Gaugino pair production at LHC for the case of nonuniversal gaugino masses

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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. We also give some preliminary results on the investigation of squark and gluino production at LHC for the case of nonuniversal gaugino masses.

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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.[1] (see, also references [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 $m_{\frac{1}{2}}$ (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 ref. [1] is that LHC is able to detect gauginos with $m_{\frac{1}{2}}$ up to 170 GeV and in some cases (small m_0) up to 420 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. [4, 5, 6, 7]. Therefore, it is more appropriate to investigate the LHC SUSY discovery potential in a model-independent way [1]. 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, $m_{\frac{1}{2}}$. Within mSUGRA model $M(\tilde{\chi}_1^0) \approx 0.4 m_{\frac{1}{2}}$ and $M(\tilde{\chi}_2^0) \approx M(\tilde{\chi}_1^{\pm}) \approx 2M(\tilde{\chi}_1^0)$.

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

three-body decay

- $\tilde{\chi}_1^{\pm} \longrightarrow \tilde{\chi}_1^0 + l^{\pm} + \nu,$

two-body decays

- $\tilde{\chi}_1^{\pm} \longrightarrow \tilde{l}^{\pm}_{L,R} + \nu,$
  $\hookrightarrow \tilde{\chi}_1^0 + l^{\pm}$
- $\tilde{\chi}_1^{\pm} \longrightarrow \tilde{\nu}_L + l^{\pm},$
  $\hookrightarrow \tilde{\chi}_1^0 + \nu$
- $\tilde{\chi}_1^{\pm} \longrightarrow \tilde{\chi}_1^0 + W^{\pm}.$
  $\hookrightarrow l^{\pm} + \nu$

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

- $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 + l^+ l^-,$
- $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^{\pm} + l^{\mp} + \nu,$
  $\hookrightarrow \tilde{\chi}_1^0 + l^{\pm} + \nu$

two-body decay

- $\tilde{\chi}_2^0 \longrightarrow \tilde{l}^{\pm}_{L,R} + l^{\mp}.$
  $\hookrightarrow \tilde{\chi}_1^0 + l^{\pm}$

[1] The early version of this study has been published in ref. [8].

For relatively large $\tilde{\chi}_2^0$ mass there are two-body decays $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 h$, $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 Z$ 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 ν'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 $3l + no\ jets + missing\ energy$.

As mentioned above, this signature has been used in ref. [1] for investigation of LHC gaugino discovery potential within mSUGRA model, where gaugino masses $M(\tilde{\chi}_1^0)$, $M(\tilde{\chi}_2^0)$ are determined mainly by a common gaugino mass $m_{\frac{1}{2}}$ and $M(\tilde{\chi}_2^0) \approx 2.5M(\tilde{\chi}_1^0)$. In our 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. For $M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} \geq M_Z$ the decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$ dominates and due the real Z-boson in final state the signal is as a rule too small to be observable due to huge background. For $M_{\tilde{\chi}_2^0}$ closed to $M_{\tilde{\chi}_1^0}$ the leptons in final state are rather soft that also prevents the signal detection. We also give some preliminary results on the investigation of squark and gluino production at LHC for the case of nonuniversal gaugino masses.

2 Simulation of detector response. Backgrounds

Our simulations are made at the particle level with parametrized detector responses based on a detailed detector simulation. To be concrete our estimates have been made for the CMS(Compact Muon Solenoid) detector. The CMS detector simulation program CMSJET 3.2 [9] is used. The main aspects of the CMSJET relevant to our study are the following.

- Charged particles are tracked in a 4 T magnetic field. 90 percent reconstruction efficiency per charged track with $p_T > 1$ GeV within $|\eta| < 2.5$ is assumed.

- The geometrical acceptances for μ and e are $|\eta| < 2.4$ and 2.5, respectively. The lepton number is smeared according to parametrizations obtained from full GEANT simulations. For a 10 GeV lepton the momentum resolution $\Delta p_T/p_T$ is better than one percent over the full η coverage. For a 100 GeV lepton the resolution becomes $\sim (1-5) \cdot 10^{-2}$ depending on η. We have assumed a 90 percent triggering plus reconstruction efficiency per lepton within the geometrical acceptance of the CMS detector.

