

Photonic and gravitino searches at LEP

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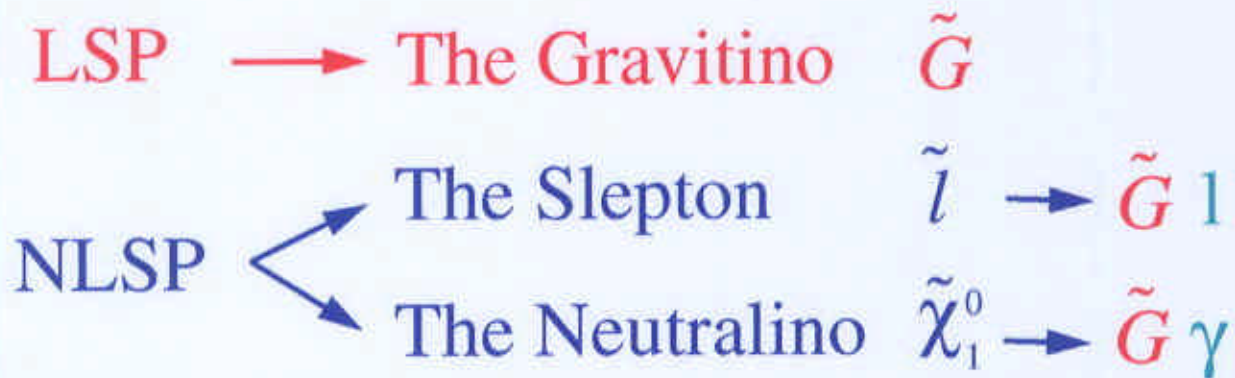
Mini-review of results from Aleph, Delphi, L3, Opal and the LEP SUSY working group.

Content:

- Gauge Mediated Supersymmetry Breaking
- Gravitino LSP + Slepton NLSP
- Gravitino LSP + Neutralino NLSP
- GMSB interpretation of the searches

Gauge Mediated Supersymmetry Breaking

The lightest and next-to-lightest SUSY particles:



The Gravitino mass: $m_{\tilde{G}} \sim \frac{(\sqrt{F})^2}{M_{Plank}}$

where \sqrt{F} is the SUSY breaking scale

$\sqrt{F} : 10 - 10\,000 \text{ TeV} \qquad m_{\tilde{G}} : 0.02 \text{ eV} - 20 \text{ keV}$

The NLSP decay length:

$L_{NLSP} \sim m_{NLSP}^{-5} m_{\tilde{G}}^2$

- $\ll \text{Exp.} \longrightarrow \text{Acoplanar lepton or } \gamma$
- $\approx \text{Exp.} \longrightarrow \text{Non-pointing lepton or } \gamma$
- $\gg \text{Exp.} \longrightarrow \text{Heavy stable particle}$

Analysis procedure

Different predicted GMSB event topologies have been searched for using the 192-202 GeV LEP data.

No signal was observed in any of the event topologies studied.

New cross section limits have been obtained.

