PROCEEDINGS OF SCIENCE

Supersymmetry searches with the ATLAS and CMS detectors

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The results of the searches for the production of supersymmetric particles with the data of the ATLAS and CMS detectors are reported, which use up to $\sim 18\,\mathrm{fb}^{-1}$ of pp collision data delivered by the CERN LHC during 2015 and 2016. Several final states have been explored and about forty different results have been made public by the two collaborations. No convincing excess above the Standard Model expectations has been observed and upper limits have been set on the production of gluinos, light squarks, stops and charginos/neutralinos reaching masses of 1.9 TeV, 1.4 TeV, 0.9 TeV and 1.0 TeV respectively, depending on the assumption on the decay.

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1. Introduction

The Standard Model (SM) of particle physics is an extremely successful theory of the interactions between fundamental particles, the predictions of which have been extensively tested against the experimental results throughout several decades.
However, many theories have been proposed which superseed the SM at higher energy scales and which may solve some of its issues. Among these, Supersymmetry (SUSY) [1] is one of the most studied. It provides an elegant solution to the so-called "hierarchy problem" and predicts coupling unification at $M_{\rm GUT} \approx 10^{16}$ GeV. By imposing R-parity conservation in SUSY, the lightest neutral supersymmetric particle (LSP) is a viable Dark Matter candidate. The SUSY theories predict the existence of a new fermion (boson) for each boson (fermion) of the SM. These new particles, sometimes referred to as "sparticles", have larger masses than their SM partners due to SUSY breaking. "Naturalness" arguments suggest that the masses of the lightest sparticles should lie at the TeV scale, thus strongly motivating the searches at the Large Hadron Collider (LHC) by the ATLAS [3] and the CMS [2] collaborations.
Despite the lack of evidence for the production of sparticles in the data collected during the first run of the LHC, the quest for SUSY is still one of the main focus of the two experiments. In fact, the increase in the center-of-mass energy from 8 TeV to 13 TeV for the run started in 2015 provides a larger increase in the cross section of SUSY particles compared to the corresponding backgrounds. For this reason the begin of the second run is a unique opportunity to probe further the parameter space of natural SUSY.
Several different final states have been considered by the two collaborations in order to cover a wide range of SUSY production mechanisms and decays. The results of the searches are interpreted using simplified models [4] which assume 100 % branching ratio to one specific decay.

This document is organised as follows: in Sec. 2 the searches for gluinos are reported; in Secs. 3 and 4 the searches for light squarks and stops are described; Sec. 5 reviews the status of "electroweakinos" (charginos and neutralinos) searches; the results of R-parity violating (RPV) SUSY and Gauge Mediated Symmetry Breaking (GMSB) SUSY searches are highlighted respectively in Sec. 7 and Sec. 6; finally in Sec 8 a brief summary is given.
Due to the large number of results covered by this document, only partial information is given about the analysis and the focus is put on the final result: the reader is invited to consult the corresponding references for more details.

2. Search for gluino pair production

The 3-body decays $\tilde{g} \to tt\chi_1^0$, $\tilde{g} \to bb\chi_1^0$ can be the dominant channels in natural SUSY scenarios with light third generation squarks and much heavier light squarks.
In CMS three all-hadronic jets+$E_{\rm T}^{\rm miss}$ inclusive searches [5, 6, 7], using different techniques and categorisation, provide interpretation for the model in which gluinos decay to two b-quarks and LSP. In ATLAS interpretation in this model is provided in the context of an all-hadronic search requiring $n_{\rm jet} \geq 4$, $n_{\rm b} \geq 3$ and large $E_{\rm T}^{\rm miss}$ [8]. Results are shown in Fig. 1.
Top-tagging techniques are used in CMS [9] to enhance the sensitivity to final states containg top quarks, like in the case of $\tilde{g} \to tt\chi_1^0$. This model is also excluded by other searches in CMS

[5, 6, 7, 10, 11, 12] and by the same ATLAS search introduced above [8], which this time includes also final states with one lepton. The results for the $\tilde{g} \to tt\chi_1^0$ simplified models are given in Fig. 2.

