Light stop NLSP at the Tevatron and LHC

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Based on work with David Shih
arXiv:1106.0030 [JHEP 08 (2011) 049]
and more recent results.

SUSY 2011, Fermilab, 1 Sep 2011

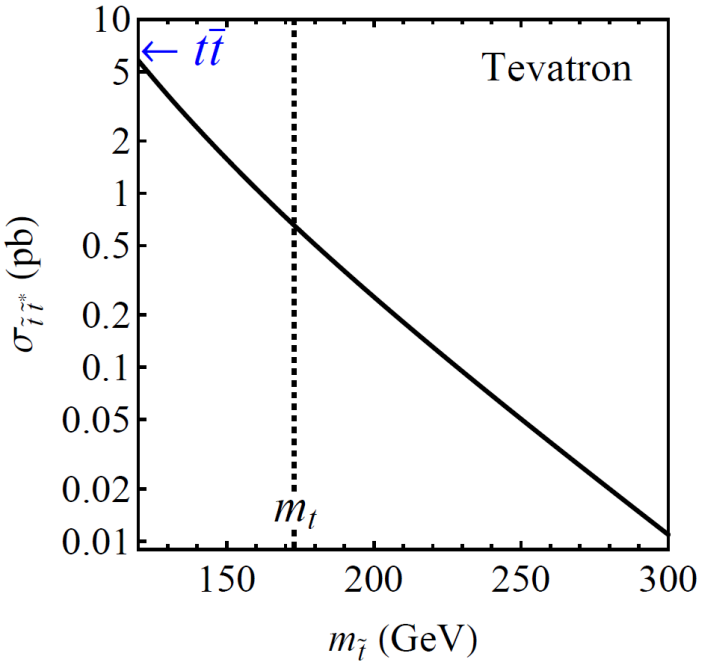
Motivations

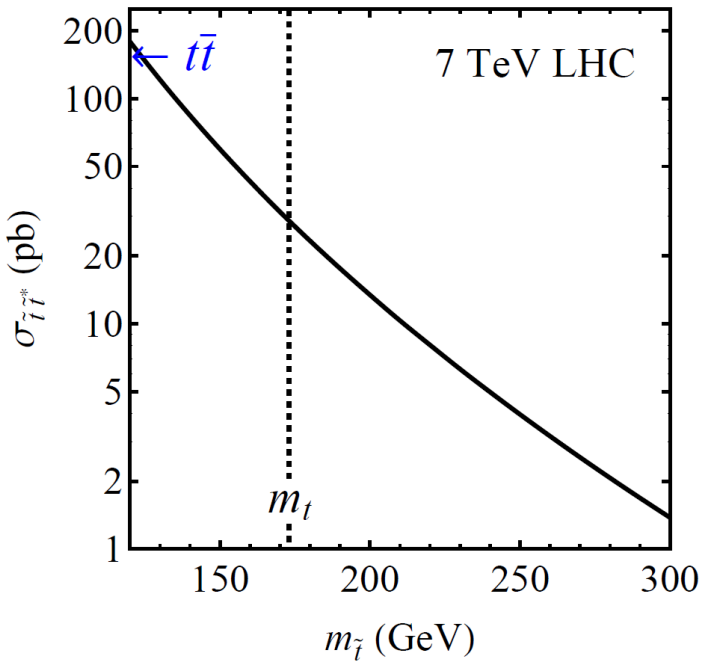
- Generic squarks and gluinos are excluded up to 0.5 – 1 TeV, but just a single stop may be much lighter.
  How light can it be? Can it be even lighter than the top?
- A light stop is good for the little hierarchy problem.
- The stop (especially its lighter mass eigenstate $\tilde{t}_1$) is typically much lighter than the other squarks.
- In GMSB, the LSP is an (almost) massless gravitino, and the stop *may* be the NLSP, decaying as

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

  - Since the signatures of $\tilde{t}\tilde{t}^*$ production would be similar to the $t\bar{t}$ background, a light stop is not obviously excluded.
  - An interesting simplified model of new physics to keep an eye on, even without the context of SUSY. No dedicated experimental searches exist!

Production cross sections: stop vs. top





Stops may be hiding in the top sample!

Some examples of stops with top-like decays:

$\tilde{t} \to b\tilde{\chi}_1^+ \quad \tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0$ addressed by recent CDF search

$\tilde{t} \to b\ell^+\tilde{\nu}$ addressed by recent D0 search

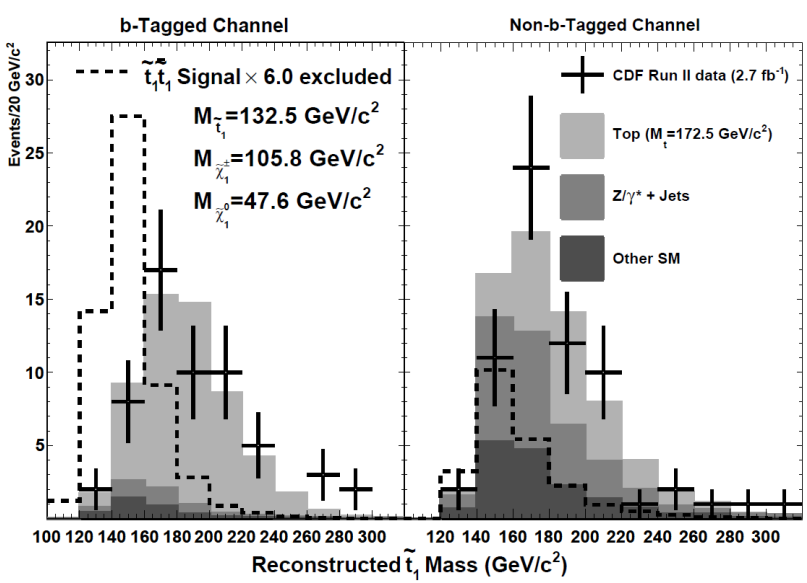
$\tilde{t} \to W^+ b\,\tilde{G}$ addressed in our work

