# ATLAS NOTE

ATL-PHYS-PUB-2015-028

23rd July 2015

# First look at $pp$ collisions data at $\sqrt{s}$ = 13 TeV in preparation for a search for squarks and gluinos in final states with jets and missing transverse momentum with the ATLAS detector

The ATLAS Collaboration

ATL-PHYS-PUB-2015-028
27 July 2015

**Abstract**

Preliminary studies of the main backgrounds to the search for squarks and gluinos in final states with jets, large missing transverse momentum and no leptons (electrons or muons), using $pp$ collision data collected by the ATLAS experiment at $\sqrt{s}$ = 13 TeV in 2015, corresponding to an integrated luminosity of 78 pb$^{-1}$are presented. The data is compared to MC simulation in three background control regions, selecting events enriched in $W$+jets, $Z$+jets and $t\bar{t}$ and single-top events, the main background processes in this search. The MC simulation is found to well describe the data.

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# 1 Introduction

Supersymmetry (SUSY) [1–9] is a theoretically favoured extension of the Standard Model (SM), which for each degree of freedom of the SM predicts another degree of freedom with a different spin. These degrees of freedom combine into physical superpartners of the SM particles: scalar partners of quarks and leptons (squarks ($\tilde{q}$) and sleptons ($\tilde{\ell}$)), fermionic partners of gauge and Higgs bosons (gluinos ($\tilde{g}$), charginos ($\tilde{\chi}_i^{\pm}$, with $i = 1,2$) and neutralinos ($\tilde{\chi}_i^0$ with $i = 1,2,3,4$)), all with identical quantum numbers to their SM partners, except spin. Since no superpartner of any of the SM particles has been observed, SUSY must be a broken symmetry, with a mechanism for breaking the symmetry being at some higher energy scale. The discovery (or exclusion) of weak-scale SUSY is one of the highest physics priorities for the LHC. The primary target for early supersymmetry searches at proton–proton ($pp$) collisions at centre-of-mass energies of 13 TeV at the LHC, given their large expected cross-section, are the production of gluinos, and first and second generation squarks.

This note describes a first look at the regions dominated by the main SM background processes for the search for pair-produced squarks and gluinos in final states with at least two jets, large missing transverse momentum and no leptons (electrons or muons). These regions, referred to as control regions (CR), select events with at least one high-purity isolated lepton and are designed to normalise Monte Carlo (MC) predictions to data. The studies rely heavily on the search designed for the analysis of the 8 TeV data collected during Run 1 at the LHC, described in Ref. [10]. The distributions presented in this note aim to demonstrate the shape agreements between data and MC and do not show the estimate of the main sources of systematic uncertainties. The sensitivity studies for gluino-pair production with a full simulation of the ATLAS detector at a centre-of-mass energy of 13 TeV, for an integrated luminosity of 1, 2, 5 and 10 fb$^{-1}$are summarised in Ref. [11]. These studies show that with an integrated luminosity of 2 fb$^{-1}$, a 3 $\sigma$ evidence can be obtained for a gluino with a mass between 1300 and 1350 GeV, which is compatible with the current reach using the full Run 1 dataset.

# 2 Dataset and trigger

The dataset used in this analysis was collected in 2015 with the LHC colliding 6.5 TeV proton beams with 50 ns bunch spacing. The peak delivered instantaneous luminosity was $L = 1.72 \times 10^{33}\text{cm}^{-1}\text{s}^{-1}$. Application of beam, detector and data-quality requirements resulted in a total integrated luminosity of 78 pb$^{-1}$. The uncertainty on the integrated luminosity is ±9%. It is derived, following a methodology similar to that detailed in Ref. [12], from a preliminary calibration of the luminosity scale using a pair of x-y beam-separation scans performed in June 2015. The trigger applied to select the data samples used to estimate the yields of background events in the analysis requires a single electron or muon with online transverse momentum thresholds of 24 GeV and 20 GeV, respectively.

# 3 Monte Carlo data samples

The SM background estimates presented in this note are derived from MC simulation.

