Supersymmetry searches with ATLAS

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Supersymmetry is one of the best motivated and studied theories of physics beyond the Standard Model. This document summarises recent ATLAS results of searches for supersymmetric particles using LHC proton–proton collision data at $\sqrt{s} = 7$ and 8 TeV. Weak and strong production Supersymmetry scenarios are considered, with particular attention to direct production of third generation supersymmetric particles. The searches involve final states including jets, missing transverse momentum, leptons, and long-lived particles. Sensitivity projections for the $\sqrt{s} = 13$ TeV data are also presented.

1   Introduction

The Standard Model of particle physics has been very successful at describing particles and their interactions. There are however several open questions about the Standard Model on topics such as dark matter and the hierarchy problem. The LHC [1] at CERN has provided the ATLAS experiment [2] with high energy proton–proton collisions to test the Standard Model and perform searches for physics beyond the Standard Model. Supersymmetry is one model that addresses some of these open questions, for example by the inclusion of a dark matter candidate usually in the form of the lightest supersymmetric particle (LSP). Supersymmetry introduces partner particles to those in the Standard Model. These supersymmetric particles differ from their Standard Model partners by half a unit of spin and are produced in pairs when assuming R-parity is conserved. Run 1 searches for Supersymmetry have explored large regions of phase space in a variety of production and decay channels. No significant excesses have been observed and so exclusion limits have been set on many different models.

This document summarises several ATLAS Run 1 searches for Supersymmetry using the proton–proton data collected by ATLAS at $\sqrt{s} = 7$ and 8 TeV. Some early Run 2 sensitivity studies of physics at $\sqrt{s} = 13$ TeV are also presented.

2   Direct strong production searches

The inclusive searches for the strong production of squarks and gluinos cover a wide range of final states. Figure 1 shows three of the many models of squark and gluino production and decay studied. A multitude of signal regions have been designed to probe different parts of the phase space using different cuts on the number of jets, the number of charged light leptons (electrons or muons), and the transverse momenta of all particles and jets in the event. Several other variables that are used are based on the scalar sum of the

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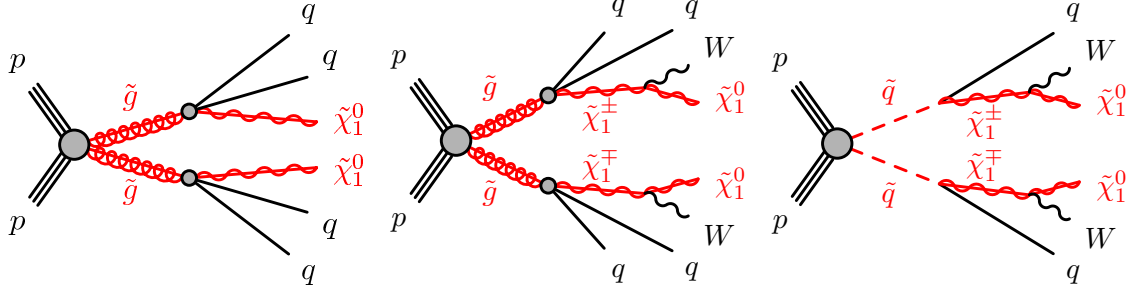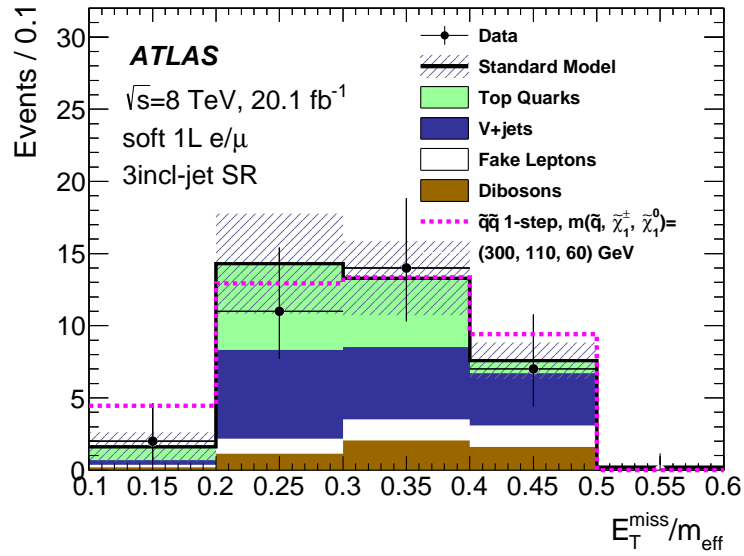[1]ewan.chin.hill@cern.ch

Figure 1: Examples of direct production and decay of strongly produced supersymmetric particles.

