

# INCLUSIVE SEARCH STRATEGIES WITH A LEPTON AND MANY JETS

NATALIA TORO

arXiv: [1107.5055](https://arxiv.org/abs/1107.5055)

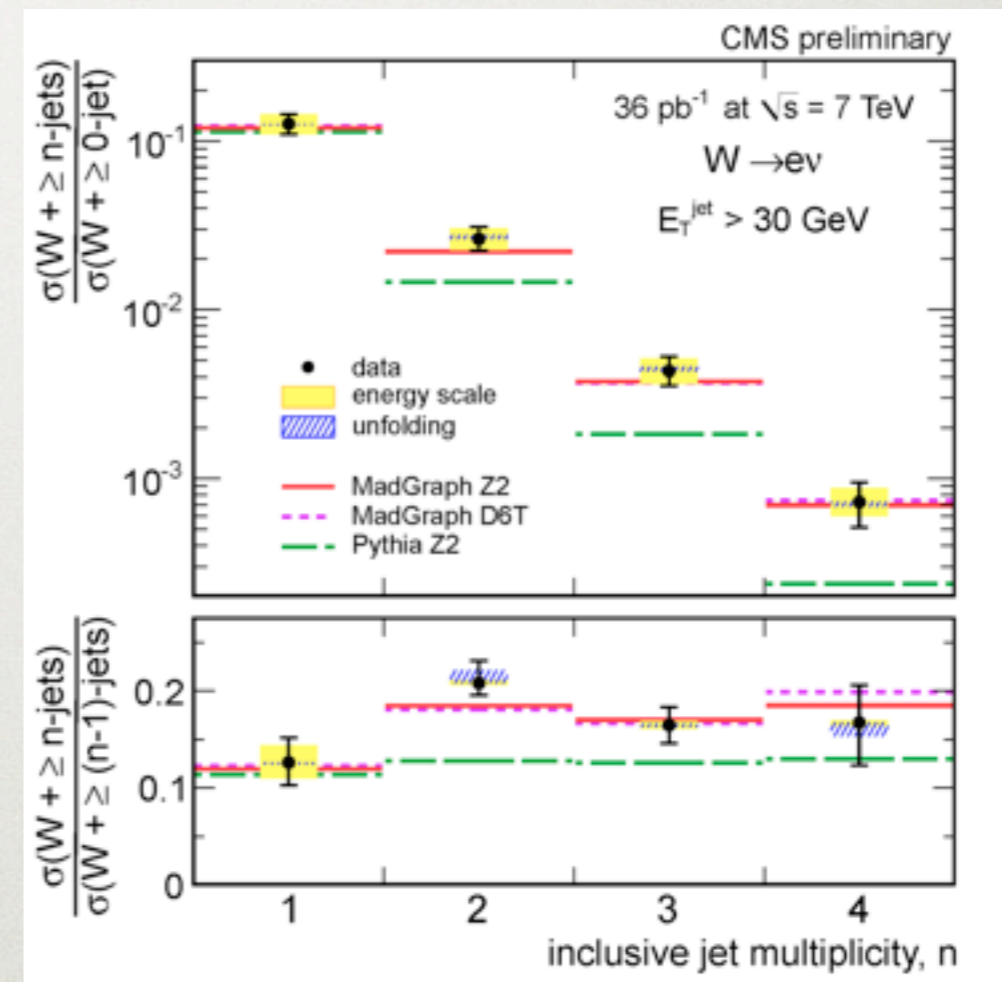
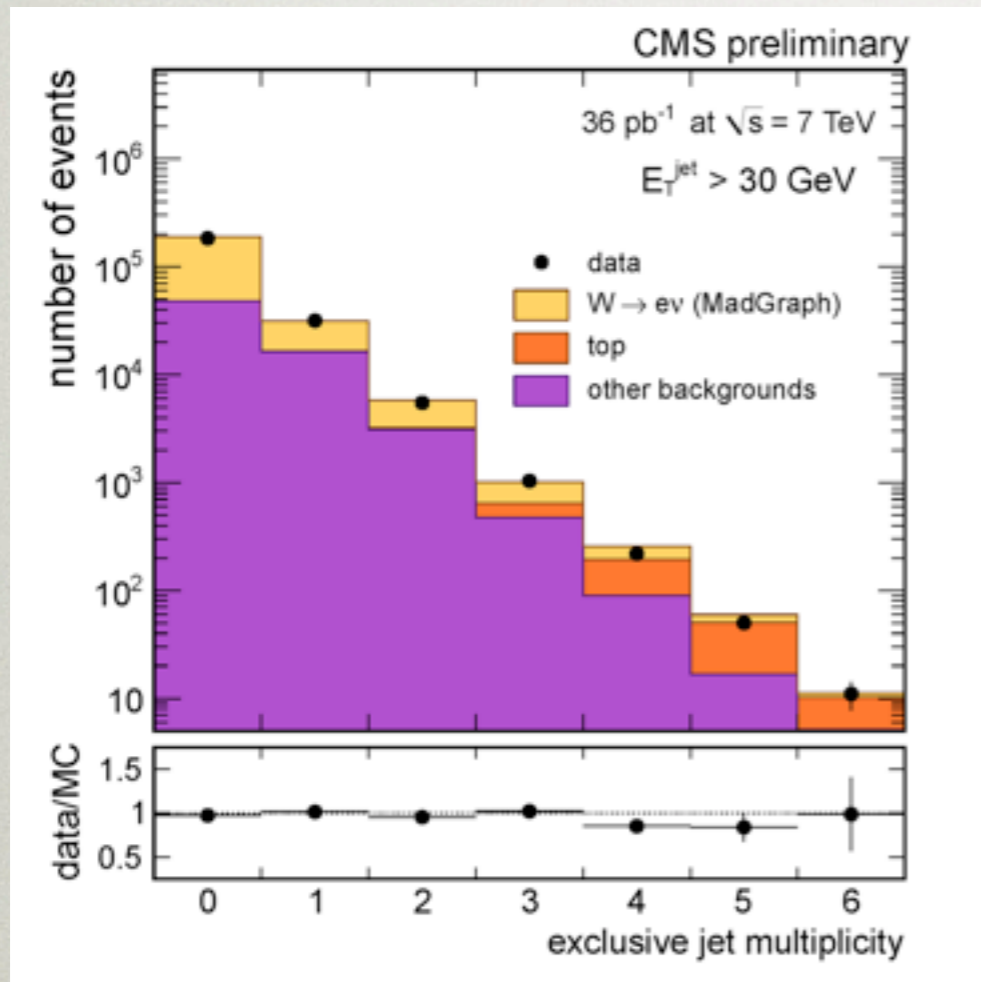
(with Mariangela Lisanti, Matthew Strassler, Philip Schuster)



# W+MULTI-JETS MEASUREMENTS

Raw W rate as a function of exclusive jet multiplicity (e channel)

Inclusive, unfolded and corrected W+  $\geq n$  jets rate (e channel)

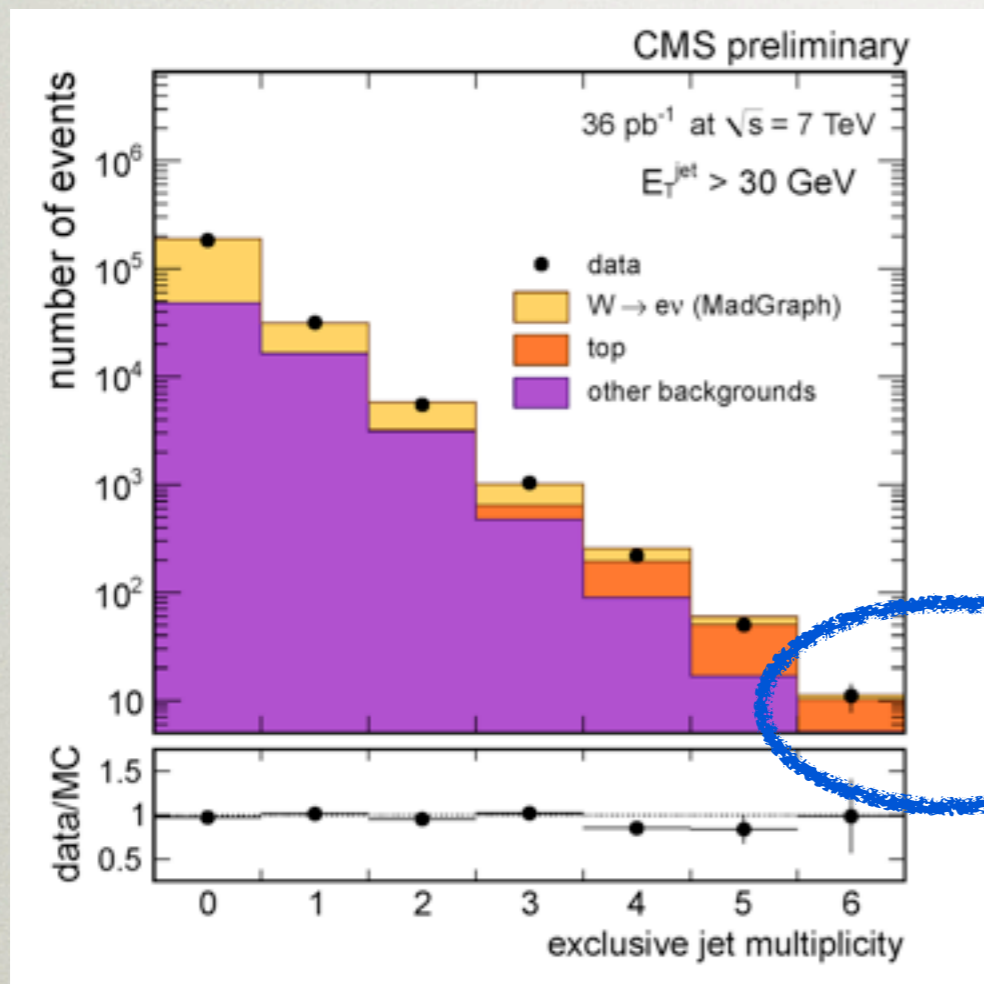


Last public results (ATLAS and CMS) at 36 pb<sup>-1</sup>  
Hard to go past 4-jet: dominated by top+jets



# W+MULTI-JETS SEARCHES?

Raw W rate as a function of exclusive jet multiplicity (e channel)



Interesting new-physics search region?  
 $W + \geq 6$  jets and high  $S_T$

$$S_T = \sum_{\text{leptons \& jets}} E_T + \cancel{E}_T$$

Last public results (ATLAS and CMS) at 36 pb<sup>-1</sup>  
Hard to go past 4-jet: dominated by top+jets



# (WHEN IS A SEARCH INTERESTING?)

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Interesting region to think about?

- Sensitive to some *plausible* new physics
- Significant mass coverage
- Complementary to existing search program

But does it motivate a dedicated search?

- Not “trivial” (i.e. not excluded by control regions for other searches)
- If there’s a signal, can one hope to convincingly demonstrate it?



# SCORECARD FOR W+MANY-JET + HIGH $S_T$

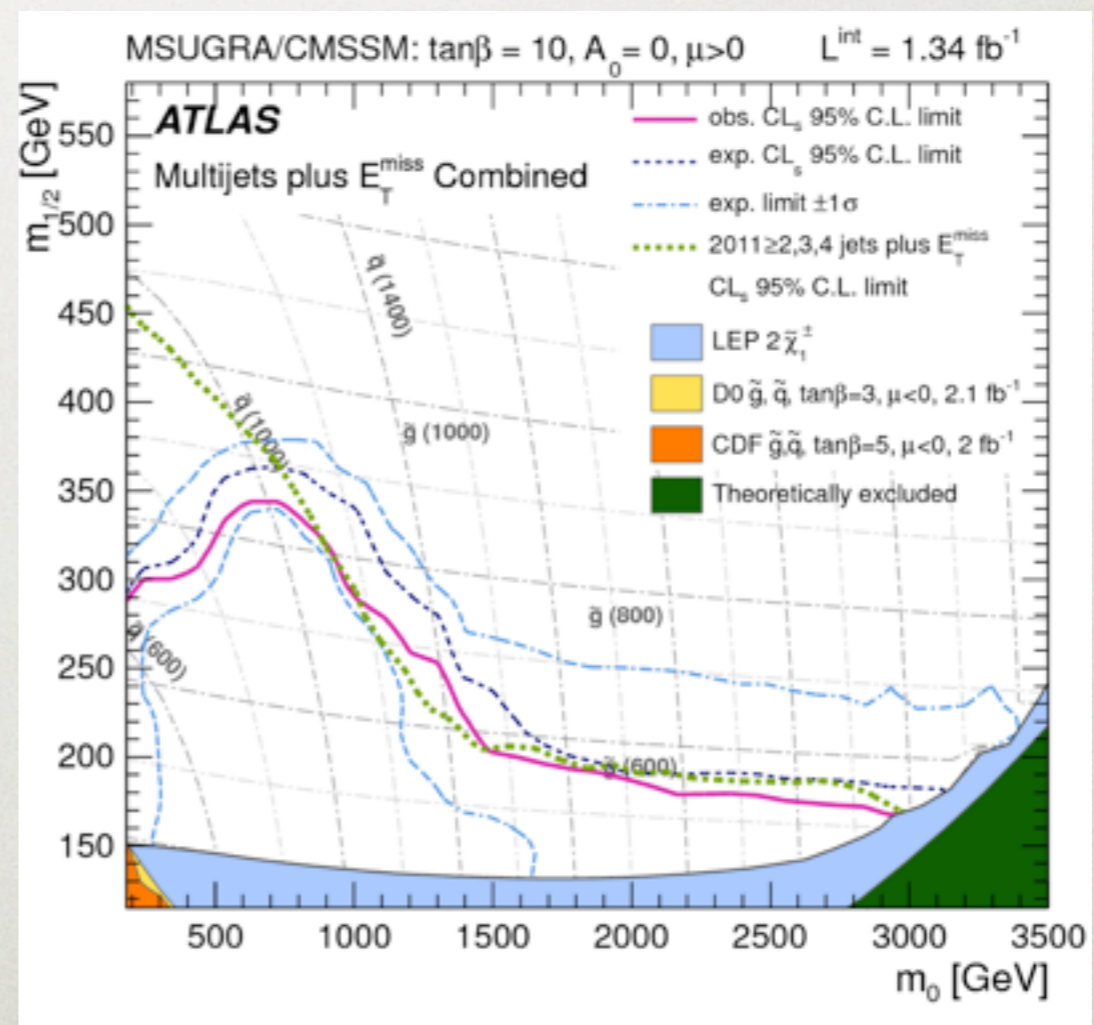
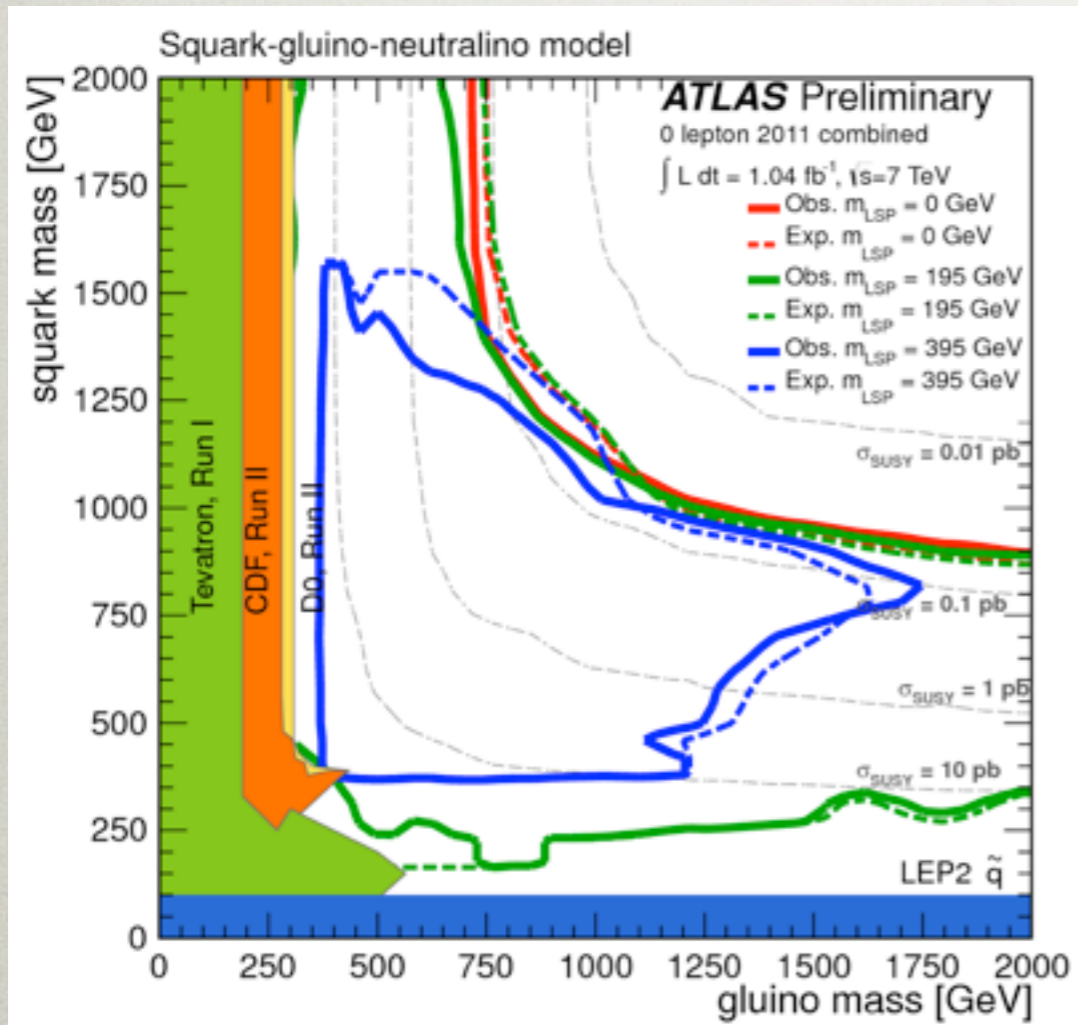
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1. Motivations & reach in exotic SUSY SM
  - More generally, what kinds of signals would show up in this signature?
2. (Non)-redundancy with other searches or control regions
3. Distinguishing a signal from backgrounds



# SUSY LIMITS (1 FB<sup>-1</sup>)

In several SUSY scenarios, squarks and gluinos below a TeV have been excluded:



...does this mean SUSY is dead?



