Lessons From the First Round of SUSY Searches on the Way to 1 fb^{-1} at the LHC

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Later part of this talk is about work in progress with:
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and
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Outline

- Introduction
- Simplified Model (SMS) interpretations from ATLAS and CMS
- Lessons from early LHC SUSY searches, with an emphasis on light stops/sbottoms (i.e. heavy-flavor)
- Suggestions for improving search coverage

Uses of Simplified Models

Describe physics reactions that can be used to
develop search selections
and
identify complementary search strategies

Use SMS to **quantify search sensitivity**
(i.e. signal efficiencies)

Use SMS for **estimating mass scales and identifying quantum numbers** for candidate new physics

Uses of Simplified Models

Describe physics reactions that can be used to
develop search selections
and
identify complementary search strategies

Most important application!

No such thing as an "optimal" search.

Search strategy depends on kinematics and decay topology. There is a clear need for complementary search strategies that target different regions of kinematics (i.e. large mass splitting vs. small, direct decays vs. cascading...etc)

Uses of Simplified Models

Use SMS to **quantify search sensitivity**
(i.e. signal efficiencies)

Very useful for letting the rest of the world study search coverage (i.e. what did the search catch or miss?)

The best way to facilitate exploration of the search coverage is to provide:

1. Information on the ID and reconstruction efficiencies of the object selections. Especially useful for multi-lepton searches! Providing this information for reference reactions in the Standard Model is great. [see CMS SUS-10-007 for a good example]
2. Efficiency for a simplified model reference, if an appropriate one exists. Serves as a validated reference point for estimating limits on other models or comparing mock-up results.

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Simplified Model Limits from ATLAS and CMS

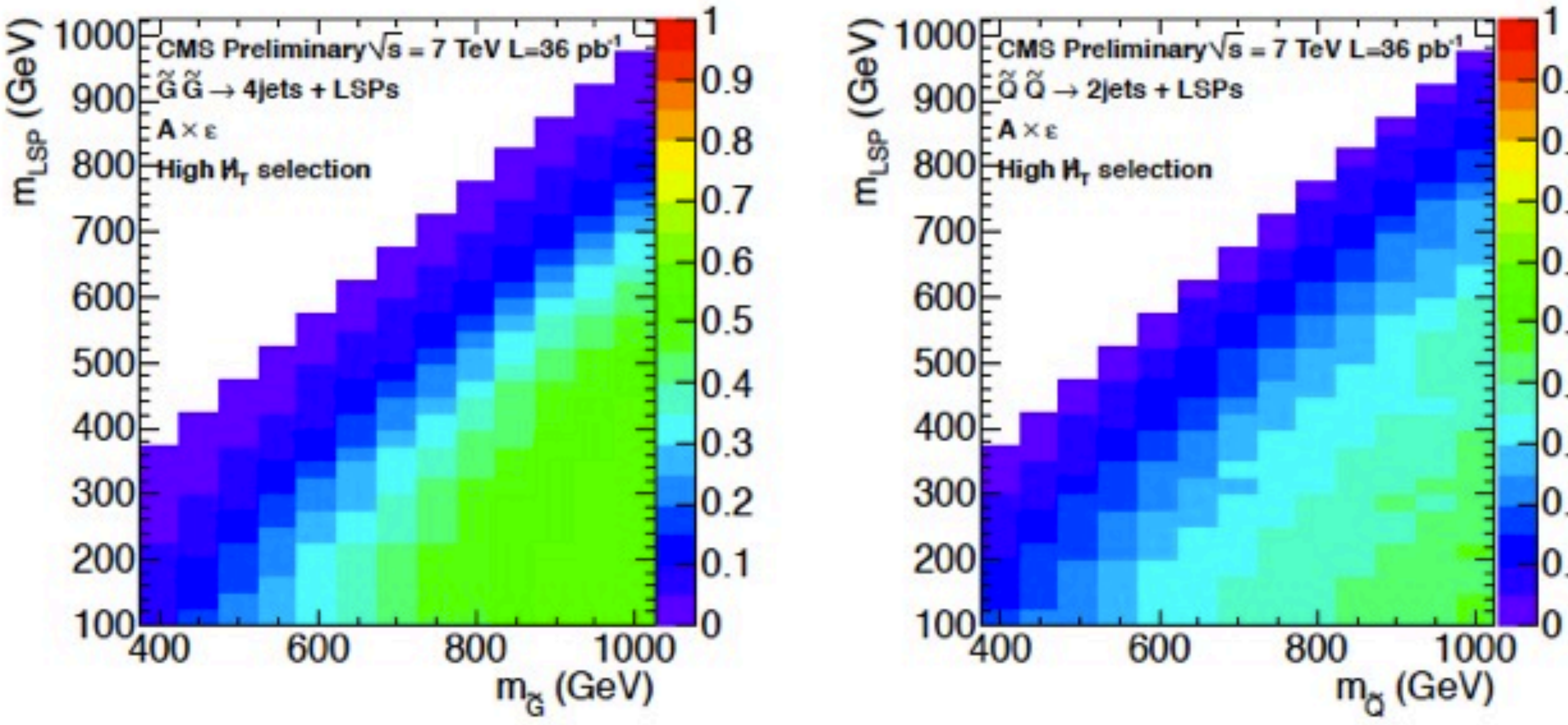


Figure 11: High-$\not{H}_T$ selection efficiency for gluino (left) and squark (right) production as a function of the gluino or squark and LSP mass.

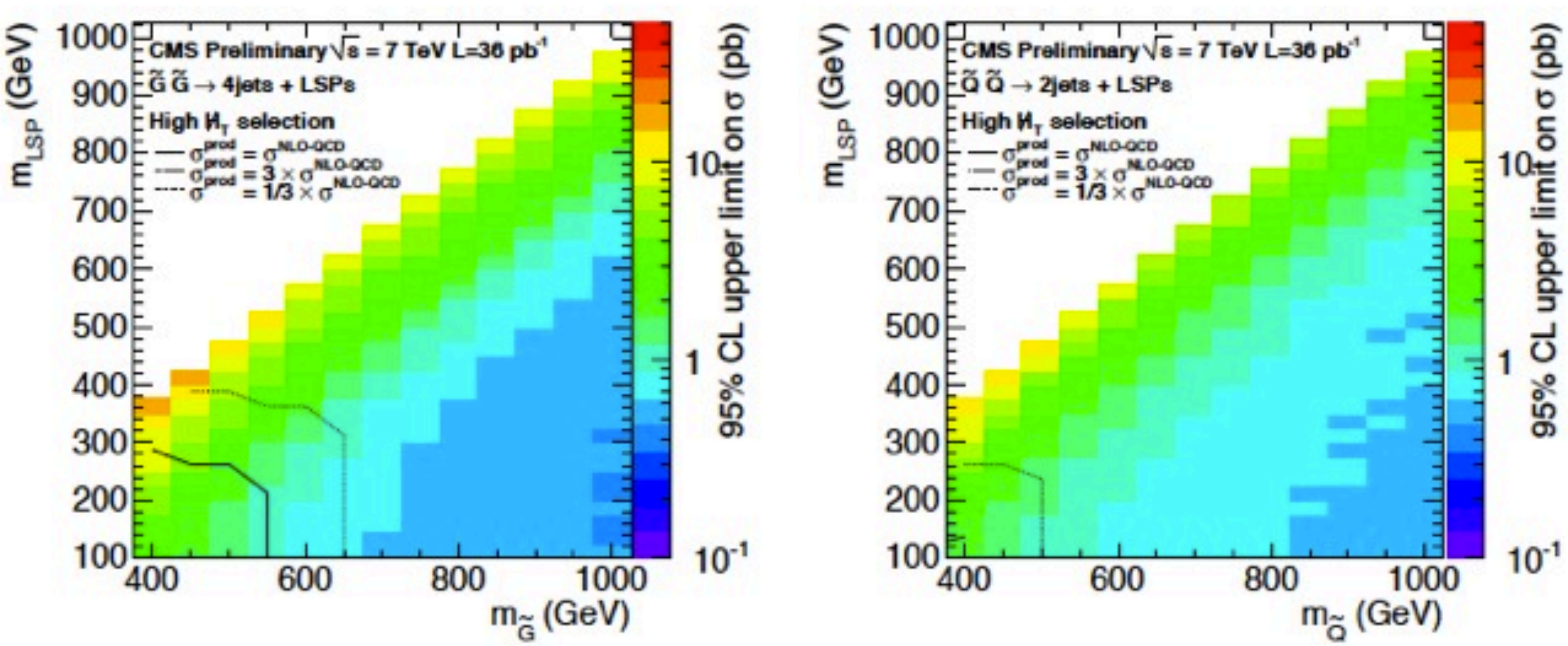


Figure 12: Estimated 95% C.L. exclusion limits for the gluino pair production (left) and squark pair production (right) for the high-$\not{H}_T$ selection.

Search for new physics at CMS with jets and missing momentum

The CMS Collaboration

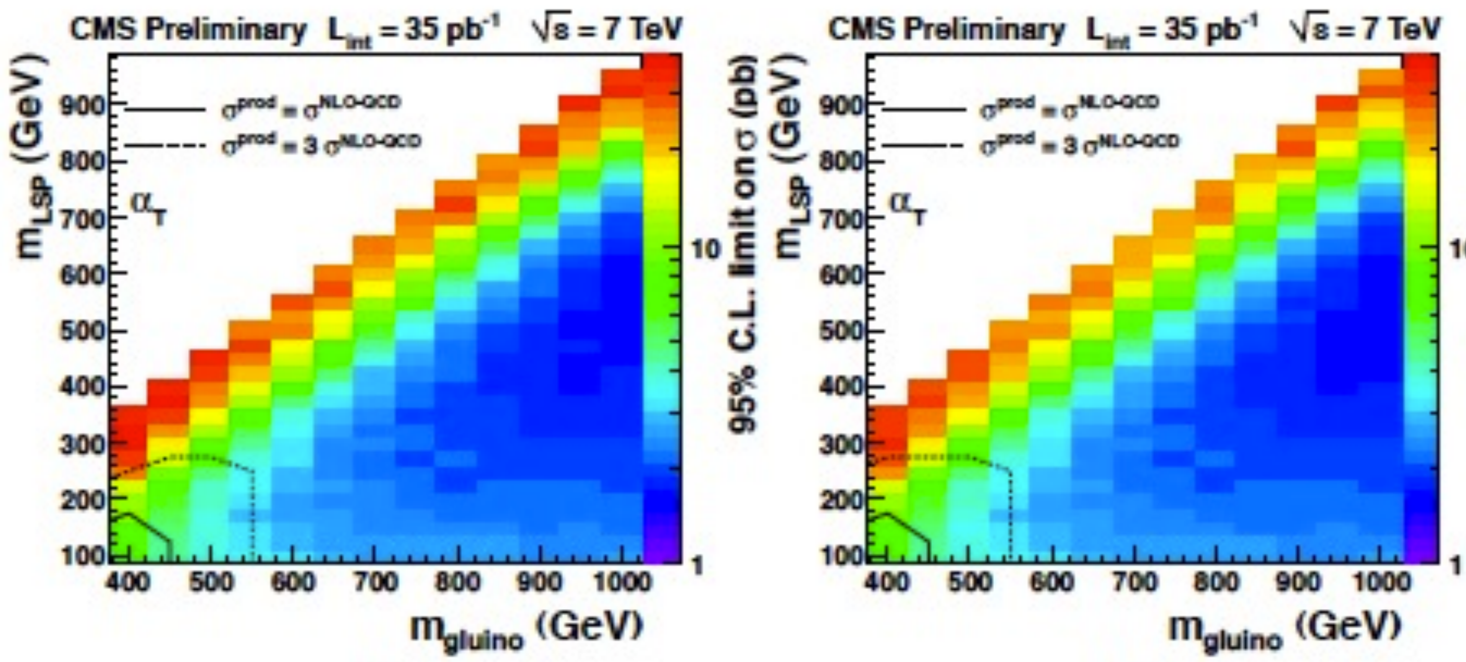
Many additional plots available online.

Efficiency plots and cross-section limits as a function of the kinematic parameters that control search sensitivity provide a clear picture of what is and is not covered.

Simplified Model Limits from ATLAS and CMS

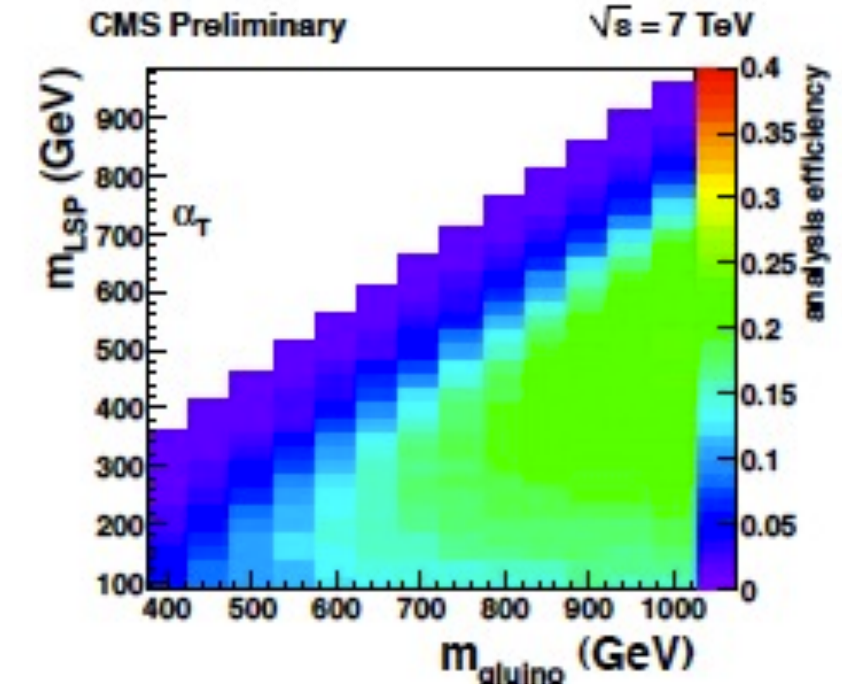
Further interpretation of the search for supersymmetry based on α_T

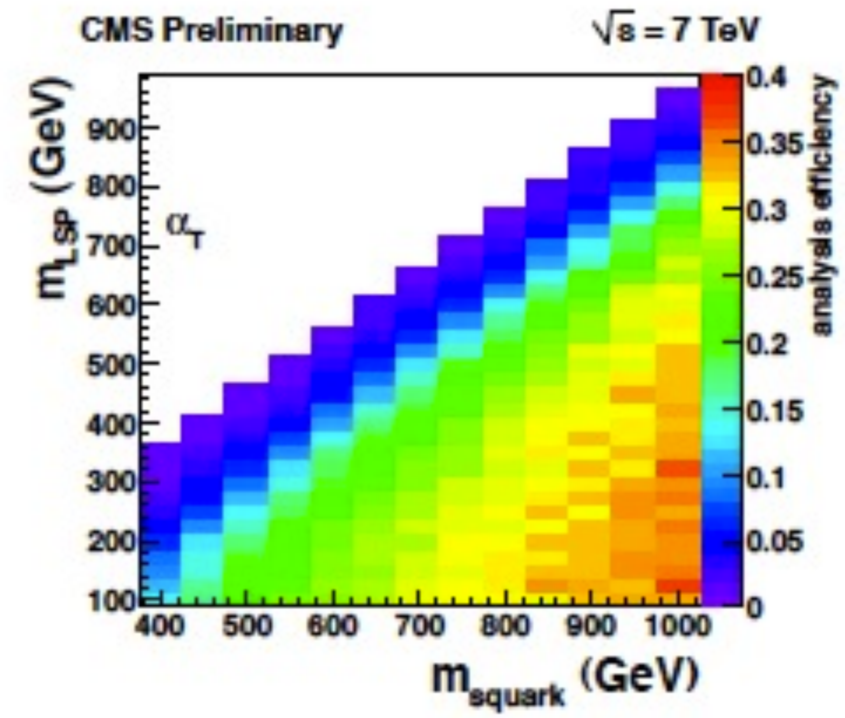
The CMS Collaboration



(a) (b)

Figure 8: Cross section for the gluino pair production topology excluded at the 95% CL. Overlaid are the excluded regions of parameter space using the reference cross sections σ^{prod}. Left: including theoretical uncertainties; Right: not including theoretical uncertainties.



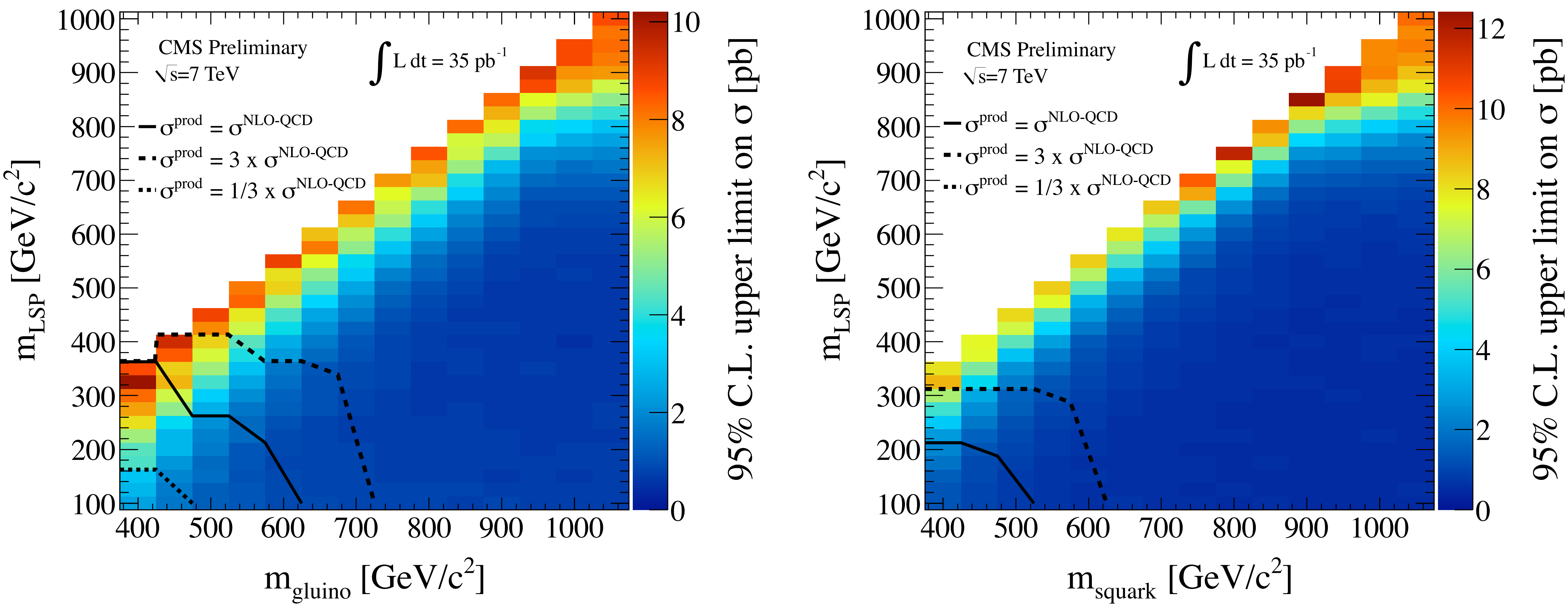


Many additional plots available online.

