(7 TeV) LHC signatures of Yukawa-unified SUSY

S. Kraml
LPSC Grenoble

in collaboration with
H. Baer, A. Lessa, S. Sekmen, S. Summy

Planck 2010

From the Planck Scale to the ElectroWeak Scale
31 May - 4 June 2010, CERN

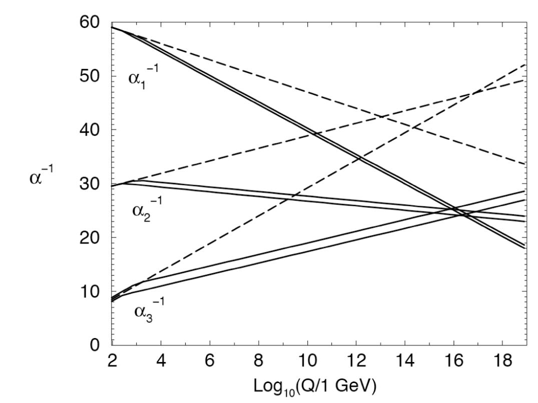
Ananthanarayan, Lazarides and Shafi, 1991
(and a long list to follow)

Framework: SUSY SO(10)

- 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

- The simplest realizations (Higgs in a10-plet) require, in addition to gauge coupling unification, unification of t-b-tau Yukawa couplings at M_{GUT}.

$$\hat{f} \ni f \hat{\psi}_{16} \hat{\psi}_{16} \hat{\phi}_{10}$$

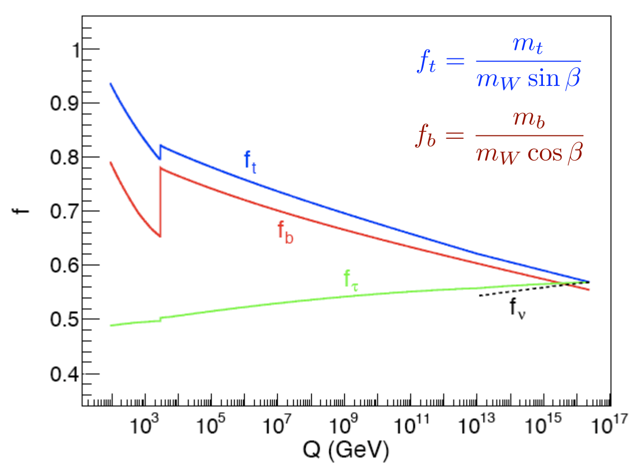


- Particle content below M_{GUT} = MSSM (+RHN)

- Parameters: $m_{1/2}$, m_{16}, m_{10}, M_D^2, A_0, $\tan\beta$, sign μ

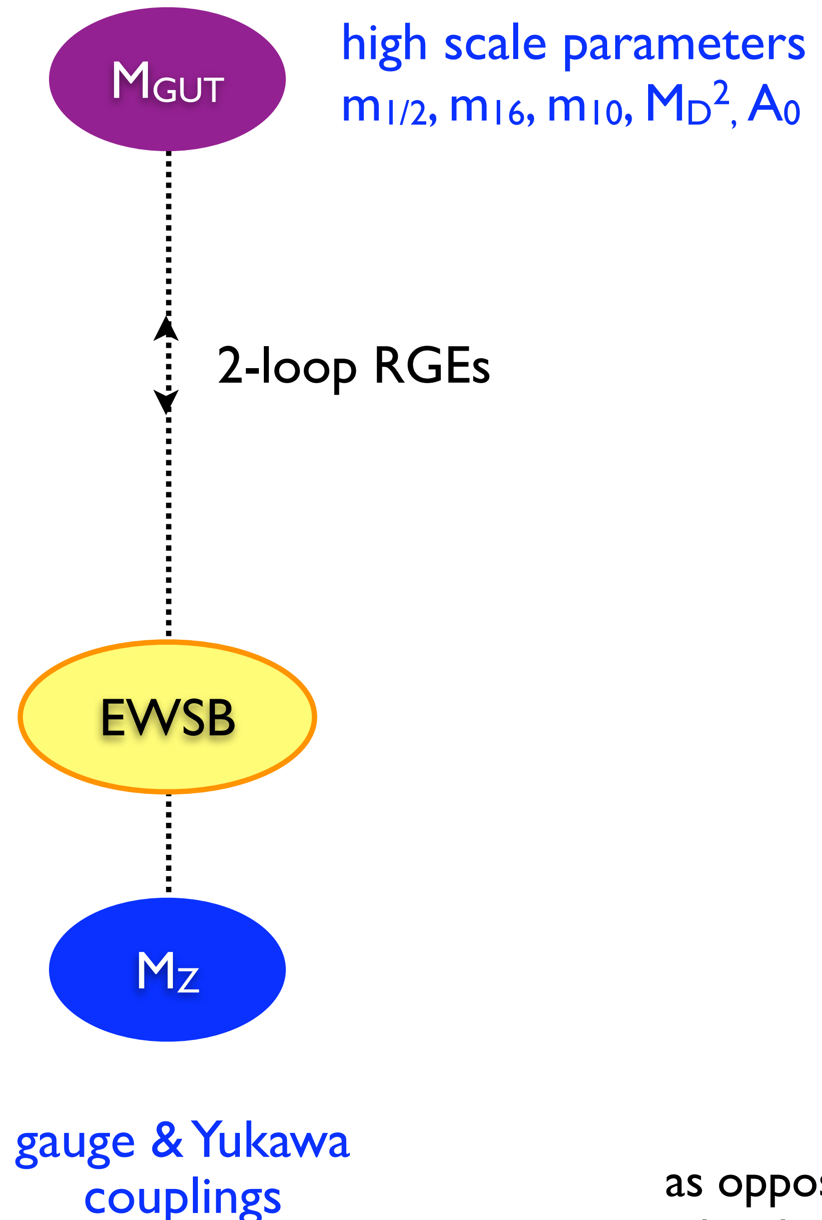
$$m^2_{H_{u,d}} = m^2_{10} \mp M^2_D$$

c.f. NUHM: $m_{1/2}$, m_0, $m_{H_{u,d}}$, A_0, $\tan\beta$, sign μ.



Bottom-up approach to Yukawa unification

using Isajet 7.79



$$\mu^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{(\tan^2\beta - 1)} - \frac{M_Z^2}{2}$$

as opposed to Blazek, Dermisek, Raby et al., who do a top-down fit imposing exact Y.U., which gives a pull in the EW observables. (see talk by D. Guadagnoli in this session)

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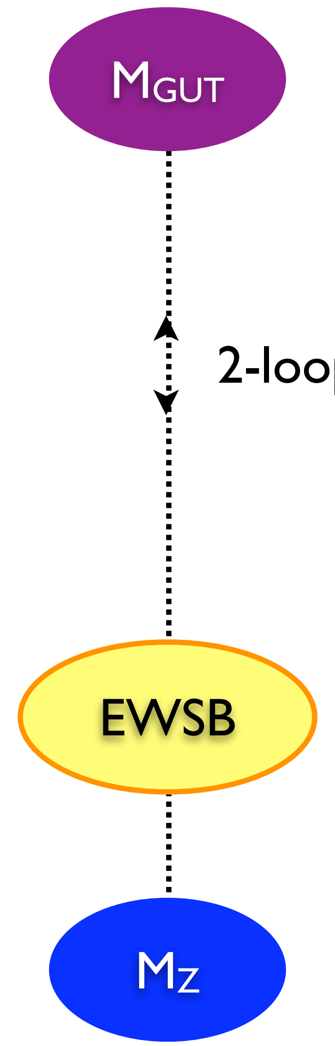
$m_{1/2}$, m_{16}, m_{10}, M_D^2, A_0



2-loop RGEs

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input from experiment → gauge & Yukawa couplings

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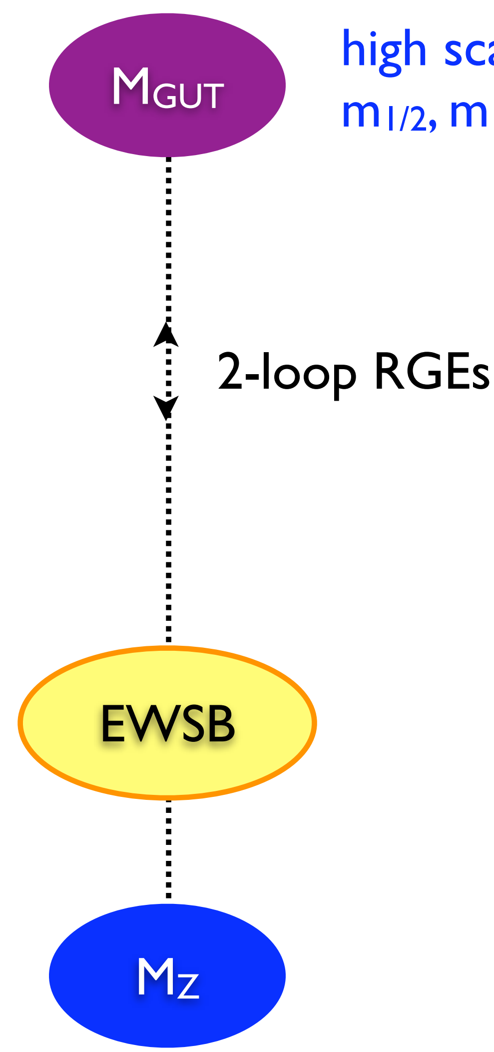

high scale parameters
$m_{1/2}, m_{16}, m_{10}, M_D^2, A_0$

vary these to minimize

$$R = \frac{max(f_t, f_b, f_\tau)}{min(f_t, f_b, f_\tau)} \to 1$$

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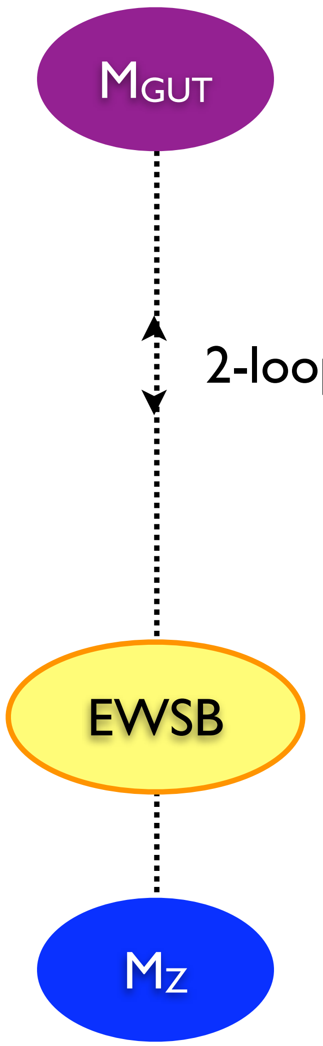

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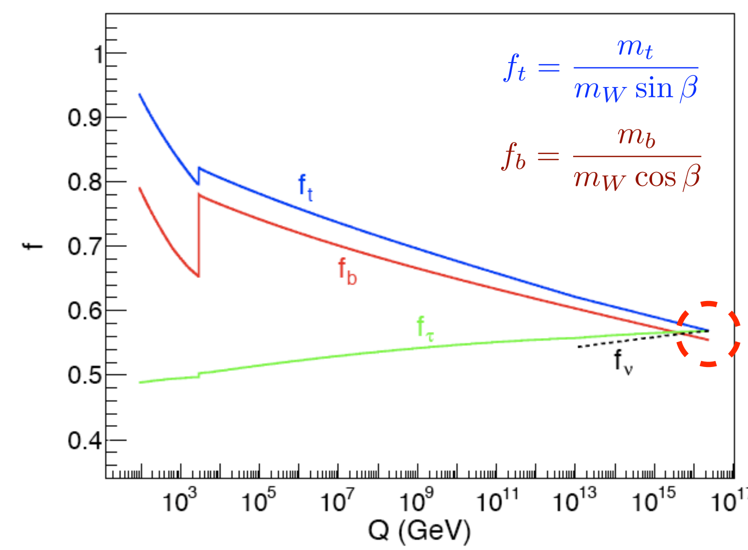

unification to few %

input from experiment → gauge & Yukawa couplings

as opposed to Blazek, Dermisek, Raby et al., who do a top-down fit imposing exact Y.U., which gives a pull in the EW observables.
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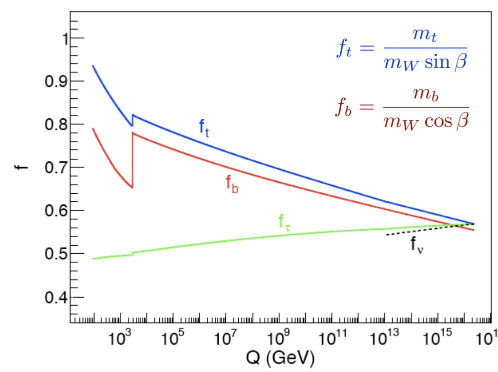
Blazek, Dermisek, Raby, hep-ph/0201081
Auto, Baer, et al., hep-ph/0302155

Conditions for Yukawa unification

★ 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

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

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

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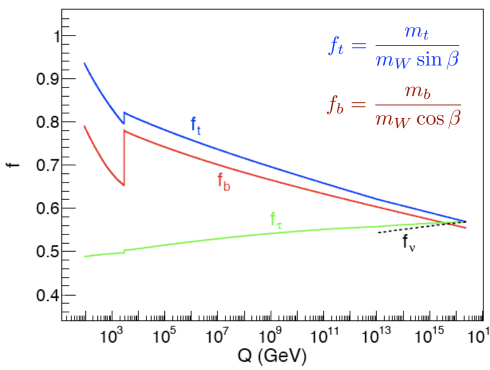

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"just-so" Higgs splitting (HS) case

