

Yukawa-unified SUSY and LHC at 7 TeV

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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 a 10-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 $M_{GUT} = \text{MSSM } (+\text{RHN})$

MSSM

Minimal supersymmetric standard model

particle	spin	superpartner	spin
quarks	1/2	squarks	0
leptons	1/2	sleptons	0
gauge bosons	1	gauginos	1/2
Higgs bosons	0	higgsinos	1/2
graviton	2	gravitino	3/2

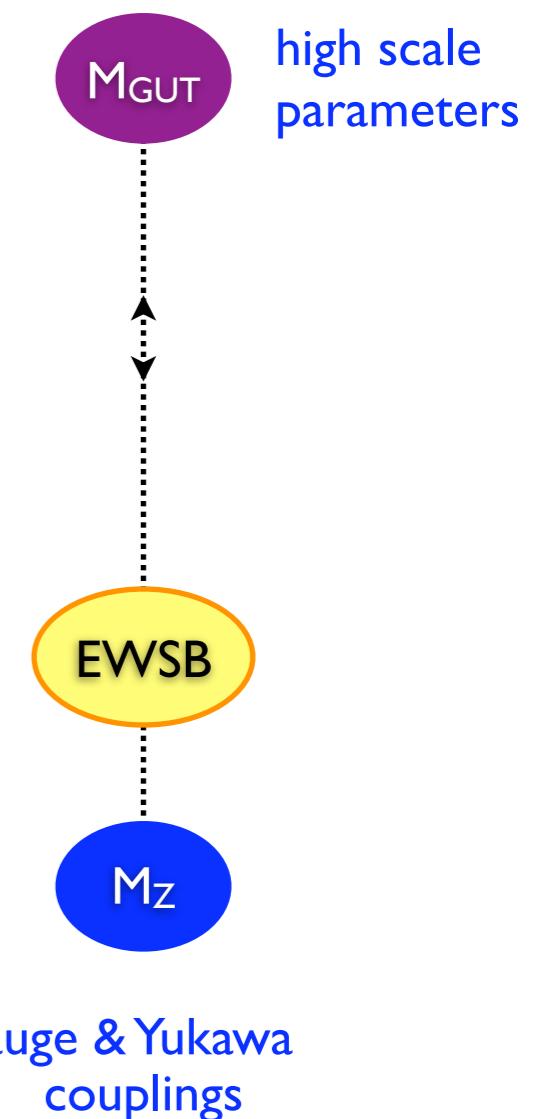
full MSSM: ~100 free parameters (soft breaking terms)

CMSSM (mSUGRA): $m_{1/2}$, m_0 , A_0 , $\tan\beta$, sign μ .

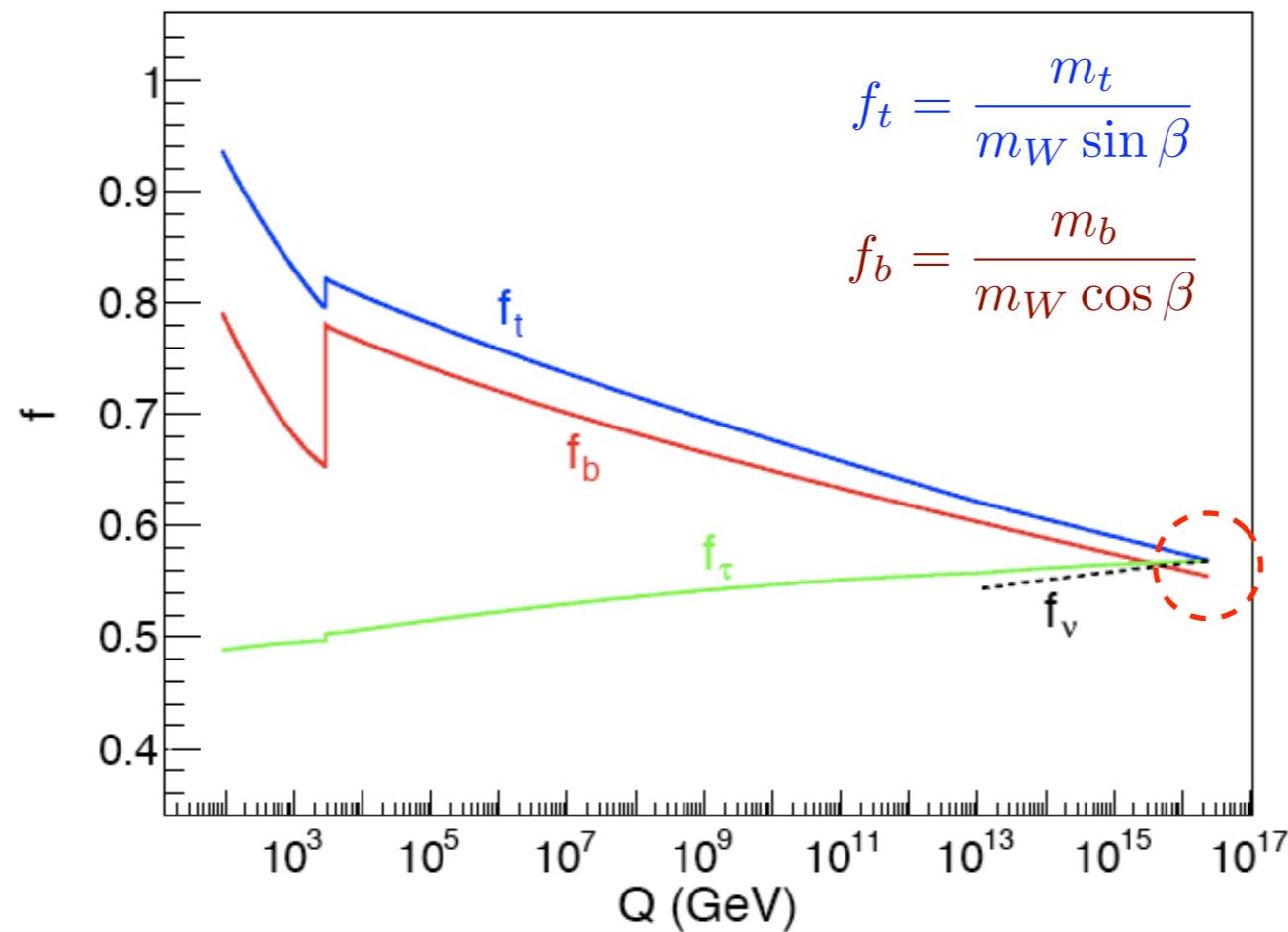
NUHM: $m_{1/2}$, m_0 , $m_{H_{1,2}}$, A_0 , $\tan\beta$, sign μ .

SO(10): $m_{1/2}$, m_{16} , m_{10} , M_D^2 , A_0 , $\tan\beta$, sign μ

$$m_{H_{u,d}}^2 = m_{10}^2 \mp M_D^2$$



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



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

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

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

unification to few %

Large $\delta m_b \rightarrow$ important constraints from B physics

Conditions for Yukawa unification

★ For $\mu > 0$, as preferred by $b \rightarrow s\gamma$, Yukawa unification (YU) can only be realized for very particular parameter relations

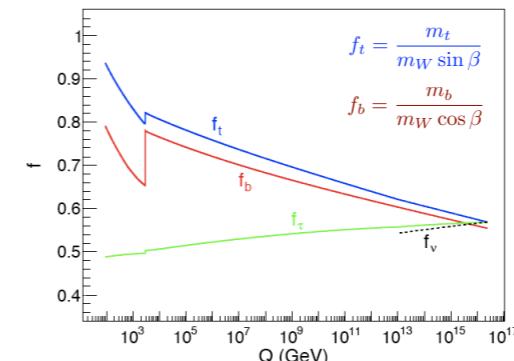
- $m_{16} \sim 5 - 15$ TeV,
- $A_0^2 \simeq 2m_{10}^2 \simeq 4m_{16}^2$, $(A_0 < 0)$
- $m_{1/2} \ll m_{16}$,
- $\tan \beta \sim 50$.