Simplified Model Limits from ATLAS and CMS

Inclusive search for squarks and gluinos at $\sqrt{s} = 7$ TeV

The CMS Collaboration



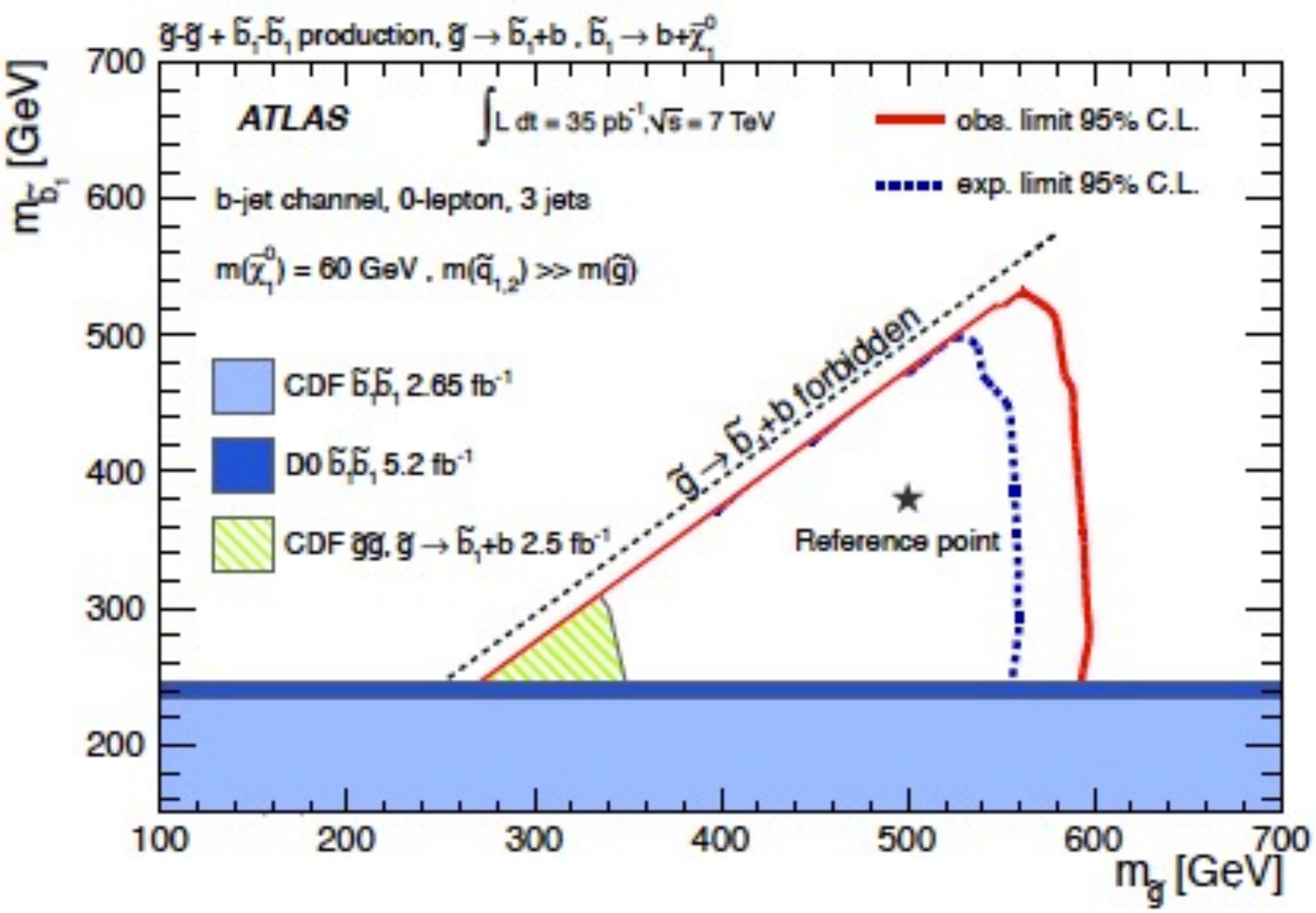
Simplified Model Limits from ATLAS and CMS

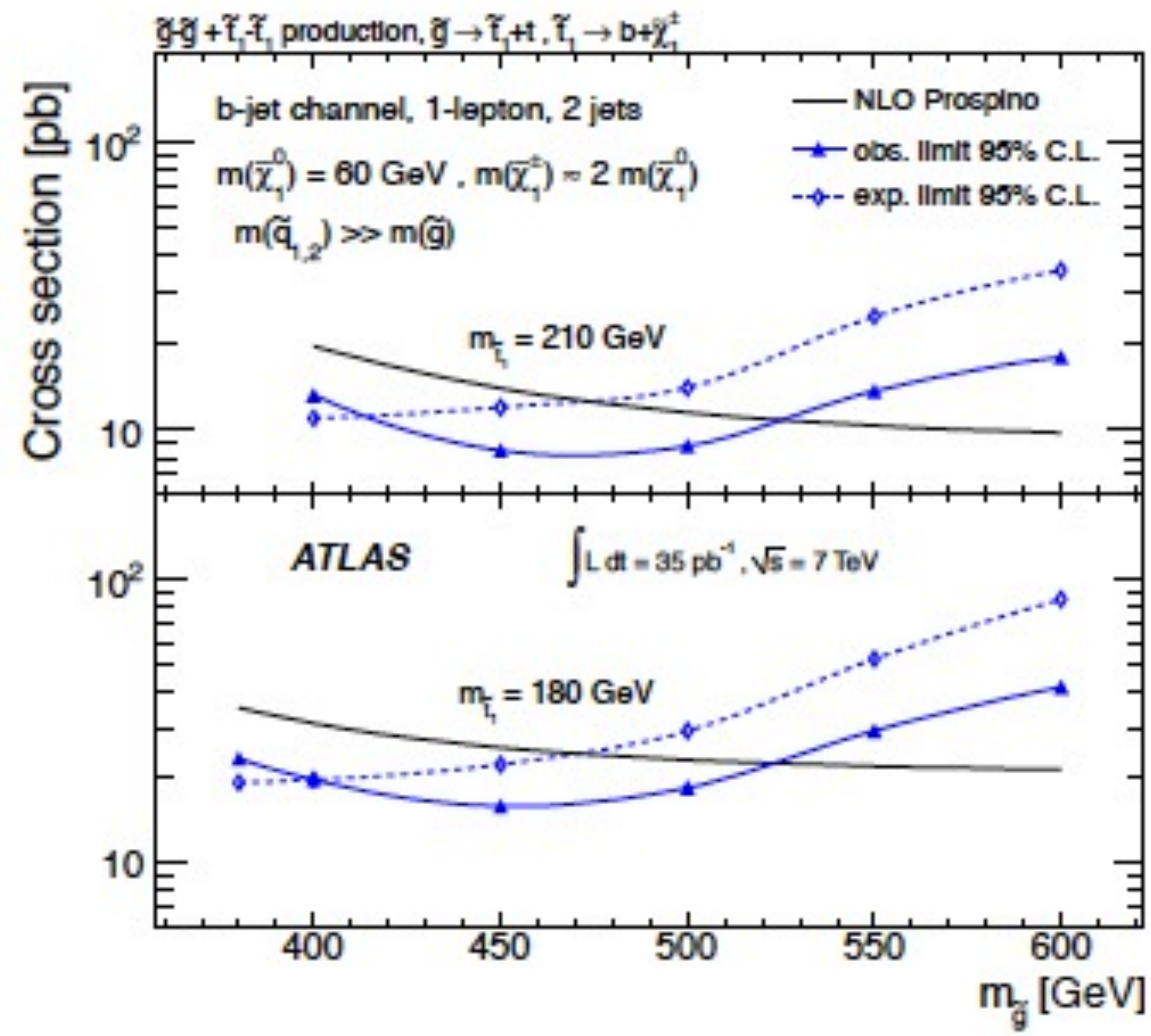
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2011-038

Search for supersymmetry in pp collisions at $\sqrt{s} = 7$ TeV in final states with missing transverse momentum and b-jets

The ATLAS Collaboration





Simplified Model Limits from ATLAS and CMS

CERN-PH-EP-2011-022, Submitted to Phys. Lett. B

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions

The ATLAS Collaboration

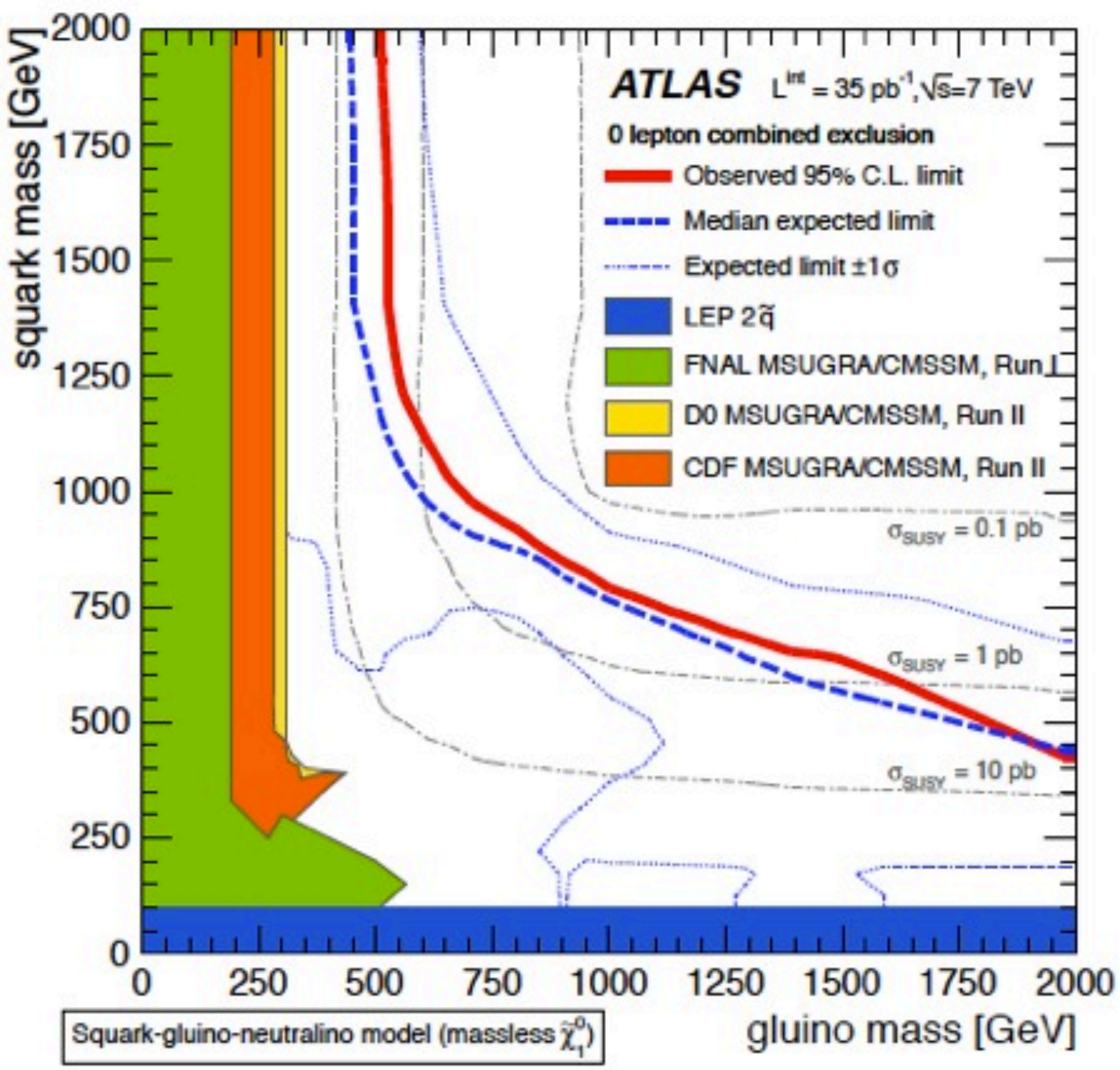


Figure 2: 95% C.L. exclusion limits in the $(m_{\tilde{g}}, m_{\tilde{q}})$ plane together with existing limits [4]. Comparison with existing limits is illustrative only as some are derived in the context of MSUGRA/CMSSM or may not assume $m_{\tilde{\chi}_1^0} = 0$.

Search for Supersymmetry in pp Collisions at $\sqrt{s} = 7$ TeV in Events with Two Photons and Missing Transverse Energy

The CMS Collaboration*

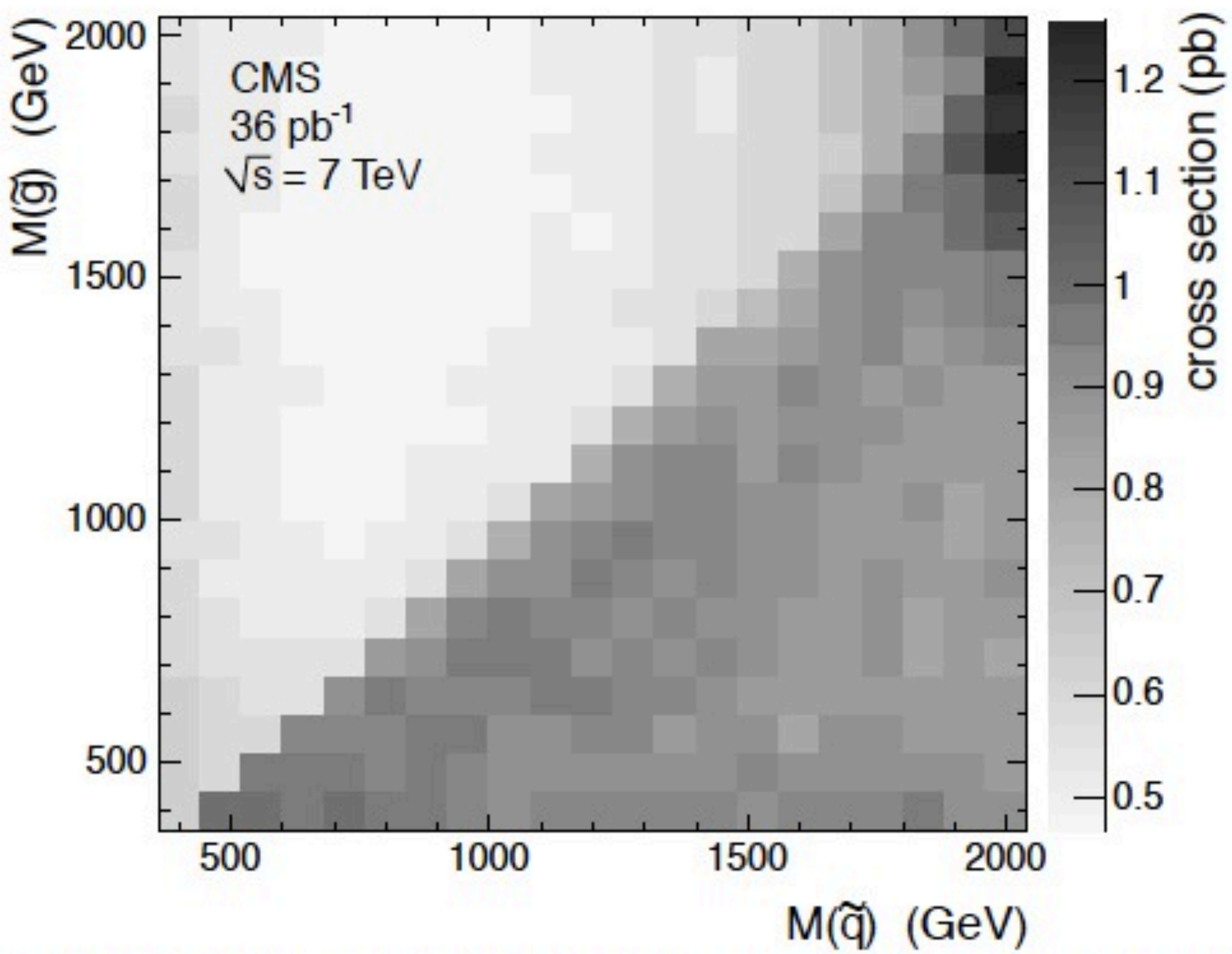


Figure 3: 95% CL upper limits for GGM production cross section as a function of squark ($\tilde{q}$) and gluino ($\tilde{g}$) masses for a neutralino mass of 150 GeV.

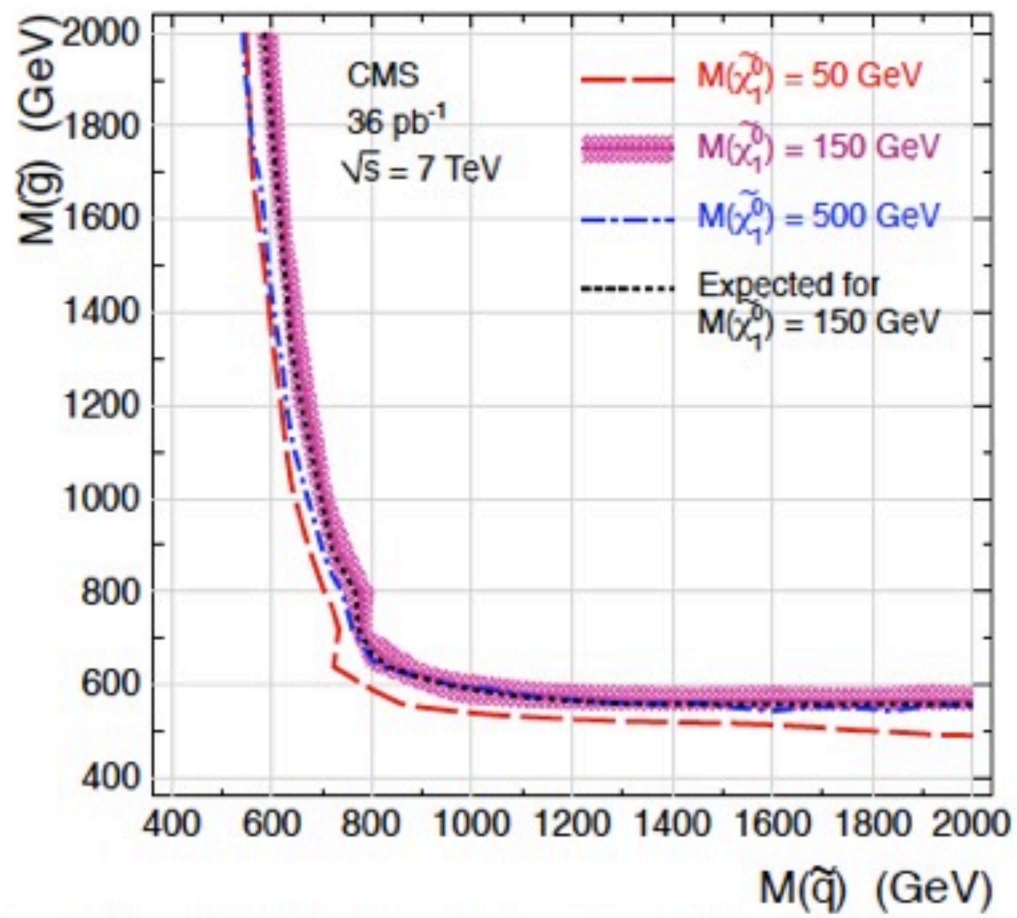


Figure 4: Lower 95% CL exclusion limits on the squark ($\tilde{q}$) and gluino ($\tilde{g}$) masses in the GGM benchmark model for 50, 150, and 500 GeV neutralino ($\tilde{\chi}_1^0$) masses. The areas below and to the left of the lines are excluded. The expected exclusion limit for 150 GeV neutralino mass is shown by the dashed line. The shaded band represents ± 1 standard deviation of theoretical uncertainty on the GGM cross section.

