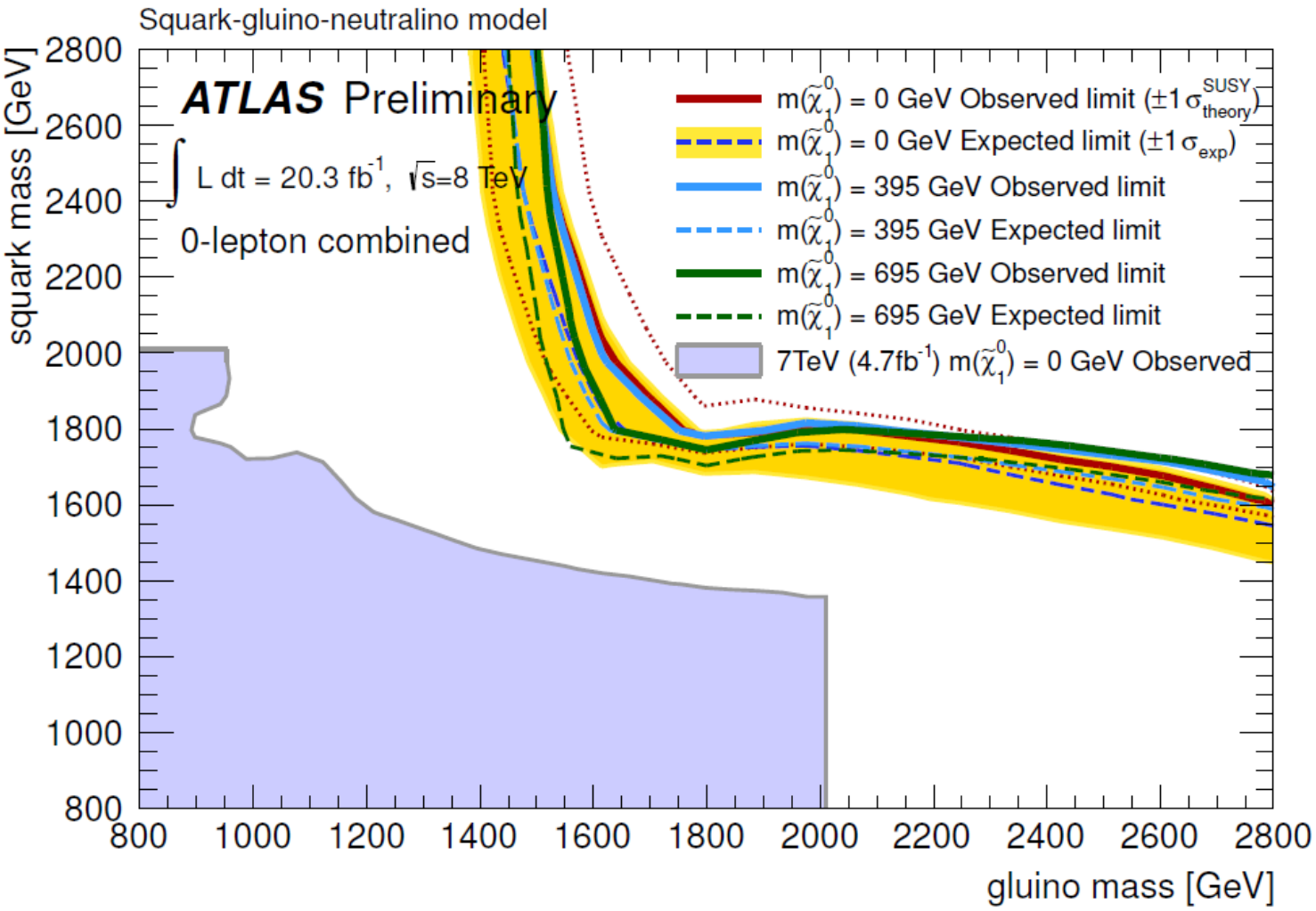
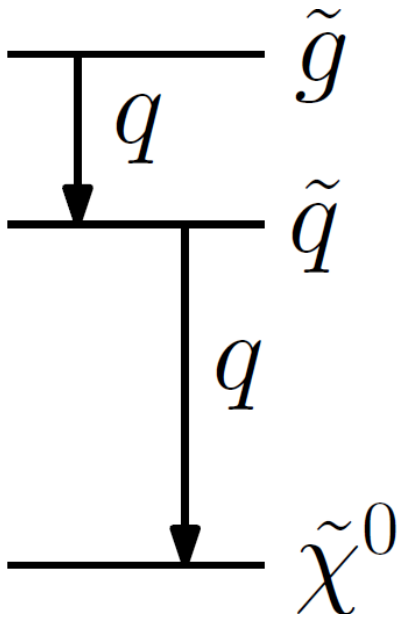
Breaking *R*-parity and Lepton Number

Prashant Saraswat

KITP Snowmass Meeting 05/29/13

The Missing Superpartner Problem





R-Parity Violation (RPV)

