Moduli Stabilization & the Pattern of Sparticle Masses

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Based on

K.C & H.P. Nilles, JHEP 04 (2007) 006 [hep-ph/0702146]

W. Cho, K.C, Y. Kim & C. Park, arXiv : 0709.0288 [hep-ph]
0711.4526 [hep-ph]

- Introduction
- Stabilization of gauge coupling modulus and the pattern of sparticle (gaugino) spectra
- Determination of gaugino mass ratios at LHC using the kink structure of M_{T2}

♦ Introduction

Weak scale SUSY is perhaps the leading candidate for new physics at TeV :

- Protect the weak scale from quadratic divergence
- Gauge coupling unification (within the MSSM)
- Good CDM candidate (under R-parity)
- Easily pass the precision EW test

If the idea of weak scale SUSY is correct, LHC will be able to discover some superparticles.

What will be the key issue if superparticles are discovered at LHC ?

$\boxed{\text{SUSY Spectroscopy}}$

(Patterns of gaugino, squark and slepton masses)

⇒ Window for the next step of fundamental physics such as supergravity or superstring

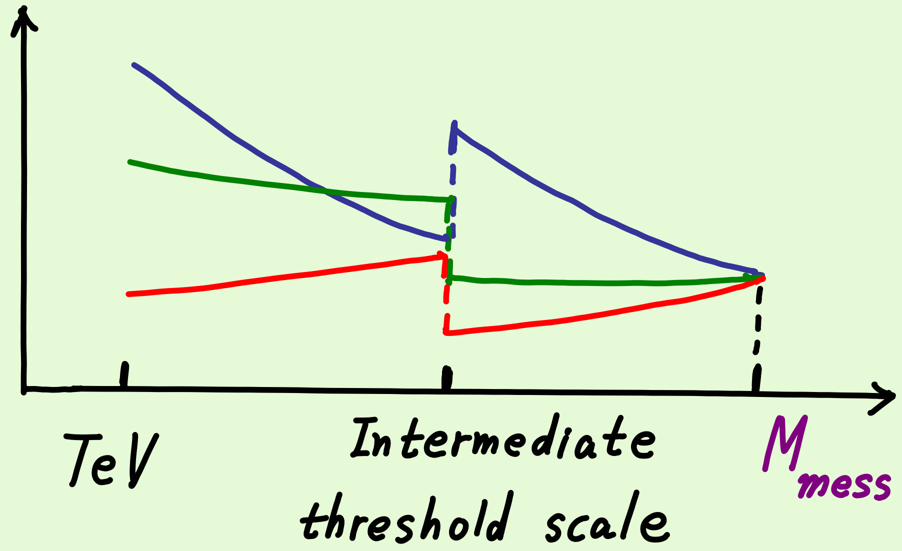
Superparticle masses at TeV are determined by

- soft parameters induced at high messenger scale M_{mess}

  $M_{mess} \sim M_{Planck}$ or M_{GUT} : gravity, anomaly, gaugino, mirage … mediations

  $M_{mess} \ll M_{GUT}$: gauge mediation

- RG running below M_{mess}
- Intermediate scale threshold effects



Generically, RG running & intermediate thresholds depend on the details of physics at scales between M_{mess} & TeV, e.g extra matter or gauge interaction.

Unlike sfermion masses, RG running & possible intermediate thresholds for gaugino masses are highly constrained by gauge coupling unification.

* At one-loop, M_a / g_a^2 do not run, while the RG runnings of g_a^2 are constrained by the measured values at TeV and the unification at $M_{GUT} \approx 2 \times 10^{16}$ GeV.

* Intermediate threshold corrections to M_a/g_a^2 have a direct connection to the RG evolution of g_a^2, thus are constrained also by the gauge coupling unification.

- Sensitivity to unknown physics at $\text{TeV} < E < M_{mess}$

Gauginos < 1st & 2nd generations < 3rd generation & Higgs

$\Rightarrow$ Gaugino mass pattern is a good 1st step to reveal the nature of the transmission of SUSY breaking at high messenger scale.

KC & Nilles

- Stabilization of gauge coupling modulus & the pattern of sparticle (gaugino) spectra

Assume

i) High scale gauge coupling unification

ii) $\frac{1}{g_a^2} \approx \langle T \rangle$

$\Rightarrow$ Holomorphic gauge kinetic function in 4D effective SUGRA :

$$f_a \approx T$$

$$\Rightarrow \left(\frac{M_a}{g_a^2}\right)_{TeV} = \frac{1}{2} F^T + \left(\begin{array}{l}\text{Loop thresholds at scales from} \\ M_{Planck} \text{ (or } M_{GUT}\text{) to TeV}\end{array}\right)$$

If $F^T \sim m_{3/2}$, one can fine-tune C.C :

$$V = |F^T|^2 - 3|m_{3/2}|^2 \approx 0 \qquad (M_{Planck} = 1)$$

without having other source of SUSY breaking, for which loop thresholds give subleading contribution of $\mathcal{O}\left(\frac{m_{3/2}}{8\pi^2}\right)$:

$$\left(\frac{M_a}{g_a^2}\right)_{TeV} \approx \frac{1}{2} F^T \; : \quad \text{Universal}$$

However most of known moduli stabilization schemes give rise to $|F^T| \ll m_{3/2}$.

