NON-MINIMAL SUPERSYMMETRY

J. F Gunion, SUSY99 (June 14 – June 19, 1999)

OUTLINE

- How big is the SUSY universe?
  - R-parity violating superpotential terms.
  - Soft–SUSY-breaking options.
  - Extra matter.
- RPV possibilities
  - Purely leptonic
  - Mixed hadronic/leptonic
  - Baryonic
- Soft–SUSY–Breaking Options: Motivations and Constraints
  - String-motivated possibilities.
  - Theoretical/experimental hints in favor of small M_3.
  - Heavy 1st and 2nd generation squarks/sleptons (not covered).
  - Extra $U(1)$'s (not covered).
  - R-parity violating soft SUSY
- Phenomenology of some unusual (possibly difficult) cases.
  - Wino-like $\widetilde\chi^0_1$ highly degenerate with $\widetilde\chi^\pm_1$, with $\tilde g$ heavier
  - Same, but with $\tilde g$-LSP
  - RP-conserving and RP-violating versions of above.

– Both light gravitino and heavy gravitino cases.

– Emphasis on implications for collider phenomenology.

- Extra Matter

  – 'Typical String Model'

  – 4th Generation?

  – Extra Higgs bosons

Some of this material was developed in the context of the RunII SUSY/Higgs workshop, BTMSSM working group. Thanks to all participants.

I am not able to cover all the many studies performed.

$\Rightarrow$ see the BTMSSM report.

- How many parameters are there? (JFG + Haber) Introducing $\widehat{L}_\alpha$ ($\alpha = 0, 1, 2, 3$), where $\widehat{L}_0 \equiv \widehat{H}_d$, the full superpotential including RPV is:

$$W = \epsilon_{ij}\Big[-\mu_\alpha \widehat{L}^i_\alpha \widehat{H}^j_u + \tfrac{1}{2}\lambda_{\alpha\beta m}\widehat{L}^i_\alpha \widehat{L}^j_\beta \widehat{E}_m + \lambda'_{\alpha nm}\widehat{L}^i_\alpha \widehat{Q}^j_n \widehat{D}_m - (y_u)_{nm}\widehat{H}^i_u \widehat{Q}^j_n \hat{U}_m\Big] + (\lambda_B)_{pnm}\widehat{U}_p \widehat{D}_n \widehat{D}_m\,, \qquad (1.1)$$

where $\lambda_{\alpha\beta m} = -\lambda_{\beta\alpha m}$ while $(\lambda_B)_{pnm} = -(\lambda_B)_{pmn}$ (due to an implicit antisymmetric contraction of the color indices). In Eq. (1.1), $\alpha, \beta, \ldots = 0, 1, 2, 3$, $i, j, k, \ldots = 1, 2, 3$, p, n, m are family indices.

The soft SUSY breaking terms, including RPV, are:

$$\begin{aligned} V_{\rm soft} &= (m^2_Q)_{mn}\, \widetilde{Q}^{i*}_m \widetilde{Q}^i_n + (m^2_{\overline{u}})_{mn}\, \widetilde{U}^*_m \widetilde{U}_n + (m^2_{\overline{d}})_{mn}\, \widetilde{D}^*_m \widetilde{D}_n \\ &+ (m^2_L)_{\alpha\beta}\, \widetilde{L}^{i*}_\alpha \widetilde{L}^i_\beta + (m^2_{\overline{e}})_{mn}\, \widetilde{E}^*_m \widetilde{E}_n + m^2_{H_u}|H_u|^2 - (\epsilon_{ij} b_\alpha \tilde{L}^i_\alpha H^j_u + \text{h.c.}) \\ &+ \epsilon_{ij}\Big[\tfrac{1}{2}a_{\alpha\beta m}\widetilde{L}^i_\alpha \widetilde{L}^j_\beta \widetilde{E}_m + a'_{\alpha nm}\widetilde{L}^i_\alpha \widetilde{Q}^j_n \widetilde{D}_m - (a_u)_{nm} H^i_u \widetilde{Q}^j_n \widetilde{U}_m + \text{h.c.}\Big] \\ &+ (a_B)_{pnm}\widetilde{U}_p \widetilde{D}_n \widetilde{D}_m + \tfrac{1}{2}\Big[M_3\, \tilde{g}\, \tilde{g} + M_2 \widetilde{W}^a \widetilde{W}^a + M_1 \widetilde{B}\widetilde{B} + \text{h.c.}\Big]\,, \end{aligned} \qquad (1.2)$$

where $a_{\alpha\beta m} = -a_{\beta\alpha m}$ and $(a_B)_{pnm} = -(a_B)_{pmn}$. The B term of the MSSM $\Rightarrow$ four-component vector, b_α. The squared-mass term for the down-type Higgs boson and the 3×3 lepton scalar squared-mass matrix $\Rightarrow$ 4×4 matrix, and the matrix A-parameters of the MSSM are extended in the obvious manner.

- But, actually we are not done! (Jack and Jones) Normally neglected (since $1/M_{\rm Planck}$ in SUGRA models) are the soft terms (soft so long as no singlets as in MSSM):

Table 1: Parameter Count in the SM and MSSM Extensions: BV=baryon-number violating; LV=lepton-number violating; BLV=both B and L violating.

model	masses and mixing angles	CP-violating phases	TOTAL
Standard Model	17	2	19
MSSM	79	45	124
$(\mathrm{MSSM})_{\mathrm{BV}}$	97	62	159
$(\mathrm{MSSM})_{\mathrm{LV}}$	157	122	279
$(\mathrm{MSSM})_{\mathrm{BLV}}$	175	140	315

$$\begin{aligned}\epsilon_{ij}\Big[&M_\alpha \psi_{L^i_\alpha}\psi_{H^j_u} + \hat{a}_{mn}(H^i_u)^* \widetilde{L}^j_m \widetilde{E}_n \\ &+\hat{a}'_{nm}(H^i_u)^* \widetilde{Q}^j_n \widetilde{D}_m + (\hat{a}')_{\alpha nm}(\widetilde{L}^i_\alpha)^* \widetilde{Q}^j_n \widetilde{U}_m + \text{h.c.}\Big]\end{aligned} \tag{1.3}$$

- Of course, most of the parameter space is excluded due to constraints from EDM's, absence of FCNC's, *etc.*
- If there is R-parity violation, much experimental input will be required to get a handle on all these parameters.
- The above parameter count is only for MSSM particle content. If we add in extra matter fields and/or gauge fields, *e.g.* as in left-right symmetric models, the SUSY universe expands very dramatically.
- The big question: how to probe and maintain full sensitivity to all non-excluded parameter choices.

- Final parameter is $\sqrt{F}$, the scale of SUSY breaking.
  -
$$m_G = \frac{F}{\sqrt{3}M_{\rm Planck}} \sim 2.5\left(\frac{\sqrt{F}}{100~\rm TeV}\right)^2~\rm eV$$
  - In usual mSUGRA model, $\sqrt{F} \sim 10^{10}$ GeV and m_G is $\sim$ TeV. G is irrelevant
  - In GMSB, G = LSP.
  - $m_G \lesssim 1$ keV (or very big) required to avoid overclosing universe. $\Rightarrow \sqrt{F} \lesssim 2000$ TeV.
  - 3–sector models (SUSY-breaking, Messenger, Normal — all communicating by gauge interactions) $\Rightarrow \sqrt{F} \gtrsim 2000$ TeV.
  - For $\sqrt{F} \lesssim 2000$ TeV, superparticle decays to G are suppressed so that all except the NLSP decay as usual, but decay to G can be delayed.
  - The $c\tau$ for NLSP decay depends on $\sqrt{F}$; *e.g.* for $N_m = 1$
$$(c\tau)_{\tilde{\chi}_1^0=\tilde{B}\to\gamma G} \sim 130\left(\frac{100~\rm GeV}{m_{\tilde{B}}}\right)^5\left(\frac{\sqrt{F}}{100~\rm TeV}\right)^4 \mu{\rm m} \qquad (1.4)$$
    γ impact parameters very interesting (see, e.g., JFG+Chen Tevatron study, not covered here); maybe a roof-array.
  - If $\sqrt{F} \sim 2000$ TeV (the upper limit from cosmology), then $c\tau \sim$ 21m for $m_{\tilde{B}} = 100$ GeV;
  - $\sqrt{F} \sim 100$ TeV implies a short but vertexable decay length.
  - Thus, the signatures for GMSB models are crucially dependent on $\sqrt{F}$.

- An important note:

  Very weak RPV coupling or very long lifetime for NLSP in GMSB scenario and/or anomalous reheating in early universe

  $\Rightarrow$ any of the normal superpartners ($\widetilde{\chi}_1^0$, $\tilde{\tau}$, $\tilde{g}$, $\ldots$) could be effectively the LSP as far as collider physics in normal sized detector is concerned.

  $\Rightarrow$ as parameters are adjusted to decrease $c\tau$, can get long-lived $\widetilde{\chi}_1^0$, $\tilde{\tau}$, $\tilde{g}$, $\ldots$ decaying non-promptly inside detector.

  $\Rightarrow$ a huge array of possible SUSY signatures.

2 GUIDANCE? FROM STRING/BRANE THEORY

Talks by Ibanez and Cvetic $\Rightarrow$ it will take a miracle for the model to be mSUGRA-like.

- Gauge unification could be an accident.
- Green-Schwarz contributions to boundary conditions generally needed to cancel anomalies.
- String scale could be low.
- Neither gaugino masses nor scalar masses are generally universal, unless SUSY-breaking is dilaton dominated.
- R-parity violation often emerges.
- Extra matter is not at all unlikely.

$\Rightarrow$ Try to explore phenomenology of models that are generic but relatively simple, and yet lead to very different (difficult) experimental searches.

2.1 One-loop / Modulus-dominated Boundary Conditions

This will illustrate some very important new types of experimental analyses that might be crucial to SUSY discovery.

- If the dilaton F component does not acquire a large vev, (natural in many models), then the M_i will arise at one-loop.

  $$M_i = \text{constant} \times b_i m_{3/2}\,, \tag{2.1}$$

  where b_i is the beta function coefficient.

First noted in modulus-dominated limit of O-II model (orbifold with all $n_i = -1$, *i.e.* all states untwisted) of Ibanez etal.

Ibanez talk makes clear this is just the simplest version of a much larger class of models.

- Including universal (the simplest case) Green-Schwarz mixing (δ_{GS}) $\Rightarrow$ (at M_S)

$$\begin{aligned} M_3^0 &= \sqrt{3} m_{3/2} [\sin\theta - (3+\delta_{GS}) K \cos\theta] \\ M_2^0 &= \sqrt{3} m_{3/2} [\sin\theta - (-1+\delta_{GS}) K \cos\theta] \\ M_1^0 &= \sqrt{3} m_{3/2} [\sin\theta - (-33/5+\delta_{GS}) K \cos\theta]\,, \end{aligned} \tag{2.2}$$

with $K = 4.6 \times 10^{-4}$ and $-5 \leq \delta_{GS} \leq 1$ preferred.

