LHC reach for supersymmetric models with compressed mass spectra

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Based on work with Tom LeCompte, to appear soon.

The LHC vs. Supersymmetric Models, 2010/2011

Searches and projections by ATLAS and CMS typically based on mSUGRA models, with common gaugino mass $M_{1/2}$, common scalar mass m_0 at the GUT scale.

Significant hierarchy between gluino/squark masses and the LSP mass leads to high-p_T jets and large E_T^{miss}.

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

What happens if the superpartner mass spectrum is more compressed?

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

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

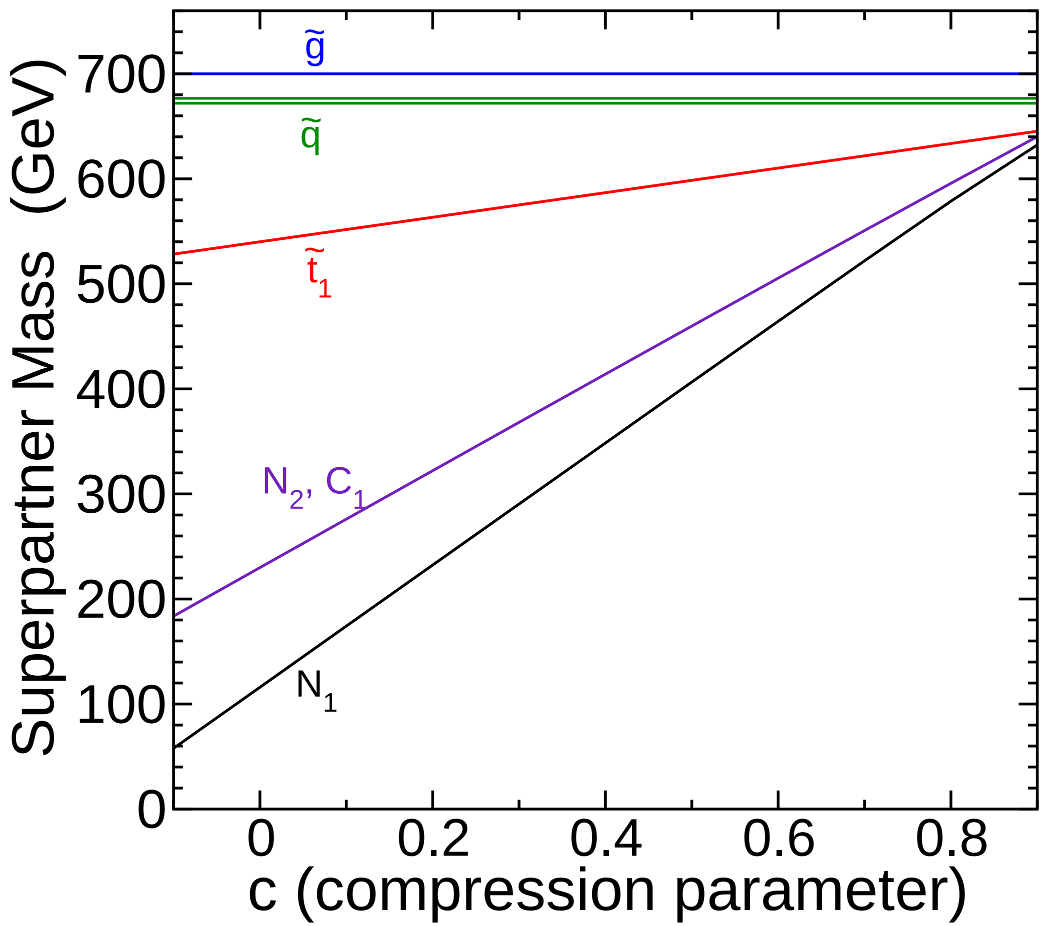
- $c = 0$ corresponds to mSUGRA.
- $c = 1$ is total compression (gauginos degenerate).

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 2010 data analyses:

	A	C	D	L
Number of jets	≥ 2	≥ 3	≥ 3	≥ 3
Leading jet p_T [GeV]	> 120	> 120	> 120	> 60
Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 30
$m_{\rm eff}$ [GeV]	> 500	> 500	> 1000	> 500
$E_T^{\rm miss}/m_{\rm eff}$	> 0.3	> 0.25	> 0.25	> 0.25
Number of leptons	$= 0$	$= 0$	$= 0$	$= 1$
Lepton p_T [GeV]	–	–	–	> 20
m_T [GeV]	–	–	–	> 100

For simplicity, I will concentrate on signals C and D in this talk.

