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

DELPHI Collaboration

Abstract

Promptly decaying lightest charginos were searched for in the context of scenarios with gravitino LSP. It was assumed that the stau is the next to lightest supersymmetric particle (NLSP). Data collected with the DELPHI detector at a centre-of-mass energy near 183 GeV were analysed combining the methods developed in previous searches. No evidence for the production of these particles was found. Hence, limits were derived at 95% confidence level. The mass of charginos was found to be greater than 85.5 GeV/c^2 for $m_{\tilde{\chi}_1^+} - m_{\tilde{\tau}_1} \geq 0.3\mathrm{GeV}/c^2$, independently of the mass of the gravitino.

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1 Introduction

Supersymmetry (SUSY) may be broken at a scale below the grand-unification scale M_{GUT}, with the ordinary gauge interaction acting as the messenger of supersymmetry breaking [1,2]. In the corresponding models, the gravitino $\tilde{G}$ turns out to be the lightest supersymmetric particle (LSP) and is expected to be almost massless. The next-to-lightest supersymmetric particle (NLSP) is therefore unstable and decays, under the assumption of R-parity conservation, into an invisible gravitino and its ordinary matter partner.

The number of generations of supersymmetry breaking messengers in minimal models and the value of $\tan\beta$, usually determine which particle is the NLSP [3–6]. In this letter, lightest chargino pair production is searched for under the assumption that the $\tilde{\tau}_1$, the lightest of the mass eigenstates produced by the mixing of $\tilde{\tau}_R$ and $\tilde{\tau}_L$ [7], is the NLSP. If kinematically allowed, charginos could be produced at LEP through the exchange of a photon or a Z in the s-channel, or through the exchange of an electron sneutrino in the t-channel. Each chargino would then promptly decay into a $\tilde{\tau}_1$ and a tau neutrino:

$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\tau}_1^+\tilde{\tau}_1^-\nu_\tau\overline{\nu}_\tau \tag{1}$$

Being the NLSP, $\tilde{\tau}_1$ is expected to decay into $\tau + \tilde{G}$ with, in the laboratory frame, a mean decay length of:

$$L = 1.76\times10^{-3}\sqrt{\frac{E^2}{m^2_{\tilde{\tau}_1}}-1}\left(\frac{m_{\tilde{\tau}_1}}{100\,\mathrm{GeV}/c^2}\right)^{-5}\left(\frac{m_{\tilde{G}}}{1\,\mathrm{eV}/c^2}\right)^{2}\ \mathrm{cm}, \tag{2}$$

which depends strongly on $m_{\tilde{\tau}}$, $m_{\tilde{G}}$ and the energy of the $\tilde{\tau}_1$, E.

It can be deduced from eq. (2) that for a given stau mass, different ranges of gravitino masses could determine three different final state topologies. For $m_{\tilde{G}} \lesssim 10\ \mathrm{eV}/c^2$ the stau decays at the interaction point. Thus, if chargino pairs were produced in this context, the final state topology would correspond to two acoplanar taus and missing energy and momentum. This signature has already been studied by the DELPHI Collaboration in the so-called leptonic channel of the search for charginos within the Minimal Supersymmetric Standard Model (MSSM) [8].

If the mass of the gravitino lay between 10 and 200 eV/c^2, the staus would decay inside the tracking devices of the detector. Thus, the signature of chargino pair production would contain one or two tracks with either a kink or a decay vertex. In the case in which a stau would decay before reaching the active tracking volume, at least one track with a large impact parameter would be observed. This final state topology is almost identical to the one which would be produced by a pair of staus for the same range of gravitino masses, and has been studied by the in ref. [9].

Finally, if the mass of the gravitino is above 200 eV/c^2, the staus would tend to decay outside the tracking devices, and would appear to be stable particles. A pair of tracks with anomalous ionization and Cerenkov radiation would then be observed. Also this final signature has been already studied by the DELPHI Collaboration in the search for stable heavy particles [10].

Thus, this letter is intended to make use without modification of the analyses already applied in the three searches described in refs. [8], [9] and [10]. Real data and simulated SM samples at $\sqrt{s} \sim 183$ GeV have already been analysed in this context, and the comparison between real and simulated data is included in refs. [8–10]. No excess over the expected SM background was observed.