Modulus-dominated SU$\not{S}$Y $\rightarrow \sin\theta \rightarrow 0$ and $\cos\theta \rightarrow \pm 1$.

- For scalar masses and A parameters one has

$$\begin{aligned} m_0^2 &= m_{3/2}^2 [\sin^2\theta - \delta_{GS} K'] \\ A_0 &= -\sqrt{3} m_{3/2} \sin\theta + 1 - loop \end{aligned} \tag{2.3}$$

with $K' \sim 10^{-3}$.

For $\sin\theta \rightarrow 0$, $A_0 \rightarrow$small and $m_0 \gg M_i^0$ unless $\delta_{GS} = 0$.

- With usual RGE EWSB, leaving B and m_0 free, the parameters are:

$$m_0\,, \quad \delta_{GS}\,, \quad \tan\beta\,, \quad \mathrm{sign}(\mu)\,. \tag{2.4}$$

$\delta_{GS} = -4$: After evolving and including the pole correction, $m_{\tilde{g}}$ is only slightly larger than $m_{\tilde{\chi}_1^0}$.

	M_U			m_Z		
	M_3	M_2	M_1	M_3	M_2	M_1
$O-II$ $\delta_{GS}=0$	3	1	$\frac{33}{5}$	~ 3	$\sim .3$	1
$O-II$ $\delta_{GS}=-4$	1	5	$\frac{53}{5}$	~ 0.6	~ 1	$\sim \frac{53}{50}$

Table 2: Relative gaugino masses at M_U and m_Z for in the O-II model with $\delta_{GS}=0$ or -4.

$\delta_{GS} = -3$: Very small $m_{\tilde g}$ relative to other gaugino masses (Note: $\tilde g$-LSP also turns up in a certain class of GMSB models (Raby, Raby+Tobe))

$\delta_{GS}=0$: $m_{\tilde g} \gg m_{\widetilde\chi_1^\pm} \simeq m_{\widetilde\chi_1^0}$

- Related approach based on conformal anomaly (Giudice *et al.*, Randall and Sundrum): $\Rightarrow$ (to all orders in perturbation theory)

$$M_i = \frac{\beta_i(g_i^2)}{2g_i^2} m_{3/2}\,. \tag{2.5}$$

Going to low energy scales this translates into

$$M_1 = \frac{11\alpha}{4\pi\cos^2\theta_W} m_{3/2} = 8.9\times 10^{-3} m_{3/2}\,, \tag{2.6}$$

$$M_2 = \frac{\alpha}{4\pi\sin^2\theta_W} m_{3/2} = 2.7\times 10^{-3} m_{3/2}\,, \tag{2.7}$$

$$M_3 = -\frac{3\alpha_s}{4\pi} m_{3/2} = -2.6\times 10^{-2} m_{3/2}\,, \tag{2.8}$$

as consistent with the evolved result of Eq. (2.2) when $\delta_{GS}=0$.

- Other crucial features:
  - $\Delta m_{\widetilde\chi} \equiv m_{\widetilde\chi_1^\pm} - m_{\widetilde\chi_1^0}$ is very small.
  - Both $\widetilde\chi_1^\pm$ and $\widetilde\chi_1^0$ are nearly pure wino: $|N_{\widetilde\chi_1^0 1}| \lesssim 0.1$ typical ($|\mu| \gg M_{1,2}$ is typical).

– As a function of δ_{GS}:

* pure conformal anomaly or $\delta_{GS} = 0 \Rightarrow$ (at 1 TeV) $m_{\tilde{g}} \gg m_{\tilde{\chi}_1^\pm} \simeq m_{\tilde{\chi}_1^0}$, $\Delta m_{\tilde{\chi}} \sim m_\pi$ (which comes almost all from radiative corrections), light sleptons.
* $\delta_{GS} = -4, -5 \Rightarrow m_{\tilde{g}} \gtrsim m_{\tilde{\chi}_1^\pm}$, $\Delta m_{\tilde{\chi}} \sim 1 - 2$ GeV, heavy sleptons (and squarks).
* $\delta_{GS} = -3 \Rightarrow m_{\tilde{g}} < m_{\tilde{\chi}_1^\pm}$, heavy sleptons, squarks, $\Delta m_{\tilde{\chi}} \sim 200 - 600$ MeV.

Each case implies very different phenomenology.

Extra sources of scalar masses, etc. can destroy above parameter connections. e.g. for conformal/$\delta_{GS} = 0$ case, ??$\Rightarrow$ scalar masses.

$\Rightarrow$ We will not assume above correlations; rather always focus on looking for the lightest sparticle as a function of $\Delta m_{\tilde{\chi}}$.

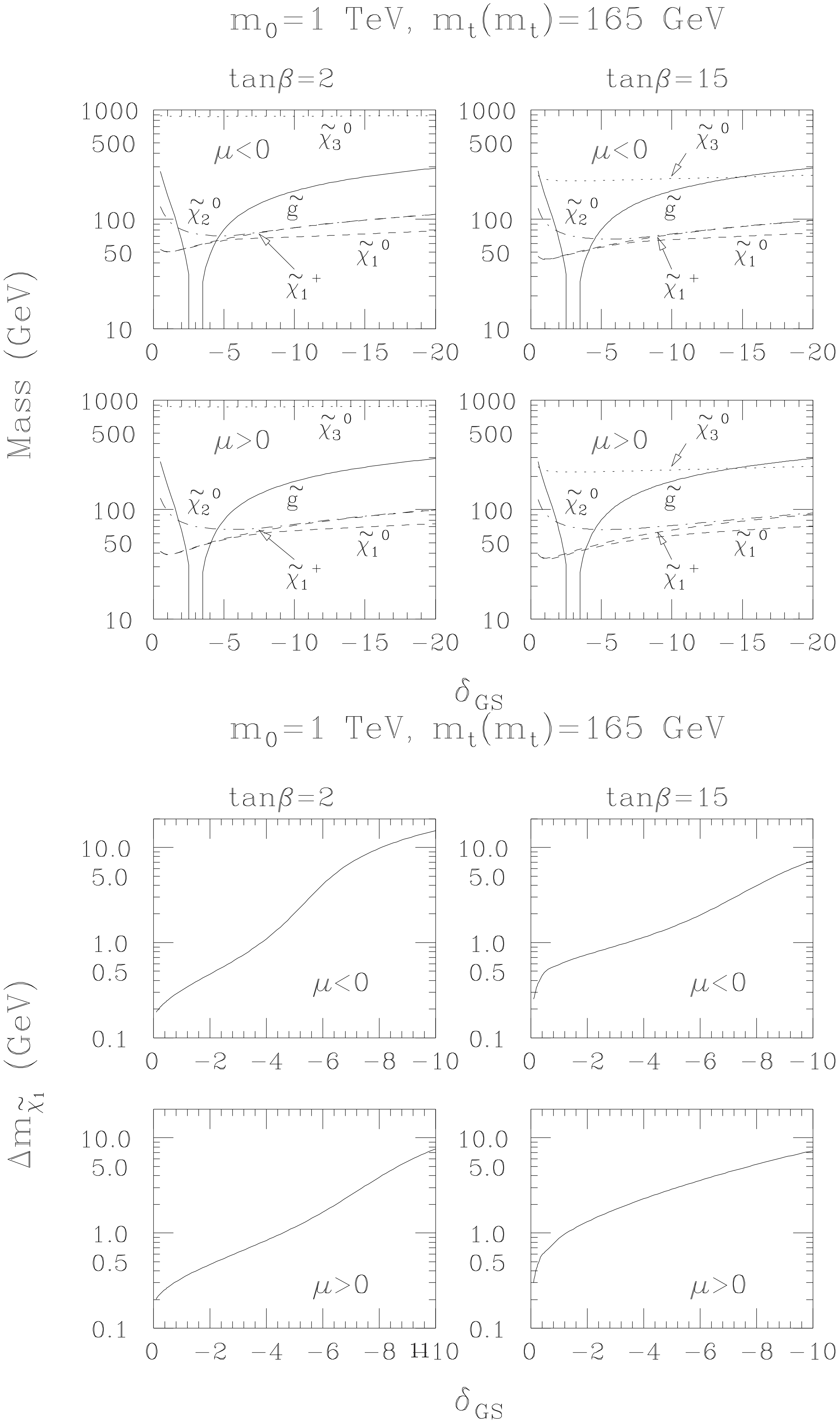

Figure 1: Gaugino masses and $\Delta m_{\tilde{\chi}}$ as a function of δ_{GS} for $\tan\beta = 2$ and 15 for $\mu < 0$ and $\mu > 0$. From Chen,Drees,JFG.

2.2 Hints in favor of small $m_{\tilde{g}}$.

There are three hints.

- Gauge Coupling Unification

  α_i unification at $M_U \sim 10^{16}$ GeV $\Rightarrow \alpha_s(m_Z) \sim 0.125 - 0.13$ vs. experimental $\alpha_s(m_Z) \lesssim 0.12$.

  $\alpha_s(m_Z) \lesssim 0.12$ can be achieved (Roszkowski and Shifman) if $m_{\tilde{g}} \lesssim m_{\tilde{\chi}_1^\pm}$

- Fine Tuning

  It is known that small M_3^0 helps.

  Example (Kane and King): $\tan\beta = 2.5 \Rightarrow$ fine tuning measure (denoting with hats $M_i(M_U)/m_Z$ and $m_i(M_U)/m_Z$)

$$\begin{aligned}\Delta_\mu \sim\ & 23.8\widehat{M}_3^2 - 1.3\widehat{M}_2^2 + 0.01\widehat{M}_1^2 \\ & + 1.66\widehat{M}_2\widehat{M}_3 + 0.206\widehat{M}_1\widehat{M}_3 + 0.045\widehat{M}_1\widehat{M}_2 \\ & - 4.7\widehat{m}_{H_2}^2 + 0.2\widehat{m}_{H_1}^2 + 3.17(\widehat{m}_Q^2 + \widehat{m}_U^2)\,, \end{aligned} \tag{2.9}$$

  $\Rightarrow$ small $M_3 \ll M_{1,2}$ makes Δ_μ small.

- Vacuum Stability

  Big danger is that potential is unbounded from below (UFB) (Casas, Ibarra, Munoz).

  Worst=UFB-3 direction involving fields $H_2, \nu_{L_i}, e_{L_j}, e_{R_j}$ with $i \neq j$.

  After minimizing V_{eff}, all fields can be expressed in terms of H_2. $\Rightarrow$ want $m_{H_2}^2$ to not be too negative and $m_{\tilde{e},\tilde{L}_e}^2$ as large as possible.

  Small $m_{\tilde{t}} \Rightarrow$ less negative $m_{H_2}^2$ after evolving down from M_U.

Evolution down from M_U with smaller $M_3 \Rightarrow$ smaller $m_{\tilde{t}}$ on average. Thus, small M_3^0 helps.

