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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 $\sqrt{s} = 8\ TeV$ at the LHC are presented. The searches use a data sample collected with the ATLAS detector 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.

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1. Introduction

Supersymmetry (SUSY) is a generalisation 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 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, stop ($\tilde{t}$) and sbottom ($\tilde{b}$) – 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 bottom 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 + E_T^{miss}, and 2 same-sign leptons + 0-3 b-jets, and use a data sample collected with the ATLAS detector [5] 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 optimisation 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 optimised 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, optimised for $\tilde{g}\tilde{g} \to bb\tilde{b}\tilde{b}$, and 0 lepton + 7 jets and 1 lepton + 6 jets, optimised for $\tilde{g}\tilde{g} \to tt\tilde{t}\tilde{t}$. The reducible background coming from mis-identified b-jets is estimated with a data-driven method. The irreducible background coming from $t\bar{t} + b\bar{b}$, $t\bar{t} + Z(b\bar{b})$ and $t\bar{t} + H(b\bar{b})$ is estimated with Monte Carlo (MC) simulations. The 1-lepton SR is new and brings a lot of additional sensitivity compared to earlier searches [6, 7].

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 + E_T^{miss} analysis documented in Ref. [3] uses seven SRs with 8-10 jets of $p_T > 50\ GeV$ and six SRs with 7 or 8 jets of $p_T > 80\ GeV$. Three additional SRs exploit a novel technique based on jet substructure observables. The multijets background is estimated with a data-driven method based on the E_T^{miss} significance. The semileptonic $t\bar{t}$ background is determined

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

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. The reducible background coming from mis-identified leptons and charge mis-measurement is estimated with data-driven methods. 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 blue 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.

Figure 1 shows expected and observed limits set by the 0-1 lepton + 3 b-jets + E_T^{miss} analysis for pair-produced gluino-mediated stop (top & middle rows) and gluino-mediated sbottom (bottom row) processes resulting in final states with 4 b-quarks and stable $\tilde{\chi}_1^0$. Different stop and sbottom masses and decay channels are considered: $\tilde{g}\rightarrow t\tilde{t}\rightarrow tt\tilde{\chi}_1^0$ (top-left), $\tilde{g}\rightarrow t\tilde{t}\rightarrow tb\tilde{\chi}_1^{\pm}$ (top-right), $\tilde{g}\rightarrow t\tilde{t}^*\rightarrow tt\tilde{\chi}_1^0$ (middle-left), $\tilde{g}\rightarrow t\tilde{t}^*\rightarrow tb\tilde{\chi}_1^{\pm}$ and $\tilde{g}\rightarrow b\tilde{b}^*\rightarrow bt\tilde{\chi}_1^{\pm}$ (middle-right), $\tilde{g}\rightarrow b\tilde{b}\rightarrow bb\tilde{\chi}_1^0$ (bottom-left)) and $\tilde{g}\rightarrow b\tilde{b}^*\rightarrow bb\tilde{\chi}_1^0$ (bottom-right), where $\tilde{t}$ ($\tilde{b}$) means on-shell stop (sbottom) with $m_{\tilde{t}(\tilde{b})} < m_{\tilde{g}}$ and $\tilde{t}^*$ ($\tilde{b}^*$) means off-shell stop (sbottom) with $m_{\tilde{t}(\tilde{b})} > m_{\tilde{g}}$. Limits set by the 0 lepton + 7-10 jets + E_T^{miss} and same-sign leptons + 0-3 b-jets analyses are also shown for $\tilde{g}\rightarrow t\tilde{t}^*\rightarrow tt\tilde{\chi}_1^0$, together with limits set by a 3 leptons + jets analysis described in Ref. [8]. For all these models, the sensitivity is dominated by the 0-1 lepton + 3 b-jets + E_T^{miss} analysis, and gluino masses are excluded for values up to 1.1 - 1.3 TeV. Remarkably, this conclusion holds for off-shell and on-shell stop and sbottom squarks of nearly any mass and decay.

In addition, Figure 2 shows expected and observed limits on gluino-mediated stop processes in specially challenging scenarios. On the left, the process $\tilde{g}\rightarrow t\tilde{t}\rightarrow tc\tilde{\chi}_1^0$ is considered, in which the on-shell stop and stable neutralino have close-by masses, $\Delta M(\tilde{t},\tilde{\chi}_1^0) = 20$ GeV, which forces the stop to decay to a charm quark instead of a top quark and hence leads to a signature with only 2 b-jets. In this case, the 0 lepton + 2-6 jets + E_T^{miss} search excludes gluino masses below 1.1 TeV for $m_{\tilde{\chi}_1^0} < 200$ GeV. However no model can be excluded for $\tilde{\chi}_1^0$ masses above $\sim$360 GeV. On the right, the process $\tilde{g}\rightarrow t\tilde{t}\rightarrow tbs$ is considered, where the stop decays through an R-Parity violating coupling [9] and does not produce experimental signatures with large E_T^{miss}. In this case, the 0 lepton + 7-10 jets + E_T^{miss} search excludes gluino masses below 900 GeV, for any stop mass.

