

SEARCHES FOR SUSY IN R-PARITY VIOLATING AND LONG-LIVED SIGNATURES WITH THE ATLAS DETECTOR

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SEARCHES FOR SUSY WITH THE ATLAS DETECTOR

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2018

ATLAS Preliminary

$\sqrt{s} = 7, 8, 13$ TeV

Model	$\epsilon, \mu, \tau, \gamma$	Jets	E_{miss}^T	$[L d](fb^{-1})$	Mass limit	$\sqrt{s} = 7, 8$ TeV	$\sqrt{s} = 13$ TeV	Reference		
Inclusive Searches	$\tilde{q}\tilde{q} \rightarrow q\tilde{q}\tilde{t}_1^0$	0 mono-jet 2 jets 1.3 jets	Yes Yes	36.1 36.1	2x, 6x Deepen 1x, 6x Deepen	0.43	0.71	1.55	$m(\tilde{t}_1^0) < 100$ GeV $m(\tilde{q}) = m(\tilde{t}_1^0) - 5$ GeV	1712.02332 1711.03301
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0$	0 2 jets	Yes	36.1	#	Forbidden	0.95-1.5	2.0	$m(\tilde{t}_1^0) < 200$ GeV $m(\tilde{t}_1^0) < 900$ GeV	1712.02332 1712.02332
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0\tilde{t}_1^0$	3 e, μ 4 jets	-	36.1	#	Forbidden	1.2	1.85	$m(\tilde{t}_1^0) < 800$ GeV $m(\tilde{q}) = m(\tilde{t}_1^0) - 50$ GeV	1706.03731 1805.11381
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}WZ\tilde{t}_1^0$	0 7.11 jets	Yes	36.1	#	#	0.98	1.8	$m(\tilde{t}_1^0) < 400$ GeV $m(\tilde{q}) = m(\tilde{t}_1^0) - 200$ GeV	1706.02794 1706.03731
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0$	0 1 e, μ 3 jets	Yes	36.1	#	#	1.25	2.0	$m(\tilde{t}_1^0) < 200$ GeV $m(\tilde{q}) = m(\tilde{t}_1^0) - 300$ GeV	1711.01901 1706.03731
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0$	3 e, μ 4 jets	-	36.1	#	#				
3 rd gen. separate direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{t}_1^0\tilde{t}_1^0$	Multiple	Yes	36.1	#	Forbidden	0.9		$m(\tilde{t}_1^0) < 300$ GeV, $BR(\tilde{t}_1^0) = 1$ $m(\tilde{b}_1) < 300$ GeV, $BR(\tilde{b}_1) = BR(\tilde{t}_1^0) - 0.5$ $m(\tilde{t}_1^0) < 200$ GeV, $m(\tilde{b}_1) < 300$ GeV, $BR(\tilde{t}_1^0) = 1$	1708.02026, 1711.03301 1708.02026 1706.03731
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0, M_2 = 2 \times M_1$	Multiple	Yes	36.1	#	Forbidden	0.59-0.82	0.7		
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0, M_2 = 2 \times M_1$	Multiple	Yes	36.1	#	Forbidden	0.7	0.9	$m(\tilde{t}_1^0) < 60$ GeV $m(\tilde{t}_1^0) < 200$ GeV	1709.04183, 1711.11520, 1708.03247 1709.04183, 1711.11520, 1708.03247
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0 \rightarrow W\tilde{A}_1^0$ or $\tilde{t}_1^0\tilde{t}_1^0$	0 2 e, μ	0-2 jets/1-2 b	Yes	36.1	#	Forbidden	1.0	$m(\tilde{t}_1^0) < 150$ GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ LSP	Multiple	Yes	36.1	#	Forbidden	0.4-0.9		$m(\tilde{t}_1^0) = 150$ GeV, $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) - 5$ GeV, $\tau_1 = \tau_2$ $m(\tilde{t}_1^0) < 300$ GeV, $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) - 5$ GeV, $\tau_1 = \tau_2$	1709.04183, 1711.11520 1709.04183, 1711.11520
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ Well-Tempered LSP	Multiple	Yes	36.1	#	Forbidden	0.48-0.84		$m(\tilde{t}_1^0) = 150$ GeV, $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) - 5$ GeV, $\tau_1 = \tau_2$	1709.04183, 1711.11520
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0 \rightarrow \tilde{t}_1^0\tilde{t}_1^0 + \tilde{t}_1^0\tilde{t}_1^0$	0	2 τ	Yes	36.1	#	0.46	0.85	$m(\tilde{t}_1^0) < 0$ GeV $m(\tilde{b}_1, \tilde{t}_1^0) = m(\tilde{t}_1^0) - 50$ GeV $m(\tilde{b}_1, \tilde{t}_1^0) = m(\tilde{t}_1^0) - 5$ GeV	1805.01649 1805.01649 1711.03301
