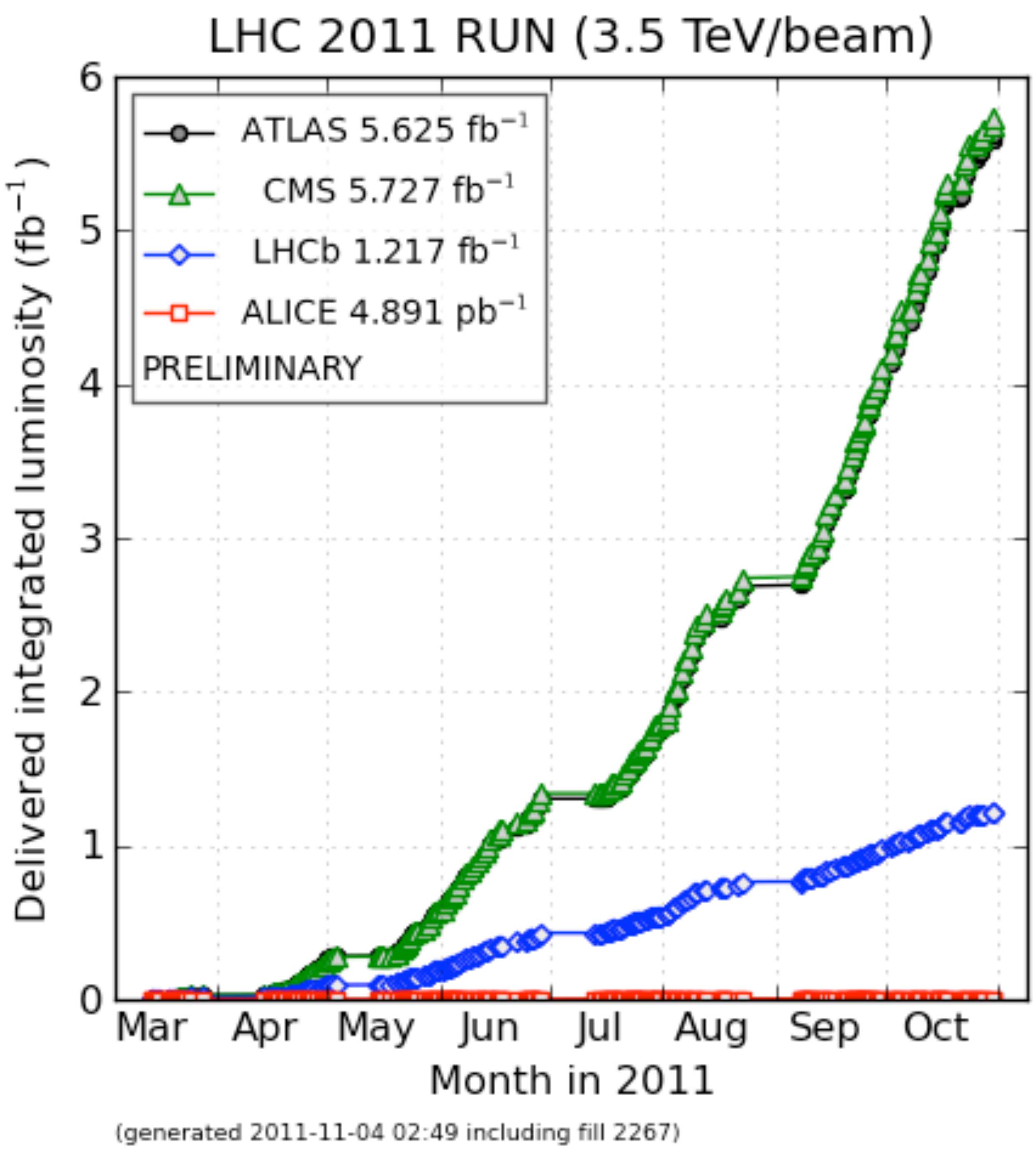
Stop NLSPs

David Shih
Rutgers University

Based on:

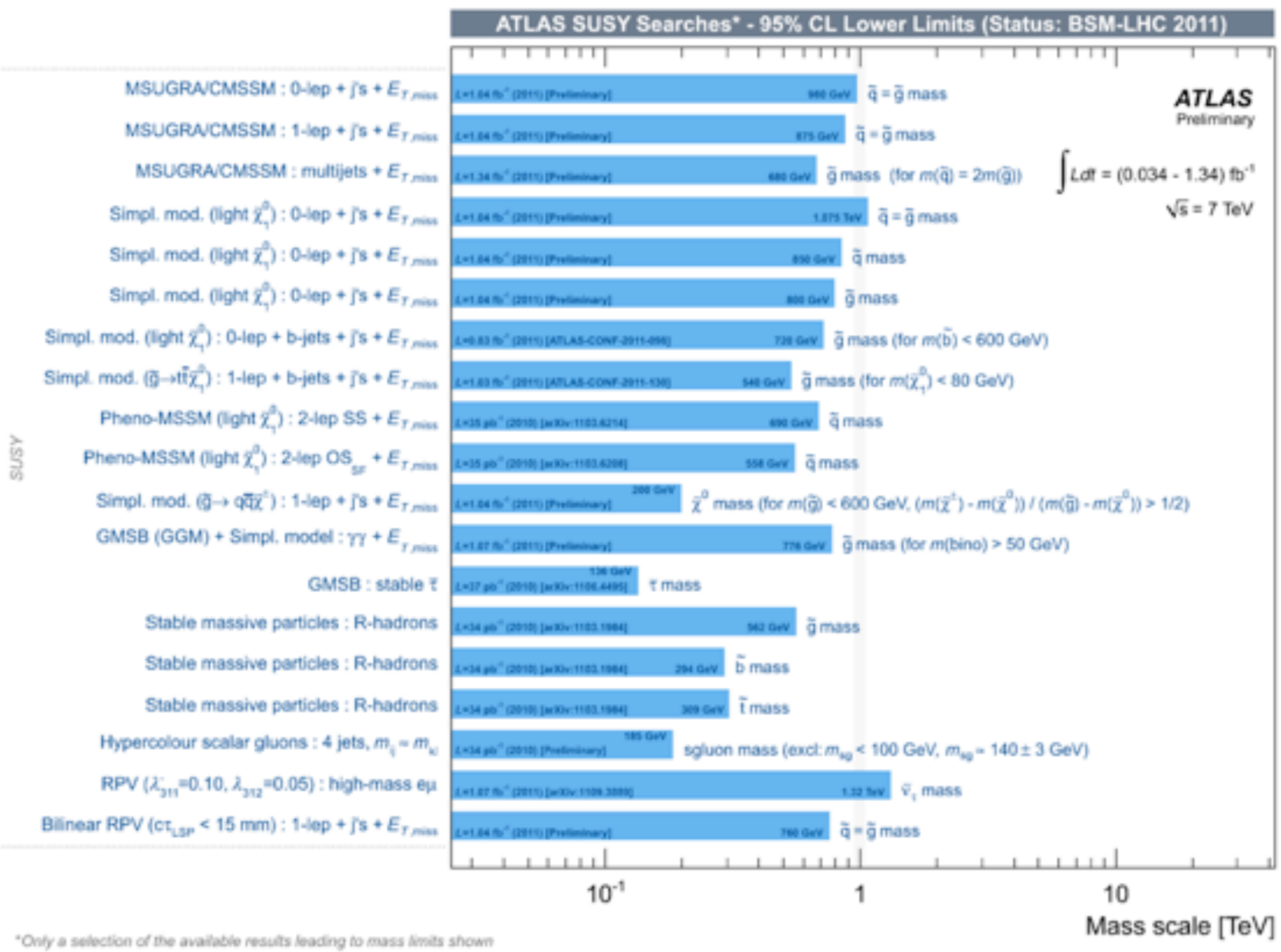
Kats & DS (1106.0030)
Kats, Meade, Reece & DS (1110.6444)

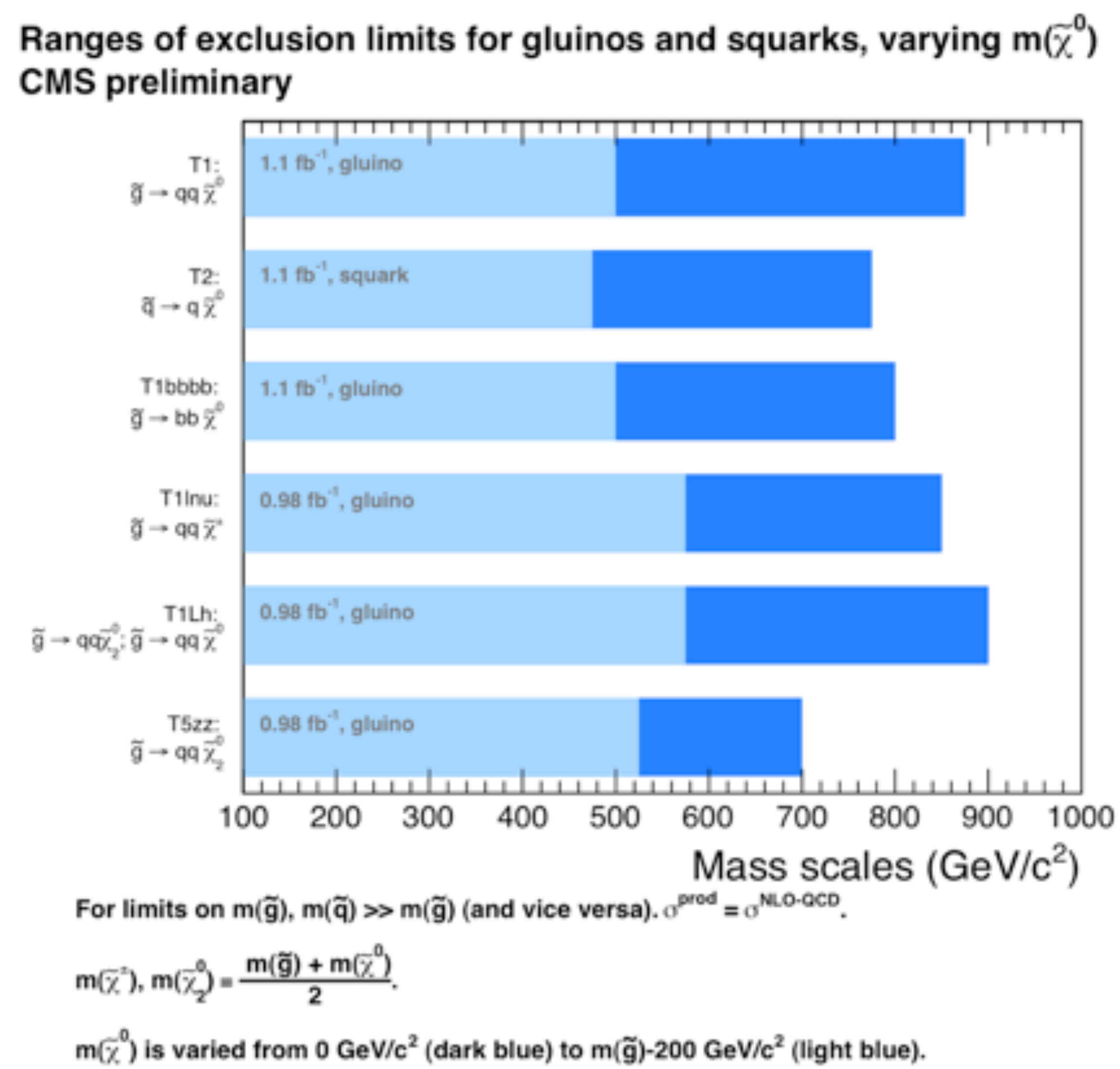
This year, the LHC has performed extremely well. ATLAS and CMS have collected over 5/fb of data each!!



Limits, limits everywhere...

ATLAS and CMS have searched for SUSY far and wide...





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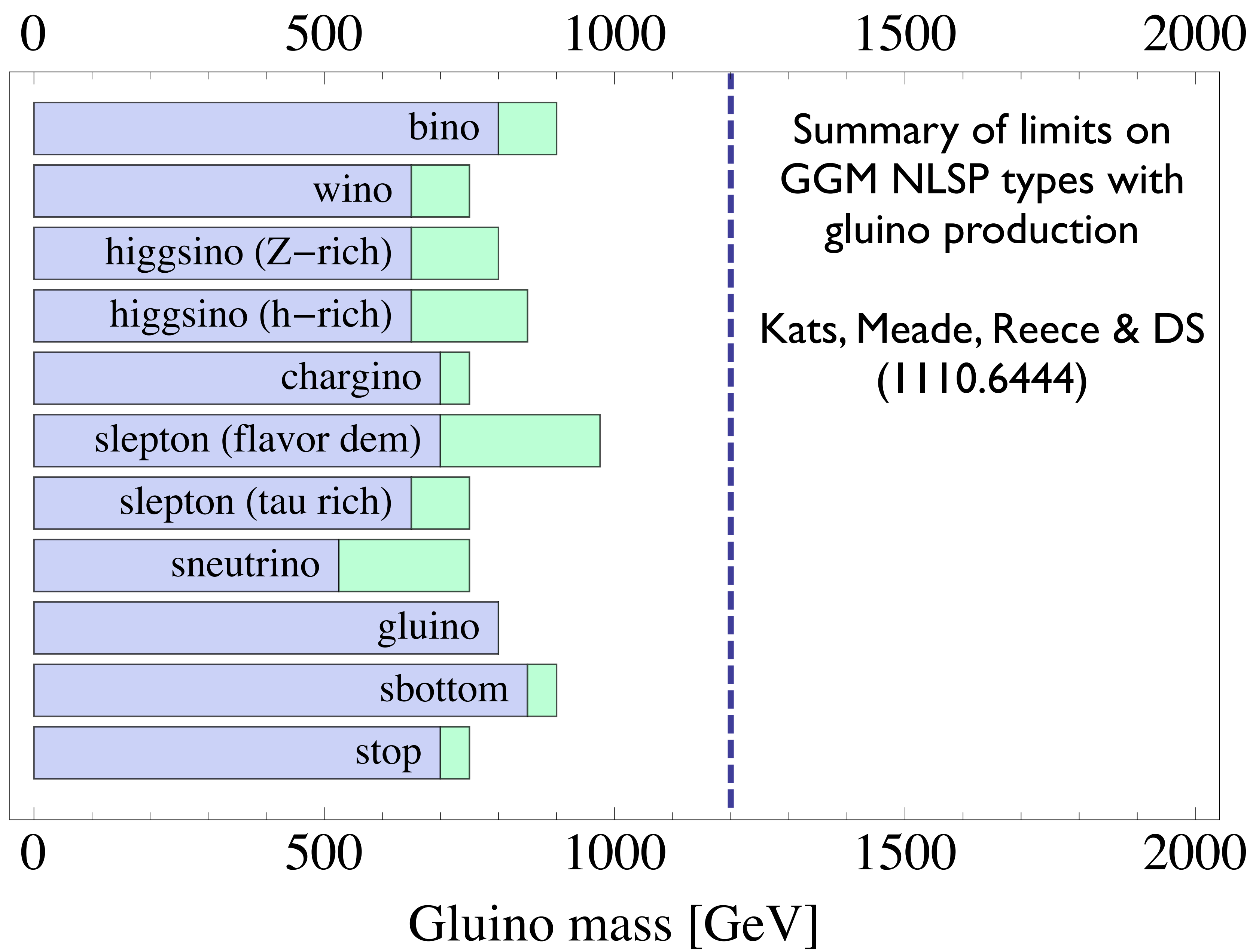

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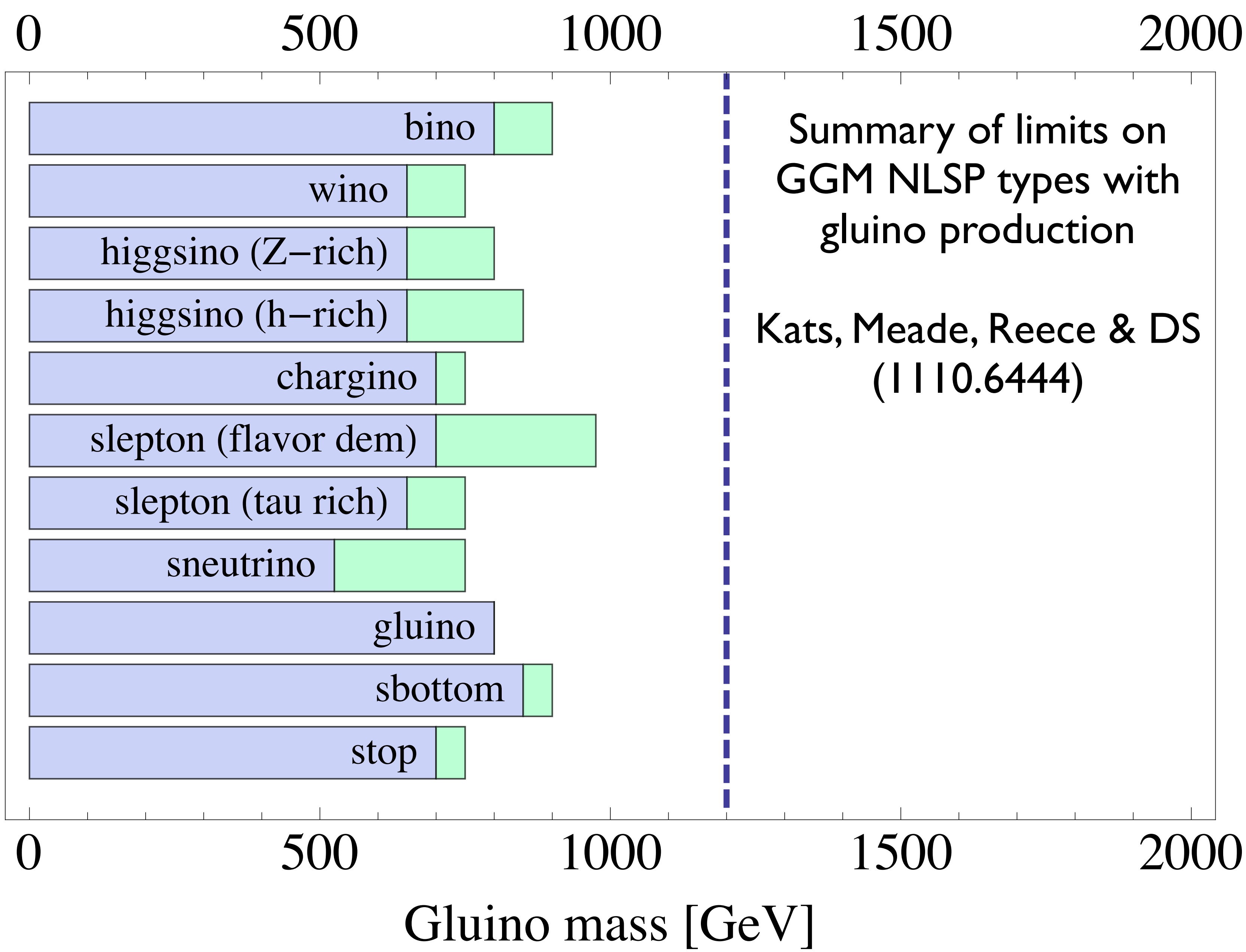

Where is SUSY hiding??

