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Search for SUSY with R–parity violating LL$\bar{\mathrm{E}}$ couplings at $\sqrt{s} = 189$ GeV

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Abstract

Searches for supersymmetric particles under the assumption that R–parity is not conserved are presented, based on data recorded by the DELPHI detector in 1998 in $\mathrm{e^+e^-}$ collisions at center-of-mass energy of 189 GeV. Only one R–parity violating LL$\bar{\mathrm{E}}$ term (i.e. one λ coupling), which couples scalar leptons to leptons, was considered to be dominant at a time.
The search for pair production of neutralinos, charginos and sleptons has been performed for both direct R–parity violating decays and indirect cascade decays. The results are in agreement with Standard Model expectations, and are used to update the constraints on the MSSM parameter values and the mass limits previously derived at $\sqrt{s} = 183$ GeV.
With R–parity violation, it is possible to produce single sparticles. If one of the couplings λ_{121} or λ_{131} is non vanishing, single neutralino ($\tilde{\chi}^0$) or chargino ($\tilde{\chi}^{\pm}$) can be produced at LEP via a sneutrino ($\tilde{\nu}$) resonance: $\mathrm{e^+e^-} \to \tilde{\nu} \to \tilde{\chi}^0_i \nu$, $\tilde{\chi}^{\pm}_j l^{\mp}$. All possible chargino and neutralino decays have been searched for. No excess of events compared to the expected background was found, therefore upper limits on the magnitude of the λ_{121} and λ_{131} couplings were derived, as a function of both the mass and the total width of the sneutrino. The best limits were obviously obtained for $m(\tilde{\nu}) \simeq \sqrt{s}$, and were at the level of about 2×10^{-3} at 95% C.L. A complementary study of the sneutrino resonance, considering charginos and neutralinos separately, as well as 100% branching ratios to specific signatures gives comparable limits.

1 Introduction

In 1998, the LEP center-of-mass energy reached 189 GeV, and an integrated luminosity of about 158 pb^{-1} has been collected by the DELPHI experiment. The data have been analyzed to search for both single and pair productions of supersymmetric particles in the hypothesis of R–parity violation ($\not\!\!R_p$) [1]. The major consequences of the non conservation of the R–parity is the allowed decay of the Lightest Supersymmetric Particle (LSP) in standard fermions and the possibility to produce single supersymmetric particles. The $\not\!\!R_p$ superpotential [2] contains three trilinear terms, two violating L conservation, and one violating B conservation. We consider here only the $\lambda_{ijk}\mathrm{L}_i\mathrm{L}_j\bar{\mathrm{E}}_k$ term (i, j, k are generation indices), which couples the sleptons to the leptons; since $\lambda_{ijk} = -\lambda_{jik}$, there are nine possible λ_{ijk}.

The Minimal Supersymmetric Standard Model (MSSM) scheme [3] with the assumption that the gaugino masses are unified at the Grand Unified Theories (GUTs) scale was assumed. Relevant parameters for these $\not\!\!R_p$ searches are then: M$_1$, M$_2$, the U(1) and SU(2) gaugino mass at the electroweak scale (with $\mathrm{M}_1 = \frac{5}{3}\tan^2\theta_W \mathrm{M}_2$), m_0, the scalar common mass at the GUT scale, μ, the mixing mass term of the Higgs doublets at the electroweak scale and tanβ, the ratio of the vacuum expectation values of the two Higgs doublets. We assume that the running of the λ couplings from the GUT scale to the electroweak, does not have a significant effect on the "running" of the gaugino and fermion masses. This is an assumption that will be reconsidered once detailed theoretical calculations, on this subject, become available.

1.1 *R*–parity violating decays

Two types of supersymmetric particle decays are considered. First, the *direct decay*, corresponding to the sfermion $\not\!\!R_p$ direct decay into two standard fermions, or to the neutralino (chargino) decay into a fermion and a virtual sfermion which then decays into two standard fermions. Second, the *indirect decay* corresponding to the supersymmetric particle cascade decay through a R–parity conserving vertices to on-shell supersymmetric particles down to the lighter supersymmetric particle decaying via one LL$\bar{\mathrm{E}}$ coupling.

The direct decay of a neutralino or a chargino via a dominant λ_{ijk} coupling leads to purely leptonic decay products, with or without neutrinos ($ll'\nu$, $ll'l''$, $l\nu\nu$). The indirect decay of a heavier neutralino or a chargino adds jets and/or leptons to the leptons produced in the LSP decay.

The sneutrino direct decay gives two charged leptons: via λ_{ijk} only the $\tilde{\nu}_i$ and $\tilde{\nu}_j$ are allowed to decay directly to $l_j^{\pm}l_k^{\mp}$ and $l_i^{\pm}l_k^{\mp}$ respectively. The charged slepton direct decay gives one neutrino and one charged lepton (the lepton flavor may be different from the slepton one). The supersymmetric partner of the right-handed lepton, $\tilde{l}_{kR}$ can only decay directly to in $\nu_{iL}l_{jL}$ or $l_{iL}\nu_{jL}$.

The indirect decay of a sneutrino (charged slepton) into a neutralino and a neutrino (charged lepton) leads to a purely leptonic final state: two charged leptons and two neutrinos (three charged leptons and a neutrino). The indirect decay of a slepton into a chargino and its isospin partner was not considered in the pair production analyses, whereas for the single production, the indirect decay of a sneutrino into a chargino and a lepton is the main channel.

When the charged leptons are τ (for example with λ_{131} or λ_{133} couplings), additional

processes	final states
$\widetilde{\chi}_i^0\widetilde{\chi}_j^0$, $\widetilde{\chi}_k^+\widetilde{\chi}_l^-$ (direct and indirect)	ee$\tau\tau$ + e$\tau\tau\tau$ + $\tau\tau\tau\tau$ + E_{miss} (+nl) (+m qq')
$\widetilde{\nu}_e\widetilde{\bar{\nu}}_e$ (direct)	$\tau\tau\tau\tau$
$\widetilde{\nu}_\tau\widetilde{\bar{\nu}}_\tau$ (direct)	ee$\tau\tau$
$\tilde{\nu}\tilde{\bar{\nu}}$ (indirect)	ee$\tau\tau$ + e$\tau\tau\tau$ + $\tau\tau\tau\tau$ + E_{miss}
$\tilde{l}^+\tilde{l}^-$ (indirect)	ee$\tau\tau$ + e$\tau\tau\tau$ + $\tau\tau\tau\tau$ + E_{miss} + l^+l^-

Table 1: Pair production final states with λ_{133} coupling

neutrinos are generated in the τ decay, producing more missing energy in the decay and leading to a smaller number of charged leptons in the final state.

1.2 Pair production of supersymmetric particles

This paper presents an update of the results described in [4] concerning the searches at the center-of-mass energy of 183 GeV, as well as an update of the preliminary results at 189 GeV [5]. Analyses have been performed considering two different couplings: the λ_{122} coupling, leading to the highest efficiencies, and the λ_{133} coupling for which efficiencies are lower. Since the results were in agreement with the Standard Model expectations, the most conservative limits were derived considering the results of the analyses performed assuming λ_{133} as the dominant coupling. Only these analyses were updated and are presented here. The direct decay via λ_{133} of a neutralino pair gives ee$\tau\tau$(25%), e$\tau\tau\tau$(50%), $\tau\tau\tau\tau$(25%) and missing energy. The indirect decay of heavier neutralino pairs or chargino pairs adds to the leptonic final state either jets or/and leptons. The direct and indirect decays of a slepton pair via λ_{133} leads to purely leptonic final states containing mainly taus and some electrons. The final states studied are summarized in table 1.

1.3 Single sparticle production

At LEP resonant sneutrino production is allowed via the coupling λ_{121} or λ_{131}. The resonant[1] cross-section for a sneutrino (J=0) can be expressed as [6]:

$$\sigma(\mathrm{e}^+\mathrm{e}^- \to \tilde{\nu} \to X)(s) = \frac{4\pi s}{M_{\tilde{\nu}}^2}\frac{\Gamma(\mathrm{ee})\Gamma(X)}{(s-M_{\tilde{\nu}}^2)^2 + M_{\tilde{\nu}}^2\Gamma_{\tilde{\nu}}^2}$$

where $\Gamma(\mathrm{ee}) = \Gamma(\tilde{\nu}_j \to \mathrm{e}^+\mathrm{e}^-) = \frac{\lambda_{1j1}^2}{16\pi}M_{\tilde{\nu}_j}$, $j = 2,3$, and $\Gamma(X)$ denotes the partial width for $\tilde{\nu}$ decay to final state X, with $X = \mathrm{e}^+\mathrm{e}^-$ (direct decay), $X = \tilde{\chi}^0\nu$ or $X = \tilde{\chi}^\pm l^\mp$ (indirect decays of the sneutrino).

Given the present upper limits, derived from Standard Model processes, on λ_{121} and λ_{131} ($\lambda_{121} < 0.04 \times \frac{m_{\tilde{e}_R}}{100\ \mathrm{GeV/c^2}}$, $\lambda_{131} < 0.05 \times \frac{m_{\tilde{e}_R}}{100\ \mathrm{GeV/c^2}}$ at 1σ C.L. [6]–[9]), the e$^+$e$^-$ decay

[1] We disregard here the t-channel contributions present for second and third generation final leptons for reasons of compactness. These contributions are included in the signal simulation and final estimation of expected events.

channel ($\sigma \propto \lambda^4$) is suppressed compared to the other two ($\sigma \propto \lambda^2$), unless both the neutralino and the chargino are heavier than the sneutrino.

The direct decay mode has already been investigated by several LEP collaborations [10]–[12] by looking for deviations to the Standard Model in the cross-sections and asymmetries of $e^+e^- \to l^+l^-$. The results were obtained assuming a 1 GeV width for the sneutrino and presented as an upper limit on λ_{1j1} as a function of the sneutrino mass.

