Highlights from SUSY Searches with ATLAS

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on behalf of the ATLAS Collaboration

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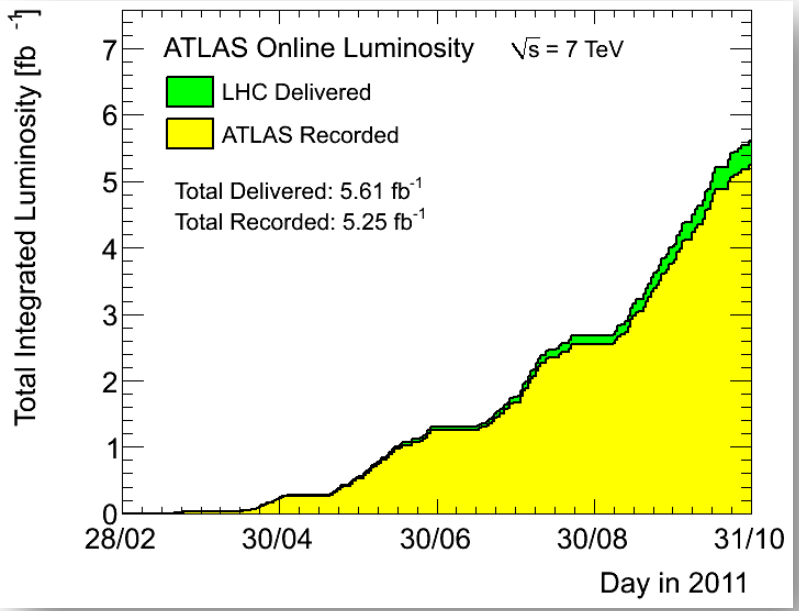
Outline

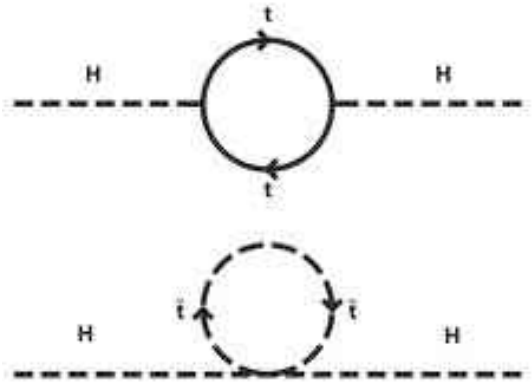
- Strategy for SUSY searches at LHC
- R-parity conserving supersymmetry
  - strong-production channels
  - 3rd-generation sparticle searches
  - direct gaugino production
- R-parity violation (RPV)
  - eμ final states
  - stau LSP in multileptons
- Long-lived particles
  - displaced vertices
  - disappearing tracks
- Summary – outlook

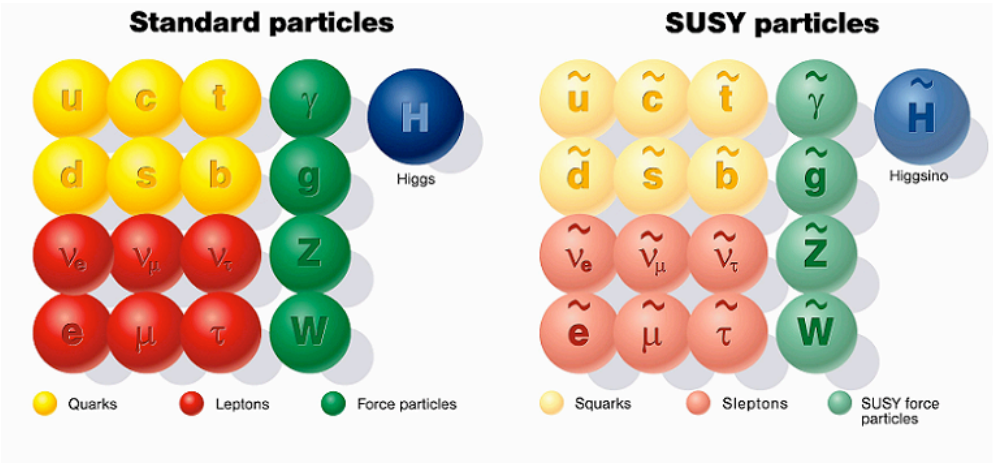


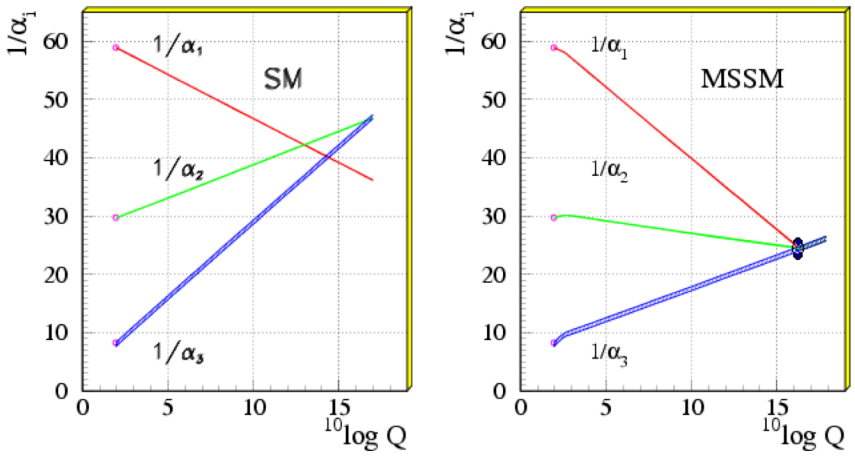
Results for up to 5 fb^{-1} pp collisions at √s = 7 TeV are presented here

Supersymmetry

- SUSY = global symmetry between fermions & bosons
  - all SM particles have SUSY-partners with spin difference of ±1/2
- Theoretical motivation
  - Higgs mass stabilisation against loop corrections (fine-tuning problem)
  - unification of gauge couplings at single scale
  - dark matter candidate: lightest supersymmetric particle (LSP)

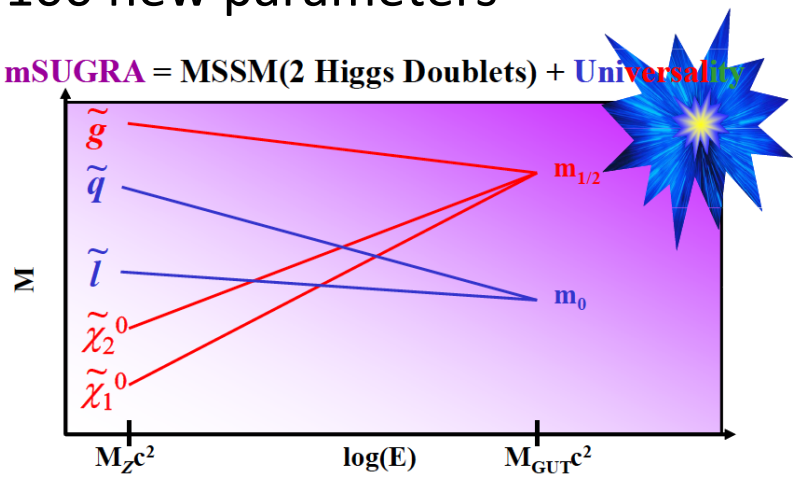




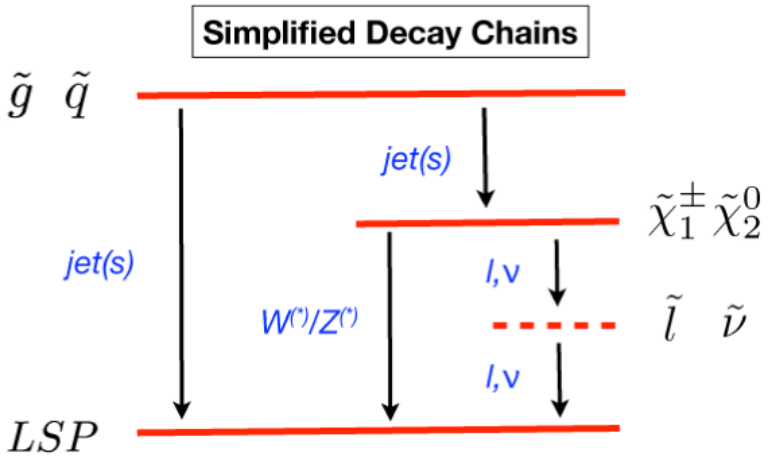


Theoretical models

- Simplest extension of SM (MSSM) has > 100 new parameters
- How to interpret LHC results?



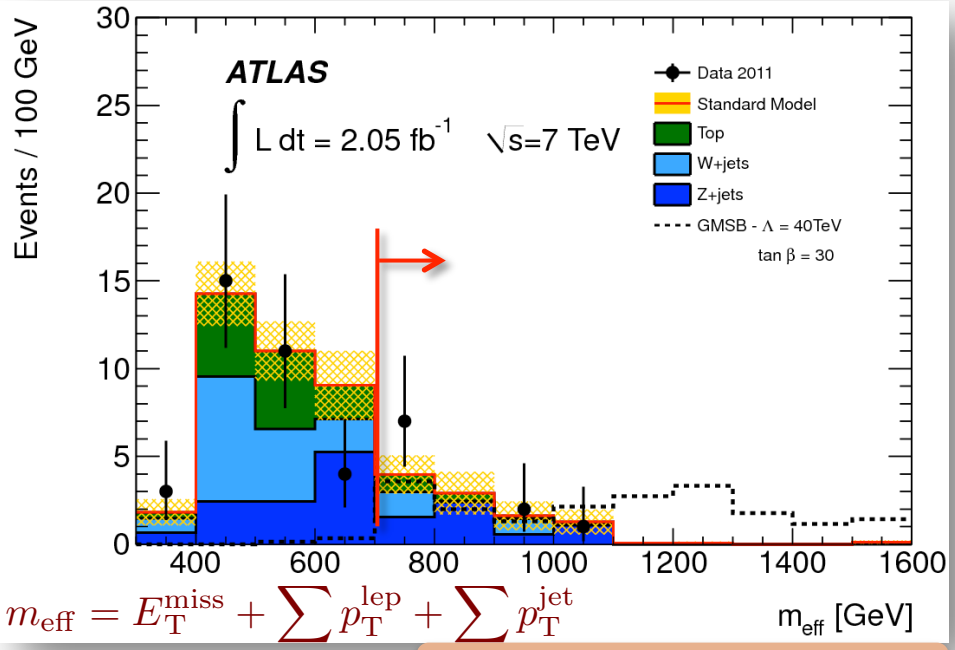
1. Top-down approach
   - SUSY breaking mechanism → different models
     - Gravity mediated (SUGRA)
     - Gauge mediated (GSMB)
     - …
   - GUT scale unification → few free parameters
2. Bottom-up approach
   - Phenomenological models
     - assume masses and hierarchy
     - scan remaining parameters
   - Simplified models
     - specific decay chain



