Supersymmetry Searches in ATLAS

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August 25, 2015

17th Lomonosov Conference on Elementary Particle Physics

Outline

- Introduction
 - Supersymmetry
 - ATLAS SUSY Search Strategy & Classification
- Strong Production Searches
- Searches for direct pair production of 3rd generation squarks
- Electroweak Production Searches
- RPV Searches
- What's next?

Introduction

Supersymmetry (SUSY)

- **SUSY = global symmetry between fermions & bosons**
 - all SM particles have SUSY-partners with spin difference of $\pm 1/2$
 - SUSY has to be a broken symmetry (superpartners heavier than SM particles)
- **Theoretical motivation**
 - Higgs mass stabilization against loop corrections (fine-tuning problem)
 - unification of gauge couplings at single scale
 - dark matter candidate:
 Lightest supersymmetric particle (LSP)

ATLAS SUSY Search Strategy

SUSY events in our data?

- Define **Signal Region(s) (SR)**: set of cuts (on EtMiss, jet multiplicity, etc) that favour signal over background
- **Background events in our SR?**
 - Minor: MC-only estimation
 - Major:
 - semi data-driven
 - ✓ Define **Control Regions (CR)**: negligible signal
 - ✓ Normalise MC to match data in CR (obtain transfer factor)
 - ✓ Apply transfer factor to MC estimation of SR bkg
 - data-driven
- **Discovery/Exclusion fit:**
 - CLs exclusion limits or discovery

Classifying SUSY searches

Searches split by production process...

- **Strong production**
 - squarks (1st & 2nd gen.) & gluinos
- **3rd generation production**
 - targeting stops and sbottoms
- **Electroweak production**
 - targeting electroweak gauginos & sleptons

... and by final state characteristics

- **R-parity conserving (RPC) SUSY:**
 - neutral stable LSP
 - sparticles produced in pairs
 - large MET
- **R-parity violating (RPV) SUSY:**
 - LSP decays into SM particles => (in some cases) single sparticle production
- **Long-Lived particles**

R-parity:

$$R = (-1)^{3B+L+2S}$$

- +1 for SM particles
- -1 for SUSY particles

Run1
 $\sqrt{s} = 8 \text{ TeV}$

Strong Production Searches

- Large range of final states has been investigated
- Results interpreted in the context of many models
- Only a few examples shown in this talk

Strong Production Searches

- **95% CL exclusion limits from:** [arXiv:1507.05525](https://arxiv.org/abs/1507.05525) (SUSY strong prod. summary paper)
- Only a few examples displayed:

Simplified model: $\tilde{q}\tilde{q} \rightarrow qqWW\tilde{\chi}_1^0\tilde{\chi}_1^0$

$\sqrt{s} = 8 \text{ TeV}, L = 20 \text{ fb}^{-1}$

- 0-lepton + 1-lepton combination extends the reach

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MSUGRA/CMSSM

$\sqrt{s} = 8 \text{ TeV}$, $L = 20 \text{ fb}^{-1}$

- Combination of all final states
- Most sensitive:
 - low m_0 : (0+1)-lepton combination
 - large m_0 : 0/1-lepton + 3b-jets + MET

Strong Production Searches

3σ excess in the Z+MET search:

Eur.Phys.J. C75 (2015) 318

arXiv:1503.03290

$\sqrt{s} = 8 \text{ TeV}, L = 20 \text{ fb}^{-1}$

Events with: $Z \rightarrow e^+e^-/\mu^+\mu^- + \geq 2\text{jets} + E_T^{\text{miss}}$

- Data-driven methods for all major backgrounds
 - thoroughly cross-checked with other methods (including data-driven, semi data-driven and MC)

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SR	Expected	Observed	Signif.
ee	4.2 ± 1.6	16	3σ
$\mu\mu$	6.4 ± 2.2	13	1.7σ
ee+ $\mu\mu$	10.6 ± 3.2	29	3σ

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- **95% CL exclusion limits** set for target model **GGM**
- Limits weaker than expected due to the excess in data