# HIDING PLACES

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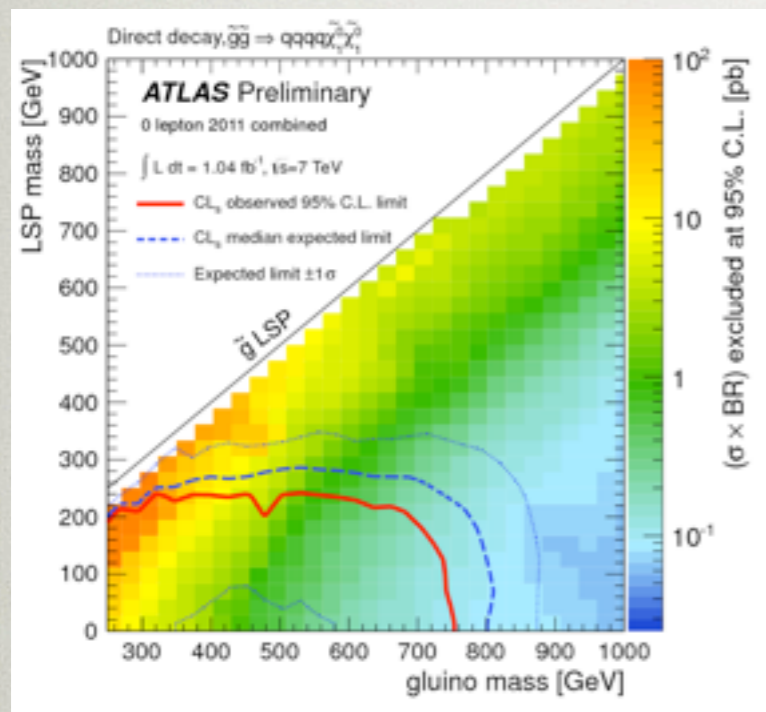
[Matt Strassler's slide – very common classification]

I will suggest the following way of thinking

- There are roughly three classes of things that can go wrong:
  - Gluino or roughly-degenerate squarks of moderate-to-high mass decaying simply to LSP easily seen in jets + MET
- **Squeezed** spectrum:
  - the gap between colored and uncolored is smaller
- **Stretched** spectrum:
  - all or most colored particles are too heavy to produce,  
color-neutral particles have higher cross-sections
- **Busy** spectrum:
  - MET (perhaps jets too) broken down into more objects, possibly soft

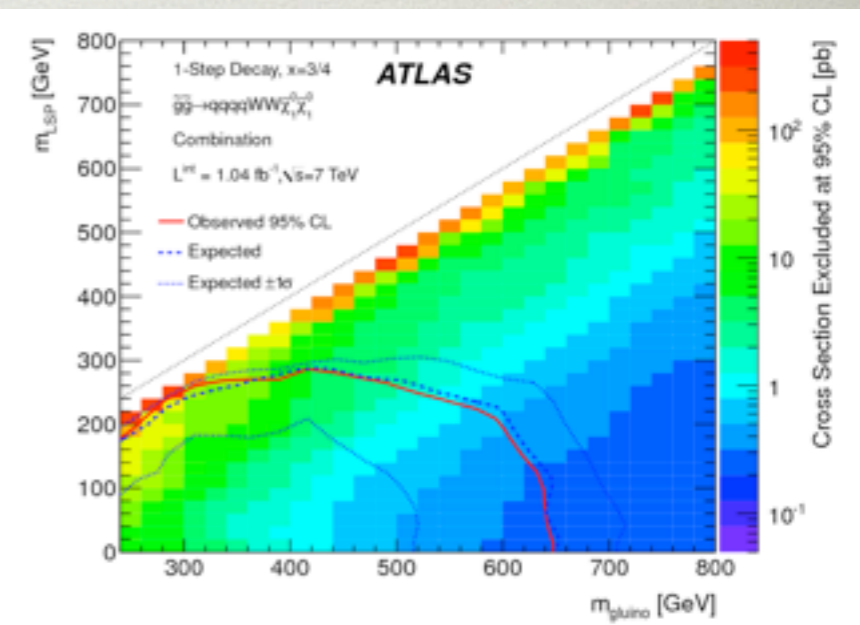
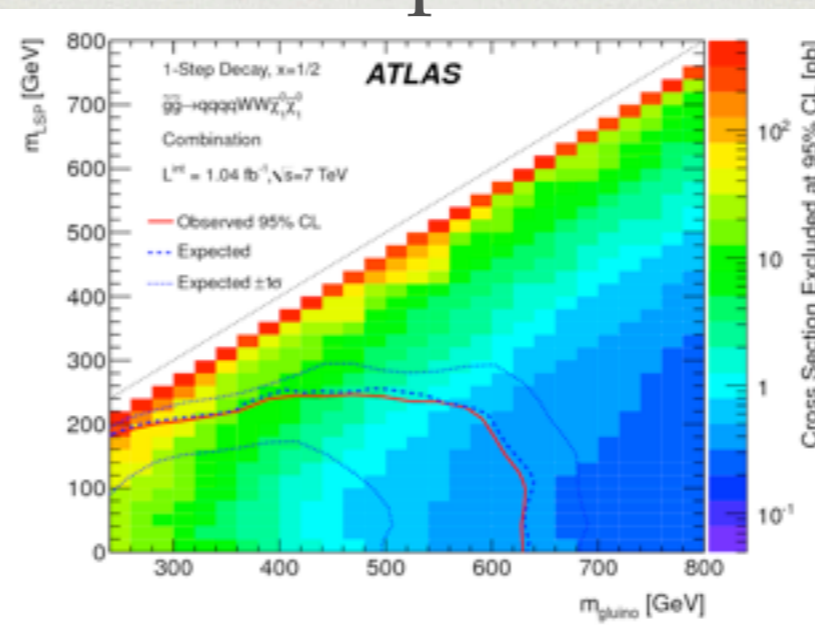
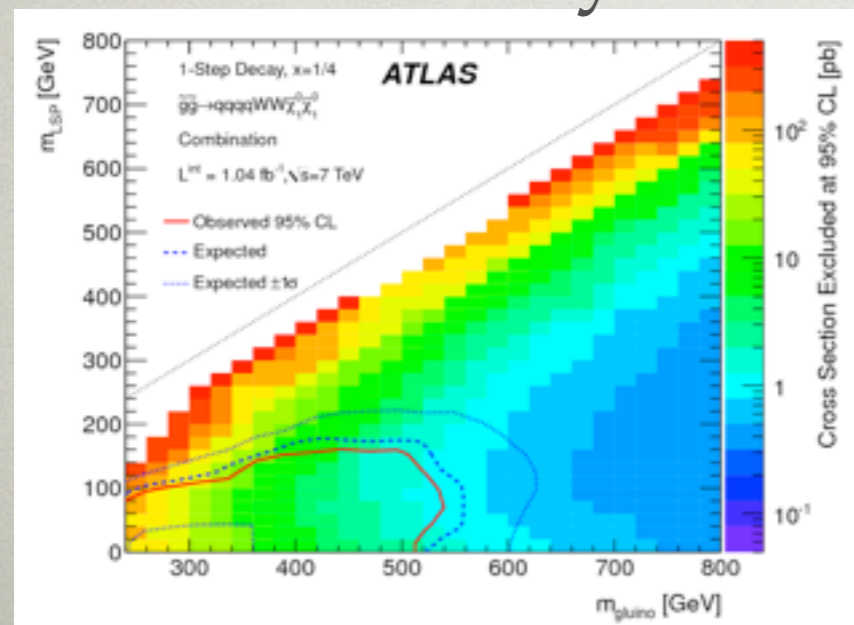


# SQUEEZED SUSY LIMITS (1 FB<sup>-1</sup>)



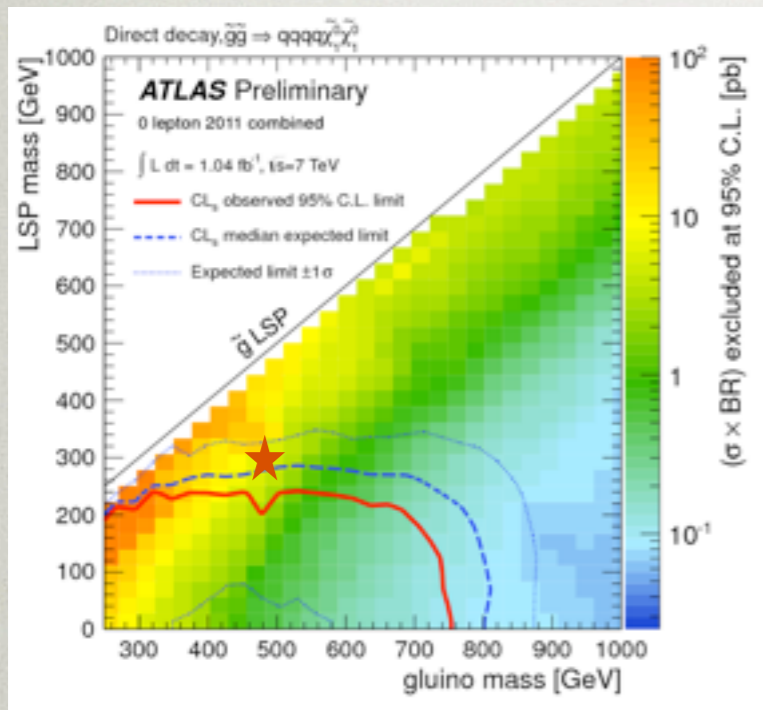
Direct decay limits  
from 0-lepton+jets+MET

Cascade decay limits from 1-lepton searches





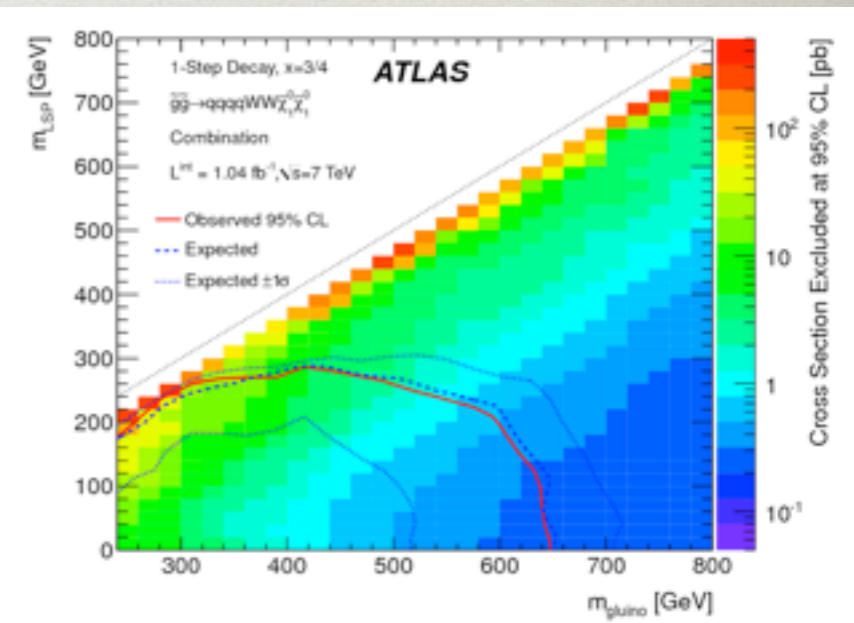
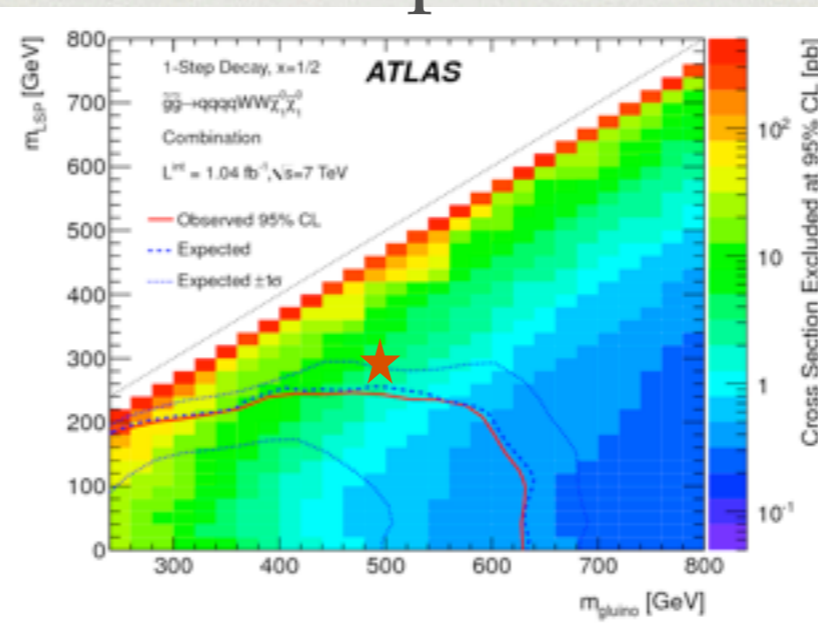
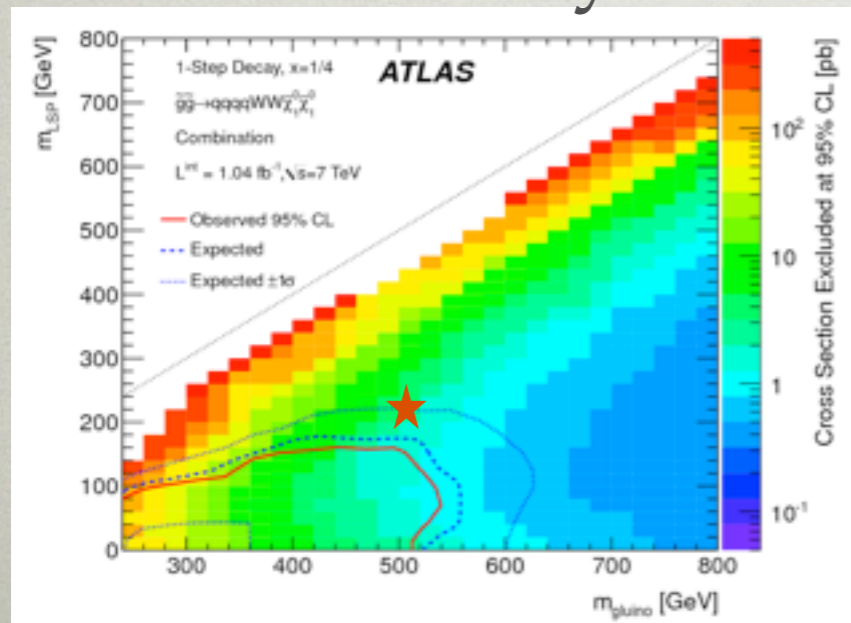
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Direct decay limits  
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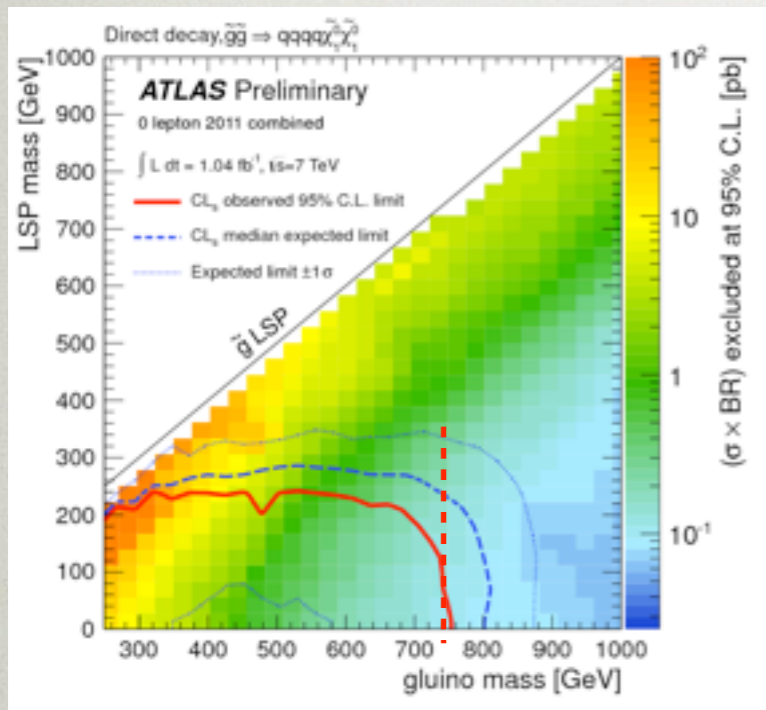
★ 500 GeV gluinos allowed!