The indirect decay channels are analyzed explicitly here, taking into account any mass and the actual width of the $\tilde{\nu}$ as a function of the MSSM parameters; some preliminary results on 189 GeV data have already been presented earlier [13].

If one takes into account all the decays, violating or not R–parity, of the neutralinos and charginos, the possible final states for both processes $\tilde{\nu} \to \tilde{\chi}^0\nu$ and $\tilde{\nu} \to \tilde{\chi}^{\pm}l^{\mp}$ are of two kinds, either leptonic: two leptons and missing energy, and four leptons (with or without missing energy), or multi-lepton multi-jet and missing energy.

1.4 λ_{ijk} couplings

Upper limits on the λ_{ijk} couplings can be derived from Standard Model processes [6]–[9], assuming that only one λ_{ijk} is dominant at a time; the same assumption was used here. In addition, it was supposed that the coupling strength is such that the Lightest Supersymmetric Particle (LSP) decays within a few centimeters close to the production vertex. This has two consequences on the analyses described here: first, they are not sensitive to light $\tilde{\chi}$ ($M_{\tilde{\chi}_{LSP}} \leq 10$ GeV/c^2); second, several analyses have a lower limit in sensitivity on the λ coupling of the order of 10^{-4}.

2 Data samples

The total integrated luminosity collected by the DELPHI detector [14] during 1998 at center-of-mass energies around 189 GeV was 158 pb^{-1}. An integrated luminosity of 153 pb^{-1} corresponding to high quality data, obtained when taking into account the status of the main sub-detectors, has been analyzed.

To evaluate background contaminations, different contributions coming from the Standard Model processes were considered. The Standard Model events were produced by the following generators:

- $\gamma\gamma$ events: `BDK` [15] for $\gamma\gamma \to l^+l^-$ processes, and `TWOGAM` [16] for $\gamma\gamma \to$ hadron processes.
- two-fermion processes: `BABAMC` [17] and `BHWIDE` [18] for Bhabhas, `KORALZ` [19] for $e^+e^- \to \mu^+\mu^-(\gamma)$ and for $e^+e^- \to \tau^+\tau^-(\gamma)$ and `PYTHIA` [20] for $e^+e^- \to q\bar{q}(\gamma)$ events.
- four-fermion processes: `EXCALIBUR` [21] and `GRC4F` for all types of four fermion processes: non resonant ($f\bar{f}f'\bar{f}'$), simply resonant ($Zf\bar{f}$, $Wf\bar{f}'$) and doubly resonant (ZZ, WW) (`PYTHIA` was used also for cross checks).

Signal events were generated with the `SUSYGEN 2.20` program [22] followed by the full DELPHI simulation and reconstruction program (`DELSIM`). A faster simulation (`SGV` [24]) was used to check that there was no efficiency "accident" in the points with no full simulation. The R–parity violating couplings were set at their experimental upper limit assuming $m_{\tilde{e}_R} = 100$ GeV/c^2 ($\lambda_{121} = \lambda_{131} = 0.05$, λ_{133}= 0.003).

Neutralino and chargino pair production was considered at several points in the MSSM parameter space. Higher neutralino and chargino pair processes have been taken into account since one can profit from the threefold increase in luminosity compared to the 1997 data collected at center-of-mass energy of 183 GeV.

For the study of slepton pair production, samples with sneutrino direct decay and samples with sneutrino or charged slepton indirect decay were generated. A $\tilde{\nu}$ ($\tilde{l}$) mass range from 50 to 90 GeV/c^2 was covered; in the case of indirect decay, several ranges of mass difference between sleptons and neutralinos were considered.

3 Analysis descriptions

For both single production and pair production studies, the applied selections were based on the criteria presented in [13, 5], using mainly topological criteria, missing quantities, lepton identification and kinematic properties, and jet characteristics. Compared to the previous analyses, the electron identification algorithm has been improved. The jets come from the hadronic decay of the W and the Z in the indirect decay of charginos and heavier neutralinos. Thin jets come from τ decay. The jets were reconstructed with the `DURHAM` [25] algorithm. In order to cover the different topologies, the jet number was not fixed, and the jet charged multiplicity could be low (thin jets with one charged particle for instance), or could be zero in case of neutral jets. In the following, the transition value of the y_{cut} in the `DURHAM` algorithm at which the event changes from a n-jet to a m-jet configuration is noted y_{mn}.

3.1 Pair production studies

3.1.1 Preselection criteria

In the search for pair production of gauginos and sleptons in case of a dominant λ_{133} coupling, it was required:

- at least one identified lepton;
- the number of charged particles greater than three, and at least two of them with a polar angle between 40° and 140°;
- the total energy and the energy from charged particles greater than $0.18\sqrt{s}$ and $0.16\sqrt{s}$ respectively;
- the missing p_t greater than 5 GeV/c;
- the polar angle of the missing momentum between 27° and 153°.

This was efficient to suppress the background coming from Bhabha scattering and two-photon processes, and to remove a large part of the $f\bar{f}\gamma$ contribution. After this preselection stage, 2114 events are selected for 1984±11 expected from the background sources (see Fig 1).

3.1.2 Neutralino and chargino search

Compared to the selection applied to 1997 data [4], it has been necessary to modify the criteria to be efficient and selective for both low and high multiplicity cases. For events with a charged particle multiplicity from 4 to 6 (which corresponds to neutralino or chargino direct decay), the following criteria were applied:

- the energy in a cone of 30° around the beam axis was restricted to be less than 40% of the total visible energy;
- the energy of the most energetic lepton had to be between 2 and 70 GeV;
- there should be no other charged particle in a 10° (6°) half cone around any identified lepton for a charged particle multiplicity equal to 4 (5, 6);
- the number of neutral particles had to be less or equal to 10.

For events with a charged particle multiplicity greater than 6, the criteria were:

- the acollinearity had to be greater than 7°;
- the energy in a cone of 30° around the beam axis was restricted to be less than 50% of the total visible energy;
- the energy of the most energetic lepton had to be between 5 and 60 GeV;
- if there was only one identified lepton, no other charged particle in a 6° half cone around it was allowed; and if there were more, there should not be any other charged particle in a 10° half cone around at least two of them;
- at least one well identified electron;
- the number of neutral particles had to be less or equal to 15.

In any case, the missing energy had to be at least 30% of the available energy, and the polar angle of at least one lepton had to be between 40° and 140°.

These criteria removed $\mathrm{f\bar{f}}\gamma$ and hadronic ZZ and $\mathrm{W^+W^-}$ events. The selection based on the jet characteristics and topologies was then applied. First, constraints have been imposed to y_{nm} values, to reduce in particular the $\mathrm{f\bar{f}}\gamma$ contribution. In events with more than six charged particles, at least one jet with low charged particle multiplicity was demanded. In four- or five-jet configuration, a minimum number of charged jets was required. In case of a four-jet topology, a cut was applied on the value of $\mathrm{E}^{j}_{\mathrm{min}} \times \theta^{j_a j_b}_{\mathrm{min}}$ where $\mathrm{E}^{j}_{\mathrm{min}}$ is the energy of the less energetic jet, and $\theta^{j_a j_b}_{\mathrm{min}}$ is the minimum angle between any pair of jets. These requirements significantly reduced the background from $\mathrm{f\bar{f}}\gamma$, $\mathrm{W^+W^-}$ production. The number of remaining real and simulated data events during the selection are reported in Table 2, and the contributions of the Standard Model processes are detailed in Table 3.

Using the events produced with DELSIM, selection efficiencies have been studied on $\tilde{\chi}^0_1\tilde{\chi}^0_1$ and $\tilde{\chi}^+_1\tilde{\chi}^-_1$ signals. In order to benefit from the high luminosity, all $\mathrm{e^+e^-} \rightarrow \tilde{\chi}^0_i\tilde{\chi}^0_j$, $\mathrm{e^+e^-} \rightarrow \tilde{\chi}^+_k\tilde{\chi}^-_l$ processes which contribute significantly have been simulated, at each MSSM point of this study. SUSYGEN followed by SGV was used for the scan. Then a global event selection efficiency has been determined for each point, since the performed analyses were sensitive to many different topologies. The global selection efficiencies obtained with SGV simulated events have been cross-checked in several points with DELSIM simulated events. The efficiencies lay between 18% and 40%.

3.1.3 Sneutrino and charged slepton searches

Considering the λ_{133} coupling, searches for sneutrino pair production and subsequent direct ($\tilde{\nu} \rightarrow l^+l^-$) or indirect ($\tilde{\nu} \rightarrow \tilde{\chi}^0_1\nu$) decay and searches for charged slepton pair production decaying indirectly ($\tilde{l} \rightarrow \tilde{\chi}^0_1 l$) have been performed. In these different searches, a large amount final state energy is missing, due to neutrinos (from τ and/or $\tilde{\chi}^0_1$ decays), except in the case of $\tilde{\nu}_\tau\tilde{\bar{\nu}}_\tau$ direct decay search (ee$\tau\tau$ final state). Two different analyses

Selection criteria			Data	MC
	$4 \leq N_{charged} \leq 6$	$N_{charged} \geq 7$		
acollinearity		$> 7^o$	1342	1301 $\pm$8
$E_{cone}^{30^o}$	$\leq$ 50% E_{total}	$\leq$ 40% E_{total}	1146	1121 $\pm$7
N_{lepton} in the barrel	≥ 1	≥ 1	929	915$\pm$6
E^l_{max}	[2 GeV, 70 GeV]	[5 GeV, 60 GeV]	652	665$\pm$5
isolation	$\Theta^{min}_{lepton-track} \geq 20^o$ if $N_{charged}$ =4 $\Theta^{min}_{lepton-track} \geq 6^o$ if $N_{charged} = 5, 6$	$\Theta^{max}_{lepton-track} \geq 6^o$ $\Theta^{max-1}_{lepton-track} \geq 10^o$ if $N_{lepton} \geq 2$		
$N_{neutral} \leq$	10	15		
$N_{electron}$		≥ 1	131	147$\pm$3
E_{miss}	$>30\%\sqrt{s}$	$> 30\%\sqrt{s}$	96	101$\pm$2
$\log_{10}(y_{23})$ $\log_{10}(y_{34})$ $\log_{10}(y_{45})$	≥ -2.7 ≥ -4	≥ -1.8 ≥ -2.3 ≥ -3	16	14.7$\pm$0.7
4 jets $E^j_{min} \times \theta^{j1,j2}_{min}$	$\geq$ 1 GeV.rad	$\geq$ 5 GeV.rad	15	13.9$\pm$0.6
	4 charged jets if 4j or 5j	at least 1 jet with 1 or 2 charged particle(s) 4 charged jets if 4j 4 or 5 charged jets if 5j	11	10.5$\pm$0.5

Table 2: Selection criteria used in the search for neutralino and chargino decay via λ_{133}. nj means n-jet topology, and a charged jet means a jet with at least one charged particle. The number of data and Monte Carlo selected events are reported.

were then performed, one applied to the channel with a large amount of missing energy, and the other one dedicated to the ee$\tau\tau$ channel, with less missing energy.

