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Motivations for and Implications of Non-Universal GUT-Scale Boundary Conditions for Soft SUSY-Breaking Parameters.*

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ABSTRACT

We outline several well-motivated models in which GUT boundary conditions for SUSY breaking are non-universal. The diverse phenomenological implications of the non-universality for SUSY discovery at LEP2, the Tevatron, the LHC and the NLC are sketched.

I Introduction

We will consider models in which the gaugino masses and/or the scalar masses are not universal at the GUT scale, M_U. The important issues are: a) the extent to non-universal boundary conditions can influence experimental signatures for the production of supersymmetric particles and possibly suggest special detector requirements needed to guarantee that the largest possible class of supersymmetric models lead to observable signatures at present and future lepton and hadron colliders; and b) the degree to which experimental data can distinguish between different hypotheses/models for the GUT scale boundary conditions. In this brief report, we attempt to develop some insight into the answers to both questions by focusing on some particularly well-motivated, but very different, scenarios for the GUT scale boundary conditions. At least one motivation for this report is to emphasize the fact that experimentalists must not rely on the phenomenology of any one model in planning their experiment or analyzing present or future data. The alternative possibilities presented here turn out to be relatively extreme in some respects, and thus may provide useful benchmarks. However, we will be conservative in that we do not allow R-parity violation; the LSP will always be the lightest neutralino and it will be invisible.

II Non-Universal Gaugino Masses at M_U

We focus on two different types of models in which gaugino masses are naturally not universal at M_U.

- Superstring-motivated models in which SUSY breaking is moduli (as opposed to dilaton) dominated. We consider the particularly attractive O-II model of Ref. [1] in which all matter fields are placed in the untwisted sector and the universal 'size' modulus field is the only source of SUSY breaking. In this model, gaugino masses derive from one-loop terms of a form that would be present in any theory. The boundary conditions at M_U are:

$$\begin{aligned} &M_a^0 \sim \sqrt{3} m_{3/2}[-(b_a+\delta_{GS})K\eta] \\ &m_0^2 = m_{3/2}^2[-\delta_{GS}K'] \\ &A_0 = 0 \end{aligned} \tag{1}$$

where b_a are the standard gauge coupling RGE equation coefficients ($b_3 = 3$, $b_2 = -1$, $b_1 = -33/5$), δ_{GS} is the Green-Schwarz mixing parameter, which would be a negative integer in the O-II model, with $\delta_{GS} = -4, -5$ preferred; and $\eta = \pm 1$. The estimates of Ref. [1] are $K = 4.6 \times 10^{-4}$ and $K' = 10^{-3}$, which imply that slepton and squark masses would be very much larger than gaugino masses. It can be argued that the general relation of the M_a to b_a and δ_{GS} is much more general than the O-II model, and very likely to even survive the non-perturbative corrections that will almost certainly be present, whereas the relation between the M_a constant K and the m_0 constant K' is much more model-dependent.

- Models in which SUSY breaking occurs via an F-term that is not an SU(5) singlet. In this class of models, gaugino masses are generated by a chiral superfield Φ that appears linearly in the gauge kinetic function, and whose auxiliary F component acquires an intermediate scale vev:

$$\mathcal{L} = \int d^2\theta W_a W_b \frac{\Phi_{ab}}{M_{\rm Planck}} + h.c. \sim \frac{\langle F_\Phi\rangle_{ab}}{M_{\rm Planck}} \lambda_a \lambda_b \,, \tag{2}$$

where the $\lambda_{a,b}$ $(a,b = 1,2,3)$ are the gaugino fields. If F is an SU(5) singlet, then $\langle F_\Phi\rangle_{ab} \propto c\delta_{ab}$ and gaugino masses are universal. More generally, Φ and F_Φ need only belong to an SU(5) irreducible representation which appears in the symmetric product of two adjoints:

$$(\mathbf{24}\times\mathbf{24})_{\rm symmetric} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75} \oplus \mathbf{200} \,, \tag{3}$$

where only $\mathbf{1}$ yields universal masses. For the other representations only the component of F_Φ that is 'neutral' with respect to the SM SU(3), SU(2) and U(1) groups should acquire a vev, assuming that these groups remain unbroken after SUSY breaking. In this case $\langle F_\Phi\rangle_{ab} = c_a\delta_{ab}$, with c_a depending upon which of the above representations Φ lies in. The c_a then determine the relative magnitude of the gauginos masses at M_U. The results for the four possible irreducible representations, Eq. (3), appear in Table I. An arbitrary superposition of the four irreducible representations is