E_T^{miss}-based analyses

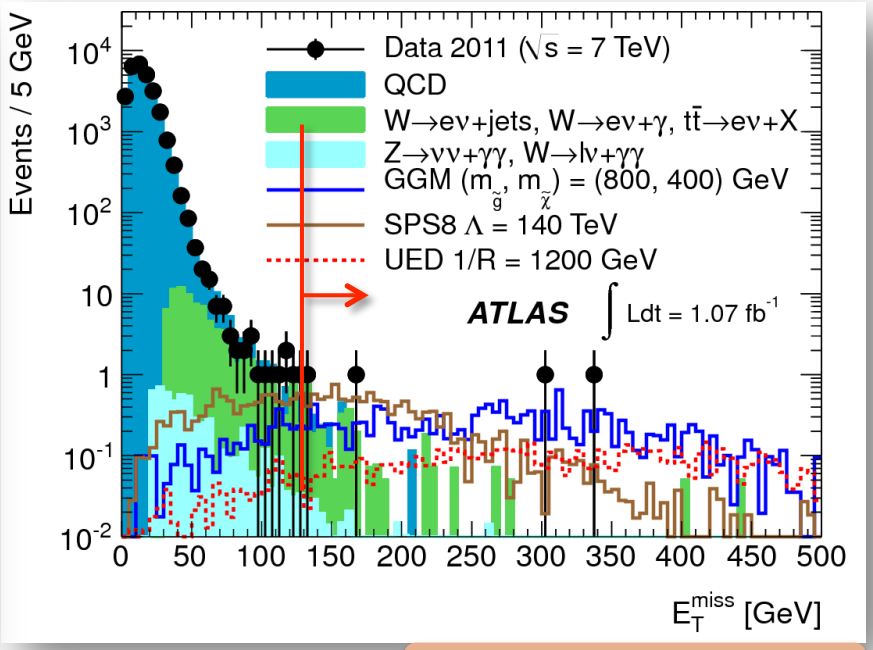
- Many jets + large E_T^{miss} + leptons(incl. taus)/photons/bjets
- Cut sufficiently hard to reduce largely unknown background processes (fake MET, fake-leptons from QCD)
- Apply discriminating cuts to enhance signal/background ratio

$2\tau + E_T^{miss}$ analysis



arXiv:1203.6580 [hep-ex]

$2\gamma + E_T^{miss}$ analysis



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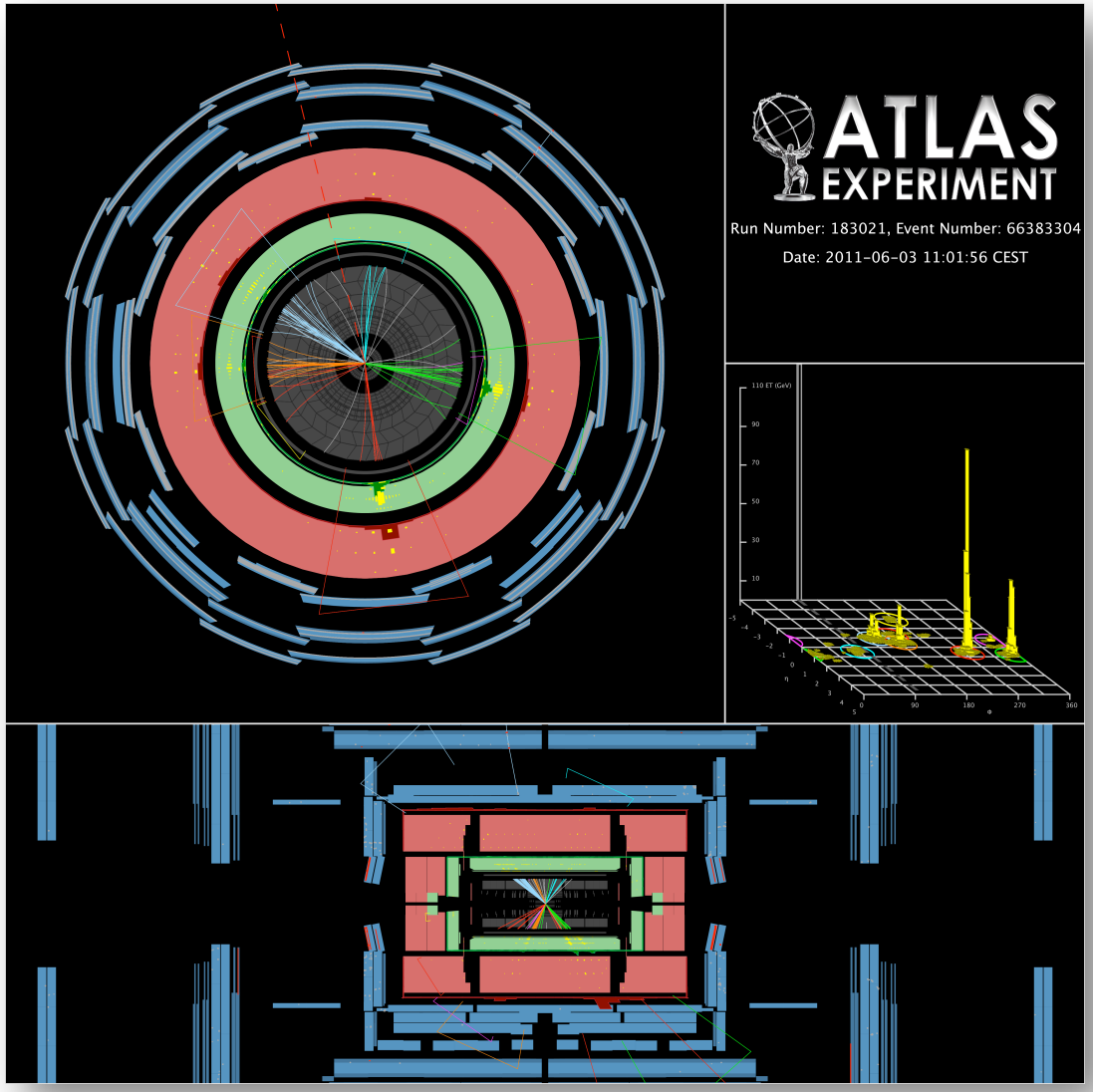
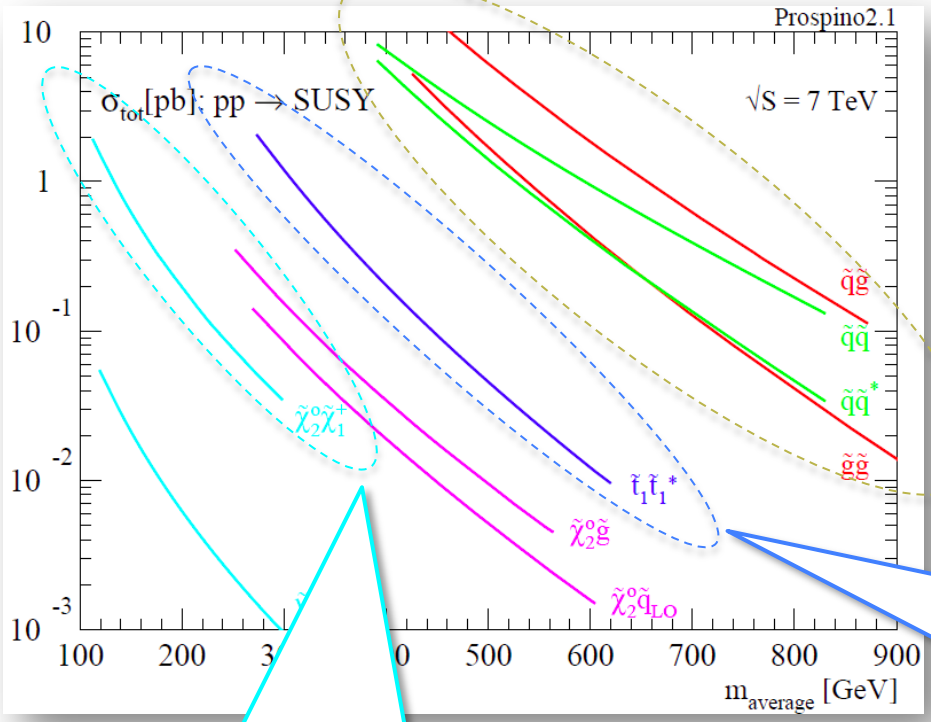
A high-missing-E_T high-M_{eff} event



- M_{eff} = 1810 GeV
- MET = 460 GeV
- 5 jets with p_T > 40 GeV (528, 418, 233, 171 and 42 GeV)

SUSY searches strategy



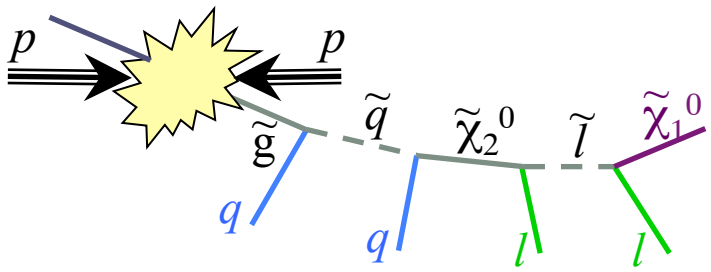
Strong-production channels
- Copious production at hadron colliders
- E_T^{miss}-based generic search channels
- Plus more exotic channels

Third-generation sparticle searches
- Expected from naturalness to be *O*(<TeV)
- Expected lighter than other squarks due to mixing
- Can search for more specific final states

Leptons/photons searches
- colored spartners too heavy
  → direct gaugino production
- RPV decays
- gauge-mediated models

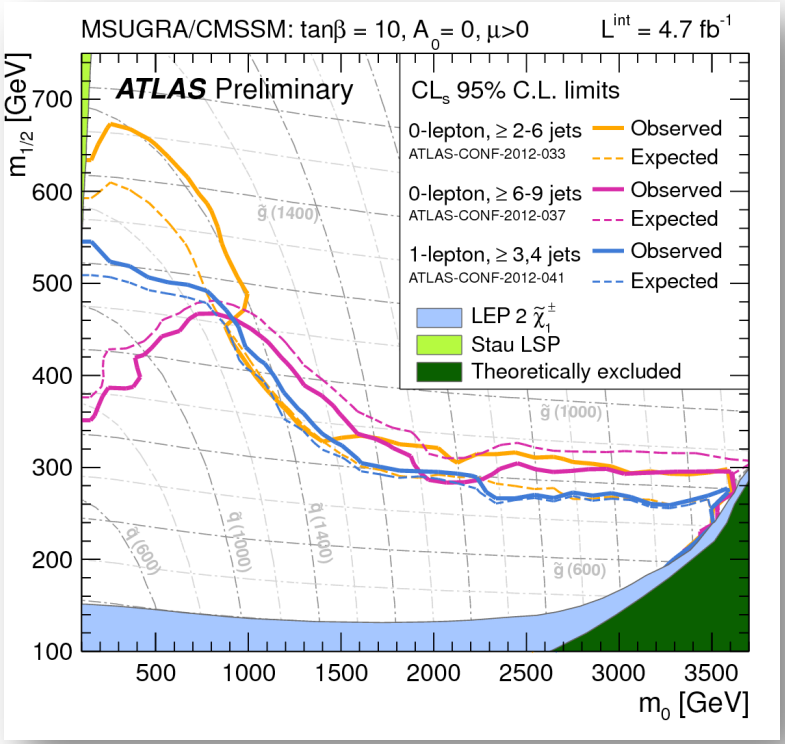
Strong production – top-down approach

- SUSY particles mainly produced via strong interaction (gluino, squarks) at hadron colliders
- If R-parity is conserved:
  - sparticles produced by pair
  - cascade decay to invisible LSP
- ⇒ Search for
  jets + E_T^{miss} + 0,1,2-leptons



