PRODUCTION OF LONG-LIVED SLEPTONS AT LHC

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Abstract

We analyse the MSSM parameter space and discuss the narrow band near the so-called co-annihilation region where sleptons may be long-lived particles. This region is consistent with the WMAP restrictions on the Dark matter and depends on the value of $\tan \beta$. In this region staus are long-lived and may go through the detector. Due to a relatively small mass ($150 \div 850$ GeV) their production cross-section at LHC may reach a few \% pb.

1 Introduction

Search for supersymmetric particles at colliders usually proceeds from the assumption that all of them are relatively heavy (few hundreds of GeV) and short-living. Being heavier than the Standard Model particles they usually decay faster and result in usual particles with additional missing energy and momenta coming from the escaping neutral LSP. This is true almost in all regions of parameter space of the MSSM and for various mechanisms of SUSY breaking \cite{1}.

There exists, however, some corner in parameter space with small $m_0$ and large $m_{1/2}$ in mSUGRA conventions where the LSP is not the usual neutralino, but a slepton (mainly stau). This corner is obviously considered as a forbidden region since the charged LSP would contradict the astrophysical observations: no charged clouds of stable particles are observed. At the border of this region stau becomes heavier than neutralino and thus unstable. It then decays very fast.

This is just this narrow region in parameter space that attracts our attention in this paper. This region is usually called the co-annihilation region since neutralinos and staus are almost degenerate here and in the early Universe they would annihilate and co-annihilate resulting in a proper amount of the dark matter defined by these annihilation and co-annihilation cross-sections.

We found out that in the narrow band near the co-annihilation region sleptons might be rather stable with the lifetime long enough to go through the detector. Due to a relatively small mass ($150 \div 850$ GeV) their production cross-section at LHC may reach few \% pb. This possibility is investigated in detail.

The analysis is close to what has been studied mainly in the framework of models with gauge mediated supersymmetry breaking \cite{2}. Also, we have to mention that searches for long-lived particles were made by LEP collaborations \cite{3}. 

2 Allowed regions in mSUGRA parameter space and long-lived staus in the MSSM

In the framework of the MSSM with supergravity inspired soft SUSY breaking one has in general more than a hundred unknown parameters. To reduce their number one usually makes a number of simplifying assumptions, one of the favourite being the universality hypothesis. Then one has basically a set of 5 parameters: \(m_0, m_{1/2}, A_0, \mu\) and \(\tan \beta\). They may be further constrained.

One of the strictest constraints is the gauge couplings unification, it fixes the threshold of supersymmetry breaking \(M_{SUSY} \sim 1\) TeV \[4\]. The second very hard constraint follows from the radiative electroweak symmetry breaking \[5\], which correlates the value of \(\mu\) with \(m_0\) and \(m_{1/2}\), leaving only the sign of \(\mu\) free. Further constraints are due to flavour changing processes like \(b \to s\gamma\) responsible for the rare \(B\)-meson decays \[6\], anomalous magnetic moment of muon which allows only a positive sign of \(\mu\) \[7\], experimental limits on the Higgs boson mass \[8\], and on the masses of SUSY particles \[9\]. Recent very precise data from the WMAP collaboration, which measured thermal fluctuations of Cosmic Microwave Background radiation and restricted the amount of the Dark matter in the Universe up to \(23 \pm 4\%\) \[10\], result in a very hard constraint on soft SUSY parameters.

