PROCEEDINGS OF SCIENCE

Search for gluinos and squarks in events with one isolated lepton, at least 2-9 jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector

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This document presents the results of a search for gluinos and squarks in events with exactly one lepton in the final state in addition to multiple jets and large missing transverse momentum. The ATLAS [1] data analysed was recorded in 2015 and 2016 and corresponds to an integrated luminosity of 36.1 fb^{-1} at a centre-of-mass energy of 13 TeV. In contrast to previous publications the latest results also contain a multijet channel, requiring at least 9 jets. To estimate the background in this regime a data-driven technique, based on the invariance of the transverse mass shape in events with different jet multiplicities, was developed. No significant excess was observed. The results are interpreted in a simplified model for two-step gluino decays and a subset of the phenomenological minimal supersymmetric standard model (pMSSM).

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1. Introduction

Supersymmetry (SUSY) predicts the existence of supersymmetric partners for the standard model particles. If it can provide a solution to the hierarchy problem, superpartners around the TeV scale may appear at the LHC. The superpartners of the quarks, the squarks, and the superpartners of the gluons, the gluinos, could decay via the emission of multiple jets. Final states with exactly one lepton (electron or muon) give a distinct signature against the standard model multijet production. If R-parity is conserved, the lightest supersymmetric particle (LSP) is stable and can leave the detector without interaction, leading to a signature with large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$). In this analysis the LSP is assumed to be the lightest neutralino ($\tilde{\chi}_1^0$).

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2. Discriminating variables

The analysis presented here [2] was optimised to search for decays of gluinos ($\tilde{g}$) and squarks ($\tilde{q}$) in events with exactly one lepton, jets and missing transverse momentum $\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}$ (absolute value denoted as $E_{\mathrm{T}}^{\mathrm{miss}}$). Transverse momentum vectors are denoted by $\boldsymbol{p}_{\mathrm{T}}$.

The *transverse mass* of the lepton and the missing transverse momentum separates well against backgrounds where the lepton and missing transverse momentum originate from a leptonic W boson decay, and thus have kinematic endpoint at the W boson mass,

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos[\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])},$$

The *effective mass* of the lepton, jets and the missing transverse momentum tends to be large for the decay of massive particles—independent of the precise structure of the decay,

$$m_{\mathrm{eff}} = p_{\mathrm{T}}^{\ell} + \sum_{i=1}^{N_{\mathrm{jet}}} p_{\mathrm{T}}^{\mathrm{jet},i} + E_{\mathrm{T}}^{\mathrm{miss}}.$$

The *aplanarity* of the lepton and jets can separate a signal with large number of high momentum final state particles, distributed spherically against backgrounds with typically more planar decays. It is defined as to $3/2 \times \lambda_3$, the 3rd eigenvalue of the sphericity tensor, build from the lepton and the jet momenta.

3. Signal regions

Several signal regions (SRs) requiring different jet multiplicities are designed to cover a wide range of possible scenarios. To target gluino and squark decays via an intermediate chargino ($\tilde{\chi}_1^{\pm}$) (one-step decays), a set of orthogonal selections in regions requiring at least 2-6 jets (**2-6J** SRs) is defined. An additional 9 jet SR (**9J** SR) targets models with longer decay chains and higher jet multiplicity, for example gluino decay via an intermediate neutralino ($\tilde{\chi}_2^0$) and chargino ($\tilde{\chi}_1^{\pm}$) (two-step decays).

The **2J** SR targets signals with compressed spectra, yielding softer leptons (6/7 GeV for e/μ $< p_{\mathrm{T}}^{\ell} <$ 35 GeV). The other SRs require a lepton p_{T} of at least 35 GeV. In compressed spectra, events with large missing transverse momentum occur when initial state radiation jets recoil against the gluino or squark decay products. Therefore, the **2J** SR requires high $E_{\mathrm{T}}^{\mathrm{miss}}$($>$ 430 GeV).

