Unconventional SUSY Signatures at LHC Run 3

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@ Pitt PACC Workshop, 2021

The Core of Supersymmetry

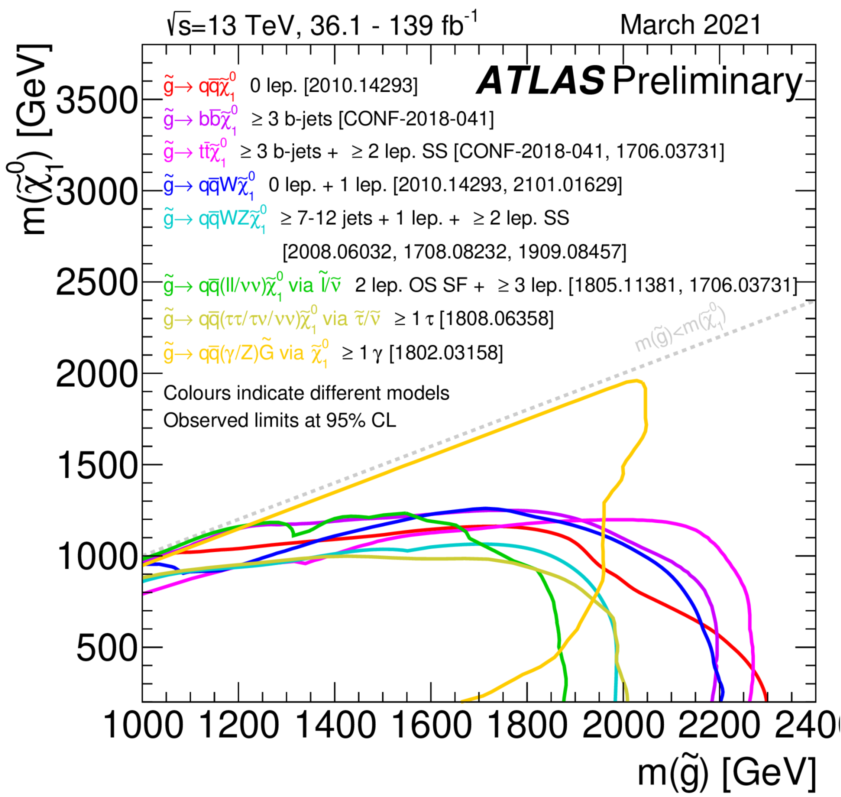
(Broken) supersymmetry pairs *bosons* with *fermions* such that their couplings are (approximately) related.

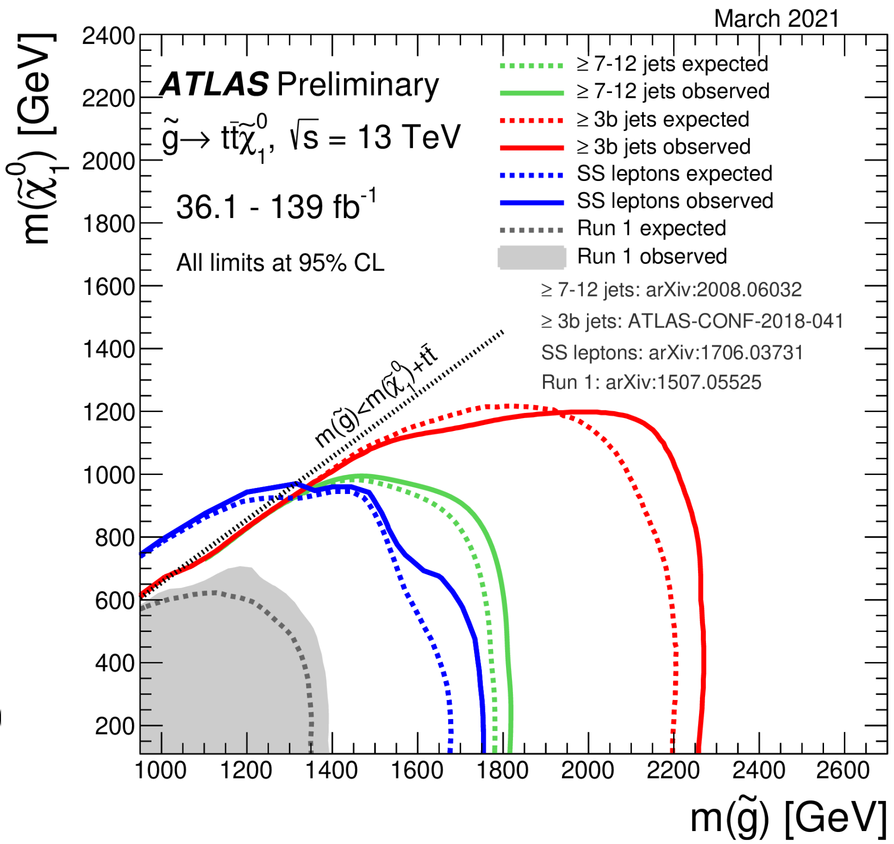
This is what we want to discover.

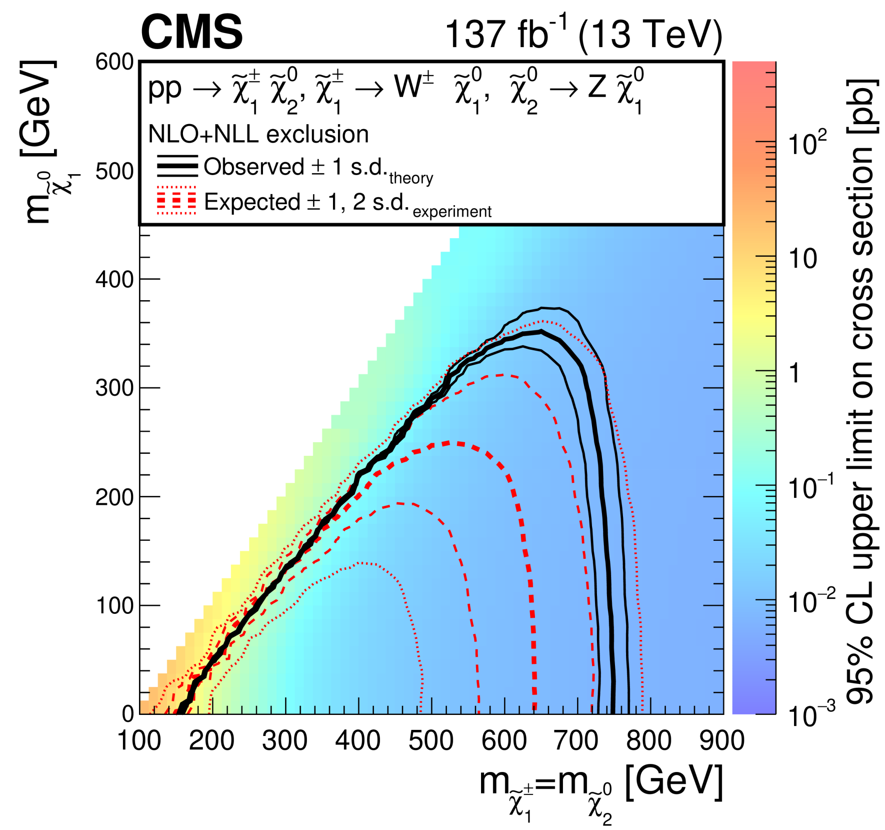
Don't need to assume:

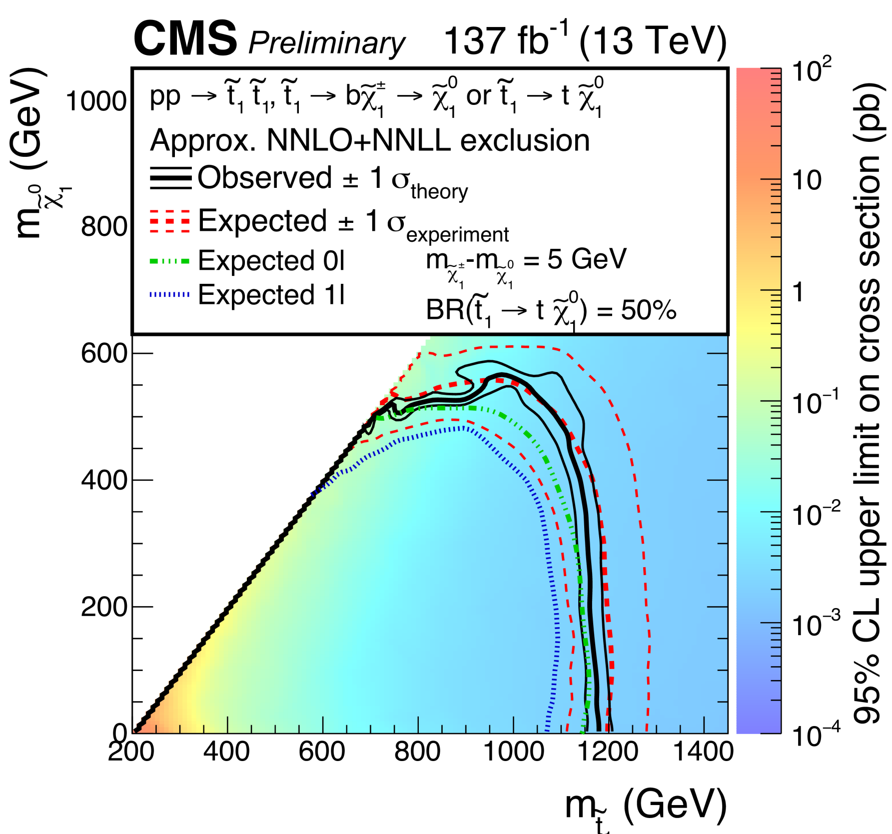
- Dark matter is a superpartner (*much less a thermal relic*)
- R-parity is conserved
- The particle content is the MSSM
- The superpartners have just one common mass scale
- Gauge couplings unify
- Any theorist has the details right

