Supersymmetry in ISAJET

H. Baer, F. Paige, S. Protopopescu, X. Tata

ISAJET 7.51: hep-ph/0001086

Outline:

- Models
  - MSSM
  - SUGRA
  - GMSB
  - AMSB
  - ino MSB
- Sparticle production
- Sparticle decays
- Event generation

General procedure for SUSY in ISAJET:

(Paige, Protopopescu, Baer, Tata)

[Progr]ams:

SSRUN (ISASUSY) - masses/BF's in MSSM

SUGRUN (ISASUGRA) - masses/BF's in {SUGRA, GMSB}

ISAJET - event generation

[Sel]ect a model: MSSM, SUGRA, GMSB, ...

[Ente]r parameters

[C]alculate sparticle/Higgs masses/Branching fracti[ons]

(valid for $1 \lesssim \tan\beta \lesssim 50$)

[S]elect production reactions via JETTYPEi cards

[G]enerate hard scattering ($2 \to 2$ or $2 \to 1$)

[G]enerate parton shower for initial/final state

[G]enerate sparticle/particles decays/hadroniza[tion]

(more showering)

Generate beam remnant evolution

Output (stable) particle identities/4-vectors/

3-generations of chiral superfiel[ds]

- $\hat{Q}_i = \begin{pmatrix} \hat{u}_i \\ \hat{d}_i \end{pmatrix}$; $\hat{L}_i = \begin{pmatrix} \hat{\nu}_i \\ \hat{e}_i \end{pmatrix}$; $\hat{U}_i^c$, $\hat{D}_i^c$, $\hat{E}_i^c$

- 2-Higgs doublet superfields

$$\underbrace{\hat{H}_u}_{2} = \begin{pmatrix} \hat{h}_u^+ \\ \hat{h}_u^0 \end{pmatrix} \quad ; \quad \underbrace{\hat{H}_d}_{\bar{2}} = \begin{pmatrix} \hat{h}_d^- \\ \hat{h}_d^0 \end{pmatrix}$$

- supersymmetric renormalizable $\mathcal{L}$ inv. under $SU_c(3) \times SU_L(2) \times U_Y(1)$

- R-conserving renormalizable superpotentia[l]

$$\hat{f} = \mu \hat{H}_u \hat{H}_d + f_u \hat{Q} \hat{H}_u \hat{U}^c + f_d \hat{Q} \hat{H}_d \hat{D}^c + f_e \hat{L} \hat{H}$$

- Add by hand all allowed soft-SUSY

$$\mathcal{L}_{SB} \ni - \sum_i m_i^2 |\phi_i|^2 - \frac{1}{2} \sum_\lambda M_\lambda \bar{\lambda} \lambda$$
$$+ A_t f_t \tilde{Q} \tilde{H}_u \tilde{t}_R^+ + \cdots + B\mu \tilde{H}_d \tilde{H}_u + \cdots$$

Minimal Supersymmetric Standard Model (MSSM)

- All model input parameters are at $Q \sim M_Z$

Must specify:

MSSMA: $m_{\tilde{g}}$, μ, m_A, $\tan\beta$

↑ pole mass → $m_{\tilde{g}}(m_{\tilde{g}}) \to M_3(M_Z)$

MSSMB: m_{Q_1}, m_{D_1}, m_{U_1}, m_{L_1}, m_{E_1}

weak-scale soft-SUSY breaking masses; (1st. gen)
(not physical masses)

MSSMC: m_{Q_3}, m_{D_3}, m_{U_3}, m_{L_3}, m_{E_3}, A_t, A_b, A_τ

3rd gen. SSB terms — weak-scale A-parameters (3rd gen)

Optional:

MSSMD: m_{Q_2}, m_{D_2}, m_{U_2}, m_{L_2}, m_{E_2}

2nd. gen SSB terms (default = 1st. gen terms)

MSSME: M_1, M_2

weak-scale U(1), SU(2) gaugino masses
(default: $M_1/\alpha_1 = M_2/\alpha_2 = M_3/\alpha_3$)

MGVTNO

Options for SUGRA models:

1.) mSUGRA (universality)

$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ sgn(\mu)$,

2.) non-universal GUT scale masses

NUSUG1: $M_1,\ M_2,\ M_3$

NUSUG2: $A_t,\ A_b,\ A_\tau$

NUSUG3: $m_{H_d},\ m_{H_u}$

NUSUG4: $m_{\tilde{Q}_1},\ m_{\tilde{d}_R},\ m_{\tilde{u}_R},\ m_{\tilde{L}_1},\ m_{\tilde{e}_R}$

NUSUG5: $m_{\tilde{Q}_3},\ m_{\tilde{b}_R},\ m_{\tilde{t}_R},\ m_{\tilde{L}_3},\ m_{\tilde{\tau}_R}$

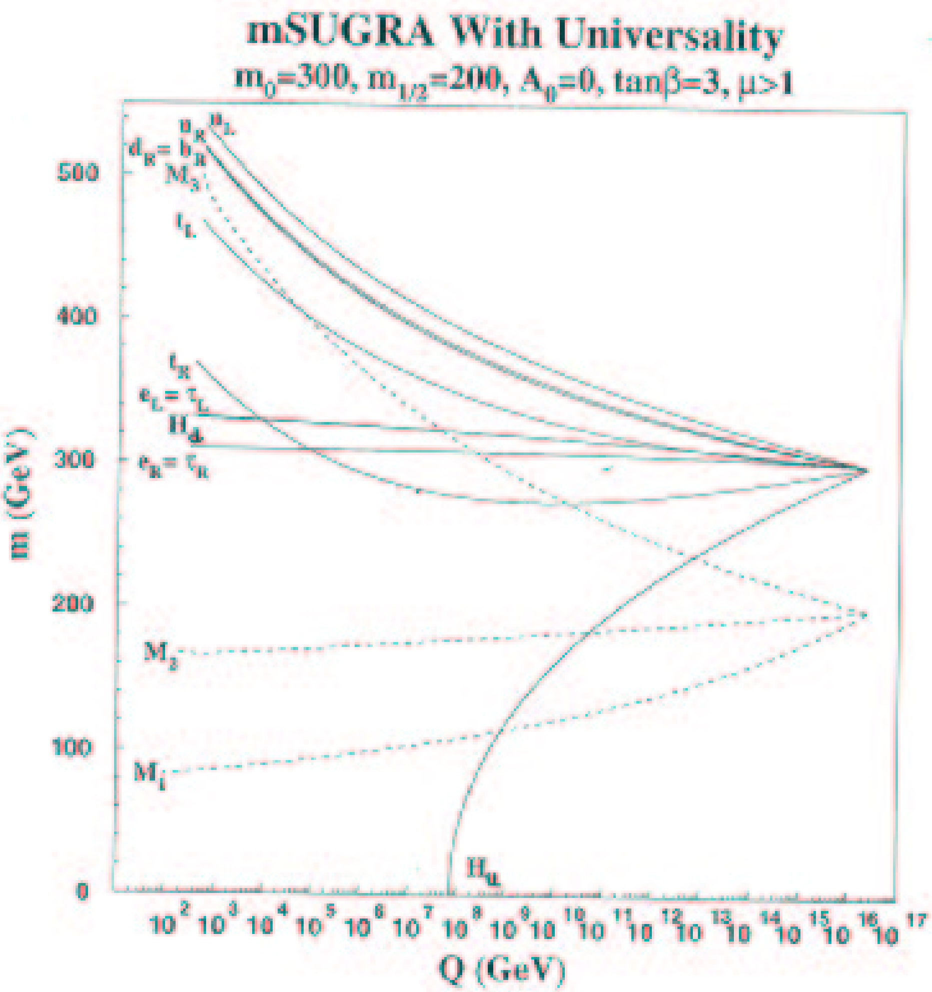
3.) mSUGRA + RHN

or non-univeral + RHN

SUGRHN: $m_{\nu_\tau},\ M_N,\ A_\nu,\ m_{\tilde{\nu}_R}$

↳ $= 0$ then $f_\nu = f_t$ at M_{GUT}

$\neq 0$ calc. f_ν via evolution


mSUGRA With Universality
m0=300, m1/2=200, A0=0, tanβ=3, μ>1
uL
uR
dR = bR
M3
tL
tR
eL = τL
Hd
eR = τR
M2
M1
Hu
m (GeV)
500
400
300
200
100
0
10 2 10 3 10 4 10 5 10 6 10 7 10 8 10 9 10 10 10 11 10 12 10 13 10 14 10 15 10 16 10 17
Q (GeV)

