Physical Science International Journal
13(3): 1-7, 2017; Article no.PSIJ.31669
ISSN: 2348-0130

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Computer Modeling of Properties of Superparticles

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/PSIJ/2017/31669
Editor(s):
(1) Lei Zhang, Winston-Salem State University, North Carolina, USA.
(2) Abbas Mohammed, Blekinge Institute of Technology, Sweden.
Reviewers:
(1) Gustavo Lopez Velazquez, Universidad de Guadalajara, Mexico.
(2) Alejandro Gutiérrez- Rodríguez, Autonomous University of Zacatecas, Mexico.
(3) Manuel Malaver de la Fuente, Maritime University of the Caribbean, Venezuela.
(4) Hesham Mansour, Cairo University, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history/17946

Original Research Article

Received 19th January 2017
Accepted 18th February 2017
Published 24th February 2017

ABSTRACT

The properties of superparticles within Constrained Minimal Supersymmetric Standard Model (CMSSM) using experimental data obtained at the LHC were studied. The first run of the LHC made it possible the selection of experimental data for purposeful SUSY searches at energies of 13 TeV. Measurements of masses of Higgs boson and top quark, which led to a conclusion about instability of electroweak vacuum, searches for missing transverse energy and charged superparticles, the mass of Higgs boson predicted by SUSY model are good indicators for determining of the four SUSY searches scenarios. Within CMSSM model with the help of computer programs SDECAY and PYTHIA 8.2 were calculated masses, decay widths, cross section for production of superparticles at the center of mass energy of 13 TeV and 33 TeV. The obtained data allow to conclude about the increasing of the production cross section of the superparticles at higher energies and provide the prediction of the most important decay channels of light superparticles. These results give concrete predictions for further SUSY searches at the LHC.

Keywords: Superparticles; constrained minimal supersymmetric standard model; Higgs boson; electroweak vacuum; production cross section.

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1. INTRODUCTION

The Standard Model (SM) as one of the most successful theories with three generations of quarks and leptons, realization of electroweak breaking, is in good agreement with experimental data. It is necessary to establish the fact that the latest observations at the LHC were "entirely consistent with SM and removes the need for the hypothesis" of an alternative theory, told leader of LHC's "beauty experiment" Guy Wilkinson. But in the TeV energy domain, SM should be expected to break down. For treating the quadratic divergence of the Higgs boson self energy were used different models, one of which is supersymmetry. This theory solves the row of problems: grand unification problem, "gauge hierarchy" problem, the problem of electroweak vacuum stability and so on. As one of the most attractive theories, supersymmetry can give an explanation to the following experiments which indicate physics beyond the SM:

- The anomalous magnetic moment of the muon at Brookhaven [1];
- The WMAP direct detection experiments – XENON-100 [2], LUX [3] et al.;
- Particle collider experiments: B-physics, Higgs boson, searches for superpartners at the Large Electron–Positron Collider, Tevatron and the LHC [4].

The purpose of the paper will be the studying of the properties of superparticles within Constrained Minimal Supersymmetric Standard Model (CMSSM) using latest experimental data obtained at the LHC.

2. CMSSM AND THE LATEST RESULTS FROM THE LHC EXPERIMENTS

The CMSSM may be regarded as the most simple and economical model of supersymmetry. A recent analysis of the CMSSM, suggests that the model is still compatible with all present experimental constraints, because the preferred masses for squarks and gluinos are about 2 TeV. Some theorists now consider other supersymmetry models for example, models with one or two non-universal Higgs mass parameters (NUHM1,2), or models in which no assumptions about the soft supersymmetry-breaking parameters are made - the pMSSM with purely phenomenological parameters [5].

