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Search for direct top squark pair production in final states with one electron or muon using 21 fb^{-1} of ATLAS data

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Abstract. This article presents latest results of the search for top squark pair production in final states with one isolated lepton, jets, and missing transverse momentum in $\sqrt{s}$ = 8 TeV pp collisions using L=21 fb^{-1} of data recorded with the ATLAS detector at the LHC. Two top squark decay scenarios are considered: (a) to a top quark and a long-lived undetected neutral particle (LSP), (b) to a bottom quark and a chargino, where the chargino decays via an on- or off-shell W boson to the LSP. The analysis also employs a new dedicated shape-fit method to target the challenging parameter region where $m(\tilde{t})$ is close to the kinematic boundary $m(t)$ +$m(LSP)$.

1 Introduction

Naturalness arguments for weak-scale supersymmetry favour a supersymmetric partner of the top quark (top squark, $\tilde{t}$, or "stop") with a mass close to its Standard Model counterpart.

This article presents a search for directly produced stop pairs, based on a recent conference contribution by the ATLAS collaboration [1]. Two decay channels are considered separately (figure 1). The search uses the full 2012 dataset of pp collisions at $\sqrt{s}$ = 8 TeV, recorded with the ATLAS detector [2] at the LHC, with an integrated luminosity of 20.7 fb^{-1}.

Left- and right-handed top quark each have a supersymmetric partner, $\tilde{t}_L$ and $\tilde{t}_R$, which mix to the mass eigenstates $\tilde{t}_1$ and $\tilde{t}_2$. Only the lighter one, $\tilde{t}_1$, is considered here.

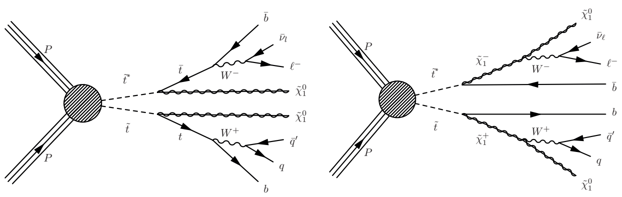

Figure 1. Stop decays targeted by this analysis. The final state objects are the same as in $t\bar{t}$ production, with additional missing momentum from the 2 neutralinos. **left**: "top+neutralino" (tN), **right**: "bottom+chargino" (bC).

2 Event Selection

Event kinematic properties differ between the decay modes and also depend on the masses of the SUSY particles. To maximise the sensitivity, six signal regions (SRs) are defined (table 1), sharing a common preselection.

- single lepton or missing transverse momentum trigger,
- one isolated electron or muon with transverse momentum $p_T > 25$ GeV, no other e or μ with $p_T > 10$ GeV,
- at least 4 jets with $p_T > 80, 60, 40, 25$ GeV, at least one b-tagged (additional requirements for SRbC2 & 3),
- high missing transverse momentum (E_T^{miss}) and missing transverse W mass ($m_T(W)$), as detailed in table 1,
- the leading two jets are not aligned with E_T^{miss}: $\Delta\phi > 0.8$, in order to reduce the impact of fake E_T^{miss} resulting from a possible jet energy mismeasurement.

Table 1. Signal region definitions (based on [1]). SRtN1 is the foundation for a shape fit in E_T^{miss} and $m_T(W)$ and applies looser cuts (section 4). Dedicated variables are described in section 5.

	SRtN1	**SRtN2**	**SRtN3**
E_T^{miss} (GeV)	100	200	275
$E_T^{miss}/\sqrt{H_T}$ (GeV $^{1/2}$)	5	13	18
$m_T(W)$ (GeV)	60	140	200
am_{T2} (GeV)	-	170	175
m_{T2}^{τ} (GeV)	-	-	80
m_{jjj}	yes	yes	yes
	SRbC1	**SRbC2**	**SRbC3**
E_T^{miss} (GeV)	150	160	160
$E_T^{miss}/\sqrt{H_T}$ (GeV $^{1/2}$)	7	8	8
$m_T(W)$ (GeV)	120	120	120
am_{T2} (GeV)	-	175	200
m_{eff} (GeV)	-	550	700
isolated track veto	yes	yes	yes
Number of b-jets ≥	1	2	2
leading b-jet p_T (GeV)	25	100	120
second b-jet p_T (GeV)	-	50	90

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3 Background Estimation

To estimate background contributions from $t\bar{t}$ and W+jets processes, two control regions (CRs) are defined for each SR: For both the $t\bar{t}$ and W+jets CR, the $m_T(W)$ requirement is lowered to 60–90 GeV. For the W+jets CR, the b-tag requirement is replaced by a b-tag veto. The remaining cuts are kept unchanged or loosened slightly to retain a sufficient number of events in every CR.