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0 \rightarrow \tilde{t}_1^0\tilde{t}_1^0 + h$	0	mono-jet	Yes	36.1	#	0.43	0.32-0.88	$m(\tilde{t}_1^0) < 0$ GeV, $m(\tilde{b}_1) = m(\tilde{t}_1^0) = 180$ GeV	1706.03986
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ via WZ	2 3 e, μ 2 $\nu, \nu\mu$	≥ 1	Yes Yes	36.1 36.1	# #	0.17	0.6	$m(\tilde{t}_1^0) = 0$ $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) = 10$ GeV	1403.5294, 1806.02293 1712.08119
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ via Wh	Multiple	Yes	20.3	#	0.25	0.22	0.76	$m(\tilde{t}_1^0) = 0$, $m(\tilde{t}_1^0) = 0.5$, $m(\tilde{t}_1^0) = m(\tilde{t}_1^0)$ $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) = 100$ GeV, $m(\tilde{t}_1^0) = 0.5$, $m(\tilde{t}_1^0) = m(\tilde{t}_1^0)$	1501.07110 1708.07875 1708.07875
$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ via $\tilde{t}_1^0\tilde{t}_1^0$	2 e, μ 2 e, μ	0 ≥ 1	Yes Yes	36.1 36.1	# #	0.18	0.5	$m(\tilde{t}_1^0) = 0$ $m(\tilde{t}_1^0) = m(\tilde{t}_1^0) = 5$ GeV	1803.02762 1712.08119	
$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ via $\tilde{t}_1^0\tilde{t}_1^0$	0	$\geq 3b$	Yes	36.1	#	0.13-0.23	0.29-0.88	$BR(\tilde{t}_1^0) = 1$ $BR(\tilde{t}_1^0) = 1$ $BR(\tilde{t}_1^0) = 2/3$	1806.04030 1806.04030 1804.03002	
$\tilde{b}_1\tilde{b}_1, \tilde{t}_1^0\tilde{t}_1^0$ via $\tilde{t}_1^0\tilde{t}_1^0$	4 e, μ	0	Yes	36.1	#	0.3				
Direct $\tilde{t}_1^0\tilde{t}_1^0$ prod., long-lived \tilde{t}_1^0	Disapp. trk	1 jet	Yes	36.1	#	0.15	0.46		Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-CONF-2017-019
	Stable \tilde{t}_1^0 R-hadron	SMP	-	3.2	#		1.6			1606.05229
	Metastable \tilde{t}_1^0 R-hadron, $\tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	Multiple	Yes	32.8	#	$m(\tilde{t}_1^0) \geq 100$ ns, 0.2 ns	1.6	2.4	$m(\tilde{t}_1^0) < 100$ GeV	1710.04801, 1604.04520
	GMSB, $\tilde{t}_1^0 \rightarrow e\tilde{e}$, long-lived \tilde{t}_1^0	2 γ	-	Yes	20.3	#	0.44		1- $\tau\tau\tilde{t}_1^0$ < 3 ns, SPSe model	1409.5542
$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	displ. $e\tilde{e}/\mu\tilde{\mu}$	-	-	20.3	#		1.3	$\tilde{c} \rightarrow \tilde{t}_1^0\tilde{t}_1^0$ < 1000 ns, $m(\tilde{t}_1^0) < 1$ TeV	1504.05162	
RPV	LFV $\tilde{p}\tilde{p} \rightarrow \tilde{t}_1^0 + X, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0/\nu\tilde{t}_1^0$	$e\mu, e\tau, \mu\tau$	-	3.2	#		1.9		$x_{12} = 0.11, A_{12} = 0.0333/0.07$	1607.08079
	$\tilde{t}_1^0\tilde{t}_1^0 \rightarrow W\tilde{Z}\tilde{t}_1^0/\nu\tilde{t}_1^0$	4 e, μ	0	Yes	36.1	#	0.82	1.33	$m(\tilde{t}_1^0) < 100$ GeV	1804.03002
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	0 4.5-large R jets	-	36.1	#	$m(\tilde{t}_1^0) < 200$ GeV (100 GeV)	1.3	1.9	Large \tilde{c}	1804.02568
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	Multiple	Yes	36.1	#	$m(\tilde{t}_1^0) < 200$ GeV	1.05	2.0	$m(\tilde{t}_1^0) < 200$ GeV, bino-like	ATLAS-COONF-2018-003
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	Multiple	Yes	36.1	#	$m(\tilde{t}_1^0) < 200$ GeV	0.55	1.8 2.1	$m(\tilde{t}_1^0) < 200$ GeV, bino-like	ATLAS-COONF-2018-003
	$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	0 2 jets + 2 b	-	36.1	#	$m(\tilde{t}_1^0) < 200$ GeV	0.42	0.61	$m(\tilde{t}_1^0) < 200$ GeV, bino-like	ATLAS-COONF-2018-003
$\tilde{t}\tilde{t} \rightarrow q\tilde{q}\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow q\tilde{q}\tilde{t}_1^0$	2 e, μ	2 b	-	36.1	#		0.4-1.45	$BR(\tilde{t}_1^0 \rightarrow \tilde{b}\tilde{t}_1^0) < 20\%$	1710.07171 1710.05544	

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

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Mass scale [TeV]