Conservation of \(R\)-parity results in the existence of the lightest supersymmetric particle. Usually it is neutralino \(\chi^0_1\), the mixture of superpartners of neutral gauge bosons - photino and zino and neutral higgsinos, the superpartners of Higgses. The precise content of neutralino depends on the choice of parameters. However, it might be also a superpartner of lepton, mainly stau. To exclude this possibility one imposes further constrains on parameter space. It is just this LSP constraint that we are interested in here. It is shown qualitatively in Fig\[\text{11}\] and is usually called the co-annihilation region \[\text{11}\]. The dark triangle shows the region where stau is the LSP. To the right of it neutralino is the LSP. The WMAP constraint leaves a very narrow band in the \(m_0 - m_{1/2}\) plane. In this

![Figure 1: LSP constraint in the \(m_0 - m_{1/2}\) plane. Dark triangle shows the region where stau is the LSP. At the boundary, the stau lifetime decreases from left to right. The WMAP bound is shown as a straight line](image)
3 Stau lifetime and LHC production cross sections

When the mass of stau becomes bigger that the neutralino one, it decays. The only decay mode in this region in case of conservation of the R-parity is

\[ \tilde{\tau} \rightarrow \tilde{\chi}_1^0 \tau. \]

The life time crucially depends on the mass difference between \( \tilde{\tau} \) and \( \tilde{\chi}_1^0 \) and quickly decreases while departing from the boundary line. If we neglect mixing in the stau sector, then the NLSP is the \( \tilde{\tau}_R \) and the decay width is given by \[ \[12\]

\[ \Gamma(\tilde{\tau} \rightarrow \tilde{\chi}_1^0 \tau) = \frac{1}{2} \alpha_{em} (N_{11} - N_{12} \tan \theta_W)^2 m_\tilde{\tau} \left(1 - \frac{m_{\tilde{\chi}_1^0}^2}{m_\tilde{\tau}^2}\right)^2, \]

where \( N_{11} \) and \( N_{12} \) are the elements of the matrix diagonalizing the neutralino mass matrix.
In Fig. 3, we show the lifetime of stau as a function of $m_0$ for different values of $m_{1/2}$ and $\tan \beta$ calculated with the help of the ISAJET V7.67 code. One can see that a small deviation from the border line results in immediate fall down of the lifetime. To get reasonable lifetimes of the order of $10^{-8}$ sec so that particles can go through the detector one needs to be almost exactly at the borderline. However, the border line itself is not fixed, it moves with $\tan \beta$.

We show below (Fig. 4) in the same way the width of stau as function of $m_0$ for various values of $m_{1/2}$ and $\tan \beta$. One can see, it rapidly approaches zero near the border line.

Consider now how these long-lived staus can be produced at LHC. The main process is given by a quark-antiquark annihilation channel shown in Fig. 5. To calculate the mass of stau and the production cross-section, we choose the benchmark points at the LSP borderline for various values of $\tan \beta = 10 \div 50$. They are summarized below.

![Figure 3: The lifetime of stau in sec as a function of $m_0$ near the border line for $\tan \beta = 50$. $m_{1/2}$ increases from left to right.](image-url)

![Figure 4: The width of stau as a function of $m_0$ near the border line for $m_{1/2} = 2000$ GeV (left) and $\tan \beta = 50$ (right); $\tan \beta$ and $m_{1/2}$ increase correspondingly from left to right.](image-url)
Figure 5: Creation of sleptons in annihilation channel

Table 1: The neutralino LSP borderline benchmark points (in GeV) as calculated by ISAJET V7.67

| #  | $m_{1/2}$ | $m_0$ | $m_0$ | $m_0$ | $m_0$ | $m_0$ |
|----|-----------|-------|-------|-------|-------|-------|
| 1  | 400       | 64    | 108   | 158   | 216   | 298   |
| 2  | 600       | 111   | 155   | 213   | 287   | 395   |
| 3  | 800       | 160   | 207   | 274   | 363   | 497   |
| 4  | 1000      | 210   | 262   | 339   | 443   | 604   |
| 5  | 1200      | 261   | 319   | 406   | 527   | 715   |
| 6  | 1600      | 367   | 437   | 545   | 699   | 944   |
| 7  | 2000      | 476   | 559   | 688   | 875   | 1179  |

