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Natural supersymmetric spectrum in mirage mediation

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1. Motivation:

One of original motivations for SUSY:

Solution of fine-tuning problem!

We do not want to give it up.

Problem arising from LHC

$\sim$ 125 GeV Higgs

VS

SUSY little hierarchy problem:

Fine-tuning problem for EWSB.

The lightest Higgs mass in SUSY models: 1-loop correction from stop is important.

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\log\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) + \cdots$$

$M_Z :\ Z-$ boson mass ≈ 91.2GeV,

$m_t :$ top quark mass ≈ 172.9GeV, $m_{\tilde{t}}^2 :$ stop mass.

$v^2 = \langle H_u \rangle^2 + \langle H_d \rangle^2 \approx (174)^2\text{GeV}^2$, $\tan\beta = \frac{\langle H_u \rangle}{\langle H_d \rangle}$

The lightest Higgs mass
1-loop correction from s

Large SUSY breaking
(> 10TeV)
for 125 GeV Higgs?

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\log\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) + \cdots$$

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SUSY little hierarchy problem: Small m_{H_u}, m_{H_d} are required.

$$-\frac{M_Z^2}{2} = |\mu|^2 + \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1}$$

$$\approx |\mu|^2 + m_{H_u}^2 - \frac{m_{H_d}^2}{\tan^2\beta} + \cdots .$$

M_Z : $Z-$boson mass ≈ 91.2GeV,

μ : higgsino mass,

$m_{H_{u,d}}$: SUSY breaking soft term of $H_{u,d}$.

SUSY lit
Small n

Small SUSY breaking
(< 1TeV)
for no fine-tuning of μ?

$$\delta m_{H_u}^2 \sim -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \log(\Lambda/m_{\tilde{t}}).$$

$$-\frac{M_Z^2}{2} =$$

$$\approx \quad |\mu|^2 + m_{H_u}^2 - \frac{m_{H_d}^2}{\tan^2\beta} + \cdots .$$

M_Z : $Z-$boson mass $\approx$ 91.2GeV,

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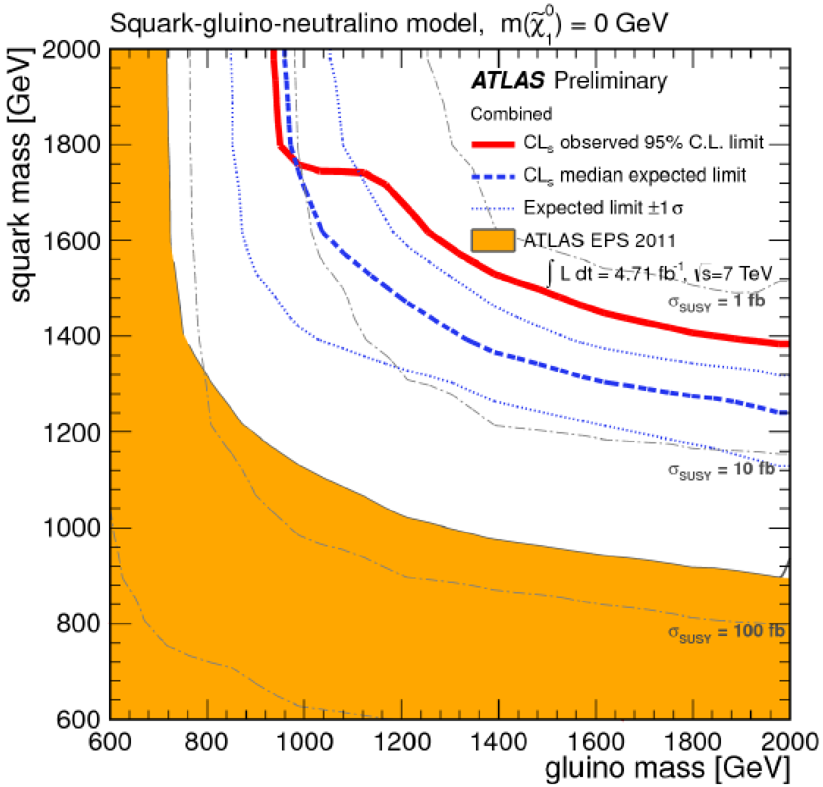
LHC constraint on SUSY

SUSY breaking soft mass > 1.5 TeV!?,

in addition to ～125 GeV Higgs.



