Compressed supersymmetry at the LHC

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`1105.4304` with Tom LeCompte, based on 2010 data, updated here to now reflect 2011 search signal regions reported by ATLAS at EPS-HEP Grenoble (1.04 fb^{-1}).

Q: What is compressed† supersymmetry?

A: Models with the ratio of the strongly interacting superpartners (gluino, squarks) masses to the LSP mass taken to be significantly smaller than in mSUGRA or minimal GMSB.

The traditional mSUGRA and minimal GMSB benchmarks have:

$$M_{\tilde{Q}} \gtrsim M_{\tilde{g}} \approx 3M_{\tilde{W}} \approx 6M_{\rm LSP}$$

Hierarchy between gluino/squark masses and the LSP mass implies plentiful high-p_T jets and large $E_T^{\rm miss}$ at LHC.

† also known as: squashed, squished, squeezed, crunched, scrunched, compacted. . .

What happens if the superpartner mass spectrum is more compressed?

Less visible energy: smaller jet p_T's, $m_{\rm eff}$ or H_T, and $E_T^{\rm miss}$.

Signal looks more like QCD, $t\bar{t}$, W+jets, and Z+jets backgrounds.

Radiation of additional QCD jets is important; supplies transverse kick. (Alves, Izaguirre, Wacker 2010, 2011.)

Motivation 1: the LHC vs. SUSY Models, 2010/2011

Motivation 2: the SUSY little hierarchy problem

Electroweak symmetry breaking seems to imply a percent-level fine-tuning:

$$\frac{1}{2}m_Z^2 \;=\; |m_{H_u}^2| - |\mu|^2 + \text{loop corrections} + \mathcal{O}(1/\tan^2\beta).$$

Less fine-tuning if $|m_{H_u}^2|$ and $|\mu|^2$ are small.

Claim: this points to a more compressed superpartner mass spectrum.

Fine tuning of the electroweak scale is reduced if the pernicious influence of the gluino is suppressed.

(G. Kane and S. King, `hep-ph/9810374`)

$$
\begin{aligned}
-m_{H_u}^2 &= 1.92 M_3^2 + 0.16 M_2 M_3 - 0.21 M_2^2 \\
&\quad -0.63 m_{H_u}^2 + 0.36 m_{t_L}^2 + 0.28 m_{t_R}^2 \\
&\quad + \text{many terms with small coefficients}
\end{aligned}
$$

The parameters on the right are at the GUT scale, result is at the TeV scale.

If one takes a smaller gluino mass at the GUT scale, say $M_3/M_2 \sim 1/3$, then $|m_{H_u}^2|$ will be much smaller.

For example, one can parametrize:

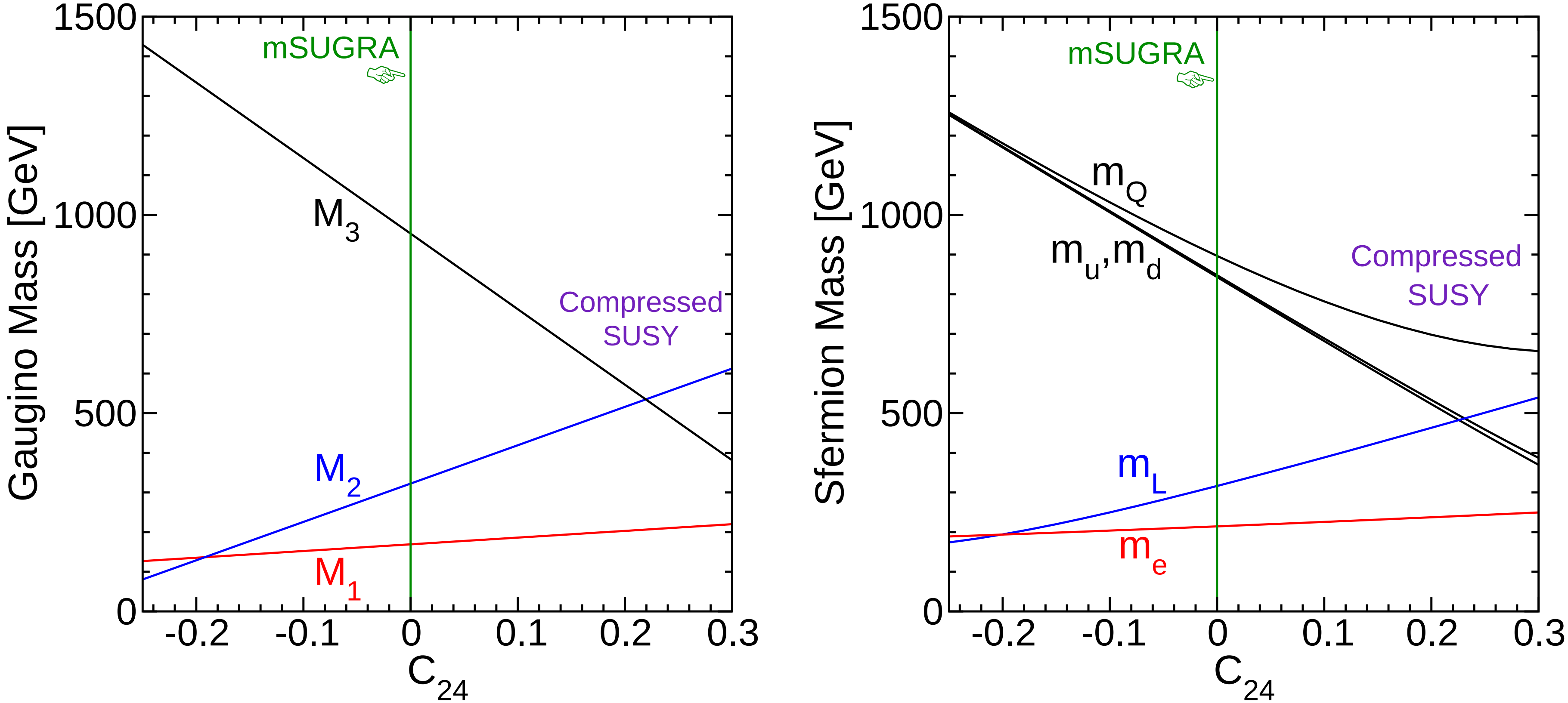
$$
\begin{aligned}
M_1 &= m_{1/2}(1 + C_{24}), \\
M_2 &= m_{1/2}(1 + 3C_{24}), \\
M_3 &= m_{1/2}(1 - 2C_{24}).
\end{aligned}
$$

if the F terms that break SUSY include both a singlet and a $\mathbf{24}$ of $SU(5)$ or a $\mathbf{54}$ of $SO(10)$.