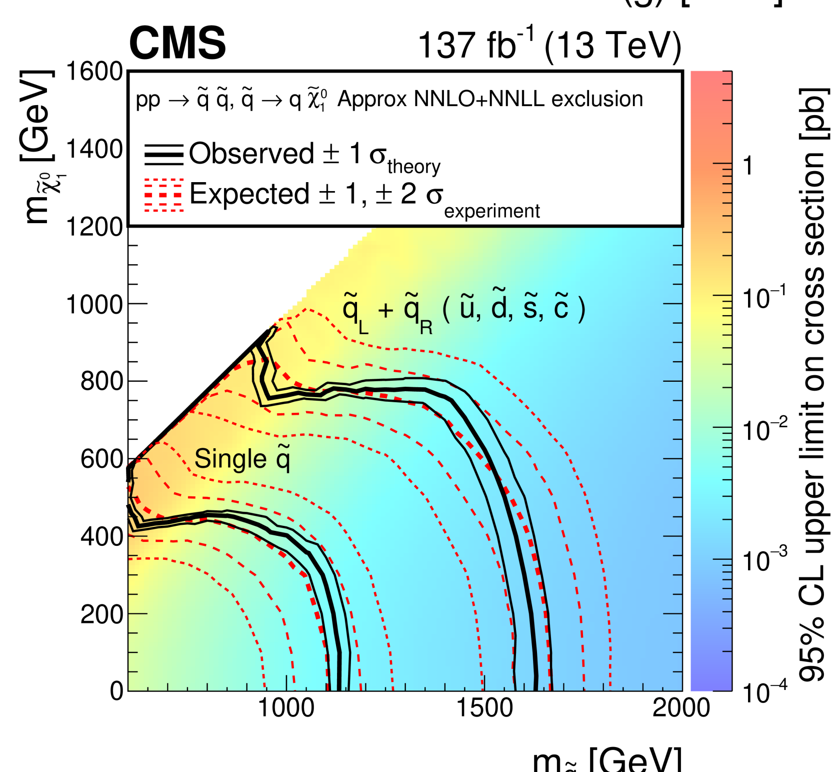
The Story So Far

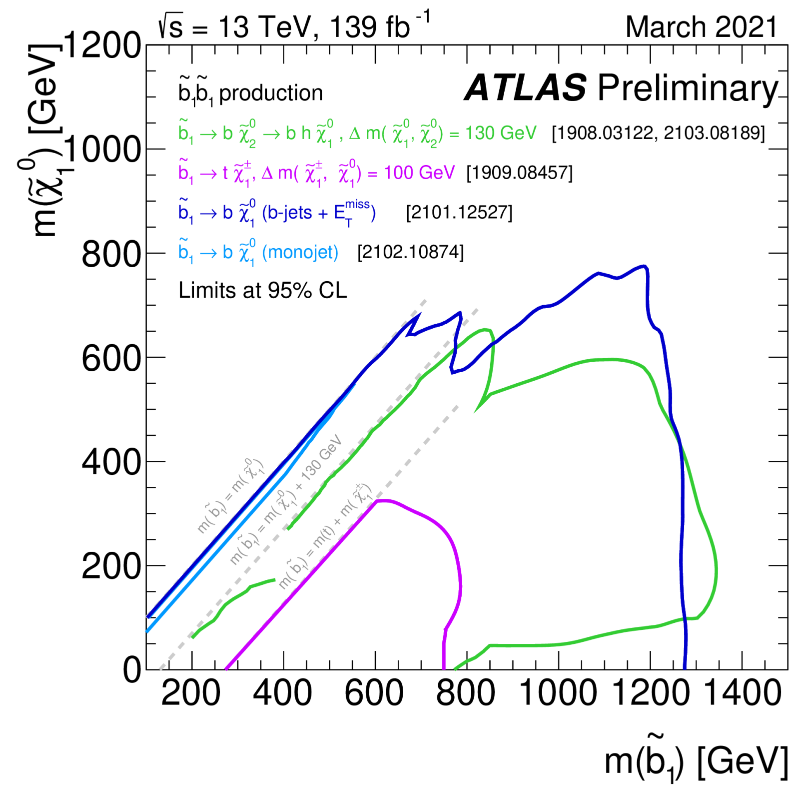




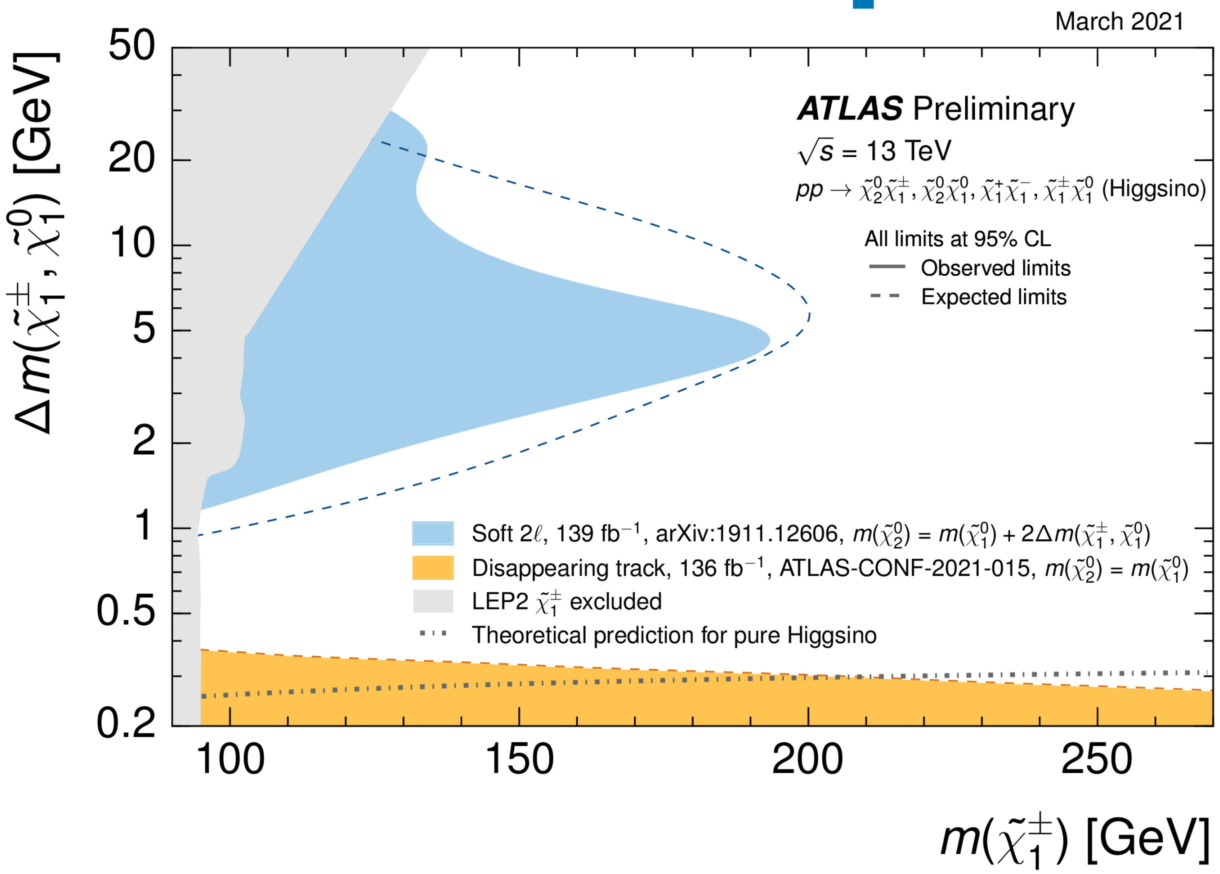


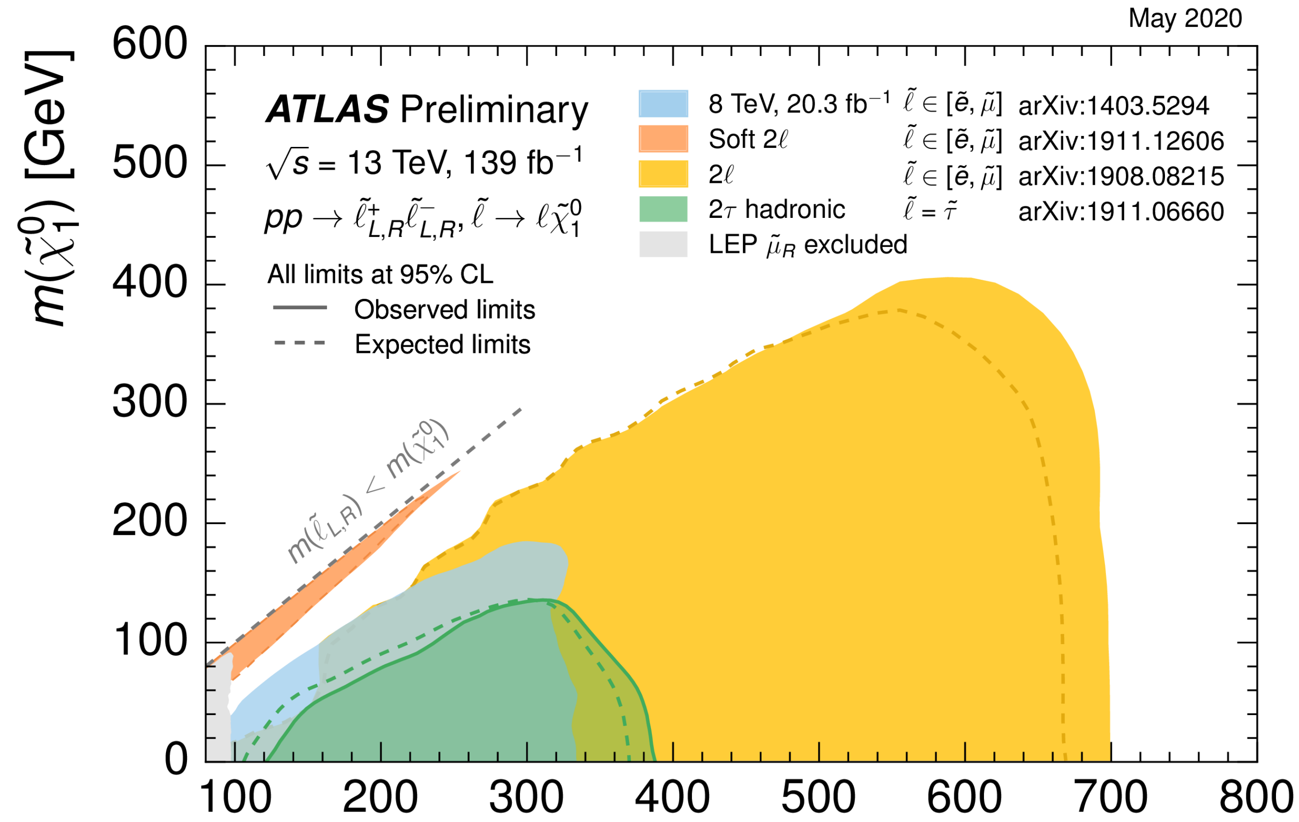






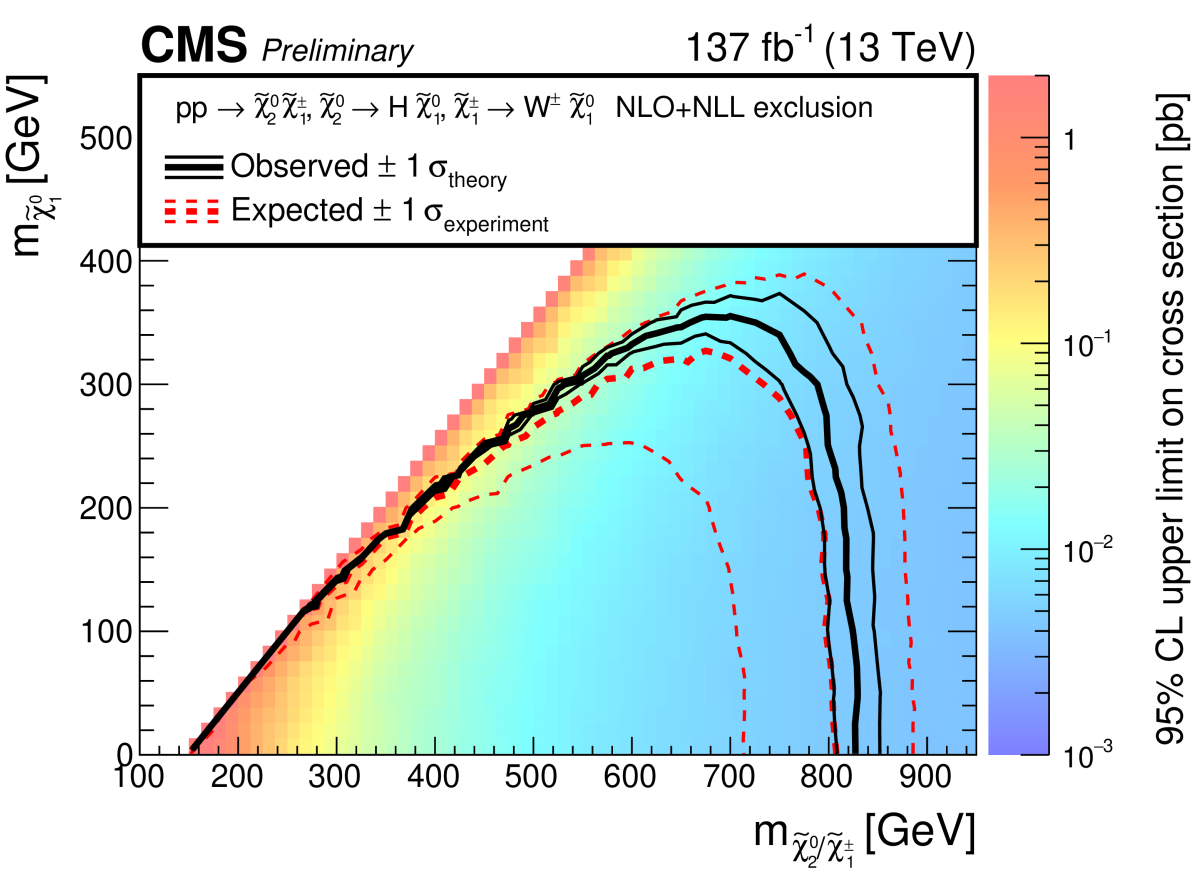
Mind the Gaps

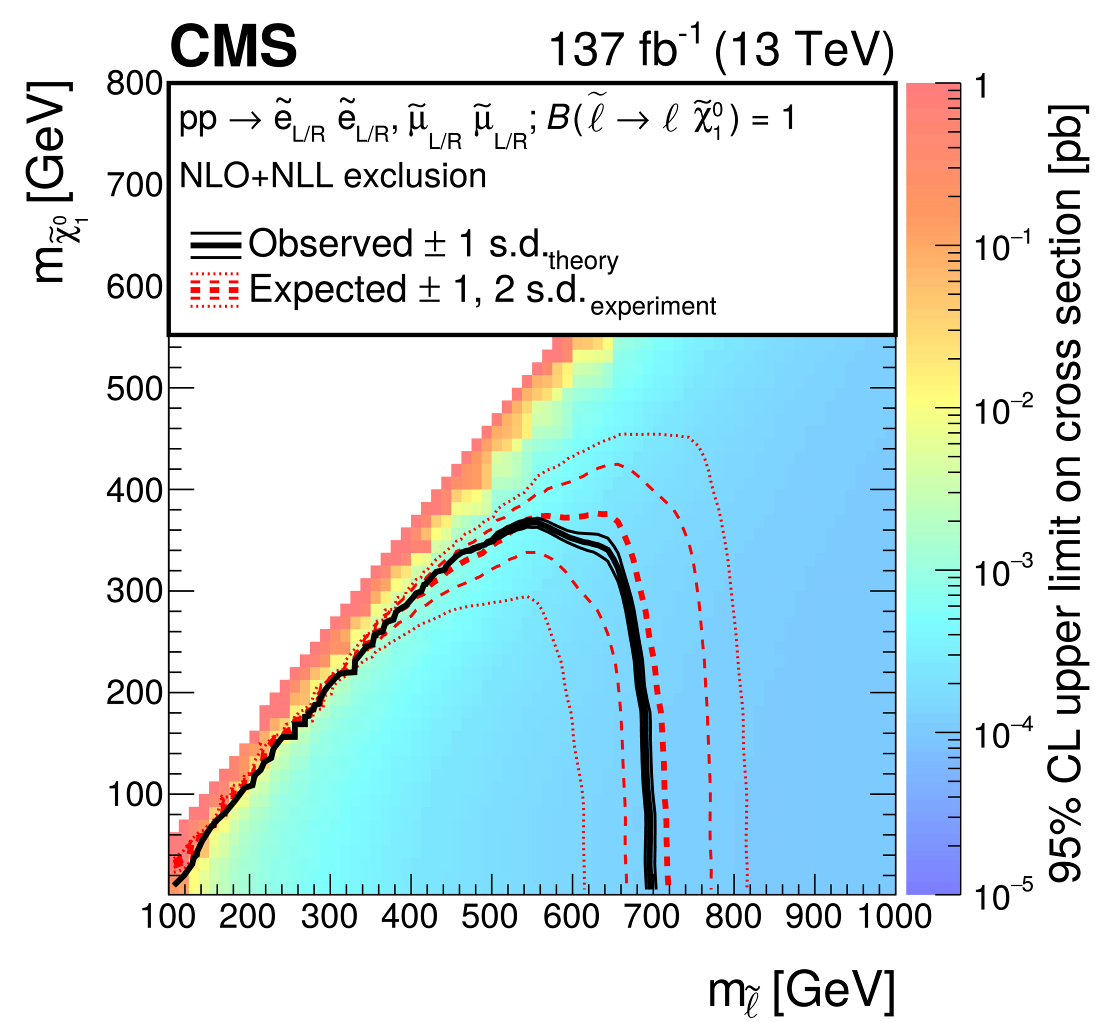




note: left *and* right

$m(\tilde{\ell}_{L,R})$ [GeV]





Electroweakinos as a Target

Can enumerate diboson signals that can appear for transitions between a given set of electroweakinos.

Wino to bino: missing p_T plus W+W-, Wh (fewer WZ)

Higgsino to bino: missing pT plus W+W-, WZ, Wh, Zh, ZZ, hh (possibly fewer of the latter two)

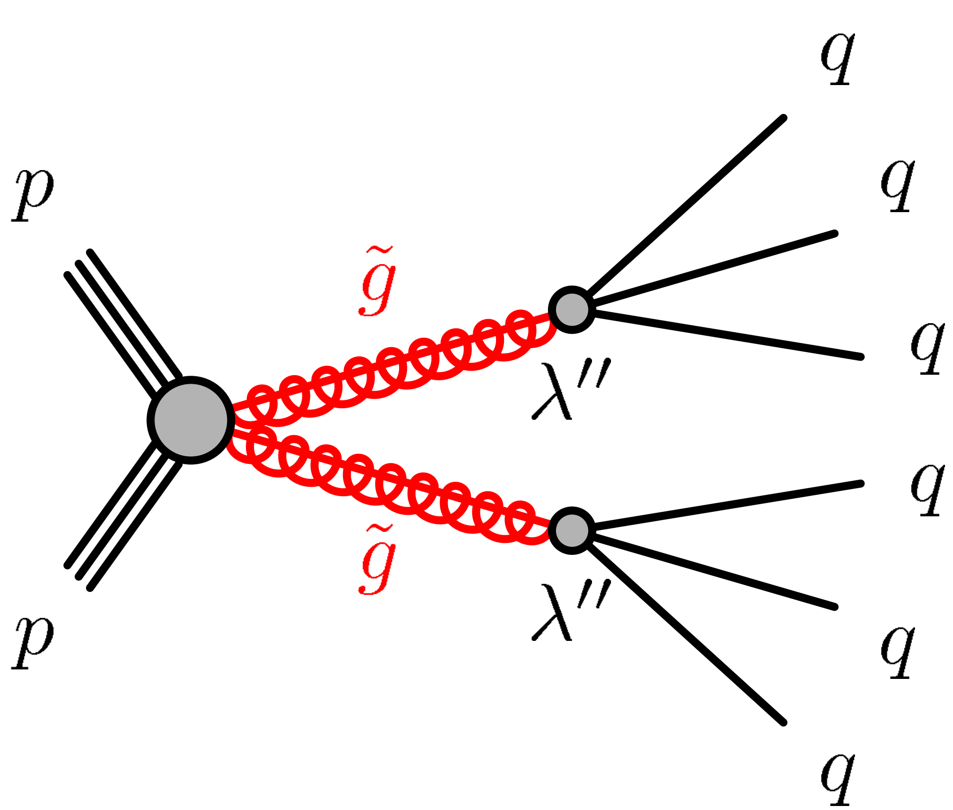
Wino to higgsino: missing pT plus soft particles plus W+W-, **W+W+, W-W-**, WZ, Wh, Zh, ZZ, hh (again possibly fewer of last 2)

… and so on. Also longer cascades involving all 3 ewkinos.