R-PARITY VIOLATING AND LONG-LIVED SIGNATURES

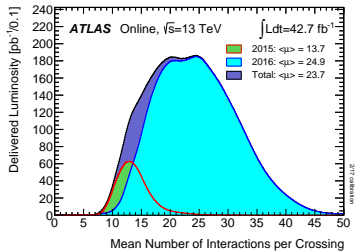
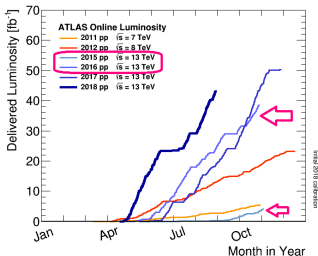
In this talk focus only on searches for long-lived (LL) particles and R-parity violating signatures

Search Category	Signature	Channel	Signature	Branching Ratio	Mass Scale [TeV]	Model/Parameters	Reference			
Long-lived particles	Direct $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ prod., long-lived $\tilde{\chi}_1^0$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^0$ $\tau_{1/2} > 0.15$	0.46	Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-PUB-2017-019	
	Stable \tilde{g} R-hadron	SMP	-	-	3.2	\tilde{g}	1.6		1608.05129	
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\tilde{q}^0$	-	Multiple	-	32.8	\tilde{g} ($\tau_{1/2} = 100$ ns, 0.2 ns)	1.6	2.4	$m(\tilde{q}) = 100$ GeV	1710.04901, 1604.04520
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$, long-lived \tilde{G}	2γ	-	Yes	20.3	\tilde{G}	0.44		1-coupling ≤ 3 ns, SP58 model	1409.5542
RPV	$\tilde{g}, \tilde{g} \rightarrow e\bar{e}e/\mu\bar{\mu}\mu/\tau\bar{\tau}\tau$	displ. ee/ $\mu\mu$	-	-	20.3	\tilde{g}	1.3		$6 < \tau(\tilde{G}) < 1000$ ns, $m(\tilde{G}) = 1$ TeV	1504.05162
	LFV $pp \rightarrow \nu + X, \nu_i \rightarrow e\mu/\tau/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	3.2	$\tilde{\nu}_i$	1.9		$A_{111}^0 = 0.11, A_{132/131/231} = 0.07$	1607.08079
	$\tilde{\chi}_1^0 \tilde{\chi}_1^0 / \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow WW/ZZ/llll/\nu\nu$	$4e, \mu$	0	Yes	36.1	$\tilde{\chi}_1^0 \tilde{\chi}_1^0$ ($A_{33} \neq 0, A_{321} \neq 0$)	0.82	1.33	$m(\tilde{G}) = 100$ GeV	1804.03602
	$\tilde{g}, \tilde{g} \rightarrow qq\tilde{q}^0, \tilde{q}^0 \rightarrow qq\tilde{q}$	0	4-5 large-R jets	-	36.1	\tilde{g} ($m(\tilde{q}) = 200$ GeV, 1100 GeV)	1.3	1.9	Large A_{112}^0	1804.03568
	$\tilde{g}, \tilde{g} \rightarrow qq\tilde{q}^0, \tilde{q}^0 \rightarrow qq\tilde{q}$	0	Multiple	-	36.1	\tilde{g} ($A_{112}^0 = 4, 2e-5$)	1.05	2.0	$m(\tilde{q}) = 200$ GeV, bino-like	ATLAS-CO NF-2018-003
	$\tilde{g}, \tilde{g} \rightarrow t\bar{b}t / \tilde{g} \rightarrow t\bar{b}\tilde{t}^0, \tilde{t}^0 \rightarrow t\bar{b}t$	36.1	Multiple	-	36.1	\tilde{g} ($A_{112}^0 = 1, 1e-2$)	1.8	2.1	$m(\tilde{q}) = 200$ GeV, bino-like	ATLAS-CO NF-2018-003
	$\tilde{g}, \tilde{g} \rightarrow t\bar{b}t / \tilde{g} \rightarrow t\bar{b}\tilde{t}^0, \tilde{t}^0 \rightarrow t\bar{b}t$	36.1	Multiple	-	36.1	\tilde{g} ($A_{112}^0 = 2e-4, 1e-2$)	0.55	1.05	$m(\tilde{q}) = 200$ GeV, bino-like	ATLAS-CO NF-2018-003
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{b}t$	0	2 jets + 2 b	-	36.7	\tilde{t}_1 [$\nu\bar{\nu}, \bar{b}b$]	0.42	0.61		1710.07171
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{b}t$	$2e, \mu$	$2b$	-	36.1	\tilde{t}_1			BR($\tilde{t}_1 \rightarrow b\bar{c}/\bar{b}c$) > 20%	1710.05544

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Mass scale [TeV]

- Data collected in (2015 &) 2016 by ATLAS at $\sqrt{s} = 13$ TeV energy in the center of mass
- Only a selected list of results presented, based on an integrated luminosity of 32-36 fb^{-1}
- All Supersymmetry group public results [here](#) (all ATLAS results [here](#))



Short lived particles: RPV SUSY models

- Results are interpreted using SUSY simplified models, where particles not involved in production or decays are decoupled
- Values of the coupling are large enough to ensure prompt decays of the lightest SUSY particle (LSP)

RPV SUPERSYMMETRY (SUSY)