Events containing $W$ or $Z$ bosons associated with jets are simulated using the Sherpa 2.1.1 [13] generator. Matrix elements are calculated for up to two partons at NLO and four partons at LO using the Comix

[14] and OpenLoops [15] matrix element generators and merged with the Sherpa parton shower [16] using the ME+PSNLO prescription [17]. The CT10 parton distribution functions (PDF) [18] is used in association to authors tuning. For the generation of $t\bar{t}$ and single-top processes in the $Wt$ and $s$-channel the Powheg-Box v2 [19] generator with the CT10 PDF sets in the matrix element calculations is used. The electroweak $t$-channel single-top events are generated using the Powheg-Box v1 generator. This generator uses the four-flavour scheme for the NLO matrix elements calculations together with the fixed four-flavour PDF set CT10f4. For this process, the top quarks are decayed using MadSpin [20] preserving all spin correlations, while for all processes the parton shower, fragmentation and the underlying event are simulated using Pythia 6.428 [21] with the CTEQ6L1 PDF sets and the corresponding Perugia 2012 tune (P2012) [22]. The top mass is set to 172.5 GeV. The EvtGen v1.2.0 program [23] is used for properties of the bottom and charm hadron decays. Diboson processes ($WW$, $WZ$, $ZZ$, $W\gamma$ and $Z\gamma$) are simulated using the Sherpa 2.1.1 generator. Matrix elements are calculated for no or one parton at NLO and up to three partons at LO using the Comix and OpenLoops matrix element generators and merged with the Sherpa parton shower using the ME+PSNLO prescription. The CT10 PDF set is used in association to authors tuning. The multi-jet production is generated with Pythia v.8.1 using the A14 [24] underlying event tune and the NNPDF2.3 LO [25] parton distribution functions. The Monte Carlo samples were generated with an expected pileup distribution, and they have been re-weighted so that distributions of the mean number of interactions per bunch crossing matches the observed distribution in the data.

## 4 Event selection

Because of the high mass scale expected for the SUSY signal, the 'effective mass', $m_{\text{eff}}$(incl.), which is defined to be the scalar sum of the transverse momenta of jets with transverse momenta greater then 40 GeV together with $E_{\text{T}}^{\text{miss}}$, is a powerful discriminant between the signal and most SM backgrounds. The effective mass, and a requirement of high $E_{\text{T}}^{\text{miss}}$ form the central discriminating variables of this search.

The dominant sources of SM background processes in this search are: $Z$+jets, $W$+jets, top quark pair production and single-top production. In addition, multi-jets and the production of boson ($W/Z/\gamma$) pairs are taken into account. The majority of the $W$+jets background is composed of $W \rightarrow \tau\nu$ events in which the $\tau$-lepton decays to hadrons, with additional contributions from $W \rightarrow e\nu, \mu\nu$ events in which no electron or muon is reconstructed. The largest part of the $Z$+jets background comes from the irreducible component in which $Z \rightarrow \nu\bar{\nu}$ decays generate large $E_{\text{T}}^{\text{miss}}$. Top quark pair production followed by semileptonic decays, in particular $t\bar{t} \rightarrow b\bar{b}\tau\nu qq'$ with the $\tau$-lepton decaying to hadrons, as well as single top quark events, can also generate large $E_{\text{T}}^{\text{miss}}$ and satisfy the jet and lepton-veto requirements at a non-negligible rate. The multi-jet background in the signal regions caused by mis-reconstruction of jet energies in the calorimeters generating missing transverse momentum, as well as by neutrino production in semileptonic decays of heavy-flavour quarks has been found to be very small in previous searches in this channel [10].

Jets and missing transverse momentum are essential physics objects for this search. Jet candidates are reconstructed using the anti-$k_t$ jet clustering algorithm [26, 27] with a radius parameter of 0.4. Jets are selected using the prescriptions described in Ref. [28], and are required to have $|\eta| < 2.8$. The $b$-jets are required to have $|\eta| < 2.5$, and are identified using a neural-network-based algorithm [29] at the 77% efficiency operating point. The missing transverse momentum is based on calorimeter energy deposits and is calculated as described in Ref. [30] except that the "unclustered" term is also computed from the calorimeters.

