Searches for strong production of SUSY particles with two opposite-sign same-flavor leptons at CMS

SERGIO SÁNCHEZ CRUZ,
on behalf of the CMS Collaboration,
Universidad de Oviedo, Spain

ABSTRACT

A search is presented for physics beyond the standard model in events with two opposite-sign, same-flavor leptons, jets and missing transverse momentum in the final state. The search is performed in a dataset of 35.9 fb$^{-1}$ of $\sqrt{s} = 13$ TeV pp collisions recorded by the CMS experiment in the year 2016. The search targets models in which a colored particle is produced. Models are considered, in which a kinematic edge is observed in the dilepton invariant mass distribution and models in which a Z boson arises in the decay chain of the SUSY particles. Such searches have been performed in 8 TeV pp collisions as well as 13 TeV collisions. This version of the search adds additional event categories as well as improved background estimation procedures substantially increasing the sensitivity of the search. The results are interpreted in the context of simplified models of Supersymmetry.

PRESENTED AT

The Fifth Annual Conference on Large Hadron Collider Physics
Shanghai Jiao Tong University, Shanghai, China
May 15-20, 2017
1 Introduction

This document reports a search for new physics in events with two opposite-sign, same-flavor leptons, jets and missing transverse momentum in pp collisions recorded by the CMS experiment[1]. These searches have been performed by both the CMS[2,3] and ATLAS Collaborations[4,5], and are motivated by several models of supersymmetry (SUSY) that involve the production of such lepton pairs in either the decay of an on-shell Z boson produced in the decay chain of SUSY particles or in the sequential two-body decays of a neutralino.

These two topologies correspond to different experimental signatures: while the former would be observed as an excess in events compatible with a Z boson, the latter would yield to an edge-shape feature in the dilepton invariant mass, $m_\ell\ell$, distribution.

Figure 1 shows the diagrams of the simplified models used for the interpretation of the results of this analysis. In such models the production and decay of a few SUSY particles is taken into account, assuming the rest of the SUSY particles are beyond the experiment scope. The first simplified model, which represents a Gauge Mediated Supersymmetry breaking model and is referred to as the GMSB scenario, involves the production of two gluinos decaying into quarks and a neutralino, that can further decay into an on-shell Z boson and a massless gravitino. In the other simplified model considered, the slepton-edge scenario, two sbottoms are produced, decaying into $b$-quarks and neutralinos, that further decay into off-shell Z bosons and the LSP.

![Diagram of simplified SUSY models](image)

Figure 1: Diagrams of the simplified SUSY models used for the interpretation of the results of the analysis. Diagram in the left shows the GMSB scenario and the diagram on the right represents the slepton-edge model.

2 Search strategy and background estimation

Events with two opposite-sign same-flavor leptons, two jets and missing transverse momentum ($E_T^{miss}$) greater than 100 GeV are considered in this analysis. On top of this common baseline selection, the spectrum of the dilepton invariant mass is splitted into an on-Z part, sensitive to the first kind of models described in the introduction, and an off-Z part, sensitive to the other kind.

The background estimation methods, described in this section, are also applied in the same way to both parts of the analysis.

The main background contribution to many of the search regions that will be described is due to so-called flavor-symmetric processes, i.e. those processes that yield a same-flavor or an opposite-flavor dilepton pair with the same probability. This class of backgrounds is dominated by $t\bar{t}$ production and is estimated in a fully data-driven fashion. In order to do so, the opposite-flavor channel is used as a side-band, and the obtained estimate is corrected by the different electron and muon trigger and identification efficiencies.

Even if they do not produce invisible particles in the final state, Drell-Yan events can contain instrumental missing transverse momentum and enter the defined baseline region. This instrumental missing transverse momentum is usually driven by the resolution in the measurement of the jet energy. In order to estimate
this contribution, the $E_T^{miss}$ distribution is determined in a dedicated $\gamma + \text{jets}$ data sample, in which the instrumental $E_T^{miss}$ is also driven by the jet resolution.

Remaining contributions from backgrounds with a Z boson and genuine $E_T^{miss}$ (WZ, ZZ, $t\bar{t}Z$) are estimated using dedicated Monte Carlo samples that are validated in background enriched control regions.

3 Search regions

In order to be sensitive to a wide range of SUSY particle masses, two sets of orthogonal signal regions are defined on top of the on-Z and off-Z search regions.

Events in the on-Z category, with $|m_\ell\ell - 91\text{ GeV}| < 5\text{ GeV}$ are classified according to the hadronic activity, the number of $b$-jets and $E_T^{miss}$.

Events in the off-Z category are further required to have $E_T^{miss} > 150\text{ GeV}$ and the kinematic observable $m_{T_2}$ to be greater than 80 GeV. Events are then further classified according to the $m_\ell\ell$ of the reconstructed dilepton system, in order to target different locations of the signal kinematic edge.

Additionally, events are classified as $t\bar{t}$-like and non-$t\bar{t}$-like according to a Negative Log Likelihood (NLL) discriminant, which is a likelihood discriminant designed to reject events due flavor-symmetric processes, the largest contribution in the off-Z regions. The observables used for the likelihood discriminant are: the $p_T$ of the dilepton system, $|\Delta(\phi)|$ between the leptons, $E_T^{miss}$ and an observable called $\sum m_{lb}$. The latter is calculated by taking all possible combinations of leptons and $b$-jets, finding the combination with the minimum mass, $m_{lb}$. If no $b$-jets are found, the combinations of leptons and light jets are considered. Then the process is repeated with the remaining lepton and $b$-jets. $\sum m_{lb}$ is defined as the sum of those masses.

