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Search for chargino pair production in light gravitino scenarios with stau NLSP at $\sqrt{s} = 183$ GeV at LEP

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Abstract

Promptly decaying lightest charginos are searched for in the context of light gravitino scenarios. It is assumed that the stau is the next to lightest supersymmetric particle (NLSP). Data collected with the DELPHI detector at a centre-of-mass energy of 183 GeV are analysed combining the methods developed in previous searches. No evidence of the production of these particles is found. Hence, lower exclusion mass limits are set at 95% C.L.. The mass of charginos is found to be greater than 85.0 GeV/c^2 independently of the mass of the gravitino.

1 Introduction

In models including supersymmetry (SUSY), it is often assumed that the messengers of supersymmetry breaking couple to the observable sector with interactions of gravitational strength and that the SUSY breaking scale in the hidden sector is of the order of 10^{11} GeV. An alternative possibility is that supersymmetry is broken at some lower scale (below 10^7 GeV), and that the ordinary gauge interaction acts as the messenger of supersymmetry breaking [1, 2]. In this case, the gravitino, $\tilde{G}$, is naturally the lightest supersymmetric particle (LSP) and the lightest Standard Model superpartner is the next to lightest supersymmetric particle (NLSP). Thus, the NLSP is unstable and decays to its Standard Model (SM) partner and a gravitino.

Since the gravitino couplings are in general, with the exception of the so-called ultra-light gravitino scenarios, suppressed compared to electroweak and strong interactions, decays to the gravitino are in general only relevant for the NLSP and therefore the production and decay of supersymmetric particles at high energy colliders would generally take place through Standard Model couplings [1]. The supersymmetric particles decay into the NLSP, which eventually decays to its SM partner and a gravitino. The specific signatures of such decays depend crucially on the quantum numbers and composition of the NLSP.

Although most of the attention has been focused on the case where the neutralino is the NLSP, it is also possible that the NLSP is any other sparticle, and in particular a charged slepton. The number of generations of supersymmetry breaking messengers in minimal models, n, determines over most of the parameter space which particle is the NLSP [3, 4, 5, 6]. For example, for one generation of messengers, the lightest neutralino tends to be the NLSP, while for two or more generations, right handed sleptons are favoured. Moreover, when left-right sfermion mixing [7] occurs, the corresponding $\tilde{\tau}$ state, $\tilde{\tau}_1$, becomes the NLSP.

Throughout this work, it is assumed that the $\tilde{\tau}_1$ is the NLSP. The $\tilde{\tau}_1$ width is given (independently of the $\tilde{\tau}$ mixing) by the two-body equation:

$$\Gamma(\tilde{\tau}_1 \to \tau + \tilde{G}) = \frac{m_{\tilde{\tau}_1}^5}{48\pi M_p^2 m_{\tilde{G}}^2} \tag{1}$$

where $m_{\tilde{\tau}_1}$ is the mass of the $\tilde{\tau}_1$, $m_{\tilde{G}}$ is the mass of the $\tilde{G}$ and M_p is the Planck mass (2.4×10^{18} GeV). In the last equation, the mass of the τ has been neglected. The mean decay length obtained from equation (1):

$$L = 1.76 \times 10^{-3} (E^2/m_{\tilde{\tau}_1}^2 - 1)^{\frac{1}{2}} \left(\frac{m_{\tilde{\tau}_1}}{100\,\mathrm{GeV/c^2}}\right)^{-5} \left(\frac{m_{\tilde{G}}}{1\,\mathrm{eV/c^2}}\right)^2 \; cm, \tag{2}$$

depends strongly on $m_{\tilde{\tau}}$, $m_{\tilde{G}}$ and the energy of the $\tilde{\tau}_1$, E. The dependence of the mean decay length, L, on $m_{\tilde{G}}$ could be also interpreted in terms of the supersymmetry breaking scale, $\sqrt{F}$, through the relation:

$$m_{\tilde{G}} = \frac{F}{\sqrt{3} M_p} \simeq 2.5 \left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^2 \; \mathrm{eV/c^2} \tag{3}$$

For $\sqrt{F} \lesssim 1000$ TeV ($m_{\tilde{G}} \lesssim 250$ eV), the decay can take place within the detector. This range of $\sqrt{F}$ is in fact consistent with astrophysical and cosmological considerations [8].

