Searches for supersymmetric particles with prompt decays with the ATLAS detector

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XXX International Workshop on Deep-Inelastic Scattering and Related Subjects
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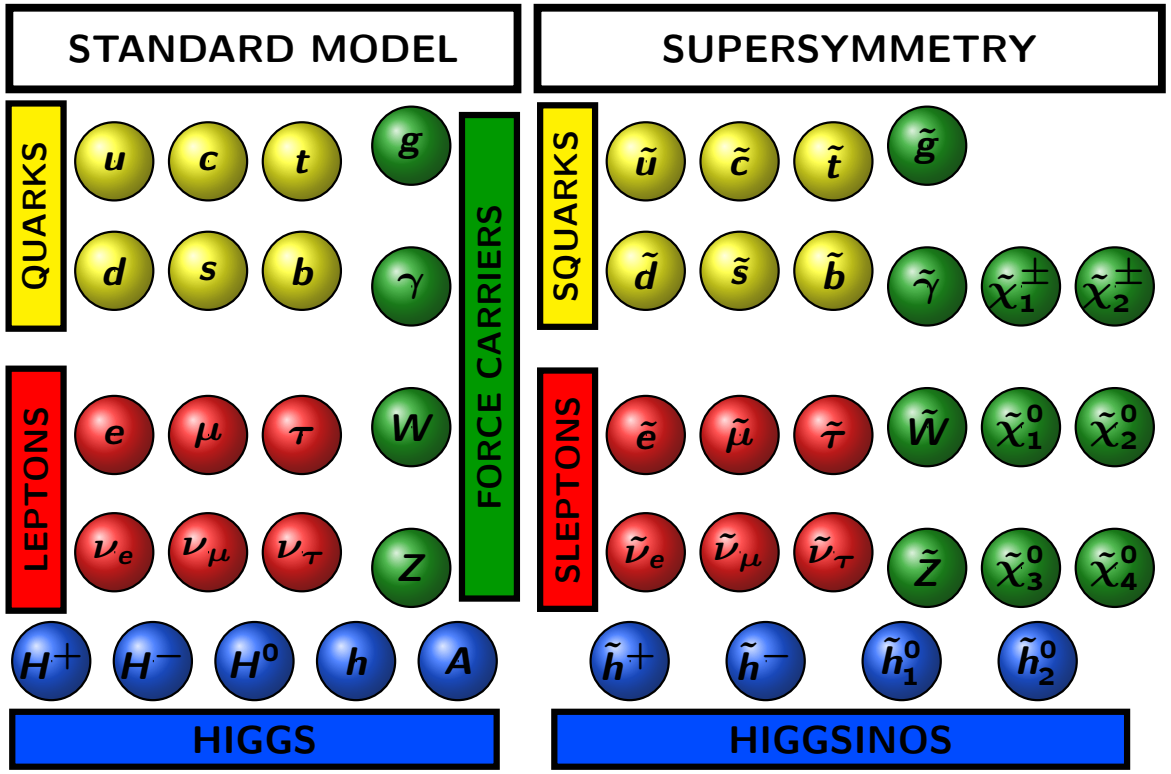
Supersymmetry (SUSY)

- New symmetry between bosons and fermions
- Introduction of superpartners, differing by 1/2 in spin
- Possible natural solution for several phenomena and Standard Model (SM) shortcomings:
  - hierarchy problem
  - dark matter
  - gauge coupling unification
  - $g-2$



Rich phenomenology available at LHC, now at $\sqrt{s} = 13.6$ TeV

Search strategy

Prompt: $c\tau < \mathcal{O}(1)$ mm (This talk)
Displaced: $c\tau > \mathcal{O}(1)$ mm (Elena's *talk*)

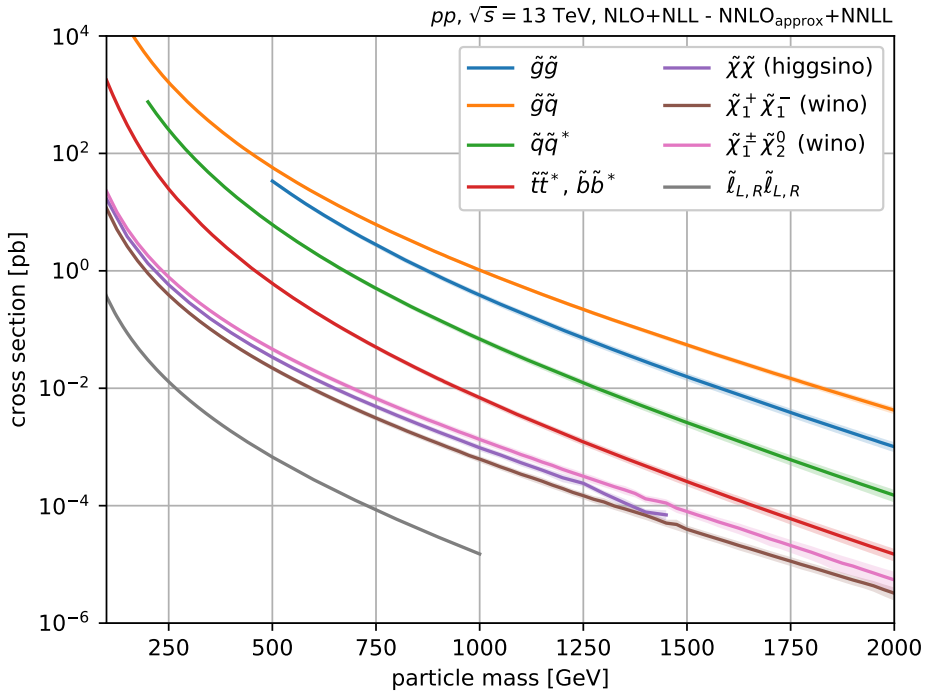
Target models

- *R-parity conserving* (RPC) scenarios with large E_T^{miss}:
  - Strong processes
  - Squarks and LeptoQuarks
  - Electroweak
- *R-parity violating* (RPV) scenarios with large lepton/jet multiplicities

Background estimation

- MC normalized to data in dedicated CR (irreducible backgrounds)
- Data-driven estimate (reducible backgrounds)
- Unscaled raw MC (rare backgrounds)

SUSY Particle *cross sections*



For $\sigma \sim 10^{-4}$ pb, estimated $\mathcal{O}(10)$ events at 140 fb^{-1}

RPV multi-jet search

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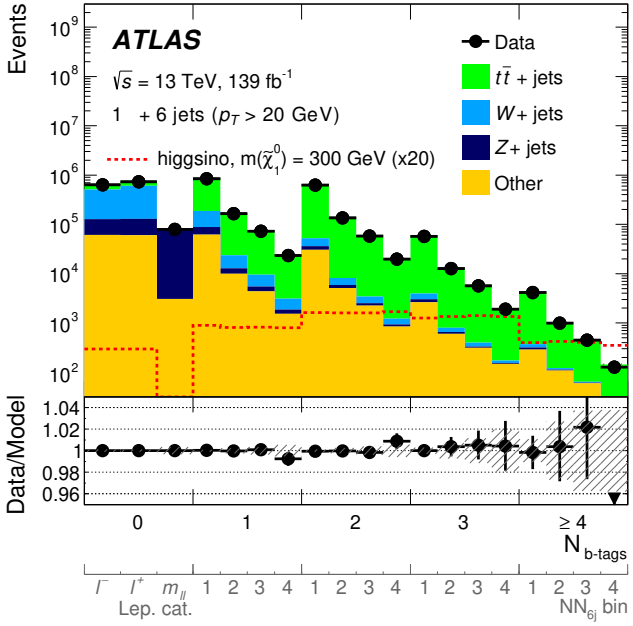
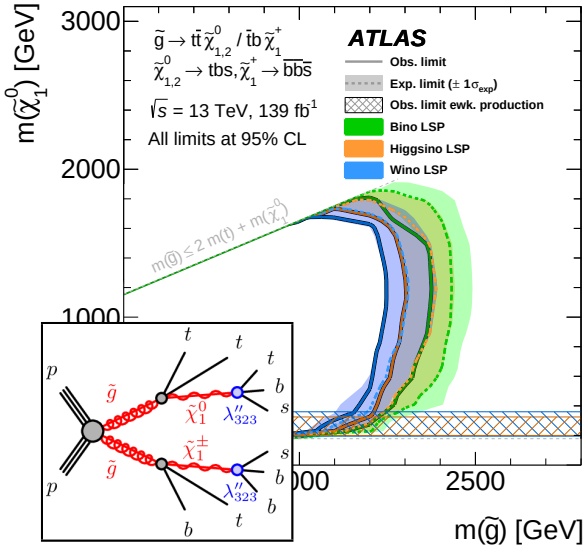
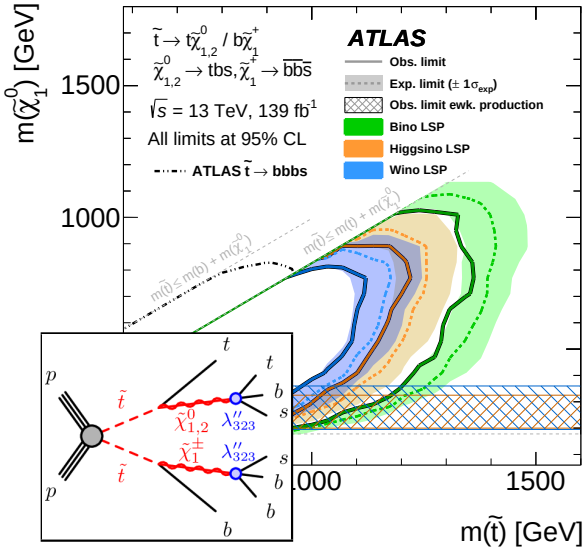
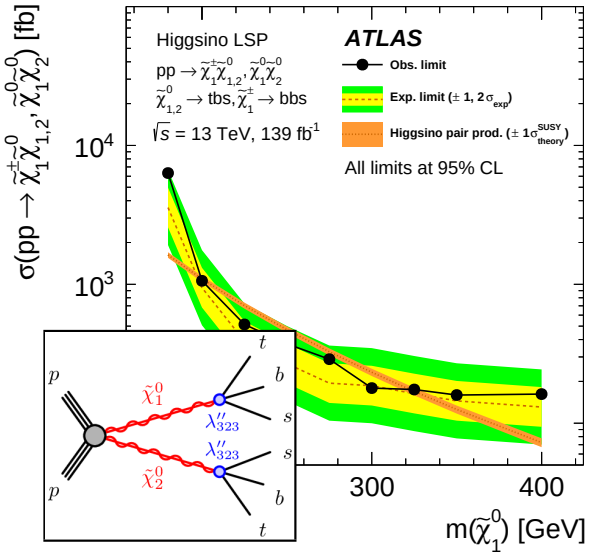
- (1L/SS 2L) + (0/$\geq$ 3) b-jets
- $\lambda''_{323}(tbs/bbs) \neq 0$
- NN to achive first LHC sensitivity to ewkinos decaying promptly to hadrons
- Results exclude gluinos, stops, higgsinos up to masses of 2380, 1360 and 320 GeV, respectively