Figure 2: Distribution of the missing transverse momentum significance, E_T^{miss}/m_{eff} for one signal region in the squark and gluino search with one or more light charged leptons [3]. The effective mass, m_{eff} is the scalar sum of the missing transverse momentum with the p_T of all the charged leptons and jets in the event.

transverse momenta of measured particles and jets in the event, often with the missing transverse momentum. Large missing transverse momentum (whose magnitude is referred to as E_T^{miss}) and its significance (see Figure 2) are also important variables in defining the signal regions.

The limits set by the search using final states with no charged leptons and the limits set by the search requiring one or more electrons or muons in the final state have been combined to extend the exclusion reach in the masses of the squarks and gluinos as a function of the LSP mass as shown in Figure 3. In these models the LSP is assumed to be the lightest neutralino, $\tilde{\chi}_1^0$. In the model of pair-produced gluinos (see middle diagram in Figure 1), gluinos below 1.3 TeV are excluded at 95% CL, for a lightest neutralino mass below 500 GeV. Squarks are excluded in a similar model (see right diagram in Figure 1) up to 850 GeV at 95% CL for a massless lightest neutralino. These limits are an improvement of approximately 50 GeV with respect to the results of the separate analyses [4].
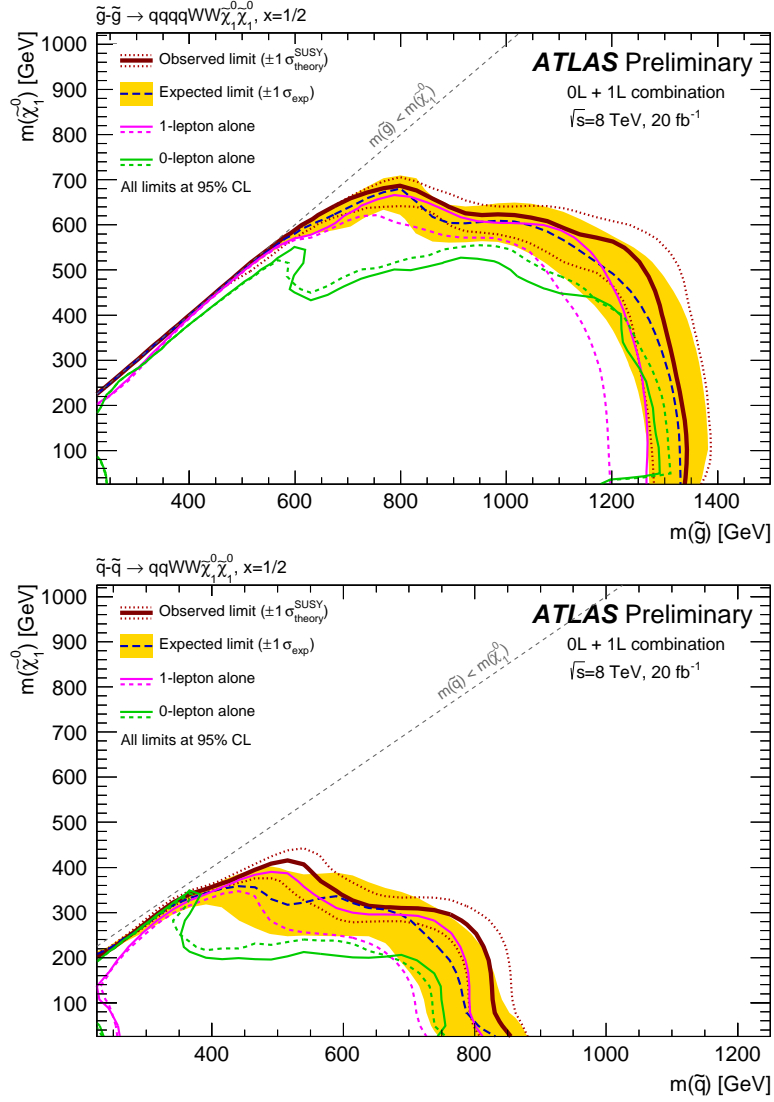
Figure 3: Expected and observed 95% CL exclusion contours for gluinos (top) and squarks (bottom) made by combining the search using final states with no charged leptons with the search requiring one or more electrons or muons in the final state [4].