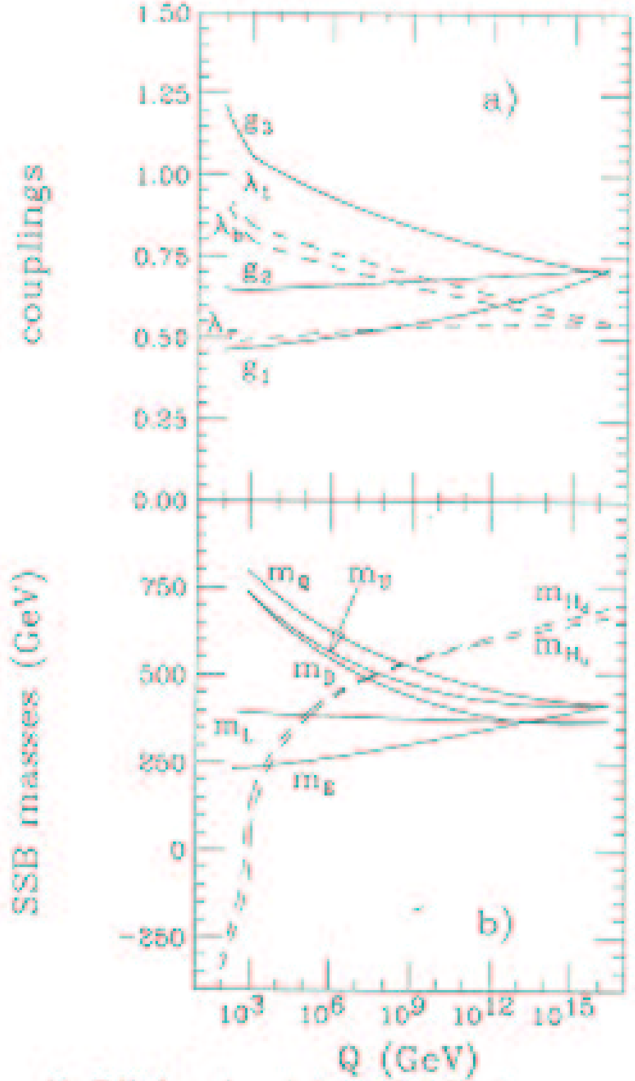


FIG. 3. For case 1 in Table I, we show a) the running of both gauge and Yukawa couplings between $Q = M_{GUT}$ and $Q = M_{weak}$. In b), we show the running of SSB Higgs masses (dashed curves) and third generation SSB masses (solid curves).

e.g. SO(10) SUSY GUT with Yukawa unification and D-term contributions to scalar masses

MSSM + right-hand neutrino:

- solar / atmospheric ν-oscillation exp's
  $\Rightarrow$ neutrinos have mass
- simplest mechanism
  add gauge singlet $\hat{N}^c$ to MSSM
- superpotential:
  $$\hat{f} = \hat{f}_{MSSM} + f_n \hat{L} \hat{H}_u \hat{N}^c + \frac{1}{2} M_N \hat{N}^c \hat{N}^c$$
- SSB terms:
  $$\mathcal{L} \ni \mathcal{L}_{MSSM} + A_n f_n \tilde{L} \tilde{H}_u \tilde{\nu}_R^{+} - m_N^2 |\tilde{\nu}_R|^2$$
- ν-mass via see-saw mechanism:
  $$m_N \sim 10^{10} - 10^{16}\ GeV$$
  $$m_D \sim f_n v$$
  $$m_\nu = \frac{m_D^2}{m_N}$$
- additional Yukawa affects
  SUSY spectrum

ISAJET MSSM+RHN solution:

Input:

m_{ν_τ}, M_N, $m_{\tilde{\nu}_R}$, A_n

RG evolution:

MSSM+RHN : $Q > M_N$

MSSM : $Q < M_N$

TABLE V. Model parameters and weak scale sparticle masses in GeV for mSUGRA and for the MSSM+right-handed neutrino model. For each case, we take $m_0 = 200$ GeV, $m_{1/2} = 200$ GeV, $A_0 = 0$, $\tan\beta = 40$ and $\mu > 0$.

parameter	$mSUGRA$	$MSSM + RHN$
m_{ν_τ}	0	10^{-9}
M_N	—	10^{13}
$m_{\tilde{\nu}_R}$	—	200
A_n	—	0
$m_{\tilde{g}}$	511.5	511.5
$m_{\tilde{u}_L}$	485.1	485.1
$m_{\tilde{t}_1}$	343.1	344.2
$m_{\tilde{b}_1}$	386.6	386.4
$m_{\tilde{\ell}_L}$	250.4	250.4
$m_{\tilde{\ell}_R}$	218.9	218.9
$m_{\tilde{\tau}_1}$	144.2	140.5
$m_{\tilde{\tau}_2}$	257.1	252.6
$m_{\tilde{\nu}_\tau}$	220.1	211.6
$m_{\widetilde{W}_1}$	146.9	147.6
$m_{\widetilde{Z}_2}$	147.5	148.2
$m_{\widetilde{Z}_1}$	79.9	80.0
m_h	111.7	111.7
m_A	243.3	249.4
μ	263.2	267.6
A_τ	-66.6	-66.5
A_b	-383.3	-383.3

mixing effect

ISAJET large $\tan\beta$ solution:

H B
C.H. Chen
M. Drees
F. Paige
X. Tata

- For large $\tan\beta$, b, τ Yukawa's are large

  Drees, Nojiri

- Calculate $\tilde{b}_{1,2}$, $\tilde{\tau}_{1,2}$ masses mixings [illegible]

- Minimization of 1-loop eff. pot'l: unstable against scale variations at large $\tan\beta$

  optimized scale choice $Q \sim \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$ in RG-improved 1-loop eff. pot'l.

  Carena, Espinosa, Quiros, Wagner / [illegible]

- Re-calculate sparticle decays including b, τ Yukawas and mixings

  $\tilde{g}$, $\tilde{b}_i$, $\tilde{t}_i$, $\tilde{\tau}_i$, $\tilde{\nu}_\tau$, $\widetilde{W}_i$, $\widetilde{Z}_i$, $h, A, H, H^\pm$

  $\tilde{g} \to t\bar{t}\widetilde{Z}_i,\ b\bar{b}\widetilde{Z}_i$
  $\to tb\widetilde{W}_i$] agrees with [illegible] et. al.

  $\widetilde{Z}_i \to b\bar{b}\widetilde{Z}_j$
  $\to \tau\bar{\tau}\widetilde{Z}_j$ } 8 diagrams (new!)

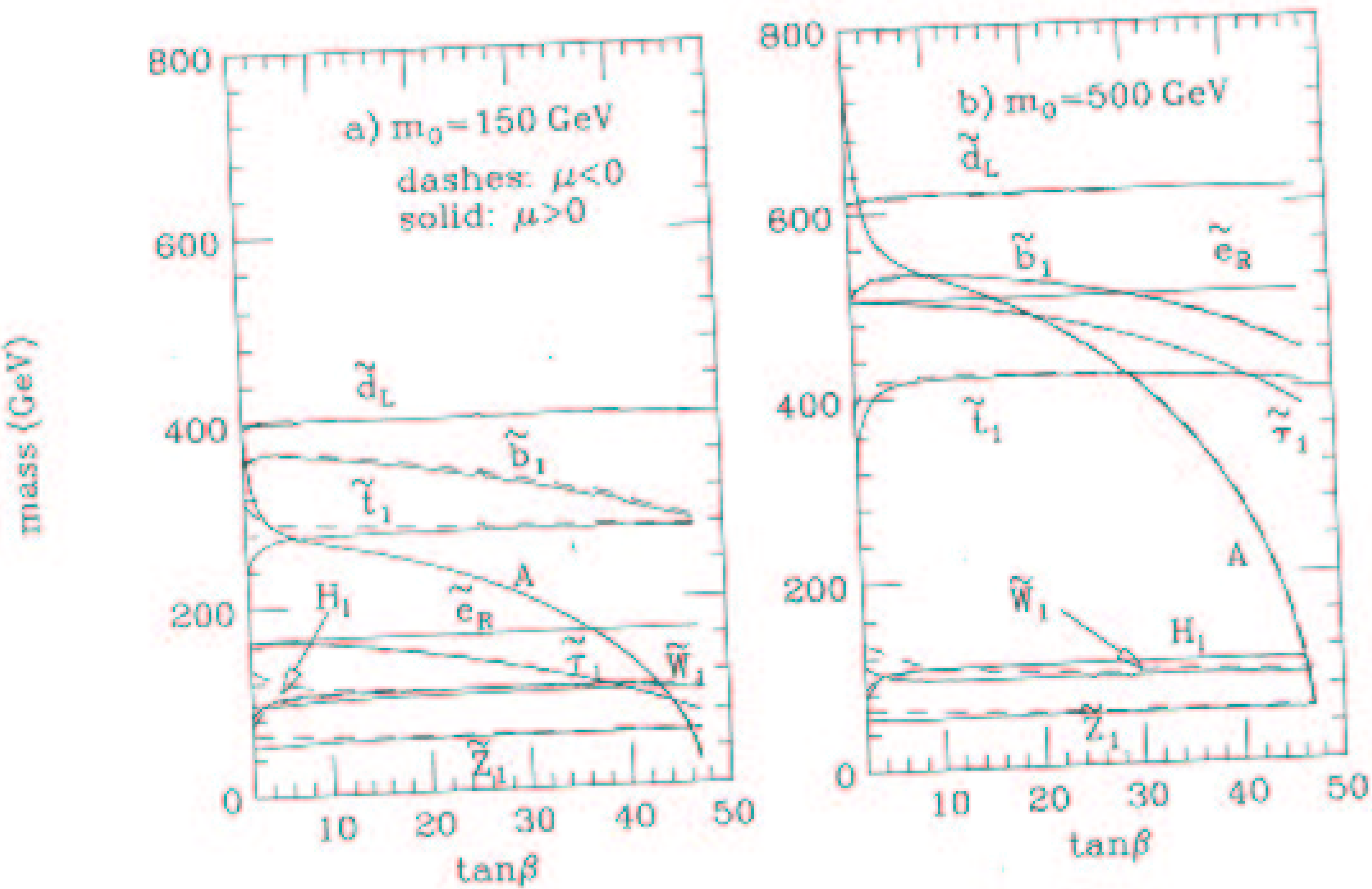
  $\widetilde{W}_i \to \tau\nu\widetilde{Z}_j$ } 5 diagrams

