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Search for Charginos, Neutralinos and Smuons in R-Parity Violating Scenario with $\lambda' LQD$ Couplings at $\sqrt{s} = 189$ GeV

Preliminary

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Search for Charginos, Neutralinos and Smuons in R-Parity Violating Scenario with $\lambda' LQD$ Couplings at $\sqrt{s} = 189$ GeV

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Abstract

A search for neutralino and chargino pair production was performed using data taken by the DELPHI experiment at LEP at a center-of-mass energy of 189 GeV. The study is based on an R-parity violating scenario with a dominant LQD (λ') coupling, leading to two jets and an electron in the final state from the R_p violating neutralino decay. This study extends a previous one where the neutralino decay into to two jets and a neutrino or a muon were considered. All couplings λ'_{1jk}, λ'_{2jk} ($j = 1, 2,\ k = 1, 2, 3$) and λ'_{i3k} ($i = 1, 3,\ k = 1, 2, 3$) are consequently covered. A search was also done for the smuon indirect decay. No deviation from the standard model is observed. The results were combined with those of 184 GeV and used to exclude domains of the Minimal Supersymmetric Standard Model parameter space. A lower limit on neutralino,chargino and smuon masses is derived.

1 Introduction

The Minimal Supersymmetric Standard Model (MSSM) [1] is the minimal extension of the Standard Model (SM) in terms of the number of particles. To each SM particle a supersymmetric partner (called sparticle in the following) is associated, whose spin differs by 1/2, and an extra $SU(2)_L$ Higgs doublet is added. One can define the R_p quantum number as $R_p = (-1)^{3B+L+2S}$ where B, L, and S are respectively the baryon number, lepton number and spin. For SM particles $R_p = +1$ and for their supersymmetric partner $R_p = -1$. The most general supersymmetric Lagrangian involves the R-parity violating terms [2] $\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$ where λ_{ijk}, λ'_{ijk} and λ''_{ijk} are Yukawa couplings, L and E (Q, U and D) denote the lepton (quark) superfields.

The main consequence of the R-parity violation, $\not{R}_p$ is that the Lightest Supersymmetric Particle (LSP) is no more stable and can decay into SM particles. The decay of a sparticle can be either *direct*, when the sparticle decays directly or via a virtual exchange of a squark or a slepton to standard particles through an $\not{R}_p$ vertex (this is always the case for the LSP), or *indirect* when the sparticle first decays through an R_p conserving vertex to a standard particle and an on-shell sparticle which then decays through an $\not{R}_p$ vertex. Figure 1 shows the $\not{R}_p$ decays of squarks and sleptons with λ' couplings, figure 2 illustrates the $\tilde{\chi}^0_1$ three body direct decay in a lepton (charged or neutral) and 2 quarks (the flavour of the lepton depends of the index i and those of the quarks of the indices j and k) and the $\tilde{\chi}^+_1$ indirect decay in a W^* and a $\tilde{\chi}^0_1$.

2 Framework of the analysis

This paper is an update of the results presented at the '99 Moriond conference concerning the search for $\tilde{\chi}^0_1$ and $\tilde{\chi}^+_1$[3]. In [3] the neutralino decays

- $\tilde{\chi}^0_1 \rightarrow \mu q q$
- $\tilde{\chi}^0_1 \rightarrow \nu_i q q$

were addressed. The case $\tilde{\chi}^0_1 \rightarrow e q q$ is studied here. Combination of results obtained at 184 and 189 GeV concerning neutralinos and charginos searches are shown. This paper also presents a search for smuon indirect decay into a muon and a neutralino.

When the λ'_{ijk} couplings involve b quarks in the three body decay of the neutralino, the AABTAG [4] package is used to tag the b's. This algorithm combines information from impact parameters and rapidities of the tracks to build a probability which is close to 1 if the event does not contain a b quark, and is near 0 if the event has a high b content. The probability variables of tagging P_E (obtained with all tracks) and P_E^+ (obtained with tracks having a positive impact parameter) are defined in [4] and [5]. Jets are reconstructed using the Durham algorithm.

The 95 % confidence level is calculated according the Feldman and Cousins prescription [6].

In the generation of signal events, the common value for λ' is set to 0.01, a value below the indirect limits on the couplings obtained from SM processes except for λ'_{111} and λ'_{133}. In that particular case the low energy measurements impose $\lambda'_{111} \leq 5.2.10^{-4}$ [7] and $\lambda'_{133} \leq 1.4.10^{-3}$ [8]. As a consequence, the length of flight of $\tilde{\chi}^0_1$ is non negligible (from a few tenths of centimetres to a few meters) in some regions of the $\mu - M_2$ plane : the present analyses are not sensitive to such cases of displaced vertices.

3 Data samples

The data corresponding to an integrated luminosity of 158 pb^{-1} collected during 1998 by DELPHI at centre-of-mass energy of 189 GeV were analyzed.

Bhabha scattering, $e^+e^- \to Z\gamma$, $\gamma\gamma$, and 4 fermions final states were considered as sources of Standard Model background. The processes $Z\gamma \to hadrons$, $\tau^+\tau^-$, $\mu^+\mu^-$ were generated by PYTHIA[9] and KORALZ[10]. The $\gamma\gamma$ interactions leading to leptonic final states were generated with the BDK program [11]; the $\gamma\gamma \to hadrons$ were generated using TWOGAM[12]. The four fermions final states were generated with EXCALIBUR[13].