* Racetrack in heterotic string Krasnikov; Casas, Lalak, Munoz, Ross

$$f_a = S \ , \quad W = A_1 e^{-a_1 S} + A_2 e^{-a_2 S}$$

$$\Rightarrow \quad F^S = 0$$

* KKLT Kachru, Kallosh, Linde, Trivedi

$$f_a = T \ , \quad W = W_{flux} + A e^{-aT} \ ,$$

Sequestered SUSY breaking yielding $\int d^4\theta \, e^{4\tilde{A}} \theta^2 \bar{\theta}^2$

(Warped sequestering : $g_{\mu\nu} = e^{2\tilde{A}} \eta_{\mu\nu}$)

KC, Falkowski, Nilles, Olechowski

$$\Rightarrow \quad F^T \sim \frac{m_{3/2}}{\ln(M_{Pl}/m_{3/2})} \sim \frac{m_{3/2}}{4\pi^2}$$

* Racetrack in G_2-compactification of M-theory

Acharya, Bobkov, Kane, Kumar, Shao

- $f_a = \sum_i k_i T_i$ ← 3-cycle moduli of G_2
- $K = -\sum_i n_i \ln(T_i + T_i^*) + Z_\phi \phi^* \phi$ ← composite meson

$$W = \underbrace{A_1 \phi^{\ell} e^{-a_1 (\sum_i \tilde{k}_i T_i)}}_{\text{ADS superpotential}} + A_2 e^{-a_2 (\sum_i \tilde{k}_i T_i)}$$

$$\Rightarrow \quad F^{T_i} \sim \frac{m_{3/2}}{\ln(M_{Pl}/m_{3/2})}, \quad F^{\phi} \sim m_{3/2}$$

If $|F^T| \ll m_{3/2}$, we need other source of SUSY breaking $F^X \sim m_{3/2}$ (uplifting sector) to get vanishing C.C, and then loop thresholds associated with $|F^X| \gg |F^T|$ (even gravity-mediated loop thresholds) can be important.

Gaugino Masses with Loop Thresholds

Randall, Sundrum ; Giudice et al ; Bagger, Moroi, Poppitz

$$\left(\frac{M_a}{g_a^2}\right)_{TeV} = \frac{1}{2}F^T + \frac{b_a(TeV)}{16\pi^2}F^{SUGRA}$$

$F^{SUGRA} = m_{3/2} + \frac{1}{3}F^I\partial_I K_0$

K_0: Kähler potential of X^I

$$- \frac{1}{8\pi^2}F^X\left[\sum_\Phi \frac{C_a(\Phi)}{X} + \sum_Q C_a(Q)\,\partial_X \ln(Y_Q) + \sum_R C_a(R)\,\partial_X \ln\left(\frac{Y_R}{|M_R|}\right)\right]$$

$Y_Q = e^{-K_0/3} Z_Q$ for the Kähler metric Z_Q of Q

$$\int d^4\theta \left[Y_Q(X^I,\bar{X}^I)\,Q\bar{Q} + Y_\Phi(X^I,\bar{X}^I)\,\Phi\bar{\Phi} + Y_R(X^I,\bar{X}^I)\,R\bar{R} \right]$$

$$+ \int d^2\theta \left[X\Phi\Phi^c + M_R(X^I)\,RR^c \right]$$

$X^I \equiv \{T, X\}$ = SUSY-breaking fields

$Q \equiv$ light chiral matters at TeV

$\Phi + \Phi^c \equiv$ intermediate scale (gauge-charged) messenger fields
renormalizable couplings with X : $\int d^2\theta\, X\Phi\Phi^c$

$R + R^c \equiv$ superheavy (gauge-charged) regulator : string & KK modes

$$\left(\frac{M_a}{g_a^2}\right)_{\text{TeV}} = \frac{1}{2} F^T + \frac{b_a(\text{TeV})}{16\pi^2} F^{SUGRA}$$

$$- \frac{1}{8\pi^2} F^X \left[\sum_{\Phi} \frac{C_a(\Phi)}{X} + \sum_{Q} C_a(Q)\, \partial_X \ln(Y_Q) + \sum_{R} C_a(R)\, \partial_X \ln\left(\frac{Y_R}{|M_R|}\right) \right]$$

anomaly mediation : Randall, Sundrum ; Giudice et. al.

- $\frac{b_a(\text{TeV})}{16\pi^2} F^{SUGRA}$: non-universal loop contribution associated with the conformal anomaly at TeV

Bagger, Moroi, Poppitz

- $\frac{C_a(Q)}{8\pi^2} F^X \partial_X \ln Y_Q$: non-universal loop contribution associated with the Konishi anomaly of light matter Q

- $\frac{C_a(\Phi)}{8\pi^2} \frac{F^X}{X}$: gauge-mediated contribution due to intermediate scale messenger $\Phi + \Phi^c$, which is favored to be universal for gauge coupling unification

- $\frac{C_a(R)}{8\pi^2} F^X \partial_X \ln\left(\frac{Y_R}{|M_R|}\right)$: UV regulator threshold encoding string, KK, GUT threshold effects of $\mathcal{O}\left(\frac{m_{3/2}}{8\pi^2}\right)$ (for Λ_{cutoff} of effective SUGRA chosen to be just below M_{GUT}), which are generically non-universal.

Generically $\left(\frac{M_a}{g_a^2}\right)_{TeV}$ are determined by

(I) Two universal contributions

- modulus mediation : $\frac{1}{2} F^T$
- gauge mediation : $\frac{1}{8\pi^2} \sum_{\Phi} C_a(\Phi) \frac{F^X}{X}$

(II) Three non-universal contributions of $\mathcal{O}\left(\frac{m_{3/2}}{8\pi^2}\right)$

- conformal anomaly mediation : $\frac{b_a(TeV)}{16\pi^2} F^{SUGRA}$
- Konishi anomaly mediation : $\frac{1}{8\pi^2} \sum_Q C_a(Q) F^X \partial_X \ln Y_Q$
- UV regulator thresholds : $\frac{1}{8\pi^2} \sum_R C_a(R) F^X \partial_X \ln \left(\frac{Y_R}{|M_R|}\right)$

The coefficients of conformal & Konishi anomaly contributions are determined by the light particle spectrum at TeV, while the regulator thresholds require information on the UV completion of 4D effective SUGRA at scales above Λ_{cutoff}.