  τ polarization info kept; used for τ-decay

- Re-calculate sparticle production including mixing effects

  $q\bar{q} \to \tilde{t}_i \bar{\tilde{t}}_j$
  $q\bar{q} \to \tilde{\tau}\bar{\tilde{\nu}}$
  $e^+e^- \to \tilde{t}_i \bar{\tilde{t}}_j$
  $\tilde{b}_i \bar{\tilde{b}}_j$

C.H. Chen
M. Drees
F. Paige
X. Tata



Models of SUSY with IMH

in place at GUT scale

restricted: 2-loop RG contributions

can drive scalar masses tachyonic:

Arkani-Hamed, Murayama;
Agashe + Graesser

$$\frac{dm_i^2}{dt} = \frac{1}{16\pi^2}\beta_{m_i}^{(1)} + \frac{1}{(16\pi^2)^2}\beta_{m_i}^{(2)}$$

$$\beta_{m_i}^{(2)} \ni a_i\, g_3^2\, \sigma_3 + b_i\, g_2^2\, \sigma_2 + c_i\, g_1^2\, \sigma_1$$

$$\sigma_1 = \frac{1}{5} g_1^2 \left\{ 3(m_{H_u}^2 + m_{H_d}^2) + Tr\left[m_Q^2 + 3m_L^2 + 8m_u^2 + 2m_d^2 + 6m_e^2 \right] \right\}$$

$$\sigma_2 = g_2^2 \left\{ m_{H_u}^2 + m_{H_d}^2 + Tr\left[3m_Q^2 + m_L^2 \right] \right\}$$

$$\sigma_3 = g_3^2\, Tr\left[2m_Q^2 + m_u^2 + m_d^2 \right]$$

Martin + Vaughn

$a_i, b_i, c_i > 0$

H.B.
Balazs
Mercadante
Tata
Wang

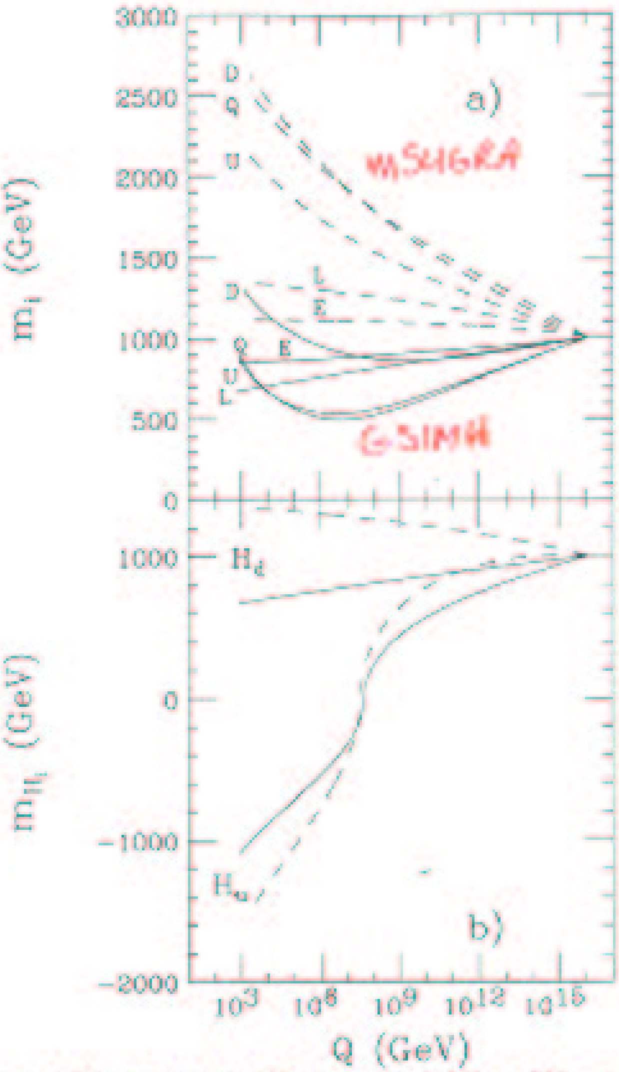


FIG. 1. Evolution of a) third generation SSB masses and b) Higgs SSB masses from M_{GUT} to M_{weak} versus scale choice Q. Dashed lines indicate mSUGRA model while solid lines indicate the GSIMH model. We take $m_0(3) = 1000$ GeV, $m_{1/2} = 1400$ GeV, $A_0 = 0$, $\tan\beta = 3$ and $\mu > 0$. In the GSIMH model, $m_0(1) = m_0(2) = 15,000$ GeV, while in mSUGRA, $m_0(1) = m_0(2) = m_0(3)$.

2-loop RG evolution of 3rd. gen.
and Higgs soft SUSY breaking masses.

Gauge Mediated SUSY Breaking Models: (GMSB)

$\langle F \rangle$

n_5 $5+\bar{5}$ mess. fields

$\langle F_M \rangle$, M

$\langle S \rangle$

$\Lambda = \frac{\langle F_M \rangle}{\langle S \rangle}$

$$m_{\tilde{G}} = \frac{\langle F \rangle}{\sqrt{3}\, M_p^*}$$

$$m_{\tilde{\lambda}_i} = \frac{\alpha_i}{4\pi} n_5 \Lambda\, g\left(\frac{\Lambda}{M}\right)$$

(threshold functions)

$$m^2_{scalar} = 2 n_5 \Lambda^2 f\left(\frac{\Lambda}{M}\right)\left[C_3\left(\frac{\alpha_3}{4\pi}\right)^2 + C_2\left(\frac{\alpha_2}{4\pi}\right)^2 + \frac{3}{5}\left(\frac{Y}{2}\right)^2\left(\frac{\alpha_1}{4\pi}\right)^2\right]$$

GMSB parameter set

- Λ: ~10 TeV → 400 TeV (SUSY breaking scale)
- M: $> \Lambda$ (messenger mass scale)
- n_5: (# of $5+\bar{5}$ messenger fields)
- $\tan\beta$: (usual ratio of vev's)
- $\mathrm{sgn}(\mu)$: (usual sign of μ-term)
- $C_{\tilde{G}}$: ≥ 1 ratio $\frac{\langle F \rangle}{\langle F_M \rangle}$ (increases NLSP lifetime)

Gauge Mediated SUSY Breaking Models: (GMSB)

$\langle F \rangle$

n_5 $5+\bar{5}$ mess. fields

$\langle F_M \rangle$, M

$\langle S \rangle$

$\Lambda = \frac{\langle F_M \rangle}{\langle S \rangle}$

$$m_{\tilde{G}} = \frac{\langle F \rangle}{\sqrt{3}\, M_p^*}$$

$$m_{\tilde{\lambda}_i} = \frac{\alpha_i}{4\pi}\, n_5\, \Lambda\, g\left(\frac{\Lambda}{M}\right)$$ (threshold functions)

$$m^2_{scalar} = 2 n_5 \Lambda^2 f\left(\frac{\Lambda}{M}\right)\left[C_3\left(\frac{\alpha_3}{4\pi}\right)^2 + C_2\left(\frac{\alpha_2}{4\pi}\right)^2 + \frac{3}{5}\left(\frac{Y}{2}\right)^2\left(\frac{\alpha_1}{4\pi}\right)^2\right]$$

GMSB parameter set

Λ : ~10 TeV → 400 TeV (SUSY breaking scale)

M : $> \Lambda$ (messenger mass scale)

n_5 : (# of $5+\bar{5}$ messenger fields)

$\tan\beta$: (usual ratio of vev's)

$sgn(\mu)$: (usual sign of μ-term)

$C_{\tilde{G}}$: ≥ 1 ratio $\frac{\langle F \rangle}{\langle F_M \rangle}$ (increases NLSP lifetime)

Beyond mGMSB model: GMSB2

(requested by S. Thomas + S. Martin)
[illegible]

$\not{R}$, $\Delta M^2_{H_d}$, $\Delta M^2_{H_u}$, $D_Y(M)$, n_{5_1}, n_{5_2}, n_{5_3}

$\not{R}\ (\leq 1)$ is gaugino mass multiplier if $U(1)_R$ symmetry broken at scale lower than Λ

$$m^2_{H_d} = m^{2\,0}_{H_d} + \Delta m^2_{H_d}$$
$$m^2_{H_u} = m^{2\,0}_{H_u} + \Delta m^2_{H_u}$$

