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Search for SUSY with spontaneously broken R-Parity at $\sqrt{s} = 183\,\text{GeV}$ and $189\,\text{GeV}$

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Search for SUSY with spontaneously broken R-Parity at $\sqrt{s} = 183\,\text{GeV}$ and $189\,\text{GeV}$

D. Moraes, M. Gandelman and L. de Paula
Instituto de Física - LAPE/UFRJ - Brasil

Abstract

Searches for R-parity spontaneously violating signals in e^+e^- collisions at centre-of-mass energy of 183 GeV and 189 GeV have been performed in 1997 and 1998 DELPHI data, under the assumption of R-parity breaking in the third lepton family. The observations are in agreement with Standard Model predictions. The chargino mass limit and constraints on the MSSM parameter space were derived.

1 Introduction

This paper presents the search for R-parity spontaneous violation using DELPHI data collected in 1997 and 1998 at centre-of-mass energy of 183 GeV and 189 GeV, with an integrated luminosity of 53 pb^{-1} and 158 pb^{-1}, respectively. The aim of the work is to update the previous analysis presented in [1].

1.1 Spontaneous Breaking of R-Parity

In the Minimal Supersymmetric Standard Model (MSSM) the R-parity symmetry, related to the particle spin (S), lepton number (L) and baryon number (B) through the associated quantum number $R_p = (-1)^{3B+L+2S}$, is assumed to be conserved. Under this assumption the supersymmetric particles can only be produced in pairs, every SUSY particle decays into another SUSY particle and the lightest of them is absolutely stable. These features underlie most of the experimental searches for new supersymmetric states.

One alternative supersymmetric scenario is to consider the R-parity as an exact Lagrangian symmetry, broken spontaneously through the Higgs mechanism [2, 3, 4] that may occur via nonzero vacuum expectation values (VEVs) for scalar neutrinos. In this case there are two main scenarios depending on whether the lepton number is a gauge symmetry or not. In the absence of an additional gauge symmetry, it leads to the existence of a physical massless Nambu-Goldstone boson, called Majoron (J) [2]. In the present model [3] the Majoron, which is the Lightest Supersymmetric Particle (LSP), remains massless and therefore stable. The Lagrangian is specified by the superpotential

$$\begin{aligned} W = \quad & h_u Q H_u U + h_d Q H_d D + h_e L H_d E \\ + \quad & (h_0 H_u H_d - \mu^2)\Phi \\ + \quad & h_\nu L H_u \nu^c + h \Phi S \nu^c \\ + \quad & h.c. \end{aligned} \tag{1}$$

that conserves total lepton number and R-parity. The couplings h_u, h_d, h_e, h_ν, h_0, h are described by arbitrary matrices in generation space which explicitly break flavour conservation. The additional chiral superfields ν^c, S [5] and Φ [6] are singlets under $SU(2) \otimes U(1)$ and carry a conserved lepton number assigned as (-1,1,0), respectively. These superfields may induce the spontaneous violation of R-parity in an acceptable way [3], so that the Majoron is mainly a singlet given by the imaginary part of

$$\frac{v_L^2}{V v^2}(v_u H_u - v_d H_d) + \frac{v_L}{V}\tilde{\nu}_\tau - \frac{v_R}{V}\tilde{\nu}^c_\tau + \frac{v_S}{V}\tilde{S}_\tau \tag{2}$$

where the isosinglet VEVs $v_R = \langle \tilde{\nu}^c_\tau \rangle$ and $v_S = \langle \tilde{S}_\tau \rangle$, with $V = \sqrt{v_R^2 + v_S^2}$, characterize R-parity breaking and the isodoublet VEVs $v_u = \langle H_u \rangle$, $v_d = \langle H_d \rangle$ and $v_L = \langle \tilde{\nu}_{L\tau} \rangle$ induce electroweak breaking and generate the fermion masses.