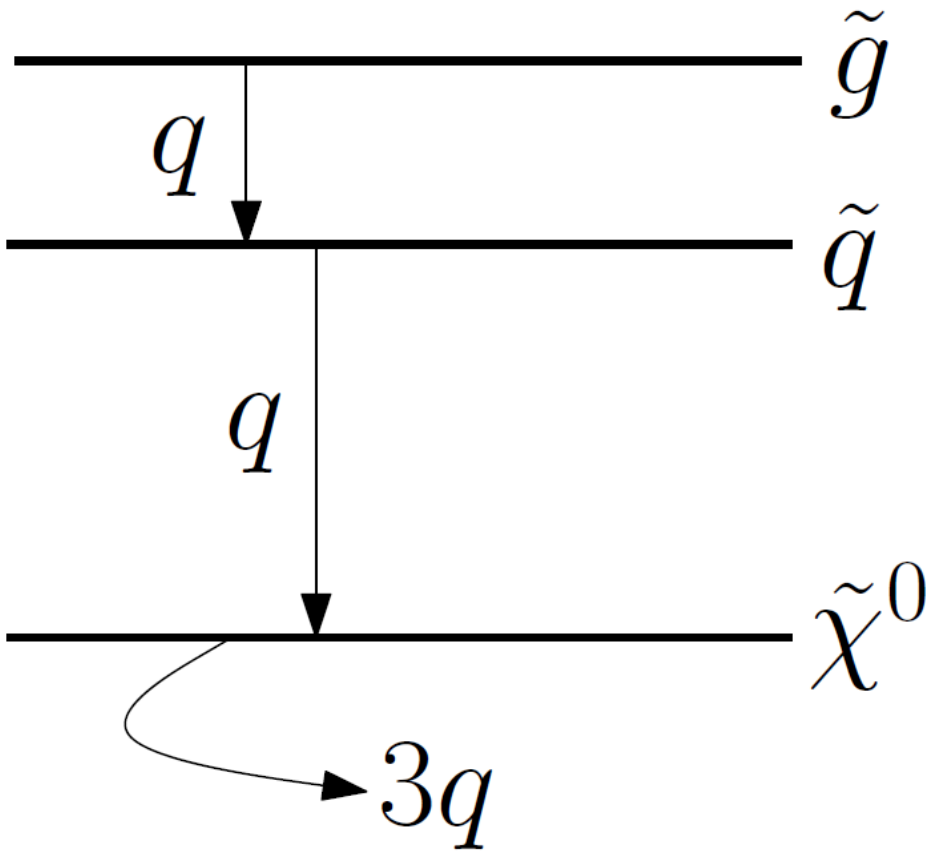
$$W_{\mathrm{RPV}} = \mu_{L_i} L_i H_u$$
$$+\lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k$$

Lepton Number Breaking

Baryon Number Breaking

No stable SUSY dark matter– but can introduce e.g. the QCD axion

A Known Remedy: Baryonic R-Parity Violation



All hadronic signal–swamped by QCD background

Not constrained by existing searches!

Lepton Number Breaking: The Other RPV

Why leptonic RPV?

- Baryonic RPV is problematic for baryogenesis
- Neutrino masses suggest that lepton number may not be a perfect symmetry
- **Can still hide SUSY at colliders while giving unique signatures!**

Bilinear R-Parity Violation

RPV with minimal SU(5) breaking

$$\bar{\mathbf{5}}_L \bar{\mathbf{5}}_L \mathbf{10} \to \lambda_{ijk}(L_i L_j E_k + L_i Q_j D_k + U_i D_j D_k)$$

v.s.

$$\bar{\mathbf{5}}_L \mathbf{5}_{H_u} \to \mu_{L,i}(L_i H_u + D_j H_u^c)$$

Doublet-triplet splitting: H^c must have *SU*(5)-breaking mass $\sim M_{GUT}$ to suppress proton decay

If colored Higgs decouples, then the bilinear operator essentially violates *L* only

Bilinear *R*-Parity Violation

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

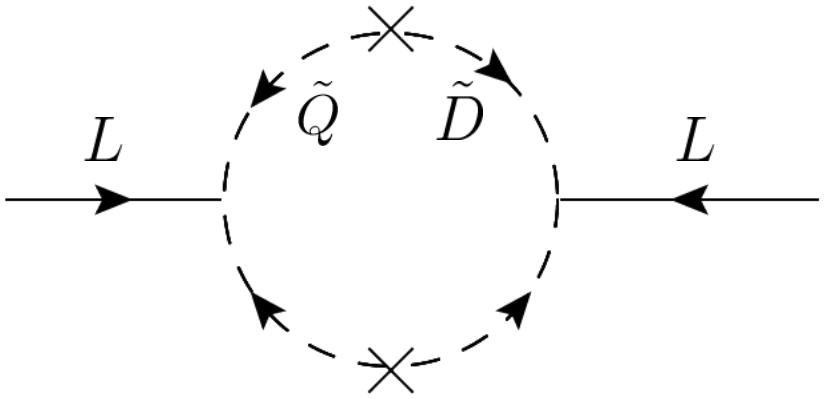
L and H_d mix with angle μ_L/μ, giving trilinears:

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

Predictive: largest *R*-parity violating effects involve heavier generation particles, particularly bottoms

Constraints on Bilinear R-Parity Violation

L violation → Contributions to neutrino masses



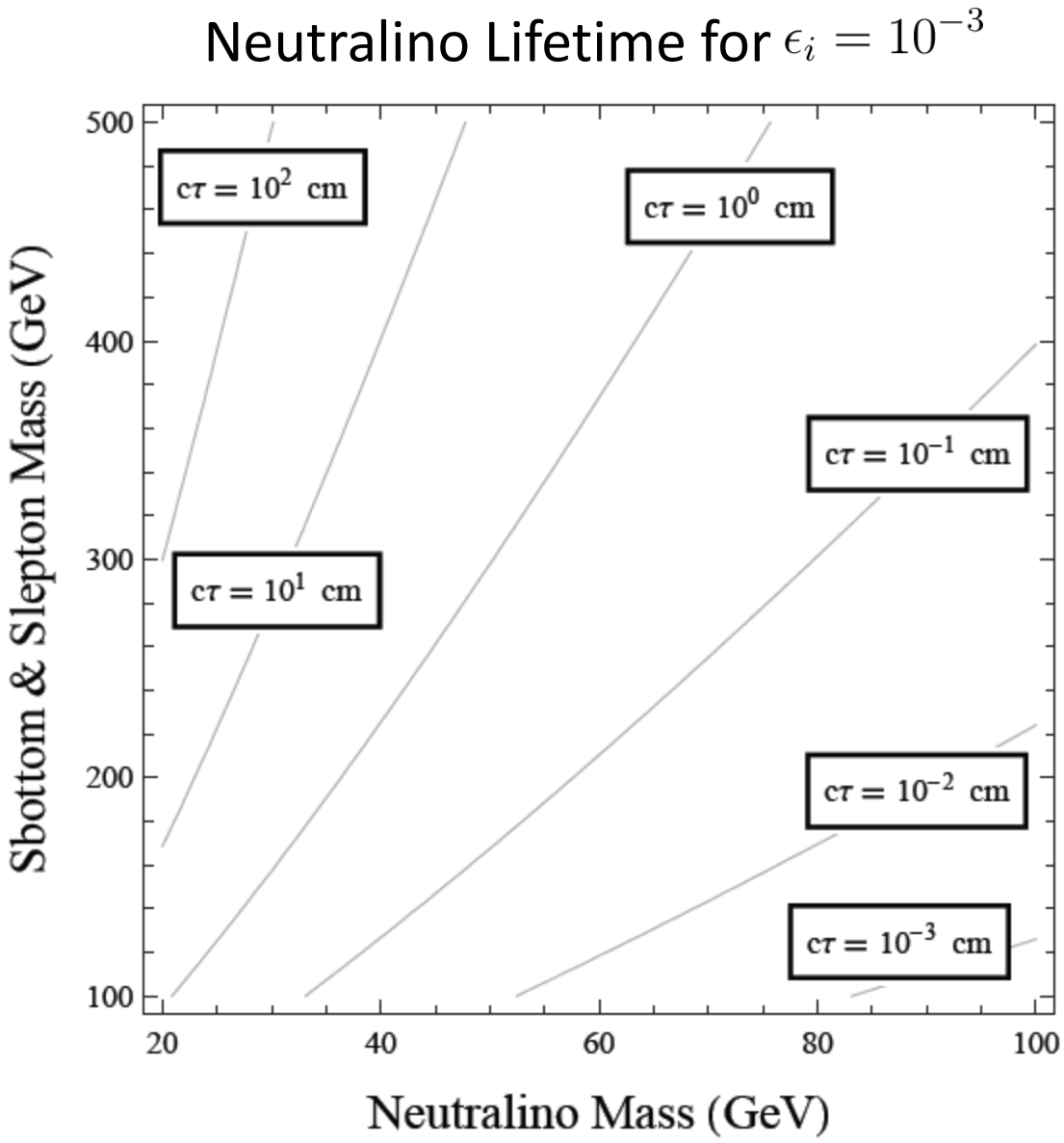
$$\Delta m_\nu \sim \frac{\epsilon^2 y_b^4}{16\pi^2} \frac{v^3}{\widetilde{m}_b^2}$$