Analysis for channels with high value of missing energy

The selection procedure was close to the one applied to low charged particle multiplicity events in the search for neutralino and chargino pair production. The same event characteristics were used. A large amount of missing energy was required, but only events with four to eight charged particles were selected. The criteria are listed in Table 4; the number of observed events and expected ones from the standard background during the selection procedure is also given. At the end, one event remains in the data compared to 2.1$\pm$0.3 from the SM processes. The different contributions are listed in Table 5. The four-fermion contributions have been checked also with `EXCALIBUR`, and apart the WW-like processes, the two other important background sources are the ee$\tau\tau$ and ee$\mu\mu$ final states.

For the 4τ channel produced in $\tilde{\nu}_e\tilde{\bar{\nu}}_e$ decay, the efficiencies were between 27 and 31%. The sneutrino indirect decay efficiencies ranged from 17% ($m_{\tilde{\nu}}$ = 50 GeV/c^2,

Data	total MC	$q\bar{q}(\gamma)$	$\tau^+\tau^-(\gamma)$	Ze^+e^-	$We\nu_e$	W^+W^-	ZZ
11	10.5±0.5	0.14±0.09	0.12±0.12	0.48±0.15	0.05±0.02	9.04±0.46	0.62±0.10

Table 3: Neutralino and chargino pair production analysis: background contributions.

Selection criteria	Data	MC
$N_{charged} \leq 8$ $E_{miss} > 30\%\sqrt{s}$	120	106.6±3.4
$2 \leq E^l_{max} \leq 70$ GeV	88	89.2±2.9
$\Theta^{min}_{lepton-track} \geq 20^o$ if $N_{charged} = 4$ $\Theta^{min}_{lepton-track} \geq 6^o$ if $N_{charged} > 4$	62	61.5±2.4
$N_{neutral} \leq 10$	55	52.3±2.2
at least 1 lepton in the barrel	25	22.4±1.3
$\log_{10}(y_{23}) \geq -2.7$ $\log_{10}(y_{34}) \geq -4$	5	4.4±0.4
case of 4 jets: $\theta^{j1,j2}_{min} \geq 20^o$ at least 1 jet with 1 or 2 charged particles	1	2.1±0.3

Table 4: Selection criteria used in the search for slepton pair production with $\not{R}_p$ decay via λ_{133}. The number of data and Monte Carlo selected events are reported.

$m_{\tilde{\chi}^0}$ = 23 GeV/c^2) to 36% ($m_{\tilde{\nu}}$ = 80 GeV/c^2, $m_{\tilde{\chi}^0}$ = 60 GeV/c^2). The charged slepton indirect decay efficiencies are higher, due to the presence of two additional leptons in the final state, and lay between 33% and 40%.

Analysis for channels with low value of missing energy

In order to obtain higher efficiencies for the $ee\tau\tau$ channel, the selection criteria were modified. In particular, it was required a missing energy greater than 8% of the available energy. The number of charged tracks was restricted to be between 4 and 6. Moreover, the lower limit on the energy of the most energetic lepton has been increased to 20 GeV, and the isolation angle had to be greater than 10°. Additional criteria were used: the acollinearity was requested be greater than 2°, and the presence of at least one identified electron was required. After the event selection 3 events remained, while 2.3±0.3 events were expected from SM processes. The main sources of background are the $ee\tau\tau$ (57%) and the $ee\mu\mu$ (29%) four-fermion processes. The efficiencies were between 38 and 46%.

Data	total MC	$\tau^+\tau^-(\gamma)$	Ze^+e^-	W^+W^-	ZZ
1	2.13±0.27	0.12±0.12	0.54±0.16	1.13±0.16	0.34±0.08

Table 5: Slepton pair production analysis: background contributions.

3.2 Single production

A first sequence of preselection criteria was applied:

- At least two charged tracks of standard quality;
- a vast majority of the recorded events consists in $\gamma\gamma$ events; it is possible to get rid of most of them by requiring:
  - total transverse momentum p_T greater than 5 GeV/c,
  - charged energy E_{ch} greater than $0.1 \times \sqrt{s}$,
  - thrust axis not parallel to the beam pipe: $|cos\theta_{th}|$ less than 0.9,
  - polar angle of the missing momentum θ_{miss} between 20^o and 160^o;
- two-fermion events were rejected by demanding:
  - acollinearity greater than 5^o,
  - acoplanarity less than 175^o,
  - total transverse momentum p_T greater than 15 GeV/c;
- in the multi-jet final state preselection instead,
  - visible mass M_{vis} more than $0.2 \times \sqrt{s}$,
  - event sphericity S_{ph} greater than 0.02.

Three series of requirements were then applied, in order to select the three kinds of topologies that were searched for. In the following, isolated means that there must be no other charged track or neutral shower in a 5^o half-cone. In the λ_{131} case, as leptons could be taus, the selections were slightly different from those first designed in the λ_{121} case. By default, the λ_{121} criteria are mentionned and the different λ_{131} criteria are indicated when necessary.

- Two leptons plus missing energy final states (same analysis for both λ_{121} and λ_{131}). The following criteria were required:
  - the charged track multiplicity N_{ch} equal to 2,
  - two identified leptons, the leading one being isolated,
  - acoplanarity below 160^o,
  - a veto on two identified muons,
  - the missing energy E_{miss} greater than $0.45 \times \sqrt{s}$,
  - the angle α between the two charged tracks between 20^o and 120^o,
  - the momentum of the non-leading track p_2 less than 35 GeV/c,
  - the invariant mass of the two leptons, M_{ll}, lower than 45 GeV/c^2.
- Four leptons (with or without missing energy) final states:
  - $3 \leq N_{ch} \leq 6$,
  - at least three (λ_{131}: two) identified leptons (electrons or muons), the leading one being isolated,
  - y_{34} bigger than $10^{-4.5}$ (λ_{131} only),

  were asked for.
- Multi-lepton multi-jet final states. The requirements were:

- at least 7 charged tracks, and at most 20,
- at least two identified leptons (electrons or muons), the leading one being isolated,
- y_{34} bigger than 10^{-3},
- the transverse momentum of the second lepton $p_T(l_2)$ above 10 GeV/c (λ_{121} only),
- E_{miss} greater than $0.25 \times \sqrt{s}$ (λ_{131} only),
- $n_{tot}(j_1)$, the total multiplicity of the leading jet (the number of jets being forced to four) should not exceed 4; in the λ_{131} case, at least two jets with a total multiplicity of at most 3,
- the invariant mass of the two leading leptons above 10 GeV/c^2 (λ_{131} only).

The average efficiency of these selections was 33%, 40% and 27% (λ_{131}: 19%, 33% and 16%) respectively on two-lepton, four-lepton and multi-lepton multi-jet signals assuming $\tan\beta = 1.5$; the efficiencies are roughly the same if one assumes $\tan\beta = 30$ (see also figures 7 and 8).

The step by step comparison of the number of data and of SM Monte Carlo events after these selections is shown in table 6. The background composition in each channel is displayed in table 7.

The agreement between data and Monte-Carlo is not excellent at early stages, because of known, still uncorrected for, inaccuracies of the SM generators. Nevertheless, there is clearly no excess of data in any of the three channels.

4 Results

The results of the searches presented in this note are in agreement with the Standard Model expectation. In the pair production study, they are used to extend the previously excluded part of the MSSM parameter space and to update limits obtained with the analysis of the 1997 data collected in DELPHI; in the single production case, this results in original limits on the R–parity violating coupling.

4.1 Results from pair production searches

In the searches for neutralino and chargino pair production, the number of expected events in each point of the explored MSSM parameter space, was obtained by:

$$\mathrm{N_{exp}} = \mathcal{L}\times\epsilon_g\times \{\textstyle\sum_{i,j=1}^{4}\sigma(\mathrm{e^+e^-} \to \tilde{\chi}_i^0\tilde{\chi}_j^0) + \sum_{k,l=1}^{2}\sigma(\mathrm{e^+e^-} \to \tilde{\chi}_k^+\tilde{\chi}_l^-)\}$$

where $\mathcal{L}$ is the integrated luminosity, and ϵ_g is the global efficiency determined as explained in section 3.1.2. This number has been compared to the number of signal events, $\mathrm{N_{95}}$, expected at a confidence level of 95% in presence of background, determined following the Feldman and Cousins prescription [26]. All points which satisfied $\mathrm{N_{exp}} > \mathrm{N_{95}}$ were excluded at 95% C.L. Compared to the results of the 1997 data analysis, the excluded area in μ, $\mathrm{M_2}$ planes obtained with the present searches are extended as shown in Fig. 2, for $m_0 = 90$, 300 GeV/c^2 and $\tan\beta = 1.5$, 30.