A solution

- Next to MSSM (NMSSM): $W_{\text{NMSSM}} \supset \lambda S H_u H_d,$

$$\Delta m_h^2 = \lambda^2 v^2 \sin^2(2\beta).$$

→ ～125 GeV Higgs.

- TeV scale mirage mediation: Choi, Jeong, Kobayashi, Okumura; Kitano, Nomura

Effective low messenger scale in soft mass sector.

→ small m_{H_u} and m_{H_d} → small μ.

(Compact SUSY spectra was also discussed in our paper.)

2. NMSSM and mirage mediation

Generalized NMSSM:

$$W = W_{\text{MSSM Yukawa}} + W_{\text{Higgs}};$$

$$W_{\text{Higgs}} = \lambda S H_u H_d + \xi_F S + \frac{\mu_S}{2} S^2 + \frac{\kappa}{3} S^3.$$

$$\mu = \lambda \langle S \rangle.$$

- ～125 GeV Higgs mass
- Compact SUSY mass spectra
- Stringy realization of S ⇔ mirage mediation

2. NMSSM and mirage mediation

Generalized NMSSM:

$$W = W_{\rm MSSM\ Yukawa} + W_{\rm Higgs},$$

$$W_{\rm Higgs} = \lambda S H_u H_d + \xi_F S + \frac{\mu_S}{2} S^2 + \frac{\kappa}{3} S^3.$$

$$\mu = \lambda \langle S \rangle.$$

- ～125 GeV Higgs mass
- Compact SUSY mass spectra
- Stringy realization of S ⇔ mirage mediation

Soft masses in the NMSSM

$$\mathcal{L}_{\rm soft} \supset -m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 - m_S^2|S|^2 \\ - \left(\lambda A_\lambda S H_u H_d + \xi_F C_S S + \frac{1}{2}\mu_S B_S S^2 + \frac{1}{3}\kappa A_\kappa S^3 + b H_u H_d + \text{h.c.}\right).$$

Independent quantities via $\partial_{S,H_u,H_d} V = 0$:

$$\lambda, \quad \kappa, \quad A_\lambda, \quad A_\kappa, \quad m_{H_d}^2, \quad m_{H_u}^2, \quad m_S^2, \quad \xi_F, \quad C_S, \quad b, \quad m_Z, \quad \tan\beta.$$

Soft masses in the NMSSM

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Independent quantities via $\partial_{S,H_u,H_d} V = 0$:

λ, ✗ $\underline{A_\lambda}$, ✗ $\underline{m_{H_d}^2}$, $\underline{m_{H_u}^2}$, $\underline{m_S^2}$, ξ_F, $\underline{C_S}$, ✗ m_Z, $\tan\beta$.

$A_\lambda \rightarrow M_0$

Soft masses in mirage mediation

Choi, Jeong, Okumura;
Endo, Yamaguchi, Yoshioka

$$m_{\mathrm{soft}}(Q) \sim cM_0 + \frac{m_{3/2}}{16\pi^2} + (\mathrm{mixings})$$

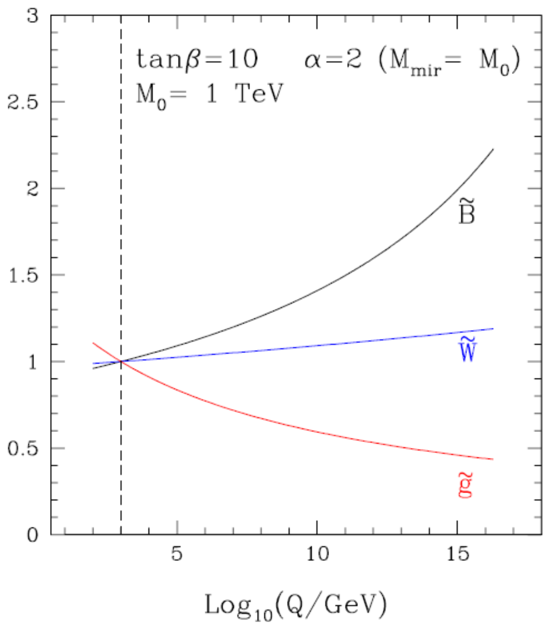
$$\sim M_0 \left[c + \frac{1}{16\pi^2} \log(\Lambda_m/Q) \right].$$