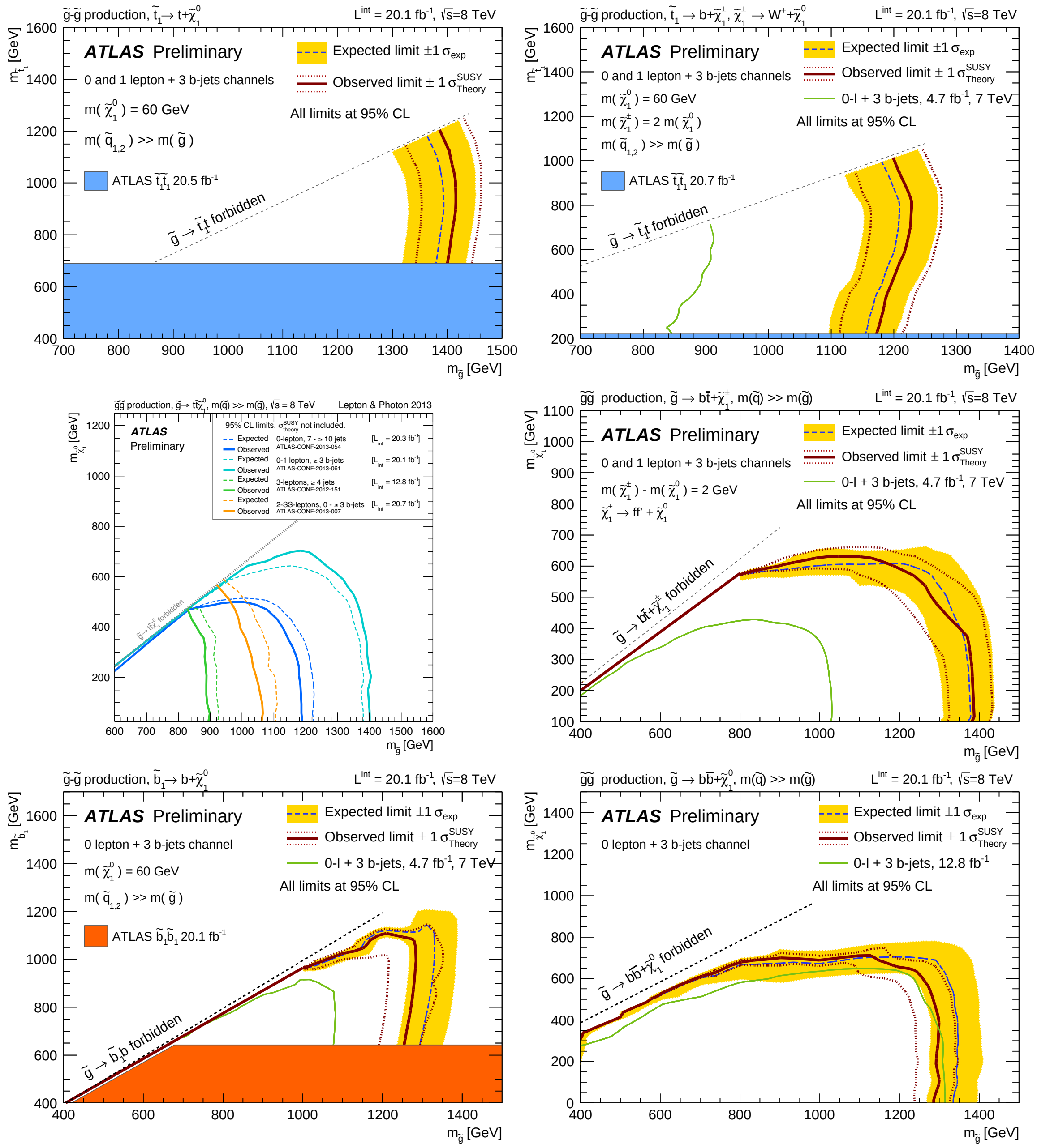

Figure 1: Expected and observed limits set by the 0-1 lepton + 3 b-jets + E_T^{miss} analysis for pair-produced gluino-mediated stop (top & middle rows) and gluino-mediated sbottom (bottom row) processes resulting in final states with 4 b-quarks and stable $\tilde{\chi}_1^0$. Different stop and sbottom masses and decay channels are considered: $\tilde{g} \to t\tilde{t} \to tt\tilde{\chi}_1^0$ (top-left), $\tilde{g} \to t\tilde{t} \to tb\tilde{\chi}_1^{\pm}$ (top-right), $\tilde{g} \to t\tilde{t}^* \to tt\tilde{\chi}_1^0$ (middle-left), $\tilde{g} \to t\tilde{t}^* \to tb\tilde{\chi}_1^{\pm}$ and $\tilde{g} \to b\tilde{b}^* \to bt\tilde{\chi}_1^{\pm}$ (middle-right), $\tilde{g} \to b\tilde{b} \to bb\tilde{\chi}_1^0$ (bottom-left)) and $\tilde{g} \to b\tilde{b}^* \to bb\tilde{\chi}_1^0$ (bottom-right), where $\tilde{t}$ ($\tilde{b}$) means on-shell stop (sbottom) with $m_{\tilde{t}(\tilde{b})} < m_{\tilde{g}}$, and $\tilde{t}^*$ ($\tilde{b}^*$) means off-shell stop (sbottom) with $m_{\tilde{t}(\tilde{b})} > m_{\tilde{g}}$. The middle-left plot shows limits set by four analyses described in Sec. 2. The blue regions (top row) show exclusions from direct stop searches [10, 11]. The orange region (bottom-left) shows exclusions from direct sbottom searches [12]. All limits are computed at 95% CL.

