SEARCHES FOR SUPERSYMMETRY IN RESONANCE PRODUCTION, R-PARITY VIOLATING SIGNATURES AND EVENTS WITH LONG-LIVED PARTICLES WITH THE ATLAS DETECTOR

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Overview

O	verview	Most Recent
1.	SUSY search in events with 4 or more leptons, [RPV] <u>8TeV, 21fb⁻¹, ATLAS-CONF-2013-036</u>	
2.	SUSY search in events with 2 same-sign leptons and jets [RP <u>8TeV, 21 fb⁻¹</u> , <u>ATLAS-CONF-2013-007</u>	
3.	Heavy narrow resonance decaying to <i>eμ, eτ, μτ</i> [RPV] 7TeV, 4.6fb ⁻¹ , <u>arxiv:1212.1272v2</u>	Resonance
4.	Pair of 2-jet resonances [scalar gluon] 7TeV, 4.6fb ⁻¹ , <u>arxiv:1210.4826v2</u>	
5.	Pair of 3-jet resonances [RPV] 7TeV, 4.6fb ⁻¹ , <u>arxiv:1210.4813v2</u>	
6.	Displaced vertex with multi-tracks and muon [RPV, LLP] 7TeV, 4.4fb ⁻¹ , <u>arxiv:1210.7451v2</u>	Long-lived
7.	Non-pointing photons[LLP] 7TeV, 4.8fb-1, <u>ATLAS-CONF-2013-016</u>	
8.	Direct chargino production based on disappearing track sig 7TeV, 4.7fb ⁻¹ , <u>arxiv:1210.2852v2</u>	nature [AMSB, LLP]
9.	Heavy long lived slepton/R-hadron [LLP] ZTeV 4.7fb ⁻¹ arxiv:1211.1597v2	

R-parity violating supersymmetry

- □ R-parity (= $(-1)^{3(B-L)+2S}$) need not be exactly conserved.
 - No experimental evidence against R-parity violation (RPV)
 - R-parity violating terms are allowed in the superpotential

$$W_{RPV} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \kappa_i L_i H_2 + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

lepton number violating baryon number violating

However, if all terms exist then the proton becomes unstable



- Partial inclusion of RPV terms allows stable proton and leads to:
 - Unstable Lightest SUSY Particle (LSP) \rightarrow Missing E_T/p_T signature reduced or absent
 - Cannot rely heavily on missing E_T/p_T
 - Lepton or Baryon number violating resonances
 - Low missing E_T/p_T allows for clear resonance detection

 $m_{\rm eff}[GeV]$

> 600

SUSY search in events with 4 or more leptons

High lepton multiplicities can be indicative of lepton number violating SUSY

SR

SRO

 $\tilde{\chi}_1^0$

 $\tilde{\bar{\nu}}_{e}^{*}(\tilde{\bar{\nu}}_{\mu}^{*})$

 $N(e) + N(\mu)$

 ≥ 4

- Very low SM background
- Search for such events with high E_{T}^{miss} or high $m_{eff}^{\lambda_{121}}$
- Two signal region types defined:
 - additional Z candidate veto/request option in each SR
 - veto removes
 Z tagged events
 - request requires
 Z tagged events



Ν(τ)

 ≥ 0

 $\mu^{-}(e^{-}$

 $= E_{\mathrm{T}}^{\mathrm{miss}} + \sum p_{\mathrm{T}}^{l} + \sum p_{\mathrm{T}}^{j}$

or

E_Tmiss[GeV]

>75

ATLAS-CONF-2013-036

SUSY search in events with 4 or more leptons



SUSY search in events with 2 same-sign leptons and jets

2.

- Same-sign lepton pairs are rare in SM
 - Low background
- Applicable to many SUSY scenarios
 RPV scenario
 gluino pair production
 \widetilde{g} \widetilde{t} $\widetilde{$
- characterised by relatively low p_T^{miss} and several b-jets
- RPV signal region:
 - $\square N_{jets} \ge 5$
 - **\Box** $E_{T}^{miss} < 150 \text{GeV} \text{ or } m_{T} < 100 \text{GeV}$

 $\square N_{obs} = 1, N_{exp} = 1.8 \pm 1.3$

 $m_{\tilde{g}} < 860 \text{GeV}$ can be excluded over the whole stop mass range



Data

W+jet

Multije

 10^{3}

 $\lambda_{132} = 0.07$

 $\lambda_{132} = 0.05$ $\lambda_{132} = 0.01$

1500

 $\lambda_{132} = 0.07(1 \text{ fb}^{-1} \text{ 7 TeV})$

2000

 $m_{\tilde{v}_{\star}}$ [GeV]

m_{eμ} [GeV]