3 Direct third generation production searches

The smaller cross-sections of the third generation squarks require there to be dedicated searches for them. These searches investigate the decays that can involve 0, 1, or 2 electrons or muons, and real or virtual intermediate Standard Model or supersymmetric particles. Three of the top squark decays studied are shown in Figure 4. Large missing transverse momentum is important in defining the signal regions as well as the tagging of jets from b quarks and variables that probe the transverse masses of the parent particles present in the decay chain. The searches for the top squark decaying to produce the lightest neutralino as
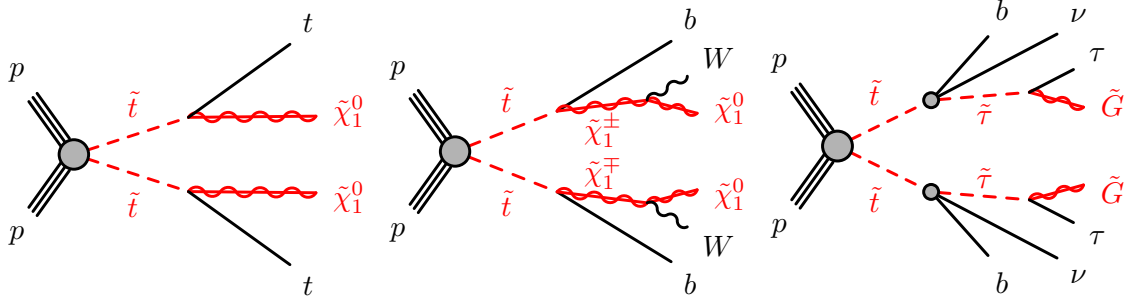
Figure 4: Three examples of direct production and decay of third generation squarks.
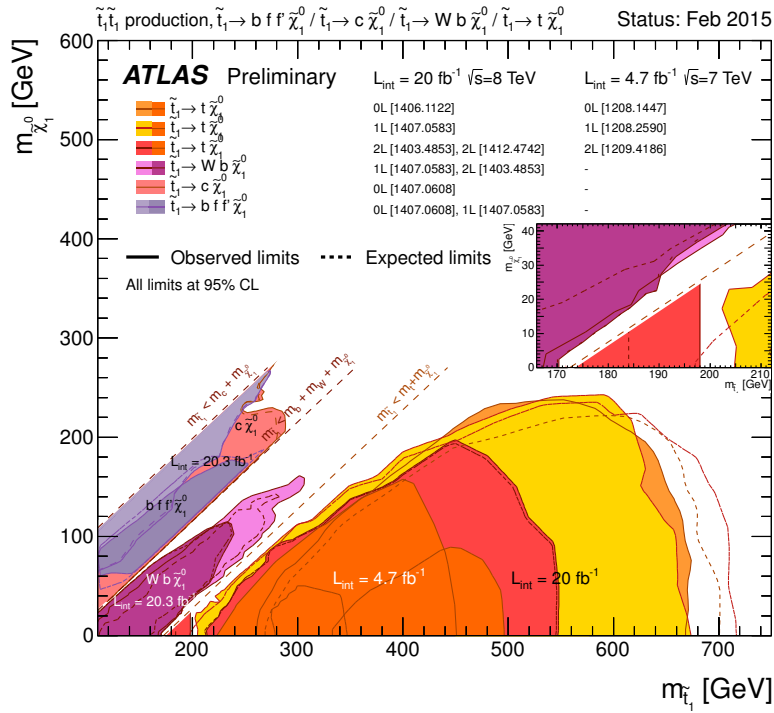

Figure 5: Summary of the ATLAS top squark searches [6]. The numbers in square brackets in the legend are the arXiv references for the relevant individual ATLAS public results.

the LSP are summarised in Figure 5.

