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Abstract

Searches for charginos, neutralinos, and sleptons at LEP2 centre-of-mass energies from 130 GeV to 189 GeV have been used to set a lower limit on the mass of the Lightest Supersymmetric Particle within the MSSM framework. R-parity conservation has been assumed.

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1 Introduction

In 1998 the LEP centre-of-mass energy reached 188.7 GeV, and the DELPHI experiment collected an integrated luminosity of 153 pb^{-1}. These data have been analysed to search for the supersymmetric particles: sfermions, charginos and neutralinos predicted by supersymmetric (SUSY) models [1].

In this paper we interpret results of searches, presented in [2]-[10]

to constrain the mass of the lightest supersymmetric particle (LSP) which is assumed to be the lightest neutralino ($\tilde{\chi}_1^0$). The conservation of R-parity, implying a stable lightest supersymmetric particle (LSP), is assumed. The stable neutralino is a good dark matter candidate and its mass is of importance in cosmology.

Unless the contrary is explicitly stated, the Minimal Supersymmetric Standard Model (MSSM) scheme with universal parameters at the high mass scale typical of Grand Unified Theories (GUT's) is assumed [1]. The parameters of this model relevant to the present analysis are the masses M_1 and M_2 of the gaugino sector (which are assumed to satisfy the GUT relation $M_1 = \frac{5}{3}\tan^2\theta_W M_2 \approx 0.5 M_2$ at the electroweak scale), the universal mass m_0 of the scalar lepton sector (which enters mainly via the sneutrino mass and the selectron mass), the Higgs mass parameter μ, and the ratio $\tan\beta$ of vacuum expectation values of the two Higgs doublets.

The mass spectrum of charginos and neutralinos and the LSP mass in particular depend on M_2 (which is traditionally taken as a free parameter), μ and $\tan\beta$. The production cross-sections and decay branching ratios depend on the sfermion masses. The chargino production cross-section at a given energy can be greatly reduced by destructive interference between the s-channel and t-channel contributions if the sneutrino mass is below 300 GeV/c^2 and the SUSY parameters take particular values [11]. On the other hand, when the selectron is light, the neutralino production cross-section can be enhanced due to t-channel contribution of the selectron exchange ($\tilde{\text{e}}_L, \tilde{\text{e}}_R$) [12].

No general unification of scalar masses was assumed. As a consequence the mass spectrum of the Higgs sector and thus the decay branching ratios of heavier neutralinos ($\tilde{\chi}_2^0$,$\tilde{\chi}_3^0$,$\tilde{\chi}_4^0$) depend on one more parameter, which is taken to be the pseudoscalar Higgs mass, m_{A^0}. This mass was assumed to be 300 GeV/c^2 in this paper, but the results depend only weakly on this assumption.

2 The method

The LSP mass depends on M_2 ,μ and $\tan\beta$. The method employed to set a lower limit on the LSP mass is to convert the negative results of searches for charginos and neutralinos into exclusion regions in the (M_2 ,μ) plane for different $\tan\beta$ values and check what is the minimal allowed LSP mass as a function of $\tan\beta$. The limits presented in this note are valid for μ between -400 and 400 GeV/c^2 and M_2 below 200 GeV/c^2. The exclusion regions obtained from chargino and neutralino searches depend on the sneutrino and selectron mass values, respectively. The searches for sleptons and neutralinos are therefore used to find a minimal allowed sneutrino mass value. The scan over the sneutrino mass is then performed with special attention to the points were the chargino cross-section has a minimum, and where the chargino is nearly degenerate with the sneutrino.

The GUT relation with the common m_0 is used to relate selectron and sneutrino masses and to obtain a minimal allowed sneutrino mass for given $\tan\beta$ and M_2. The exclusion regions resulting from searches for charginos, neutralinos and sleptons are discussed in more detail below.

