1 Nov 2011 *Implications of LHC results for TeV-scale physics* *CERN*

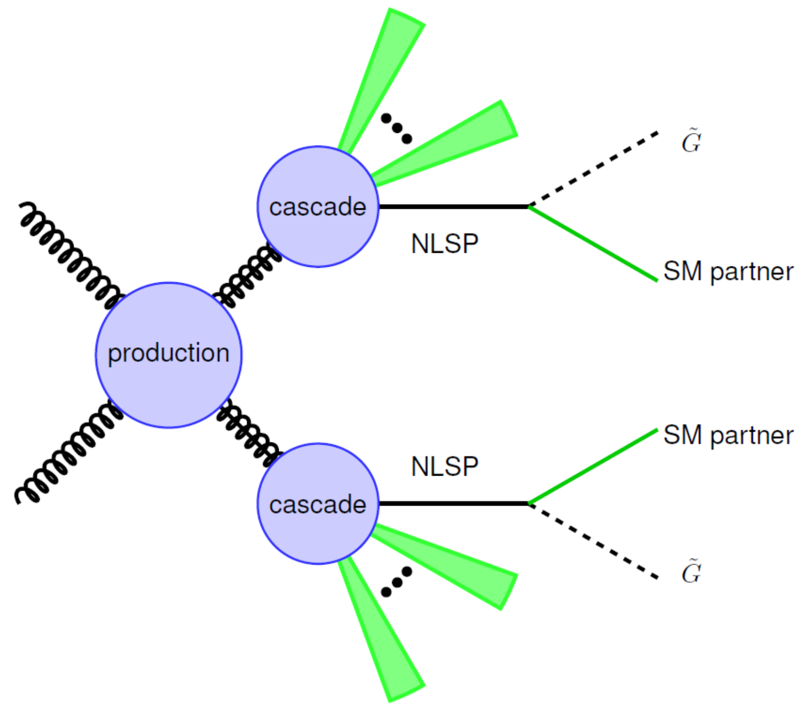
Limits on GMSB-motivated simplified models

Yevgeny Kats
Rutgers University

Based on work with:
Patrick Meade
Matt Reece
David Shih

arXiv:1110.6444

GMSB phenomenology



+ The LSP is a massless gravitino.
+ Any superpartner can be the NLSP.
+ All cascade decays pass through the NLSP.
+ The NLSP identity and the production mechanism determine most of the phenomenology.

Today I will emphasize cases with electroweak production or 3rd generation NLSPs.

LHC searches taken into account

All-hadronic:

+ ATLAS jets + MET (arXiv:1109.6572)
+ ATLAS 6-8 jets + MET (arXiv:1110.2299)
+ CMS jets + MET (PAS SUS-11-004)
+ CMS α_T (PAS SUS-11-003)

… also with b-jets:

+ ATLAS (CONF-2011-098)
+ CMS (PAS SUS-11-006)

Photons:

+ ATLAS $\gamma\gamma$ +MET (PHYS-SLIDE-2011-523)
+ CMS $\gamma\gamma$ + jet +MET (PAS SUS-11-009)
+ CMS γ + jets + MET (PAS SUS-11-009)

Photon + lepton:

+ CMS (arXiv:1105.3152)

Single lepton:

+ ATLAS (arXiv:1109.6606)
+ CMS (PAS SUS-11-015)

… also with b-jets:

+ ATLAS (CONF-2011-130)

SS dileptons:

+ CMS (PAS SUS-11-010)

OS dileptons:

+ CMS (PAS SUS-11-011)

with Z:

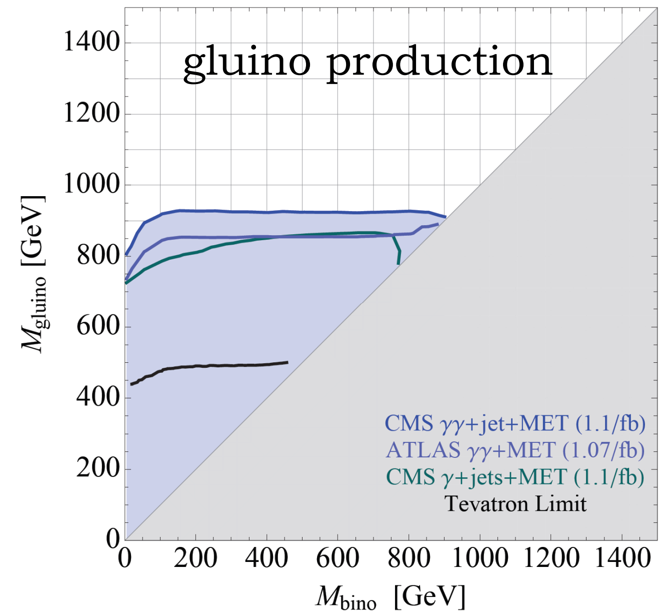
+ CMS (PAS SUS-11-017)

$t\bar{t}$+MET:

+ ATLAS (arXiv:1109.4725)

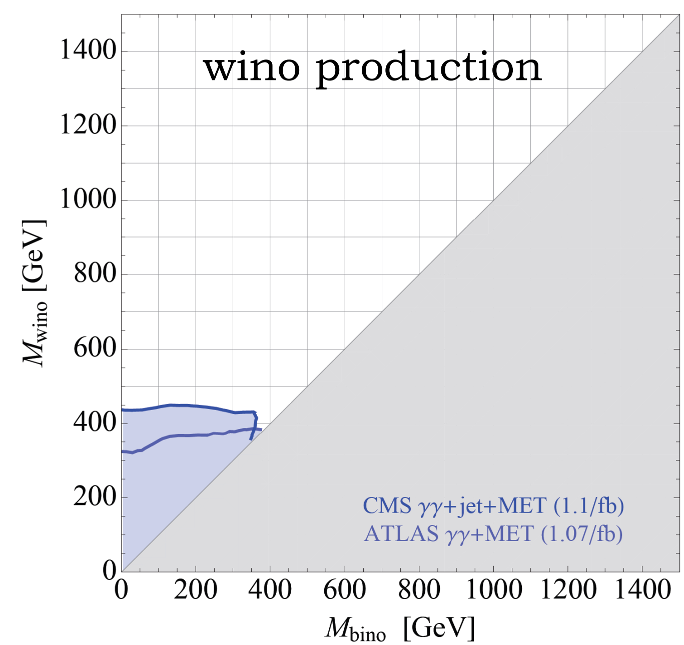
Bino NLSP $\quad \chi_1^0 \to (\gamma \text{ or } Z)\,\tilde{G}$

The photons lead to one of the easiest final states. Gluinos decaying to binos are excluded up to ~900 GeV.