$\boxed{\text{Scenario A}}$

UV sensitive regulator thresholds are negligible if

$$F^T \sim m_{3/2} \quad \text{(conventional gravity mediation)}$$

or there exist intermediate scale gauge thresholds :

$$\frac{1}{8\pi^2} F^X \sum_{\Phi} \frac{C_a(\Phi)}{X} \gg m_{3/2} \quad \text{(gauge mediation)}$$

$\Rightarrow$ mSUGRA pattern

$$\left(\frac{M_a}{g_a^2}\right) = \text{Universal} \quad \underbrace{\frac{1}{2} F^T}_{\text{(modulus mediation)}} \quad \text{or} \quad \underbrace{\frac{1}{8\pi^2} F^X \sum_{\Phi} \frac{C_a(\Phi)}{X}}_{\text{(gauge mediation)}}$$

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \approx g_1^2 : g_2^2 : g_3^2 \approx 1 : 2 : 6 \text{ at TeV}$$

- A moduli stabilization scheme yielding $F^T \sim m_{3/2}$

Gersdorff, Hebecker ; Berg, Haack, Kors

Stabilization by perturbative Kähler corrections :

$$K = -n_0 \ln(T+T^*) + \frac{\xi_{\alpha'}}{(T+T^*)^{3/2}} + \frac{\xi_s}{(T+T^*)^2}$$

$W = W_{flux}$ = flux-induced T-independent superpotential

If (i) $n_0 = 3$ (no-scale form at leading order) ,

(ii) $\xi_{\alpha'}$ (α'- correction) $\propto$ Euler number > 0 ,

(iii) ξ_s (string loop correction) < 0 ,

then T is stabilized with $F^T \sim m_{3/2}$.

If $|F^T| \ll m_{3/2}$ as non-perturbative (or flux) stabilization of T suggests, and there is no gauge mediation at scales below M_{GUT}, then one needs to know the UV sensitive regulator thresholds in order to make a reliable prediction for the pattern of gaugino masses, and this requires information on the UV completion of 4D effective SUGRA, e.g on the underlying string compactification.

"Is the uplifting sector X (required for vanishing C.C when $|F^X| \ll m_{3/2}$) sequestered from the visible sector ?"

Sequestered SUSY breaking

Randall, Sundrum

No (even gravitational strength) contact interaction between X and visible sector fields in superspace effective action :

$$\int d^4\theta \Big[\underbrace{\Omega_{lift}(X, X^+) + \Omega_{vis}(\Phi_I, \Phi_I^+)}_{\leftarrow\, -3e^{-K/3}} \Big] + \int d^2\theta \big[W_{lift}(X) + W_{vis}(\Phi_I) \big]$$

($K \equiv$ Kähler potential)

Φ_I: generic fields charged under the visible sector gauge group

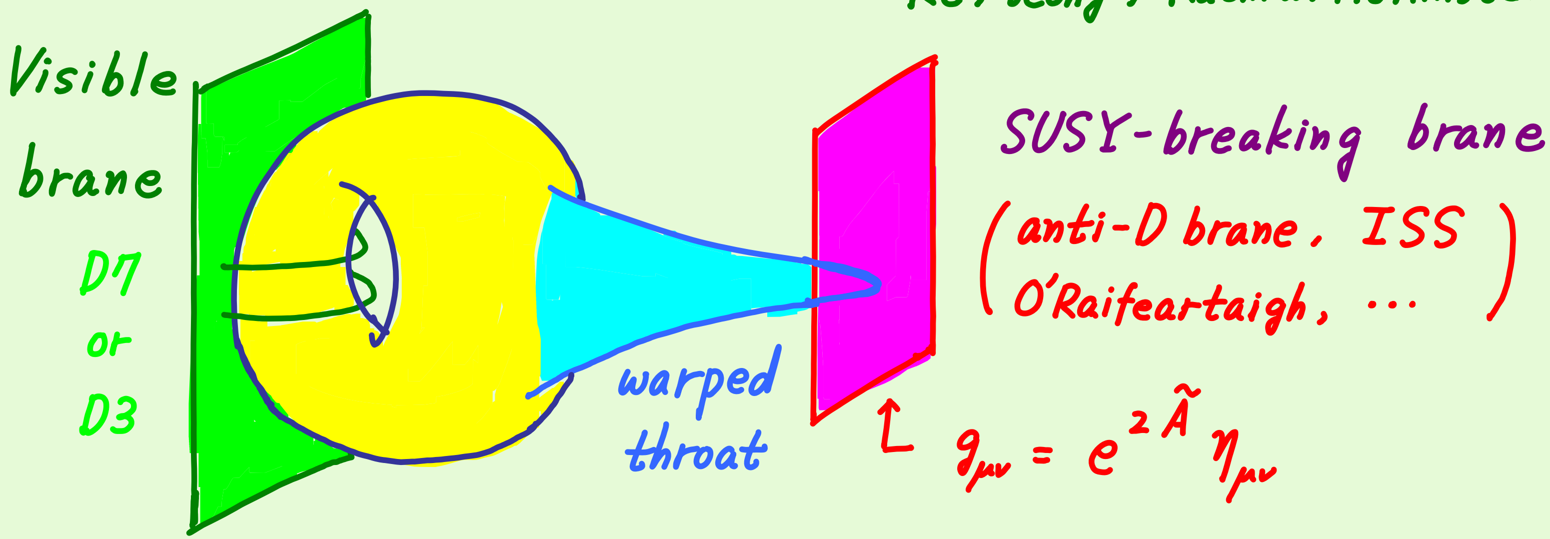
$$\Rightarrow \quad \partial_X Y_Q = \partial_X Y_R = \partial_X M_R = 0$$

$$\Rightarrow \quad \left(\frac{M_a}{g_a^2}\right) = \frac{1}{2} F^T + \frac{1}{16\pi^2} b_a\, m_{3/2}$$

(No Konishi anomaly & regulator threshold contribution)

Warped sequestering in KKLT set-up

KC, Jeong ; Kachru, McAllister, Sundrum



- Flux compactification generically produces warped throat
- Any SUSY-breaking brane introduced into warped geometry is stabilized at the IR end of throat.
- SUSY breaking in visible sector at the UV end is totally independent of the nature of SUSY-breaking brane (anti-brane, ISS brane, O'Raifeartaigh brane, ⋯)

Scenario B

$|F^T| \ll m_{3/2}$, and $F^X \sim m_{3/2}$ is sequestered.

$$\Rightarrow \left(M_a / g_a^2 \right)_{TeV} = \frac{1}{2} F^T + \frac{b_a(TeV)}{16\pi^2} m_{3/2}$$