Meanwhile, RGE $\Rightarrow$ larger $m^2_{\tilde{e}}$ and $m^2_{\tilde{L}}$ for larger $M_{1,2}$.

Note: universal $M_i(M_U)$ and universal $m_i(M_U)$ in ratio predicted by dilaton dominated SUSY breaking is more or less excluded by this difficulty.

Net result:

$\Rightarrow$ O-II bc with $\delta_{GS} \sim -3, -4, -5$ are good.

3 FOUR CHALLENGING SCENARIOS FOR $m_{\widetilde\chi_1^\pm} \simeq m_{\widetilde\chi_1^0}$

These will all assume that the G is heavy (non-GMSB). Signals change substantially if not.

- $m_{\tilde g} > m_{\widetilde\chi_1^\pm} \simeq m_{\widetilde\chi_1^0}$, no R-parity breaking$\Rightarrow$ JFG+Chen+Drees; more recent JFG+Mrenna; see also Feng etal., Wells etal.

  $\widetilde\chi_1^\pm$ decay products very soft $\Rightarrow$ possible problems:

  – hard to trigger in e^+e^-

  – fewer jets in pp

  – no tri-lepton signal in pp

  – no like-sign di-lepton in pp for $\tilde g\tilde g$

  But, if the $\widetilde\chi_1^\pm$ is long-lived we have some excellent new signals.

  Cosmology: When $\Delta m_{\widetilde\chi}$ is small, $\widetilde\chi_1^\pm$–$\widetilde\chi_1^0$ co-annihilation is large and Ωh^2 is generally very small; dark matter=?

- $m_{\tilde g} < m_{\widetilde\chi_1^\pm} \simeq m_{\widetilde\chi_1^0}$, no R-parity breaking$\Rightarrow$ $\tilde g$-LSP paper by JFG+Baer+Cheung (see also Raby+Tobe).

  Must understand detector response to a heavy, slow, but stable gluino.

  – Longer hadronic path length than light hadron or jet.

  – Much less energy deposit per collision than light hadron.

  – If part of charged bound state, get big ionization deposits.

  Cosmology: High annihilation rate in early universe (see talk by Cheung; earlier work by Mohapatra+Nussinov and by Raby) means $\tilde g$ density can be very small (as needed to have hope of evading anomalous isotope searches etc.), but then dark matter=?

- $m_{\tilde g} > m_{\tilde\chi_1^\pm} \simeq m_{\tilde\chi_1^0}$, with baryonic RPV $\Rightarrow$ JFG+Baer+Cheung.

  $\Rightarrow$ no $\not\!\!E_T$; must look for anomalously large number of jets, with 3-jet masses $\sim m_{\tilde\chi_1^\pm}$; typically some of the jets are c's or b's.

  Cosmology: Everything decays: dark matter=?

- $m_{\tilde g} < m_{\tilde\chi_1^\pm} \simeq m_{\tilde\chi_1^0}$, with baryonic RPV $\Rightarrow$ JFG+Baer+Cheung.

  In practice, very similar to previous case, but 3-jet cluster masses $\sim m_{\tilde g}$.

  Cosmology: Everything decays: dark matter=?

4 THE R-PARITY CONSERVING $\widetilde{\chi}_1^0$-LSP SCENARIO WHEN $M_2 < M_1$. (Chen, Drees, Gunion papers, JFG+Mrenna — see also, Feng etal, Wells etal.)

4.1 General Features

- Extreme degeneracy for the $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^\pm$, $\Delta m_{\widetilde{\chi}} \equiv m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0} < 1$ GeV, is the norm. $\Rightarrow$

  For $m_\pi < \Delta m_{\widetilde{\chi}} < 1$ GeV $\Rightarrow$ 100 cm $> c\tau >$ 100 μm + single π.

  For $\Delta m_{\widetilde{\chi}} < m_\pi$ (hard after one-loop corrections) we get many meters.

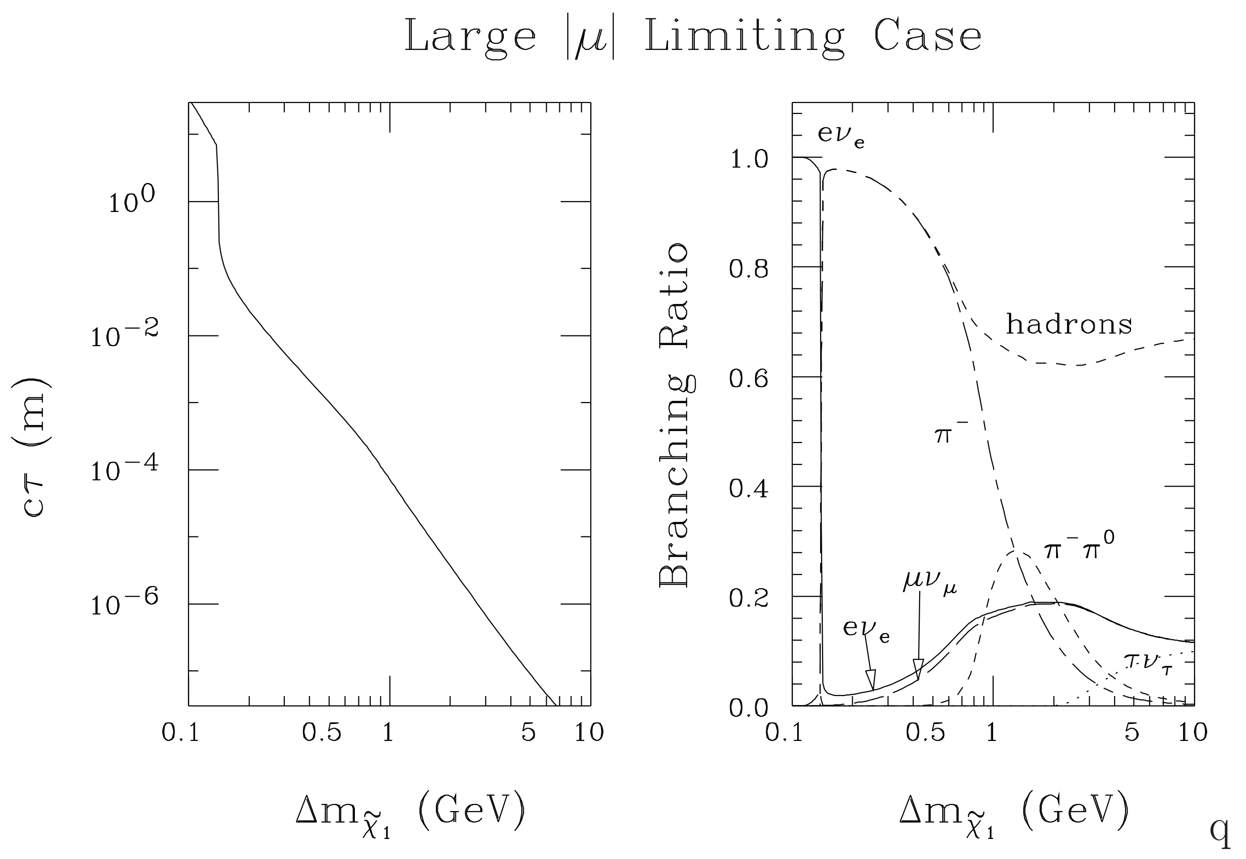

Figure 2: Lifetime and branching ratios for the $\widetilde{\chi}_1^\pm$ as a function of $\Delta m_{\widetilde{\chi}}$.

Numerically,

$\Delta m_{\widetilde{\chi}}$(MeV)	125	130	135	138	140	142.5	150
$c\tau$(cm)	1155	918.4	754.1	671.5	317.2	23.97	10.89
$\Delta m_{\widetilde{\chi}}$(MeV)	160	180	185	200	250	300	500
$c\tau$(cm)	6.865	3.719	3.291	2.381	1.042	0.5561	0.1023

Table 3: Summary of $c\tau$ values as a function of $\Delta m_{\widetilde{\chi}}$ as employed in Monte Carlo simulations.

- Gluinos could be either close in mass to the $\widetilde{\chi}_1^0$ or much heavier (as preferred if δ_{GS} is small).
- Contrary to Randal etal, once δ_{GS} is introduced all squarks, sleptons are heavy. Giudice etal have additional scalar mass source.
- $|\mu|$ is probably large for correct EWSB $\Rightarrow$ Higgsino $\widetilde{\chi}_2^\pm$, $\widetilde{\chi}_3^0$ and $\widetilde{\chi}_4^0$ are heavy.

4.2 Implications for SUSY searches

e^+e^- colliders

Best illustrated by DELPHI LEP2 analysis.

- $\Delta m_{\widetilde{\chi}} < 200$ MeV: $m_{\widetilde{\chi}_1^\pm} < 90$ GeV excluded by searching for long heavily ionizing tracks.
- 200 MeV $< \Delta m_{\widetilde{\chi}} < 300 - 500$ MeV: $m_{\widetilde{\chi}_1^\pm} < 45$ GeV from Z data, $\gamma\nu\overline{\nu}$ too big to see $\gamma \not{E}_T$ signal for higher $m_{\widetilde{\chi}_1^\pm}$.

  Could the $\gamma Z^* \to \gamma + soft$ etc. backgrounds be cut down by looking for impact parameter of soft (but visible in SVX and tracker) π?

- $300 - 500$ MeV $< \Delta m_{\tilde{\chi}} < 3$ GeV: search for γ-tag + soft π track or (higher $\Delta m_{\tilde{\chi}}$) several tracks excludes $m_{\tilde{\chi}_1^\pm} < 48$ GeV (60 GeV) for $m_{\tilde{\nu}} \sim m_{\tilde{\chi}_1^\pm}$ (large $m_{\tilde{\nu}}$) — no impact b info used.

- 3 GeV $< \Delta m_{\tilde{\chi}}$: normal mSUGRA search techniques exclude $m_{\tilde{\chi}_1^\pm} <$ 90 GeV.

Tevatron

Will give results of JFG+Mrenna; for more, go to talk by Mrenna. Related work by 2 other collaborations was presented on Tuesday by Shu and by Wells.

- Typical detector has:

Component	Description
SVX	Silicon vertex detector from close to beam pipe to $\sim$11 cm.
CT	Central tracker starting just past SVX.
PS	Pre–shower just outside the tracker.
EC	Electromagnetic calorimeter.
HC	Hadronic calorimeter.
TOF	Time–of–flight measurement after HC and just before MC.
MC	Muon chamber with first layer after the HC and just beyond the TOF.

Table 4: Summary of detector components referred to in the text.

- Possible signals for $\tilde{\chi}_1^+\tilde{\chi}_1^- + \tilde{\chi}_1^\pm\tilde{\chi}_1^0$ (only these 2 reactions are not suppressed) are in Table 5.

The already low efficiency for tri-lepton signal is killed by small $\Delta m_{\tilde{\chi}}$ and by suppression of $\sigma(\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0)$

- Mass reach in $m_{\tilde{\chi}_1^{\pm}}$ of different signals: see Table 6.

