Status of RPV SUSY

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RPV SUSY in short

Supersymmetry (MSSM or beyond) may conserve **R-parity:**

+1 for SM particles

–1 for superpartners

→ LSP is stable (if neutral → DM candidate, MET signatures)

→ Prohibits certain operators that easily lead to proton decay, violate flavor constraints, etc.

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+1 for SM particles

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→ LSP is stable (if neutral → DM candidate, MET signatures)

→ Prohibits certain operators that easily lead to proton decay, violate flavor constraints, etc.

But it doesn't have to.

Much of the R-parity violating (RPV) parameter space is viable.

RPV SUSY in short

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk}\, L_i L_j E^c_k + \lambda'_{ijk}\, L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk}\, U^c_i D^c_j D^c_k$$

L = left-handed lepton/neutrino

E = right-handed lepton

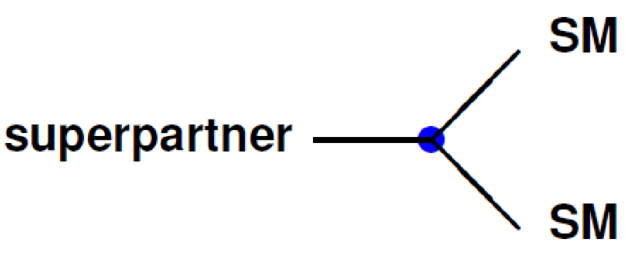
Q = left-handed quark

U, D = right-handed quark

i, j, k = generation indices

*Bilinear terms, soft SUSY breaking terms, and other RPV possibilities are omitted only for simplicity.

R-parity violating superpotential terms as above allow the LSP to decay to SM particles.



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- Any coupling (incl. choice of flavor) is allowed, at least in isolation.
  → **Diverse possibilities for phenomenology.**
  Anything from jets-only to multileptons.

- Couplings may be tiny, and would still induce the decays because the LSP has nothing else to do. → **Decays can easily be displaced.**

Displaced decays

Two comprehensive reinterpretation studies:

[1] "The Fate of Long-Lived Superparticles with Hadronic Decays after LHC Run 1"
Liu and Tweedie, arXiv:1503.05923

[2] "Phenomenology of a Long-Lived LSP with R-Parity Violation"
Csaki, Kuflik, Lombardo, Slone, Volansky, arXiv:1505.00784

Searches included

CMS dijet in [1] and [2]
arXiv:1411.6530; CMS-PAS-EXO-12-038

ATLAS DV+μ/e/jets/MET in [2]
arXiv:1504.05162

CMS dileptons in [1]
arXiv:1411.6977

CMS e+μ in [1]
arXiv:1409.4789

ATLAS muon spectrometer in [1]
arXiv:1203.1303 (7 TeV data)