To evaluate signal efficiencies, neutralino and chargino pair production is generated with SUSYGEN 2.20.3[14]. Several points in the MSSM parameter space, corresponding to different values of $tan\beta$ (1, 1.5, 5 and 30), m_0 (90, 300 and 500 GeV/c^2), μ ($-300 \leq \mu \leq 300$ GeV/c^2) and M_2 ($0 < M_2 \leq 400$ GeV/c^2) were considered. All generated signal events were processed with the DELPHI full simulation program.

4 Case $\tilde{\chi}^0_1 \to eqq$

There are first very general preselection criteria on the charged multiplicity, the charged energy, the effective energy in the centre-of-mass $\sqrt{s'}$ and the missing momentum (which must not be large since we expect no missing energy in the process $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$ and $\tilde{\chi}^0_1 \to eqq$). The event has to contain at least two acolinear electrons. The most energetic one should be in the barrel acceptance. This electron has to be tagged as "tight". A constraint is applied on the product of its energy E_{elec1} multiplied by its isolation angle θ_{isol1} with respect to the nearest charged particle since energetic and isolated electrons are expected. Then a two-dimensional cut is made in the plane $log_{10}(Y_5)$ vs $log_{10}(1-thrust)$ (Y_5 is the Durham distance at which the event topology flips from 4 to 5 jets). In the case of λ'_{113} and λ'_{123} when a b quark is also present in the $\tilde{\chi}^0_1$ decay the b-tagging variable $log_{10}(-log_{10}(P_E^+))$ is used. The number of remaining data and Monte-Carlo events are reported in table 1.

In order to cover the largest area in the MSSM parameter space the same analysis was also applied to $\tilde{\chi}^+_1\tilde{\chi}^-_1$ and $\tilde{\chi}^0_1\tilde{\chi}^0_3$ (where $\tilde{\chi}^+_1$ and $\tilde{\chi}^0_3$ have indirect decays). The last process was considered only in a small region of the $\mu - M_2$ plane (-40 GeV/$c^2 \leq \mu \leq$ -80 GeV/c^2 and 80 GeV/$c^2 \leq M_2 \leq 130$ GeV/c^2 for $tan\beta \leq 1.5$ and $m_0 = 90$ GeV/c^2) not covered by $\tilde{\chi}^0_1\tilde{\chi}^0_1$ or $\tilde{\chi}^+_1\tilde{\chi}^-_1$. No systematic study was made on the process $\tilde{\chi}^0_1\tilde{\chi}^0_2$ since areas where the corresponding cross-section is non-negligible are a subset of those covered by the preceding processes (though the analysis is also efficient for $\tilde{\chi}^0_1\tilde{\chi}^0_2$ decays). The efficiencies obtained for $\tilde{\chi}^+_1\tilde{\chi}^-_1$ ($\tilde{\chi}^0_1\tilde{\chi}^0_3$) were 20% (25%) if no b-tagging criteria is applied and 15%(20%) after the b-tagging requirement. The b-tagging analysis probes the couplings λ'_{113} and λ'_{123}.

The distributions of the variables used after the first step of the analysis for real events and Monte-Carlo events are shown in figure 3. The two-dimensional histogram $log_{10}(Y_5)$ vs $log_{10}(1-thrust)$ is displayed in figure 4 just before it is used in selection criteria (step 4 of table 1).

Step	Selection criteria	Data	Background	Efficiency
1	Charged multiplicity ≥ 10 $E_{charged} \geq 35$ GeV $\sqrt{s'} \geq 150$ GeV $P_{miss} \leq 40$ GeV/c	4588	4531.5±14.3	72
2	At least 2 electrons $\theta(most\ energ\ elec) \in [35^o; 145^o]$ Acolinearity of electrons $\leq 155^o$	219	220.3±3.6	31
3	most energ. elec=tight	64	58.6±1.8	29
4	$log_{10}(E_{elec1} \times \theta_{isol1}) \geq 2.25$	33	32.0±1.3	28
5	$log_{10}(Y_5) \geq$ $-2 + log_{10}((1 - thrust)$	6	6.9±0.6	24
$N_{95} = 5.8$				
Case of λ'_{113} and λ'_{123} couplings				
6	$log_{10}(-log_{10}(P_E^+)) \geq 0$	2	1.9±0.3	21
$N_{95} = 4.8$				

Table 1: $\tilde{\chi}_1^0$ direct decay analysis with $\tilde{\chi}_1^0 \rightarrow eqq$, The efficiency corresponds to $\tilde{\chi}_1^0\tilde{\chi}_1^0$ simulated signal with $m_{\tilde{\chi}_1^0} = 40$ GeV/c^2. The b-tagging variable $log_{10}(-log_{10}(P_E^+))$ is used only for λ'_{113} and λ'_{123} when a b quark is present

5 Combination of 184 and 189 GeV results on neutralino and chargino search

The total number of data and background simulation events at 184 and 189 GeV for different neutralino decay channels are shown in table 2.

No excess of data with respect to the Standard Model expectation has been observed. The results obtained are then used to constrain domains of the MSSM parameter space with the given value of N_{95} as previously explained [3]. The exclusion plots for λ'_{i3k} ($i = 1, 2, 3,\ k = 1, 2, 3$) in different $\mu - M_2$ planes are shown on figure 5. From these exclusion plots, limits on the neutralino and chargino masses can be derived. Figure 6 represents the evolution of the limit as a function of $tan\beta$ for the couplings λ'_{1jk}, λ'_{2jk} ($j = 1, 2,\ k = 1, 2, 3$) and λ'_{i3k} ($i = 1, 3,\ k = 1, 2, 3$). The limits obtained are :

- $m(\tilde{\chi}_1^0) \geq 30$ GeV/c^2
- $m(\tilde{\chi}_1^+) \geq 89$ GeV/c^2.

