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ATLAS and CMS searches for third generation SUSY particles

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Recent highlights of searches for supersymmetric partners of the top and bottom quark (top and bottom squark) in a variety of final states are presented. The ATLAS and CMS collaborations have published a large range of results using the respective proton-proton collision data at $\sqrt{s} = 13$ TeV collected during the LHC Run 2. No significant deviations from the expected SM background rates are observed. Stringent constraints on top and bottom squark masses have been placed, reaching up to 1.3 TeV for some simplified models with a massless lightest neutralino (LSP). These limits are decreased for models with smaller mass splitting between the third generation squarks and the LSP as well as models involving cascade decays or R-parity violating couplings. Interpretations in terms of leptoquark or simplified dark matter models highlight the impact of these results beyond SUSY models.

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1. Searches for direct top squark production

Searches for third generation SUSY particles are well motivated by naturalness arguments and their distinct experimental signatures. This document highlights a selection of new results based on the entire proton-proton collision data set collected by the ATLAS and CMS experiments [1, 2] during Run 2 of the LHC.

Direct top squark pair production with prompt decays to top quarks and the lightest neutralino (LSP), $\tilde{t} \rightarrow t\tilde{\chi}_1^0$, yields final states with 0, 1 or 2 charged leptons that are covered by a large search program [3–8]. A variety of simplified models [9] are considered for the interpretation of these results. In the CMS Run 2 search in the all-hadronic final state [6] events with large $p_{\mathrm{T}}^{\mathrm{miss}}$, expected to arise from the LSP, are selected. Novel tools to reconstruct hadronic decays of top quarks that employ machine learning have been implemented in this search in order to reduce substantial backgrounds from semileptonic $t\bar{t}$ decays where the charged lepton is lost. Kinematics of the final state depend on the details of the model, most importantly the mass splitting $\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}_1^0}$. Sensitivity to different signal scenarios is maximized by defining a large set of signal categories based on kinematic variables, jet and b-tagged jet multiplicities as well as numbers of hadronic top quark and W boson candidates.

Sensitivity is further enhanced by performing a statistical combination with searches in the leptonic final states [7, 8], resulting in constraints on top squark and LSP masses that are shown in Fig. 1 [10]. Additionally, a dedicated analysis in the dilepton final state targeting signal models with top squark masses very close to the top quark mass ("top corridor") has been performed. A parametric neural network [11] is employed in order to distinguish SUSY signal and the $t\bar{t}$ background in this region of parameter space.

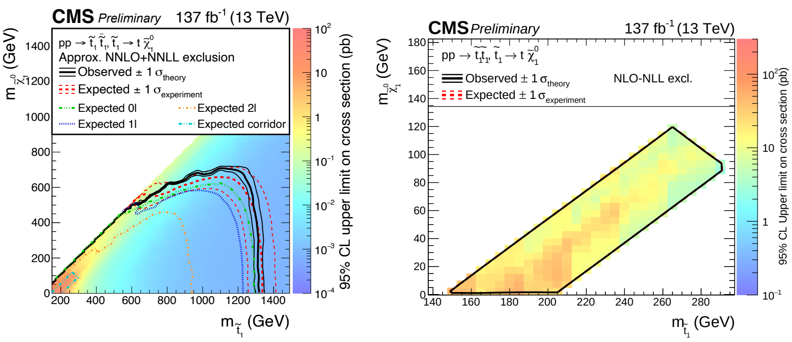

Figure 1: Left: Expected limits for direct top squark pair production with prompt decays $\tilde{t} \rightarrow t\tilde{\chi}_1^0$ for the individual and combined CMS analyses, as well as the combined observed limit [10]. Right: Detail view of the cross section limits in the top corridor region, obtained by a dedicated CMS analysis [10].

