Title: Cornering Gluinos at the LHC

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Abstract: Gluinos are expected to be light for a natural electroweak scale, but the LHC has not seen them yet. Many possibilities have been proposed to hide natural gluinos in the LHC data, but are these methods really effective? In this talk, I will discuss the current status of kinematically accessible gluinos. By noting the most common features - MET, tops, and high multiplicity - which pervade natural gluino decays, I will argue that there are few places left to hide. I will briefly discuss the remaining weaknesses in LHC coverage and how to bolster them.

Cornering Gluinos at the LHC

Jared A. Evans

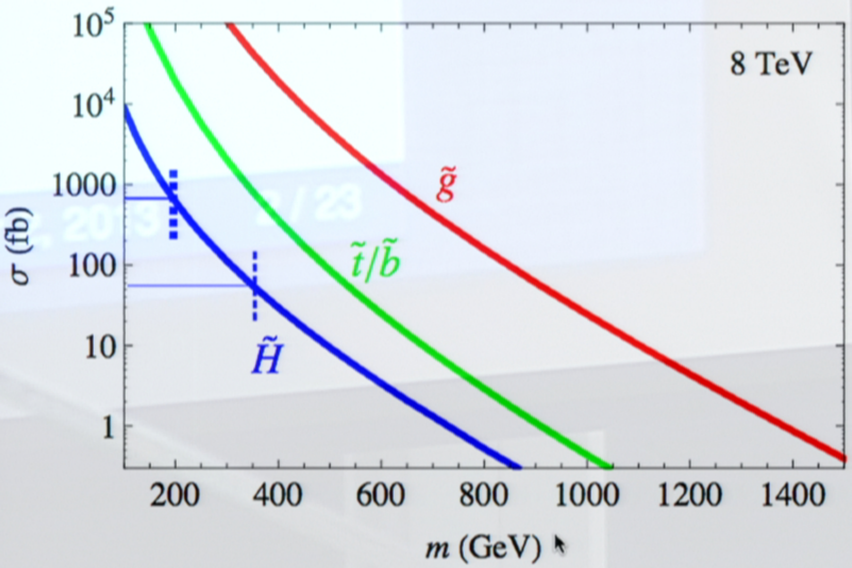
jaevans@physics.rutgers.edu

New High Energy Theory Center
Department of Physics and Astronomy
Rutgers University

arxiv:1310.5758 – JAE, Y. Kats, D. Shih, M. J. Strassler

Naturalness

A natural MSSM EW scale $\Rightarrow$ light Higgsinos, stops and gluinos



Higgsinos

Naturalness suggests:

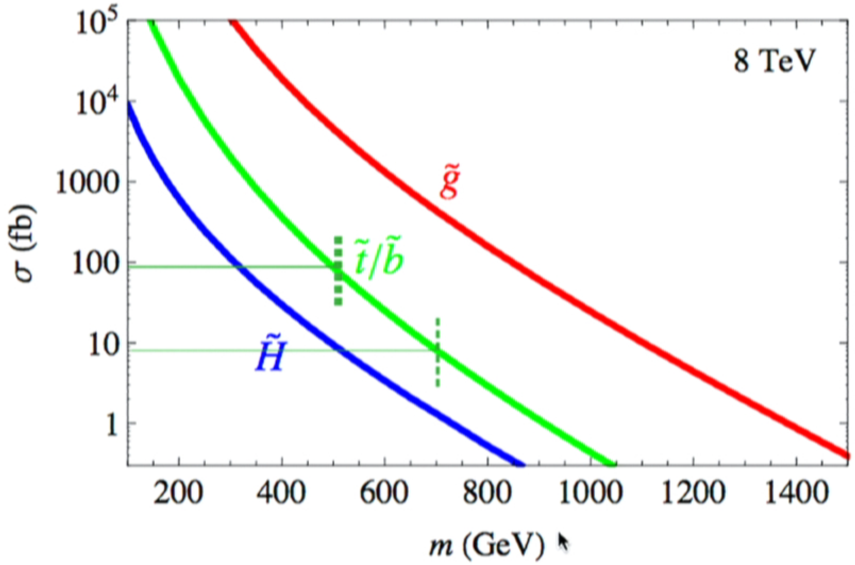
$m_{\tilde{H}} \lesssim 200 - 350$ GeV

$\sigma \times \mathcal{L} \gtrsim 1k - 10k$ events

Low S_T, but high σ

Naturalness

A natural MSSM EW scale $\Rightarrow$ light Higgsinos, stops and gluinos



Stops

Naturalness suggests:

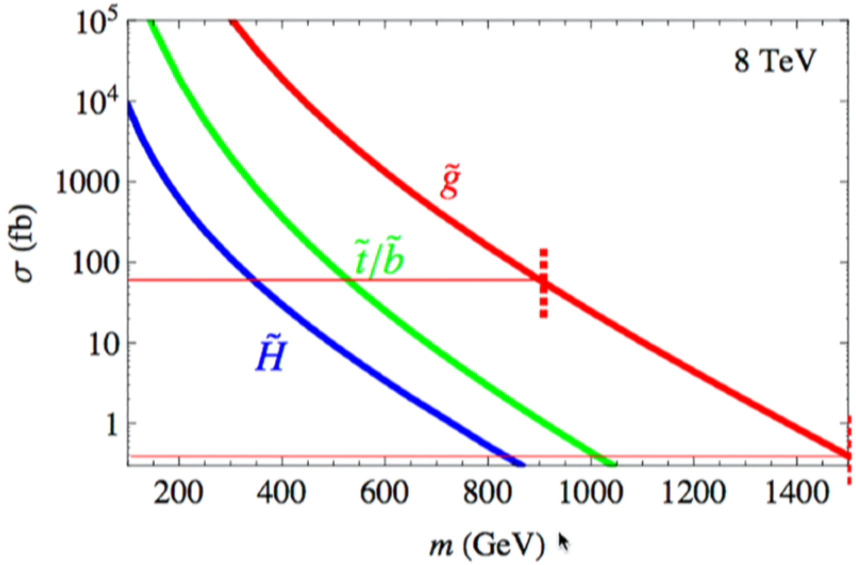
$m_{\tilde{t}} \lesssim 500 - 700$ GeV

$\sigma \times \mathcal{L} \gtrsim 150 - 2000$ events

Moderate σ and S_T

Naturalness

A natural MSSM EW scale $\Rightarrow$ light Higgsinos, stops and gluinos



Gluinos

Naturalness suggests:

$m_{\tilde{g}} \lesssim 900 - 1500$ GeV

$\sigma \times \mathcal{L} \gtrsim 5 - 1000$ events

Low σ, but HUGE S_T

Gluinos

...hiding in plain sight?

It is hard to miss a gluino

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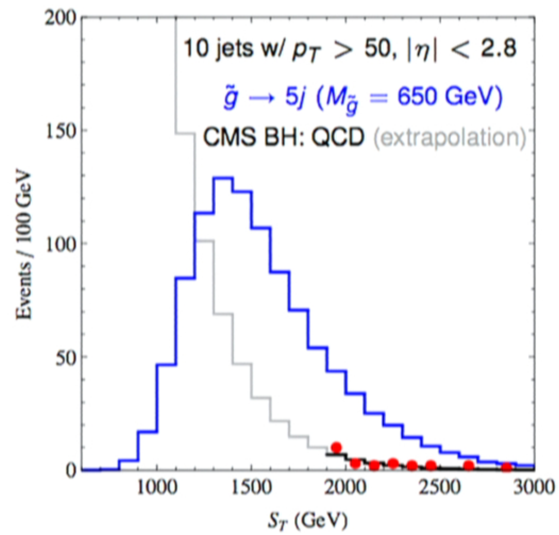
Gluinos at high multiplicity can actually exceed SM QCD!



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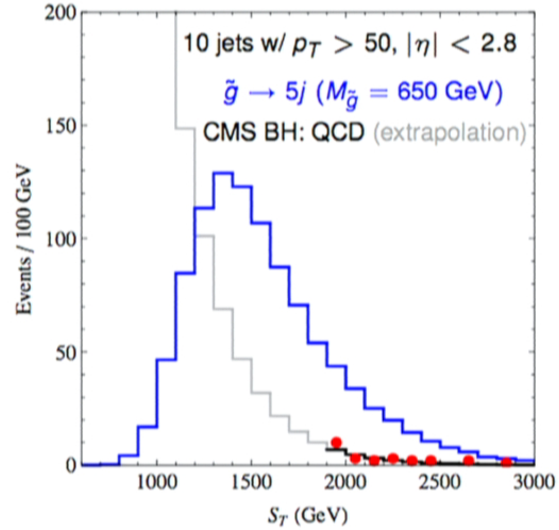

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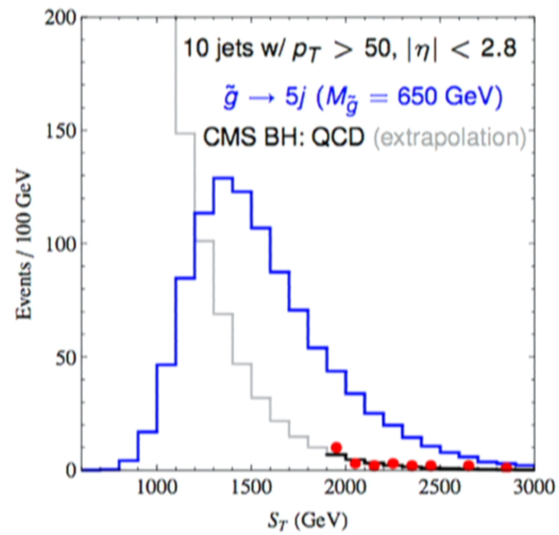
How are we doing?

Could we miss something?

