Sleptons at post-WMAP benchmark points at LHC(CMS)

Yu.M.Andreev $^1$, S.I.Bityukov $^2$ and N.V.Krasnikov $^3$

Institute for Nuclear Research RAS,
Moscow, 117312, Russia

Abstract

We study a possibility to detect sleptons at post-WMAP benchmark points at LHC(CMS). We find that at $L_{tot} = 30 fb^{-1}$ it would be possible to detect sleptons at points A, B, C, D, G. We also investigate the production and decays of right and left sleptons separately. We find that at $L_{tot} = 30 fb^{-1}$ it would be possible to detect right sleptons with a mass up to 200 GeV and left ones with a mass up to 300 GeV.

$^1$e-mail: andreyev@inr.ru
$^2$e-mail: bityukov@mx.ihep.su
$^3$e-mail: krasniko@ms2.inr.ac.ru
1 Introduction

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

In this paper we investigate the possibility to discover sleptons at LHC(CMS) for post-WMAP supersymmetric benchmark scenarios [8]. These benchmark points take into account WMAP and other cosmological data, as well as the LEP and $b \to s\gamma$ constraints. We also reanalyze the LHC(CMS) discovery potential for the case of direct production of right and left sleptons in the MSSM model with arbitrary relation between the mass of lightest stable superparticle (LSP) and the slepton mass. One of the important “technical” differences between this paper and the previous studies is that we use PYTHIA program [9] for both simulation of background and signal supersymmetric events whereas in Refs.[5]-[7] the PYTHIA program was used for the simulation of background events and ISAJET program [10] for simulation of supersymmetric events. As in Refs. [5]-[7] we use the CMS fast detector simulation program CMSJET [10]. We find that at total luminosity $L_{tot} = 30 fb^{-1}$ it would be possible to detect sleptons at post-WMAP points B, C, D, G. We also find that at $L_{tot} = 30 fb^{-1}$ it would be possible to detect right sleptons with a mass up to 200 GeV and left ones with a mass up to 300 GeV. The organization of the paper is the following. In Section 2 we review the main features of the mSUGRA model [12] and describe proposed in Ref.[8] post-WMAP benchmark points for supersymmetry. In Section 3 we describe sleptons production mechanisms and sleptons decays relevant for this study. Section 4 is devoted to the discussion of the background and cuts used to suppress the background. In Section 5 we present the results of our numerical calculations. Section 6 contains concluding remarks.

2 Post-WMAP benchmarks

In the MSSM supersymmetry is broken at some high scale $M$ by generic soft terms so in general all soft SUSY breaking terms are arbitrary that complicates the analysis and spoils the predictive power of the theory. In mSUGRA model [12] the universality of different soft parameters at Grand Unified Theory (GUT) scale $M_{GUT} \approx 2 \cdot 10^{16}$ 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 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 quadratic and cubic SUSY soft breaking terms are postulated to be equal. The renormalization group equations are 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 by two. So mSUGRA model depends on five unknown parameters. At present more or less standard choice of free parameters in mSUGRA model includes $m_0, m_{1/2}, \tan \beta, A$ and $\text{sign}(\mu)$ [12]. All sparticle masses depend on these parameters. For instance, the slepton masses of the first two generations are determined by the formulae [12]

$$m_{\tilde{l}_R}^2 = m_0^2 + 0.15m_{1/2}^2 - \sin^2 \theta_W M_Z^2 \cos 2\beta,$$

(1)

$$m_{\tilde{l}_L}^2 = m_0^2 + 0.52m_{1/2}^2 - \frac{1}{2}(1 - 2\sin^2 \theta_W)M_Z^2 \cos 2\beta,$$

(2)

$$m_{\tilde{\nu}}^2 = m_0^2 + 0.52m_{1/2}^2 + \frac{1}{2}\cos^2 \theta_W M_Z^2 \cos 2\beta.$$  

(3)

Charged left sleptons are the heaviest sleptons whereas the right sleptons are the lightest sleptons. For gaugino masses the following approximate formulae take place:

$$M_{\tilde{\chi}^0_1} \approx 0.45m_{1/2},$$

(4)

$$M_{\tilde{\chi}^0_2} \approx M_{\tilde{\chi}^\pm_1} \approx 2M_{\tilde{\chi}^0_1},$$

