DELPHI Collaboration

DELPHI 98-166 PHYS 806
10 November, 1998

Search for SUSY decays of the W

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Abstract

A search for $W^{\pm} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$ followed by $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\nu}_l l^{\pm}$ is performed using the data collected by DELPHI in 1997 at the average centre-of-mass energy of 182.7 GeV and in 1996 at the average centre-of-mass energy of 171.2 GeV. If the difference between the chargino and the sneutrino masses is below few GeV/c^2 the visible decay products of the chargino carry very little energy and it is impossible to select such a chargino when looking for $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ using the usual criteria developed for that search. The present analysis applies an alternative technique able to partially recover such a *blind spot*. After having combined the results obtained with the two samples at the two centre-of-mass energies, a limit on the Branching Ratio $BR(W^{\pm} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0) < 1.6\%$ at 95% CL is found. This limit translates directly into exclusion regions in the space of the SUSY parameters which enlarge the validity of those already set with different methods.

1 Introduction

It has been suggested [1] that decays like[1]:

$$W^+ \to \tilde{\chi}_1^+ \tilde{\chi}_1^0 \qquad (1)$$

can be a good place to look for charginos when their mass is only slightly above that of the sneutrino. In such case the charginos decays predominantly into a sneutrino and a charged lepton [2]:

$$\tilde{\chi}_1^+ \to \tilde{\nu}_l l^+ \qquad (2)$$

Given the small mass difference between the chargino and the sneutrino, the charged lepton is emitted at very low momentum. The usual search for charginos pair produced in e^+e^- annihilations [3] is then very inefficient in selecting those final states composed of two extremely soft particles and nothing else.

Instead, at LEP2, where W^+W^- pairs are copiously produced, a typical signature of the existence of those mass-degenerate charginos and sneutrinos would be the presence of 'mixed' decays in which one of the W of the pair decays according to (1), whenever kinematically allowed, followed by (2), while the other W decays in a standard way into $l\nu$ or $q\bar{q}'$.

This method has already been proposed for DELPHI in [4] and applied tentatively on the data collected in 1996 at $\sqrt{s} \simeq 172$ GeV. In the present work, a detailed analysis has been performed of all data collected by DELPHI during the high energy run of 1997 at an average centre-of-mass energy of 182.7 GeV [5] and of the data collected in 1996 at an average centre-of-mass energy of 171.2 GeV [6]. The two samples will be shortly referred as '183 GeV' and '172 GeV' samples in the following.

2 Data samples and event generators

During 1997 DELPHI collected approximately 54 pb^{-1} of data at high energy. Out of them, 51.65 pb^{-1} have been used in the present search, the others being discarded because of some problem or inefficiency in the detectors considered most relevant for the analysis. The data collected in 1996 at energies around 172 GeV amount to about 10 pb^{-1}, and 9.98 pb^{-1} have been used in the analysis. In 1996 DELPHI collected also 10 pb^{-1} at 161 GeV, the production threshold for W^+W^- pairs. However, at that energy the $e^+e^- \to W^+W^-$ cross section is smaller than in the other two points and, since each W is produced at rest, it is more difficult to separate the signal from the background in the hadronic channel: it has been therefore decided not to use those data in the search.

To evaluate the signal efficiency and the background contamination, events were generated using several programs, all relying on JETSET 7.4 [7] for quark fragmentation. All the generated events passed through a complete simulation of the DELPHI detector [8], and then they were processed in the same way as the real data.

The signal is composed of W^+W^- events in which one of the W decays into two standard particles ($l\nu$ or $q\bar{q}'$) and the other decays according to (1) and then (2). The simulated sample has been created using PYTHIA, after having added the decay (1)

[1]throughout the text, all the relations described are implicitly assumed to be valid also for the charge conjugate states

to the ones already allowed by the generator and accepting only events with mixed W decays (one standard and one SUSY) in the final state. For the decay of the chargino the formulae in [9] have been implemented into PYTHIA. The masses of the standard leptons have been taken into account when modelling the decay, while all the sneutrinos have been considered mass degenerate amongst themselves. However, this last assumption is not fundamental. In fact, provided that at least one sneutrino is lighter than the chargino, the predominant chargino decay mode is into this sneutrino and its flavour-related charged lepton (very few three bodies $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 f f'$ decays being allowed also when the chargino is mostly an higgsino): flavour dependent masses of the $\tilde{\nu}$'s would only enhance or diminish a particular flavour of the soft particle in the final state, with a negligible effect on the selection efficiencies. The masses of the sparticles used in the simulation of the signal are listed in table 1. At the centre-of-mass energy of 183 GeV several points were simulated, in order to assess the dependance of the efficiencies on the masses of the sparticles. The conclusions drawn at this E_{cms} were extrapolated down to 172 GeV, allowing there a reduced set of simulation samples.

For the SM background, several samples of the different final states were generated with statistics well above the one expected in all the relevant channels. The process $e^+e^-(n\gamma) \to q\bar{q}(n\gamma)$ was generated using PYTHIA 5.7 [7] (but the events were reweighted as a function of the generated s' to match the cross sections obtained with ZFITTER [10]). KORALZ [11] and DYMU3 [12] were used to simulate $\tau^+\tau^-(\gamma)$ and $\mu^+\mu^-(\gamma)$ events respectively. The generator of ref. [13] was used for $e^+e^- \to e^+e^-$ events and TEEGG [14] for Compton events. All four fermion processes were generated with EXCALIBUR [15], except the $e\nu qq'$ final state for which the GRC4F generator [16] was used. In the $\gamma\gamma$ collisions, the BDK generator [17] was used for the leptonic final states. In the $\gamma\gamma$ collisions leading to hadronic final states, the QCD and VDM components were simulated using the TWOGAM [18] generator while BDK was used for the QPM part.