* Flux stabilization of T

$$m_T \sim \langle \partial_T^2 W_{flux} \rangle , \quad m_{3/2} \sim \langle W_{flux} \rangle$$

AdS vacuum energy

Vanishing C.C : $e^{4\tilde{A}} - 3\, m_{3/2}^2 \approx 0$

warped uplifting

$$\Rightarrow m_{3/2} \sim e^{2\tilde{A}} \ll m_T \quad \Rightarrow \quad F^T \ll \frac{m_{3/2}}{8\pi^2}$$

big hierarchy enforced by vanishing C.C

$\Rightarrow$ Anomaly Pattern

at TeV

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} = b_1 g_1^2 : b_2 g_2^2 : b_3 g_3^2 = 3.3 : 1 : 9$$

* Nonperturbative stabilization of T

$$m_T \sim m_{3/2} \ln\left(M_{Pl}/m_{3/2}\right)$$

(Little hierarchy due to the nonperturbative factor $\sim 8\pi^2/g^2$)

$$\Rightarrow \quad F^T \sim \frac{m_{3/2}}{\ln\left(M_{Pl}/m_{3/2}\right)} \sim \frac{m_{3/2}}{8\pi^2}$$

$\Rightarrow$ Mirage Pattern

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} = g_1^2\left(1+\frac{b_1\alpha}{10}\right) : g_2^2\left(1+\frac{b_2\alpha}{10}\right) : g_3^2\left(1+\frac{b_3\alpha}{10}\right)$$

at TeV

$$= (1+0.66\alpha) : (2+0.2\alpha) : (6-1.8\alpha)$$

$$= \begin{cases} 1 : 1.6 : 3.8 & (\alpha = 0.5) \\ 1 : 1.3 : 2.5 & (\alpha = 1) \\ 1 : 1.2 : 1.7 & (\alpha = 1.5) \end{cases}$$

$\alpha = \dfrac{g^2_{hidden}}{g^2_{GUT}} \to 1$ at leading order in α'-expansion

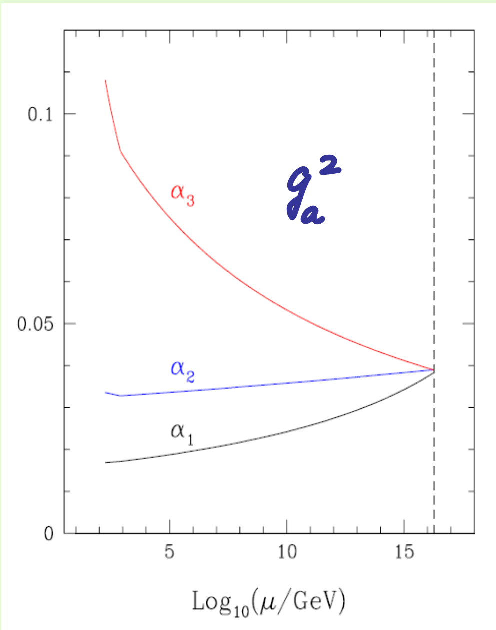
$\Rightarrow$ Compressed spectrum compared to other patterns

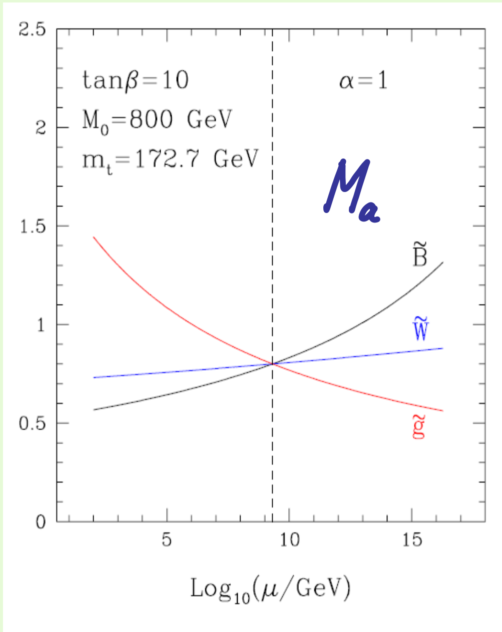
Mirage unification of sparticle masses

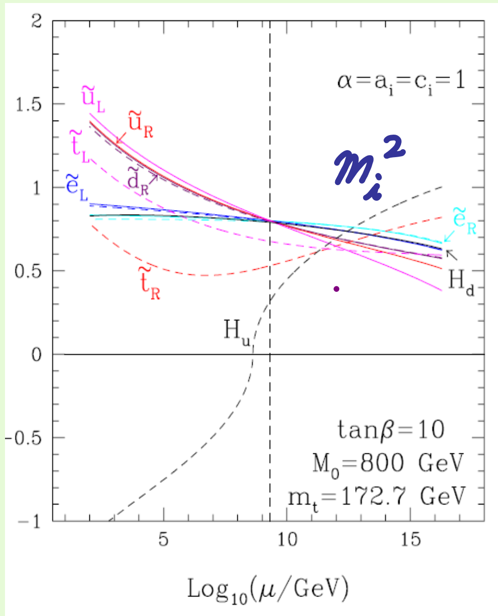
KC, Jeong, Okumura

$$M_a(\mu) = M_0\left[1 - \frac{b_a}{8\pi^2}\, g_a^2(\mu)\ln\left(M_{mirage}/\mu\right)\right]$$

$$m_i^2(\mu) = m_0^2 + M_0^2\left\{\gamma_i(\mu) - \frac{\dot{\gamma}_i(\mu)}{16\pi^2}\ln\left(M_{mirage}/\mu\right)\right\}\frac{\ln\left(M_{mirage}/\mu\right)}{4\pi^2}$$







Nonpertubative stabilization of T $\oplus$ sequestered uplifting

$\Rightarrow$ Mirage unification at $M_{mirage} \sim e^{-2\pi^2\alpha} M_{GUT}$ $\left(\alpha = \frac{g^2_{hidden}}{g^2_{GUT}}\right)$

Scenario C

$|F^T| \ll m_{3/2}$, and $F^X \sim m_{3/2}$ is not sequestered.

