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Searches for gluino-mediated production of third generation squarks with the ATLAS detector

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Four searches for gluino-mediated production of third generation squarks in proton-proton collisions at $\sqrt{s} = 8\ TeV$ with the ATLAS detector are presented. The searches use a data sample collected in 2012, corresponding to a total integrated luminosity of approximately 20 fb^{-1}. No deviation from the Standard Model expectation is observed. Exclusion limits are set on simplified supersymmetry models motivated by naturalness arguments.

The European Physical Society Conference on High Energy Physics -EPS-HEP2013
18-24 July 2013
Stockholm, Sweden

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1. Introduction

Supersymmetry (SUSY) is a generalization of space-time symmetries that provides a framework for the unification of particle physics and gravity. It predicts new bosonic partners for the fermions and fermionic partners for the bosons of the Standard Model (SM). If R-parity is conserved, SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable. In a large variety of models, the LSP is the lightest neutralino ($\tilde{\chi}_1^0$) and provides a possible candidate for dark matter. Moreover, SUSY can solve the the fine-tuning problem of the electroweak symmetry breaking mechanism (also referred as the *hierarchy* or *naturalness* problem of the SM) if the superpartners of the gluons, Higgs bosons and third generation quarks – the gluinos ($\tilde{g}$), higgsinos, top squark ($\tilde{t}$) and bottom squark ($\tilde{b}$) – are sufficiently light. It is hence compelling that gluinos could be pair-produced in strong interaction processes at the Large Hadron Collider (LHC), and decay predominantly to top and sbottom squarks[1] via cascades ending with a stable $\tilde{\chi}_1^0$. The undetected $\tilde{\chi}_1^0$ would result in missing transverse momentum ($\mathbf{p}_T^{miss}$ and its magnitude E_T^{miss}) while the rest of the cascade would yield final states with multiple jets and b-jets, and possibly leptons.

In these proceedings, four searches for gluino-mediated stop and sbottom production documented in Refs. [1, 2, 3, 4] are presented in Sec. 2. The searches are based on the following experimental signatures: 0/1 lepton + 3 b-jets + E_T^{miss}, 0 lepton + [2-6] jets + E_T^{miss}, 0 lepton + [7-10] jets, and 2 same-sign leptons + [0-3] b-jets, and use a data sample collected with the ATLAS detector in 2012, corresponding to a total integrated luminosity of approximately 20 fb^{-1}. Several different decay channels of the top and bottom squarks are considered for the optimization of the analyses and the interpretation of the results presented in Sec. 3.

2. Analysis of Experimental Data

The 0/1 lepton + 3 b-jets + E_T^{miss} analysis documented in Ref. [1] is optimized for 4 b-quarks signals, typical of gluino-mediated stop and sbottom pair-production. Three classes of signal regions (SR) are defined: 0 lepton + 4 jets, optimized for $\tilde{g}\tilde{g} \to bb\tilde{b}\tilde{b}$, and 0 lepton + 7 jets and 1 lepton + 6 jets, optimized for $\tilde{g}\tilde{g} \to tt\tilde{t}\tilde{t}$. The reducible background coming from mis-identified b-jet is estimated with a data-driven loose-to-tight matrix method. The irreducible background coming from $t\bar{t} + b\bar{b}$ is estimated with Monte Carlo (MC) simulations. The 1-lepton SR is new and brings a lot of additional sensitivity compared to earlier searches [5, 6].

The 0 lepton + [2-6] jets + E_T^{miss} analysis documented in Ref. [2] makes use of five classes of SRs based on the jet multiplicity and on kinematic observables such as $m_{eff} = E_T^{miss} + \sum p_T^{jet}$. The main backgrounds from $t\bar{t}$, W+jets and $Z \to \nu\nu$ are determined in control regions, independently in each SR, and extrapolated to SRs using MC. This search is very sensitive to gluino and squark pair-production in general. The signal region SRE (6 jets) provides the best sensitivity to $\tilde{g} \to t\tilde{t} \to tc\tilde{\chi}_1^0$ processes.

The 0 lepton + [7-10] jets analysis documented in Ref. [3] uses seven SRs with 8-10 jets of $p_T > 50\ GeV$, six SRs with 7 or 8 jets of $p_T > 80\ GeV$, or three SRs using a novel technique based on jet substructure observables. The multijets background is estimated with a data-driven method

[1] These processes are referred as gluino-mediated stop and gluino-mediated sbottom, respectively.

based on the E_T^{miss} significance. The semileptonic $t\bar{t}$ background is determined in control regions and extrapolated to SRs with MC. The signal regions with 50 GeV jets provide the best sensitivity to gluino-mediated stop pair-production.

