SUSY searches in multi-lepton final states

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IOP HEPP meeting, University of Liverpool

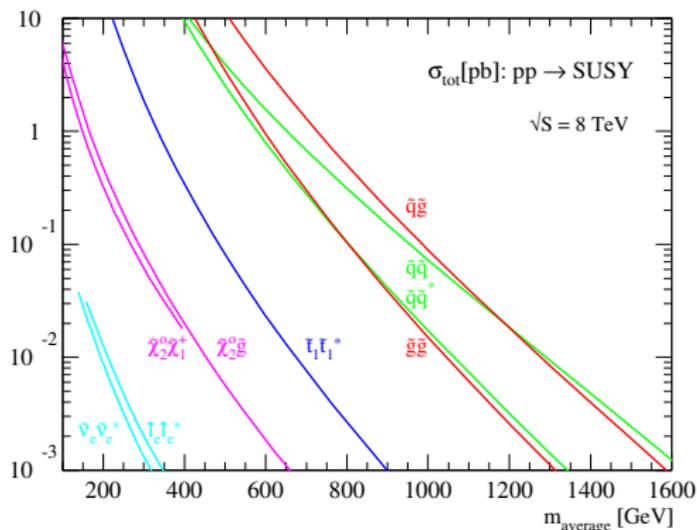9th April 2013

Introduction

- Present search for weakly produced SUSY particles (gauginos)
- Multileptons: ($= 3$) leptons ($\ell = e/\mu$)
    - Weak production $\rightarrow$ low number of jets
    - R-parity conserving models: missing energy
- Full 2012 ATLAS dataset ($\sqrt{s} = 8$ TeV, 20.7 fb^{-1}) analysed
- Results interpreted in models of weak gaugino production
- Details: ATLAS-CONF-2013-35

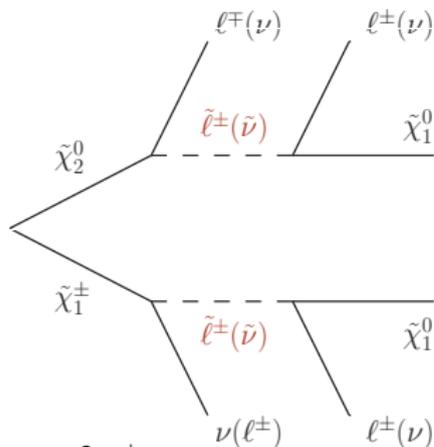# Gaugino searches: motivation

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- Gauginos = linear combination of higgsinos, winos and binos
  - Charginos ($\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm$) or neutralinos ($\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$)
- Limits on coloured SUSY particle ($\tilde{q}$, $\tilde{g}$) masses **much higher** than on uncoloured SUSY particles (sleptons, gauginos)

- Weak production of gauginos and sleptons could dominate at LHC
- Search for events with multiple leptons, missing energy and few jets
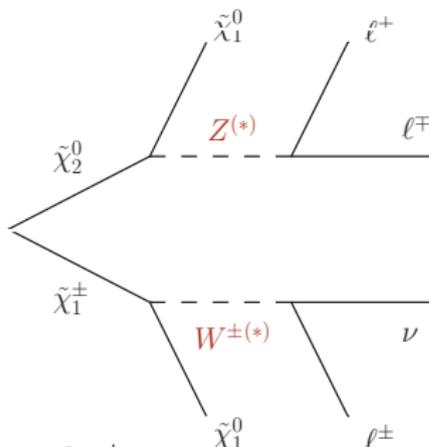
Simplified models

- ▶ Simulate a single process/diagram
- ▶ Simplified phenomenology (set most particle masses to > 1 TeV: effective theory)

- ▶ Reasonable assumptions about branching ratios
- ▶ Can translate into realistic model results
- ▶ Used for all results shown here

$$qq' \to \tilde{\chi}^0_2 \tilde{\chi}^\pm_1 \to 3\ell + \not{E}_T$$

1) $\tilde{\chi}^0_2 \tilde{\chi}^\pm_1$ decay via $\tilde{\ell}/\tilde{\nu}$ **2)** $\tilde{\chi}^0_2 \tilde{\chi}^\pm_1$ decay via W/Z

