Searches for direct stop production within the ATLAS experiment

Paolo Dondero *on behalf of the ATLAS Collaboration*

Universit`a degli Studi di Pavia, INFN Pavia E-mail: `paolo.dondero@cern.ch`

Abstract. The ATLAS experiment at the LHC, in conjunction with the discovery of the Higgs boson is looking for signs of physics which go beyond the Standard Model of Electroweak interactions. Among possible theories for physics beyond Standard Model, Supersymmetry seems to be the most promising one. This theory indeed addresses the Standard Model naturalness problem and offers a perfect candidate for the dark matter. Within this scenario the search for a supersymmetric partner of the top quark, called stop, plays a key role. The ATLAS Experiment has developed a dedicated strategy for the discovery of this particle, focusing on achieving a complete coverage of the available parameter space for this particle, based on the combined search for all of its possible decay modes. The results obtained using the complete ATLAS 2012 statistics will be presented, targeting different decay modes and explaining the procedure to obtain the exclusion limits on the existence of a supersymmetric partner of the top quark at the electroweak scale. [1]

1. Introduction

Supersymmetry (SUSY) is an extension of the Standard Model (SM) which introduces partners (called superpartners) for each of the known Standard Model bosons and fermions in order to solve open issues in the SM such as the hierarchy problem [1].

In order to avoid violation of baryon and lepton numbers in the theory a new multiplicative absolutely conserved number is introduced, defined as $R = (-1)^{3(B-L)+2S}$ and called R-parity. In the framework of a generic R-parity conserving minimal supersymmetric extension of the SM, the MSSM (Minimal Supersymmetric Standard Model), SUSY particles are produced in pairs and the lightest particle is stable (LSP). In multiple models this particle is the lightest neutralino $\tilde{\chi}_1^0$, that is also a natural candidate for dark matter.

Arguments related to the quantum stability of the mass of the Higgs boson suggest that the SUSY partners of the top (stop) and the bottom (sbottom) quarks have masses below the TeV scale. In this situation the direct production of a stop pair can be observed at LHC in the ATLAS detector, a general-purpose experiment described in details in Ref. [7]. An extensive search program has been developed to this purpose.

In these proceedings the latest results on direct stop production searches within the ATLAS experiment are interpreted and summarized. Among the many analyses published to date on this topic, in the following sections two stop searches, both requiring two leptons in the final state, will be presented in order to illustrate the procedure used in ATLAS to explore a given

stop squark decay topology and phase space region. At the end a brief overview of the current ATLAS results will be given.

2. Event selection
The two searches share a common preselection and some discriminatory event-level variables. The following variables are defined:

- m_{ll}: the invariant mass of the two final state leptons
- m_{T2}^{ll} and m_{T2}^{b-jet}: a generalization of the invariant mass [5, 6] defined as

$$m_{T2}^2(\vec{p}_T^{\alpha}, \vec{p}_T^{\beta}, \vec{p}_T^{miss}) = \min_{\vec{q}_T^1 + \vec{q}_T^2 = \vec{p}_T^{miss}} \left[\max(m_T^2(\vec{p}_T^{\alpha}, \vec{q}_T^1), m_T^2(\vec{p}_T^{\beta}, \vec{q}_T^2)) \right]$$

  where m_T indicates the transverse mass, $\vec{p}_T^{\alpha}$ and $\vec{p}_T^{\beta}$ are the transverse momenta of two particles, $\vec{q}_T^1$ and $\vec{q}_T^2$ are vectors which satisfy $\vec{q}_T^1 + \vec{q}_T^2 = \vec{p}_T^{miss}$. The minimisation is performed over all the possible decompositions of q_T. If α and β are taken as the two leptons in the final state of the event (indicated with m_{T2}^{ll}, simply m_{T2} in the following) the distribution is bound sharply from above by the mass of the W. Selecting events with $m_{T2} > m_W$ is thus possible to enhance the signal over background ratio.
- $\Delta\phi_j$: the azimuthal angle difference between p_T^{miss} and the direction of the closest jet.
- $\Delta\phi_b$: the azimuthal angle between p_T^{miss} and $p_{Tb}^{ll} = p_T^{miss} + p_T^{l1} + p_T^{l2}$.
- E_T^{miss}: missing transverse energy in the event.