M_0 : Gravity mediation, $\frac{m_{3/2}}{16\pi^2}$: Anomaly mediation.

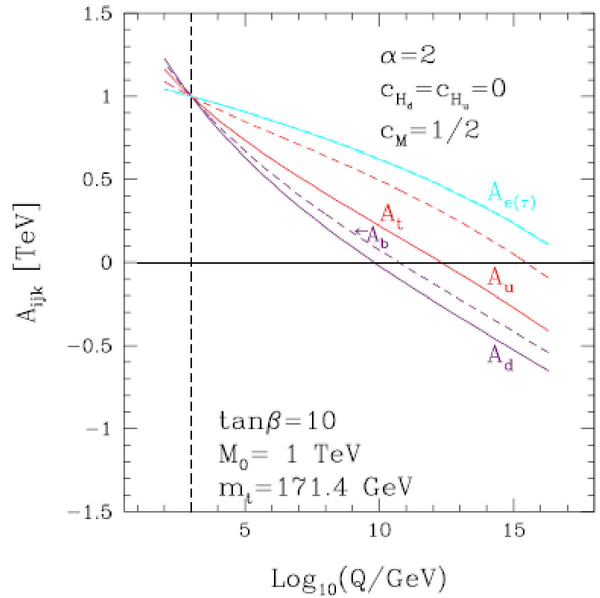
Λ_m : Mirage messenger scale

This scale is determined by the ratio of the above.

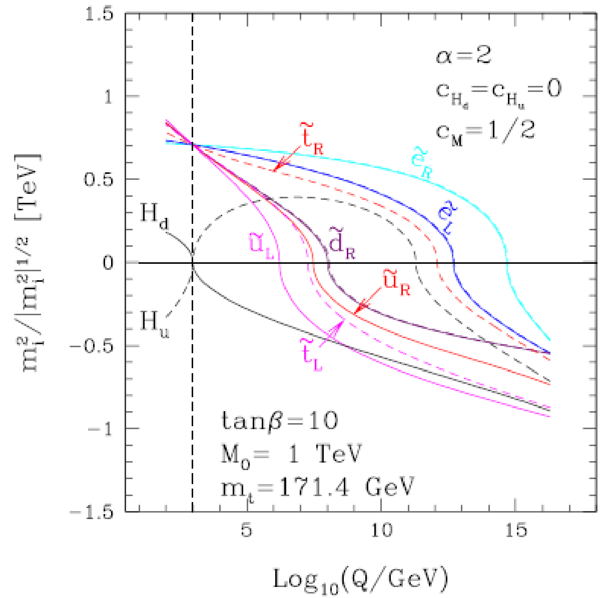
Running of soft masses



Gaugino masses



A-terms



Scalar masses

Choi, Jeong, Kobayashi, Okumura

TeV Λ_m = "TeV messenger scale"
for the gravity mediation!

