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Searches for supersymmetry with the ATLAS detector

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Summary. — First ATLAS searches for signals of Supersymmetry in proton-proton collisions at the LHC are presented. These searches are performed with the full data sample recorded in 2010, corresponding to an integrated luminosity of $35\,\mathrm{pb}^{-1}$. Results for various channels with large missing transverse energy and different lepton and jet multiplicities are reported. A search for long-lived strongly interacting particles is also presented. Good consistency with the Standard Model prediction has been found in all channels; limits on squark and gluino masses are derived, which considerably improved previous results.

PACS 12.60.Jv – Supersymmetric models.

1. – Introduction

Supersymmetry (SUSY) is one of the most promising candidates for extending the Standard Model. It is based on a new symmetry between fermions and bosons and therefore predicts a large number of new particles [1]. These new particles need to be heavier than their Standard Model counterparts, since they have not been discovered yet. On the other hand, if they are not too heavy, and accessible with TeV scale energies, they would reduce the fine-tuning problem of the Standard Model. This argument makes the search for SUSY particles an important part of the LHC physics program.

In addition, a new quantum number called R-parity is introduced to avoid a fast proton decay. The conservation of this quantum number implies that the lightest SUSY particle (LSP) is stable, providing a promising candidate to explain the nature of Dark Matter.

The production at the LHC of scalar quarks and gluinos decaying (possibly with intermediate steps) into a weakly interacting LSP would be observed as an excess of events with large missing transverse energy ($\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$) and high transverse momentum (p_T) jets. Additional particles, such as leptons or photons, might also be produced in the SUSY decay chains, depending on the mass pattern of the new particles.

Since the SUSY breaking mechanism that determines this pattern is not known, the experimental searches need to be quite generic. In the following searches for supersymmetry performed with the ATLAS detector [2] are presented for final states with large

$\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$ and no (sect. **2**), one (sect. **3**) or two (sect. **4**) leptons. In sect. **5** searches which require b-jets to enhance the sensitivity to third generation squarks are presented. Finally, in sect. **6** a search for the scenario in which gluinos or squark have a lifetime larger than the time of flight through the detector are presented.

These searches use the full 2010 data set. After application of beam, detector and data quality requirements the integrated luminosity is $35\,\mathrm{pb}^{-1}$ with an uncertainty of 11%.

2. – Searches with jets and missing transverse momentum

This analysis [3] defines several signal selections, which aim at maximal sensitivity for different regions of the squark-gluino mass plane.

All the selections require the presence of one jet with $p_T > 120\,\mathrm{GeV}$ and $\vec{E}_{\mathrm{T}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$, which guarantees a trigger efficiency larger than 97%, and veto the presence of an isolated electron or muon with $p_T > 20\,\mathrm{GeV}$. They differ for the number of jets with $p_T > 40\,\mathrm{GeV}$ (at least two or at least three) and for the cuts on the effective mass and m_{T2}. The former is the scalar sum of the selected jet p_T and $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$, while the latter is a generalization of transverse mass for two particles decaying into a jet and missing transverse momentum [3].

The two jet selections are optimal for squark pair production, followed by $\tilde{q} \rightarrow q\chi_1^0$, while the requirement of three jets is more suited to signal involving gluinos, for which more jets are expected from $\tilde{g} \rightarrow qq\chi_1^0$.

The main backgrounds are multi-jet production (QCD), Z+jets, W+jets, and top pair production. The multi-jet background is suppressed by a cut on the azimuthal angular difference between the $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$ vector and the leading jets; control regions are obtained reversing this cut. The Monte Carlo prediction normalized to the rate observed in these control regions is consistent with a data-driven estimate obtained smearing a multi-jet control sample with low $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$ with the measured jet resolution. The Monte Carlo description of the $\mathrm{Z}(\nu\nu)$+jets and $\mathrm{W}(\tau\nu)$+jets backgrounds was verified using control selections of Z candidates decaying into two leptons and leptonic W decays.

The number of observed data events in the four signal regions was found to be consistent with the expected Standard Model background. Limits have been placed on both a simplified model containing only squarks of the first two generations, a gluino octet and a massless neutralino, as well as on minimal supergravity (also called constrained MSSM) models (mSUGRA/CMSSM) [4]. In the simplified model, gluino masses below 500 GeV are excluded at the 95% confidence level with the limit increasing to 870 GeV for equal mass squarks and gluinos. In the mSUGRA models equal mass squark and gluinos below 775 GeV are excluded. Both exclusion plots are shown in fig. 1(1).

