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The quest for natural SUSY: ATLAS searches

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Summary. — This document presents the status of the searches for supersymmetric particles with the ATLAS detector at LHC, in proton proton collisions at $\sqrt{s} = 8\,\text{TeV}$ in the context of natural Supersymmetry. This covers an extensive list of scenarios including the production of third generation squarks (both direct and gluino mediated), charginos and neutralinos. No deviation from the background expectations has been observed in data and it has been possible to put stringent limits on the masses of gluinos, third-generation squarks and light gauginos in a wide range of models.

PACS 12.60.Jv – Supersymmetric models.

1. – Introduction

Supersymmetry (SUSY) provides an extension of the Standard Model (SM) by introducing supersymmetric partners of the known bosons and fermions. In the framework of an R-parity conserving minimal supersymmetric extension of the SM, SUSY particles are produced in pairs and the lightest supersymmetric particle (LSP), in many models the lightest neutralino χ^0_1, is stable and a possible candidate for dark matter.

SUSY can naturally resolve the hierarchy problem by preventing a large fine-tuning in the Higgs sector: a typical natural SUSY spectrum contains light third generation squarks (stops and sbottoms), charginos and neutralinos. This spectrum is motivated by the fact that the dominant radiative corrections to the Higgs boson mass arise from the top quark in the SM. Thus a relatively light stop can cancel out these corrections. Furthermore the SM Z boson mass, the neutralino and chargino masses are related to the μ parameter in SUSY, implying gaugino masses as low as the electroweak scale.

This document reports several ATLAS searches in the context of natural supersymmetry, carried out using LHC proton proton collision data collected at $\sqrt{s} = 8\,\text{TeV}$.

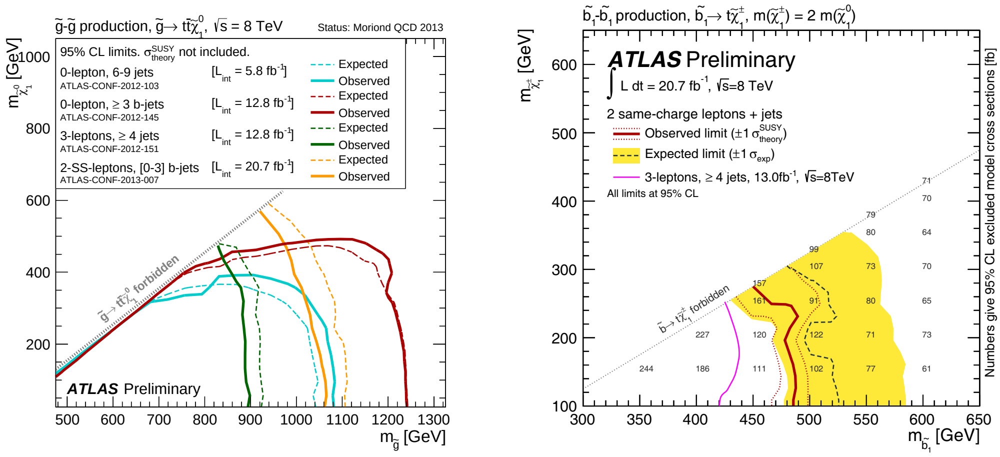

Fig. 1. – Left: Exclusion limits at 95% CL for analyses using pp collision data at $\sqrt{s} = 8\,\text{TeV}$ in the ($m(\tilde{\text{g}})$-$m(\tilde{\chi}_1^0)$) plane. A simplified model is assumed where a pair of gluinos decays via off-shell stop to four top quarks and two neutralinos LSPs. Right: 95% CL exclusion limits on the cross section for the direct production of bottom squarks in a model assuming $\tilde{\text{b}}_1 \to \text{t}\tilde{\chi}_1^\pm$ with $m(\tilde{\chi}_1^\pm) = 2 \times m(\tilde{\chi}_1^0)$ obtained with $20.7\,\text{fb}^{-1}$ at $\sqrt{s} = 8\,\text{TeV}$ [1].

2. – Search for direct sbottom and gluino production

If gluinos are light enough (up to about 1 TeV), the production of third generation squarks is expected to be found first through gluino decay. A large number of b-tagged jets, large missing transverse momentum E_{T}^{miss} and possibly leptons (coming from top quark's leptonic decays) are expected in the final state. If instead the top and bottom squarks are heavier than the gluino, the latter can still decay to a similar final state through virtual third generation squarks.

