Beautiful early SUSY searches

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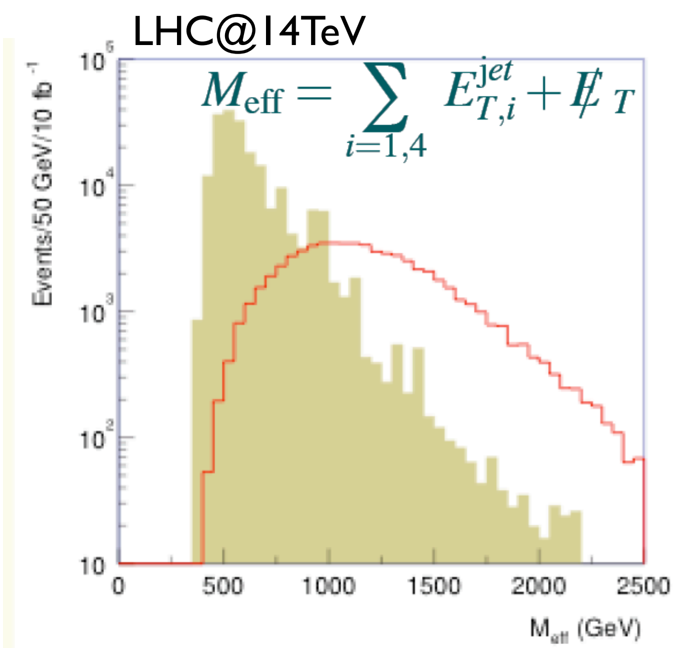
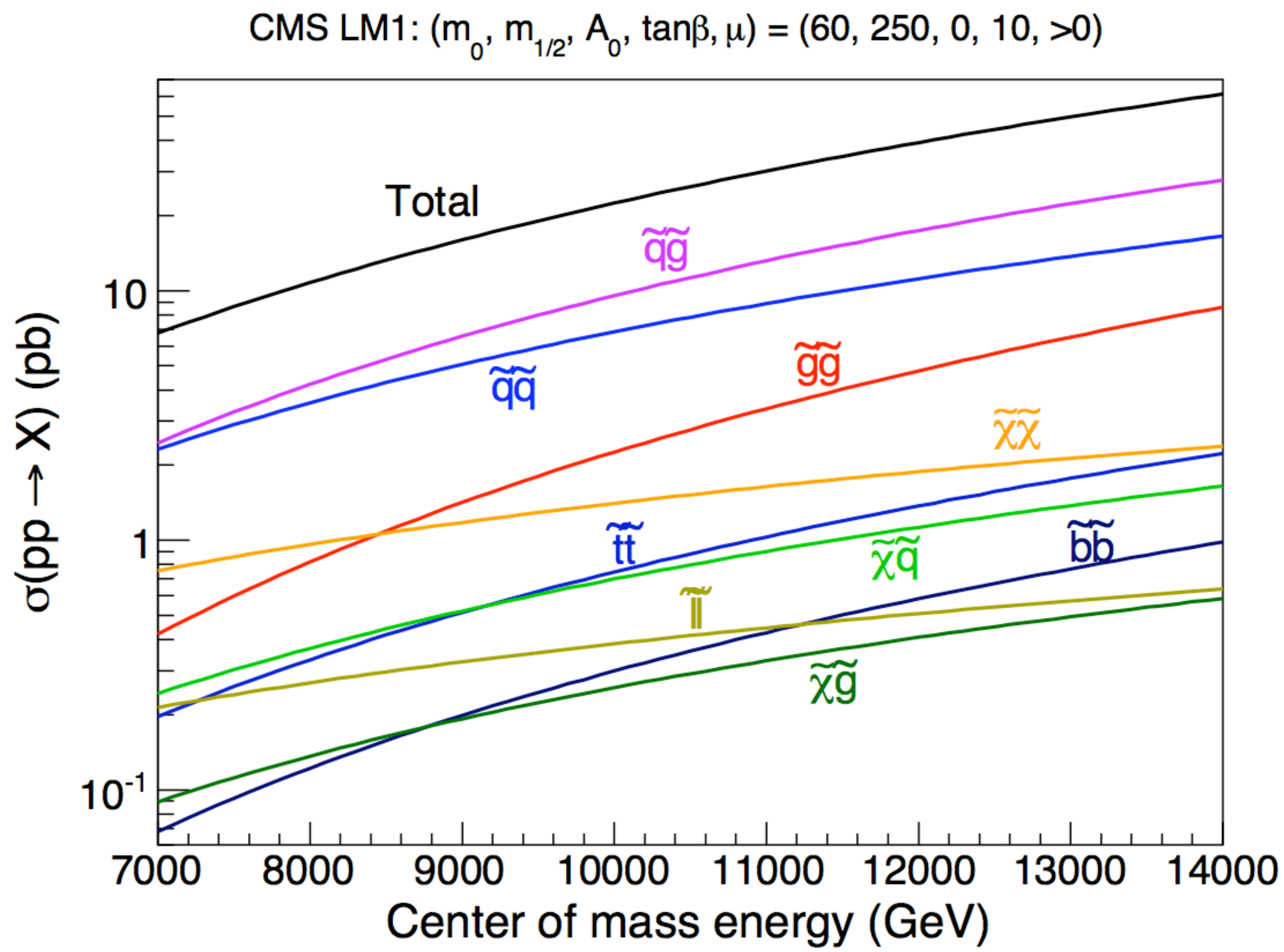
SUSY at LHC

- General expectation at LHC: large Xsections for squarks and/or gluinos. Strong interaction + the power of phase-space.
- Once produced, squarks/gluinos will decay into lighter sparticles until the LSP* is reached
  - ➡ cascade decays
  - ➡ high-p_T jets
  - ➡ large missing E_T





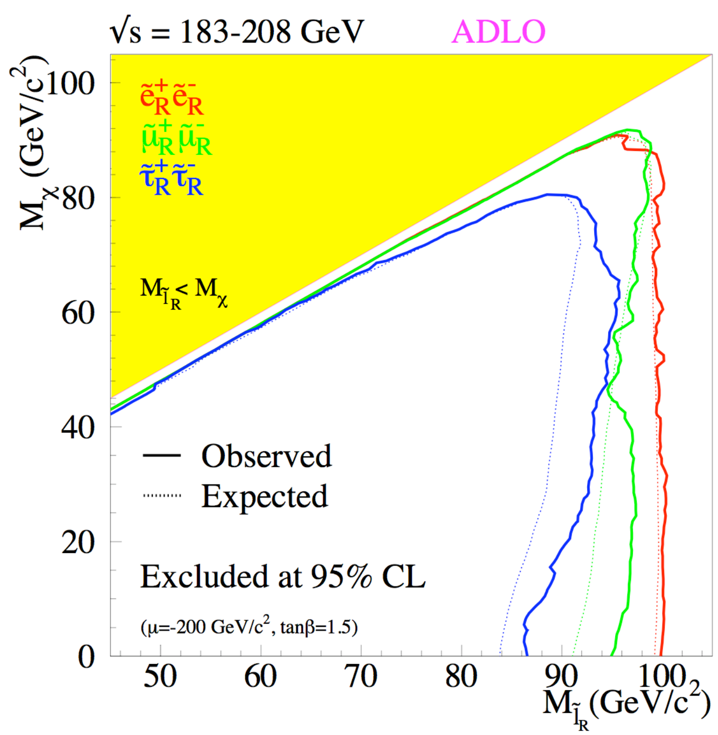
courtesy S. Sekmen

*) LSP = lightest SUSY particle, stable if R-parity is conserved

Limits and constraints

So far only lower mass limits and indirect constraints, e.g.,

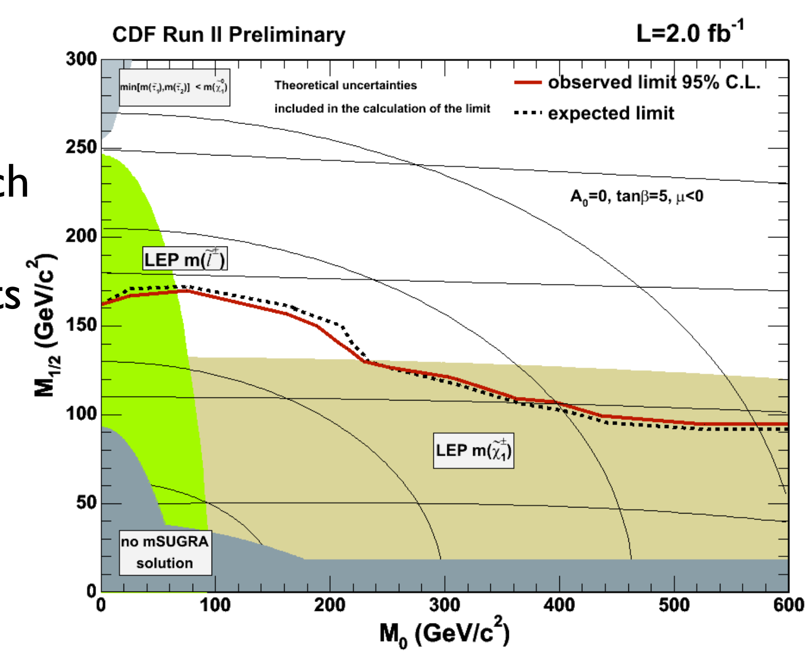
LEP: charged sparticle $M \gtrsim 100$ GeV