Signal	Definition
LHIT	Long, heavily–ionizing ($\geq$ 2MIP's as measured by SVX+CT+PS), large–p_T track that reaches the MC. The energy deposit in the HC in the track direction must be consistent with expected ionization energy deposit for the β measured (using TOF and/or SVX+CT+PS), i.e. no hadronic energy deposit.
TOF	A large–p_T track seen in the SVX and CT along with a signal in the TOF delayed by 500 ps or more (vs. a particle with $\beta = 1$). HC energy deposit (in the direction of the track) is required to be consistent with the ionization expected for the measured β (i.e. no hadronic deposit).
DIT	An isolated, large–p_T track in the SVX and CT that fails to reach the MC and deposits energy in the HC no larger than that consistent with ionization energy deposits for the measured (using SVX+CT+PS) β. Heavy ionization in the SVX+CT+PS, corresponding to $\beta < 0.8$ or $\beta < 0.6$ (DIT8 or DIT6), may be required.
KINK	A track that terminates in the CT, turning into a soft, but visible, charged–pion daughter–track at a substantial angle to parent.
STUB	An isolated, large–p_T (as measured using SVX) track that registers in all SVX layers, but does not pass all the way through the CT. Energy deposits in the EC and HC in the direction of the track should be minimal.
SNT	One or more STUB tracks with no additional trigger. Heavy ionization of the STUB in the SVX, corresponding to $\beta < 0.6$ (SNT6), may be required.
SMET	One or more STUB tracks with an $\not\!\!E_T$ > 35 GeV trigger. Heavy ionization of the STUB in the SVX, corresponding to $\beta < 0.6$ (SMET6), may be required.
HIP	A high–impact–parameter ($b \geq 5\sigma_b$) track in the SVX, with large $\not\!\!E_T$ triggering, perhaps in association with a visible KINK in the SVX.
$\gamma + \not\!\!E_T$	Isolated, large–p_T photon and large $\not\!\!E_T$.
monojet+$\not\!\!E_T$	Large–p_T jet and large $\not\!\!E_T$.
mSUGRA–like	jet(s)+$\not\!\!E_T$, tri–leptons, like–sign di–leptons, *etc.*, except that the cross section for the $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$ tri–lepton signal can be suppressed.

Table 5: Summary of signals. MIP refers to a minimally–ionizing–particle such as a $\beta = 1$ muon. For detector component notation, see Table 4.

$\Delta m_{\widetilde{\chi}}$ (MeV)	$c\tau$ (cm)	Run2 signal(s)	Trigger	Crucial measurements and associated detector components	Reach (GeV)
0	∞	TOF	MC	TOF, p_T (SVX+CT)	460
		LHIT	MC	p_T (SVX+CT), dE/dx (SVX+CT+PS)	450
125	1155	TOF	MC	TOF, p_T (SVX+CT)	430
		LHIT	MC	p_T (SVX+CT), dE/dx (SVX+CT+PS)	425
		DIT	CT	p_T (SVX+CT), HC veto	425
		DIT6	CT	same + dE/dx (SVX+CT+PS),	420
135	754	LHIT	MC	p_T (SVX+CT), dE/dx (SVX+CT+PS)	425
		TOF	MC	TOF, p_T (SVX+CT)	420
		DIT	CT	p_T (SVX+CT), HC veto	430
		DIT6	CT	same + dE/dx (SVX+CT+PS)	420
140	317	DIT	CT	p_T (SVX+CT), HC veto	430
		DIT6	CT	same + dE/dx (SVX+CT+PS)	420
142.5	24	SMET	$\not{E}_T$	p_T (SVX), PS+EC+HC veto	345
		SMET6	$\not{E}_T$	same + dE/dx (SVX)	320
150	11	SMET	$\not{E}_T$	p_T (SVX), PS+EC+HC veto	310
		SMET6	$\not{E}_T$	same + dE/dx (SVX)	270
185	3.3	SMET	$\not{E}_T$	p_T (SVX), PS+EC+HC veto	215
		SMET6	$\not{E}_T$	same + dE/dx (SVX)	120
200	2.4	SMET	$\not{E}_T$	p_T (SVX), PS+EC+HC veto	185
250	1.0	SMET	$\not{E}_T$	p_T (SVX), PS+EC+HC veto	125
300	0.56	HIP	$\gamma, \not{E}_T$	b^π (SVX,L0), p_T^γ, $\not{E}_T$, p_T^π (CT), EC,HC veto	95
600	0.055	HIP	$\gamma, \not{E}_T$	b^π (SVX,L00), p_T^γ, $\not{E}_T$, p_T^π (CT), EC,HC veto	75
750−?	~ 0	$\gamma + \not{E}_T$	$\gamma, \not{E}_T$	p_T^γ, $\not{E}_T$	< 60

Table 6: Summary of the best signals at RunII for $\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ and $\widetilde{\chi}_1^\pm\widetilde{\chi}_1^0$ production and important detector components and measurements as a function of $\Delta m_{\widetilde{\chi}}$. Mass reaches quoted are 95% CL for $L = 30$ fb^{-1}. Detector component notation is summarized in Table 4. Signal definitions are summarized in Table 5. The PS, EC, or HC veto requires no preshower, small EC, or small HC energy deposits in a $\Delta R < 0.4$ cone around the $\widetilde{\chi}_1^\pm$ track candidate. p_T (p_T^π) is the p_T of the $\widetilde{\chi}_1^\pm$ ($\pi^\pm$ from $\widetilde{\chi}_1^\pm \to \pi^\pm\widetilde{\chi}_1^0$). b^π is the $\pi^\pm$ impact parameter.

5 THE R-PARITY CONSERVING $\tilde{g}$-LSP SCENARIO (JFG+Baer+Cheung, see also Raby+Tobe)

- Keep in mind that $m_{\tilde{g}}$ is big (not light-gluino scenario).
- Simplest (and most likely) case to think about is when $\tilde{g}$ fragments mainly to $R^0 = \tilde{g}g$ and other neutral states.

  $\Rightarrow$ the $\tilde{g}$ is like bowling ball moving through ping-pong balls, and does not deposit much of its energy

  $\Rightarrow jets + \not{E}_T$ signal
- Opposite extreme is if $\tilde{g} \to R^\pm$ mainly. The most reliable searches are for heavily–ionizing stable track.

Define $1 - P$ (P) as probability of $\tilde{g} \to R^0$ ($\tilde{g} \to R^\pm$).
Apply P at each hadronic collision of the $\tilde{g}$ as it moves through the detector.

Bottom lines:

- $3 \lesssim m_{\tilde{g}} \lesssim 130-150$ GeV is excluded by combining LEP and Tevatron RunI data, except for possible hole $m_{\tilde{g}} \in [25\text{ GeV}, 50\text{ GeV}]$ for $P \sim 1$, which can easily be filled by reanalysis by CDF of their heavily-ionizing track data.
- RunII can extend excluded domain, but no further gain from Tev33 unless $S/B < 10\%$ can be trusted.
- If the G is light (GMSB-like), then $\tilde{g} \to gG$ and jets+$\not{E}_T$ signal is very strong. LEP + RunI currently excludes $m_{\tilde{g}} < 240$ GeV.

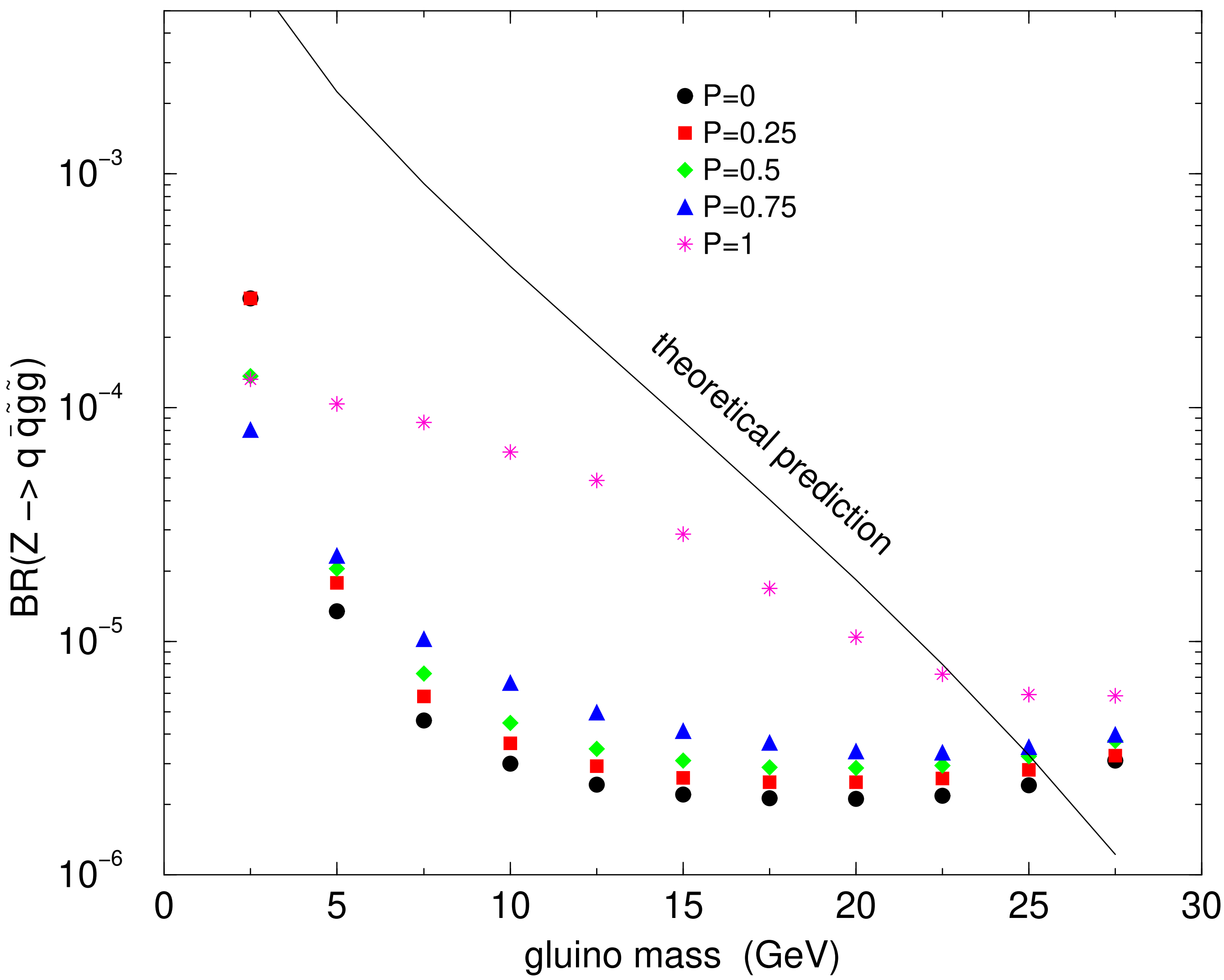

Figure 3: We consider $q\bar{q}\tilde{g}\tilde{g}$ for $P = 0, 1/4, 1/2, 3/4, 1$ using event-by-event determination of the measured $\tilde{g}$ jet energies. For $P \neq 0, 1$, changes of the R-hadron charge as it passes through the detector are randomly implemented. Both smearing and fragmentation effects are included. The figure gives, as a function of $m_{\tilde{g}}$, the OPAL 95% CL upper limits compared to the theoretical prediction for $B(Z \to q\bar{q}\tilde{g}\tilde{g})$. Results are for $\lambda_T = 19$ cm and a middle-of-the-road model for $\langle \Delta E \rangle$.

