Reinterpretation of searches for supersymmetry in models with variable R-parity-violating coupling strength using the full ATLAS Run 2 Dataset

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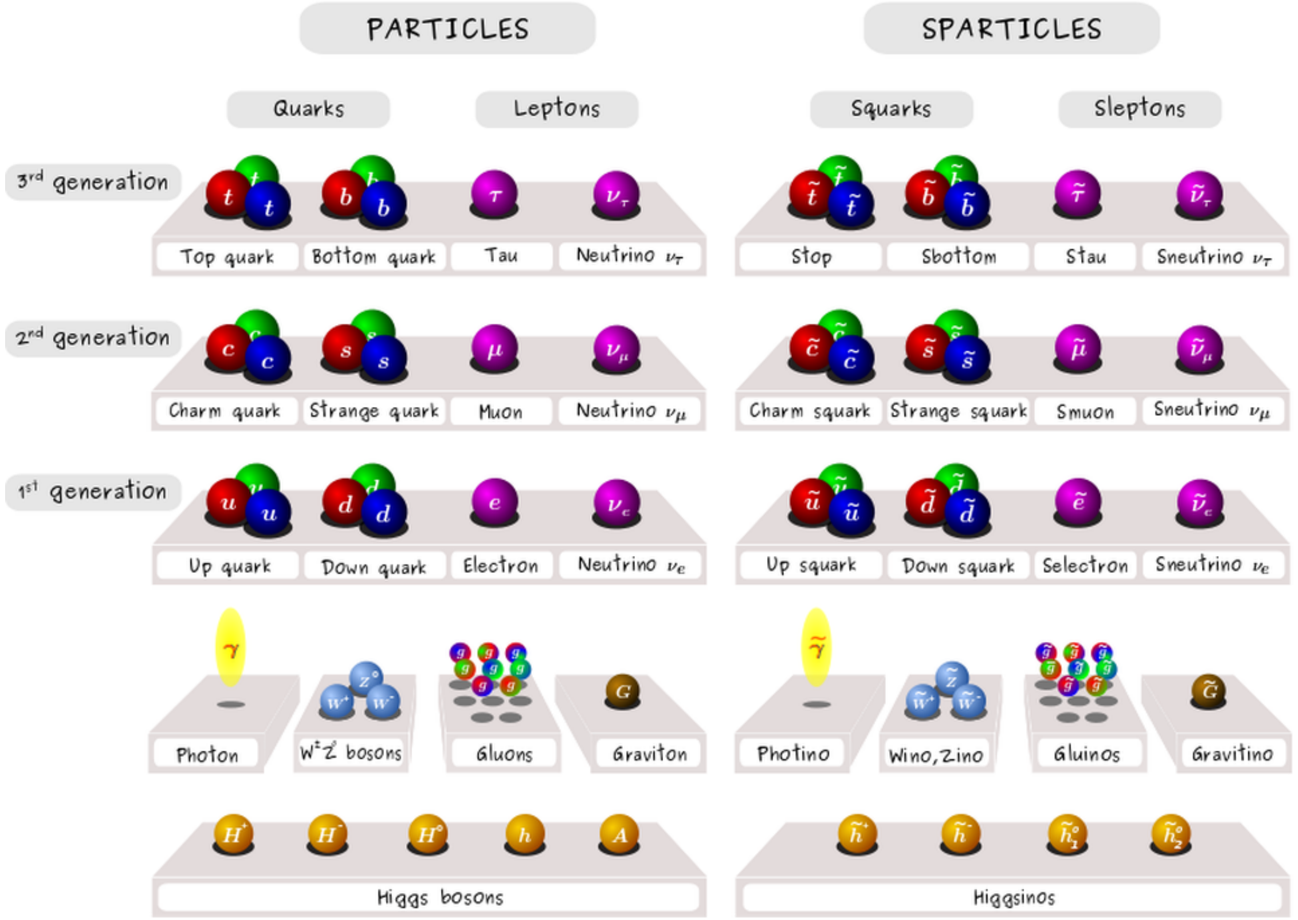
CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

Supersymmetry

- Most general superpotential allows for baryon- (B) and lepton-number (L) violation
- In order to avoid this a new symmetry is imposed R-parity

$$P_R = (-1)^{3(\mathrm{B}-\mathrm{L})+2s}$$

  - +1 SM particles
  - -1 superpartners



$$\mathcal{W}_{\mathrm{RPV}} = \underbrace{\frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\Delta L=1} + \underbrace{\frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k}_{\Delta B=1} + \underbrace{\kappa_i L_i H_u}_{\Delta L=1}$$

Supersymmetry

RPC

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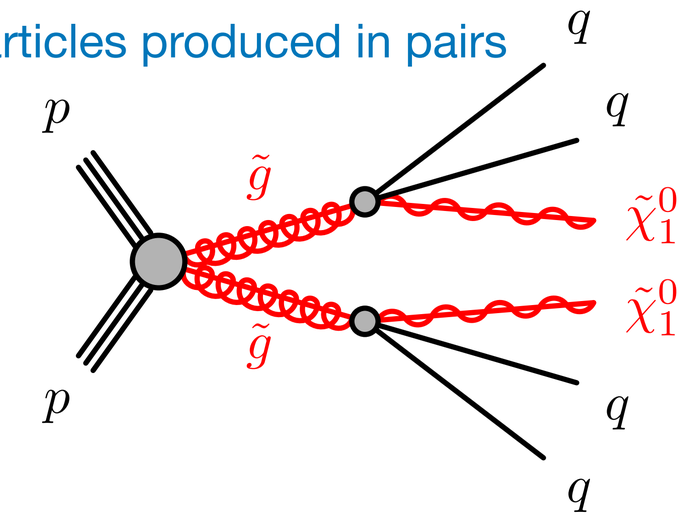
R-Parity conserving scenario (RPC):

sparticles produced in pairs



LSP behaving like a neutrino escaping detection→Large missing transverse energy (MET)

However there is no real theoretical motivation to choose RPC

$$\mathcal{W}_{\mathrm{RPV}} = \underbrace{\frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\Delta \mathrm{L}=1} + \underbrace{\frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k}_{\Delta \mathrm{B}=1} + \underbrace{\kappa_i L_i H_u}_{\Delta \mathrm{L}=1}$$

Supersymmetry

RPV

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- In order to avoid this a new symmetry is imposed R-parity

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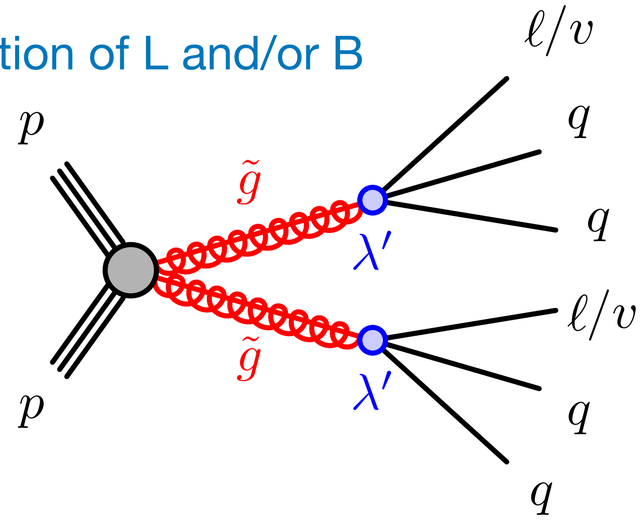
- +1 SM particles
- -1 superpartners