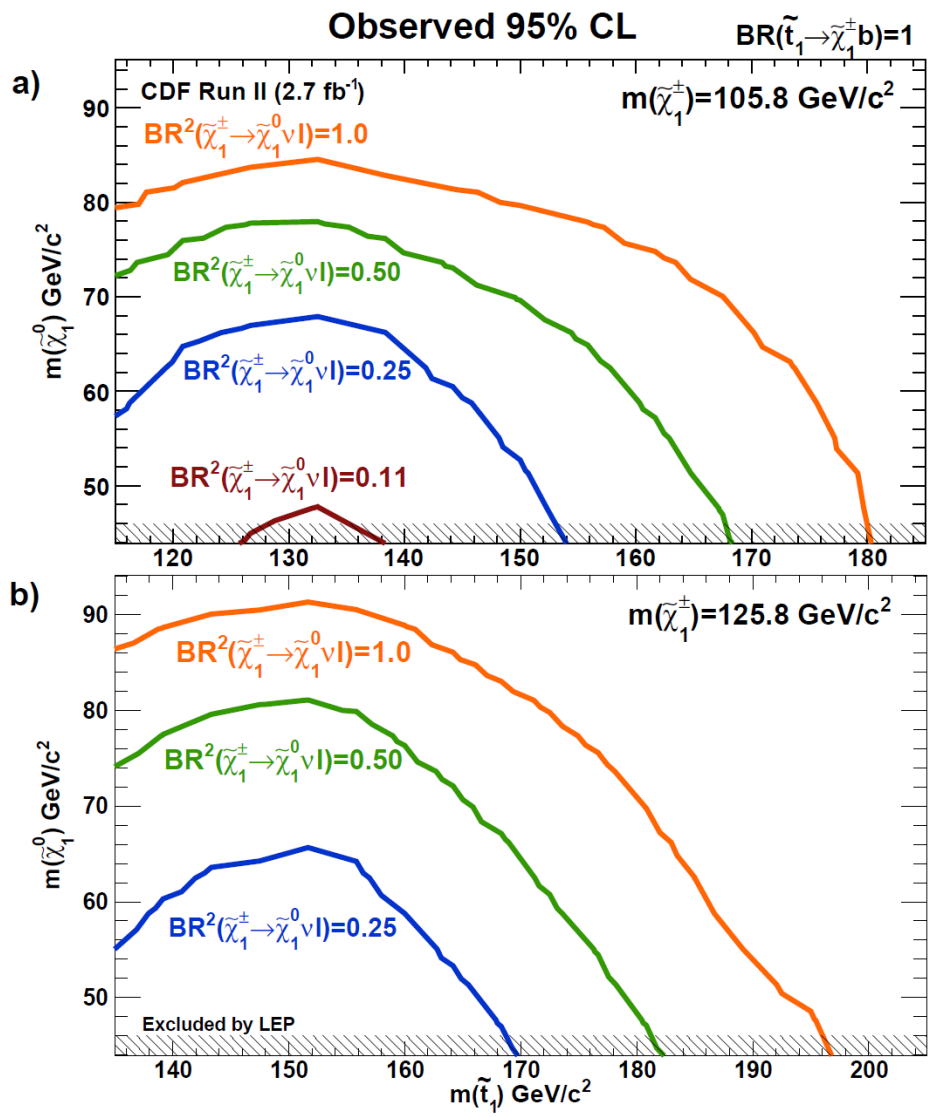
CDF stop search

arXiv:0912.1308
PRL 104 (2010) 251801

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

Uses the "stop mass" variable:
Models each neutrino-neutralino pair as a single "pseudoparticle" with mass 75 GeV and width 10 GeV, assumes a mass for the chargino, and determines the best fit "stop mass".
While maybe not a rigorous method for determining the stop mass, it does produce a useful discriminant:



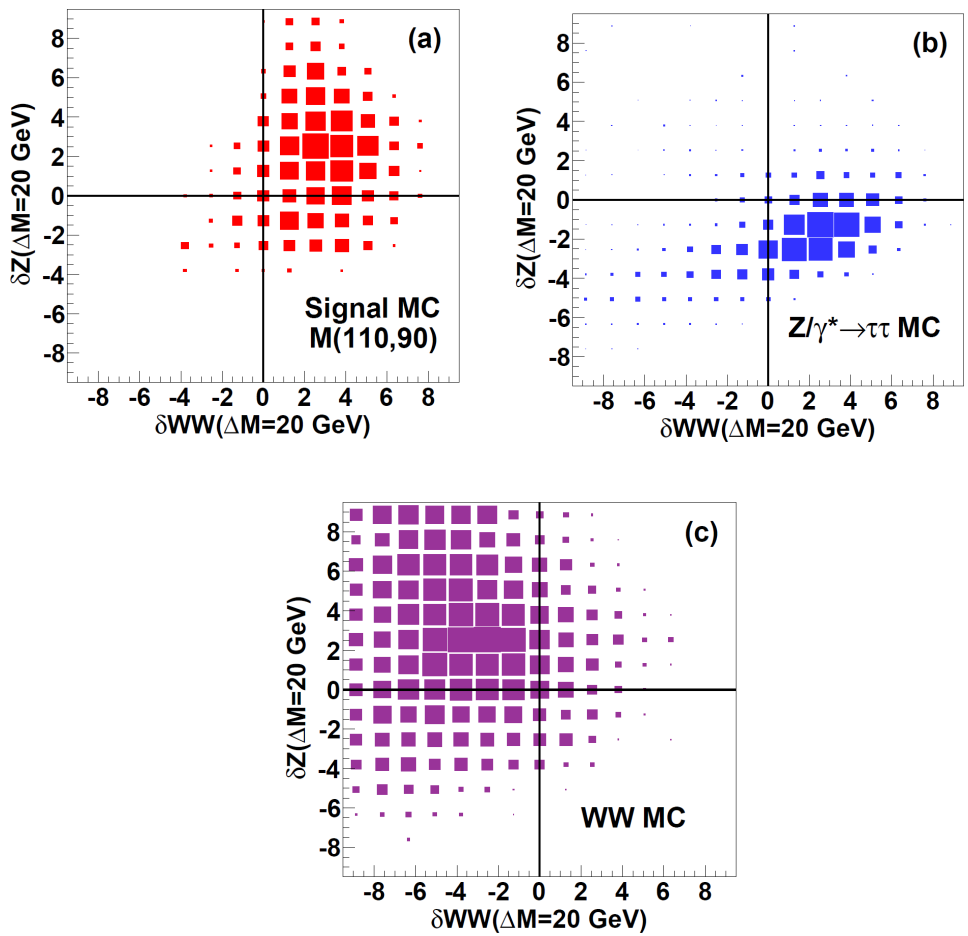


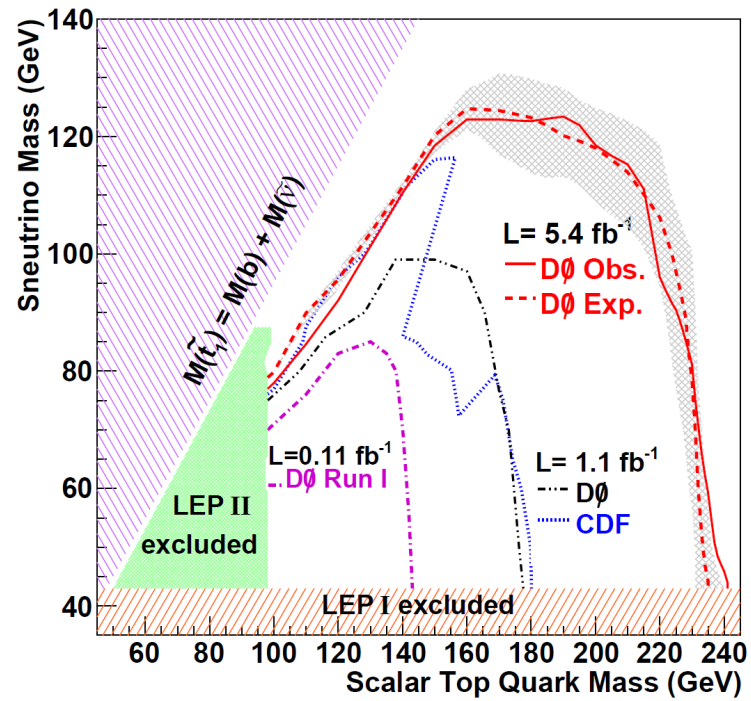
D0 stop search

arXiv:1009.5950
PLB 696 (2011) 321

$$\tilde{t} \to b\ell^+\tilde{\nu}$$

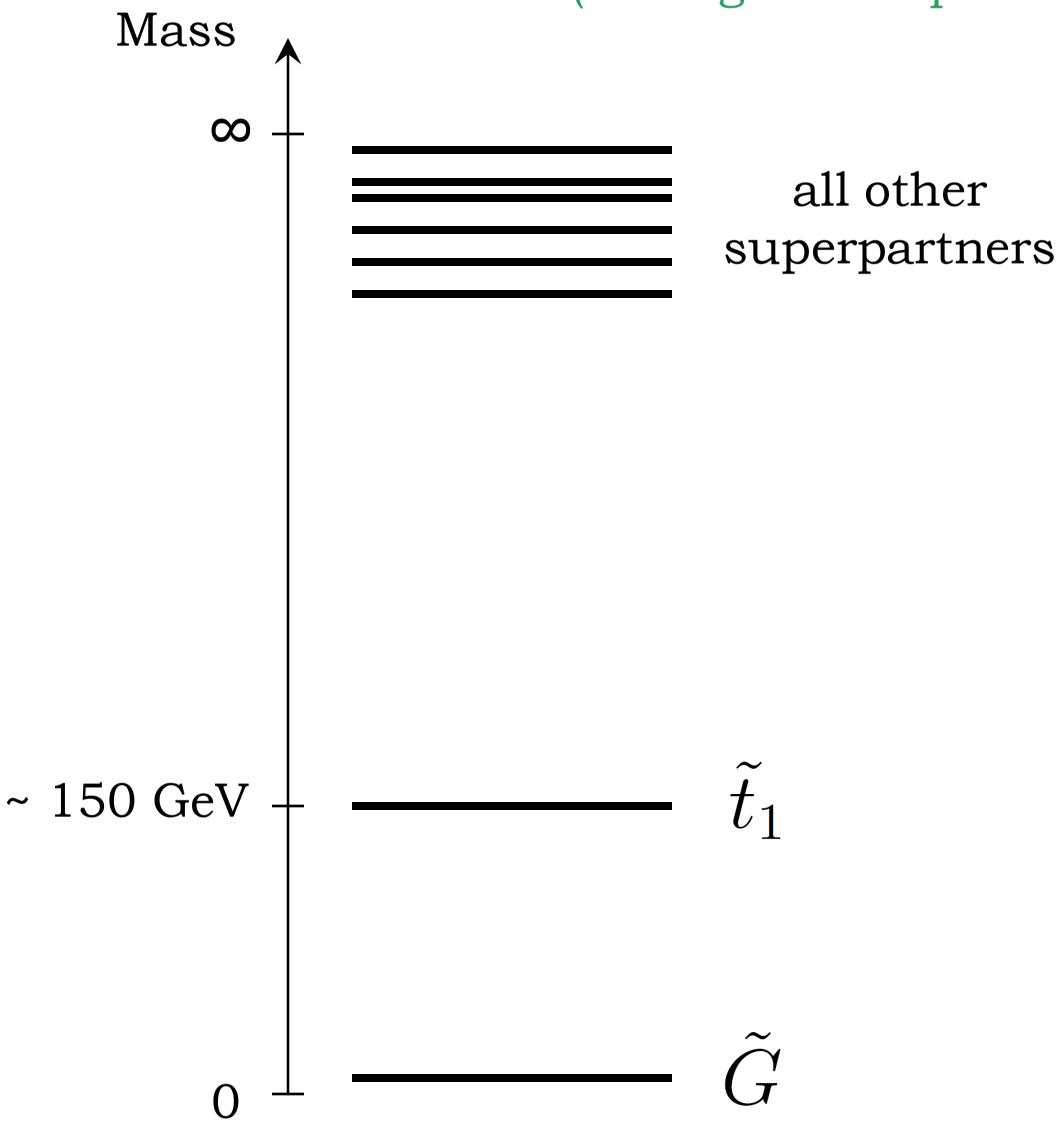
Uses distributions of composite discriminating variables, optimized separately for each point in the parameter space.

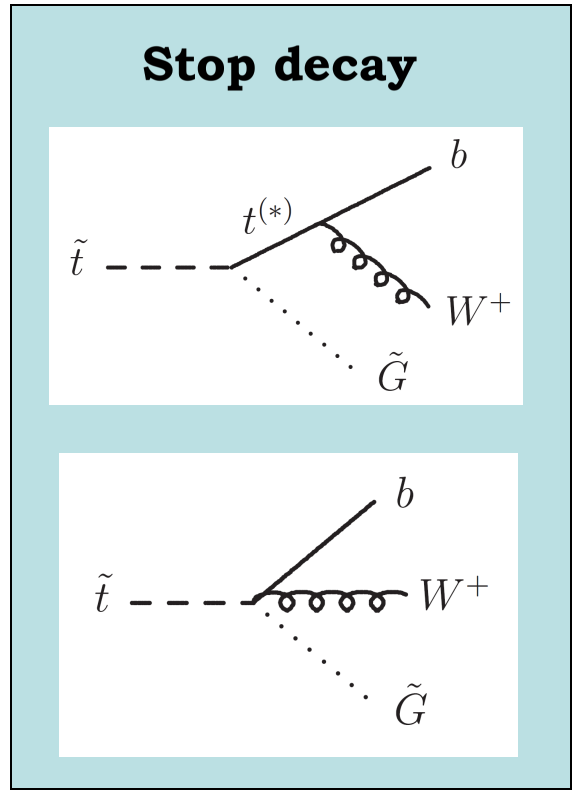




Minimal stop NLSP scenario

(more general spectra will be discussed later...)





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

Analyses examined in this work

- Measurements of $t\bar{t}$ production cross section:
  – Tevatron (~5 fb^{-1}) and LHC (~35 pb^{-1}, 700 pb^{-1}).
  – Dilepton and lepton+jets channels.
  – With and without *b*-tagging.
  – Only cut-and-count methods.

- CDF stop search $\tilde{t} \to b\tilde{\chi}_1^+ \quad \tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0$

- D0 stop search (only the initial selection) $\tilde{t} \to b\ell^+\tilde{\nu}$

- ATLAS search for anomalous MET in $t\bar{t}$ events (35 pb^{-1}).
  Fermionic top partner $T \to tA_0$
  ATLAS-CONF-2011-036

  invisible

- ATLAS SUSY search with lepton + *b*-jet + jets + MET (35 pb^{-1}, 1 fb^{-1})
  arXiv:1103.4344, ATLAS-CONF-2011-130

Simulation

Tools for signal simulation

- Private code implementing the stop decay matrix element and sampling the phase space.
- Pythia 8 (with LHAPDF and FastJet).
- Private code for simulating detector acceptances, lepton isolation requirements, *b*-tagging, etc., and the analysis cuts.

Validation and scale factors

- Simulate $t\bar{t}$ production. Compare the event yields with those simulated in the experimental papers. Agreement within ~30%.
- Correct the results for the signal by the same scale factors (to account for some of the imperfections of our detector simulation).
- Simulate stops in gravity-mediated scenarios from CDF search (in multiple points of the parameter space). Agreement within ~10%.

Backgrounds and systematic uncertainties

- Taken from the experimental analyses, to the extent possible.
- $t\bar{t}$ cross sections were corrected to more recent theoretical values.

