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Search for Charginos with a Small Mass Difference to the Lightest Supersymmetric Particle at $189\ \text{GeV} \leq \sqrt{s} \leq 202\ \text{GeV}$.

The L3 Collaboration

Abstract

An update of the search for charginos nearly mass-degenerate with the lightest supersymmetric particle is presented using the 408 pb^{-1} of data collected from 189 GeV to 202 GeV in 1998 and 1999 with the L3 detector. Mass differences between the chargino and the lightest supersymmetric particle below 4 GeV are considered. The presence of a high transverse momentum photon is required to single out the signal from the photon-photon interaction background. No evidence for charginos is found and upper limits on the cross section for chargino pair production are set. In the case of heavy scalar leptons, chargino mass limits are obtained for any $\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^0$ mass difference.

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1 Introduction

Supersymmetry (SUSY) is one of the most appealing extensions of the Standard Model. In SUSY theories with minimal particle content (MSSM) [1], in addition to the ordinary particles, there is a supersymmetric spectrum of particles with spins which differ by one half with respect to their Standard Model partners.

Charginos ($\tilde{\chi}_1^{\pm}$), which are a mixture of the supersymmetric partners of $W^{\pm}$ (gaugino state) and $H^{\pm}$ (higgsino state), are pair produced via s-channel γ/Z exchange. The production cross section can be reduced by an order of magnitude when the t-channel scalar neutrino ($\tilde{\nu}$) exchange is important.

In this paper the hypothesis of R-parity conservation is made. The R-parity is a quantum number which distinguishes ordinary particles from supersymmetric particles. If R-parity is conserved supersymmetric particles are pair-produced and their decay chain always contains, besides standard particles, two Lightest Supersymmetric Particles (LSP). The LSP, which is stable and for cosmological arguments [2] weakly-interacting, escapes detection. The LSP can be the lightest neutralino ($\tilde{\chi}_1^0$), a mixture of the supersymmetric partners of Z, γ, and neutral Higgs bosons, or the scalar neutrino.

As long as charginos are sufficiently heavier than the LSP, their decay products can be detected with high trigger and selection efficiencies. When the mass difference ($\Delta M = M_{\tilde{\chi}_1^{\pm}} - M_{\tilde{\chi}_1^0}$) is smaller than 4 GeV, the search described in Ref. [3] (hereafter referred as standard) becomes very inefficient, because in that range the signal and the photon-photon interaction background are indistinguishable.

For ΔM between a few hundred MeV and a few GeV, charginos decay near the interaction vertex and the energy carried by the visible decay products is so small that trigger inefficiencies become substantial. In addition, such a signal is overwhelmed by the photon-photon interaction background, which is rapidly increasing for decreasing masses of the photon-photon system. The trigger efficiency and the signal to background ratio can be improved by requiring in the event an Initial State Radiation (ISR) photon with high transverse momentum. Therefore, in this paper we report a search for the process

$$e^+e^- \;\rightarrow\; \gamma\tilde{\chi}_1^+\tilde{\chi}_1^- \;\rightarrow\; \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0 X$$

where X stands for low energy standard charged particles. We did publish this search for the 189 GeV data sample [4].

This method was previously used in the Mark II experiment [5] in the search for a fourth lepton doublet, whose members are close in mass. It was then suggested [6] for the search at LEP for charginos nearly mass-degenerate with the LSP. The DELPHI collaboration recently published such a search in a data sample collected at $\sqrt{s} \leq 183$ GeV [7].

2 Data Sample and Monte Carlo Simulations

This search uses the data collected from 189 GeV to 202 GeV with the L3 detector [8] for an integrated luminosity of 408 pb^{-1} . The following background processes are simulated: $e^+e^- \rightarrow \tau^+\tau^-\gamma(\gamma)$, $e^+e^- \rightarrow \mu^+\mu^-\gamma(\gamma)$ and $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$ with `KORALZ` [9], $e^+e^- \rightarrow W^+W^-\gamma(\gamma)$ with `KORALW` [10] and radiative Bhabha scattering with `TEEGG` [11]. The statistics of the Monte Carlo is equivalent to 6 to more than 60 times the integrated luminosity depending on the centre of mass energy and on the process.