3 Event selection

The criteria used to select events were defined on the basis of the simulated signal and background events. The selection was intended to extract events in which one of the W produced in the e^+e^- collision decays into standard particles and the other decays into $\tilde{\chi}_1^+\tilde{\chi}_1^0$.

After a common track selection and event preselection, aimed at reducing the overall size of the samples used in the analysis, the final event selection is performed. At that stage, specific criteria are designed to select independently events in which the standard decay of the W is either hadronic ($W \to q\bar{q}'$) or leptonic ($W \to l\nu_l$, where $l = e, \mu, \tau$).

When the standard decay of one W is hadronic, the soft lepton coming from the SUSY decay of the other W is usually hidden inside the particles accompanying the hadronic jets and it does not contribute, in practice, to the determination of the properties of the whole event. On the contrary, when one W decays into $l\nu$, the low event multiplicity can allow the observation of the soft SUSY decay products: then the selection criteria can take profit of the presence of these soft particles and, in this analysis, they have been optimized by further subdividing the search into two different ranges of $\Delta M = M_{\tilde{\chi}_1^+} - M_{\tilde{\nu}}$, which correspond to different energy spectra of the visible particles.

$M_{\tilde{\chi}_1^+}$ (GeV/c^2)	$M_{\tilde{\chi}_1^0}$ (GeV/c^2)	$M_{\tilde{\nu}}$ (GeV/c^2)	$\sqrt{s}$ (GeV)	Events generated
45.0	14.0	44.995	183	2000
45.0	14.0	43.0	"	600
45.0	14.0	44.5	"	600
45.0	20.0	43.0	"	600
45.0	20.0	44.5	"	600
45.0	30.0	43.0	"	600
45.0	30.0	44.5	"	600
50.0	14.0	48.0	"	600
50.0	14.0	49.5	"	600
50.0	20.0	48.0	"	600
50.0	20.0	49.5	"	600
50.0	30.0	48.0	"	600
50.0	30.0	49.5	"	600
55.0	14.0	53.0	"	600
55.0	14.0	54.5	"	600
55.0	20.0	53.0	"	600
55.0	20.0	54.5	"	600
60.0	14.0	58.0	"	600
60.0	14.0	59.5	"	600
60.0	20.0	58.0	"	600
60.0	20.0	59.5	"	600
60.0	20.0	58.0	"	600
60.0	20.0	59.5	"	600
65.0	14.0	63.0	"	600
65.0	14.0	64.5	"	600
45.0	14.0	44.995	172	2000
50.0	20.0	49.5	"	2000
60.0	14.0	58	"	2000

Table 1: *Samples of simulated signal events used in the analysis*

3.1 Tracks and showers selection

The requirements used to select charged tracks in the event and the procedure adopted to rescale badly measured momenta are derived, with minor modifications, from the one used in the DELPHI analysis package for the WW analysis, WWANA [19].

Charged tracks can be used in the event reconstruction if:

- $|\vec{p}| > 200$ MeV/c;
- track length above 20 cm, unless the track is a VD-only track; those VD-only tracks must have both $r\phi$ and z information and their polar angle (θ) must stay outside $\pm 3^o$ from the 90^o;
- the impact parameter in the $r\phi$ plane must be below 4 cm and the one in z must fulfill $ip_z \sin\theta < 4$ cm.

At this point, if the track momentum is above $0.75 \cdot p_{beam}$ and its error is above 100% (for events with 7 or more charged tracks) or the track momentum is above $1.25 \cdot p_{beam}$ (for lower multiplicity events), a rescaling of the track momentum is attempted. First, the momentum is computed using only TPC information (when available) and it is retained if the relative error computed in such a way is below 50%. As a second attempt, the particle momentum is assumed to be equal to the associated calorimetric deposits, if they are above 8 GeV. Failing also this, the momentum is arbitrarily fixed to 15 GeV (for events with 7 or more charged tracks) or to p_{beam} (for lower multiplicity events).

All charged tracks not fulfilling the requirements above do not enter in the calculations of the overall event properties, but they are kept as well as *locked* tracks.

Unassociated showers in the calorimeters are accepted provided that their energy is above 0.5 GeV (0.75 GeV for the Hadron Calorimeter) and if there are at least two towers hit, if the shower is in the STIC or in the FEMC.

3.2 Preselection

There must be at least one charged particle with energy above 2 GeV and at least 15 GeV of charged energy in the region of polar angle between 10^o and 170^o.

Then, if the charged multiplicity is above 6:

- the visible energy (E_{vis}) must be between 40 and 120 GeV;
- the transverse energy must be above 20 GeV;
- the missing transverse momentum must be above 15 GeV;
- the polar angle of the thrust axis (θ_{thr}) must be comprised between 30^o and 50^o.

If the charged multiplicity is less or equal 6:

- $E_{vis} > 10$ GeV;
- the fraction of energy carried by the most energetic particle (jet) must be above 80% (90%) of E_{vis};
- $30^o < \theta_{thr} < 150^o$, if the event contains at least two particles.

To define the energy carried by a track, the maximum between the energy computed in the tracking and the associated deposits in the calorimeters is added to the energy present in a cone centered on the track direction and with a half opening angle of 5^o.

All the cuts described in the following are applied on the samples of already preselected events.

3.3 Hadronic selection

Events with more than 6 charged track are accepted in the hadronic channel if:

- $E_{vis} < 90$ GeV;
- the effective centre-of-mass energy reconstructed $sqrts'$ [20] is above 100 GeV;
- the invariant mass of all charged and neutral particles in the event (M_{vis}) is between 55 and 85 GeV/c^2;
- the minimum jet resolution parameter D_{join}^{2jets} able to get exactly two jets from the event using the LUCLUS algorithm [7] is below 7 GeV;
- the acoplanarity between the directions of the two jets reconstructed in the previous step is above 10^o;
- there are no identified electrons or muons in the event with energy above 5 GeV, nor isolated charged particles (at more than 15^o from the nearest charged particle in the event) with energy above 15 GeV.