Minor backgrounds from $t\bar{t}$+V, VV (diboson) or single top quark events are estimated directly from Monte Carlo (MC) simulations. Contributions from Z+jets and QCD multijet events are negligible.

The dominant systematic uncertainty in this analysis results from theoretical and modelling uncertainties affecting the transfer factors in the CR→SR extrapolation. The uncertainties are determined from MC comparisons and are found to be 7–42% for the $m_T(W)$ extrapolation, and an additional 25% for the extrapolation from events with no b-jets to events with at least one b-jet.

4 Shape Fit

When the mass difference between $\tilde{t}$ and its decay products is small, signal events have similar kinematics properties to $t\bar{t}$ background events.

Region tN1 targets this challenging part of the mass plane close to the diagonal. Instead of defining signal and control regions, tN1 is subdivided into 3×5 bins of and $m_T(W)$; some more signal-like, others more background-like, an example is shown in figure 2.

While the statistical treatment is more complex than for the single-bin regions, the additional shape information greatly improves the sensitivity.

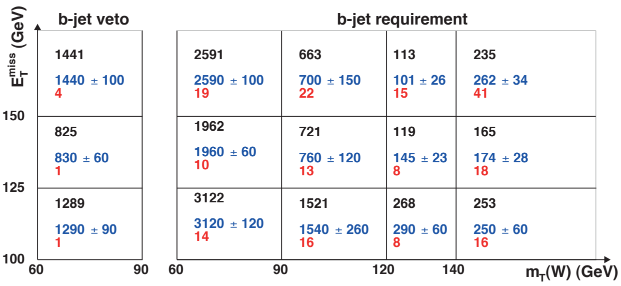

Figure 2. The shape fit uses bins of E_T^{miss} and $m_T(W)$ with different b-jet requirements. Observed counts are shown in black, SM expectations in blue, and a signal benchmark point with $m_{\tilde{t}} = 350$ GeV, $m_{\chi_1^0} = 150$ GeV in red (based on [1]).

5 Dedicated Variables

The transverse W mass combines E_T^{miss} and lepton p_T: $m_T(W) = \sqrt{2p_T^\ell E_T^{miss} \cdot (1 - \cos(\Delta\varphi))}$. Its distribution has a kinematic endpoint at m_W and hints at the presence of an intermediate W boson.

am_{T2} and m_{T2}^τ are two specialized extensions of the $m_T(W)$ variable for events with two invisible particles, as illustrated in figure 3. They are related to the minimal invisible transverse mass compatible with observed kinematics. Examples are shown in figure 4.

Two variables further suppress dileptonic $t\bar{t}$ events: a hadronic top mass cut, based on the invariant mass of 3 jets; and a veto against isolated tracks not assigned to the reconstructed lepton (events with an unidentified lepton or a 1-prong τ decay).

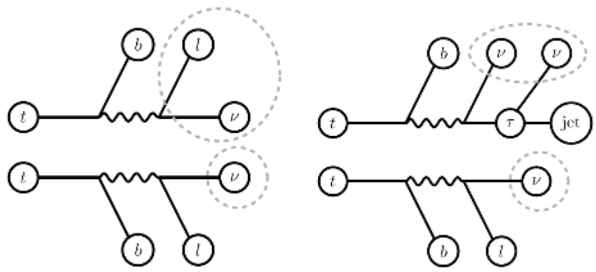

Figure 3. Purpose of m_{T2} variations. **left**: partially reconstructed dileptonic $t\bar{t}$ event. am_{T2} combines visible objects and invisible masses of m_W and 0 GeV to reconstruct 2 tops, **right**: event with hadronic τ decay. m_{T2}^τ uses two invisible masses of 0 GeV.

