Using the $l^+l^- + E_T^{miss} + \text{jet veto}$ signature for slepton detection

Yu. Andreev, S. Bityukov, N. Krasnikov and A. Toropin

Institute for Nuclear Research RAS,
Moscow, 117312, Russia

Abstract

A possibility to detect slepton production at the LHC is studied. The LM1 test point is studied with a full simulation of the CMS detector. It is found that for this benchmark it would be possible to detect sleptons for a total luminosity $\mathcal{L} = 10 \, fb^{-1}$ with significance $S > 5$. The slepton discovery potential is determined within the mSUGRA model with $\tan \beta = 10$, $sign(\mu) = +$ in the $(m_0, m_{1/2})$ plane.
1 Introduction

One of the main goals of the Large Hadron Collider (LHC) [1], [2] is the discovery of supersymmetry [3]. In particular, it is very important to investigate the possibility to discover nonstrongly interacting superparticles (sleptons, higgsino, gaugino). In Refs.[4],[5] the slepton discovery potential was investigated for direct slepton production via Drell-Yan mechanism and a “generic” LHC detector. In Ref.[6] the LHC slepton discovery potential was investigated within the minimal supersymmetric model (MSSM) in the minimal supergravity (mSUGRA) scenario (tan β = 2 case) for the Compact Muon Solenoid (CMS) detector. In Refs.[7],[8] the CMS slepton discovery potential and the possibility to discover lepton number violation in slepton decays were investigated for direct production of right and left sleptons within the MSSM model for different scenarios.

In the MSSM model supersymmetry is broken at some high scale \( M \) by generic soft terms so in general all soft SUSY breaking terms are arbitrary which complicates the analysis and spoils the predictive power of the theory. In the mSUGRA model [9] the universality of different soft parameters at Grand Unified Theory (GUT) scale \( M_{\text{GUT}} \approx 2 \cdot 10^{16} \text{ GeV} \) is postulated. Namely, all the spin zero particle masses (squarks, sleptons, higgses) are postulated to be equal to the universal value \( m_0 \) at the GUT scale. All gaugino particle masses are postulated to be equal to the universal value \( m_{1/2} \) at GUT scale. Also the coefficients in front of SUSY soft breaking terms are postulated to be equal. The renormalization group equations are then used to relate GUT and electroweak scales. The equations for the determination of nontrivial minimum of the electroweak potential are used to decrease the number of unknown parameters. Thus mSUGRA model depends on five unknown parameters. At present the standard choice of free parameters in mSUGRA model includes \( m_0, m_{1/2}, \tan \beta, A \) and \( \text{sign}(\mu) \) [9]. All sparticle masses depend on these parameters. For instance, the slepton masses of the first two generations are determined by the formulae [9]

\[
\begin{align*}
    m_{\tilde{\tau}_L}^2 &= m_0^2 - 0.15 m_{1/2}^2 - \sin^2 \theta_W M_Z^2 \cos 2 \beta, \\
    m_{\tilde{\tau}_R}^2 &= m_0^2 - 1/2 (1 - 2 \sin^2 \theta_W) M_Z^2 \cos 2 \beta, \\
    m_{\tilde{\mu}}^2 &= m_0^2 + 0.52 m_{1/2}^2 + 1/2 \cos^2 \theta_W M_Z^2 \cos 2 \beta.
\end{align*}
\]

Charged left sleptons are the heavier sleptons whereas the right sleptons are the lighter sleptons. For gaugino masses the following approximate formulae are valid:

\[
\begin{align*}
    M_{\tilde{\chi}_1^\pm} &\approx 0.45 m_{1/2}, \\
    M_{\tilde{\chi}_2^0} &\approx M_{\tilde{\chi}_1^\pm} \approx 2 M_{\tilde{\chi}_1^\pm}, \\
    M_{\tilde{\chi}_1^0} &\approx (0.25 - 0.35) M_{\tilde{\chi}_1^\pm}.
\end{align*}
\]

In the mSUGRA model the \( \tilde{\chi}_1^0 \) gaugino is the lightest stable superparticle (LSP).