Outline

- Introduction
- Simplified Model (SMS) interpretations from ATLAS and CMS. The SMS results are very clear so far!
- Lessons from early LHC SUSY searches, with an emphasis on light stops/sbottoms (i.e. heavy-flavor)
- Suggestions for improving search coverage

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, ΔR=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%)

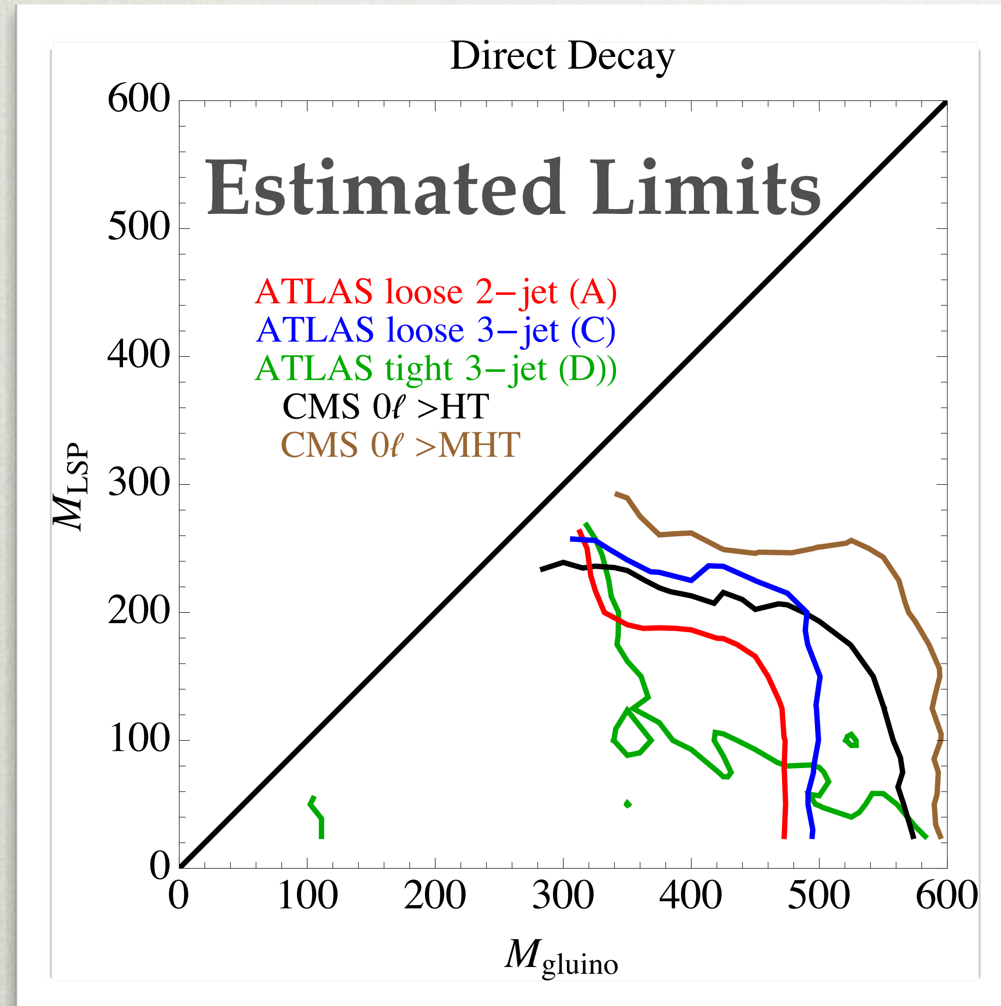
For Background

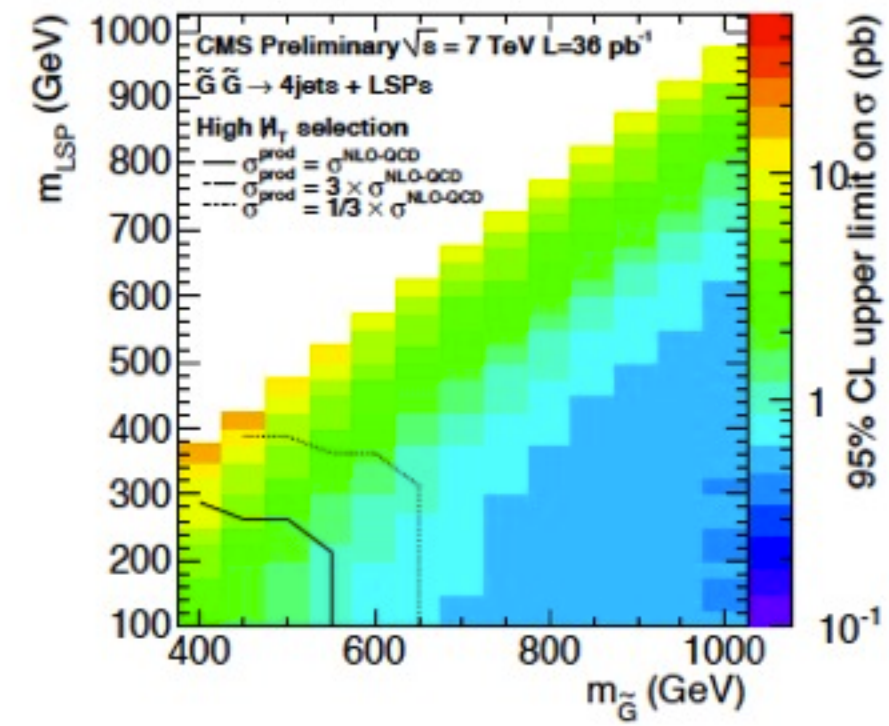
We only use published limits (except distributions on slides 27-30)

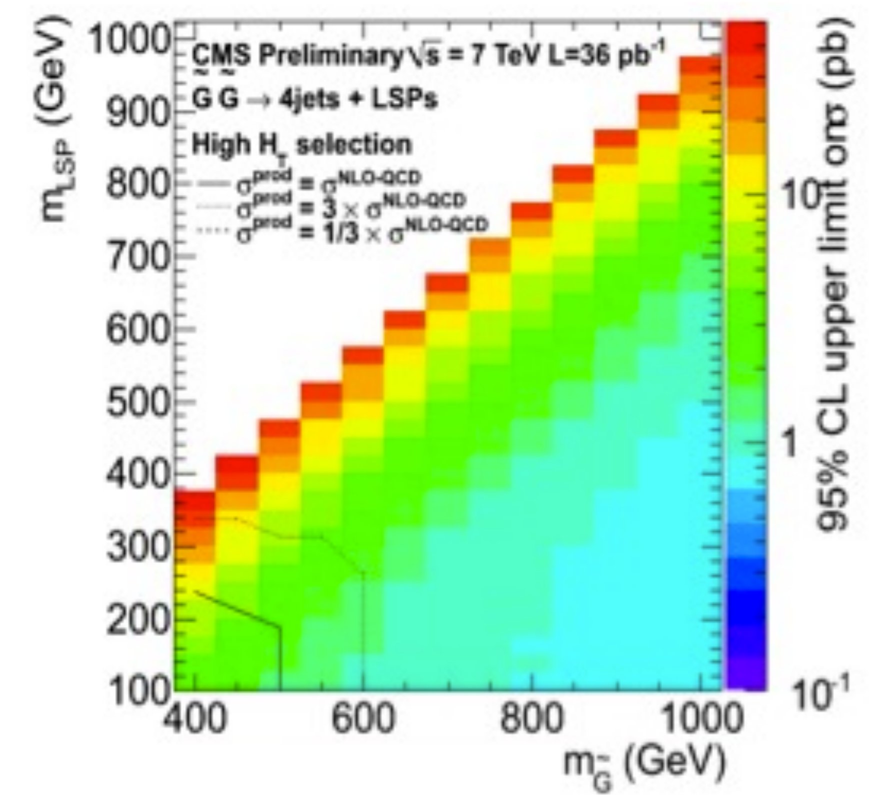
Obviously, everything we do is <u>only an estimate</u>!

Baseline Comparison

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

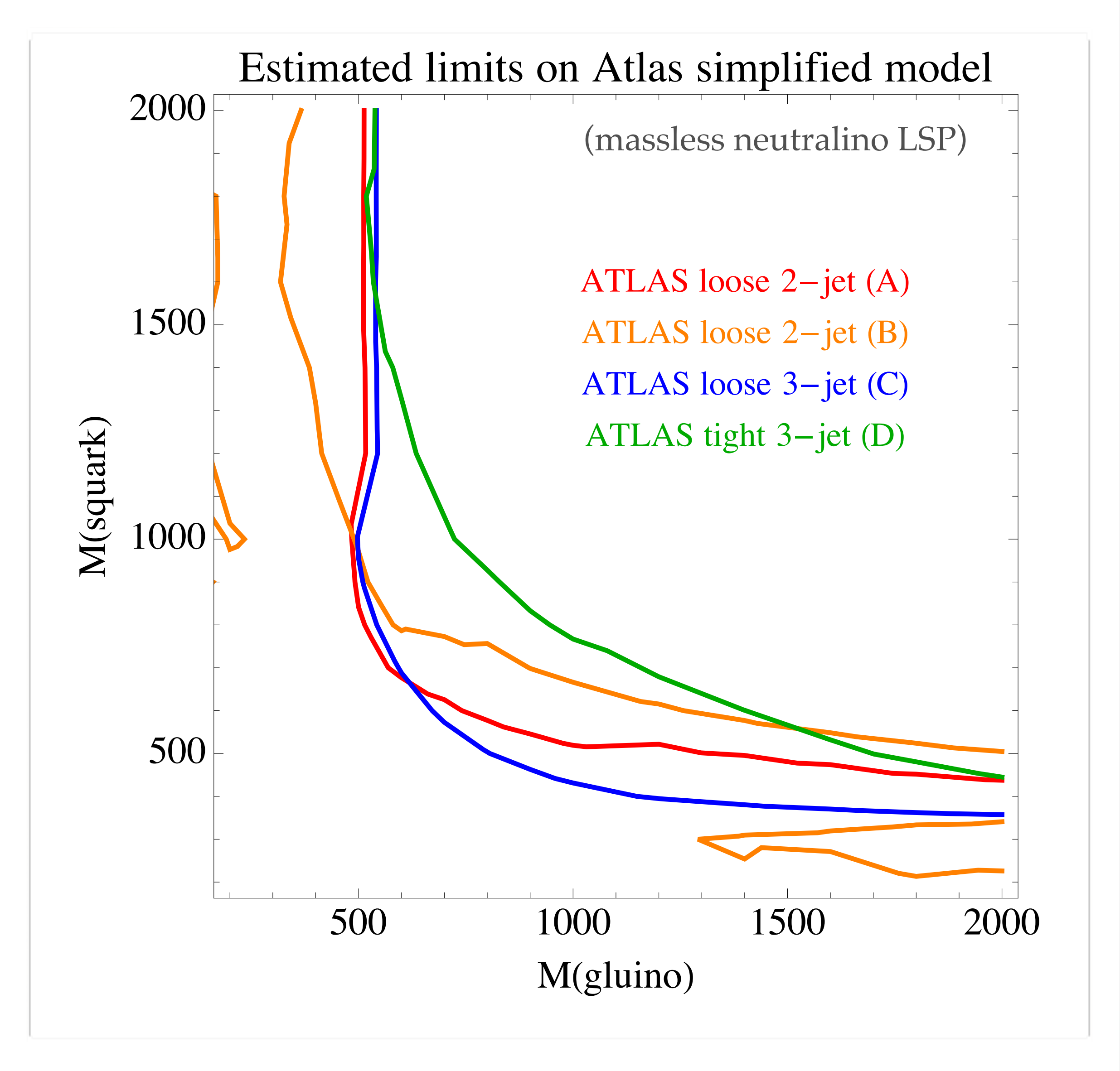


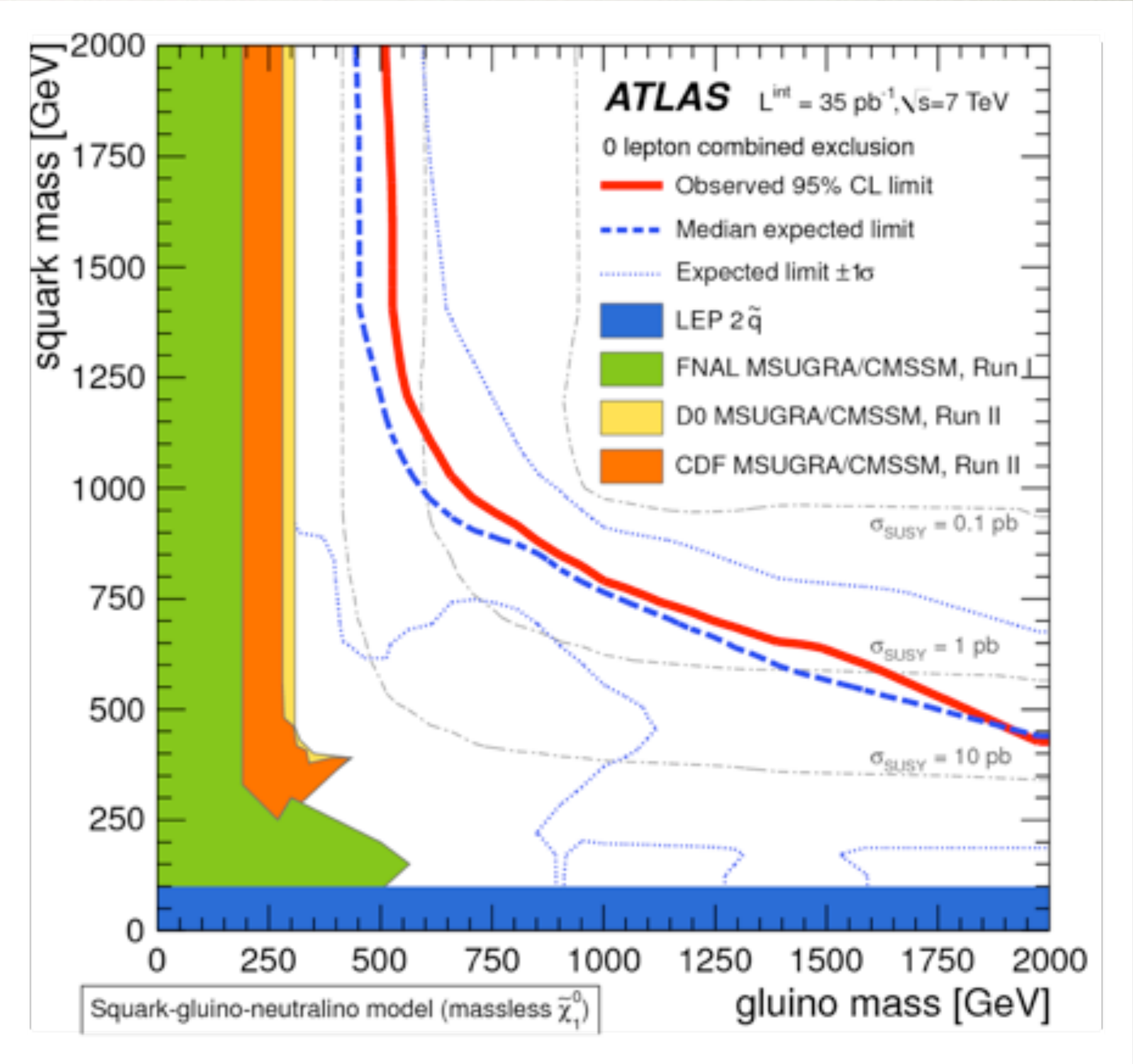




mock-up limit agrees within 50 GeV, efficiencies also appear consistent
CMS has results in same planes for R&M_R analysis and for α_T analysis

Another Comparison

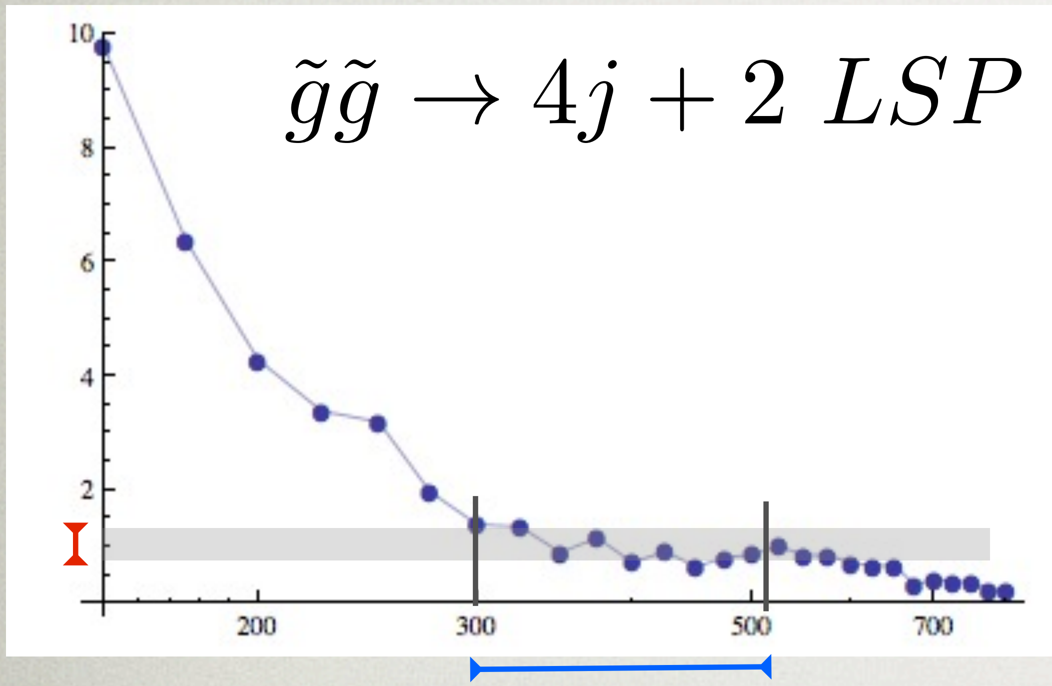


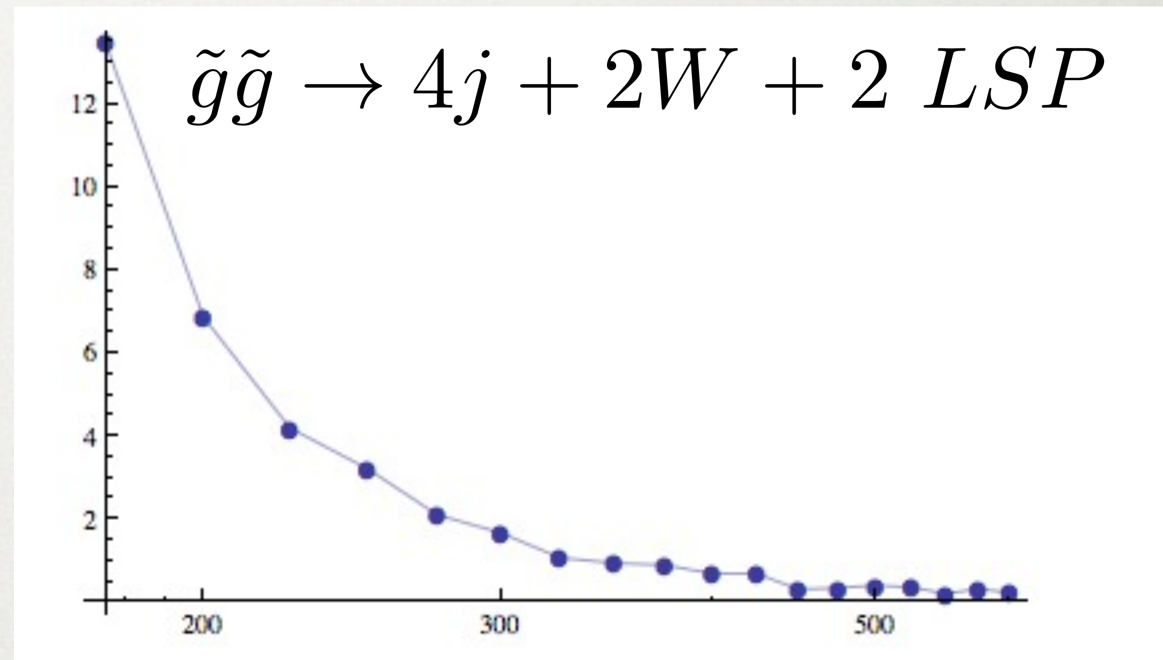


Detailed efficiency plots on search website (**very** much appreciated!)