Photon-photon interactions with hadronic final state ($e^+e^- \to e^+e^-q\bar{q}$) can not be reliably simulated in the range of interest of this analysis, because of the large theoretical uncertainties on the differential cross section in the non-perturbative regime. For photon-photon interactions with leptonic final states ($e^+e^- \to e^+e^-\ell^+\ell^-\gamma(\gamma)$) there is no complete Monte Carlo including the simulation of initial state radiation. For this reason, no photon-photon background is used.

Signal events are simulated with `SUSYGEN` [12] for chargino masses between 45 GeV and 95 GeV, ΔM from 30 MeV to 4 GeV and decay lengths ($c\tau$) up to 5 m. Only events with a photon more than 10° away from the beam pipe and with an energy greater than 4 GeV are considered. These requirements will be referred as fiducial cuts. The chargino partial widths as in Ref. [6] are used. For ΔM smaller than 200 MeV, $\tilde{\chi}_1^\pm$ decay lengths of a few centimetres may occur. In this case, $\tilde{\chi}_1^\pm$ decays are treated by the `GEANT` [13] package. The dependence of the chargino partial widths on the scalar particle masses is calculated with `SUSYGEN` neglecting interferences and non-perturbative effects when scalar quarks are involved.

The detector response is simulated using the `GEANT` package. It takes into account effects of energy loss, multiple scattering and showering in the detector materials and in the beam pipe. Hadronic interactions are simulated with the `GHEISHA` program [14]. Time dependent inefficiencies of the different subdetectors and of the trigger are also taken into account in the simulation procedure.

3 Low ΔM phenomenology

The search for low ΔM charginos accompanied by ISR photons does not suffer from the large photon-photon interaction background if the transverse momentum of the photon is large enough. While in signal events the missing momentum is due to weakly interacting particles, in photon-photon interactions it is due to the electrons escaping in the beam pipe. In the latter case, if a high transverse momentum photon is present at least one of the final state electrons must be deflected into the detector. To suppress the photon-photon interactions, the following requirement on the photon transverse momentum is applied:

$$E_{T\gamma} \geq 2E_{\text{beam}} \frac{\sin\theta_d}{1+\sin\theta_d} \tag{1}$$

where $\theta_d = 1.7°$ is the minimum detection angle for the deflected electron and E_{beam} is the beam energy. With this requirement the photon energy is large enough to trigger the detector.

The ISR energy spectrum in signal events depends on the relative contribution of the s-channel Z exchange, which in turn depends on the $Z\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ coupling. A softer photon spectrum is expected in the case of higgsino-like charginos than in the case of gaugino-like charginos. In addition, when scalar neutrinos are as light as charginos the t-channel diagram becomes important and modifies the shape of the ISR energy spectrum.

Chargino decay branching ratios in the low ΔM region change according to the opening of the various decay channels. For $\Delta M < 1.5$ GeV, the hadronic decay channel in one or two pions is enhanced and the decay spectrum is more similar to $\tau^\pm$ decays than to $W^\pm$ decays.

The $\tilde{\chi}_1^\pm$ decay length increases with decreasing ΔM. For $\Delta M \gtrsim 300$ MeV, the $\tilde{\chi}_1^\pm$ decays near the interaction vertex within 1 cm. For $m_{\pi^\pm} < \Delta M \lesssim 300$ MeV, the $\tilde{\chi}_1^\pm$ decays often inside the detector but a few centimetres away from the interaction vertex. For ΔM less than the $\pi^\pm$ mass, the $\tilde{\chi}_1^\pm$ decays outside the detector and appears as a heavy stable charged particle.

Chargino decays via virtual scalar lepton exchange occur if scalar leptons are as light as charginos, but only for gaugino-like charginos whose coupling to scalar leptons is strong enough.