The special case $C_{24} = 0$ recovers the usual mSUGRA model.

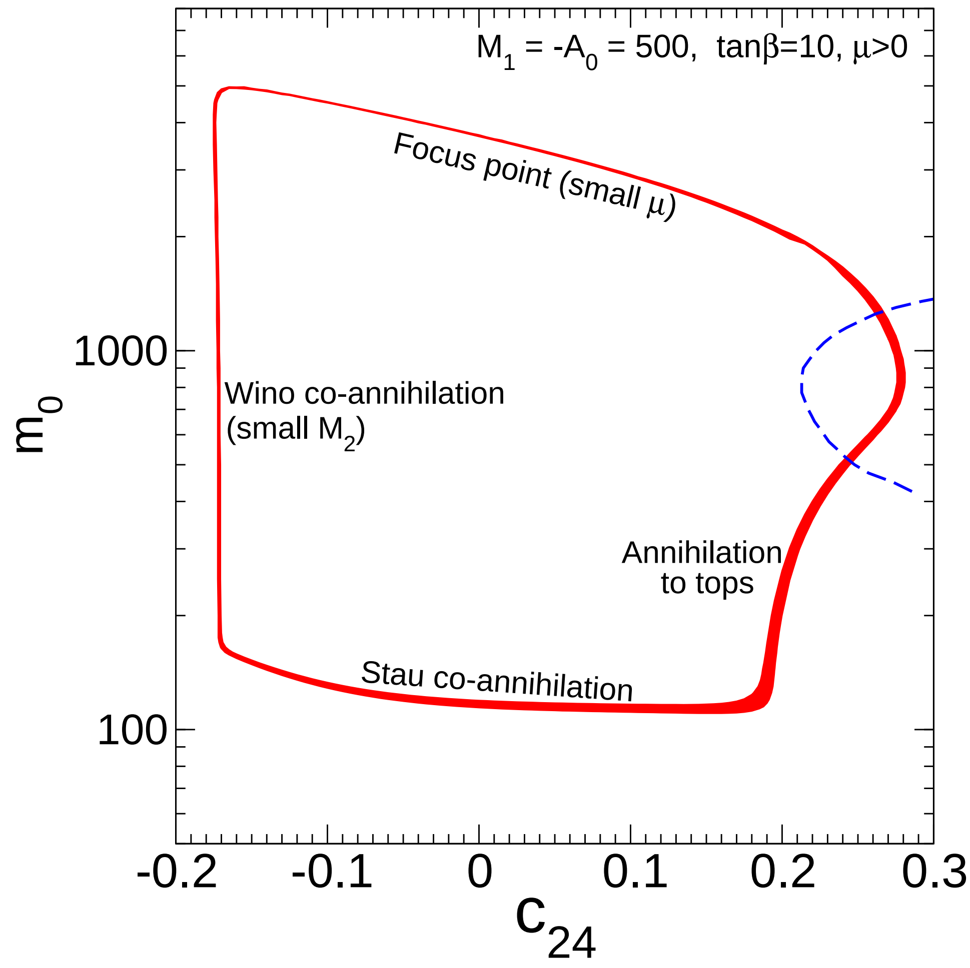
What are the effects of C_{24} on the MSSM mass spectrum?

For $m_{1/2} = 500$ GeV, $m_0 = 150$ GeV, weak-scale parameters are:



"Compressed SUSY" arises for $C_{24} \gtrsim 0.15$. This ameliorates the little hierarchy problem, and allows for the correct thermal abundance of LSP dark.

In this enlarged parameter space, different dark matter allowed regions are continuously connected:



Red region is allowed by $\Omega_{\mathrm{CDM}} h^2 = 0.11 \pm 0.02$.

Points to the right of the dashed blue line have $M_h < 113$ GeV.

Too much dark matter inside the pentagon, too little outside.

For study: consider models that generalize mSUGRA by including a "compression factor" c. At the TeV scale:

$$M_1 = \left(\frac{1+5c}{6}\right) M_{\tilde{g}}, \qquad M_2 = \left(\frac{1+2c}{3}\right) M_{\tilde{g}},$$

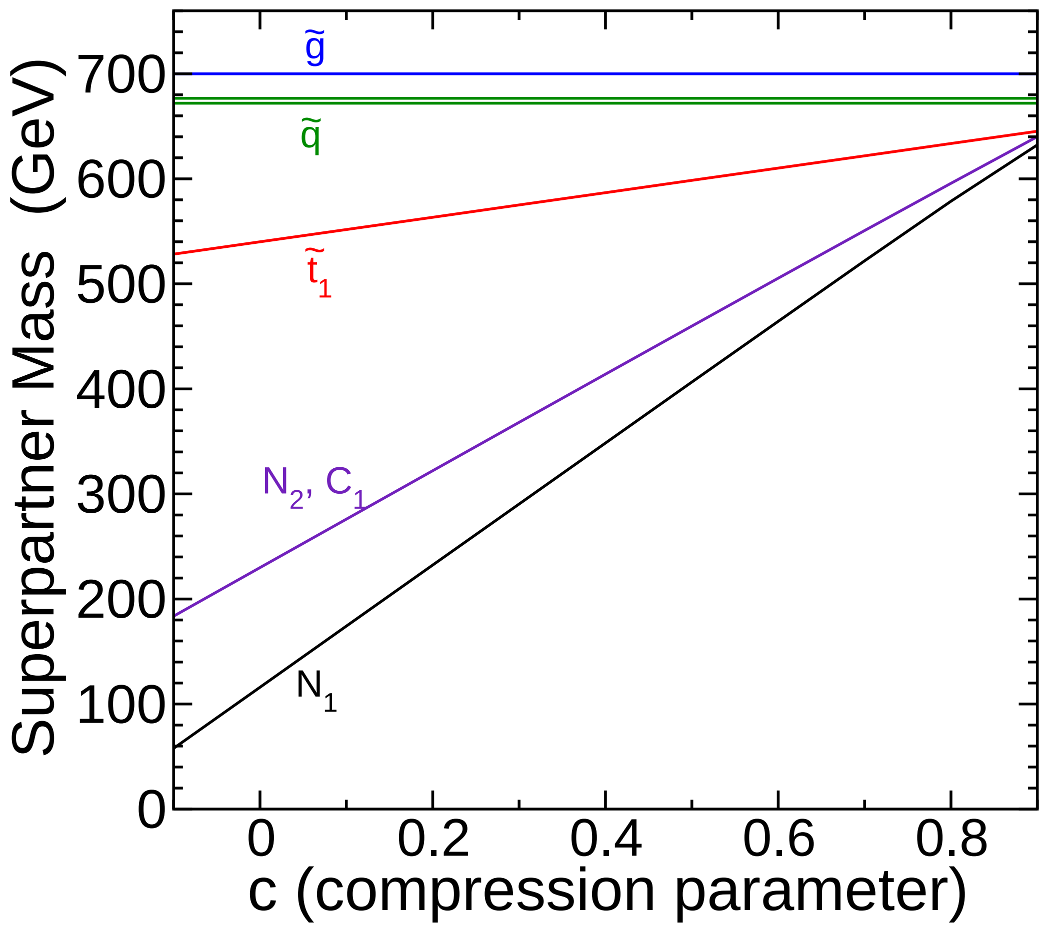
- $c = 0$ corresponds to mSUGRA.
- $c = 1$ is total compression (gauginos degenerate).

