# SUSY with Light Stops at 35 $pb^{-1}$ and Beyond

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with

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# Outline

- Orientation
  - Searches and their performance (excellent!) on simplified models
  - Challenges to watch out for in 2011 analyses: squeezed spectra, cascades ⇒ low MET, heavy-flavor
- Implications for SUSY & the EW Hierarchy
  - Quick reminder: radiative stability in supersymmetric standard model
  - Search implications for light-stop scenarios

# The Searches

Many SUSY searches by ATLAS and CMS

What kinds of SUSY can they see? What regions might they miss?

- Simplified model limits provide performance snapshot (see examples below and **many** more)
- Also kinematic distributions: essential to test any complementary ideas
- Thanks! We'll try to make useful suggestions based on all this information

ArXiV:1103.4344,

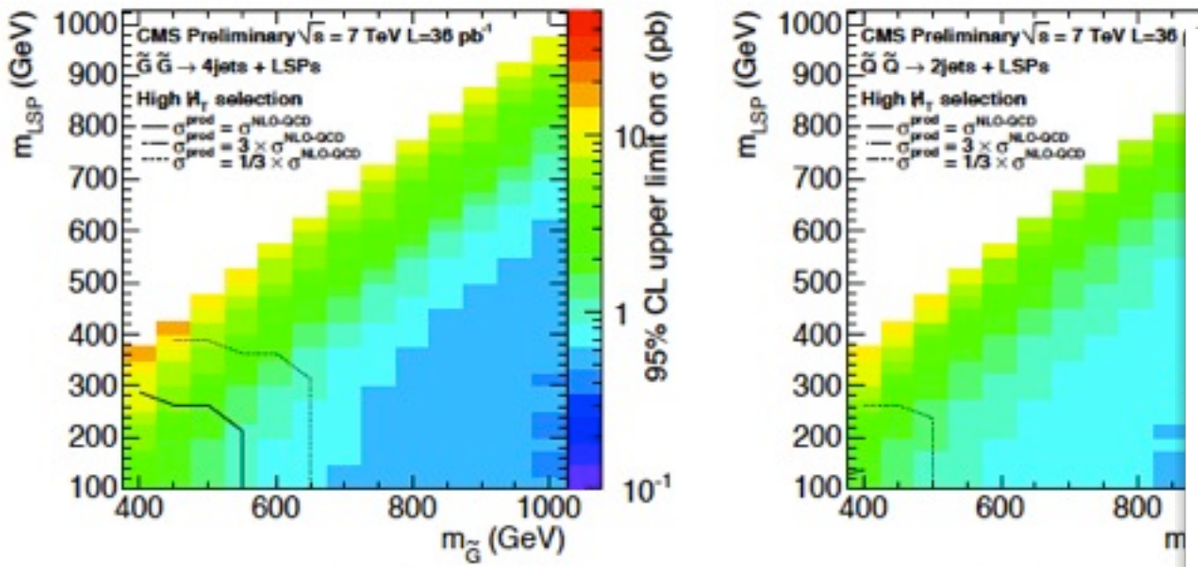
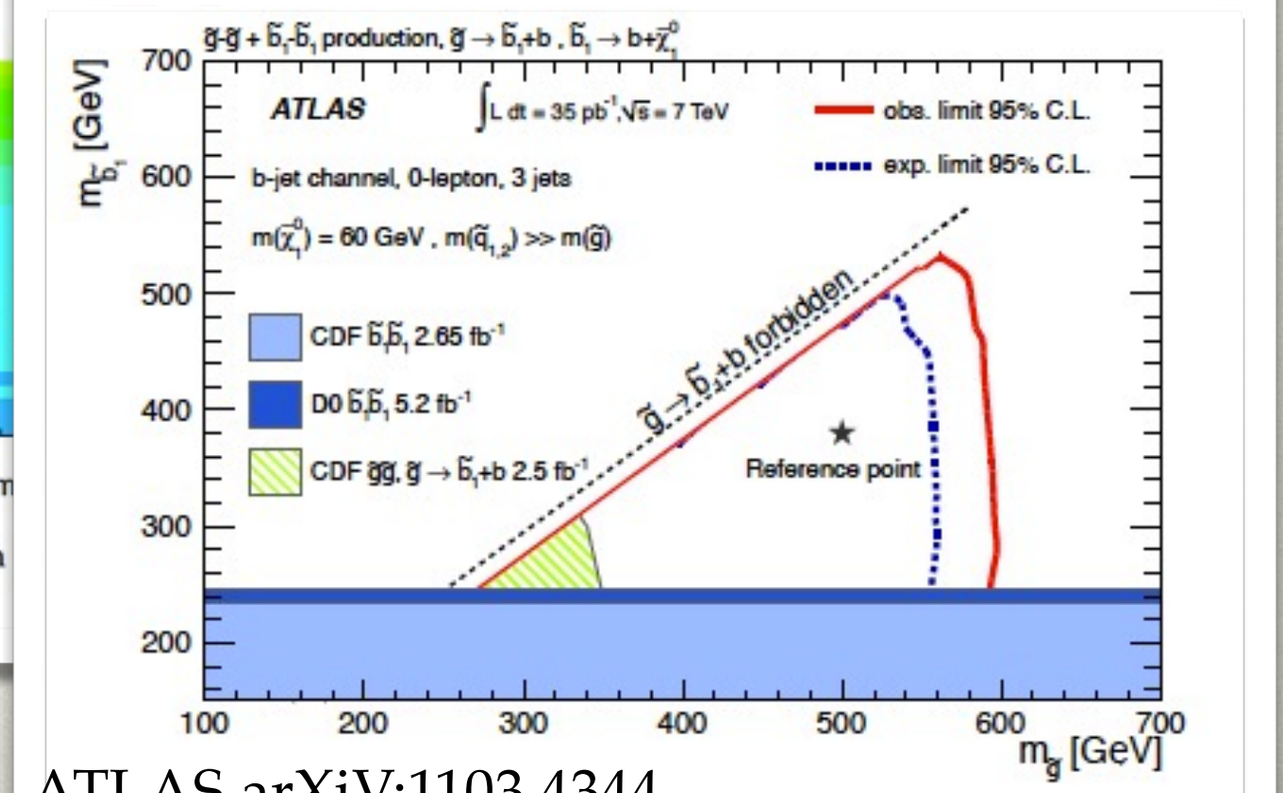



Figure 12: Estimated 95% C.L. exclusion limits for the gluino pair production pair production (right) for the high-$\not{H}_T$ selection.

CMS SUS-10-005 PAS




ATLAS arXiV:1103.4344

# Estimating Coverage

- Searches designed for SUSY with stable LSP or GMSB*
  - main discriminators: HT/$M_{eff}$ and missing $E_T$
  - various lepton multiplicities
  - several focused on top/bottom sector!
- Considering sensitivity of:

| Hadronic | 1-Lepton | ≥ Multi-Lepton |
|---|---|---|
| ArXiV:1102.5290, (ATLAS hadronic, A-D) | ATLAS 1102.2357 (1-lepton) | ATLAS-CONF-2011-039 (multileptons) |
| ArXiV:1103.4344, (ATLAS B-tag, 0 and 1 lepton) | | CMS-SUS-10-007 (opposite-sign leptons) |
| CMS-SUS-10-003 (alphaT) | (many other searches we just haven't looked at yet! Especially leptonic, $\gamma$, and R/$M_R$) | |
| CMS-SUS-10-005 (HT and MHT regions) | | |

(*) I (mostly) won't discuss GMSB; see Josh Ruderman's talk

# Exploring Search Coverage

To explore a wider range of signals than were explicitly studied in this round of searches, made generator-level mock-ups of analysis cuts. To answer **qualitative** questions, the below is more than sufficient.

**For Signal**

We generate events in Pythia 6, build jets from hadron-level MC truth in fastJet (anti-$k_T$, $\Delta R$=0.5), match leptons and b-tags to parton-level truth then apply parametrized ID/reconstruction efficiency + naive isolation for leptons, and build MET using several methods

A second analysis is done using PGS (cone jets)

We compare to published distributions (Std. Model and signal MC) as sanity check – should not trust beyond ±50% (*where we've checked* agreement is better, w/in 10-20%)