Benchmark interpretation in mSUGRA/CMSSM

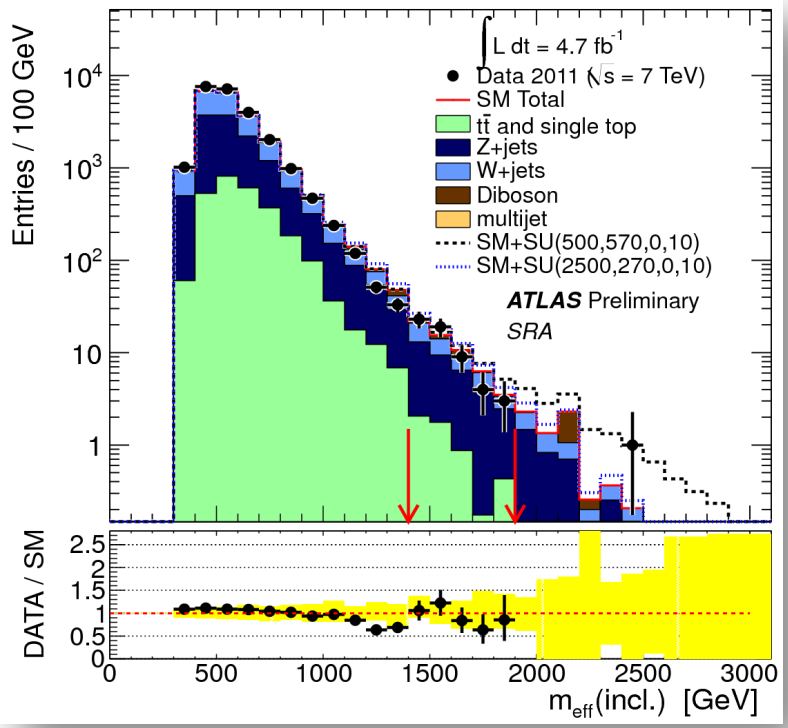
- Exclude m ~ 1400 GeV for m(~q) = m(~g)
- 3 very different analyses confirm exclusion limit at high m_0

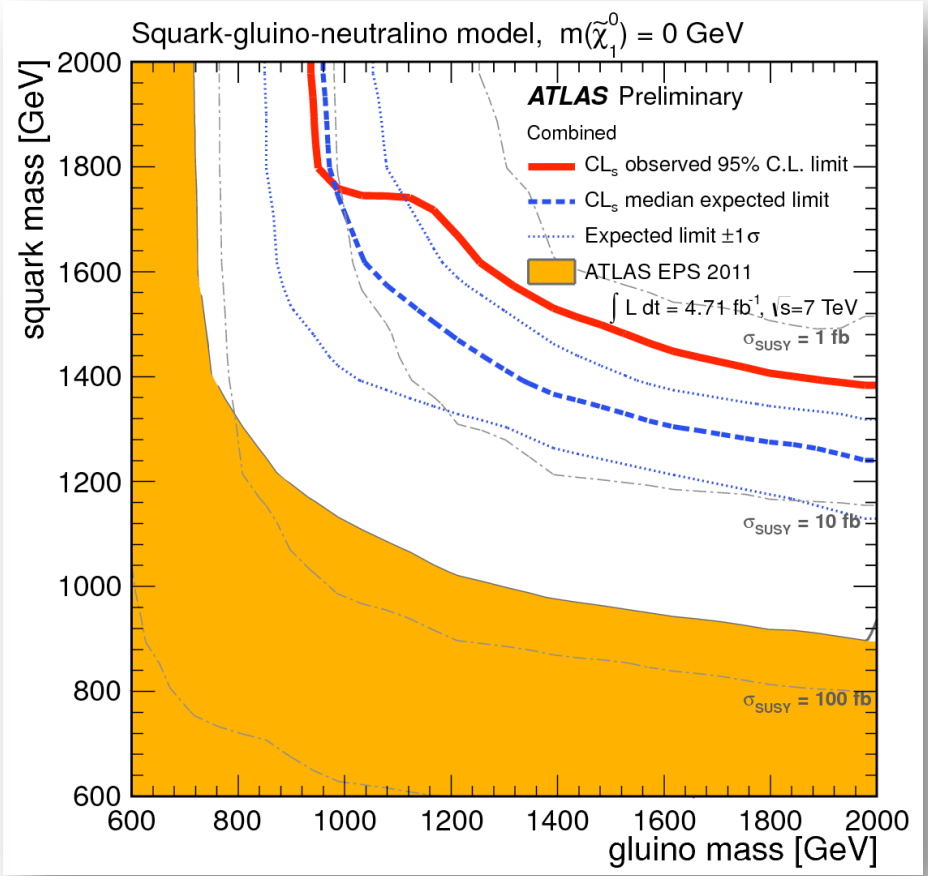


ATLAS-CONF-2012-041

Strong production – bottom-up interpretation

- Pheno MSSM model
  - only gluino + squark + (light) LSP
  - 0-lepton + jets + MET





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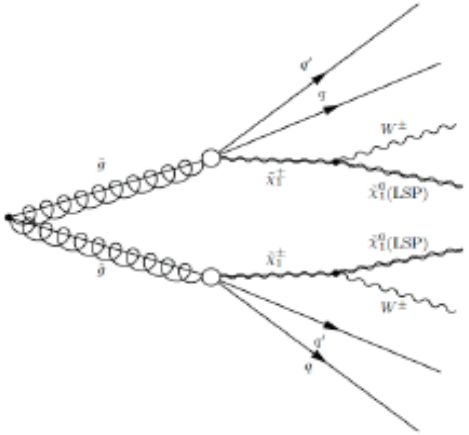
Strong production – bottom-up interpretation

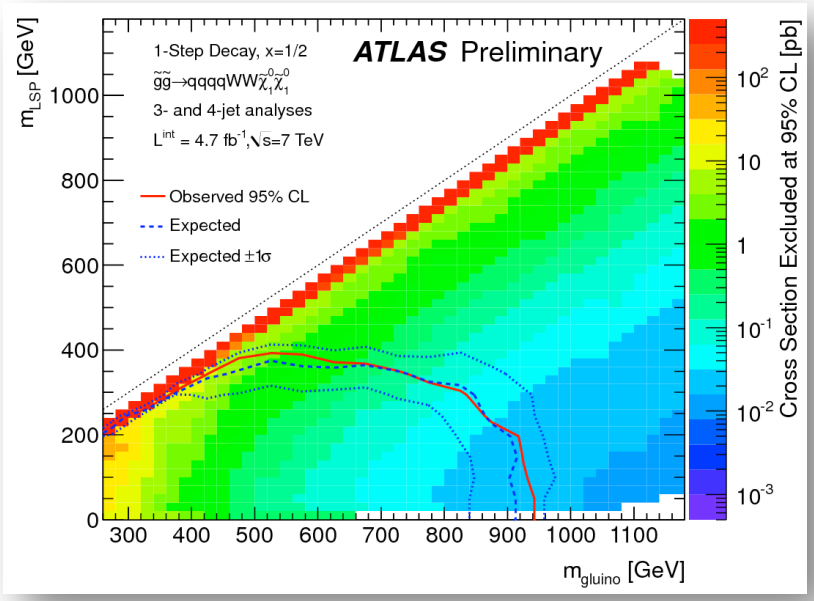


$$x = \frac{m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}/\tilde{q}} - m_{\tilde{\chi}_1^0}}$$

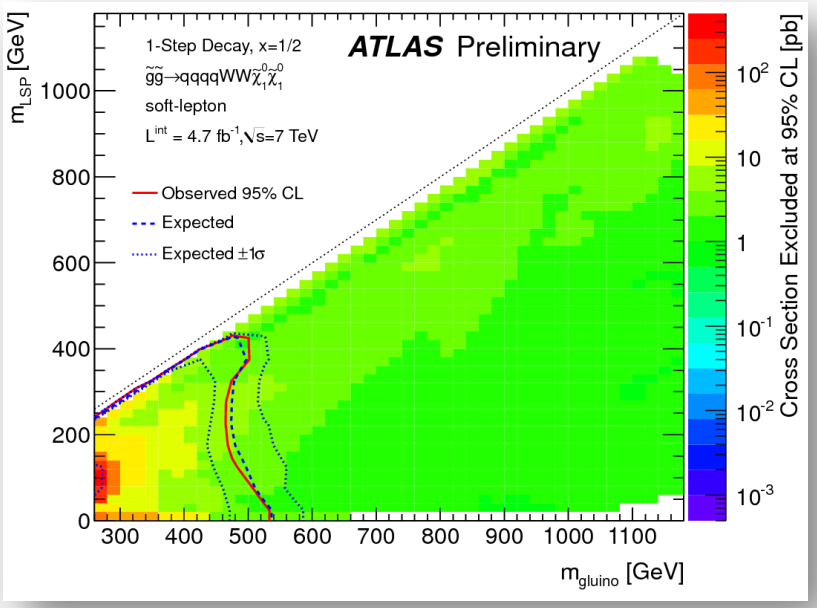
Simplified models

- Only gluino + chargino + LSP are accessible
- 1-step decay → 1-lepton + jets + MET

1 high-p_T lepton + jets +MET



1 low-p_T lepton + jets +MET
Enhanced sensitivity on compressed spectrum: gluino and LSP almost degenerate in mass → soft lepton



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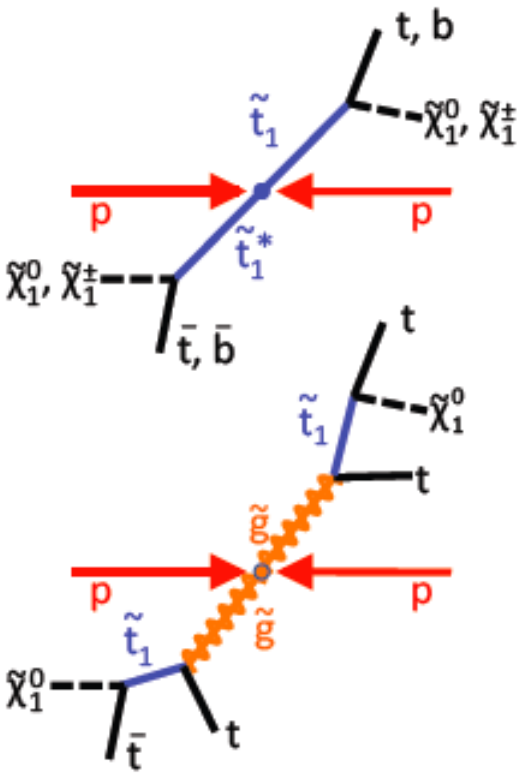
Third-generation squarks

- Main motivation for TeV-scale SUSY is solving hierarchy problem
- If SUSY solves the hierarchy problem **naturally**, then 3rd gen. squarks must be light (few hundred GeV)