The possibility to discover sleptons using the \( l^+ l^- + E_T^{\text{miss}} + \text{jet veto} \) signature (here \( l^+ l^- \) means \( e^+ e^- + \mu^+ \mu^- \)) at the level of full detector simulation is investigated in this paper. The Drell-Yan slepton production \( pp \rightarrow \tilde{\chi}_1 \tilde{\chi}_1 \) and direct gaugino production \( pp \rightarrow \tilde{\chi}_2 \tilde{\chi}_1 \) (\( MSEL = 42 \) in PYTHIA [10]) and direct gaugino production \( pp \rightarrow \tilde{\chi}_2 \tilde{\chi}_1 \) (\( MSEL = 44 \)) with subsequent decays of sleptons and charginos into leptons which leads to the signature \( l^+ l^- + E_T^{\text{miss}} + \text{jet veto} \) are studied as a signal.

The organization of the paper is the following. In Section 2 some important simulation details of the calculations performed are described. Section 3 is devoted to the description of the slepton production mechanisms and slepton decays. In Section 4 the backgrounds and cuts used to suppress the backgrounds are discussed. Section 5 describes the results of simulations. In Section 6 the influence of the systematic uncertainties on the value of signal significance is discussed. Section 7 contains concluding remarks.

2 Simulation details

The coupling constants and cross sections in the leading order (LO) approximation for SUSY processes and backgrounds were calculated with ISASUGRA 7.69 [11], PYTHIA 6.227 [10] and CompHEP 4.2pl [12]. For the calculation of the next-to-leading order (NLO) corrections to the SUSY cross sections the PROSPINO [13] code was used. For considered signal events and backgrounds the NLO corrections are known and the values of NLO cross sections (or \( k \)-factors) were used for normalization of the numerical results.
Official datasets (DST) production was used for the study of CMS SUSY test point LM1 [14] and of backgrounds tt, ZZ, WW, Wt, Zb$b$, DY2e, DY2$\tau$. The ISASUGRA 7.69 + PYTHIA 6.225 codes were used in official production. The full detector simulation was made with OSCAR$_{2.6.5}$ or OSCAR$_{3.6.0}$ codes [15]. Digitization was made with ORCA$_{7.6.1}$, ORCA$_{8.5.0}$ or ORCA$_{8.7.1}$ codes [15].

For the sleptons study, WZ, DY2$\mu$ and W+jet backgrounds the events were generated with ISASUGRA 7.69 + PYTHIA 6.227 codes and CMKIN$_{4.4.1}$ [15] was used as an interface program. The detector simulation and hits production for the sleptons study and WZ background were made with OSCAR$_{3.6.5}$ and for digitization ORCA$_{8.7.3}$ was used. To study the DY2$\mu$, W+jet backgrounds and to prepare the CMS discovery plot, the CMS fast simulation program FAMOS$_{1.3.1}$ [15] was used.

The pile-up for the signal events are not taken into account, but backgrounds in DSTs were produced with pile-up luminosity.

The reconstructed electrons and muons were passed through packages defining lepton isolation criteria. For each electron and muon the following parameters are defined:

- **TrackIsolation** is a number of additional tracks with $p_T > 2$ GeV/c inside a cone with $R \equiv \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.3$ around the lepton.

- **CaloIsolation** is a ratio of energy deposited in the calorimeters (electromagnetic (ECAL) + hadronic (HCAL)) inside a cone with $R = 0.13$ around the lepton to the energy deposited inside a cone with $R = 0.3$.

- **HERatio** is defined as a ratio of energy deposited in the HCAL inside a cone with $R = 0.13$ to the energy deposited in the ECAL inside the same cone.

- **EPRatio** is a ratio of energy deposited in the ECAL inside a cone with $R = 0.13$ to the momentum of the reconstructed track.

Data with reconstructed electrons, muons, jets and missing energy were stored into ROOT [16] files for the final analysis.

The official datasets used for these analysis were processed with CRAB [17].