Requires $\epsilon \lesssim 10^{-3}$ – also avoids bounds from proton decay in GUT completion

BRPV with Neutralino LSP

Neutralino can decay to $\nu b\bar{b}$ or $\nu\tau l$ depending on sfermion masses

ϵ small enough to satisfy neutrino mass constraints implies macroscopic decay length

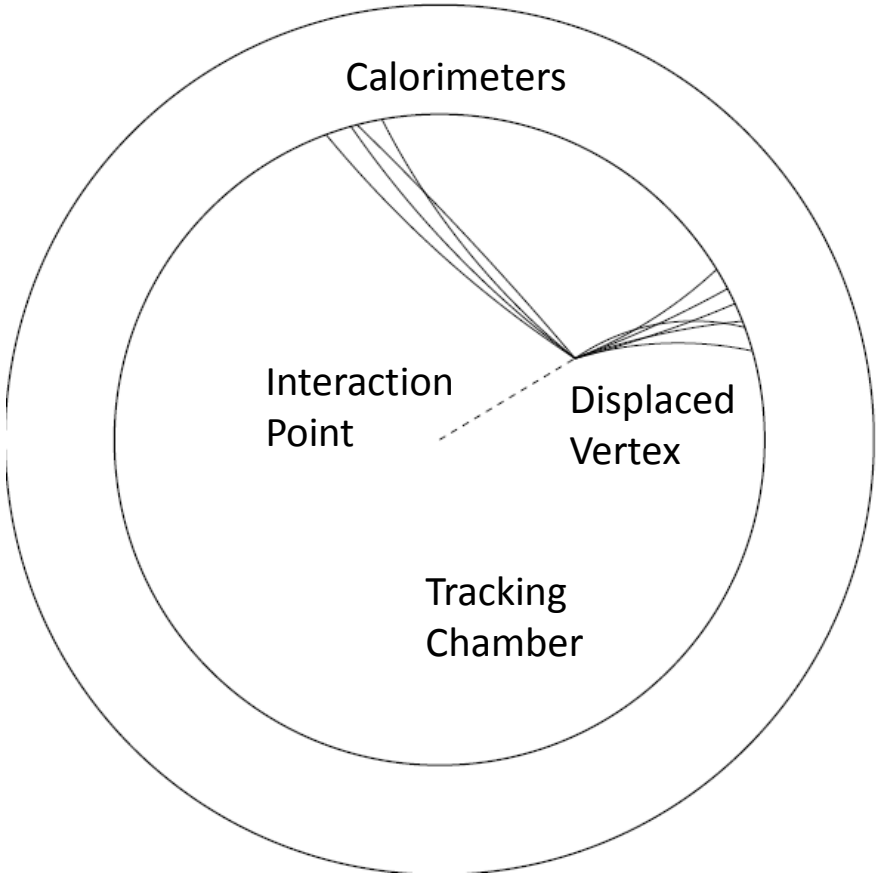


Displaced Vertices

Small R-parity violating couplings →

Macroscopic LSP decay length (> .1 mm)

Unlike any Standard Model signal!



