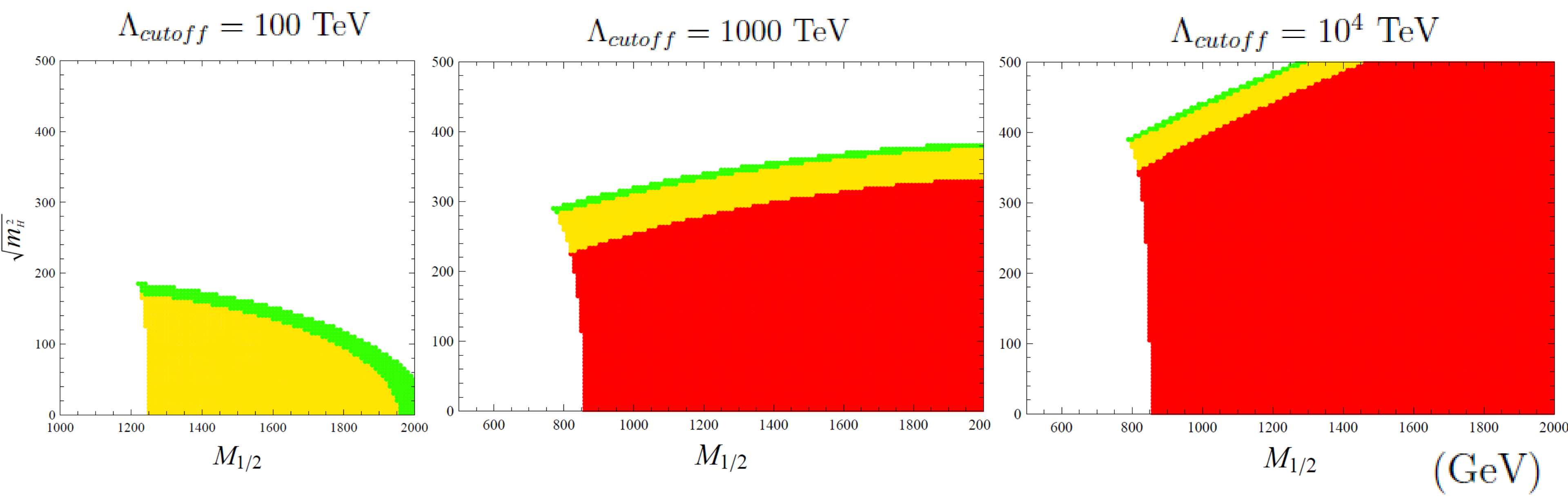
- Mass spectrum is calculated by solving RGE from **cutoff = KK scale** to **SUSY breaking scale** with matter soft mass at cutoff being all zero.



- We checked how the **"level of tuning"** $\equiv \; (\, 1/2 M_Z^2[M_s] \,) \, / \, \mu^2[M_s]$ of each spectrum changes for various values of cutoff $\Lambda_{cutoff} \simeq k e^{-kR\pi}$.

Results

- For simplicity, we assumed **universal** gaugino mass $M_{1/2}$, Higgs soft mass m_H^2 and A-term A_0 **at cutoff**.
- We plotted the **“level of tuning”** of each spectrum in ($M_{1/2}$, m_H^2) space for fixed A_0 and $\tan\beta$.
- For example, with $A_0 = 500$ GeV and $\tan\beta = 45$:



Blank : unrealistic spectrum,

Red : tuning < 0.1 (bad), Yellow : 0.1 < tuning < 0.3 (good), Green : 0.3 < tuning (good)

Discussion

When $\Lambda_{cutoff} < 10^4$ TeV, fine-tuning is **absent in large parameter regions**.

↓

If we consider the "SUSY fine-tuning problem", Λ_{cutoff} lower than 10^4 TeV is preferred.

↓

Warped spacetime works here.

Gravitino Phenomenology

Gravitino DM

- Since gravitino is the LSP,
  we want gravitino to be the DM.
- However, the mass of gravitino is

$$m_{3/2} \sim \mathrm{TeV} \times e^{-kR\pi} \lesssim \mathrm{eV} \; ,$$

i.e. it is hot DM and disfavored.

