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# Search for slepton decays in a light gravitino scenario using the impact parameter method

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**Abstract**

A search for $\tilde{l} \to l\tilde{G}$ decays is reported, where $\tilde{l} = \tilde{\tau}, \tilde{\mu}, \tilde{e}$, in the framework of Gauge Mediated SUSY Breaking models, with $\tilde{G}$ Lightest Supersymmetric Particle (LSP) and $\tilde{l}$ Next to LSP. No evidence of these processes was found, for a decay length ranging from $\sim 1$ mm to $\sim 40$ cm, in the data collected by DELPHI in 1995-1998 at center of mass energies from 130 to 189 GeV. Limits were derived on $M_{\tilde{l}}$ and $M_{\tilde{G}}$.

# 1 Introduction

The analysis described in this note is an update of the one reported in [1] as "Small impact parameter search". We briefly recall that in the framework of Gauge Mediated SUSY Breaking Models (GMSB), the gravitino $\tilde{G}$ is expected to be the Lightest Supersymmetric Particle (LSP) and therefore the Next to LSP (NLSP) is expected to decay into a gravitino plus its Standard Model partner, with a mean lifetime increasing with increasing $M_{\tilde{G}}$.

The NLSP is often considered to be the lightest neutralino, which would decay into a gravitino plus a photon: this channel has been already studied in DELPHI [2]. However, it has been shown that for extended regions of the SUSY parameter space, the NLSP could be a slepton [3]. In this case the favoured NLSP candidate is the $\tilde{\tau}_1$: in fact, for large values of $tan\beta$, due to the mixing effect in the mass matrix which is proportional to $M_l$, the $\tilde{\tau}_1$ could be the lightest slepton. On the other hand, the mass difference between the $\tilde{e}_R$ or the $\tilde{\mu}_R$ and the $\tilde{\tau}$ could be so little that insufficient phase space is left for the three body decays $\tilde{e}_R, \tilde{\mu}_R \rightarrow \tilde{\tau}\nu\nu$, the dominant decay of the heavier sleptons would then be $\tilde{e}_R(\tilde{\mu}_R) \rightarrow e(\mu)\tilde{G}$.

The expected signal from the decay $\tilde{l} \rightarrow l\tilde{G}$ ($\tilde{l} = \tilde{\tau}, \tilde{\mu}, \tilde{e}$) depends on the mean decay length.

In this analysis we considered mean decay lengths shorter than $\sim 40$ cm. Therefore the signal events we searched for had low particle multiplicity, high missing energy and missing momentum (due to the undetected gravitinos) and large impact parameters of the charged tracks (due to the distance travelled by the undetected slepton).

For longer decay lengths, when most of the slepton tracks are well detected and reconstructed, methods based on a secondary vertex search [4] and on heavy stable particle identification [5] are more effective. All these different methods can be combined together [1] and with the standard slepton search [6] in order to set limits on the slepton masses independent of the gravitino mass.

With respect to our previous work [1], in this analysis we included 158 pb$^{-1}$ of data at $\sqrt{s}$=189 GeV; moreover we extended our search to the $\tilde{\mu} \rightarrow \mu\tilde{G}$ and $\tilde{e} \rightarrow e\tilde{G}$ decays.

The theoretical cross sections for slepton pair production [7], computed at different center of mass energies, are shown in fig. 1, as a function of the slepton mass. For the stau and smuon production only the s channel is effective whilst for selectron production also the t channel contribution has to be taken into account. Since the latter involves a neutralino exchange, in this case the cross section depends not only on the slepton mass but also on the SUSY parameters $\mu$ and tan$\beta$. The values assumed for these parameters in fig.1 ($\mu = -200\, GeV/c^2$, $tan\beta = 2$) correspond to a cross section value near the minimum of the allowed interval.

# 2 Event selection

As mentioned in [1], the event selection was optimized using samples of Montecarlo signal events generated by SUSYGEN [7] and fully simulated by DELSIM [8] through the DELPHI detector. Four more data sets with $\tilde{\tau}$ decays were added at $\sqrt{s}$ = 184 and 189 GeV, with $M_{\tilde{\tau}}$= 50, 70, 80 GeV and different mean decay lengths. The smuon and selectron decays were studied using 14 samples of Montecarlo generated events for each channel, spanning the relevant intervals of slepton and gravitino masses. Five samples of