Several analyses have focused on probing close to kinematic boundaries and others on probing top squark masses that are very close to the masses of other known particles. The results of a $t\bar{t}$ cross-section measurement have been interpreted in terms of a top squark exclusion, shown in Figure 6, and exclude top squark masses between the top mass threshold and 177 GeV, assuming a 100% branching ratio for $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ and $m_{\tilde{\chi}_1^0} = 1$ GeV [5]. Searches for pair-produced top squarks decaying to final states including two light charged leptons (electrons or muons) have been re-interpreted to probe a different model where a top squark decays into a scalar tau with an effectively massless gravitino as the LSP, where the model is illus-
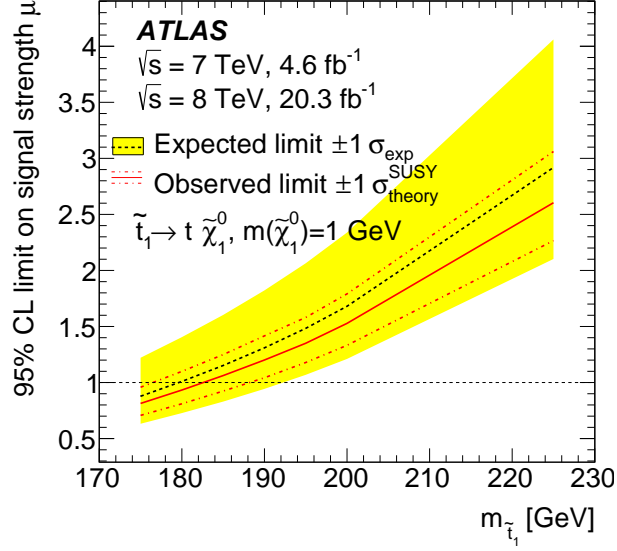
Figure 6: Expected and observed limits at 95% CL on the signal strength, μ, as a function of the top squark mass, for top squark pair production where $\tilde{t}_1$ decays with 100% branching ratio to predominantly right-handed top quarks, assuming $m_{\tilde{\chi}_1^0} = 1$ GeV [5]. The effective top squark pair production cross-section is multiplied by the signal strength and used to fit the difference between the measured $t\bar{t}$ cross-sections and the theoretically predicted Standard Model QCD production cross-sections.
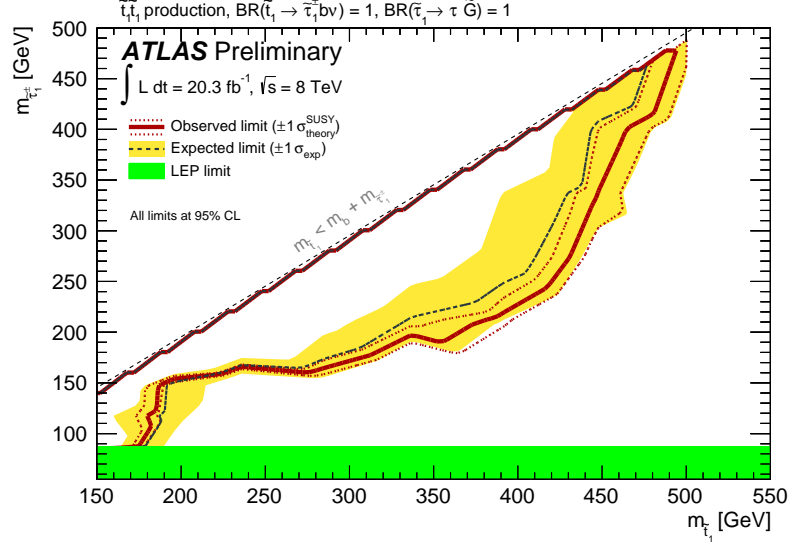

Figure 7: Expected and observed 95% CL exclusion contours for a top squark decaying into scalar tau [7].

