Surprises even in low energy supersymmetry !!

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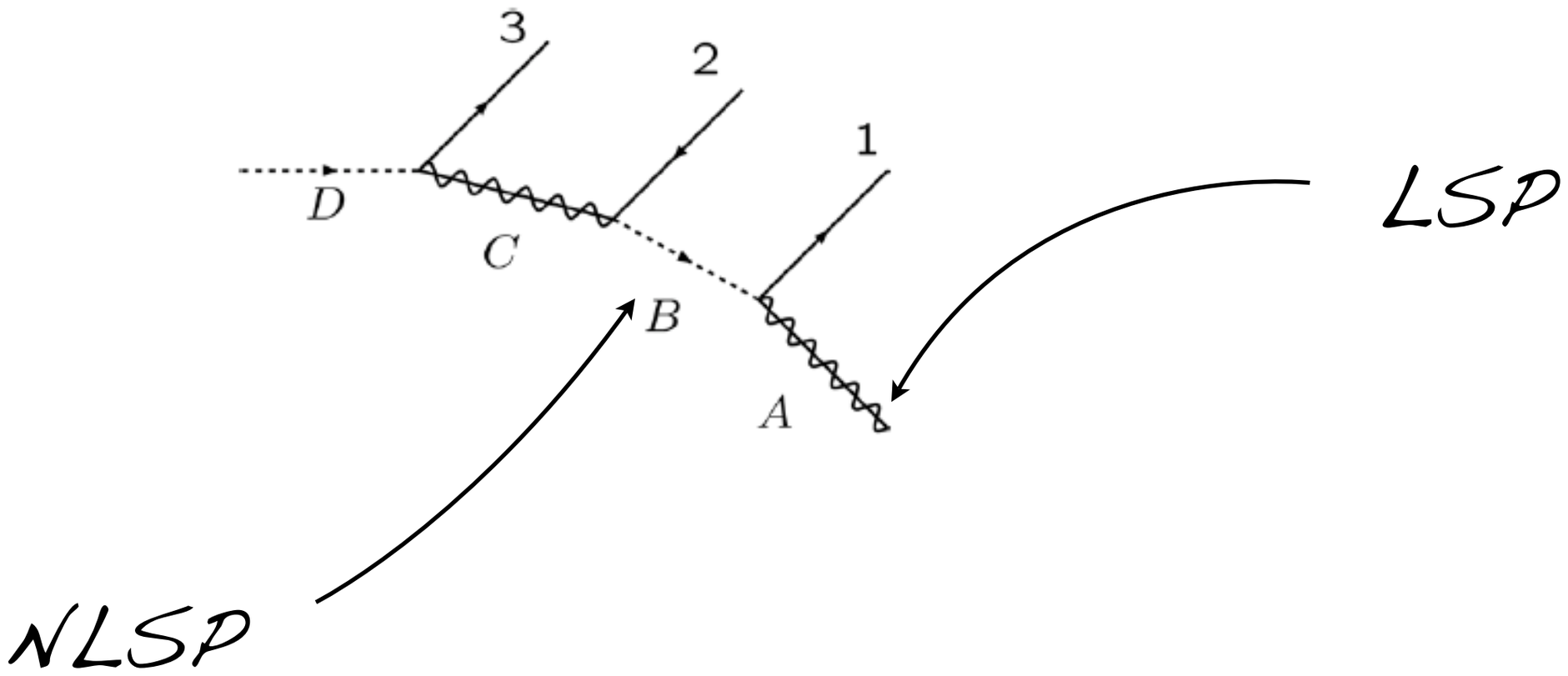
This talk is about low energy supersymmetry



The whole talk is in
a scenario where the
gravitino is the LSP

Outline

1. 15% of the talk is about the LSP (gravitino).
2. 85% of the talk is about an exciting (new) NLSP.

Part I of the talk

Gravitino mass is not tied to the rest of the superpartner spectrum

simple exercise:

$$\omega_a \frac{X}{M} W^a W^a$$

$$m_{\frac{3}{2}} = \frac{F_X}{M_{\rm Pl}}$$

$$\omega_a \frac{F_X}{M} \lambda^a \lambda^a$$

$$\frac{m_{\frac{3}{2}}}{M_a} = \frac{1}{\omega_a} \frac{M}{M_{\rm Pl}}$$

$$M_a$$

$$\frac{m_{\frac{3}{2}}}{M_a} = \frac{1}{\omega_a}\frac{M}{M_{\rm Pl}}$$

But this relation is true only

in special scenarios

where there is no

hidden sector (susy breaking)