3. – Searches with jets, a lepton and missing transverse energy

The signal region of this analysis [6] requires the presence of one isolated electron or muon with $p_T > 20\,\mathrm{GeV}$, three jets with $p_T > 30\,\mathrm{GeV}$, of which at least one possesses $p_T > 60\,\mathrm{GeV}$, $\vec{E}_{\mathrm{T}}^{\mathrm{miss}} > 125\,\mathrm{GeV}$, $\vec{E}_{\mathrm{T}}^{\mathrm{miss}} > 0.25 m_{\mathrm{eff}}$ and $m_{\mathrm{eff}} > 500\,\mathrm{GeV}$, where the effective mass m_{eff} is defined as the scalar sum of the p_T of the three leading jets, the p_T of the lepton and $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$. The lepton is the basis of the trigger selection and greatly

(1) More stringent preliminary limits have been recently placed by ATLAS in this search channel using 2011 data [5].

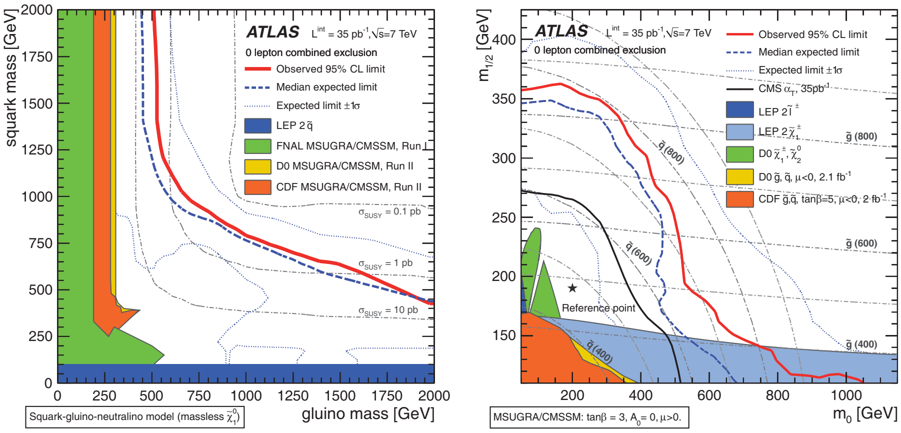

Fig. 1. – Left plot: 95% exclusion limits in the (gluino, squark) mass plane for a simplified MSSM model with a massless neutralino. Comparison with existing limits is illustrative only as some are derived in the context of mSUGRA/CMSSM and might not assume a massless neutralino. Right plot: 95% CL exclusion limits in the slice of mSUGRA/CMSSM defined by $\tan(\beta) = 3, A_0 = 0$ and $\mu = 0$ [4], together with existing limits with the different model assumptions given in the legend.

reduces the QCD multi-jet background. Further reduction is achieved by a cut on the smallest azimuthal separation between the $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$ vector and the three leading jets. The main backgrounds which survive these cuts are W+jets and top pair production, which are suppressed by requiring the transverse mass M_T between the lepton and the missing transverse momentum to be larger than 100 GeV.

In order to determine the background prediction for the signal region, several control selections have been defined. The W and top control selections are defined by keeping the same jet and lepton selection of the signal region but requiring $30 < \vec{E}_{\mathrm{T}}^{\mathrm{miss}} < 80\,\mathrm{GeV}$ and $40 < M_T < 80\,\mathrm{GeV}$. The requirement of no or at least one b-tag jet creates two control selections dominated by W and top pair production, respectively. The transfer of the normalization factors measured in the control region to the signal region is done by Monte Carlo and the uncertainty is carefully studied.

The left plot of fig. 2 shows the distribution of effective mass after all the other cuts. In the electron selection 1.81 ± 0.75 background events are expected and one observed. In the muon channel 2.25 ± 0.94 are expected and one is observed. The resulting limit on the effective cross section of new processes in the signal region, including the effects of experimental acceptance and efficiency, is 0.065 pb and 0.073 pb for the electron and muon channels, respectively. Limits are also set on the parameters of the mSUGRA/CMSSM model, shown in the right plot of fig. 2. For equal squark and gluino masses, gluino masses below 700 GeV are excluded at 95% confidence level. Preliminary results from the analysis of 2011 data are reported in [7].

4. – Searches with two leptons and missing transverse energy

Events with two isolated leptons are a potentially clean signal for SUSY particles. A search was performed [8] for events with opposite sign or same sign lepton pairs. The signal region was defined by $\vec{E}_{\mathrm{T}}^{\mathrm{miss}} > 150\,\mathrm{GeV}$ for opposite sign pairs and $\vec{E}_{\mathrm{T}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$