Possible search strategies

- If gluino is light enough ➞ dominant process
  - gluino pair production
  - $\tilde{g} \to b\tilde{b}_1, \tilde{g} \to t\tilde{t}_1$
  - search for b-jets + MET + jets
- If only 3rd gen. squarks are light
  - sbottom pair production ➞ 2 b-jets + MET
  - stop pair production ➞ 2 opposite-sign leptons + MET + jets

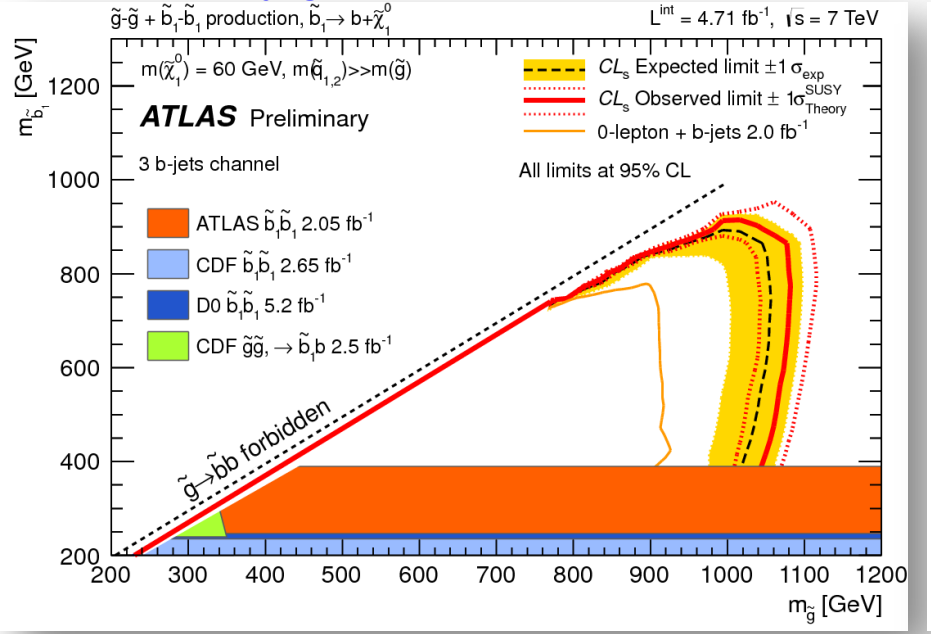


Gluino-mediated scalar top and bottom

- Gluino pair production and on- or off-shell decay to stop-top or sbottom-bottom $\tilde{g} \to \tilde{b}_1 b$ or $\tilde{g} \to \tilde{t}_1 t$
- Selection: large MET + 3 or 6 jets (3 b-jets) + ℓ-veto

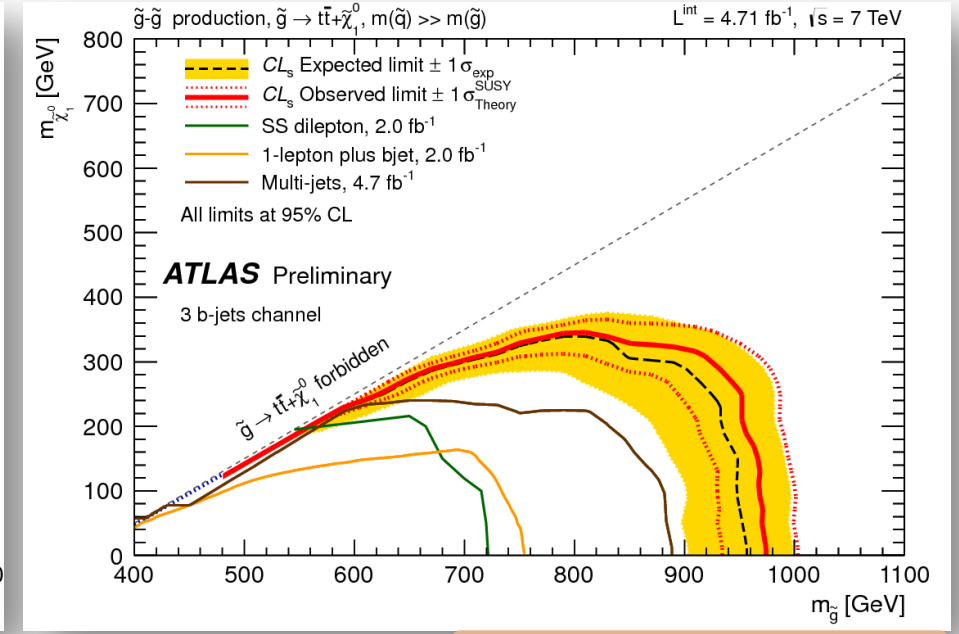
Pheno MSSM

only gluino + sbottom + LSP



Simplified model: Gtt

only gluino + stop + LSP



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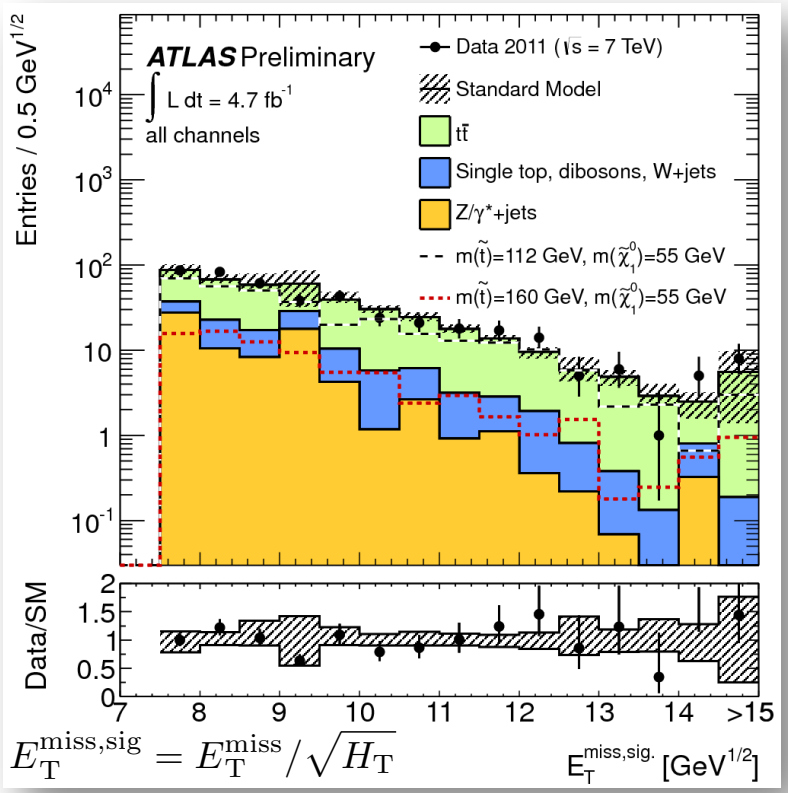
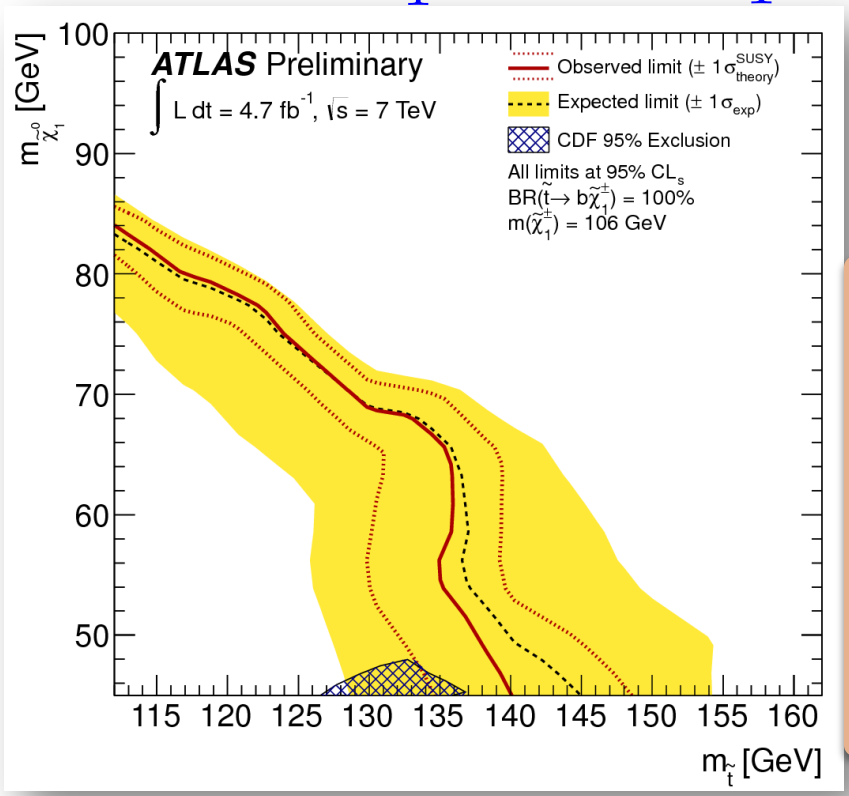
Light scalar top pair production

- Large mixing effects can lead to a scalar top significantly lighter than other squarks
- Selection: 2 opposite-sign leptons + 1 jet + high MET

$m(\tilde{t}_1) < m(t)$ $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to b\ell\nu\tilde{\chi}_1^0$





ATLAS-CONF-2012-059

Direct weak gaugino production

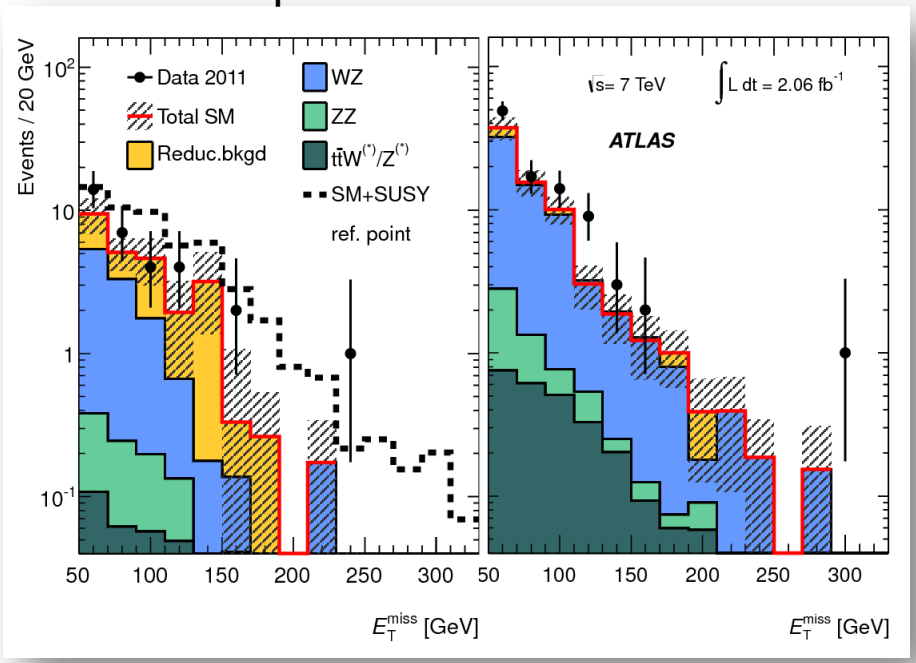
arXiv:1204.5638 [hep-ex]