R-Parity violating scenario (RPV):

violation of L and/or B



LSP not necessary neutral nor stable

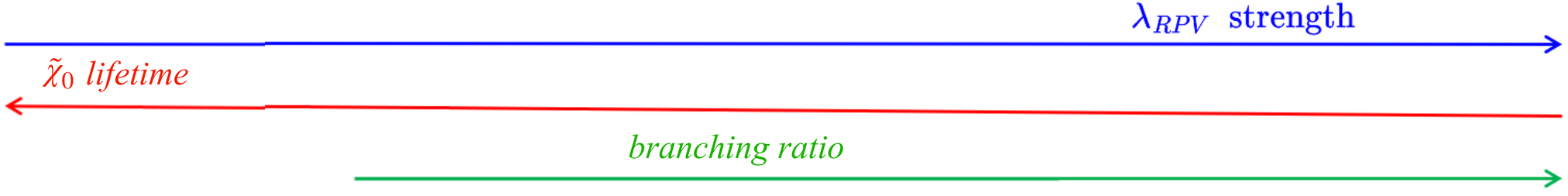
Single production is possible

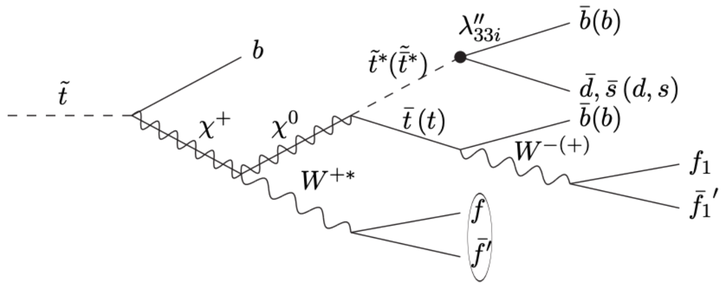
$$\mathcal{W}_{\mathrm{RPV}} = \underbrace{\frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\Delta \mathrm{L}=1} + \underbrace{\frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k}_{\Delta \mathrm{B}=1} + \underbrace{\kappa_i L_i H_u}_{\Delta \mathrm{L}=1}$$

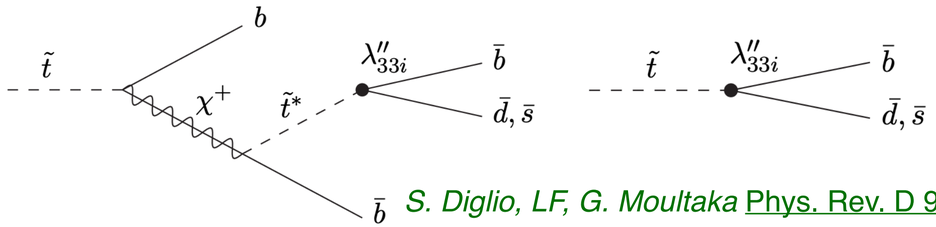
RPV SUSY phenomenology

Constraining RPV couplings

RPC limit



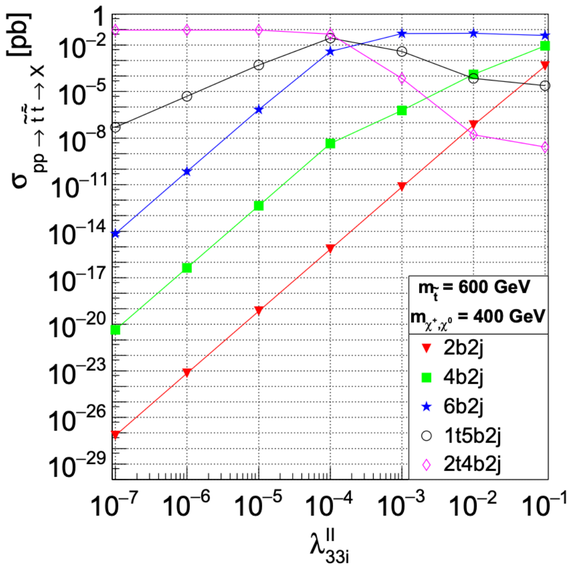




S. Diglio, LF, G. Moultaka Phys. Rev. D 96 (2017)

- Values of RPV couplings O(1) allow sparticle direct decays into SM particles
- *Intermediate values* favor long decay chains
- Lifetime depends on RPV couplings and other squark masses, e.g.:

$$L[cm] = \frac{0.9\beta\gamma}{\lambda''^2}\left(\frac{m(\tilde{q})}{100\ \text{GeV}}\right)^4\left(\frac{1\ \text{GeV}}{m(\tilde{\chi}_1^0)}\right)^5$$



ATLAS Run 2 Reinterpretation

ATLAS Collaboration arXiv:2603.15007

Signal models

- ATLAS just released a reinterpretation of 13 complementary searches on simplified models
  - Full Run 2 dataset (~140 fb^{-1})
- Scan⁕ over RPV couplings, testing different signatures: stable → long-lived → prompt
  - 6 models, mixture of sparticles and couplings
  - Only one non-zero coupling per model
- Cover many combinations of production and decays of sparticles

Analysis name	$\ell/\tau^M_{\text{had}}/\tau^T_{\text{had}}$	Jets / b-tags	$E_{\text{T}}^{\text{miss}}$ selection	Representative cuts	Model targeted	RECAST
RPV MJ	0 / – / –	≥ 8 / ≥ 2	–	$C \geq 0.85$	Gqq+UDD	No
RPC 0L, 2-6 jets	0 / – / –	≥ 6 / –	$E_{\text{T}}^{\text{miss}}/\sqrt{H_T} > 10$	$m_{\text{eff}} > 3400$ GeV	Gqq+LQD Gqq+UDD	Yes
RPV DV+jets	–	≥ 4 / –	–	$R_{DV} < 300$ mm	Gqq+UDD, Gtt, Stop	No
RPC multi-b	0 / – / – 1 / – / –	≥ 5 / ≥ 3 ≥ 4 / ≥ 3	$E_{\text{T}}^{\text{miss}} > 600$ GeV $E_{\text{T}}^{\text{miss}} > 300$ GeV	$m_{\text{eff}} > 2900$ GeV $m_{\text{eff}} > 800$ GeV	Gtt	Yes
RPV SS/3L	2 SS / – / –	≥ 5 / – ≥ 6 / = 1 ≥ 5 / ≥ 2	–	$m_{\text{eff}} > 2600$ GeV $\sum p_{\text{T}}^{\text{jet}} > 1600$ GeV $\sum p_{\text{T}}^{\text{jet}} > 1600$ GeV	Gqq+LQD, Gtt	No
RPV 1L	1 / – / –	≥ 10 / ≥ 3	–	–	Gtt, Stop	Yes
RPC Stop 0L	0 / – / –	≥ 4 / ≥ 2	$E_{\text{T}}^{\text{miss}} > 250$ GeV	$m_1^{R=1.2} > 120$ GeV	Stop	Yes
RPV stop dijet	–	≥ 4 / ≥ 2	–	$\mathcal{A} < 0.05$	Stop	No
RPV dijet resonance	–	≥ 2 / ≥ 2	–	$m_{jj} > 1133$ GeV	Stop	No
RPV multi-b	0 / – / –	≥ 9 / ≥ 5	–	–	Gtt	No
RPC Di-τ	– / = 2, OS$_{1,2}$ / ≥ 1	– / veto	∈ [60, 150] GeV	$m_{\text{T2}} > 80$ GeV	Stau, Higgsino	No
	– / = 2, OS$_{1,2}$ / –	– / veto	> 150 GeV	$m_{\text{T2}} > 85$ GeV $m_{\text{Tsum}} > 400$ GeV		
	– / ≥ 2, OS$_{1,2}$ / ≥ 1	– / veto	∈ [60, 150] GeV	$m_{\text{T2}} > 70$ GeV		
	– / ≥ 2, OS$_{1,2}$ / –	– / veto	> 150 GeV	$m_{\text{T2}} > 85$ GeV $m_{\text{Tsum}} > 400$ GeV		
RPC/RPV 4L	≥ 4 / ≥ 0 / –	– / veto	> 100 GeV > 200 GeV	–	Stau, Higgsino	Yes
			–	$m_{\text{eff}} > 600$ GeV $m_{\text{eff}} > 1250$ GeV		
	= 3 / ≥ 1 / –	– / veto	–	$m_{\text{eff}} > 600$ GeV $m_{\text{eff}} > 1000$ GeV		
	= 2 / ≥ 2 / –	– / veto	–	$m_{\text{eff}} > 600$ GeV $m_{\text{eff}} > 1000$ GeV		
RPC DL	2 / – / –	– / –	–	$\Delta R_{\ell\ell} > 0.2$	Higgsino	Yes

