HEP'99 # 7_373
Submitted to Pa 7
Pl 7, 8

DELPHI 99-90 CONF 277
15 June 1999

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Preliminary

DELPHI Collaboration

Paper submitted to the HEP'99 Conference
Tampere, Finland, July 15-21

DELPHI Collaboration

Search for chargino pair production in gravitino LSP and stau NLSP scenarios at LEP

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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 centre-of-mass energies of 183 and 189 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 91.8 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.

1 Introduction

In some supersymmetric models, supersymmetry (SUSY) may be broken at a scale below 10^7 GeV, with the ordinary gauge interaction acting as the messenger of supersymmetry breaking [1, 2]. In this case, the gravitino, $\tilde{G}$, is 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.

The number of generations of supersymmetry breaking messengers in minimal models usually determines which particle is the NLSP [3, 5, 6, 7].

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 $\tilde{\tau}_L$ [8], 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:

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-\nu_\tau\overline{\nu}_\tau \qquad (1)$$

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

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

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 $m_{\tilde{G}} \lesssim 10$ eV/c^2 the stau decays at the interaction point. Thus, if chargino pairs would be 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 its search for charginos within the Minimal Supersymmetric Standard Model (MSSM) [9].

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

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 Cherenkov radiation would then be observed. Also this final signature has been already studied by the DELPHI Collaboration in the search for stable heavy particles [11].

Thus, this letter is intended to make use without modification of the analyses already applied in the three searches described in refs. [9], [10] and [11]. Real data and simulated SM samples at $\sqrt{s}$ = 183 GeV have already been analysed in this context, and the comparison between real and simulated data is included in refs. [9, 10, 11]. No excess over the expected SM background has been 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 regions in the $(m_{\tilde{\tau}_1}, m_{\tilde{\chi}_1^+})$ space which are excluded at 95% confidence level (CL).

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 [5].

2 Event sample and results

The search is based on data collected by the DELPHI collaboration during 1997 at centre-of-mass energies of 183 and 189 GeV. The total integrated luminosities were 53.9 and 158 pb^{-1} respectively. 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 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 charginos decay into Ws and gravitinos 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 [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. 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]. Figure 1 shows the distributions of the three main variables used the analysis described in [10] for real data, expected standard model background, and a simulated signal of $m_{\tilde{\chi}_1^+} = 90$ GeV/$c^2$and $m_{\tilde{\tau}_1^+} = 85$ GeV/c^2.

Sample	Efficiencies (%)	Main bgds.	Expected bgd.	Obs. evts.
$m_{\tilde{G}} = 1$ eV/c^2	24 - 36	WW , $\gamma\gamma$	38.9±4.9	36
$m_{\tilde{G}} = 100$ eV/c^2	28 - 50	$\gamma\gamma$	2.05±0.91	1
$m_{\tilde{G}} = 1000$ eV/c^2	0 - 63	$\mu\mu(\gamma)$	1.7±0.3	1

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

[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 [9], with errors added in quadrature.