Today's Talk

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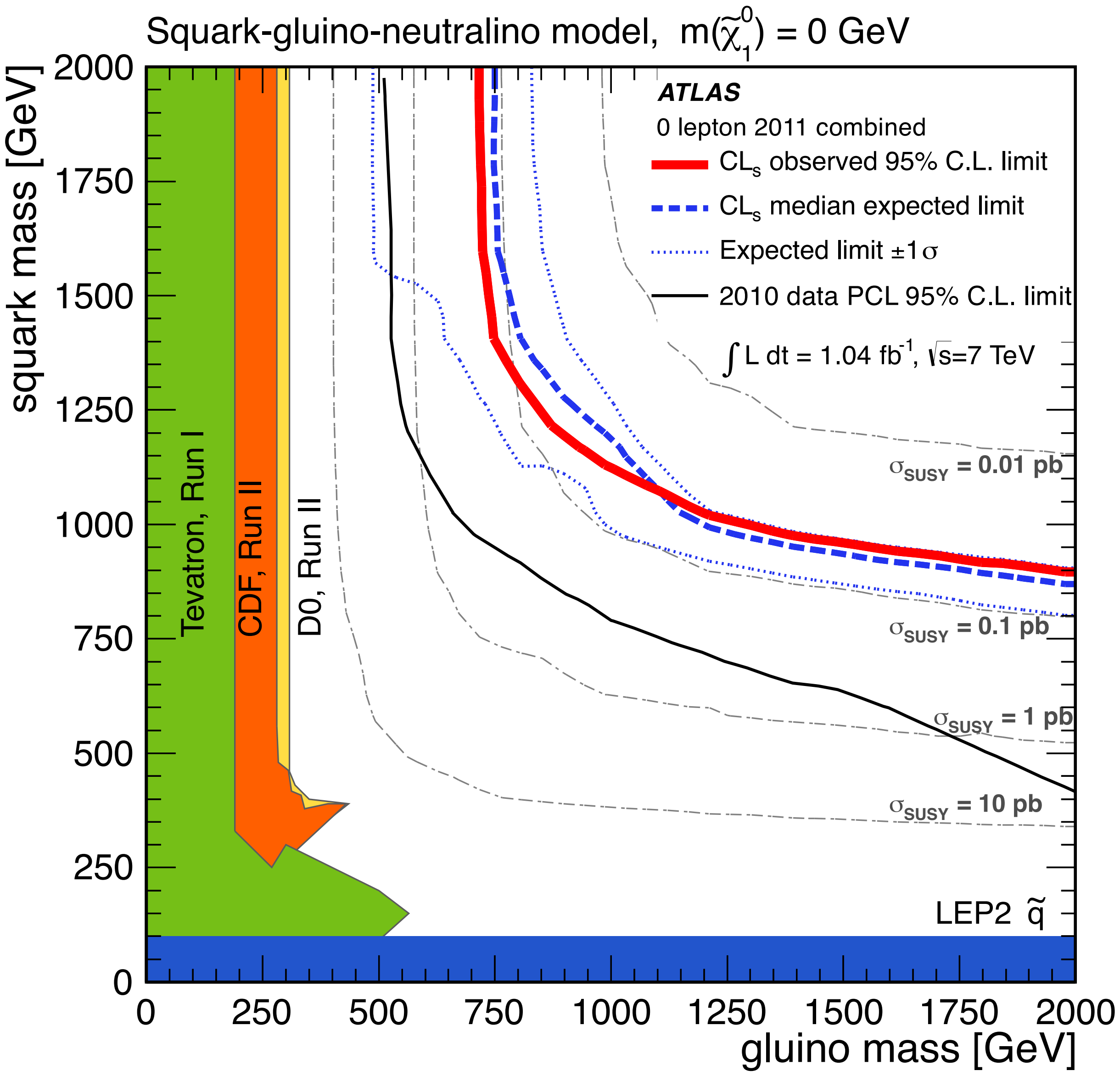
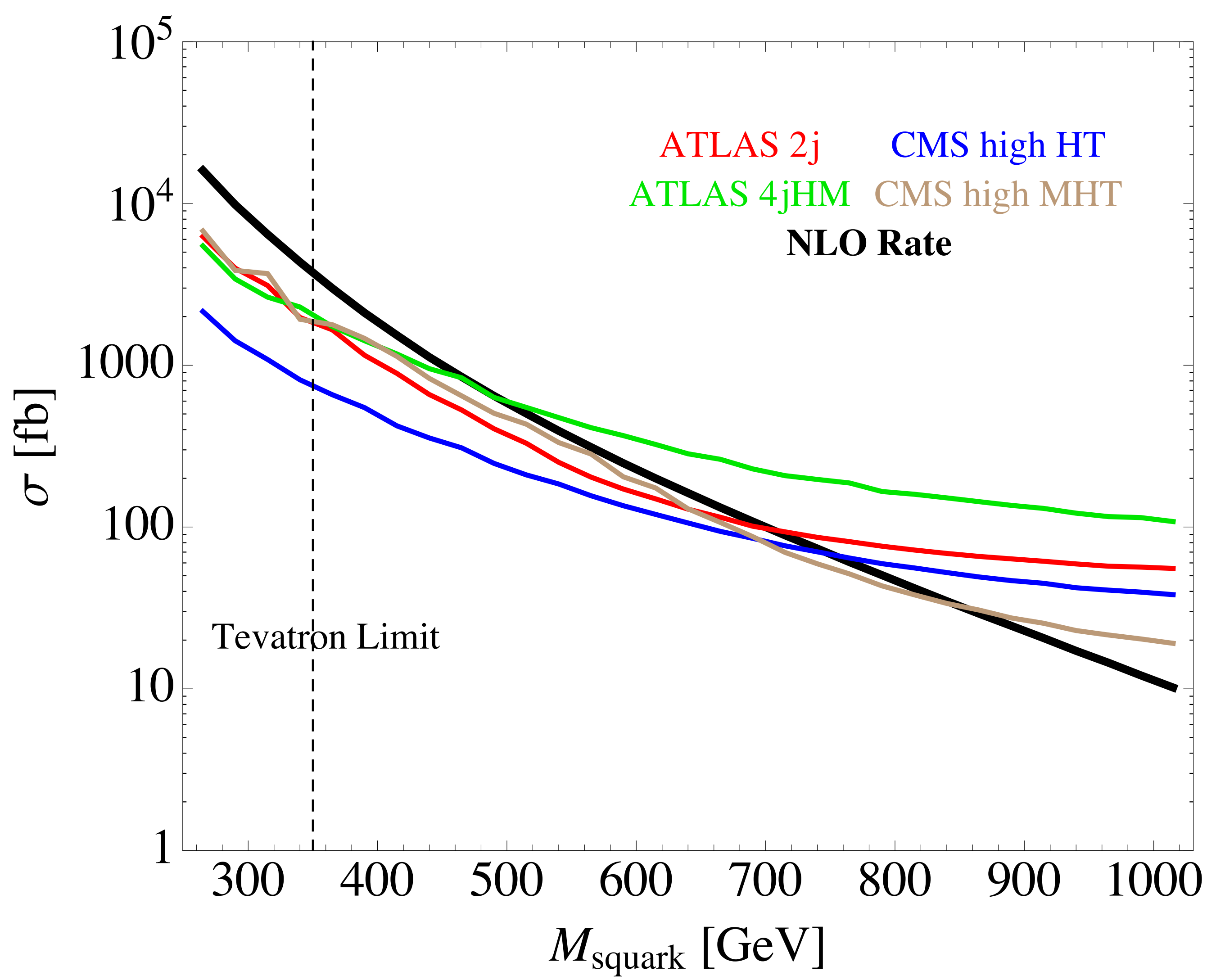
  - suggest ways to improve searches for stop NLSPs

Motivations

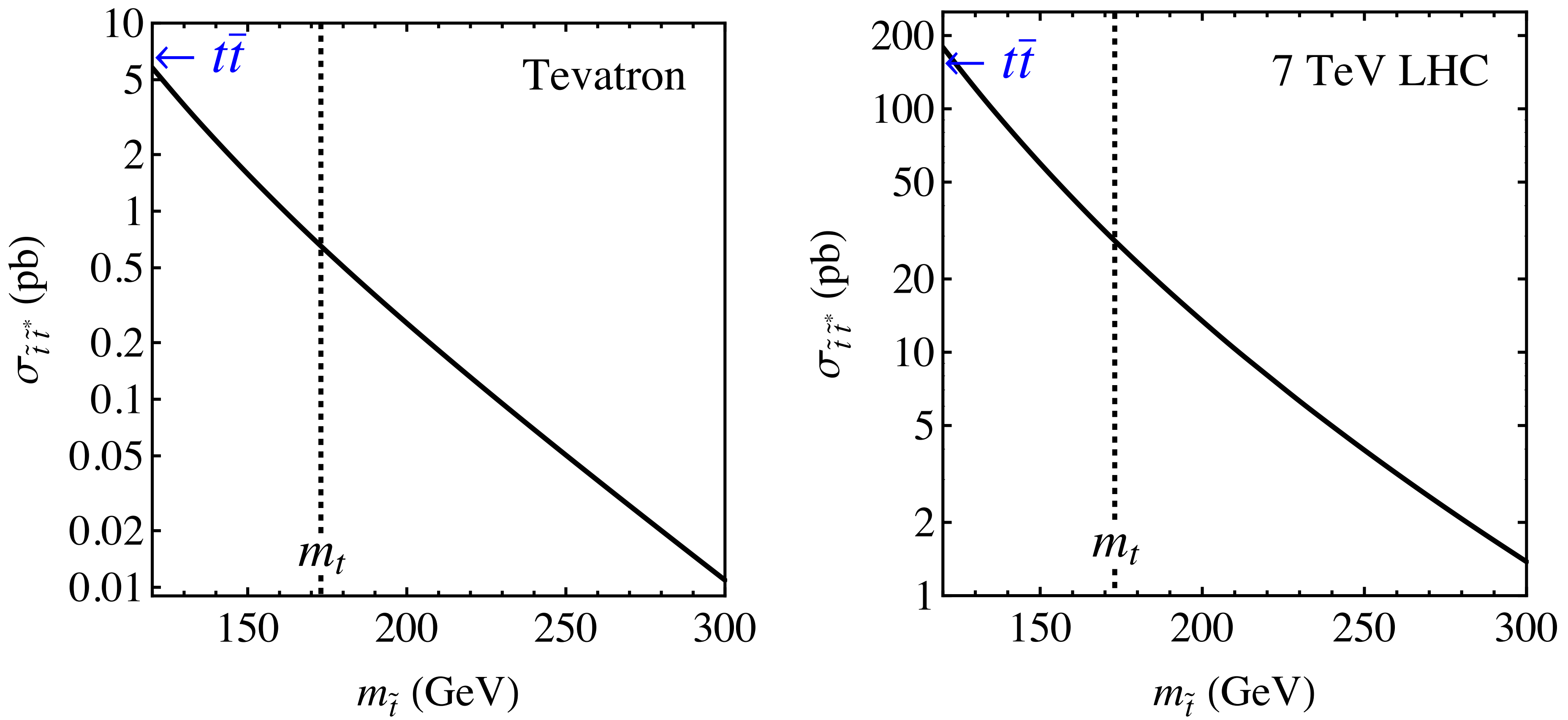
Degenerate squarks are highly constrained by LHC searches:





Motivations

- However, a single stop can be much lighter. Cross section reduced by a factor of ~10.



- As we will see, stop decays usually lead to top-like final states. Light stops could be hiding in the top sample!

Motivations

- Other reasons for considering light stops include
  - Loosely motivated by SUSY naturalness. See Papucci et al (1110.6926) and Sundrum et al (1110.6770) for a recent discussion
  - Light stops can occur even in flavor-blind mediation schemes, through RGEs and L-R splitting
  - Light stops are also possible in models of "effective SUSY", for instance those with composite 1st/2nd generations
- Summary: light stops are theoretically possible, detecting them presents an interesting experimental challenge, and currently they represent a big "blind spot" for LHC searches.

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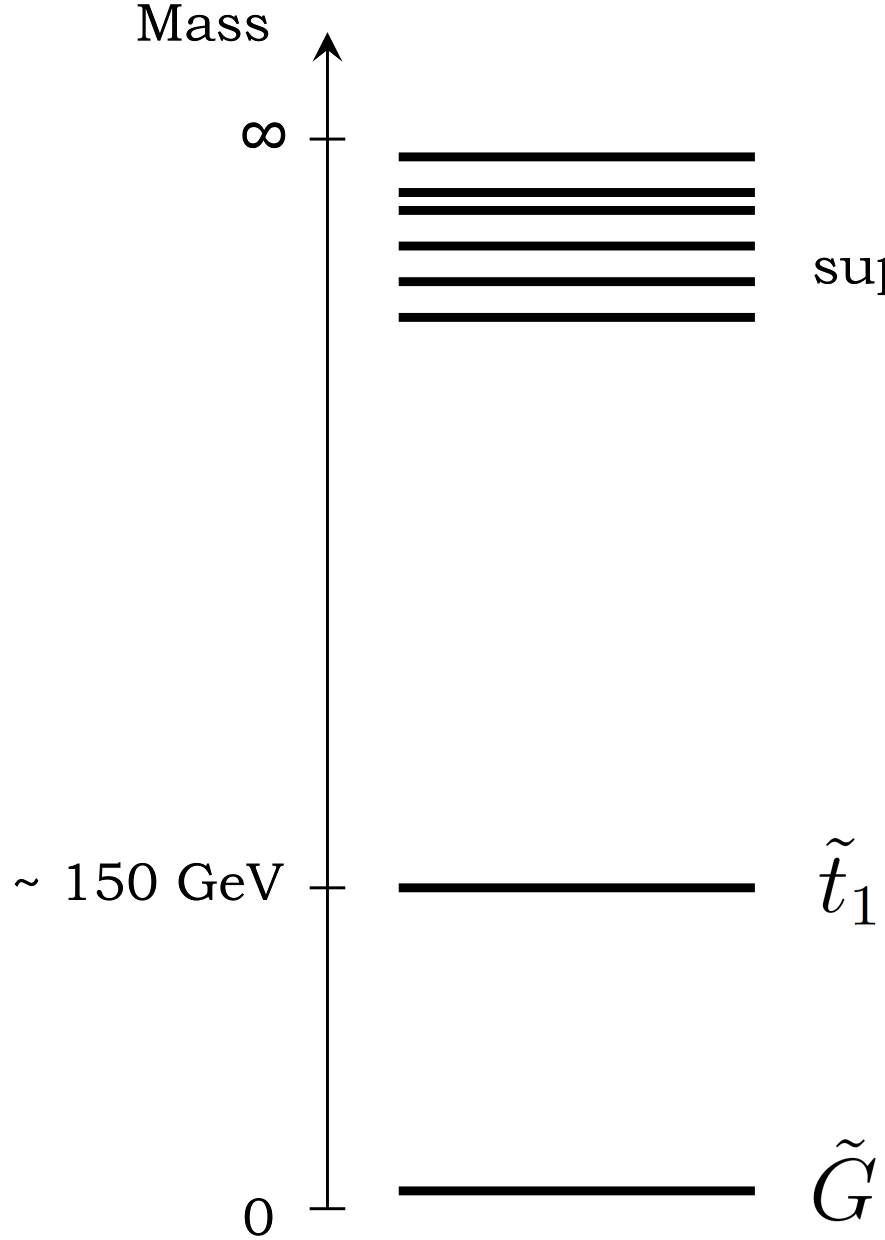
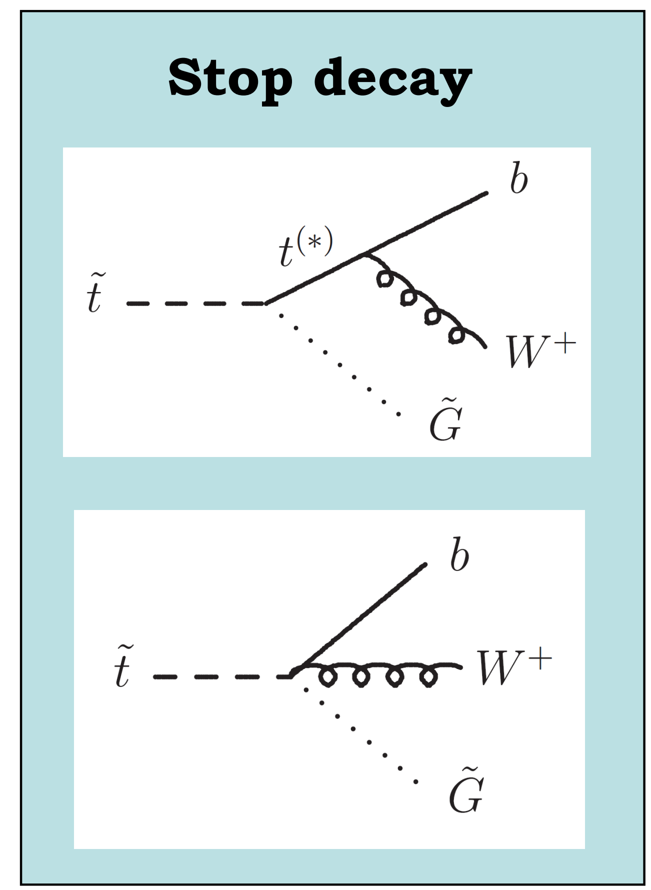
$$\tilde{t} \to t + \tilde{G} \quad (m_{\tilde{t}} > m_t)$$

$$\tilde{t} \to W^+ + b + \tilde{G} \quad (m_{\tilde{t}} \lesssim m_t)$$

"Stop NLSP"