interactions below

the messenger scale

M

$X^\dagger X$

$\omega_a^0 \ \dfrac{1}{M} \ X\, W^a W^a$

Renormalization

1 TeV

$Z_X \ \ X^\dagger X$

$\omega_a^0 \ \dfrac{1}{M} \ X\, W^a W^a$

M

$X^\dagger X$

$\omega_a^0 \, \dfrac{1}{M} \; X \, W^a W^a$

Renormalization

1 TeV

$Z_X \;\; X^\dagger X$

$\omega_a^0 \, \dfrac{1}{M} \; X \, W^a W^a$

canonical basis

$X^\dagger X$

$\omega_a^0 \, \dfrac{1}{M} \sqrt{\dfrac{1}{Z_X}} \; X \, W^a W^a$

$$\frac{m_{\frac{3}{2}}}{M_a} = \frac{1}{\omega_a}\frac{M}{M_{\rm Pl}}\sqrt{Z_X}$$

$$\frac{m_{\frac{3}{2}}}{M_a} = \frac{1}{\omega_a}\frac{M}{M_{\rm Pl}}\left(\frac{M}{M_{\rm int}}\right)^{\gamma/2}$$

gravitino mass can be anything

Advertisement

Renormalization of scalar soft masses
in the presence of susy breaking
dynamics

Cohen, Roy, Schmaltz (hep-ph/0612100)

Applications:
use hidden sector dynamics to solve non-trivial
problems in the MSSM

Roy, Schmaltz
Murayama, Poland, Nomura

Beginning of the partII
of the talk

Gravitino is the LSP

what do we know about

the NLSP ?

NLSPs

charge \ spin	0	1/2
0	sneutrino	neutralino
1	slepton	×

A well appreciated fact:

A neutralino is always
lighter than the lightest
chargino

The neutralino/chargino mass system

$$\begin{bmatrix} \tilde{B} & \tilde{W}_3^0 & \tilde{H}_u^0 & \tilde{H}_d^0 \end{bmatrix} \begin{bmatrix} M_1 & 0 & g'v_u/\sqrt{2} & -g'v_d/\sqrt{2} \\ 0 & M_2 & -gv_u/\sqrt{2} & g'v_d/\sqrt{2} \\ g'v_u/\sqrt{2} & -gv_u/\sqrt{2} & 0 & \mu \\ -g'v_d/\sqrt{2} & gv_d/\sqrt{2} & \mu & 0 \end{bmatrix} \begin{bmatrix} \tilde{B} \\ \tilde{W}_3^0 \\ \tilde{H}_u^0 \\ \tilde{H}_d^0 \end{bmatrix}$$

$$\begin{bmatrix} \tilde{W}^+ & \tilde{H}_u^+ \end{bmatrix} \begin{bmatrix} M_2 & gv_d \\ gv_u & \mu \end{bmatrix} \begin{bmatrix} \tilde{W}^- \\ \tilde{H}_d^- \end{bmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & \frac{g' v_d}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ \frac{g' v_d}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} M_2 & g v_d \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & \frac{g' v_d}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ 0 & -\frac{g v_d}{\sqrt{2}} & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} M_2 & g v_d \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & \frac{g' v_d}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ 0 & 0 & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} M_2 & g v_d \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ 0 & 0 & -\mu & 0 \end{pmatrix}$$

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$$\begin{pmatrix} M_2 & g v_d \\ g v_u & \mu \end{pmatrix}$$

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$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ 0 & 0 & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

Higgsino Limit: $\mu < M_2$

$$m^2_{N_1} = \mu^2 - \frac{\mu\, g^2 v_u^2}{2M_2} + \mathcal{O}\left(\frac{1}{M_2^2}\right)$$

$$m^2_{C_1} = \mu^2 - \frac{\mu^2 g^2 v_u^2}{M_2^2} + \mathcal{O}\left(\frac{1}{M_2^4}\right)$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & 0 & -\mu \\ 0 & 0 & -\mu & 0 \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ -\frac{g' v_u}{\sqrt{2}} & \frac{g v_u}{\sqrt{2}} & -\mu & 0 \\ 0 & 0 & 0 & -\mu \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