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F_Φ	M_U M_3	M_2	M_1	m_Z M_3	M_2	M_1
1	1	1	1	~ 6	~ 2	~ 1
24	2	-3	-1	~ 12	~ -6	~ -1
75	1	3	-5	~ 6	~ 6	~ -5
200	1	2	10	~ 6	~ 4	~ 10
$O-II$ $\delta_{GS}=-4$	1	5	$\frac{53}{5}$	~ 6	~ 10	$\sim \frac{53}{5}$

Table I: Relative gaugino masses at M_U and m_Z for the four possible F_Φ irreducible representations and in the O-II model with $\delta_{GS} \sim -4$.

also, in principle, possible. In what follows, we shall assume that only one of the irreducible representations is present.

To understand the implications of GUT-scale choices for the M_a, we need only recall that $M_3^0 : M_2^0 : M_1^0$ at M_U evolves to $M_3 : M_2 : M_1 = 3M_3^0 : M_2^0 : \frac{1}{2}M_1^0$ at m_Z, as indicated in Table I. Physical masses of the gauginos are influenced by $\tan\beta$-dependent off diagonal terms in the mass matrices and by corrections which boost $m_{\widetilde{g}}(pole)$ relative to $m_{\widetilde{g}}(m_{\widetilde{g}})$. If μ is large, the lightest neutralino (which is the LSP) will have mass $m_{\widetilde{\chi}_1^0} \sim \min(M_1, M_2)$ while the lightest chargino will have $m_{\widetilde{\chi}_1^\pm} \sim M_2$. Thus, in the **200** and O-II scenarios with $M_2 \lesssim M_1$, $m_{\widetilde{\chi}_1^\pm} \simeq m_{\widetilde{\chi}_1^0}$ and the $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_1^0$ are both wino-like. The $\tan\beta$ dependence of the masses at m_Z for the universal, **24**, **75**, and **200** choices appears in Fig. 1. The gaugino masses in the O-II scenario are plotted as a function of δ_{GS} for $\tan\beta = 2$ and 15 in Fig. 2. The $m_{\widetilde{g}} - m_{\widetilde{\chi}_1^0}$ mass splitting becomes increasingly smaller in the sequence **24**, **1**, **200** **75**, O-II ($\delta_{GS} \sim -4$), as could be anticipated from Table I. Indeed, in the O-II case $m_{\widetilde{g}} < m_{\widetilde{\chi}_1^0}$ (even after including the gluino pole mass correction) at $\delta_{GS} = -4$; $\delta_{GS} \gtrsim -4.2$ yields $m_{\widetilde{g}} > m_{\widetilde{\chi}_1^0}$ by just a small amount. It is interesting to note that at high $\tan\beta$ values μ decreases to a level comparable to M_1 and M_2, and there is substantial degeneracy among the $\widetilde{\chi}_1^\pm$, $\widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^0$.

The two models described above are certainly not the only ones in which gaugino masses are non-universal. For example, in Ref. [4] a scenario is developed in which non-universal gaugino masses are intimately related to a solution of the doublet-triplet Higgs mass splitting naturalness problem [5]. One finds:

$$\frac{M_a}{g_a^2} = \frac{M_{H_a}}{k_a g_{H_a}^2} + \frac{M_G}{g_G^2}, \quad (a = 1, 2, 3), \tag{4}$$

where $M_{H_2} = 0$, $k_3 = 1$, $k_1 = 15$, G is the usual SU(5) group, H_1 and H_3 are new groups with associated coupling constants $g_{H_{1,3}}$, the g_a are the usual coupling constants, and all M/g^2 ratios are RG invariants. Since there are essentially no constraints on $M_{H_{1,3}}/g_{H_{1,3}}^2$ at M_U, the gaugino masses become independent parameters.