Single Top Ω_v(500GeV)

ww

Heavy narrow resonance decaying to $e\mu$, $e\tau$, $\mu\tau$

Events / 10 GeV

10³

10²

10

ATLAS

10²

eμ

Ldt = 4.6 fb

eμ

1000

s = 7 TeV



- Lepton number violation can lead to decays of heavy particles into pairs of different generation leptons
 - imes o Resonance in lepton pairs
- Search performed for $\widetilde{\mathcal{O}}_{\tau}$ decays 10 Data/SM 1.5 $\lambda'_{311} > 0.003$ exclusions $e\mu$ channel: 0.5 at $m_{\tilde{\nu}_{\tau}} = 500 \text{GeV}$ $\lambda'_{311} > 0.01$ $e\tau$ channel: $\lambda_{i3k} = 0.07$ $\lambda'_{311} > 0.01$ $\mu\tau$ channel: $\lambda^{'}_{311}$ 10^{5} ATLAS 95% CL $\sigma \times BR$ [fb] ATLAS Theory $\lambda'_{311} = 0.11, \lambda_{132} = 0.07$ $L dt = 4.6 \text{ fb}^{-1}$ 10⁴ Theory $\lambda'_{311} = 0.10, \lambda_{132} = 0.05$ eμ 10 $Ldt = 4.6 \text{ fb}^{-1}$ √s = 7 TeV Observed Limit √s = 7 TeV 10³ Expected Limit Expected Limit ±1 or 10² Expected Limit $\pm 2 \sigma$ 10⁻² 10 10^{-3} 500 10⁻¹ 500 1000 1500 2000 m_ṽ [GeV]

4.

Search performed in framework of pair produced scalar gluons (sgluon) Massive, colored, present in Decays other than $g_{\text{scalar}} \rightarrow gg$ are suppressed extended SUSY models \rightarrow pair of 2-jet resonances with similar mass g 0000 in Signal Region (Region A): $\frac{|m_1 - m_2|}{(m_1 + m_2)} < 0.15$, $|\cos(\theta^*)| < 0.15$ $g_{\rm scalar}$ Events / 10 GeV $L dt = 4.6 \text{ fb}^{-1} \text{ ATLAS}$ $p_{\tau}(4^{th} jet) > 80 \text{ GeV}$ 14000 Data; Region A ∖s = 7 TeV 12000 95% CL Limit $\sigma \times BR$ [pb] Observed ABCD result ATLAS $L dt = 4.6 fb^{-1}$ 10⁴ 10000 --- Expected MC sgluon; Region A $\sqrt{s} = 7 \text{ TeV}$ ±1σ 8000 $m_{sgluon} = 150 \text{ GeV}$ 2σ 6000 Scalar gluon 10³ Hyperpion 4000 **ATLAS 2010** 2000 10² Data / ABCD 1.2 10⊨ 08 150 100 200 250 300 350 Significance [0] 2 Mass [GeV] $150 \text{GeV} < m_{\text{sgluon}} < 287 \text{GeV}$ excluded 100 150 200

(m_+m_)/2 [GeV]

- In RPV, gluino may decay into 3 quarks
- Two orthogonal search channels:
 - \rightarrow resolve all 6 jets High \tilde{g} mass



Low \tilde{g} mass

 \rightarrow jets are heavily boosted and difficult to resolve \rightarrow analyse jets for structure indicative of 3 sub-jets



Long-lived particles (LLPs)

- 10
- R-parity violating (RPV) scenarios:
 - Lifetimes proportional to λ^{-2} , λ'^{-2} , λ''^{-2}
 - \rightarrow if λ is very small, long-lived $\widetilde{\chi}$ LSPs are possible
- R-parity conserving (RPC) scenarios:
 - Slow NLSP decay to LSP due to mass degeneracy or weak coupling
 - $\widetilde{\chi}$ in Anomaly-Mediated SUSY Breaking (medium decay length)
 - **\widetilde{ au}** in Gauge-Mediated SUSY Breaking (long decay length)
 - R-hadron (generic SUSY)

(long decay length)

Short decay length (~10mm) Displaced vertex



Medium decay length (~100mm) Disappearing/Kinked track

Long decay length ($>\sim$ 1000mm) Stable massive particle (SMP)

low β high dE/dx

Displaced vertex with multi-tracks and muon

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- Search conducted in the framework of a search for neutralino decay in RPV SUSY
- Short, but measurable, flight length leads to displaced secondary vertex
 - Require impact parameter (d0) > 1.5mm
 - Require high mass vertex to reduce background
 - Random "fake vertexes" of real and fake tracks, gas interactions
 - Require high number of tracks to increase vertex reconstruction reliability





Non-pointing photons

7.