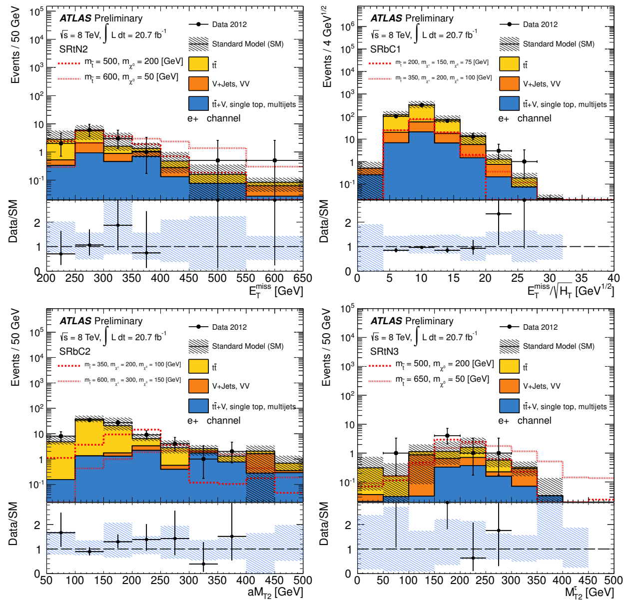

Figure 4. Data/MC comparison of important variables in different signal regions (from [1]). **top**: E_T^{miss} and E_T^{miss} significance, **bottom**: the m_{T2} variations am_{T2} and m_{T2}^τ.

6 Results and Statistical Interpretation

The yields summarized in table 2 are used in a likelihood ratio test based on simultaneous fits of corresponding signal and control regions. It is run in several variations to test the SM-only hypothesis and to compute exclusion limits for the signal processes (figure 5), using the signal region with the best expected sensitivity at each mass point.

Upper limits for a generic BSM model are derived to allow simple exclusion estimates for alternative models