Minimal Stop NLSP Scenario





$$\tilde{t} \to W^+ b\, \tilde{G}$$

Relevant Analyses

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- Measurements of ttbar cross section
  - Tevatron (~5/fb) and LHC (35/pb and 1/fb)
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  - With and without b-tagging
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Apart from the CDF stop search, we have not reinterpreted analyses with sophisticated kinematic discriminants. These include xsec measurements, top mass measurements, and the D0 stop search.

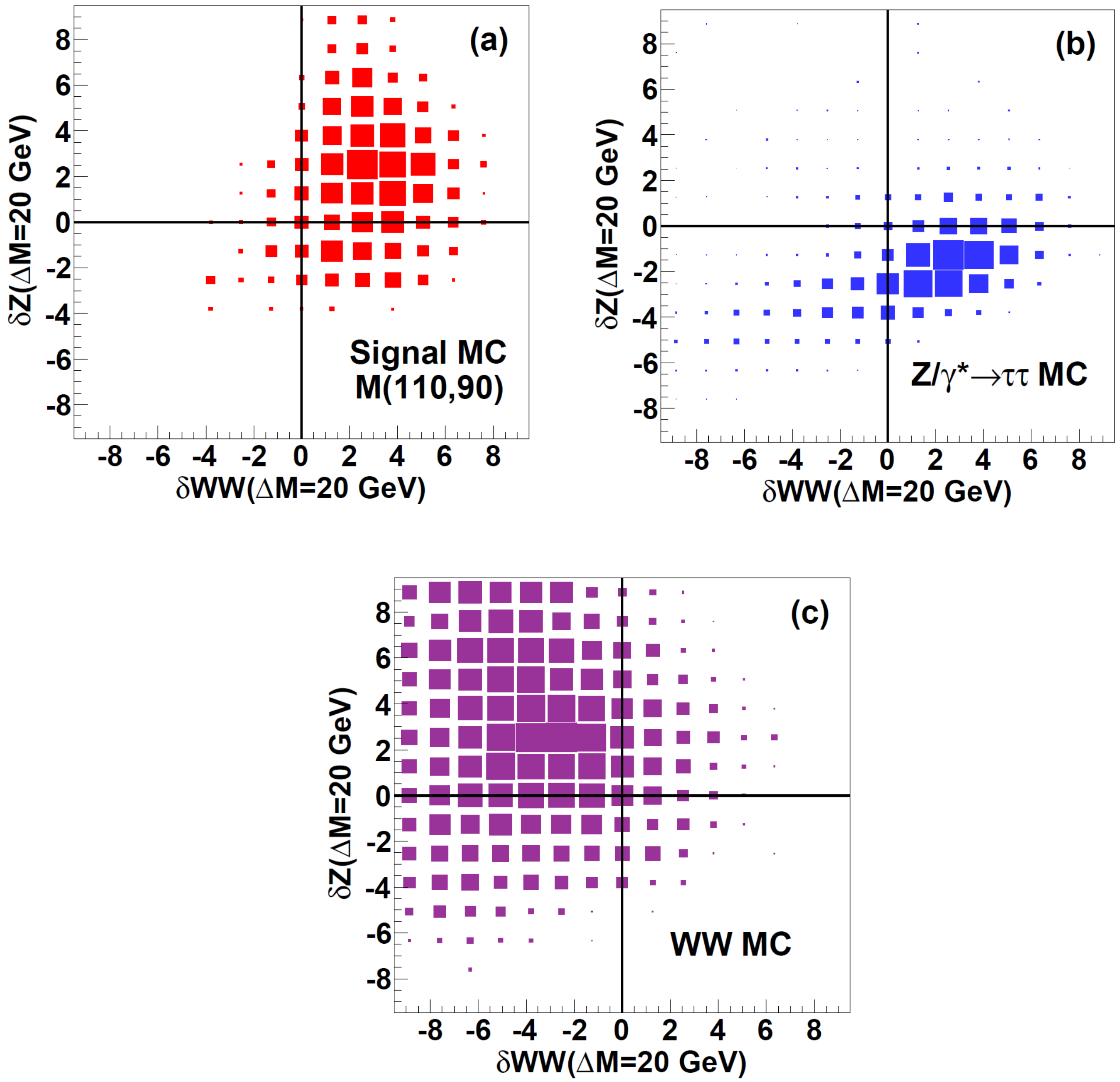
Our Modus Operandi

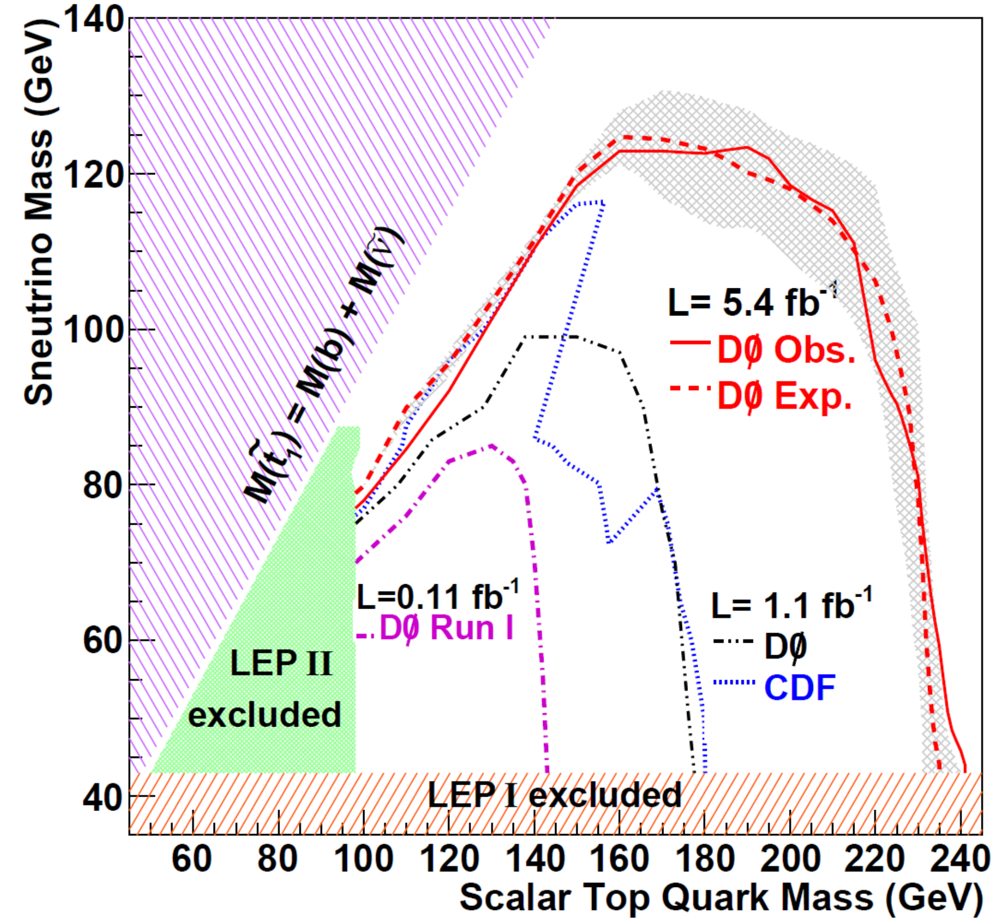
- Generate events with combination of
  - Pythia 8 for initial hard process, showering and hadronization
  - Homemade code to decay stops to W+b+gravitino.
    (Available at: http://www.physics.harvard.edu/~kats/stop_NLSP)
- Reconstruct events using basic homemade detector sim (jet algorithms via FastJet, lepton isolation, b-tagging requirements)
- Code up relevant analyses, validate them on publicly available results (ttbar; stop signal where applicable). Correct by scale factors where necessary (~10-30%).
- Infer limits on stop NLSPs using published backgrounds and systematic errors.

D0 stop search

(hep-ex/1009.5950)

- Integrated luminosity: 5.4/fb
- Search for stop pair production with $\tilde{t} \to b\ell^+\tilde{\nu}$
- Initial selection
  - Exactly one OS (e,mu) with pT > (15,10) GeV
  - MET>7
  - MET>20 or DeltaPhi(e,mu)<2.8 (to reject Z->tautau)
- This is all we were able to simulate from this search. The final selection involves using multiple composite discriminants, optimized separately for each point in parameter space.





D0 publication did not provide enough information (e.g. the definition of these discriminants) to allow us to reinterpret this search.

It would be very interesting for D0 to apply this analysis to stop NLSP, it could a strong limit!!

CDF Stop Search

(hep-ex/0912.1308)

- Integrated luminosity: 2.7/fb
- Search for stop pair production with $\tilde{t} \to b\tilde{\chi}_1^+, \quad \tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0$
- Basic selection:
  - two leptons with pT > 20 GeV
  - at least two jets with ET > (15,12) GeV
  - MET > 20 GeV
  - >=1 btags

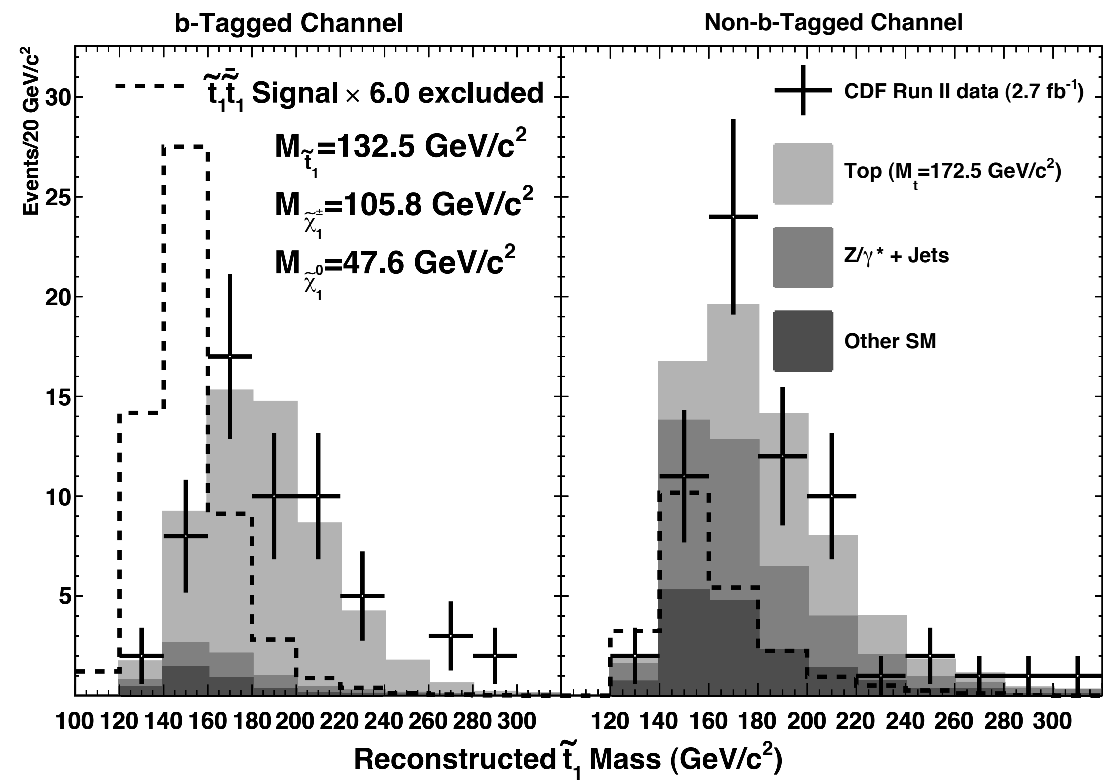
There is also a 0 btag selection, but the limits for this are not shown.

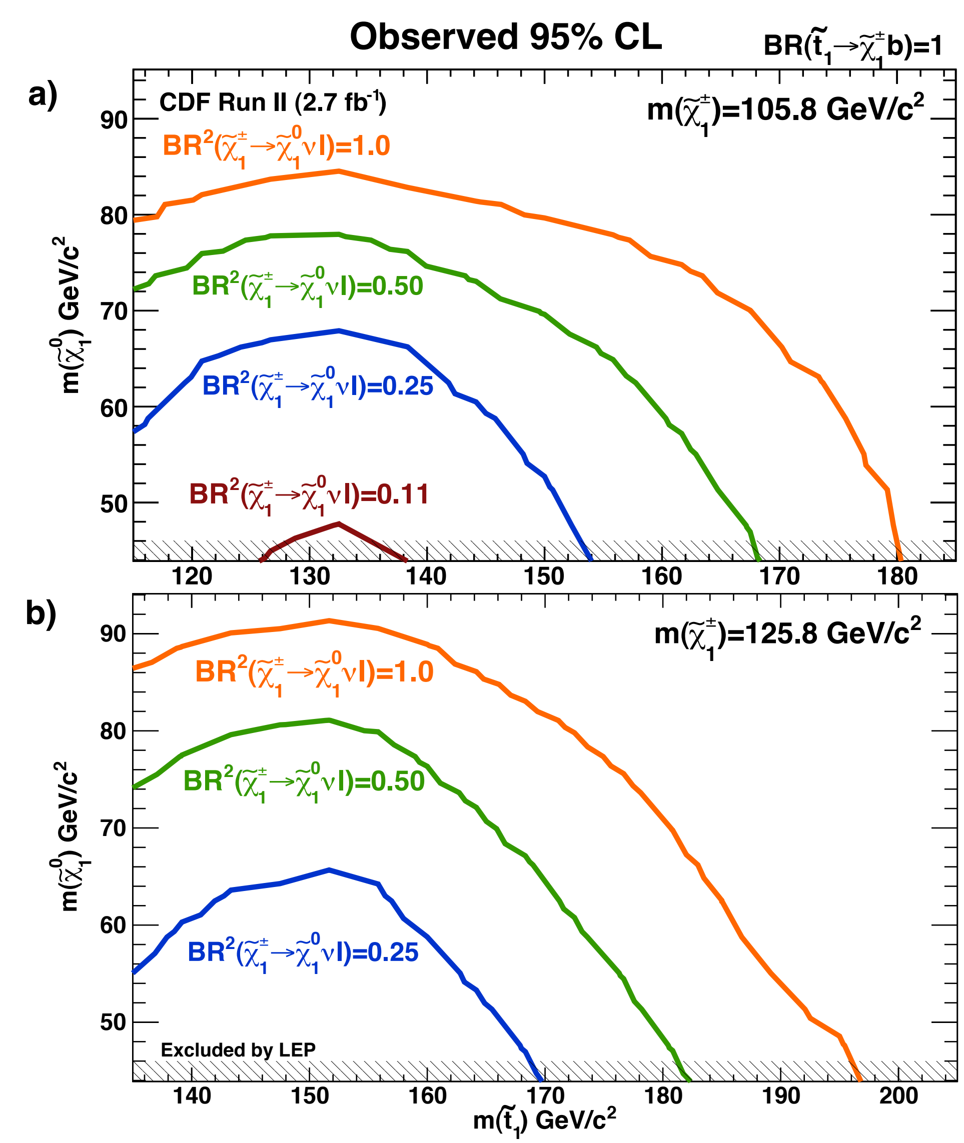
- Final limits are based on comparing signal and background distributions for the "reconstructed stop mass" variable

$$\tilde{t} \to b\tilde{\chi}_1^+, \quad \tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0$$