In SPS8 GMSB, NLSP $\tilde{\chi}_1^0$ is long lived (c τ = free parameter)
 Decays to $\gamma + \tilde{G}$ $\tilde{\chi}_1^0$

• Search for signature of E_T^{miss} plus:

- Pairs of high (>75GeV) E_T photons not pointing back to primary vertex (in practice, pointing of only one can be checked)
- Evidence of late photon detection
 - Only used as a cross-check, not to generate limits
- Requires specialist use of ATLAS EM calorimeter
- Pointing distribution templates generated from MC (signal) and Data (background)



Timing distributions

Non-pointing photons

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- Limits obtained by fitting templates to SR photon pointing distribution
- Cross check on photon times is consistent with prompt photon production





9.

Search performed for LLPs with decay lengths >1000mm

Particle passes through all detectors

- Slepton \rightarrow constant charge, low energy loss
 - Measure β across whole detector
- R-hadron → charge may change during flight, high energy loss
 - For full detector search, measure dE/dx as well as eta
 - Additional searches over shorter ranges to account for possible loss of charge



Summary

- Certain SUSY models predict interesting signatures
 - RPV: resonances, multi-jet, multi-lepton
 - LL: displaced vertex, non-pointing photons, disappearing tracks, SMP
- □ These analyses can require unusual reconstruction techniques
 - Low E_{T} , time of flight measurements, non-pointing photon identification...
 - Challenging to perform!
- No evidence of SUSY observed as of yet
- 20fb⁻¹ of new 8TeV data allows significant increases in exclusion limits over previous searches
 - Most analyses on 8TeV data not yet finished, watch for updates

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: March 26, 2013)