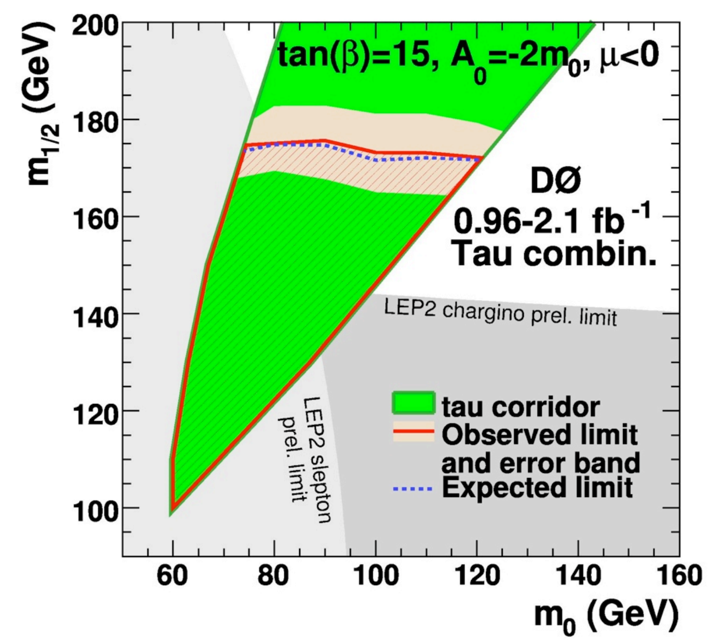


$\mathrm{BR}^{\mathrm{exp}}_{b\to s\gamma}/\mathrm{BR}^{\mathrm{SM}}_{b\to s\gamma}$	$1.117 \pm 0.076_{\mathrm{exp}} \pm 0.082_{\mathrm{th(SM)}}$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$< 4.7 \times 10^{-8}$
$\mathrm{BR}^{\mathrm{exp}}_{B\to\tau\nu}/\mathrm{BR}^{\mathrm{SM}}_{B\to\tau\nu}$	$1.25 \pm 0.40_{[\mathrm{exp+th}]}$
$\mathrm{BR}(B_d \to \mu^+\mu^-)$	$< 2.3 \times 10^{-8}$
$\mathrm{BR}^{\mathrm{exp}}_{B\to X_s\ell\ell}/\mathrm{BR}^{\mathrm{SM}}_{B\to X_s\ell\ell}$	0.99 ± 0.32
$\mathrm{BR}^{\mathrm{exp}}_{K\to\mu\nu}/\mathrm{BR}^{\mathrm{SM}}_{K\to\mu\nu}$	$1.008 \pm 0.014_{[\mathrm{exp+th}]}$
$\mathrm{BR}^{\mathrm{exp}}_{K\to\pi\nu\bar{\nu}}/\mathrm{BR}^{\mathrm{SM}}_{K\to\pi\nu\bar{\nu}}$	< 4.5
$\Delta M^{\mathrm{exp}}_{B_s}/\Delta M^{\mathrm{SM}}_{B_s}$	$0.97 \pm 0.01_{\mathrm{exp}} \pm 0.27_{\mathrm{th(SM)}}$
$\frac{(\Delta M^{\mathrm{exp}}_{B_s}/\Delta M^{\mathrm{SM}}_{B_s})}{(\Delta M^{\mathrm{exp}}_{B_d}/\Delta M^{\mathrm{SM}}_{B_d})}$	$1.00 \pm 0.01_{\mathrm{exp}} \pm 0.13_{\mathrm{th(SM)}}$
$\Delta\epsilon^{\mathrm{exp}}_K/\Delta\epsilon^{\mathrm{SM}}_K$	$1.08 \pm 0.14_{[\mathrm{exp+th}]}$
$a^{\mathrm{exp}}_\mu - a^{\mathrm{SM}}_\mu$	$(30.2 \pm 8.8) \times 10^{-10}$
M_h [GeV]	> 114.4 (see text)
$\Omega_{\mathrm{CDM}}h^2$	0.1099 ± 0.0062

B-physics!

