Supersymmetric Crevices: Missing Signatures of R-Parity Violation at the LHC

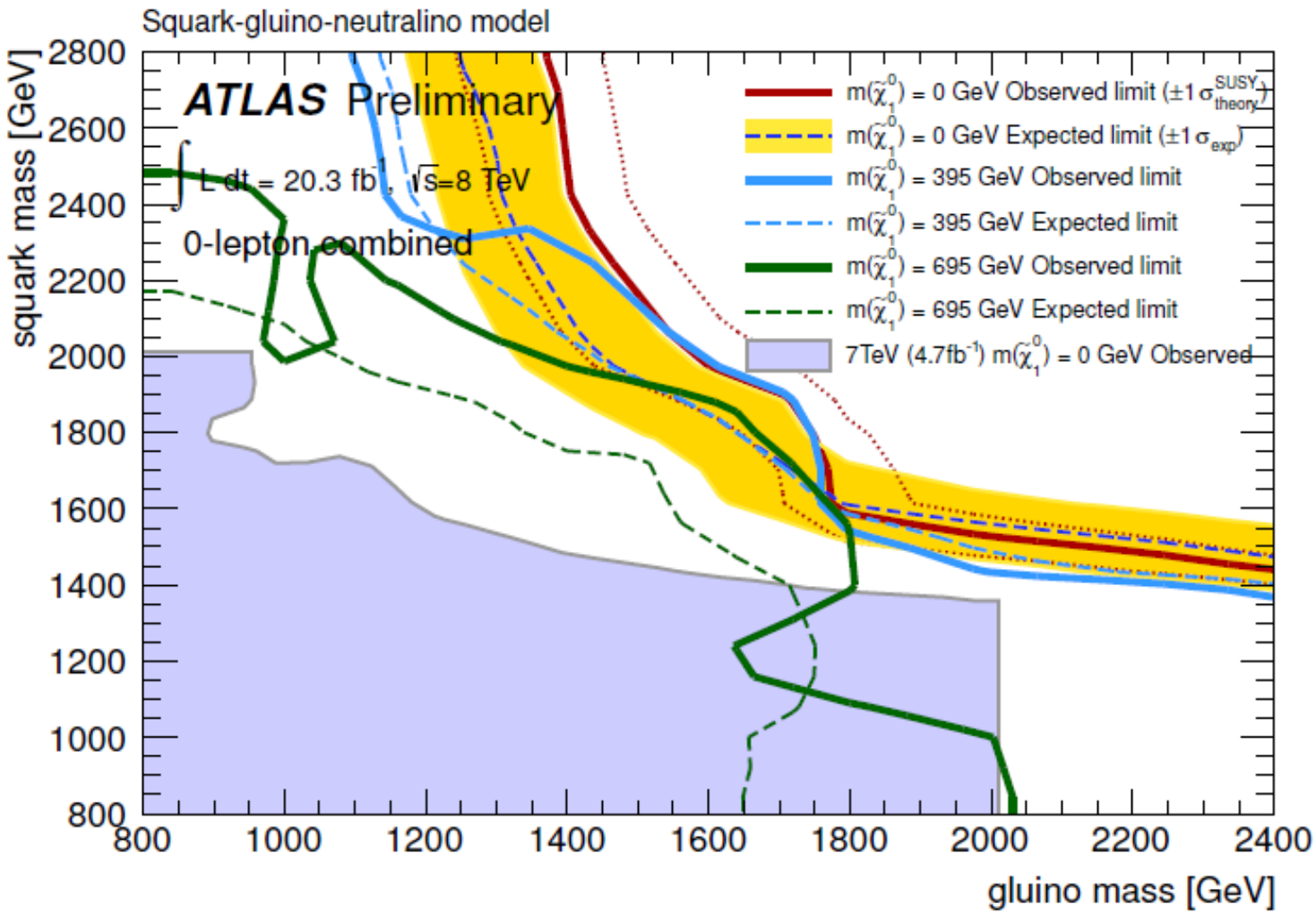
Prashant Saraswat

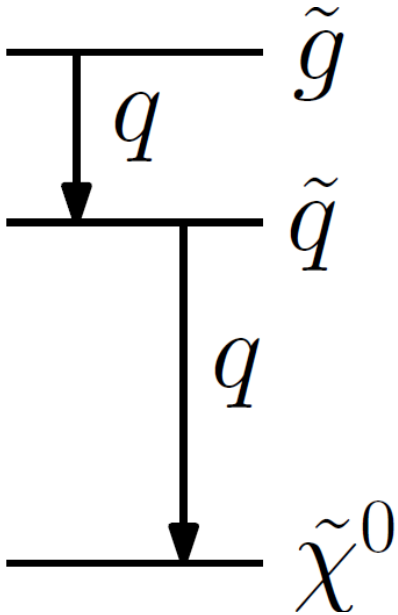
University of Maryland and Johns Hopkins University

Work in progress with Peter Graham and Surjeet Rajendran

arXiv:1403.7197

SUSY searches reach the limits of 8 TeV





At the edge of constraint, only produce 10 SUSY events total *before* cuts!

Time to give up on the 8 TeV LHC?

?

Time to give up on the 8 TeV LHC?

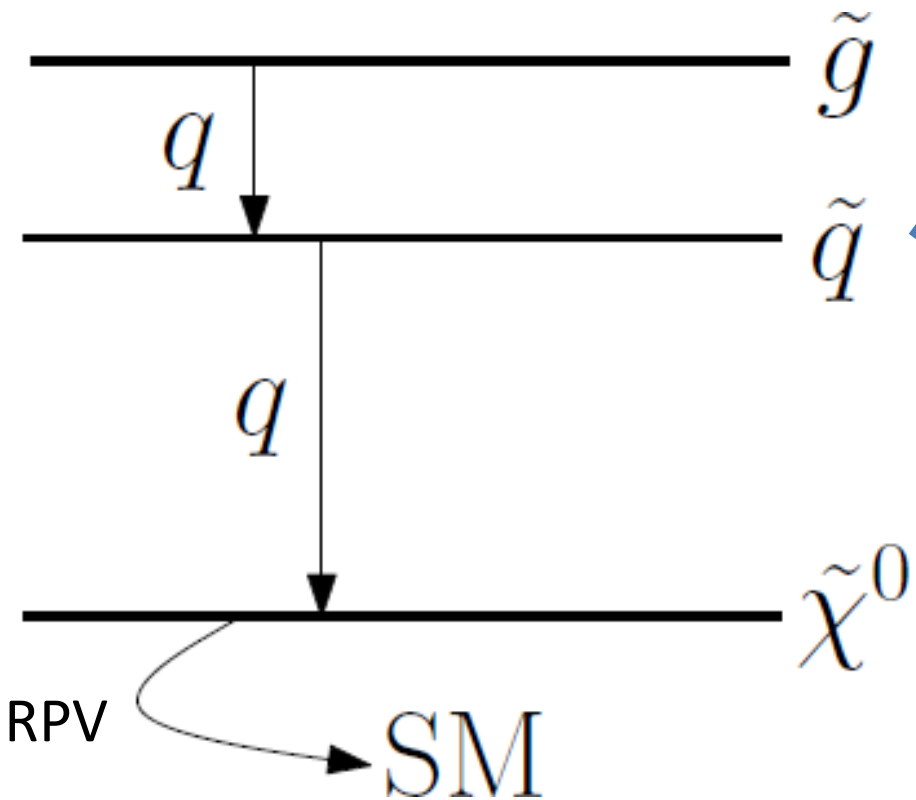
NO!

This talk:

There remain potential SUSY signatures not adequately covered by current searches

Some surviving models predict > 10000 SUSY events in the 8 TeV data– still potential for discovery?

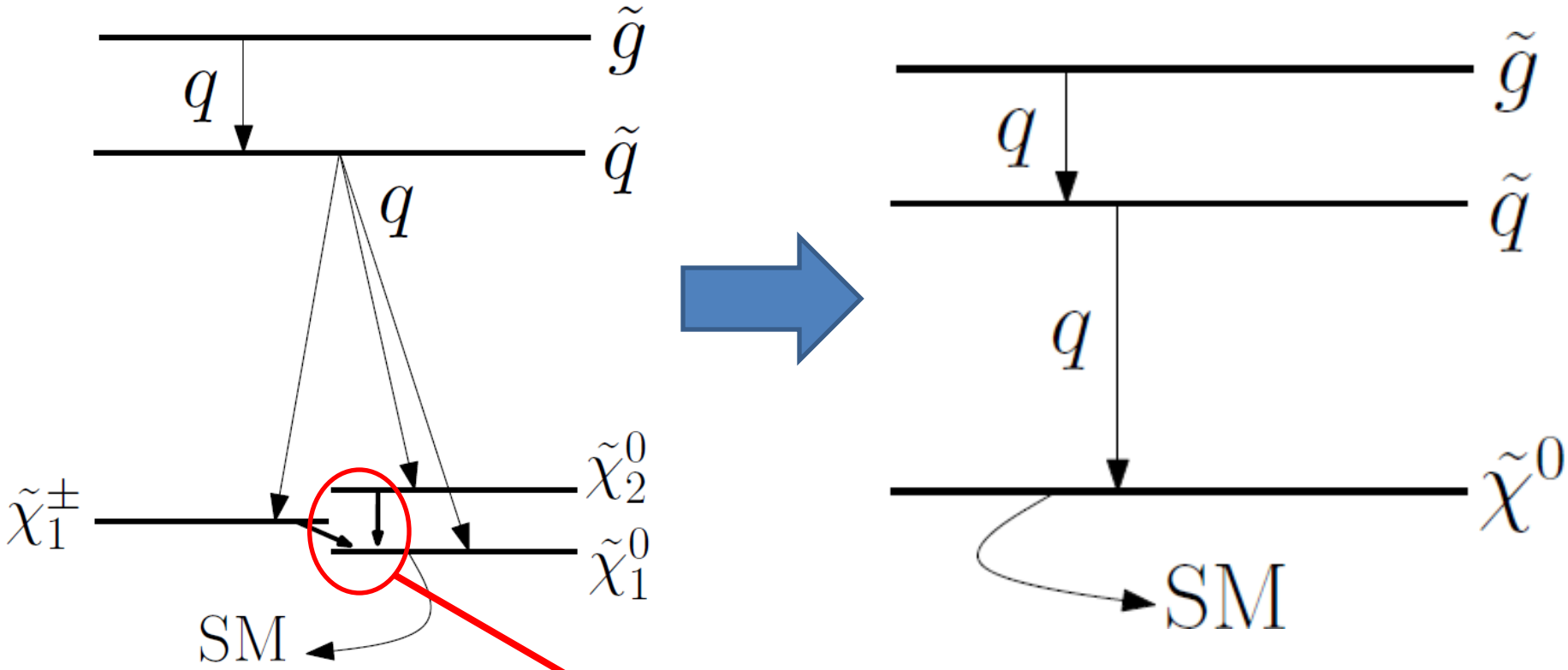
Simplified Model



ALL squarks are degenerate, ensuring large production cross-section

Contrast to "natural" SUSY with low cross-section but distinctive events

Simplified Model



Soft particles-- negligible for collider studies

Simulation techniques

Use the MadGraph-PYTHIA-PGS package

Modified PGS to more closely mimic ATLAS/CMS *b*-jet tagging and lepton isolation