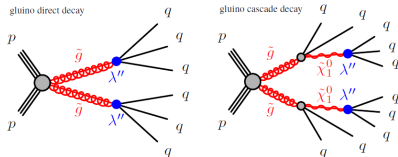
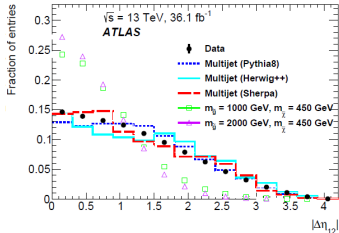
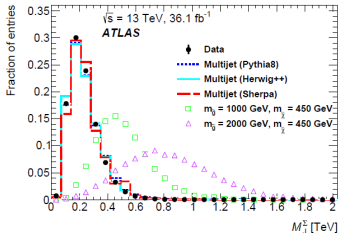
Supersymmetry, a fundamental theory which unifies fermions (matter) and bosons (forces)

- Extends the Standard Model (SM) by introducing supersymmetric (heavy) partners for every SM particle with identical quantum numbers except for a half-unit difference in spin
- R-parity, $(-1)^{3(B-L)+2S}$: protects the baryon number and lepton number conservation
 - In SM $R=+1$, in SUSY $R=-1$
- If R-parity conserved (RPC): SUSY particles produced/annihilated in pairs, lightest SUSY particle (LSP) stable and a potential Dark Matter (DM) candidate
- If R-parity violated (RPV): allows the possibility of some RPV couplings to be non-zero
 - LSP unstable and decays in SM particles
 - The LSP lifetime depends on the RPV coupling strength & masses of the sfermions involved in the decay
 - Can have resonant sparticle production with long-lived particles (LLP) in the cascade decay
- Today: focus on only few experimental signatures predicted by selected RPV SUSY simplified models

RPV SUSY WITH MULTI-JET FINAL STATES

Results with 36.1 fb^{-1} of 13 TeV ATLAS data published in Phys. Lett. B. ([arxiv/1804.03568](https://arxiv.org/abs/1804.03568))

- Final state formed by jets (≥ 6 or ≥ 10): multi-jets background dominates
- Events are selected with a H_T trigger ($H_T = \text{sum of all jets } p_T$)



* all quark generations allowed in the final state

- Key variable to separate the (potential) signal from the bkg: the reconstructed "mass" of the heavy particle, which is the total jet mass defined as

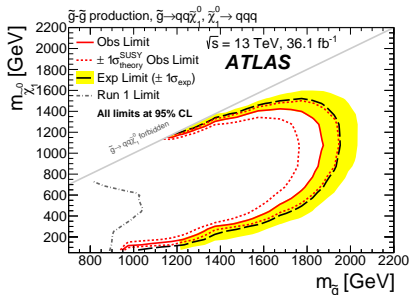
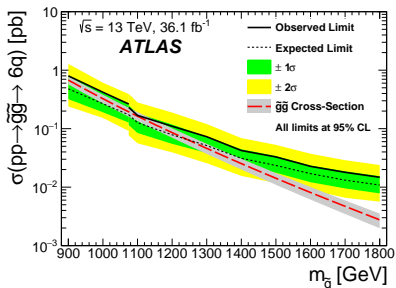
$$M_J^\Sigma = \sum_{\substack{p_T > 200 \text{ GeV} \\ |\eta| < 2.0 \\ j=1-4}} m_{jet}^j$$

- Other variables \rightarrow the pseudorapidity difference between the two leading large-R jets, $|\Delta\eta_{12}|$
- \rightarrow number of ($b-$) jets in the event and the leading jet p_T

RESULTS

Five signal regions defined to look for new physics

- No significant excess observed in any of the SRs: place exclusion limits at 95% CL on the production of gluinos
- Gluino direct decay and cascade decay models in the UDD scenarios of RPV SUSY



LHS Gluino direct decay model: signals with a x-section as small as 0.8 fb ($m_{gl\tilde{u}ino} = 900$ GeV) - 0.011 fb ($m_{gl\tilde{u}ino} = 1.8$ TeV) are excluded at 95% CL

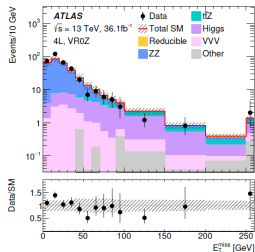
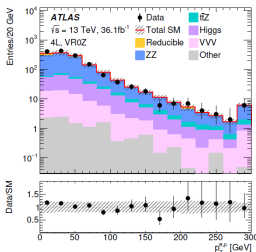
RHS Gluino cascade decay model: gluinos with masses below 1 TeV and 1.9 TeV are excluded at 95% CL, depending on the neutralino mass

RPV SUSY WITH MULTI-LEPTON FINAL STATES

Results with 36.1 fb^{-1} of 13 TeV ATLAS data published in PRD ([arxiv/1804.03602](https://arxiv.org/abs/1804.03602))

- Lepton number violating coupling (λ): neutralino (the LSP) decays through a virtual slepton or sneutrino
- To ensure prompt decays, LSP mass restricted to $10 \text{ GeV} \leq m_{\text{LSP}} \leq m_{\text{NLSP}} - 10 \text{ GeV}$
- Final state formed by ≥ 4 charged leptons (electrons, muons or hadronically decaying tau)