Figure 1 shows the distribution of the most relevant variables entering in the selection procedure for the hadronic case at 183 GeV, in the subsample of preselected events with high charged multiplicity. The data (dots) are compared to the sum of all SM backgrounds (histograms) in the left column, while on the right the corresponding distributions are shown for the signal searched for, with arbitrary normalization. The same good agreement between data and simulation has been verified at 172 GeV.

3.4 Leptonic selections

Slightly different selection cuts are applied when searching for W decays in charginos with $0 < \Delta M < 0.5$ GeV/c^2 or in charginos with $0.5 < \Delta M < 2$ GeV/c^2. Larger ΔM's would result in harder spectra of the decay products and the usual criteria used in the search for charginos [3] can be used with enough residual sensitivity.

3.4.1 Discrepancy between data and sinulation at low E,θ

Before proceding further in describing the selections adopted for the leptonic channel, it is worth to mention the main discrepancy encountered between data and the sum of all simulations of the SM background. Figure 2 shows the scatter plot for the data in the plane energy carried vs polar angle of the hardest (possibly the only) charged track in the events with just one track or, at most, two tracks with the energy imbalance required by the preselection criteria. The definition of the energy carried by the particle is the same as in the preselection. By comparing figure 2 with figure 3, which displays the same

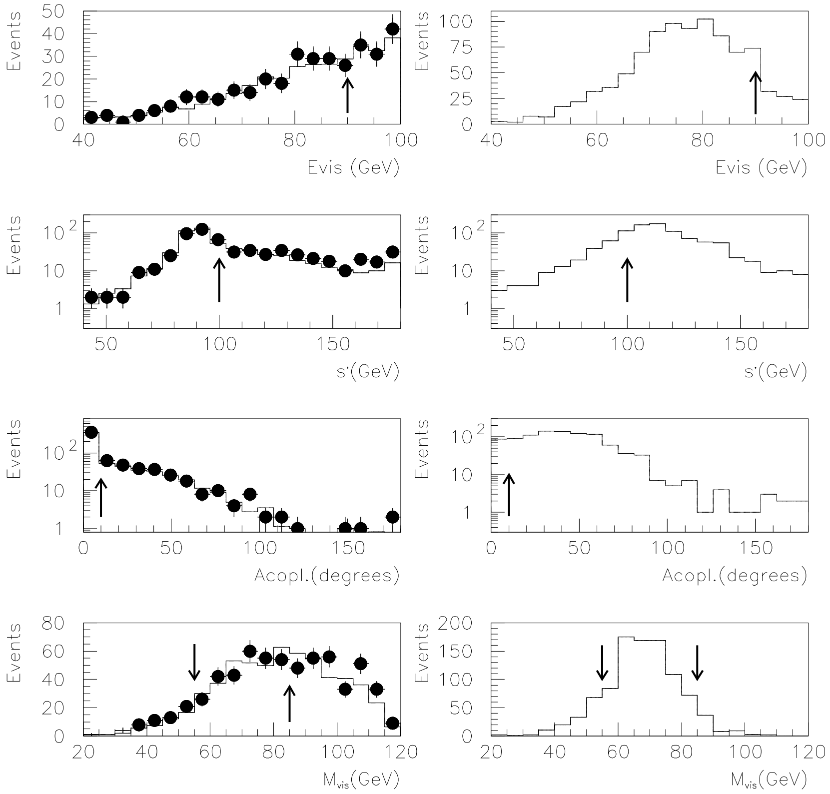

Figure 1: *Distribution in the preselected samples at 183 GeV of some of the most relevant variables for the selection of events with large charged multiplicity: visible energy, effective energy available in the centre-of-mass, acoplanarity between the two forced jets, visible mass. On the left data (dots) and background simulation (histogram); on the right the corresponding distribution expected for the signal, with arbitrary normalization. The arrows indicate the points from where the cuts are applied.*

quantities for the sum of all SM backgrounds, one can notice in the MC an accumulation of events in the region at low E and θ which is not there in the data. In other parts of the plots there is, indeed, good agreement between data and MC. The same behaviour shows up in both samples at 183 and 172 GeV and it was there also in the previous DELANA processings.

It is reasonable to think that this is caused by a slightly different efficiency between data and MC for the track finding algorithms in the two forward regions. However, figure 4 shows that the region affected by the discrepancy is not where the simulated signal is expected to be. This region can be easily discarded without lowering the selection efficiency or, however, biasing the final result.

To discard low energy and low angles events, the energy and the polar angle of the hardest charged particle is required to fulfill the relation $E_1 < A/\sin^2\theta_1$, where $A =$ 18 GeV at 183 GeV and $A = 16.9$ GeV at 172 GeV. This cut is superimposed on figures 2, 3 and 4, together with the upper and lower limit on the energy of the main track which will be described in the next sections.