6 Smuon indirect search

The pair production of smuon $e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^-$ with a subsequent indirect decay $\tilde{\mu}^\pm \rightarrow \mu^\pm\tilde{\chi}_1^0$ is addressed in this paragraph. The neutralino is decaying directly with one of the λ'_{ijk} couplings into a lepton (charged or neutral) and two quarks. The analysis is close to the one described in [3] for the case $\tilde{\chi}_1^0 \rightarrow \mu qq$. Only the results are presented in table 3. The

Channel	Data	Background
$\tilde{\chi}^0_1 \to \mu qq\ q \neq b$	5	6.0±0.6
$N_{95} = 5.3$		
$\tilde{\chi}^0_1 \to \mu bq$	2	2.6±0.4
$N_{95} = 4.2$		
$\tilde{\chi}^0_1 \to eqq\ q \neq b$	9	10.2±0.8
$N_{95} = 6.7$		
$\tilde{\chi}^0_1 \to ebq$	2	3.3±0.6
$N_{95} = 3.6$		
$\tilde{\chi}^0_1 \to \nu qq\ q \neq b$		
$\tilde{\chi}^+_1$ indirect	37	36.7±1.9
$N_{95} = 13.9$		
$\tilde{\chi}^0_1 \to \nu bq\ q \neq b$		
$\tilde{\chi}^0_1$ direct	27	30.8±2.0
$N_{95} = 10.0$		
$\tilde{\chi}^+_1$ indirect	8	13.9±1.3
$N_{95} = 3.3$		
$\tilde{\chi}^0_1 \to \nu bb$		
$\tilde{\chi}^0_1$ direct	6	7.5±0.9
$N_{95} = 5.4$		
$\tilde{\chi}^+_1$ indirect	5	8.7±0.9
$N_{95} = 3.3$		

Table 2: Combination of results at 184 and 189 GeV for different neutralino decay channels.

analysis presented here does not consider the different λ'_{ijk} couplings separately, but the efficiencies do not depend strongly on the couplings. The least efficient case is obtained when $\tilde{\chi}^0_1 \to \nu qq$ but it not much less efficient than the case where a charged lepton is present. The efficiencies for this least efficient case are shown in figure 7. They were determined with the fast simulation program *SGV* [15] and cross-checked on many full simulation points.

Since no excess of data with respect to the standard model expectation is observed, we can derive an exclusion plot in the plane m($\tilde{\mu}$) vs m($\tilde{\chi}^0_1$). The result presented in figure 8 is the most conservative case $e^+e^- \to \tilde{\mu}^+_R\tilde{\mu}^-_R$. The limits obtained on the smuon mass are:

- $m(\tilde{\mu}_R) \geq 78$ GeV/c^2
- $m(\tilde{\mu}_L) \geq 79$ GeV/c^2.

If one takes into account the limit on the neutralino mass given in paragraph 5, then the limits become:

Step	Selection criteria	Data	Background	Efficiency %
1	Charged multiplicity ≥ 7 $E_{charged} \geq 40$ GeV $\sqrt{s'} \geq 110$ GeV $\vert cos(\theta_{miss})\vert \leq 0.95$ 6 jets or more for $Y_c = 5 \times 10^{-3}$	2825	2702.9±10.9	91
2	At least 2 standard muons with opposite charges Acolinearity of muons $\leq 150^o$	17	16.8±1.0	58
3	$E_{\mu 2}/E_{\mu 1} \geq 0.2$	14	12.2±0.8	58
4	$log_{10}(E_{\mu 2} \times \theta_{isol2}) \geq 1.6$	5	4.8±0.5	57
$N_{95} = 6.3$				

Table 3: Indirect smuon decay $\tilde{\mu}^{\pm} \rightarrow \mu^{\pm}\tilde{\chi}^0_1$. The neutralino decays with one of the λ'_{ijk} couplings into a lepton (charged or neutral) and two quarks. The efficiency corresponds to a simulated signal $\tilde{\mu}^+\tilde{\mu}^-$ with a smuon mass of 85 GeV/c^2 a neutralino mass of 40 GeV/c^2 and $\tilde{\chi}^0_1 \rightarrow \nu qq$.

- $m(\tilde{\mu}_R) \geq 81$ GeV/c^2 if $m(\tilde{\chi}^0_1) \geq 30$ GeV/c^2
- $m(\tilde{\mu}_L) \geq 82$ GeV/c^2 $m(\tilde{\chi}^0_1) \geq 30$ GeV/c^2.

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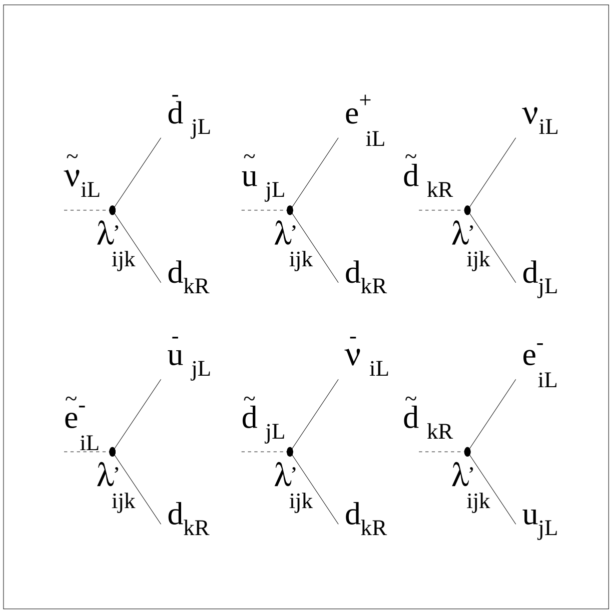

Figure 1: $\not{R}_p$ decays of sfermions with λ' couplings.