The selected events are required to have two leptons (electrons or muons) opposite sign. The leading selected lepton must have transverse momentum greater than 25 GeV and the dilepton invariant mass m_{ll} greater than 20 GeV.

3. Leptonic m_{T2} analysis
The stop squark can decay into several final states depending in particular on the hierarchy of the mass eigenstates set up from the mixing of the Higgs and gauge bosons superpartners. The eigenstates addressed by the present analysis are the lightest chargino ($\tilde{\chi}_1^{\pm}$) and the neutralino ($\tilde{\chi}_1^0$), supposed to be the LSP in this scenario.

To study the stop squark decay in the dileptonic channel three different approaches have been developed, depending on the mass hierarchy of the involved sparticles: the leptonic m_{T2}, the hadronic m_{T2} and the multivariate (MVA) analyses (figure 1, respectively a,b and c). These searches address events with two isolated leptons (electrons or muons) with opposite charge, two b-quarks and significant missing transverse momentum (E_T^{miss}) in the final state [2].

In particular the leptonic m_{T2} analysis is designed to focus on the stop decay channel $\tilde{t} \to b + \tilde{\chi}_1^{\pm}$ in the case $m(\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^0) > m_W$, so the $\tilde{\chi}_1^{\pm}$ can decay into the LSP and a W boson.

After base preselections, events with same flavour leptons are required to have the invariant mass of the pair outside the 71 - 111 GeV range in order to reduce the number of background events containing two leptons due to the decay of a Z boson.

Two additional cuts are applied to reduce events with high m_{T2} arising from events with large E_T^{miss} due to an error in the jets measure: $\Delta\phi_b < 1.5$ and $\Delta\phi_j > 1$.

The expected dominant Standard Model background contributions in the signal regions (SRs) are $t\bar{t}$ and dibosons decays. These contributions are normalized to data using control regions (CRs) where each background source is dominant with respect to signal. Dedicated control regions are defined for $t\bar{t}$, WW and Z (for WZ and ZZ).
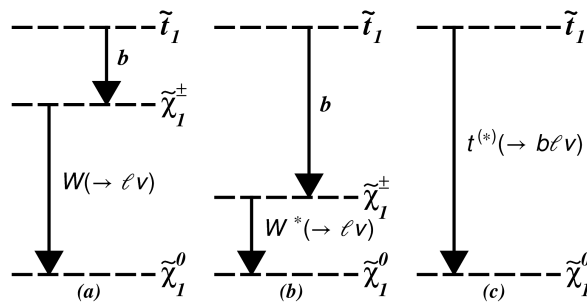
Figure 1. Stop decays channels addressed by the leptonic m_{T2} (a), hadronic m_{T2} (b) and MVA (c) analises. The leptonic m_{T2} analysis focuses on the case $\tilde{t} \to b + \tilde{\chi}_1^{\pm}$ with $m(\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^0) > m_W$. The figure is taken from Ref. [2].

Four signal regions are defined with different selections on m_{T2} and on the transverse momentum of the two leading jets, sensitive to different configuration of $\Delta m(\tilde{t}, \tilde{\chi}_1^{\pm})$ and $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$. In table 1 a summary of the SRs selections is presented.

| SR	L90	L100	L110	L120
Leading lepton p_T [GeV]		> 25		
$\Delta\phi_j$ [rad]		> 1		
$\Delta\phi_b$ [rad]		< 1.5		
m_{T2} [GeV]	> 90	> 100	> 110	> 120
Leading Jet p_T [GeV]	-	> 100	> 20	-
Second leading Jet p_T [GeV]	-	> 50	> 20	-

Table 1. Summary of signal regions used in the leptonic m_{T2} analysis. The table is taken from Ref. [2].

4. Stop into stau in the dileptonic channel

In gauge-mediated supersymmetry breaking (GMSB) models the spin 3/2 partner of the graviton, called gravitino ($\tilde{G}$), can be the lightest supersymmetric particle. Moreover, in a generic R-parity conserving SUSY model like that, the scalar partners of charged leptons, $\tilde{l}_R$ and $\tilde{l}_L$, can mix to form two sleptons mass eigenstates. The lighter of the two sleptons eigenstates is denoted as $\tilde{\tau}_1$. In the hypothesis that staus are lighter than stops, the stop decay into stau is allowed. The analysis presented focuses on the decay chain in figure 2 with the $\tilde{t}$ decaying into a $\tilde{\tau}_1$ slepton and finally into gravitino [3].

