R-Parity violating SUSY Searches at ATLAS

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Energy Frontier in Particle Physics:
LHC and Future Colliders

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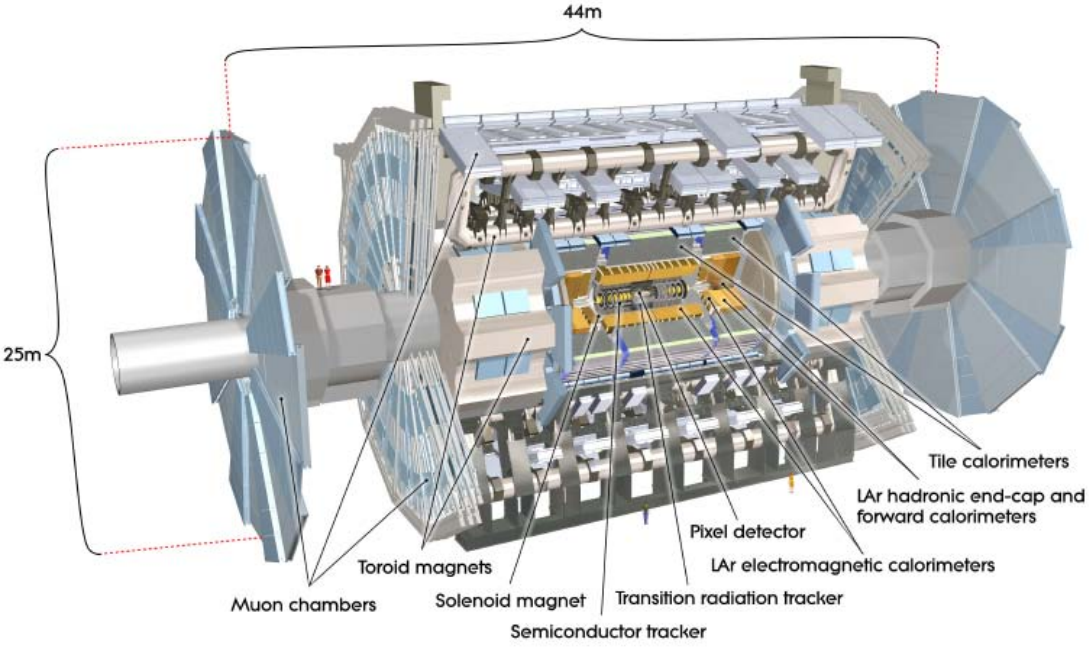
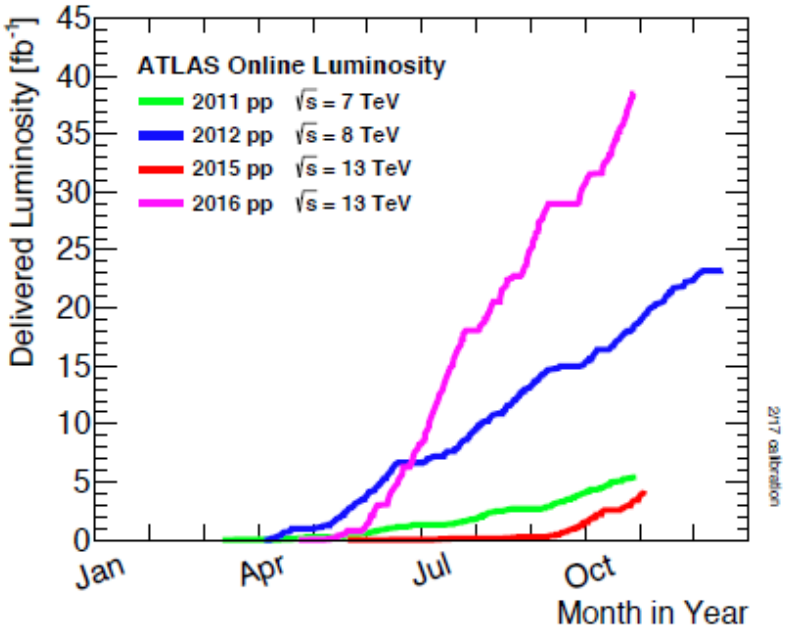
ATLAS in LHC Run II

Major upgrades for Run 2 - detectors, trigger, DAQ, reconstruction
Excellent performance under challenging LHC conditions

- peak lumi 1.38 x 10^{34} cm^{-2} s^{-1}
- up to 50 interactions per crossing

36 fb^{-1} of good 13 TeV *pp collision collected in 2015 and 2016*

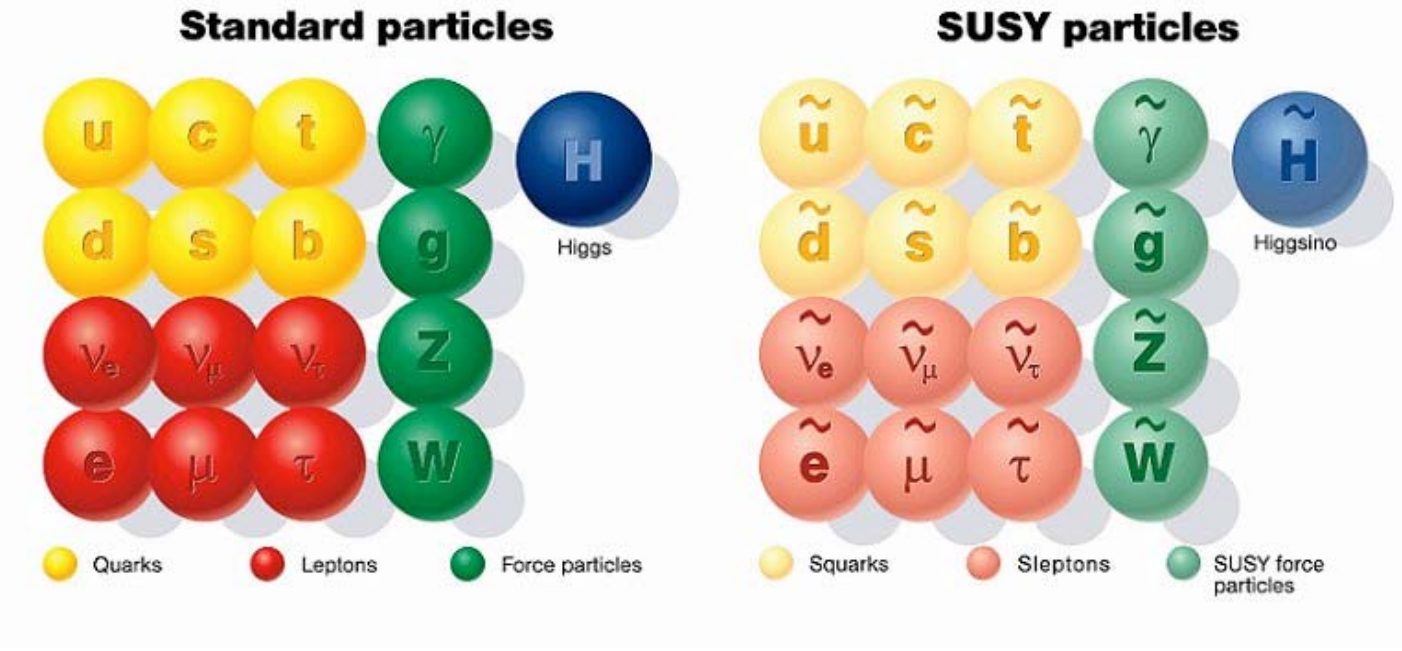




SUSY extending the Standard Model

SUSY suggest phenomenon for searches
A convenient framework well presented in MC generators

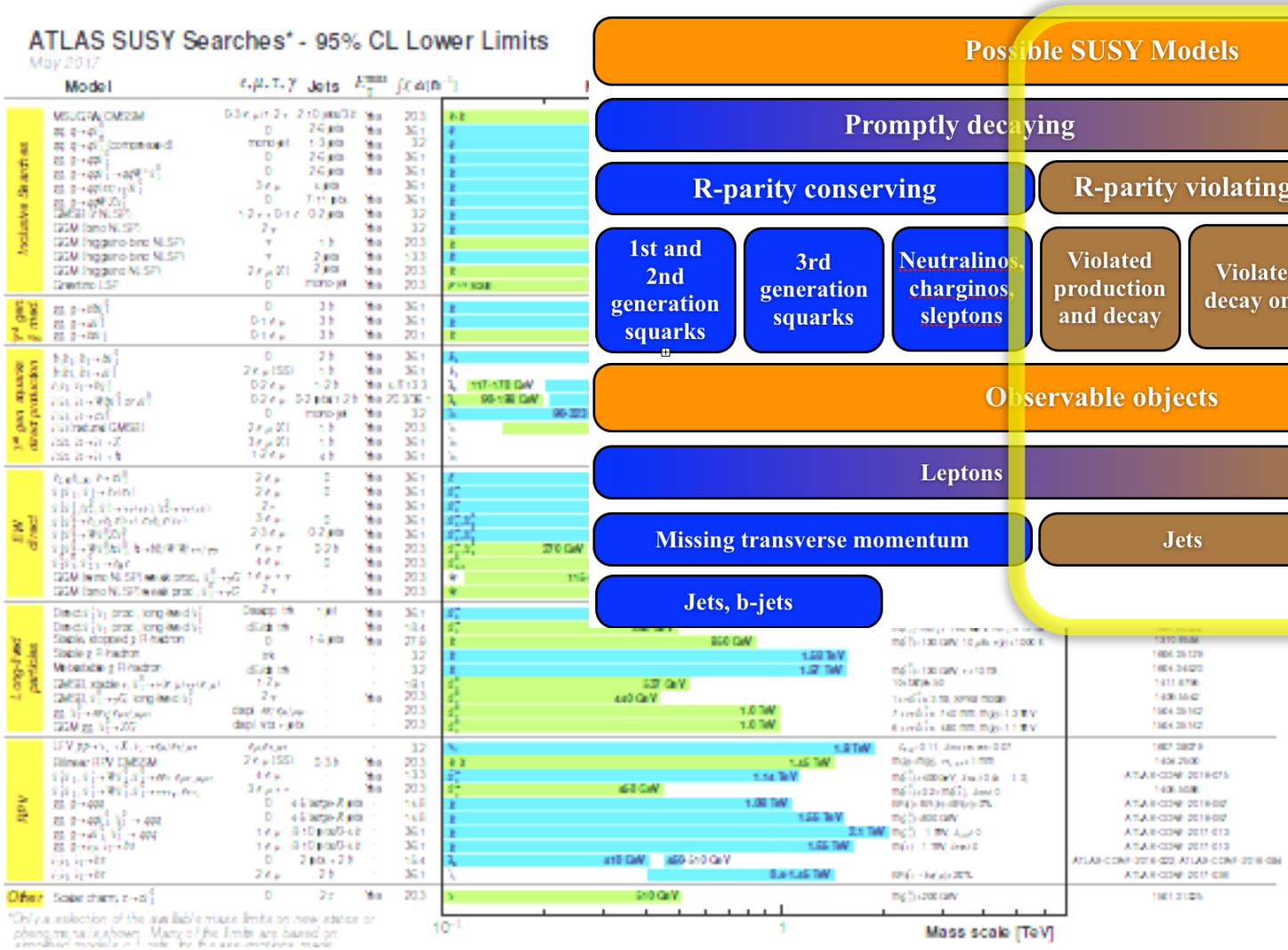
- SUSY links a SM particle to a SUSY partner differing by ½ spin unit
- If R parity is conserved, SUSY LSP is a natural Dark Matter candidate



SUSY searches at ATLAS

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Topics of this discussion



ATLAS RPV searches @8TeV

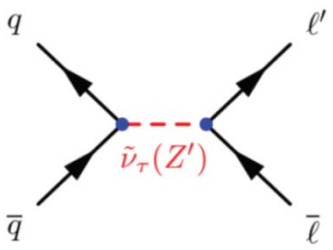
SUSY RPV publications of 8 TeV (July 2016)