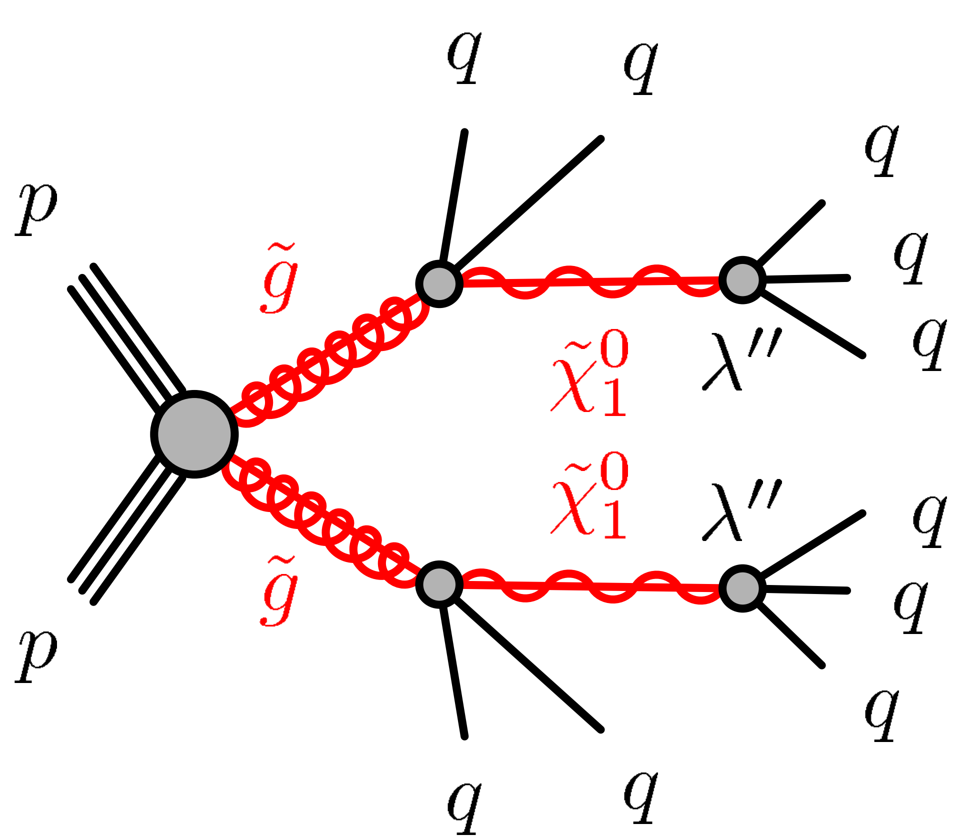
R-Parity or Not?

Motivated by proton stability, but neither necessary nor sufficient to solve that problem.

Trilinear RPV terms: **QLD, LLE, UDD**
UDD only: compatible with Minimal Flavor Violation (Csaki, Grossman, Heidenreich ’11)

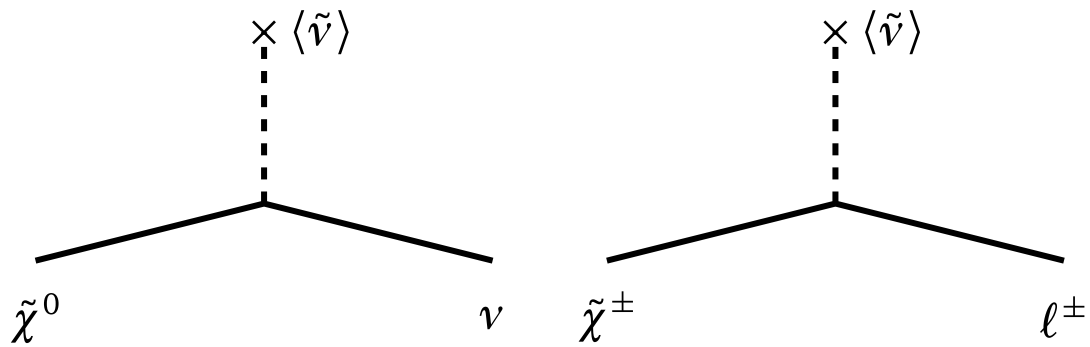


(a) 6-quark model



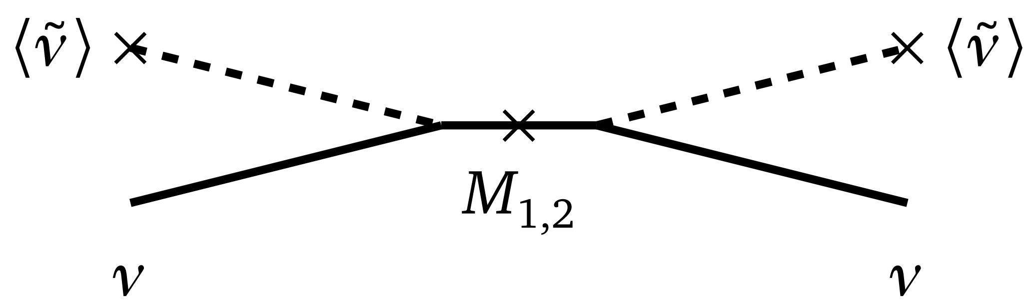
(b) 10-quark model

Bilinear RPV: Neutrino/Neutralino Mix



$$\tilde{W}^0 \to Z\nu, W^\pm \ell^\mp$$
$$\tilde{W}^\pm \to Z\ell^\pm, W^\pm \nu$$

Contributes to neutrino masses:



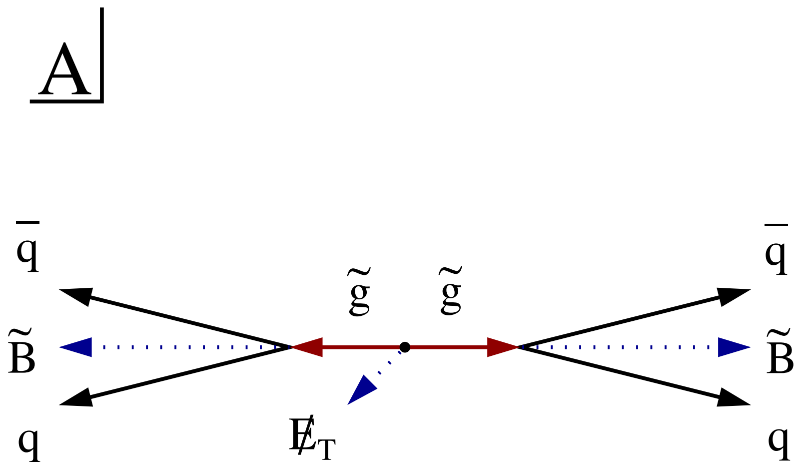
$$m_\nu \sim \epsilon^2 \frac{v^2}{M_{1,2}}$$

This implies an upper bound $\epsilon \lesssim 10^{-6}$.

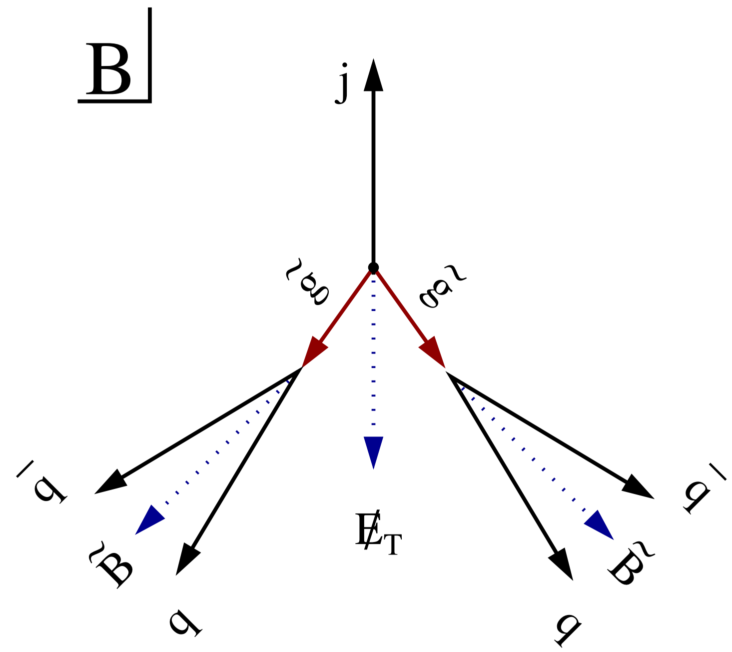
Lower bound on the lifetime of the two-body wino decays, ~ 100 microns. **Displaced vertices!** (Possibly macroscopically displaced; **standard lepton ID may fail**.)

Large literature, e.g., papers by Valle et al.

Squeezing the Signals

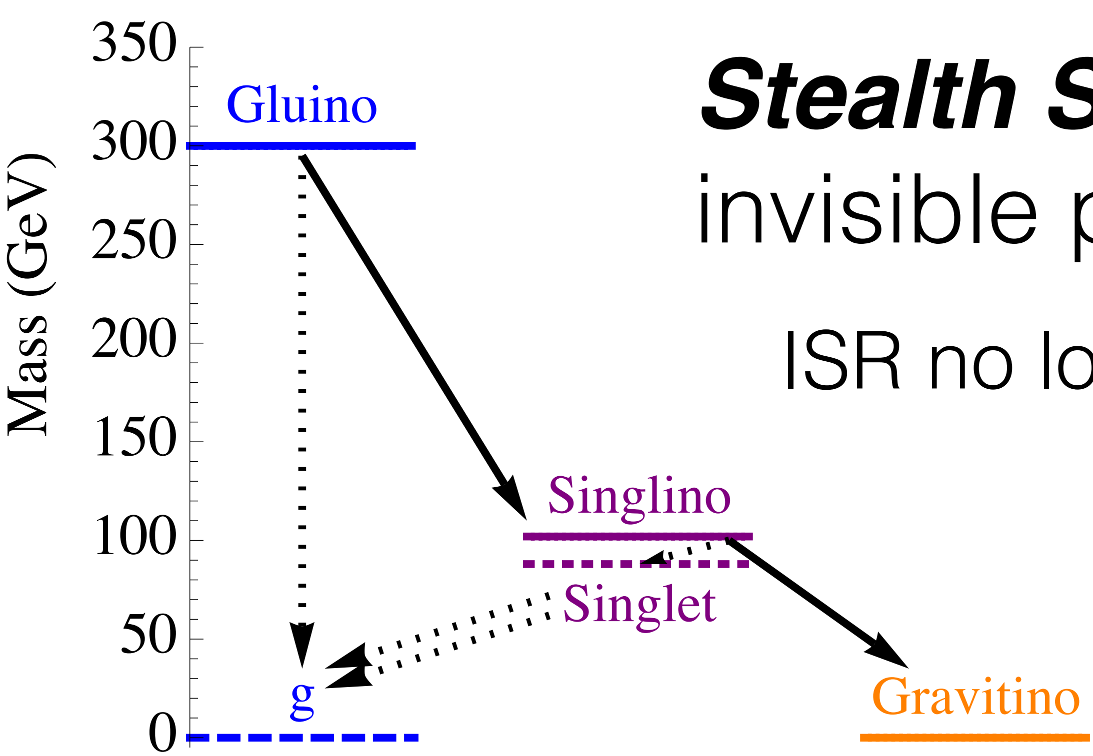


heavy invisible particle



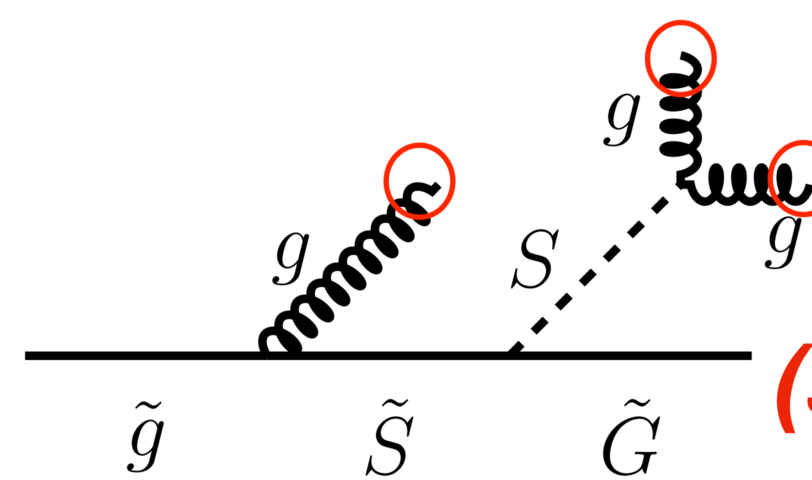
Compressed SUSY: softer visible particles from smaller mass differences

Missing momentum if ISR recoil (“monojet”-like): Alwall, Le, Lisanti, Wacker 0803.0019



Stealth SUSY: light invisible particle

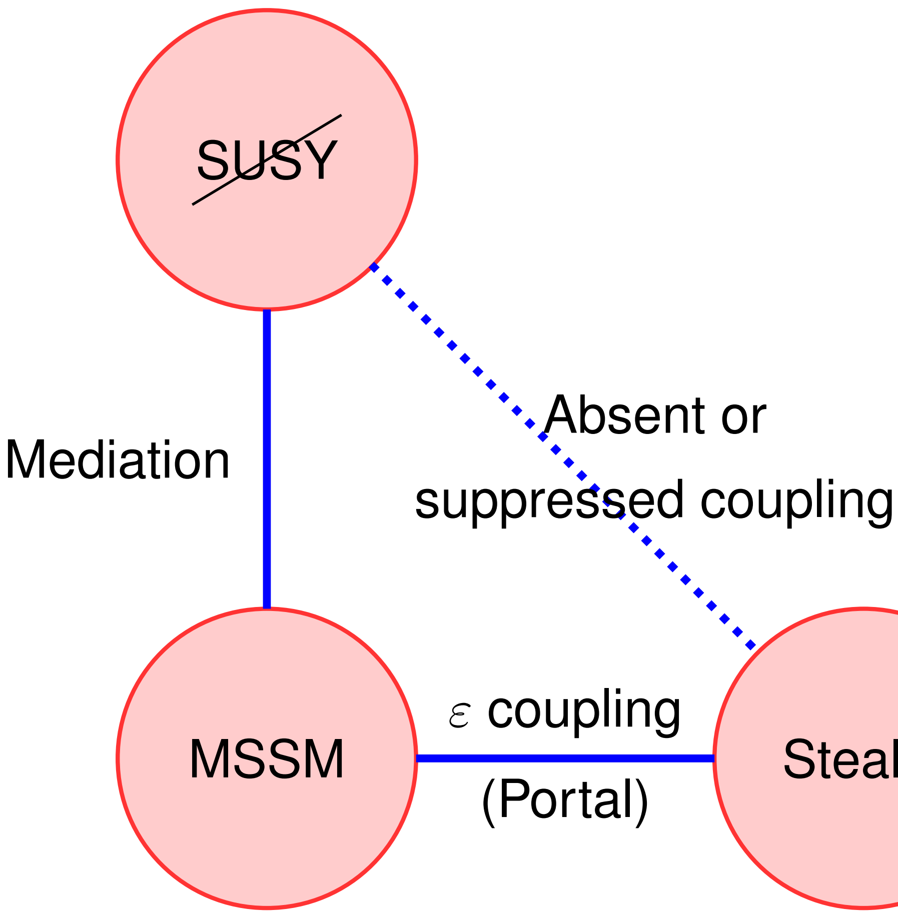
ISR no longer helps



(soft!)

Fan, Reece, Ruderman 1105.5135

Stealth Supersymmetry Modeling



A ***mechanism*** for suppressing missing ET — ***not tuning it***.

