"New Physics Discernment Challenges at the LHC: $\tilde{g}$ supersymmmetric example"

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w/ Manuel Toharia

What we want/like from susy:

- gauge coupling unification
- source of dark matter
- String theory connection
- "obvious" space-time symmetry extension

What we do not want from SUSY:

- FCNCs
- CP violation
- Proton decay problems
- moduli/gravitino problem

★ = Hierarchy stabilized, natural weak scale, no quadratic divergence...

If we take ★ seriously in susy then we have many theory challenges in susy to rid ourselves of bad things while keeping good things.

If we ignore ★ the path is much clearer:

$$\tilde{m}_{\text{scalars}} \gg \tilde{m}_{\text{fermions}}$$

suppresses FCNC, CP, ...

retains gauge coupling unification, DM, ...

Where we are at

Eliminating bad things (FCNC, CP violation, Higgs mass, etc.) but preserving good things (SUSY, dark matter, gauge coupling unification) has led us to

light Higgs prediction

Large scalar superpartner masses, but light fermion superpartner masses (gauginos and higgsino)

Is there a good theory for this type of hierarchy?

A very general answer is YES. Gaugino and higgsino masses are charged (R-symmetry and PQ symmetry), whereas scalar masses are not.

Supersymmetry breaking scenario

A particularly simple, and perhaps best, approach to this phenomenology is to assume that the susy breaking multiplet is charged (not a singlet).

Recall, we said supersymmetry breaking can be parametrized by chiral supermultiplet,

$$X = x + \sqrt{2}\psi\theta + F\theta^2$$

If X is charged we cannot write down the simple gaugino mass terms

$$\int d^2\theta \frac{X}{M_{\rm Pl}} \mathcal{W}\mathcal{W} \quad \text{(not allowed)}$$

No gaugino mass at this level

Supersymmetry breaking scenario (cont.)

On the other hand, the scalar masses are allowed

$$\int d^2\theta d^2\bar{\theta}\frac{X^\dagger X}{M_{\mathrm{Pl}}^2}\Phi_i^\dagger\Phi_i \to m_{3/2}^2\phi_i^*\phi_i$$

If S is charged (i.e., not a singlet) the scalar mass equation is unaffected but the gaugino mass expression is no longer gauge invariant (ignoring GUT group $S_{ab}\mathcal{W}^a\mathcal{W}^b$ possibilities).

The leading contribution to gaugino masses is the anomaly-mediated expression

$$M_\lambda = \frac{\beta(g_\lambda)}{g_\lambda}m_{3/2}$$

Randall, Sundrum; Giudice, Luty, Murayama, Rattazzi

Superpartner spectrum

Unless there is a special Kähler potential suppressing scalar masses, they will be very heavy compared to the gauginos.

In terms of the gravitino mass $m_{3/2}$ the superpartner spectrum is

$$\begin{aligned} M_1 &\simeq m_{3/2}/120 \\ M_2 &\simeq m_{3/2}/360 \\ M_3 &\simeq m_{3/2}/45 \\ \tilde{m}_i &\sim m_{3/2} \end{aligned}$$

where $\tilde{m}_i$ are the various scalar superpartner masses.

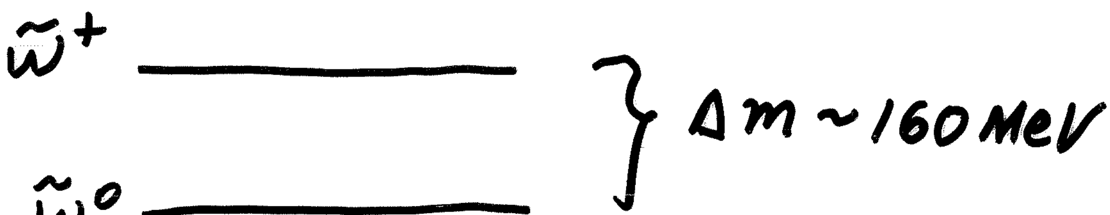
Requiring $M_2 > m_W$ implies $m_{3/2} > 28\,\mathrm{TeV}$.