In order to define the NLL discriminant, a parametric model for the probability distribution functions (pdfs) of each of the four observables is assumed. The particular pdf is then extracted by fitting the parametric model to data in the opposite-flavor side-band, which is $t\bar{t}$ enriched. Then, for each event the NLL discriminant can be calculated as

$$\text{NLL} = -\sum_i \log f_i(x_i),$$

where $x_i$ are the four observables taken into account and $f_i$ are their fitted pdfs. The NLL coincides with the opposite of the logarithm of the likelihood for an event been produced in a $t\bar{t}$ process in the approximation in which the $x_i$ variables are independent. These four variables were verified to be only mildly correlated and the NLL has been observed to be a powerful discriminant to a wide range of parameter sets in the slepton-edge model.

Based on the value of the NLL discriminant, a $t\bar{t}$-like and a non-$t\bar{t}$-like region are defined.

The complete list of search regions is shown in tab. 1.

Table 1: Summary of all search regions. $H_T$ is defined as the scalar sum of the transverse momenta of the selected jet.

| Region               | $N_{jets}$ | $N_{b\text{-jets}}$ | $H_T$ [GeV] | $M_{T_2(\ell\ell)}$ [GeV] | $E_T^{miss}$ binning [GeV] |
|----------------------|------------|---------------------|-------------|--------------------------|----------------------------|
| SRA b veto           | 2–3        | 0                   | > 500       | > 80                     | 100–150, 150–250, > 250    |
| SRB b veto           | 4–5        | 0                   | > 500       | > 80                     | 100–150, 150–250, > 250    |
| SRC b veto           | ≥ 6        | 0                   | -           | > 80                     | 100–150, > 150             |
| SRA b tag            | 2–3        | ≥ 1                 | > 200       | > 100                    | 100–150, 150–250, > 250    |
| SRB b tag            | 4–5        | ≥ 1                 | > 200       | > 100                    | 100–150, 150–250, > 250    |
| SRC b tag            | ≥ 6        | ≥ 1                 | -           | > 100                    | 100–150, > 150             |

| Region               | $N_{jets}$ | $E_T^{miss}$ [GeV] | $M_{T_2(\ell\ell)}$ [GeV] | NLL | $m_\ell\ell$ binning [GeV] |
|----------------------|------------|-------------------|---------------------------|-----|---------------------------|
| $t\bar{t}$-like      | ≥ 2        | > 150             | > 80                      | < 21| 20–60, 60–86, 96–150, 150–200, 200–300, 300–400, > 400 |
| not-$t\bar{t}$-like  | ≥ 2        | > 150             | > 80                      | ≥ 21| same as $t\bar{t}$-like   |
4 Results and interpretation

Figure 2 shows the observed and expected number of events in the off-Z search regions, and in Fig. 3 the same is shown for the on-Z regions. All the results are compatible with SM expectations.

![PressEvent](image)

Figure 2: Results of the off-Z part of the search. For each search region, the number of observed events (black dots) is compared to the total number of expected events (blue line).

No sign of Beyond Standard Model Physics has been observed. Using these results, upper limits on cross sections and lower limits on masses can be set, assuming 100% branching fractions for the models under consideration. These limits are shown in Fig. 4. In the GMSB scenario, we exclude gluino masses up to 1500–1700 GeV depending on the neutralino mass. In the slepton-edge scenario, we exclude sbottom masses up to 1000–1200 GeV depending on the neutralino mass.

5 Conclusions

A search for new physics has been performed in events with two opposite-sign same-flavor lepton, jets and missing transverse momentum. The analysis targets two different kind of topologies, one in which the signal would be observed as an excess of events compatible with a Z boson, while in the other an edge-like feature would be observed in the di-lepton mass distribution. Those topologies are motivated by simplified SUSY models.

The results obtained are compatible with Standard Model expectations, allowing us to exclude gluino masses below 1500-1700 GeV and sbottom masses below 1000 to 1200 GeV in these simplified models.

References

[1] CMS Collaboration, JINST 3 S08004 (2008)

[2] CMS Collaboration, 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 04 (2015) 124

[3] 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. J. High Energy Phys. 12 (2016) 013

[4] ATLAS Collaboration, Search for supersymmetry in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector. Eur. Phys. J. C 75 (2015) 318
Figure 3: Results of the on-Z part of the search. Figures show the $E_T^{miss}$ distributions in events in search regions A (left), B (center) and C (right) without $b$-jets (top) and with $b$-jets (bottom).

Figure 4: The upper limit on the production cross-section are shown of the GMSB scenario as a function of the gluino and neutralino masses (left) and the slepton-edge scenario as a function of the stop and neutralino masses (right). The upper limit is shown in the color scale, while the red and black lines shown the expected and observed exclusion limits on the masses based on a reference SUSY cross section.

[5] ATLAS Collaboration, Search for new phenomena in events containing a same-flavour opposite-sign dilepton pair, jets, and large missing transverse momentum in $\sqrt{s}=13$ TeV pp collisions with the ATLAS detector. Eur. Phys. J C 77 (2017) 144

[6] C. G. Lester and D. J. Summers, Measuring masses of semi invisibly decaying particles pair produced at hadron colliders, Phys. Lett. B 463 (1999) 99

[7] CMS Collaboration, Search for new physics in final states with two opposite-sign, same-flavor lepton, jets, and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV. CMS-PAS-SUS-16-034