Lessons From the First Round of Searches at the LHC

Philip Schuster (Perimeter Institute)

UC Davis SUSY Recast Workshop
April 8 2011

In collaboration with Natalia Toro, Josh Ruderman, Matt Strassler, Mariangela Lisanti, Neal Weiner, and Nima Arkani-Hamed

New Physics in LHC Data?

As CMS & ATLAS explore the weak-scale:

- How robust is the sensitivity to new physics?
- Where are there weaknesses?
- What are we already learning from null results?
- What does the Standard Model look like at 7 TeV, and what does this mean for future search strategies?

Topics of this workshop:

Benchmarks for new physics that might be missed?

Developing a method for recasting search results applied to new models?

ATLAS/CMS/Theory Workshop
(CERN June 4 2010 & CERN Nov. 5-6 2010):
"Characterization of New Physics at the LHC I & II"
http://indico.cern.ch/conferenceDisplay.py?confId=94910
http://indico.cern.ch/conferenceDisplay.py?confId=107769

Discussed approaches to characterizing new physics; identified need for a 'canonical' set of topologies

Theory Workshop (SLAC Sep 22-25, 2010):
"Topologies for early LHC searches"
http://www-conf.slac.stanford.edu/topologies10/

Developing a proposal for a baseline set of "simplified models" (SMS) to encapsulate important topologies

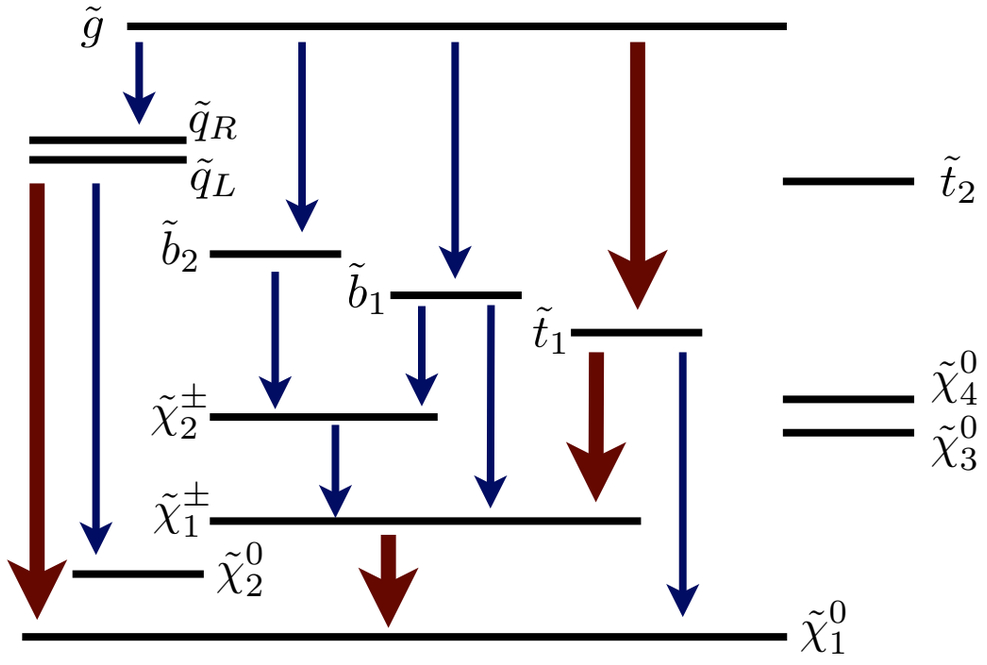
Simplified Models **For** Collider Physics

Most **Simplified Models** are perfectly valid models, but they are not built to illustrate theoretical mechanisms

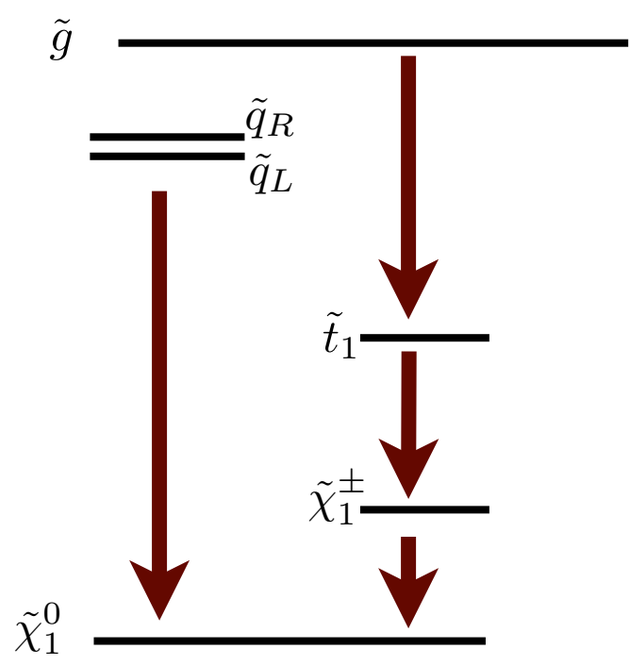
SMS are built to emphasize features of an underlying spectrum that matter in a collider search, or in characterizing signals.

Example

Spectrum Inspired from SUSY



Simplified Model



What set of SMS represent SUSY topologies?

Uses of Simplified Models

Describe physics reactions that can be used to develop or optimize search selections

Use SMS to quantify search sensitivity (i.e. signal efficiencies): clearer and more exhaustive than specific benchmarks

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

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LHC New Phyics Working Group

We are a group of theorists who have formed a "New Physics Working Group" (NPWG) to address questions surrounding characterization of search results from the LHC. Of particular emphasis is improving the model-independence of methods used in new physics searches and any characterization of signals.

This effort was initiated by a workshop on this topic at a joint ATLAS, CMS, and Theory meeting at CERN in June 2010. One outcome of this workshop was a request by ATLAS and CMS to the theory community to help develop a collection of topology sets representative of new physics that could appear at the LHC. The intention is to use these topology sets to ensure that searches explore all relevant phase space, and to facilitate more effective communication of results from the LHC.

At the meeting Topologies for Early LHC Searches, the participants (theorists largely) began defining a set of baseline topology sets, or simplified models. These simplified models are designed to cover signature space and include detail important for optimizing searches. Particular attention was paid to including topologies inspired from a broad array of well-motivated theories.

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  Composite Gluon To Invisible
- J.006
  Two Jets, Leptons and MET
- L.008
  Gluon partner with single stage W & Z cascade decays
- L.001
  SSL1: A Simplified Model for Same-Sign Dilepton + MET + X Search

LHC New Phyics Working Group

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Jets Signatures

J.000: Composite Gluon To Invisible
Author: Jay Wacker
Latest Revision: 000

J.001: Multi-jets plus MET from an initial resonance
Author: Julia Shelton
Latest Revision: 002

J.003: Multijet Resonances (2->2 production only, no MET)
Author: Can Kilic
Latest Revision: 000

J.004: Multijet Resonances Including 2->1 Production (no MET)
Author: Can Kilic
Latest Revision: 000

J.005: Squark Neutralino Associated Production
Author: Jay Wacker
Latest Revision: 000

J.006: Two Jets, Leptons and MET
Author: Eder Izaguirre
Latest Revision: 000

J.007: Three (or more) Jets, Leptons and MET
Author: Eder Izaguirre
Latest Revision: 000

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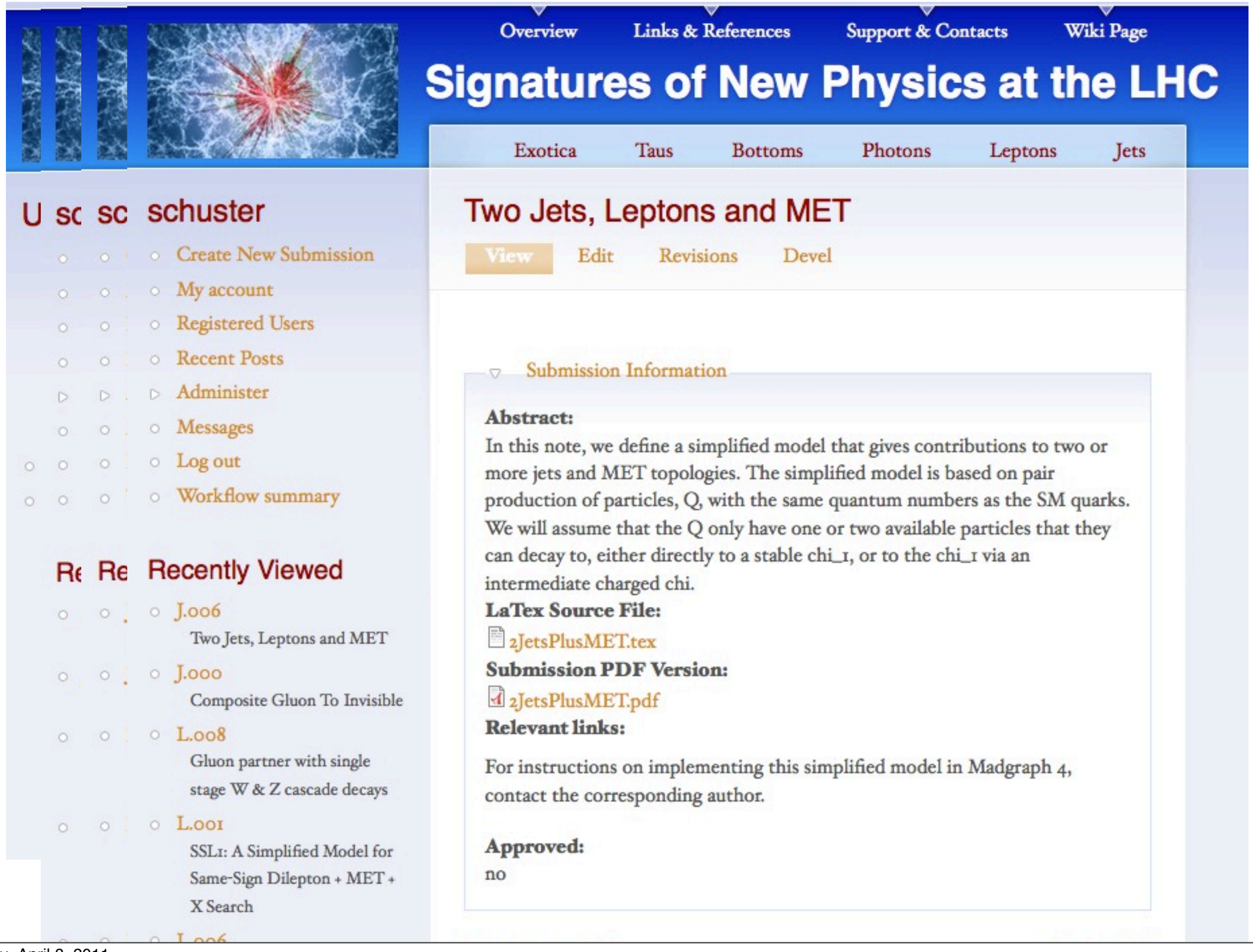

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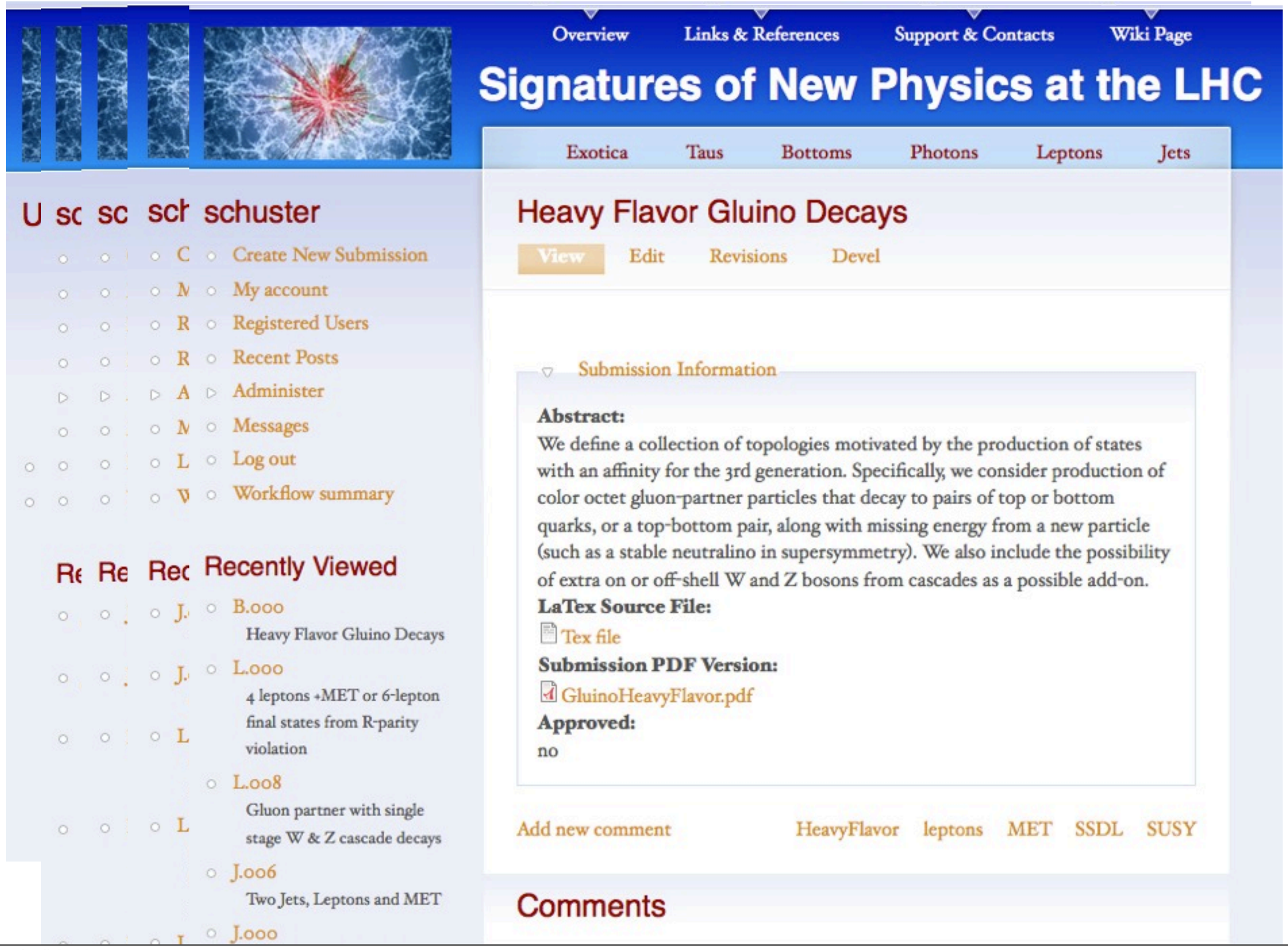

Topologies and Interpreting LHC Search Results

Simplified Models for LHC New Physics Searches

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(LHC New Physics Working Group)

SLAC workshop note in circulation and being edited.
Hopefully public in late April.

Both ATLAS and CMS have provided simplified model interpretations for a variety of searches (in addition to the CMSSM/MSUGRA limits)

This is very encouraging and useful!

SMS are designed mainly to help quantify search coverage. SMS can also be used to set limits on models with related topologies (more on this in tomorrow's talks)

Something like RECAST is designed to make it easier for theorists (or experimentalists) with new models to directly compare the full model against existing searches
This would be great!

Simplified Model Limits from ATLAS and CMS

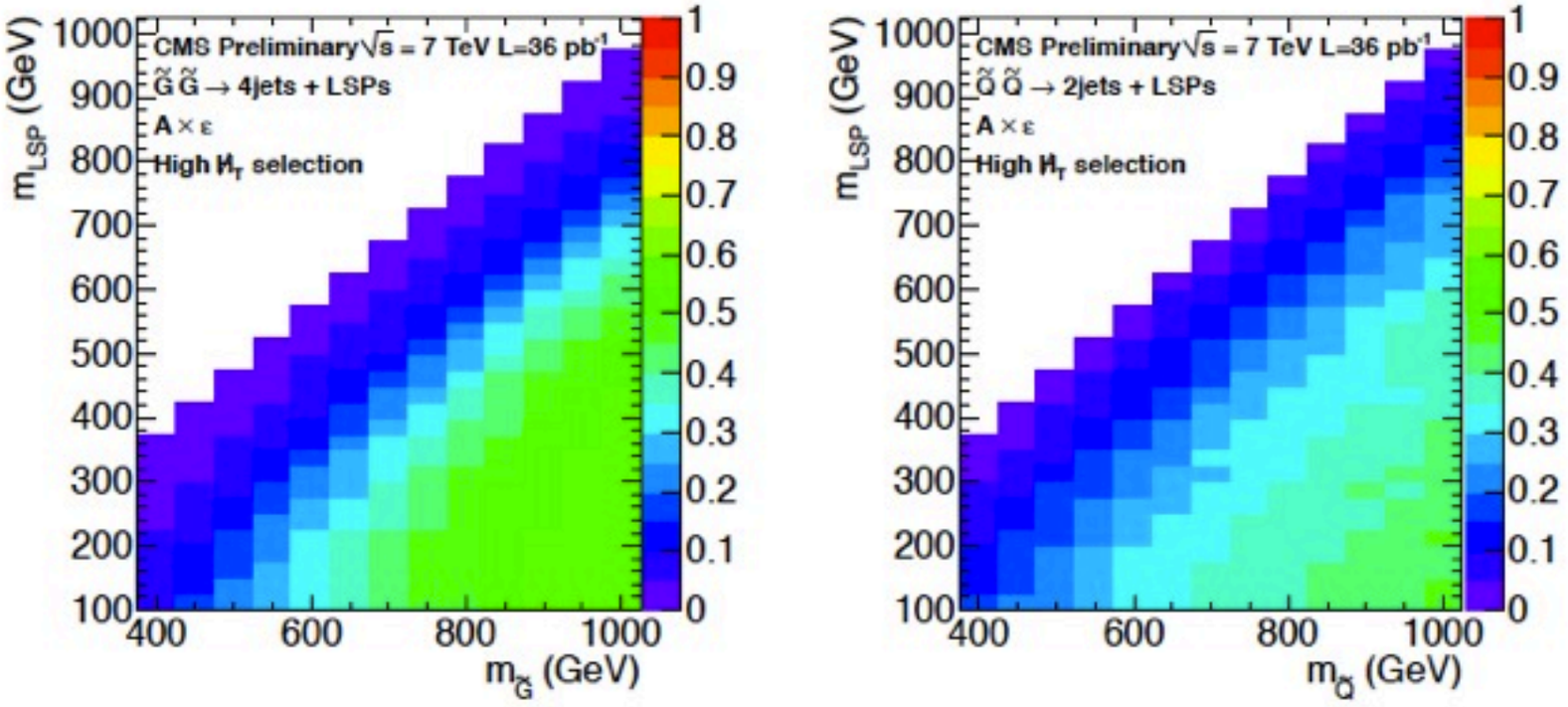


Figure 11: High-$\not{H}_T$ selection efficiency for gluino (left) and squark (right) production as a function of the gluino or squark and LSP mass.