1

	MSUGRA/CMSSM : 0 lep + i's + E_{-}	(=58.6b ⁻¹ .8.TeV IATLAS-CONF-2012-199)	
	MSUGRA/CMSSM : 1 lep + i's + E_{-}	$1 = 56.6^{-1}$ a TeV (AT) AS CONF-2012-1041 124 TeV $\alpha = 0$ mass	
10	Pheno model : 0 lep + i's + E_{-}	$\frac{1}{158} \frac{1}{100} \frac{1}$	ATLAS
Jes	Pheno model : 0 lep + i's + $E_{T,miss}$	$\frac{1}{2} = 56 \text{ fm}^{-1} \text{ fm} $	Preliminary
1cz	Gluipo med $\widetilde{\alpha}^{\pm}$ ($\widetilde{\alpha}_{\sigma}$ d $\widetilde{\alpha}^{\pm}$): 1 lep + i's + E		i rommary
69	CMSR (INISP) : 2 lop (OS) + i's + E	$ = \frac{1}{2} = \frac$	
0	GMSB (τ NLSP) : 1-2 τ + 1's + E	L=207 ft ⁻¹ 8 Tay (1201 1314) 1 4 4 Tay (1 m 285 (tang > 18)	
Siv	GGM (bino NLSP) : $\gamma\gamma + E^{T,miss}$	$L = 4.6 h^{-3} / 7.6 V [1200.0753]$ 107 $L = 7.6 V (200.0753)$ 107 $L = 7.6 V (200.0753)$	
slu	GGM (wino NLSP) : γ + lep + $E^{T, miss}$	$L = 4.65^{-1} \text{ Toylatt Ascone 2012-144} $ $E19 \text{ Gay ass} \qquad Ldt = (4.1)^{-1} \text{ Cover 2012-144} $	4 - 20.7) fb⁻¹
Inc	GGM (higgsino-bino NLSP) : $\gamma + b + E^{T, miss}$		
	GGM (higgsing NLSP) : $7 \pm \text{iets} \pm F_{-}^{T,\text{miss}}$	$L \to 516^{-1}$ For (1211-1107) 500 500 (1212-1107) 500 500 (1012-1102) (1012-	s = 7, 8 TeV
	Gravitino LSP : 'monoiet' + E_{-}	$E = 0.5 \text{ fb}^{-1}$ structure scone-solizing $e^{-1/2}$ structure $e^$	
	$\overline{a}_{\mathcal{F}} = b\overline{a}_{\mathcal{F}}^{\mathcal{O}} : 0 \text{ log } + 2 \text{ b is } + \overline{F}$		
en. tec	$g \notin DD\chi$. 0 lep + 3 D-JS + $E_{T,miss}$		ll 2012 data
l ge luir dia	$g \notin tt_{\overline{x}^0}$: 0 lop + multi-i's + E		
3rc gi	$g \notin t \chi^0$: 0 lop + 3 b is + E		artial 2012 data
	$g \notin t(\chi_1, 0) = 0 + 3 b - 1 s + L_{T,miss}$	L_{1220} (b), o toty (ALAG-GOM-22012-145) Let a toty (ALAG-GOM-22012-145) L_{1220} (b), o toty (ALAG-GOM-	II 2011 data
0 0	$\sum_{n=1}^{\infty} DD, D \notin DY$. $O = P + 2 - D - Jets + E_{T,miss}$	$L = 12.6 \text{ H}_{2} = 00 \text{ (m}(\chi_{1}) < 120 \text{ GeV}) \qquad 1160, \text{ and } 120 \text{ GeV} \qquad 1160, \text{ and } 120 \text{ GeV} \qquad 1160, \text{ and } 1160, an$	II ZUTT Uala
ior	$DD, D \notin T$. 233-lep + (0-3D-)]S + E T, miss	$\frac{1}{430} \frac{1}{60} \frac{1}{60} \frac{1}{100} \frac{1}{1$	
nct	tt (light), t \notin D_{χ}^{\pm} . 1/2 lep (+ D-jet) + $L_{T,miss}$	$\frac{1}{2} = \frac{1}{2} + \frac{1}{2} = \frac{1}{2} + \frac{1}{2} = \frac{1}$	
sq	tt (medium), $t \notin b \chi_1$, the p + b-jet + $E_{T,miss}$	$\frac{1}{100410} \frac{1}{60} \frac{1}{100410} \frac{1}{60} \frac{1}{100410} \frac{1}{100410} \frac{1}{100410} \frac{1}{100400} \frac{1}{100400} \frac{1}{100400} \frac{1}{100400} \frac{1}{100400} \frac{1}{1004000} \frac{1}{100400000000000000000000000000000000$	
pn.	\widetilde{tt} (heavy) \widetilde{t}_{\neq} $\widetilde{ts}_{\circ}^{\circ}$ \cdot 1 lop + b int + E	$[100-440 \text{ GeV} (17)] = 0 \text{ GeV}, m(\chi_1) = 0 \text{ GeV}, m(\chi_1) = 0 \text{ GeV}, m(\chi_1) = 10 $	
ge	$\underset{T}{\overset{r}}$	$L = 20.7 \text{ tr} (8 \text{ tev} (\text{ALAS-CONF-2013-037}))$ 200-501 GeV $L = 1000 \text{ tr} (700 \text{ cm}^2) = 0$	
3rd Jire	It (neavy), $l \notin l\chi$: 0 lep + 6(2D-)Jets + E _{T,miss}	$L=20.5 \text{ tr}$; 8 lev (ALAS-COM-2013)224] 320-560 GeV [THOS5] $(m(\chi_1)=0)$	
., 0	$t \in T$, miss	L=20.7 to , 8 lev (A1LAS-CON-2013/025) 500 GeV (11:055 (m(2,1) > 150 GeV)	