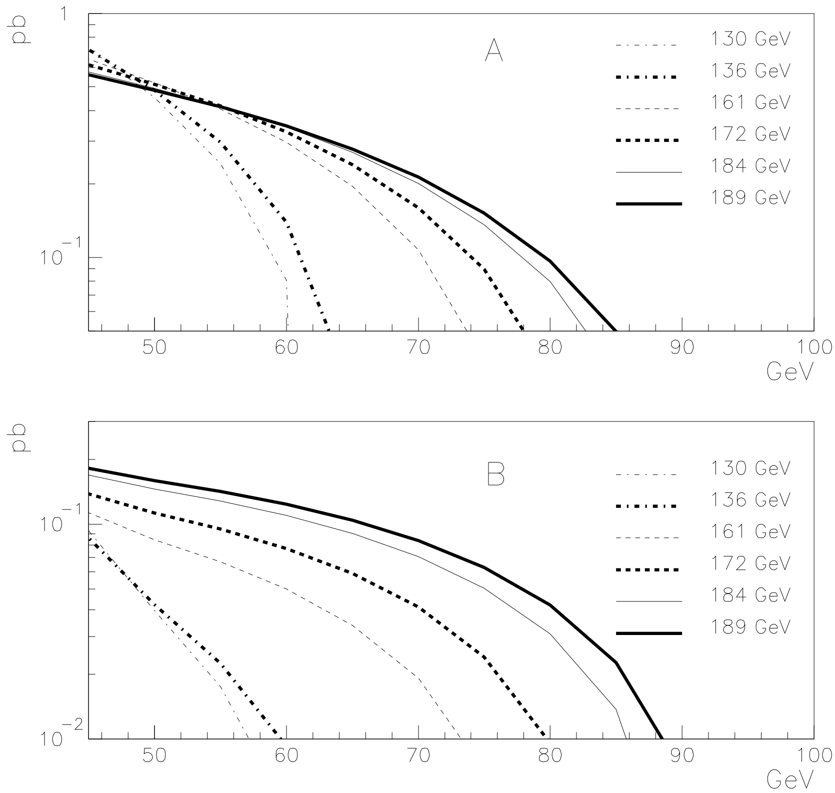


Figure 1: *Theoretical cross section for* $\tilde{l}_R\tilde{l}_R$ *production as a function of the the slepton mass for various center of mass energies. A: cross section for* $\tilde{\tau}_R\tilde{\tau}_R$, $\tilde{\mu}_R\tilde{\mu}_R$ *and s channel contribution for* $\tilde{e}_R\tilde{e}_R$*; B: total cross section for* $\tilde{e}_R\tilde{e}_R$ *(including t channel contribution) assuming* $\mu = -200\, GeV/c^2$, $tan\beta = 2$

fully simulated events for the smuon and five for selectron channel were used to check the effect of the detector smearing.

Also the Standard Model background for $\tilde{\tau}$'s was studied by Montecarlo at higher energies and was found to behave in the same way as at lower energies. Therefore basically the same event selection [1] was applied to reduce it. However, as the statistics increased, we also observed some background due to detector noise or failure and more cosmic events.

Events with anomalous noise in the TPC were rejected requiring less than 20 charged tracks before the track selection. The track quality criteria were tightened, for the leading tracks only, by the condition $\frac{\Delta p}{p} < 0.5$. Finally we observed a few events with gamma conversions and one standard $\tau\tau$ event, with a 1-3 topology, where the single track had not been reconstructed. Both these classes of events were discarded requiring that any leading track had at least one track at an angular distance greater than five degrees.

In order to reject standard $\tau\tau$ events, in particular WW $\rightarrow \tau\nu\tau\nu$, we used the variable $b_c \equiv \sqrt{b_1^2 + b_2^2}$, where $b_1$ and $b_2$ are the impact parameters of the leading tracks on the plane transverse to the beam.

Using the event selection described in [1], with the additional cuts described above, the $b_c$ distributions, shown in fig. 2, for simulated SM events and real data were in good agreement.

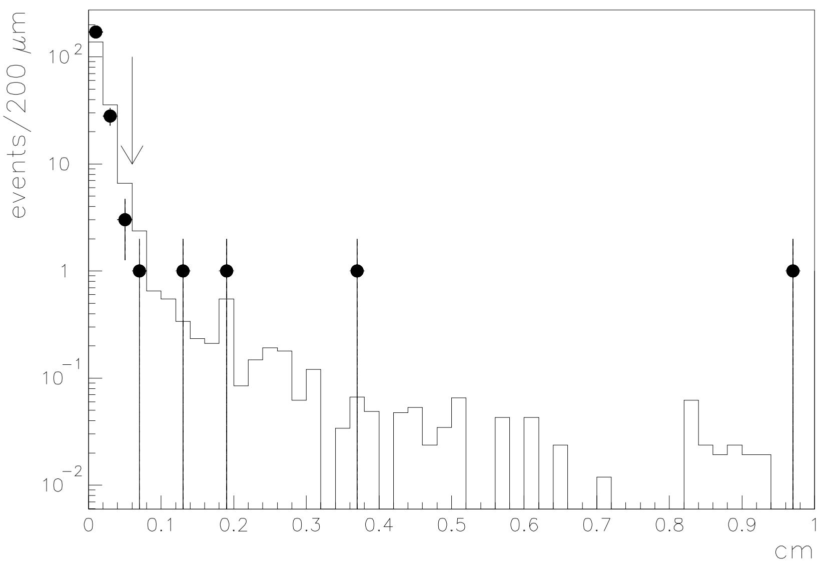


Figure 2: *$b_c$ distribution for Montecarlo Standard Model background and real data (dots). The arrow shows the cut chosen.*

The cut $b_c > 600\ \mu$m was chosen as in the previous analysis [1].

The same selection was used to search for $\tilde{\mu} \to \mu\tilde{G}$ events.

Instead, for the suppression of the Bhabha background in the $\tilde{e} \to e\tilde{G}$ search, a different requirement was applied. In fact, as expected, the cut $(E_1 + E_2) < 0.7 \cdot E_{beam}$ (where $E_1, E_2$ are the electromagnetic deposits associated to the leading tracks), used for the stau and smuon search, significantly reduced the efficiency for selectrons. The Bhabha events that passed the selection when the anti-Bhabha cut was not applied, were those where at least one of the electrons underwent a secondary interaction, thus acquiring a large impact parameter. However it was found that in these cases the measured momentum of the electron track was always much smaller than the electromagnetic deposit, the latter resulting of the superimposition of the electron energy with the accompanying photons (see fig.3A). Therefore the cut $(E_1/p_1 + E_2/p_2) < 2.2$ was used for this search (fig.3C,D).

# 3 Efficiency evaluation

A complete list of the Montecarlo signal samples used to evaluate the efficiency for the $\tilde{\tau} \to \tau\tilde{G}$ decay is reported in tab. 1.

Fig. 4 shows the efficiency versus the mean decay length. We verified that in the considered range of masses and up to $\sqrt{s} = 189$ GeV, the efficiency can be treated as a function of the decay length only, therefore we extended the interpolation method used in [1] to the 1998 data.