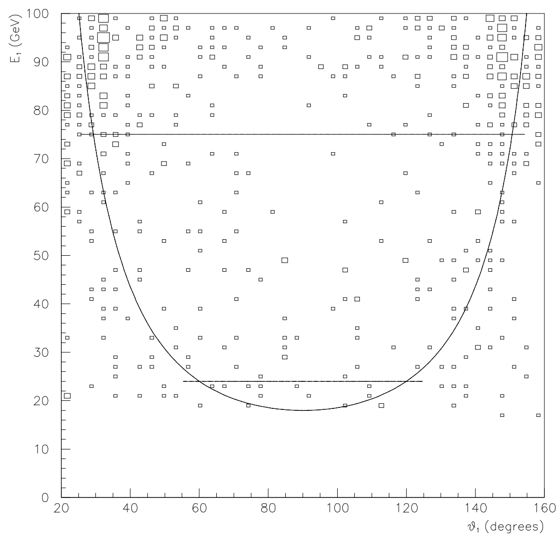

Figure 2: *Energy carried by the most energetic track vs polar angle in the data collected at 183 GeV. The lines surround the region accepted in the analysis.*

3.4.2 $0 < \Delta M < 0.5$ GeV/c^2

- Charged multiplicity must be 1 or 2 or 3;
- the events with 3 tracks are considered only if their invariant mass is below 1.7 GeV/c^2: in such case, the three momenta are added together and the event is considered as a single track event in the following;
- $E_{vis} < 80$ GeV;
- the energy carried by the hardest track, according to the definition given in the preselection, must lie between 24 and 75 GeV (for $\sqrt{s} = 183$ GeV) or between 26 and 62 GeV (for $\sqrt{s} = 172$ GeV); the energy carried by the weakest below 3 GeV; their ratio below 0.04;
- the impact parameter in the $r\phi$ plane of the hardest track must be less than 4 mm;
- the main track must not point, within $\pm 4^o$, to any of the six TPC ϕ cracks;
- the polar angle of the possible second track must be between 25^o and 155^o;
- if there are two tracks, their acollinearity must be above 10^o;
- there must be no locked tracks, according to the definition given in 3.1, with an energy above 3 GeV;
- there must be no neutral showers above 5 GeV (10 GeV if they are in a cone of 15^o half opening angle centered on the direction of the hardest track).
- to take profit of the charge asymmetry of the W^+W^-, the product of the charge of the main track times the cosinus of its polar angle must be above 0.2;

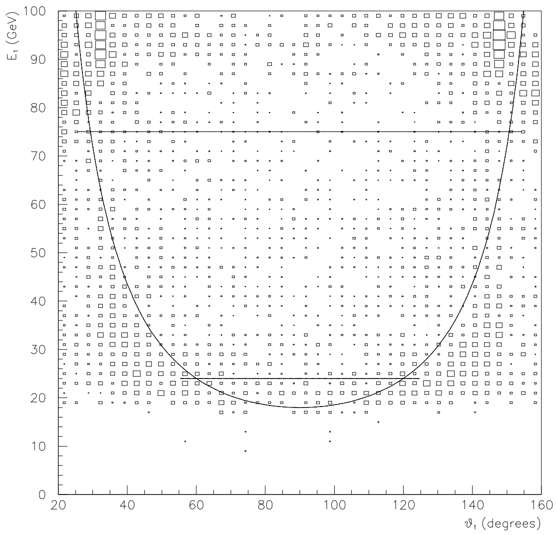

Figure 3: *Energy carried by the most energetic track vs polar angle in the sum of all simulated SM backgrounds, normalized to the same luminosity as the data, in the search at 183 GeV. The lines surround the region accepted in the analysis.*

Some of the distributions most relevant in the analysis of the events with one or two charged tracks at 183 GeV are shown in figure 5. Since cosmics are not taken into account in the simulated background, only the events passing the impact parameter cut enter in the plots. After the preliminary cuts, there is a reasonable agreement between data and simulation; the same can be stated also at 172 GeV.

3.4.3 $0.5 < \Delta M < 2$ GeV/c^2

The selection is almost the same as those for the more degenerate case, but some of the cuts have been modified to allow for a second charged particle, which is usually more energetic with respect to the previous case.

- Charged multiplicity must be exactly 2;
- $E_{vis} < 80$ GeV;
- the energy carried by the hardest track, according to the definition given in the preselection, must lie between 24 and 75 GeV (for $\sqrt{s} = 183$ GeV) or between 26 and 62 GeV (for $\sqrt{s} = 172$ GeV); the energy carried by the weakest below 5 GeV; their ratio below 0.10;
- the impact parameter in the $r\phi$ plane of the hardest track must be less than 4 mm;
- the polar angle of the second track must be between 25^o and 155^o;
- the acollinearity must be above 10^o;
- there must be no locked tracks with an energy above 5 GeV;

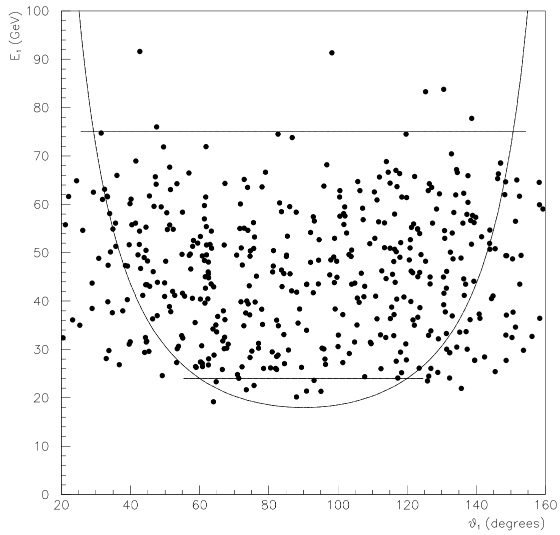

Figure 4: *Energy carried by the most energetic track vs polar angle in the signal simulated at 183 GeV, with arbitrary normalization. The lines surround the region accepted in the analysis.*

- there must be no neutral showers above 5 GeV (10 GeV if they are in a cone of 15^o half opening angle centered on the direction of the hardest track).
- to take profit of the charge asymmetry of the W^+W^-, the product of the charge of the main track times the cosinus of its polar angle must be above 0.2;

Some of the distributions most relevant in the analysis of the events with just two charged tracks at 183 GeV are shown in figure 6. Since cosmics are not taken into account in the simulated background, only events passing the impact parameter cut enter in the plots. After the preliminar cuts, there is a reasonable agreement between data and simulation: some excess in the data is visible for events almost symmetric ($E_2/E_1 > 0.5$) and at low polar angle, but it disappears as far as the cuts are applied. The same behaviour shows up at 172 GeV.

