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Inclusive searches for squarks and gluinos with the ATLAS detector

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Despite the absence of experimental evidence, TeV-scale supersymmetry remains one of the best-motivated and studied Standard Model extensions at the Large Hadron Collider. These proceedings summarise recent ATLAS results on inclusive searches for supersymmetric squarks and gluinos, including third-generation squarks produced in the decay of gluinos. The searches involve final states containing jets and missing transverse momentum, with and without light leptons or photons, and were performed with pp collisions at a centre-of-mass energy of 13 TeV.

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1. Introduction

The existence of all particles predicted by the Standard Model (SM) has been verified experimentally following the discovery of the Higgs boson in 2012 by the ATLAS [1] and CMS collaborations at CERN's Large Hadron Collider (LHC). This discovery was a triumph of modern collaborative science, but also raises new questions about our understanding of the universe.

The Higgs boson is the first known fundamental scalar particle, and so introduces new tension within the SM: its mass receives quadratically-divergent corrections which require precise fine-tuning of the bare mass in order to be consistent with the observed Higgs boson mass. Supersymmetric (SUSY) models are among the leading candidates to mitigate this problem. In SUSY scenarios which offer a solution to this problem, the gluino and third-generation squarks are expected to have masses near the TeV-scale, and so evidence of their existence have been searched for in the early Run 2 data set provided by the LHC at $\sqrt{s} = 13$ TeV during 2015 and 2016, where a considerable increase in sensitivity over previous results is expected due to the increased centre-of-mass energy.

2. ATLAS

The ATLAS collaboration consists of approximately three thousand scientific authors and another two thousand engineers, technicians and administrative staff. These diverse members are associated with 231 institutes in 38 countries around the globe. The collaboration operates, develops and analyses the pp collision data acquired by its eponymous detector, one of two general-purpose pieces of experimental apparatus installed at the LHC.

The ATLAS detector consists of three principle sub-systems. The inner detector (ID) tracks charged particles within $|\eta| < 2.5$ using silicon pixel and strip detectors, and a transition radiation tracker which provides a large number of hits in the ID's outermost layers in addition to particle identification capabilities. This sub-detector is immersed in a 2 T axial magnetic field. A sampling calorimeter surrounds the ID and barrel solenoid, providing energy measurements of electromagnetically- and hadronically-interacting particles within $|\eta| < 4.9$ using liquid argon and scintillating tile-based sub-detectors. The muon spectrometer (MS) is situated behind the calorimeter, and consists of one barrel and two end-cap superconducting toroidal magnets around which precision chambers provide measurements for all muons within $|\eta| < 2.7$. Separate trigger chambers allow for the online selection of events with muons within $|\eta| < 2.4$.

As writing events to disk at the nominal LHC collision rate of 40 MHz is currently unfeasible, a two-level trigger system is used to select events for analysis. The hardware-based Level-1 trigger reduces the event rate to ~ 100 kHz using a subset of available detector information. The software-based High Level Trigger then reduces the event rate to ~ 1 kHz, which is retained for further studies.

3. Early Run 2 results (2015 + 2016 dataset)

The early Run 2 ATLAS search programme targeting strongly-produced SUSY is comprehensive [2, 3, 4, 5, 6, 7], and maximizes its sensitivity to many regions of SUSY parameter space by