For each $\tan\beta$, the highest value of neutralino mass which can be excluded has been determined in the μ, $\mathrm{M_2}$ plane (–200 GeV/$c^2 \leq \mu \leq 200$ GeV/c^2, $0 < \mathrm{M_2} \leq 400$ GeV/c^2)

2l selection	# of data evts	Nb of SM MC evts
Preselection + $N_{ch} < 7$	805	861.7
$N_{ch} = 2$	578	657.6
2 id. leptons	103	127.7
Acoplanarity$< 160^o$	70	93.1
not 2μ	37	47.9
$E_{miss} \geq 0.45 \times \sqrt{s}$	28	34.0
$20^o \leq \alpha \leq 120^o$	16	21.0
$p(l_2) < 35$ GeV/c	12	16.8
$M_{ll} \leq 45$ GeV/c^2	**11**	**11.3±1.1**
4l selection	# of data evts	Nb of SM MC evts
Preselection + $N_{ch} < 7$	805	861.7
$3 \leq N_{ch} \leq 6$	227	204.
≥ 3 id. leptons (λ_{121})	**2**	**2.5±0.5**
≥ 2 id. leptons (λ_{131})	15	23.8
$y_{34} > 10^{-4.5}$	**6**	**4.8±0.7**
Multi-l multi-j selection	# of data evts	Nb of SM MC evts
Preselection + $N_{ch} \geq 4$	6061	5822.
$7 \leq N_{ch} \leq 20$	2908	2831.2
≥ 2 id. leptons	112	140.
$y_{34} > 10^{-3}$	54	74.6
$p_T(l_2) > 10$ GeV/c (λ_{121})	6	8.0
$n_{tot}(j_1) < 5$	**6**	**4.2±0.5**
$E_{miss} \geq 50$ GeV (λ_{131})	37	54.3
$\geq$ 2j($n_{tot} \leq 3$)	7	11.6
$M_{ll} > 10$ GeV/c^2	**5**	**7.7±0.6**

Table 6: Single production analysis: data/MC comparison at each step of the selection.

	$\gamma\gamma \to$ ee	$\gamma\gamma \to \mu\mu, \tau\tau$	$l\nu l\nu$	All
2l	2.7	0.5	8.1	**11.3**

	Bhabha	$ll(\gamma)$	$\gamma\gamma \to ll$	$llll$	WW-like	All
4l (λ_{121})	0.5	0.7	0.15	0.9	0.25	**2.5**
4l (λ_{131})	0.15	1.1	1.5	1.5	0.5	**4.8**

	$q\bar{q}(\gamma)$	$llq\bar{q}$	WW-like	All
leptons+jets (λ_{121})	0.25	2.25	1.7	**4.2**
leptons+jets (λ_{131})	0.4	0.6	6.7	**7.7**

Table 7: Single production analysis: background composition.

for several m_0 values varying up to 500 GeV/c^2. The most conservative mass limit was obtained for high m_0 values, for which it reaches a plateau. The corresponding limit on neutralino mass as a function of tanβ is plotted on Fig. 3. From these studies, a neutralino lighter than 30 GeV/c^2 was excluded at 95% C.L. The same procedure has been applied to determine the most conservative lower limit on the chargino masses. The result is less dependent on tanβ, allowing to almost reach the kinematic limit for any value of tanβ: a chargino lighter than 94 GeV/c^2 was excluded at 95 % C.L. Finally, a lower limit of 50 GeV/c^2 for the $\tilde{\chi}^0_2$ mass has been derived at 95 % C.L.

The results obtained from the sneutrino pair production studies were used to derive limit on the sneutrino mass. In the case of the sneutrino direct decay, the results improved the upper limit on the sneutrino pair production cross-section. Taking into account the results of the two analyses and the efficiencies obtained when varying the sneutrino mass, the cross-section limits for 2e2τ and 4τ channels were derived and reported on Fig. 4. The $\tilde{\nu}_e\bar{\tilde{\nu}}_e$ cross-section depends not only on the $\tilde{\nu}_e$ mass but also on other MSSM parameters (due to the eventual $t-$channel $\tilde{\chi}^+_1$ exchange contribution) and it is plotted for a specific MSSM point: M_2 = 100 GeV/c^2 and μ = –200 GeV/c^2. The upper limit on the cross-section in case of the sneutrino direct decay lead to a lower limit on the sneutrino mass of 78 GeV/c^2.

In the case of the $\tilde{\nu}$ indirect decay in $\nu\tilde{\chi}^0_1$ with the $\not{R}_p$ decay of the neutralino via λ_{133}, the efficiencies depend on the sneutrino and neutralino masses. The search results allowed to exclude an area in the $m_{\tilde{\chi}^0}$ versus $m_{\tilde{\nu}}$ plane, as shown on Fig. 5. The same procedure has been followed for the charged slepton indirect decays, and the area excluded in the $m_{\tilde{\chi}^0}$ versus $m_{\tilde{\tau}_R}$ plane is plotted on Fig. 6. The region where $m_{\tilde{\tau}_R}$ - $m_{\tilde{\chi}^0}$ is less than 2–3 GeV/c^2 is not covered by the present analysis, since then the direct decay becomes the dominant mode, leading to two leptons and missing energy signature. The indirect decay of a $\tilde{\tau}$ pair gives two taus and two neutralinos, and the final state selection is less efficient than e.g. for the $\tilde{e}$ or $\tilde{\mu}$ pair. But the exclusion plot is valid for any slepton flavor. The results obrtained for the $\tilde{\tau}_R$ pair production give the most conservative limits on the slepton mass for any flavor, in the hypothesis of a branching fraction $\tilde{l}\to l\tilde{\chi}^0_1$ equal to 1.

Taking into account the limit on the neutralino mass at 30 GeV/c^2, sneutrinos with mass lower than 78 GeV/c^2 and right-handed staus with mass lower than 84 GeV/c^2 were excluded at 95% C.L. when considering their indirect decay.

4.2 Results from single production searches

The results of this kind of analysis are usually presented as a limit on λ as a function of the sneutrino mass, assuming a fixed width for the sneutrino. This is an over simplification given that $\Gamma_{\tilde{\nu}}$ changes with μ, M_2, $\tan\beta$, m_0 (and λ in case of a very small $\Gamma_{\tilde{\nu}}$) and enters directly in the production. We therefore explored the robustness of the limits against this assumption and presented the results as a function of both the mass and the total width of the sneutrino, for a low and for a high value of $\tan\beta$.

We have used the `SUSYGEN 2.20` program to scan a wide portion of the MSSM parameter space (111,848 points for each $\tan\beta$ and each λ) and compute all the cross-sections of our final states. The parameter ranges were:

- $\tan\beta = 1.5$ or 30.,

- $m_0 = 60$ to 220 GeV/c^2 in steps of 10 GeV/c^2 ($m_0 = 170$ to 200 GeV/c^2 in steps of 1 GeV/c^2),
- $\mathrm{M}_2 = 5$ to 405 GeV/c^2 in steps of 10 GeV/c^2,
- $\mu = \pm 5$ to ± 305 GeV/c^2 in steps of 10 GeV/c^2.

Several sets of MSSM parameters lead to the same ($M_{\tilde{\nu}}$, $\Gamma_{\tilde{\nu}}$) couple. In order to derive parameter independent limits, one should then use the minimum cross-section obtained in a given ($M_{\tilde{\nu}}$, $\Gamma_{\tilde{\nu}}$) bin for a given λ. In other words, the highest value of the λ upper limit was kept in each bin.

Existing limits

During the scan, one should not consider parameter combinations that have already been excluded by LEP precision studies. Using the LEP line shape data and the SLD left-right asymmetry, a limit on the decay width of the Z into unpredicted modes has been derived: $\Gamma_{\mathrm{Z}}^{new} < 6.3$ MeV at 95% C.L. [27]. This limit on $\Gamma_{\mathrm{Z}}^{new}$ can be converted into an upper limit on the cross-section for new decay modes of the Z: $\sigma_{\mathrm{Z}}^{new}(\sqrt{s} \simeq M_{\mathrm{Z}}) < 150$ pb at 95% C.L, and it therefore excludes some parameter combinations of the MSSM space, which would permit pair production of neutralinos and charginos.

Limits on λ_{1j1}

The three channels are totally independent thanks to the charged multiplicity criterion. They could therefore be summed: the number of candidates was then 19 (22), whereas the number of expected events was 18.0 (23.8) for the "λ_{121}-type"("λ_{131}-type") analysis . This gives an upper limit on the number of signal events of 11(10) at 95% C.L.

The resulting exclusion plots are shown in figure 7. (resp. 8.) in the case λ_{121}, $\tan\beta = 30$ (resp. λ_{131}, $\tan\beta = 1.5$): for each sneutrino mass and width, an upper limit on λ_{1j1} is given at 95% C.L.

One can also derive an upper limit on λ_{1j1} as a function of $M_{\tilde{\nu}}$ only, assuming a not too small sneutrino width, e.g. $\Gamma_{\tilde{\nu}} \geq 0.2$ GeV. This is shown in figures 7. and 8.

Because the cross-section is proportional to λ^2, the limits on λ are only weakly dependent on the efficiency of the analysis, therefore the results obtained for λ_{131} are almost equivalent to those obtained for λ_{121}.

5 Model independent search of single chargino and neutralino production

The previous single production study assumes that the values of the SUSY parameters are those given by the minimal MSSM model (e.g. gaugino mass unification at the GUT scale) and it is optimized for the discovery/exclusion of charginos and neutralinos with branching ratios given in a proportion determined by the MSSM. In this section a quasi-model independent and complementary study is reported, where the production of charginos and neutralinos and their subsequent decay through the coupling λ_{121} is studied separately for each branching ratio.