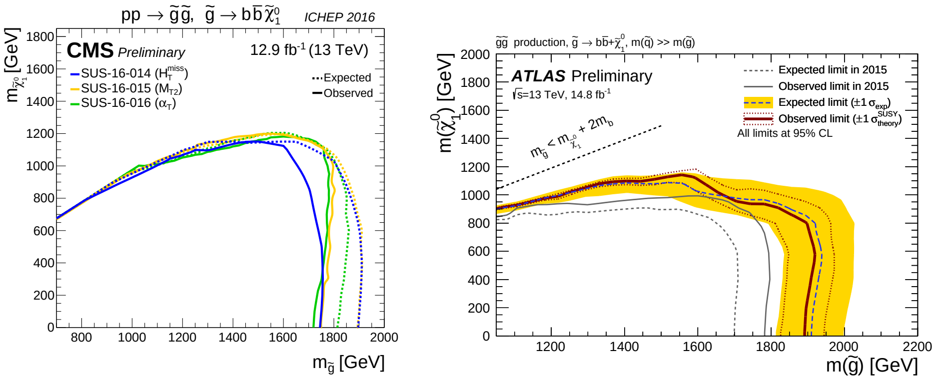

Figure 1: The excluded region in the parameter space for the $\tilde{g} \to bb\chi_1^0$ decay for CMS (left) and ATLAS (right) searches.

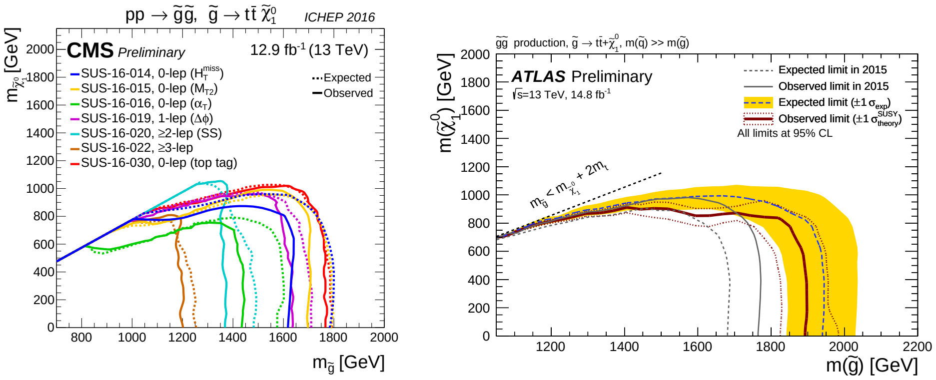

Figure 2: The excluded region in the parameter space for the $\tilde{g} \to tt\chi_1^0$ decay for CMS (left) and ATLAS (right) searches.

3. Search for light squark pair production

Light squarks can decay to quark+neutralino ($\tilde{q} \to q\chi_1^0$) or quark+chargino ($\tilde{q} \to q'\chi_1^{\pm}$). The lightest chargino will decay preferentially to W+LSP if it has a larger wino component. For sbottoms, which are usually expected to be relatively light in natural SUSY, $\tilde{b} \to b\chi_1^0$ decay may be the only one which is kinematically accessible.
CMS excludes a large portion of the parameter space for $\tilde{q} \to q\chi_1^0$ (Fig. 3 left) and for $\tilde{b} \to b\chi_1^0$ (Fig. 3 middle) using inclusive all-hadronic searches [5, 6, 7]. ATLAS provides interpretation for $\tilde{q} \to q'\chi_1^{\pm}$ model using events with one lepton, jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ [13].

4. Search for stop pair production

Stops are special sparticles in natural SUSY, as they are the main responsible for curing the large radiative correction to the Higgs boson mass due to the top quark loop. For this reason natural

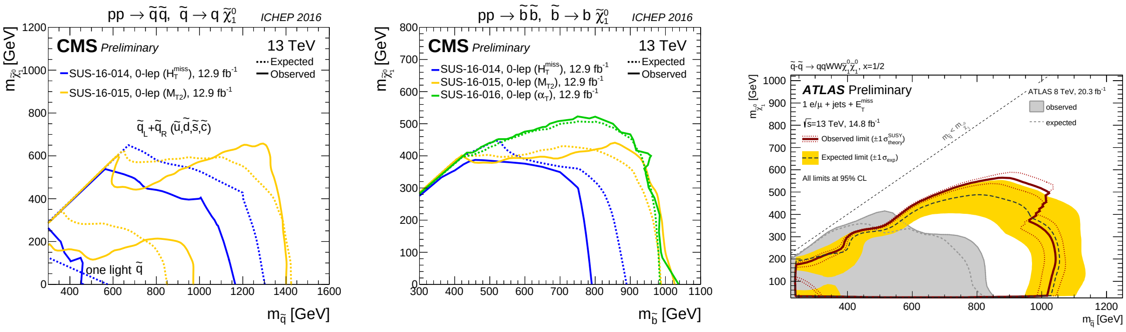

Figure 3: The excluded region in the parameter space for the $\tilde{q} \to q\chi_1^0$ decay (left), $\tilde{b} \to b\chi_1^0$ (middle) and $\tilde{q} \to q'\chi_1^{\pm}$ (right).