⁕ Lifetimes and BRs as a function of coupling values are calculated using SPheno+SARAH

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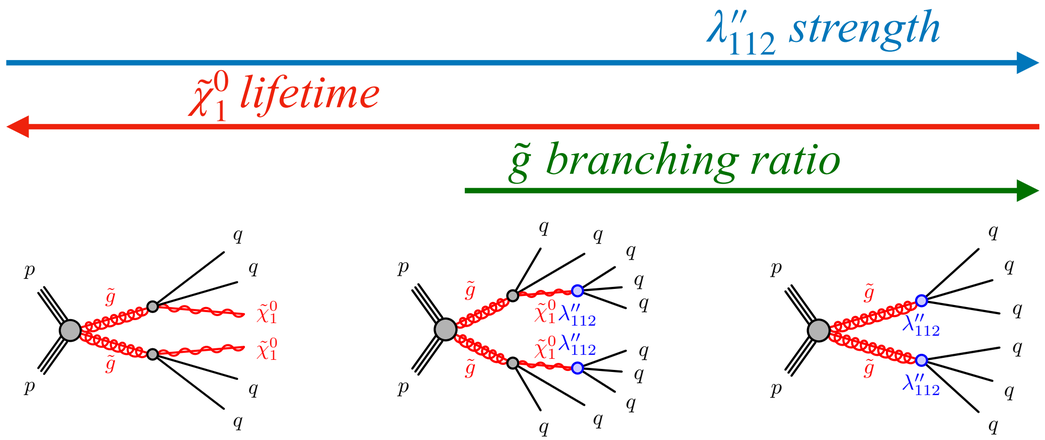
Model name	Coupling	Decay	Other sparticle masses	LSP
Gqq+LQD	$\lambda'_{111} = \lambda'_{211}$	$\tilde{g} \to qq\tilde{\chi}_1^0$ $\tilde{g} \to qq\tilde{\chi}_1^0(\to \ell qq'/\nu qq')$ $\tilde{g} \to \ell qq'/\nu qq'$	$m(\tilde{q}) = 3$ TeV $m(\tilde{t}, \tilde{b}) = 5$ TeV	bino-like $\tilde{\chi}_1^0$, $m(\tilde{\chi}_1^0) = 500$ GeV
Gqq+UDD	λ''_{112}	$\tilde{g} \to qq\tilde{\chi}_1^0$ $\tilde{g} \to qq\tilde{\chi}_1^0(\to qqq)$ $\tilde{g} \to qqq$	$m(\tilde{q}) = 3$ TeV $m(\tilde{t}, \tilde{b}) = 5$ TeV	bino-like $\tilde{\chi}_1^0$, $m(\tilde{\chi}_1^0) = 200$ GeV
Gtt	λ''_{323}	$\tilde{g} \to tt\tilde{\chi}_1^0$ $\tilde{g} \to tt\tilde{\chi}_1^0(\to tbs)$ $\tilde{g} \to tbs$	$m(\tilde{q}) = 5$ TeV $m(\tilde{t}, \tilde{b}) = 3$ TeV	
Stop	λ''_{323}	$\tilde{t}_1 \to t\tilde{\chi}_1^0$ $\tilde{t}_1 \to t\tilde{\chi}_1^0(\to tbs)$ $\tilde{t}_1 \to bs$	$m(\tilde{q}, \tilde{g}) = 3$ TeV $m(\tilde{t}_2, \tilde{b}) = 3$ TeV	
Stau	λ_{i33}, $i \in \{1, 2\}$	$\tilde{\tau} \to \tau\tilde{\chi}_1^0$ $\tilde{\tau} \to \tau\tilde{\chi}_1^0(\to \ell\tau\nu/\tau\tau\nu)$ $\tilde{\tau} \to \tau\nu$	m($\tilde{\ell}$) = 5 TeV	bino-like $\tilde{\chi}_1^0$, $m(\tilde{\chi}_1^0) = 50$ GeV
		$\tilde{\nu}_\tau \to \nu\tilde{\chi}_1^0$ $\tilde{\nu}_\tau \to \nu\tilde{\chi}_1^0(\to \ell\tau\nu/\tau\tau\nu)$ $\tilde{\nu}_\tau \to \tau\ell$		
Higgsino	λ_{i33}, $i \in \{1, 2\}$	$\tilde{\chi}_1^\pm \to qq'\tilde{\chi}_1^0/\ell\nu\tilde{\chi}_1^0$ $\tilde{\chi}_1^\pm \to qq'\tilde{\chi}_1^0/\ell\nu\tilde{\chi}_1^0(\to \ell\tau\nu/\tau\tau\nu)$ $\tilde{\chi}_1^\pm \to \ell\tau\tau/\ell\nu\nu/\tau\nu\nu$	m($\tilde{\tau}$) = 3 TeV m($\tilde{\ell}$) = 5 TeV	higgsino-like $\tilde{\chi}_1^0$, $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 0.25$ GeV $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 0.5$ GeV
		$\tilde{\chi}_2^0 \to qq\tilde{\chi}_1^0/\ell\ell\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to qq\tilde{\chi}_1^0/\ell\ell\tilde{\chi}_1^0(\to \ell\tau\nu/\tau\tau\nu)$ $\tilde{\chi}_2^0 \to \ell\tau\nu/\tau\tau\nu$		

* Lifetimes and BRs as a function of coupling values are calculated using SPheno+SARAH