- ▶ Simplified models **1** and **2** have different kinematics
- ▶ Distinct background compositions
- ▶ Different signal regions required

3 lepton signal regions (SRs)

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
$m_{\ell\ell}$ [GeV]	<60	60–81.2,	Z veto		Z request	
$\not{E}_T$ [GeV]	>50	>75	>75	75–120	75–120	>120
m_T [GeV]	–	–	>110	<110	>110	>110
p_T $3^{\rm rd}$ ℓ [GeV]	>10	>10	>30	>10	>10	>10
SR veto	SRnoZc	SRnoZc	–	–	–	–
Main target	$\tilde{\ell}$	WZ^*	$\tilde{\ell}$		WZ	

- ▸ Different signal regions target distinct gaugino decays
  - ▸ Via sleptons/WZ
  - ▸ Low/high mass differences
- ▸ Z request = $m_{\ell\ell} \pm 10$ GeV from Z mass
- ▸ Signal regions do not overlap: all statistically combined for final interpretation

3 lepton analysis background estimation

Matrix method

- ► Data made up of "**real**" (**R**) leptons (Z/γ^*, SUSY decays) and "**fake**" (**F**) leptons (conversions, light and heavy flavour decays): $N(R, F)$

- ► Only observe "**tight**" (**T**: high efficiency, low purity) and "**loose**" (**L**: low efficiency, high purity) leptons: $N(T, L)$
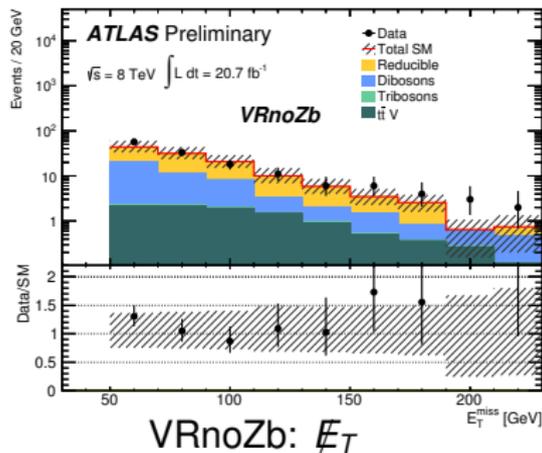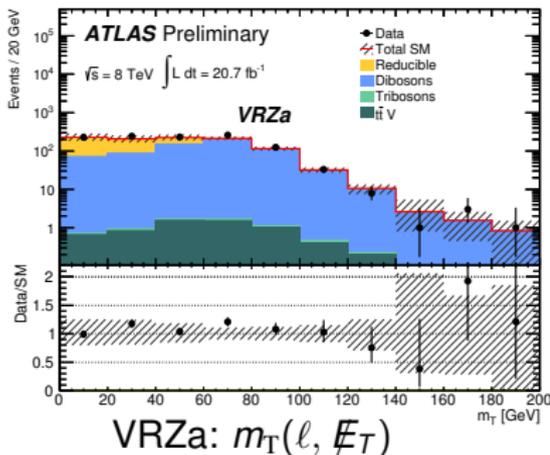
$$N(L, T) = \mathbf{M} \; N(R, F)$$
$$\rightarrow N(R, F) = \mathbf{M}^{-1} N(T, L)$$

- ► $\mathbf{M}(\epsilon, \mathbf{f})$ = matrix of lepton efficiencies and mis-identification rates