1998-1999				
selection	low ΔM ΔM $\sim$3GeV	very low ΔM ΔM $\sim$1GeV	ultra low ΔM ΔM $\sim$300MeV	Combined
189 GeV(176 pb^{-1})	6/2.3	1/1.1	1/0.9	8/3.1
192-202 GeV(232 pb^{-1})	8/2.9 (7.9 ± 3.2)	4/1.5 (1.3 ± 1.1)	2/1.4 (1.3 ± 1.1)	9/3.8 (10.6 ± 3.7)
All (408 pb^{-1})	14/5.2	5/2.6	3/2.3	17/6.8

Table 1: Number of recorded and expected events for the ISR analyses. The number in parenthesis for $\sqrt{s} = 192 - 202$ GeV is the number of expected events estimated by scaling the observed number of events in the $\sqrt{s} = 189$ GeV data sample to the luminosity collected for the 192 GeV $\leq \sqrt{s} \leq$ 202 GeV data sample assuming that what we see at 189 GeV is background.

In general, the chargino width is not affected by supersymmetric scalar particles as long as they are more than 15 GeV heavier than the $\tilde{\chi}_1^{\pm}$. The same is true for chargino branching ratios if supersymmetric scalar particles are at least 30 GeV heavier than the $\tilde{\chi}_1^{\pm}$.

As an example, chargino decays are purely leptonic and the chargino decay length is extremely short when the $\tilde{\nu}$ is mass degenerate with or lighter than the chargino. In the latter case, where the two-body decay channel $\tilde{\nu}_{\rm e}{\rm e}^{\pm}$ is open, chargino decay lengths are smaller than 1 cm as long as ΔM is more than the electron mass.

4 Results

The complete analysis is described in [4]. This analysis is divided in 3 subselections : low ΔM for ΔM $\sim$ 3 GeV, very low ΔM for ΔM $\sim$ 1 GeV, ultra low ΔM for ΔM $\sim$ 300 MeV. The efficiencies are the same than in [4].

Overall we select 17 data events for 6.8 expected from the simulated Standard Model processes. The number of selected and expected events for each selection and for the combined one is shown in table 1. In the assumption that what we see at 189 GeV is background then we can use our previous observation as a prediction for this year. We use the signal efficiency, the simulated background prediction and the number of selected events, to derive a 95% confidence level upper limit on the chargino pair-production cross section as a function of ΔM and $M_{\tilde{\chi}_1^{\pm}}$ as shown in Figure 1. Those limits are obtained by combining the three selections, according to the method in Ref. [15] modified to include the background subtraction.

5 Interpretations in the MSSM

In the MSSM, chargino and neutralino masses depend on 4 parameters: M_1 the U(1) gaugino mass, M_2 the SU(2) gaugino mass, μ the Higgs mixing parameter and $\tan\beta$ the ratio of the two Higgs vacuum expectation values.

Generally, equal gaugino masses at the GUT scale are assumed, such that M_1 and M_2 are not independent parameters. In this case, low ΔM values are possible only if $|\mu| \ll M_2$ and for M_2 values larger than a few TeV. However, models with gaugino mass non-universality can be considered [16, 17] and as mentioned in Ref. [6] low ΔM regions become more natural in these models.

Once the unification relation is relaxed, three main regions can lead to low ΔM: $|\mu| \gg M_2$; in this region the $\tilde{\chi}_1^\pm$ mass is almost equal to M_2, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are both gaugino-like and ΔM can be small if $M_1 \gtrsim M_2$. $|\mu| \ll M_2$; in this region $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ are both higgsino-like and nearly mass degenerate, independently of the values of M_1 and M_2. Their masses are almost equal to $|\mu|$. $M_1 \gtrsim 4M_2$; in this region of the parameter space $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ mass degeneracy can be obtained for pure or mixed $\tilde{\chi}_1^\pm$ states.