[1] One exception to this rule being the process $e^+e^- \to Z^*/\gamma^* \to \tilde{G}\tilde{\chi}_1^0$ for the case of ultra-light $\tilde{G}$ scenarios.

Within this scenario, the lightest chargino would promptly decay into a stau and a tau neutrino. The stau would subsequently decay into a tau and a gravitino. For a light gravitino, (up to O(10 eV)), the stau would decay at the vertex, and the signature would consist of two taus and missing energy. Such final topology is studied in the leptonic channel of the search for charginos within the MSSM scenario [9].

For a medium mass gravitino, the staus would decay within the detector volume. The signature of such an event will be a track of a charged particle with a kink or a decay vertex when the $\tilde{\tau}_1$ decays inside the tracking devices. If the decay length is too short (small $m_{\tilde{G}}$) to allow for the reconstruction of the $\tilde{\tau}_1$ track, only the decay products of the τ will be seen in the detector, and the search will then be based on track impact parameter. Such final topology is studied in the search for sleptons within the light gravitino scenario scenario [10].

Finally, if the decay takes place outside the tracking devices (large $m_{\tilde{G}}$), the signature will be that of a heavy charged particle already studied in DELPHI [11]. All these searches have been combined to obtain a limit on $m_{\tilde{\tau}_R}$ independent of the $\tilde{G}$ mass.

We use the results from these three searches to analyse data samples produced for different gravitino masses, and interpret the results as 95% C.L. exclusion limits in the $(m_{\tilde{\tau}_1}, m_{\tilde{\chi}_1^+})$ space.

Next section describes the samples used for this work and presents the experimental results.

2 Event sample and results

The search is based on data collected by the DELPHI collaboration during 1997 at a centre-of-mass energy of 183 GeV.The total integrated luminosity corresponds to 53.9 pb^{-1}. A detailed description of the DELPHI detector can be found in [12] and its performance in [13].

The program `SUSYGEN` [14] was used to generate the chargino pair events and their subsequent decay products. In order to compute detection efficiencies, a total of 45 samples of 500 events each were generated with gravitino masses of 1, 100 and 1000 eV/c^2, and 69 GeV/c$^2 \leq m_{\tilde{\tau}_1} + 1$ GeV/c$^2 \leq m_{\tilde{\chi}_1^+} \leq \sqrt{s}/2$. The different background samples are described in references [9, 10, 11]

The generated signal and background events were passed through the detailed simulation [13] of the DELPHI detector and then processed with the same reconstruction and analysis programs used for real data.

The $m_{\tilde{G}} = 1$, 100 and 1000 eV/c^2 events were passed respectively through the chargino MSSM, the long lived stau and stable slepton analyses. Table 1 shows the range of efficiencies, the expected background and observed data events for each sample.

Sample	Efficiencies (%)	Expected b.g.	Observed
$m_{\tilde{G}} = 1$ eV/c^2	24 - 35	10.7±1.3	8
$m_{\tilde{G}} = 100$ eV/c^2	28 - 45	0.63±0.55	0
$m_{\tilde{G}} = 1000$ eV/c^2	25 - 63	0.7±0.3	0

Table 1: Range of efficiencies, expected background and observed data events for the different signal samples.

3 Results and interpretation

Since no evidence for a signal was found in the data, a limit on the production cross-section for chargino pairs was derived for each ($m_{\tilde{G}}$,$m_{\tilde{\tau}_1}$,$m_{\tilde{\chi}_1^+}$) combination. Figure 1 shows the 95% C.L. upper limit on the chargino pair production cross-section at $\sqrt{s} = 183$ GeV as a function of $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ for the samples at $m_{\tilde{G}} = 1$, 100 and 1000 eV/c^2. These limits are explained as follows:

$m_{\tilde{G}} = 1$ eV/c^2: for smaller $\Delta m = m_{\tilde{\chi}_1^+} - m_{\tilde{\tau}_1}$, the stau takes a growing fraction of the energy of the chargino. This in turn increases the boost of the tau, making it more collinear with the original direction of the initial charginos, and the signal more like back-to-back SM events.