Model	observables		mass limit $\sqrt{s}$ = 7, 8 TeV	$\sqrt{s}$ = 13 TeV	reference
LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e\mu/e\tau/\mu\tau$	$\tilde{\nu}_\tau$	$e\mu, e\tau, \mu\tau$	-	1.7 TeV	1503.04430
Bilinear RPV CMSSM	$\tilde{q}, \tilde{g}$	2 e, μ (SS)	0-3 b	1.45 TeV	1404.2500
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	$\tilde{\chi}_1^\pm$	4 e, μ	-	760 GeV	1405.5086
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	$\tilde{\chi}_1^\pm$	3 $e, \mu + \tau$	-	450 GeV	1405.5086
$\tilde{g}\tilde{g}, \tilde{g} \to qqq$	$\tilde{g}$	0	6-7 jets	917 GeV	1502.05686
$\tilde{g}\tilde{g}, \tilde{g} \to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to qqq$	$\tilde{g}$	0	6-7 jets	980 GeV	1502.05686
$\tilde{g}\tilde{g}, \tilde{g} \to \tilde{t}_1 t, \tilde{t}_1 \to bs$	$\tilde{g}$	2 e, μ (SS)	0-3 b	880 GeV	1404.2500
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \to bs$	$\tilde{t}_1$	0	2 jets + 2 b	345 GeV	ATLAS-CONF-2016-022
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \to b\ell$	$\tilde{t}_1$	2 e, μ	2 b	0.4-1.0 TeV	ATLAS-CONF-2015-015

8 TeV analyses

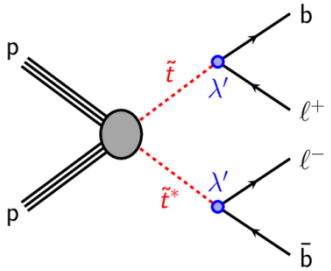
LLĒ+LQD̄ di-leptons

1503.04430



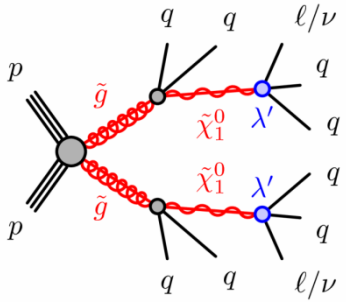
LQD̄ $\tilde{t} \to \ell b$

ATLAS-CONF-2015-015



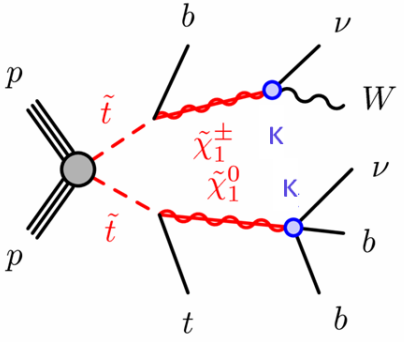
LQD̄ *1-lepton*

ATLAS-CONF-2015-018



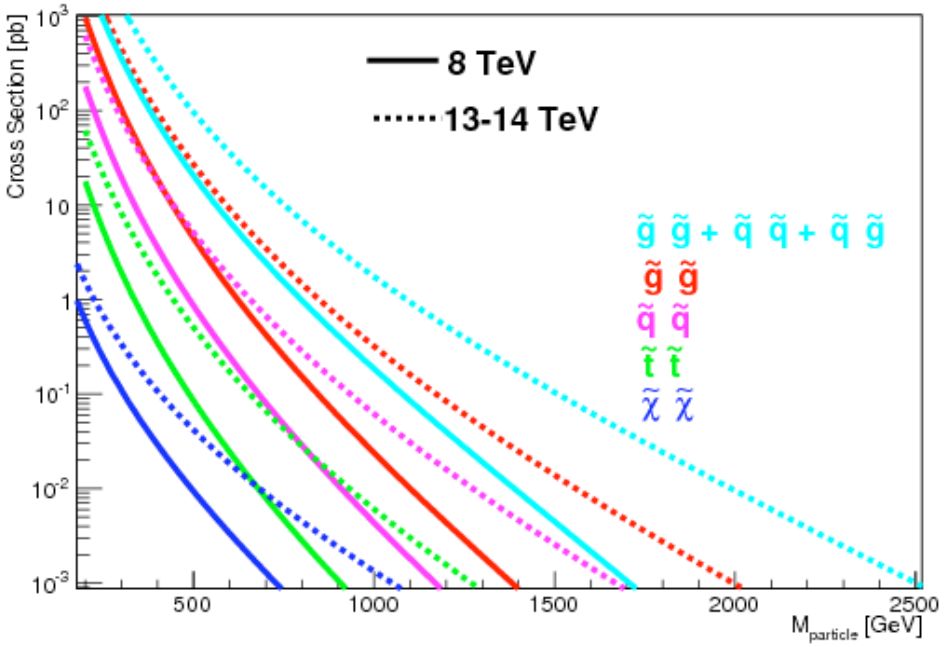
bilinear

ATLAS-CONF-2015-018



SUSY in Run II

Increase of cross section at 13 TeV, reach to higher SUSY masses



- **R-parity conservation:**
  - strong/EW pair production with cascade decay to LSP
  - many high P_T SM particles + $\not{E}_T$ due to LSP escaping detection
- **R-parity Violation:**
  - Multi Jet/Multi leptons from LSP decays
  - Displaced vertices due to late LSP decays
- **Long lived particles:**
  - Sparticles with long lifetimes due to mass degeneracy, small couplings
  - Secondary vertexes, mainly detector driven

R-Parity violating search

Search for R-parity violating SUSY $R = (-1)^{2s+3(B-L)}$

Super-potential with RPV of lepton or baryon number

$$\mathcal{W}_{\Delta L=1} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_d$$

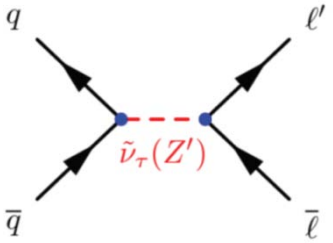
$$\mathcal{W}_{\Delta B=1} = \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

*Analyses updated to **13 TeV** data*

$LL\bar{E}$+$LQ\bar{D}$ di-leptons

1607.080793

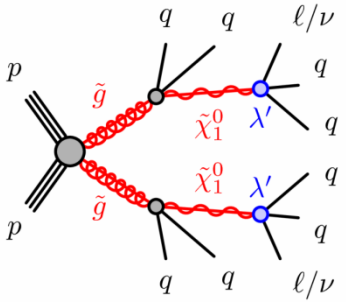
3.2 fb^{-1}



$LQ\bar{D}$ *1-lepton*

ATLAS-CONF-2017-013

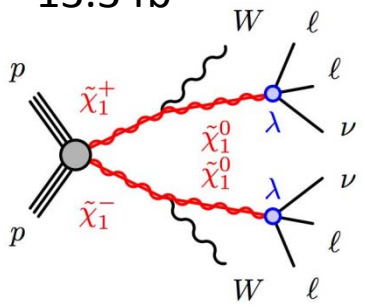
36.1 fb^{-1}



$LL\bar{E}$ 4 leptons

ATLAS-CONF-2016-075

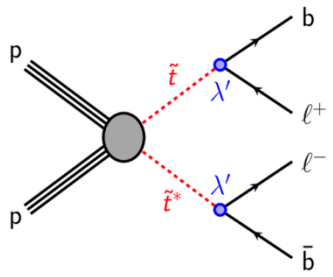
13.3 fb^{-1}



$LQ\bar{D}$ $\tilde{t} \rightarrow \ell b$

ATLAS-CONF-2017-036

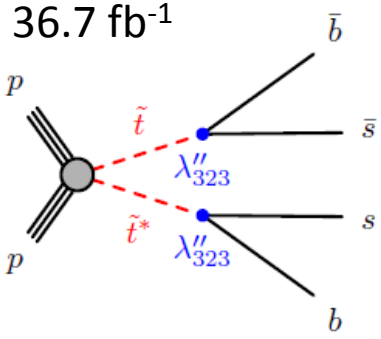
36.1 fb^{-1}



$\bar{U}\bar{D}\bar{D}$ stop 4-jet

ATLAS-CONF-2017-025

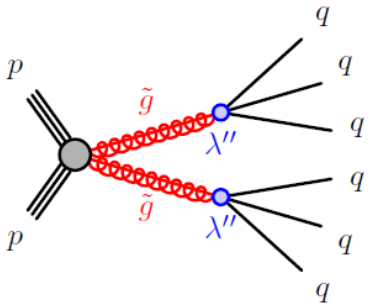
36.7 fb^{-1}



$\bar{U}\bar{D}\bar{D}$ multi-jet

ATLAS-CONF-2016-057

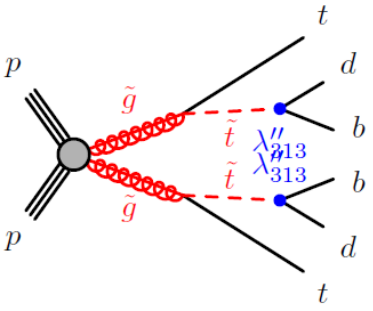
14.8 fb^{-1}



$\bar{U}\bar{D}\bar{D}$ SS/3Leptons

ATLAS-CONF-2016-037

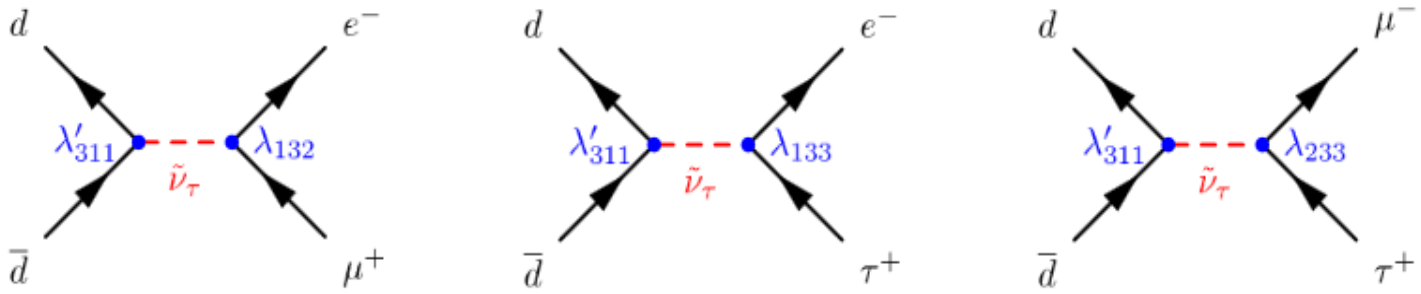
13.2 fb^{-1}



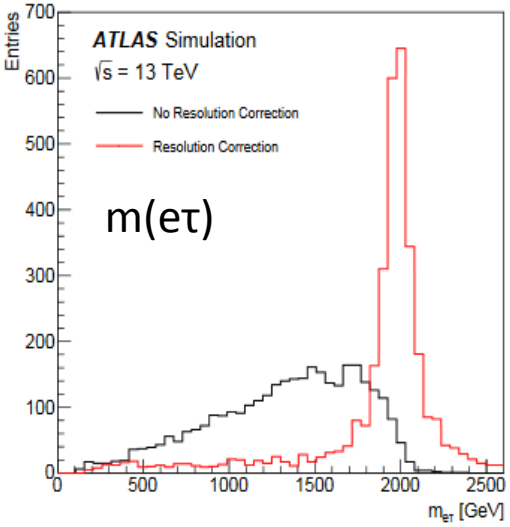
$\lambda'_{311}\lambda_{i3j}$: 2-lepton LFV tau sneutrino (1)

Lepton Flavor Violation

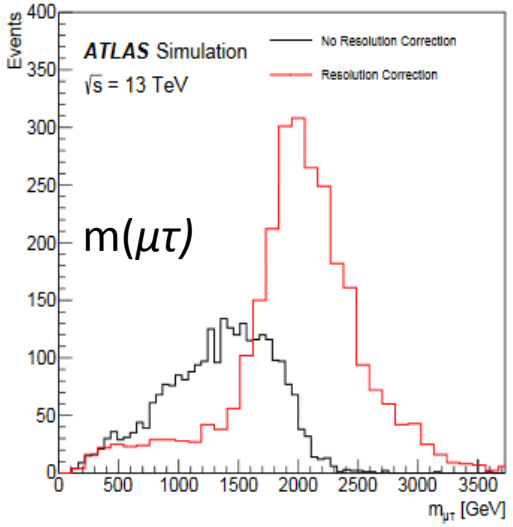
by λ'_{311}, λ_{i3j}



- 13 TeV data of 3.2 fb^{-1}
  lepton (e, μ), p_T > 65 GeV
  τ to single hadron decay,
  ν assuming p_T, ϕ of E_t^{miss},
  η of hadron
- Background: QCD, W+jet