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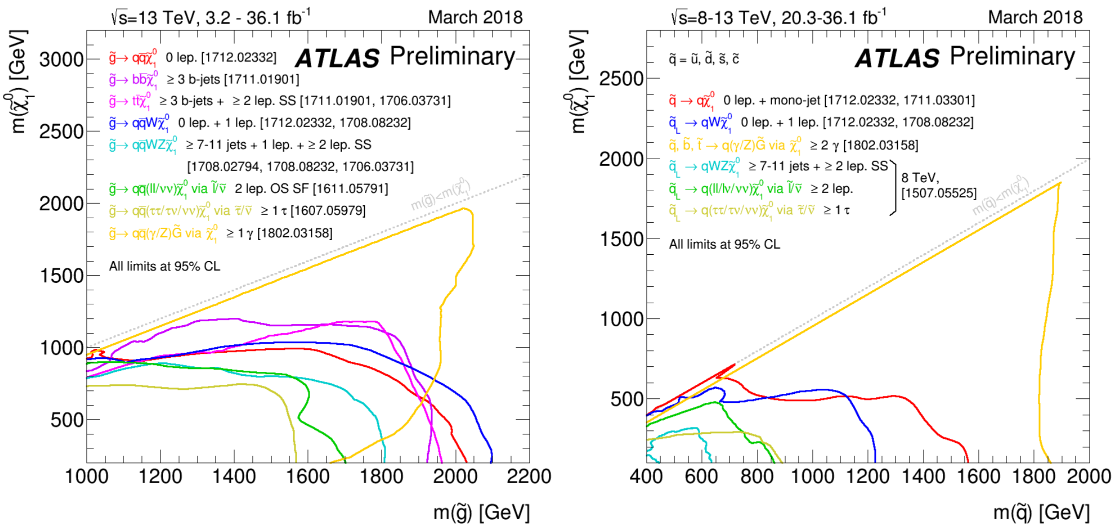
searching with canonical methods [8] and cutting-edge reconstruction techniques. These six analyses study a dataset of 36.1 fb^{-1} collected with the ATLAS detector during 2015 and 2016. The average number of simultaneous interactions per bunch-crossing in this dataset is 24.

The reach of this programme is shown in Figure 1 in terms of exclusion contours placed on benchmark simplified models which make specific assumptions about SUSY parameters in order to reduce the number of free parameters to one which is amenable for a general experimental pursuit. Pair-produced gluinos may each decay to pairs of light, b- or t-quarks and the stable lightest SUSY particle (LSP), which is the neutralino $\tilde{\chi}_1^0$ except in the gauge-mediated SUSY breaking (GMSB) scenario studied by the search with $\geq$ 1 γ, where it is instead the gravitino $\tilde{G}$. The gluinos may produce additional partcles such as W or Z bosons through cascades, or they may produce additional SUSY particles which in-turn may decay to pairs of leptons or additional $p_{\mathrm{T}}^{\mathrm{miss}}$. Details of the 24 different simplified models considered by these searches may be found in their respective publications, along with additional interpretations of these search results in terms of these models.



(a) (b)

Figure 1: Summary of exclusion limits in the $\tilde{\chi}_1^0 - \tilde{g}$ mass plane for (a) gluino pair production and (b) squark pair production. The dashed and solid lines show the 95% CL expected and observed limits for searches targetting strongly produced SUSY scenarios in the early Run 2 data ([9]).

Searches for SUSY broadly consider three categories of variables which provide sensitivity to exotic signatures with large jet multiplicities and $p_{\mathrm{T}}^{\mathrm{miss}}$ characteristic of the bulk of strong-SUSY parameter space, such as the M_{eff}, M_J^{Σ} and $p_{\mathrm{T}}^{\mathrm{miss}}$ significance. Some searches take more sophisticated approaches to event reconstruction, such as the 0-lepton SUSY search, which uses the Recursive Jigsaw Reconstruction technique to increase sensitivity in the challenging compressed region of parameter space [10]. Others perform more complex statistical treatments: the search for SUSY with $\geq$ 3 b-jets and the 1-lepton search perform multi-bin profile likelihood fits which incorporate information about the shape of the M_{eff} distribution when determining their exclusion limits.

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Among a total of 151 considered and possibly overlapping signal regions no significant excess has been observed. Exclusion limits placed on simplified models are between 1.55-2.1 TeV and 0.6-1.75 TeV, respectively, for gluino and squark pair production with a light LSP. In scenarios where the LSP mass increases, exclusion power as a function of the gluino or squark mass degrades. The search for SUSY with $\geq 1\ \gamma$ sets strong limits on simplified GMSB models, where the nature of the LSP differs, excluding gluinos (squarks) with masses of up to 2 TeV (1.85 TeV) in such cases.