By construction, neutrinos are massless before breaking of R-parity and, as a result, all R-parity violating observables are directly correlated to the neutrino mass, with the magnitude of this correlation depending upon the choice of the R-parity SUSY parameters.

1.2 Chargino Decay Modes

In this scenario the chargino can be pair produced via e^+e^- annihilations into $\gamma, Z, \tilde{\nu}$ and their decay modes are modified by the existence of new channels:

$$\begin{array}{l} \tilde{\chi}^{\pm} \to \nu_\tau W^{\star\pm} \to \nu_\tau q\bar{q}', \nu_\tau l_i^{\pm}\nu_i \\ \tilde{\chi}^{\pm} \to \tilde{\chi}^0 W^{\star\pm} \to \tilde{\chi}^0 q\bar{q}', \tilde{\chi}^0 l_i^{\pm}\nu_i \\ \tilde{\chi}^{\pm} \to \tau^{\pm} J \end{array} \quad (3)$$

This last decay is allowed if we consider that the R-parity breaking occurs in the third generation. The chargino cross section at 183 GeV and 189 GeV varies typically from 0 to 8 pb and in a large range of the R-parity violation parameter the chargino decays predominantly into $\tau^{\pm}J$, as can be observed in figure 1.

All the results discussed in the following sections were achieved by considering the new two body chargino decay as the dominant decay mode. In order to simplify the analysis we assumed that all sfermions are sufficiently heavy ($M_{\tilde{\nu}} \geq 300\,\mathrm{GeV/c^2}$) not to influence the chargino production, as well as its decays. Typical values for SUSY parameters $\mu \equiv h_0\langle\Phi\rangle$, $\mathrm{M_2}$ and $\tan\beta$ lie in the range

$$-200\,\mathrm{GeV/c^2} \leq \mu \leq 200\,\mathrm{GeV/c^2} \qquad 40\,\mathrm{GeV/c^2} \leq \mathrm{M_2} \leq 400\,\mathrm{GeV/c^2} \quad (4)$$

$$2 \leq \tan\beta = \frac{v_u}{v_d} \leq 40 \quad . \quad (5)$$

We take the GUT relation $\mathrm{M_1/M_2} = 5/3\tan^2\theta_W$.

2 Data Samples

The data collected by the DELPHI detector [7] during 1997 at $\sqrt{s} \simeq 183$ GeV and 1998 at $\sqrt{s} \simeq 189$ GeV, corresponding to an integrated luminosity of 53 $\mathrm{pb^{-1}}$ and 158 $\mathrm{pb^{-1}}$ respectively, were analysed.

To evaluate background contaminations, different contributions from the Standard Model processes were considered. The background processes WW, $We\nu_e$, Z^0Z^0, $Z^0e^+e^-$ and $Z^0/\gamma \to q\bar{q}(\gamma)$ were generated using PYTHIA [8], while the events $Z^0/\gamma \to \tau^+\tau^-(\gamma), \mu^+\mu^-(\gamma)$ were produced by KORALZ [9] and DYMU3 [10] respectively. A cross-check was performed using the four-fermion final states generated with EXCALIBUR [11]. The generator of [12] was used for the Bhabha scattering. Two-photon interactions leading to leptonic and hadronic final states were produced by the BDK [13] and TWOGAM [14] programs, respectively. All the background events were passed through a detailed detector response simulation (DELSIM [15]) and reconstructed as the real data.

The RP-generator II program [16] was used to generate chargino production and decay events and to calculate masses, cross sections and branching ratios. The chargino pair production was considered for different values of R-parity violation parameter (ϵ) and in several points of the MSSM parameter space ($\tan\beta, \mu, \mathrm{M_2}$). For the signal, a faster simulation program SGV [17] was used to check the points that were not generated by the full DELPHI simulation program.