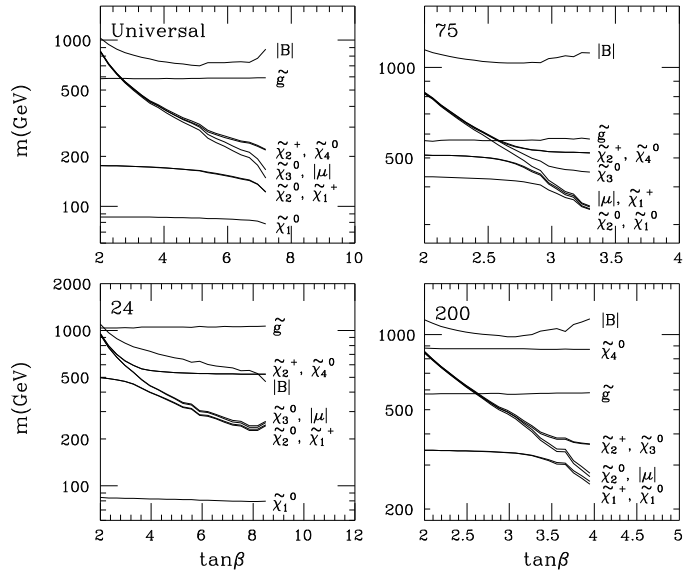

Figure 1: Physical (pole) gaugino masses as a function of $\tan\beta$ for the **1** (universal), **24**, **75**, and **200** F representation choices. Also plotted are $|B|$ and $|\mu|$. We have taken $m_0 = 1\,\text{TeV}$ and $M_a(M_U) = m_{1/2}$ times the number appearing in Table I, with $m_{1/2} = 200\,\text{GeV}$.

III Non-universal scalar masses at M_U

Two classes of model come immediately to mind.

- Models in which the SUSY-breaking scalar masses at M_U are influenced by the Yukawa couplings of the corresponding quarks/leptons. This idea is exemplified in the model of Ref. [6] based on perturbing about the $[U(3)]^5$ symmetry that is present in the absence of Yukawa couplings. One finds:

$$m_{\widetilde{Q}}^2 = m_0^2(I + c_Q\lambda_u^\dagger\lambda_u + c'_Q\lambda_d^\dagger\lambda_d + \ldots) \tag{5}$$

$$m_{\widetilde{U^c}}^2 = m_0^2(I + c_U\lambda_u\lambda_u^\dagger + \ldots) \tag{6}$$

$$m_{\widetilde{D^c}}^2 = m_0^2(I + c_D\lambda_d\lambda_d^\dagger + \ldots) \tag{7}$$

where Q represents the squark partners of the left-handed quark doublets and U^c (D^c) the partners of the left-handed up (down) antiquarks. The m^2's, I and λ_u, λ_d are 3×3 matrices in generation space, the latter containing the Yukawa couplings of the quarks. The $\ldots$ represent terms of order λ^4 that we will neglect. A, c_Q, c'_Q, c_U and c_D should all be similar in size, in which case the large top quark Yukawa coupling implies that the primary deviations from universality will occur in $m_{\widetilde{t_L}}^2$, $m_{\widetilde{b_L}}^2$ (equally and in the same direction) and $m_{\widetilde{b_R}}^2$. We also recall that A terms can be present that will mix the Q and U^c, D^c squark

