PROCEEDINGS OF SCIENCE

A search for supersymmetry in events containing a leptonically decaying Z boson, jets and missing transverse momentum in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector

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A search for supersymmetric particles in final states characterized by a leptonically decaying Z boson, missing transverse momentum and jets is presented. The analysis uses proton-proton collision data collected by the ATLAS detector at a center-of-mass energy $\sqrt{s} = 13$ TeV corresponding to a total integrated luminosity of 3.2 fb^{-1}. An excess of events above the Standard Model expectation, with a significance of 2.2σ, is observed.

Fourth Annual Large Hadron Collider Physics
13-18 June 2016
Lund, Sweden

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PoS(LHCP2016)232

1. Introduction

In R-parity-conserving supersymmetry (SUSY) models, gluinos and squarks can be pair-produced in strong interaction processes at the Large Hadron Collider (LHC). These SUSY particles will subsequently decay directly or via cascades into the Lightest SUSY Particle (LSP). The LSP is stable, only weakly interacting and escapes detection, producing substantial missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) in the final state.

In this analysis, SUSY-inspired simplified models are considered, where a Z boson is produced in the cascade decay of pair-produced squarks or gluinos. An example decay topology is illustrated in Figure 1. Signal events are characterized by two or more jets, large $E_{\mathrm{T}}^{\mathrm{miss}}$ and a Z boson in the final state. The analysis makes use of the 3.2 fb^{-1} of $\sqrt{s} = 13$ TeV data collected by the ATLAS detector [1] during 2015. A detailed description of the search is presented in Ref. [2].

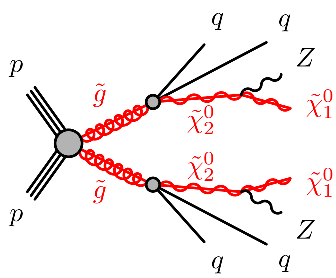

Figure 1: Decay topology for a simplified model considered in this search, involving gluino pair production, with the gluinos following an effective three-body decay for $\tilde{g} \to q\bar{q}\tilde{\chi}_2^0$, with $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$.

2. Analysis overview

Events considered in this analysis are required to contain at least two signal leptons forming a same-flavour opposite-sign pair (ee or $\mu\mu$) with an invariant mass compatible with the Z boson. The leading lepton must have a transverse momentum $p_{\mathrm{T}} > 50$ GeV and the subleading lepton $p_{\mathrm{T}} > 25$ GeV. At least two signal jets are required and the azimuthal opening angle between the two leading jets and the $E_{\mathrm{T}}^{\mathrm{miss}}$ is required to be larger than 0.4 in order to remove events with large $E_{\mathrm{T}}^{\mathrm{miss}}$ resulting from jet mismeasurements. The signal region, SRZ, is defined using requirements on $E_{\mathrm{T}}^{\mathrm{miss}}$ and $H_{\mathrm{T}} = \sum_i p_{\mathrm{T}}^{\mathrm{jet},i} + p_{\mathrm{T}}^{\mathrm{lep},1} + p_{\mathrm{T}}^{\mathrm{lep},2}$ (where lep,1 and lep,2 are the two leading leptons), motivated by SUSY signals with high gluino mass and high jet activity. Control regions (CRs) are defined to estimate the contributions from the Standard Model (SM) backgrounds in the signal region. These regions have similar selection criteria to the SRZ. Furthermore, several validation regions (VRs) are defined with lower $E_{\mathrm{T}}^{\mathrm{miss}}$ and H_{T} cuts in order to provide cross-checks on the background estimation procedures. The regions are listed in Table 1.

3. Background estimation

Several SM processes can result in signatures appearing like SUSY signals with two jets, $E_{\mathrm{T}}^{\mathrm{miss}}$ and two same-flavour opposite-sign leptons. The dominant background is comprised of the

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Table 1: Overview of signal, control and validation regions used in this search [2]. The flavour combination of the dilepton pair is denoted as either "SF" for same-flavour or "DF" for different flavour. In the case of VR-WZ, VR-ZZ and VR-3L the number of leptons is indicated.

