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Searches for direct pair production of third generation squarks in 13 TeV pp collision data in final states with leptons with ATLAS

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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. Top or bottom squarks with masses less than or around one TeV can thus give rise to direct pair production rates at the LHC that can be observed in the recent data sample recorded by the ATLAS detector at the centre-of-mass energy of 13 TeV. This proceedings contribution summarises recent ATLAS results from searches for direct stop and sbottom pair production in final states with one or more charged leptons.

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1. Introduction

Supersymmetry (SUSY) [1] provides an extension of the Standard Model (SM) that solves the hierarchy problem by introducing partners of the known bosons and fermions. In the framework of R-parity conserving models, SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP) is stable, providing a possible candidate for dark matter [2, 3]. In a large variety of models, including the ones considered here, the LSP is the lightest neutralino ($\tilde{\chi}_1^0$). Naturalness considerations [4, 5] suggest that the supersymmetric partners of the third-generation SM quarks are the lightest coloured supersymmetric particles. This may lead to relatively large pair production cross-sections of the lightest bottom squark ($\tilde{b}_1$) and top squark ($\tilde{t}_1$) at the Large Hadron Collider (LHC).

Dedicated searches for these particles have been developed within the ATLAS Collaboration search programme. The optimisation of these searches and the interpretation of the results have all been performed under a few common assumptions. A minimal supersymmetric extension of the SM conserving R-parity is assumed, where all particles are produced in pairs and decay in a chain of SUSY and SM particles down to the LSP. The LSP is stable and escapes the detector without interacting. The models used for the search optimisation are simplified models [6] where only a few SUSY particles ($\tilde{t}_1, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0$ and in some cases $\tilde{t}_2$ or $\tilde{\chi}_2^0$) compose the low-mass SUSY spectrum. Unknown sparticle masses are free parameters and each specific decay is assumed to occur with a 100% branching ratio (BR). In an attempt to broaden the interpretation of the results of these searches for third generation squarks, an additional set of models is considered, chosen to benchmark more complex decay patterns and phenomenology within the context of the Minimal Supersymmetric Standard Model (MSSM). These models are categorised as a function of the higgsino and electroweak gaugino content of the lightest neutralino and chargino mass eigenstates, after the mixing caused by the electroweak symmetry breaking. The mass spectrum relevant to each scenario, described in more details in the following, is schematically represented in Figure (1). The masses of all other SUSY particles are set to values much higher than the top squark mass.

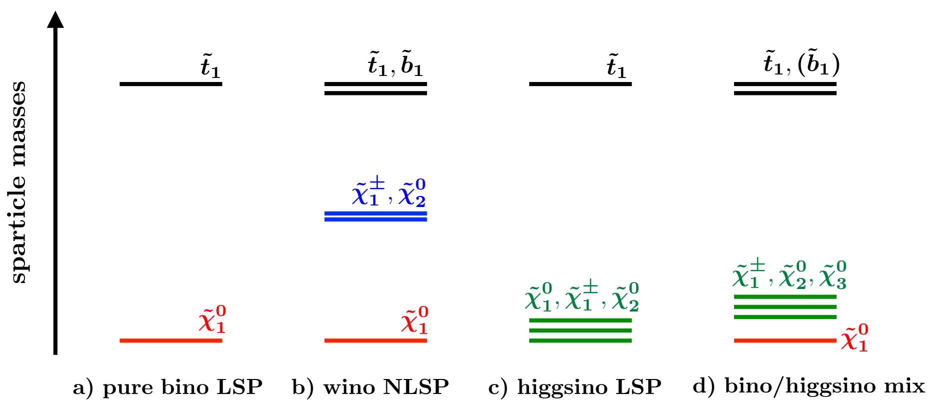

Figure 1: Schematic representation of the mass spectrum of the different SUSY scenarios considered in this proceedings contribution.

a) **Bino-like** $\tilde{\chi}_1^0$. This scenario represents the limit in which electroweak symmetry breaking effects can be viewed as a small perturbation to the initial neutralino mass matrix. Due to the assumed mass-spectrum, the top squark can only decay into the $\tilde{\chi}_1^0$ in this scenario. The lightest top squark mass eigenstate is dominantly composed of the right-handed component of the chirality eigenstate ($\tilde{t}_R$). Depending on the mass difference between the $\tilde{t}_1$ and the $\tilde{\chi}_1^0$, $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$, different decay channels dominate: $\tilde{t}_1 \to t\tilde{\chi}_1^0$, $\tilde{t}_1 \to bW\tilde{\chi}_1^0$, or $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$. The loop-suppressed decay $\tilde{t}_1 \to c\tilde{\chi}_1^0$ is also allowed in competition with this decay chain. However, due to its very different final state, it is investigated elsewhere [7].