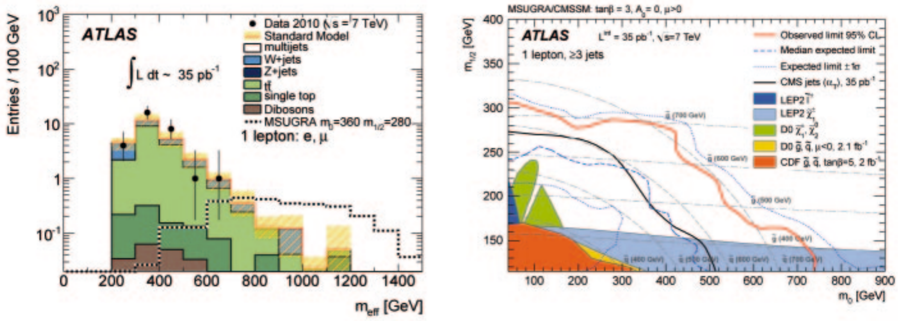

Fig. 2. – Left plot: effective mass of the candidates selected by the 1-lepton analysis after all selection criteria except the cut on effective mass itself. The hatched band indicates the uncertainty on the Monte Carlo prediction. Right plot: 95% CL exclusion limits in the mSUGRA/MSSM slice defined by $\tan(\beta) = 3$, $A_0 = 0$ and $\mu = 0$ [4], together with existing limits with the different model assumptions given in the legend.

for same sign pairs. The main backgrounds are top pair production for the opposite sign channel and events with at least one fake or non-isolated lepton for the same sign channel. The fake background is estimated from the number of observed events with a looser lepton selection and measurements in a control sample of the probability of isolated and fake lepton to pass the tighter selection. The top background is estimated from a dedicated control selection. Again no significant excess is observed in either the opposite or same sign selection.

Under the hypothesis of a scalar lepton lighter than the second lightest neutralino (which enhances the fraction of signal events with leptons) limits are placed on the squark and gluino masses, as shown in fig. 3.

Dilepton events were also studied with the "flavour subtraction" method [9]. This search is sensitive to the correlated production of leptons of the same flavour, for example in $\chi_2^0 \to l\tilde{l} \to l^+l^-\chi_1^0$ and subtracts the observed number of $e\mu$ events from the observed same flavour pairs. Background in which the production of the two leptons is uncorrelated, like top pair events, cancel in the subtraction. Again, no significant excess was observed.

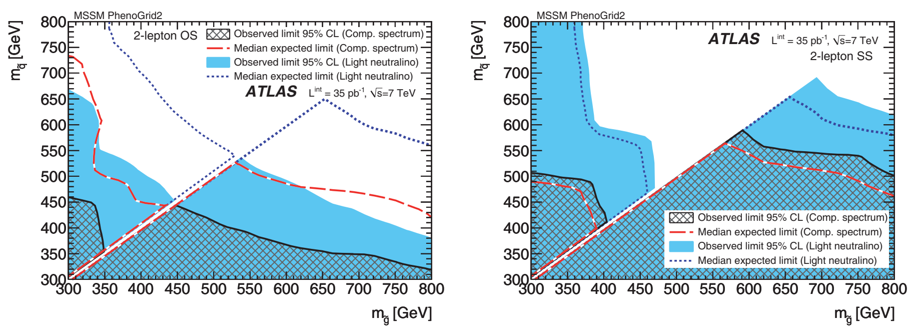

Fig. 3. – Limits on the squark and gluino masses placed by the searches for opposite sign (left) and same sign (right) lepton pairs and large missing transverse momentum.

5. – Searches with b-jets and missing transverse momentum

Events with jets, no or one lepton and missing transverse momentum are also studied with a *b*-tag requirement, in order to increase the sensitivity to SUSY decay chains involving third generation squarks [10]. The dominant background source is top pair production in both the zero and one lepton selection. Since no significant excess is found over Standard Model expectations, limits have been placed on several scenarios. Under the hypothesis that the gluino decays in sbottom-bottom pairs with 100% branching ratio, gluino masses below 590 GeV are excluded.

6. – Searches for new slow-moving massive particles

ATLAS also pursued a search for slow-moving particles (SMPs) with color charge [11]. Such particles are expected if small couplings or decays proceeding via highly virtual particles makes the lifetime of some squark or gluinos much longer than the time of flight through the detector. These particles would hadronize, forming so called R hadrons.

In this search, the ionization measured by the pixel detector ($\mathrm{d}E/\mathrm{d}x$) and the time of flight measured by the tile calorimeter were used to measure the speed of charged particles. Events are triggered by $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$ and an Inner Detector track requirement. For each event, the mass is determined by dividing the momentum by $\beta\gamma$. Since the two velocity measurements and the momentum measurements are not correlated, the background is estimated by random combinations of measured momentum and velocity values.

No event with both measurements of the mass larger than 100 GeV was found. Depending on the model assumed for the interactions of R-hadrons with matter, a 95% CL limit on stable gluinos between 562 and 586 GeV is derived, while the lower mass limits for scalar sbottom and stops are found to be 294 GeV and 309 GeV. Each of these constraints is the most stringent to date.

7. – Conclusions

Due to the large cross section for squark and gluinos the sensitivity of 2010 LHC data to these particles exceeds by far that of all previous collider experiments. ATLAS performed a search for a supersymmetric signal in a variety of final states. No signal has been observed yet, and the most stringent limits have been placed in many scenarios.

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