ATLAS HCAL in [1]
ATLAS-CONF-2014-041

ATLAS μ + tracks in [1]
ATLAS-CONF-2013-092

Very recent – not included

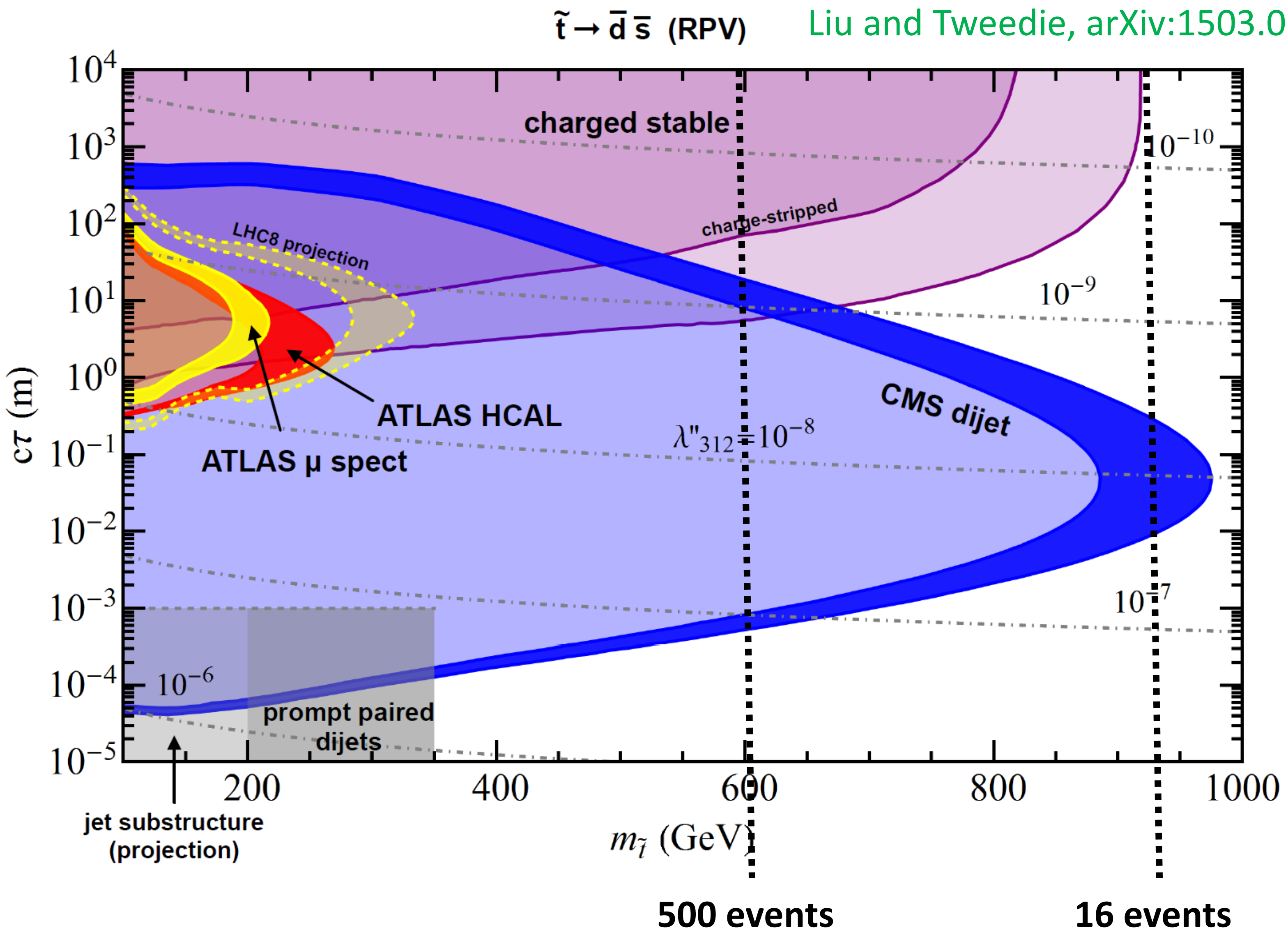
ATLAS calorimeter
arXiv:1501.04020

ATLAS tracker or muon spectrometer
arXiv:1504.03634

CMS: displaced dimuons
CMS-PAS-EXO-14-012

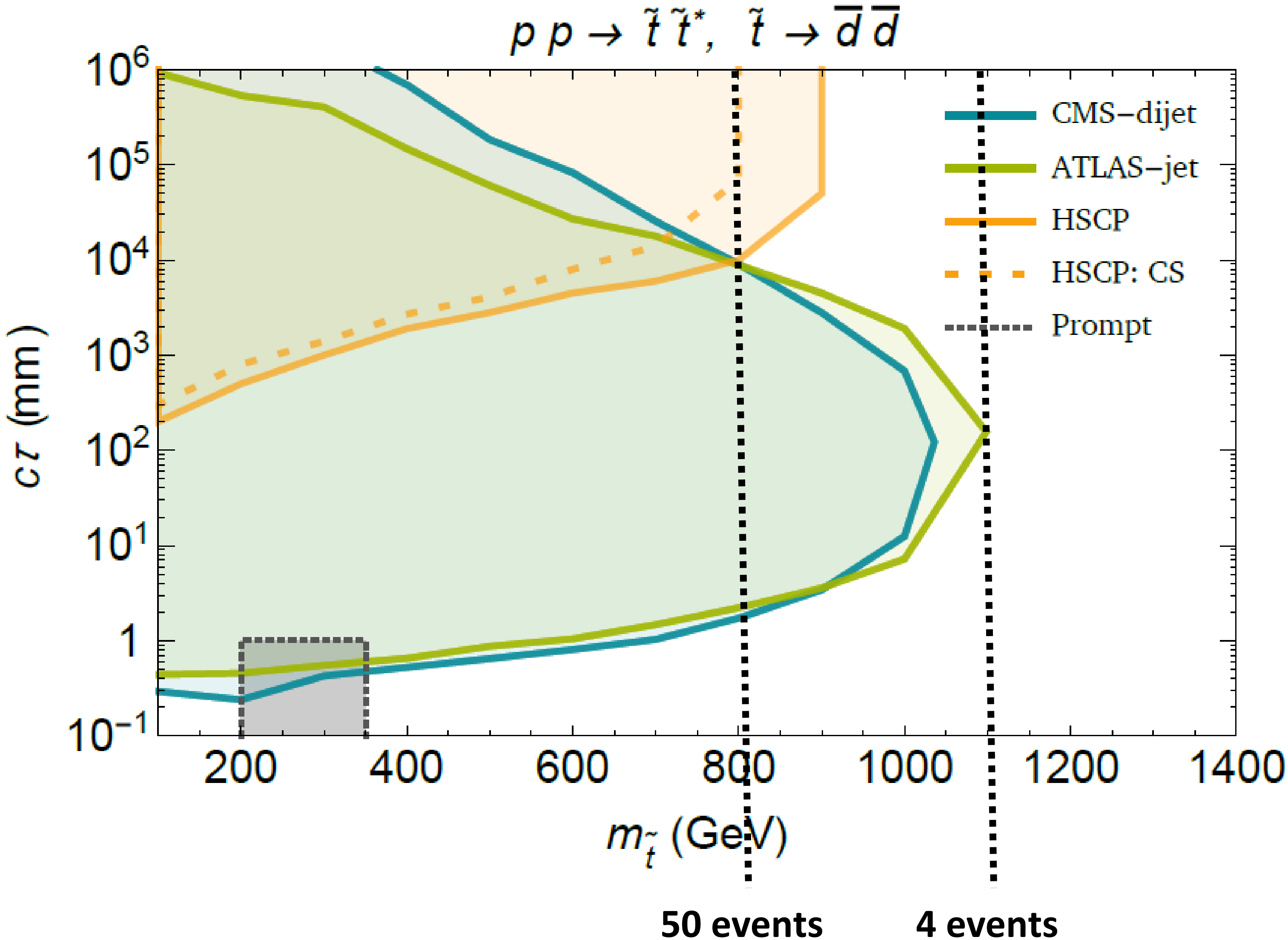
Displaced decays

Liu and Tweedie, arXiv:1503.05923



Displaced decays

Csaki, Kuflik, Lombardo, Slone, Volansky, arXiv:1505.00784



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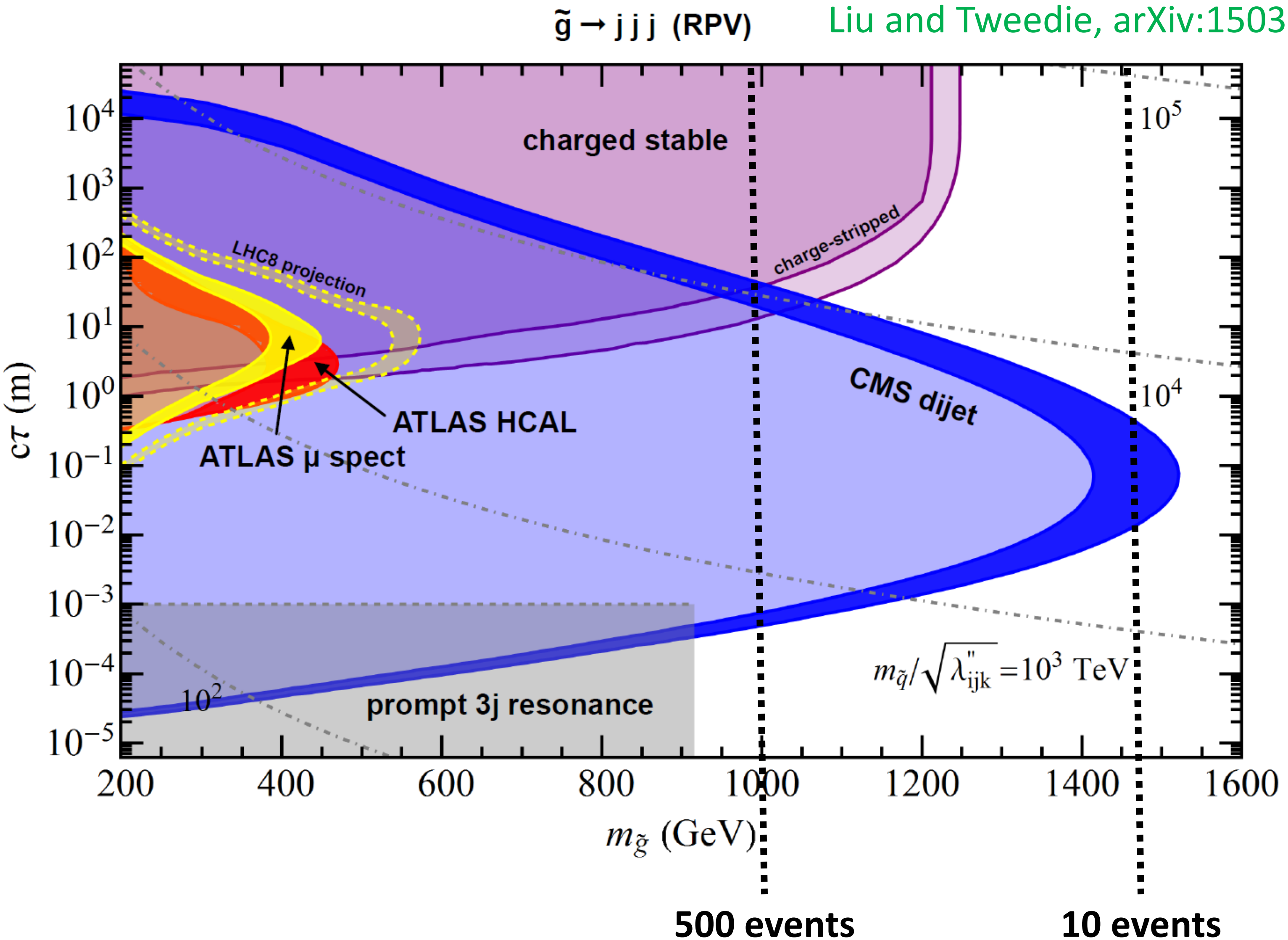
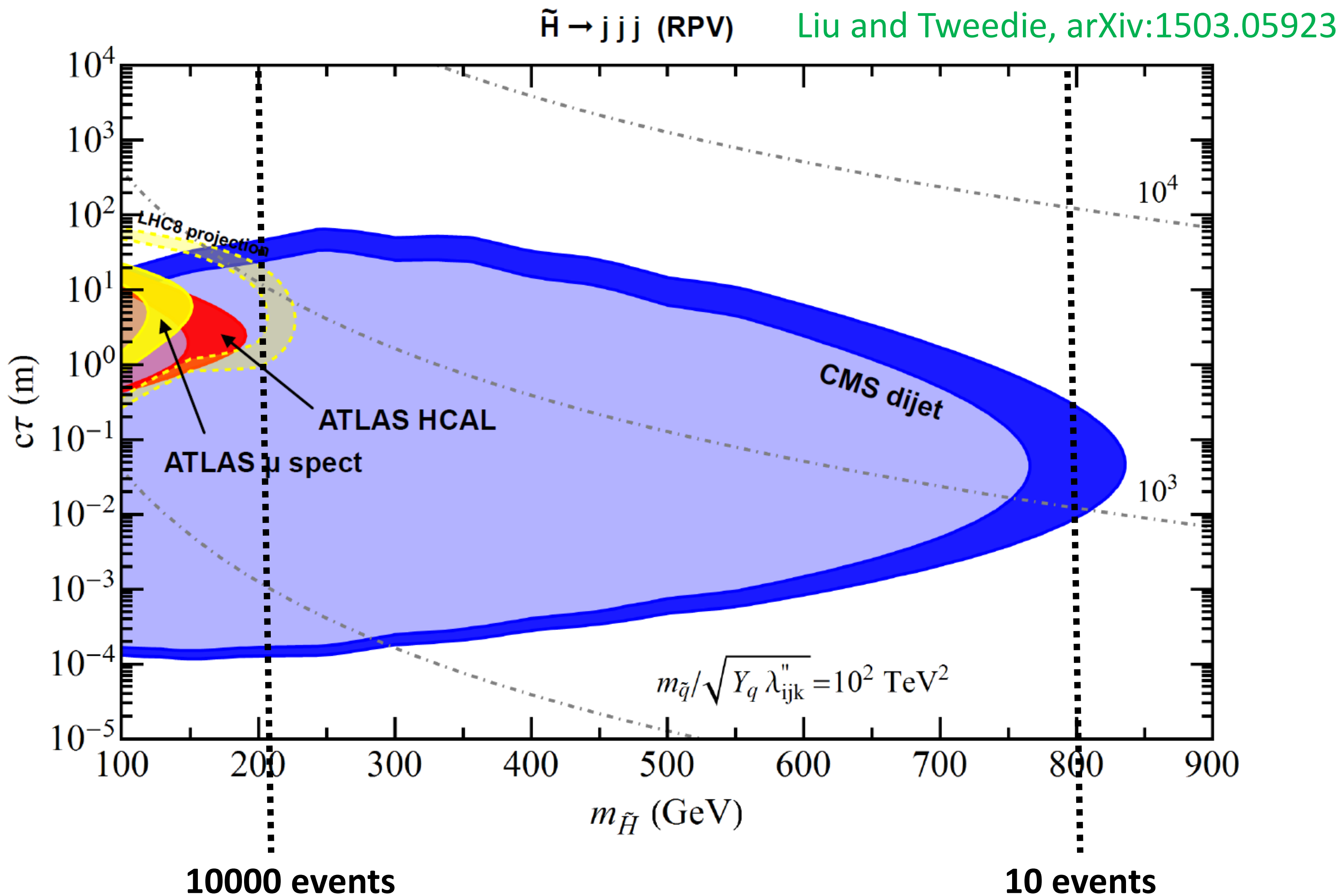