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

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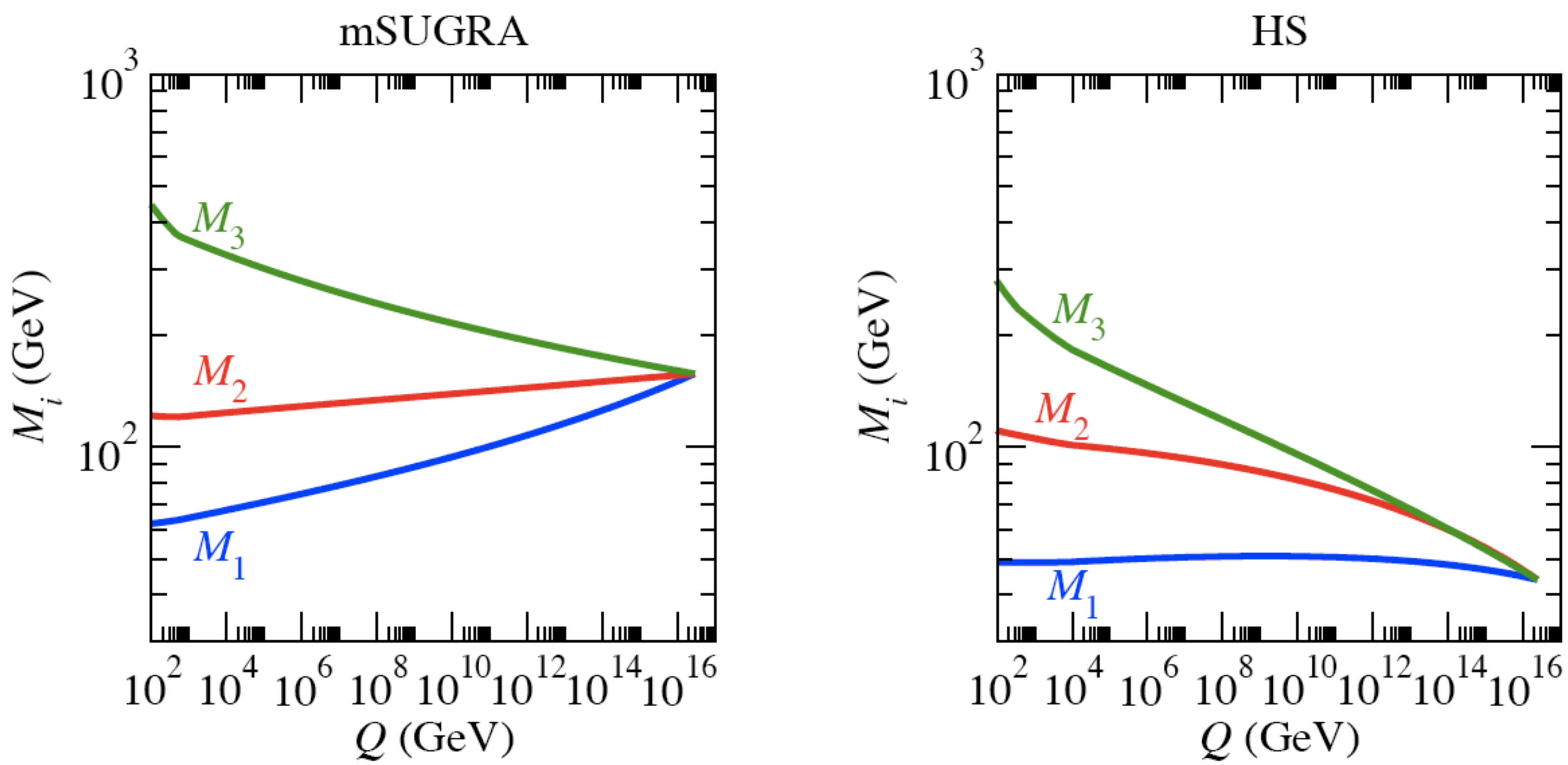
Typical mass spectra

- 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



Evolution of gaugino masses in mSUGRA and Yukawa-unified SO(10) HS model

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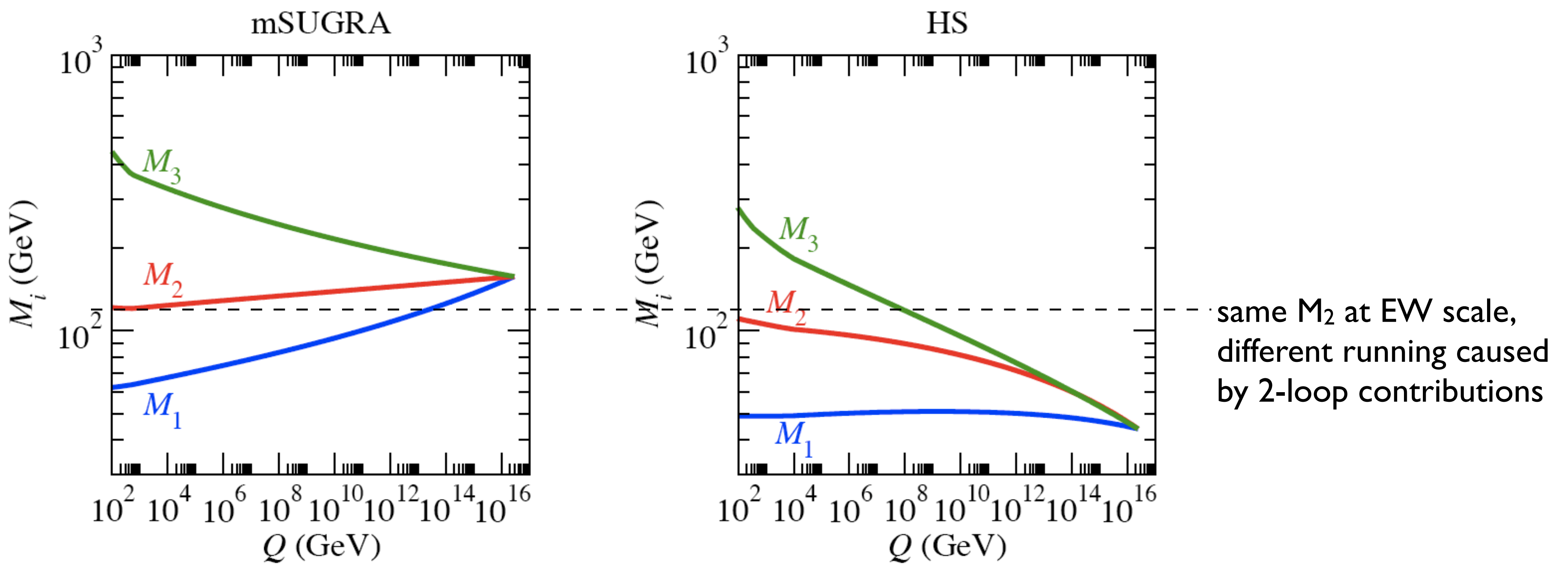

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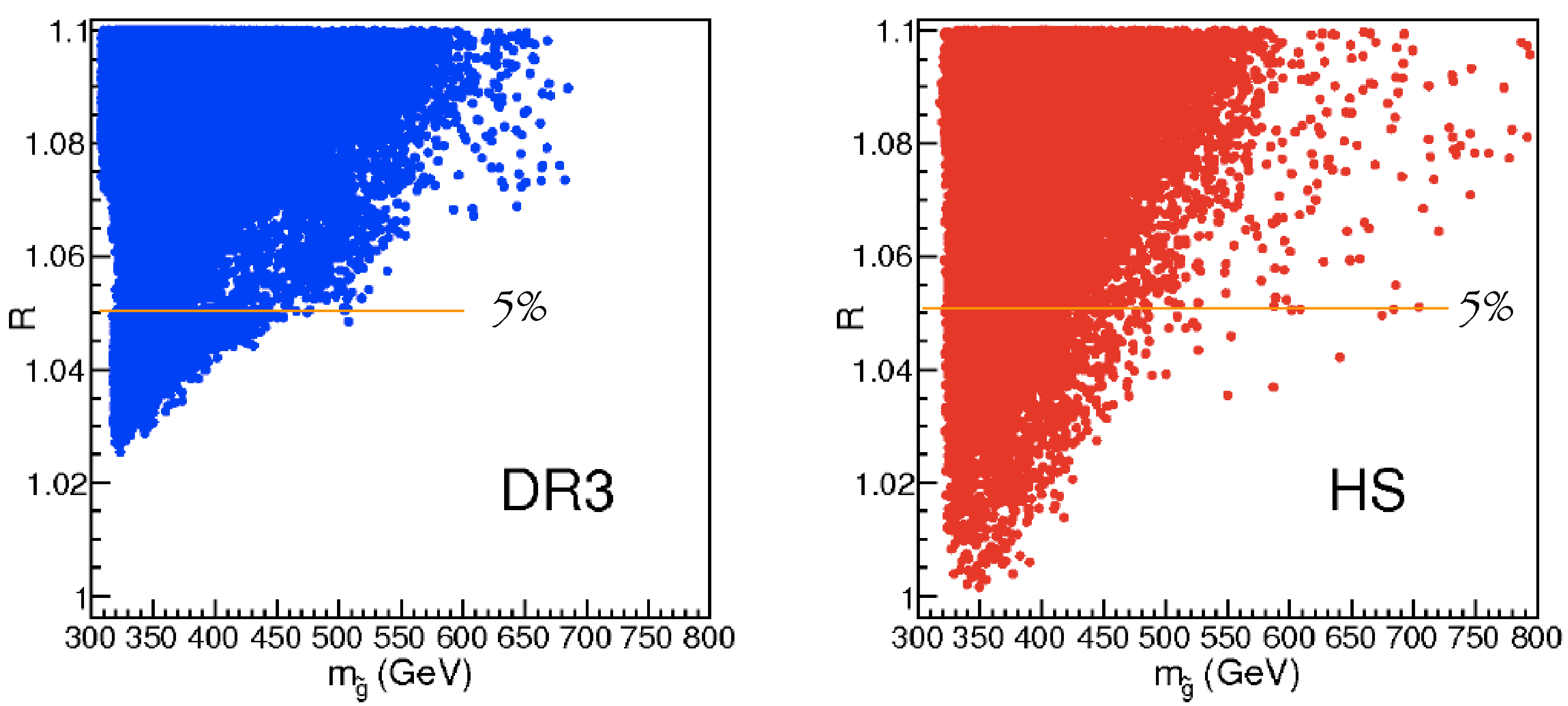
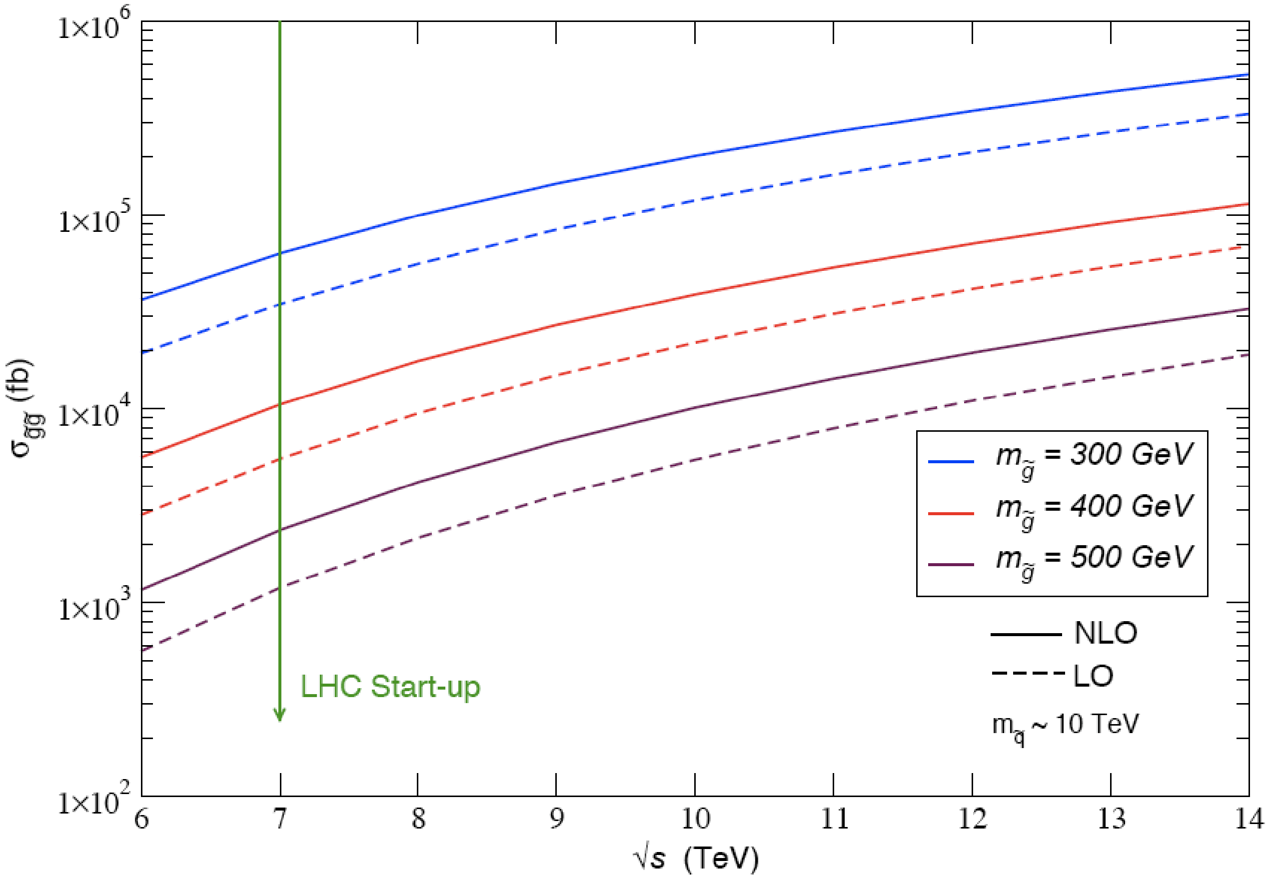