J. Fan, MR, J. Ruderman
1105.5135, 1201.4875

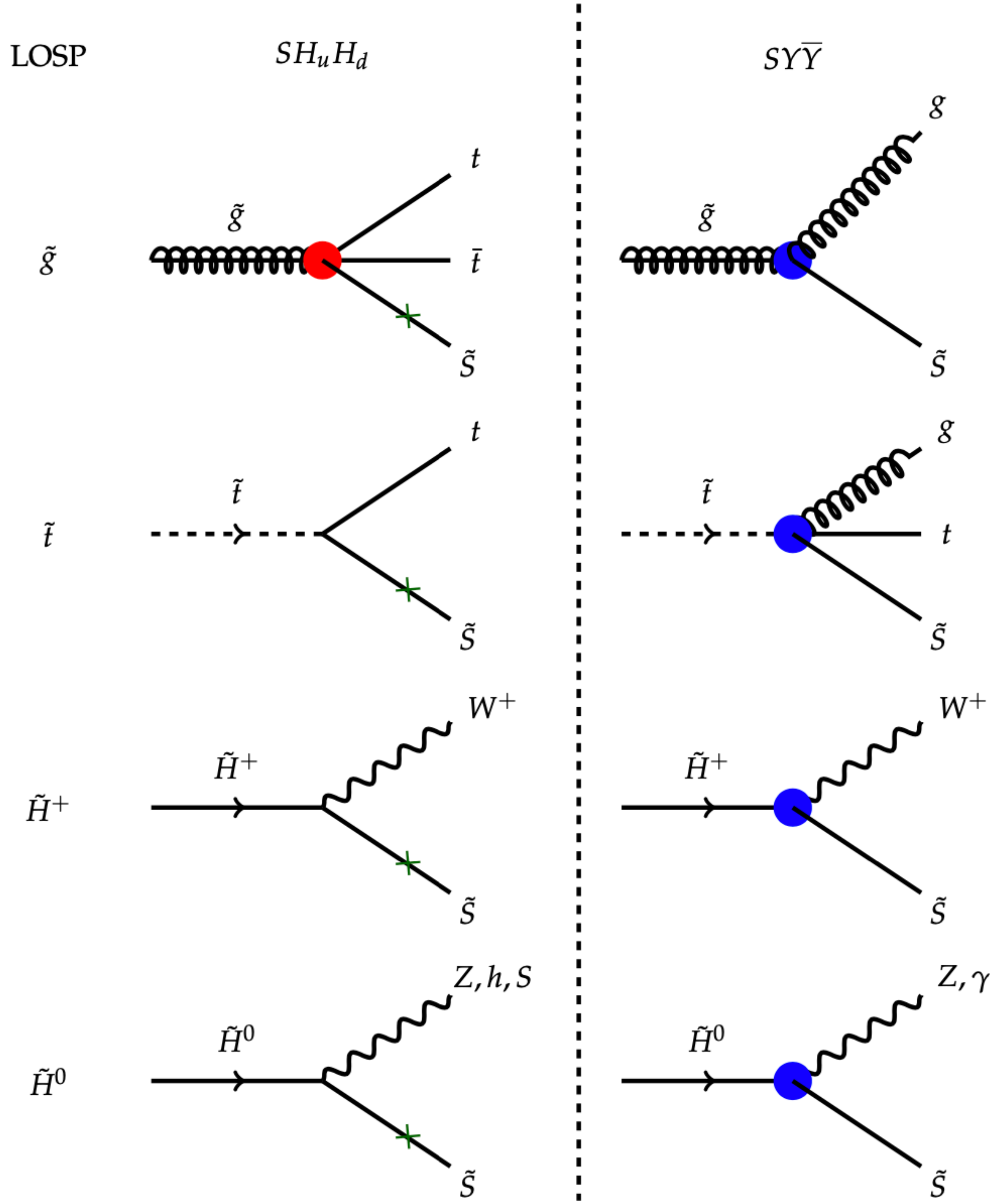
$$M_{\rm SUSY} \sim M_{\rm EWK}$$

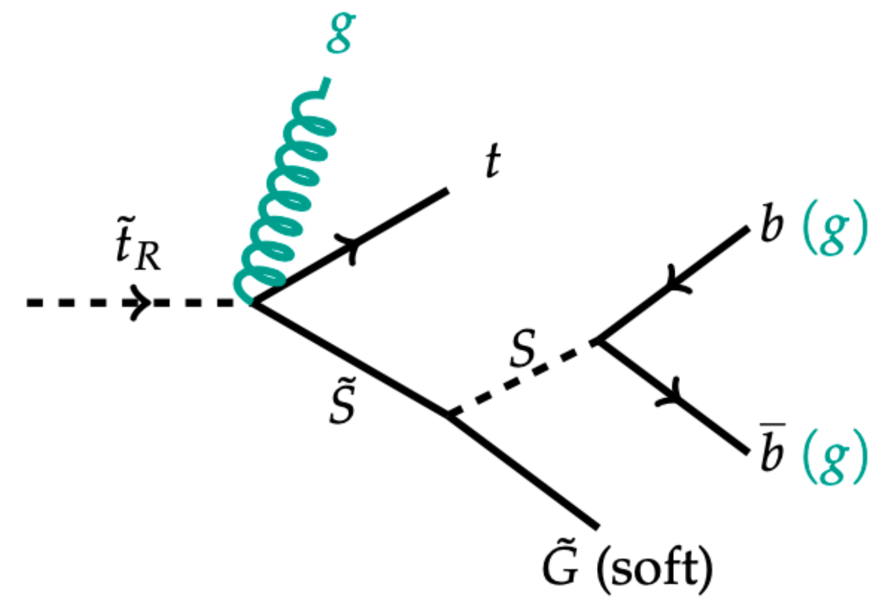
$$M_{\not{\rm SUSY}} \sim \varepsilon M_{\rm EWK}$$

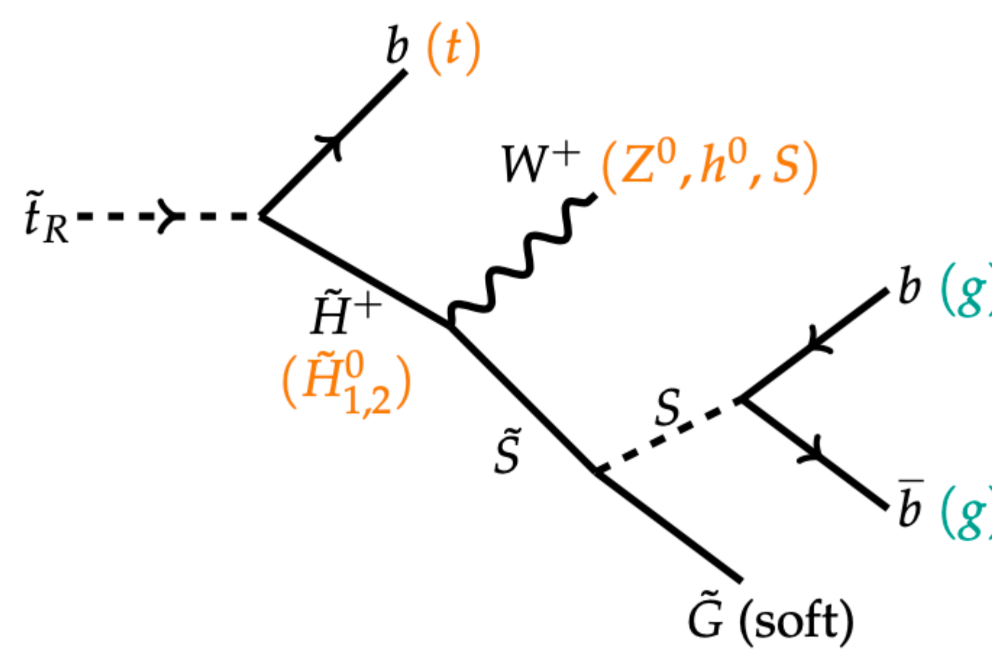
Supersymmetry can hide itself!

Have a *parametric* limit: hidden sector SUSY breaking → 0 and missing ET → 0.