SUSY scenarios predict the lightest stop to be below 1 TeV in mass.
The stop can have different decays depending on the mass splitting with the LSP $\Delta m = m_{\tilde{t}} - m_{\chi_1^0}$.

- $\Delta m > m_t$: $\tilde{t} \to t\chi_1^0$ is the dominant decay but $\tilde{t} \to b\chi_1^{\pm}$ can be important if the chargino is kinematically accessible;
- $m_W + m_b < \Delta m < m_t$: the 3-body decay $\tilde{t} \to bW\chi_1^0$ is dominant;
- $\Delta m < m_W + m_b$: the 4-body decay $\tilde{t} \to bff'\chi_1^0$ is dominant, but the CKM-suppressed 2-body decay $\tilde{t} \to c\chi_1^0$ should also be considered.

Several searches are carried out considering different final states (0-2 leptons) in both ATLAS [15, 14, 16] and CMS [5, 6, 7, 18, 9, 17]. CMS also features a combination of the 0- and 1-lepton channels.
The results in terms of excluded parameter space are summarised in Fig. 4. It has to be reported that the ATLAS 1-lepton search [16] sees a 2-3 σ excess above the SM predictions.

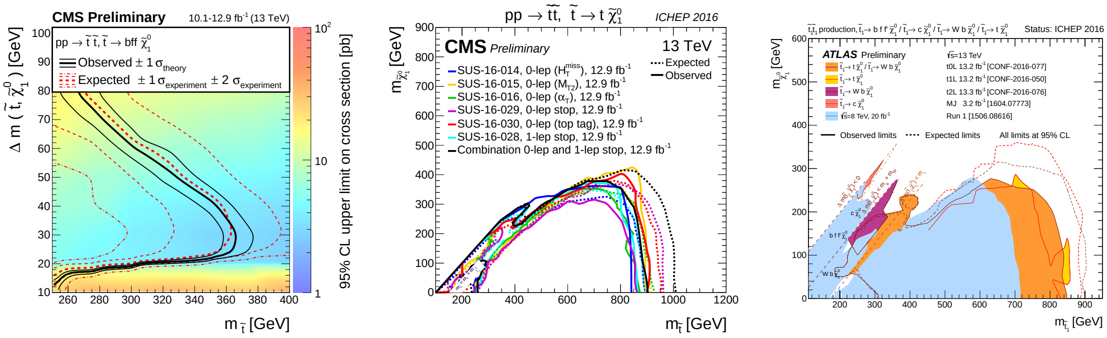

Figure 4: (left) CMS exclusion in the $(m_{\tilde{t}}, \Delta m)$ plane in the 4-body decay parameter space. (middle) Excluded region in the 2/3-body stop decay parameter space for CMS. (right) Summary of ATLAS searches in 2/3/4-body stop decay parameter space.

5. Search for electroweakino production

The cross sections for the production of charginos and neutralinos at the LHC are much smaller compared to "strong" SUSY production, which is mediated by α_S. However the final states arising from a typical electroweak SUSY "cascade" are much cleaner, because they contain typically a high lepton multiplicity.
Multi-lepton searches are carried out in CMS [19] and ATLAS [20] to target the $\chi_1^\pm \chi_2^0$ associated production, with each of the electroweakinos (assumed to be degenerate in mass) decaying to a slepton and a lepton with each slepton decaying to lepton+LSP.
The results of these searches in terms of exclusion limits are presented in Fig. 5. The branching ratio of charginos and neutralinos to staus is enhanced in many natural SUSY models compared to the other sleptons, which are assumed to be heavier. ATLAS has dedicated search using tau-reconstruction techniques, requiring at least two reconstructed taus, large E_T^{miss} and Z-veto [21].
The interpretation in a simplified model with electroweakinos decaying to staus is summarised in Fig. 6, where the CMS result comes from the multi-lepton analysis mentioned above [19].