- $\frac{M_a}{g_a^2} = \mathcal{O}\left(\frac{m_{3/2}}{8\pi^2}\right)$ are highly UV sensitive due to the regulator thresholds which are generically of the order of $\frac{m_{3/2}}{8\pi^2}$.

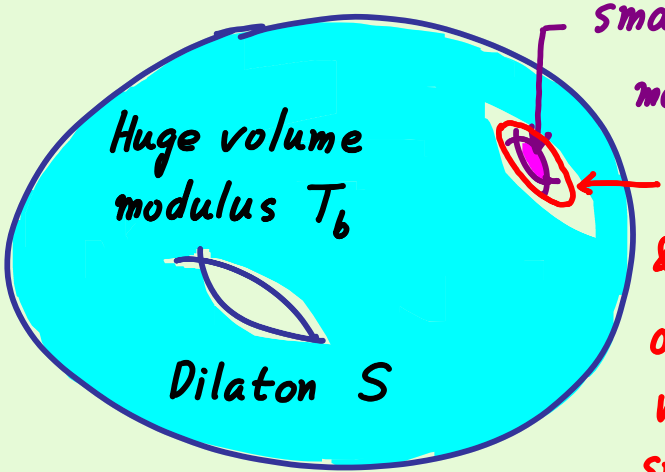
- $m_{\tilde{q},\tilde{\ell}} \sim F^X = \mathcal{O}(8\pi^2 M_{1/2})$: Loop split SUSY
  Wells

Nonperturbative stabilization of T & unsequestered F-term uplifting scenario generically leads to such pattern of sparticle masses.

Lebedev, Nilles, Ratz ; Abe, Higaki, Kobayashi, Omura ; Gomez-Reino, Scrucca
Acharya, Bobkov, Kane, Kumar, Shao ; Dudas, Papineau, Pokorski

- An exotic scenario : Exponentially large volume compactification without gauge coupling unification

(Balasubramanian , Berglund , Conlon , Quevedo)



small cycle modulus T_s

Visible gauge & matter fields on D-brane wrapping small cycle

$$K = -3 \ln (T_b + T_b^*) + \frac{(T_s + T_s^*)^{3/2} - \xi_0'}{(T_b + T_b^*)^{3/2}}$$

$$W = W_{flux} + A e^{-a T_s}$$

$$* \quad \underline{T_b \sim e^{\frac{2}{3} a T_s}} \sim \left(M_{Planck} / m_{3/2} \right)^{2/3} \sim 10^{10}$$

Exponentially large volume under certain assumption

$$* \quad M_{string} \sim T_b^{-3/4} M_{Planck} \sim 10^{11} \text{ GeV}$$

Can not accomodate gauge coupling unification around 10^{16} GeV

SUSY breaking pattern :

no scale feature

$$\frac{F^{T_b}}{T_b+T_b^*} = m_{3/2}\ , \qquad F^{SUGRA} = m_{3/2} + \frac{1}{3} F^I \partial_I K = 0$$

T_b = uplifting modulus

$$\frac{F^{T_s}}{T_s+T_s^*} \approx \frac{m_{3/2}}{\ln(M_{Pl}/m_{3/2})}\ , \qquad F^S = 0$$

T_s = gauge coupling modulus

No constraint from gauge coupling unification

$$\Rightarrow \quad f_a = k_a T_s + \epsilon_a S$$

$(k_{SU(3)} = k_{SU(2)} = 1\ ,\ k_{U(1)} = k_Y$ = rational # of $\mathcal{O}(1)$)

$\Rightarrow$ Semi - mSUGRA pattern

$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \simeq k_Y : 2 : 6$ at TeV

Summary

- **mSUGRA pattern** : perturbative Kähler stabilization of T, gauge mediation, gaugino mediation, ...

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \approx 1 : 2 : 6 \Rightarrow \frac{M_{\tilde{g}}}{M_{\chi}} \gtrsim 6$$

M_{χ} ← LSP mass

- **mirage pattern** : nonperturbative stabilization of T with sequestered uplifting
  (e.g KKLT with SM on D7)

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \approx 1 : 1.3 : 2.5 \Rightarrow \text{Compressed spectra}$$

(at leading order in α')

- **anomaly pattern** : flux stabilization of T with sequestered uplifting
  (e.g KKLT with SM on D3)

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \approx 3.3 : 1 : 9 \Rightarrow \frac{M_{\tilde{g}}}{M_{\chi}} \gtrsim 9$$

- Semi-mSUGRA pattern : Exponentially large volume

$$M_{\tilde{B}} : M_{\tilde{W}} : M_{\tilde{g}} \approx k_Y : 2 : 6$$

* Sfermion masses ($m_{\tilde{q},\tilde{\ell}}$) in the above 4 scenarios are more model-dependent, but generically

$$m_{\tilde{q}} \sim M_{\tilde{g}} \quad , \quad m_{\tilde{\ell}_L} \sim M_{\tilde{W}} \quad , \quad m_{\tilde{\ell}_R} \sim M_{\tilde{B}}$$

- UV sensitive pattern

Flux or nonperturbative stabilization of T with unsequestered uplifting (e.g M-theory on G_2 with racetrack stabilization of 3-cycle moduli) :

Highly UV sensitive gaugino mass ratios &

Loop split pattern : $m_{\tilde{q},\tilde{\ell}} \sim 8\pi^2 M_{1/2}$

♦ Determination of gaugino mass ratios at LHC using the kink structure of M_{T2}

2nd-lightest neutralino

$\tilde{g}$, χ_2 , χ_1

lightest neutralino assumed to be LSP

(If Higgsinos are heavier than $\tilde{W}$ & $\tilde{B}$, $\chi_1 = \tilde{B}$ or $\tilde{W}$ & $\chi_2 = \tilde{W}$ or $\tilde{B}$.)