Displaced decays



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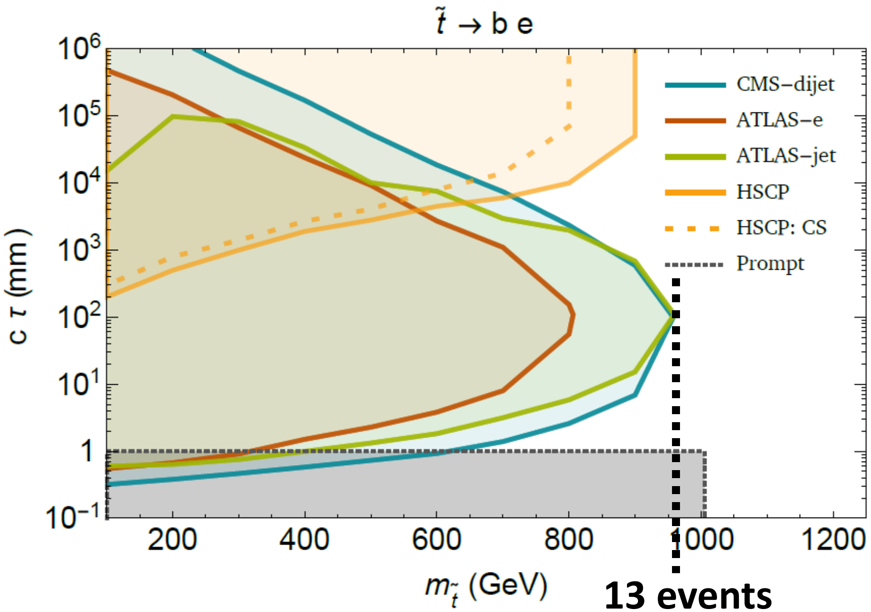
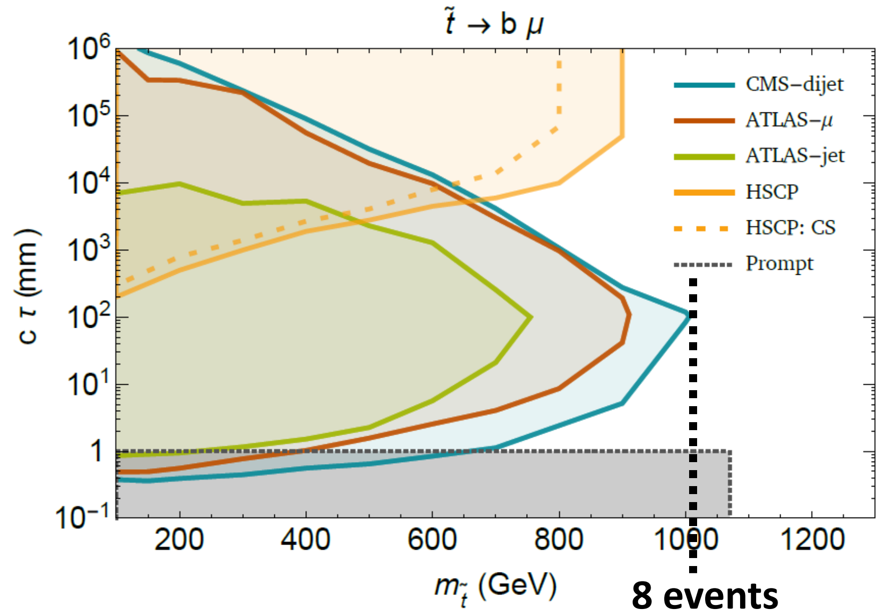
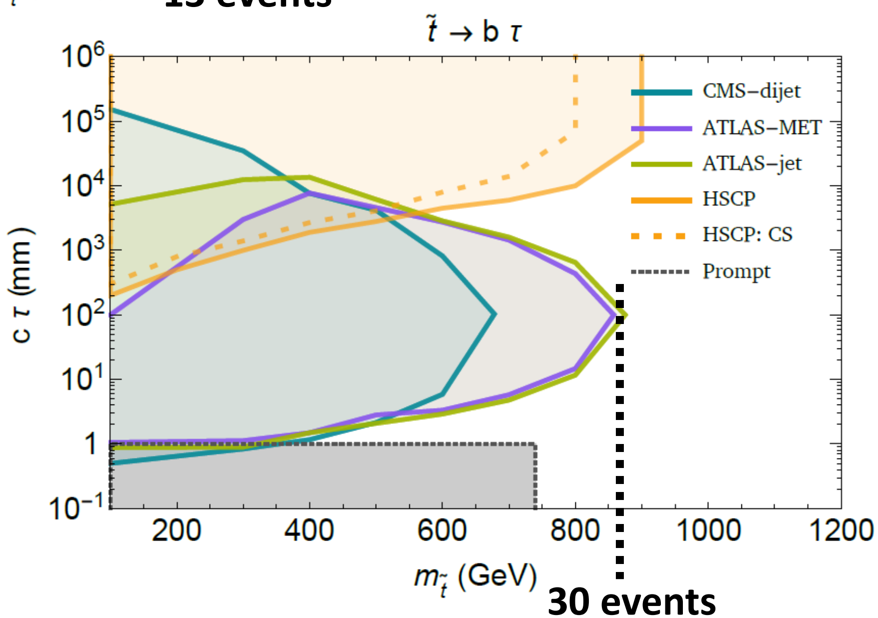






Csaki, Kuflik, Lombardo, Slone, Volansky
arXiv:1505.00784

Prompt decays

For a naturally light LSP (< 400 GeV), essentially **all possible gluino decays** (RPV or anything else) are covered up to roughly 1 TeV.

