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Update of the search for charginos nearly mass-degenerate with the lightest neutralino

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Abstract

The data collected by DELPHI in 1998 at the centre-of-mass energy of 189 GeV have been used to update the search for charginos nearly mass-degenerate with the lightest supersymmetric particle, supposed to be the lightest neutralino.

1 Introduction

This note updates the results of the search for degenerate charginos in radiative events, reported in [1], with the data collected by DELPHI in 1998 at the centre-of-mass energy of 189 GeV.

The experimental techniques used depend on the mass difference $\Delta M^{\pm}$ between the chargino and the lightest neutralino, as described in [1].

When $\Delta M^{\pm}$ is below the mass of the pion, the chargino lifetime is usually long enough to let it pass through the entire detector before decaying. This range of $\Delta M^{\pm}$ can be covered by the search for long-lived heavy charged particles. For $\Delta M^{\pm} \sim$ few hundred MeV/c^2 the $\tilde{\chi}_1^{\pm}$ can decay inside the main tracking devices of DELPHI. Therefore, a search for secondary vertices or kinks can be used to cover this region. As far as the mass difference increases, the mean lifetime shortens and the position of the $\tilde{\chi}_1^{\pm}$ decay can hardly be distinguished from the main event vertex. In this case, the tagging of a hard Initial State Radiation (ISR) photon can help in exploring the $\Delta M^{\pm}$ region between few hundred MeV/c^2 and 3 GeV/c^2.

With respect to the previous report [2] of the preliminary analysis of the 1998 data, the two searches for long-lived charginos could be exploited. Moreover, in the search which uses the tag of an ISR photon a new variable was included in the selection and a new range of mass differences between the chargino and the lightest neutralino has been explored by tuning the values of some sensible cut. Those improvements allowed for a better sensitivity in a region of the SUSY parameters space that will probably never be covered in the searches at hadron machines [3].

All the new data have been combined with the one already used in [1]. In the search which uses ISR, all the old data have been reanalysed according to the new prescriptions.

As far as the SUSY scenarios are concerned, three cases were considered [4], depending on the values of the SU(2) gaugino mass M_2, on the U(1) gaugino mass M_1, on the Higgs mixing parameter μ, and on the mass of the sneutrino:

1. $M_{1,2} \gg |\mu|$ (higgsino-like);
2. $|\mu| \gg M_1 \geq M_2$ and $M_{\tilde{\nu}} \geq 500$ GeV/c^2 (gaugino-like);
3. $|\mu| \gg M_1 \geq M_2$ and $M_{\tilde{\nu}} < 500$ GeV/c^2 (gaugino-like).

A charged gaugino (cases 2 and 3) can have a mass difference with the lightest neutralino below approximately 1 GeV/c^2 only if the constraint of gaugino mass unification at the GUT scale is released. The degree of deviation from the mass unification hypothesis is controlled by the parameter R_f, defined with:

$$M_1 = R_f \cdot \frac{5}{3} \tan^2 \theta_W \cdot M_2 \qquad (1)$$

R_f is equal to one in the Minimal Supersymmetric Standard Model (MSSM) with gaugino mass unification at GUT.

All signal samples where generated using SUSYGEN [5] and then passed through the full DELPHI simulation [6].

The integrated luminosity available at the centre-of-mass energy of 189 GeV was approximately 156 pb^{-1} out of which 153.9 pb^{-1} could be used in the searches for long-lived particles and 152.4 pb^{-1} in the search for soft particles accompanied by an ISR photon.

2 Search for long-lived charginos

2.1 Search for heavy stable charged particles

The results on heavy stable charged particles at 189 GeV are described in [7], where all the details on the techniques used and on the efficiency can be found. One candidate remained after the analysis of the data collected at 189 GeV, while 0.96 ± 0.13 events were expected from standard sources.