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Model Independent Limits

Channel	$\langle \epsilon \sigma \rangle_{\text{obs}}^{95}$ [fb]	S_{obs}^{95}	S_{exp}^{95}
ee	1.00	20.2	$8.2^{+3.9}_{-1.6}$
$\mu\mu$	0.72	14.7	$8.6^{+3.8}_{-2.3}$
ee+ $\mu\mu$	1.46	29.6	$12.4^{+5.2}_{-2.4}$

Run1
 $\sqrt{s} = 8 \text{ TeV}$

Searches for direct pair production of 3rd generation squarks

- Large range of final states has been investigated
- Results interpreted in the context of many models
- Only a few examples shown in this talk

Direct pair production of 3rd generation

- **95% CL exclusion limits from:** [arXiv:1506.08616](https://arxiv.org/abs/1506.08616) (3rd gen. $\tilde{q}$ direct prod. summary paper)
- **Example:** Stop decays with no charginos in the decay chain

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Electroweak Production Searches

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$\sqrt{s} = 8 \text{ TeV}, L = 20 \text{ fb}^{-1}$

- Small cross-sections but:
 - Clean multi-lepton final states
 - Low hadronic activity
- Searches using e, μ, τ

Summary plot showing
95% CL exclusion limits
for SM bosons mediated decays

Publication references shown in the plot

Electroweak Production Searches

$\sqrt{s} = 8 \text{ TeV}, L = 20 \text{ fb}^{-1}$

- Small cross-sections but:
 - Clean multi-lepton final states
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- Searches using e, μ, τ

Summary plot showing
95% CL exclusion limits
for slepton mediated decays

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

Run1
 $\sqrt{s} = 8 \text{ TeV}$

RPV Searches

- Dedicated searches probing RPV signatures +
- + re-interpretations of RPC searches
- Only a few examples shown in this talk

RPV Searches

Re-interpretations of RPC searches

Examples with 2 different bRPV models

fully compatible with: observed Higgs boson mass and measurements of neutrino physics

bRPV-MSUGRA

mostly strong production

bRPV-MSUGRA: $\tan\beta = 30$, $A_0 = -2m_0$, $\mu > 0$

arXiv:1507.05525 (strong prod. summary paper)

Natural bRPV pMSSM

Natural bRPV pMSSM: $\tan\beta = 30$, $M_2 = 3\mu$, $m_{\text{gluino}} = 1.7 \text{ TeV}$

ATLAS-CONF-2015-018 (RPV summary conf. note)

Run1 SUSY Searches in Summary

Run1 SUSY Searches in Summary

- 19 dimensional phenomenological MSSM (**pMSSM**) **sampled**
- $\sim 310,000$ models surviving all theory and non-LHC experimental constraints interpreted **using the searches in 22 ATLAS run1 papers**
- **fraction of models excluded is shown**

What's next?

Prospects for RUN2

Estimated discovery reach at 13 TeV for 1, 2, 5 and 10 fb⁻¹

ATL-PHYS-PUB-2015-005

1-lepton+jets+E_T^{miss}

A first look in RUN2

- First data collected
- Performance assessment has started:
 - E.g. Control Region distributions in strong production searches

Summary

- Many different SUSY searches performed with Run1 data:
 - targeting many production processes and
 - covering a wide range of final states
- 95% CL exclusion limits set for a variety of models but...
- 1 exciting excess observed in the Z+MET analysis
- Great potential in Run2...
- which **has already started!!**