Cascade decay limits from 1-lepton searches





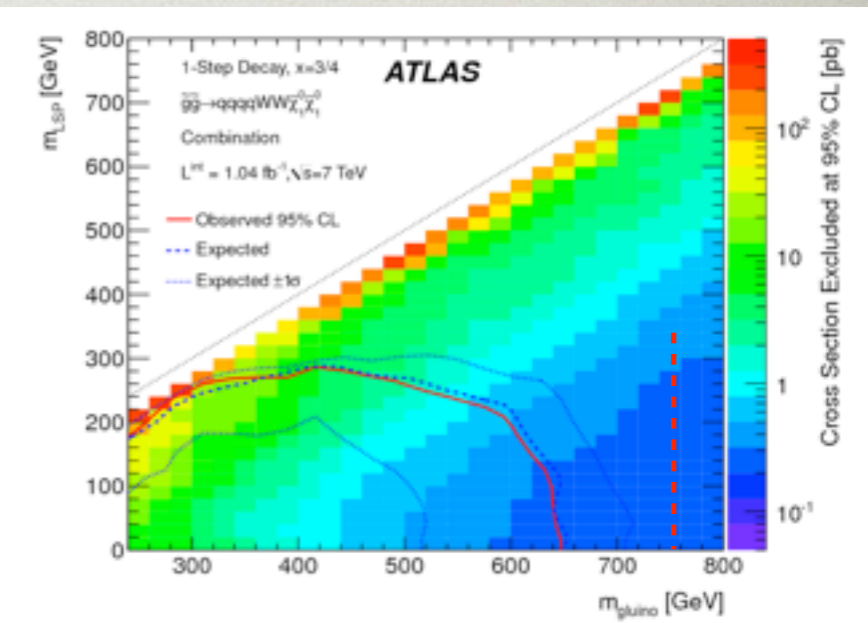
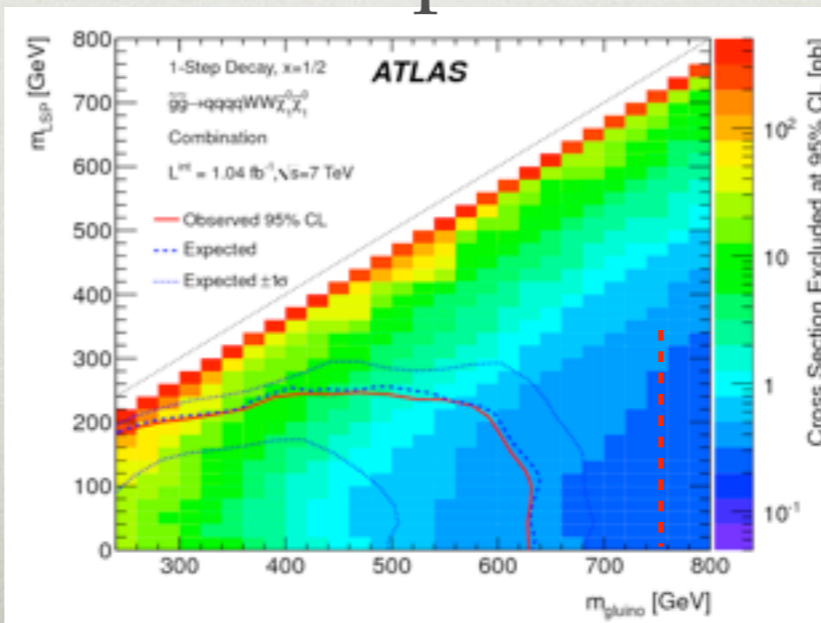
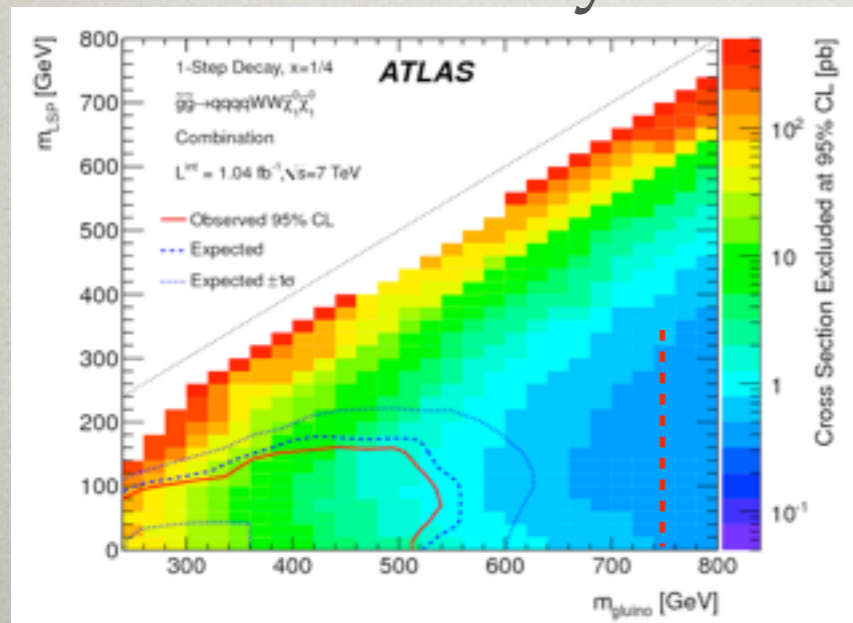
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Direct decay limits  
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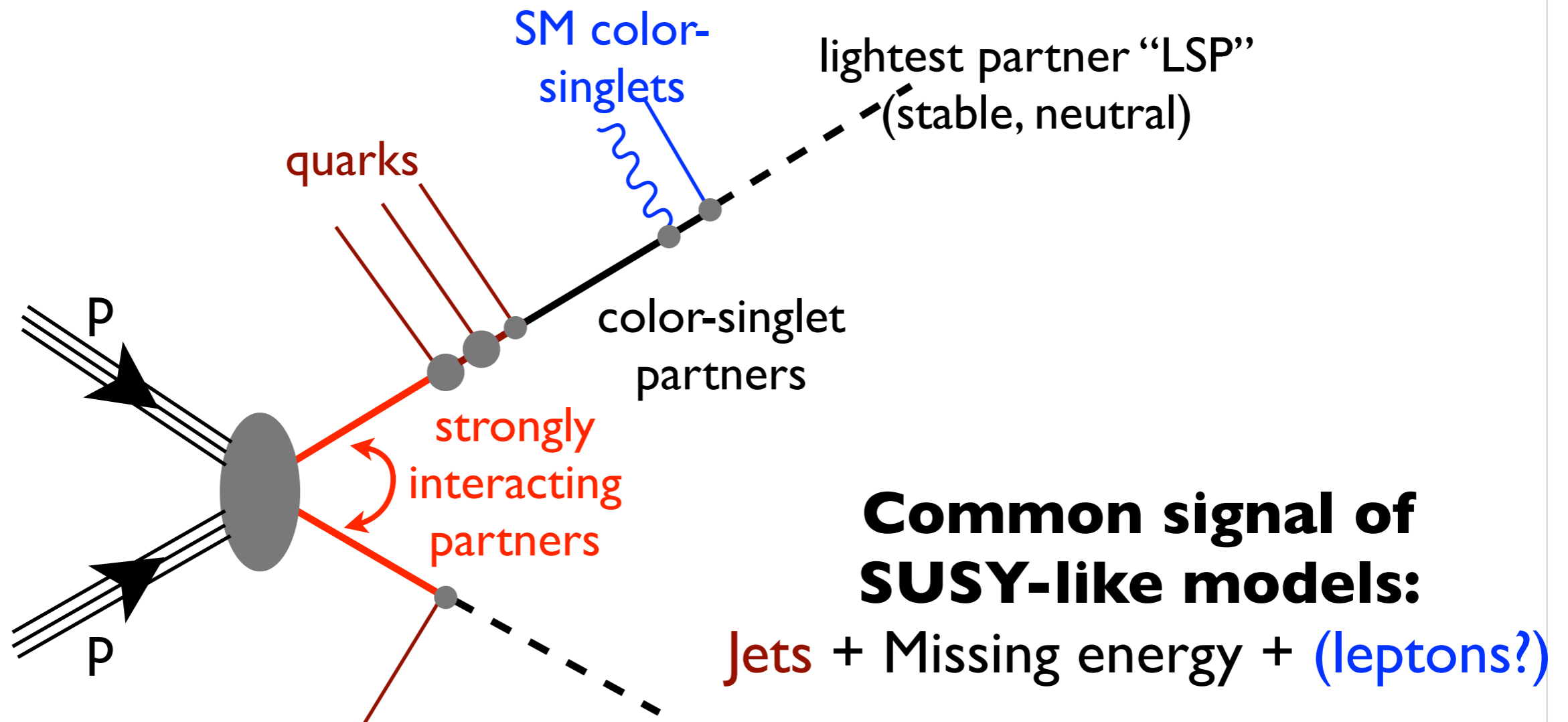
*can see weakening of sensitivity  
from cascade decays ("busy")  
→ extreme case: "stealthy"*

Cascade decay limits from 1-lepton searches





# WHERE ELSE SHOULD WE LOOK?



Produce jets **because they're strongly coupled** (well established)  
Produce missing energy because there's nothing for LSP to decay to  
(just a guess, motivated by dark matter & minimality)



# WHERE ELSE SHOULD WE LOOK?

---

Many scenarios with LSP decay:

- low-scale gauge mediation → decay to gravitino + gauge/higgs bosons
- light hidden sectors → decay to collimated “lepton-jets”
- hidden valleys at 10-100 GeV → multi-jet or multi-track (can be complex)
  - stealth SUSY → dijet + very low MET
- NMSSM → decay to higgs-like scalars
- R-parity violation → decay to leptons or jets  
or anomalous T-parity

Top-rich decays can also reduce typical LSP momentum and typical jet energy

*These decays reduce or eliminate stable neutralino's  $\cancel{E}_T$  signal  
⇒ require complementary searches.*



# AN EXAMPLE: 3 SUSY MODELS

A vanilla CMSSM-like spectrum with

stable bino-like LSP

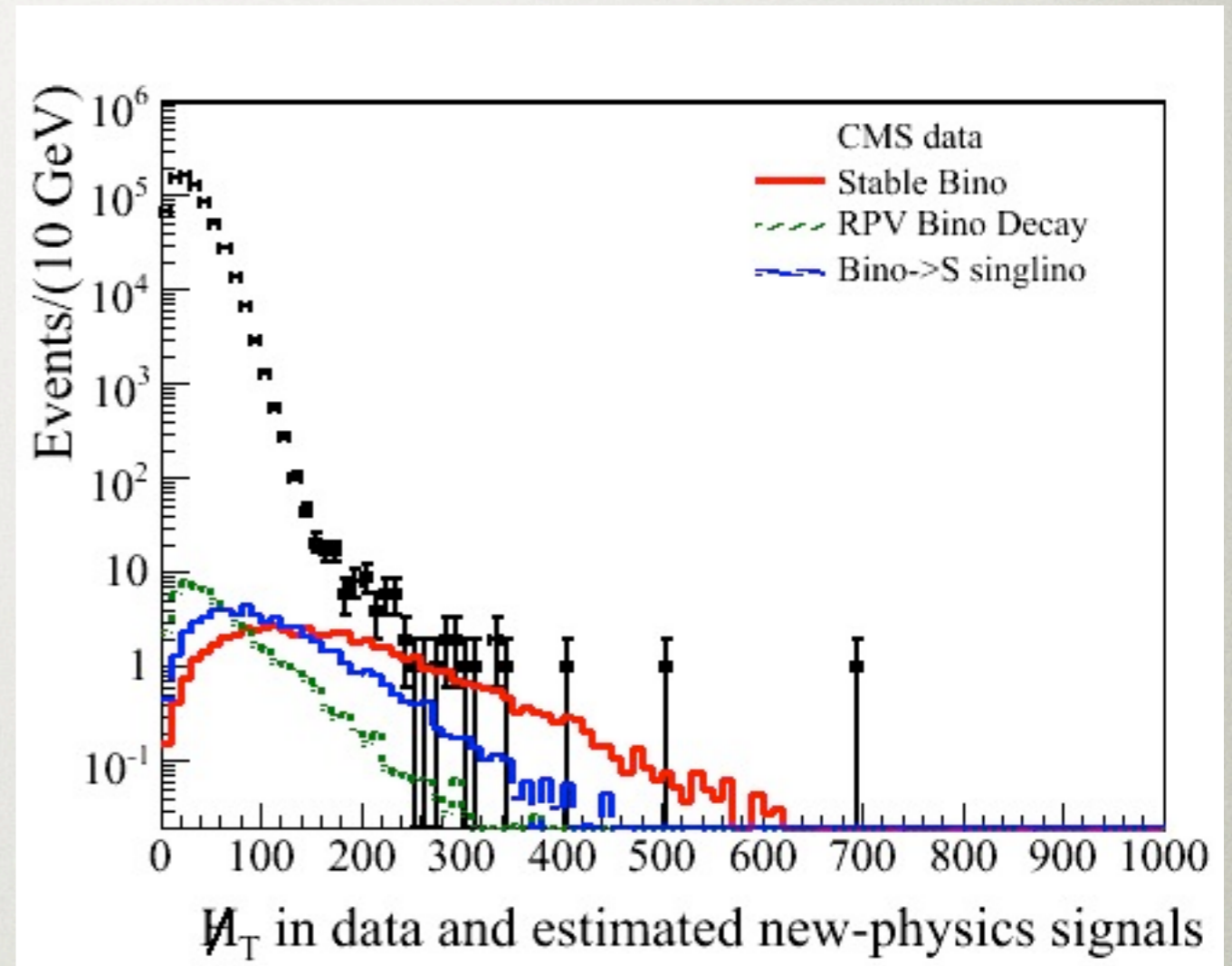
or

bino  $\rightarrow$  singlet + singlino  
 $\rightarrow b \sim b$

or

bino  $\rightarrow$  3 jets (RPV)

How can you find the low-MET signals?