How about electroweak production?
Binos cannot be produced directly, but we can study the electroweak production of winos that decay to binos.

particle	mass	relevant decays
χ_2^0	M_{wino}	$\chi_2^0 \to h^{(*)}\chi_1^0,\ Z^{(*)}\chi_1^0$
$\chi_1^\pm$	M_{wino}	$\chi_1^\pm \to W^{\pm(*)}\chi_1^0$
χ_1^0	M_{bino}	$\chi_1^0 \to (\gamma \text{ or } Z)\,\tilde{G}$



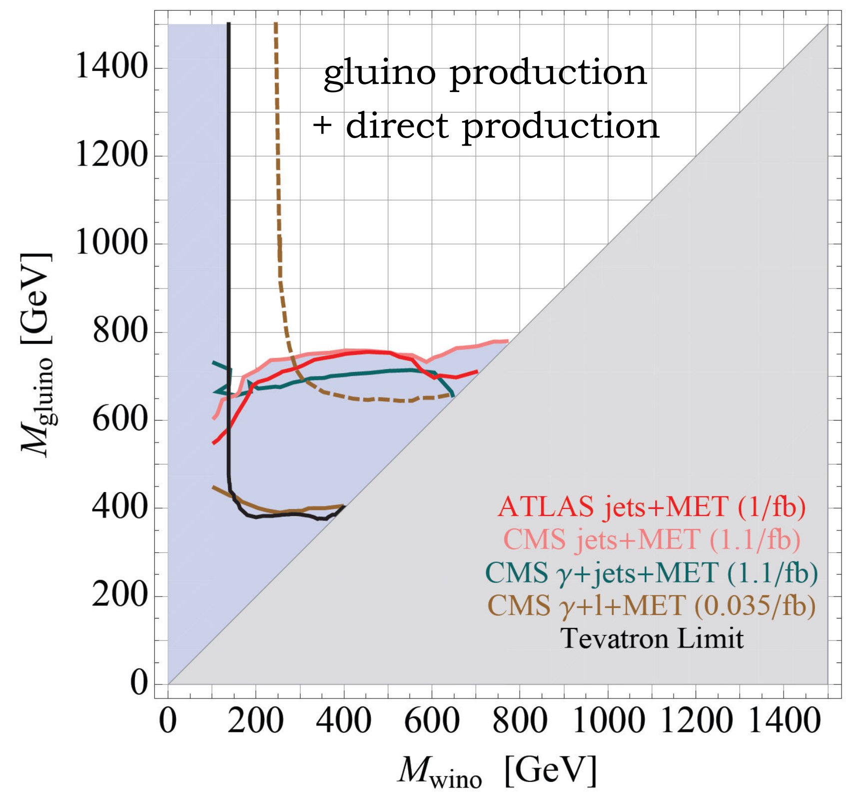
$\gamma\gamma$+MET searches set a limit of ~400 GeV on the wino!

Wino co-NLSPs $\chi_1^0 \to (Z \text{ or } \gamma)\,\tilde{G}\,, \;\; \chi_1^\pm \to W^\pm\,\tilde{G}$

A variety of mixed final states with photons, leptons and jets.

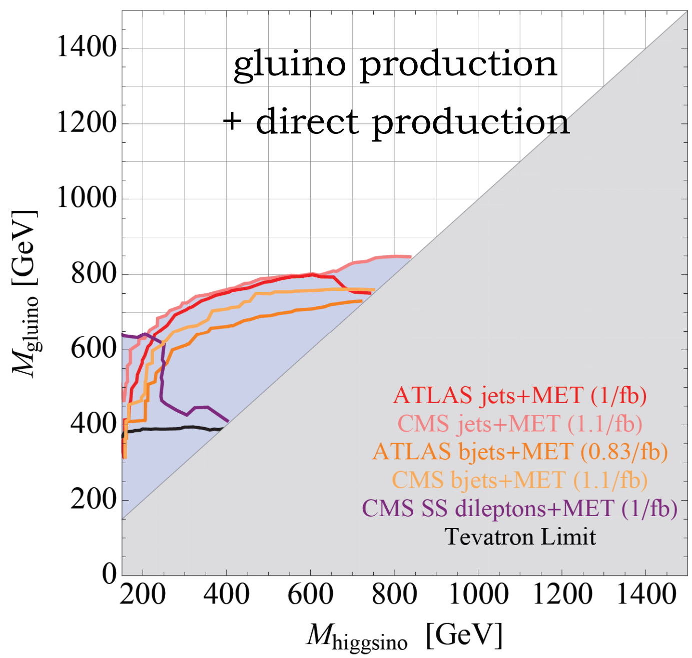
Gluinos are excluded only up to ~700 GeV.