- Signal regions dominated by ZZ, $t\bar{t}Z$, VVV and Higgs production, and fake leptons
- Key discriminant variables: missing transverse energy (E_T^{miss}) and effective mass of the event (m_{eff} , scalar sum of E_T^{miss} , p_T of all leptons and p_T of all jets with $p_T > 40 \text{ GeV}$)

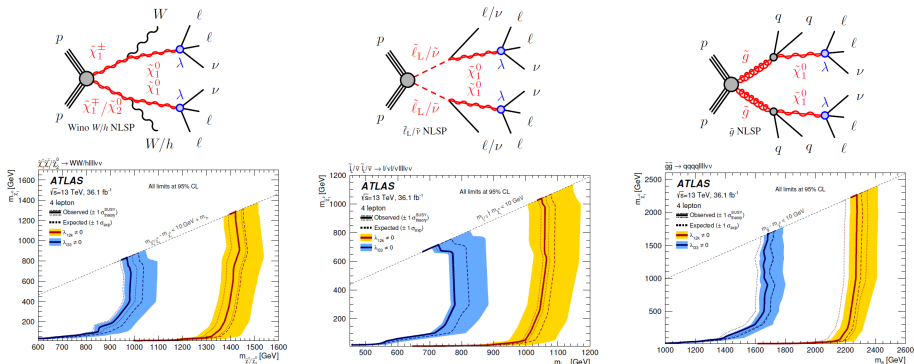


RESULTS

Data observations are consistent with the SM expectations in all designed signal region

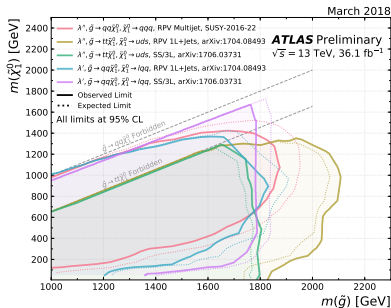
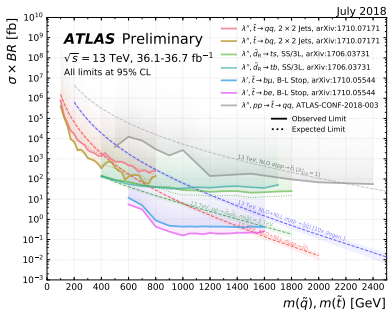
Sample	SR0A	SR0B	SR0C	SR0D	SR1	SR2
Observed	13	2	47	10	8	2
SM Total	10.2 ± 2.1	1.31 ± 0.24	37 ± 9	4.1 ± 0.7	4.9 ± 1.6	2.3 ± 0.8
p_0	0.23	0.25	0.15	0.011	0.13	0.61
Z	0.75	0.69	1.0	2.3	1.2	0

Maximum local significance of the data-bkg disagreement around 2.3σ



ATLAS RPV SEARCHES: SUMMARY

Limits on squark and gluino masses using simplified SUSY models:



- Several results from different teams/final states \rightarrow complementary of the ATLAS searches
- \rightarrow Depending on the considered RPV model, only one of the λ' or λ'' couplings are non-zero and all the remaining couplings are set to 0
 - The choice of having only one non-zero baryonic coupling is made for simplicity and the availability of a theoretical upper limit

Long Lived Particles (LLP)

- Results are interpreted using SUSY simplified models, where particles not involved in production or decays are decoupled
- When RPV SUSY: if small RPV couplings and/or large sfermion masses the LSP can become long-lived

LONG-LIVED PARTICLES

Simplest definition for the long-lived particles (LLP):

- Neutral particles decaying a macroscopic distance from the interaction point (IP)
- Charged particles that decay as above or are quasistable on the detector scale

LLP can be (only few examples!):

- Supersymmetric (SUSY) models

- Long-lived gluinos (\tilde{g}) due to very heavy squarks, or \tilde{g} -Bino co-annihilation
- Long-lived charginos ($\tilde{\chi}$): Wino/Higgsino Lightest Stable Particle (LSP)
- Long-lived neutralino/LSP ($\tilde{\chi}^0$): Gravitino LSP, R-parity violation, Wino-Bino co-annihilation

- Hidden/dark sector scenario

- Long-lived dark photon: Higgs portal model
- Long-lived neutral scalar: Heavy neutral boson portal model

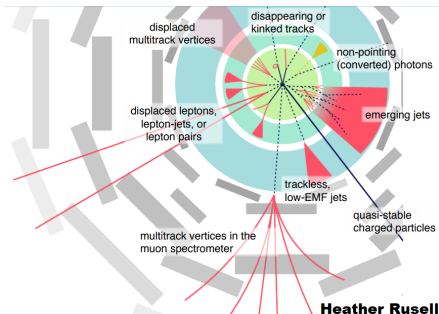
- Others

- Long-lived right-handed neutrino: Left-right symmetry extension of SM
- Long-lived multi-charged particle: Monopole, Q-ball

LONG-LIVED PARTICLES (CONT'D)

