THIRD GENERATION SUSY SEARCHES AT THE LHC

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The ATLAS and CMS experiments have recently searched for evidence of third generation squark production in a variety of final states, using proton-proton collision data from the Large Hadron Collider (LHC) operating at $\sqrt{s} = 8$ TeV. A summary of the most recent results obtained in these searches is presented.

1 Introduction

Supersymmetry (SUSY [1]) is an extension of the Standard Model (SM) which naturally resolves the hierarchy problem by introducing supersymmetric partners to the known fermions and bosons. In the framework of a generic R-parity conserving minimal supersymmetric extension of the SM (MSSM), 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,$\tilde{\chi}_1^0$, which only interacts weakly. The scalar partners of right-handed and left-handed quarks (squarks) can mix to form two mass eigenstates ($\tilde{q}_1$, $\tilde{q}_2$).

Naturalness arguments for weak-scale supersymmetry favour supersymmetric partners of the third generation quarks with masses not too far from those of their Standard Model counterparts. Production of third generation squarks (stop and sbottom, $\tilde{t}$, $\tilde{b}$) via decay of a gluino can be significant at the LHC if the mass of the gluino does not exceed the TeV scale. Stop and sbottoms with masses of a few hundred GeV can also give rise to direct pair production rates that can be observed in the data sample recorded by the ATLAS [2] and the CMS [3] detectors.

ATLAS and CMS have an extensive search program for third generation SUSY particles. These proceedings focus on new results that are interpreted in two simplified SUSY scenarios stemming from assumptions made regarding the mass spectrum: gluino-mediated and direct production of stops and sbottoms.

Production via gluino decay dominates if gluinos are not too heavy, i.e. less than about 1 TeV, and if the gluino decay branching fractions into stops or sbottoms are large. Assuming that the stop and sbottom squarks are heavier than the gluino ($\tilde{g}$), and additionally that the gluino is also heavier than the neutralino, indirect production is possible. The processes $\tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$ via an off-shell stop (*Gtt* scenario) and $\tilde{g}\tilde{g} \to b\bar{b}\tilde{\chi}_1^0 b\bar{b}\tilde{\chi}_1^0$ via an off-shell sbottom (*Gbb* scenario) are studied. Results are interpreted in this case in the $\tilde{g} - \tilde{\chi}_1^0$ mass plane.

In the direct production of third generation quarks scenario, four models of squark decay modes are considered. The sbottom can decay either via $\tilde{b} \to b\tilde{\chi}_1^0$ or $\tilde{b} \to t\tilde{\chi}_1^{\pm}$. For top squarks, the decays $\tilde{t} \to t\tilde{\chi}_1^0$ or $\tilde{t} \to b\tilde{\chi}_1^{\pm}$ are studied.

The final states of third generation squark production are typically extremely rich, they might include leptons (electrons or muons), multiple jets (some of which may be b-tagged), and

missing transverse energy ($E_T^{\rm miss}$). The signal is seeked in complementary search channels.

The dominant backgrounds are estimated by normalising the event yields in background dominated control regions to reduce their systematic uncertainties. Sub-dominant backgrounds (such as diboson or $t\bar{t}+W/Z$ production) are estimated using the MC simulation.

Where no significant signal is observed, limits can be set on SUSY models. The numbers of predicted and measured events in each signal region are translated into 95% confidence-level (CL) upper limits on contributions from new physics using the CLs prescription [4] with a profile log-likelihood ratio as a test statistic. The correlation of the systematic uncertainties between the signal and background is taken into account where appropriate.

All the analyses described below are performed using proton-proton collision data at $\sqrt{s} = 8$ TeV, unless stated otherwise.

2 Gluino-mediated stop and sbottom searches

One of the most sensitive analyses to the indirect production of sbottom and stop quarks specifically selects events with b-tagged jets, because the final state is rich in b-jets and top quarks. Both the ATLAS and CMS experiments have recently published some new results for gluino-mediated stop and sbottom production. In particular CMS published two new analyses selecting respectively all-hadronic [5] and single lepton [6] events. While ATLAS published a new analysis based on a same-sign dilepton selection [7].

The all-hadronic CMS analysis is based on events with large missing transverse energy, no isolated electron or muon, and at least three jets, at least one of which must be identified as a b-jet. A simultaneous examination of the number of events in exclusive bins of H_T, missing transverse energy, and b-jet multiplicity is performed, where H_T is the scalar sum of jet transverse momenta. The sample consists of an integrated luminosity of 19.4 fb^{-1} of proton-proton collision data recorded at a center-of-mass energy of 8 TeV. The results are interpreted in the context of the *Gtt* and *Gbb* models.