} additional messenger sector interactions can induce extra contributions (+ or −) to soft Higgs masses

$$\delta m^2(M) = g' Y D_Y(M)$$

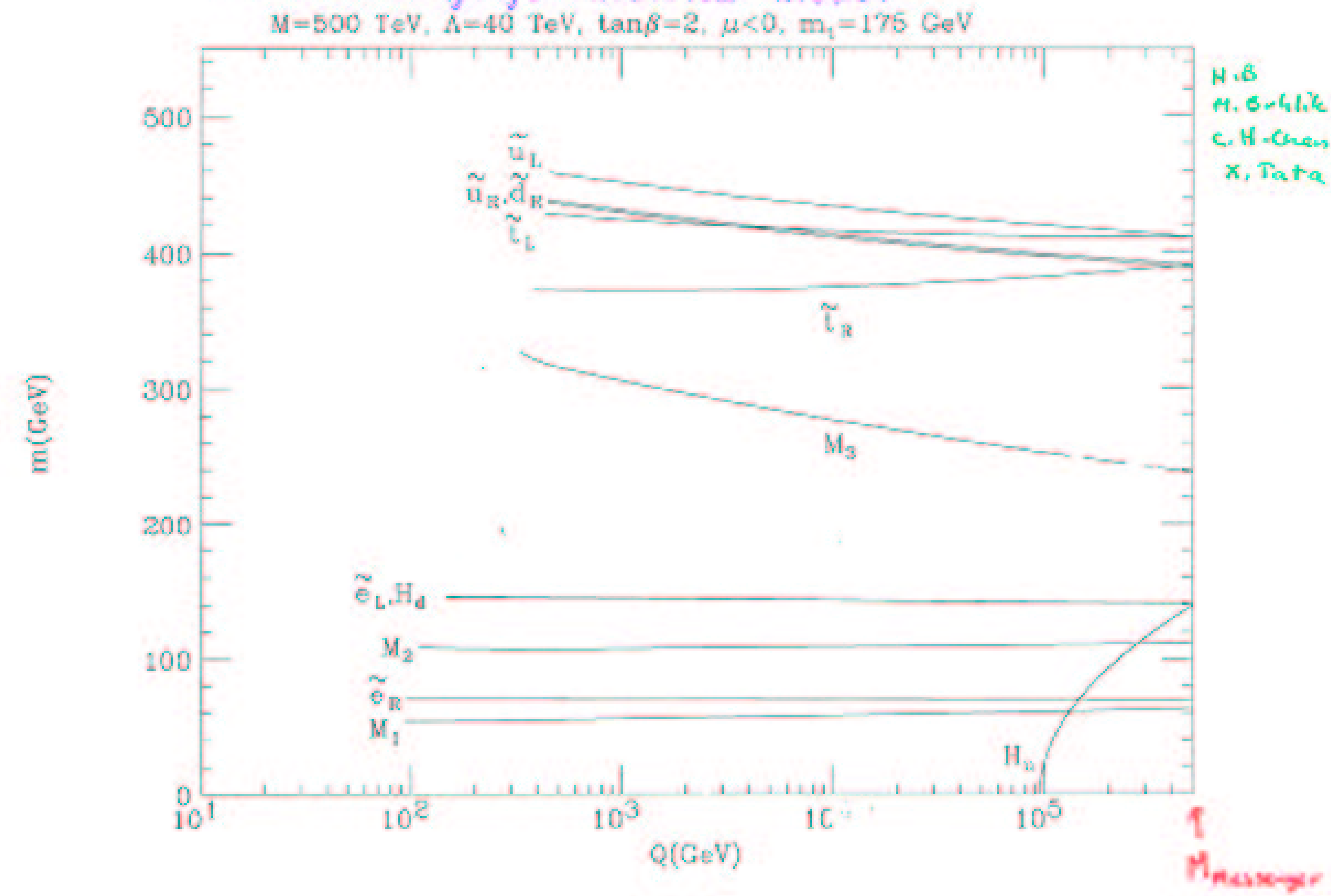
} a $U(1)_Y$ D-term contribution at messenger scale (mass-squared!)

$n_{5_1}, n_{5_2}, n_{5_3}$ } independent messenger # for each gauge group; need not be integers!

Default values:

$$(\not{R}, \Delta M^2_{H_d}, \Delta M^2_{H_u}, D_Y(M), n_{5_1}, n_{5_2}, n_{5_3}) = (1, 0, 0, 0, n_5, n_5, n_5)$$

Soft - SUSY breaking terms evolve with scale
in minimal gauge-mediated model



Anomaly-mediated SUSY breaking

Randall
Sundrum

- Assume multi-dimensional world
  e.g. $d = 10$ or 11

- Visible sector in 3+1 spacetime dim'ns
- Hidden sector in other dimensions
  - "sequestered sector"

- SUSY breaking in hidden sector

- Anomalous rescaling violations ⇒
  - gaugino masses at 1-loop:

    $$M_i = -b_i g_i^2 F_\Phi$$

  - scalar mass² at 2-loop:

    $$m_{\tilde q}^2 = -\frac{1}{4}\left(\frac{d\gamma}{dg}\beta_g + \frac{d\gamma}{dy}\beta_y\right)|F_\Phi|^2$$

    $$\gamma = \frac{\partial \ln Z}{\partial \ln \mu}$$

- Slepton masses tachyonic;
  add universal m_0^2 contribution?

AMSB model in ISAJET:

- Input: $m_{3/2}$, m_0, $\tan\beta$, $sgn(\mu)$

  $M_1 : M_2 : M_3 \sim 2.8 : 1 : 7.1$

  so $\widetilde{W}_1$ is lightest

  - LSP = wino-like
  - $m_{\widetilde{W}_1} \approx m_{\widetilde{Z}_1}$
  - $\widetilde{W}_1 \to \pi \widetilde{Z}_1$ or $e\nu\widetilde{Z}_1$
  - long-lived
    - $\to e\nu\widetilde{Z}_1$ outside detector
    - $\to \pi\widetilde{Z}_1$ inside detector
      π is very soft

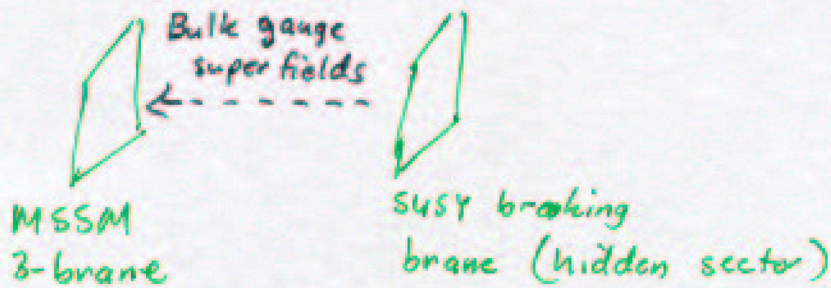
Kaplan
Kribs
Schmaltz

Chacko
Luty
Ponton
Nelson

Schmaltz
Skiba

HB
Diaz
Quintana
Tata

Gaugino mediated SUSY breaking



- gaugino mass $m_{1/2}$ at M_c
- scalar masses $m_0 \approx 0$ at M_c
  (as in no-scale models)
- Assume a SUSY GUT at
  $M_{GUT} < Q < M_{Pl}$

  so additional e.g. SU(5) or SO(10) running
  from $M_c \rightarrow M_{GUT}$
- e.g. pick SU(5) and where $f_b = f_\tau$
  ($\tan\beta \approx 35$?) , λ, λ' add'l SU(5) couplings
  generate non-universal masses
  at M_{GUT} $m_{1/2}, M_c, \tan\beta, sgn(\mu)$

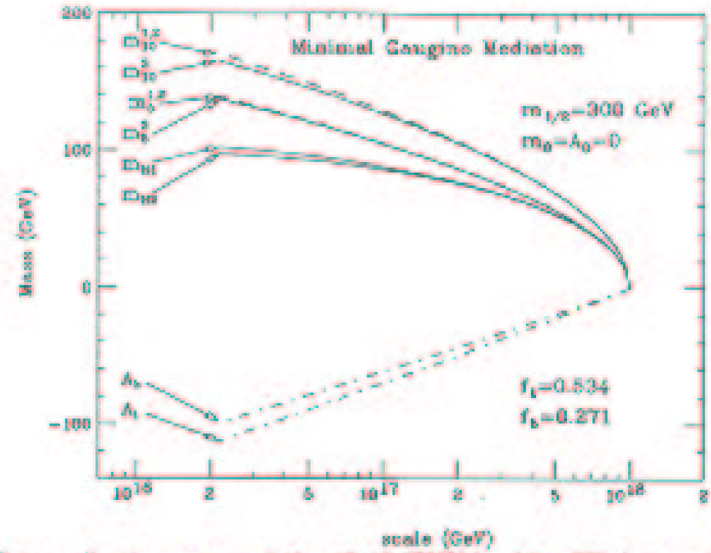


FIG. 6. Renormalization group evolution of soft SUSY breaking $SU(5)$ masses versus scale in the minimal gaugino mediation model. We take $\tan\beta = 35$ and $\mu < 0$ to achieve $b-\tau$ Yukawa coupling unification.