Our signal efficiencies generally match official ATLAS/CMS results to within 30%

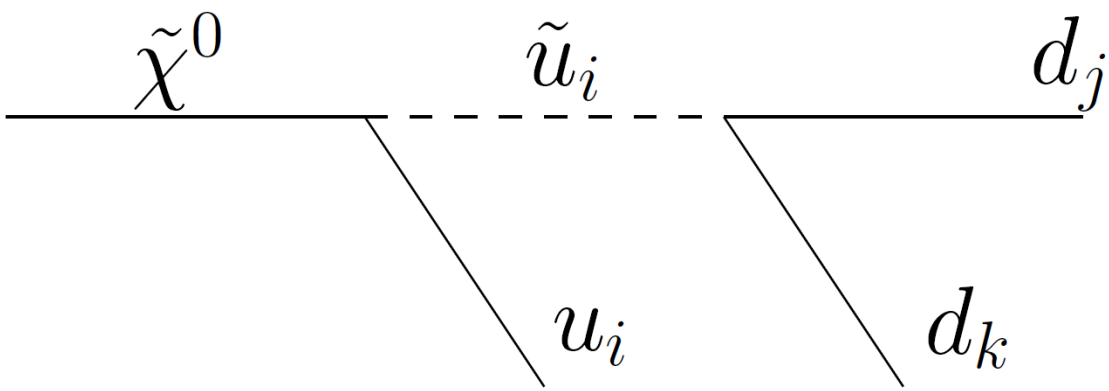
R-Parity Violation (RPV)

$$W_{\mathrm{RPV}} = \mu_{L_i} L_i H_u$$

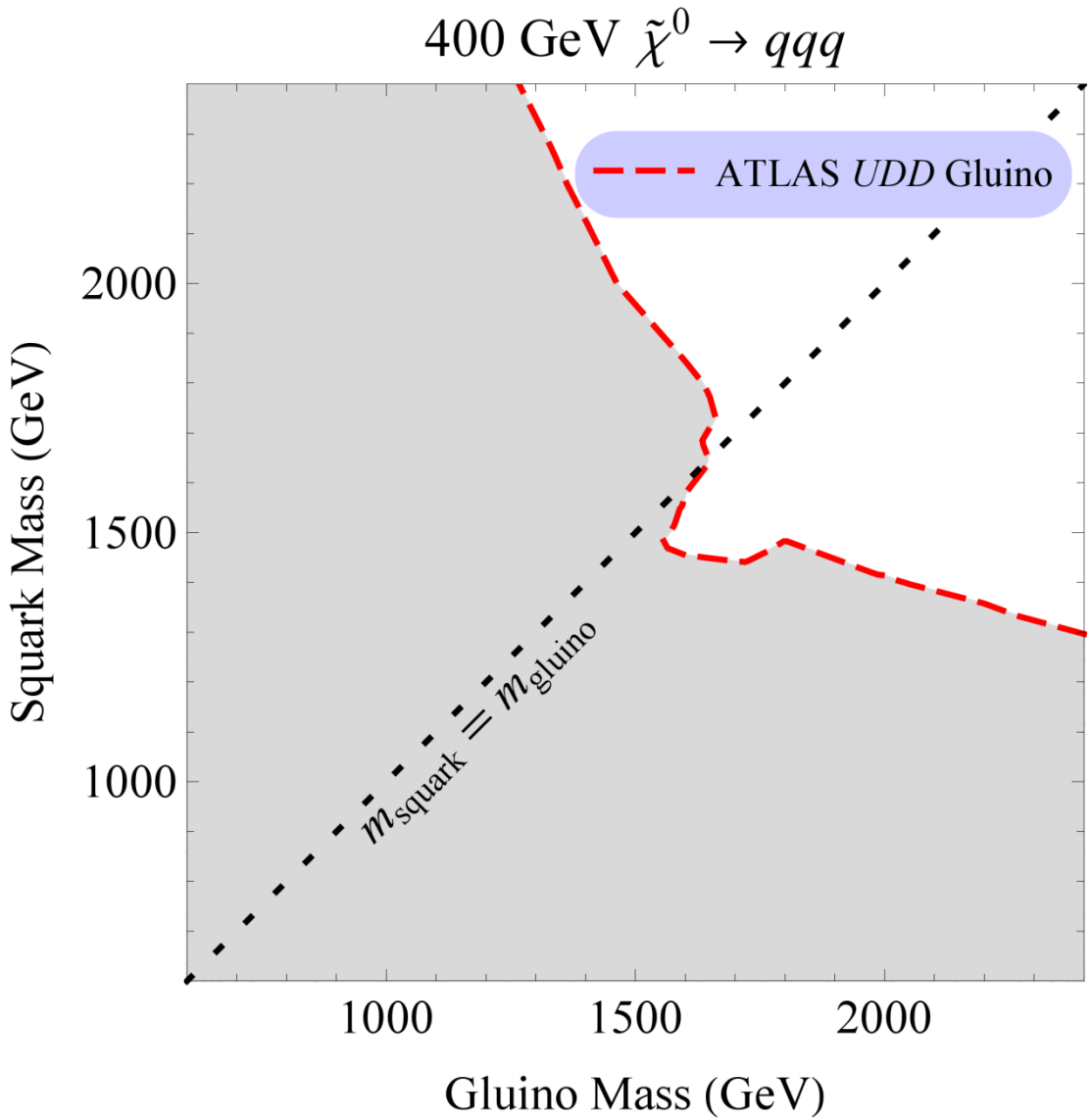
$$+\lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k$$

Lepton Number Violation

Baryon Number Violation



Constraints on baryonic RPV

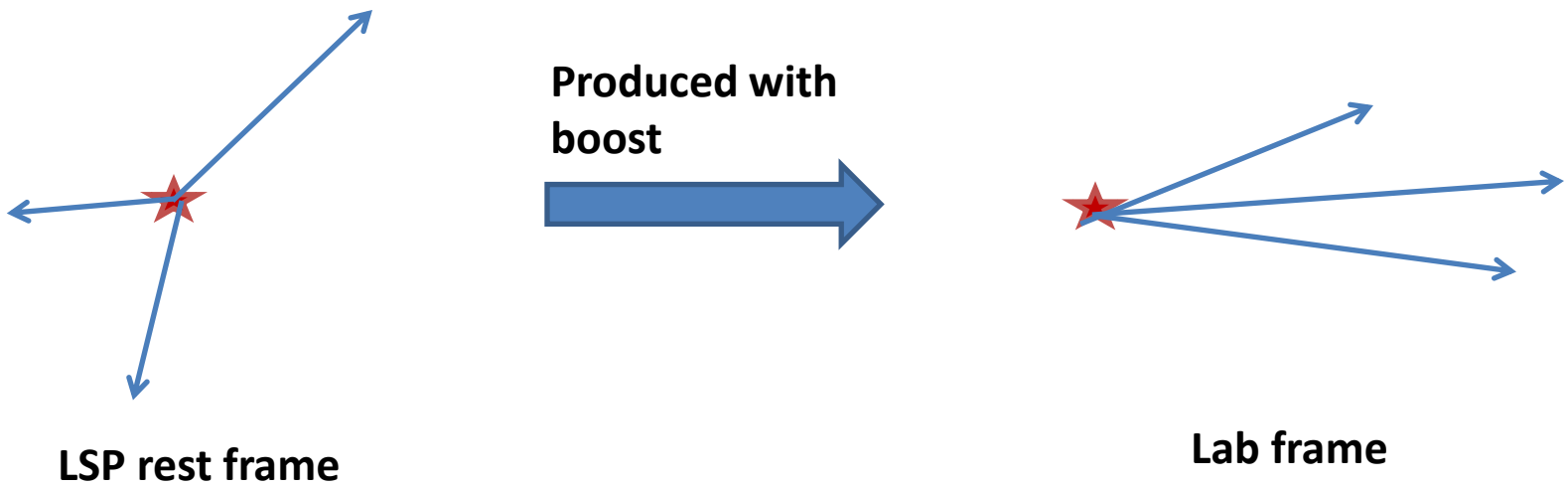


ATLAS search for 7 jets with $p_T > 180$ GeV

Official interpretation only considers gluino production, but squarks can also be constrained

Boosted decays

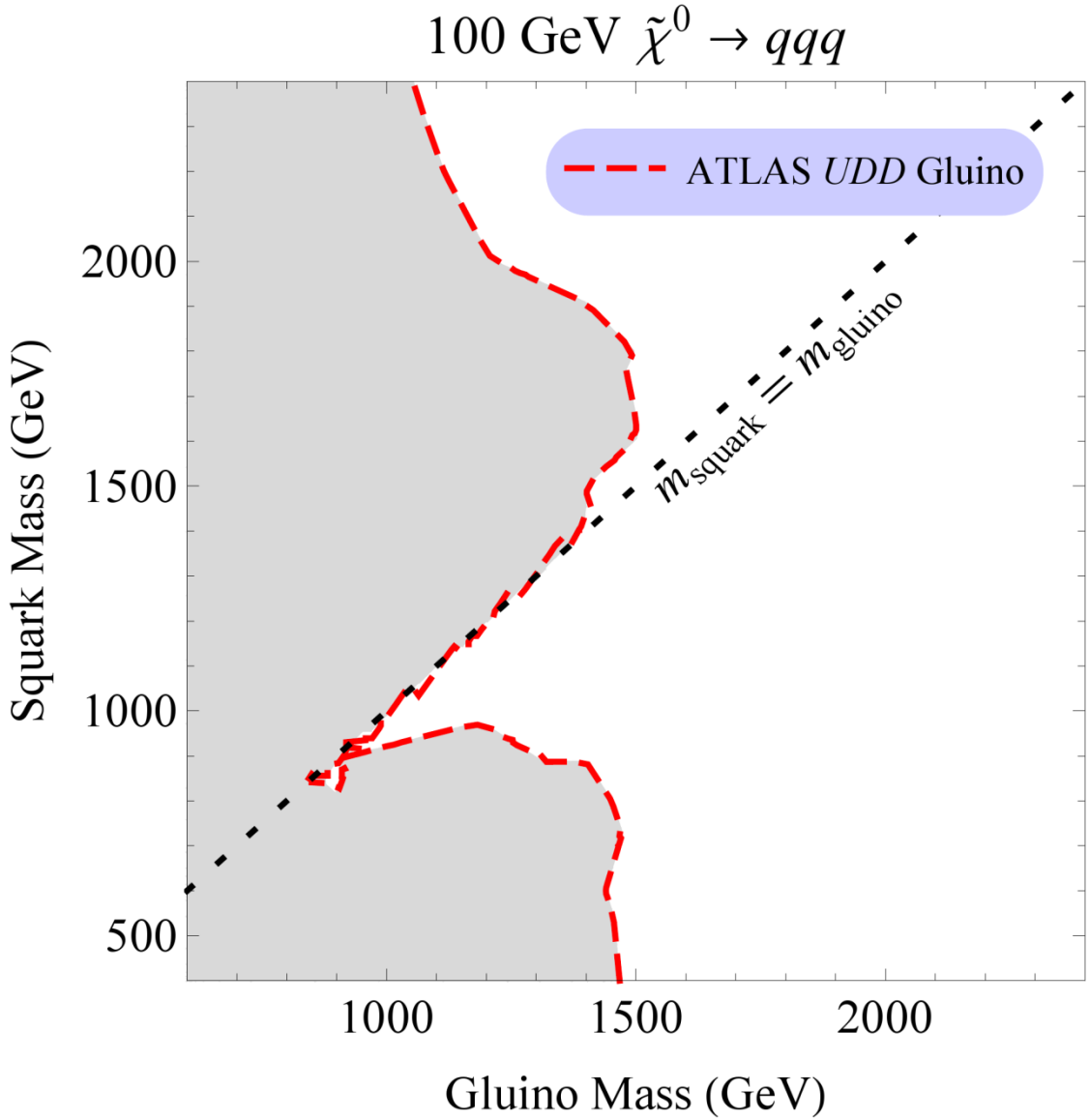
A light LSP can be produced with high boost from cascade decays



Decay products merge into a (high-p_T) jet

Leptons from decay are not isolated!