The searches discussed above are designed to be sensitive to a large set of signal scenarios. However, tau leptons are usually not explicitly considered, reducing sensitivity to GMSB motivated models of top squark pair production as shown in Fig. 2. In this model the tau slepton $\tilde{\tau}$ is the only particle that decays to the almost massless gravitino LSP $\tilde{G}$. The ATLAS analysis [12] selects events with b-tagged jets, hadronically decaying tau leptons and $p_{\mathrm{T}}^{\mathrm{miss}}$. A signal category that requires just one hadronically decaying tau lepton is added to enhance sensitivity to signal models with small mass splitting between $\tilde{\tau}$ and $\tilde{G}$. Exclusion limits as functions of $m_{\tilde{t}}$ and $m_{\tilde{\tau}}$ are shown in Fig. 3.

Leptoquark models that could explain recently observed flavor anomalies [13–21] can produce a similar final state containing b jets and taus [22, 23]. The leptoquarks either decay into a top quark and neutrino, or a bottom quark and a tau. The free parameters of the model are the leptoquark mass and its decay branching fraction. Only single tau signal regions are used for this interpretation, and resulting constraints are shown in Fig. 3. A dedicated CMS analysis is discussed in [24].

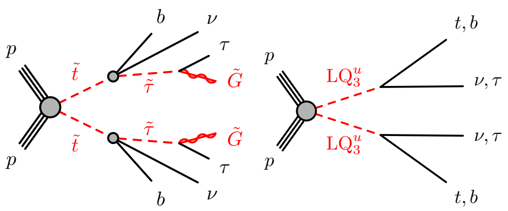

Figure 2: GMSB model of top squark pair production with an almost massless gravitino LSP (left), leptoquark model producing a similar final state (right) [12].

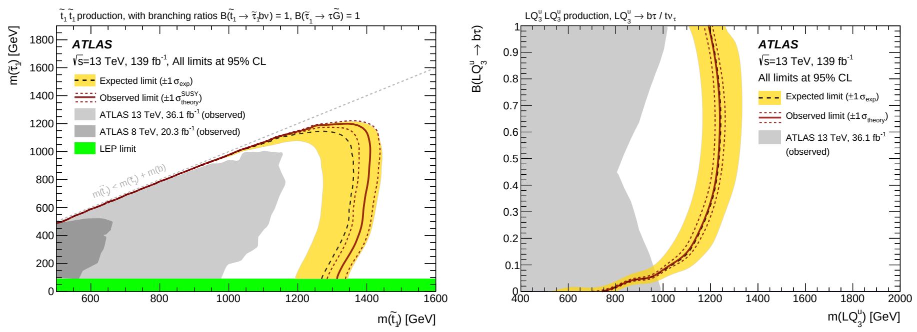

Figure 3: Exclusion limits for the GMSB model as function of $m_{\tilde{t}_1}$ and $m_{\tilde{\tau}_1}$ assuming a massless gravitino $\tilde{G}$ (left). Constraints on the leptoquark model depend on the leptoquark mass and branching fraction (right) [12].

2. Searches for bottom squark production

Several searches for bottom squark production have been carried out by the ATLAS collaboration [25, 26], with some of the obtained constraints shown in Fig. 4. The b-jet + $p_{\mathrm{T}}^{\mathrm{miss}}$final state is sensitive to models with prompt bottom squark decays $\tilde{b}_1 \to b\tilde{\chi}_1^0$ as well as simplified dark matter or leptoquark models. Recoiling jets from initial state radiation are required for enhanced sensitivity to signal models with low mass splitting $\Delta m = m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0}$. A boosted decision tree with low and high level inputs is used for medium Δm signals, while the high Δm signal category is optimized using kinematic variables. For a different mixture of the bottom squark the branching fraction $\tilde{b}_1 \to b\tilde{\chi}_2^0$ can be enhanced, leading to a cascade decay that e.g. involves $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$, depending on the nature of $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$. The Higgs boson in this decay chain opens up a large variety of different final states. A dedicated search in final states with tau leptons, targeting $h \to \tau\tau$ decays, has led to enhanced constraints on this simplified model for low $m_{\tilde{\chi}_2^0}$ where reduced sensitivity is observed in a previous $h \to b\bar{b}$ analysis [27].