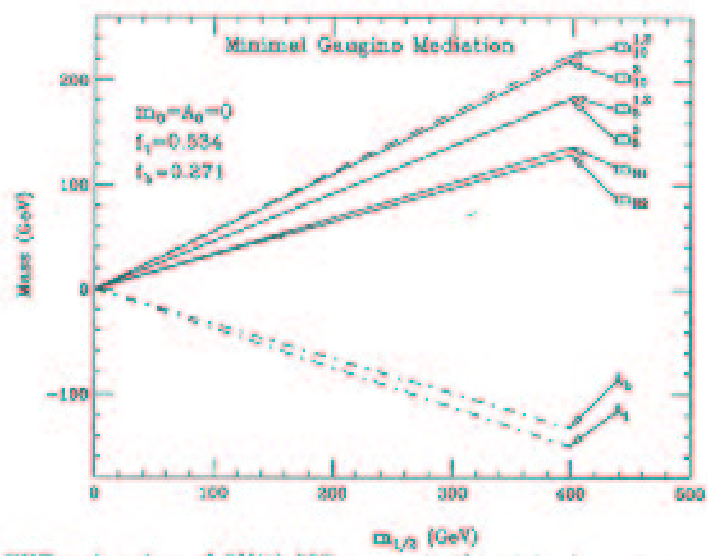


FIG. 7. GUT scale values of $SU(5)$ SSB masses in the minimal gaugino mediation model. We take $\tan\beta = 35$ and $\mu < 0$ to achieve $b-\tau$ Yukawa coupling unification. We take the compactification scale $M_c = 1\times 10^{18}$ GeV. Models with $m_{1/2} < 275$ GeV lead to a breakdown in REWSB or a charged LSP.

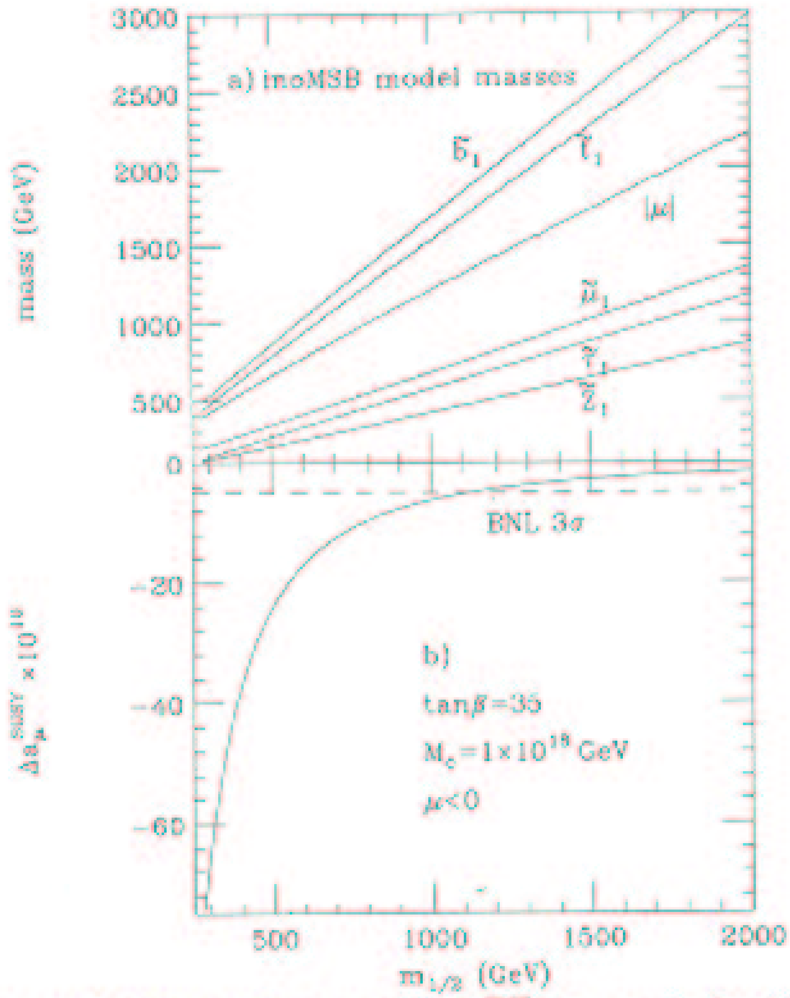
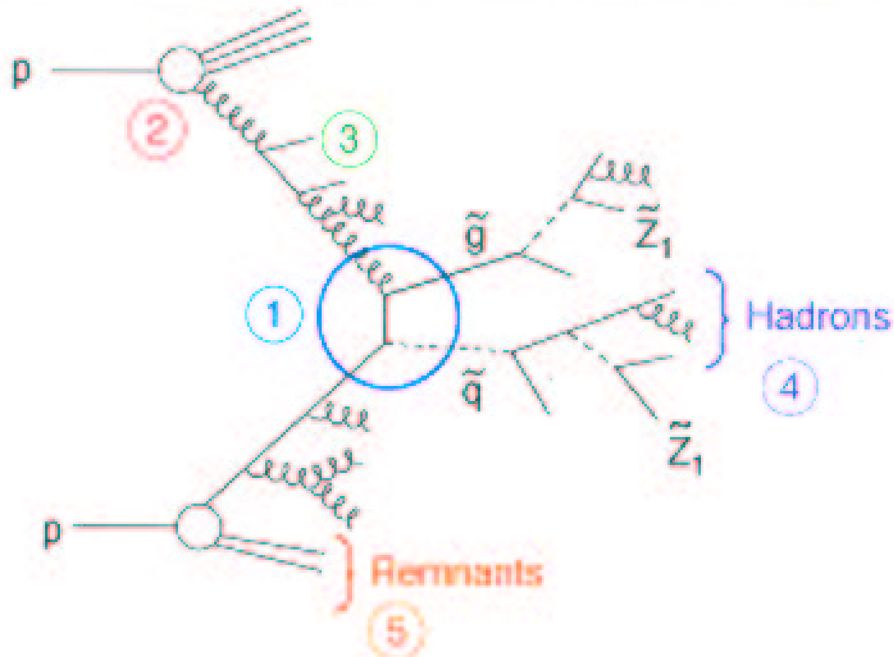


FIG. 10. A plot of *a*) sparticle masses and *b*) Δa_μ^{SUSY} versus $m_{1/2}$ in the minimal gaugino-mediated SUSY breaking model, for $\tan\beta = 35$, and $\mu < 0$. We assume $SU(5)$ unification between M_c and M_{GUT}.



Event generation in LL - QCD

1) Hard scattering

2) Convolution with PDF's

3) Intial / Final State showers

4) Hadronization

5) Beam remnants

Sparticle production processes (ISAJET)

$gg, q\bar{q} \to \tilde{g}\tilde{g}$
$gq \to \tilde{g}\tilde{q}_i$
$gg, q\bar{q}, qq \to \tilde{q}_i\tilde{q}_j, \tilde{q}_i\bar{\tilde{q}}_j$

} α_s^2 : strong production
$\tilde{u}_L, \tilde{u}_R, \tilde{d}_L, \tilde{d}_R, \tilde{s}_L, \tilde{s}_R, \tilde{c}_L, \tilde{c}_R$
$\tilde{b}_L, \tilde{b}_R, \tilde{t}_1, \tilde{t}_2$
($\tan\beta$ [redacted]

$gq \to \tilde{q}_i\widetilde{W}_j, \tilde{q}_i\widetilde{Z}_j$
$q\bar{q} \to \tilde{g}\widetilde{W}_i, \tilde{g}\widetilde{Z}_j$

} associated production

$q\bar{q} \to \widetilde{W}_i\widetilde{Z}_j$
$q\bar{q} \to \widetilde{W}_i\bar{\widetilde{W}}_j$
$q\bar{q} \to \widetilde{Z}_i\widetilde{Z}_j$
$q\bar{q} \to \tilde{\ell}\bar{\tilde{\ell}}, \tilde{\nu}\bar{\tilde{\nu}}$

} chargino/neutralino production
slepton/sneutrino production

$q\bar{q}, gg \to h, H, A$ } s-channel Higgs production

$q\bar{q} \to Wh, Zh, WH, ZH, Ah, AH, H^+H^-$

$e_i\bar{e}_j \to \tilde{q}_k\bar{\tilde{q}}_k, \tilde{\ell}_k\bar{\tilde{\ell}}_k, \tilde{\nu}_L\bar{\tilde{\nu}}_L$
$e_i\bar{e}_j \to \widetilde{W}_m\bar{\widetilde{W}}_m, \widetilde{Z}_k\widetilde{Z}_\ell$
$e_i\bar{e}_j \to hZ, HZ, Ah, AH, H^+H^-$

} polarized production of sparticles/Higgs/SM particles

Select subprocesses via JETTYPE1, JETTYPE2
keywords: 'ALL', 'GAUGINOS', 'SLEPTONS', 'SQUARKS',
'MSSL', 'MBSSL', ...

Factor of 2 ambiguity: JETTYPE1 'GAUGINOS' JETTYPE2 'SQUARKS' } gives ½ total σ

Supersymmetry at NLC / JLC

$\tilde{e}_L \bar{\tilde{e}}_R$ + c.c.