Boosted LSP Constraints



Bound on squarks vanishes!

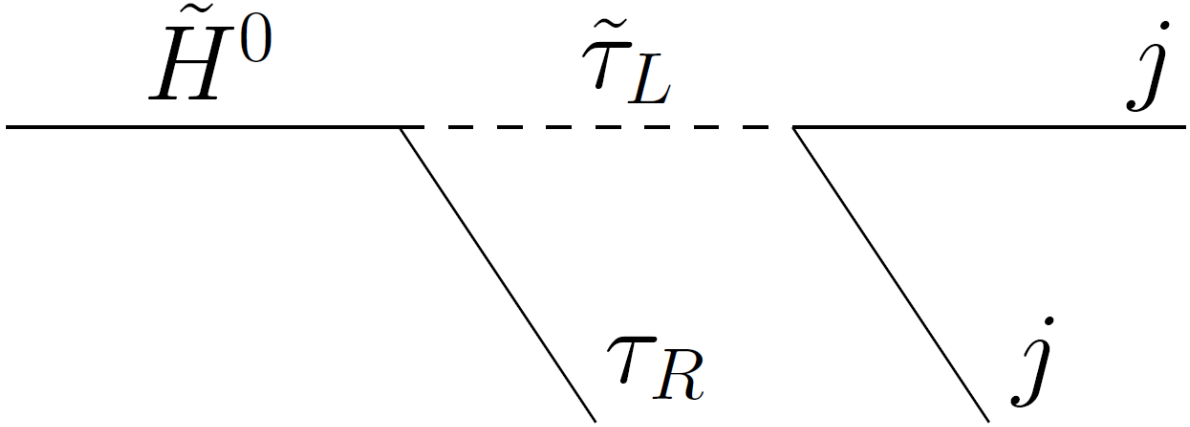
Bounds weaken when squarks are just below the gluino– jets are squeezed out

Taus + Jets from LRPV

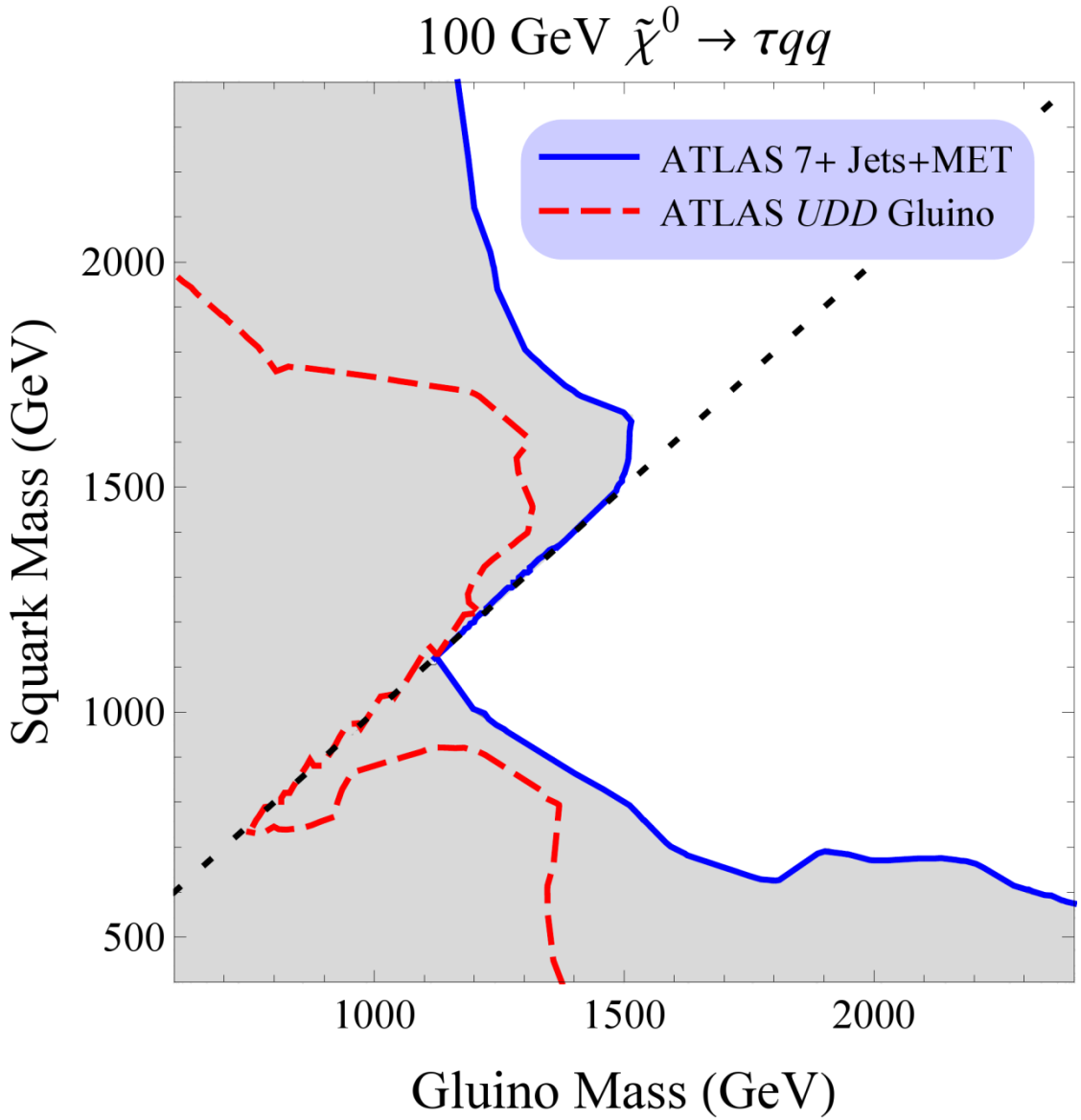
Assume:

- LQD couplings are larger than LLE couplings
- Neutral Higgsino is the LSP
- Sleptons are lighter than squarks

Then the LSP decays dominantly to tau + 2 jets:



Constraints on $\tilde{\chi}^0 \to \tau qq$



Tau decay gives measurable missing energy

Tuning can be comparable to baryonic RPV case

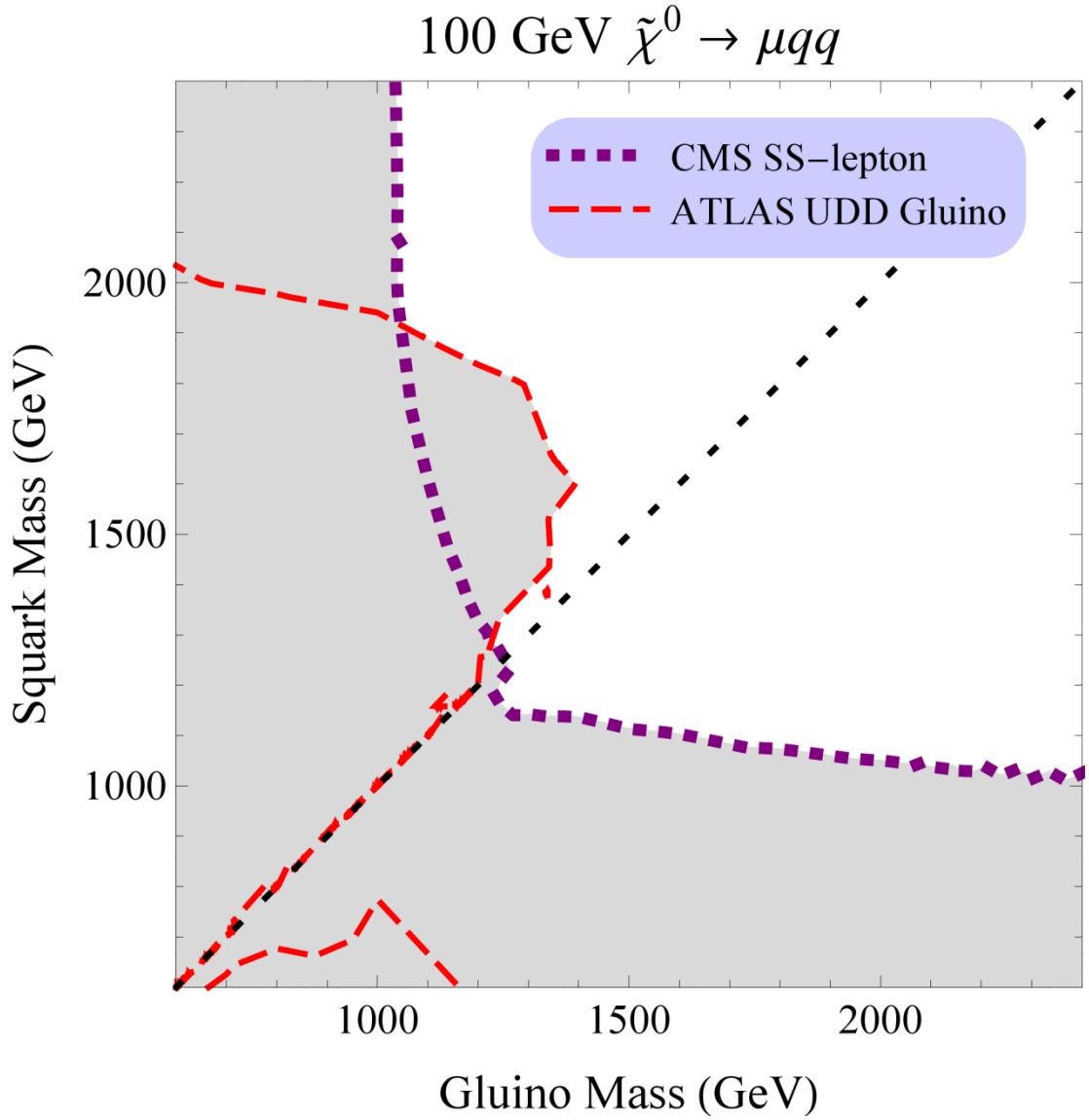
No current search for multijet + taus with small MET!