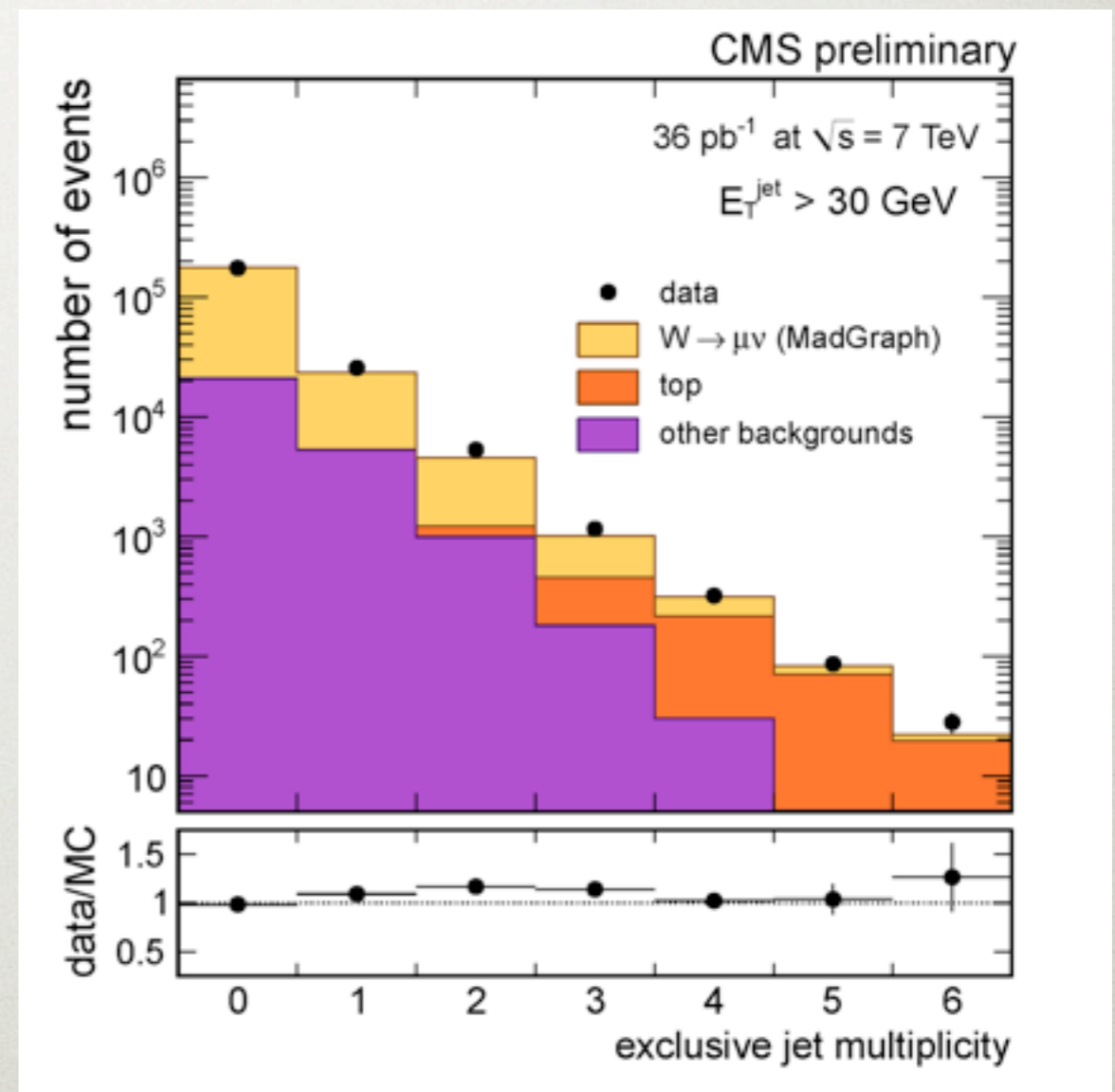
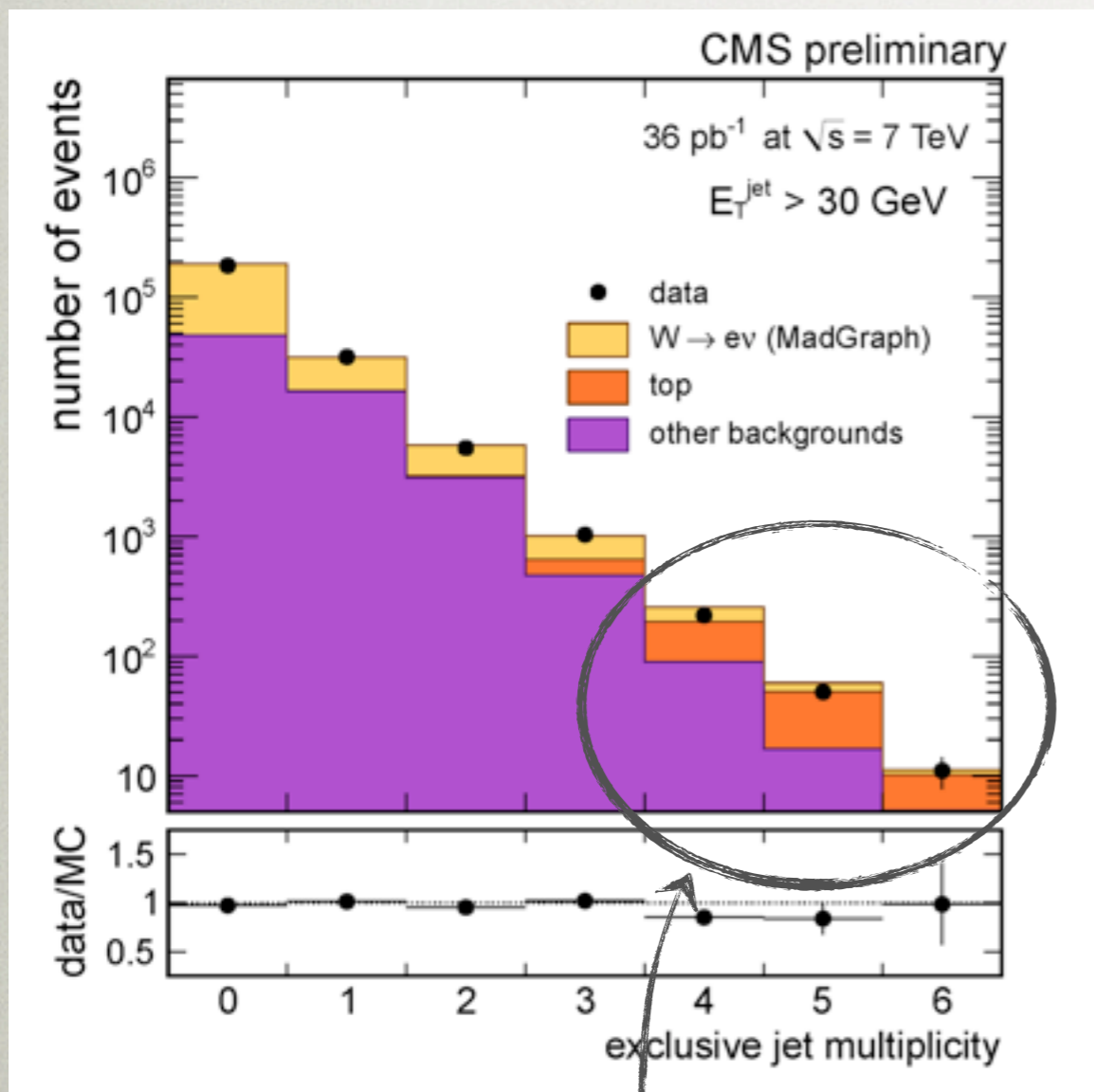


Estimated  $H_T$  distributions in CMS jets+MET search ( $36 \text{ pb}^{-1}$ )



# W+MULTI-JETS MEASUREMENTS

Raw W and Z rates as a function of exclusive jet multiplicity (e and  $\mu$  channels)

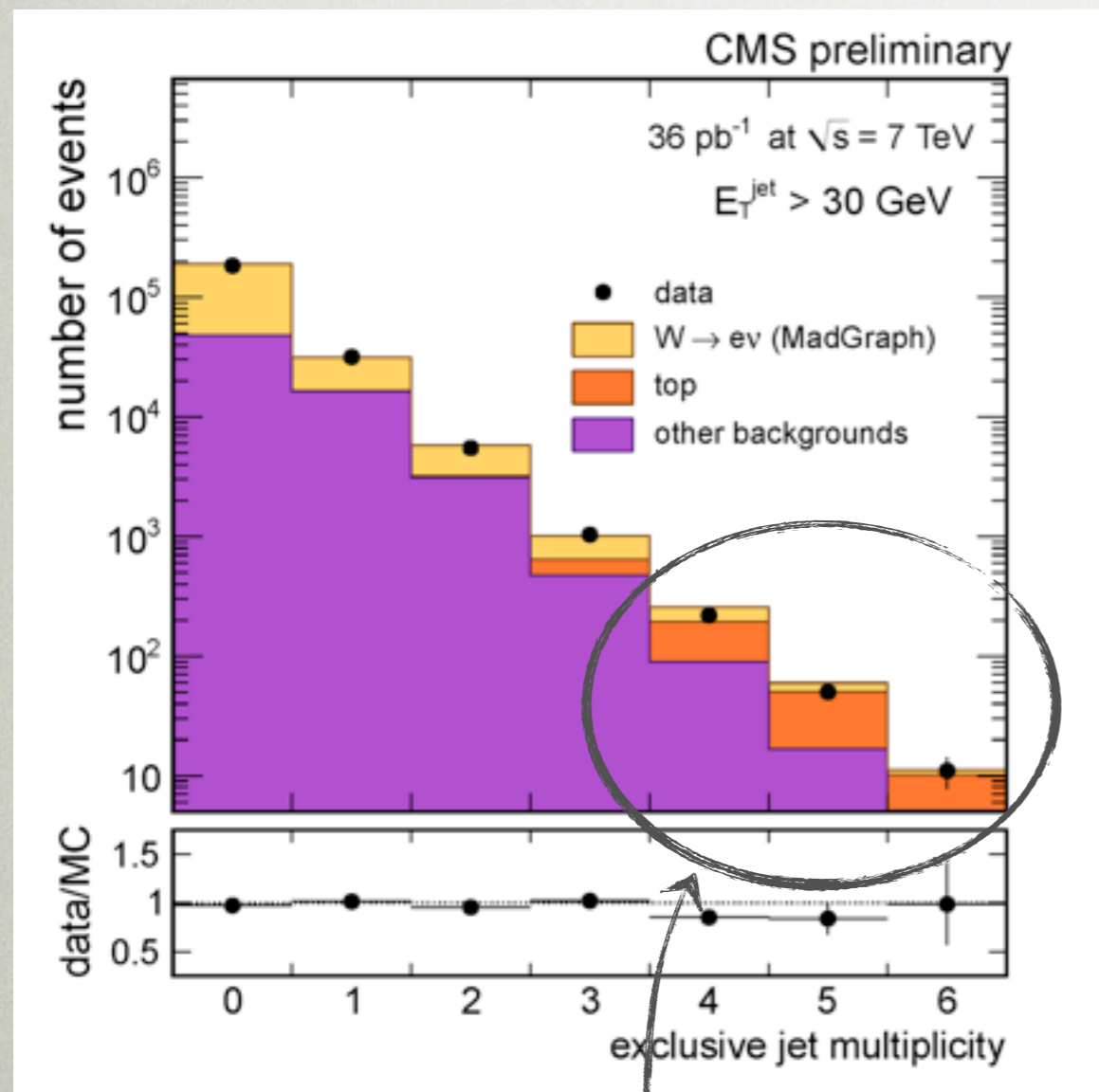


*top-dominated tail*

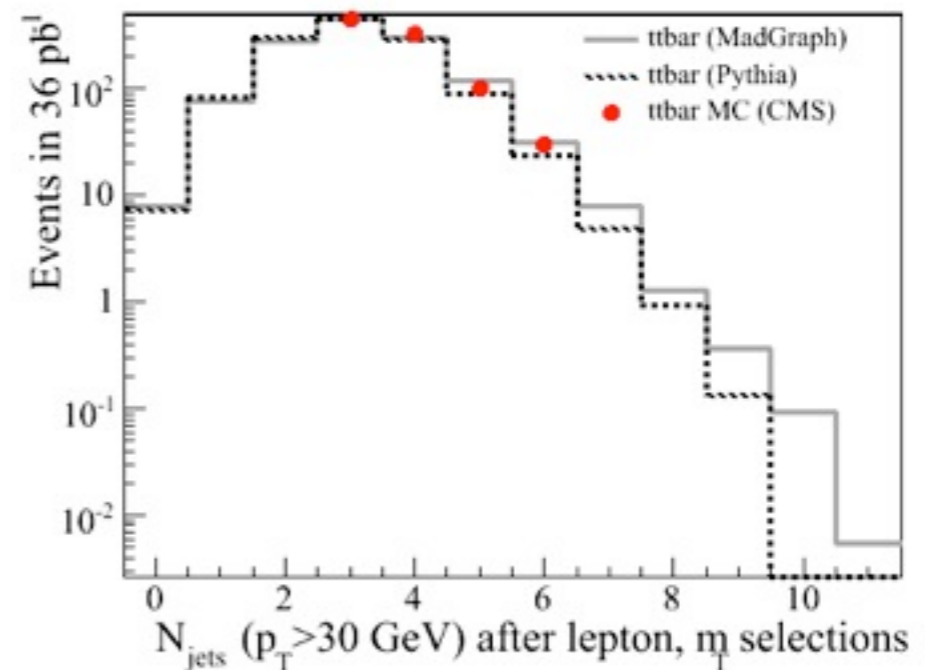


# W+MULTI-JETS MEASUREMENTS

Raw W and Z rates as a function of exclusive jet multiplicity (e and  $\mu$  channels)



*top-dominated tail*



*Reasonable agreement up to 6 jets between our MC, CMS MC, and CMS data — will only use for motivation, search need not be MC-based!*



# THE 3 MODELS IN LEPTON +MULTI-JET FINAL STATES

A vanilla CMSSM-like  
spectrum with

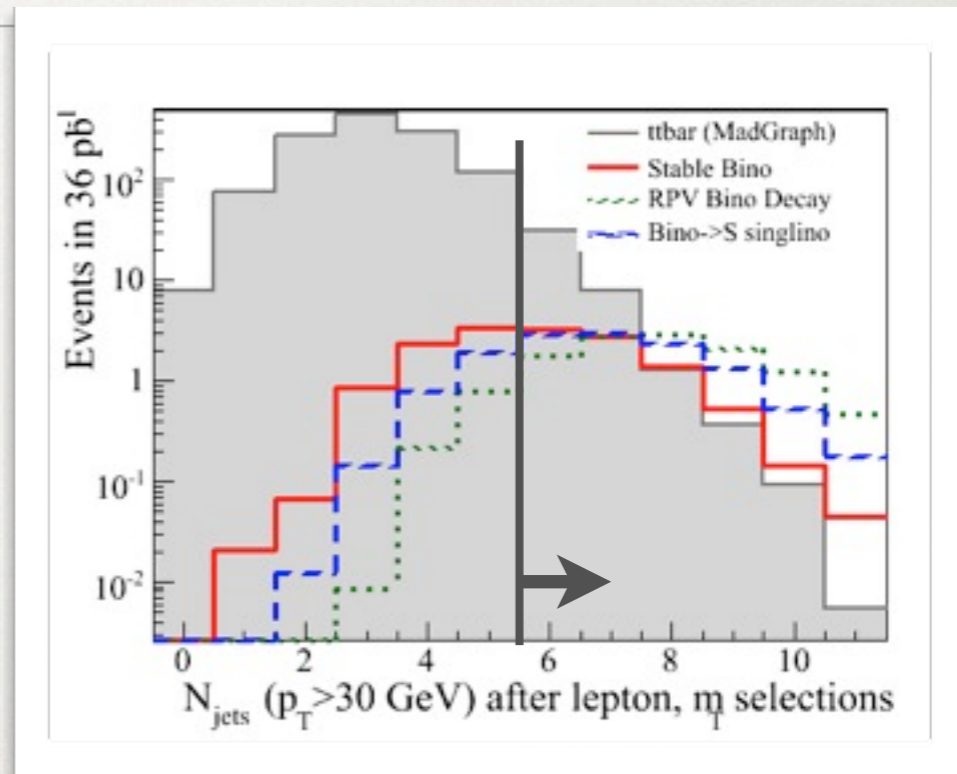
stable bino-like LSP

or

bino  $\rightarrow$  singlet + singlino  
 $\rightarrow b \sim b$

or

bino  $\rightarrow$  3 jets (RPV)



# of 30-GeV jets (require  
 $p_T(l) > 20$  GeV,  $m_T > 20$  GeV)

*High jet multiplicity increases S/B, but still small...*



# THE 3 MODELS IN LEPTON + MULTI-JET FINAL STATES

A vanilla CMSSM-like spectrum with

stable bino-like LSP

or

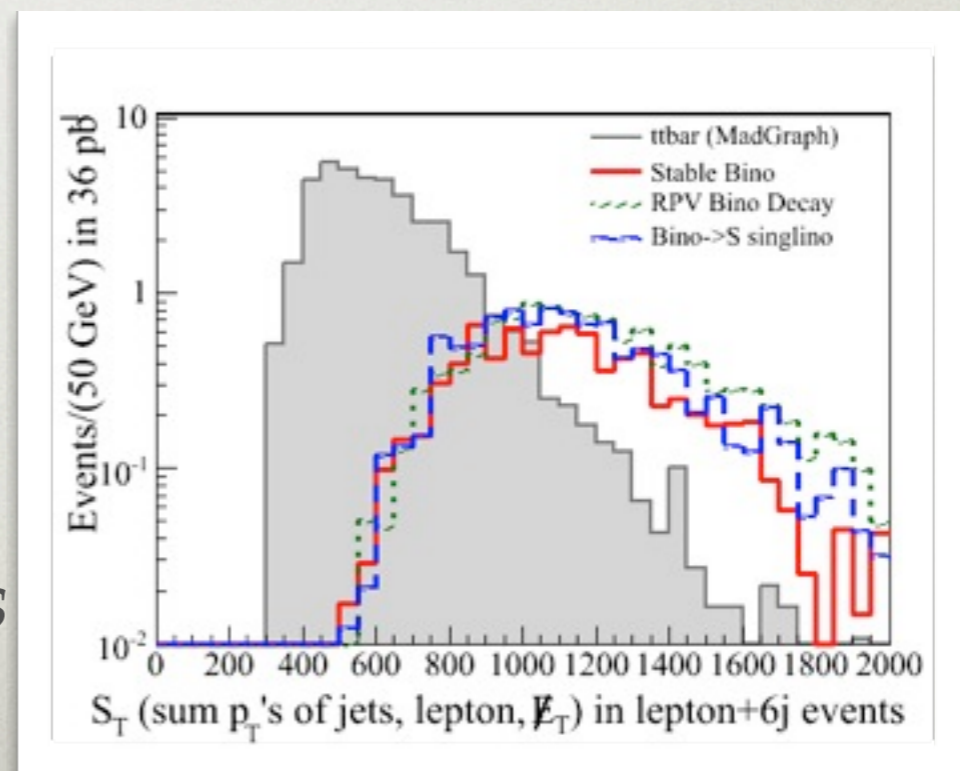
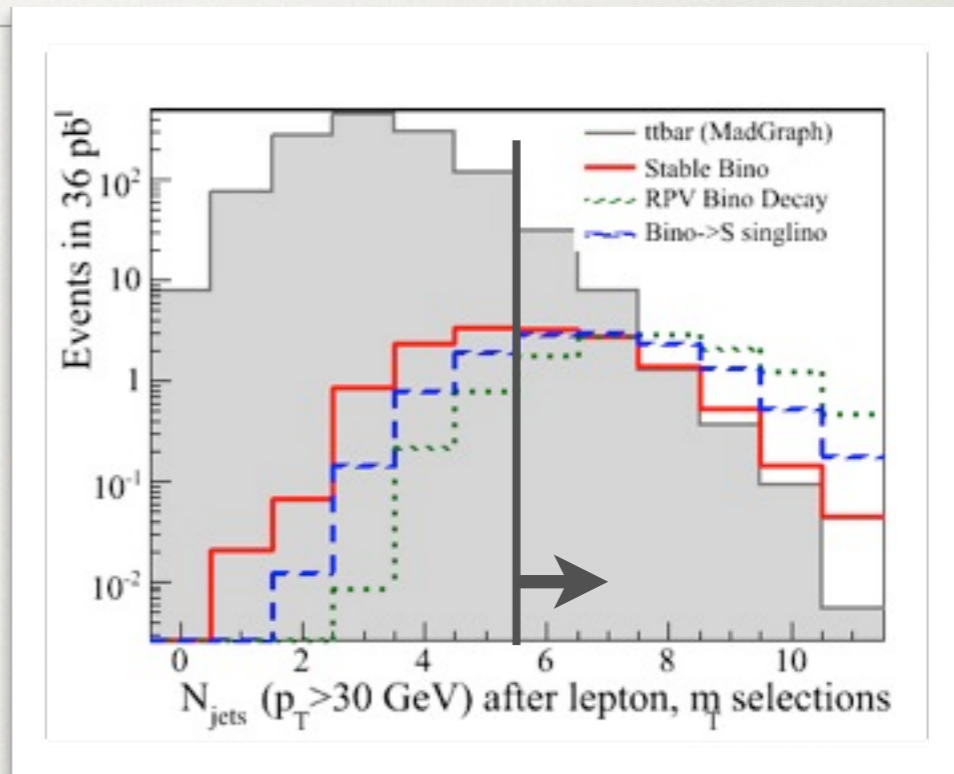
bino  $\rightarrow$  singlet + singlino  
 $\rightarrow b \sim b$

