Search for SUSY at LHC in Jets + E_T^{miss} Final States for the Case of Nonuniversal Gaugino Masses

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Abstract

We investigate squark and gluino pair production at LHC (CMS) with subsequent decays into quarks and LSP for the case of nonuniversal gaugino masses. Visibility of signal by an excess over SM background in $(n \geq 2)jets + E_T^{miss}$ events depends rather strongly on the relation between LSP, gluino and squark masses and it decreases with the increase of LSP mass. For relatively heavy LSP mass closed to squark or gluino masses and for $(m_{\tilde{q}}, m_{\tilde{g}}) \geq 1.5$ TeV signal is too small to be observable. For the case when only third generation squarks and LSP are relatively light signal is not visible without b-tagging.

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1 Introduction

One of the LHC supergoals is the discovery of the supersymmetry. In particular, it is very important to investigate a possibility to discover strongly interacting superparticles (squarks and gluino). In ref.[1] (see, also references [2]) the LHC squark and gluino discovery potential has been investigated within the minimal SUGRA-MSSM framework [3] 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 squarks and gluino at LHC is $(n \geq 0)$ leptons + $(n \geq 2)jets + E_T^{miss}$ events. The conclusion of ref. [1] is that LHC is able to detect squarks and gluino with masses up to (2 - 2.5) TeV.

In this paper we investigate the squark and gluino 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 production of strongly interacting superparticles

$$pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{g}, \tilde{q}\tilde{q} \tag{1}$$

depends on gluino and squark masses. Within SUGRA-MSSM model the following approximate relations among sparticle masses take place:

$$m_{\tilde{q}}^2 \approx m_0^2 + 6m_{\frac{1}{2}}^2, \tag{2}$$

$$m_{\tilde{\chi}_1^0} \approx 0.45 m_{\frac{1}{2}}, \tag{3}$$

$$m_{\tilde{\chi}_2^0} \approx m_{\tilde{\chi}_1^\pm} \approx 2m_{\tilde{\chi}_1^0}, \tag{4}$$

$$m_{\tilde{g}} \approx 2.5 m_{\frac{1}{2}} \tag{5}$$

The decays of squarks and gluino depend on the relation among squark and gluino masses. For $m_{\tilde{q}} > m_{\tilde{g}}$ squarks decay mainly into gluino and quarks

- $\tilde{q} \to \tilde{g}q$

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

and gluino decays mainly into quark-antiquark pair and gaugino

- $\tilde{g} \to q\bar{q}\tilde{\chi}_i^0$
- $\tilde{g} \to q\bar{q}^{'}\tilde{\chi}_1^{\pm}$

For $m_{\tilde{q}} < m_{\tilde{g}}$ gluino decays mainly into squarks and quarks

- $\tilde{g} \to \bar{q}\tilde{q}, q\bar{\tilde{q}}$

whereas squarks decay mainly into quarks and gaugino

- $\tilde{q} \to q\tilde{\chi}_i^0$
- $\tilde{q} \to q^{'}\tilde{\chi}_1^{\pm}$

The lightest chargino $\tilde{\chi}_1^{\pm}$ has several leptonic decay modes giving a lepton and missing energy:
three-body decay

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

two-body decays

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

Leptonic decays of $\tilde{\chi}_2^0$ give two 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

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

As a result of chargino and second neutralino leptonic decays besides classical signature

- $(n \geq 2)$ jets plus E_T^{miss}

signatures

- $(k \geq 1)$ leptons plus $(n \geq 2)$ jets plus E_T^{miss}

with leptons and jets in final state arise. As mentioned above, these signatures have been used in ref. [1] for investigation of LHC(CMS) squark and gluino discovery potential within SUGRA-MSSM model, in which gaugino masses $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$ are determined mainly by a common gaugino mass $m_{\frac{1}{2}}$.