Stealth SUSY Simplified Models

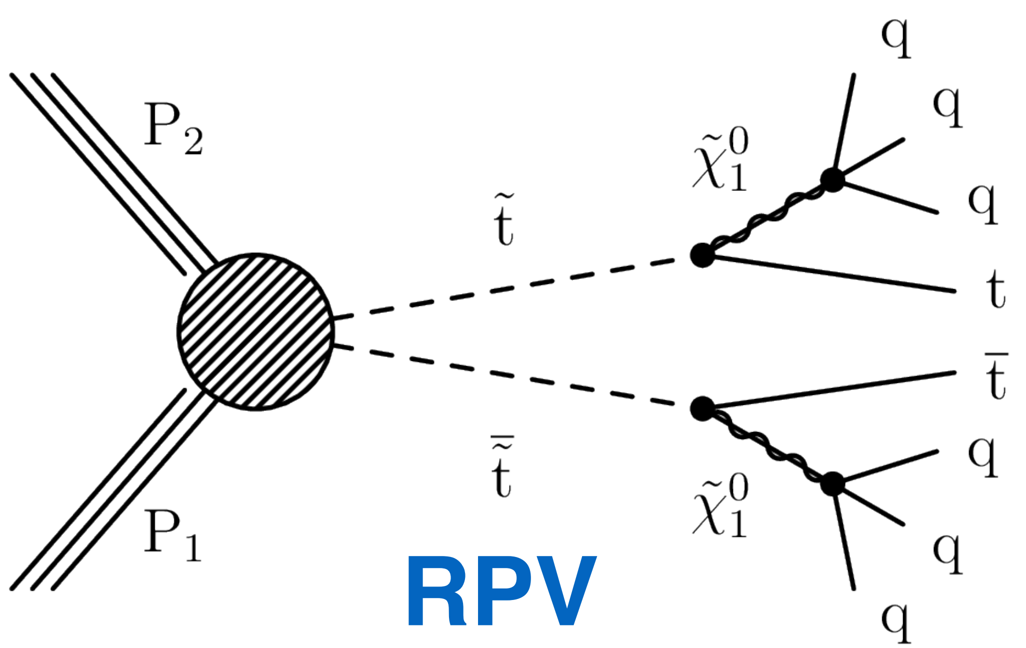


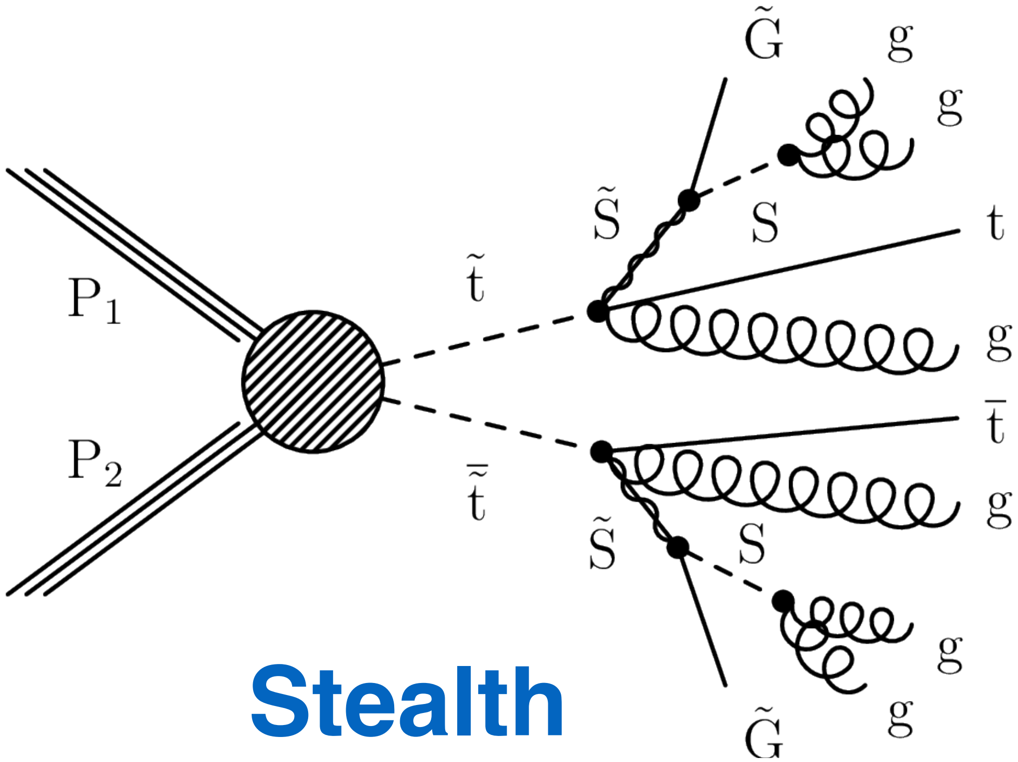


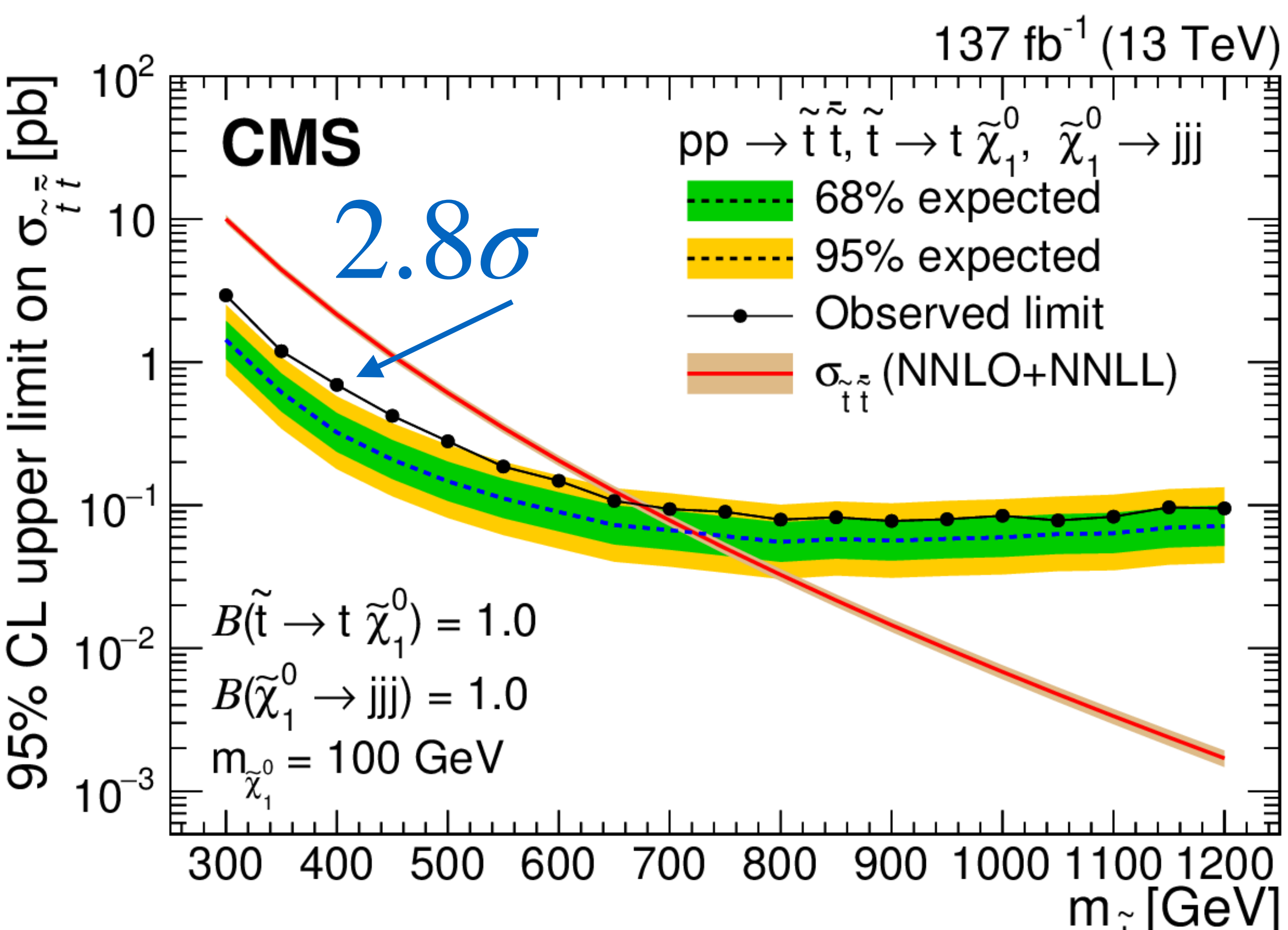


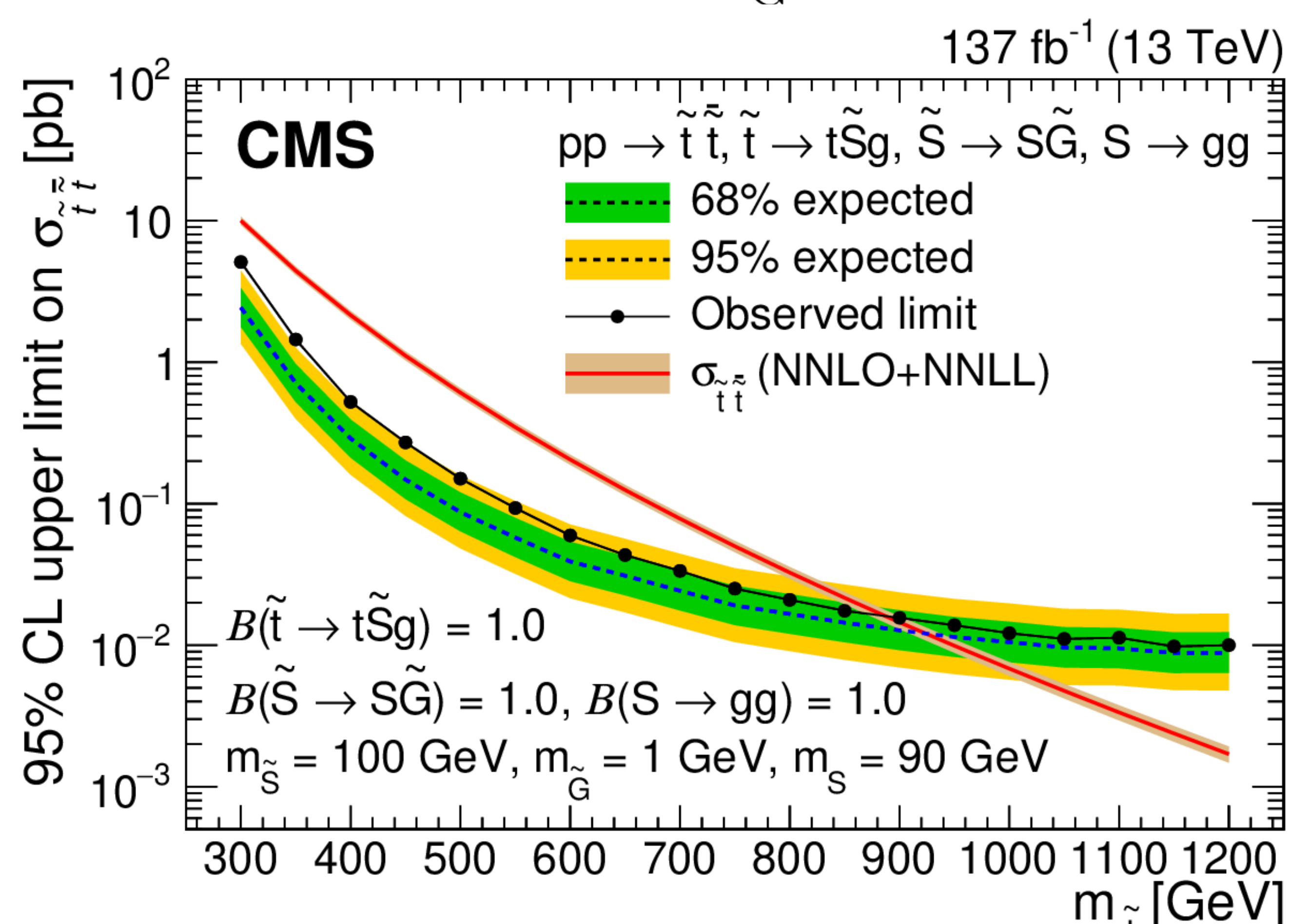
Fan, Krall, Pinner, Reece, Ruderman 1512.05781

CMS RPV/Stealth Stop Search



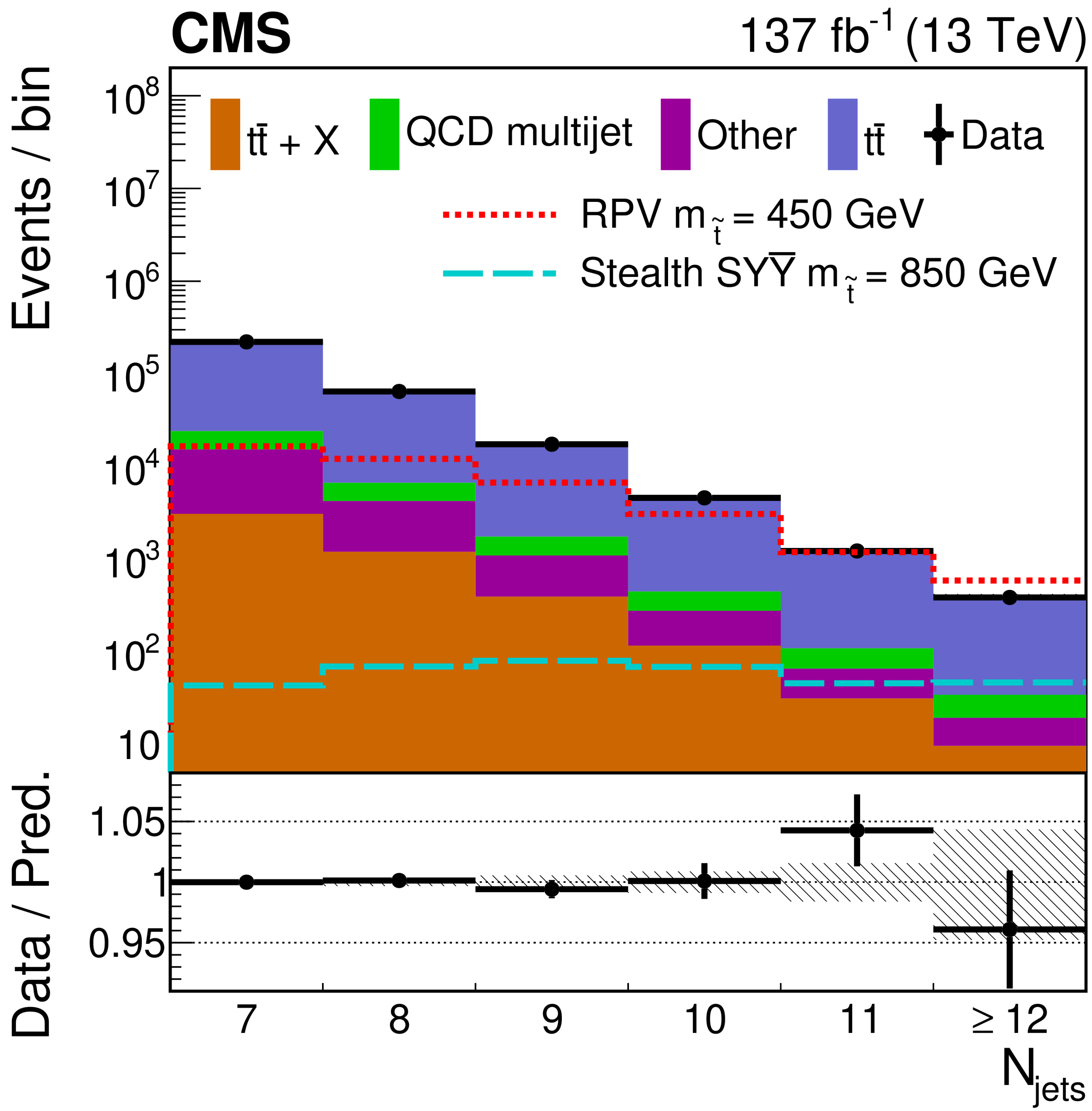




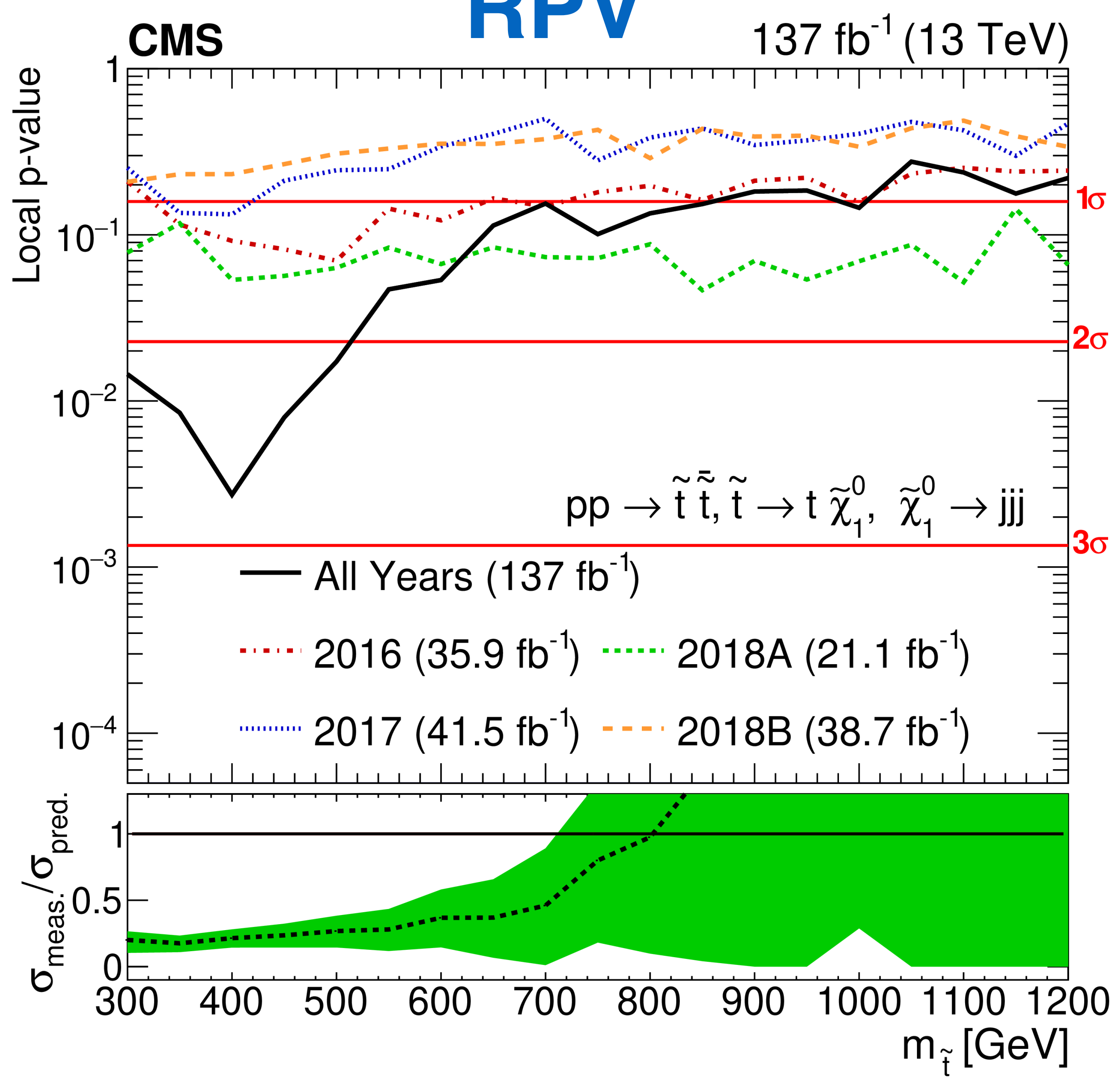


CMS RPV/Stealth Stop Search

Looked at many-jet events

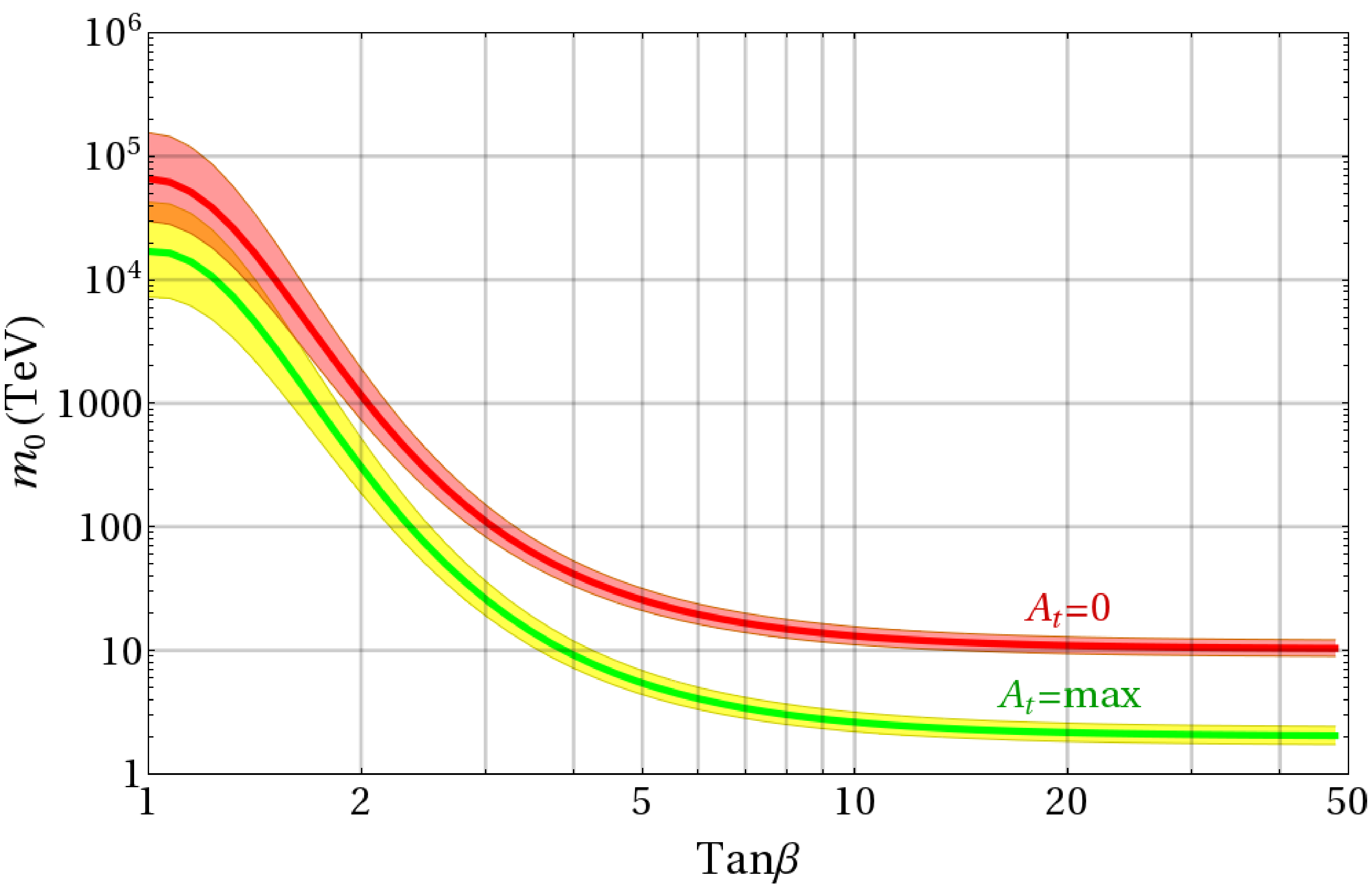


RPV



Don't Assume Naturalness

SUSY could solve the big hierarchy problem, but we could have a small accident making the hierarchy a little tuned.