Charged lepton + jets

More generally there are a few ways to avoid decays to neutrinos with LRPV:

- Higgsino LSP
- Decay through operator $\frac{H_d Q U E}{\Lambda}$
- Large slepton left-right mixing

Constraints on $\tilde{\chi}^0 \to \mu qq$

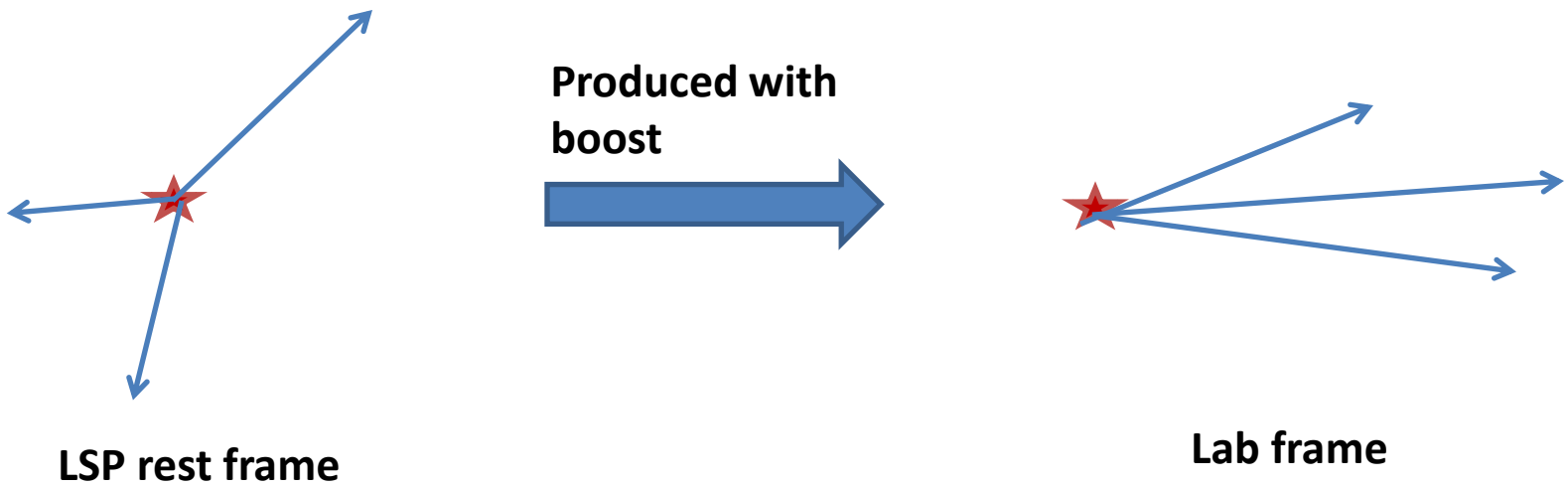


Most same-sign lepton selections require MET; don't make use of high jet multiplicity

Reduced efficiency due to identify leptons due to LSP boost

Boosted decays

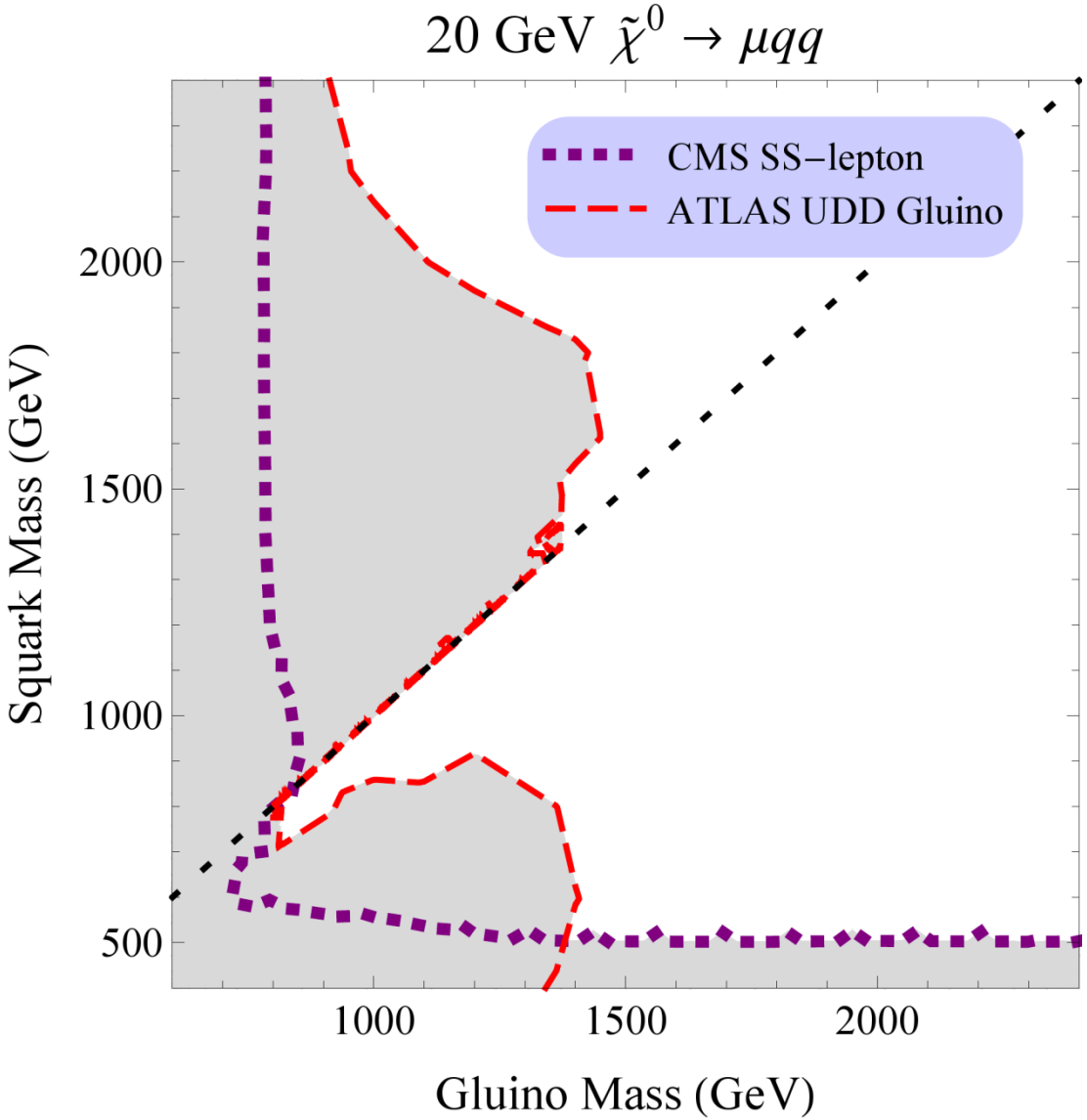
A light LSP can be produced with high boost from cascade decays



Decay products merge into a (high-p_T) jet

Leptons from decay are not isolated!

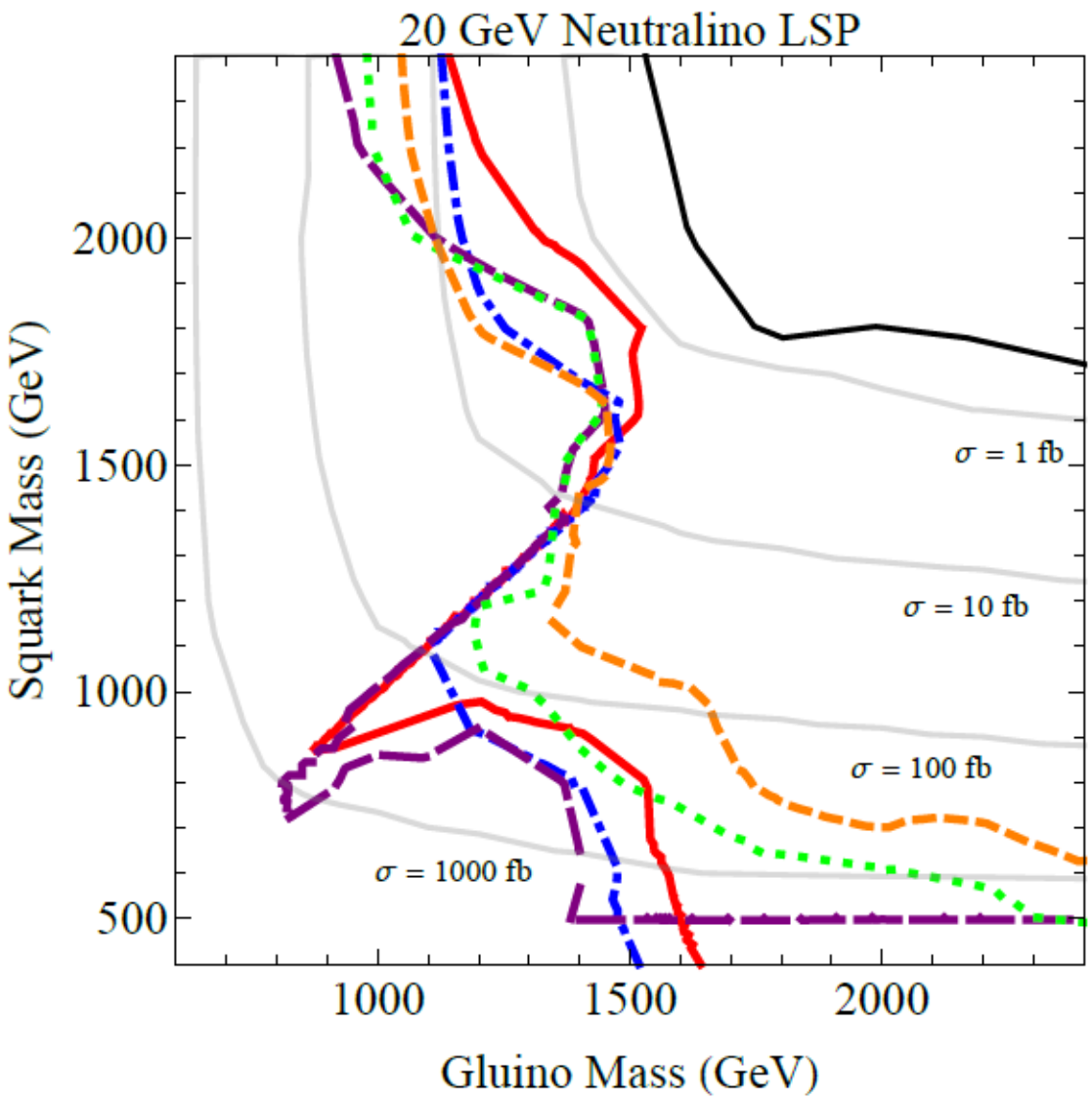
Boosted Limit $\tilde{\chi}^0 \to \mu q q$



Constraints are similar to baryonic RPV, though every SUSY event contains two muons

Need a search accepting *non-isolated* leptons!