The "reconstructed stop mass" is computed using the leptons, the two highest ET jets, and the MET as follows:

- Fix a chargino mass, perform reconstruction for different values (in the paper, 105.8 GeV and 125.8 GeV).
- Treat invisible $\nu\tilde{\chi}_1^0$ as coming from a "pseudoparticle" with mass 75 GeV and width 10 GeV. Scan over pseudoparticle phi directions.
- Pair jets and leptons to minimize summed invariant masses
- Minimize "chi-squared", varying observables within their experimental resolutions, to obtain best fit reconstructed top mass





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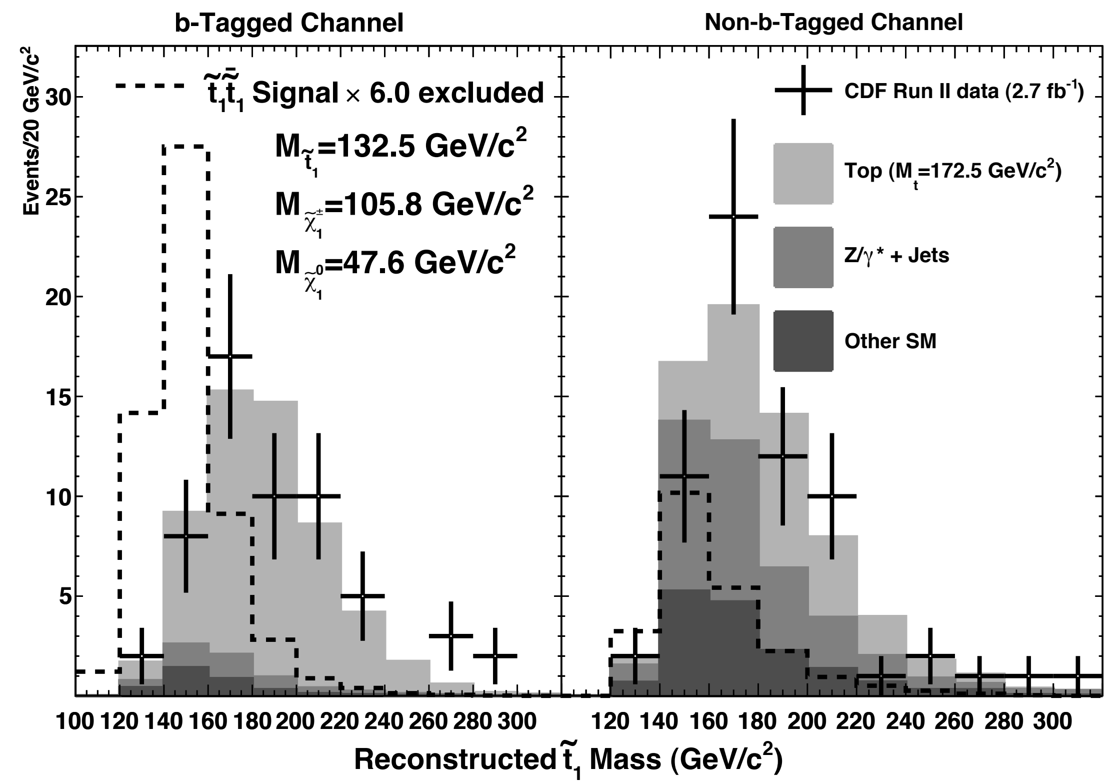

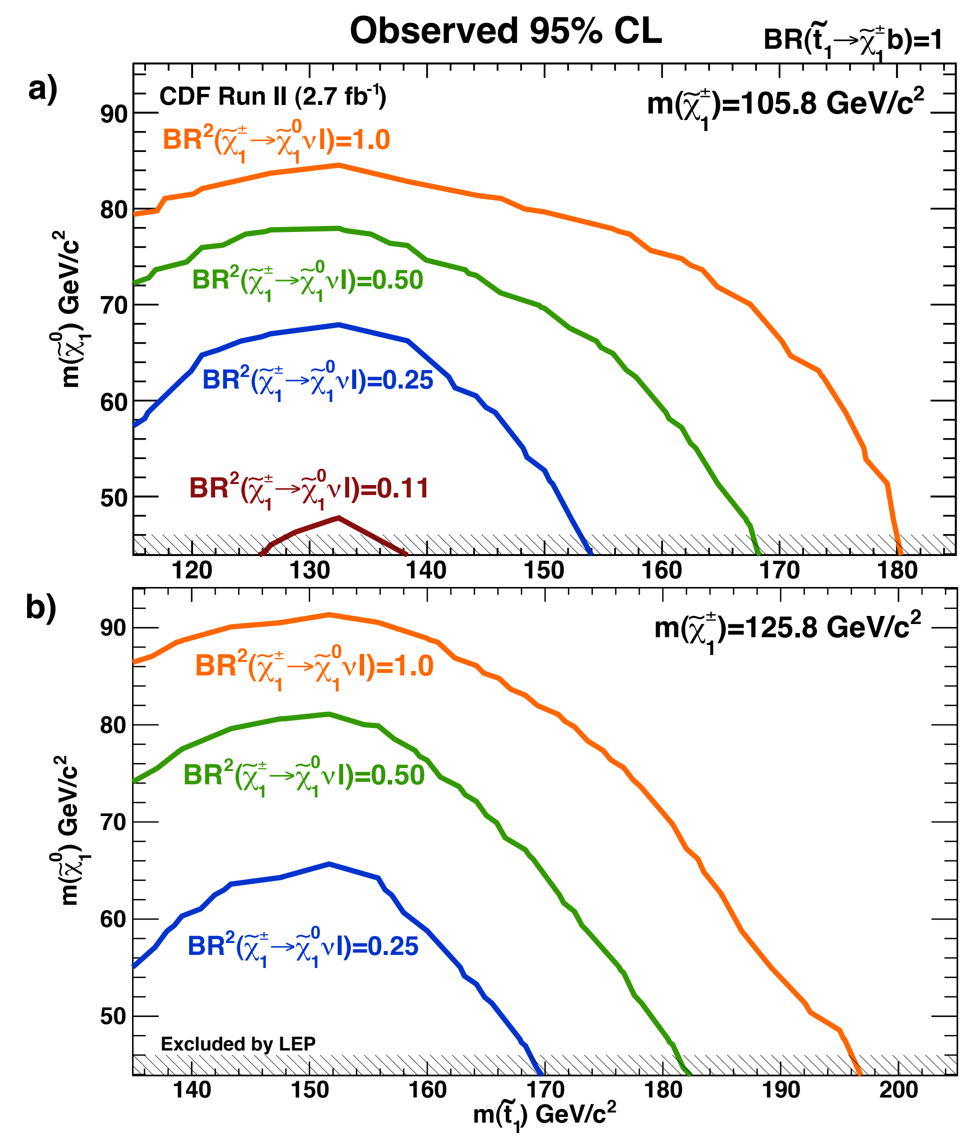

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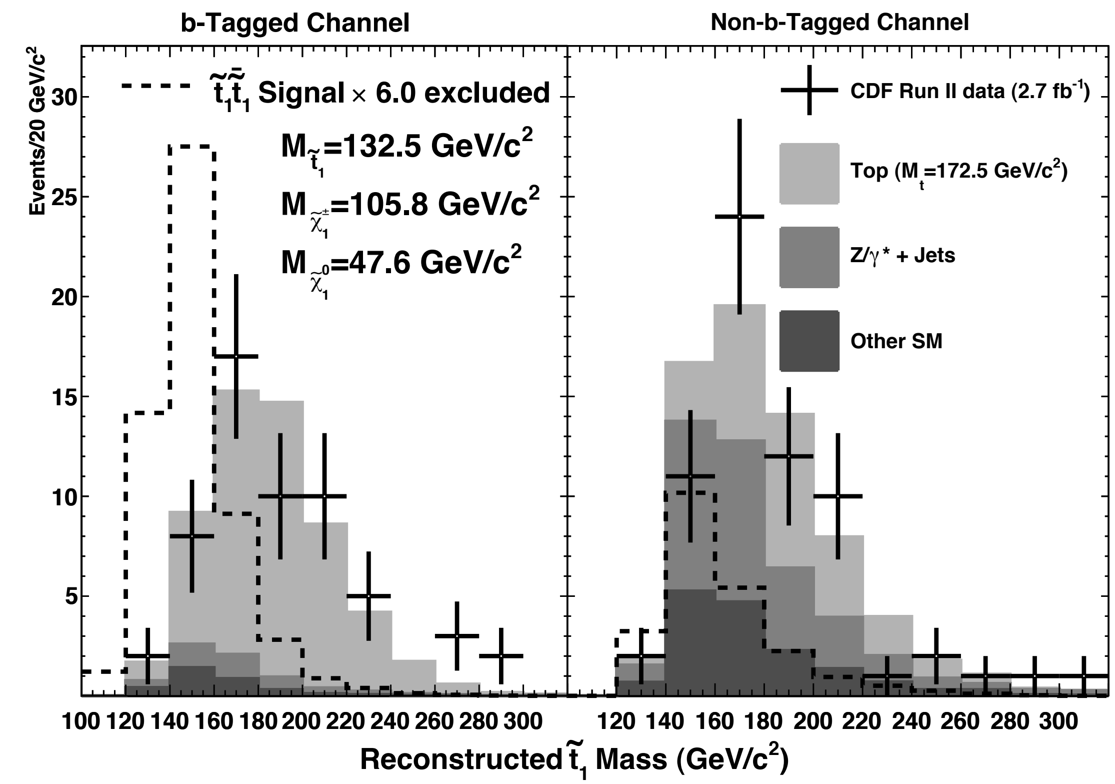
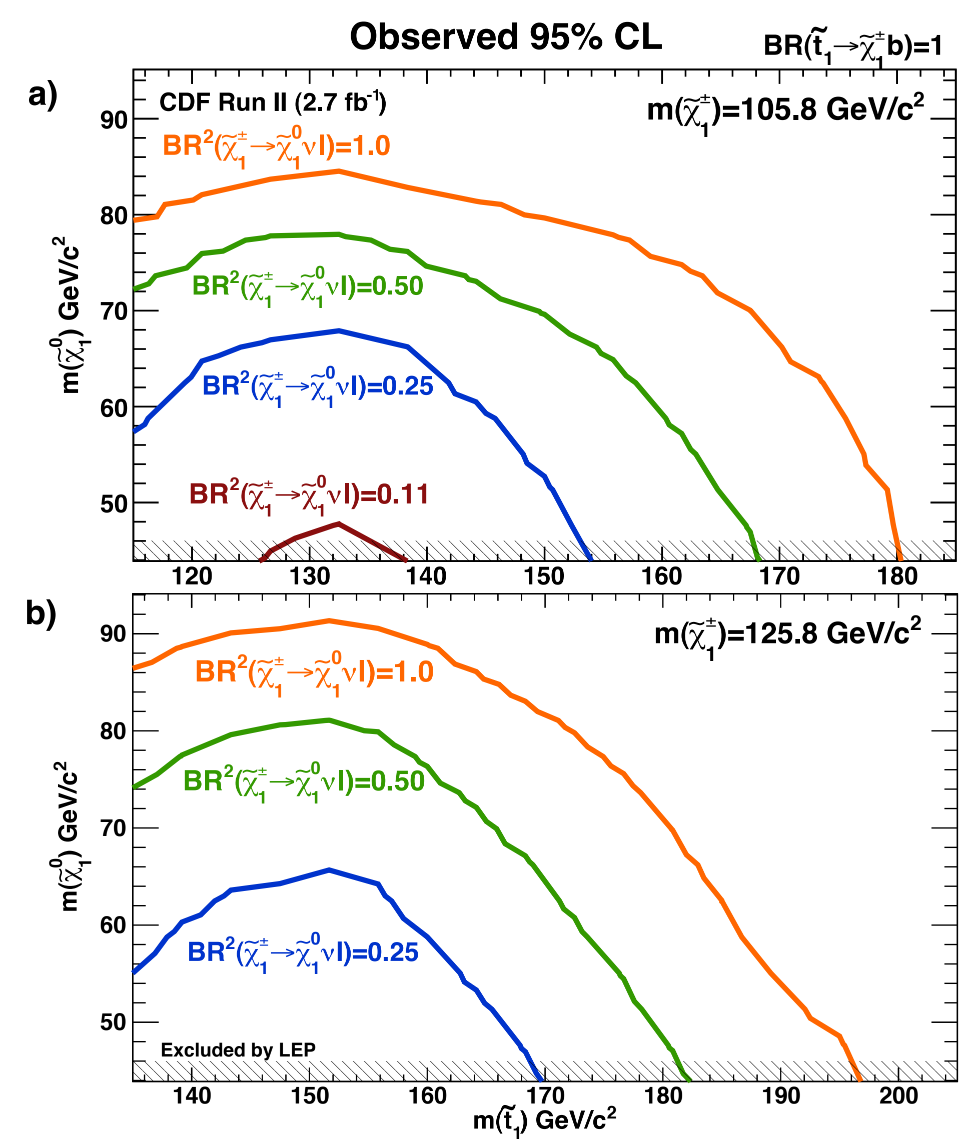
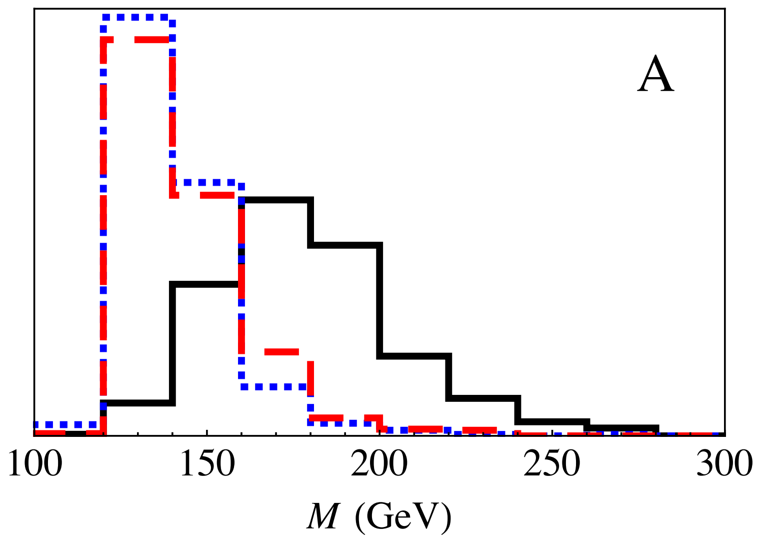


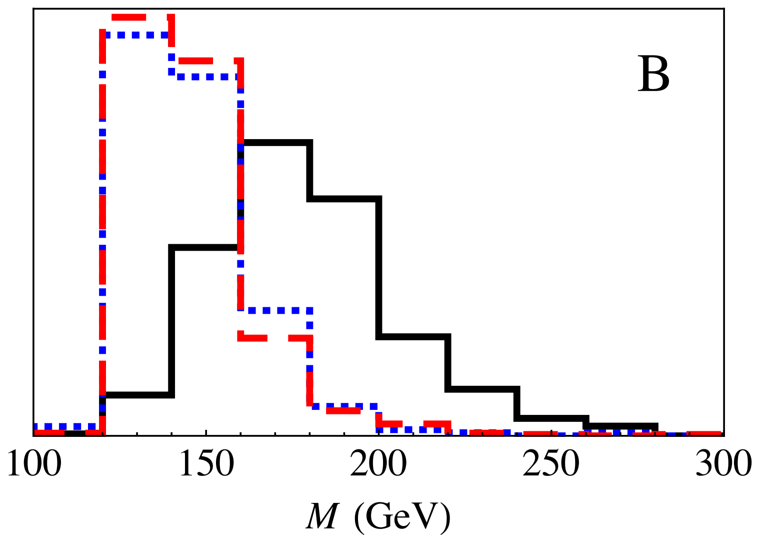


Not a rigorous process, but it gives a useful discriminant...