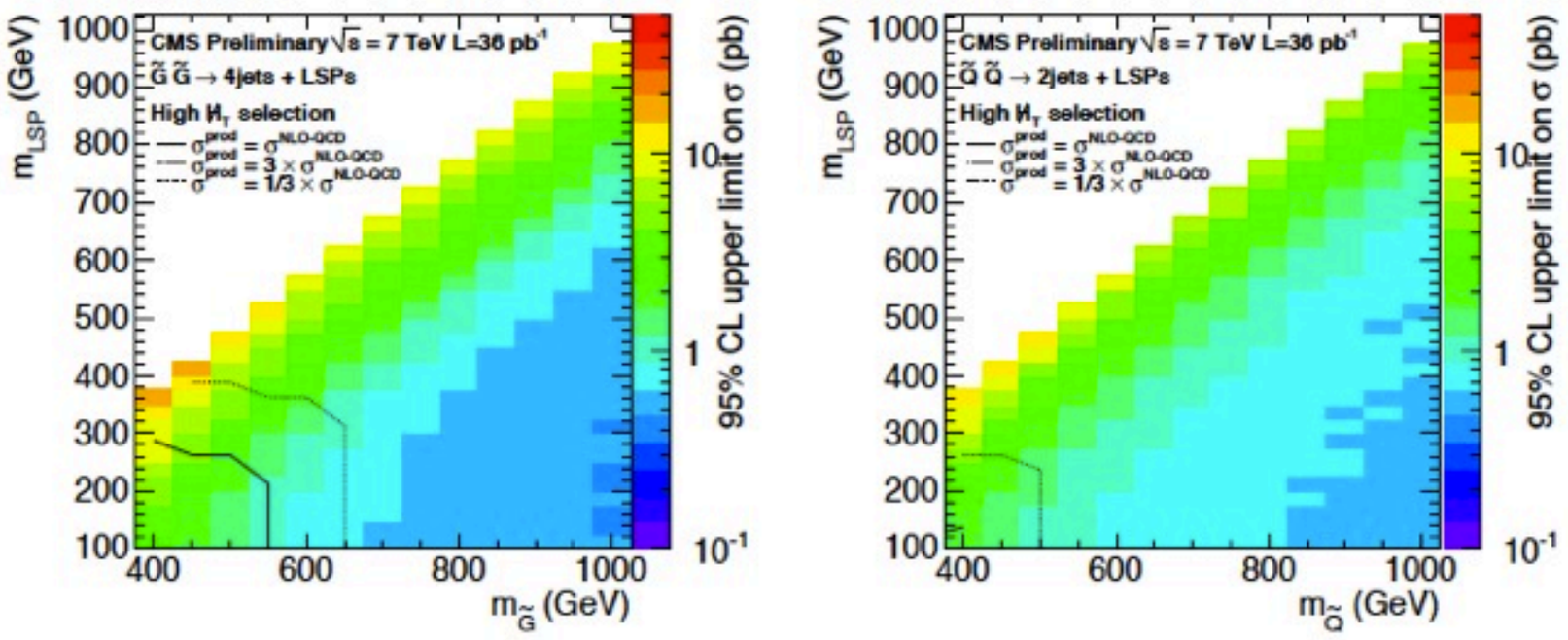


Figure 12: Estimated 95% C.L. exclusion limits for the gluino pair production (left) and squark pair production (right) for the high-$\not{H}_T$ selection.

Search for new physics at CMS with jets and missing momentum

The CMS Collaboration

Many additional plots available online.

Simplified Model Limits from ATLAS and CMS

Further interpretation of the search for supersymmetry based on α_T

The CMS Collaboration

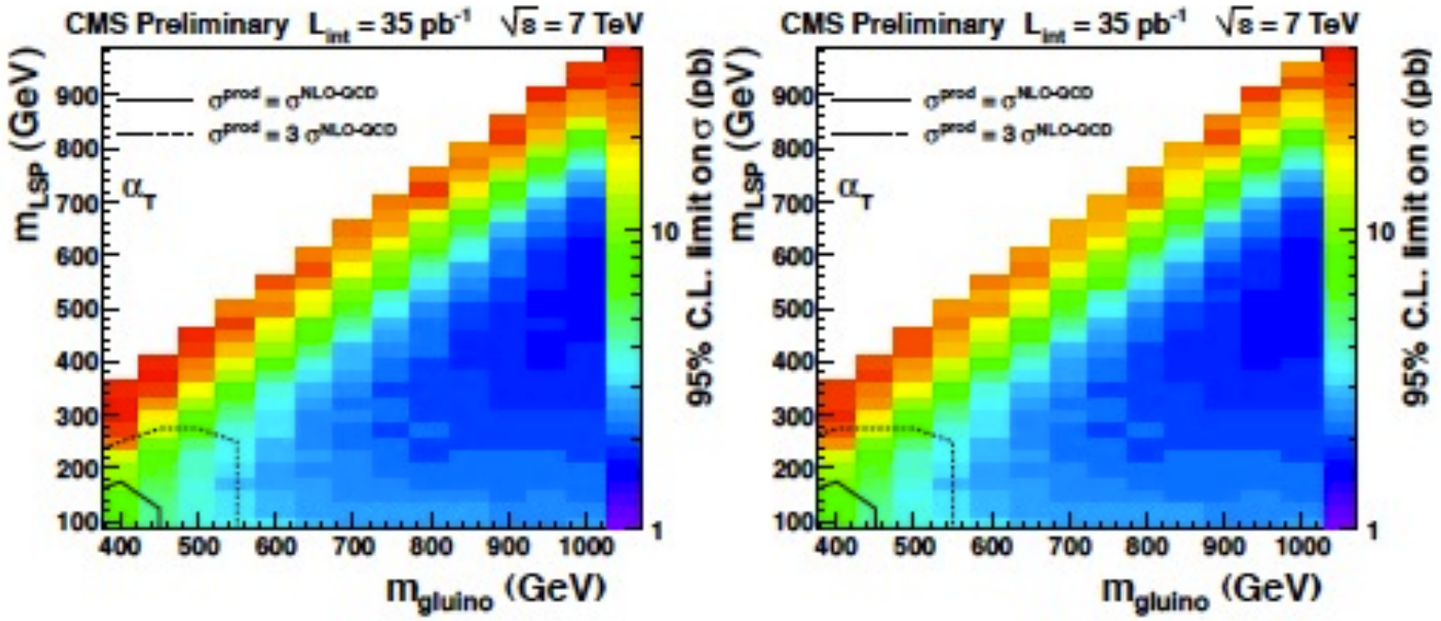
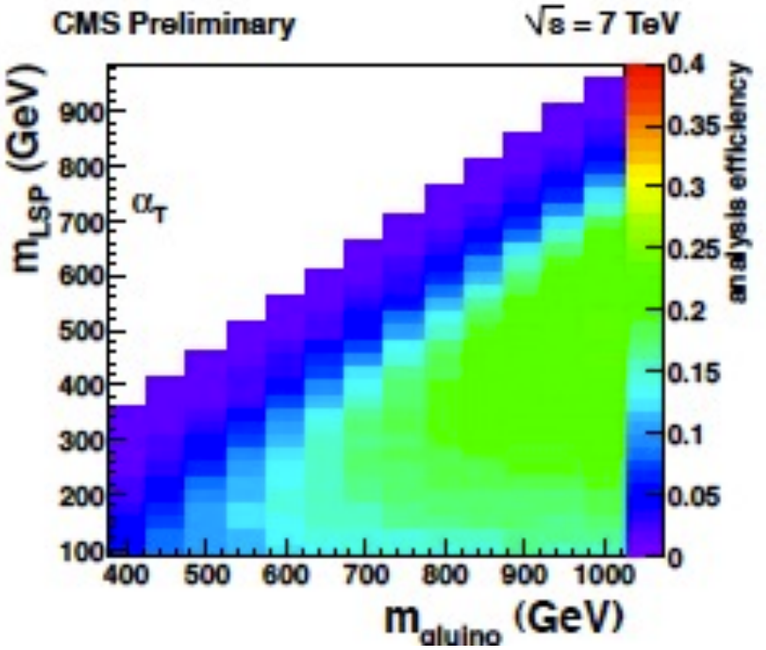
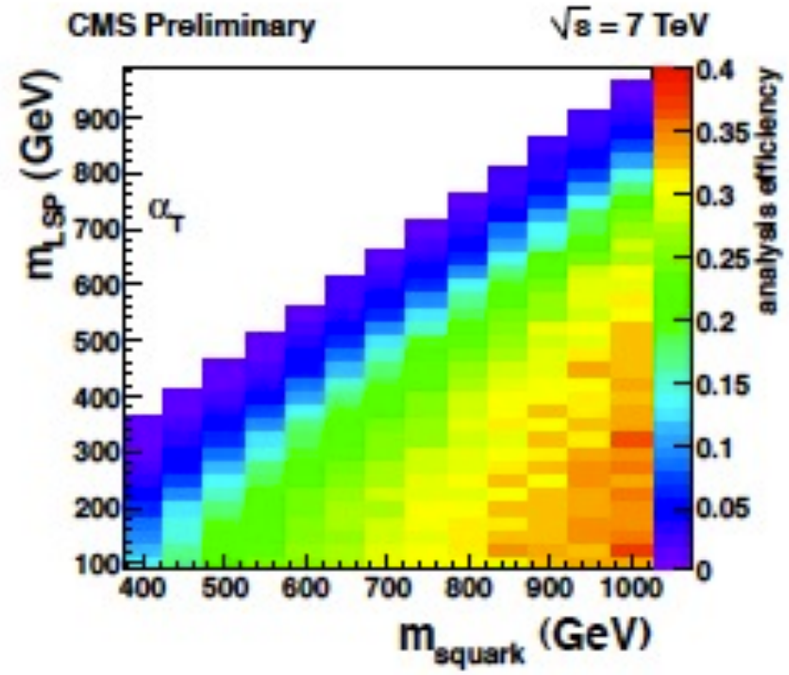


Figure 8: Cross section for the gluino pair production topology excluded at the 95% CL. Overlaid are the excluded regions of parameter space using the reference cross sections σ^{prod}. Left: including theoretical uncertainties; Right: not including theoretical uncertainties.





Many additional plots available online.

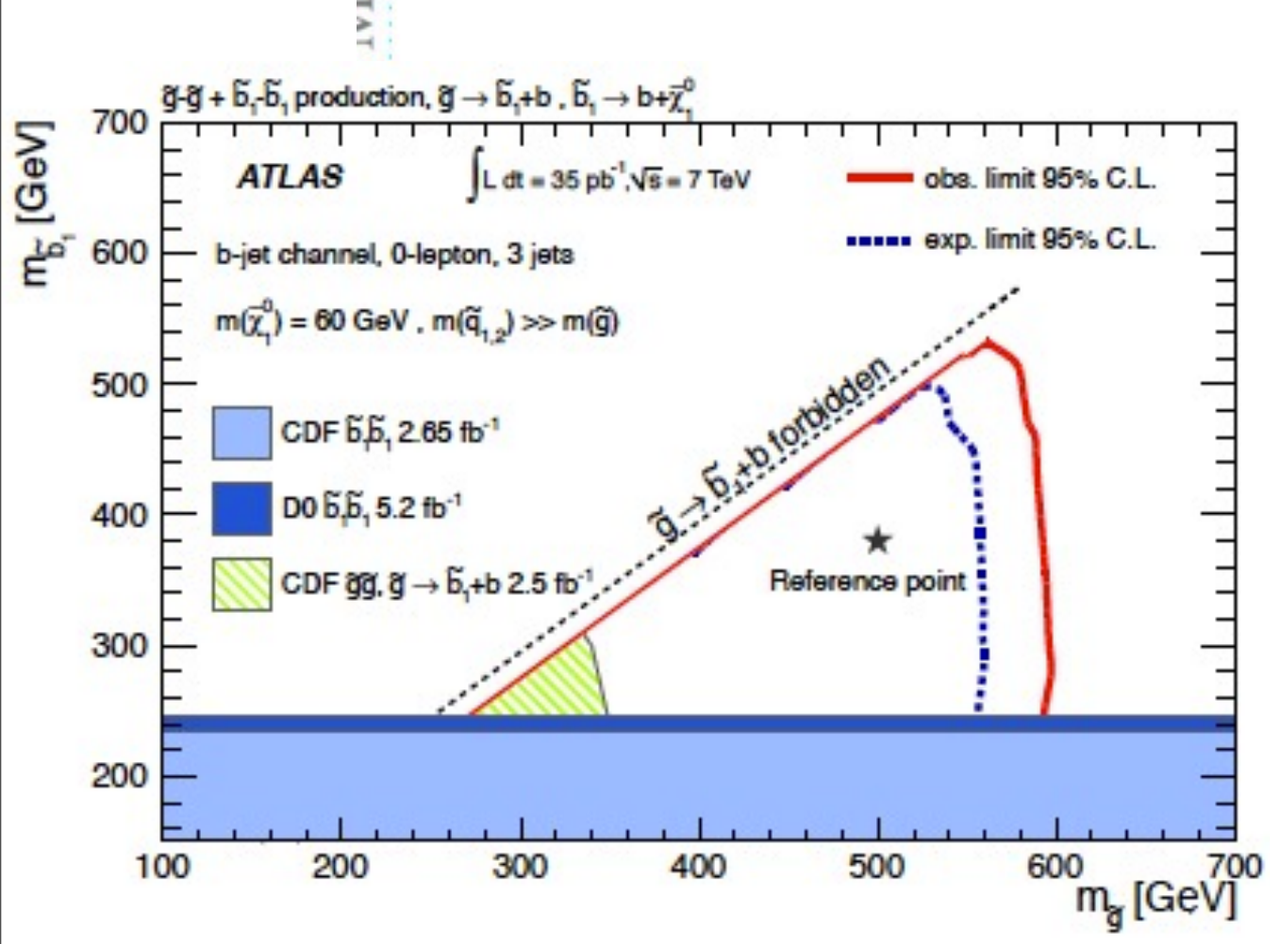
Simplified Model Limits from ATLAS and CMS

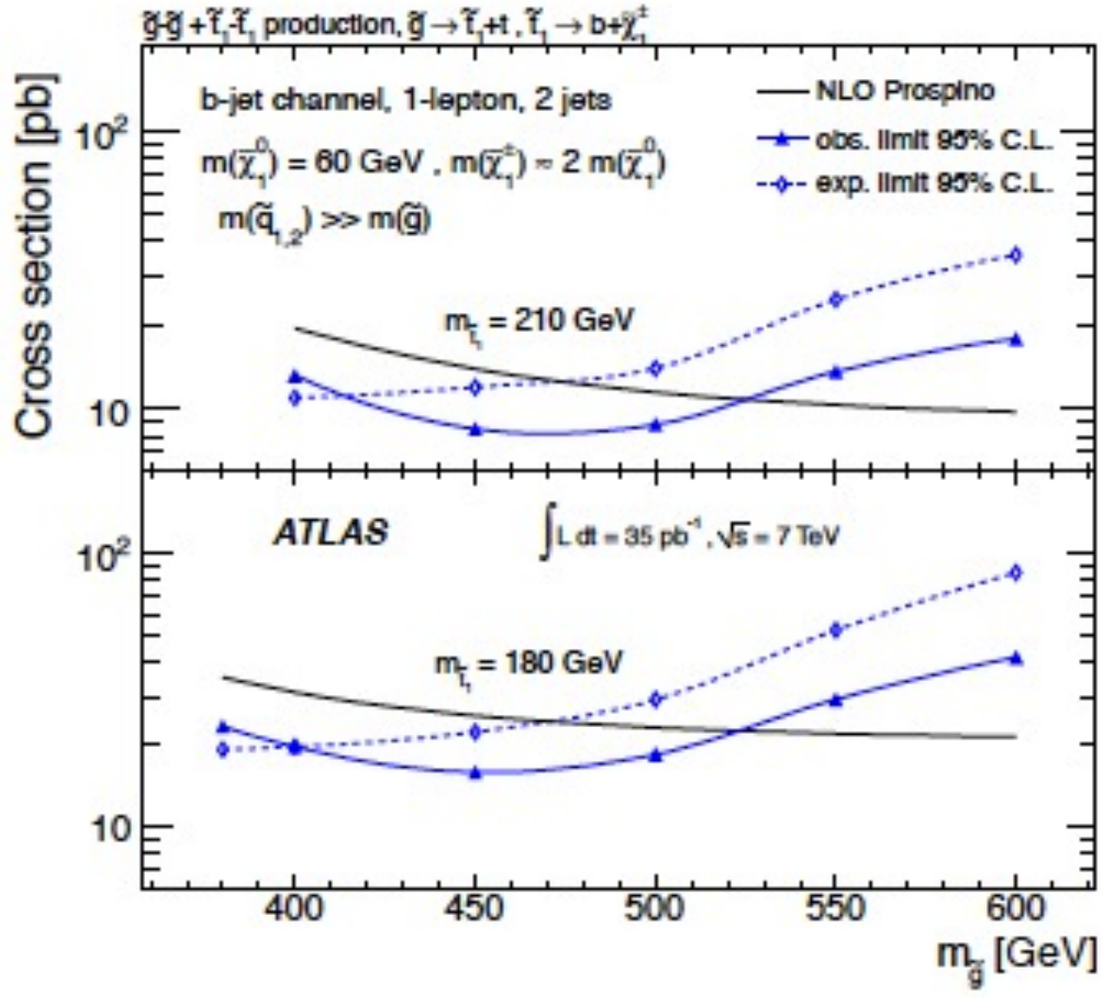
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

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

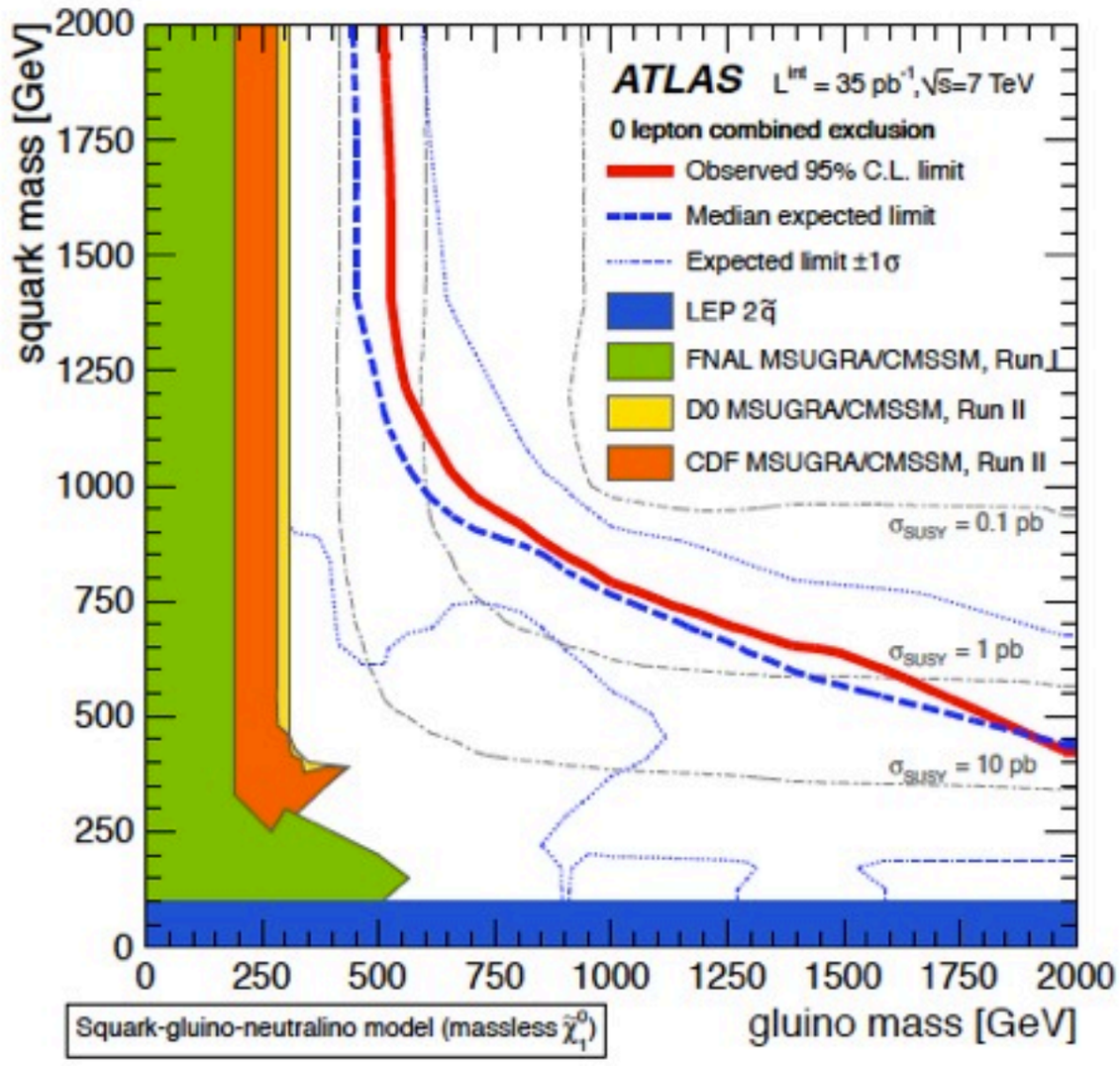


Figure 2: 95% C.L. exclusion limits in the $(m_{\tilde{g}}, m_{\tilde{q}})$ plane together with existing limits [4]. Comparison with existing limits is illustrative only as some are derived in the context of MSUGRA/CMSSM or may not assume $m_{\tilde{\chi}_1^0} = 0$.