★ 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

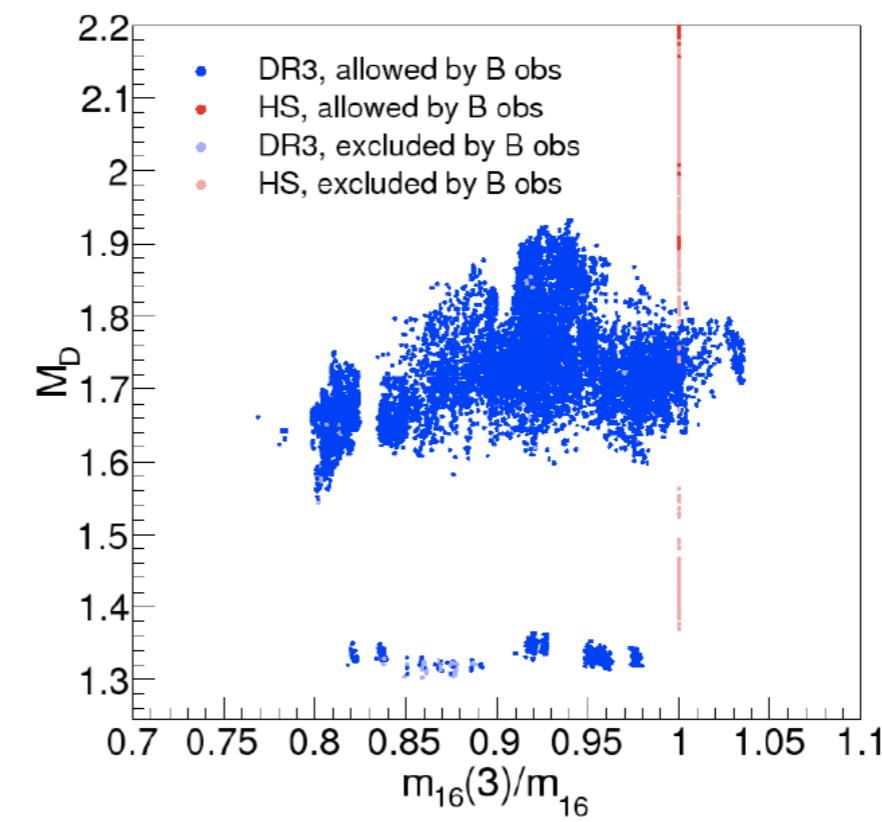
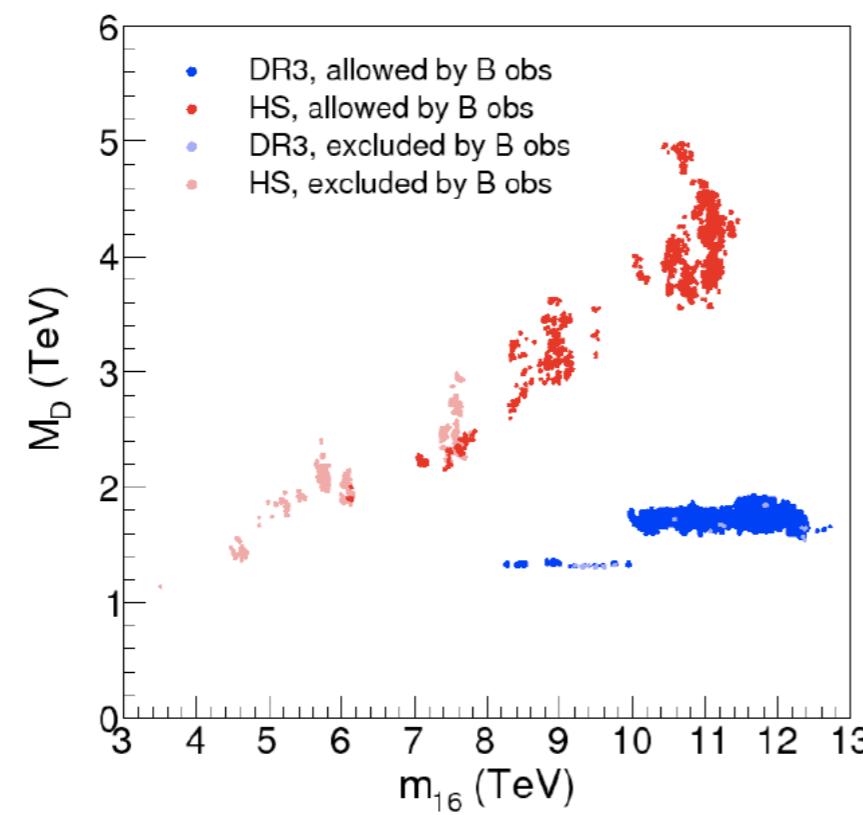
NB: we need $m_{H_u}^2 < m_{H_d}^2$ at M_{GUT} , so $M_D^2 > 0$.



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

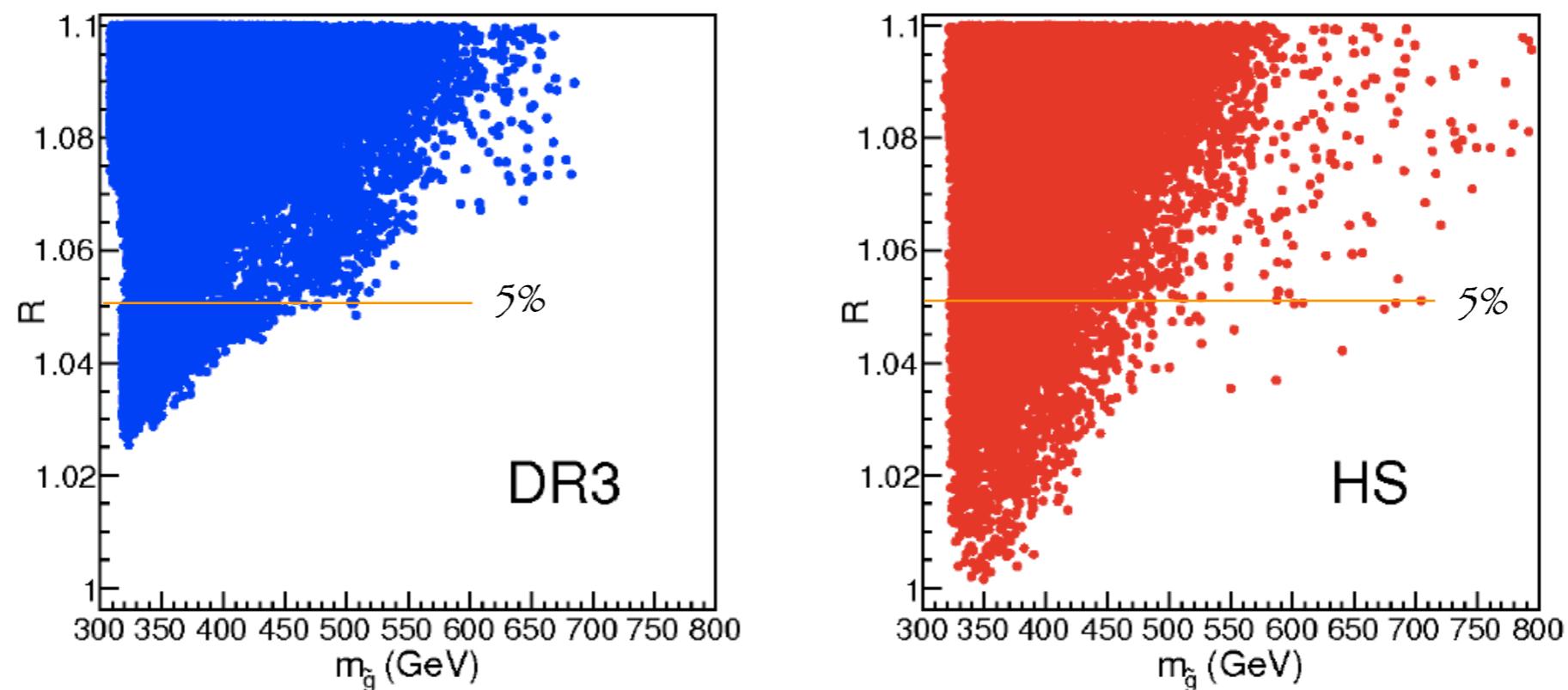
- D-term splitting w/o RHN gives $R \sim 1.08$ (i.e. 8% unification)
- Splitting of only m_H 's (“just-so HS”) allows for $R \sim 1.01$
- D-term splitting with RHN gives $R \sim 1.04, \dots$
- ... but if we allow in addition small non-degeneracy of 3rd vs. 1st/2nd generation, we get $R \sim 1.02$