4 Results

At the end of the selection, in the sample at 183 GeV 8, 2 and 4 events remained in the data in the hadronic, leptonic at lower ΔM and leptonic at larger ΔM samples respectively. The number of events expected from the Standard Model background sources were 8.9 ± 0.9, 2.6 ± 0.2 and 5.0 ± 0.7 respectively (the error associated comes from the limited MC statistics), in good agreement with the experimental finding. The number of events which remain after the selections and the ones expected from the various background contributions are detailed in table 2.

In the sample at 172 GeV 2, 0 and 0 events remained in the data in the hadronic, leptonic at lower ΔM and leptonic at larger ΔM samples respectively. The number of events expected from the Standard Model background sources were 1.9 ± 0.3, 0.6 ± 0.3

Process	Hadronic selection	Leptonic selection ($0 < \Delta M < 0.5$)	Leptonic selection ($0.5 < \Delta M < 2$)
$e^+e^- \to Z^0(n\gamma) \to q\bar{q}(n\gamma)$	2.12 ± 0.64		
$e^+e^- \to Z^0(n\gamma) \to \mu^+\mu^-(n\gamma)$		0.17 ± 0.08	0.52 ± 0.18
$e^+e^- \to Z^0(n\gamma) \to \tau^+\tau^-(n\gamma)$			0.97 ± 0.25
$e^+e^- \to e^+e^-$ (Bhabha)		0.55 ± 0.39	0.28 ± 0.28
$e^+e^- \to e^+e^-\gamma$ (Compton)		1.75 ± 0.41	
$e^+e^- \to \mu\nu_\mu q\bar{q}'$	0.74 ± 0.18		
$e^+e^- \to \tau\nu_\tau q\bar{q}'$	3.22 ± 0.39		
$e^+e^- \to e\nu_e q\bar{q}'$	1.98 ± 0.31		
$e^+e^- \to l\nu_l l'\nu_{l'}$		2.03 ± 0.27	1.32 ± 0.22
$e^+e^- \to \nu\bar{\nu}q\bar{q}$	0.55 ± 0.03		
$e^+e^- \to \mu^+\mu^- q\bar{q}$	0.02 ± 0.02		
$e^+e^- \to \tau^+\tau^- q\bar{q}$	0.01 ± 0.01		
$e^+e^- \to e^+e^- q\bar{q}$			
$e^+e^- \to q\bar{q}'q''\bar{q}'''$			
$e^+e^- \to l^+l^-l'^+l'^-$			
$e^+e^- \to (e^+e^-)$ hadr (QPM)	0.25 ± 0.25		
$e^+e^- \to (e^+e^-)$ hadr (VDM)			
$e^+e^- \to (e^+e^-)$ hadr (QCD)			
$e^+e^- \to (e^+e^-)\mu^+\mu^-$			
$e^+e^- \to (e^+e^-)\tau^+\tau^-$			
$e^+e^- \to (e^+e^-)e^+e^-$			
Σ backgrounds	8.89 ± 0.87	5.02 ± 0.66	2.57 ± 0.43
Data	8	4	2

Table 2: *Number of candidates remaining in the 1997 data at 183 GeV and number of background events expected after the selections used for the search. The errors associated to the background are the ones coming from the limited statistics of the MC samples.*

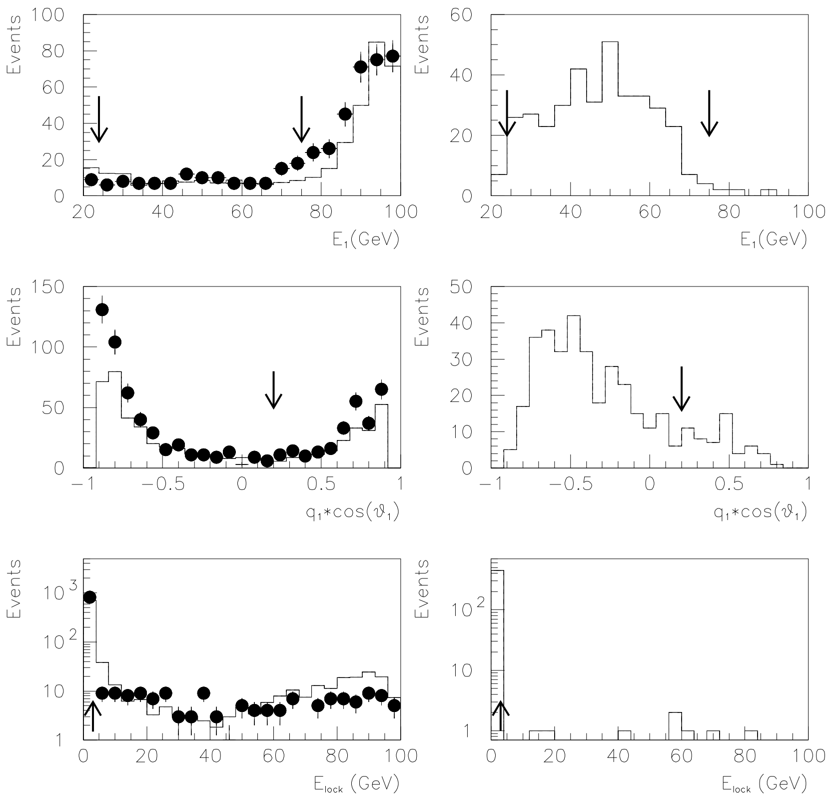

Figure 5: *Distribution in the preselected samples at 183 GeV of some of the most relevant variables for the selection of events with one or two charged tracks: energy carried by the particle, its charge times the cosinus of the polar angle, the energy of the hardest charged track discarded during the track selection (zero if no tracks are discarded). On the left data (dots) and background simulation (histogram); on the right the corresponding distribution expected for the signal, with arbitrary normalization. The arrows indicate the points from where the cuts are applied.*

and 0.3 ± 0.1 respectively (the error associated comes from the limited MC statistics), in good agreement with the experimental finding. The number of events which remain after the selections and the ones expected from the various background contributions are detailed in table 3.