The selections developed for these three searches were thus applied to simulated data samples with different gravitino masses, and the results were interpreted in terms of 95% confidence level (CL) excluded regions in the $(m_{\tilde{\tau}_1}, m_{\tilde{\chi}_1^+})$ plane.

Section 2 describes the samples used for this work and presents the experimental results. Section 3 describes the interpretation of the results within one model with a gravitino LSP [4].

2 Event sample and results

The search is based on data collected by the DELPHI collaboration during 1997 at a centre-of-mass energy around 183 GeV. The total integrated luminosity was 53.9 pb^{-1}. A detailed description of the detector can be found in [11] and its performance in [12].

The program SUSYGEN [13] was used to generate the chargino pair production and decay. 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, $m_{\tilde{\tau}_1} + 0.3$ GeV/$c^2 \leq m_{\tilde{\chi}_1^+} \leq \sqrt{s}/2$ and $m_{\tilde{\tau}_1} \leq 68$ GeV/c^2. Samples with smaller $\Delta m = m_{\tilde{\chi}_1^+} - m_{\tilde{\tau}_1}$ were not generated because in that region each chargino decays into a W and a gravitino with an appreciable branching ratio. In the aforementioned samples, charginos decay exclusively into a stau and a tau neutrino. The different background samples and event selections are described in references [8–10].

The generated signal and background events were passed through the detailed simulation [12] of the DELPHI detector and then processed with the same reconstruction and analysis programs used for real data. Table 1 shows the range of efficiencies, the main components and the total amount of the expected background events, and the number of observed data events for each sample [1]. Figures 1 and 2 show the distributions of some of the main variables used in the analyses described respectively in [8] and [9] for real data, expected standard model background, and a simulated signal of $m_{\tilde{\chi}_1^+} = 85$ GeV/c^2 and $m_{\tilde{\tau}_1^+} = 69$ GeV/c^2.

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

Table 1: Range of efficiencies, main sources of background, expected background and observed data events for the different analyses.

3 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 3 shows the 95% CL 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 $\Delta m \geq 0.3$ GeV/c^2 and $m_{\tilde{G}} = 1$, 100 and 1000 eV/c^2. These

[1] In the case of $m_{\tilde{G}} = 1$ eV/c^2, the expected background and observed events correspond to the sum of the degenerate and non-degenerate scenarios in the leptonic channels of [8], with errors added in quadrature.

limits, which directly reflect the efficiencies of the applied selections, can be understood as follows:

$m_{\tilde{G}} = 1$ eV/c^2: When $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ approach m_{W}, the final state resembles that of W pair production, and the efficiency becomes smaller. On the other hand, for small chargino masses the visible energy increases and the efficiency is affected by the requirement that some missing energy must be observed. In both cases, the 95% CL limit on the chargino production cross section is increased.

$m_{\tilde{G}} = 100$ eV/c^2: The map of efficiencies is the result of the convolution of two factors. First, larger stau masses imply a smaller lifetime, and hence a smaller efficiency [9]. Secondly, a larger chargino mass leads to smaller stau momenta, and to smaller decay lengths.

$m_{\tilde{G}} = 1000$ eV/c^2: In this case, the map of efficiencies 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 in DELPHI's RICH detectors. To remove SM backgrounds, low momentum particles are removed, thus reducing the efficiency for higher chargino masses, especially in the region of small Δm.

Limits were derived in the frame of the model described in reference [4]. This general model assumes only radiatively broken electroweak symmetry and null trilinear couplings at the scale of the messengers' masses. 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 4 shows the regions excluded at 95% CL in the ($m_{\tilde{\chi}_1^+}$,$m_{\tilde{\tau}_1}$) plane. The positive-slope area is excluded for all gravitino masses. The negative-slope area is excluded for $m_{\tilde{G}} \geq 100$ eV/c^2. The area below $m_{\tilde{G}} = 68.5$ GeV/c^2 is excluded by the direct search for stau pair production [9]. The area of $\Delta m \leq 0.3$ GeV/c^2 is not excluded because in this region the charginos do not decay mainly into $\tilde{\tau}_1$ and ν_τ but on W and $\tilde{G}$. Therefore no events were generated in this region. Thus, if $\Delta m \geq 0.3$ GeV/c^2, limits at 85.5, 89.0 and 89.0 GeV/c^2 can be set for $m_{\tilde{G}} = 1$, 100 and 1000 eV/c^2 respectively. The limit at $m_{\tilde{G}} = 1$ eV/c^2 is also valid for smaller masses of the gravitino, because they lead to the same final state topologies. The same argument is true for $m_{\tilde{G}} \geq 1$ keV/c^2. The chargino mass limit decreases with decreasing $m_{\tilde{\tau}_1}$ because in scenarios with gravitino LSP, small stau masses correspond to small sneutrino masses (both are proportional to Λ), and hence to smaller production cross-sections 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 (the same as for MSSM chargino pair production with leptonic final states) produced eight candidate events to be compared to