In our study we consider the general case when the relation between $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{g}}$ is arbitrary. We investigate the detection supersymmetry using classical signature $(n \geq 2)$ jets plus E_T^{miss}. Signatures with several leptons in final state are more model dependent and besides classical signature leads to the highest discovery potential within SUGRA-MSSM model. We find that LHC squarks and gluino discovery potential depends rather strongly on the relation between $\tilde{\chi}_1^0$, $\tilde{g}$ and $\tilde{q}$ masses and it decreases with the increase of the LSP mass.

2 Simulation of detector response

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 [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.

3 Backgrounds. SUSY kinematics

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 also generated with ISAJET 7.32.

The following SM processes give the main contribution to the background:
WZ, ZZ, $t\bar{t}$, Wtb, $Zb\bar{b}$, $b\bar{b}$ and QCD $(2 \to 2)$ processes.

As it has been mentioned above in our paper we consider only classical signature $(n \geq 2)$ jets plus E_T^{miss} for squarks and gluino detection. We considered 3 different kinematical regions:

A. $m_{\tilde{g}} \gg m_{\tilde{q}}$

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

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

We also considered the case when all sparticles are heavy except the third generation sfermions and LSP [12]. For the case A squarks $pp \to \tilde{q}\tilde{q}$ production dominates at LHC. The squark decays into quarks and LSP $\tilde{q} \to q\tilde{\chi}_1^0$ lead to the signature 2 jets plus E_T^{miss}. For the case B gluino pair production $pp \to \tilde{g}\tilde{g}$ dominates. The gluino decays $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ lead to $(n \geq 3)$ jets plus E_T^{miss} signature. For the case C both squarks and gluino are produced $pp \to \tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$ at the similar rate. Their decays give both 2 jets and $(n \geq 3)$ jets events. We considered two types of cuts:

Cuts a. $(n \geq 2)$ jets with $E_{Tjet1} \geq E_{T1}$, $E_{Tjet2} \geq E_{T2}$, $E_T^{miss} \geq E_{T0}$.

Cuts b. $(n \geq 3)$ jets with $E_{Tjet1} \geq E_{T1}$, $E_{Tjet2} \geq E_{T2}$, $E_{Tjet3} \geq E_{T3}$, $E_T^{miss} \geq E_{T0}$. Cuts a and b are appropriate for the investigation of the kinematical points A and B correspondingly, whereas for the point C both cuts a and b are useful. We have calculated SM backgrounds for different values E_{Tjet1}, E_{Tjet2}, E_{Tjet3}, E_{T0} of the cut parameters. Our results are presented in Tables 1-2.

In this paper we considered the case when all squarks have the same mass and $m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^\pm} > min(m_{\tilde{g}}, m_{\tilde{q}})$. The last requirement leads to the suppression of the events with leptons, only classical signature with

Table 1: Cuts a and the corresponding value of background events for $L = 10^5 pb^{-1}$.

# of cut	E_t^{miss} [GeV]	E_{t1} [GeV]	E_{t2} [GeV]	N_b
1	200	40	40	4995783
2	200	100	100	3292494
3	200	100	150	3097944
4	200	50	100	4478452
5	400	200	200	180868
6	400	200	300	173889
7	400	100	200	247991
8	600	300	300	8992
9	600	300	450	7771
10	600	150	300	17662
11	800	400	400	1120
12	800	400	600	963
13	800	200	400	2708
14	1000	500	500	229
15	1000	500	750	183
16	1000	250	500	616
17	1200	600	600	38
18	1200	600	900	28
19	1200	300	600	115

($n \geq 2$) jets plus E_T^{miss} is essential. The shape of the squark and gluino differential decay width depends rather strongly on the relation among squark, gluino and LSP masses. We considered different values of squark and gluino masses. We took LSP mass equal to $m_{\tilde{\chi}_1^0} = k \times min(m_{\tilde{g}}, m_{\tilde{q}})$ with $k = \frac{1}{6}, 0.5, 0.75, 0.9$. The $k = \frac{1}{6}$ corresponds approximately to the standard case with universal gaugino masses.