2.2 Search for decay vertices inside the detector

Using the same selection as in [1], no events remained in the data collected at 189 GeV. The number of events expected from Standard Model (SM) background was 0.87 ± 0.65 (0.63 from Bhabhas, 0.12 from $e^+e^- \to Z \to \mu^+\mu-$ and 0.12 from $e^+e^- \to Z \to \tau^+\tau^-$).

Signal efficiencies have been computed using SUSYGEN simulated samples of charginos with different decay lengths. Figure 1 shows, as an example, the efficiencies as function of the decay radius obtained for 60 GeV/c^2 charginos. The first plot shows the efficiency for selecting a single chargino. The second plot displays the trigger efficiencies for the charginos passing the selection criteria. The third plot instead shows the trigger efficiency for all charginos of that mass, when decaying at a given radius in DELPHI.

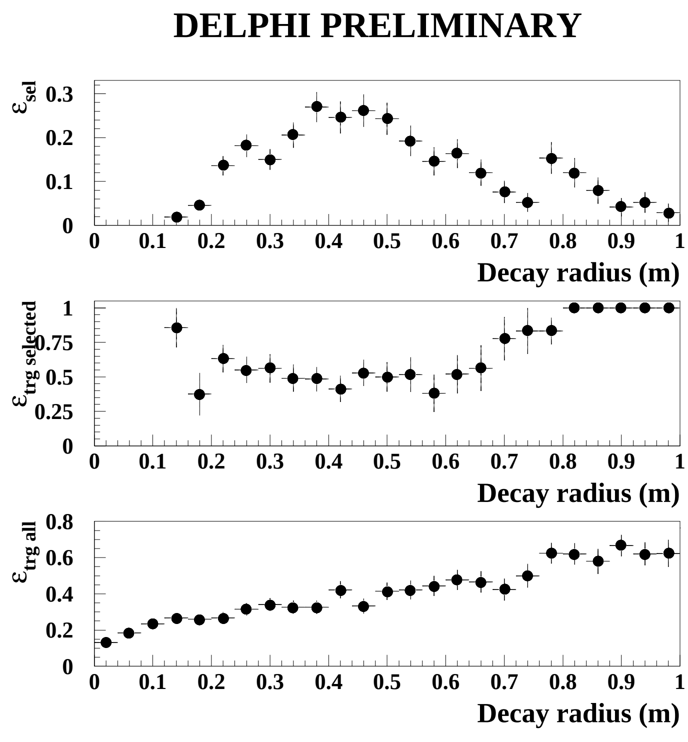

Figure 1: On top: efficiency for selecting a single 60 GeV/c^2 chargino in the search for displaced decay vertices (kinks), as function of its decay radius in DELPHI. In the middle: trigger efficiency for the selected charginos. Below: trigger efficiency for all 60 GeV/c^2 charginos, whether or not they are selected.

2.3 Results in the search for long-lived charginos

Having no evidence of signal in any of the searches for long-lived charginos at 189 GeV, the results of the two methods can be combined together, as explained in [1]. Again, these results can be further combined with the outcomes of the search at lower centre-of-mass energies, also described in [1].

The combination gives the regions excluded in the plane $M_{\tilde{\chi}_1^+}$ versus lifetime shown in figure 2 in the three scenarios considered.

