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Searches for direct pair production of third generation squarks with the ATLAS detector

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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. This article presents recent results of the ATLAS experiment searches for direct top and bottom squark pair production at the LHC. No evidence of deviations from the Standard Model prediction has been found, and limits have been placed on the masses of the top and bottom squarks for different assumptions on their decay mode and on the mass of the lightest supersymmetric particle.

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1. Introduction

Supersymmetry (SUSY) is an extension of the Standard Model (SM) which introduces a bosonic (fermionic) partner for each known fermion (boson). In the R-parity conserving supersymmetric models, SUSY particles are produced in pairs and the lightest of them, in many models the lightest neutralino $\tilde{\chi}_1^0$, is stable and provides a dark matter particle candidate.

SUSY can naturally resolve the hierarchy problem: if the supersymmetric partner of the top quark (top squark or stop) has a mass below the TeV range, loop diagrams involving the top quarks, which are the dominant contribution to radiative corrections to the Higgs mass, can be canceled to a large extent. A light bottom squark is also likely because the partners of the left-handed top and bottom squarks share the same mass term in the SUSY-breaking Lagrangian. This motivates the searches for direct pair production of third generation squarks at the LHC.

Here, recent searches performed by the ATLAS collaboration with 20 fb^{-1} of 8 TeV proton-proton collision data are reported.

2. Bottom squark searches

The ATLAS experiment [1] has addressed the direct pair production of bottom squarks in complementary search channels, in order to be sensitive to different possible decay modes.

The analysis described in [2] selects events with two b-jets and large missing transverse momentum, and it is sensitive to the $\tilde{b}_1 \to b\tilde{\chi}_1^0$ decay mode. A selection requiring large values of invariant and cotransverse [3] mass of the two b-jets is sensitive to large values of $m(\tilde{b}_1) - m(\tilde{\chi}_1^0)$. Sensitivity to small values of this mass difference is achieved looking for events with a hard jet produced by initial and final state radiation: the leading jet is required not to be tagged, and events with large transverse missing momentum and small values of $H_T = \Sigma p_T$ are selected, where the (scalar) sum of transverse momenta is performed over all the jets except the leading three. The observed number of events is in agreement with the SM expectations for both selections, and the resulting limits in the $m(\tilde{b}_1), m(\tilde{\chi}_1^0)$ plane are shown in the left part of Fig. 1.

The analysis described in [4] selects events with two same sign leptons and it is sensitive to the $\tilde{b}_1 \to t\tilde{\chi}_1^\pm \to tW^{(*)}\tilde{\chi}_1^0$ decay mode; the limits placed by the analysis on the $m(\tilde{b}_1), m(\tilde{\chi}_1^\pm)$ plane for $m(\tilde{\chi}_1^0) = 60$ GeV are shown in the right part of Fig. 1. Finally, an analysis dedicated to the channel [5] with three b-jets in the final state has placed limits on models with $\tilde{b}_1 \to b\tilde{\chi}_2^0 \to bh\tilde{\chi}_1^0$ where h is the CP-even Higgs boson.

3. Top squark searches

Evidence for direct production of pairs of top squarks, each decaying to a top quark and a neutralino or a b-quark and a chargino, has been investigated in final states with jets, missing transverse momentum, and zero [6], one [7], or two leptons [8]. Another dedicated search [9] addresses the decay mode in charm and neutralino. In the following, more details are given on recent results from the two-lepton channel searches and from the charm-neutralino decay mode search.

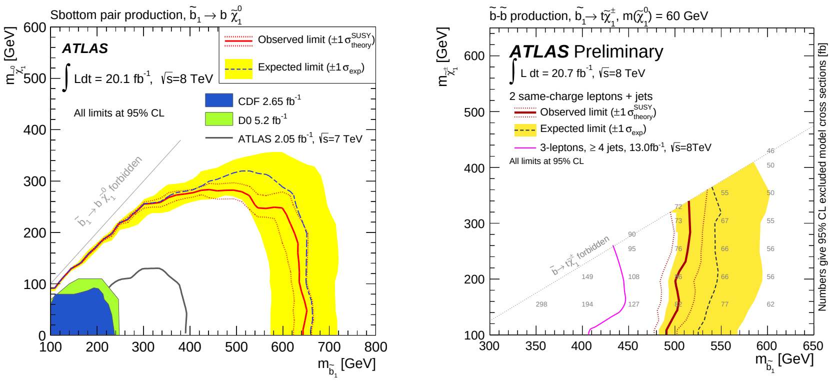

Figure 1: Left: Exclusion limits at 95% confidence level (CL) on the masses of the lightest bottom squark and neutralino, assuming that the decay $\tilde{b}_1 \to b\tilde{\chi}_1^0$ proceeds with 100% branching ratio (BR). Right: exclusion limits at 95% CL on the masses of the lightest bottom squark and chargino, assuming $m(\tilde{\chi}_1^0) = 60$ GeV and BR($\tilde{b}_1 \to t\tilde{\chi}_1^{\pm} \to tW^{(*)}\tilde{\chi}_1^0$) = 1.