4 Results

The results of our calculations are presented in Tables 3-6 and in Figures 1-6. 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 [11]. We also imposed additional requirement that the ratio of signal to background events has to be bigger than 0.5 ($S/B > 0.5$). For the comparison we also give the values of often used significance [1] determined as $S = \frac{N_s}{\sqrt{N_s + N_b}}$ and 5σ discovery probability [11] for two values of background N_{back}. Here $N_s = \sigma_s \cdot L$ is the average number of signal events and $N_b = \sigma_b \cdot L$ is the average number of background events for a given total luminosity L.

As it follows from our results for fixed values of squark and gluino masses the visibility of signal decreases with the increase of the LSP mass. This fact has trivial explanation. Indeed, in the rest frame of squark or gluino the jets spectrum becomes more soft with the increase of LSP mass. Besides in parton model pair produced squarks and gluino are produced with total transverse momentum closed to zero. For high LSP masses partial cancellation of missing transverse momenta from two LSP particles takes place. The fact that with rise of LSP mass the E_T^{miss} spectrum becomes more soft is explicitly seen in Figures 1-3.

Figures 4-6 demonstrate that within well defined cut the number of signal events decreases with increase of the LSP masses that complicates supersymmetry detection for LSP masses closed to gluino or squark masses. For the case when all sparticles are heavy except third squark generation and LSP we have found that signal is too small to be observable for all values of third generation squark masses and LSP mass. In this case possible b-tagging will be able to suppress the background an make signal

observable [2].

5 Conclusion

In this paper we have presented the results of the calculations for squark and gluino pair production at LHC (CMS) with their subsequent decays into jets for the case of nonuniversal gaugino masses. We have found that the visibility of signal by an excess over SM background in $(n \geq 2)$ $jets + E_T^{miss}$ events depends rather strongly on the relation between LSP mass $\tilde{\chi}_1^0$ and $\tilde{q}, \tilde{g}$ masses. The visibility of the signal for fixed values of squark and gluino masses decreases with the increase of the LSP mass. For relatively heavy LSP mass closed to gluino or squark masses and for $(m_{\tilde{g}}, m_{\tilde{q}}) \geq 1.5\ TeV$ signal is too small to be observable.

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Table 2: Cuts b and the corresponding value of background events for $L = 10^5 pb^{-1}$.

# of cut	E_t^{miss} [GeV]	E_1 [GeV]	E_2 [GeV]	E_3 [GeV]	N_b
1	200	40	40	40	2953667
2	200	100	125	150	957089
3	200	167	208	250	315594
4	200	233	292	350	104932
5	200	300	375	450	79970
6	400	100	125	150	151076
7	400	167	208	250	20392
8	400	233	292	350	9025
9	400	300	375	450	4113
10	600	100	125	150	8774
11	600	167	208	250	4547
12	600	233	292	350	2599
13	600	300	375	450	1701
14	800	100	125	150	1693
15	800	167	208	250	754
16	800	233	292	350	372
17	800	300	375	450	194
18	1000	100	125	150	425
19	1000	167	208	250	234
20	1000	233	292	350	147
21	1000	300	375	450	59
22	1200	100	125	150	99
23	1200	167	208	250	58
24	1200	233	292	350	31
25	1200	300	375	450	22

Table 3: The number of events for cut with maximal value of "significances" S_2 and S_{12} and the corresponding value of the 5σ discovery probability for $L = 10^5 pb^{-1}$. Case A.