The analysis presented in [1] addresses the channel $\tilde{\text{g}} \to \text{t}\bar{\text{t}}\tilde{\chi}_1^0$, which is expected to present a very rich final state, requiring two isolated leptons (e or μ) with the same charge and multiple energetic jets. This analysis is also sensitive to the direct production of bottom squarks decaying into a top quark and a chargino. Three event classes are distinguished depending on the number of jets identified as originating from b-quark decays: zero (b-jet veto), at least one and three b-jets. The data sample consists of an integrated luminosity of $20.7\,\text{fb}^{-1}$.

No deviation from the SM expectation is observed. In particular, focusing on processes that involve third generation SUSY particles, limits are set in the $m(\tilde{\text{g}})$-$m(\tilde{\chi}_1^0)$ and $m(\tilde{\text{b}}_1)$-$m(\tilde{\chi}_1^\pm)$ planes (fig. 1) assuming a 100% branching ratio towards the targeted final state.

3. – Search for direct stop production

If the gluino is too heavy, third generation squarks can only be produced directly. Final states of third generation squark production are typically extremely rich: they might include leptons, multiple jets (possibly b-tagged) and E_{T}^{miss}. ATLAS has a set of analyses covering many complementary search channels (fig. 2): the main results in the search for direct stop production are documented in the following.

3$\cdot$1. *Fully hadronic final state.* – The analysis presented in [2] assumes top squarks decaying exclusively into a top quark and the LSP. The analysis uses $20.7\,\text{fb}^{-1}$ of data.

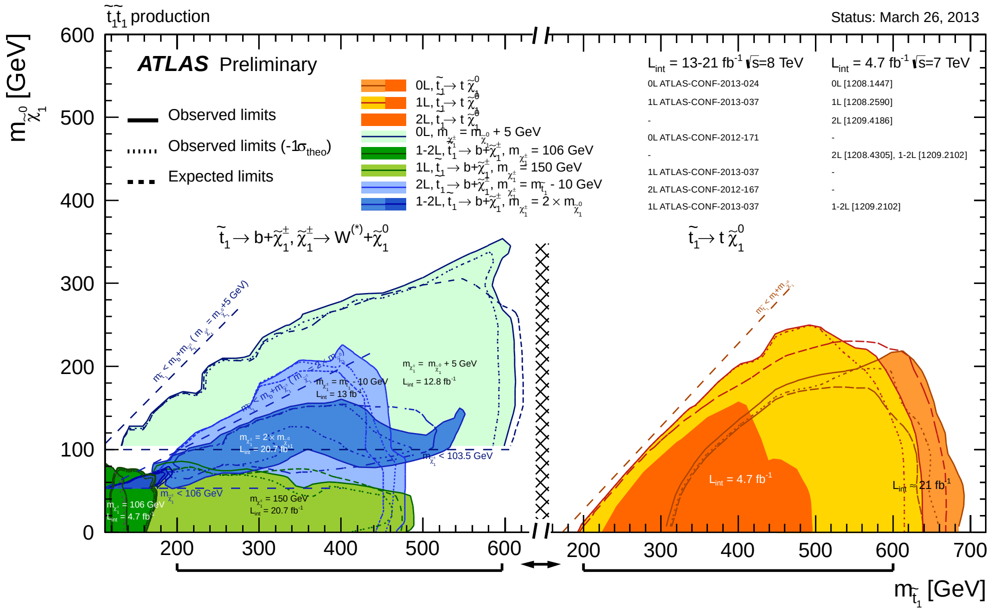

Fig. 2. – Summary of the dedicated ATLAS searches for top squark (stop) pair production based on up to $20.7\,\mathrm{fb}^{-1}$ of pp collision data taken at $\sqrt{s} = 8\,\mathrm{TeV}$ and $4.7\,\mathrm{fb}^{-1}$ of pp collision data taken at $\sqrt{s} = 7\,\mathrm{TeV}$. Exclusion limits at 95% CL are shown in the $\tilde{\mathrm{t}}_1$-$\tilde{\chi}_1^0$ mass plane. The dashed and solid lines show the expected and observed limits, respectively, including all uncertainties except the theoretical signal cross section uncertainty (PDF and scale). The dotted lines represent the results obtained when reducing the nominal signal cross section by 1σ of its theoretical uncertainty. Two decay modes are considered separately with 100% branching ratio: $\tilde{\mathrm{t}}_1 \to \tilde{\chi}_1^0$, where the $\tilde{\mathrm{t}}_1$ is mostly $\tilde{\mathrm{t}}_R$ and $\tilde{\mathrm{t}}_1 \to \mathrm{b} + \tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to \mathrm{W}^{(*)} + \tilde{\chi}_1^0$. In the latter case, several hypotheses on the $\tilde{\mathrm{t}}_1$, $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$ mass hierarchy are assumed: fixed $\tilde{\chi}_1^{\pm}$ mass, $m(\tilde{\chi}_1^{\pm}) \sim 2 \times m(\tilde{\chi}_1^0)$, fixed $m(\tilde{\mathrm{t}}_1) - m(\tilde{\chi}_1^{\pm}) = 10\,\mathrm{GeV}$ and fixed $m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0) = 5\,\mathrm{GeV}$.