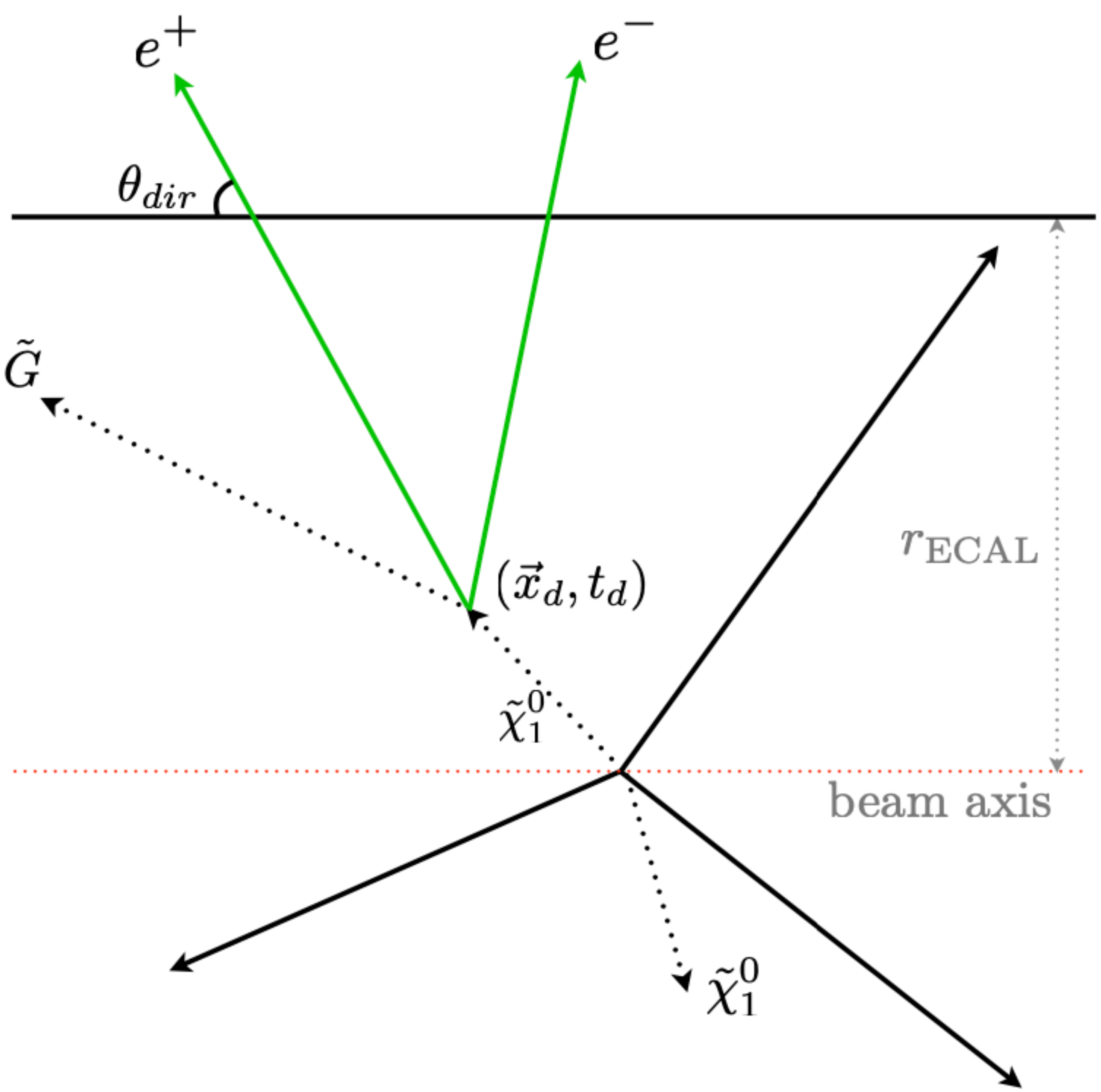
Arvanitaki, Craig, Dimopoulos, Villadoro 1210.0555

"Mini-Split"?

The 125 GeV Higgs actually *favors* heavy scalars in simple models.

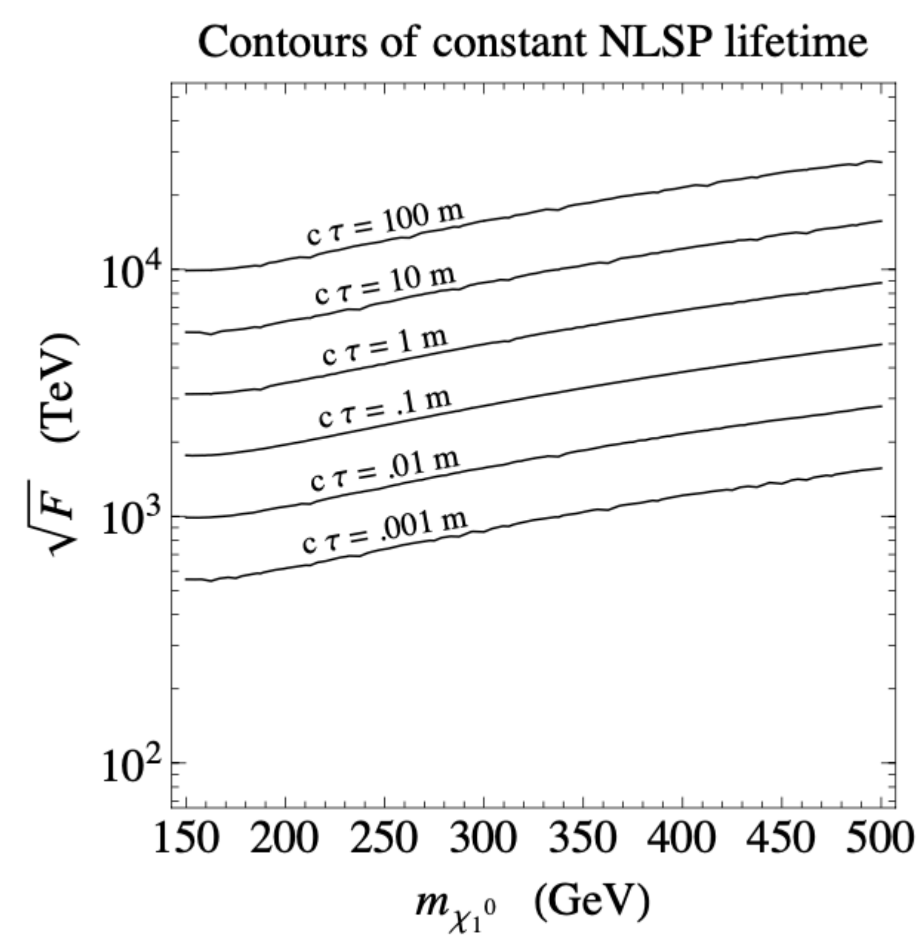
Gauginos lighter in many models.

Look for Long Liftimes



$$\mathcal{A} = \frac{m_{\tilde{\chi}_1^0}^5}{16\pi F^2} \approx \left(\frac{m_{\tilde{\chi}_1^0}}{100 \text{ GeV}}\right)^5 \left(\frac{100 \text{ TeV}}{\sqrt{F}}\right)^4 \frac{1}{0.1 \text{ mm}}.$$

SUSY events can have ***macroscopically displaced*** decays, e.g., to light gravitino or axino.

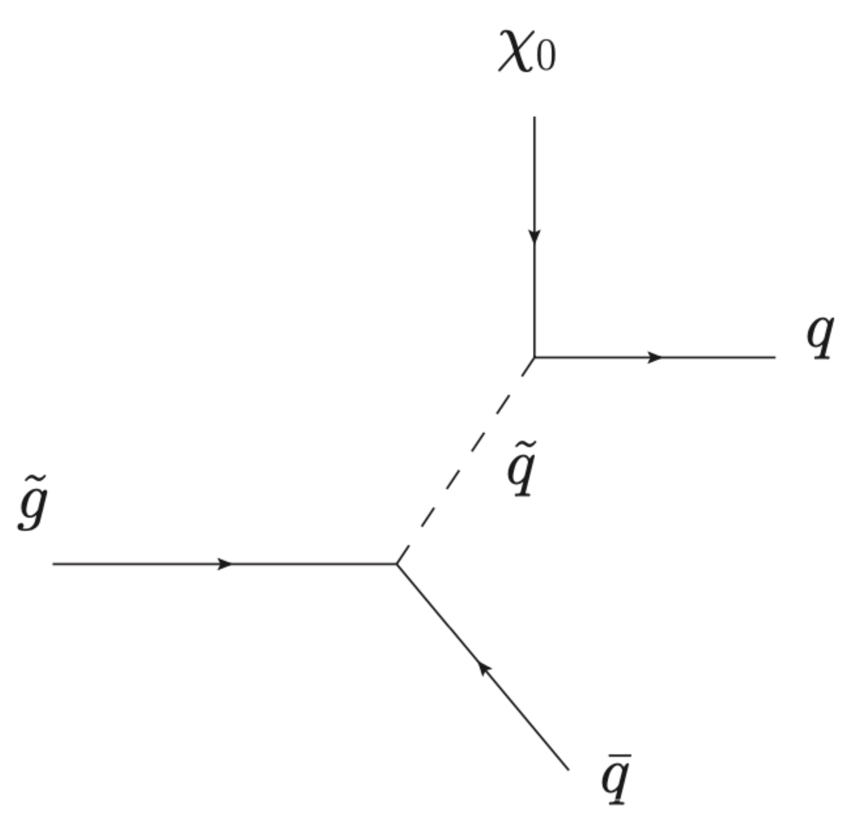


Meade, Reece, Shih 1006.4575

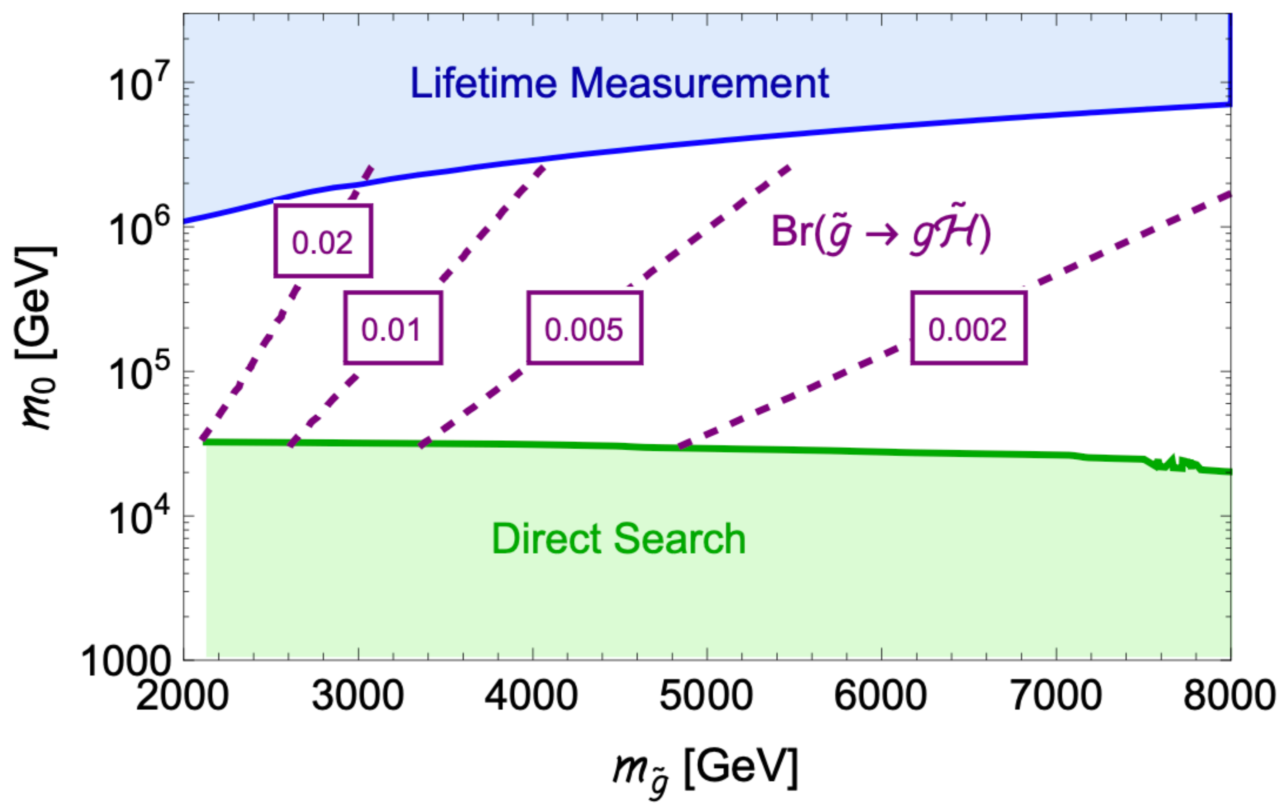
Don't Assume Promptness

SUSY events can have ***mildly displaced*** decays, e.g., hundred micron ~ millimeters. Predicted for gluinos in "Mini-Split" or "Simply Unnatural" scenario.

$$c\tau \approx 10^{-5}\mathrm{m}\left(\frac{m_{\tilde{q}}}{\mathrm{PeV}}\right)^4\left(\frac{\mathrm{TeV}}{m_{\tilde{g}}}\right)^5 .$$



Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski '12



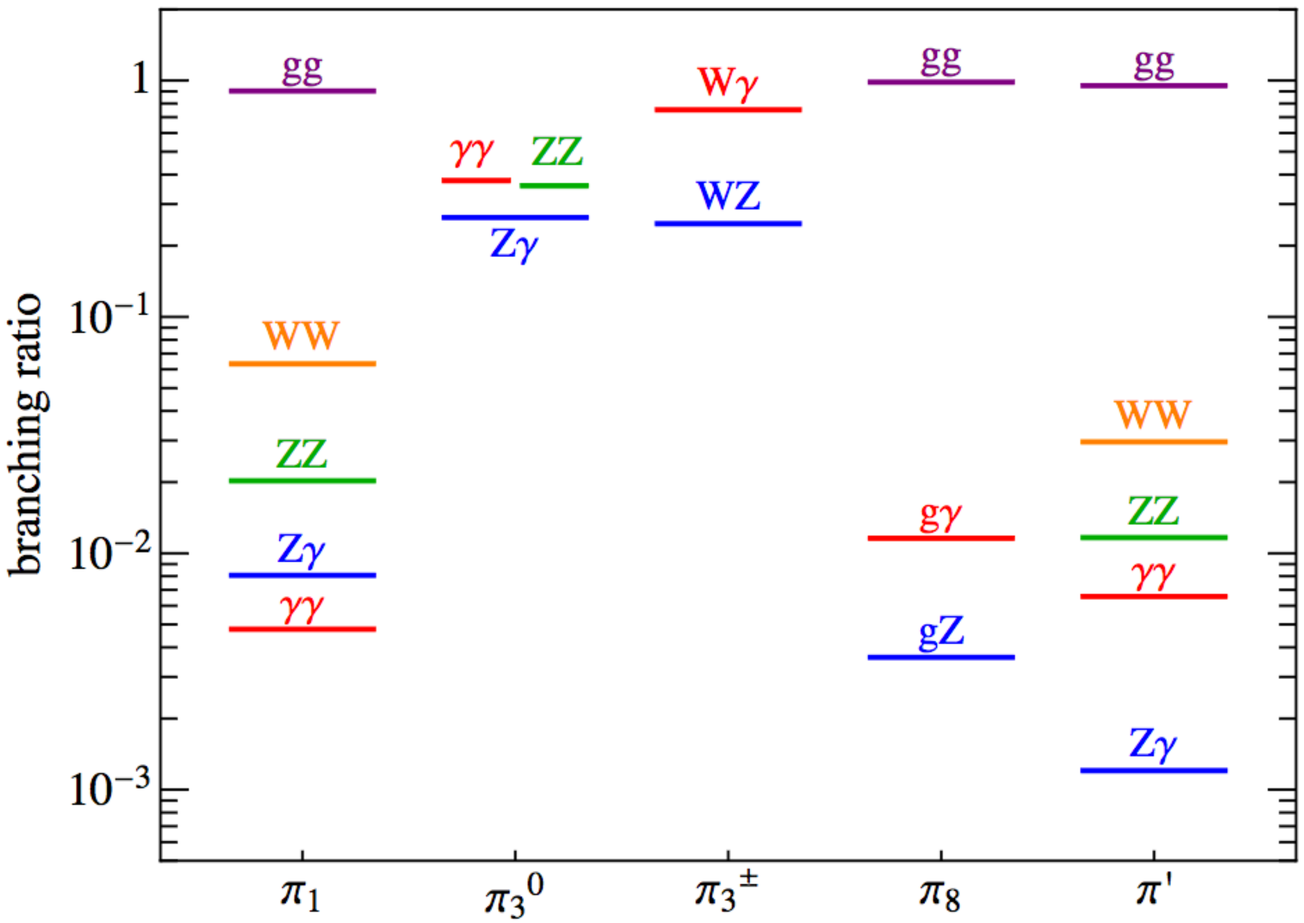
Agrawal, Fan, MR, Xue, '17

Don't Assume the MSSM

Example: **Composite Pions**

Arkani-Hamed, D'Agnolo, Low, Pinner 1608.01675

meson	constituents	$(\mathrm{SU}(3)_c, \mathrm{SU}(2)_L)_Y$
π_8	$D^c D$	$(\mathbf{8}, \mathbf{1})_0$
π_3	$L L^c$	$(\mathbf{1}, \mathbf{3})_0$
π_1	$2D^c D - 3LL^c$	$(\mathbf{1}, \mathbf{1})_0$
$Q_X = (X_{-1/3}, X_{-4/3})$	LD	$(\mathbf{3}, \mathbf{2})_{-5/6}$
$Q_X^* = (X_{4/3}, X_{1/3})$	$D^c L^c$	$(\bar{\mathbf{3}}, \mathbf{2})_{5/6}$
π'	$D^c D + LL^c$	$\mathbf{1}$



