ATLAS NOTE

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Interpretation of same-sign dilepton events at ATLAS with a simplified SUSY model

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Abstract

A search for supersymmetric particles was performed in events with two like-sign leptons using 35 pb^{-1} of integrated luminosity recorded by the ATLAS detector in pp collisions at $\sqrt{s}$=7 TeV. No excess above the Standard Model prediction is observed. The results are expressed in terms of a simplified model which contains the minimal particle content and is parametrized directly in terms of the sparticle masses. Upper limits on the production cross section times branching ratios are calculated for three specific decay modes which would produce like-sign dilepton events, and presented as a function of the sparticle masses.

1 Introduction

The discovery of supersymmetry (SUSY) would solve several outstanding theoretical problems, such as the hierarchy problem [1] and may provide important clues as to the nature of dark matter [2]. However, the complexities of current supersymmetry theories encumber the experimental exploration. The first complication is that supersymmetric theories contain more than one hundred free parameters even in the case of the Minimal Supersymmetric Standard Model (MSSM). A space of this dimensionality is difficult to search efficiently, even though many of the parameters can be constrained from the upper bounds on the flavor changing neutral currents (FCNC) [3] and electric dipole moments (EDM) of neutrons and electrons [4]. The most common approach relies on freezing the vast majority of the parameters to theoretically natural values and focusing on a smaller set of parameters, perhaps five or fewer (e.g. Minimal Supergravity model (mSUGRA) [5]). Naturally, any experimental results which assume a particular set of frozen values are only valid within the choice of those parameters, many of which could strongly affect the experimental predictions. Those supersymmetric theories are expressed at a higher energy scale, and therefore, small changes in the theoretical parameters can result in large changes in the phenomenology. Finally, specific supersymmetric theories make assumptions about relative couplings and mixing rates which result in a preference for some decay modes over others.

Recently, a series of workshops have outlined the growing interest in using simplified models to ensure that all the relevant phase space is covered and to interpret the data [6]. In this note, a search for production and decay of supersymmetric particles leading to a final state of two like-signed leptons [7] is presented, where the results are expressed in terms of a simplified model [8, 9]. This note complements the results presented in [10] where the data is interpreted in the frameworks of mSUGRA and PhenoGrid.

The simplified model presented in this note includes several important features. It contains only the SUSY-like particle content necessary for signals to contribute to like-signed dilepton final states, naturally reducing the dimensionality of the theoretical parameter space. Furthermore, it is expressed directly in terms of the masses of the new particles at the weak scale. Finally, within the simplified model framework no assumption about the relative couplings at each vertex is made. Thus, the results are expressed in terms of limits on cross-section times branching ratios as a function of new particle masses, separately for each event topology, or even down to each diagram. The results are therefore generic and can be applied to any theories with additional Standard Model (SM) partner particles (*e.g.* Universal Extra Dimensions, UED [11]), which make predictions in these topologies.

Interpretation of the results within a simplified model approach differs from interpretation made within high energy scale SUSY models for the following reasons: Those SUSY models have strict constraints on the sparticle spectrum. For example, in mSUGRA, the masses of the lightest neutralino, chargino and gluino are almost proportional to each other with fixed ratios. Therefore, only a small region of the phase space of sparticle mass planes is covered. Additionally, in other SUSY searches done in ATLAS, which use either mSUGRA or PhenoGrid samples [10], limits are inclusively set for multiple diagrams at once. Such a procedure relies on the model-dependent relative values between the cross sections and branching ratios of relevant sub-processes, even in the general MSSM approach.

2 A simplified SUSY model

The simplified SUSY model presented in this note is built so that it has the minimal particle content necessary to produce SUSY-like events in the like-sign dilepton final states and is parametrized directly in terms of the sparticle masses. The model was built to satisfy the following conditions:

- To have leptons in the final state, the model must contain a chargino $\tilde{\chi}_1^{\pm}$ and a neutralino $\tilde{\chi}_2^0$, which decay to W/Z bosons and the lightest SUSY particle (LSP), or sleptons which decay down to leptons and LSP's.