Points with $R < 1.05$ from a MCMC scan

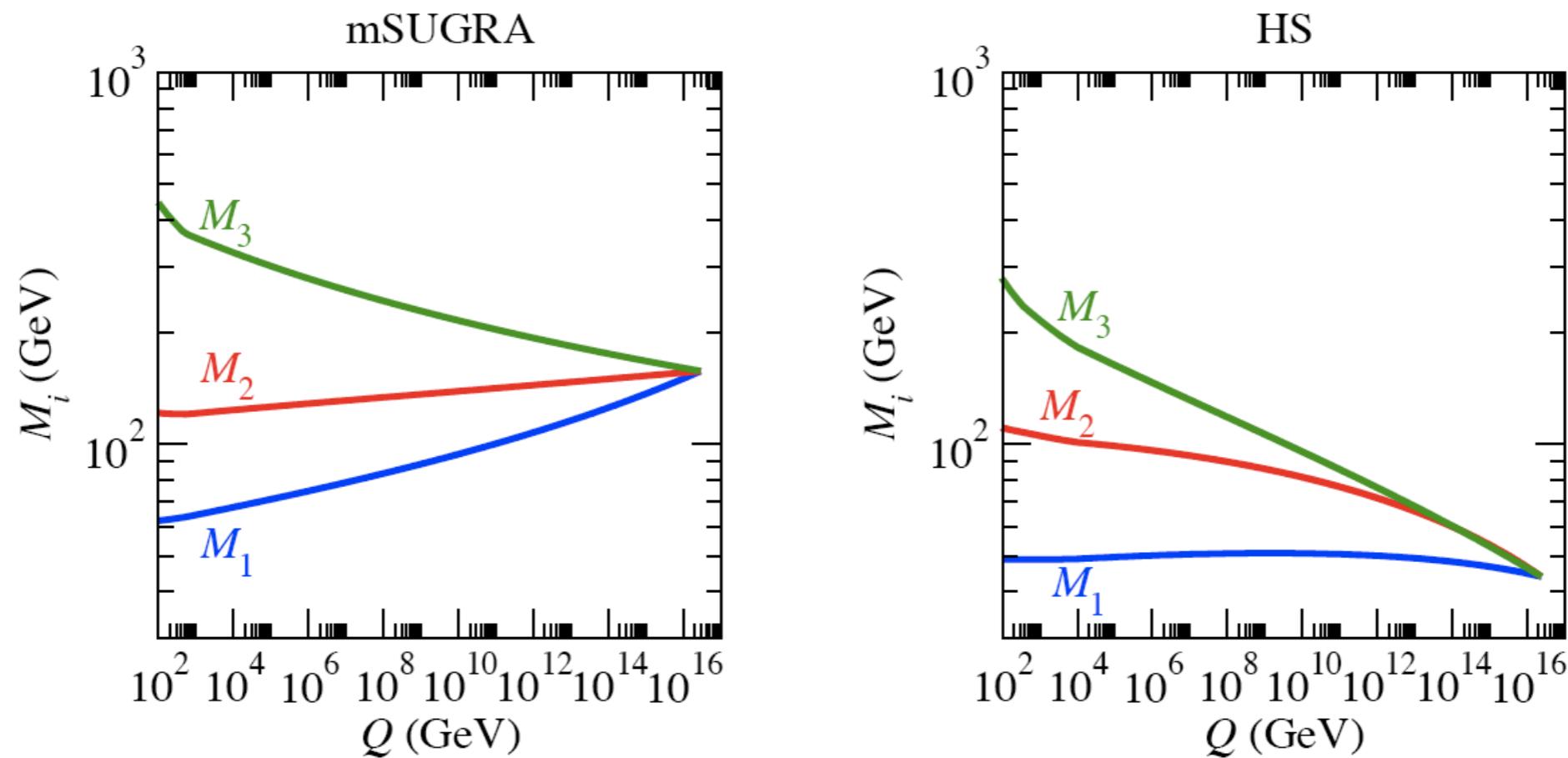


Typical mass spectra

- 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 \sim 50-80 GeV, gluino \sim 300-500 GeV
- c.f “effective SUSY” by Cohen, Kaplan, Nelson ’1996