	$l_2 l_2, l_2 \neq l_1 + Z \cdot Z (\neq II) + T Iep + D - jel + Z = T, miss$	$L=20.7 \text{ fb}^{\circ}, 8 \text{ TeV} \text{ [ATLAS-CONF-2013-025]} \qquad 520 \text{ GeV} L_2 \text{ [IIASS} \qquad (m(t_1) = m(\chi_1) + 180 \text{ GeV})$	
8378	Γ_{L} Γ_{L	$L = 4.7 \text{ tb}^{-1}$, 7 lev [1208.2884] 85-195 GeV 1111dSS $(m_{\pi}^{+}, \gamma) = 0$	
Nect	$\chi_{1}\chi_{2}, \chi_{2} \notin \mathbb{N}(\mathbb{N}): \mathbb{Z} = \mathbb{P} + \mathbb{E}_{T, \text{miss}}$	$L=4.7 \text{ tb} \cdot 7 \text{ leg [1208.2884]} \qquad 110-340 \text{ GeV } \chi \cdot 11 \text{ loss} \qquad (m(\chi_1)<10 \text{ GeV}, m((\chi_1)=m(\chi_1)) + m(\chi_1))$	
din E	$\approx^{\pm}\approx^{0}$ \neq 1×1 1 1 1 1 1 1 1 1 1	$L=20.7 \text{ tb}; 8 \text{ tev} [\text{A1LAS-CON-2013}028] \qquad 180-330 \text{ Gev} \chi_1 \text{ intacs} \qquad (m(\chi_1) < 10 \text{ Gev}, m(\chi_1) = \frac{m(\chi_1)}{m(\chi_1) + m(\chi_1)})$	
-	$\chi_1 \chi_2 \not\in L^{T,miss}$	L=20.7 fb ⁺ , 8 TeV [ATLAS-CONF-2013/035] 6000 GeV χ_1 [IIIIdSS $(m(\chi_1) = m(\chi_2), m(\chi_1) = 0, m(i_X)$ as above)	
	$\chi \chi \notin W^{-1}\chi \angle \chi : 3 \text{ lep } + E_{\tau \text{ mise}}$	L=20.7 fb ⁻ , 8 TeV [ATLAS-CONF-2013-035] 315 GeV χ , ITIASS ($m(\chi_{\chi}) = m(\chi_{\chi_{\chi}}), m(\chi_{\chi}) = 0$, sleptons decoupled)	
s	Direct χ_1 pair prod. (AMSB) : long-lived χ_1	$L = 4.7 \text{ fb}^2, 7 \text{ fb}^2 [1210.2852]$ 220 GeV χ_1 [IIIASS $(1 < \tau(\chi_1) < 10 \text{ ns})$	
-liva cle	Stable g, R-nadrons : low β , $\beta\gamma$	2=4.7 tb ', / lev [1211.159/] 985 GeV 9 (11355	
ng-	GIVISB, stable τ : low β	L=4.7 fb ⁻⁷ , 7 TeV [1211.1597] 300 GeV t THASS (5 < tan) < 20)	
Гo	GMSB, $\chi \notin \gamma G$: non-pointing photons	L=4.7 fb ⁻¹ , 7 TeV [ATLAS-CONF-2013-016] 230 GeV χ_1 ITIASS (0.4 < $\tau(\chi_1)$ < 2 ns)	
	$\chi \notin qq\mu (RPV) : \mu + neavy displaced vertex$	L=4.4 fb ⁻¹ , 7 TeV [1210.7451] 700 GeV Q (IIIASS (1 mm < ct < 1 m, g decoupled)	
	LFV : $pp \notin v_\tau + X, v_\tau \notin e + \mu$ resonance	L=4.6 fb ⁻⁷ , 7 TeV [1212.1272] 1.61 TeV ∇_{τ} (Hass $(\lambda_{341}^2=0.10, \lambda_{142}^2=0.05)$	
	LFV: $pp \notin v_{\tau} + X, v_{\tau} \notin e(\mu) + \tau$ resonance	L=4.6 fb ⁻¹ , 7 TeV [1212.1272] 1.10 TeV v_z mass $(\lambda_{311}^2 = 0.0, \lambda_{1(2)33}^2 = 0.05)$	
>	Billnear RPV CIVISSIM: 1 lep + 7 J's + $E_{T,miss}$	L=4.7 fb ⁻¹ , 7 TeV [ATLAS-CONF-2012-140] $1.2 \text{ TeV} = g \text{ mass} (c_{T_{LSP}} < 1 \text{ mm})$	
RP	$\chi_1 \chi_1, \chi_1 \notin W \chi_1, \chi_1 \notin e v_{\mu}, e \mu v_{\mu}: 4 \text{ lep } + E_{T, \text{miss}}$	L=20.7 fb ⁻ , 8 TeV [ATLAS-CONF-2013-036] 760 GeV $\chi_1 \max_{1,2}^{-1} (m(\tilde{\chi}_1) > 300 \text{ GeV}, \chi_{121} > 0)$	
	$\chi_1 \chi_1,, \chi_1 \notin \tau \tau v_e, e \tau v_\tau : 3 \text{ lep } + 1 \tau + E_{T, \text{miss}}$	L=20.7 fb ⁻ , 8 TeV [ATLAS-CONF-2013-036] 350 GeV χ_1 [MASS $\sim (m(\chi_1) > 80 \text{ GeV}, \lambda_{133} > 0)$	
	$g \notin qqq: 3$ -jet resonance pair	L=4.6 fb ⁻¹ , 7 TeV [1210.4813] 666 GeV g mass	
	$g \notin tt, t \notin bs : 2 SS-lep + (U-3b-)Js + E_{T,miss}$	L=20.7 fb ⁻ ', 8 TeV [ATLAS-CONF-2013-007] 880 GeV g mass (any m(t))	
10/10	Scalar gluon : 2-jet resonance pair	L=4.6 fb ⁻¹ , 7 TeV [1210.4826] 100-287 GeV SGIUON MASS (incl. limit from 1110.2693)	
VVII	T,miss	L=10.5 fb ⁻ , 8 TeV [ATLAS-CONF-2012-147] 704 GeV M [*] SCale (m _{\chi} < 80 GeV, limit of < 687 GeV for D8)	