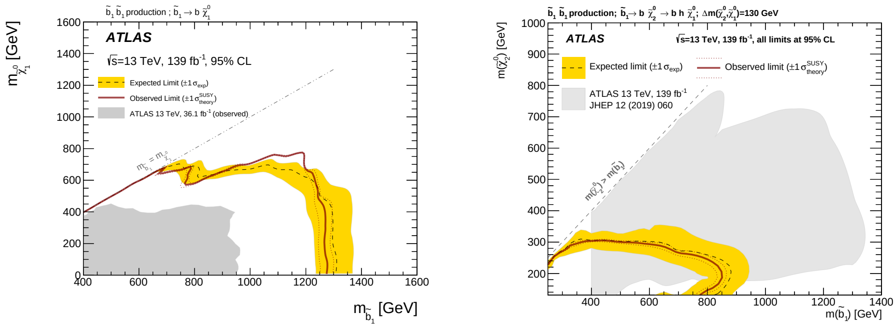

Figure 4: Exclusion limits as function of the $m_{\tilde{b}_1}$ and $m_{\tilde{\chi}_1^0}$ in the $\tilde{b}_1 \to b\tilde{\chi}_1^0$ model (left) [25], and as function of the $m_{\tilde{b}_1}$ and $m_{\tilde{\chi}_2^0}$, assuming $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = 130$ GeV, in the $\tilde{b}_1 \to b\tilde{\chi}_2^0 \to bh\tilde{\chi}_1^0$ model (right) [26].

3. Searches for R-parity violating top squarks

Final states without significant $p_{\mathrm{T}}^{\mathrm{miss}}$ arise in SUSY models that violate R-parity (RPV) or models with a stealth sector [28]. In such a RPV model the $\tilde{\chi}_1^0$ decays to quarks via a baryon number violating coupling, $\tilde{\chi}_1^0 \to qqq$, resulting in a large number of jets.

A dedicated CMS analysis [29] selects events with a single charged lepton, b-tagged jets and additional light-flavor jets. The leading background from $t\bar{t}$ production with a large number of additional jets is challenging to predict directly from simulation. Therefore, a data driven background prediction using jet scaling functions [30] is chosen. The resulting distribution of N_{jets} is shown in Fig. 5 together with the resulting limits on top squark masses.

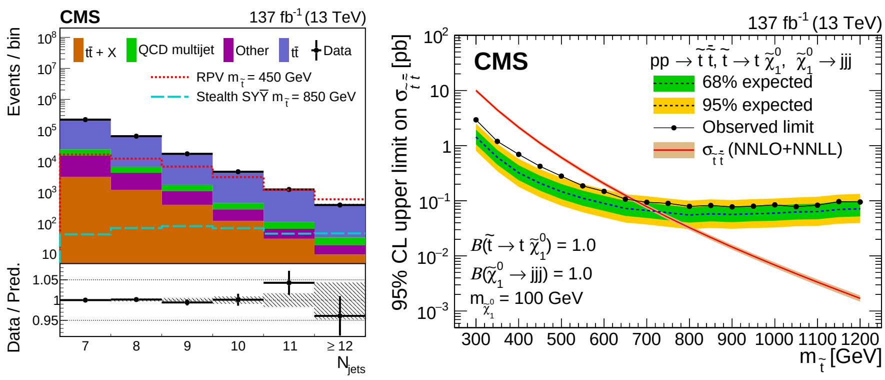

Figure 5: Expected signal and background rates as function of jet multiplicity (left), resulting limits on top squark masses for the RPV model (right) [29].

4. Conclusions

Results from both ATLAS and CMS put very tight constraints on natural top and bottom squarks in many simplified models, with limits reaching up to masses of 1.3 TeV and above. Several dedicated searches and interpretations constrain a similar mass range even for more complex decay chains like cascade decays or R-parity violating SUSY.

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