SUSY Searches for Electroweak Production of Gauginos and Sleptons at the LHC

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The searches for direct electroweak production of supersymmetric particles in proton-proton collisions at the LHC are presented. The focus is on gaugino and slepton production, which yield final states with two or more leptons. A wide variety of complementary searches are discussed with none of them showing any indication for physics beyond the standard model.

1 Introduction

During the first years of LHC running most searches for supersymmetry (SUSY) have focused on the strong production of supersymmetric particles because of its large production cross-section. Thanks to these studies, gluinos and inclusive squarks have been probed up to masses of above 1 TeV. Electroweak production of SUSY has in general smaller cross-sections, but the production cross-sections for winos, binos or higgsinos of around 300–400 GeV are similar to those of squarks and gluinos with masses around 1–1.5 TeV. Therefore CMS[1] and ATLAS[2] have developed a set of analyses focusing on the case when squarks and gluinos would be heavy, but electroweakinos would be light.

1.1 General strategy

The focus of this note is on direct electroweak production of supersymmetric particles at a center-of-mass energy of 8 TeV. Electroweak SUSY particles such as gauginos and sleptons are pair produced and there is very little hardronic activity present in the event, other than initial-state-radiation. As a result top backgrounds can be highly suppressed by applying a veto on the amount of hadronic activity and/or the presence of b-tagged jets. The other major backgrounds of such searches are the diboson backgrounds. The easiest way to suppress these backgrounds is by requiring that there would be no Z candidate present. Of course such a cut can only be applied if no intermediate vector bosons are expected in the electroweakino decay. To further distinguish signal from background, the missing transverse energy and other kinematic variables (e.g. transverse mass) are used.

The backgrounds due to non-prompt or misidentified leptons are usually estimated using data-driven techniques that measure the probability of a non-prompt lepton to be isolated in a control sample. Simulation is used to estimate the diboson backgrounds and other rare processes, but cross-checks and corrections are applied when feasible. The normalization is usually derived from a control region; for the diboson backgrounds, corrections to the missing transverse energy and lepton resolutions are applied to make the final estimate more precise. Both CMS and ATLAS also look at cascade decays, where gluinos or squarks are pair-produced and then decay to electrokweakinos[3,4,5,6,7] but this is not discussed further in this note.

2 Chargino-Neutralino Pair production

The first model of direct electroweak SUSY production considered here is chargino-neutralino pair production. Depending on the masses of the sleptons and the sneutrinos, two different decay modes can take place. If the sleptons and sneutrinos are light, then the decay happens through intermediate sleptons and sneutrinos, and the final state contains three leptons and two lightest supersymmetric particles (LSP). This gives rise to a signature with three leptons and considerable missing transverse energy and is targeted by a three-lepton analysis, looking explicitly in events without a Z candidate.[8,9] If the intermediate slepton mass is very close to the chargino/neutralino or the LSP mass, or if the intermediate particles are predominantly staus, then the leptons are expected to be soft and then it is more likely to miss at least one of them. For this reason, targeted dilepton analyses have been developed to complement the three-lepton one.[8,10,11] If the sleptons and sneutrinos are heavy, the electroweakinos decay through vector bosons, WZ if we consider chargino-neutralino production. The W and Z boson then decay according to the standard model and have the possibility to decay into quarks or leptons. For these decays, the three-lepton analysis is still useful, but in this case, a Z candidate is explicitly required. To target the hadronic decay mode of the vector bosons, a search in the Z + dijet + E_T^{miss} final state is also performed.[8,10]