Bilinear RPV models

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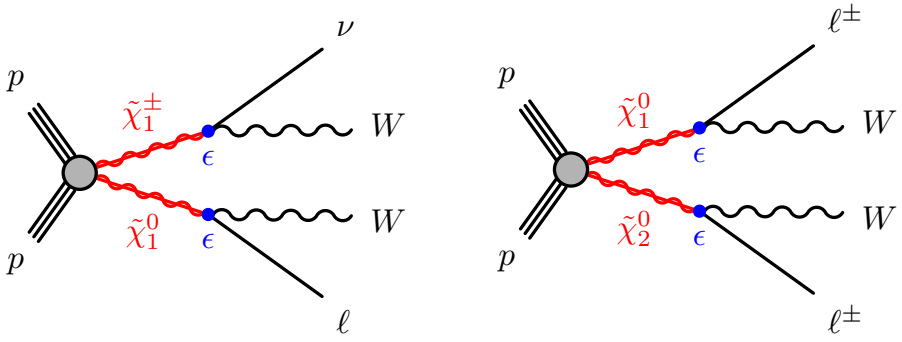
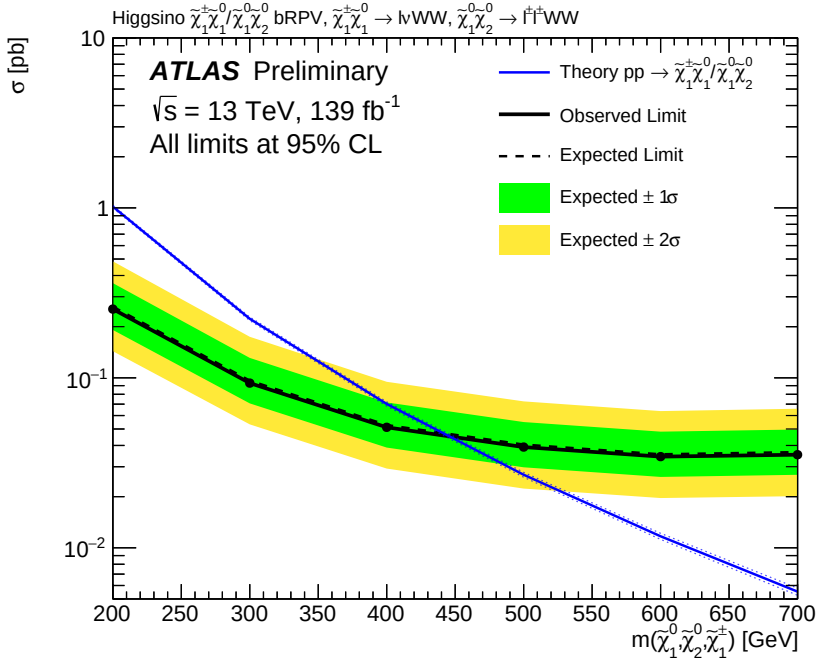




- Never exploited in EWK SUSY production
- Natural RPV model with bilinear terms:

$$W_{RPV} \propto \lambda_{ijk} + \lambda'_{ijk} + \lambda''_{ijk} + \epsilon_i L_i H_2$$

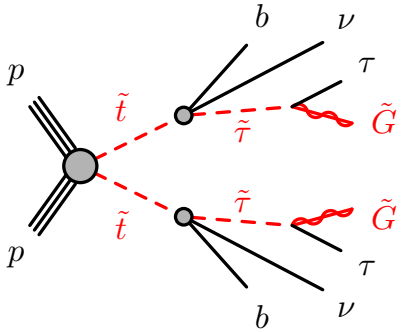
- Inclusive production considered
- Statistical combination of two SR, taking into account 2L SS and 3L final states

Mass-degenerate higgsinos $\tilde{\chi}_1^0/\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ excluded up to masses of 440 GeV

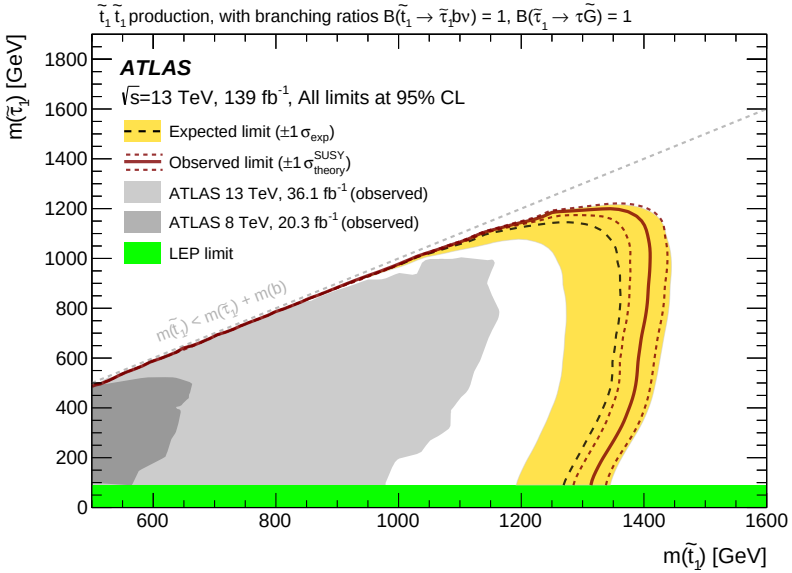
LeptoQuarks

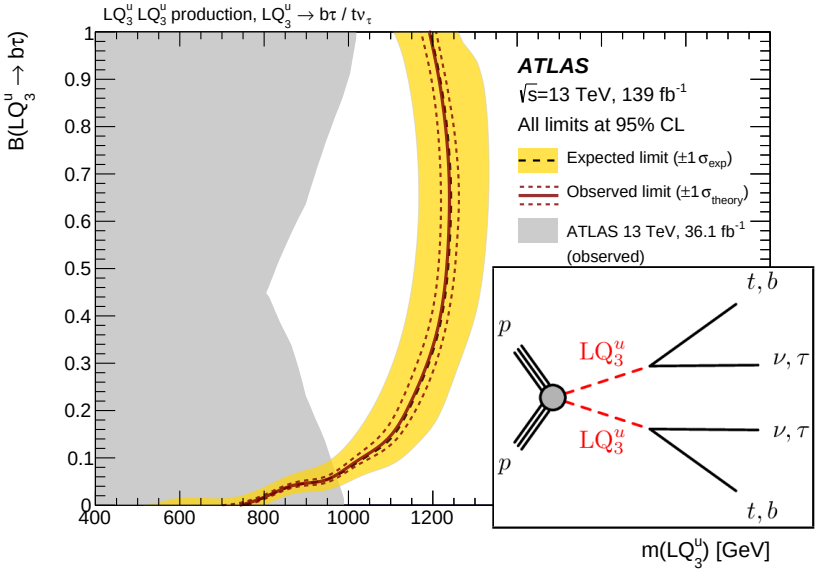
Phys. Rev. D 104 (2021) 112005

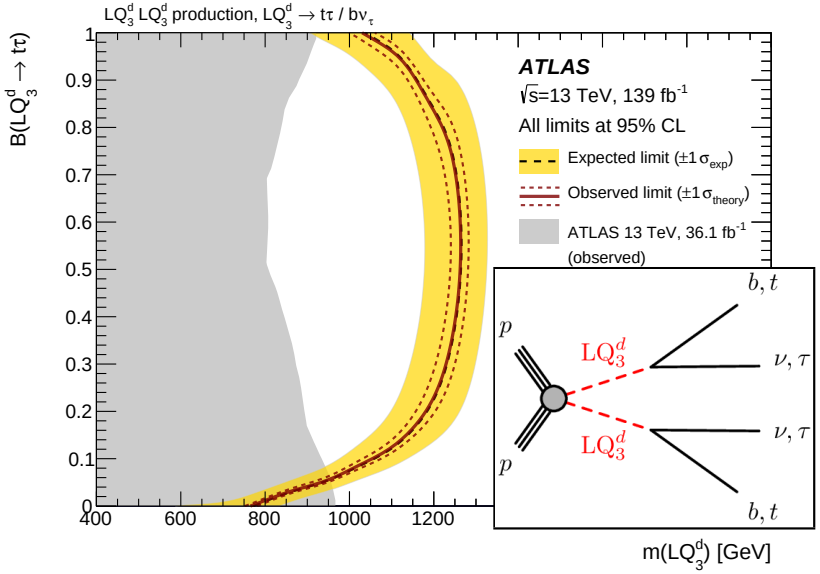
Dedicated analysis for final states with τ-leptons and scalar LQ



- Reconstruct hadronic $\tilde{\tau}$ using RNN
- Split events into $1\tilde{\tau}$ and $2\tilde{\tau}$ categories
- Masses up to 1.4 TeV excluded for nearly massless $\tilde{G}$







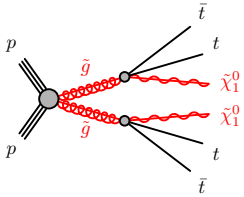
Excluded $LQ_3^{u/d}$ masses up to 1.25 TeV

