Search for direct top squark production and decay in top and lightest neutralino in final states with two leptons in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

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1. Introduction

Consideration of naturalness and its impact on the SUSY particle spectrum suggests that top squarks cannot be too heavy, to keep the Higgs boson mass close to the electroweak scale. Thus it could be pair-produced with relatively large cross-sections at the Large Hadron Collider (LHC).

The top squark can decay into a variety of final states, depending, amongst other factors, on the hierarchy of the mass eigenstates formed from the linear superposition of the SUSY partners of the Higgs boson and electroweak gauge bosons.

An analysis has been carried out and published [1] with 2012 pp collision data (20.3 fb^{-1}) collected by ATLAS experiment [2], searching for evidence of pair production of the top squark, each one later decaying to an on-shell top-quark and a weakly interacting particle which escapes detection ($\tilde{\chi}_1^0$). Only the leptonic decay mode of the W from of $t \to Wb$ is considered, thus the events are characterised by the presence of two isolated leptons (e,μ) with opposite charge, and two b-quarks:
$\tilde{t}_1\tilde{t}_1 \to \tilde{\chi}_1^0 t\tilde{\chi}_1^0\bar{t} \to \tilde{\chi}_1^0 bl^+\overline{\nu}\tilde{\chi}_1^0\bar{b}l^-\nu$.

The main criterion to separate the signal from the background is based on a multivariate analysis, with a learning algorithm based on Monte Carlo generated signal and background events. The Toolkit for Multivariate Analysis (TMVA), providing a ROOT-integrated [3] environment for the application of multivariate classification, is used, by applying a boosted decision trees method (BDTG) with a gradient-boosting algorithm, found to be the most sensitive method for signal-background separation among the investigated ones. Distinguishing variables exploit several geometrical and kinematical properties of the searched events.

A set of preselection requirements has been applied in the analysis, requiring events to have exactly two oppositely charged (OS) leptons (electrons, muons or one of each). At least one of the selected electrons or muons must have $p_T > 25$ GeV, in order for the event to be triggered with high efficiency, and the invariant mass of the two leptons in the event must be $m_{\ell\ell} > 20$ GeV (regardless of the flavours of the leptons in the pair), in order to remove leptons from low mass resonances. If the event contains a third preselected electron or muon, the event is rejected.

Events with both different-flavour (DF) and same-flavour (SF) lepton pairs are separately used to train the MVA decision[1] and then they are explicitly separated when defining the signal regions (SRs) for this analysis. Events are also required to have at least two jets, a leading jet with $p_{\mathrm{T}} > 50$ GeV and $m_{\mathrm{eff}} > 300$ GeV, where m_{eff} is defined as the scalar sum of the missing transverse momentum E_T^{miss} and the transverse momenta of the two leptons and of the two most energetic jets in the event. The selected events are first divided into four (non-exclusive) categories, with the requirements in each category designed to target different $\tilde{t}_1$ and $\tilde{\chi}_1^0$ mass intervals: (C1) $E_T^{miss} > 50$ GeV, providing good sensitivity for $m(\tilde{t}_1)$ in the range 200–500 GeV and for low neutralino masses; (C2) $E_T^{miss} > 80$ GeV, providing good sensitivity along the $m(\tilde{t}_1) = m(t) + m(\tilde{\chi}_1^0)$ boundary; (C3) $E_T^{miss} > 50$ GeV and leading lepton $p_T > 50$ GeV, providing good sensitivity for $m(\tilde{t}_1)$ in the range 400–500 GeV, and $m(\tilde{t}_1) > 500$ GeV for high neutralino masses; (C4) $E_T^{miss} > 50$ GeV and leading lepton $p_T > 80$ GeV, providing good sensitivity for $m(\tilde{t}_1) > 500$ GeV. Categories (C1), (C2) and (C4) are considered for DF events, and categories (C1) and (C3) for SF events.

The BDTG discriminant is then employed to further optimise the five subcategories (three for DF, two for SF) described above.

[1]MVA uses events which are known to belong to signal or background to determine the mapping function from which it is possible to subsequently classify any given event into one of these two categories. This "learning" phase is usually called "training".

Several BDTGs are trained using the simulated Standard Model (SM) background against one or more representative signal samples, chosen appropriately for each of the five subcategories. The BDTG training parameters are chosen to best discriminate signal events from the background, without being overtrained (MC subsamples, which are statistically independent of the training sample, are used to check that the results are reproducible). The resulting discriminants are bound between -1 and 1. The value of the cut on each of these discriminants is chosen to maximise sensitivity to the signal points considered. A total of nine BDTGs (five for DF events, four for SF events) and BDTG requirements are defined, setting the "signal regions" (SRs) for this analysis.

The dominant SM background processes are top-quark pair production and diboson production. The Z/γ^*+jets contribution, relevant only for the SF channel, is strongly suppressed by the BDTG requirement. Events with fake leptons are estimated with a data-driven technique.

