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Search for top squarks in final states with one isolated lepton, jets, and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions using 3.2 fb^{-1} of ATLAS data

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The results of a search for the stop, the supersymmetric partner of the top quark, in final states with one isolated electron or muon, jets, and missing transverse momentum are reported. The search uses the 2015 LHC pp collision data at a center-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS detector and corresponding to an integrated luminosity of 3.2 fb^{-1}. The analysis targets two types of signal models: gluino-mediated pair production of stops with a nearly mass-degenerate stop and neutralino; and direct pair production of stops, decaying to the top quark and the lightest neutralino. The experimental signature in both signal scenarios is similar to that of a top quark pair produced in association with large missing transverse momentum. No significant excess over the Standard Model background prediction is observed, and exclusion limits on gluino and stop masses are set at 95% confidence level. The results extend the LHC Run-1 exclusion limit on the gluino mass up to 1460 GeV in the gluino-mediated scenario in the high gluino and low stop mass region, and add an excluded stop mass region from 745 to 780 GeV for the direct stop model with a massless lightest neutralino. The results are also reinterpreted to set exclusion limits in a model of vector-like top quarks.

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1. Introduction

Supersymmetry (SUSY) is a theory providing a natural solution to the hierarchy problem [1]. For this, the super partner of the top quark, the top squark or stop ($\tilde{t}$), is expected to be relatively light. Several models also suggest a TeV mass scale for the gluino ($\tilde{g}$), the superpartner of the gluon. Typical models, as used in this analysis, assume the conservation of a multiplicative quantum number called R-parity, leading to pair production of SUSY particles and to a stable lightest supersymmetric particle (LSP).

The ATLAS collaboration [2] published a search targeting the stop in two scenarios [3], gluino-mediated pair production of the $\tilde{t}$ with a small $\tilde{t}$-LSP mass splitting, and direct pair production of the $\tilde{t}$. Experimentally, the final states of the two scenarios are similar, as the small mass difference between the $\tilde{t}$ and the LSP results in decay products with a momentum typically below the threshold for reconstruction and identification. The detector signature consists of the decay products of a pair of top quarks and large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) from the two LSPs: $t\bar{t}+E_{\mathrm{T}}^{\mathrm{miss}}$. The analysis targets the one-lepton final state. The results are also reinterpreted in a model of direct pair production of vector-like top quarks T (referred to as VLQ), for which the decay mode $T \to tZ$ with $Z \to \nu\bar{\nu}$ has a similar signature.

2. Event selection and background estimation

The events used for this search were recorded using a trigger that accepts events with $E_{\mathrm{T}}^{\mathrm{miss}}$ above 70 GeV. Three signal regions (SR1–3) are constructed and optimized using three distinct benchmark signal models from the gluino-mediated stop models, characterized by increasing $E_{\mathrm{T}}^{\mathrm{miss}}$ requirements.

In order to reduce the dominant $t\bar{t}$ and W+jets background processes, the transverse mass of the lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$, m_{T}, is required to be much larger than the W boson mass, with cuts between 170–200 GeV. The top quark mass, computed using the m_{top}^{χ} variable which is based on small-radius jets, is useful for rejecting background events without a hadronic top quark in SR1. In contrast, the p_{T} of the hadronically decaying top quarks in the SR2 and SR3 benchmarks is often sufficient to capture all decay products inside a single large-radius jet of $R = 1.2$ (SR2) or $R = 1.0$ (SR3). Additionally, the dileptonic $t\bar{t}$ background is further suppressed by requirements on *topness* [4] and am_{T2} [5]. The *topness* is calculated in a kinematic χ^2 fit, based on the hypothesis of a $t\bar{t}$ decay with an invisible W boson, for which the charged lepton is either outside the acceptance or fails the identification requirements. The same hypothesis is used as a basis for the asymmetric m_{T2} variable, which reconstructs the transverse top mass based on two b-tagged jets, the signal lepton and the missing transverse momentum. It is bound from above by the top mass for dileptonic $t\bar{t}$ decays. The signal regions have additional requirements on the $H_{\mathrm{T,sig}}^{\mathrm{miss}}$, in order to further exploit the large $E_{\mathrm{T}}^{\mathrm{miss}}$. $H_{\mathrm{T,sig}}^{\mathrm{miss}}$ is the vectorial sum of the lepton and the jet momenta, divided by the resolution, computed using the per-event jet energy resolution uncertainties [6]. At least one b-tagged jet is required in order to reduce the W+jets and diboson backgrounds.