- The electromagnetic calorimeter of CMS extends up to $|\eta| = 2.61$. There is a pointing crack in the ECAL barrel/endcap transition region between $|\eta| = 1.478 - 1.566$ (6 ECAL crystals). The hadronic calorimeter covers $|\eta| < 3$. The Very Forward calorimeter extends from $|\eta| < 3$ to $|\eta| < 5$. Noise terms have been simulated with Gaussian distributions and zero suppression cuts have been applied.

- e/γ and hadron shower development are taken into account by parametrization of the lateral and longitudinal profiles of showers. The starting point of a shower is fluctuated according to an exponential law.

- For jet reconstruction we have used a slightly modified UA1 Jet Finding Algorithm, with a cone size of $\Delta R = 0.8$ and 25 GeV transverse energy threshold on jets.

All SUSY processes with full particle spectrum, couplings, production cross section and decays are generated with ISAJET 7.32, ISASUSY [10]. The Standard Model backgrounds are generated with PYTHIA 5.7 [11].

The following SM processes give the main contribution to the background: WZ, ZZ, $t\bar{t}$, Wtb, $Zb\bar{b}$, $b\bar{b}$. In this paper we use the results of the background simulation of ref. [1]. Namely following ref. [1] we require 3 isolated leptons with $p_T^l > 15~GeV$ in $|\eta^l| < 2.4$ (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 $|\eta^l| < 3$. The last requirement is that the two same-flavour opposite-sign lepton invariant mass $M_{l^+l^-} < 81~GeV$. Lepton isolation is useful for the suppression of the background events with leptons originating from semileptonic decays of b-quarks. The central jet veto requirement allows to get rid of the internal SUSY background coming from $\tilde{g}$ and $\tilde{q}$ cascade decays, which otherwise overwhelms $\tilde{\chi}_1^{\pm}~\tilde{\chi}_2^0$ direct production. Also this cut reduces $t\bar{t}$, Wtb, $Zb\bar{b}$, $b\bar{b}$ SM background.

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]. If we refuse from the M_Z-cut, namely if we refuse from the requrement that the two same-flavour opposite-sign lepton invariant mass $M_{l^+l^-} < 81$ GeV, then the background cross section is $\sigma_{back} = 0.11~pb$ [1].

3 Results

The results of our calculations are presented in Tables 1-9. In estimation of the LHC(CMS) gaugino discovery potential we have used the significance determined as $S_{12} = \sqrt{N_s + N_b} - \sqrt{N_b}$ which is appropriate for the estimation of discovery potential in the case of future experiments [12]. For the comparison we also give the values of often used significance determined as $S = \frac{N_S}{\sqrt{(N_S+N_B)}}$. 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 $M(\tilde{\chi}_1^0) \geq 0.7 M(\tilde{\chi}_1^{\pm})$ signal is too small to be observable. For small LSP masses $M(\tilde{\chi}_1^0)$ two body decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0~Z$ dominates and due to M_Z-cut signal is as a rule too small to be observable. However if we refuse from M_Z cut in some cases it is possible to detect two body decay mode $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0(Z \to l^+l^-)$. As an illustration consider several examples wich correspond to total luminosity $L = 3 \cdot 10^4\ pb^{-1}$ (for such luminosity the number of baskground events is expected to be equal 3300).

A. $M_{\tilde{q}} = M_{\tilde{l}} = M_{\tilde{g}} = 2$ TeV. $\tan(\beta) = 5$, $M(\tilde{\chi}_2^0) \approx M(\tilde{\chi}_1^{\pm}) = 104$ GeV, $M(\tilde{\chi}_1^0) = 11\ GeV, N_{ev} = 1921, S_{12} = 14, S = 26$.

B. $M_{\tilde{q}} = M_{\tilde{l}} = M_{\tilde{g}} = 2$ TeV. $\tan(\beta) = 5$, $M(\tilde{\chi}_2^0) \approx M(\tilde{\chi}_1^{\pm}) = 126$ GeV, $M(\tilde{\chi}_1^0) = 21\ GeV, N_{ev} = 924, S_{12} = 8, S = 14$.