Gqq+UDD model

λ' dependent jet multiplicity

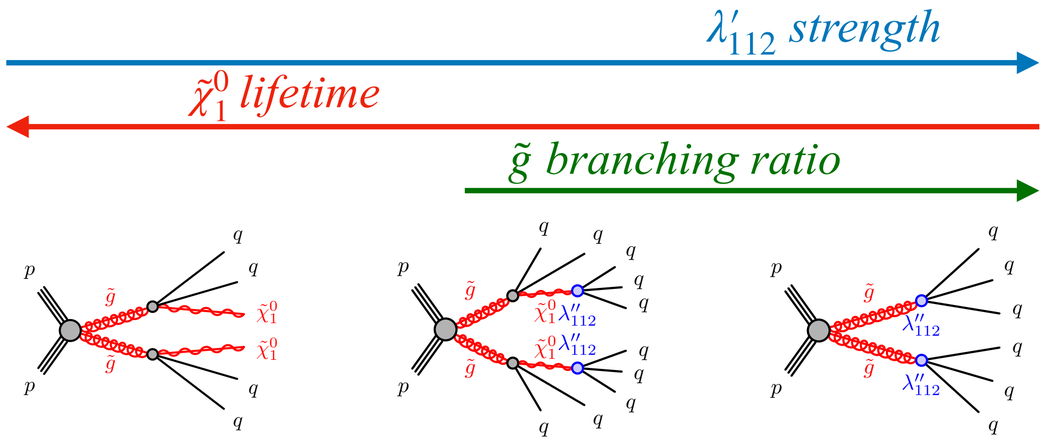
- λ''_{112} ~1: direct RPV decay to quarks B($\tilde{g} \to qqq$)=1
  - ~6 jets in the final state
- λ''_{112} ~10^{-1}: prompt neutralino mediated RPV decay B($\tilde{g} \to qq\chi_1^0(\to qqq)$) ~1
  - $\gtrsim$ 10 jets in the final states
- $10^{-3} \lesssim \lambda''_{112} \lesssim 10^{-2}$: neutralino non prompt decay
  - Jet reconstruction starts to fail for some jets
- $\lambda''_{112} \lesssim 10^{-4}$: non negligible lifetime
  - Presence of MET, low jet multiplicity



Gqq+UDD model

Run 2 limits

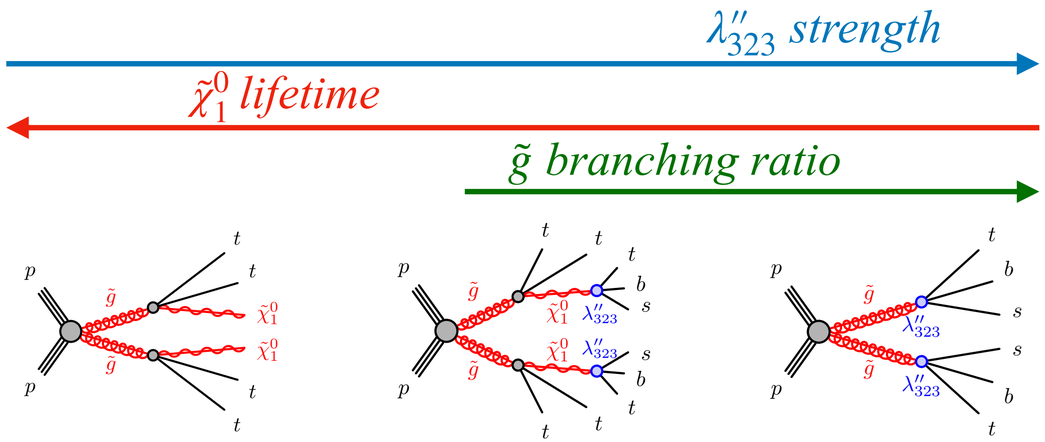
- RPC 0L *ATLAS Collaboration, JHEP 02 (2021)*
  - Jets and MET, with veto on leptons
- RPV DV + jets *ATLAS Collaboration, JHEP 06 (2023) 200*
  - Massive, displaced vertex with energetic jets
- RPV multijet *ATLAS Collaboration, Eur. Phys. J. C 83 (2023) 561*
  - High multiplicity of hard jets
- The region $\lambda''_{112} > 1.25$ is forbidden by constraints from the renormalization group equations.
- The exclusion limits are derived assuming the squark masses indicated.

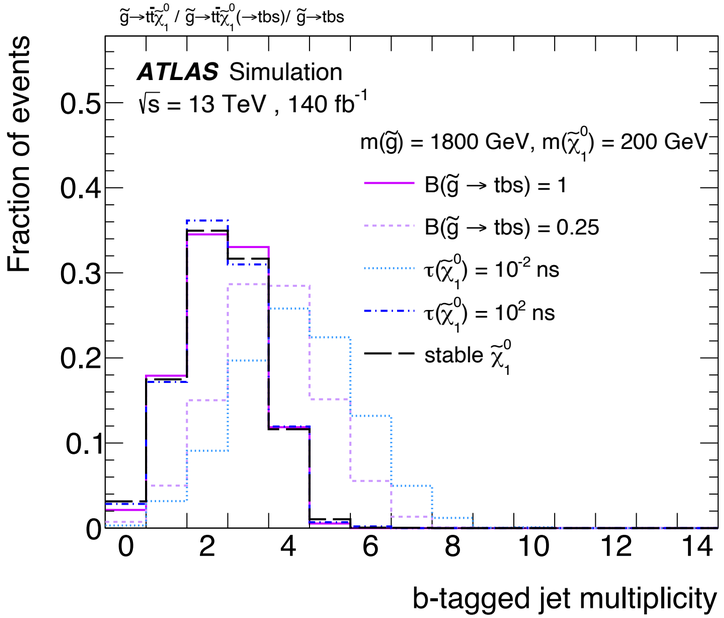


Gtt model

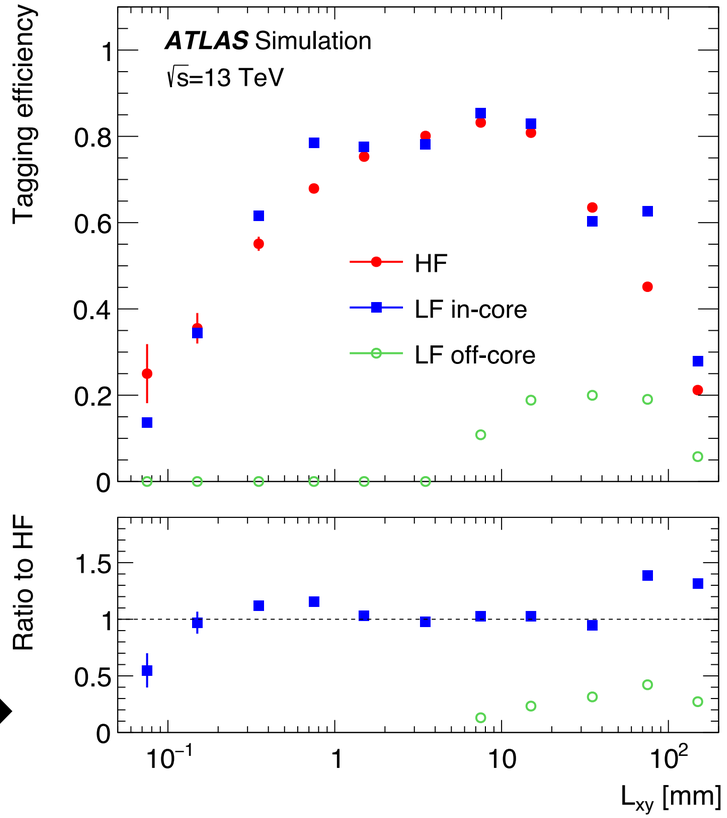
λ'' dependent *b*-jet multiplicity

- λ''_{323} ~1: B($\tilde{g} \to tbs$)=1
  - $t\bar{t}$ + heavy flavor final state
- λ''_{323} ~10^{-1}: B($\tilde{g} \to tbs$)=0.25
  - ~8 *b*-jets in the final states
- $\lambda''_{112} \lesssim 10^{-1}$: $\tau(\tilde{\chi}_0)$~10^{-2} ns
  - Presence of secondary vertices from light jets
- $\lambda''_{112} \lesssim 10^{-3}$: $\tau(\tilde{\chi}_0)$~10^{2} ns
  - Presence of MET, lower number of (*b*-)jets reconstructed