The regions designed to normalise the $W$+jets background (CRW) and the combined $t\bar{t}$ and single-top backgrounds (CRT), use respectively a $b$-jet veto or $b$-jet requirement together with a requirement on the transverse mass, $m_{\mathrm{T}}$, of a high-purity, isolated electron or muon and $E_{\mathrm{T}}^{\mathrm{miss}}$ to select samples of $W(\to \ell\nu)$+jets and semileptonic $t\bar{t}$ background events. The selected isolated lepton with $p_{\mathrm{T}} > 25$ GeV is treated as a jet in these selections, with the same momentum. The treatment of leptons as jets is motivated by the observation that typically $\sim 75\%$ of $W(\to \ell\nu)$+jets and semi-leptonic $t\bar{t}$ events appearing in the signal regions of the search [10] have leptons which have faked jets, either through mis-identification of electrons or by the production of $\tau$-leptons decaying hadronically (hadronic $\tau$ identification is not used in this analysis). The events are required to satisfy the following criteria:

– quality criteria designed to remove events with noise, non collision backgrounds or mismeasured physics objects,
– exactly one high-purity isolated lepton (electron or muon) with $p_{\mathrm{T}} > 25$ GeV,
– 30 GeV $< m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV,
– at least two jets with $p_{\mathrm{T}}>$ 100, 60 GeV, respectively,
– $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV,
– no $b$-tagged jets in CRW; at least one $b$-tagged jet in CRT.

A total of 1402 (647) data events are selected in the CRW (CRT) regions. The $m_{\mathrm{eff}}$(incl.) distributions, after selecting events passing the CRW and CRT requirements, are shown in Figure 1.

A possible control region that can be used to estimate the contribution of $Z(\to \nu\bar{\nu})$+jets background selects events by requiring isolated lepton pairs of opposite sign and identical flavour for which the dilepton invariant mass lies within 25 GeV of the mass of the $Z$ boson (CRZ). In this control region the leptons are treated as contributing to $E_{\mathrm{T}}^{\mathrm{miss}}$. The events are required to satisfy the following criteria:

– quality criteria designed to remove events with noise, non collision backgrounds or mismeasured physics objects,
– exactly two isolated leptons of opposite sign and identical flavour with $p_{\mathrm{T}} > 25$ GeV,
– 66 GeV $< m_{\ell\ell} <$ 116 GeV,
– at least two jets with $p_{\mathrm{T}}>$ 100, 60 GeV, respectively,
– $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV.

A total of 274 data events are selected in the CRZ region. The $m_{\mathrm{eff}}$(incl.) distribution, after selecting events passing the CRZ requirements is shown in Figure 2.

# 5 Conclusions

The early 2015 $pp$ data at $\sqrt{s} = 13$ TeV collected by the ATLAS experiment already provide an excellent opportunity to test the modelling of the dominant sources of the SM background processes in preparation of the search for pair-produced squarks and gluinos in final states with jets, large missing transverse momentum and no leptons (electrons or muons). In a dataset corresponding to an integrated luminosity of 78 pb$^{-1}$, the data is compared to MC simulation in three background control regions, selecting events enriched in $W$+jets, $Z$+jets and $t\bar{t}$ and single-top events, the main background processes in this search. The MC simulation is found to well describe the data demonstrating the good level of control over these backgrounds to searches for Supersymmetry.