BACKUP

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	$\sqrt{s} = 7 \text{ TeV}$	$\sqrt{s} = 8 \text{ TeV}$	Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ /1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(1^{\text{st}} \text{ gen. } \tilde{q})=m(2^{\text{nd}} \text{ gen. } \tilde{q})$	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV	$m(\tilde{q})=m(\tilde{\chi}_1^0)<10 \text{ GeV}$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	2 e, μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^{\pm} \rightarrow q\tilde{q}W^{\pm}\tilde{\chi}_1^0$	0-1 e, μ	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV	$m(\tilde{\chi}_1^0)<300 \text{ GeV}, m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1507.05525
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	2 e, μ	0-3 jets	-	20	$\tilde{g}$	1.32 TeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	$\tan\beta > 20$	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.29 TeV	$c\tau(\text{NLSP})<0.1 \text{ mm}$	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)<900 \text{ GeV}, c\tau(\text{NLSP})<0.1 \text{ mm}, \mu<0$	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)<850 \text{ GeV}, c\tau(\text{NLSP})<0.1 \text{ mm}, \mu>0$	1507.05493
3 rd gen. $\tilde{g}$ med.	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV	$m(\text{NLSP})>430 \text{ GeV}$	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2} \text{ scale}$	865 GeV	$m(\tilde{G})>1.8 \times 10^{-4} \text{ eV}, m(\tilde{g})=m(\tilde{q})=1.5 \text{ TeV}$	1502.01518
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)<400 \text{ GeV}$	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)<350 \text{ GeV}$	1308.1841
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)<400 \text{ GeV}$	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)<300 \text{ GeV}$	1407.0600
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)<90 \text{ GeV}$	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow \tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	$m(\tilde{\chi}_1^{\pm})=2 m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{\chi}_1^+$	1-2 e, μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^{\pm})=2 m(\tilde{\chi}_1^0), m(\tilde{\chi}_1^0)=55 \text{ GeV}$	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$ or $\tilde{t}\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$	90-191 GeV	$m(\tilde{\chi}_1^0)=1 \text{ GeV}$	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)<85 \text{ GeV}$	1407.0608
3 rd gen. squarks direct production	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)>150 \text{ GeV}$	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}$	1403.5222
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$	1403.5294
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow \tilde{\ell}\nu(\ell\bar{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$	140-465 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\ell}, \bar{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow \tau\nu(\tau\bar{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	100-350 GeV	$m(\tilde{\chi}_1^0)=0 \text{ GeV}, m(\tilde{\tau}, \bar{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0 \rightarrow \tilde{\ell}_L\tilde{\nu}_L, \tilde{\ell}(\bar{\nu}), \tilde{\ell}\tilde{\nu}_L\ell(\bar{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$	700 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, m(\tilde{\ell}, \bar{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$	420 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, \text{ sleptons decoupled}$	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h \rightarrow b\tilde{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0$	250 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)=0, \text{ sleptons decoupled}$	1501.07110
	$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h \rightarrow b\tilde{b}/WW/\tau\tau/\gamma\gamma$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_1^0, \tilde{\chi}_2^0$	620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0), m(\tilde{\chi}_1^0)=0, m(\tilde{\ell}, \bar{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
	GGM (wino NLSP) weak prod.	1 e, μ + γ	-	Yes	20.3	$\tilde{W}$	124-361 GeV	$c\tau<1 \text{ mm}$	1507.05493
EW direct	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$	270 GeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)\sim 160 \text{ MeV}, \tau(\tilde{\chi}_1^{\pm})=0.2 \text{ ns}$	1310.3675
	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$	482 GeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)\sim 160 \text{ MeV}, \tau(\tilde{\chi}_1^{\pm})<15 \text{ ns}$	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)=100 \text{ GeV}, 10 \mu\text{s}<\tau(\tilde{g})<1000 \text{ s}$	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$	1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{\ell}, \bar{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV	$10<\tan\beta<50$	1411.6795
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	435 GeV	$2<\tau(\tilde{\chi}_1^0)<3 \text{ ns}, \text{SPS8 model}$	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow e\bar{e}\nu/\mu\bar{\mu}\nu$	displ. $e\bar{e}/\mu\bar{\mu}$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	$7<c\tau(\tilde{\chi}_1^0)<740 \text{ mm}, m(\tilde{g})=1.3 \text{ TeV}$	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	$6<c\tau(\tilde{\chi}_1^0)<480 \text{ mm}, m(\tilde{g})=1.1 \text{ TeV}$	1504.05162
Long-lived particles	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e\mu/\tau\mu/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV	$\lambda'_{111}=0.11, \lambda'_{132/133/233}=0.07$	1503.04430
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.35 TeV	$m(\tilde{q})=m(\tilde{g}), c\tau_{LS} p<1 \text{ mm}$	1404.2500
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow e\bar{e}\nu_\mu, e\bar{\mu}\nu_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	750 GeV	$m(\tilde{\chi}_1^0)>0.2 \times m(\tilde{\chi}_1^{\pm}), \lambda_{121} \neq 0$	1405.5086
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e, μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	450 GeV	$m(\tilde{\chi}_1^0)>0.2 \times m(\tilde{\chi}_1^{\pm}), \lambda_{133} \neq 0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}q$	0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV	$\text{BR}(h)=\text{BR}(b)=\text{BR}(c)=0\%$	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow q\tilde{q}q$	0	6-7 jets	-	20.3	$\tilde{g}$	870 GeV	$m(\tilde{\chi}_1^0)=600 \text{ GeV}$	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow b s$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b s$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$	100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\ell$	2 e, μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	$\text{BR}(\tilde{t}_1 \rightarrow b e/\mu)>20\%$	ATLAS-CONF-2015-015
RPV	Scalar charm, $\tilde{c} \rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV	$m(\tilde{\chi}_1^0)<200 \text{ GeV}$	1501.01325