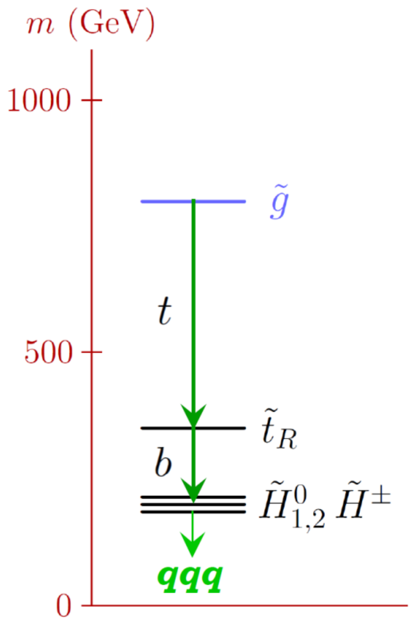
Few exceptions: e.g. some contrived all-hadronic final states.

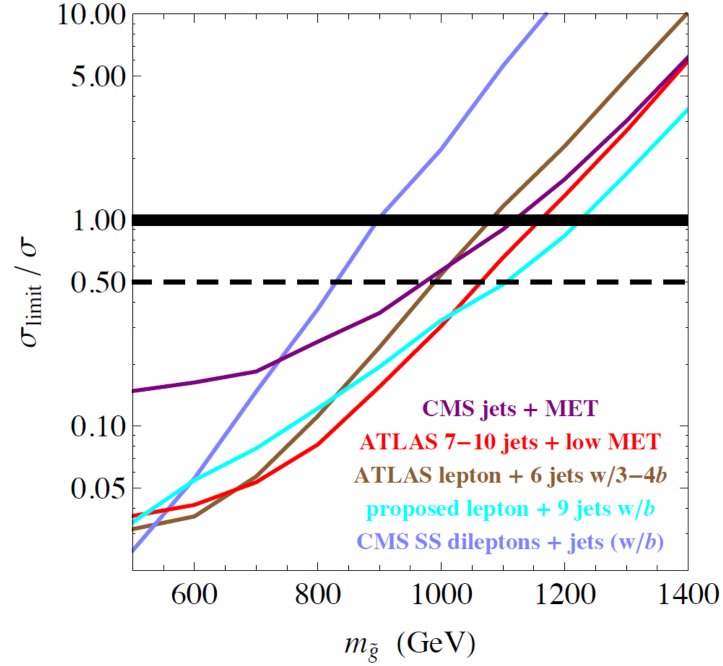
Evans, Kats, Shih, Strassler
arXiv:1310.5758

Argument: gluino decays always contain either **MET**, or **tops**, or **high object multiplicity**, and there exist **model-independent searches** sensitive to each.

Example: gluino → jets + tops (no MET)

Evans, Kats, Shih, Strassler
arXiv:1310.5758





Neutrinos from tops suffice for low MET + many jets SUSY searches.
See also: Asano, Rolbiecki, Sakurai, arXiv:1209.5778

Only events with $\tau_{\rm h}$ / lost e, μ are being utilized (**lepton veto**).

→ Supplement this with a search for a **lepton + many jets**.
See also: Lisanti, Schuster, Strassler, Toro, arXiv:1107.5055

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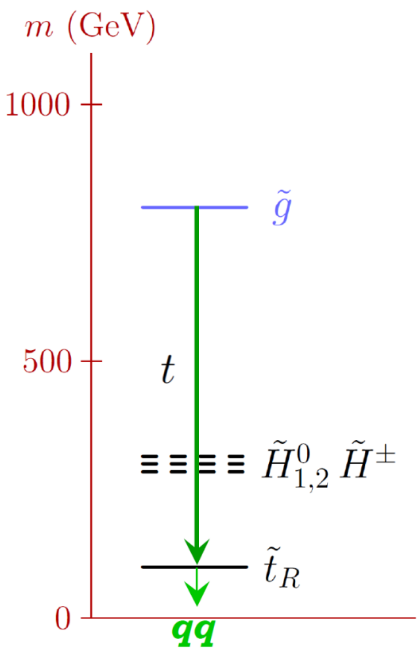

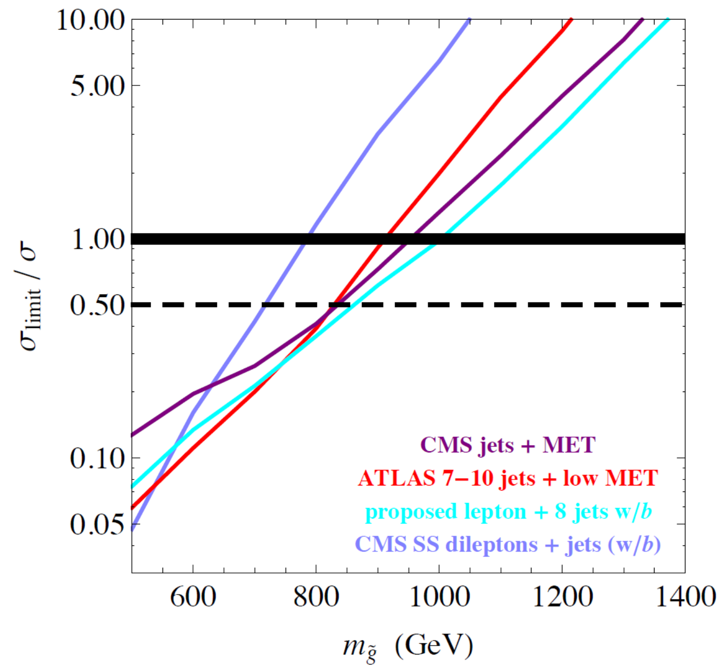

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Example: gluino → jets + tops (no MET)

Motivated ATLAS to add a reduced-MET, increased-multiplicity search region.

ATLAS, arXiv:1507.05525

	1L(H)_7-jet	**1L(H)_WR_7-jet**	**1L(H)_TR_7-jet**	**1L(H)_VR_7-jet E_T^{miss}**	**1L(H)_VR_7-jet m_T**
N_{lep}	$== 1$				
$p_T^{\ell_1}$ [GeV]	> 25 (20)				
$p_T^{\ell_2}$ [GeV]	< 10				
N_{jet}	≥ 7				
p_T^{jet} [GeV]	$> 80, 25, 25, 25, 25, 25, 25$				
N_{b-tag}	–	$== 0$	≥ 1	–	–
E_T^{miss} [GeV]	> 180	$\in[100, 180]$	$\in[100, 180]$	$\in[180, 500]$	$\in[100, 180]$
m_T [GeV]	> 120	$\in[40, 80]$	$\in[40, 120]$	$\in[60, 120]$	$\in[120, 320]$
m_{eff}^{incl} [GeV]	> 750				