2.1 Three-lepton analysis

Both CMS and ATLAS have a three-lepton analysis to search for chargino-neutralino pair production.[8,9] Both analyses focus on three light leptons (e, μ) with an opposite-sign same flavor lepton pair present. The main backgrounds for this analysis are WZ and top pair production. To suppress the WZ production, the sample is split between a sample with and a sample without a Z candidate. The first sample can be used for cases with intermediate vector bosons, the second one for the case with intermediate sleptons and sneutrinos. A transverse mass cut, calculated with the E_T^{miss} and the third lepton, is also very efficient to suppress WZ backgrounds. To suppress the top quark backgrounds, a veto is applied on the presence of b-tagged jets in the event. The two analyses differ slightly because the ATLAS analysis focuses on 3 inclusive search regions, while the CMS analysis has 45 exclusive search regions. CMS also tries to focus on those cases where staus are prefered as intermediate particles, by looking at cases without an opposite-sign same flavor lepton pair, and at cases where one of the leptons is a hadronic tau candidate.

2.2 Same-sign dilepton analysis

In some cases one of the leptons can be too soft or fail the lepton identification. If this happens to one of the leptons from the neutralino decay, then we end up with same-sign dileptons. Same-sign dileptons are easier to use than opposite-sign dileptons since they suffer from smaller amounts of standard model backgrounds. CMS has a 8 TeV analysis for same-sign dileptons, while ATLAS provides results both for opposite-sign and same-sign dileptons but only at 7 TeV.[8,10] One of the problems in going to a dilepton analysis is that the contribution of the backgrounds due to non-prompt and misidentified leptons increases considerably. This can be countered by tightening the requirements on the lepton transverse momenta, the E_T^{miss}, or the hadronic activity. The 8 TeV analysis follows both these options with its two inclusive search regions: one of the search regions cuts very tight on the E_T^{miss} (> 200 GeV) while the other one relaxes the E_T^{miss}-requirement (> 120 GeV) but has tighter cuts on the hadronic activity.

2.3 Opposite-sign tau analysis

There is a possibility that intermediate staus are the preferred option in supersymmetry. In such cases, there is still the option of having three light leptons, but due to the branching fractions of the tau decay, it is more likely to have one or more hadronic taus in the event. Therefore ATLAS developed a new analysis focusing on two opposite-sign hadronic taus.[11] To suppress the major backgrounds, a Z-veto and a hard cut on the the hadronic activity (a [b-tagged] jet veto) are applied. Then the stransverse mass, m_{T2}, is used for the final discrimination. The stransverse mass variable is designed for events with two undetected particles and represents a lower bound on the parent particle's mass. The major standard model backgrounds, such as WW and top pair production, have a kinematic endpoint at around 80 GeV in this variable. To estimate the non-prompt and misidentified tau backgrounds, a so-called ABCD method using the stransverse mass variable and the tau identification criteria was used.

2.4 Z+dijet analysis

If a W or a Z boson decays hadronically, the dijet signature can be used to identify this vector boson.[8] The invariant mass of the dijet pair is required to be consistent with a W or Z hypothesis, and a veto on b-tagged jets is applied to reduce the top backgrounds. The second Z boson is required to decay leptonically and to be fully reconstructed. Using the E_T^{miss} shape, a distinction can then be made between Z + jets background and the electroweakino signal. For this a template fit is performed with the Z+jets template shape derived from a γ + jets control sample and the non-prompt and misidentified leptons estimated from an eμ sample. The other backgrounds are estimated using simulated samples. The E_T^{miss} spectrum is split into different bins because the E_T^{miss} in the SUSY events depends on the chargino/neutralino and LSP masses.

2.5 Results

None of the described analyses shows any significant discrepancy between the data and the predicted yields. Limits are derived for the pair production of charginos and neutralinos. Figure 1 shows the results for the case with light intermediate sleptons and a slepton mass which is halfway between the chargino and LSP masses. The limits for the cases when intermediate staus or intermediate vector bosons are prefered can be found in Ref. [8,9,10,11].