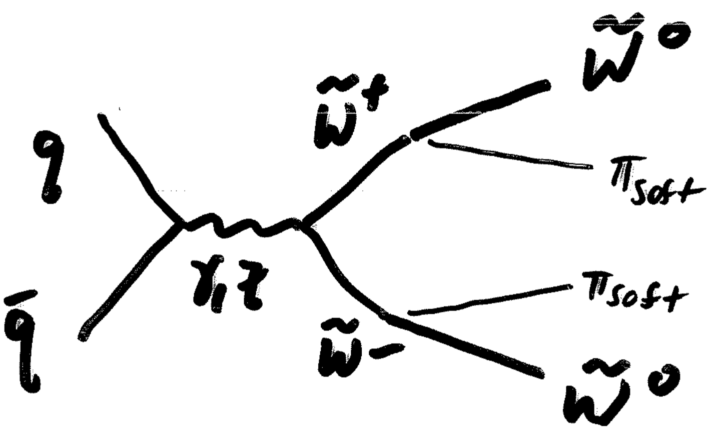
This is perhaps the simplest manifestation of "split supersymmetry."

Arkani-Hamed, Dimopoulos;
Giudice, Romanino;
etc.

Scalars (squarks, sleptons, heavy Higgs) are 100 TeV-ish. (inaccessible)

Wino is lightest gaugino





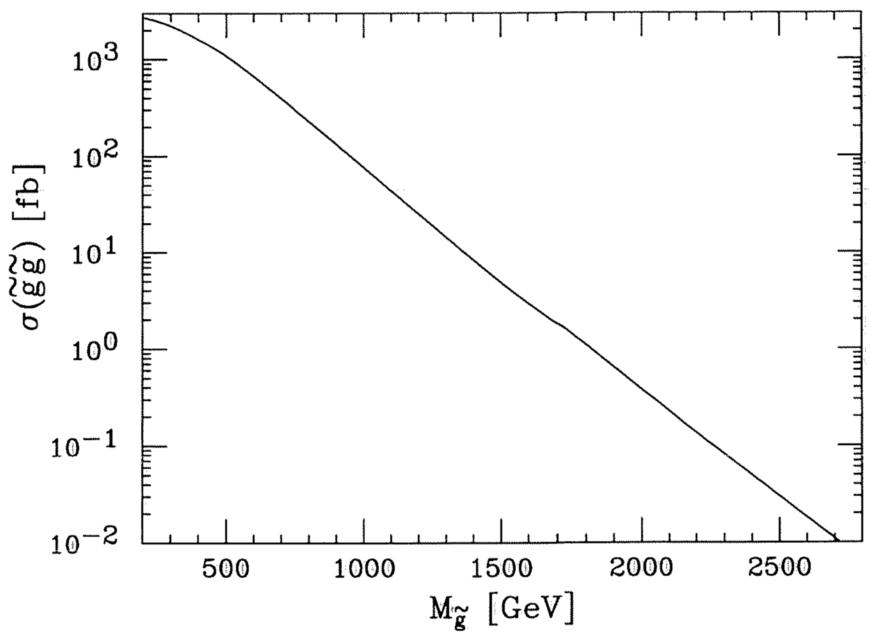
$pp \to \tilde{W}^+ \tilde{W}^-$
$\to \tilde{W}^0 \tilde{W} \pi_{soft} \pi_{soft}$

(No way to see!)

