Search for direct top squark production and decay in top and lightest neutralino in final states with two leptons in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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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).

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. The current exclusion limits set by the ATLAS Collaboration on stop $\tilde{t}_1$ and neutralino $\tilde{\chi}_1^0$ masses parameters phase space [1] indicate that there are some regions in which all the analyses carried out on Run I and Run II data haven't shown any sensitivity. In particular, the current limits do not cover the area in which $m_{\tilde{t}_1} \simeq m_{\tilde{\chi}_1^0}$ (*compressed scenario*).

Only the leptonic decay mode of the W from $t \to Wb$ is considered, thus the searched events are characterized by the presence of two isolated leptons (e,μ) with opposite charge, two b-quarks and large $E_T^{\rm miss}$: $\tilde{t}_1\tilde{t}_1 \to \tilde{\chi}_1^0 t \tilde{\chi}_1^0 \bar{t} \to \tilde{\chi}_1^0 b l^+ \overline{\nu} \tilde{\chi}_1^0 \bar{b} l^- \nu$. When $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) \approx m(t)$, the neutralinos are produced at rest in the $\tilde{t}_1$ frame, thus leading to an E_T^{miss} suppression and signal signature that is similar to the one from a top-quark pair production decay. A dedicated study in this region with Run II data at $\sqrt{s}$=13 TeV and 36.5 fb^{-1} integrated luminosity has been devised. For this analysis, as suggested by some theoretical studies [2], an additional energetic initial state radiation jet (ISR jet) is also required for the studied process: this leads to a boosted event with enhanced E_T^{miss} and help in identifying signal against background events.

The distinguishing variables involved in the analyses exploit several geometrical and kinematical properties of the searched events. A set of preselection requirements has been applied:

- exactly two oppositely charged (OS) leptons (electrons or muons),
- at least one of the selected electrons or muons must have $p_T > 25$ GeV, the other one must have $p_T > 20$ GeV,
- invariant mass of the two leptons in the event must be $m_{\ell\ell} > 20$ GeV,
- invariant mass of the two leptons in the event must be outside of the Z-peak $m_{\ell\ell} >$ 111 GeV and $m_{\ell\ell} < 71$ GeV for event with same flavour leptons (ee and $\mu\mu$),
- at least three jets with $p_T > 25$ GeV,
- at least one b-tagged jet,
- E_T^{miss} >200 GeV.

After this preselection cuts, the signal candidates are required to belong to the signal region (SR) defined by cutting on the variables m_{T2}[1] and R_{ll}[2]:

$m(\tilde{t}_1, \tilde{\chi}_1^0)$ [GeV]	(400,175)	
	DF	SF
Label	$SR_{1,DF}$	$SR_{1,SF}$
m_{T2} [GeV]	110	
R_{ll}	1.2	

Table 1: Signal regions targeting the top squark decays to $t + \tilde{\chi}_1^0$. The SRs have been optimized independently for the SF (same flavour: ee and $\mu\mu$) and DF (different flavour: $e\mu$) cases considering the signal model $m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0} = (400, 175)$ GeV as benchmark.

These cuts have been obtained by simultaneous scan on the two variables in order to maximize the significance[3] of the analysis and by using MC generated samples for SM background processes and 99 signal points, corrisponding to $m_{\tilde{t}_1} \in [200, 850]$

[1] $m_{T2}^2 = \min_{\vec{q}_T^1 + \vec{q}_T^2 = \vec{p}_T^{\rm m}} \max(m_T^2(p_T^\alpha, \vec{q}_T^1), m_T^2(p_T^\beta, \vec{q}_T^2))$ Here, m_T indicates the transverse mass, $\vec{p}_T^\alpha$ and $\vec{p}_T^\beta$ are the momenta of the two leptons, and $\vec{q}_T^1$ and $\vec{q}_T^2$ are vectors which satisfy $\vec{q}_T^1 + \vec{q}_T^2 = \vec{p}_T^{\rm m}$. The minimum is taken over all the possible choices of $\vec{q}_T^1$ and $\vec{q}_T^2$[3].