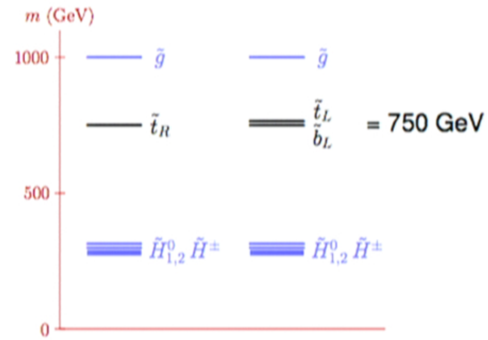
Where can we do better?

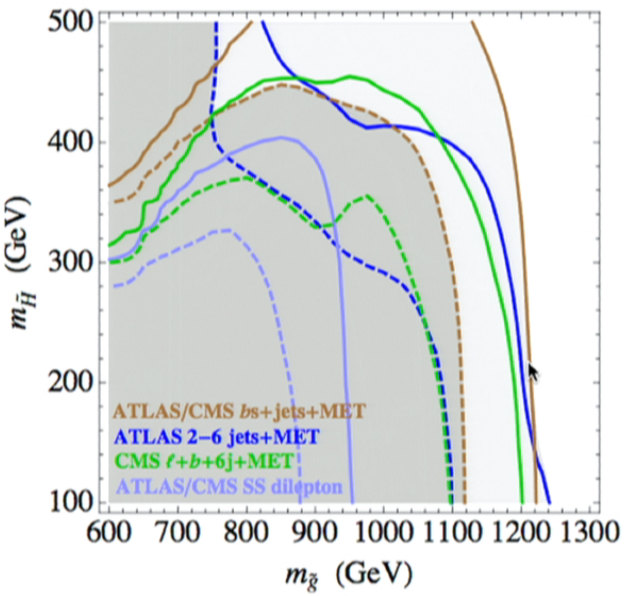


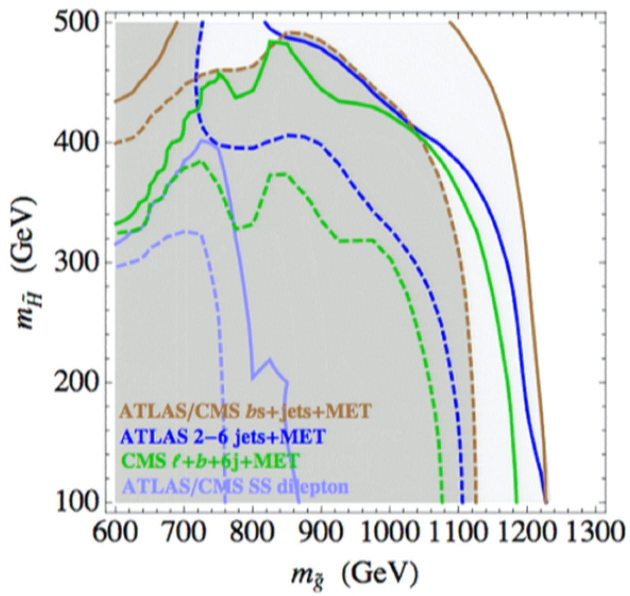
The Natural, "Vanilla" MSSM

"Vanilla" MSSM gluinos are excluded!

Light gray ⇒ excluded regions
Dark gray ⇒ excluded by factor of two







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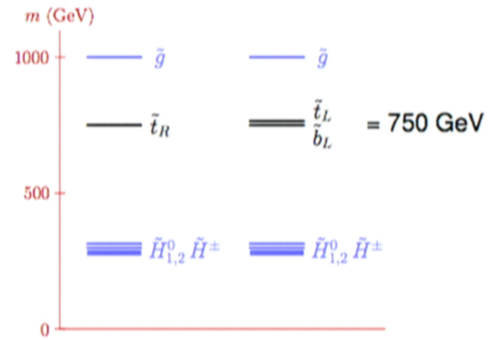
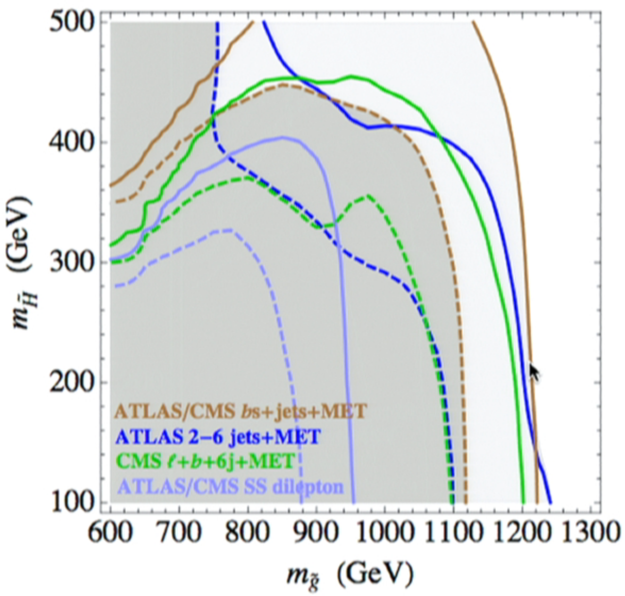
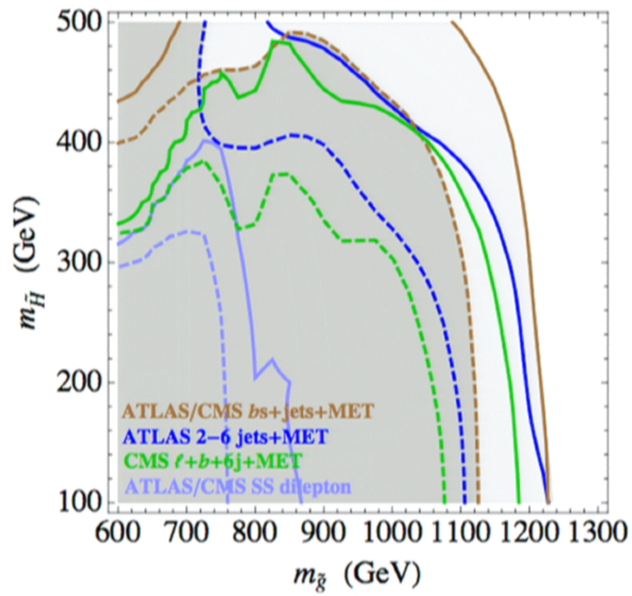
Natural Benchmark: $m_{\tilde{H}} < 400$ GeV
$m_{\tilde{g}} \lesssim 1$ TeV







The logic used to corner gluinos

Naturalness assumption: $m_{\tilde{H}} \leq 400$ GeV

Consider kinematically accessible gluinos: $m_{\tilde{g}} \lesssim 1.5$ TeV

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Consider kinematically accessible gluinos: $m_{\tilde{g}} \lesssim 1.5$ TeV

Make no other assumptions. Allow for all modifications, e.g.

- Not mSUGRA / CMSSM
- Allow extended Higgs sector
- Allow GMSB, AMSB, etc.
- Allow any masses
- Allow *R*-parity violation
- Allow hidden sector
- Allow extra colored states
- Allow squeezing

What features remain?

The logic used to corner gluinos

What is common in natural gluino decays? (ignoring exotic objects)

1. Large $\not{E}_T$ (usually, from a stable LSP)
2. Tops (either from $\tilde{g} \to t\tilde{t}$, or elsewhere)

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Modifications or assumptions tend not to remove ALL of these

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Modifications or assumptions tend not to remove ALL of these

I will argue that:

- Gluinos yielding $\not\!\!E_T$ are well constrained (unless $\not\!\!E_T$ is very small)
- Gluinos producing tops are well constrained (unless tops are very rare)
- Gluinos producing high multiplicity are constrained to ~ 1 TeV
- Gluinos that have none of these suffer from a jet p_T hierarchy

Essential Searches: Jets + MET

Several searches are essential to constraining gluinos

Implemented in a private detector simulator, which includes:

- cut-and-count searches recast
- $\mathcal{O}(100)$ 7 and 8 TeV searches
- lepton ID efficiencies
- lepton isolation
- *b*-tagging
- jet energy resolution
- limit set by best observed bin
- efficiency threshold: 10^{-4}

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First, jets + $\not{E}_T$ searches:

- ATLAS 2-6 jets + $\not{E}_T$: ATLAS-CONF-2013-047
- ATLAS 7-10 jets + low $\not{E}_T$: ATLAS-CONF-2013-054
- CMS jets + $\not{E}_T$: PAS-SUSY-13-012 (covers low and high multiplicity)

Essential Searches: Atlas 6-7 jets (no MET)

ATLAS RPV gluino search: ATLAS-CONF-2013-091

Only cuts on 6-7 High p_T jets with no $\not{E}_T$ requirement

p_T cut (GeV)	# jets	# b-tags	Background	Data
180	6	0	170±40	187
80	7	0	17200±2100	15885
80	7	1	5900±700	5800
80	7	2	1670±190	1560
100	7	0	2460±350	2477
100	7	1	940±140	936
120	7	0	370±60	444
120	7	1	138±26	178
120	7	2	38±17	56
140	7	0	105±25	107
140	7	2	10±5	18
180	7	0	6.1±2.2	4
180	7	1	2.3±1.0	1
180	7	2	0.5±0.4	0

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Note: CMS RPV gluino search could set powerful limits – but needs CMS reinterpretation