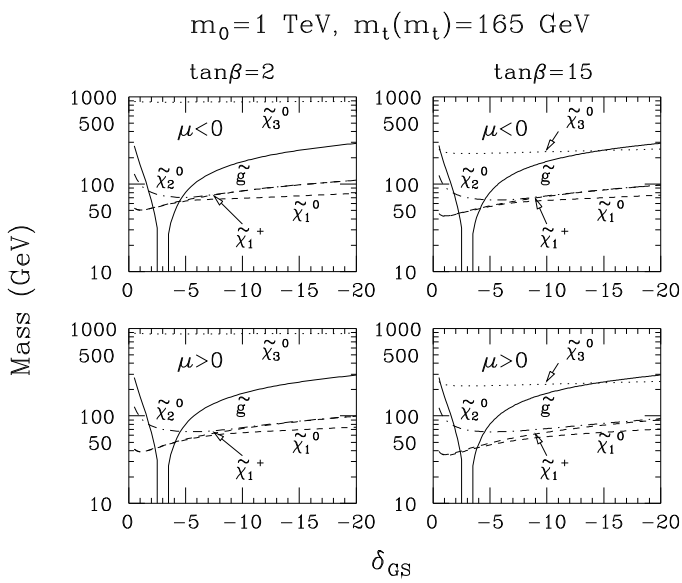

Figure 2: Masses for the $\widetilde{\chi}_1^0$, $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_1^+$, and $\widetilde{g}$ are plotted as a function of δ_{GS} at $\tan\beta = 2$ and 15 and for $\mu > 0$ and $\mu < 0$.

fields, with

$$A_U = A_0(\lambda_u + \ldots)\,, \quad A_D = A_0(\lambda_d + \ldots)\,, \qquad (8)$$

where A_U (A_D) describes $Q - U^c$ ($Q - D^c$) mixing, respectively, and ... represents cubic and higher terms that we neglect. It is the fact that $m^2_{\widetilde{t}_L}$ and $m^2_{\widetilde{b}_L}$ are equally shifted that will distinguish m^2 non-universality from the effects of a large A_0 parameter at M_U; the latter would primarily introduce $\widetilde{t}_L - \widetilde{t}_R$ mixing and yield a low $m_{\widetilde{t}_1}$ compared to $m_{\widetilde{b}_1}$.

- A second source of non-universal scalar masses is closely related to the second non-universal gaugino mass scenario discussed earlier. In close analogy, scalar masses will arise from the effective Lagrangian form:

$$\mathcal{L} \propto \frac{\langle F_\Phi F_\Phi \rangle_{ij}}{M^2_{\rm Planck}} \phi_i^\dagger \phi_j\,, \qquad (9)$$

where the $\phi_{i,j}$ are the scalar fields and we implicitly assume that only a single F_Φ in an irreducible representation of SU(5) is active. Since the ϕ_i's associated with the partners of the (left-handed) SM fermion and antifermion fields appear in both $\overline{\mathbf{5}}$ and $\mathbf{10}$ representations, while the doublet Higgs fields that must remain light appear in a $\mathbf{5}$, the representation $\mathbf{R}$ of Φ must be chosen so that $\mathbf{R} \times \mathbf{R}$ overlaps one or more of the representations common to $\mathbf{10} \times \overline{\mathbf{10}} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75}$ and $\mathbf{5} \times \overline{\mathbf{5}} = \mathbf{1} \oplus \mathbf{24}$. For example, $\mathbf{R} = \mathbf{1}$ and [see Eq. (3)] $\mathbf{R} = \mathbf{24}$ both would work, and illustrate the possibility that a single F_Φ could simultaneously give rise to both gaugino and squark soft mass terms. The analysis of squark masses in the general situation is complex and will be left to a future work. There are clearly many possible patterns of non-universality.

Finally, we note that universality is predicted for the scalar masses in the O-II model, although in modest variants thereof a limited amount of non-universality can be introduced.

IV Phenomenology

We separately consider gaugino mass non-universality and squark mass non-universality, although the two could be interrelated in the F_Φ models. Even if these different types of non-universality do not derive from the same mechanism, both could be simultaneously present. We note that we found it to be very straightforward to incorporate alternate non-universal boundary conditions into event generators such as ISASUGRA/ISASUSY. Interested parties are encouraged to contact us for specific instructions.

A Non-universal gaugino masses

The gaugino mass patterns outlined in Table I have important phenomenological implications, only a few of which we attempt to sketch here.

