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 data haven't shown any sensitivity. However, the Run II data provide the ideal framework to investigate the still unexcluded regions: an higher sensitivity should be in fact reached, thanks to the increase of $\sigma_{\tilde{t}_1\tilde{\bar{t}}_1}$ switching from $\sqrt{s}$=8 TeV to $\sqrt{s}$=13 TeV and thanks to the foreseen considerable integrated luminosity at the end of Run II (~100 fb^{-1}). Two different regions are investigated: the one characterized by a massless neutralino resulting from a massive top squark decay and the one characterized by $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) \approx m(t)$, the so called *diagonal region*.

For both analyses, 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^{miss}: $\tilde{t}_1\tilde{\bar{t}}_1 \to \tilde{\chi}_1^0 t\tilde{\chi}_1^0\bar{t} \to \tilde{\chi}_1^0 bl^+\bar{\nu}\tilde{\chi}_1^0\bar{b}l^-\nu$.
The dominant SM background processes for this final state signature are top-quark pair production and dibosons production. 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,
- invariant mass of the two leptons in the event must be $m_{\ell\ell} > 20$ GeV,
- ISR jet with $p_T > 150$ GeV (only for the analysis in the region close to the diagonal)
- at least two more jets with $p_T > 20$ GeV
- E_T^{miss} >50 GeV
- m_{eff} >300 GeV

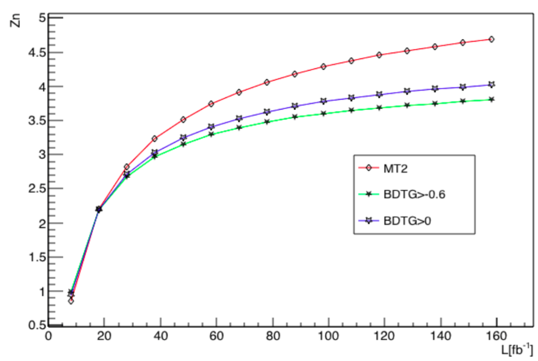
with m_{eff} defined as the scalar sum of the missing transverse momentum E_T^{miss} and the transverse momenta of the two leptons and of the two most energetic jets in the event (excluding the ISR jet). A multivariate approach is exploited in both analyses to separate the signal from the background: the Toolkit for Multivariate Analysis (TMVA), providing a ROOT-integrated [2] 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. The resulting BDTG discriminant variable is bound between -1 and 1. The value of the cut on this variable is chosen to maximise sensitivity to the signal and, thus, to define *Signal Regions* (SRs, one for each considered signal point).

For the analysis concerning the high stop mass region, five MC generated signal point have been used corresponding to $m(\tilde{\chi}_1^0) = 1$ GeV and $m(\tilde{t}_1) = (600, 700, 800, 900, 1000)$ GeV. Here an optimized SR has been searched both using the BDTG discriminant and the m_{T2} variable[3] studying its significance[1], which is maximized im-

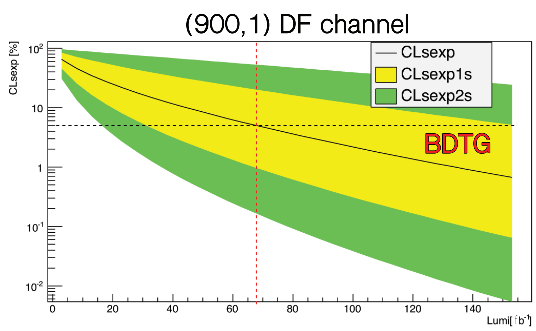
[1]Significance is defined as $\xi = \frac{N_S}{\sqrt{N_S+N_B+(\Delta N_B)^2_{syst}}}$. N_S and N_B are, respectively, number of signal and background events after BDTG cut. $(\Delta N_B)^2_{syst}$ approximates systematic background errors (here roughly estimated to 50% of N_B).

posing BDTG > -0.6 and $m_{T2} > 200$ GeV respectively, as a function of integrated luminosity.

As shown in Figure 1 (a), even for the lowest stop mass point not yet excluded during Run I (800 GeV) the analysis is not able to reach enough sensitivity for a discovery assuming the expected luminosity gathered by the end of Run 2,while (Figure 1 (b)) it is possible to extend the existing exclusion limits up to $\sim$ 900 GeV assuming to collect an integrated luminosity of ~ 70 fb^{-1}.



(a)



(b)

Figure 1. (a) Significance [4] as a function of integrated luminosity for $m(\tilde{t}_1) = 800$ GeV. (b) CL$_s$[5] as a function of integrated luminosity for $m(\tilde{t}_1) = 900$ GeV.

The search in the compressed mass spectrum region close to the diagonal is challenging as well. In the regions where $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$ is large enough, signal events can be identified with respect to $t\bar{t}$ events thanks to an enhanced E_T^{miss}. On the contrary, 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. The sensitivity of a dedicated study in this region with Run II data at $\sqrt{s}$=13 TeV is under evaluation, starting from the extension and optimization of the analysis that has already been carried out and published [6] with 2012 data at $\sqrt{s}$=8 TeV (20.3 fb^{-1}) that was not optimized for this compressed mass spectrum. For this analysis, as suggested by some theoretical studies [7], 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.

This analysis is still in optimization phase, but some promising preliminary results have been reached studying *Different Flavour* events (DF, events with different flavour leptons).
The BDTG method has been trained using the two signals characterized by $(m(\tilde{t}_1), m(\tilde{\chi}_1^0))$=(450,200)GeV and $(m(\tilde{t}_1), m(\tilde{\chi}_1^0))$=(450,250)GeV against the $t\bar{t}$ background (taken as the main background).
Results obtained analyzing MC simulated events, normalized to 10 fb^{-1} of integrated luminosity (corresponding to the foreseen integrated luminosity at the end of July 2016), are shown in Figure 2.

The reached significance for each one of the two signal points by setting SRs definition to BDTG>-0.65 are:
$\xi_{(450,200)GeV} = 1.42$
$\xi_{(450,250)GeV} = 1.59$.
The results obtained at $m(\tilde{t}_1)$= 450 GeV are promising, at least to exclude this point with the Run II data, and allow to expect a larger sensitivity in the stop low mass diagonal region thanks to the higher cross section.

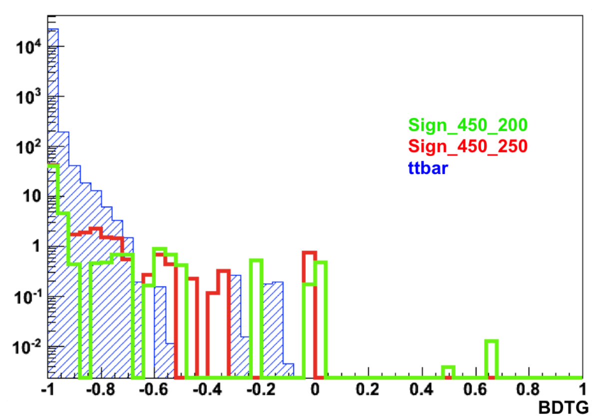


Figure 2. BDTG variable distribution for $(m(\tilde{t}_1), m(\tilde{\chi}_1^0))$=(450,200)GeV and $(m(\tilde{t}_1), m(\tilde{\chi}_1^0))$=(450,250)GeV signals events and for $t\bar{t}$ events. Distributions are normalized to an integrated luminosity of 10 fb^{-1}.

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