Simplified Model Limits from ATLAS and CMS

And there are several more public and on the way...

Baseline interpretations using simplified models have provided clear snapshots of how the searches are performing

Along with kinematic and control region distributions, this is making it much easier to asses search coverage

Please provide plots of control regions and as much in the way of kinematic information about the Standard Model as possible

Exploring Search Robustness

Existing benchmarks emphasize MET and HT as primary signal regions

We all know that MET and HT sensitivity is reduced by squeezing the new physics spectrum, increasing the fraction of events that undergo cascade decays, or letting the LSP decay further (or entirely)

Some of this behaviour is evident in the simplified model results

The natural way to assess what to do next is to throughly identify the boundaries of the existing signal regions

Exploring Search Robustness

Using the existing simplified model results, and mock-ups of the search regions, we explored a range of signals.

For Signal

We generate/shower/hadronize events in Pythia, build jets from truth hadrons, electrons, muons and photons using fastJet (anti-kt of R=0.5), match leptons and b-jets, apply parametrized ID/reconstruction efficiency and isolation for leptons and b-jets, and build MET using several methods

We also use PGS and compare

We compare to published standard model distributions and simplified model limits for sanity checks

For Background

We only use published measurements + sanity checks with Monte Carlo

Obviously, everything we do is only an estimate!

My Opinion of the Current Situation

First searches provide very good coverage in cases where there is intrinsic MET (examples later in the talk), and in cases where the signal is heavy-flavor rich

Sensitivity will increase dramatically for **many** searches with luminosity (slow fall off of cross-section x efficiency!)

Don't prioritize the design of whole new search strategies around benchmarks for which an O(10) increase in luminosity would provide sensitivity in existing search regions

My Opinion of the Current Situation

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

Examples in this talk are largely of this variety

Could be higher/lower...

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

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

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

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

My Opinion of the Current Situation

Most valuable lesson to me from early search results is the behaviour of the Standard Model in numerous control regions!

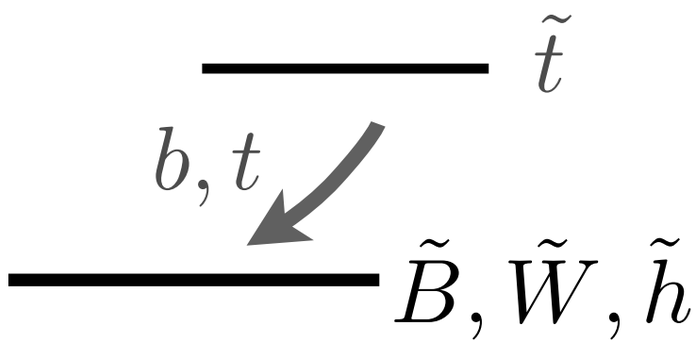
The 35 pb-1 Standard Model results are providing a strong clue for the types of search strategies that may increase sensitivity to broad classes of new physics (examples in this talk).

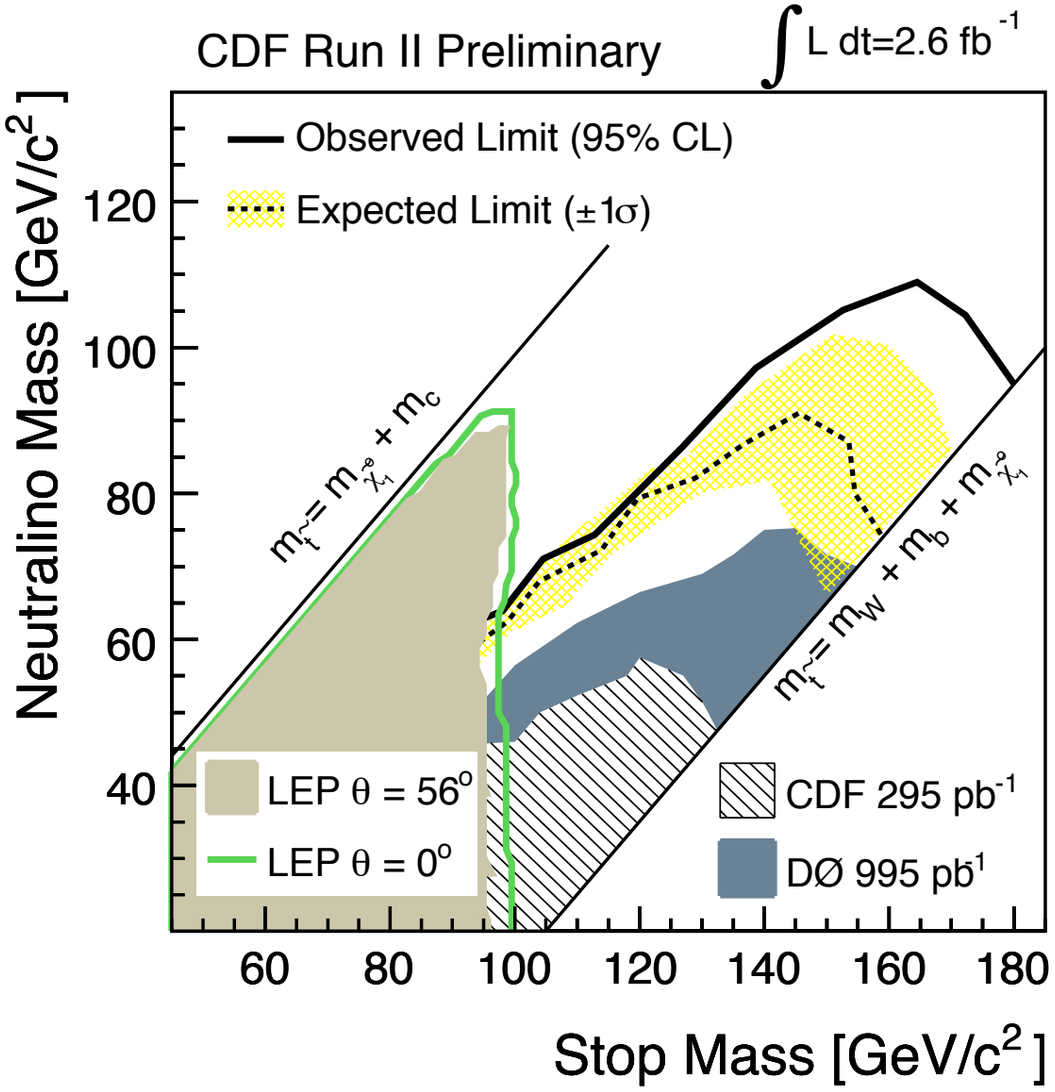
For example, how do we see signals with no intrinsic MET?

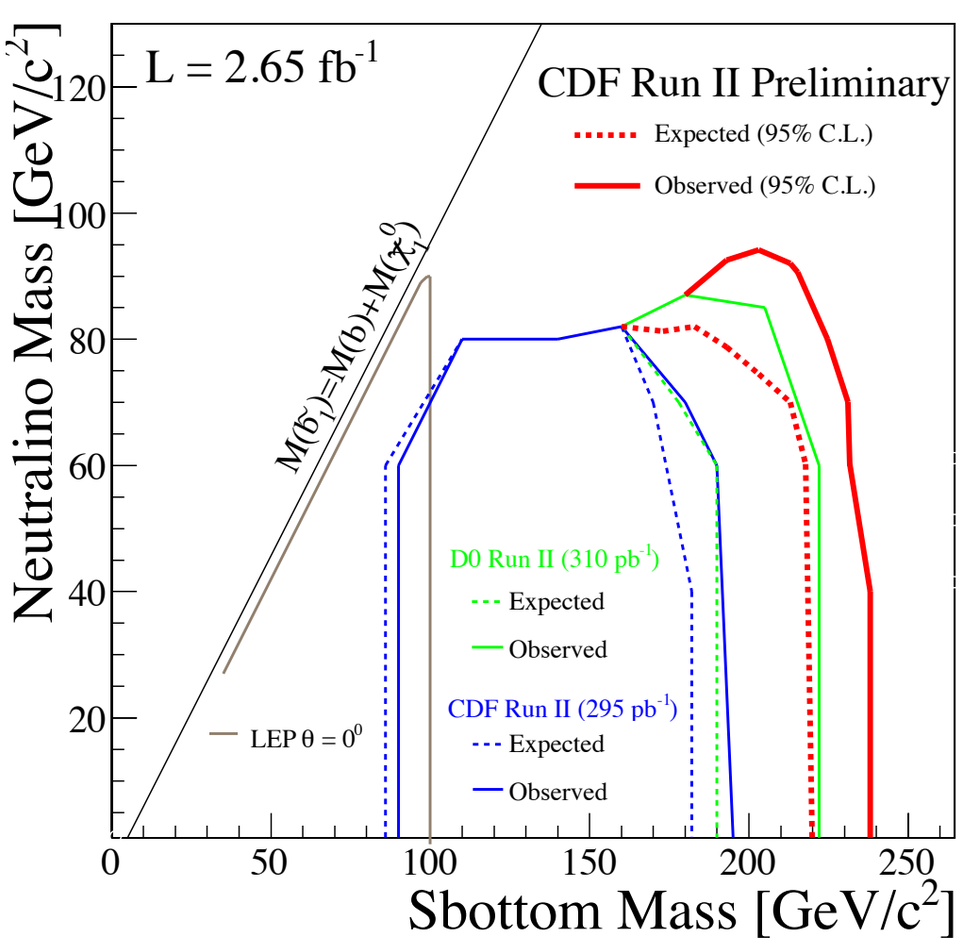
Examples...

Now for some examples...

Light Top Partner Expectation - Status from Tevatron

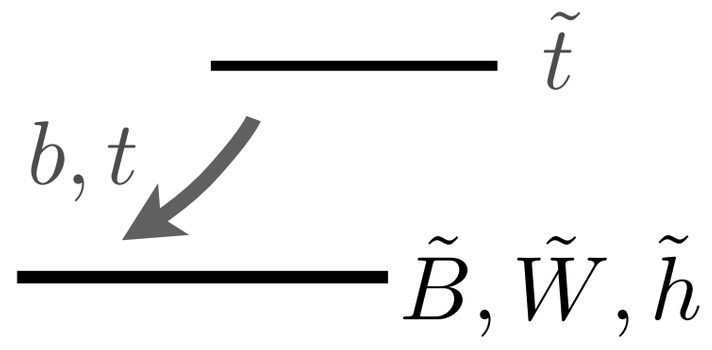


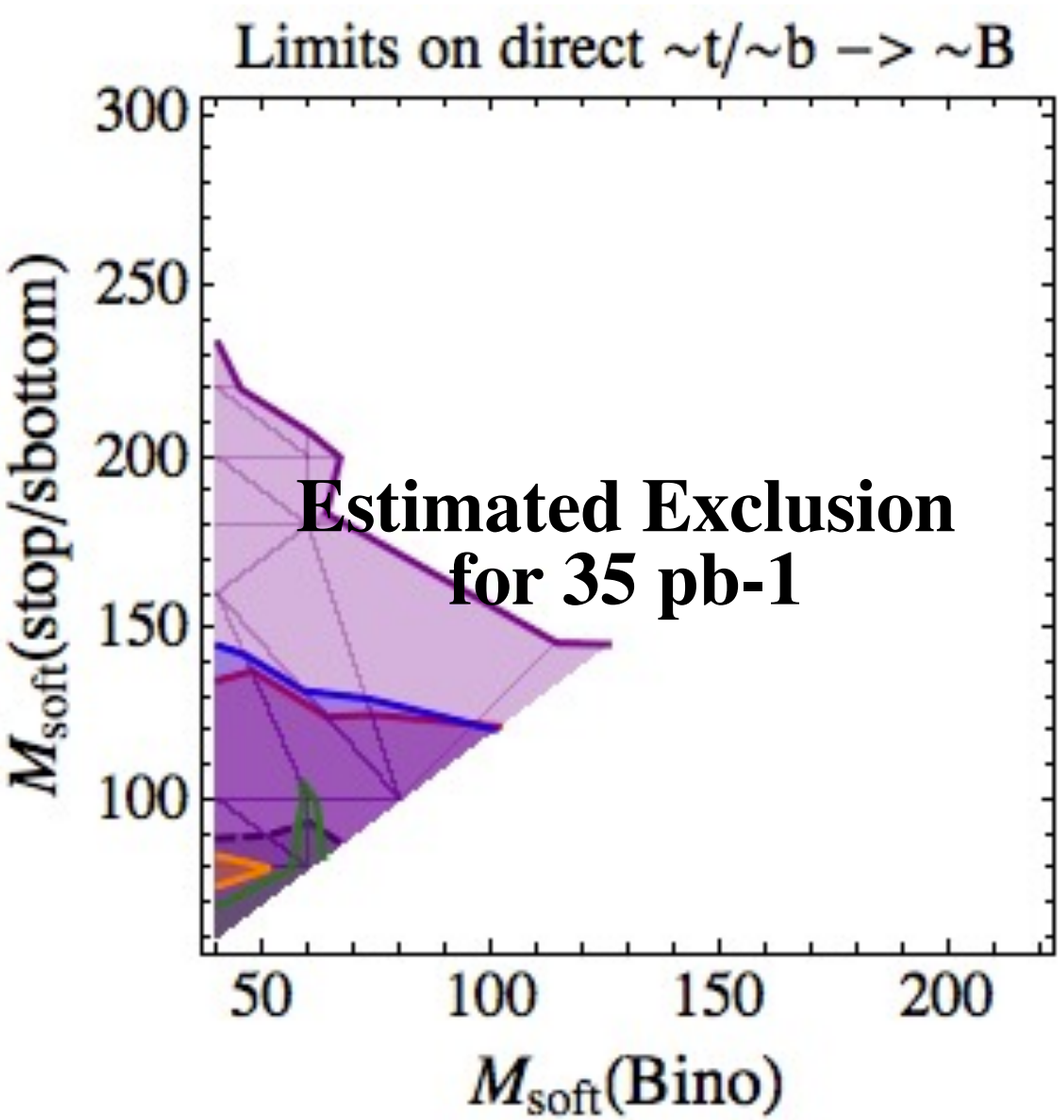




Tevatron limits do not rule out a natural top/bottom partner ... they do constrain this possibility...

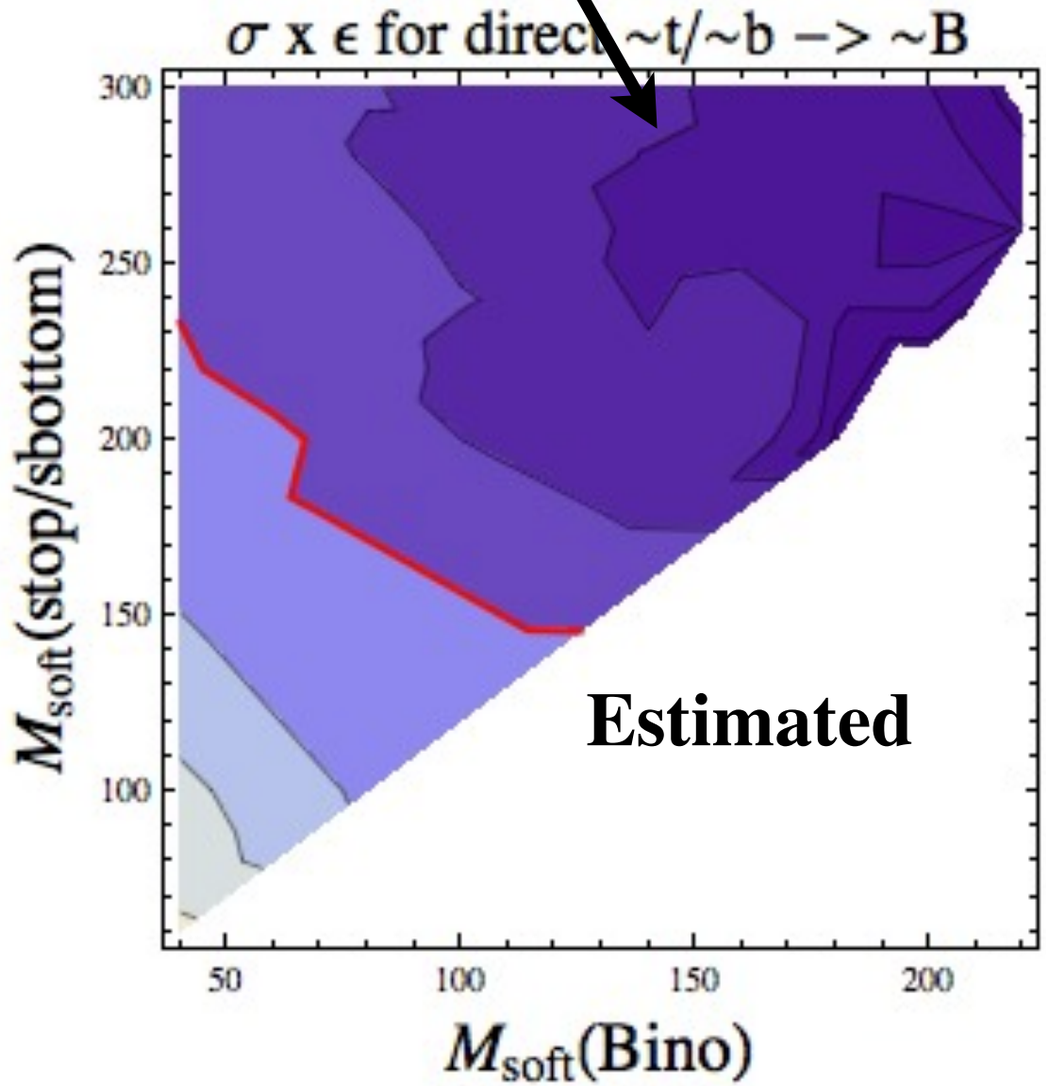
Light Top Partner Sensitivity Estimates for the LHC





1 fb-1 LHC data will likely cover top/bottom partner production beneath ~300 GeV

This region only x4 below existing sensitivity!