10.7 ± 1.3 events expected from the SM background. An upper limit on the corresponding production cross-section between 0.36 and 0.48 pb was derived at 95% CL.

The search in the context of medium range gravitino mass (leading to stau production with impact parameters or kinks), selected no events from the data, to be compared to 0.63 ± 0.55 events expected from the SM background. The 95% CL upper limit on the corresponding production cross-section varies between 0.13 and 0.23 pb.

The search in the context of heavier gravitinos (leading to the production of stable staus) gave no candidate events, with 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% CL in the kinematically allowed region.

When combined, these results imply a 95% CL lower limit on the mass of the lightest chargino of 85.5 GeV/c^2, valid for $\Delta m \geq 0.3$ GeV/c^2 and independently of the mass of the gravitino.

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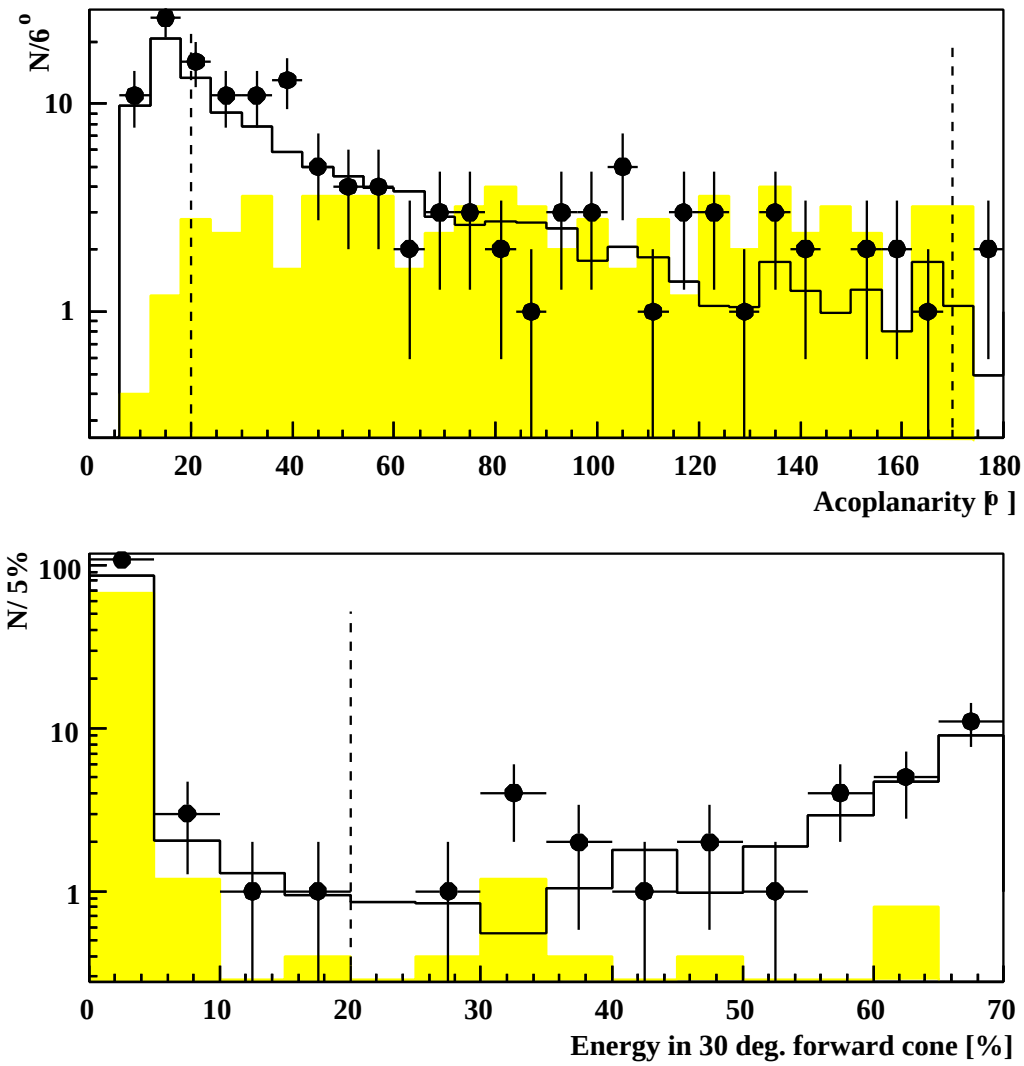