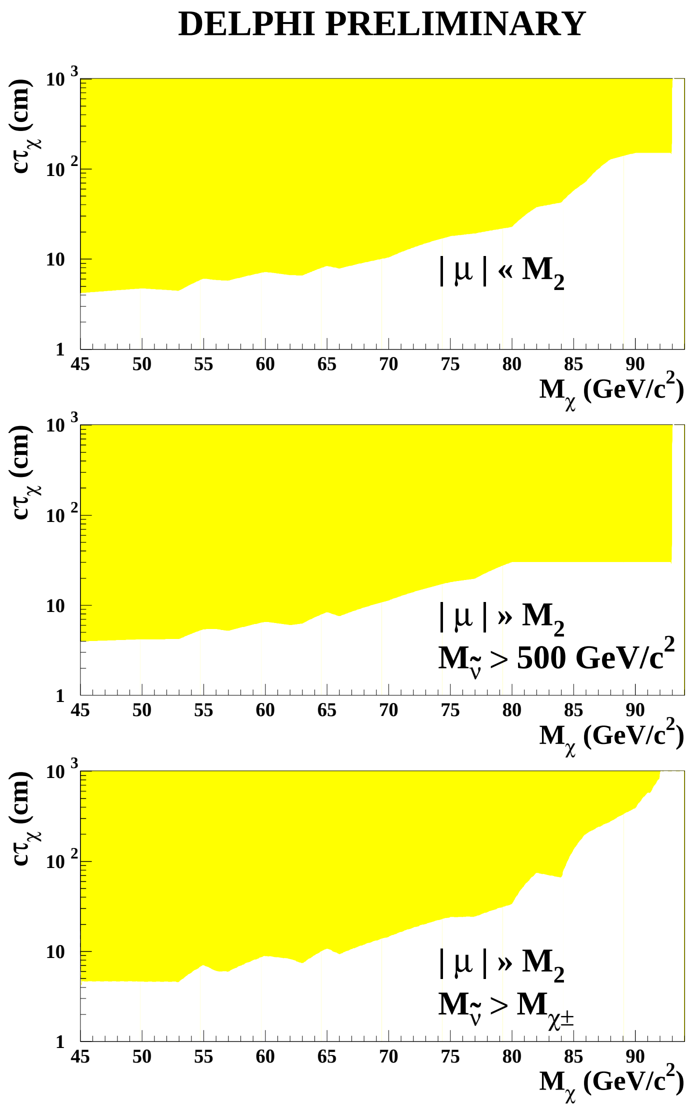

Figure 2: Chargino lifetimes excluded at the 95% CL (shaded) with the combination of the searches for long-lived charginos, as a function of $M_{\tilde{\chi}_1^+}$, in the three scenarios taken into account in the analysis.

3 Search for charginos with ISR photons

Three slightly different selections are addressed to three different ranges of $\Delta M^{\pm}$, the mass difference between the chargino and the lightest neutralino: selection **A** for $\Delta M^{\pm} <$ 300 MeV/c^2, selection **B** for 300 MeV/c^2 $\leq \Delta M^{\pm} <$ 1 GeV/c^2 and selection **C** for 1 GeV/c^2 $\leq \Delta M^{\pm} \leq$ 3 GeV/c^2.

With respect to the cuts described in [1] a new variable was taken into account to better discriminate between nearly mass-degenerate charginos and the dominant two-photon background. This variable is the ratio between the missing transverse momentum ($P_T^{\rm miss}$) and the visible transverse energy ($E_T^{\rm vis}$) in the event. Its distribution for the data and for the SM background, together with the distribution expected for the signal, is shown in the two plots at the bottom of figure 3. Since cutting on that ratio leads to a reduced efficiency for the samples at larger $\Delta M^{\pm}$ studied here, it has been decided to release a bit the cut on $\frac{E_{\rm vis}-E_{\gamma}}{E_{\rm cms}}$ for the selection **C**, in order to recuperate a similar selection efficiency as it was in the previous analysis. Another improvement added to the analysis at 189 GeV is that for selections **A** and **B** it is not required any more the presence of a common primary vertex, thus increasing the efficiency for events with charginos decaying up to few cm apart from the interaction point.

In summary, after a common preselection which remains unchanged with respect to [1], the list of cuts applied to the data and to the simulated signal and background samples were the following.