The same-sign leptons + [0-3] b-jets analysis documented in Ref. [4] has three SRs with 0, $\geq$1 and $\geq$3 b-jets, respectively. The reducible background coming from mis-identified leptons is estimated with a data-driven loose-to-tight matrix method. The irreducible background coming from dibosons and $t\bar{t}+W/Z/H$ is estimated with MC. This search is sensitive to a wide variety of new physics scenarios. The signal region SR3b ($\geq$3 b-jets), featuring no E_T^{miss} requirement, is notably sensitive to "compressed" gluino-mediated stop scenarios with small mass differences $\Delta M(\tilde{g},\tilde{\chi}_1^0)$.

3. Interpretation

No significant deviation from the Standard Model expectation is observed in any of the searches. Exclusion limits are set on a variety of simplified gluino-mediated stop and sbottom models. The resulting observed and expected limits are displayed as solid red lines and dashed grey lines, respectively, on Fig. 1 and Fig. 2. The $\pm 1\sigma^{\rm SUSY}_{\rm theory}$ lines around the observed limits are obtained by changing the SUSY cross section by $\pm 1\sigma$. All mass limits of supersymmetric particles quoted later in this section are derived from the $-1\sigma^{\rm SUSY}_{\rm theory}$ theory line. The yellow band around the expected limit shows the $\pm 1\sigma$ uncertainty, including all statistical and systematic uncertainties except the theoretical uncertainties on the SUSY cross section.

The most stringent limits are generally set by the 0/1 lepton + 3 b-jets + E_T^{miss} analysis, as shown on Fig. 1 for $\tilde{g}\to t\tilde{t}^{(*)}\to tt\tilde{\chi}_1^0$ and $\tilde{g}\to b\tilde{b}^{(*)}\to bb\tilde{\chi}_1^0$ processes. In both processes, gluino masses are excluded below $\sim$1.1 TeV for any stop mass, and for $\tilde{\chi}_1^0$ masses below $\sim$600 GeV. Similar limits are obtained for on-shell or off-shell $\tilde{t}^{(*)}$ and $\tilde{b}^{(*)}$ squarks.

In addition, Fig. 2 shows limits on gluino-mediated stop obtained when the $\tilde{t}$ is decayed through four different channels. Limits from up to 900 GeV to 1.3 TeV are set in each case. The top-left plot compares the sensitivity of the four analyses presented in Sec. 2, for $\tilde{g}\to t\tilde{t}^*\to tt^*\tilde{\chi}_1^0$ processes. The sensitivity is dominated by the 0/1 lepton + 3 b-jets + E_T^{miss} analysis, with contributions from the same-sign leptons analysis at small $\Delta M(\tilde{g},\tilde{\chi}_1^0)$. The top-right plot shows that nearly equally stringent limits are obtained by the 0/1 lepton + 3 b-jets + E_T^{miss} analysis when considering $\tilde{g}\to t\tilde{t}\to tb\chi_1^{\pm}$ processes instead. Together with Fig. 1, this demonstrates that $m_{\tilde{g}}\lesssim 1.1\ TeV$ is robustly excluded for on-shell or off-shell top and sbottom squarks of any mass, as long as they lead to four b-jets + E_T^{miss} signatures. The bottom plots of Fig. 2 show exclusion limits for specially challenging scenarios. On bottom-left, the $\tilde{t}\to c\tilde{\chi}_1^0$ process is considered, in which the on-shell top squark and stable neutralino have close-by masses, $\Delta M(\tilde{t},\tilde{\chi}_1^0)=20\ GeV$, which forces the top squark decay to a charm quark instead of a top quark and hence leads to a signature with only 2 b-jets. In this special case, the 0 lepton + [2-6] jets + E_T^{miss} search excludes gluino masses up to 1.1 TeV. However no models can be excluded for $\tilde{\chi}_1^0$ masses above $\sim$360 GeV. Finally, the bottom-right plot shows limits on the $\tilde{g}\to t\tilde{t}\to tbs$ process, where the stop decays through an R-Parity violating coupling [10] and does not produce experimental signatures with large E_T^{miss}. In this challenging scenario, the 0 lepton + [7-10] jets search still excludes gluino masses below 900 GeV, for any stop mass.