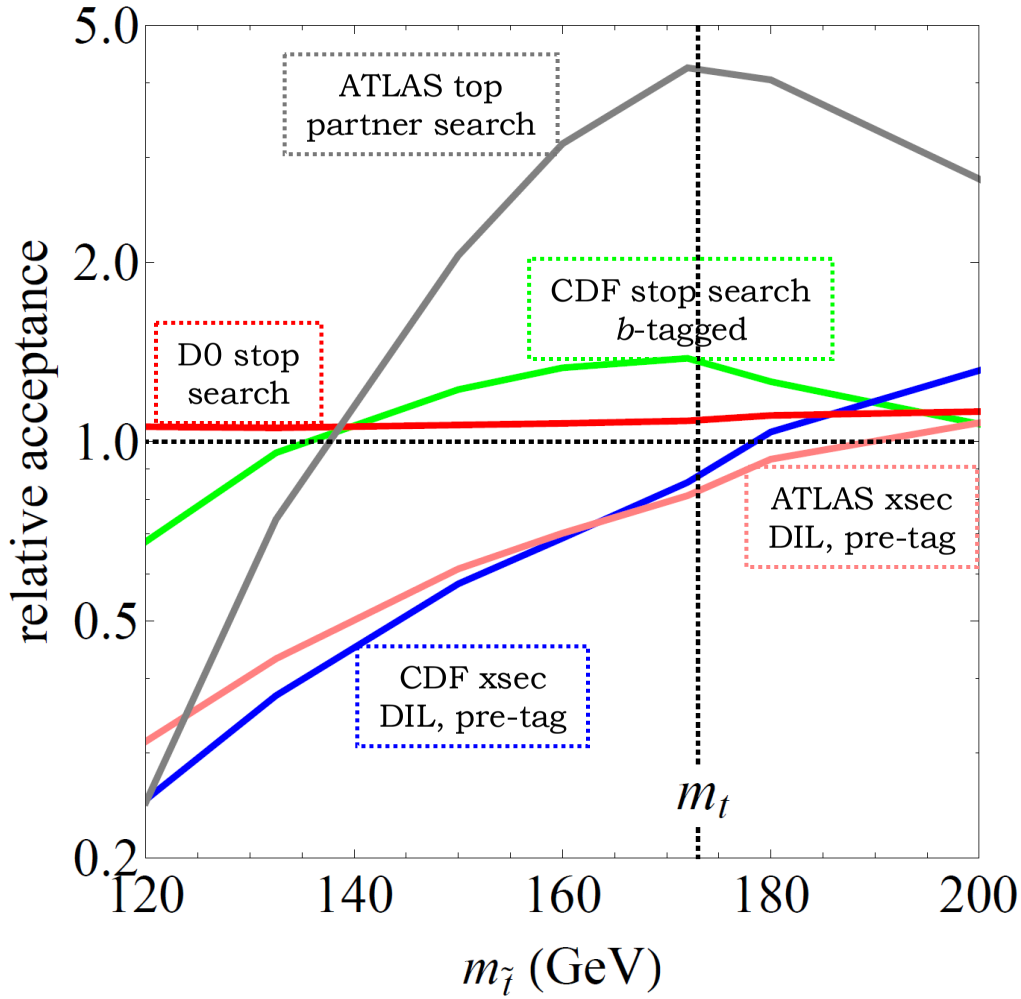
Acceptances of cut-and-count analyses

(only the most useful measurements are shown)

The acceptance for stop events is of the same order of magnitude as that for top events.

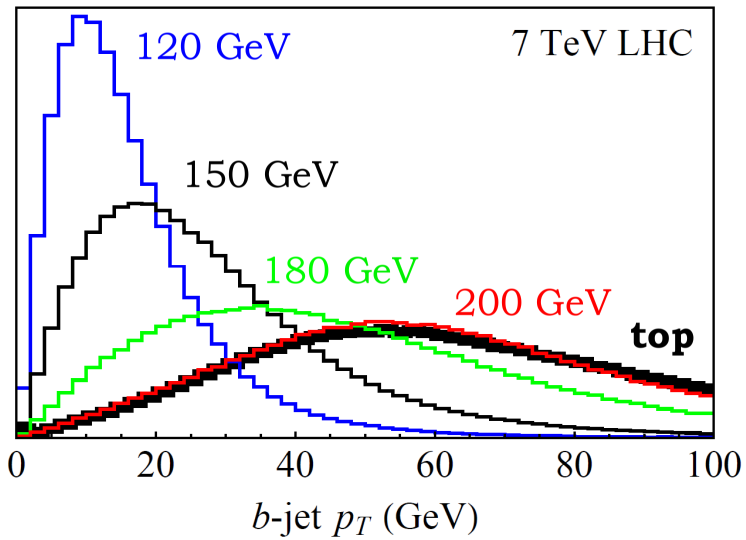
For light stops, it is very sensitive to the jet p_T cut which reduces it significantly in many cases.

On the other hand, a cut on m_T improves the relative acceptance very significantly.

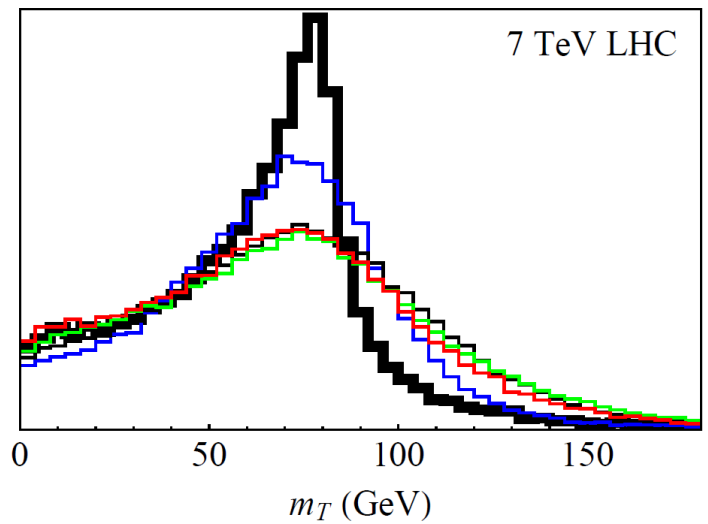


Kinematic distributions: stop vs. top

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



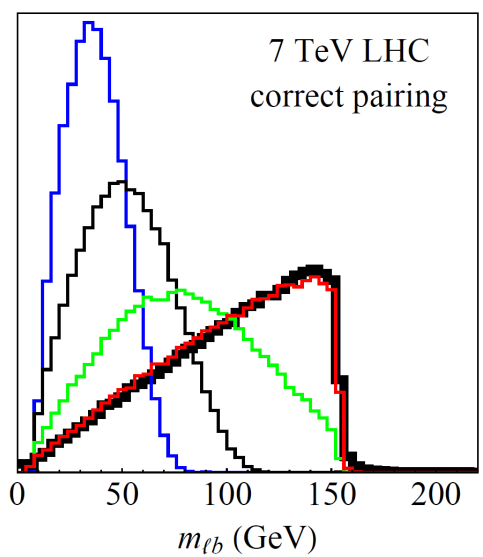
The transverse mass of the W is a good discriminator:

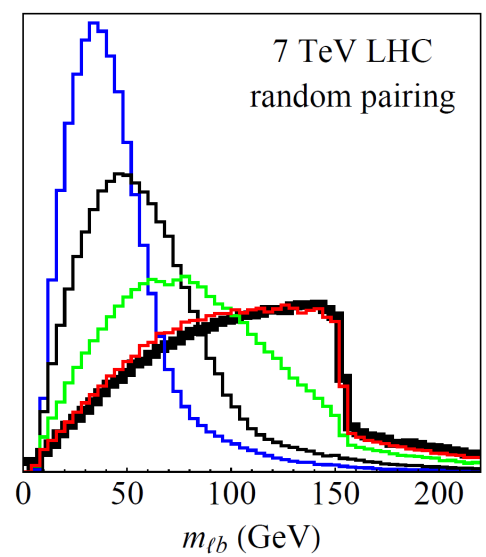


The lepton-*b* invariant mass has been suggested a while ago but *never used*.