In this article, we'll consider the impact of the latest experimental data on the CMSSM model. For this purpose we will extend the experimental searches for superparticles to the CMSSM region of parameter space. For the receiving of the particle content of CMSSM model let's consider the superpotential for SUSY fields (up and down quarks and squarks, other quarks and squarks, electrons and selectrons, leptons and sleptons, Higgs doublets) is the following [6]:

$$W_{MSSM} = y^u_{IJ} H_u Q_I U_J + y^d_{IJ} H_d Q_I D_J + y^e_{IJ} H_d L_I E_J + \mu H_u H_d \, .$$

The CMSSM is attractive extension of the Standard Model because of a minimal five parameters (the common scalar mass m_0, the common fermion mass $m_{1/2}$, the trilinear scalar couplings A_0, the ratio of vacuum expectation values (VEVs) of the two Higgs boson doublets (at the electroweak scale), which is denoted by tanβ and the Higgsino-mixing parameter μ) at some high energy scale below the Planck scale. At this scale, all the soft SUSY-breaking terms are generated purely by gravitational interactions. For the theory with sparticle masses we need in the generation of the soft SUSY-breaking terms at a high energy scale:

$$L_{soft} = -\frac{1}{2}\sum_{a=1}^{3} M_a tr \lambda_a \lambda_a + h.c. - m^2_{QIJ}\tilde{q}_I^+ \tilde{q}_J - m^2_{UIJ}\tilde{u}_I^+ \tilde{u}_J - m^2_{DIJ}\tilde{d}_I^+ \tilde{d}_J - m^2_{LIJ}\tilde{l}_I^+ \tilde{l}_J - m^2_{EIJ}\tilde{e}_I^+ \tilde{e}_J$$
$$- a_{UIJ} h_u \tilde{q}_I \tilde{u}_J - a_{DIJ} h_d \tilde{q}_I \tilde{d}_J - a_{EIJ} h_d \tilde{l}_I \tilde{e}_J - m^2_{H_u}|h_u|^2 - m^2_{H_d}|h_d|^2 - (b h_u h_d + h.c.).$$

Here M_a are complex gaugino masses, $m^2_{Q,U,D,L,E}$ are hermitian squark and slepton mass matrices, $a_{U,D,E}$ are general complex matrices of trilinear scalar couplings, $m^2_{H_u}$ and $m^2_{H_d}$ are real mass parameters for the up-type and down-type Higgs fields, and *b* is a complex mass mixing parameter for the Higgs scalars. The CMSSM is often given priority whenever experimental searches for physics beyond the SM are considered. This is indeed so, in spite of the fact that all such searches gave negative results and only restricted the CMSSM parameter space. It is important to see how these restrictions arise from four main sources, listed below [7]:

- Theoretical Considerations;
- Indirect effects at low-energy experiments;
- Dark matter requirements;
- Direct searches at high energy colliders.

It is interesting to consider the last restriction in more details by applying the latest data received from the experiments. Using the present status of experimental measurements and searches:

- Direct searches for SUSY particles at the LHC;
- Typical inputs coming from the searches for rare B decays;
- The g-2 anomalous magnetic moment measurement;
- LHC Higgs measurements;
- The dark matter measurements;

provided the allowed regions of the CMSSM parameter space of $(m_0, m_{1/2})$ planes, presented in Fig. 1-4. The best-fit points of Fig. 1 and Fig. 4 are indicated by a green star. Red and blue lines of Fig. 1 correspond to the 68 and 95% CL boundaries respectively. The color coding of the figure is in accordance with the mechanism of bringing the relic LSP (Lightest Supersymmetric Particle) density into the cold dark matter density [8].

Fig. 2 shows the contributions of different observables (of the flavour observables, of the electroweak precision observables, the dark matter density constraint and so on [10]) to build χ^2 function along the m_0 axis (left column), and along the $m_{1/2}$ axis (right column).

As the sensitivity of the supersymmetric experiment to a long-lived $\tilde{\tau}_1$ is comparable with E_T events sensitivity and give the information to the direct searches for colored sparticles, this fact is used in Fig. 3 for a good approximation to parameter sets of CMSSM model. The red and blue contours show the regions with the lowest $\Delta\chi^2 \prec 2.3(5.99)$ relative to the absolute minimum. The solid lines of Fig. 4 show the prospective results at the LHC with energy 14 TeV and luminosity 300 fb^{-1} and dashed lines represent the global fit to the CMSSM model: the red and blue contours correspond to the 68 and 95% CL regions, respectively. All these data were used to construct a global χ^2 function. Using these data, we present a Table 1 of four scenarios on the search for supersymmetry within CMSSM (with sgn(μ) = +1) by application of computer programs.