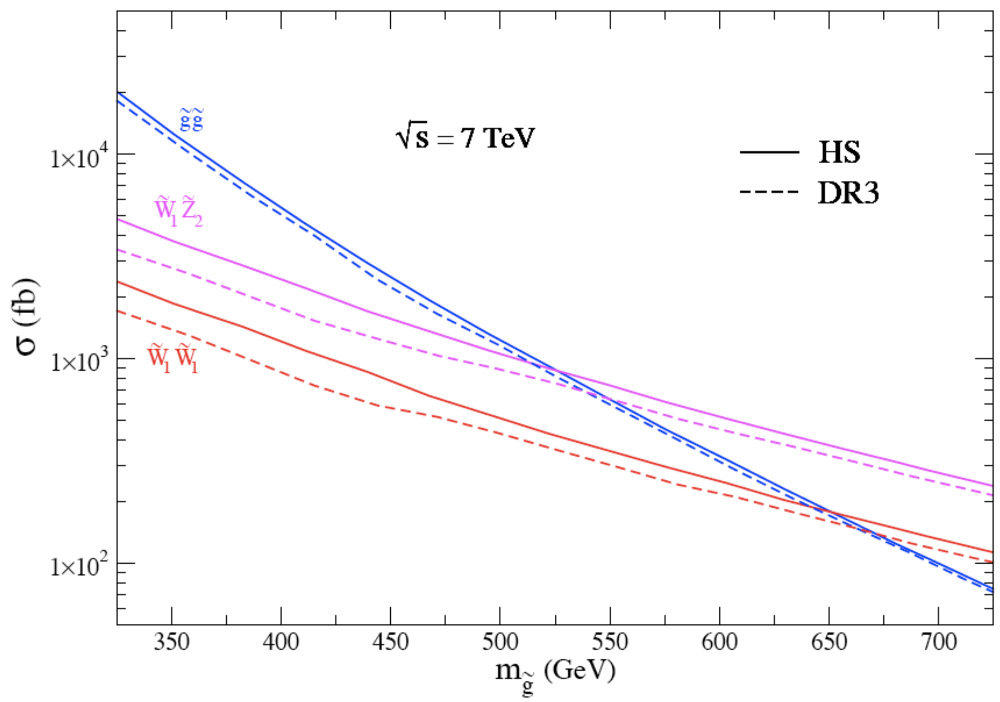
R versus gluino mass,
points from a MCMC scan for small R

Light gluino
↓
LHC potential at 7 TeV ?



Baer et al, arXiv:0911.4739

LHC reach at 7 TeV

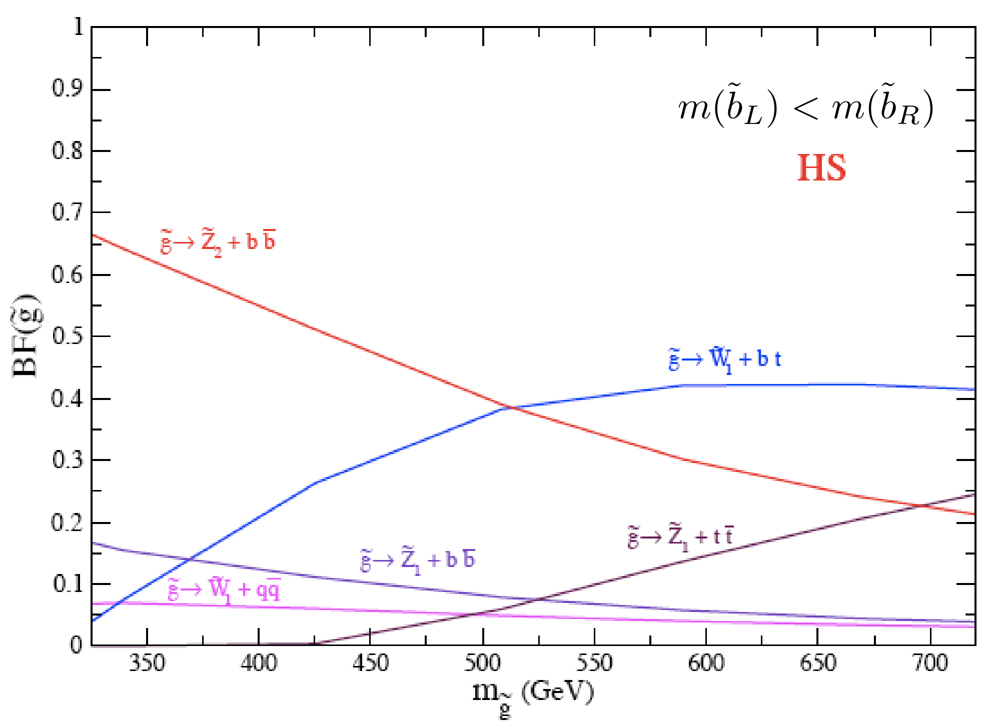


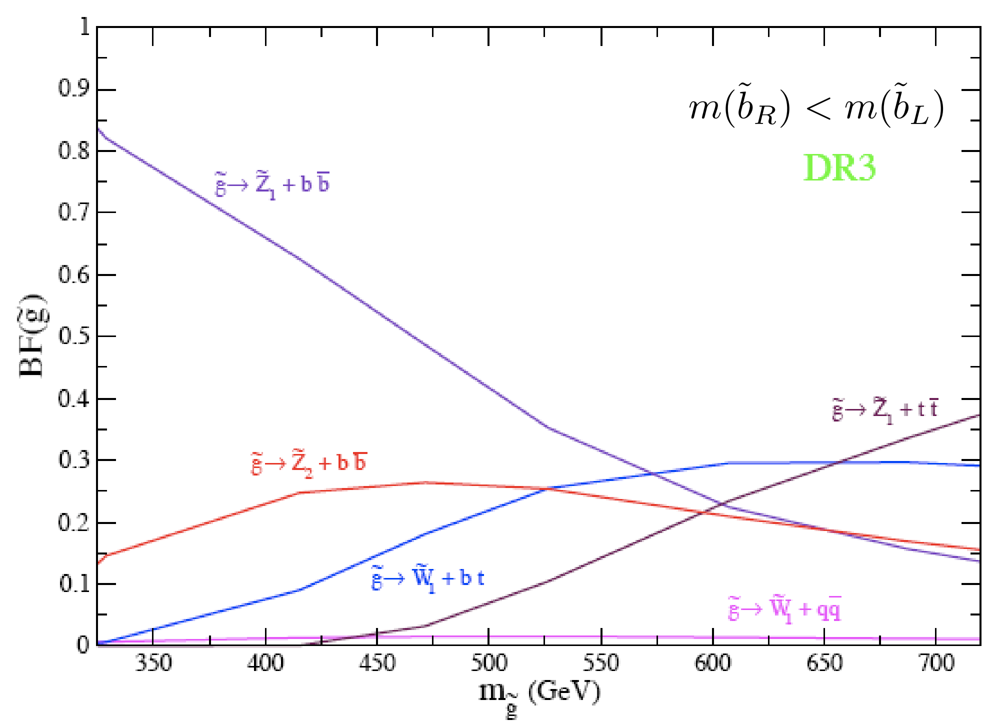
We consider model lines for HS and DR3 cases as function of m(gluino) up to 700 GeV.

Gluino-pair prod. dominated by gg fusion, σ(LO)~1 pb at m(gluino)~525 GeV.

Gluino signatures are dominanted by 3-bdy decays into heavy flavours:

$$\tilde{g} \to \tilde{\chi}^0_{1,2} b\bar{b},\ \tilde{\chi}^\pm_1 tb$$





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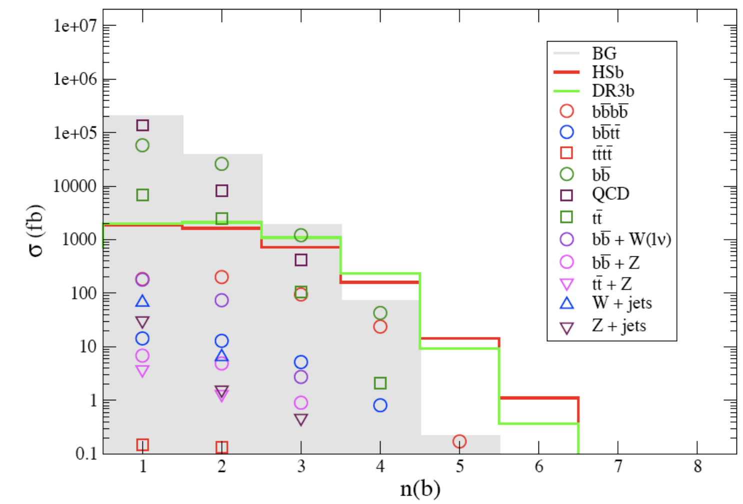
LHC reach at 7 TeV

Event simulation for HS and DR3 model lines:

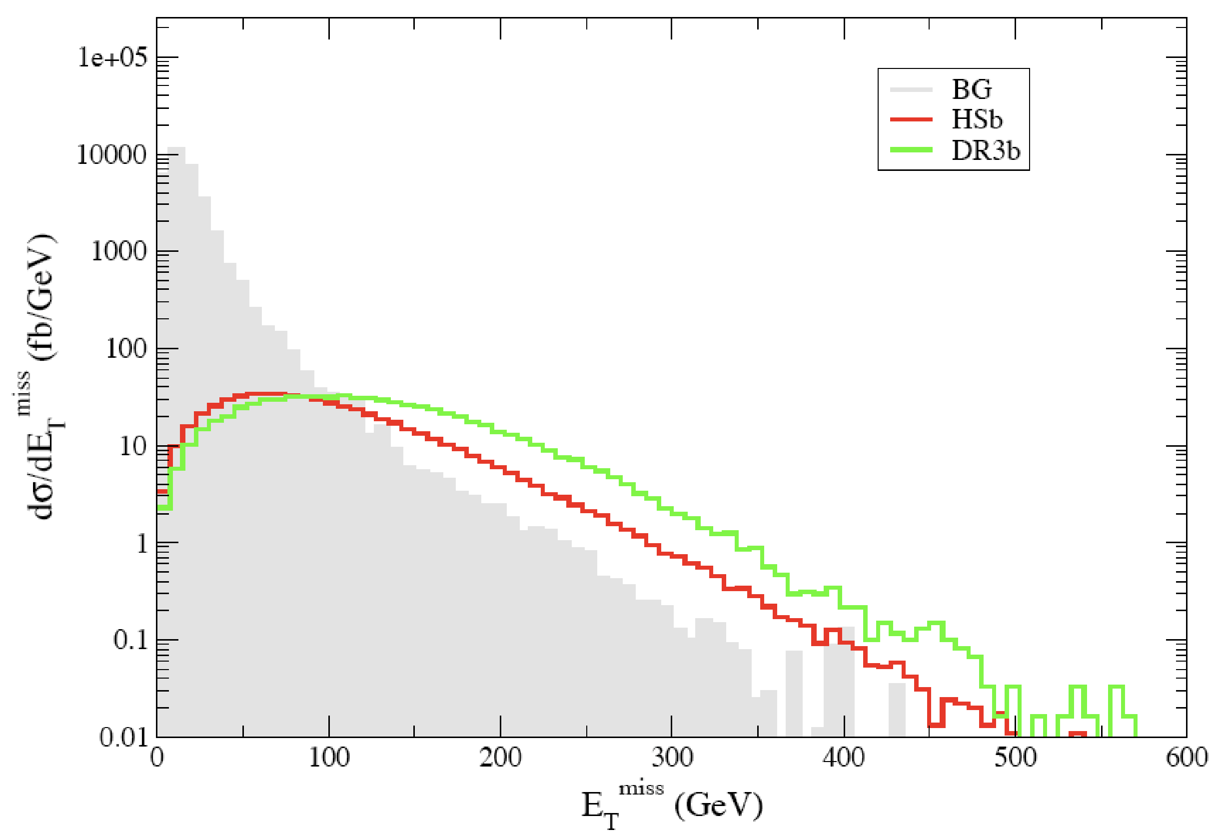
- Isajet 7.79 for the signal
- QCD, 2- and 3-bdy BGs with Alpgen
- 4t, 4b, 2t2b BGs with Madgraph
- Phythia for showering and hadronization
- Generic toy detector simulation



Basic Cuts "C0":

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

Results after C0-based selection			
	$\sigma(n(b) \geq 3)$	$\sigma(n(b) \geq 4)$	$\sigma(\mathrm{OS})$
HSb	899 fb	176 fb	99 fb
DR3b	1334 fb	243 fb	22 fb
BG	1911 fb	70 fb	11 fb



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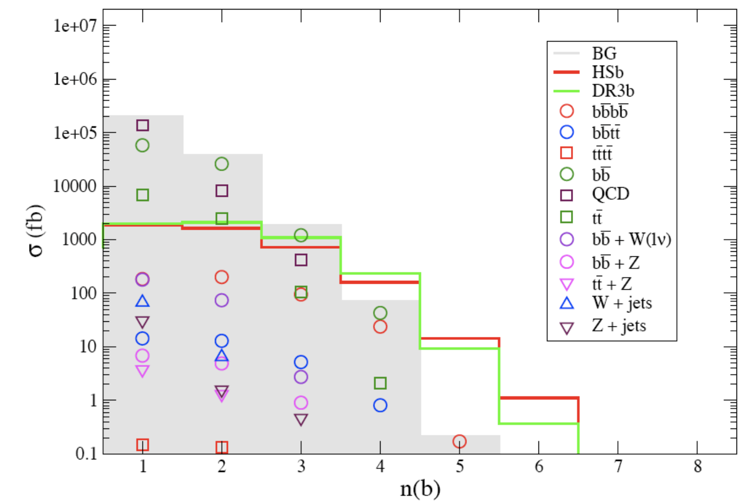