(a) $e\tau$ channel

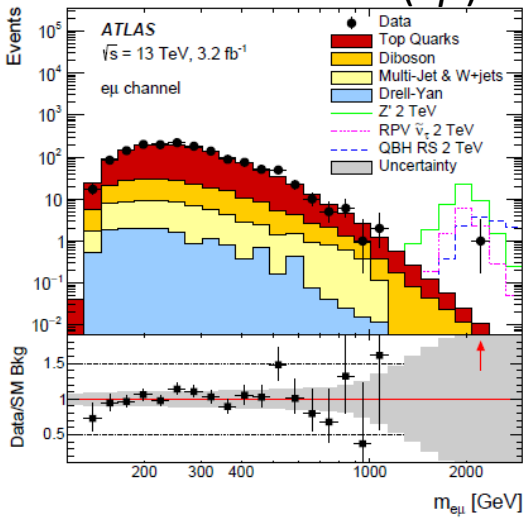


(b) $\mu\tau$ channel

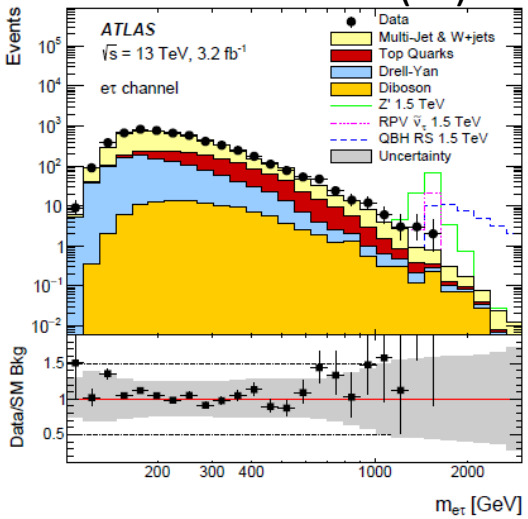
λ'_{311} : 2-lepton LFV tau sneutrino (2)

tau sneutrino invariant mass (13 TeV, 3.2 fb^{-1})

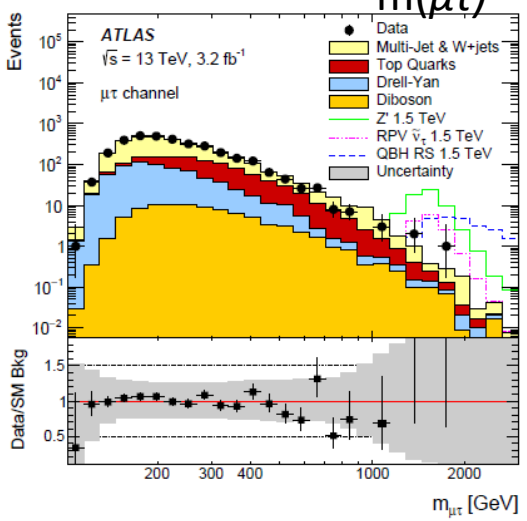
m(eμ)



m(eτ)

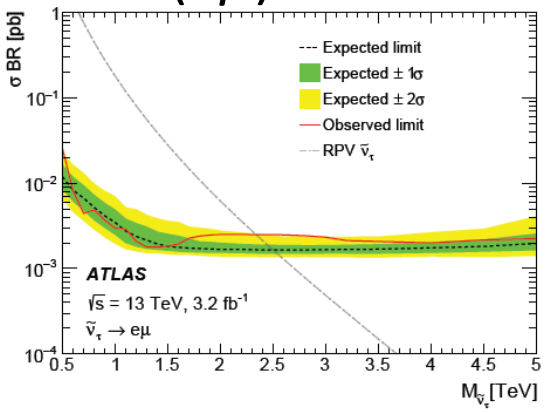


m(μτ)

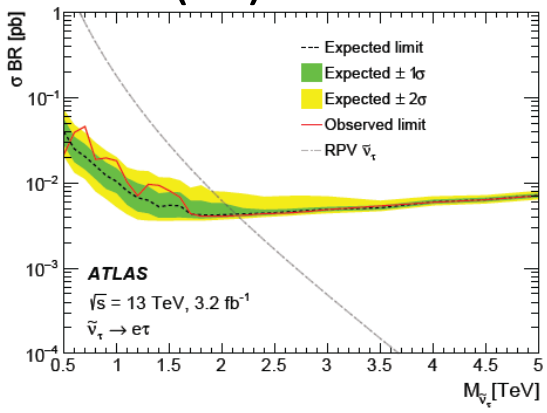


95% CL on σ·Br

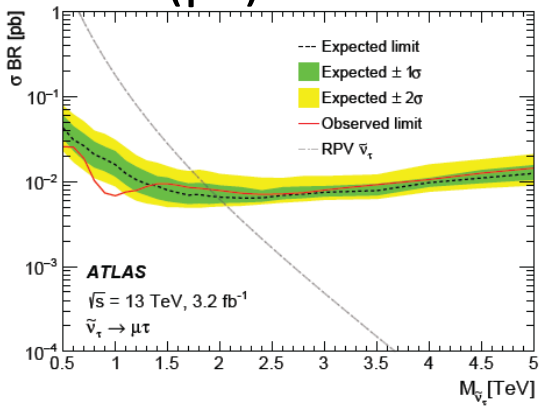
m(eμ) > 2.3 TeV



m(eτ) > 2.2 TeV



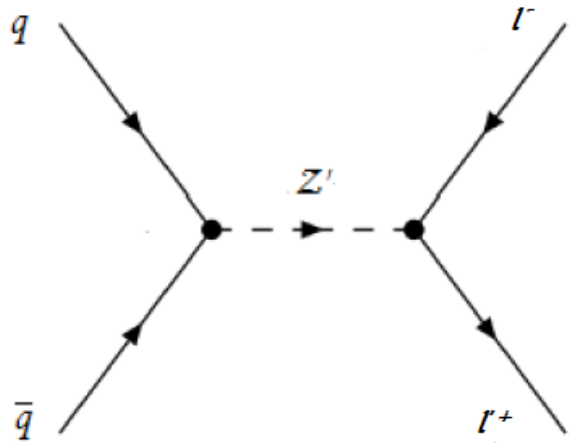
m(μτ) > 1.9 TeV



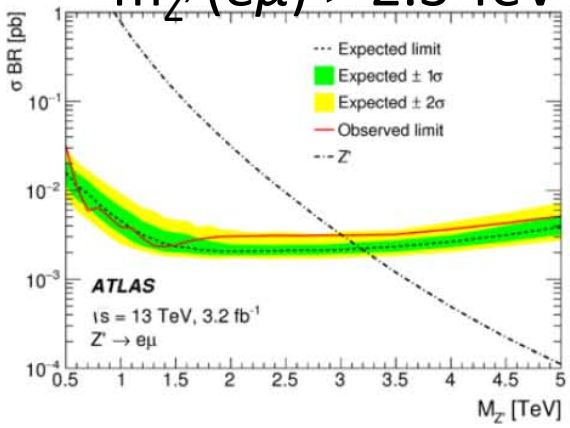
2-lepton LFV decay interpreted as Z'

- Extended SSM Z'
- Same coupling as the SM,

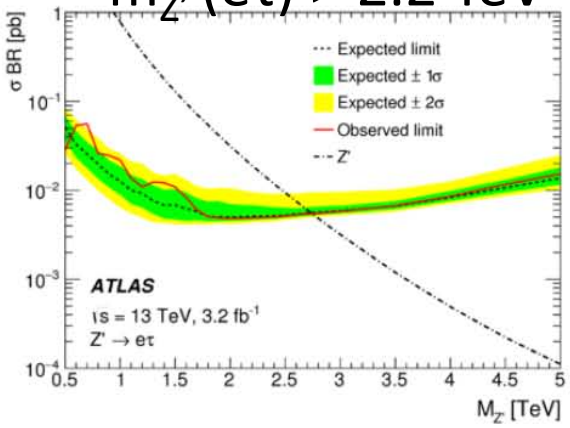
$$\sigma(Z' \to l_i l'_j) \propto \frac{g'^2_Z Q^2_{ij} M^2_{ll'}}{(M^2_{ll'} - M^2_{Z'})^2 + M^2_{Z'} \Gamma^2_{Z'}}$$



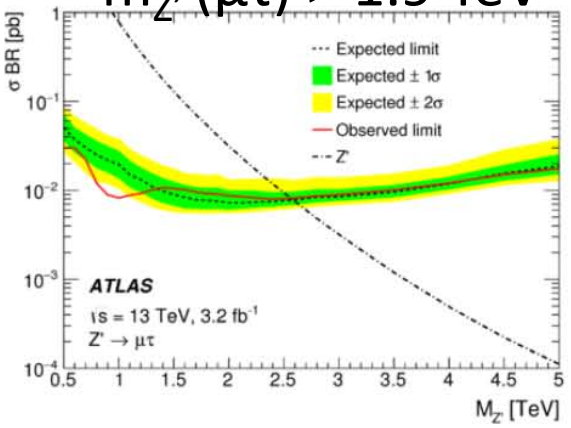
$m_{Z'}(e\mu) > 2.3$ TeV



$m_{Z'}(e\tau) > 2.2$ TeV



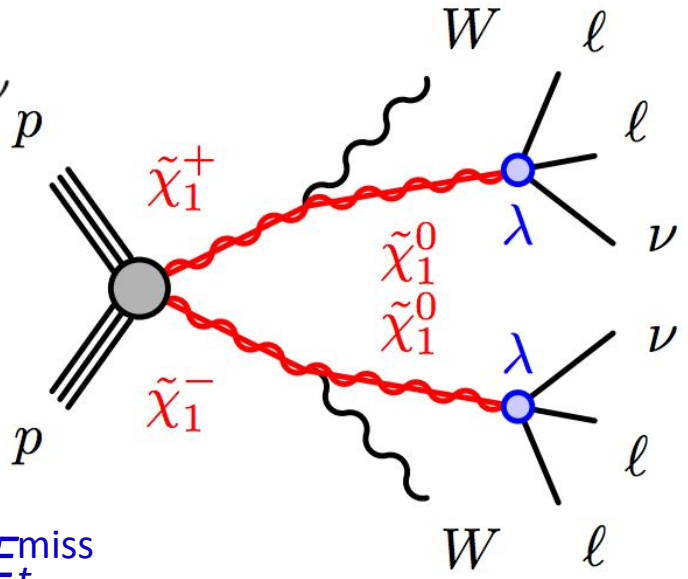
$m_{Z'}(\mu\tau) > 1.9$ TeV



λ_{12k} : 4-lepton RPV search

Chargino pair production to neutralino (LSP)
Lepton number RPV by λ_{121}, λ_{122} of

$$\tilde{\chi}_1^0 \to e^+e^-\nu,\ \tilde{\chi}_1^0 \to e^\pm\mu^\mp\nu,\ \tilde{\chi}_1^0 \to \mu^+\mu^-\nu$$

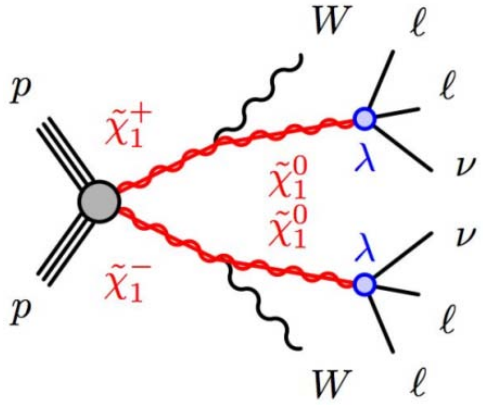


- Data of 13 TeV, 13.3 fb^{-1}
  ≥ 4 leptons (e, $\not{\mu}$),
  Z veto, $m_{\ell+\ell-}$ [81.2, 101.2]
  effective mass: $m_{\text{eff}} = p_T(\ell)+p_T(\text{jet})+E_t^{\text{miss}}$
- Signal region: ≥4ℓ, m_{eff} >600, 800 GeV
- Validation conducted using
  events in m_{eff} < 600 GeV
  dominated by *ZZ, tt̄, Z+jets*