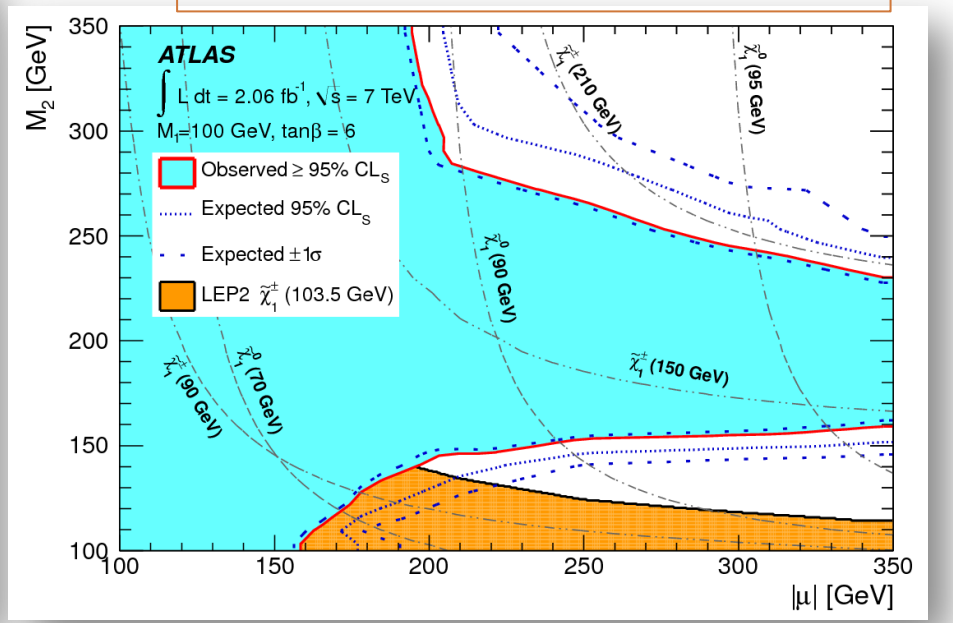
- If both gauginos decay leptonically → 3 leptons + high MET
- Selection
  - exactly 3 leptons; $E_T^e > 25$ GeV, $p_T^\mu > 20$ GeV ; one SFOS pair
  - MET > 20 GeV

pMSSM $m_{\tilde{q}}, m_{\tilde{g}}, m_{\tilde{\ell}_R} > 1$ TeV

$m_{\tilde{\ell}_L} = (m_{\tilde{\chi}_2^\pm} + m_{\tilde{\chi}_1^0})/2$

Z-depleted Z-enriched





Searches for R-parity violating SUSY

- eμ final state
- stau LSP in multilepton signature

R-parity violation (RPV)

- R-parity: $R = (-1)^{3(B-L)+2s}$ → $R = \begin{cases} +1, \text{ for SM particles} \\ -1, \text{ for superpartners} \end{cases}$

L-number violating terms

$$W_{\not R p} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \epsilon_i\hat{L}_i\hat{H}_u + \lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k$$

bilinear terms

B-number violating terms

- R-parity conservation hinted but not required by proton stability

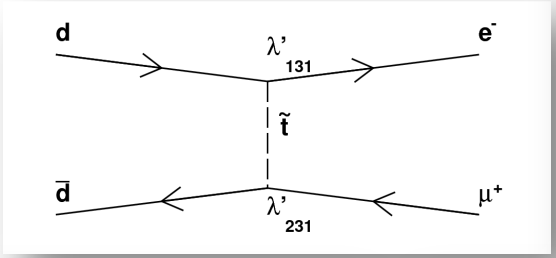
Rp conservation	Rp violation
Sparticles produced in pairs	Single sparticle production possible
Neutral and colorless LSP	LSP may be charged and/or carry color
Stable LSP → gives rise to high missing momentum	LSP decays → possibility for new signals • exploit LSP invariant mass • potentially long LSP lifetime • MET may or may not be high

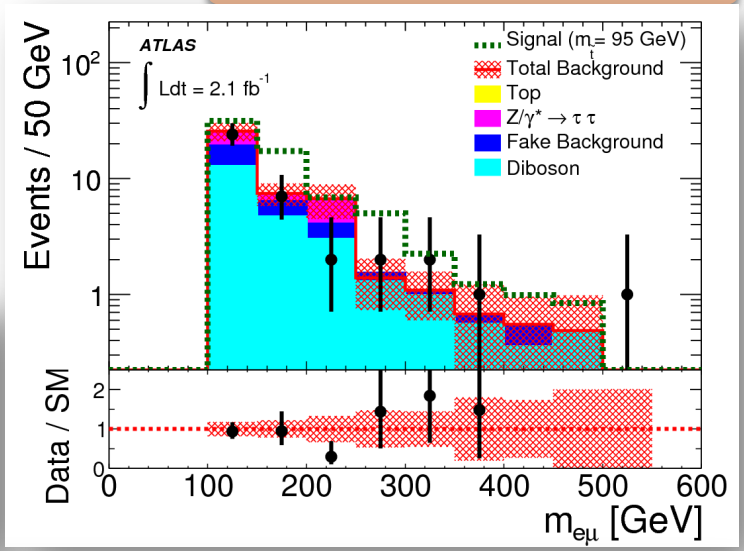
RPV: eμ continuum

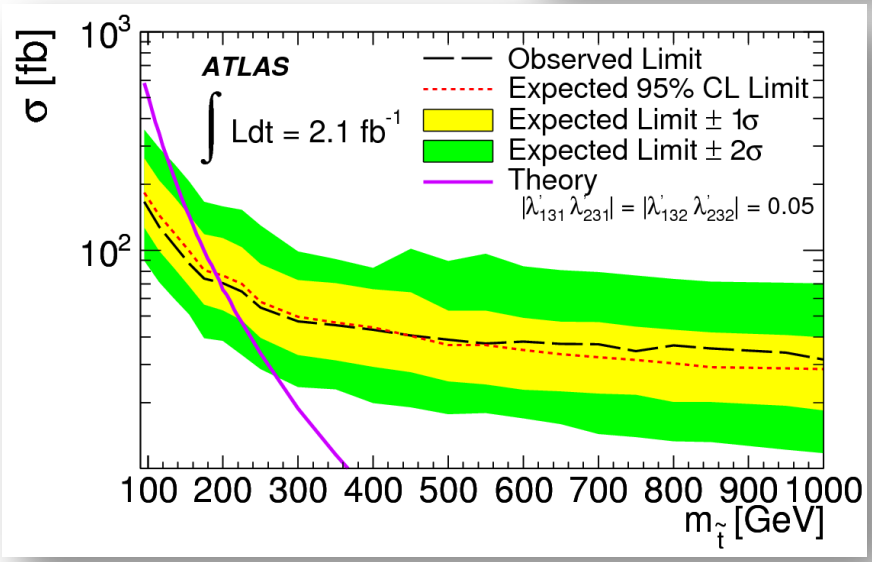
arXiv:1205.0725 [hep-ex]

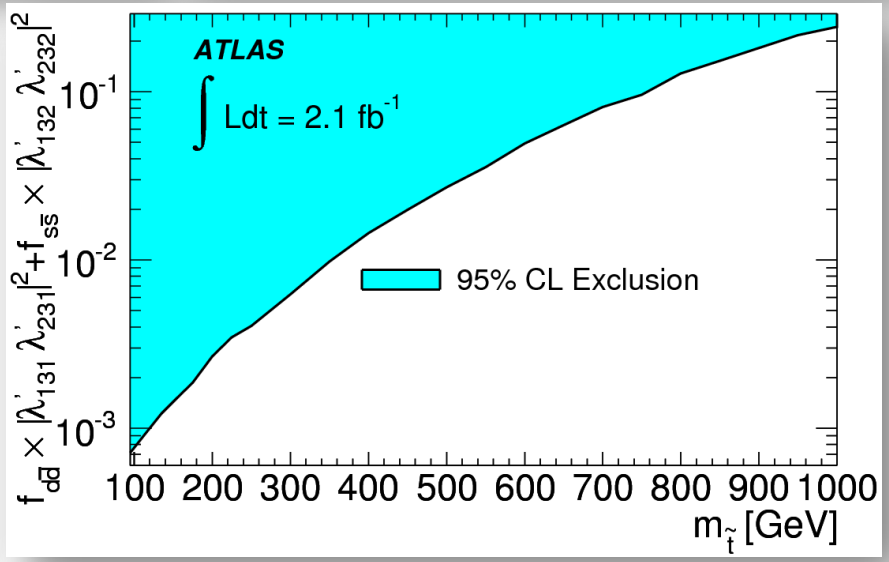
Looking for exactly one isolated electron and exactly one isolated muon with opposite charge $m_{e\mu} > 100$ GeV