trated in Figure 4 (right diagram) [7]. The signal regions in this analysis heavily depend on stransverse mass variables [8] and exclude regions close to the kinematic boundaries of the model, as shown in Figure
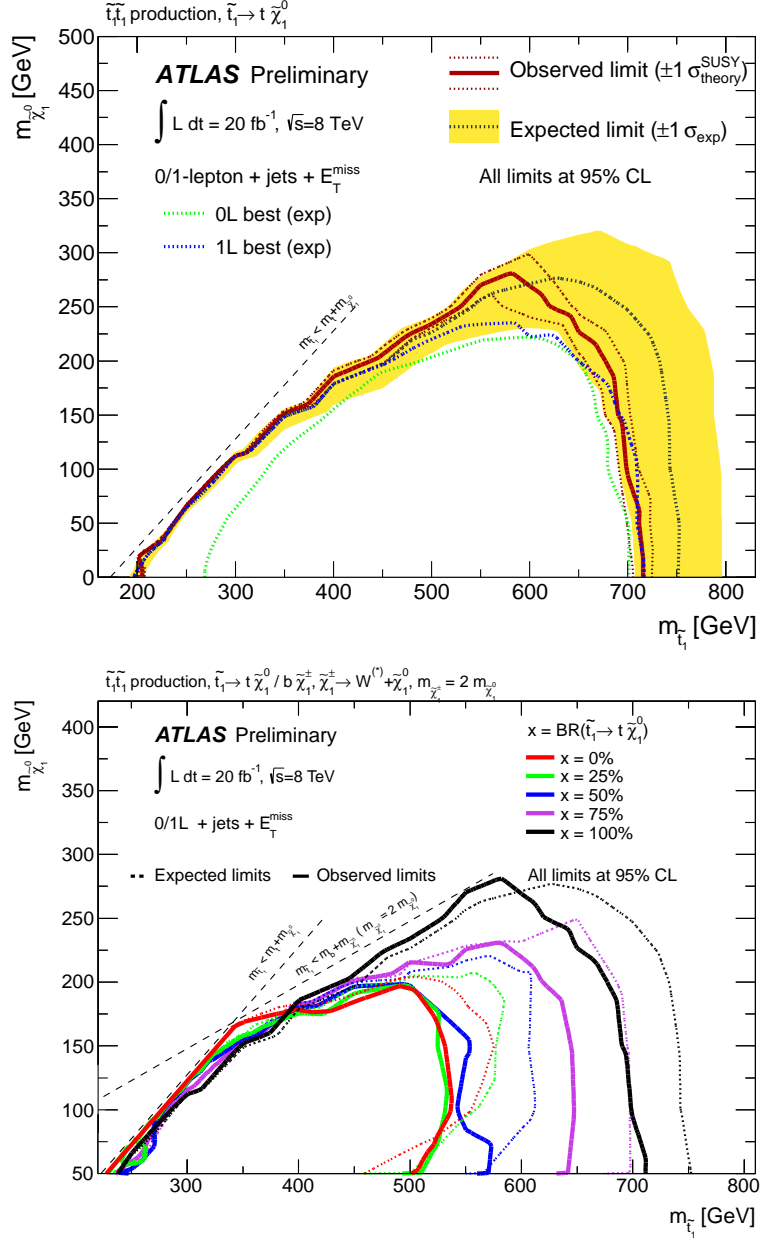
Figure 8: Expected and observed 95% CL exclusion contours for top squarks using the combination of searches using 0-2 leptons. Top: Exclusions assuming a 100% branching ratio to $t\tilde{\chi}_1^0$. Bottom: Exclusions assuming several different branching ratios of top squark decays to $t\tilde{\chi}_1^0$ and $b\tilde{\chi}_1^\pm$ [9].

7. In the searches for $\tilde{t}_1 \to t\tilde{\chi}_1^0$ where it is assumed that there is a 100% branching ratio for the decay and $m_{\tilde{\chi}_1^0} = 1$ GeV, the combination of the fully hadronic and the single electron or muon searches increases the exclusion limit by about 50 GeV compared to the individual analyses. This combination produces an observed exclusion limit on the top squark mass of 700 GeV at 95% CL (see Figure 8 - top) [9]. The limits

are weaker when $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$ is also allowed and $\tilde{\chi}_1^{\pm}$ is the lightest chargino (see Figure 8 - bottom).