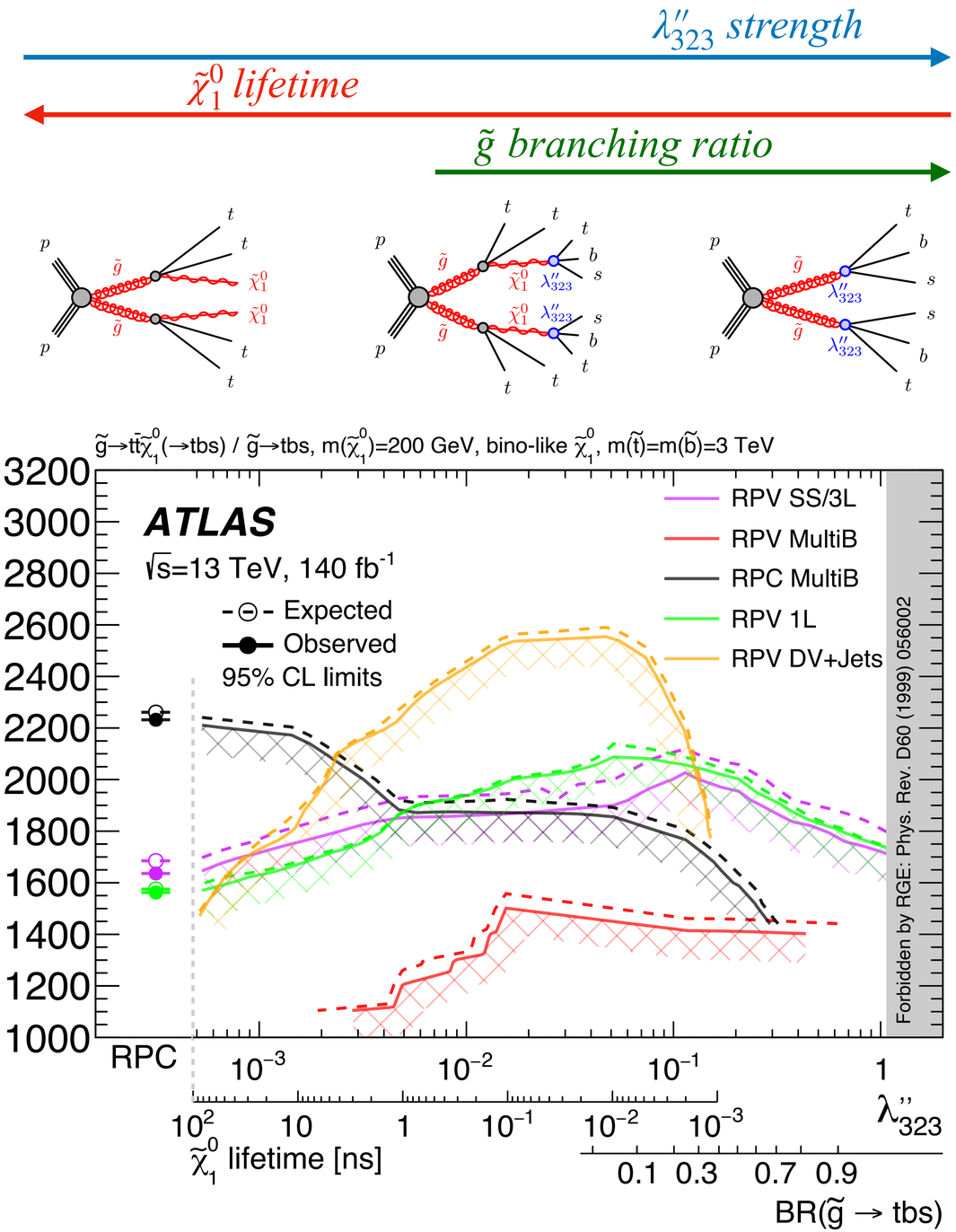
- Light-jets from $\tilde{\chi}_0$ decay are identified as *b*-jets



Gtt model

Run 2 limits

- RPV SS/3L *ATLAS Collaboration, JHEP 02 (2024) 107*
  - 2 same-sign leptons or 3 leptons + jets
  - No MET requirement
- RPV MultiB *ATLAS Collaboration, Eur. Phys. J. C 83 (2023)*
  - High (*b*-)jet multiplicity, no MET requirement
- RPC MultiB *ATLAS Collaboration, Eur. Phys. J. C 81 (2021)*
  - High (*b*-)jet multiplicity and large MET
- RPV 1L *ATLAS Collaboration, Eur. Phys. J. C 81 (2021)*
  - ≥1 lepton and high jet multiplicity
- RPV DV + jets *ATLAS Collaboration, JHEP 06 (2023) 200*
  - Massive, displaced vertex with energetic jets