Scans of the minimal GMSB parameter space

\sqrt{F} The SUSY breaking scale

M The messenger mass scale

N The number of messenger pairs

Λ The sparticle mass scale

μ The higgsino mass parameter

$\tan \beta$ Ratio of the expectation values of the two Higgs doublets

yield new exclusion plots

\tilde{G} LSP + \tilde{l} NLSP

Large $\tilde{\tau}_R - \tilde{\tau}_L$ mixing
Large $\tan\beta$

Small $\tilde{\tau}_R - \tilde{\tau}_L$ mixing
Small $\tan\beta$

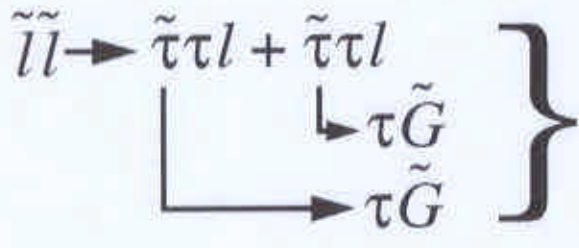
$\tilde{\tau}_1$ NLSP

$\tilde{\tau}_R \tilde{e}_R \tilde{\mu}_R$ co-NLSP

$e^+e^- \rightarrow \tilde{l}\tilde{l}$

$\tilde{\tau}\tilde{\tau} \rightarrow \tau\tilde{G} + \tau\tilde{G}$ <p style="text-align: center; color: red;">$2\tau + \cancel{E}$</p> <hr style="border-top: 1px dashed black;"/> $\tilde{l}\tilde{l} \rightarrow \tilde{\tau}\tau l + \tilde{\tau}\tau l$ <div style="display: flex; justify-content: center; align-items: center; margin-left: 100px;"> <div style="border-left: 1px solid black; border-bottom: 1px solid black; width: 20px; height: 20px; margin-right: 5px;"></div> <div style="margin-right: 5px;"> $\tau\tilde{G}$ $\tau\tilde{G}$ </div> </div> <p style="text-align: center; color: red;">$4\tau + 2l + \cancel{E}$</p>	$\tilde{l}\tilde{l} \rightarrow l\tilde{G} + l\tilde{G}$ <p style="text-align: center; color: red;">$2l + \cancel{E}$</p> <p style="color: green;">$L_{\tilde{l}} \ll \text{Experiment} :$ Acoplanar leptons</p> <p style="color: green;">$L_{\tilde{l}} \approx \text{Experiment} :$ Kinks + Impact param.</p> <p style="color: green;">$L_{\tilde{l}} \gg \text{Experiment} :$ Heavy stable particles</p>
<p style="color: magenta;">$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$</p> $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{\tau}\tau + \tilde{\tau}\tau$ <div style="display: flex; justify-content: center; align-items: center; margin-left: 100px;"> <div style="border-left: 1px solid black; border-bottom: 1px solid black; width: 20px; height: 20px; margin-right: 5px;"></div> <div style="margin-right: 5px;"> $\tau\tilde{G}$ $\tau\tilde{G}$ </div> </div> <p style="text-align: center; color: red;">$4\tau + \cancel{E}$</p>	$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{l}\tilde{l} + \tilde{l}\tilde{l}$ <div style="display: flex; justify-content: center; align-items: center; margin-left: 100px;"> <div style="border-left: 1px solid black; border-bottom: 1px solid black; width: 20px; height: 20px; margin-right: 5px;"></div> <div style="margin-right: 5px;"> $l\tilde{G}$ $l\tilde{G}$ </div> </div> <p style="text-align: center; color: red;">$4l + \cancel{E}$</p>

\tilde{G} LSP + \tilde{l} NLSP



Opal 192-202 GeV data:

5 events observed

5.1 events expected from bkg.

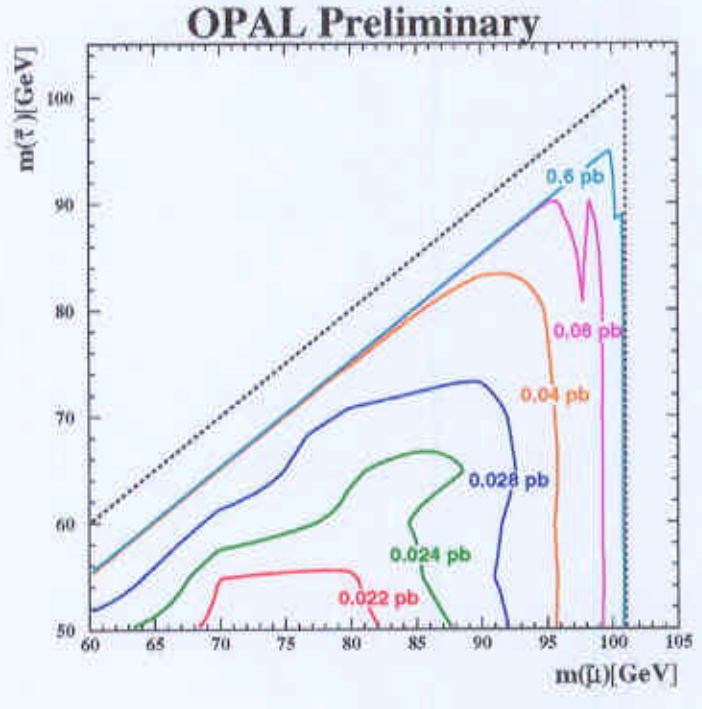
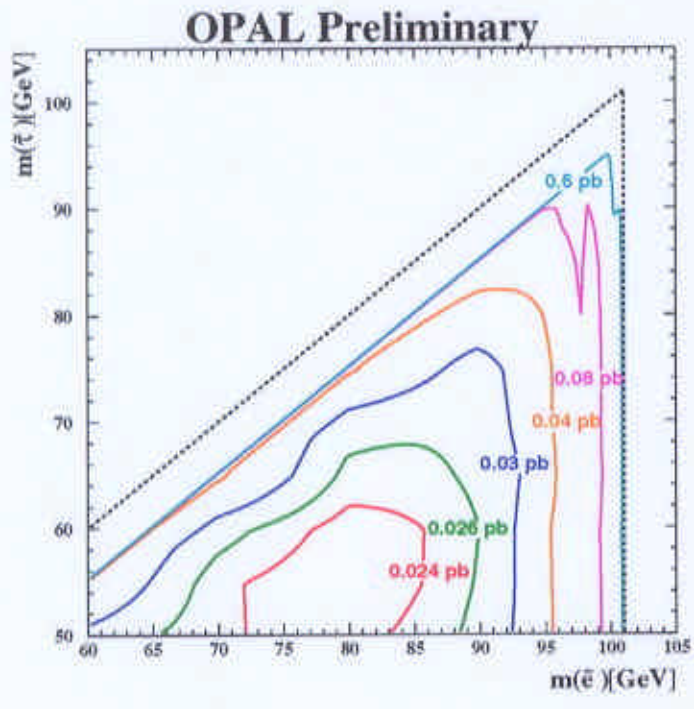
$$4\tau + 2l + \cancel{E}$$

Cross section limits:

$L_{\tilde{l}} \ll \text{Experiment}$

$m_{\tilde{\tau}}$ versus $m_{\tilde{e}}$

$m_{\tilde{\tau}}$ versus $m_{\tilde{\mu}}$

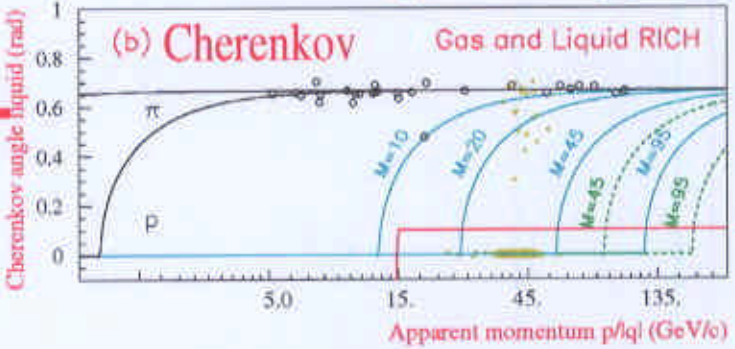
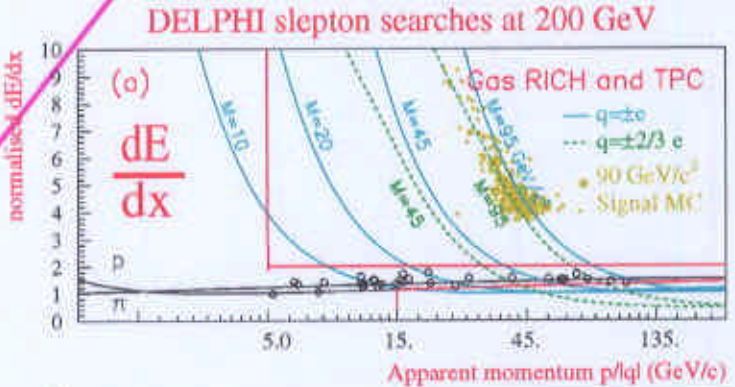
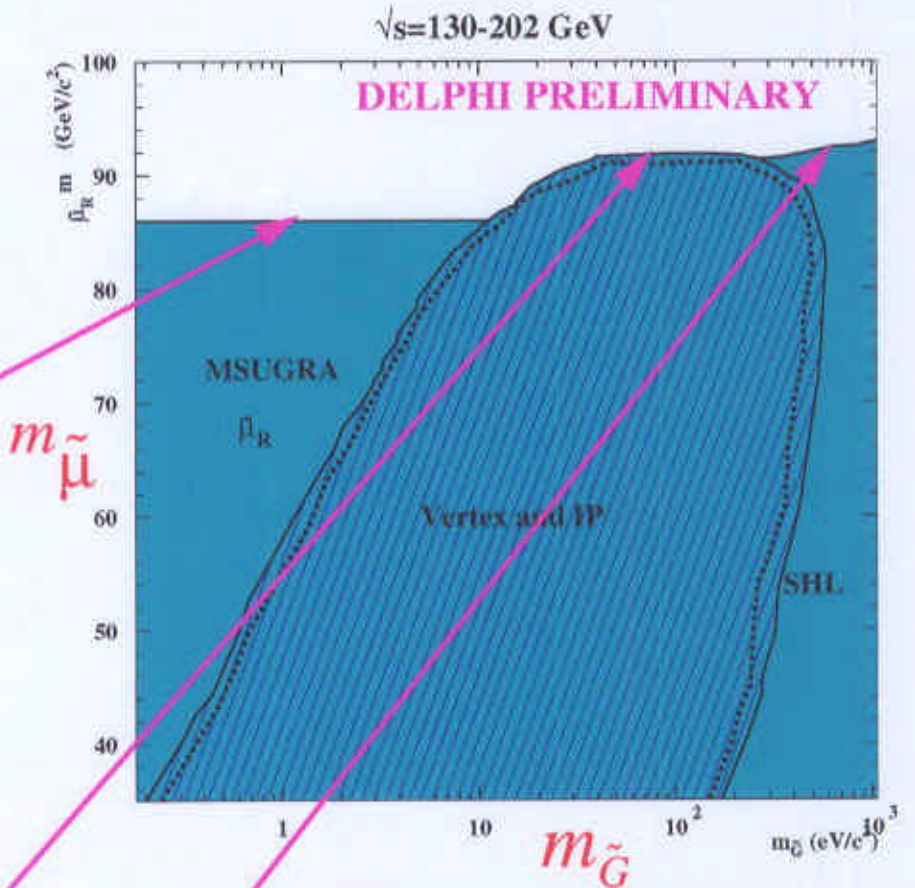


$$e^+e^- \rightarrow \tilde{l}\tilde{l}$$

$L_{\tilde{l}} \ll \text{Experiment}$:
 Acoplanar leptons
MSUGRA
 $\tilde{l}\tilde{l} \rightarrow \tilde{\chi}_1^0 l + \tilde{\chi}_1^0 l$
 $2l + \cancel{E}$

$L_{\tilde{l}} \approx \text{Experiment}$:
 Kinks + Displ. vertex
GMSB
 $\tilde{l}\tilde{l} \rightarrow l\tilde{G} + l\tilde{G}$
 $2l + \cancel{E}$

$L_{\tilde{l}} \gg \text{Experiment}$:
 Heavy stable particles
 $e^+e^- \rightarrow \tilde{l}\tilde{l}$



\tilde{G} LSP + $\tilde{\chi}_1^0$ NLSP

Photon pair production:

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

$L_{\tilde{\chi}} \ll \text{Experiment} :$
 Acoplanar photon pairs

$L_{\tilde{\chi}} \approx \text{Experiment} :$
 Non-pointing single γ

Single photon production with ultralight \tilde{G} :

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \gamma \tilde{G} \tilde{G}$$