Summary



Lepton number violation is competitive with baryon violation for a boosted LSP

$\tilde{\chi}^0$ decay modes

- qqq
- τqq
- μqq
- $\mu qq/\nu qq$
- νbb
- Stable (ATLAS)

Conclusions

RPV models can allow for light squarks and for gluinos as light as 1 TeV

1 TeV squarks+gluino → 4000 events at 8 TeV LHC

Lepton number violating models are not necessarily more constrained than baryon violation

The Missing Signatures

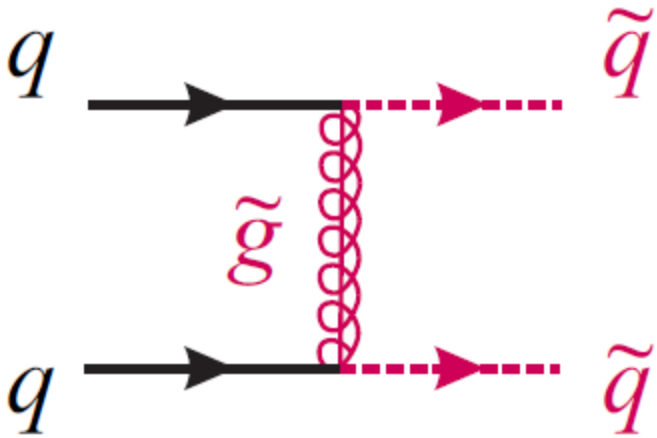
All of the models that hide have very little MET but many hard jets

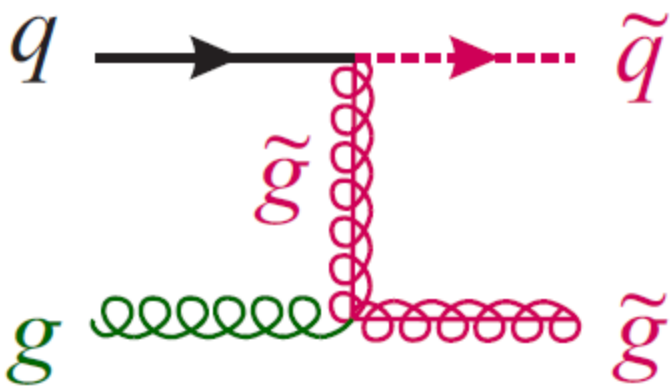
LHC searches so far have searched for MET + *X*, leptons + *X*: for RPV we need Multijet + *X*, where *X* should include one or more leptons (including taus), very low MET, substructure

Searches accepting non-isolated leptons are necessary to probe models with boosted particles– new variables to separate signal from heavy flavor?

There is still potential for discovery at 8 TeV!

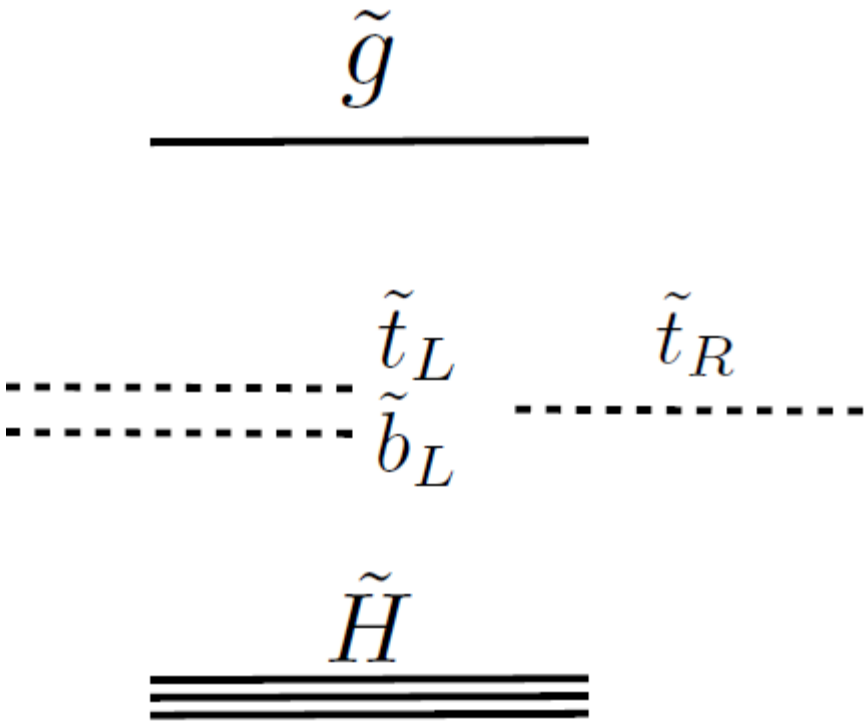
Backup





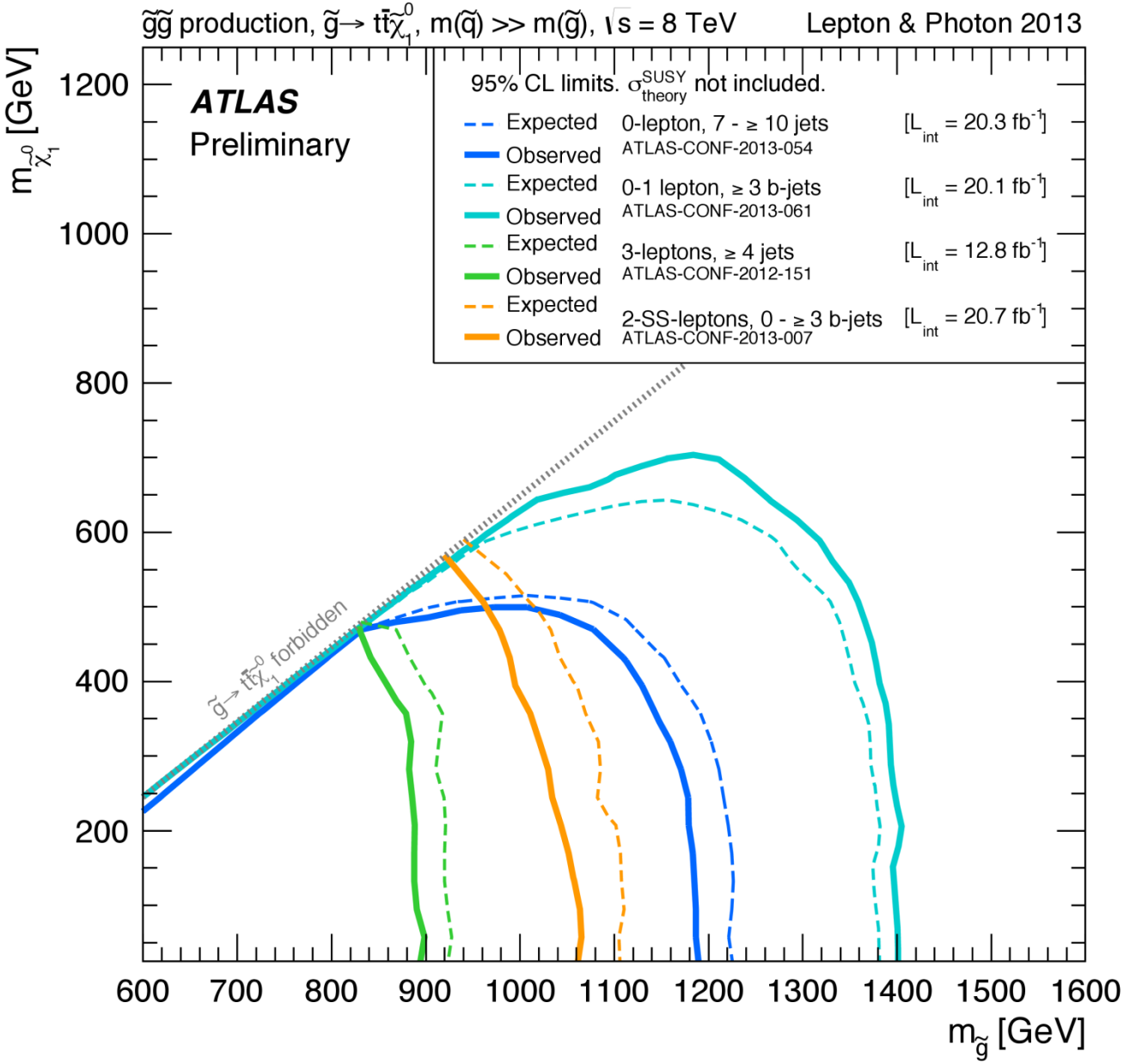
The dominant SUSY production processes involve valence quarks of the proton (*u, d*)

“Natural” SUSY



Decoupling the first two generation squarks greatly reduces the SUSY production cross-section