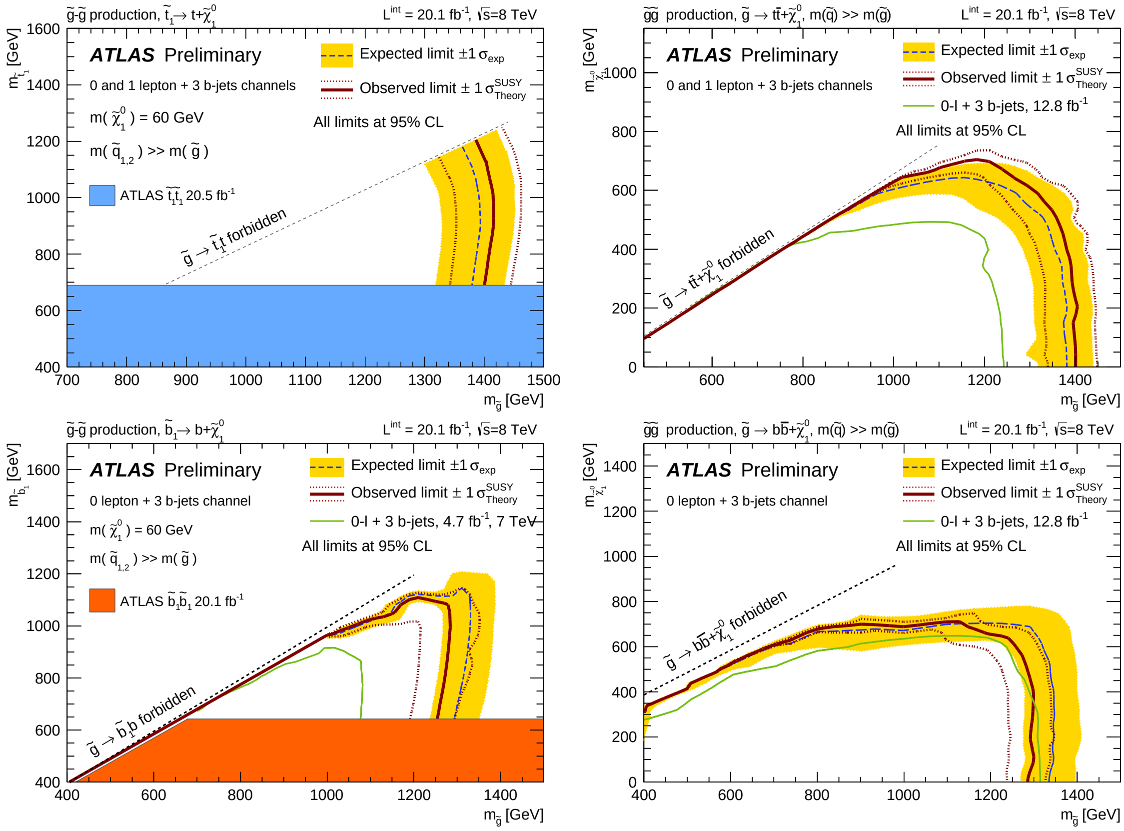

Figure 1: Top row: expected and observed limits for gluino-mediated stop, $\tilde{t}^{(*)} \to t\tilde{\chi}_1^0$, for $m_{\tilde{t}} < m_{\tilde{g}}$ (left) and $m_{\tilde{t}} > m_{\tilde{g}}$ (right). Bottom row: expected and observed limits for gluino-mediated sbottom, $\tilde{b}^{(*)} \to b\tilde{\chi}_1^0$, for $m_{\tilde{b}} < m_{\tilde{g}}$ (left) and $m_{\tilde{b}} > m_{\tilde{g}}$ (right). The blue region (top-left) shows exclusions from direct stop searches [7, 8]. The orange region (bottom-left) shows the exclusions from direct sbottom searches [9]. All other limits are set by the 0/1 lepton + 3 b-jets + E_T^{miss} analysis. All limits are computed at 95% CL.

4. Summary

Four searches for gluino-mediated production of third generation squarks with the ATLAS detector have been presented. No deviation from the Standard Model expectation is observed. Stringent and robust limits have been placed on gluino-mediated stop and gluino-mediated sbottom production, excluding $m_{\tilde{g}} \lesssim 0.9 - 1.3$ TeV for almost any stop and sbottom masses and decay scenarios. Gluino-mediated stop$\to c\tilde{\chi}_1^0$ is also excluded for $m_{\tilde{g}} \lesssim 1$ TeV and $m_{\tilde{\chi}_1^0} \lesssim 300$ GeV.

References

[1] ATLAS Collaboration, ATLAS-CONF-2013-061, http://cds.cern.ch/record/1557778

[2] ATLAS Collaboration, ATLAS-CONF-2013-047, http://cdsweb.cern.ch/record/1547563

[3] ATLAS Collaboration, accepted by JHEP, arXiv:1308.1841

[4] ATLAS Collaboration, ATLAS-CONF-2013-007, https://cds.cern.ch/record/1522430

[5] ATLAS Collaboration, ATLAS-CONF-2012-145, http://cdsweb.cern.ch/record/1493484