The search is conducted in events with large missing transverse momentum and six or more jets, targeting the fully hadronic top final state. The final discriminating variable between signal and background is E_{T}^{miss}. Three signal regions have been defined, targeting different ranges of the top squark mass, with increasingly tighter requirements on the event E_{T}^{miss}: 200 GeV, 300 GeV and 350 GeV.

No evidence is found for physics beyond the SM and results are interpreted in a R-parity-conserving minimal supersymmetric scenario of direct top squark pair production. Top squarks in this model with masses between 320 and 660 GeV are excluded at 95% CL for a nearly massless LSP. For a LSP mass of 150 GeV the exclusion interval is between 400 and 620 GeV.

3·2. *One-lepton final state*. – A search is presented for direct top squark pair production in final states with one isolated electron or muon, jets, and E_{T}^{miss} [3] . The analysis is based on $20.7\,\mathrm{fb}^{-1}$ of data. The stop is assumed to decay to a top quark and the LSP or to a bottom quark and a chargino, where the chargino decays to an on- or off-shell W boson and to the LSP. Six signal regions are defined in order to optimize the sensitivity to different stop and LSP masses, as well as the two considered stop decay scenarios. Three signal regions target the $\tilde{\mathrm{t}}_1 \to \mathrm{b} + \tilde{\chi}_1^{\pm}$ decay: the loosest one relies on the E_{T}^{miss} and the transverse mass m_{T} (from the lepton p_{T} and E_{T}^{miss}) to discriminate signal from

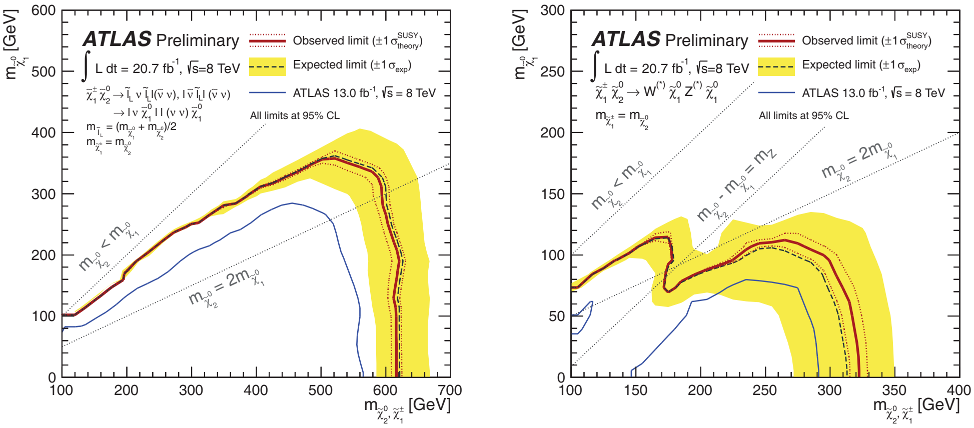

Fig. 3. – Observed and expected 95% CL limit contours for chargino and neutralino production in the simplified model scenario with decay via sleptons (left) and decay via gauge bosons (right) [5]. The band around the median expected limit shows the $\pm1\sigma$ variations on the median expected limit, including all uncertainties except theoretical uncertainties on the signal cross-section. The dotted lines around the observed limit indicate the sensitivity to $\pm1\sigma$ variations on these theoretical uncertainties. The blue lines correspond to the 8 TeV, 13 fb^{-1} limits from the ATLAS three lepton analysis. The limits are calculated using the statistical combination of all signal regions for each of the model points.

background. The other two signal regions have been designed for models with high stop masses and medium-to-high mass difference between the stop and chargino, leading to b-jets with a transverse momentum significantly higher than the main SM backgrounds. Consequently, two or more b-jets are required in these signal regions, each with large p_{T}. The remaining three signal regions target the $\tilde{t}_1 \to t\tilde{\chi}^0_1$ decay: in order to enhance their sensitivity, they all require three jets with an invariant mass compatible with the top quark mass. The loosest selection exploits a shape fit of E_{T}^{miss} and m_{T}, that targets the parameter space where the stop and its decay products are nearly mass degenerate. The two tighter selections rely mostly on tight cuts on both E_{T}^{miss} and m_{T}. The data are found to be consistent with SM expectations. Assuming both top squarks decay to a top quark and the LSP, top squark masses between 200 and 610 GeV are excluded at 95% confidence level for massless LSP, and top squark masses around 500 GeV are excluded for LSP masses up to 250 GeV. Assuming both top squarks decay to a bottom quark and the lightest chargino, top squark masses up to 410 GeV are excluded for massless LSPs and an assumed chargino mass of 150 GeV.

3·3. *Two leptons final state.* – The analysis presented in [4] shows the results of a search for direct top squark pair production with 13.0 fb^{-1} of integrated luminosity. The scalar tops are assumed to decay into a b quark and a chargino in events with two leptons in the final state. To separate the signal from the large SM background contributions dominated by top pair and W pair production, the m_{T2} variable is used. It is defined as

$$m_{\mathrm{T2}} = (\mathbf{p}_{\mathrm{T}}^{\ell_1}, \mathbf{p}_{\mathrm{T}}^{\ell_2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) = \min_{\mathbf{q}_{\mathrm{T}}+\mathbf{r}_{\mathrm{T}}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}} \left\{ \max[m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{\ell_1}, \mathbf{q}_{\mathrm{T}}), m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{\ell_2}, \mathbf{r}_{\mathrm{T}})] \right\},$$

where m_{T} indicates the transverse mass, $\mathbf{p}_{\mathrm{T}}^{\ell_1}$ and $\mathbf{p}_{\mathrm{T}}^{\ell_2}$ are the transverse momenta of the two leptons, and $\mathbf{q}_{\mathrm{T}}$ and $\mathbf{r}_{\mathrm{T}}$ are vectors which satisfy $\mathbf{q}_{\mathrm{T}}+\mathbf{r}_{\mathrm{T}} = \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$. The minimization is performed over all the possible decompositions of $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$.

Three signal regions are defined with increasingly tighter m_{T2} lower cuts: 90 GeV, 100 GeV and 110 GeV. No excess above the SM expectation is observed. A scalar top quark with mass between 150 and 450 GeV is excluded at 95% confidence level for a chargino approximately degenerate in mass with the stop and a massless lightest neutralino.

4. – Search for direct gaugino production

A search for the direct production of charginos and neutralinos in final states with three leptons (e or μ) and E_{T}^{miss} is presented in [5]. The analysis is based on 20.7 fb^{-1} of data. The presence of at least one same-flavour opposite-sign lepton pair (SFOS) is required in the event, as the decays of $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0$ through sleptons or Z bosons yield such pairs. Six mutually exclusive signal regions are defined: three *Z-depleted* regions targeting neutralino decays via sleptons, with no SFOS pairs having an invariant mass within 10 GeV of the Z-boson mass; and three *Z-enriched* regions targeting neutralino decays via on-shell Z bosons, where the invariant mass cut is inverted.

The final selection based on the E_{T}^{miss} and m_{T} (computed using E_{T}^{miss} and the lepton which is not included in the SFOS lepton pair with invariant mass closest to the Z-boson mass) of the event.

No excess above the SM expectation is observed and limits are placed at the 95% CL on the masses of the charginos and neutralinos in simplified supersymmetric models. First chargino and second neutralino masses are excluded up to 600 GeV if these particles decay through sleptons and up to 315 GeV in cases where they decay via gauge bosons to a massless lightest neutralino (fig. 3).

5. – Conclusions

ATLAS is conducting a comprehensive set of searches aiming at the natural SUSY models. No excess in data with respect to the SM expectation has been observed so far. However, much of the parameter space remains to be probed, and the search for SUSY at the LHC will continue to be pursued as the study of new channels will bring new opportunities for the discovery of a potential excess.

REFERENCES

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[3] ATLAS Collaboration, ATLAS-CONF-2013-037, `https://cds.cern.ch/record/1532431`.
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[5] ATLAS Collaboration, ATLAS-CONF-2013-035, `https://cds.cern.ch/record/1532426`.