b) **Wino-like** $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$. This model is based on the phenomenological MSSM (pMSSM) [8, 9]. The ratio of vacuum expectation values of the up- and down-type Higgs bosons ($\tan\beta$), the SUSY breaking scale (M_s) and the top-quark trilinear coupling (A_t) are set to obtain a low top squark mass while within the constraints imposed by the measured Higgs boson mass ($A_t - \mu/\tan\beta \sim \sqrt{6}M_S$). The running mass parameters of the electroweakino mass spectrum M_1, M_2, μ are set to follow the so-called gauge-universality condition: $M_1 = 0.5M_2 \ll \mu$ (M_3 is set beyond the current gaugino mass bounds). The lightest top squark mass eigenstate is dominantly composed of the left-handed component of the chirality eigenstate ($\tilde{t}_L$). This corresponds to a $\tilde{b}_1$ mass eigenstate relatively close in mass to the $\tilde{t}_1$, which is considered in the model. The $\tilde{t}_1$ and $\tilde{b}_1$ can decay with large branching fractions either directly into the LSP or indirectly via $\tilde{\chi}_1^\pm$ or $\tilde{\chi}_2^0$, leading to the emission of a W or a Z/H boson, respectively.

c) **Higgsino-like** $\tilde{\chi}_1^0$. This is the condition favoured by naturalness arguments. In this simplified model, various mass splittings are considered between the charginos and the LSP, $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$, satisfying the condition $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = \frac{1}{2}\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$. The dominant decay channels involve 1-step decay chains into the lightest chargino via $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$. Due to the mass splitting assumed, the signature is characterised by low-momentum particles from the gaugino decays. Both $\tilde{t}_L$ and $\tilde{t}_R$ contributions to the $\tilde{t}_1$ squark are considered as separate scenarios, thus contributing to the definition of the branching ratio fraction of the different top squark decays. To investigate the dependence of the branching fractions on $\tan\beta$ for the $\tilde{t}_L$, two values of this parameter are considered: 20 and 60.

d) **Dark Matter** $\tilde{\chi}_1^0$. This scenario [10] seeks to provide a viable dark matter (DM) candidate with minimal tuning by considering the lightest gaugino as being a mixture of bino and higgsino eigenstates. A pMSSM signal model is designed under these constraints [11] and such that the annihilation rate of neutralinos is consistent with the observed dark matter relic density ($0.10 < \Omega h^2 < 0.12$).

2. Summary of the search channels

The most recent results from ATLAS searches for top squark direct production and their decay into final states with leptons and missing transverse energy (E_T^{miss}) are summarised in the following based on Refs. [12–14]. All results are based on 36.1 fb^{-1} of integrated luminosity with the LHC operating at a centre-of-mass energy of 13 TeV during the years 2015-2016. The data have been recorded with the ATLAS detector, a general-purpose experiment that detects and records collisions produced at the LHC and has been extensively described in Ref. [15].

For all the analyses discussed here, the SM backgrounds contributing to each signal selection (denote as signal regions, SRs) are estimated with the aid of the MC simulation, except for the multi-jet and fake/non-prompt lepton backgrounds which are estimated using fully data-driven methods. Control regions (CRs), constructed to enhance a particular background and to be kinematically similar but distinct from the SRs, constrain the normalisation of the dominant SM background processes. The background expectation is determined separately in each SR through a profile likelihood fit. The systematic uncertainties are included as nuisance parameters in the fit. The background estimates in the SRs are validated by extrapolating the results of the likelihood fit in the CRs to dedicated validation regions (VRs), which are designed to be orthogonal to both the signal and the control regions and are usually kinematically closer to the SR than the CR.

2.1 Final states with one lepton

The analysis presented in Ref. [12] selects final states with one isolated lepton, jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. The search is based on 16 SRs. The results are extracted from each SR independently, either by counting events in a single region of phase-space and its associated CRs (cut-and-count technique) or by exploiting the shape information of a specific discriminating variable (shape-fit). Five SRs (the tN-regions of Ref. [12]) are dedicated to reach an optimal sensitivity to the models of scenario a), with a special attention to the compressed regime close to the kinematic boundary of $m(\tilde{t}_1) \sim m(t) + m(\tilde{\chi}_1^0)$, where the sensitivity is obtained by means of dedicated BDT-based selections, two exploiting initial state radiation requirements and one exploiting a recursive jig-saw approach [16]. Four SRs (bffN and the three bCsoft-regions in Fig 2a) exploit instead soft-lepton requirements to target the $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$ final states of scenario a) and scenario c) and finally, three SRs (the bC2x-regions and bCbv) are optimally sensitive to the models categorised by scenario b). The comparison between the observed data with the predicted SM background in the soft-lepton SRs and associated VRs for this analysis is presented in Figure 2a. No significant deviations from SM expectations are observed.