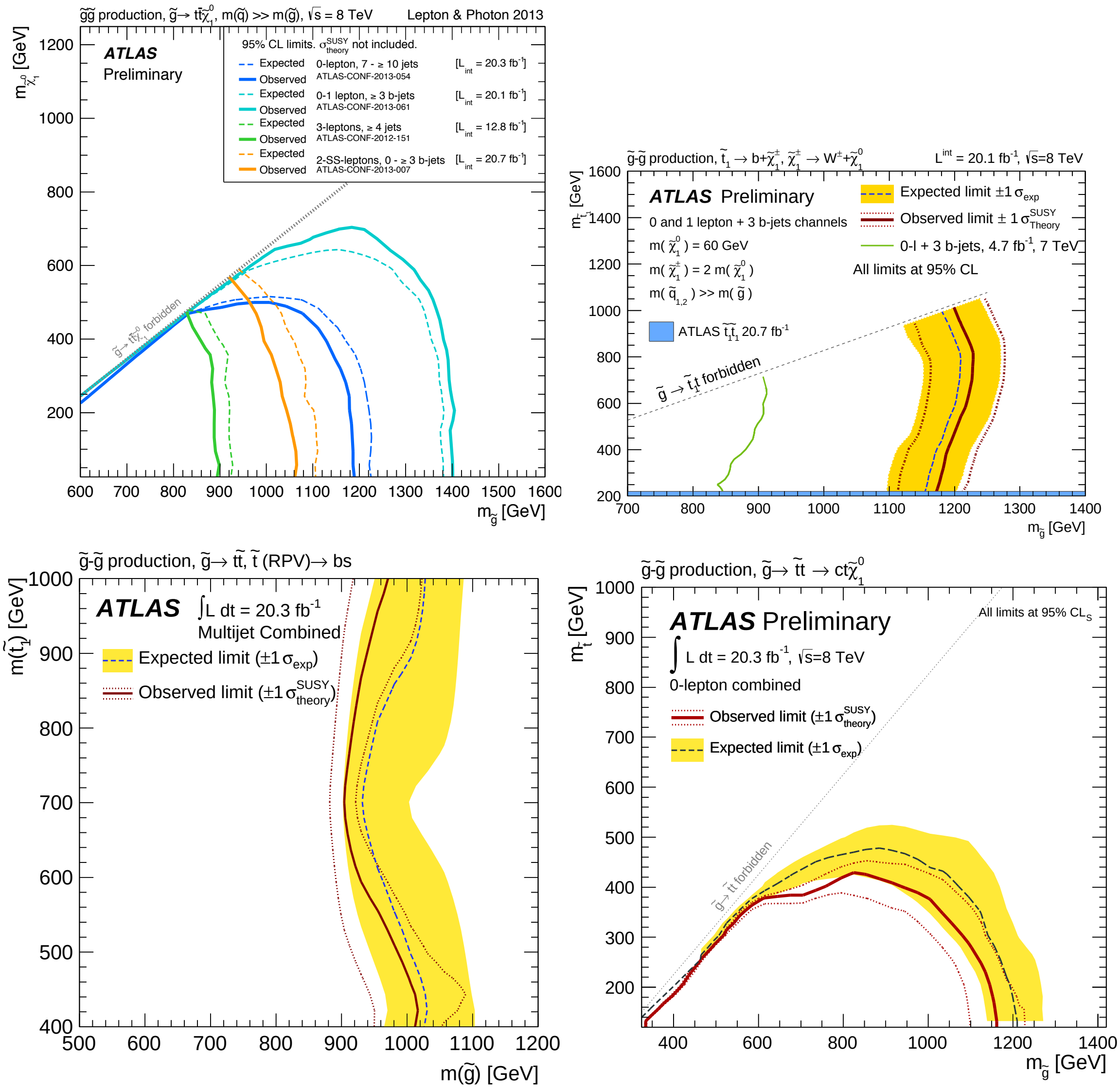

Figure 2: Expected and observed limits on gluino-mediated stop production, for four different decay channels: $\tilde{g} \to t\tilde{t}^* \to tt^*\tilde{\chi}_1^0$ (top-left), $\tilde{g} \to t\tilde{t} \to tb\tilde{\chi}_1^{\pm}$ (top right), $\tilde{g} \to t\tilde{t} \to tc\tilde{\chi}_1^0$ (bottom-left) and $\tilde{g} \to t\tilde{t} \to tbs$ (bottom-right). All models assume a stable $\tilde{\chi}_1^0$, except for the $\tilde{t} \to bs$ model in which the stop decays through an R-parity violating coupling. The limits are set by four different searches (see text). All limits are computed at 95% CL.

[6] ATLAS Collaboration, EPJC 72 (2012) 2174, arXiv:1207.4686

[7] ATLAS Collaboration, ATLAS-CONF-2013-024, http://cdsweb.cern.ch/record/1525880

[8] ATLAS Collaboration, ATLAS-CONF-2013-037, http://cdsweb.cern.ch/record/1533431

[9] ATLAS Collaboration, ATLAS-CONF-2013-053, http://cdsweb.cern.ch/record/1547570

[10] B.C. Allanach and Ben Gripaios, JHEP 1205 (2012) 062, arXiv:1202.6616