We derive chargino mass limits as a function of ΔM assuming, unless otherwise stated, that all scalar particles are sufficiently heavy to be neglected in chargino production and decay. The limits are shown in Figures 2 and 3. For ΔM between 300 MeV and 1 GeV, gaugino-like $\tilde{\chi}_1^\pm$ are excluded up to 88.3 GeV if the $\tilde{\nu}$ is heavy (Figure 2a) and up to 67.6 GeV for any $\tilde{\nu}$ mass (Figure 3a), where cross sections smaller by an order of magnitude are predicted. In Figure 3a the limit is shown as a function of $\mathrm{M}_{\tilde{\chi}_1^\pm} - \mathrm{M}_{\mathrm{inv}}$, where the invisible particle can be either the lightest neutralino or the scalar neutrino. For the same ΔM range, $\tilde{\chi}_1^\pm$ are excluded up to 86.0 GeV for any mixture (Figure 2b).

The results of this search are combined with the results of the stable heavy charged particles search [18]. The resulting exclusion domain is superimposed on the one obtained by the standard $\tilde{\chi}_1^\pm$ search [3] as shown in Figures 2 and 3. The search with an ISR photon fills the gap between the two previous analyses and allows to derive direct search $\tilde{\chi}_1^\pm$ mass limits independent of ΔM.

The intersection between the ISR search and the stable heavy charged particles search occurs for decay lengths of order 10 cm. However, the relation between the chargino decay length and the ΔM is dependent on the supersymmetric parameters. Due to the mild dependence of the efficiency on ΔM, a scan on the MSSM parameters is done[1)] to search for the minimum overlap between these two searches. The relation between the decay length and ΔM used to derive the limits shown in Figures 2a, 2b and 3a is always the most conservative and it is found for mixed gaugino-higgsino states. In Figure 2b we use at the same time the most conservative relation between the decay length and ΔM and the smallest chargino cross section corresponding to pure higgsino state. On the contrary, in Figure 3b, where the Constrained MSSM [19] is used, chargino and neutralino mixtures are uniquely defined and used both for the decay length and cross section calculations.

Assuming that scalar particles are sufficiently heavy to be able to neglect their contributions in chargino production and decay, the following chargino mass limits are derived at 95% C.L.:

$$\begin{array}{ll} \mathrm{M}_{\tilde{\chi}_1^\pm} > 86.1 \text{ GeV} & \text{gaugino-like charginos} \\ \mathrm{M}_{\tilde{\chi}_1^\pm} > 82.4 \text{ GeV} & \text{any chargino mixture.} \end{array}$$

No direct search mass limits are derived for light $\tilde{\nu}_\mathrm{e}$ or $\tilde{\mathrm{e}}$ masses, because there is still an uncovered ΔM region between the stable heavy charged particles search and the search with an ISR photon. This gap is due to the shorter $\tilde{\chi}_1^\pm$ decay length when these scalar particles are mass degenerate with or lighter than the chargino. In such a case, charginos are stable only for ΔM below the electron mass.

Figure 3b shows the exclusion in the Constrained MSSM [19] in the higgsino region (very large M_2 values). The exclusion from the standard search is obtained by combining the contribution of the $\mathrm{e^+e^-} \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ process [3] with the chargino pair production:

$$\mathrm{M}_{\tilde{\chi}_1^\pm} > 84.2 \text{ GeV} \quad \text{Constrained MSSM.}$$

[1)] 45 GeV $< M_{\tilde{\chi}_1^\pm} <$ 95 GeV, $0.3 < M_1/M_2 < 50$, $1 < \tan\beta < 50$, $0 < |\mu| <$ 2 TeV. No scalar particle mass unification is assumed.

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† Deceased.

References

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

[2] J. Ellis *et al.*, Nucl. Phys. **B 238** (1984) 453.

[3] L3 Collaboration, M. Acciarri *et al.*, Phys. Lett. **B 472** (2000) 420-433.

[4] L3 Collaboration, M. Acciarri et al., Phys. Let. **B 482** (2000) 31–42.

[5] K. Riles *et al.*, Phys. Rev. **D 42** (1990) 1.