Essential Searches: CMS black holes

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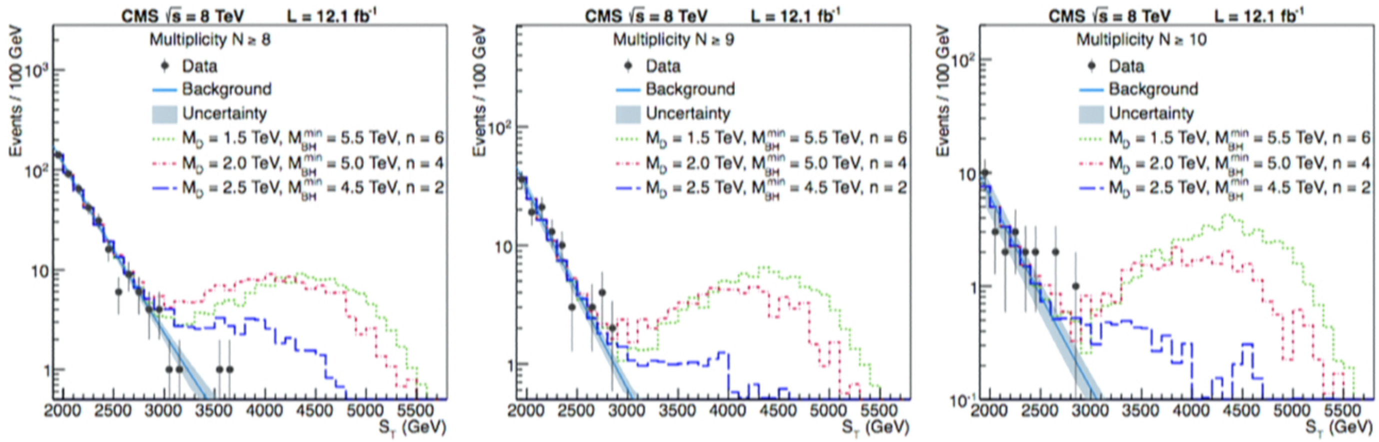


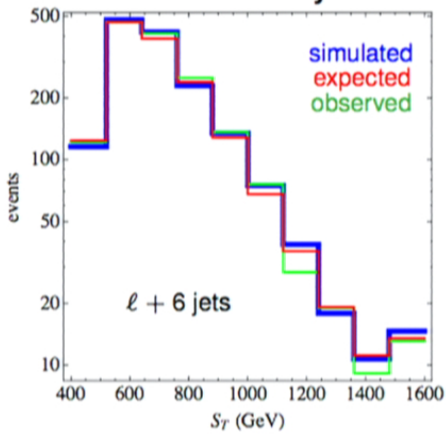
Essential Searches: Lepton + Jets (w/o MET)

Also, use $\ell + n$ jet search (Lisanti, Schuster, Strassler, Toro 2011)

Search does not exist (as we want it), so we designed it

ALPGEN @ 7 TeV
Matched $t\bar{t}$ + 0-5 jets
Compare to arXiv:1210.7471

Normalized by 1.6



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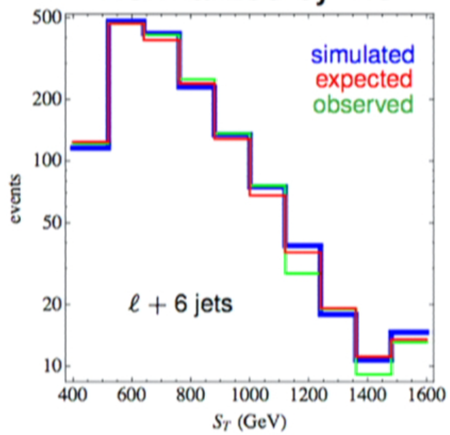

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Cuts:

Jet $p_T > 35$ GeV

Require 1 b-tag

Bin 6+, 7+, 8+, 9+ jets

Bin $S_T \geq X$

$X \in \{400, 600, 800, \ldots, 3000\}$ GeV

Light second generation squarks

2nd gen squarks can be light (Mahbubani, Papucci, Perez, Ruderman, Weiler 2012)

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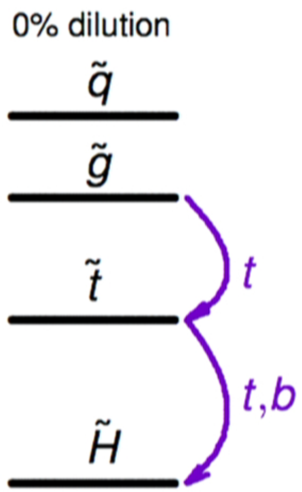

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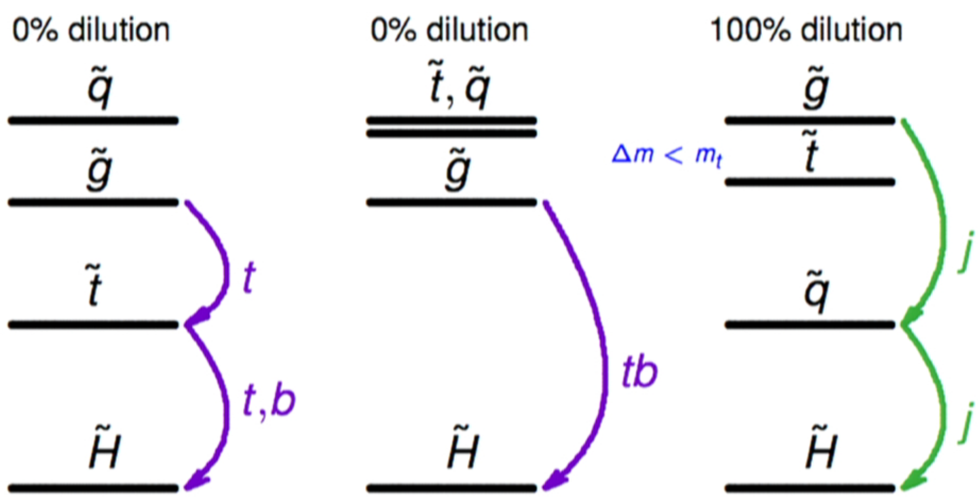

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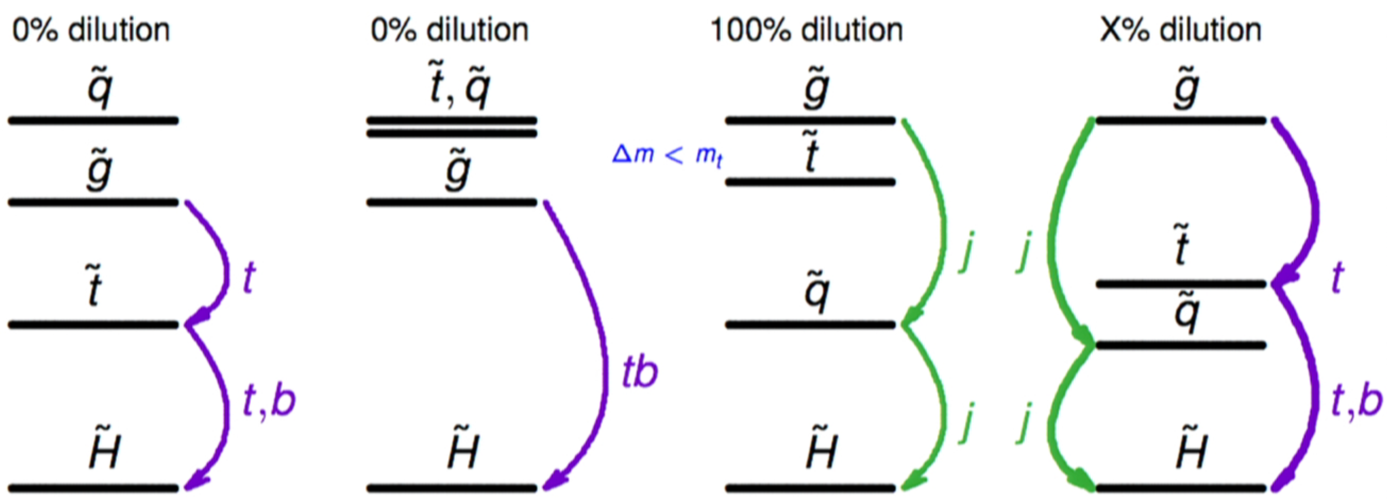

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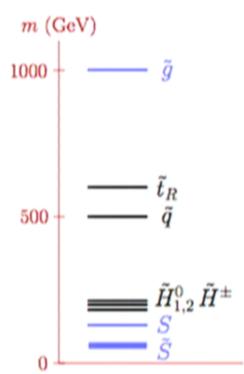
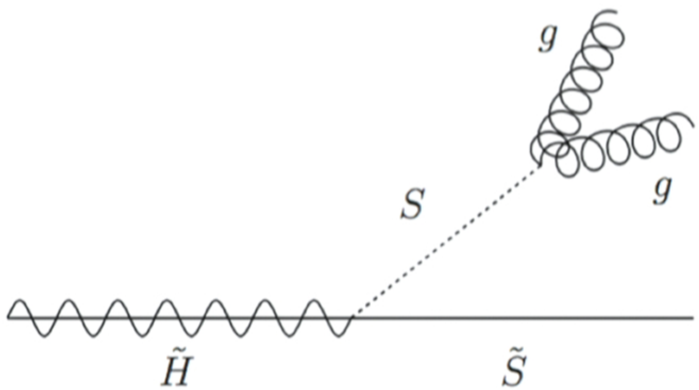
But how *much* $\not{E}_T$ is needed?