After the preselection the events with same flavour leptons are required to have the invariant mass of the pair outside the 71 - 111 GeV range. The angle $\Delta\phi_b$ is required to be smaller than 1.5 and $\Delta\phi_j$ greater than 1.

Signal regions targeting high ($m_{\tilde{t}_1} > 250$ GeV) and low ($m_{\tilde{t}_1} < 250$ GeV) stop masses are than defined, using further selections on the number of jets, m_{T2}^{ll} and m_{T2}^{jl}. The relevant backgrounds for this analysis are the same of the leptonic m_{T2} analysis and are estimated using dedicated control regions for top and Z boson contributions.
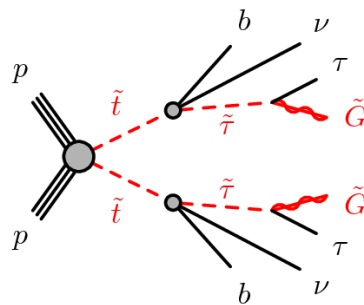
Figure 2. Top squark pair production diagram, decaying into $b\tilde{\tau}_1\nu$ followed by the $\tilde{\tau}_1$ decay into a τ lepton and the gravitino. $BR(\tilde{t}_1 \to b\tilde{\tau}_1\nu) = 1$ is assumed.
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## 5. Summary of the results

A summary of the ATLAS searches for stop squark pair production using 20.3 fb^{-1} LHC data collected by the ATLAS experiment during 2012 at 8 TeV energy have been presented. All the results are in agreement with the SM predictions and are interpreted in terms of simplified models where two stop squarks decay with 100% BR to a targeted channel.

A wide variety of analyses has been studied in two, one and zero leptons channels, summarized in figure 3. All the results are in agreement with the Standard Model and a large portion of the stop phase space has been excluded. A stop decay into $b + \tilde{\chi}_1^{\pm}$ with $m_{\tilde{t}_1}$ between 150 and 445 GeV is excluded at 95% CL in the case $m_{\tilde{\chi}_1^{\pm}} \sim m_{\tilde{t}_1}$ and $m_{\tilde{\chi}_1^0} = 1$ GeV. Stop with mass between 215 GeV and 530 GeV that decays into a top quark and a neutralino (red contour in figure 3) and between 90 and 170 GeV for the three body decay mode (purple contour in figure 3) are excluded at 95% CL.

The analysis described in section 3 contributes significantly to the whole stop exclusion scenario (light-blue areas in figure 3). The case $\tilde{t} \to b + \tilde{\chi}_1^{\pm}$ with $m_{\tilde{\chi}_1^{\pm}} = 2 \cdot m_{\tilde{\chi}_1^0}$ is excluded up to $m_{\tilde{t}} < 500$GeV, as well as the case $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{t}} - 10$GeV.