$M_{\tilde{q}}$ ($M_{\tilde{g}}$), GeV	$M_{\chi_1^0}$, GeV	*cut#*	*Signal*	S_2	S_{12}	probability $N_{back} = N_b$ (see Tab.I)	of discovery $N_{back} = 2 \cdot N_b$
2450	400	18	33.	4.23	2.52	0.667	0.211
(3050)	1200	17	21.	2.73	1.52	0.055	0.006
2050	350	19	176.	10.32	6.33	1.000	1.000
(3000)	1025	19	63.	4.72	2.62	0.684	0.198
	1500					$\frac{N_s}{N_b} < 0.5$	
	1950					$\frac{N_s}{N_b} < 0.5$	
1550	260	16	1773.	36.27	24.06	1.000	1.000
(2000)	770	13	1697.	25.57	14.33	1.000	1.000
	1162					$\frac{N_s}{N_b} < 0.5$	
	1395					$\frac{N_s}{N_b} < 0.5$	
1050	175	10	18793.	98.43	58.03	1.000	1.000
(2000)	525	10	10954.	64.75	36.26	1.000	1.000
	788	19	74.	5.38	3.02	0.900	0.417
	945	19	86.	6.07	3.45	0.983	0.681
550	92	7	180270.	275.47	156.43	1.000	1.000
(2000)	225	10	20210.	103.85	61.71	1.000	1.000
	412	10	9939.	59.82	33.24	1.000	1.000
	495	13	2560.	35.27	20.54	1.000	1.000

Table 4: The number of events for cut with maximal value of "significances" S_2 and S_{12} and the corresponding value of the 5σ discovery probability for $L = 10^5 pb^{-1}$. Case B.

$M_{\tilde{g}}$ ($M_{\tilde{q}}$), GeV	$M_{\chi_1^0}$, GeV	*cut#*	*Signal*	S_2	S_{12}	probability $N_{back} = N_b$ (see Tab.II)	of discovery $N_{back} = 2 \cdot N_b$
2000	350	24	18.	2.57	1.43	0.031	0.004
(2950)	1000					$\frac{N_s}{N_b} < 0.5$	
1500	251	16	720.	21.79	13.75	1.000	1.000
(1950)	750	15	456.	13.11	7.32	1.000	1.000
	1125					$\frac{N_s}{N_b} < 0.5$	
	1350					$\frac{N_s}{N_b} < 0.5$	
1000	175	7	10970.	61.94	34.29	1.000	1.000
(1950)	500	11	3050.	34.99	19.73	1.000	1.000
	750	14	1271.	23.34	13.29	1.000	1.000
	900	14	1100.	20.81	11.70	1.000	1.000
500	94	2	1164159.	530.81	300.77	1.000	1.000
(1950)	250	7	30710.	135.85	83.26	1.000	1.000

Table 5: The number of events for cut with maximal value of "significances" S_2 and S_{12} and the corresponding value of the 5σ discovery probability for $L = 10^5 pb^{-1}$. Case C, cuts a.

$M_{\tilde{q}}$ ($M_{\tilde{g}}$), GeV	$M_{\chi_1^0}$, GeV	*cut#*	*Signal*	S_2	S_{12}	probability $N_{back} = N_b$ (see Tab.I)	of discovery $N_{back} = 2 \cdot N_b$
2400	400	19	85.	6.01	3.41	0.980	0.661
(2300)	1150					$\frac{N_s}{N_b} < 0.5$	
	1700					$\frac{N_s}{N_b} < 0.5$	
2100	350	19	191.	10.92	6.77	1.000	1.000
(2000)	1000	19	63.	4.72	2.62	0.684	0.198
	1500					$\frac{N_s}{N_b} < 0.5$	

Table 6: The number of cut with maximal value of "significances" S_2 and S_{12} and corresponding value of probability of discovery. Case C, cuts b.