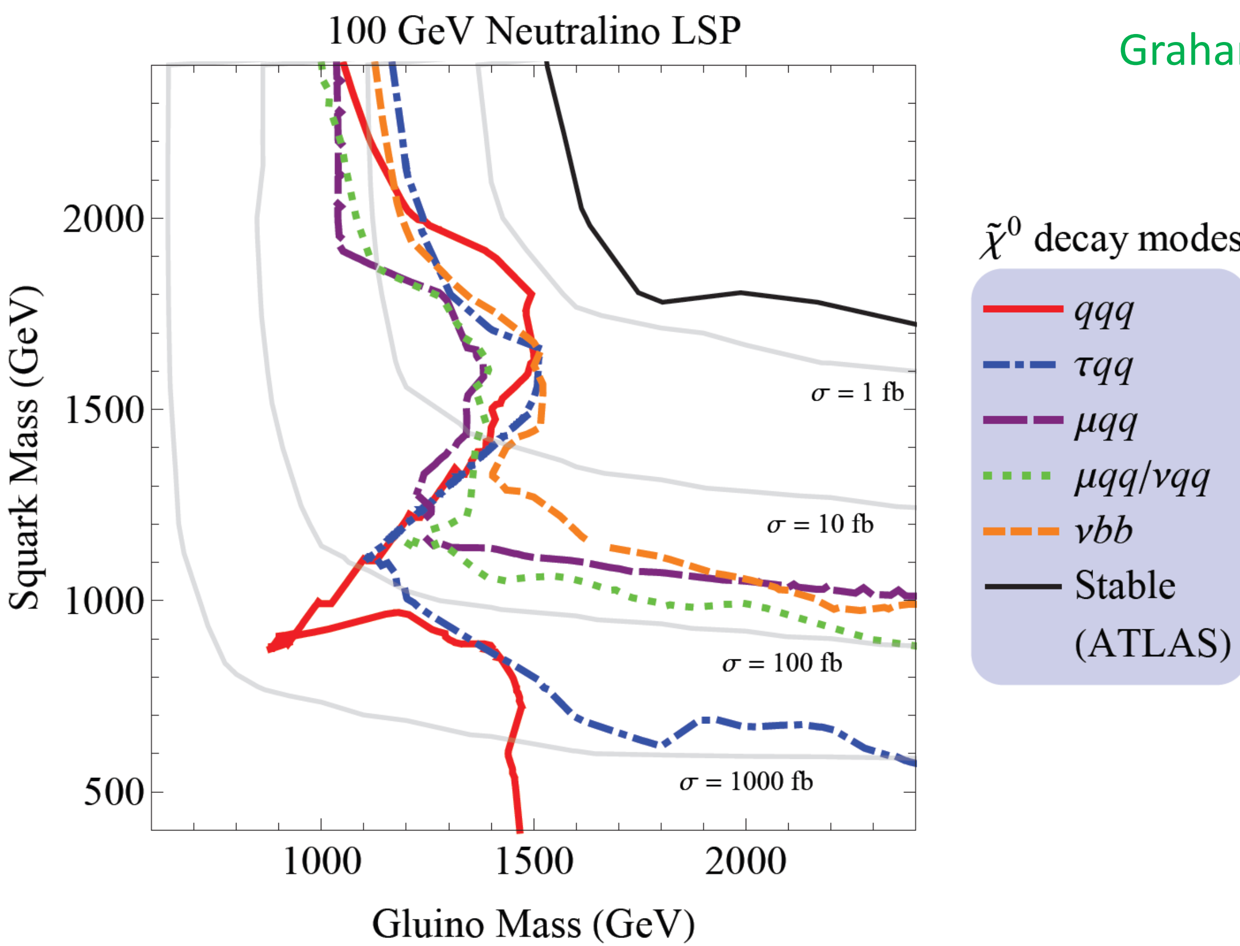
Not very effective when top → lepton, because of the m_T cut.

MET cut is also quite harsh.

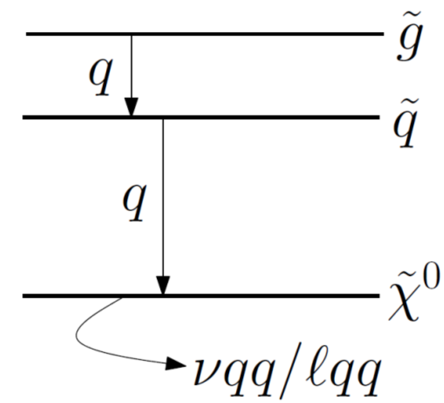
Instead suppress top background by demanding more jets and higher m_{eff}^{incl} (gluino signal efficiency almost unaffected).

*Similar to *b*′, *t*′ searches, but more model-independent and higher jet multiplicity.

Prompt decays



Graham, Rajendran, Saraswat,
arXiv:1403.7197

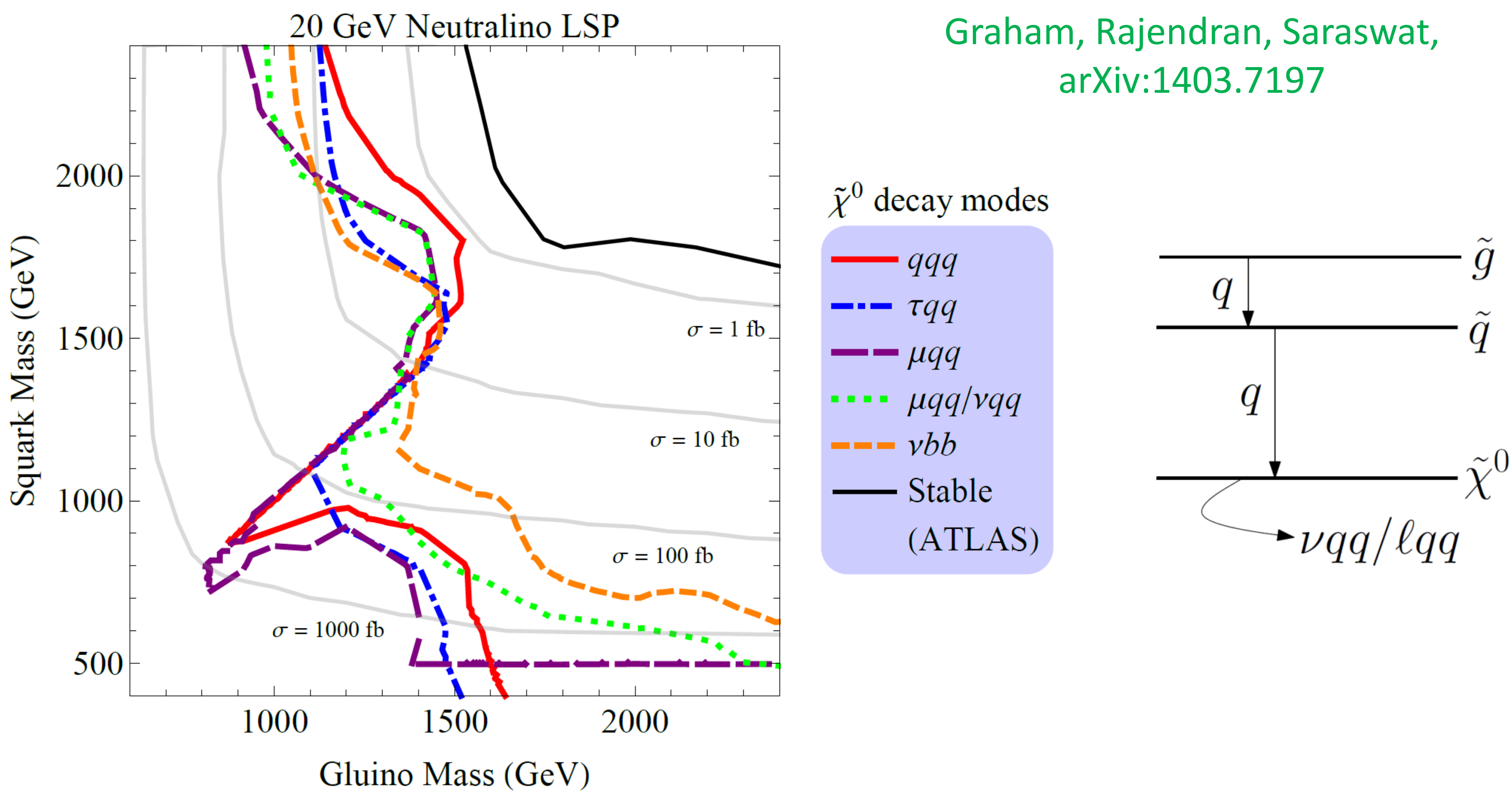


Limits on gluinos are indeed quite universal.

But limits on squarks are model dependent.