Also take $\tan\beta = 10$, $\mu > 0$, and squark masses

$$M_{\tilde{Q}} = 0.96 M_{\tilde{g}}.$$

Variable input parameters: $M_{\tilde{g}}$ (overall superpartner mass scale) and c (compression factor).

Masses of important superpartners, as a function of c, for $M_{\tilde{g}} = 700$ GeV:



Use ATLAS cuts from Summer 2011 (EPS) data analyses, including:

	A	B	C	D	E
number of jets	≥ 2	≥ 3	≥ 4	≥ 4	≥ 4
$p_T(j_1)$ [GeV]	> 130	> 130	> 130	> 130	> 130
$p_T(j_n)$ [GeV]	> 40	> 40	> 40	> 40	> 80
$m_{\rm eff}$ [GeV]	> 1000	> 1000	> 500	> 1000	$> 1100^\dagger$
$E_T^{\rm miss}/m_{\rm eff}$	> 0.3	> 0.25	> 0.25	> 0.25	> 0.2
1.04 fb^{-1} limit	$<$ 24 fb	$<$ 30 fb	$<$ 477 fb	$<$ 32 fb	$<$ 17 fb

I. Vivarelli talk, EPS-HEP Grenoble 2011

† inclusive $m_{\rm eff}$: sum jets with $p_T > 40$

Limits are 95% CL on cross-section times acceptance.

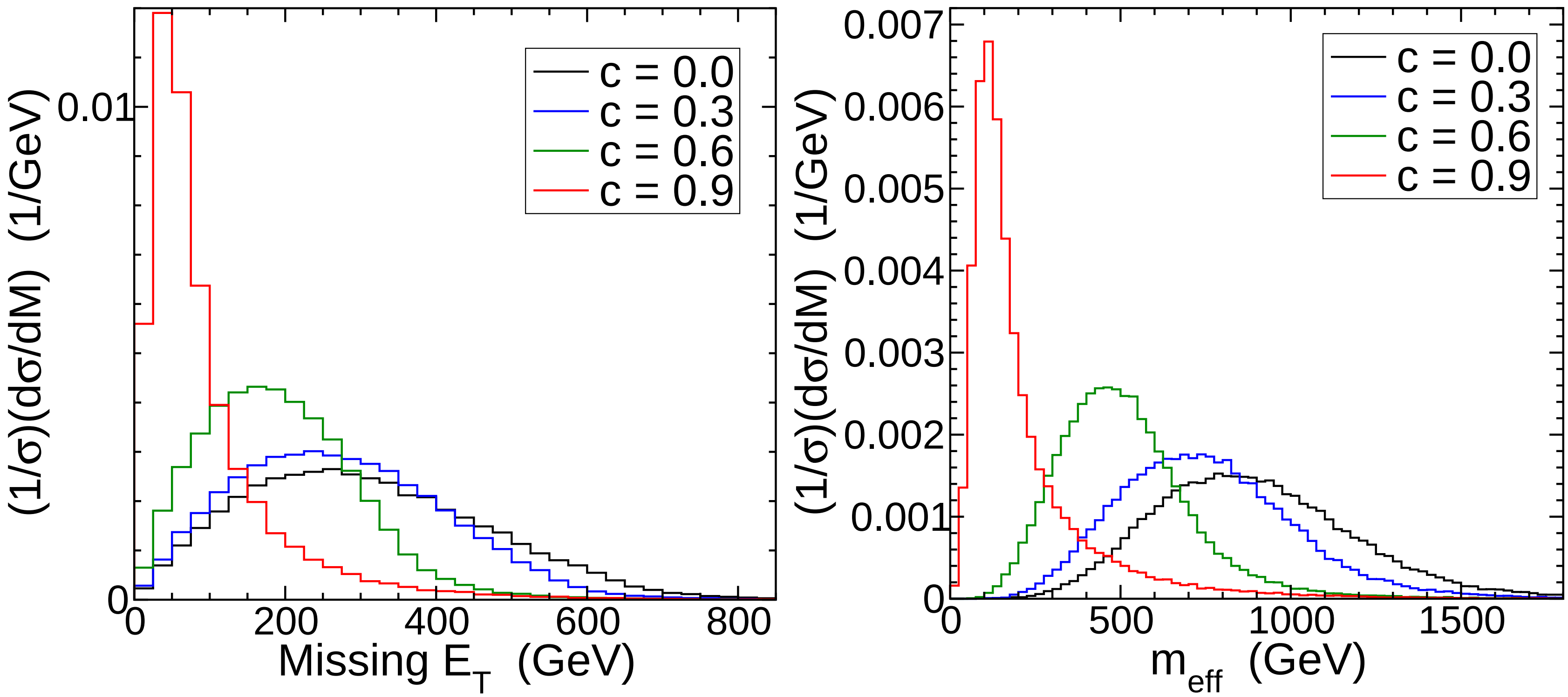
Used MadGraph/MadEvent to generate hard scattering events, Pythia for decays and showering and hadronization, PGS4 for detector simulation.