The efficiency for smuons and selectrons is shown in fig. 5 and 6.

| $\sqrt{s}$ (GeV) | $M_{\tilde{\tau}}$ (GeV) | $M_{\tilde{G}}$ (eV) | $ct$ (cm) | $\beta\gamma ct$ (cm) | $\epsilon(\%)$ |
|---|---|---|---|---|---|
| 130 | 40 | 0.7 | 0.075 | 0.082 | 12 ± 1 |
| | 50 | 15.0 | 12.38 | 9.86 | 22 ± 2 |
| | 60 | 15.0 | 4.97 | 1.98 | 39 ± 2 |
| 161 | 40 | 5.4 | 4.91 | 7.41 | 28 ± 1 |
| | 50 | 1.3 | 0.093 | 0.12 | 20 ± 1 |
| | 50 | 1.7 | 0.16 | 0.19 | 23.8 ± 0.9 |
| | 50 | 3.8 | 0.81 | 0.97 | 35 ± 1 |
| | 60 | 14.1 | 4.39 | 3.77 | 37 ± 2 |
| | 60 | 30.0 | 19.87 | 17.02 | 14 ± 1 |
| 172 | 40 | 6.4 | 6.90 | 11.66 | 20 ± 1 |
| | 50 | 1.7 | 0.16 | 0.21 | 26.1 ± 0.9 |
| | 50 | 3.8 | 0.81 | 1.08 | 35 ± 1 |
| | 50 | 7.4 | 3.01 | 4.01 | 34 ± 1 |
| | 50 | 10.4 | 5.95 | 8.01 | 24 ± 1 |
| | 60 | 1.7 | 0.064 | 0.063 | 11.2 ± 0.5 |
| | 60 | 3.8 | 0.32 | 0.32 | 30.3 ± 0.7 |
| | 60 | 10.6 | 2.48 | 2.47 | 37 ± 1 |
| | 60 | 20.7 | 9.46 | 9.39 | 22 ± 1 |
| | 65 | 1.8 | 0.05 | 0.041 | 4.6 ± 0.7 |
| | 65 | 11.6 | 1.99 | 1.65 | 38 ± 1 |
| | 65 | 17.4 | 4.48 | 3.71 | 35 ± 1 |
| 184 | 50 | 25.0 | 34.39 | 50.63 | 6.2 ± 0.7 |
| | 80 | 14.2 | 1.05 | 0.58 | 35 ± 1 |
| 189 | 70 | 14.7 | 2.21 | 1.92 | 38 ± 1 |
| | 80 | 8.2 | 0.35 | 0.21 | 23 ± 1 |

Table 1: *List of fully simulated Montecarlo* $\tilde{\tau} \to \tau\tilde{G}$ *events*

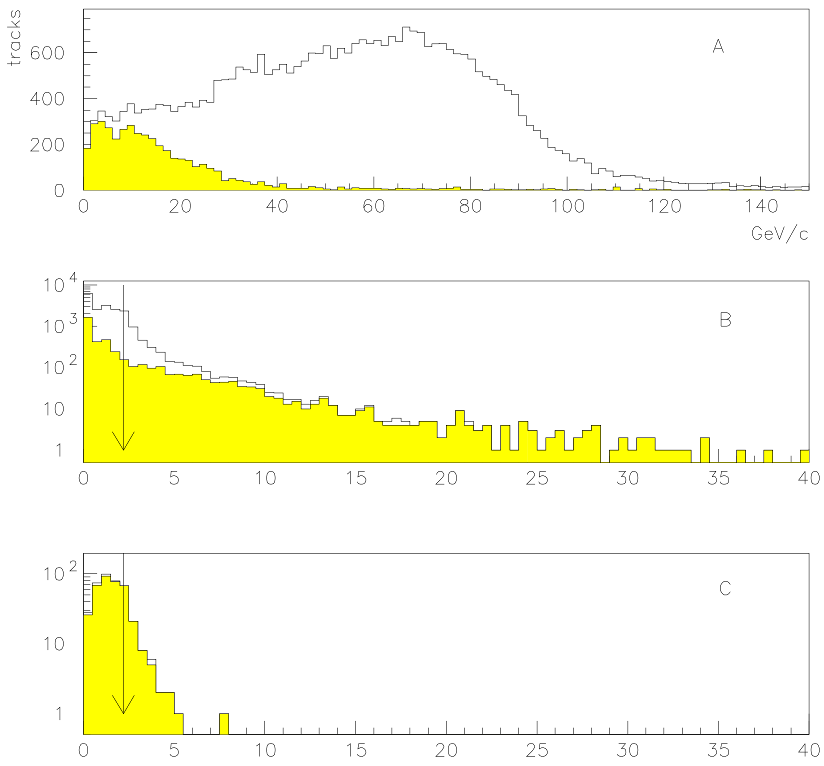


Figure 3: *A: momentum distribution for MC Bhabha events at 184 GeV. The shaded histogram is for large impact parameter tracks. B: $E_1/p_1 + E_2/p_2$ distribution for MC Bhabha events. The shaded histogram is for events passing the $b_c$ cut. C: same as B, for $\tilde{e}\tilde{e}$ events ($M_{\tilde{e}} = 70\,GeV$, $M_{\tilde{G}} = 20\,eV$). The arrows show the cut chosen.*

MC events generated with several values of $\sqrt{s}$, $M_{\tilde{l}}$ and $M_{\tilde{G}}$ were used to verify that in the considered intervals of these parameters the efficiency can be interpolated as a function of the mean decay length. Samples of events with full detector simulation were used to take the detector smearing into account. The ratio between the efficiency obtained on fully simulated events and the one computed at the generation level, was fitted with an exponential function. This function was then used to determine the efficiency for the limit calculation.