CDF Stop Search

- To reinterpret this search as a limit on stop NLSP, we computed the "reconstructed stop mass" distribution for stop NLSPs and for the benchmark stop scenarios used by CDF, using their method.
- By matching distributions and comparing to the CDF limits on the benchmark scenarios, we obtained the limit on the effective cross section for stop NLSPs.
- This procedure obviates the need to understand the limit-setting procedure and systematic uncertainties. It should also cancel out many of the systematic biases from our simulations.





case	NLSP	gravity-mediated			
	$m_{\tilde{t}}$	$m_{\tilde{t}}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_1^0}$	BR
A	132.5	132.5	105.8	47.6	0.17
B	145	137	105.8	47.6	0.13
C	155	140	105.8	47.6	0.11
D	165	150	105.8	47.6	0.10

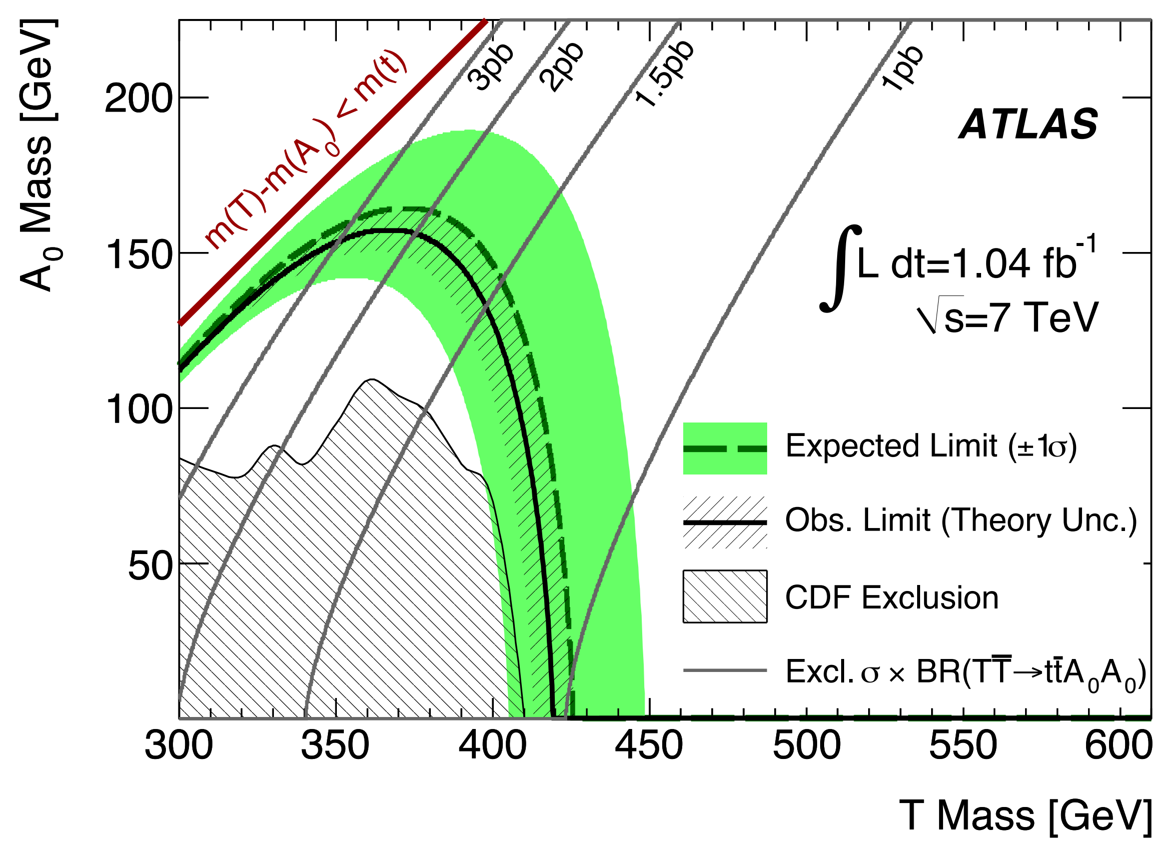
ATLAS ttbar+MET

ATLAS-CONF-2011-036 (35/pb)

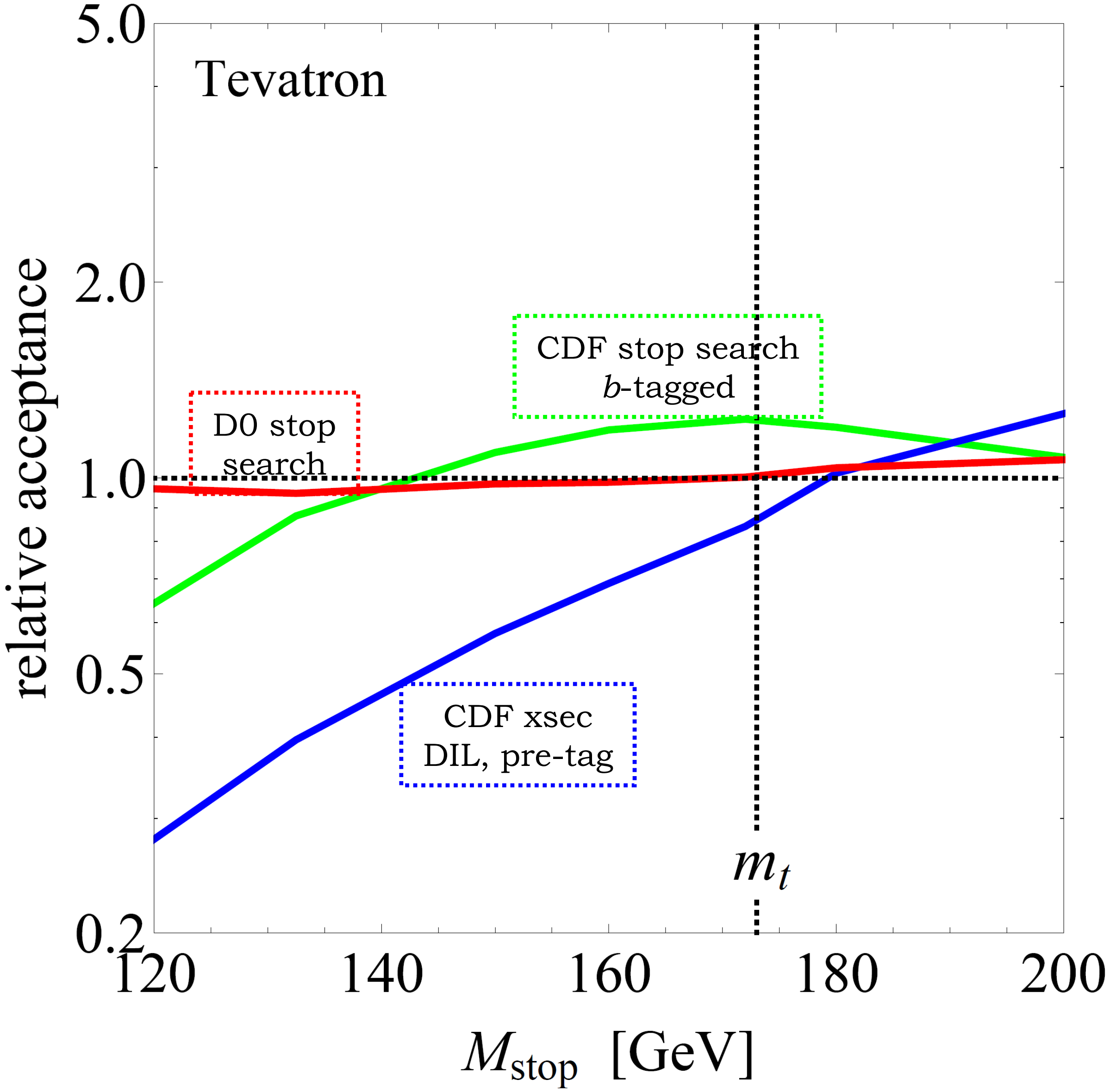
hep-ex/1109.4725 (1.04/fb)

- Search for fermionic T->t+MET in lepton+jets final state.
- Exactly one lepton with pT > 20 → 25 (e)
- At least four jets with pT > 20 → 25
- MET > 80 → 100
- mT > 120 → 150
- No btag requirement

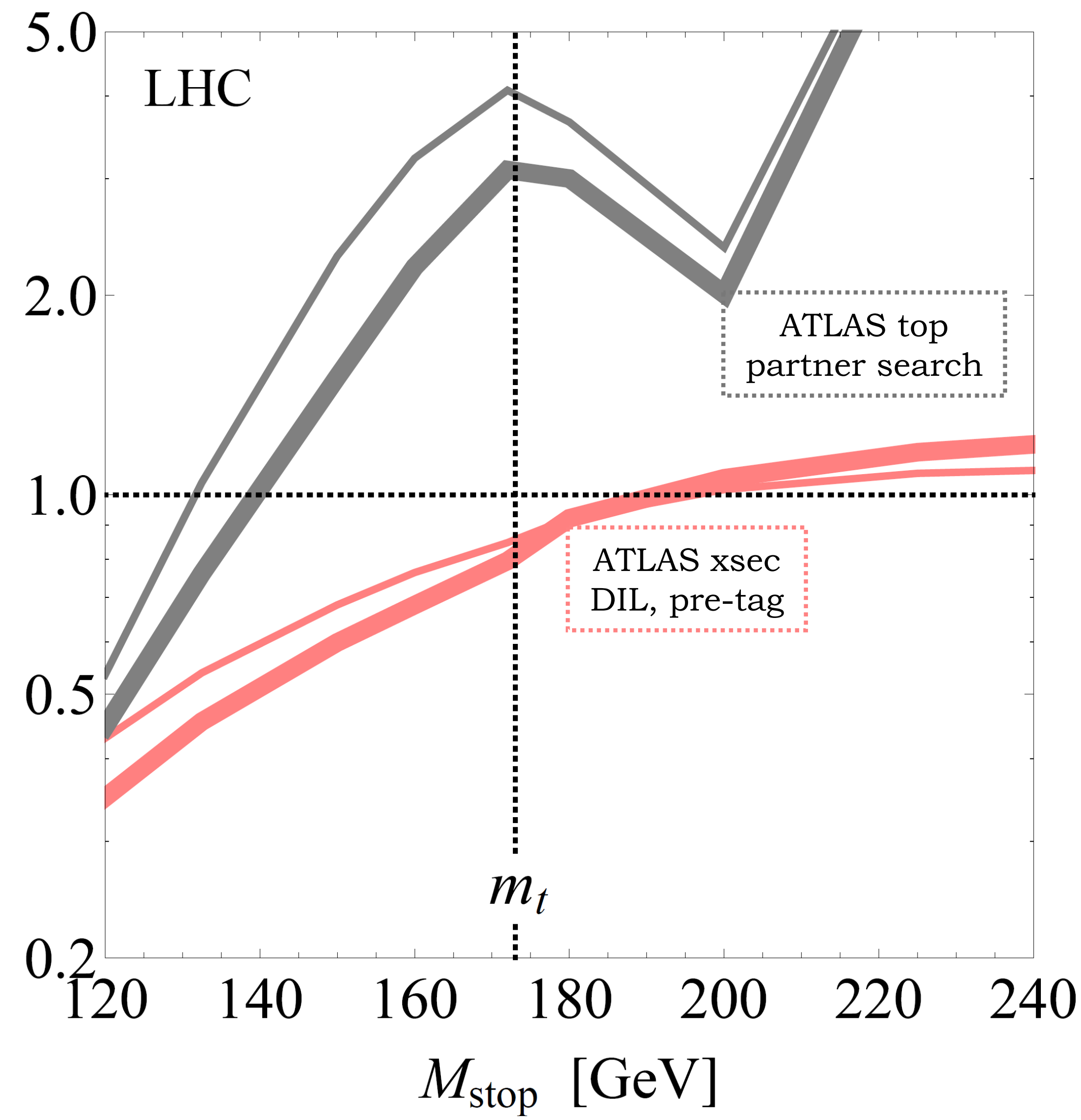
Large xsecs
=> limits in 300-400 GeV range.



Acceptances (relative to ttbar)



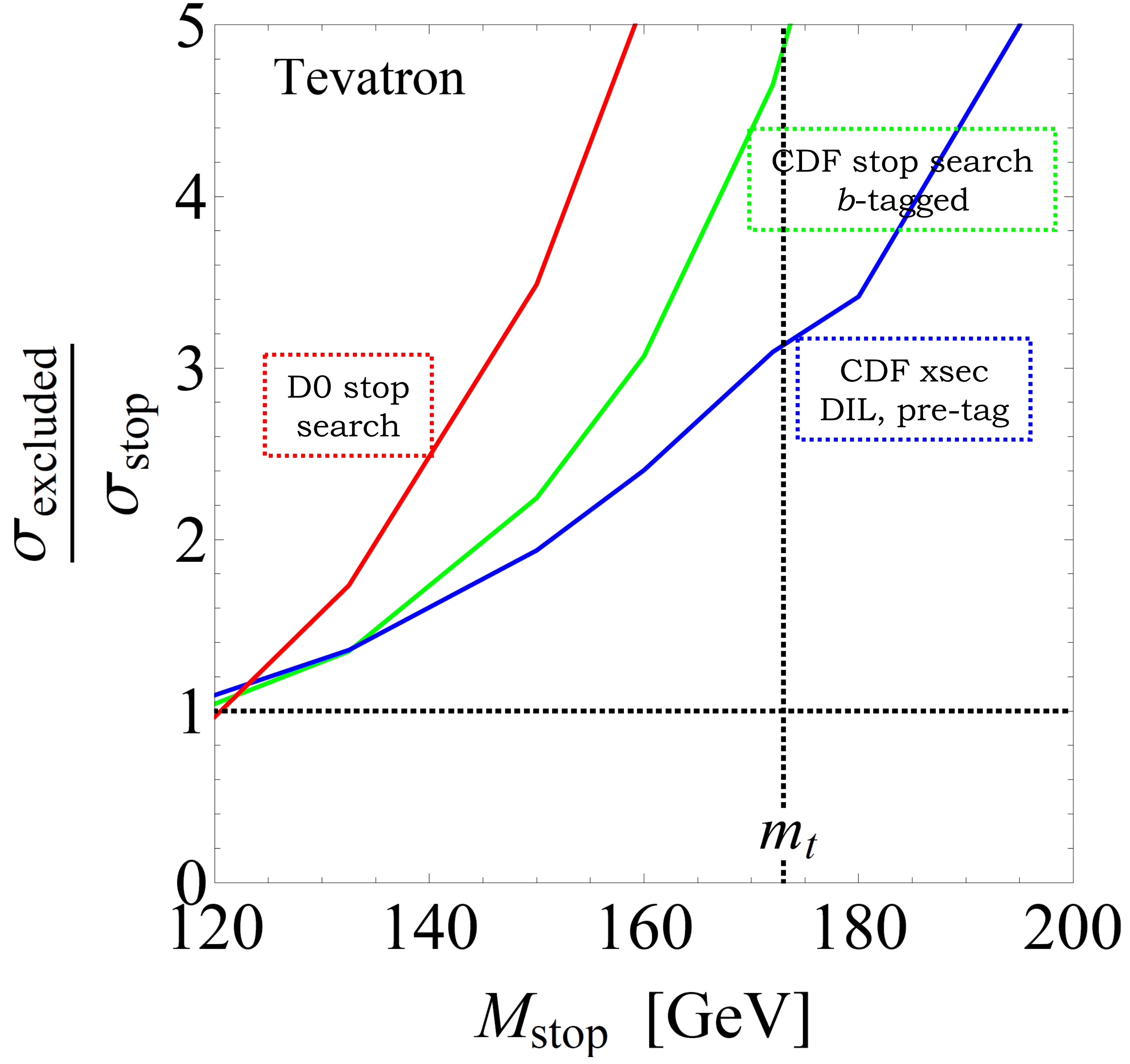
Generally, we find that the efficiency of standard cut-and-count analyses is around the same for stops as for tops.



ATLAS ttbar+MET does better because of its mT cut!