Figure 1: Coplanarity between the two lepton tracks (above) and percentage of energy deposited in a 30° forward cone (below), for real data (dots), expected Standard Model background (blank histogram) and simulated signal for $m_{\tilde{\chi}_1^+} = 85$ GeV/c^2 and $m_{\tilde{\tau}_1^+} = 69$ GeV/c^2 decaying with a mean distance of 50 cm (dark histogram). The segmented lines indicate selection criteria imposed as explained in [8].

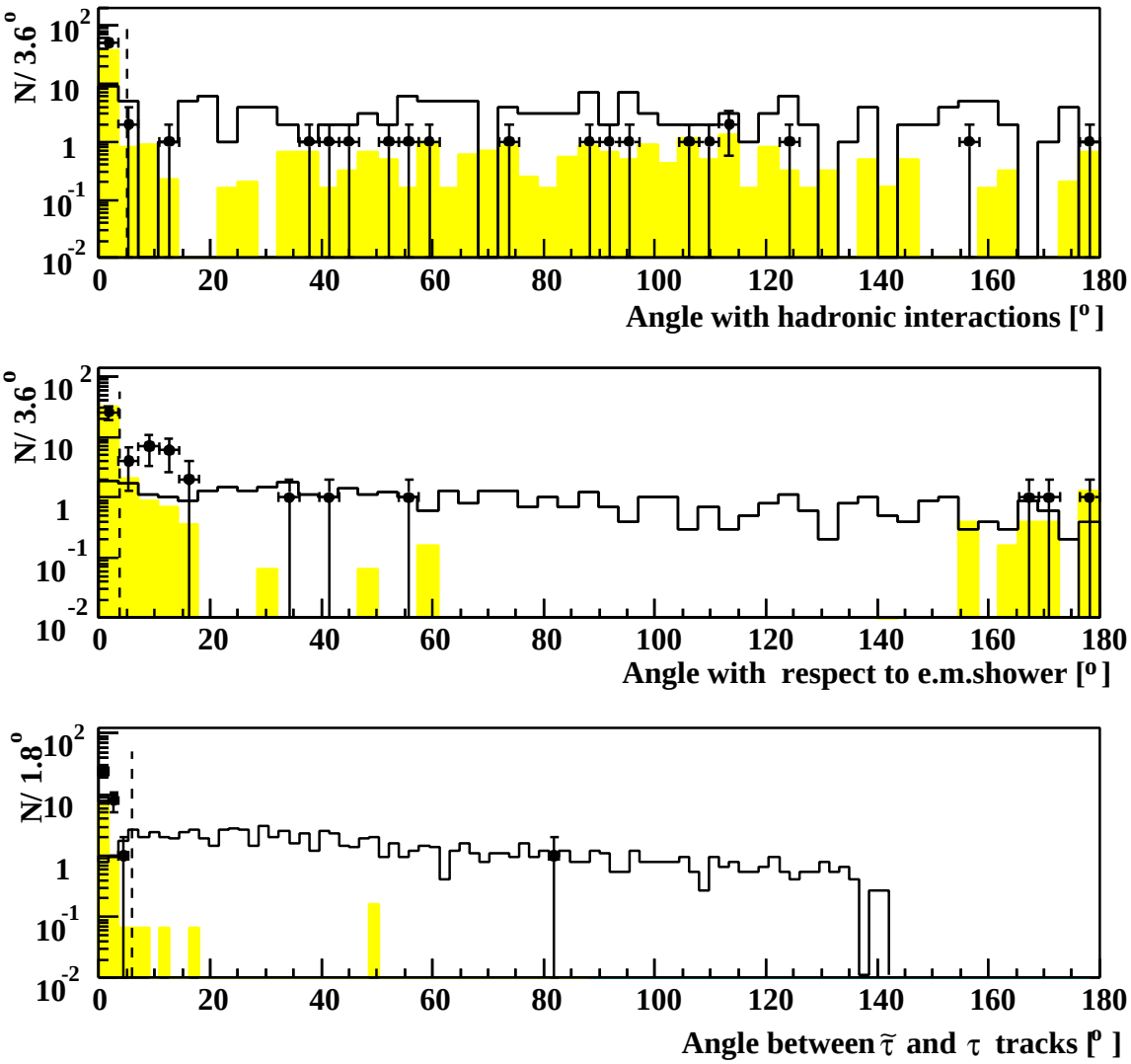

Figure 2: Angle between the hadronic interaction (if any) and the reconstructed vertex (above), angle between the electromagnetic shower and the direction defined by the difference between the momenta of $\tilde{\tau}_1$ and its associated τ, defined at the crossing point (middle), and angle between the tracks of the kink (below), for real data (dots), expected Standard Model background (dark histogram) and simulated signal for $m_{\tilde{\chi}_1^+} = 85$ GeV/c^2 and $m_{\tilde{\tau}_1^+} = 69$ GeV/c^2 decaying with a mean distance of 50 cm (blank histogram). The segmented lines indicate selection criteria imposed as explained in [9].