Gluino production

arXiv:2211.08028

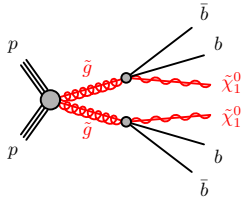
Gtt model

Deep Neural Network



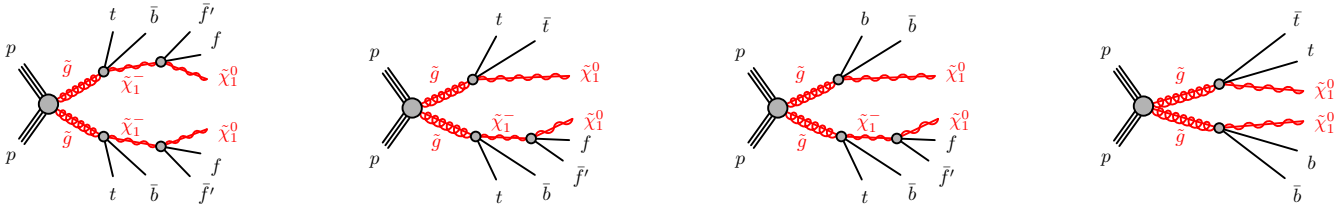
Gbb model

Deep Neural Network

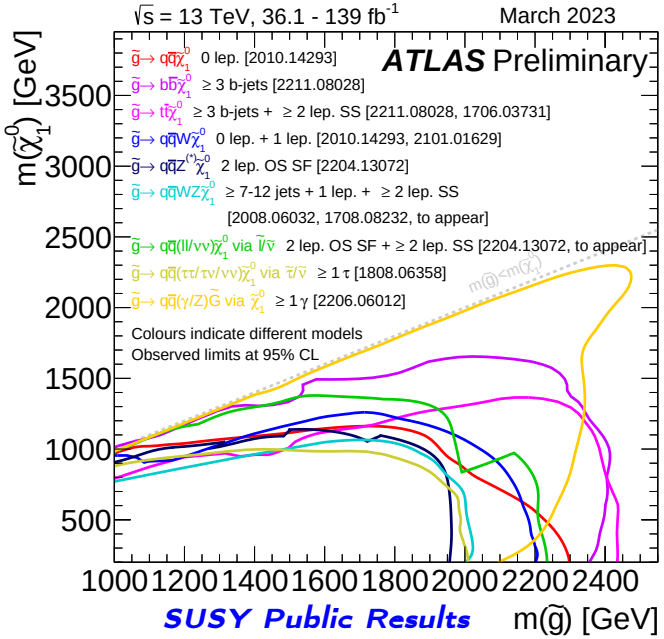


Gtb model

Cut & Count



- 0/1L SRs, according to models
- NN input vars: 4-momenta of 10 leading jets (b-tag bool), 4 leading large-R jets, leptons and $\vec{p}_T^{miss}$ components
- 4 output scores (probabilities):
  - $\mathcal{P}(Gtt)$ or $\mathcal{P}(Gbb)$
  - $\mathcal{P}(t\bar{t})$
  - $\mathcal{P}(Z)$



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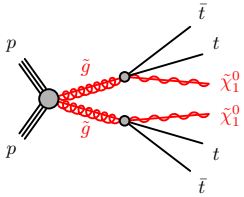

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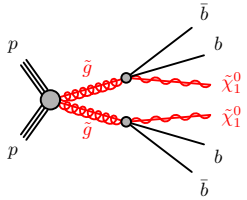

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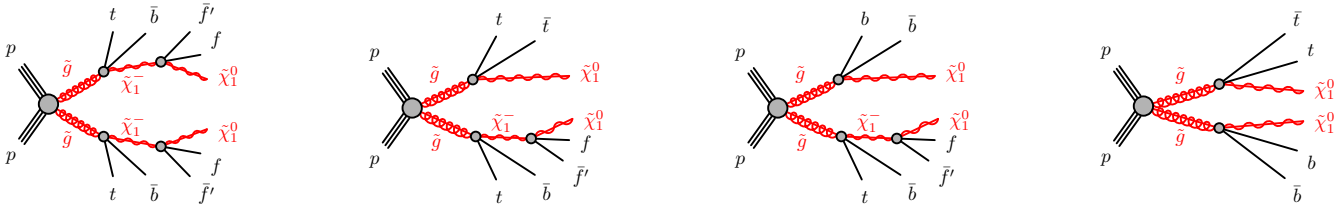
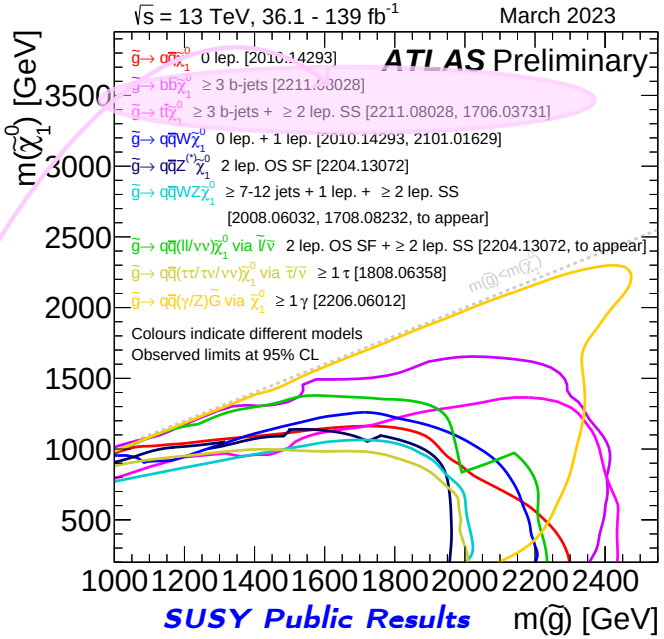
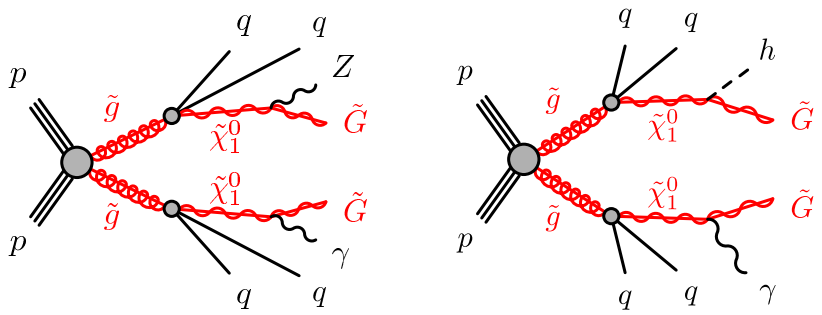


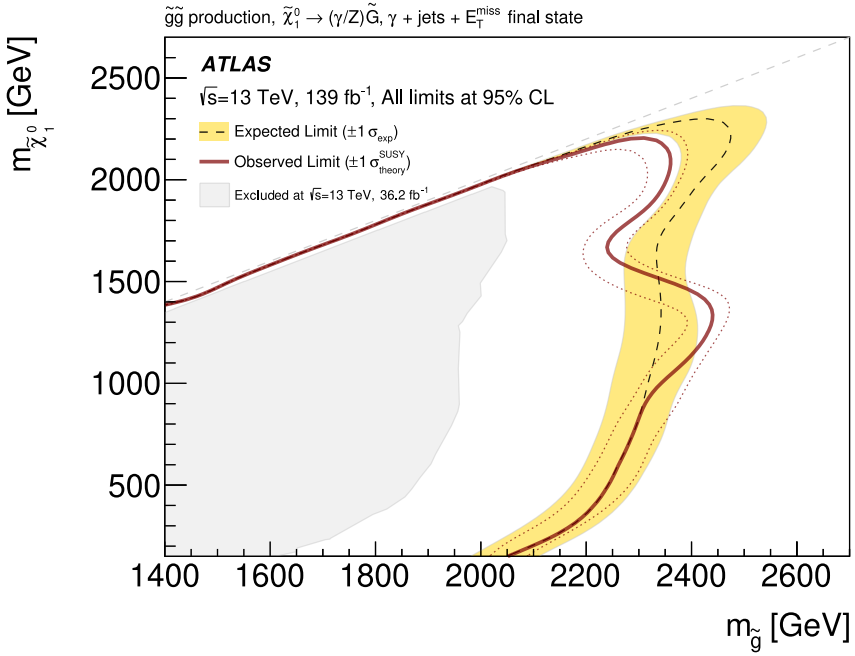
- 0/1L SRs, according to models
- NN input vars: 4-momenta of 10 leading jets (b-tag bool), 4 leading large-R jets, leptons and $\vec{p}_T^{miss}$ components
- 4 output scores (probabilities):
  - $\mathcal{P}(Gtt)$ or $\mathcal{P}(Gbb)$
  - $\mathcal{P}(t\bar{t})$
  - $\mathcal{P}(Z)$
- $\tilde{g}$ excluded up to $\sim$ 2.4 TeV for massless $\tilde{\chi}_1^0$



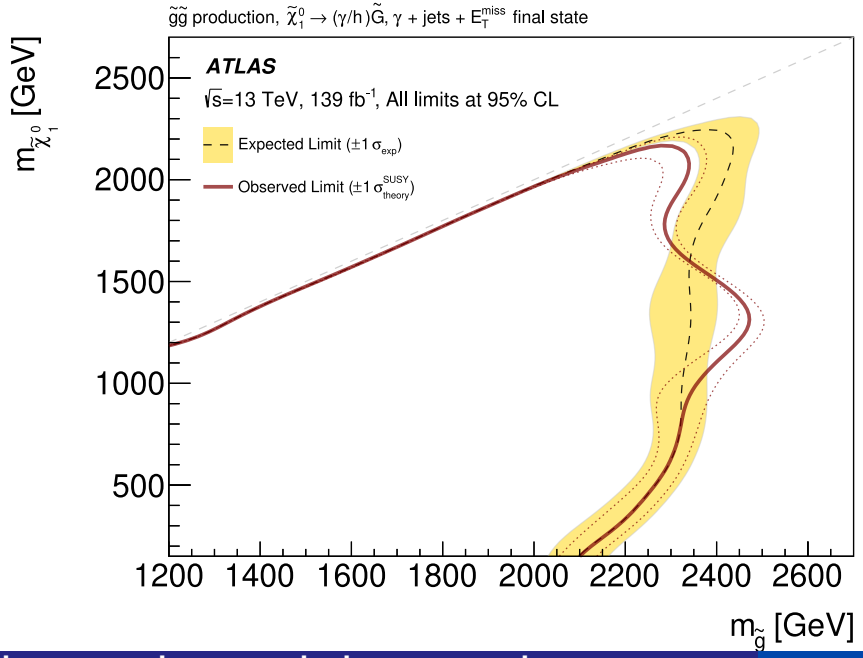
Gluino production with photons

arXiv:2206.06012





- Gravitino as LSP, NLSP $\tilde{\chi}_1^0$
- High jet multiplicities $\leftrightarrow$ High E_T^{miss}
- High-p_T leading photon: $p_T^{\gamma} > 145$ GeV
- $\tilde{g}$ masses excluded up to ~ 2.1 TeV, for most of NLSP masses
- ATLAS First Run2 limits in the $\tilde{\chi} \to (\gamma/h)\tilde{G}$ channel

