PROCEEDINGS OF SCIENCE

Inclusive searches for squarks and gluinos with the ATLAS detector

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The latest results from searches for squarks and gluinos by the ATLAS experiment [1] at the Large Hadron Collider in final states containing jets, large missing transverse momentum and, in some cases, isolated leptons are summarized in these proceedings. The kinematic reach of the analysis including a single isolated lepton is extended to soft leptons to increase the sensitivity to compressed supersymmetric spectra. The sensitivity of the analyses vetoing events with isolated leptons is enhanced by considering the number of *b*-tagged jets and the scalar sum of masses of large-radius jets in an event. The searches are based on the proton-proton collision data at a centre-of-mass energy $\sqrt{s} = 8$ TeV collected in 2012, corresponding to an integrated luminosity of 20 fb^{-1}. No significant excess above the Standard Model expectation is observed. The results are used to set limits on sparticle masses for various simplified models covering the pair production of gluinos and first-/second-generation squarks.

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1. Introduction

Supersymmetry (SUSY) [2] is a popular theory that describes physical phenomena beyond the Standard Model (SM), and solves several of its fundamental shortcomings. It postulates the existence of SUSY particles which differ by half a unit of spin with respect to their SM partners. If strongly interacting supersymmetric particles are present at the TeV-scale, they should be accessible at the Large Hadron Collider (LHC). These coloured superparticles, the squarks ($\tilde{q}$)[1] and gluinos ($\tilde{g}$), would be strongly produced and could consequently have a large enough production cross section to ensure a high probability of discovery.

In the minimal supersymmetric extension of the Standard Model such particles decay into jets, possibly leptons and the lightest supersymmetric particle (LSP). Owing to R-parity conservation, the LSP is stable (assumed here to be the lightest neutralino, denoted by $\tilde{\chi}_1^0$), and is weakly interacting and therefore escapes detection, leading to large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) in the final state. Figure 1 shows three possible cascade decays of pair produced squarks and gluinos, either via an intermediate chargino ($\tilde{\chi}_1^{\pm}$), or via two intermediate steps containing a chargino and a next-to-lightest neutralino ($\tilde{\chi}_2^0$). These three decay topologies represent the simplified models discussed here, where a 100% branching ratio is assumed for each topology/model.

In these proceedings, we first describe three inclusive searches, followed by results and interpretations in the simplified models.

2. Searches with jets and missing transverse momentum

The *0-lepton analysis* [3] was one of the first published SUSY analyses at ATLAS, sensitive to potential new physics from the very first pb^{-1} of recorded data. The 0-lepton final state has the largest branching ratio, considering the simplified models shown in Figure 1.

The main discriminating variable in this analysis is effective mass ($m_{\mathrm{eff}}(\mathrm{incl.})$), defined as the sum of transverse momenta of all jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. A set of five channels is defined by requiring different jet multiplicites, starting from at least two and going up to at least six reconstructed jets, thus giving this analysis sensitivity from the very short to relatively long decay chains. Ten signal regions (SRs) are defined based on jet multiplicity and $m_{\mathrm{eff}}(\mathrm{incl.})$ cuts. Figure 2 shows the $m_{\mathrm{eff}}(\mathrm{incl.})$ distributions for the 4-jets and 5-jets channels, and good agreement is observed between data and SM Monte Carlo (MC) prediction.

Each SR comes with four associated control regions (CRs) that are targetting each of the dominant background components: $Z \to \nu\nu$+jets, W+jets, $t\bar{t}$ and QCD multijets. These control

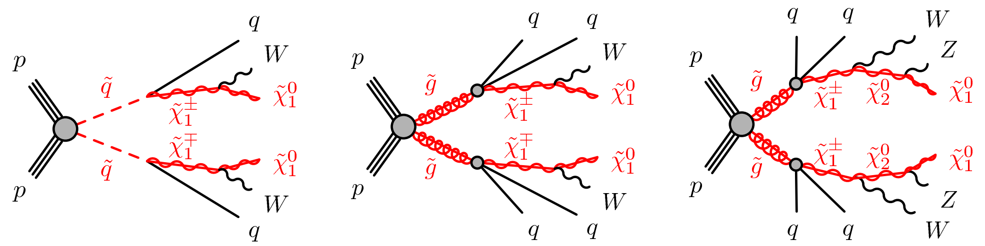

Figure 1: A selection of possible squarks and gluino decay topologies of some simplified models considered in these proceedings: squark decay via a chargino (left), gluino decay via a chargino (middle) and gluino decay via a chargino and a next-to-lightest neutralino (right).