The efficiency for the signal has been estimated using the samples listed in table 1. It has been verified that, in general, the efficiency depends only on the mass difference ΔM between the chargino and the sneutrino; it does not depend on the mass of the neutralino, neither on $M_{\tilde{\chi}_1^+}$ and $M_{\tilde{\nu}}$ separately, provided that ΔM remains in the range searched for, $0 < \Delta M < 2$ GeV/c^2. Further, as expected, the efficiency in the hadronic channel does not depend even on ΔM, when ΔM is in the range searched for, since the selection does not rely on the characteristics of the soft particle coming from the SUSY decay of the W. On the other hand, for the leptonic decays, there is a twofold dependence on ΔM through the momentum of the soft visible particle remaining after the SUSY decay of the W: for small ΔM the visible particle is very soft and, thus, less detectable; on the other hand, in

Process	Hadronic selection	Leptonic selection ($0 < \Delta M < 0.5$)	Leptonic selection ($0.5 < \Delta M < 2$)
$e^+e^- \to Z^0(n\gamma) \to q\bar{q}(n\gamma)$	0.73 ± 0.23		
$e^+e^- \to Z^0(n\gamma) \to \mu^+\mu^-(n\gamma)$			
$e^+e^- \to Z^0(n\gamma) \to \tau^+\tau^-(n\gamma)$		0.18 ± 0.08	0.15 ± 0.07
$e^+e^- \to e^+e^-$ (Bhabha)			
$e^+e^- \to e^+e^-\gamma$ (Compton)		0.49 ± 0.37	
$e^+e^- \to \mu\nu_\mu q\bar{q}'$	0.12 ± 0.05		
$e^+e^- \to \tau\nu_\tau q\bar{q}'$	0.78 ± 0.12		
$e^+e^- \to e\nu_e q\bar{q}'$	0.19 ± 0.07		
$e^+e^- \to l\nu_l l'\nu_{l'}$	0.01 ± 0.01	0.26 ± 0.03	0.22 ± 0.03
$e^+e^- \to \nu\bar{\nu}q\bar{q}$	0.01 ± 0.01		
$e^+e^- \to \mu^+\mu^- q\bar{q}$			
$e^+e^- \to \tau^+\tau^- q\bar{q}$			
$e^+e^- \to e^+e^- q\bar{q}$			
$e^+e^- \to q\bar{q}'q''\bar{q}'''$			
$e^+e^- \to l^+l^-l'^+l'^-$	0.01 ± 0.01		
$e^+e^- \to (e^+e^-)$ hadr (QPM)			
$e^+e^- \to (e^+e^-)$ hadr (VDM)			
$e^+e^- \to (e^+e^-)$ hadr (QCD)			
$e^+e^- \to (e^+e^-)\mu^+\mu^-$			
$e^+e^- \to (e^+e^-)\tau^+\tau^-$			
$e^+e^- \to (e^+e^-)e^+e^-$			
Σ backgrounds	1.85 ± 0.27	0.93 ± 0.38	0.37 ± 0.08
Data	2	0	0

Table 3: *Number of candidates remaining in the 1996 data at 172 GeV and number of background events expected after the selections used for the search. The errors associated to the background are the ones coming from the limited statistics of the MC samples.*

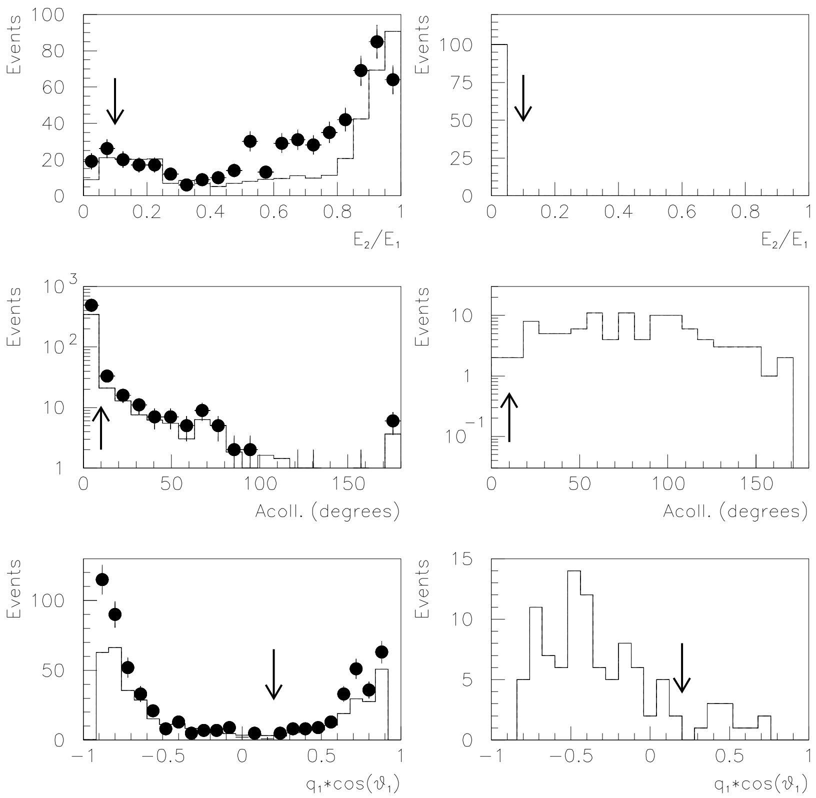

Figure 6: *Distribution in the preselected samples at 183 GeV of some of the most relevant variables for the selection of events with just two charged tracks: ratio of the energies carried by the two particles, acollinearity, charge times the cosinus of the polar angle of the most energetic particle. On the left data (dots) and background simulation (histogram); on the right the corresponding distribution expected for the signal, with arbitrary normalization. The arrows indicate the points from where the cuts are applied.*

correspondence of larger ΔM and because of the boost, the visible charged lepton from the SUSY decay can get enough energy to be discarded by the requirement of having an event with large energy imbalance between its two particles.