Prompt decays

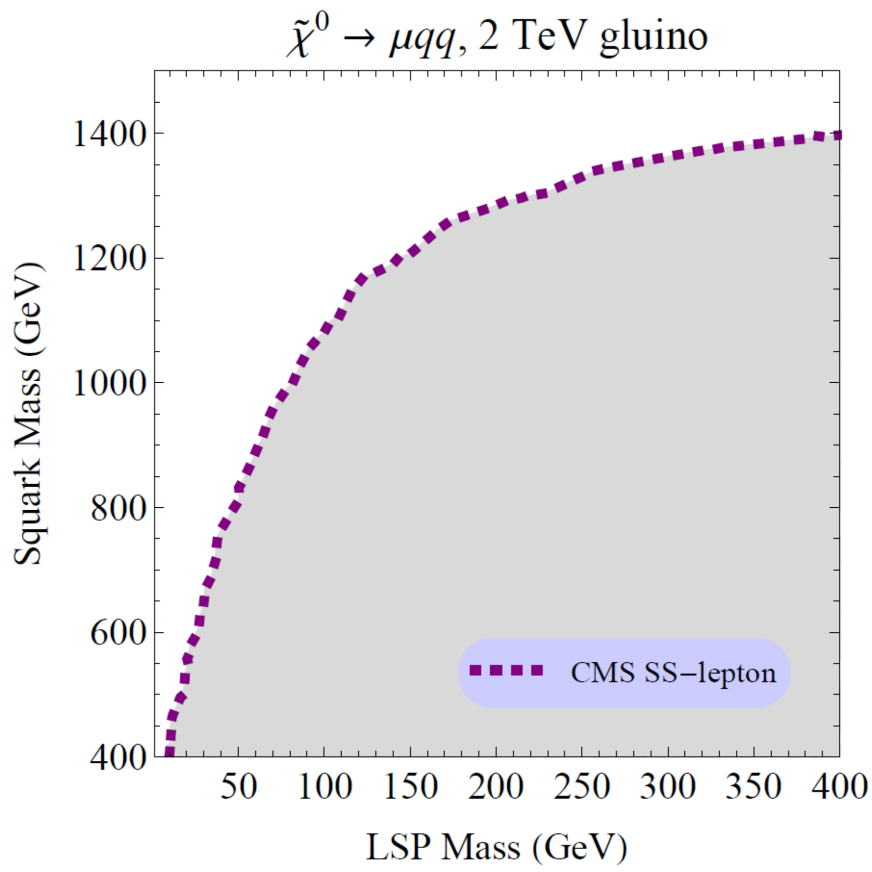
Graham, Rajendran, Saraswat, arXiv:1403.7197



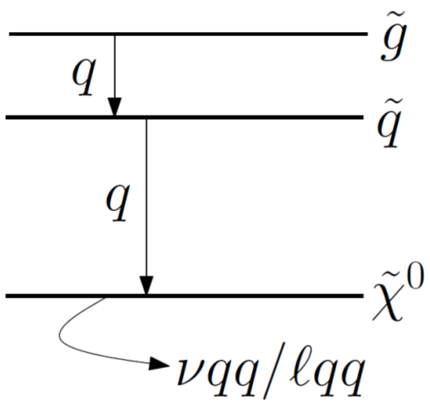
Much weaker limits on squarks for a lighter LSP.

Prompt decays

Limits on squarks weaken as the LSP becomes lighter, i.e. more boosted, because leptons fail isolation requirements.



Graham, Rajendran, Saraswat, arXiv:1403.7197



Boosted objects

Boosted decays will be even more important in Run 2:
Heavier particles can be produced, but the LSP can be as light as before.

Example:

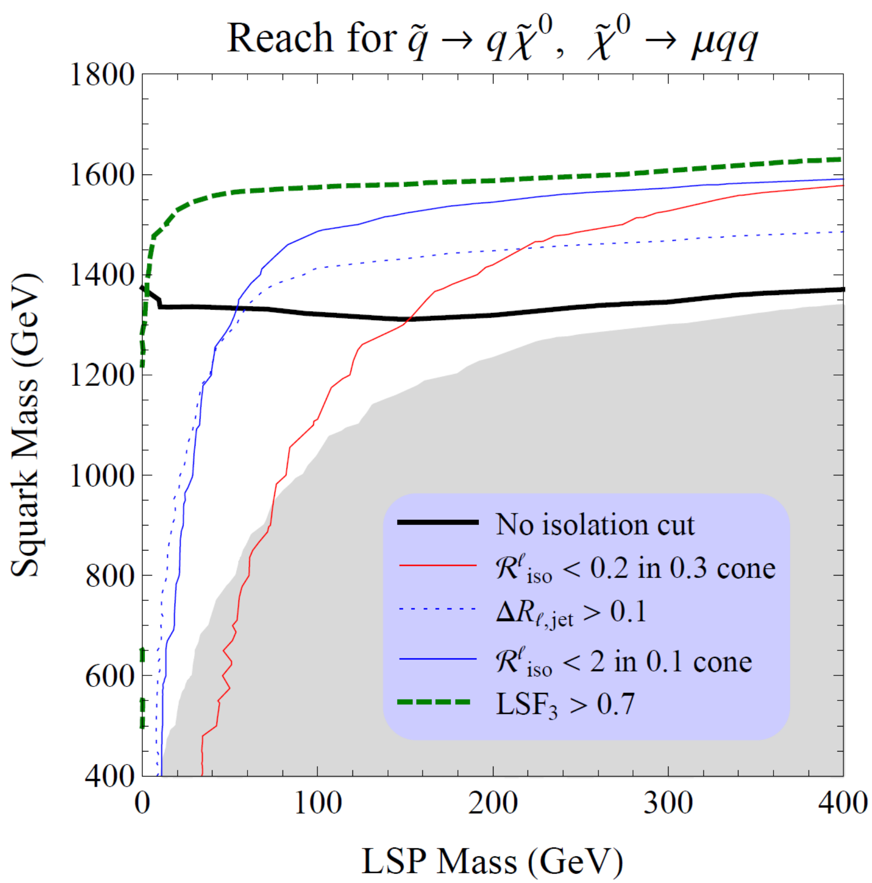
$p_T(\tilde{\chi}_1^0) = 600\ \mathrm{GeV}$ (from a 2 TeV squark / gluino)

$m(\tilde{\chi}_1^0) = 30\ \mathrm{GeV}$

$\Delta R \sim \frac{2m}{p_T}$ → $\tilde{\chi}_1^0$ decay products separated by $\Delta R \sim 0.1$
Lepton isolation cone or jet cone of $R = 0.4$ will miss the signature.

Boosted objects

Jet substructure techniques, or even just relaxed isolation requirements, can help a lot.



Brust, Maksimovic, Sady, Saraswat, Walters, Xin
arXiv:1410.0362

All-hadronic signatures

With **UDD** operators, signatures can be jets-only.