Tevatron: begins to reach beyond LEP but mass limits quite model dependent



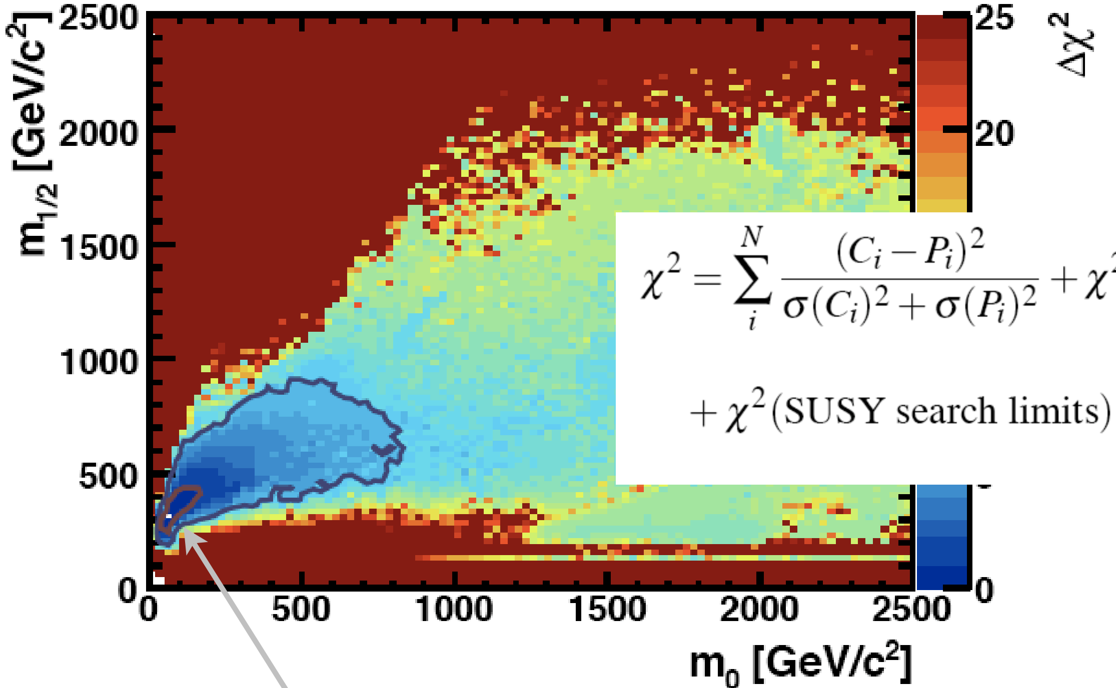


→ severe constraints on parameter space

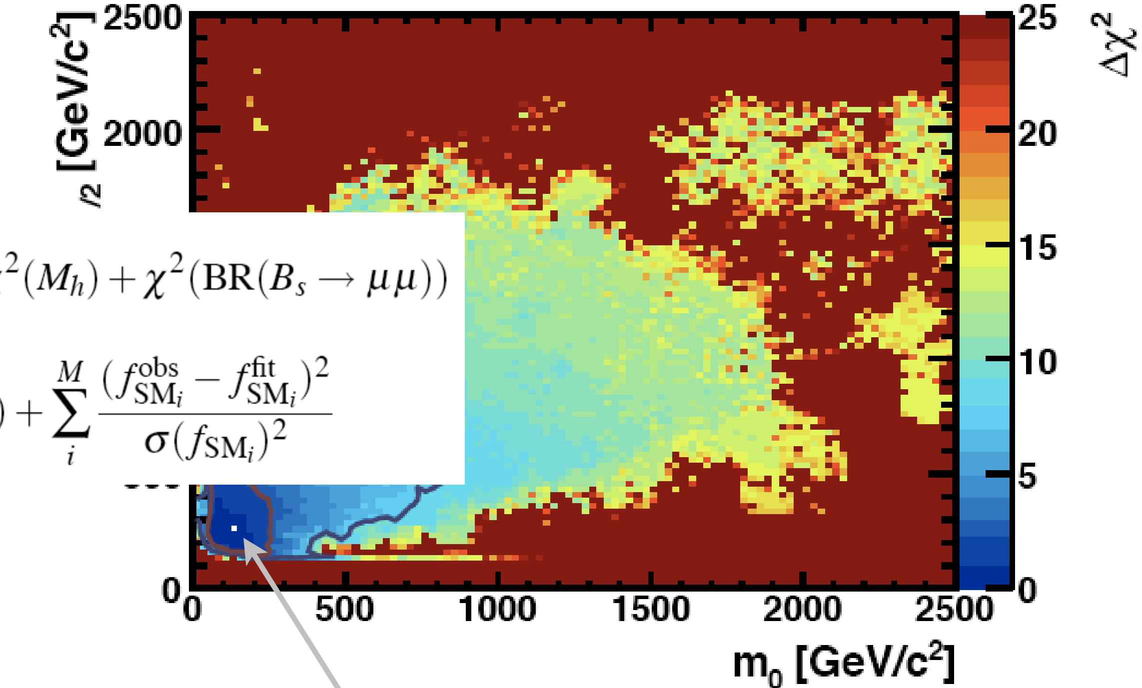
O. Buchmüller et al, arXiv:0907.5568
("Mastercode")

Fits to available data (frequentist)

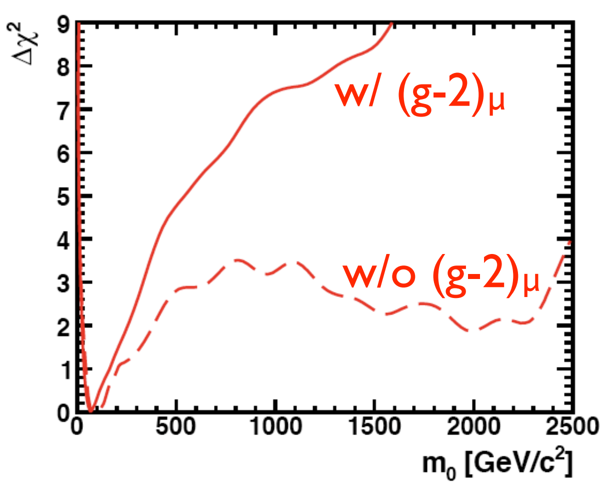
CMSSM

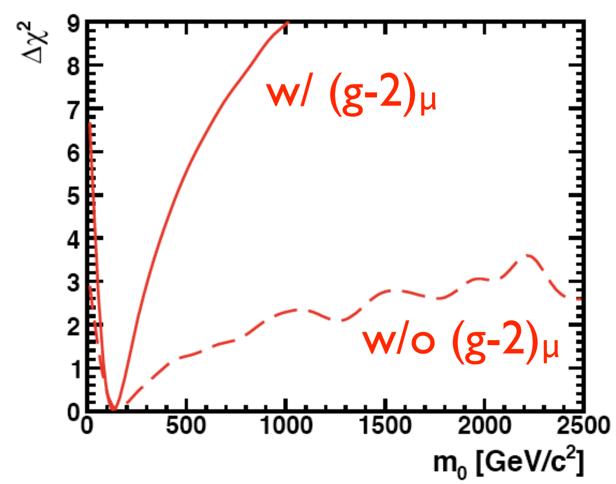


NUHM-1



$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \chi^2(M_h) + \chi^2(\mathrm{BR}(B_s \to \mu\mu))$$
$$+ \chi^2(\text{SUSY search limits}) + \sum_i^M \frac{(f^{\mathrm{obs}}_{\mathrm{SM}_i} - f^{\mathrm{fit}}_{\mathrm{SM}_i})^2}{\sigma(f_{\mathrm{SM}_i})^2}$$





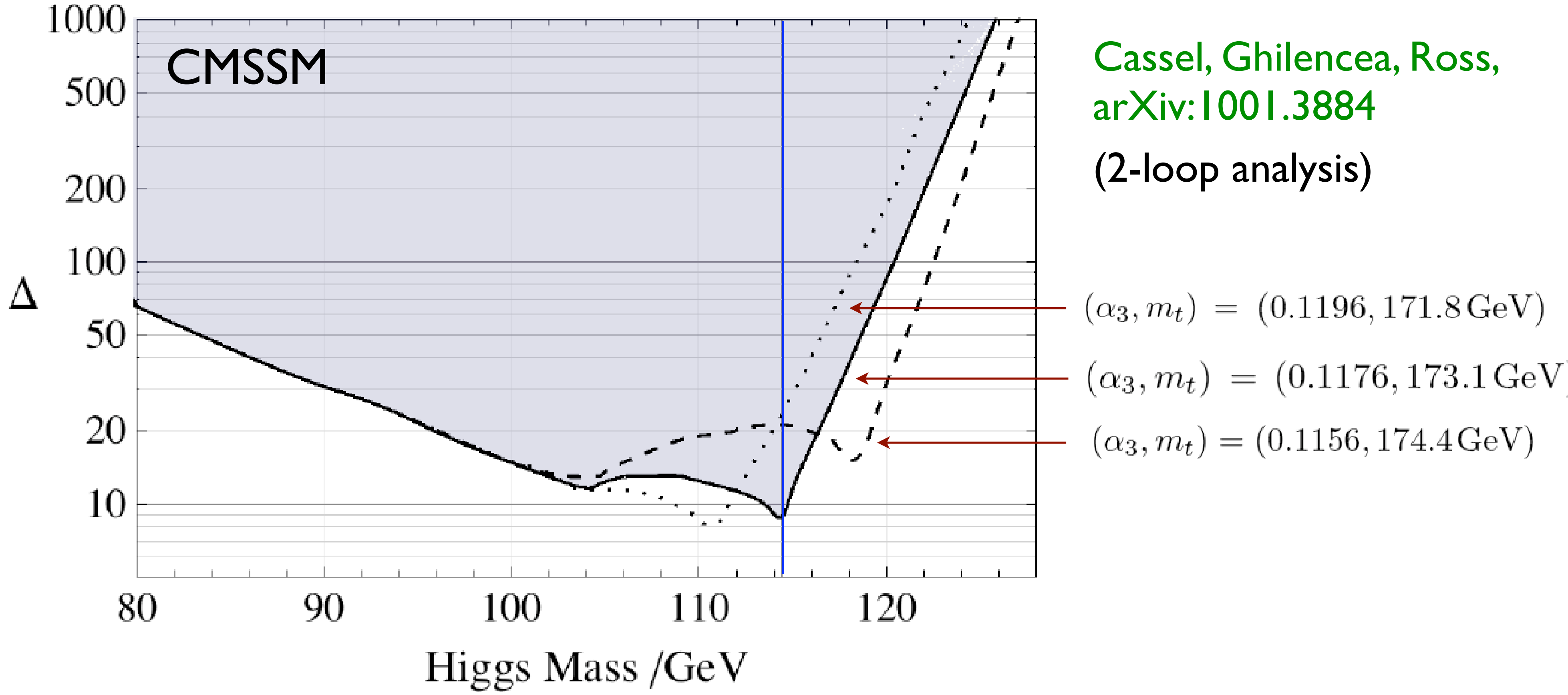
Best fit at $m_{\tilde{g}} \approx \mathbf{750/600}$ GeV, $\tan\beta \approx 11$.

see also
Barbieri et al.,
Chankowski et al.,
....