Points from a MCMC scan for small R

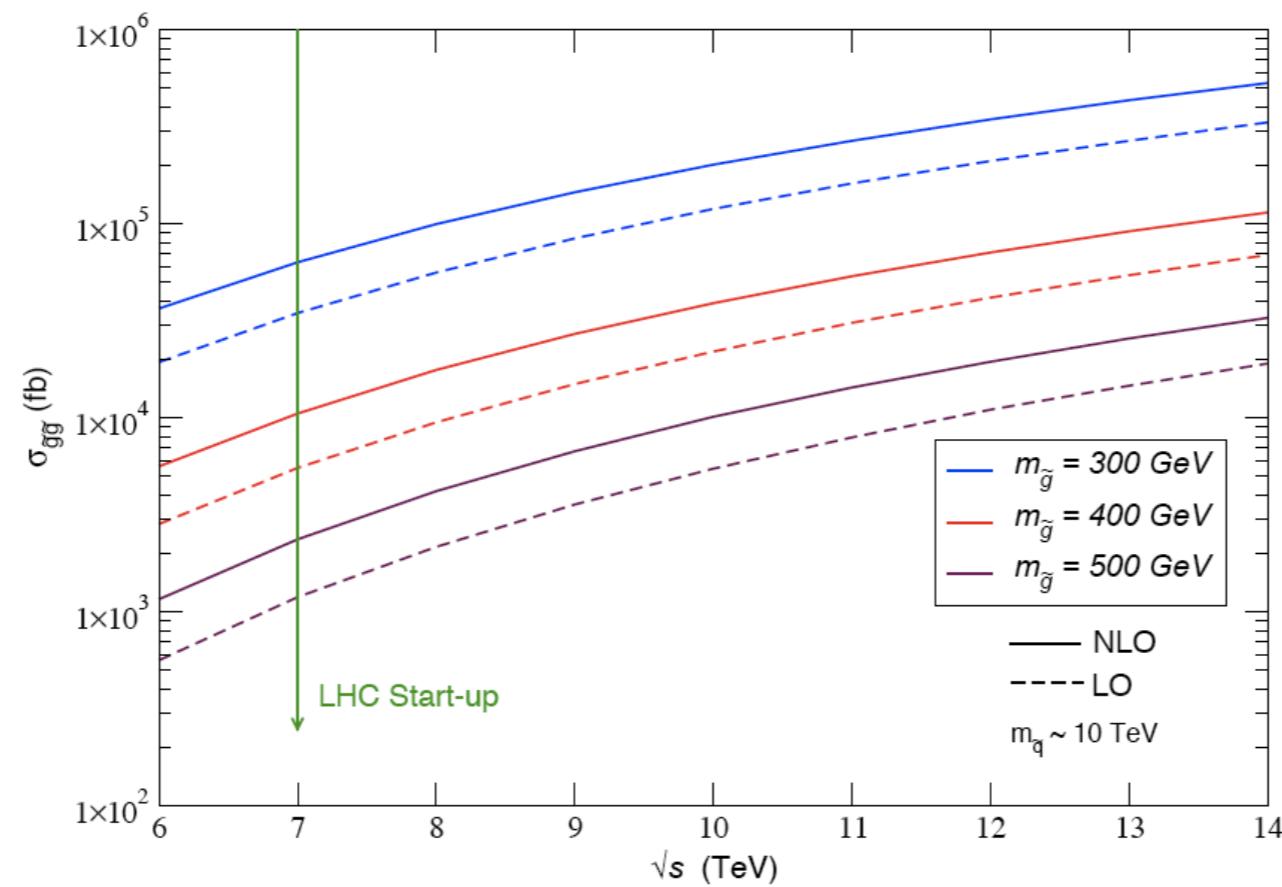


Evolution of gaugino masses in mSUGRA and Yukawa-unified SO(10) HS model

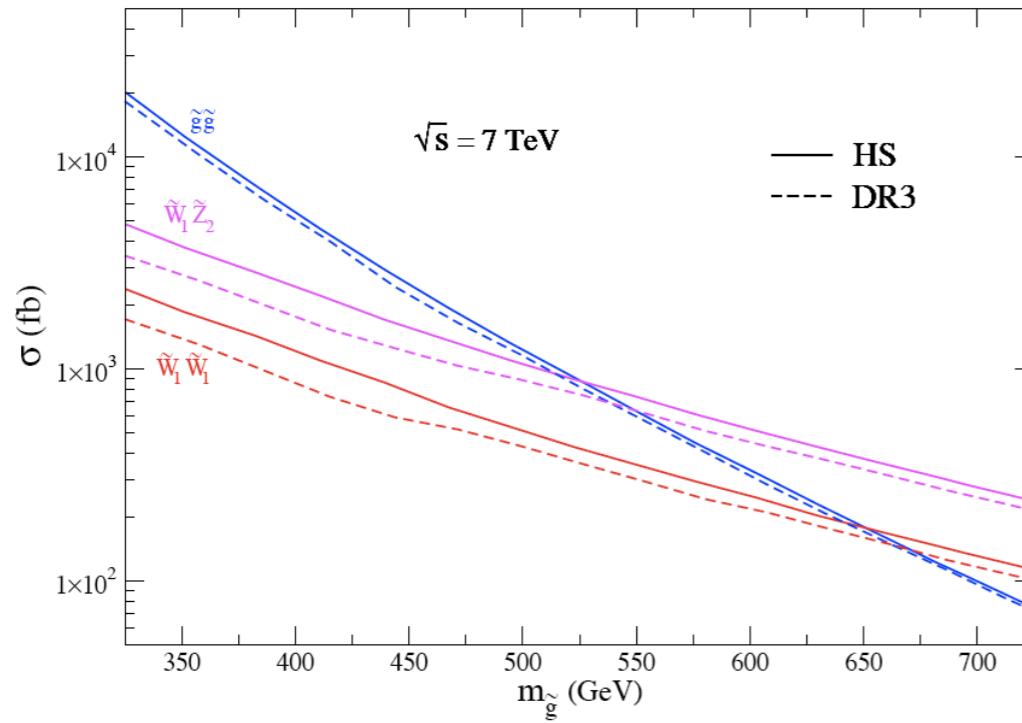
Light gluino



LHC potential at 7 TeV



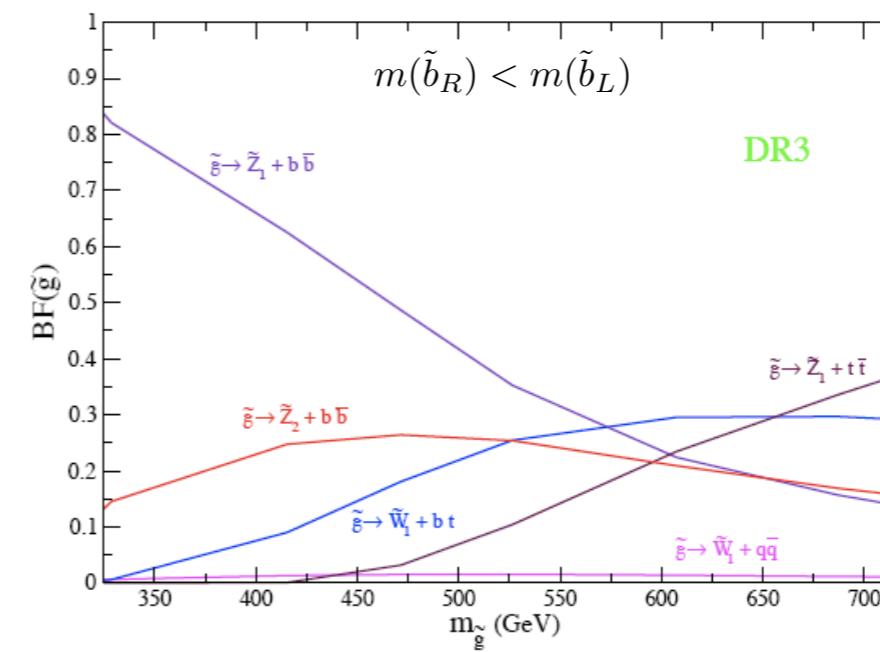
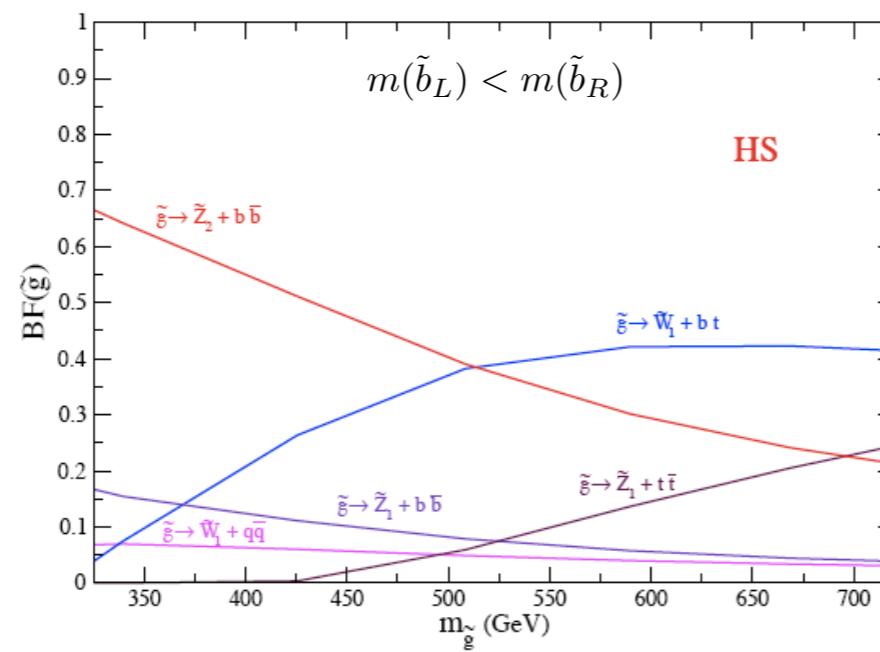
LHC reach at 7 TeV



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

Gluino-pair prod. dominated by gg fusion,
 $\sigma(\text{LO}) \sim 1$ pb at $m(\text{gluino}) \sim 525$ GeV.

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



parameter	H Sb	D R3b
$m_{16}(1, 2)$	10000	11805.6
$m_{16}(3)$	10000	10840.1
m_{10}	12053.5	13903.3
M_D	3287.1	1850.6
$m_{1/2}$	43.9442	27.414
A_0	-19947.3	-22786.2
$\tan \beta$	50.398	50.002
R	1.025	1.027
μ	3132.6	2183.4
$m_{\tilde{g}}$	351.2	321.4
$m_{\tilde{u}_L}$	9972.1	11914.2
$m_{\tilde{t}_1}$	2756.5	2421.6
$m_{\tilde{b}_1}$	3377.1	1359.5
$m_{\tilde{e}_R}$	10094.7	11968.5
$m_{\widetilde{W}_1}$	116.4	114.5
$m_{\widetilde{Z}_2}$	113.8	114.2
$m_{\widetilde{Z}_1}$	49.2	46.5
m_A	1825.9	668.3
m_h	127.8	128.6