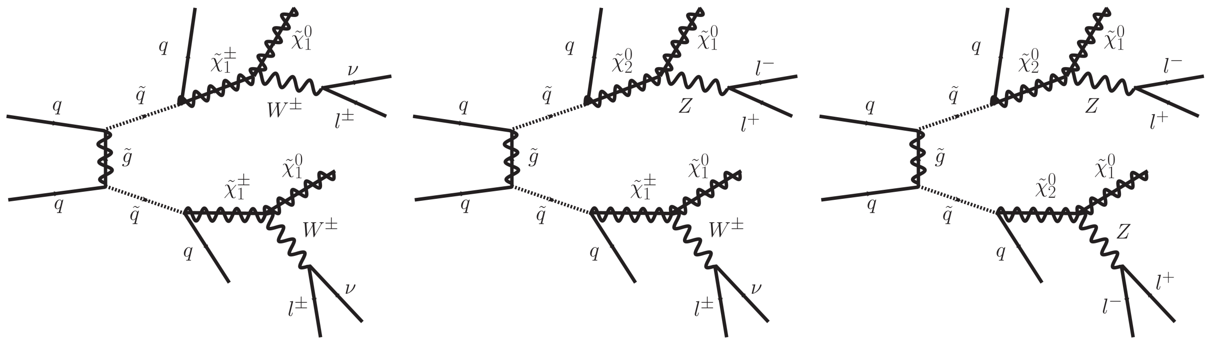

Figure 1: Feynman diagrams of the squark pair production with subsequent decays leading to same-sign dilepton (left), trilepton (center), and four-lepton (right) final states.

- Conservation of R-parity was assumed, which requires the presence of the LSP.
- To perform searches with the early data, processes with large cross-sections are investigated. Pair productions of colored states such as gluinos and squarks are the dominant contribution.

As a starting point, simple cascade decays are considered. The simplified model is constructed in MadGraph [12] to generate the initial sparticle-pair production for the Monte Carlo simulation, considering only the first generation of squarks. BRIDGE [13] handled the following decay chains of the sparticles, restricting to the diagrams of interest.

If $m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0} \ll m_{\tilde{l},\tilde{\nu}}$, the chargino and neutralino decay primarily to the LSP and W or Z, and the kinematics of the process, and therefore the selection efficiency, is independent of the slepton mass. This note focuses on these modes. Assuming that the chargino and neutralino are largely degenerate, this results in four mass parameters for the model: $m_{\rm LSP}, m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0}, m_{\tilde{g}}, m_{\tilde{q}}$.

Considering the requirements mentioned above, final states that lead to the exclusive same-sign dilepton signature can be grouped into three main categories, where the first two are the most dominant:

- Final state with exactly two same-signed leptons.
- Trilepton final state, where one lepton is not reconstructed.
- Four lepton final state coming from Z decays in both branches. This mode has much smaller acceptance due to the third lepton veto.

There are five initial sparticle pair-production mechanisms that will contribute to these final states: (1) gluino-gluino, (2) gluino-squark, (3) squark-squark, (4) squark-antisquark, and (5) direct weakino pair productions. The same-sign squark pair production will provide all the categories mentioned above (same sign two-lepton, trilepton, and four-lepton final states). This process is considered in this paper as a first step towards a more comprehensive simplified model which would cover more broadly all the relevant production mechanisms and decay topologies.

The processes shown in Figure 1 are dependent only on three mass parameters (i.e. $m_{LSP}, m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0}, m_{\tilde{q}}$). When $m_{\tilde{g}} > m_{\tilde{q}}$, squarks directly decay to $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$, therefore the effects from $m_{\tilde{g}}$ can be embedded in the cross section value since the kinematics of the event are unaffected. The efficiency for each process was calculated using simulated samples, which allows limits to be set on cross-section times branching ratios. The branching ratios included in the limits are described explicitly below.

$$Br(\tilde{q}\tilde{q} \to qq\ell\nu\ell\nu\tilde{\chi}_1^0\tilde{\chi}_1^0) = \left[Br(\tilde{q} \to q\tilde{\chi}_1^{\pm})Br(\tilde{\chi}_1^{\pm} \to \ell\nu\tilde{\chi}_1^0)\right]^2 \quad (1)$$

$$Br(\tilde{q}\tilde{q} \to qq\ell\nu\ell^+\ell^-\tilde{\chi}_1^0\tilde{\chi}_1^0) = 2Br(\tilde{q} \to q\tilde{\chi}_1^\pm)Br(\tilde{q} \to q\tilde{\chi}_2^0)Br(\tilde{\chi}_1^\pm \to \ell\nu\tilde{\chi}_1^0)Br(\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0) \quad (2)$$

$$Br(\tilde{q}\tilde{q} \to qq\ell^+\ell^-\ell^+\ell^-\tilde{\chi}_1^0\tilde{\chi}_1^0) = \left[Br(\tilde{q} \to q\tilde{\chi}_2^0)Br(\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0)\right]^2 \quad (3)$$