The **4J-lowx** and **4J-highx** SRs are designed to target partially compressed spectra with low and high $x = \frac{\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)}{\Delta m(\tilde{g}, \tilde{\chi}_1^0)}$. The **4J-highx** SR requires high $m_{\rm T}$ ($>$ 450 GeV) and high $E_{\rm T}^{\rm miss}$ ($>$ 300 GeV). The **4J-lowx** SR requires more moderate $m_{\rm T}$ ($150 - 450$ GeV) and $E_{\rm T}^{\rm miss}$ ($>$ 250 GeV). The **6J** SR targets scenarios with large mass differences and more balanced spectra ($x = \frac{1}{2}$). It is characterised by large $E_{\rm T}^{\rm miss}$ ($>$ 350 GeV) and a moderate $m_{\rm T}$ requirement ($>$ 175 GeV). For all **2-6J** SRs, a binned fit in $m_{\rm eff}$ is performed. Additionally, each SR is split into categories requiring at least one and no b-tagged jet. All regions are fitted simultaneously.

The **9J** SR is characterised by moderate $E_{\rm T}^{\rm miss}$ ($>$ 200 GeV) and $m_{\rm T}$ ($>$ 175 GeV) cuts. The region is further split into two bins of $m_{\rm eff}$ ($1000 - 1500$ GeV and $>$ 1500 GeV).

4. Background estimation

The main background contributions arise from top quark production ($t\bar{t}$ and Wt) and W+jets. For the **2-6J** SRs there is one control region (CR) per bin—applying the same selections as in the SR, except for two well modelled variables like $m_{\rm T}$ and aplanarity. For each bin, one normalisation factor for the top backgrounds and one for the W+jets background are fitted. The CR data is extrapolated to the SR by using transfer factors ($\frac{N_{\rm SR}}{N_{\rm CR}}$) from simulation. The extrapolation is validated in validation regions (VRs), where typically one of the two selection criteria in which the SR and CR selections differ is adjusted to match the SR selection.

In the **9J** SR the background is estimated using the approximate invariance of the $m_{\rm T}$ shape for events with different number of jets. Therefore, the transfer factor in $m_{\rm T}$ can be determined from data. The setup is built using three control regions A, B, C (see Figure 1). Two control regions determine the $m_{\rm T}$ transfer factor in events with 5-6 jets (A, B) and a third control region is used for the 9-jet normalisation (C). In case of no correlation between $m_{\rm T}$ and the number of jets, the estimated background in the signal region is given by $\frac{N_{\rm CR_A}}{N_{\rm CR_B}} N_{\rm CR_C}$.

Any residual correlation and the uncertainty on the non-correlation are determined from simulation, expressed in terms of the closure parameter $f_{\rm closure}$. The equation is reformulated in terms of a set of two normalisation parameters, that are determined from a fit,

$$N^{\rm est}_{\rm SR_{9J}} = f_{\rm closure} \cdot \frac{N^{\rm obs}_{\rm CR_A}}{N^{\rm obs}_{\rm CR_B}} \cdot N^{\rm obs}_{\rm CR_C} = N^{\rm sim}_{\rm SR_{9J}} \cdot \underbrace{\frac{N^{\rm obs}_{\rm CR_C}}{N^{\rm sim}_{\rm CR_C}}}_{\mu_{\rm C}} \cdot \underbrace{\frac{\left(\frac{N_{\rm CR_A}}{N_{\rm CR_B}}\right)^{\rm obs}}{\left(\frac{N_{\rm CR_A}}{N_{\rm CR_B}}\right)^{\rm sim}}}_{\mu_{\rm A/B}} .$$

All three control regions are split in a category requiring at least one (no) b-tagged jet, thereby enhancing the top (W+jets) backgrounds. The normalisations of the top and W+jets backgrounds are controlled by one $\mu_{\rm C}$ and $\mu_{\rm A/B}$ parameter each. Two validation regions, VR $m_{\rm T}$ (7-8 jets) and VR $N_{\rm jet}$ (medium $m_{\rm T}$) are defined with the same scheme of control regions to validate the procedure (see Figure 1).