4. New interpretations

Simplified models play an important role, providing a medium through which experimental results may be communicated clearly by multiple collaborations. The assumptions which are required to draw exclusion contours in a two-dimensional plane are occasionally seen as an over-simplification of the complex manner in which SUSY could manifest should it exist. ATLAS has begun providing more sophisticated interpretations of its searches alongside traditional limits on simplified models in an effort to both communicate more accurately the current state of experimental coverage, and to look for uncovered regions of parameter space which may be better-targeted by future efforts.

The search for SUSY with ≥ 3 b-jets presents limits as a function of the branching fraction for gluinos to decay via virtual stops to final states with either light quarks, b-jets or t-quarks. These limits are shown in Figure 2. The dependence of the sensitivity on the gluino branching fraction is apparent, with a variance in the limit on the gluino mass shown in Figure 2(a) of nealy 200 GeV for cases with a light neutralino. Particularly, the mass limit in the region where gluinos decay predominantly to final states with tb and the LSP (the lower-left corner) is lower than other scenarios. The limit on the LSP mass for a gluino with a mass of 1.9 TeV is shown in Figure 2(b), and shows that the expected limit is weaker in this same region even for a massless LSP.

Another novel extension of the usual interpretations provided by ATLAS has been provided in [11], where searches for R-parity conserving (RPC) SUSY have been extended into scenarios where R-parity is progressively violated (RPV). Partial-RPV models may give rise to long-lived particles in the final state, while models which fully violate RPV do not contain stable LSPs. Figure 3(a) shows the mass exclusion limit from the 0-lepton and 0-lepton, 7-11 jet searches for gluino pair-production where the gluino decays via the RPC decay $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$ and the RPV decay $\tilde{g} \rightarrow qqq$, and the branching fraction depends on the magnitude of the RPV coupling λ''_{112}. The exclusion limit extends from the fully-RPC scenario into RPV parameter space, indicating that these models provide additional sensitivity, despite not having been optimised for final states with displaced objects. For LSPs with a lifetime up to 1 ns, these searches are still sensitive to gluinos with masses below 1 TeV. A similar interpreation for models where the gluino decays via the RPC decay $\tilde{g} \rightarrow tt\tilde{\chi}_1^0$ and the RPV decay $\tilde{g} \rightarrow tbs$ is provided in figure 3(b). The search for SUSY with ≥ 3 b-jets is the most sensitive both in the fully-RPC scenario and for LSPs with lifetimes less than 1 ns. This highlights the complementarity between the ATLAS searches for strongly-produced SUSY and those targeting R-parity violating decays, such as the RPV search for SUSY with 1-lepton, which becomes the most sensitive for larger values of λ''_{323}.