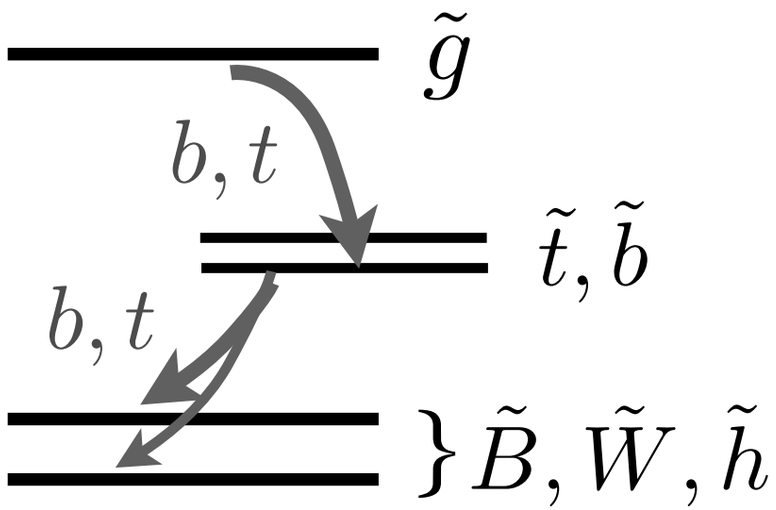


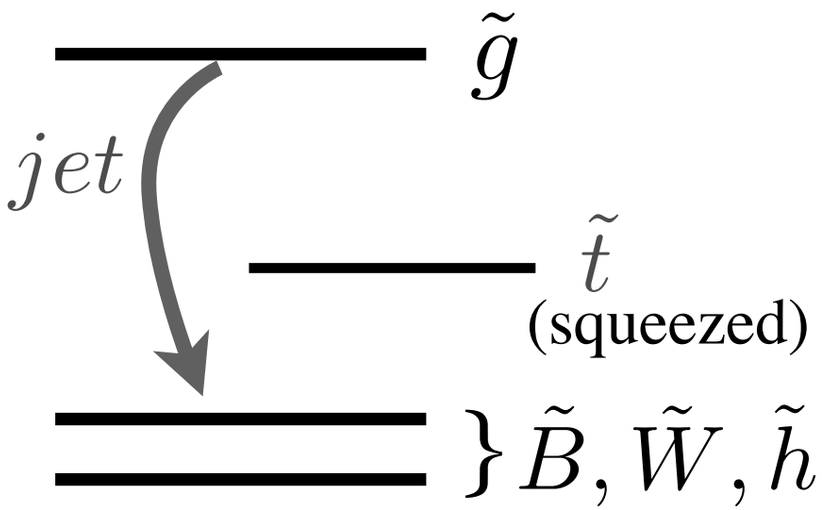
Scenarios

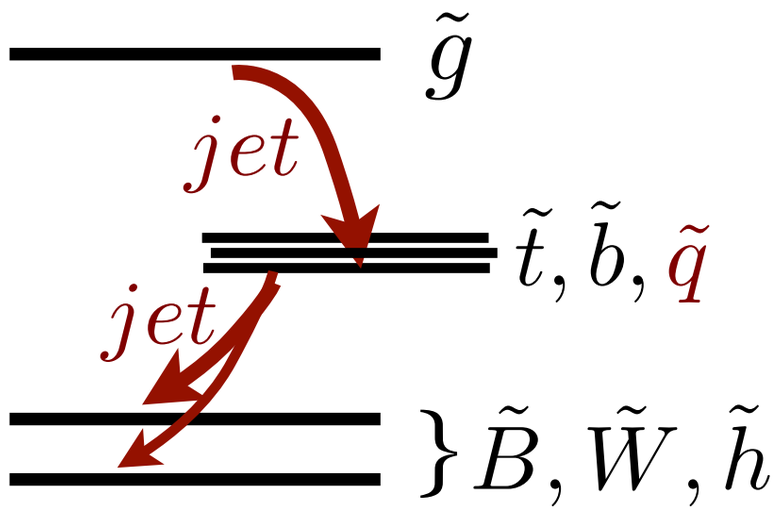
We look at several light stop/sbottom scenarios, with squarks both below and above (but mainly above) the gluino

We look at the impact of cascading, squeezing, and altering gaugino unification assumptions

We're still investigating "non-minimal" possibilities (additional decay channels, lepton jets, LSP decays)

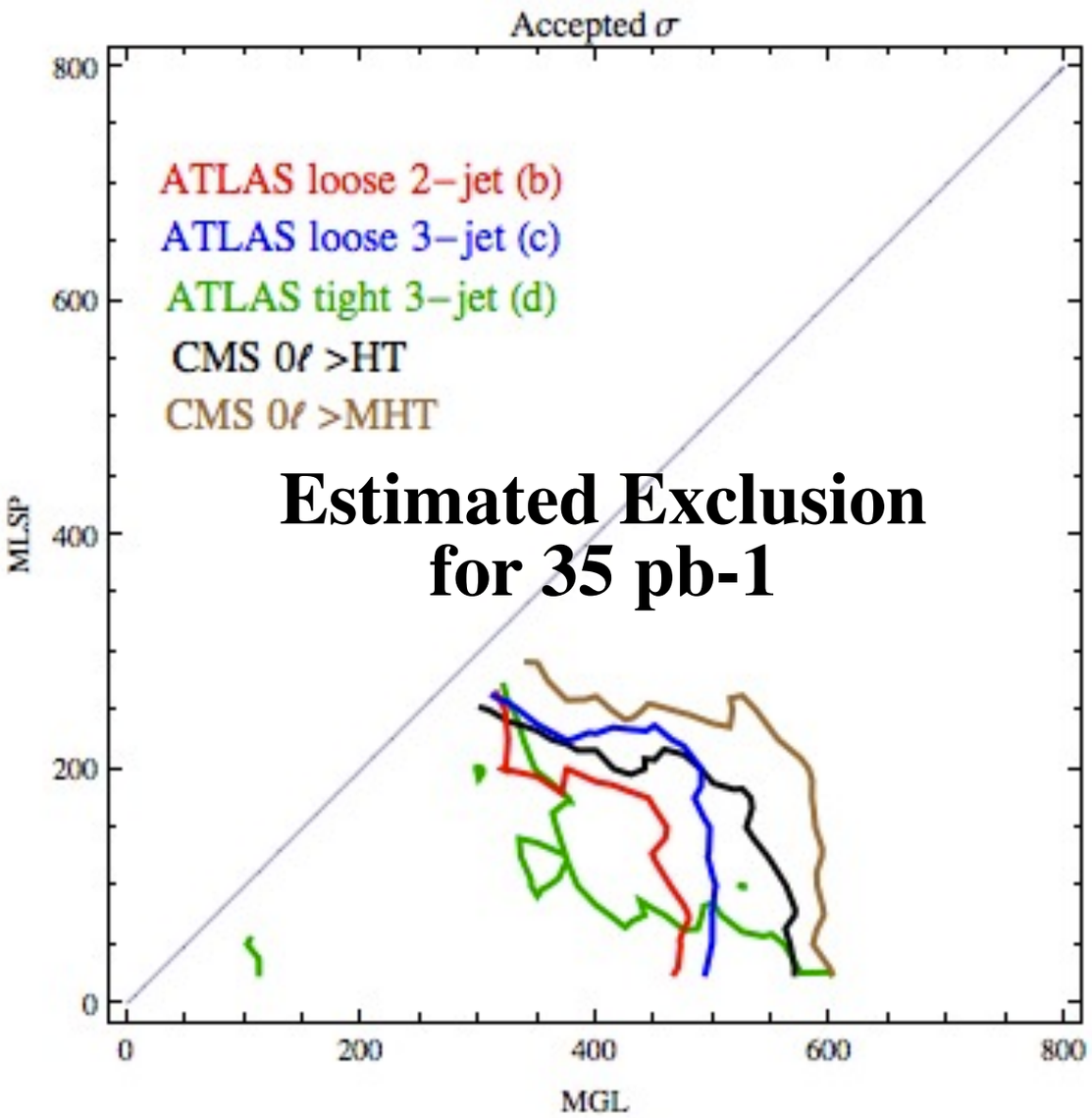


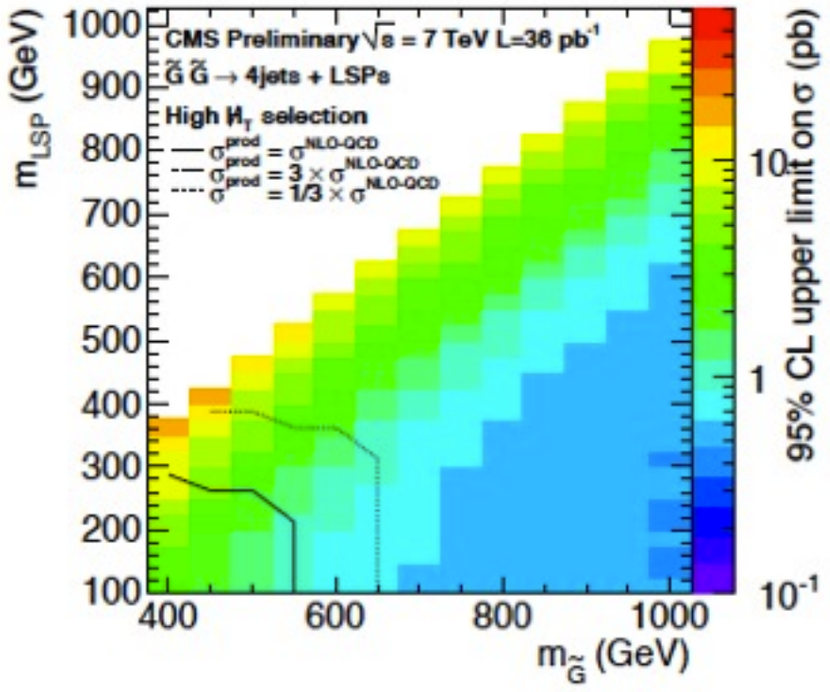


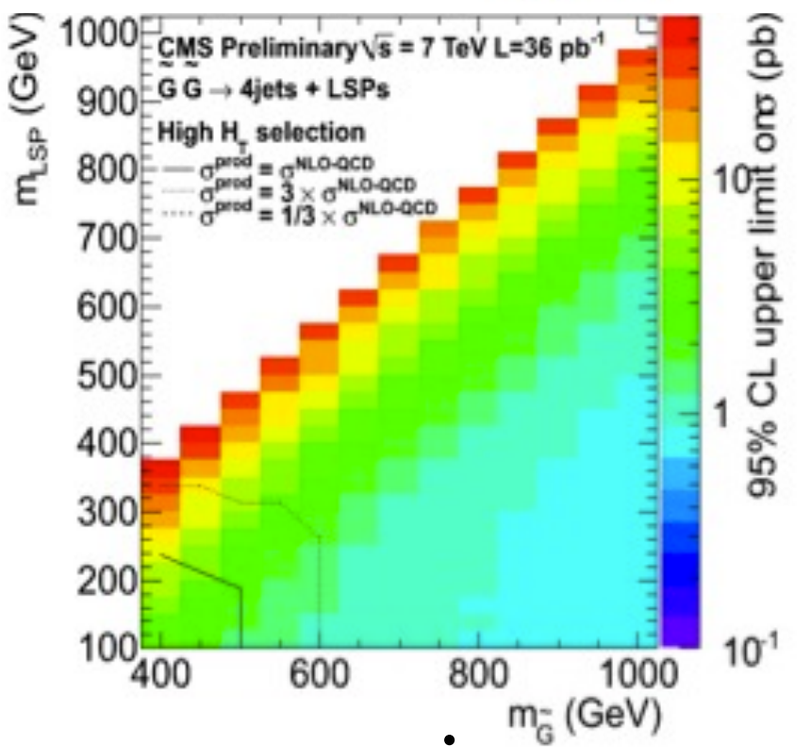


Gluino Pair Production Model for Comparison

Baseline comparisons... (wiggles are MC statistics)