- There must be at least two and at most six accepted charged particles and, in any case, not more than ten tracks in the event.
- The transverse energy of the ISR photon was required to be greater than $(E_T^{\gamma})^{\rm min}$, where $(E_T^{\gamma})^{\rm min} \simeq 0.03 \cdot E_{\rm cms}$ (see [1]).
- The mass recoiling against the photon, $M_{\rm opp}$, must be above 96 GeV/c^2.
- The photon was required to be isolated by at least 30^o with respect to any other charged or neutral particle in the event.
- The sum of the energies of the particles emitted within 30^o of the beam axis (E_{30}) was required to be less than 25% of the total visible energy. The photon was not considered in any of the two energy sums if its direction was inside that cone.
- If the ISR photon candidate was detected in the very forward DELPHI calorimeter (STIC), it must not be correlated with a signal in the veto counters.
- (In the data collected since 1997) if the ISR photon candidate was at an angle between 10^o and 25^o with respect to the beam direction, the region where the Time Projection Chamber (TPC) cannot be used in the tracking, it must not be correlated with hits in the Silicon Tracker.
- The visible energy of the event, excluding the photon, must be below 1% (selection **A**), 2% (selection **B**) or 6% (selection **C**) of $E_{\rm cms}$.
- $P_T^{\rm miss}/E_T^{\rm vis}$ must be above 0.75 (selection **A**) or 0.40 (selections **B** and **C**).

Selection **A** was applied only to the samples at the centre-of-mass energy of 189 GeV.