[1] Used throughout these proceedings to represent only the first- and second-generation squarks

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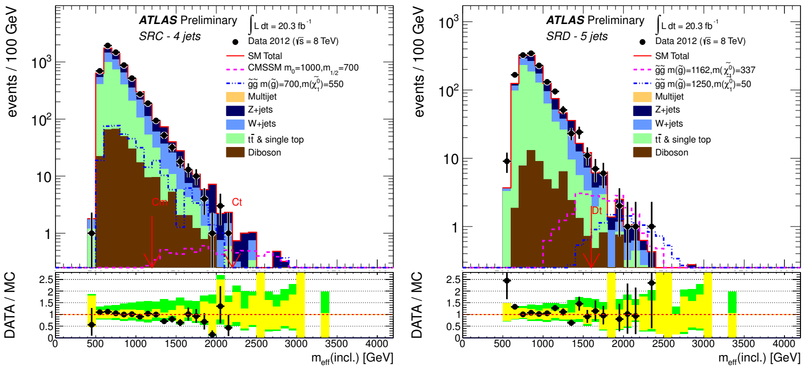

Figure 2: Observed $m_{\text{eff}}(\text{incl.})$ distributions for 4-jets (left) and 5-jets (right) channels with 0 leptons [3]. The yellow error bands denote the experimental and MC statistical uncertainties, while the green bands show the total uncertainty. The red arrows indicate the $m_{\text{eff}}(\text{incl.})$ cuts applied for signal regions. Expected distributions for two benchmark model points are also shown for comparison (masses in GeV).

regions are used in a simultaneous likelihood fit to normalize the background prediction from MC generators to data. The fitted background prediction is then extrapolated to the signal region, using transfer factors taken from MC. The multijet background, caused by misreconstruction of jet energies in the calorimeters leading to apparent missing transverse momentum, is estimated from data.

3. Searches with a large number of jets

The *multijets analysis* [4] focuses on very long supersymmetric decay chains with a large number of jets in the final state, together with significant missing transverse momentum in the absence of isolated electrons or muons. The signal regions are defined by requirements ranging from at least seven to at least ten jets. Jets are reconstructed using the jet radius parameter $R = 0.4$ by the anti-k_t clustering algorithm. The sensitivity is further enhanced by the subdivision into several categories. Firstly, event classification based on the number of b-jets (jets identified as coming from b-quarks) gives enhanced sensitivity to models which predict either more or fewer b-jets than the Standard Model background. Secondly, in a complementary stream of the analysis, the $R = 0.4$ jets are reclustered into large ($R = 1.0$) composite jets to form an event variable, the