3.1 Two lepton decay mode

The pair production of top squarks decaying as $\tilde{t} \to b\tilde{\chi}_1^{\pm} \to bW^{(*)}\tilde{\chi}_1^0$ has been searched for by selecting events with two isolated electrons or muons, transverse missing momentum, and exactly two b-jets. The momenta of the two b-jets and the missing transverse momentum, to which the lepton momenta are added, are used to compute the m_{T2} variable [10], which is required to be larger than 160 GeV. This selection suppresses the background from top pair production while retaining sensitivity to a signal with large values of $m(\tilde{t}) - m(\tilde{\chi}_1^{\pm})$. This sensitivity is complementary to that of a previous search [11] which selected large values of the m_{T2} of the lepton pair instead.

The observed event rates are in agreement with the Standard Model expectations, and limits are derived on the mass of the lightest chargino and neutralino under the assumption of a 300 GeV mass for the top squark (Fig. 2).

Another analysis uses events with two isolated electrons and muons to seek evidence for a supersymmetric signal with $\tilde{t}_1 \to t\tilde{\chi}_1^0$. A boosted decision tree algorithm (BDTG) is used to separate the signal from the Standard Model backgrounds. Seven signal selections are defined for events with an $e\mu$ pair and four for events with same flavor (ee or $\mu\mu$) pairs, with different selections optimized for different hypothesis on the mass of the top squark and lightest neutralino. Events with lower (more background-like) values of the BDTG output are used to normalize the top pair production background to the observed rate in data. No evidence for a signal is found for any of the signal selections, and limits are derived on the masses of the top squark and lightest neutralino. In the right plot of Fig. 2 a summary of the limits obtained by the ATLAS searches on the masses of these particles, assuming BR($\tilde{t}_1 \to t\tilde{\chi}_1^0$) = 1, is reported.

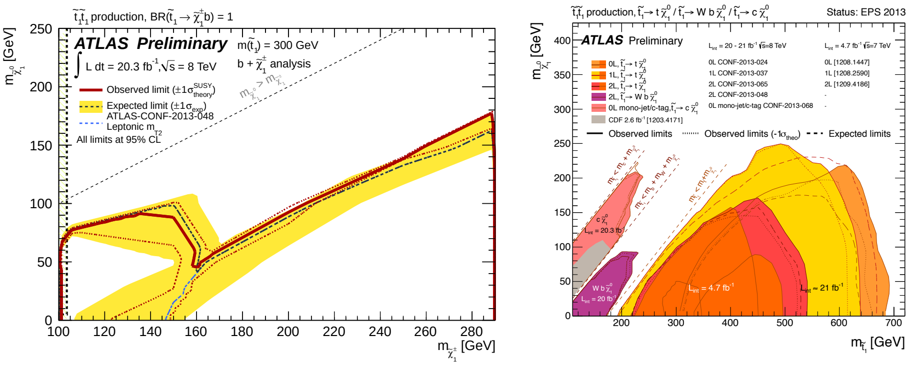

Figure 2: Left: Exclusion limits at 95% confidence level (CL) on the masses of the lightest chargino and neutralino, assuming that the decay $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$ proceeds with 100% branching ratio (BR) and for a top squark mass of 300 GeV. Right: exclusion limits at 95% CL on the masses of the lightest top squark and neutralino, assuming BR($\tilde{t}_1 \to t\tilde{\chi}_1^0$) = 1.