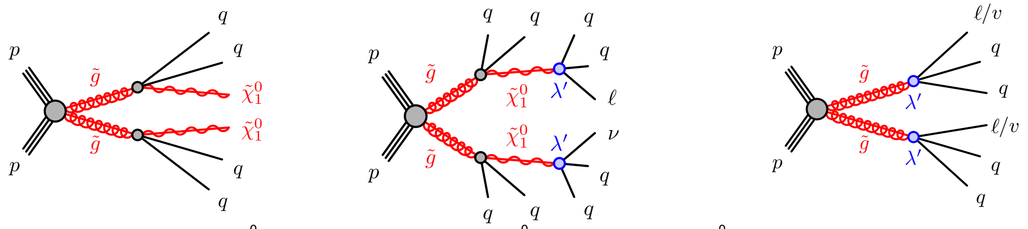
Gqq+LQD model

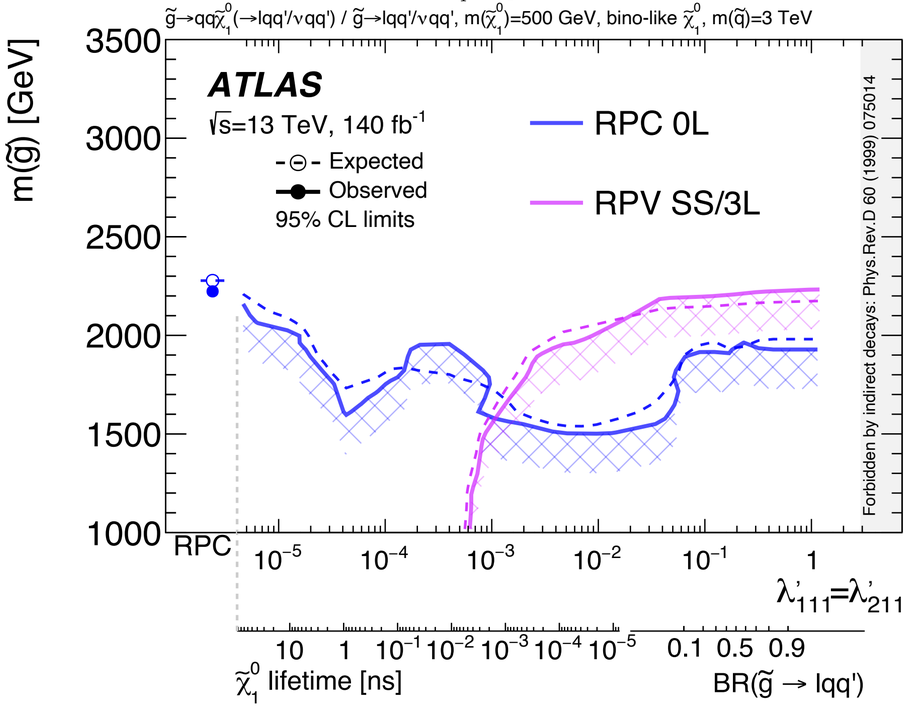
Run 2 limits

λ' strength

$\tilde{\chi}_1^0$ lifetime

$\tilde{g}$ branching ratio





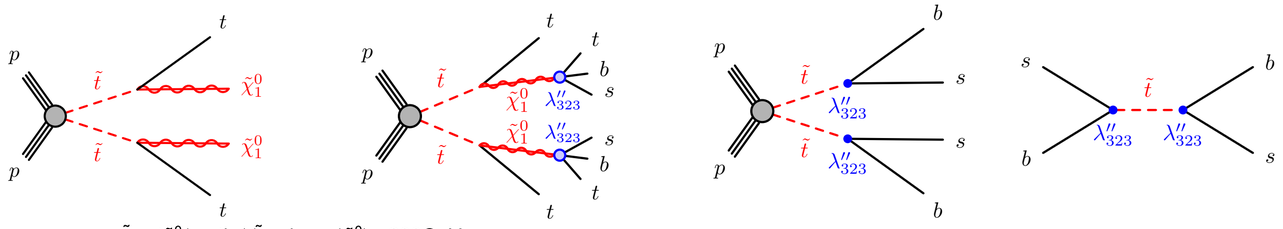
Stop model

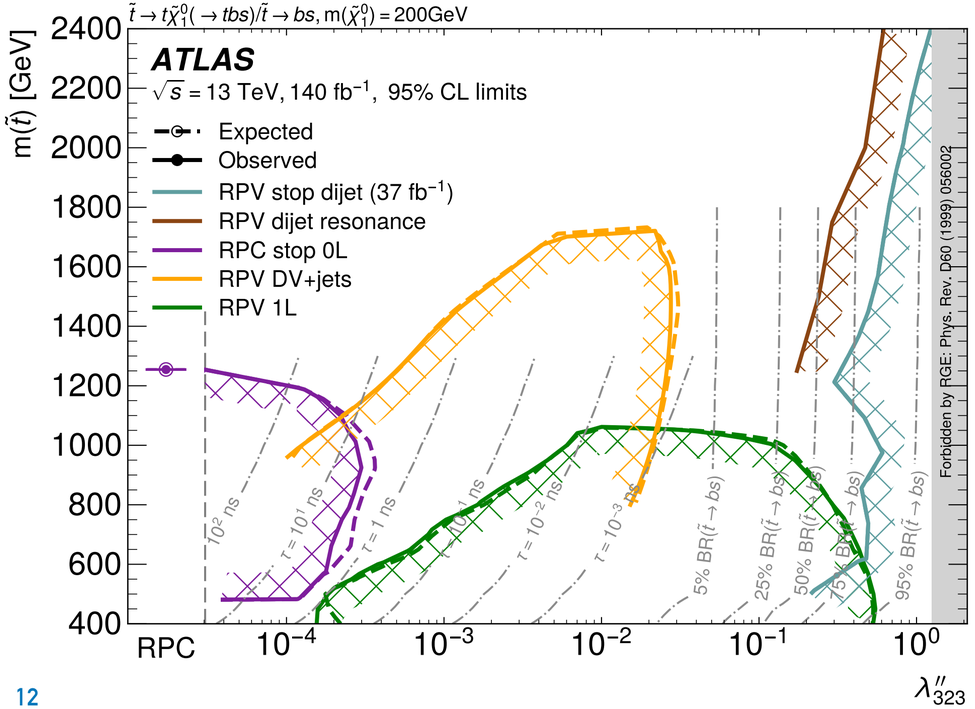
Run 2 limits

λ''_{323} strength

$\tilde{\chi}_1^0$ lifetime

$\tilde{t}$ branching ratio

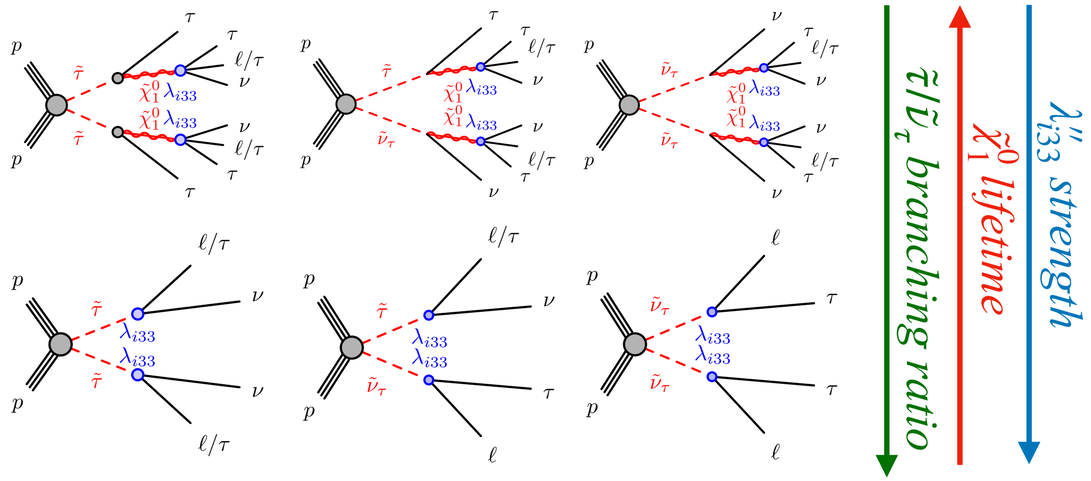