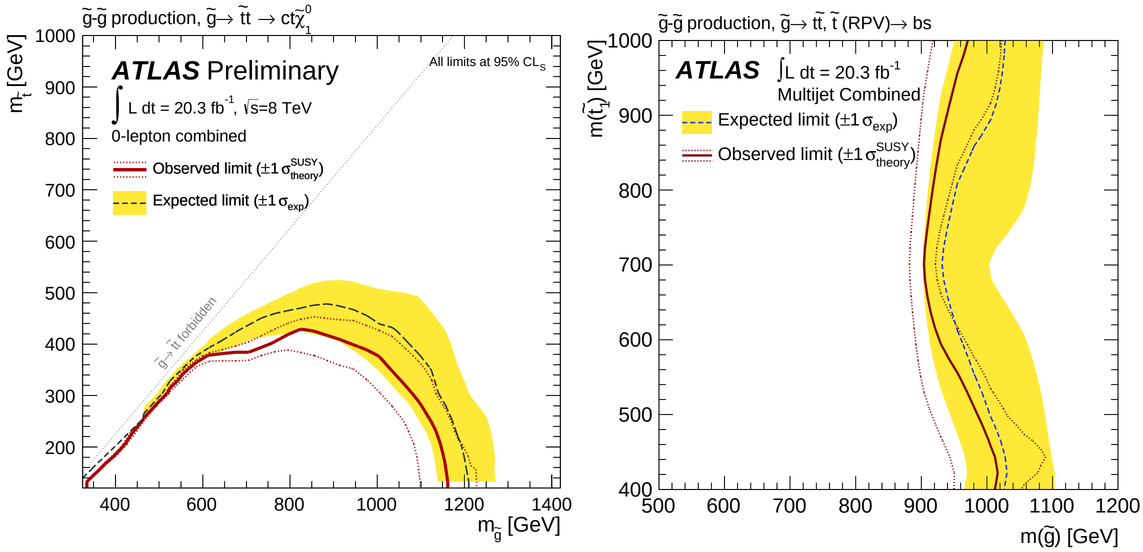

Figure 2: Expected and observed limits on gluino-mediated stop processes in specially challenging scenarios. Left: limits set by the 0 lepton + 2-6 jets + E_T^{miss} search when the stop decays to a charm quark and a stable neutralino: $\tilde{g} \to t\tilde{t} \to tc\tilde{\chi}_1^0$. Right: limits set by the 0-lepton + 7-10 jets + E_T^{miss} search when the stop promptly decays through an R-parity violating coupling: $\tilde{g} \to t\tilde{t}^{(*)} \to tbs$. 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. Gluino masses up to 1.1 - 1.3 TeV are excluded by a 0-1 lepton + 3 b-jets + E_T^{miss} search, nearly independently of the stop and sbottom masses and decay, in SUSY scenarios resulting in final states with 4 b-quarks and stable $\tilde{\chi}_1^0$. In specially challenging scenarios, gluino masses below 1.1 TeV from $\tilde{g} \to t\tilde{t} \to tc\tilde{\chi}_1^0$ processes are still excluded for $m_{\tilde{\chi}_1^0} < 200$ GeV by a 0 lepton + 2-6 jets + E_T^{miss} search, and gluino masses below 900 GeV from R-parity violating $\tilde{g} \to t\tilde{t} \to tbs$ processes are excluded by a 0 lepton + 7-10 jets + E_T^{miss} search. Stringent and robust limits have hence been placed on gluino pair-production processes expected to be dominant in natural SUSY scenarios.

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