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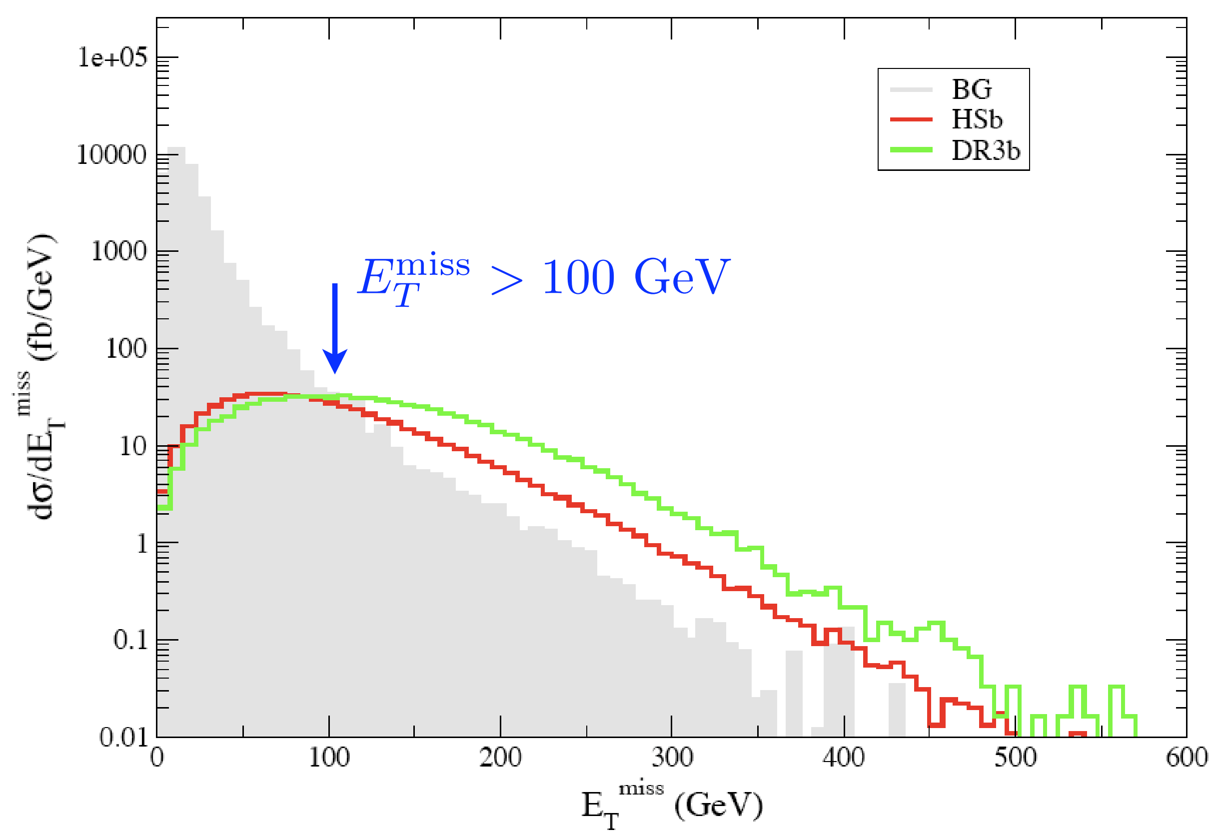

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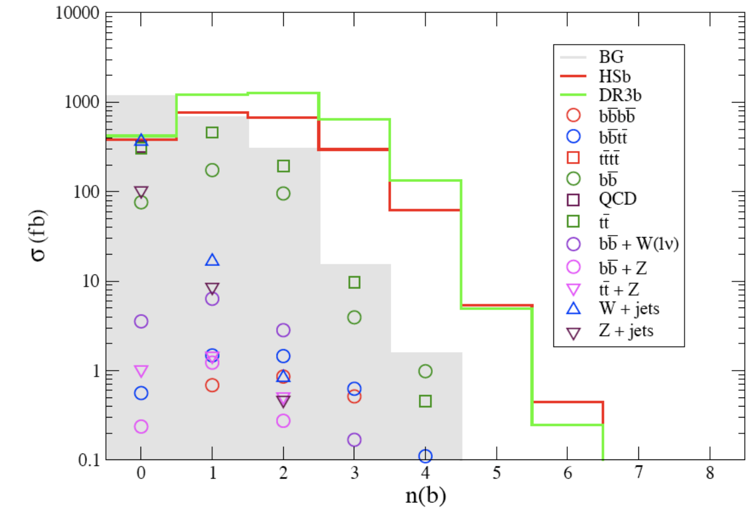
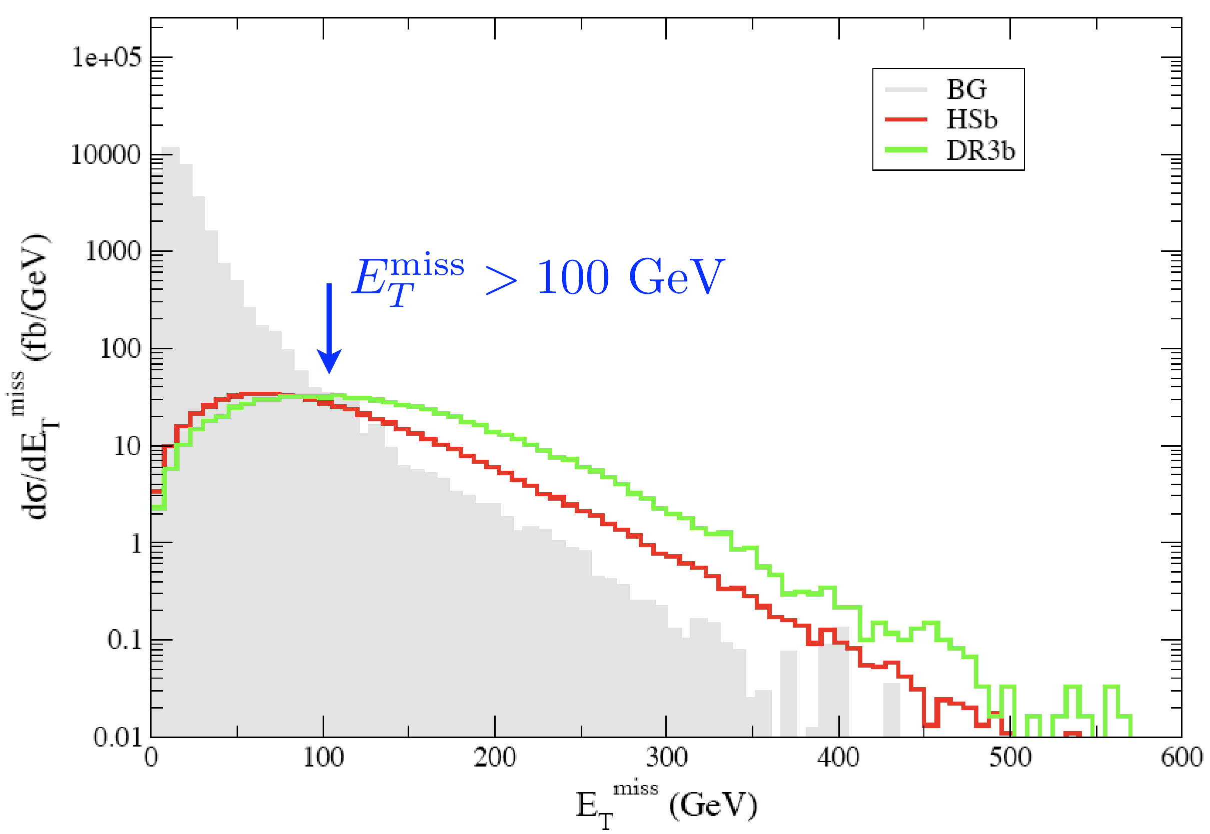
with cut on E_T^{miss}



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



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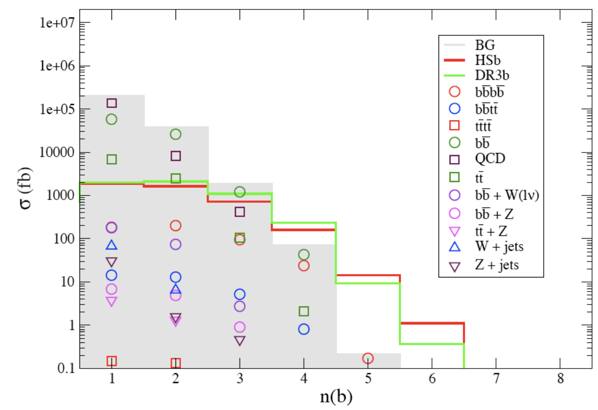
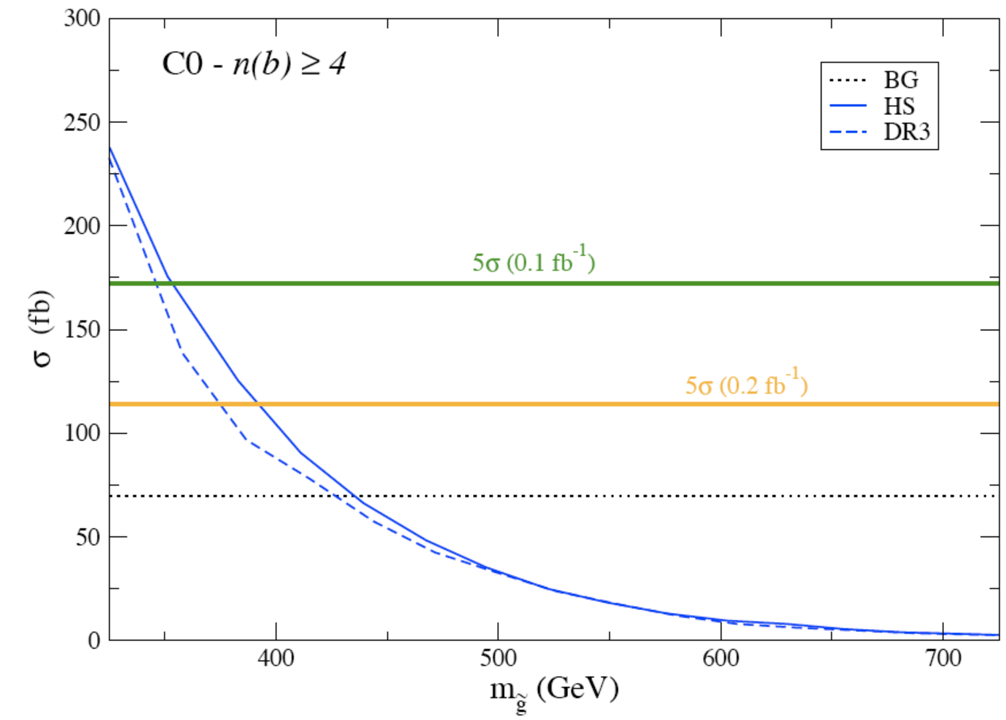
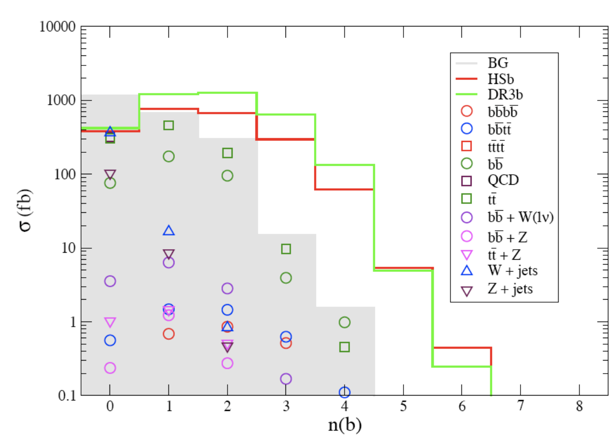
LHC reach at 7 TeV

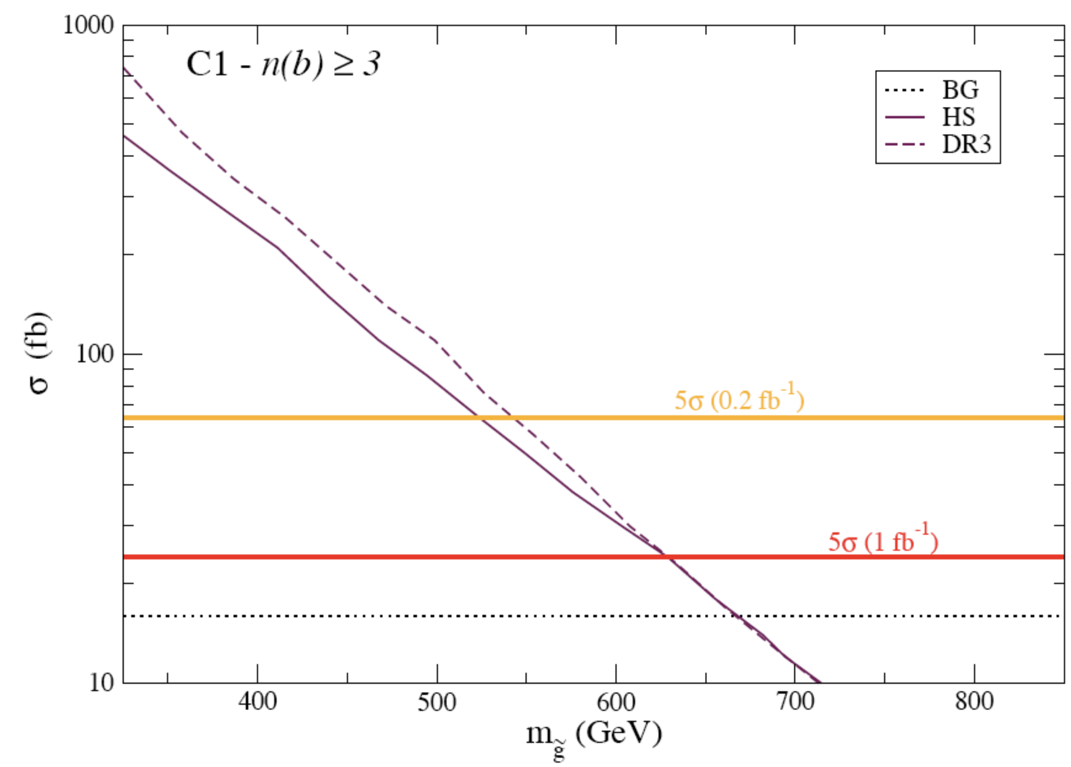
Without missing energy measurement:
up to m(gluino)=400 GeV with 0.2 fb^{-1} of data
requiring 4 b-jets





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





Conclusions

- Yukawa-unified SUSY GUT based on SO(10) is quite compelling.
- Typical mass spectrum has inverted hierarchy, c.f. "effective SUSY" with multi-TeV first/second generation & (sub)TeV 3rd generation.
  - ★ light gluino of ca 300-500 GeV mass !
- Quite good discovery potentials for such scenarios:
  - ★ Tevatron: m(gluino)~430 GeV with 10 fb^{-1}
  - ★ LHC@7TeV: m(gluino)~630 GeV with 1 fb^{-1}
- Search in multi-b channels is essential for early discovery.
- LHC [and Tevatron] may soon discover or rule out the simplest case of a SO(10) SUSY GUT.