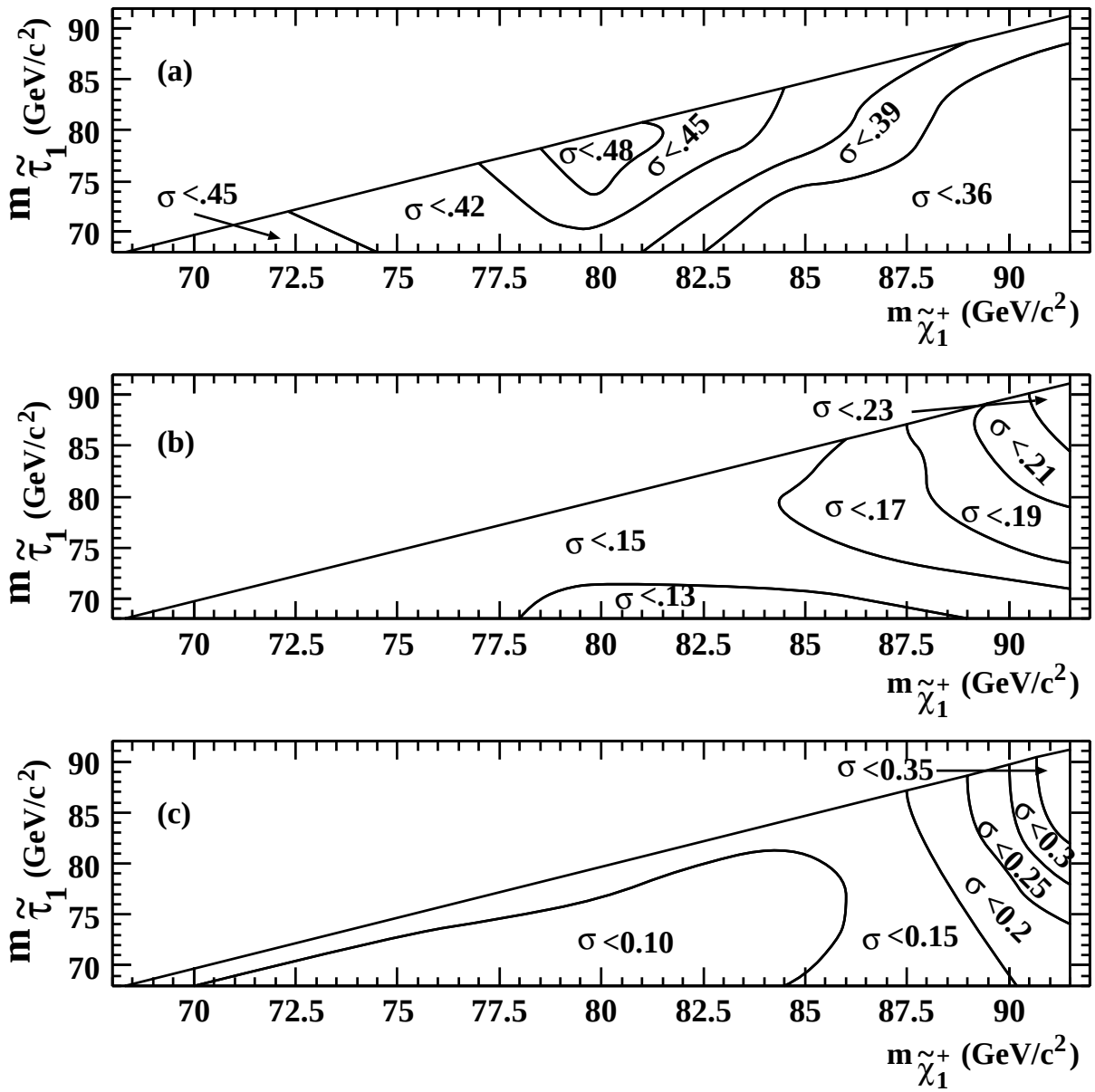

Figure 3: Limits in picobarn on lightest chargino pair production cross-section at 95% CL. Limits are shown as functions of $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ for (a) $m_{\tilde{G}} = 1$ eV/c^2, (b) $m_{\tilde{G}} = 100$ eV/c^2 and (c) $m_{\tilde{G}} = 1000$ eV/c^2.