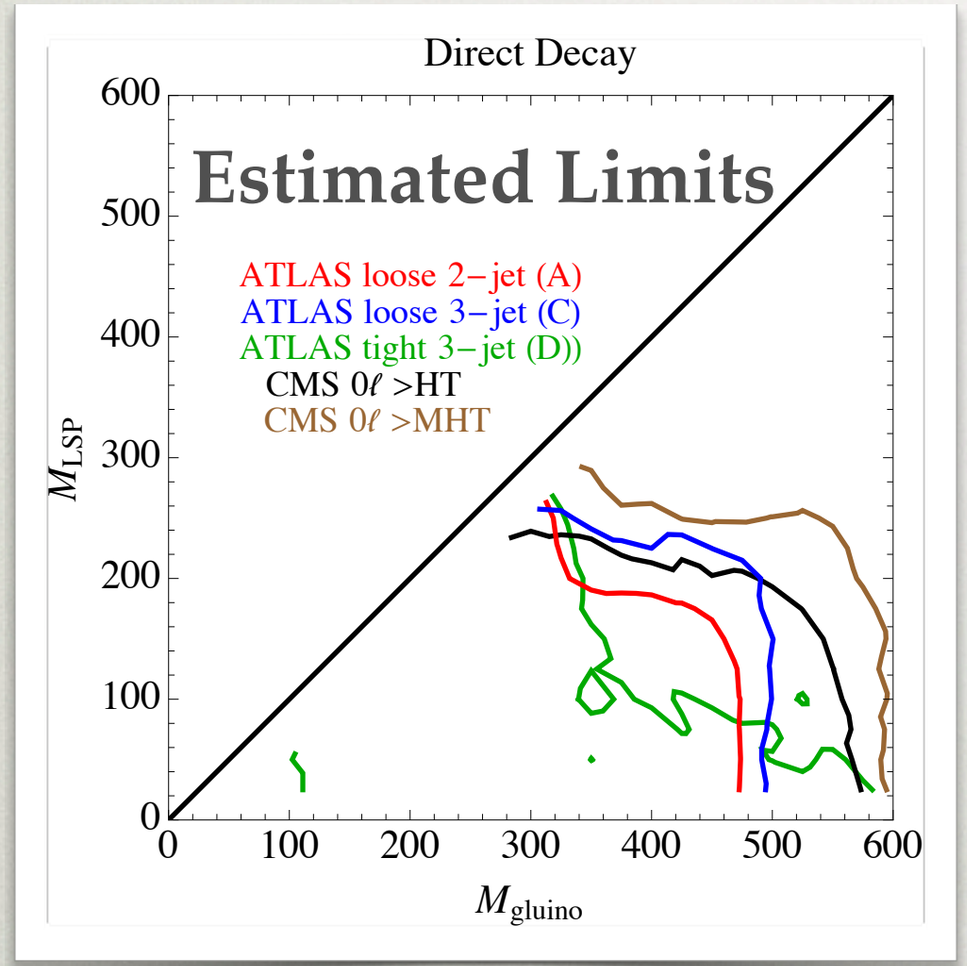
**For Background**

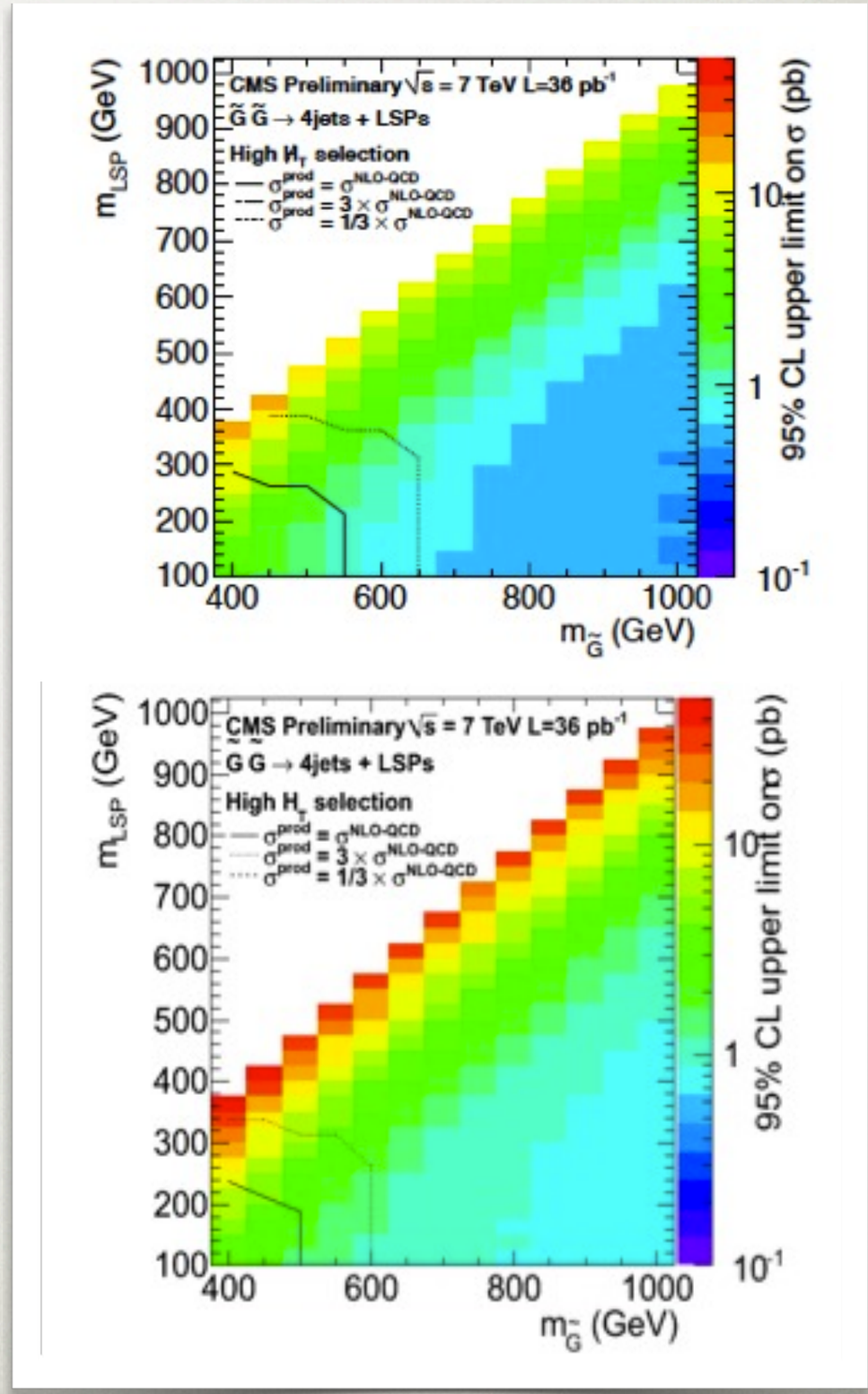
We only use published limits (except distributions on slides 27-30)

Obviously, everything we do is only an estimate!

# Baseline Comparison

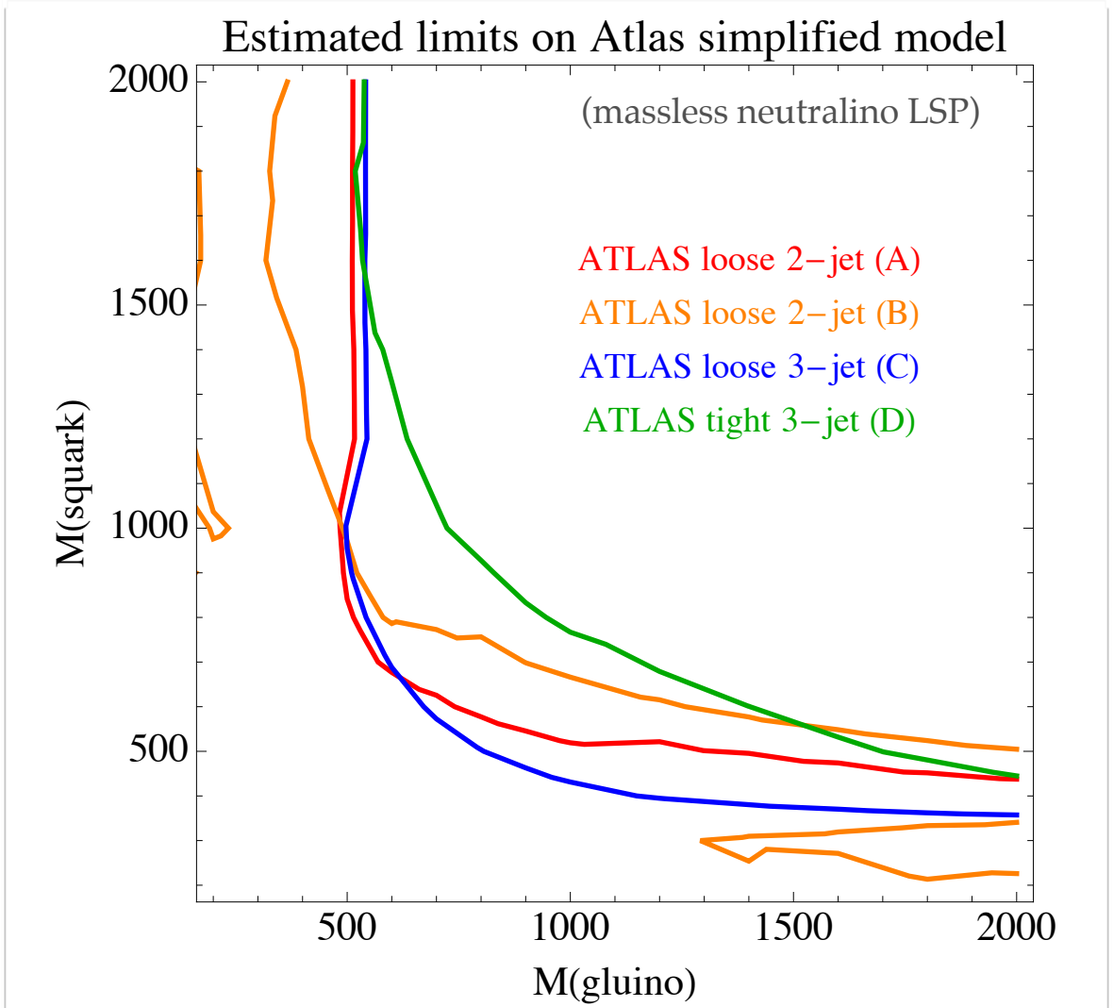
Gluino simplified model: CMS high-HT and high-MHT
(wiggles are MC statistics)

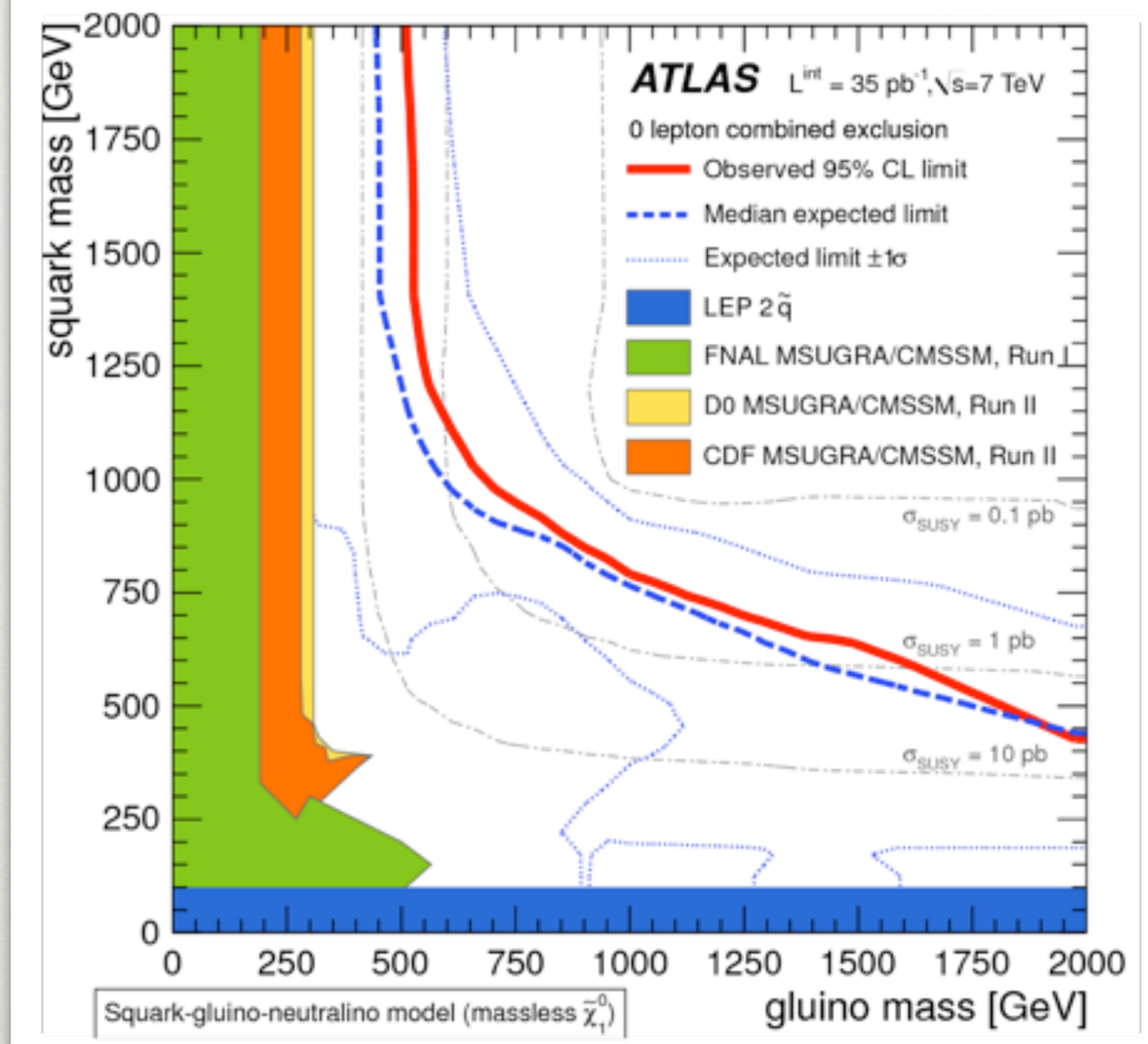



mock-up limit agrees within 50 GeV, efficiencies also appear consistent
CMS has results in same planes for R&$M_R$ analysis and for $\alpha_T$ analysis