Matrix element and shower/hadronization jet matching done with MLM method by including 1 extra jet at matrix element level for each signal process.

This is potentially important when the mass spectrum is compressed, but with our setup we found it didn't make a huge difference.

Cross-sections for $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{Q}$, $\tilde{g}\tilde{Q}^*$, $\tilde{Q}\tilde{Q}$, $\tilde{Q}\tilde{Q}^*$, $\tilde{Q}^*\tilde{Q}^*$, $\tilde{t}_i\tilde{t}_i^*$, $\tilde{b}_i\tilde{b}_i^*$, normalized to Prospino.

$E_T^{\rm miss}$, $m_{\rm eff}$ distributions for $M_{\tilde{g}} = 700$ GeV, and $c = 0.0$, 0.3, 0.6, 0.9.

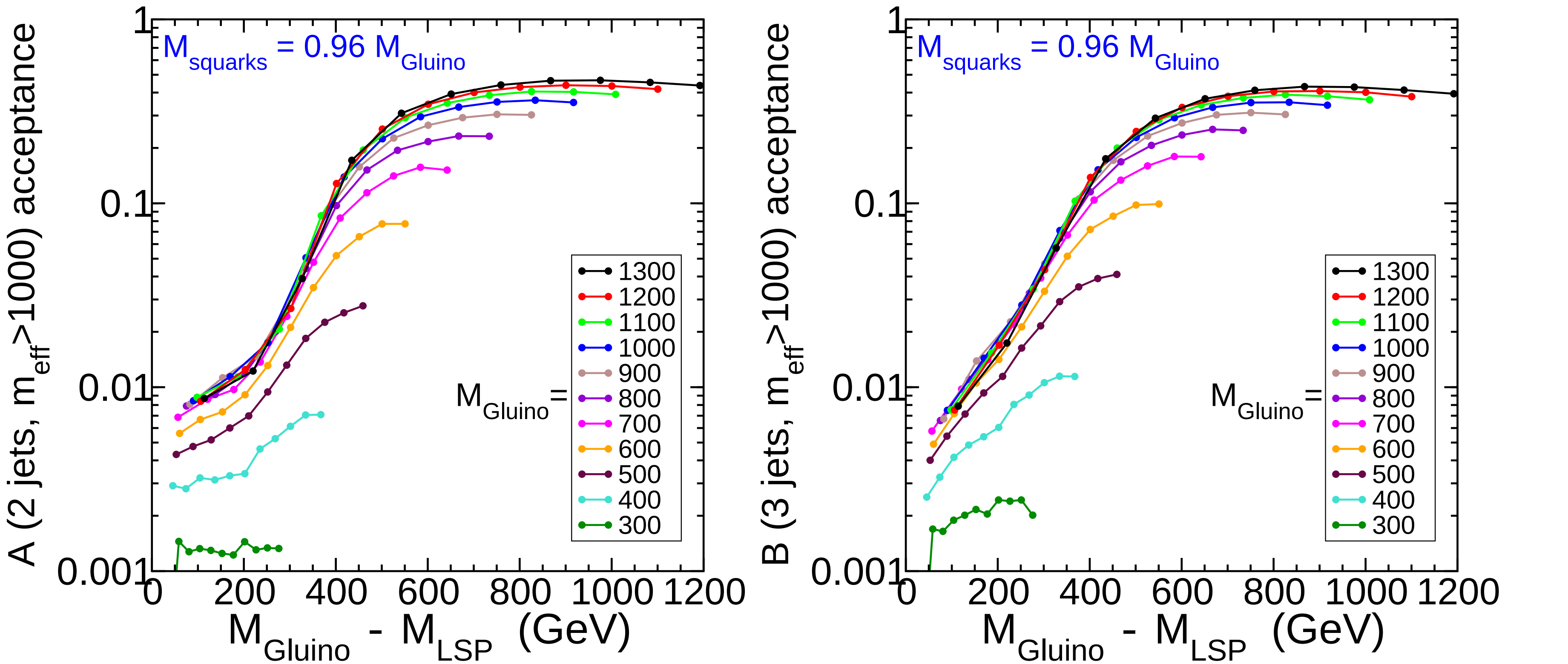


As c increases, $m_{\rm eff}$ gets soft faster than $E_T^{\rm miss}$ does.

For moderate compression, acceptance can even increase with c; more events pass $E_T^{\rm miss}/m_{\rm eff} >$ cuts.

