Search for a scalar top decay through a bottom quark and a chargino in final states with two leptons using 2012 ATLAS data

M. Bianco[1] , A. De Lorenzis[2] , E. Gorini[2 3] , L. Longo[2] , M. Primavera[3] , M. Reale[2] , A. Ventura[2 3] (and the ATLAS Collaboration)

[1]CERN, Geneva, Switzerland

[2]Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento, Italy

[3]Istituto Nazionale di Fisica Nucleare, sezione di Lecce, Italy

1. Introduction

This work describes an analysis developed within the ATLAS [1] experiment at the LHC (Large Hadron Collider) [2], which seeks evidence for pair production of a heavy partner of the top quark in final states with two leptons, where the top partners can decay through the pattern:

$$\tilde{t}_1\tilde{t}_1 \rightarrow \tilde{\chi}_1^+ b \;\; \tilde{\chi}_1^- \bar{b} \rightarrow \tilde{\chi}_1^0 b l^+ \nu \;\; \tilde{\chi}_1^0 \bar{b} l^- \nu \qquad (1)$$

or

$$\tilde{t}_1\tilde{t}_1 \rightarrow bW^+\tilde{\chi}_1^0 \;\; bW^-\tilde{\chi}_1^0 \rightarrow bl^+\nu\tilde{\chi}_1^0 \;\; \bar{b}l^-\nu\tilde{\chi}_1^0 \qquad (2)$$

where $\tilde{t}_1$ is the supersymmetric (SUSY) scalar top quark, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are, respectively, the charginos and the lightest neutralino (which is supposed to be the lightest supersymmetric particle, or LSP).

The decay mode of equation (1) requires the chargino to be real: $m(\tilde{t}_1) - m(b) > m(\tilde{\chi}_1^\pm)$. The final states contain two b-jets, two W bosons, real or virtual, and two invisible particles, which is the same final state as for the production and decays of pairs of top quarks, which thus constitute an irreducible background. The present work concerns the signature with two leptons (e or μ) in the final state, produced in the decay of the two W bosons, as illustrated in the top diagram of figure 1.

The 3-body decay pattern $\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$ of equation (2) is expected to be dominant if $m(\tilde{t}_1) - m(b) < m(\tilde{\chi}_1^\pm)$ (off-shell chargino) or if $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < m(t)$ (off-shell top). The process also requires $m(\tilde{t}_1) > m(b) + m_W + m(\tilde{\chi}_1^0)$. The signature where both Ws decay in a lepton and a neutrino $W \rightarrow l\nu$ leads to the same final state with two leptons considered for the previous scenario, as illustrated in the bottom diagram of figure 1.

Previous ATLAS searches have used 2011 data to place constraints on a scalar top with a mass around or below the top quark mass [3,4]. Preliminary results using up to 21 fb^{-1} of 8 TeV data [5–7] collected by ATLAS in 2012 have excluded some values of the lightest neutralino and chargino masses for scalar top with masses between 150 GeV and 610 GeV and assuming 100% branching ratio for the decay mode into a b-quark and a chargino.

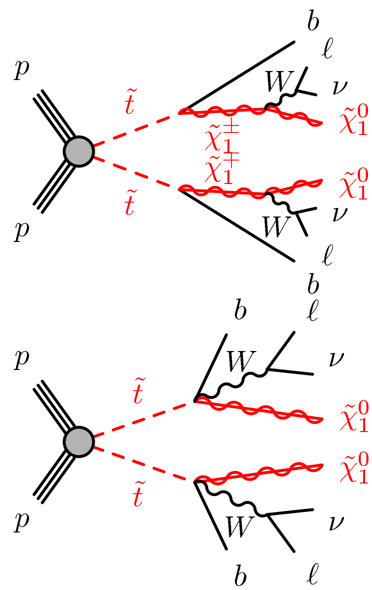

Figure 1. Feynman diagrams representing the processes considered. The figure on top illustrates the 2-body decay of the stop to a bottom quark and a chargino ($\tilde{t}_1 \rightarrow b\tilde{\chi}_1^+$), while the figure below shows the case of a 3-body decay of the stop to a bottom quark, a W boson and a neutralino ($\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^+$).

2. Event selection

The analysis is presently concentrated on the 2D projection on the $m(\tilde{\chi}_1^0) - m(\tilde{\chi}_1^\pm)$ plane for $m(\tilde{t}_1) = 300$ GeV. In addition to the basic object definitions and event selection criteria which can be found in [5,8], the present preliminary study requires a missing transverse momentum $E_T^{miss} >$ 50 GeV and $m_{eff} > 200$ GeV, where m_{eff} is defined as the scalar sum of E_T^{miss} and of the transverse momenta of the two leptons and of the two most energetic jets in the event. Such cuts enhance the separation between the possible SUSY signal and the Standard Model (SM) background. Exactly two leptons (electrons, muons, or one of each) are required in the final state. Events with different-flavour (DF) and with same-flavour (SF) lepton pairs are considered separately.