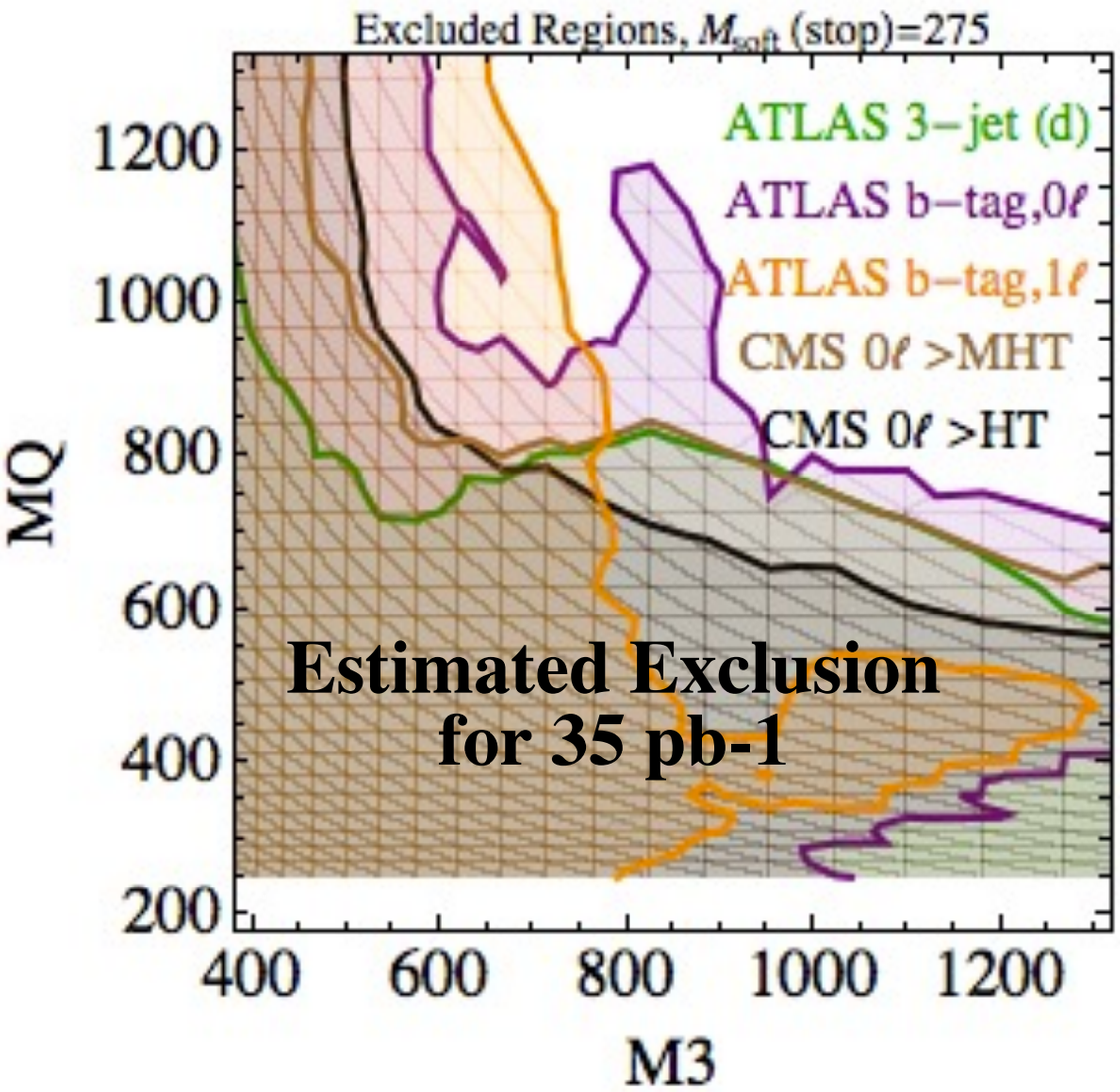


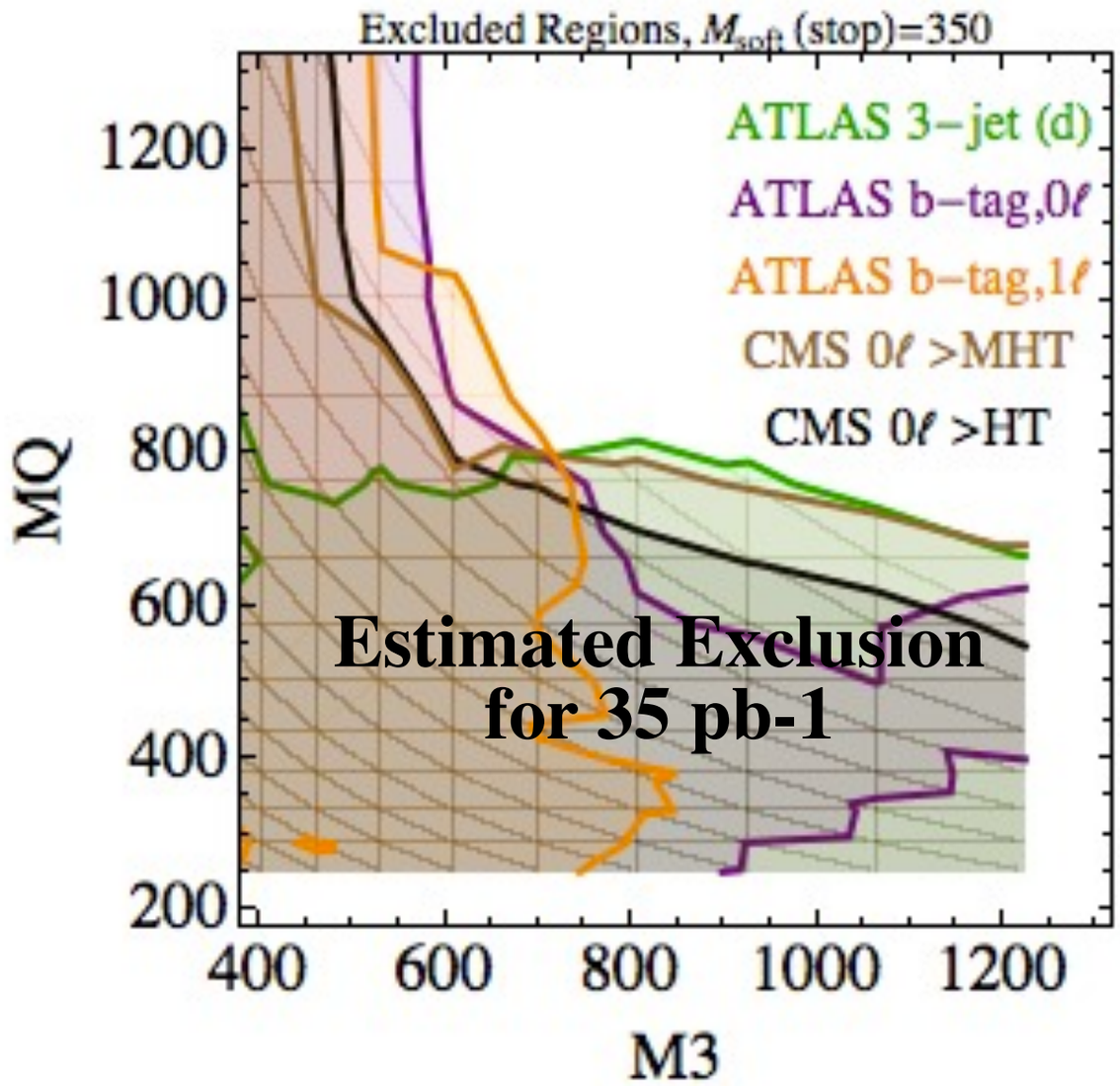




Good agreement in efficiency comparison

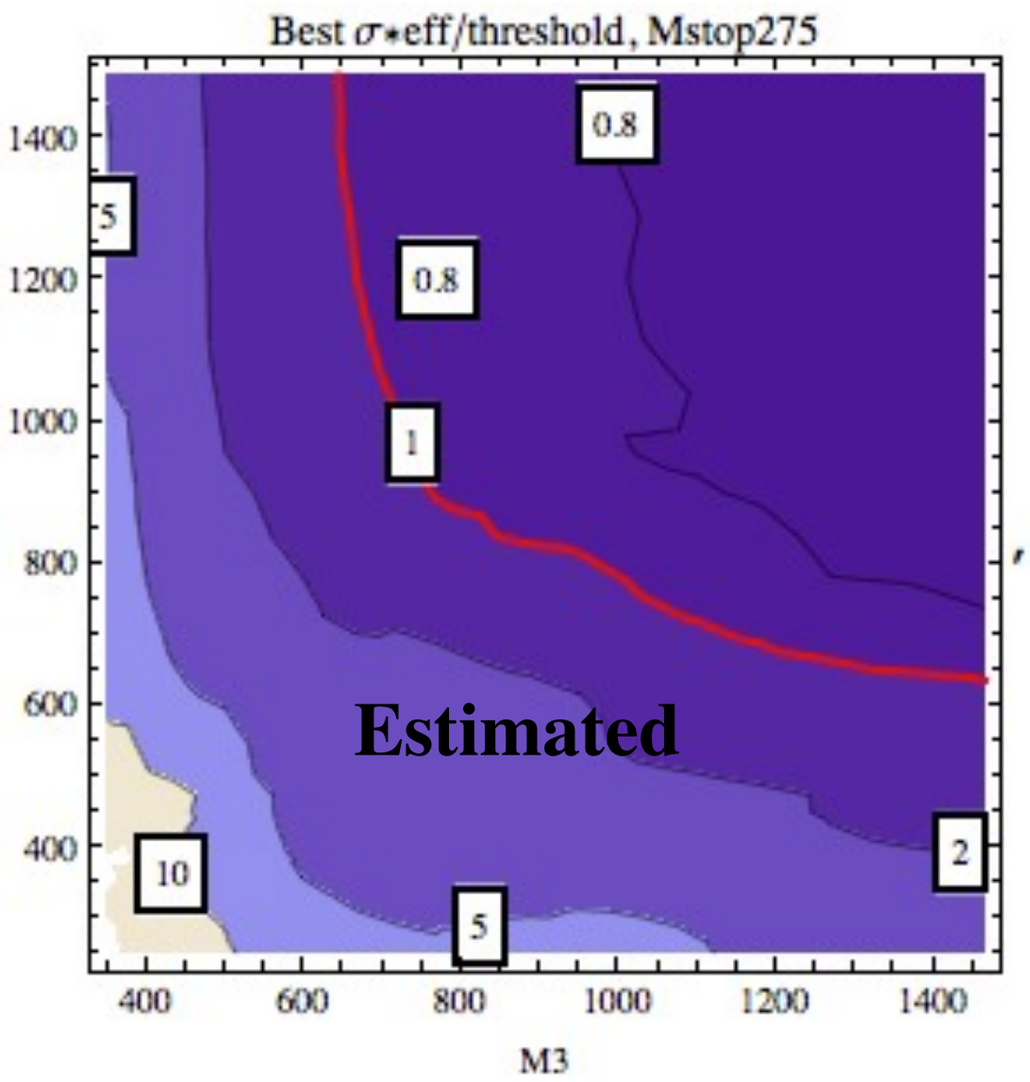
Gluinos and Squarks with Light Stops

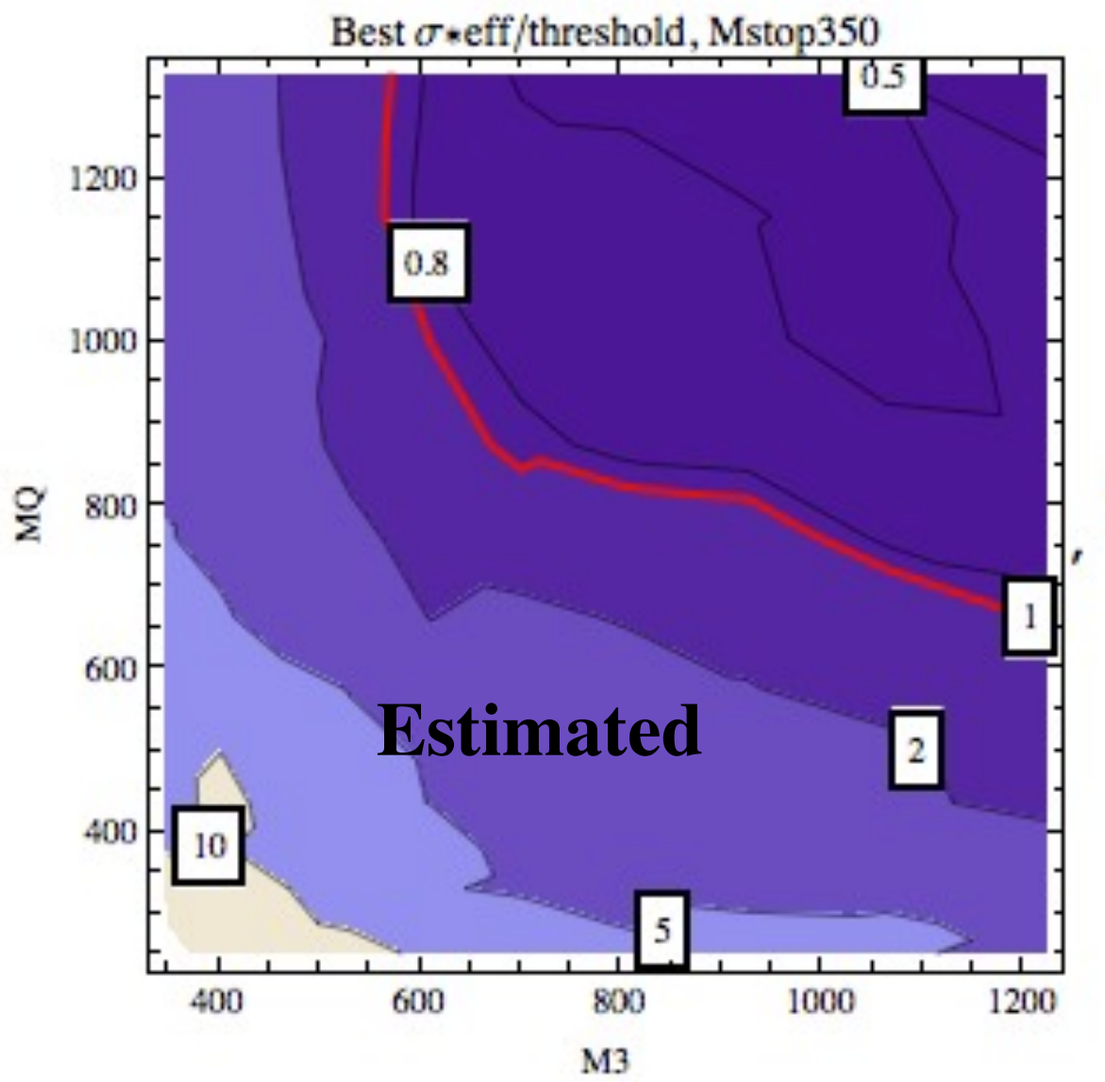




Already some tension with a radiatively natural spectrum!

Gluinos and Squarks with Light Stops





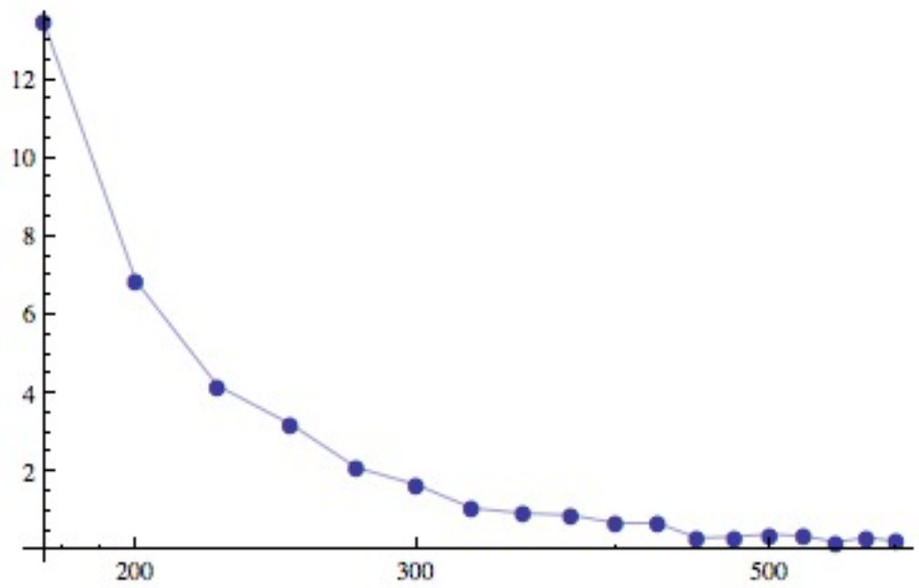
Searches **just below** required sensitivity out to ~TeV. Modest luminosity increase will improve sensitivity dramatically.

1 fb-1 LHC data will likely cover light stop scenarios with gluinos lighter than ~1-1.5 TeV

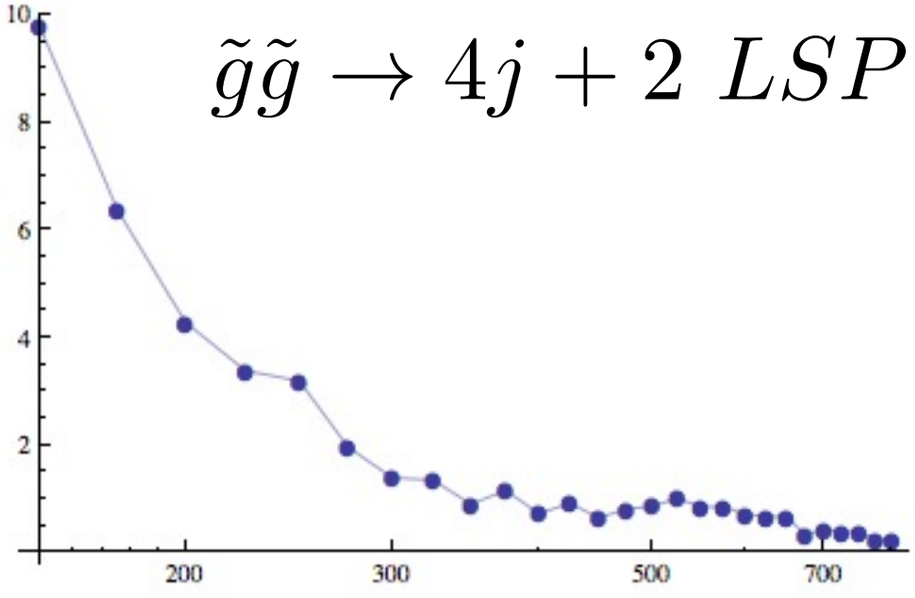
Added Luminosity will Help!

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

$\tilde{g}\tilde{g} \rightarrow 4j + 2W + 2\ LSP$



$\tilde{g}\tilde{g} \rightarrow 4j + 2\ LSP$

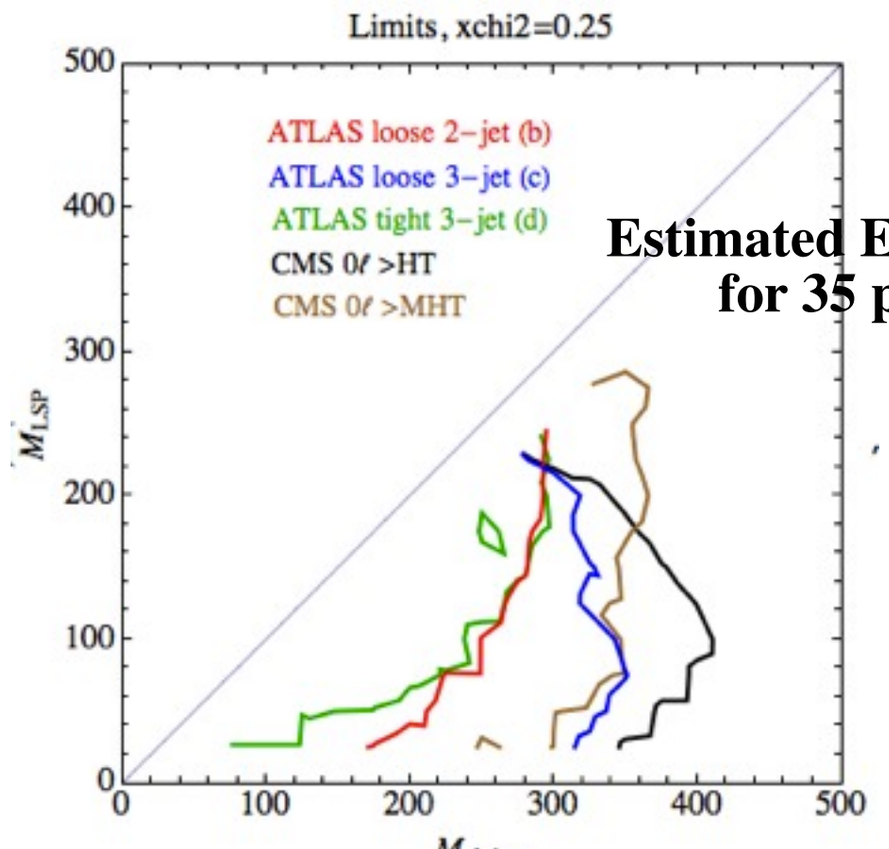


Note the slow variation is cross-section x efficiency as a function of mass!

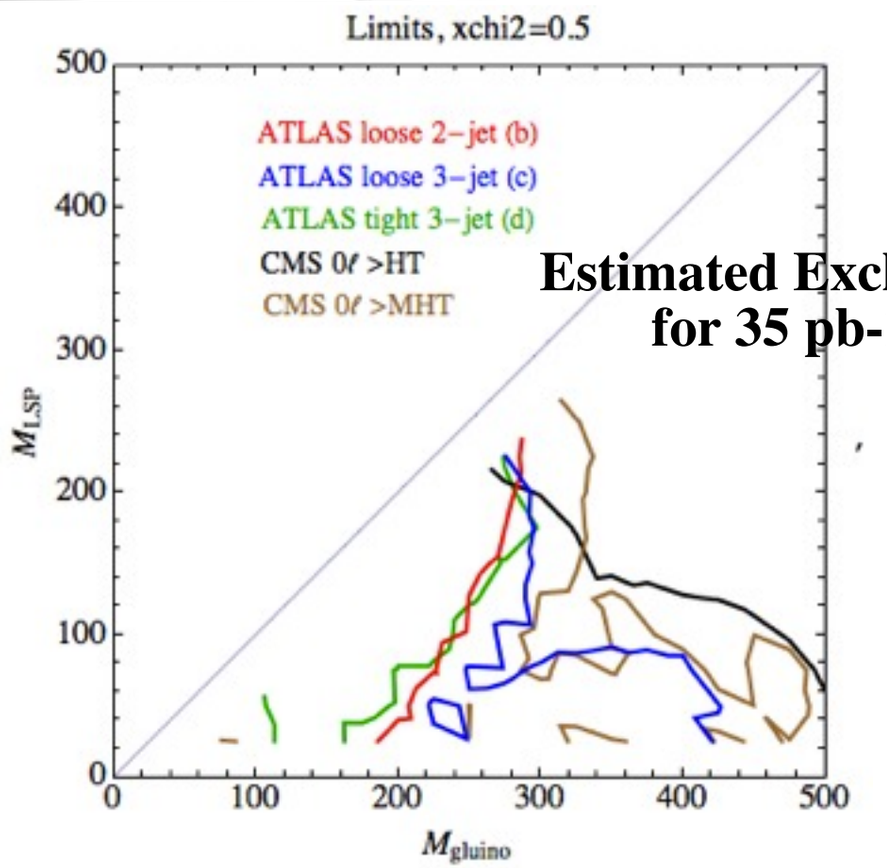
This is a common feature that we keep finding.

Several searches will have greatly improved sensitivity with only a modest gain in luminosity

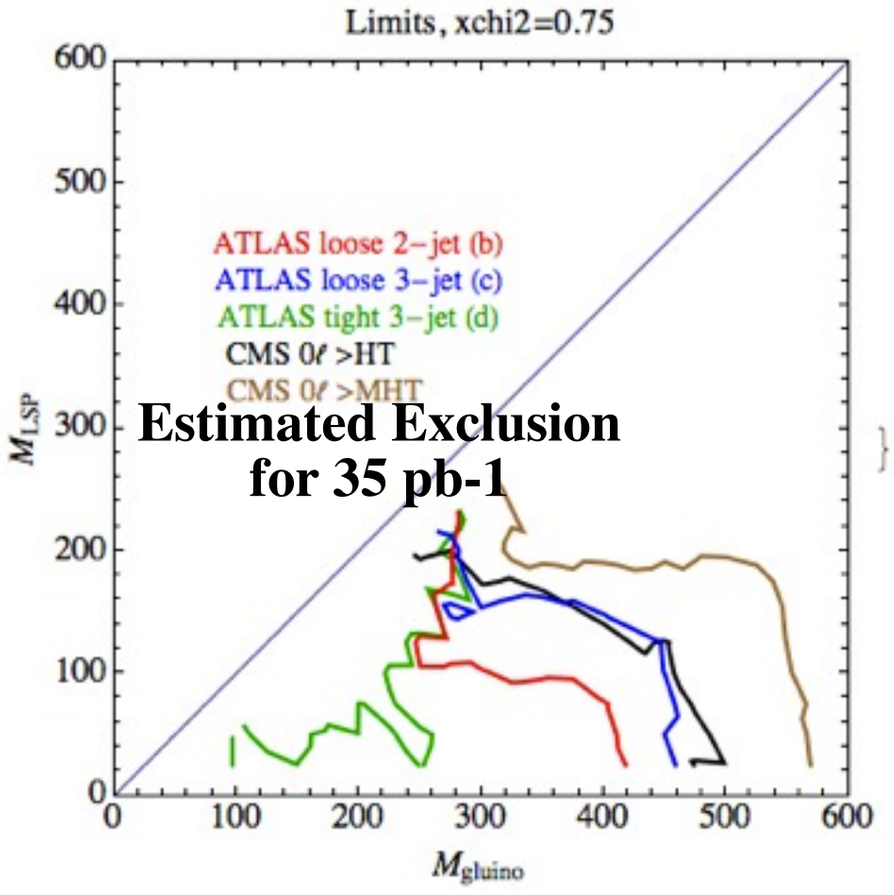
Scenarios with Enhanced Cascading



Estimated Exclusion for 35 pb-1



Estimated Exclusion for 35 pb-1



Estimated Exclusion for 35 pb-1

$$M_{\chi 2} = xM_{gluino} + (1-x)M_{LSP}$$

Cascading does weaken limits.