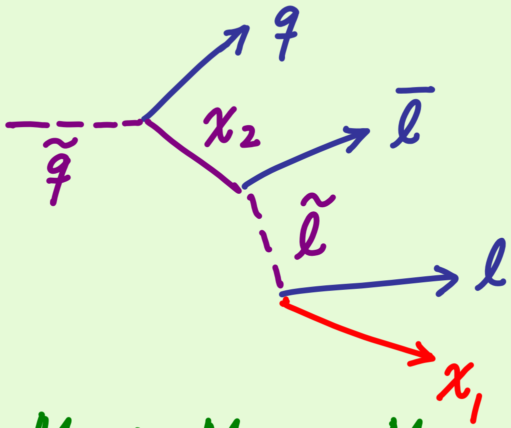
$$M_{\tilde{g}} : M_{\chi_2} : M_{\chi_1} = ?$$

$\Rightarrow$ mSUGRA , anomaly , mirage , $\cdots$?

As the sparticle decay always involves the invisible LSP in the final state (assume R-parity), measuring the sparticle masses is a nontrivial job.

- Invariant mass endpoints in long cascade decays

Hinchliffe et al ; Weiglein et al ; ...



$M_{\tilde{q}} > M_{\chi_2} > M_{\tilde{\ell}}$

$$m_{\ell\ell}^{max} = \frac{\sqrt{(m_{\chi_2}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\chi_1}^2)}}{m_{\tilde{\ell}}}$$

$$m_{q\ell\ell}^{max} = \frac{\sqrt{(m_{\tilde{q}}^2 - m_{\chi_2}^2)(m_{\chi_2}^2 - m_{\chi_1}^2)}}{m_{\chi_2}}$$

$m_{q\bar{\ell}}^{max}$, $m_{q\ell}^{max}$, $m_{qq\ell}^{min}$

* The accuracy of the overall mass determination is not good.

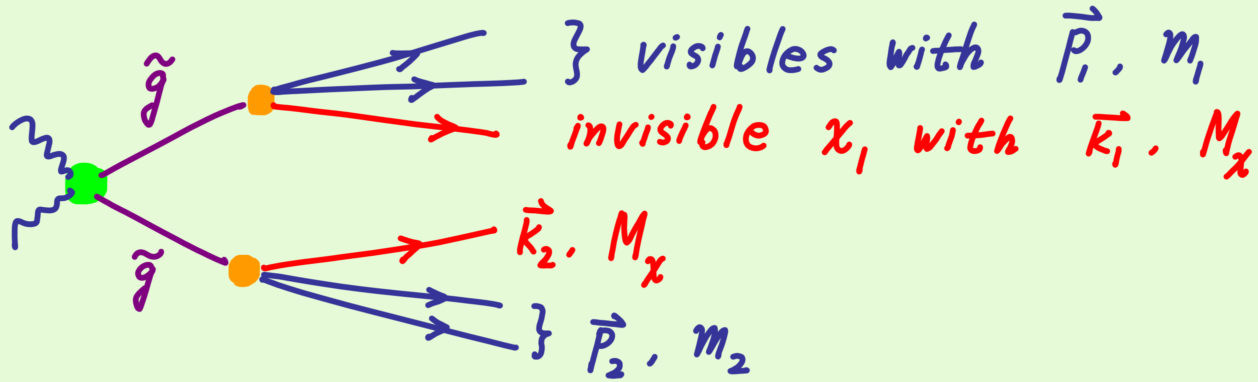
* Such a long decay is not available in models with heavier sfermions.

- Kink structure of M_{T2}

Cho, KC, Kim, Park

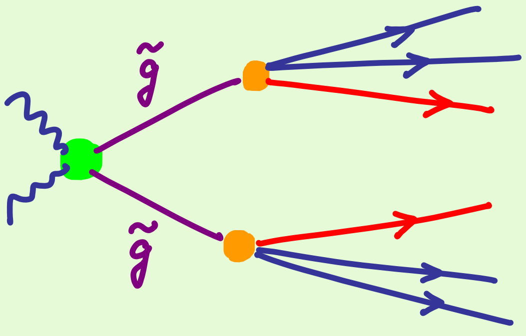
M_{T2} : Generalization of the transverse mass to the events with two missing particles

Lester, Summers ; Barr, Lester, Stephens



$\vec{k}_1$, $\vec{k}_2$, M_χ are unknown except for $\vec{k}_{1T} + \vec{k}_{2T}$,

thus regard them as trial variables under the constraint $\vec{k}_{1T} + \vec{k}_{2T} = -(\vec{p}_{1T} + \vec{p}_{2T})$.



$\}$ visibles with $\vec{P}_1$, m_1

invisible with $\vec{k}_1$, χ

$\vec{k}_2$, χ

$\}$ $\vec{P}_2$, m_2

χ = trial LSP mass

$\vec{k}_i$ = trial LSP momenta

satisfying $\vec{k}_{1T} + \vec{k}_{2T} = -(\vec{P}_{1T} + \vec{P}_{2T})$

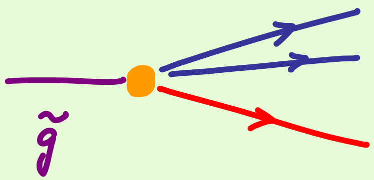
$$M_{T2}(\vec{P}_{1T}, m_1, \vec{P}_{2T}, m_2 ; \chi)$$

Lester, Summers

take minimization to be bounded above by $M_{\tilde{g}}$ for $\chi = m_\chi$

$$= \min_{\{\vec{k}_{iT}\}} \left[\max \left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

take maximum to have a better chance to reach $M_{\tilde{g}}$



$\}$ $\vec{P}$, E, m

$\vec{k}$, $\mathcal{E}$, χ

$$M_T^2 = m^2 + \chi^2 + 2(E_T \mathcal{E}_T - \vec{P}_T \cdot \vec{k}_T)$$

$$\leq m^2 + \chi^2 + 2(E\mathcal{E} - \vec{P}\cdot\vec{k})$$

$$= M_{\tilde{g}}^2$$

We are interested in

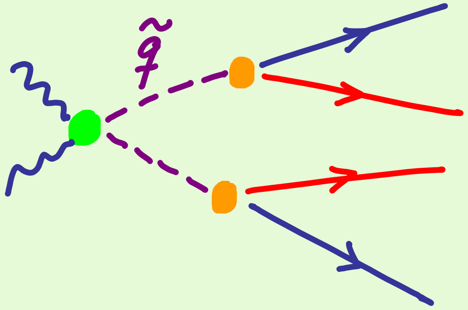
$$M_{T2}^{max}(\chi) = \max_{\{\text{all events}\}} \left\{ M_{T2}(\vec{p}_{1T}, m_1, \vec{p}_{2T}, m_2 ; \chi) \right\}$$