In the scan of the SUSY parameter space described above the efficiencies of the different searches, as obtained for the dominating channels using the SUSYGEN generator [13] and the full simulation of the DELPHI detector were used. These efficiencies were parametrised as functions of masses and mass differences, and applied to the many different modes of production and decay of supersymmetric particles. The procedure was checked using a very fast simulation program [14], together with SUSYGEN, to simultaneously simulate all channels of chargino and neutralino production and decay. This was done for about 4000 SUSY points, for which the selection criteria of the neutralino search could then be directly applied. The preliminary results of this study indicate that the results obtained using parametrised efficiencies are conservative.

2.1 Slepton limits

The unification of slepton masses to a common m_0 at the GUT scale allows to calculate slepton masses at the Electroweak Scale, as functions of $\tan\beta$, M_2 and m_0. In particular, sneutrino and left and right slepton masses can be expressed as:

$$M_{\tilde{\nu}}{}^2 = m_0^2 + 0.77M_2^2 + 0.5M_Z^2 cos(2\beta)$$
$$M_L^2 = m_0^2 + 0.77M_2^2 - 0.27M_Z^2 cos(2\beta)$$
$$M_R^2 = m_0^2 + 0.22M_2^2 - 0.27M_Z^2 cos(2\beta)$$

whereas the relationship between $M_{\tilde{\nu}}$ and $M_{\tilde{e}_L}$,

$$M_{\tilde{\nu}}{}^2 = M_{\tilde{e}_L}{}^2 + 0.77M_Z^2 cos(2\beta),$$

results from gauge invariance and does not depend on the unification assumption. The lower limits on the left and right slepton masses imply a lower limit on the sneutrino mass and that for every M_2 and $\tan\beta$ value there is a minimal slepton mass allowed by the slepton mass unification condition.

The results [9] of the DELPHI selectron search at 188.7 GeV were used. These exclude selectron production with cross-section greater than (0.05-0.2)pb, depending on the neutralino mass.

Figure 1 (right-hand side, upper part) illustrates exclusion region in M_2 vs μ plane for $\tan\beta$=1 and $m_0 = 70$ GeV/c^2 originating from the slepton searches.

2.2 Neutralino limits

The search for neutralino production is described in [5], [6] and [15]. Topologies with two acoplanar jets, leptons or gammas were searched for, as well as the single gamma topology. The search covers $\tilde{\chi}_k^0\tilde{\chi}_1^0$ final states with $\tilde{\chi}_k^0 \to \tilde{\chi}_1^0 + \mathrm{f\bar{f}}$ or $\tilde{\chi}_k^0 \to \tilde{\chi}_1^0 + \gamma$ ($k = 2,3,4$). Also the following states are covered:

- $\tilde{\chi}_2^0\tilde{\chi}_2^0$ with $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$;
- $\tilde{\chi}_4^0\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0\tilde{\chi}_2^0$ with $\tilde{\chi}_{3,4,}^0 \to \tilde{\chi}_2^0 + \nu\bar{\nu}$ and $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + \gamma$, giving to two acoplanar gammas in the final state.

The latter decay channel is enhanced in the small M_2 and $\mu < 0$ region, due the light sneutrino mediating the decay.

The LEP 1 search for $\tilde{\chi}^0_2\tilde{\chi}^0_1$ production with $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\gamma$ was also included.

Figure 1 (right hand side) illustrate exclusion region in M_2 vs μ plane for $\tan\beta$=1, $m_0 = 70$ GeV/c^2 and $m_0 = 1000$ GeV/c^2 originating from neutralino searches.

2.3 Chargino limits

The results of the search for charginos in DELPHI were described in [3, 5, 6, 7]. With the high luminosity collected this in 1989 chargino pair production with cross-section larger than 0.14 pb can be excluded, if $\Delta M > 20$ GeV/c^2.