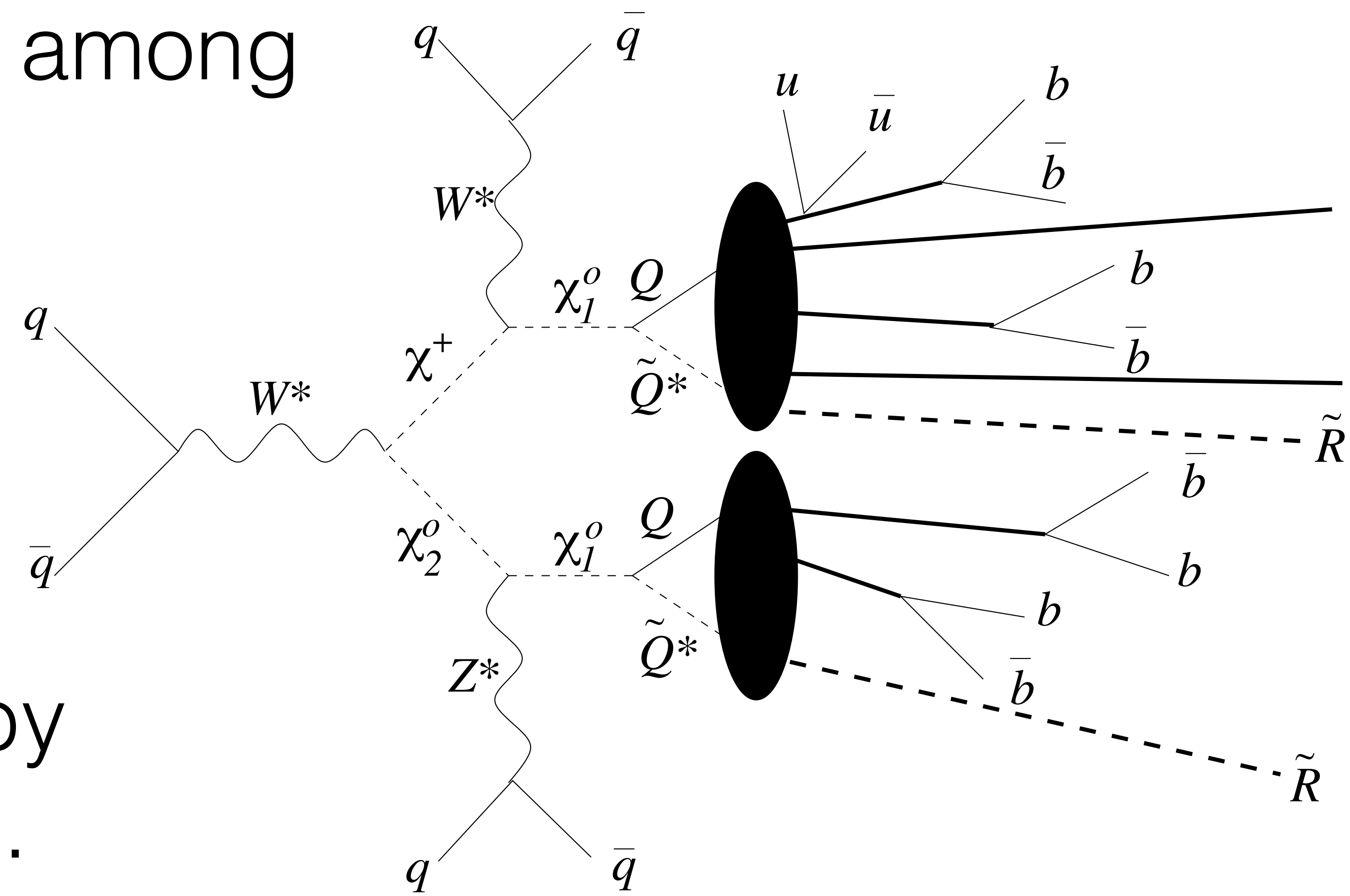
Largest diboson rates are always 2 gluons; but gluon + photon, W + photon, WZ, ZZ, … also arise.

Don’t Assume the MSSM

Example:

“Hidden Valley” (Strassler/Zurek): divide energy among many particles

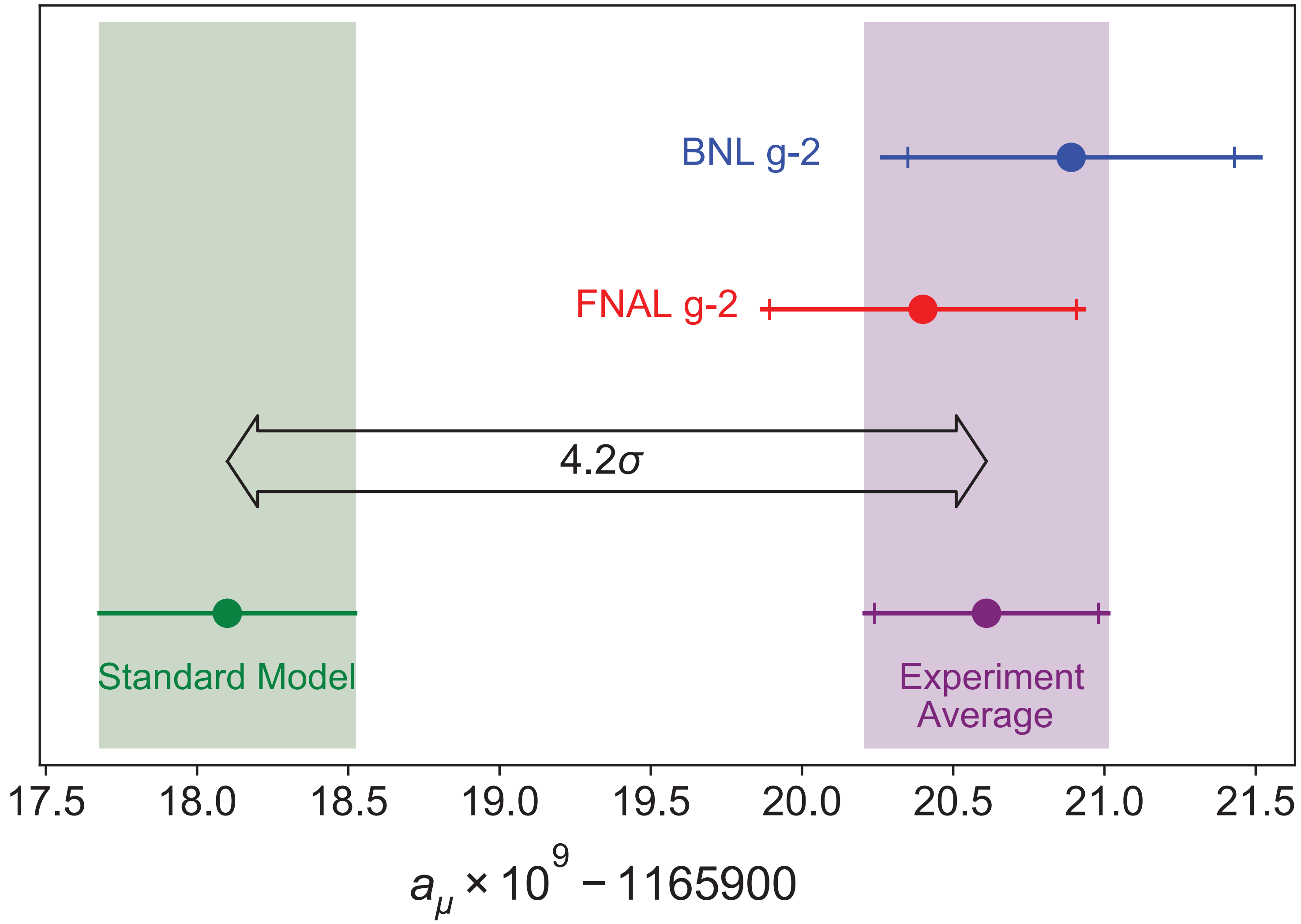
figure from M. Strassler, hep-ph/0607160



Roughly divide MET by #(final state particles). See also lepton jets, etc.

Anomalies to Watch

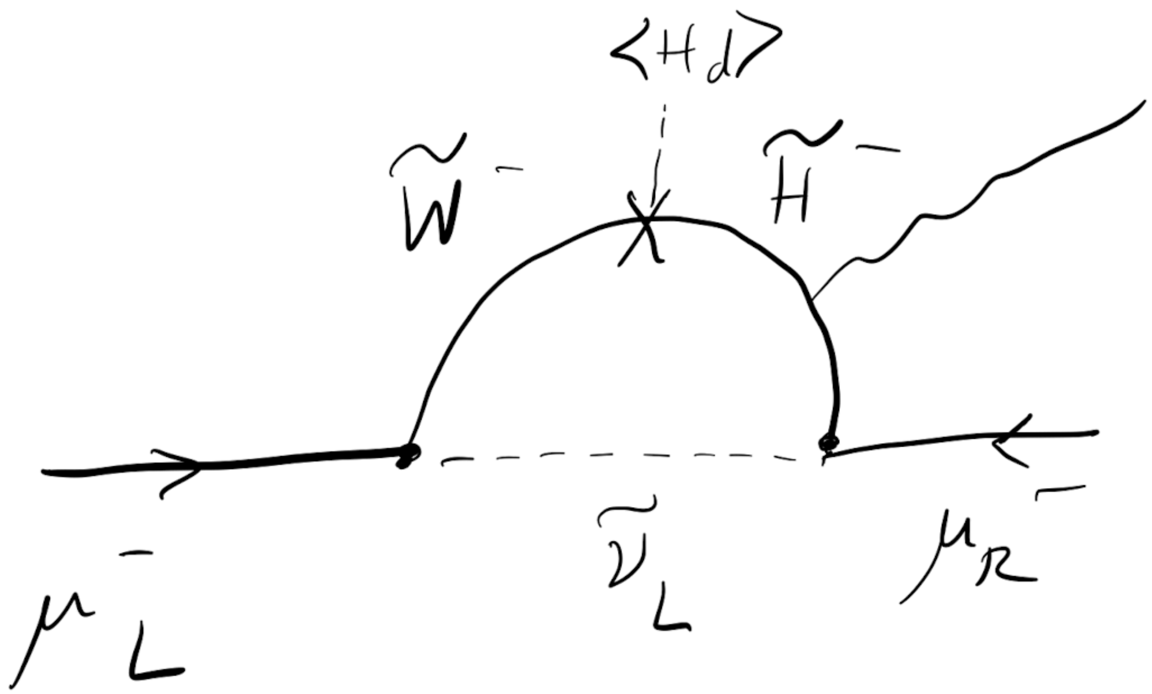
- Return of muon g-2



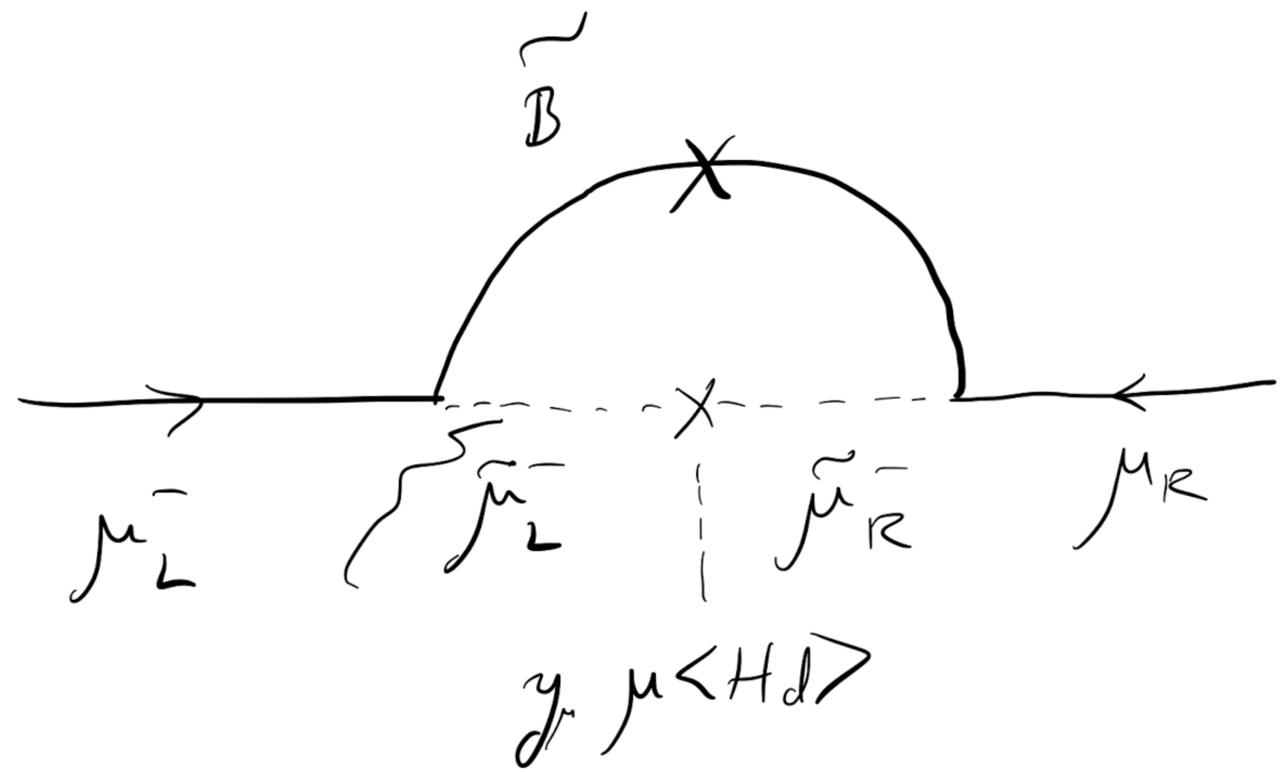
Muon g-2 collaboration

g-2: Light Sleptons, Electroweakinos

e.g., Endo, Hamaguchi, Iwamoto, Kitahara 2104.03217



case 1: “chargino dominated”



case 2: “bino dominated”