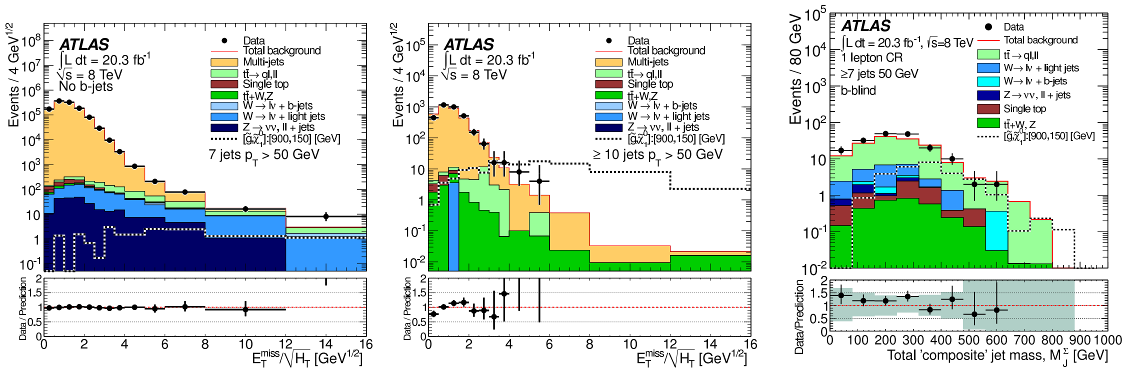

Figure 3: Distribution of $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ for b-jet vetoed control region with exactly seven jets with $p_{\mathrm{T}} \geq$ 50 GeV and $|\eta| < 2.0$ (left), and the multijet + flavour stream with $p_{\mathrm{T}}^{\mathrm{min}} = 50$ GeV and at least ten jets (middle) of the multijet analysis [4]. The M_J^{Σ} distribution (right) for an inclusive selection of seven jets with $p_{\mathrm{T}}^{\mathrm{min}} = 50$ GeV. For reference and comparison, a supersymmetric model is shown where gluinos of mass 900 GeV are pair produced and each decays to a $t\bar{t}$ pair and a $\tilde{\chi}_1^0$ with a mass of 150 GeV.

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sum of the masses of the composite jets (M_J^Σ), which gives additional discrimination in models with a large number of objects in the final state. In total the multijets analysis defines nineteen signal regions.

Figure 3 shows the distribution of the final discriminating variable $E_T^{miss}/\sqrt{H_T}$ for the 7-jets and the 10-jets channels, as well as the M_J^Σ distribution in the 7-jets channel. The fully data-driven background determination method is based on the observation that the E_T^{miss} resolution of the detector is approximately proportional to $\sqrt{H_T}$ (where H_T is the scalar sum of p_T of all jets) and almost independent of the jet multiplicity in events dominated by jet activity, including hadronic decays of top quarks and gauge bosons. The distribution of the ratio $E_T^{miss}/\sqrt{H_T}$ therefore has a shape that is almost invariant under changes in the jet multiplicity. The multijet backgrounds are determined using control regions with lower $E_T^{miss}/\sqrt{H_T}$ and/or lower jet multiplicity than the signal regions. The leptonic backgrounds arising from W/Z+jets and semi-leptonic $t\bar{t}$ decays are estimated in dedicated CRs, using the same technique discussed for the 0-lepton analysis.

4. Searches with an isolated lepton

The *1-lepton analysis* [5] uses a statistically independent set of events, compared to 0-lepton and multijets analyses, by requesting the presence of one isolated lepton (electron or muon) in the event. In the busy hadronic environment of the LHC, isolated leptons are clear signatures that strongly help to reduce the predominant QCD multijet background.

The leptonic search probes events characterized by the presence of low ($10(6) < p_T \leq 25$ GeV) or high ($p_T > 25$ GeV) transverse momentum electrons (muons): in the following, the former class of events is referred to as the soft-lepton channel, the latter as the hard-lepton channel. Soft-lepton signal regions are optimized to be sensitive to compressed SUSY spectra, where the

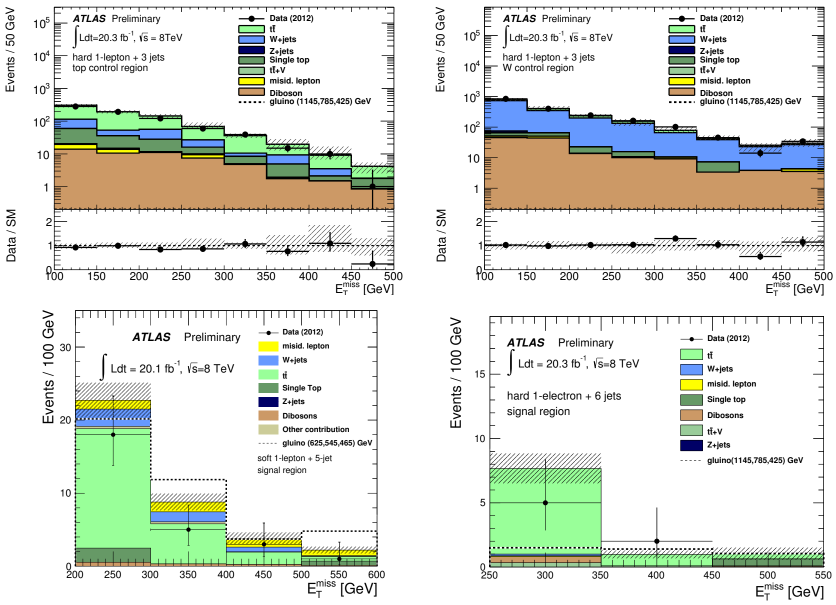

Figure 4: E_T^{miss} distribution in the hard-lepton 3-jets ttbar (top left) and W+jets (top right) control regions [5], before the upper E_T^{miss} requirements are applied. E_T^{miss} distribution in the soft-lepton 5-jets (bottom left) and the hard-lepton 6-jets (bottom right) signal regions. For illustration, the expected signal distributions are shown for gluino pair production with $m_{\tilde{g}} = 625$ (1145) GeV , $m_{\tilde{\chi}_1^\pm} = 545$ (785) GeV and $m_{\tilde{\chi}_1^0} = 465$ (425) GeV in the soft- (hard-)lepton channel.