- LL particles can be light or heavy
- **Experimental signature: LLP itself if it's stable, otherwise its decay products (jets, ℓ , etc)**
- Can have an unique signature (lifetimes in the pico to nanoseconds range), for example:

- **Meta-stable LL charged particles:** travel all the detector components, like muons but with a very different signature (interactions with the detector material)
- **Non-stable charged LLP:** Disappearing or kinked tracks → presence of secondary (kinked) track dependent on the phase space of the decay vertex
- **LLP can decay to leptons:** can look for displaced leptons or for displaced di-lepton vertices (with no track pointing back to the IP)



- **Usually lower Standard Model (SM) background than in the traditional BSM searches**
 - Cannot rely on MC simulations, and most of the time a fully data-driven background estimation is used
- **Requires a deep understanding of the detector!**

SEARCH FOR MASSIVE CHARGED LLP USING AN IONISATION MEASUREMENT

Results with 36.1 fb^{-1} of 13 TeV ATLAS data submitted to Phys. Lett. B ([arxiv/1808.04095](https://arxiv.org/abs/1808.04095))

- The LLP are expected to travel with a velocity significantly below the speed of light
- ⇒ have a specific (higher) ionisation distinguishable from SM particles
- **Key variable: ionisation energy loss (dE/dx) of all reconstructed charged particles**
- measured with the ATLAS pixel sub-detector
- Search for excesses in the mass distribution of reconstructed tracks with high transverse momentum (p_T) and large dE/dx
- Two signal regions designed to look for meta-stable and stable R-hadrons produced in pairs:

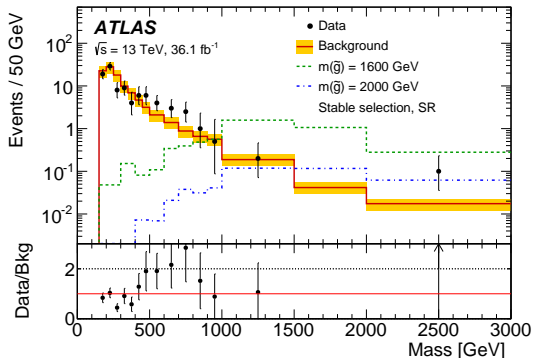
	SR	VR	p -CR		dE/dx -CR	
			for SR	for VR	for SR	for VR
Track Momentum [GeV]	>150	50–150	>150	50–150	>150	50–150
E_T^{miss} [GeV]	>170		>170		<170	
Ionisation [$\text{MeV g}^{-1} \text{cm}^2$]	> 1.8		< 1.8		–	

Events are selected with a trigger based on E_T^{miss} , with a threshold which varies from 70 GeV to 110 GeV

- 1) Meta-stable: Decay before muon spectrometer, $c\tau_{\text{Lab}}(\text{R-hadron}) \lesssim 4 \text{ m}$ (muon veto)
- 2) Stable: Decay outside detector or not at all, $c\tau_{\text{Lab}}(\text{R-hadron}) \gtrsim 4 \text{ m}$ (tighter isolation)

RESULTS IN THE SIGNAL REGIONS

- Background: tracks from SM processes like vector boson, top-q and multi-jet production
→ Characterized by high dE/dx

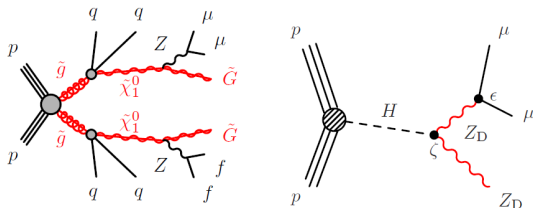


- When looking at the results in the two signal region:
 - Data observation is consistent with the background estimation ...
- Largest deviation from the bkg-only hypothesis has a local significance of 2.4σ
- Stable R-hadron SR, around 500–800 GeV for the reconstructed mass of candidate tracks

LLP SEARCHES WITH DISPLACED DIMUON VERTICES

Results with 32.9 fb^{-1} of 13 TeV ATLAS data submitted to Phys. Rev. D. ([arxiv/1808.03057](https://arxiv.org/abs/1808.03057))

- Signature: displaced (several cm from IP) pair of muons with opposite-sign electric charge
- Target specific BSM models:



LHS LL neutralino ($\tilde{\chi}_1^0$) decay in a Gauge-mediated supersymmetry (GGM) scenario

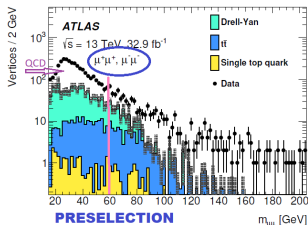
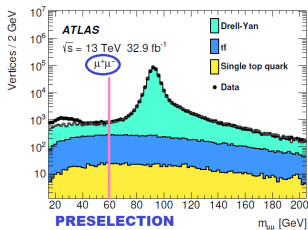
- Neutralino NLSP: heavy, long-lived
- High p_T muons

RHS LL dark photons Z_D produced from Higgs boson decay (dark-sector gauge boson model)