[6] C.H. Chen, M. Drees and J.F. Gunion, Phys. Rev. Lett. **76** (1996) 2002; Phys. Rev. **D 55** (1997) 330; Erratum Phys. Rev. Lett. **82** (1999) 3192.

[7] DELPHI Collaboration, P. Abreu et al., Eur. Phys. J. **C 11** (1999) 1–17.

[8] L3 Collaboration, B. Adeva *et al.*, Nucl. Instr. and Meth. **A 289** (1990) 35;
M. Chemarin *et al.*, Nucl. Instr. and Meth. **A 349** (1994) 345;
M. Acciarri *et al.*, Nucl. Instr. and Meth. **A 351** (1994) 300;
G. Basti *et al.*, Nucl. Instr. and Meth. **A 374** (1996) 293;
I.C. Brock *et al.*, Nucl. Instr. and Meth. **A 381** (1996) 236;
A. Adam *et al.*, Nucl. Instr. and Meth. **A 383** (1996) 342.

[9] The `KORALZ` version 4.02 is used.
S. Jadach, B.F.L. Ward and Z. Wąs, Comp. Phys. Comm. **79** (1994) 503.

[10] `KORALW` version 1.33 is used.
M. Skrzypek *et al.*, Comp. Phys. Comm. **94** (1996) 216;
M. Skrzypek *et al.*, Phys. Lett. **B 372** (1996) 289.

[11] The `TEEGG` version 7.1 is used.
D. Karlen, Nucl. Phys. **B 289** (1987) 23.

[12] `SUSYGEN` version 2.2 is used.
S. Katsanevas and P. Morawitz, Comp. Phys. Comm. **112** (1998) 227.
ISR simulation with `REMT`.
F.A. Berends and R. Kleiss, Nucl. Phys. **B 260** (1985) 32.

[13] The L3 detector simulation is based on GEANT Version 3.15.
See R. Brun et al., "GEANT 3", CERN DD/EE/84-1 (Revised), September 1987.

[14] The `GHEISHA` program, H. Fesefeldt, RWTH Aachen Report PITHA 85/02 (1985).

[15] J.F. Grivaz and F. Le Diberder, Complementary analyses and acceptance optimization in new particle searches, Preprint Lal 92-37 (June 1992).

[16] G. Anderson *et al.*, in DPF/DPB Summer Study on New Directions for High Energy Physics: Snowmass '96, Snowmass, CO, USA; 25 Jun - 12 Jul 1996, (D.G. Cassel, L. Trindle-Gennari and R.H. Siemann, APS, New York, 1997), p. 669.

[17] L. Randall and R. Sundrum, Nucl. Phys. **B 557** (1999) 79.

[18] L3 Collaboration, M. Acciarri *et al.*, Phys. Lett. **B 462** (1999) 354.

[19] See for instance:
L. Ibanez, Phys. Lett. **B 118** (1982) 73;
R. Barbieri, S. Farrara and C. Savoy, Phys. Lett. **B 119** (1982) 343.

[20] C. Caso *et al.*, *Review of Particle Physics*, Eur. Phys. J. **C 3** (1998) 1.

