SEARCHES FOR SUPERPARTICLES OF CMSSM MODEL AT THE LHC

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Using the discovery of a SM-like Higgs boson by ATLAS and CMS Collaborations and the observation by CMS and LHCb of BR($B_s \to \mu^+\mu^-$) decay as well as 8 TeV ATLAS 20 fb^{-1} jets + E$_T$ data set we received an indirect constraint on SUSY model parameters. Considering the constrained versions of the minimal supersymmetric extension of the Standard Model (CMSSM) we used SOFTSUSY and PROSPINO computer programs for calculations of masses and production cross sections of the superparticles, that could be discovered at the LHC.

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1. INTRODUCTION

One of the main goals of LHC is the discovery of physics beyond the Standard Model. Its aim is to test the predictions of high-energy physics: supersymmetry, extra dimensions, dark matter, CP violation, properties of quark-gluon plasma. Despite the lack of positive information on any new physics, opened at the LHC, scientists have discovered the SM-like Higgs boson, very accurately check the widths of particle decays and specified properties of the particles of Standard Model. This information can be used for further predictions and more accurate searches for new phenomena in collider experiments.

The direct supersymmetrization of the Standard Model leads to the Minimal Supersymmetric Standard Model (MSSM). The MSSM receives indirect support from experiment in:

1) the weak scale gauge couplings unify at M_{GUT} under MSSM renorm group conversion;

2) radiative corrections are consistent with $m_t \sim 173$ GeV;

3) a light SM-like Higgs boson has mass within the narrow window predicted by the MSSM.

The lack of SUSY signal at the LHC is reconciled by models of natural supersymmetry, which are characterized by light higgsinos of mass $\sim$ 100...300 GeV, light third generation squarks and gluinos with mass about 1.5 TeV.

We have used the constrained versions of the minimal supersymmetric extension of the Standard Model (CMSSM) with universal soft supersymmetry breaking parameters m_0 for scalars and $m_{1/2}$ for fermions as well as a trilinear coupling A_0 at an input grand unification scale and tanβ – the ratio of the two vacuum expectation values of the H_u and H_d (Higgs sector of MSSM model consisting of two $SU(2)$ doublets) [1]. We will try to use LHC data in the context of this model parameters.

2. OBSERVABLE DATA AS SELECTION CRITERIA FOR THE PARAMETERS OF CMSSM MODEL

As is known, the Z-boson mass can exist at just 91.2 GeV. The little hierarchy problem is connected with question, how TeV values of SUSY model parameters yield Z-boson mass? The value of M_Z in the MSSM is given by

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2 ,$$

where Σ_u^u, Σ_d^d represent the sum of various radiative corrections. To obtain a natural value of M_Z one would like each term C_i (with $i = H_d, H_u, \mu$) to have an absolute value of order $M_Z^2/2$, so we can define the electroweak fine-tuning parameter

$$\Delta_{EW} \equiv \max_i(C_i)/(M_Z^2/2) ,$$

where $C_{H_u} = |-m_{H_u}^2(\tan^2\beta - 1)|$, $C_{H_d} = |m_{H_d}^2/(\tan^2\beta - 1)|$ and $C_\mu = |-\mu^2|$ with analogous definitions for $C_{\Sigma_u^u(k)}$ and $C_{\Sigma_d^d(k)}$. To get low Δ_{EW} we require

$$|-m_{H_u}^2| \sim M_Z^2/2 \text{ and } \mu^2 \sim M_Z^2/2 .$$

We need the model to find a set of model parameters such that

$$\Delta_{EW} \sim 1 - 30 .$$

For mSUGRA/CMSSM model a minimum

$$\Delta_{EW} \sim 100$$

has been found [2]. The radiative natural SUSY model [3] or RNS is based on the MSSM which may

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be valid up to GUT scale. The sparticle spectra for RNS models with $\Delta_{EW} \leq 30$ is characterized by:
1) a low value of higgsino mass $|\mu| \sim 100...300$ GeV;
2) gluinos with mass $m_{\tilde{g}} \sim 1...4$ TeV;
3) top squarks with $m_{\tilde{t}_1} \sim 1...2$ TeV and $m_{\tilde{t}_2} \sim 2...5$ TeV;
4) first/second generation squarks and sleptons with masses $m \sim 1...8$ TeV .

The RNS model with the above spectra yields branching fractions BF$(b \to s\gamma)$ and BF$(B_s \to \mu^+\mu^-)$ in accord with measured experimental values.