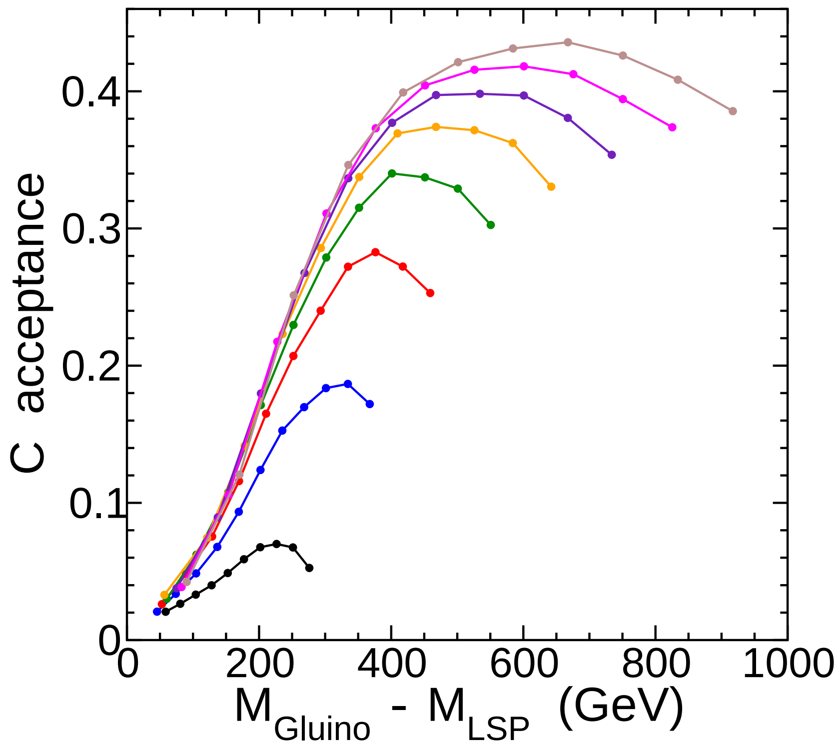
Used MadGraph/MadEvent to generate hard scattering events, Pythia for decays and showering and hadronization, PGS4 for detector simulation.

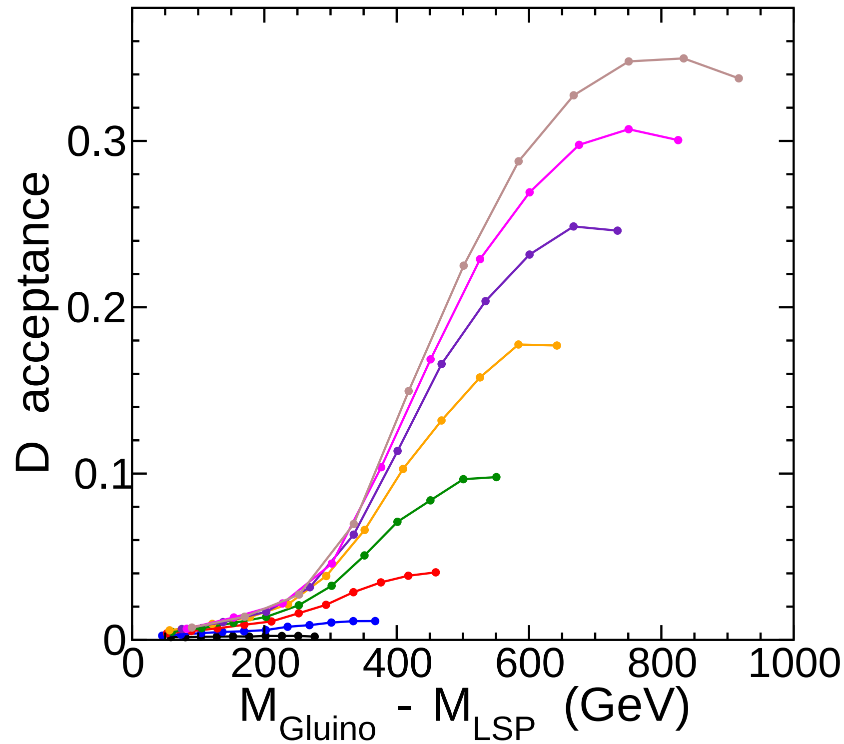
Matrix element and shower/hadronization jet matching done with MLM method by including 1 extra jet at matrix element level for each signal process.

This is potentially important when the mass spectrum is compressed, but we found it doesn’t make a huge difference.