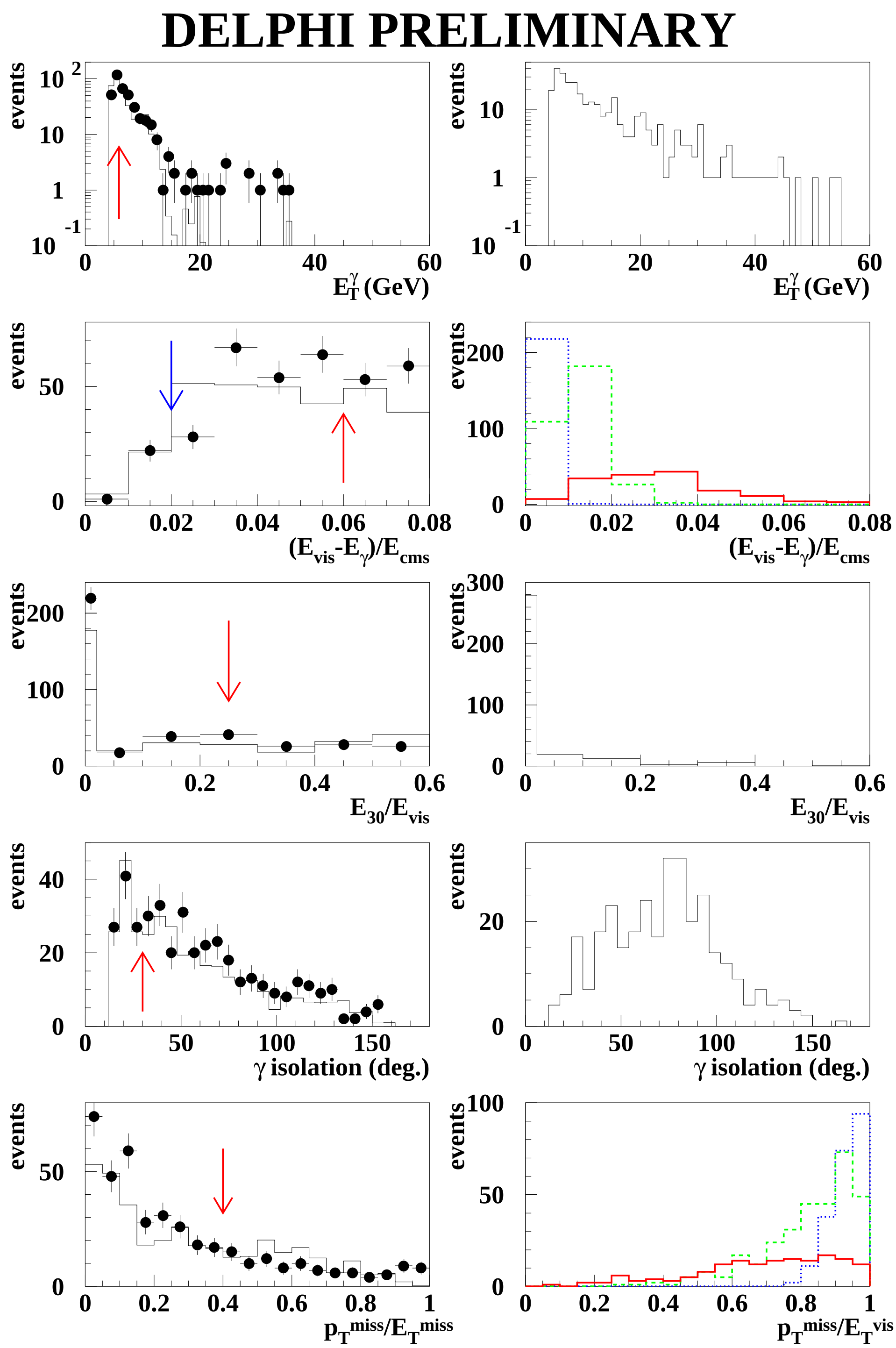

Figure 3: Some of the variables used in the selection at 189 GeV. In the left plots the data (dots) are compared with the SM expectations. On the right, as an example, the corresponding distributions (with arbitrary normalisation) are shown for the signal with $M_{\tilde{\chi}_1^+} = 60$ GeV/c^2 and $\Delta M^\pm = 1$ GeV/c^2. In the plot of the visible energy (second row) and of the ratio $P_T^{\rm miss}/E_T^{\rm vis}$ (last row) three different mass splittings are shown for the signal: dotted, $\Delta M^\pm = 0.3$ GeV/c^2; dashed, $\Delta M^\pm = 1$ GeV/c^2; solid line, $\Delta M^\pm = 3$ GeV/c^2.

3.1 Results in the search for charginos with ISR photons

In table 3.1 are listed the candidates and the expected background in the search at 189 GeV and those remaining after having reanalysed all the data collected at the other centre-of-mass energies. With respect to the previous analysis, the former candidate at $\sqrt{s}$ = 136 GeV disappeared; one candidate also disappeared from the data collected at 183 GeV (selection **C**), but it has been replaced by a new one accepted because of the release of the cut on the visible energy.

As discussed in [1], in the past analyses the yield of the SM background is expected to be slightly underestimated because of the lack of ISR in some of the two-photon generators. In addition, in this preliminary analysis of the data collected at 189 GeV there were no two-photon samples simulated with enough statistics, and the estimate of the two-photon background content in the final sample was obtained by rescaling the corresponding contribution already computed for the search at 183 GeV. In spite of that, the agreement between the data and such simulation is rather good, as can be seen in figure 3, where the distributions of the transverse energy of the photon, of the visible energy besides the ISR photon, of the visible energy within 30^o to the beam line, of the photon isolation angle and of the ratio $P_T^{\rm miss}/E_T^{\rm vis}$ are shown for the data (dots), for the sum of the SM backgrounds (left histograms) and for the signal sample with $M_{\tilde{\chi}_1^+}$ = 60 GeV/c^2 (histograms at the right).

An intriguing excess of data above the MC background simulation can be observed in the preselected samples at large E_T^γ or when $P_T^{\rm miss}/E_T^{\rm vis} > 0.9$. It is possible that this is related to the underestimation of the $\gamma\gamma$ background because of the lack of ISR in some of the two-photon MC samples. In any case, these excesses cancel out (or, at least, they became much less significant) after having applied the final selection.

