Gaugino pair production at LHC (CMS)

S.I. Bityukov\textsuperscript{1}, N.V. Krasnikov

\textit{Institute for Nuclear Research RAS,}
\textit{Moscow, 117312, Russia}

Abstract

We investigate $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production at LHC (CMS) with subsequent decays into leptons for the case of nonuniversal gaugino masses. Visibility of signal by an excess over SM background in $3l + no\ jets + E_T^{miss}$ events depends rather strongly on the relation between LSP mass $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ mass.

1 Introduction

One of the LHC goals is the discovery of the supersymmetry. In particular, it is very important to investigate a possibility to discover nonstrongly interacting superparticles (sleptons, higgsino, gaugino). In ref.\cite{1} (see, also references \cite{2,3}) the LHC gaugino discovery potential has been investigated within the minimal SUGRA-MSSM framework where all sparticle masses are determined mainly by two parameters: $m_0$ (common squark and slepton mass at GUT scale) and $m_{1/2}$ (common gaugino mass at GUT scale). The signature used for the search for gauginos at LHC is 3 isolated leptons + no jets + $E_T^{miss}$ events. The conclusion of these studies is that LHC is able to detect gauginos with $m_{1/2}$ up to 150 GeV and in some cases (small $m_0$) up to 400 GeV.

In this paper we investigate the gaugino discovery potential of LHC for the case of nonuniversal gaugino masses. Despite the simplicity of the SUGRA-MSSM framework it is a very particular model. The mass formulae for sparticles in SUGRA-MSSM model are derived under the assumption that at GUT scale ($M_{GUT} \approx 2 \cdot 10^{16}$ GeV) soft supersymmetry breaking terms are universal. However, in general, we can expect that real sparticle masses can differ in a drastic way from sparticle masses pattern of SUGRA-MSSM model due to many reasons, see for instance refs. \cite{4,5,6,7}.

\textsuperscript{1} Institute for High Energy Physics, Protvino, Russia
Therefore, it is more appropriate to investigate the LHC SUSY discovery potential in a model-independent way. The cross section for the $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ chargino second neutralino pair production depends mainly on the mass of chargino which is approximately degenerate in mass with the second neutralino $M(\tilde{\chi}_1^\pm) \approx M(\tilde{\chi}_2^0)$. The two lightest neutralino and the lightest chargino $(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm)$ have, as largest mixing components, the gauginos, and hence their masses are determined by the common gaugino mass, $m_1$. Within mSUGRA model $M(\tilde{\chi}_1^0) \approx 0.4m_2$ and $M(\tilde{\chi}_2^0) \approx 2M(\tilde{\chi}_1^0)$.

The lightest chargino $\tilde{\chi}_1^\pm$ has several leptonic decay modes giving an isolated lepton and missing energy:

- **three-body decay**
  \[ \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + l^\pm + \nu, \]

- **two-body decays**
  \[ \tilde{\chi}_1^\pm \rightarrow \tilde{t}_{L,R}^\pm + \nu, \]
  \[ \rightarrow \tilde{\chi}_1^0 + l^\pm \]

- \[ \tilde{\chi}_1^\pm \rightarrow \tilde{\nu}_L + l^\pm, \]
  \[ \rightarrow \tilde{\chi}_1^0 + \nu \]

- \[ \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + W^\pm. \]
  \[ \rightarrow l^\pm + \nu \]

Leptonic decays of $\tilde{\chi}_2^0$ give two isolated leptons and missing energy:

- **three-body decays**
  \[ \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^+ l^-, \]

- \[ \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^\pm + l^\mp + \nu, \]
  \[ \rightarrow \tilde{\chi}_1^0 + l^\pm + \nu \]

- **two-body decay**
  \[ \tilde{\chi}_2^0 \rightarrow \tilde{t}_{L,R}^\pm + l^\mp. \]
  \[ \rightarrow \tilde{\chi}_1^0 + l^\pm \]

For relatively large $\tilde{\chi}_2^0$ mass there are two-body decays $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h, \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z$ which suppress three-body decay of $\tilde{\chi}_2^0$. Direct production of $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ followed by leptonic decays of both gives three high $p_T$ isolated leptons accompanied by missing energy due to escaping $\tilde{\chi}_1^0$'s and $\nu$'s. These events do not contain jets except jets coming from initial state radiation. Therefore the signature for $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production is $3l + no \ jets + missing \ energy$. 

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As mentioned above, this signature has been used in ref. [1] for investigation of LHC gaugino discovery potential within mSUGRA model, where gaugino masses $M(\tilde{\chi}_0^0)$, $M(\tilde{\chi}_2^0)$ are determined mainly by a common gaugino mass $m_{1/2}$ and $M(\tilde{\chi}_2^0) \approx 2.5M(\tilde{\chi}_1^0)$. In our preliminary study we consider the general case when the relation between $M(\tilde{\chi}_1^\pm)$ and $M(\tilde{\chi}_1^0)$ is arbitrary. We find that LHC gaugino discovery potential depends rather strongly on the relation between $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ masses.

2 Results

Our simulations are made at the particle level with parametrized detector responses based on a detailed detector simulation. The CMS detector simulation program CMSJET 3.2 [3] is used. All SUSY processes with full particle spectrum, couplings, production cross section and decays are generated with ISAJET 7.32, ISASUSY [4]. The Standard Model backgrounds are generated with PYTHIA 5.7 [10].