- For $m_{\widetilde{\chi}_1^\pm} \sim m_{\widetilde{\chi}_1^0}$ (**200**, O-II), in $\widetilde{\chi}_1^+ \to \widetilde{\chi}_1^0 \ell\nu, \widetilde{\chi}_1^0 2j$ decays the ℓ and jets are very soft implying:
  1. $e^+e^- \to \widetilde{\chi}_1^+\widetilde{\chi}_1^-$ detection may require using a photon tag [2];
  2. the like-sign signal for $\widetilde{g}\widetilde{g}$ production disappears;
  3. the tri-lepton signal for $\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$ disappears.
- For $m_{\widetilde{g}} \sim m_{\widetilde{\chi}_1^\pm} \sim m_{\widetilde{\chi}_1^0}$ (O-II, $\delta_{GS} \sim -4$), the $jets + \not{E}_T$ signal for $\widetilde{g}\widetilde{g}$ production is more difficult to extract — softer jet cuts must be employed than in other scenarios, implying larger backgrounds, see [3];
- Decay patterns and mass ratios are a strong function of scenario, implying experiment can distinguish different scenarios from one another.

It is particularly amusing to examine the phenomenological implications of these boundary conditions for the standard Snowmass overlap point specified by $m_t = 175\,\mathrm{GeV}$, $\alpha_s = 0.12$, $m_0 = 200\,\mathrm{GeV}$, $M_3^0 = 100\,\mathrm{GeV}$[1] $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. For the given M_3^0, m_0 is very large in the O-II scenario if the strict 1-loop values of K and K' noted earlier are employed. However, the relation between K and K' could be drastically altered by non-perturbative corrections. Thus, in treating the O-II model

[1] We fix M_3 to be the same in all scenarios so that $m_{\widetilde{g}}$ will have roughly the same value in all models.

	1	**24**	**75**	**200**	$O-II$ $\delta_{GS}=-4.7$
$m_{\widetilde{g}}$	285	285	287	288	313
$m_{\widetilde{u}_R}$	302	301	326	394	-
$m_{\widetilde{t}_1}$	255	257	235	292	-
$m_{\widetilde{t}_2}$	315	321	351	325	-
$m_{\widetilde{b}_L}$	266	276	307	264	-
$m_{\widetilde{b}_R}$	303	303	309	328	-
$m_{\widetilde{\ell}_R}$	207	204	280	437	-
$m_{\widetilde{\ell}_L}$	216	229	305	313	-
$m_{\widetilde{\chi}_1^0}$	44.5	12.2	189	174.17	303.09
$m_{\widetilde{\chi}_2^0}$	97.0	93.6	235	298	337
$m_{\widetilde{\chi}_1^\pm}$	96.4	90.0	240	174.57	303.33
$m_{\widetilde{\chi}_2^\pm}$	275	283	291	311	-
m_{h^0}	67	67	68	70	82

Table II: Sparticle masses for the Snowmass comparison point in the different gaugino mass scenarios. Blank entries for the O-II model indicate very large masses.

below, we shall take $m_0 = 600\,\mathrm{GeV}$, a value that yields a (pole) value of $m_{\widetilde{g}}$ not unlike that for the other scenarios; $m_0 = 200\,\mathrm{GeV}$ would imply that the $\widetilde{\chi}_1^0$ would not be the LSP. By comparing these scenarios we can gain a first insight as to the degree to which experiment will allow us to determine the appropriate GUT/String scale boundary conditions.

The masses of the supersymmetric particles for each scenario are given in Table II. As promised, the $\widetilde{\chi}_1^\pm$ is very degenerate with the $\widetilde{\chi}_1^0$ in the **200** and O-II models.

The phenomenology of these scenarios for e^+e^- collisions is not absolutely straightforward.

- In the **1** and **24** models the masses for the $\widetilde{\ell}_L$, $\widetilde{\ell}_R$, $\widetilde{\chi}_1^\pm$, $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0$ are such that the standard array of SUSY discovery channels at the NLC would be present and easily observable since all mass splittings are substantial.

- In the **75** model, $\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ and $\widetilde{\chi}_2^0\widetilde{\chi}_2^0$ pair production at $\sqrt{s} = 500\,\mathrm{GeV}$ are barely allowed kinematically; the phase space for $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$ is only somewhat better. All the signals would be rather weak, but could probably be extracted with sufficient integrated luminosity. It might prove fruitful to look for $e^+e^- \to \gamma\widetilde{\chi}_1^0\widetilde{\chi}_1^0$.

