Searches for supersymmetry in leptonic final states at CMS

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Results from searches for supersymmetry in single lepton, same-sign dilepton, opposite-sign same-flavor dilepton, and multilepton final states are reported. The observed yields in data samples corresponding to an integrated luminosity of 2.1–2.3 fb$^{-1}$ at $\sqrt{s} = 13$ TeV, recorded by the CMS experiment at the LHC, are consistent with the expectations from standard model backgrounds. For a massless lightest-supersymmetric-particle, bottom squarks below 650 GeV, top squarks below 730 GeV, and gluinos below 1600 GeV are excluded at 95% CL for various decay modes. These values match or extend previous limits set with 8 TeV data.

1 Introduction

Supersymmetry (SUSY) is a compelling extension of the standard model (SM) that could provide answers to some of the most pressing questions in fundamental physics. One of these questions, the so-called hierarchy problem, refers to the extreme level of fine-tuning required for the mass of the Higgs boson to be 32 orders of magnitude below the Planck scale. A natural answer to this problem could be found in a low mass realization of SUSY$^1$, with light Higgsinos, top squarks, and left-handed bottom squarks, and with gluinos about a factor of two heavier than the lightest squark.

In 2015, the LHC at CERN increased the center-of-mass energy of pp collisions to 13 TeV. At this energy, the production cross-section of the not-yet-excluded Higgsinos (with masses of 200-400 GeV) increases by a factor of 2-3 with respect to the corresponding 8 TeV cross section. The cross sections for 800 GeV top squarks and 1300 GeV gluinos increase by factors of 10 and 24, respectively. Given that the total amount of integrated luminosity recorded by the CMS experiment at 13 TeV was 2.3 fb$^{-1}$, about 9 times lower than the 8 TeV dataset employed in previous SUSY searches, the 2015 CMS SUSY program focused on searches for strongly produced sparticles, for which the sensitivity is expected to improve.

This note presents searches for top squarks and gluinos in the single lepton final state in Secs. 2 and 3. Searches in the same-sign dilepton and three lepton or more (multilepton) final states are presented in Sec. 4, and the results of the opposite-sign same-flavor (OSSF) dilepton search is discussed in Sec. 5.
2 Search for top squarks in the single lepton final state

This search selects events with a single isolated 20 GeV lepton (electron or muon), $E_{\text{miss}} \geq 250$ GeV, $N_{\text{jets}} \geq 2$ and at least one $b$-tag. After these requirements, the background is dominated by $t\bar{t}$ and $W$+jets. This background is greatly reduced by requiring that $m_T$, the transverse mass of the lepton and the missing momentum, be greater than 150 GeV, far above the $W$ mass. The remaining background, $2\ell$ $t\bar{t}$ primarily, is further reduced by vetoing additional soft leptons, isolated tracks, and reconstructed $\tau$ leptons.

To increase signal sensitivity, the search region is divided into bins of $E_{\text{miss}}$, $N_{\text{jets}}$, and two variables that reconstruct the event under the $2\ell$ $t\bar{t}$ hypothesis to further discriminate against this background: $M_{W\gamma}$ and modified topness.

The $2\ell$ $t\bar{t}$ background is estimated in a control sample with two reconstructed leptons, and the transfer factors are taken from simulation. The remaining $W$+jets background is estimated from the $N_0 = 0$ sample, while other small backgrounds are taken from simulation scaled to their theoretical cross sections.

![Figure 1](image-url)

Figure 1 – (Left) Results of the search for top squarks in the different signal regions. (Right) 95% CL exclusion limits for top squarks decaying to neutralinos or charginos for various branching fractions.

Figure 1 (left) shows the results in the various signal bins. The observed yields are consistent with the expectations from SM backgrounds, so exclusion limits on top squark production are set [Fig. 1 (right)]. For low $m_{\chi^0}$ and top squarks decaying to top quarks and neutralinos, $m_\chi < 730$ GeV is excluded. This limit is comparable to the 8 TeV searches, as expected from cross sections considerations (Sec. 1). As the $t \rightarrow b\chi^+\chi^-$ branching fraction increases (for almost degenerate chargino/neutralino), the limits degrade rapidly.

3 Searches for gluinos in the single lepton final state

Two searches target gluino pair-production in the single-lepton final state with the gluinos decaying as $g \rightarrow t\bar{t}\chi^0_1$. The background estimation methods of these analyses fully exploit the high multiplicity of this signal model by requiring significant amounts of initial state radiation, which makes the hadronic activity in $1\ell$ $t\bar{t}$ and $2\ell$ $t\bar{t}$ events similar. The search region (single high-$p_T$ lepton, high $E_{\text{miss}}$, $N_{\text{jets}} \geq 5-6$) is divided into 4 regions and ABCD methods separating $1\ell$ $t\bar{t}$ from $2\ell$ $t\bar{t}$, and moderate hadronic activity from high hadronic activity, are applied. One analysis defines the ABCD regions with the $m_T$ and $M_J$ (sum of masses of $R = 1.2$ jets) variables, while the other uses $\Delta\phi$ (the angle between the reconstructed lepton and the missing transverse momentum) and $N_{\text{jets}}$.