Table 1. Four scenarios of CMSSM model

No.	m_0 GeV	$m_{1/2}$ GeV	A_0	tan β
I	500	1000	-1000	30
II	650	1000	-1300	30
III	1200	1700	-2400	30
IV	2000	1500	-4000	30

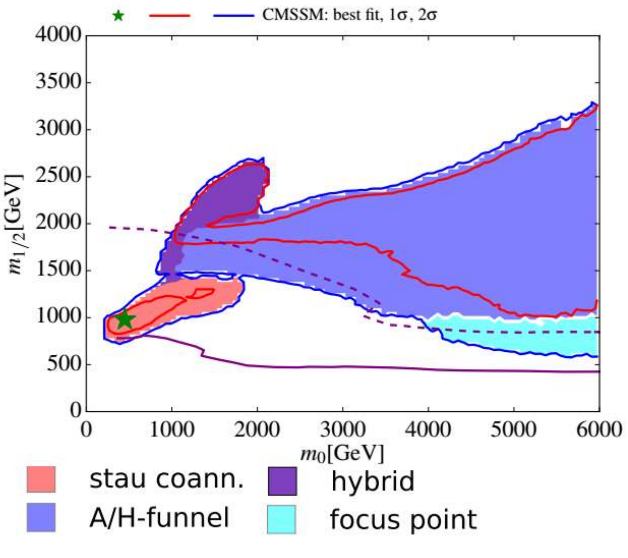

Fig. 1. The m_0, $m_{1/2}$ planes in the CMSSM from [9]

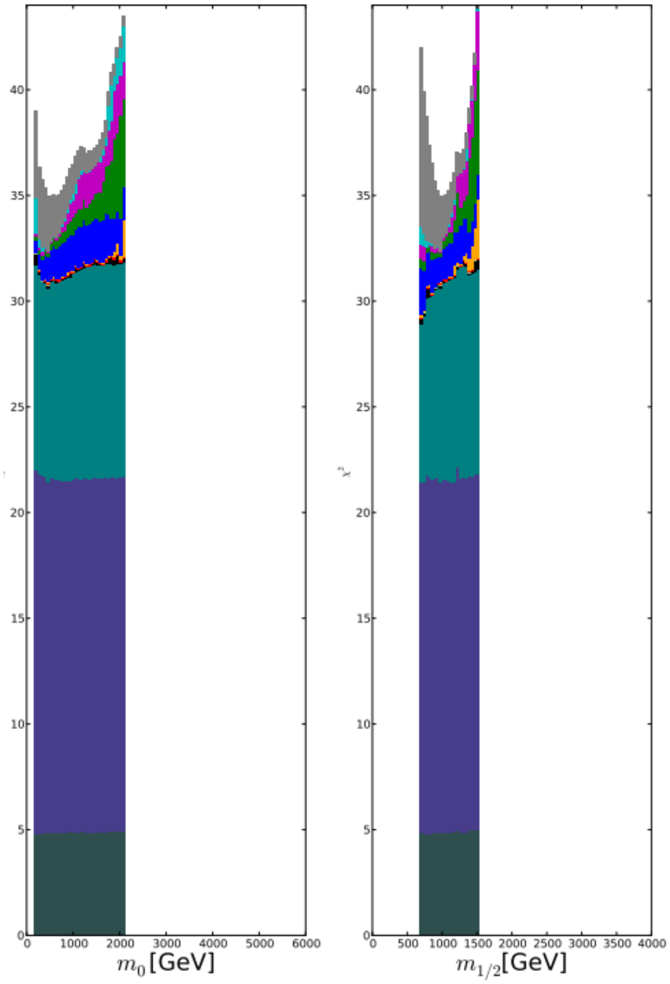

Fig. 2. The m_0, $m_{1/2}$ planes in the CMSSM from [10]