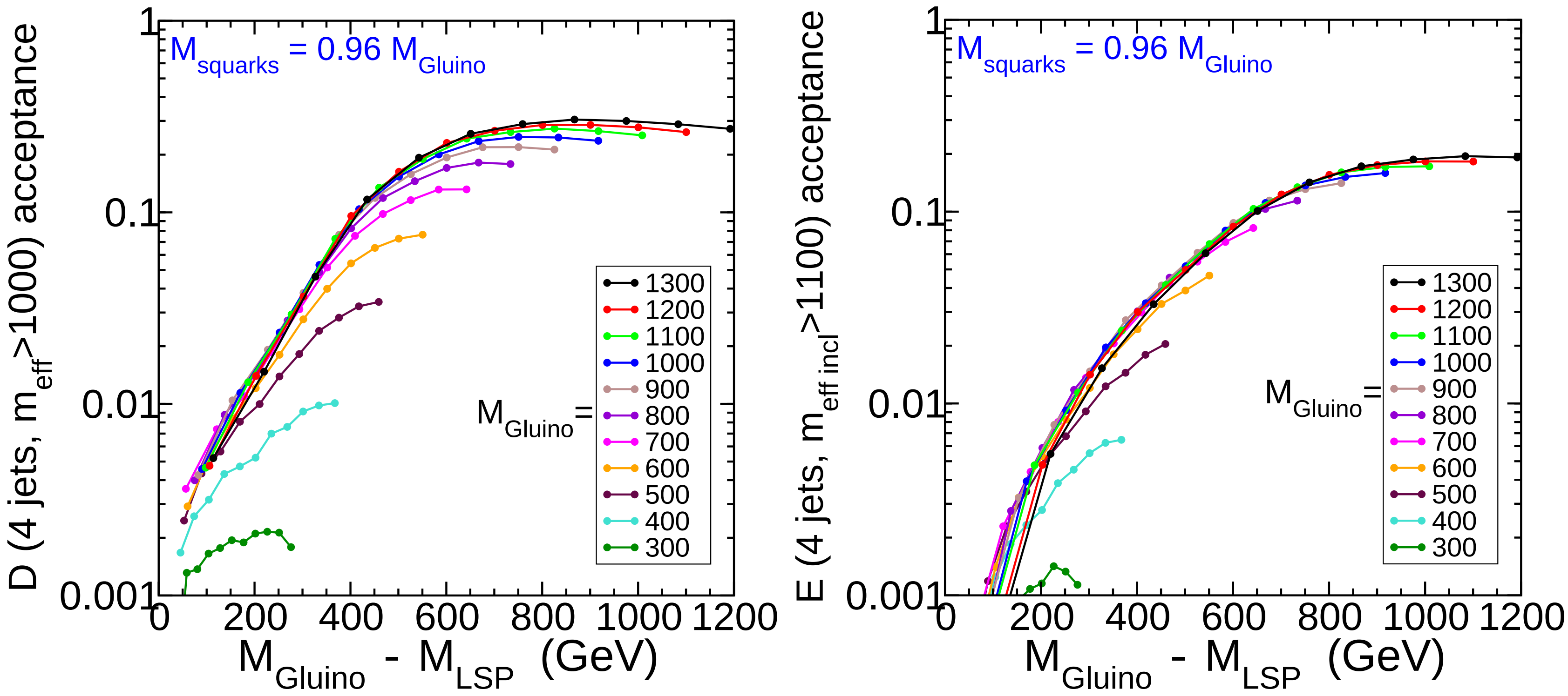
Distributions become very soft at high compression c.

A and B acceptances for $M_{\tilde{g}} = 300, 400, 500, \ldots 1300$ GeV:

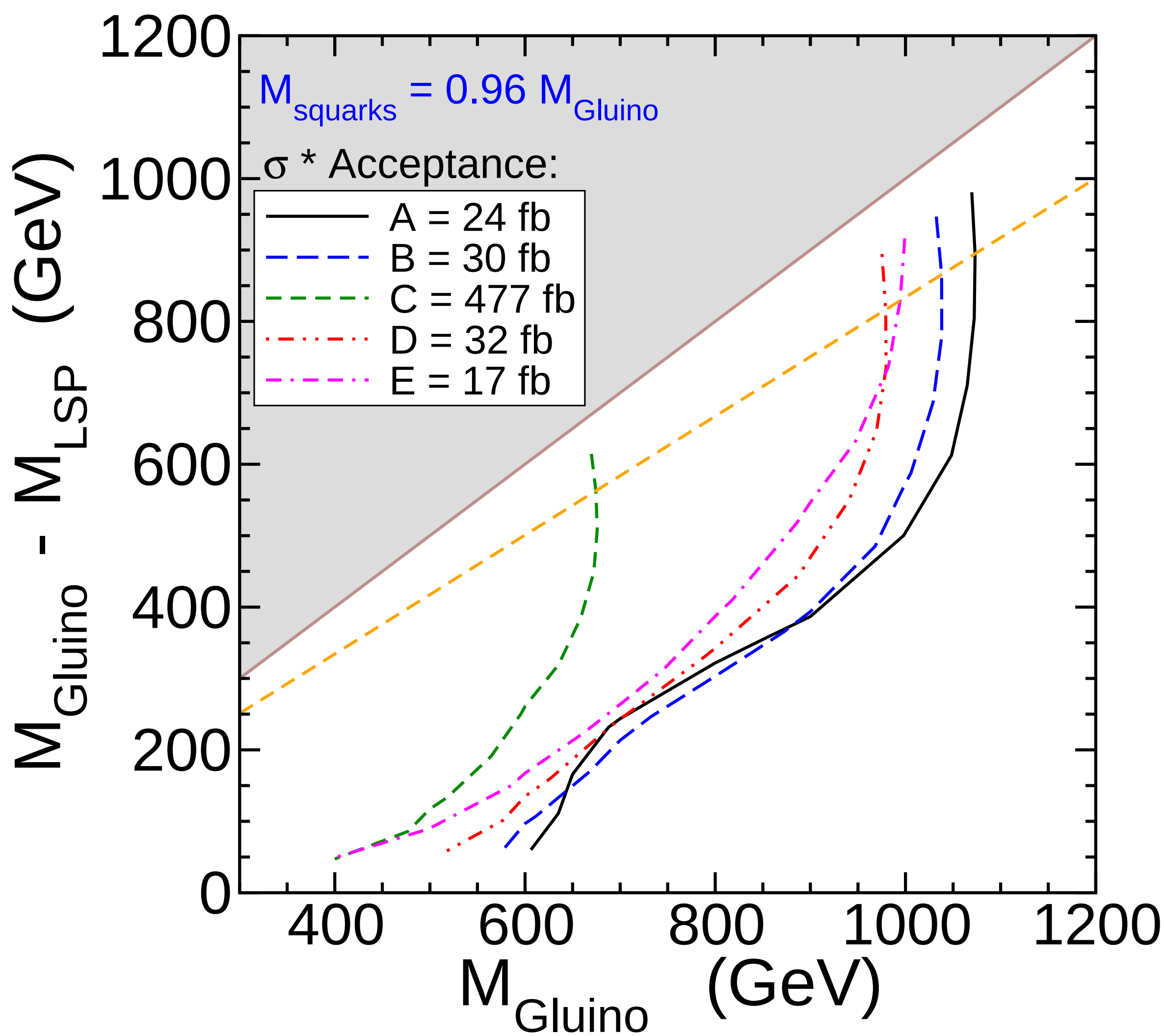


Dots on each line are at $c = -0.1,\ 0,\ 0.1,\ \ldots,\ 0.9$ from right to left.