[2] $R_{ll} = E_T^{\rm miss}/(p_T^{l_1} + p_T^{l_2})$. Here, l_1 and l_2 are the two leptons in the event

[3] The significance is defined as the Z-value Z_n assuming Gaussian distribution for the error of the background[4]

GeV and $m_{\tilde{\chi}_1^0} \in [1, 600]$ GeV. The analysis has also been applied as it is to the "3-body" decay[4] signal grid.

The main sources of uncertainties in the analysis come from systematic uncertainties (dominated by Jet Energy Scale and Jet Energy Resolution systematics for top pair production) and statistical uncertainties coming from limited MC statistics. The dominant SM background contribution to the SR are expected to be $t\bar{t}$, diboson production with final state in $ll\nu\nu$ and $t\bar{t}+Z$ production with $Z \to \nu\nu$. For each of these backgrounds a set of dedicated control regions (CR) and validation regions (VR) has been devised in order to check MC predictions in regions with high purity and high statistics for the analysed process, resulting in good agreement between MC and data. The expected sensitivity of the analysis is reported in Figure 1 which shows that the best sensitivity is obtained by using a combination of the two SR. However, the analysis is not able to reach enough sensitivity for a discovery with 36.5 fb^{-1}.

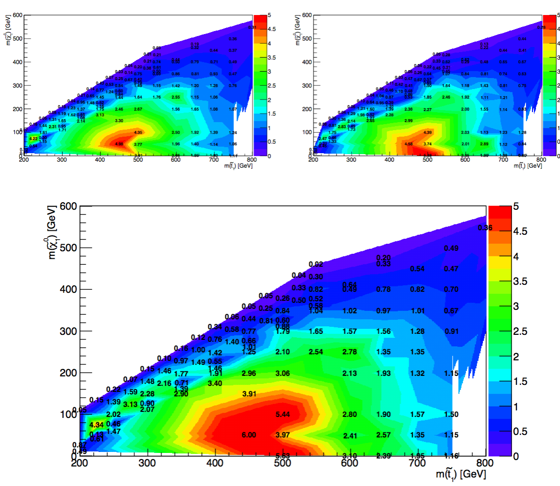

Figure 1: Sensitivity plot for $SR_{1,DF}$ (top-left), $SR_{1,SF}$ (top-right) and their sum (bottom). The color scale shows the significance obtained along the $m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}$ mass plane. The sum of the contribution coming from the two SRs provides a better sensitivity.

In case no excess in the data will be found by the analysis, the sensitivity for discovery can be reinterpreted as exclusion limits by using the CL_s variable[5]. The expected limits are reported in Figure 2. which shows that the analysis is able to expand the current limits covering a larger area near the compression line.

[4] $m_W < m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_t$. The stop quark decays through an off-shell t into $W\tilde{\chi}_1^0$

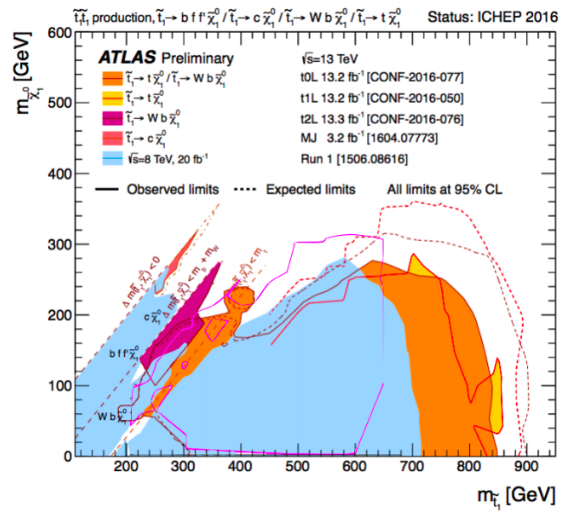

Figure 2: Expected exclusion contour (purple line) obtained in case of no excess in the data using CL_s

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