C. $M_{\tilde{q}} = M_{\tilde{l}} = M_{\tilde{g}} = 500$ GeV. $\tan(\beta) = 5$, $M(\tilde{\chi}_2^0) \approx M(\tilde{\chi}_1^{\pm}) = 122$ GeV, $M(\tilde{\chi}_1^0) = 26\ GeV, N_{ev} = 744, S_{12} = 6, S = 11$.

D. $M_{\tilde{q}} = M_{\tilde{l}} = M_{\tilde{g}} = 1$ TeV. $\tan(\beta) = 5$, $M(\tilde{\chi}_2^0) \approx M(\tilde{\chi}_1^{\pm}) = 124$ GeV, $M(\tilde{\chi}_1^0) = 32\ GeV, N_{ev} = 864, S_{12} = 7.1, S = 13$.

4 Squark and gluino production for the case of nonuniversal gaugino masses

Here we give first preliminary results on the squark and gluino production for the case of nonuniversal gaugino masses [13, 14]. We investigated 3 cases:

A. $m_{\tilde{q}} \ll m_{\tilde{g}}$,

B. $m_{\tilde{q}} \gg m_{\tilde{g}}$,

C. $m_{\tilde{q}} \geq m_{\tilde{g}}$, $m_{\tilde{q}} \sim m_{\tilde{g}}$.

We used the signature $n \geq 2\ jets + E_T^{miss}$ for the supersymmetry search. As for the signature $n \geq 2\ jets + n \geq 1\ leptons + E_T^{miss}$, it depends on the relation among $\tilde{\chi}_2^0, \tilde{\chi}_1^0, \tilde{q}$ and $\tilde{g}$ masses. For the instance, for $m_{\tilde{\chi}_2^0} \geq min(m_{\tilde{g}}, m_{\tilde{q}})$ there are no cascade decays of $\tilde{\chi}_2^0$ and, hence, the signature with $n \geq 1\ leptons$ is not essential.

We have found that for the case of arbitrary relations among gaugino masses the number of signal events for the signature $n \geq 2\ jets + E_T^{miss}$ depends rather strongly on the relation among $m_{\tilde{g}}$, $m_{\tilde{q}}$ and $m_{\tilde{\chi}_1^0}$. For $m_{\tilde{\chi}_1^0}$ closed to $min(m_{\tilde{g}}, m_{\tilde{q}})$ the perspectives of SUSY detection become very problematic. For instance, for $min(m_{\tilde{g}}, m_{\tilde{q}}) \geq 1\ TeV$ and $m_{\tilde{\chi}_1^0} \geq 0.75 \cdot min(m_{\tilde{g}}, m_{\tilde{q}})$ it is extremely difficult or even impossible to detect SUSY using the channel $n \geq 2\ jets + E_T^{miss}$.

As a concrete example consider the SUSY detection for $m_{\tilde{q}} = 1550\ GeV$, $m_{\tilde{g}} = 1500\ GeV$. For cut with $n_{jet} \geq 3$, $p_{T_{jet1}} \geq 350\ GeV$, $p_{T_{jet2}} \geq 290\ GeV$, $p_{T_{jet3}} \geq 230\ GeV$, $E_T^{miss} \geq 1200\ GeV$ for luminosity $L = 10^5 pb^{-1}$ the number of background events is 35 whereas the number of signal events is 334, 66, 9, 5 for $m_{\tilde{\chi}_1^0} = 250\ GeV,\ 750\ GeV,\ 1125\ GeV$ and $1350\ GeV$, correspondingly.

5 Conclusion

In this paper 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 $3l + no\ jets + E_T^{miss}$ events depends rather strongly on the relation between LSP mass $\tilde{\chi}_1^0$ and chargino $\tilde{\chi}_1^{\pm}$ mass. For relatively heavy LSP mass $M_{\tilde{\chi}_1^0} \geq M_{\tilde{\chi}_1^{\pm}}$ signal is too small to be observable. Also for small values of LSP mass $M_{\tilde{\chi}_1^0}$ two body decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ Z$ complicates the observation of the signal. For total luminosity $L = 3 \cdot 10^4 pb^{-1}$ signal could be observable for chargino mass $M(\tilde{\chi}_1^{\pm})$ up to 150 GeV .