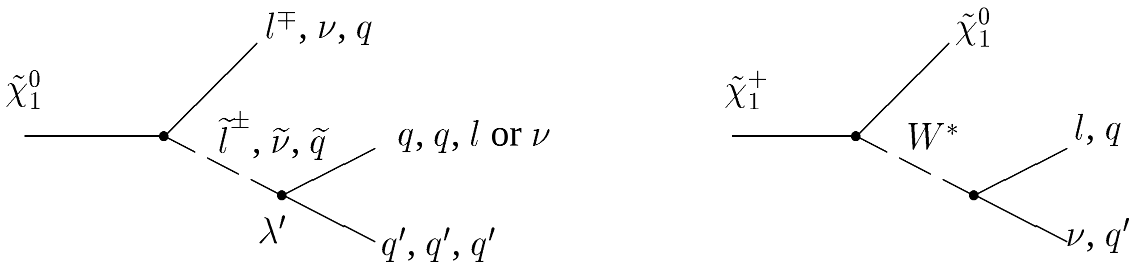

Figure 2: $\tilde{\chi}^0_1$ direct decay with λ' couplings (left) and $\tilde{\chi}^+_1$ indirect decay(right).

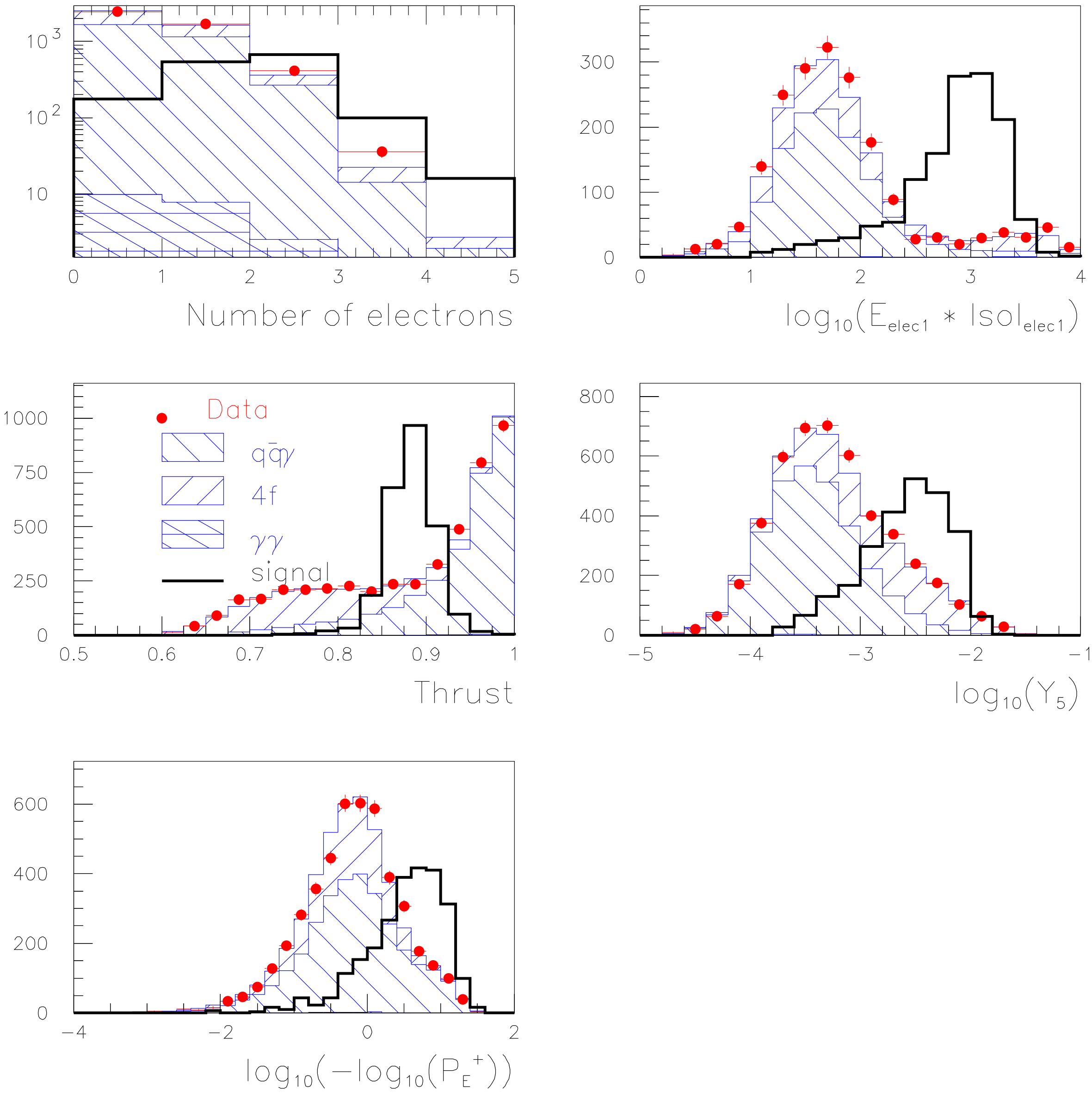

Figure 3: Distributions of the event variables for $e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1$ and $\tilde{\chi}^0_1 \rightarrow eqq$ analysis at the step 1 level of table 1 for data (dots), expected SM background (hatched histograms) and signal (full line histograms). $log_{10}(E_{elec1} \times \theta_{isol1})$ is the product (GeV.deg) of the energy of the most energetic electron by its isolation angle w.r.t the nearest charged particle. Y_5 is the Durham distance at which the event topology flips from 4 to 5 jets. P_E^+ is the b-tagging variable defined in paragraph 2 .