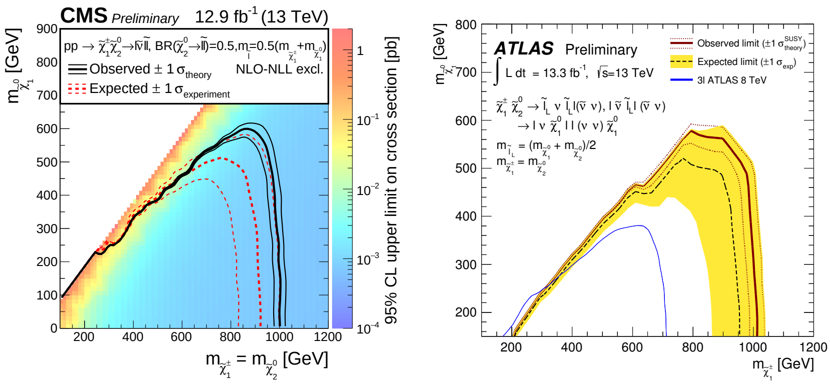

Figure 5: Excluded region in the $(m_{\chi_1^\pm}, m_{\chi_1^0})$ parameter space in models with electroweakinos decaying to sleptons, for the CMS (left) and the ATLAS (right) searches. $\chi_1^\pm$ and χ_2^0 are assumed to be degenerate in mass.

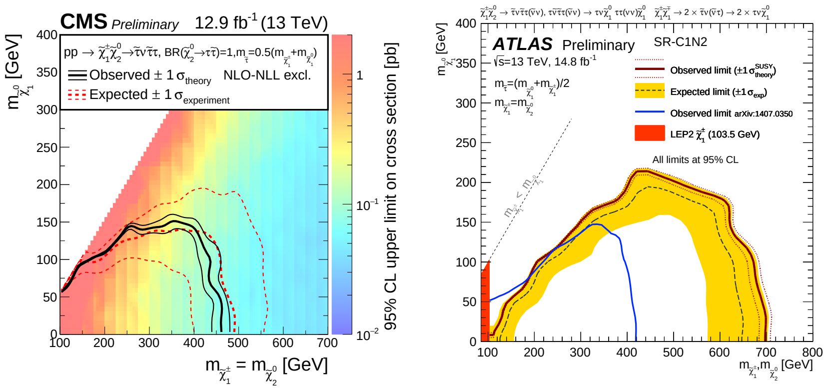

Figure 6: Excluded region in the $(m_{\chi_1^\pm}, m_{\chi_1^0})$ parameter space in models with electroweakinos decaying to staus, for the CMS (left) and the ATLAS (right) searches. $\chi_1^\pm$ and χ_2^0 are assumed to be degenerate in mass.

6. Search for CMSB SUSY production

In GMSB theories [22] the LSP is the ultra-light gravitino $\tilde{G}$, while the lightest neutralino χ_1^0 is the next-to-lightest supersymmetric particle (NLSP) in a large part of the parameter space. Depending on whether it is bino-like or higgsino-like the preferred decay is $\chi_1^0 \to \gamma\tilde{G}$ or $\chi_1^0 \to Z\tilde{G}$ respectively.

In CMS an opposite-sign same-flavour di-lepton search [24], with the lepton pair invariant mass required to be compatible with the mass of the Z boson, is carried out to target the decay $\chi_1^0 \to Z\tilde{G}$. The result of this search is presented in Fig. 7 (left).

The ATLAS analysis described in [23] targets the gluino pair-production, with the following assumptions on the decay: $\tilde{g} \to qq\chi_1^0$ and $\chi_1^0 \to \gamma\tilde{G}$. The selected sample is enhanced in this type of signal by requiring one photon, jets and large $E_{\mathrm{T}}^{\mathrm{miss}}$. A mild excess at the level of $\sim 2\sigma$ results in weaker-than-expected exclusion, as can be seen in Fig. 7 (right).