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Table 1: The number of events N_{ev} and significances S_{12}, S for $M(\tilde{\chi}_2^0) = 104\ GeV$, $M(\tilde{q}) = 2\ TeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	11	14	21	26	31	36	41	46	51	56	61	71	81
N_{ev}	181	662	571	330	331	241	240	182	179	181	121	21	4
S_{12}	4.6	13.8	12	7.7	7.7	6.0	6.0	4.6	4.6	4.6	3.2	0.6	0.12
S	8.2	21.4	19.2	13.2	13.2	10.4	10.4	8.3	8.3	8.3	6.2	1.2	0.2

Table 2: The number of events N_{ev} and significances S_{12} , S for $M(\tilde{\chi}_2^0) = 126\ GeV$, $M(\tilde{q}) = 2\ TeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	11	21	34	38	46	66	76	86
N_{ev}	31	28	73	321	211	161	136	79
S_{12}	0.85	0.76	1.9	7.6	3.1	4.2	3.5	2.1
S	1.6	1.5	3.8	12.8	9.3	7.6	6.4	4.0

Table 3: The number of events N_{ev} and significances S_{12}, S for $M(\tilde{\chi}_2^0) = 150\ GeV$, $M(\tilde{q}) = 2\ TeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	11	41	56	61	66	71	81	91
N_{ev}	15	10	35	161	102	94	65	42
S_{12}	0.4	0.3	1	4.2	2.8	2.5	1.8	1.2
S	0.9	0.6	1.9	7.5	5.1	4.7	3.4	2.3

Table 4: The number of events N_{ev} and significances S_{12}, S for $M(\tilde{\chi}_2^0) = 101\ GeV$, $M(\tilde{q}) = 1000\ GeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	10	20	25	30	35	45	50	60
N_{ev}	451	571	439	239	302	298	178	61
S_{12}	9.9	12.1	9.9	5.5	7.2	7.2	4.4	1.1
S	16.5	19.2	16.5	10.4	12.1	12.1	8.2	3.3

Table 5: The number of events N_{ev} and significances S_{12} , S for $M(\tilde{\chi}_2^0) = 124\ GeV$, $M(\tilde{q}) = 1\ TeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	10	31	34	36	40	50	60	70	80
N_{ev}	31	24	353	305	207	166	134	92	63
S_{12}	0.9	0.7	8.3	7.3	5.2	4.2	3.4	2.4	1.7
S	1.7	1.4	13.8	12.4	9.2	7.6	6.4	4.7	3.3

Table 6: The number of events N_{ev} and significances S_{12} , S for $M(\tilde{\chi}_2^0) = 151\ GeV$, $M(\tilde{q}) = 1\ TeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	10	60	62	65	70	80	90	100	110
N_{ev}	3	19	157	123	98	93	85	83	17
S_{12}	0.005	0.03	4.0	3.3	2.6	2.4	2.2	1.9	0.5
S	0.01	0.06	7.3	6.0	4.8	4.7	4.3	3.8	1.0

Table 7: The number of events N_{ev} and significances S_{12}, S for $M(\tilde{\chi}_2^0) = 98\ GeV$, $M(\tilde{q}) = 500\ GeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	4	10	19	29	39	49	59
N_{ev}	151	619	211	180	178	148	60
S	4.4	13.2	5.3	4.6	4.6	3.9	1.7
S	7.2	20.9	9.4	8.3	8.3	7.2	3.3

Table 8: The number of events N_{ev} and significances S_{12} , S for $M(\tilde{\chi}_2^0) = 122\ GeV$, $M(\tilde{q}) = 500\ GeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	9	29	35	39	43	51	58	75
N_{ev}	15	26	191	155	129	124	71	63
S_{12}	0.4	0.7	4.8	3.5	3.5	3.3	1.9	1.7
S	0.9	1.4	9.0	7.3	6.2	6.0	3.6	3.3

Table 9: The number of events N_{ev} and significances S_{12} , S for $M(\tilde{\chi}_2^0) = 146\ GeV$, $M(\tilde{q}) = 500\ GeV$, $L = 3 \cdot 10^4\ pb^{-1}$ and for different LSP masses $M(\tilde{\chi}_1^0)$.

$M(\tilde{\chi}_1^0)$ (GeV)	9	53	56	59	65	69
N_{ev}	18	6	109	105	52	48
S_{12}	0.3	0.1	2.9	2.8	1.4	1.4
S	0.6	0.2	5.4	5.3	2.8	2.6