The finetuning price

- Finetuning = sensitivity of EW scale to input parameters

$$\frac{M_Z^2}{2} \approx -m_{H_2}^2 - |\mu|^2$$



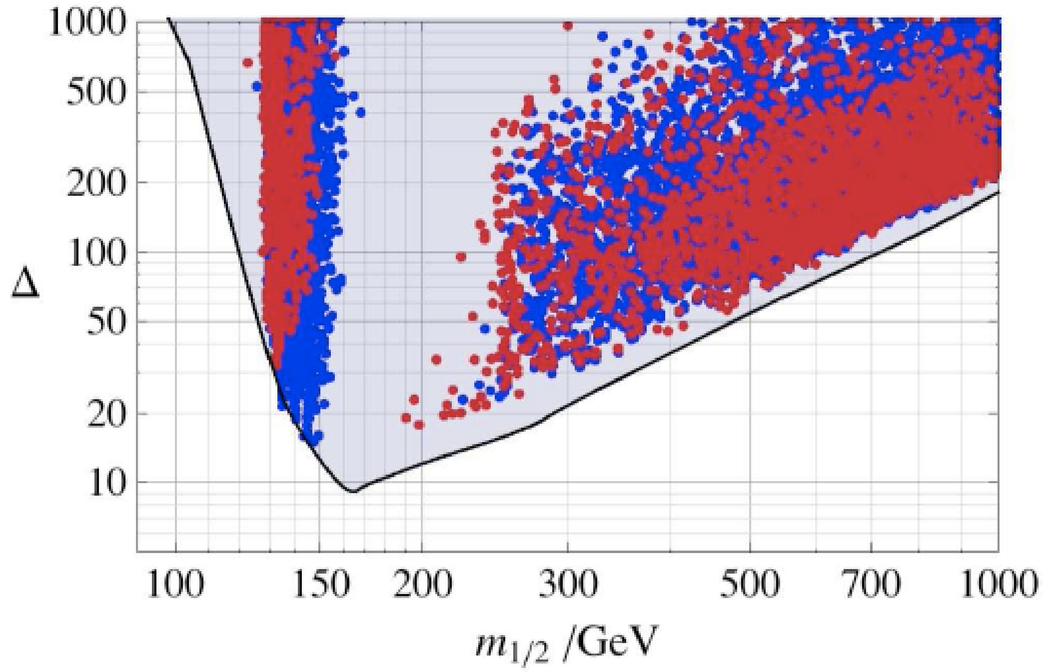
Cassel, Ghilencea, Ross, arXiv:1001.3884

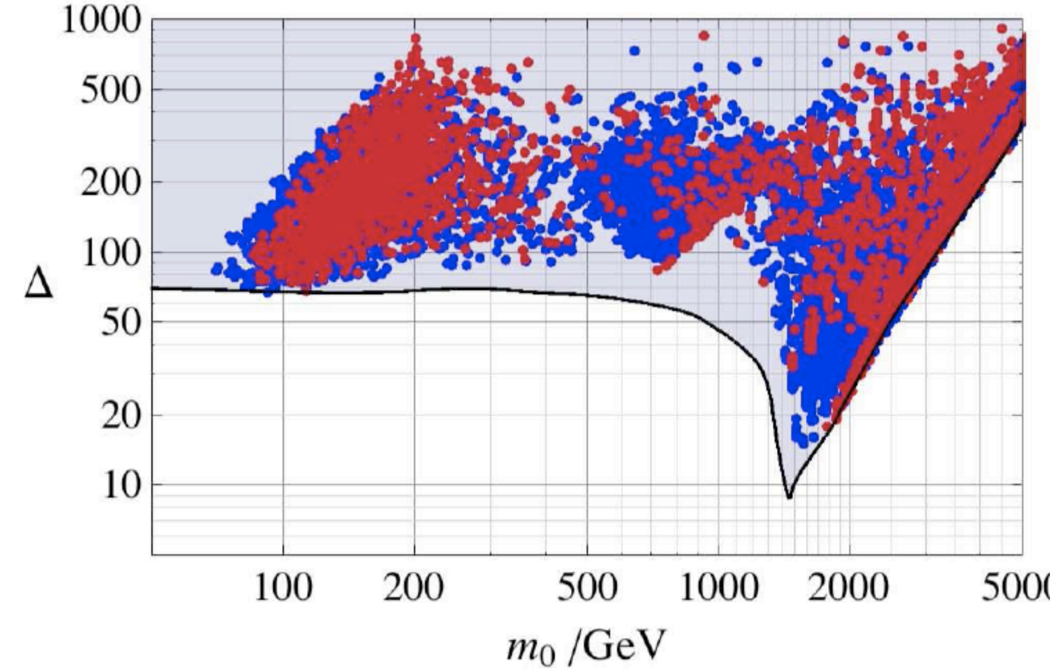
(2-loop analysis)

$$\Delta \equiv \max \left|\Delta_p\right|_{p=\{\mu_0^2, m_0^2, m_{1/2}^2, A_0^2, B_0^2\}}, \qquad \Delta_p \equiv \frac{\partial \ln v^2}{\partial \ln p}$$

Cassel, Ghilencea, Ross,
arXiv:1001.3884

CMSSM low finetuning





red points: Relic density within WMAP limit (at 3σ)

NB: points with lowest finetuning lie in the focus point region
- gaugino-higgsino mixing
- light gluino
- Xsections a few pb at 7TeV LHC

$BR(\tilde{g} \to \tilde{\chi}_i^0 g) \sim 10 - 20\%$

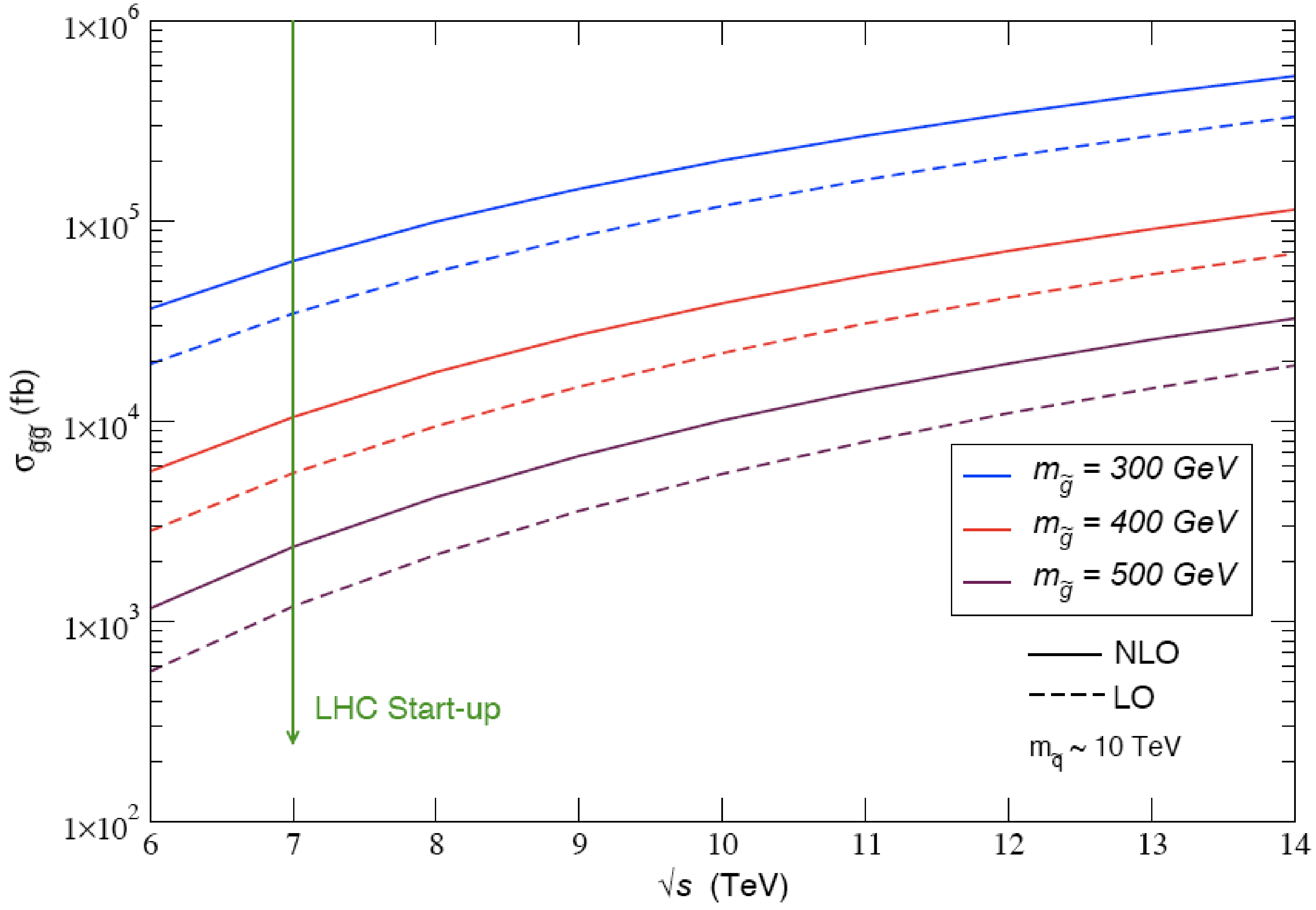
$BR(\tilde{g} \to \tilde{\chi}_i^0 b\bar{b}, \tilde{\chi}_i^{\pm} tb) \sim 20\%$