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

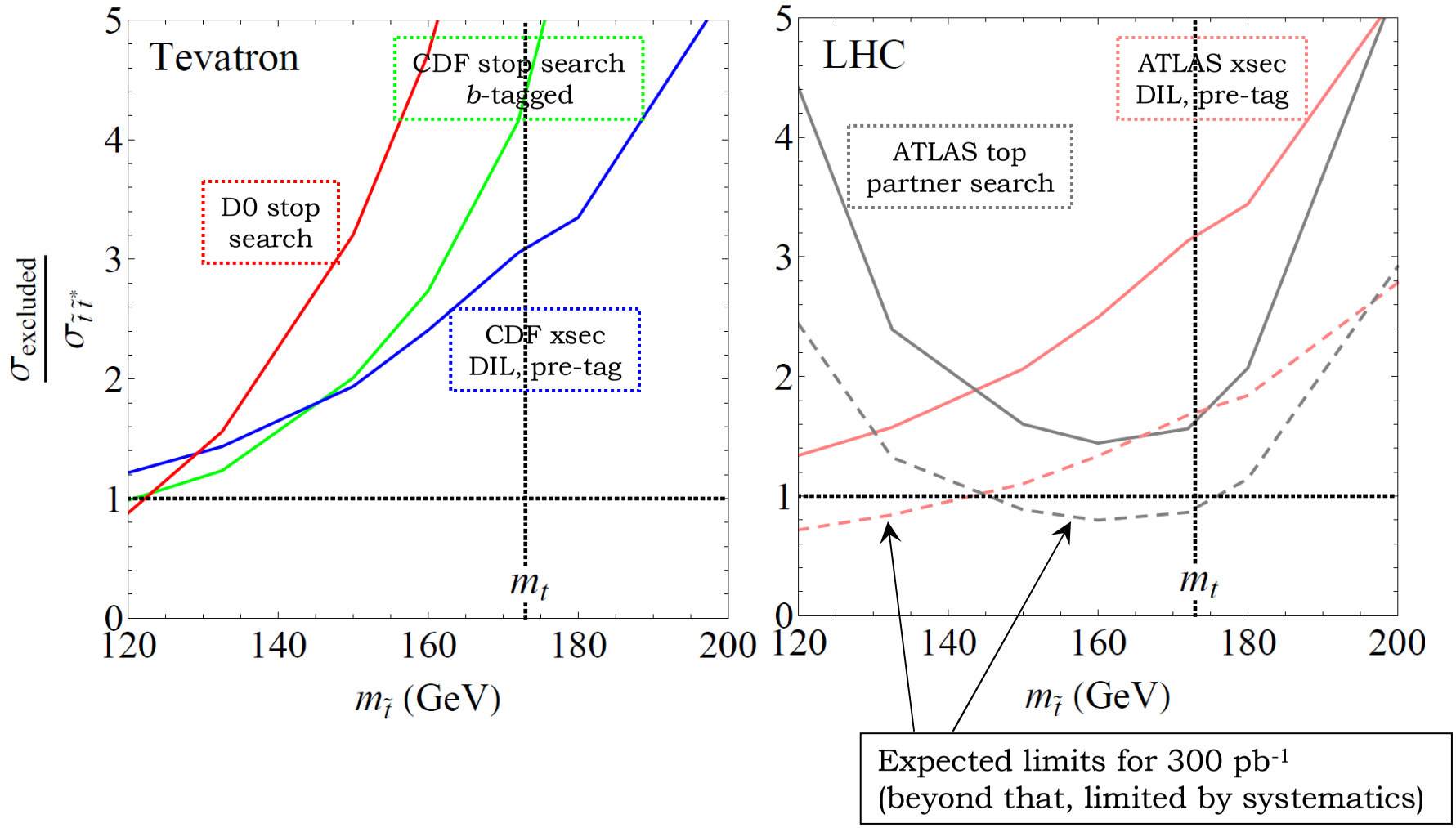
You don't even have to get the combinatorics right:





95% CL exclusion from cut-and-count analyses

(only the most useful measurements are shown)



95% CL exclusion from cut-and-count analyses

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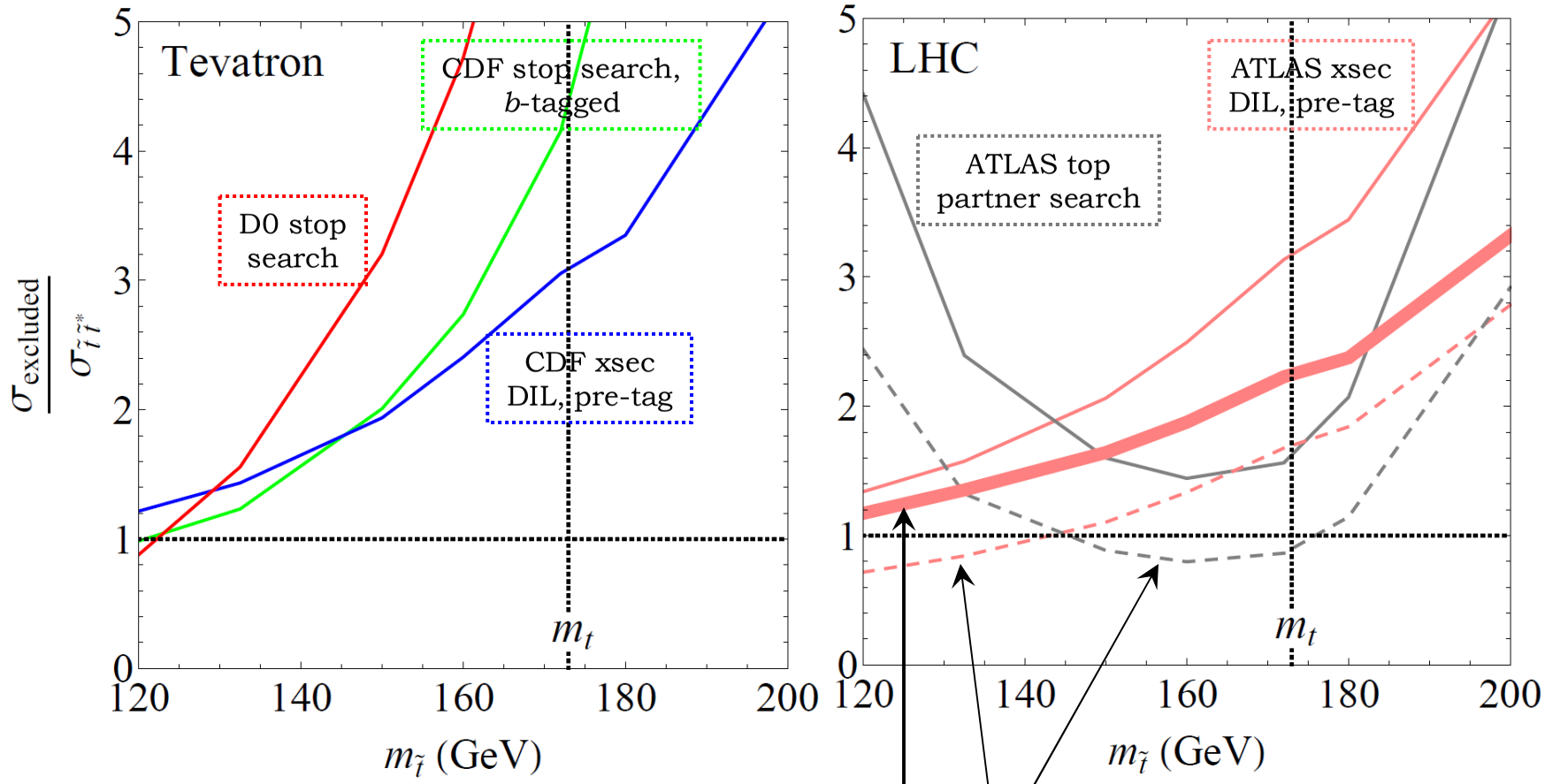