The analysis of final states with a single lepton (electron or muon) is also sensitive to the *Gtt* model. The same data sample of the all-hadronic analysis has been considered. Events with large missing transverse energy and multiple jets, at least two of which are tagged as originating from b-quarks, are used. The distributions of several kinematic variables are examined to discriminate signal from background using two complementary methods: the *Lepton Spectrum method* (LS) and the *Delta Phi method* (DP). In the LS method, the $E_T^{\rm miss}$ distribution is examined in events with a high H_T, while in the DP method, the angle between the lepton and W momentum vectors, $\Delta\phi(W,l)$, and the leptonic mass scale of the event, $S_T^{\rm lep} = \sqrt{p_T(W)^2 + M_T(W)^2}$, are used to suppress the $t\bar{t}$ background.

In both these analyses, based on 19.4 fb^{-1}, the event yields observed across several kinematic regions are consistent with SM backgrounds predicted using a mix of simulated event samples and control samples in the data.

The new ATLAS analysis presents the search for the production of supersymmetric particles decaying into final states with jets, b-jets, $E_T^{\rm miss}$ and two isolated leptons, e or μ, with the same electric charge (same-sign leptons). Three event classes are distinguished depending on the number of jets identified as originating from b-quark decays; zero (b-jet veto), at least 1 or 3 b-jets. The sample consists of an integrated luminosity of 20.7 fb^{-1}. No deviation from the Standard Model expectation is observed. In particular, focusing on processes that involve third generation susy particles, limits for the *Gtt* scenario are set.

Previous results from other additional channels are used to set limits in both the *Gbb* and *Gtt* scenarios. CMS presented an analysis using events with isolated same-sign leptons and at least two b-jets in the final state [8], which uses 10.5 fb^{-1}. The summary of observed and expected limits of the CMS dedicated searches for gluino pair production with gluino decaying via the

3-body decay top anti-top neutralino is shown in Fig. 1(a).

ATLAS published two all-hadronic analyses [9,10], which use respectively 12.8 fb^{-1} and 5.8 fb^{-1}. The former requires events with large $E_T^{\rm miss}$, at least 4 or 6 jets and at least three jets originating from b-quarks, and the latter requires $E_T^{\rm miss}$ and from at least 6 to at least 9 jets. ATLAS also presented an analysis [11] based on 13.0 fb^{-1} that uses events with three leptons, at least 4 jets, and $E_T^{\rm miss}$.

3 Direct stop and sbottom searches

The new ATLAS two same-sign lepton analysis described in Sec. 2 is also used to set limits on direct sbottom pair production, via the decay channel $\tilde{b} \to t\tilde{\chi}_1^{\pm}$ followed by $\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$. Two scenarios are considered which make different assumptions about the mass relationship between the chargino and neutralino. In the first case, the assumption $m_{\tilde{\chi}_1^{\pm}} = 2 \times m_{\tilde{\chi}_1^0}$ is made, and in the second scenario, the neutralino mass is fixed to $m_{\tilde{\chi}_1^0} = 60$ GeV. Final states consist of pairs of top quarks, W bosons (real or virtual) and missing transverse momentum. Same-sign dilepton combinations arise from the decays of the top quarks and the W bosons. Limits are expressed as a function of the $\tilde{b}$ and $\tilde{\chi}_1^{\pm}$ masses. Under the assumption $m_{\tilde{\chi}_1^0} = 60$ GeV, sbottom masses of 470-480 GeV are excluded with 95% CL for chargino masses below 280 GeV. Similar limits on bottom squark masses are obtained in the other model for chargino masses up to 250 GeV.

ATLAS and CMS also presented other searches for direct sbottom pair production in both the $\tilde{b} \to t\tilde{\chi}_1^{\pm}$ and $\tilde{b} \to b\tilde{\chi}_1^0$. In particular ATLAS presented a search for direct pair production of bottom squarks, each decaying into a bottom quark and a neutralino, in events with large missing transverse momentum and 2 b-jets in the final state [12] using 12.8 fb^{-1}. The CMS two same-sign lepton analysis cited in Sec. 2 includes also a search for direct sbottom pair production decaying in $\tilde{b} \to t\tilde{\chi}_1^{\pm}$. CMS also presented an analysis focusing on the $\tilde{b} \to b\tilde{\chi}_1^0$ scenario selecting final states with 2 or 3 jets, one or two of which must be identified as a b-jet, and missing transverse energy [13]. The data sample corresponds to an integrated luminosity of 11.7 fb^{-1}.

Direct stop production has been covered in ATLAS and CMS by multiple dedicated searches, targeting different stop masses and decays. New results have been recently published. CMS presented a search for direct stop pair production in susy *R-Parity Violation* models (RPV) with leptons [14], while ATLAS presented two new analyses selecting respectively all-hadronic [15] and leptons in association with Z boson [16].