Difficult final states → can hide light superpartners

→ model building of scenarios with UDD couplings

(or similar possibilities beyond the minimal model):

- Minimal flavor violation (MFV)

  Csaki, Grossman, Heidenreich, arXiv:1111.1239
  Krnjaic and Stolarski, arXiv:1212.4860
  Csaki and Heidenreich, arXiv:1302.0004

- Partial compositeness

  Keren-Zur, Lodone, Nardecchia, Pappadopulo, Rattazzi, Vecchi, arXiv:1205.5803

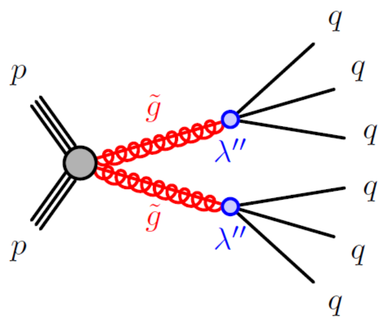
- Gauged flavor models Franceschini and Mohapatra, arXiv:1301.3637

- Soft UDD-like terms Krnjaic and Tsai, arXiv:1304.7004

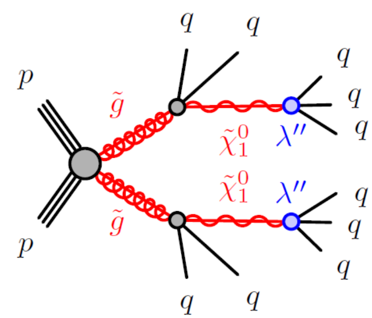
- Dynamical RPV Csaki, Kuflik, Volansky, arXiv:1309.5957
  Csaki, Kuflik, Slone, Volansky, arXiv:1502.03096

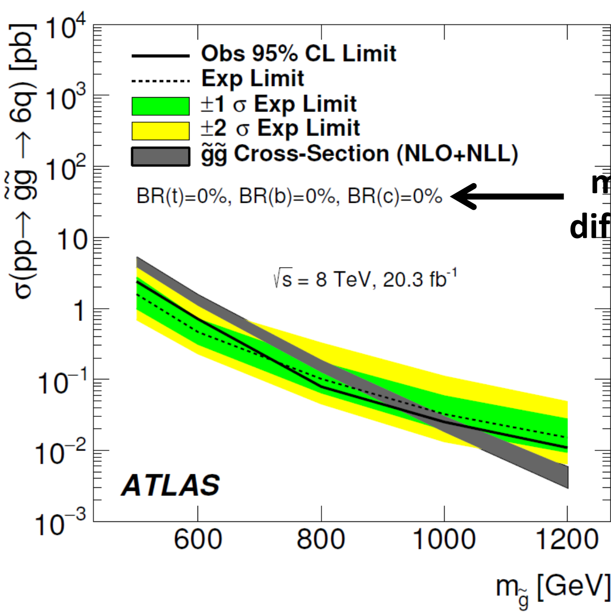
All-hadronic signatures

A variety of gluino benchmark models are addressed by ATLAS.

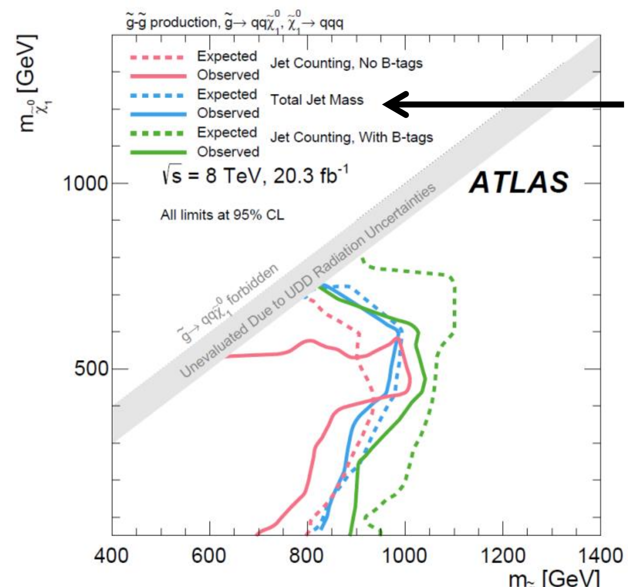


ATLAS
arXiv:1502.05686





most
difficult



Cohen, El Hedri, Hook,
Izaguirre, Jankowiak,
Lisanti, Lou, Wacker
arXiv:1202.0558
arXiv:1302.1870
arXiv:1402.0516

Good coverage already. Hopefully robustness will improve in Run 2.

All-hadronic signatures

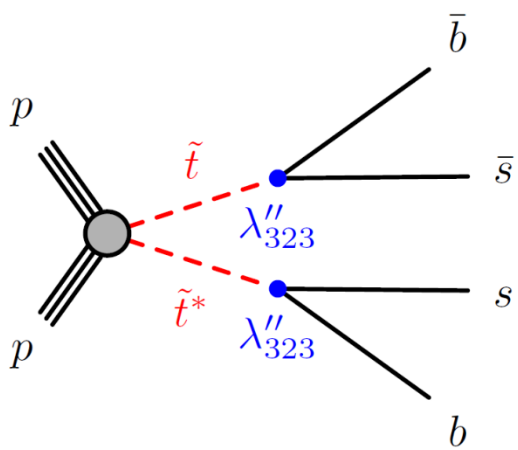
Stops → lower cross section

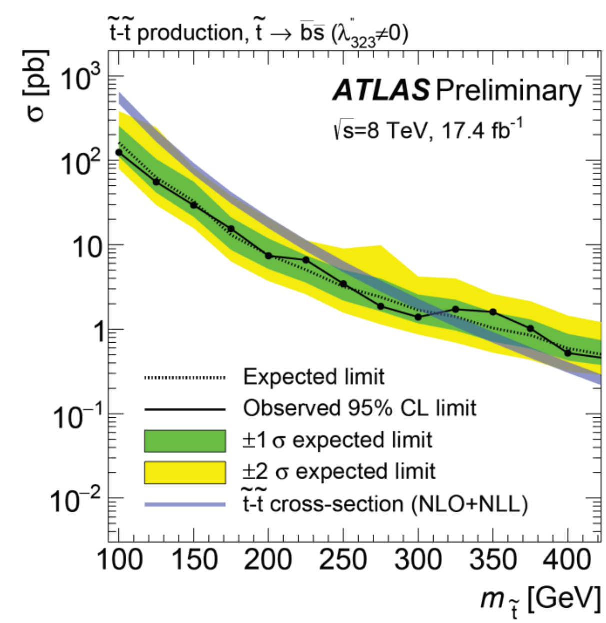
→ lower masses are relevant

→ trigger limitations

For two-body decays, low masses are covered only for scenarios with *b*'s.

ATLAS-CONF-2015-026





All-hadronic signatures

Stops → lower cross section

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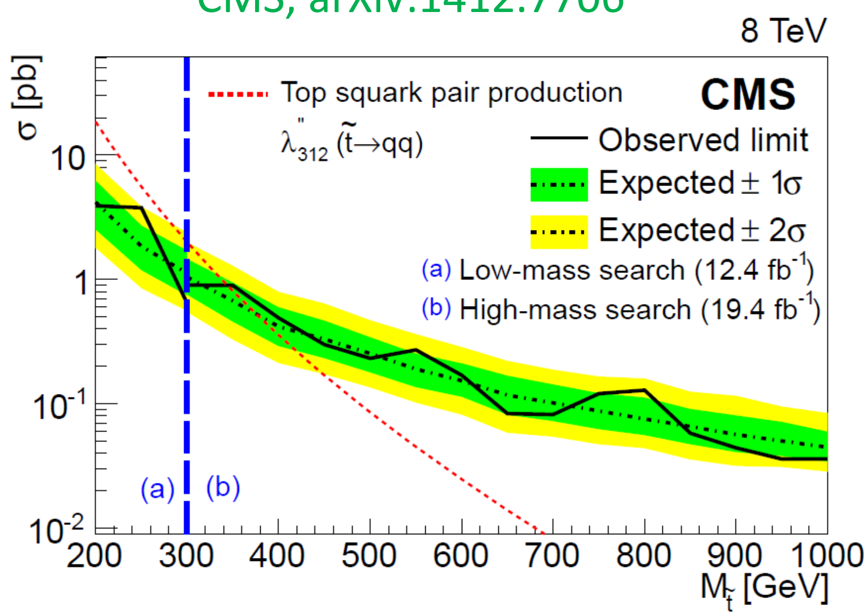
For two-body decays without *b*'s, coverage only for M > 200 GeV.