Cross-sections for $\tilde{g}\tilde{g},\quad \tilde{g}\tilde{Q},\quad \tilde{g}\tilde{Q}^*,\quad \tilde{Q}\tilde{Q},\quad \tilde{Q}\tilde{Q}^*,\quad \tilde{Q}^*\tilde{Q}^*$ normalized to Prospino 2.1.

C and D acceptances for $M_{\tilde{g}} = 300$, 400, 500, 600,. . . , 1000 GeV:



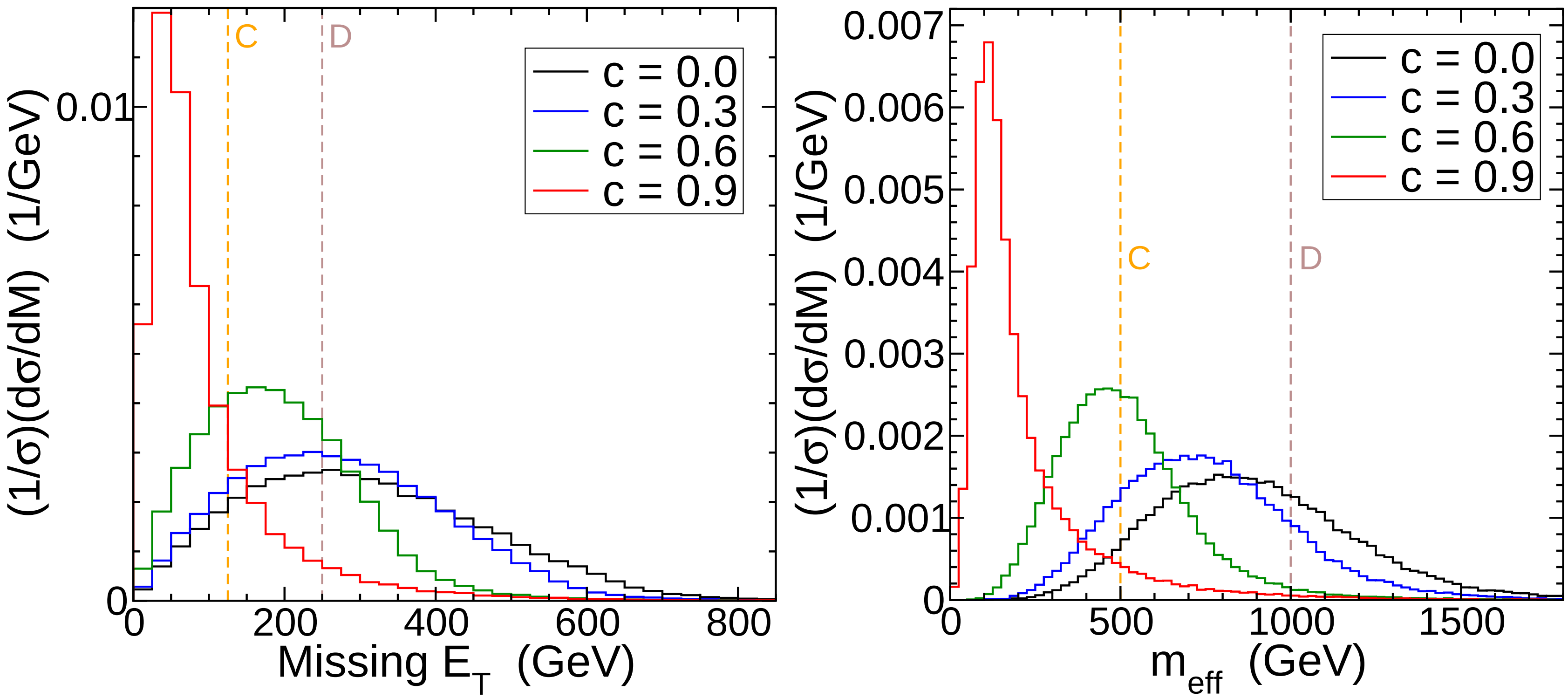


Dots on each line are at $c = -0.1,\ 0,\ 0.1,\ \ldots,\ 0.9$ from R to L.

For C (and A), acceptance largest at *higher* compression than mSUGRA.

For D (and L), acceptance very low at moderate to high compression.