10⁻¹

10 Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.



SUSY search in events with 4 or more leptons

1.

Main backgrounds processes:

Sample	SR0noZa	SR0noZb	SR1noZ	SR0Z	SR1Z
ZZ	0.6 ± 0.5	0.50 ± 0.26	0.19 ± 0.05	1.2 ± 0.4	0.49 ± 0.10
ZWW	0.12 ± 0.12	0.08 ± 0.08	0.05 ± 0.05	0.6 ± 0.6	0.13 ± 0.13
tīZ	0.73 ± 0.34	0.75 ± 0.35	0.16 ± 0.12	2.3 ± 0.9	0.29 ± 0.24
Higgs	0.26 ± 0.07	0.22 ± 0.07	0.23 ± 0.06	0.58 ± 0.15	0.14 ± 0.05
Irreducible Bkg.	1.7 ± 0.8	1.6 ± 0.6	0.62 ± 0.21	4.8 ± 1.8	1.1 ± 0.4
Reducible Bkg.	$0^{+0.16}_{-0}$	$0.05\substack{+0.14 \\ -0.05}$	1.4 ± 1.3	$0^{+0.14}_{-0}$	$0.3^{+1.0}_{-0.3}$
Total Bkg.	1.7 ± 0.8	1.6 ± 0.6	2.0 ± 1.3	4.8 ± 1.8	$1.3^{+1.0}_{-0.5}$
Data	2	1	4	8	3
p_0 -value	0.29	0.5	0.15	0.08	0.13
N _{signal} Excluded (exp)	3.9	3.6	5.3	6.7	4.5
N _{signal} Excluded (obs)	4.7	3.7	7.5	10.4	6.5
$\sigma_{\mathrm{visible}}$ Excluded (exp) [fb]	0.19	0.17	0.26	0.32	0.22
$\sigma_{ m visible}$ Excluded (obs) [fb]	0.23	0.18	0.36	0.50	0.31

SUSY search in events with 4 or more leptons

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SUSY search in events with 4 or more leptons

21



ATLAS-CONF-2013-036

SUSY search in events with 4 or more leptons

22



Heavy narrow resonance decaying to $e\mu$, $e\tau$, $\mu\tau$

Main Background Processes:

		$m_{\ell\ell'} < 200 { m ~GeV}$	V	$m_{\ell\ell'} > 200 { m ~GeV}$			
Process	$N_{e\mu}$	$N_{e au_{ m had}}$	$N_{\mu au_{ m had}}$	$N_{e\mu}$	$N_{e au_{ m had}}$	$N_{\mu au_{ m had}}$	
$Z/\gamma^* \to \tau \tau$	1880 ± 150	4300 ± 600	5300 ± 600	8 ± 1	24 ± 3	28 ± 4	
$Z/\gamma^* \to ee$		1050 ± 80			44 ± 3		
$Z/\gamma^* ightarrow \mu \mu$			3030 ± 290			29 ± 3	
$t\overline{t}$	760 ± 110	96 ± 18	94 ± 14	251 ± 30	90 ± 15	70 ± 13	
Diboson	260 ± 27	57 ± 8	60 ± 7	71 ± 8	26 ± 3	24 ± 3	
Single top quark	87 ± 8	11 ± 2	9 ± 1	39 ± 4	10 ± 2	8 ± 1	
W+jets	420 ± 260	3500 ± 700	3200 ± 600	90 ± 40	370 ± 80	470 ± 110	
$\operatorname{multijet}$	37 ± 13	2200 ± 700	730 ± 230	6 ± 2	150 ± 50	24 ± 18	
Total							
background	3440 ± 300	11200 ± 900	12400 ± 800	460 ± 60	720 ± 80	650 ± 90	
Data	3345	11212	12285	498	795	699	