If neutralinos are Dirac

a chargino can become

lighter than the lightest

neutralino

The Minimal R-symmetric Supersymmetric Model

Kribs, Poppitz, Weiner

The Minimal R-symmetric Supersymmetric Model

Kribs, Poppitz, Weiner

$$\frac{X}{M} W_a W_a \longrightarrow \frac{W'}{M} W_a \Phi_a$$

$$\mu H_u H_d \longrightarrow \mu_u H_u R_u \qquad \mu_d H_d R_d$$

The Minimal R-symmetric Supersymmetric Model

Kribs, Poppitz, Weiner

$M\lambda_a\lambda_a$ ⟶ $\frac{W'}{M}W_a\Phi_a$

$\mu H_u H_d$ ⟶ $\mu_u H_u R_u$, $\mu_d H_d R_d$

The Minimal R-symmetric Supersymmetric Model

Kribs, Poppitz, Weiner

$M\lambda_a\lambda_a$ ⟶ $M\lambda_a\psi_a$

$\mu H_u H_d$ ⟶ $\mu_u H_u R_u$, $\mu_d H_d R_d$

The neutralino mass matrix

$$\begin{bmatrix} \tilde{B} & \tilde{W}_3^0 & \tilde{R}_u^0 & \tilde{R}_d^0 \end{bmatrix} \begin{bmatrix} M_1 & 0 & -g'v_u/\sqrt{2} & g'v_d/\sqrt{2} \\ 0 & M_2 & gv_u/\sqrt{2} & -gv_d/\sqrt{2} \\ 0 & 0 & \mu_u & 0 \\ 0 & 0 & 0 & \mu_d \end{bmatrix} \begin{bmatrix} \psi_0 \\ \psi_3 \\ \tilde{H}_u^0 \\ \tilde{H}_d^0 \end{bmatrix}$$

$R = +1$

$R = -1$

The chargino mass system

$$\begin{bmatrix} \psi^+ & \tilde{H}_u^+ \end{bmatrix} \begin{bmatrix} M_2 & 0 \\ -gv_u & \mu_u \end{bmatrix} \begin{bmatrix} \tilde{W}^- \\ \tilde{R}_u^- \end{bmatrix}$$

$\mathcal{R}$ = +1
$\mathcal{Q}$ = +1

$\mathcal{R}$ = -1
$\mathcal{Q}$ = -1

$$\begin{bmatrix} \tilde{W}^+ & \tilde{R}_d^+ \end{bmatrix} \begin{bmatrix} M_2 & 0 \\ -gv_d & \mu_d \end{bmatrix} \begin{bmatrix} \psi^- \\ \tilde{H}_d^- \end{bmatrix}$$

$\mathcal{R}$ = -1
$\mathcal{Q}$ = +1

$\mathcal{R}$ = +1
$\mathcal{Q}$ = -1

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & \frac{g' v_d}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & \mu \end{pmatrix}$$

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$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & \mu \end{pmatrix}$$

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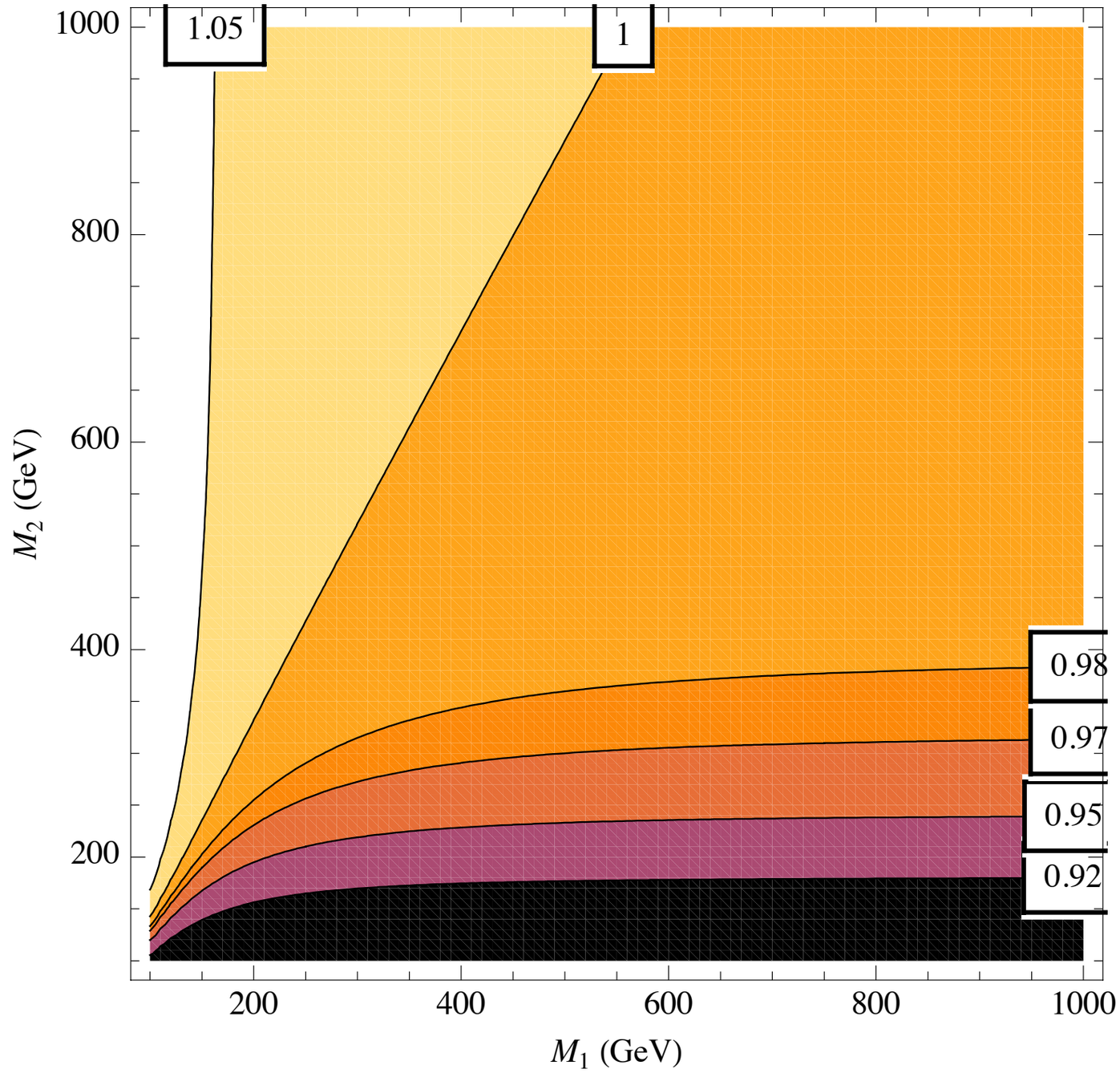
$$\begin{pmatrix} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & 0 \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & 0 \\ 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & \mu \end{pmatrix}$$