Introduce a simple model to interpolate $\not{E}_T \to$ jets





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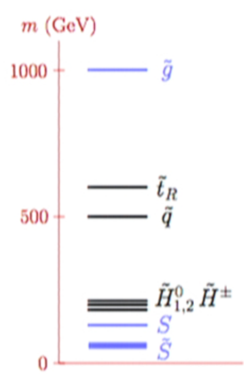
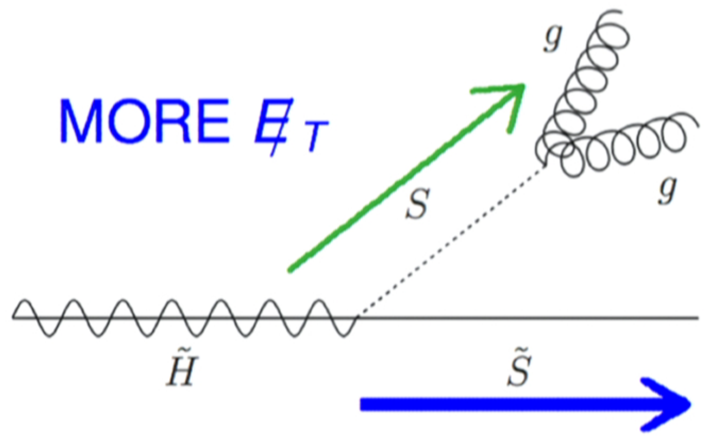
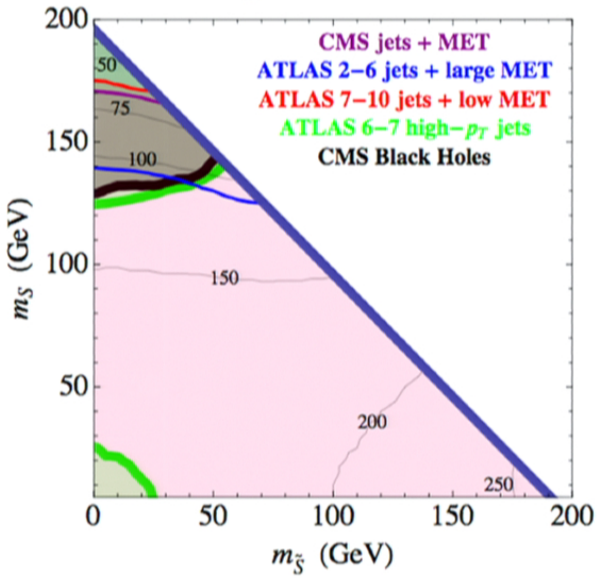


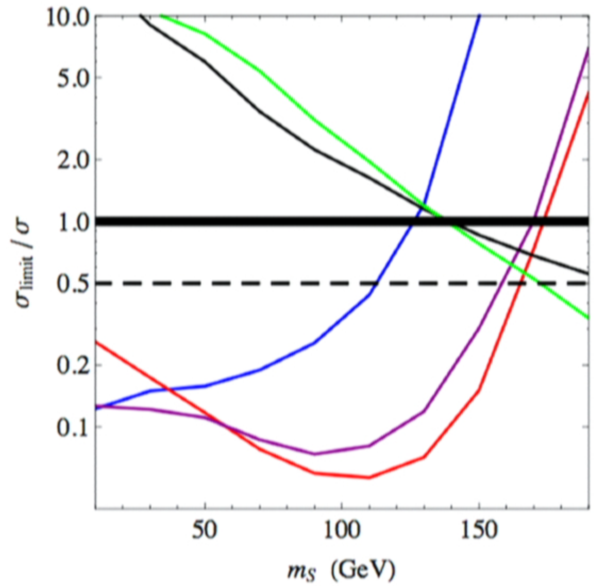


Trading MET for jets

$m_{\tilde{g}} = 750$ GeV
$m_{\tilde{q}} = 500$ GeV
$m_{\tilde{H}} = 200$ GeV



$m_S + m_{\tilde{S}} = 190$ GeV



$$\tilde{g} \to j\tilde{q} \to jj\tilde{H} \to jjS\tilde{S} \to jj(jj)\tilde{S}$$

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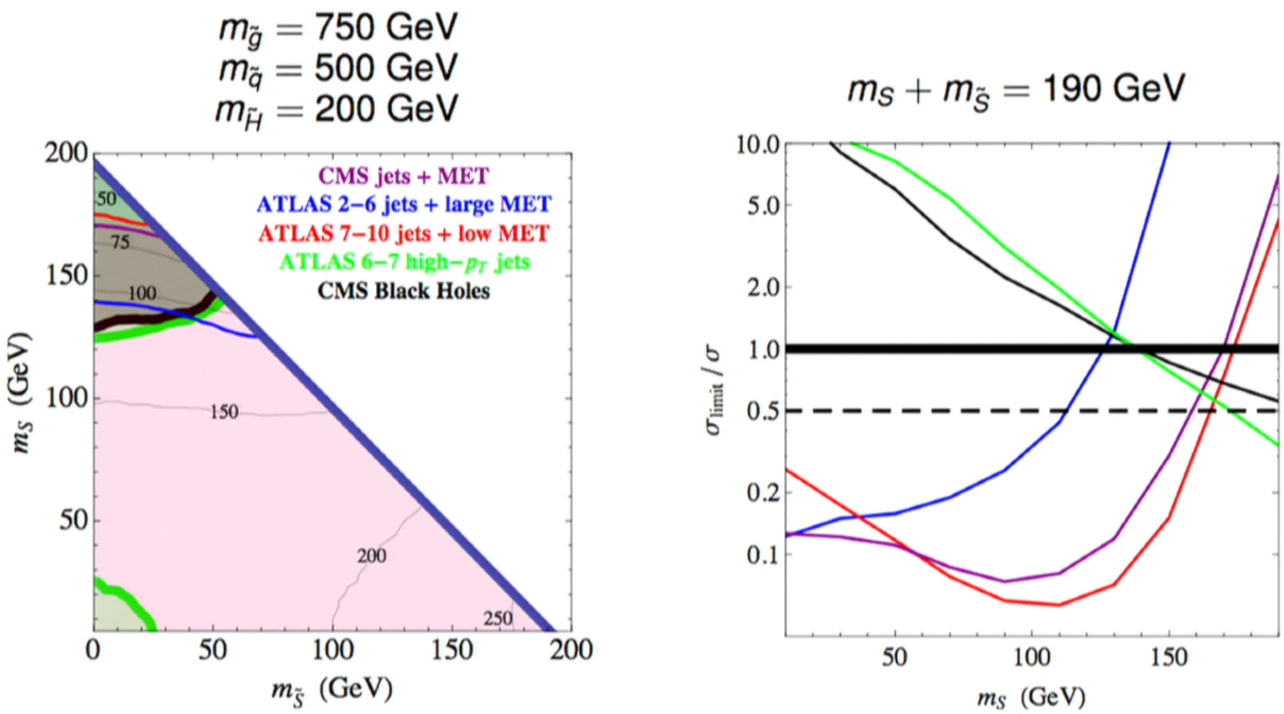

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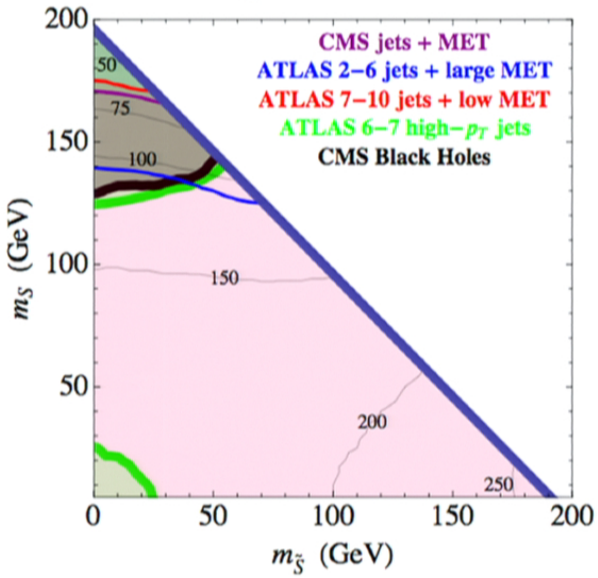

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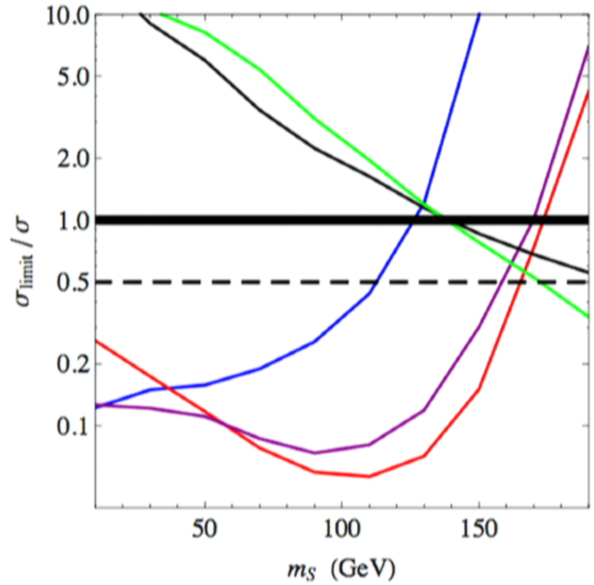

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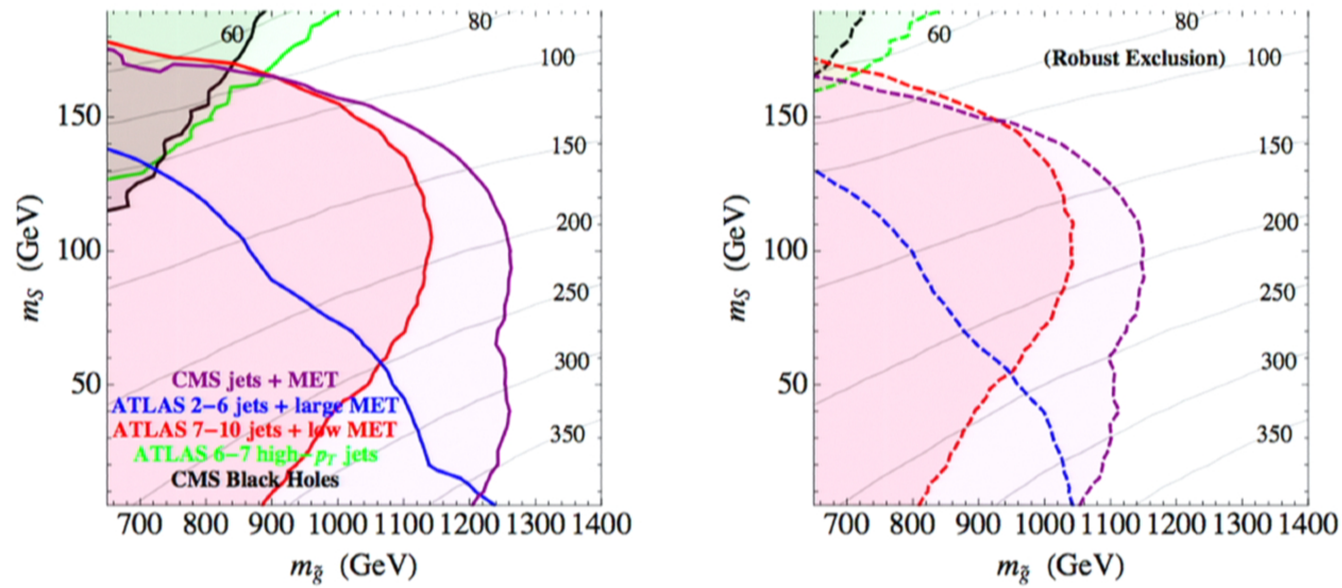
Trading MET for jets