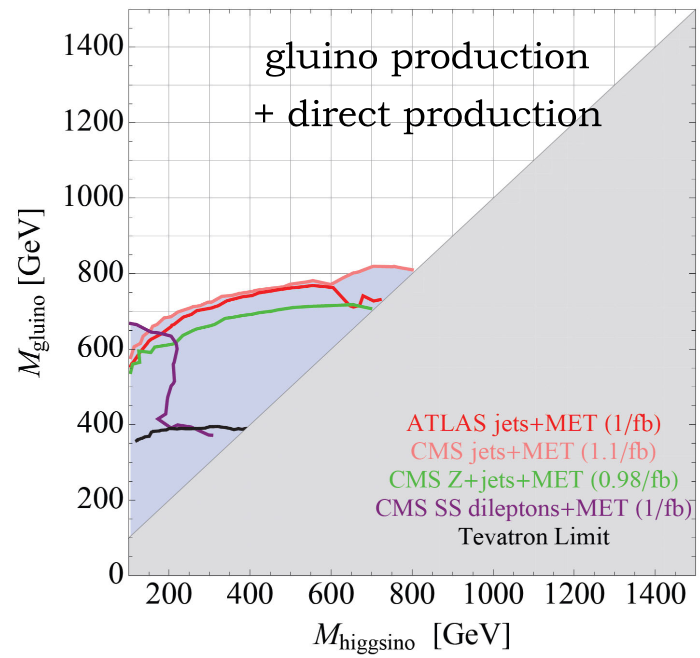
How about electroweak production?
Once updated to 1/fb, the CMS γ+ℓ+MET search has the potential to exclude direct production of winos up to ~250 GeV.



Higgsino NLSP $\chi_1^0 \to (h \text{ or } Z)\,\tilde{G}$

Neither h nor Z is a super-easy final state. Gluinos are excluded only up to ~650 GeV.





Still, why is the best limit set by jets+MET searches, despite the multi-b events from higgs decays or the leptonic decays of the Z? This happens because jets+MET searches designed search regions with harder requirements on hadronic activity.

How about electroweak production?

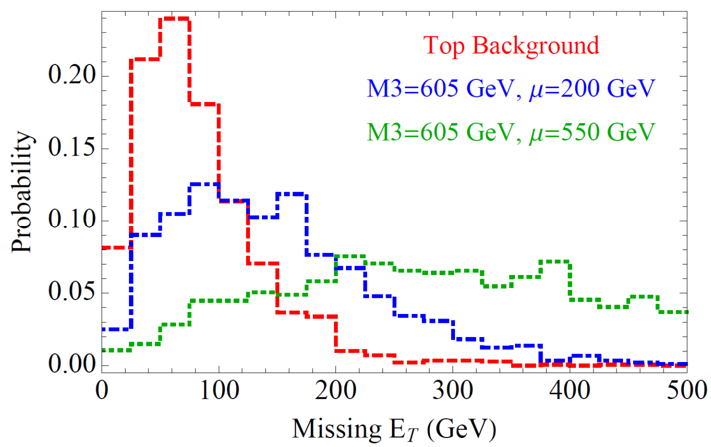
Not yet. As can be seen above, the limits actually degrade at low masses.

But the Z+jets+MET search can be improved significantly by using leptonic M_{T2}!

Leptonic M_{T2}

The variable m_T is well-known for distinguishing MET coming solely from the leptonic decay of a W (background) vs. additional sources of MET in the signal. "Leptonic M_{T2}" does the same trick for events with two W's .

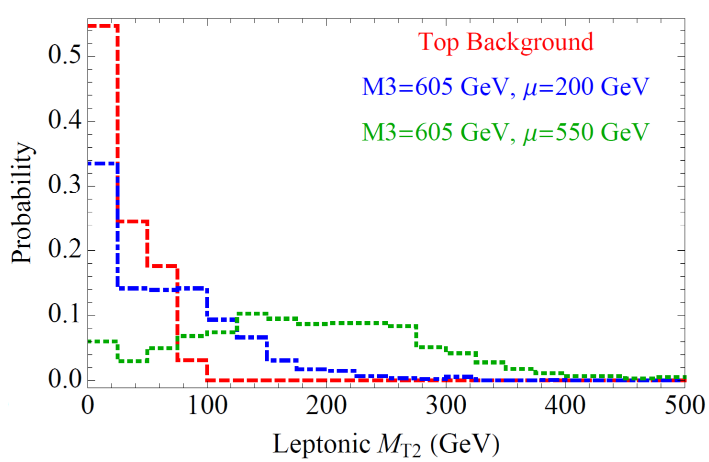
Replacing the MET cut in the CMS Z+jets+MET search with a cut on M_{T2} can help eliminate the top background in light Z-rich higgsino NLSP events much more efficiently.

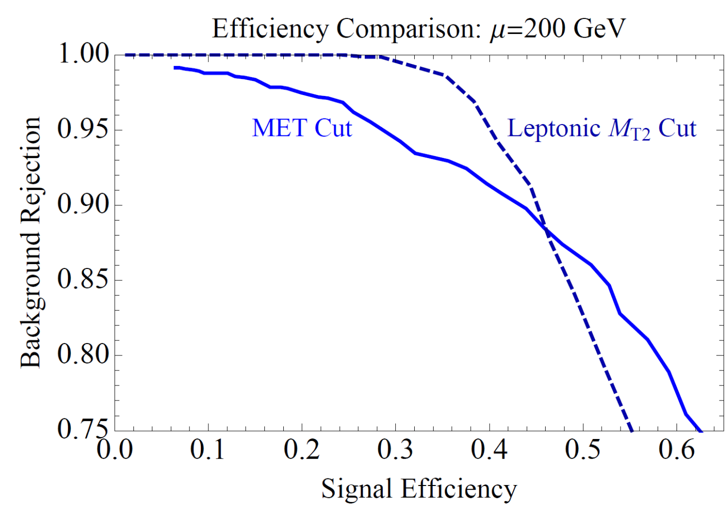


$$M_{T2}^2 = \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left(\max\left(m_T^2(\ell_1,\nu_1), m_T^2(\ell_2,\nu_2)\right)\right)$$