This analysis is based on the same data and SM background Monte Carlo samples as the previous ones. The assumption that the lifetime of the LSP is negligible is retained

Single neutralino production at $E_{CM} = 189\ GeV$		
λ_{121} coupling , Signature: $2l^{\pm} + \not{P}_T$		
Cuts	Observed events	Expected S.M events
$N_{ch} = 2$ $P_{ch} \geq 10 GeV/c$ $20° < \theta < 160°$ $E_{STIC} < 10\ GeV$ $E_{ch} > 40\ GeV$ $E_{neut} \leq 10\ GeV$ $\Sigma Q_i = 0, N_{neu} \leq 1$	9962	8902 ± 73
$N_{lep} = 2$ at least one e$^{\pm}$ $\theta_{lep}^{min} \geq 20°$ $E_{miss} > 50\ GeV$	69	78 ± 5
$\Sigma \not{P}_T \geq 30\ GeV/c$ $Acopl \leq 165°$	3	2.06 ± 0.60

Table 8: Number of data and SM background events after each step normalized to the data luminosity of 158 pb^{-1} at 189 GeV for the leptonic topology of single neutralino production decaying through the coupling λ_{121}.

and the signal events are generated by using SUSYGEN 2.20/03 [22] to scan neutralinos or charginos of different masses and composition for each value of $m_{\tilde{\nu}}$. The $tan\beta$ was set to 1.5 for this study. For the signal simulation the simulation program SGV [24] is used. The charginos and neutralinos decay via the R-parity violating coupling, either directly, or via cascade decay, depending on the $\chi^{\pm}$ and χ^0 mass difference and the λ coupling.

Single neutralino production: Signature $2l^{\pm} + (\not{P}_T)$ (λ_{121})

A search for signals of single neutralino production from the sneutrino resonance has also been performed under the assumption that the dominant $\not{R}_p$ couplings involve only leptonic fields $\tilde{\nu_\mu} \to \tilde{\chi^0}\nu$.

An analysis has been performed for the final state of two charged leptons with missing energy. The events selected satisfy the criteria given in Table 8. The events are selected according to their charged multiplicity (N_{ch}) and their neutral multiplicity (N_{neu}). Conditions are imposed on the charged particle momentum (P_{ch} and polar angle θ. Criteria on the energy of the charged (E_{cha}) and neutral (E_{neu}) particles and the energy of the STIC calorimeter (E_{STIC}) are also imposed. The second step includes restrictions on the number of leptons (N_{lep}), their isolation angle (θ_{lep}^{min}) and the missing energy (E_{miss}). Finally the third step imposes criteria on the missing transverse momentum ($\Sigma \not{P}_T$) and the acoplanarity ($Acopl$) of the lepton pair.

The number of data and expected SM background events are reported in Table 8. The observed candidate events in the data are in agreement with the SM background. The average efficiency of the signal is 12% for $m_{\chi_1^0} \geq 30\ GeV/c^2$.

Fig 9a shows the 95% CL excluded cross-section ($\sigma_{upper} \times BR$) for single neutralino production as a function of the sneutrino mass.We assume a BR of 50% for each of the two final topologies $\nu_\mu e^+ e^- \nu_e$ and $\nu_\mu e^{\pm} \mu^{\pm} \nu_e$. Fig 9b shows the 95% CL excluded region

Single chargino production at $E_{CM} = 189\ GeV$		
λ_{121} coupling , Signature: $4l^{\pm} + (\not{P}_T)$		
Cuts	Observed events	Expected S.M events
$N_{ch} = 4$ $P_{ch} \geq 5\ GeV/c$ $20^{\circ} < \theta < 160^{\circ}$ $E_{STIC} < 15\ GeV$ $E_{tot} > 40\ GeV$ $E_{neut} < 20\ GeV$ $E_{ch} > 30\ GeV$	664	611 ± 16
$\Sigma Q_i = 0$ $N_{lep} \geq 2$ at least one μ	30	28 ± 3
$\theta_{cha}^{min} \geq 10^{\circ}$ $M_{ll} > 2\ GeV/c^2$	1	0.62 ± 0.15

Table 9: Number of data and SM background events after each step normalized to the data luminosity of 158 pb^{-1} at 189 GeV, for the leptonic topology of single chargino production decaying through the coupling λ_{121}.

for the λ_{121} coupling. The smallest coupling at the sneutrino resonance is 0.0066 .

Single chargino production: Signature $4l^{\pm}$ **+ (**$\not{P}_T$**)(**λ_{121}**)**

A dedicated search for signals from the sneutrino resonance producing a single chargino production has been performed under the assumption that the dominant $\not{R}_p$ couplings involve only leptonic fields ($\tilde{\nu} \rightarrow l_i^{\pm}\chi^{\pm}$) ,where in this part of the analysis, i=2 and gives a charged muon. The resulting four charged lepton topology with or without missing energy is the most promising signature for the search of the $\not{R}_p$ signals [23].

The events are selected according to their charged multiplicity (N_{ch}),the total energy (E_{tot}), the energy of the charged particles (E_{ch}) and the energy of the neutral particles (E_{neu}). Conditions are imposed on the energy measured by the STIC calorimeter (E_{STIC}), the momentum of the selected charged particles (P_{ch}) and the polar angle θ. The second step contains a check of the total charge of the particles and a cut on the number of identified leptons (muons or electrons) of the final state (N_{lep}). During the third step conditions on the isolation angle of the final charged particles (θ_{cha}^{min}) and on the invariant mass of every two tracks (M_{ll}) are imposed. There is also a requirement for the M_{ll} to be outside the Z^0 mass band.

The number of events selected in the data and the expected SM background samples are reported in Table 9. The data and the Monte Carlo simulation are in a good agreement.

The efficiency of the single chargino production $\chi_1^{\pm}$ has typical values in the range $35 - 40$ % in the single chargino mass interval $90 \leq m_{\chi_1^{\pm}} \leq 160\ GeV/c^2$.

Fig 10a shows the 95% CL excluded cross-sections ($\sigma_{upper} \times BR$) for single chargino production as a function of the sneutrino mass. The smallest efficiency and cross-section is used for this calculation in the chargino mass interval of $90 \leq m_{\chi^{\pm}} \leq 160\ GeV/c^2$. We assume a branching ratio ,$BR = 100\%$, for the reaction $e^+e^- \rightarrow \tilde{\nu_{\mu}} \rightarrow 4l_i^{\pm} + (\not{P}_T)$. Fig 10b shows the 95% CL excluded region for λ_{121} coupling. The smallest coupling at the point

$E_{CM} = 189\ GeV$		
λ_{121} coupling, Signature: multi-leptons/jets		
Cuts	Observed events	Expected S.M events
$PreselectionCuts$ $7 \leq N_{ch} \leq 22$ $20^\circ < \theta < 160^\circ$ $E_{tot} > 0.3\sqrt{s}\ GeV$ $E_{ch} > 40GeV$ $N_{lep} \geq 2$	797	682 ± 33
$N_{jet} > 2$ $\theta^{min}_{lep1} \geq 10^\circ$ $\theta^{min}_{lep2} \geq 10^\circ$	7	10.40 ± 2
$\not{P}_z < 40GeV/c$ $\not{P}_T > 15\ GeV/c$	3	4.42 ± 0.98

Table 10: Number of data and SM background events after each step normalized to the data luminosity of 158 pb^{-1} at 189 GeV for the multi-lepton/jet topology for the λ_{121} coupling.

of the sneutrino resonance is 0.0012. The region excluded by low energy measurements is also indicated in the same figure.

Single Chargino/Neutralino production: Signature multi-lepton/multi-jet topologies (λ_{121})

The MSSM cascade decays of heavier gauginos into lighter gaugino states in addition to the leptonic final states can give multi-lepton/multi-jet topologies. The jets were reconstructed with the DURHAM algorithm [25] requiring that the Durham resolution variable (y_{cut}) is greater than 0.001. The selection criteria for this topology are shown in Table 10, with preselection criteria based on the number of leptons (N_{lep}), the total and charged energy (E_{tot}, E_{ch}) and the number of charged particles (N_{ch}). The second step contains conditions on the effective mass of the two leptons (M_{ll}, Z^0 band cut) followed by the restrictions of the third step on the transverse missing momentum ($\not{P}_T$) and the missing momentum with respect to the z axis ($\not{P}_z$).

The number of events selected in the data and the expected SM background events are reported in Table 10. Data and Monte-Carlo simulation are in good agreement. The signal of this topology, single chargino and single neutralino production, is studied separately. The mean efficiencies found are 20% for the single chargino ($m_{\chi_1^\pm} \geq 90\ GeV/c^2$) and 12% for the single neutralino ($m_{\tilde{\chi_1}^0} \geq 30\ GeV/c^2$).

Fig 11a shows the 95% CL excluded region for λ_{121} coupling for both single chargino and neutralino signals. The smallest coupling at the sneutrino resonance is 0.0012 for the single chargino production (best case) and 0.0026 for the single neutralino production, (worst case), assuming a BR=100 % for each case.

6 Summary

Searches for $\not{R}_p$ effects in e^+e^- collisions at $\sqrt{s} = 189$ GeV have been performed with the DELPHI detector.

The pair production of neutralinos, charginos and sleptons have been studied under the assumption that the LL$\bar{\text{E}}$ term is responsible for the supersymmetric particle decays into standard particles. No evidence for R–parity violation has been observed, allowing to update the limits previously obtained at $\sqrt{s}$ =183 GeV; the present limits are:

- $m_{\tilde{\chi}^0}$ >30 GeV/c^2 and $m_{\tilde{\chi}^\pm}$ >94 GeV/c^2;
- $m_{\tilde{\nu}}$ >78 GeV/c^2 (direct and indirect decays);
- $m_{\tilde{l_R}}$ >84 GeV/c^2 (indirect decay only).

The single production of a neutralino or a chargino via a sneutrino resonance has been searched for. This analysis has given at the best point, namely $M_{\tilde{\nu}} \simeq \sqrt{s}$, $\lambda_{121} < 0.0015$ and $\lambda_{131} < 0.002$ at 95% C.L. A complementary study of the sneutrino resonance, considering charginos and neutralinos separately, as well as 100% branching ratios to specific signatures gives comparable limits.