A solution for SUSY little hierarchy

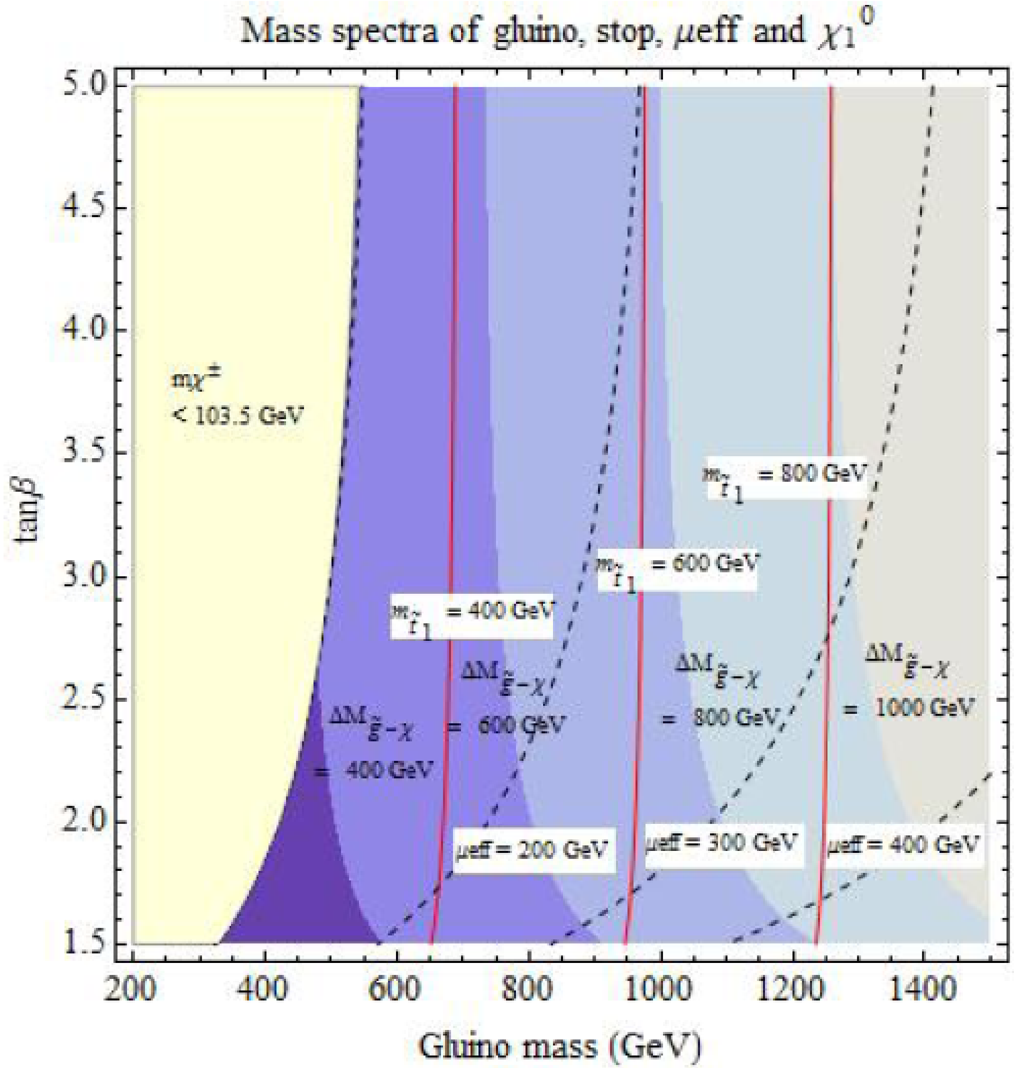
Take $\quad c_{H_u} = c_{H_d} = 0, \;\; c_S = 1,$

and $\quad c_{\text{matter}} = \mathcal{O}(1).$

$$m_{H_u}^2 \sim m_{H_d}^2 \sim \frac{M_0^2}{8\pi^2}.$$

$$m_i^2 \simeq |M_0|^2 \Bigg[\boxed{c_i} - \frac{g_Y^2(Q)}{8\pi^2} Y_i \Big(\sum_k c_k Y_k\Big) \log\left(\frac{M_X}{Q}\right) + \left(2\gamma_i(Q) - \dot{\gamma}_i(Q) \log\left(\frac{\Lambda}{Q}\right)\right) \log\left(\frac{\Lambda}{Q}\right) \Bigg],$$

Mass spectrum



Small μ

for M0 =O(1) TeV.

$$-\frac{M_Z^2}{2} = |\mu|^2 + \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1}$$