or

bino  $\rightarrow$  3 jets (RPV)

$$S_T = \sum_{\substack{\text{leptons} \\ \& \text{ jets}}} E_T + \cancel{E}_T$$

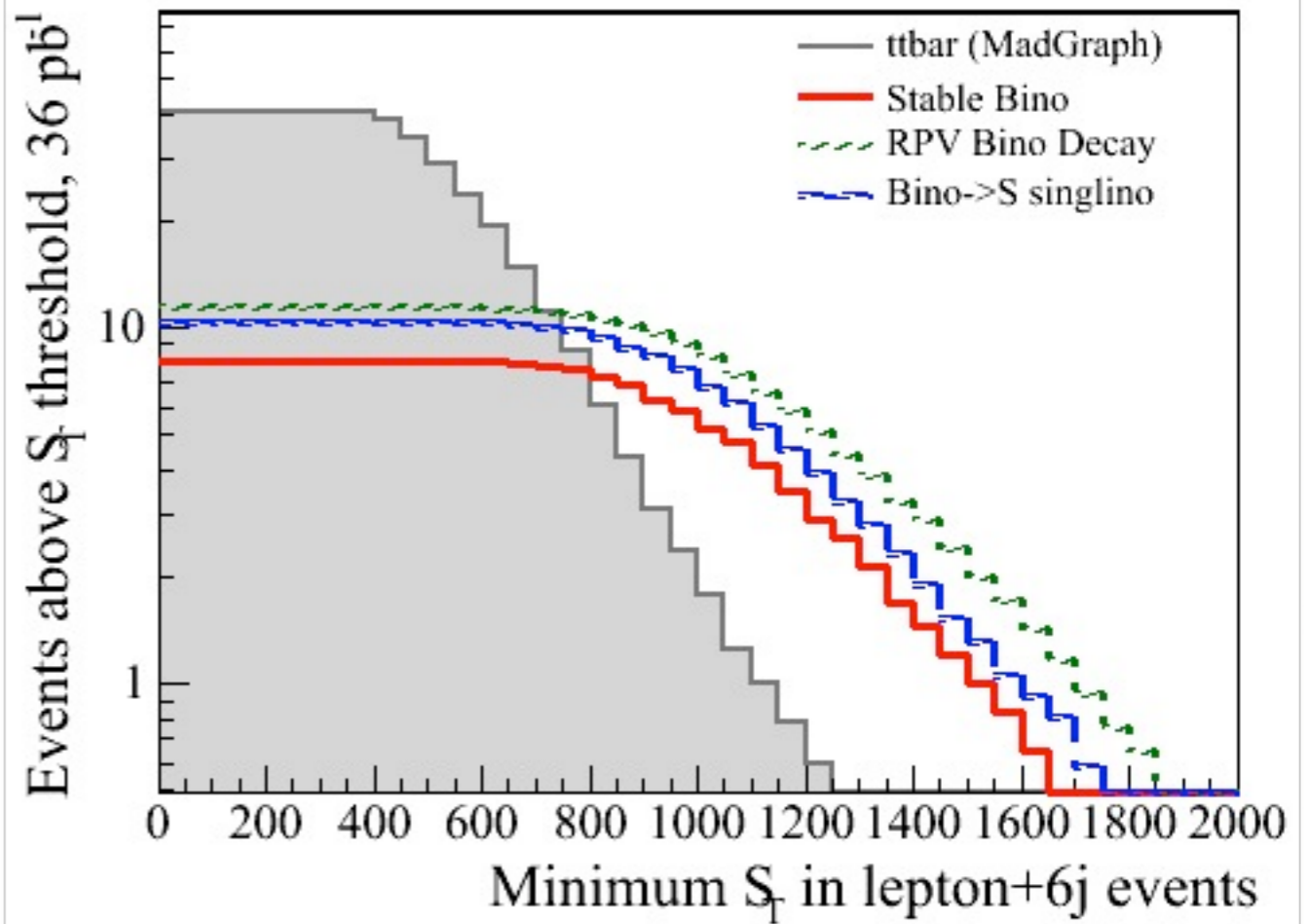
*in lepton+6 jet events*





# LEPTON+MANY JET SENSITIVITY

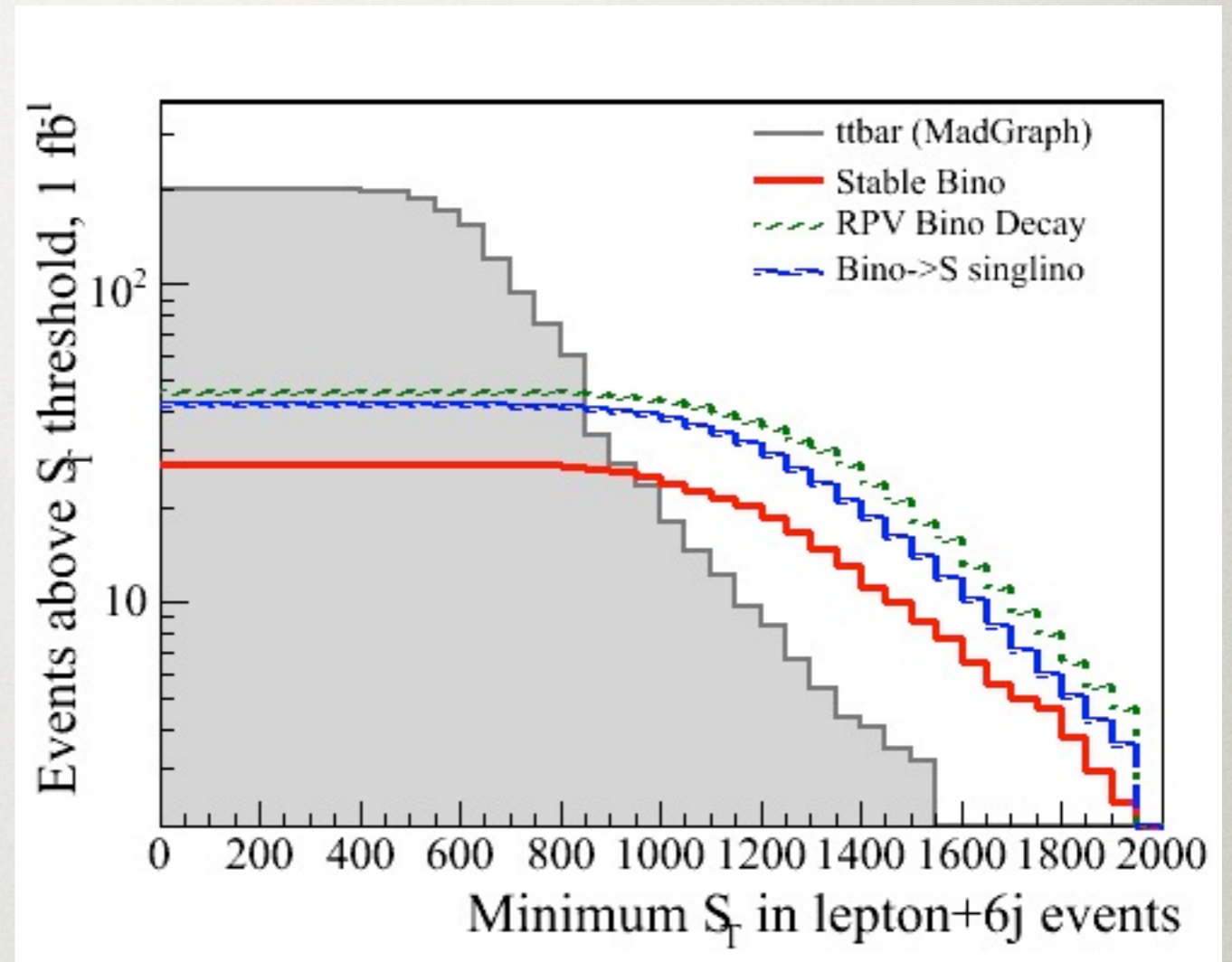
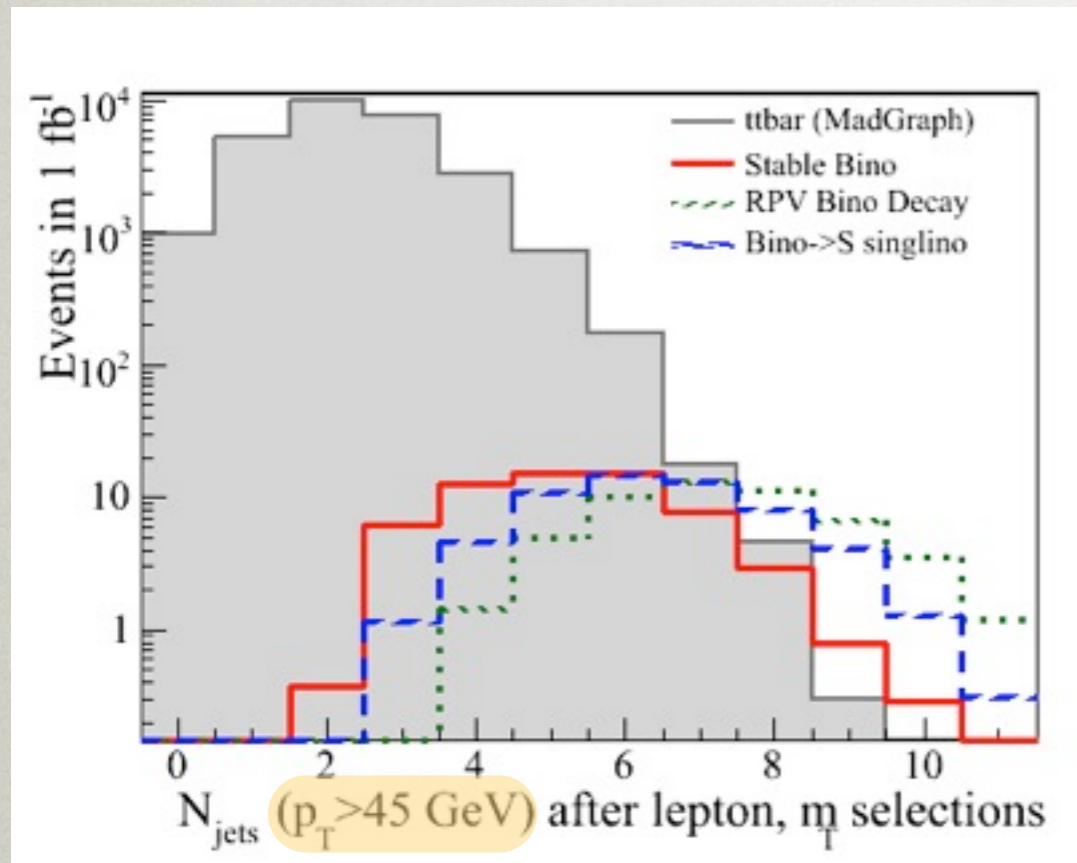
*e.g. cut at 1 TeV  $S_T$ : 5-8 events  
over background of 2*





# SENSITIVITY

## SURVIVES WITH $1 \text{ FB}^{-1}$

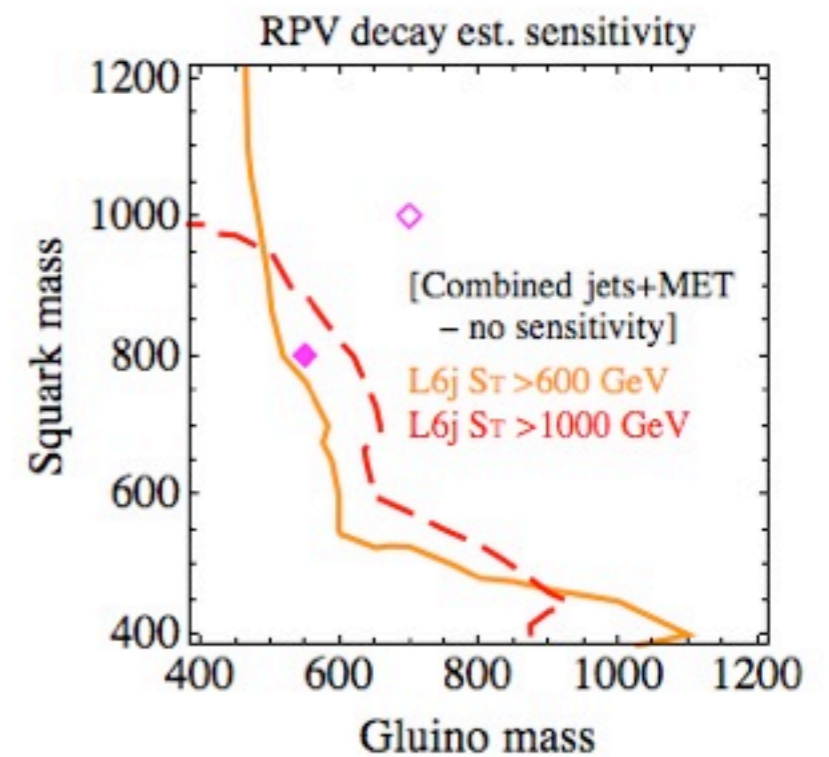
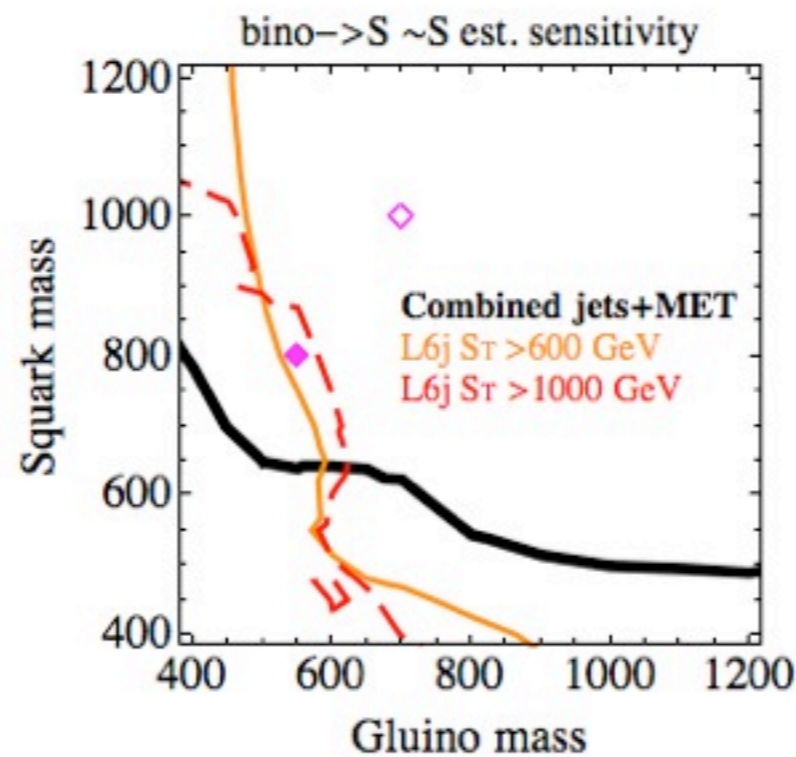
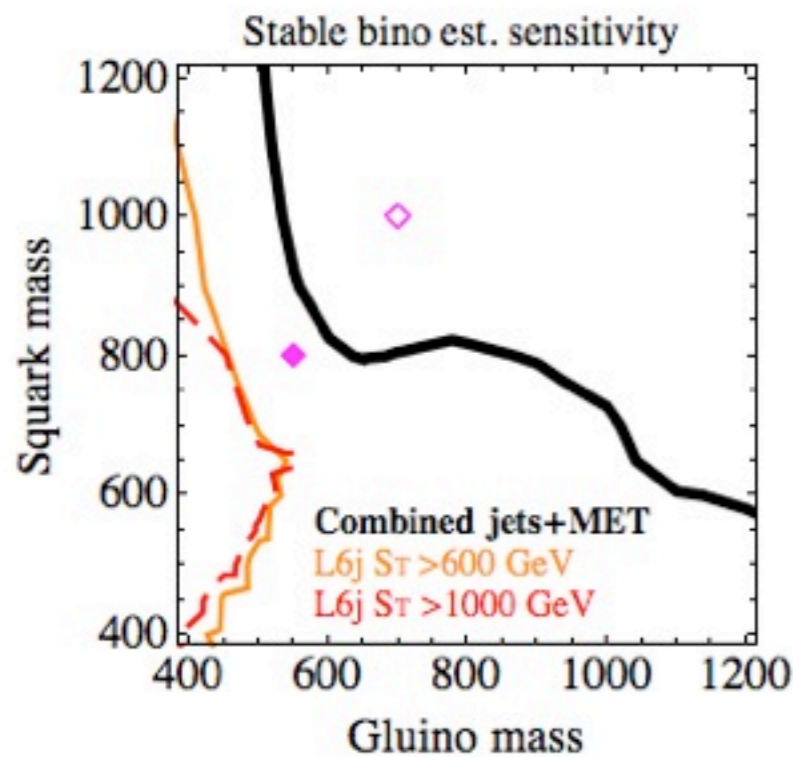