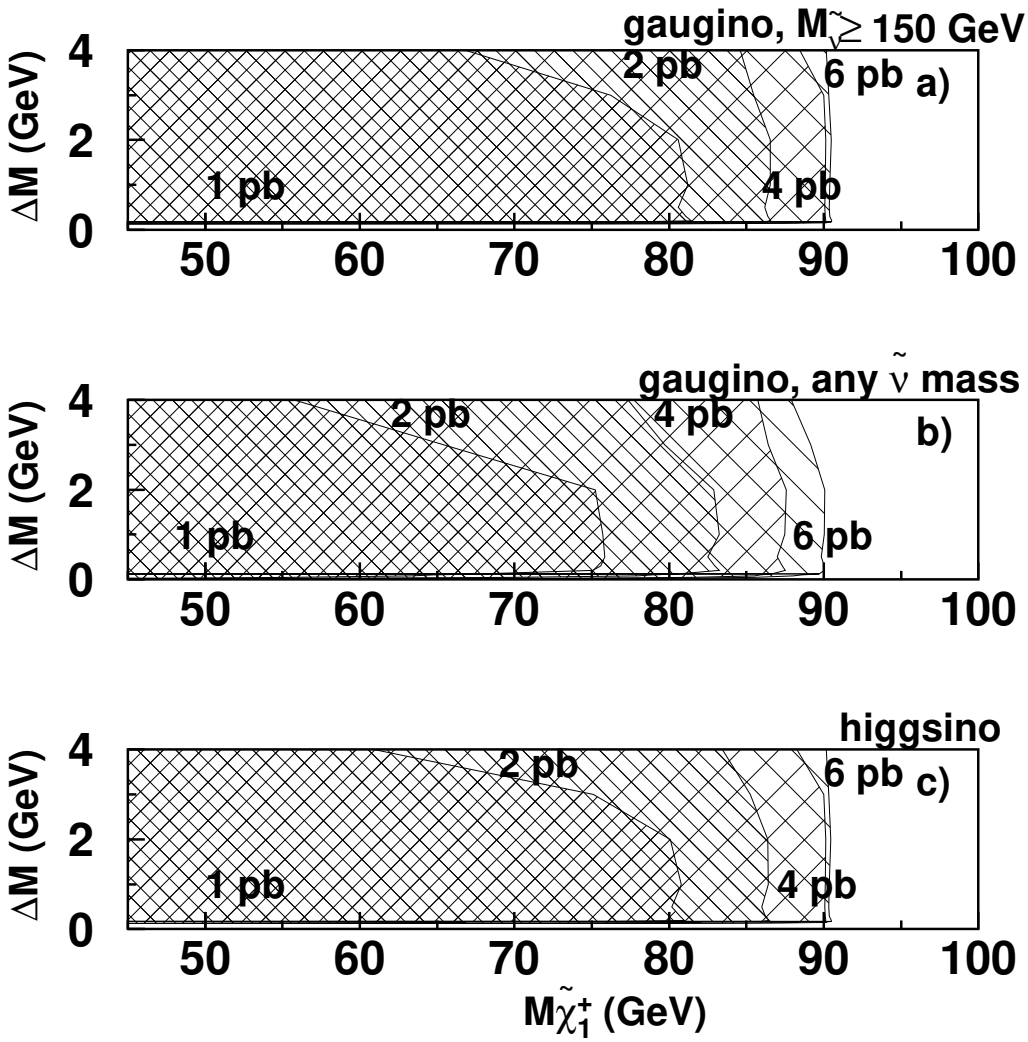

Figure 1: 95% C.L. cross section upper limits as a function of $M_{\tilde{\chi}_1^\pm}$ and ΔM for gaugino-like charginos with a) $M_{\tilde{\nu}} \gtrsim 150$ GeV and b) any $\tilde{\nu}$ mass, and c) for higgsino-like charginos.

