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Search for Beyond the Standard Model Physics in final states with multiple leptons

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Abstract

Multilepton final states provide a variety of opportunities to search for beyond the standard model physics with low backgrounds. Summarized are searches with multiple leptons, with and without missing transverse energy, b-tags, or large amount of hadronic energy.

Keywords:

The search for supersymmetry is one of the main aspects of the physics programs at the LHC. The production of leptons can be a signature of the decay of supersymmetric particles for example in the case of production of third generation squarks or if the decay chain includes electroweak bosons or, in the case of R-parity violation, leptonically decaying neutralinos.

For the majority of the different search strategies summarized in the following, events are selected with a trigger selecting two light leptons (ee,eμ,$\mu\mu$) with $p_T > 17$ GeV for the leading and $p_T > 8$ GeV for the trailing lepton. In general, leptons are required to exceed a p_T of 20 GeV and pseudorapidity $|\eta| < 2.4(2.3)$ for light leptons (taus). Commonly used quantities for the separation of the potential signal from the background are the hadronic activity H_T, defined as the scalar sum of the p_T of all selected jets and the missing transverse energy (E_T^{miss}).

In the following several searches are presented that utilizes the full dataset of proton-proton collision at a center of mass energy of $\sqrt{s} = 8$ TeV collected with the CMS detector [1] at the CERN LHC, corresponding to an integrated luminosity of about 20 fb^{-1}. Searching for the pair production of gluinos, each decaying into two top quarks and the LSP, events with two opposite-sign light leptons are selected [2]. The events also are required to have $E_T^{miss} > 180$ GeV, more than four jets, of

which more than two have to be b-tagged. The two leading jets are required to be reconstructed within $|\eta| < 1$. The background from standard model (SM) processes is estimated from a data sample obtained by inverting the jet-$|\eta|$ selection by applying a transfer factor derived from events with exactly two b-tagged jets. Good agreement between observation and prediction is observed and in the framework of a Simplified Model LSP masses below 450 GeV are excluded for gluino masses below 1 TeV, as shown in Fig. 1.

While the production of opposite-sign lepton pairs is common in the SM, this is not the case for same-sign pairs, which therefore offer a high sensitivity to new physics processes. Therefore, events are selected containing two same-sign light leptons and at least two jets [3]. For events selected with a dedicated dilepton+H_T trigger, the p_T requirement is lowered to 10 GeV. Events containing a third lepton, which together with one of the same-sign pair forms a pair with an invariant mass below 12 GeV or are located within a window of ±25 GeV around the Z mass, are vetoed. The events are categorized in 24 search regions with respect to the number of jets and b-tags, H_T, and E_T^{miss}. The most abundant background consists of misidentified jets or photons or leptons originating from the decay of heavy flavor quarks inside a jet. These are estimated from data control samples. Rare SM processes
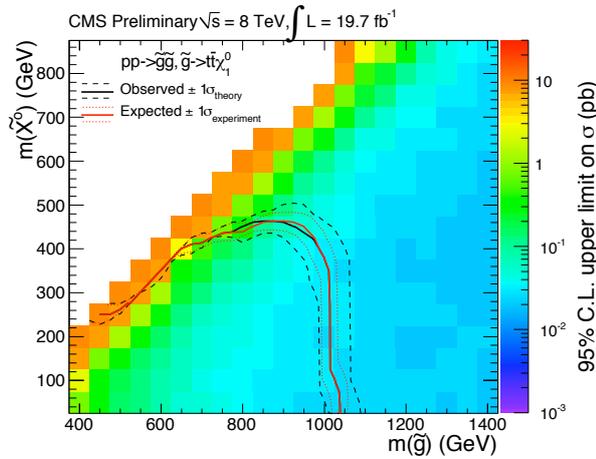
Figure 1: Exlcusion limits in the gluino-neutralino mass plane in the case of gluinos decaying into top pairs and LSP.

Figure 2: Exclusion limits in the sbottom-chargino mass plane for a model of sbottom pair production.

are estimated from simulation, while the background arising from the mismeasurement of the electron charge is estimated from data. Good agreement of the observed data with the background prediction is observed and the results are interpreted in various models. For example, for gluino induced production, gluino masses up to 1050 GeV are probed. For direct production of sbottom pairs, sbottom masses are probed up to 500 GeV, as shown in Fig. 2.

Searching for new physics in events with multiple W or Z bosons and b-jets in the final state, events are selected with three light leptons with $p_T > 10$ GeV (> 20 GeV for the leading lepton). The events are also required to have $E_T^{miss} > 50$ GeV, $H_T > 60$ GeV, at least two jets and one b-tag [4]. The events are categorized in E_T^{miss}, H_T and the numbers of jets, b-tags, and Z candidates. Backgrounds with misidentified leptons are estimated from data and those with multiple bosons or more rare processes are estimated from simulation. For WZ and ZZ production, the simulation is validated on data. No excess above expectations is observed in data. Limits are set on the mass of the gluino for wide ranges of the masses of stop, sbottom and the lightest neutralino, as for example seen in Fig. 3.