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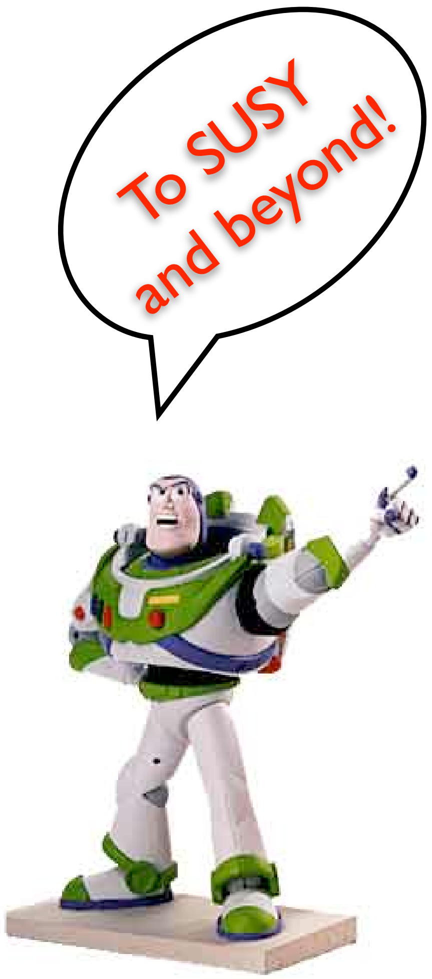
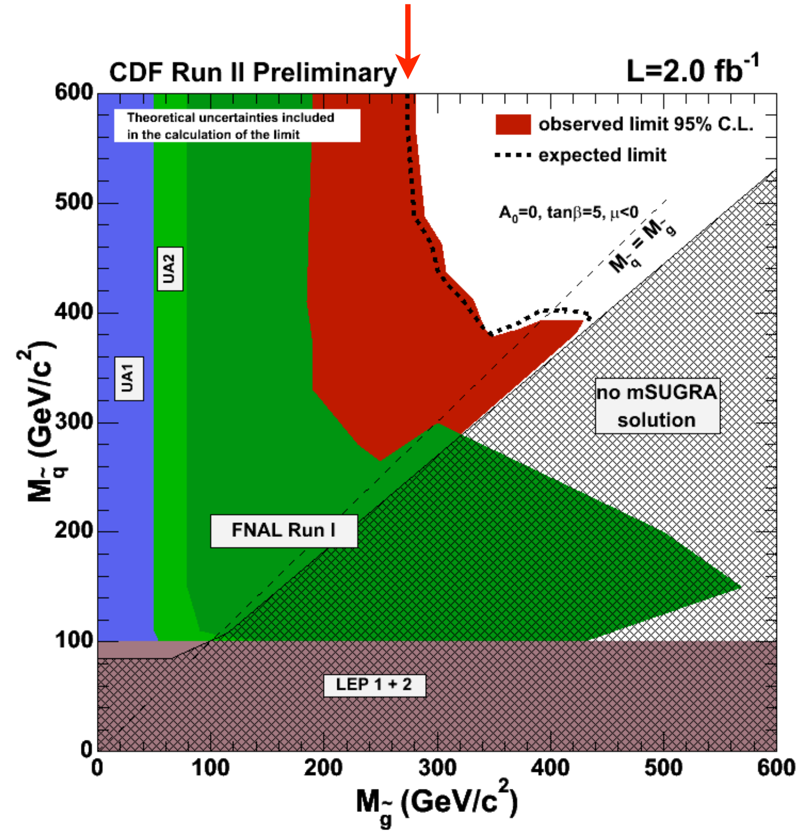


Backup

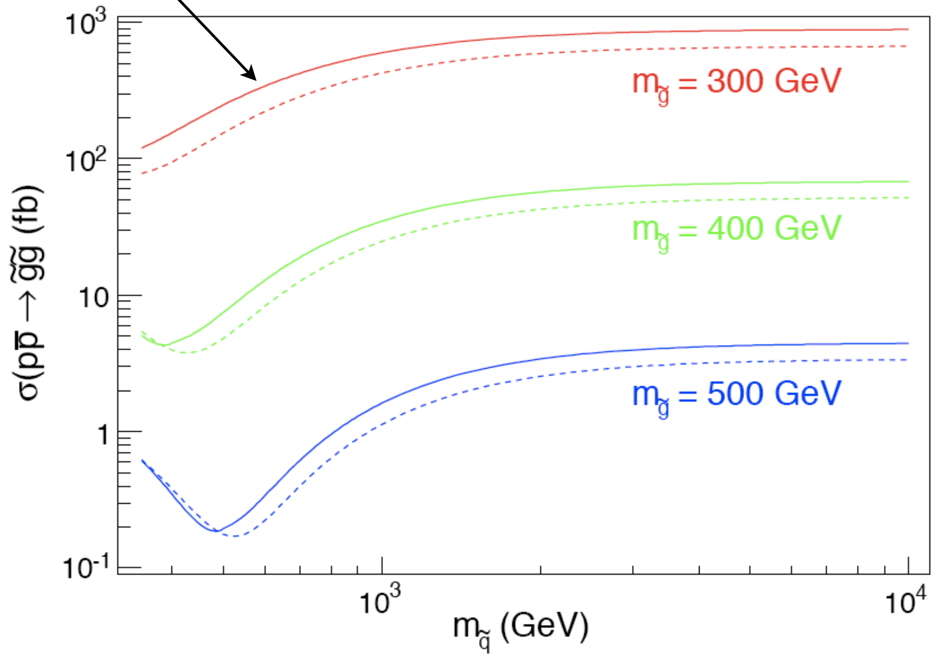
What about the Tevatron?



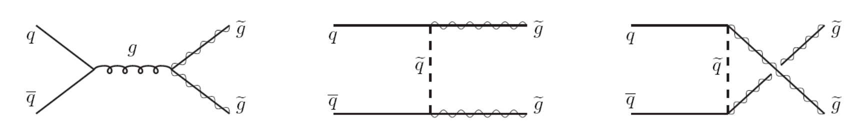
Baer et al, arXiv:0910.2988

Tevatron reach

current mSUGRA limit
for heavy squarks ($2fb^{-2}$)



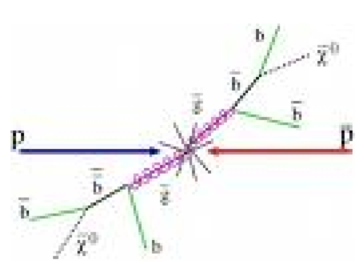
Gluino-pair prod. dominated by $q\bar{q}$ fusion.
Negative interference of s-, t-, u-channels for m(squark)~m(gluino)!

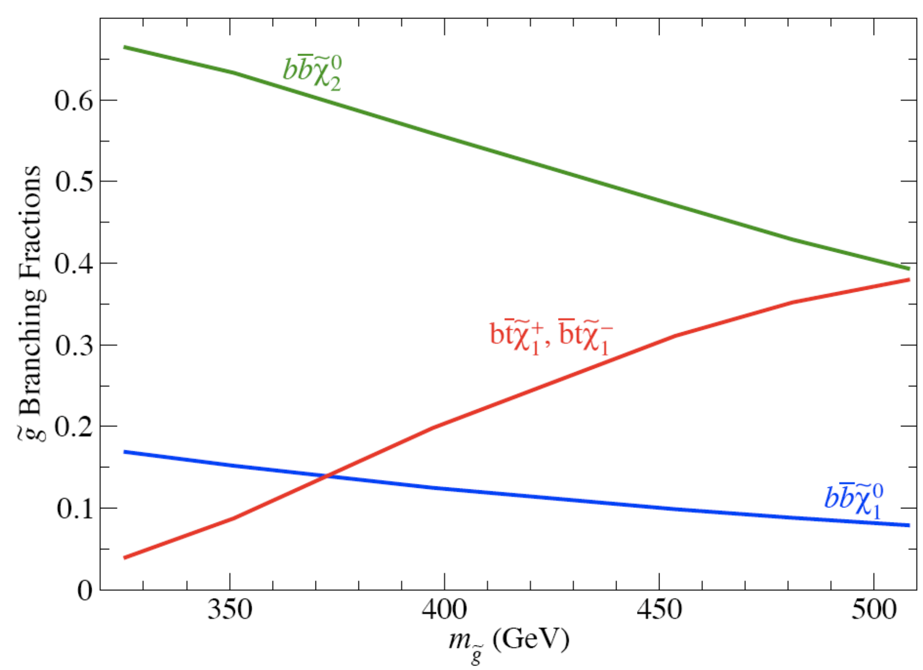


Xsection grows with increasing squark mass!

Gluino decays dominated by $\tilde{\chi}_2^0 b\bar{b}$ channel.
We adopt a YU model line by starting from a HS point with m_{16}=10 TeV and R~1.02 and varying $m_{1/2}$.

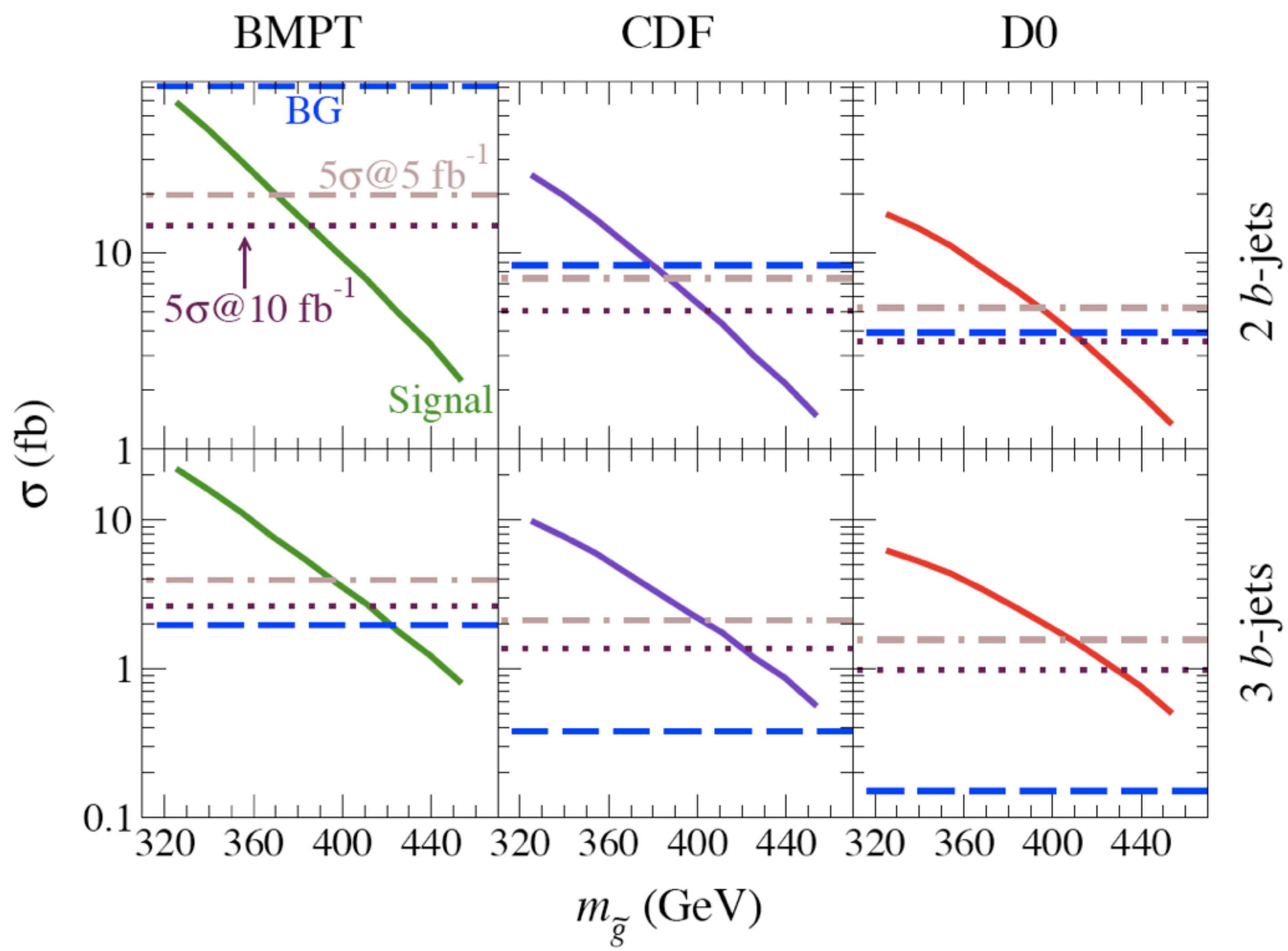
$$m_{1/2} = 35 - 100 \text{ GeV},$$
$$m_{\tilde{g}} = 325 - 508 \text{ GeV},$$
$$R \to 1.07$$