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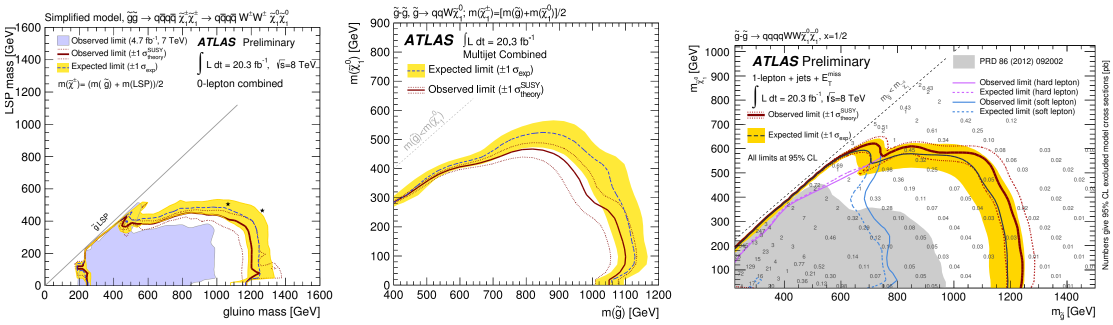

Figure 5: 95% CL exclusion limits for the 0-lepton [3] (left), multijets [4] (middle) and the 1-lepton [5] (right) analyses in the gluino simplified model presented in the $m_{\tilde{g}}$–$m_{\tilde{\chi}_1^0}$ mass plane for the case in which the chargino mass is fixed at x=1/2, where $\mathrm{x} = (m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0})/(m_{\tilde{g}} - m_{\tilde{\chi}_1^0})$. The blue dashed line shows the expected limits at 95% CL, with the light (yellow) bands indicating the $\pm 1\sigma$ variation on the median expected limit due to the experimental uncertainties. The observed nominal limit is indicated by a solid dark red line with the dark red dotted lines being obtained by varying the signal cross section by the scale and PDF uncertainties. The observed limits set by the previous ATLAS 1-lepton [6] (0-lepton [7]) analysis using 7 TeV data are shown as a grey (light blue) area.

lightest chargino (or a part of the chargino/neutralino sector) is nearly mass-degenerate with the LSP. Several signal regions are defined in each channel, based on jet multiplicity and $E_{\mathrm{T}}^{\mathrm{miss}}$-$m_{\mathrm{eff}}$-$m_{\mathrm{T}}$ cuts, where m_{T} is transverse mass defined as the effective mass of the lepton+$E_{\mathrm{T}}^{\mathrm{miss}}$ system in the transverse plane.

Each SR comes with two control regions, defined by a b-jet requirement or veto, to target either the $t\bar{t}$ or the W+jets backgrounds. An example of one pair of control regions for the 3-jets hard-lepton channel is shown in Figure 4. The same figure also shows one representative SR for the hard- and soft-lepton channels. In the hard-lepton case, the shape of the $E_{\mathrm{T}}^{\mathrm{miss}}$-distribution in the SR (as shown) is used in the exclusion fit to be sensitive to a wide range of models.

5. Results and interpretations

None of the signal regions defined in the searches described, shows a significant excess over the predicted SM background. As such, exclusion limits on SUSY models are set, ruling out large portions of previously unconstrained SUSY parameter phase space.