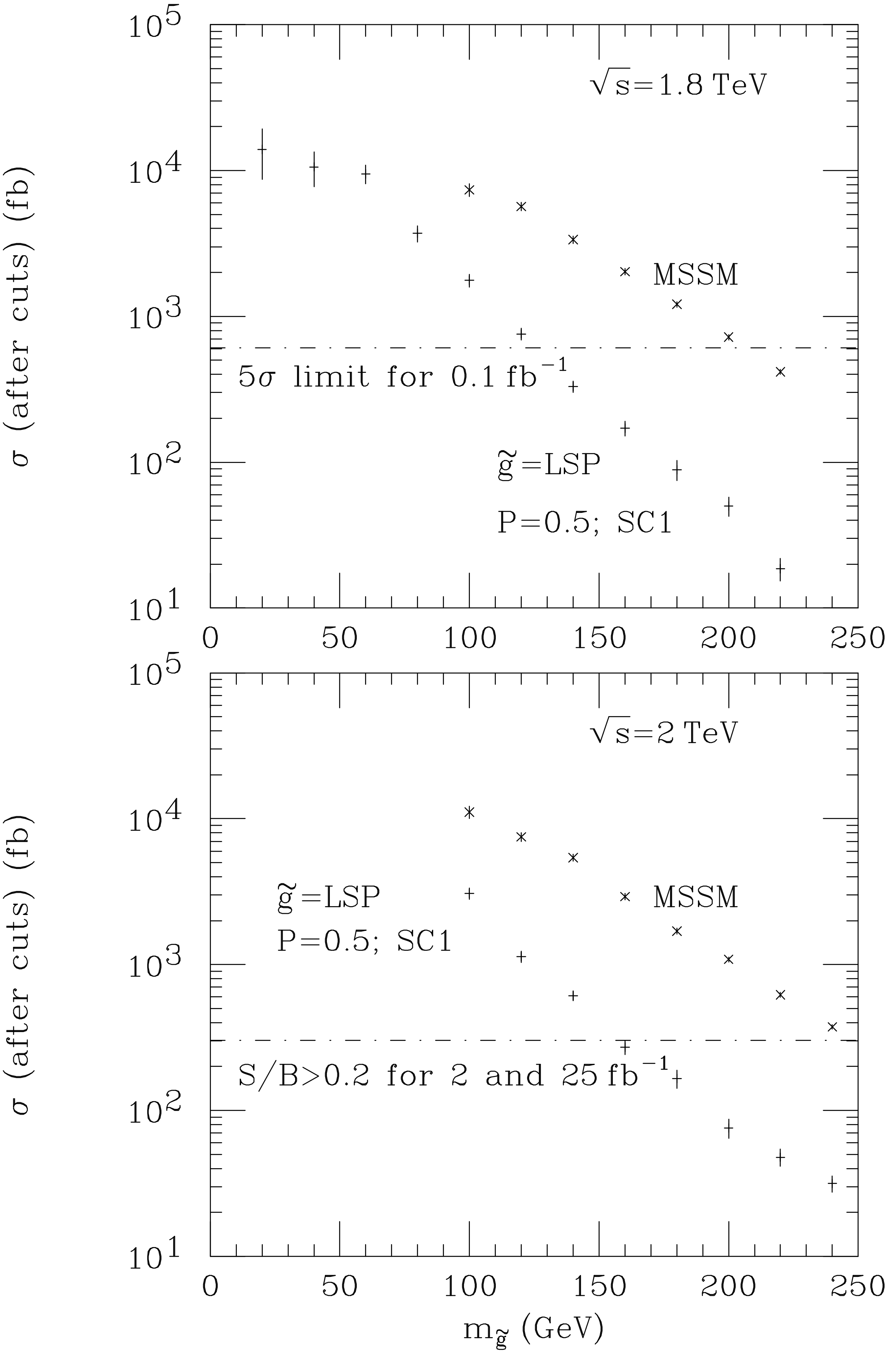

Figure 4: The cross section (after cuts) in the jets $+\not{p}_T$ channel is compared to (a) the 5σ level for $L = 0.1$ fb^{-1} (also roughly the 95% CL upper limit for $L = 19$ pb^{-1}) at $\sqrt{s} = 1.8$ TeV and (b) the $S/B = 0.2$ level at RunII ($L \geq 2$ fb^{-1}, $\sqrt{s} = 2$ TeV) as a function of $m_{\tilde{g}}$ for $P = 1/2$, using event-by-event determination of the momentum (=energy) of each $\tilde{g}$-jet (including the probabilistic treatment of charge-exchanges at each hadronic collision) in events such that neither $\tilde{g}$-jet is "muonic". We use $\lambda_T = 19$ cm and a middle-of-the-road $\langle \Delta E \rangle$ model.

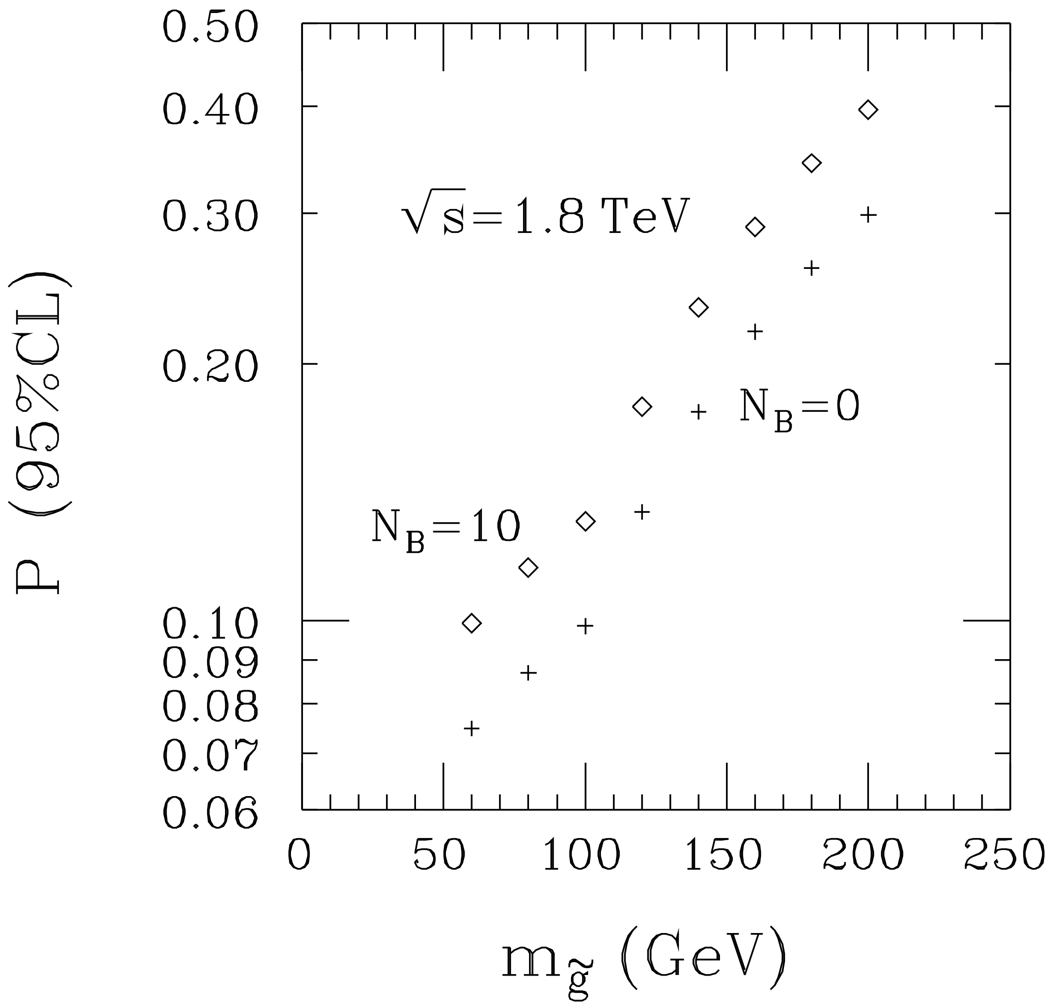

Figure 5: The 95%CL upper limit on the probability P for a $\tilde{g}$ to fragment to a singly-charged $R^{\pm}$ hadron after production and collision is given as a function of $m_{\tilde{g}}$ for $N_B = 0$ and $N_B = 10$ background events.

6 BARYONIC R-PARITY VIOLATION W. $\widetilde{\chi}^0_1$-LSP WHEN $M_2 < M_1$. (JFG+Baer+Cheung)

Shorten baryonic RPV parameterization to

$$\epsilon^{ijk}(\lambda'')_{pnm}\widehat{U}^i_p\widehat{D}^j_n\widehat{D}^k_m\,, \tag{6.1}$$

where $i,j,k =$ color indices, λ''_{pnm} is antisymmetric under $n \leftrightarrow m$

6.1 λ'' Bounds

- Perturbativity to $M_U \Rightarrow \lambda''$'s $\lesssim 1$.
- No $\Delta B = \Delta S = -2$ decay $^{16}O \to^{14} C + K^+ + K^+ \Rightarrow$

$$|\lambda''_{usd}| < 5.6 \times 10^{-7}\left(\frac{200\text{ MeV}}{\widetilde{\Lambda}_{QCD}}\right)^{5/2}\left(\frac{m_{\widetilde{g}}}{100\text{ GeV}}\right)^{1/2}\left(\frac{m_{\widetilde{q}}}{1\text{ TeV}}\right)^2\,. \tag{6.2}$$

- Constraints on λ''_{ubd}, λ''_{tsd} and λ''_{tbd} from $N \leftrightarrow \overline{N}$ vanish if $L-R$ mixing in the squark sector is small.
- Influence of $2 \to 2$ processes such as $u + d \to \tilde{d}^*_R \to \overline{d}\widetilde{\chi}^0_1$ on baryogenesis. are $|\lambda''| <\sim 5 \times 10^{-7}(m_{\widetilde{q}}/1\text{ TeV})^{1/2}$, if sphalerons are present at this epoch.
- For our analysis, bounds on products of λ'''s are not relevant.