Region	$E_{\mathrm{T}}^{\mathrm{miss}}$ **[GeV]**	H_{T} **[GeV]**	n_{jets}	$m_{\ell\ell}$ **[GeV]**	**SF/DF**	$\Delta\phi\left(\mathbf{jet}_{12}, p_{\mathrm{T}}^{\mathrm{miss}}\right)$
Signal regions						
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4
Control regions						
CR-FS	> 225	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4
Validation regions						
VRT	100–200	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4
VRS	100–200	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4
VR-FS	100–200	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4
VR-WZ	100–200	-	-	-	3ℓ	-
VR-ZZ	< 100	-	-	-	4ℓ	-
VR-3L	60–100	> 200	≥ 2	$81 < m_{\ell\ell} < 101$	3ℓ	> 0.4

so-called flavour-symmetric processes, $t\bar{t}$, WW, Wt and $Z \to \tau\tau$. These backgrounds are estimated using a data-driven method where a ratio of 1:1:2 for the ee, $\mu\mu$ and $e\mu$ dileptonic branching fractions is assumed. The yields in the ee and $\mu\mu$ channels are then estimated from data events in an $e\mu$ control sample, CR-FS, defined in Table 1. In order to account for triggering and reconstruction efficiency differences between electrons and muons, p_{T} and η dependent correction factors are applied to the $e\mu$ events. Furthermore, CR-FS has an expanded $m_{\ell\ell}$ window to increase statistics. The procedure is validated at lower $E_{\mathrm{T}}^{\mathrm{miss}}$ by applying the same method to VR-FS to estimate the flavour-symmetric contribution in VRS.

In order to cross-check the flavour-symmetry estimate, a profile likelihood fit of Monte Carlo (MC) to data is performed in the Z-mass sidebands and the result propagated to the signal region. The fit is performed in the region CRT, defined in Table 1, and then repeated for validation in VRT and propagated to VRS. The predictions in VRS and SRZ obtained from the flavour-symmetry method and the sideband fit are shown in Table 2 for comparison. Both methods result in consistent estimates in these regions.

Table 2: The predicted flavour-symmetric event yields in SRZ according to the nominal data-driven method using the $e\mu$ channel, compared with the prediction from the sideband fit of MC to data [2].

Region	Flavour-symmetry	Sideband fit
SRZ	5.1 ± 2.0	6.1 ± 1.7
VRS	18.9 ± 4.8	20.5 ± 5.6

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To enter the signal region, Z/γ^*+jets events require large $E_{\mathrm{T}}^{\mathrm{miss}}$ from instrumental effects or neutrinos from hadronic decays. Such events constitute a small but important background that peaks in the Z window. The background is estimated using a data-driven method with a control sample of γ+jets events. A smearing is applied to account for the difference in the photon and muon resolution and the γ+jets events are reweighted to match the p_{T} distribution of the Z/γ^*+jets events. Figure 2 shows a comparison of the full $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum in data and the Z/γ^*+jets background estimated via the γ+jets method.

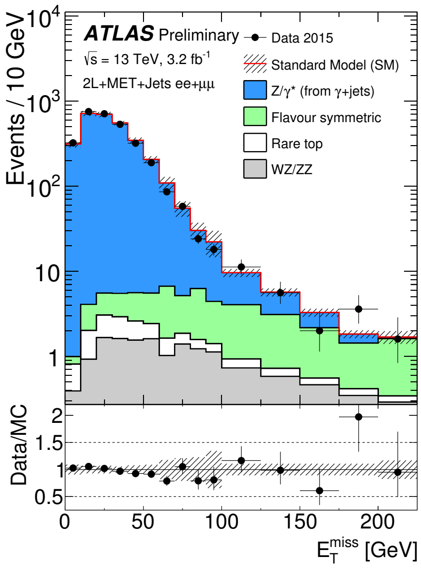

Figure 2: The $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum when the γ+jets method is applied to data [2]. Here the shapes of the backgrounds other than Z/γ^*+jets are taken from MC. The bottom panel shows the ratio of the observed data to the total background prediction.