2.2 Final states with two leptons

The analysis presented in Ref. [13] targets final states with exactly two opposite-charge leptons, electrons or muons, either same- or different-flavour. A same-flavour pair is accepted if found to be incompatible with a Z-boson decay. Three different sets of signal regions are designed in this analysis to be optimally sensitive to different decays of the top squark. Following the notation of Ref. [13], the 2-body regions target the decay of the top squark into either a top-neutralino or a bottom-chargino pair and are sensitive to scenarios a) and b). These selections exploit a shape fit to the distribution of a specific transverse mass variable (m_{T2}), which is constructed to provide an end-point at the mass of the W-boson for the top pair background, which is the most important background for this selection. The 3-body selections instead target the decay of the top squark into $bW\tilde{\chi}_1^0$, following the assumptions of scenario a) under the condition that $m(W) + m(b) < \Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m(t)$. These selections exploit discriminative variables constructed using a recursive jig-saw approach [16]. Finally, the 4-body selections target compressed models with leptons characterised by soft momenta and exploits ratios of objects momenta

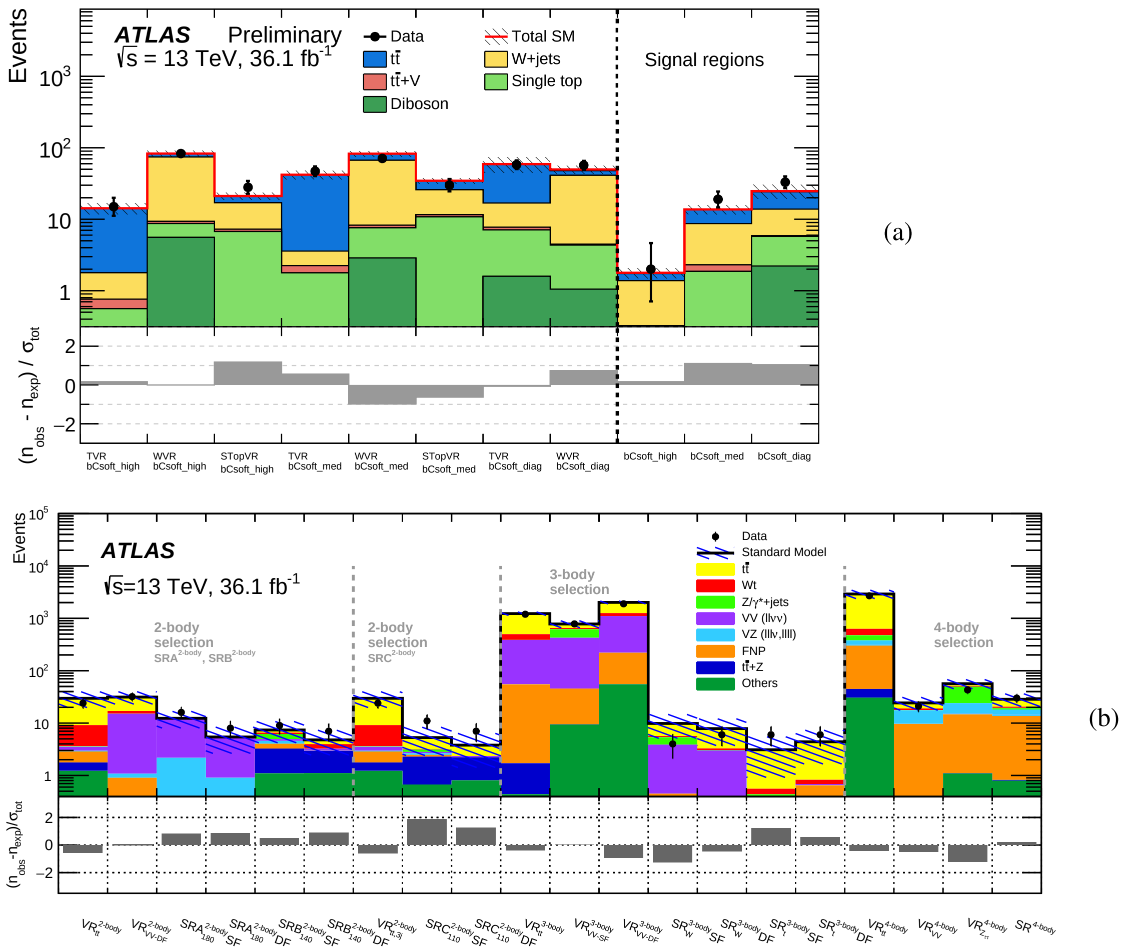

Figure 2: Comparison between the observed data with the predicted SM background in (a) the soft-lepton SRs and associated VRs of the one-lepton analysis [12] and (b) the SRs and VRs of the two-leptons analysis [13].

and $E_{\mathrm{T}}^{\mathrm{miss}}$ to enhance the soft topologies that characterise scenario a) (under the condition that $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m(W) + m(b)$) and scenario c). The comparison between the observed data with the predicted SM background in all SRs and associated VRs for this analysis is presented in Figure 2b.