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

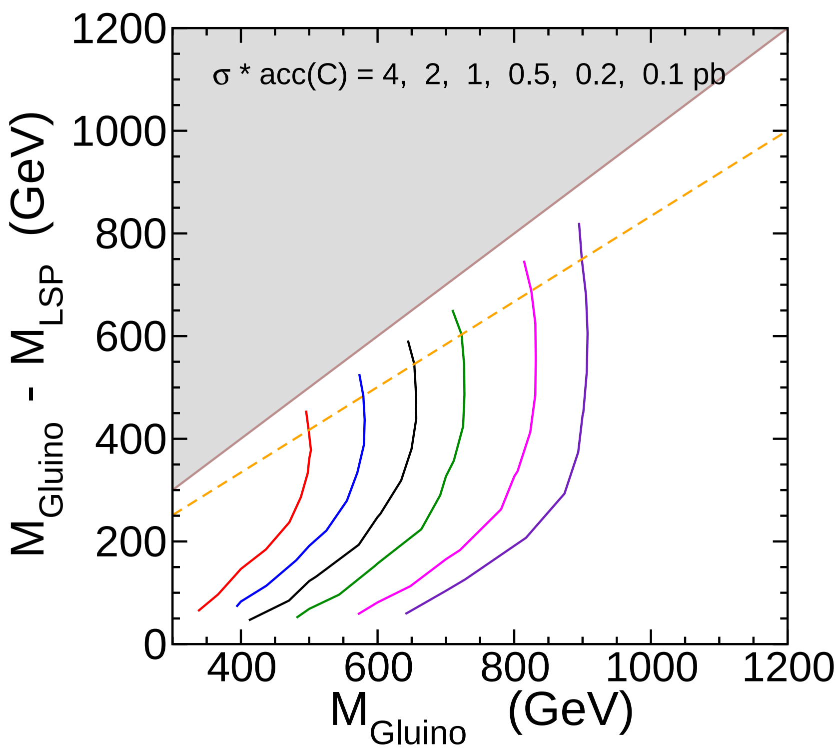


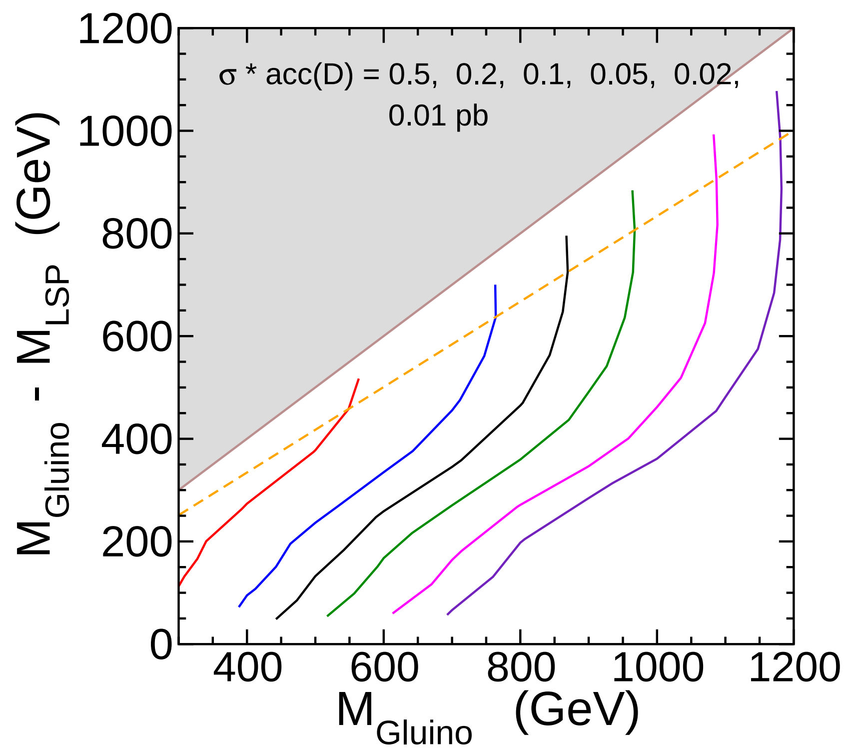
As c increases, $m_{\rm eff}$ gets soft faster than $E_T^{\rm miss}$ does.

For moderate compression, acceptance can even increase with c; more events pass $E_T^{\rm miss}/m_{\rm eff} > 0.25$ cut.

Distributions become very soft at high compression c.