- ► Control regions used to measure terms in **M**
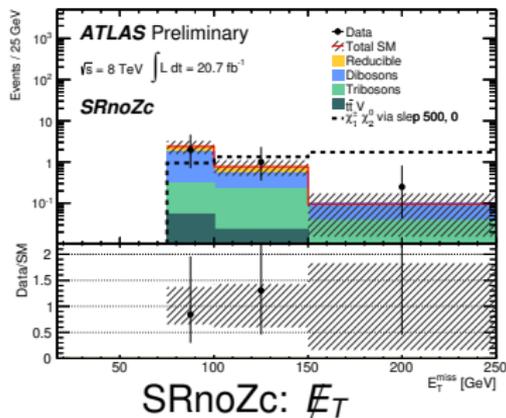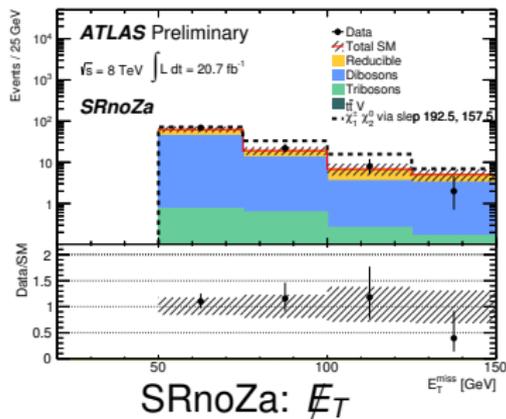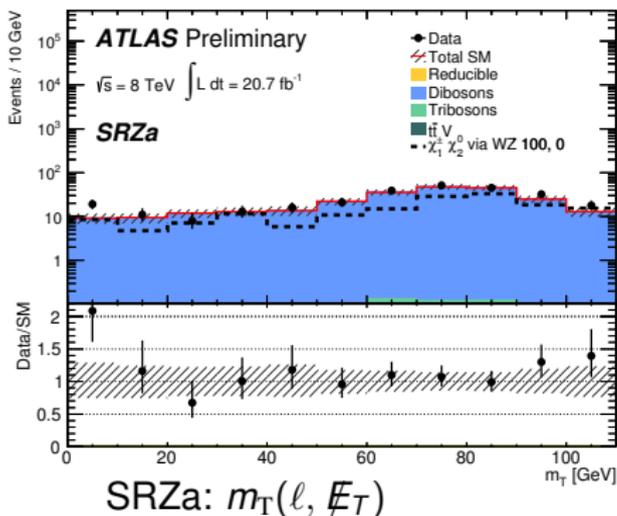
3 lepton analysis background estimation

- Irreducible backgrounds = ≥ 3 "**real**" leptons → MC prediction

- Reducible backgrounds = ≤ 2 "**real**" leptons → matrix method estimation

- Background validation regions (VRs) formed by reversing signal region cuts
  - VRZ/noZa: $\not{E}_T < 50$ GeV
  - VRZ/noZb: $\not{E}_T > 50$ GeV, require ≥ 1 *b*-jet

VRZa: $m_T(\ell, \not{E}_T)$

VRnoZb: $\not{E}_T$

3 lepton analysis results

- ▶ Distributions in signal regions
  - ▶ Others in backup
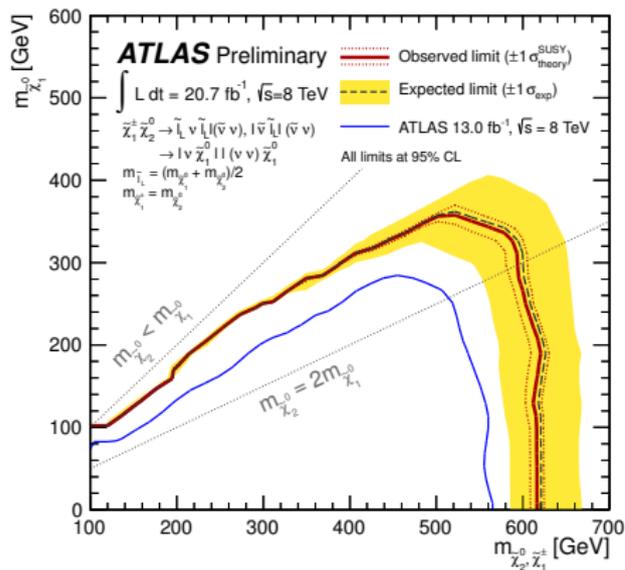- ▶ Excellent agreement between data and background prediction