$M_{\tilde{g}}$ ($M_{\tilde{q}}$), GeV	$M_{\chi_1^0}$, GeV	*cut#*	*Signal*	S_2	S_{12}	probability $N_{back} = N_b$ (see Tab.2)	of discovery $N_{back} = 2 \cdot N_b$
2300	400	22	73.	5.55	3.16	0.943	0.508
(2400)	1150	24	18.	2.57	1.43	0.031	0.004
	1700					$\frac{N_s}{N_b} < 0.5$	
2000	350	16	283.	11.06	6.30	1.000	1.000
(2100)	1000	22	51.	4.15	2.29	0.446	0.088
	1500					$\frac{N_s}{N_b} < 0.5$	
1500	251	14	2910.	42.89	26.70	1.000	1.000
(1550)	750	14	1180.	22.01	12.45	1.000	1.000
	1125					$\frac{N_s}{N_b} < 0.5$	
	1350					$\frac{N_s}{N_b} < 0.5$	
1000	167	7	51260.	191.50	124.88	1.000	1.000
(1050)	500	7	24240.	114.74	68.46	1.000	1.000
	750	10	5700.	47.38	26.64	1.000	1.000
	900	14	1460.	26.00	15.00	1.000	1.000
500	84	1	4330000.	1604.4	980.20	1.000	1.000
(550)	250	1	3456000.	1365.1	813.11	1.000	1.000
	375	1	1794000.	823.3	460.28	1.000	1.000
	450	6	108528.	213.0	120.83	1.000	1.000