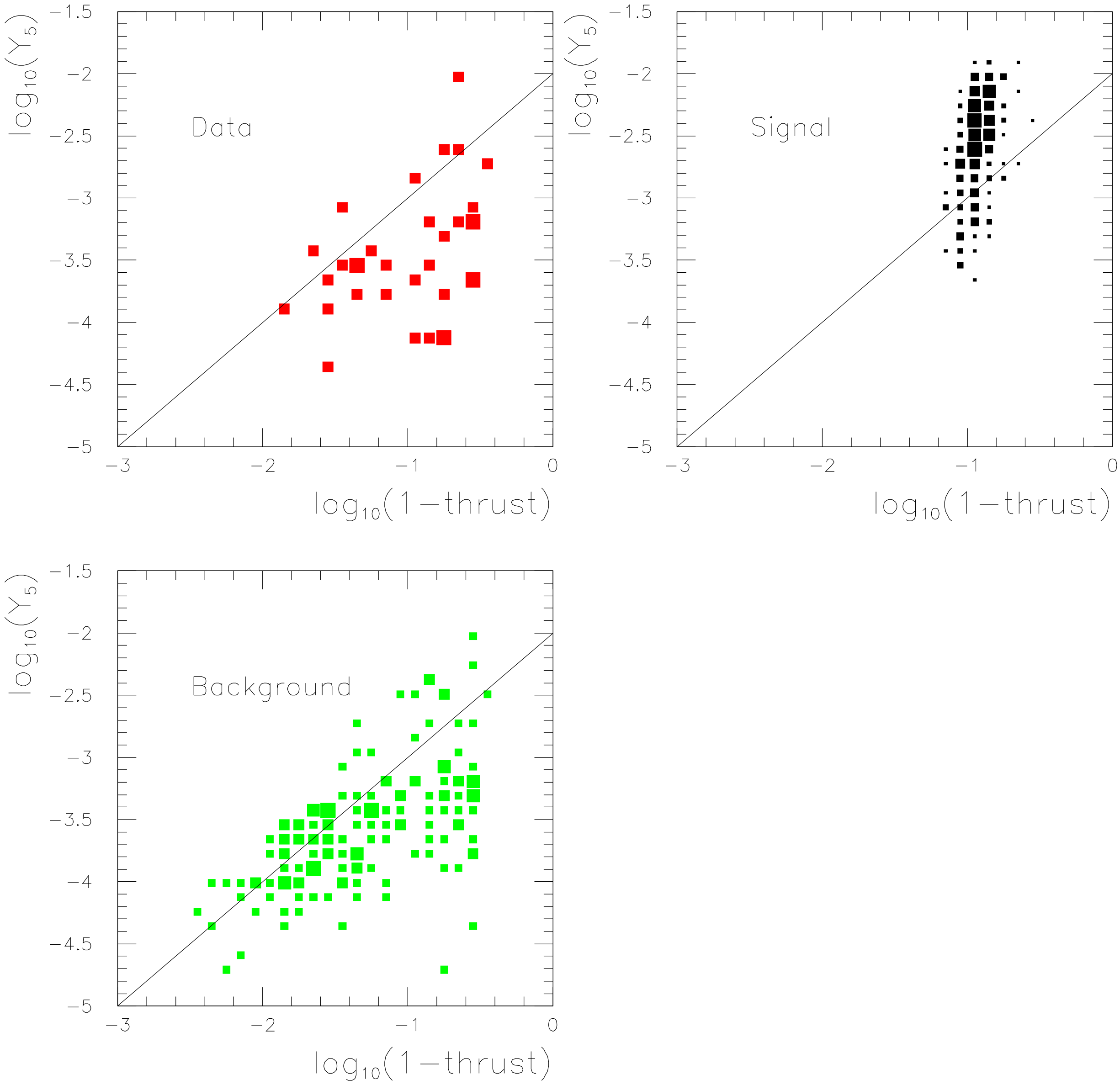

Figure 4: Two-dimensional histogram $log_{10}(Y_5)$ vs $log_{10}(1-thrust)$ used in the the analysis $\tilde{\chi}_1^0 \rightarrow eqq$ at the step 4 level of table 1 for data, expected SM background and signal. Only the events located above the line are kept in the analysis.