h^0	114.5	$\tilde{\chi}_1^0$	79	$\tilde{b}_1$	1147	$\tilde{u}_L$	1444
H^0	1264	$\tilde{\chi}_2^0$	142	$\tilde{b}_2$	1369	$\tilde{u}_R$	1446
$H^\pm$	1267	$\tilde{\chi}_3^0$	255	$\tilde{\tau}_1$	1328	$\tilde{d}_L$	1448
A^0	1264	$\tilde{\chi}_4^0$	280	$\tilde{\tau}_2$	1368	$\tilde{d}_R$	1446
$\tilde{g}$	549	$\tilde{\chi}_1^\pm$	142	$\tilde{\mu}_L$	1406	$\tilde{s}_L$	1448
$\tilde{\nu}_\tau$	1366	$\tilde{\chi}_2^\pm$	280	$\tilde{\mu}_R$	1406	$\tilde{s}_R$	1446
$\tilde{\nu}_\mu$	1404	$\tilde{t}_1$	873	$\tilde{e}_L$	1406	$\tilde{c}_L$	1444
$\tilde{\nu}_e$	1404	$\tilde{t}_2$	1158	$\tilde{e}_R$	1406	$\tilde{c}_R$	1446

upper limits for Δ<100

$\tilde{g}$	χ_1^0	χ_2^0	χ_3^0	χ_4^0	$\chi_1^\pm$	$\chi_2^\pm$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
1720	305	550	660	665	550	670	2080	2660	2660	3140

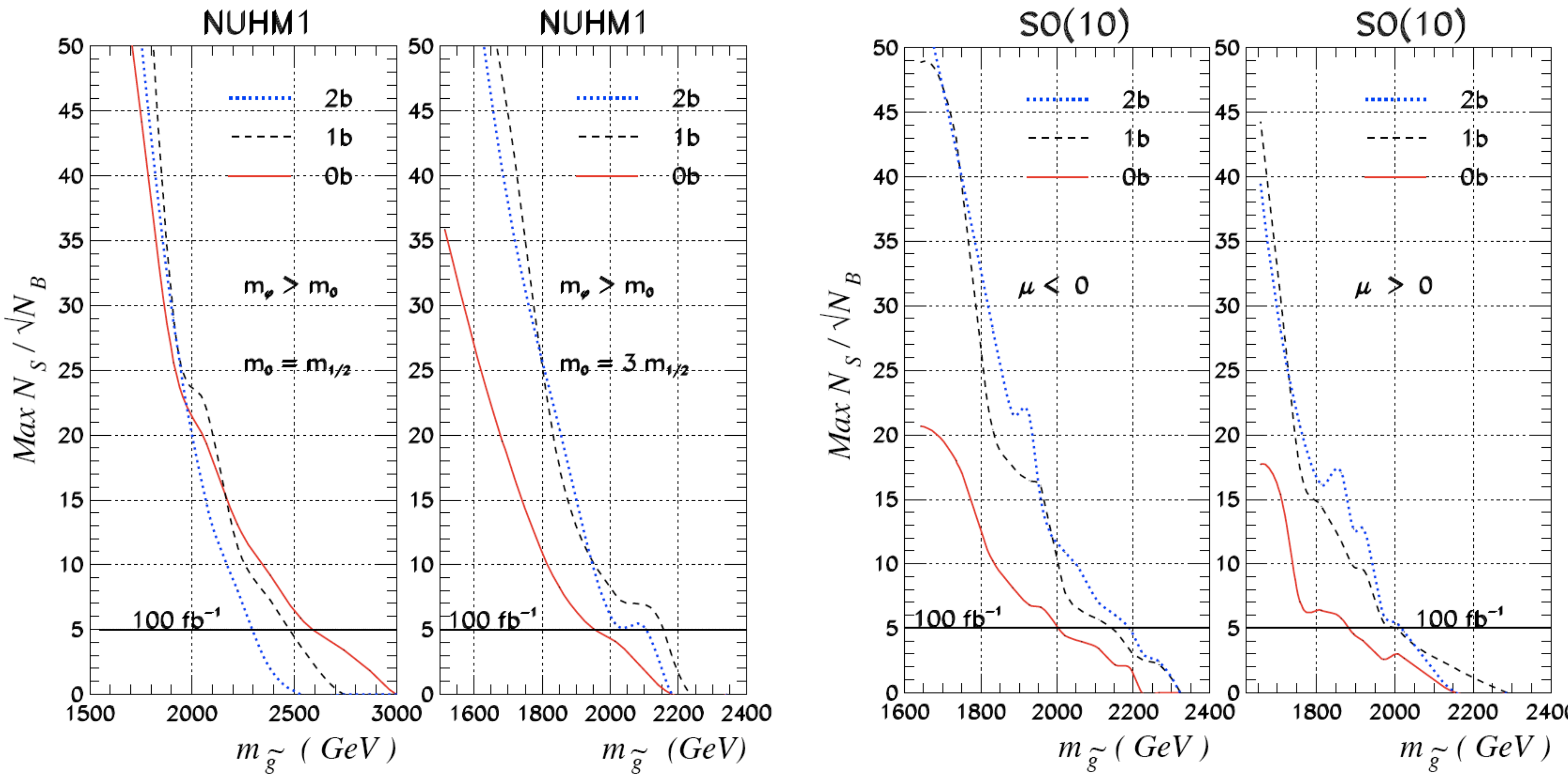
Light gluino: promising for LHC at 7 TeV



Kadala, Mercadante, Mizukoshi, Tata,
arXiv:0803.0001

Importance of b-tagging

- Requiring 1, 2, or more b-jets can significantly enhance the signal/bg in certain scenarios, e.g., 15-20% in the CMSSM focus point region.



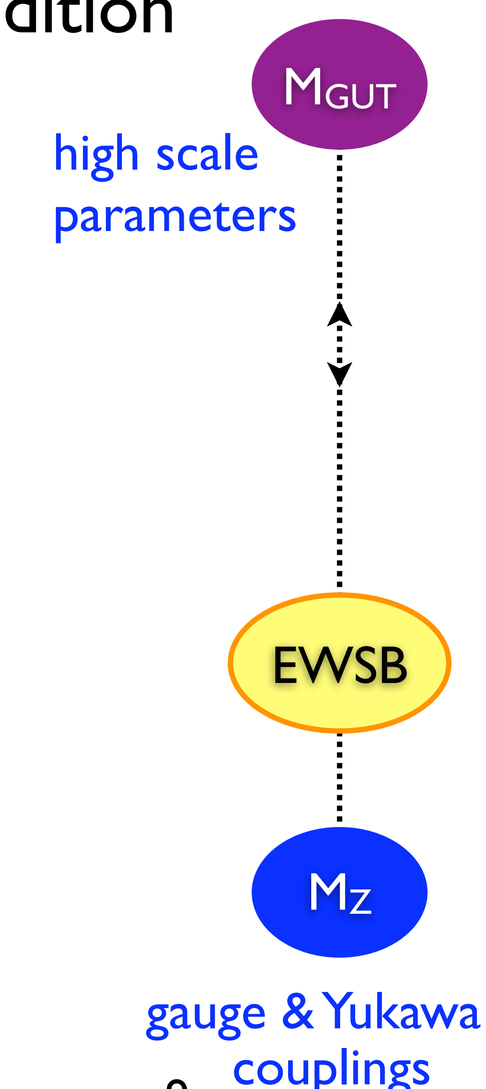
14 TeV

- Typical if 3rd generation is lighter then 1st/2nd gen. and $m_{\tilde{g}} \ll m_{\tilde{q}}$; enhances gluino decays into t or b via on- or off-shell stop/sbottom

Yukawa-unified SUSY

- SUSY GUTs based on SO(10) are particularly compelling
  - unify all matter of one generation in a 16-plet (incl. r.h. neutrino!)
  - automatic anomaly cancellation
- In the simplest realization the Higgs doublets reside in a10-plet. This then requires t-b-tau Yukawa coupling unification in addition to gauge coupling unification at M_{GUT}.
- Parameter space:
  - common gaugino mass $m_{1/2}$
  - common sfermion mass parameter m_{16}
  - common Higgs mass parameter m_{10}
  - common trilinear coupling A_0
  - $\tan\beta$ and sign(μ)
  - D-term contribution M_D^2 from SO(10) breaking

$$m^2_{H_{u,d}} = m^2_{10} \mp M^2_D$$

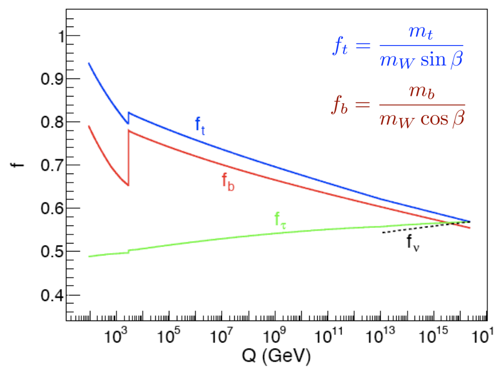


Blazek, Dermisek, Raby, hep-ph/0201081
Auto et al., hep-ph/0302155

Conditions for Yukawa unification (YU)