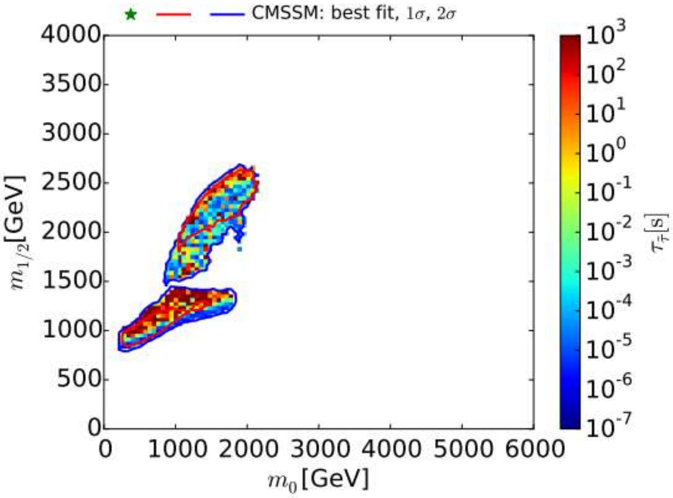

Fig. 3. The m_0, $m_{1/2}$ planes in the CMSSM from [8]

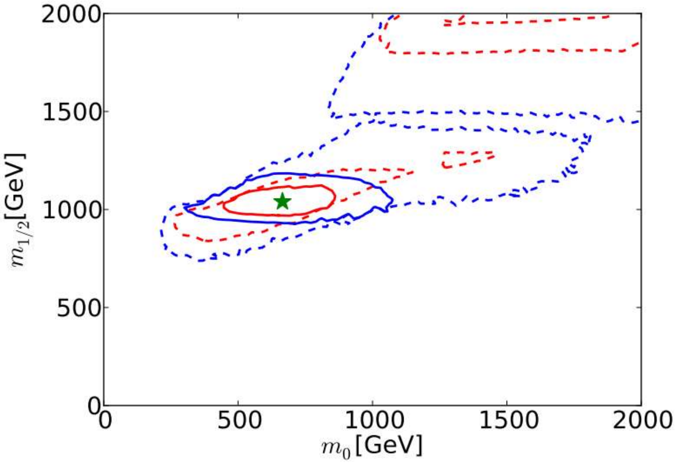

Fig. 4. The m_0, $m_{1/2}$ planes in the CMSSM from [11]

3. RESULTS OF COMPUTER MODELLING OF PROPERTIES OF SUPERPARTICLES

For the calculations of Higgs masses and masses of superpartners, which are presented in Table 2 and Table 3 respectively, was used the software program SDECAY [12].

Table 2. Higgs states masses of CMSSM model, GeV

No.	h GeV	H^0 GeV	A	$H^\pm$
I	121.5	1301.7	1301.6	1304.3
II	121.9	1376.4	1376.4	1379
III	124.7	2306.6	2306.7	2308.2
IV	126.0	2668.4	2668.5	2670

From Table 2 it can be seen, that masses of lightest Higgs boson of third and fourth scenarios are in experimental mass range of measured SM-like Higgs boson, while the other masses of CMSSM model Higgs bosons (CP-even H^0, CP-odd A and charged $H^\pm$) are essentially larger.

Since the masses of quark superpartners are degenerate, the masses of first generation left- and right-chiral squarks, (u_L , u_R) and (d_L , d_R), and the masses of gluino, *g*, stau lepton $\tilde{\tau}_1$, stop quark $\tilde{t}_1$, chargino, $\chi^\pm$ and neutralino, χ^0 , (a candidate for the dark matter), are represented in Table 3.