Extreme sensitivity of limits

$\sigma \times \epsilon$ (arb units) vs Mass (GeV)

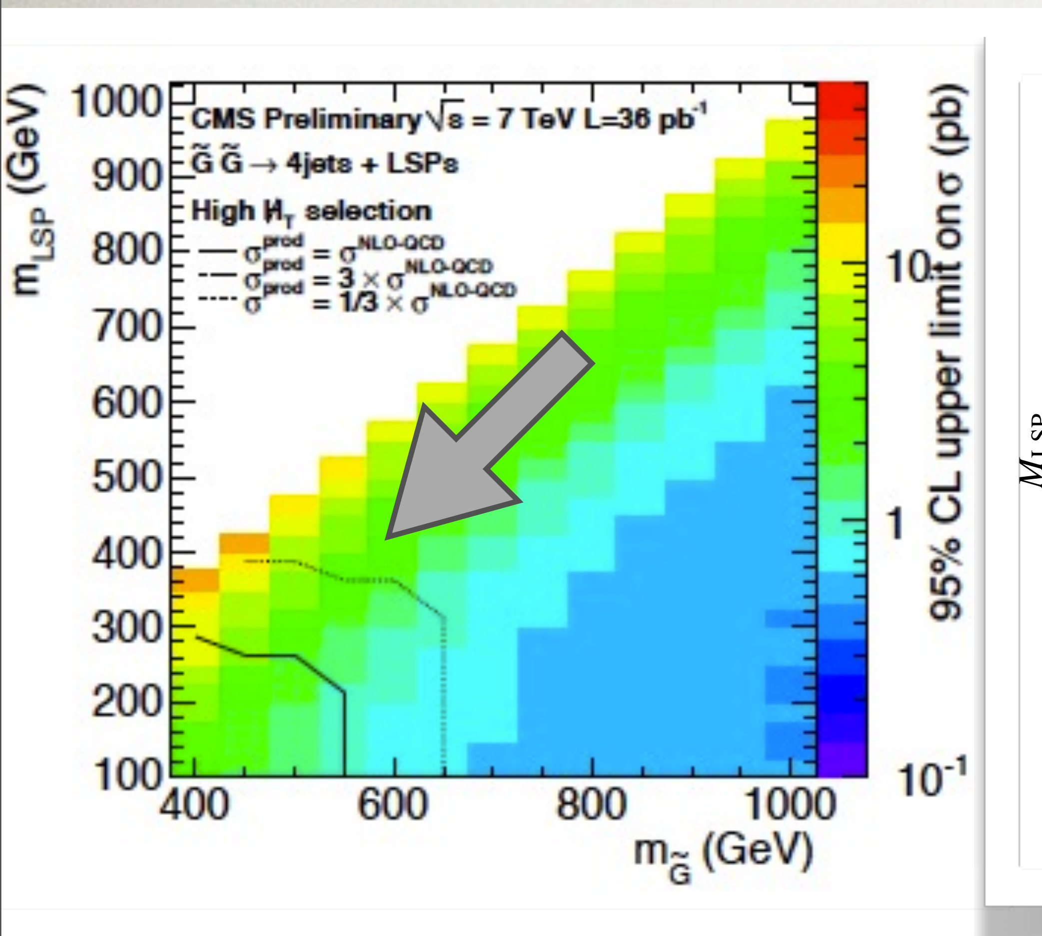


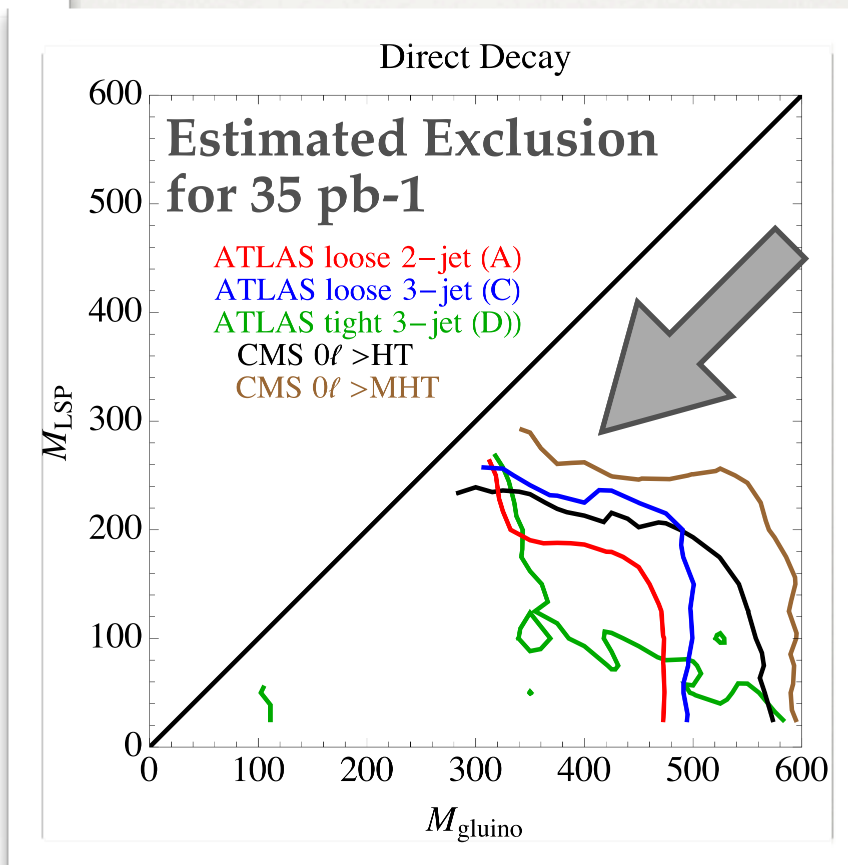


Very slow drop of σ x efficiency at high mass (we've found this for many searches) ⇒ small change in ε yields large impact on mass exclusion

Why is this? Accident at 35 pb^{-1}? (now just starting to be sensitive to mass scales that are really well separated from background) ...are exclusions at the high end of such a plateau meaningful?

Reduced Sensitivity to Squeezed Spectra





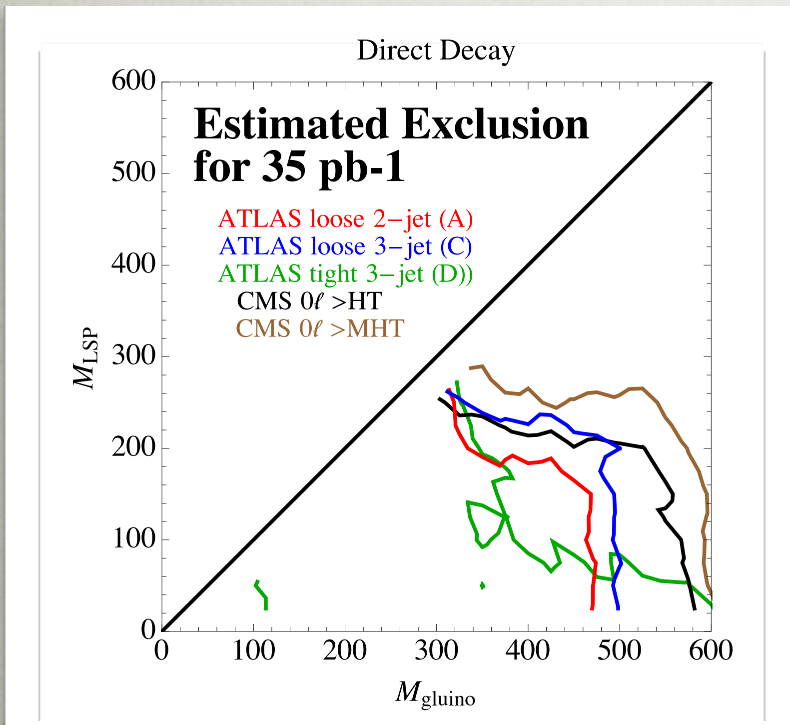
$\sigma \ll \sigma_{top}$ (set by M_{gluino})
$p_T \sim p_{T,top}$ (set by δM)

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

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

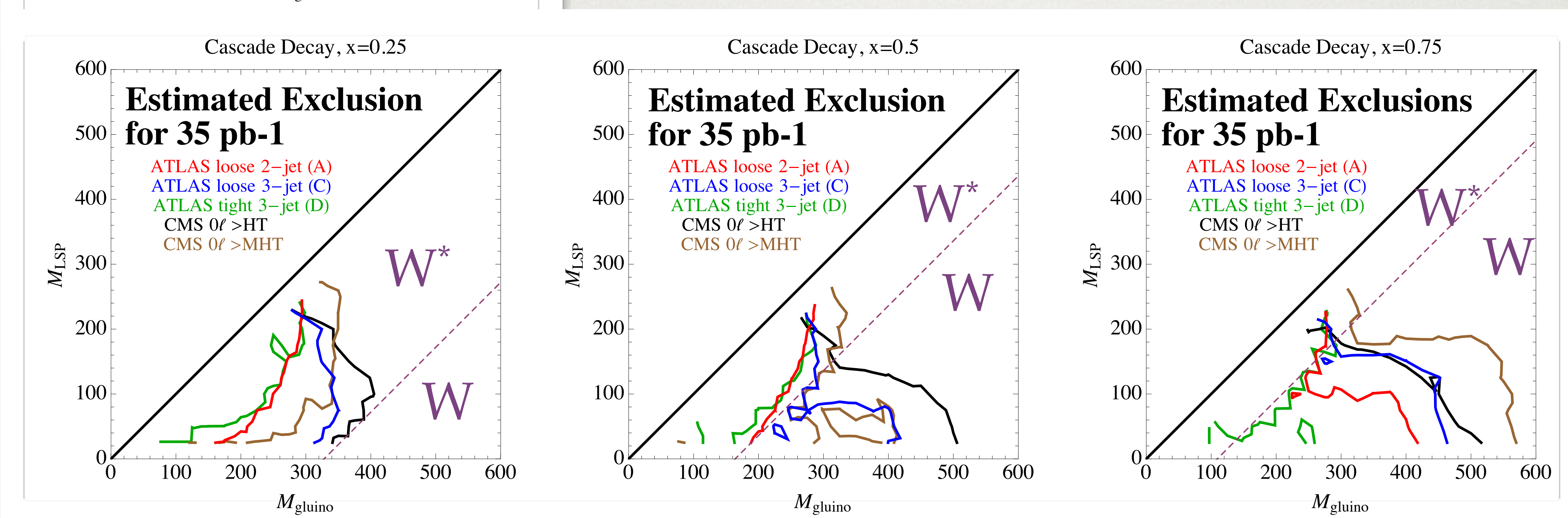
One possibility: hard MET cut, look for ISR events (here recoil set by Mgluino) – see papers by Wacker and collaborators (esp. recent w/ Alvez, Izaguirre)

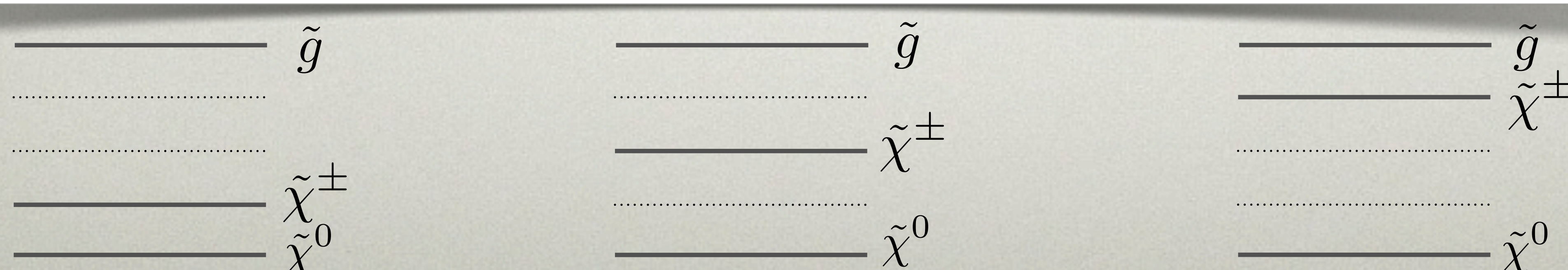
Reduced Sensitivity to Cascades



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

Could be higher/lower...

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

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

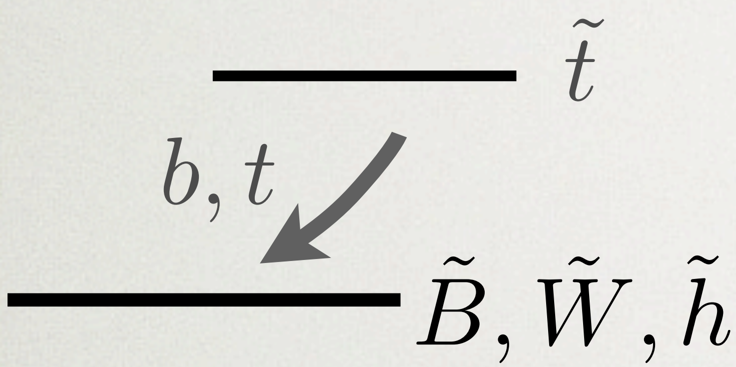
$$|\delta \tilde{m}_t| \lesssim \tilde{m}_t \approx 150\ \mathrm{GeV} \longrightarrow M_3 \lesssim 200 - 500\ \mathrm{GeV}$$

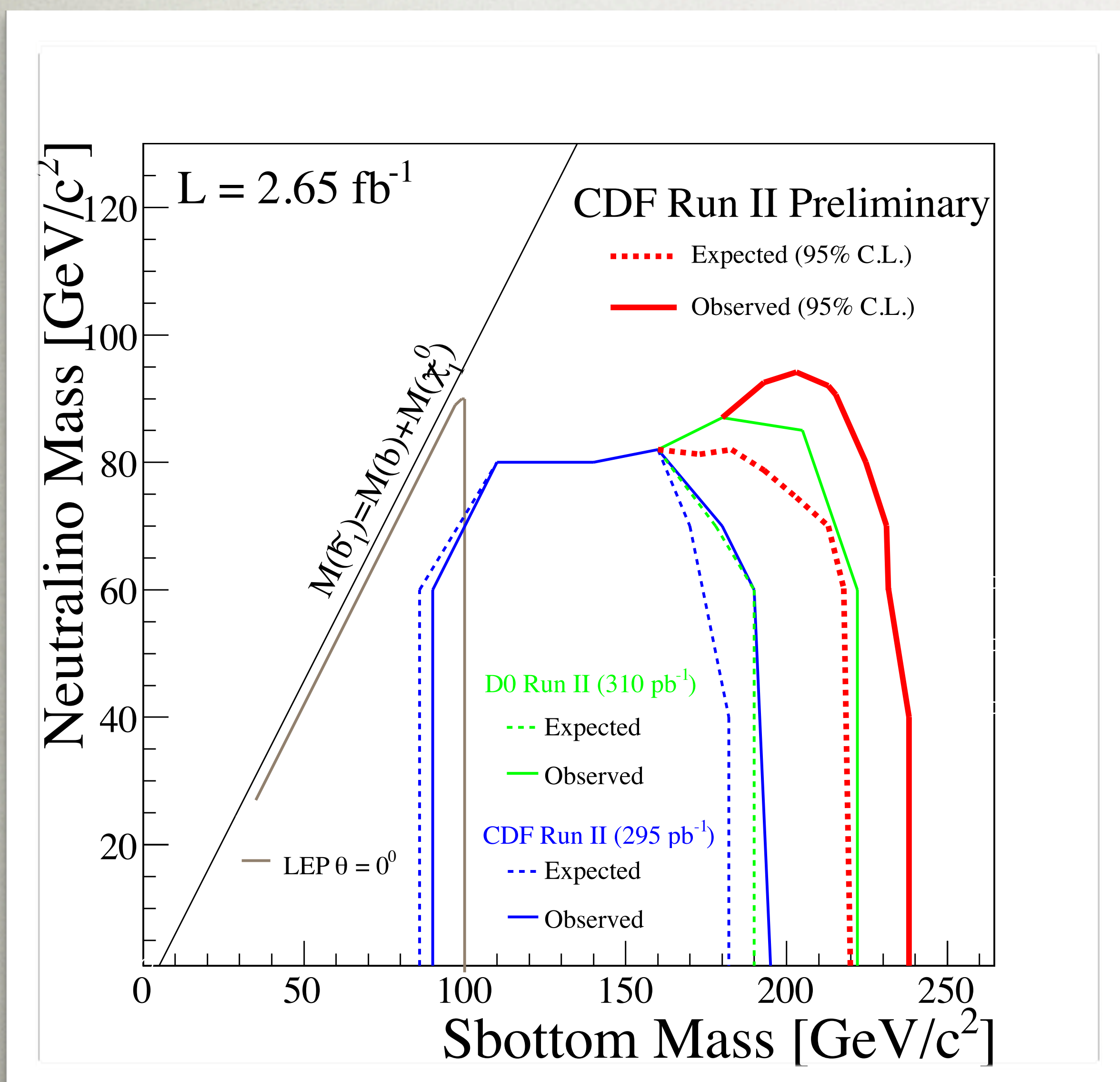
$$|\delta \tilde{m}_t| \lesssim \tilde{m}_t \approx 350\ \mathrm{GeV} \longrightarrow M_3 \lesssim 500 - 1200\ \mathrm{GeV}$$