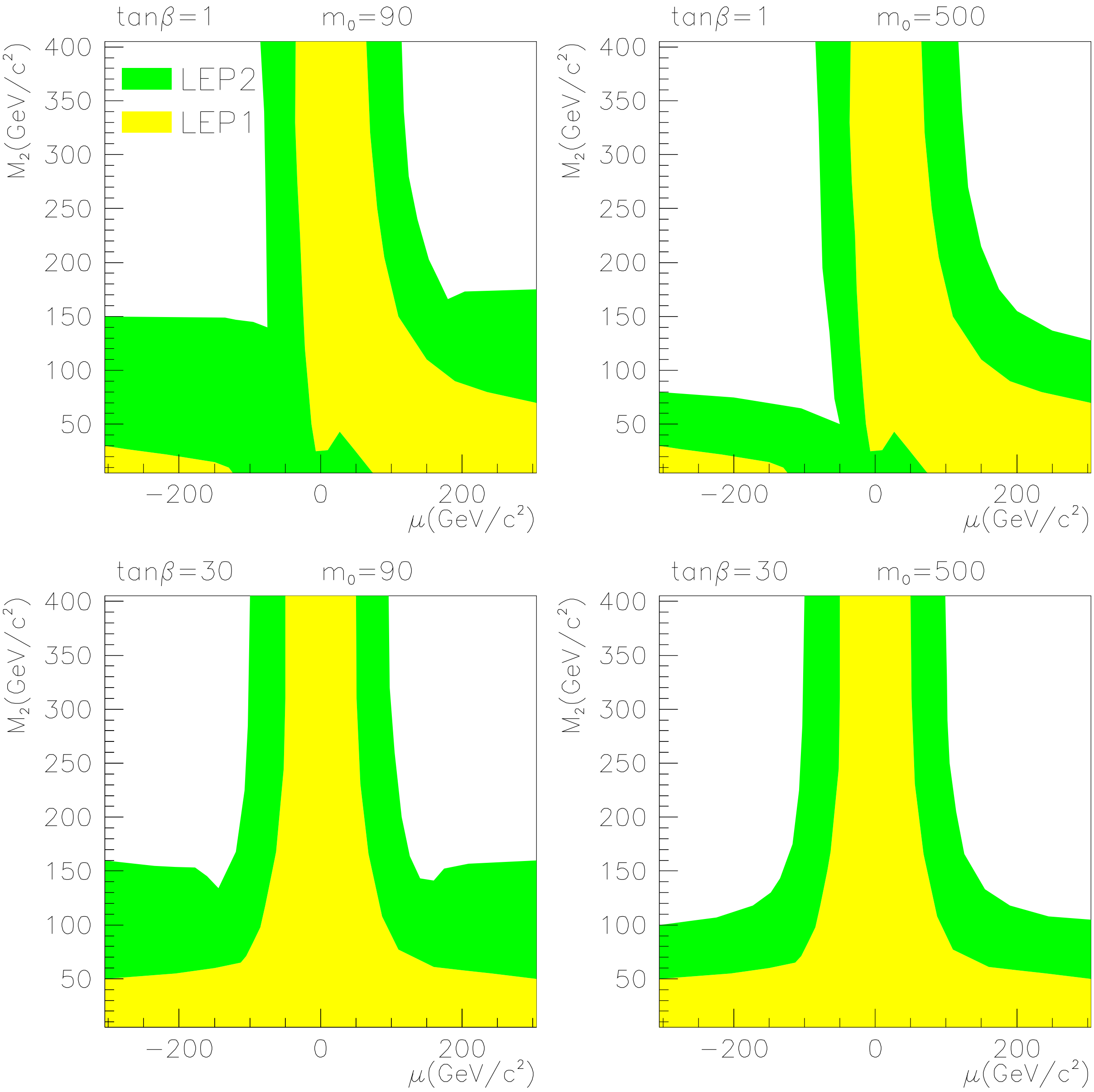

Figure 5: Exclusion area at 95 % CL for λ'_{i3k} ($i = 1, 3$, $k = 1, 2, 3$) dominant couplings (with the value $\lambda'_{i3k} = 0.01$) in four $\mu - M_2$ planes ($tan\beta = 1$, $tan\beta = 30$ and $m_0 = 90$ GeV/c^2, $m_0 = 500$ GeV/c^2). The light grey regions (or yellow in colour) are excluded by LEP1 results, the dark grey (or green in colour) are those excluded by the present analysis.