Heavy narrow resonance decaying to $e\mu$, $e\tau$, $\mu\tau$



Heavy narrow resonance decaying to $e\mu$, $e\tau$, $\mu\tau$



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Sgluon Mass [GeV]	$p_{\mathrm{T}}^{\mathrm{min}}$ [GeV]	Data	ABCD prediction	Shape p -value(A,B)
150	80	102162	$101100 \pm 800 \pm 2000$	0.22
200	90	55194	$54500 \pm 600 \pm 1100$	0.10
250	105	23404	$22500 \pm 340 \pm 500$	0.28
300	120	11082	$10640 \pm 230 \pm 210$	0.24
350	135	5571	$5330\pm180\pm110$	0.70



5.

Resolved Analysis



Model $(m_{\tilde{g}})$	$p_{\mathrm{T,min}}^{\mathrm{6th-jet}}$	Data	Background	Signal bias [%]	Signal
$100 { m ~GeV}$	$80 { m GeV}$	23600	23500 ± 2800	8.5	99200 ± 20000
$200~{\rm GeV}$	$120 { m GeV}$	856	851 ± 140	3.7	2700 ± 500
$300~{\rm GeV}$	$120 { m GeV}$	856	851 ± 140	1.0	1460 ± 240
$400~{\rm GeV}$	$160 { m GeV}$	57	62 ± 13	0.8	110 ± 13
$500~{\rm GeV}$	$160 { m GeV}$	57	62 ± 13	0.3	67 ± 9
$600~{\rm GeV}$	$160~{\rm GeV}$	57	62 ± 13	0.1	43 ± 7
$800~{\rm GeV}$	$160~{\rm GeV}$	57	62 ± 13	0.0	20 ± 3

Boosted Analysis:

Main decay products form large-R jet, other jets offshoot

Selection	Baseline Selection	SR1	SR2
Small- R ($R = 0.4$) jet $p_{\rm T}^{\rm jet}$	$p_{\rm T}^{\rm jet} > 30 { m ~GeV}$	$p_{\rm T}^{\rm jet} > 30~{ m GeV}$	$p_{\rm T}^{\rm jet} > 30 { m ~GeV}$
Large- $R \ (R = 1.0)$ jet $p_{\rm T}^{\rm jet}$	$p_{\rm T}^{ m jet} > 200~{ m GeV}$	$p_{\rm T}^{\rm jet} > 200~{ m GeV}$	$p_{\rm T}^{ m jet} > 350~{ m GeV}$
Scalar sum $\sum_{i=1}^{N_{\text{jet}}^{R4}=4} p_{\text{T}}^{\text{jet}}$	(—)	$600 {\rm GeV}$	(—)
Small- R jet multiplicity	(—)	$N_{ m jet}^{R4} \ge 4$	$N_{ m jet}^{R4} \ge 4$
Large- R jet multiplicity	$N_{ m jet} \geq 2$	$N_{ m jet} \geq 2$	$N_{ m jet} \geq 2$
Large- R jet mass	(—)	$m_{J_1,J_2}^{\text{jet}} > 60 \text{ GeV}$	$m_{J_1,J_2}^{\text{jet}} > 140 \text{ GeV}$
Large- R jet τ_{32}	(—)	$ au_{32} < 0.7$	$ au_{32} < 0.7$

(M_{threshold} used in control region)

Model $(m_{\tilde{g}})$	$M_{\rm threshold}$	Data	Background	Signal Bias [%]	Signal
$100 {\rm GeV}$	$60 {\rm GeV}$	40683	42400 ± 9700	65	77900 ± 16000
$200 {\rm GeV}$	$140~{\rm GeV}$	1059	860 ± 460	31	2400 ± 670
$300 {\rm GeV}$	$140~{\rm GeV}$	1059	860 ± 460	9	590 ± 55

5.