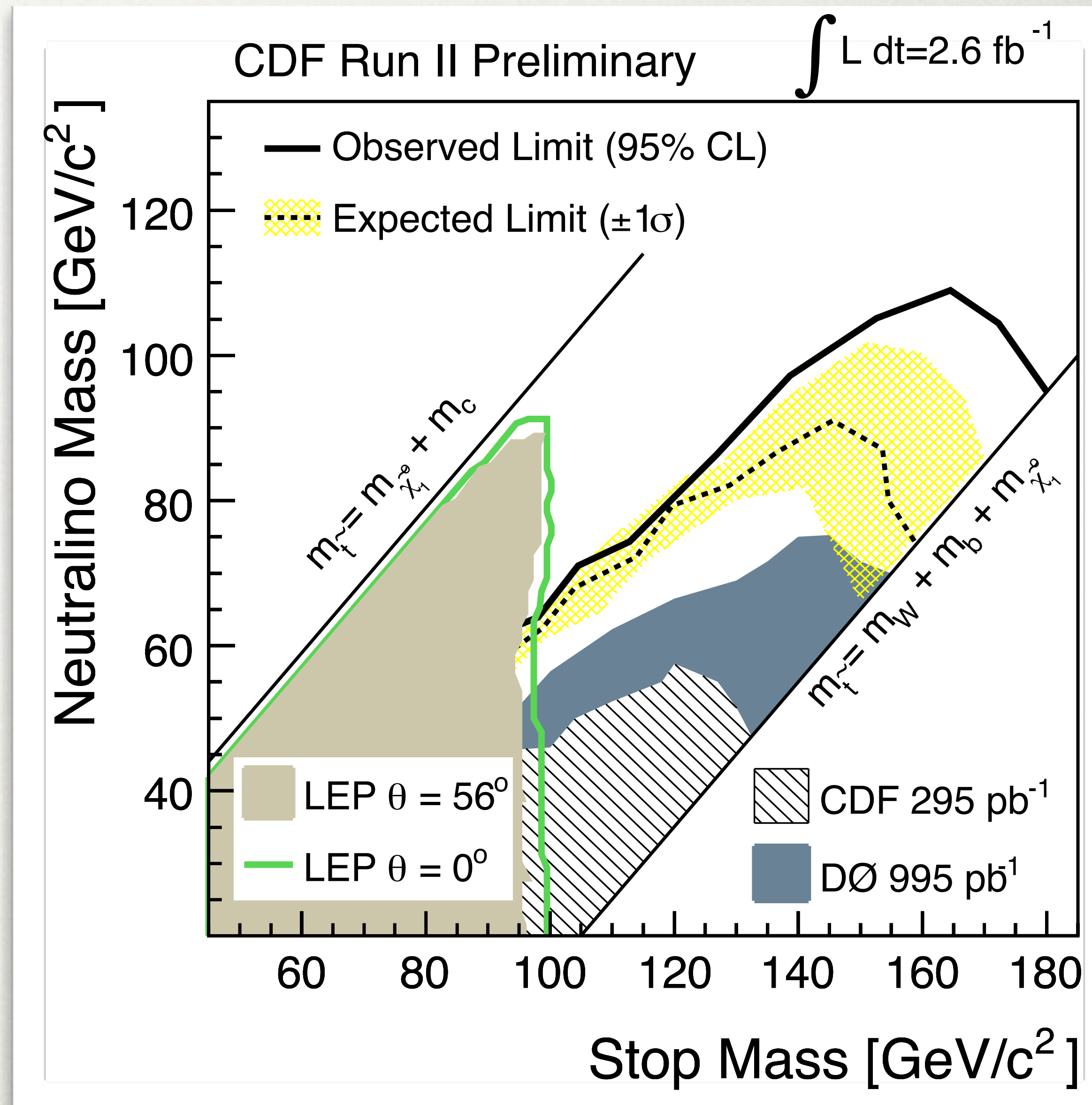
Scenarios with light stops/sbottoms (i.e. relatively natural SUSY) are important to cover thoroughly! Early search results indicate that this is very doable.

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

How light can stops be? (Tevatron)

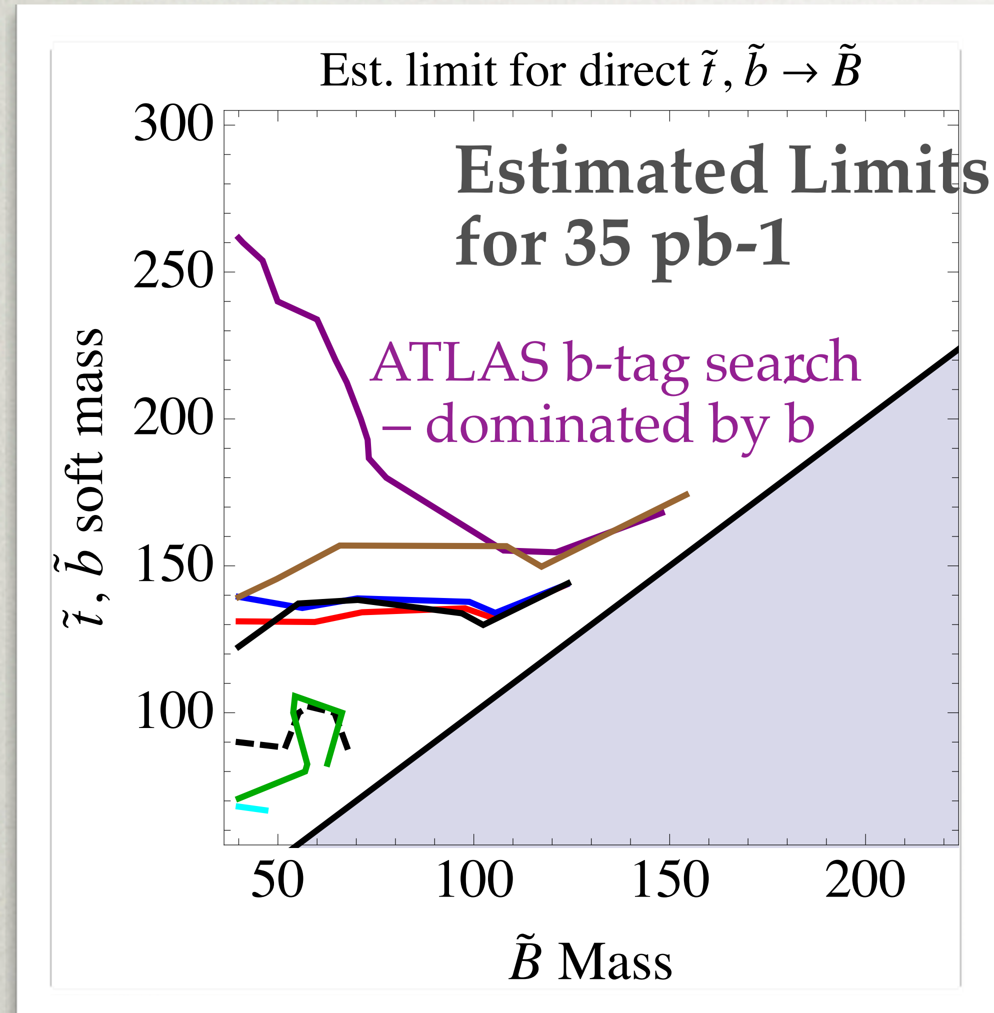


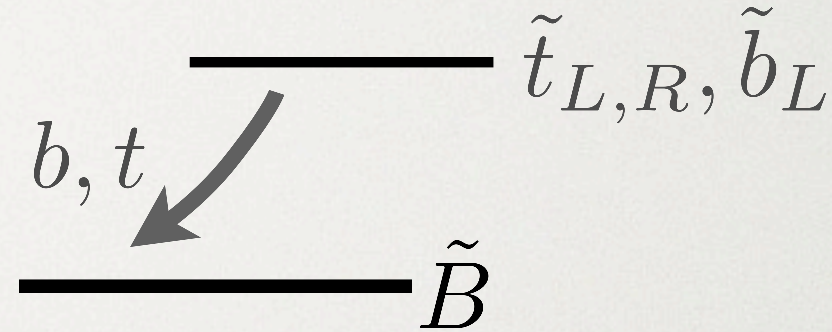




Tevatron limits do not rule out a natural top/bottom partner
... they do constrain this possibility...

Estimated LHC Sensitivity to light stops

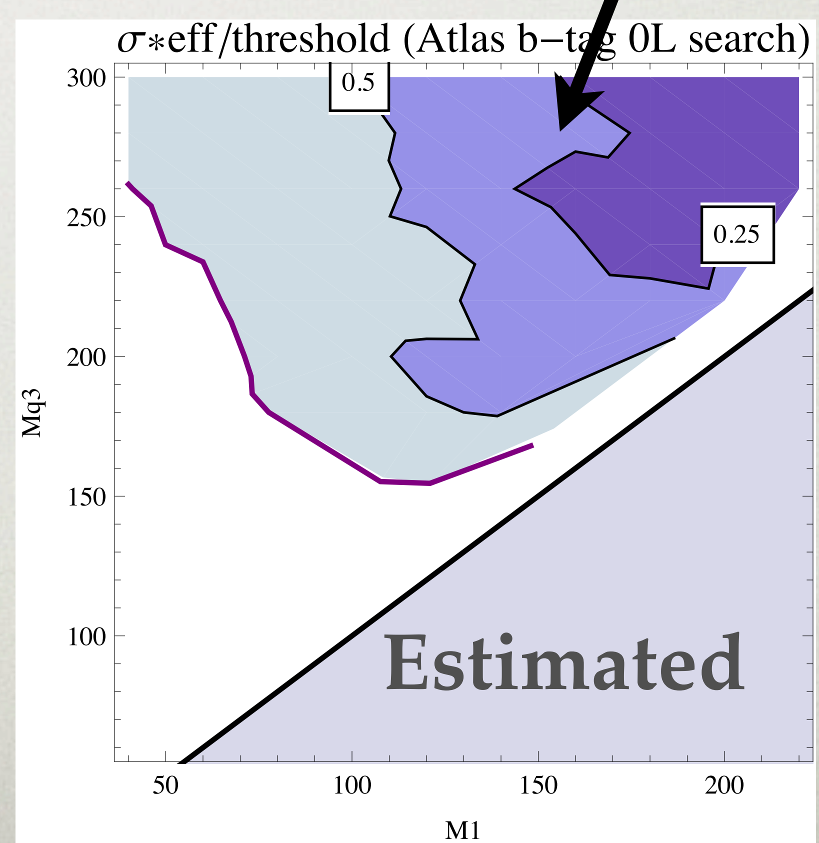




1 fb^{-1} LHC data will likely cover top/bottom partner production beneath ~300 GeV, especially with dedicated search

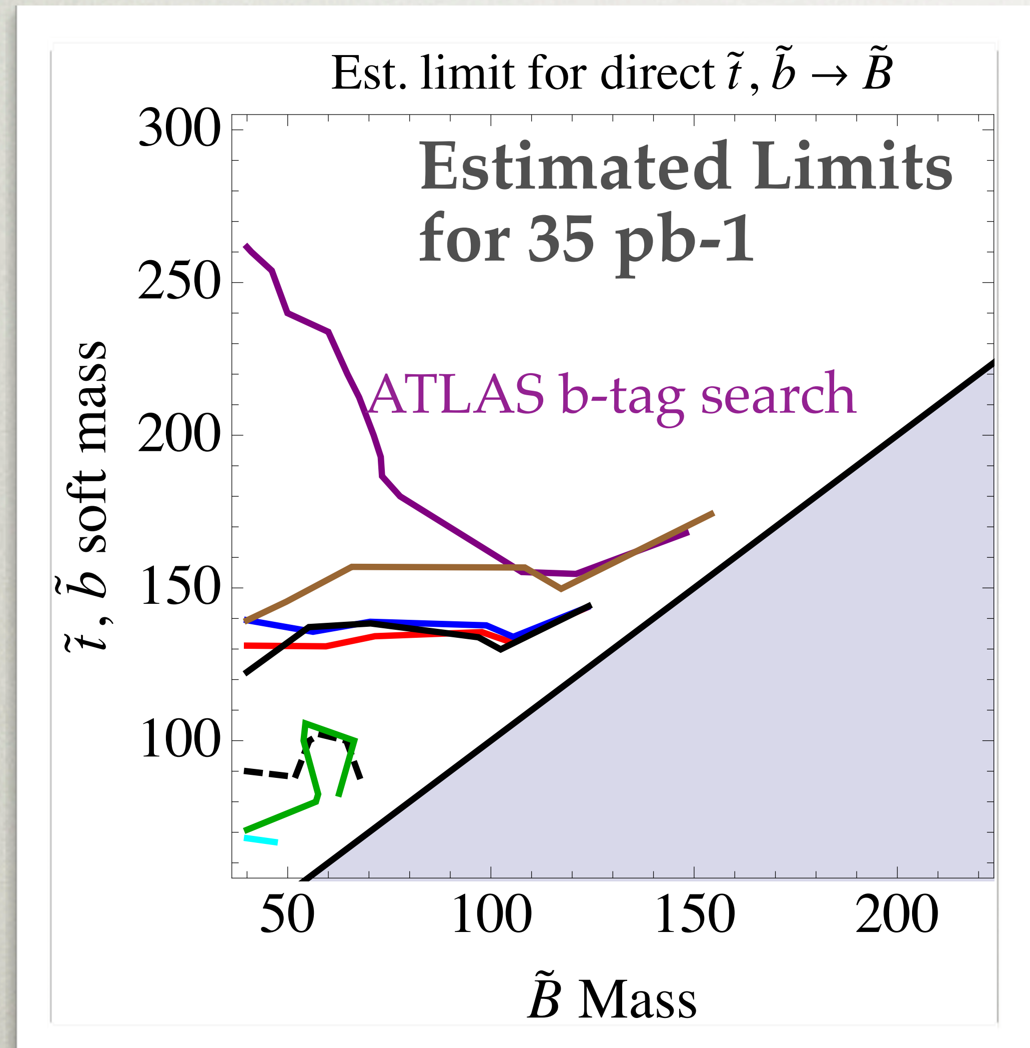
This region only x4 below existing sensitivity!

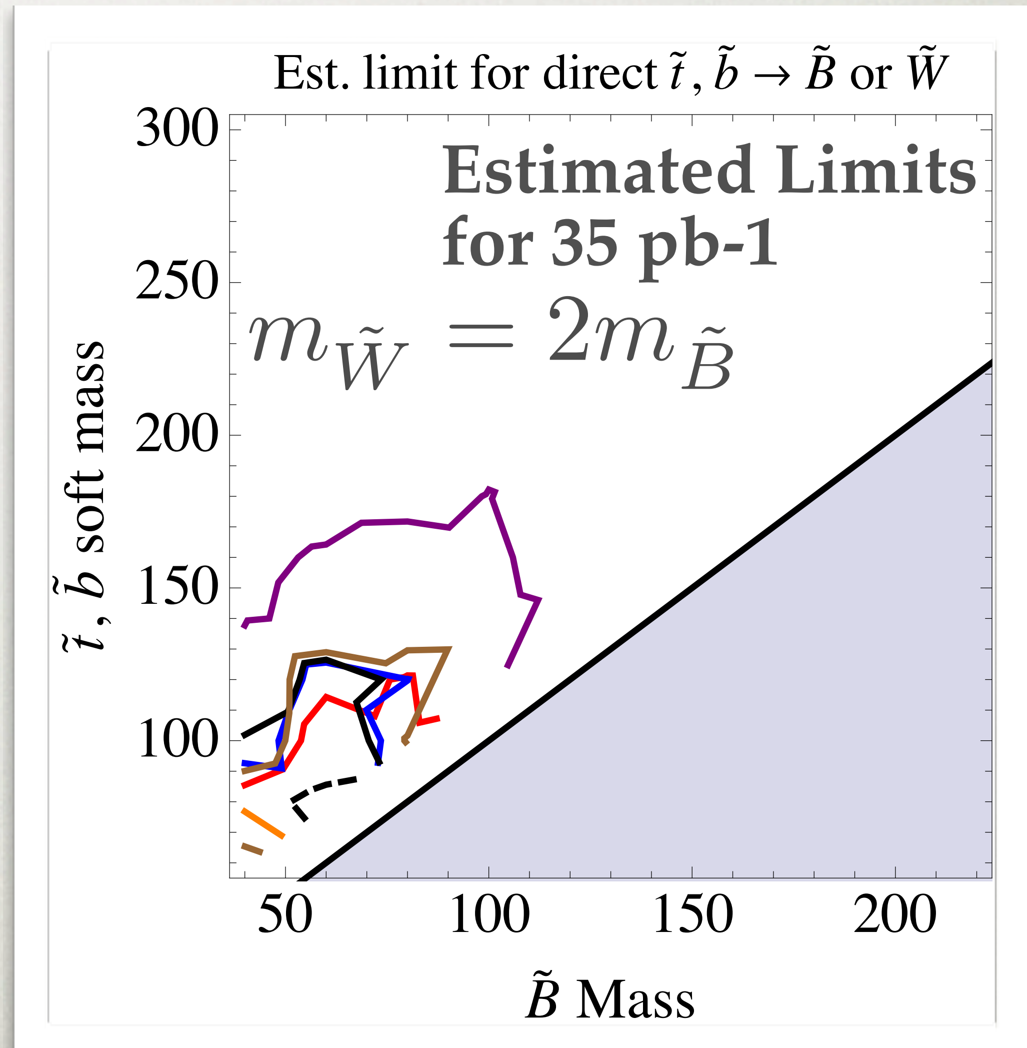
(despite low efficiency of M_{eff} cut)