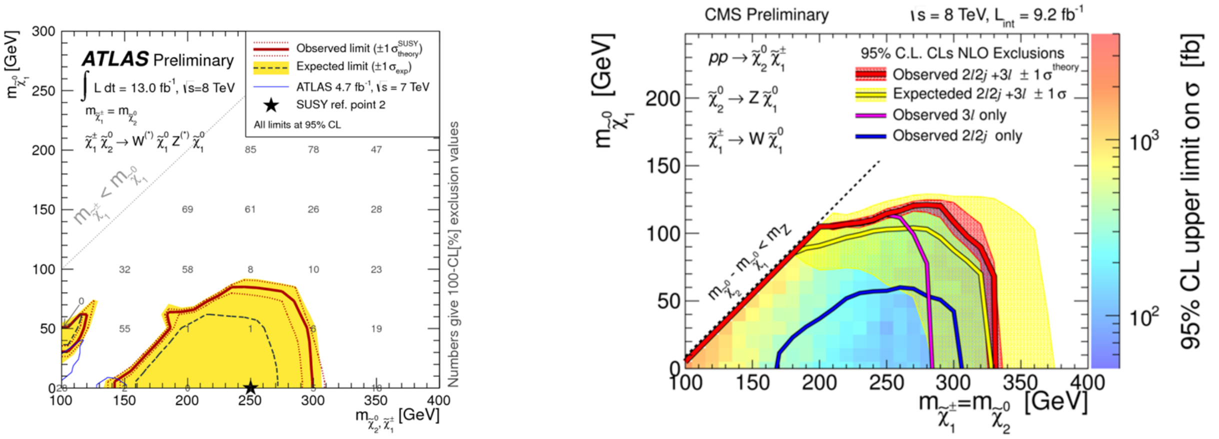

Figure 1: Limits on chargino-neutralino pair production using the three-lepton analysis. The ATLAS analysis[9] is shown on the left and the CMS one[8] on the right.

3 Slepton and chargino pair production

Slepton and chargino pair production both lead to signatures with two opposite-sign dileptons and LSPs giving large E_T^{miss}.[8,10] In the chargino case, there are extra neutrinos present in the event but the E_T^{miss} from those is expected to be considerable smaller than from the LSPs. In the slepton case the two leptons have the same flavor because the sleptons decay to a specific lepton flavor, while the two charginos decay independently to both lepton flavors and are thus just as likely to have an opposite-flavor as a same-flavor pair. ATLAS and CMS both have an analysis which focuses on opposite-sign dileptons. To remove the large Z-related background, a mass constraint is added to the dilepton pair: the mass has to be at least 15 GeV away from the Z mass. Both analyses apply cuts on the hadronic activity (a [b-tagged] jet veto) and apply a moderate E_T^{miss} cut of around 50–60 GeV. Both analyses then perform a cut-and-count analysis using a kinematic variable that has an endpoint for W-related backgrounds. ATLAS uses the stransverse mass m_{T2} discussed in section 2.3 while CMS uses the $MC_{T,Perp}$ variable which has a similar behavior with a kinematic endpoint around 80 GeV for WW and top pair production. Chargino pair production decaying through intermediate staus has also been probed by the opposite-sign ditau analysis discussed in section 2.3.

4 R-parity violating supersymmetry

All of the SUSY searches discussed so far assume that R-parity is conserved. If R-parity is violated, the LSPs could be unstable and decay into leptons.[12] The decay of the two LSPs would lead to four leptons in the final state. ATLAS has a targeted analysis looking for four leptons with no Z candidates to search for electroweak production of gauginos and sleptons in R-parity violating models.[12] The similar CMS analysis only focuses on the production of stops[13] in R-parity violating models. If the LSP decays into a pair of leptons, the final state would have very little E_T^{miss}. All the E_T^{miss} present would come from neutrinos. That is why the analysis uses two exclusive search regions that only rely mildly on E_T^{miss}. One search region applies a moderate E_T^{miss} cut (50 GeV) to target final states with neutrinos, while the other one only cuts on the scalar sum of the transverse momenta of the leptons, jets and E_T^{miss} in the event. Again no significant excesses are observed and limits are placed on the production of winos, sleptons and sneutrinos in R-parity violating SUSY.