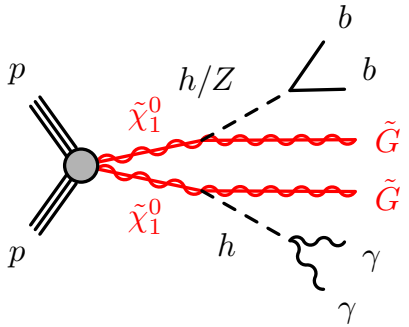


Higgsinos pair production

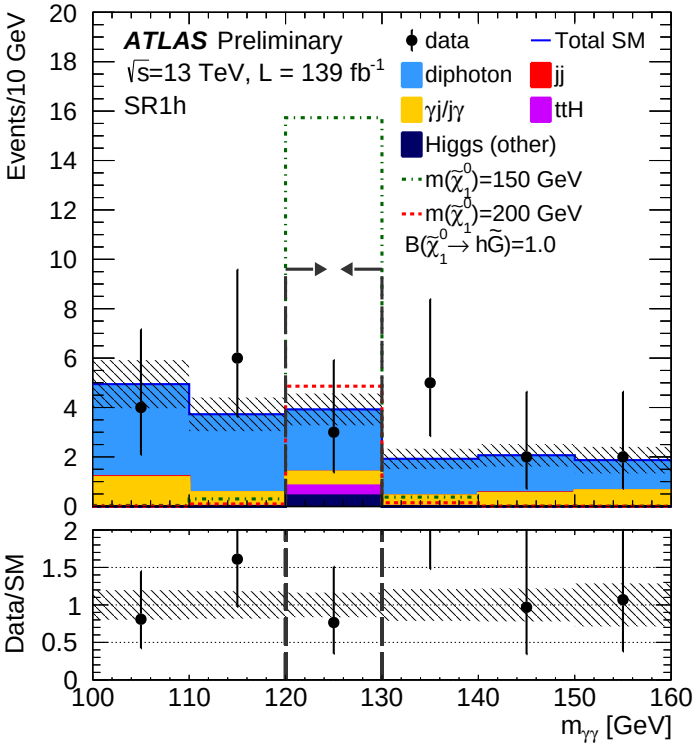
ATLAS-CONF-2023-009

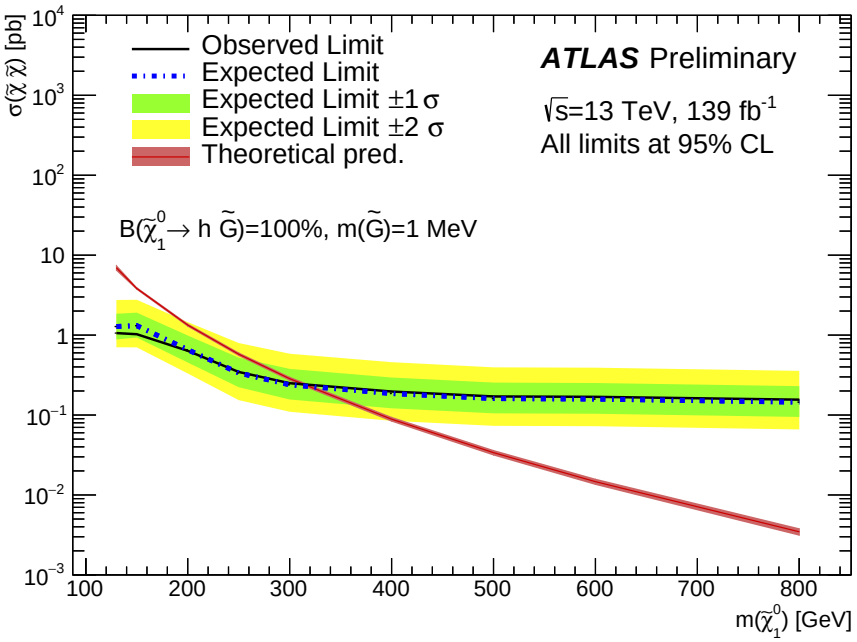
- $\mathcal{B}(\tilde{\chi}_1^0 \to h\tilde{G}) + \mathcal{B}(\tilde{\chi}_1^0 \to Z\tilde{G}) = 100\%$
- 3 SRs identified by E_T^{miss} and m_{bb} cuts

requirement	SR1h	SR1Z	SR2
$\lvert m_{\gamma\gamma} - 125\,GeV\rvert$	$< 5\,GeV$		
E_T^{miss}	$\leq 100\,GeV$		$> 100\,GeV$
m_{bb}	$\in (100, 140)\,GeV$	$\in (60, 100)\,GeV$	$\in (35, 145)\,GeV$
$p_T^{\gamma\gamma}$	$\geq 90\,GeV$		-
$p_T^{\gamma\gamma}/m_{\gamma\gamma}$	≥ 0.4		≥ 0.2



- $m_{\gamma\gamma}$ around nominal Higgs mass

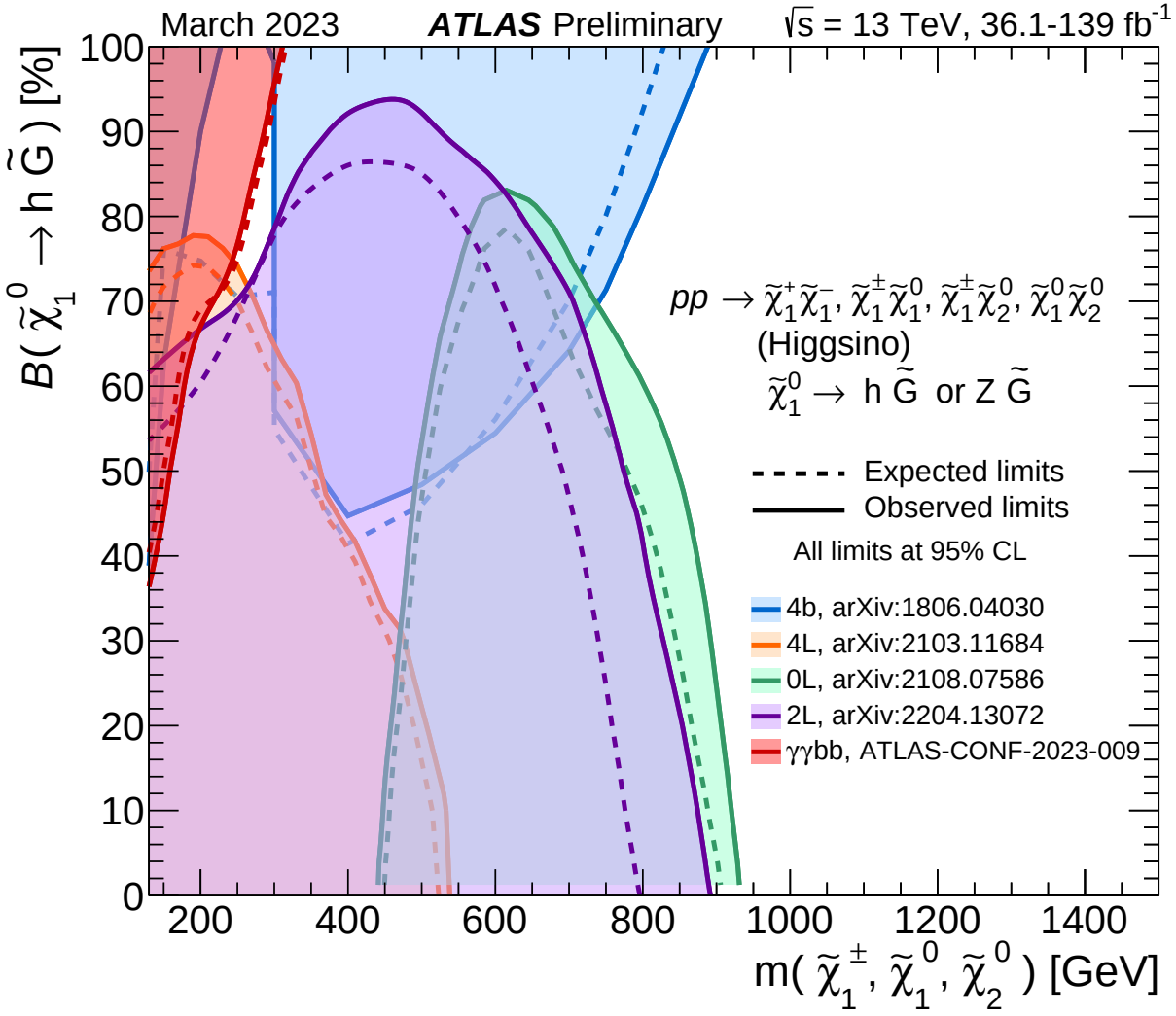




Exclusion down to $\mathcal{B}(\tilde{\chi}_1^0 \to b\tilde{G}) = 36\%$ for $m(\tilde{\chi})_1^0 \sim 130$ GeV

Higgsinos pair production

SUSY Public Results



Filling the gap at high $\mathcal{B}(\tilde{\chi}_1^0 \to h\tilde{G})$ fractions, not covered by previous analyses