The mass value of recently discovered Higgs-like resonance at the CERN LHC [4], $m_h \sim 125$ GeV, falls within the window predicted by the MSSM model. In the MSSM for Higgs mass we have the following expression

$$m_h^2 \simeq M_Z^2 cos^2 2\beta + \frac{3g^2}{8\pi^2}\frac{m_t^4}{m_W^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12m_{\tilde{t}}^2}\right)\right],$$

where $X_t = A_t - \mu\ \cos\beta$ and $m_{\tilde{t}}^2 \simeq m_{Q_3} m_{U_3}$. With top-squark masses about 500 GeV, the radiative corrections are not large to yield m_h. Our goal is to determine CMSSM model parameters due to the comprehensive picture presented by the following data:
1) the value of M_Z;
2) the value of m_h;
3) low $\Delta_{EW} \leq 30$;
4) respecting LHC constraints on sparticle masses;
5) the implementation of ATLAS 20 fb^{-1} events with E$_T$ and from 2 to 6 jets, whereas at large $m_0 \succ$3000 GeV there were considered several ATLAS limits using different events with jets, leptons, b-quarks and E$_T$ [5].

With the help of MasterCode [6] framework, MultiNest tool [7], a new version of FeynHiggs 2.10.0 [8] we present the results of new CMSSM fit using the above five inputs, considering the case of sign$\mu \succ$0. In each parameter space in Fig.1 the best-fit point is indicated by a star. This compilation of parameter planes in the CMSSM model for sign$\mu \succ$0 is presented after implementing the ATLAS 20 fb^{-1} jets + E$_T$, BR$(B \to \mu^+\mu^-)$, m$_h$. The results of the CMSSM fit are indicated by solid lines of red color for 68 % CL and contour that corresponds approximately to the 95 % CL is shown as blue line.

In Table 1 are summarized the best-fit points found in the analysis [9] of the low-mass and high-mass regions of the CMSSM parameter space for sign $\mu \succ$0.

Table 1. *The best-fit points found in global CMSSM fits*

Data set	m$_0$	m$_{1/2}$	A$_0$	tanβ
ATLAS 7 TeV	340	910	2670	12
ATLAS$_{20/fb}$ low mass	670	1040	3440	21
ATLAS$_{20/fb}$ high mass	5650	2100	-780	51

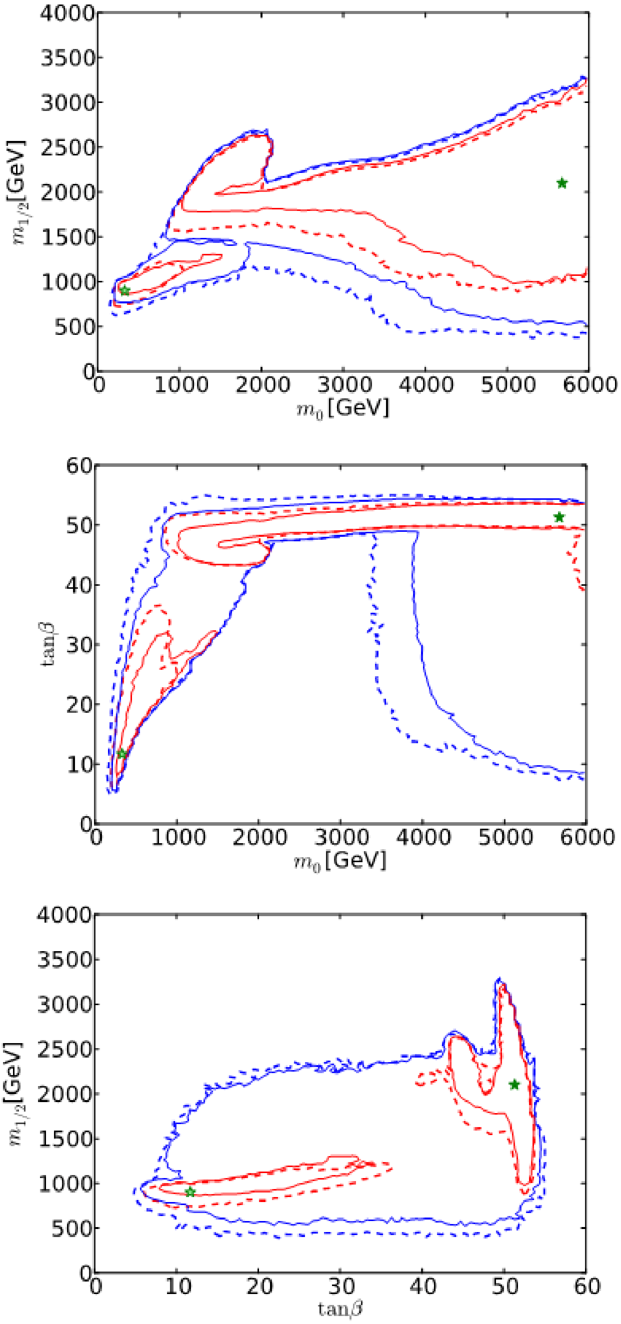

Fig.1. *Parameter planes in the CMSSM for $\mu \succ 0$ including the $(m_0, m_{1/2})$ plane (upper), the $(m_0, tan\beta)$ plane (middle) and the $(tan\beta, m_{1/2})$ plane (lower)*

3. CALCULATION OF THE MASS SPECTRUM AND PRODUCTION CROSS SECTION OF SUPERPARTNERS

Using the parameter sets of Table 1, restricted by the observational data, it is possible to calculate the mass spectrum of superpartners by application of the computer program SOFTSUSY [10]. This spectrum for three regions of the CMSSM parameter space is shown in Table 2.