CMS search strategy shows some degree of robustness against cascading

Suggests search regions with softer jets, but higher multiplicity + multiple HT vs. MHT regions

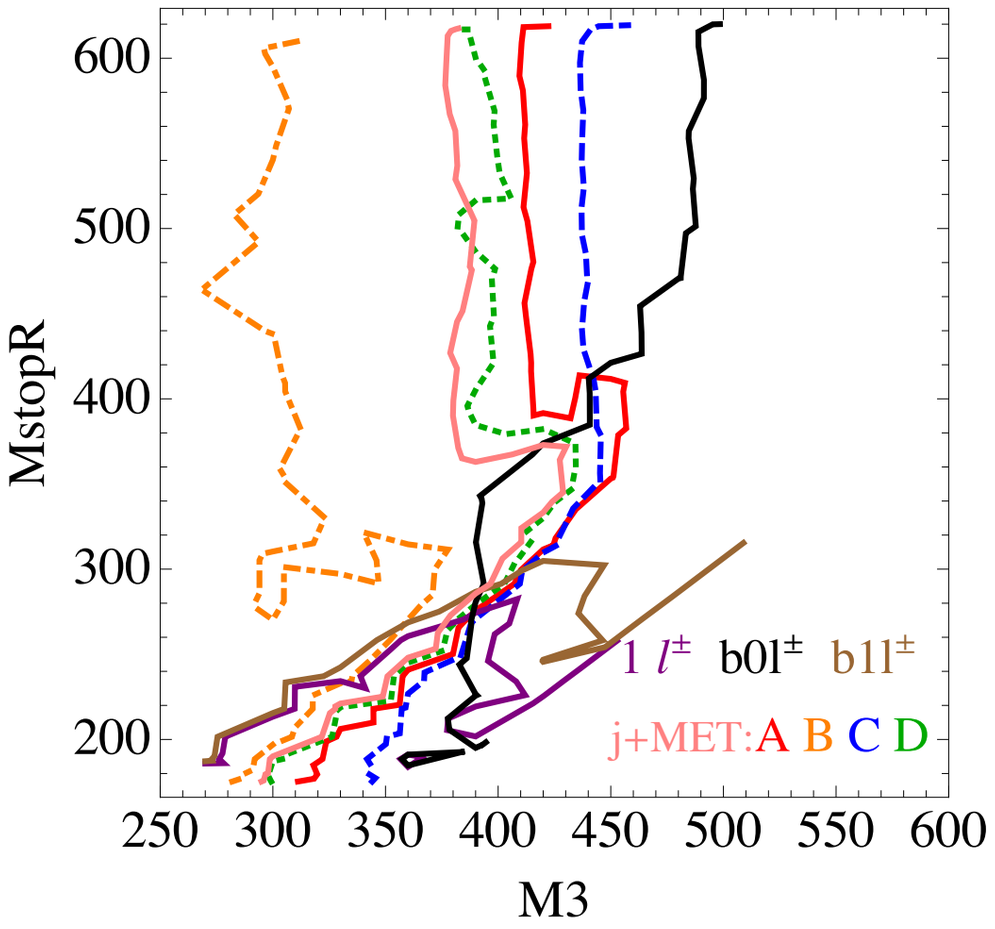
Looking for un-expected corners of SUSY parameter space...

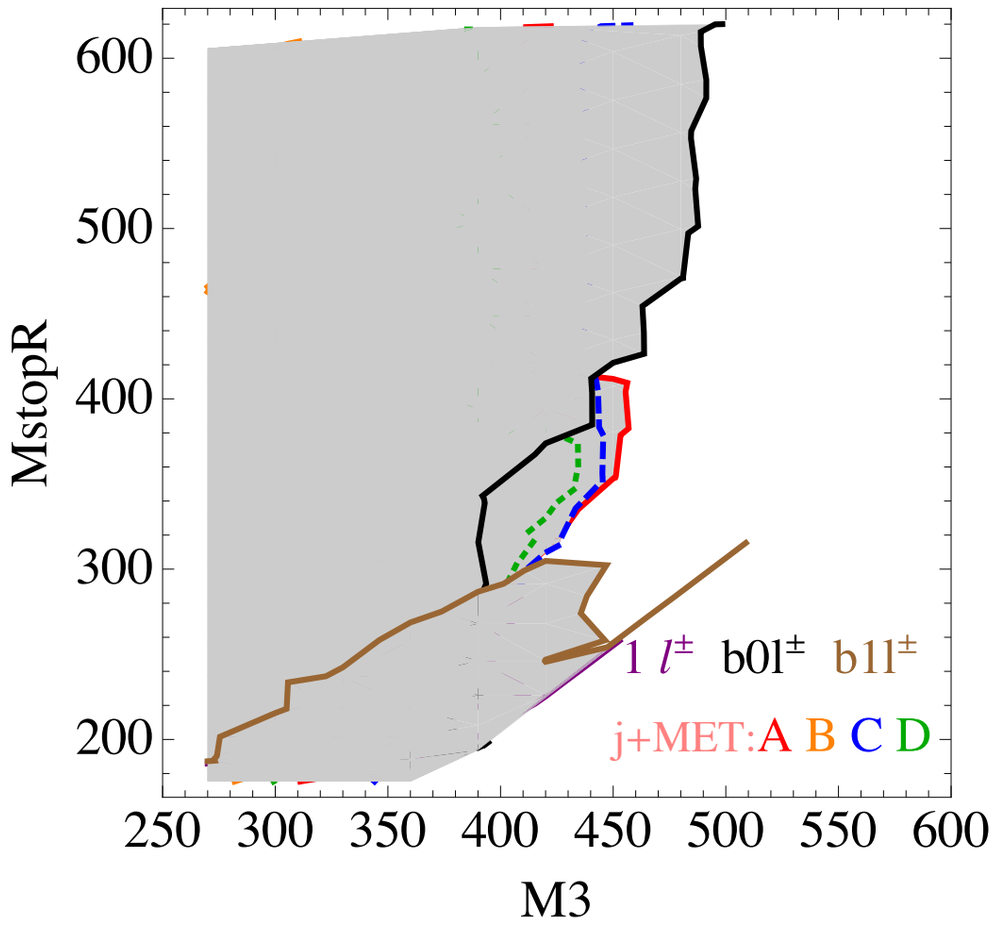
Gluino

$\tilde{t}$ Right handed stop

Bino at M3-200 GeV

Gluino decays to jet+LSP via a loop





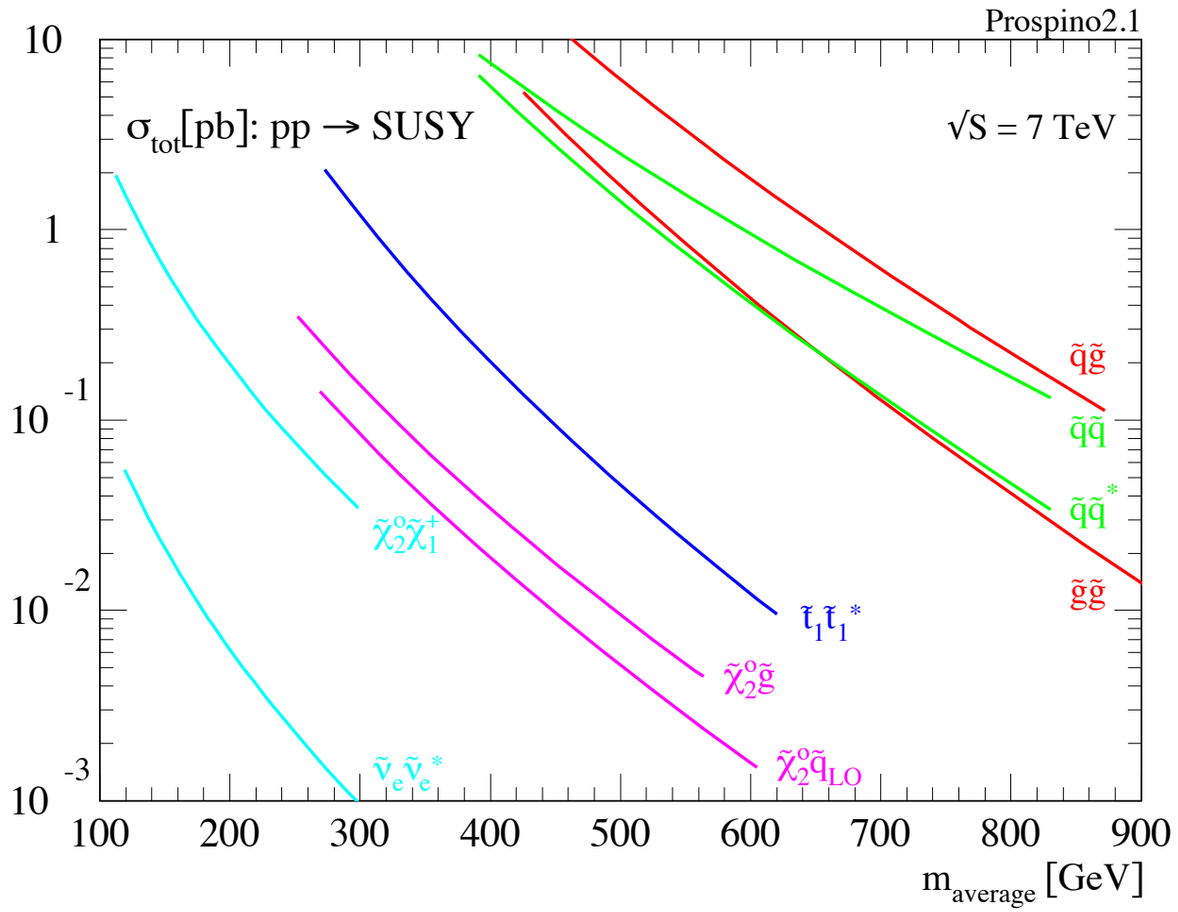
Improving Search Robustness and Sensitivity

To test SUSY as an explanation of the hierarchy problem and dark matter, robustly searching in MET + X makes good sense.

To test SUSY as an explanation of the hierarchy problem in general, robustly searching in channels without large MET is important. Even with an LSP, MET can be squeezed out or reduced depending on the model...

In SUSY, we can say with more certainty what will happen with the strong part of the production and decay (fewer options) than with the bottom of the decay chains (many options)
(LSP could decay, lepton jets, NMSSM singlets...etc)

Improving Search Robustness and Sensitivity



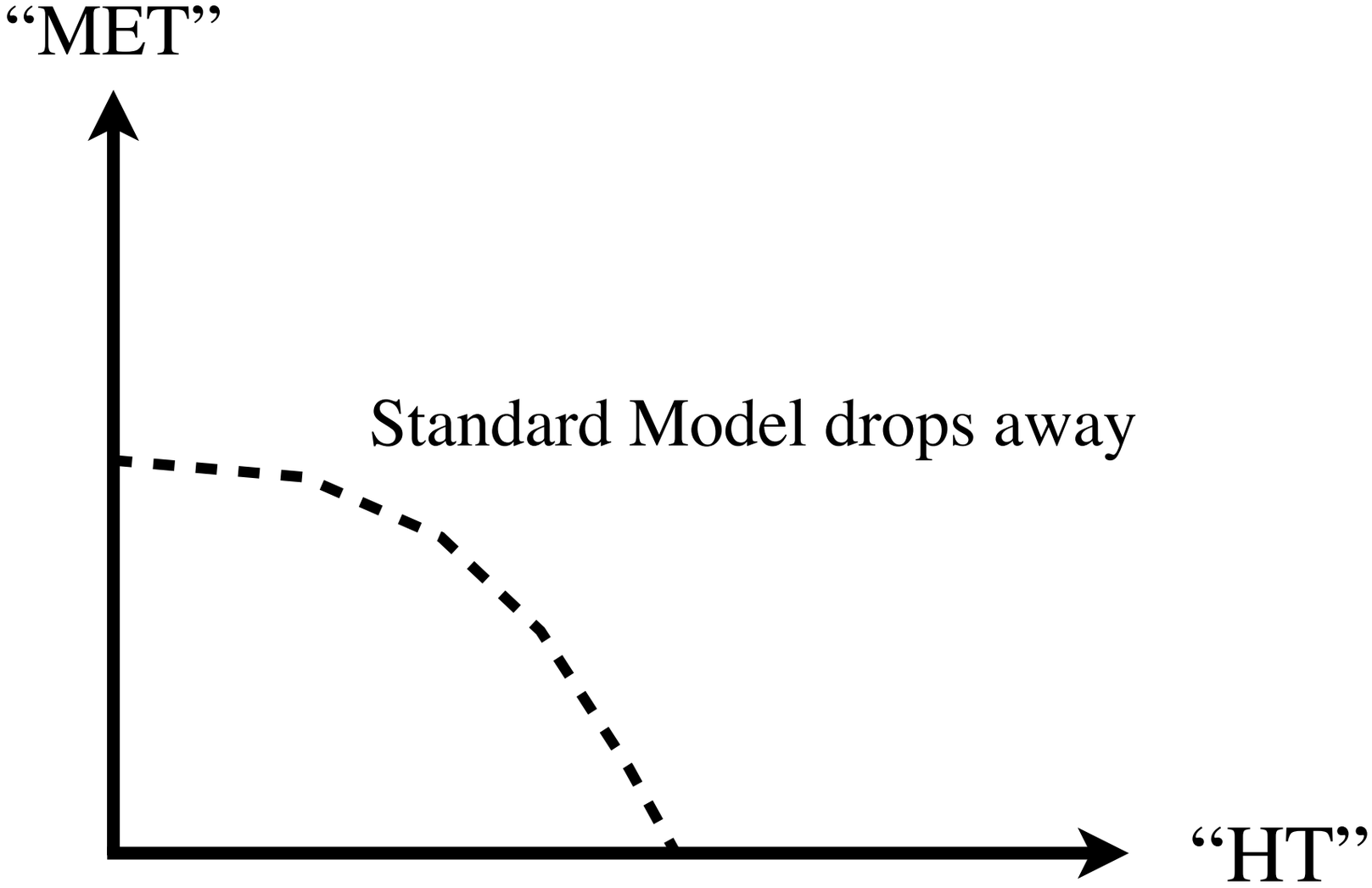
For strong production, the generic expectation is x-section~100 pb for M~300 GeV, dropping to x-section~100 fb for M~800 GeV

Identifying regions where the Standard Model has less than ~1 pb x-section (i.e. comparable to possible signals) is an important starting point for identifying additional signal regions

Improving Search Robustness and Sensitivity

Currently, ATLAS and CMS SUSY search regions cut away from the Standard Model by exploiting MET and HT, as a function of electro-weak activity (leptons/photons)

LHC early data shows where one can search without exploiting MET.

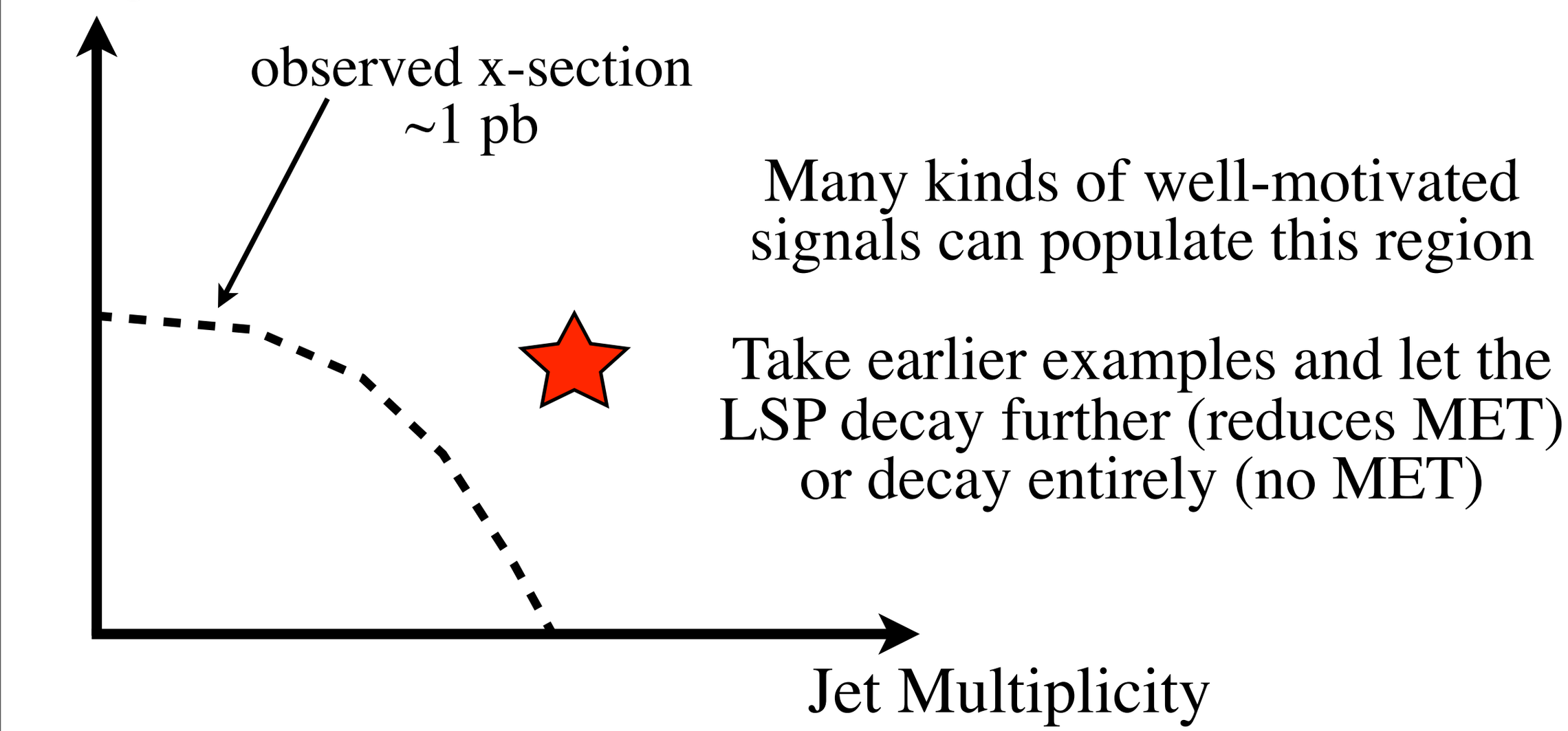


Improving Search Robustness and Sensitivity

ATLAS and CMS can answer the following question:

As a function of electro-weak activity (i.e. leptons, photons), how much hadronic activity is seen, and with what characteristics?