6.2 Decays

$\widetilde{\chi}_1^0$ decay.

$$c\tau = .03\,\mu\mathrm{m}\left(\frac{0.1}{N_{\widetilde{\chi}_1^0 1}}\right)^2\left(\frac{1}{\lambda''}\right)^2\left(\frac{100\ \mathrm{GeV}}{m_{\widetilde{\chi}_1^0}}\right)^5\left(\frac{\widetilde{m}}{1\ \mathrm{TeV}}\right)^4\left[1-\frac{4}{5}\left(\frac{m_{\widetilde{\chi}_1^0}^2}{\widetilde{m}^2}\right)+\ldots\right], \tag{6.3}$$

where N is the usual neutralino mixing matrix in the B, W_3, H_1^0, H_2^0 basis and tiny Higgsino components of $\widetilde{\chi}_1^0$ are neglected.

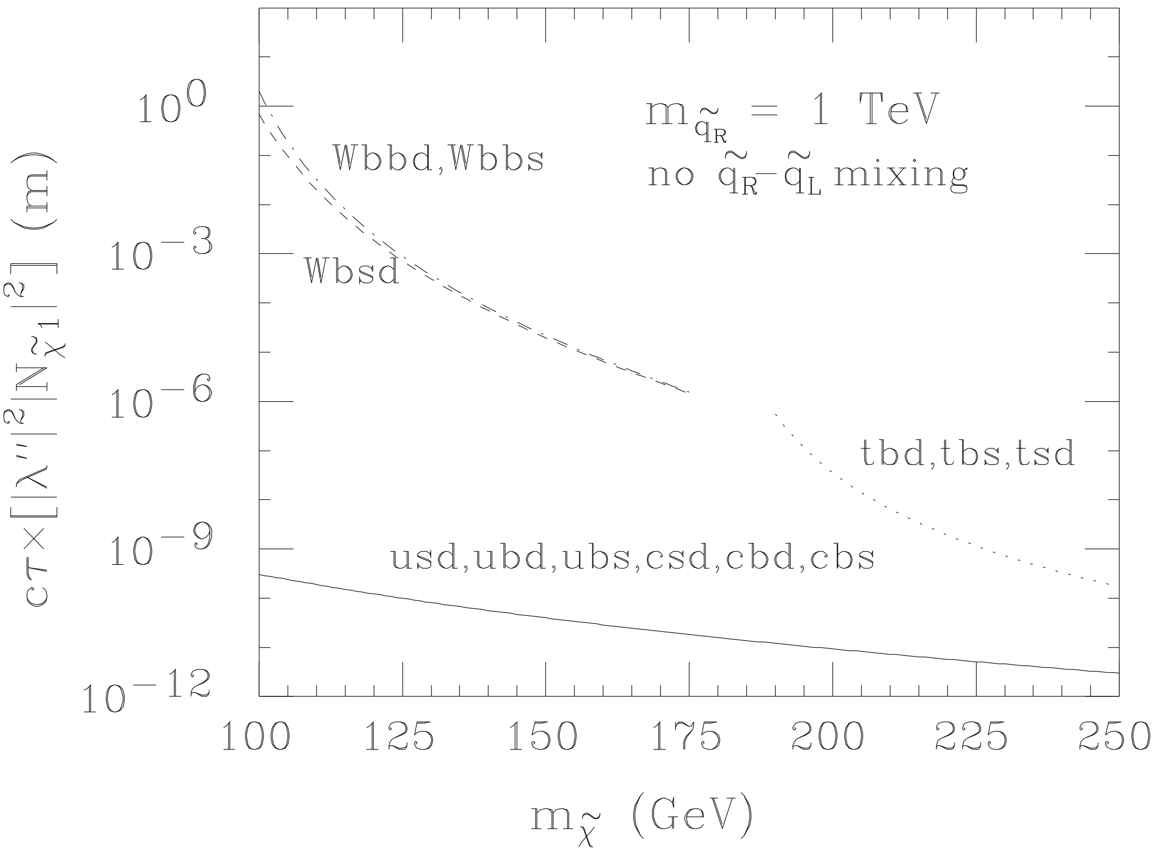

Figure 6: We plot $c\tau \times [|\lambda''|^2 |N_{\widetilde{\chi}_1^0 1}|^2]$ as a function of $m_{\widetilde{\chi}_1^0}$ for a variety of final states, including those arising from virtual top intermediate states.

$\Rightarrow$ look for STUB's and/or high-b tracks from the $\widetilde{\chi}_1^0$ decay.

Neglecting λ''_{usd}, the crucial issue is relative sizes of:

λ''_{tbd}, λ''_{tbs}, λ''_{tsd} vs. λ''_{usd}, λ''_{ubd}, λ''_{ubs}, λ''_{csd}, λ''_{cbd}, λ''_{cbs}.

If all but $\lambda''_{t\ldots}$ are very small, then $c\tau(\widetilde{\chi}^0_1) \sim 100$ m (100 μm) for $m_{\widetilde{\chi}^0_1} \sim 100$ GeV ($\sim m_t$).

$\widetilde{\chi}^\pm_1$ decays.

For small $\Delta m_{\widetilde{\chi}}$, RPV decays could compete with normal SUSY modes, but phenomenology hardly cares; $\widetilde{\chi}^\pm_1 \to 3j + soft$.

$\tilde{g}$ decays.

If $m_{\tilde{g}} - m_{\widetilde{\chi}^\pm_1}$ is small, then RPV and SUSY decays compete, but again $\tilde{g} \to 3j + soft$.

6.3 General Phenomenology

e^+e^- collisions:

- Small $c\tau$

  $e^+e^- \to \widetilde{\chi}^\pm_1\widetilde{\chi}^0_1$ and $e^+e^- \to \widetilde{\chi}^+_1\widetilde{\chi}^-_1$ (the non-suppressed processes) $\Rightarrow$ 6-jet final states; easy to see up to kinematic limit, as indicated by current LEP2 analyses presented at this conference.

- Moderate $c\tau$

  6-jet events with 3-jet decay vertices for each $\widetilde{\chi}^0_1$. Discovery for masses $\leq \sqrt{s}/2$ a certainty.

- Big $c\tau$

  Equivalent to no RPV as discussed earlier.

pp collisions:

- Large $c\tau$

  Return to $m_{\tilde{g}} \gtrsim m_{\widetilde{\chi}^\pm_1} \simeq \widetilde{\chi}^0_1$ studies outlined earlier.

- Moderate $c\tau$

  Expect visible vertex in SVX or tracker or outer segments of detector.

  $\Rightarrow$ no background.

  Discovery reach is event rate limited; being studied.

- Small $c\tau$

  - Cannot look for like-sign di-leptons + jets.

    This contrasts with usual $m_{\widetilde\chi_1^\pm} \sim 2m_{\widetilde\chi_1^0}$ baryonic RPV case, where (Binetruy+JFG, many more recent studies) even in absence of $\not{E}_T$ ($\widetilde\chi_1^0 \to 3j$) this signal is robust.

  - Depending upon $m_{\tilde g}$ we will be looking for $\geq 6-jet$ final states, where even if $m_{\tilde g} \sim m_{\widetilde\chi_1^\pm}$ extra jets can come from initial state radiation.

  - Dropping usd case, the most difficult is csd.

Examine

$$\delta_{GS} = -4.1,\ \ m_0 = 1800\,\mathrm{GeV},\ \ m_{1/2} = 10\,\mathrm{GeV},\ \ A_0 = 0,\ \ \tan\beta = 3,\ \ \mu > 0\,, \tag{6.4}$$

leading to

$$\begin{aligned} &m_{\tilde g} = 102\ \mathrm{GeV},\ \ m_{\widetilde\chi_1^0} \simeq m_{\widetilde\chi_1^\pm} \sim 100\ \mathrm{GeV},\ \ m_{\widetilde\chi_2^0} \sim 120\ \mathrm{GeV}, \\ &m_{\widetilde\chi_2^\pm} \sim m_{\widetilde\chi_3^0} \sim m_{\widetilde\chi_4^0} \sim 1140\ \mathrm{GeV},\ \ m_{\tilde\ell,\tilde q} \sim 1.4-1.8\ \mathrm{TeV}. \end{aligned} \tag{6.5}$$

Note the low gaugino masses, including the $\tilde g$, and the high mass scales of sfermions and higgsinos.

  - Without tagging or cluster-mass cuts:

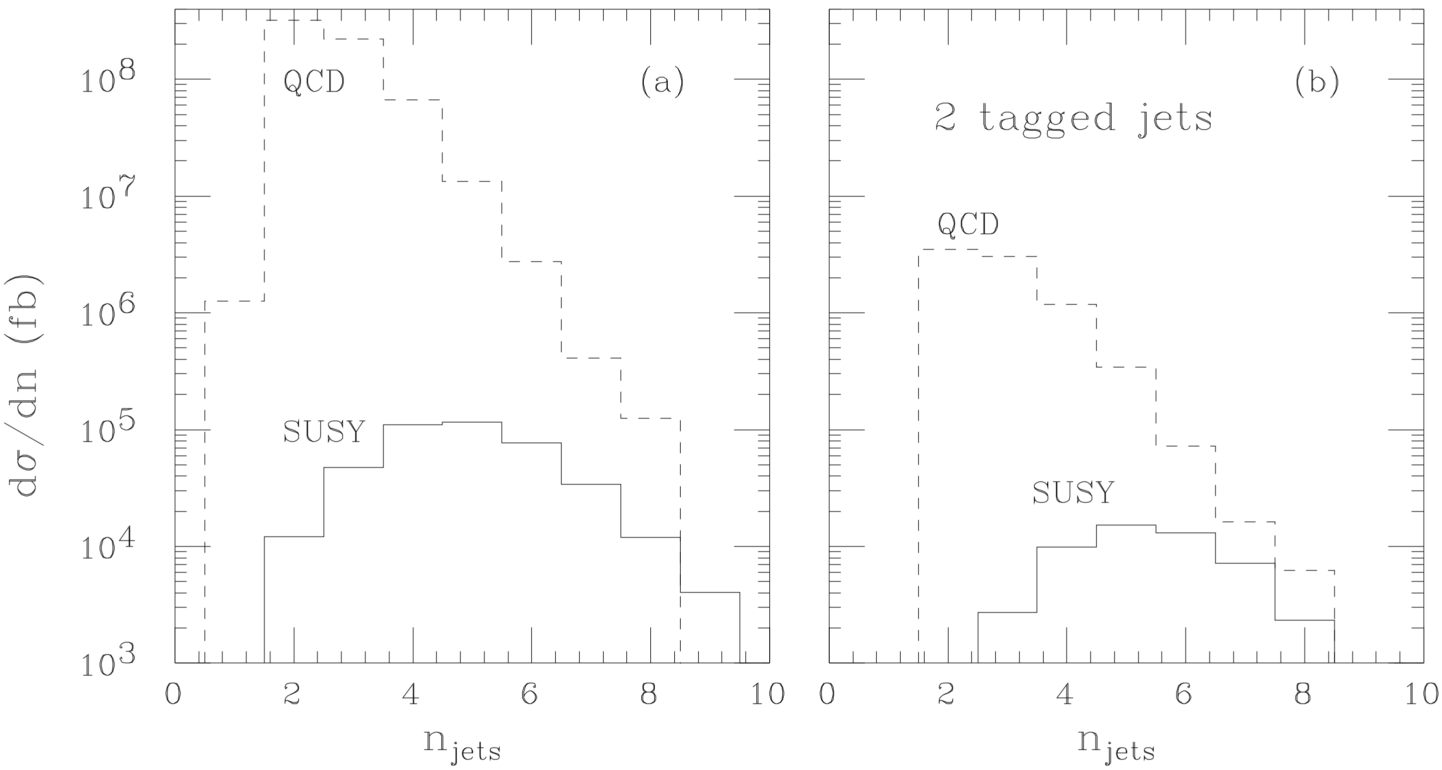

Figure 7: The number of events is plotted as a function of the number of jets for the QCD background (dashes) and for SUSY production processes (solid) (a) without tagging (b) after requiring that at least two jets be tagged (using the CDF JP charm tagging algorithm). O-II model parameters as in Eq. (6.4).