Upper limits at 95% confidence level (CL) on the number of beyond-the-SM (BSM) events for each SR are derived using the CL_s likelihood ratio and shown in Fig. 1. Normalising these by the integrated luminosity of the data sample, they can be interpreted as upper limits on the visible BSM cross-section, $\sigma_{\mathrm{vis}} = \sigma \times \epsilon \times \mathcal{A}$, where σ is the production cross-section for the BSM signal, $\mathcal{A}$ is the acceptance defined by the fraction of events passing the geometric and kinematic selections at particle level, and ϵ is the detector reconstruction, identification and trigger efficiency. The exclusion contour for an on-shell top-quark in a $\tilde{t}_1 \to t + \tilde{\chi}_1^0$ decay is quantified in the $m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$ plane, taking the best expected DF and SF SRs (defined as the regions with the lowest value of the expected CL_s), for each point, and combining them statistically. Results are shown in Fig. 2.

Signal channel	N_{obs}	N_{exp}	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$
$\mathrm{SR}_1^{\mathrm{DF}}$	9	5.79 ± 1.94	0.48	9.7	$7.7^{+3.1}_{-2.2}$	0.74	0.15
$\mathrm{SR}_2^{\mathrm{DF}}$	3	1.84 ± 1.30	0.32	6.6	$5.2^{+1.9}_{-1.0}$	0.76	0.24
$\mathrm{SR}_3^{\mathrm{DF}}$	11	13.32 ± 3.99	0.46	9.4	$10.5^{+3.9}_{-2.9}$	0.38	0.43
$\mathrm{SR}_4^{\mathrm{DF}}$	5	5.13 ± 1.95	0.35	7.1	$7.1^{+2.5}_{-1.7}$	0.53	0.48
$\mathrm{SR}_5^{\mathrm{DF}}$	3	1.33 ± 0.95	0.32	6.5	$4.5^{+1.8}_{-0.7}$	0.86	0.15
$\mathrm{SR}_6^{\mathrm{DF}}$	2	0.91 ± 0.70	0.26	5.3	$4.0^{+1.4}_{-0.7}$	0.82	0.19
$\mathrm{SR}_7^{\mathrm{DF}}$	1	1.04 ± 0.53	0.18	3.7	$3.7^{+1.3}_{-0.4}$	0.54	0.48
$\mathrm{SR}_1^{\mathrm{SF}}$	6	7.62 ± 2.24	0.33	6.7	$7.6^{+3.0}_{-2.0}$	0.37	0.44
$\mathrm{SR}_2^{\mathrm{SF}}$	9	9.48 ± 2.13	0.41	8.2	$8.4^{+3.4}_{-2.1}$	0.48	0.47
$\mathrm{SR}_3^{\mathrm{SF}}$	0	1.14 ± 0.73	0.15	3.1	$3.1^{+1.2}_{-0.0}$	0.22	0.33
$\mathrm{SR}_4^{\mathrm{SF}}$	5	2.54 ± 1.04	0.39	8.0	$5.2^{+2.2}_{-1.1}$	0.89	0.11

Figure 1. Left to right: observed events, total expected background events, 95% CL upper limits on the visible cross section ($\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$) and on the number of signal events (S^{95}_{obs}). The fifth column (S^{95}_{exp}) shows the 95% CL upper limit on the number of signal events, given the expected number (and $\pm 1\sigma$ excursions on the expectation) of background events. The last two columns indicate the CL_B value, i.e. the confidence level observed for the background-only hypothesis, and the discovery p-value ($p(s=0)$).

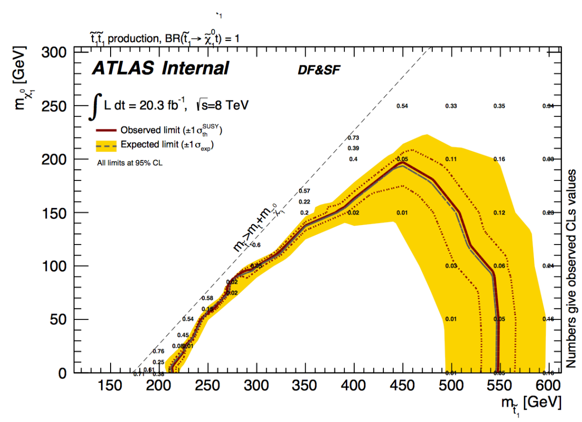

Figure 2. Observed and expected exclusion contours at 95% CL in the $m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$ plane for the combination of DF channel and SF channels. The dashed and solid lines show the 95% CL expected and observed limits, respectively, including all uncertainties except for the theoretical signal cross-section uncertainty (PDF and scale). The band around the expected limit shows the $\pm 1\sigma$ expectation. The dotted $\pm 1\sigma$ lines around the observed limit represent the results obtained when moving the nominal signal cross-section up or down by the theoretical uncertainty. The numbers shown in the plots are the observed CLs values.

REFERENCES

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