From the point of view of the LSP limit it is important that the chargino search includes topologies with photons stemming from the decays $\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_2 W^* \to \tilde{\chi}^0_1\gamma W^*$. The search for topologies with γ's does not suffer from W^+W^- background and is effective for large ΔM (close to M_{W}). This is important in the region of low M_2 and $|\mu|$. At 183 GeV in the region of $\Delta M > 35$GeV/c^2 a dedicated search of W^+W^--like events with additional missing mass signature was performed, leading to a cross-section limit for chargino pair production $\sigma_{\tilde{\chi}^\pm,\tilde{\chi}^\pm} < 2.5$ pb. This search helps to cover the region of large ΔM. At 189 GeV, the chargino analysis described in [7] is sufficiently sensitive in the large ΔM region

The chargino search is not effective for small ΔM, given by $\Delta M = M_{\tilde{\chi}^\pm_1} - M_{\tilde{\chi}^0_1}$ (for $\tilde{\chi}^+_1 \to \tilde{\chi}^0_1$) or $\Delta M = M_{\tilde{\chi}^\pm_1} - M_{\tilde{\nu}}$ (for $\tilde{\chi}^+_1 \to \tilde{\nu}l$). $M_{\tilde{\chi}^0_1}$ is close to $M_{\tilde{\chi}^\pm_1}$ for large M_2, where either both masses are large ($\mu \lessapprox -50$GeV/c^2) or where the ΔM independent LEP1 limit on the chargino mass is effective (small $|\mu|$) [10].

The region of chargino-sneutrino degeneracy is potentially more dangerous, as it can occur where $M_{\tilde{\chi}^0_1}$ is small. For small $\tan\beta$ the slepton searches and neutralino searches imply a sufficiently high limit on the sneutrino mass (see Fig 2). The sneutrino is bound to be heavier than 94.5 GeV for $\tan\beta < 1.3$ which is above the kinematical limit for the chargino production. In fact for $\tan\beta < 1.3$, the M_2 vs μ region excluded by combined neutralino and slepton searches at low m_0 is larger than the region excluded by chargino searches for large m_0. Thus for $\tan\beta < 1.3$ the limit on the neutralino mass for "any m_0" is given by the high m_0 limit of 31.2 GeV/c^2 . Figure 1 illustrates exclusion regions in M_2 vs μ plane originating from chargino, slepton, and neutralino searches at $m_0 = 70$ GeV/c^2 and $m0 = 1000$ GeV/c^2 .

At large $\tan\beta$ for $M_2 < 100$ a sneutrino mass as small as 63 GeV/c^2 is allowed by slepton and neutralino searches, which degrades the chargino mass limit to about the same value. At high $\tan\beta$ the lightest neutralino mass is close to half of the chargino mass, thus the neutralino limit does not degrade.

3 Results

Fig 2 gives the lower limit on $M_{\tilde{\chi}^0_1}$ a function of $\tan\beta$. The minimal sneutrino mass allowed by the slepton and neutralino searches as a function of $\tan\beta$ is shown in the lower part of the figure together with the chargino mass corresponding to the neutralino mass limit. The lightest neutralino is constrained to have a mass:

$$M_{\tilde{\chi}^0_1} > 31.2 \text{ GeV}/c^2$$

The limit arises from combined searches for charginos, neutralinos and sleptons.

4 Summary

Searches for sleptons, charginos and neutralinos at $\sqrt{s} = 188.7$ GeV allow the exclusion of a large domain of SUSY parameters.

Within the Minimal Supersymmetric Standard Model (MSSM) scheme with gauge mass unification and slepton mass unification at the GUT scale the lightest neutralino has been constrained to have a mass [1] $M_{\tilde{\chi}_1^0} > 31.2$ GeV/c^2 . The result does not depend on m_0.

The result depends slightly on the mass of the pseudoscalar Higgs boson which was assumed to be $M_A = 300$ GeV/c^2.

[1]The limit occurs at high m_0. The number presented here is an update of the result of the [7] (31.4 GeV/c^2), which was obtained with smaller scan accuracy.