λ_{12k} : 4 leptons RPV exclusion

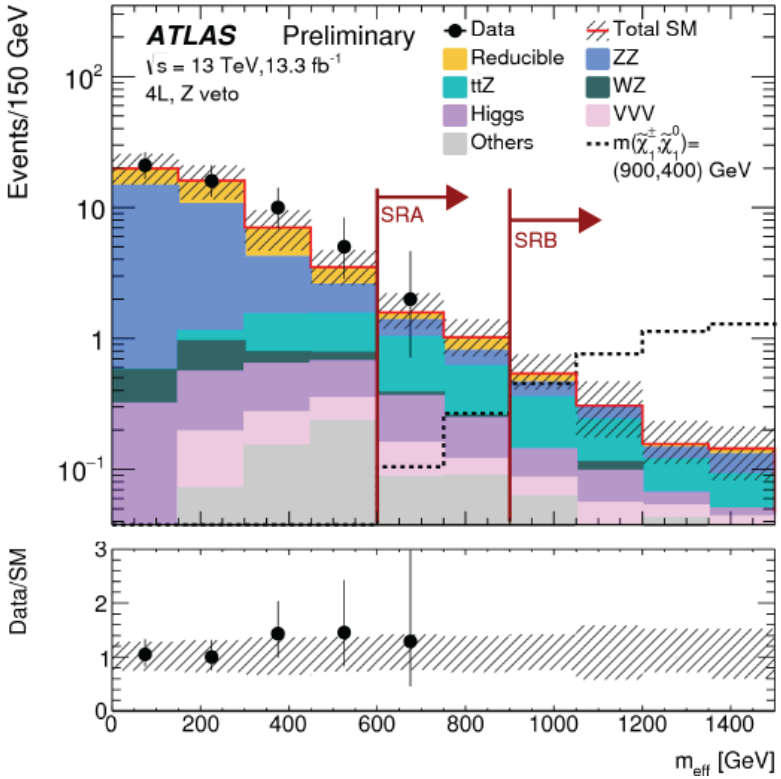
Chargino pair production assuming RPV

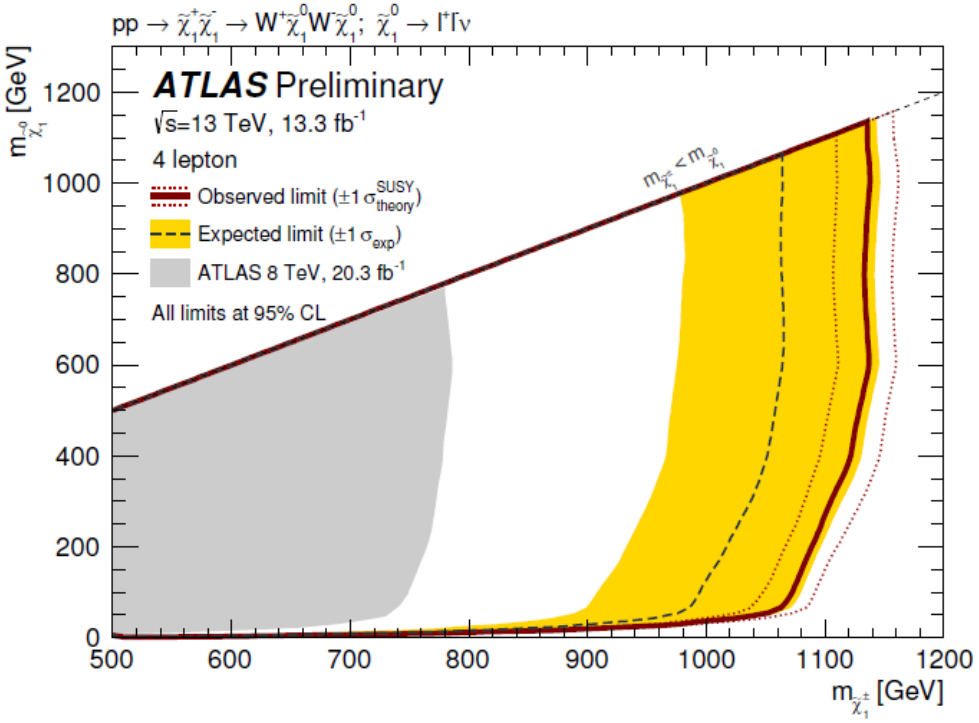
with $\lambda_{ijk} L_i L_j \bar{E}_k$ coupling of $\tilde{\chi}_1^0 \rightarrow \ell_k^{\pm} \ell_{i/j}^{\mp} \nu_{j/i}$



Exclusion of $\chi_1^{\pm}$ with mass up to 1.1 TeV

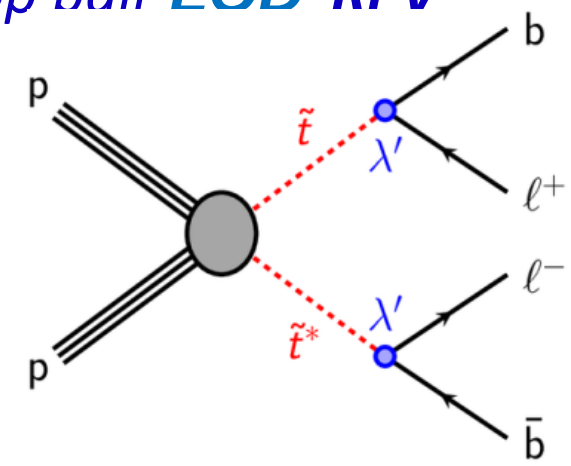
for m(χ_1^0) > 400 GeV





Resonance pair: $\tilde{t} \rightarrow \ell b$

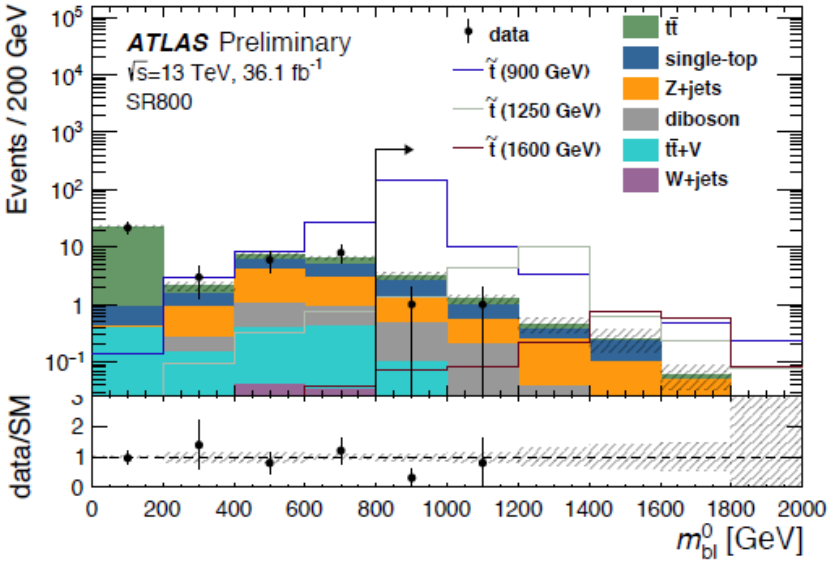
stop pair **LQD RPV**

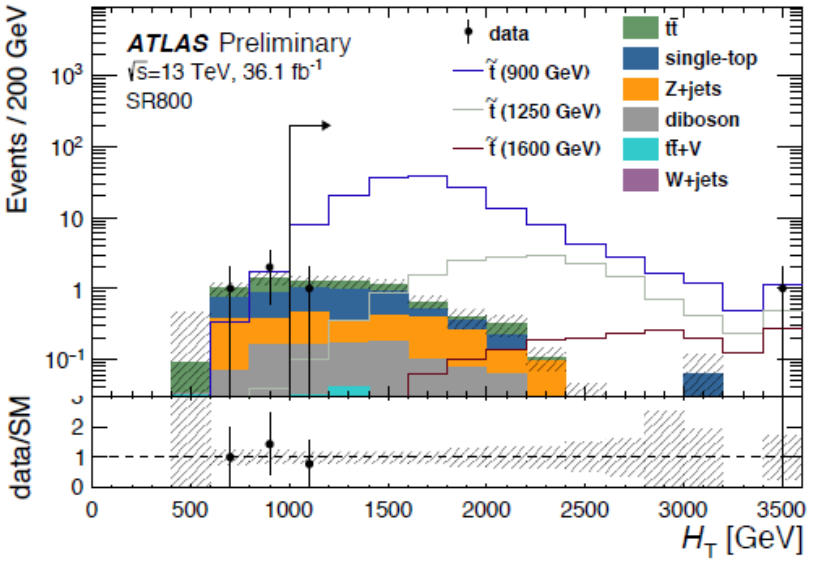


2ℓ (e, μ), $N_{jets} = 2$, $N_{b\text{-}jets} \geq 1$

- stop pair production
- RPV decay, minimal B-L model
- violating lepton number
- Signal Regions defined in H_T $m_{b\ell}$ and $m_{\ell\ell}$

$$H_{\mathrm{T}} = \sum_{i=1}^{2} p_{\mathrm{T}}^{\ell_i} + \sum_{j=1}^{2} p_{\mathrm{T}}^{\mathrm{jet}_j}$$

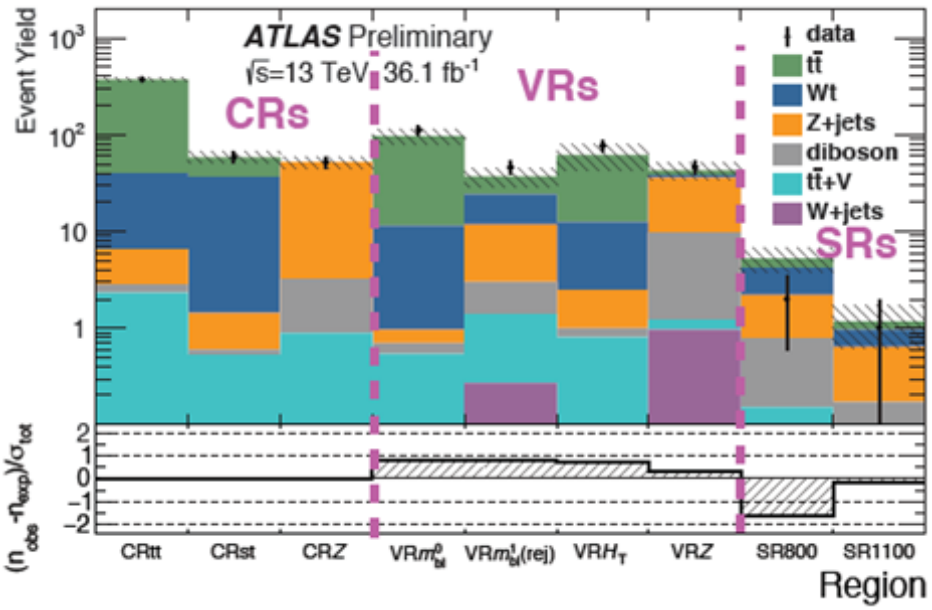


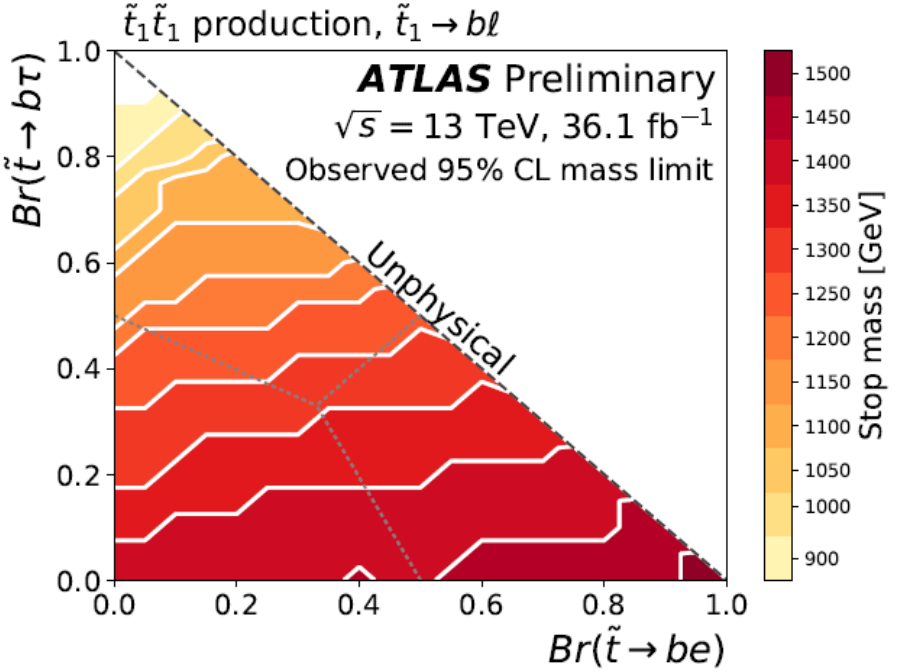


Resonance pair: $\tilde{t} \rightarrow \ell b$

No significant excesses observed

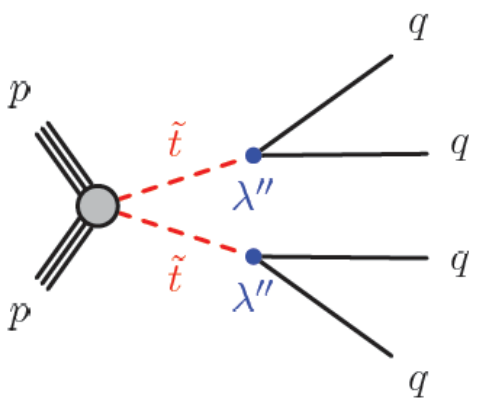
- BR-dependent limits set on stop masses
- Stop with masses up to 1.55 TeV excluded (100% BR to *eb*)