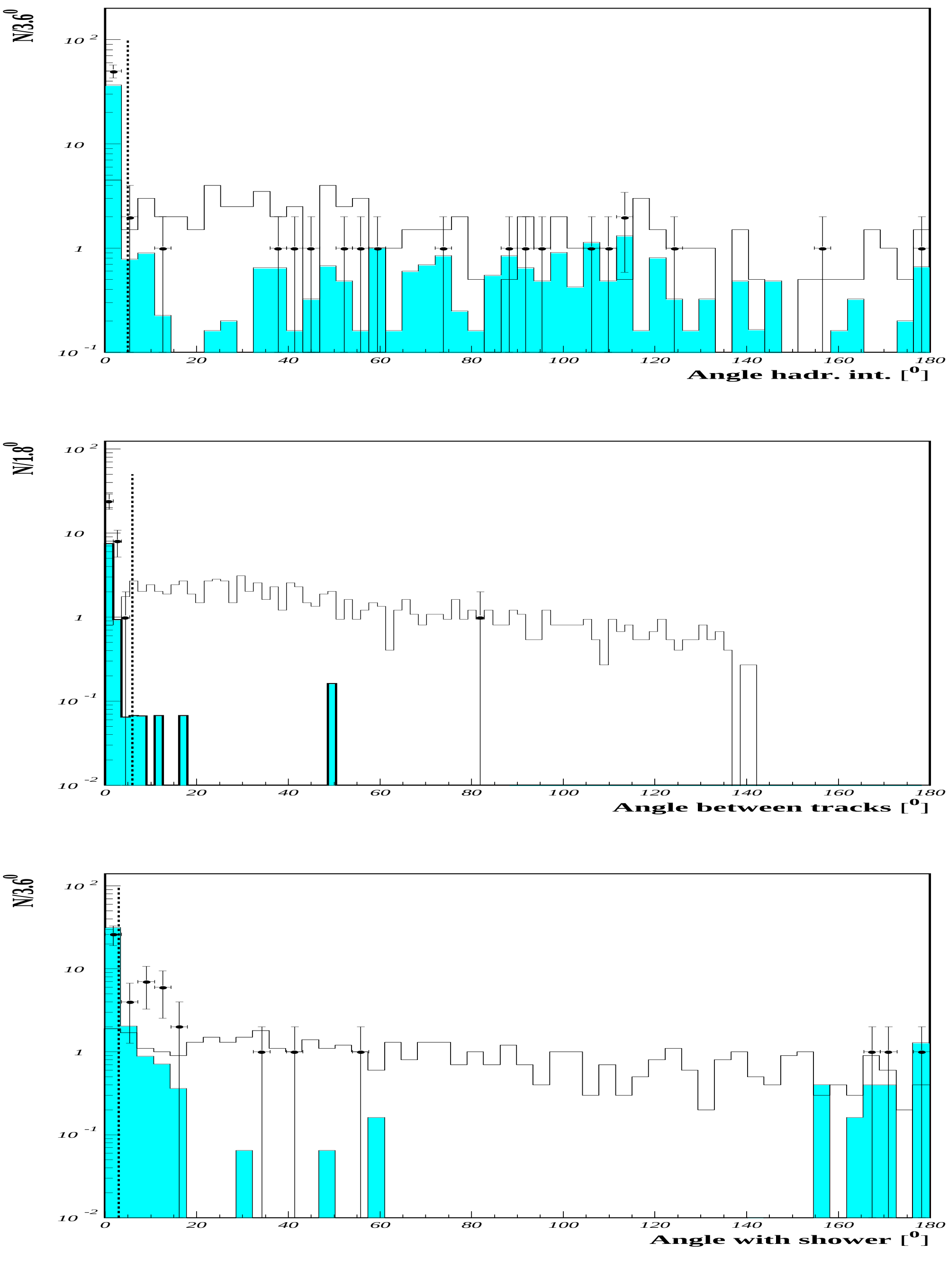

Figure 1: (a) angle between the hadronic interaction and the reconstructed vertex, (b) angle between the electromagnetic shower and the direction defined by the difference between the momenta of $\tilde{\tau}_1$ and its associated τ, defined at the crossing point, and (c) angle between the tracks of the kink, for real data (dots), expected Standard Model background (cross-hatched histogram) and simulated signal for $m_{\tilde{\chi}_1^+} = 90$ GeV/c^2 and $m_{\tilde{\tau}_1^+} = 85$ GeV/c^2 decaying with a mean distance of 50 cm (blank histogram). The arrows indicate selection criteria imposed as explained in [10].

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 2 shows the 95% C.L. upper limit on the chargino pair production cross-section at $\sqrt{s}$ = 189 GeV as a function of $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ after combining the results of the searches at $\sqrt{s}$ = 183 and 189 GeV with the maximum likelihood ratio method [4] for $\Delta m \geq 0.3$ GeV/c^2 and $m_{\tilde{G}}$ = 1, 100 and 1000 eV/c^2. These limits, which directly reflect the efficiencies of the applied selections, can be understood as follows:

$m_{\tilde{G}} = 1$ eV/c^2: The efficiency of this analysis is essentially flat over the kinematically allowed region. Thus, the main effect on the production cross section limit is given by the 211.9 pb^{-1} used for the region $m_{\tilde{\chi}_1^+} < 91.5$ GeV/c^2, and the 158 pb^{-1} for $m_{\tilde{\chi}_1^+} > 91.5$ GeV/c^2.