The precision with which the simplified model can reproduce specific SUSY models was evaluated by comparing kinematic distributions at the generator-level with a corresponding mSUGRA point. The mSUGRA point with $m_0 = 150$ GeV, $m_{1/2} = 220$ GeV, $\tan\beta = 3$, $A_0 = 0$, and $\mu > 0$ was chosen as a benchmark point. In this region, weakino decays to sleptons are negligible, and therefore this point provides the same event topology as the ones studied with the simplified model with a similar mass hierarchy. Lepton transverse momentum and pseudorapidity (η) as well as missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) were found to be in good agreement. After requirements on lepton p_T, η and $E_{\mathrm{T}}^{\mathrm{miss}}$ matching the same-sign dilepton analysis selection, the difference in acceptances between the simplified model and the mSUGRA point was found to be less than 4%, which is negligible compared to uncertainties arising from detector effects.

Similar studies were performed to evaluate the impact of spin configurations by comparing simplified models with SUSY-like and SM-like spin. The UED model is an example of the latter. Although small variations in kinematic variables such as lepton p_T, η and $E_{\mathrm{T}}^{\mathrm{miss}}$ were observed, the impact on the generator-level acceptance was found to be less than 3%. However, the spin effects should be carefully studied for each event topology, mass region and event selection in order to extend the interpretation to physics model with different spin configurations.

3 Data and SM background simulated events

The data used in this analysis were recorded in 2010 at the LHC at a center-of-mass energy of 7 TeV. The event selection, SM background estimate and evaluation of systematic uncertainties follow the ones described in [10] and are briefly summarized here.

Application of beam, detector, and data-quality requirements results in a total integrated luminosity of 35 pb^{-1}with an estimated uncertainty of 11% [14]. The data have been selected with single lepton (e or μ) triggers. The detailed trigger requirements vary throughout the data-taking period owing to the rapidly increasing LHC luminosity and the commissioning of the trigger system, but always ensure that leptons with p_{T}>20 GeV lie in the efficiency plateau. Monte Carlo (MC) simulation samples for background processes are generated as described in [10].

4 Object reconstruction and event selection

The same object reconstruction and event selection are used as in [10]. Electrons in the signal region are required to pass the "tight" selection criteria, with $E_T > 20$ GeV and $|\eta| < 2.47$. Events are removed if a "medium" electron is found in the electromagnetic calorimeter transition region, $1.37 < |\eta| < 1.52$. The summed E_T in a cone of $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.2$ around the electron is required to be less than $0.15 E_T$.

Muons are required to be identified either in both the inner tracking detector (ID) and muon spectrometer (MS) systems or as a match between an extrapolated ID track and one or more segments in the MS. The summed p_T of other ID tracks within a distance of $\Delta R < 0.2$ around the muon track is required to be less than 1.8 GeV. Only muons with $p_T > 20$ GeV and $|\eta| < 2.4$ are considered.

Jets are reconstructed using the anti-k_t jet clustering algorithm [15] [16] with a radius parameter $R = 0.4$. Only jets with $p_T > 20$ GeV and $|\eta| < 2.5$ are considered. The closest jet to a candidate electron within a distance $\Delta R < 0.2$ is discarded. On the other hand, identified electrons and muons are considered only if they satisfy $\Delta R > 0.4$ with respect to the closest remaining jets. Events are discarded if they contain any jet failing basic quality selection criteria, which reject detector noise and non-collision backgrounds [17].

Events are required to have at least one reconstructed primary vertex with at least five associated tracks. Furthermore, the distance between the z coordinate of the primary vertex and that of the extrapolated muon track at the point closest to the primary vertex must be less than 10 mm to suppress cosmic background. The signal region is defined as events with exactly two identified same-sign leptons with $p_T > 20$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV. $E_{\mathrm{T}}^{\mathrm{miss}}$ is computed from a vector sum of the transverse momenta of the reconstructed objects, (jets with $p_T > 20$ GeV over the full calorimeter coverage $|\eta| < 4.9$, leptons at the object selection level), together with calorimeter clusters not belonging to reconstructed objects.

5 Estimation of background and systematic uncertainties

Backgrounds from several Standard Model processes could contaminate the signal regions. The main background to the same-sign dilepton final state arises from SM W+jets and QCD multijet production where one or more jet is misidentified as an isolated lepton, which is referred as "fake lepton" background. The other significant backgrounds arise from charge misidentification of an electron due to a hard bremsstrahlung process in $t\bar{t}$. Contributions from Z+jets are negligible due to high $E_{\mathrm{T}}^{\mathrm{miss}}$ cut. Contributions from diboson production are also considered. The fake background is estimated in a data-driven way using the matrix method, and MC-based estimations were used for the other backgrounds. The cosmic background was considered for the $e^{\pm}\mu^{\pm}$-channel as in [10].