Lester and Summers, hep-ph/9906349

Lester, arXiv:1103.5682



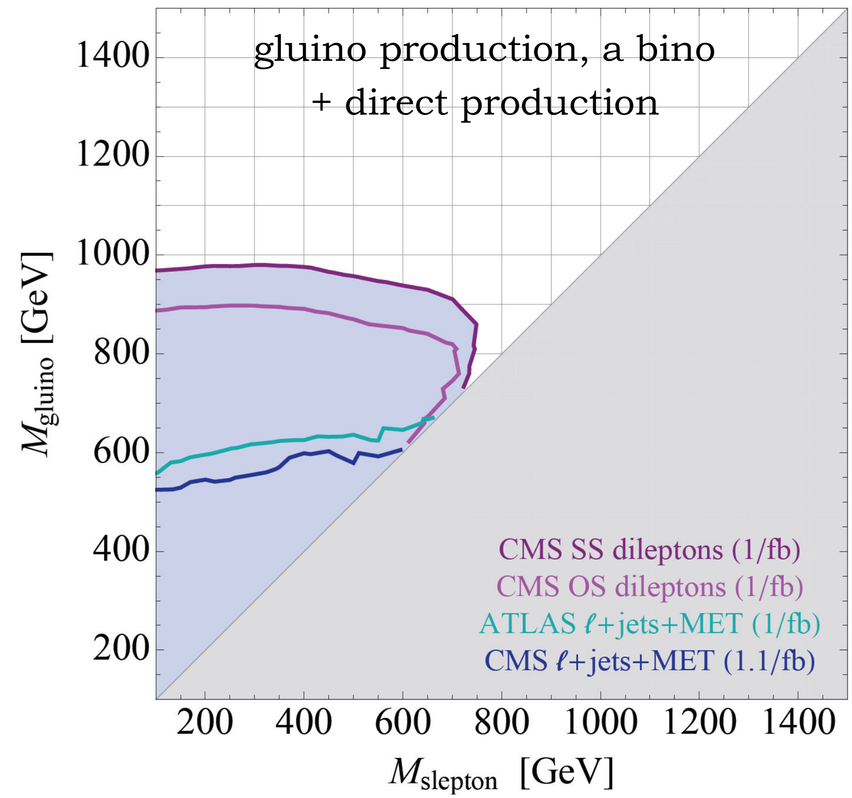


Right-handed slepton co-NLSPs $\tilde{\ell}_R^\pm \to \ell^\pm \tilde{G}$

The sleptons decay to leptons, which leads to a distinct signature if additional leptons are produced in the cascade decay: the limit on gluinos is close to 1 TeV.

How about electroweak production?
As can be seen from this plot, there is no limit on direct production of sleptons.

But can we see winos decaying to sleptons?



particle	mass	relevant decays
$\chi_1^\pm$	M_{wino}	$\chi_1^\pm \to \nu_\tau \tilde{\tau}_1^\pm$
χ_1^0	M_{wino}	$\chi_1^0 \to \ell^\pm \tilde{\ell}_R^\mp$
$\tilde{\ell}_R^\pm$	M_{slepton}	$\tilde{\ell}_R^\pm \to \ell^\pm \tilde{G}$

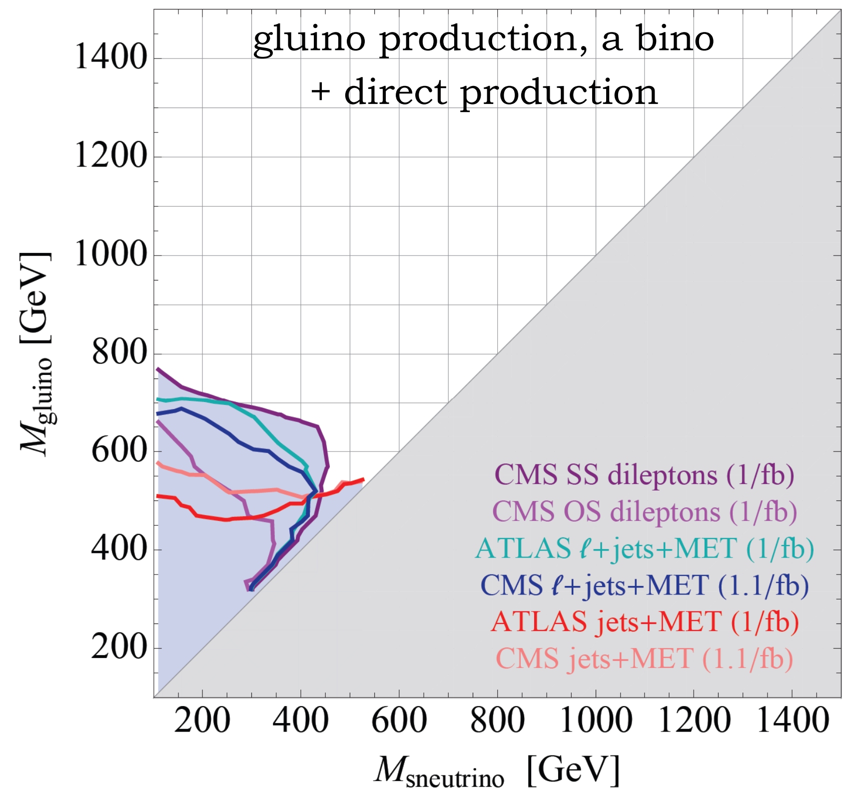
This could be easy because same-sign dileptons are abundant.
However, the jets and H_T requirements of the CMS SS (and OS) dilepton searches make them insensitive to these electroweak production processes.

* Even stronger limits on these scenarios can be obtained from multilepton searches which were released recently.