Results: Tevatron

(Kats & DS 1106.0030)

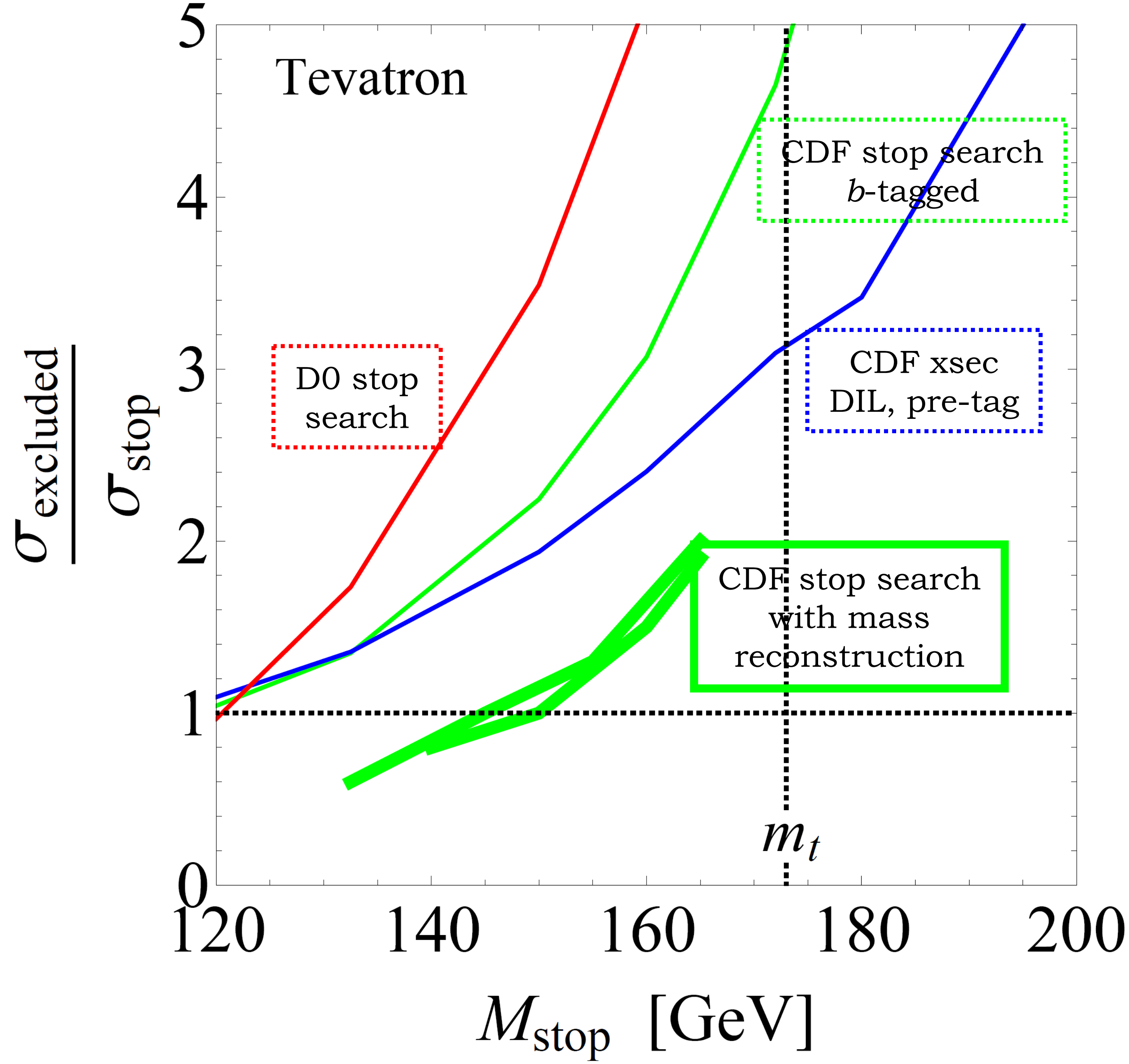


Standard "cut and count" techniques only.

Basically no limit.

Results: Tevatron

(Kats & DS 1106.0030)

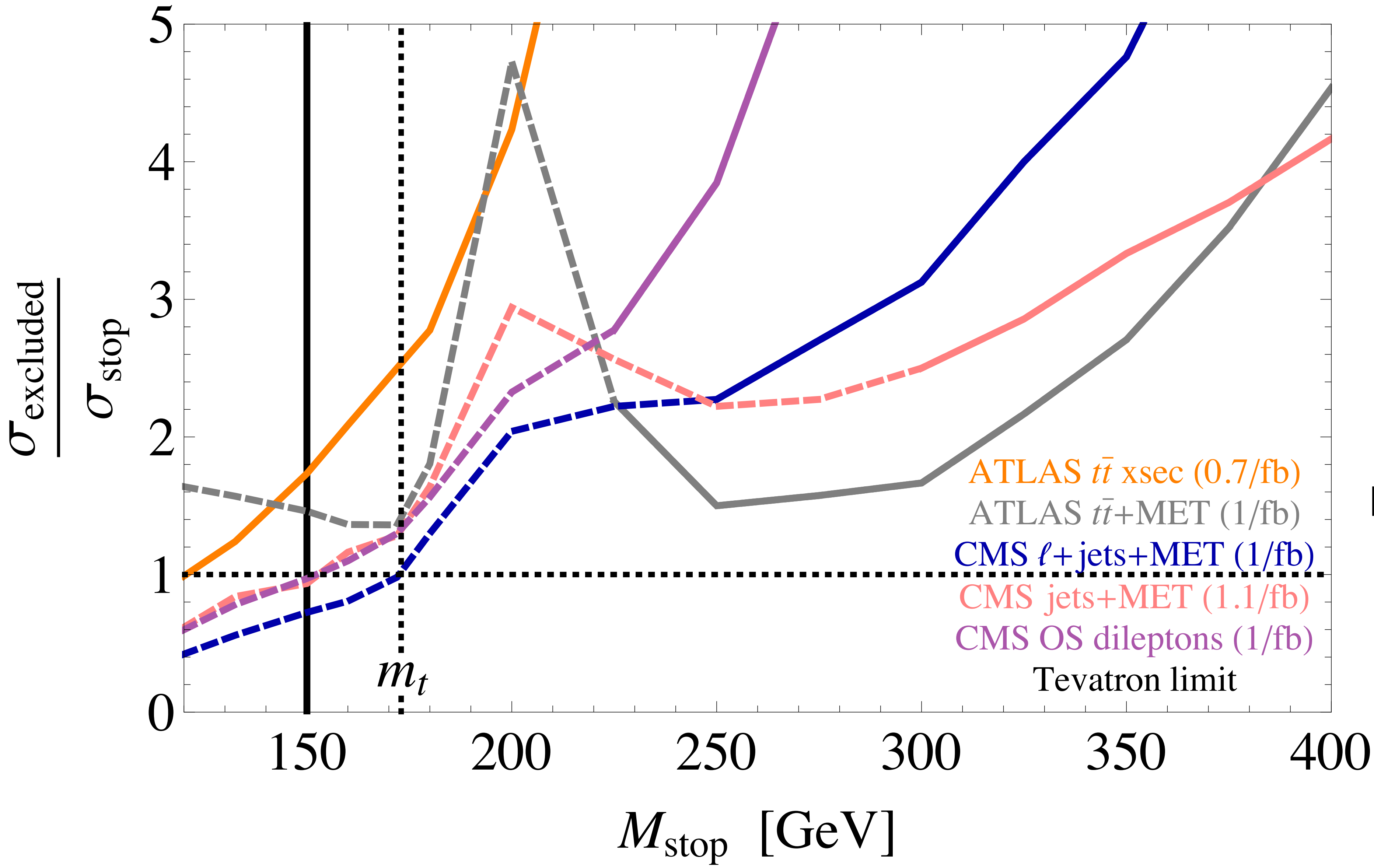


Best limit from Tevatron:
$m_{stop} > 150$ GeV

Use of sophisticated discriminant was essential!!

Results: LHC

(Kats, Meade, Reece, DS 1110.6444)



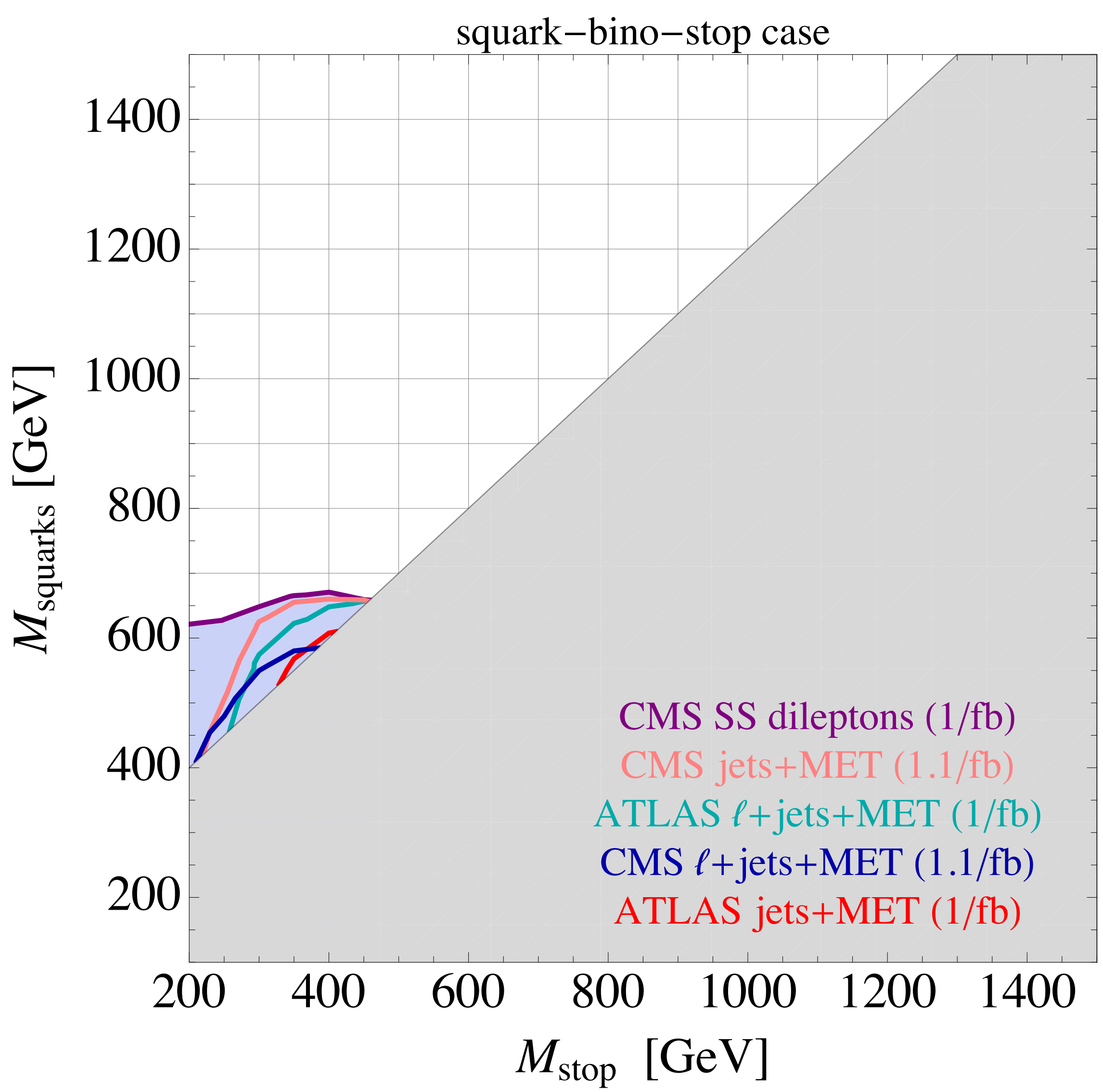
ATLAS ttbar+MET will have good coverage over widest range of stop mass.

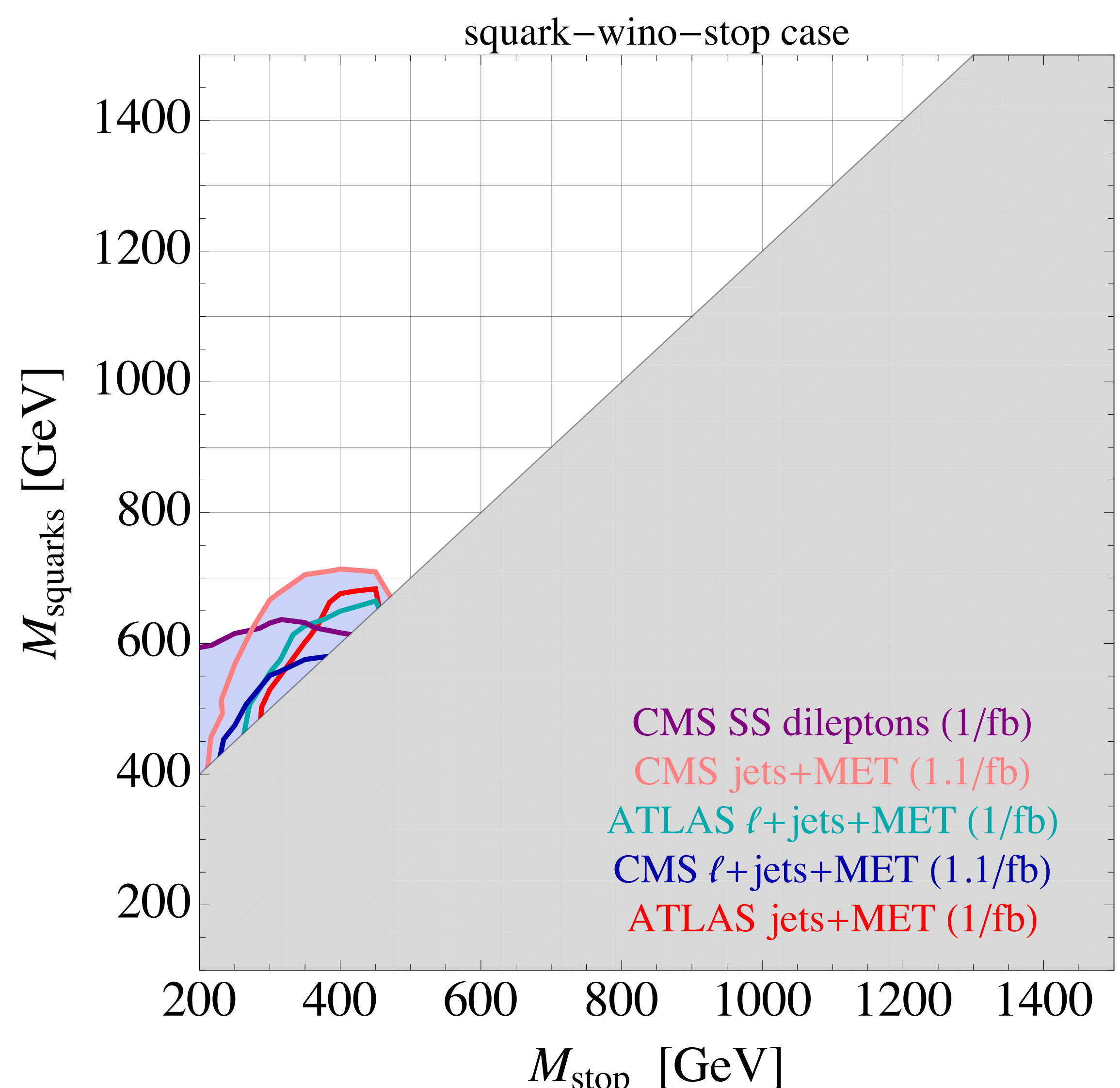
A surprise: a number of 1/fb SUSY searches could be sensitive to light stops!

Dashed lines indicate ultra-low acceptances (~10^{-4}-10^{-3}) where we don't trust our simulation of the signal tails.

There are still no firm LHC limits on direct stop pair production.
Stop could still be lighter than the top??!!

Stop NLSPs w/ Squark Production





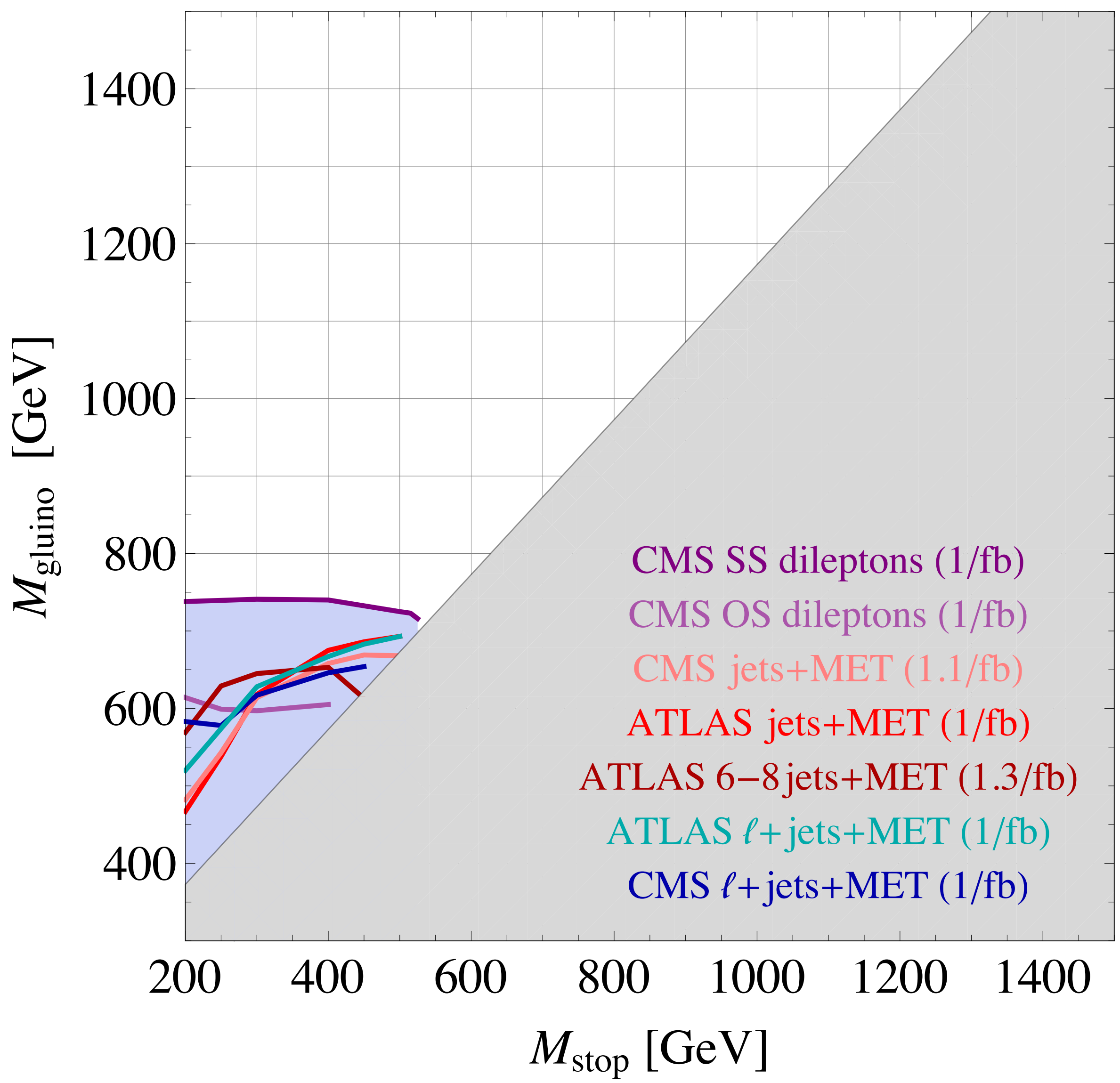
$4t^{(*)}$+jets+MET

Now events have multiple tops, SS tops.
SS dileptons becomes a major constraint!