For very short slepton decay lenghts, the effect of the tau lifetime is not negligible. In this region the efficiency is mainly determined by the cut on $b_c$, therefore it is higher for staus than for smuons and selectrons. On the contrary, for larger decay lengths, the efficiency for smuons becomes a bit higher, due to the larger momentum of the leading tracks. In the case of selectrons the loss of efficiency is due, as mentioned, to the cut on the leading track electromagnetic deposit.

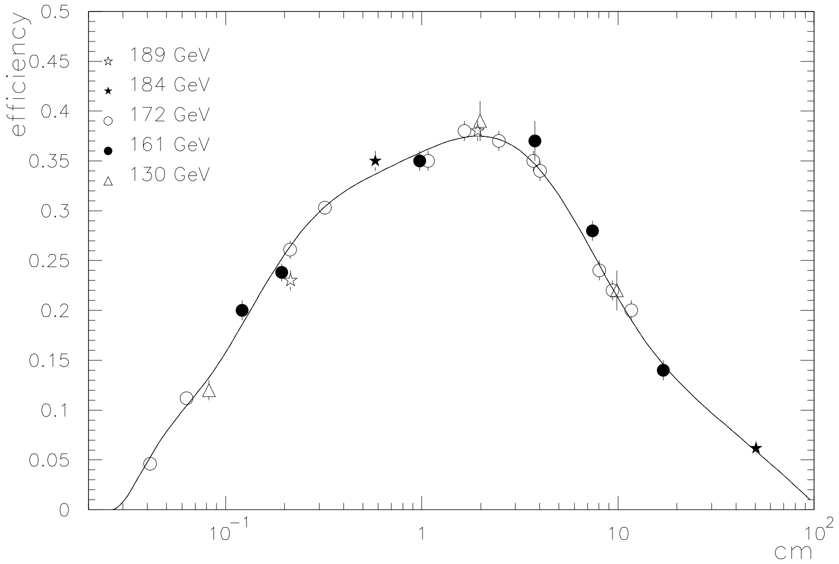


Figure 4: Efficiency for $\tilde{\tau} \to \tau\tilde{G}$ as a function of the mean decay length for various center of mass energies, $M_{\tilde{\tau}}$ and $M_{\tilde{G}}$ values

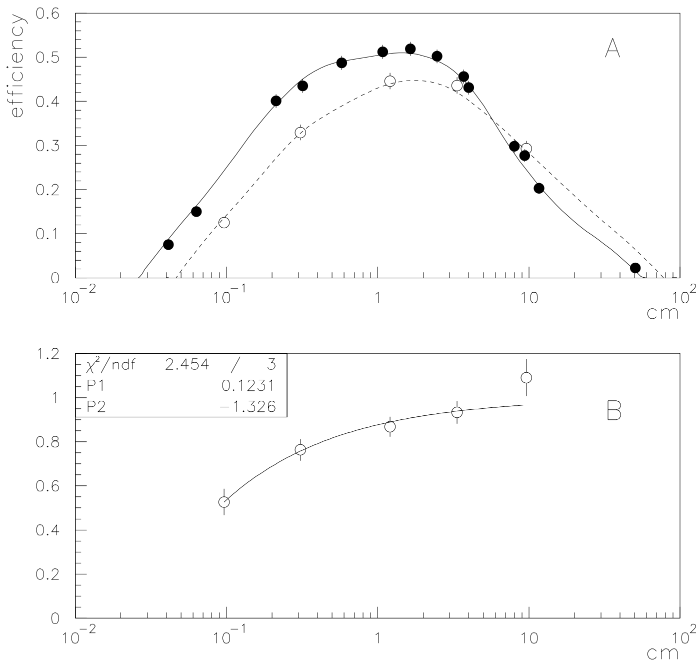


Figure 5: *A: efficiency for $\tilde{\mu} \to \mu\tilde{G}$ as a function of the mean decay length: the solid line is for MC events at the generation level with various center of mass energies, $M_{\tilde{\mu}}$ and $M_{\tilde{G}}$; the dashed line includes the detector response. B: ratio between the two efficiencies in A.*

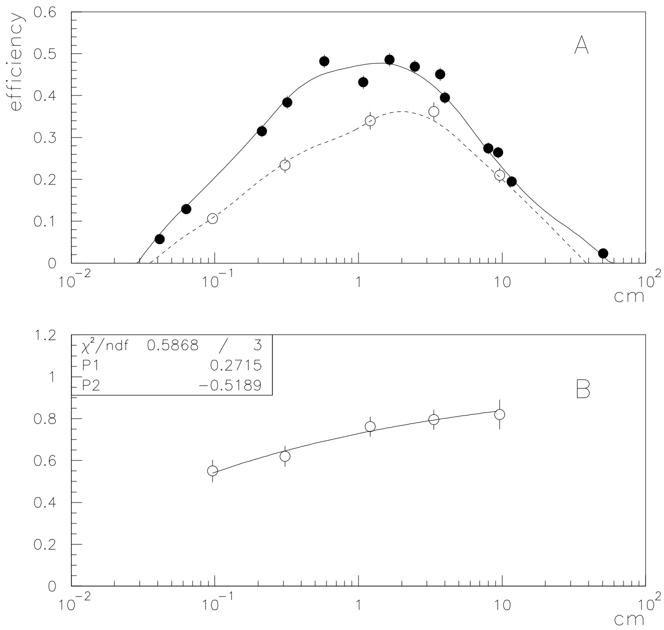


Figure 6: *Same as the previous figure, for the $\tilde{e} \to e\tilde{G}$ search*

# 4 Results

The non negligible contributions to the background expected from the relevant Standard Model processes are the same, within the errors, for the $\tilde{\tau}/\tilde{\mu}$ search and for the $\tilde{e}$ search. Also the real events surviving the cuts are the same for both selections. In tab. 2 the expected background and selected events are listed for each set of real data.