Sneutrino co-NLSPs $\tilde{\nu}_\ell \to \nu_\ell \tilde{G}$

The sneutrinos decay invisibly, although leptons produced in the cascade decays give some exclusion power. Still, the limit on the gluino mass is only ~550 GeV!

particle	mass	relevant decays
$\tilde{g}$	M_{gluino}	$\tilde{g} \to jj\chi_1^0$
χ_1^0	M_{bino}	$\chi_1^0 \to \ell^\pm \tilde{\ell}_L^\mp,\ \nu\tilde{\nu}$
$\tilde{\ell}_L^\pm$	$M_{\text{sneutrino}} + \Delta m$	$\tilde{\ell}_L^\pm \to W^* \tilde{\nu}_\ell$
$\tilde{\nu}_\ell$	$M_{\text{sneutrino}}$	$\tilde{\nu}_\ell \to \nu_\ell \tilde{G}$



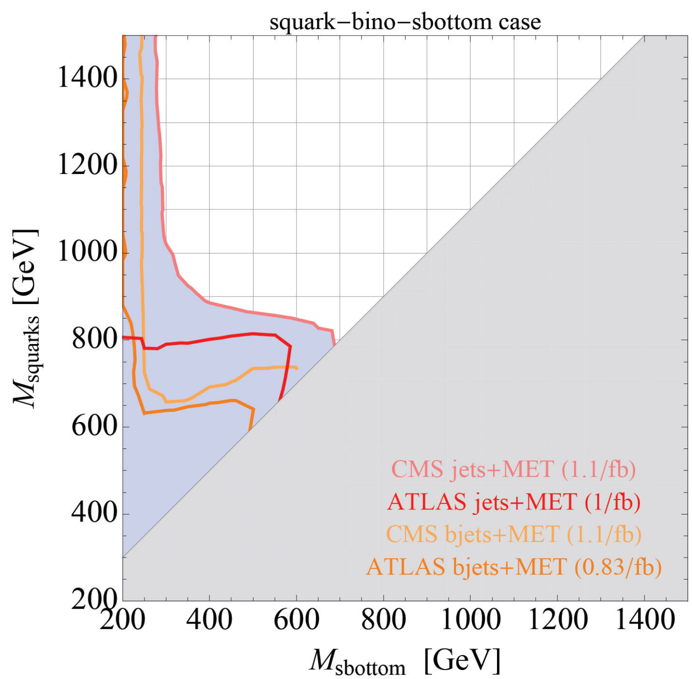
How about electroweak production?
Not obviously promising.

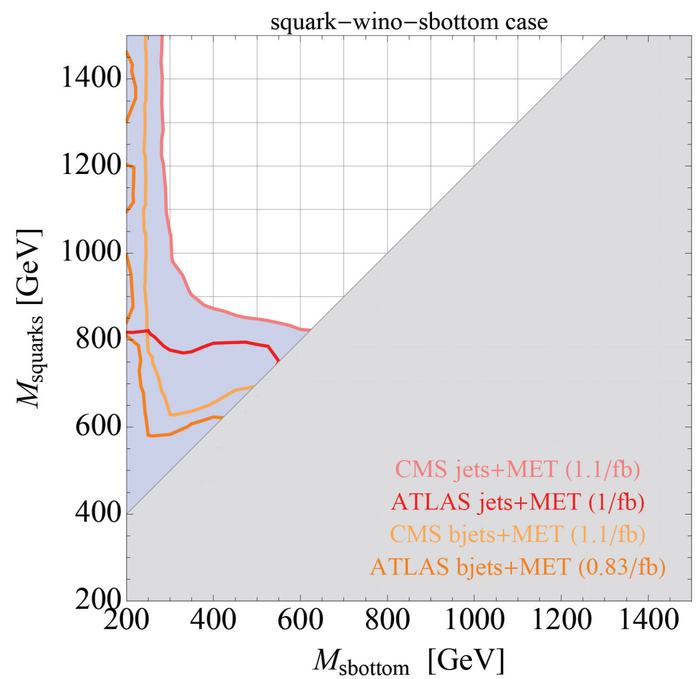
Sbottom NLSP $\tilde{b}_1 \to b\,\tilde{G}$

Production from squarks decaying via an intermediate bino (left) or wino (right):

particle	mass	relevant decays
$\tilde{q}$	M_{squark}	$\tilde{q} \to j\chi_1^0$
$\tilde{b}_2$	M_{squarks}	$\tilde{b}_2 \to h\tilde{b}_1$
χ_1^0	M_{bino}	$\chi_1^0 \to b\tilde{b}_1$
$\tilde{b}_1$	M_{sbottom}	$\tilde{b}_1 \to b\tilde{G}$

particle	mass	relevant decays
$\tilde{q}$	M_{squarks}	$\tilde{q} \to j\chi$
$\tilde{b}_2$	M_{squarks}	$\tilde{b}_2 \to h\tilde{b}_1$
$\chi_1^0, \chi_1^\pm$	M_{wino}	$\chi_1^\pm \to t^{(*)}\tilde{b}_1$ or $\chi_1^0 \to b\tilde{b}_1$
$\tilde{b}_1$	M_{sbottom}	$\tilde{b}_1 \to b\tilde{G}$





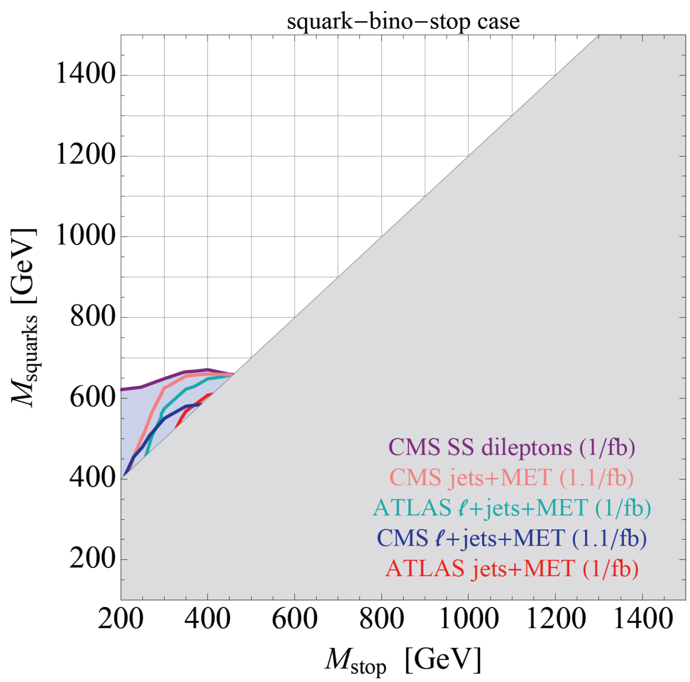
Jets + MET searches exclude direct sbottom NSLP production up to ~280 GeV!

