Search for SUSY with multileptons in proton proton collisions in $\sqrt{s}$ = 13 TeV data using CMS detector

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Abstract
A search for new physics is performed using events with multileptons (≥ 3 electrons or muons) in the final state using the CMS detector. Results are based on a sample of proton-proton collisions at a centre-of-mass energy of 13 TeV at the LHC corresponding to an integrated luminosity of 2.3 fb^{1}. Search regions have been defined by the number of b-tagged jets, missing transverse energy, hadronic transverse energy, and the invariant mass of opposite-sign, same-flavor dilepton pairs in the events. No excess above the standard model background expectation is observed.

Introduction

The multilepton (three or more leptons) final state is a strongly motivated place to search for new physics. Many different types of beyond the standard model (BSM) theories can produce multilepton events, with a wide array of unique signatures. The analysis is designed to have broad sensitivity to these possibilities by examining the event yields as a function of several kinematic quantities. The results of this analysis are interpreted in the context of the supersymmetric (SUSY) models that feature strong squark and gluino production and R-parity conversation with mass spectra that produce final state leptons through the decays of vector bosons. In addition to multiple leptons, these models contain multiple jets and missing transverse energy. For these final state, the expected irreducible backgrounds come from di-boson production ($W^{\pm}Z$, ZZ) or rare SM processes (including $ttW^{\pm}$, ttZ, ttH, etc.). Reducible backgrounds are processes that produce one or more misidentified or nonprompt leptons, i.e. those that come from jets or meson decays, that pass all reconstruction, identification and isolation criteria.

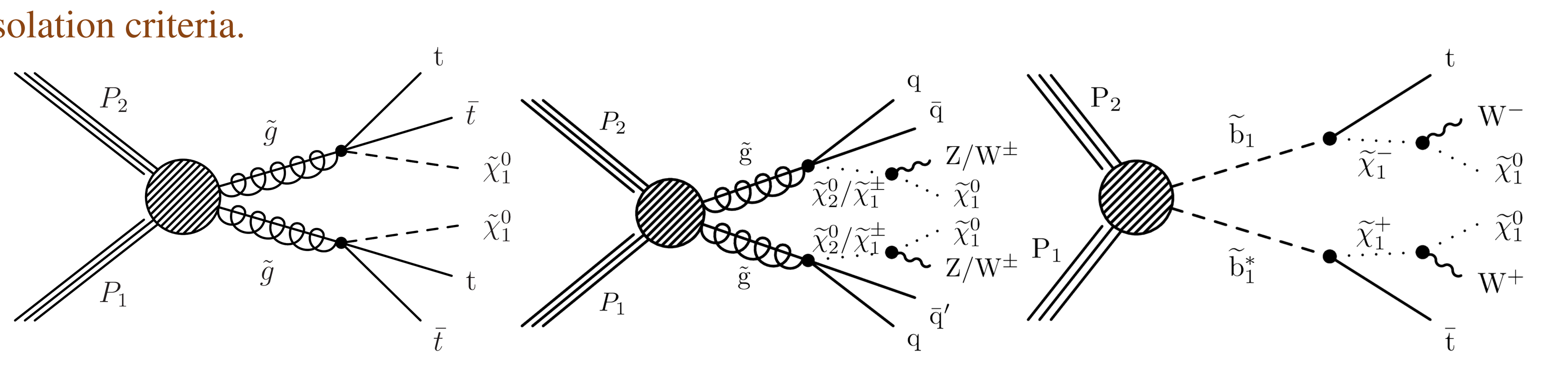


Figure 1: Diagrams for gluino and bottom squark pair production which can produce multi-lepton events: T1tttt (left), T5qqqqWZ (central) and T6ttWW (right).

Event selection

- **Di-lepton triggers** are used for selection
- **At least three leptons (e or μ)** with $p_T >$ **20, 15, 10 GeV**
- **At least 2 jets** with $p_T > 30$ GeV and $|\eta| < 2.4$, **MET** $>$ **50 GeV**
- Invariant mass of two opposite-sign same-flavor leptons $>$ **12 GeV**

Search strategy

For the definition of the signal regions we use several event variables:

- **number of b-jets ($N_{\textbf{b-jets}}$)**
- **hadronic activity (H_T)**
- **the missing transverse energy (E_T^{miss})**,
- and whether the event contains any opposite-sign, same-flavor dilepton pairs with an invariant mass between 76 and 106 GeV (on-Z if so, off-Z otherwise).