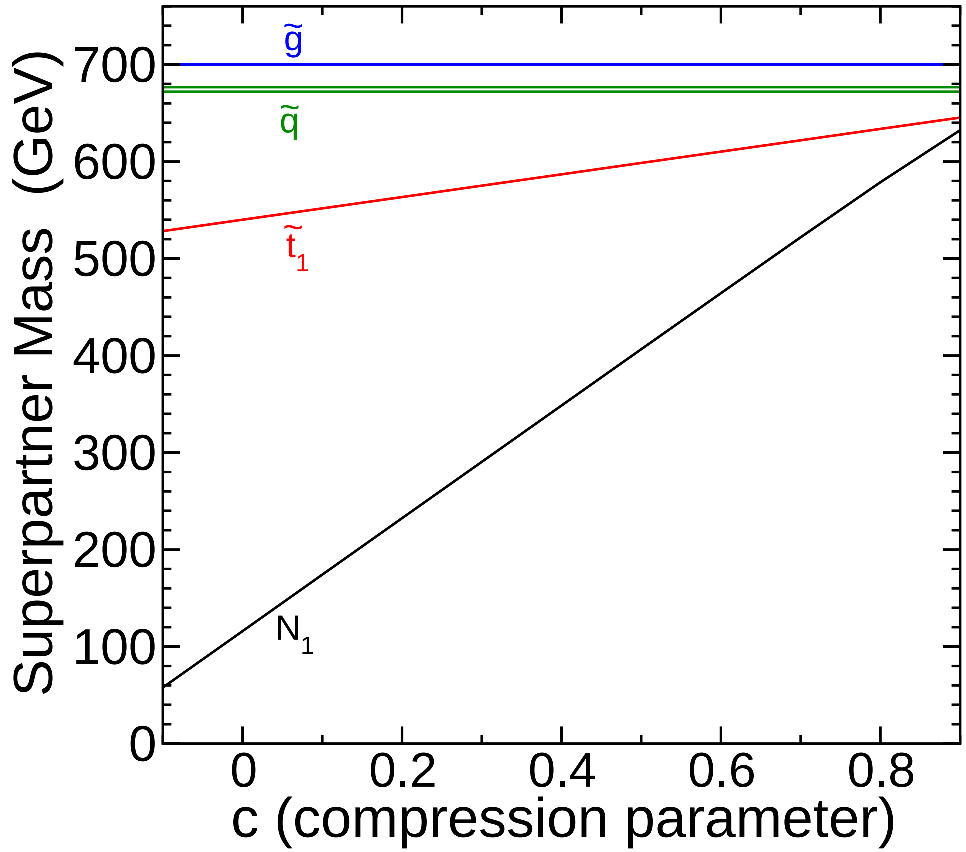
D and E acceptances are somewhat worse for this class of models, especially at extreme compression:



$\sigma \times$ Acceptance contours, corresponding to the ATLAS 1.04 fb^{-1} limits reported at EPS-HEP Grenoble 2011:

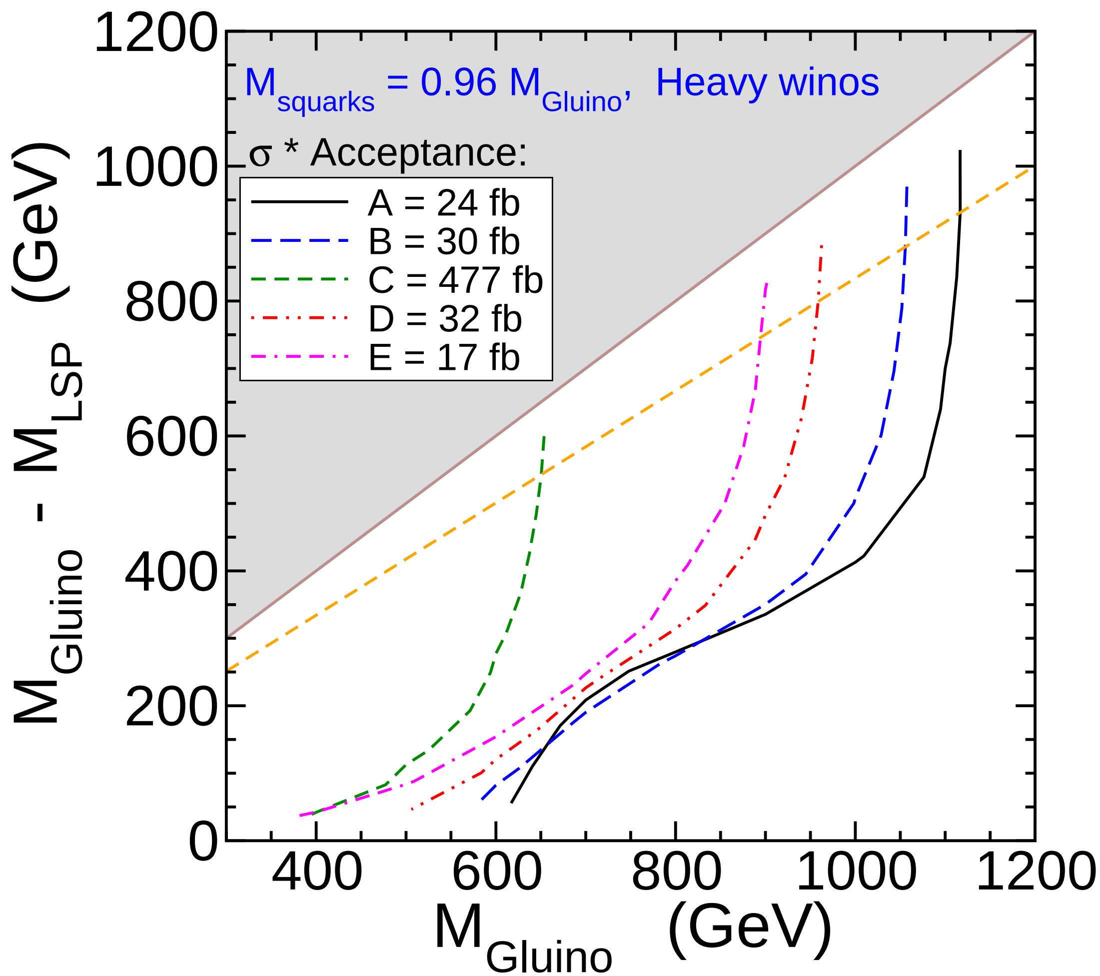


Now consider a modified model in which the winos are taken much heavier, spectrum otherwise the same:



This gives a stronger signal, because visible energy is shared among fewer jets. Note $\tilde{g} \to t\tilde{t}_1$ is kinematically forbidden.