( $1 \text{ fb}^{-1}$  distributions for a higher-mass benchmark point)



# LEPTON+MANY JET SENSITIVITY

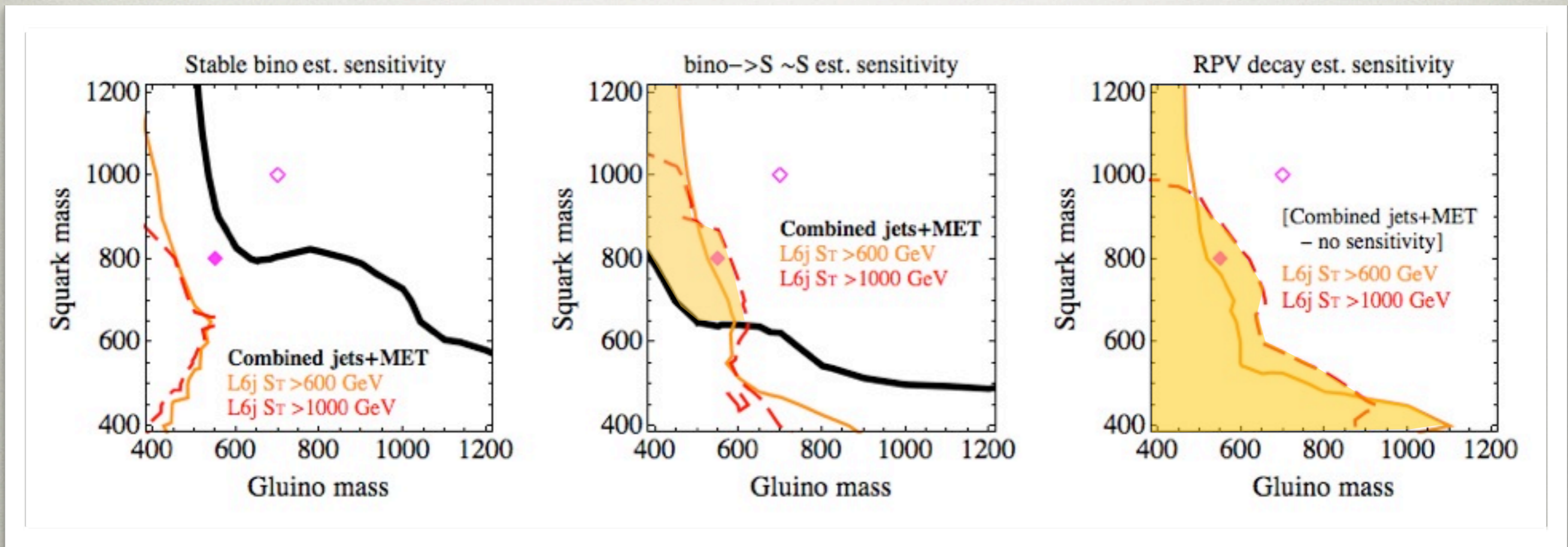
**New exclusion coverage** from lepton+many-jets  
(optimistic estimate: stat. only errors)





# LEPTON+MANY JET SENSITIVITY

**New exclusion coverage** from lepton+many-jets  
(optimistic estimate: stat. only errors)



**Where applicable,** comparable mass-scale sensitivity to jets+MET



# LEPTON+MANY JET SENSITIVITY

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Significant potential sensitivity to:

- SUSY with long cascade-decays
  - RPV, singlino cascades, GMSB with NLSP  $\rightarrow h/Z$
- Any theory with exotic SU(3)-octet or sextet decaying into top quarks + visible

Limited sensitivity (reliant on background predictions):

- $t'$  quarks or, more generally, a single SU(3)-triplet fermion
  - $d\sigma/dS_T$  comparable for  $t$  and  $t' \Rightarrow S/B \sim 1$
- direct stop production ( $S/B < 1$ )



# SCORECARD FOR W+MANY-JET + HIGH $S_T$

---

1. Motivations & reach in exotic SUSY SM
  - More generally, what kinds of signals would show up in this signature?
2. (Non)-redundancy with other searches or control regions
3. Distinguishing a signal from backgrounds



# WOULDN'T WE HAVE NOTICED IT ALREADY?

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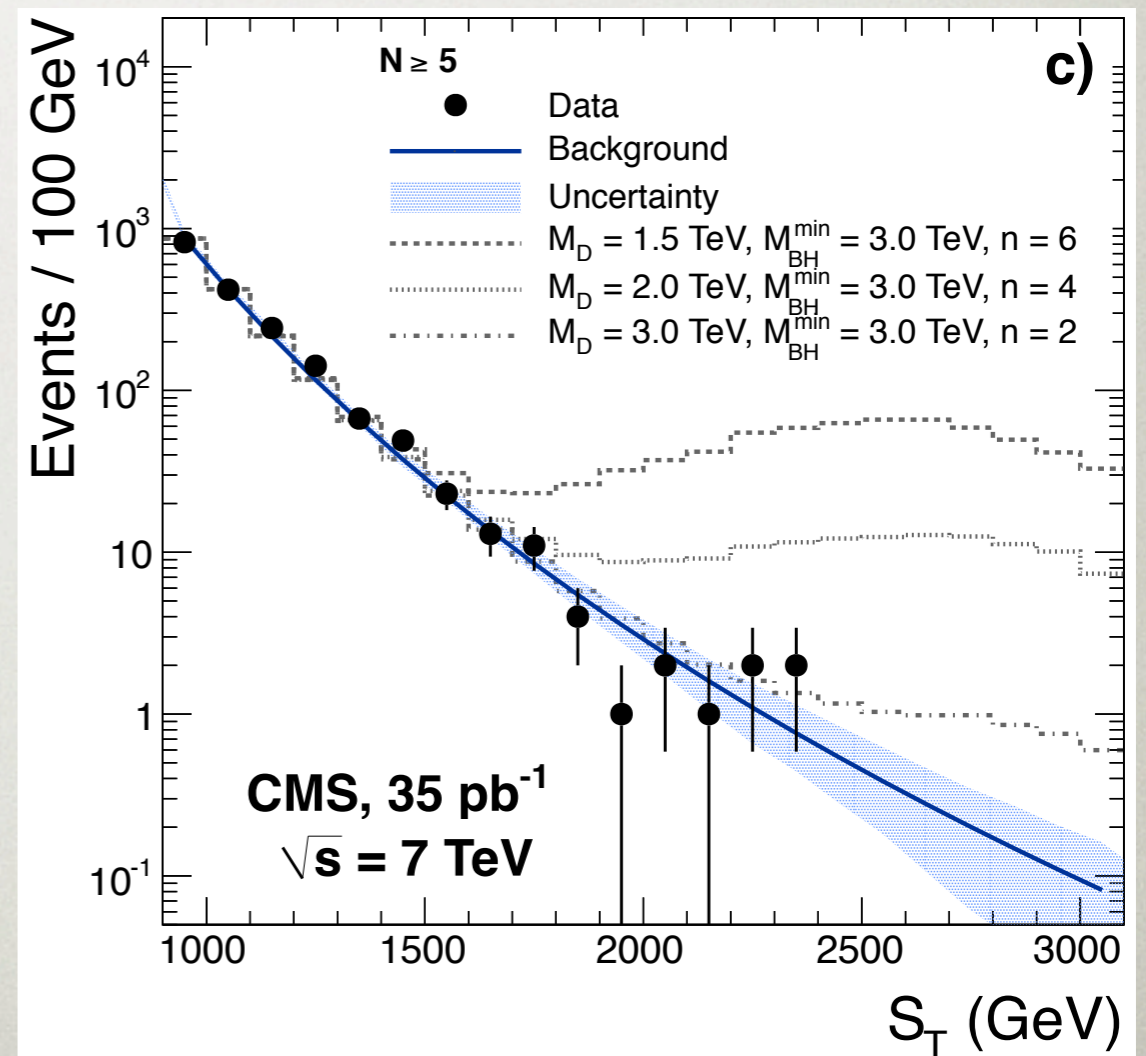
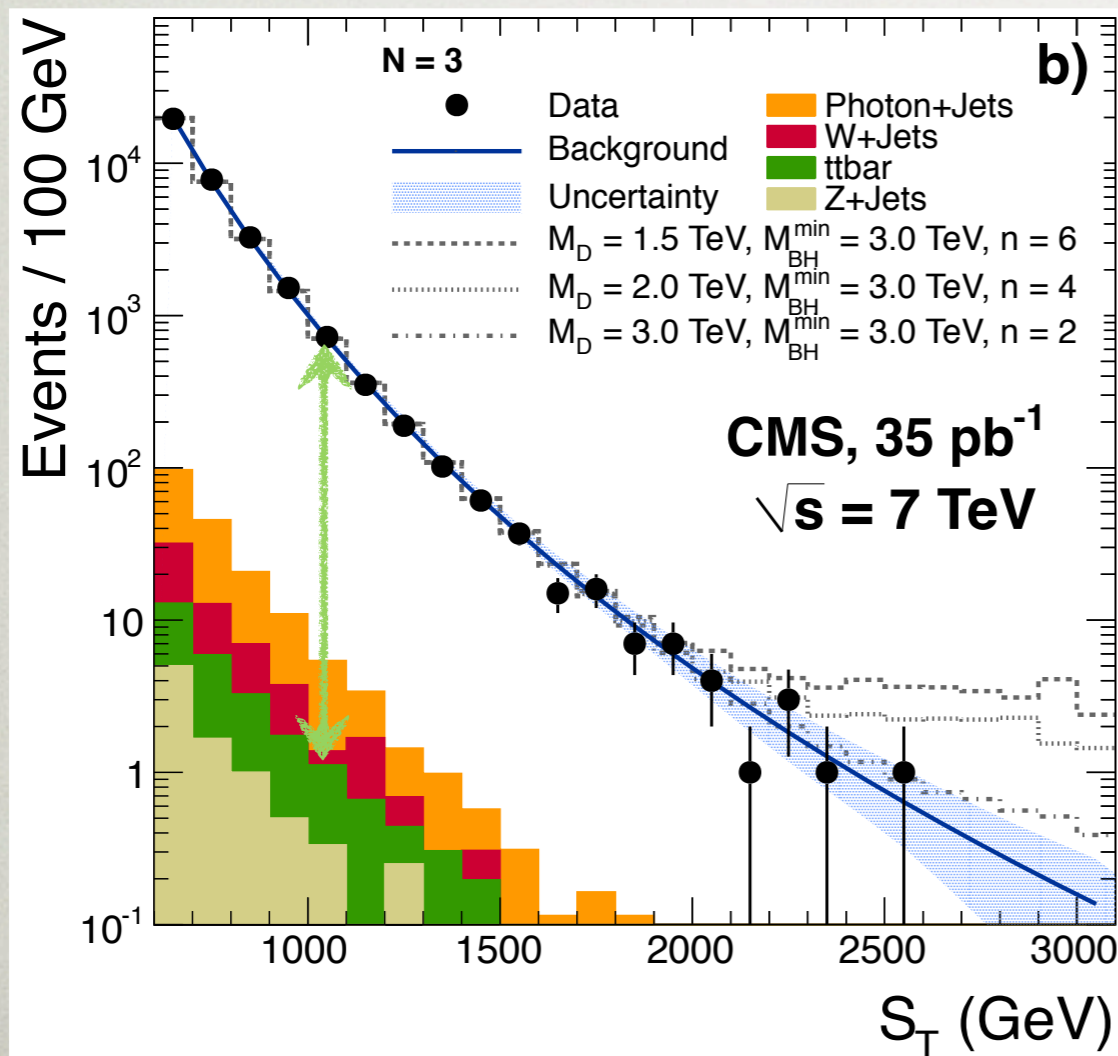
- High  $S_T$ , high  $N_{\text{jet}}$  searches (black holes)
- Lower-MET SUSY searches
  - $\geq 6-8$  jets +MET SUSY searches
  - same-sign & trilepton searches
- Control regions
  - SUSY searches (low MET regions)
  - exotica / higgs (high  $N_{\text{jet}}$  controls)



# BLACK-HOLE SEARCHES

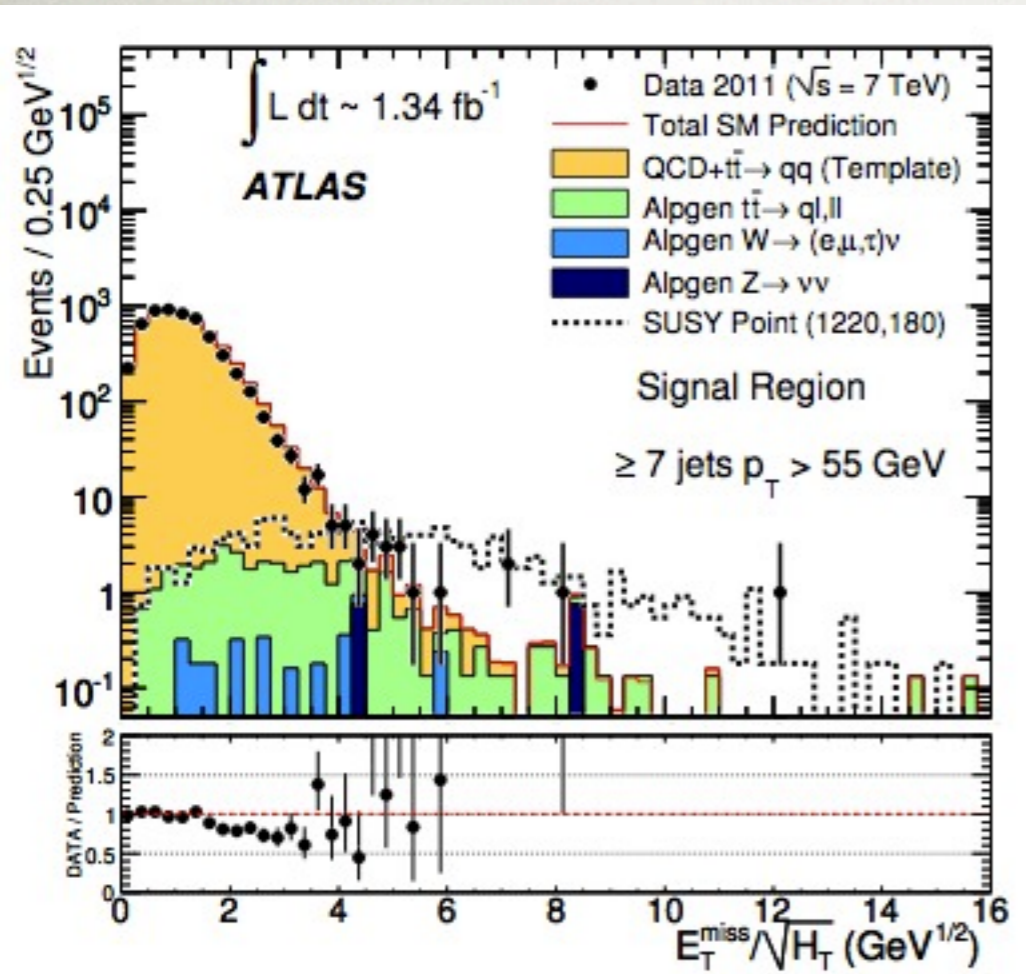
Present searches cut too hard on  $S_T$  for perturbative physics  
*In principle* much harder search: 300x bigger background!