★ For μ>0, as preferred by b→sγ, Yukawa unification (YU) can only be realized for very particular parameter relations

- $m_{16} \sim 5 - 15$ TeV,
- $A_0^2 \simeq 2m_{10}^2 \simeq 4m_{16}^2, \quad (A_0 < 0)$
- $m_{1/2} \ll m_{16}$,
- $\tan\beta \sim 50.$



$$R = \frac{max(f_t,\ f_b,\ f_\tau)}{min(f_t,\ f_b,\ f_\tau)}$$

★ D-term splitting

$$\begin{aligned} m_Q^2 = m_E^2 = m_U^2 &= m_{16}^2 + M_D^2 \\ m_D^2 = m_L^2 &= m_{16}^2 - 3M_D^2 \\ m_{\tilde{\nu}_R}^2 &= m_{16}^2 + 5M_D^2 \\ m_{H_{u,d}}^2 &= m_{10}^2 \mp 2M_D^2. \end{aligned}$$

"just-so" Higgs splitting (HS) case

NB: we need $m_{H_u}^2 < m_{H_d}^2$ at $M_{\rm GUT}$, so $M_D^2 > 0$.

- D-term splitting w/o RHN gives R~1.08 (i.e. 8% unification)
- Splitting of only m_H's ("just-so HS") allows for R~1.01
- D-term splitting with RHN gives R~1.04, ...
- ... but if we allow in addition small non-degeneracy of 3rd vs. 1st/2nd generation, we get R~1.02

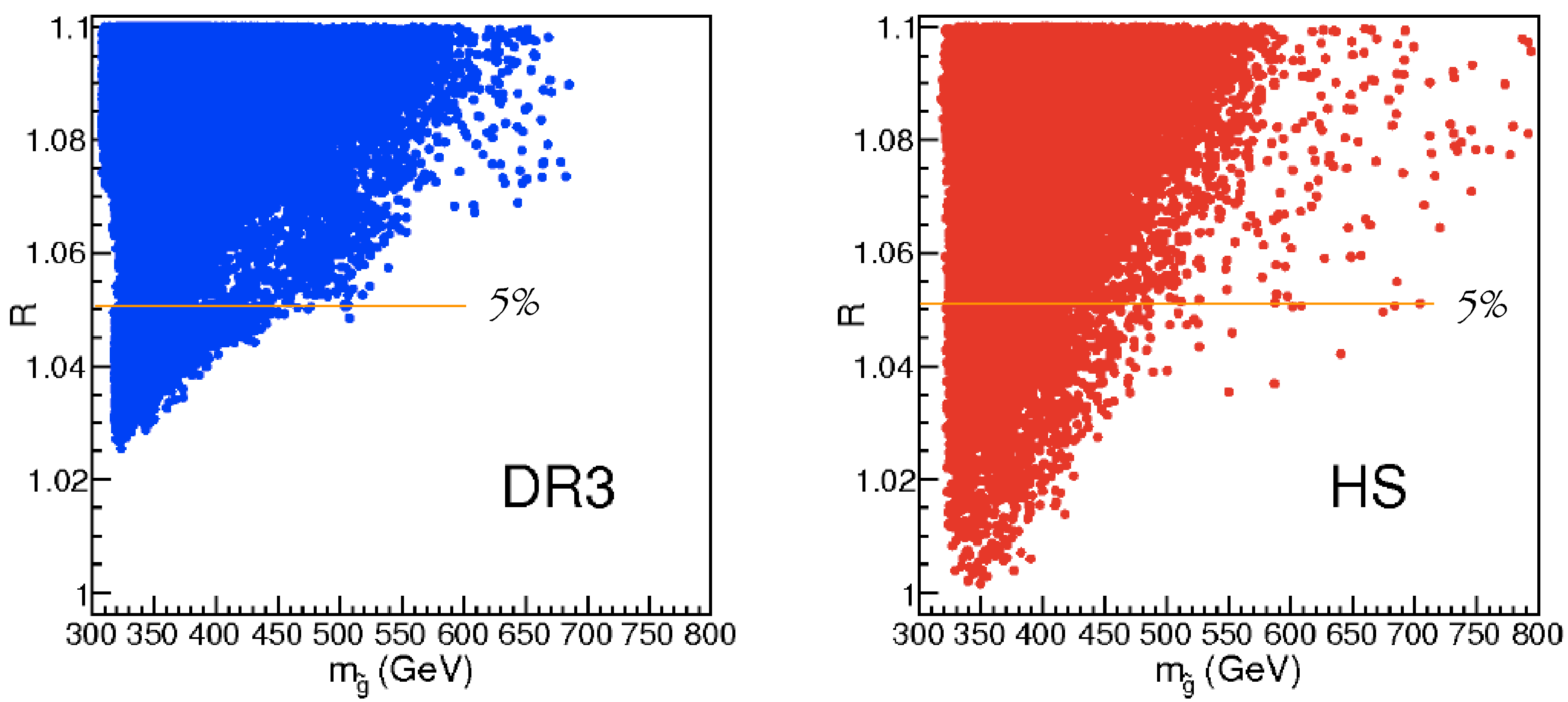
Baer et al., 0908.0134

Baer et al, 0801.1831, 0809.0710, 0812.2693, 0908.0134, 0910.2988, 0911.4739.

YU: Typical mass spectra

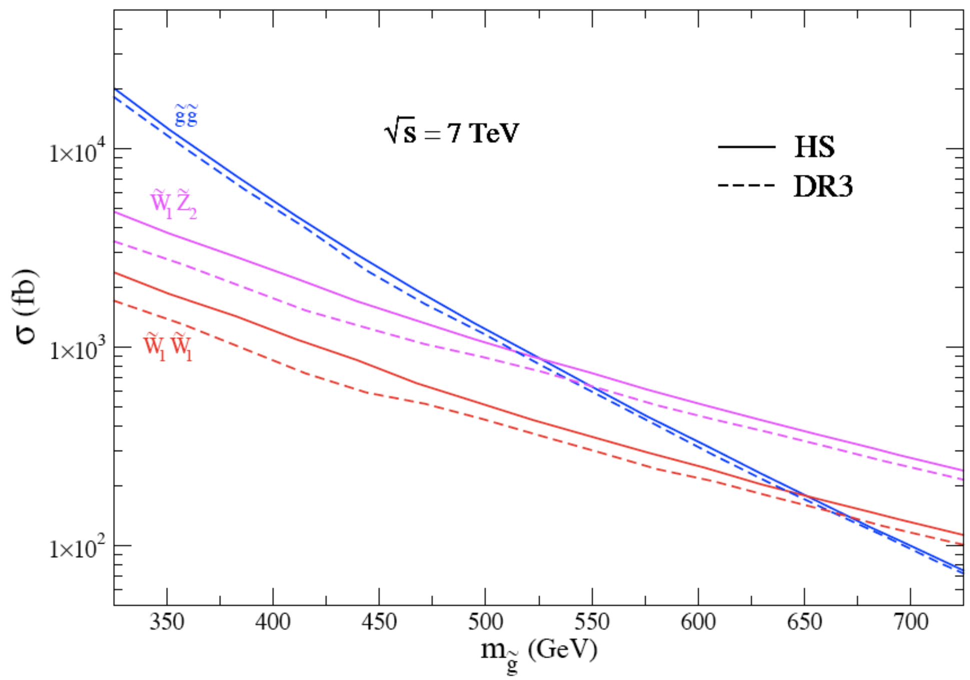
- 1st/2nd generation scalars in the multi-TeV range (5-15 TeV)
- 3rd gen. scalars, heavy Higgses and higgsinos in the 1-3 TeV range
- light gauginos: LSP ~ 50-80 GeV, gluino ~ 300-500 GeV
- c.f "effective SUSY" by Cohen, Kaplan, Nelson '1996