In the hypothesis of staus lighter than stops the exclusion limit at 95% CL in figure 4 has been obtained by the analysis described in section 4. A significant portion in the $(m_{\tilde{t}_1}, m_{\tilde{\tau}_1})$ plane is covered, for a stop and a stau lighter than 500GeV. The observed data are in agreement with the Standard Model background expectation, assuming $BR(\tilde{t}_1 \to b\tilde{\tau}_1\nu) = 1$ and $BR(\tilde{\tau}_1 \to \tilde{G}\tau) = 1$ in the exclusion limit calculation.
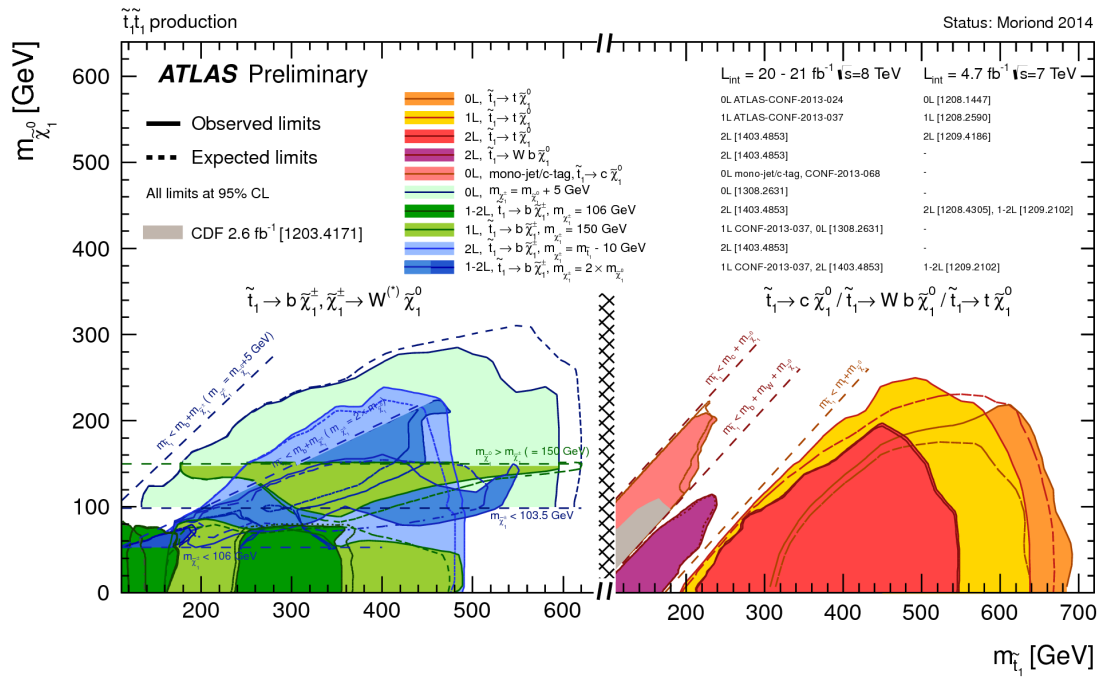
Figure 3. Summary of the ATLAS top squark pair production searches based on $20\,fb^{-1}$ of pp collision data taken at $\sqrt{s} = 8$ TeV and $4.7\,fb^{-1}$ of pp collision data taken at $\sqrt{s} = 7$ TeV. Exclusion limits at 95% CL in the stop - neutralino mass plane are shown. Image from [4].
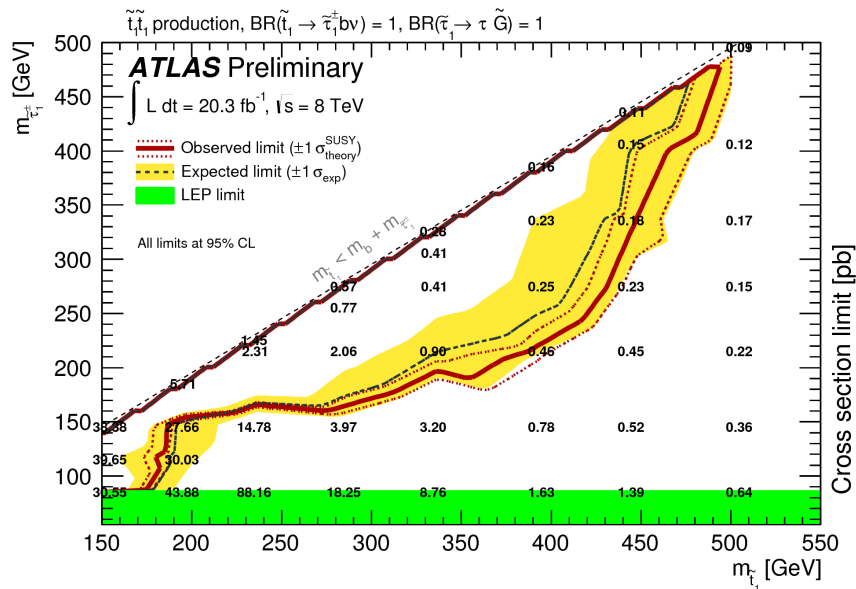
Figure 4. $\tilde{t}_1$ into $\tilde{\tau}_1$ exclusion limit at 95% CL using $20.3\,fb^{-1}$ of 8 TeV collision data, assuming $BR(\tilde{t}_1 \to b\tilde{\tau}_1\nu) = 1$, taken from [3]. The blue dashed line and the yellow band are the expected limit and its uncertainty. The thick solid line is the observed limit for the central value of the signal cross section. The dotted lines show the effect on the observed limit when varying the signal cross section by $\pm 1\sigma$ of the theoretical uncertainty. The green band represents the LEP limit on the τ slepton mass.

References

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