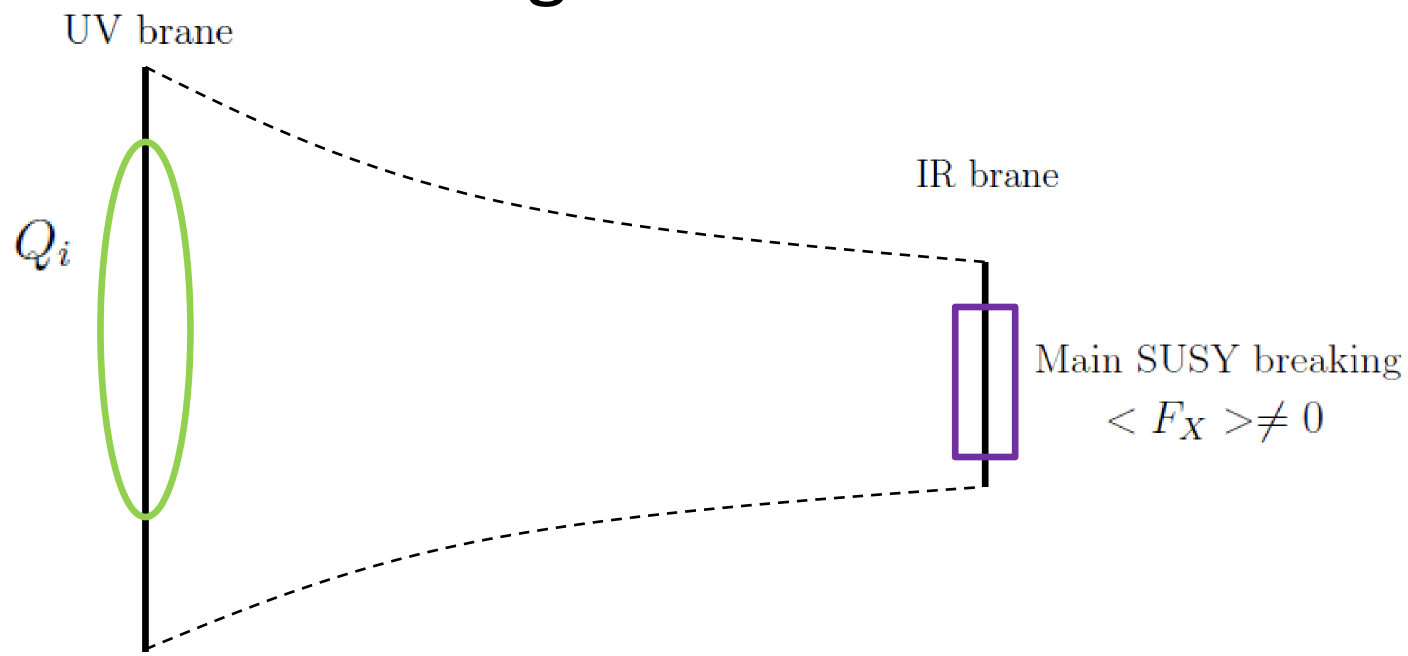
⬇

- There is a way to lift up the gravitino mass.

➡ Adding small SUSY breaking on UV brane

SUSY breaking on UV brane

- Additional SUSY breaking on **UV** brane is allowed.



- Dominant contribution to **gravitino mass** : $m_{3/2} \sim | < F_Y > | / M_5$

  Gravity superfield is localized towards UV brane.

- Flavor **non-diagonal** soft mass : $c_{ij} \frac{| < F_Y > |^2}{M_5^2} Q_i Q_j \quad (c_{ij} \sim O(1))$

  Gravity mediation contribution.

Gravitino mass and FCNC rates are related.