⇒ dwarfs *any* BSM search





# MANY-JETS+MET



$$H_T \geq 400 \text{ (~800)}$$

$$\Rightarrow \text{MET} > 100$$

Bkg  $\sim 40$  events at  $1 \text{ fb}^{-1}$

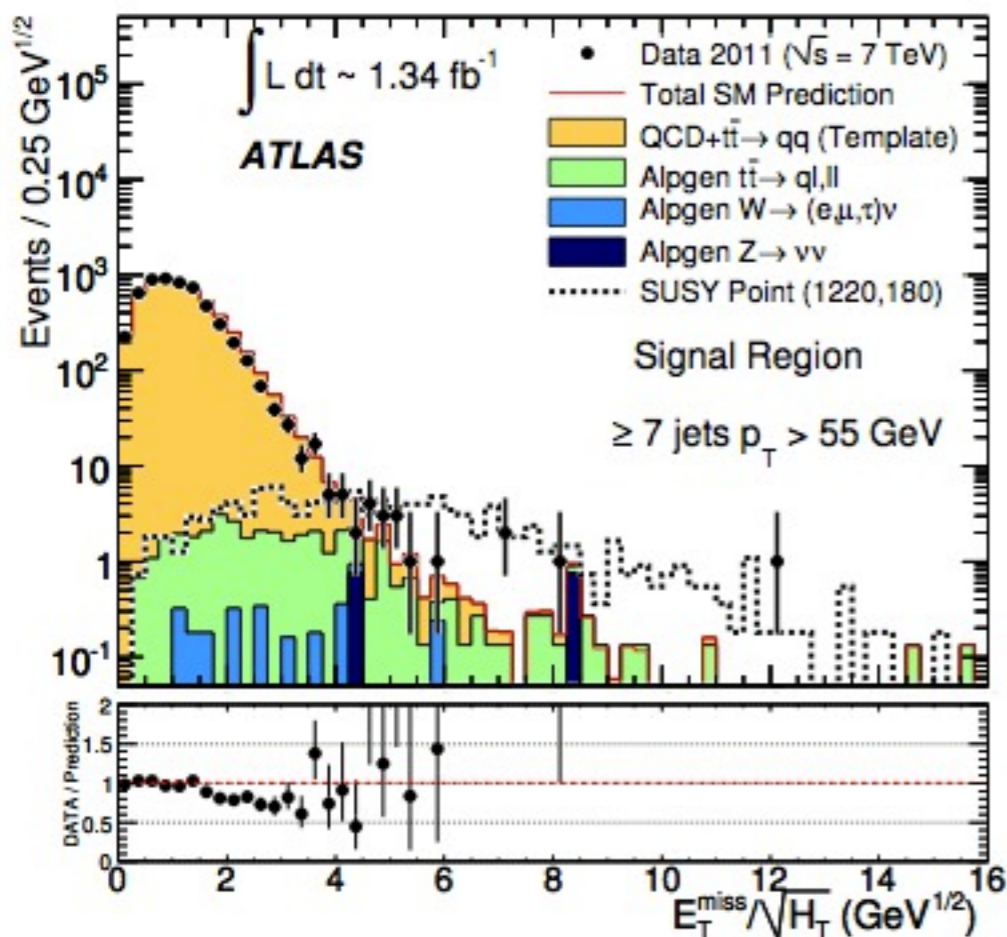
*might be competitive for signals with low but nonzero MET*

Signal region	7j55	8j55	6j80	7j80
Jet $p_T$	$> 55 \text{ GeV}$		$> 80 \text{ GeV}$	
Jet $ \eta $	$< 2.8$			
$\Delta R_{jj}$	$> 0.6$ for any pair of jets			
Number of jets	$\geq 7$	$\geq 8$	$\geq 6$	$\geq 7$
$E_T^{\text{miss}} / \sqrt{H_T}$	$> 3.5 \text{ GeV}^{1/2}$			



# MANY-JETS+MET

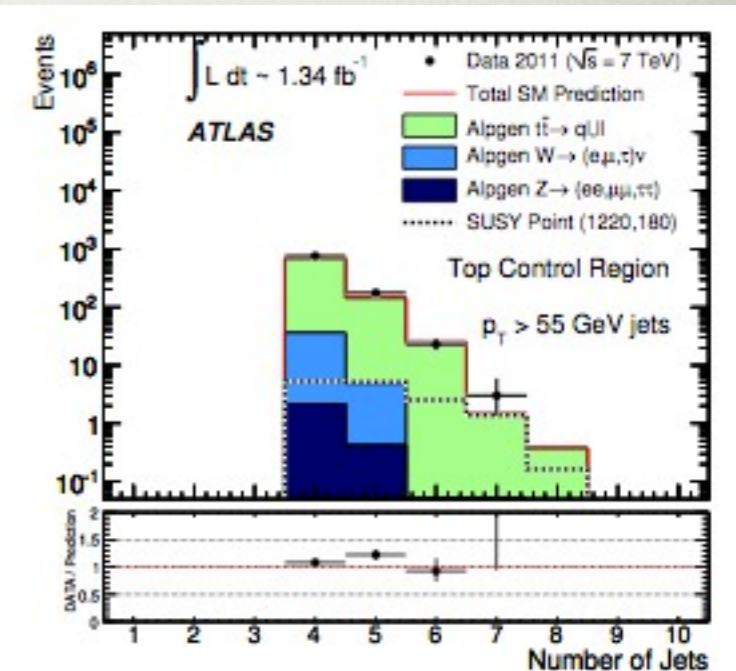
## — CONTROL REGIONS —



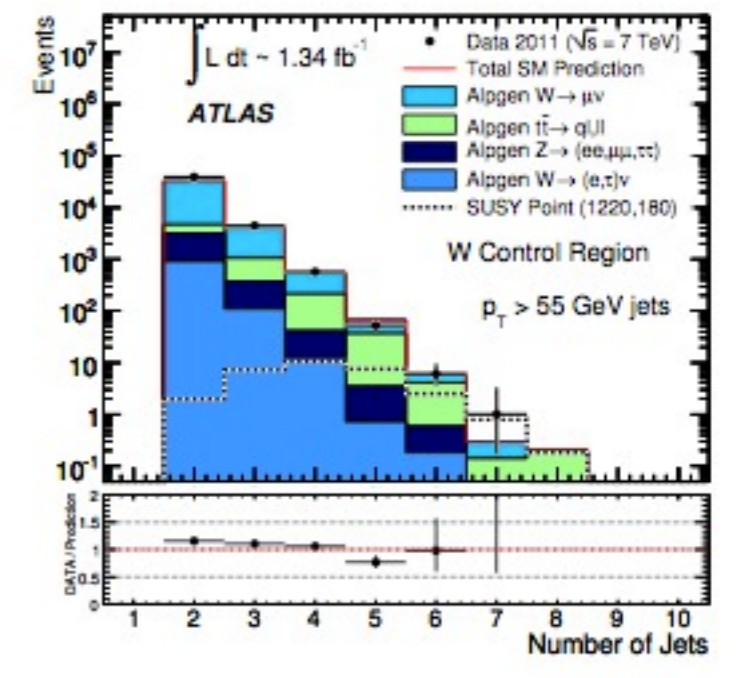
Include regions of interest  
 ( $20 < m_T / \text{GeV} < 100$ ),  
 but need to look at  $S_T$   
 distribution after  
 high  $N_{\text{jets}}$  cut to  
 derive constraints

Have right  
 distributions been  
 looked at?

Signal region	7j55	8j55	6j80	7j80
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(a)





# WOULD YOU HAVE NOTICED IT ALREADY?

---

- High  $S_T$ , high  $N_{\text{jet}}$  searches (black holes)
  - No: background too big
- $\geq 6$ -8 jets + MET SUSY searches
- trilepton searches (low MET cuts)
  - Model-dependent (just like relative strength of different SUSY searches)
- Control regions for SUSY / Exotica searches
  - No obvious constraints: signals are  $\geq$  two cuts removed from public plots
  - Examples welcome!



# SCORECARD FOR W+MANY-JET + HIGH $S_T$

---

1. Motivations & reach in exotic SUSY SM
  - More generally, what kinds of signals would show up in this signature?
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# CALIBRATION/DISCOVERY POTENTIAL

---

Is there hope for reliably calculating or measuring the background from  $tt+n$  jets?

measurements and theory are both less advanced than for  $W/Z+n$  jets

But meets base requirements for data-driven method:

lepton+4,5-jet data is already top-dominated  
(but caution: different PDFs)

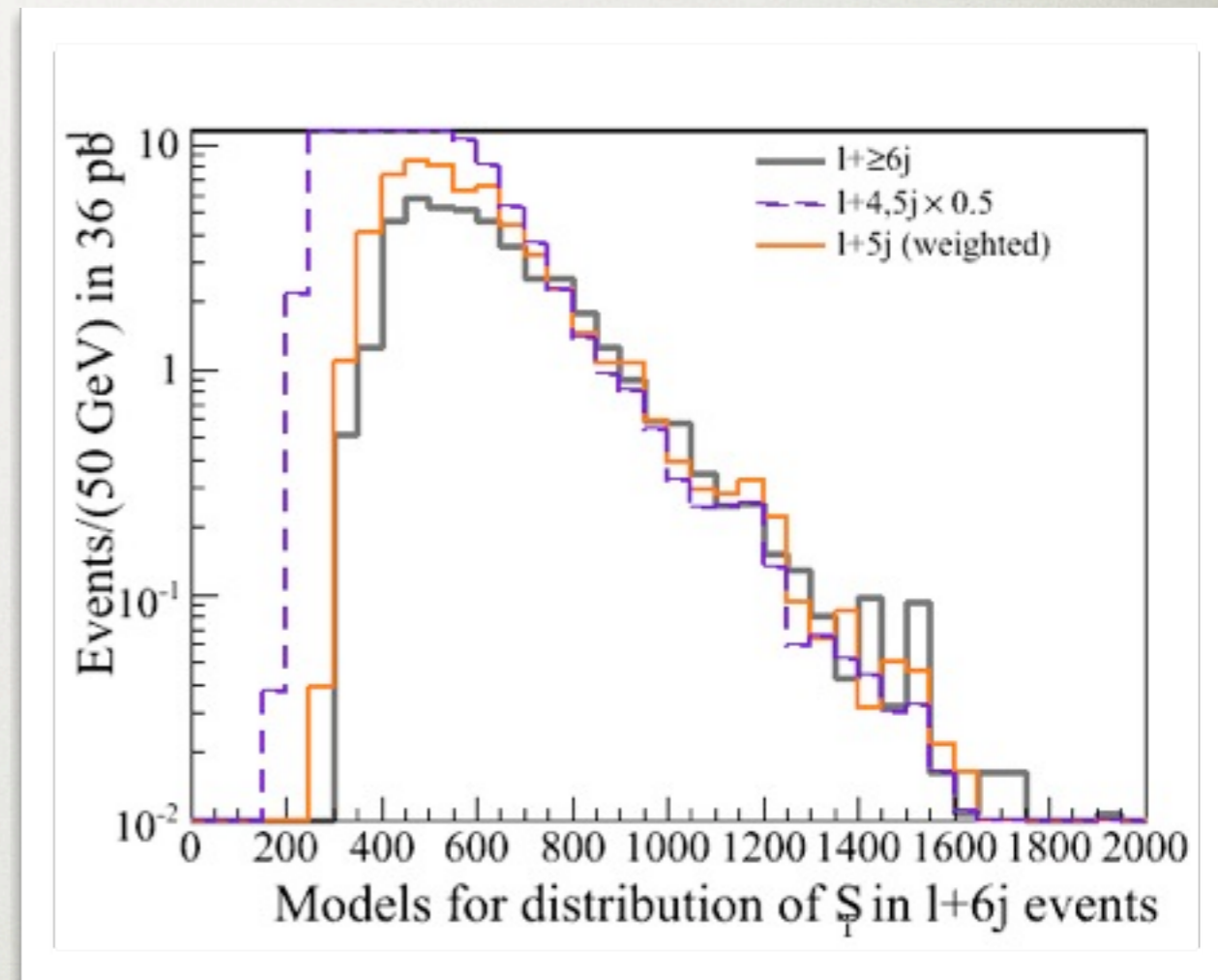
Does a data-driven method work?



# CALIBRATION/DISCOVERY POTENTIAL

$S_T$  distribution in  $1+ \geq 6j$  events,  
(weighted down)  $4+5j$  events

similar approach used in  
ATLAS  $\geq 6-8j + \text{MET}$  searches





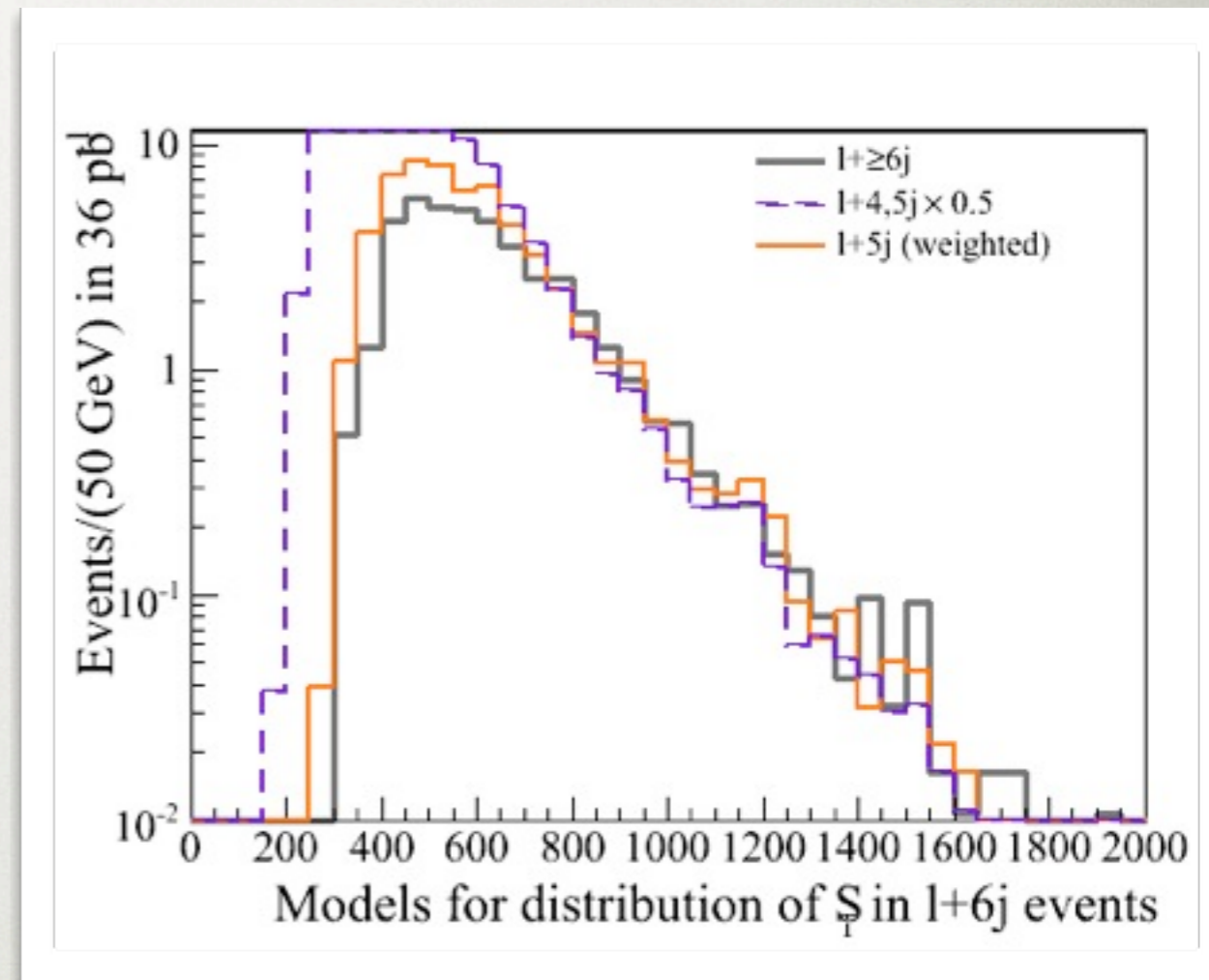
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Tail is ok, but  $S_T$  threshold is  
*too correlated with no. of jets*

More phase space at low  $S_T$   
for 4 jets than for 6 jets!





# CALIBRATION/DISCOVERY POTENTIAL

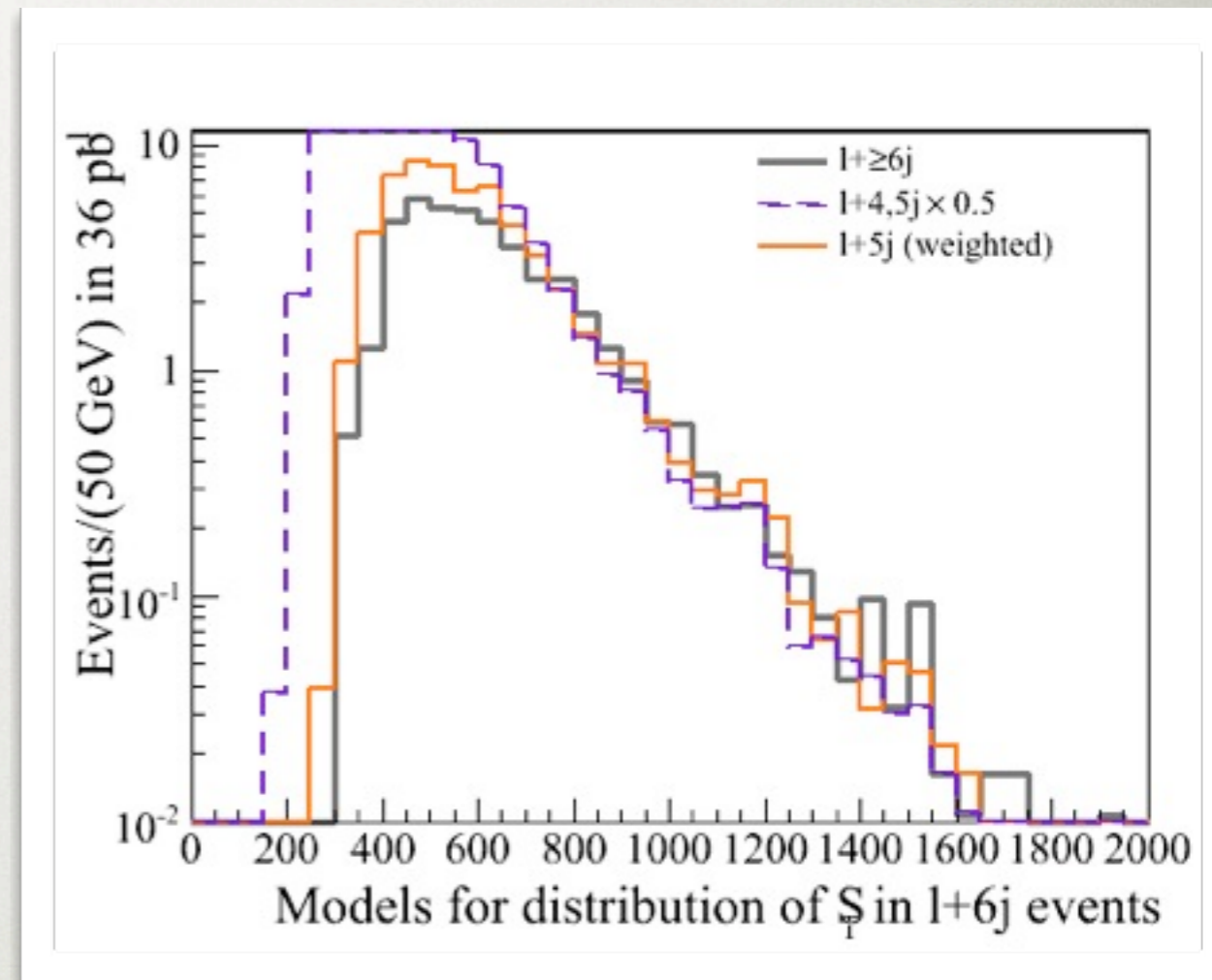
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Tail is ok, but  $S_T$  threshold is  
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More phase space at low  $S_T$   
for 4 jets than for 6 jets!