We found one candidate in the 184 GeV data and four in the 189 GeV. They are listed in tab. 3.

The 184 GeV event is shown in fig. 7. It is a clean $\tau\tau$ event with a 1-3 topology.

The leading track of the three has an impact parameter of 1.3 mm. It might be due to an interaction in the vertex detector material which produced two soft tracks of $\sim$ 400 and $\sim$ 700 MeV respectively. Two of the 189 GeV candidates are likely to suffer from track fitting problems. Fig. 8 shows one of them as an example: the track with large impact parameter ($\sim$ 3 mm) has no hit in the VD. On the other hand, three VD hits are visible which could be included in the fit with the possible effect of decreasing the i.p. It should be stressed that both secondary interactions and bad track reconstruction are included in the background simulation, therefore these events must be taken into account in the calculation of the limits.

The other two 189 GeV selected events show no evident reconstruction problem. One of them is shown in fig. 9. They are compatible with the tail of the $b_c$ distribution for SM $\tau\tau$ events.

Fig. 10 shows the exclusion limits, at 95% confidence level, in the plane $M_{\tilde{G}}M_{\tilde{l}}$, obtained for $\tilde{l} = \tilde{\tau}, \tilde{\mu}, \tilde{e}$. The limits for selectrons were computed considering only the s channel contribution to the cross section (fig.1A), and considering the most pessimistic case with t and s channel interference (fig.1B).

| channel | 130 GeV + 136 GeV | 161 GeV | 172 GeV | 183 GeV | 189 GeV |
|---|---|---|---|---|---|
| $\gamma\gamma \to \tau\tau$ | $0.00^{+0.65}_{-0.00}$ | $0.09^{+0.14}_{-0.06}$ | $0.00^{+0.08}_{-0.00}$ | $0.20^{+0.33}_{-0.12}$ | $0.61^{+0.99}_{-0.38}$ |
| $\gamma^*/Z^* \to \tau\tau$ | $0.19^{+0.14}_{-0.08}$ | $0.21^{+0.13}_{-0.09}$ | $0.07^{+0.07}_{-0.04}$ | $0.99^{+0.29}_{-0.22}$ | $1.33^{+0.46}_{-0.35}$ |
| WW | - | $0.03^{+0.01}_{-0.01}$ | $0.12^{+0.04}_{-0.03}$ | $0.76^{+0.13}_{-0.11}$ | $2.52^{+0.26}_{-0.23}$ |
| ZZ | - | - | - | $0.02^{+0.02}_{-0.01}$ | $0.08^{+0.04}_{-0.03}$ |
| total | $0.19^{+0.66}_{-0.08}$ | $0.33^{+0.19}_{-0.11}$ | $0.19^{+0.12}_{-0.05}$ | $1.97^{+0.46}_{-0.27}$ | $4.54^{+1.12}_{-0.57}$ |
| candidates | 0 | 0 | 0 | 1 | 4 |

Table 2: *Expected background events (Monte Carlo) and selected data events at the various center of mass energies*

| Run | Event | $N_{track}$ | $p_1 (GeV)$ | $b_1$ (mm) | $p_2$ (GeV) | $b_2$ (mm) |
|---|---|---|---|---|---|---|
| 78267 | 16989 | 4 | 21.4 | 1.314 | 2.0 | 0.290 |
| 85066 | 20727 | 2 | 2.4 | 0.692 | 47.6 | 0.135 |
| 85689 | 3658 | 3 | 25.1 | 9.748 | 60.2 | 0.059 |
| 88211 | 1258 | 2 | 0.6 | 1.950 | 17.1 | 0.119 |
| 88810 | 3805 | 2 | 1.4 | 0.020 | 14.6 | 3.635 |