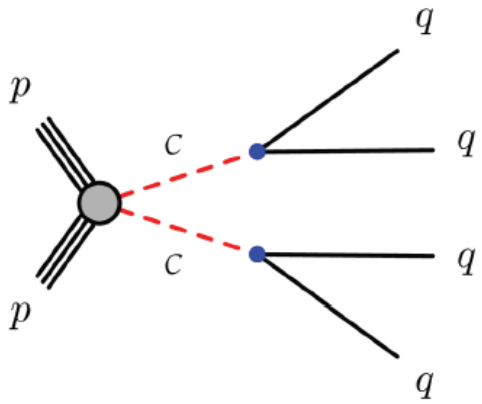




Resonance pair: 4-jet search

stop pair λ''_{3jk} ***RPV***





coloron pair

4-jet final states in search of

- top squark pair, RPV λ''_{3jk} coupling to quarks

Event selection: 13 TeV data, **36.7** fb^{-1}

- anti-k_t jet of R= 0.4, p_T>120 GeV
- 4 jets, paired by $\Delta R_{min} = \sum_{i=1,2} |\Delta R_i - 1.0|$
- background suppression $\Delta R_{min} < 0.03\, m_{avg}/\mathrm{GeV}$

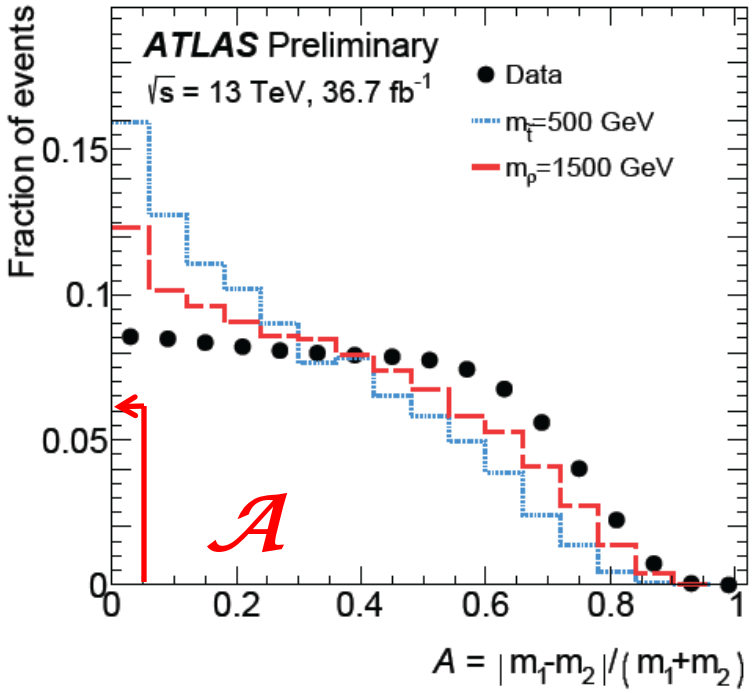
  for two resonances of equal masses $m_{avg} < (m_1 + m_2)/2$
- b-tag not required

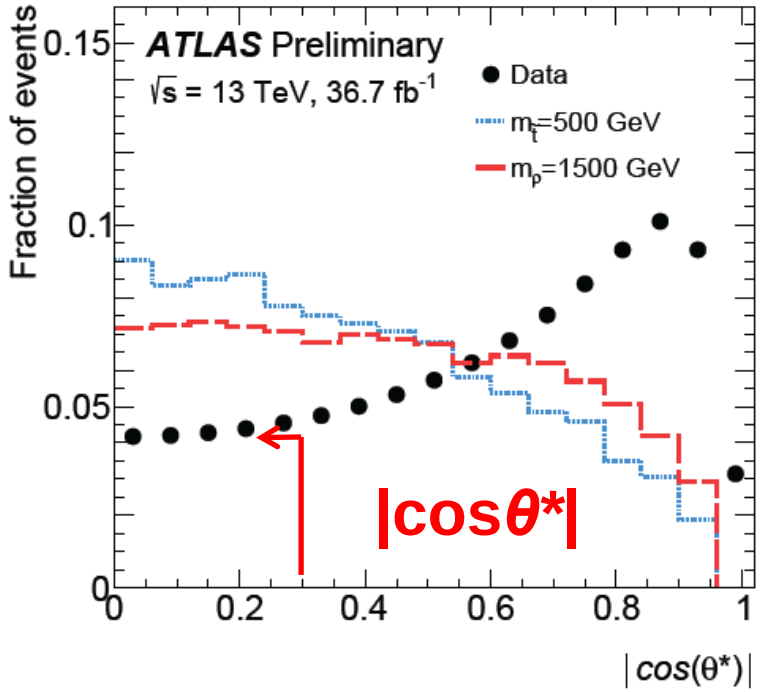
Resonance pair, 4-jet final state

Pair production of heavy resonances
each decay into a jet-pair

- jet-pair $|\cos\vartheta^*|$ are more central
- masses of the two jet pairs about equal $\mathcal{A} = \frac{|m_1 - m_2|}{m_1 + m_2}$

Distributions compared to stop $m(\tilde{t})$ = 500 GeV, coloron m_C= 1250 GeV





4-jets discriminant

- Signal region (***SR***):

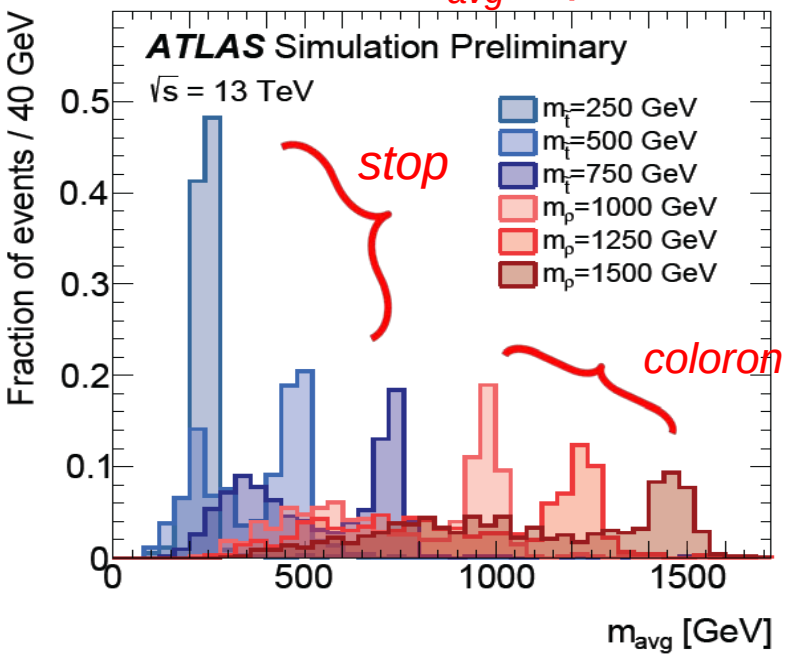
  $\mathcal{A}$<0.05, | cosϑ*|<0.3

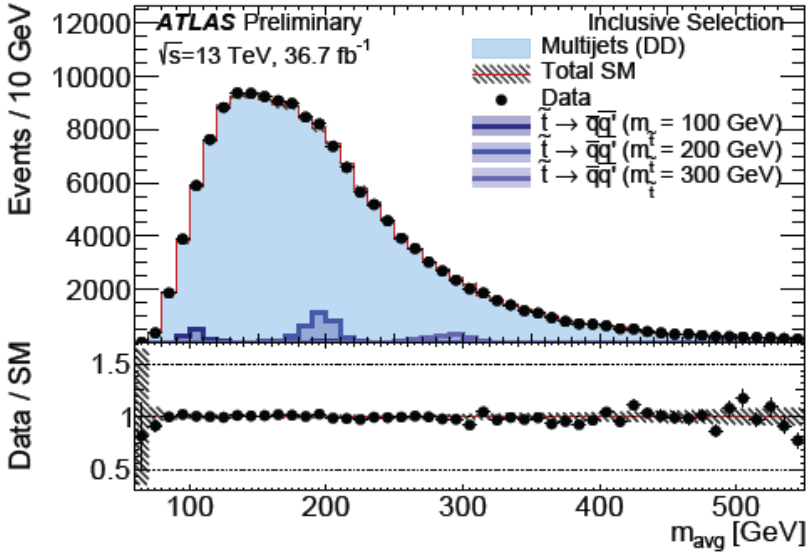
- Discriminant variable:

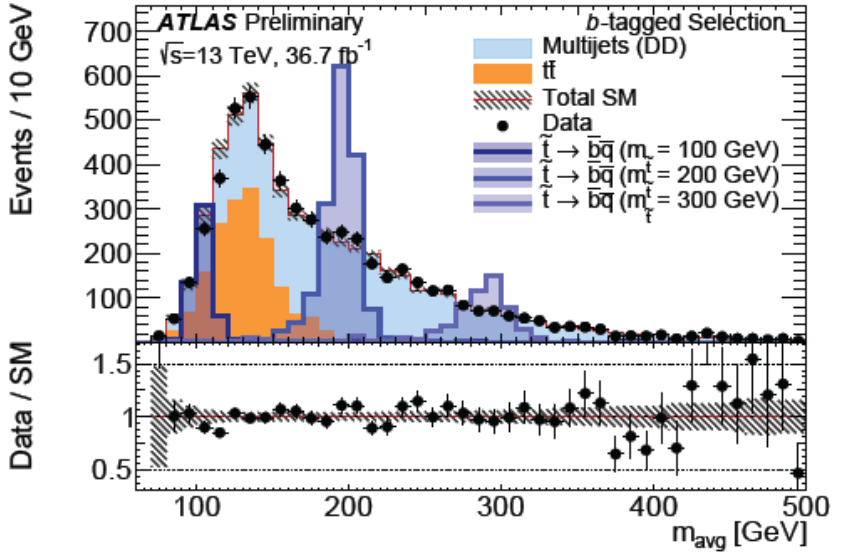
  $m_{avg}=(m_1+m_2)/2$

- Background in ***SR***:
  SM multi-jets, by distributions in quardrants of $\mathcal{A}$, | cosϑ*|
  (ABCD method)

m_{avg} *expectation*







Resonance pair: 4-jet exclusion

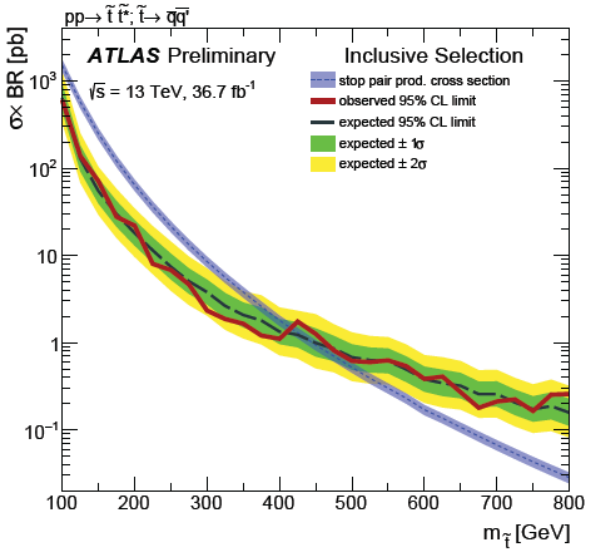
- m_{avg} in signal region: counted for stop, coloron in mass of hypotheses
- Exclusion 95% CL (13 TeV, 36.7 fb^{-1})