- In the **200** model, $e^+e^- \to \widetilde{\chi}_1^+\widetilde{\chi}_1^-$ production would be kinematically allowed at a $\sqrt{s} = 500\,\mathrm{GeV}$ NLC, but not easily observed due to the fact that the (invisible) $\widetilde{\chi}_1^0$ would take essentially all of the energy in the $\widetilde{\chi}_1^\pm$ decays. However, according to the results of Ref. [2], $e^+e^- \to \gamma\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ would be observable at $\sqrt{s} = 500\,\mathrm{GeV}$. The only other directly visible (i.e. without a γ tag) sparticle pair channel would be $e^+e^- \to \widetilde{\chi}_2^0\widetilde{\chi}_1^0$; the small phase space would imply a very weak signal.

- The O-II model with δ_{GS} near -4 predicts that $m_{\widetilde{\chi}_1^\pm}$ and $m_{\widetilde{\chi}_1^0}$ are both rather close to $m_{\widetilde{g}}$, so that $e^+e^- \to \widetilde{\chi}_1^+\widetilde{\chi}_1^-, \widetilde{\chi}_1^0\widetilde{\chi}_1^0$ would not be kinematically allowed. The only SUSY 'signal' would be the presence of a very SM-like light Higgs boson.

At the LHC, the strongest signal for SUSY would arise from $\widetilde{g}\widetilde{g}$ production. The different models lead to very distinct signatures for such events. To see this, it is sufficient to list the primary easily identifiable decay chains of the gluino for each of the five scenarios. (In what follows, q denotes any quark other than a b.)

$$
\begin{aligned}
\mathbf{1}: \quad & \widetilde{g} \stackrel{90\%}{\to} \widetilde{b}_L\overline{b} \stackrel{99\%}{\to} \widetilde{\chi}_2^0 b\overline{b} \stackrel{33\%}{\to} \widetilde{\chi}_1^0(e^+e^- \text{ or } \mu^+\mu^-)b\overline{b} \\
& \qquad\qquad\qquad\qquad \stackrel{8\%}{\to} \widetilde{\chi}_1^0\nu\overline{\nu}b\overline{b} \\
& \qquad\qquad\qquad\qquad \stackrel{38\%}{\to} \widetilde{\chi}_1^0 q\overline{q}b\overline{b} \\
& \qquad\qquad\qquad\qquad \stackrel{8\%}{\to} \widetilde{\chi}_1^0 b\overline{b}b\overline{b} \\
\mathbf{24}: \quad & \widetilde{g} \stackrel{85\%}{\to} \widetilde{b}_L\overline{b} \stackrel{70\%}{\to} \widetilde{\chi}_2^0 b\overline{b} \stackrel{99\%}{\to} h^0\widetilde{\chi}_1^0 b\overline{b} \stackrel{28\%}{\to} \widetilde{\chi}_1^0 b\overline{b}b\overline{b} \\
& \qquad\qquad\qquad\qquad\qquad\qquad \stackrel{69\%}{\to} \widetilde{\chi}_1^0\widetilde{\chi}_1^0\widetilde{\chi}_1^0 b\overline{b} \\
\mathbf{75}: \quad & \widetilde{g} \stackrel{43\%}{\to} \widetilde{\chi}_1^0 g \text{ or } \widetilde{\chi}_1^0 q\overline{q} \\
& \stackrel{10\%}{\to} \widetilde{\chi}_1^0 b\overline{b} \\
& \stackrel{20\%}{\to} \widetilde{\chi}_2^0 g \text{ or } \widetilde{\chi}_2^0 q\overline{q} \\
& \stackrel{10\%}{\to} \widetilde{\chi}_2^0 b\overline{b} \\
& \stackrel{17\%}{\to} \widetilde{\chi}_1^\pm q\overline{q} \\
\mathbf{200}: \quad & \widetilde{g} \stackrel{99\%}{\to} \widetilde{b}_L\overline{b} \stackrel{100\%}{\to} \widetilde{\chi}_1^0 b\overline{b} \\
\mathrm{O-II}: \quad & \widetilde{g} \stackrel{51\%}{\to} \widetilde{\chi}_1^\pm q\overline{q} \\
& \stackrel{17\%}{\to} \widetilde{\chi}_1^0 g \\
& \stackrel{26\%}{\to} \widetilde{\chi}_1^0 q\overline{q} \\
& \stackrel{6\%}{\to} \widetilde{\chi}_1^0 b\overline{b}
\end{aligned}
$$