The systematic uncertainties on the data-driven fake background estimates mainly come from the parametrization of fake rate. For the MC-driven background estimates, the jet energy scale and resolution, lepton energy scale, resolution and identification, luminosity, cross section, and parton distribution function (PDF) uncertainties were considered. More details are mentioned in [10].

The observed numbers of data events and the expected numbers of background events in the signal regions for the same-sign dilepton final states are shown in Table 1. The uncertainty in the cosmic background has not been included in the results shown in Section 6. This is conservative, because the discreteness of a Poisson process leads to overcoverage for upper limits, and additional continuous nuisance parameters reduce the overcoverage and thus lead to tighter upper limits [18, 19]. The total number of expected SM events is 0.28 ± 0.14 with zero events observed in the data.

Table 1: Summary of the background yields and observed number of events for the same sign dilepton channels.

	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$
Fakes	0.12 ± 0.13	0.030 ± 0.026	0.014 ± 0.010
Di-bosons	0.015 ± 0.008	0.035 ± 0.014	0.021 ± 0.006
Charge misidentification	0.019 ± 0.008	0.026 ± 0.011	-
Cosmics	-	$0^{+1.17}_{-0}$	-
Total	0.15 ± 0.13	$0.09^{+1.17}_{-0.03}$	0.04 ± 0.01
Data	0	0	0

6 Limits and interpretations

No excess above the Standard Model prediction is observed, thus upper limits on the cross-sections times branching ratios for new physics based on the simplified models are obtained. Classical confidence intervals in the theoretical cross section are constructed by generating ensembles of pseudo-experiments that describe the expected fluctuations of statistical and systematic uncertainties on both signal and backgrounds, following the likelihood ratio ordering prescription proposed by Feldman and Cousins [20].

The PDF uncertainty for the signals was estimated in the same way as the SM background, adopting a conservative uncertainty of 5.5%.

Figure 2-4 show 95% confidence level (CL) upper limits for each diagram as a function of $m_{\tilde{q}}$ and $m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0}$ for fixed LSP masses. Each figure corresponds to a specific diagram, where the branching ratios are explicitly described in (1)-(3). For each diagram, a grid of 26 signal points is produced and used for the limit setting. The upper limits were interpolated linearly from those points in three coordinates. The impact of the interpolation on the signal acceptance is found to be below a few percent and therefore does not impact the results.

From the observed number of data events and the background expectations, 0.053 pb (1.9 events) was obtained as the upper limit on the cross section times branching ratios times acceptance times efficiency.

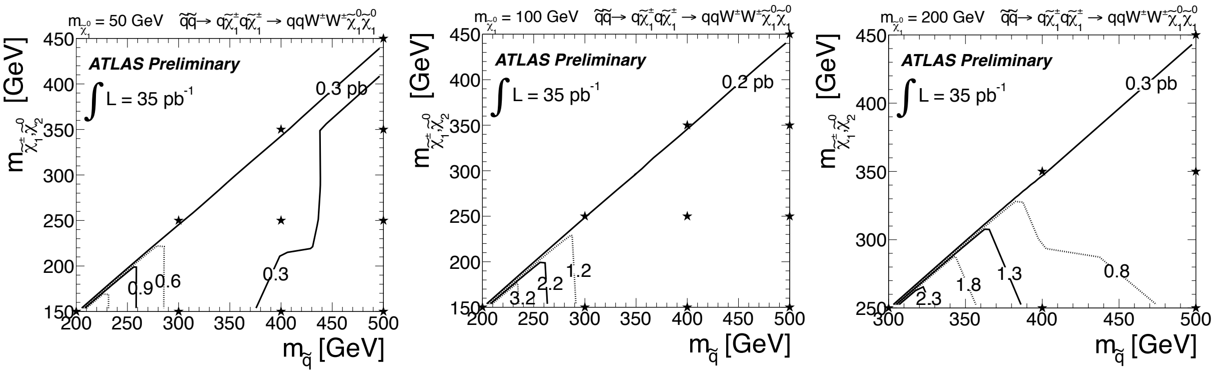

Figure 2: Upper limits (95% CL) on $\sigma\times$ Br in pb for the $\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^\pm q\tilde{\chi}_1^\pm \rightarrow qqW^\pm W^\pm\tilde{\chi}_1^0\tilde{\chi}_1^0$ process as a function of $m_{\tilde{q}}$ and $m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0}$ for the fixed LSP mass (left: 50 GeV, center: 100 GeV, right: 200 GeV). The stars indicate the grid mass points generated.