The dominant background processes are $t\bar{t}$, single top Wt, $t\bar{t}+Z(\to \nu\bar{\nu})$, and W+jets. Most of the $t\bar{t}$ and Wt events in the signal region are from the dileptonic decay mode, with either a hadronic tau, or a lepton that is not reconstructed or fails the identification or selection criteria. The main

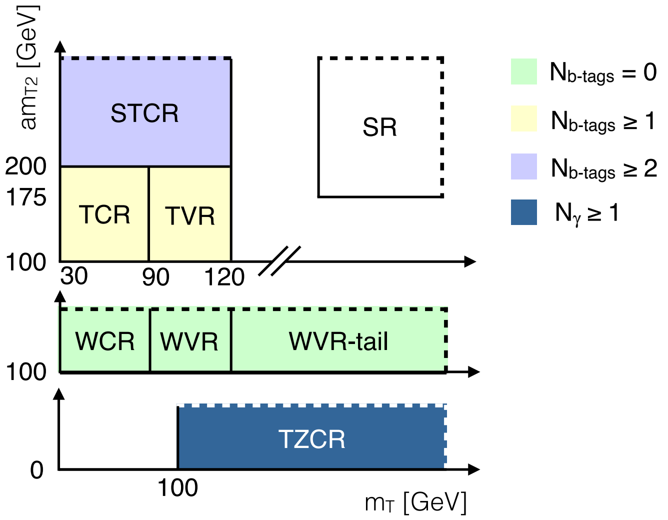

Figure 1: A schematic diagram for the various event selections for the signal and control regions [3].

backgrounds are estimated in dedicated control regions, as shown in Fig. 1, by normalizing the expected yields to match data in a simultaneous fit to all regions. The control regions are defined by inverting key variables of the SR definition, m_{T}, am_{T2} and the b-tagging requirement, while keeping the selection kinematically close to the SR. In addition, validation regions are defined using a higher m_{T} window, in order to test the extrapolation. In order to estimate the $t\bar{t}+Z(\rightarrow \nu\bar{\nu})$ background, a control region based on $t\bar{t}+\gamma$ events is constructed. There, the photon is treated as an invisible particle and included in the $E_{\mathrm{T}}^{\mathrm{miss}}$definition. Figure 2 shows exemplary distributions in the control regions for Wt and $t\bar{t}+Z$.