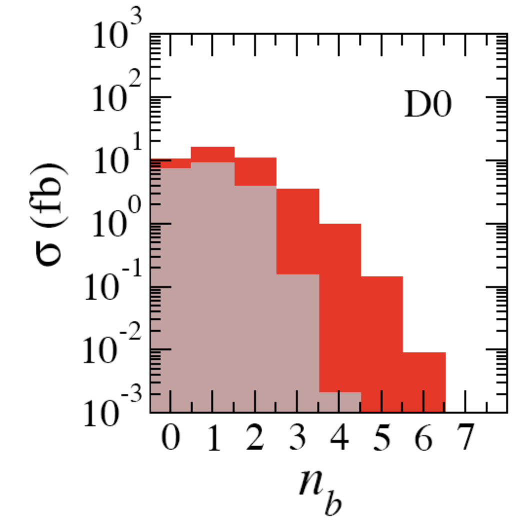




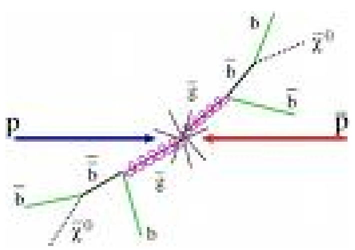
Baer et al, arXiv:0910.2988

Tevatron reach

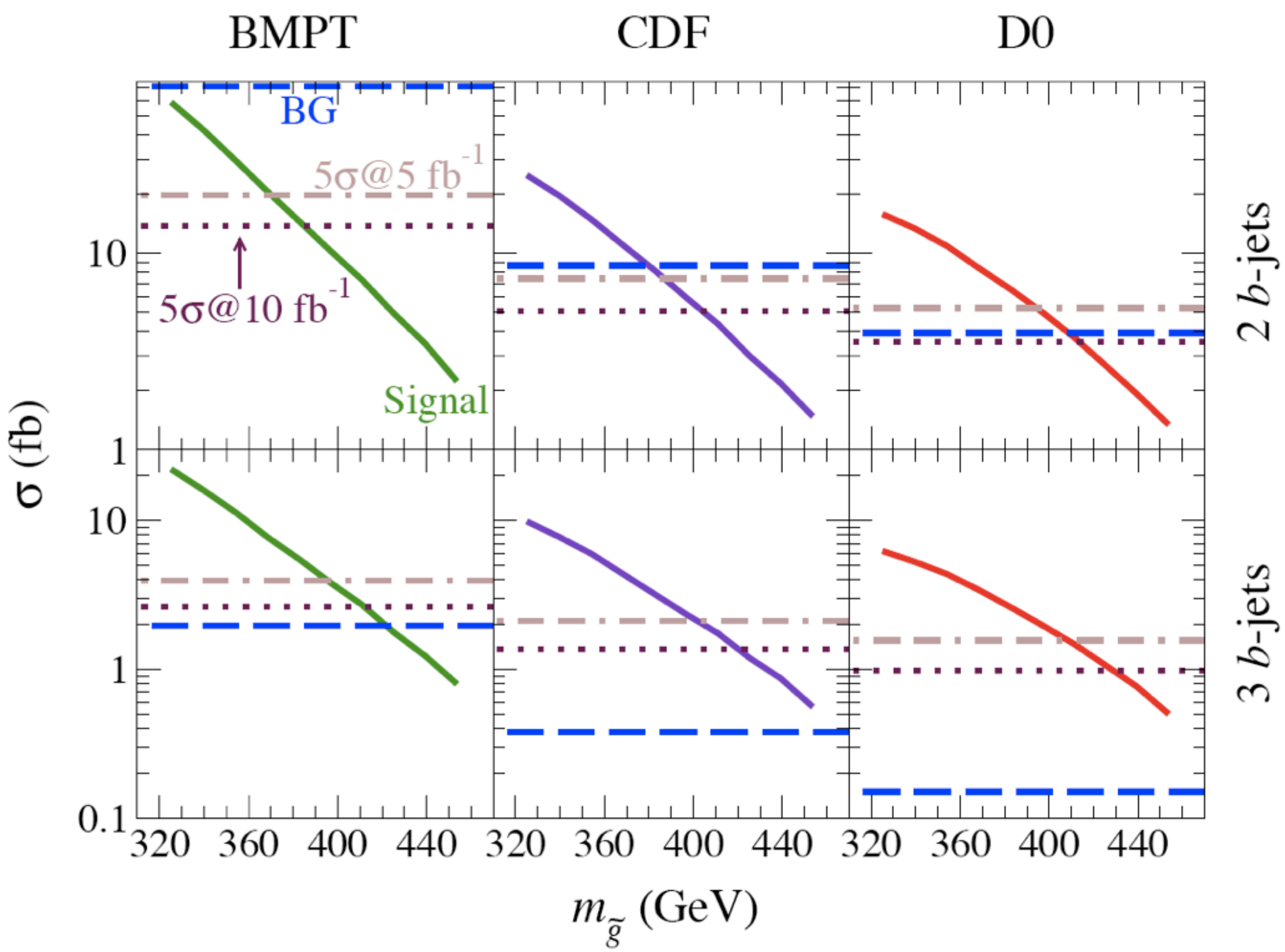


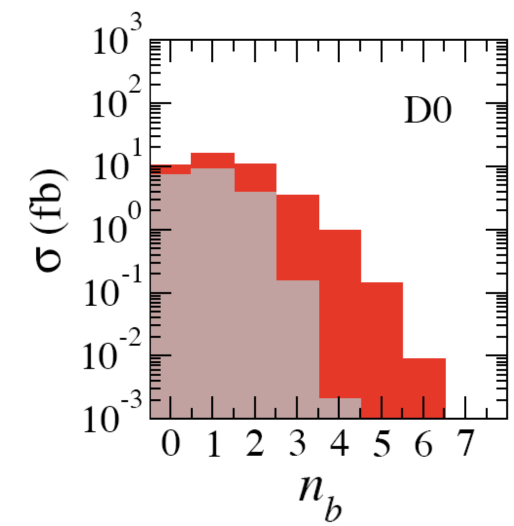


cuts	$E_T^{\rm miss}$	H_T	$E_T(j1)$	$E_T(j2)$	$E_T(j3)$	$E_T(j4)$
BMPT	$\geq$ 75 GeV	–	15	15	15	15
CDF	$\geq$ 90 GeV	280	95	55	55	25
D0	$\geq$ 100 GeV	400	35	35	35	20



Tevatron reach





With "D0" cuts and requiring ≥3 b-jets, 5σ discovery reach with 10 fb^{-1} about m(gluino)=430 GeV!

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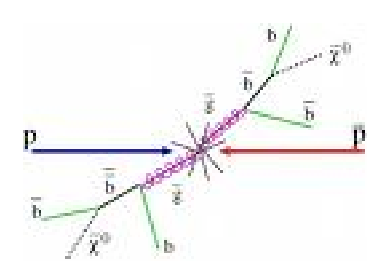
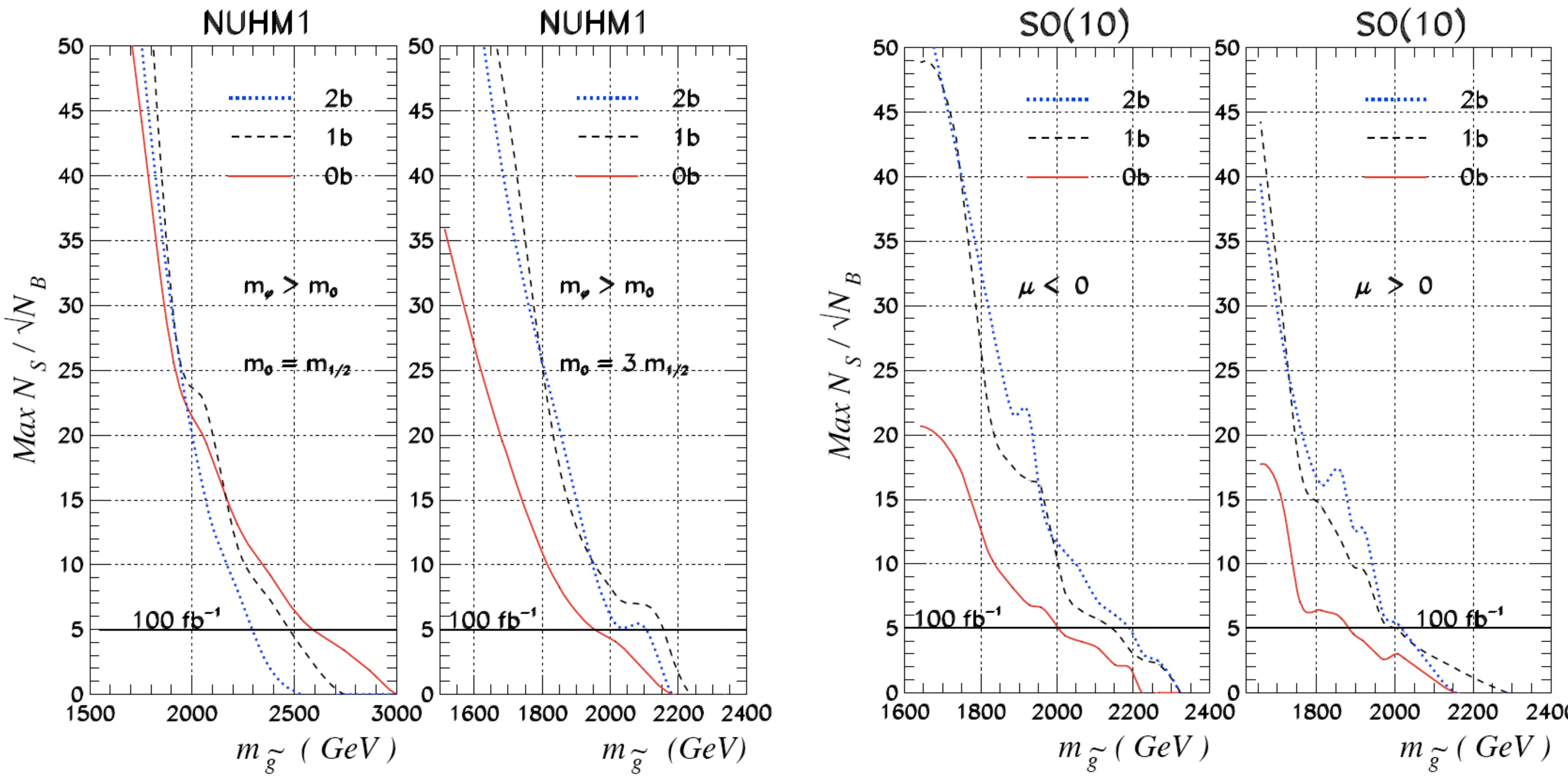
CDF	$\geq$ 90 GeV	280	95	55	55	25
D0	$\geq$ 100 GeV	400	35	35	35	20



Kadala, Mercadante, Mizukoshi, Tata,
arXiv:0803.0001

NB: importance of b-tagging

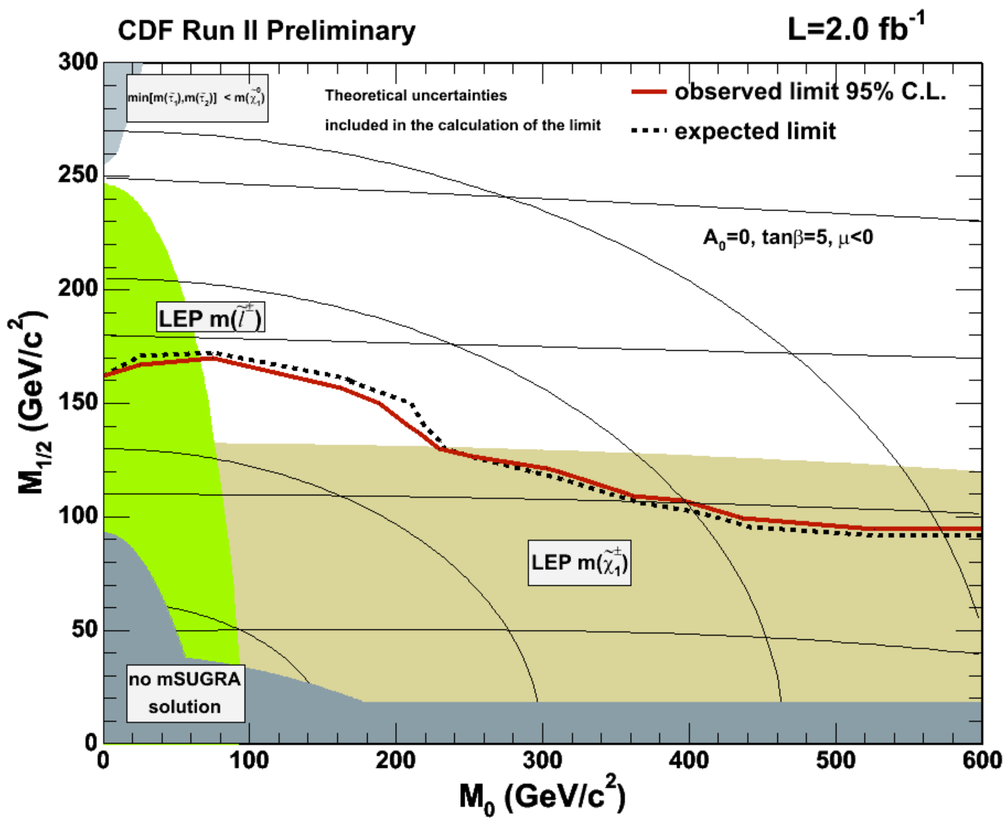
- Requiring 1, 2, or more b-jets can significantly enhance the signal/bg in many scenarios, e.g., 15-20% in the CMSSM focus point region.