### 3 Sleptons production and decays

When sleptons are heavy relative to $\tilde{\chi}^0_1$, sleptons are produced significantly at the LHC through the Drell-Yan mechanism (direct slepton production), via $q\bar{q}$ annihilation with neutral or charged boson exchange in the s-channel (Fig.1), namely, $pp \rightarrow \tilde{l}_L\tilde{l}_L, \tilde{l}_R\tilde{\nu}_R, \tilde{\nu}_L\tilde{l}_L, \tilde{l}_R\tilde{l}_R$. Note that the $\tilde{l}_L\tilde{l}_L$ production for $\tilde{l} = \tilde{e}, \tilde{\mu}$ is much smaller than $\tilde{l}_L\tilde{l}_L$ and $\tilde{l}_R\tilde{l}_R$ productions due to small mixing for the first and second slepton generations whereas for the third generation $\tilde{\tau}_L \tilde{\tau}_R$ mixing is not small. The left sleptons decay to charginos and neutralinos via the following (kinematically accessible) decays:

$$\tilde{l}_L^\pm \rightarrow l^\pm + \tilde{\chi}^0_1, \tilde{\chi}^\pm_1, \tilde{\chi}^0_{1,2} \tag{7}$$

$$\tilde{l}_L^0 \rightarrow \nu_l + \tilde{\chi}^\pm_1 \tag{8}$$

$$\tilde{\nu} \rightarrow \nu_l + \tilde{\chi}^0_1 \tag{9}$$

$$\tilde{\nu} \rightarrow l^\pm + \tilde{\chi}^\mp_1 \tag{10}$$

For right sleptons only decays to neutralino are possible and they decay mainly to LSP:

$$\tilde{l}_R^0 \rightarrow l^\pm + \tilde{\chi}^0_1 \tag{11}$$

Slepton production $pp \rightarrow \tilde{l}_L\tilde{l}_L, \tilde{l}_R\tilde{\nu}_R, \tilde{\nu}_L\tilde{l}_L, \tilde{l}_R\tilde{l}_R$ can therefore be divided into four parts of kinematically accessible decays (here $\tilde{\tau}_1$ and $\tilde{\tau}_2$ are the mixtures of $\tilde{\tau}_L$ and $\tilde{\tau}_R$):

$$pp \rightarrow \tilde{e}_L\tilde{e}_L, \tilde{\mu}_L\tilde{\mu}_L \tag{12}$$

$$pp \rightarrow \tilde{e}_R\tilde{e}_R, \tilde{\mu}_R\tilde{\mu}_R \tag{13}$$

$$pp \rightarrow \tilde{\tau}_1\tilde{\tau}_1, \tilde{\tau}_2\tilde{\tau}_2 \tag{14}$$
In the case of the point LM1 reactions (14) and (15) do not contribute significantly into $l^+l^- + E_T^{miss} + jet$ veto signature due to suppression factor $0.5 \times Br^2(\tau \to l\nu)$ arising due to the decay chain $\tilde{\tau}_R \tilde{\tau}_R \rightarrow l^+l^-\nu\bar{\nu} \chi_{i1}^0 \chi_{i1}^0$, for case (14) and for the case (15) due to the fact that sneutrino decays mainly into neutrino and $\tilde{\chi}_1^0\rightarrow l\nu$. $Br(\tilde{\nu} \rightarrow \nu \chi_1^0) \approx 100\%$. Moreover it is found that for the point LM1 the contribution of \( pp \to \tilde{\nu}_L e_L, \tilde{\mu}_L \tilde{\mu}_L \) dominates and it gives approximately 90\% of signal events for \( l^+l^- + E_T^{miss} + jet \) veto signature (Section 5).

If sleptons are light relative to $\tilde{\chi}_1^+ \tilde{\chi}_2^0$, sleptons can also be abundantly produced from chargino and neutralino decays $\tilde{\chi}_1^+ \tilde{\chi}_2^0$ (indirect production, Fig.2), namely:

\[
\tilde{\chi}_1^0 \rightarrow \tilde{\tau}_{LR}^\pm \nu_L, \quad \tilde{\chi}_2^0 \rightarrow \nu_L \nu_L, \quad \tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_{LR}^\pm \nu, \quad \tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_{LR}^\pm \nu L, \quad \tilde{\chi}_1^0 \rightarrow \tilde{\tau}_{LR}^0 \nu L. 
\]

The first three processes have the highest cross sections and give the main contribution into the number of signal events. For the point LM1 the decays (16) - (19) into sleptons dominate and direct decays into leptons like $\tilde{\chi}_1^+ \rightarrow \chi_1^0 W^+ \rightarrow \tilde{l}_1 l^+\nu$ are small with $Br(\tilde{\chi}_1^+ \rightarrow \chi_1^0 W^+) \approx 6.6 \times 10^{-3}$ and $Br(\tilde{\chi}_2^0 \rightarrow \chi_1^0 e^+e^- , \chi_1^0 \mu^+\mu^- ) \approx 4.5 \times 10^{-4}$.