$m_{\tilde{G}} = 100$ 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 [10]. Second, 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 Cherenkov 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 [5]. This is a general model which 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 3 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 $m_{\tilde{G}} = 75.8$ GeV/c^2 is excluded by the direct search for stau pair production [10]. The area of $\Delta m \leq 0.3\,$GeV/c^2 is not excluded because no simulated events were generated in this region. Thus, if $\Delta m \geq 0.3\,$GeV/c^2, limits at 91.8, 93.0 and 93.0 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.

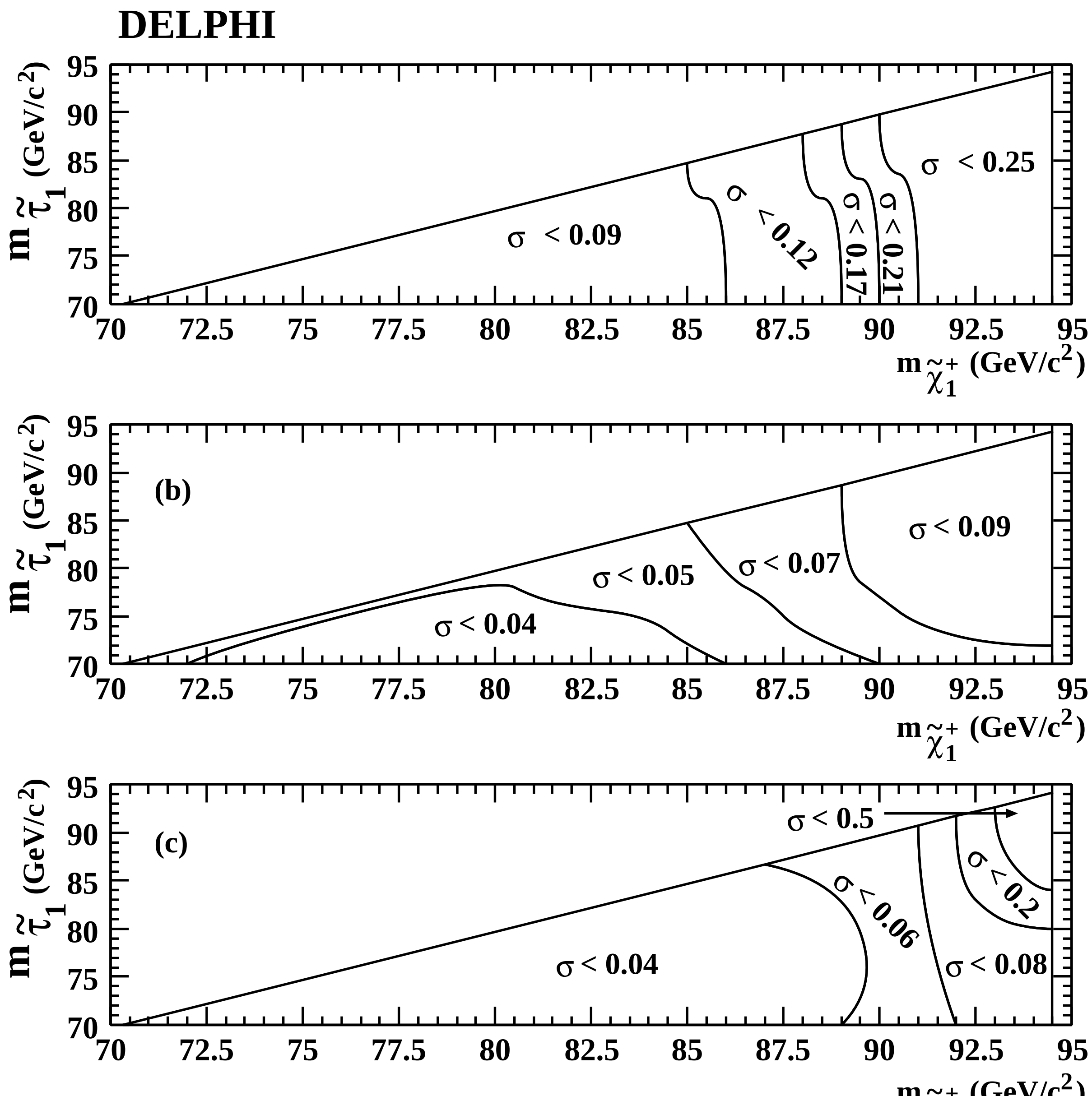

Figure 2: Limits in picobarn on the lightest chargino pair production cross-section at 95% CL. Limits are shown as functions of $m_{\tilde{\chi}_1^+}$ and $m_{\tilde{\tau}_1}$ for (a) $m_{\tilde{G}} = 1$ eV/c^2, (b) $m_{\tilde{G}} = 100$ eV/c^2 and (c) $m_{\tilde{G}} = 1000$ eV/c^2.