EWK: lepton channels

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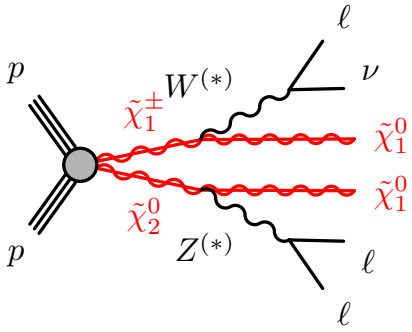
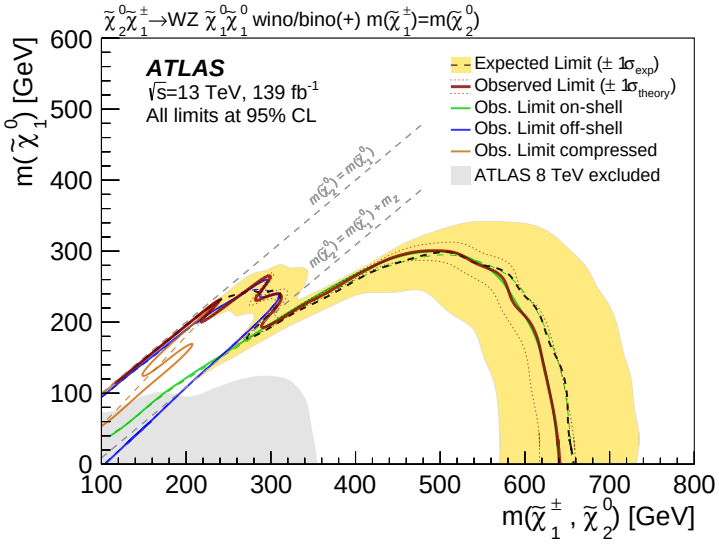
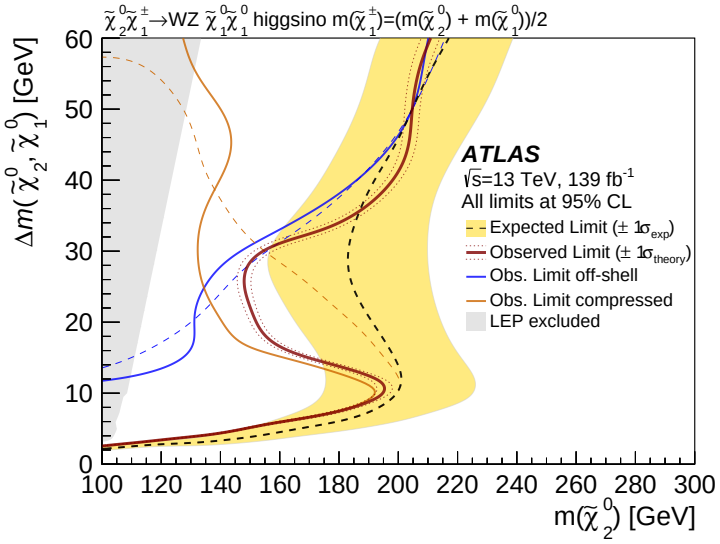
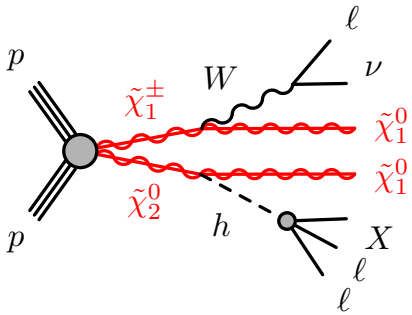
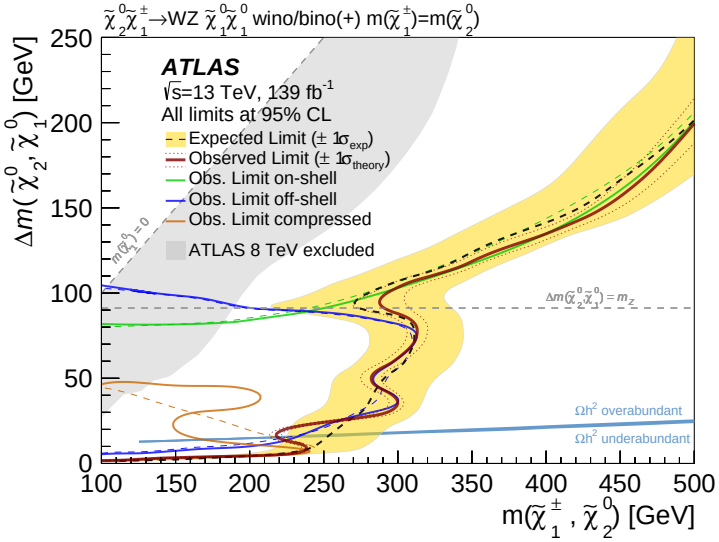
Combine results from **3L on-shell**, **3L off-shell**, **soft 2L**

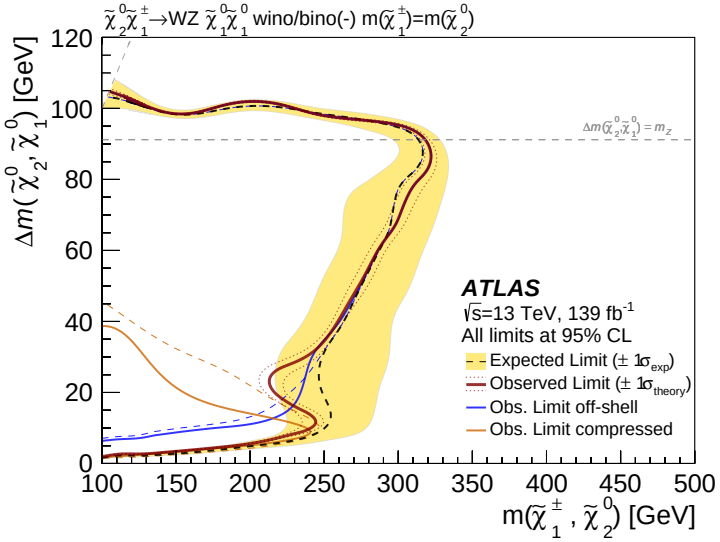








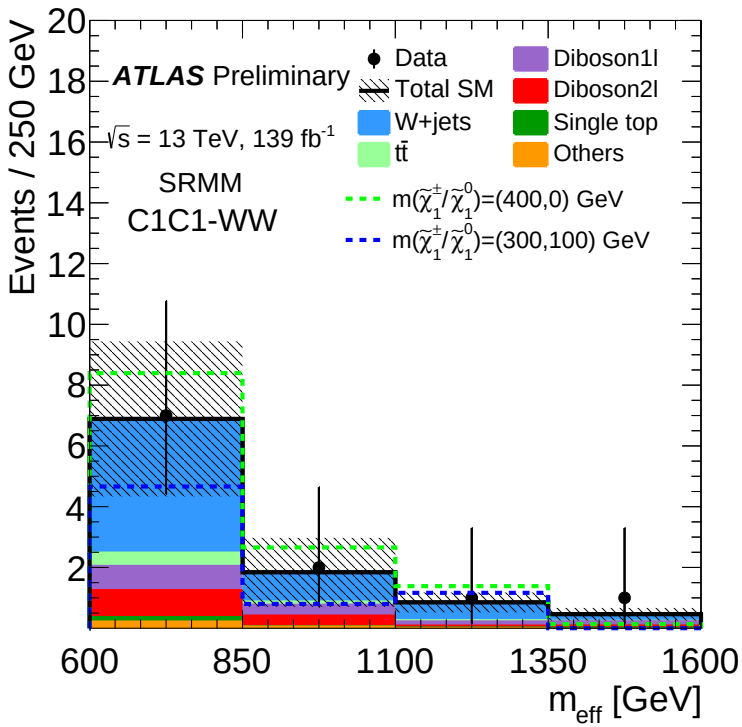


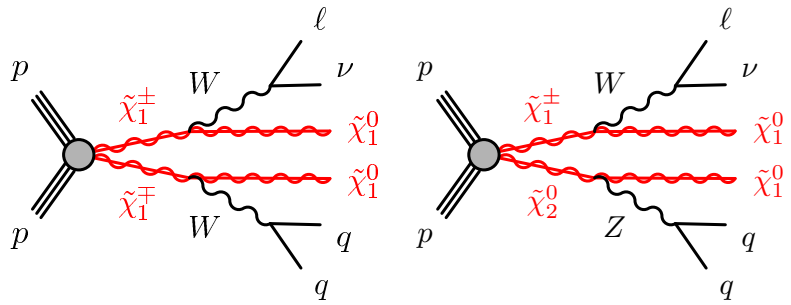


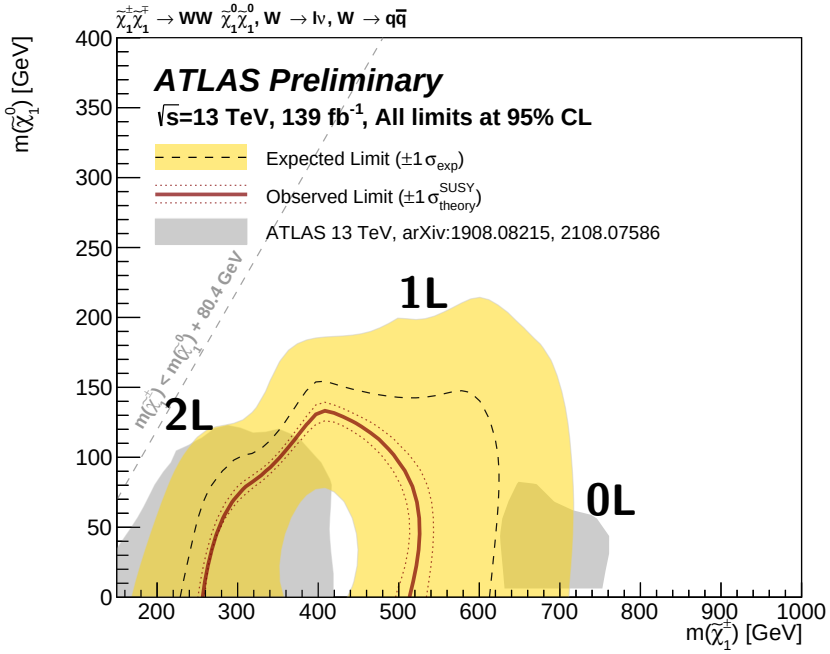
EWK: mixed channels

ATLAS-CONF-2022-059

- Boson tagging with large-R jets
- 3 SRs according to the different transverse mass
- 2 additional m_{eff} bins for resolved and boosted topologies, over 1 TeV