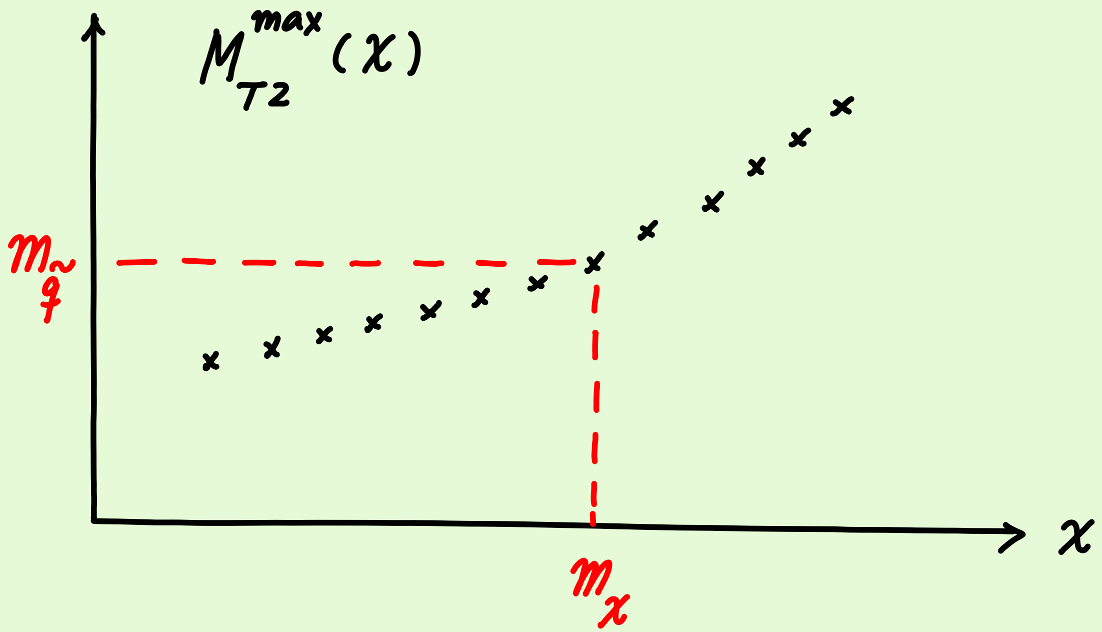
$$= \max_{\{\vec{p}_{iT}, m_i\}} \left\{ \min_{\{\vec{k}_{iT}\}} \left[\max \left(M_T^{(1)}, M_T^{(2)} \right) \right] \right\}$$

which has the property

$$M_{T2}^{max}(\chi = M_\chi) = M_{\tilde{g}}$$

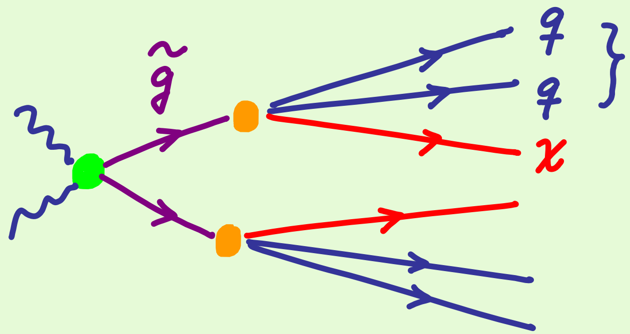
So far, M_{T2} has been studied only numerically for the simplest situation that



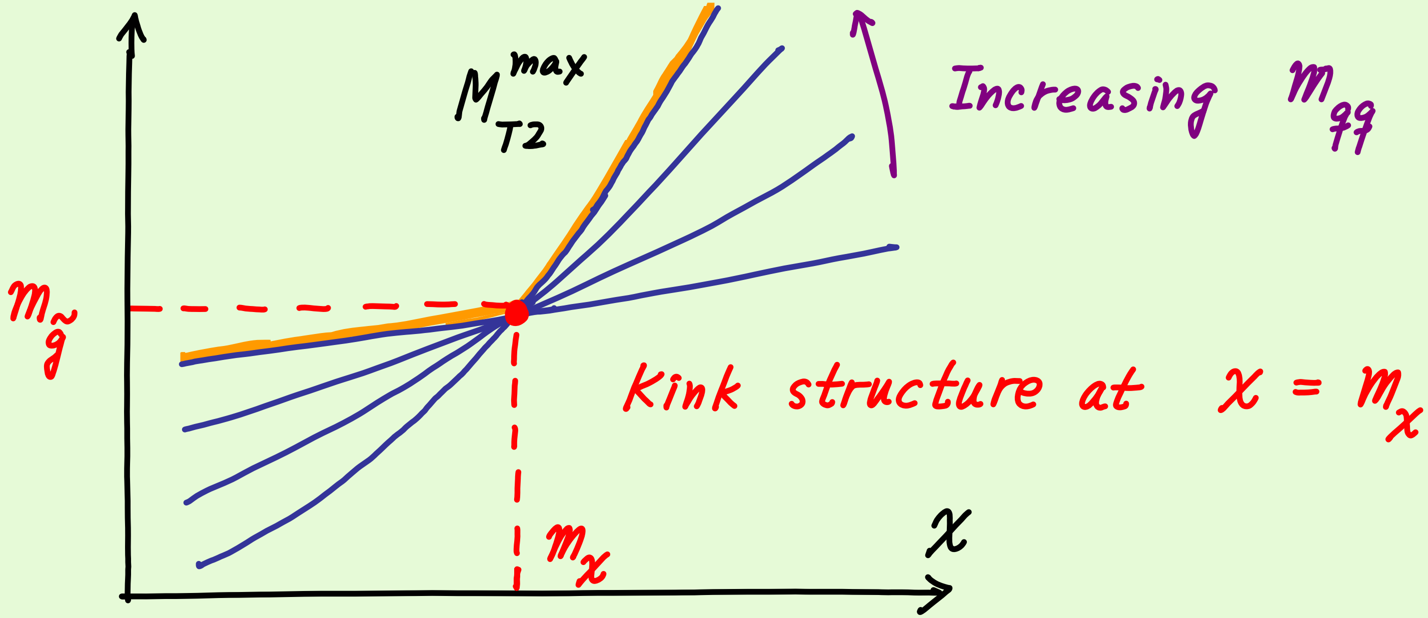


M_{T2}(gluino) has a quite different structure.