$$\begin{pmatrix} M_2 & 0 \\ g v_u & \mu \end{pmatrix}$$

In the Higgsino limit
the lightest chargino
is lighter
than the lightest
neutralino if

$$\frac{M_1}{M_2} > \frac{1}{\tan\theta_W}$$

$$\frac{\text{lightest chargino mass}}{\text{lightest neutralino mass}}$$



$$\mu = 120 \text{ GeV}$$

$$\tan\beta = 10$$

additional couplings consistent with all symmetries

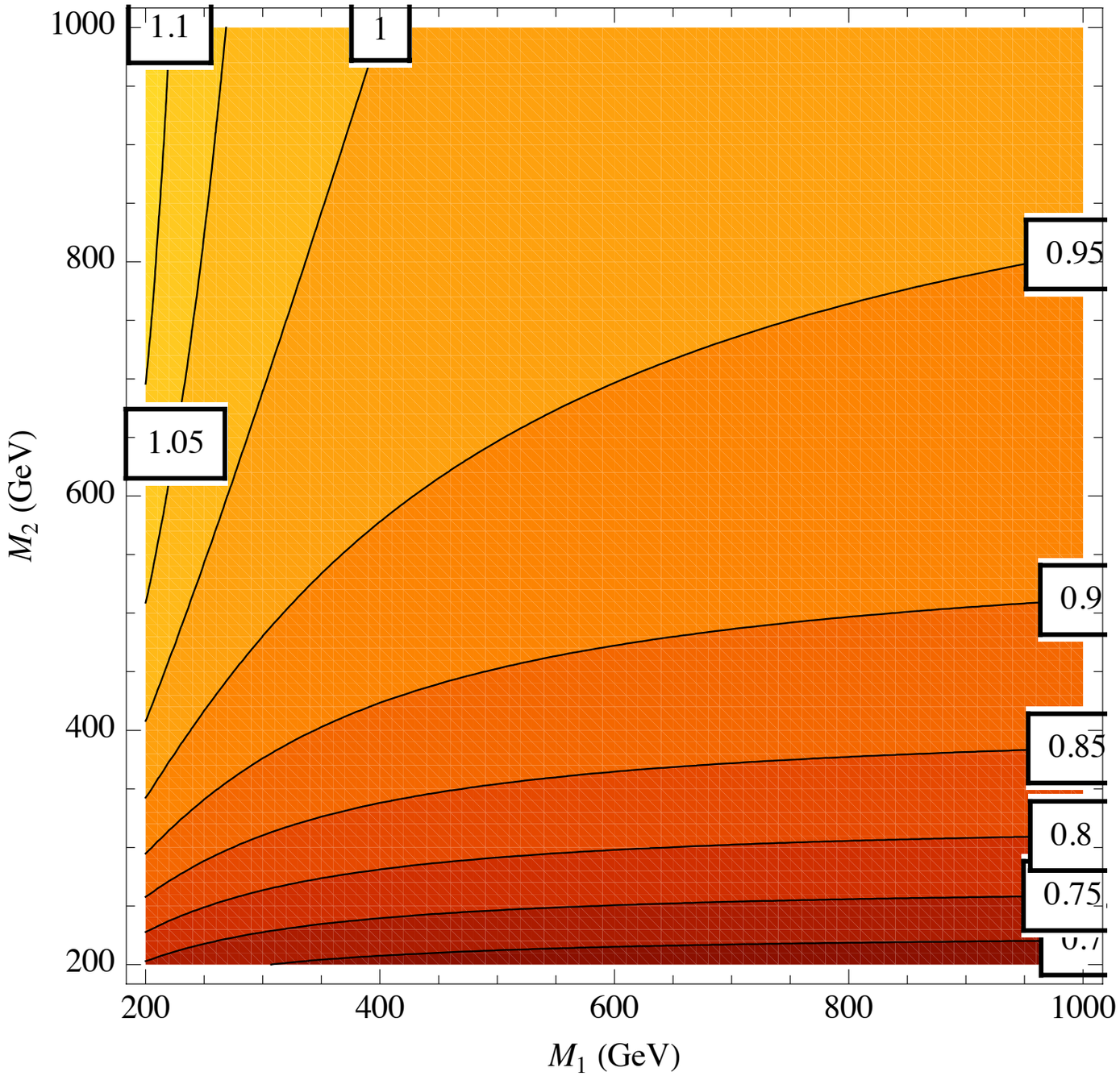
$$\lambda'_u \; \Phi_1 H_u R_u \qquad\qquad \lambda_u \; \Phi_2 H_u R_u$$