Figure 4 shows the efficiencies in the search for nearly mass-degenerate charginos accompanied by high p_T ISR, computed with the fully simulated samples at 189 GeV, for some values of $M_{\tilde{\chi}_1^+}$ and $\Delta M^\pm$. The overall trigger efficiency for these samples has been estimated to be always above 80%.

There is no evidence of any significant excess above the SM expectations. Thus, the data collected at 189 GeV can be combined with those collected at LEP2 at lower energies. The regions excluded in the plane ($M_{\tilde{\chi}_1^+}$,$\Delta M^\pm$) obtained after such combination are shown in figure 5. In the same figure, the limits on the chargino lifetime computed with the searches for long-lived charginos are also translated into excluded regions in the plane ($M_{\tilde{\chi}_1^+}$,$\Delta M^\pm$).

The limits in figure 5 take into account a variation of $\tan\beta$ between 1 and 50, a variation of the M_1, M_2 and μ parameters so that the mass difference between the chargino and the neutralino remains below 3 GeV/c^2 and $M_2 \leq 2M_1 \leq 10M_2$.

The sneutrino is always considered to be heavier than the chargino. Whenever $M_{\tilde{\nu}} \leq M_{\tilde{\chi}_1^+}$ the limits derived in the search for long-lived charginos are not valid any more (because the two body $\tilde{\chi}_1^+ \to \tilde{\nu} l^+$ decay opens up). Moreover, the upper end of the region excluded by means of the ISR tag is expected to be at a bit larger $M_{\tilde{\chi}_1^+}$ with respect to what was found for heavier sneutrinos at the smallest $\Delta M^\pm$ studied with that method, and at a bit smaller $M_{\tilde{\chi}_1^+}$ when approaching from below $\Delta M^\pm$ = 3 GeV/c^2 (because of the increased mean energy of the visible products in the chargino decay).

Selection A		Selection B		Selection C	
Data	**Σ bckg**	**Data**	**Σ bckg**	**Data**	**Σ bckg**
$\boldsymbol{E_{\rm cms}}$ **= 130/136 GeV** ($\int \mathcal{L} = 11.7$ pb^{-1})					
0	0.10 ± 0.10	0	$\simeq 0$	–	–
$\boldsymbol{E_{\rm cms}}$ **= 161 GeV** ($\int \mathcal{L} = 9.7$ pb^{-1})					
0	0.85 ± 0.37	0	0.43 ± 0.24	–	–
$\boldsymbol{E_{\rm cms}}$ **= 172 GeV** ($\int \mathcal{L} = 9.9$ pb^{-1})					
1	0.21 ± 0.10	0	0.03 ± 0.03	–	–
$\boldsymbol{E_{\rm cms}}$ **= 183 GeV** ($\int \mathcal{L} = 50.0$ pb^{-1})					
4	1.67 ± 0.74	2	0.26 ± 0.19	–	–
$\boldsymbol{E_{\rm cms}}$ **= 189 GeV** ($\int \mathcal{L} = 152.4$ pb^{-1})					
7	5.3 ± 2.2	3	0.75 ± 0.56	1	0.05 ± 0.04

Table 1: Events remained in the data and in the sum of the expected SM backgrounds after the three selections in the search for nearly mass degenerate charginos accompanied by high p_T ISR photons.

4 Conclusions

Charginos nearly mass-degenerate with the lightest neutralino were searched for in DELPHI using the data collected at 189 GeV. An improved selection was used for the search method which uses the tag of an ISR photon, compared with previous years analyses. No evidence of such a signal was found. The results of the search at 189 GeV could then be combined with the results of the searches performed in DELPHI at lower centre-of-mass energies, where the old samples were reanalysed according to the new selection criteria. This combination was able to extend the regions excluded at the 95% CL in the space of SUSY parameters in all scenarios in which there is a small mass difference between the chargino and the lightest neutralino.