5. Results

No significant excess over the standard model background is observed. The results are interpreted in different SUSY scenarios, using a model-dependent limit fit. The fit in the **2-6J** SRs is

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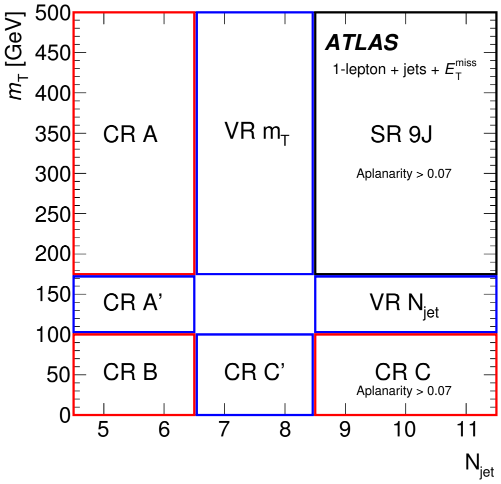

Figure 1: Illustration of the control and validation region configuration in the 9J analysis [2]. The control regions that are used for the background estimation in the signal region are indicated by red lines, while the blue lines indicate control regions that are used for the background estimation in the validation regions and the validation regions themselves.

interpreted in simplified models for gluino and squark decays via an intermediate chargino (each squark (gluino) yielding one (two) light quark(s), a W boson and the LSP). The fit for the **9J** SR is interpreted in a simplified model for gluino decay via an intermediate neutralino ($\tilde{\chi}_2^0$) and chargino ($\tilde{\chi}_1^{\pm}$) (each gluino yielding two light quarks, a W boson, a Z boson and the LSP) and a subset of the phenomenological minimal supersymmetric standard model (pMSSM). Figure 2 shows the limits on sparticle masses in the different scenarios. Depending on the scenario, limits reach up to approximately 2.1 TeV for gluino masses and up to 1.25 TeV for squark masses.

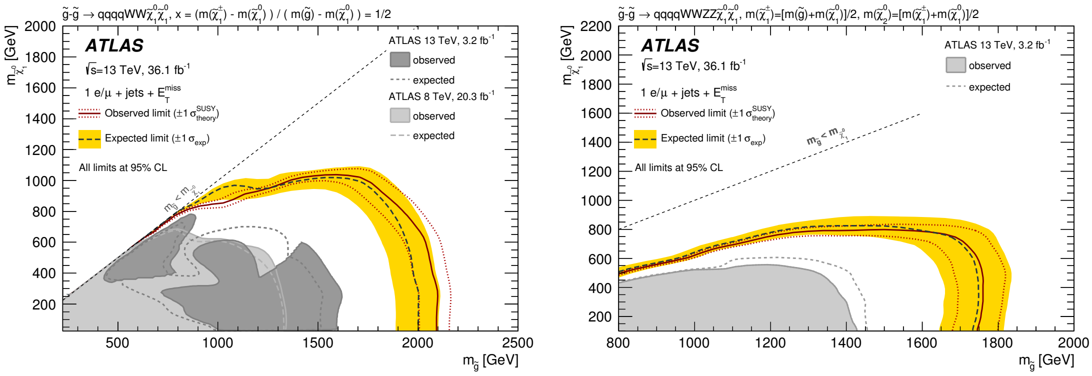

Figure 2: Example exclusion contours for gluino simplified models with a one-step decay and $x = 1/2$ (left), interpreted in the **2-6J** SRs and gluino simplified models with a two-step decay (right), interpreted in the **9J** SR [2].

References

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

[2] ATLAS Collaboration, *Search for squarks and gluinos in events with an isolated lepton, jets and missing transverse momentum at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, `arXiv:1708.08232 [hep-ex]` CERN-EP-2017-140.

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