Where does the observed x-section approach ~1 pb or less (even roughly)?



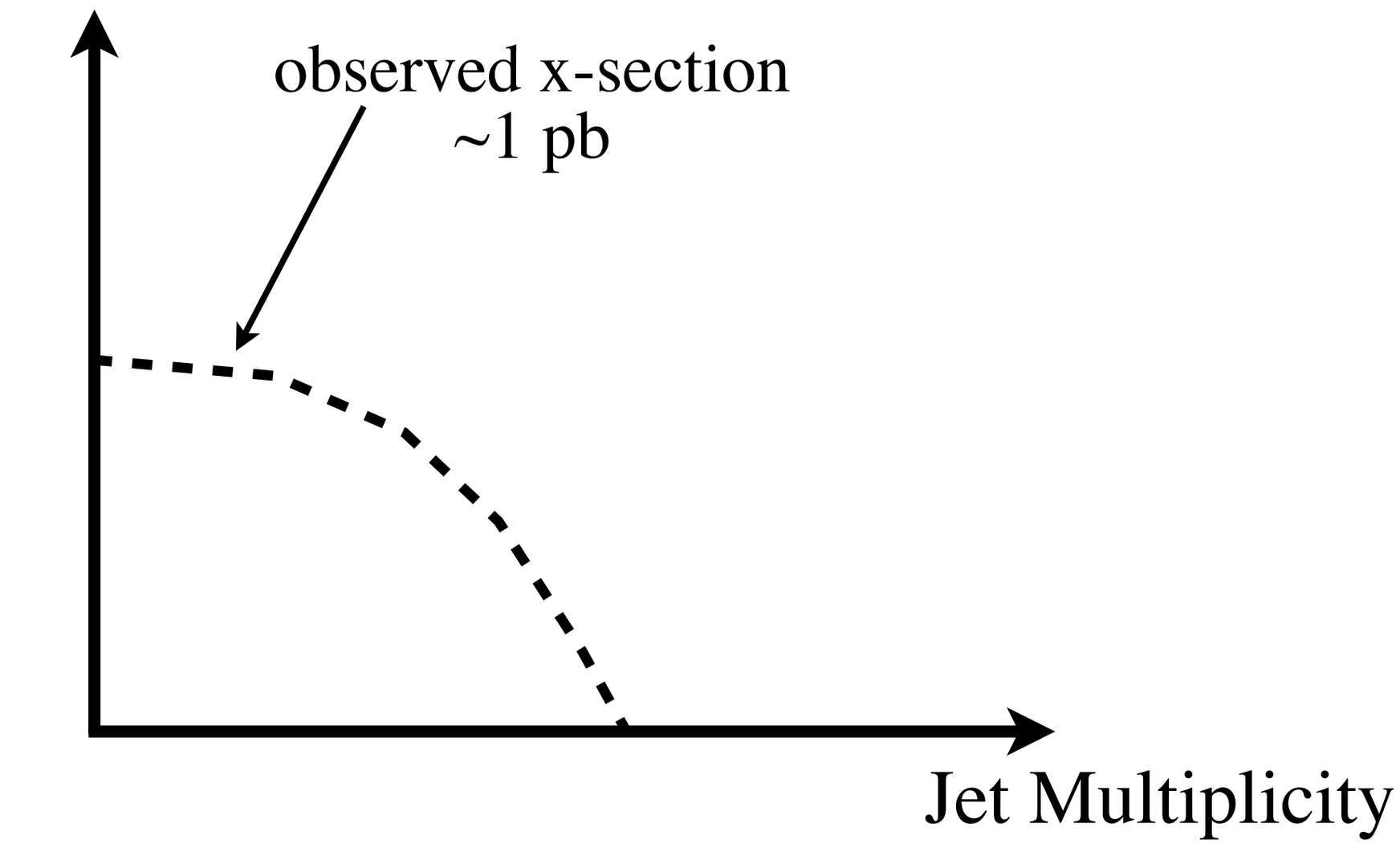
Many kinds of well-motivated signals can populate this region

Take earlier examples and let the LSP decay further (reduces MET) or decay entirely (no MET)

Improving Search Robustness and Sensitivity

It may be useful to propose benchmarks with this boundary in mind.

Focus on signals that parametrically escape detection in existing signal regions.



Improving Search Robustness and Sensitivity

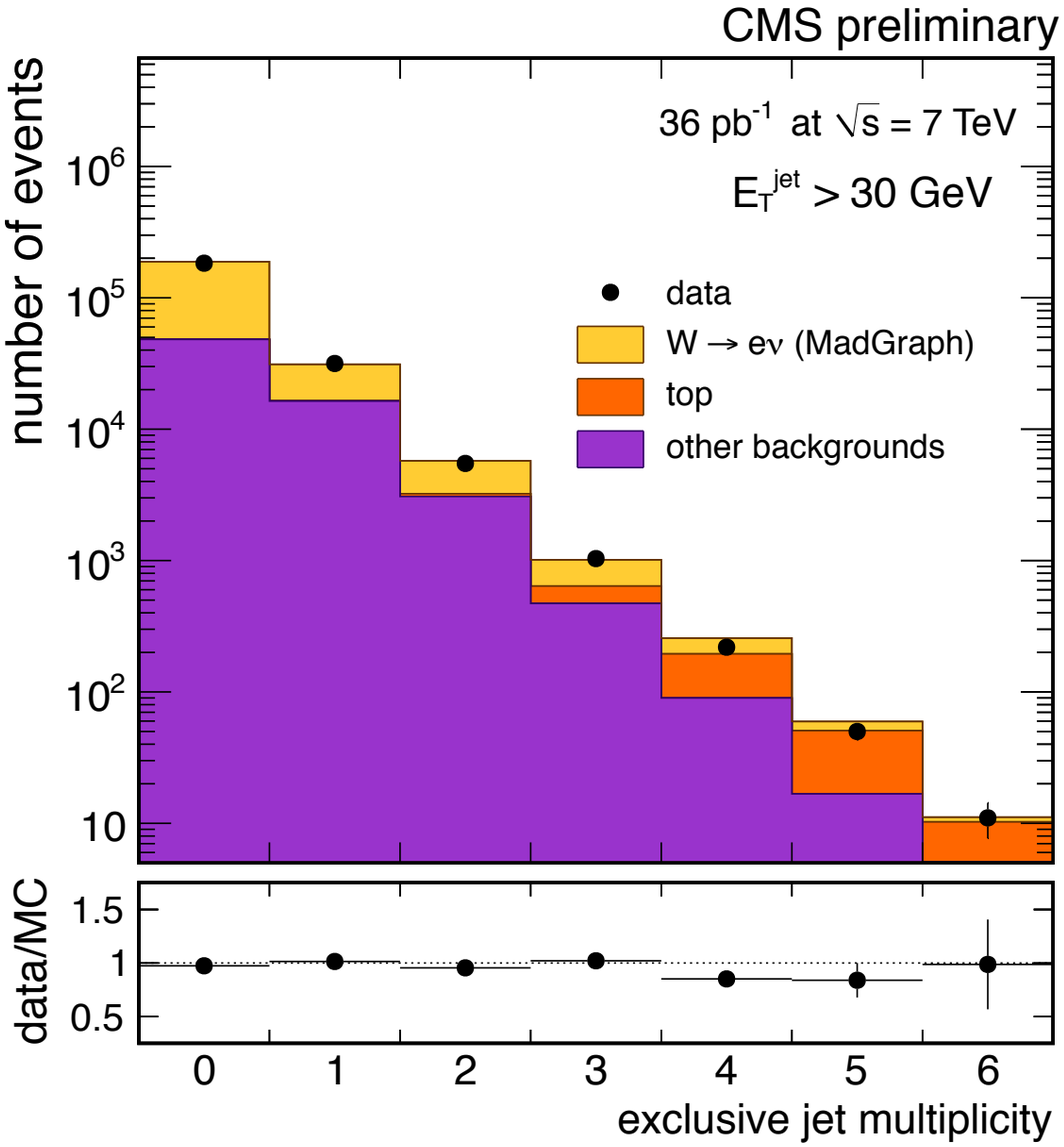
Take a look at the control regions of existing searches, as well as published Standard Model measurements.

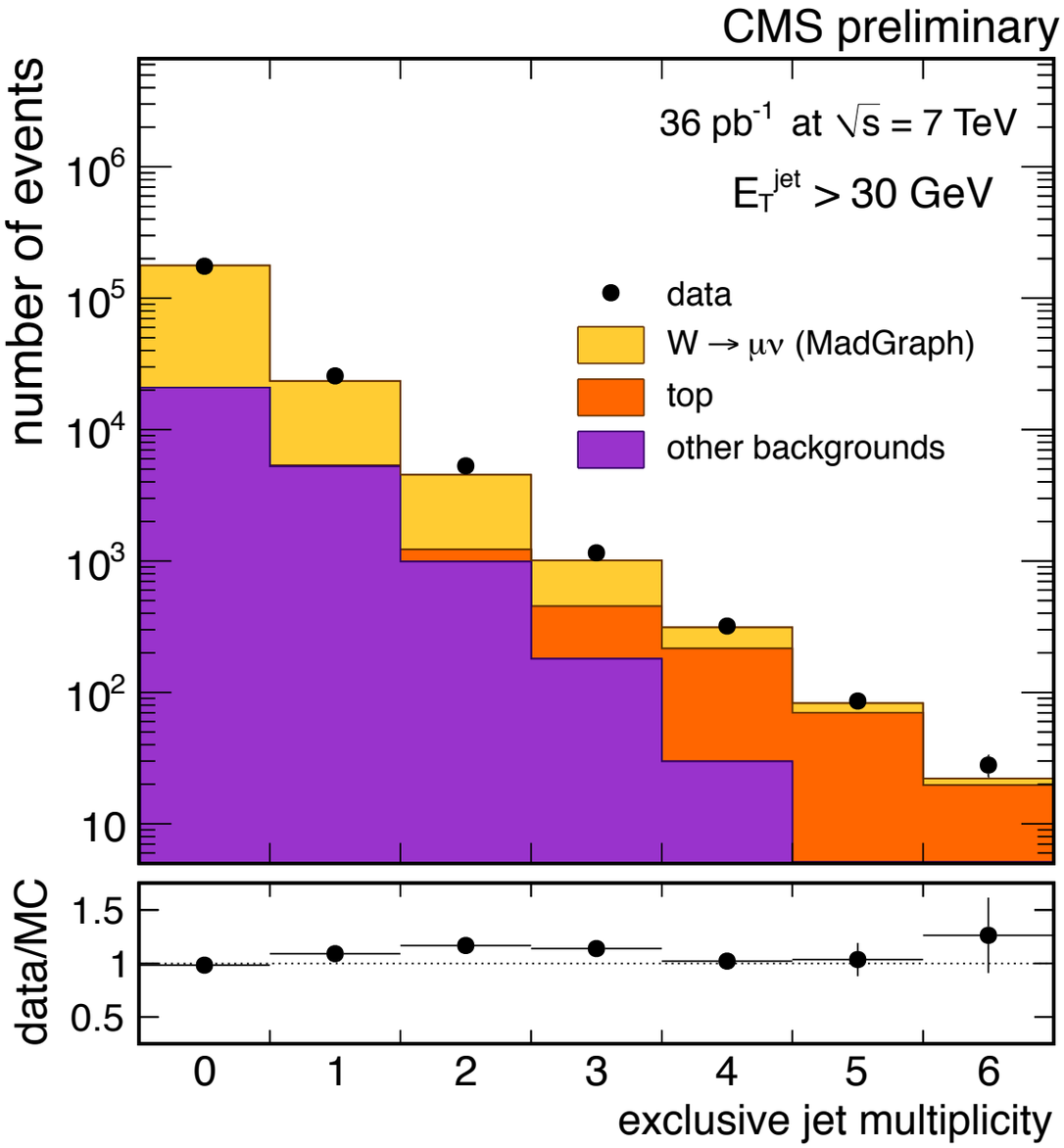
Don’t yet have the boundary for the 0-lepton/photon case.

Ok, this is the most difficult case, so move on to 1 or more lepton/photon...

Improving Search Robustness and Sensitivity

Example: CMS W+ jets measurement "1-lepton region"



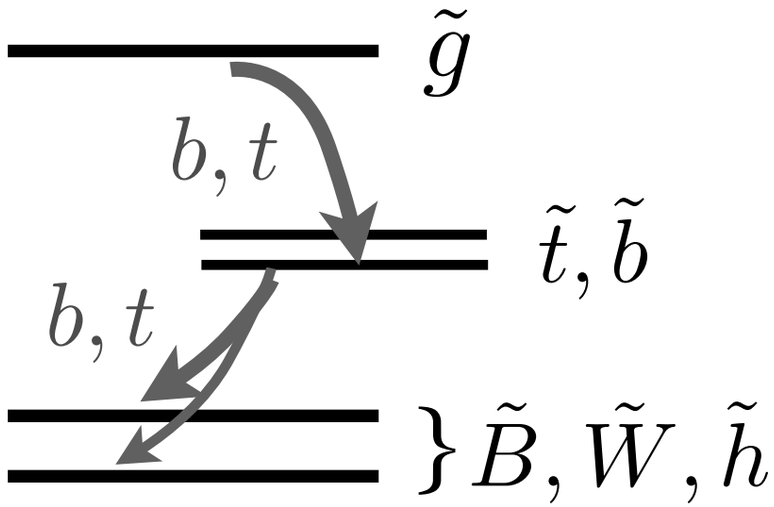


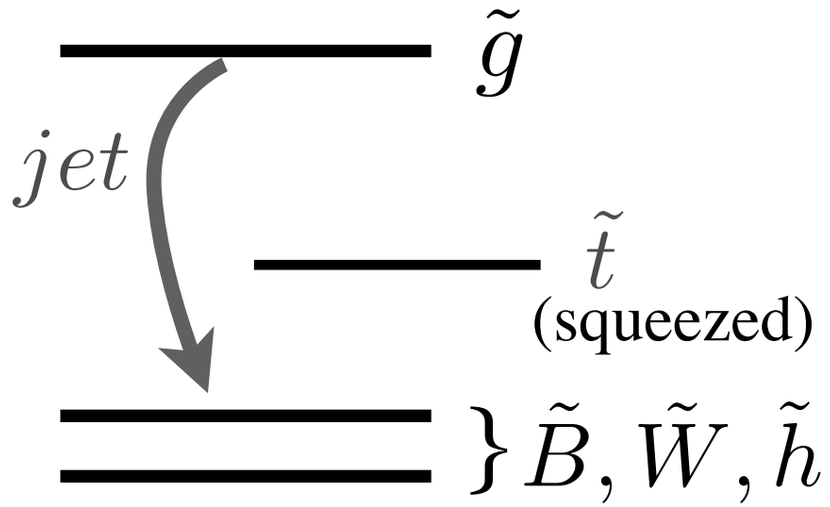
We can tell that 6 jets (certainly fewer with b-tags) above 30 GeV looks like a boundary

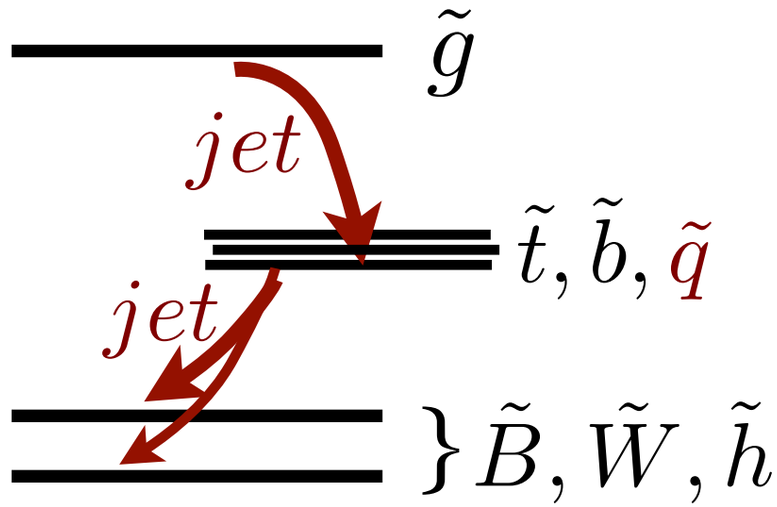
Improving Search Robustness and Sensitivity

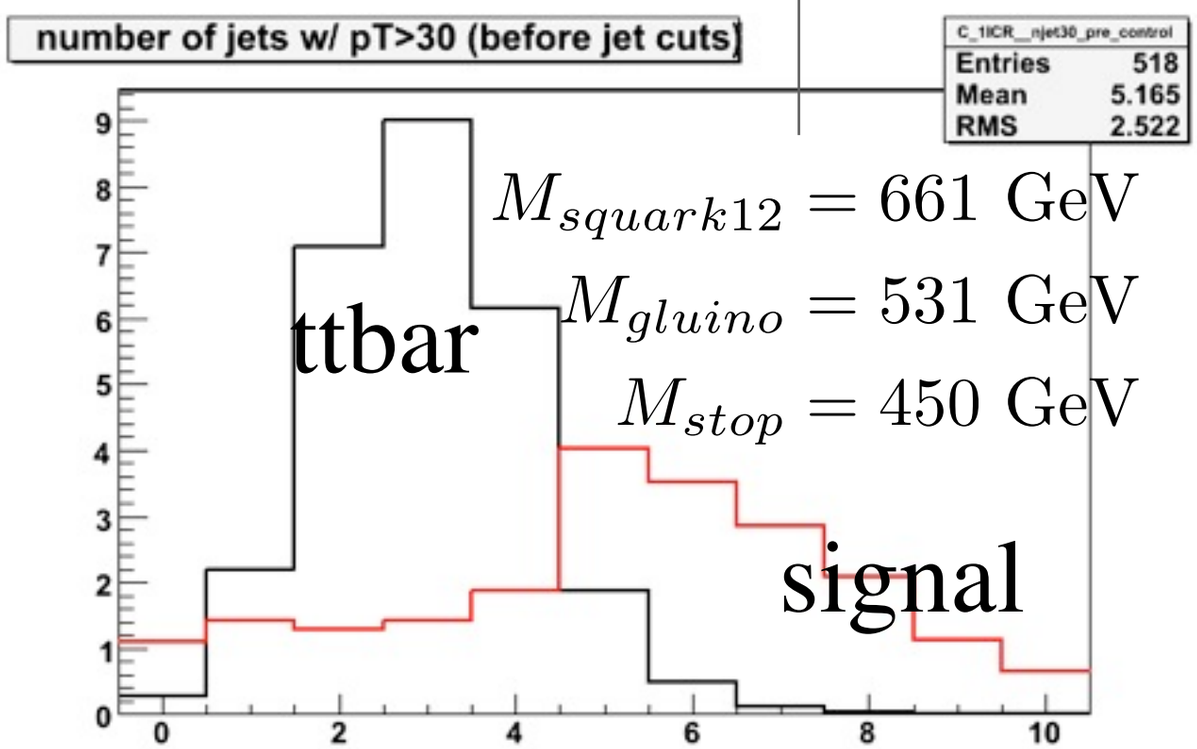
Signals with 1 lepton and 6 or more jets above 30 GeV are well within the standard realm of BSM!!