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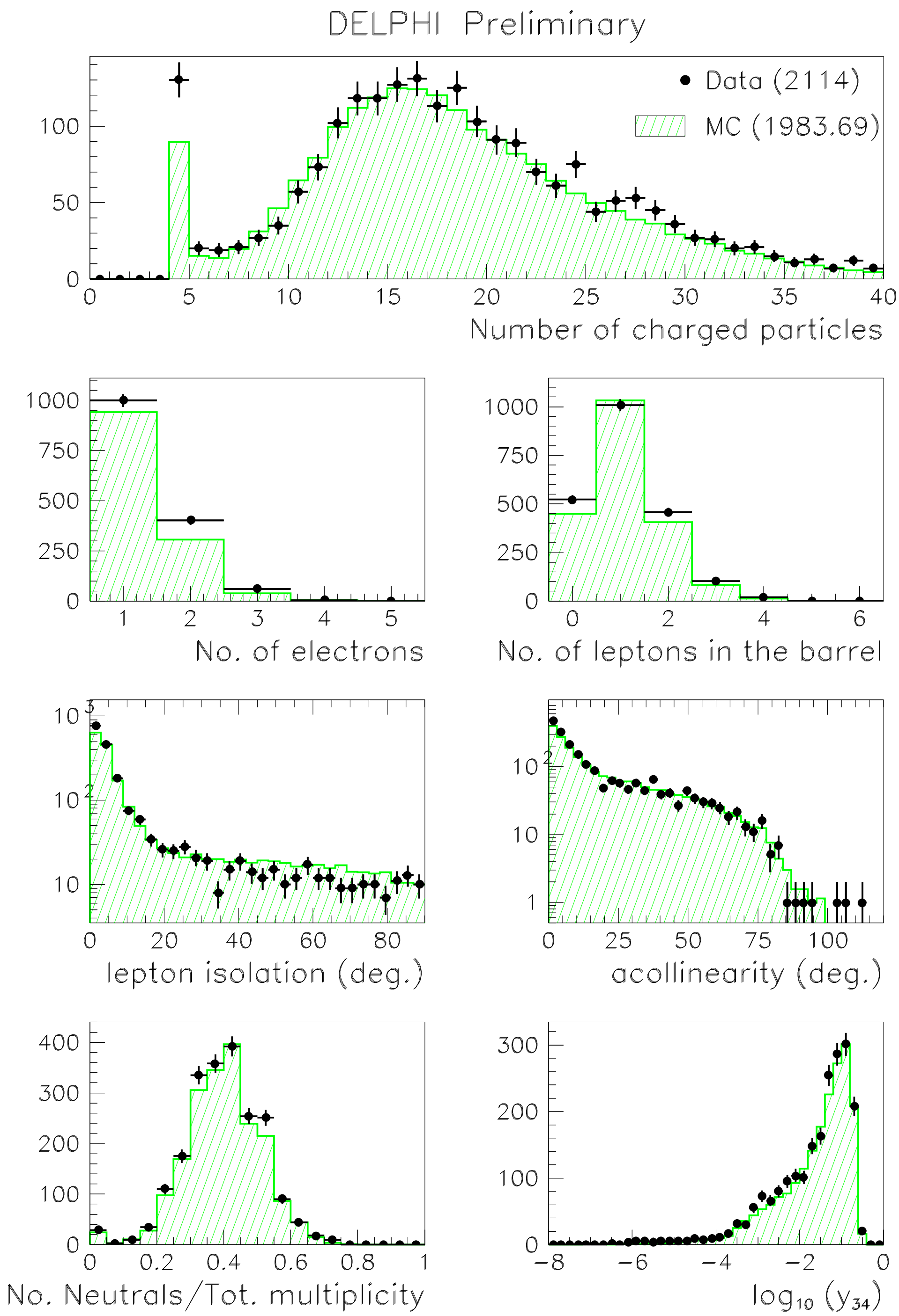


Figure 1: Distributions, after the preselection (pair production analyses), of the number of charged particles, the number of well identified electrons in the event, the number of identified leptons with a polar angle between 40° and 140°, the lepton isolation angle, the acollinearity, the ratio of the number of neutral particles to the total event multiplicity, and the $\log_{10}(y_{34})$. The black dots show the real data distributions, and the hatched histograms the expected background from Standard Model processes.

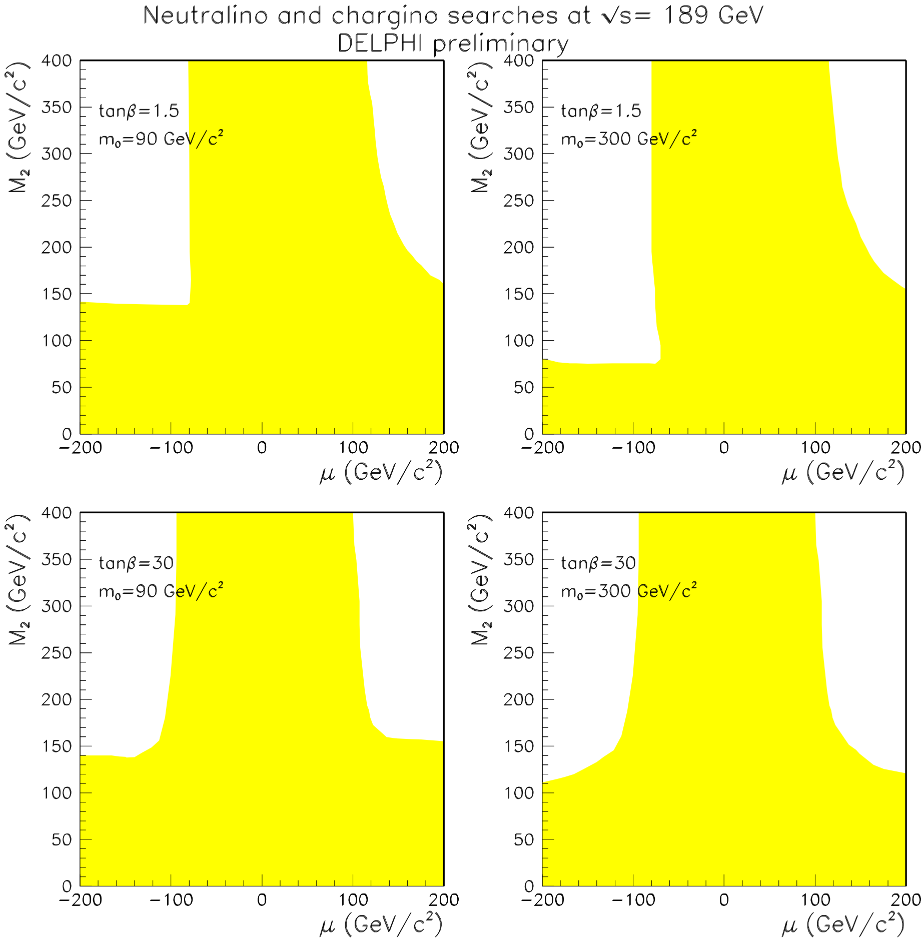


Figure 2: Neutralino and chargino searches in DELPHI data at 189 GeV with a dominant λ coupling: regions in μ, M_2 parameter space excluded at 95 % C.L. for two values of tanβ and two values of m_0.

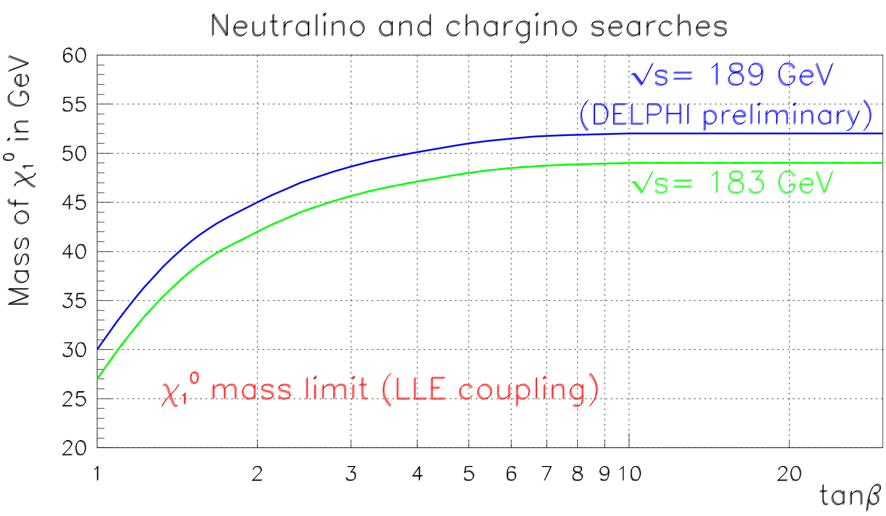


Figure 3: The lightest neutralino mass as a function of tanβ at 95 % confidence level. This limit is independent of the choice of m_0 in the explored range and of the generation indices i,j,k of the λ_{ijk} coupling.