LHC reach at 7 TeV

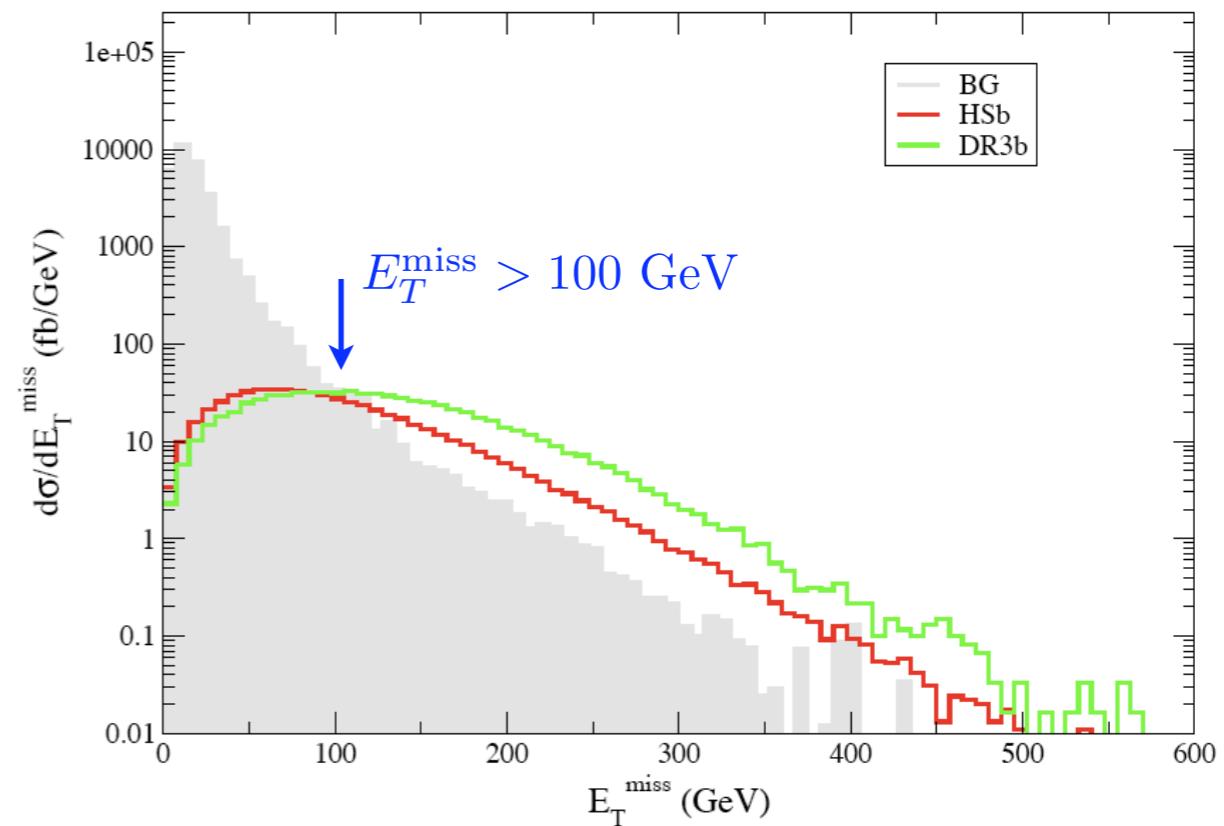
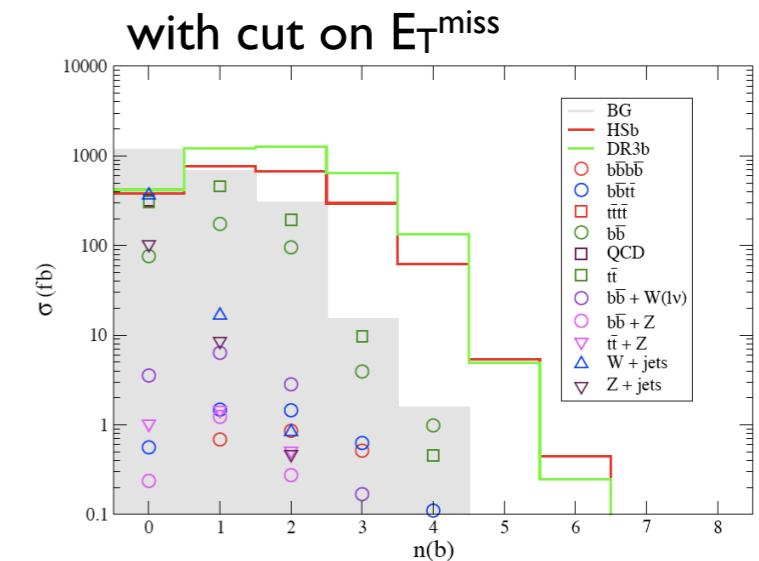
Event simulation:

- 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

Basic Cuts “C0”:

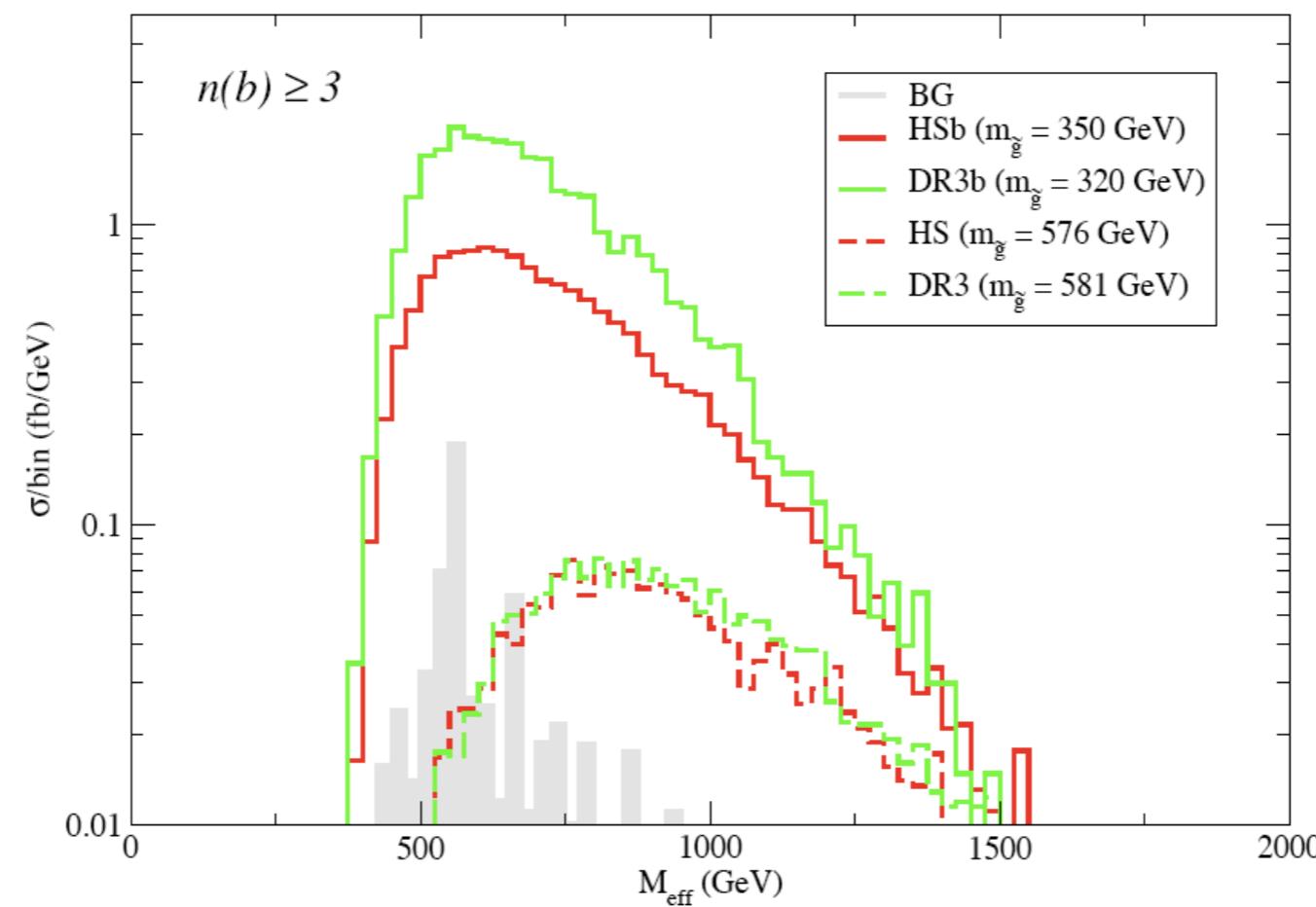
- $n(\text{jets}) \geq 4$ with $p_T > 50\text{GeV}$
- hardest jet $p_T > 100\text{ GeV}$
- $S_T \geq 0.2$ (transv sphericity)
- $n(b) \geq 1$ (b-eff. 60%)