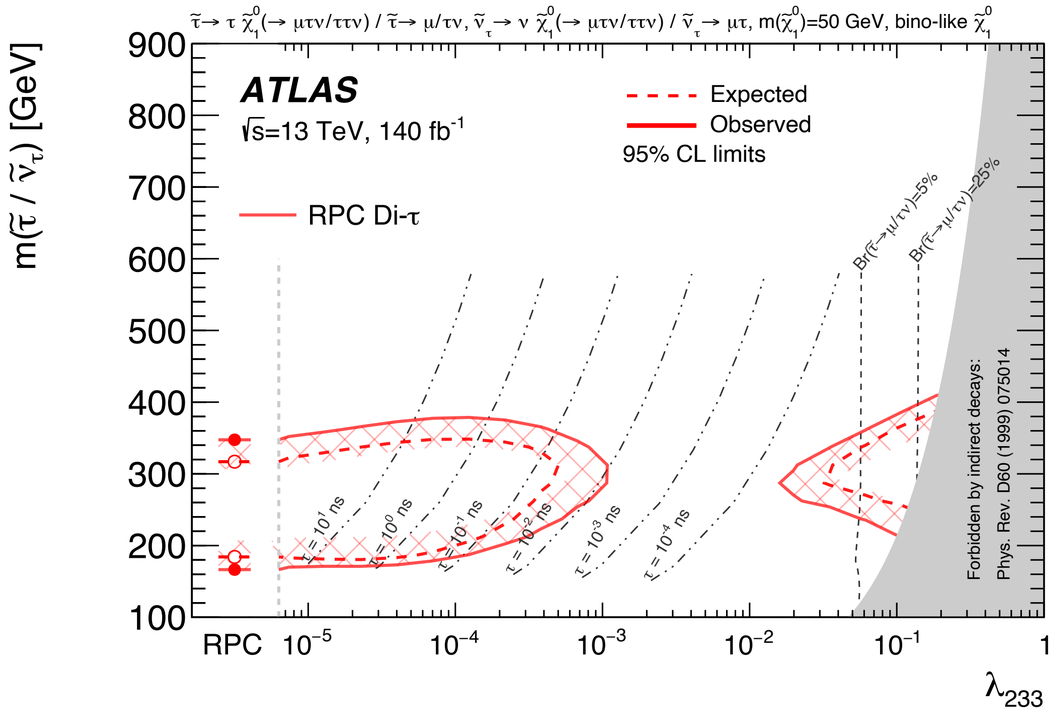


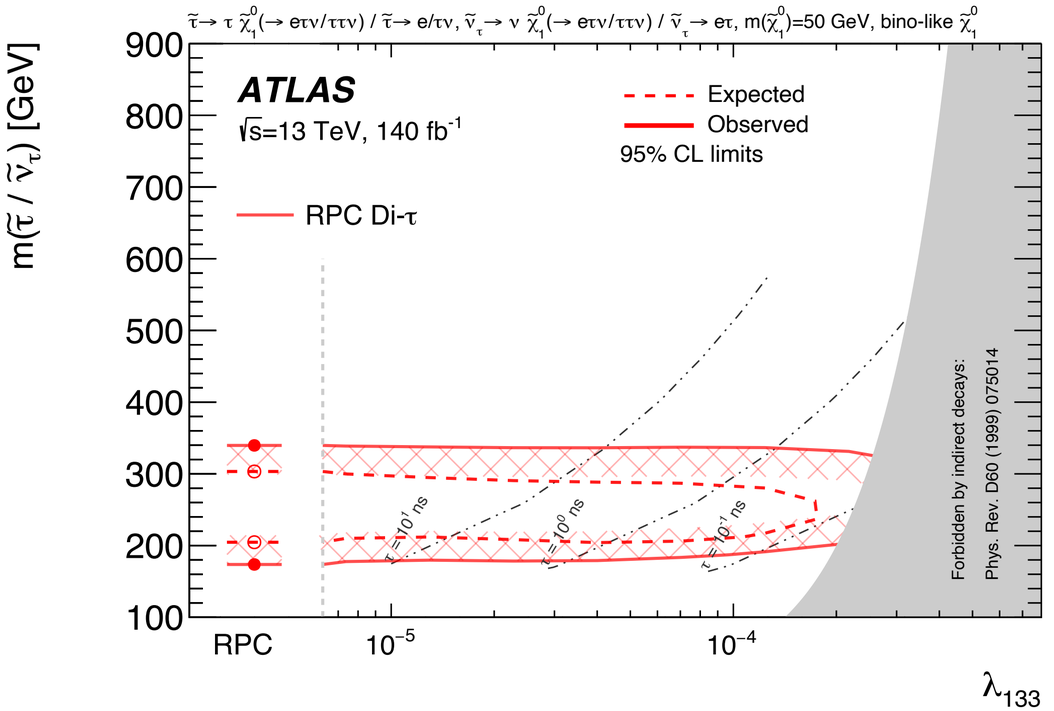
Stau model

Run 2 limits

- RPC Di-stau *ATLAS Collaboration, JHEP 05 (2024) 150*
  - ≥ 2 hadronic taus and large MET
- $10^{-3} \lesssim \lambda''_{112} \lesssim 10^{-1}$: 10^{-2} ns $\gtrsim \tau(\tilde{\chi}_0) \gtrsim 10^{-4}$ ns
  - Prompt tau reconstruction fails to reconstruct stau product decays