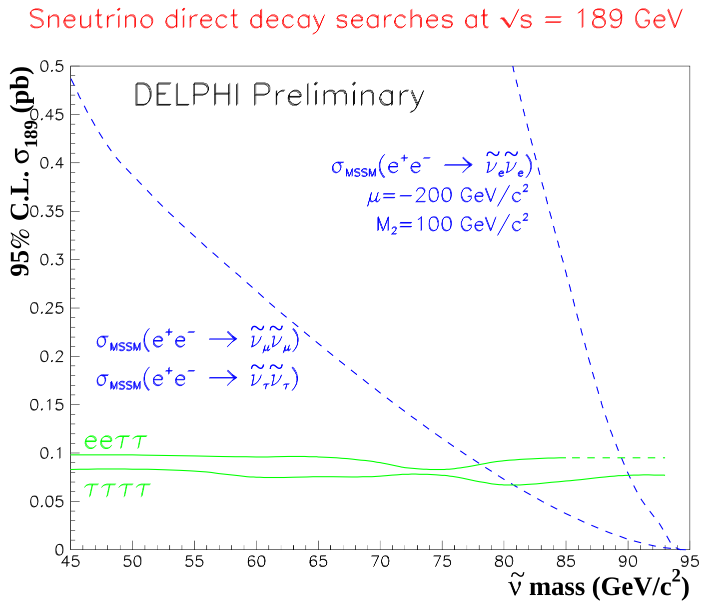


Figure 4: Sneutrino direct decay with λ_{133} coupling: limit on the $\tilde{\nu}\tilde{\bar{\nu}}$ production cross-section as a function of the mass for two different final states. The MSSM cross-sections are reported in order to derive a limit on the sneutrino mass in the case of direct $\not{R}_p$ decay. The dashed upper curve on the plot is the $\tilde{\nu}_e\tilde{\bar{\nu}}_e$ cross-section obtained for $\mu = -200$ GeV$/c^2$ and $M_2 = 100$ GeV$/c^2$, the corresponding chargino mass lies between 90 and 120 GeV$/c^2$.

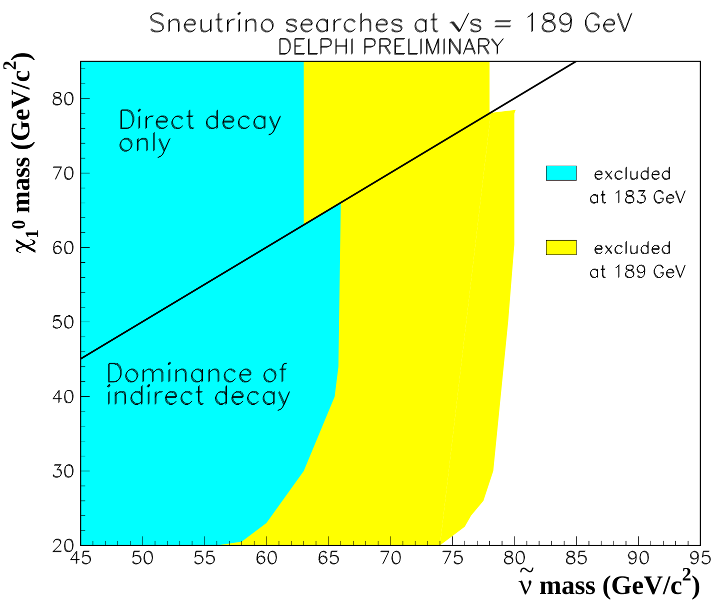


Figure 5: Sneutrino indirect decay with λ_{133} coupling: exclusion domain in $m_{\tilde{\chi}^0}$ versus $m_{\tilde{\nu}}$ for $\tilde{\nu}$ pair production cross-section; the diagonal line separates the plot into two regions: in the upper part, only the direct decay is allowed; in the lower part, the indirect decay is dominant, so the exclusion limit also depends on the neutralino mass. The dark grey area shows the part excluded by the searches at 183 GeV, the light grey area the one excluded by the present analysis.

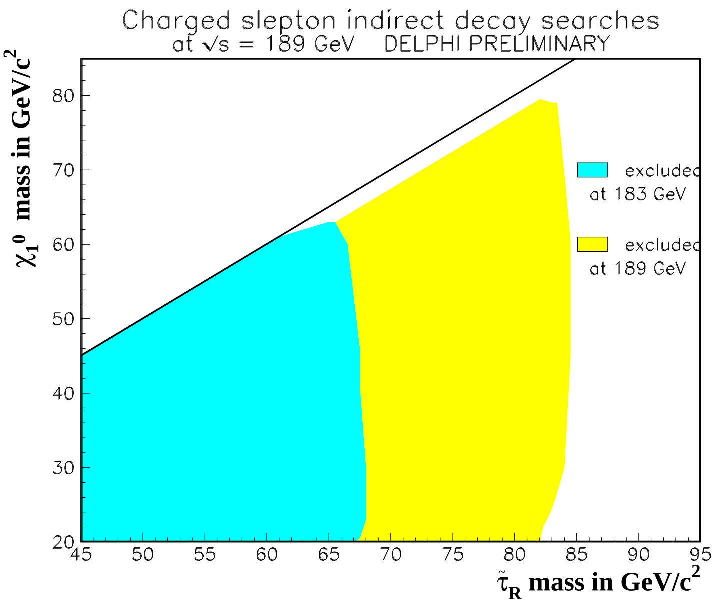


Figure 6: Charged slepton indirect decay with λ_{133} coupling: exclusion domain in $m_{\tilde{\chi}^0}$ versus $m_{\tilde{\tau}_R}$ for $\tilde{\tau}_R$ pair production cross-section; the diagonal line separates the plot into two regions: in the lower part, the indirect decay is dominant, so the exclusion limit also depends on the neutralino mass. The dark grey area shows the part excluded by the searches at 183 GeV, the light grey area the one excluded by the present analysis.

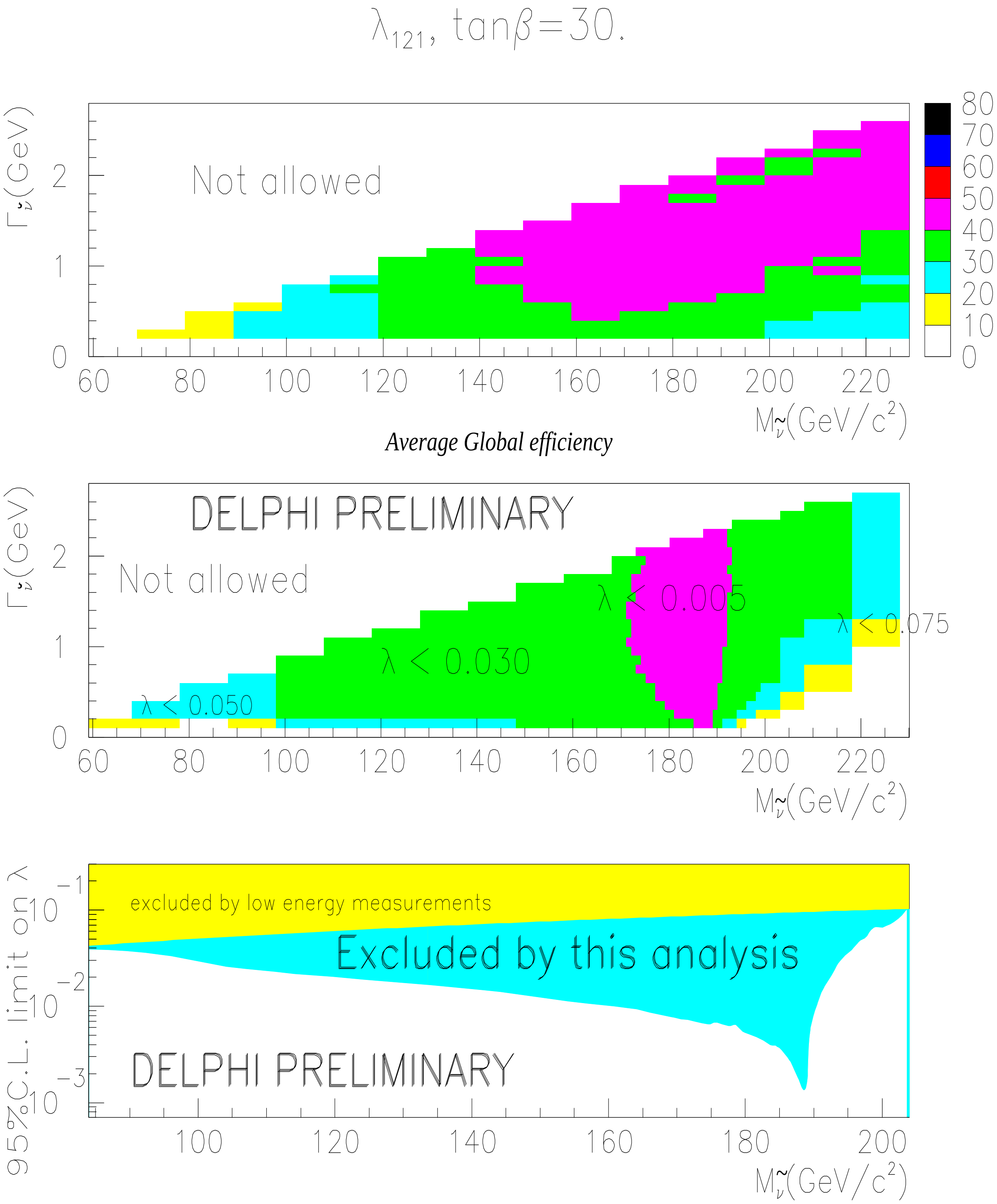


Figure 7: As a function of $M_{\tilde{\nu}}$ and $\Gamma_{\tilde{\nu}}$, for $\tan\beta = 30$, top: average efficiency; middle: upper limit on λ_{121}; bottom: upper limit on λ_{121} assuming $\Gamma_{\tilde{\nu}} > 0.2$ GeV (the indirect limit given by low energy measurements is given assuming $M_{\tilde{\nu}} = M_{\tilde{e}_R}$).