As it has been mentioned before, particle masses in mSUGRA model depend on five unknown parameters $m_0$, $m_{1/2}$, $\tan \beta$, $A$ and $\text{sign}(\mu)$ which complicates the numerical analysis of the LHC SUSY discovery potential. In this paper the point LM1 which coincides with the post-WMAP point B [18] is studied. For the point LM1 $m_0 = 60\text{ GeV}, m_{1/2} = 250\text{ GeV}, \tan \beta = 10, A = 0$ and $\text{sign}(\mu) = +$. For the point LM1 the masses of sleptons, $\chi_1^0$ and $\chi_2^0$ are given in Table 1.

Table 1: The sleptons and gaugino masses for the point LM1 (in GeV).

<table>
<thead>
<tr>
<th>Particle</th>
<th>$\tilde{\chi}_1^0$</th>
<th>$\tilde{\chi}_2^0$</th>
<th>$\tilde{e}_L, \tilde{\mu}_L$</th>
<th>$\tilde{e}_R, \tilde{\mu}_R$</th>
<th>$\tilde{\nu}<em>e, \tilde{\nu}</em>\mu$</th>
<th>$\tilde{\nu}_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>95</td>
<td>180</td>
<td>189</td>
<td>119</td>
<td>168</td>
<td>111</td>
</tr>
</tbody>
</table>

The most interesting neutralino and slepton branchings are the following:

$Br(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R l) = 11.2\%$, $Br(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau) = 46\%$, $Br(\tilde{\chi}_1^+ \rightarrow \tilde{\nu}_l l) = 36\%$, $Br(\tilde{\nu}_e \rightarrow \chi_1^0 e) = 85\%$, $Br(\tilde{\mu}_L \rightarrow \chi_1^0 \mu) = 85\%$, $Br(\tilde{e}_R \rightarrow \chi_1^0 e) \approx 100\%$, $Br(\tilde{\mu}_R \rightarrow \chi_1^0 \mu) \approx 100\%$, $Br(\tilde{\tau}_1 \rightarrow \chi_1^0 \tau) \approx 100\%$, $Br(\tilde{\tau}_2 \rightarrow \chi_1^0 \tau) \approx 82\%$.

4 Signal selection and backgrounds

The slepton production and decays described in the previous section lead to the signature with the simplest event topology: \textit{two leptons} + $E_T^{miss}$ + \textit{jet veto}. This signature arises for both produced direct and also indirect slepton pair production from Drell-Yan and chargino/neutralino processes. In the case of indirectly produced sleptons not only event topology with two leptons but also with single, three and four leptons are possible. Indirect slepton production from decays of squarks and gluino through charginos, neutralinos also leads predominantly to event topology \textit{two leptons} + $E_T^{miss}$ + \textit{jets veto}.

In this paper the possibility to use the event topology \textit{two leptons} + $E_T^{miss}$ + \textit{jets veto} (here two leptons mean $e^+e^-$ or $\mu^+\mu^-$) for sleptons detection is studied.
The events are required to pass the Global Level 1 Trigger (L1) [19] and the High Level Trigger (HLT) [20]. The events have to pass at least one of the following triggers: single electron, double electron, single muon, or double muon. The used cut on leptons is more stringent than the cuts used in the HLT for these triggers.

In the final analysis the events with the following isolation criteria for electrons were used: $\text{TrackIsolation} < 1.0$, $\text{CaloIsolation} > 0.85$, $0.85 < E_{\text{Pratio}} < 2.0$, $H_{\text{Eratio}} < 0.25$. The same criteria for muons were the following: $\text{TrackIsolation} < 1.0$, $\text{CaloIsolation} > 0.50$, $E_{\text{Pratio}} < 0.20$, $H_{\text{Eratio}} > 0.70$. These numbers were adjusted by studying electron and muon tracks in the process $pp \to WW \to 2l$.

