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# Inclusive searches for squarks and gluinos with the ATLAS detector

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**Abstract.** Searches for squarks and gluinos in final states with high-$p_{\mathrm{T}}$ jets, missing transverse momentum, electrons, muons, taus and photons are presented. The data were recorded in 2012 by the ATLAS experiment in $\sqrt{s}$ = 8 TeV proton-proton collisions at the Large Hadron Collider, with a total integrated luminosity of 20.3 fb$^{-1}$. No significant excess above the Standard Model expectation is observed. Results are interpreted in a variety of simplified and specific supersymmetry models assuming that R-parity is conserved with the lightest supersymmetric particle being a neutralino or a gravitino. These limits extend the region of supersymmetric parameter space excluded by previous searches at the Large Hadron Collider.

## 1 Introduction

The potential production of supersymmetric particles at the Large Hadron Collider (LHC) [1] is dominated by squark-gluino ($\tilde{q}\,\tilde{g}$), gluino-gluino ($\tilde{g}\,\tilde{g}$) and squark-squark ($\tilde{q}\,\tilde{q}$) pair production. Assuming R-parity conservation, the decay chains of these particles contain the Lightest Supersymmetric Particle (LSP). The LSP escapes the detector unseen, thus leading to final states with jets and missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$). Additional objects, such as electrons, muons, taus or photons may also be observed in the detector, depending on the exact decay chain considered. The ATLAS detector [2] is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and nearly $4\pi$ coverage. Data from proton-proton collisions recorded in 2012 at the LHC at 8 TeV center of mass energy, corresponding to an integrated luminosity of 20.3 fb$^{-1}$, have been analyzed. A selection of most recent searches for supersymmetry in final states with jets and missing transverse momentum, electrons, muons, taus or photons with the ATLAS detector are presented in the following.

## 2 Selection of most recent searches for squarks and gluinos with the ATLAS detector

Standard Model (SM) processes have been measured with high precision at the LHC in proton-proton collisions. However the phase spaces, in which searches for supersymmetric particles are carried out, cover most often much smaller regions than these measurements, because if strict requirements on e.g.

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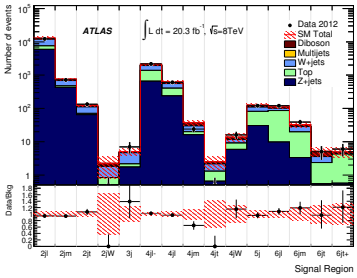


**Figure 1.** Comparison of the observed and expected event yields in the search in final states with jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ as a function of signal region from Ref.[3]. Signal regions are labelled according to their minimum jet multiplicity 2-6 and background rejection power 'very loose' ('l-') to 'very tight' ('t+').

large transverse momentum of the objects in the final states or of large missing transverse momentum. Dedicated techniques have been developed therefore to estimate the irreducible backgrounds to potential SUSY signals. These are usually estimated via partially data-driven techniques, where the normalisation between data and predictions is performed in control regions, as pure as possible in the process of interest and as close as possible to the search phase space. The residual reducible backgrounds after the full event selection are estimated via fully data-driven methods. All background estimates are validated in additional phase-space regions, as close as possible to the search region, prior to carrying out hypothesis tests in the signal regions.

- **Searches in final states with jets and missing transverse momentum:**
  If a LSP exists, e.g. the lightest stable neutralino ($\tilde{\chi}_1^0$), the primarily produced squarks and gluinos will decay subsequently to the LSP. The most general signal in a detector in this case would be jets and missing transverse momentum originating from e.g. $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ or $\tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$. In Ref.[3] a search is carried out investigating final states with jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. The effective mass ($m_{eff}$) has been found to be the most discriminant observable to distinguish between signal and most SM backgrounds. This is defined to be the scalar sum of the transverse momenta of all jets and the missing transverse momentum. The main kinematic requirements in the event selection are cuts on the transverse momentum of the hardest and subsequent hard jets of 130 GeV and 60 GeV, respectively. In addition a cut on the missing transverse momentum of 130 GeV is applied. Several signal regions are defined with minimum jet-multiplicity of two to six and with varying requirements on $m_{eff}$. Fig.1 shows observed data compared to the expected background in all signal regions. No significant excess above the SM expectation is observed. Thus exclusion limits are set on various models. A selection of limits on simplified decay chains is depicted in Fig.2. An exclusion limit at the 95% confidence level (CL) on the mass of the gluino is set at 1330 GeV for a simplified model incorporating only a gluino and the lightest neutralino. For a simplified model involving the strong production of first- and second-generation squarks, squark masses below 850 GeV (440 GeV) are excluded for a massless lightest neutralino, assuming mass degenerate (single light-flavor) squarks.