Other background processes are WZ/ZZ diboson production and "rare top" including $t\bar{t}W$, $t\bar{t}Z$ and $t\bar{t}WW$ processes. These are estimated from MC and validated in dedicated validation regions. The expected background yields in VRS and the diboson validation regions are shown in Table 3. Good agreement can be seen in all regions.

Table 3: Expected and observed event yields in the four validation regions, VRS, VR-WZ, VR-ZZ, and VR-3L [2].

	VRS	VR-WZ	VR-ZZ	VR-3L
Observed events	56	89	20	7
Total expected background events	52.6 ± 9.1	87 ± 10	15.5 ± 3.4	6.5 ± 1.6
Flavour symmetric events ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$)	18.9 ± 4.8	1.3 ± 0.4	0	0.3 ± 0.2
WZ/ZZ events	7.5 ± 1.7	82 ± 10	15.5 ± 3.4	4.9 ± 1.6
Z/γ^*+jets events	24.8 ± 7.6	2.7 ± 2.8	0	0.2 ± 0.2
Rare top events	1.4 ± 0.2	0.9 ± 0.4	0.04 ± 0.02	1.0 ± 0.1

4. Results

A total of 21 events are observed in data compared to a predicted background of 10.3 ± 2.3. 10 events are observed in the ee channel and 11 events in the $\mu\mu$ channel. The significance of the result in SRZ corresponds to 2.2σ. Table 4 shows the expected and observed event yields in SRZ. The dilepton invariant mass distribution is shown over the full $m_{\ell\ell}$ range and in SRZ in Figure 3.

Table 4: Expected and observed event yields in SRZ [2].

Observed events	21
Total expected background events	10.3 ± 2.3
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	5.1 ± 2.0
WZ/ZZ events	2.9 ± 0.8
Z/γ^*+jets events	1.9 ± 0.8
Rare top events	0.4 ± 0.1

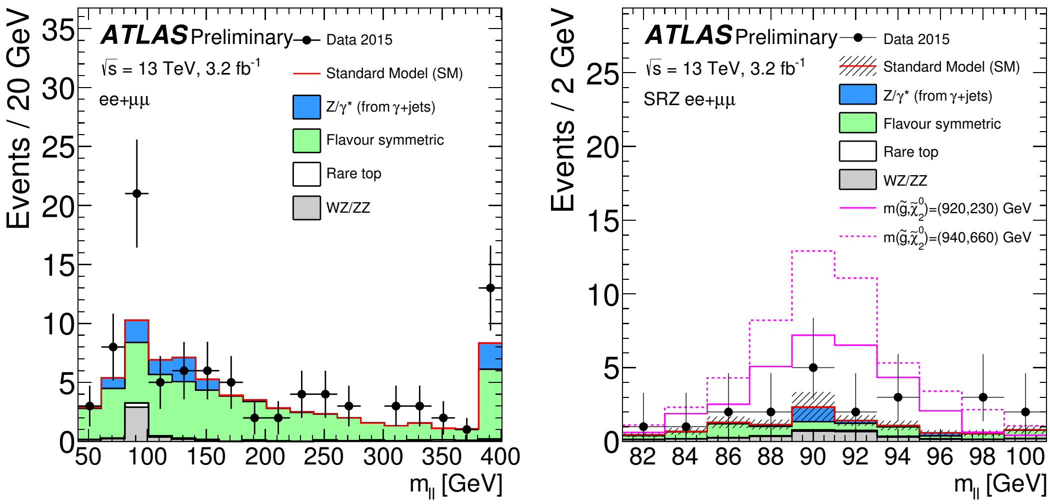

Figure 3: The dilepton invariant mass distribution over the full $m_{\ell\ell}$ range (left) and in SRZ with two example signal models overlaid (right) [2]. Here MC is used to show the expected shape of the $m_{\ell\ell}$ distributions, with the backgrounds being normalized according to their SRZ expectation.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the Large Hadron Collider*, JINST 3 (2008) S08003

[2] ATLAS Collaboration, *A search for supersymmetry in events containing a leptonically decaying Z boson, jets and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector*, ATLAS-CONF-2015-082, 2015, URL: https://cds.cern.ch/record/2114854