- $*$ Must cut on large n_j to make any progress.
- $*$ For the $n_j = 8$ bin, $S/B \sim 0.1$ and $L = 2$ fb^{-1} (30 fb^{-1}) $\Rightarrow$ $S/\sqrt{B} = 45$ (170) per detector.
- $*$ $\Rightarrow$ need $< 10\%$ systematic uncertainty for background. Possible by studying the $n_j \leq 7$ bins?

– With tagging (CDF 'JP' procedure), but no other cuts:

- $*$ $\Rightarrow$ use $n_j = 7$ bin.
- $*$ $\Rightarrow S = 1.4 \times 10^4, B = 3.2 \times 10^4$ ($S = 2.1 \times 10^5, B = 4.8 \times 10^5$) for $L = 2$ fb^{-1} ($L = 30$ fb^{-1}).
- $*$ $\Rightarrow$ $S/\sqrt{B} = 78$ ($S/\sqrt{B} = 303$) with $S/B \sim 45\%$ (a big

improvement).

$*$ So, no problem at low $m_{\tilde{g}} \sim m_{\tilde{\chi}_1^\pm} \sim 100$ GeV.

Must study mass reach. Work in progress.

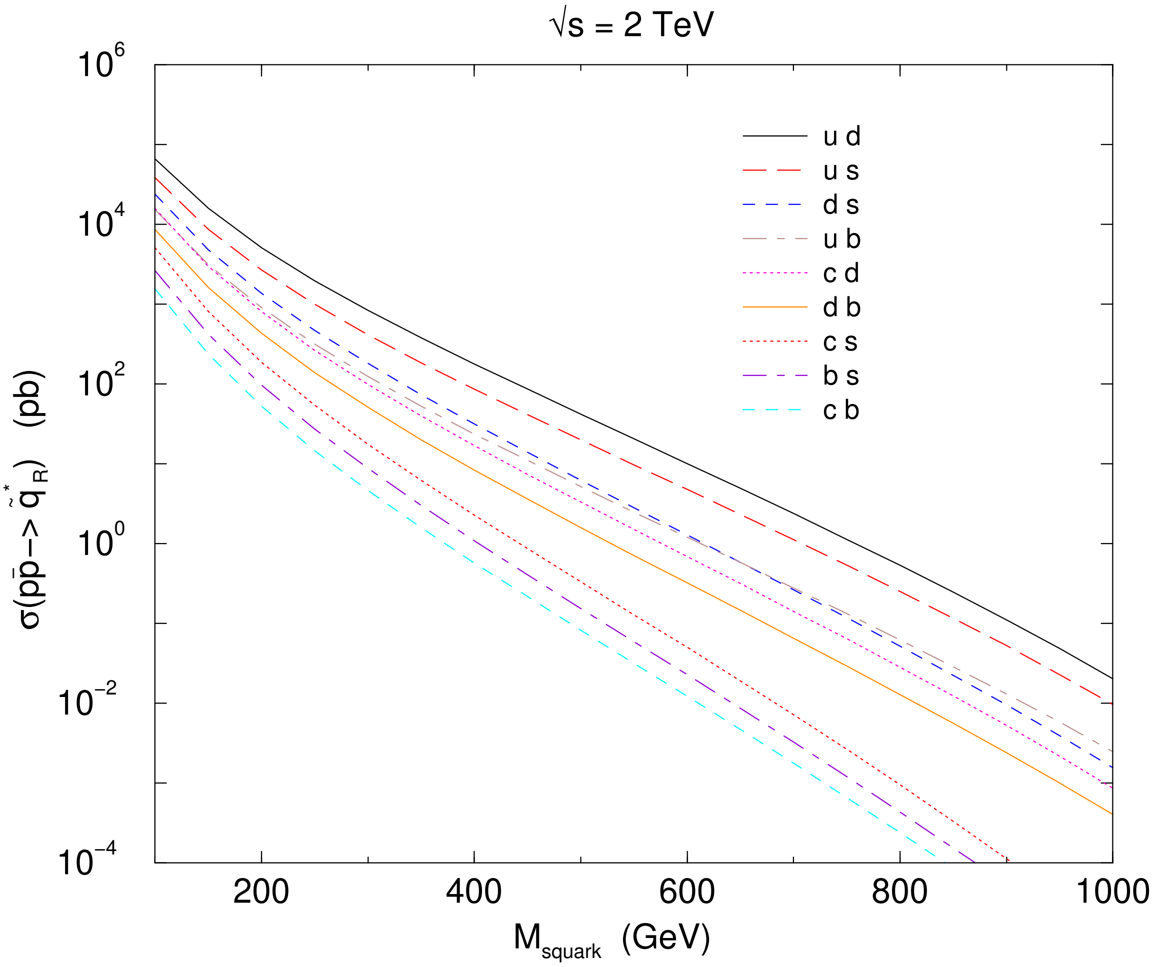

Figure 8: We plot the $\sqrt{s} = 2$ TeV (Tevatron) cross sections for production of a $\tilde{q}_R^*$ via a $\lambda'' = 1$ with appropriate flavor indices to communicate to the indicated initial quark parton distribution functions. Corresponding $\tilde{q}_R$ cross sections are the same for $p\overline{p}$ collision since the effective qq' luminosity is equal to the $\overline{qq}'$ luminosity.

- Additional probe = squark production

  – The sum of the RPV-induced single $\tilde{q}_R$ and $\tilde{q}_R^*$ σ's is big if λ'' is substantial.

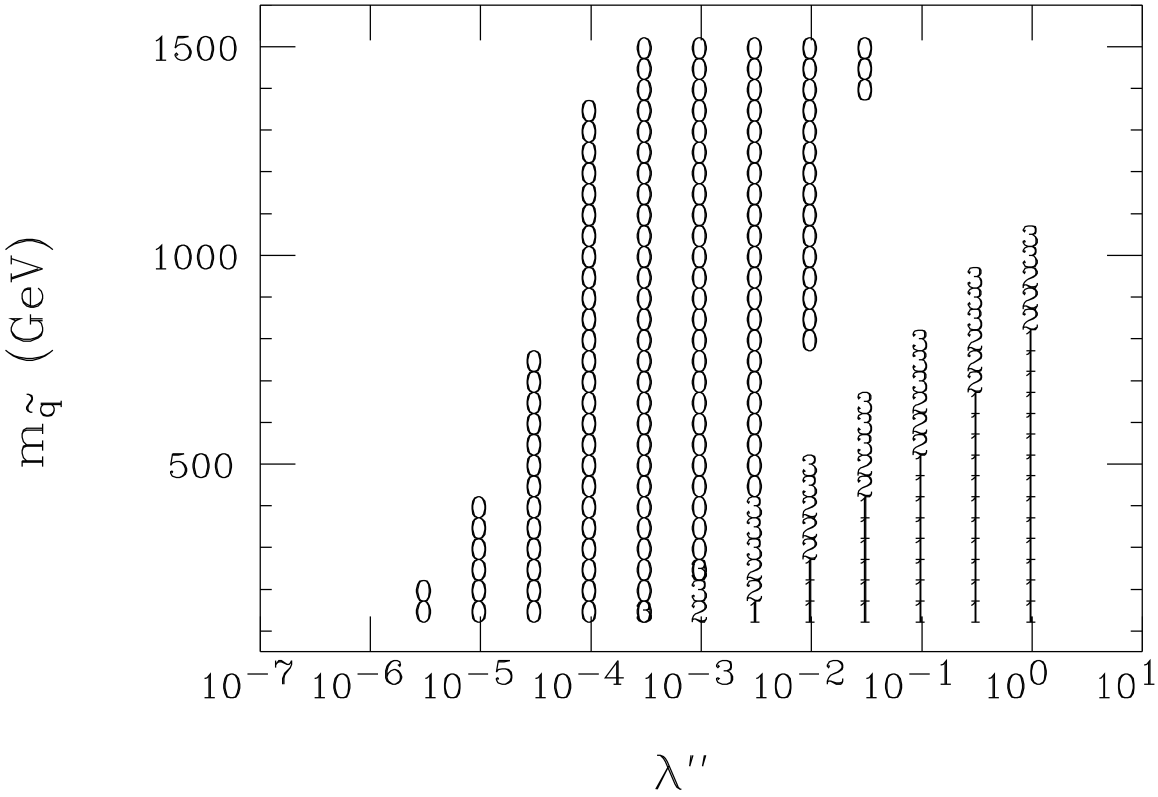

Figure 9: In $\lambda'' - m_{\tilde{q}_R}$ parameter space, we indicate by 0 the points where 100 μm $\leq c\tau \leq$ 10 m and by 1, 2, 3 the points where $\sigma(p\overline{p} \to sd \to \tilde{c}_R^* + \ldots) > 100, 10, 1$ fb, respectively. We take $m_{\widetilde{\chi}_1^0} = 100$ GeV, $|N_{\widetilde{\chi}_1^0 q}| = 0.1$ and consider $\sqrt{s} = 2$ TeV at the Tevatron. We assume dominance of a single λ''_{pnm} $(p \neq t)$ RPV coupling.

– $c\tau$ decay path lengths for the $\widetilde{\chi}_1^0$ might be observable if λ'' is sufficiently small.

– Measurement of either $\Rightarrow$ determination of λ''.

– Can we always see one or the other, and thus measure λ''?

Some first estimates:

* Suppose 100 μm $\leq c\tau \leq$ 10 m $\Rightarrow$ measurable $c\tau$.
* Suppose $\Sigma\, \sigma(p\overline{p} \to \tilde{q}_R^* + \tilde{q}_R) > 100$, 10, or 1 fb (cases 1, 2, 3, respectively) $\Rightarrow$ detection of direct $\tilde{q}_R^* + \tilde{q}_R$ production.
* Points satisfying these criteria in $\lambda'' - m_{\tilde{q}_R}$ space are indicated by 0, 1, 2, 3, respectively, in Fig. 9.