References

[1] P. Fayet and S. Ferrara, Phys. Rep. **32** (1977) 249;
H.P. Nilles, Phys. Rep. **110** (1984) 1;
H.E. Haber and G.L. Kane, Phys. Rep. **117** (1985) 75.

[2] DELPHI Coll., P. Abreu *et al.*, Phys. Lett. **B380** (1996) 471.

[3] DELPHI Coll., P. Abreu *et al.*, Phys. Lett. **B382** (1996) 323.

[4] DELPHI Coll., P. Abreu *et al.*, Phys. Lett. **B387** (1996) 651.

[5] DELPHI Coll., P. Abreu *et al.*, Eur. Phys. J. C 1, 1-20 (1998).

[6] DELPHI Coll., P. Andersson *et al.*, "Search for charginos, neutralinos, and gravitinos at $\sqrt{s}$=183 GeV", ICHEP'98, Vancouver, contributed paper 201, DELPHI 98-66 CONF 134;
DELPHI Coll., P. Abreu *et al.*, Phys. Lett. **B446** (1999) 75.

[7] DELPHI Coll., "Search for charginos at 189 GeV" ,DELPHI 99-9 CONF 209.

[8] DELPHI Coll., "Search for neutralinos at 189 GeV" ,DELPHI 99-11 CONF 211.

[9] DELPHI Coll., "Search for Scalar SUSY Particles at 189 GeV" ,DELPHI 99-24 CONF 223

[10] P.Rebecchi, *Optimisation de l'herméticité du détecteur DELPHI pour la recherche de particules supersymétriques à LEP2*, Ph.D. thesis, LAL 96-30 (May 1996), Université Paris XI Orsay, CERN THESIS-96-003.

[11] A.Bartl, H.Fraas and W. Majerotto, Z. Phys. **C30** (1986) 441;
A.Bartl, H.Fraas and W. Majerotto, Z. Phys. **C41** (1988) 475;
A.Bartl, H.Fraas, W. Majerotto and B.Mösslacher, Z. Phys. **C55** (1992) 257.

[12] S. Ambrosanio and B. Mele, Phys. Rev. **D52** (1995) 3900;
S. Ambrosanio and B. Mele, Phys. Rev. **D53** (1996) 2451.

[13] S. Katsanevas and S. Melachroinos in *Physics at LEP2*, CERN 96-01, Vol. 2, p. 328.
S. Katsanevas and P. Morawitz, Comp. Phys. Comm. **122** (1998) 227.

[14] M. Berggren, SGV 2.22, http://home.cern.ch/~berggren/sgv.html

[15] DELPHI Coll., Search for neutralino-pair production in topologies with gammas and missing energy at $\sqrt{s}$=130 GeV to 183 GeV, Vancouver, paper 207

[16] ALEPH Coll., D. Decamp *et al.*, Phys. Rep. **216** (1992) 253;
A. Lopez-Fernandez, DELPHI note 92-95 (Dallas) PHYS 206;
L3 Coll., M. Acciarri *et al.*, Phys. Lett. **B350** (1995) 109;
OPAL Coll., G. Alexander *et al.*, Phys. Lett. **B377** (1996) 273.