Typical inner detector size ~ meter

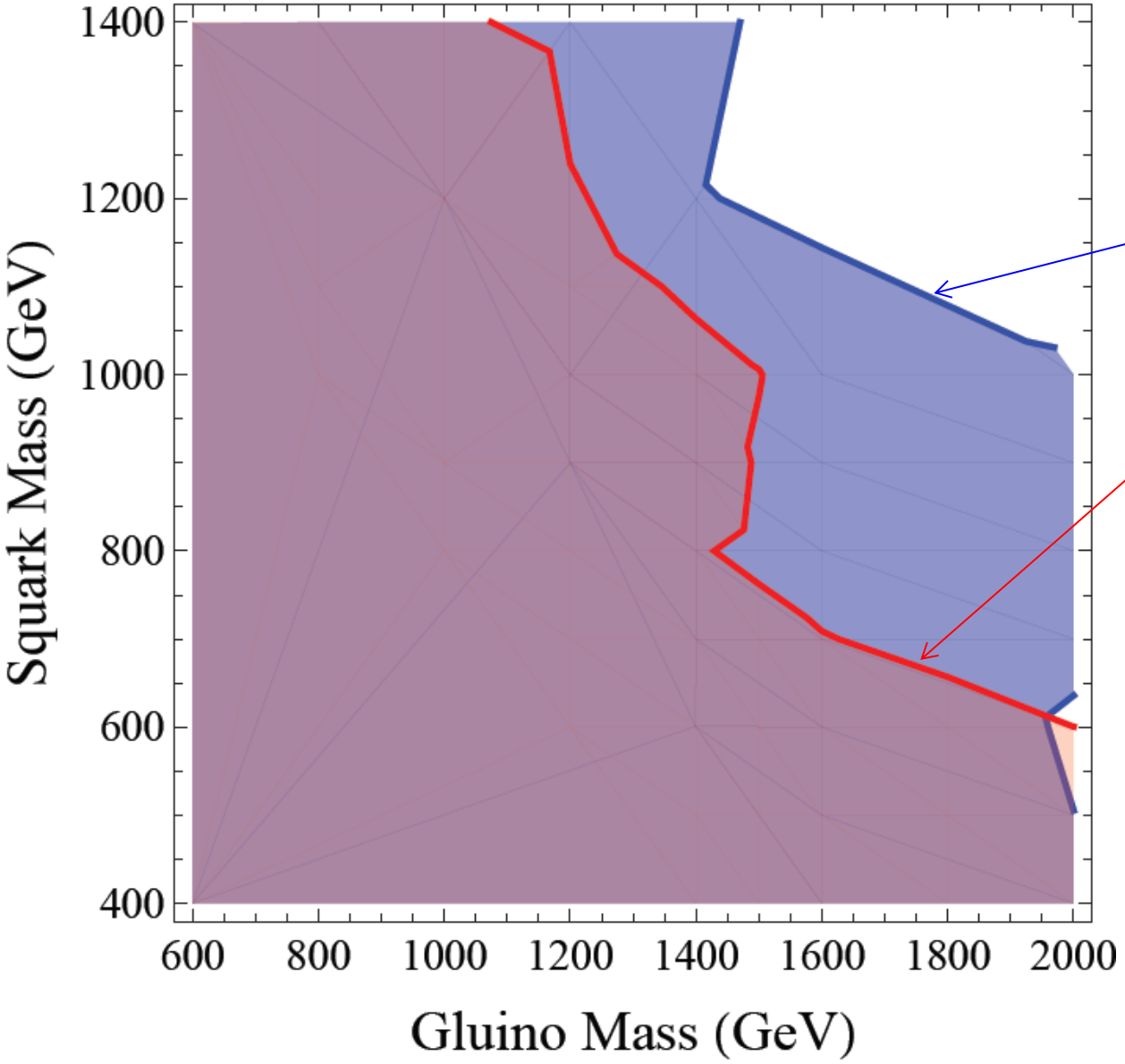
Displaced Vertices and LHC Searches

LHC searches usually require charged tracks to pass within ~1 mm of beamline

- Lepton reconstruction typically fails
- B-tagging of jets fails
- CMS analyses reject jets without good tracks

Many searches no longer place constraints!

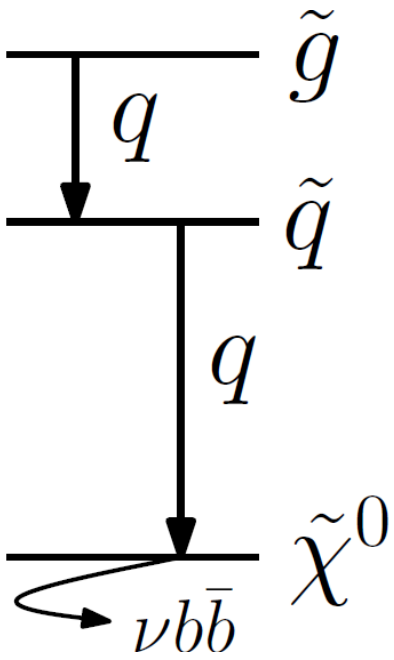
Constraints on Bilinear RPV



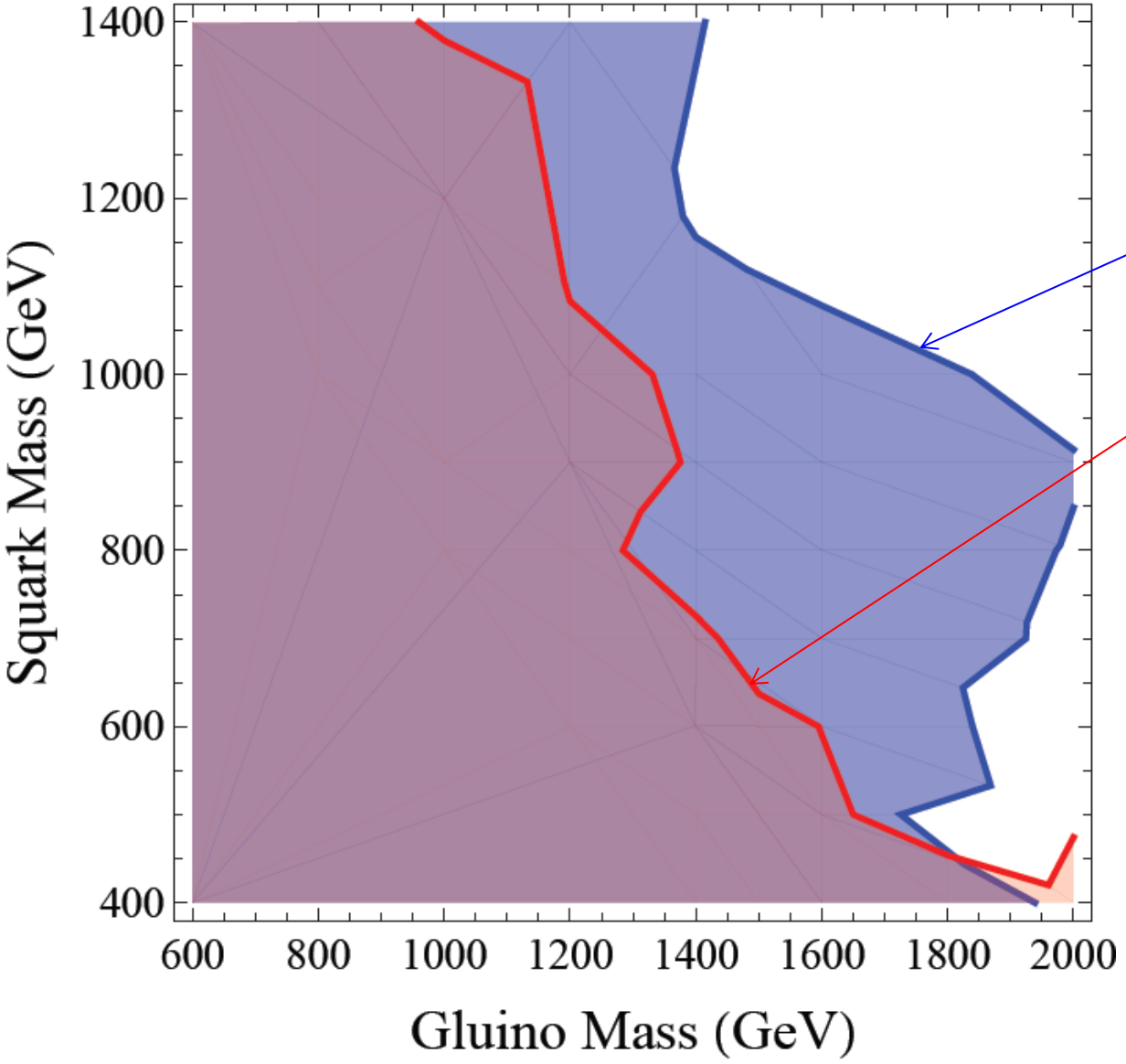
ATLAS Jets + MET Searches:

8 TeV 6 fb^{-1}

7 TeV 5 fb^{-1}



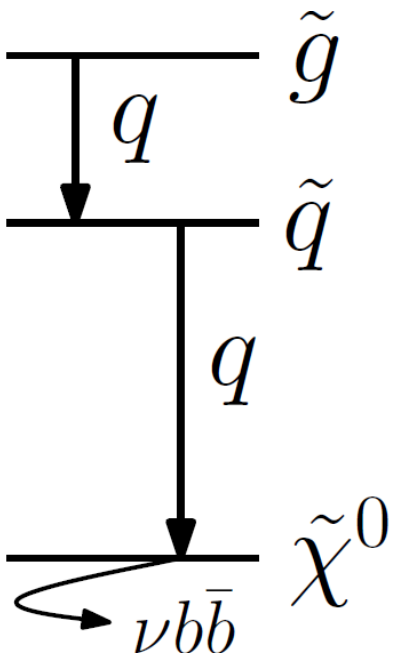
BRPV Constraints, Fudge Factor 1.3



ATLAS Jets + MET Searches:

8 TeV 6 fb^{-1}

7 TeV 5 fb^{-1}



A Natural LRPV Scenario: Taus + Jets

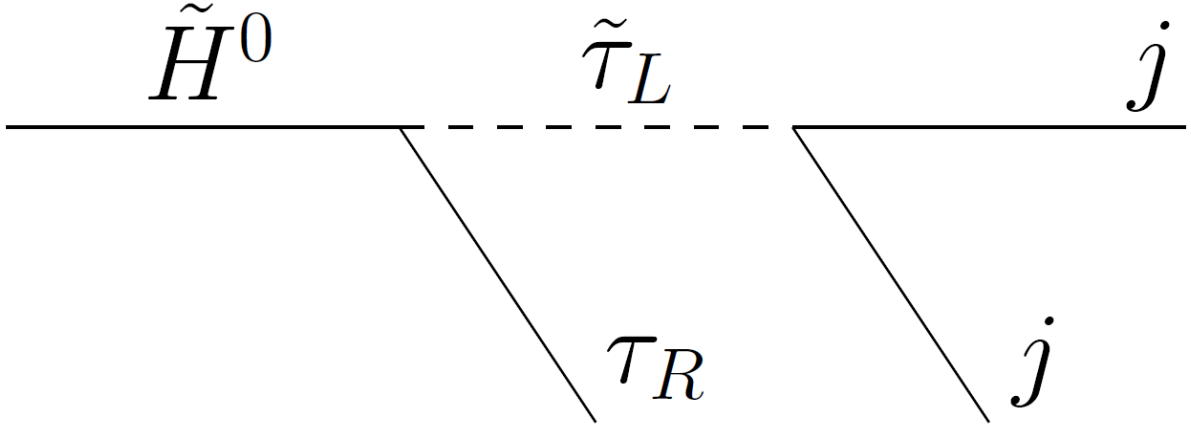
(Preliminary)

Taus + Jets from LRPV

Assume:

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

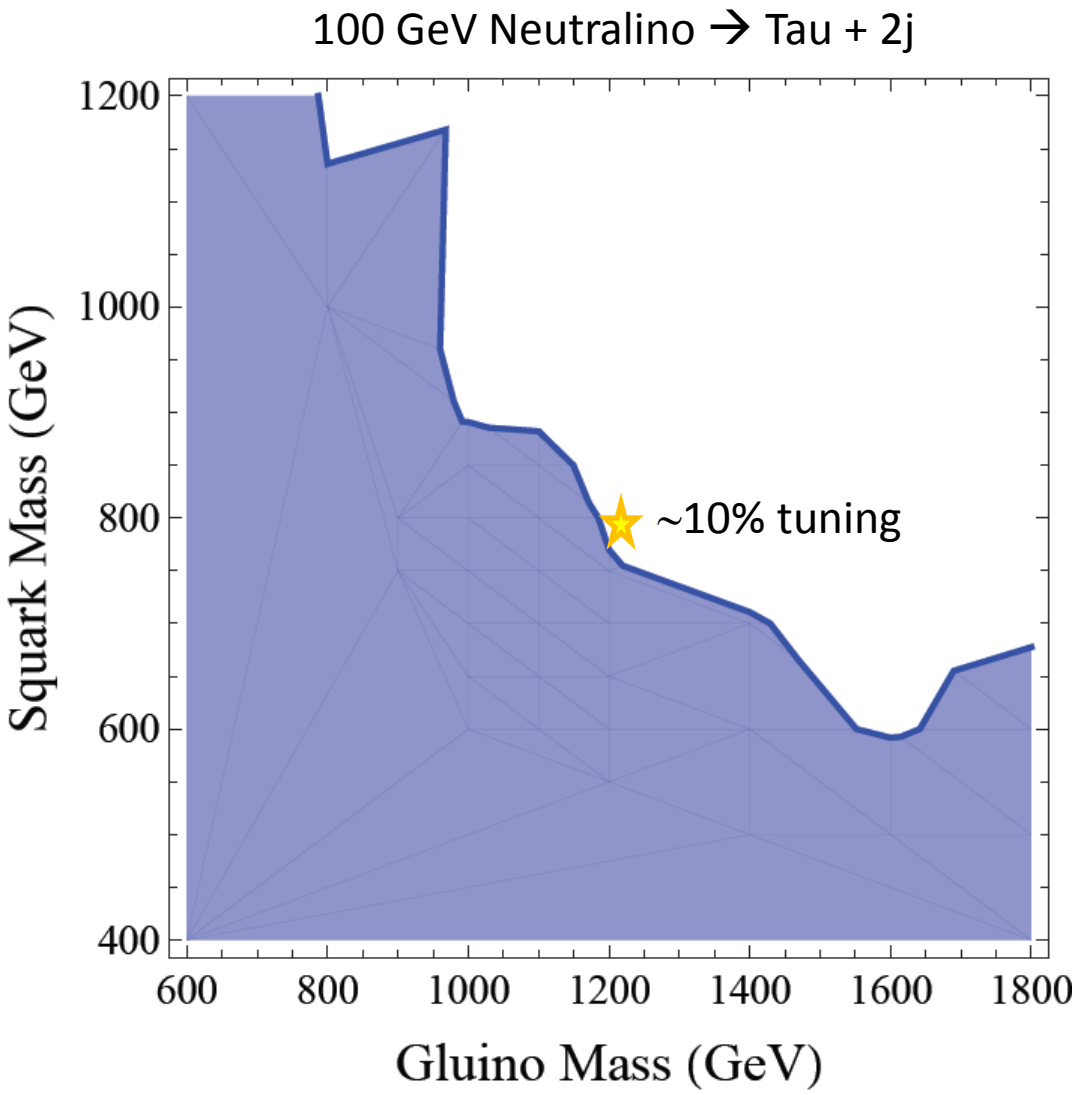
Then the LSP decays dominantly to tau + 2 jets:



Bounds on Taus + Jets

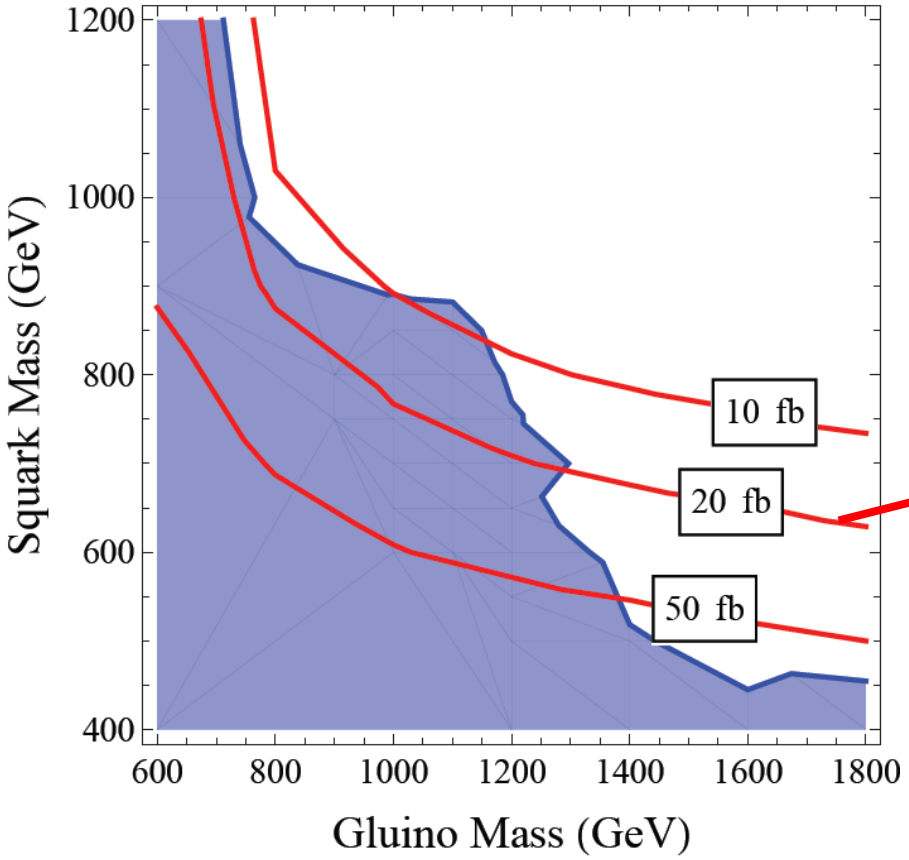
Main constraints:

- ATLAS taus + MET (21 fb^{-1})
- ATLAS many (6+) jets + MET (6 fb^{-1})

