Searches for supersymmetry at CMS in leptonic final states with 13 TeV Data

C. Vince Welke on behalf of the CMS Collaboration[1]

[1]University of California - San Diego, La Jolla, California

May 20, 2016

Abstract

The CMS SUSY program is very active in performing searches with the 13 TeV data including multiple analyses done in regions with leptonic final states. The results of these analyses are used to expand the reach of the searches done by CMS at 8 TeV and additionally to investigate two excesses seen in run I, namely a 2.6 sigma excess seen by CMS and a 3.0 sigma excess seen by ATLAS. These excesses were observed in two separate signal regions both having final states of at least 2 opposite sign same flavor leptons, jets, and E_T^{miss}.

Supersymmetry (SUSY) [1] is an extension to the standard model that can be used to explain some open problems in physics such as providing a solution the hierarchy problem as well as providing potential candidates for dark matter. Searches for SUSY are performed by the CMS collaboration in a variety of final states, including those with leptons (e or μ). Simplified models [2] are used to interpret results of these searches, where two examples of a simplified model are shown in figure 1. On the left is a diagram of a gauge mediated SUSY breaking (GMSB) model with a massless gravitino as the lightest SUSY particle (LSP). In this model, gluinos are pair produced, and each decays to a pair of quarks and a neutralino, which subsequently decays to a Z boson and a gravitino. Another model showing direct stop production with one of the stops eventually decaying to a top that decays leptonically is shown on the right. The results presented in these proceedings focus on direct squark and gluino production. In all of the following results, no significant deviation from the SM was observed, and limits are set on the maximum value of the production cross section of different simplified models at the 95% level using the CLs method [3, 4].

The SUSY analyses performed by CMS share very similar object definitions for electrons, muons, and jets. The analyses are then grouped by the number of leptons in the final state, and for analyses with at least two leptons, they are categorized according to the charge of the two leptons

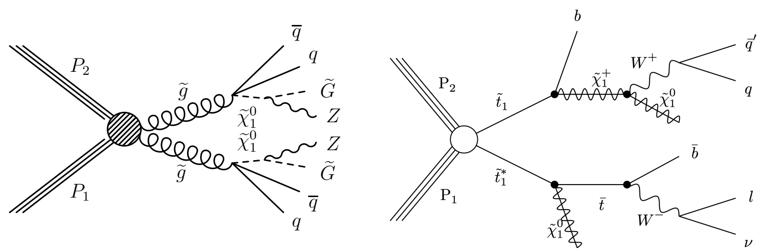

Figure 1: Diagrams showing different SUSY processes which may contain leptons in the final state are shown in this figure. On the left, gravitinos are pair-produced, where each eventually decays to a Z boson, two quarks, and a gravitino. On the right, stops are pair-produced, where one leg eventually decays to a top and a neutralino where the top decays leptonically.

with the largest $\mathrm{p_T}$ in same-sign, or opposite-sign final states. Additionally, a large range of topologies are targeted by varying event variables to quantify the visible energy, invisible energy, and jet multiplicity and jet flavor content. Visible energy in the event can be quantified using the variables $\mathrm{H_T}$, and $\mathrm{M_J}$, where $\mathrm{H_T}$ is the scalar sum of the jet $\mathrm{p_T}$ in the event, and $\mathrm{M_J}$ is the sum of reclustered jets; this is explained in more detail in the $\mathrm{M_J}$ analysis section. Invisible energy is quantified using $\mathrm{E_T^{miss}}$, $\mathrm{M_T}$, $\mathrm{M_{T2}}$, $\Delta\Phi(\mathrm{W},\ell)$, and $\mathrm{L_T}$. $\mathrm{E_T^{miss}}$ is the magnitude of the vector sum of all the objects in the event, which is corrected to be consistent with the corrections applied to jets. $\mathrm{M_T}$ is the transverse mass made using a lepton and the $\mathrm{E_T^{miss}}$ vector. $\mathrm{M_{T2}}$ is the stransverse mass, which is made from two visible objects and the $\mathrm{E_T^{miss}}$ vector; This is explained in more detail in the 1-lepton stop search section. $\Delta\Phi(\mathrm{W},\ell)$ is the difference in ϕ between the lepton and the W-candidate in the 1-lepton inclusive analysis. $\mathrm{L_T}$ is defined as the vector sum of the lepton and the $\mathrm{E_T^{miss}}$ in the 1-lepton inclusive analysis. Jet multiplicity and flavor content are quantified using $\mathrm{N_{jets}}$ and $\mathrm{N_{b-tags}}$.