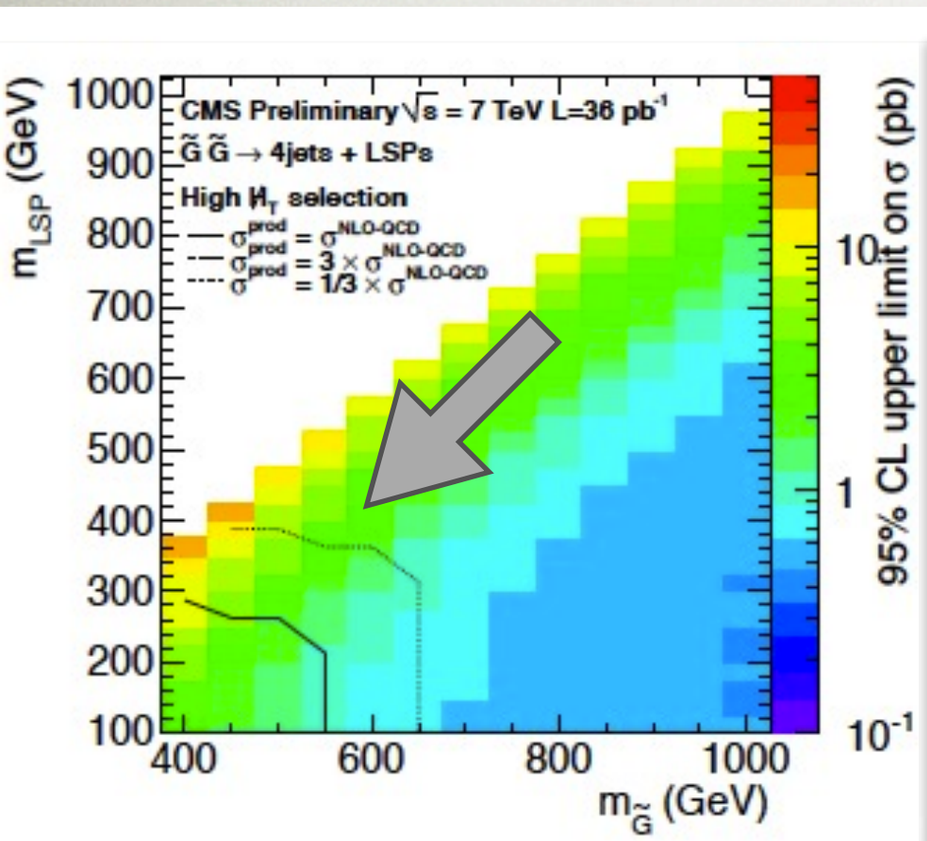
# Another Comparison

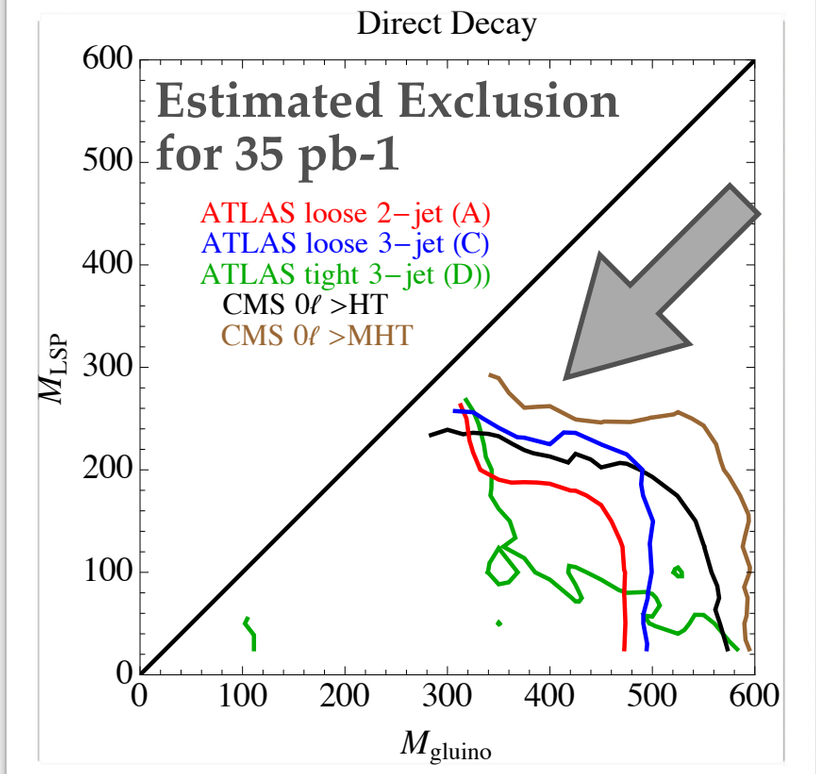



Detailed efficiency plots on search website (**very** much appreciated!)

# Reduced Sensitivity to Squeezed Spectra



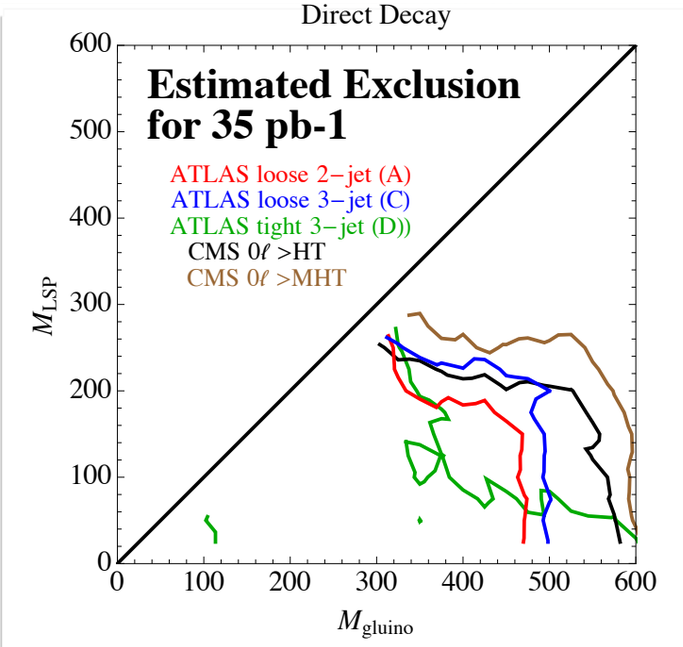

$\sigma \ll \sigma_{top}$ (set by $M_{gluino}$)
$p_T \sim p_{T,top}$ (set by $\delta M$)

Squeezed spectra are more visible at LHC than Tevatron, but still a challenge.

⇒ keep an eye on them when setting cuts in 2011 analyses

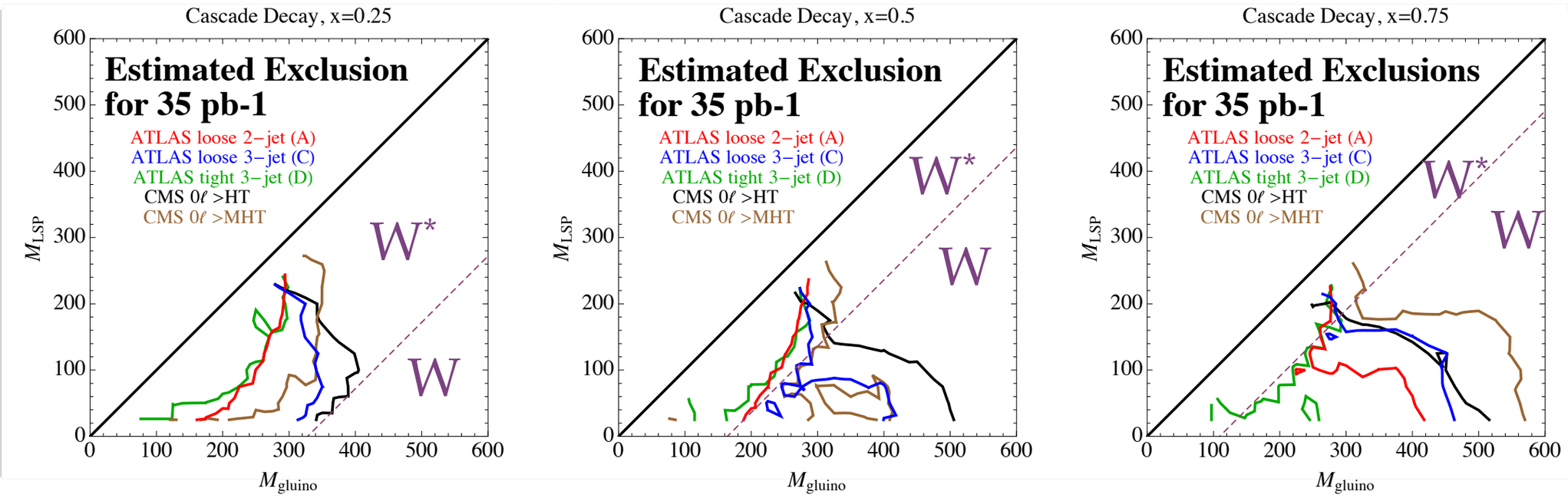
One possibility: hard MET cut, look for ISR events (here recoil set by Mgluino) – see papers by Wacker and collaborators (esp. recent w/ Alvez, Izaguirre)

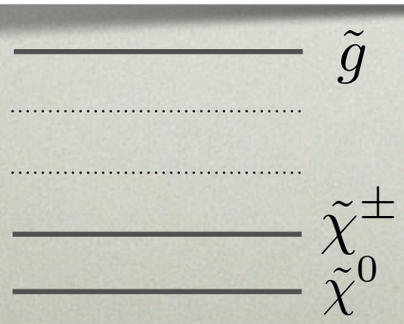
# Reduced Sensitivity to Cascades

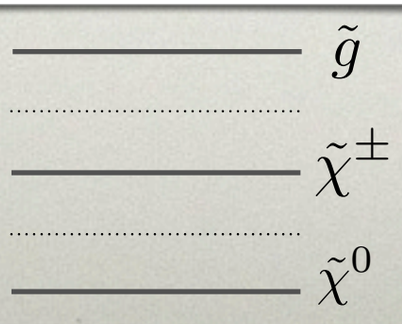


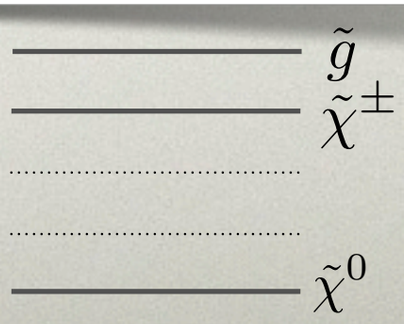

For **robustness against cascades**, HT and MET are complementary; MET/HT can be too harsh

Direct and cascade simplified models are useful for designing cut flows. Impact of W mass is important; useful to disentangle this effect from gluino mass.



# Superpartner Mass Range for radiatively stable hierarchY

$$|\delta m_{H_u}^2| \approx \frac{12 y_t^2}{16\pi^2} \tilde{m}_t^2 \ln\left(\frac{100\ \text{TeV}}{m_{H_u}}\right) \lesssim m_W^2$$

Could be higher/lower...

$$|\delta \tilde{m}_t^2| \approx \frac{8\alpha_3}{3\pi} M_3^2 \qquad |\delta \tilde{m}_t^2| \approx \frac{8\alpha_3}{3\pi} M_3^2 \ln\left(\frac{100\ \text{TeV}}{\tilde{m}_t}\right)$$

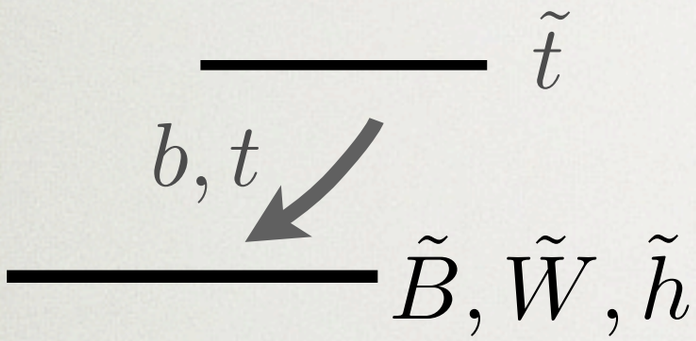
$$|\delta \tilde{m}_t| \lesssim \tilde{m}_t \approx 150\ \text{GeV} \longrightarrow M_3 \lesssim 200 - 500\ \text{GeV}$$