$m_{\tilde{G}} = 100$ eV/c^2: the map of efficiencies is the result of the convolution of two factors. Firstly, bigger masses of stau imply a smaller lifetime, and hence a smaller efficiency [10]. Secondly, bigger chargino masses lead to smaller stau momenta, and to smaller lifetime.

$m_{\tilde{G}} = 1000$ eV/c^2: Efficiency for this scenario is mainly affected by the momentum of the stau, because the method used to identify heavy stable particles relies on the lack of Cerenkov radiation on DELPHI's RICH detectors. To cut away SM backgrounds, small momentum particles are removed, thus reducing the efficiency for higher chargino masses, and specially in the region of small Δm.

In what follows, the model described in reference [4] will be used in order to derive limits. This is a general model which assumes only radiatively broken electroweak symmetry and null trilinear couplings at the messenger scale. The corresponding parameter space was scanned as follows: $1 \leq n \leq 4$, 5 TeV $\leq \Lambda \leq$ 900 TeV, $1.1 \leq M/\Lambda \leq 9000$, $1.1 \leq \tan\beta \leq 50$, and $\mu > 0$, where n is the number of messenger generations in the model, Λ is the ratio between the vacuum expectation values of the auxiliary component superfield and the scalar component of the superfield and M is the messenger mass scale, tan β and μ are defined as for the MSSM.

Figure 2 shows the regions excluded at the 95% C.L. in the ($m_{\tilde{\tau}_1}$,$m_{\tilde{\chi}_1^+}$) space. Limits at 85, 89 and 89 GeV/c^{2}can be set for $m_{\tilde{G}} = 1$, 100 and 1000 eV/c^2 respectively. The smaller exclusion limit for smaller $m_{\tilde{\tau}_1}$ is due to the fact that in GMSB scenarios, small stau masses correspond to small sneutrino masses, which generate a smaller cross section due to the destructive interference between the s- and t-channels.

4 Summary

Lightest chargino pair production was searched for in the context of light gravitino scenarios. It was assumed that the $\tilde{\tau}_1$ is the NLSP. Three different searches were used in order to explore the ($m_{\tilde{\chi}_1^+}$, $m_{\tilde{\tau}_1}$) plane in different domains of the gravitino mass.

The search in the context of very light gravitinos (MSSM chargino pair production with leptonic final states) produced eight candidate events to be compared to 10.7±1.3 events