$e^+e^- \to$ $\tilde{e}_L \bar{\tilde{e}}_L$ } large due to t-channel graphs
$\tilde{e}_R \bar{\tilde{e}}_R$
$\tilde{\nu}_{e_L} \bar{\tilde{\nu}}_{e_L}$

$\tilde{\ell}_L \bar{\tilde{\ell}}_L$ } $\ell = \mu, \tau$; s-channel only
$\tilde{\ell}_R \bar{\tilde{\ell}}_R$
$\tilde{\nu}_\ell \bar{\tilde{\nu}}_\ell$

HB
N Baer-H
D Karatas
W. Majerotto
X. Tata

HB
R Munroe
X. Tata

$\tilde{q}_L \bar{\tilde{q}}_L$
$\tilde{q}_R \bar{\tilde{q}}_R$
$\tilde{t}_1 \bar{\tilde{t}}_1$
$\tilde{t}_1 \bar{\tilde{t}}_2$
$\tilde{t}_2 \bar{\tilde{t}}_2$

$\tilde{W}_1 \bar{\tilde{W}}_1$ } ← large { light / t-channel graphs
$\tilde{W}_1 \bar{\tilde{W}}_2$
$\tilde{W}_2 \bar{\tilde{W}}_2$

$\tilde{Z}_1 \tilde{Z}_1$ }
$\tilde{Z}_1 \tilde{Z}_2$
$\tilde{Z}_1 \tilde{Z}_3$ } 10 reactions – very model dependent
$\vdots$
$\tilde{Z}_4 \tilde{Z}_4$

and Higgs sector $H_\ell, H_h, H_p, H^\pm$ — polarized beams

$H_\ell Z, H_h Z, H_\ell H_p, H_h H_p, H^+H^-$ — ISAJET 7.16

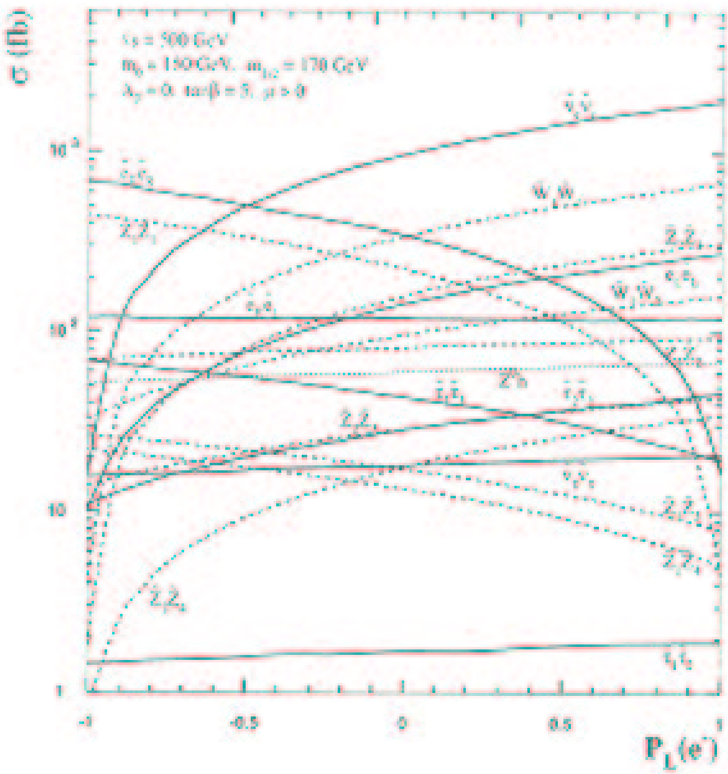
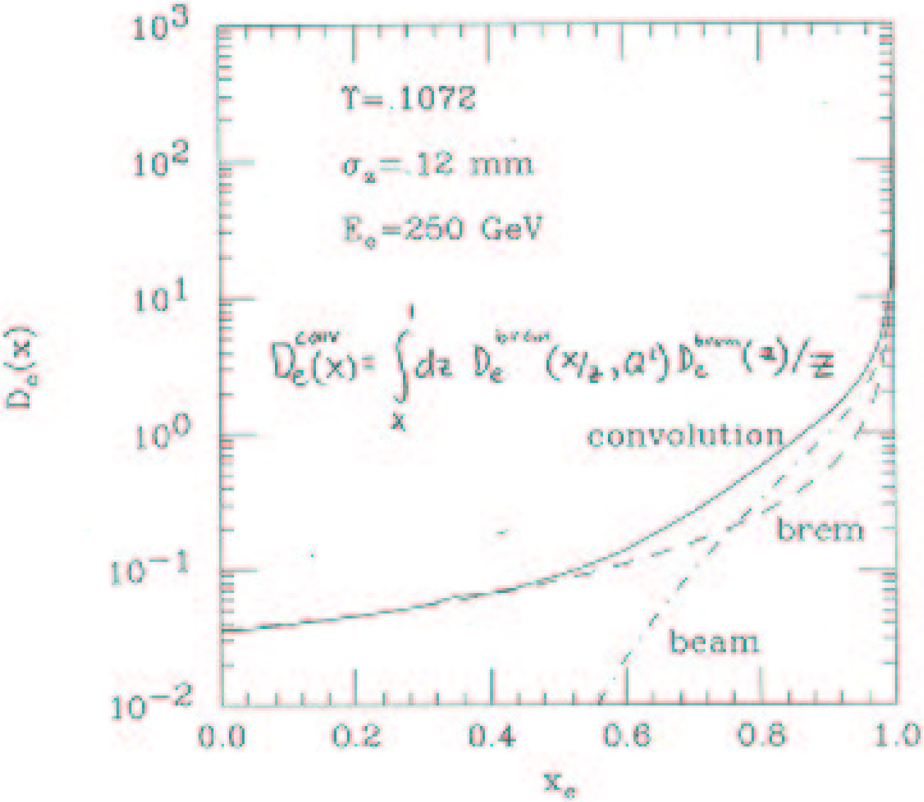


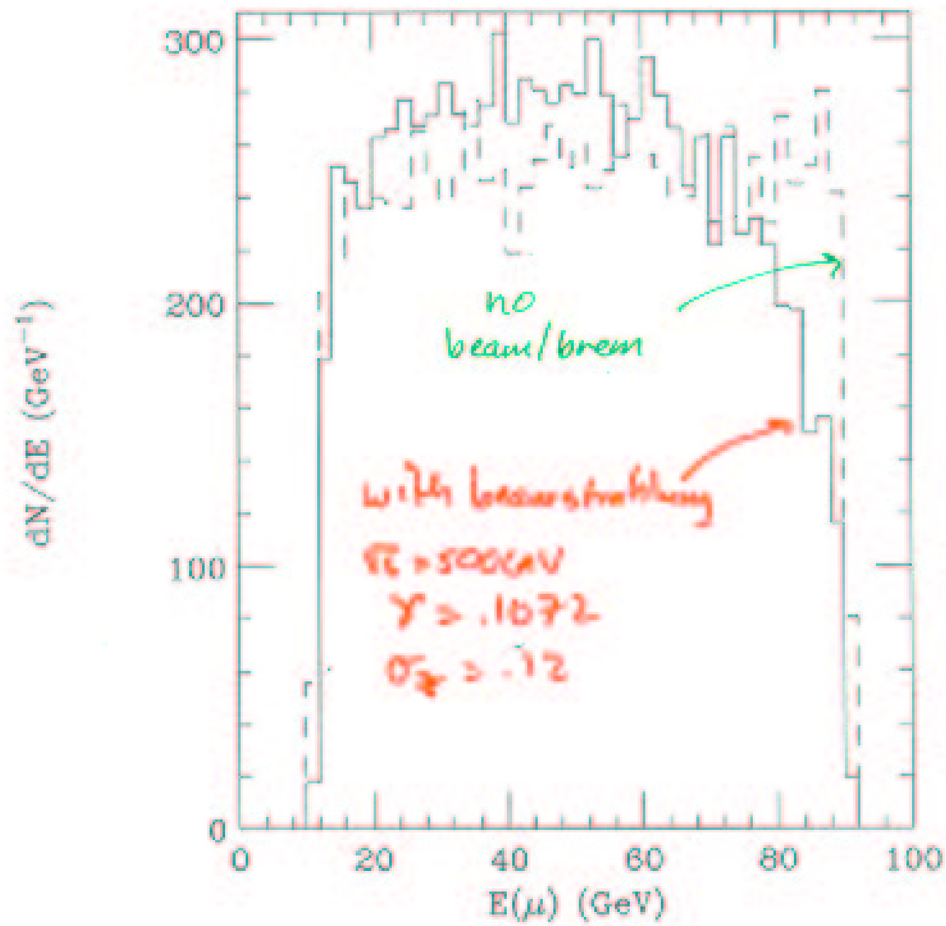
FIG. 6. Cross sections for various SUSY production processes at an e^+e^- collider with $\sqrt{s}$ = 500 GeV versus the electron beam polarization parameter $P_L(e^-)$ for the case study in Sec. III. The solid lines show cross sections for sleptons, the dashed lines for charginos and neutralinos and the dotted lines for Higgs boson production mechanisms. The cross sections for Ah and ZH production are below the 1 fb level.