* Very small $\lambda'' \Rightarrow$ no luck.
* As λ'' increases, $c\tau$ becomes measurable (larger λ'' is, of course, required for larger $m_{\tilde{q}_R}$).
* As λ'' increases further, $c\tau$ becomes too short to be measurable.
* Still higher λ'' values yield significant $\tilde{q}_R$ and $\tilde{q}_R^*$ cross sections.
* Worry: the region of λ'' at each $m_{\tilde{q}_R}$ for which neither $c\tau$ nor σ will be measurable.

  In this region, direct determination of λ'' requires that an RPV decay mode of the $\tilde{g}$ or $\widetilde{\chi}_1^{\pm}$ is competitive with the relevant SUSY decay modes; the relative size of the branching ratios $\Rightarrow$ measure of λ''.
* At an e^+e^- collider the only means for measuring λ'' would be via the $\widetilde{\chi}_1^0$ decay length. (No analogue of hadron collider single $\tilde{q}_R$ production even at high $\sqrt{s}$.)

7 PHENOMENOLOGY WHEN R-PARITY IS BROKEN BY λ'' AND THE $\tilde{g}$ IS THE LSP (JFG+Baer+Cheung)

If this decay is within the detector, then the $\tilde{g}$-LSP phenomenology changes dramatically.

$\tilde{g}$ decays.

- Same final states as for $\widetilde{\chi}^0_1$ decay of previous section.
- For degenerate squarks, $\tilde{g}$ decay is obtained from $\widetilde{\chi}^0_1$ decay by $g'^2|N_{\widetilde{\chi}^0_1 1}|^2 \to (3/4)g_s^2$.
- $c\tau(\tilde{g}) = c\tau(\widetilde{\chi}^0_1)|N_{\widetilde{\chi}^0_1 1}|^2/8.87$ (see Fig. 6).
- $\Rightarrow$ A $\tilde{g}$-LSP is more likely to decay inside the detector than a $\widetilde{\chi}^0_1$-LSP.

$\widetilde{\chi}^0_1$ decays.

- Two basic decay modes:
  - The SUSY decay $\widetilde{\chi}^0_1 \to q\bar{q}\tilde{g}$ via squark exchanges (both $\tilde{q}_R$ and $\tilde{q}_L$ contribute), followed by $\tilde{g} \to 3j$.
  - The direct $\widetilde{\chi}^0_1 \to 3j$ RPV decay.
- $\Rightarrow$ if $m_{\tilde{g}}$ is small, then the SUSY decay mode will dominate.
- But, $m_{\tilde{g}}$ close to $m_{\widetilde{\chi}^0_1} \Rightarrow$ dominance by direct RPV decay if λ''_{usd}, λ''_{ubd}, λ''_{ubs}, λ''_{csd}, λ''_{cbd}, or λ''_{cbs} is large.
  - E.g, $m_{\widetilde{\chi}^0_1} - m_{\tilde{g}} \sim 20$ GeV $\Rightarrow c\tau \sim 0.8 - 0.9 \times 10^{-7}$ m for all $m_{\widetilde{\chi}^0_1}$,
  - $\Rightarrow$ RPV decay could be dominant for $\lambda'' > 0.2 - 0.3$.
  - For the boundary conditions being considered, this latter degree of degeneracy is not at all improbable.

- $\widetilde{\chi}_1^0$ phenomenology dependence on whether SUSY decays dominate over RPV decays is not great.
  - The extra 2 jets of the SUSY decay would be relatively soft.
  - At an e^+e^- collider, the extra jets would be observable $\Rightarrow$ signal that SUSY decay modes are dominant $\Rightarrow$ bound on the RPV coupling (or indirect measurement if some RPV decays are seen).
  - At a hadron collider, only $\tilde{g}\tilde{g}$ pair production is important (given that $m_{\tilde{g}} < m_{\widetilde{\chi}_1^0}, m_{\widetilde{\chi}_1^\pm}$).

    Small σ for direct $\widetilde{\chi}_1^0$ production $\Rightarrow$ little hope of looking for the extra two jets that might (or might not) be present in $\widetilde{\chi}_1^0$ decays.
- The $\widetilde{\chi}_1^\pm$ looks like the $\widetilde{\chi}_1^0$ for $m_{\widetilde{\chi}_1^\pm} \simeq m_{\widetilde{\chi}_1^0}$.

8 Extra Matter and/or Gauge Fields

Typical string model (Cvetic talk) $\Rightarrow$

- Exotic matter fields, both extra generations and exotic reps.
- Extra gauge fields, esp. Z'.
- Extra Higgs fields.

What are phenomenological implications? Just a few points.

8.1 4th generation (with heavy N) in SUSY

- Raises M_U enough to help p decay problem.
- Increases upper bound on lightest Higgs, as may be needed if TeV33 fails to find the H.
- Constraints
  - $S < 0.15$ limits m_L and m_N (Maksymyk, Burgess and London).
  - Direct searches for $b' \to bZ$.

    The limits can still apply even if $BR(b' \to bH)$ is substantial so long as enough $b' \to bZ$ decays on one side remain for triggering.

    $\Rightarrow m_{b'} > 140$ GeV, pending detailed study required to know if bH mode could obviate this limit for $m_H \sim 100 - 150$ GeV.
  - If we must evolve to $M_U \sim M_{\rm Planck}$ or so, Yukawas (especially leptonic) blow up quickly.

    If m_L and m_N are $> m_Z/2$, $m_{b'} < 100$ GeV and $m_{t'} < 120$ GeV are required (JFG+McKay+Pois) if run to standard M_U.

As LEP2 pushes up the L and N limits (be careful of small mass splitting case – Thomas+Wells), $\Rightarrow$ no room unless we lower maximum scale (GMSB, low scale M_S, ...).

Even if we use 100 TeV, the constraints are still very strong if $m_L \sim (0.5 - 1.1) m_Z$; $m_{b'} = m_{t'} < 1.9 m_Z$ required (McKay).

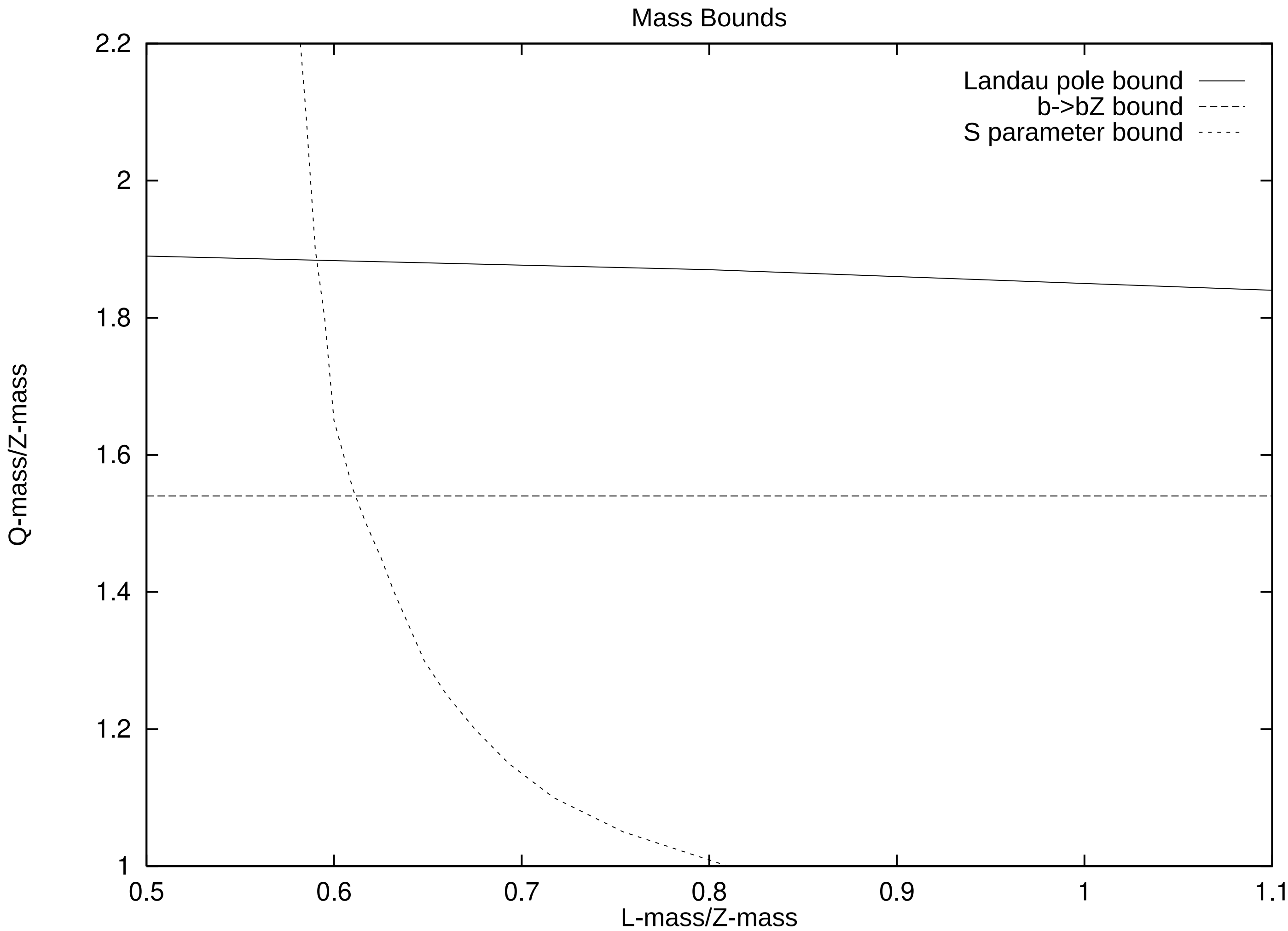

Figure 10: 4th generation limitations. Allowed region is small 'square' to left and midway on m_Q/m_Z axis. From D. McKay.

8.2 Extra Higgs bosons.

- There could be many.
- Worst case for discovery (JFG+Espinosa):

  Make them share the WW/ZZ coupling and overlap in mass.

  $\Rightarrow$ No clear peak and all peaks are reduced in size.

  This is even hard for NLC with $L = 500\ \mathrm{fb}^{-1}$.

9 CONCLUSIONS

- The experimental community should be prepared for almost anything.
- Delayed decays, special triggers, ... could play a vital role.

  In particular, only by measuring the decay vertex radial distribution will we be able to measure the most interesting parameter of the 'typical' unusual model.

  - $\sqrt{F}$
  - $\Delta m_{\tilde{\chi}}$
  - λ''
  - ...

- While the non-minimal scenarios may make SUSY discovery more difficult in some cases, once something is seen it will be sufficiently unique to give strong early hints as to the nature of the boundary conditions.
- Much more work to do to fully explore non-minimal SUSY options.
- Keep an eye on CMB etc.

  If a convincing case can be made that the $\widetilde{\chi}_1^0$ is the dark matter, then all the scenarios discussed here are more or less ruled out.