 10^{-1}

1

Mass scale [TeV]

Electroweak Production Searches

$\sqrt{s} = 8 \text{ TeV}, L = 20 \text{ fb}^{-1}$

- Small cross-sections but:
 - **Clean multi-lepton final states**
 - **Low hadronic activity**
- Searches using e, μ, τ

Summary plot showing
95% CL exclusion limits
obtained by different searches

Publication references shown in the plot

Long-lived particles

$\tilde{g}$ R-hadron $\rightarrow g/q\bar{q}\tilde{\chi}_1^0$; $m_{\tilde{\chi}_1^0} = 100$ GeV

Status: June 2015

$\sqrt{s} = 8$ TeV, $L = 20$ fb $^{-1}$

ATLAS SUSY Search Strategy

SUSY events in our data?

- Define **Signal Region(s) (SR)**: set of cuts (on EtMiss, jet multiplicity, etc) that favour signal over background

- Discovery/Exclusion fit:**
 - CLs exclusion limits or discovery

Classifying SUSY searches

Searches split by production process

- Strong production
 - targeting 1st and 2nd generation squarks and gluinos
 - largest cross-sections
- 3rd generation production
 - targeting stops and sbottoms
- Electroweak production
 - targeting:
 - electroweakinos (charginos & neutralinos)
 - sleptons

... and by final state characteristics

- R-parity conserving (RPC) SUSY: neutral stable LSP, sparticles produced in pairs, large MET
- R-parity violating (RPV) SUSY: LSP decays into SM particles => single sparticle production
- Long-Lived particles, within RPC and RPV

mSUGRA/CMSSM Parameters

- $\rightarrow$ gravity-mediated SUSY breaking
- m_0 : mass of scalar particles
- $m_{1/2}$: gaugino masses
- A_0 : trilinear Higgs-sfermion-sfermion coupling parameter
- $\tan \beta = \nu_u / \nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter μ

GMSB Parameters

- $\rightarrow$ gauge-mediated SUSY breaking
- Λ : SUSY breaking mass scale felt by the low-energy sector
- M_{mes} : mass scale of the messenger fields
- N_5 : number of SU(5) messenger fields
- C_{grav} : scale factor of the gravitino coupling
- $\tan \beta = \nu_u / \nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter μ

NGM

- starts from General Gauge Mediation
- GGM: no specific SUSY mass hierarchy is predicted for colored and uncolored states
 $\Rightarrow$ gluinos and squarks can be below the TeV scale = within reach of LHC
- NGM: decouple all sparticles not related to fine-tuning of Higgs sector
 $\Rightarrow$ light stop and light gluino as only light (relevant) coloured sparticle
- some additional mechanism needed (as in GMSB) to produce “correct” Higgs mass

Target models

- General Gauge Mediation (GGM)

- RPC model
- LSP always the gravitino (escapes detection => E_T^{miss})
- Phenomenology depends on NLSP (next to lightest SUSY particle): $\tilde{\chi}_1^0$ for most of the parameter space

- **This analysis:**

- $\tilde{\chi}_1^0$ higgsino-like
- Parameters: $M_1 = M_2 = 1\text{TeV}$, $c\tau_{\text{NLSP}} < 0.1\text{ mm}$; m_{gluino} and μ : free parameters; all other sparticle masses ≈ 1.5