$m_{\tilde{q}} = 500$ GeV, $m_{\tilde{t}} = 600$ GeV, $m_{\tilde{H}} = 200$ GeV, $m_S + m_{\tilde{S}} = 190$ GeV



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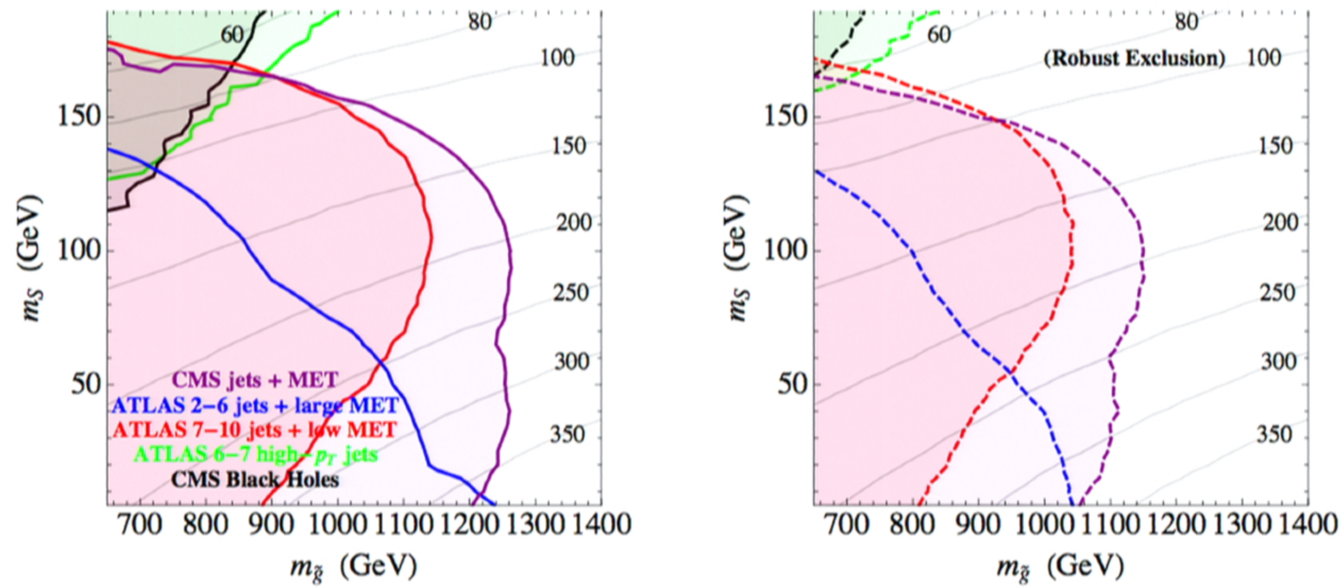


$\not{E}_T$-based searches effective until $Avg(\not{E}_T)$ to $\lesssim 2\sqrt{H_T(1\,\mathrm{GeV})}$

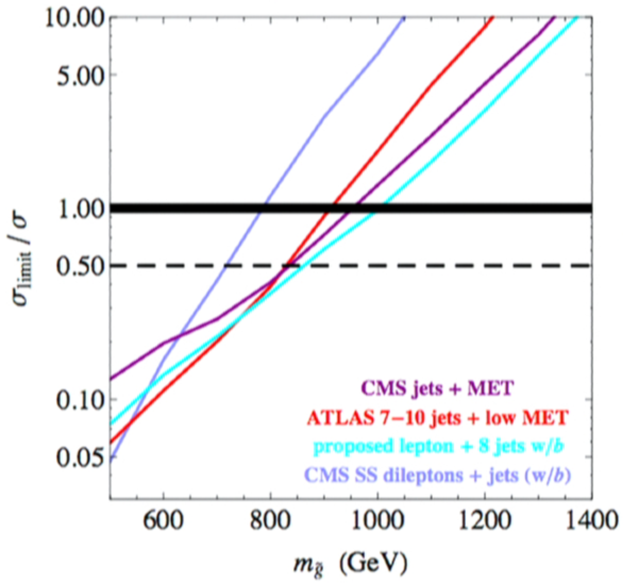
Tops

Gluinos yielding tops are also excluded

(RPV examples)

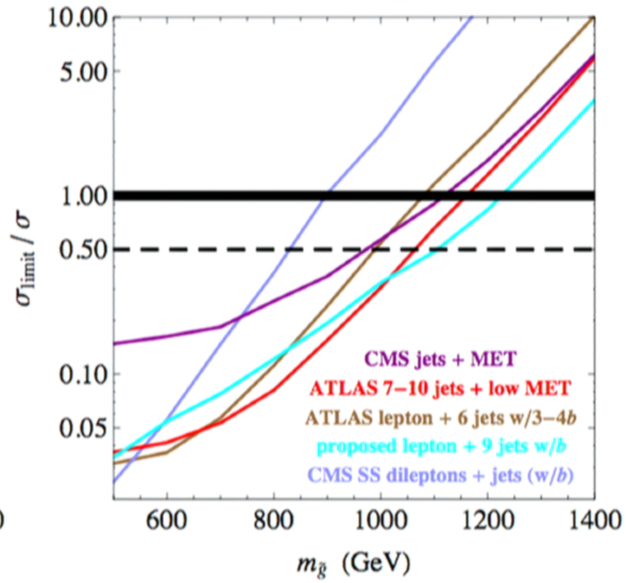
$\tilde{g} \to t\tilde{t} \to tjj$

$m_{\tilde{t}} = 100$ GeV



$\tilde{g} \to t\tilde{t} \to tb\tilde{H} \to tbjjj$

$m_{\tilde{t}} = 350$ GeV, $m_{\tilde{H}} = 200$ GeV



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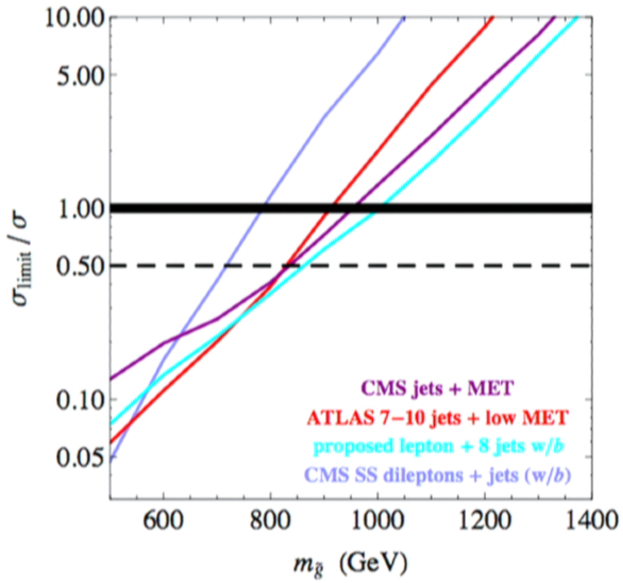

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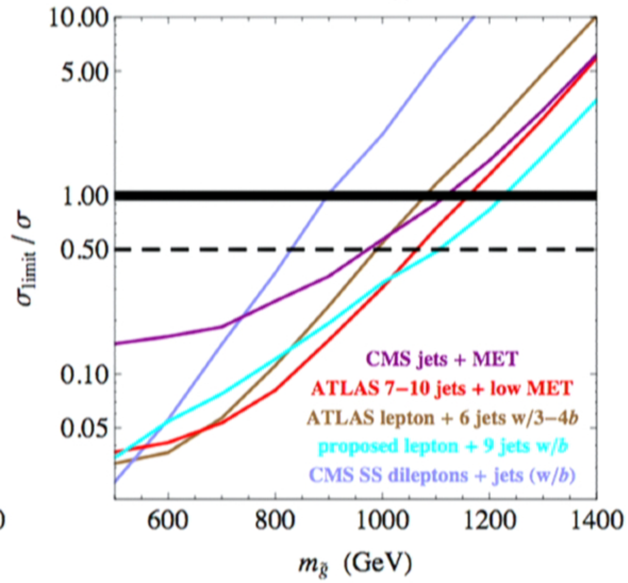

Jets + $\not{E}_T$ effective due to τs and lost leptons (signal contamination)

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But how often are tops needed for constraints?