$$\lambda'_d \; \Phi_1 H_d R_d \qquad\qquad \lambda_d \; \Phi_2 H_d R_d$$

$$\begin{array}{cccc} M_1 & 0 & -\frac{g' v_u}{\sqrt{2}} & \frac{g' v_d}{\sqrt{2}} \\ 0 & M_2 & \frac{g v_u}{\sqrt{2}} & -\frac{g v_d}{\sqrt{2}} \\ \times & \times & \mu & 0 \\ \times & \times & 0 & \mu \end{array}$$

$$\begin{array}{cc} M_2 & \times \\ g v_u & \mu \end{array}$$

$$\frac{\text{lightest chargino mass}}{\text{lightest neutralino mass}}$$



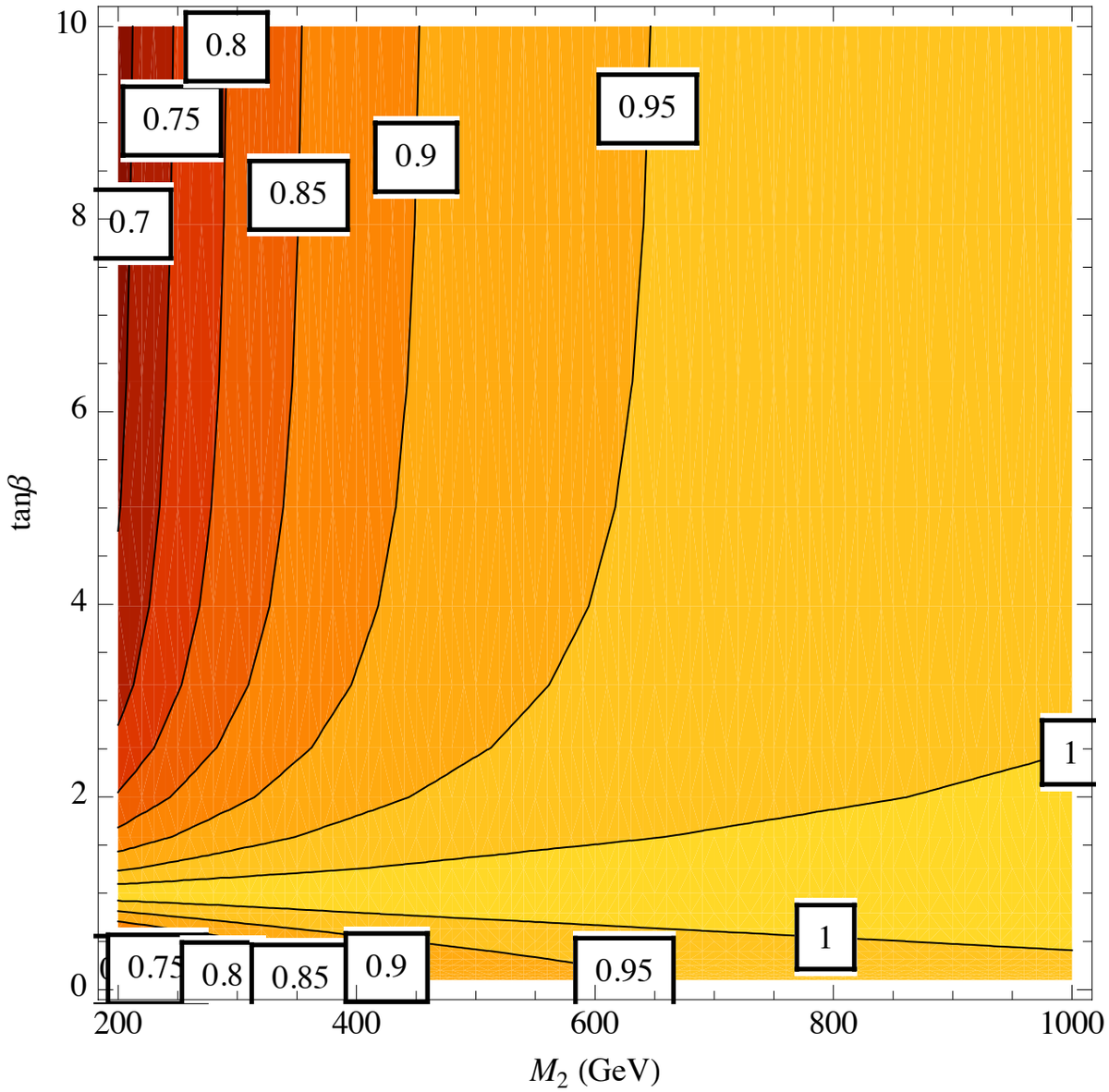
$$\mu = 150 \text{ GeV}$$

$$\tan\beta = 10$$

$$\lambda = g$$

$$\lambda' = g'$$

$$\frac{\text{lightest chargino mass}}{\text{lightest neutralino mass}}$$



$$\mu = 150 \text{ GeV}$$

$$M_1 = 500 \text{ GeV}$$

Experimantal signatures

every superpartner cascades down
to a chargino and finally to
an on-shell W and a gravitino.

Long lived NLSP - charge track of
the chargino.