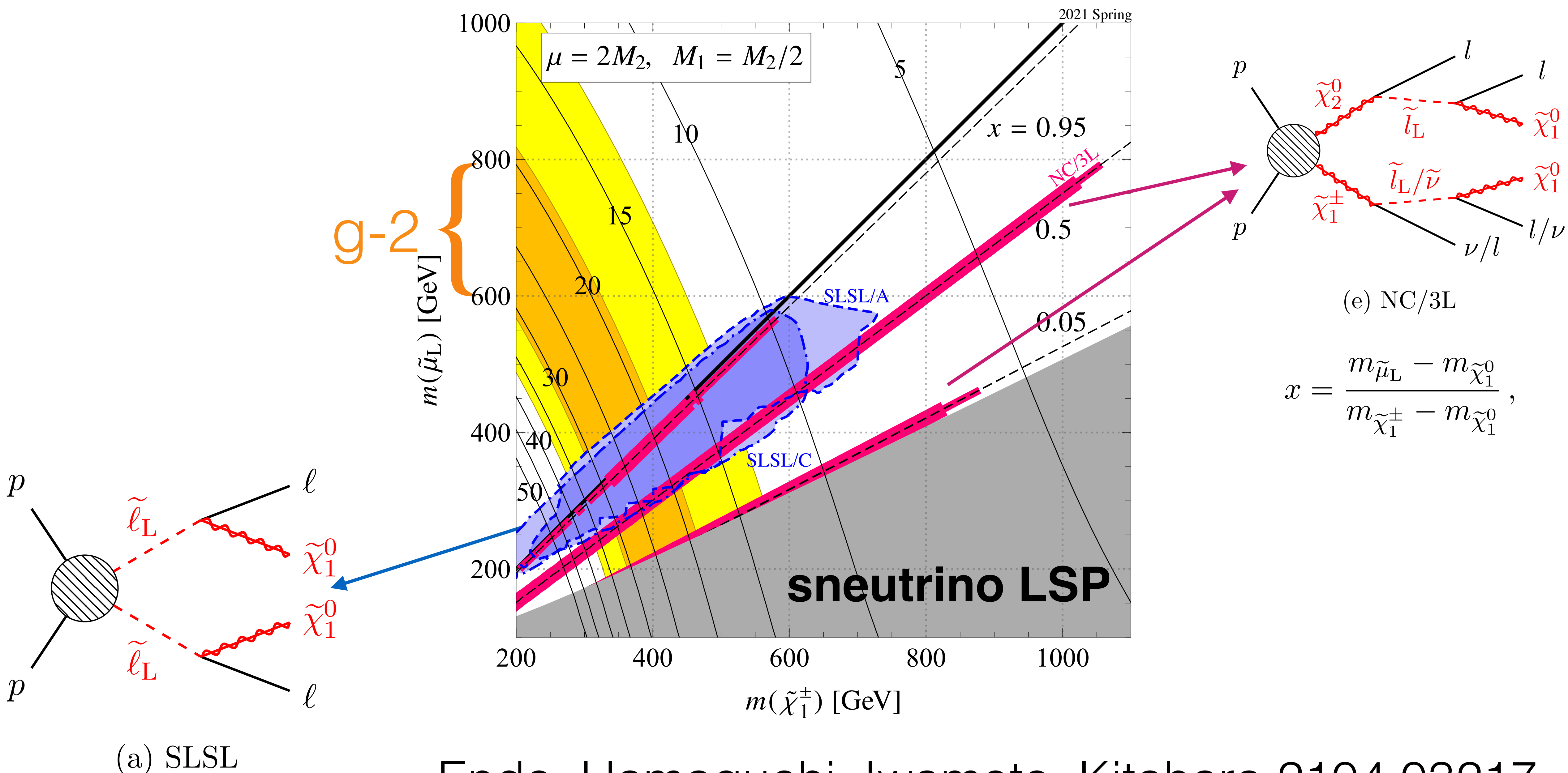
See also: Baum, Carena, Shah, Wagner 2104.03302; numerous others

g-2

- Implications for SUSY

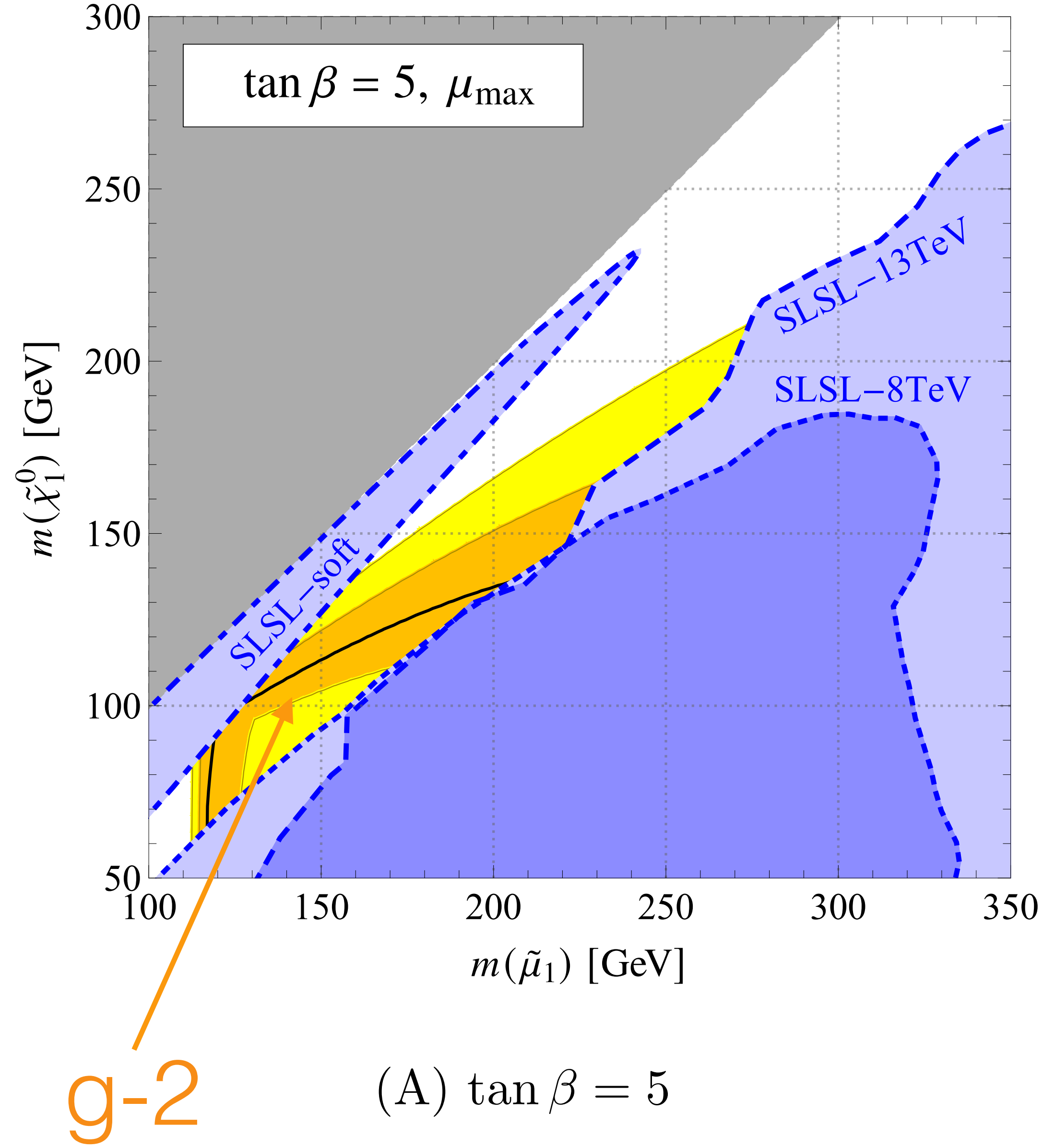
case 1: chargino dominated loop $\propto \dfrac{\alpha_2}{4\pi}\dfrac{m_\mu^2}{M_2\mu}\tan\beta$

(left-handed) smuon, wino, higgsino, bino (LSP)

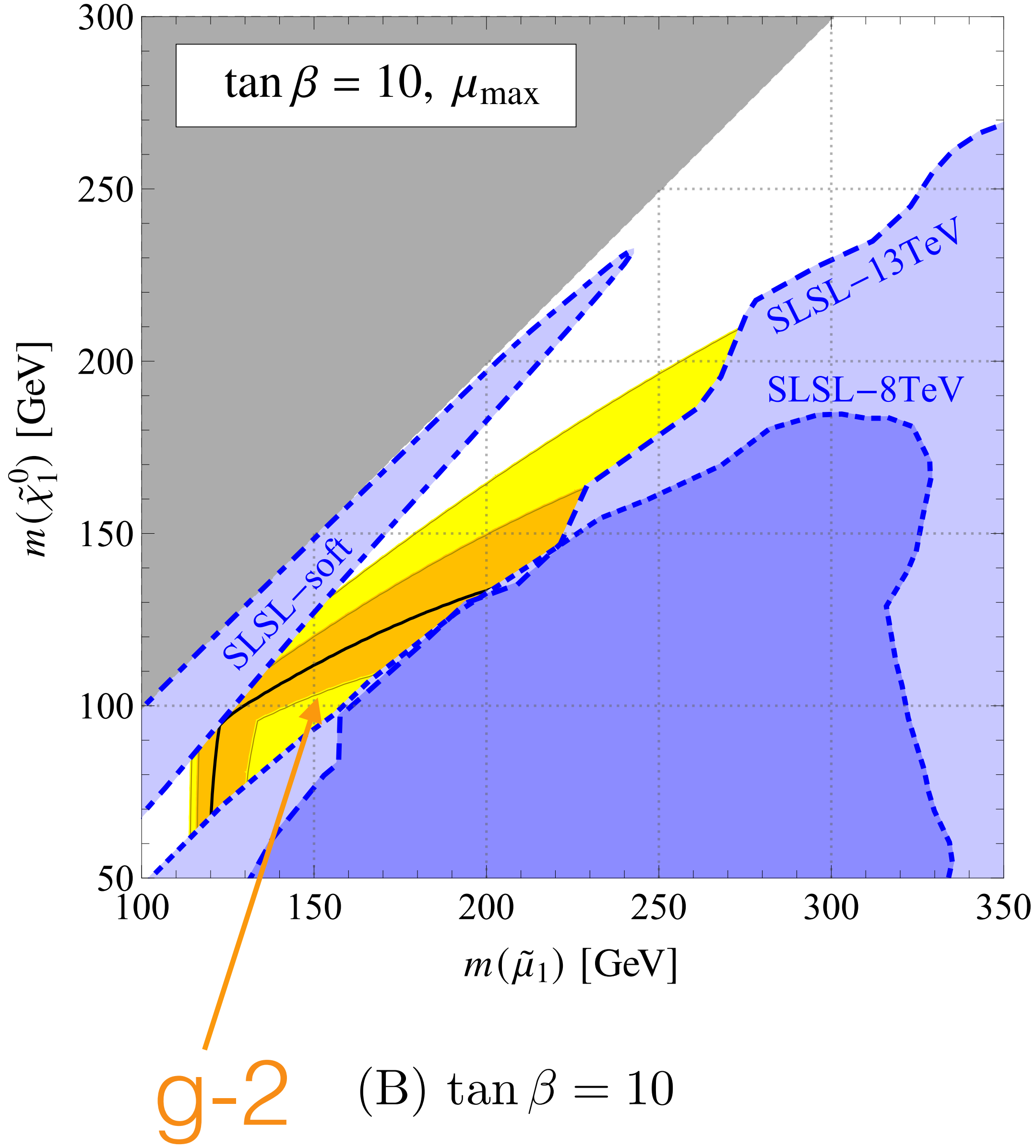


Endo, Hamaguchi, Iwamoto, Kitahara 2104.03217 *case 2*: bino dominated loop $\propto \frac{\alpha_Y}{4\pi} \frac{m_\mu^2 M_1 \mu}{m_{\tilde{\mu}_L}^2 m_{\tilde{\mu}_R}^2} \tan\beta$

smuons, bino



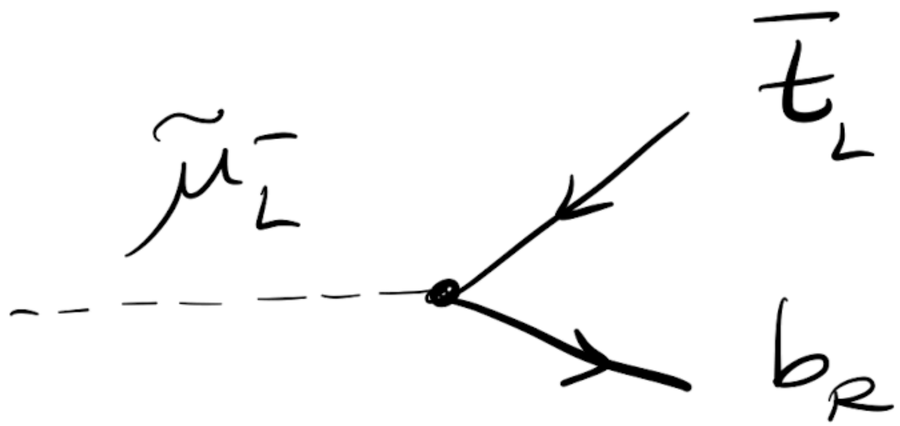
(A) $\tan\beta = 5$



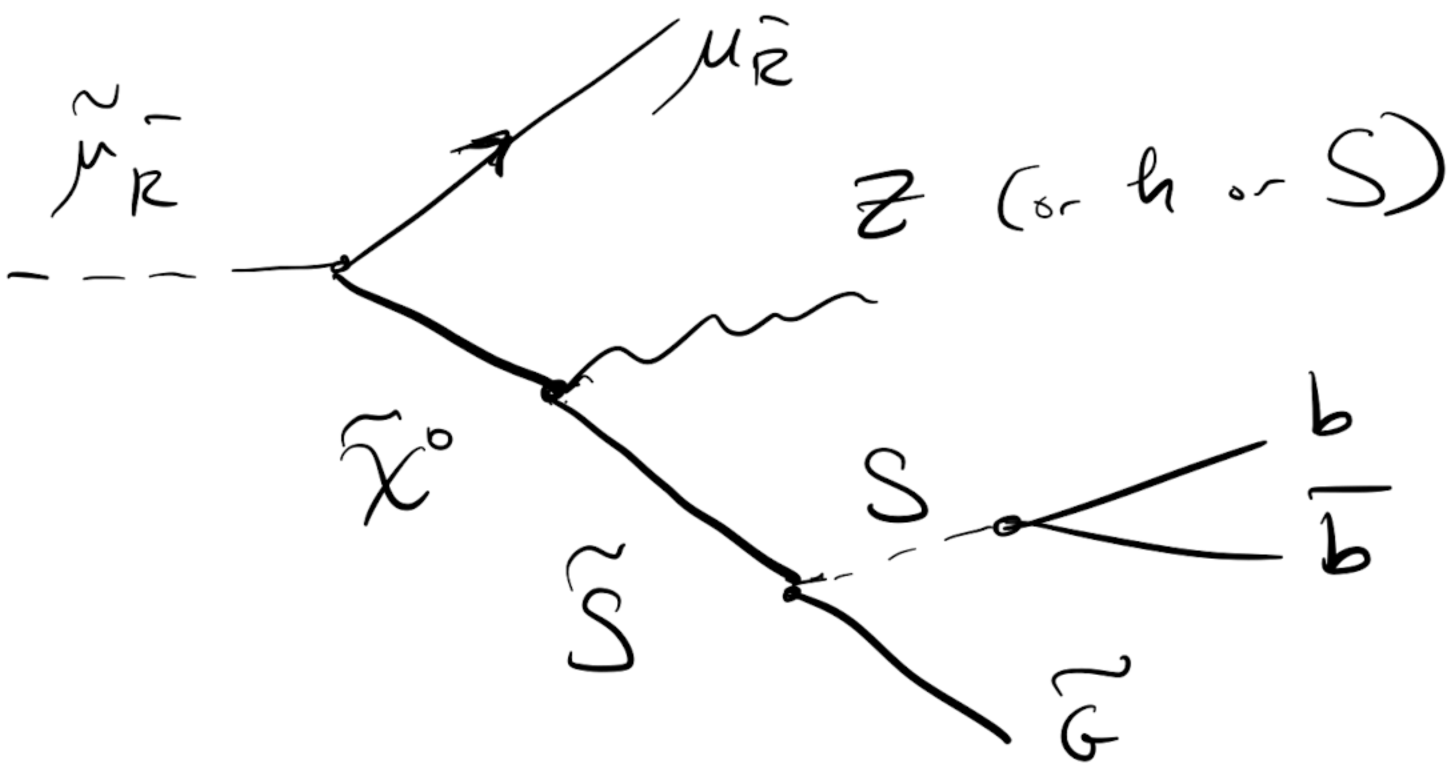
(B) $\tan\beta = 10$

Endo, Hamaguchi, Iwamoto, Kitahara 2104.03217

Putting Pieces Together



A possible smuon decay in RPV SUSY through the QLD-type Yukawa.



(soft)

A possible smuon decay in Stealth SUSY.

Concluding Remarks

(also see Meenakshi's remarks early in the conference: complex topologies, weak couplings, applying new tools like jet substructure methods)

- Electroweak signals (low rates) or many-jet signals (high backgrounds) need more attention
- Don't assume leptons + missing p_T is "easy"; low cross sections need more work! **Test g-2**.
- Be careful not to miss mildly displaced vertices! **Test Higgs mass origin**.
- SUSY can have many guises. RPV, Stealth, Hidden Valleys; SUSY can mimic a wide range of signals. **Search broadly!**