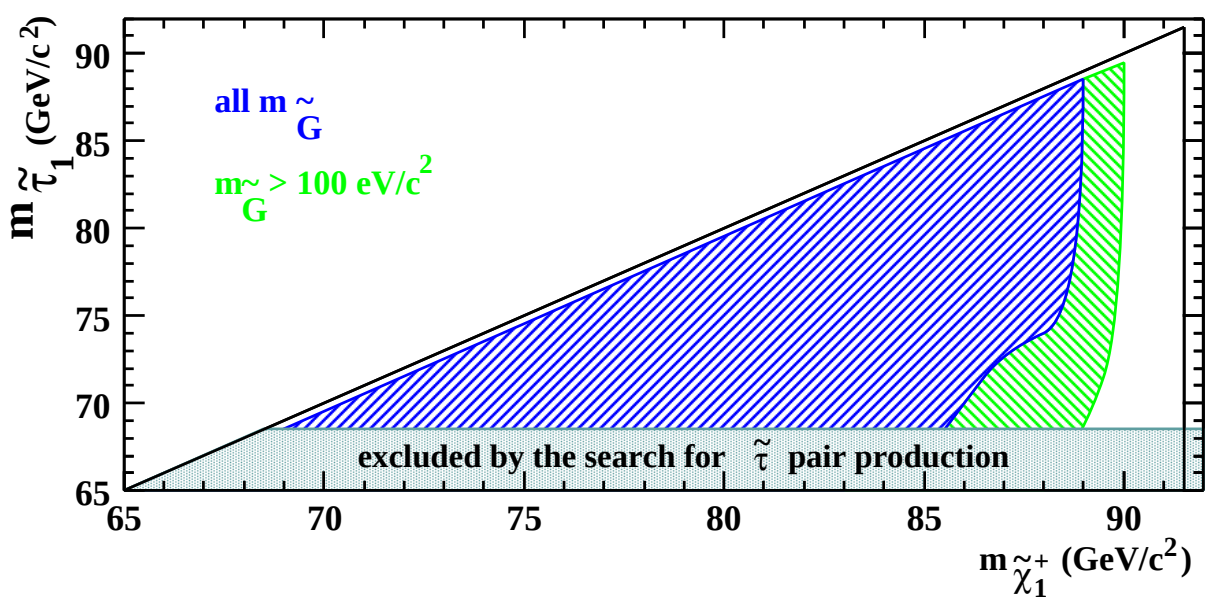

Figure 4: Areas excluded at 95% CL in the $(m_{\tilde{\chi}_1^+}, m_{\tilde{\tau}_1})$ plane. The positive-slope area is excluded for all $m_{\tilde{G}}$. The negative-slope area is excluded for $m_{\tilde{G}} \geq 100$ eV/c^2. The grey area is excluded by the direct search for stau pair production.