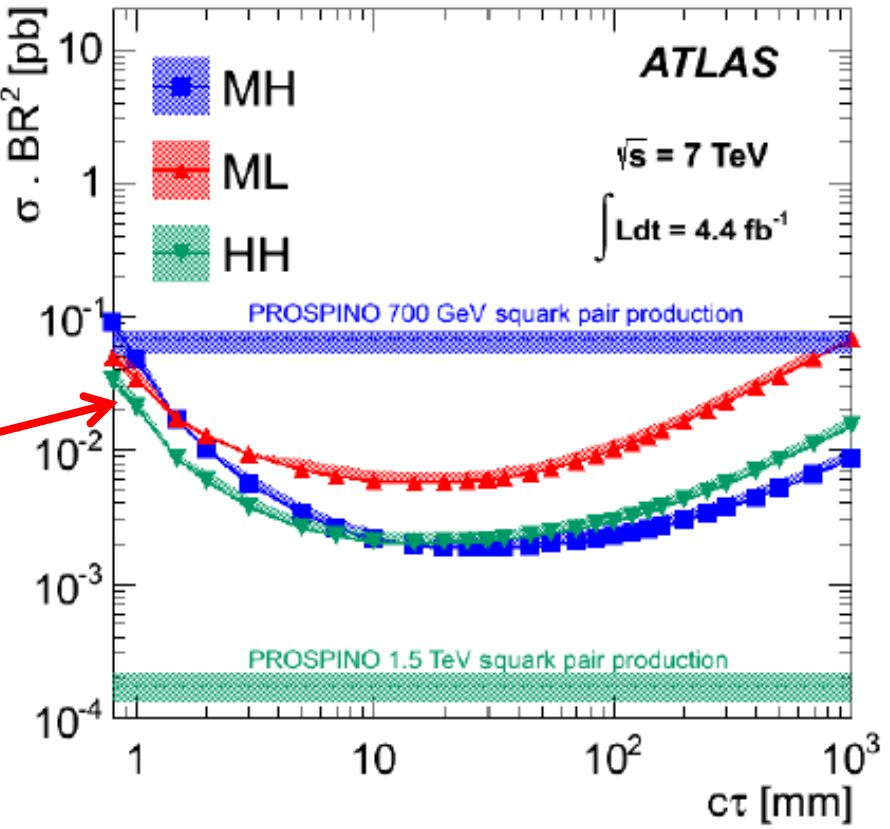


Displaced Taus + Jets

Search for prompt taus no longer sensitive
Some signal efficiency for displaced vertex w/muon search



ATLAS Displaced Vertex with Muon



Conclusions

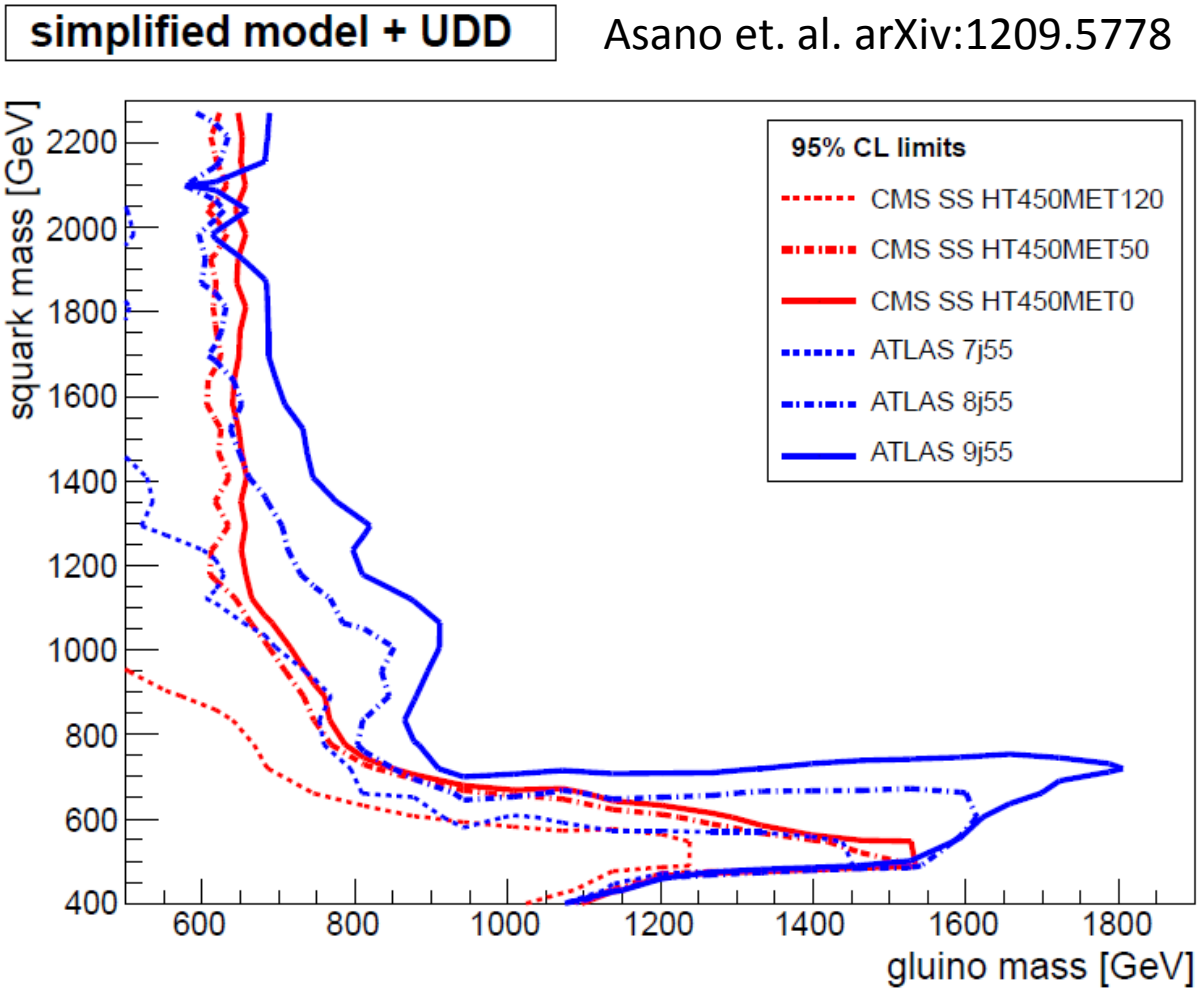
Leptonic RPV can greatly relax the bounds on SUSY, despite the presence of leptons and MET

Motivates LHC searches:

- Many jets + small MET
- Many jets + leptons (including taus)
- Displaced vertices

Backups

How Not to Hide SUSY (very well)



If cascade decays producing W and Z bosons are allowed, many bounds come into effect, e.g.

$$\tilde{q} \to q\tilde{\chi}^{\pm}$$
$$\to qW^{\pm}\tilde{\chi}_0$$
$$\to 4qW^{\pm}$$

Searches for Displaced Vertices

Currently a limited number of LHC searches:

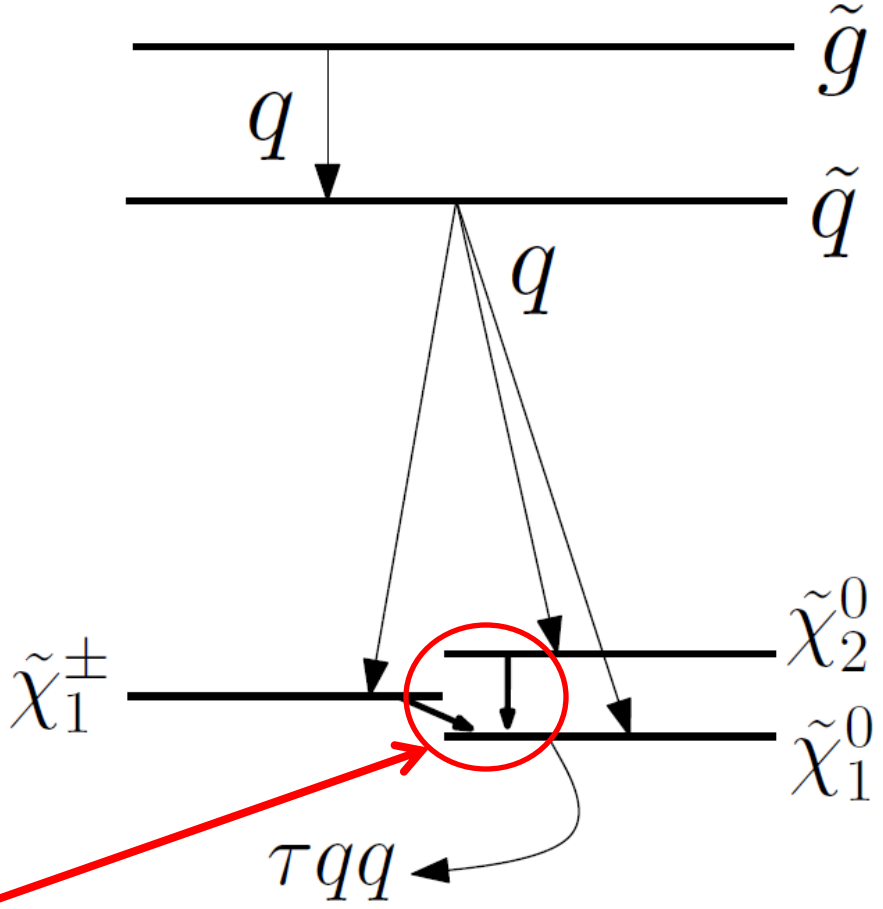
- ATLAS: Displaced vertex with muon
- ATLAS: Decays in the muon spectrometer
- CMS: Displaced dileptons (opposite sign, same flavor)
- ATLAS and CMS searches for displaced photons

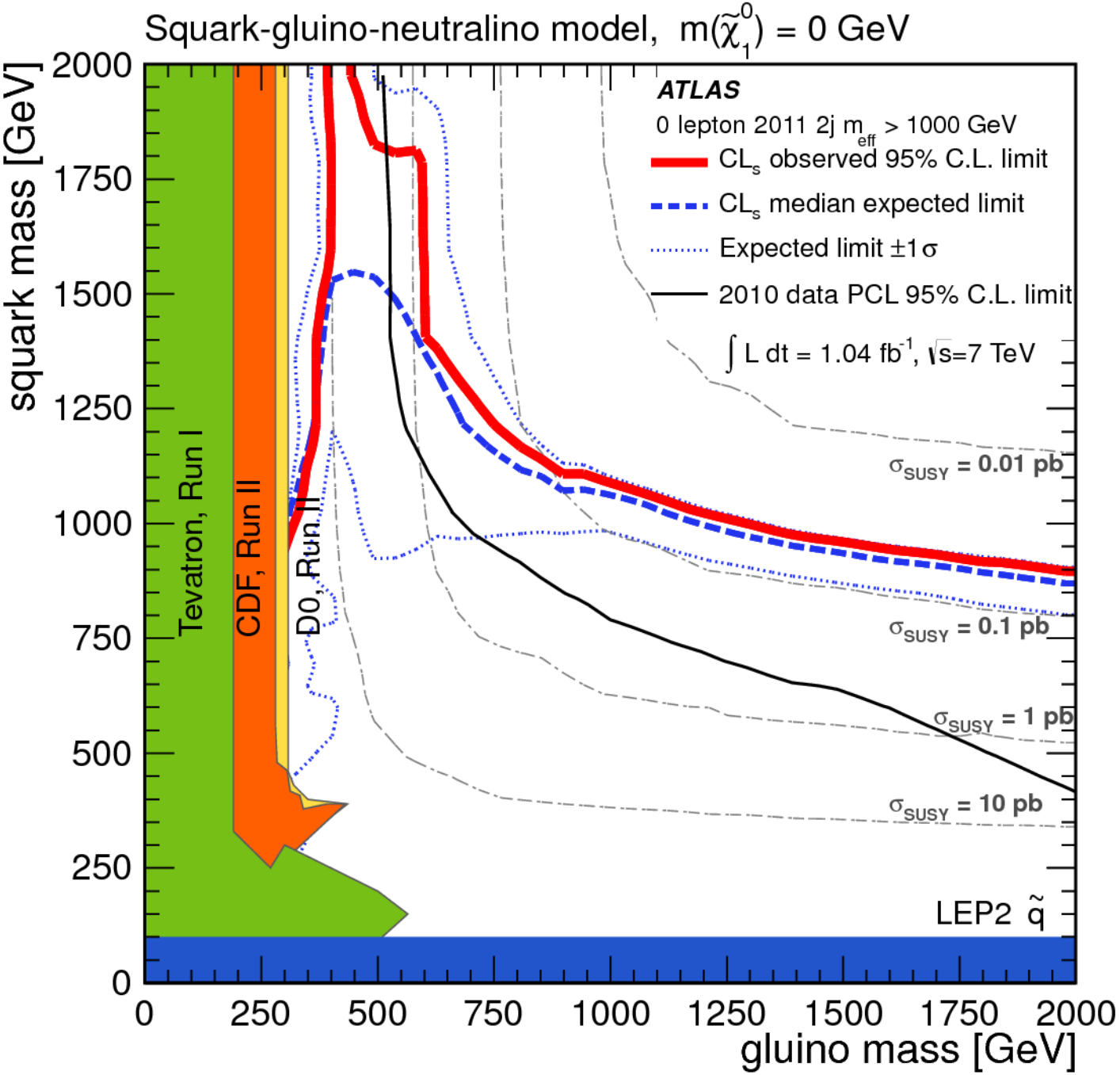
Higgsino LSP spectrum

All squarks are degenerate

Bino and wino are heavier than squarks

Higgsinos are nearly degenerate: their cascades only produce soft particles





Bounds from 2-jet + MET search only