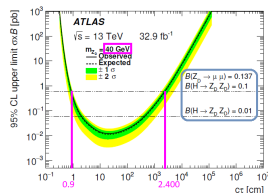
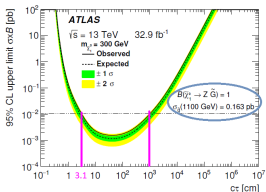
- Z_D is lighter than half the H mass
- Small Z-ZD coupling: long-lived
- Low p_T muons

SEARCH STRATEGY AND RESULTS

- Define low $m_{\mu\mu}$ mass (15 - 60 GeV) and high $m_{\mu\mu}$ mass (> 60 GeV) regions
 - Events selected with E_T^{miss} and muon triggers
 - Two displaced (1-400 cm from IP) muons of opposite sign (same-sign for bkg CRs)



Yield	SR _{low}	SR _{high}
N^{bkgd}	13.8 ± 4.9	$0.50^{+1.42}_{-0.07}$
N^{obs}	15	2



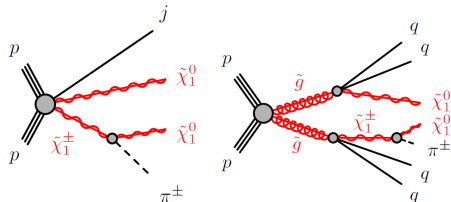
- No significant excess of vertices over the SM background expectation

- Place upper limits (95% CL) on the signal event yields and production x-sections for different values of the LLP proper decay distance $c\tau$

LL $\tilde{\chi}^\pm$ SEARCHES WITH DISAPPEARING-TRACK

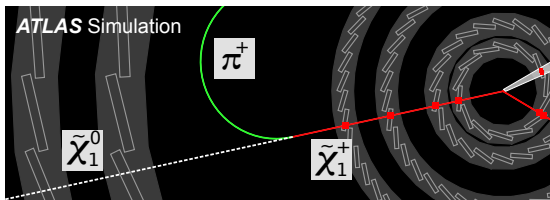
Results with 36.1 fb^{-1} of 13 TeV ATLAS data published in JHEP ([arxiv/1712.02118](https://arxiv.org/abs/1712.02118))

- Aims for SUSY models with a LL chargino ($\tilde{\chi}^\pm$) and neutralino ($\tilde{\chi}^0$) nearly mass-degenerate
- Sensitive to $\tilde{\chi}^\pm$ lifetimes from 10 ps to 10 ns (maximum sensitivity for lifetimes $\sim 1 \text{ ns}$)
 - $\tilde{\chi}^\pm$ lifetime is nearly uniquely determined only by the $\tilde{\chi}^\pm$ mass



Experimental signature:

- Emitted pion has very low momentum and it's not reconstructed in the detector
- $\tilde{\chi}^0$ passing through the detector without interacting
- ⇒ Track from the LL $\tilde{\chi}^\pm$ can therefore *disappear*
 - Leave hits only in the innermost layers (no hits in the detector at higher radii)

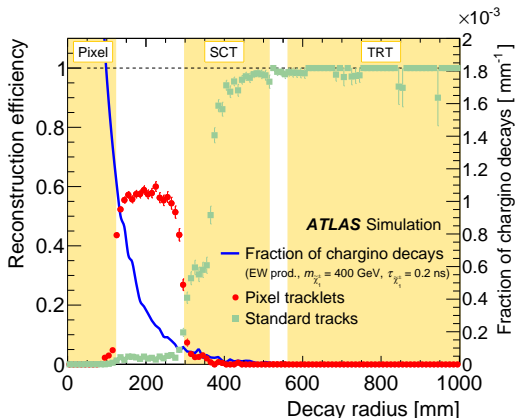


CHARGINO RECONSTRUCTION EFFICIENCY

Compared to other searches, it uses tracklets

(tracklet = very short track, $p_T > 5$ GeV, should have hits in all 4 Pixel layers and no holes)

→ Allows the reconstruction of charginos decaying at radii from about 12 cm to 30 cm



RED Reconstruction efficiency of pixel tracklets before applying the fake-rejection criteria

GREEN Reconstruction efficiency for standard tracks

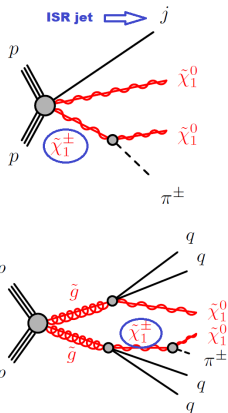
BLUE Distribution of the decay radius for charginos with a lifetime of 0.2 ns

→ Extends the sensitivity to smaller chargino lifetimes

EVENT SELECTION

≥ 1 isolated tracklet with $p_T > 20$ GeV, within $0.1 < |\eta| < 1.9$ and with hits in all 4 pixel layers