Table 3: *List of the selected events*

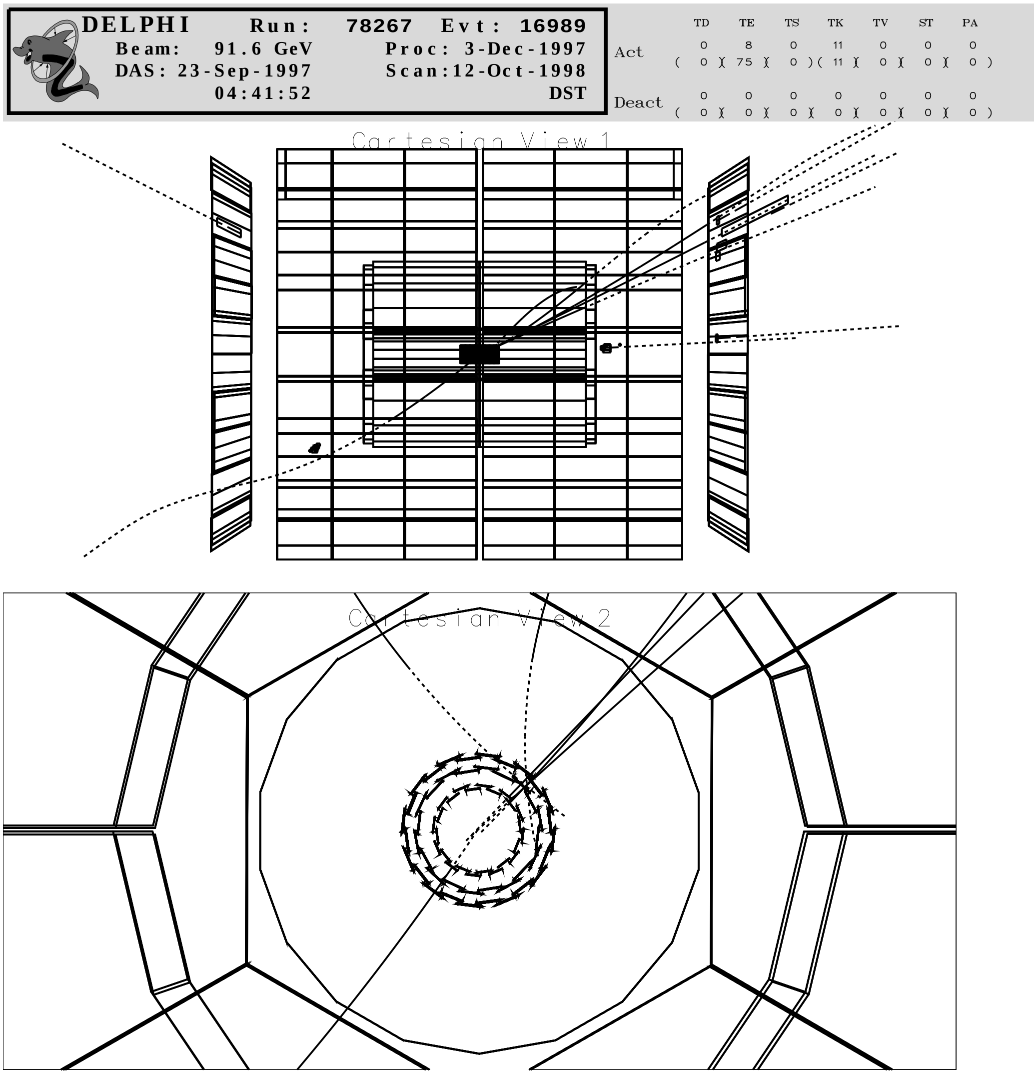


Figure 7: *The event selected in the 184 GeV data*

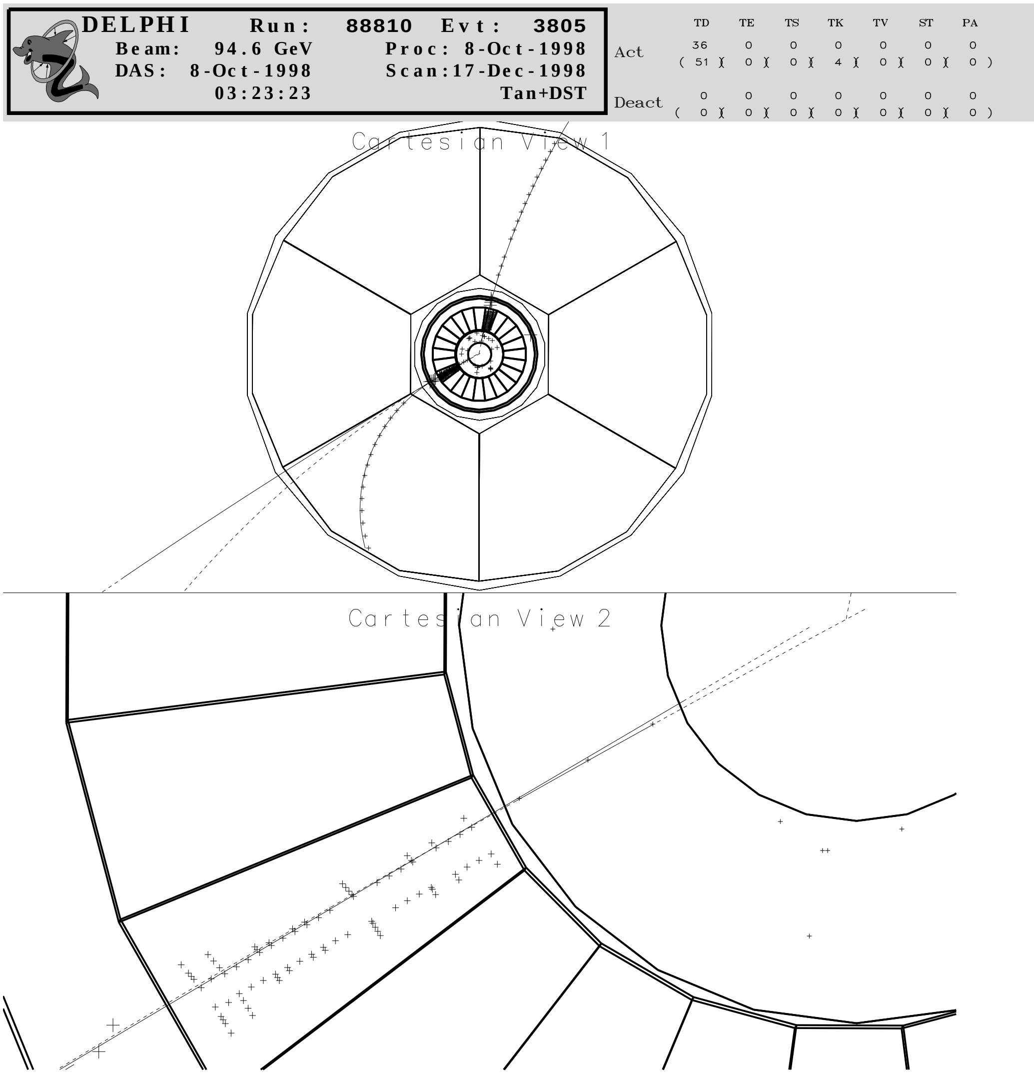


Figure 8: *One of the events selected in the 189 GeV data*

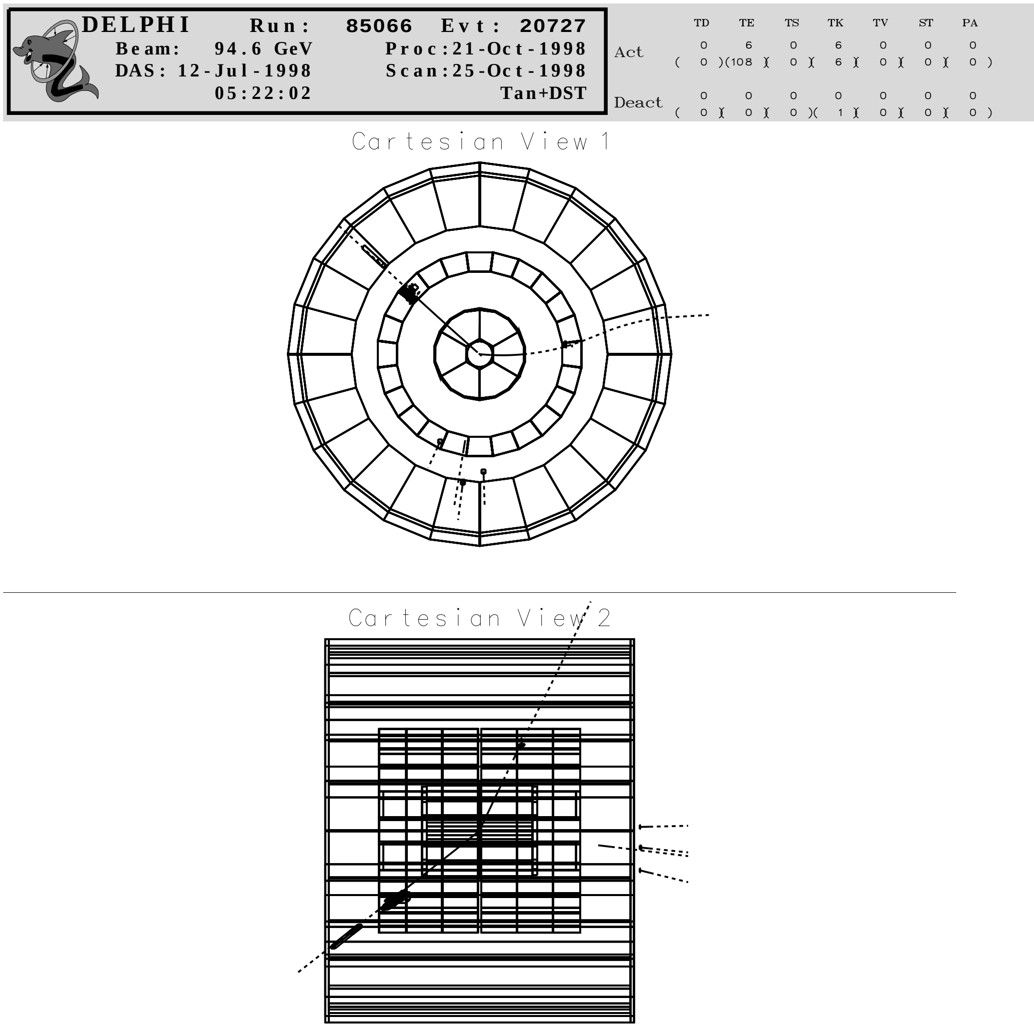


Figure 9: *One of the events selected in the 189 GeV data*

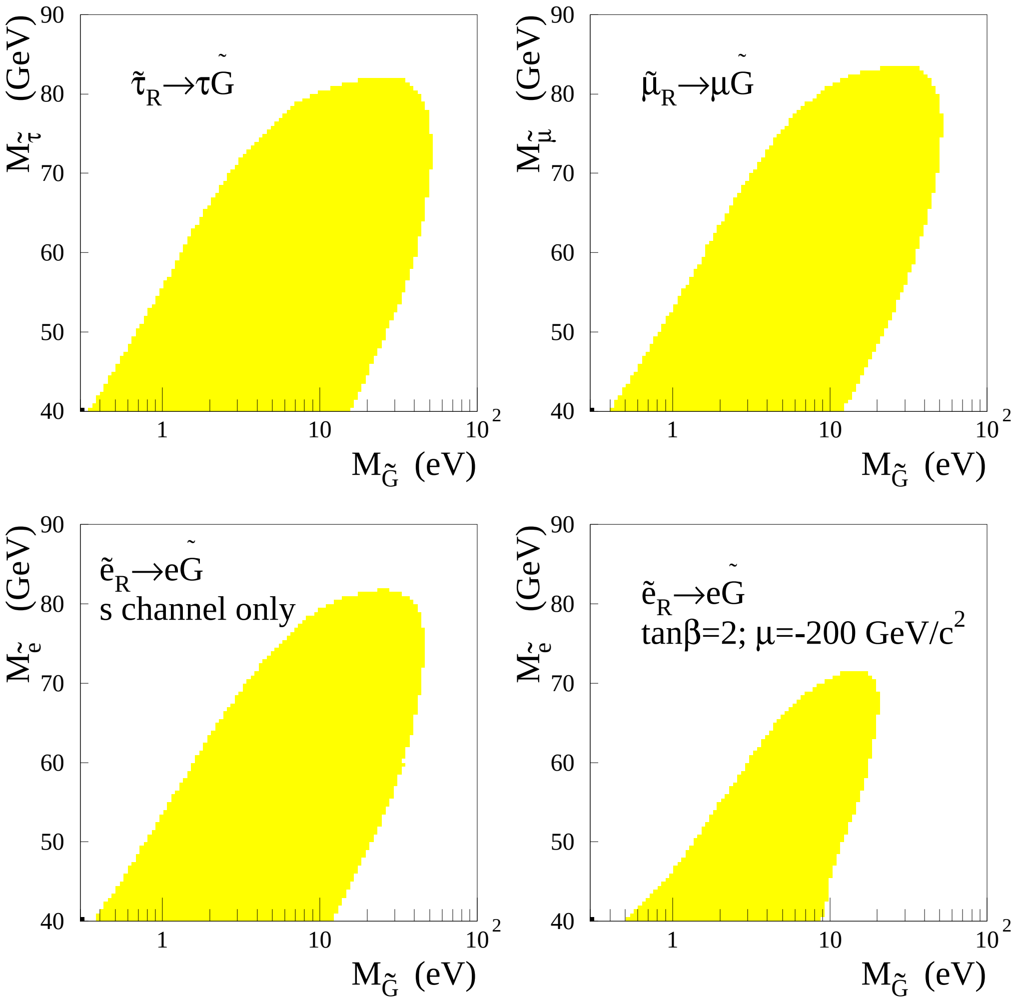


Figure 10: *95% c.l. exclusion limits for $\tilde{\tau} \to \tau\tilde{G}$; $\tilde{\mu} \to \mu\tilde{G}$; and $\tilde{e} \to e\tilde{G}$: considering only the s channel contribution to the $\tilde{e}\tilde{e}$ production cross section, and considering the lowest possible cross section resulting from s and t channel*

In fig. 11 the corresponding results were derived in the hypothesis that the three sleptons have the same mass and considering only the s channel contribution to the $\tilde{e}$ production.

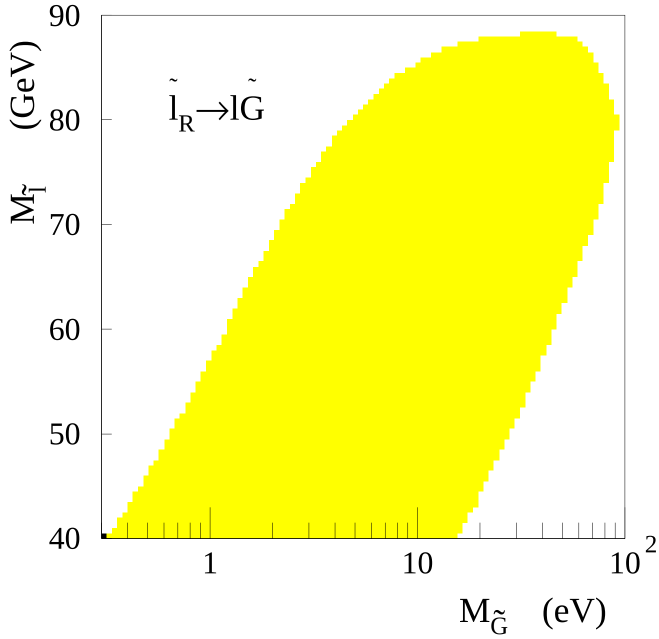