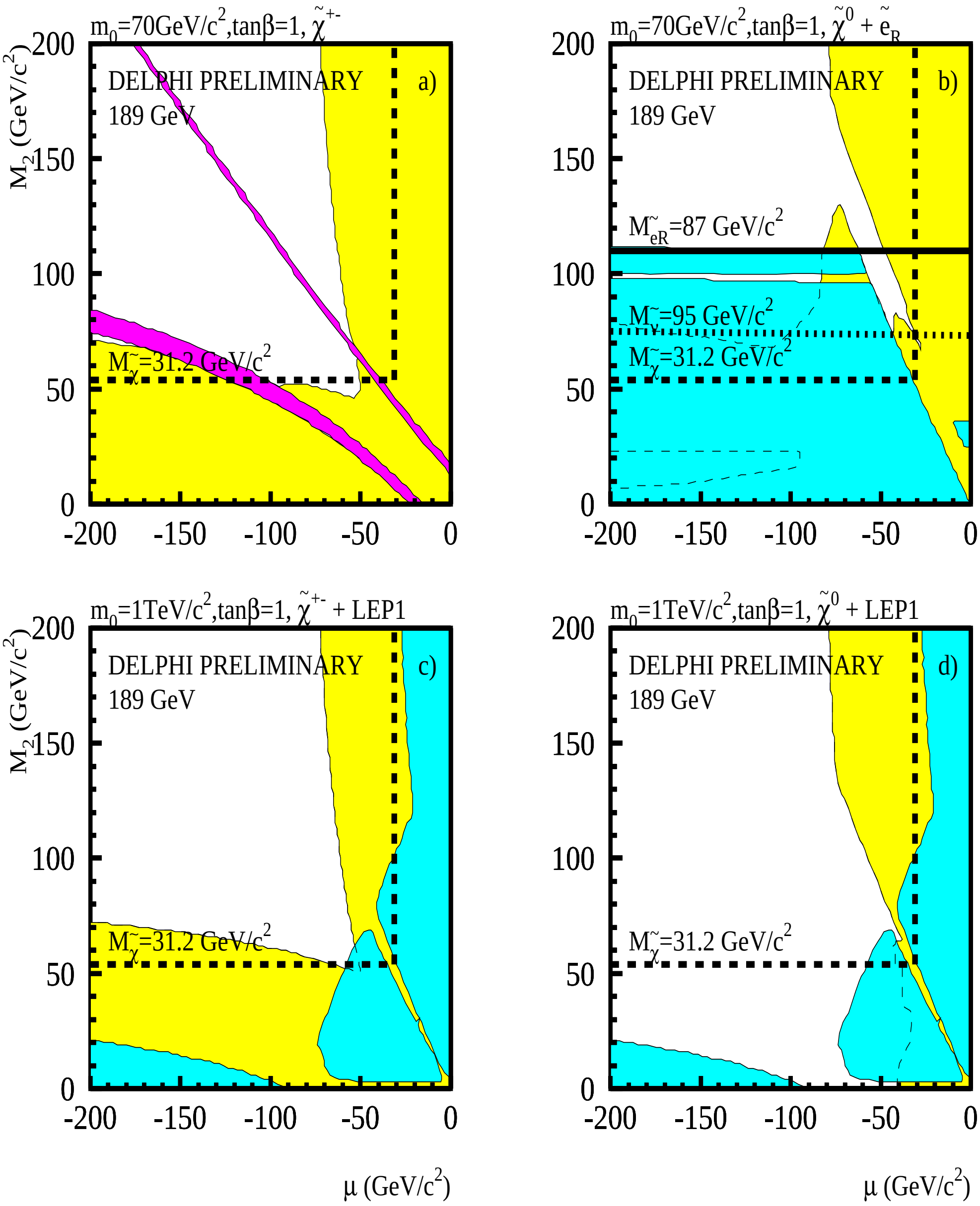

Figure 1: Excluded regions in the (μ,M_2)-plane for $m_0 = 70\text{GeV}/c^2$ (top) and $m_0 = 1\text{TeV}/c^2$ (bottom). The light shading and thin dashed curves show the regions excluded by searches for charginos (left) and neutralinos (right). The dark shading in (a) shows the non-excluded regions where $0 < M_{\tilde{\chi}_1^\pm} - M_{\tilde{\nu}} < 3$ GeV$/c^2$. In (b) the region excluded by the selectron search is shown in dark, while in (c) and (d) the dark region is the one excluded by LEP 1. Also shown are relevant isomass curves for $\tilde{\chi}_1^0$, $\tilde{e}_R$, and $\tilde{\nu}$.