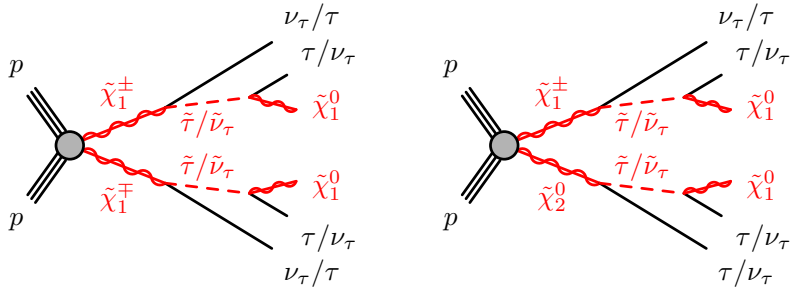


Combination will benefit from considering the different decay modes, as targeting complementary $m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ phase space

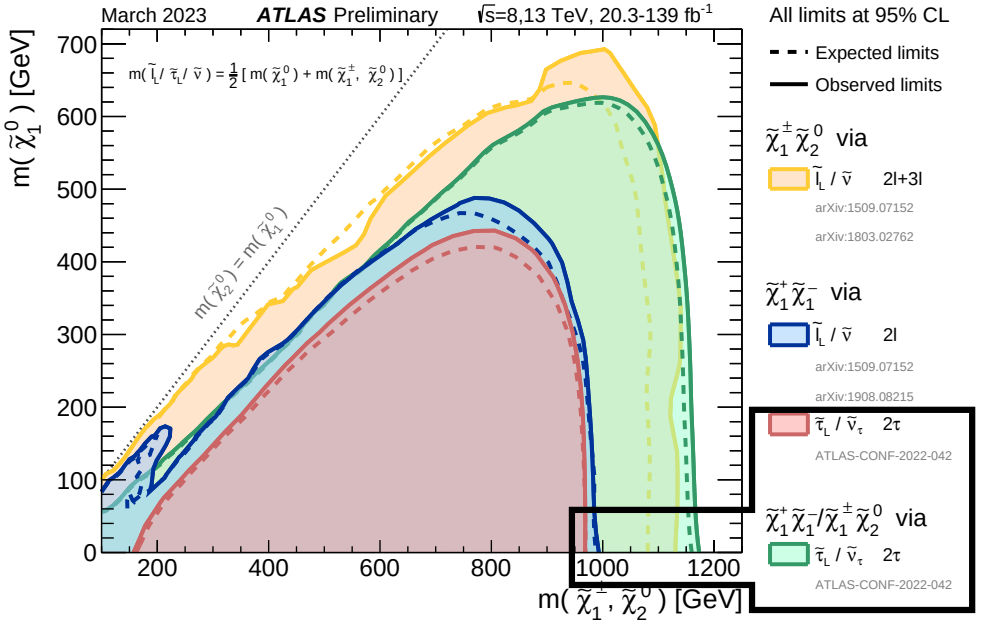
EWK: slepton channels

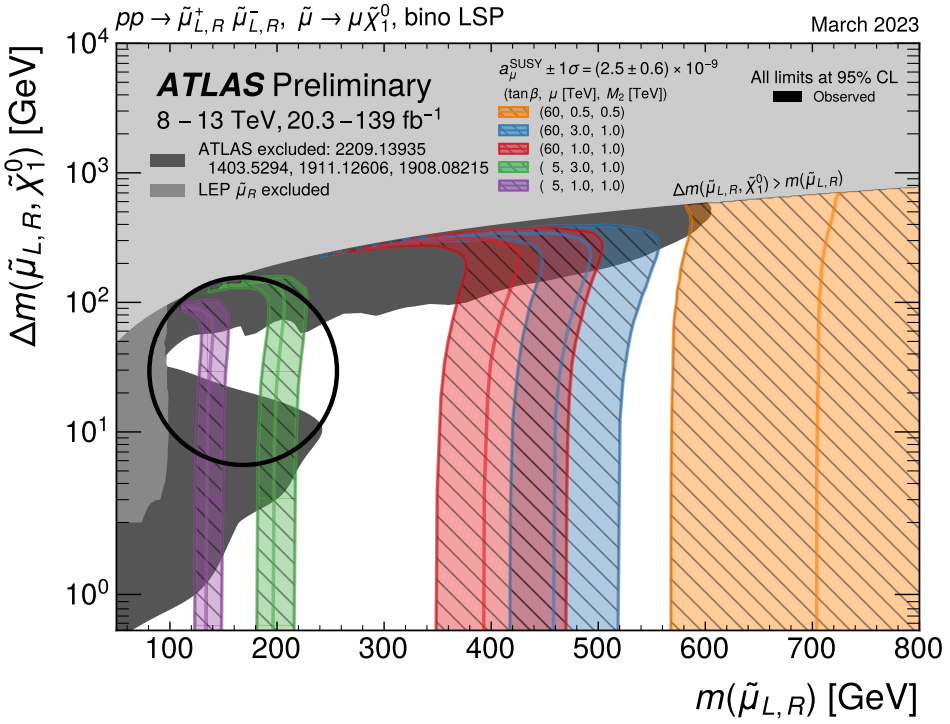
SUSY Public Results

ATLAS-CONF-2022-042



- $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ direct production with intermediate $\tilde{\tau}$ decays
- Excluded $m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0)$ up to 1 and 1.2 TeV





- Direct $\tilde{\mu}$ pair production
- Colored bands consistent with $g-2$ under different assumptions of SUSY parameters
- Hard to tackle $\tilde{\mu}$-*corridor*: interesting area for new searches and improvements

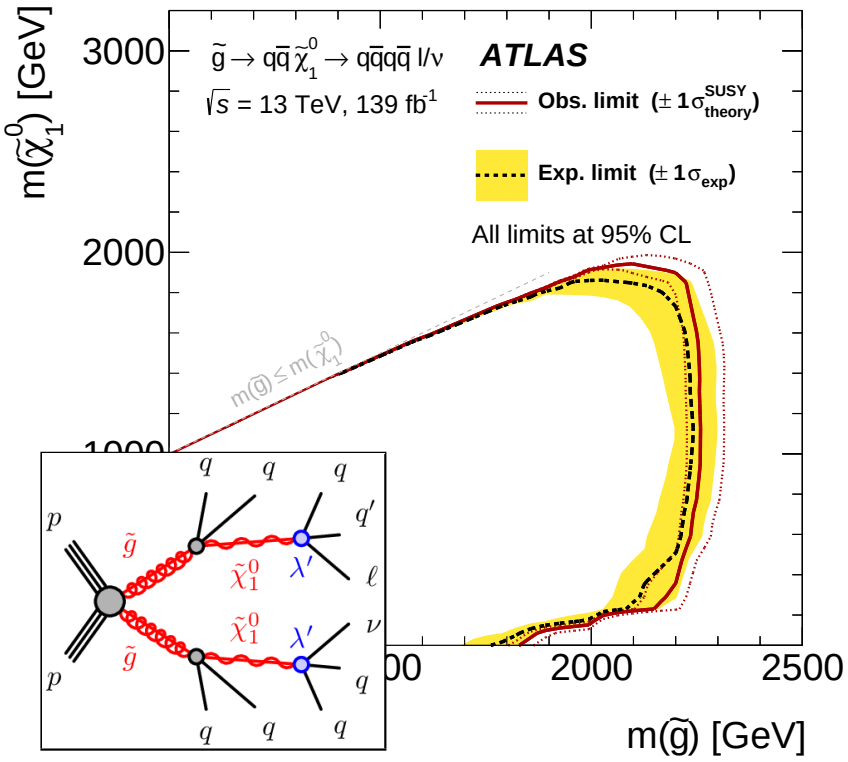
Conclusions

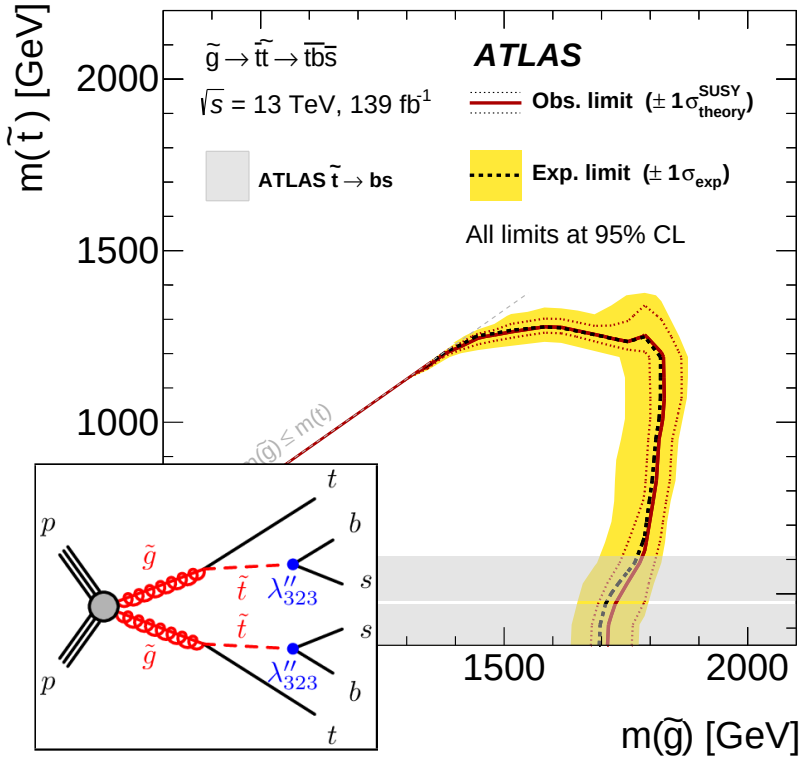
- ATLAS SUSY searches in a wide variety of final states
- Enhanced sensitivity by combining channel, in some cases $\rightarrow$ Expect more to come with Run2 analysis wrap ups and final combinations
- Unfortunately, no evidence of SUSY so far
- TeV-scale limits set in a wide variety of models, corresponding to fine tune probing as small as $\mathcal{O}(1)\%$
- Run3 analyses already started: stay tuned for new exciting results!