3 Chargino Searches

With the R-parity spontaneous breaking, the chargino can decay into $\tau^\pm J$ events that have the topology of two acoplanar taus plus a high missing energy due to the undetectable Majoron. To select events with this signature it was demanded that there were exactly two clusters of well reconstructed charged and neutral particles with invariant mass below 5.5 GeV/c^2, less than 7 charged tracks in the event, a total event charge of 0 or ± 1, no calorimetric energy in a 30° cone around the beam axis. A good agreement between data and simulated events is observed after this preselection. Figure 2 shows this agreement for some variable distributions at 183 GeV and 189 GeV.

After the preselection, the applied criteria were depending on the centre-of-mass energy and are described in the sections below.

3.1 Event Selection at 183 GeV

At this energy, the events were selected by the following requirements: the acoplanarity had to be between 4° and 175°; the energy of the most energetic isolated photon had to be below 5 GeV; at least 2 tracks with momentum above 1 GeV/c, and at least one track with momentum above 5 GeV/c and below 60 GeV/c were required; the square of transverse momentum with respect to the thrust axis had to be above 0.75 (GeV/c)^2; there should be no signal in the 40° and 90° taggers.

The events passed the above criteria were then classified, according to the momentum of their most energetic charged particle (P_{max}). If P_{max} was below 10 GeV/c, the event was classified as a $\gamma\gamma$ and the track transverse momentum was required to be above 10.5 GeV/c. For events regarded as $Z/\gamma \to \tau^+\tau^-$ background, $P_{max} > 10$ GeV/c and acoplanarity below 165°, the polar angle of the vectorial sum of momenta must be between 30° and 150°.

To reduce the remaining backgrounds, WW, the momentum of the most energetic lepton had to be below 23.5 GeV/c and the polar angle of the vectorial sum of momenta had to be between 34.5° and 145.5°.

3.2 Event Selection at 189 GeV

In order to reduce the background contamination, the analysis for 189 GeV was modified. In this analysis it was demanded that there were no isolated photon in the event. The acoplanarity had to be between 4° and 170°. The momentum of each of the two particle clusters must be above 5 GeV/c and below 55 GeV/c. The missing transverse momentum had to be greater than 4 GeV/c and the polar angle of the vectorial sum of momenta must be between 35° and 145°. There should be no signal in any isolated tagger.

To suppress the events were the tau decays asymmetrically in visible momentum, the square of transverse momentum with respect to the thrust axis had to be above 1 (GeV/c)^2.

The events from radiative return to Z and WW processes were mainly rejected by requiring a total transverse momentum greater than 9 GeV/c and that the momentum of the most energetic lepton was below 23 GeV/c.

If one cluster had a momentum above 10 GeV/c and an acoplanarity below 165° it was also demanded that the value of $\sqrt{s'}$ did not fall in the region between 90 GeV and

94 GeV. For an acoplanarity greater than 165° we required that the polar angle of the vectorial sum of momenta should be between 40° and 140° and that the visible mass was lower than 70 GeV/c^2. This last cut is very efficient to remove WW background.

4 Results

The analysis presented in this paper considers the $\tilde{\chi}^{\pm} \rightarrow \tau^{\pm} + J$ as the dominant decay mode. The main signal events were simulated by SGV [17], where the taggers are not taken into account. To correct this effect, ten chargino mass points, with 1000 events in each one, were simulated by the full DELPHI simulation program (DELSIM) and the selection efficiency[1] from SGV was compared with the selection efficiency from DELSIM. This procedure was done for 183 GeV analysis and the correction factors for the SGV efficiency if the taggers are considered, showed in figure 3, were also used for 189 GeV simulation. This efficiency varies weakly with the chargino mass, as can be seen in figure 4.

As a result of the described selection procedure, 6 candidates of $\tilde{\chi}^{\pm} \rightarrow \tau^{\pm} + J$ were found at 183 GeV and 9 candidates at 189 GeV. The number of events selected in the data and the expected number of background events are summarized in table 1.