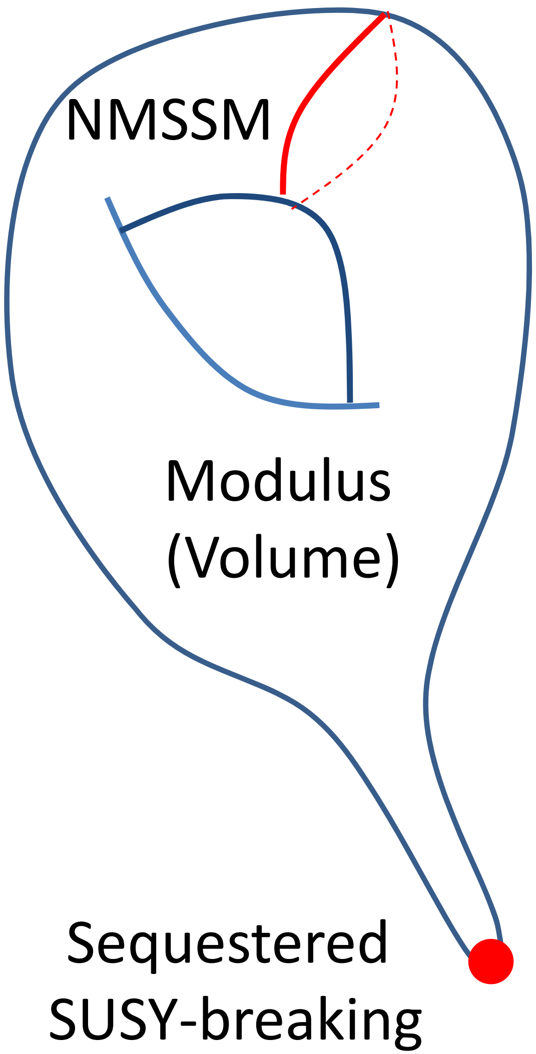
Input parameters	Point III
(c_{H_u}, c_{H_d}, c_S)	(0,0,1)
$(c_{q_{1,2}}, c_l)$	(4, 4)
$(\lambda, \kappa, \tan\beta)$	(0.72, 0, 3)
$\log(\Lambda/m_{\tilde{t}})$	1
Input parameters	**value (GeV)**
M_0	1000
(ξ_F, C_S)	$(-(663)^2$, 1180)
(μ_S, B_S)	(319, 2110)
$\mu_{\rm eff}$	272
A_t	1030
mass difference	**(GeV)**
$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$	824
$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$	432
$m_{\tilde{u}_L} - m_{\tilde{\chi}_1^0}$	1800

particles	Mass (GeV)
$\tilde{g}$	1060
$\tilde{\chi}_{1,2}^{\pm}$	266, 1000
$\tilde{\chi}_5^0$	1000
$\tilde{\chi}_4^0$	984
$\tilde{\chi}_3^0$	368
$\tilde{\chi}_2^0$	294
$\tilde{\chi}_1^0$	233
$\tilde{u}, \tilde{c}_{L,R}$	2030, 2020
$\tilde{t}_{1,2}$	664, 866
$\tilde{d}, \tilde{s}_{L,R}$	2030, 2020
$\tilde{b}_{1,2}$	766, 775
$\tilde{e}, \tilde{\mu}_{L,R}$	2000, 2000
$\tilde{\tau}_{1,2}$	2000, 2000
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	2000, 2000, 2000
$H^{\pm}$	299
$a_{1,2}$	283, 664
$h_{1,2,3}$	125, 300, 1570