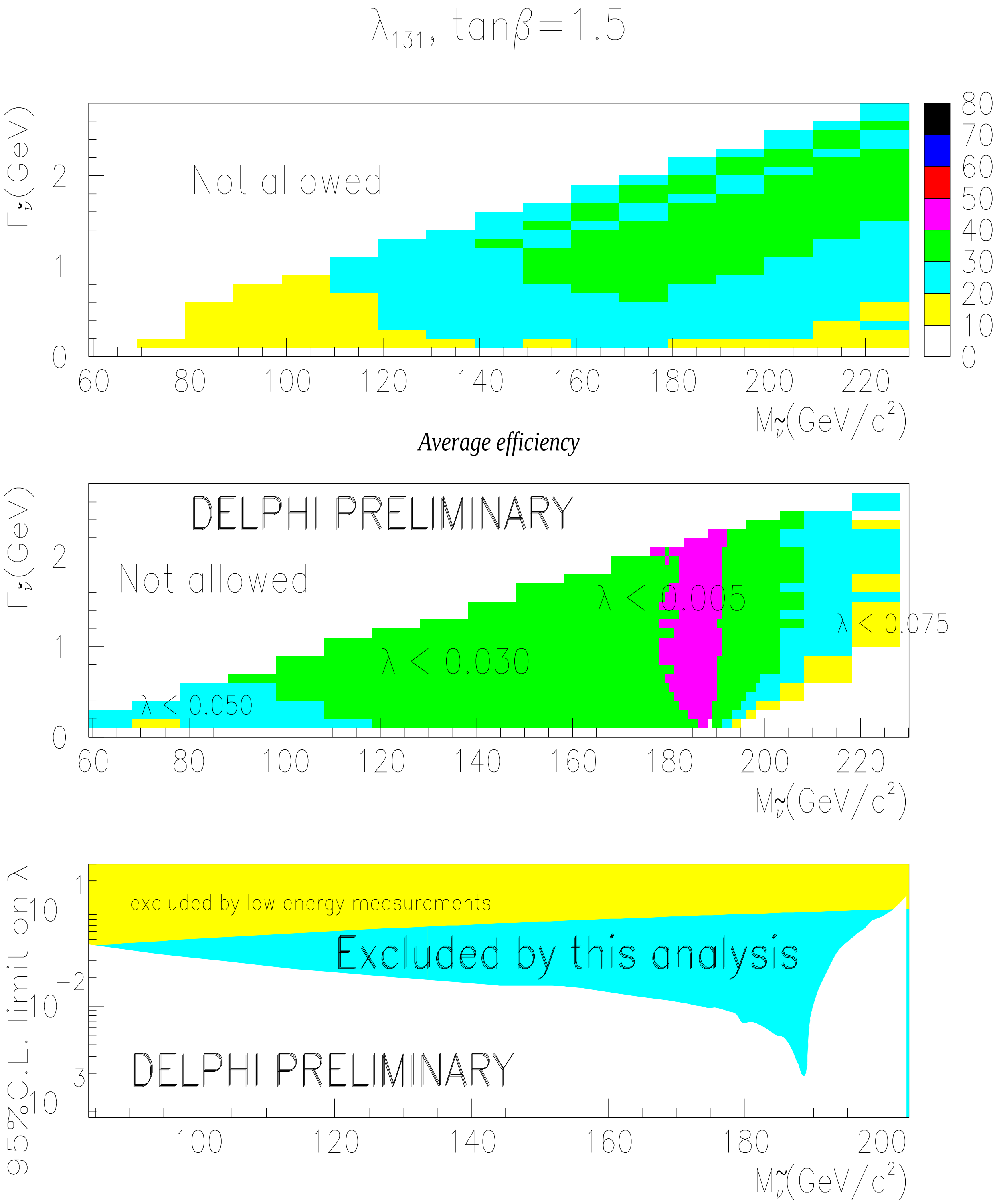
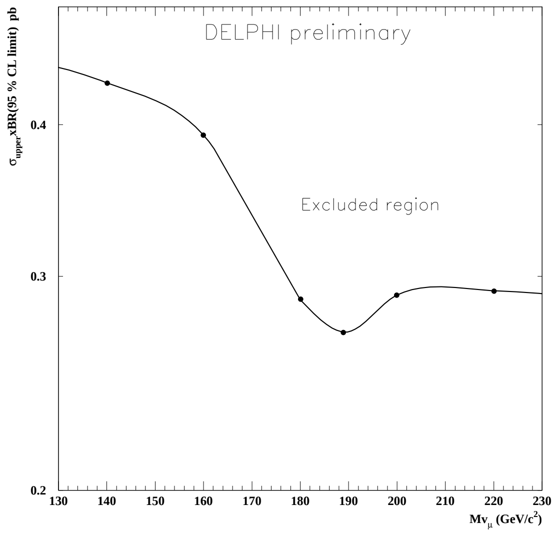
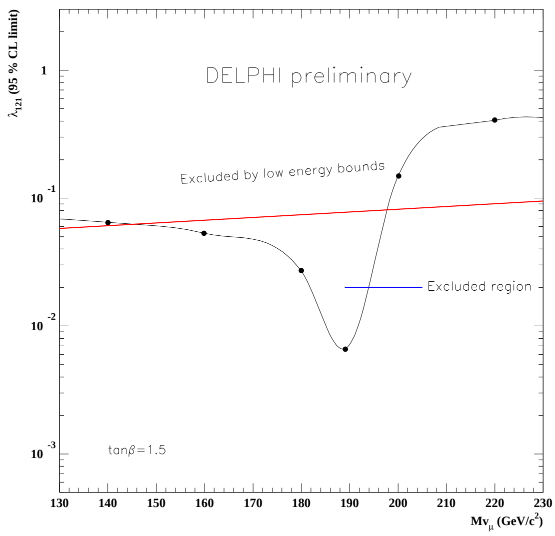


Figure 8: As a function of $M_{\tilde{\nu}}$ and $\Gamma_{\tilde{\nu}}$, for $\tan\beta = 1.5$, top: average efficiency; middle: upper limit on λ_{131}; bottom: upper limit on λ_{131} assuming $\Gamma_{\tilde{\nu}} > 0.2$ GeV (the indirect limit given by low energy measurements is given assuming $M_{\tilde{\nu}} = M_{\tilde{e}_R}$).

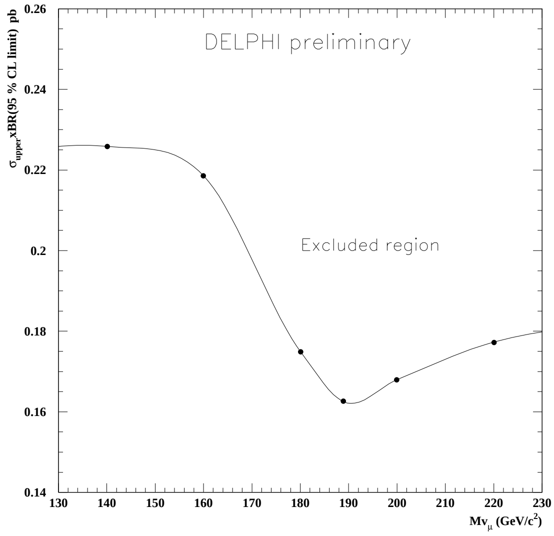


(a)

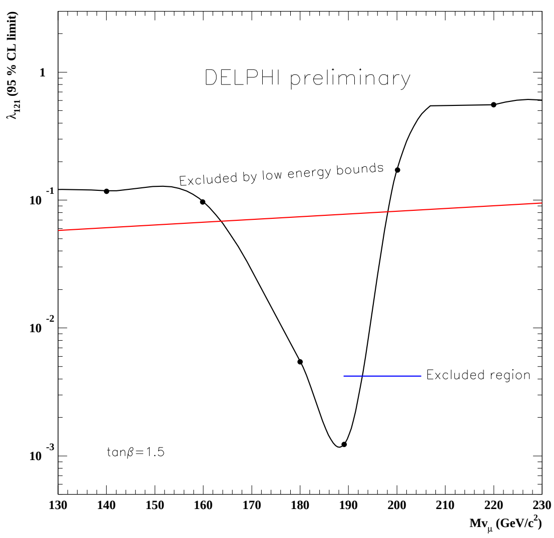


(b)

Figure 9: Single neutralino production. Signature: $2l^{\pm} + \not{P}_T$ (a):$\sigma_{upper} \times BR$ cross-section upper limit(in pb) at 95 % CL, as a function of $M_{\tilde{\nu}}$.(b):Upper limit for the coupling λ_{121} as a function of $M_{\tilde{\nu}}$.The region excluded by low energy measurements is also indicated.For both figures $tan\beta = 1.5$.



(a)



(b)

Figure 10: Single chargino production. Signature: $4l^{\pm} + (\not{P}_T)$ (a): $\sigma_{upper \times BR}$ cross-section upper limit(in pb) at 95 % CL, as a function of $M_{\tilde{\nu}}$.(b):Upper limit for the coupling $\lambda_{121} \times BR$ as a function of $M_{\tilde{\nu}}$. The region excluded by low energy measurements is also indicated. For both figures $tan\beta = 1.5$.

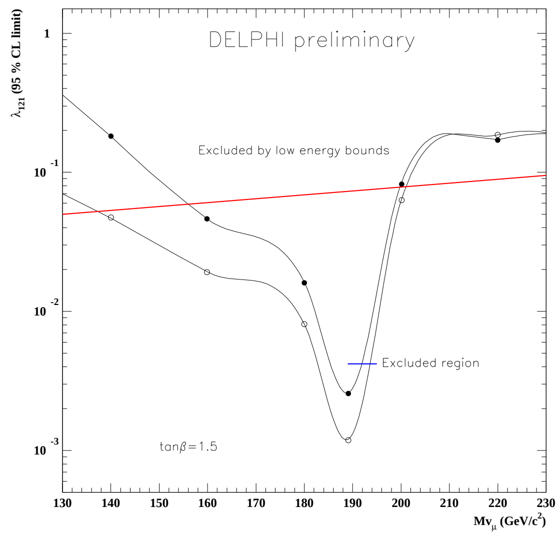


Figure 11: Single chargino and neutralino production: upper limit for the coupling λ_{121} for the "multi-lepton/jet" topology for $tan\beta = 1.5$ (*Worst case:* single neutralino production; *Best case:* single chargino production). The region excluded by low energy measurements is also indicated.