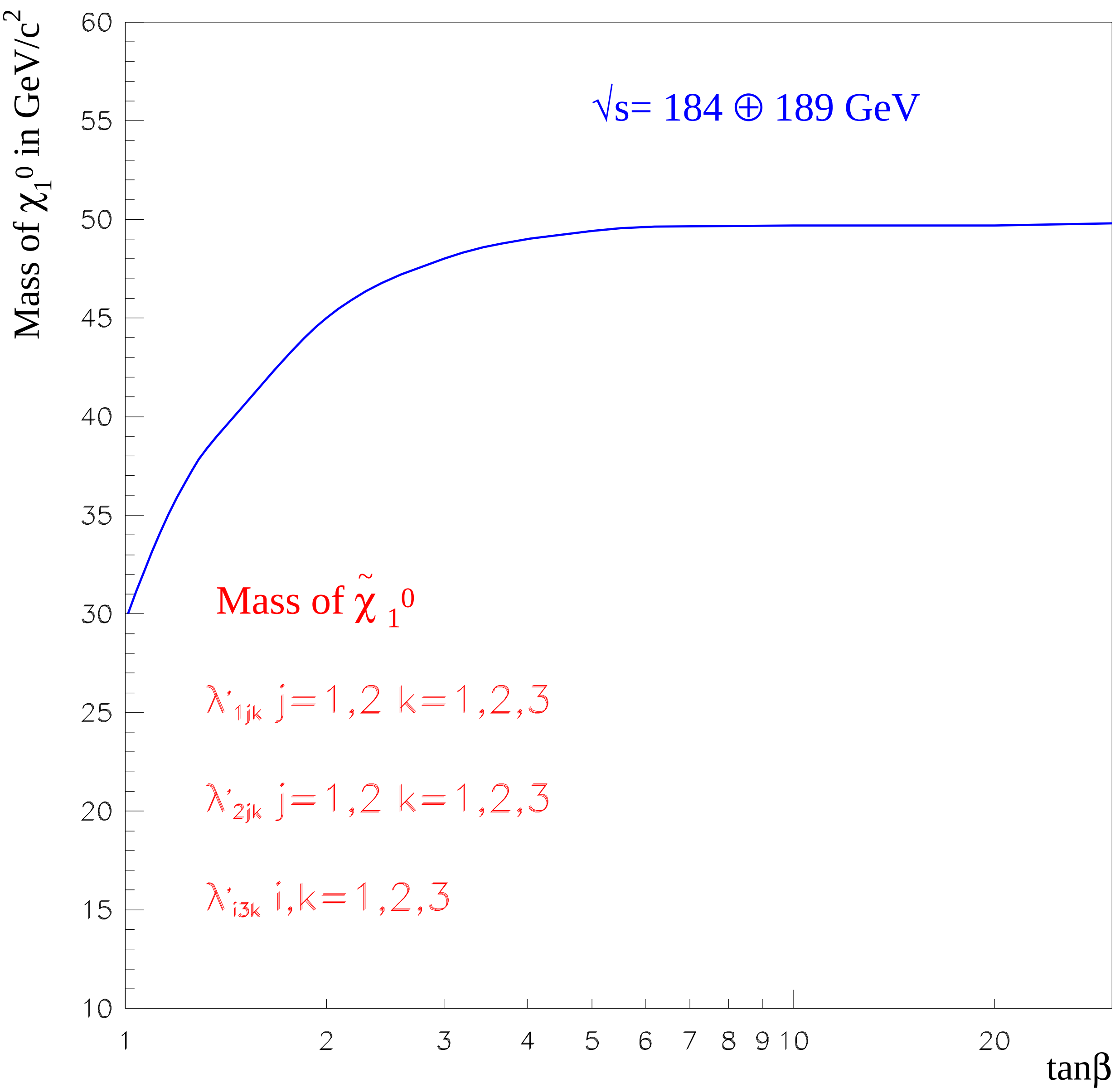

Figure 6: Mass limit of $\tilde{\chi}^0_1$ as a function of $tan\beta$ for the couplings λ'_{1jk}, λ'_{2jk} ($j = 1, 2$, $k = 1, 2, 3$) and λ'_{i3k} ($i = 1, 3$, $k = 1, 2, 3$)