According to the previous observations, the efficiencies for the signal at the two centre-of-mass energies considered are listed in table 4 as a function of ΔM in the leptonic channel, and with a common value for the hadronic channel. These efficiencies are normalized over all W^+W^- events with one standard (both leptonic and hadronic) and one SUSY decay; the overall efficiency for the signal can thus be simply obtained by adding up the hadronic and the leptonic efficiencies. In the tables, selections A and B refer, respectively, to the leptonic selection optimized for the search when $0 < \Delta M < 0.5$ GeV/c^2 and to the one optimized for $0.5 < \Delta M < 2$ GeV/c^2, as described in par. 3.4.

The trigger efficiency for the signal is practically one, also for the leptonic case: in fact, the selection requires at least a track above 20 GeV/c, a value of the momentum which is well above the threshold for triggering on a single charged particle in DELPHI [21].

	$\Delta M = 0$	$\Delta M = 0.5$ GeV/c^2	$\Delta M = 2$ GeV/c^2
HADRONIC CHANNEL (183 GeV)			
	0.159 ± 0.004		
LEPTONIC CHANNEL (183 GeV)			
selection A	0.131 ± 0.008	0.121 ± 0.004	
selection B		0.104 ± 0.004	0.110 ± 0.004
HADRONIC CHANNEL (172 GeV)			
	0.166 ± 0.005		
LEPTONIC CHANNEL (172 GeV)			
selection A	0.111 ± 0.007	0.118 ± 0.007	
selection B		0.106 ± 0.007	0.104 ± 0.007

Table 4: *Efficiency for selecting $e^+e^- \to W^+W^-$ events with one W decaying into standard particles (either hadrons or leptons) and the other W into $\tilde{\chi}_1^+\tilde{\chi}_1^0$, followed by $\tilde{\chi}_1^+ \to \tilde{\nu}_l l^+$. The two leptonic selections refer to the ones optimized for $0 < \Delta M < 0.5$ GeV/c^2 and $0.5 < \Delta M < 2$ GeV/c^2 described in the text.*

5 Limits

The experimental outcomes listed in tables 2 and 3 do not show any evidence of excess above the Standard Model expectations. One can then use these results to constrain the possible amount of the branching ratio of the W into $\tilde{\chi}_1^+\tilde{\chi}_1^0$. If one defines

$$x = BR(W^\pm \to \tilde{\chi}_1^\pm\tilde{\chi}_1^0) \tag{3}$$

then the fraction of $e^+e^- \to W^+W^-$ events in which one of the W decays into standard particles and the other W decays into $\tilde{\chi}_1^+\tilde{\chi}_1^0$ is $2x \cdot (1-x)$. The number of events expected in the data is given by

$$N = 2x(1-x) \cdot \sum_{E_{cms}} \mathcal{L}_i \, \sigma_i^{th} \, \varepsilon_i \tag{4}$$

where the luminosities $\mathcal{L}_i$ have been given in paragraph 2, σ_i^{th} are the theoretical cross sections of the process $e^+e^- \to W^+W^-$ at the given centre-of-mass energies and the efficiencies ε_i are derived from table 4. If one wants to refere to the WW cross sections measured in the experiment, it must be taken into account that they strictly refer to the case in which both W's decay into standard particles, that is a fraction $(1-x)^2$ of the total. Then equation (4) becomes

$$N = \frac{2x}{1-x} \cdot \sum_{E_{cms}} \mathcal{L}_i \, \sigma_i^{meas} \, \varepsilon_i \tag{5}$$

where the cross sections measured in DELPHI at 183 and 172 GeV are, respectively, $16.01 \pm 0.71 \pm 0.43$ pb [5] and $11.58^{+1.44}_{-1.35} \pm 0.32$ pb [6].

Once N in equation (5) is replaced with the upper limit at 95% CL of the number of signal events compatible with the MC expectations and the experimental results, which is derived using the Poissonian distribution [22], one can solve that equation for x thus getting the 95% CL upper limit on the $BR(W^\pm \to \tilde{\chi}_1^\pm\tilde{\chi}_1^0)$. These limits are shown in

$\Delta M = 0$	$\Delta M = 0.5$ GeV/c^2	$\Delta M = 2$ GeV/c^2
ALL STANDARD W DECAYS (183 GeV)		
1.64%	1.80%	1.68%
ALL STANDARD W DECAYS (172 GeV)		
6.85%	7.22%	7.26%
ALL STANDARD W DECAYS (combined)		
1.48%	1.61%	1.57%

Table 5: *Upper limits at 95% CL for the $BR(W^{\pm} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0)$ in the two samples taken first separately and then after the combination. All the systematics detailed in the text are already included in the limits.*

table 5 for any of the two samples taken singularly and after their combination, at the three values of ΔM considered for the computation of the efficiencies. For other values of ΔM inside the range explored, the limit stays at an intermediate position between those listed in the table.