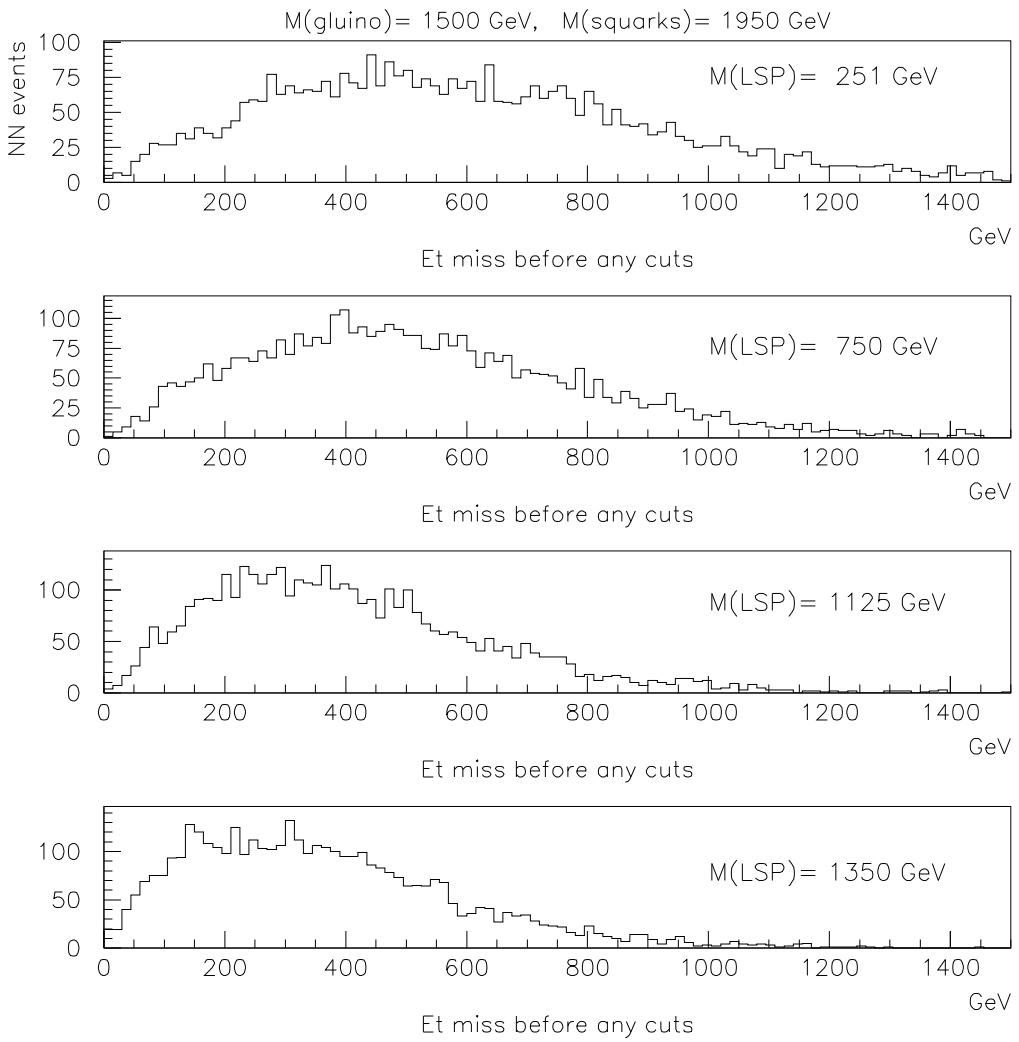

Figure 1: The Et miss distribution for different LSP masses ($M_{\tilde{g}} = 1500\ GeV,\ M_{\tilde{q}} = 1950\ GeV$). Case B.

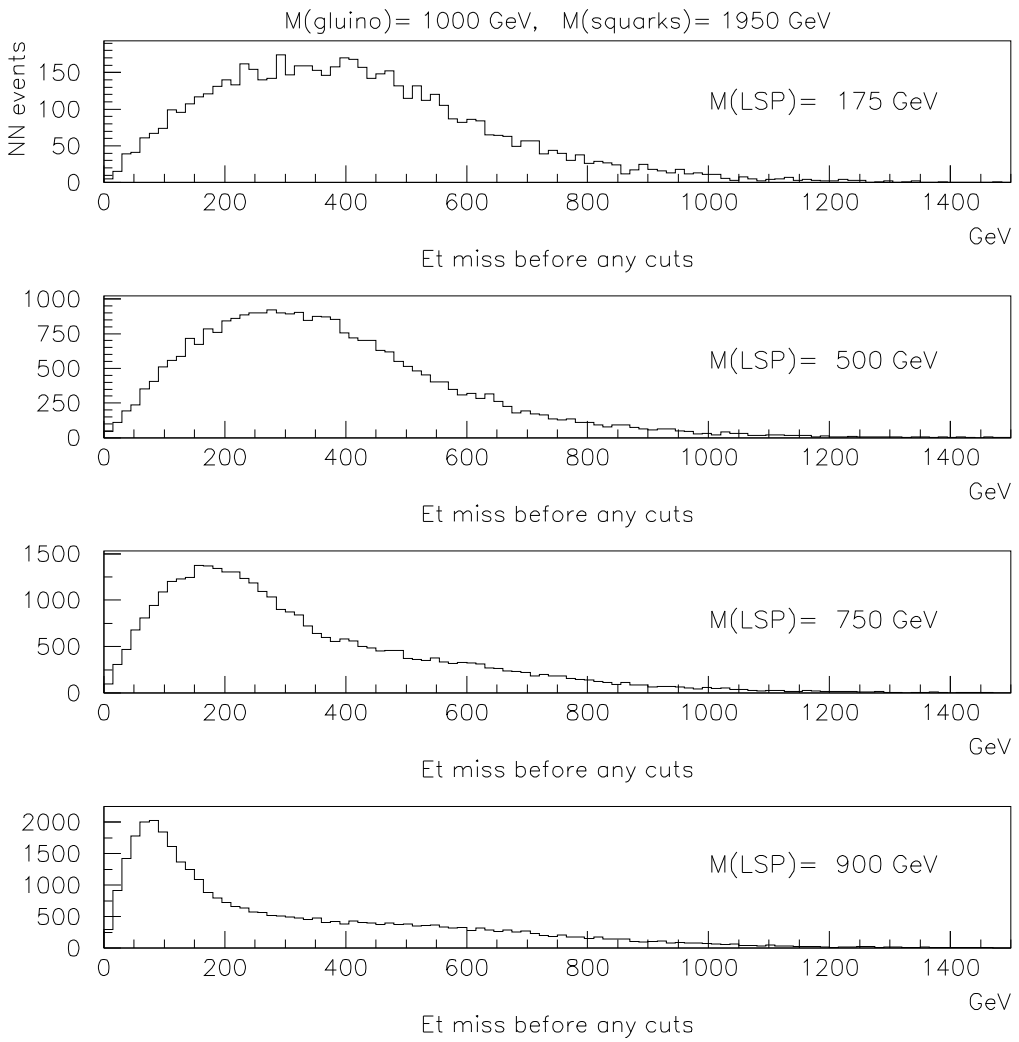

Figure 2: The Et miss distribution for different LSP masses ($M_{\tilde{g}} = 1000\ GeV,\ M_{\tilde{q}} = 1950\ GeV$). Case B.