$\sigma \times$ Acceptance contours for signals C and D:



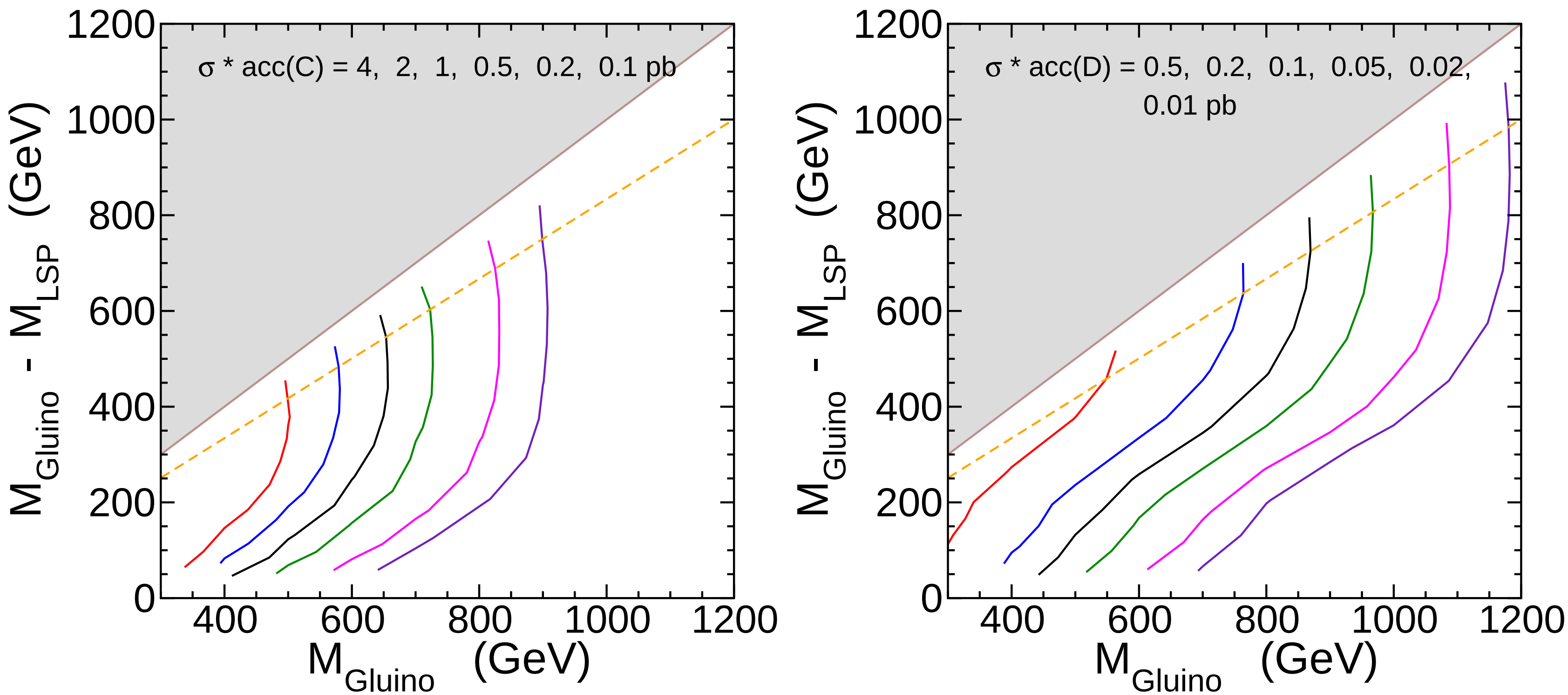


ATLAS 35 pb^{-1} data from 2010 excludes perhaps

$\sigma \times$ Acceptance = 1.1 pb for C and 0.11 pb for D,

if background estimates are same as for mSUGRA models.

$\sigma\times$ Acceptance contours for signals C and D:

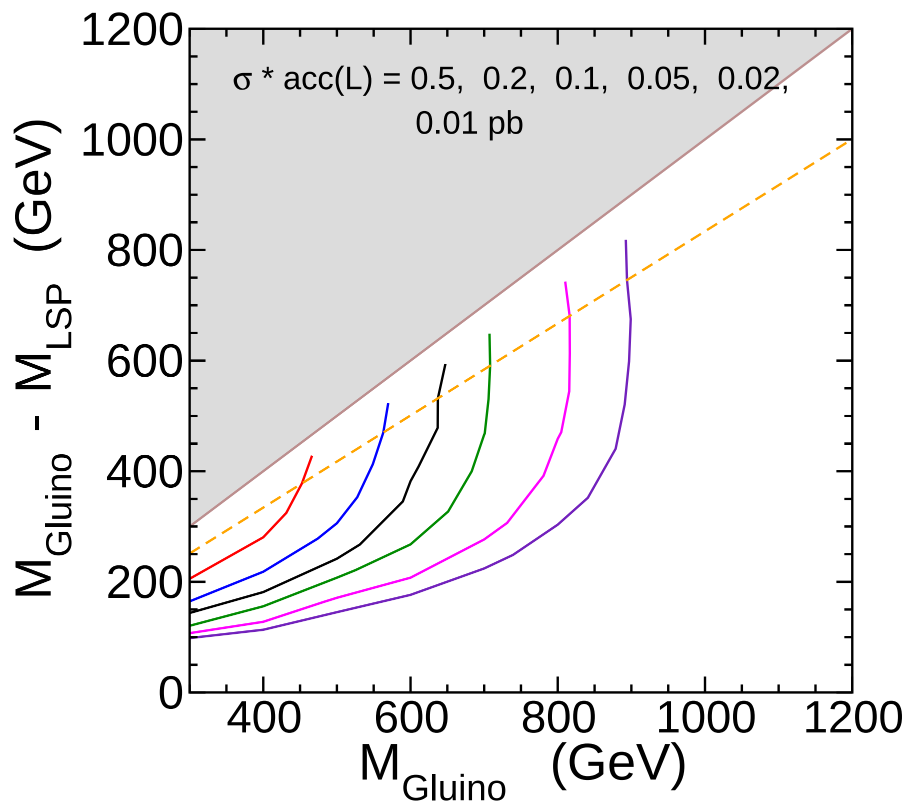


If $M_{\tilde{g}} < 850$ GeV is excluded in mSUGRA model, then estimate:

$M_{\tilde{g}} < 650$ GeV is excluded for $M_{\tilde{g}} - M_{\mathrm{LSP}} = 300$ GeV,

$M_{\tilde{g}} < 500$ GeV is excluded if $M_{\tilde{g}} - M_{\mathrm{LSP}} = 100$ GeV.

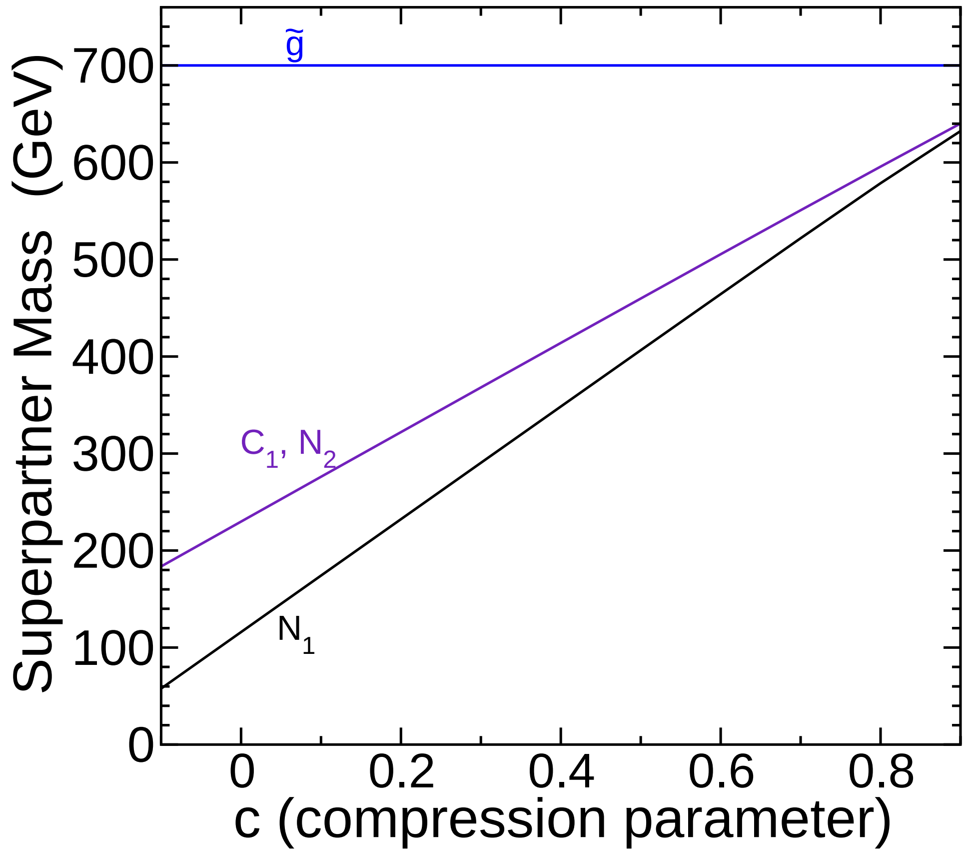
The single lepton signal L performs much worse than the all-jets signals at high compression:



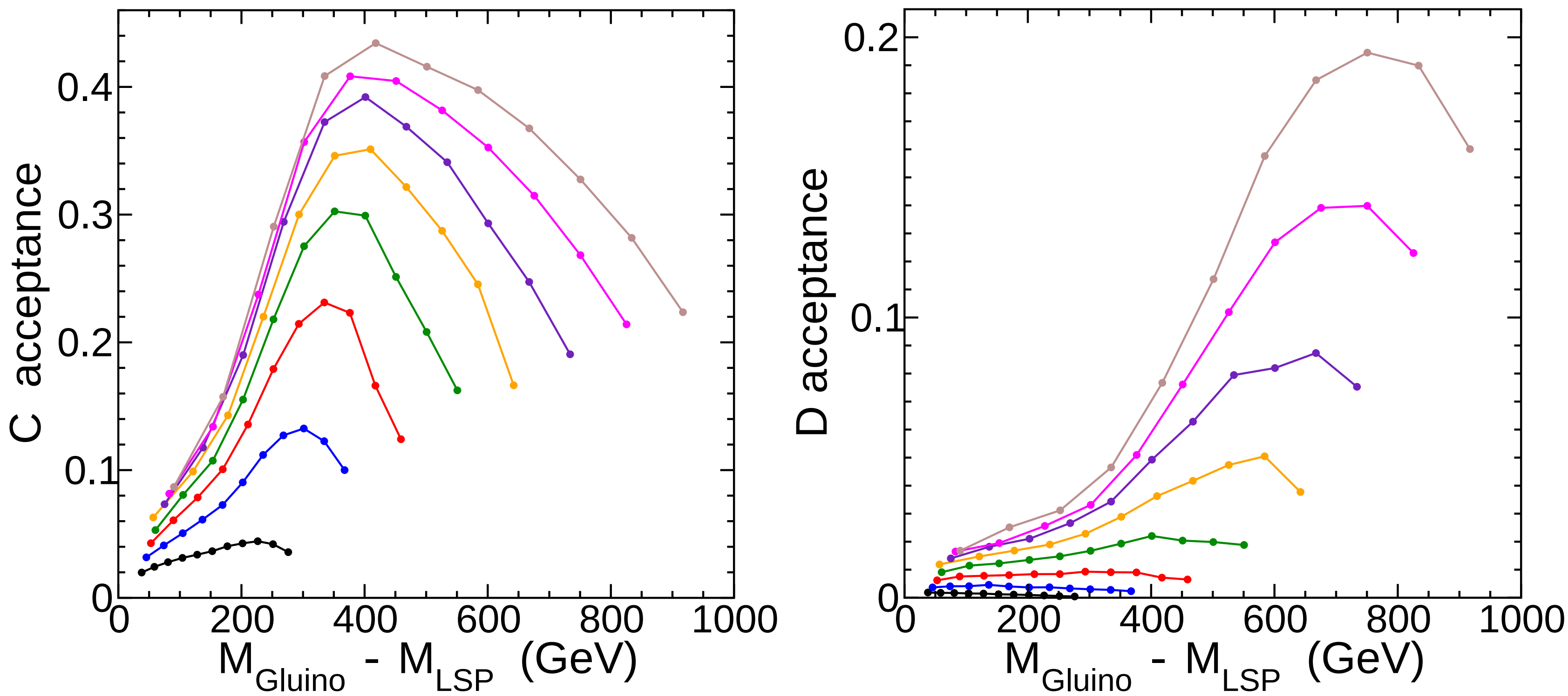
Leptons pass the $p_T^\ell > 20$ GeV and $m_T > 100$ GeV cuts very rarely when $M_{\tilde{g}} - M_{\tilde{N}_1} \lesssim 200$ GeV, and never when $\lesssim 100$ GeV.

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: $M_{\tilde{Q}} = M_{\tilde{g}} + 1000 \text{ GeV}.$