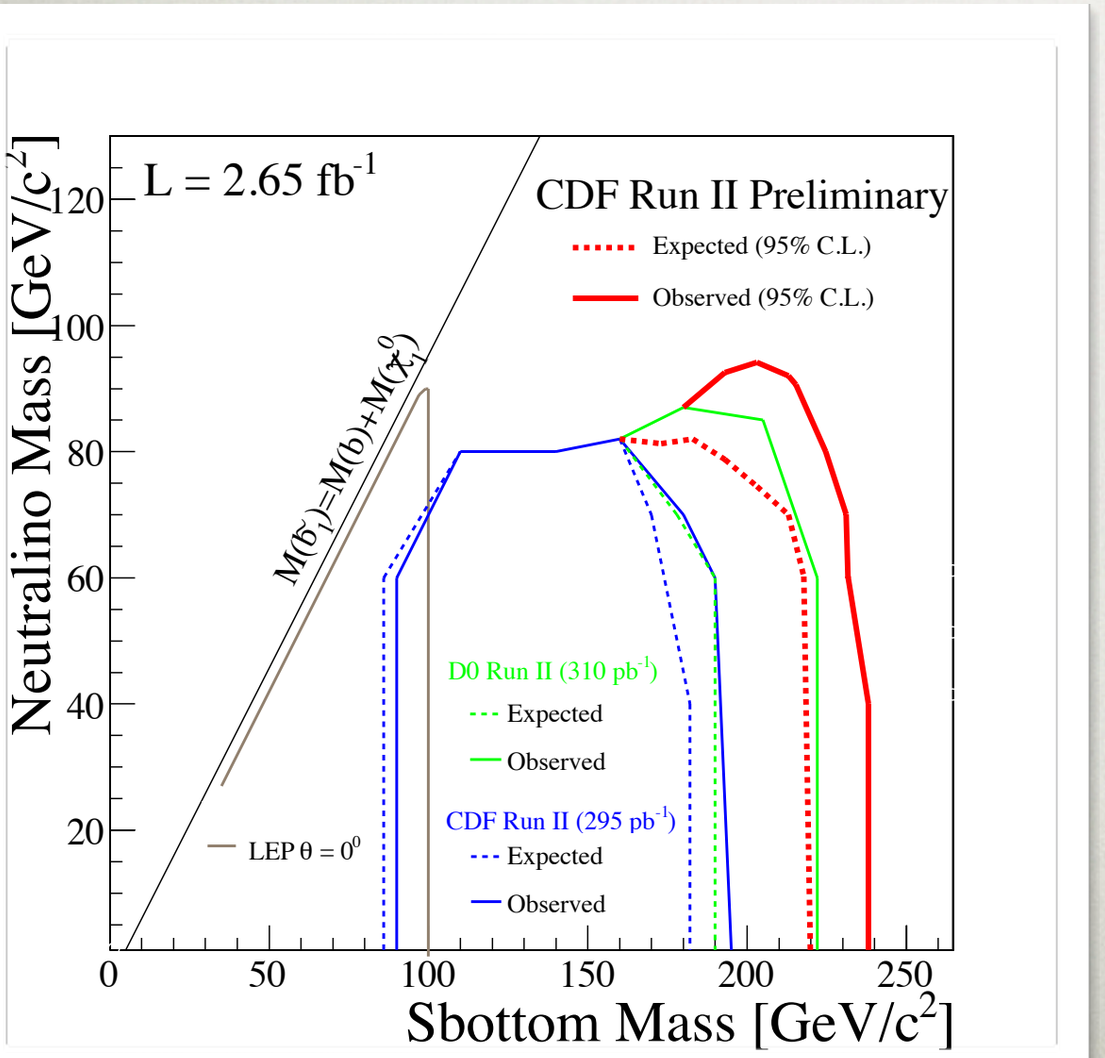
$$|\delta \tilde{m}_t| \lesssim \tilde{m}_t \approx 350\ \text{GeV} \longrightarrow M_3 \lesssim 500 - 1200\ \text{GeV}$$

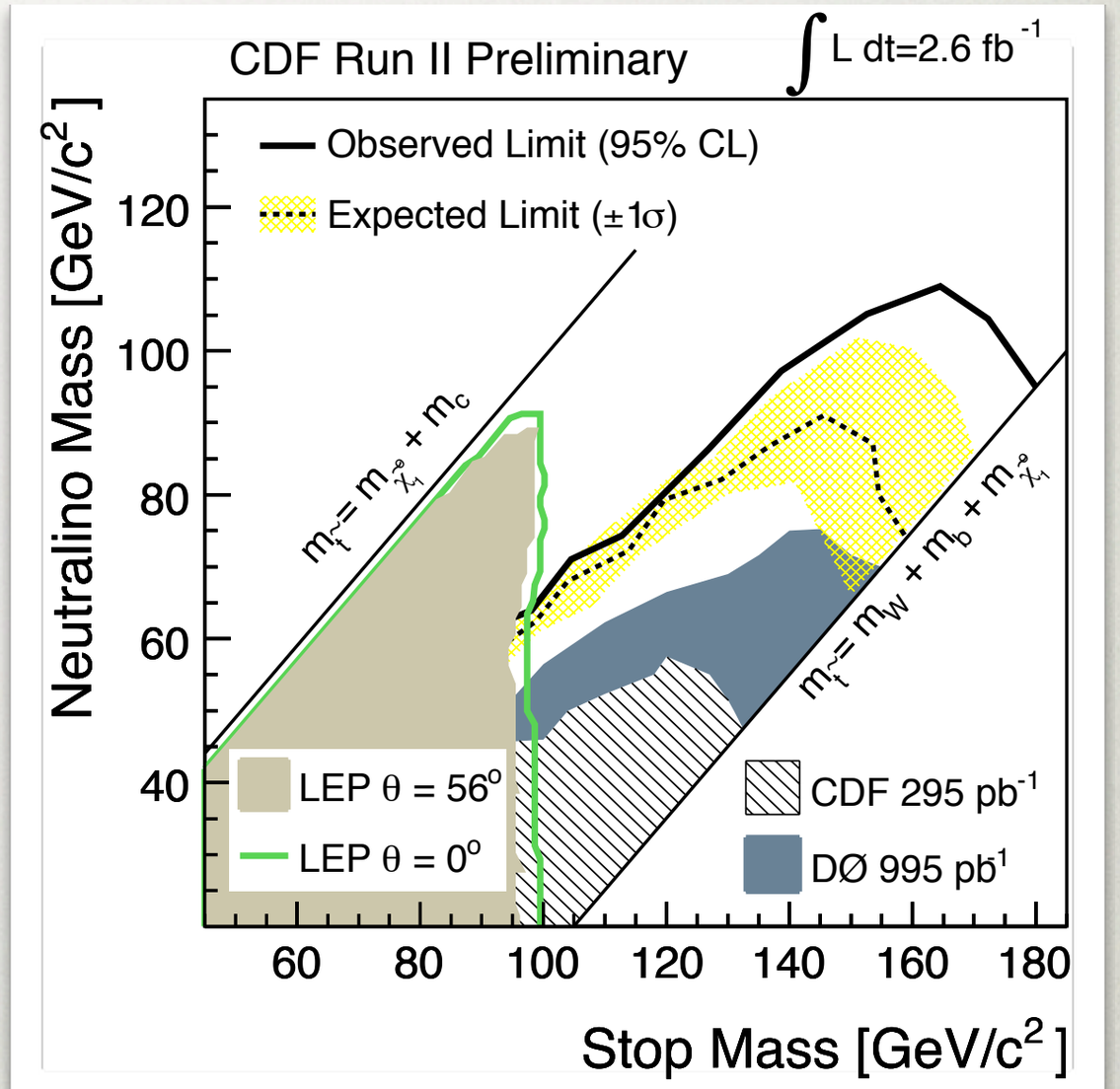
Scenarios with light stops/sbottoms (i.e. relatively natural SUSY) are important to cover thoroughly! Early search results indicate that this is very doable.

*(We presume some physics beyond the MSSM to lift higgs mass above LEP limit)*

# How light can stops be? (Tevatron)

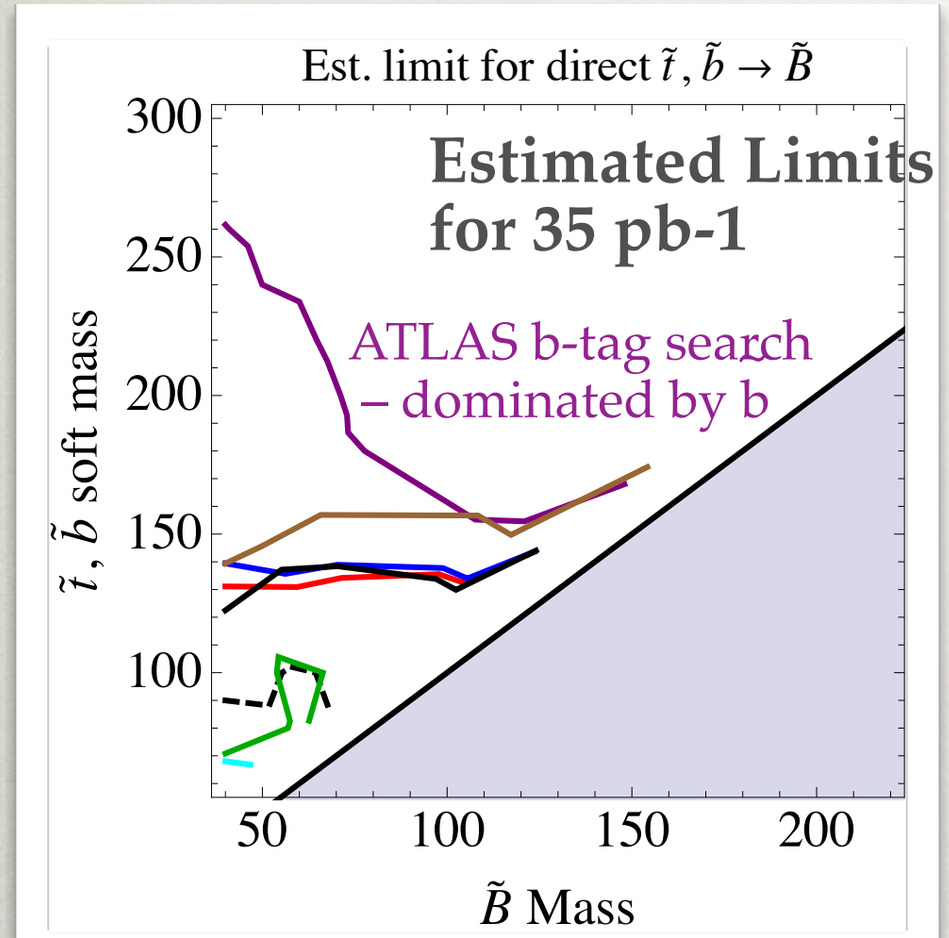


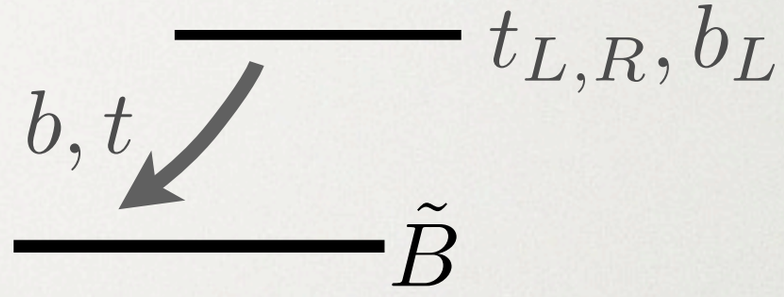




Tevatron limits do not rule out a natural top/bottom partner
... they do constrain this possibility...

# Estimated LHC Sensitivity to light stops

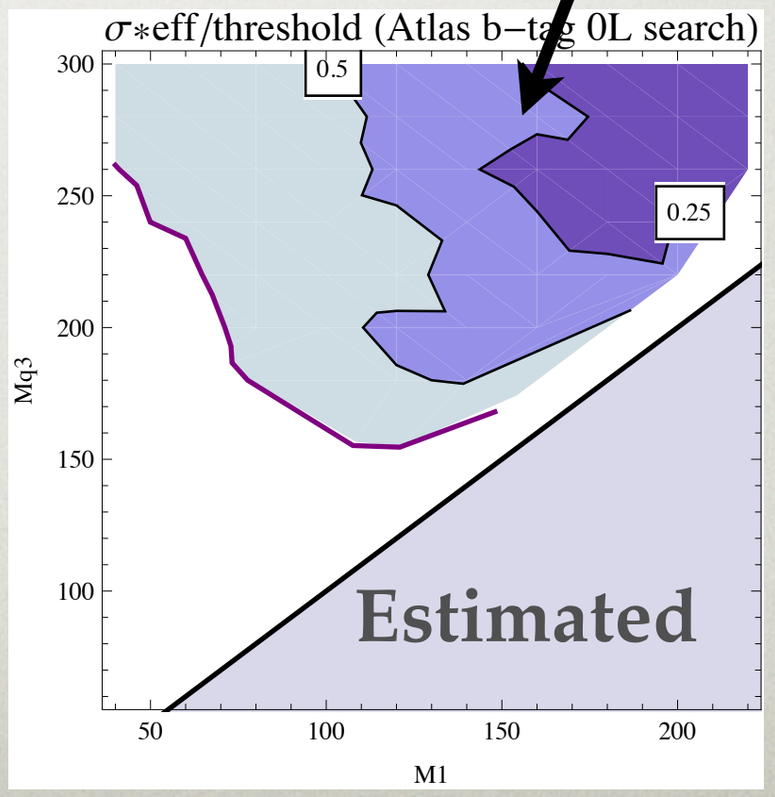



1 fb$^{-1}$ LHC data will likely cover top/bottom partner production beneath ~300 GeV, especially with dedicated search