The combined results obtained for 183 GeV and 189 GeV were used to calculate the maximum number of signal events in presence of a background with 95% of confidence level, given by the standard formula in [18], the minimal excluded cross section and the chargino mass limit, showed in figure 5. We also constrained the domains of the MSSM parameter space for $\tan\beta = 2$ and $\tan\beta = 40$ (figure 6).

5 Conclusion

Searches for R-parity spontaneous violating signals were performed in a data sample of about 211 pb^{-1} collected by the DELPHI detector during 1997 and 1998 at centre-of-mass energy of 183 GeV and 189 GeV. No evidence for R-parity spontaneously breaking has been observed, assuming a sneutrino mass above 300 GeV/c^2. A limit on the chargino production cross section of 0.23 pb is obtained. For this analysis the lower limit on the chargino mass is 94.4 GeV/c^2, at 95% confidence level.

6 Acknowledgements

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Centre-of-mass Energy	**183 GeV**	**189 GeV**
Observed events	**6**	**9**
Total background	**6.28 ± 0.40**	**9.55 ± 0.44**
$Z^{\circ}/\gamma \rightarrow ee, \mu\mu, \tau\tau, q\bar{q}$	0.86 ± 0.23	0.57 ± 0.12
4-fermion events except WW	0.60 ± 0.05	1.2 ± 0.16
$\gamma\gamma \rightarrow ee, \mu\mu, \tau\tau$	0.28 ± 0.13	0.21 ± 0.21
$W^{+}W^{-}$	4.38 ± 0.28	7.57 ± 0.33
$e^{+}e^{-} \rightarrow e^{+}e^{-}$	0.16 ± 0.09	—

Table 1: Chargino candidates with the total number of background expected and the contributions from major background sources at centre-of-mass energy of 183 GeV and 189 GeV.

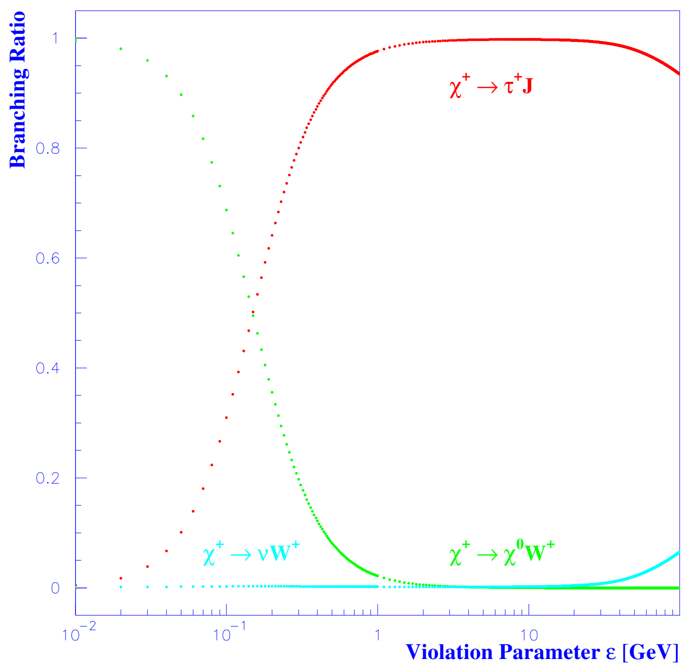

Figure 1: Chargino decay branching ratios as a function of the effective violation parameter ϵ at 189 GeV for $\tan\beta = 2$, $\mu = 100$ GeV/c^2 and $M_2 = 400$ GeV/c^2.