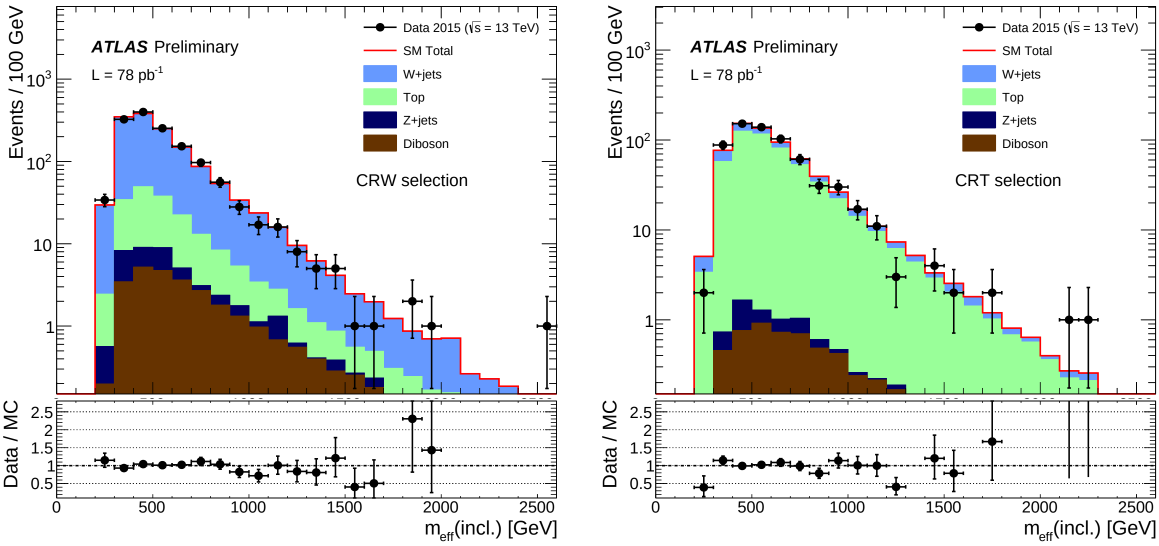


Figure 1: The distribution of the observed effective mass, $m_{\mathrm{eff}}$(incl.), calculated as the scalar sum of the transverse momenta of jets with $p_{\mathrm{T}} > 40$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}}$ in control regions CRW (left) and CRT (right), after requiring an isolated electron or muon with $p_{\mathrm{T}} > 25$ GeV, at least two jets with $p_{\mathrm{T}}$> 100, 60 GeV respectively, $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV and 30 GeV $< m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV. The total MC background expectation is normalised to data. In the lower panels the ratio of data to total MC background expectation is presented. The contribution from the multi-jet production is found to be negligible. Only statistical uncertainties are shown, without any experimental or theoretical systematic uncertainties.

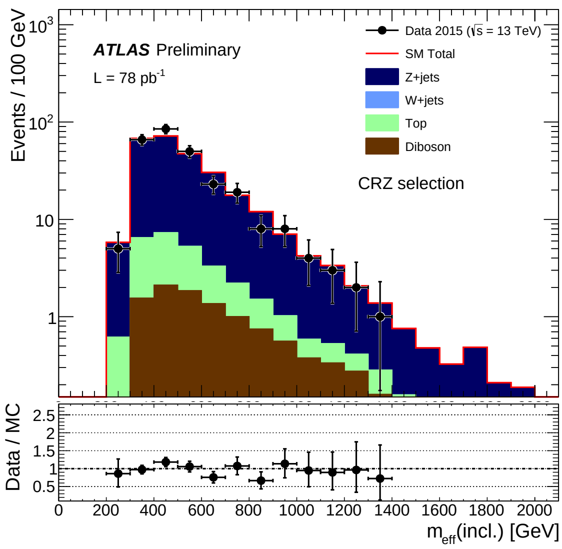


Figure 2: The distribution of the observed effective mass, $m_{\mathrm{eff}}$(incl.), calculated as the scalar sum of the transverse momenta of jets with $p_{\mathrm{T}} > 40$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}}$ in control region CRZ after requiring two isolated leptons of opposite sign and identical flavour with $p_{\mathrm{T}} > 25$ GeV, at least two jets with $p_{\mathrm{T}}$> 100, 60 GeV respectively, $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV and 66 GeV $< m_{\ell\ell} <$ 116 GeV. The total MC background expectation is normalised to data. In the lower panels the ratio of data to total MC background expectation is presented. The contribution from the multi-jet production is found to be negligible. Only statistical uncertainties are shown, without any experimental or theoretical systematic uncertainties.

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