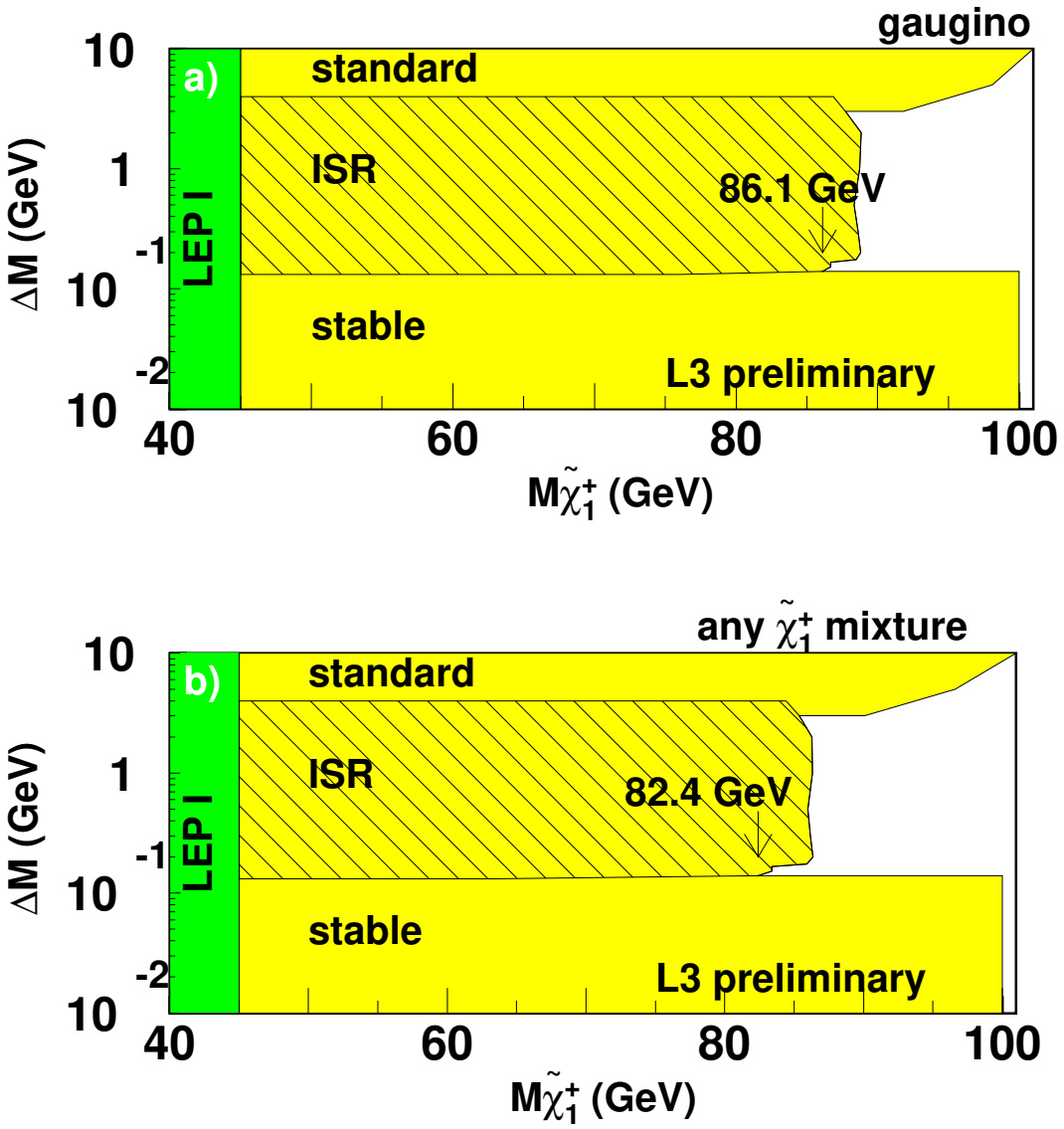

Figure 2: 95% C.L. chargino mass limits as a function of ΔM a) for a gaugino-like $\tilde{\chi}_1^{\pm}$ with a heavy $\tilde{\nu}$ and b) for any $\tilde{\chi}_1^{\pm}$ mixture. On each plot the top area corresponds to the standard search [3]. The search for heavy stable charged particles [18], shown in the bottom area, is combined to this search shown as the grey hatched area. The exclusion from LEP1 results on the Z width [20] is also shown.