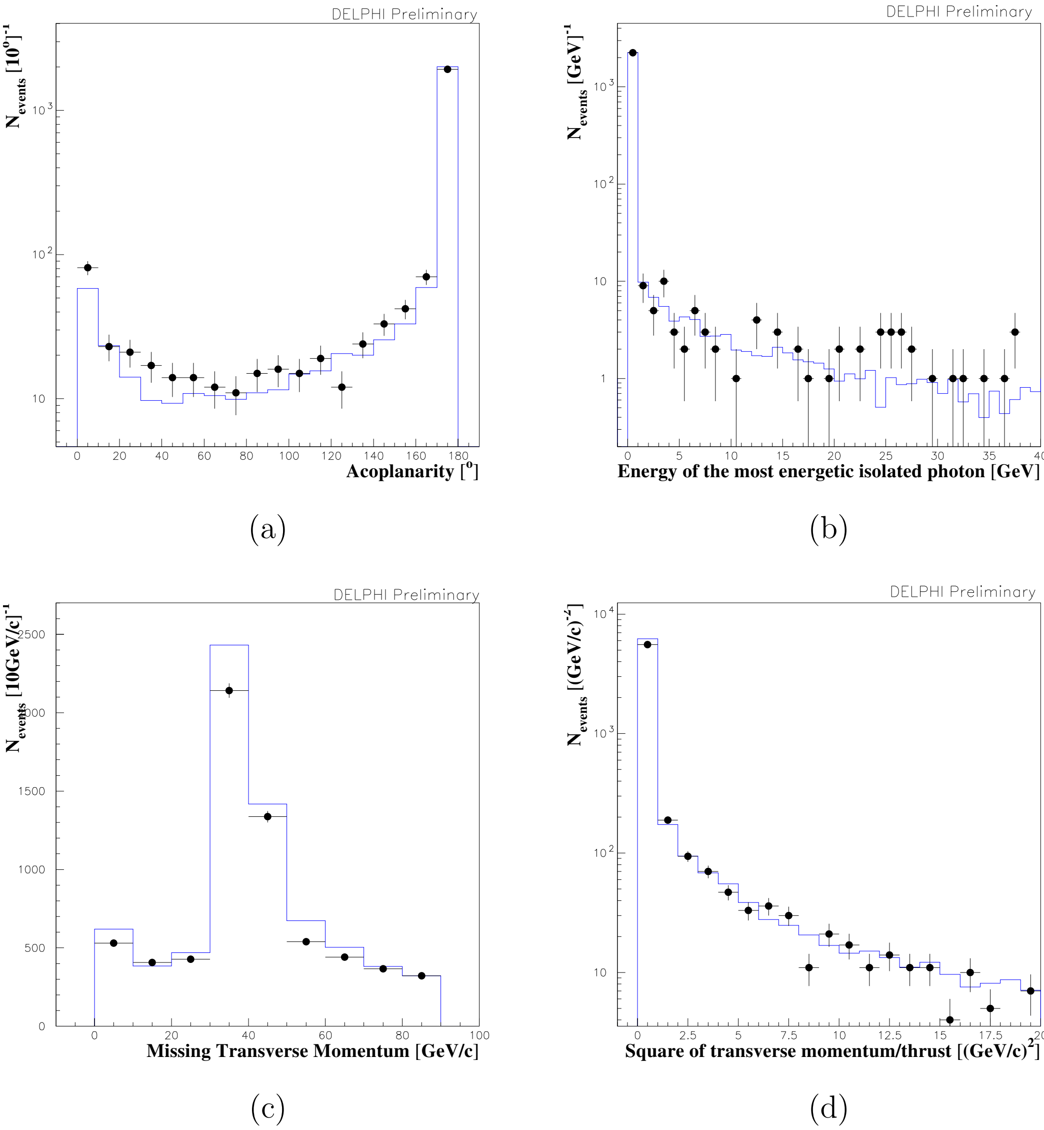

Figure 2: (a) Acoplanarity distribution, (b) energy of the most energetic isolated photon, (c) angle between the vectorial sum of momenta and the beam axis and (d) square of transverse momentum with respect to the thrust axis. The upper graphics were generated at 183 GeV and the others at 189 GeV. The points with error bars show the real data and the histograms show the simulated backgrounds.