Expected limits for 300 pb^{-1}
(beyond that, limited by systematics)

UPDATES WITH MORE DATA

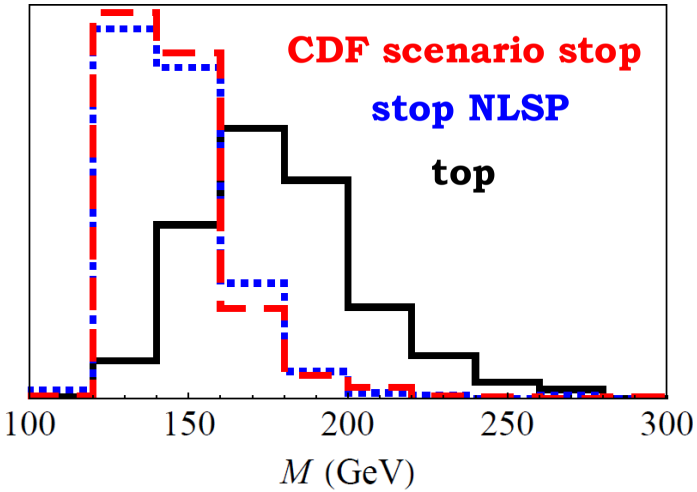
ATLAS xsec, DIL, pre-tag: updated to 700 pb^{-1}
Limit weaker than expected due to modified selection:
the jet p_T cut changed from 20 to 25 GeV
(CMS is even worse for our purpose since it uses 30 GeV)

ATLAS top partner search:
1 fb^{-1} plot was shown at LP2011
(no excess observed), but the details
of the analysis aren't available yet.

Using the CDF stop mass reconstruction

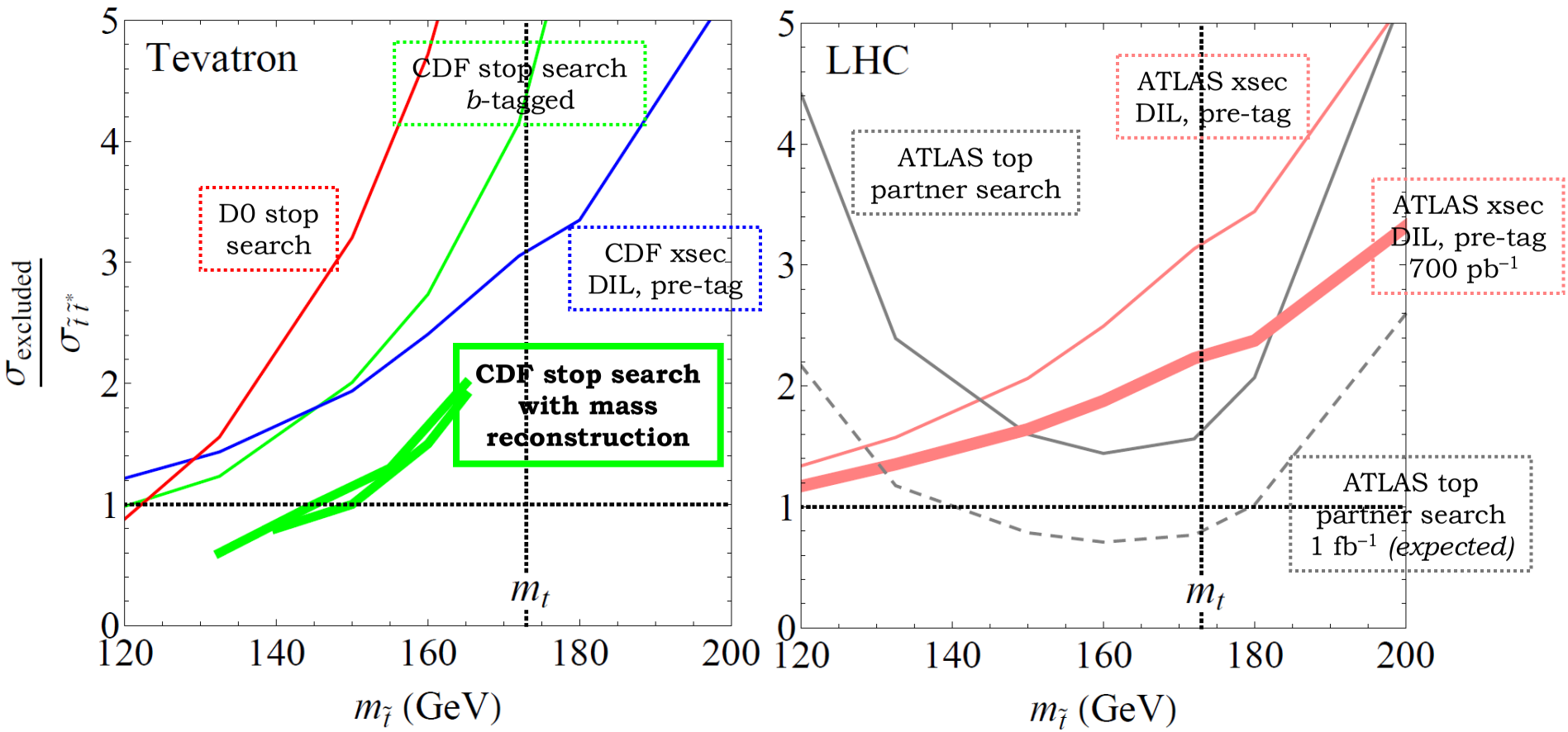
For each stop NLSP mass, we compute the distributions of the CDF "stop mass" variable and find a point in the parameter space of the gravity-mediated SUSY scenario studied by CDF (which we also simulated) that has a similar distribution.

For example, a 145 GeV stop NLSP is equivalent to a CDF scenario with a 137 GeV stop, 105.8 GeV chargino, 47.6 GeV neutralino, and dilepton branching fraction of 0.13



By using this distribution matching approach, we don't need to deal with systematic uncertainties. The matching also cancels some of the possible effects of the imperfections in our detector simulation and/or the event reconstruction procedure.

95% CL exclusion w/CDF stop mass reconstruction



Minimal stop NLSP scenario – summary

We find from simulating existing analyses:

- Several cut-and-count analyses from the Tevatron exclude stop masses up to ~120 GeV.
- The CDF stop search (with mass reconstruction) excludes stop masses up to ~150 GeV.
- The 1 fb^{-1} update of the ATLAS top partner search (to be released soon) will likely be able to exclude stop masses from ~140 to ~180 GeV.