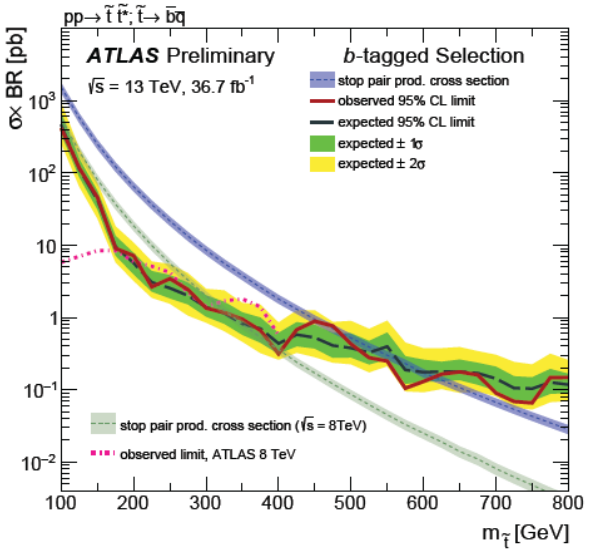
stop λ''_{3jk} ***RPV decay to 2 quarks*** $100 < m(\tilde{t}) < 410$ GeV excluded

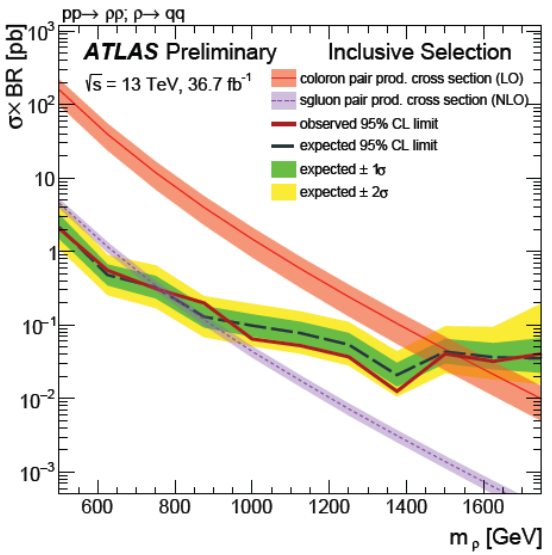
decat to b + q $100 < m(\tilde{t}) < 470$ GeV excluded

$480 < m(\tilde{t}) < 610$ GeV

coloron $m_C < 1500$ GeV excluded





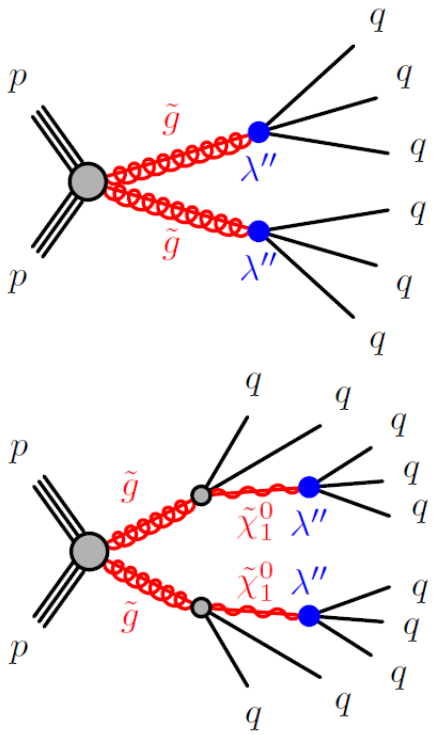


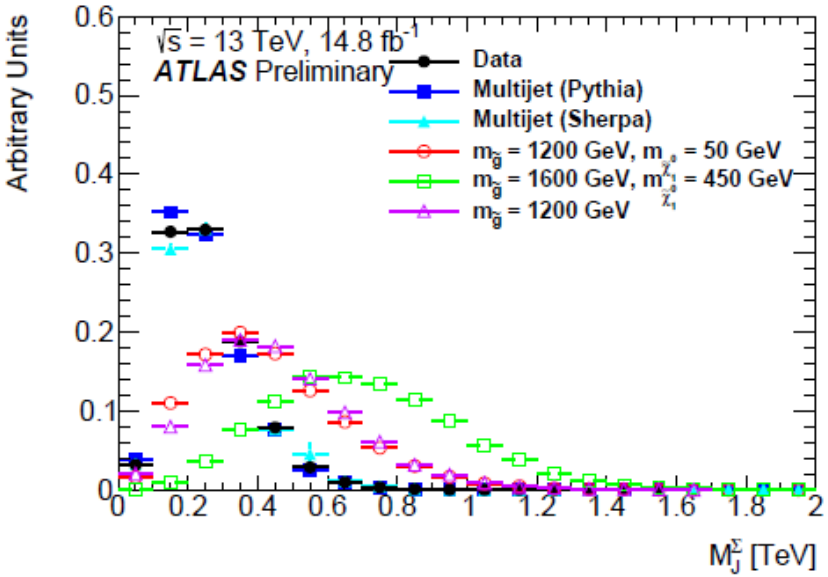
λ''_{ijk} : multi-jet RPV gluino search

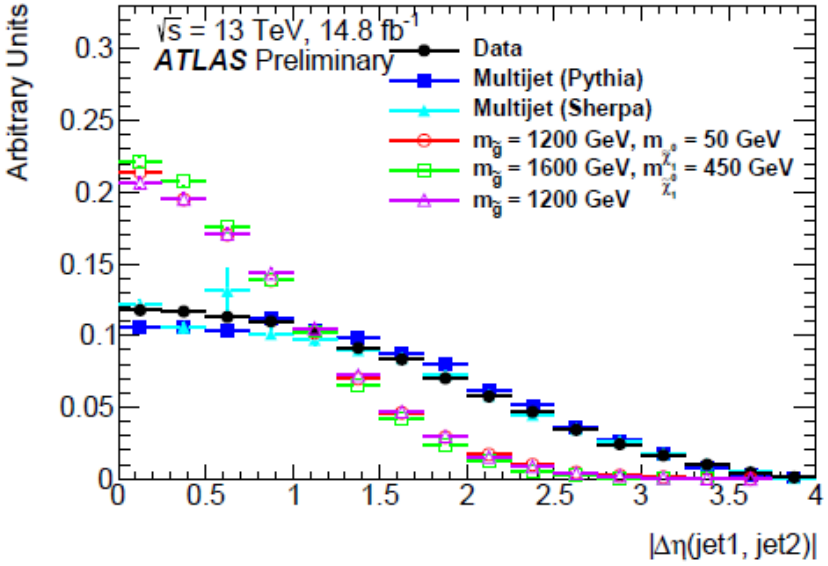
Gluino pair production RPV, λ''_{ijk} coupling to jets

Event selection: 13 TeV, 14.8 fb^{-1}

- multiple jets and b-tag
  anti-k$_t$ of **large *R=1.0***, leading jet of p_T>440 GeV
- topological variable:
  jet mass of 4 leading jets $M_J^{\Sigma} = \sum^4 m^{\text{jet}}$
- discriminant on pseudorapidity: $|\Delta\eta_{12}|$
  difference of the 2 leading jets







λ''_{ijk} : multi-jet validation

Gluino Signal (***SR***), Validation (***VR***) and Control (***CR***) regions

divided on **N_{jet}, $|\Delta\eta_{12}|$, b-tag/inclusive**

b-tag of small R=0.4 jets

N_{jet}	$\lvert\Delta\eta_{12}\rvert > 1.4$	$\lvert\Delta\eta_{12}\rvert < 1.4$
$= 3$	3j CR	–
≥ 4	4j VR	4j SR
≥ 5	5j VR	5j SR

Data-driven background

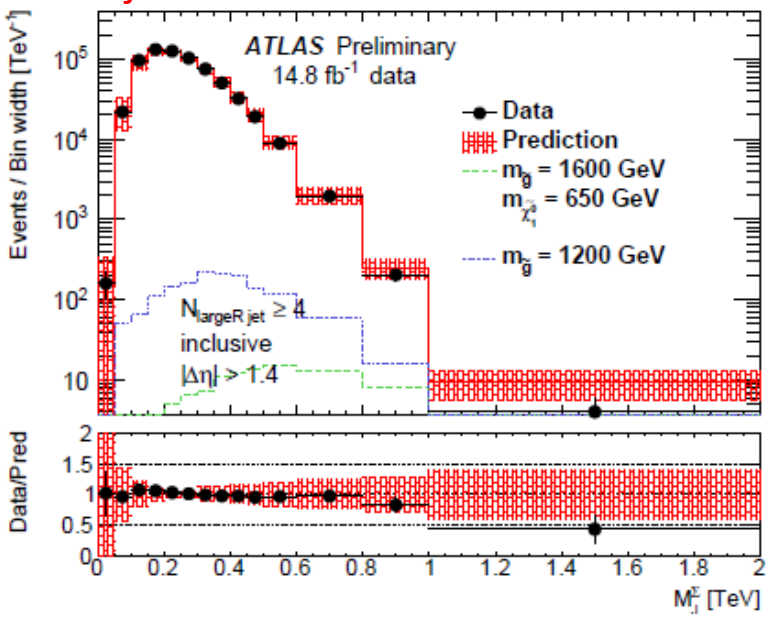
single-jet mass template from ***CR*** binned in p_T,η

jets of sample ➔ mass randomly picked from the template, for each jet p_T,η

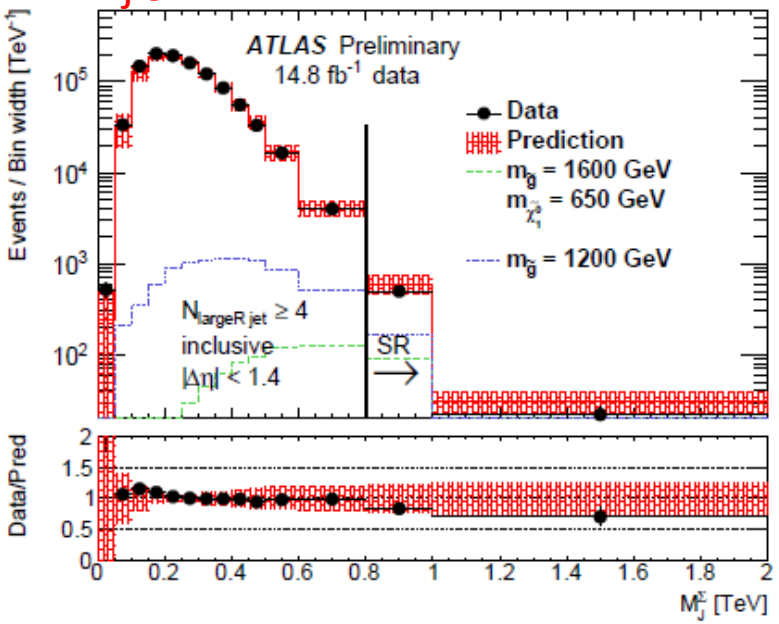
M_J^{Σ} background calculated

Topological M_J^{Σ} : examined for samples in ***VR***, ***SR***

4j VR



4j SR



λ''_{ijk} : multi-jet exclusion

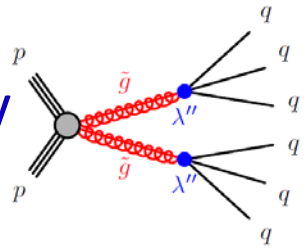
Observables in SR's

w/w.o. b-tag, M_J^Σ cuts

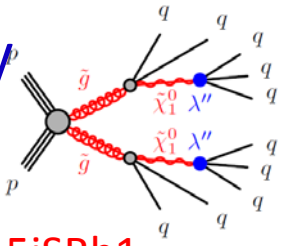
Region	M_J^Σ cut	observed	predicted
4jSRb1	> 0.8 TeV	24	36.5 ± 7.7 ± 3.9 ± 7.5
4jSR		66	88.2 ± 10.7 ± 8.6 ± 11.8
5jSRb1	> 0.6 TeV	15	9.0 ± 2.6 ± 0.9 ± 1.5
5jSR		35	27.5 ± 5.5 ± 3.3 ± 3.5