CMS, arXiv:1412.7706



For some ideas using jet substructure, see Bai, Katz, Tweedie, arXiv:1309.6631

All-hadronic signatures

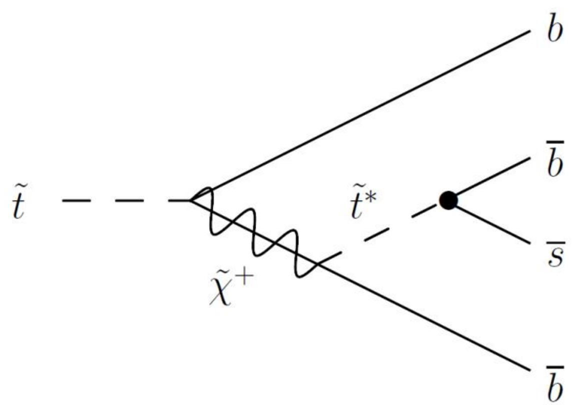
Stops → lower cross section

→ lower masses are relevant

→ trigger limitations

For many-body decays – no relevant searches at all.

Seems possible to design searches for at least the (quite motivated) cases with high *b* multiplicity.



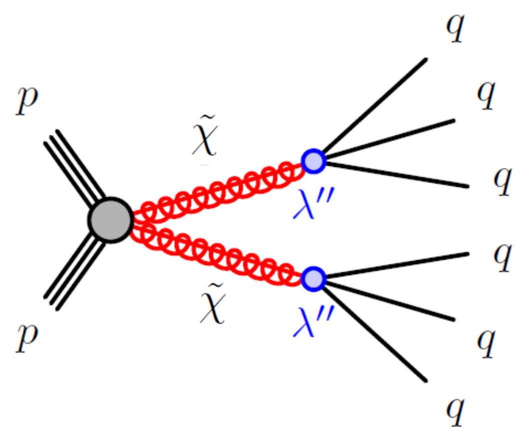
Evans and Kats, arXiv:1209.0764
arXiv:1311.0890
Evans, arXiv:1402.4481

All-hadronic signatures

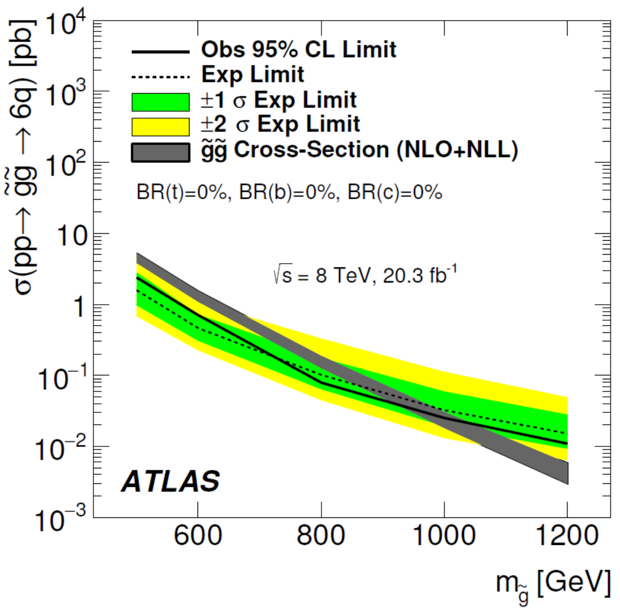
Want a real challenge for Run 2?

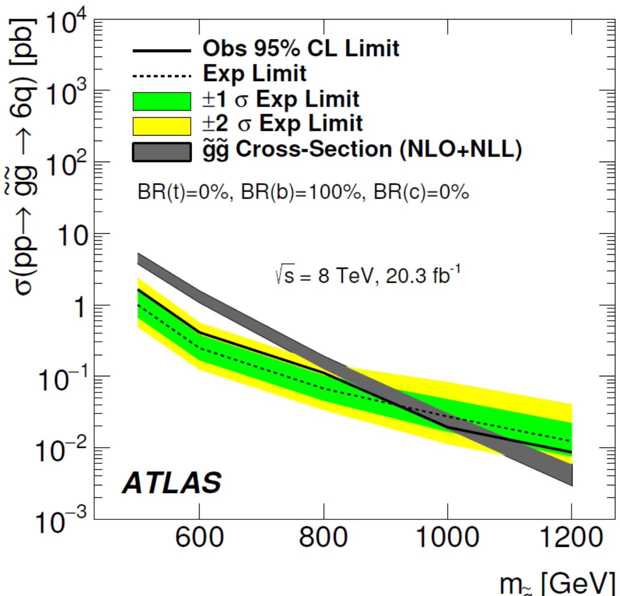
Replace the gluinos with higgsinos:

Cross section is down by 3 orders of magnitude, lower masses are relevant.



ATLAS limits on gluinos arXiv:1502.05686





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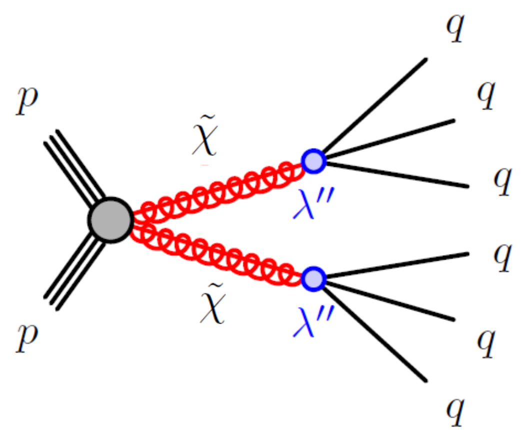
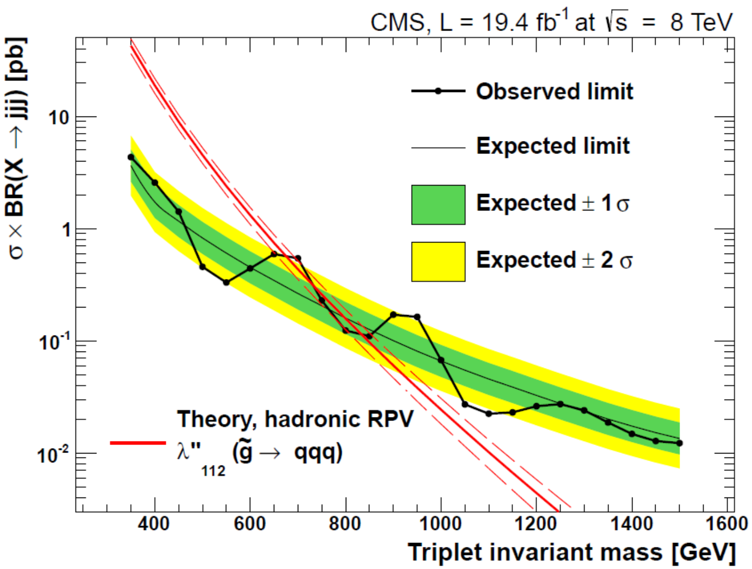
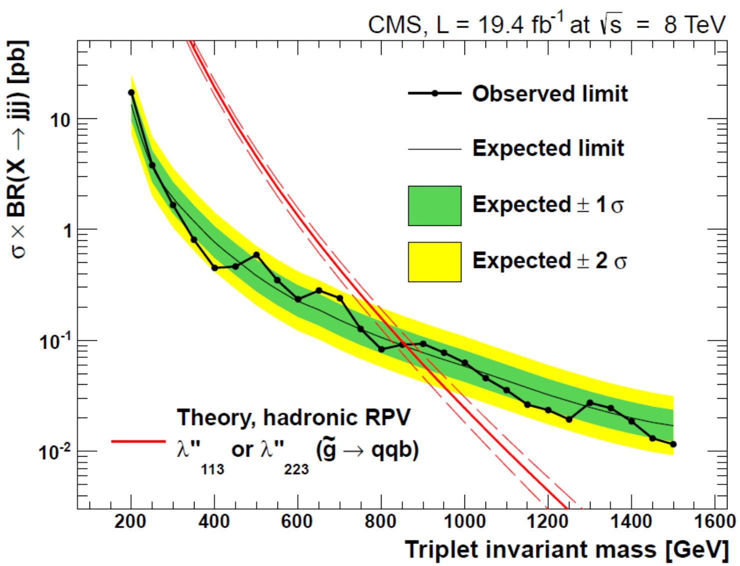


CMS limits on gluinos

arXiv:1311.1799





Thank You!

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