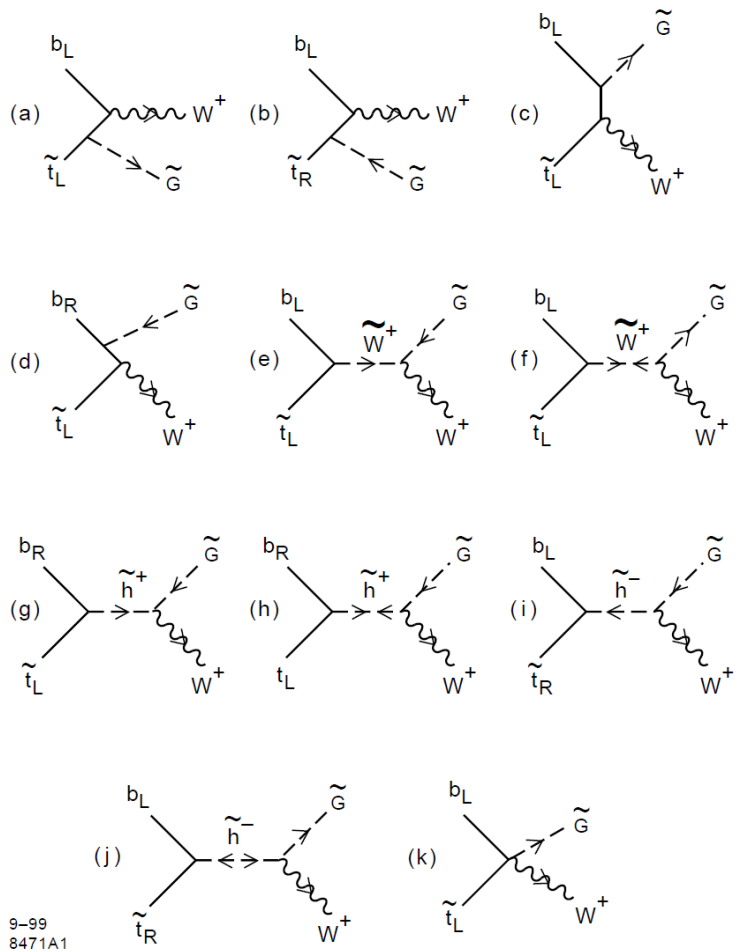
Suggestions for the Tevatron and LHC experimental collaborations:

- It is important to verify the above limits by using the full detector simulation of the relevant experiments.
- For more dedicated searches, it can be useful to allow as soft jets as feasible or relax the requirement on the number of jets to increase the light stop acceptance.
- Consider the distributions of the following variables that distinguish light stop events from top events:
  - W transverse mass m_T
  - b-jet p_T
  - lepton-b invariant mass
- Our choice of analyses was limited by our ability to simulate them reliably. Some more sophisticated analysis techniques may be able to improve the reach. Additional channels, especially jets + MET, where the acceptance of stop events is naturally enhanced relative to the top, may be useful.

More general stop NLSP scenarios

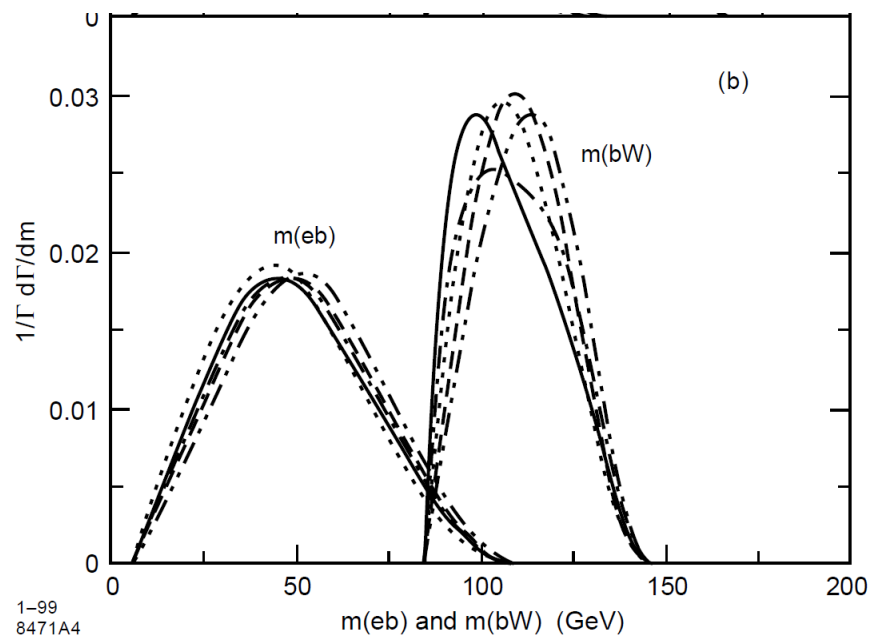
If charginos or sbottoms are not very heavy, additional diagrams contribute to the stop NLSP decay matrix element.

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



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

But the basic kinematic properties of the decay products do not depend strongly on these details. Therefore our limits won't be sensitive to this aspect of the more general scenarios.



More general stop NLSP scenarios (cont'd)

What if some other *colored* superpartners are not much heavier than the stop?

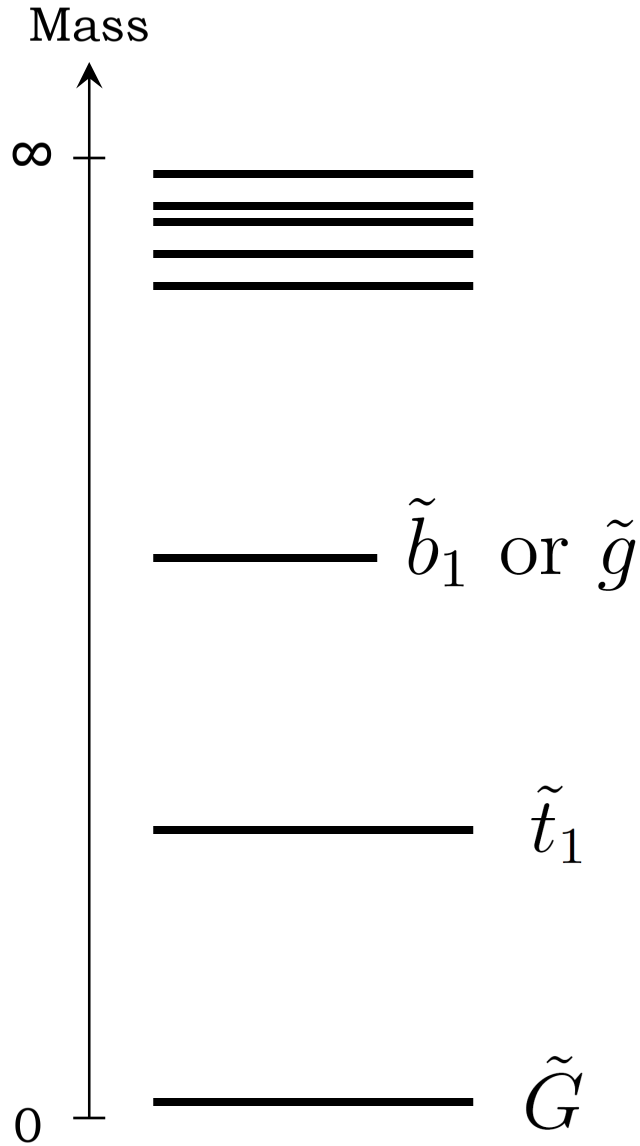
We will consider two examples:

(1) sbottom: $\tilde{b}_1 \to \tilde{t}_1 W^-$

(2) gluino: $\tilde{g} \to \tilde{t}_1 \bar{t}$ or $\tilde{t}_1^* t$

Same-sign dilepton (and multilepton) searches will be very sensitive to both scenarios!