The set of cuts used for this study is the following:

a. for leptons:

- $p_T$ - cut on leptons ($p_T^{\text{lep}} > p_T^{\text{thresh}}$, $| \eta | < 2.4$) and lepton isolation within $R < 0.3$ cone containing calorimeter cells and tracker;
- cut on effective mass of two same-flavour-opposite-sign leptons;
- cut on angle between two leptons $\Phi(l,l) < \Phi_0^{\text{thresh}}$;

b. for $E_T^{\text{miss}}$:

- $E_T^{\text{miss}} > E_T^{\text{thresh}}$ cut on missing transverse energy;
- $\Phi(E_T^{\text{miss}},ll) > \Phi_0^{\text{thresh}}$ cut on relative azimuthal angle between dilepton and $E_T^{\text{miss}}$;

c. for jets:

- jet veto cut: $N_{jet} = 0$ for a $E_T^{\text{jet}} > 30$ GeV threshold (corrected jets), in the pseudorapidity interval $| \eta | < 4.5$.

The main Standard Model (SM) backgrounds are: $t\bar{t}$, WW, WZ, ZZ, Wt, Zb$b$, DY2e, DY2$\mu$, DY2$\tau$, W+jet. The following values for NLO SM background cross sections [21] were used, Table 2.

<table>
<thead>
<tr>
<th>Process</th>
<th>$\sigma_{LO}$</th>
<th>$\sigma_{NLO}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>tt</td>
<td>505</td>
<td>830</td>
</tr>
<tr>
<td>WW</td>
<td>70</td>
<td>117</td>
</tr>
<tr>
<td>WZ</td>
<td>27</td>
<td>50</td>
</tr>
<tr>
<td>ZZ</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Wt</td>
<td>30</td>
<td>62</td>
</tr>
<tr>
<td>Zb$b$</td>
<td>790</td>
<td>1580</td>
</tr>
<tr>
<td>DY2$e$</td>
<td>39600</td>
<td></td>
</tr>
<tr>
<td>DY2$\mu$</td>
<td>39600</td>
<td></td>
</tr>
<tr>
<td>DY2$\tau$</td>
<td>39600</td>
<td></td>
</tr>
<tr>
<td>W+jet</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>ckin(3) = 150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The distributions of the background, SUSY signal samples ($MSEL = 39$ in PYTHIA) and slepton signal ($MSEL = 42$ and $MSEL = 44$) on $p_T^{\text{lep}}$, $E_T^{\text{jet}}$, $E_T^{\text{miss}}$, $\Phi(E_T^{\text{miss}},ll)$ and $\Phi(l,l)$ are shown in Figs.3-10. The main contributions come from WW and $t\bar{t}$ backgrounds. There are also internal SUSY backgrounds which arise through $q\bar{q}$, $gg$ and $q\bar{q}$ productions and subsequent squarks and gluino cascade decays into leptons and jets with jets outside acceptance or below threshold. In the case of new physics discovery (the first stage of any data analysis) the calculated number of SM background events $N_{5Mbg}$ and new physics signal events $N_{\text{new physics}} = N_{\text{decpt}} + N_{\text{SUSY bg}}$ have to be compared, so SUSY background events increase the discovery potential of SUSY in the specific case. Note that the jet veto cut allows to suppress the $t\bar{t}$, Wt, Zb$b$, internal SUSY backgrounds from $q\bar{q}$ decays largely. $\Phi(E_T^{\text{miss}},ll)$ cut also helps to suppress $t\bar{t}$, Wt, Zb$b$ and internal
SUSY background and to select Drell-Yan slepton production. Cut on the effective mass of two same-flavour-opposite-sign leptons serves to suppress WZ and ZZ backgrounds. $p_T$ cut on isolated leptons is used mainly to choose events which pass the HLT lepton trigger.

An optimal set of cuts (set #1) was found, after optimization, and required: two isolated same-flavour-opposite-sign leptons with $p_T^{lep} > 20$ GeV/c, no jets in $|\eta| < 4.5$ with $E_T^{jet} > 30$ GeV (jet veto), $\Phi(E_T^{miss}, l^+l^-) > 170^\circ$, $E_T^{miss} > 135$ GeV and $\Phi(l,l) < 140^\circ$ are required. Besides the dilepton invariant mass is required to be outside the $(M_Z - 15$ GeV,$M_Z + 10$ GeV) interval.