SRnoZa: $\not{E}_T$

SRZa: $m_T(\ell, \not{E}_T)$

SRnoZc: $\not{E}_T$

3 lepton analysis results

- $\sqrt{s} = 8$ TeV, 20.7 fb^{-1}

- $\sigma_{\mathrm{visible}}$ = Upper limit on $\sigma \times$ acceptance $\times$ efficiency at 95% confidence level

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	**96 ± 19**	**29 ± 6**	**4.4 ± 1.8**	**249 ± 35**	**22 ± 5**	**6.3 ± 1.5**
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5
$\sigma_{\mathrm{visible}}$ excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
$\sigma_{\mathrm{visible}}$ excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31

3 lepton analysis results

- Simplified models of chargino-neutralino ($\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$) production
- Limits significantly extend previous results (blue)

Intermediate decay through sleptons/sneutrinos
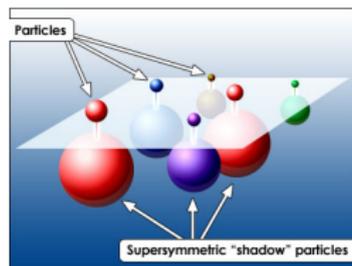
Intermediate decay through W and Z bosons

Conclusions

- 20.7 fb^{-1} of 8 TeV *pp* data (full 2012 dataset) analysed in 3 lepton final state
- No significant excess observed
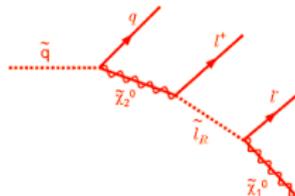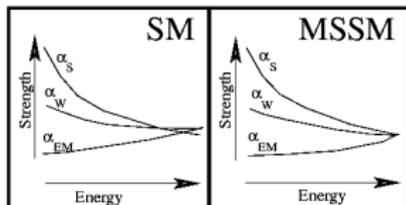- Limits set in simplified models of gaugino production

More information:

- Search for weak gaugino production
  - ATLAS-CONF-2013-35

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- Supersymmetry
- m_{eff}, m_T
- Matrix method details
- Full results in validation regions
- Extra distributions in signal regions

Supersymmetry

- Symmetry between fermions and bosons
    - Entirely new spectrum of "superpartners"
    - Solution to hierarchy problem
    - Dark matter candidate (lightest supersymmetric particle (LSP) stable, weakly interacting)
    - Unification of gauge couplings at GUT scale

- Phenomenology
    - "Cascade" decays → multiple jets and leptons
    - Significant missing energy from LSP