For SUSY searches at the LHC especially interesting is the studying of decays of lightest superparticles (chargino, stop quark) thanks to their detectable decay channels. Fig. 5 presents calculations according to the pMSSM10 model. This model also offers the possibility of a relatively light stop squark, as can be seen in the right panel of Fig. 5. Here the many LHC searches that constrain the allowed regions of the pMSSM10 parameter space were analysed sing the Fastlim/Atom [13] and Scorpion [14] codes. The light blue shading shows that $\tilde{t}_1 \to b\chi_1^\pm$ is the dominant decay and the solid black line shows the projected reach for $\tilde{t}_1 \to t\chi$ if this is the dominant decay, but however this is not the case in pMSSM10 model.

For CMSSM model we have another situation of exchanging of the order of dominant decays, the largest is $\tilde{t}_1 \to \chi t$ and the following is $\tilde{t}_1 \to \chi_1^\pm b$ as is presented in Table 4. In any case, we can say about two dominant $\tilde{t}_1$ decays without model approximation. Among it, left panel of Fig. 5 presents the most probability $\tilde{\chi}_1^+$ and $\tilde{\chi}_2^0$ decay channels for pMSSM10 model calculations. The same decays for $\tilde{\chi}_1^+$, $\tilde{\chi}_2^0$ with various branching ratios according to CMSSM model calculations are also seen from Table 4. As these channels are presented in two models, we can say about their universality and freedom to choose the SUSY model. The decay channels of first generation left- and right-chiral squarks, $(\tilde{u}_R, \tilde{u}_L)$ and $(\tilde{d}_R, \tilde{d}_L)$ proof the hypothesis of $\tilde{\chi}_1^0$ as lightest supersymmetric particle.

Table 3. Masses of superpartners, GeV

No.	$m_{\tilde{u}_L}$	$m_{\tilde{u}_R}$	$m_{\tilde{d}_L}$	$m_{\tilde{d}_R}$	m_g	$m_{\tilde{\tau}_1}$	$m_{\tilde{t}_1}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_1^0}$
I	2032	1957	2033	1948	2185	468	1485	811	429
II	2074	2000	2075	1992	2192	570	1468	814	430
III	3423	3297	3424	3282	3595	1055	2402	1402	750
IV	3471	3379	3471	3368	3259	1647	2058	1250	665

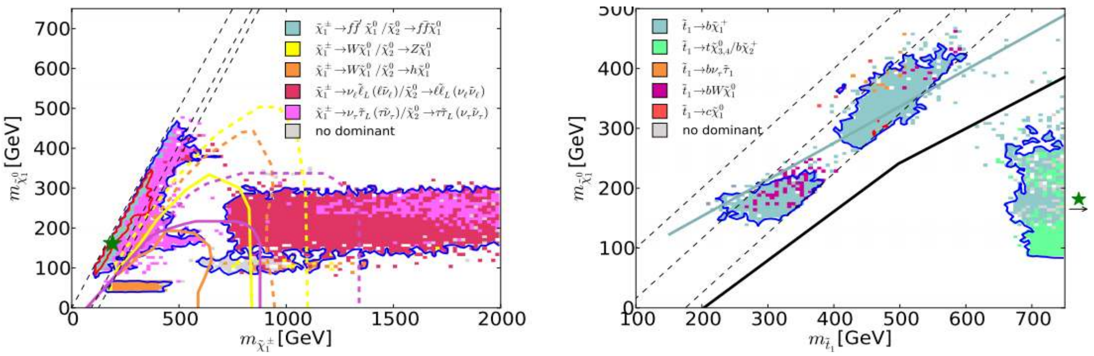

Fig. 5. Left ($m_{\chi_1^\pm}, m_\chi$) and right ($m_{\tilde{t}_1}, m_\chi$) planes with 68% and 95% CL contours shown as solid red and blue lines, respectively. The colored shadings indicate where the corresponding branching ratios exceed 50% [14]