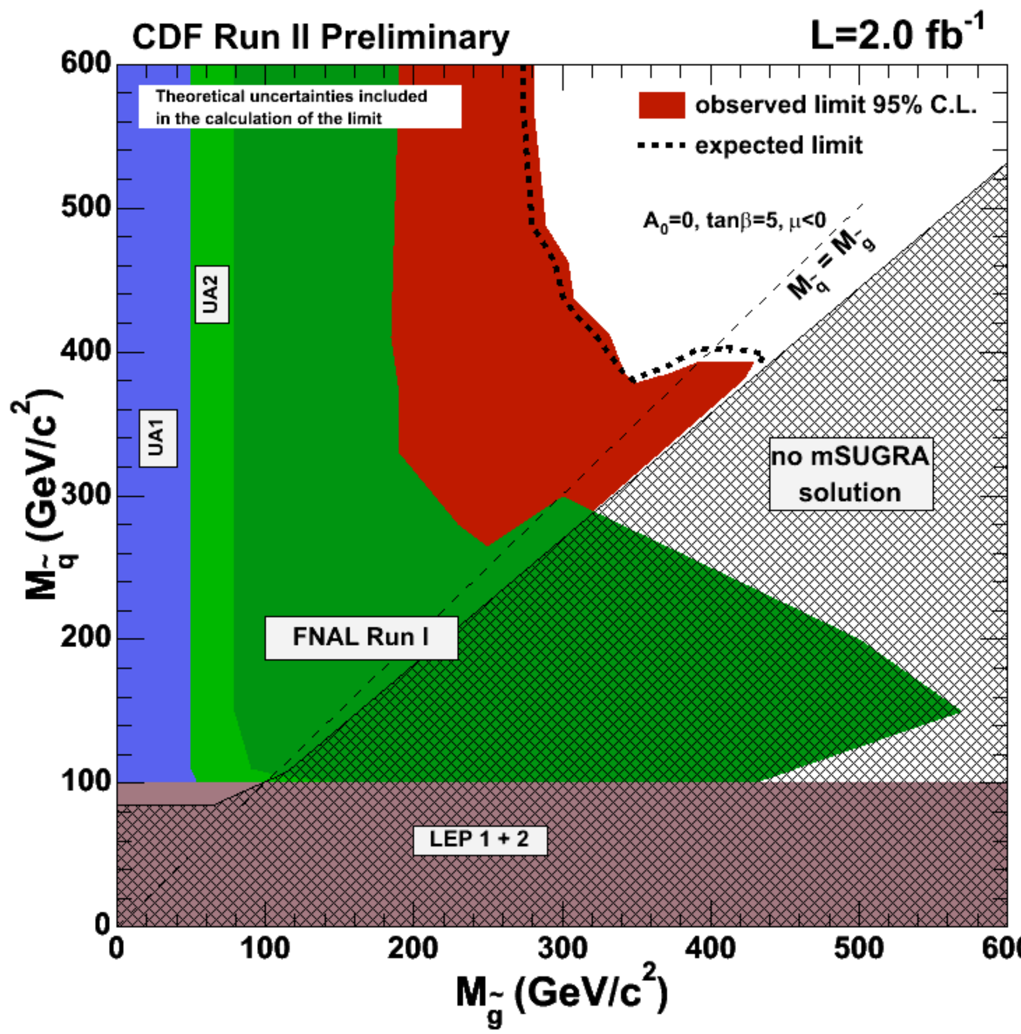


14 TeV

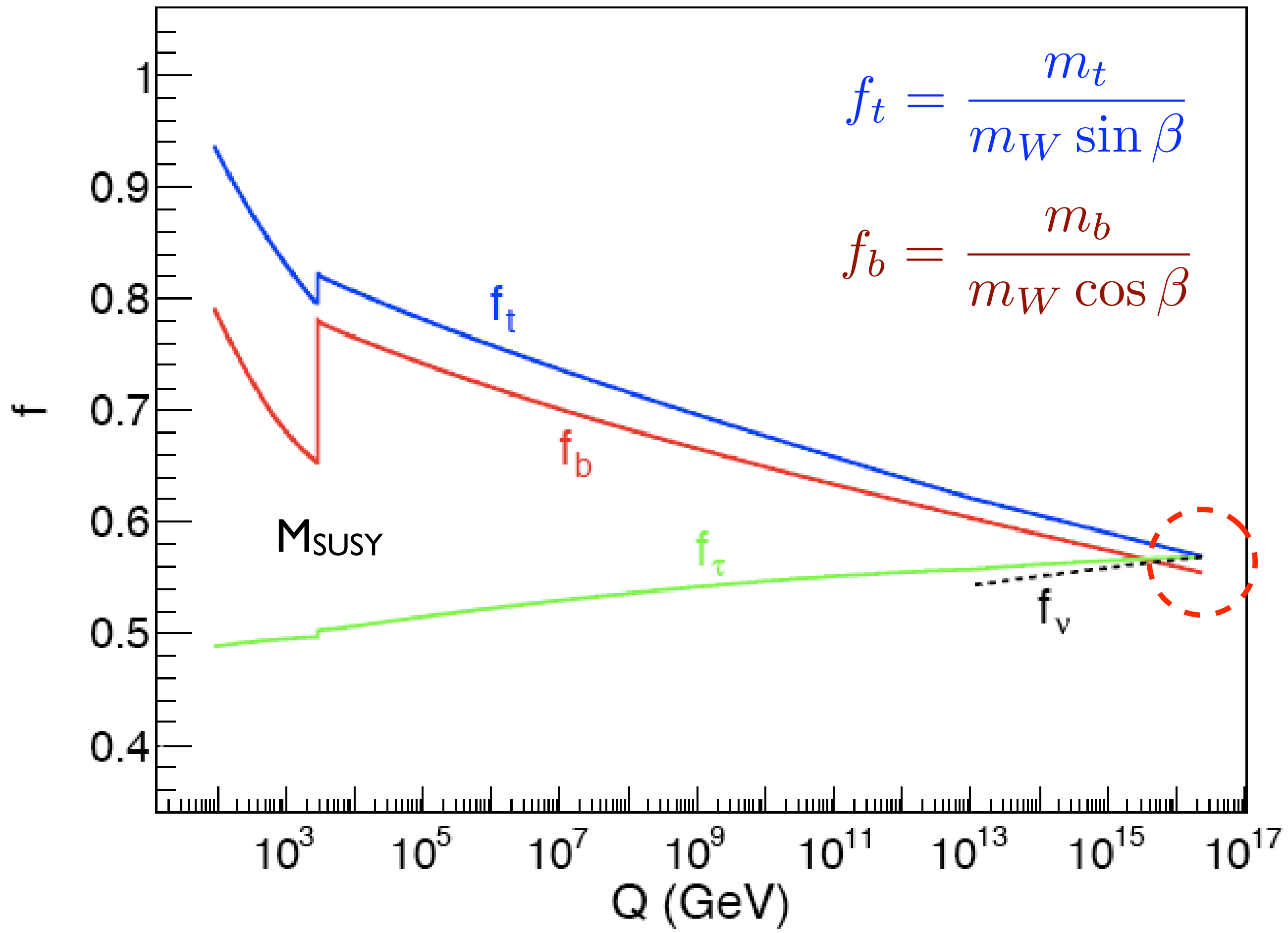
- Typical if 3rd generation is lighter then 1st/2nd gen. and $m_{\tilde{g}} \ll m_{\tilde{q}}$; enhances gluino decays into t or b via on- or off-shell stop/sbottom

CDF search for gluinos/squarks





$$R = \frac{max(f_t,\ f_b,\ f_\tau)}{min(f_t,\ f_b,\ f_\tau)} \longrightarrow 1$$



$$\tan\beta \sim m_t/m_b$$

$$\left(\frac{\delta m_b}{m_b}\right)^{\tilde{g}} \sim \frac{2\alpha_3}{3\pi}\,\mu\tan\beta\,\frac{m_{\tilde{g}}}{M^2_{SUSY}}$$

$$\left(\frac{\delta m_b}{m_b}\right)^{\tilde{\chi}^\pm} \sim \frac{\lambda_t^2}{16\pi^2}A_t\,\tan\beta\,\frac{\mu}{M^2_{SUSY}}$$

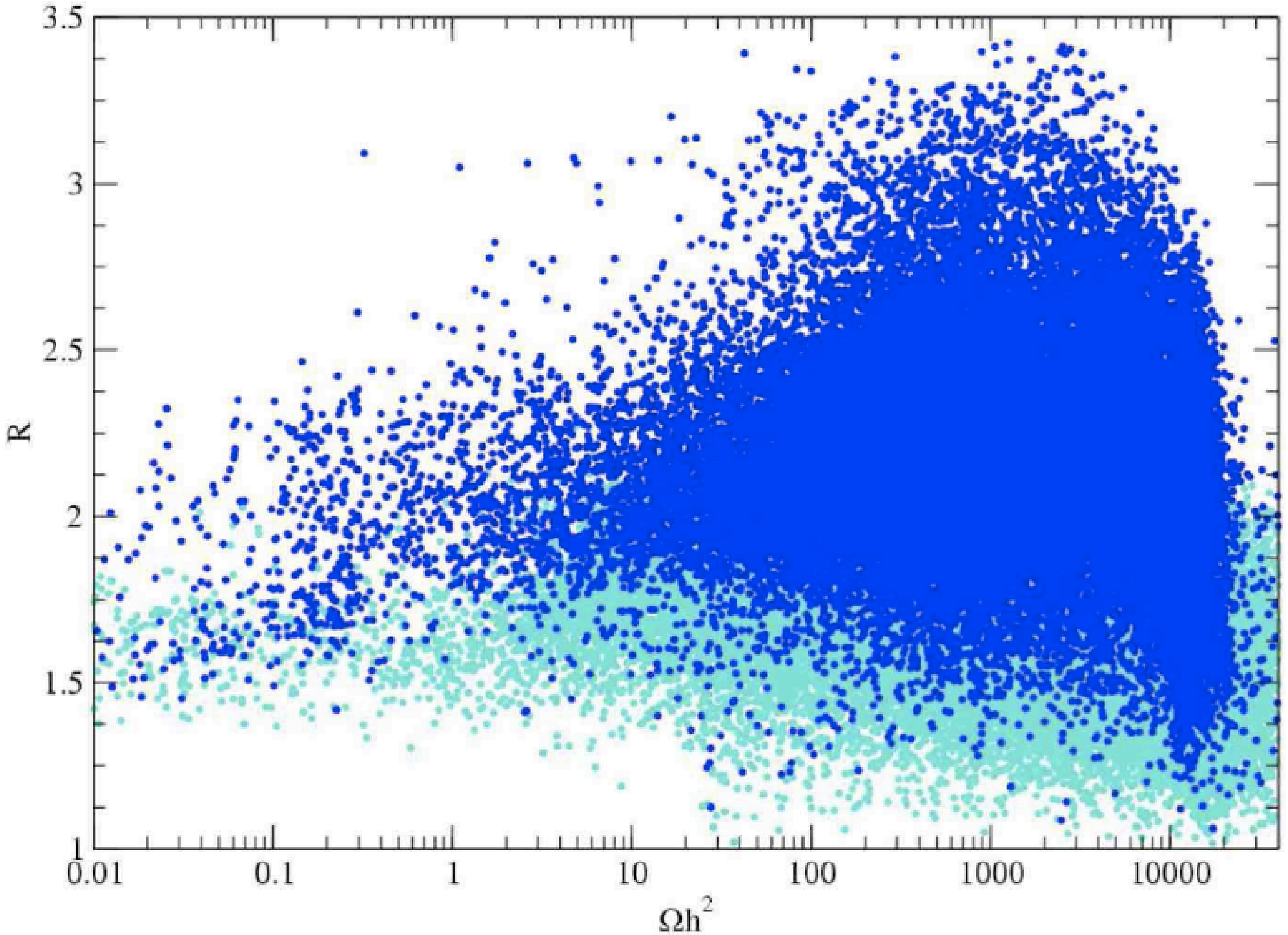
unification to few %

$$m_b^{\rm MSSM} = m_b^{\rm SM}\left[1 + \left(\frac{\delta m_b}{m_b}\right)\right]^{-1}$$