m_{eff}, m_T

Transverse mass of 4-vectors L_1, L_2

- $m_T = 2\sqrt{p_T^{L_1} p_T^{L_2}(1 - \cos\phi(L_1, L_2)}$
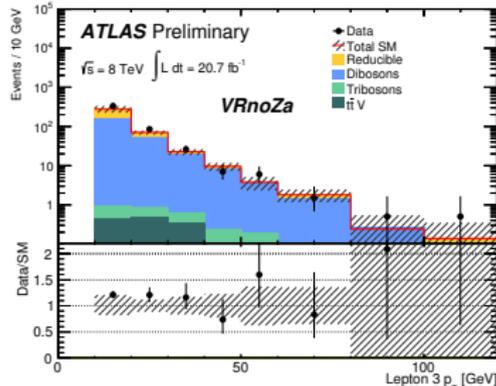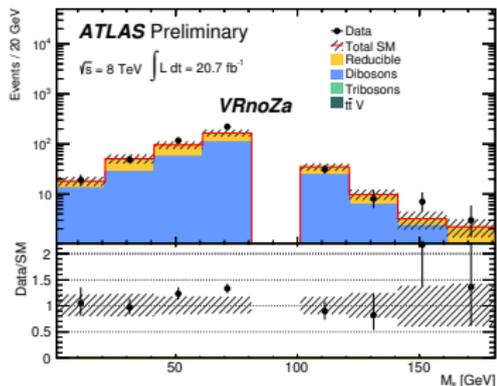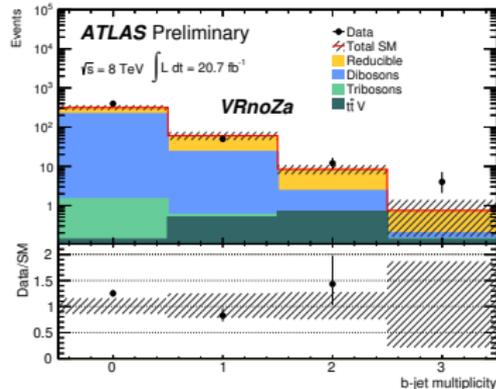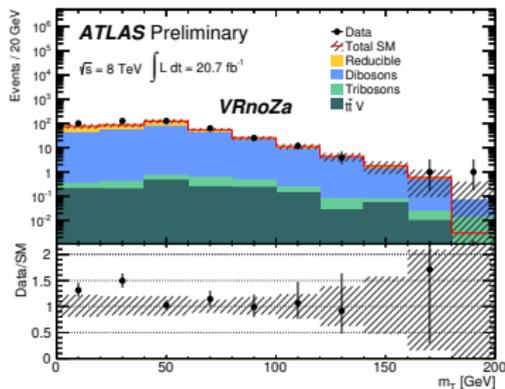 - Here, always referring to $m_T(\ell, \not{E}_T)$

Effective mass of an event

- $m_{\text{eff}} = \not{E}_T + \sum(p_T^{\text{lepton}} + p_T^{\text{jet}})$
- Jet p_T above 40 GeV, lepton p_T above 10 GeV
- Scalar sum

3 leptons: matrix method: extra details

- ► Highest p_T lepton is real in 99% of cases (from MC)
- ► Always treating it as real reduces matrix dimension from 8×8 to 4×4
- ► Final matrix equation:

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

Validation regions

Selection	VRnoZa	VRnoZb	VRZa	VRZb
m_{SFOS} [GeV]	<81.2 or >101.2	<81.2 or >101.2	81.2–101.2	81.2–101.2
b-jet	veto	request	veto	request
E_T [GeV]	35–50	>50	30–50	>50
Dominant process	WZ^*, Z^*Z^*, Z^*+jets	$t\bar{t}$	WZ, Z+jets	WZ

Selection	VRnoZa	VRnoZb	VRZa	VRZb
Tri-boson	1.4 ± 1.4	0.5 ± 0.5	0.6 ± 0.6	0.26 ± 0.26
ZZ	$(1.3 \pm 0.9) \times 10^2$	4.5 ± 2.8	108 ± 23	6.9 ± 2.2
$t\bar{t}V$	2.9 ± 1.2	21 ± 7	7.4 ± 2.6	26 ± 8
WZ	110 ± 21	34 ± 15	$(5.5 \pm 0.9) \times 10^2$	$(1.4 \pm 0.4) \times 10^2$
Σ SM irreducible	$(2.4 \pm 0.9) \times 10^2$	60 ± 16	$(6.6 \pm 0.9) \times 10^2$	$(1.7 \pm 0.4) \times 10^2$
SM reducible	$(1.5 \pm 0.6) \times 10^2$	$(0.7 \pm 0.4) \times 10^2$	$(3.8 \pm 1.4) \times 10^2$	27 ± 13
Σ SM	$(3.9 \pm 1.1) \times 10^2$	$(1.3 \pm 0.5) \times 10^2$	$(10.4 \pm 1.7) \times 10^2$	$(2.0 \pm 0.4) \times 10^2$
Data	463	141	1131	171

VRnoZa distributions

VRZa and VRZb distributions

VRnoZb distributions

E_T and m_T in SRnoZa,b,c