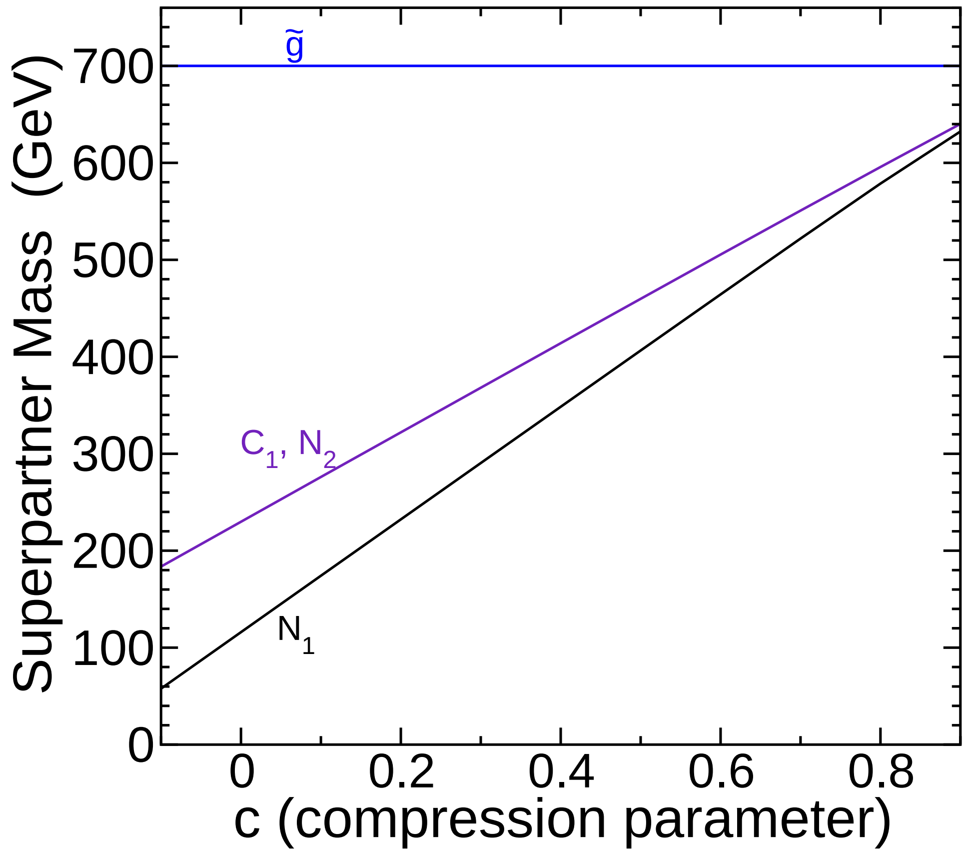
$\sigma\times$ Acceptance contours corresponding to the ATLAS 2011 EPS 1.04 fb^{-1} limits, for Heavy Wino models:



Limits slightly stronger, still down to nearly $M_{\tilde{g}} = 600$ for $c = 1$.

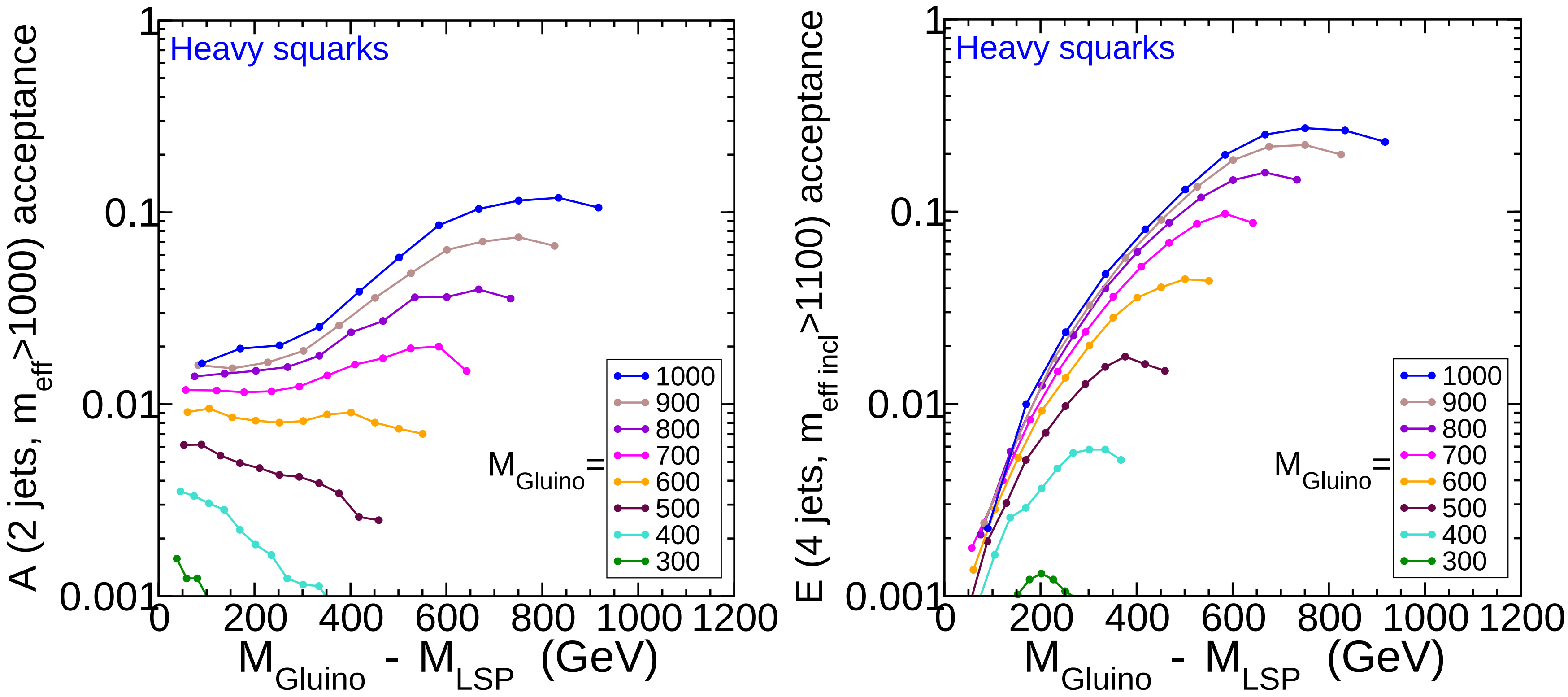
What if squarks are much heavier?