Constraints on Natural SUSY

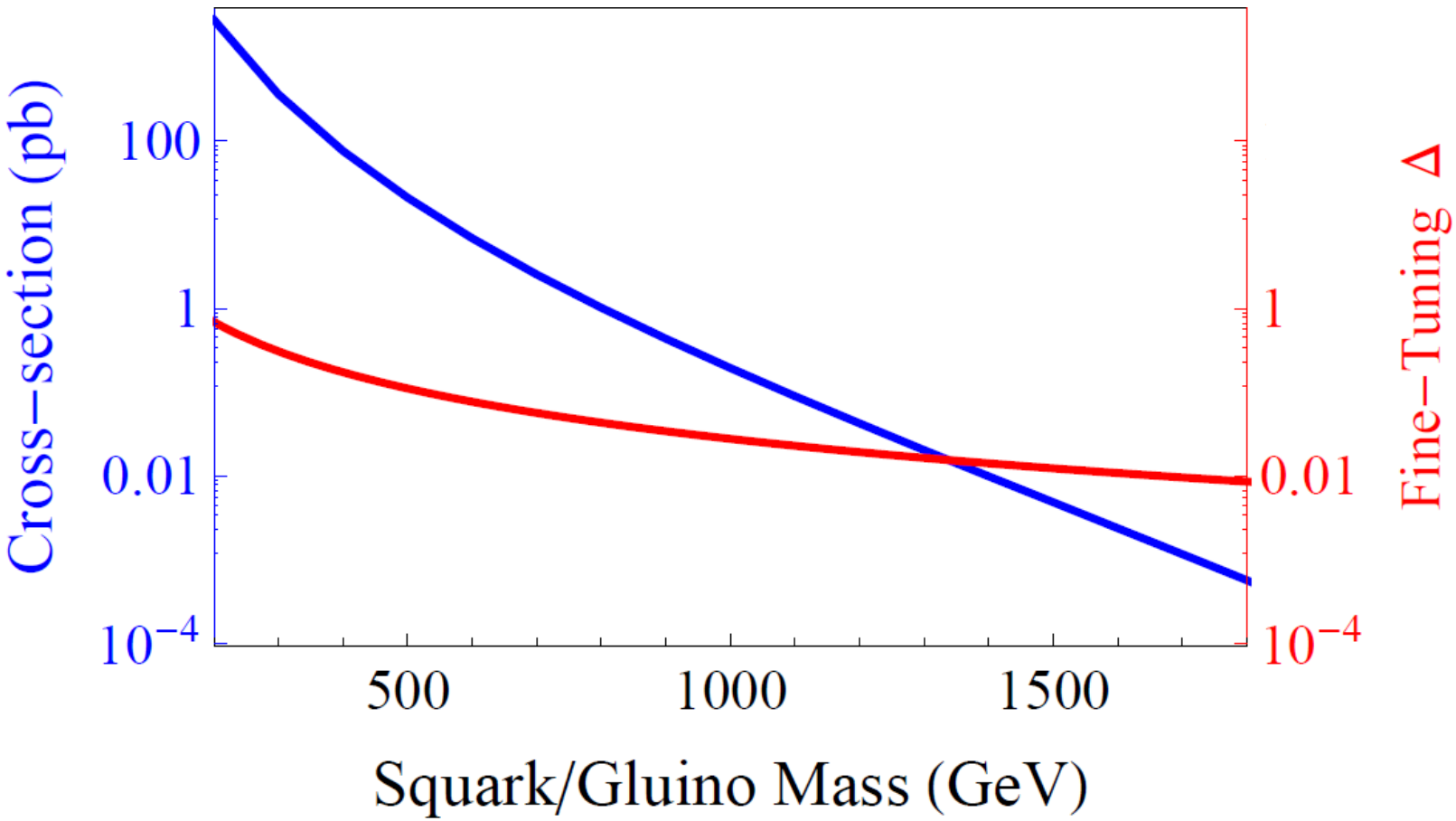


$$\tilde{g} \to t\bar{t}\tilde{\chi}^0$$

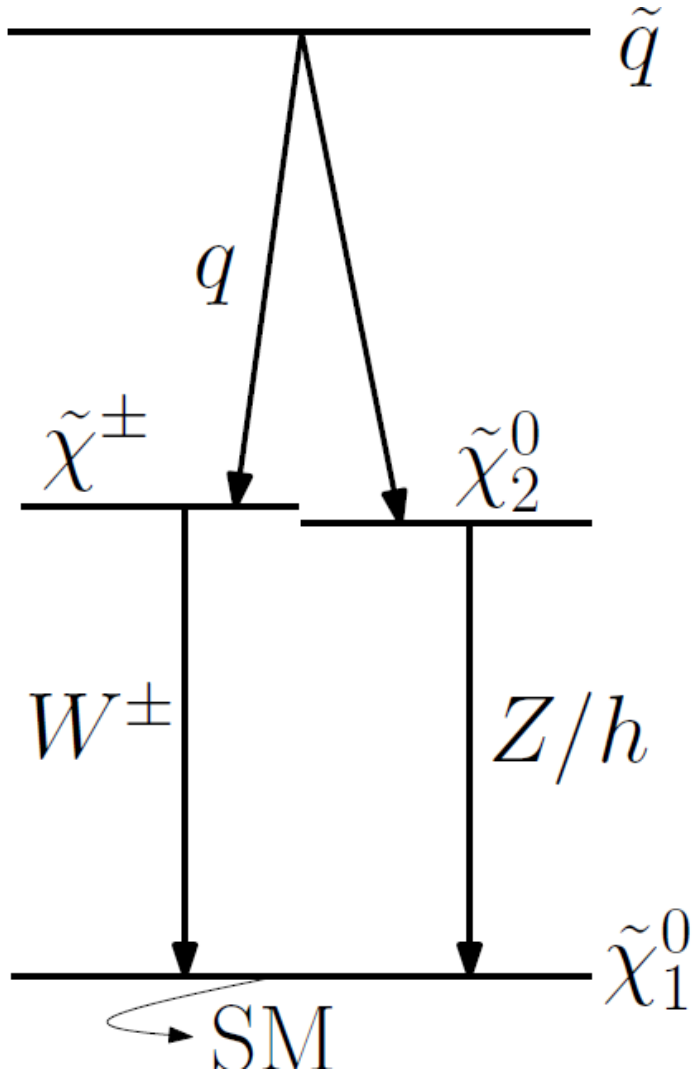
is also constrained to the kinematic limit

Fine tuning ~10% or worse

Why Hide SUSY?

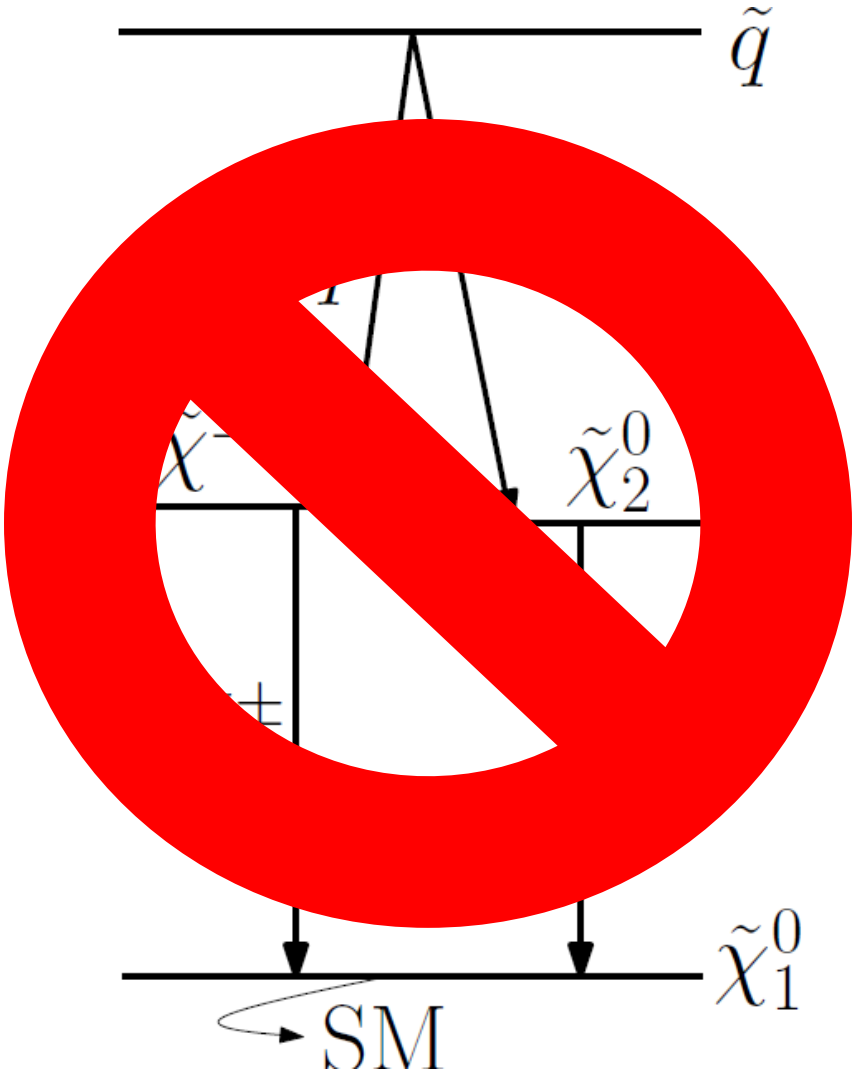


How Not to Hide SUSY (very well)



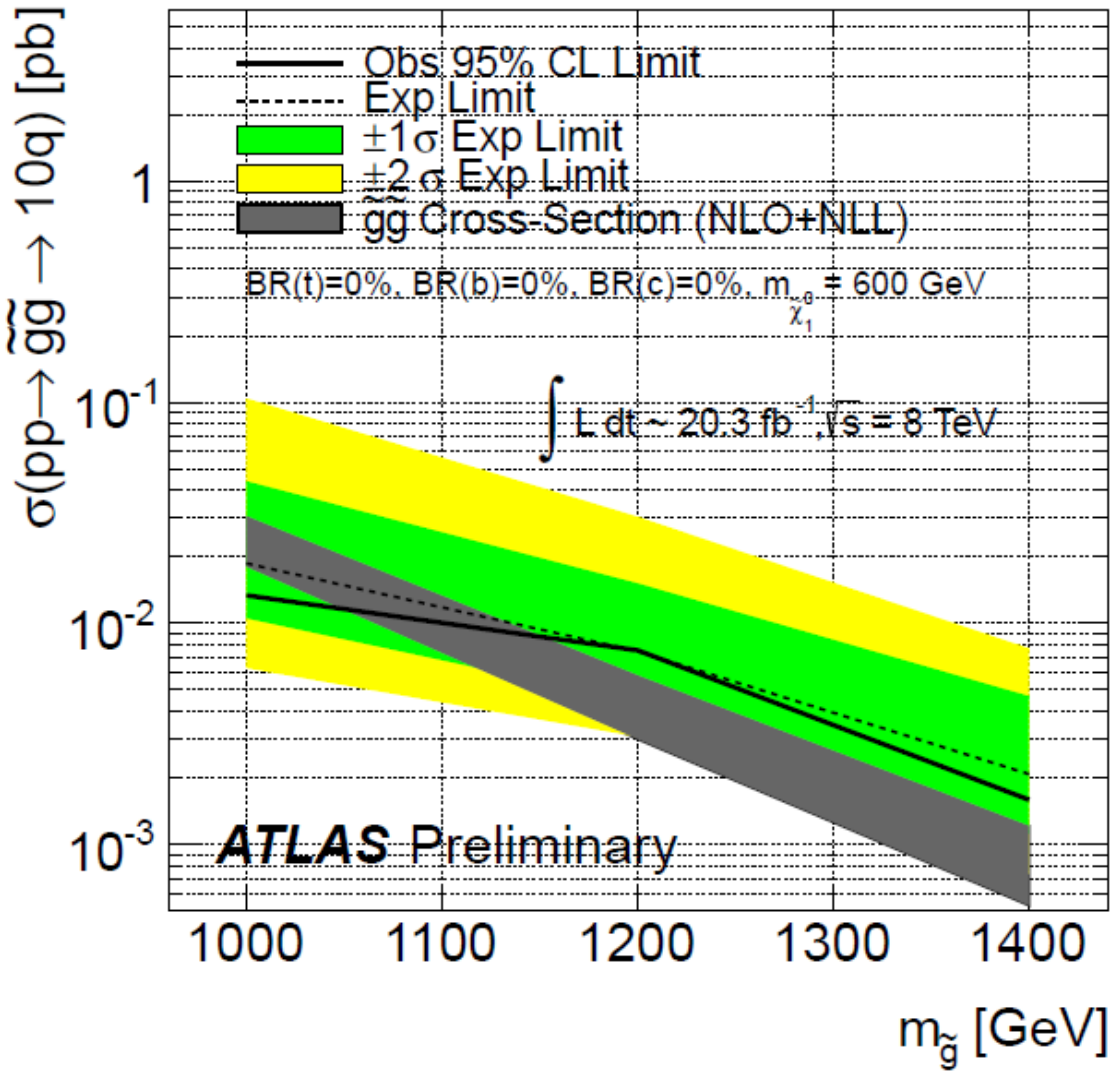
If cascade decays producing W and Z bosons are allowed, bounds from leptons + MET come into effect

