SUSY SEARCHES AT 13 TEV AT ATLAS

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In 2015, the ATLAS detector at the CERN Large Hadron Collider (LHC) recorded 3.2 fb\(^{-1}\) of data at the unprecedented centre-of-mass energy of 13 TeV. Predicted cross sections for strong production of squark or gluino pairs increase as much as tenfold between 8 TeV and 13 TeV for masses in the TeV range, just above the limits set at 8 TeV, so this was a particularly interesting early search for Run-2 of the LHC. Many final-state signatures were investigated, and lower limits set on squark and gluino masses in a number of simplified models.

1 Signatures with Jets

In case they had masses slightly above the LHC Run-1 limits from 7 and 8 TeV data, strongly produced squark (\(\tilde{q}\)) or gluino (\(\tilde{g}\)) pairs could have had a large enough cross section to surpass those limits with the smaller 2015 data set at 13 TeV. In the simplest cases, each squark decays to a quark and the lightest supersymmetric particle (LSP), typically the lightest neutralino (\(\tilde{\chi}_1^0\)), yielding a final state with two jets and missing transverse momentum (\(E_T^{\text{miss}}\)); or each gluino undergoes a three-body decay to two quarks and an LSP, yielding four jets and \(E_T^{\text{miss}}\). If there are additional light neutralinos or charginos, supersymmetric cascade decays can yield larger numbers of jets, possibly accompanied by leptons. Most of the analyses presented are similar: signal regions (SR) are defined, and for each SR, corresponding control regions (CR) target kinematically similar regions enriched in each of the main backgrounds: typically top quarks, \(W\) or \(Z\) bosons produced in conjunction with jets, and multi-jet events from Standard Model (SM) strong production of quarks and gluons. Fits to data distributions in these CR determine the normalizations for the backgrounds in the SR. Validation regions (VR) orthogonal to both SR and CR, and (like the CR) not expected to contain many events from the predicted signals, are also defined for each SR and used to cross-check the background estimates from the CR.

The first analysis described here\(^1\) focuses on final states with two to six jets and substantial \(E_T^{\text{miss}}\). Seven SR are defined, depending on the number of jets and compression of the mass spectrum targeted, which determines the level of background rejection required. All SR are based on cuts on \(m_{\text{eff}}\), an effective mass computed as the scalar sum of transverse momenta of the leading jets and \(E_T^{\text{miss}}\). Figure 1 shows the \(m_{\text{eff}}\) distribution for a four-jet SR, and the limit on gluino mass in a simplified model where pair-produced gluinos decay exclusively to \(q\tilde{\chi}_1^0\).

In case bottom squarks are the lightest strongly-interacting supersymmetric particles, the signatures are even more striking. A pair of bottom squarks in the mass range considered would produce a final state with two \(b\)-jets and \(E_T^{\text{miss}}\). The analysis is similar to the one described above for ordinary jets but requires \(b\)-tagged jets and uses a discriminant called the contransverse mass \(^2\) instead of \(m_{\text{eff}}\). A slight deficit is observed in all signal regions, improving the limit on the bottom squark mass in simplified models where pair-produced bottom squarks decay to \(b\tilde{\chi}_1^0\) by around 200 GeV with respect to the Run-1 limit.
In very compressed scenarios, where the mass difference between the squark and LSP is small, the resulting quark jets are not energetic enough to measure, and the search is instead optimized for events with a single energetic jet from initial state radiation, and large $E_T^{\text{miss}}$. This analysis greatly improves the limits of the squark pair-production analyses described above in the region close to the diagonal, where the squark mass is not much greater than the $\tilde{\chi}_1^0$ mass.

If third-generation squarks are too heavy to be produced as real particles, but are dominant virtual mediators in gluino three-body decays, gluino pair production can result predominantly in four-top-quark or four-bottom-quark final states comprising four $b$-jets (at least three $b$-tagged) and $E_T^{\text{miss}}$, also accompanied by additional jets or leptons in case the $b$-jets arise from top quark decay. Since a slight deficit was observed in this analysis, the limits set on gluino masses in this scenario are stronger than expected, as shown in Fig. 2.
2 Signatures with Jets and Leptons

The presence of $W$ or $Z$ bosons among the electroweak decay products of gluinos or squarks implies that there can be energetic leptons in the final state, making it easier to trigger on these events; however, in case the $W$ is virtual and its decay lepton too soft to trigger on, an $E_T^{\text{miss}}$ trigger can still recover these events. In this analysis, several $E_T^{\text{miss}}$-dependent variables are used to define six signal regions with either hard or soft leptons and between two and six jets, and the results are combined to set limits in various simplified models, as shown in Fig. 3.

One specific scenario that has been closely studied is the case where decay chains include $\tilde{\chi}_0^2 \rightarrow Z \tilde{\chi}_1^0$ and the $Z$ decays leptonically to same-flavour opposite-sign leptons, yielding a final state with an on-shell leptonic $Z$, at least two jets and $E_T^{\text{miss}}$. A control region with different-flavour lepton pairs is used to estimate the flavour-symmetric backgrounds from top and $W$ pair decay. In the results shown, 21 events were observed, with $10.3 \pm 2.3$ expected, and limits set were correspondingly lower than expected, as shown in Fig. 4.

When pair-produced gluinos undergo three-body decays to quarks and a chargino, it can happen that the electroweak particles in both chargino decay branches carry the same charge, resulting in signatures with two leptons of the same charge, as well as jets and $E_T^{\text{miss}}$. This signature can also occur in other supersymmetric decay cascades or, alternatively, these can have a final state containing three leptons, from multiple leptonically decaying $W$ or $Z$ bosons or top quarks. Both signatures are very rare in the Standard Model and were studied in four SR classified according to the number of $b$-jets or light jets, using $E_T^{\text{miss}}$ as the final discriminant. One SR and an interpretation of the results are shown in Fig. 5.
3 Lifetime

In scenarios with highly compressed mass spectra, or those where three-body decays are highly suppressed by very large hierarchies among sparticle masses, there may be little phase space for decays to the LSP, resulting in a long-lived next-to-lightest supersymmetric particle (NLSP). A search for highly-ionizing heavy particles leaving large dE/dx deposits in the silicon pixel detectors excludes stable charged gluino R-hadrons with masses below 1570 GeV, and sets limits on gluino R-hadrons with lifetimes greater than 0.4 ns under the assumption they decay to a 100 GeV LSP.

4 Summary

The 3.2 fb\(^{-1}\) of data collected in 2015 by the ATLAS detector at a centre-of-mass energy of 13 TeV were analyzed in many different final states for hints of strong production of gluinos or squarks. While there were a few very modest discrepancies from Standard Model predictions, most notably an excess of about 2.2 standard deviations in the search for an on-shell leptonically decaying Z boson accompanied by jets and \(E_T^{\text{miss}}\), no evidence was found for squarks or gluinos in any of these searches, and limits were set at 95 % confidence level in a number of simplified models, typically excluding gluino masses below around 1.4 – 1.7 TeV, and squark masses below around 600 – 900 GeV.

References