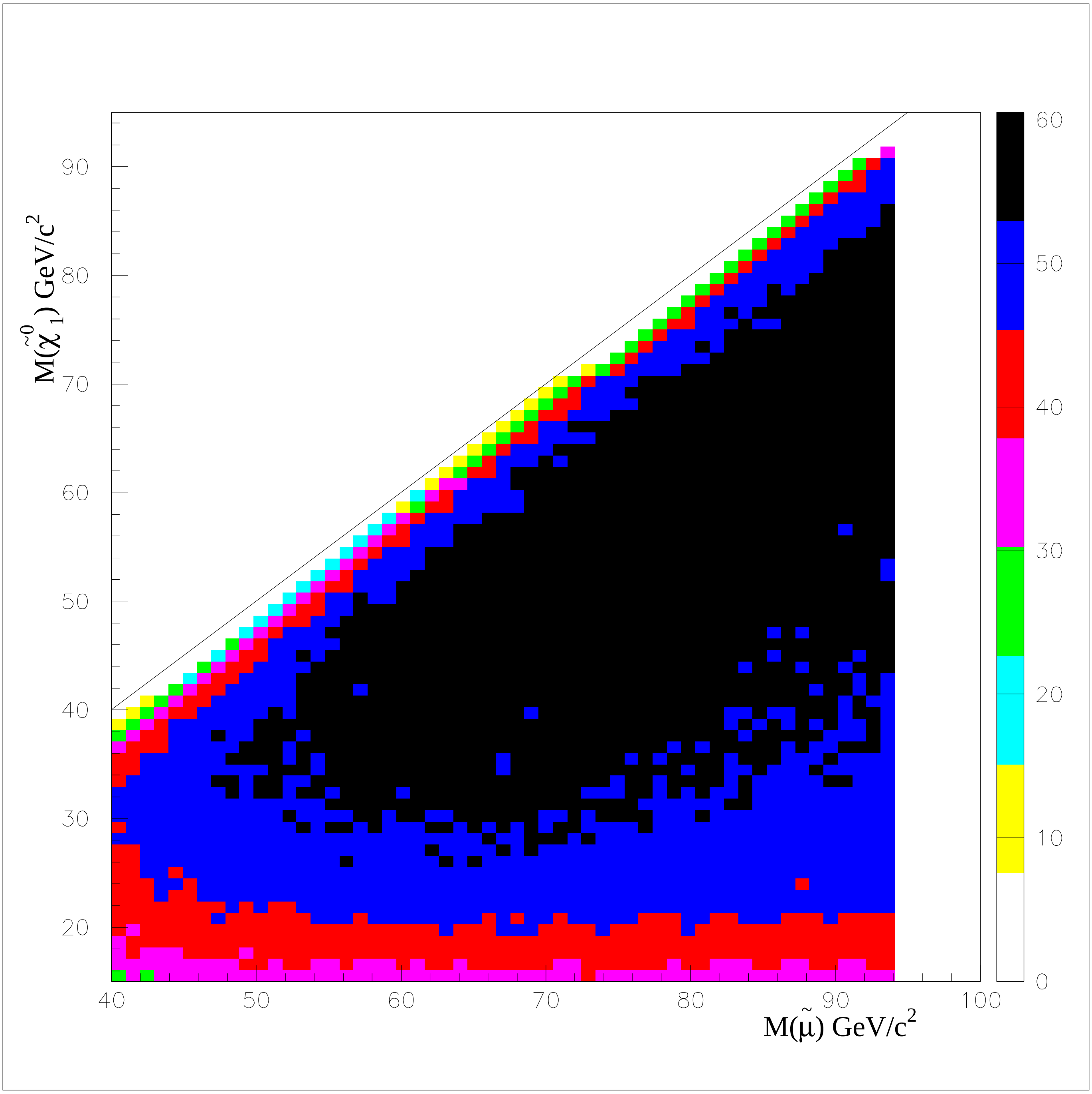

Figure 7: Minimum efficiency (%) obtained in the plane mass of the smuon / mass of $\tilde{\chi}^0_1$ for indirect decay $\tilde{\mu}^{\pm} \rightarrow \mu^{\pm}\tilde{\chi}^0_1$ and a subsequent direct decay of the $\tilde{\chi}^0_1$ with any of the λ'_{ijk} couplings. The minimum is obtained when $\tilde{\chi}^0_1 \rightarrow \nu qq$

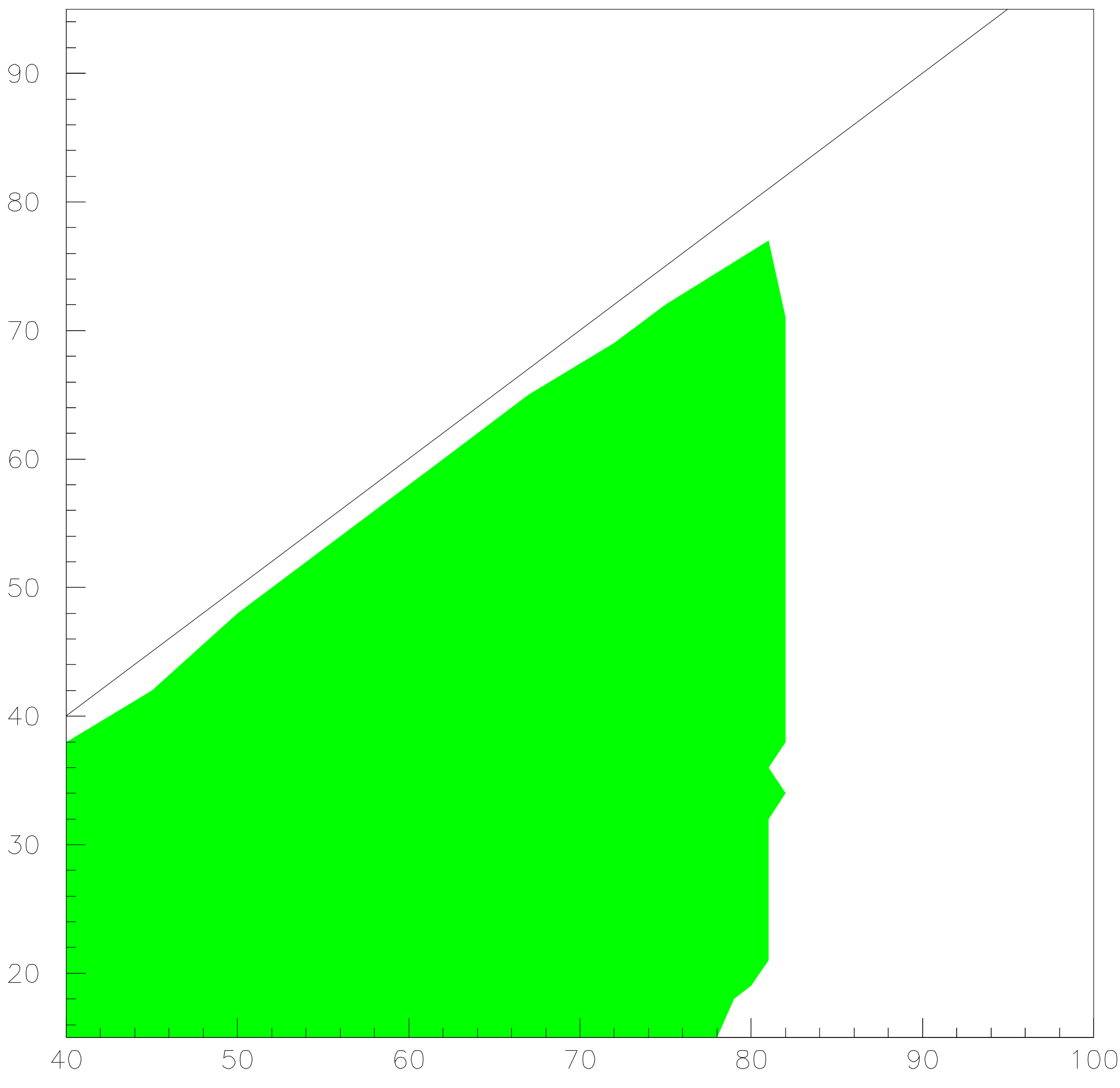

Figure 8: Excluded area in the plane mass of the smuon / mass of $\tilde{\chi}^0_1$ for indirect decay $\tilde{\mu}^{\pm} \rightarrow \mu^{\pm}\tilde{\chi}^0_1$ and a subsequent direct decay of the $\tilde{\chi}^0_1$ with any of the λ'_{ijk} couplings in the conservative case $e^+e^- \rightarrow \tilde{\mu}^+_R\tilde{\mu}^-_R$.