Simple event-by-event weighting of lower  $n$ -jet events: imagine  
“splitting” any jet in  $5j$  event in two jets of energy  $E \cdot z$  and  $E(1-z)$   
– weight each event by the fraction of  $z$ 's such that  $E \cdot z > 30$  GeV  
and  $E(1-z) > 30$  GeV.

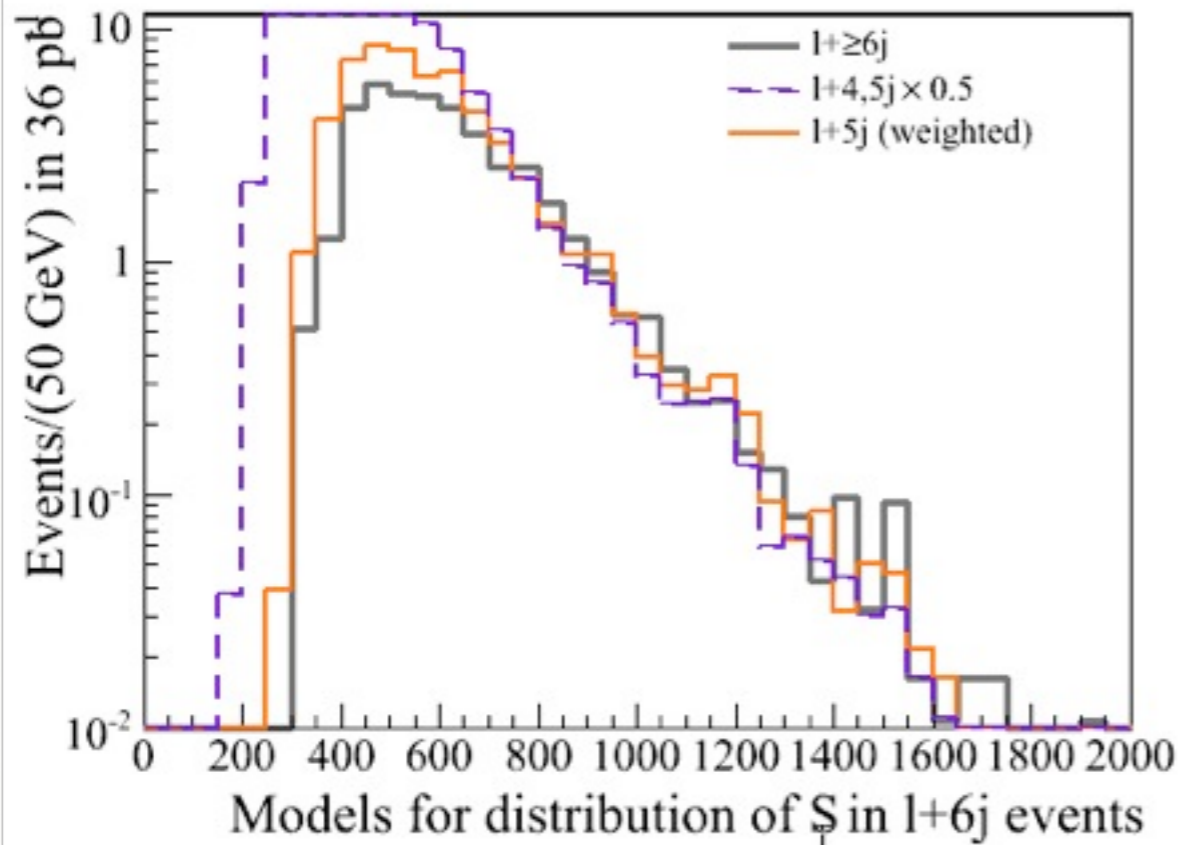




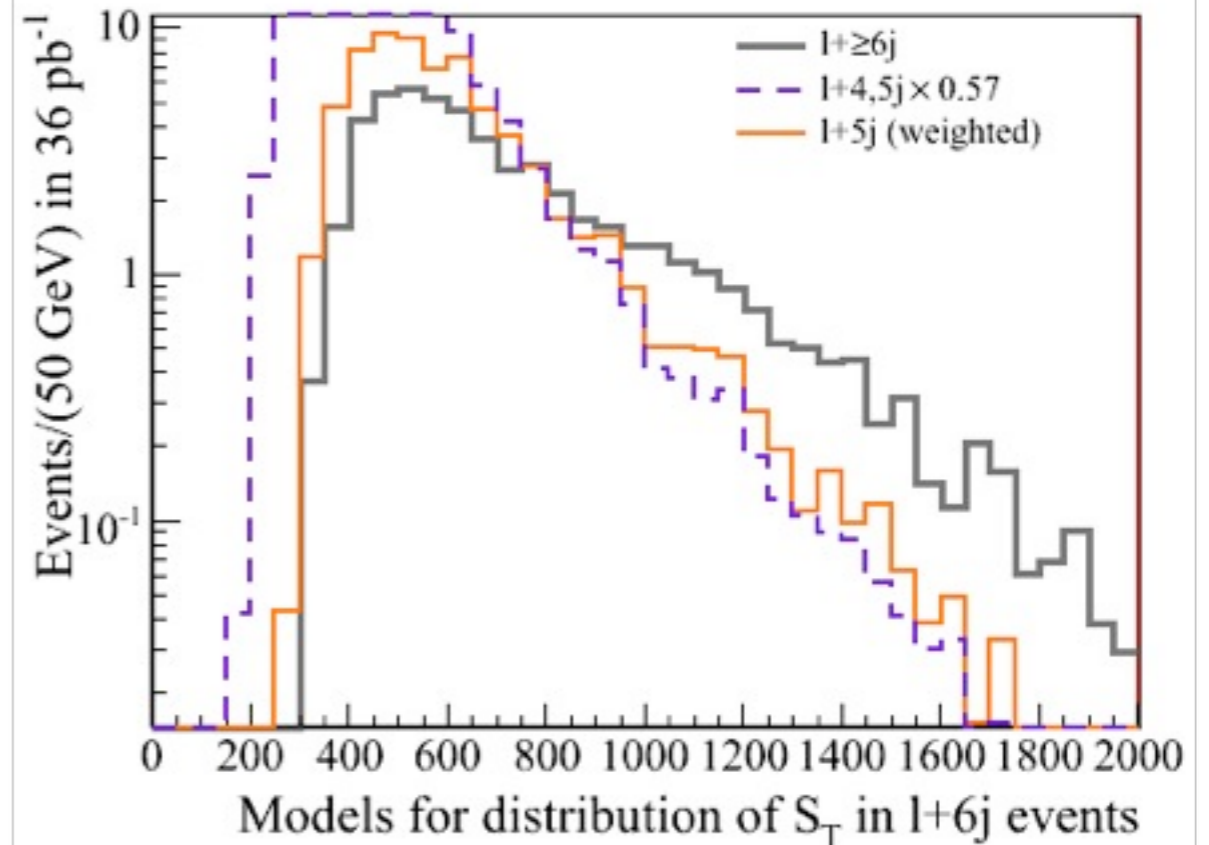
# CALIBRATION/DISCOVERY POTENTIAL

$S_T$  distribution in  $1+ \geq 6j$  events,  
(weighted down)  $4+5j$  events  
splitting-weighted  $5j$  events

background-only



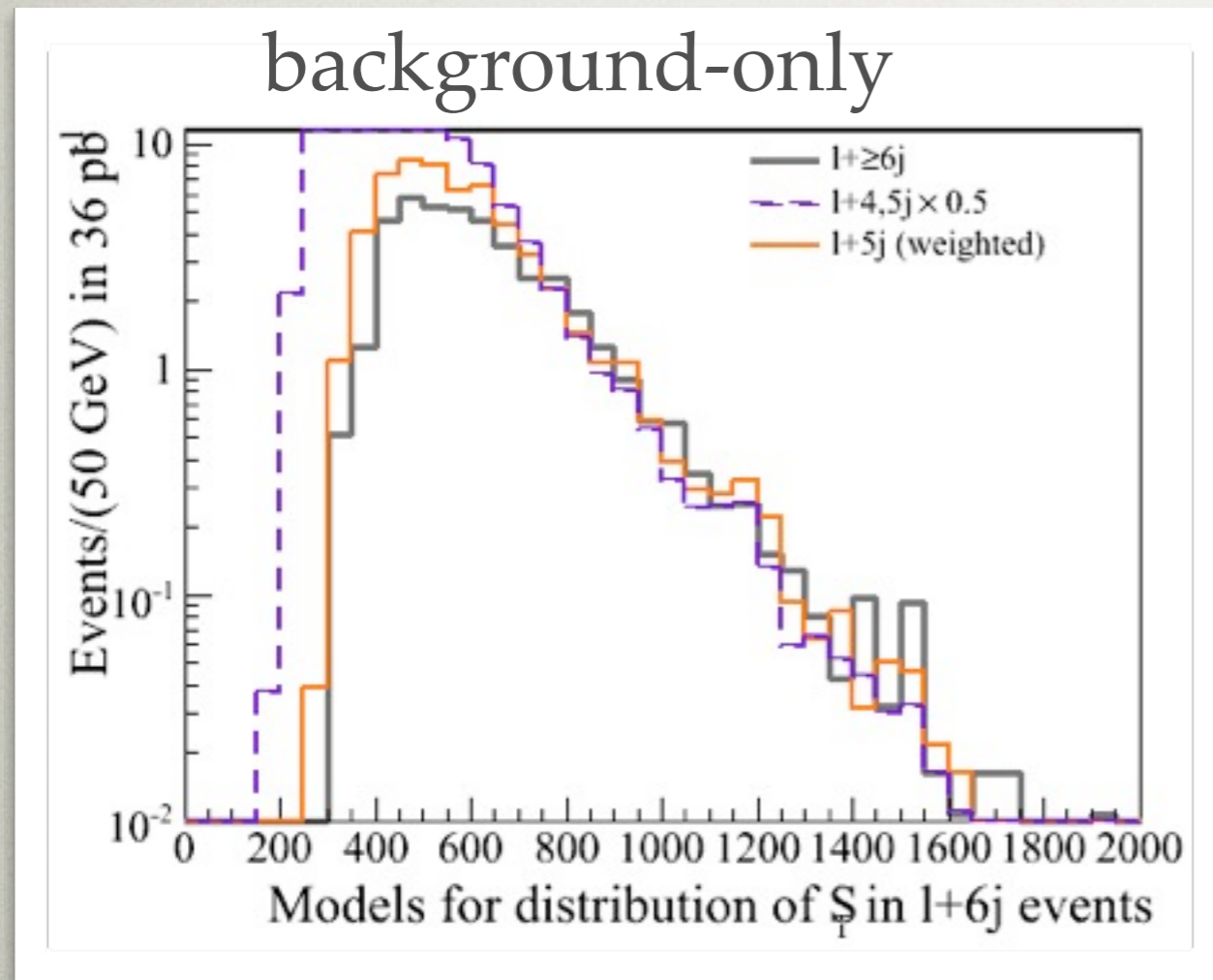
...with SUSY signal





# CALIBRATION/DISCOVERY POTENTIAL

$S_T$  distribution in  $1+ \geq 6j$  events,  
(weighted down)  $4+5j$  events  
splitting-weighted  $5j$  events



## Caveats:

works pretty well for  $=6j$ ets, but  
must extend for  $>6j$ ets

improvable by accounting for  
 $z$ -dependence of splitting fns?

“splitting” picture isn’t physical  
for many events (6th jet is ISR)  
 $\Rightarrow$  just a device for capturing  
phase-space

different PDFs? (at LO with  
 $S_T > \text{TeV}$ , not by much...)



# CALIBRATION/DISCOVERY POTENTIAL

---

Other cross-checks and handles:

- Signal falls slower than bkg at high  $N_{\text{jet}}$
- jet  $\eta$  distribution: more central for hard NP than for top+jets
- Potential for non-SM-like lepton sign asymmetry, b-tag distributions
- Background is known physics: angular distributions should look “top-like”



# CONCLUSION

---

- Estimated potential for searches in events with one lepton & many jets
- Motivated:
  - SUSY with exotic cascades (R-parity violation, gauge mediation, singlet/singlino, ...) can swallow MET
  - In same net, capture any model with strong production & decay to tops (or many gauge bosons?)
- The search is not redundant – there could be new physics here!
- Data-driven methods & cross-checks exist to help distinguish signal from background



# CONCLUSION

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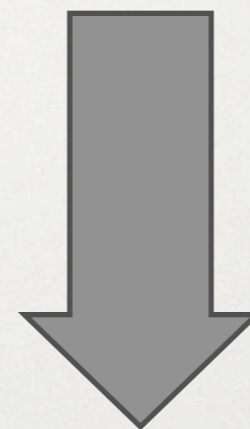
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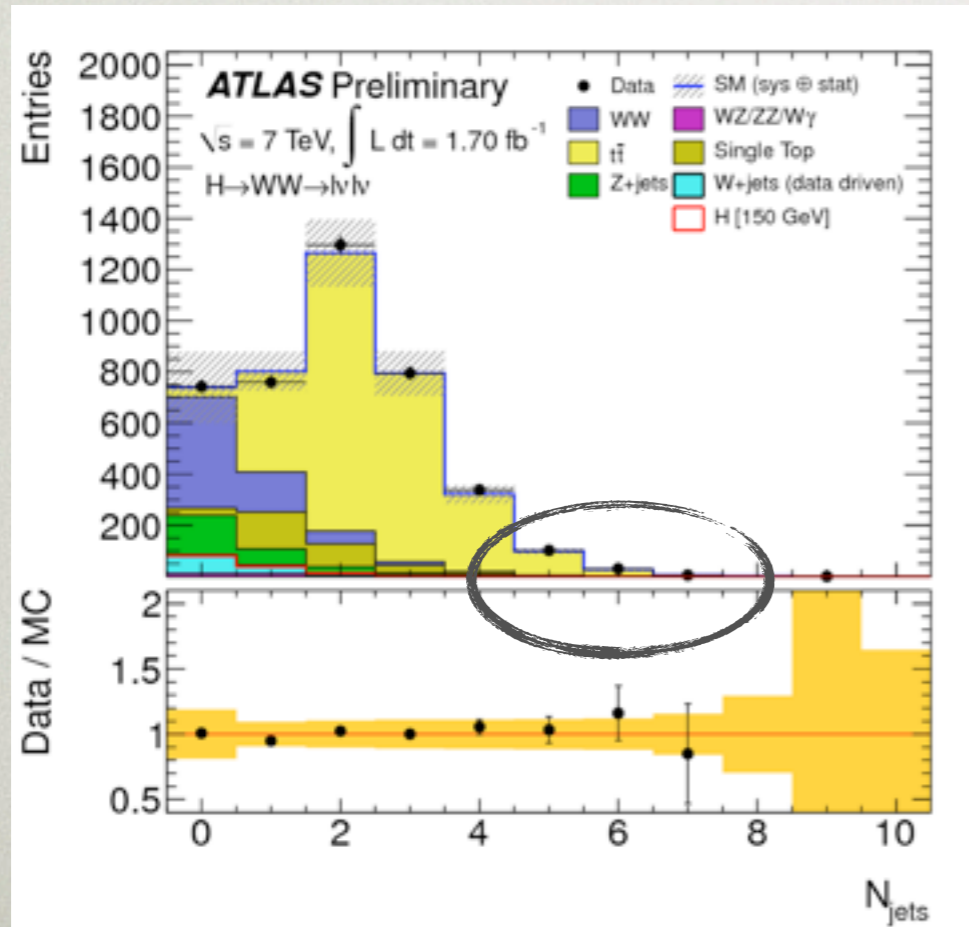
# EPILOGUE

## (OTHER CHANNELS)

- ✓ Inclusive many jets
- ✓ Moderate MET + many jets
- 1 lepton + many jets [this talk]
- dilepton + many jets?



Extending the search program for “busy” new physics



# of 25 GeV jets after metrel cut  
(ATLAS  $h \rightarrow WW$   $1.7 \text{ fb}^{-1}$ )  
Again, seems like fertile ground