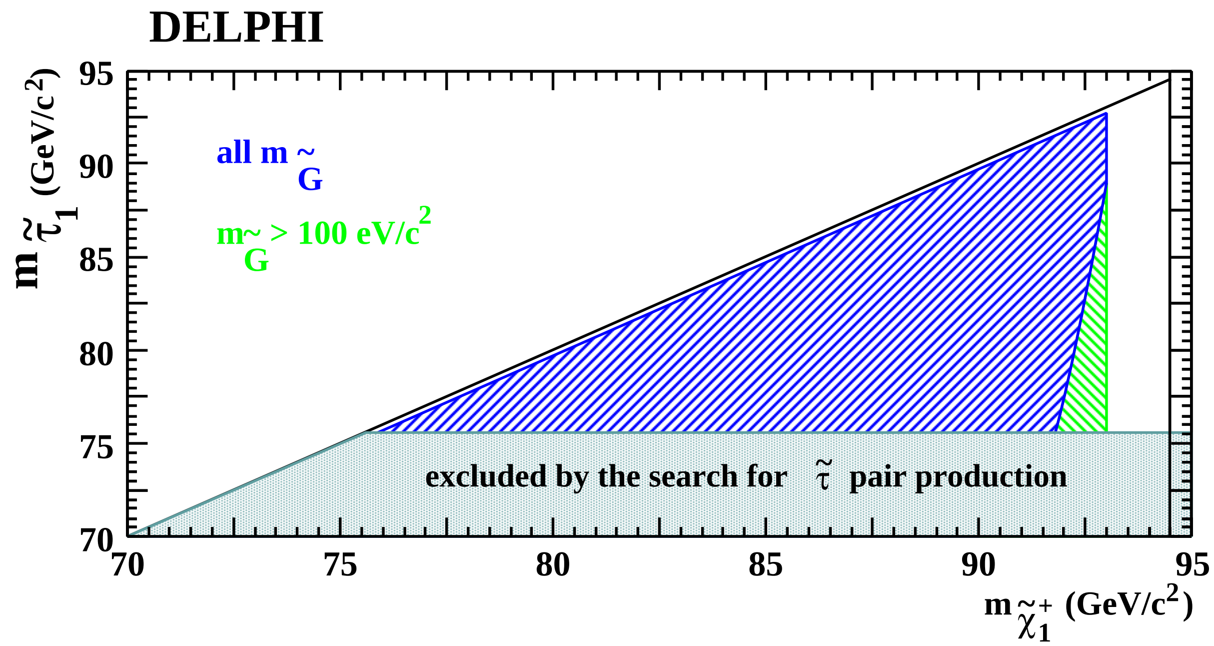

Figure 3: Areas excluded at 95% CL in the ($m_{\tilde{\chi}_1^+}$,$m_{\tilde{\tau}_1}$) plane. The positive-slope area is excluded for all $m_{\tilde{G}}$. The negative-slope area is excluded for $m_{\tilde{G}} \geq 100$ eV/c^2. The grey area is excluded by the direct search for stau pair production [10].

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 36 candidate events to be compared to 38.9±4.9 events expected from the SM background. An upper limit on the corresponding production cross-section between 0.09 and 0.25 pb was derived at 95% CL.

The search in the context of medium range gravitino masses (leading to stau production with impact parameters or kinks), selected one event from the data, to be compared to 2.05±0.91 events expected from the SM background. The 95% CL upper limit on the corresponding production cross-section varies between 0.04 and 0.09 pb.

The search in the context of heavier gravitinos (leading to the production of stable staus) gave one candidate event, with 1.7±0.3 events expected from the SM background. An upper limit on the corresponding production cross-section between 0.04 and 0.5 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 91.8 GeV/c^2, valid for $\Delta m \geq 0.3$ GeV/c^2, independently of the mass of the gravitino.