Taking the worst combined result, this can be interpreted as a conservative upper limit on $BR(W^{\pm} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0)$ when the sneutrino is lighter than the chargino and $\Delta M <$ 2 GeV/c^2:

$$BR(W^{\pm} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0) < 1.6\% \quad \text{at 95\% CL} \tag{6}$$

provided that $BR(\tilde{\chi}_1^+ \to \tilde{\nu}_l l^+) \simeq 1$. This limit is computed by taking into account also the effect of the error on the luminosities, on the measured WW cross sections, on the efficiencies and on the background contents. To include the first three systematic errors (the 'experimental sensitivity') in the computation, the method of [23] has been used, while for the error on the background, the poissonian distribution of the number of events expected has been convoluted with a gaussian distribution of the background, with the standard deviation of the distribution given by the error reported in tables 2 and 3. Just to show the effect of the systematic uncertainties on the result, the worst combined result used to set the upper limit on $BR(W^{\pm} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0)$ (0.0161) in the whole range of ΔM, would have been: 0.0160 without taking into account the experimental sensitivity (as expected, this error does not propagate significantly on the final limit); 0.0156 without taking into account the errors on the expected background.

The limit in 6 can be more generally considered as the limit on the BR of all invisible or almost invisible decays of the W boson. When restricted to the original interpretation of upper limit of the BR of the W into chargino and neutralino, this result can be used to exclude regions in the plane of the SUSY parameters at the same level of confidence. To find the excluded regions, the analytical expressions of the branching ratios of the W into charginos and neutralinos as function of μ, M_1, M_2 and $\tan\beta$ reported in [1] have been used. As an example, figure 7 shows the regions excluded at 95% CL in the plane M_2 vs μ in correspondence of four different values of $\tan\beta$ ($\tan\beta = 1$, 2, 5, 30). These excluded regions complement, for example, those reported in [3], the last ones holding only for mass differences between the chargino and the sneutrino larger than those addressed in the present analysis.

The limit obtained in the present work can be compared with the upper limit on the

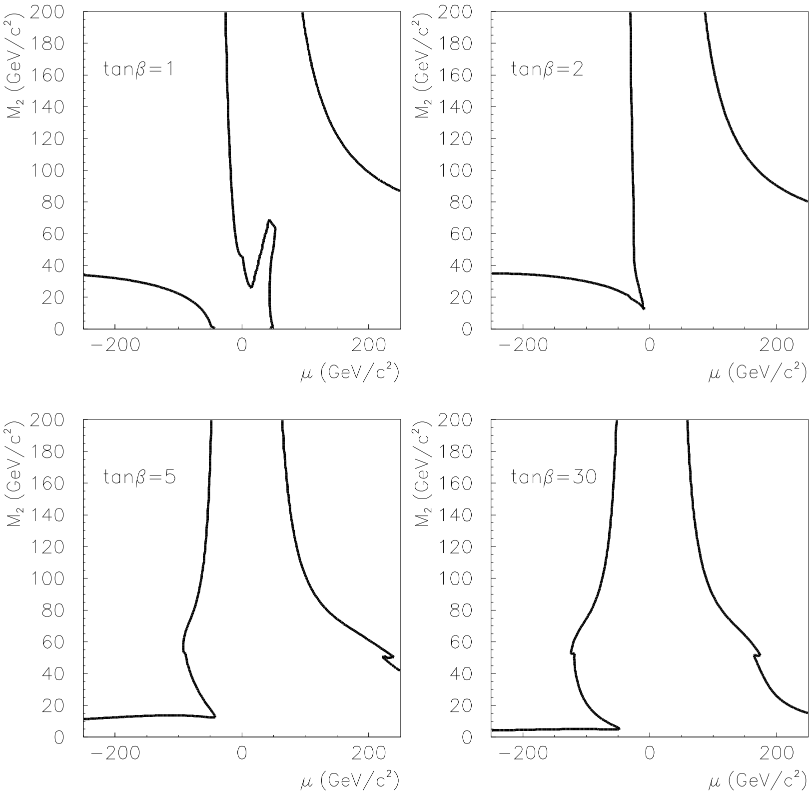

Figure 7: *Points in the plane of the SUSY parameters M_2 versus μ excluded at 95% CL in correspondence of four different possible value for* $\tan\beta$ *when* $0 \leq M_{\tilde{\chi}_1^+} - M_{\tilde{\nu}} \leq 2$ *GeV.*

branching ratio for non standard W decays, as derived from the measurement of the W width obtained at Tevatron [24]: $BR(W^\pm \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0) < 5.3\%$ at 95% CL. Preliminary results from the ALEPH experiment at LEP [25] yeld exclusion region in the space of the SUSY parameters which are comparable with the present ones.

6 Conclusion

A search for W's decaying into $\tilde{\chi}_1^+ \tilde{\chi}_1^0$, in the special case in which there is at least one sneutrino lighter than the chargino and almost mass degenerate with it ($\Delta M < 2$ GeV/c^2) has been performed using the data collected by DELPHI during the 1997 runs of LEP at centre-of-mass energies close to 183 GeV and during the runs of 1996 at energies close to 172 GeV. 16.7 (13.7) events from standard background sources are expected in the search optimized for $0 < \Delta M < 0.5$ GeV/c^2 ($0.5 < \Delta M < 2$ GeV/c^2); with the same selection criteria 14 (12) events are found in the data, with no evidence of excess above the SM expectations.

This allows to set an upper limit on the $BR(W^\pm \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0)$, which must be below 1.6% at 95% CL, if $BR(\tilde{\chi}_1^+ \rightarrow \tilde{\nu}_l l^+) \simeq 1$. This limit has been translated into regions in the space of the SUSY parameters excluded at 95% CL; these regions can complement the corresponding ones derived from the standard search for charginos and neutralinos, and they cover the very special and challenging case in which the sneutrino is lighter than the chargino and almost mass degenerate with it.

Acknowledgements

We thank A. Tonazzo for the useful discussions at the beginning of the analysis. We are also grateful to J. Kalinowsky and A. Lipniacka for providing us with the program computing the decay width of the W into SUSY particles as function of the SUSY parameters.

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