Table 1 shows the definition of the subdivision of the baseline selection into 15 signal regions (SR) each for events that contain on-Z and off-Z dilepton pairs.

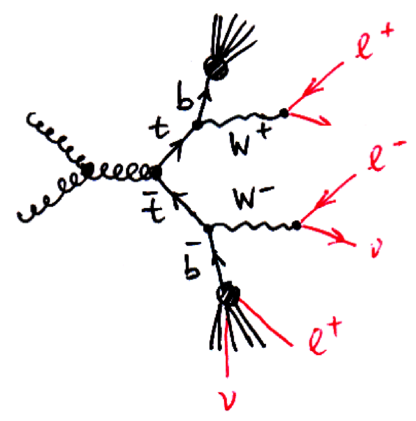
N_{jets}	$N_{b\text{-}jets}$	E_T^{miss} (GeV)	60 GeV $\leq H_T <$ 400 GeV	400 GeV $\leq H_T <$ 600 GeV	$H_T \geq$ 600 GeV
≥ 2	0	$50-150$	SR1	SR3	SR14
		$150-300$	SR2	SR4	
	1	$50-150$	SR5	SR7	
		$150-300$	SR6	SR8	
	2	$50-150$	SR9	SR11	
		$150-300$	SR10	SR12	
	≥ 3	$50-300$	SR13		
	inclusive	≥ 300	SR15		

Table 1: Multilepton signal region definition

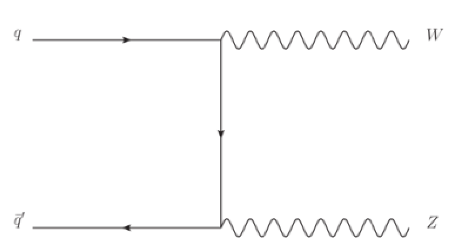
Multilepton background from Standard Model processes

Backgrounds for the multilepton final state can be divided in three categories:

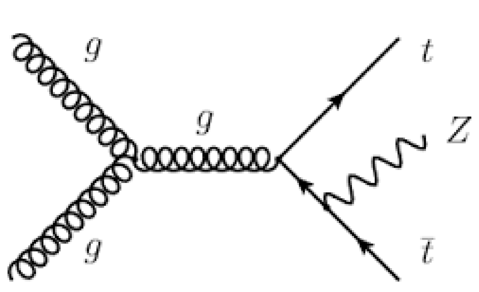
- **Nonprompt leptons:** *Nonprompt* or *misidentified* leptons are leptons from heavy-flavour decays, misidentified hadrons, muons from light-meson decays in flight, or electrons from unidentified photon conversions. For this analysis $\mathbf{t\bar{t}}$ events can enter the signal regions if nonprompt leptons are present in addition to the prompt leptons from the W decays. This background is estimated using data-driven technique and the systematic uncertainty is assigned from the level of closure of the method.



- **Diboson production:** Diboson production could yield multilepton final states with up to three prompt leptons in **WZ** production and up to four prompt leptons in **ZZ** production, being therefore an irreducible background. Especially in signal regions without b-tagged jets, WZ production has a sizable contribution. To estimate this background, its yield as obtained from simulation is scaled using a scale factor measured in a dedicated control region enriched in WZ events and systematic uncertainty is assigned from the statistical uncertainty of the scale factor.



- **Rare SM processes:** Other rare SM processes that can yield three or more leptons are $\mathbf{t\bar{t}}W$, $\mathbf{t\bar{t}}Z$, and tri-boson production **VVV** where V= W, Z. We also include the contribution from the SM Higgs boson produced in association with a vector boson or a pair of top quarks in this category of backgrounds, as well as processes that produce additional leptons from internal conversions, which are events that contain a virtual photon that decays to leptons.



Systematic uncertainties

- The major experimental source of uncertainty is the knowledge of the **jet energy scale (JES)** as well as the uncertainties associated with the corrections for the **b-tagging** efficiencies for light and bottom flavour jets, affecting all the simulated backgrounds and signal events, which accounts for differences between data and simulation.
- The uncertainty on the **QCD renormalization (μ_R) and factorization scales (μ_F)**, and on the knowledge of the **Parton Density Functions (PDF)** as well as the uncertainties due to renormalization and factorization scale are considered for some of the rare processes, namely $t\bar{t}W$, $t\bar{t}Z$, and ttH.
- A conservative 50% of theoretical uncertainty is assigned to the remaining rare processes.