Backup

RPV multi-jet search: other interpretations

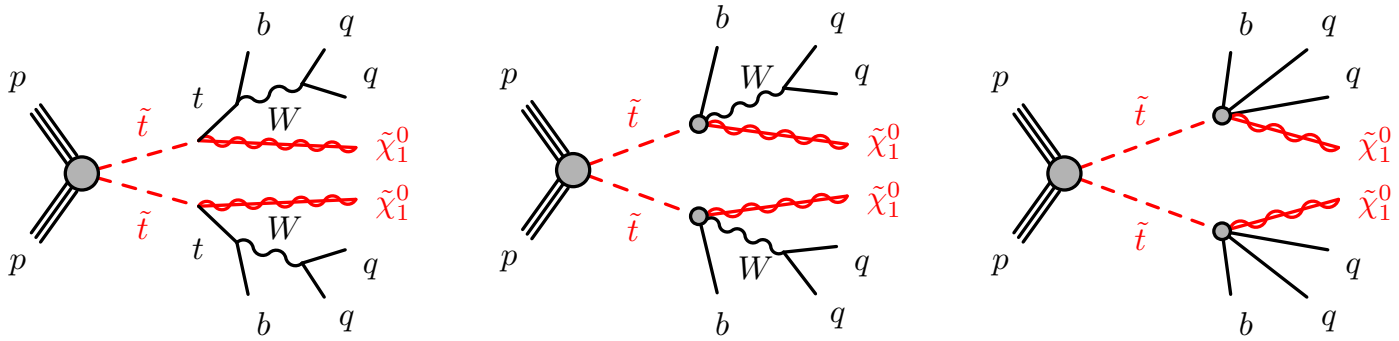
Eur. Phys. J. C 81 (2021) 1023





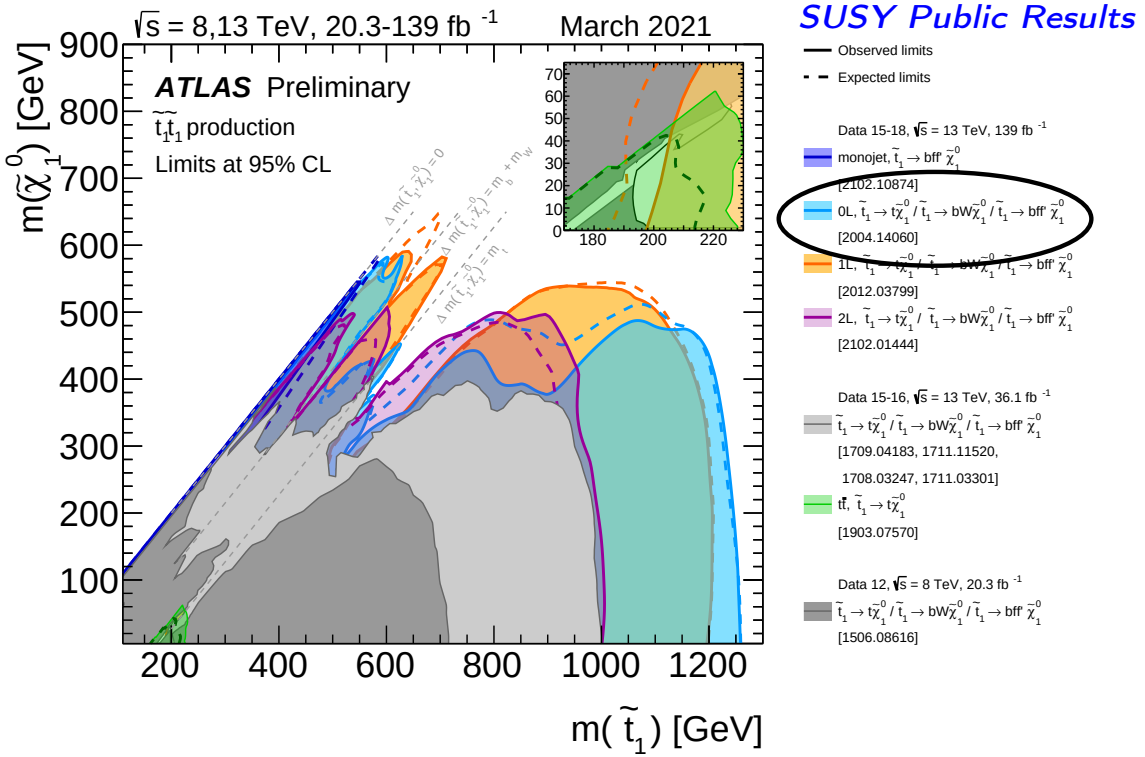
III Gen. squark production

Eur. Phys. J. C 80 (2020) 737



- Direct stop production in 2/3/4-body decay channels (all hadronic)
- High-E_T^{miss} analysis, with a complementary Low-E_T^{miss} approach (exploring softer hadronic $t\bar{t}$ pairs with b-tagged jet triggers) in DM combined search → John's *talk*

- Excluded $\tilde{t}_1$ masses:
  - 2-body: 1.25 TeV
  - 3-body: 300 – 630 GeV
  - 4-body: 300 – 660 GeV
- Complementary results to 1L and 2L channels
- Results interpreted for *up*-type, III Gen. scalar LQ



EWK: Hadronic channels

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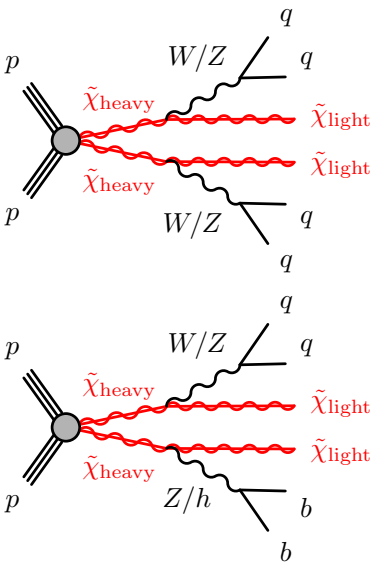
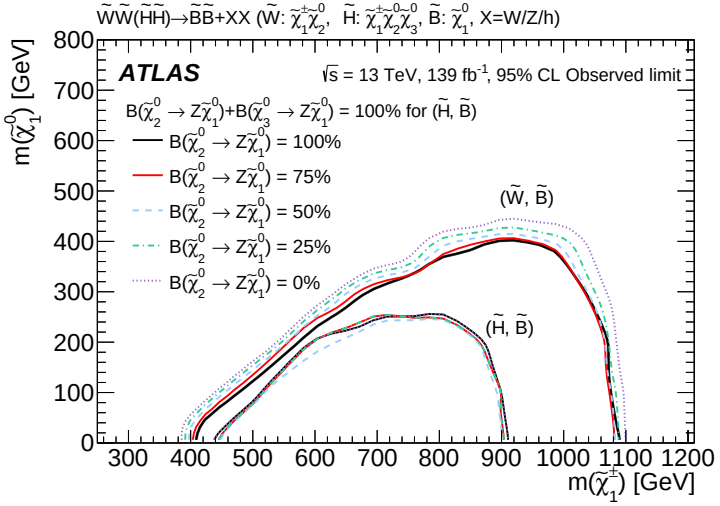
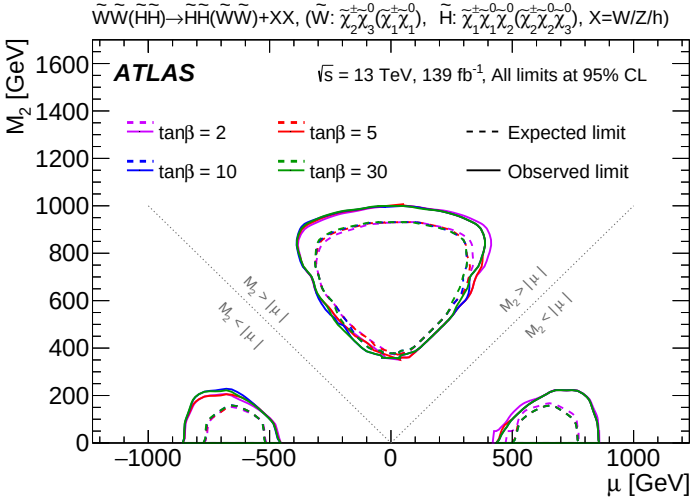
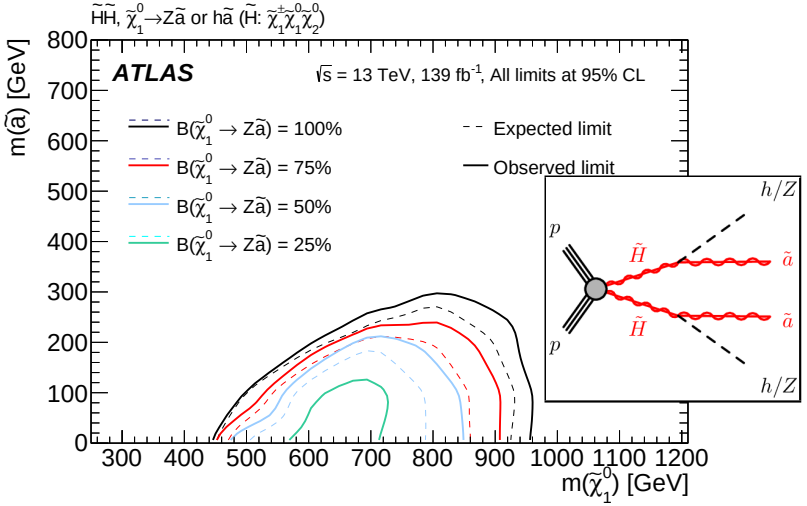






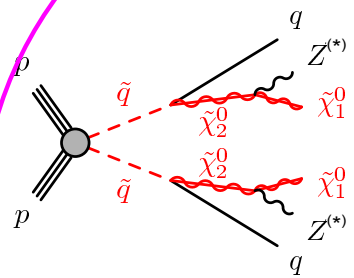
- Bino ($\tilde{B}$), Wino ($\tilde{W}$) and Higgsino ($\tilde{H}$) models
- V_{qq} boson tagging and large-R jet requirements