$\boxed{\text{Focus on gluino pair production.}}$

Event rates from $\tilde{g}\tilde{g}$ production

Gluino pair production in the appropriate limit of heavy squarks is

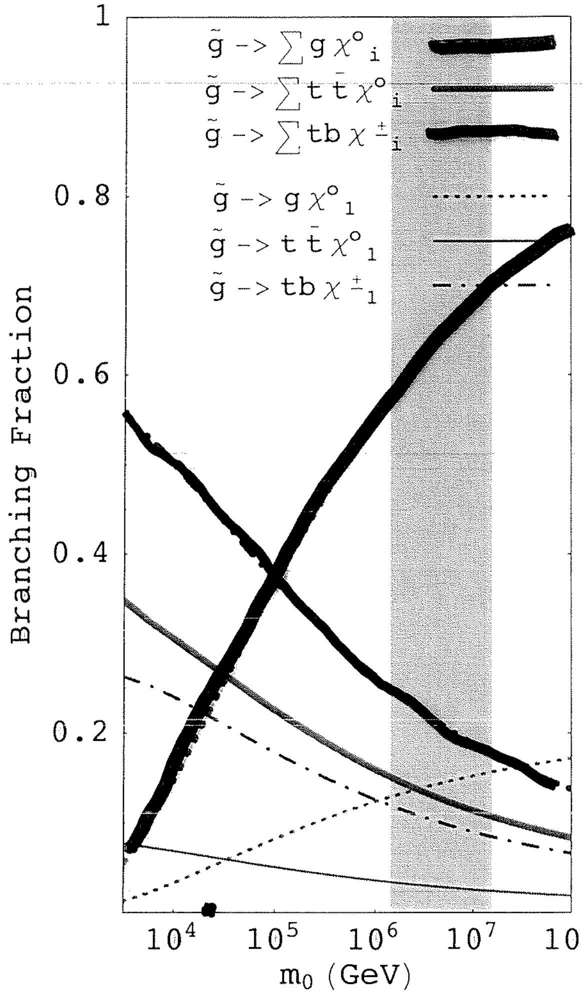


Obtained from Isajet v7.44

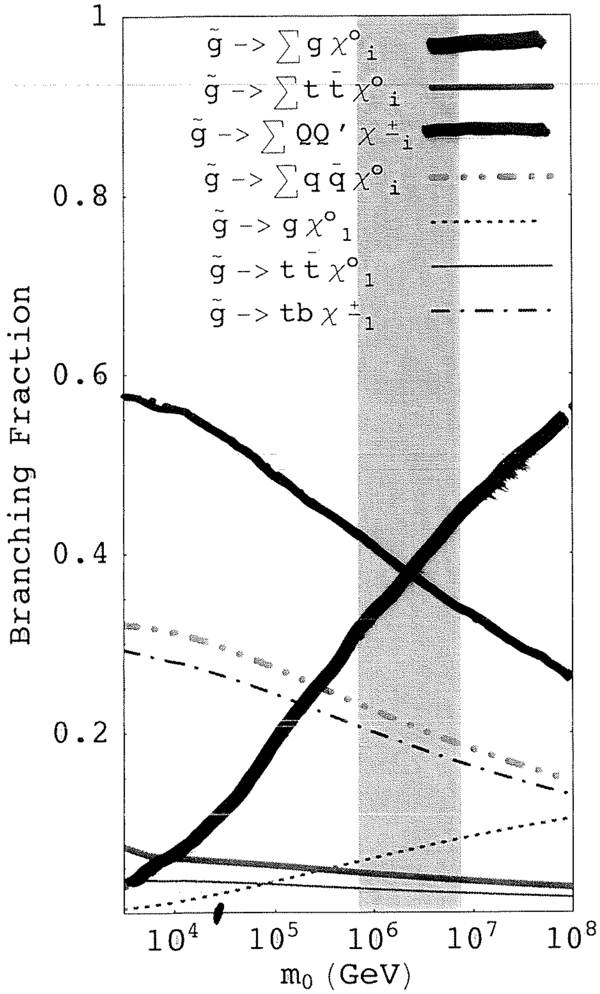
Expect mass reach of gluinos to almost 2 TeV with 200 fb^{-1} of data. (Nearly 100 events to work with.) 2 TeV gluino mass is equivalent to gravitino mass, and therefore scalar mass, of nearly 90 TeV in this scenario.

Scalars and Winos are probed indirectly from gluino decays, and decays cascading through the Bino. Direct probes of the Wino (scalars) would have to wait for the LC (VLHC) ....

M. Toharia



$\mu = 120$ GeV



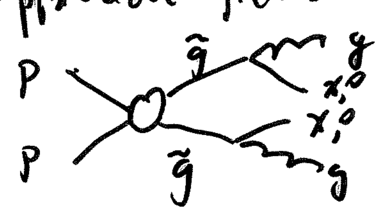
$\mu = 700$ GeV

$m_{\tilde{g}} \simeq 900$ GeV $\quad$ $m_0 \simeq 40$ TeV (AMSB)

$m_{\tilde{t}_R} = 0.4\, m_0$, $m_{\tilde{Q}_{L3}} = 0.7\, m_0$ (RGE flow from universal masses)

Measuring the various decay modes of $\tilde{g}$ would be huge challenge — and very important!