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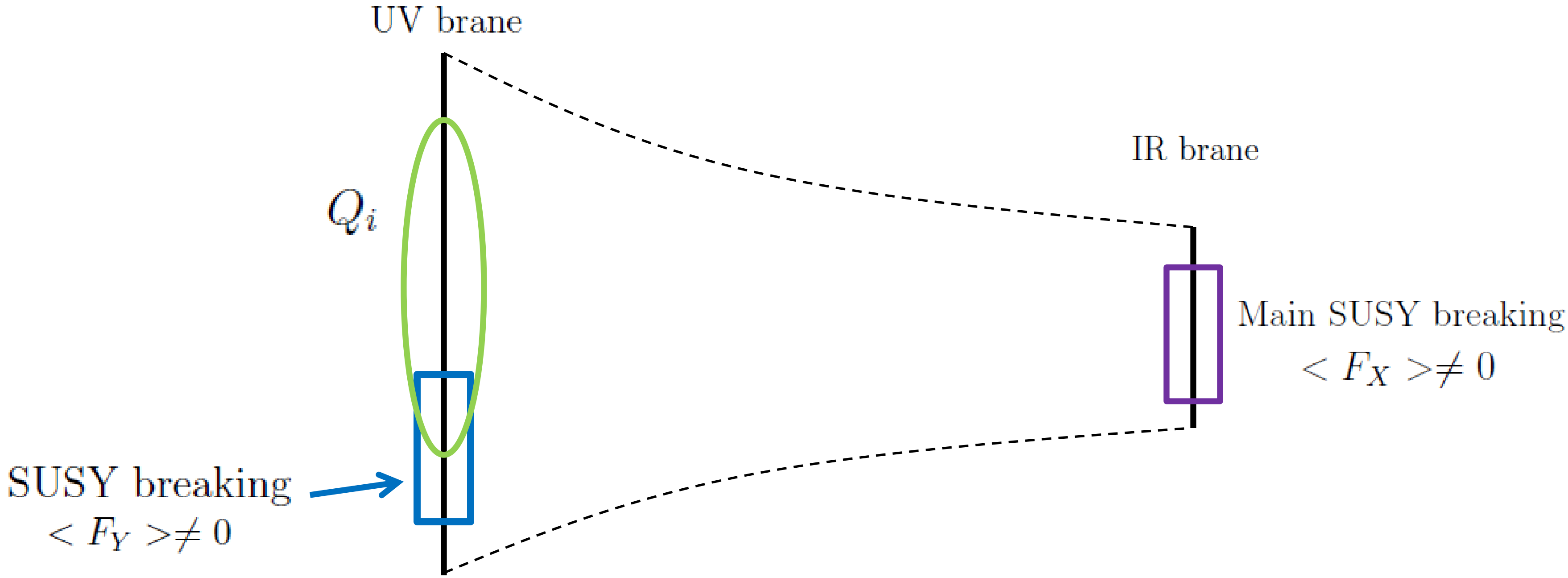

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Notes on Multiple SUSY Breakings

C. Cheung, Y. Nomura and J. Thaler (2010)

- Two SUSY breaking sectors : $< F_1 > \neq 0$, $< F_2 > \neq 0$.

  ➡ **Two Goldstinos**

➡ { One becomes ±1/2 components of gravitino.
    The other remains **uneaten**.

- The uneaten goldstino, ζ , is **not** massless.

  ➡ It gets mass through SUGRA effects :

$$m_\zeta = 2m_{3/2} .$$

- It couples to SUSY current as

$$\left(-\frac{F_2}{F_1} + \frac{F_1}{F_2}\right) \frac{1}{\sqrt{F_1^2 + F_2^2}} \zeta^\alpha \, \partial_\mu j^\mu_\alpha .$$

In Our Case, …

- Two SUSY breakings : $< F_Y > \gg < F_{\tilde{X}} >$.

$$\frac{< F_Y >}{M_5} \sim \text{GeV} \qquad \frac{< F_{\tilde{X}} >}{M_5 e^{-kR\pi}} \sim \text{TeV}$$