## 5 Results

The results for the cut set #1 for the point LM1 for the integral luminosity $\mathcal{L} = 10$ $fb^{-1}$ are presented in Table 3. Namely for cut set #1 the numbers of signal events (direct sleptons plus chargino/neutralino) for cut sets #1 is $N_S = 60$. In the case of new physics discovery the number of signal events is $N_S = N_{direct\ sleptons} + N_{chargino/neutralino} + N_{SUSYbg} = N_{inductive\ SUSY} = 64$ and the significances $S_{c12} = 7.7$ and $S_{cL} = 8.3$. Here $S_{c12} = 2(\sqrt{N_S + N_B - \sqrt{N_B}})$ [22] and $S_{cL} = \sqrt{2((N_S + N_B)ln(1 + \frac{N_S}{N_B}) - N_S)}$ [23].

Because the goal of this study is to check a possibility of the sleptons detection the knowledge of the sparticles spectrum has to be assumed. In the case of the sleptons detection the SUSY background $N_B = N_{SMbg} + N_{SUSYbg} = 45$ has to be taken into account. The number of signal events in this case is $N_S = N_{direct\ sleptons} + N_{chargino/neutralino} = 60$. For the point LM1 the use of the signature two leptons + $E_T^{miss} + jet\ veto$ allows to detect signal production (direct slepton production + slepton production in chargino/neutralino decays) for $\mathcal{L} = 10$ $fb^{-1}$ for cut set #1 with significances $S_{c12} = 7.1$ and $S_{cL} = 7.6$ ($N_S/N_B = 60/45$). So taking into account SUSY background decreases the significances of the observability of the direct production of sleptons or via direct chargino/neutralino production.

The distributions on $p_T^{lep}$ and $M_{inv}(l^+l^-)$ after selected cuts in the case of inclusive SUSY production are presented in Figs.11,12.

<table>
<thead>
<tr>
<th>Process</th>
<th>$2 isolated\ leptons$</th>
<th>$M_{inv}(l^+l^-)$</th>
<th>jet veto</th>
<th>$\Phi(l,l) &gt; 140^\circ$</th>
<th>$\Phi(E_T^{miss}, l^+) &gt; 170^\circ$</th>
<th>$E_T^{miss} &gt; 135$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>41232</td>
<td>33870</td>
<td>2566</td>
<td>1378</td>
<td>322</td>
<td>11</td>
</tr>
<tr>
<td>WW</td>
<td>4598</td>
<td>3733</td>
<td>2796</td>
<td>1271</td>
<td>714</td>
<td>16</td>
</tr>
<tr>
<td>WZ</td>
<td>1954</td>
<td>396</td>
<td>242</td>
<td>138</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>ZZ</td>
<td>1032</td>
<td>131</td>
<td>74</td>
<td>41</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>Wt</td>
<td>3991</td>
<td>3347</td>
<td>745</td>
<td>417</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>Zbb</td>
<td>26572/22</td>
<td>114382</td>
<td>53515</td>
<td>5609</td>
<td>1175</td>
<td>0</td>
</tr>
<tr>
<td>DY (2\ e+ 2\ \mu + 2\ \tau)</td>
<td>7090802</td>
<td>690667</td>
<td>500146</td>
<td>38056</td>
<td>11287</td>
<td>0</td>
</tr>
<tr>
<td>W+$jet$</td>
<td>126</td>
<td>118</td>
<td>42</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>total SM bg</td>
<td>7409457</td>
<td>846664</td>
<td>561926</td>
<td>46918</td>
<td>13563</td>
<td>41</td>
</tr>
<tr>
<td>SUSY bg</td>
<td>5623</td>
<td>4818</td>
<td>452</td>
<td>384</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>direct sleptons</td>
<td>414</td>
<td>338</td>
<td>233</td>
<td>86</td>
<td>63</td>
<td>31</td>
</tr>
<tr>
<td>direct chargino/neutralino</td>
<td>327</td>
<td>286</td>
<td>170</td>
<td>143</td>
<td>94</td>
<td>29</td>
</tr>
<tr>
<td>inclusive SUSY</td>
<td>6364</td>
<td>5442</td>
<td>855</td>
<td>613</td>
<td>170</td>
<td>64</td>
</tr>
</tbody>
</table>

It has to be emphasized again that in this paper the direct production of sleptons ($MSEL = 42$ in PYTHIA) and direct production of gauginos ($MSEL = 44$ in PYTHIA) with subsequent decays into sleptons which lead to the signature $l^+l^- + E_T^{miss} + jet\ veto$ are studied. Both the SM background ($t\bar{t}, WW, WZ, Wt, \ldots$) and the SUSY background ($pp \rightarrow q\bar{q}, g\bar{g}, gg \rightarrow l^+l^-\ldots$) are considered. It was found that for the point LM1 with the chosen cuts 90% of slepton contribution into signal events comes from the production of the first and the second charged slepton generations $pp \rightarrow e\ell\ell_L, \mu\mu\mu_L$.