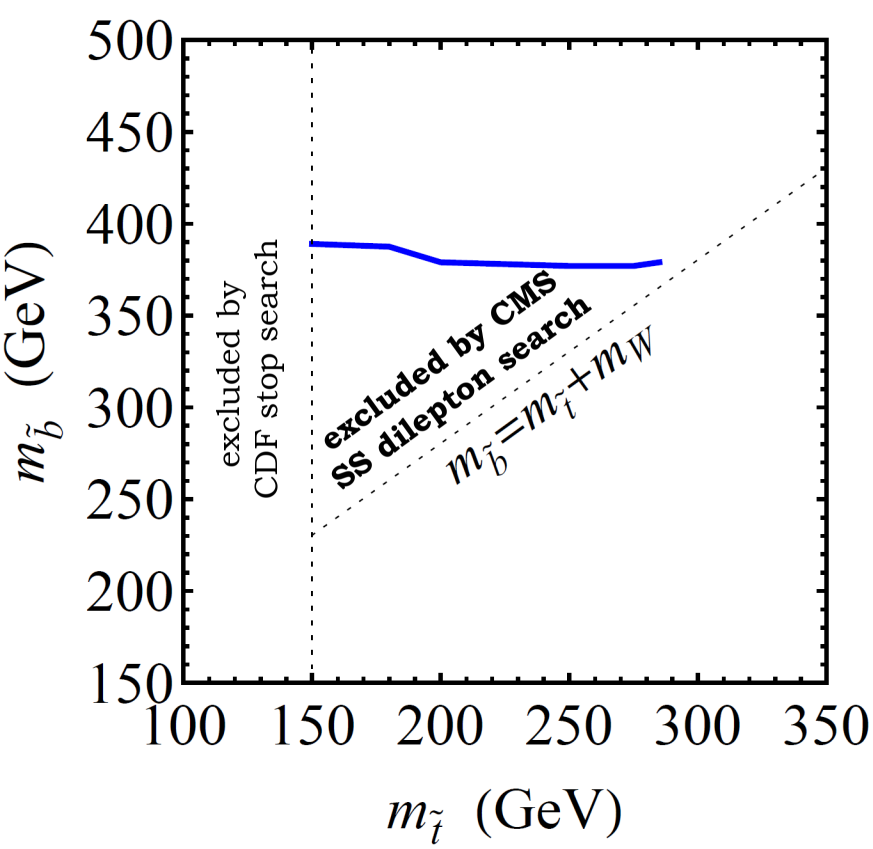
(Less importantly, there will be additional events contributing to the analyses discussed earlier.)

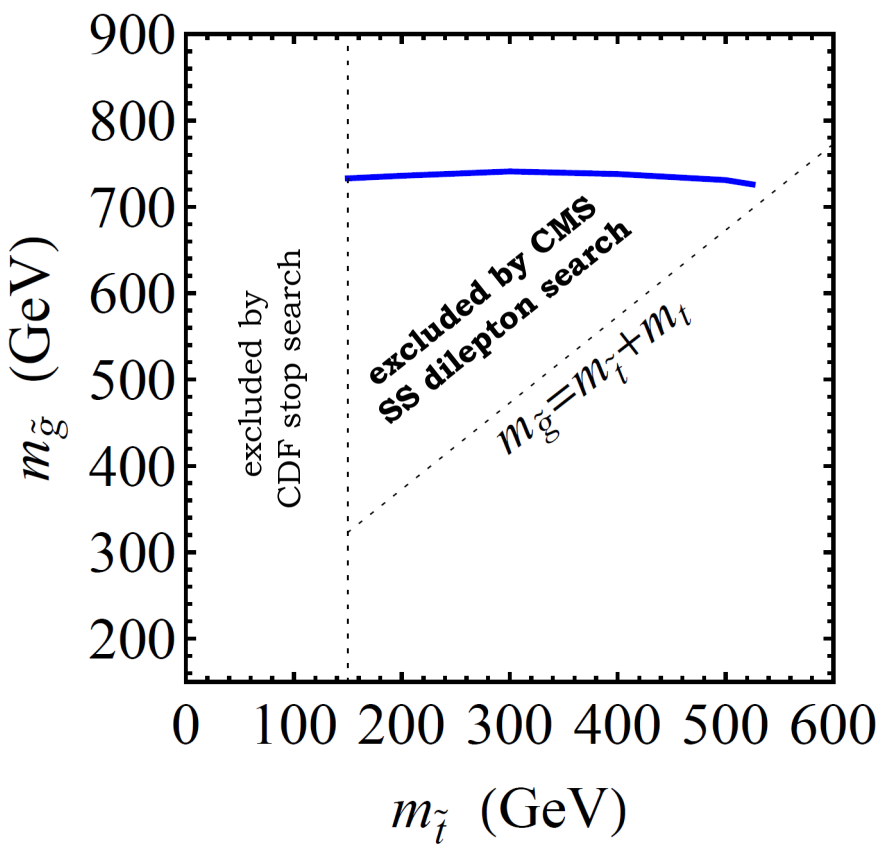


More general stop NLSP scenarios (cont'd)

For setting limits we use the CMS same-sign dilepton search (1 fb^{-1})
CMS PAS SUS-11-010

We find that the sbottom needs to be above ~375 GeV
and the gluino above ~700 GeV:



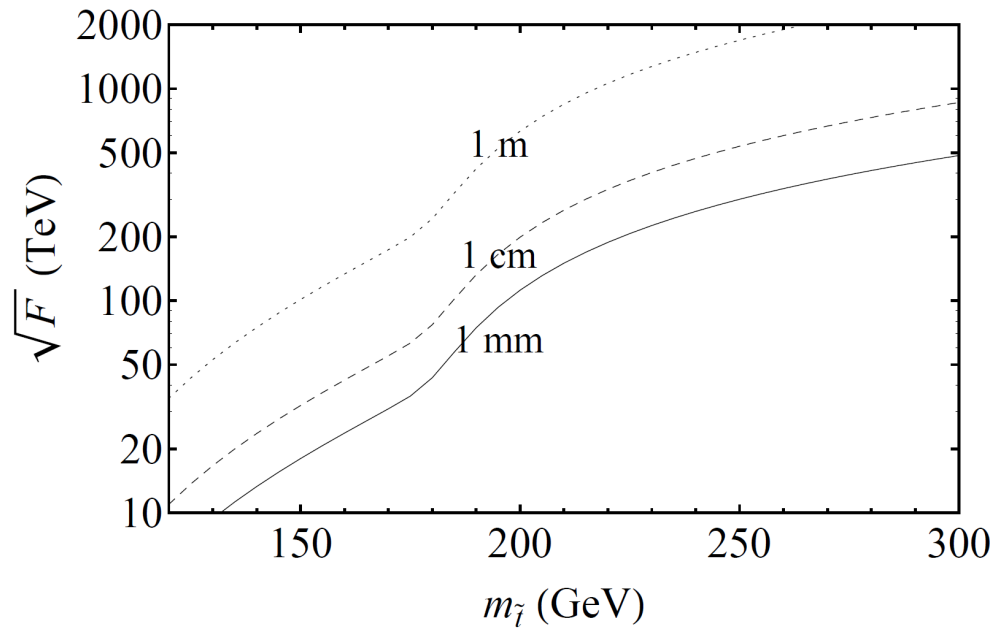


Stop NLSP is generically long-lived

Gravitino couplings are non-renormalizable, effectively suppressed by F (the square of SUSY breaking scale), so the decay

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

may be very slow!



- All the measurements we analyzed assumed prompt decays.
- R-hadron searches (which exclude stops up to 620 GeV) assume detector-stable stops.

The information needed for determining the sensitivity to **displaced decays** is not provided, and no dedicated searches have been done.

- As a result, displaced stop NLSPs, **which are maybe even more likely than prompt**, remain unconstrained.

Conclusions

There is a viable possibility for the stop to be light and hiding in the $t\bar{t}$ sample.

However, existing and ongoing Tevatron and LHC searches do have sensitivity to the stop NLSP scenario, at least if the decay is prompt.

Now is therefore the right time to search for the stop NLSP (both prompt and displaced cases) and perhaps discover supersymmetry in our backyard.