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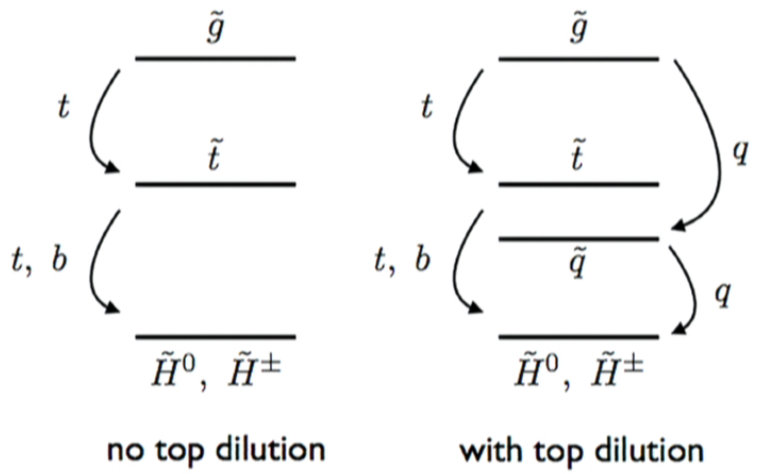

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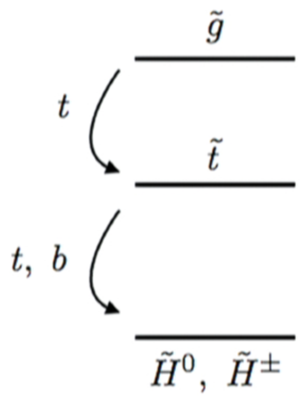
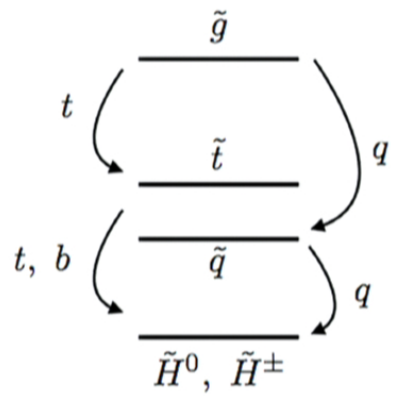
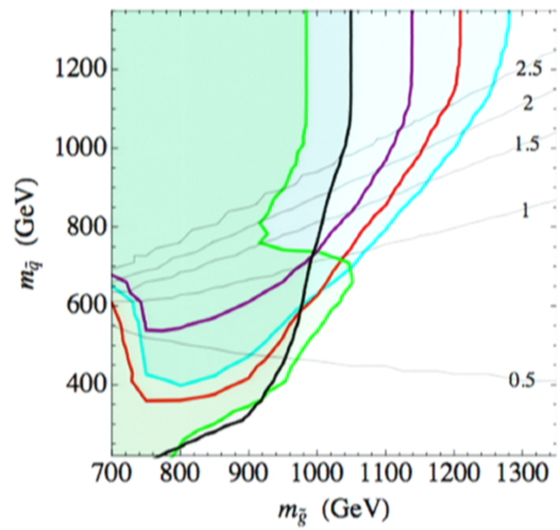


no top dilution



with top dilution

$m_{\tilde{t}} = 500$ GeV, $m_{\tilde{H}} = 200$ GeV



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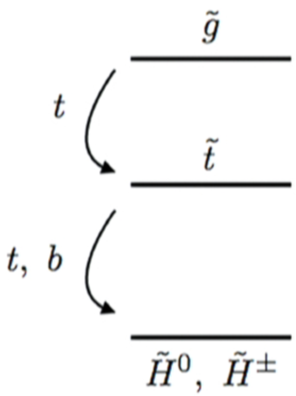

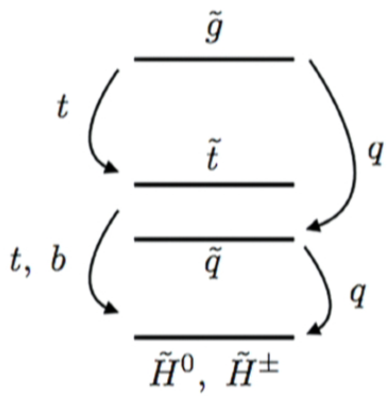

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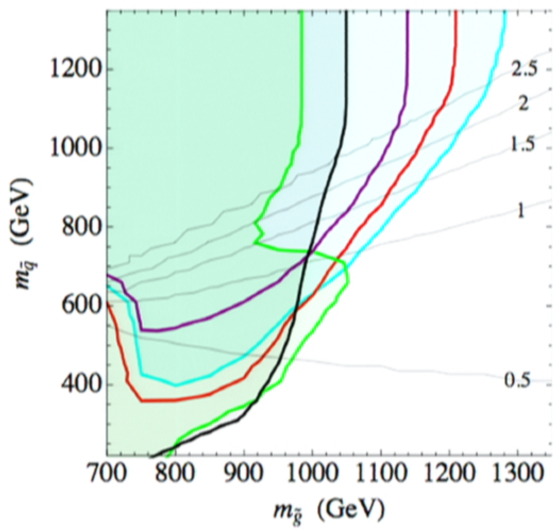
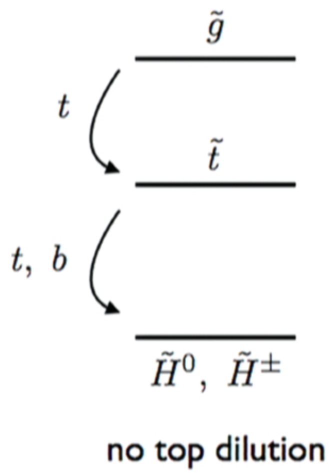
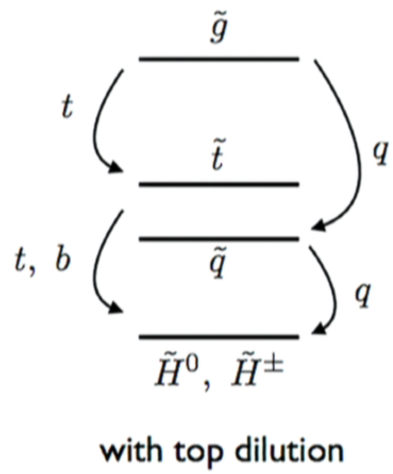


But how often are tops needed for constraints?





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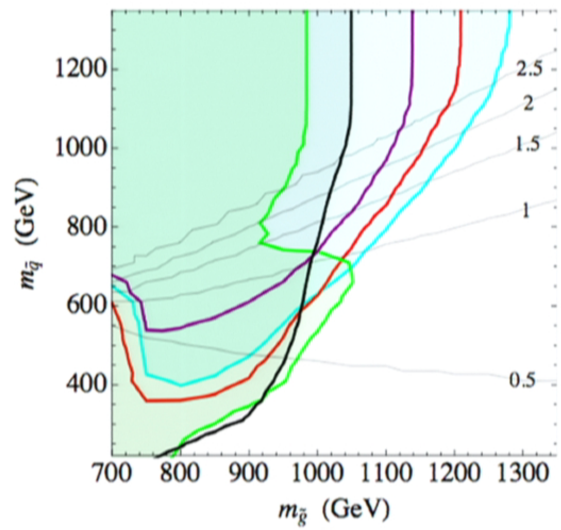


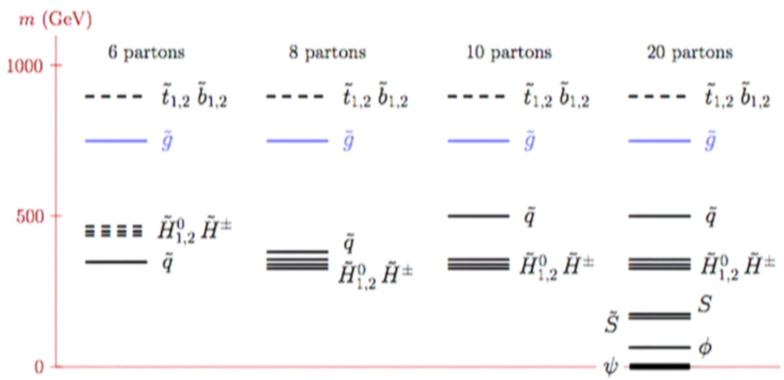
Tops rare before coverage drops below 1 TeV

All-hadronic limits

Without leptons or $\not{E}_T$, gluinos must give at least 3 colored partons

With no tops and no $\not{E}_T$

high multiplicity final states remain



Page 64 of 99

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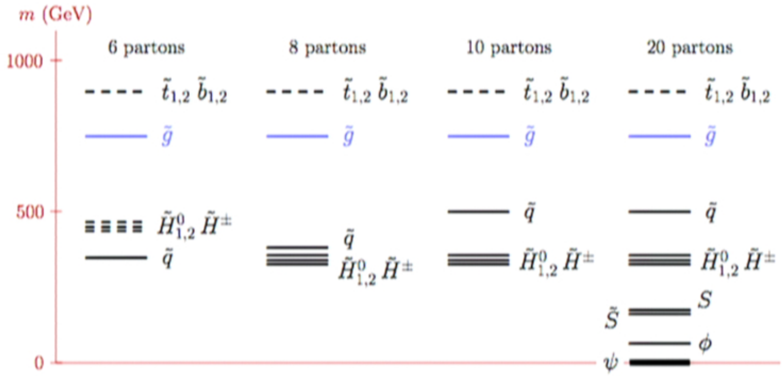

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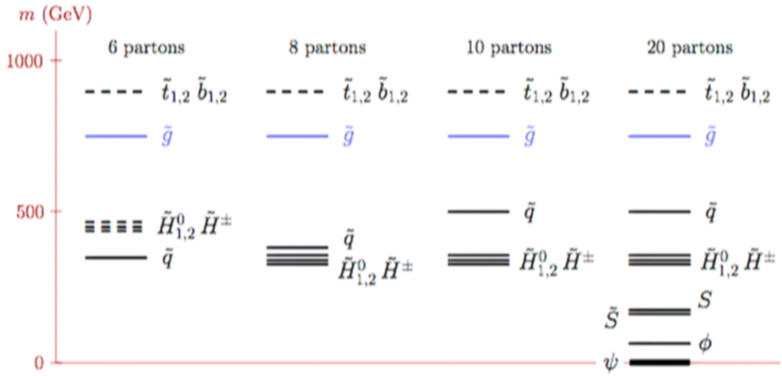