Table 2. *Mass spectrum of superpartners (GeV)*

	$m_{\tilde{u}_L}$	$m_{\tilde{u}_R}$	$m_{\tilde{d}_L}$	$m_{\tilde{d}_R}$	$m_{\tilde{g}}$	$m_{\tilde{\chi}_1^0}$
I	1844	1771	1845	1763	1997	381
II	2152	2073	2154	2064	2269	440
III	6780	6690	6780	6680	4619	943

By application of the computer program PROSPINO [11] it is possible to calculate production cross sections of superpartners. The results, presented in Fig.2, were obtained for NLO (next-to-leading-order) for squark-squark (blue) and gluino-gluino (green) production as the function of mass of superparticles. The calculations were carried out for the center-of-mass energy 14 TeV.

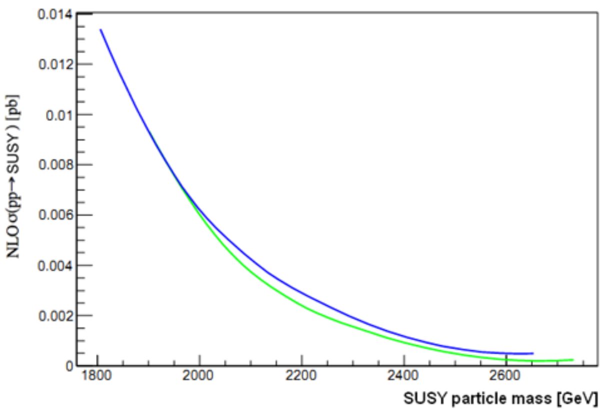

Fig.2. *Squark-squark (blue) and gluino-gluino (green) production cross sections as the function of mass of superparticles for the center-of-mass energy 14 TeV*

4. CONCLUSIONS

In this paper we have presented analyses of the CMSSM with positive sign μ and all the relevant constraints from the LHC run. From the results presented in Table 2, we see, that the masses of superparticles exceed the lower limits on the masses measured by the LHC experiment. This fact confirms the correctness of the selected parameter set presented in Table 1. In Table 2 we presented the masses of possible dark matter candidate - neutralino. Thus, recent precision measurements of B-meson decay widths BR($B_s \to \mu^+\mu^-$) and BR($B_d \to \mu^+\mu^-$), ATLAS and CMS measurements of the mass of the Higgs boson, Z boson mass, as well as ATLAS searches for events with E_T accompanied by jets with the full 7 and 8 TeV data, lead us to the conclusion about the rigid connection between the measured experimental data and the properties of the new superparticles, predicted with a relatively high probability by the computer programs. The production cross sections with NLO corrections for squark-squark and gluino-gluino production as the function of mass of superparticles have the same character, but it is different for two final states. The calculations were carried out for the center-of-mass energy 14 TeV, which are of importance for future experiments at the LHC.

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ПОИСКИ СУПЕРЧАСТИЦ $CMSSM$ - МОДЕЛИ НА LHC

Т. В. Обиход

Используя данные открытого $ATLAS$ и CMS коллаборациями CM-подобного бозона Хиггса, измерения CMS и $LHCb$ коллаборациями $BR(B_s \to \mu^+\mu^-)$, а также набор данных 8 ТэВ $ATLAS$ $20\,fb^{-1}$ $jets + E_T$, получено непрямое ограничение на параметры $SUSY$ модели. Рассматривая ограниченную версию Минимальной суперсимметричной стандартной модели ($CMSSM$), мы использовали компьютерные программы $SOFTSUSY$ и $PROSPINO$ для расчета масс и поперечных сечений образования суперчастиц, которые могут быть открытыми на LHC.

ПОШУКИ СУПЕРЧАСТИНОК $CMSSM$ - МОДЕЛІ НА LHC

Т. В. Обіход

За допомогою даних відкритого $ATLAS$ і CMS колабораціями CM-подібного бозону Хігса, вимірів CMS і $LHCb$ колабораціями $BR(B_s \to \mu^+\mu^-)$, а також набору даних 8 ТеВ $ATLAS$ $20\,fb^{-1}$ $jets + E_T$, отримано непряме обмеження на параметри $SUSY$ моделі. Розглядаючи обмежену версію Мінімальної суперсиметричної стандартної моделі ($CMSSM$), ми використовували комп'ютерні програми $SOFTSUSY$ і $PROSPINO$ для розрахунку мас і поперечних перерізів утворення суперчасток, які можуть бути відкриті на LHC.