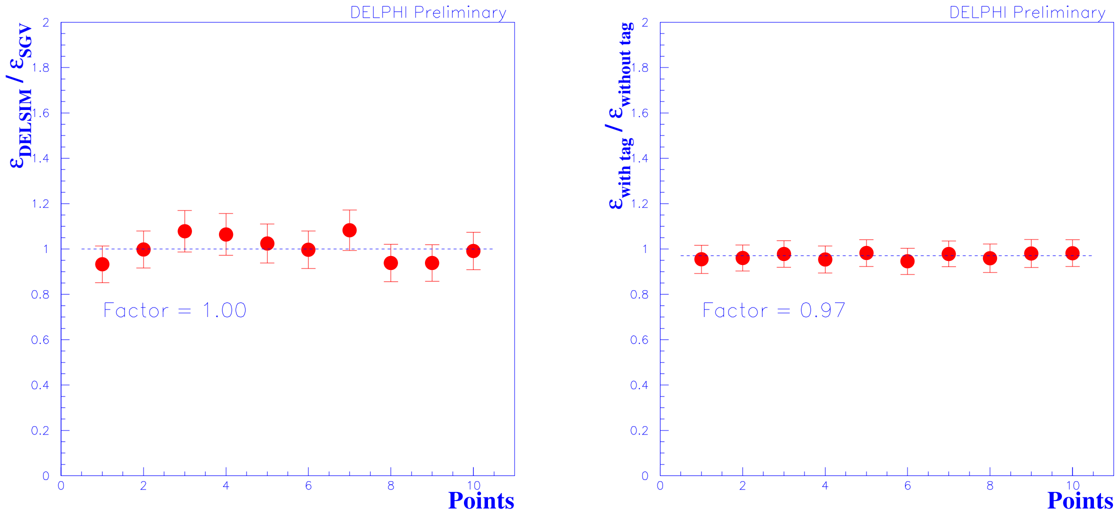

Figure 3: Efficiency correction factors for SGV simulated signals. The left picture shows the selection efficiency rate between the DELSIM simulated events and the SGV simulated events, if the taggers are not considered in the DELSIM simulated events. The right picture shows the rate between the selection efficiency for the DELSIM simulated events if we consider the tagger cut and DELSIM simulated events if we don't consider the tagger cut.

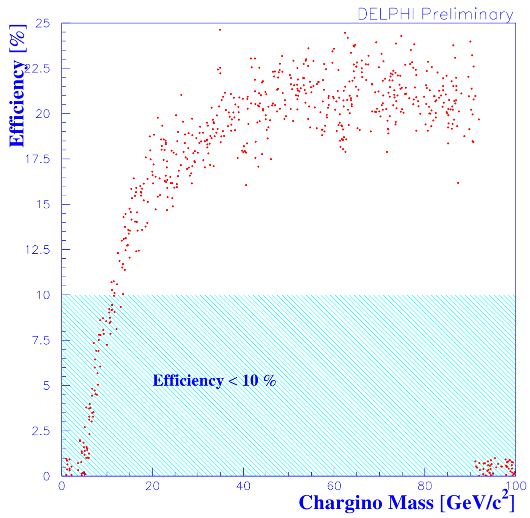

Figure 4: Selection efficiency as a function of the chargino mass for $\tan\beta = 2$ and 183 GeV of centre-of-mass energy. The hatched area is the region we do not consider for the analysis, because of very low efficiency.