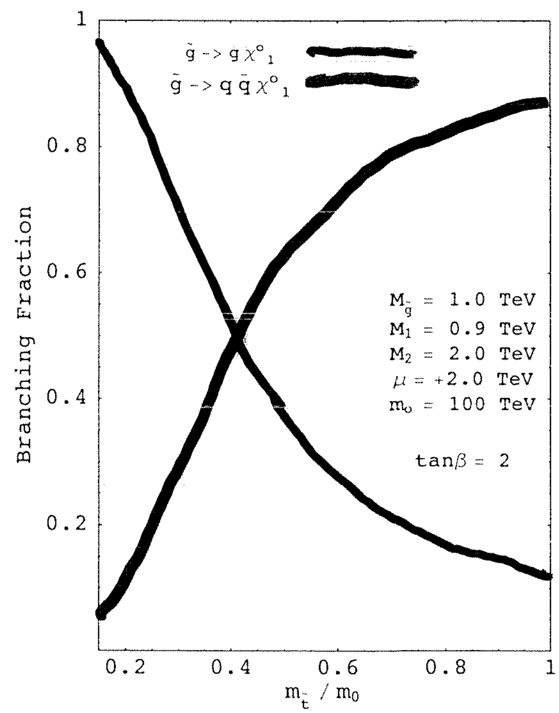
More general approach yields many interesting possibilities.



$gg + \not{E}_T$

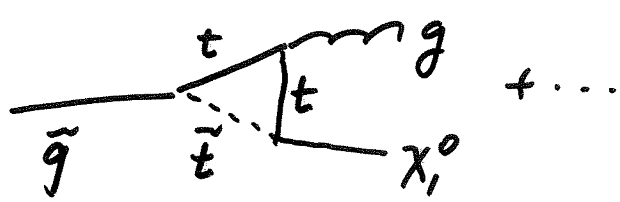
— $\tilde g \to g \chi_1^0$

— $\tilde g \to q \bar q \chi_1^0$

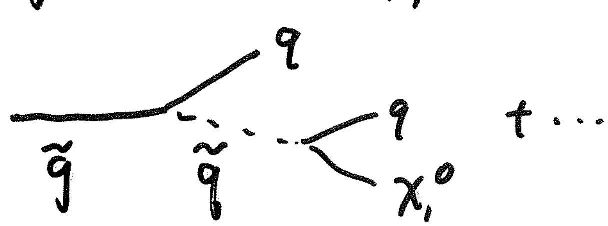


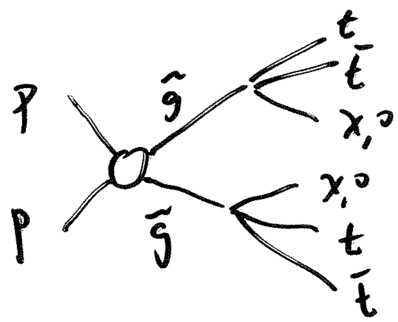
$m_{\tilde t_R} / \tilde m_0$

When $\tilde t_R$ light



and wins over





$4t + \cancel{E}_T$

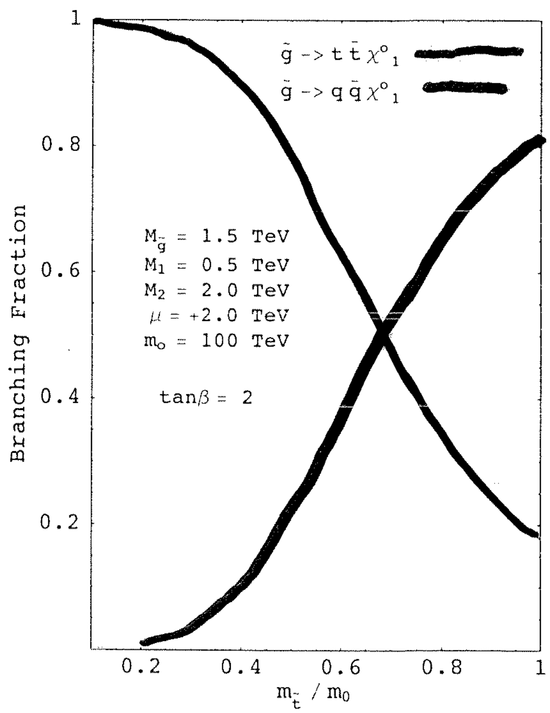
(Potentially only signal at LHC)

"It's the way Nature Planned It".