$$R = \frac{max(f_t,\ f_b,\ f_\tau)}{min(f_t,\ f_b,\ f_\tau)}$$



Points from a MCMC scan for small R

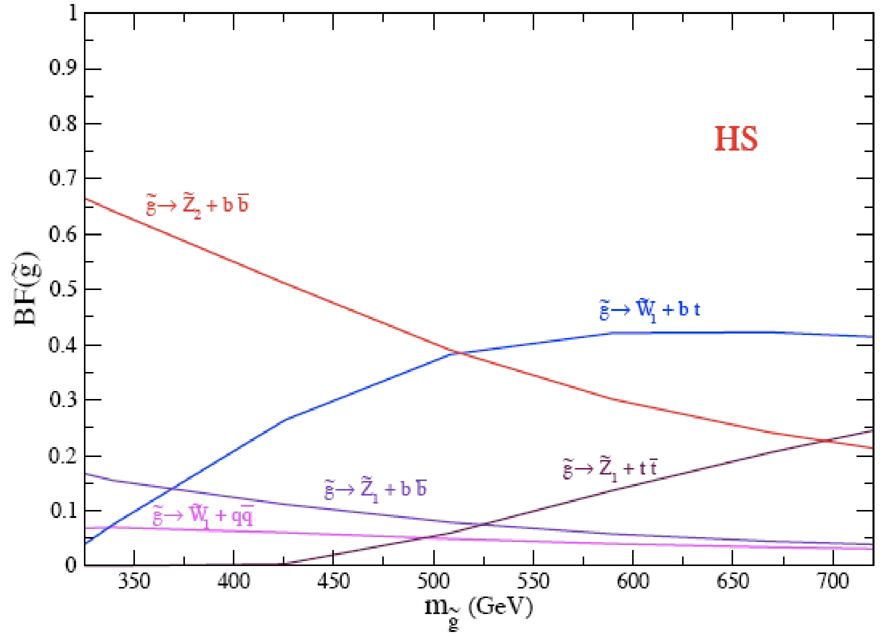
LHC reach at 7 TeV

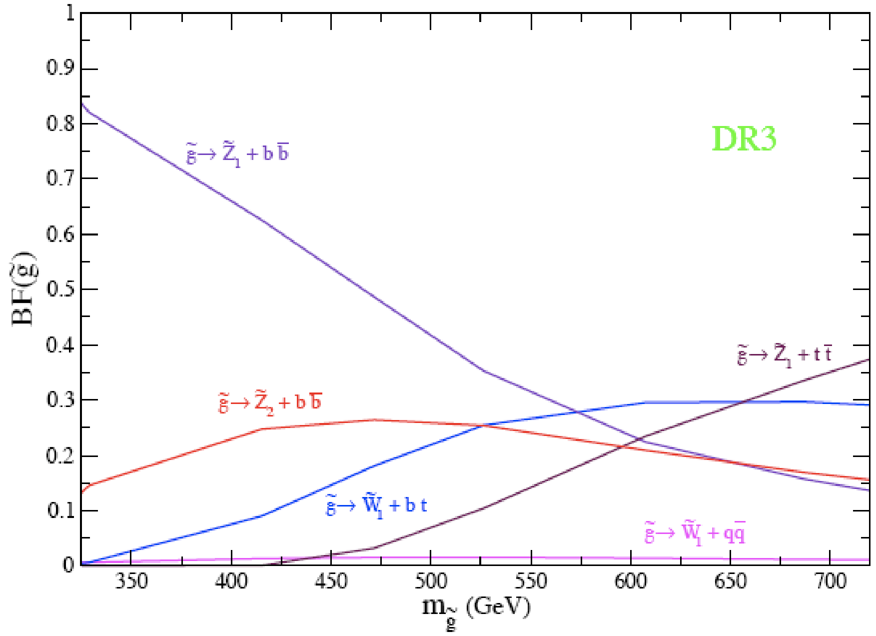


Gluino-pair prod. dominated by gg fusion.
Much less enhancement from heavy squarks.
σ(LO)~1 pb at m(gluino)~525 GeV

We consider model lines for HS and DR3 cases as function of m(gluino) up to 700 GeV.

Gluinos decays are again dominanted by heavy flavours: $\tilde{g} \to \tilde{\chi}^0_{1,2} b\bar{b},\ \tilde{\chi}^{\pm}_1 tb$



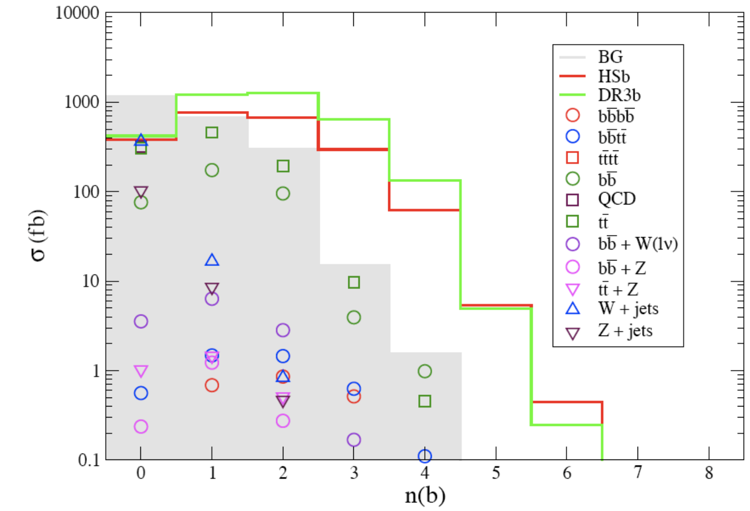


LHC reach at 7 TeV

Event simulation:

- Isajet 7.79 for the signal
- QCD, 2- and 3-bdy BGs with Alpgen
- 4t, 4b, 2t2b BGs with Madgraph
- Phythia for showering and hadronization
- Generic toy detector simulation

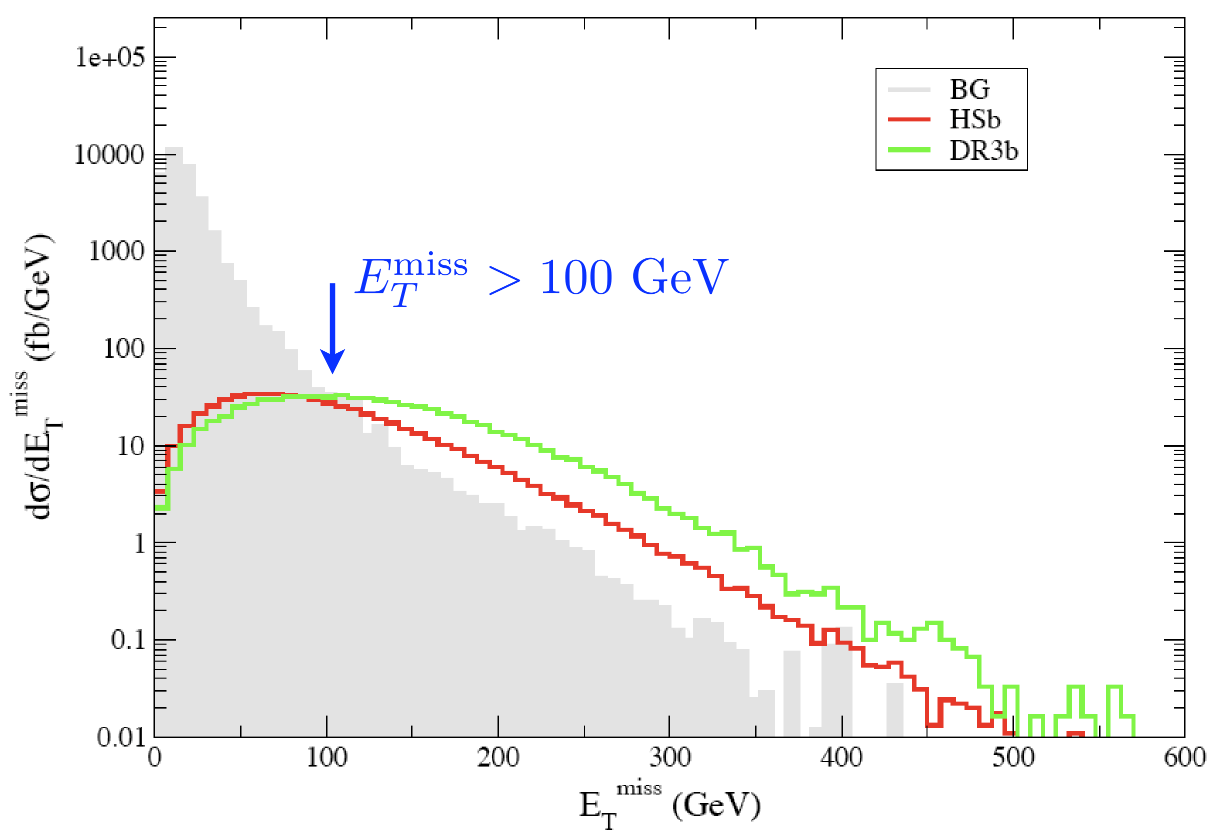
with cut on E_T^{miss}



Basic Cuts "C0":