It was found that for the gaugino production the main contribution is due to $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production with subsequent
decays into sleptons.

If a cut set #2 is defined, namely, two isolated same-flavour-opposite-sign leptons with $p_T^{lep} > 20$ GeV/c, no jets in $|\eta| < 4.5$ with $E_T^{jet} > 30$ GeV (jet veto), $\Phi(E_T^{miss}, l^+l^-) > 170^\circ$, invariant mass $M_{pro}(l^+l^-) > M_Z + 10$ GeV, $E_T^{miss} > 150$ GeV and $\Phi(l,l) < 170^\circ$ are required, it is found that direct slepton production (42 process) dominates, namely, $N_B(SM) = 24$, $N_S(44) = 0$, $N_S(42) = 20$, $N_{SUSYh_g} = 4$. For these values of signal and background events the significances are $S_{c12} = 3.5$, $S_{cL} = 3.7$. For the total luminosity $L = 30$ fb$^{-1}$ the significances are $S_{c12} = 6.1$, $S_{cL} = 6.4$. It indicates a possibility to detect the direct sleptons.

The slepton potential discovery for mSUGRA model with $\tan \beta = 10$, sign($\mu$) = + in $(m_0, m_{1/2})$ plane for the luminosities $L = 10$, 30, and 60 fb$^{-1}$ was also studied. Fast simulation code FAMOS+1-3-1 was used for the determination of slepton discovery plot. The results are presented in Fig.13.

6 Influence of the systematic uncertainties on the signal significance

In this Section the influence of systematic uncertainties on the value of signal significance is estimated. The systematic uncertainties in the signal significance calculation include the experimental selection uncertainty of the background events, luminosity uncertainty, and the theoretically calculated uncertainties of the $t\bar{t}$, WW and other backgrounds. Theoretically calculated uncertainty in background cross sections consists of the uncertainty related with inexact knowledge of parton distribution functions (PDF) and higher order corrections to the NLO cross sections [24]. There are several experimental uncertainties related with lepton identification, jet energy scale, missing energy and luminosity.

In accordance with Ref.[25] the systematic error related with the lepton identification is 3%, the systematic error related with the missing energy is 2% [26], the systematic error related with the jet energy scale is 3% [27]. The systematic uncertainty in the luminosity is 5% [28]. The total 5% uncertainty in luminosity leads to 5% uncertainty in the number of background events.

In this study the $t\bar{t}$ and the WW backgrounds dominate. The PDF uncertainty of $t\bar{t}$ cross section is equal to 5% and the uncertainty due to unknown higher order corrections to the NLO background cross sections is equal to 10%.

If only variations in the numbers of background events are taken into account, it was found that uncertainties related with missing energy, jet energy scale and lepton identification lead to 17%, 7% and 5% uncertainties in the number of background events. In the assumption that the systematic uncertainties are added quadratically it was found that the overall uncertainty in the number of background events is about 23%. Following the prescriptions of the CMS PRS group the influence of the systematic uncertainties on signal significance was calculated with the program for calculations of significance $S_{c\Phi}$ from Ref.[29]. The significance $S_{c12}$ degrades from 7.7 to 4.3.

In the study of the sleptons detection the pairs of leptons with the same flavour and opposite signs are used. Another channel, namely, the pairs of leptons with different flavour and opposite signs can be used to control the level of background. The efficiencies of reconstruction and selection of electrons and muons are different due to the different behavior of these particles in CMS detectors and because of the different detectors used for their reconstruction. In this study for $t\bar{t}$ and WW backgrounds (the dominant backgrounds) a ratio of the numbers of background events is $k = N(e^+e^- + \mu^+\mu^-)/N(e^+\mu^-) = 1.37$ for the events passed the cut set #1. After selection of two isolated leptons (after the first cut in the cut set) the ratios of $e^-/\mu^-$ and $e^+/\mu^+$ are the following: $N(e^-)/N(\mu^-) = 1.46$, $N(e^+)/N(\mu^+) = 1.41$.

