Search for a heavy top partner in final states with two leptons with a multi-variate analysis technique in the ATLAS detector at LHC

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1. Introduction

Naturalness considerations require that the super-partners of third generation quarks are lighter than approximately 500 GeV. The existing Tevatron and previous LHC searches set limits for such particles are between 100 GeV and ∼580 GeV depending on the SUSY scenario.

An analysis, already performed on 2011 data and whose results have been described in full details in a dedicated ATLAS[?] Internal note [1], has been carried out and optimized to 2012 pp collision data (20.3 fb^{-1}), searching for evidence of pair production of the top quark heavy supersymmetric partner, each one later decaying into a b-jet, a lepton, a neutrino and a weakly interacting particle which escapes detection ($\tilde{\chi}_1^0$): $\tilde{t}\tilde{t} \rightarrow \tilde{\chi}_1^0 t \tilde{\chi}_1^0 \bar{t} \rightarrow \tilde{\chi}_1^0 b l^+ \bar{\nu} \tilde{\chi}_1^0 \bar{b} l^- \nu$ The process requires $m(\tilde{t}) - m(\tilde{\chi}_1^0) > m(t)$. It produces two top quarks and two additional invisible particles in the final state, then only 4.9% of the events contain two opposite sign (OS) leptons (electrons or muons). 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 [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 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.

As an example, in Figure 1 the distributions of two of the variables given in input to the MVA trainings, E_T^{miss} and $m_{\ell\ell}$, are shown after cuts (C1) for the 2012 data and for all background sources with two isolated leptons for DF and for SF events. Errors in figures are only statistical, and residual discrepancies are found to be fully within systematic errors. The BDTG discrimi-

[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".

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

As an example, in Figures 1 the distributions of two of the input variables, E_T^{miss} and $m_{\ell\ell}$ are shown after cuts (C1) in the 2012 data and for all background sources with two isolated leptons for DF and for SF . Errors in figures are only statistical, and residual discrepancies are found to be fully within systematic errors for DF and SF. 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. Normalising these by the integrated luminosity of the data sample, they can be interpreted as upper limits on the visible BSM cross-section, $\sigma_{\rm vis} = \sigma \times \epsilon \times \mathcal{A}$, 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.

Final results and plots from this analysis are not shown in this report, since they are part of the paper draft which is presently going to be submitted to the international physics journal chosen by the ATLAS Collaboration to publish them. Preliminary results have been presented in the EPS-HEP 2013 International Conference and can be found in [3].

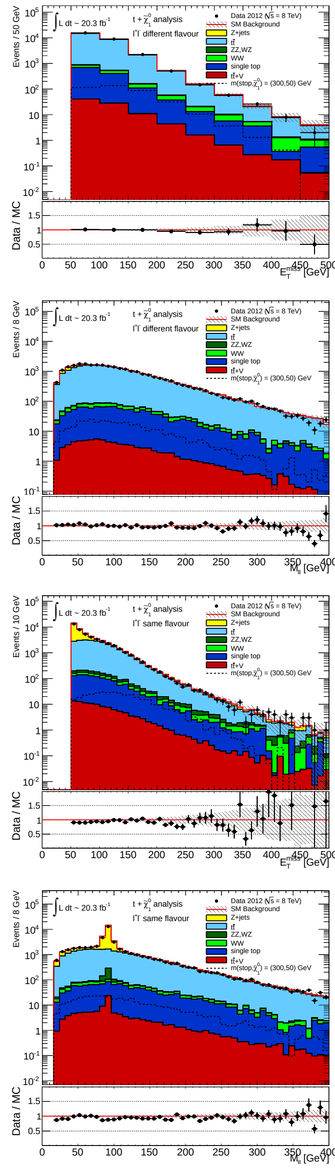

Figure 1. Distributions of some of the input variables to the MVA training after cuts (C1) in data and in Monte Carlo. From top to bottom: E_T^{miss} and $m_{\ell\ell}$, respectively for DF and SF events. For comparison, the distributions for the reference signal point with a scalar top mass of 300 GeV and a neutralino of 50 GeV are also shown. Only statistical errors are shown.

REFERENCES

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