In the analyses with exactly one lepton, three separate searches are performed. In the first search, a search for direct stop pair production [5], the signal region is defined by having exactly 1 lepton, at least 2 jets with at least one of the jets passing the criteria to be tagged as a b-jet, and $\mathrm{E_T^{miss}} > 250$ GeV. In order to further suppress backgrounds from ttbar, a cut is then made on $\mathrm{M_{T2W}}$, which is an $\mathrm{M_{T2}}$-like variable that uses the b-jets and leptons as visible objects, and has a kinematic cut-off at the top mass. After the cuts are applied, the largest background comes from SM $\mathrm{t\bar{t}}$ to dilepton where one of the leptons is not reconstructed leading to increased $\mathrm{E_T^{miss}}$ in the event. The results of this analysis increase the sensitivity to models where stop pairs are produced directly to exclude scenarios where the stop mass is up to 750 GeV, which is an improvement on the previous result which was sensitive to models with a stop mass up to 650 GeV.

The next analysis is a search targeting final states with exactly one lepton [6], and many jets from hadronic top decay. In this analysis, events with exactly 1 lepton in the final state, and at least one b-tagged jet are selected. The jets in the event, which are made using the anti-kt clustering algorithm with a cone size of R = 0.4, are reclustered to form large-R jets (R = 1.2). The masses of all the large-R jets in the event are then summed to form the variable $\mathrm{M_J}$ which tends to be large for events where large mass particles decay hadronically, for example in SUSY in final states with many top quarks. In order to reduce backgrounds where a lepton comes from a W not from a top decay, a cut is made of $\mathrm{M_T} > 140$ GeV. The results of this analysis are interpreted in the context of a SUSY model where gluinos are pair-produced then each decays to a $\mathrm{t\bar{t}}$ pair and a stable LSP, and gluinos up to a mass of 1600 GeV are excluded.

The final analysis with exactly one lepton [7] is an inclusive search which uses the $\Delta\Phi(\mathrm{W}, \ell)$ and $\mathrm{L_T}$ variables to suppress SM backgrounds which mostly consist of $\mathrm{t\bar{t}}$ and W+jets. The search is binned in the $\mathrm{H_T}$, $\mathrm{N_{jets}}$, $\mathrm{N_{b-tags}}$ in order for the search to be inclusive as possible. The results of the search are interpreted many SUSY scenarios, for example the same model as the $\mathrm{M_J}$ analysis, and this analysis is seen to have similar sensitivity when interpreting the results within the context of this simplified model.

The rest of the analyses all require at least 2 leptons in the final state [8]. The first analysis in this category is a search for SUSY in a final state with two same sign leptons. The baseline selection requires at least two same sign leptons with $\mathrm{p_T} >$ 10-15 GeV depending on the trigger, $\mathrm{E_T^{miss}} > 50$ GeV. The analysis is then binned in $\mathrm{H_T}$, $\mathrm{N_{jets}}$ and $\mathrm{N_{b-tags}}$. The largest background in this analysis comes from fake lepton signatures in the detector, and a data-driven method was developed to predict this background which ends up with an uncertainty of about 40%.

The next analysis is a search in events with three or more leptons [9]. This analysis is binned in $\mathrm{H_T}$, $\mathrm{N_{jets}}$ and $\mathrm{N_{b-tags}}$, and the largest backgrounds in the signal region comes from either SM WZ associated production, or non-prompt leptons passing all the lepton ID requirements.

The final analysis is a search in final states with at least two opposite-sign same-flavor leptons and at least two jets [10]. A separate search is performed in events where $\mathrm{M_{\ell\ell}}$ of the two highest $\mathrm{p_T}$ leptons is between 81-101 GeV (the on-Z region), as well as an inclusive search with $\mathrm{M_{\ell\ell}} >$ 20 GeV (the "edge" region). The main backgrounds in this analysis are grouped into three categories, Z+jets, flavor-symmetric (FS), and other SM processes. Z+jets with no real $\mathrm{E_T^{miss}}$ is defined as any background with Z+jets, but no $\mathrm{E_T^{miss}}$ from invisble particles, such as neutrinos. The FS background is defined as any process where ee or $\mu\mu$ pairs are produced at equal rates as eμ, such as $\mathrm{t\bar{t}}$, WW, and single top. Other SM processes include Z+jets with real $\mathrm{E_T^{miss}}$, multiboson production, and ttV. In order to predict the Z+jets background, a fully data-driven method was developed where the $\mathrm{E_T^{miss}}$ shape is predicted using a γ+jets control region in data. The γ+jets sample is reweighted such that the shape of the $\mathrm{p_T}$ of the photon in the event matches that of the Z boson $\mathrm{p_T}$ of the events that pass the baseline selection. This background is then normalized in a region where Z+jets is the dominant SM background, namely $\mathrm{E_T^{miss}}\ M <$ 50 GeV. The FS background is predicted using a sample of eμ data events which is corrected for the difference in reconstruction and trigger efficiencies between electrons and muons. The largest systematic uncertainty on this background is about 5% and is mostly due to the trigger uncertainty. Other SM processes are predicted using simulated monte-carlo datasets which are validated in 3 and 4 lepton control regions. A conservative systematic uncertainty of 50% is assigned to these backgrounds. In order to reduce these backgrounds, cuts are made on $\mathrm{N_{jets}}$, $\mathrm{H_T}$, and $\mathrm{E_T^{miss}}$.