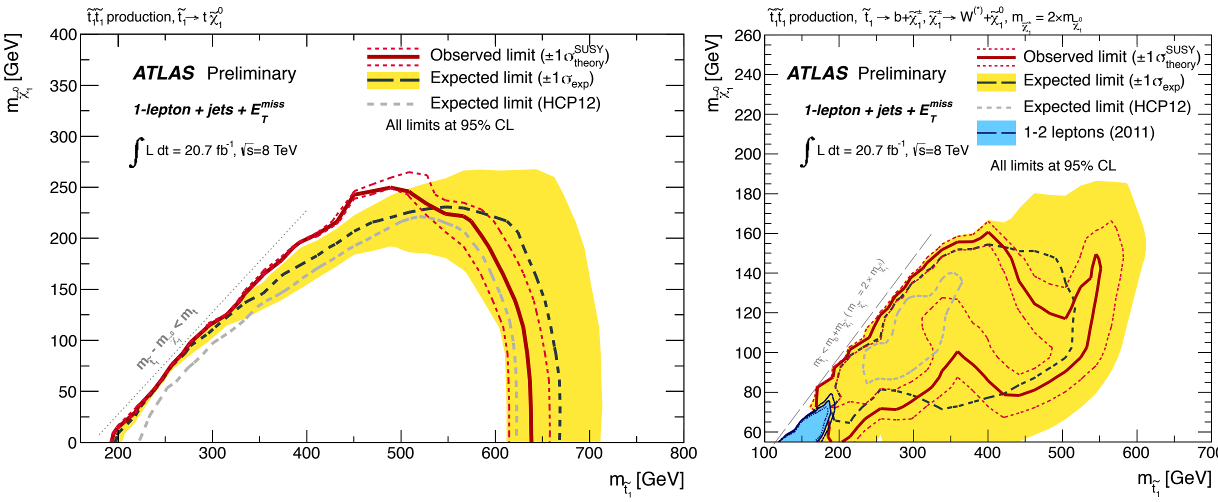

Figure 5. Excluded $\tilde{t}$ and LSP masses at 95% CL (from [1]). Expected limits are shown in black. Observed limits (in red) are affected by uncertainties on the predicted cross-sections. Results based on 13 fb^{-1} are shown in grey for comparison. **Left**: $\tilde{t} \to t + \chi_1^0$ decay; improvements stem from the shape fit close to the diagonal, and from the m_{T2} variations at higher $m(\tilde{t})$. **Right**: $\tilde{t} \to b + \chi_1^{\pm}$ decay (with $\chi_1^{\pm} \to \chi_1^0 + W$ and $m(\chi_1^{\pm}) = 2 \times m(\chi_1^0)$); exclusion at higher $m(\tilde{t})$ is improved by adding new SRs with tighter b-jet requirements.

Table 2. Expected and observed event yields (based on [1]). Masses are given in GeV. For the shape fit region tN1, the sum of bins with a b-jet requirement is shown.

$m(\tilde{t})$ $m(\chi_1^0)$	SRtN1	SRtN2	SRtN3
225 25	1075± 26	2.2±1.0	0.9±0.6
350 150	201± 5	2.0±0.5	0.5±0.3
500 200	71.9± 1.4	14.9±0.6	6.8±0.4
600 50	30.2± 0.5	13.9±0.4	11.6±0.3
SM expectation	11833±378	13± 3	5± 2
Data observed	11733	14	7
$m(\tilde{t})$ $m(\chi_1^{\pm})$ $m(\chi_1^0)$	SRbC1	SRbC2	SRbC3
200 150 75	233± 18	8± 4	3.1±3.1
350 200 100	166± 5	38.3±2.5	11.1±1.4
600 300 150	26.3± 0.6	12.5±0.4	9.0±0.4
SM expectation	482± 76	18± 5	7± 3
Data observed	456	25	6

(table 8 in [1]). They can be used as long as the expected signal contamination in the CRs is low. The effect of different assumptions on the stop mixing and the resulting top polarization in stop decays is illustrated in figure 6 for a fixed LSP mass of 50 GeV.

7 Summary

A search for stop quarks using the full dataset of 2012 ATLAS pp collisions was performed. No significant excesses were observed in the event yields. Using additional variables and a more sophisticated fit technique, the previously derived exclusion limits could be pushed closer to the diagonal in the $\tilde{t}$-LSP mass plane and toward higher $\tilde{t}$ masses.

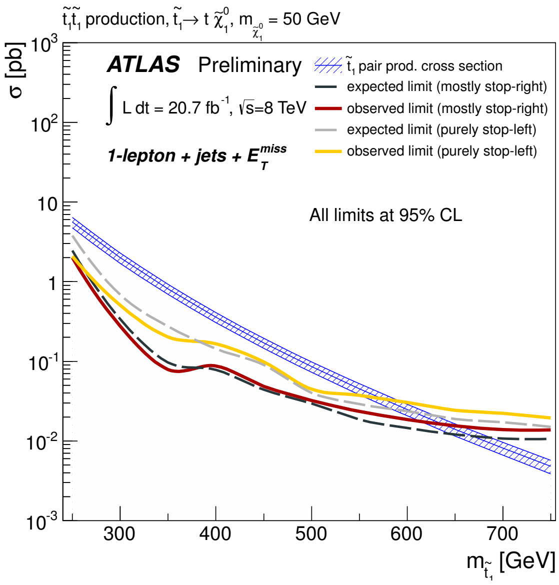

Figure 6. Impact of $\tilde{t}_1$ mixing for a fixed neutralino mass of 50 GeV (from [1]). A mostly (~70%) $\tilde{t}_R$ model is used throughout the analysis (red line). A purely $\tilde{t}_L$ model assumption reduces the exclusion reach by about 75 GeV (yellow line).

References

[1] ATLAS collaboration, *Search for direct top squark pair production in final states with one isolated lepton, jets, and missing transverse momentum in $\sqrt{s}$ = 8 TeV pp collisions using 21 fb^{-1} of ATLAS data* (2013), ATLAS-CONF-2013-037, `https://cds.cern.ch/record/1532431`

[2] ATLAS collaboration, Journal of Instrumentation **3**, S08003 (2008)