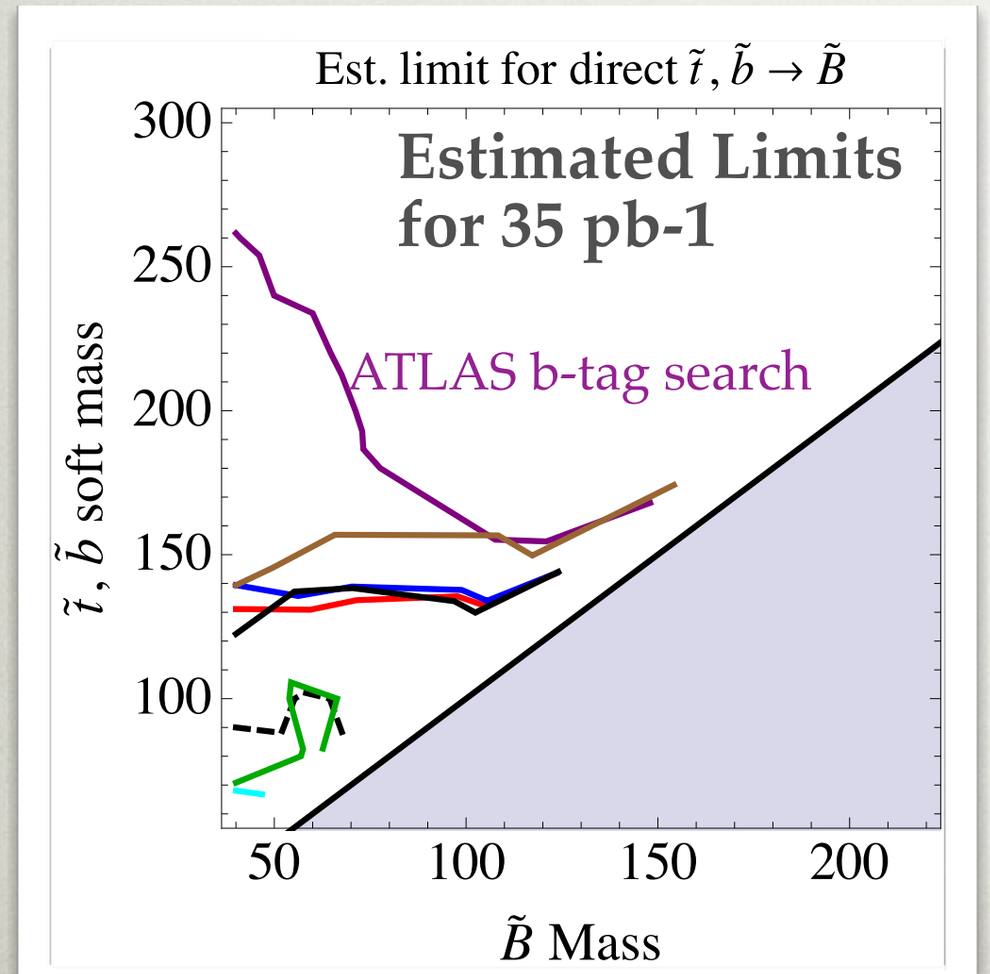

This region only x4 below existing sensitivity!

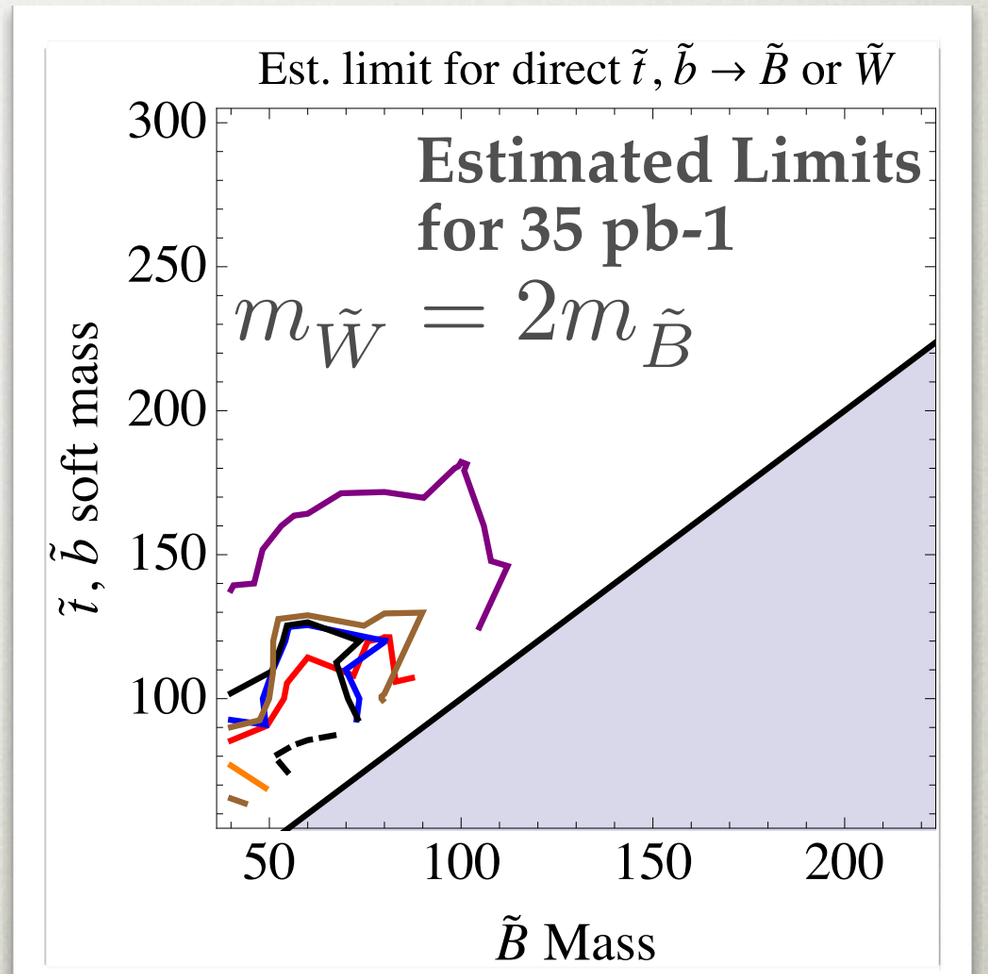
(despite low efficiency of $M_{eff}$ cut)



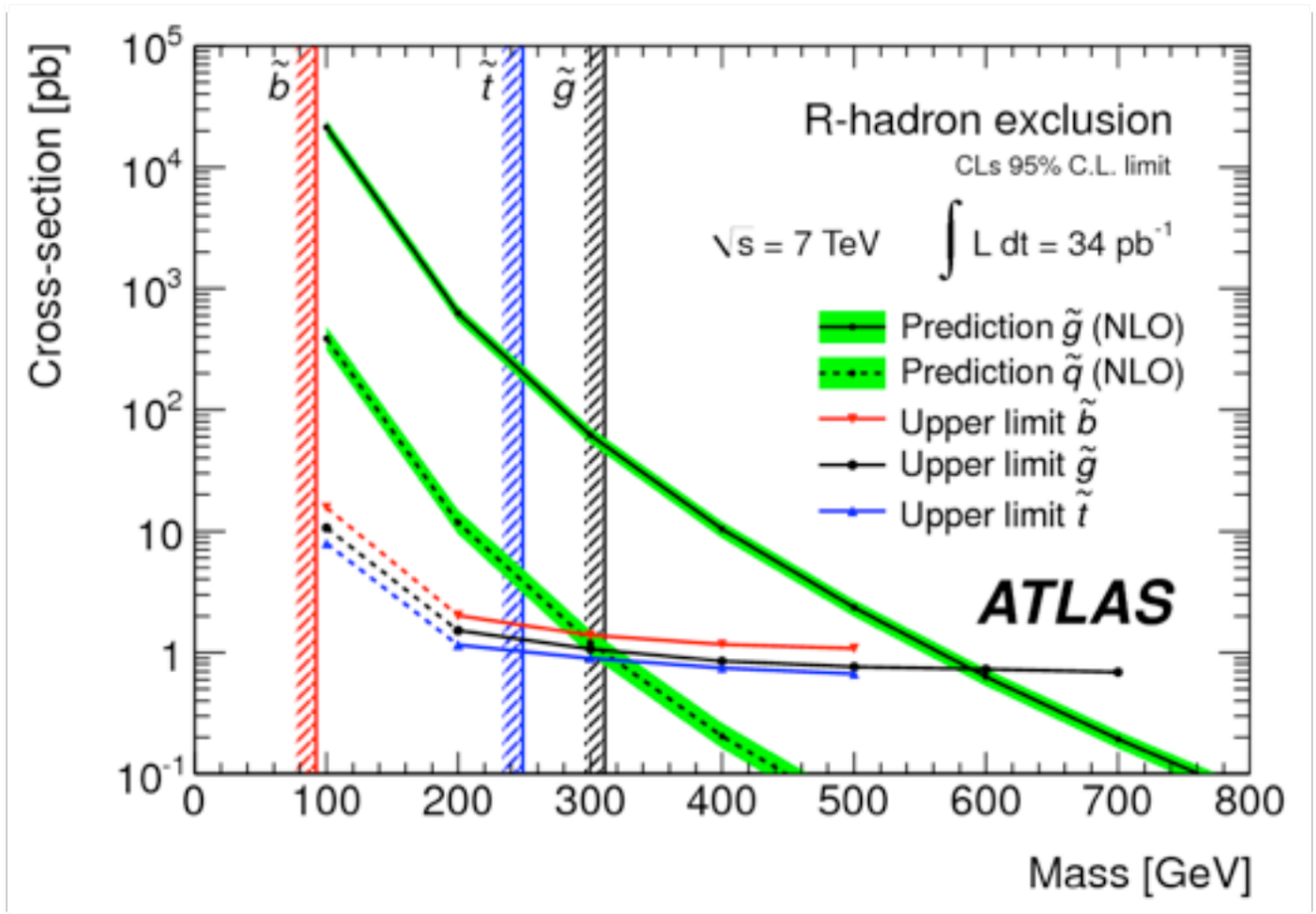
# Estimated LHC Sensitivity to light stops

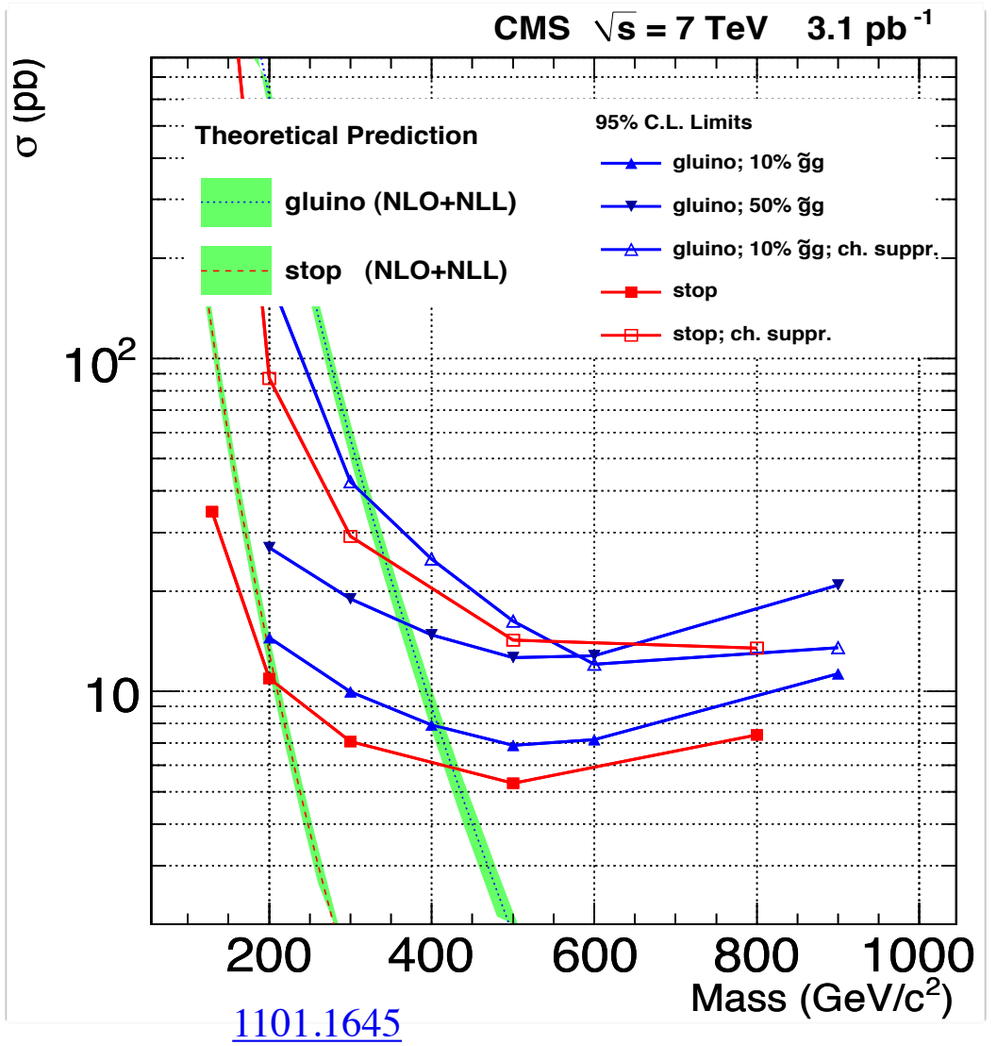
But note that sensitivity is far lower with cascade decays!
→ points to need for dedicated analyses of stop & sbottom production, with and without cascade decay