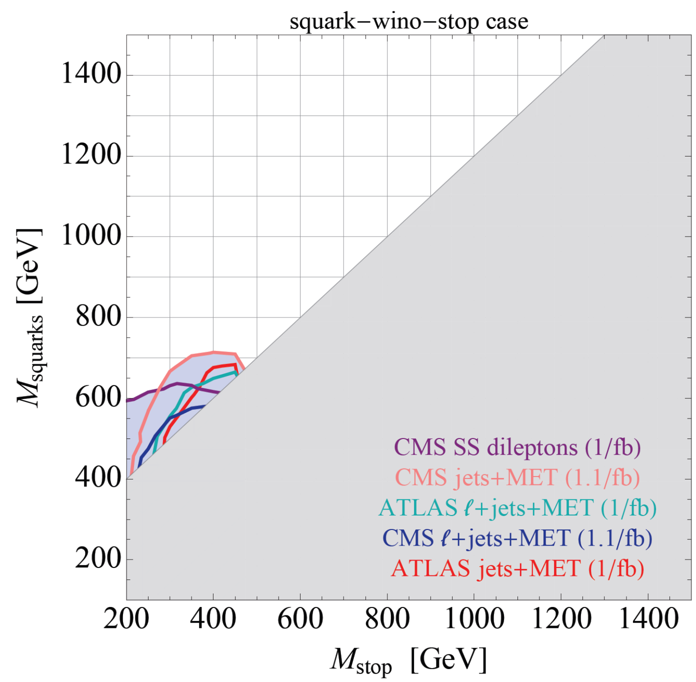
Stop NLSP $\tilde{t}_1 \to t\,\tilde{G}$

Production from squarks decaying via an intermediate bino (left) or wino (right):

particle	mass	relevant decays
$\tilde{q}$	$M_{\rm squark}$	$\tilde{q} \to j\chi_1^0$
$\tilde{t}_2$	$M_{\rm squarks}$	$\tilde{t}_2 \to h\tilde{t}_1$
χ_1^0	$M_{\rm bino}$	$\chi_1^0 \to t^{(*)}\tilde{t}_1$
$\tilde{t}_1$	$M_{\rm stop}$	$\tilde{t}_1 \to t\tilde{G}$

particle	mass	relevant decays
$\tilde{q}$	$M_{\rm squarks}$	$\tilde{q} \to j\chi$
$\tilde{t}_2$	$M_{\rm squarks}$	$\tilde{t}_2 \to h\tilde{t}_1$
$\chi_1^0, \chi_1^\pm$	$M_{\rm wino}$	$\chi_1^\pm \to b\tilde{t}_1$ or $\chi_1^0 \to t^{(*)}\tilde{t}_1$
$\tilde{t}_1$	$M_{\rm stop}$	$\tilde{t}_1 \to t\tilde{G}$





All the other squarks together can be sitting at just 600 GeV!

Stop NLSP: direct production (Tevatron)

The detection of a stop NLSP is challenging because of the large top background. The stop may even be lighter than the top, in which case it decays as $\tilde{t} \to W^+ b \tilde{G}$ with very soft b-jets.

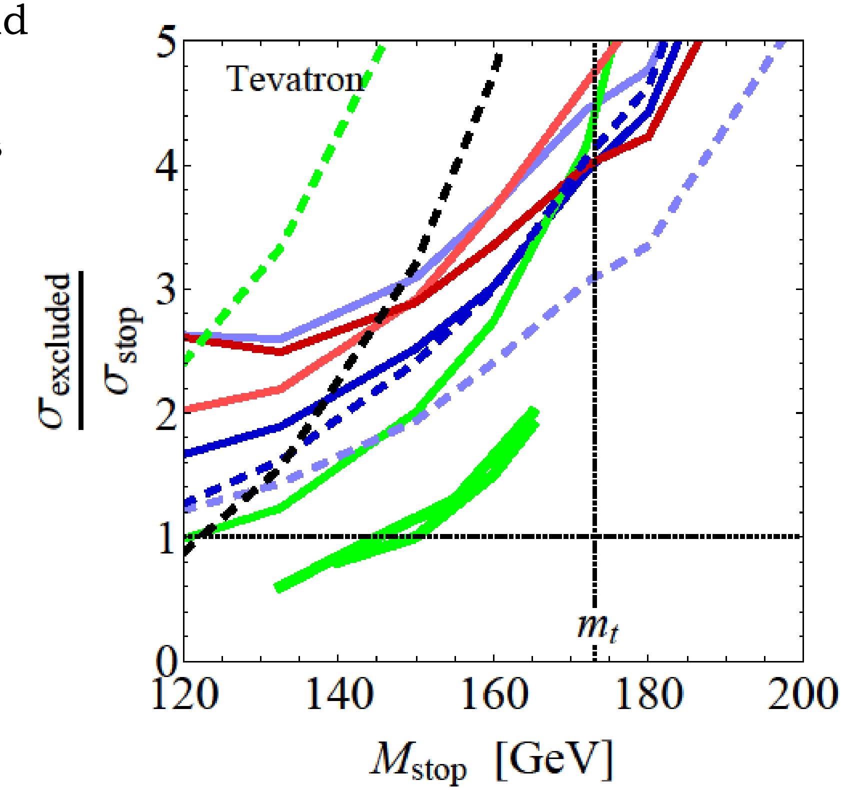
In a previous work, we examined various Tevatron measurements: $t\bar{t}$ production cross sections (dilepton and lepton+jets channels, with and without b-tagging, etc.) and new physics searches with top-like final states.