$$m_i^2 \sim c_i |M_0|^2$$

3. Stringy motivation: KKLT

Kachru, Kallosh, Linde, Trivedi;
Choi, Falkowski, Nilles, Pokorski

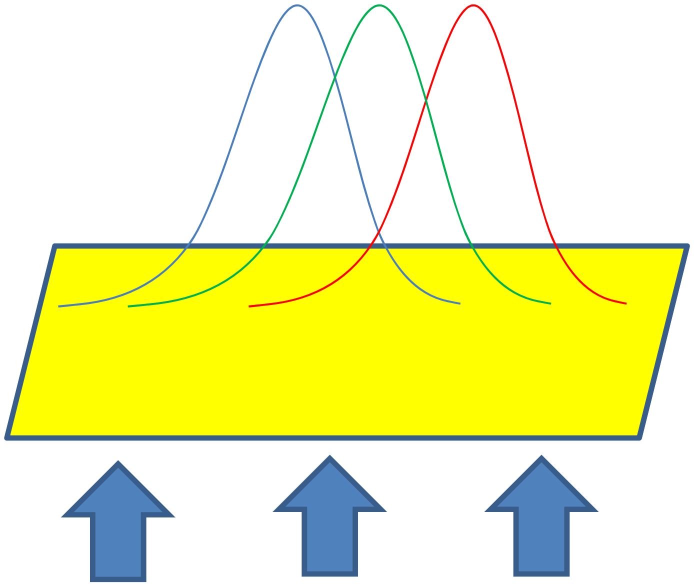


Moduli: SUSY-breaking source coupled to the NMSSM.