- $\Delta\phi_{e\mu} > 3$
- MET < 25 GeV



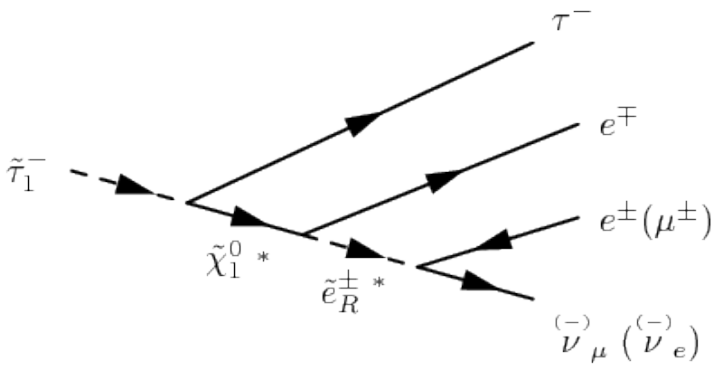


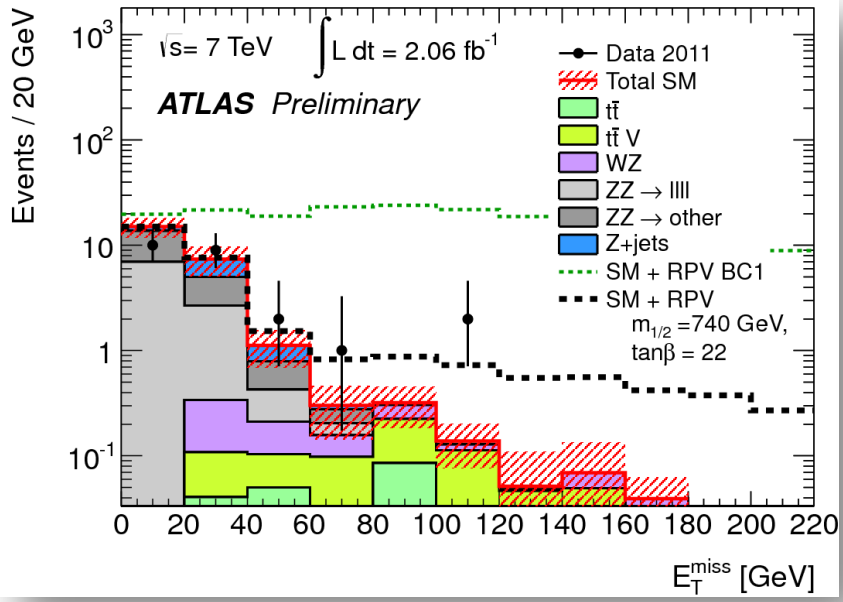


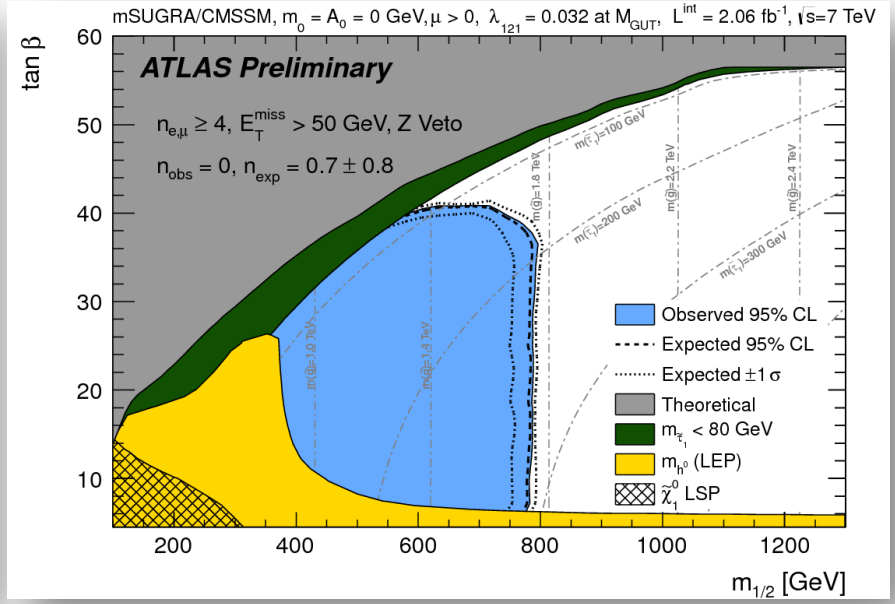


RPV: stau LSP in multilepton signature

- mSUGRA with $m_0 = A_0 = 0$, $\mu > 0$ and one RPV parameter $\lambda_{121} = 0.032$ at m_{GUT}
- Require at least four isolated leptons (e, μ) and moderate MET







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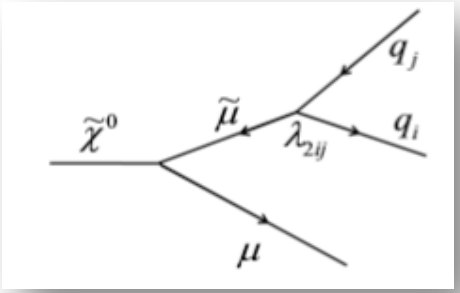
First limits from an LHC experiment on a model with a stau LSP

Searches for long-lived particles

- displaced vertices
- disappearing tracks

Displaced vertices: analysis



- RPV: LSP decays 4 – 180 mm from the interaction point for couplings $\lambda'_{2ij} \neq 0$
- Search for high-impact-parameter vertices: $|d_0| > 2$ mm
  - trigger: high-p_T muon
  - SM-particle late decays ⟶ require high mass & high track multiplicity
  - overlap of high-p_T track with hadronic interaction vertex ⟶ veto to vertices reconstructed within regions of high-density material

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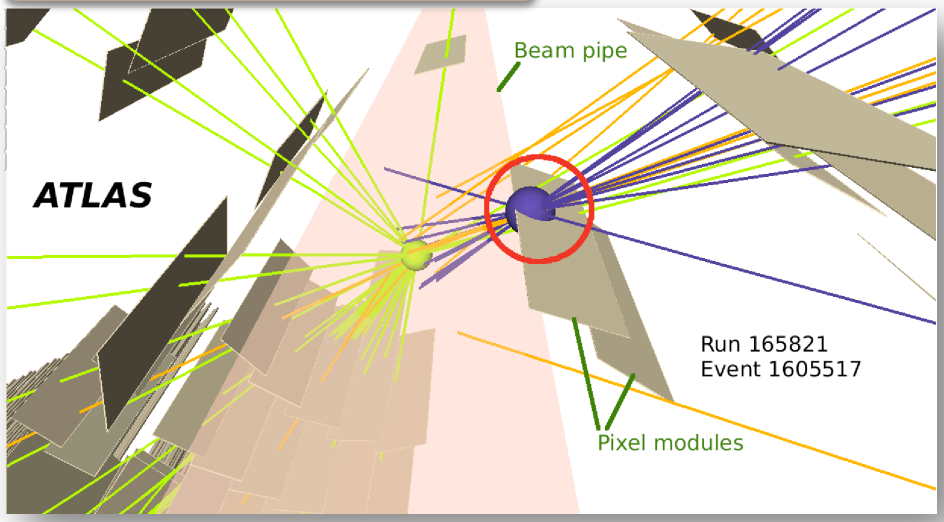
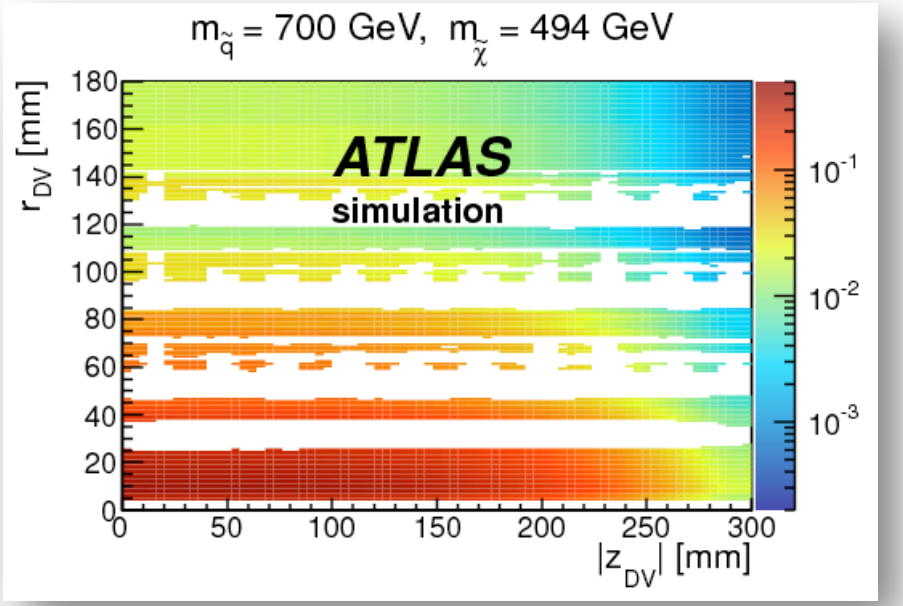
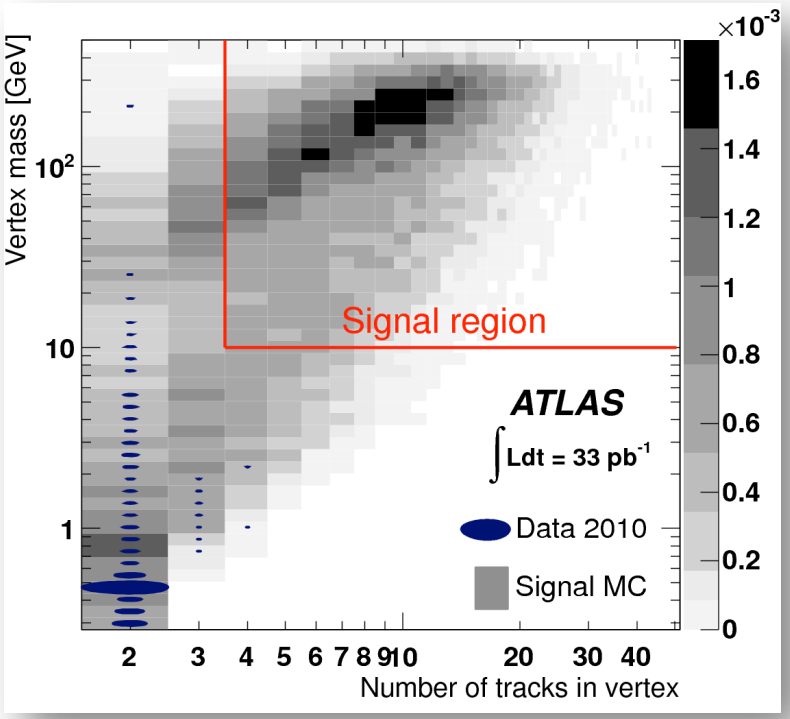




Displaced vertices: results

- Number of events passing the selected requirements except for the m_{DV} and $N_{DVtracks}$
- No data events observed in the signal region



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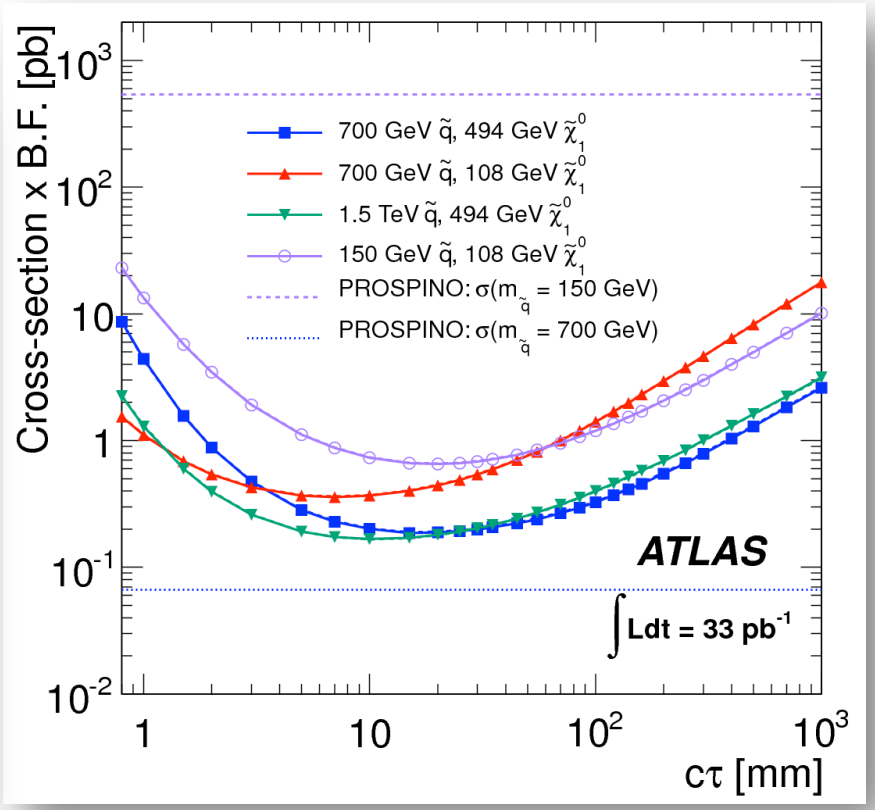
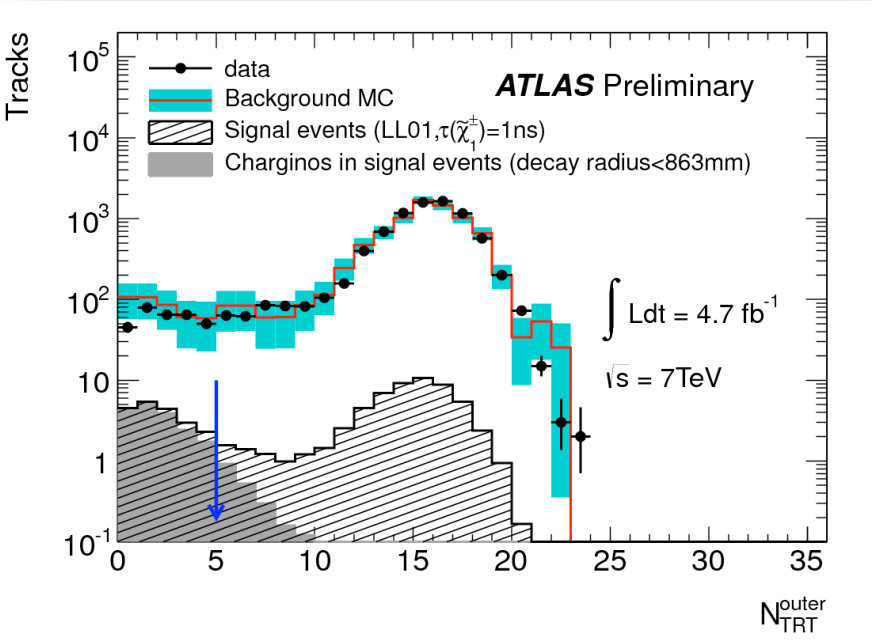
- Upper exclusion limits at 95% CL for different squark and neutralino masses