}

$L_{\tilde{\chi}} \ll \text{Experiment} :$
 Single photons

Cascade decays to photons:

$$e^+e^- \rightarrow \tilde{l}\tilde{l} \rightarrow \dots \rightarrow 2\gamma + \cancel{E} + \text{leptons}$$

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \dots \rightarrow 2\gamma + \cancel{E} + \text{leptons, jets}$$

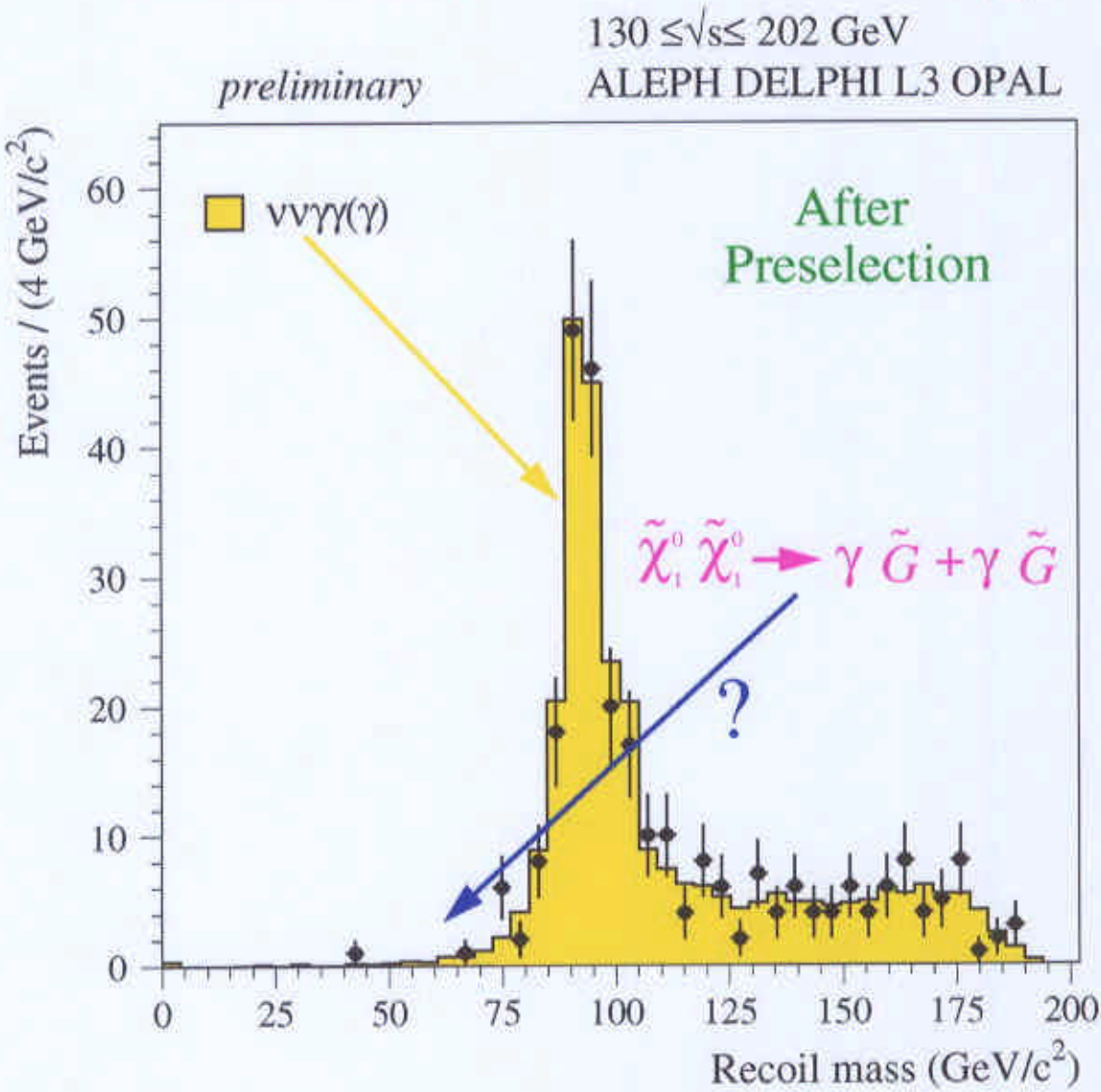
$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \dots \rightarrow 2\gamma + \cancel{E} + \text{jets}$$

$$\tilde{G} \text{ LSP} + \tilde{\chi}_1^0 \text{ NLSP}$$

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

$L_{\tilde{\chi}}$ Experiment : Acoplanar photon pairs + Missing energy

Recoil mass (or missing mass) distribution of $\gamma\gamma$ events:

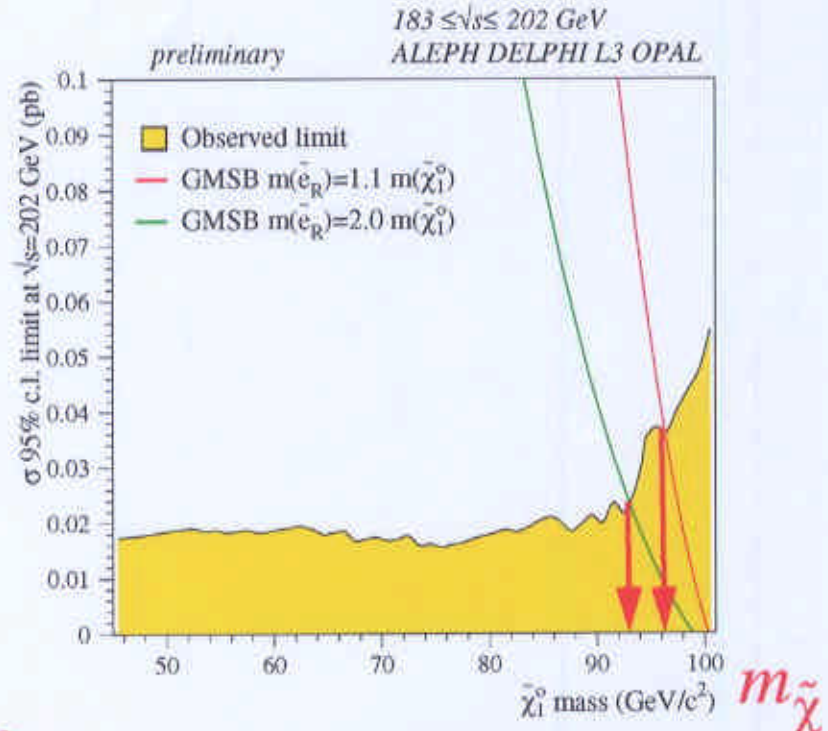


$$\tilde{G} \text{ LSP} + \tilde{\chi}_1^0 \text{ NLSP}$$

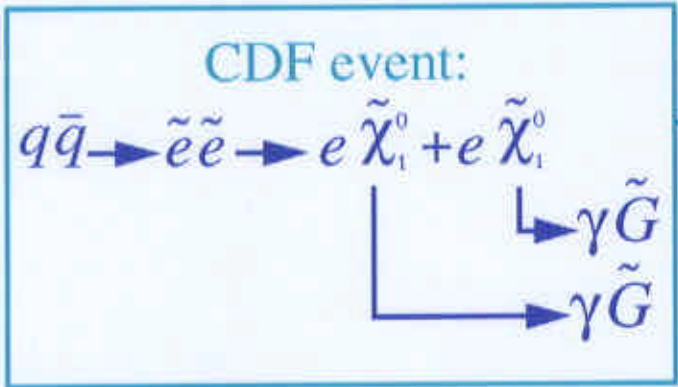
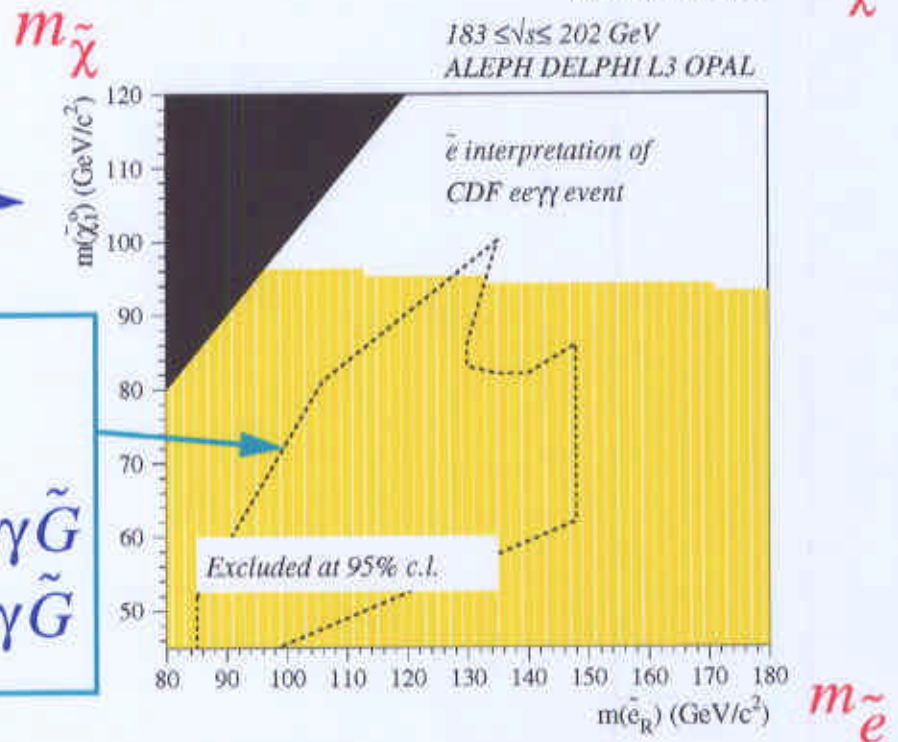
$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