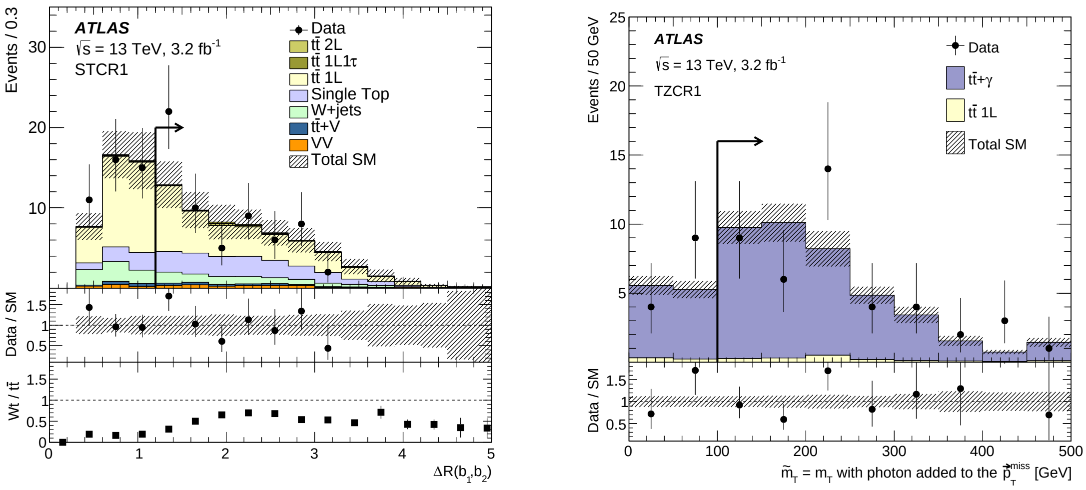

Figure 2: Comparison of data with estimated backgrounds after the simultaneous fit in the $\Delta R(b,b)$ distribution in the STCR1 (left) and the $\tilde{m}_{\mathrm{T}}$ distribution in the TTZCR1 (right), before applying the cut on the displayed variable. In the left plot, the middle panel shows the ratio of the data to the SM prediction and the lower panel gives the ratio of the single top to the $t\bar{t}$ production. In the right plot the lower panel gives the data to SM ratio. The error band includes statistical and all experimental systematic uncertainties [3].

3. Results

Table 1 shows the observed number of events in the three SRs together with the background estimates, as obtained in the simultaneous fit. The predicted yields agree well with the observed data in the validation regions and in the signal regions. The largest difference can be seen in SR1, where the data exceed the background prediction by 2.3 σ.

Table 1: Number of observed events in the three SRs together with the expected number of background events and the background-only p_0 values [3].

Signal region	SR1	SR2	SR3
Observed	12	1	1
Total background	5.50 ± 0.72	1.25 ± 0.26	1.03 ± 0.18
p_0	0.012 (2.3 σ)	0.50 (0.0 σ)	0.50 (0.0 σ)

As no significant excess over the SM prediction is found, the data are used to derive exclusion limits for the considered models. The expected and observed exclusion contours are shown in Figure 3. For each signal model the signal region with the lowest expected $\mathrm{CL_s}$ value is selected. The yellow uncertainty band shows the impact of all included uncertainties on the expected limit, while the red dotted error lines show the change of the observed limits, when scaling the signal cross-section by $\pm 1\sigma$ of the theoretical cross-section uncertainty.

In the gluino mediated production model, gluino masses of up to 1460 GeV can be excluded, for light stop squarks up to 700 GeV. This result significantly extends the LHC Run-1 limits. In the direct stop production model, $\tilde{t}$ masses between 740 GeV and 790 GeV are excluded for low LSP masses. The gap in the observed exclusion between about 600 and 740 GeV is due to a transition between signal regions and the excess observed in SR1. SR1 has the best expected sensitivity up to around 740 GeV for a massless $\tilde{\chi}_1^0$, at larger $\tilde{t}$ masses SR2 has the best sensitivity