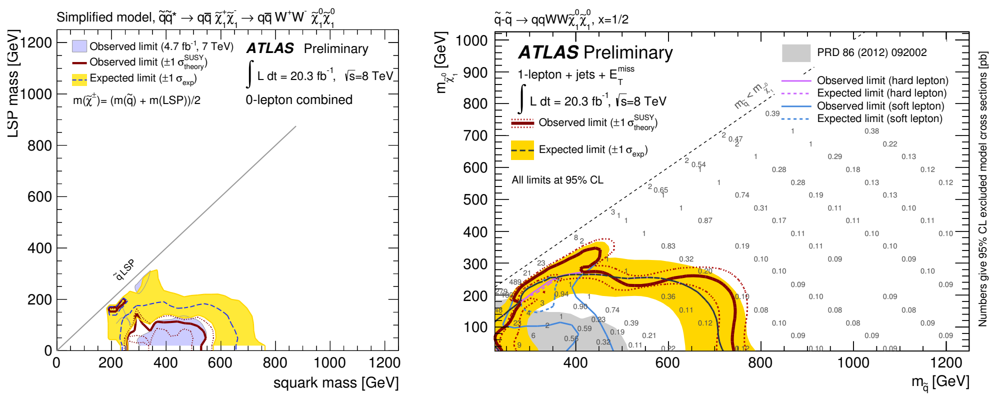

Figure 6: 95% CL exclusion limits for the 0-lepton [3] (left) and the 1-lepton [5] (right) analyses in the first and second generation squark simplified model presented in the $m_{\tilde{q}}$–$m_{\tilde{\chi}_1^0}$ plane for the case in which the chargino mass is fixed at x=1/2, where $\mathrm{x} = (m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0})/(m_{\tilde{q}} - m_{\tilde{\chi}_1^0})$. Other details as for Figure 5.

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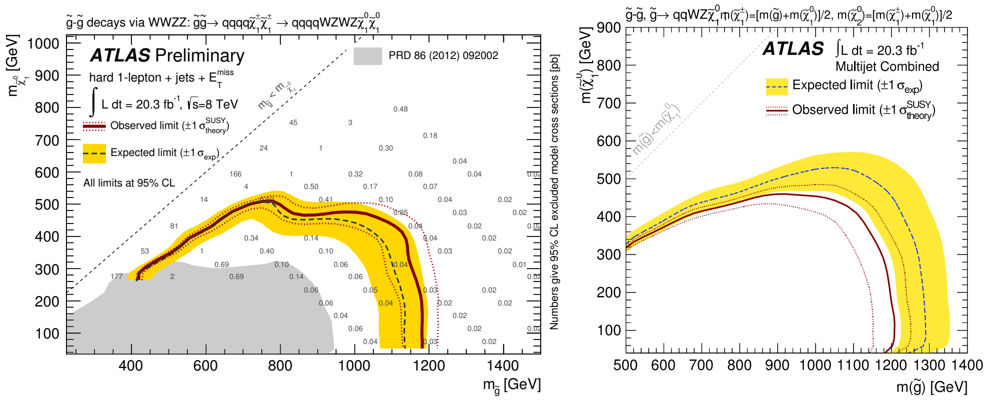

Figure 7: 95% CL exclusion limits for the 1-lepton [5] (left) and multijets [4] (right) analyses in the gluino (via $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$) simplified model presented in the $m_{\tilde{g}}$–$m_{\tilde{\chi}_1^0}$ plane. Other details as for Figure 5.

All three analyses set comparable limits on gluino pair production simplified models with decay via charginos, as shown in Figure 5, excluding gluino masses up to 1200 GeV. The soft lepton analysis shows a much improved reach close to the $m_{\tilde{g}} = m_{\tilde{\chi}_1^0}$-diagonal, as expected. For the equivalent squark simplified model, shown in Figure 6, only the 0-lepton and 1-lepton analyses present interpretations, excluding squark masses up to 700 GeV. These squark limits are much softer compared to the gluino excluded regions, as the production cross section is lower and the final state is harder to distinguish from the SM. The last simplified model discussed here, the two-step model via $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$, is shown in Figure 7, excluding gluino masses up to 1150 GeV. This longer decay chain is specifically attractive for the multijets analysis, but the 1-lepton analysis shows a good exclusion reach as well.

6. Summary and conclusions

Discovery of supersymmetry was one of the anticipated highlights from the LHC and was taken into account when designing the ATLAS experiment. But so far, no sign of an excess over the Standard Model backgrounds has been reported in any of the searches performed. A large portion of the SUSY parameter phase space has been excluded. During the long shutdown, before the 13-14 TeV collisions, the community needs to take a step back and make sure that no stone has been left unturned in the search for SUSY, while simultaneously devising new search strategies to get the best results possible.

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