$L_{\tilde{\chi}}$ Experiment : Acoplanar photon pairs + Missing energy

Cross section limit →



Exclusion plot →

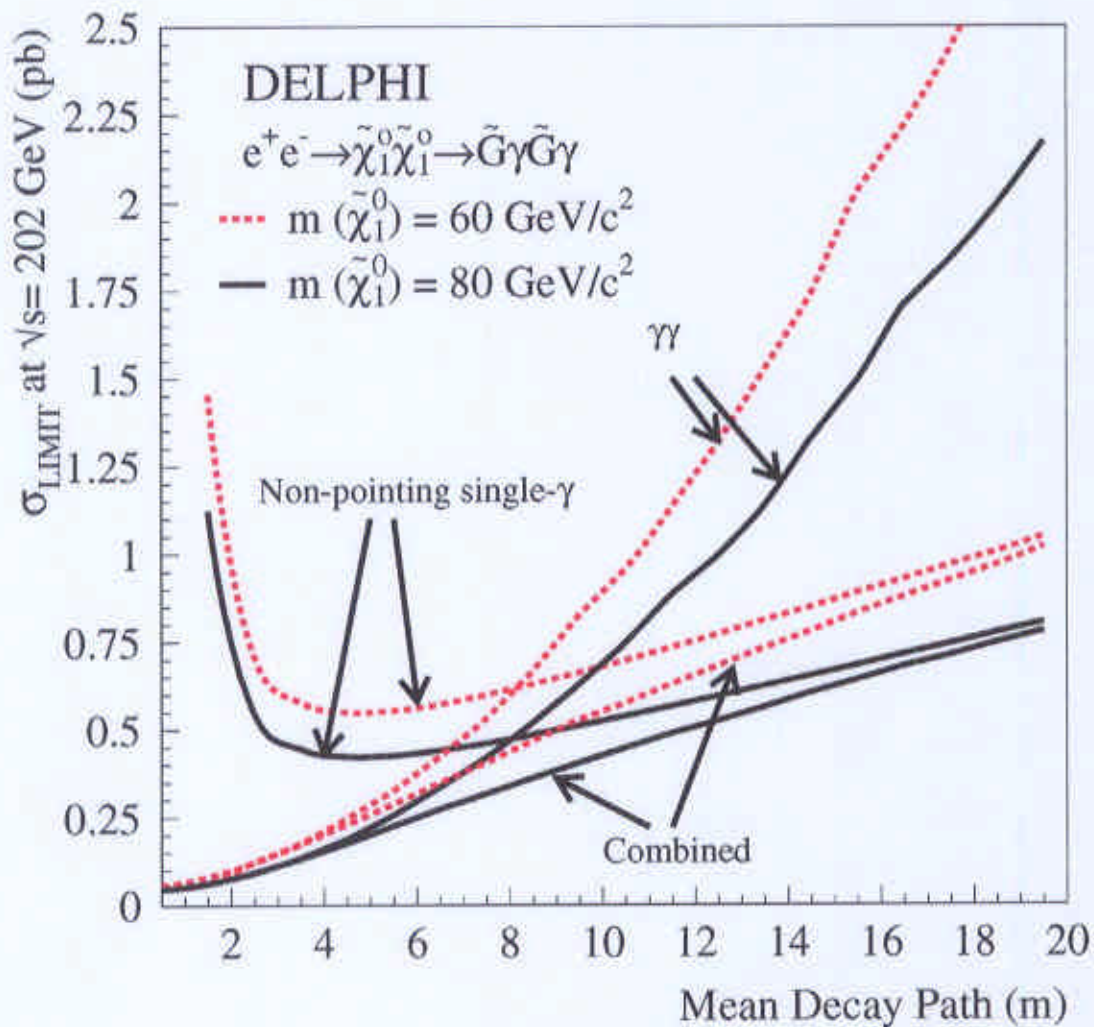


$$\tilde{G} \text{ LSP} + \tilde{\chi}_1^0 \text{ NLSP}$$

$$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

$L_{\tilde{\chi}} \approx$ Experiment : Single photons which does not point towards the interaction region.

Cross section limit versus $L_{\tilde{\chi}}$:



\tilde{G} LSP + $\tilde{\chi}_1^0$ NLSP

$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \gamma \tilde{G} \tilde{G}$
 $e^+e^- \rightarrow \gamma \tilde{G} \tilde{G}$

The cross section is only sizable for ultra-light gravitinos:

$$m_{\tilde{G}} \sim 10^{-4} - 10^{-5} \text{ eV} \quad L_{\tilde{\chi}} \ll \text{Experiment}$$

Recoil mass dist. of single photon events:

$e^+e^- \rightarrow \gamma \tilde{G} \tilde{G}$

Gravitino mass limit
using 192-202 GeV
data:

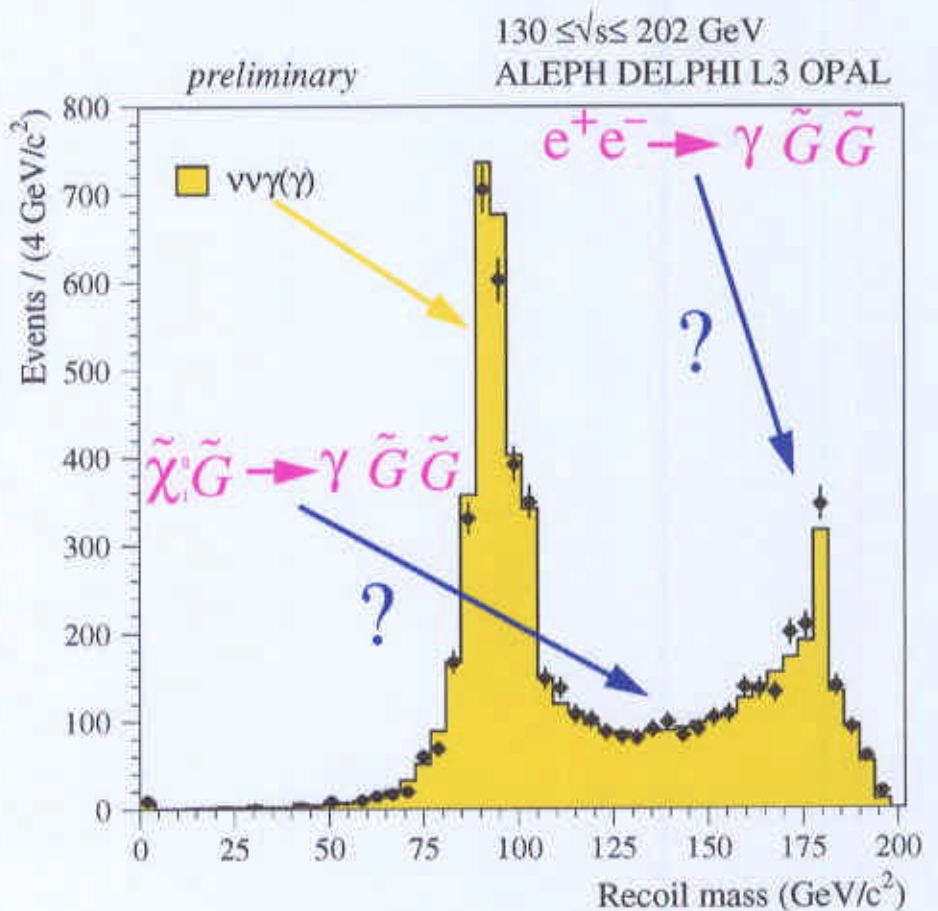
ALEPH

$$m_{\tilde{G}} > 1.1 \cdot 10^{-5} \text{ eV}$$

DELPHI

$$m_{\tilde{G}} > 1.2 \cdot 10^{-5} \text{ eV}$$

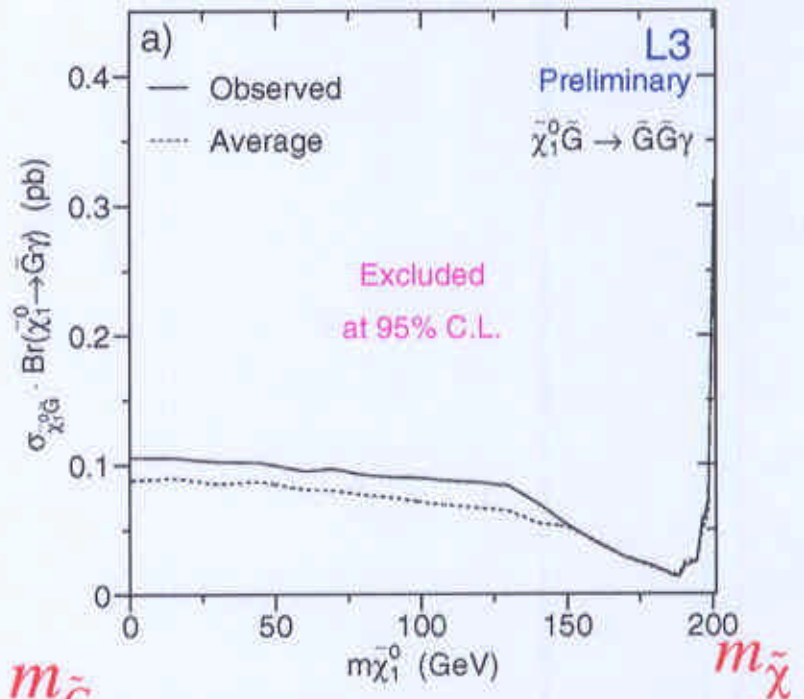
$$\sqrt{F} > 225 \text{ GeV}$$



\tilde{G} LSP + $\tilde{\chi}_1^0$ NLSP

$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \gamma \tilde{G} \tilde{G}$

Cross section limit \rightarrow



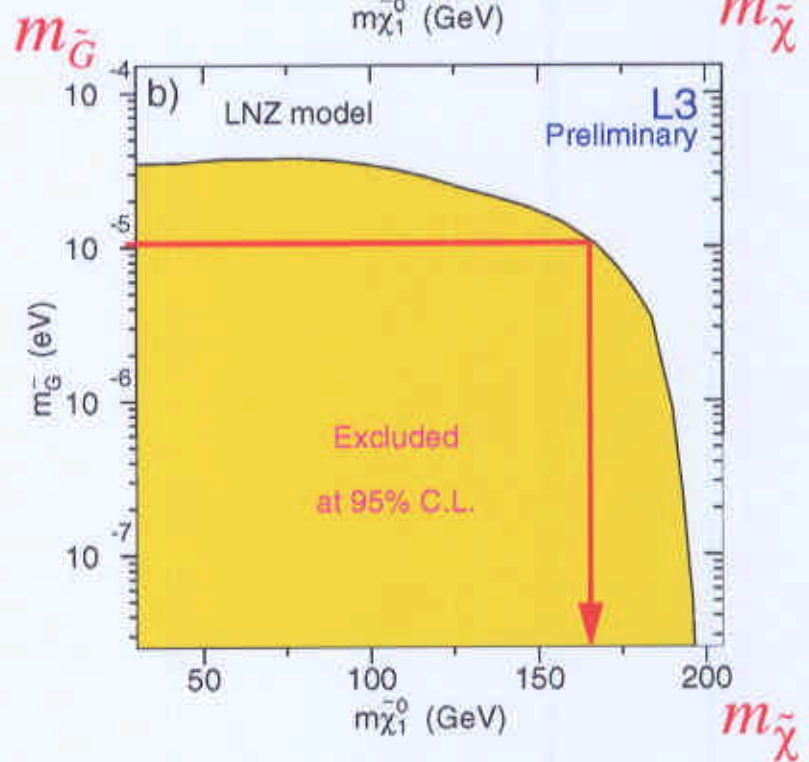
Exclusion plot \rightarrow

LNZ (no-scale SUGRA)