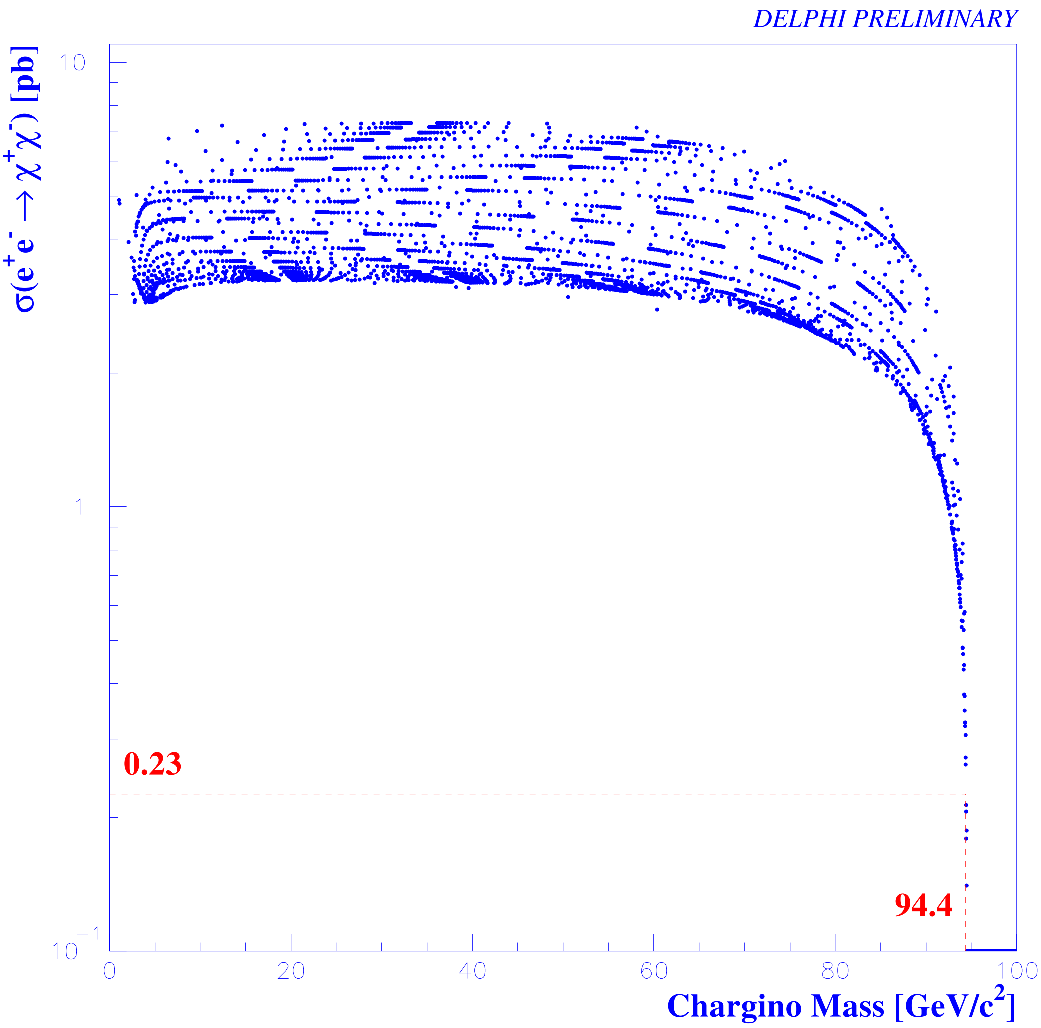

Figure 5: Expected $e^+e^- \rightarrow \tilde{\chi}^+\tilde{\chi}^-$ cross section at 189 GeV (dots) as a function of chargino mass, assuming a heavy sneutrino ($M_{\tilde{\nu}} \geq 300\,\mathrm{GeV/c^2}$). The indicated values are the minimal cross section in the excluded mass region and the chargino mass limit.