Cho, KC, Kim, Park



two visible particles with varying value of m_{qq}



We could also determine the analytic expression of $M_{T2}^{max}(\chi)$ which is greatly useful to determine the kink point from data.

Kink structure of $M_{T2}^{max}(\chi)$ for gluino might make it possible to determine $M_{\tilde{g}}$ & M_{χ_1} simultaneously (and hopefully accurately), so $M_{\tilde{g}} : M_{\chi_2} : M_{\chi_1}$ also.

Can we construct $M_{T2}^{max}(\chi)$ from real collider data ?

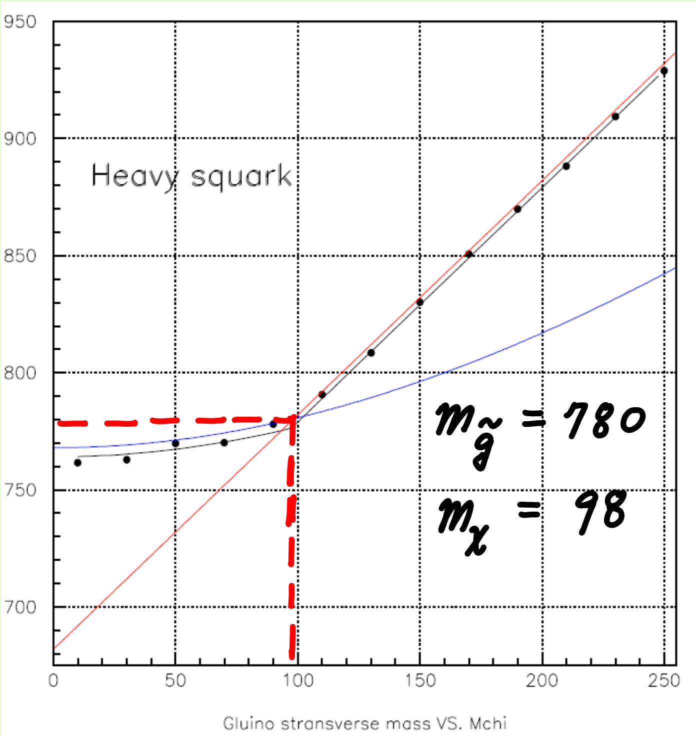
Generate SUSY events by PYTHIA for $\mathcal{L} = 100\ fb^{-1}$

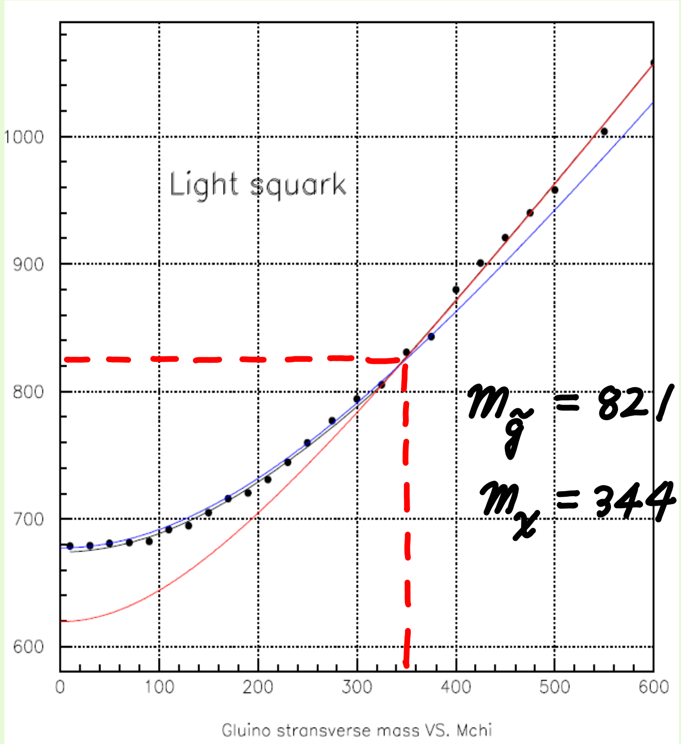
Include SM backgrounds & proceed with PGS

Event selection cuts :

* At least 4 jets with $P_T > 200, 150, 100, 50$ GeV
* $\not{E}_T > 250$ GeV , $S_T > 0.25$, no b-jets & no-leptons
* (P_1, P_2) & (P_3, P_4) : P_1 = highest momentum ,

  P_3 = largest $|P|\sqrt{\Delta\phi^2 + \Delta\eta^2}$ w.r.t P_1





Conclusion

- One can classify the patterns of sparticle masses based on possible schemes of moduli stablization.

  This might provide a useful tool probing string compactification with sparticle spectra.

  Known schemes of moduli stabilization suggest that non-universal M_a/g_a^2 are plausible possibility.

- Experimental measurement of $\mathbb{R} = M_{\tilde{q}}/M_{\chi_1}$ will be able to discriminate different SUSY-breaking schemes:

  mSUGRA pattern : $\mathbb{R} \gtrsim 6$

  anomaly pattern : $\mathbb{R} \gtrsim 9$

  mirage pattern : $\mathbb{R}$ can be significantly smaller

- M_{T2}-kink might provide a useful tool to determine the gaugino mass ratios (possibly other sparticle masses also) at LHC.