Table 2: The stau mass (in GeV) and production cross-sections in pb at LHC for the center of mass energy of 14 TeV

| #  | $\tan \beta = 10$ | $\tan \beta = 20$ | $\tan \beta = 30$ | $\tan \beta = 40$ | $\tan \beta = 50$ |
|----|-------------------|-------------------|-------------------|-------------------|-------------------|
|    | $m_\tilde{\tau}$ | $\sigma_1$, $\sigma_2$ | $m_\tilde{\tau}$ | $\sigma_1$, $\sigma_2$ | $m_\tilde{\tau}$ | $\sigma_1$, $\sigma_2$ |
| 1  | 160               | 1.7E-2, 5.0E-4    | 1.6E-2, 1.3E-3    | 1.5E-2, 1.8E-3    | 1.4E-2, 1.7E-3    | 1.1E-2, 1.2E-3 |
| 2  | 245               | 3.9E-3, 4.4E-5    | 3.7E-3, 1.3E-4    | 3.4E-3, 2.1E-4    | 3.0E-3, 2.3E-4    | 2.5E-3, 1.7E-4 |
| 3  | 332               | 1.3E-3, 7.1E-6    | 1.2E-3, 2.3E-5    | 1.1E-3, 3.8E-5    | 1.0E-3, 4.4E-5    | 8.3E-4, 3.4E-5 |
| 4  | 418               | 5.2E-4, 1.6E-6    | 5.0E-4, 5.2E-6    | 4.5E-4, 9.0E-6    | 1.8E-4, 3.0E-6    | 3.3E-4, 8.2E-6 |
| 5  | 506               | 2.4E-4, 4.4E-7    | 2.3E-4, 1.5E-6    | 2.1E-4, 2.5E-6    | 4.6E-5, 3.5E-7    | 1.5E-4, 2.4E-7 |
| 6  | 684               | 6.2E-5, 5.0E-8    | 5.9E-5, 1.7E-7    | 5.3E-5, 2.9E-7    | 4.6E-5, 3.5E-7    | 3.7E-5, 2.6E-7 |
| 7  | 863               | 1.9E-5, 8.0E-9    | 1.8E-5, 2.7E-8    | 1.6E-5, 4.6E-8    | 1.4E-5, 5.4E-8    | 1.1E-5, 3.9E-8 |
Figure 6: Cross-sections for slepton production at LHC in pb as functions of $m_0$ for various values of tan $\beta$ in co-annihilation region: double stau production (left) and single stau production (right)

At each point we calculated the values of stau mass and the cross-section for stau production at LHC at the center of mass energy equal to 14 TeV. For this purpose we used the CALCHEP 3.2 code [14], which takes into account the parton distributions inside protons. For our purposes we took the MRST [15] parton distribution functions. The results are presented in Table 2 below. Two cross-sections correspond to the pair production of staus and single production accompanied by sneutrino, respectively, as shown in Fig. 5. We show the plot for both the cross-sections as a function of $m_0$ for various values of tan $\beta$ in Fig. 6.

One can see that for a small stau mass, which corresponds to the left bottom corner of $m_0, m_{1/2}$ plane, the cross sections are relatively large for staus to be produced at LHC with the luminosity around 100 pb$^{-1}$. They may well be long-lived and go through the detector, though the precise lifetime is very sensitive to the parameter space point and, hence, can not be predicted with high accuracy. Still this leaves a very interesting possibility of production of a heavy charged long-lived spinless particle.

4 Conclusions and discussions

We have shown that within the framework of the MSSM with mSUGRA supersymmetry breaking mechanism in principle there exists an interesting possibility to get long-lived sleptons which might be produced at LHC in annihilation channels. The cross-section crucially depends on a single parameter – the stau mass and for light staus can reach a few % pb. This might be within the reach of LHC. Such a process would have an unusual signature if heavy staus could indeed go through the detector and decay with a considerable delay. This situation differs from that in the gauge-mediated SUSY breaking scenario where the lifetime of NLSP is typically much larger [2].
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