$$m_{\tilde{G}} > 1.0 \cdot 10^{-5} \text{ eV}$$

for

$$m_{\tilde{\chi}} < 168 \text{ GeV}$$



GMSB interpretation

GMSB: \tilde{G} LSP + $\tilde{\chi}_1^0$ NLSP

$$\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

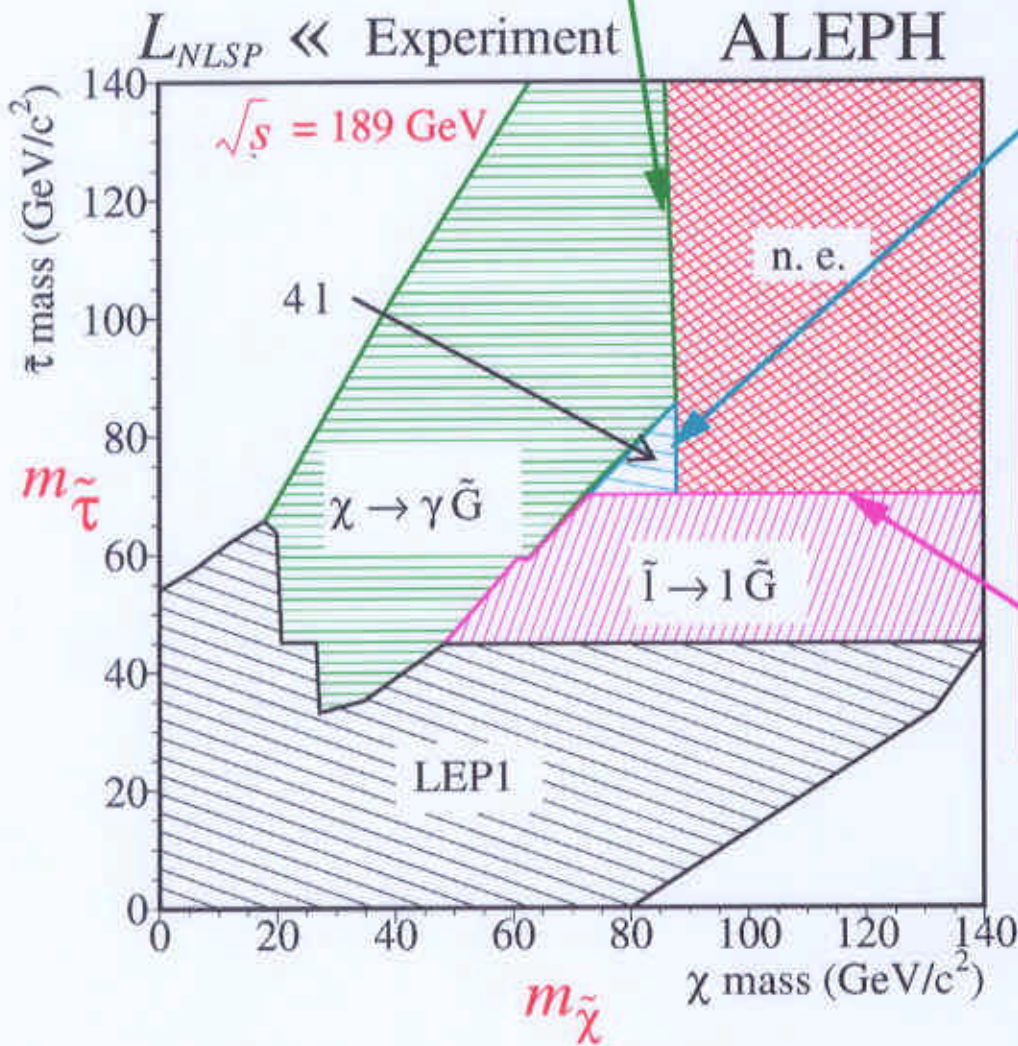
$$2\gamma + \cancel{E}$$

GMSB: \tilde{G} LSP + \tilde{l} NLSP

$$\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow l\tilde{l} + l\tilde{l}$$

$$\begin{array}{l} \downarrow \\ l\tilde{G} \\ \downarrow \\ l\tilde{G} \end{array}$$

$$4l + \cancel{E}$$



MSUGRA:

$\tilde{\chi}_1^0$ LSP + \tilde{l} NLSP

$$\tilde{l}\tilde{l} \rightarrow l\tilde{\chi}_1^0 + l\tilde{\chi}_1^0$$

$$2l + \cancel{E}$$

Summary

Many LEP SUSY searches with the \tilde{G} as the LSP
has been updated with the data collected at

$$\sqrt{s} = 192\text{-}202 \text{ GeV}$$

No signal has been observed in any of
the topologies studied.



New cross section limits and exclusion plots
have been produced.

The transparencies are available at
<http://hedberg.home.cern.ch/hedberg/osaka.ps>