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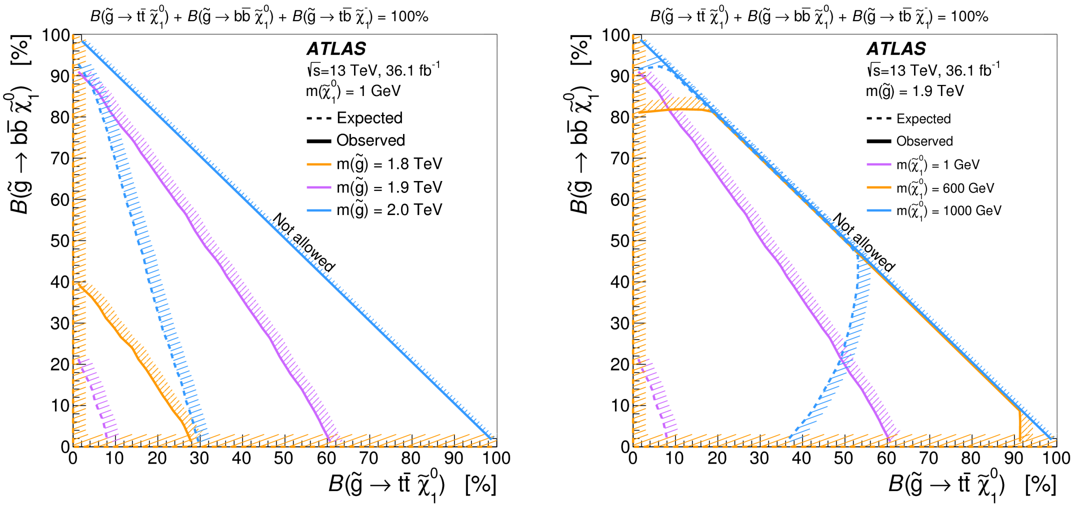
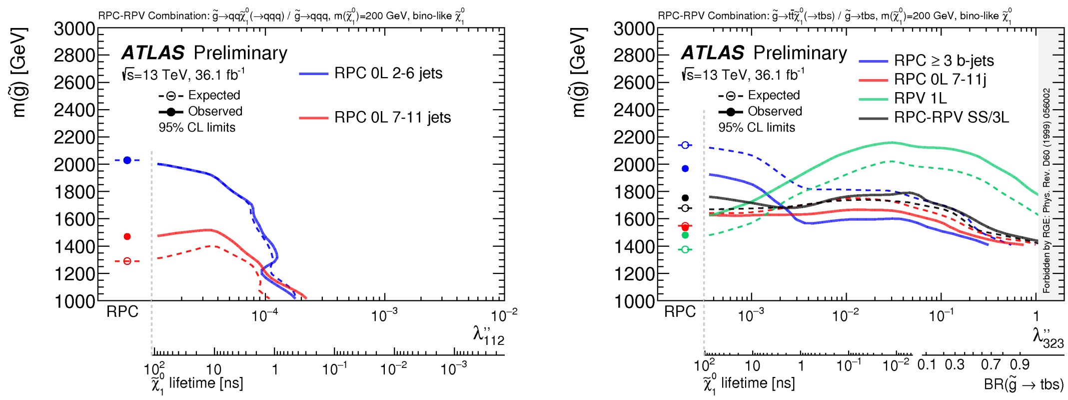


(a) (b)

Figure 2: Exclusion presented as a function of the $\tilde{g}$ branching fraction to $b\bar{b}\tilde{\chi}_1^0$ (upper-left corner), $t\bar{t}\tilde{\chi}_1^0$ (lower-right corner) and $b\bar{t}\tilde{\chi}_1^0$ (implicit, lower-left corner) are shown for (a) a $\tilde{\chi}_1^0$ mass of 1 GeV and various $\tilde{g}$ masses, and (b) a $\tilde{g}$ mass of 1.9 TeV and various $\tilde{\chi}_1^0$ masses ([3]).



(a) (b)

Figure 3: Exclusion limits for simplified models of $\tilde{g}$ pair-production where the $\tilde{g}$ decays via mixed RPC and RPV decays (a) $\tilde{g} \to qq\tilde{\chi}_1^0, \tilde{g} \to qqq$ or (b) $\tilde{g} \to tt\tilde{\chi}_1^0, \tilde{g} \to tbs$, as a function of the RPV couplings λ''_{112} and λ''_{323} ([11]).

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5. Concluding remarks

Searches for strongly produced SUSY at the TeV-scale were among the most well-motivated analyses to be performed during early Run 2 LHC operation, due to the large increase in the cross-sections for gluino and squark pair-production when moving from $\sqrt{s} = 8$ to 13 TeV relative to those of relevant background processes. A comprehensive search programme employing the first 36.1 fb^{-1} data set has been performed by ATLAS, revealing no signs of SUSY in nature so-far.

ATLAS has begun to produce more sophisticated interpretations of its searches. Limits presented as a function of the gluino branching fraction and reinterpretations as a function of R-parity violating couplings are more illustrative of the true sensitivity of these searches. These efforts are also critical for identifying gaps in coverage, providing exciting future directions to pursue.

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