2.3 Final states with Higgs- or Z-bosons

Reference [14] presents a search for direct top squark pair production, composed of two sets of three SRs each, named $3\ell 1b$ and $1\ell 4b$ regions in the reference, designed to specifically target simplified models with long decay chains involving Z or Higgs bosons, respectively. They select events with either a same-flavour opposite-sign dilepton pair with invariant mass compatible with a Z boson or a pair of b-jets compatible with a Standard Model Higgs boson. This analysis is interpreted in dedicated simplified models where the lightest stop decays with 100% BR into a t-$\tilde{\chi}_2^0$ pair and considerably extends the previous ATLAS limits for these final states.

3. Interpretation of the results

The exclusion limits obtained by the analyses in one and two lepton final states summarised in this proceedings contribution are compared in Figure 3a with the state of the art of ATLAS exclusion limits in scenario a). Particularly important is the ability of these analyses to extend the sensitivity on and below the compressed regime of $m(\tilde{t}_1) \sim m(t) + m(\tilde{\chi}_1^0)$. The exclusion limits of the two-lepton analysis in scenario b) and of the one-lepton analysis in scenario c) are shown in Figures 3b and 3c, respectively. Finally, the sensitivity of the one-lepton analysis to the DM assumptions of scenario d) are shown in Figure 3d. No observed exclusion is obtained in the case where the lightest top squark is dominantly right-handed, showing a low sensitivity of the current analyses in this interesting scenario and highlighting the need of dedicated searches for these models.