(5)

$$M_{\tilde{\chi}^\pm_2} \approx (0.25 - 0.35)M_{\tilde{g}}.$$  

(6)

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

As it has been mentioned before in mSUGRA model sparticle masses depend on five unknown parameters that complicates numerical analysis of the LHC SUSY discovery potential. In Ref.[13] benchmark sets of supersymmetric parameters (13 post-LEP points) within mSUGRA model were suggested for further careful analysis. The suggested points take into account the constraints from LEP, Tevatron, $b \to s\gamma, g_\mu - 2$ and cosmology. Recently in Ref.[8] upgraded benchmark sets (post-WMAP benchmarks) were proposed. These post-WMAP benchmarks take into account new WMAP data on dark matter density of the Universe. The mSUGRA model parameters and some sparticle masses for these post-WMAP benchmark points are given in Table 1.

### 3 Sleptons production and decays

When sleptons are heavy relative to $\tilde{\chi}^\pm_1, \tilde{\chi}^0_1$ sleptons are produced at the LHC only through Drell-Yan mechanism (direct slepton production), via $q\bar{q}$ annihilation with neutral or charged boson exchange in the s-channel, namely, $pp \to \tilde{l}_L\tilde{l}_L, \tilde{l}_R\tilde{l}_R, \tilde{\nu}\tilde{\nu}, \tilde{\nu}\tilde{l}_L, \tilde{l}_L\tilde{l}_R$. The left sleptons decay to charginos and neutralinos via the following (kinematically accessible) decays:

$$\tilde{l}_L^\pm \to l^\pm + \tilde{\chi}^0_{1,2},$$

(7)

$$\tilde{l}_L^\pm \to \nu_l + \tilde{\chi}^\pm,$$

(8)

$$\tilde{\nu} \to \nu_l + \tilde{\chi}^0_{1,2},$$

(9)

$$\tilde{l}_L \to l^\pm + \tilde{\chi}^\mp_1.$$  

(10)
Table 1: The mSUGRA parameters and some sparticle masses for proposed post-WMAP benchmarks (all masses in GeV), as calculated in ISASUGRA 7.67 (see Table 2 in Ref.[8]).

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

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

Note that an account of the mixing between left and right charged sleptons slightly complicates the situation and allows decays (7,8) for eigenstates of $\tilde{l}_L$ and $\tilde{l}_R$. If decays to second neutralino or first chargino are kinematically possible, the most interesting decays of $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ are the following:

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + l^+ l^-,$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + \nu \bar{\nu},$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + Z^0,$$
$$\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + l^\pm + \nu,$$
$$\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + W^\pm.$$

If sleptons are light relative to $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$ sleptons can be produced besides Drell-Yan mechanism from chargino and neutralino decays ($\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ indirect production), namely:

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}_{L,R}^\pm l^\mp,$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\nu} \nu,$$
$$\tilde{\chi}_1^\pm \rightarrow \tilde{\nu} l^\pm,$$
$$\tilde{\chi}_1^\pm \rightarrow {\tilde{l}}^\pm \nu.$$
4 Signature and background

The slepton production and decays described in previous section lead to the signature with the simplest event topology: two leptons + $E_T^{\text{miss}}$ + no jets. This signature arises for both direct and indirect slepton pair production. In the case of indirectly produced sleptons not only event topology with two leptons but with single, three and four leptons are possible. Besides indirect slepton production from decays of squarks and gluino through charginos, neutralinos can lead to event topology two leptons + $E_T^{\text{miss}}$ + $(n \geq 1)$ jets.

In this paper we use the event topology two leptons + $E_T^{\text{miss}}$ + no jets to detect sleptons at LHC(CMS). Our simulations are made at the particle level with parametrized detector responses based on a detailed detector simulation. The CMS detector simulation program CMSJET 4.703 [11] is used. It incorporates the full ECAL and HCAL granularity. The energy resolutions for electrons (photons), hadrons and jets are parametrized. Transverse and longitudinal profiles are also included according to parameterizations.