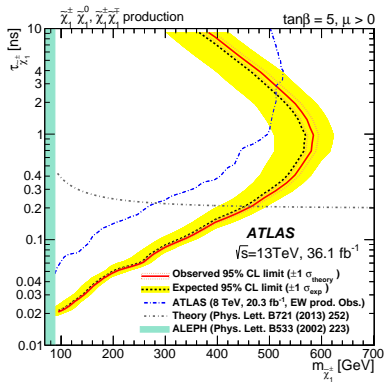
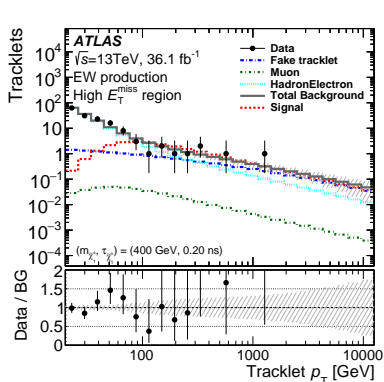
- **In electroweak-gaugino production:** one ($p_T > 140$ GeV) ISR jet present/required in the event
 - Leads to high E_T^{miss} (> 90 GeV) in the event
- **$\tilde{g}\tilde{g}$ production:** expect at least four jets in the event
 - Require ≥ 1 high p_T jet (> 100 GeV) and ≥ 2 additional softer jets ($p_T > 50$ GeV)
 - $E_T^{miss} > 100$ GeV
- Lepton veto applied suppress bkg events from W/Z + jets and top-pair production processes
- Cuts on $\Delta\varphi$ between the missing transverse momentum and each of the four highest- p_T jets ($p_T > 50$ GeV)



RESULTS

After selection: look for an excess of candidate events in the p_T distribution of pixel tracklets

→ No excess observed in any of the SRs: place exclusion limits at 95% CL



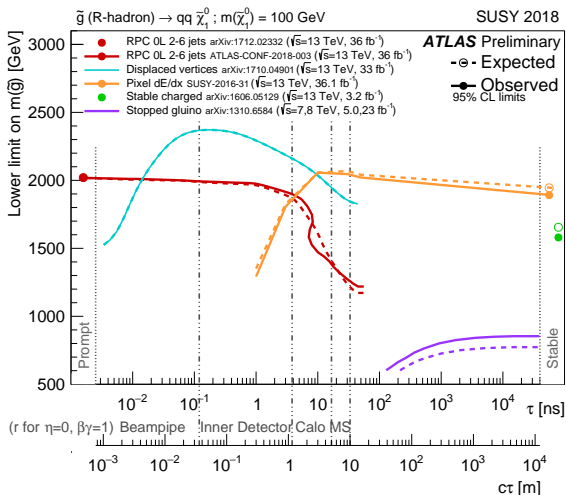
● Electroweak production: LL $\tilde{\chi}^\pm$ (0.2 ns life-time) are excluded below 460 GeV

→ Pure wino LSP model; mass-splitting between the charged and neutral wino of 160 MeV

● Results can be interpreted also using other SUSY simplified models, e.g. pure-higgsino

ATLAS LLP SEARCHES: SUMMARY

Limits on the gluino mass-vs-lifetime plane for a split-supersymmetry simplified model with the gluino R-hadron decaying into a gluon or light quarks and a neutralino with mass of 100 GeV:



- Several results from different teams/final states \rightarrow complementary of the ATLAS searches

BACKUP

SUSY

		Proper states in		Spartners	Proper states in	
		interaction term	mass term		interaction term	mass term
$\begin{pmatrix} \nu \\ L \end{pmatrix}, l$	Leptons $S = 1/2$	$\begin{pmatrix} \nu_e \\ e_L \end{pmatrix}, e_R$		Sleptons $S = 0$	$\begin{pmatrix} \tilde{\nu}_e \\ \tilde{e}_L \end{pmatrix}, \tilde{e}_R$	
		$\begin{pmatrix} \nu_\mu \\ \mu_L \end{pmatrix}, \mu_R$			$\begin{pmatrix} \tilde{\nu}_\mu \\ \tilde{\mu}_L \end{pmatrix}, \tilde{\mu}_R$	
		$\begin{pmatrix} \nu_\tau \\ \tau_L \end{pmatrix}, \tau_R$			$\begin{pmatrix} \tilde{\nu}_\tau \\ \tilde{\tau}_L \end{pmatrix}, \tilde{\tau}_R$	$\tilde{\tau}_1, \tilde{\tau}_2, \tilde{\nu}_\tau$
$\begin{pmatrix} U \\ D \end{pmatrix}, u, d$	Quarks $S = 1/2$	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R$		Squarks $S = 0$	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}, \tilde{u}_R, \tilde{d}_R$	
		$\begin{pmatrix} c_L \\ s_L \end{pmatrix}, c_R, s_R$			$\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix}, \tilde{c}_R, \tilde{s}_R$	
		$\begin{pmatrix} t_L \\ b_L \end{pmatrix}, t_R, b_R$			$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}, \tilde{t}_R, \tilde{b}_R$	$\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2$
H_u, H_d	Gauge Bosons $S = 1$	W^\pm, W^0, B, g	W^\pm, Z^0, γ, g	Gauginos $S = 1/2$	$\tilde{W}^\pm, \tilde{W}^0, \tilde{B}, \tilde{g}$	Glauino \tilde{g}
	Higgs Boson $S = 0$	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$	h^0, H^0, A^0, H^\pm	Higgsinos $S = 1/2$	$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$	Neutralinos $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$ Charginos $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$
G	Graviton $S = 2$	G		Gravitino $S = \frac{3}{2}$	\tilde{G}	