$4t^{(*)}$+jets+MET,
$3t^{(*)}$+b+jets+MET,
$2t^{(*)}$+2b+jets+MET

M_{squark} > 600-700 GeV
Somewhat weaker non-top-rich scenarios

Stop NLSPs w/ Gluino Production

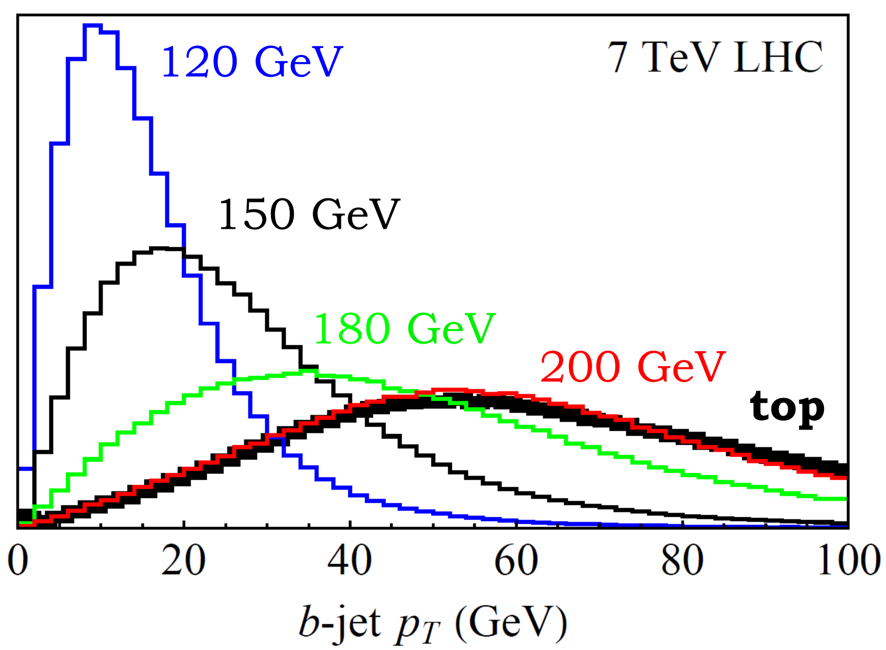


$4t^{(*)}$+MET

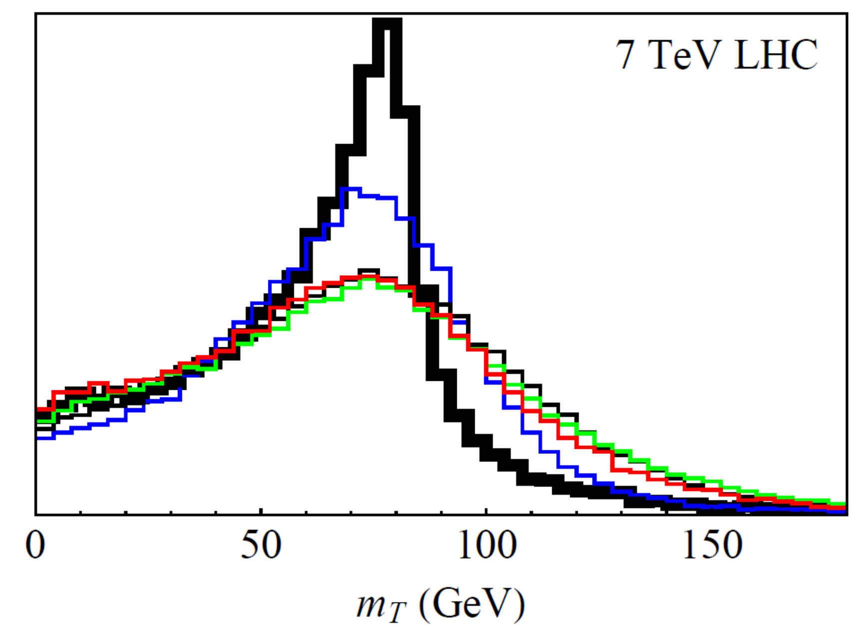
M_{gluino} > 700-750 GeV
Somewhat weaker non-top-rich scenarios

Suggestions for future analyses

The *b*-jets from light stops are soft:



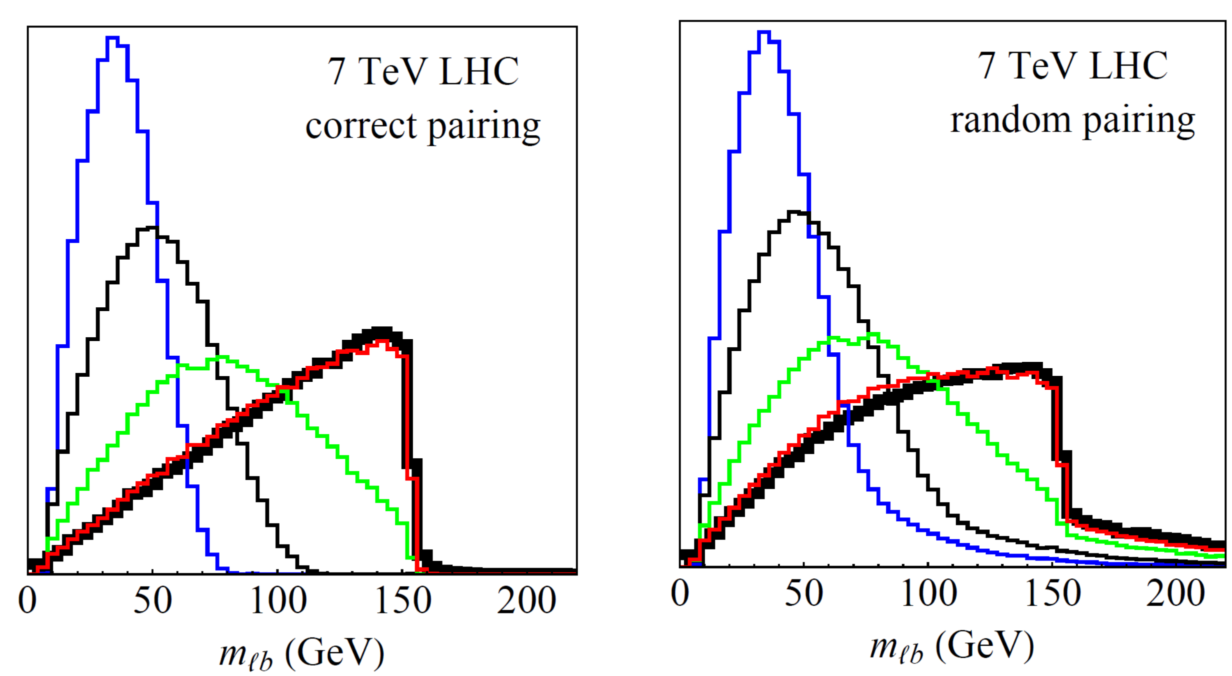
The transverse mass of the W is a good discriminator:



The lepton-*b* invariant mass has been suggested a while ago but *never used.*

Chou and Peskin
PRD 61 (2000) 055004; hep-ph/9909536

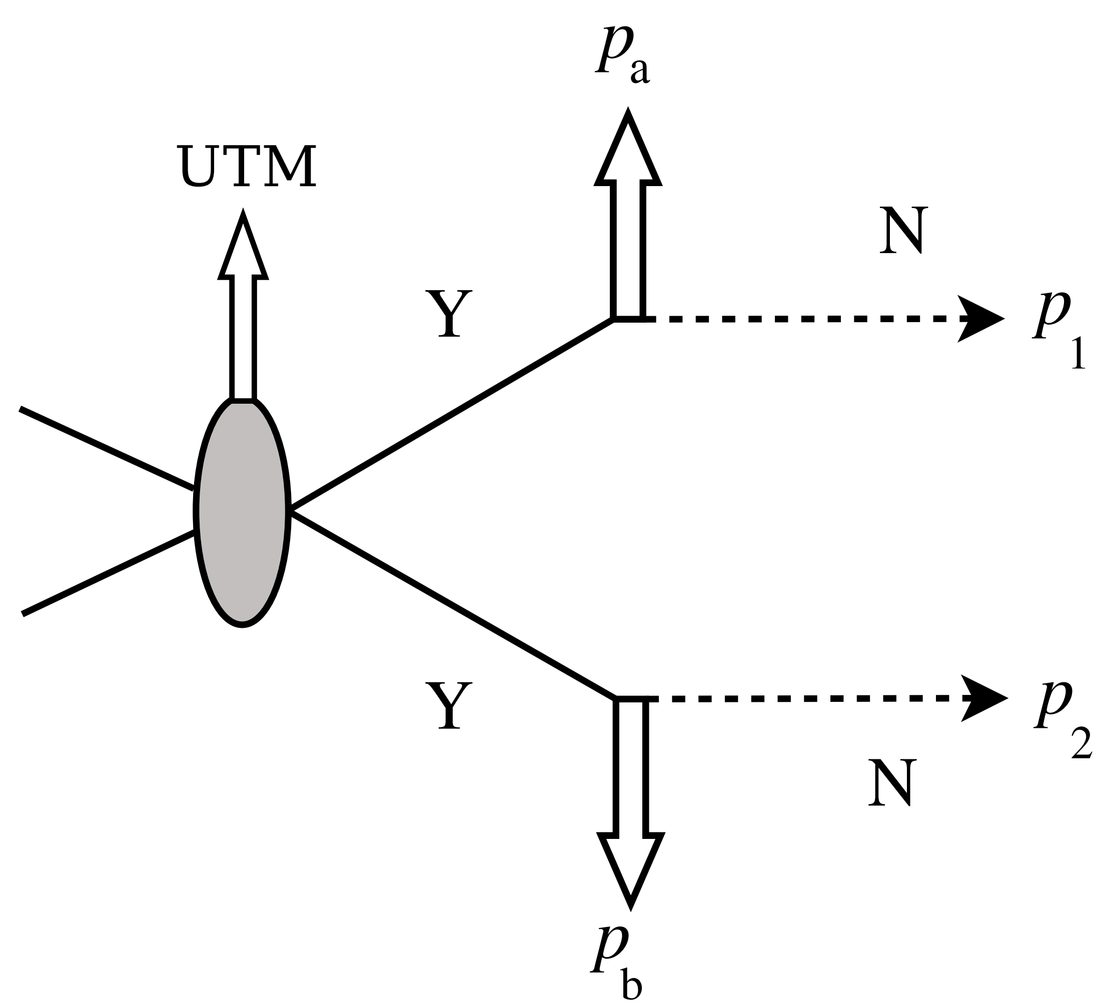
You don't even have to get the combinatorics right:



Suggestions: leptonic MT2

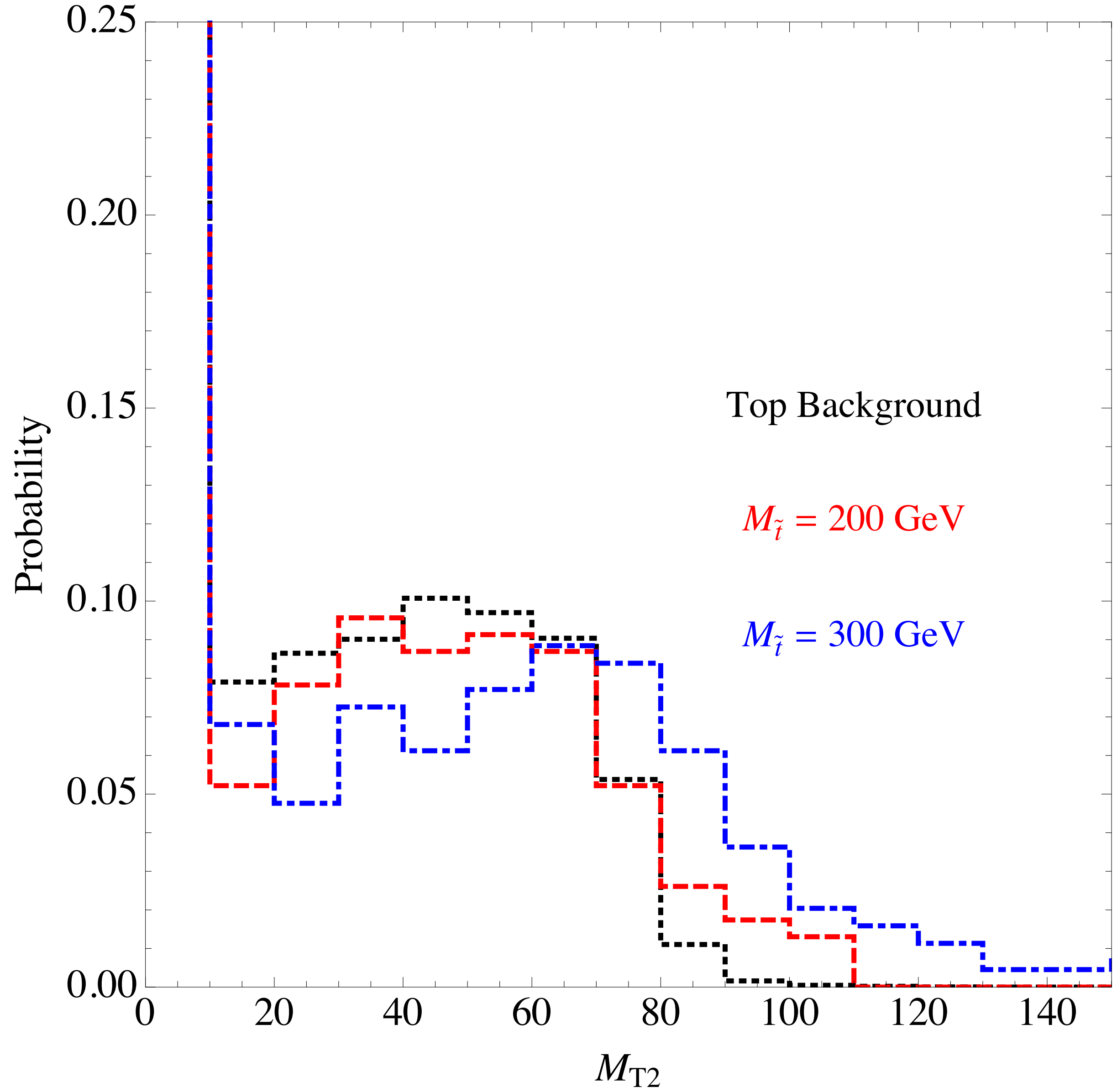
(for details, see 1110.6444)

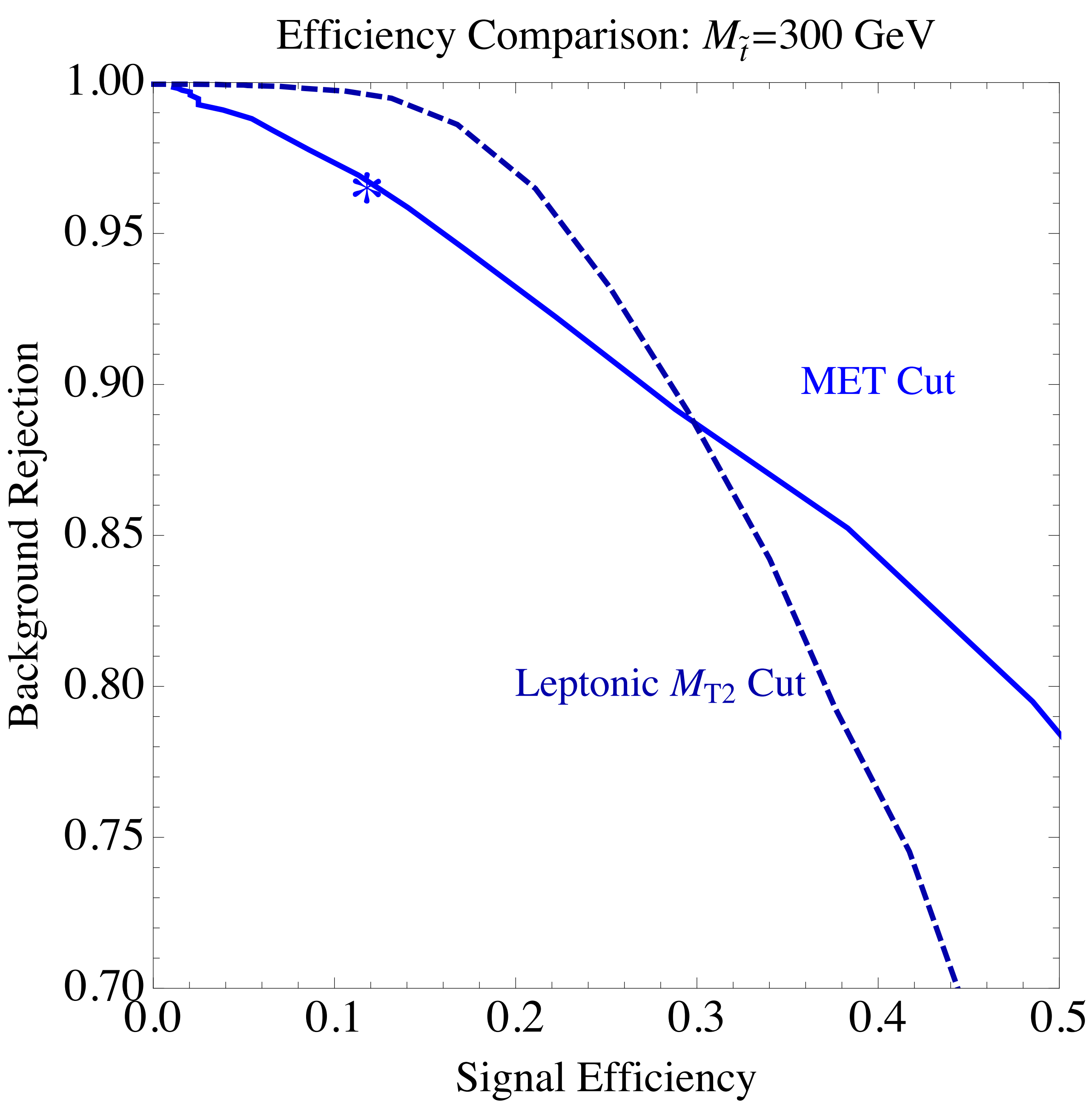
- mT2: generalization of W transverse mass to events with double decay chains ending in invisible particles.
(Barr, Lester, Stephens, Summers, ...)
- mT2 has been used for measurements of top properties, but in all cases, the full event was used (leptons+bjets+MET). Expect an endpoint at the top mass, but combinatorics is an issue.
- ttbar is the dominant background to stop NLSP, especially at the LHC. We propose computing mT2 using only the leptons and MET to reject ttbar background. Expect an endpoint at W mass and no combinatorial confusion.