To search for supersymmetry in a variety of multilepton final states, events with three or more leptons are selected [5]. In this analysis also tau leptons are considered. Only one tau candidate per event is allowed. Light leptons, except for the first, have a relaxed requirement of $p_T > 10$ GeV. The events are categorized in the number of opposite-sign same-flavor lepton pairs, their invariant mass relative to the Z mass, two bins in H_T (above and below 200 GeV) and five
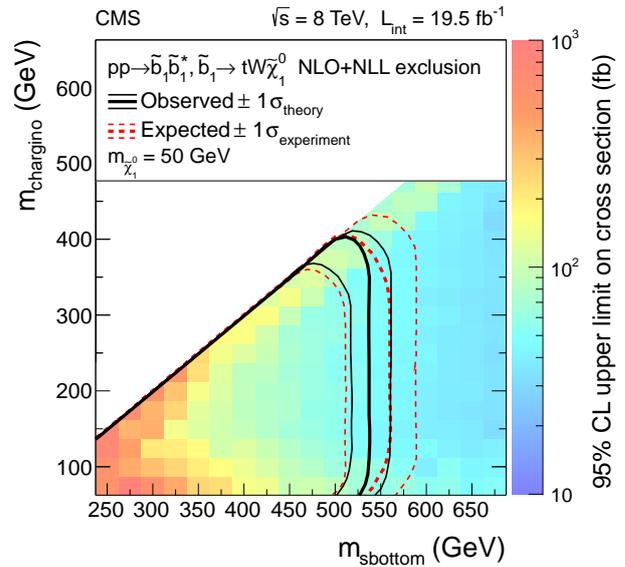
bins in E_T^{miss}. Backgrounds from the production of a Z boson or two W bosons with additional jets are estimated from a dilepton control sample in data. Jets that are misidentified as tau leptons are estimated from a data sample of non-isolated taus. Contributions from the production of WZ, ZZ and $t\bar{t}$ are estimated from simulation, which is validated on data and the background from photons converting into a pair of leptons is estimated from data. No significant excess is observed when comparing the observed data to the background prediction. The result is interpreted in a variety of signal models. Different models are considered for the nature of the next-to-lightest supersymmetric particle (NLSP), i.e. higgsino (see Fig. 4), slepton, or stau. Also considered is the production of gluino pairs, each decaying into top quarks and the LSP. The results are further used to set an upper limit of 1.3% on the branching ratio of a top quark decaying into a charm quark and a Higgs boson at 95% confidence level. A dedicated search for stop squarks in the context of R-parity violation is performed in which an important part of the signature is the decay of the LSP into leptons [6]. Events with three or more leptons, including taus, are selected. Only one tau candidate per event is allowed. Light leptons, except for the first, have a relaxed requirement of $p_T > 10$ GeV. The relevant background processes and therefore their estimation is very similar to the search for three or more leptons described above. The events are sorted into eight signal regions depending on the
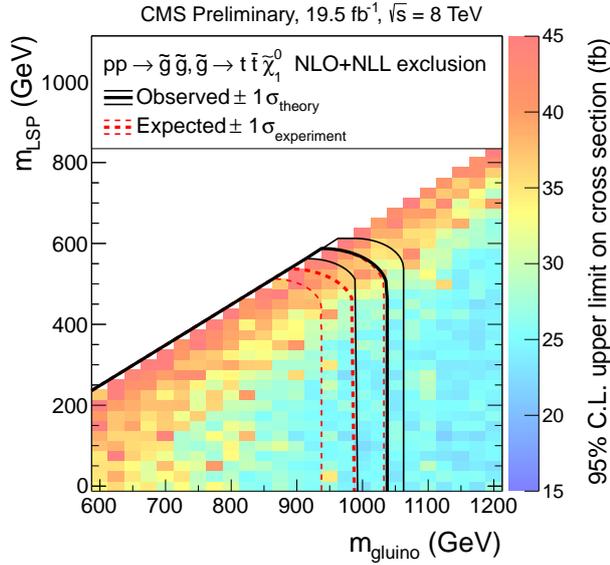
Figure 3: Exclusion limit in the gluino-neutralino mass plane for a model where pair produced gluinos decay into top pairs and the LSP.
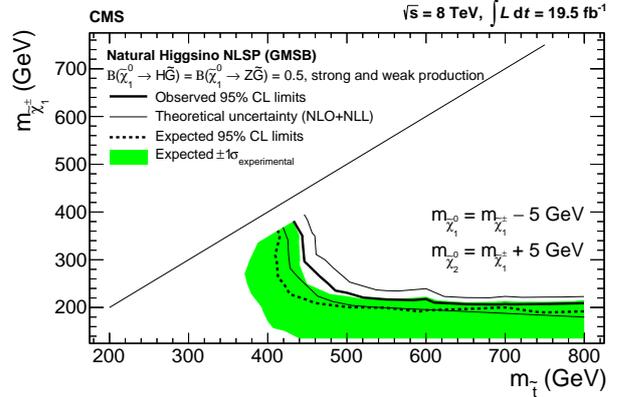