3.2 Charm neutralino decay mode

If the mass difference Δm between the lightest top squark and the lightest neutralino is smaller than the sum of the W boson and b-quark masses, then the dominant decay mode of the top squark might be the loop decay to a charm quark and the lightest neutralino. Two analyses have been performed by the ATLAS collaboration, which target this challenging scenario. Both analyses rely on the presence of a hard jet produced by initial or final state radiation and large missing transverse momentum to trigger signal candidate events, and place a veto on the presence of isolated electrons or muons in the event. The "mono-jet" selection then requires one jet with $p_T > 280$ GeV, at most two other jets with $p_T > 30$ GeV and pseudo-rapidity $|\eta| < 2.8$, and missing transverse momentum larger than 220 GeV. This selection has the best sensitivity for very small values of Δm, for which it is difficult to detect the two charm jets produced by the top squark decay. The "charm-tagged" selection requires instead one jet with $p_T > 270$ GeV, at least three other jets (beside the leading jet) with $p_T > 30$ GeV and $|\eta| < 2.8$, and missing transverse momentum larger than 410 GeV. The fourth jet (in order of decreasing p_T) is required to be a charm jet candidate. The tagging of charm jets is performed by a multivariate algorithm which provides light (P_u), charm (P_c), and b (P_b) hypothesis weights. Cuts on $\log(P_c/P_u)$ and $\log(P_c/P_b)$ allow charm jets to be separated from light and b-jets respectively. The value of the cuts used in the analysis correspond to an identification efficiency for charm jets of about 20%, while the rejection factor for light and b-jets is 140 and 5 respectively.

The production of W and Z bosons in association with hadronic jets is an important background for both analyses. These backgrounds are estimated with Monte Carlo event samples using data in control regions: events with a single muon or a single electron provide a selection dominated by W+jets while events with two muons with an invariant mass compatible with a Z boson decay provide a control sample populated by Z+jets events. The top pair background is a very small background for the mono-jet selection and it is estimated by Monte Carlo, while it is important for the charm tagged selection and it is estimated with Monte Carlo samples normalized in a top-enriched control region. The small background contributions from diboson and single top-quark production

Signal Region	M1	C1
Observed events (20.3fb^{-1})	30793	25
SM prediction	29800 ± 900	29 ± 7
$W(\to e\nu)$	2700 ± 420	0.5 ± 0.3
$W(\to \mu\nu)$	2900 ± 330	0.8 ± 0.4
$W(\to \tau\nu)$	6600 ± 300	7 ± 4
$Z(\to \nu\bar{\nu})$	15600 ± 900	10 ± 5
$Z/\gamma^{\star}(\to e^+e^-)$	-	-
$Z/\gamma^{\star}(\to \mu^+\mu^-)$	50 ± 28	0.01 ± 0.01
$Z/\gamma^{\star}(\to \tau^+\tau^-)$	80 ± 24	0.09 ± 0.04
Top	700 ± 86	7 ± 3
Dibosons	900 ± 420	2 ± 2
Multijets	340 ± 340	-

Table 1: Data and background prediction in the signal region for the mono jet (M1) and charm tagged (C1) selections.

are taken from Monte Carlo for both analyses, while the multi-jet background is extracted from data but found to be very small.

The observed and expected event rates are reported in Table 1: the observation is consistent with the Standard Model hypothesis for both selections. The limits placed on the masses of the lightest stop and neutralino are reported in Fig. 3, under the hypothesis that BR$(\tilde{t}_1 \to c\tilde{\chi}_1^0) = 1$. The analysis extends considerably the previous limits from the LEP experiments and CDF, excluding at 95% confidence level a top squark lighter than 200 GeV for $\Delta m < 85$ GeV.

4. Conclusions

ATLAS is conducting a comprehensive set of searches for third generation scalar quarks. The last results, presented here, probed the existence of top squark decaying into a b quark and a chargino, a top quark and a neutralino, or a charm quark and a neutralino. No excess in data compared to the Standard Model expectation has been observed.

References

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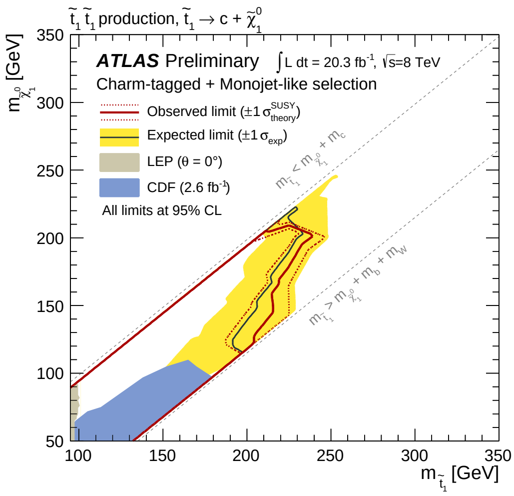

Figure 3: Left: Exclusion limits at 95% confidence level (CL) on the masses of the lightest top squark and neutralino, assuming $BR(\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0) = 1$.

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