Acknowledgements

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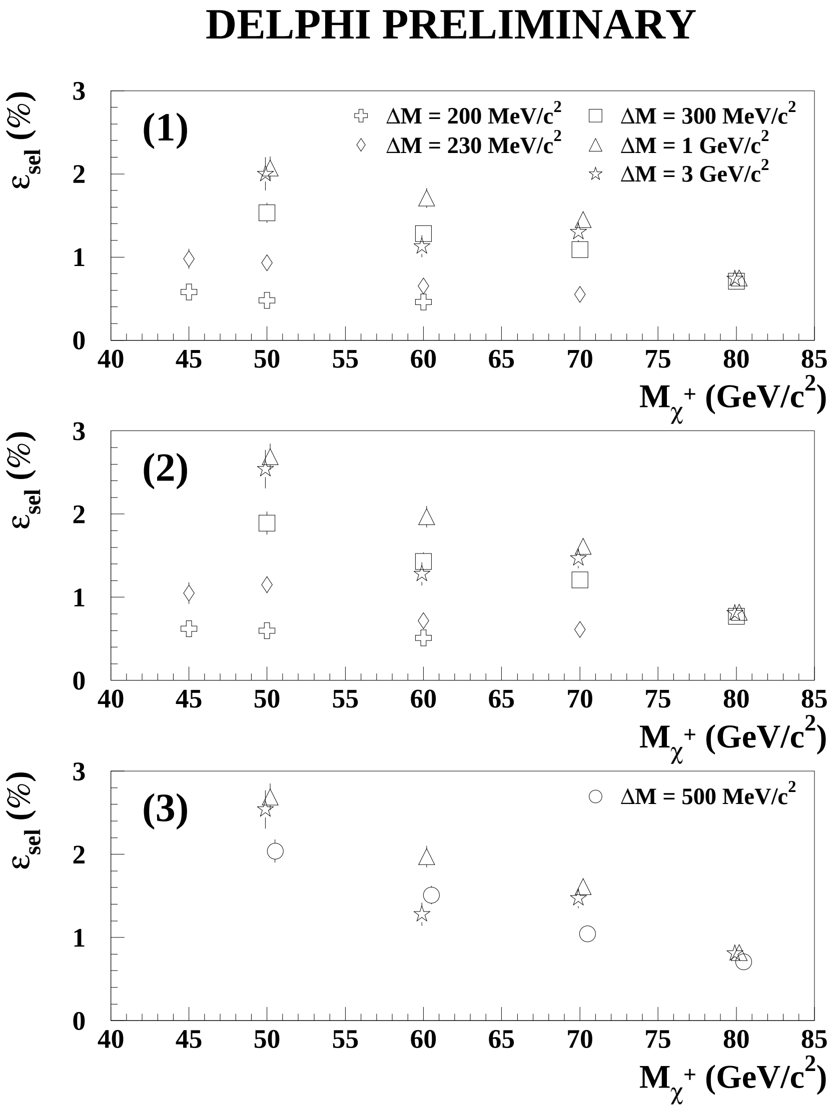

Figure 4: Selection efficiencies for charged higgsinos (1), charged gauginos in case of heavy snetrinos (2) and charged gauginos in case of light snetrinos (3) at the centre-of-mass energy of 189 GeV, as a function of their mass and of the mass difference with the lightest neutralino.