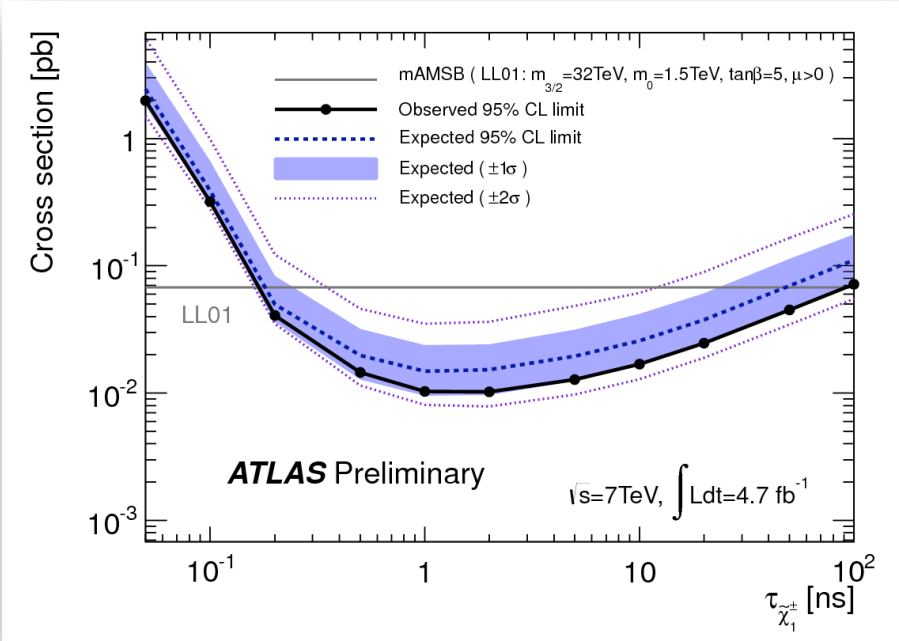


Disappearing track search

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^{0} + \pi^{\pm}$$

Meta-stable next-to-lightest particles may be created, fly some distance, and disappear / decay within the inner detector

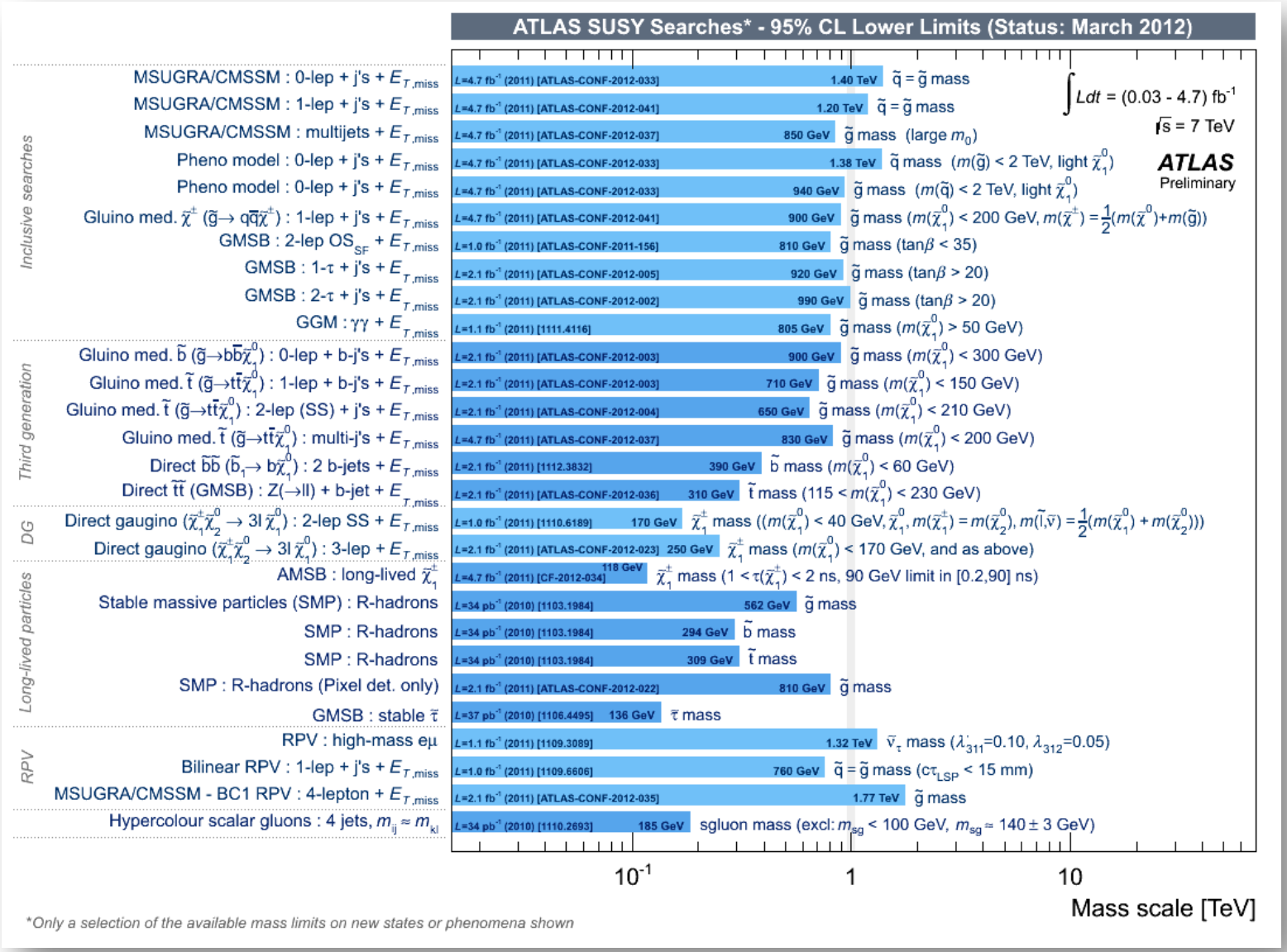




Chargino mass below 90 GeV excluded for particle lifetimes between 0.2 and 90 ns

arXiv:1202.4847 [hep-ex]

ATLAS SUSY searches limits

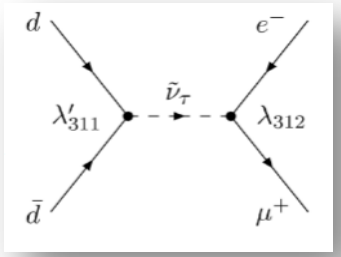


Summary

- Supersymmetry signals have been sought after by the ATLAS experiment
  - motivated by various models/topologies: strong production, 3rd generation fermions, degeneracies, R-parity violation ….
  - … leading to a wide spectrum of signatures: MET + jets + leptons/photons/b-jets/taus, displaced vertices, …
  - both techniques and strategy keep evolving
- No deviation from known SM processes observed so far (5 fb^{-1} at $\sqrt{s}$ = 7 TeV)
  → approaching/reaching the 1-TeV scale