The strongest limit (150 GeV) was obtained from a CDF search that assumed

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

and used stop mass reconstruction in the dilepton channel.

CDF, arXiv:0912.1308



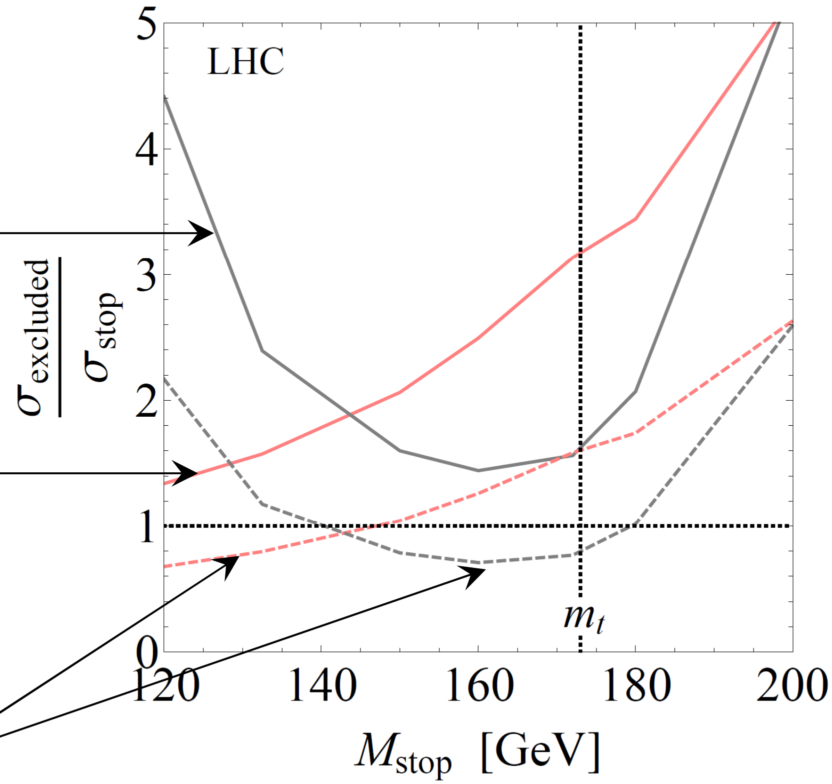
YK and D.Shih, arXiv:1106.0030

Stop NLSP: direct production (35/pb LHC)

No constraints on stop NLSP yet.

The most sensitive analyses were:

- ATLAS search for anomalous missing energy in $t\bar{t}$ events. Lepton+jets channel, with a cut on m_T of the W. ATLAS-CONF-2011-036
- ATLAS $t\bar{t}$ cross section measurement in the dilepton channel without b tagging. ATLAS-CONF-2011-034



Together, they could exclude stops up to ~180 GeV with less than 1/fb!

YK and D.Shih, arXiv:1106.0030

Stop NLSP: direct production

$t\bar{t}$ cross section: ATLAS-CONF-2011-034 (35/pb) → ATLAS-CONF-2011-100 (0.7/fb)

jet p_T cut: 20 GeV → 25 GeV } disfavors stop's soft b-jets

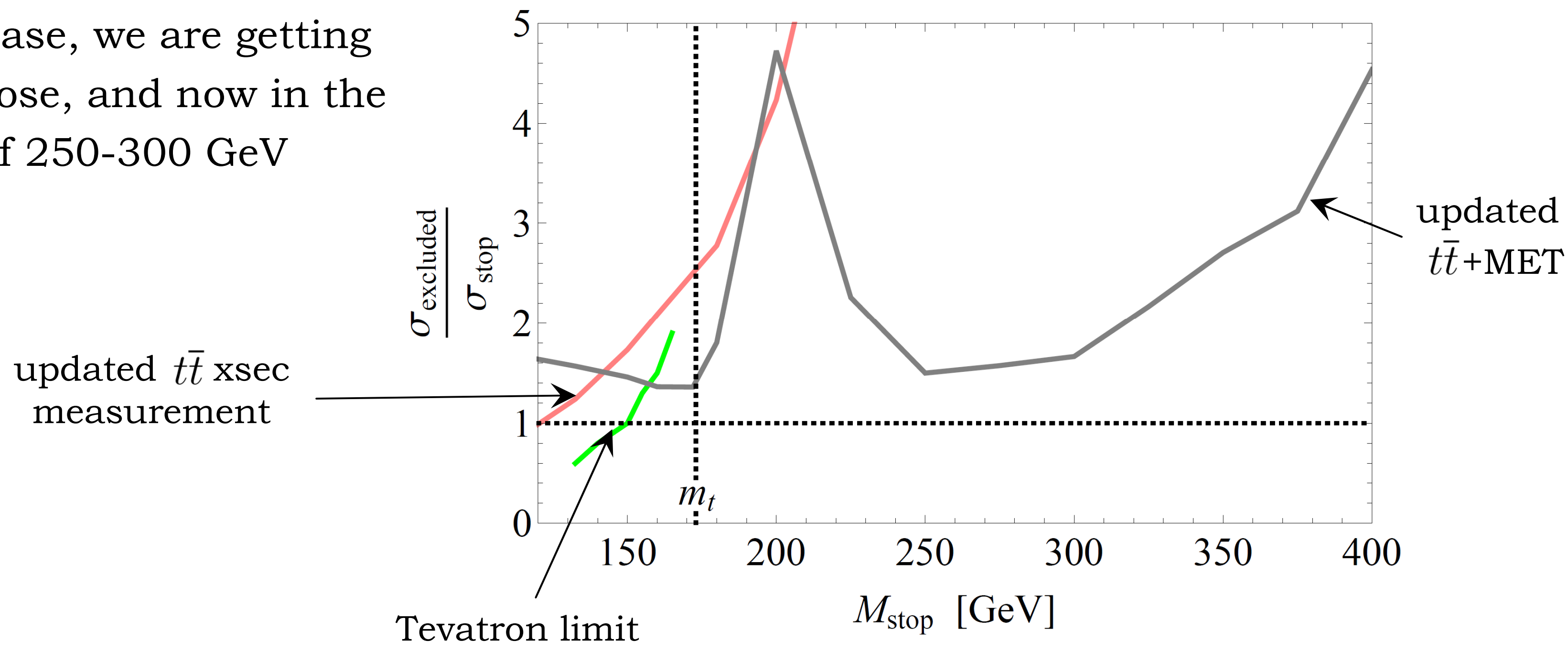
$t\bar{t}$+MET with m_T: ATLAS-CONF-2011-036 (35/pb) → arXiv:1109.4725 (1/fb)