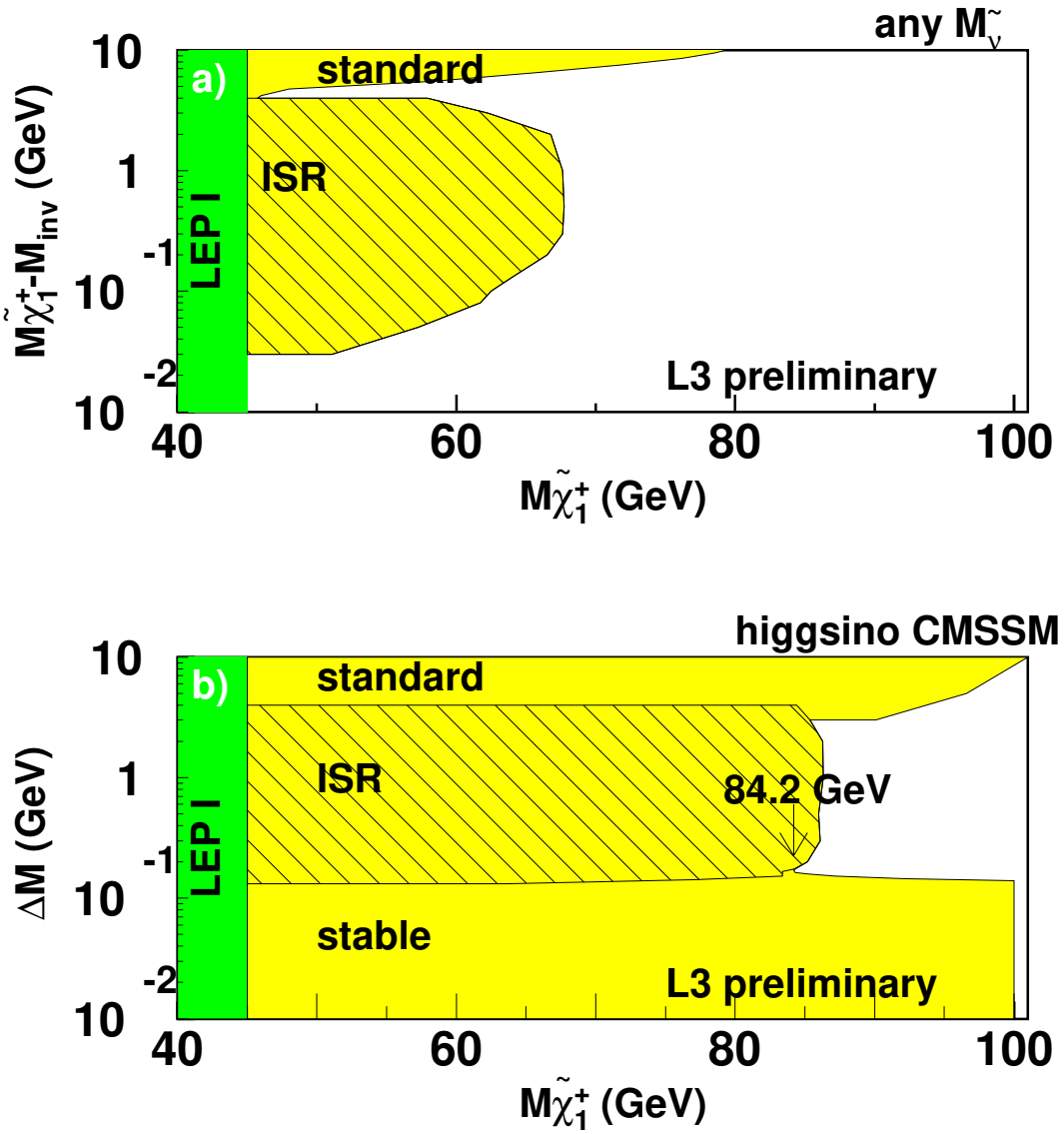

Figure 3: 95% C.L. chargino mass limits a) as a function of $M_{\tilde{\chi}_1^\pm} - M_{inv}$ for a gaugino-like $\tilde{\chi}_1^\pm$ and for any $\tilde{\nu}$ mass and b) as a function of ΔM for a higgsino-like $\tilde{\chi}_1^\pm$ in the Constrained MSSM (CMSSM). On each plot the top area corresponds to the standard search [3]. The search for heavy stable charged particles [18], shown in the bottom area, is combined to this search shown as the grey hatched area. The exclusion from LEP1 results on the Z width [20] is also shown.