$$M_0 \sim F^{\text{moduli}} \sim \frac{m_{3/2}}{8\pi^2}.$$

$$m_{\text{moduli}} \sim 8\pi^2 m_{3/2}.$$

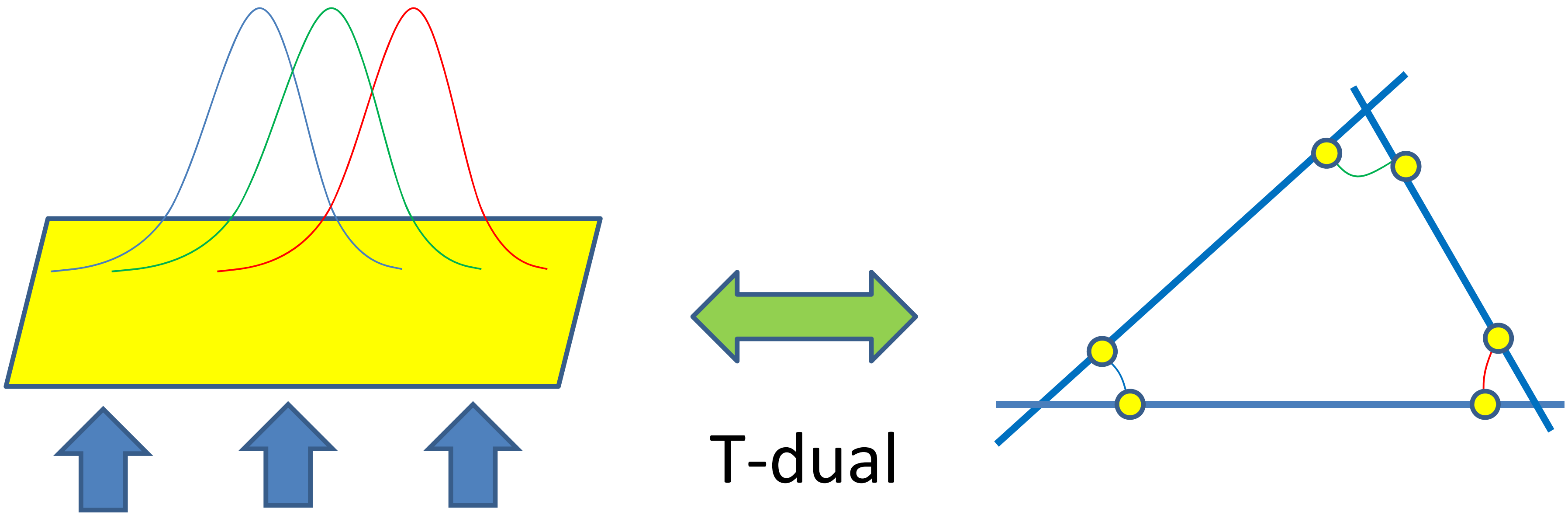
NMSSM on a fluxed-brane



$$\langle F_{mn} \rangle \neq 0.$$

$$\mathcal{D}_m = \partial_m + i\langle F_{mn} \rangle y^n.$$

NMSSM on a fluxed-brane



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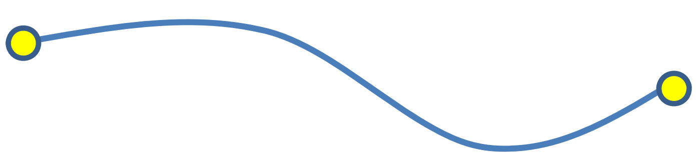
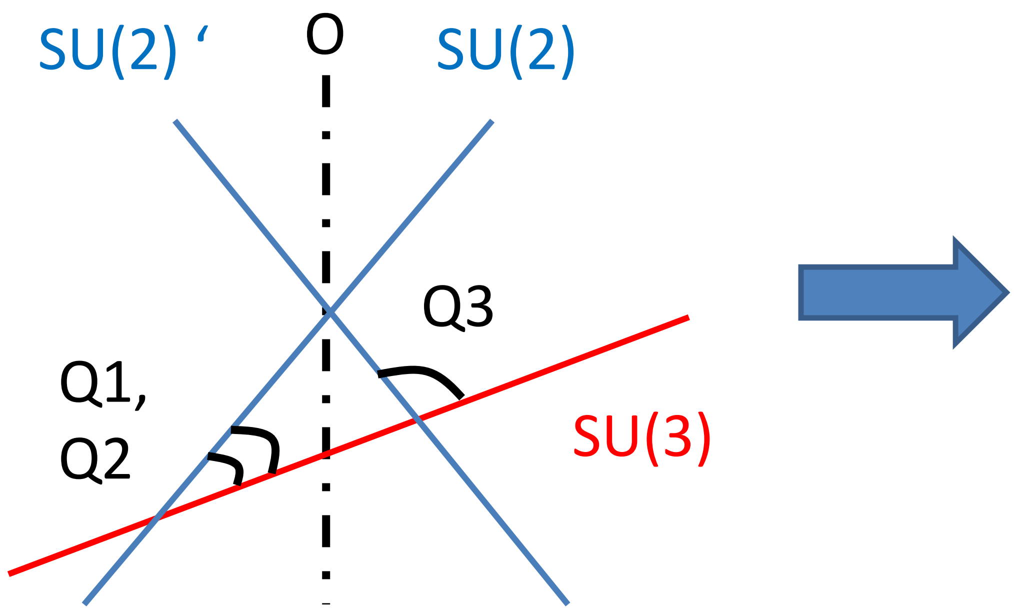


Open string has a charge!

Is Yukawa flavor structure telling 3 = 2+1 Generation?



(Perturbative) brane model ???

$$m^2_{Q_{1,2}} \gtrsim m^2_{Q_3} \ ?$$

$$c_{\mathrm{matter}} = \mathcal{O}(1).$$

$$m_i^2 \sim c_i |M_0|^2$$

Is Yukawa flavor structure telling
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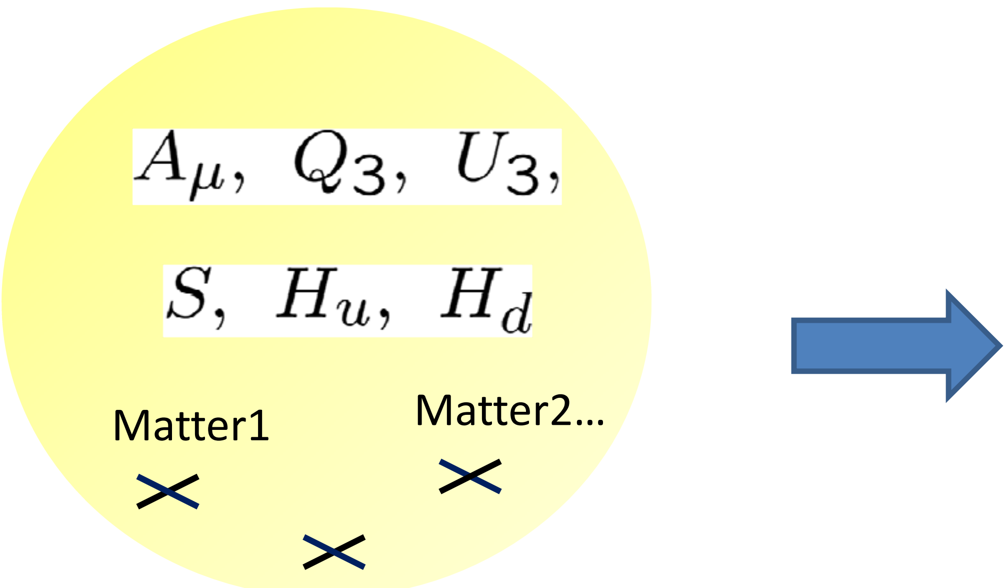