Consider variable $M_{\tilde{g}}$ and compression parameter c as before, but now take squarks out of the picture: $M_{\tilde{Q}} = M_{\tilde{g}} + 1000\ \mathrm{GeV}$.

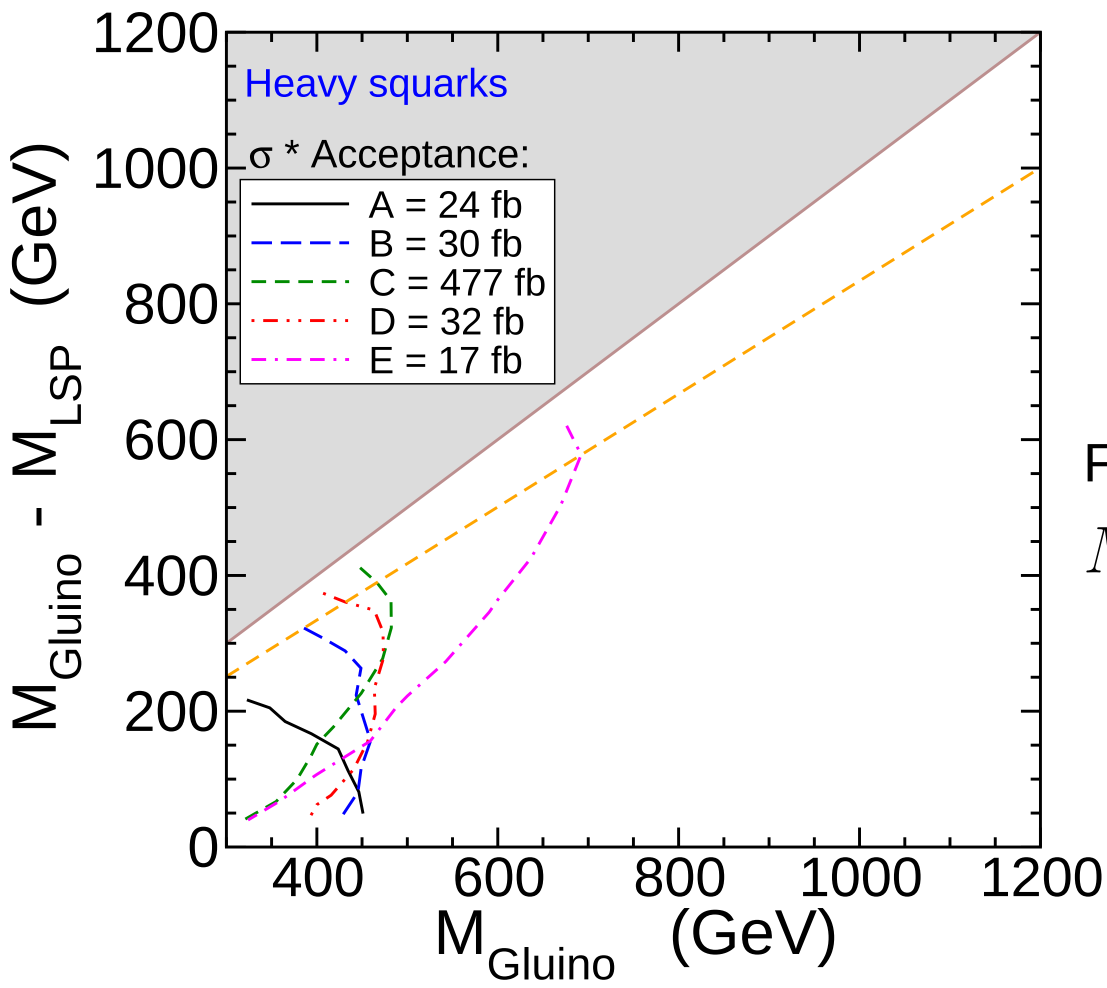


Now $\tilde{g} \to jj\tilde{W} \to jjjj + E_T^{\mathrm{miss}}$ dominates.

For low compression, signal E (4 jets, inclusive $m_{\rm eff}$) wins, but as the compression increases, B (3 jets) and then A (2 jets) take over.



$\sigma\times$ Acceptance contours corresponding to the ATLAS 2011 EPS 1.04 fb^{-1} limits, for Heavy Squark models:



For extreme compression, $M_{\tilde{g}}$ limit is only $\sim$450 GeV.

What to do?

ATLAS defines:

$$m_{\text{eff}} = E_T^{\text{miss}} + \sum_{i=1}^{n} p_T(j_n)$$

where $n =$ the number of jets required by the signal (except for signal E).

For more compression of masses, m_{eff} gets soft faster than E_T^{miss} does. A high m_{eff} cut is deadly unless one includes many (≥ 4) jets.

But, with compressed SUSY, requiring 4 hard jets also kills the signal.

Suggestions:

- Require fewer jets (or lower p_T threshold for subleading jets), but sum over more of them in defining $m_{\rm eff}$,

  AND/OR

- Choose lower cut on $m_{\rm eff}$ (750 GeV?), and a higher cut on $E_T^{\rm miss}/m_{\rm eff}$ (0.35?) to compensate.
- Collect more data and be patient. . .

Outlook

- With mild to moderate compression, acceptances are not bad, and sometimes even better than mSUGRA.

- Acceptances do drastically decrease for more severe compression. (Even more dramatic for 1-lepton signal, not shown.)

- Compressed SUSY might contribute to QCD background control regions (used to estimate backgrounds from data) in a more significant way than in mSUGRA (?)

- Try lower $m_{\rm eff}$ cut, including more jets but requiring fewer, and higher $E_T^{\rm miss}/m_{\rm eff}$ cut?