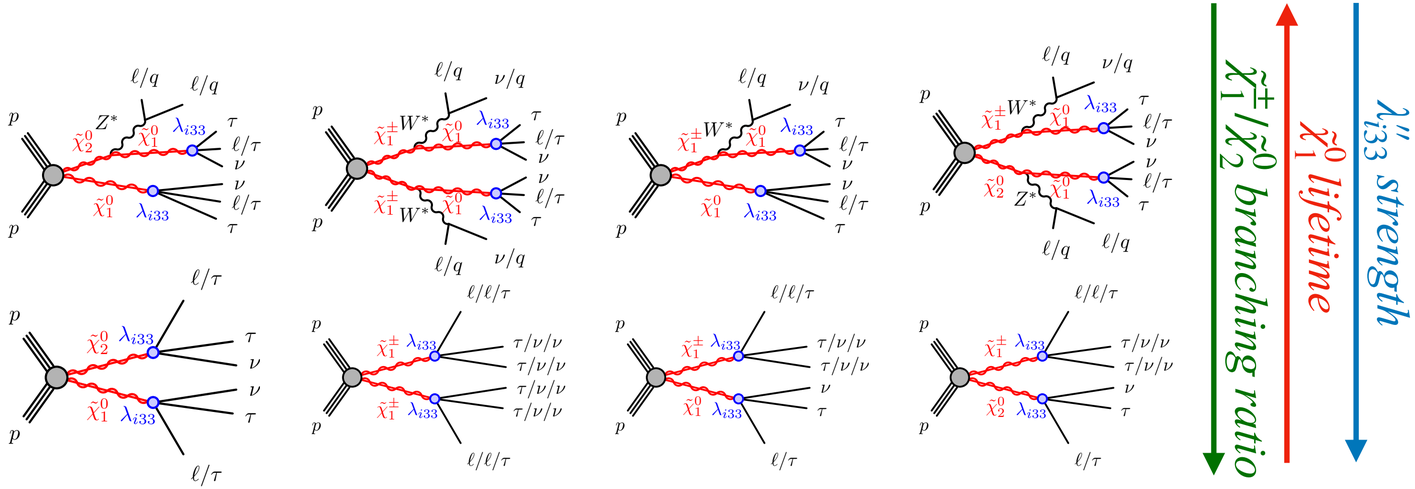


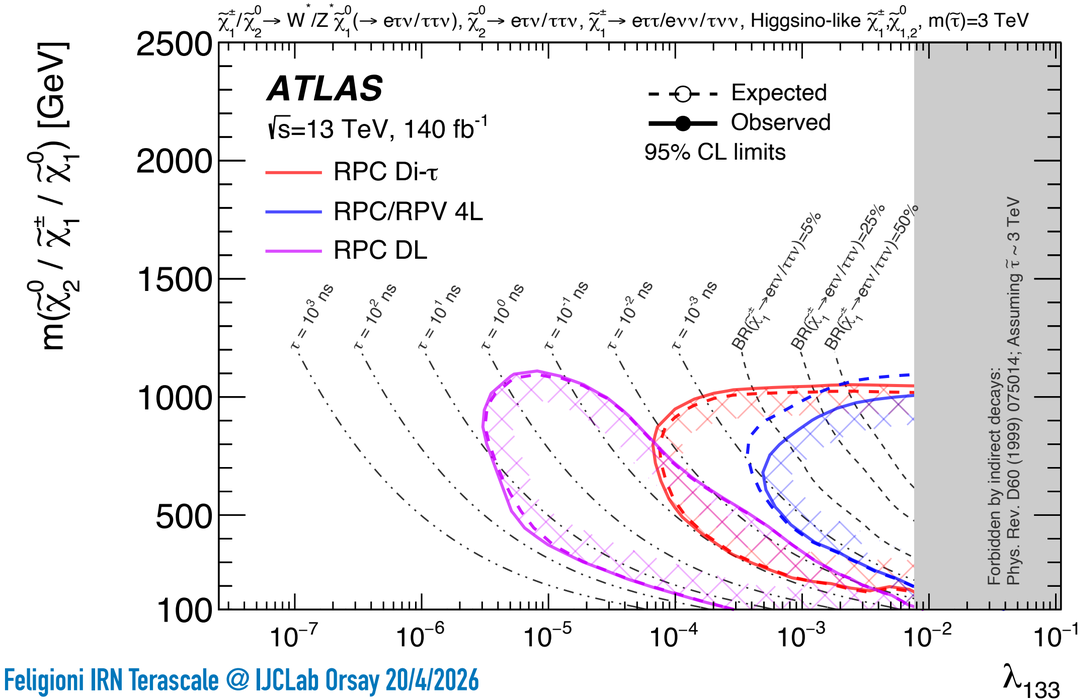


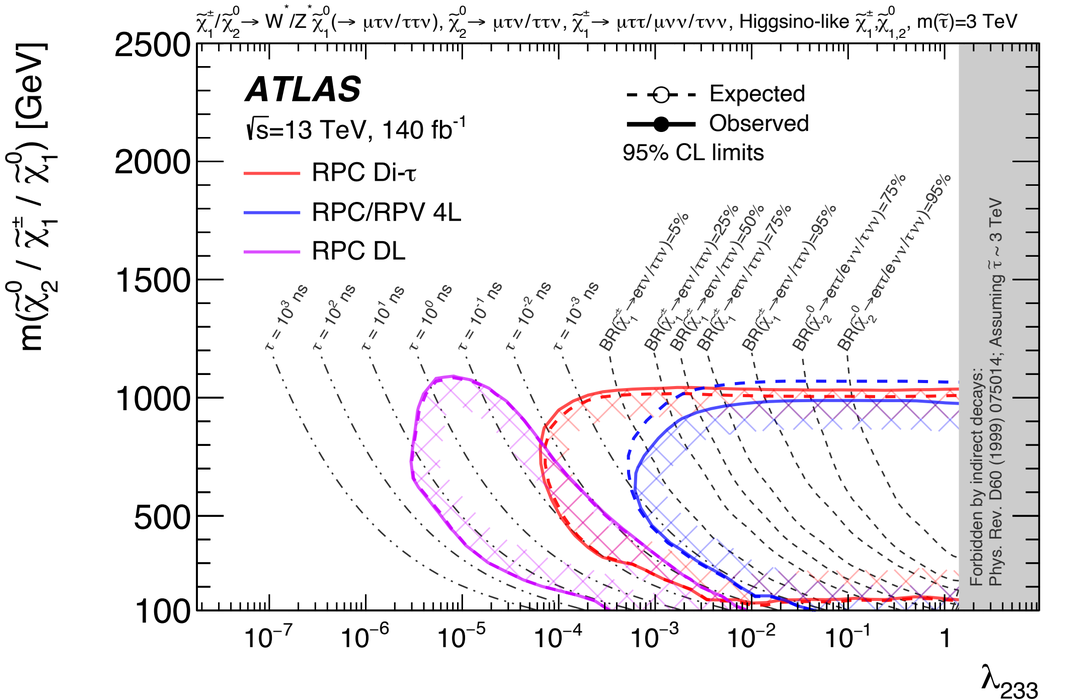
Higgsino model

Run 2 limits

- RPC Di-stau *ATLAS Collaboration, JHEP 05 (2024) 150*
  - ≥ 2 hadronic taus and large MET
- RPC/RPV 4L *ATLAS Collaboration, JHEP 07 (2021) 167*
  - ≥4 charged leptons and MET
- RPC DL *ATLAS Collaboration, Phys. Rev. Lett. 127 (2021)*
  - High p_T leptons with large impact parameter







RPV SUSY as a signature generator

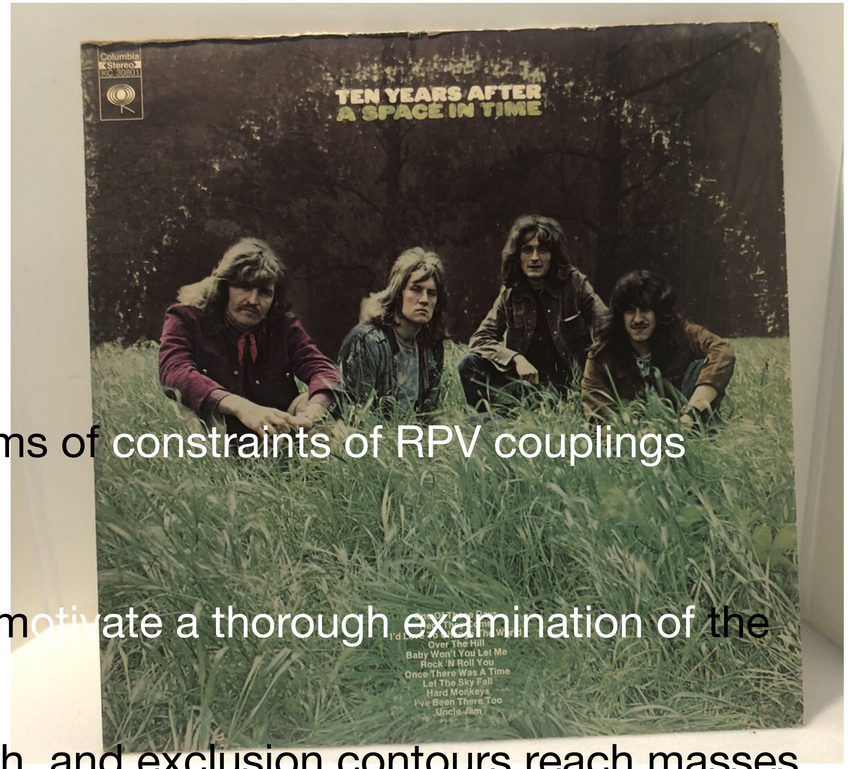
Presented @ GDR Terascale 2016

SUMMARY

- The RpV SUSY model offers a variety of interesting final states not yet explored by experiments
- RPV opens the possibility of light SUSY spectrum
- Depending on the spectrum and the (likely) small magnitude of RPV couplings, SUSY can be hiding in high multiplicity final states
- Possible reinterpretation of ATLAS and CMS results in cases where the stop is NOT the LSP
- The strong sensitivity to different channels apply more generally than the case we presented

Thanks for your attention!

Summary



- ATLAS produced a first thorough reinterpretation of SUSY analysis in terms of constraints of RPV couplings
- Results for models with variable R-parity coupling strength
- Large variations in sensitivity as a function of the RPV coupling strength motivate a thorough examination of the ATLAS SUSY program's coverage
  - Gluinos below 1.6 TeV are excluded for all the tested coupling strength, and exclusion contours reach masses close to 2.5 TeV for intermediate values of λ”
    - For the λ′ coupling, masses below 1.7 TeV are ruled out, limits extends up to 2.2 TeV for both high and low values of λ’
  - Stops models show also large variations: excluded mass ranges from 1 TeV to 1.6 TeV for small and intermediate values of λ”, extending up to 2.4 TeV for λ” approaching 1
  - Staus with masses between 180 GeV and 340 GeV excluded, but with a gap in $10^{-3} < \lambda_{i33} < 10^{-1}$
- Higgsinos with masses up 800 GeV excluded for high λi33, down to couplings close to 10-6