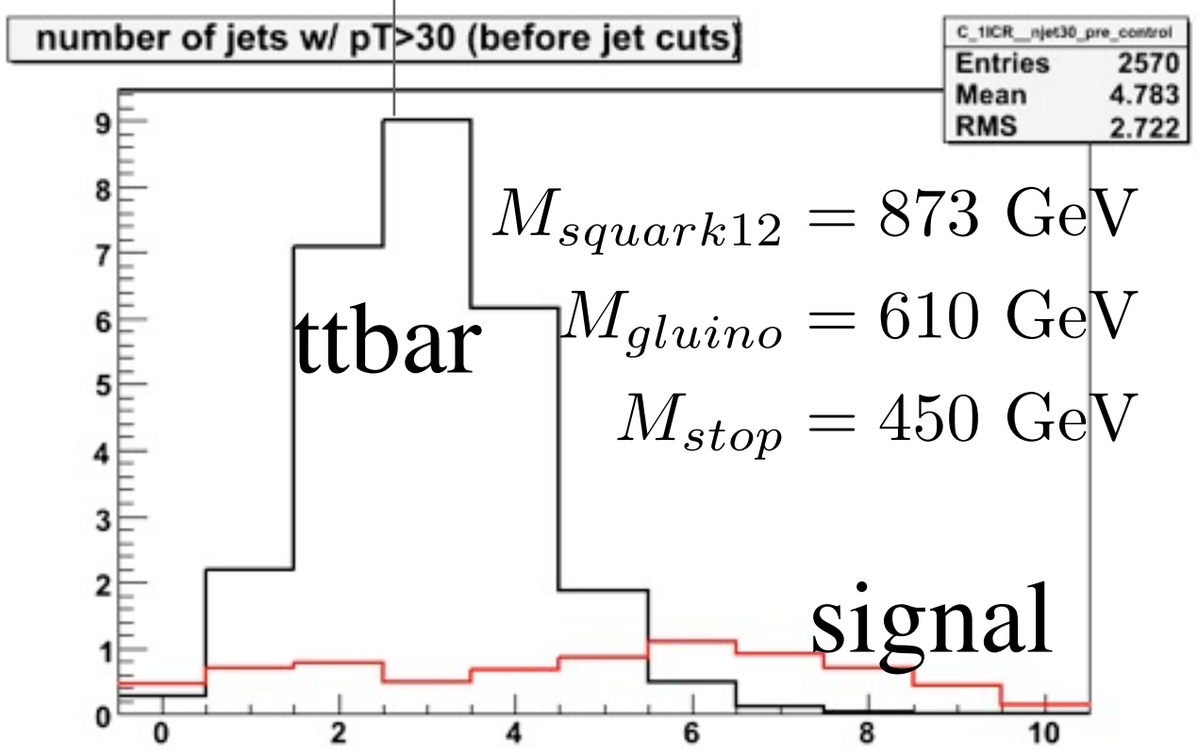
Consider the light stop/sbottom scenario earlier in the talk





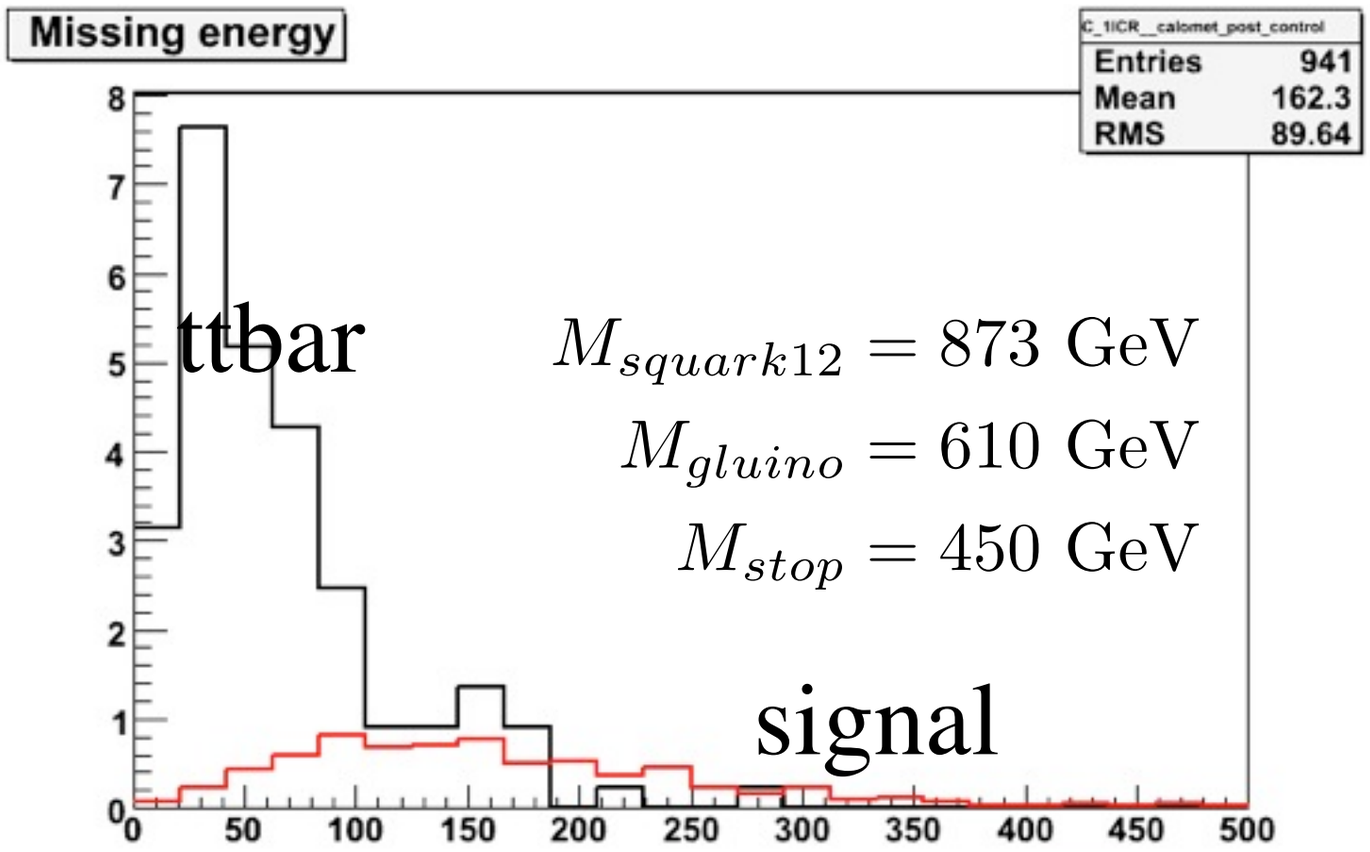






Improving Search Robustness and Sensitivity

Look in the 1-lepton + 6-jet region (or even 5-jets)



MET is fine for this case...

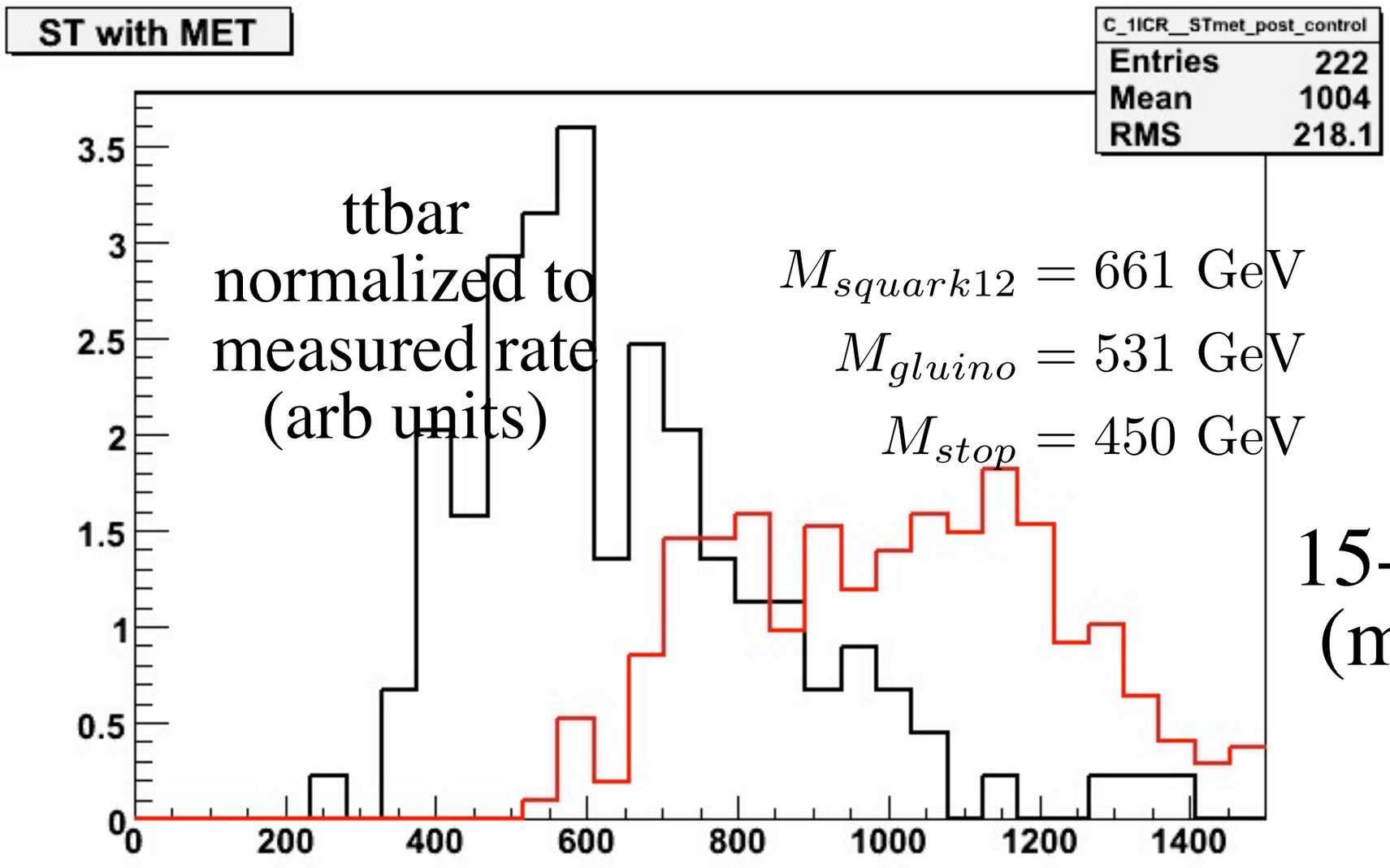
What if the LSP decays further?

Improving Search Robustness and Sensitivity

MET with HT = ST

Note: If the LSP decays, or with additional cascades, we get more jets (still high ST)

Look in the 1-lepton + 6-jet region (or even 5-jets)



Signal:
15-20% efficiency
(mostly from the lepton req.)

Improving Search Robustness and Sensitivity

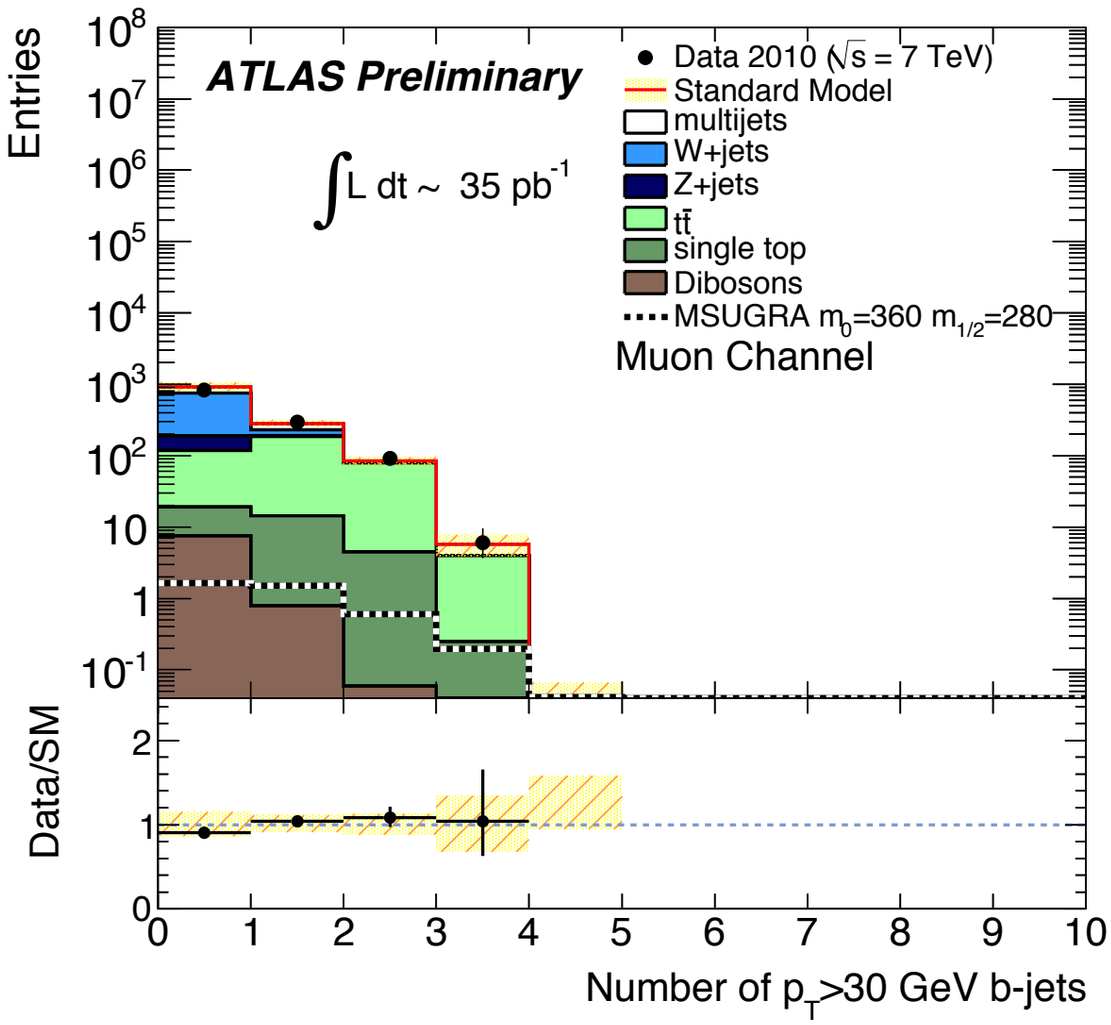
Without any MET requirement, gluino-like reactions may still be visible, as long as there is a lepton.

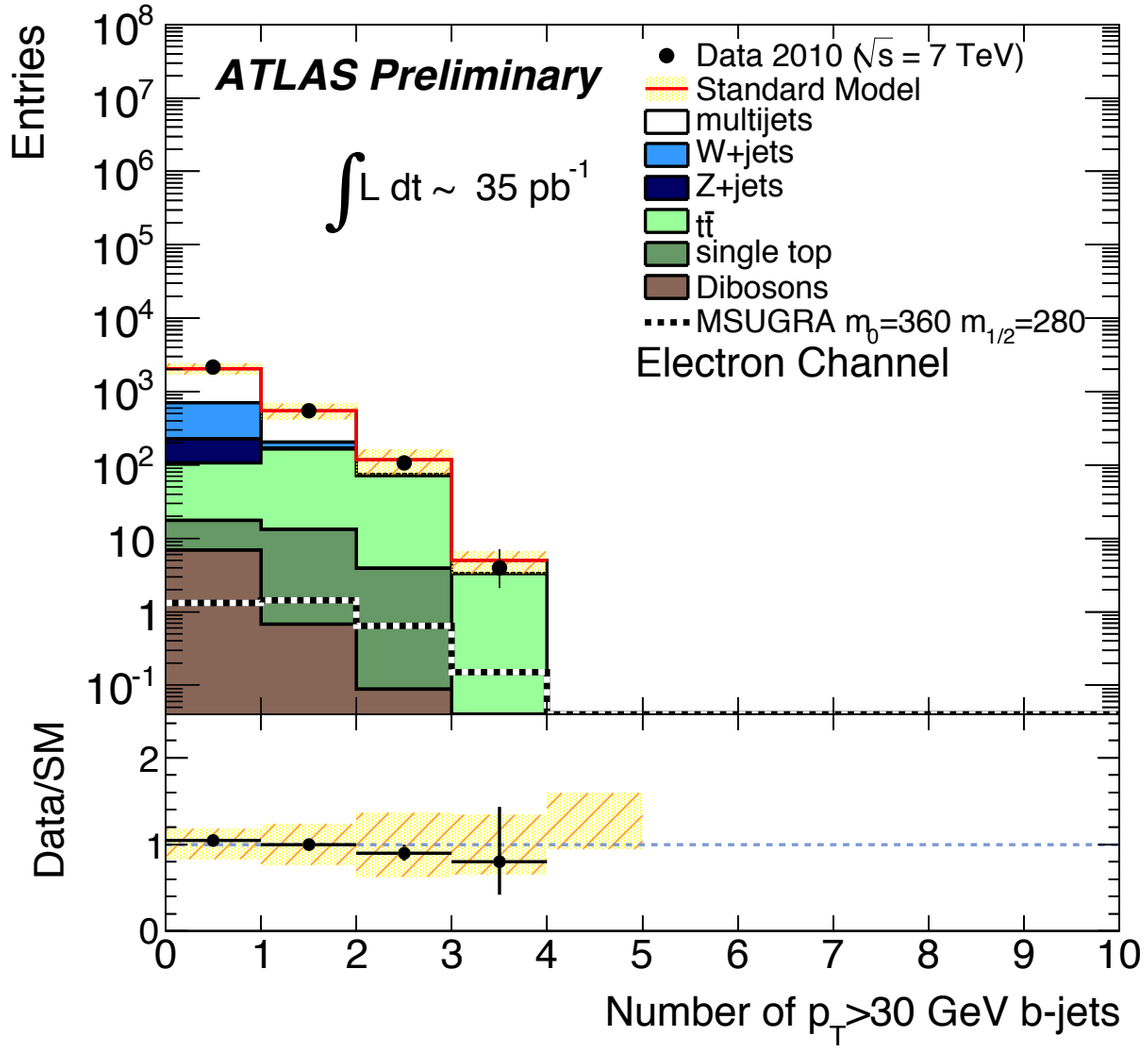
With cascades, the sensitivity is roughly comparable to MET based signal regions (based on preliminary estimates)!

Systematics and Standard Model control regions?

Improving Search Robustness and Sensitivity

Example: Control region with "1-lepton and 3-jet requirement" from the ATLAS 1-lepton + jets + MET search





3 (or even 2) b-tags, with 3 jets defines a boundary

Summary-I

MET based searches look fairly robust in ATLAS and CMS

There do seem to be directions for improvement (what can be done about tight squeezing?), but the impact of increased luminosity will swamp everything else...

Measurements of the Standard Model provide sharp clues for good places to do searches that *don't rely so heavily on MET* (or HT) (e.g. jet and b-tag multiplicity)

We should provide benchmarks for such possibilities!