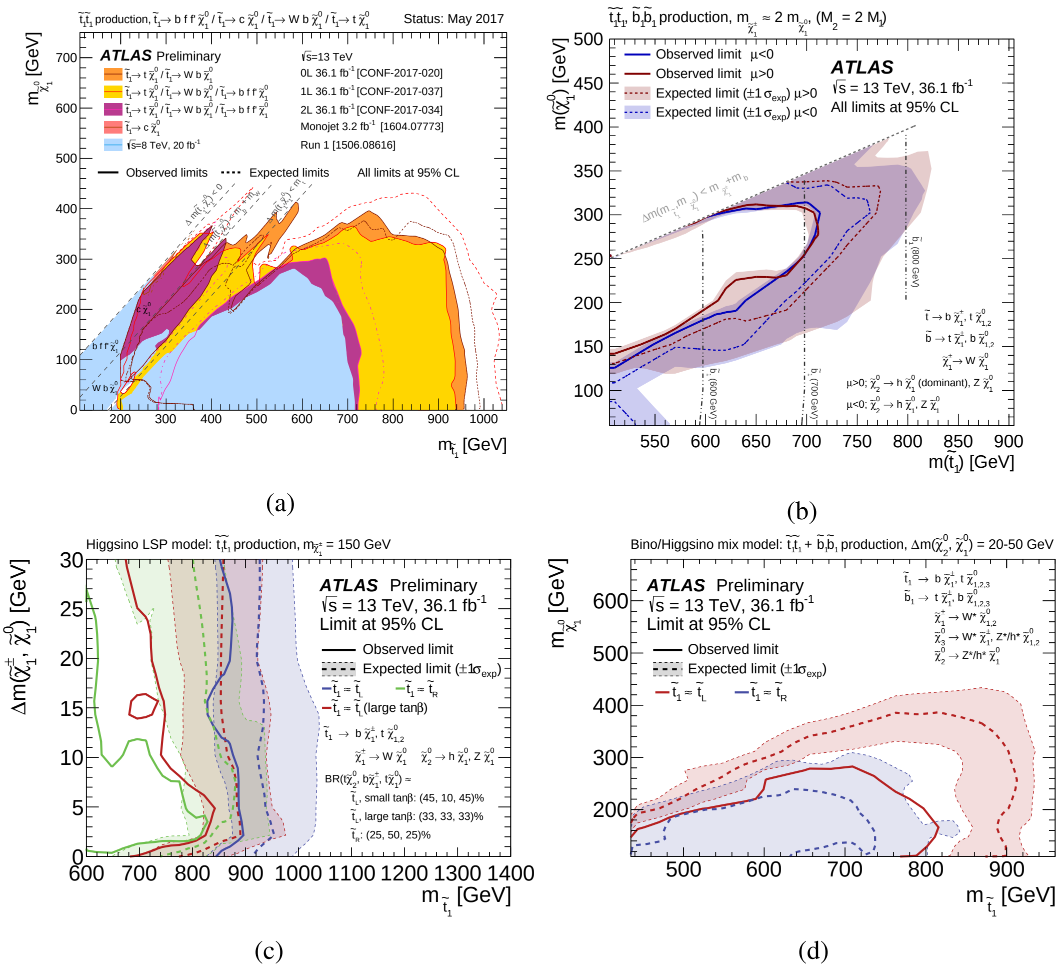

Figure 3: Interpretation of the results in terms of exclusion limits for the four considered scenarios. In addition to the parameters described in the text, Figure (c) assumes $m(\tilde{\chi}_1^{\pm}) = 150$ GeV and Figure (d) assumes $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 20\text{-}50$ GeV. Figs. (a), (c) and (d) show the one-lepton limits [12, 17] and Figs. (a) and (b) the two-lepton ones [13].

4. Outlook and conclusions

A summary of the most recent top squark direct production in final states with leptons and missing transverse energy are summarised in this proceedings contribution. The results are interpreted in terms of exclusion limits in a broad range of models, ranging from simplified model scenario to more complex pMSSM inspired ones. Also in the case of the more complex final states considered here, limits close to the TeV range in $m(\tilde{t}_1)$ are obtained. However, for the DM scenario, no exclusion limit is observed when the top squark is assumed to be right-handed.

References

[1] S. P. Martin, arXiv: hep-ph/9709356, [Adv. Ser. Direct. High Energy Phys.18,1].

[2] H. Goldberg, Phys. Rev. Lett. **50** (1983) 1419, [Erratum: Phys. Rev. Lett. 103 (2009) 099905].

[3] J. R. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. A. Olive, and M. Srednicki, Nucl. Phys. B **238** (1984) 453.

[4] R. Barbieri and G. F. Giudice, Nucl. Phys. B **306** (1988) 63.

[5] B. de Carlos and J. A. Casas, Phys. Lett. B **309** (1993) 320, arXiv: hep-ph/9303291.

[6] N. Arkani-Hamed et al., J. Phys. G **39** (2012) 105005, arXiv: 1105.2838 [hep-ph].

[7] ATLAS Collaboration, Phys. Rev. D **90** (2014) 052008, arXiv: 1407.0608 [hep-ex].

[8] A. Djouadi et al., arXiv: hep-ph/9901246.

[9] C. F. Berger, J. S. Gainer, J. L. Hewett, and T. G. Rizzo, JHEP **02** (2009) 023, arXiv: 0812.0980 [hep-ph].

[10] N. Arkani-Hamed, A. Delgado, and G. F. Giudice, Nucl. Phys. **B741** (2006) 108–130, arXiv: hep-ph/0601041.

[11] ATLAS Collaboration, JHEP **10** (2015) 134, arXiv: 1508.06608 [hep-ex].

[12] ATLAS Collaboration, ATLAS-CONF-2017-037, URL: https://cds.cern.ch/record/2266170.

[13] ATLAS Collaboration, arXiv: 1708.03247.

[14] ATLAS Collaboration, JHEP **08** (2017) 006, arXiv: 1706.03986 [hep-ex].

[15] ATLAS Collaboration, JINST **3** (2008) S08003.

[16] M. R. Buckley, J. D. Lykken, C. Rogan, and M. Spiropulu, Phys. Rev. **D89** (2014) 055020, arXiv: 1310.4827 [hep-ph].

[17] ATLAS Collaboration, "Summary plots from the ATLAS Supersymmetry physics group", URL: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/.

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