Table 4. Masses of superpartners, GeV

Sparticle	Channel	BR	Channel	BR
$\tilde{u}_R$	$\tilde{\chi}_1^0 u$	0.999		
$\tilde{u}_L$	$\tilde{\chi}_2^0 u$	0.326	$\tilde{\chi}_1^+ d$	0.665
$\tilde{d}_R$	$\tilde{\chi}_1^0 d$	0.999		
$\tilde{d}_L$	$\tilde{\chi}_2^0 d$	0.326	$\tilde{\chi}_1^- u$	0.650
$\tilde{t}_1$	$\tilde{\chi}_1^0 t$ $\tilde{\chi}_2^0 b$	0.547 0.157	$\tilde{\chi}_1^+ b$	0.203
$\tilde{g}$	$\tilde{t}_1 t$	0.152	$\tilde{t}_1^* t$	0.152
$\tilde{\chi}_2^0$	$\tilde{\tau}_1^- \tau^+$ $\tilde{\nu}_{\tau_1} \bar{\nu}_\tau$	0.333 0.098	$\tilde{\tau}_1^+ \tau^-$ $\tilde{\nu}_{\tau_1}^* \nu_\tau$	0.333 0.098
$\tilde{\chi}_1^+$	$\tilde{\nu}_{\tau_1} \tau^+$ $\tilde{\tau}_2^+ \nu_\tau$	0.202 0.083	$\tilde{\tau}_1^+ \nu_\tau$ $\tilde{\chi}_1^0 W^+$	0.664 0.051

Using the set of parameters from Table 1, it is possible to calculate the cross-sections of superpartner production with the help of the software program PYTHIA [15]. The corresponding results, listed in Table 5 and Table 6, were obtained for the squark-squark, squark-gluino, and gluino-gluino production. The calculations were carried out for the center-of-mass energy √s = 13 TeV (Table 5) and √s = 33 TeV (Table 6) for first and second scenarios.

Table 5. Production cross sections of superpartners for √s = 13 TeV, fb

Channel	Scenario I	Scenario II
$qg \to \tilde{u}_L \tilde{g}$	16.1	14.5
$qg \to \tilde{u}_R \tilde{g}$	19.1	17.1
$qq' \to \tilde{u}_L \tilde{u}_L$	19.1	16.3
$qq' \to \tilde{u}_L \tilde{d}_L$	24.6	20.9
$qq' \to \tilde{u}_R \tilde{u}_R$	20.4	17.4
$qq' \to \tilde{u}_R \tilde{d}_R$	21.3	18.0
$q\bar{q}' \to \tilde{\chi}_1^+ \tilde{\chi}_2^0$	16.1	16.3
$q\bar{q}' \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$	10.8	10.8

Table 6. Production cross sections of superpartners for √s = 33 TeV, nb

Channel	Scenario I	Scenario II
$gg \to \tilde{g}\tilde{g}$	1.03	1.02
$gg \to \tilde{t}_1 \bar{\tilde{t}}_1$	0.23	0.25
$qg \to \tilde{u}_L \tilde{g}$	1.35	1.28
$qg \to \tilde{u}_R \tilde{g}$	1.48	1.39
$q\bar{q}' \to \tilde{\chi}_1^+ \tilde{\chi}_2^0$	0.10	0.10

4. CONCLUSION

The CMSSM is the best model beyond the SM with features of naturalness and an elegant explanation of electroweak symmetry-breaking. We have investigated the implications of constraints on the CMSSM model from the experimental data produced by experiments. It is necessary to stress, that a Higgs boson discovery will be only the start of searches for supersymmetry, not only because of theoretical necessity, but also because of crucial information for parameter space in the searches for the superparticles. Using the restricted parameter space of CMSSM model we have calculated masses, decay widths, cross sections for production of superparticles at the center of mass energy of 13 TeV and 33 TeV. Consideration of pMSSM10 and CMSSM models made it possible to conclude about the preferable decay channels of $\tilde{t}_1$, $\tilde{\chi}_1^+$ and $\tilde{\chi}_2^0$ superpartners. Comparing the cross-sections for different energies, we can conclude, that the probability of SUSY signal is larger at larger energies of the LHC. In addition, we must choose only first two scenarios of Table 1, because of small value of production cross section for other two scenarios. We also must stress the difference between the channels of superparticle production for 13 TeV and 33 TeV in the c.m.s. All these calculations are purposeful for future SUSY experimental searches, especially at higher energies and luminosities at the LHC.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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