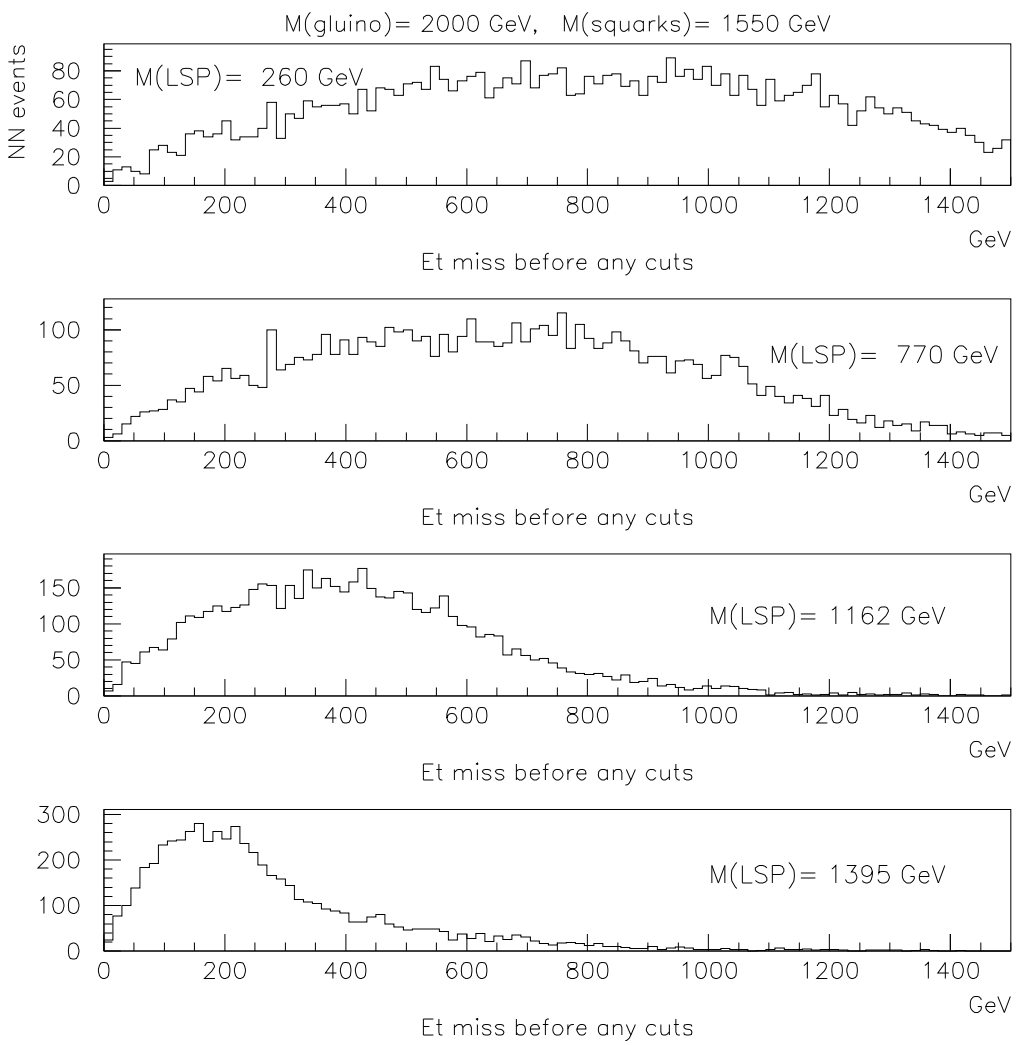

Figure 3: The Et miss distribution for different LSP masses ($M_{\tilde{g}} = 2000\ GeV,\ M_{\tilde{q}} = 1550\ GeV$). Case A.