7 Conclusion

In this note a study of the discovery potential for direct Drell-Yan sleptons and sleptons from chargino/neutralino decays into the same flavour leptons decay channel with the CMS detector has been performed. The CMS test point LM1 was studied at the full simulation level. The event selection using two isolated leptons + $E_T^{miss}$ + jet veto removes most of the SM background. It was found that for the point LM1 it is possible to detect the presence of sleptons with a total luminosity $L = 10$ fb$^{-1}$. Slepont discovery potential for the mSUGRA model with $\tan \beta = 10$, sign($\mu$) = + in the $(m_0, m_{1/2})$ plane was also determined.

8 Acknowledgments

The authors would like to thank D.Denegri and L.Rurua for careful reading of the manuscript, useful discussions and suggestions concerning the note.
The authors also would like to express their thanks to L.Pape and M.Spiropulu for interest and very useful comments.
The authors would like to thank S.Slabospitsky for useful discussions.

This work has been supported by RFFI grant No 04-02-16020.
Figure 1: Examples of direct Drell-Yan slepton pair production at LHC.

Figure 2: Examples of indirect slepton production through chargino and neutralino decays.
Figure 3: SM background distribution on $p_T^{lep}$ (left) and $E_T^{jets}$ (right) after selection of two isolated leptons. Both leptons from selected pair are presented on the left plot. DY and W+jet backgrounds are not added.

Figure 4: SM background distribution on $E_T^{miss}$ (left) and $\Phi(E_T^{miss}, p_T^{lep})$ (right) after selection of two isolated leptons. Both leptons from selected pair are presented on the left plot. DY and W+jet backgrounds are not added.
Figure 5: SM background distribution on angle between two leptons $\Phi(l, l)$ after selection of two isolated leptons (without DY and W+jet).

Figure 6: LM1 point slepton signal distribution (left, MSEL = 42 and MSEL = 44 processes in PYTHIA) and SUSY signal distribution (right, MSEL = 39 process in PYTHIA) on $p_T^{lept}$ after selection of two isolated leptons. Both leptons from selected pair are plotted.
Figure 7: LM1 point slepton signal distribution (left, MSEL = 42 and MSEL = 44 processes in PYTHIA) and SUSY signal distribution (right, MSEL = 39 process in PYTHIA) on $E_T^{jets}$ after selection of two isolated leptons.

Figure 8: LM1 point slepton signal distribution (left, MSEL = 42 and MSEL = 44 processes in PYTHIA) and SUSY signal distribution (right, MSEL = 39 process in PYTHIA) on $E_T^{miss}$ after selection of two isolated leptons. Both leptons from selected pair are plotted.
Figure 9: LM1 point slepton signal distribution (left, MSEL = 42 and MSEL = 44 processes in PYTHIA) and SUSY signal distribution (right, MSEL = 39 process in PYTHIA) on $\Phi(E_T^{miss}, p_{T}^{(l, l)})$ after selection of two isolated leptons.

Figure 10: LM1 point slepton signal distribution (left, MSEL = 42 and MSEL = 44 processes in PYTHIA) and SUSY signal distribution (right, MSEL = 39 process in PYTHIA) on $\Phi(l, l)$ after selection of two isolated leptons.
Figure 11: LM1 point inclusive SUSY signal and SM background distributions on $p_T^{\text{lep}}$ after cuts.

Figure 12: LM1 point inclusive SUSY signal and SM background distributions on $M_{\text{inv}} (l^+l^-)$ after cuts.
Figure 13: Discovery potential plot for $\tan \beta = 10$, $\text{sign}(\mu) = +$, $A = 0$. Calculations are made for $S_{c12}$ and cut set #1.

References


[2] As a recent review, see:

[3] Y.A.Golfand and E.P.Likhtman, JETP Lett.13(1971)323;
D.V.Volkov and V.P.Akulov, JETP Lett.16(1972)438;


[9] Reviews and original references can be found in:
H.E.Haber and G.L.Kane, Phys. Rep. 117 (1985) 75;

    http://www.thep.lu.se/~torbjorn/Pythia.html


[27] J.D’Hondt et al., Light quark jet energy scale calibration using the W mass constraint in single-leptonic t$t\bar{t}$ events, CMS Note 2006/025.


[29] S.Bityukov et al., http://cmsdoc.cern.ch/~bityukov/