$$m^2_{Q_{1,2}} \gtrsim m^2_{Q_3}\ ?$$

$$c_{\mathrm{matter}} = \mathcal{O}(1).$$

$$m_i^2 \sim c_i |M_0|^2$$

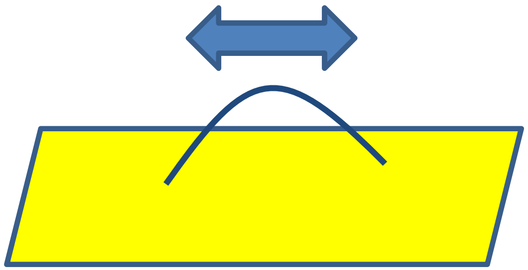
Hetero, M/F-theory???

Gauge-top Yukawa-λ unification

is required for mirage mediation.

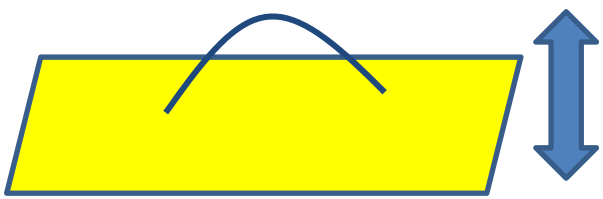
The Higgs sector
= Open string moduli?

$$A_m = \begin{pmatrix} & H_u \\ H_d & \end{pmatrix}$$



$$c_{H_u} = c_{H_d} = 0$$

$$\Phi_{\text{position}} = \begin{pmatrix} & & \\ & S & \\ & & \end{pmatrix}$$



$$c_S = 1$$

$$m_i^2 \sim c_i |M_0|^2$$

The Higgs sector
= Open string moduli?

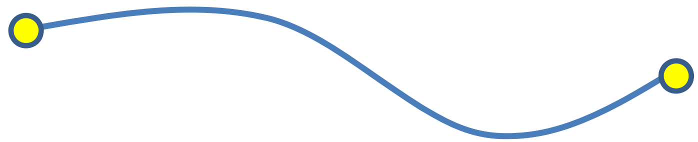
$$A_m = \begin{pmatrix} & H_u \\ H_d & \end{pmatrix}$$

Gauge-Higgs unification.

$$\Phi_{\text{position}} = \begin{pmatrix} & & \\ & S & \\ & & \end{pmatrix}$$

Even if this is not the case,

the SM singlet S should be charged under an $U(1)_{PQ}$ which are to be broken.



$$W_{\text{singlet}} = \xi_F S + \frac{\mu_S}{2} S^2 + \frac{\kappa}{3} S^3$$

$$\xi_F \ll M^2_{\text{cutoff}}, \quad \mu_S \ll M_{\text{cutoff}}, \quad \kappa \ll 1.$$

4. Conclusion

TeV scale mirage mediation in the NMSSM can

solve SUSY little hierarchy problem

and

realize $\sim$ 125 GeV Higgs.

Gauge-Higgs-Yukawa unification

for mirage mediation?

ArXiv:1207. 2771 [hep-ph]

Higgs, Moduli Problem, Baryogenesis and Large Volume Compactifications

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