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



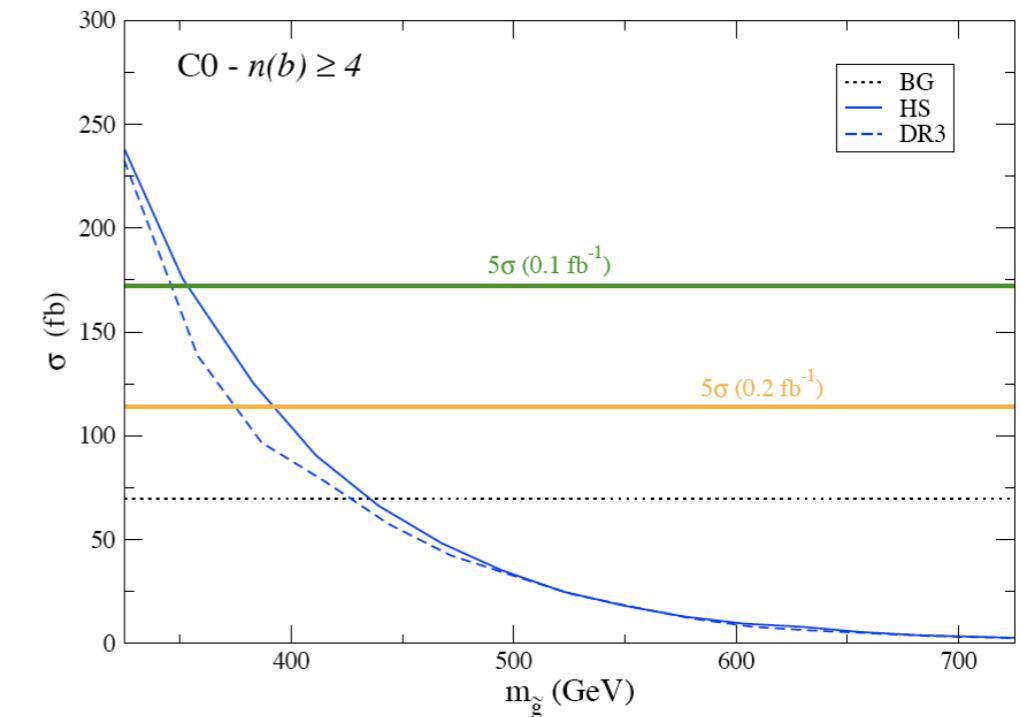
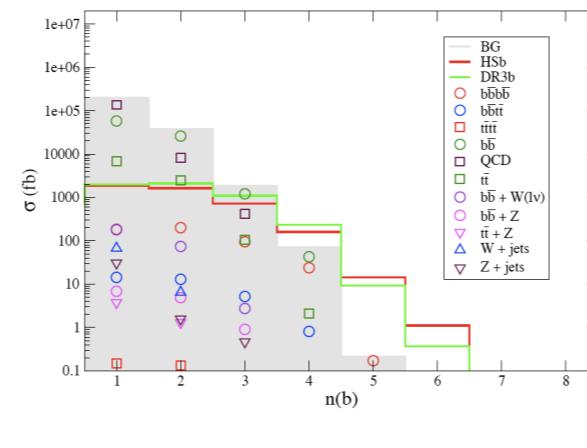
LHC reach at 7 TeV

- Effective mass

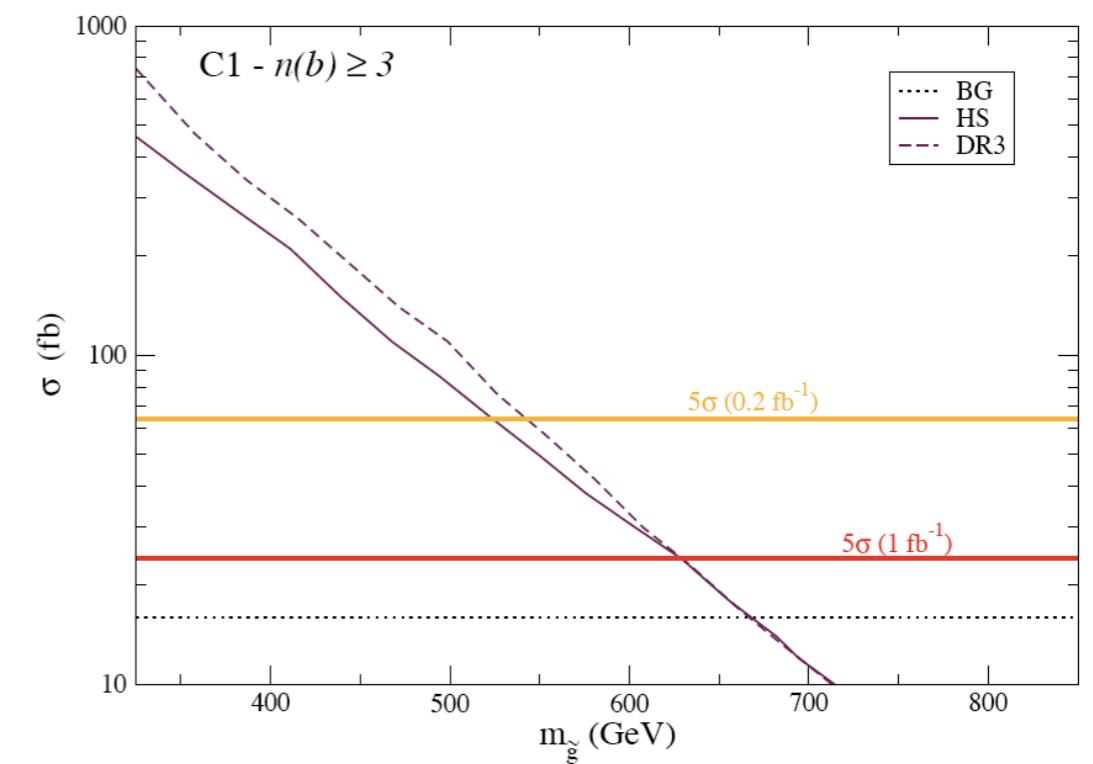
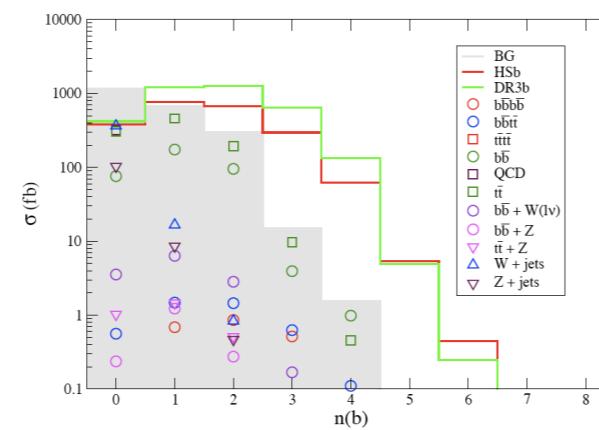


LHC reach at 7 TeV

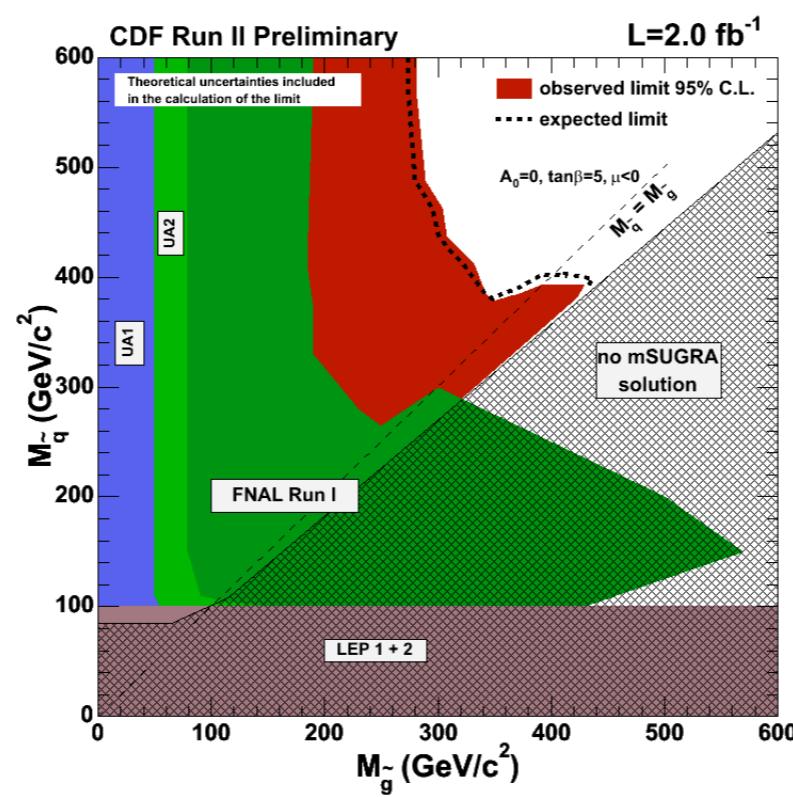
Without missing energy measurement:
up to $m(\text{gluino})=400$ GeV with 0.2 fb^{-1} of data
requiring 4 b-jets