With respect to models with low $m_{\chi^0}$, compressed models tend to have softer $M_J$ distributions but similarly high jet multiplicities. As a result, the $\Delta\phi$ analysis has better sensitivity to models where $m_{\chi^0}$ is close to $m_g$, as the exclusion limits in Fig. 2 (left) show. These limits assume decoupled top squarks, but the impact of intermediate top squarks with $m_\tilde{t} < m_\chi$ is also studied. Figure 2 (right) compares the decoupled limit with the exclusion limits obtained for the
extreme case in which the top squark has almost the smallest mass consistent with a two-body decay, \( m_{\tilde{t}} = m_{\chi^0_1} + 175 \text{ GeV} \). For this mass combination, the \( \chi^0_1 \) and top quark are almost at rest in \( \tilde{t} \) frame, which results in lower signal efficiency than for other values of \( m_{\tilde{t}} \). The exclusion limits only degrade slightly in most of the parameter space, except for low \( m_{\chi^0_1} \) where the \( \chi^0_1 \) carries very little momentum and the \( m_T \) distribution of signal events becomes similar to that of 1\ell + \ell \bar{t} \) events.

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\begin{array}{cccc}
\text{GeV} & 600 & 800 & 1000 & 1200 & 1400 & 1600 & 1800 \\
\chi^0 & 200 & 400 & 600 & 800 & 1000 & 1200 & 1400 & 1600 & 1800 & 2000 \\
\end{array}
\]

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Figure 2 – (Left) Exclusion limits at 95% CL for gluino pair production with top squarks decoupled. (Right) Comparison of the gluino exclusion limits with decoupled (red) and intermediate (blue) top squarks with \( m_{\tilde{t}} = m_{\chi^0_1} + 175 \text{ GeV} \) for the \( M_J \) analysis.

4 \ Searches for SUSY in the same-sign dilepton and multilepton final states

SUSY searches in final states with \( E_{\text{miss}} \) and a pair of same-sign leptons or three or more leptons have reduced sensitivity to squarks and gluinos in the simplified model interpretation due to branching fraction considerations. However, in realistic SUSY scenarios with several cascade decays, the lepton multiplicity is generally higher. Moreover, events in these final states are rare in the SM and thus can be a powerful probe of physics beyond the SM.

The main sources of background in these analyses are events with non-prompt leptons typically due to mis-identification, semileptonic decays from \( b \) or \( c \) quarks, or conversions. These two searches\(^5,6\) estimate this contribution with the loose-but-not-tight method, which uses a sample with leptons that satisfy loose requirements, but fail tight ones, and extrapolate its contribution into the signal region by applying the factor \( \epsilon_{\text{TL}}/(1 - \epsilon_{\text{TL}}) \). Here, \( \epsilon_{\text{TL}} \) is the probability of a fake lepton that passes loose requirements to pass tight ones as well, and is measured in a QCD control sample. The next largest background comes from \( WZ \) events, which are estimated from the simulation with a normalization obtained in a 3\ell sample. Other rare irreducible backgrounds are taken directly from simulation scaled to their theoretical cross sections.

Figure 3 – Comparison of the observed and expected \( E_{\text{miss}} \) distributions for the same-sign dilepton (left), multilepton off-Z (middle), and multilepton on-Z (right) selections.
Figure 3 compares the observed $E_T^{\text{miss}}$ distribution with that of the expected SM background. No significant deviation is found, so exclusion limits are set on various signal models. Bottom squarks decaying as $b_L \rightarrow tW \tilde{\chi}^0_1$ are excluded for $m_{b_L} < 650$ GeV. Additionally, a model-independent exclusion limit is set on any process beyond the SM with $\sigma \cdot A \cdot \epsilon > 1.3$ fb.

5 Searches for SUSY in the opposite-sign same-flavor dilepton final state

Both 8 TeV searches in the OSSF dilepton final state at ATLAS\textsuperscript{7} and CMS\textsuperscript{8} showed moderate excesses over the SM, albeit in different kinematic regions: a $3.0 \sigma$ excess in the on-Z region for ATLAS and a $2.6 \sigma$ excess in the off-Z region for CMS. More recently, ATLAS observed a similar excess in the on-Z region at 13 TeV\textsuperscript{9}. A new search\textsuperscript{10} selects events with two isolated, OSSF leptons with $p_T > 20$ GeV, $N_{\text{jets}} \geq 2$, and $E_T^{\text{miss}} > 100$ GeV. The majority of the background processes produce as many events with a $e\mu$ pair as with $ee + \mu\mu$ pairs, and, thus, this background can be estimated in the opposite-flavor sample, after appropriate corrections are applied to account for differences in lepton reconstruction. The $Z$+jets background is estimated from the $E_T^{\text{miss}}$ spectrum of $\gamma$+jets, after reweighting the photon momentum to that of the $Z$ boson and taking the $Z$+jets normalization from a $\ell^+\ell^-$ sample with low $E_T^{\text{miss}}$.

Figure 4 (left) shows the results for the off-Z analysis. There is no sign of the excess seen at 8 TeV in the $20 < m_{\ell\ell} < 70$ GeV region. A similar excess would have produced 61–86 additional events in the 13 TeV dataset, but the observed yields exclude excesses of 57 events or more at 95% CL. Figure 4 (right) shows the results for the on-Z analysis. A bin with the same requirements as the ATLAS search that saw a $3.0 \sigma$ excess was added for this analysis. A similar excess would have produced 12–19 additional events in the 13 TeV dataset, but the observed yields exclude excesses of 9 events or more at 95% CL.

References