Figure 11: *95% c.l. exclusion limits for $\tilde{l} \rightarrow l\tilde{G}$, where $\tilde{l} = \tilde{\tau}, \tilde{\mu}, \tilde{e}$, in the hypothesis $M_{\tilde{\tau}}$=$M_{\tilde{\mu}}$=$M_{\tilde{e}}$*

# 5 Conclusions

The data taken by DELPHI at energies between 130 and 189 GeV were analysed to search for sleptons with mean decay lengths between about 1 mm and 40 cm. No evidence for a signal was found and exclusion limits were derived at the 95% confidence level in the $M_{\tilde{G}}$ $M_{\tilde{l}}$ plane. Considering the range of $M_{\tilde{l}}$ values above the limits already set at LEP1 [9], the sensitivity of this search extends down to a gravitino mass $\sim 0.5\ eV/c^2$. The maximum sensitivity is for $M_{\tilde{G}} \sim 20\,eV/c^2$. The limits set in this region are: $M_{\tilde{\tau}} > 82\,GeV/c^2$; $M_{\tilde{\mu}} > 83.5\,GeV/c^2$ and $M_{\tilde{e}} > 71.5\,GeV/c^2$ (in the most pessimistic hypothesis for the $\tilde{e}\tilde{e}$ production cross section). If the three sleptons were mass degenerate, their common mass should be larger than $88\,GeV/c^2$, for $18\,eV/c^2 < M_{\tilde{G}} < 50\,eV/c^2$.

# References


[1] DELPHI Coll., CERN-EP 98-170 (submitted to E. Phys. J. C.)

[2] P. Checchia, A. De Min, M. Margoni, F. Mazzucato and M. Verlato, DELPHI 98-79 ICHEP'98 CONF 147

DELPHI Coll., Phys. Lett. B446 (1999) 75

[3] see for instance: G.F. Giudice and R. Rattazzi, CERN-TH/97380

[4] DELPHI Coll., CERN-EP 98-116 (Accepted by E. Phys. J.C.)

[5] DELPHI Coll., Phys. Lett. B444 (1998) 491

[6] W. Adam et al., DELPHI 98-92 CONF 160, contribution to ICHEP'98, Vancouver, n.204

[7] S. Katsanevas and S. Melachroinos in CERN 96-01, vol.2, p. 328. See also the SUSYGEN manual, by S. Katsanevas and P. Morawitz, in http://lyohp5.in2p3.fr/delphi/katsan/susygen.html

[8] DELPHI Coll., Nucl. Instr. Meth. A378 (1996) 57

[9] DELPHI Coll., Phys. Lett. B247 (1990) 157