# Stable Stop



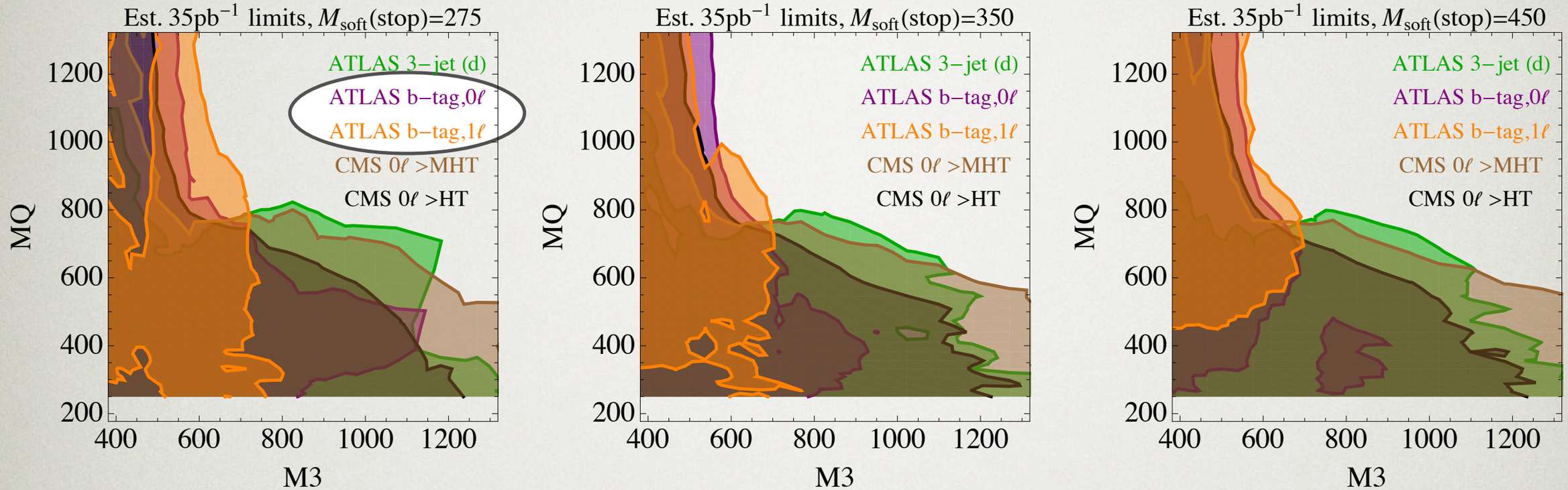

1101.1645

Sensitivity to $\beta\gamma<1.5 \Rightarrow$ Probably significant constraints on

gluino → top + (stable stop)

from same analysis — is such a study something the R-hadron search groups could look into for next round?

# Gluinos, Squarks, and Light Stops

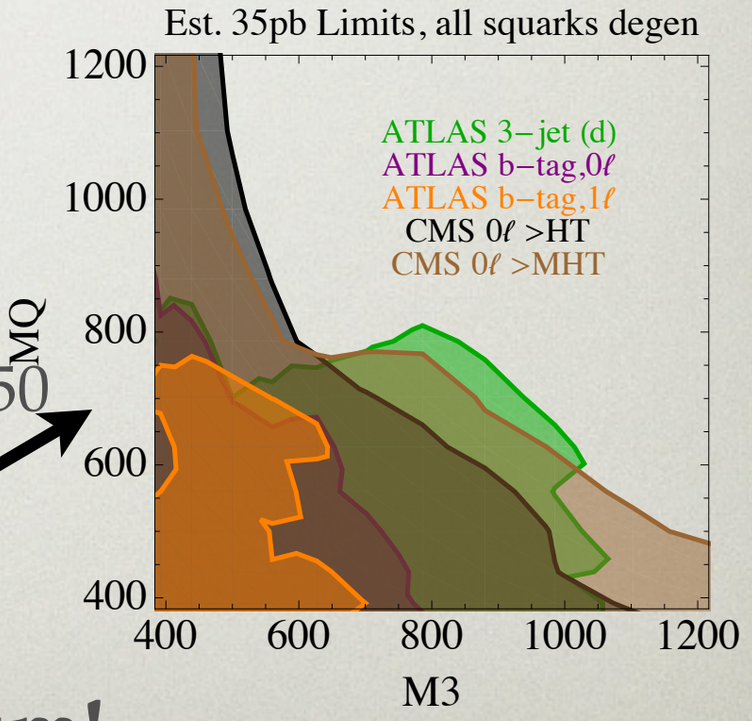



Note b-tag searches with and without leptons

**Top Row:**

–approx. gaugino unification (M3:M2:M1 = 6:2:1)
–all light-flavor squarks degenerate at MQ
– ~tL, ~tR, ~bL soft masses degenerate at 275, 350, 450

**As above, but all squarks (including stop) degenerate.**




**Already some tension with natural spectrum!**
(will be relaxed somewhat for squeezed gaugino spectrum)

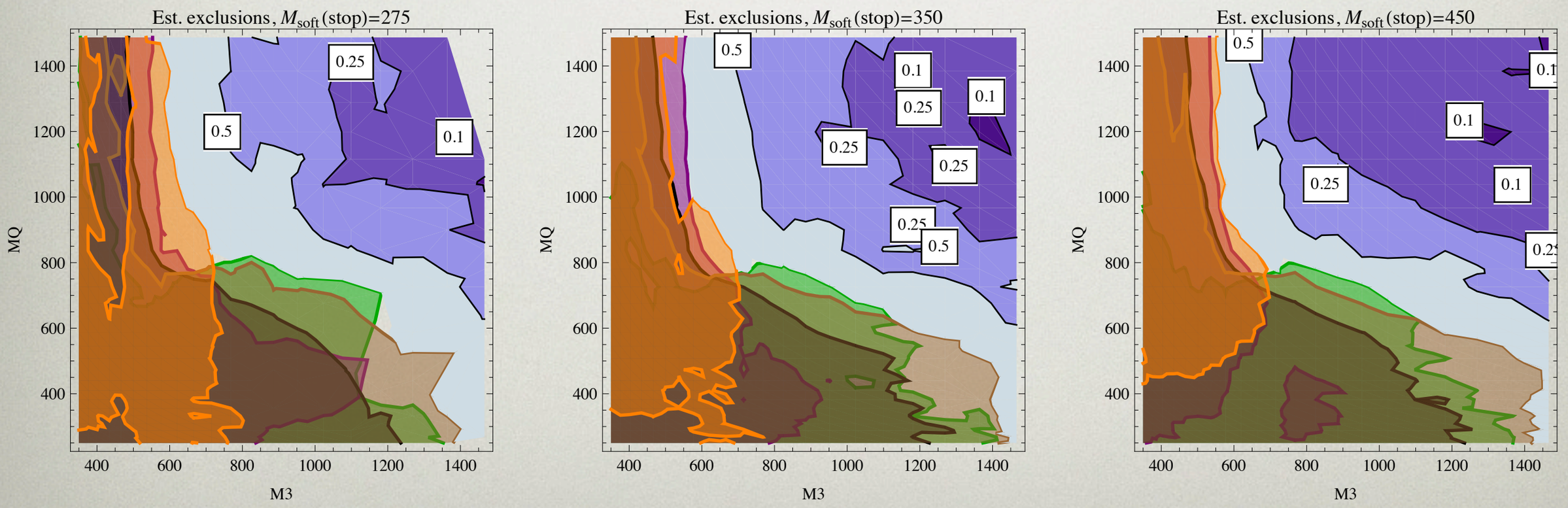
# Gluinos, Squarks, & Light Stops: Good news for 1 fb$^{-1}$

Difficult to extrapolate to higher luminosity…
(more data will improve statistics and systematics, allow tighter cuts)

In this instance, unexplored region is kinematically **more distinct** from Standard Model

Quantify "how far" (but not exactly "how soon") by highest

$(\sigma \times \epsilon)/(\sigma_{\text{search limit}})$ among searches considered (white boxes)




Sub-TeV parameter space should be testable in 2011.

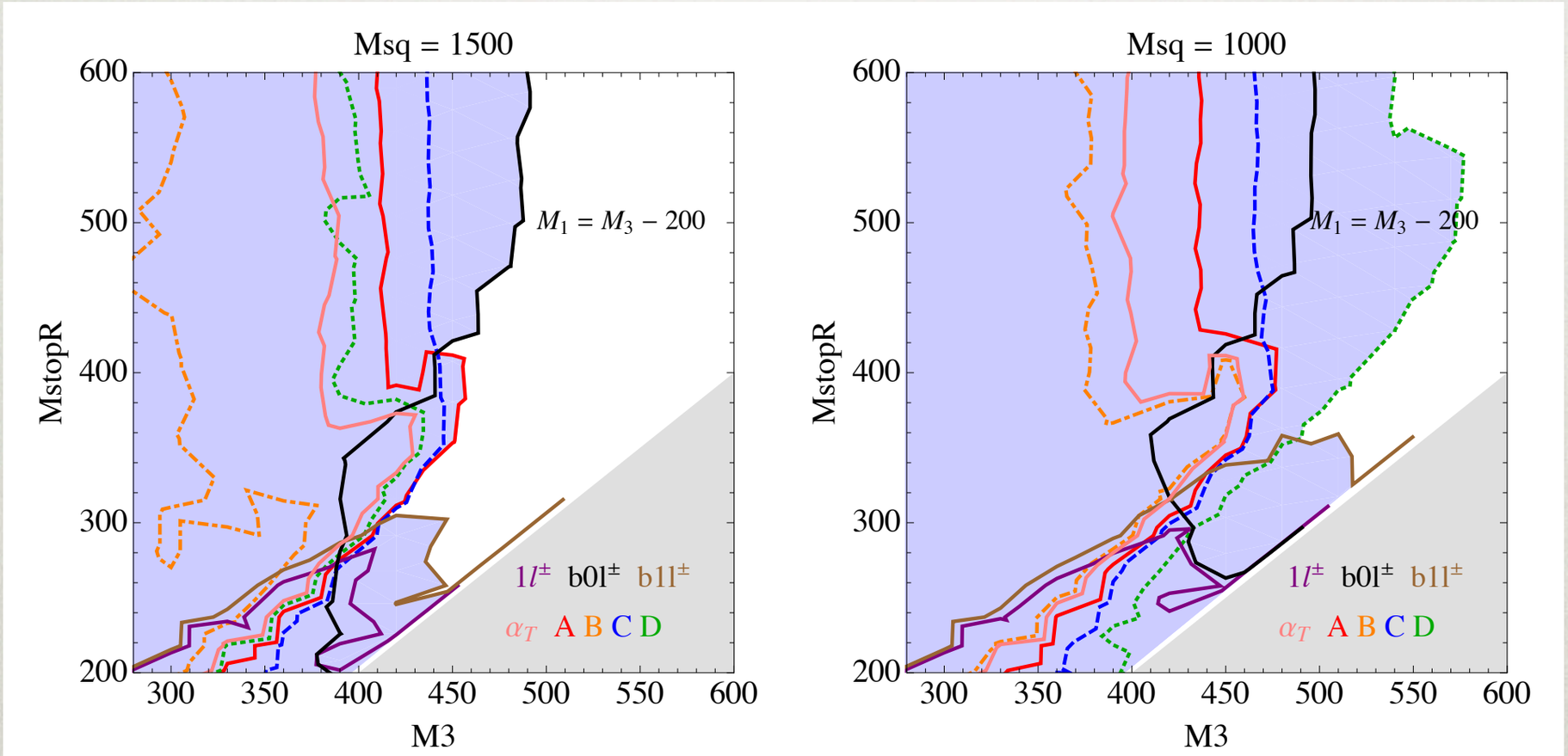
# Looking for allowed corners of low-mass SUSY