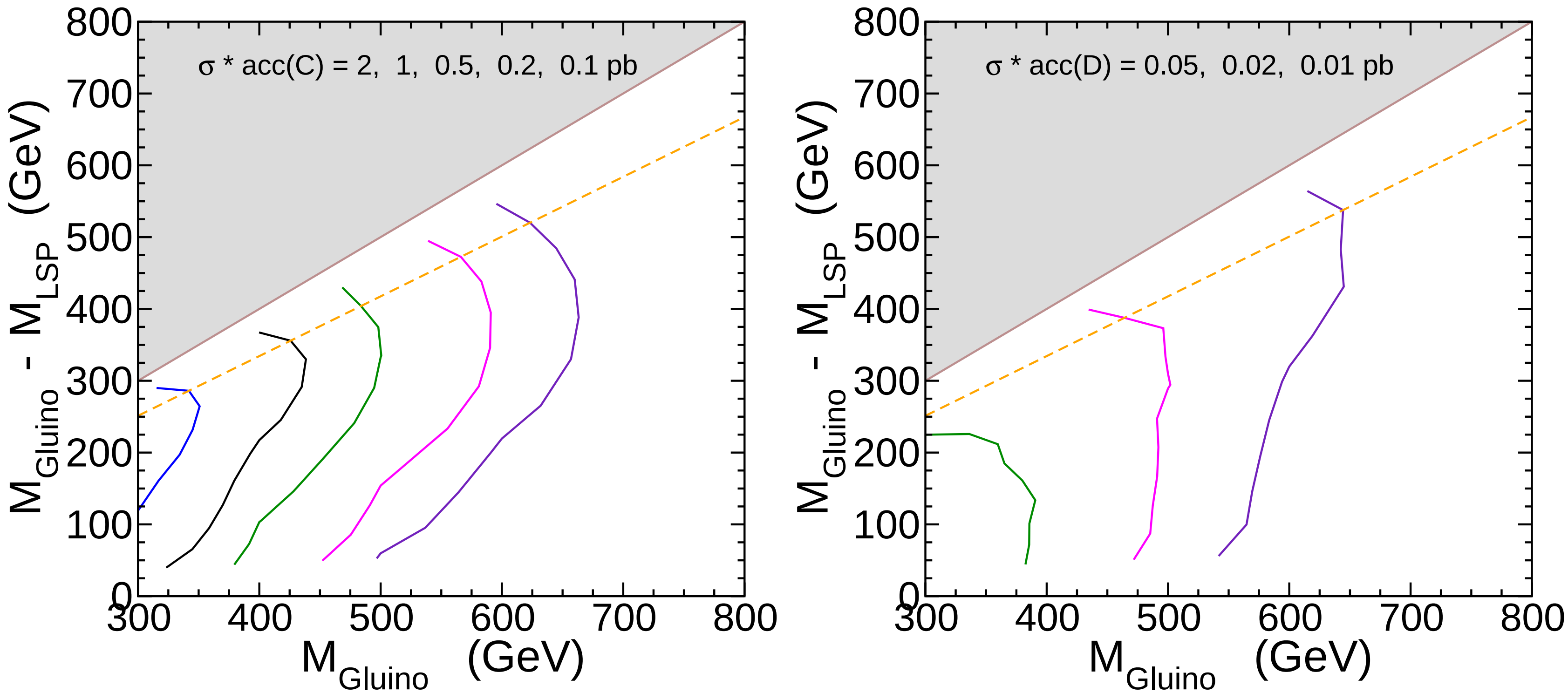
C and D acceptances for $M_{\tilde{g}} = 300, 400, 500, 600, \ldots, 1000$ GeV:



Multi-stage decays lead to strongly **enhanced** C acceptance for moderate compression.

As before, more events pass the $E_T^{\rm miss}/m_{\rm eff} > 0.25$ cut, because $m_{\rm eff}$ gets softer much faster than $E_T^{\rm miss}$ does.

$\sigma\times$ Acceptance contours for signals C and D, with heavy squarks:



Reach is much lower with only gluino-gluino production (squarks decouple).

Exclusion from 2010 data is only about $M_{\tilde{g}} > 400$ GeV for mSUGRA (from signal C), worse for compressed cases.

What to do?

The most devastating cut at high compression is on $m_{\rm eff}$.

ATLAS defines:

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

where $n = 2$ or 3, the number of jets required by the signal.

SUSY cascade decays naturally split the visible energy into more than 3 jets.

Signals might be enhanced by

- Summing over leading 4 jets in $m_{\rm eff}$, or even all jets in the event.
- Choosing an intermediate cut on $m_{\rm eff}$, say 700 GeV, instead of 500 GeV or 1000 GeV.

Conclusion

- With mild to moderate compression, acceptances are not bad, and sometimes even better than mSUGRA. This is especially true for lower m_{eff} cut.
- Acceptances do drastically decrease for more severe compression, especially for signal D ($m_{\text{eff}} >$ 1000 GeV) and for 1-lepton signal.
- Compressed SUSY might contribute to QCD background control regions (used to estimate backgrounds from data) in a more significant way than in mSUGRA (?)
- Suggest intermediate cut on m_{eff}, between 500 and 1000 GeV.
- Signals that cut on m_{eff} involving more than 3 jets should be tried.