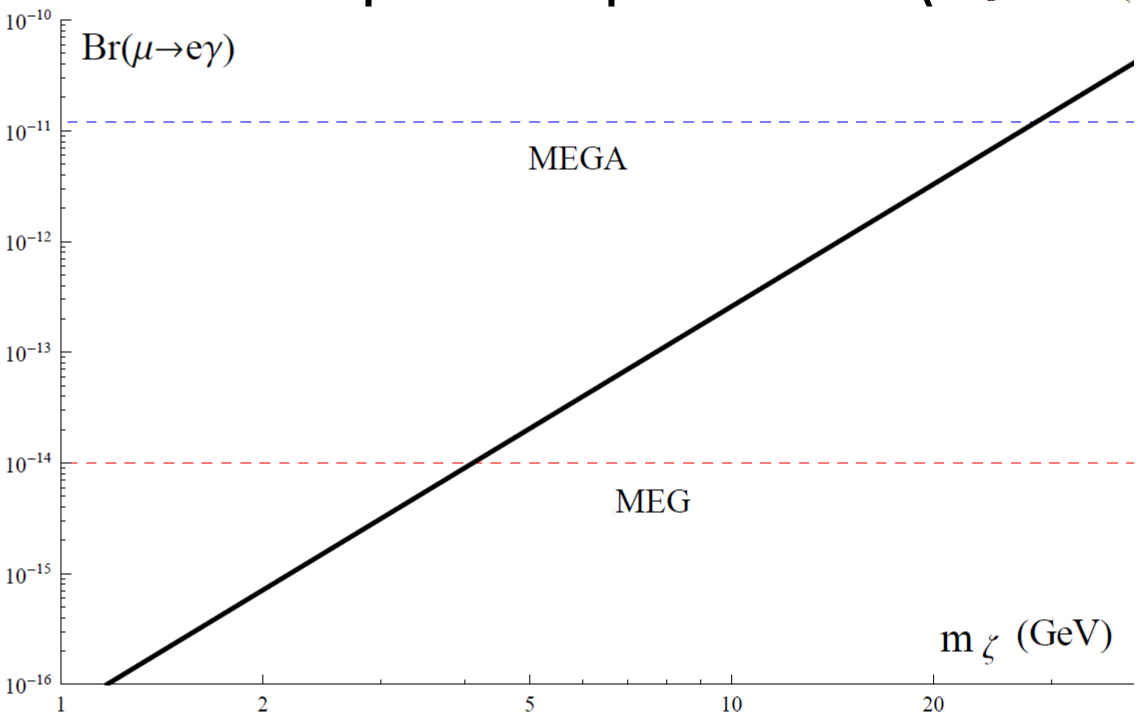
- Uneaten goldstino mass : $m_\zeta \sim | < F_Y > | \, / \, M_5$.
- Uneaten goldstino coupling : $\simeq \dfrac{1}{| < F_{\tilde{X}} > |} \zeta^\alpha \, \partial_\mu j^\mu_\alpha$.

Uneaten goldstino couples to MSSM sector **much more strongly** than gravitino of the same mass.

BBN constraints on gravitino mass no longer exist.

Goldstino Mass vs. Flavor Violation

- We calculated the correlation between goldstino mass m_ζ and $\mu \to e\gamma$ branching ratio $Br(\mu \to e\gamma)$ for a specific spectrum. ($c_{ij} \sim O(1)$ assumed)



$$
\begin{aligned}
\Lambda_{cutoff} &= 1000 \text{ TeV} \\
M_{1/2} &= 1500 \text{ GeV} \\
m_H^2 &= 200^2 \text{ GeV}^2 \\
A &= 500 \text{ GeV} \\
\tan\beta &= 45
\end{aligned}
$$

stau NLSP

MEGA : Current experimental bound on $Br(\mu \to e\gamma)$

MEG : Future accessible limit on $Br(\mu \to e\gamma)$

Conclusions

- We have studied **"Gaugino mediation in warped spacetime"**, where Gauge and Higgs superfields live in the bulk, Matter on UV brane and Main SUSY breaking on IR brane.
- Gaugino mediation in warped spacetime solves **"SUSY fine-tuning problem"** and **"stau LSP problem"**, as well as flavor problem and μ -problem.
- In particular, warped geometry is desired to solve "SUSY fine-tuning problem" in gaugino mediation models.
- Additional SUSY breaking on UV brane gives **correlation between $m_{3/2}$ and FCNC processes**.