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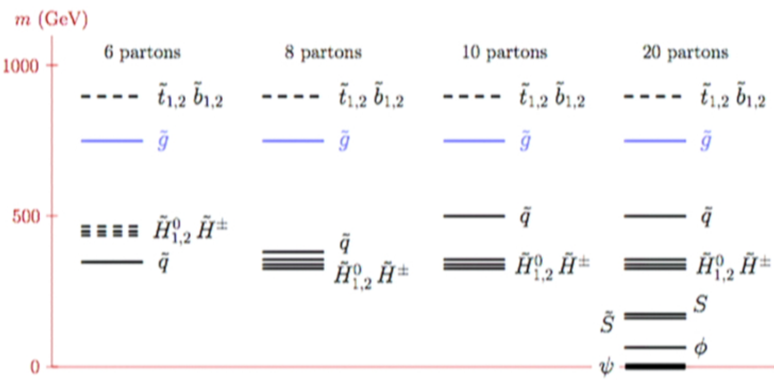
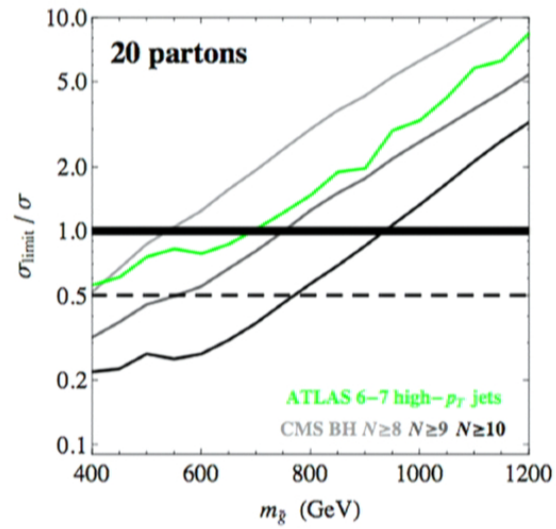
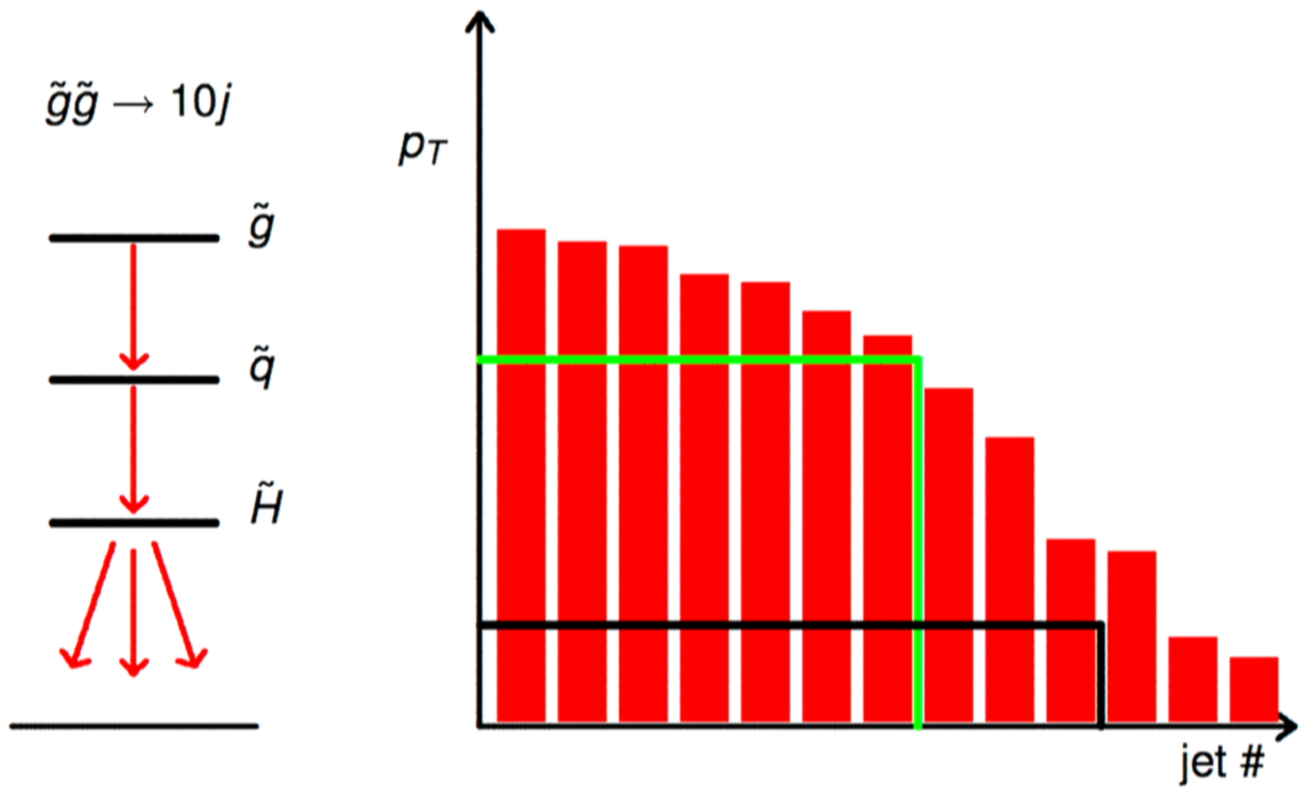