$\tilde{g}$ (M3)

$\tilde{t}_R$ (MstopR)

$\tilde{B}$ (M3-200 GeV)

Gluino decay to 1 jet+LSP dominates over 3-body through off-shell squarks




Theoretically interesting region (but same topology as squark pair, probably no need for targeted analysis)

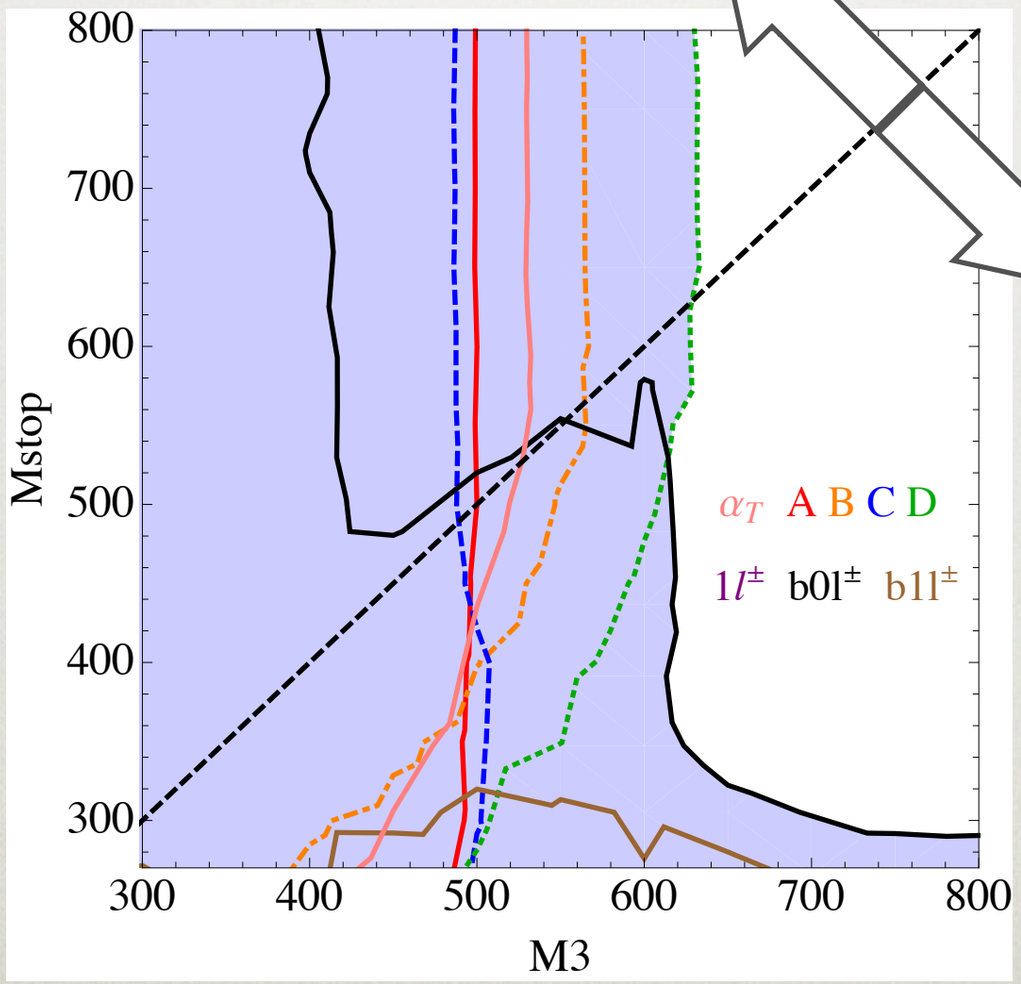
# Gauge-Mediation-Inspired Final States w/ colored LSP

(other gauginos & squarks decoupled)

$\tilde{g}$ (M3)

$\tilde{t}_R, \tilde{t}_L, \tilde{b}_R$

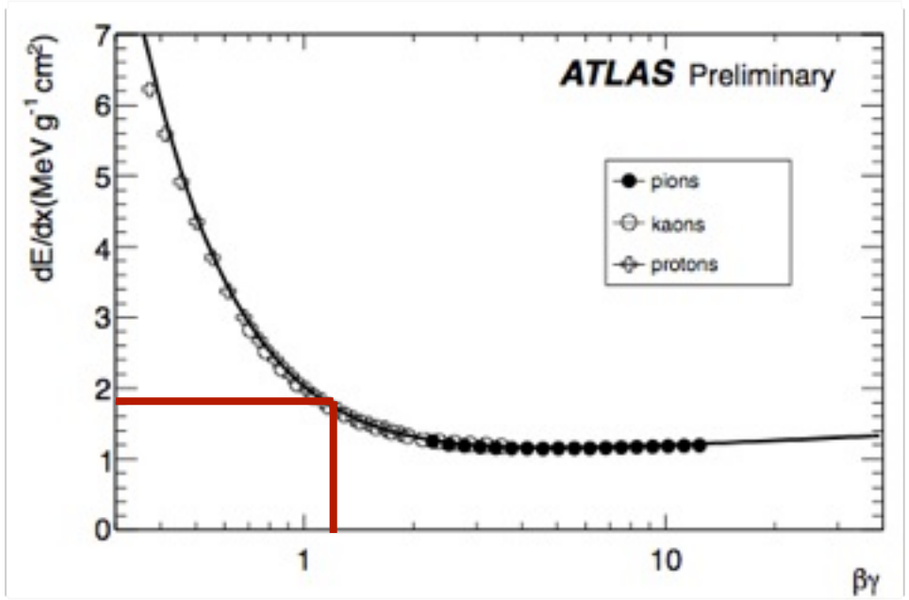
$\tilde{g}$ NLSP $\rightarrow g + \tilde{G}$




$\tilde{b}$ NLSP $\rightarrow b + \tilde{G}$

Limits are comparable to case of stable LSP.

# Stable Stops ...and light Gluinos




*Rough estimate: stable charged particle (SMP) searches **potentially** relevant if 10-30 events where **one** SMP has*

- *MET>40 GeV (incl. SMP)*
- *$p_T$>50, $|\eta|$<1.7*
- *$\beta\gamma$<1.2*
- *$\Delta R$>0.5 from jet (parton)*

much more efficient in cascade than direct prod.