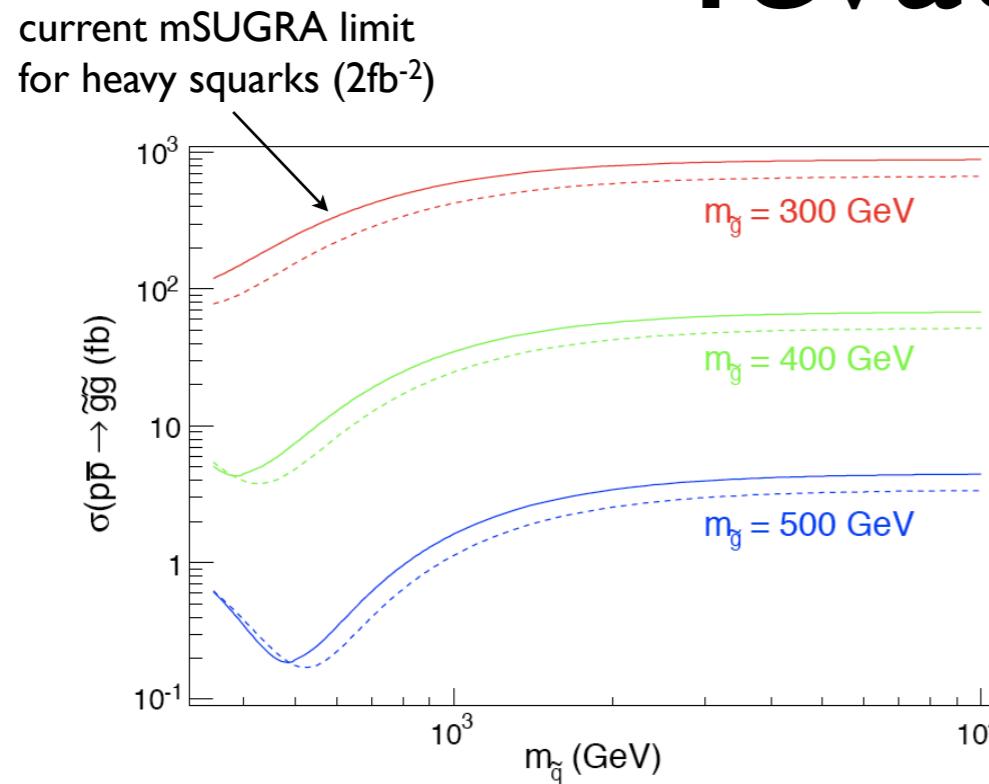
With reliable missing energy measurement:
reach up to $m(\text{gluino})=540-630$ GeV
with $0.2-1 \text{ fb}^{-1}$ of data,
 $n(b) \geq 3$



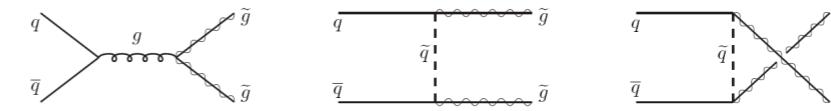
What about the Tevatron?



Tevatron reach



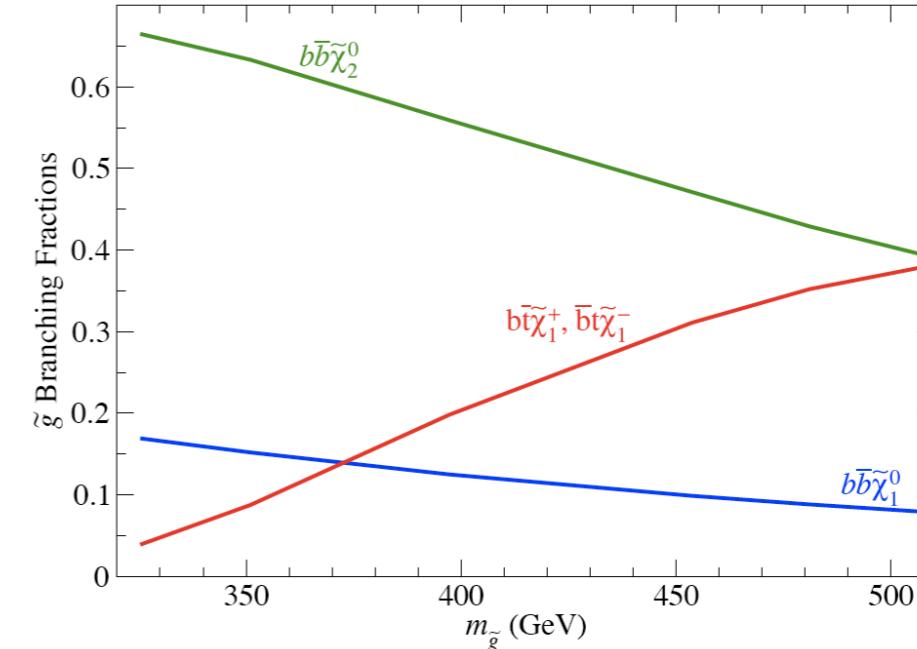
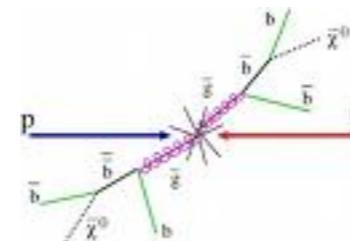
Gluino-pair prod. dominated by $q\bar{q}$ fusion.
Negative interference of s-, t-, u-channels
for $m(\text{squark}) \sim m(\text{gluino})$!