signal of low energy SUSY but not MSSM

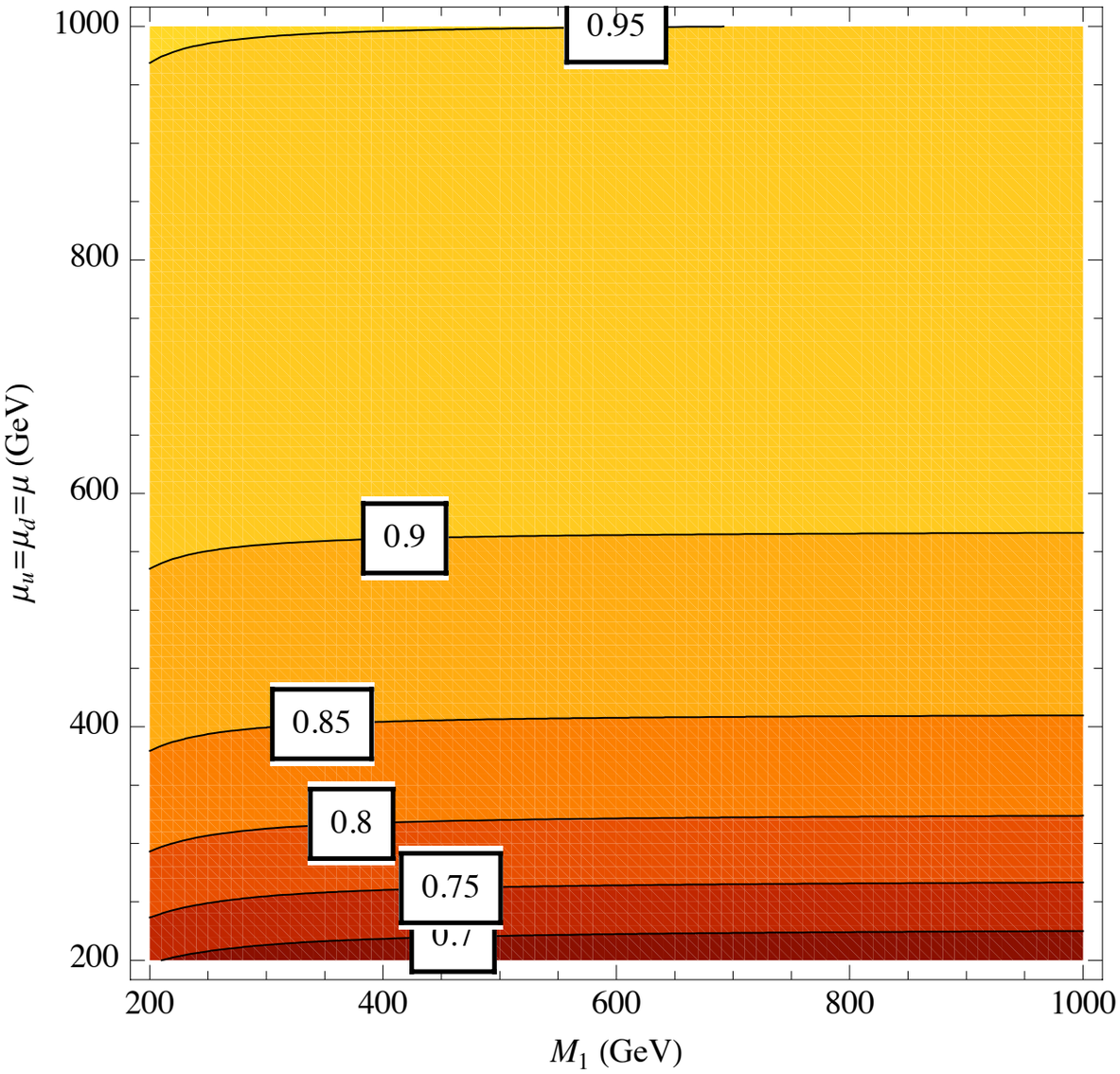
Conclusions I

A gravitino is not tied to the rest of the superpartner spectrum

Conclusions II

- A chargino can be lighter than the lightest neutralino when gauginos are Dirac.
- A new candidate for the NLSP when gravitino is the LSP.
- New signals in the low energy supersymmetry
  - unique signals of Dirac gauginos. (to appear Kribs, Martin, Roy)