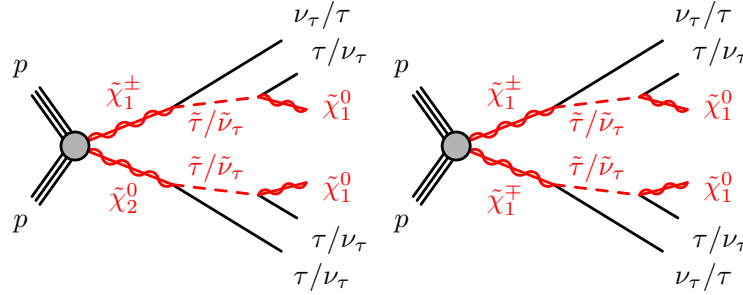## 4 Direct electroweak production searches

Figure 9: Two examples of direct production and decay of electroweak supersymmetric particles.
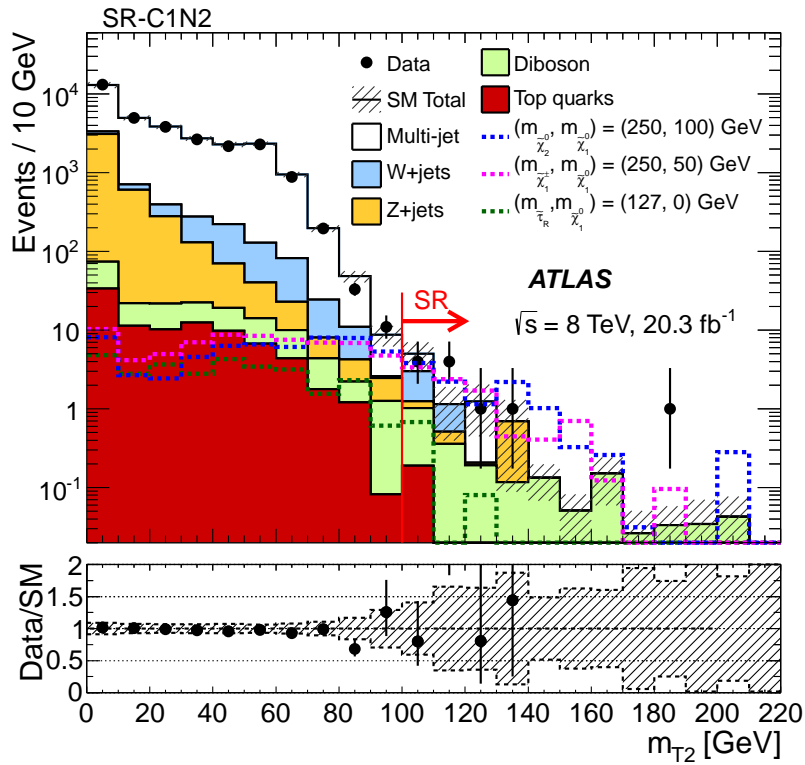

Figure 10: Distribution of the stransverse mass involving two hadronically decaying taus in a search for electroweak supersymmetric particles [10].

Electroweak processes in the LHC have fairly clean signatures due to the small amounts of hadronic activity produced by the signal. This allows for good separation between signal and the dominant strongly-
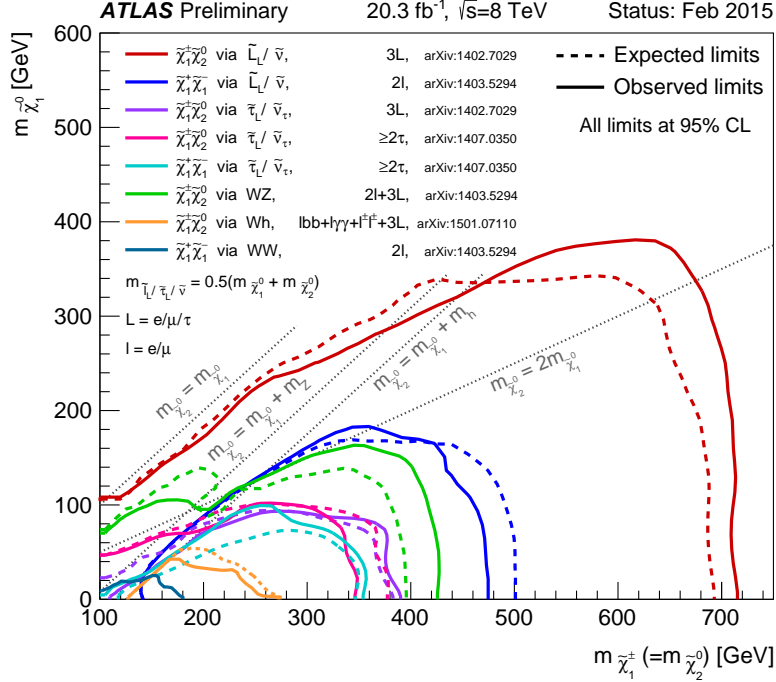
Figure 11: Summary of the ATLAS searches for electroweak Supersymmetry [6].