Results and Conslusions

Fig. 2 graphically presents a summary of predicted backgrounds and observed event yields in individual SRs. The hatched band represents the total background uncertainty in each bin.

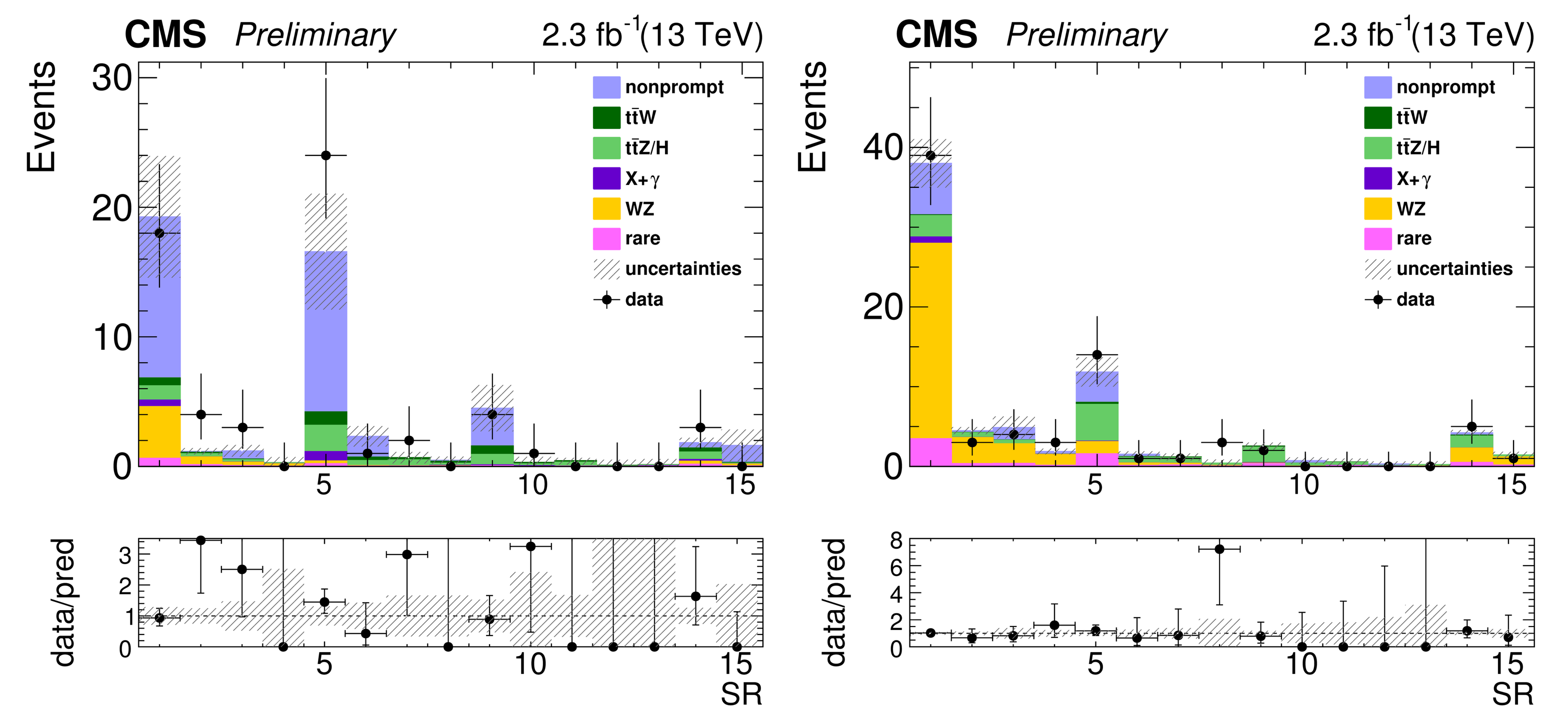


Figure 2: The total predicted background and number of events observed in 15 off-Z SRs (left) and 15 on-Z SRs (right)

- The number of events observed in data are found to be **consistent** with predicted background yields. The results are used to calculate cross **section upper limits** on production of gluinos or squarks for SUSY models as a function of the **gluino** or **squark** and the **chargino** or **neutralino** masses.
- The results of the limit setting procedure are shown in Figures 3 for the considered simplified models. In these figures, the thick black lines delineate the observed exclusion region, which is to the left of the line.