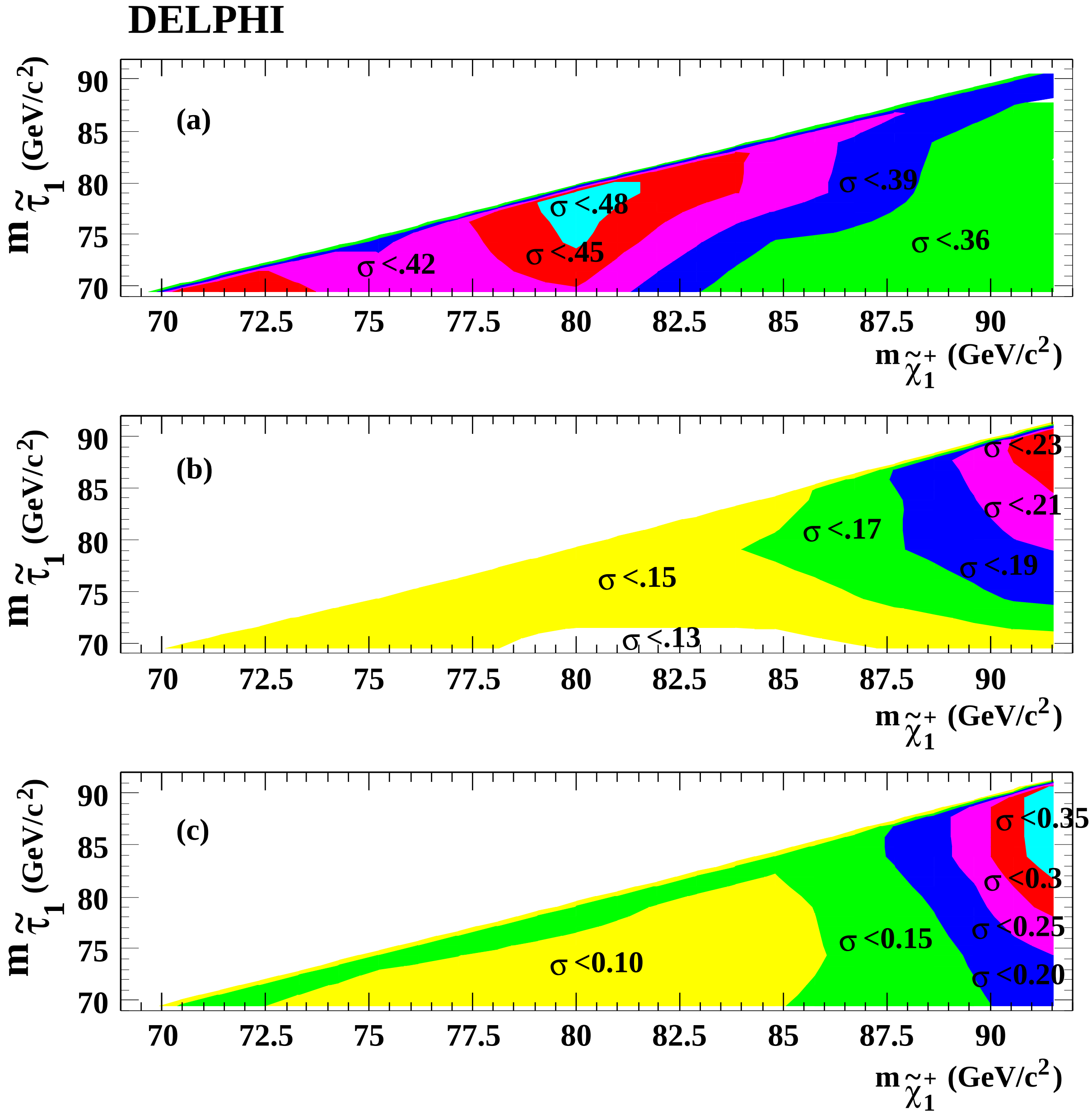

Figure 1: Limits on lightest chargino pair production cross section at the 95% C.L.. Limits are shown as functions of $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ for (a) $m_{\tilde{G}} = 1$ eV/c^2, (b) $m_{\tilde{G}} = 100$ eV/c^{2}and (c) $m_{\tilde{G}} = 1000$ eV/c^2.