Acceptances and Exclusions:





Model (mr)	Theory [ph]	Theory [ph]	Acceptance (%)		
Model $(m_{\tilde{g}})$	σ_{\min} [pb]	$\sigma_{\rm max}$ [pb]	Resolved	Boosted	
$100 { m ~GeV}$	18700	25400	0.098	0.077	
$200~{\rm GeV}$	584	790	0.094	0.070	
$300~{\rm GeV}$	57.6	77.9	0.451	0.182	
$400~{\rm GeV}$	9.61	13.0	0.210	_	
$500~{\rm GeV}$	2.13	3.01	0.565	_	
$600~{\rm GeV}$	0.574	0.843	1.30	_	
$800 {\rm GeV}$	0.0572	0.0913	5.73	_	

Displaced vertex with multi-tracks and muon

6.

Re-tracking:

- Recover tracks lost through standard reconstruction by re-running SCT/Pixel seeded tracking algorithms with looser requirements on r_{DW} z_{DV} and n hits allowed to be shared between tracks.
- Reduce false track rate by applying: p₁>1GeV (up from 0.4GeV)



Non-pointing photons

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□ Acceptance:

τ		Λ (TeV)	
(ns)	80	120	160
0.25	15.3 ± 0.3	29.6 ± 0.3	45.1 ± 0.3
1	11.1 ± 0.1	27.0 ± 0.2	35.9 ± 0.3
6	2.01 ± 0.02	5.38 ± 0.02	8.06 ± 0.06
20	0.39 ± 0.01	1.006 ± 0.005	1.43 ± 0.01
40	0.175 ± 0.005	0.384 ± 0.002	0.510 ± 0.004
80	0.090 ± 0.004	0.164 ± 0.001	0.196 ± 0.002

□ Observed events:

Fit	Event		Range of $ z_{DCA} $ values [mm]							
Туре	Туре	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100 - 200	200 - 400	400 - 600	> 600
-	Data	27	7	4	1	1	3	2	0	1
Bkg Only	Bkg	25.0±2.2	9.1±0.8	3.8±0.3	2.1±0.5	1.4±0.4	3.0±1.1	1.3±0.5	0.2±0.1	0.08 ± 0.03
Signal	Total	25.1±4.2	9.3±1.5	3.3±0.7	1.6±0.6	1.1±0.4	2.6±1.0	1.8±0.8	0.7±0.5	0.5±0.4
Plus	Sig	0.7±0.6	0.5±0.5	0.4±0.3	0.3±0.3	0.3±0.3	1.2±1.1	1.3±1.2	0.6±0.5	0.4±0.4
Bkg	Bkg	24.4±4.2	8.8±1.5	2.9±0.8	1.3±0.7	0.8±0.6	1.4±1.5	0.5±0.7	0.1±0.1	0.03 ± 0.04

Signal is for $\Lambda = 120$ TeV, $\tau = 6$ ns

Direct chargino production based on disappearing track signature

arxiv:1210.2852v2

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\Box Candidate track p_T :



Observed events:

Requirement	Observed	Signal events	(efficiency [%])
		$m_{\tilde{\chi}_1^{\pm}} = 100 \text{ GeV}$	$m_{\tilde{\chi}_1^{\pm}} = 200 \text{ GeV}$
Quality requirements and trigger	3765627	1983(3.0)	283.3(6.7)
Non-collision background rejection	2899498	1958(3.0)	279.6(6.6)
Lepton veto	2186581	1906(2.9)	274.8(6.5)
Leading jet $p_{\rm T} > 90 \text{ GeV}$	2054262	1497(2.3)	237.7(5.6)
$E_{\rm T}^{\rm miss} > 90 {\rm GeV}$	1233864	1420 (2.2)	230.2(5.5)
$\Delta \phi_{\min}^{\text{jet}-E_{\text{T}}^{\text{miss}}} > 1.5 \text{ rad}$	1191298	1402(2.1)	227.4(5.4)
High- $p_{\rm T}$ isolated track selection	18493	90.5(0.14)	9.1 (0.26)
Disappearing-track selection	710	42.9(0.066)	4.1 (0.12)

9.

□ Slepton:

- Particle β measurement
- **\square** Require 2 candidates with $\beta < 0.95$
- Plot candidate with lower mass:





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9.

High dE/dx deposition characteristic of LLPs:
 Measure in ID pixel detector and calorimeter



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Rhadron:

Particle β and d*E*/dx measurements across detector:

