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Searches for SUSY at the LHC

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Summary. — The ATLAS and CMS Collaborations have a very active program of searches for Supersymmetric particles. In this paper recent results obtained with the data collected during the second run of the Large Hadron Collider are discussed.

1. – Introduction

Supersymmetry is an extension of the Standard Model (SM), which postulates the existence of new particles (super partners) whose spin differs by half a spin unit from the corresponding SM particle. Supersymmetry has several advantages over the Standard Model. The loop corrections to the bare Higgs boson mass are of the order of the mass of the super partners, thus addressing the hierarchy problem if this mass is of the same order of magnitude as the electroweak symmetry breaking scale. This would also make the super partners production possible at the Large Hadron Collider (LHC). In models with conserved R-parity, the lightest supersymmetric particle is stable and it is a Dark Matter candidate.

Both ATLAS [1] and CMS [2] have made the search of supersymmetric particles a priority. Here, the most recent results obtained by the two experiments using the data collected during the second run of the LHC at a center of mass energy of 13 TeV are discussed.

2. – Strong production

The supersymmetric particles with color charge are expected to be produced with relatively large cross section at an hadron collider. For example, the cross section for pair production of a gluino of 2 TeV is about 1 fb (see footnote(1)). The pair production of colored super partners that decay to a stable, weakly interacting particle gives final

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(1) For comparison, the cross section for the production of a top quark-antiquark pair in association with a Higgs boson is 507 fb in the SM.

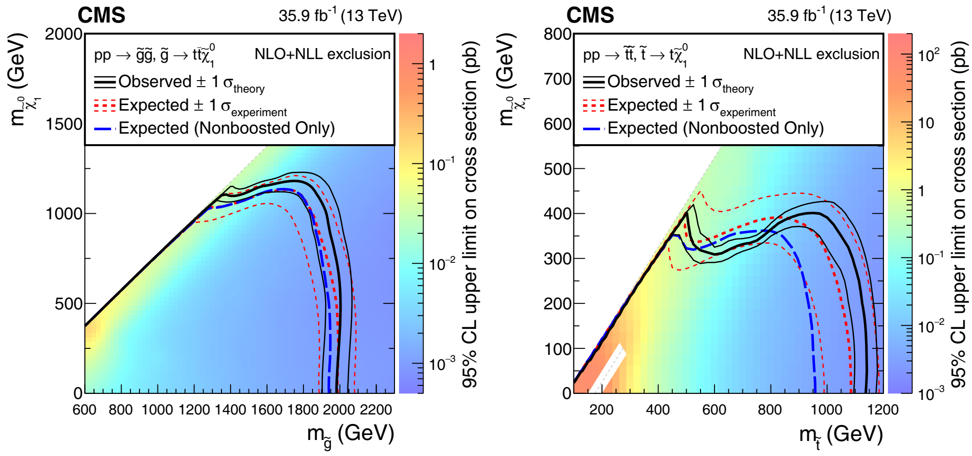

Fig. 1. – Expected and observed 95% confidence level limits on the production cross section for pair produced gluinos decaying to a top quark pair and the LSP (left) or pair produced squarks decaying to a top quark and the LSP (right) [3].

states with high transverse momentum (p_{T}) jets and large missing trasverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$). Depending on the decay chain, leptons and photons might or might not be produced.

The CMS collaboration has used 35.9 fb^{-1}of proton-proton collisions to search for supersymmetry in events with large transverse energy, large jet multiplicity, and large $E_{\mathrm{T}}^{\mathrm{miss}}$ [3]. Events with zero or one charged lepton (electron or muon) are considered. The charged lepton (if any) and jets are grouped in two hemispheres called megajets, minimizing the invariant mass of the two megajets. The megajets four-momenta are defined as the vector sum of the momenta of the constituent jets and leptons, and used to compute the razor variables M_R and R [3]. These discriminate the signal from the Standard Model backgrounds for a broad variety of SUSY signatures, since for signal M_R peaks at the mass difference between the produced particles and the lightest SUSY particle (LSP), and R is sensitive to the presence of invisible particles at the end of the decay chain. Events are divided in categories according to the presence of a boosted hadronically decaying W boson or top quark, the number of leptons, the number of jets and identified b-jets, and the values of the razor kinematic variables.

Control selections in data are used to derive correction factors to the Monte Carlo (MC) predictions of background processes. Validation regions with kinematics close to those of the signal selection and closure tests are used to verify the background estimation procedure. In the signal selection, data are observed to be consistent with the SM estimate in all categories.

Results are used to set limits on a variety of signal scenarios. In fig. 1, limits are placed on a simplified model featuring a gluino decaying to a top quark pair and the lightest neutralino and a simplified model with a top squark decaying to the lightest neutralino and a top quark. The solid (red dashed) lines correspond to the observed (expected) mass limits for the nominal cross section and 100% branching ratio in the specified decay mode. The colour scale provides limits on the cross section times branching ratio as a function of the mass of the supersymmetric particle masses.

The white diagonal band in fig. 1 (right) corresponds to the region where the mass difference between the top squark $\widetilde{t}_1$ and the LSP $\widetilde{\chi}_1^0$ is very close to the top quark

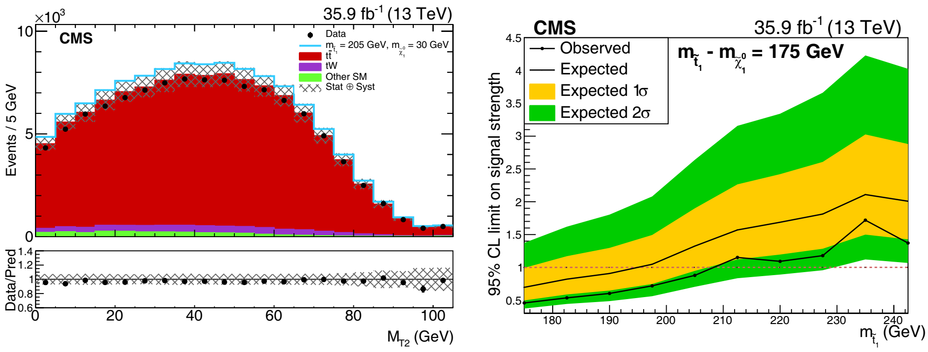

Fig. 2. – Left: distribution of M_{T2} for data and the predicted background. Right: expected and observed upper limits at 95% CL on the signal strenght as a function of the stop quark mass for $m(\widetilde{t}_1) - m(\widetilde{\chi}^0_1) = m(t)$ [4].

mass. In this region the signal acceptance is difficult to model. Another analysis [4] of the CMS experiment addresses this scenario. For events near the decay threshold $(m(\widetilde{t}_1) - m(\widetilde{\chi}^0_1) = m(t))$, the top squark signal kinematics is very close to that of the $t\bar{t}$ background. In particular the two neutralinos in the final states are very soft if the neutralino is light; however the signal presence can be inferred from the number of selected events (the cross section is a significant fraction of the $t\bar{t}$ cross section) and observables sensitive to spin correlation effects (since the signal is from scalar particles). For heavier masses, the neutralinos carry significant momentum.

The analysis uses 36 fb^{-1}of proton-proton collisions data, and selects events with an electron, a muon, at least two jets and at least one identified b-jet. The resulting event sample is composed 98% by top quark events in the SM hypothesis. The M_{T2} variable is used to be sensitive to the momentum carried by the neutralinos, and the azimuthal angle difference between the two leptons is used for its sensitivity to spin correlation effects. Good agreement is found for both variables between the data and the SM prediction, the distribution of the M_{T2} variable being shown in fig. 2 (left). A maximum likelihood fit was used to set limits. For $m(\widetilde{t}_1) - m(\widetilde{\chi}^0_1) = m(t)$, the top squark is excluded at 95% CL up to a mass of 210 GeV, as shown in fig. 2 (right).

The lightest neutralino is not necessarily the LSP. In models of gauge mediated supersymmetry breaking, the LSP is the gravitino, and the $\widetilde{\chi}^0_1$ would decay to a gravitino and either a photon, a Z boson, or a Higgs boson. Two recent papers submitted by the CMS Collaboration and using 36 fb^{-1}of proton-proton collisions data address scenarios where the $\widetilde{\chi}^0_1 \rightarrow \tilde{G}\gamma$ decay occurs.

One paper [5] considers events with one photon, jets, and $E_{\mathrm{T}}^{\mathrm{miss}}$. Signal-like events are categorized based on the number of jets, the number of b-jets, and missing transverse momentum. The observed yields are found to be in agreement with the SM expectations, and limits are derived in scenarios with gravitino LSP and gluino or top squark pair production. Gluino masses up to 2.12 TeV and top squark masses up to 1.23 TeV are excluded at 95% confidence level.

The other paper [6] uses events with a photon, an electron or muon, and large missing transverse momentum. Results are again in agreement with the SM predictions and limits are set on several benchmark simplified models. For models of gluino (squark) pair production, gluino (squark) masses up to 1.75 TeV (1.43 TeV) are excluded at 95% confidence level.

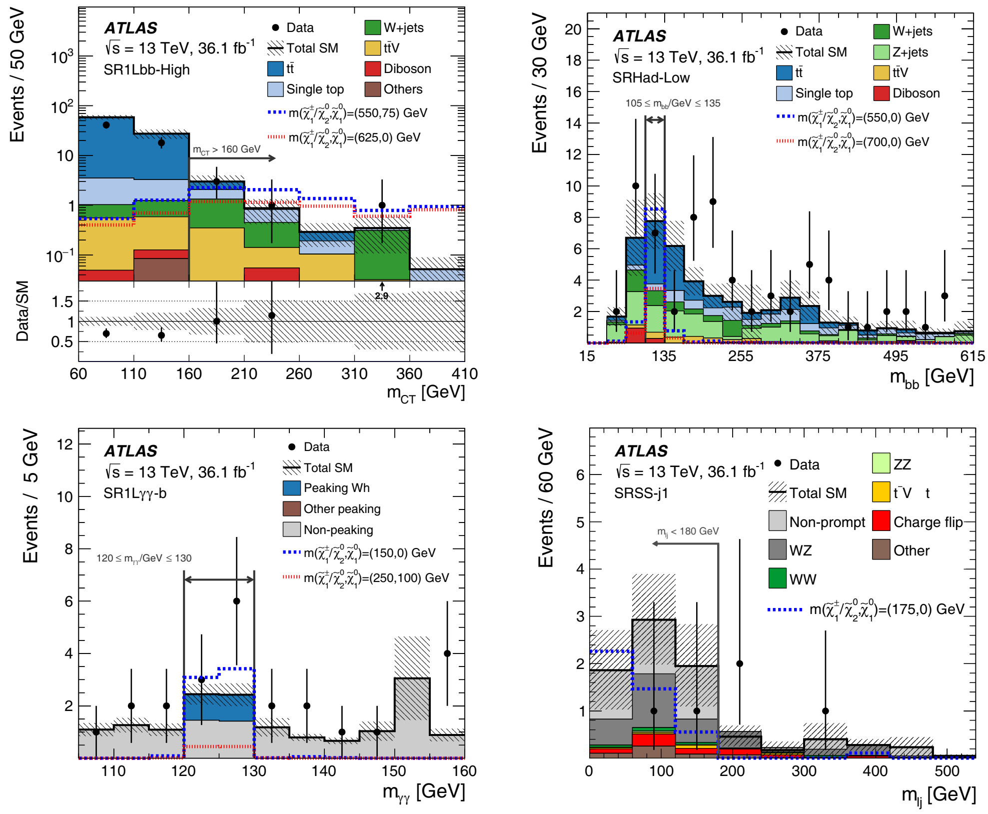

Fig. 3. – Data and SM background predictions for the $1\ell b\bar{b}$ channel and the cotransverse mass (top left), the hadronic channel and the $b\bar{b}$ invariant mass (top right), the di-photon invariant mass and the $1\ell\gamma\gamma$ channel (bottom left), and the lepton-jet invariant mass in the multilepton channel (bottom right). For each channel, all criteria of one of the signal selections are applied, except that on the variable which is shown [7].

3. – Electroweak production

Direct production of charginos, neutralinos and sleptons might be the dominant process for supersymmetric particle production at the LHC, if these states are much lighter than squarks and gluinos. The ATLAS Collaboration has recently submitted a paper [7] that searches for supersymmetry in final states with a W boson, a Higgs boson, and missing transverse momentum. The benchmark signal used for optimization and interpretation of the results features the production of the lightest chargino $\tilde{\chi}_1^{\pm}$ and the next to lightest neutralino $\tilde{\chi}_2^0$ followed by the decays $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0\, W$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, h$ where h is the lightest CP even Higgs boson observed in 2012 and the $\tilde{\chi}_1^0$ is assumed to be the LSP and be stable. Several channels are considered, according to the targeted decay modes of the W and h bosons.

The fully hadronic channel targets final states with both bosons decaying into quarks. The event selection requires four or five jets, two of which tagged as b-jets, large missing transverse momentum, cotransverse [8, 9] and transverse mass selections, and the invariant mass of the two b-jets between 105 and 135 GeV. The largest backgrounds are due

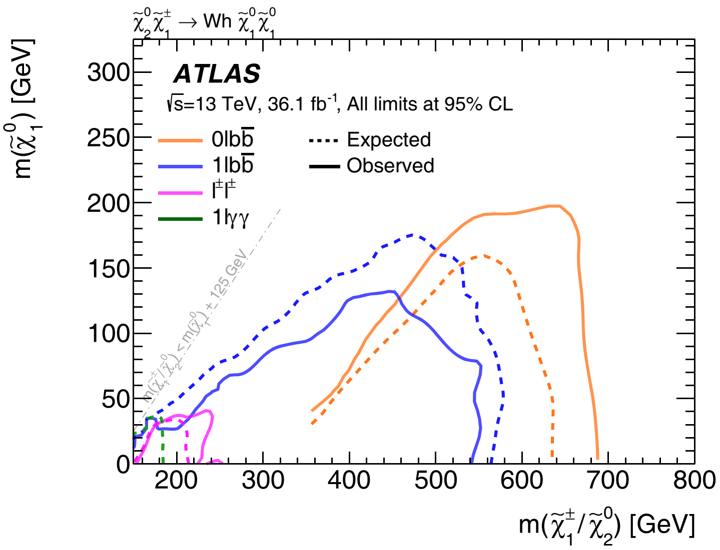

Fig. 4. – Expected and observed 95% confidence level limits for each channel in [7]. Only the expected exclusion is shown for the $1\ell\gamma\gamma$ channel since no observed exclusion is set due to the mild excess observed in that channel [7].

to top quark pair production and $Z \to \nu\bar{\nu}$ in association with jets. These are estimated with MC samples normalized to data in dedicated control selections.

The $1\ell b\bar{b}$ channel targets the leptonic decay of the W boson and $h \to b\bar{b}$. Events are required to have one isolated electron or muon, large missing transverse momentum, two or three jets, and pass cotransverse and transverse mass selections. Two of the jets must be tagged as b-jets and have an invariant mass between 105 and 135 GeV. The largest backgrounds are due to top pair production and $W \to \ell\nu$ in association with jets. These are estimated with MC samples normalized to data in dedicated control selections.

The $1\ell\gamma\gamma$ channel targets the leptonic decay of the W boson and $h \to \gamma\gamma$. Events are required to have one isolated electron or muon, have large missing transverse momentum, pass cotransverse and transverse mass selections, and have two photons with an invariant mass between 120 and 130 GeV. The backgrounds are estimated with a fit to data in the sidebands of the invariant mass window, except for the SM $h(\gamma\gamma)$ background which is taken from MC.

The channels with two same sign or three leptons targets the leptonic decay channel of the W boson and events where the Higgs boson produces leptons through its $\tau\tau$, $ZZ^\star$, and $WW^\star$ decays. Selections are applied on the number of jets, $E_{\mathrm{T}}^{\mathrm{miss}}$, invariant mass combinations and angular variables. The largest backgrounds are events with fake and non prompt leptons and WZ production.

The distributions of one key variable for each channel are shown in fig. 3 for data and the estimated background; all selections are applied except that on the variable which is shown. Event yields in the signal selections are in agreement with the SM expectation, the largest excesses being observed in two orthogonal $1\ell\gamma\gamma$ selections with p-values of 0.03 and 0.09 respectively. Limits are derived in a simplified model where the $\tilde{\chi}_2^0$ and the $\tilde{\chi}_1^\pm$ are the partners of the W bosons before electroweak symmetry breaking, and they decay with 100% branching ratio in the $\tilde{\chi}_1^0$ and a W and h boson respectively. These limits are shown in fig. 4 separately for each of the search channels. For a massless lightest neutralino, masses of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ smaller than 680 GeV are excluded at 95% confidence level, the fully hadronic channel providing the best sensitivity at high mass.

4. – Conclusions

Searches for supersymmetry are pursued vigorously by the ATLAS and CMS Collaborations. The first results with the full dataset collected during the second run of the Large Hadron Collider are now available. No statistically significant excess of events has been observed, and limits on the masses of supersymmetric particles have been improved.

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