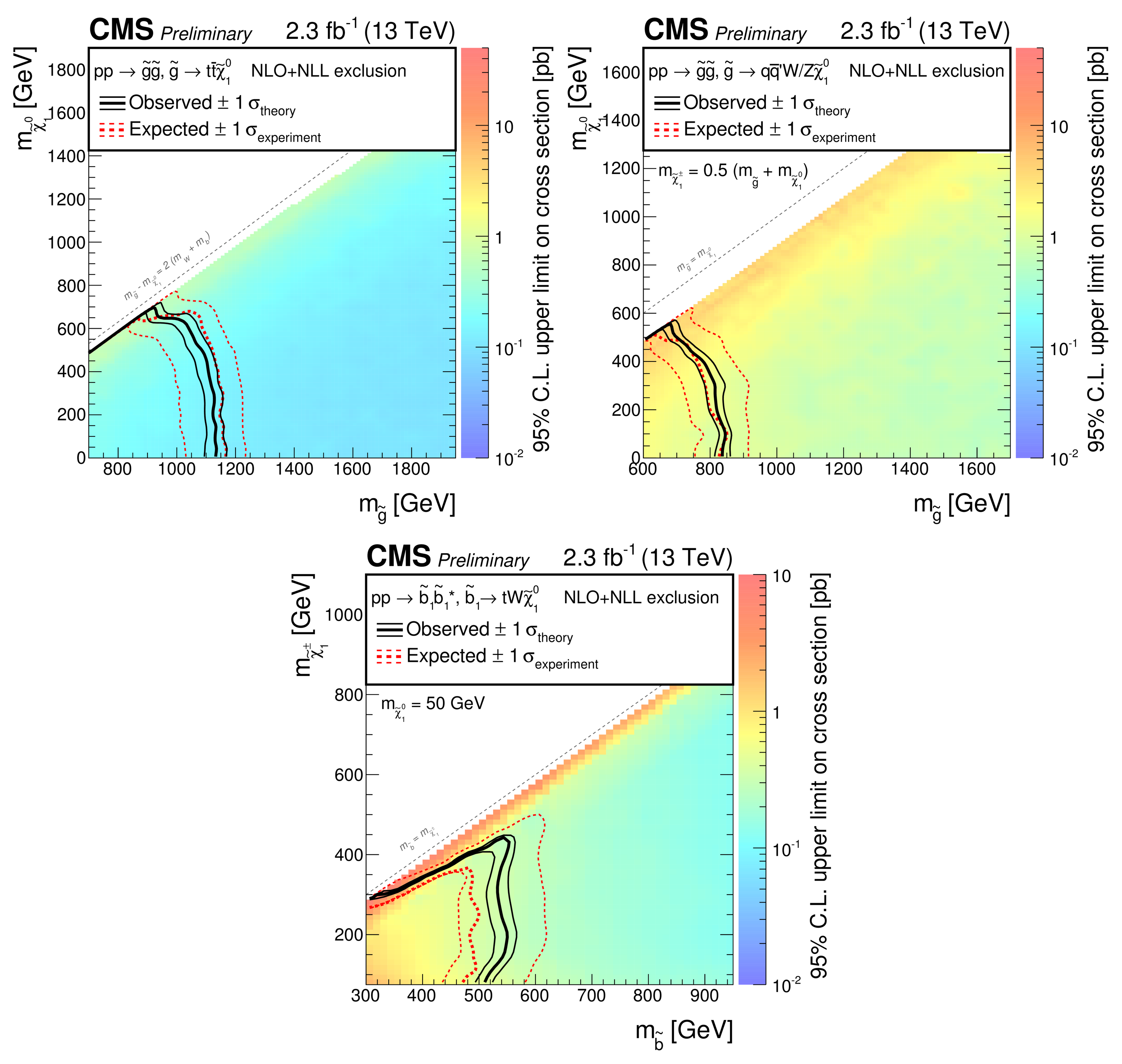


Figure 3: Excluded region at 95% confidence in the $m(\tilde{\chi}_1^0)$ versus $m(\tilde{g})$ plane for the T1tttt (top left), T5qqqqWZ (top right) and T6ttWW (bottom) simplified models. The color scale indicates the excluded cross section at a given point in the mass plane. The excluded regions are to the left and below the observed and expected limit curves.

We exclude gluinos with a mass of up to 1125 GeV, LSP mass - up to 650 GeV, bottom squarks - 550 GeV, chargino mass - 400 GeV.

References

[1] CMS PAS 16-003. Search for SUSY with multileptons in 13 TeV data . *CMS Physics Analysis Summary*, 2016.