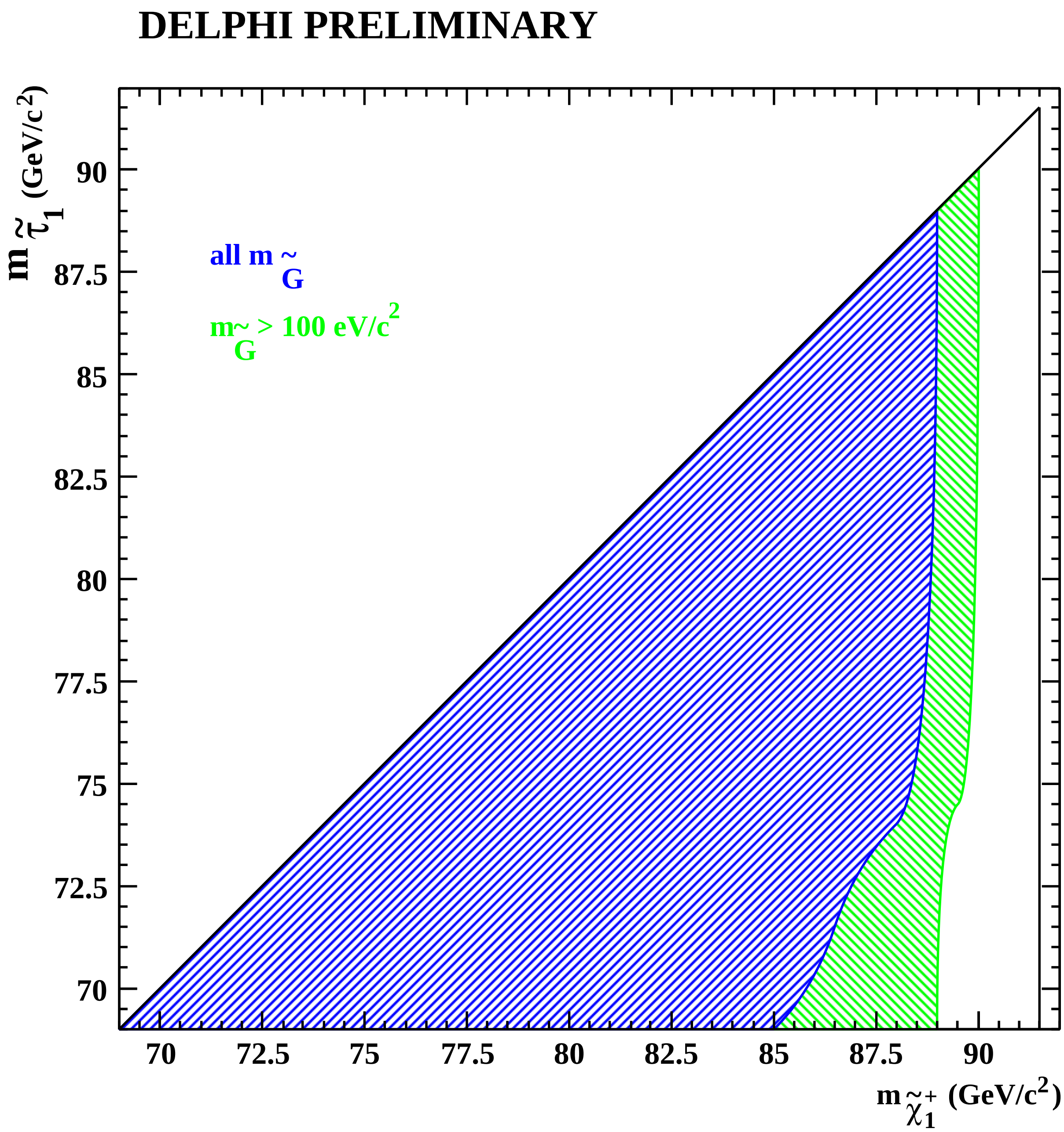

Figure 2: Areas excluded at 95% C.L. in the $m_{\tilde{\chi}_1^+}$ *vs.* $m_{\tilde{\tau}_1}$ plane. The dark shaded area is excluded for all $m_{\tilde{G}}$. The light shaded region is excluded for $m_{\tilde{G}} > 100$ eV/c^2.

expected from the SM background. An upper limit on the corresponding production cross-section between 0.36 and 0.48 pb was set at 95% C.L. in the kinematically allowed region.

The search in the context of medium range gravitinos (stau production with impact parameters or kinks) produced no candidate events to be compared to 0.63±0.55 events expected from the SM background. An upper limit on the corresponding production cross-section between 0.13 and 0.23 pb was set at 95% C.L. in the kinematically allowed region.

The search in the context of heavier gravitinos (stable stau production) produced no candidate events to be compared to 0.7±0.3 events expected from the SM background. An upper limit on the corresponding production cross-section between 0.10 and 0.35 pb was set at 95% C.L. in the kinematically allowed region.

These results, allow the DELPHI collaboration to set the lower limit on the mass of the $\tilde{\chi}_1^+$ at 85 GeV/c^2 at 95% C.L. independently of the mass of the gravitino.

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