How Not to Hide SUSY (very well)



If cascade decays producing W and Z bosons are allowed, bounds from leptons + MET come into effect

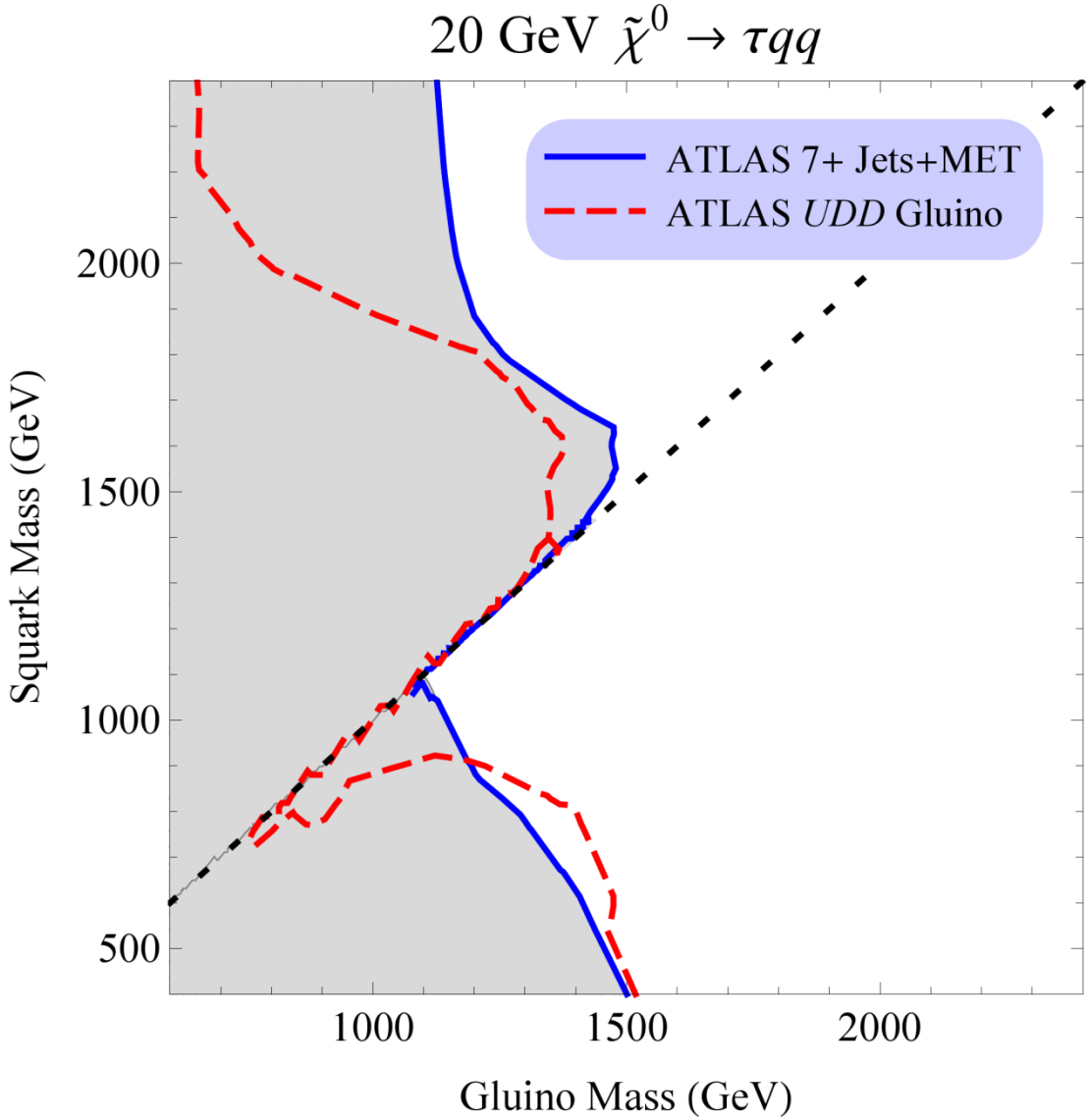
Searches for baryonic RPV



ATLAS search for baryonic RPV: requires many very high-p_T jets

Official interpretation assumes the squarks are decoupled

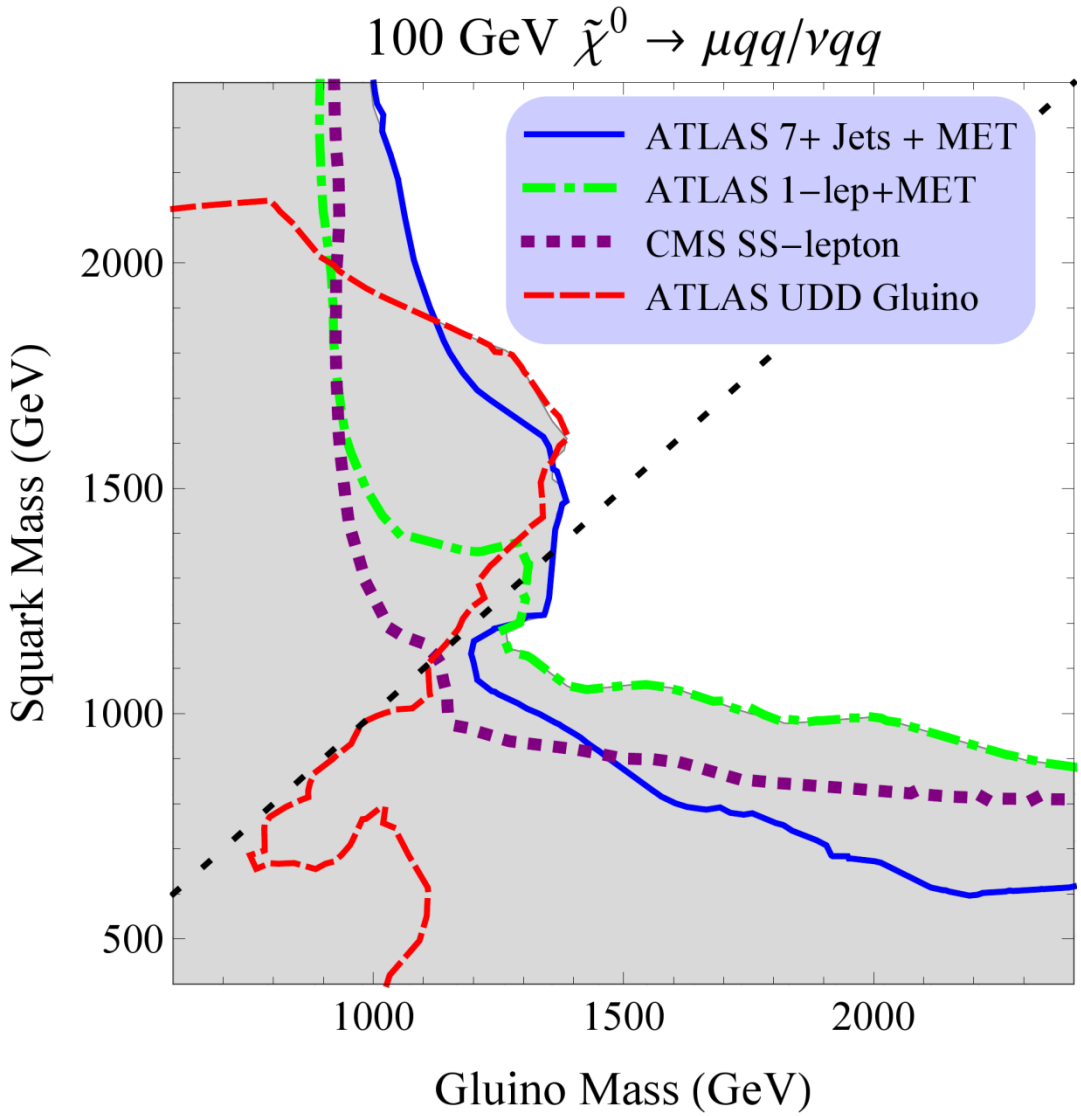
Boosted $\tilde{\chi}^0 \to \tau qq$



A light LSP is produced with large boost from squark/gluino decays

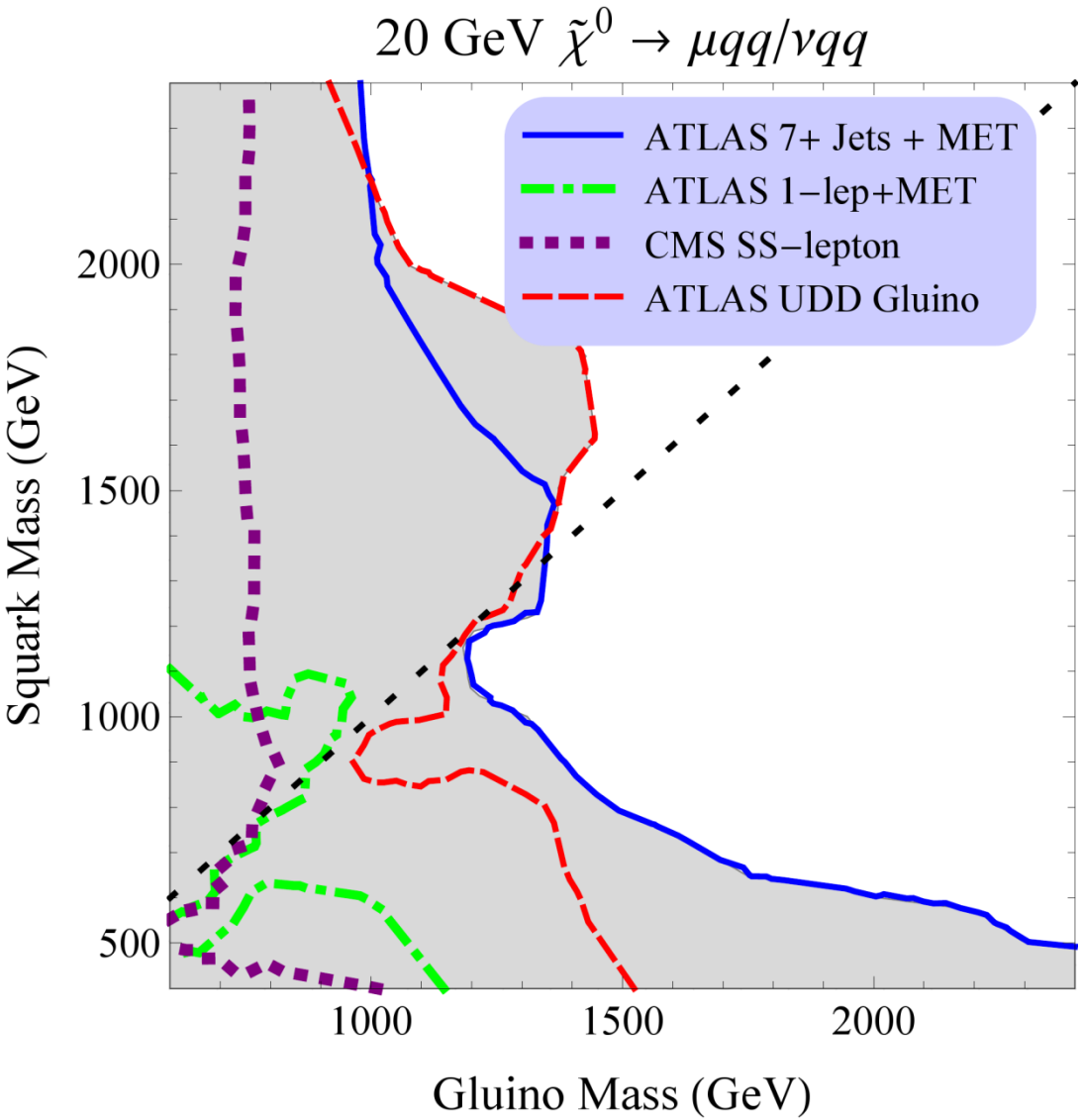
LSP decay products merge into single jet → squark production no longer gives multijet signature