5 General Gauge Mediated SUSY breaking

Assuming that the gravitino is the LSP and the next-to-lightest supersymmetric particle is a neutralino, this neutralino can decay to the gravitino and a photon or a Z. In this case, neutralino pair production decaying to two Z bosons and gravitinos can be enhanced. For this final state, a four-lepton analysis is performed to complement the Z+dijet analysis (section 2.4).[8] The four lepton analysis follows the techniques of the CMS three-lepton analysis (section 2.1), but divides the data up in slightly different boxes, like number of opposite-sign same-flavor pairs, the E_T^{miss} and whether there is a Z candidate or not. ATLAS has a search focusing on the direct production of a chargino-neutralino pair where the neutralino then decays to a photon and a gravitino.[14] This search has a lepton + photon signature. Both searches did not yield any indications for physics beyond the Standard Model.

6 Conclusions

CMS and ATLAS have performed a wide variety of complementary analyses searching for direct electroweak production of SUSY. No indications for new physics are found and stringent constraints are placed on the slepton and gaugino masses. For the R-parity conserving case, chargino masses up to 600 GeV and slepton masses up to 250 GeV are probed, while for the R-parity violating case, the reach is slightly enhanced to 700 GeV for charginos and 430 GeV for sleptons.

References

1. CMS Collaboration, "The CMS Experiment at the CERN Large Hadron Collider", *JINST* 3 S08004 (2008).
2. ATLAS Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider", *JINST* 3 S08003 (2008).
3. ATLAS Collaboration, "Search for supersymmetry in final states with jets, missing transverse momentum and a Z boson at sqrt(s) = 8 TeV with the ATLAS detector", ATLAS-CONF-2012-152.
4. ATLAS Collaboration, "Search for New Phenomena in Monojet plus Missing Transverse Momentum Final States using 10 fb^{-1} of pp Collisions at sqrt(s) = 8 TeV with the ATLAS detector at the LHC", ATLAS-CONF-2012-147.
5. ATLAS Collaboration, "Search for supersymmetry in events with photons, bottom quarks, and missing transverse momentum in protonproton collisions at a centre-of-mass energy of 7 TeV with the ATLAS detector", *Phys. Lett. B* 719 (2013) 261-279.
6. CMS Collaboration, "Search for supersymmetry in events with photons and missing energy", CMS-PAS-SUS-12-018.
7. CMS Collaboration, "SUSY Search in Photon(s)+jets+MET final state with the Jet-Gamma Balance method", CMS-PAS-SUS-12-013.
8. CMS Collaboration, "Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states in pp collisions at sqrt(s) = 8 TeV", CMS-PAS-SUS-12-022.
9. ATLAS Collaboration, "Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in 13.0 fb^{-1} of pp collisions at sqrt(s)=8 TeV with the ATLAS detector", ATLAS-CONF-2012-154.
10. ATLAS Collaboration, "Search for direct slepton and gaugino production in final states with two leptons and missing transverse momentum with the ATLAS detector in pp collisions at sqrt(s) = 7 TeV", ATLAS-CONF-2012-076.
11. ATLAS Collaboration, "Search for electroweak production of supersymmetric particles in final states with at least two hadronically decaying taus and missing transverse momentum with the ATLAS detector in proton-proton collisions at sqrt(s) = 8 TeV", ATLAS-CONF-2013-028.
12. ATLAS Collaboration, "Search for supersymmetry in events with four or more leptons in 13.0 fb^{1} pp collisions at sqrt(s) = 8 TeV with the ATLAS detector", ATLAS-CONF-2012-153.
13. CMS Collaboration, "Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags", CMS-PAS-SUS-13-003.
14. ATLAS Collaboration, "Search for supersymmetry in events with at least one photon, one lepton, and large missing transverse momentum in protonproton collision at a center-of-mass energy of 7 TeV with the ATLAS detector", ATLAS-CONF-2012-144.