Two excesses were observed in separate $\mathrm{M}_{\ell\ell}$ regions in run I, one by CMS [11] and another seen by ATLAS [12]. CMS saw an excess in events with $\mathrm{M}_{\ell\ell}$ between 20-70 GeV with a significance of 2.6 σ while ATLAS saw no excess in a similar region. ATLAS observed a 3 σ excess in events with two leptons having $\mathrm{M}_{\ell\ell}$ between 81-101, large $\mathrm{H_T}$, and large $\mathrm{E_T^{miss}}$. In the CMS analysis performed in run I, a similar signal region was explored and showed no significant deviation from the SM prediction. In the analysis done by CMS in 2015, and an additional signal region was added in order to search where ATLAS saw an excess at 8 TeV. No significant excess was seen in either region where an excess was reported in 8 TeV, and the result of this analysis can be seen in figure 2.

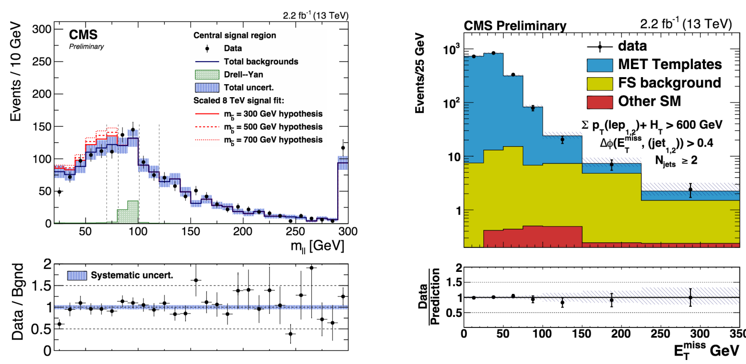

Figure 2: Observed yields and background predictions are shown for the "edge" signal regions (left) and ATLAS-like on Z signal region (right).

Overall, the SUSY program is well underway in run II, and many exciting results have already been released including many in leptonic final states.

References

[1] S. P. Martin, "A supersymmetry primer," 1997. [Adv. Ser. Direct. High Energy Phys.18,1(1998)].

[2] D. Alves *et al.*, "Simplified models for LHC new physics searches," *J. Phys. G*, vol. 39, p. 105005, 2012. Model of Section IV.E with topology (B+B).

[3] T. Junk, "Confidence level computation for combining searches with small statistics," *Nucl. Instrum. Meth. A*, vol. 434, p. 435, 1999.

[4] A. L. Read, "Presentation of search results: The CL_s technique," *J. Phys. G*, vol. 28, p. 2693, 2002.

[5] T. C. Collaboration, "Search for stop pairs in the 1l final state with 13 tev data," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-16-002, 2016.

[6] T. C. Collaboration, "Search for supersymmetry in pp collisions at sqrt (s) = 13 tev in the single-lepton final state using the sum of masses of large radius jets," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-15-007, 2015.

[7] T. C. Collaboration, "Search for supersymmetry in events with one lepton," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-15-006, 2015.

[8] T. C. Collaboration, "Search for susy in same-sign dilepton events at 13 tev," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-15-008, 2015.

[9] T. C. Collaboration, "Search for susy with multileptons in 13 tev data," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-16-003, 2016.

[10] T. C. Collaboration, "Search for susy in final states with opposite-sign dileptons at 13 tev," *CMS Physics Analysis Summary*, vol. CMS-PAS-SUS-15-011, 2015.

[11] V. Khachatryan *et al.*, "Search for Physics Beyond the Standard Model in Events with Two Leptons, Jets, and Missing Transverse Momentum in pp Collisions at sqrt(s) = 8 TeV," *JHEP*, vol. 04, p. 124, 2015.

[12] T. A. Collaboration, "Search for supersymmetry in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{\mathrm{s}} = 8$tev pp collisions with the atlas detector," *The European Physical Journal C*, vol. 75, no. 7, 2015.