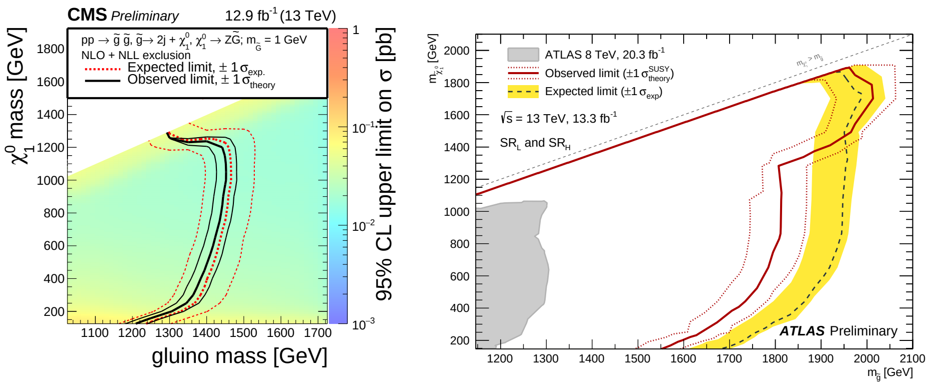

Figure 7: CMS (ATLAS) excluded region in the parameter space of GMSB model considering the decay $\chi_1^0 \to Z\tilde{G}$ ($\chi_1^0 \to \gamma\tilde{G}$) on the left (right).

7. Search for RPV SUSY production

The most general potential in SUSY theories contains RPV interactions [25] mediated by the couplings $\lambda_{ijk}, \lambda'_{ijk}$ and λ''_{ijk}, where $i, j, k = 1, 2, 3$ are generation indices. However, most of the RPV SUSY theories assume only the λ'' couplings to be non-zero, in order to protect the proton from rapid decay.

This scenario is tested by two ATLAS analyses, requiring no lepton [26] and one lepton [27] in the final state, as well as a large jet multiplicity. For the 0-lepton analysis, a model with gluino-pair production decaying to two light quarks and the LSP is used for the interpretation, where the RPV-violating decay $\chi_1^0 \to qqq$ is assumed with 100 % branching ratio. The results are presented in Fig. 8. A modest excess is seen in this channel, at the level of $\sim 2\sigma$. The RPV-decay $\tilde{t} \to \bar{b}\bar{s}$ is assumed for the interpretation of the 1-lepton analysis, where the pair-produced gluinos decay to a stop-top pair.

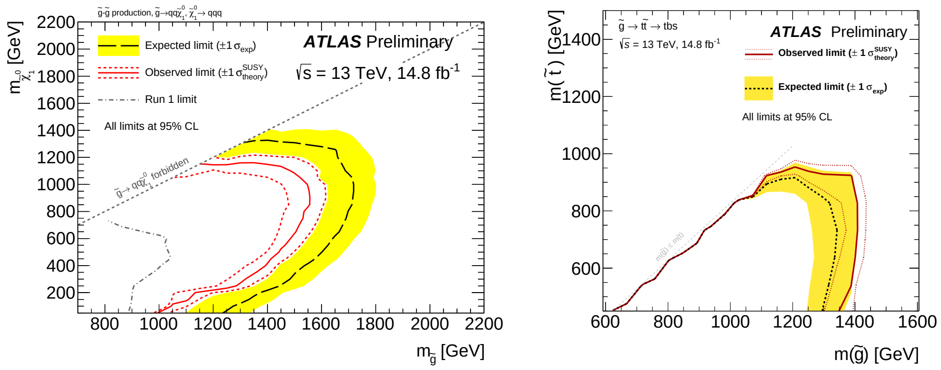

Figure 8: Excluded region for the gluino models with RPV decay $\chi_1^0 \to qqq$ (left) and $\tilde{t} \to \bar{b}\bar{s}$ (right) from ATLAS.

8. Summary

The CMS and ATLAS searches for SUSY using the LHC data at $\sqrt{s} = 13$ TeV have been presented. Several final states have been explored but no significant excess has been found and exclusion limits are set in the parameter space of simplified models, which supersede the previous results published by the two collaborations.

References

[1] Gol'fand, Yu. A. and Likhtman, E. P., *Extension of the Algebra of Poincaré Group Generators and Violation of p Invariance*, *JETP Lett.* **13** (1971) 323.

[2] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004.

[3] ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[4] J. Alwall, P. Schuster and N. Toro, *Simplified models for a first characterization of new physics at the LHC*, *Phys. Rev. D* **79** (2009) 075020.

[5] CMS Collaboration, *Search for supersymmetry in events with jets and missing transverse momentum in proton-proton collisions at 13 TeV*, CMS-PAS-SUS-16-014 (2016).

[6] CMS Collaboration, *Search for new physics in the all-hadronic final state with the MT2 variable*, CMS-PAS-SUS-16-014 (2016).