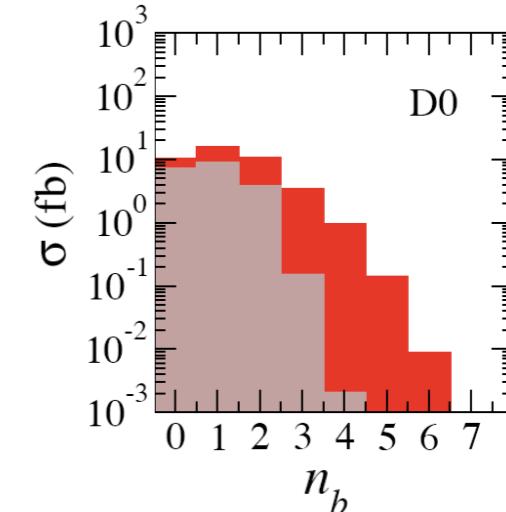
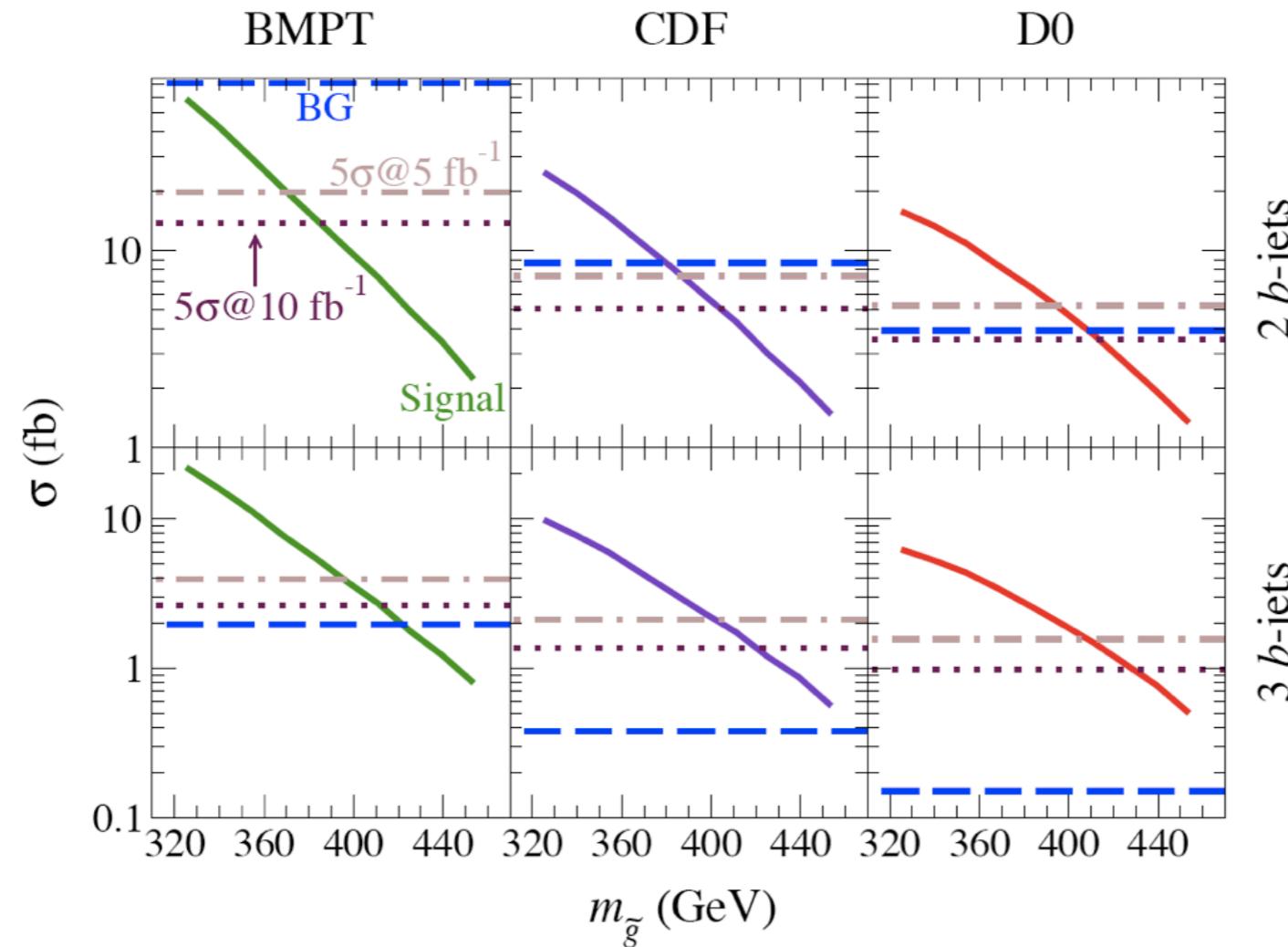
Xsection grows with increasing squark mass!

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 $m_{16}=10\text{ TeV}$ and $R \sim 1.02$
and varying $m_{1/2}$.

$$\begin{aligned} m_{1/2} &= 35 - 100 \text{ GeV}, \\ m_{\tilde{g}} &= 325 - 508 \text{ GeV}, \\ R &\rightarrow 1.07 \end{aligned}$$

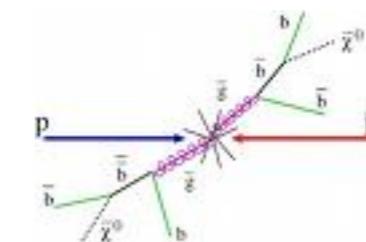


Tevatron reach



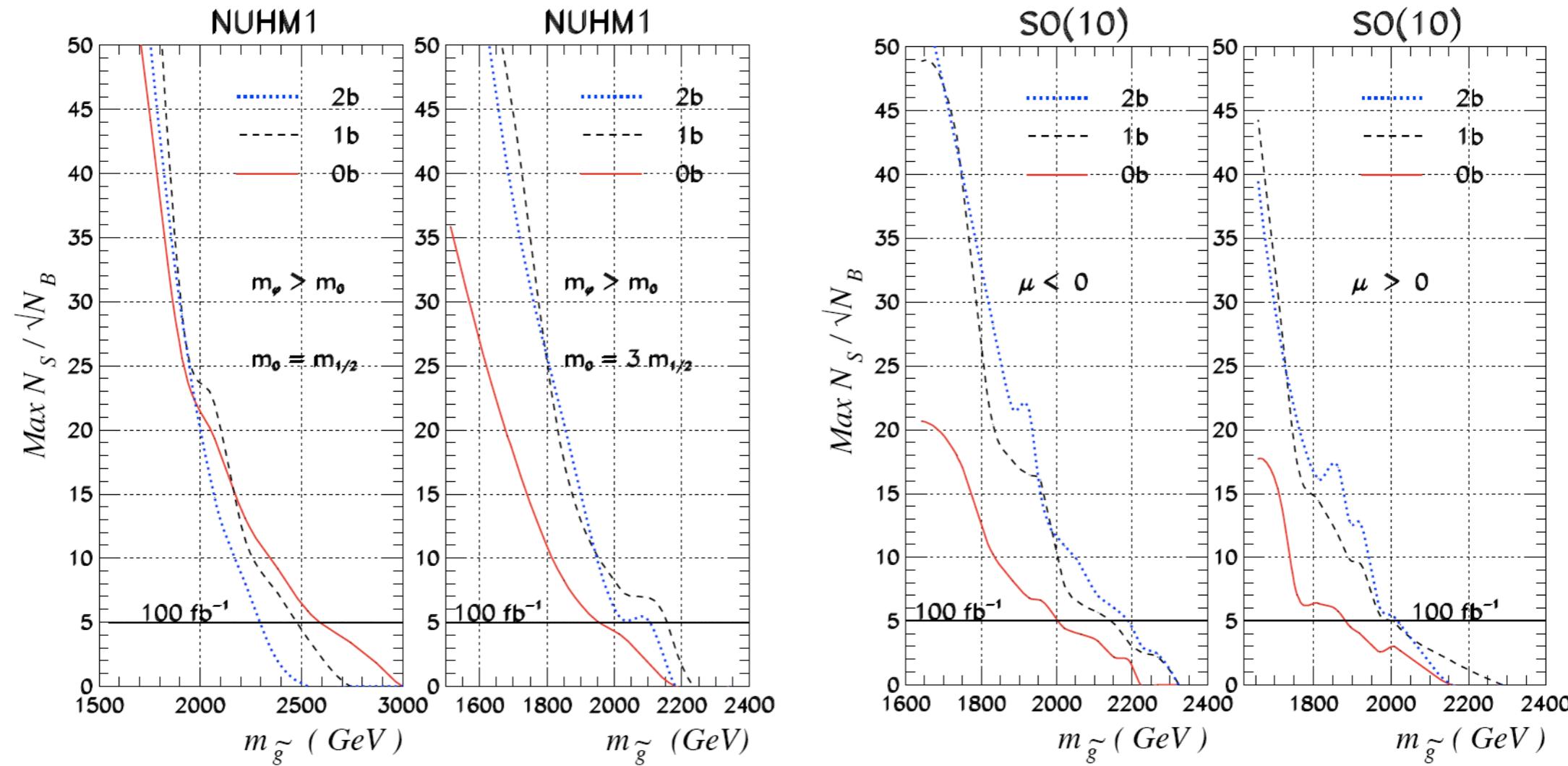
With “D0” cuts and requiring ≥ 3 b-jets, 5σ discovery reach with 10 fb^{-1} about $m(\text{gluino})=430 \text{ GeV}!$

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



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.



- Typical if 3rd generation is lighter than 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

Conclusions

- Yukawa-unified SUSY GUT based on SO(10) is quite compelling.
- Typical mass spectrum: light gluino of 300-500 GeV mass, TeV-scale 3rd generation, multi-TeV 1st/2nd generation. (c.f. “effective SUSY”)
- Quite good discovery potentials for such scenarios:
 - ★ Tevatron: $m(\text{gluino}) \sim 430 \text{ GeV}$ with 10 fb^{-1}
 - ★ LHC@7TeV: $m(\text{gluino}) \sim 630 \text{ GeV}$ with 1 fb^{-1}
- Search in multi- b channels is essential for early discovery.
- Tevatron and/or LHC may soon discover or rule out the simplest case of a SO(10) SUSY GUT.

There are exciting times ahead of us