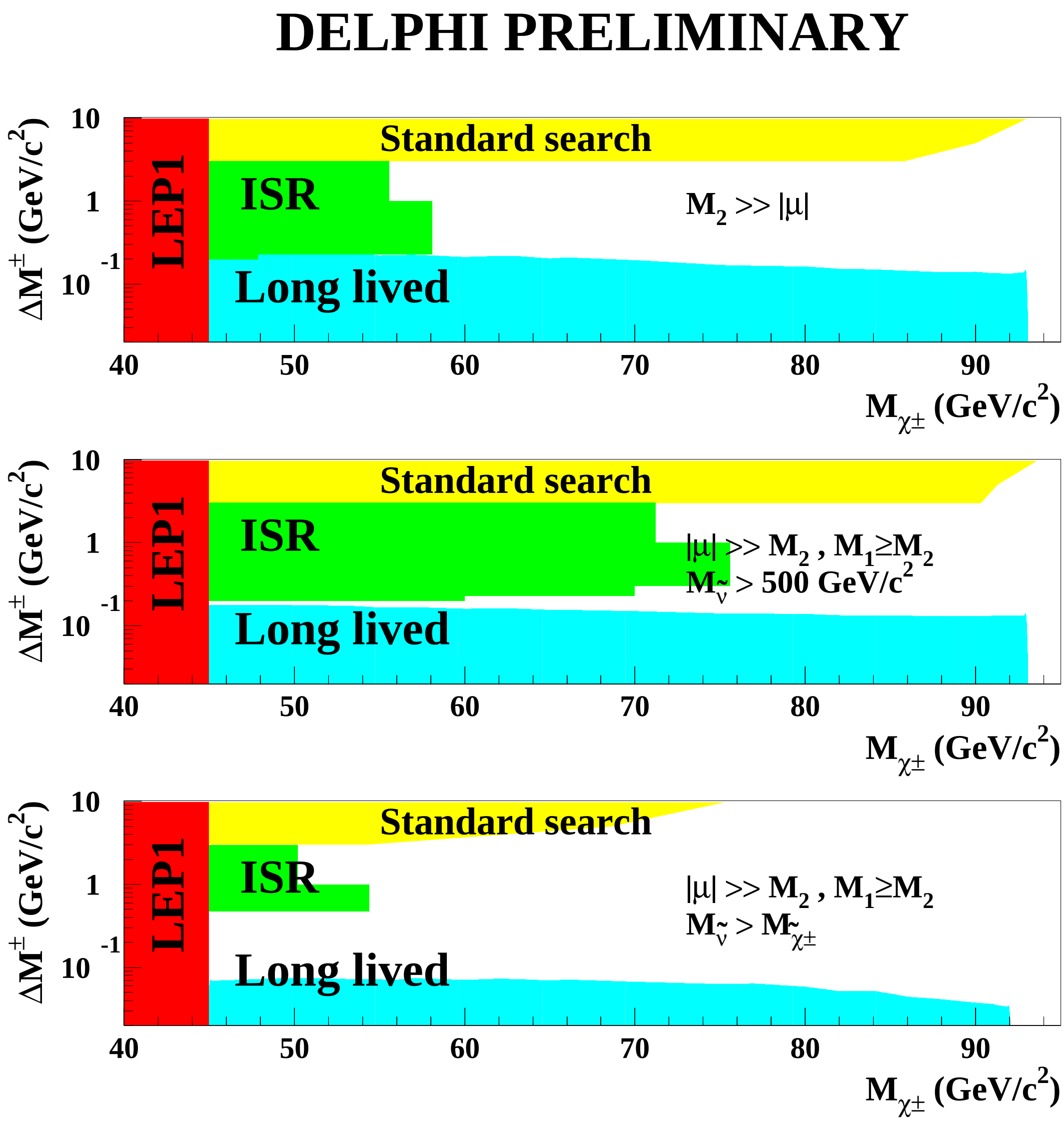

Figure 5: Regions in the plane ($M_{\tilde{\chi}_1^+}$,$\Delta M^{\pm}$) excluded by DELPHI at the 95% CL using the search for high $\Delta M^{\pm}$ charginos, the search for soft particles accompanied by ISR and the search for long-lived charginos. The three scenarios are the ones which allow low $\Delta M^{\pm}$: the lightest chargino is a higgsino; the lightest chargino is a gaugino and $M_{\tilde{\nu}} > 500$ GeV/c^2; the lightest chargino is a gaugino and $M_{\tilde{\nu}} > M_{\tilde{\chi}_1^+}$.