[7] CMS Collaboration, *An inclusive search for new phenomena in final states with one or more jets and missing transverse momentum at 13 TeV with the AlphaT variable*, CMS-PAS-SUS-16-016 (2016).

[8] ATLAS Collaboration, *Search for pair production of gluinos decaying via top or bottom squarks in events with b-jets and large missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, ATLAS-CONF-2016-052 (2016).

[9] CMS Collaboration, *Search for supersymmetry in the all-hadronic final state using top quark tagging in pp collisions at $\sqrt{s} = 13$ TeV*, CMS-PAS-SUS-16-030 (2016).

[10] CMS Collaboration, *Search for supersymmetry in events with one lepton and multiple jets in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2016*, CMS-PAS-SUS-16-019 (2016).

[11] CMS Collaboration, *Search for SUSY in same-sign dilepton events at 13 TeV*, CMS-PAS-SUS-16-020 (2016).

[12] CMS Collaboration, *Search for SUSY with multileptons in 13 TeV data*, CMS-PAS-SUS-16-022 (2016).

[13] ATLAS Collaboration, *Search for squarks and gluinos in events with an isolated lepton, jets and missing transverse momentum at* $\sqrt{s} = 13$ *TeV with the ATLAS detector*, ATLAS-CONF-2016-0 (2016).

[14] ATLAS Collaboration, *Search for the Supersymmetric Partner of the Top Quark in the Jets+Emiss Final State at* $\sqrt{s} = 13$ *TeV*, ATLAS-CONF-2016-077 (2016).

[15] ATLAS Collaboration, *Search for direct top squark pair production and dark matter production in final states with two leptons in* $\sqrt{s} = 13$ *TeV pp collisions using 13.3* fb^{-1}*of ATLAS data*, ATLAS-CONF-2016-0 (2016).

[16] ATLAS Collaboration, *Search for top squarks in final states with one isolated lepton, jets, and missing transverse momentum in* $\sqrt{s} = 13$ *TeV pp collisions with the ATLAS detector*, ATLAS-CONF-2016-050 (2016).

[17] CMS Collaboration, *Search for direct top squark pair production in the single lepton final state at* $\sqrt{s} = 13$ *TeV*, CMS-PAS-SUS-16-028 (2016).

[18] CMS Collaboration, *Search for direct top squark pair production in the fully hadronic final state in proton-proton collisions at* $\sqrt{s} = 13$ *TeV corresponding to an integrated luminosity of 12.9* fb^{-1}, CMS-PAS-SUS-16-029 (2016).

[19] CMS Collaboration, *Search for electroweak SUSY production in multilepton final states in pp collisions at* $\sqrt{s} = 13$ *TeV with 12.9* fb^{-1}, CMS-PAS-SUS-16-024 (2016).

[20] ATLAS Collaboration, *Search for supersymmetry with two and three leptons and missing transverse momentum in the final state at* $\sqrt{s} = 13$ *TeV with the ATLAS detector*, ATLAS-CONF-2016-096 (2016).

[21] ATLAS Collaboration, *Search for electroweak production of supersymmetric particles in final states with tau leptons in* $\sqrt{s} = 13$ *TeV pp collisions with the ATLAS detector*, ATLAS-CONF-2016-093 (2016).

[22] M. Dine and W. Fischler, *A phenomenological model of particle physics based on Supersymmetry*, *Phys. Lett. B* **110** (1982) 227.

[23] ATLAS Collaboration, *Search for Supersymmetry in events with photons, jets and missing transverse energy with the ATLAS detector in 13 TeV pp collisions*, ATLAS-CONF-2016-066 (2016).

[24] CMS Collaboration, *Search for new physics in final states with two opposite-sign, same-flavor leptons, jets, and missing transverse momentum in pp collisions at* $\sqrt{s} = 13$ *TeV*, CMS-PAS-SUS-16-021 (2016).

[25] J. Hall and M. Suzuki, *Explicit R-Parity Breaking in Supersymmetric Models*, *Nucl. Phys.* **B231** (1984) 419.

[26] ATLAS Collaboration, *Search for massive supersymmetric particles in multi-jet final states produced in pp collisions at* $\sqrt{s} = 13$ *TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2016-057 (2016).

[27] ATLAS Collaboration, *Search for new physics in a lepton plus high jet multiplicity final state with the ATLAS experiment using sqrts* = 13 *TeV proton-proton collision data*, ATLAS-CONF-2016-094 (2016).