Gluino pair production will then lead to the following strikingly different signals.

- In the **1** scenario we expect a very large number of final states with missing energy, four b-jets and two lepton-antilepton pairs.

- For **24**, an even larger number of events will have missing energy and eight b-jets, four of which reconstruct to two pairs with mass equal to (the known) m_{h^0}.

- The signal for $\widetilde{g}\widetilde{g}$ production in the case of **75** is much more traditional; the primary decays yield multiple jets (some of which are b-jets) plus $\widetilde{\chi}_1^0$, $\widetilde{\chi}_2^0$ or $\widetilde{\chi}_1^\pm$. Additional jets, leptons and/or neutrinos arise when $\widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0$ + two jets, two leptons or two neutrinos or $\widetilde{\chi}_1^\pm \to \widetilde{\chi}_1^0$ + two jets or lepton+neutrino.

- In the **200** scenario, we find missing energy plus four b-jets; only b-jets appear in the primary decay — any other jets present would have to come from initial or final state radiation, and would be expected to be softer on average. This is almost as distinctive a signal as the $8b$ final state found in the **24** scenario.

- In the final O-II scenario, $\widetilde{\chi}_1^\pm \to \widetilde{\chi}_1^0$ + very soft spectator jets or leptons that would not be easily detected. Even the $q\overline{q}$ or g from the primary decay would not be very energetic given the small mass splitting between $m_{\widetilde{g}}$ and $m_{\widetilde{\chi}_1^\pm} \sim m_{\widetilde{\chi}_1^0}$. Any energetic jets would have to come from initial or final state radiation. Soft jet cuts would have to be used to dig out this signal, but it should be possible given the very high $\widetilde{g}\widetilde{g}$ production rate expected for this low $m_{\widetilde{g}}$ value; see Ref. [3].

Thus, for the particular m_0, M_3, $\tan\beta$, etc. values chosen for the Snowmass comparison point, distinguishing between the different boundary condition scenarios at the LHC will be extremely easy. Further, the event rate for a gluino mass this low is such that the end-points of the various lepton, jet or h^0 spectra will allow relatively good determinations of the mass differences between the sparticles appearing at various points in the final state decay chain [7]. We are optimistic that this will prove to be a general result so long as event rates are large.

B Non-universal scalar masses

In this section, we maintain gaugino mass universality at M_U, but allow for non-universality for the squark masses, in which case it is natural to focus on LHC phenomenology.

We perturb about the Snowmass overlap point, taking $c_Q \neq 0$ with $c_U = c_D = A_0 = 0$. In Fig. 3 we plot the $\widetilde{g}$ branching ratios as a function of $m_{\widetilde{t}_L} = m_{\widetilde{b}_L}$ as c_Q is varied from negative to positive values. As the common mass crosses the threshold above which the $\widetilde{g} \to \widetilde{b}_1 b$ decay becomes kinematically disallowed, we revert to a more standard SUSY scenario in which $\widetilde{g}$ decays are dominated by modes such as $\widetilde{\chi}_1^\pm q\overline{q}$, $\widetilde{\chi}_1^0 q\overline{q}$ (not plotted), $\widetilde{\chi}_2^0 q\overline{q}$ and (more exotically) $\widetilde{\chi}_2^0 b\overline{b}$, not unlike the **75** non-universal gaugino mass scenario as far as the important channels are concerned. To distinguish between such a $c_Q \neq 0$ case vs. the **75** scenario would require using the lepton/jet spectra in the final state to determine if the $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^\pm$ are light vs. heavy, respectively. (Of course, at the NLC the light $\widetilde{\chi}_1^\pm$ present in the $c_Q \neq 0$, universal-gaugino-mass scenario would be immediately detected and its mass easily measured.) As $m_{\widetilde{b}_1}$ and $m_{\widetilde{t}_1}$ increase in the $c_Q \neq 0$ scenario, the $\widetilde{b}_1$ and $\widetilde{t}_1$ branching ratios also change; e.g. $\widetilde{b}_1 \to \widetilde{g}b$ goes from zero to dominant as the $\widetilde{b}_1 \to \widetilde{\chi}_2^0 b, \widetilde{\chi}_1^- t$ modes decline.