Acknowledgements

We are greatly indebted to our technical collaborators, to the members of the CERN-SL Division for the excellent performance of the LEP collider, and to the funding agencies for their support in building and operating the DELPHI detector.
We acknowledge in particular the support of
Austrian Federal Ministry of Science and Traffics, GZ 616.364/2-III/2a/98,
FNRS–FWO, Belgium,
FINEP, CNPq, CAPES, FUJB and FAPERJ, Brazil,
Czech Ministry of Industry and Trade, GA CR 202/96/0450 and GA AVCR A1010521,
Danish Natural Research Council,
Commission of the European Communities (DG XII),
Direction des Sciences de la Matière, CEA, France,
Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Germany,
General Secretariat for Research and Technology, Greece,
National Science Foundation (NWO) and Foundation for Research on Matter (FOM), The Netherlands,
Norwegian Research Council,
State Committee for Scientific Research, Poland, 2P03B06015, 2P03B03311 and SPUB/P03/178/98,
JNICT–Junta Nacional de Investigação Científica e Tecnológica, Portugal,
Vedecka grantova agentura MS SR, Slovakia, Nr. 95/5195/134,
Ministry of Science and Technology of the Republic of Slovenia,
CICYT, Spain, AEN96–1661 and AEN96-1681,
The Swedish Natural Science Research Council,
Particle Physics and Astronomy Research Council, UK,
Department of Energy, USA, DE–FG02–94ER40817.

References

[1] M. Dine, W. Fischler and M. Srednicki, Nucl. Phys. **B189** (1981) 575 ; S. Dimopoulos and S. Raby, Nucl. Phys. **B192** (1981) 353 ; M. Dine and W. Fischler, Phys. Lett. **B110** (1982) 227 ; M. Dine and M. Srednicki, Nucl. Phys. **B202** (1982) 238 ; L. Alvarez-Gaumé, M. Claudson and M. Wise, Nucl. Phys. **B207** (1982) 96 ; C. Nappi and B. Ovrut, Phys. Lett. **B113** (1982) 175 .

[2] M. Dine and W. Fischler, Nucl. Phys. **B204** (1982) 346 ; S. Dimopoulos and S. Raby, Nucl. Phys. **B219** (1983) 479.

[3] J. A. Bagger, K. Matchev, D. M. Pierce and R. Zhang, Phys. Rev. **D55** (1997) 3188.

[4] A.L. Read, *Optimal statistical analysis of search results based on the likelihood ratio and its application to the search for the MSSM Higgs boson at* $\sqrt{s} = 161$ *and 172 GeV*, DELPHI 97-158 PHYS 737 (1997) and references therein.

[5] D. A. Dicus, B. Dutta, S. Nandi, Phys. Rev. **D56** (1997) 5748 ; D. A. Dicus, B. Dutta, S. Nandi, Phys. Rev. Lett. **78** (1997) 3055.

[6] F. Borzumati, *On the Minimal Messenger Model*, hep-ph/9702307 and WIS/96-50-PH, Dec. 1996.

[7] G. F. Giudice, R. Rattazzi, *Theories with Gauge-Mediated Supersymmetry Breaking*, CERN-TH/97-380, Jan. 1998 and hep-ph/980127. Submitted to Phys. Rev. D.

[8] A. Bartl *et. al.*, Z. Phys. **C73** (1997) 469.

[9] DELPHI Collaboration, P. Abreu *et al.*, CERN-EP/98-176, Phys. Lett. **B446** (1999) 75; Paper 7_213 of this Conference.

[10] DELPHI Collaboration, P. Abreu *et al.*, E. Phys.J. **C7** (1999) 595; Papers 7_230 and 7_372 of this Conference.

[11] DELPHI Collaboration, P. Abreu *et al.*, CERN-EP/98-171, Phys. Lett. **B444** (1998) 491; Paper 7_119 of this Conference.

[12] DELPHI Collaboration, P. Aarnio *et al.*, Nucl. Instr. and Meth. **303** (1991) 233.

[13] DELPHI Collaboration, P. Abreu *et al.*, Nucl. Instr. and Meth. **378** (1996) 57.

[14] SUSYGEN 2.2, S. Katsanevas and S. Melachroinos in *Physics at LEP2*, CERN 96-01, Vol. 2, p. 328 and http://lyoinfo.in2p3.fr/susygen/susygen.html ; S. Katsanevas and P. Moravitz, Comp. Phys. Com. 122 (1998) 227.