jet p_T cut: 20 GeV → 25 GeV
MET cut: 80 GeV → 100 GeV
m_T cut: 120 GeV → 150 GeV

} smaller acceptance and smaller statistics than expected

Due to the modified cuts, there is still no exclusion on the stop. However, the original cuts can probably be restored (since the analyses use lepton triggers).

In any case, we are getting really close, and now in the region of 250-300 GeV as well.



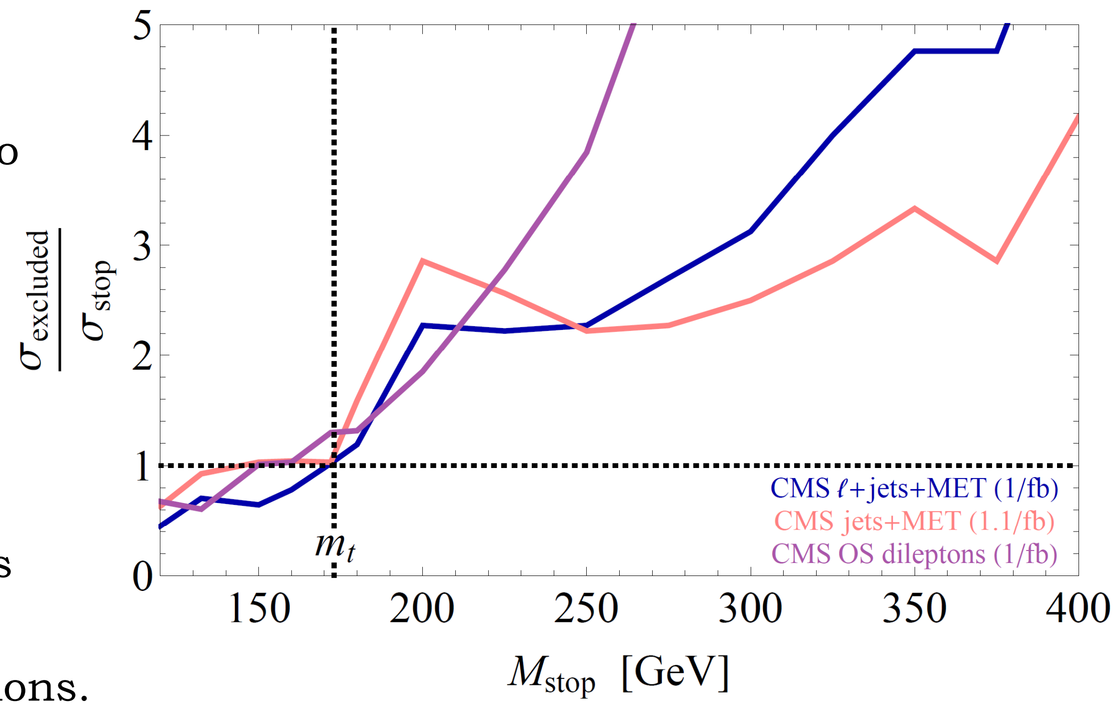
Stop NLSP: direct production

The acceptances for light stops (e.g., 150 GeV) in the generic SUSY searches are tiny (~10^{-4}) because they use hard cuts on MET, H_T and m_{eff}.

Nevertheless, since the stops can be so light their cross sections are large, and some events make it into the sample.

As shown in the plot, these searches may be sensitive to stops up to ~175 GeV.

However, at this stage we cannot trust these results as precise limits since the acceptance comes from the tails of the kinematic distributions.



A more careful simulation (beyond the showering available in Pythia) is needed, along with an estimate of the remaining systematic uncertainty.

A better approach would be designing more dedicated searches, which are so important in view of the central role that the stop plays in the question of naturalness.

Summary of highlights

- Limits on EW production of winos:
  - In the bino NLSP case: ~400 GeV from $\gamma\gamma$ + MET.
  - In the slepton co-NLSP case: limit may be easy to obtain if the jet and H_T requirements can be eliminated from SS dilepton searches.
  - In the wino co-NLSP case: potential limit of ~250 GeV with the CMS lepton+photon+MET search updated to 1/fb.
- Leptonic M_{T2} can be very helpful for light Z-rich higgsino NLSPs (and other cases).
- The gluino can still be very light (~550 GeV) if the NLSP is the sneutrino.
- All the squarks can be as light as ~600 GeV if the stop is the NLSP.
- Limit on direct sbottom NLSP production: ~280 GeV.
- The LHC now has the sensitivity for excluding direct production of stop NLSPs. However, this cannot be done without designing a more dedicated analysis or (if feasible) a sufficiently reliable simulation of some of the existing ones.
- See our paper for many additional results.