Large $\tan\beta$, large δm_b → important constraints from B physics

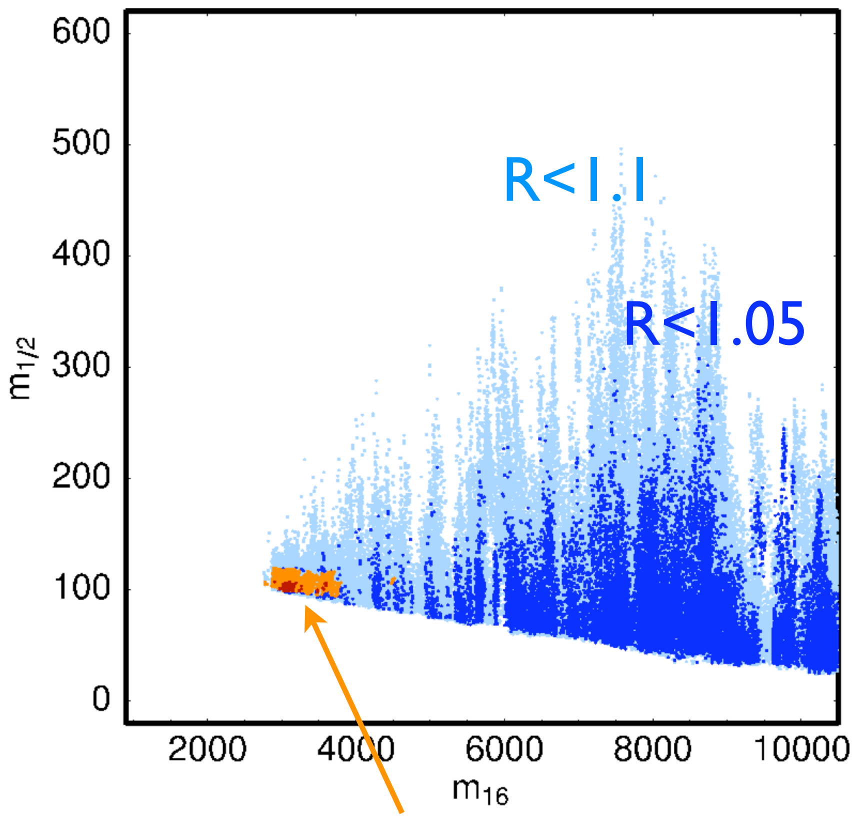
Relic density

- Yukawa-unified solutions typically feature a bino-like neutralino LSP whose relic density is way too large



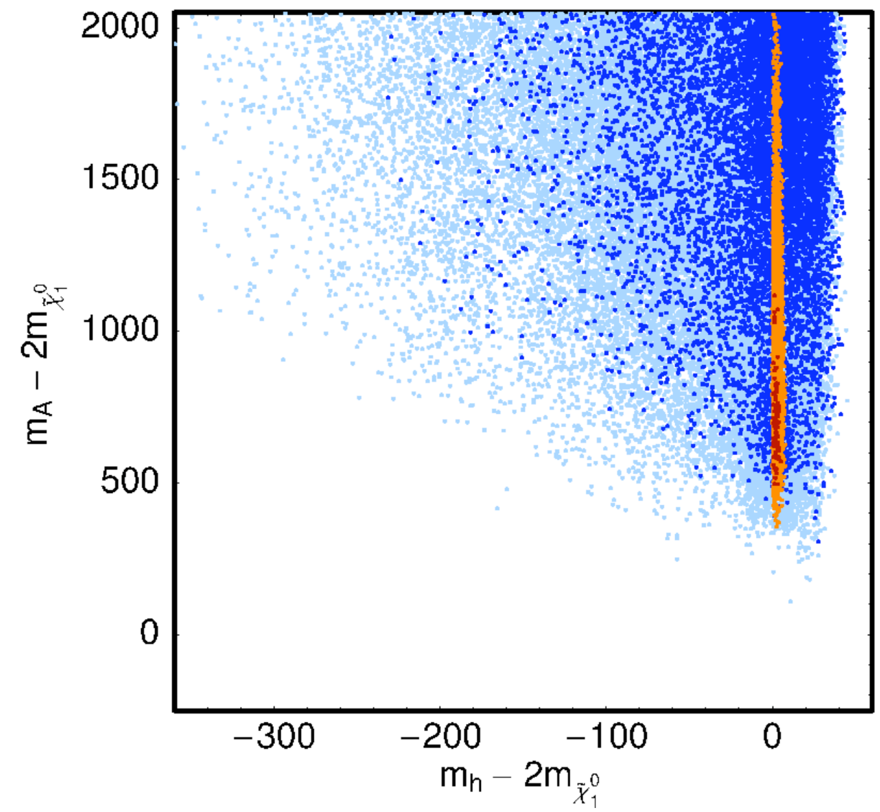
Random scan

- MCMC scan over $m_{1/2}$, m_{16}, m_{10}, M_D^2, A_0, $\tan\beta$ for small R (and $\Omega h^2 = 0.115 \pm 0.021$)



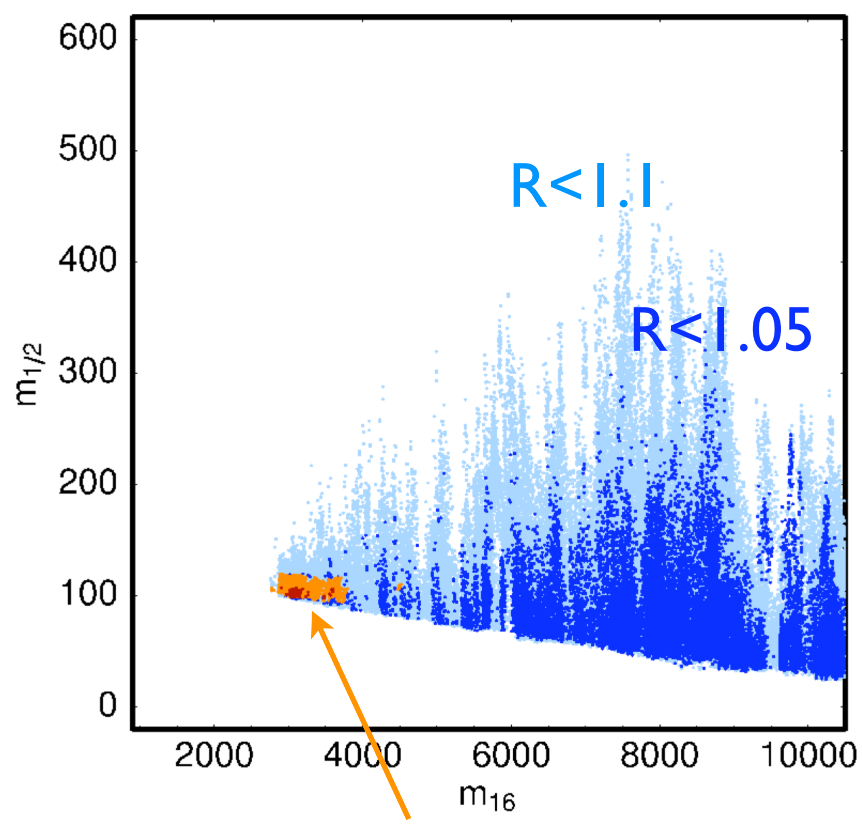
R<1.1 + Ωh^2<0.136

R<1.05 + Ωh^2<0.136



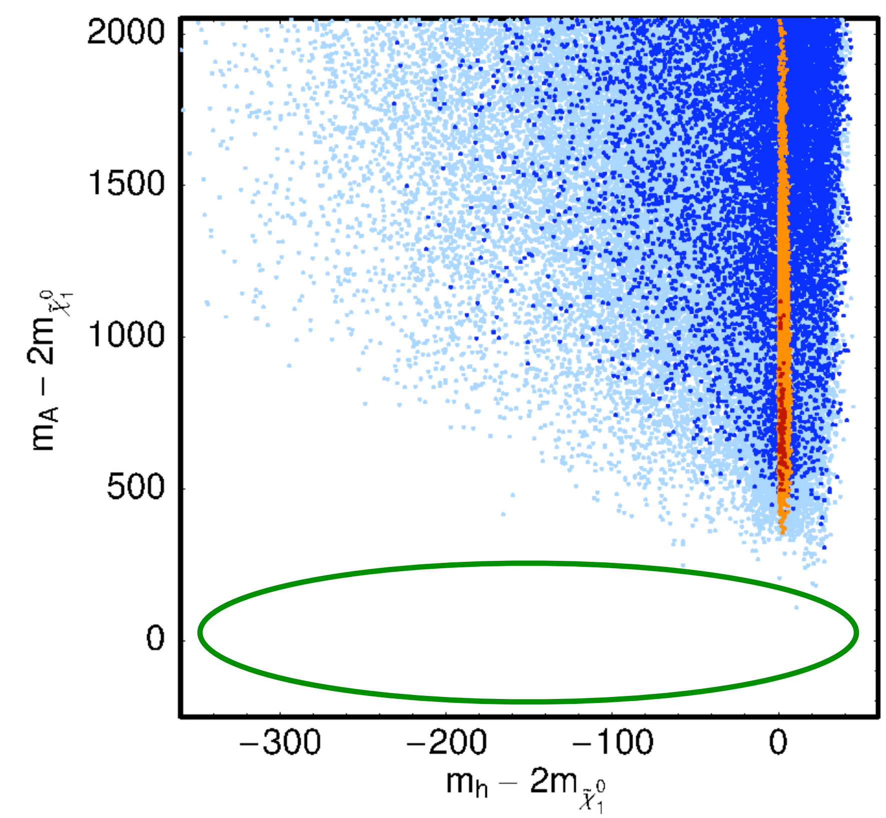
mechanism:
annihilation through h !

- MCMC scan over $m_{1/2}$, m_{16}, m_{10}, M_D^2, A_0, $\tan\beta$ for small R (and $\Omega h^2 = 0.115 \pm 0.021$)



R<1.1 + Ωh^2<0.136

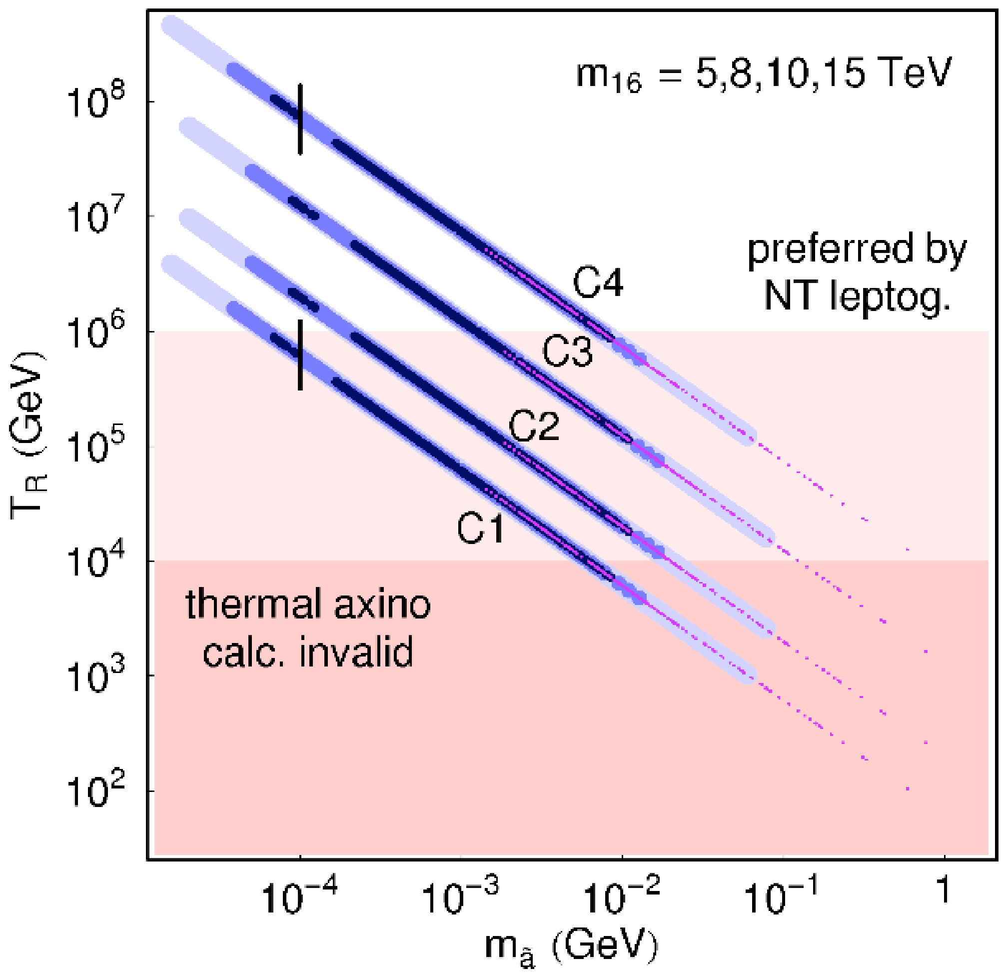
R<1.05 + Ωh^2<0.136



NB: we find neither the A-funnel nor the higgsino region of BDR (excluded by B-constr's)

mechanism:
annihilation through h !

Yukawa-unified scenarios with mixed axion/axino dark matter



C1: $f_a/N = 10^{11}$ GeV, $\Omega_{axion}h^2 \sim 0.017$;
DM dominantly therm. produced axinos.

C2: $f_a/N = 4\mathrm{x}10^{11}$ GeV, $\Omega_{axion}h^2 \sim 0.084$;
DM dominantly axions + some mixed cold and warm axinos.

C3: $f_a/N = 10^{12}$ GeV, $\Omega_{axion}h^2 \sim 0.084$;
DM dominantly axions + some mixed cold and warm axinos.

C4: $f_a/N = 10^{12}$ GeV, $\langle a \rangle \sim 0$, $\Omega_{axion}h^2 \sim 0$;
DM dominantly axinos, we choose $(\Omega_{axino}h^2)^{TP}=0.1$ and $(\Omega_{axino}h^2)^{NTP}=0.01$

Message: can achieve consistent cosmology for Yukawa-unified SUSY

Baer et al, arXiv:0812.2693