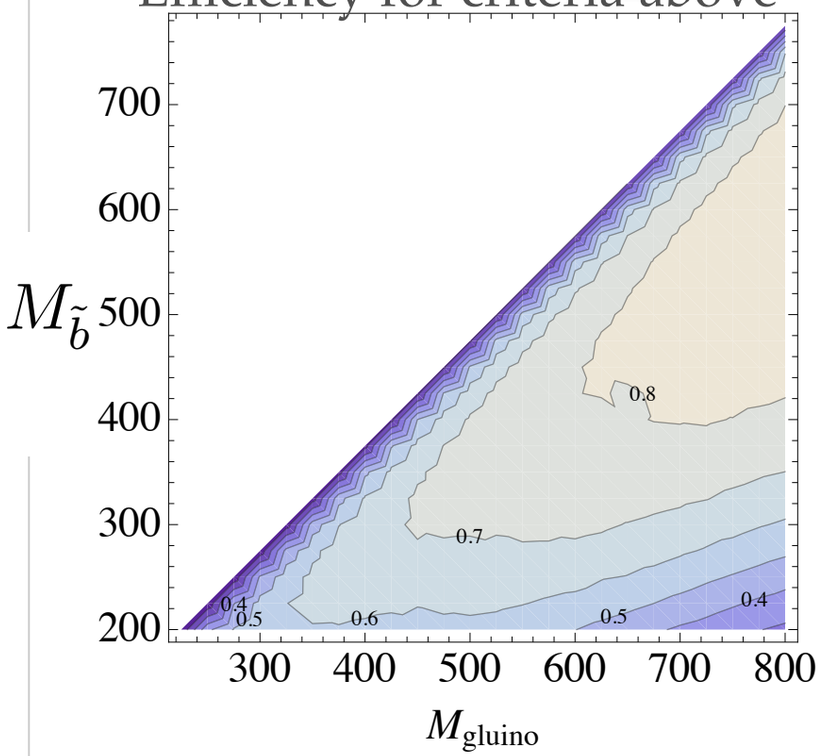
$\tilde{g}$

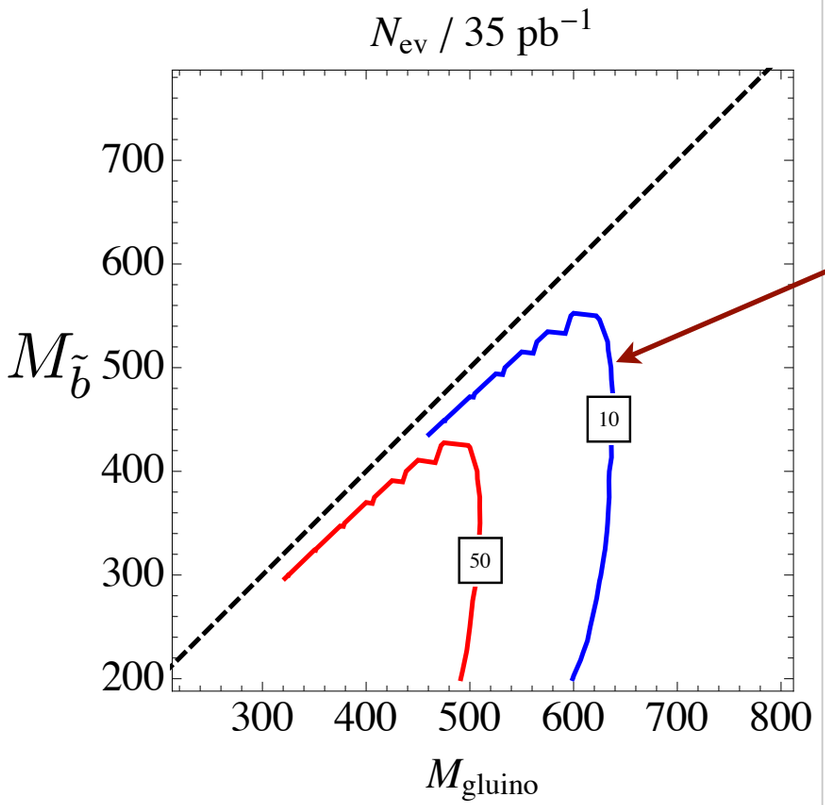
$\tilde{t}_{L,R}$

$\tilde{b}_L$

$m_{\tilde{t}} = \sqrt{m_{\tilde{b}}^2 + m_t^2}$

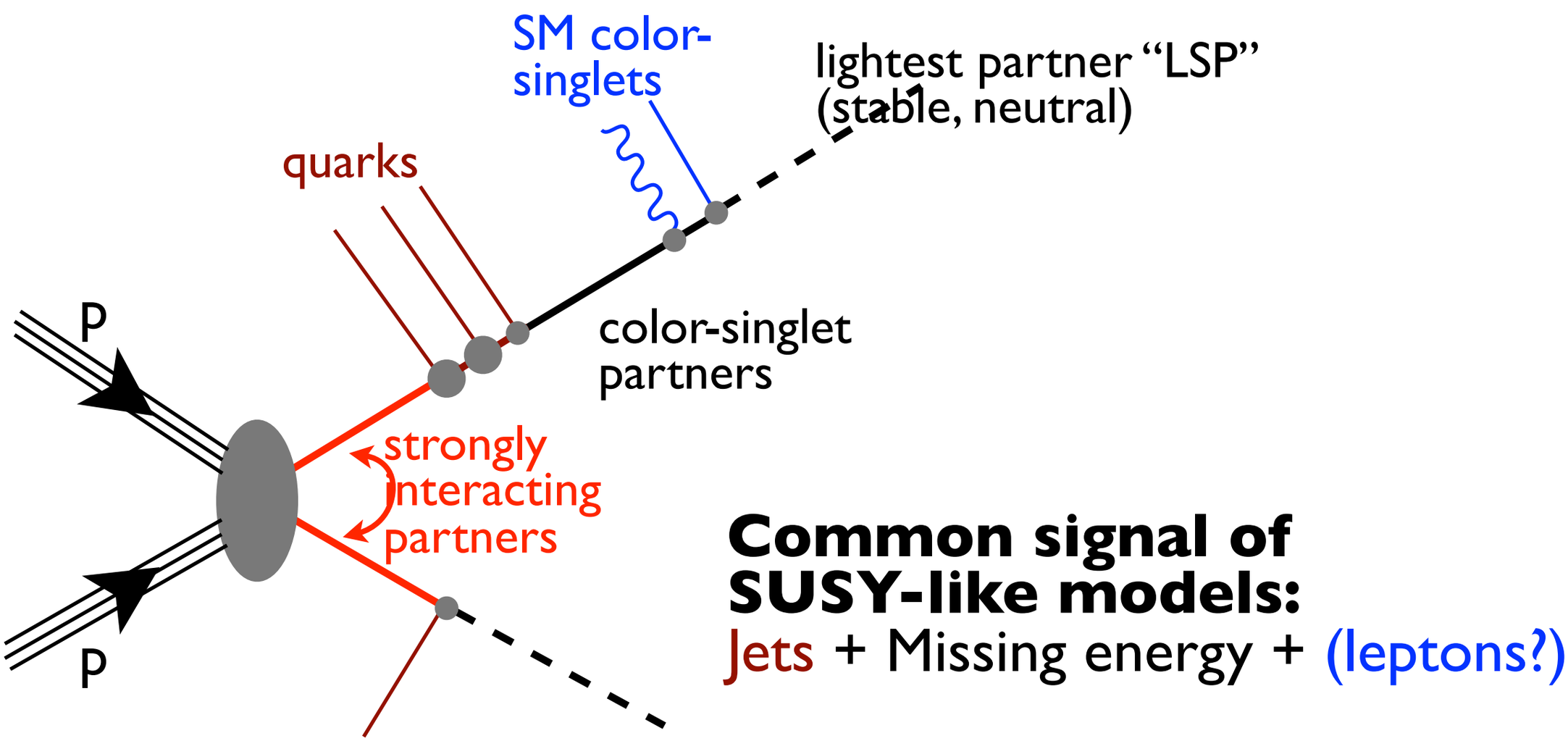
Efficiency for criteria above




does not include probability of charged hadron or inefficiency of selection near thresholds – these will lower 10-event signal to ~ limit of observability

# Where else should we Look?




**Common signal of SUSY-like models:**
Jets + Missing energy + (leptons?)

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 and gauge bosons

– light hidden sectors → decay to collimated leptons

– NMSSM → decay to higgs-like scalars

– hidden valleys at 10-100 GeV → complex multi-jet or multi-track

– R-parity violation or anomalous T-parity → decay to leptons or jets

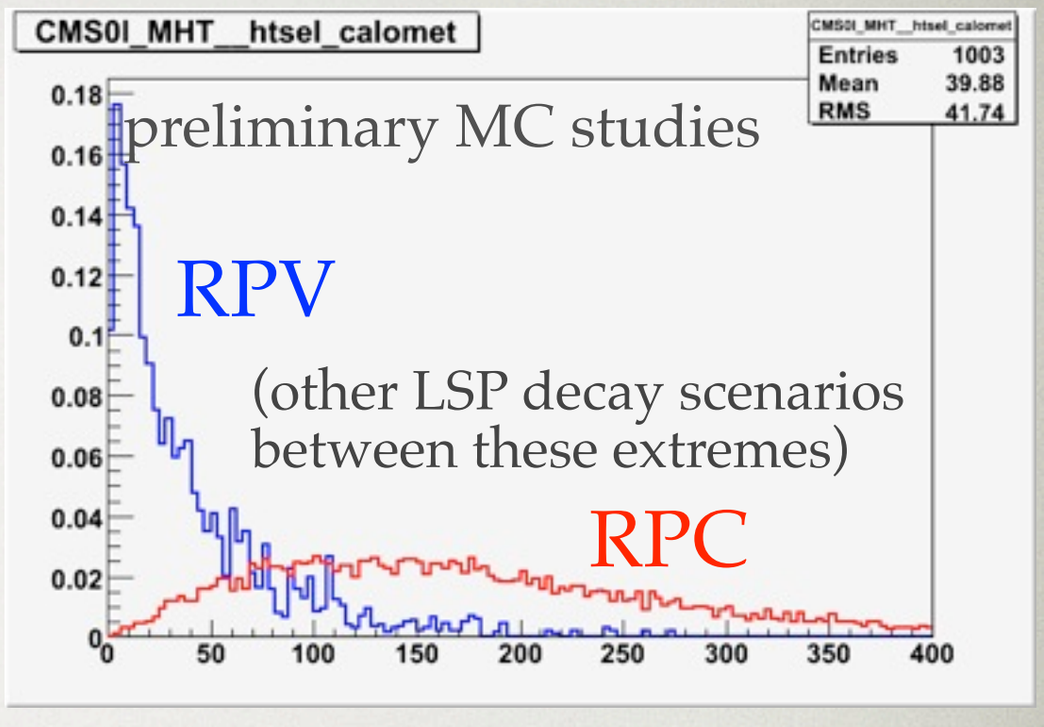
*Should try to develop **robust** and/or **complementary** searches. Particularly challenging for hadronic/track cases.*

Until last few months, backgrounds were **highly** uncertain.

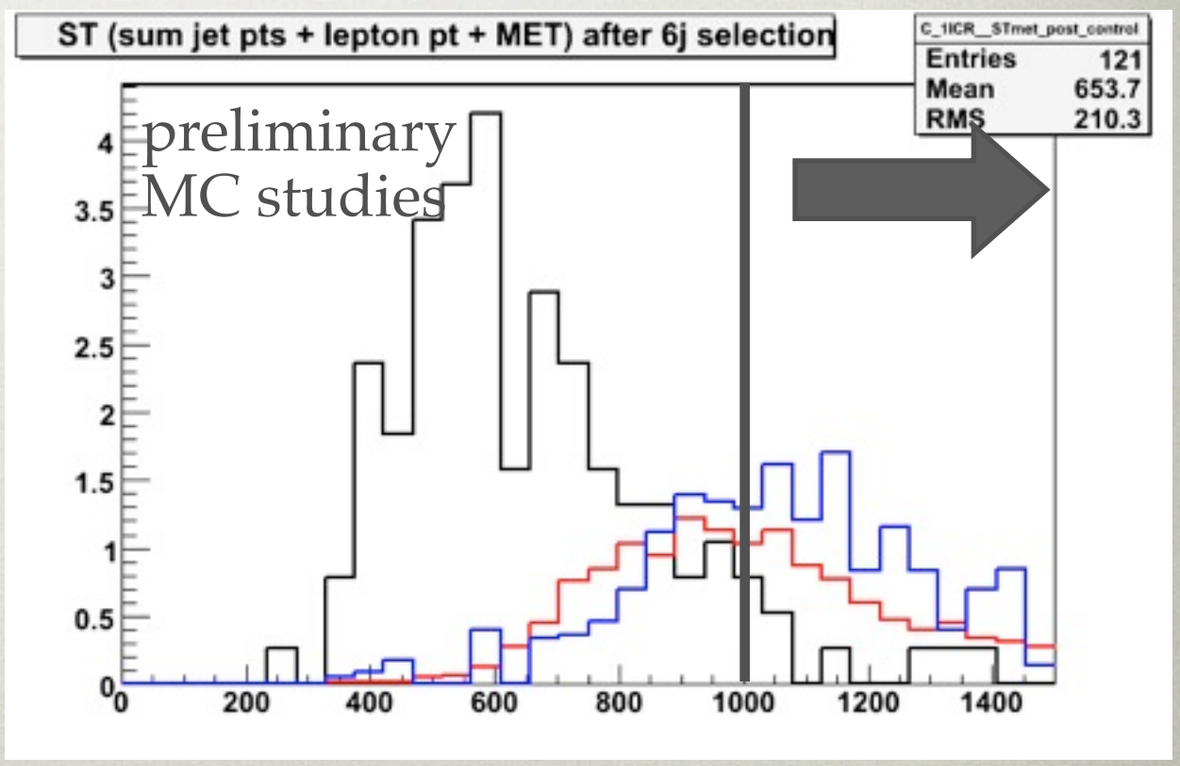
# Searching in W+6 jets?

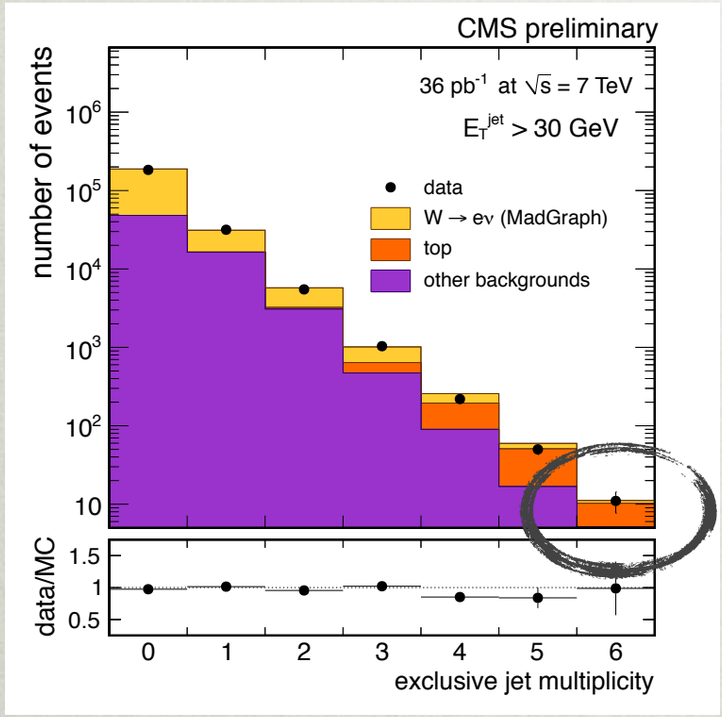
## Candidate signal:

- "vanilla" SUSY model with 560 GeV gluino and 700 GeV squarks
- Hadronic RPV: MET distribution falls dramatically.
- Efficiency comparable to MET searches for RPC models; clearly much better than MET searches for RPV.




Further separation with $S_T$ or $H_T$ potentially effective




...ongoing work (with M. Lisanti, P. Schuster, M. Strassler) exploring viability for various signatures

# Conclusion

- 35pb$^{-1}$ ATLAS and CMS searches are complementary, probe masses ~6–800 GeV.
  - radiative stability of weak scale leads us to expect stop at ≲ 400 GeV, gluino at ≲1 TeV
  - 2011 searches will be exciting, cover much of this range!
- Some "survivors" ~4–500 GeV:
  - lst, 2nd gen. squarks much heavier (e.g. direct mediation)
  - parameter ranges where 2-body gluino decays dominate
  - squeezed spectra, or long cascades
- Some regions to pay attention to:
  - squeezed spectra
  - cascade decays, possibly requiring handles besides MET
  - stop and sbottom direct searches, and b-rich gluino decay

# BACKUP

gluino 1-jet branching fraction from SDecay, with M(gluino)-M(bino)=200 GeV