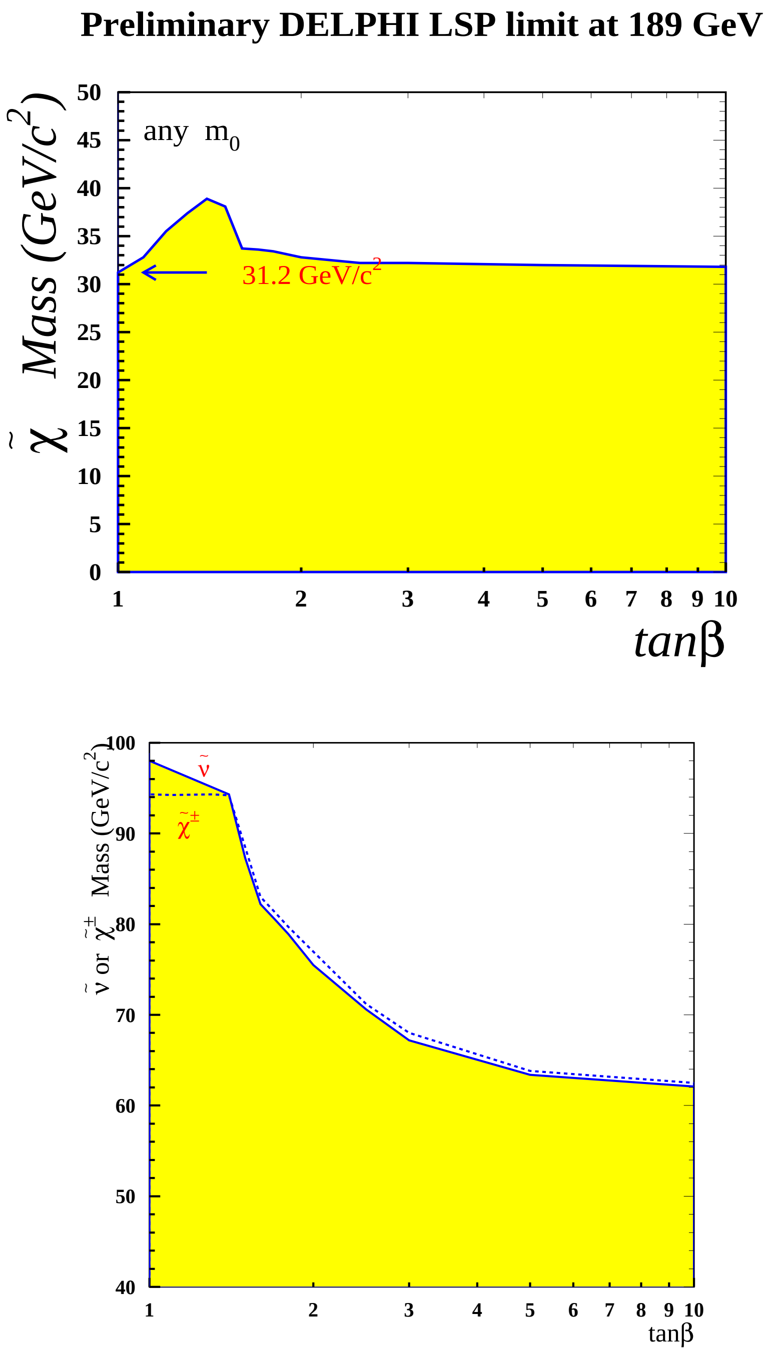

Figure 2: The upper figure shows the lower limit at 95% confidence level on the mass of the lightest neutralino, $\tilde{\chi}_1^0$, as a function of $\tan\beta$ assuming a stable $\tilde{\chi}_1^0$ and light sneutrino. On the left-hand side below, the minimal sneutrino mass alowed by the slepton and neutralinp searches is shown, as a function of $\tan\beta$, together with the chargino mass corresponding to the neutralino mass limit.