Figure 4: Exclusion limits in the stop-chargino mass plane for the case of a higgsino NLSP.
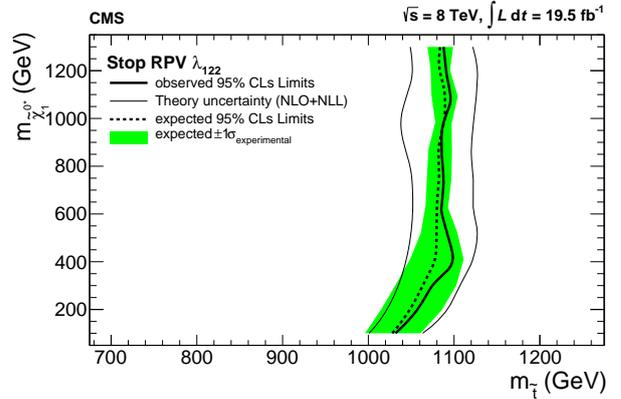

Figure 5: Exclusion limit in the stop-neutralino mass plane for the case of a non-zero λ_{122} R-parity violating coupling.

number of leptons and the presence of b-tags and electron or muon pairs with an invariant mass compatible with the Z mass. In each search region the distribution of S_T, defined as the scalar sum of E_T^{miss} and the p_T of the leptons and jets, is studied. Again there is no significant excess above expectation observed in data. The result is interpreted in a signal model which focusses on the production of right-handed stops, decaying to bino and a top quark. For the bino there are three potential decay channels; two charged leptons and one neutrino, one charged lepton and two quarks, or one neutrino and two quarks, depending on the allowed R-parity violating couplings λ and λ'. For a bino mass of 200 GeV, a limit on the stop mass of 1020(820) GeV is set at 95% confidence level for the case of non-zero $\lambda_{122}(\lambda_{233})$, as can be seen in Fig. 5. Limits are also set for the case of none-zero λ'_{233}, excluding a more complex contour in the stop-mino mass plane. To be sensitive to the R-parity violating couplings λ_{121} and λ_{122} four lepton final states are considered [7]. In the considered scenario the leptons are produced in the decay of a neutralino into two charged and one neutral lepton. Events with four isolated light leptons are selected, of which at least two must form a opposite-sign same-flavor pair. The invariant mass of a pair closest to the Z mass is called M_1 and M_2 is defined as the invariant mass of the remaining leptons. The selected events are required to have either a M_1 above the Z mass or M_2 above and M_1 below the Z mass. Background from SM processes producing four

prompt leptons are estimated from simulation while all backgrounds containing misidentified leptons are estimated from data. Again, no excess of events above the expectation from SM backgrounds is observed. The results are interpreted in a signal model where either squarks, each decaying into a quark and a neutralino, or gluinos, which decay into two quarks and a neutralino, are produced in pairs. The neutralino decays in turn via the R-parity violating coupling. For a neutralino mass higher than 400 GeV gluinos with a mass below 1.4 TeV are generally excluded. In the case of stop-quark production, squark masses below 950 GeV can be excluded. For a gluino mass of 2.4 TeV squarks with masses below 1.6 TeV are exluded. General limits on the SUSY cross-section are set, depending on the LSP mass.
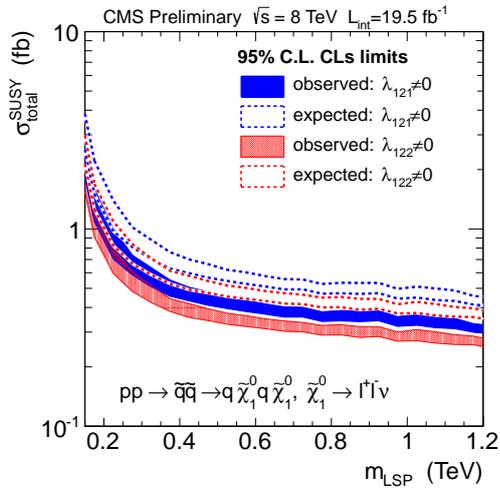
Figure 6: Upper cross section limits on the SUSY cross section as a function of LSP mass in the case of squark pair production and non-zero RPV-couplings λ_{121} or λ_{122}.

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