  An analysis investigating final states with jets and missing transverse momentum, but covering higher jet multiplicities (>6) is presented in Ref.[4]. The analysis is more sensitive to models including the pair production of gluinos, where each gluino decays to the LSP via intermediate states, thus leading to a large number of jets from emissions of quarks and/or gluons.

- **Searches in final states with missing transverse momentum and at least three b-jets:**
  If top squarks are produced in decay chains, requiring b-tagged jets adds sensitivity to the search. The analysis in Ref.[5] is performed separately in events with either zero or at least one high-$p_{\mathrm{T}}$ lepton (electron or muon), large missing transverse momentum, high jet multiplicity and at least three jets identified as originating from the fragmentation of a b-quark. Selected events must have $E_{\mathrm{T}}^{\mathrm{miss}}$ larger than 150 GeV and at least four jets with a $p_{\mathrm{T}}$ larger than 30 GeV. The leading jet is

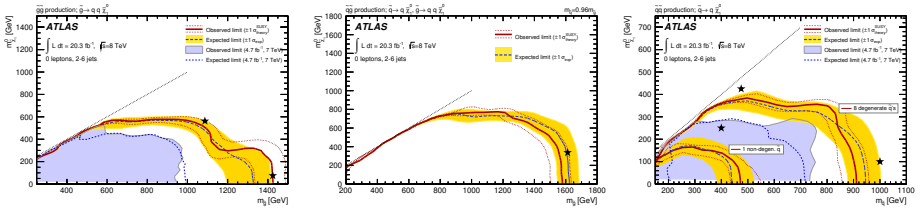


**Figure 2.** Exclusion limits for direct production of (left) gluino pairs with decoupled squarks, (middle) light-flavor squarks and gluinos and (right) light-flavor squark pairs with decoupled gluinos from Ref.[3]. Gluinos (light-flavor squarks) are required to decay to two quarks (one quark) and a neutralino LSP. In the right-hand figure, limits are shown for scenarios with eight degenerate light-flavor squarks, or with only one non-degenerate light-flavor squark produced. Exclusion limits are obtained by using the signal region with the best expected sensitivity at each point. The blue dashed lines show the expected limits at 95% CL , with the light (yellow) bands indicating the $1\sigma$ excursions due to experimental and background-only theory uncertainties. Observed limits are indicated by medium dark (maroon) curves, where the solid contour represents the nominal limit, and the dotted lines represent the uncertainty on the signal cross-section.

required to have a $p_{\mathrm{T}}$ larger than 90 GeV. No excess is observed with respect to the SM predictions. The results are interpreted in the context of several supersymmetric models involving gluinos and scalar top and bottom quarks, as well as a mSUGRA/CMSSM model. Gluino masses up to 1340 GeV are excluded, depending on the model.

- **Searches in final states with jets and two same-sign leptons or three leptons:**
  In Ref.[6], a search is carried out in final states with missing transverse momentum, high jet multiplicity, jets originating from b-quarks and either two isolated leptons (electron or muons) with the same electric charge, or at least three isolated leptons. Selected events are required to have $E_{\mathrm{T}}^{\mathrm{miss}}$ larger than 80 GeV and selected events contain either exactly two leptons with the leading (sub-leading) one having a $p_{\mathrm{T}}$ larger than 20 (15) GeV or three or more leptons with the leading ones having a $p_{\mathrm{T}}$ larger than 20,15,15 GeV. This selection allows for a large background suppression and sensitivity to a variety of supersymmetric models in which the lightest squark can be of the first, second or third generation. No significant excess above the SM is observed and limits are placed on various supersymmetric models. Gluino-mediated top quark scenarios favored by naturalness arguments are excluded for gluino masses smaller than 600 up to 1000 GeV, depending on the decay mode considered.