All the SUSY processes except particle spectrum are generated with PYTHIA 6.152 [9]. Sparticle masses for updated post-WMAP benchmark points were taken from Ref.[8]. The Standard Model backgrounds are also generated with PYTHIA 6.152. In our calculations we used the CTEQ 5L parton distribution set. The signature used for the search for sleptons at LHC is: two same-flavour opposite-sign leptons + $E_T^{\text{miss}}$ + no jets [2] - [7]. Our cuts are the following:

a. for leptons:

- $p_T$ - cut on leptons ($p_T^{\text{lept}} \geq p_T^{\text{lept,0}}$) and lepton isolation within $\Delta R < 0.3$ cone with ISOL<0.1 (CMSJET default);
- effective mass of two opposite-sign leptons of the same flavour: outside $M_Z \pm \delta M_Z$ band ($\delta M_Z = 10 \text{ GeV}$);
- $\Delta \Phi(l^+l^-) < \Delta \Phi_0^l$ cut;

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

- $E_T^{\text{miss}} > E_T^{\text{miss,0}}$ cut;
- $\Delta \Phi (E_T^{\text{miss}}, ll) > \Delta \Phi_0^l$ cut for relative azimuthal angle between two same-flavour opposite sign leptons

c. for jets:

- jet veto cut: $N_{\text{jet}} = 0$ for some $E_T^{\text{jet}} > E_T^{\text{jet,0}}$ threshold in pseudorapidity interval $|\eta_{\text{jet}}| < 4.5$.

Such type of cuts is the standard one and it was used in previous Refs.[2] - [7]. In this paper we use the set of 10 cuts, see Table 2.

The main Standard Model (SM) backgrounds are: $WW$, $WZ$, $Wtb$, $t\bar{t}$, $\tau\bar{\tau}$, $b\bar{b}$. The distributions of the SM background on $p_T^{\text{lept}}$ and $E_T^{\text{miss}}$ are presented in Figs.1-4. The contribution
of $WW$ background is (40-80)\% in the dependence on the cut number. There are also internal SUSY backgrounds which arise through $\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ productions and subsequent cascade decays with jets outside acceptance or below threshold. SUSY backgrounds depend on SUSY masses and as a rule they are small compared to SM backgrounds. Note that when we are interested in new physics discovery (the first stage of any data analysis) we have to compare the calculated number of standard background events $N_{bg}$ with new physics signal events $N_{\text{new physics}} = N_{\text{slept}} + N_{\text{susy, bg}}$, so SUSY background events increase the discovery potential of new physics.

SM background cross sections after cuts are given in Table 3. (in fb)

$$
\begin{array}{cccccccccc}
\text{Cut} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\
\sigma_{bg} & 288 & 775 & 3.6 & 6.7 & 0.68 & 1.9 & 3.3 & 3.0 & 101 & 24
\end{array}
$$

Table 3: The SM background cross sections after cuts (in fb).

### 5 Results

For post-WMAP points (A - M) our results are the following. We found that at $L_{tot} = 10 fb^{-1}$ it would be possible to discover sleptons only at point B.\(^4\) For cut 3 we found that $N_S = 45$, $N_B = 38$, $S = 5.9$. For $L_{tot} = 30 fb^{-1}$ it is possible to discover sleptons at points $B, C, D, F$, see Table 4.\(^5\).

\(^4\)In our calculations we used the approximate formula for the significance $S = \frac{2N_S}{\sqrt{N_B + N_S + N_B}}$ that is appropriate characteristic for future experiments, see Refs.[14] and also Ref.[15].

\(^5\)See also Figs.5-6 for an illustration of the dependence of the background and the signal on the cut parameters.
Figure 1: Leptons $p_T^{\text{lept}}$ distributions for main SM background (WW, $t\bar{t}$) before any cuts ($L_{\text{tot}} = 10 \text{ fb}^{-1}$).