produced background processes for searches for Supersymmetry in the electroweak sector. The low hadronic activity in the signal means that not only are the electrons and muons very important search tools but so too are hadronically decaying taus. The searches for charginos and the next-to-lightest neutralinos ($\tilde{\chi}_2^0$), with several models shown in Figure 9, focus especially on hadronically decaying taus and require a small maximum number of high-p_T jets in the final state [10]. The missing transverse momentum is again important for separating signal from the background processes along with stransverse mass involving two hadronically decaying taus, which is shown for a signal region in Figure 10. The summary of all the electroweak sector searches is illustrated in Figure 11. These searches have shown that the lightest chargino has been excluded for masses below roughly 710 GeV at 95% CL when it is assumed that $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^0}$ and the lightest neutralino is massless.

5   Long-lived and R-parity violating searches

Searches for supersymmetric particles with long lifetimes have been performed focusing on directly pair produced squarks and gluinos, also including R-parity violating models (see Figure 12). These searches allow for non-negligible lifetimes, meaning that the long-lived supersymmetric particles decay at different locations within the ATLAS detector, resulting in signal signatures such as displaced vertices. The summary of the constraints on the gluino mass-vs-lifetime plane for a split-Supersymmetry model, with the gluino (bound with quarks into an R-hadron) decaying into a gluon or light quarks (see left diagram in Figure 1) and $m_{\tilde{\chi}_1^0} = 100$ GeV, is shown in Figure 13 [6].
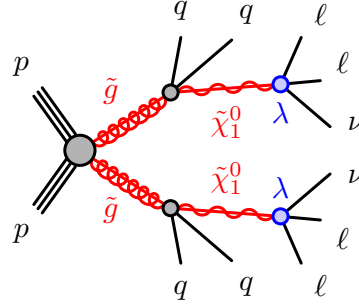
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Figure 12: An example of direct production and decay of strongly produced supersymmetric particles for a model where the lightest neutralino is long-lived and R-parity is not conserved.
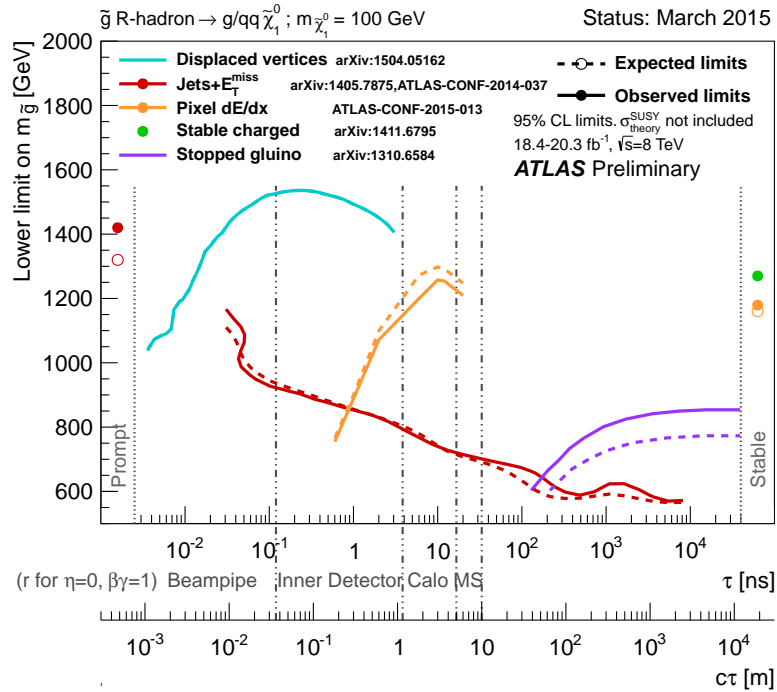

Figure 13: Summary of the ATLAS long-lived supersymmetric particle searches [6].