The following SM processes give the main contribution to the background: $WZ$, $ZZ$, $tt$, $Wtb$, $Zb\bar{b}$, $bb$. In this paper we use the results of the background simulation of ref. [1]. Namely following ref. [1] we require 3 isolated leptons with $p_T > 15$ GeV in $|\eta| < 2.4$ (2.5) for muons (electrons) and with the same-flavour opposite-sign leptons. As an lepton isolation criterium we require the absence of charged tracks with $p_T > 1.5$ GeV in a cone $R = 0.3$ around lepton. We require also the absence of jets with $E_T^{jet} > 30$ GeV in $|\eta| < 3$. The last requirement is that the two same-flavour opposite-sign lepton invariant mass $M_{l^+l^-} < 81$ GeV.

For such set of cuts the background cross section $\sigma_{back} = 10^{-2}$ pb [1] that corresponds to the number of background events $N_b = 10$ (100) for total luminosity $L = 10^3$ (10$^4$) pb$^{-1}$. See for details ref.[1].

The results of our calculations are presented in Tables 1-4. In estimation of the LHC gauginos discovery potential we have used the significance determined as $S = \sqrt{N_s + N_b} - \sqrt{N_b}$ which is appropriate for the estimation of discovery potential in the case of future experiments [11]. Here $N_s = \sigma_s \cdot L$ is the number of signal events and $N_b = \sigma_b \cdot L$ is the number of background events for a given total luminosity $L$. As it follows from our results for given value of chargino mass $M(\tilde{\chi}_1^\pm)$ the number of signal events depends rather strongly on the mass of the lightest superparticle $M(\tilde{\chi}_1^0)$ and for $M(\tilde{\chi}_1^0) \geq 0.6M(\tilde{\chi}_1^\pm)$ signal is too small to be observable. For $L = 3 \cdot 10^4$ pb$^{-1}$ signal could be observable for $M(\tilde{\chi}_1^\pm) \leq 130$ GeV.

3 Conclusion

In this report we have presented the results of the calculations for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ pair production at LHC (CMS) with their subsequent decays into leptons for the case of nonuniversal gaugino masses. We have found that the visibility of signal by an excess over SM background in $3l + \text{no jets} + E_T^{miss}$ events depend rather strongly
on the relation between LSP mass $\tilde{\chi}_1^0$ and chargino $\tilde{\chi}_1^\pm$ mass. For total luminosity $L = 3 \cdot 10^4 pb^{-1}$ signal could be observable for chargino mass $M(\tilde{\chi}_1^\pm) \leq 130$ GeV.

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Table 1: The number of events $N_{ev}$ and significance $S$ for $M(\tilde{\chi}^0_2) = 104$ GeV, $M(\tilde{q}) = 2$ TeV, $L = 3 \cdot 10^4$ pb$^{-1}$ and for different LSP masses $M(\tilde{\chi}^0_1)$.

| $M(\tilde{\chi}^0_1)$ (GeV) | 11  | 21  | 31  | 41  | 51  | 61  | 71  | 81  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| $N_{ev}$                    | 181 | 152 | 331 | 242 | 179 | 121 | 21  | 4   |
| $S$                         | 4.6 | 3.9 | 7.8 | 6.0 | 4.6 | 3.2 | 0.6 | 0.12|

Table 2: The number of events $N_{ev}$ and significance $S$ for $M(\tilde{\chi}^0_2) = 126$ GeV, $M(\tilde{q}) = 2$ TeV, $L = 3 \cdot 10^4$ pb$^{-1}$ and for different LSP masses $M(\tilde{\chi}^0_1)$.

| $M(\tilde{\chi}^0_1)$ (GeV) | 11  | 31  | 51  | 71  | 81  | 101 |
|-----------------------------|-----|-----|-----|-----|-----|-----|
| $N_{ev}$                    | 25  | 19  | 124 | 59  | 35  | 3   |
| $S$                         | 0.7 | 0.5 | 3.3 | 1.6 | 1.0 | 0.1 |

Table 3: The number of events $N_{ev}$ and significance $S$ for $M(\tilde{\chi}^0_2) = 173$ GeV, $M(\tilde{q}) = 2$ TeV, $L = 3 \cdot 10^4$ pb$^{-1}$ and for different LSP masses $M(\tilde{\chi}^0_1)$.

| $M(\tilde{\chi}^0_1)$ (GeV) | 11  | 21  | 31  | 41  | 81  | 86  | 91  | 96  | 101 | 131 |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $N_{ev}$                    | 3   | 10  | 7   | 13  | 19  | 88  | 74  | 89  | 43  | 25  |
| $S$                         | 0.1 | 0.3 | 0.2 | 0.4 | 0.5 | 2.4 | 2.0 | 2.4 | 1.2 | 0.7 |

Table 4: The number of events $N_{ev}$ and significance $S$ for $M(\tilde{\chi}^0_2) = 122$ GeV, $M(\tilde{q}) = 500$ GeV, $L = 3 \cdot 10^4$ pb$^{-1}$ and for different LSP masses $M(\tilde{\chi}^0_1)$.

| $M(\tilde{\chi}^0_1)$ (GeV) | 9   | 19  | 29  | 39  | 51  | 58  | 79  | 88  | 97  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $N_{ev}$                    | 15  | 16  | 25  | 158 | 126 | 70  | 33  | 16  | 1   |
| $S$                         | 0.4 | 0.4 | 0.7 | 4.1 | 3.3 | 1.9 | 0.9 | 0.5 | 0.03|