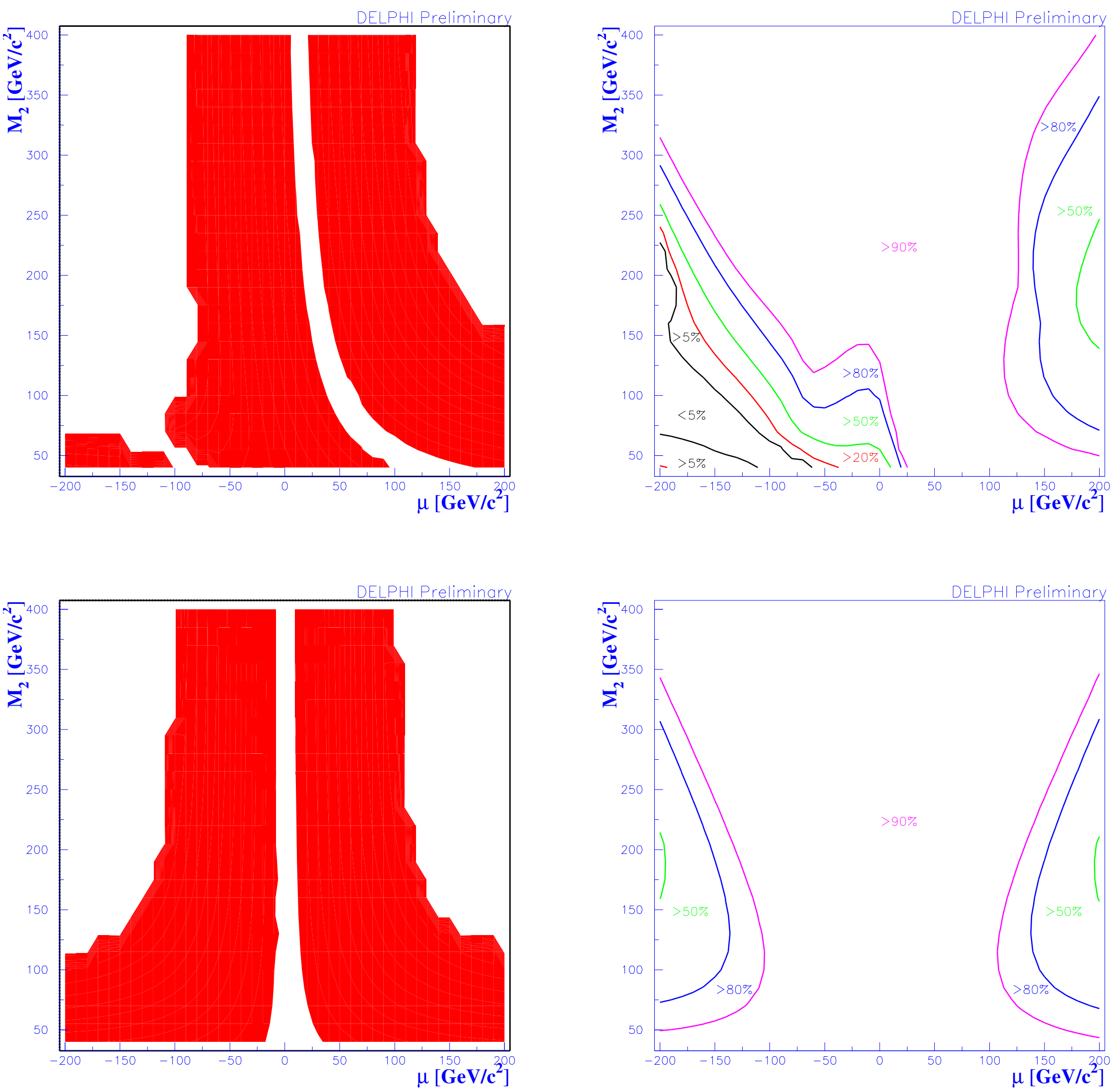

Figure 6: The left pictures show the excluded regions in (μ, M_2) plane at 95% confidence level for $\tan\beta = 2$ (upper graphics) and $\tan\beta = 40$ (lower graphics), assuming $M_{\tilde{\nu}} \geq 300\,\mathrm{GeV/c^2}$. The right pictures show branching ratio levels in (μ, M_2) plane. The central areas on the left pictures were not excluded because the selection efficiency is lower than 10%. For $\tan\beta = 2$ there is a region for small M_2 values and negative μ values that was not excluded due to the weakly $\tilde{\chi}^{\pm} \rightarrow \tau^{\pm} + J$ production, showed in branching ratio levels on the right side.