(figure from Cheng & Han 0810.5178)

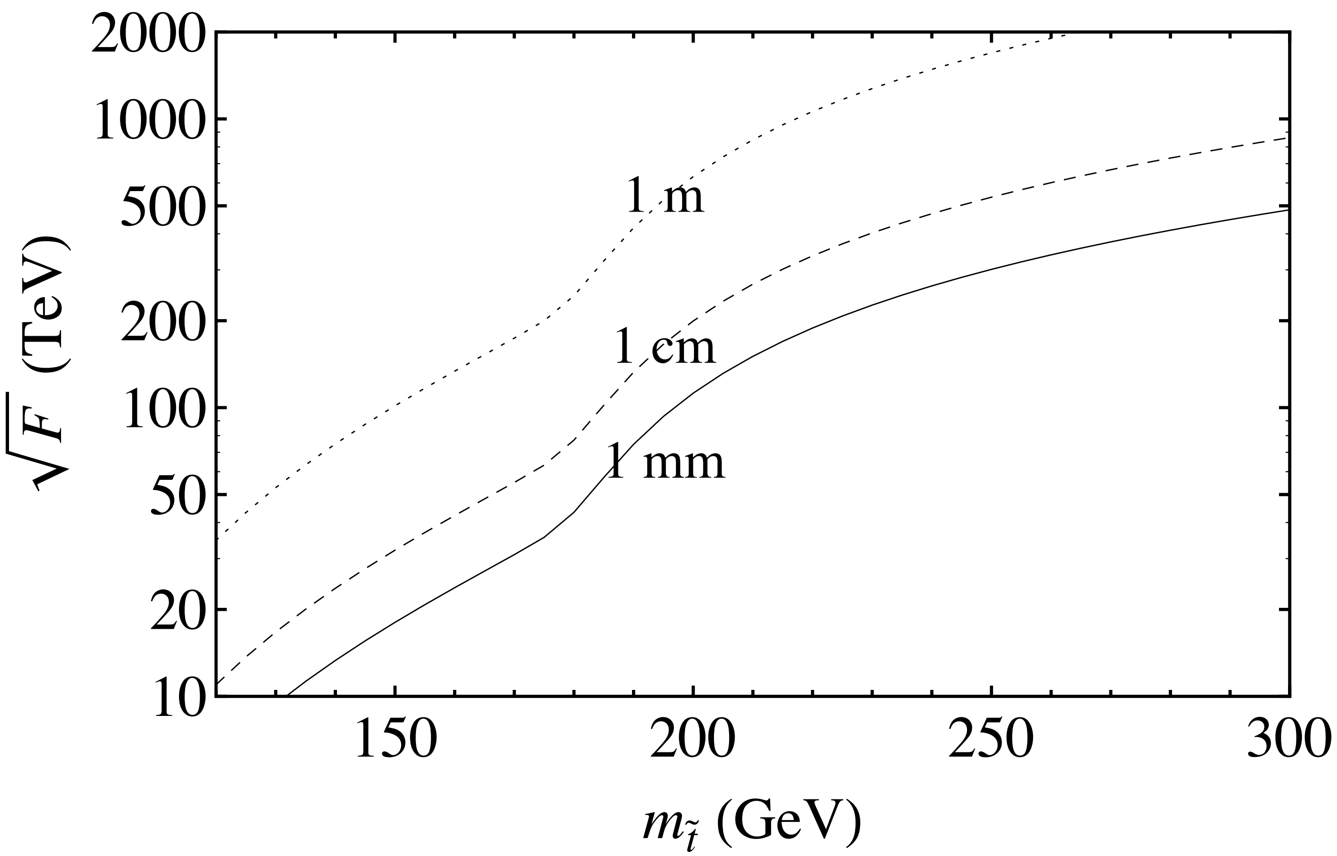
Suggestions: leptonic MT2





Based on CMS OS dileptons+MET search, after all cuts except for MET>275 GeV.

Long-lived stop NLSPs



- Light stop NLSPs actually tend to be long-lived. The promptly-decaying case which we have focused on here only happens for the lowest-possible SUSY-breaking scales.

- Long-lived stop NLSPs would lead to R-hadrons, kinked tracks, displaced jets and leptons. Well-motivated benchmark scenario for many interesting searches!

Remaining Theory Hurdles

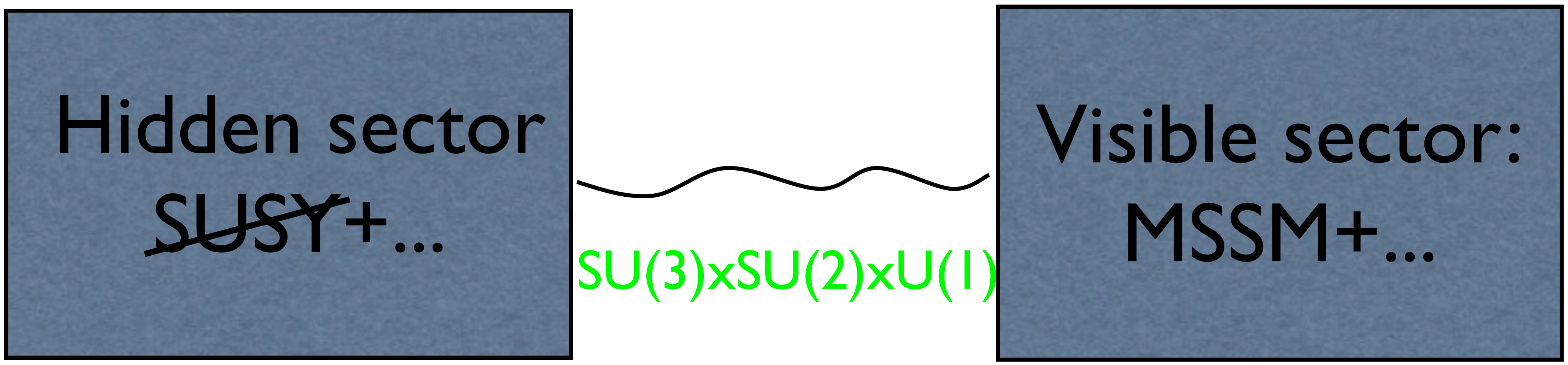
- We find that efficiencies of current LHC searches to light stop NLSP are extremely low, largely due to hard jet and HT cuts. This is problematic, because:
    - We don't trust Pythia for modeling of extra hard jets from ISR/FSR.
    - Problems with Madgraph 4 implementation of gravitino LSP in simulating light stops. (4-body phase space?)
    - Gravitino LSP not yet implemented in Madgraph 5.
- The current situation is unsatisfactory. Dedicated experimental searches will either have to wait for Madgraph 5 to catch up, or (our preference) design searches with higher signal efficiencies which are less sensitive to the kinematic tails.

Summary and Outlook

- We have reviewed the current constraints on stop NLSP, and suggested ways to improve analyses.
    - The stop NLSP could still be lighter than the top!
    - Current limits are estimated to be $m_{stop} > 150$ GeV from the Tevatron.
    - There are no firm LHC limits yet on direct stop production.
    - LHC should be sensitive to $m_{stop} \sim 300$ GeV in the near future.
- No dedicated search exists yet for stop NLSP. Currently a "blind spot" at both the Tevatron and the LHC.
- This could be a good opportunity to discover supersymmetry hiding in our backyard!

The End

Gauge Mediation



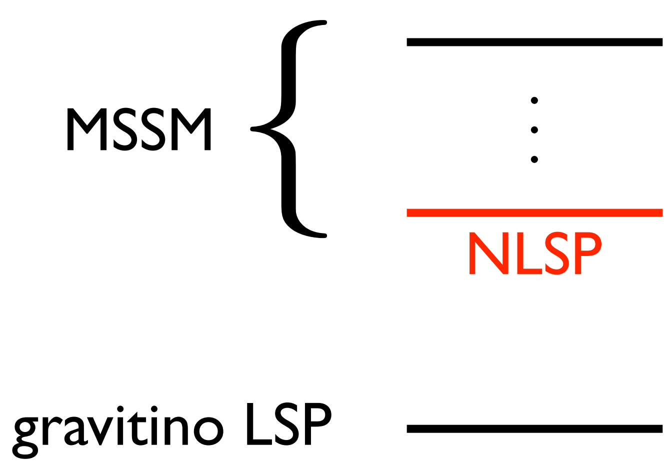
- Gauge mediation is a very attractive scenario for the MSSM:
  - Solves SUSY flavor problem
  - Calculable framework
- Recently, a model-independent framework for GMSB was formulated, and the full parameter space was understood:
- "General Gauge Mediation" (Meade, Seiberg & DS; Buican, Meade, Seiberg & DS)
- LHC searches are now being designed with GGM in mind!

The NLSP

- Gravitino LSP is a universal prediction of gauge mediation models:

$$m_{3/2} = \frac{F}{\sqrt{3}M_{pl}} \quad (\sim \mathrm{eV} - \mathrm{GeV})$$

- Lightest MSSM sparticle becomes the next-to-lightest superpartner (NLSP).



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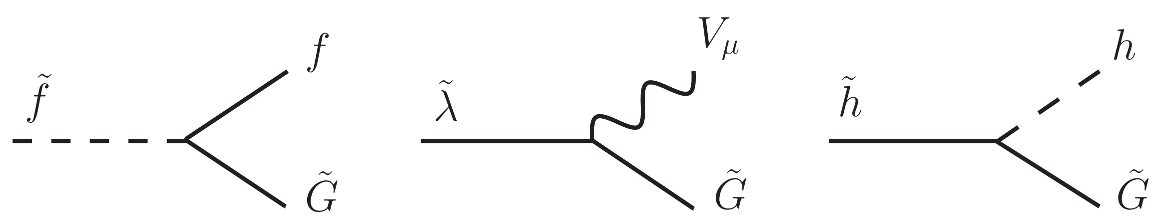

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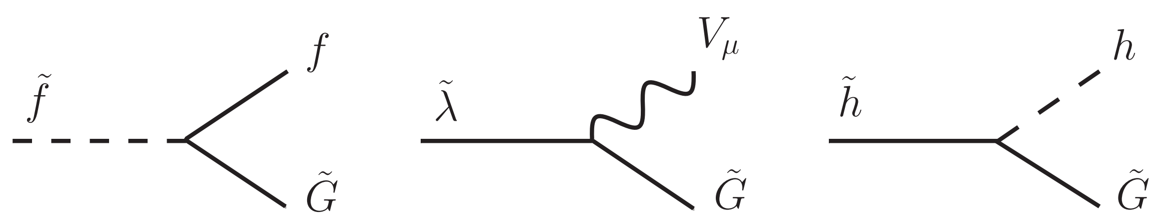

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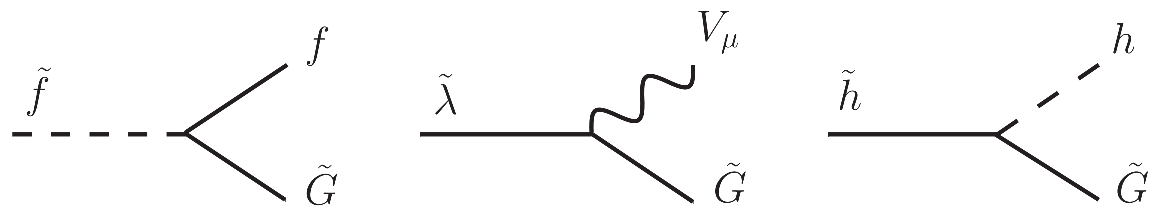

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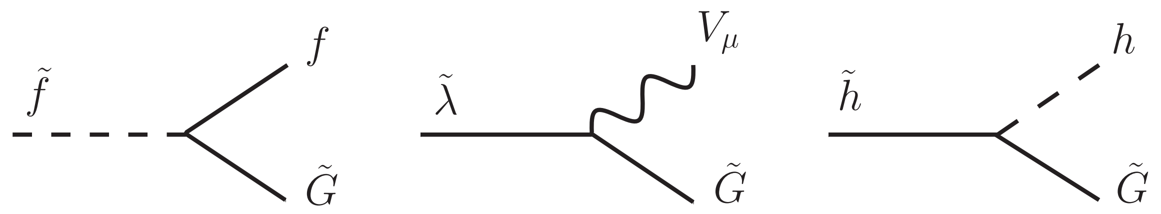

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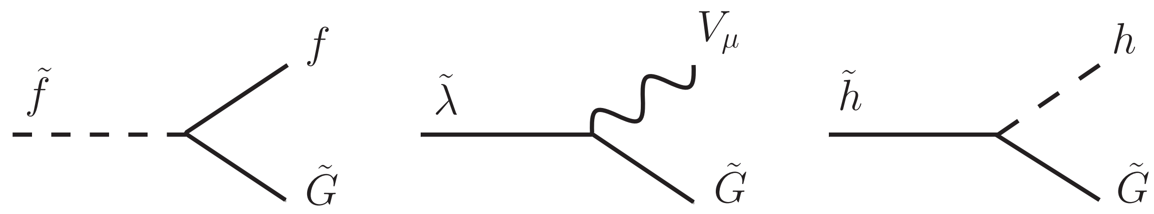

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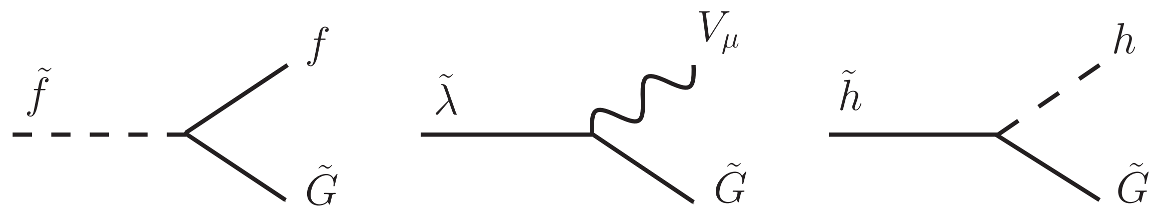

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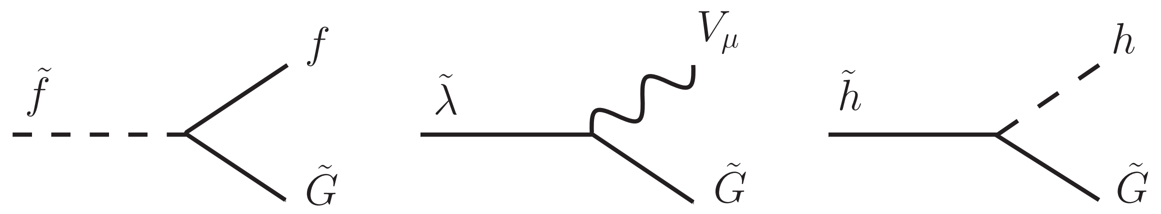

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  - So all events contain:
    - high pT objects determined by the NLSP type
    - missing energy