3. Signal to background separation

The discrimination between SUSY and SM simulated samples is obtained, for both DF and SF event categories, by means of the Toolkit for Multivariate Analysis (TMVA [9]), which provides a ROOT integrated environment for the application of multivariate classification. Among the various available methods implemented in TMVA, the Boosted Decision Trees with gradient boosting (BDTG) has been found to be the most sensitive and reliable for signal-background separation. Ten variables have been identified to train the BDTG algorithm: E_T^{miss}, M_{T2} [1], the sum of the leptons' tranverse momenta $|\vec{p}_T^{\ell}|$, the ratio between the sum of the two most energetic jets' tranverse momenta and the sum of the leptons' tranverse momenta, the two leptons' invariant mass $m_{\ell\ell}$, the azimuthal angle and pseudorapidity differences between the two leptons $\Delta\phi_{\ell\ell}$ and $\Delta\eta_{\ell\ell}$, the azimuthal angle difference between the missing transverse momentum vector and the $\vec{p}_T^{\ell}$ of the most energetic lepton, the azimuthal angle difference between the transverse momenta of the most energetic lepton and of the most energetic jet, the azimuthal angle difference between the missing transverse momentum vector and the opposite of the vector sum of all the transverse hadronic activity in the event $\vec{p}_b^{\ell\ell}$ [5].

Some of the variables listed above are slightly correlated between each other (such as $m_{\ell\ell}$ and $\Delta\phi_{\ell\ell}$), but such correlations are taken into account by the TMVA package. The resulting discriminant variable BDTG is finally used to isolate the SUSY signal from the background. The expected statistical significance, normalized to 20.3 fb^{-1} (i.e. the integrated luminosity collected by ATLAS in 2012), is defined as $S = N_s/\sqrt{N_b + \delta N_b}$. N_s and N_b are, respectively, the signal and background events surviving after cutting on a suitable BDTG value (defining the final choice of the signal regions, SRs), and the systematic term δN_b is assumed to be 50% of the background.

In figure 2 the signal significance S is separately shown for the DF and the SF channels. Owing to the large fraction of $Z \to \ell\ell$ background events, the SF channel looks less promising than the DF channel. Further studies are needed to improve significance in suitably defined SRs, to include the various sources of systematics and to obtain updated exclusion limits on lightest neutralino and chargino masses.

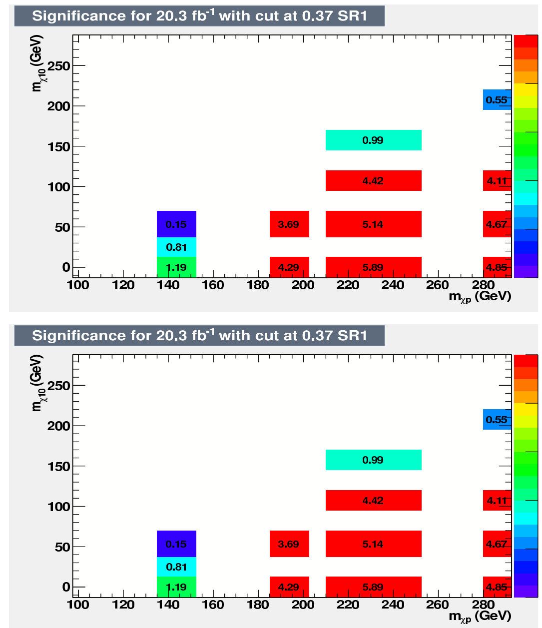

Figure 2. Expected signal significance as a function of the chargino and neutralino masses for the decay $\tilde{t}_1 \to \tilde{\chi}_1^{\pm} b$ in the case of $m(\tilde{t}_1) = 300$ GeV: the plot on top is obtained for DF events, the one below is for SF events.

[1]The M_{T2} variable was introduced in the framework of SUSY studies, and is used in the case where two identical particles (*legs*) are produced, and both decay into an invisible particle.

REFERENCES

1. ATLAS Collaboration, JINST 3 S08003 (2008) 1-407.
2. L. Evans and P. Bryant, LHC Machine, JINST 3 S08001 (2008).
3. ATLAS Collaboration, Phys.Lett. B720 (2013) 13-31.
4. ATLAS Collaboration, Eur.Phys.J. C72 (2012) 2237.
5. ATLAS Collaboration, Tech. Rep. ATLAS-CONF-2013-048 (2013) CERN, Geneva.
6. ATLAS Collaboration, Tech. Rep. ATLAS-CONF-2013-037 (2013) CERN, Geneva.
7. ATLAS Collaboration, Tech. Rep. ATLAS-CONF-2012-171 (2012) CERN, Geneva.
8. M.I. Besana et al., Tech. Rep. ATL-COM-PHYS-2013-1077 (2013) CERN, Geneva.
9. A. Hoecker, *TMVA 4 Toolkit for Multivariate Data Analysis with ROOT, Users Guide*, CERN-OPEN-2007-007 (2009) arXiv:physics/0703039.