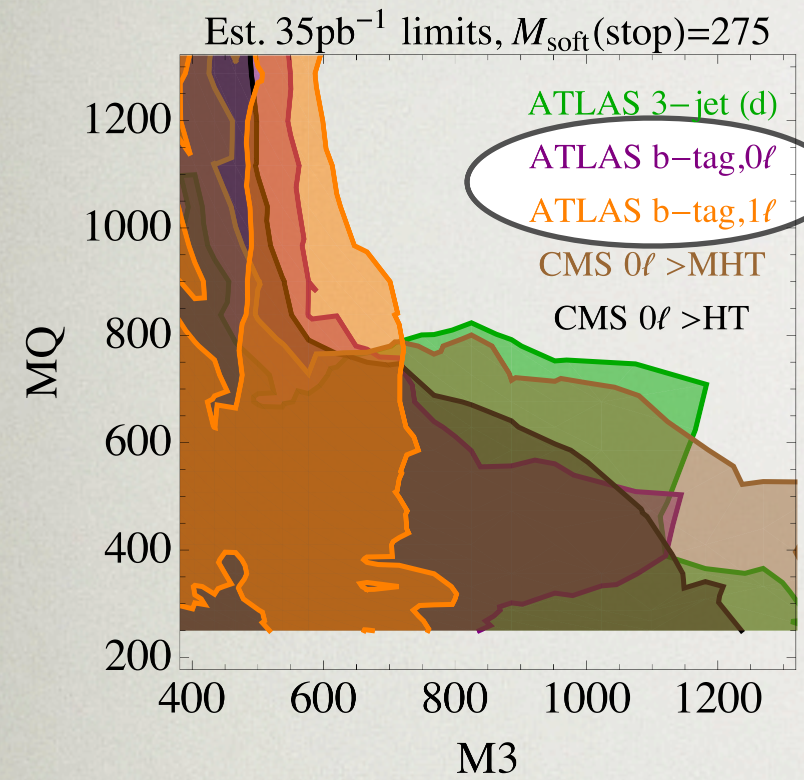
Estimated LHC Sensitivity to light stops

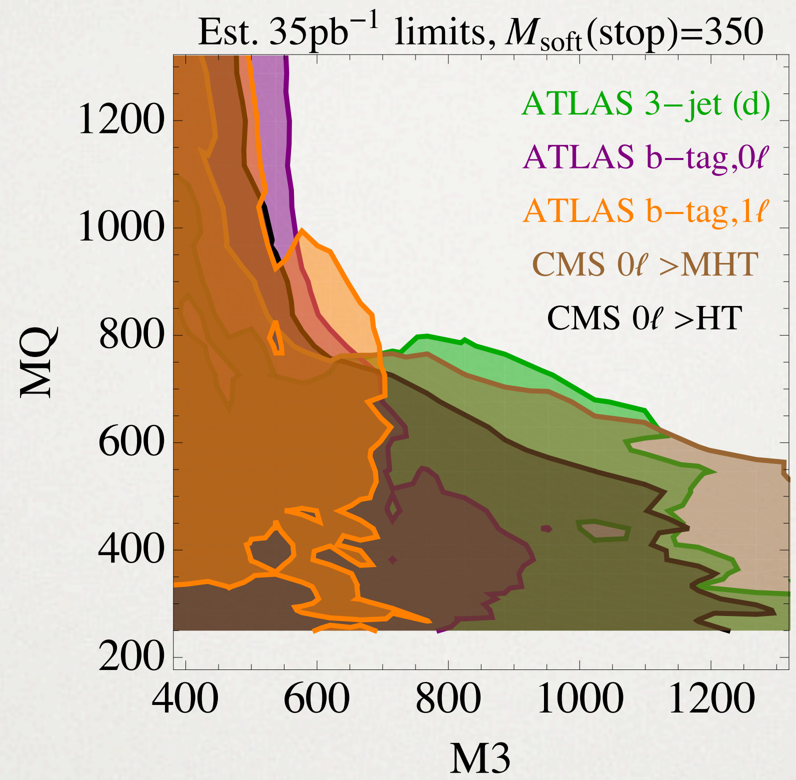
But note that sensitivity is far lower with cascade decays!
→ points to need for dedicated analyses of stop & sbottom production, with and without cascade decay

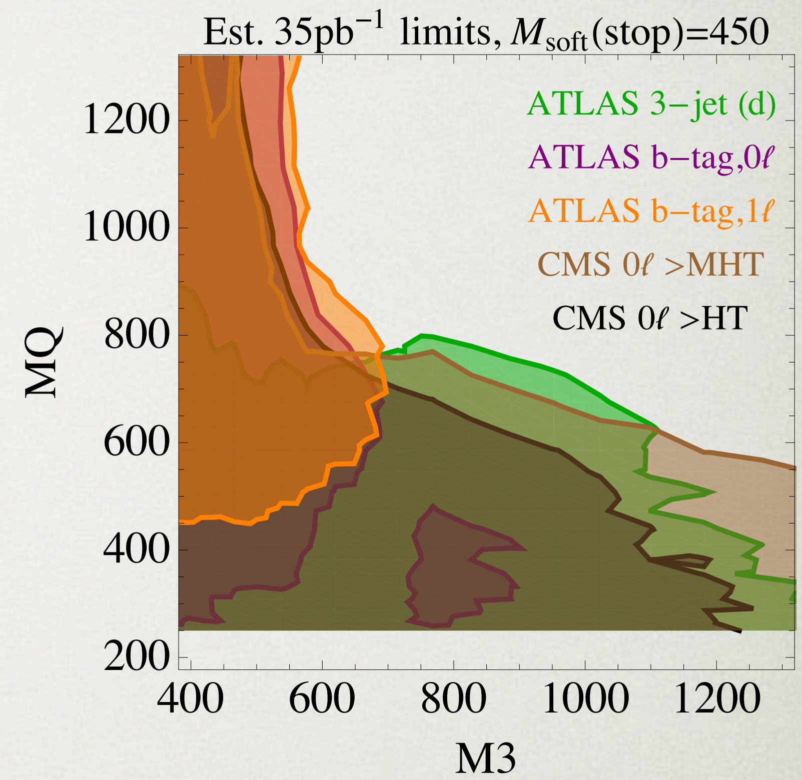




Gluinos, Squarks, and Light Stops





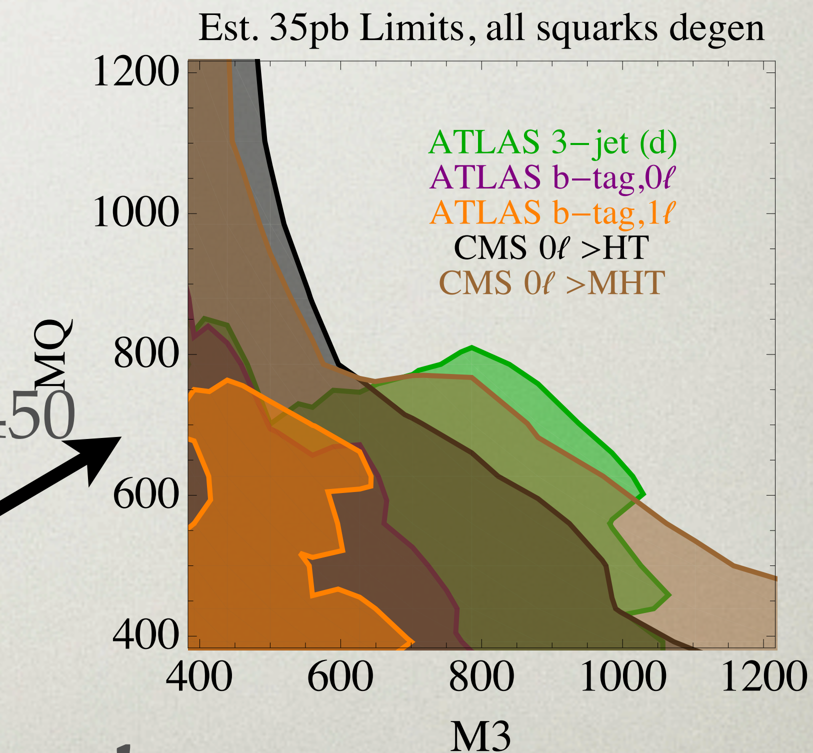


Note b-tag searches with and without leptons

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!

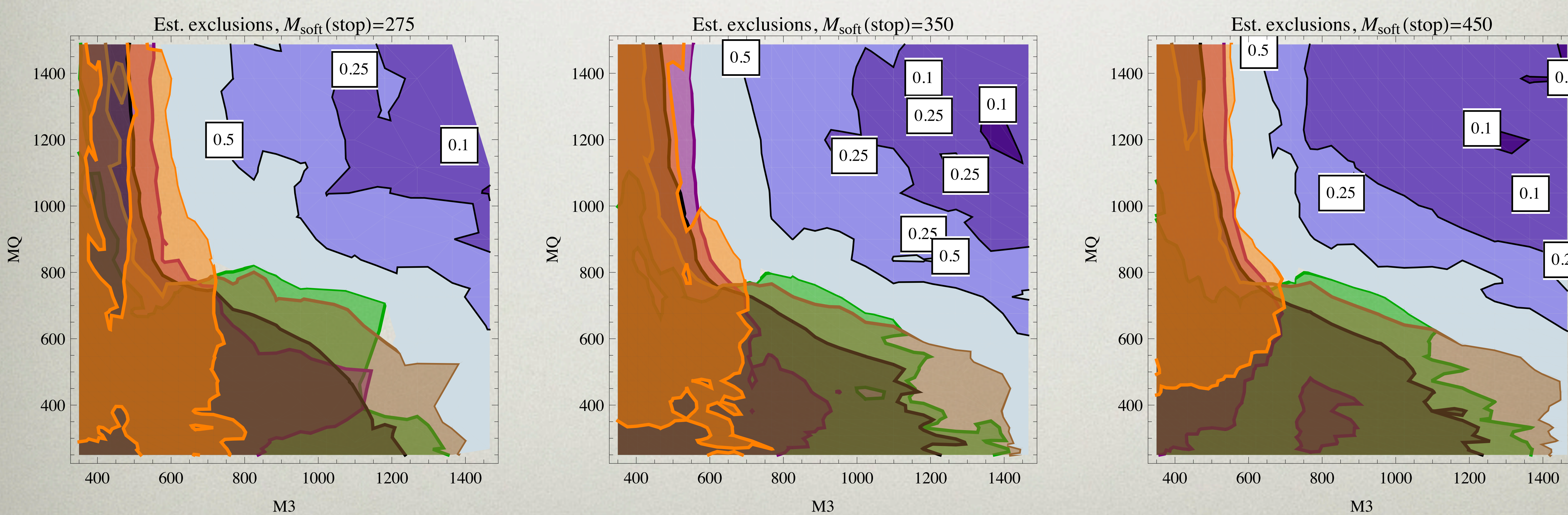
(will be relaxed somewhat for squeezed gaugino spectrum)

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.

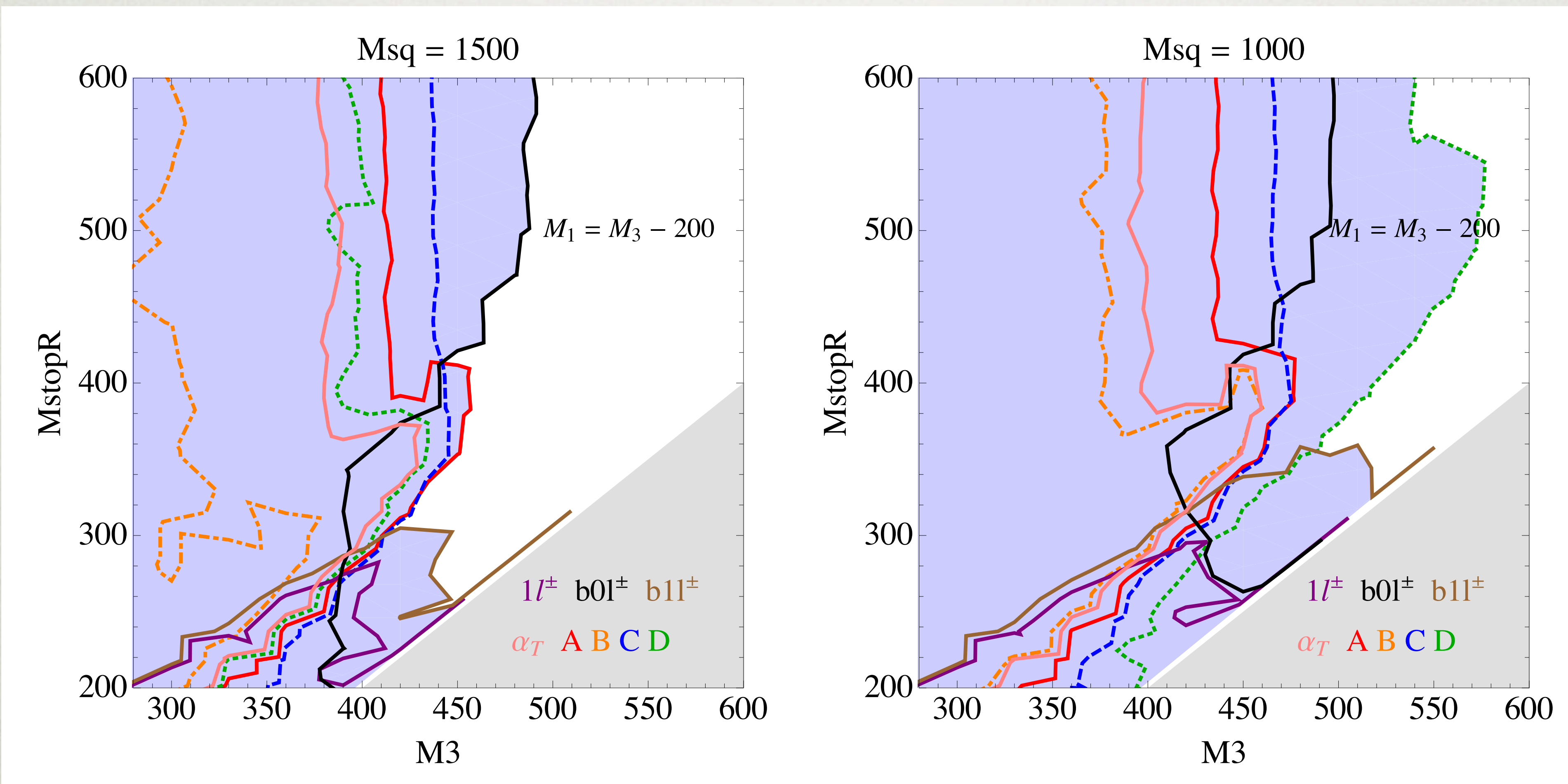
Looking for allowed corners of low-mass SUSY

$\tilde{g}$ (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)

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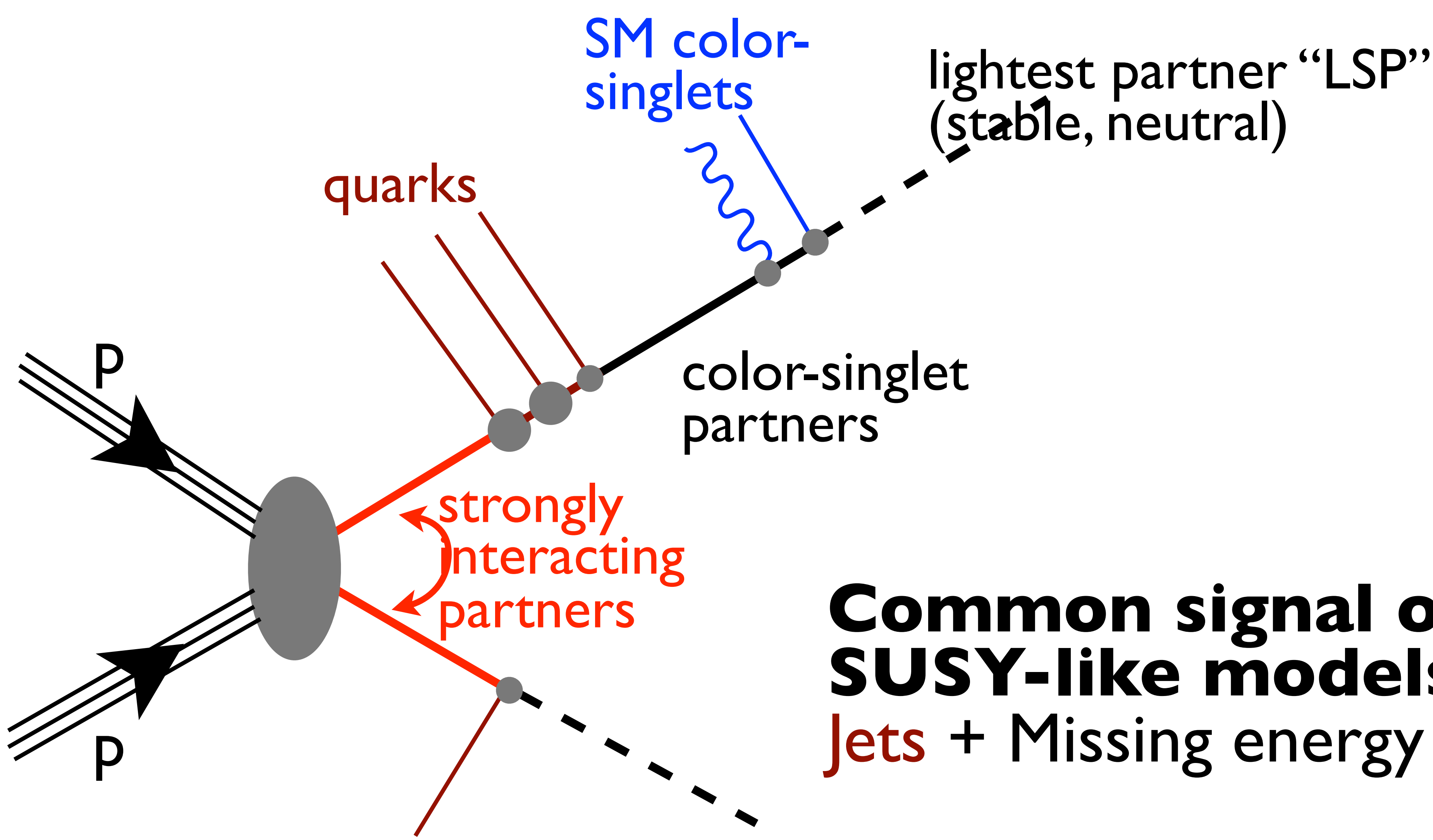
Where else should we Look?



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?