Experimental determination of the squark masses will be very important for deciding if corrections to scalar mass universality are present at M_U and for illuminating their nature.

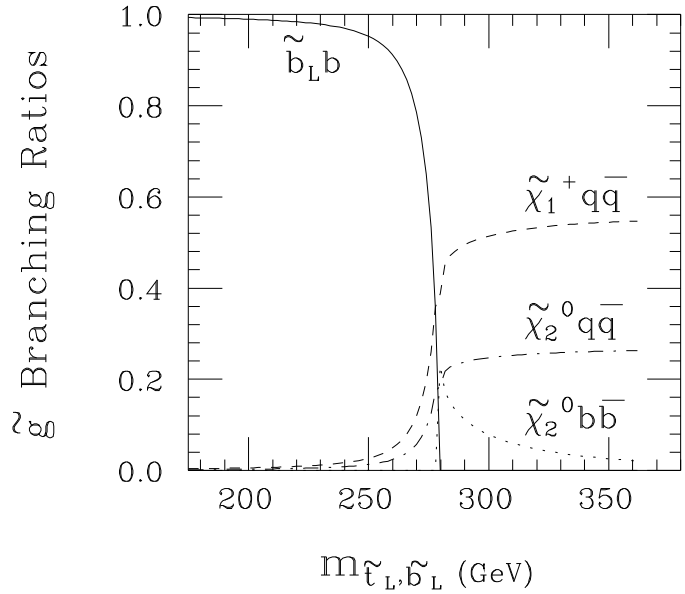

Figure 3: Gluino branching ratios as a function of $m_{\widetilde{t}_L}$ in the case of $c_Q \neq 0, c_U = c_D = A_0 = 0$. We employ the Snowmass overlap point values of $M_a^0 = 100\,\text{GeV}$ ($a = 1, 2, 3$), $m_0 = 200\,\text{GeV}$, $\tan\beta = 2$, with $\mu < 0$.

V Conclusions

By combining well-motivated GUT-scale gaugino mass non-universality and squark mass non-universality scenarios an enormous array of boundary conditions at M_U becomes possible. Thus, it will be dangerous to focus on one signal/channel or even short list of channels for discovery of supersymmetry. Indeed, a thorough search and determination of the rates (or lack thereof) for the full panoply of possible channels is required to distinguish the many possible GUT-scale boundary conditions from one another.

REFERENCES

[1] A. Brignole, L.E. Ibanez, and C. Munoz, Nucl. Phys. B422, 125 (1994), Erratum, ibid., B436 747 (1995). A. Brignole, L.E. Ibanez, C. Munoz, and C. Scheich, hep-ph/9508258.

[2] C.-H. Chen, M. Drees, and J.F. Gunion, Phys. Rev. Lett. 76, 2002 (1996).

[3] C.-H. Chen, M. Drees, and J.F. Gunion, hep-ph/9607421.

[4] N. Arkani-Hamed, H.-C. Cheng, and T. Moroi, hep-ph/9607463.

[5] T. Hotta, K.-I. Izawa and T. Yanagida, Phys. Rev. D53, 3913 (1996).

[6] L.J. Hall and L. Randall, Nucl. Phys. B352, 289 (1991).

[7] R.M. Barnett, J.F. Gunion and H.E. Haber, Phys. Lett. B315, 349 (1993); see also the supersymmetry group reports in this volume.