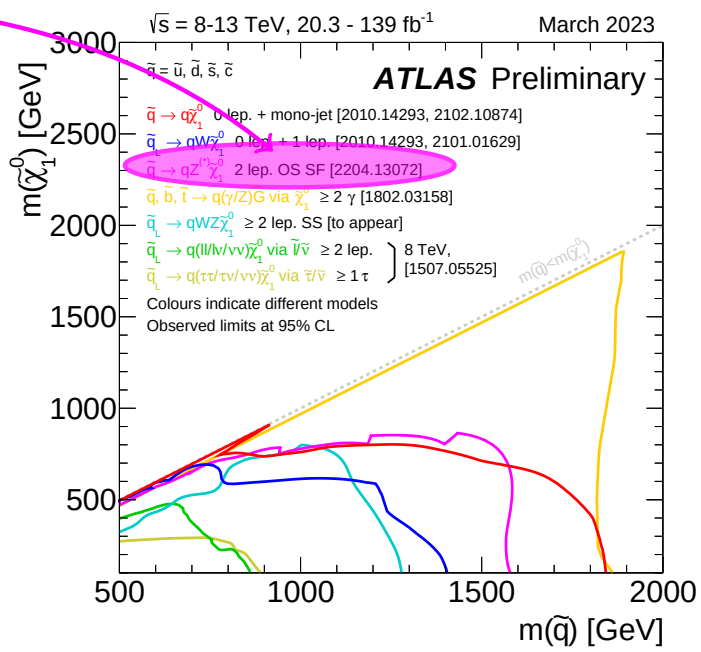


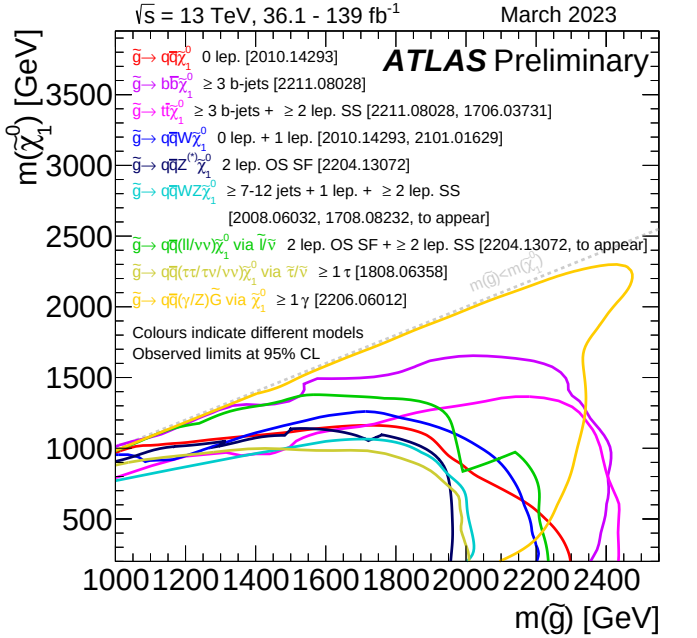
Exclusion limits for different BR, 3D model space ($M_2, \mu, \tan\beta$)

Gluino production

- $\tilde{q} \to qZ^{(\star)}\tilde{\chi}_1^0$

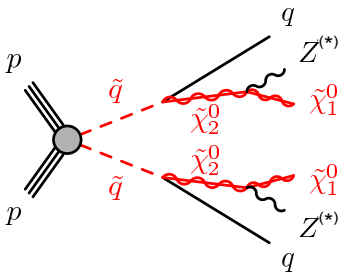




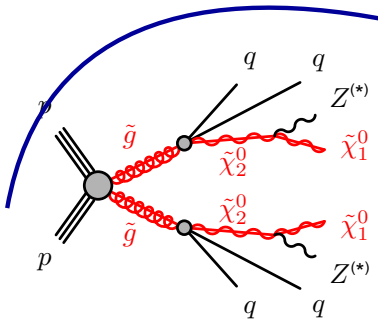


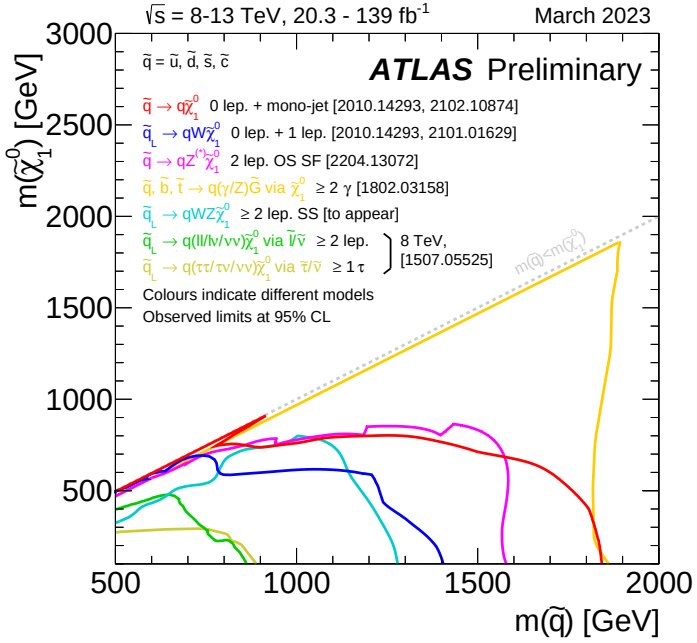
Gluino production

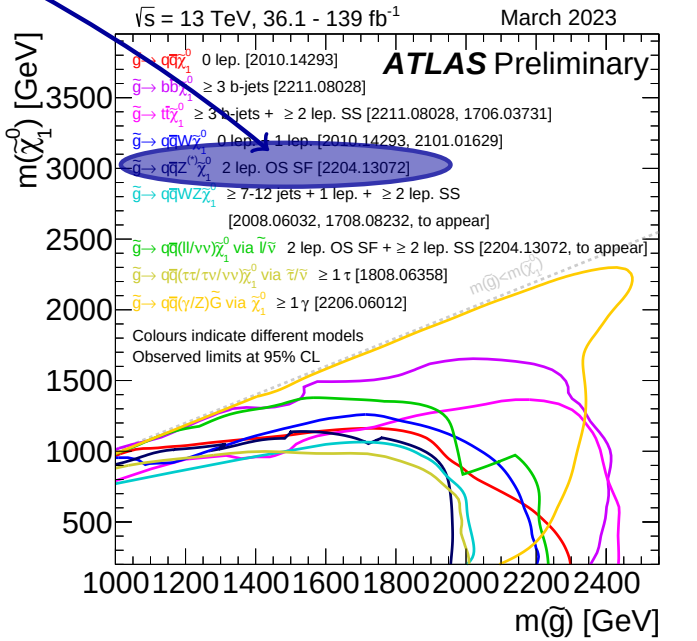
- $\tilde{q} \to qZ^{(\star)}\tilde{\chi}_1^0$



- $g \to q\bar{q}Z^{(\star)}\tilde{\chi}_1^0$

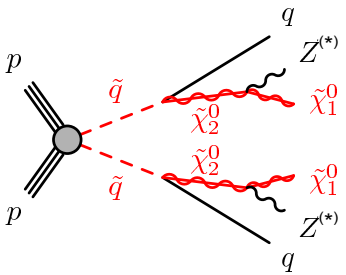




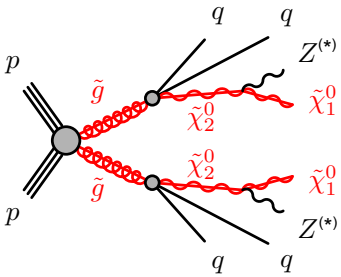
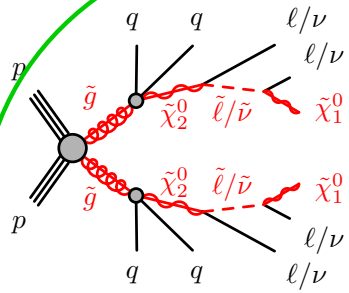
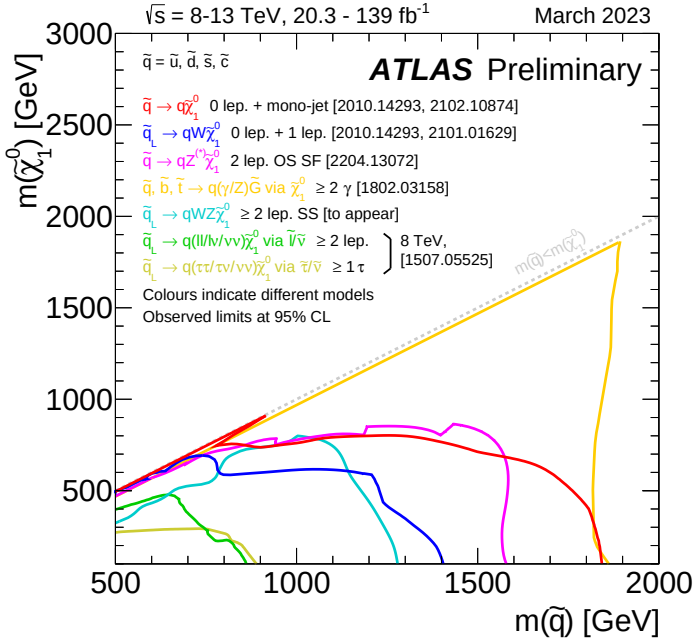
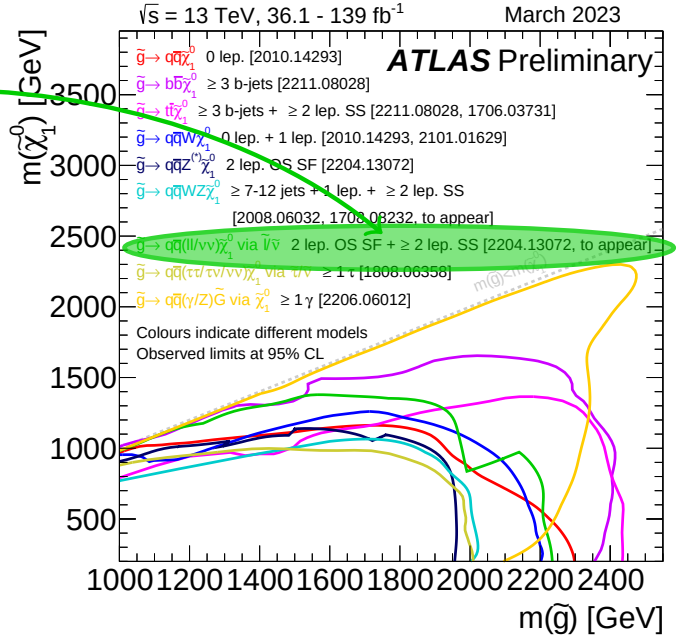


Gluino production

- $\tilde{q} \to qZ^{(\star)}\tilde{\chi}_1^0$



- $g \to q\bar{q}Z^{(\star)}\tilde{\chi}_1^0$



- $g \to q\bar{q}(ll/\nu\nu)\tilde{\chi}_1^0$ via $(\tilde{\ell}/\tilde{\nu})$