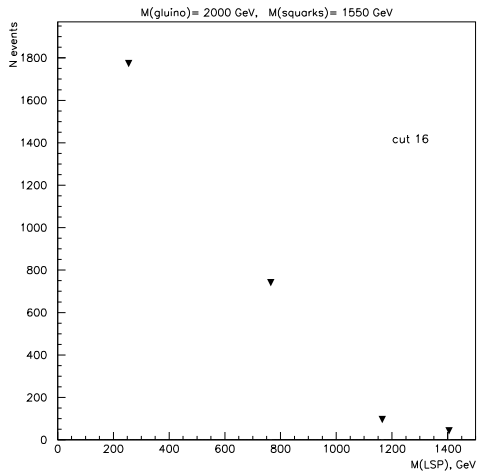

Figure 4: The dependence of the signal events on the LSP mass. Case A, cut 16a.

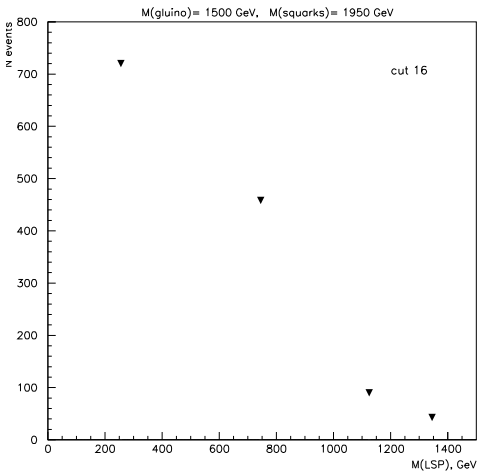

Figure 5: The dependence of the signal events on the LSP mass. Case B, cut 16b.

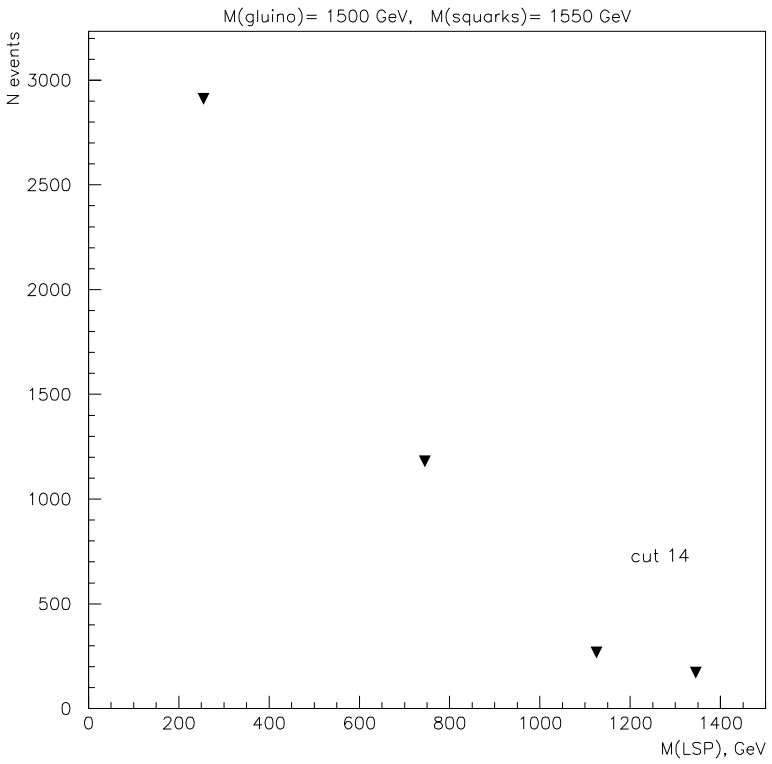

Figure 6: The dependence of the signal events on the LSP mass. Case C, cut 14b.