Figure 2: $E_T^{\text{miss}}$ distributions for main SM background (WW, $t\bar{t}$) events with two isolated leptons $p_T^{\text{lept}} > 20 \text{ GeV}$ ($L_{\text{tot}} = 10 \text{ fb}^{-1}$).
Figure 3: Leptons $p_T^{\text{lep}}$ distributions for main SM background (WW, $t\bar{t}$) for cut 3 ($L_{\text{tot}} = 10 \, fb^{-1}$).

Figure 4: $E_T^{\text{miss}}$ distributions for main SM background (WW, $t\bar{t}$) events for cut 3 ($L_{\text{tot}} = 10 \, fb^{-1}$).
Figure 5: $E_T^{\text{miss}}$ distributions for main SM background (WW, $t\bar{t}$) and signal at point B for events with two isolated leptons $p_T^{\text{lep}} > 50$ GeV for cut 3 before cuts on $E_T^{\text{miss}}$ and $\Delta \Phi^0$ ($L_{tot} = 10$ fb$^{-1}$).

Figure 6: $E_T^{\text{miss}}$ distributions for main SM background (WW, $t\bar{t}$) and signal at point B for cut 3 ($L_{tot} = 10$ fb$^{-1}$).
At $L_{tot} = 100 fb^{-1}$ we also investigated the slepton discovery potential for post-LEP benchmark points [13] and found that the LHC(CMS) slepton discovery potential for post-LEP points coincides with the slepton discovery potential for post-WMAP points.

In this paper we studied also the production and decays of right and left sleptons separately.\(^7\)

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

Of course, in real life we expect that the decays of other sparticles will also contribute to the signature two leptons + $E_T^{miss}$ + no jets. But if we are interested in new physics signal discovery additional contribution only increases new physics discovery potential of this signature.

We made simulations for LSP mass $m_{LSP}$ equal to $0.2 \ m_\tilde{l}$, $0.4 \ m_\tilde{l}$, $0.6 \ m_\tilde{l}$ and $0.8 \ m_\tilde{l}$.\(^8\) The dependence of the cross section for the production of right and left sleptons for the case of two flavour degenerate right and left charged sleptons is presented in Fig.7. Our results are given in Table 5.

As it follows from our results the sleptons discovery potential depends on the LSP mass. For $m_{LSP} = 0.2 \ m_\tilde{l}$ it would be possible to detect right sleptons with a mass up to 200 GeV and left ones with a mass up to 300 GeV. For instance, for right slepton with a mass $m_{\tilde{e}_R} = 200 \ GeV$ and LSP with a mass $m_{LSP} = 40 \ GeV$ we found that $N_S = 70$, $N_B = 108$, $S = 5.9$ (cut 3, $L_{tot} = 30 \ fb^{-1}$). For left slepton with a mass $m_{\tilde{e}_L} = 200 \ GeV$ and LSP with a mass $m_{LSP} = 40 \ GeV$ we found that $N_S = 140$, $N_B = 108$, $S = 10.7$ (cut 3, $L_{tot} = 30 \ fb^{-1}$).

\(^6\)We did not take into account pileup effects therefore the results for high luminosity $L_{tot} = 100 \ fb^{-1}$ are rather preliminary. We think that the use of “hard” cuts 3 - 8 allows to minimize the influence of pileup effects on the significance.

\(^7\)To be precise we considered the production and decays of the first and second generation sleptons $\tilde{e}_R, \tilde{e}_L, \tilde{\nu}_e, \tilde{\mu}_R, \tilde{\mu}_L, \tilde{\nu}_\mu$. An account of the third generation sleptons with the masses equal to the masses of the first and second generation sleptons is not essential since $Br(\tau \rightarrow lepton) \approx 0.35$.

\(^8\)We assume that $m_{\tilde{e}_R} = m_{\tilde{\mu}_R}$ and $m_{\tilde{e}_L} = m_{\tilde{\mu}_L}$.
Figure 7: Cross section $\sigma(pp \rightarrow \tilde{\ell}_R \tilde{\ell}_R)$ for various values of the right slepton masses and cross section $\sigma(pp \rightarrow \tilde{\ell}_L \tilde{\ell}_L)$ for various values of the left slepton masses at LHC (in fb).