All limits go nearly to 1 TeV

As multiplicity increases, ATLAS 6-7 weakens, **CMS BH strengthens**

A jet p_t hierarchy

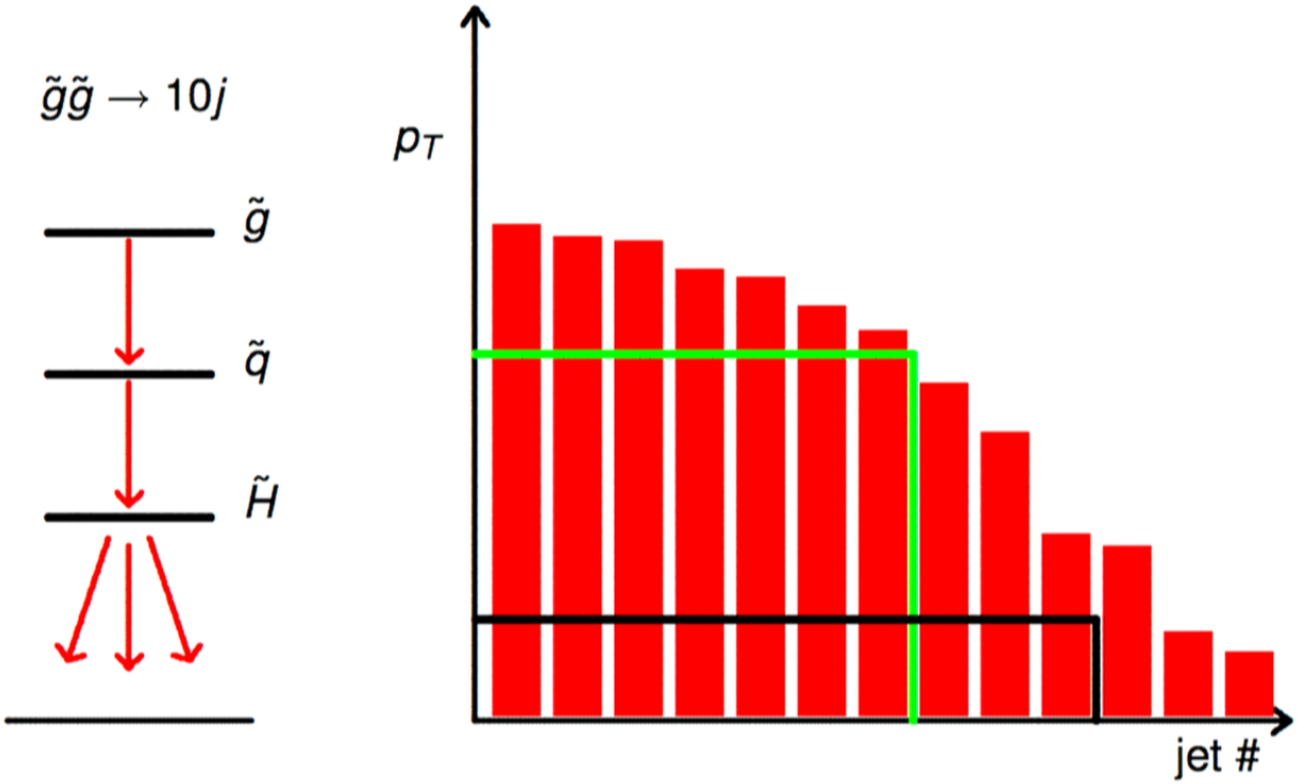


ATLAS 6-7

CMS BH

A jet p_t hierarchy

$\tilde{g}\tilde{g} \rightarrow 10j$



ATLAS 6-7 **CMS BH**

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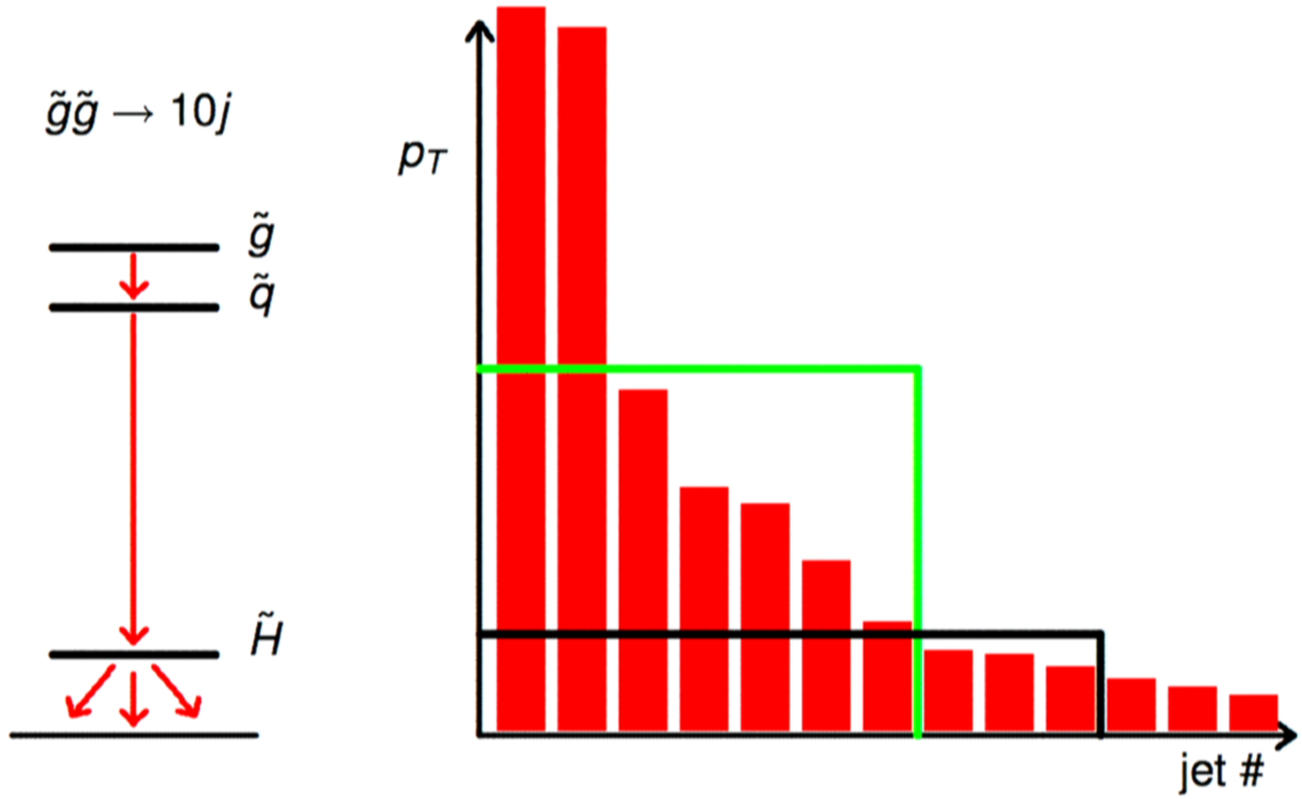
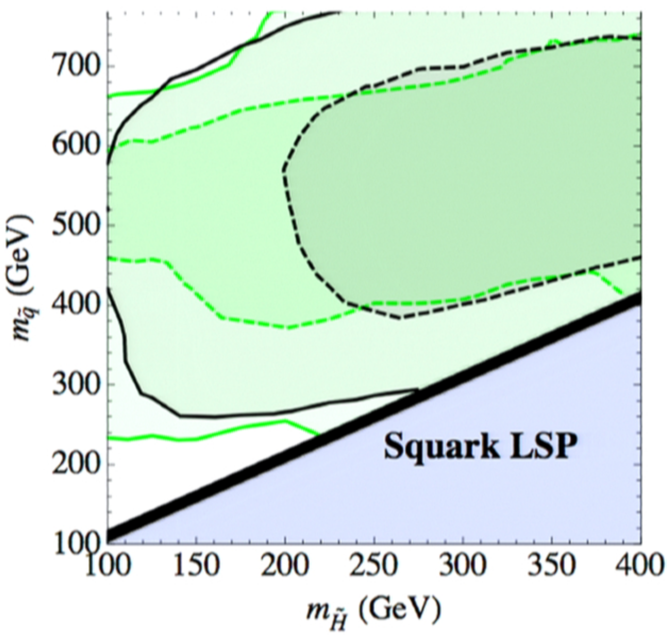


ATLAS 6-7 **CMS BH**

A jet p_t hierarchy

$$\tilde{g} \to j\tilde{q} \to jj\tilde{H} \to jjjjj$$

$m_{\tilde{g}} = 800$



$$\tilde{g} \to j\tilde{q} \to jjj$$

Thick: $m_{\tilde{q}} = 150$ GeV
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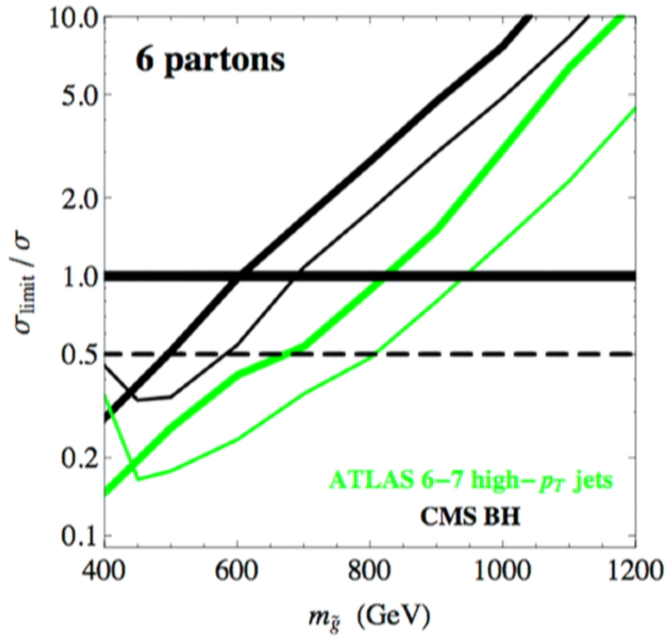

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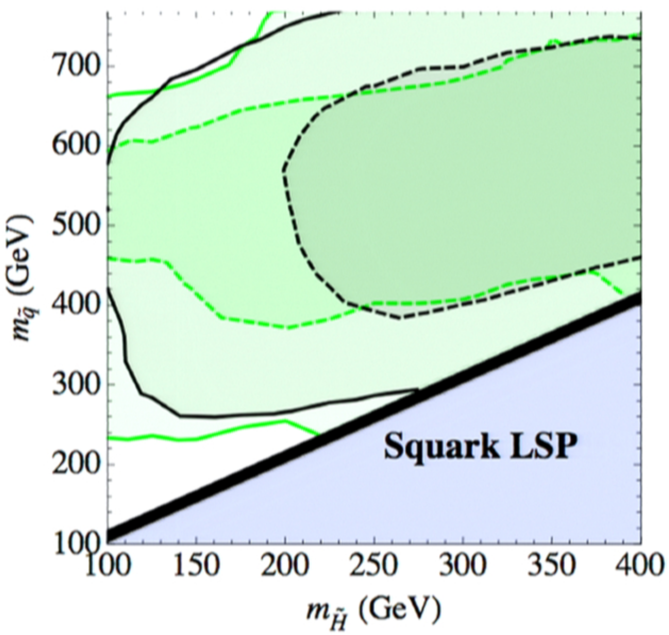

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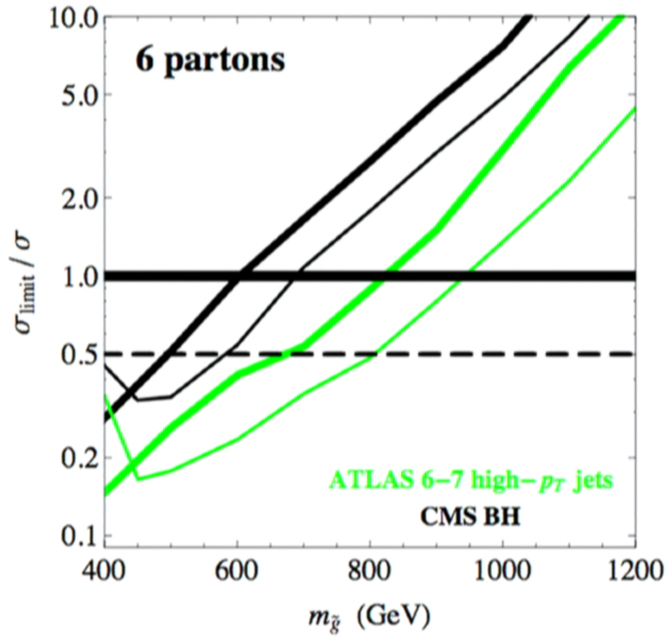

Cornering jet p_t hierarchies

Jet p_T hierarchies make events more QCD-like

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How can we corner these at the LHC?

1. Lower S_T in CMS BH (control region issues – $\sim$ 1.5 TeV okay)
2. Staggered p_T cuts in ATLAS 6-7 (admits more QCD)
3. Substructure – two hard jets + two fat jets (untested)

Loopholes

1st gen squarks?

- Used decoupled squark cross-section, can lower total by $\sim$ 25%

Leptons & τs (gap in ℓ veto vs. ℓ selection)?

Page 86 of 99

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- With large $\not{E}_T$, strong limits (CMS-PAS-SUS-13-007)
- With no $\not{E}_T$ & high multiplicity, CMS BH & ATLAS 6-7 do not veto
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Conclusions

- Natural gluinos are well-motivated and should be LHC accessible
- If decays give $\not\!\!E_T$ or tops: Limits to well above 1 TeV
- If they don't, high multiplicity is typical: Limits $\sim$ 1 TeV
- High multiplicity reduced by a jet p_T hierarchy: Limits $\ll$ 1 TeV
- The jets+MET, lepton+jets & all-hadronic searches could be designed to be exclusive for maximum gluino reach
- Minor loopholes exist
  - 1-2 soft ℓ + small $\not\!\!E_T$
  - Photon + jets
  - Lepton + photon + $\not\!\!E_T$
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  - Exotic objects
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Thank you!