RPV gluino pair excluded for

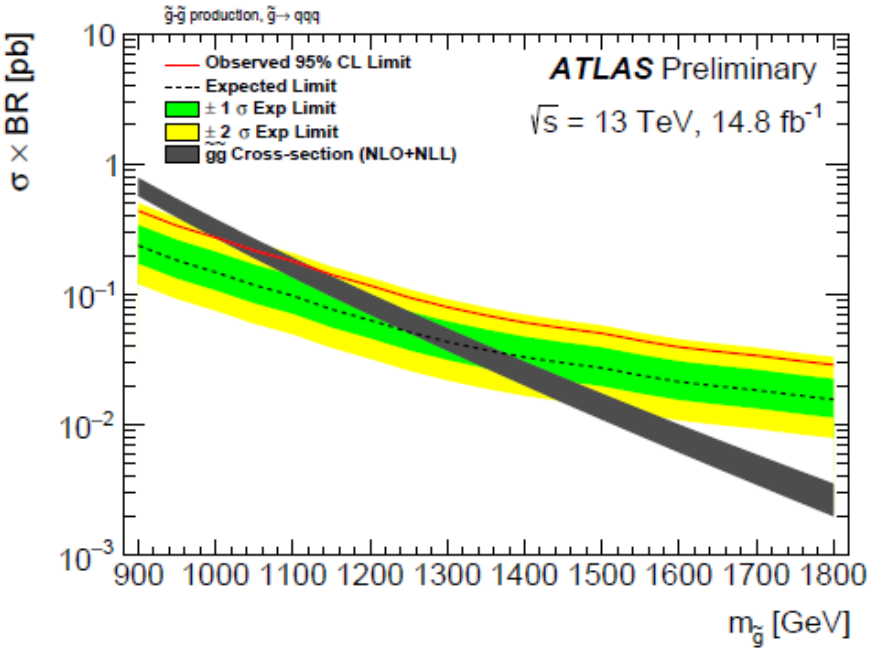
$m(\tilde{g})$ up to 1080 GeV

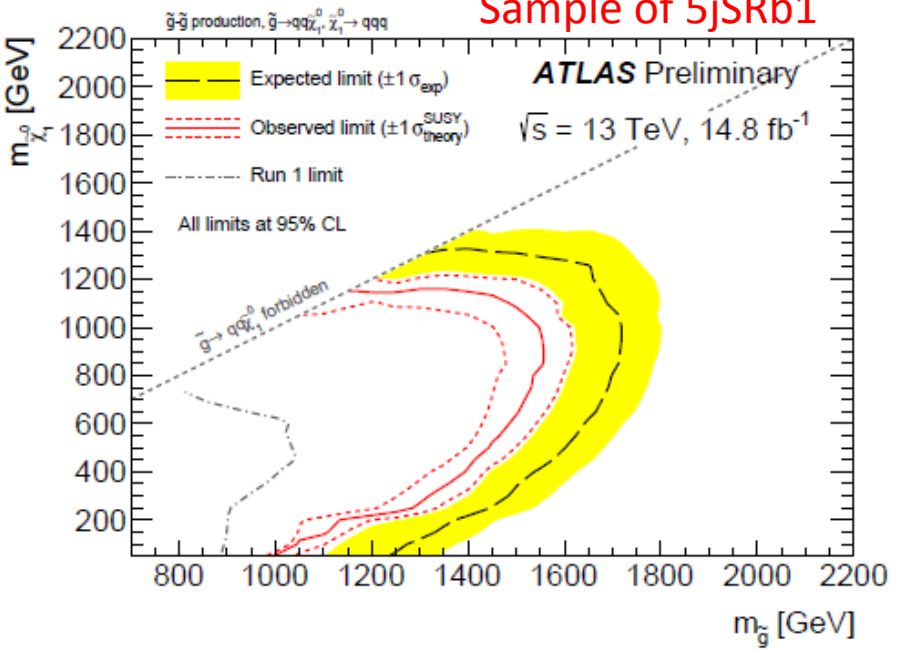


$m(\tilde{g})$ to 1050 ~1550 GeV vs $m(\chi_1^0)$



Sample of 5jSRb1



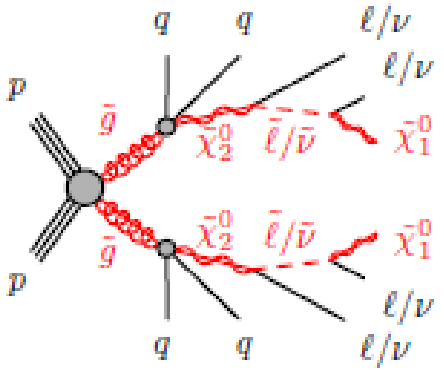


λ''_{ijk} : Same-Sign di-lepton, 3 leptons

ATLAS-CONF-2016-037

Same-Sign dilepton (e,μ) or 3 leptons + jets

- Analysis conducted for **RPC** and **RPV** scenarios
- Results of ***RPV*** $\boldsymbol{\lambda''_{ijk}}$ coupling are presented here

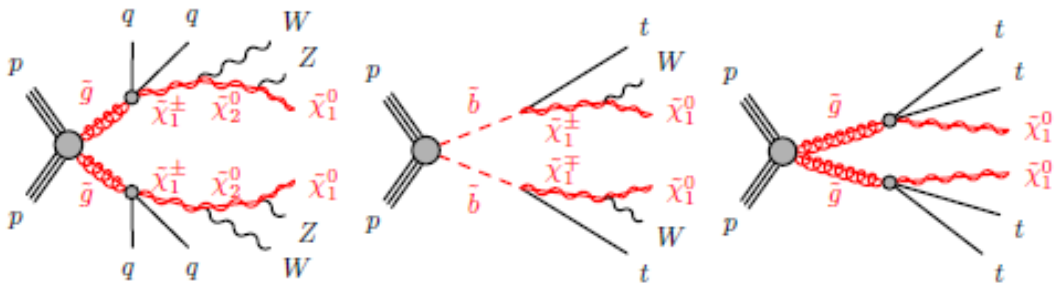


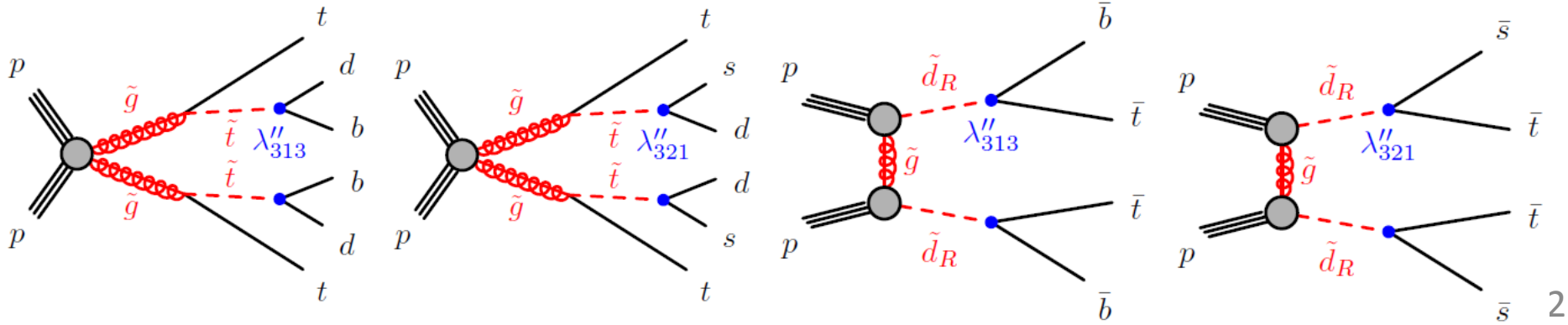
Event selection: 13 TeV, 13.2 fb^{-1}

Final states are clean to SM

- lepton (e or μ) , p_T> 10 GeV
- SS or 3L
- jet of anti-k_t R=0.4, p_T> 50 GeV
- b-jets of p_T> 20 GeV

RPC diagrams





λ''_{ijk} : SS, 3-Lepton signals

Discriminant: effective mass

$$m_{\mathrm{eff}} = \sum p_{\mathrm{T}}^{\mathrm{lep}} + \sum p_{\mathrm{T}}^{\mathrm{jet}} + E_{\mathrm{T}}^{\mathrm{miss}}$$

Background:

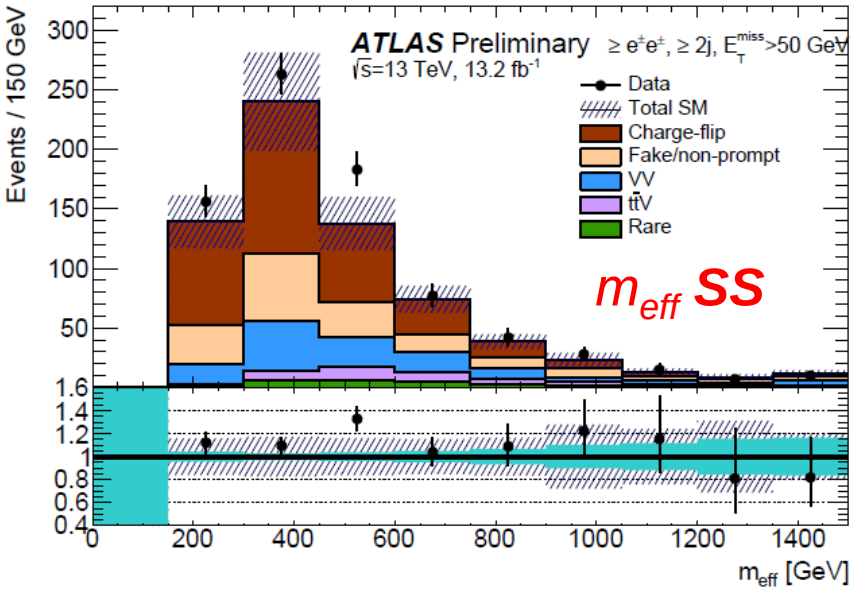
- SM processes: $t\bar{t}V$, diboson, .. by MC
- Detector charge mis-ID :
  electrons, estimated using $Z \rightarrow ee$ events
  fake, non-prompt leptons :
  estimated with data, $Z \rightarrow \ell\ell$ in p_T, η

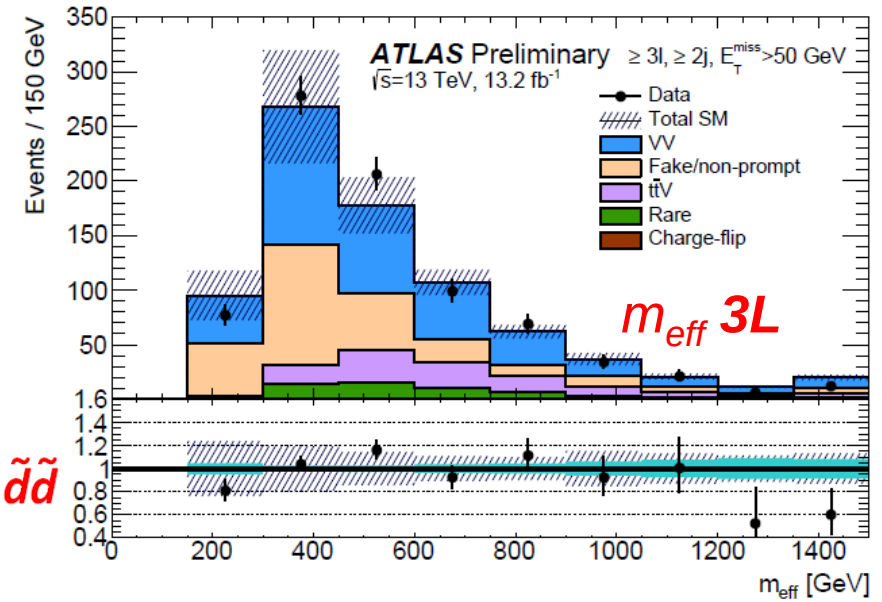
Validation:

- Regions close to signal selection
- Regions with data dominated by $t\bar{t}V$ or diboson compared to MC

Signal region:

Signal region	$N_{\mathrm{lept}}^{\mathrm{signal}}$	$N_{b-\mathrm{jets}}^{20}$	N_{jets}	$p_{\mathrm{T,jets}}$	m_{eff} [GeV]	
SR1b-DD	≥2	≥1	≥4	50	>1200	$\tilde{d}\tilde{d}$
SR3b-DD	≥2	≥3	≥4	50	>1000	
SR1b-GG	≥2	≥1	≥6	50	>1800	$\tilde{g}\tilde{g}$