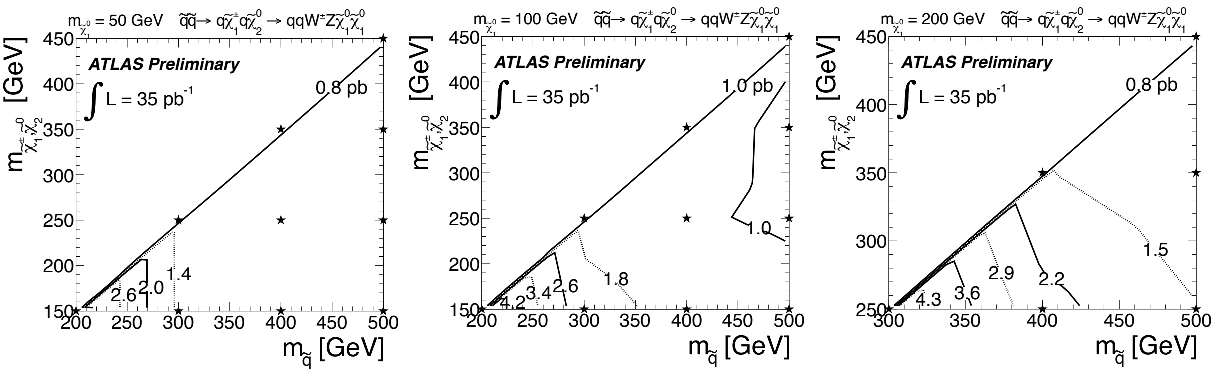

Figure 3: Upper limits (95% CL) on $\sigma\times$ Br in pb for the $\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^\pm q\tilde{\chi}_2^0 \rightarrow qqW^\pm Z\tilde{\chi}_1^0\tilde{\chi}_1^0$ process as a function of $m_{\tilde{q}}$ and $m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0}$ for the fixed LSP mass (left: 50 GeV, center: 100 GeV, right: 200 GeV). The stars indicate the grid mass points generated.

7 Conclusions

A search for supersymmetric particles was performed in events with two like-sign leptons using data with 35 pb^{-1} of integrated luminosity recorded by the ATLAS detector in pp collisions at $\sqrt{s}$=7 TeV.

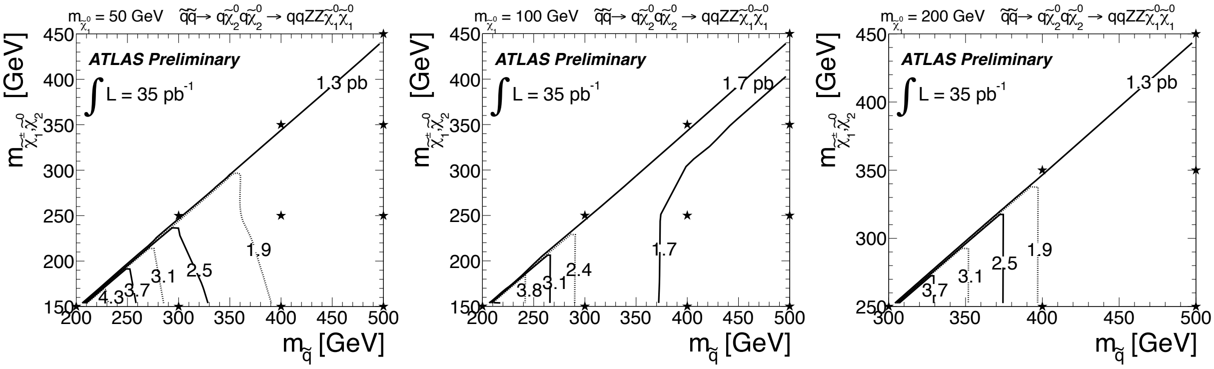

Figure 4: Upper limits (95% CL) on $\sigma\times$ Br in pb for the $\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_2^0 q\tilde{\chi}_2^0 \rightarrow qqZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ process as a function of $m_{\tilde{q}}$ and $m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0}$ for the fixed LSP mass (left: 50 GeV, center: 100 GeV, right: 200 GeV). The stars indicate the grid mass points generated.

No excess above the Standard Model prediction is observed. The results are expressed in terms of a simplified model which contains the minimal particle content and is parametrized directly in terms of the sparticle masses. Upper limits on the production cross section times branching ratios are calculated for three specific decay modes which would produce like-sign dilepton events and presented as a function of the sparticle masses. This allows the application of these limits to any theories with additional SM partner particles, which includes these decays. This is the first supersymmetry search results in ATLAS using a simplified model approach.

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