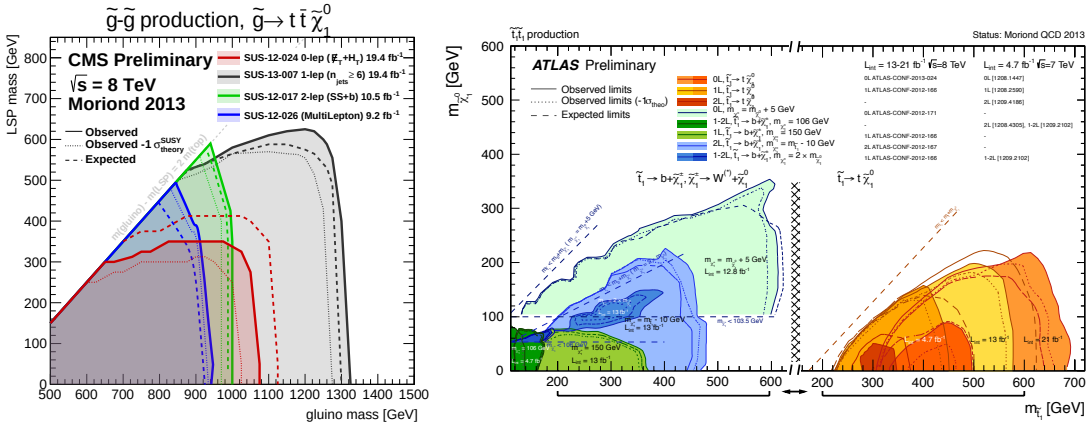
The new CMS analysis presents a search for pair production of top squarks in multilepton (at least three isolated leptons) events with one or more b-jets. The data used in this analysis correspond to 19.5 fb^{-1}. The search results are interpreted in the context of supersymmetric models with diminished missing transverse energy signatures arising from light stop pair production with RPV decays of the lightest supersymmetric particle. No excesses above the Standard Model expectations are observed.

The all-hadronic ATLAS analysis is conducted in events with large missing transverse momentum and at least 6 jets, at least two of which b-jet. The data sample correspons to an integrated luminosity of 20.5 fb^{-1}. Observations are consistent with SM expectations and exclusion limits have been placed in a model of top squark pair production, followed by the decay $\tilde{t} \to t\tilde{\chi}_1^0$.

The other new ATLAS analysis uses events with a Z boson, b-jets and large missing transverse momentum in final states with two or three leptons forming a same-flavour opposite-sign lepton pair with invariant mass consistent with the Z boson mass. The analysis is performed with 20.7 fb^{-1}. Also in this case no excess beyond the Standard Model expectation is observed. Interpretations of this result are provided for two different scenarios. The first one consist in natural gauge-mediated supersymmetry breaking scenarios where the neutralino, coming from

$\tilde{t} \to b\tilde{\chi}_1^{\pm}$ with $\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$, is the *next-to-lightest supersymmetric particle* (NLSP) producing a Z boson and a gravitino ($\tilde{G}$) in the $\tilde{\chi}_1^0 \to Z\tilde{G}$ decay. The neutralino and chargino masses are assumed to be similar. The second scenario addresses models based on the direct production of heavy stop states ($\tilde{t}_2$) that decay to stop states ($\tilde{t}_1$) via $\tilde{t}_2 \to Z\tilde{t}_1$. In this scenario the first limits of this kind are set excluding with 95% confidence level the parameter space regions with $m_{\tilde{t}_2} < 530$ GeV and $m_{\tilde{\chi}_1^0} < 245$ GeV.

Several analyses in different final states are used to set exclusion limits in direct stop pair production scenarios, targeting again different stop masses and decay. CMS presented two analyses using respectively events with E_T^{miss}, one lepton and at least 4 jets (at least 1 b-jet) [17] with 9.7 fb^{-1}, and all-hadronic multijet events with E_T^{miss} [18] with 4.98 fb^{-1} collected with proton-proton collision data at $\sqrt{s} = 7$ TeV. ATLAS published three analyses based on events with respectively two leptons and E_T^{miss} [19] with 13.0 fb^{-1}, one lepton, at least 4 jets and E_T^{miss} [20] with 13.0 fb^{-1}, and zero leptons, 2 b-jets and E_T^{miss} [21] with 12.8 fb^{-1}. The summary of observed and expected limits of the ATLAS dedicated searches for direct stop pair production is shown in Fig. 1(b).



(a) (b)

Figure 1: CMS: summary of observed and expected limits of the dedicated searches for gluino pair production with gluino decaying via the 3-body decay top anti-top neutralino (a) [22]; ATLAS: summary of observed and expected limits of the dedicated searches for direct stop pair production (b) [23]

4 Conclusions

ATLAS and CMS are conducting a comprehensive set of searches sensitive to both indirect and direct production of third generation squarks. These proceedings give a summary of such searches, with emphasis on new results. The individual searches are sensitive to different complementary regions of the SUSY parameter space with sufficient overlap. Observed data are consistent with the SM background expectation, and exclusion limits are set on squark masses for the *Gbb*, *Gtt* and direct production models. The parameter space given by the naturalness argument is being filled up, but many other results using the complete 2012 data set are forthcoming.

There is so far no sign of physics beyond the SM. However, much of the parameter space remains to be probed, and the search for SUSY at the LHC will continue to be vigorously pursued.

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