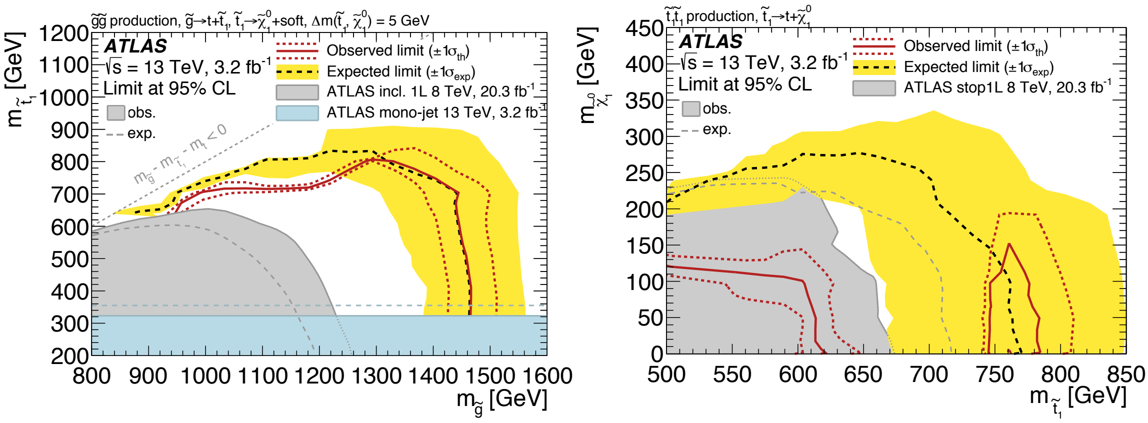

Figure 3: Expected and observed 95% excluded regions in the plane of $m_{\tilde{g}}$ versus $m_{\tilde{t}}$ for gluino-mediated stop production (left), and in the plane of $m_{\tilde{t}}$ versus $m_{\tilde{\chi}_1^0}$ for direct stop pair production (right). The gap in the observed exclusion between about 600 and 750 GeV in the direct stop model is due to a transition between signal regions and the excess observed in SR1 [3].

The data are also used to set limits on vector-like top quark models. The T quark is assumed to decay in three possible ways: $T \to tZ$, $T \to tH$, and $T \to bW$. This analysis is sensitive mostly to the $T \to tZ$ decay mode with $Z \to \nu\bar{\nu}$ due to the large $E_{\mathrm{T}}^{\mathrm{miss}}$ requirements. For a T quark with a mass of 800 GeV, branching ratios $B(T \to tZ)$ above about 90% are excluded. Figure 4 shows the exclusion limit as a function of the T quark mass. Assuming a branching ratio for $T \to tZ$ of 100%, T masses up to about 850 GeV are excluded.

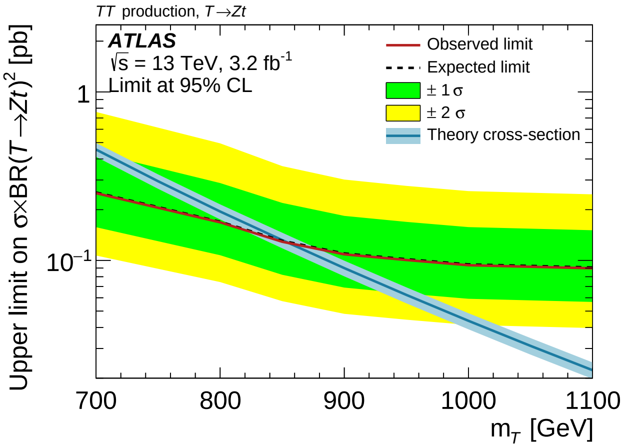

Figure 4: The observed and expected upper limits on T quark pair production times the squared branching ratio for $T \to tZ$ as a function of the T quark mass. The theory cross-section is shown assuming a 100% branching ratio for $T \to tZ$ [3].

4. Conclusion

A search for pair production of gluino-mediated stops with a small mass splitting between the stop and the LSP, and direct pair production of stops decaying to two top quarks and two lightest neutralinos in final states with one isolated lepton, jets, and missing transverse momentum is presented. Three signal region selections are optimized for benchmark models just beyond the exclusion limits from LHC Run-1 searches. The search uses 3.2 fb^{-1} of LHC pp collision data collected by the ATLAS experiment at $\sqrt{s} = 13$ TeV. The observed data are consistent with data-driven background estimates in all three regions and 95% CL exclusion limits are derived. The results extend the LHC Run-1 exclusion limit on the gluino mass up to 1460 GeV in the gluino-mediated scenario in the high gluino and low stop mass region, and add an excluded stop mass region from 745 to 780 GeV for the direct stop model with a massless lightest neutralino. The analysis results are also reinterpreted to set exclusion limits in a model of vector-like top quarks. Assuming a branching ratio for $T \to tZ$ of 100%, T masses up to about 850 GeV are excluded.

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