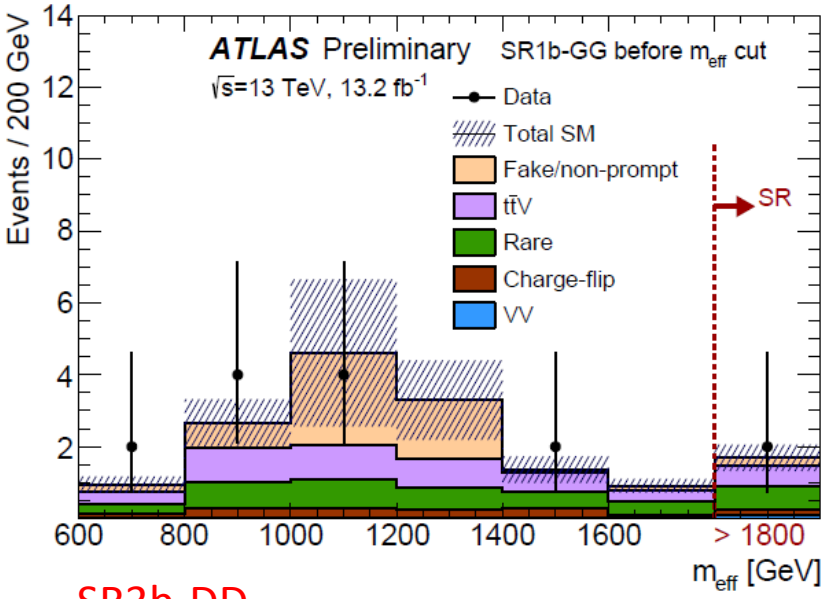


λ''_{ijk} : SS/3L distributions

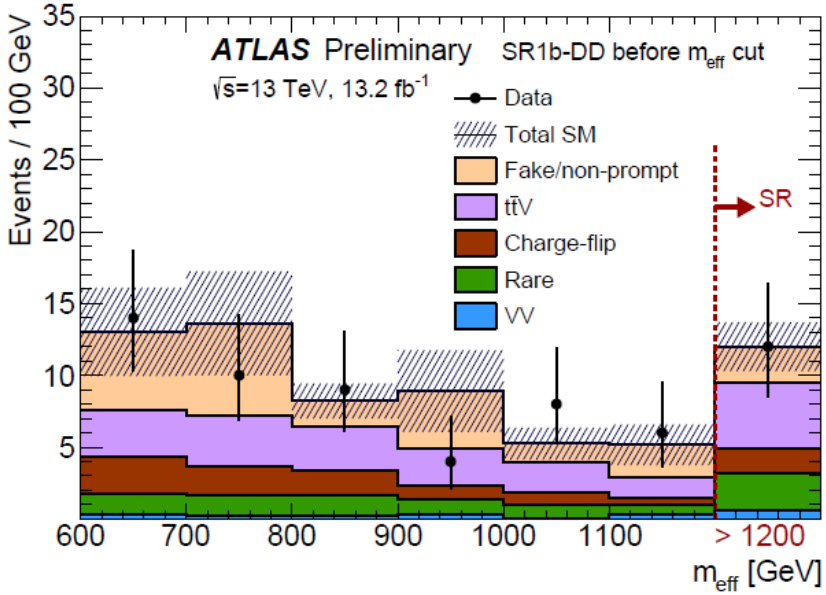
Number of events selected

	SR1b-GG	SR1b-DD	SR3b-DD
Observed	1	10	2
Total SM	1.24 ± 0.34	8.4 ± 2.0	1.14 ± 0.35
$t\bar{t}Z$	0.18 ± 0.06	2.0 ± 0.7	0.21 ± 0.07
$t\bar{t}W$	0.25 ± 0.09	1.3 ± 0.4	0.13 ± 0.05
Diboson	0.05 ± 0.06	0.5 ± 0.4	< 0.1
Rare	0.46 ± 0.25	1.9 ± 1.0	0.53 ± 0.28
Fake/non-prompt le	0.15 ± 0.15	1.5 ± 1.3	0.15 ± 0.15
Charge-flip	0.15 ± 0.07	1.21 ± 0.18	0.11 ± 0.04

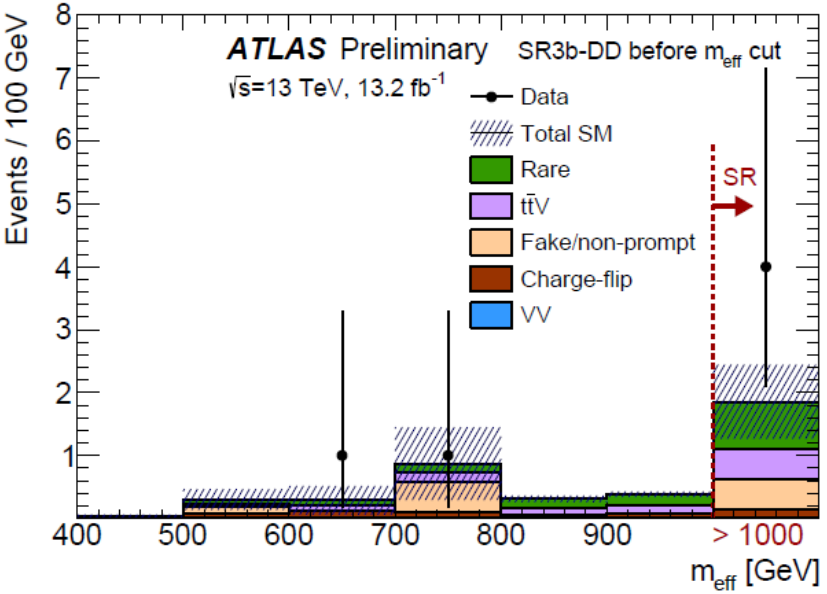
SR1b-GG



SR1b-DD



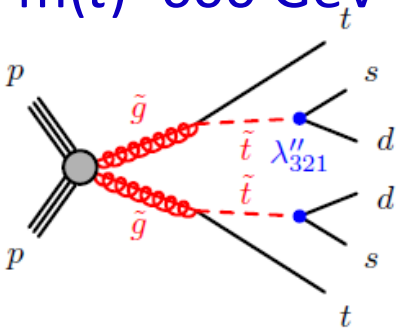
SR3b-DD



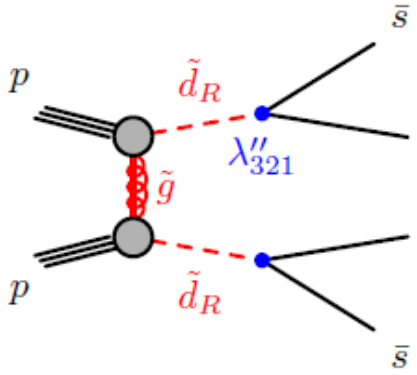
λ''_{ijk} : SS/3L RPV exclusion

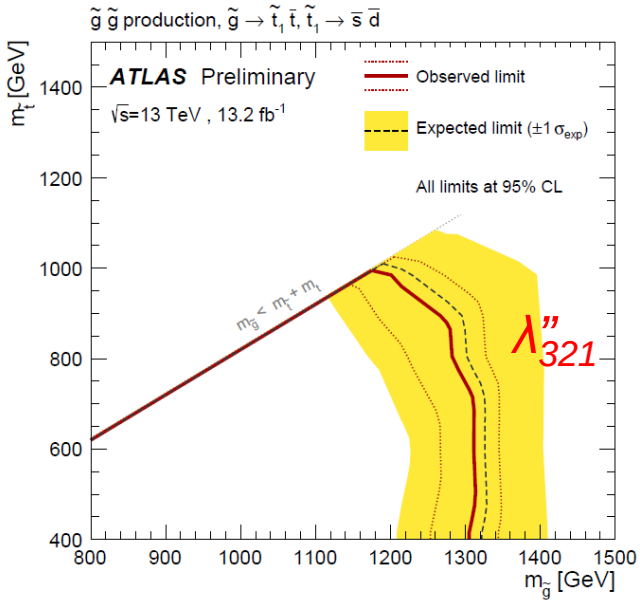
RPV $\lambda''_{321}\,\lambda''_{313}$ exclusion, 95% CL

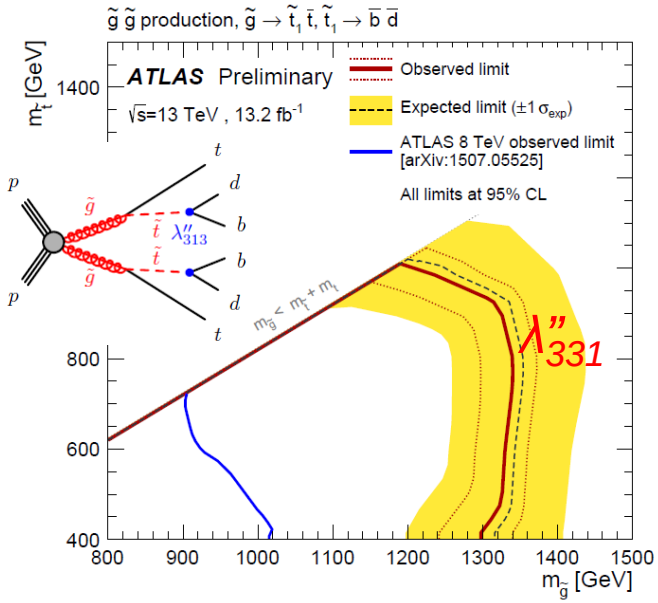
$m(\tilde{g}) \approx 1.3$ TeV for $m(\tilde{t})$=600 GeV

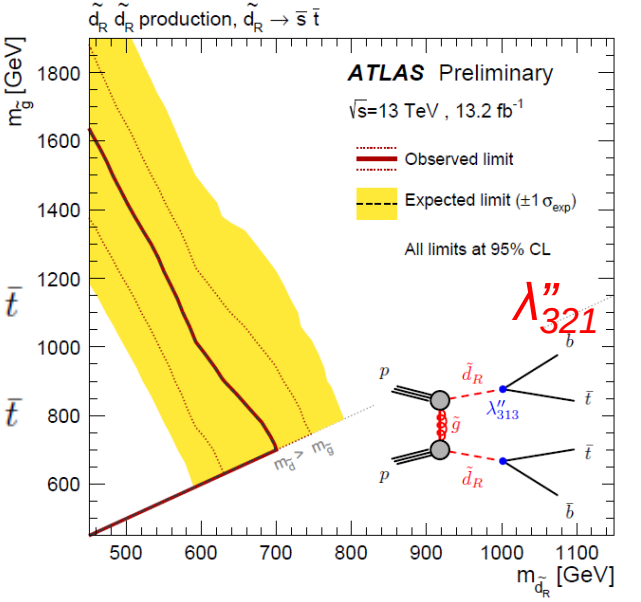


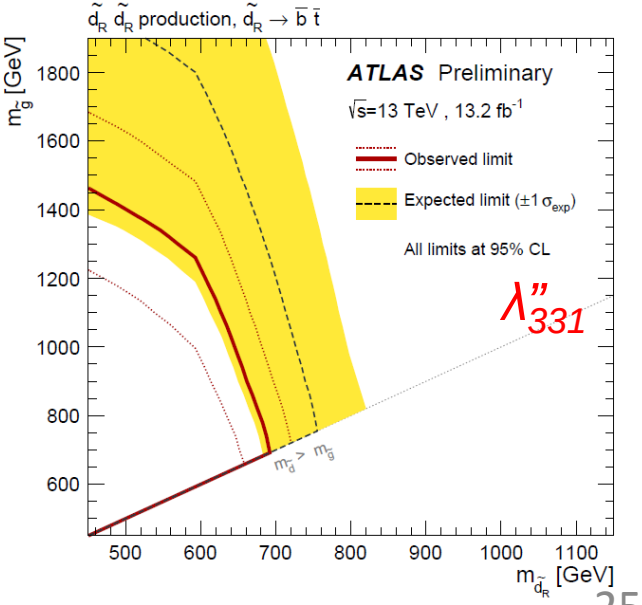
$m(\tilde{d}_R)$ to 700 GeV











Summary

- Predictions of R-Parity Violating SUSY are searched
- Analyses updated with 13 TeV data reveal no evidence
- Higher mass limits excluded for SUSY particles