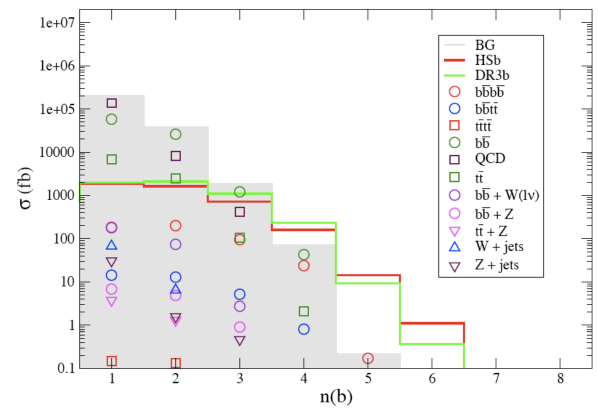
- n(jets)≥4 with p_T > 50GeV
- hardest jet p_T >100 GeV
- S_T ≥ 0.2 (transv sphericity)
- n(b) ≥ 1 (b-eff. 60%)

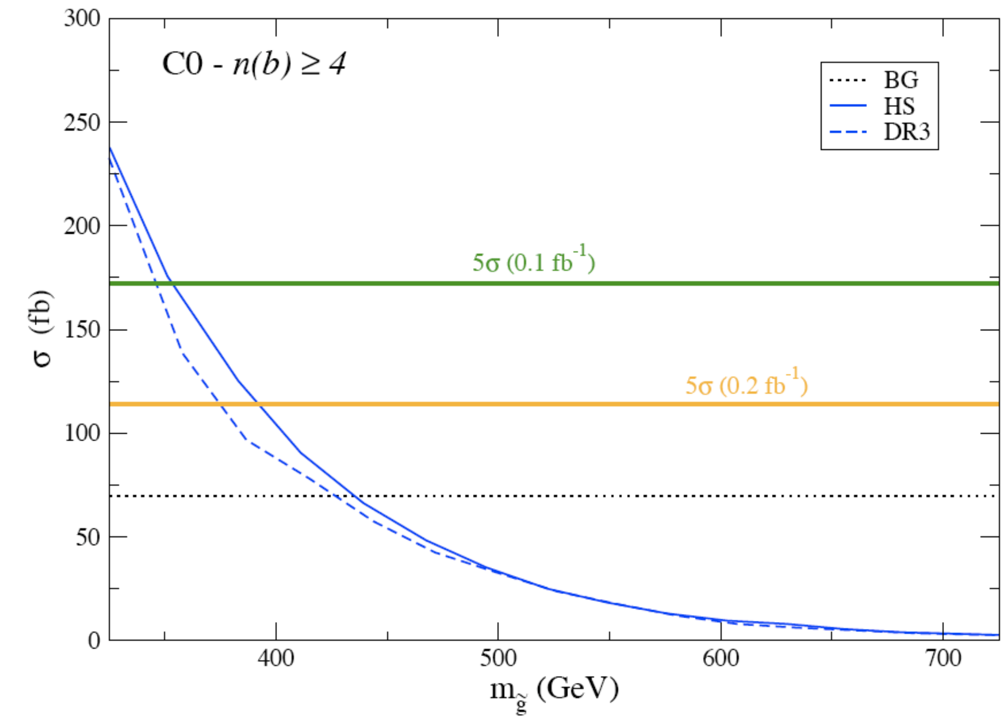
Results after C1-based selection			
	$\sigma(n(b) \geq 3)$	$\sigma(n(b) \geq 4)$	$\sigma(OS)$
HSb	364 fb	68 fb	81 fb
DR3b	782 fb	139 fb	23 fb
BG	16 fb	2 fb	9 fb



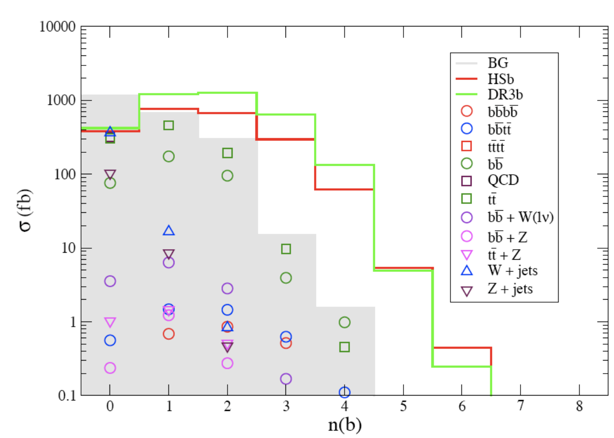
LHC reach at 7 TeV

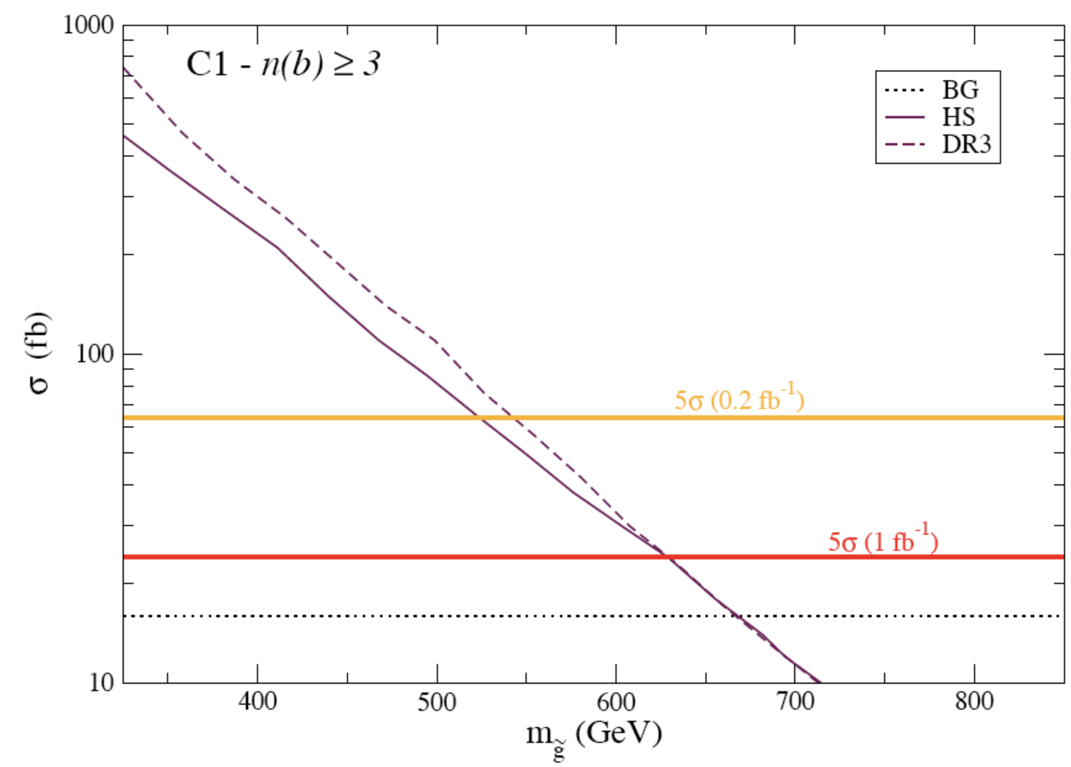
Without missing energy measurement:
up to m(gluino)=400 GeV with 0.2 fb^{-1} of data
requiring 4 b-jets





With reliable missing energy measurement:
reach up to m(gluino)=540-630 GeV
with 0.2-1 fb^{-1} of data,
$n(b) \geq 3$





Conclusions

- Many well-motivated SUSY scenarios feature light gluinos, often in combination with heavy scalars, e.g.,
  - Focus point SUSY
  - Low finetuning scenarios
  - Yukawa-unified SUSY GUTs based on SO(10)
  - Effective SUSY
- Promising potential for LHC @ 7 TeV
- Gluinos often decay into heavy flavours ....
  Search in multi-b channels may essential for early discovery.

There are exciting times ahead of us