"Generic" LRPV: $\tilde{\chi}^0 \to \mu qq, \nu qq$



MET is highly suppressed compared to R-parity conserving case, but MET searches are still effective

Boosted $\tilde{\chi}^0 \to \mu qq, \nu qq$



A light squark window exists if the LSP is produced with large boost

Bilinear RPV

$$W \supset \mu_{L,i}(L_i H_u + D_i H_u^c) + \mu H_d H_u$$

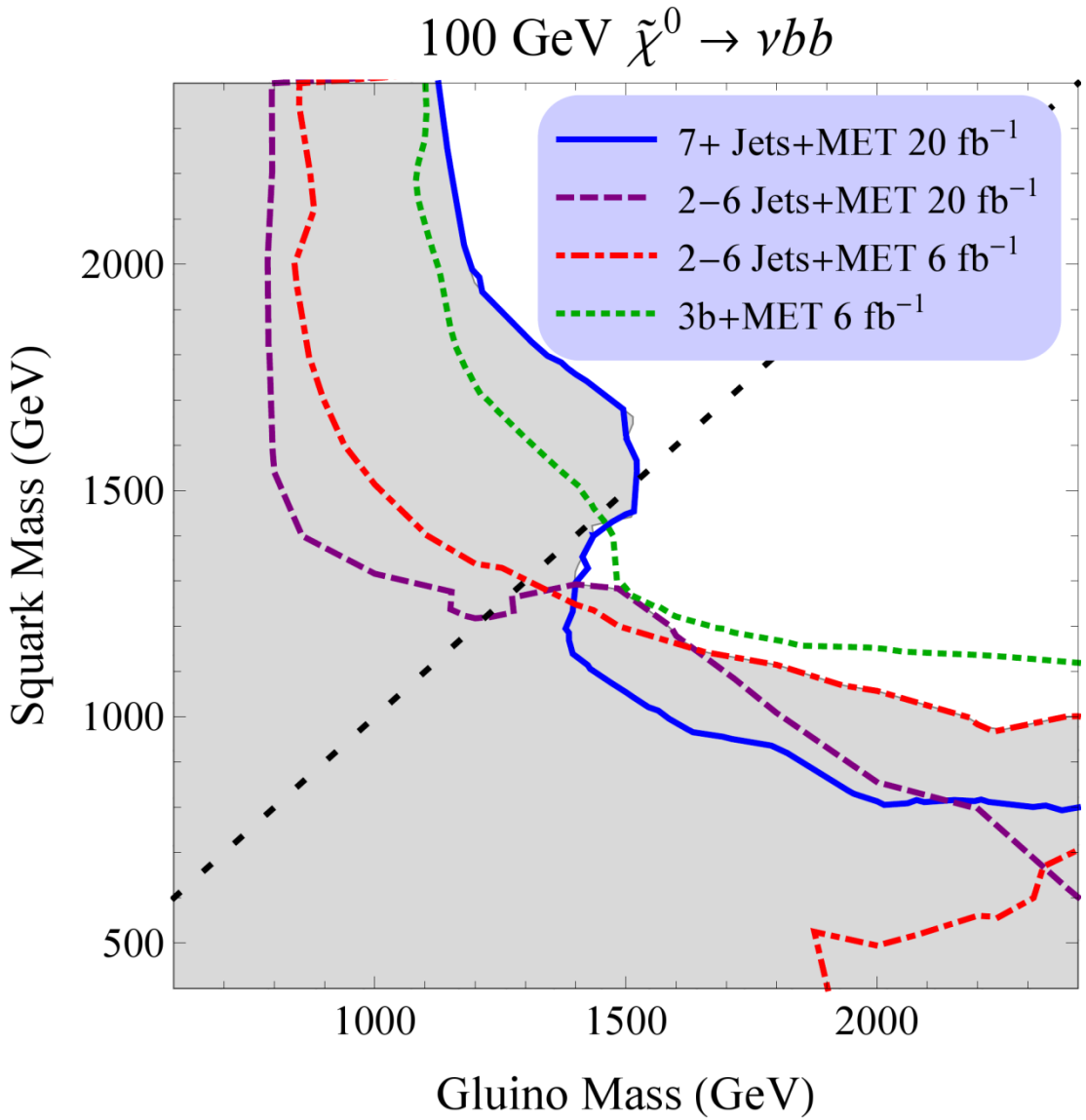
L and H_d mix with angle μ_L/μ, giving trilinears:

$$W \supset \epsilon_i y^e_{jk} L_i L_j E_k + \epsilon_i y^d_{jk} L_i Q_j D_k \qquad \epsilon_i \equiv \frac{\mu_{L,i}}{\mu}$$

Dominant operator is $\epsilon_i y_b L_i Q_3 D_3$:

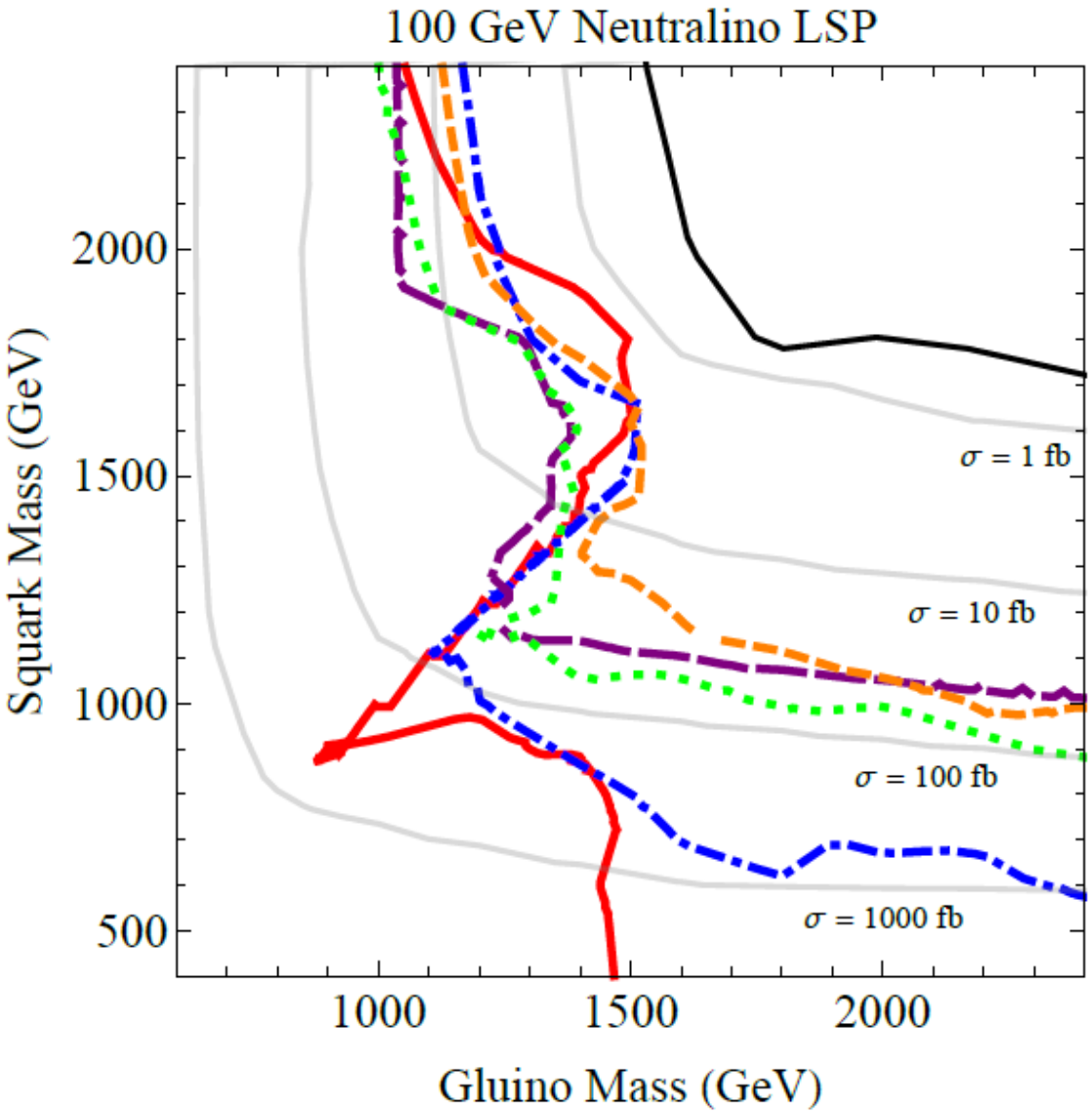
$$m_{\tilde{\chi}^0} < m_t \quad \Longrightarrow \quad \tilde{\chi}^0 \to \nu b \bar{b}$$

Constraints on $\tilde{\chi}^0 \to \nu b\bar{b}$



Light squark window is now closed by jets + MET searches, but displaced decays could still be observed

Summary



All of these RPV scenarios are much less constrained than R-parity conservation

$\tilde{\chi}^0$ decay modes

- qqq
- τqq
- μqq
- $\mu qq/\nu qq$
- νbb
- Stable (ATLAS)

A more realistic spectrum