$$P_L(e^-) = \frac{n_L - n_R}{n_L + n_R}$$



Υ=.1072
σz=.12 mm
Eo=250 GeV
convolution
brem
beam
De(x)
xe

ISAJET run



$$e^+e^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^-$$

$\tilde{\mu}_R^- \to \mu \tilde{\chi}_1^0$

$\tilde{\mu}_R^+ \to \mu \tilde{\chi}_1^0$

Gluino cascade decay possibilities from ISAJET

Abdullin
Charles
CMS

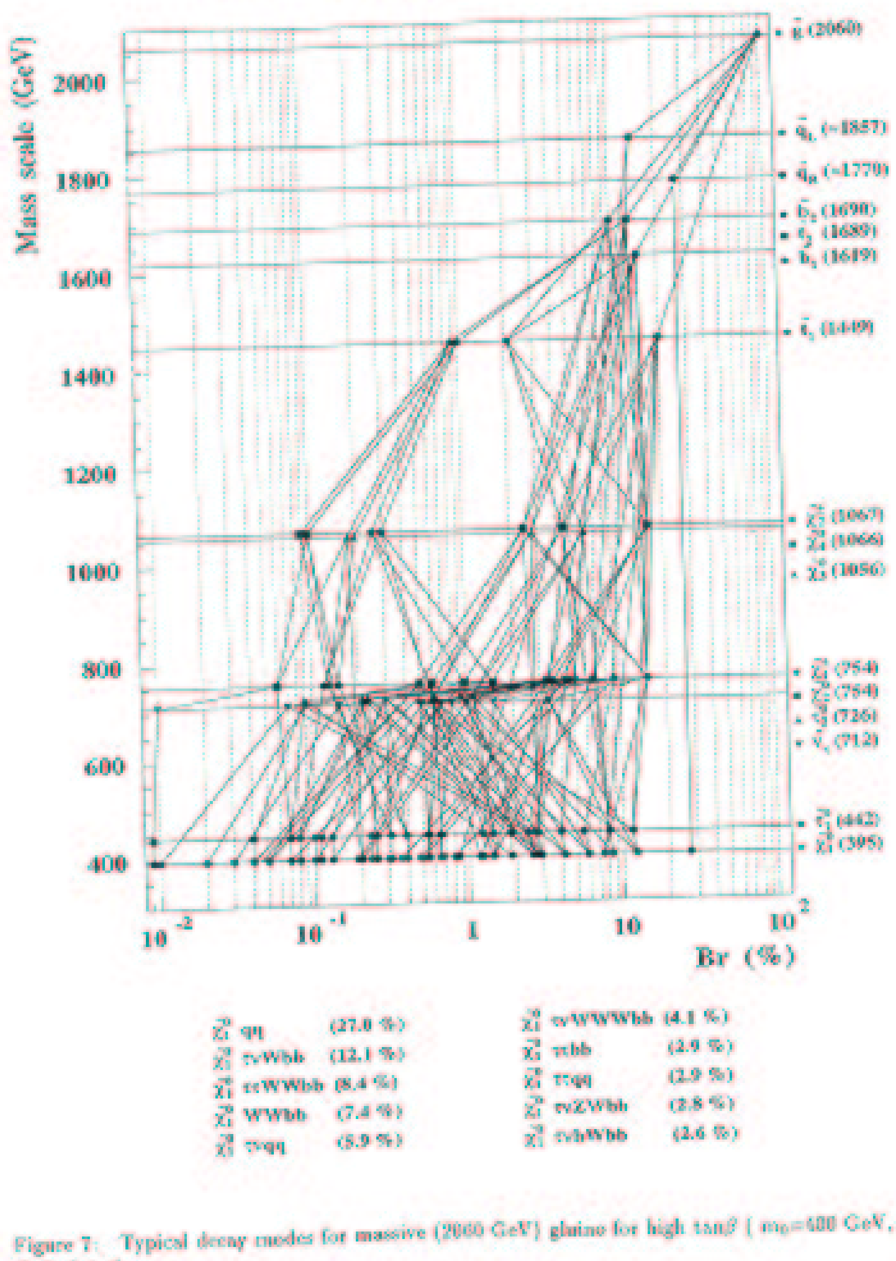
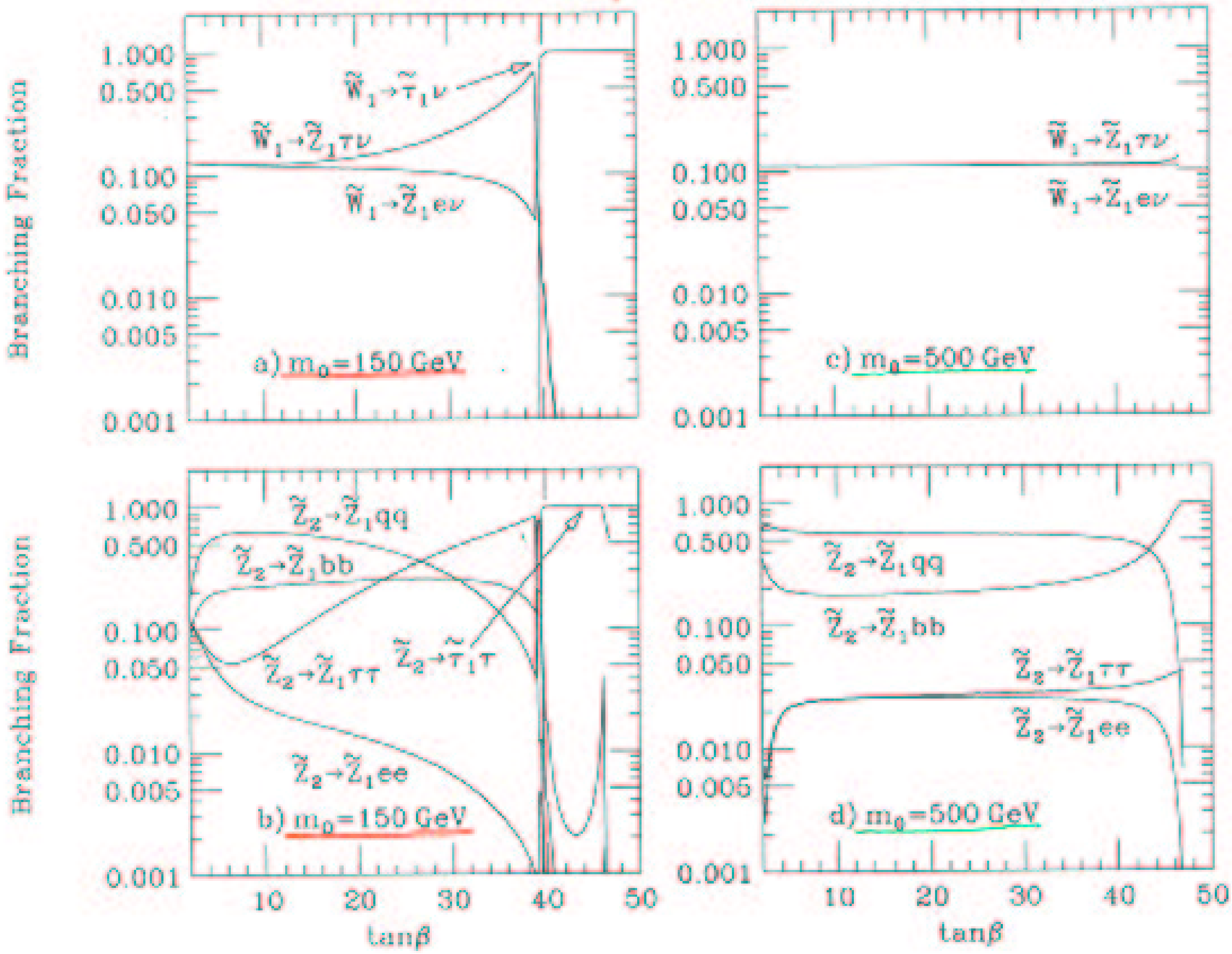


Figure 7: Typical decay modes for massive (2060 GeV) gluino for high $\tan\beta$ (m_0=400 GeV, $m_{1/2}$=900 GeV, Set 4).

Variation of branching fractions with $\tan\beta$

HB
C.H. Chen
M. Drees
F. Paige
X. Tata



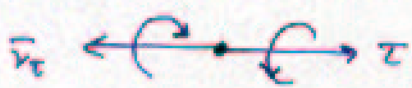
τ-polarization in ISAJET:

- ISAJET uses V–A matrix elements for heavy flavor decays
- Also, matrix elements for various τ-decay modes:

  $\tau \to \nu_\tau e \nu_e$, $\tau \to \pi \nu_\tau$, $K \nu_\tau$, $\rho \nu_\tau$, ...