- **Searches in final states with jets, missing transverse momentum and at least one tau lepton:**
  A search in events with $E_{\mathrm{T}}^{\mathrm{miss}}$, jets, at least one hadronically decaying tau lepton and zero or one additional light leptons (electron or muon) is presented in Ref.[7]. In the framework of general gauge-mediated SUSY breaking models the stau can be the LSP, thus the final state contains tau leptons. The main kinematic requirements are $E_{\mathrm{T}}^{\mathrm{miss}}$ to be larger than 150 GeV, the $p_{\mathrm{T}}$ of the hardest jet to be larger than 130 GeV and of the sub-leading jets to be larger than 30 GeV. Final states with one tau lepton with a $p_{\mathrm{T}}$ larger than 30 GeV, two tau leptons with $p_{\mathrm{T}}$ larger than 20 GeV and one tau and an electron or a muon with a $p_{\mathrm{T}}$ of more than 20 or 25 GeV, respectively, have been investigated. No significant excess above the SM is observed and limits are placed on various supersymmetric models. In the framework of minimal gauge-mediated SUSY breaking models, values of the SUSY breaking scale below 63 TeV are excluded, independently of the ratio of the vacuum expectation values of the two Higgs fields ($tan(\beta)$).

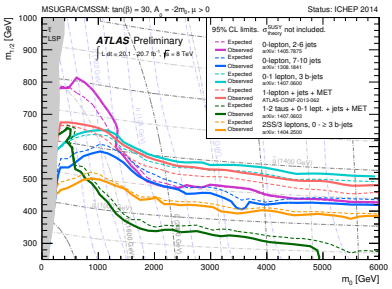


**Figure 3.** Exclusion limits at 95% CL for 8 TeV analyses in the ($m_0$, $m_{1/2}$) plane for the MSUGRA/CMSSM model from Ref.[9], with the remaining parameters set to $tan(\beta) = 30$, $A_0 = -2m_0$, $\mu > 0$, where $m_0$ being the universal scalar mass, $m_{1/2}$ the universal gaugino mass, $A_0$ the universal trilinear scalar coupling and $\mu$ the sign of the higgsino mass parameter. Over a large part of the plane, the lightest neutral scalar Higgs boson mass is close to 125 GeV as indicated by the light grey dashed-and-dotted line. Theoretical signal cross section uncertainties are not included in the limits shown.

- **Searches in final states with missing transverse momentum and two photons:** A search in di-photon events with large missing transverse momentum is performed in Ref.[8]. Depending on the nature of the Next to Lightest Supersymmetric Particle (NLSP) the final state can contain photons. Selected events are required to have at least two photons with $E_{\mathrm{T}}^{\mathrm{miss}}$ larger than 75 GeV. No significant excess above the SM is observed. In a model of gauge-mediated supersymmetry breaking with a bino-like lightest neutralino, gluinos below 1280 GeV and degenerate triplets of wino-like charginos and next-to-lightest neutralinos below 570 GeV are excluded for any neutralino mass above 50 GeV.

Some of the analyses described above are compared in Fig.3 within the mSUGRA/CMSSM model in a parameter space described in the caption. At large $m_{1/2}$ and small $m_0$ the analysis of jets, $E_{\mathrm{T}}^{\mathrm{miss}}$ and a veto on leptons yields the largest sensitivity. At large $m_0$ the search in $E_{\mathrm{T}}^{\mathrm{miss}}$ and at least three b-jets signatures is most sensitive.

## 3 Conclusions

Inclusive searches for squarks and gluinos, using data recorded with the ATLAS detector in 2012 in $\sqrt{s} = 8$ TeV proton-proton collisions are presented. Final states with jets, missing transverse momentum, electrons, muon, taus and photons have been investigated. No significant excess above the Standard Model expectation is observed. Results are interpreted in a variety of simplified and specific supersymmetry breaking models assuming that R-parity is conserved with the lightest supersymmetric particle being a neutralino or a gravitino. At 13 TeV center of mass energy of proton-proton collisions which will be provided by the Large Hadron Collider in 2015, the production cross section for squarks and gluinos is significantly enhanced. Thus the upcoming data taking period provides the hope of discovering supersymmetric particles, if they exist at the TeV scale.

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