- Two grids studied:

- $\tan\beta = 1.5$: $\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$

- $\tan\beta = 30$: $\begin{cases} \tilde{\chi}_1^0 \rightarrow Z\tilde{G} \\ \tilde{\chi}_1^0 \rightarrow h\tilde{G} \end{cases}$

Common object definitions

Representative object definitions used by the ATLAS SUSY Working Group

1. Jets: Built from calorimeter clusters using the anti- k_t association scheme with radius parameter $R = 0.4$, and calibrated to correct for dead material, calorimeter response, pile-up etc. Analyses use jets with $|\eta| < 2.8$ and varying thresholds on p_T and the fraction of tracks originating from the primary vertex (JVF), whereas all jets with $|\eta| < 4.9$ and $p_T > 20$ GeV enter $\cancel{E}_T$.
2. Muons: Identified as ID tracks combined with MS track segments, with $p_T > 10$ GeV and $|\eta| < 2.4$. “Signal” muons have $p_T > 20$ GeV and have higher object quality and isolation requirements.
3. Electrons: Identified as ID tracks combined with calorimeter clusters, with $p_T > 20$ GeV and $|\eta| < 2.47$. “Signal” electrons have $p_T > 25$ GeV and have higher object quality and isolation requirements.
4. Photons: Identified on the basis of shower shape in the calorimeter or from conversion tracks, with $p_T > 20$ GeV, $|\eta| < 2.37$ and $(1.52 < |\eta| \text{ or } 1.37 > |\eta|)$. Additional “ambiguity resolution” criteria reduce contamination from electrons. A transverse energy isolation requirement of < 5 GeV is imposed in a narrow cone of $\Delta R < 0.2$.
5. Tau jets: Identified using a multivariate discriminator (BDT) taking into account track information and calorimeter shower shapes, with $p_T > 20$ GeV, $|\eta| < 2.5$ and containing 1 or 3 tracks of $p_T > 1$ GeV and with a charge sum of ± 1 .
6. b-jets: Identified using multivariate discriminators taking into account impact parameter and secondary vertex information.

Background Estimation

Z + jets background

Jet smearing method:

SM backgrounds:

- QCD and inclusive W+jets
- WZ, ZZ
- top, WW, Z($\tau\tau$); top = $t\bar{t}$ bar + Wt
- Z + jets

Signal: Z + jets + EtMiss

(Instrumental) bkg: Z + jets + fake Etmiss

Estimating number of events in SR with high fake Etmiss Estimating of number of Z + jets bkg events in SR

How do we estimate the number of events with high fake EtMiss?

SEED REGION

region with well
measured jets => low
EtMiss region

×

RESPONSE FUNCTION

modeling the
response of the
calorimeters

=

PSEUDO-DATA

simulation of events with no
real EtMiss after passing
through the calorimeter

Applying SR cuts to pseudo-data => Estimation of number of Z + jets bkg events in SR

bRPV Phenomenology

- Model that we consider:
 - LSP = lightest neutralino
 - minimal Supergravity (mSUGRA): 5 parameters
 - $m_0, m_{1/2}$: scalar and gaugino masses at GUT scale
 - A_0 : trilinear scalar coupling
 - $\tan\beta$: ratio of Higgs vacuum expectation values
 - $\text{sign}(\mu)$: sign of the higgsino mass parameter

- R-Parity is violated through bilinear terms in the superpotential:
- The new terms in $W_{\text{bRPV}} = W_{\text{MSSM}} + \epsilon_i L_i H_u$ | trinos and neutralinos:
 - Explanation for neutrino masses and mixings
 - Connection between neutrino parameters and neutralino decays:

- Hence, bRPV | $\tan^2 \theta_{23} \approx \frac{\text{BR}(\tilde{\chi}_1^0 \rightarrow \mu^\pm + W^\mp)}{\text{BR}(\tilde{\chi}_1^0 \rightarrow \tau^\pm + W^\mp)}$ to be consistent with constraints from neutrino experiments

1-2 taus + jets + EtMiss

yellow band → 1 σ statistical and systematic uncertainties on the expected background

dashed red lines → influence of the theoretical uncertainties on the signal cross section on the limit