- τ's from $W^- \to \tau \bar{\nu}_\tau$ have $P_\tau = \dfrac{\Gamma_{\tau_R} - \Gamma_{\tau_L}}{\Gamma_{\tau_R} + \Gamma_{\tau_L}} = -1$

- τ's from $H^- \to \tau \bar{\nu}_\tau$ have $P_\tau = +1$



e.g. $\tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tau \bar{\nu}_\tau$

$$\Gamma_{\tau_L} = \Gamma_W + \Gamma_{\tilde{\nu}}^L + \Gamma_{\tilde{\tau}}^L + \Gamma_{W\tilde{\nu}} + \Gamma_{W\tilde{\tau}} + \Gamma_{\tilde{\nu}\tilde{\tau}}^L$$

$$\Gamma_{\tau_R} = \Gamma_{\tilde{\nu}}^R + \Gamma_{\tilde{\tau}}^R + \Gamma_H + \Gamma_{\tilde{\nu}\tilde{\tau}}^R + \Gamma_{\tilde{\nu}H} + \Gamma_{\tilde{\tau}H}$$

Also $H \to \tau \bar{\tau}$; $P_\tau = 0$ (ave)

$\tilde{\tau}_{1,2} \to \tilde{\chi}_1^0 \tau$

$\tilde{\chi}_i^0 \to \tau \tilde{\tau}_1$

$\tilde{\chi}_2^0 \to \tau \bar{\tau} \tilde{\chi}_1^0$ (P_τ ave)

$\tilde{\chi}_i^\pm \to \tau \tilde{\nu}_\tau$

Decay matrix elements for sparticles for event generation using ISAJET 7.43:

exchange graphs:

- $\tilde{g} \to Q\bar{Q}\tilde{\chi}_i^0$ — $\tilde{Q}_1, \tilde{Q}_2, \bar{\tilde{Q}}_1, \bar{\tilde{Q}}_2$
- $\tilde{g} \to q\bar{Q}\tilde{\chi}_i^\pm$ — $\tilde{q}_1, \tilde{q}_2, \bar{\tilde{q}}_1, \bar{\tilde{q}}_2$
- $\tilde{\chi}_i^0 \to f\bar{f}\tilde{\chi}_j^0$ — $\tilde{f}_1, \tilde{f}_2, \bar{\tilde{f}}_1, \bar{\tilde{f}}_2, Z, h, A, H$
- $\tilde{\chi}_i^\pm \to f\bar{f}'\tilde{\chi}_j^0$ — $\tilde{f}_1, \tilde{f}_2, \tilde{f}'_L, W, H^\pm$

- Previously, ISAJET used phase space for event generation, but exact results for B.F.'s.
  - PYTHIA uses phase space
  - SUSYGEN uses approximate MEs valid for low $\tan\beta$
  - Recent article by Nojiri/Yamada

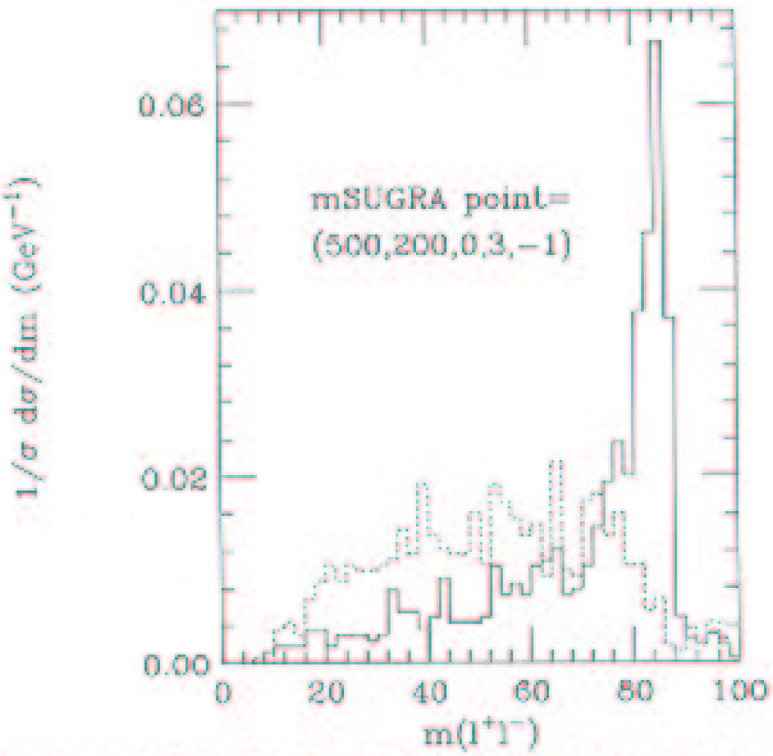


FIG. 11. The same as Fig. 9 except for case C where the model parameters are as listed.

Here, $\tilde{Z}_2 \to \tilde{Z}_1 l\bar{l}$ is dominated by Z-pole, so phase space is really bad approximation.

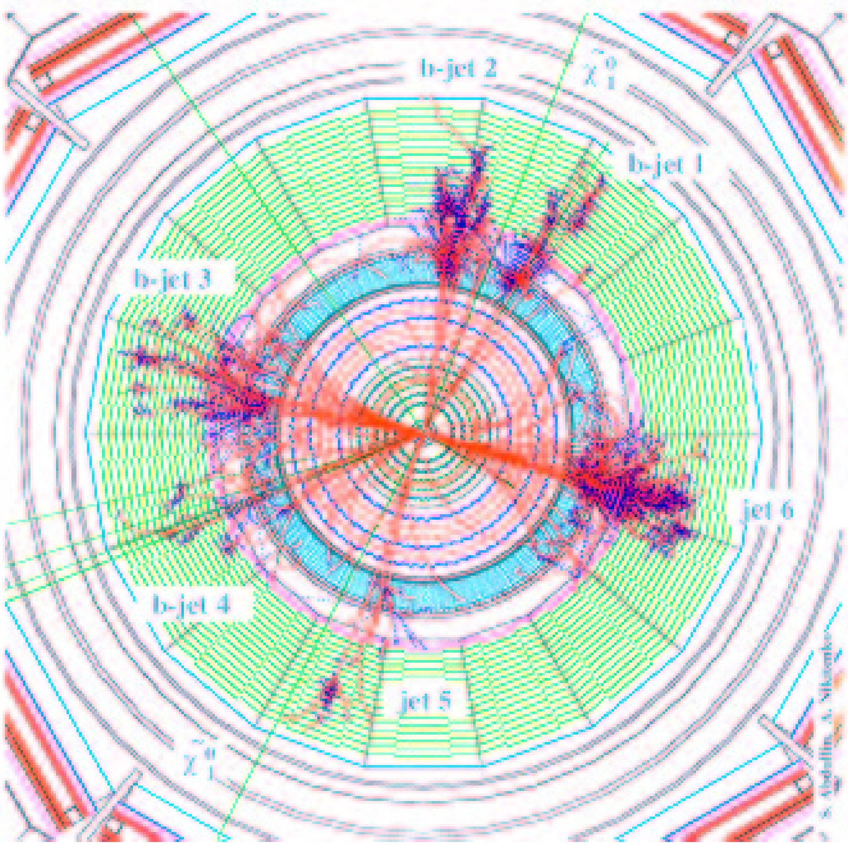
GEANT figure

mSUGRA : $m_0 = 1000$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$, $\tan\beta = 35$, $\mu > 0$

$\tilde{g} \to \tilde{t}_1 \bar{t}$
- $\bar{t} \to W^- + \bar{b}$ (jet4, E_T = 113 GeV)
  - $W^- \to s$ (jet6, E_T = 79 GeV) $+ \bar{c}$
- $\tilde{t}_1 \to \tilde{\chi}_2^{\pm} + b$ (jet3, E_T = 536 GeV)
  - $\tilde{\chi}_2^{\pm} \to \tilde{\chi}_1^{\pm} + Z \to \nu\bar{\nu}$
    - $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + W^+ \to \tau^+ \nu$
      - $\tau^+ \to e^+ \nu$

$\tilde{u}_L \to \tilde{\chi}_2^0 + u$ (jet5, E_T = 1186 GeV)
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + h$
  - $h \to b$ (jet1, E_T = 286 GeV)
  - $h \to \bar{b}$ (jet2, E_T = 328 GeV)

$E_T^{miss} = 380$ GeV



$m_{\tilde{g}} = 1266$ GeV

$m_{\tilde{u}_L} = 1450$ GeV

$m_{\tilde{t}_1} = 1026$ GeV

$m_{\tilde{\chi}_2^0} = 410$ GeV

$m_{\tilde{\chi}_1^0} = 214$ GeV

$m_h = 119$ GeV

Summary: SUSY in ISAJET

Models:
- MSSM
- SUGRA
  - minimal
  - large $\tan\beta$
  - 2 loop evolution
  - Yukawa loop corr'ns
  - non-universal
  - RHN
- GMSB
  - minimal
  - extended
- AMSB
- inoMSB (possible, not hard-wired)

Production:
- all SUSY/Higgs $2\to1$, $2\to2$
- e^+e^-: beam pol; beam/bremsstrahlung

Decays:
- all major modes
- valid large $\tan\beta$
- τ polarization
- decay ME's

Lacking:
- $\not{C}\not{P}$ phases
- non-simple $\not{R}$
- spin-correlations
- $2\to3$ Higgs ($Ab\bar{b}$, $Ht\bar{t}$, $ht\bar{t}$)