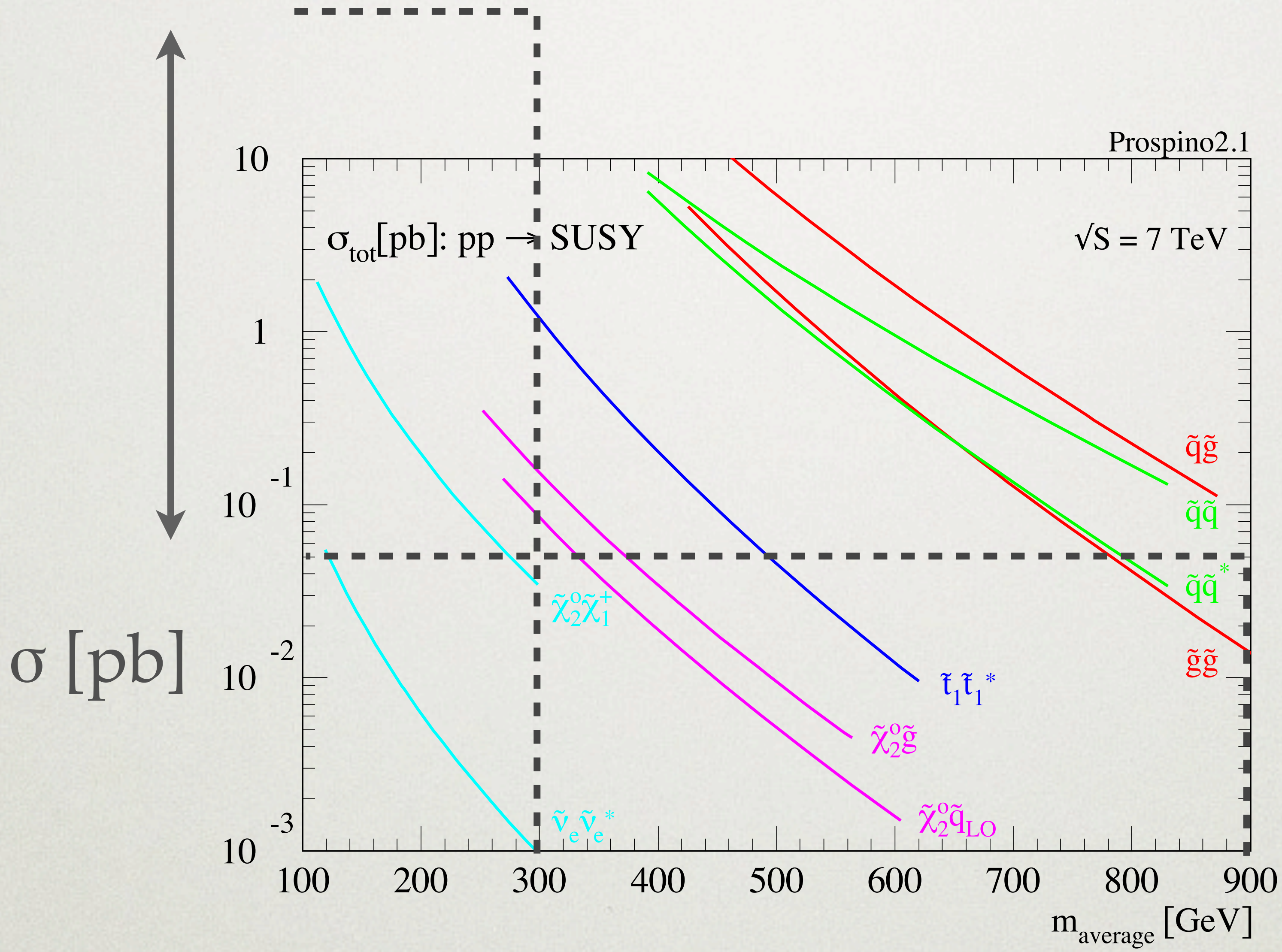
Many scenarios with LSP decay:

- – 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.

Looking for Robust Search Regions

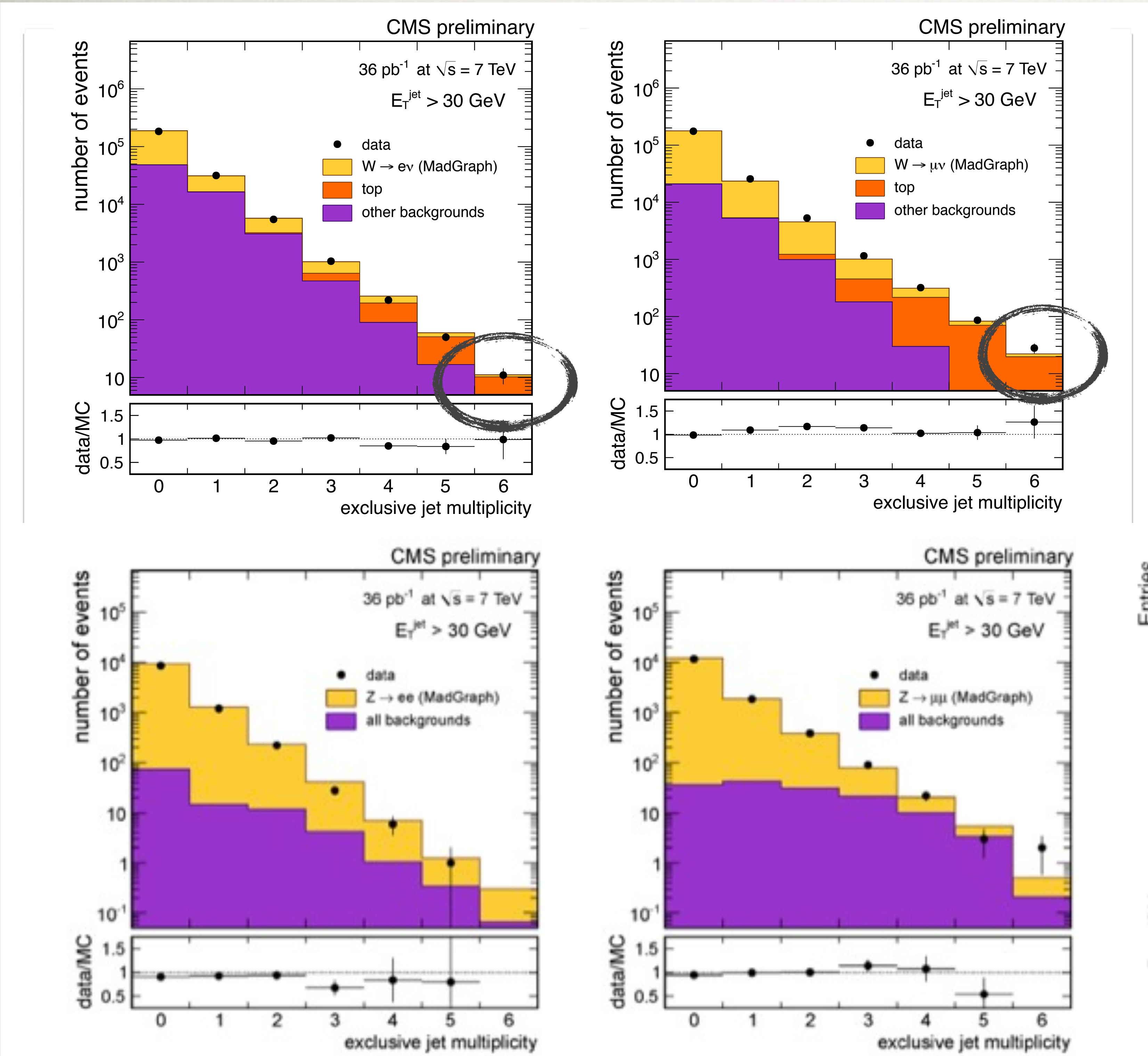


Sub-TeV strong production cross-sections ~30 fb – 100 pb

⇒ All regions with ≲ pb Standard Model rates are potentially fruitful search regions

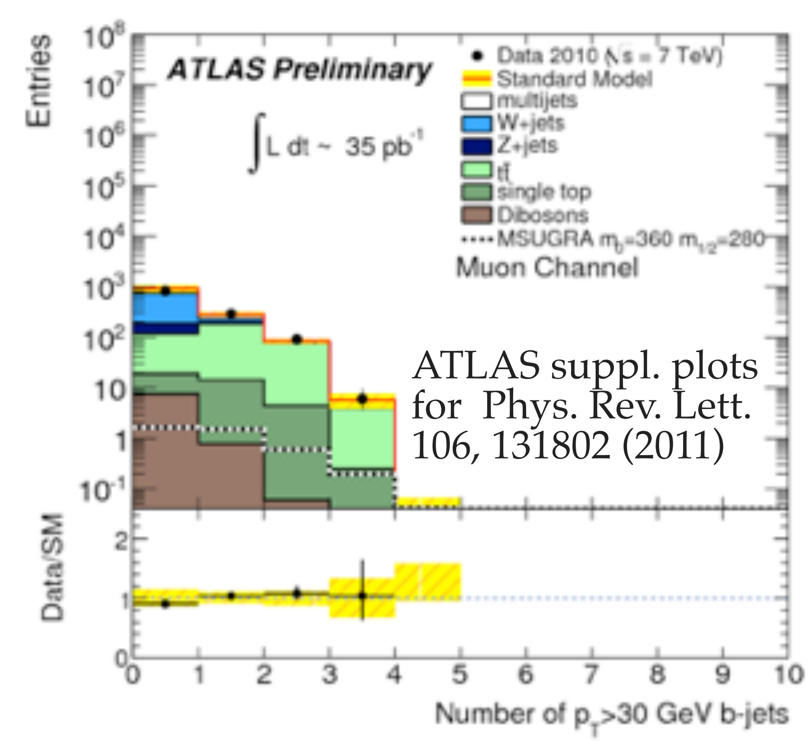
Candidate High-Multiplicity Final States

CMS-PAS-EWK-10-012



W(e and μ)+6j channels ~1 pb after efficiency, dominated by top+jets

γ+jets and QCD multijet could be interesting too

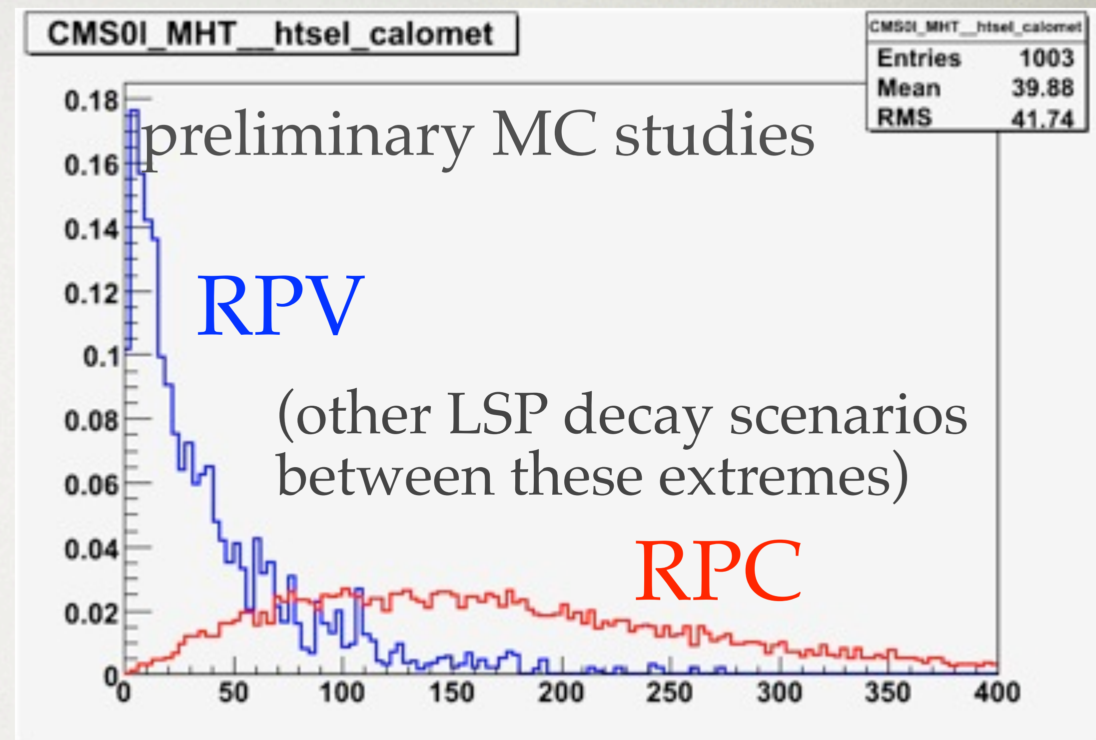


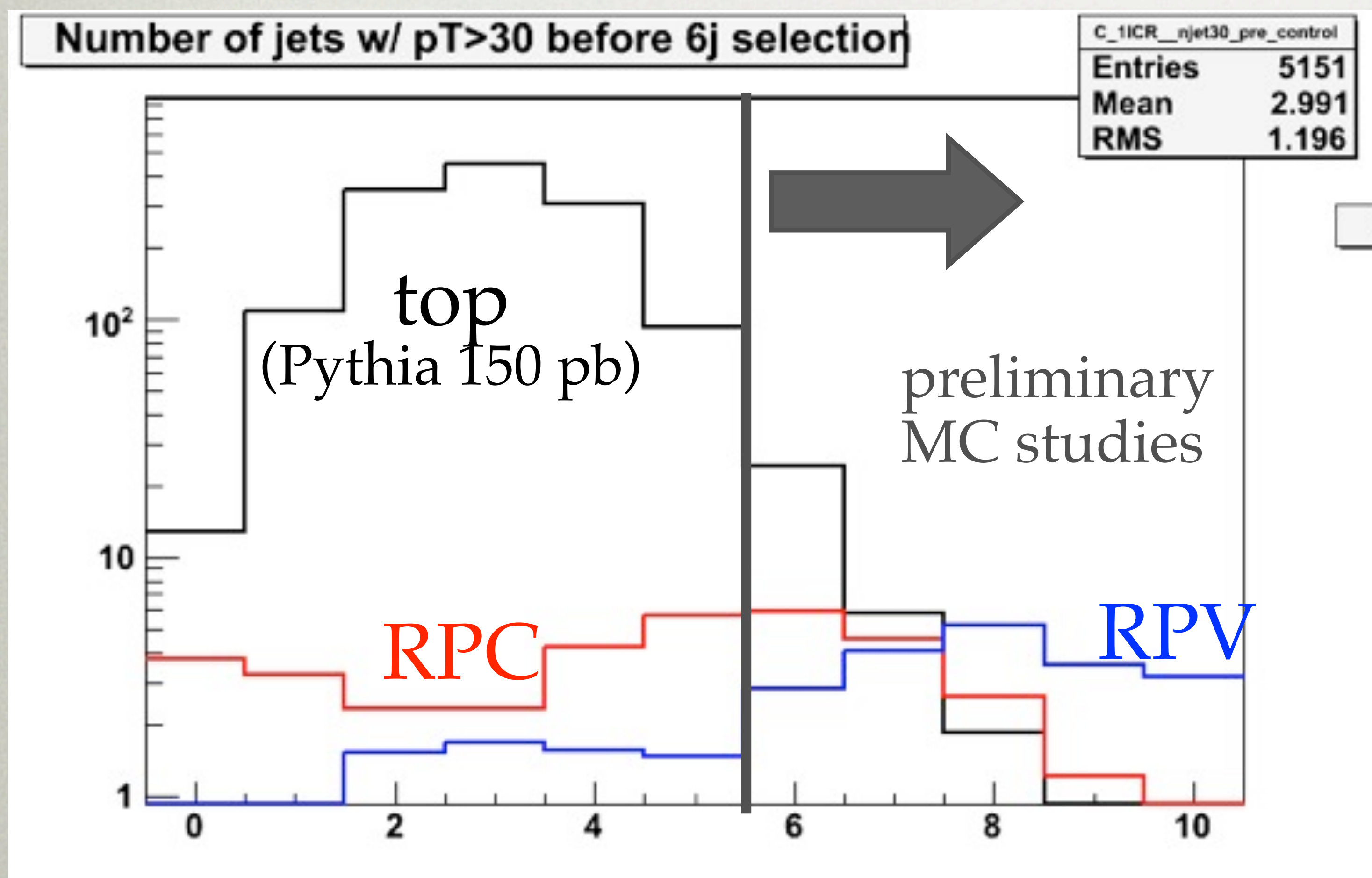
ATLAS suppl. plots for Phys. Rev. Lett. 106, 131802 (2011)

Searching in W+6 jets?

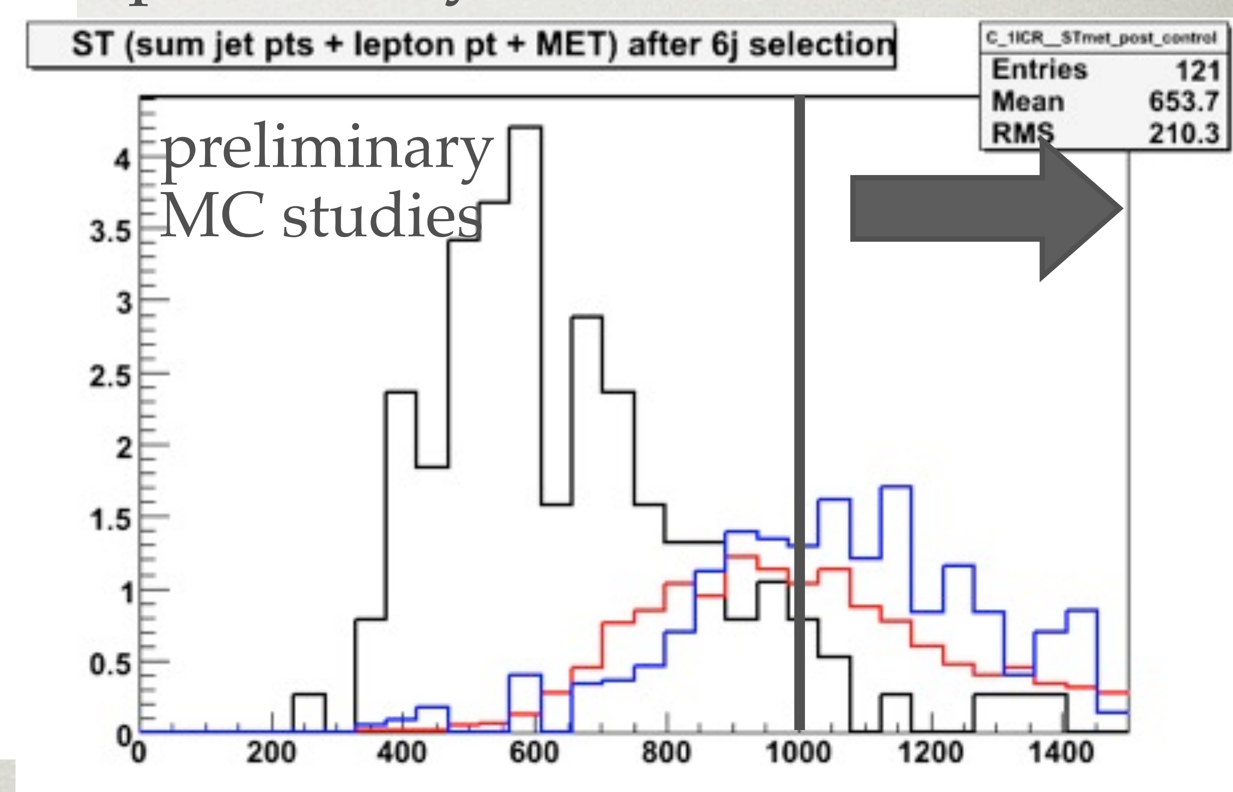
Candidate signal:

- "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



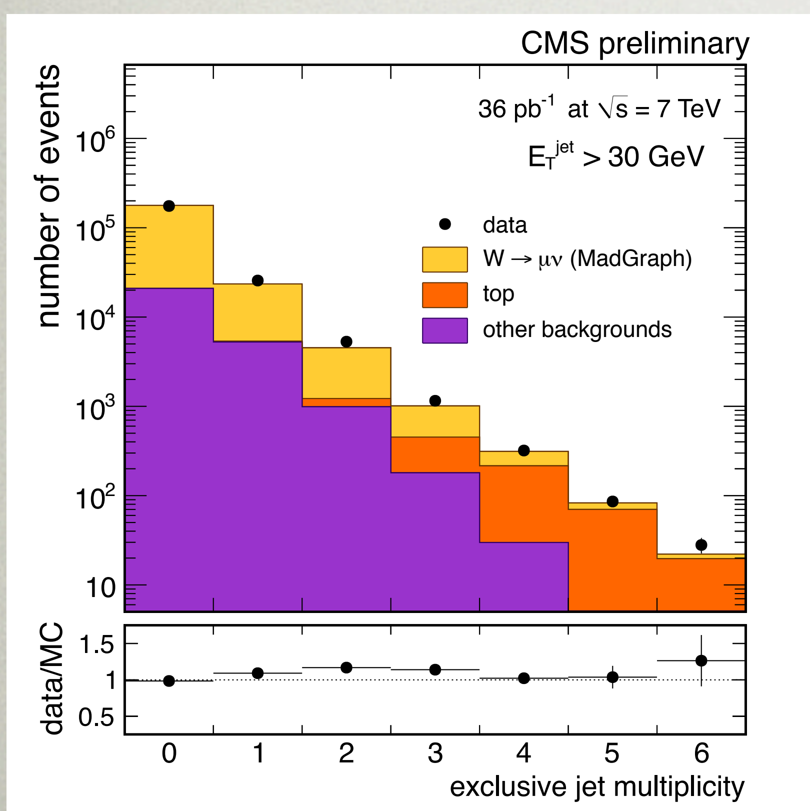
...ongoing work (with M. Lisanti, M. Strassler, N. Toro) exploring viability for various signatures

Rough guesses at where such a search might be useful

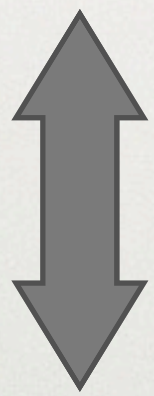
(vanilla SUSY model, with and without RPV)

Dashed lines are rough count requirements: 50%, 50%, and 100% of ttbar rate after increasingly hard S_T cuts

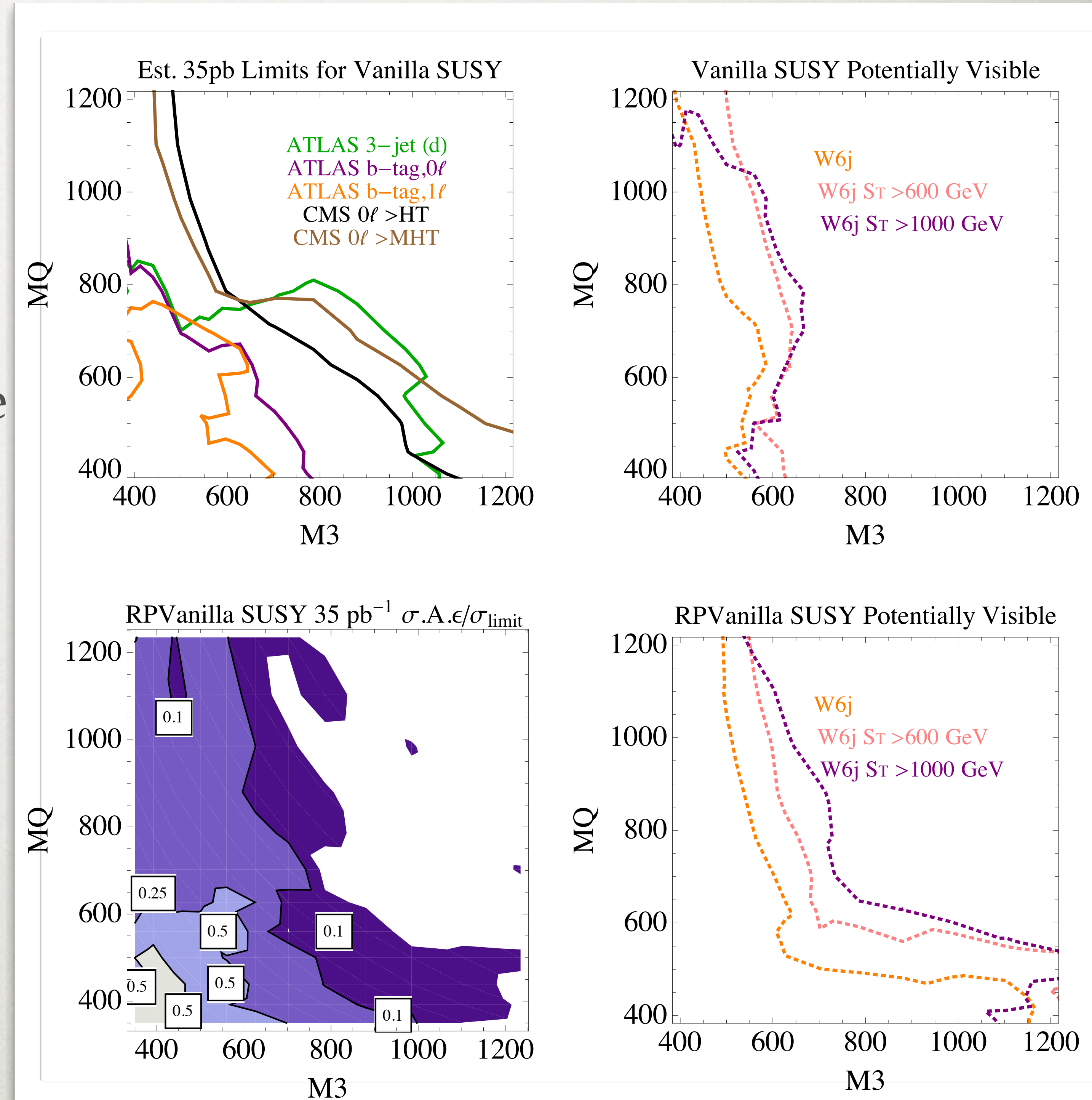
could be sensitive to gluinos with *or* without LSP decay, and to squarks when LSP is unstable



Stable LSP

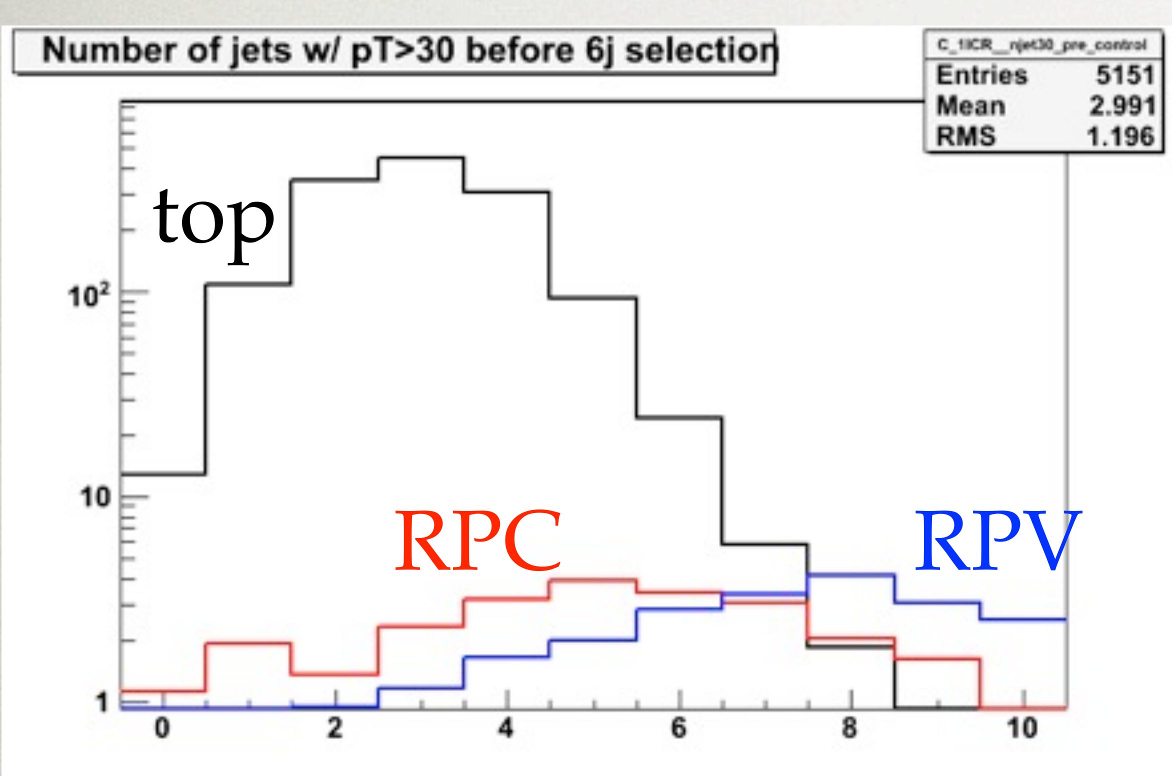


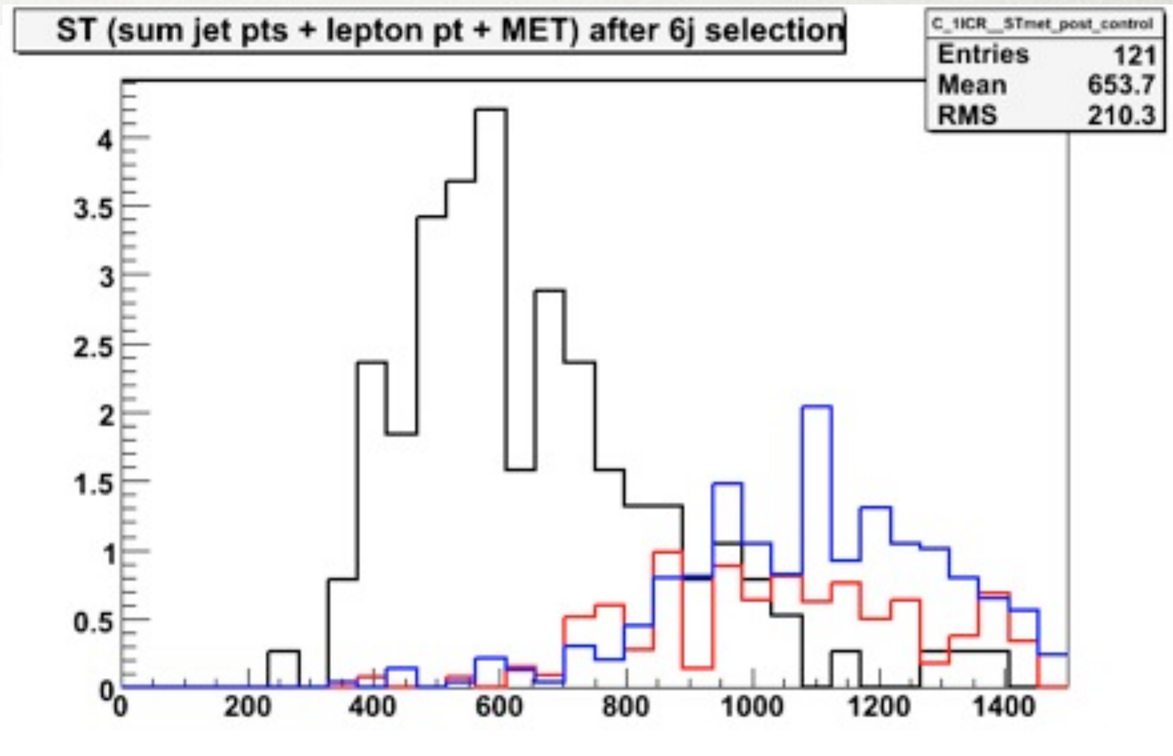
RPV: LSP →3jets

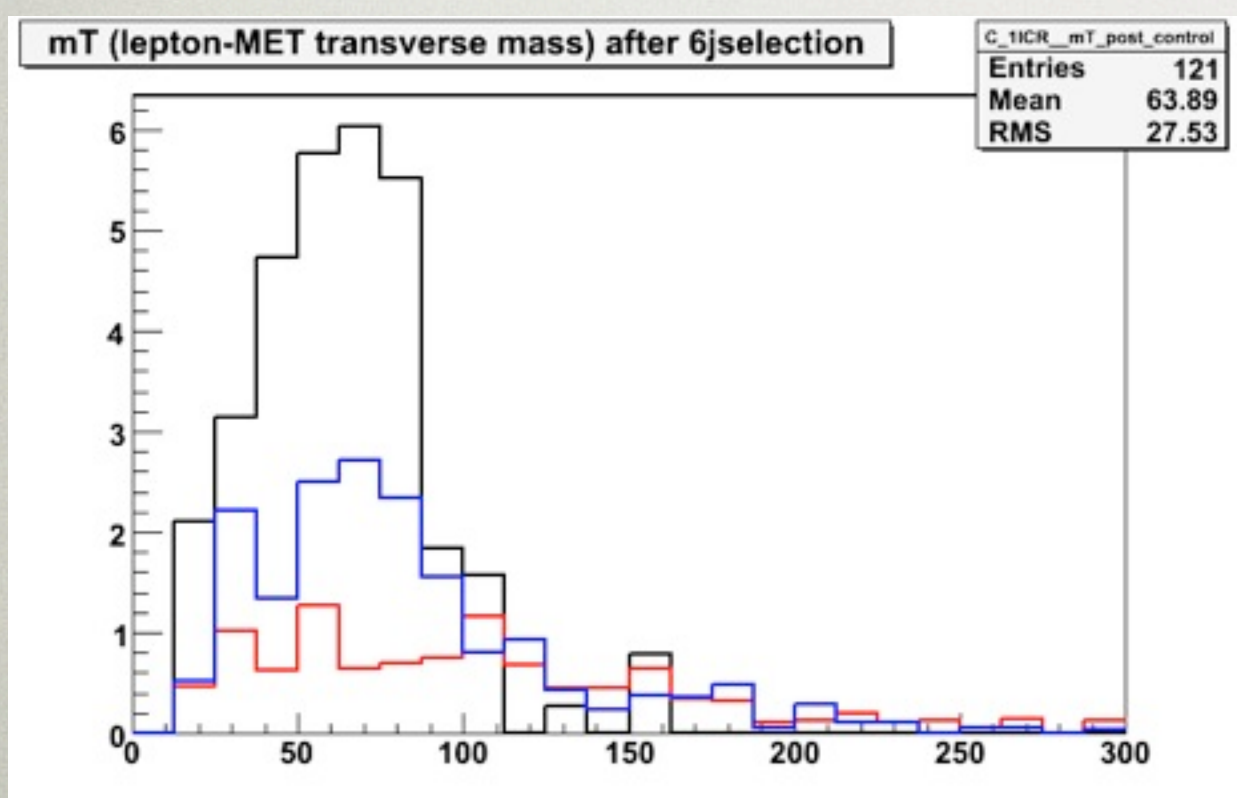


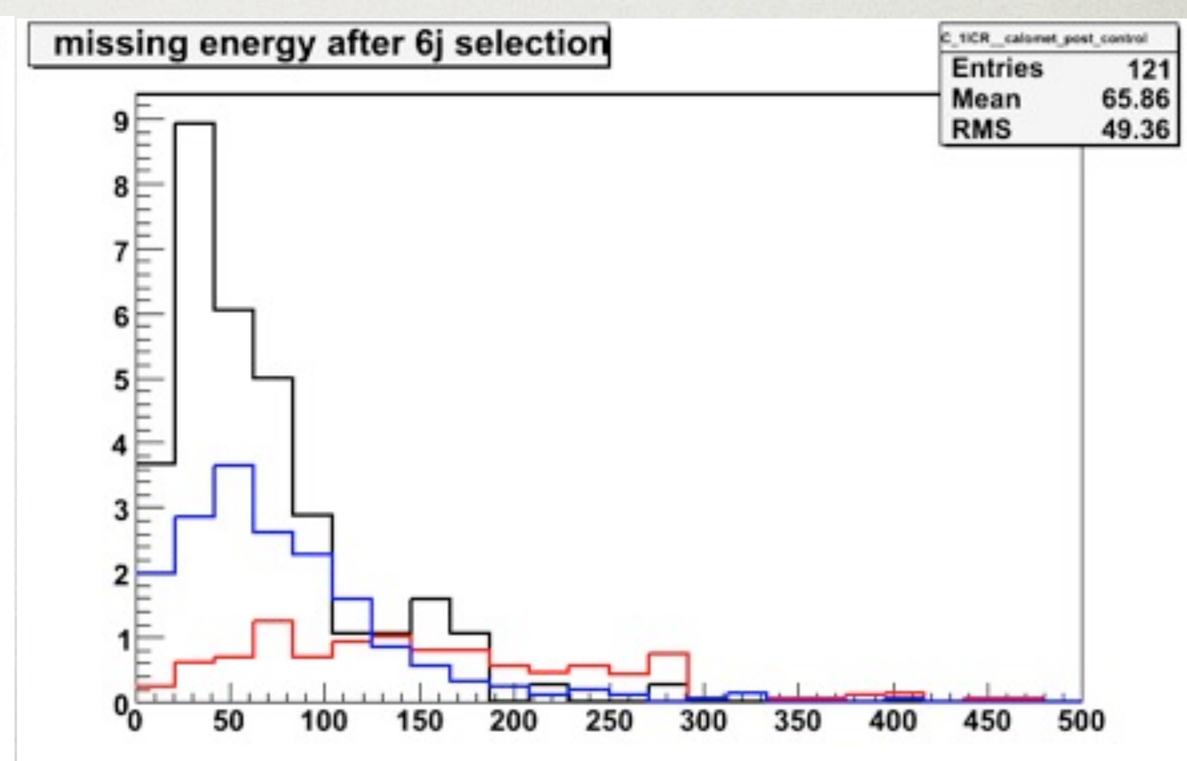
(note LSP → invis + 1 or 2 jets is very reasonable, falls between these extremes)

Same channel also seems promising for light-stop cases (enhanced jet multiplicity from top in cascades)









RPV almost identical to top in MET, m_T!

Thoughts and Questions

- It's pretty clear that many signals I thought were "hard" to see can be excluded by counts alone, and even more using high-S_T tails (contributions to high enough jet multiplicity will exceed signals from SM processes)
  - for this reason, the multijet and W,Z+jets samples will be interesting.
- What's much less clear to me is what it takes to measure 6-jet background and either argue that theres a signal there, or set tighter exclusions.

Summary

- Studying searches using simplified models makes it clearer what is being covered and where the boundaries of sensitivity are located. Efficiency information is very useful!

- ATLAS and CMS can likely make a strong statement about light stop/sbottom scenarios this year -- good to be especially thorough with the heavy flavor searches.

- Standard Model measurements and kinematic plots make it possible to identify "high impact" regions where additional searches may be possible -- want to maximize sensitivity to a broad range of new physics.
- Ready to characterize any new physics evidence.