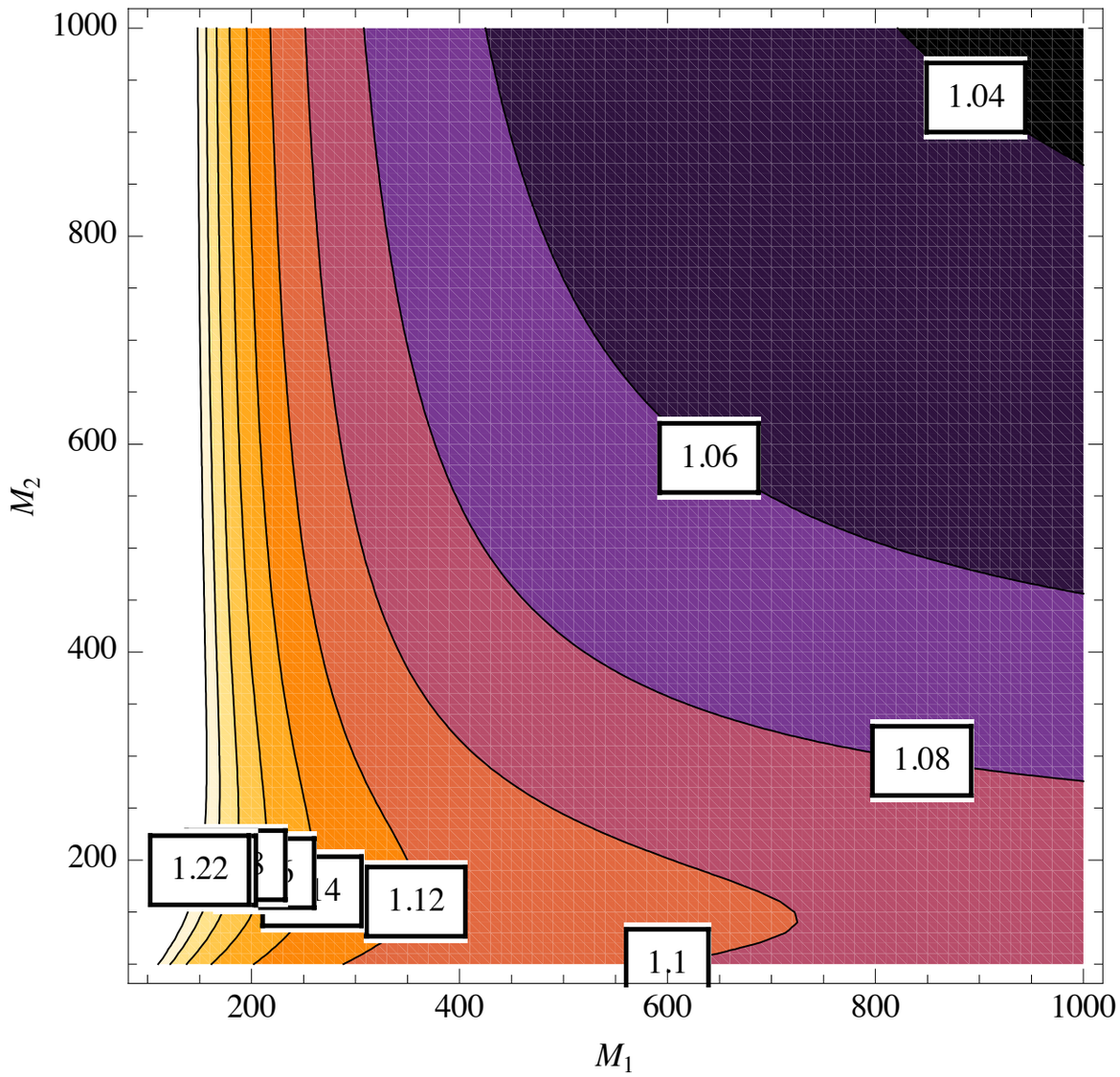
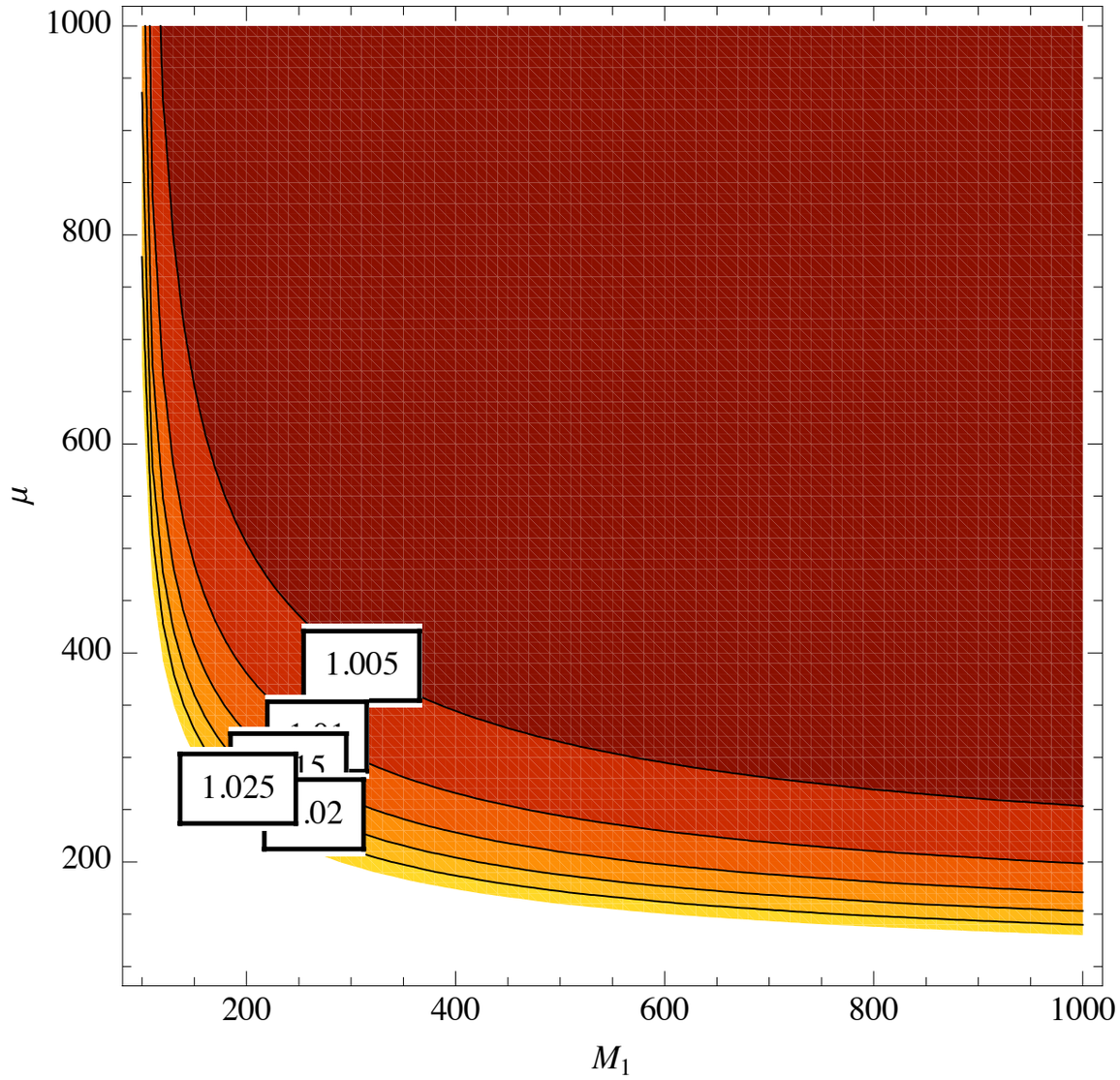
$$\frac{\text{lightest chargino mass}}{\text{lightest neutralino mass}}$$



$M_2 = 150$ GeV

$\tan\beta = 10$

$\lambda = g$

$\lambda' = g'$

$\dfrac{\text{lightest chargino mass}}{\text{lightest neutralino mass}}$