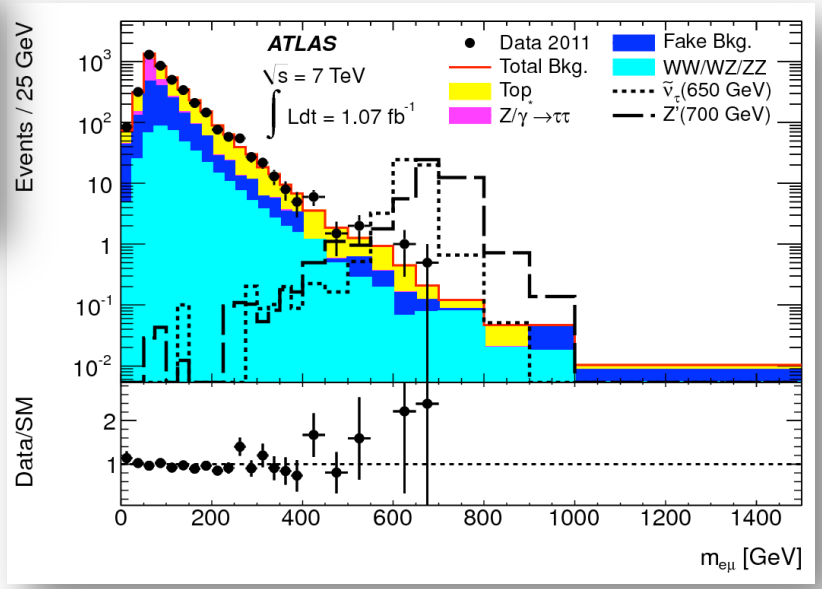
Backup…

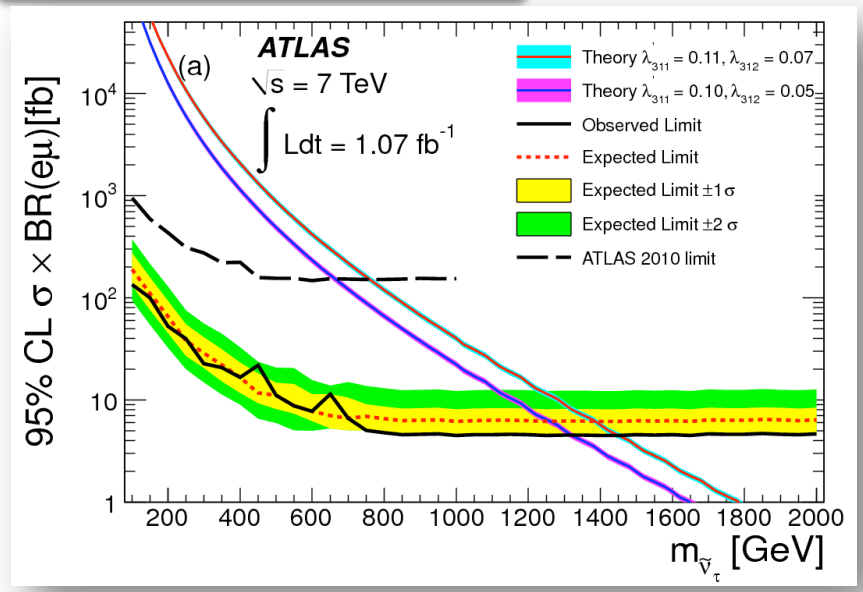
eμ resonance

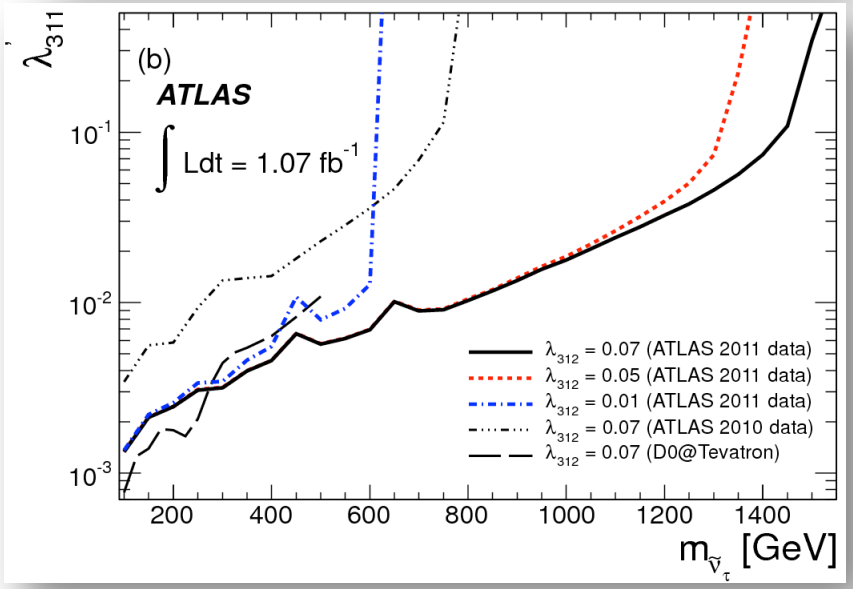


- Search for an excess in high eμ invariant mass
- Clean signal: look for exactly one isolated **electron** and exactly one isolated **muon** with opposite charge and $p_T > 25$ GeV

EPJC 71 (2011) 1809



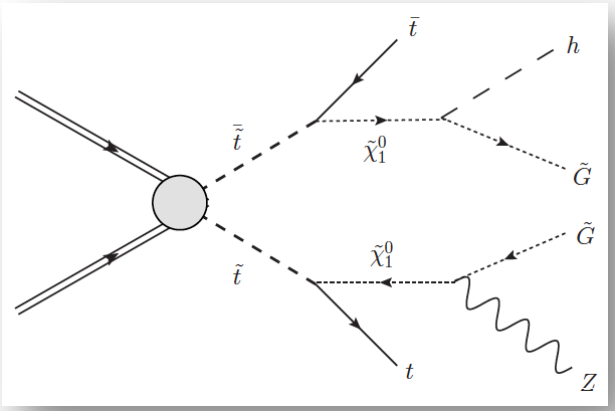


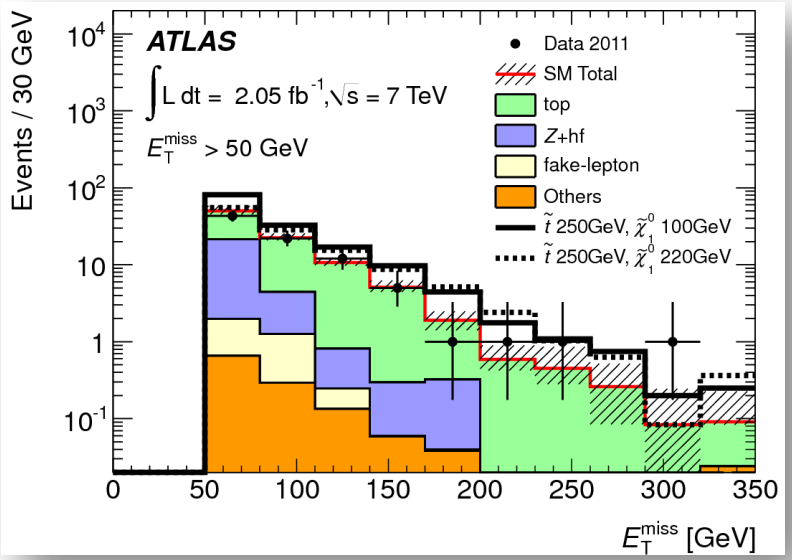


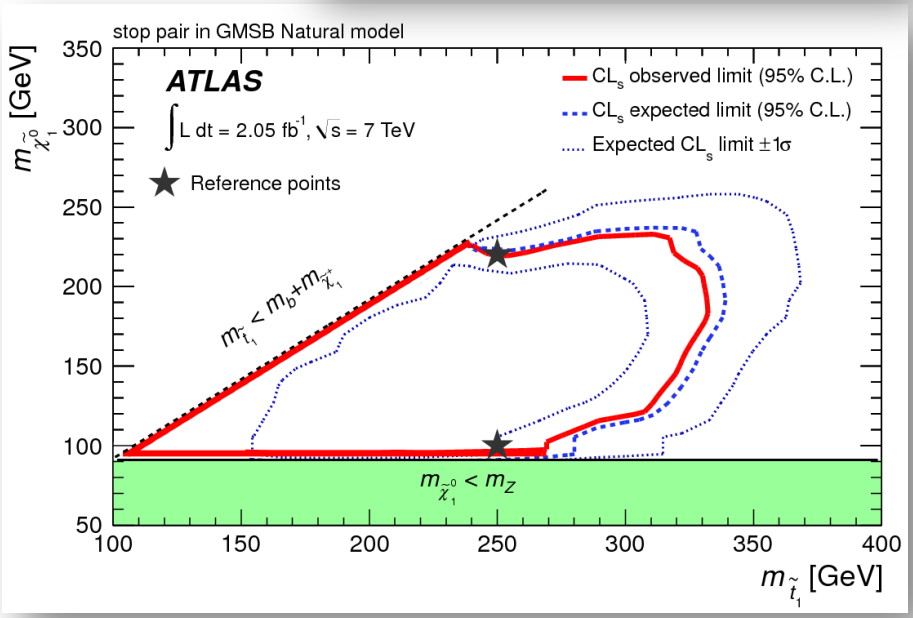
Direct stop production

arXiv:1204.6736 [hep-ex]

- Event selection: 1 b-jet, 2 OSSF leptons consistent with m_Z, MET and jets
- Exclusion
  - neutralino masses below 220 GeV for stop masses below 270 GeV
  - stop masses below 310 GeV for 125 GeV < m($\tilde{\chi}_1^0$) < 220 GeV

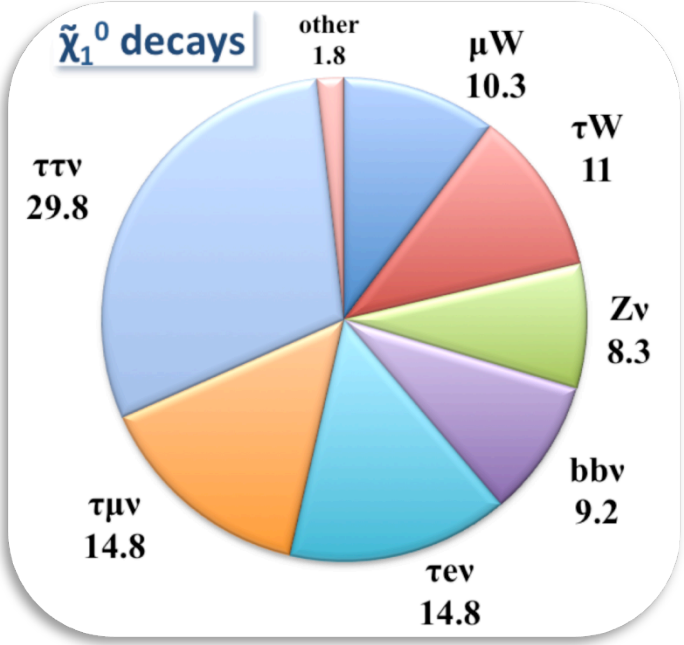






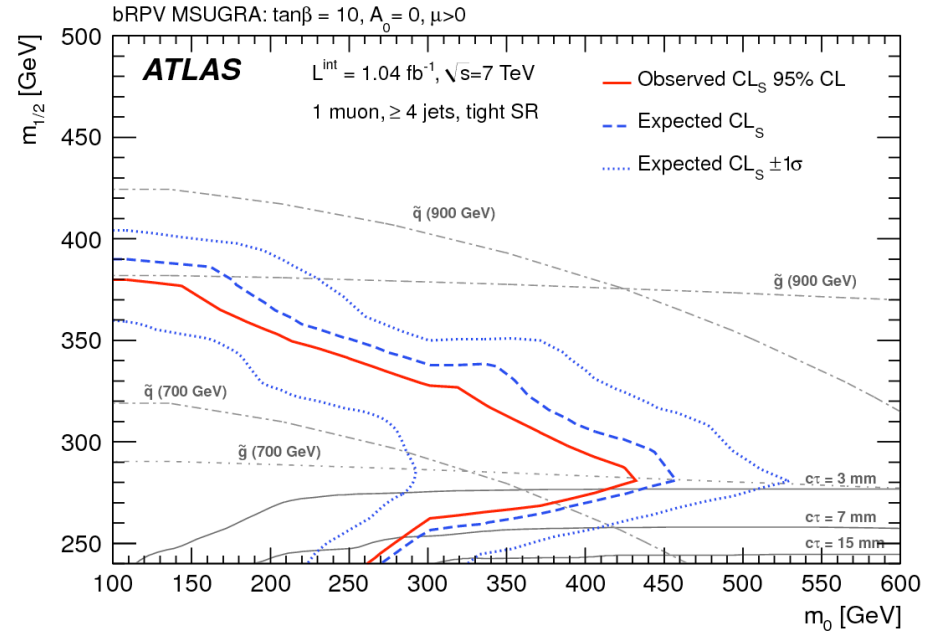
Bilinear RPV

- Bilinear R-parity violating (bRPV) terms in superpotential introduce **neutrino masses and mixings** in an natural way
  - RPV parameters constrained by neutrino measurements: Δm_{atm}^2, Δm_{sol}^2, $\tan^2\theta_{atm}$, $\tan^2\theta_{sol}$
- bRPV couplings embedded in mSUGRA
  - same cascade decay
  - LSP decays at the end
- Large variety of final states
  - most involve leptons and taus
- Features high MET originating mainly from various LSP decays to neutrinos



Bilinear RPV & 1-lepton analysis

- Event selection:
  - exactly one isolated muon with $p_T > 20$ GeV
  - veto for events with at least one electron with $p_T > 20$ GeV
  - requiring 3 or 4 jets with loose or tight cuts



PRD 85 (2012) 012006

Muon channel		
Signal region	Observed	Fitted background
3JL	58	64 ± 19
3JT	11	13.9 ± 4.3
4JL	50	53 ± 16
4JT	7	6.0 ± 2.7

- 95% CL exclusion limits for mSUGRA bRPV