6 Sensitivity studies at 13 TeV

The discovery reach in Run 2 will quickly exceed that of the Run 1 searches with the increase to a centre-of-mass energy of 13 TeV. A study of the ATLAS sensitivity to gluinos and squarks (see left and middle diagrams in Figure 1) for early Run 2 integrated luminosities has been performed using similar cuts to those used in the Run 1 searches (see Figure 14). These have shown that approximately $2 - 10$ fb^{-1} of data will be sufficient to detect excesses at the level of 3σ (see Figure 15) for a variety of signals and for masses of supersymmetric particles that are just beyond the reach of the Run 1 exclusions.
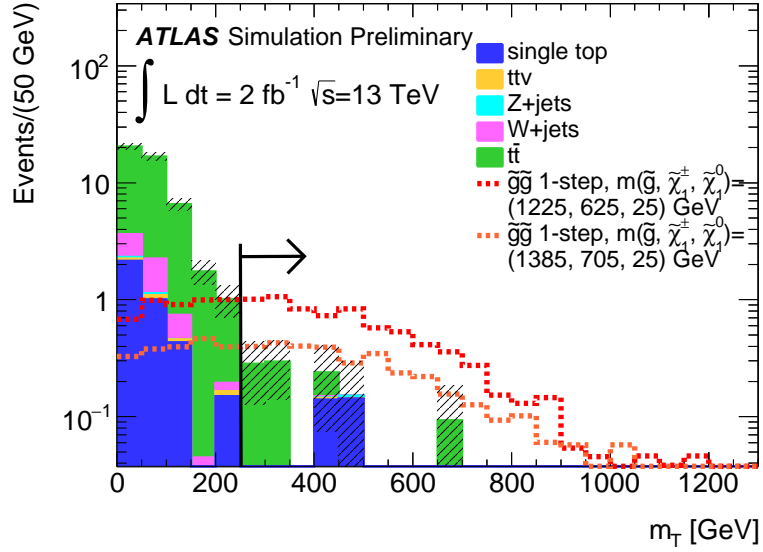
Figure 14: Simulated distribution of the transverse mass with all cuts applied accept those on the transverse mass itself in a search for strongly produced supersymmetric particles for early Run 2 integrated luminosities [11].
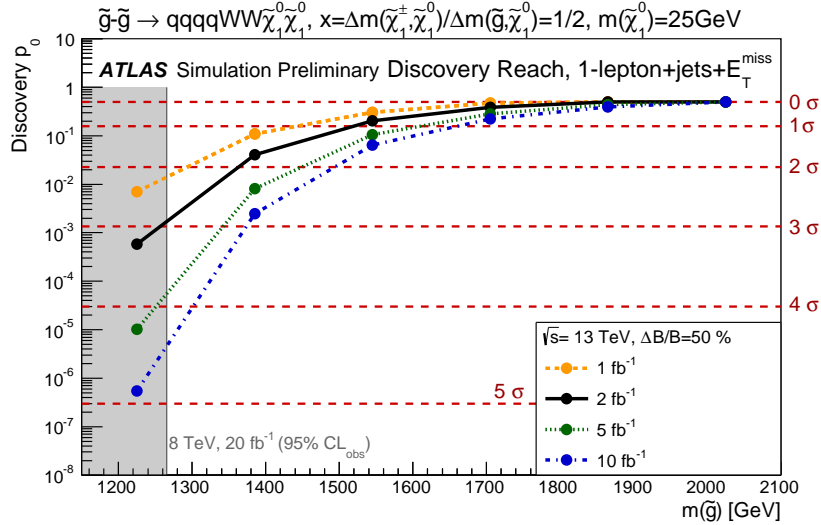

Figure 15: Sensitivity for observing an excess in strongly produced supersymmetric particle searches early in Run 2 [11].

7 Conclusions

The ATLAS Run 1 data have been explored to investigate a wide variety of supersymmetric models in different regions of phase space. No significant excesses have been observed in the Run 1 data set and limits have been set on many models and particle masses. The Run 2 data, with its higher centre-of-mass energy, will allow Supersymmetry to be studied further. With only a fraction of the luminosity collected in the 2010-2012 Run 1 data set the early Run 2 searches will probe regions of phase space that have so far been out of reach.

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