6 Conclusion

In this paper we studied the possibility to detect sleptons at LHC(CMS). For post-WMAP benchmark points we found that it is possible to discover sleptons at point $B$, points $B,C,D,F$ and points $A,B,C,D,G,I$ for total luminosities $L_{tot} = 10 \, fb^{-1}$, $L_{tot} = 30 \, fb^{-1}$ and $L_{tot} = 100 \, fb^{-1}$ correspondingly. We also investigated the possibility to detect sleptons for the case when they decay dominantly to leptons and LSP. For $L_{tot} = 30 \, fb^{-1}$ we found that it is possible to discover right sleptons with masses up to $200 \, GeV$ and left sleptons with masses up to $300 \, GeV$.

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References

[1] As a recent review, see for example:
N.V.Krasnikov and V.A.Matveev, Search for new physics at LHC, Preprint INR-1104/2003; hep-ph/0309200.

[2] F. del Aguila and Ll.Ametller, Phys. Rev. Lett. B261 (1991) 325.

[3] H.Baer, C. h. Chen, F.Paige and X.Tata, Phys. Rev. D 49 (1994) 3283.

[4] H. Baer, C. h. Chen, F. Paige and X. Tata, Phys. Rev. D 53 (1996) 6241; hep-ph/9512383.

\[^9\] For right sleptons they really decay mainly to leptons and LSP while for left sleptons for $m_\tilde{\ell} > m_\chi_2$ cascade decays can dominate.
[5] D.Denegri, L.Rurua and N.Stepanov, CMS Note TN/96-059, 1996.
[6] N.V.Krasnikov, Jetp. Lett. 65 (1997) 148; hep-ph/9611282.
[7] S.I.Bityukov and N.V.Krasnikov, Yad. Fiz. 62 (1999) 1288; hep-ph/9806504.
[8] M.Battaglia et al., hep-ph/0306219.
[9] T.Sjorstrand et al., Comp. Phys. Comm. 135 (2001) 238.
[10] H.Baer, F.E.Paige, S.D.Protopopescu and X.Tata, hep-ph/0001086.
[11] S.Abdullin, A.Khanov and N.Stepanov, CMS Note TN/94-180.
[12] Reviews and original references can be found in:
    R.Barbieri, Riv.Nuovo.Cim. 11 (1988) 1;
    D.V.Nanopoulos, Phys.Rep. 145 (1987) 1;
    H.P.Nilles, Phys.Rep. 110 (1984) 1;
    N.V.Krasnikov and V.A.Matveev, Phys.Part.Nucl. 28 (1997) 441; hep-ph/9703204.
[13] M.Battaglia et al., hep-ph/0112013.
[14] S.I.Bityukov and N.V.Krasnikov, Mod.Phys.Lett. A 13 (1998) 3235;
    S.I.Bityukov and N.V.Krasnikov, Nucl.Instrum.Meth. A 452 (2000) 518.
[15] V.Bartsch and G.Quast, Expected signal observability at future experiments,
    CMS-IN-2003/039.
| $L_{\text{LHC}}$ | $m_{\text{LSP}}/m_{\tilde{e}_R}$ | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 |
|-----------------|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| $10 fb^{-1}$    | 0.8             |     |     |     |     |     |     |     |     |
|                 | 0.6             |     |     |     |     |     |     |     |     |
|                 | 0.4             |     |     |     |     |     |     |     |     |
|                 | 0.2             |     |     |     |     |     |     |     |     |
| $30 fb^{-1}$    | 0.8             |     |     |     |     |     |     |     |     |
|                 | 0.6             |     |     |     |     |     |     |     |     |
|                 | 0.4             |     |     |     |     |     |     |     |     |
|                 | 0.2             |     |     |     |     |     |     |     |     |
| $100 fb^{-1}$   | 0.8             |     |     |     |     |     |     |     |     |
|                 | 0.6             |     |     |     |     |     |     |     |     |
|                 | 0.4             |     |     |     |     |     |     |     |     |
|                 | 0.2             |     |     |     |     |     |     |     |     |

Table 5: The right and left sleptons LHC(CMS) $5 \sigma$ discovery potential for different luminosities.