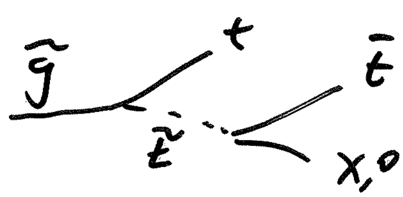
—The Four Tops

$\tilde{g} \to t\bar{t}\chi_1^0$

$\tilde{g} \to q\bar{q}\chi_1^0$

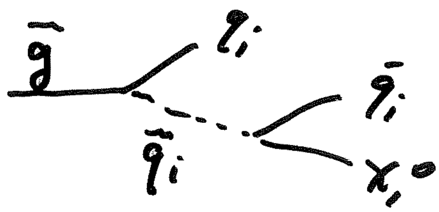


When $\tilde{t}_R$ light



wins

When $\tilde{t}_R = \tilde{q}_i$



wins (more q_i)

Higgs boson mass

In minimal supersymmetry the lightest Higgs mass is computable:

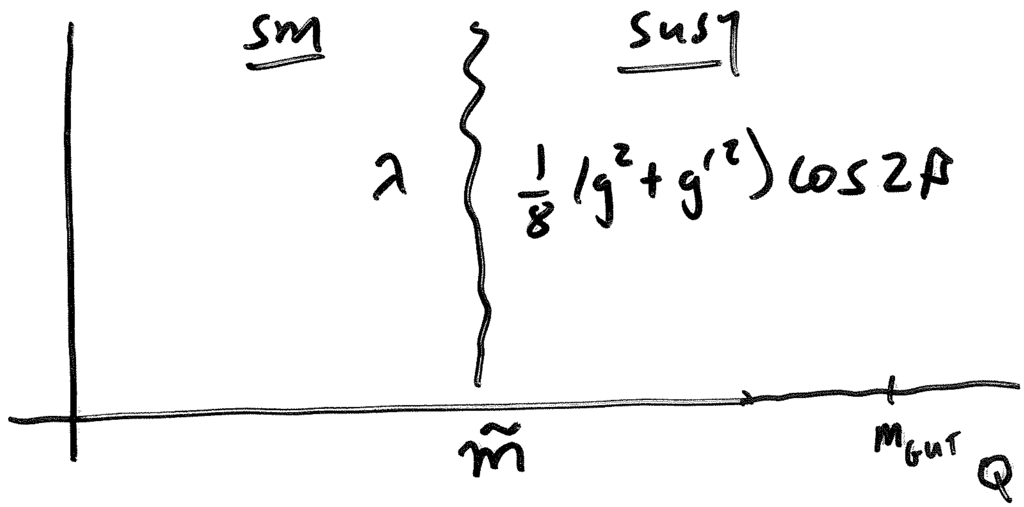
$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{\tilde{m}_t^2}{m_t^2} + \cdots$$

Tree-level value is bounded by $m_Z = 91\,\mathrm{GeV}$. Current lower limit on Higgs boson mass is $114\,\mathrm{GeV}$. Thus, we need $\sim (70\,\mathrm{GeV})^2$ contribution from quantum correction.

Need $\tilde{m}_t \gtrsim 5\,\mathrm{TeV}(0.8\,\mathrm{TeV})$ for $\tan\beta = 2(30)$

For "radical naturalists," this is intolerable. [They go to NMSSM, etc.]

However, Remember: Heavy scalar masses (in particular top squarks) solves this problem. (But Higgs mass stays $\lesssim 170\,\mathrm{GeV}$)



$\tilde{m}_{\text{scalars}} \sim m_{3/2} \gg \tilde{m}_{\text{fermions}}$

Neutrinos and the PeV scale

$\sim 1\,\text{PeV}$ $\sim 1\,\text{TeV}$

The PeV scale might be of independent interest to neutrinos.

Grander picture: Many sectors live at the scale of supersymmetry breaking masses (PeV scale). EW scale happens to be much lighter.

ν^c is not a pure singlet under all the symmetries of these extra sectors. ν^c (and other MSSM states) are charged under a $U(1)'$ such that $LH_u\nu^c$ is not invariant, but we have

$$W = \frac{\lambda}{M_{\text{Pl}}}\phi L H_u \nu^c$$

where ϕ is an exotic field that breaks the $U(1)'$ at the PeV scale and whose charge assignments allow the above operator (but not $\phi^2\nu^c\nu^c$).

We find that

$$m_\nu = \frac{\lambda}{M_{\text{Pl}}}\langle \phi H_u \rangle = (0.07\,\text{eV})\,\lambda \sin\beta \left(\frac{\langle\phi\rangle}{1\,\text{PeV}}\right)$$

This is a very interesting scale for neutrinos.

Atmospheric neutrinos $\Delta m_\nu \simeq 10^{-3}\,\text{eV}$, which can be nicely accommodated by the PeV-scale Dirac neutrinos.

Physics could be very rich at $E \sim 0.1-1$ PeV!