Non "standard" SUSY searches at LEP

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Outline

- R-parity violation

▷ Introduction

▷ Gaugino pair production

▷ Sfermion pair production

▷ Single sparticle production

- GMSB

▷ Introduction

▷ right handed scalar lepton $\tilde{\ell}_R^{\pm}$ NLSP

▷ neutralino $\tilde{\chi}_1^0$ NLSP

▷ Interpretation

Results from the 4 LEP experiments ADLO

mainly from $192 \text{ GeV} \leq \sqrt{s} \leq 202 \text{ GeV}$

some preliminary data from $\sqrt{s} \simeq 205 \text{ GeV}$

Introduction to $\not{R}_P$

$$R_P = (-1)^{3B+L+2S}$$

Standard particles: $R_P = +1$ SUSY particles: R_P = -1

R_P conserved

Stable LSP, SUSY particles are pair produced

R_P violated

- SUSY particles may decay into standard ones
  $\Longrightarrow$ LSP not stable, signatures differ from MSSM ones
  ADLO
- single sparticle production ADLO

Superpotential includes 3 trilinear terms:

$$W_R = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

λ_{ijk}, λ'_{ijk} and λ''_{ijk} Yukawa couplings
i, j, k generation indices
λ_{ijk}, λ'_{ijk} couplings violate the leptonic quantum number
λ''_{ijk} couplings violate the baryonic quantum number
Negligible LSP lifetime

Spontaneous R-parity violation through Higgs mechanism:
$\tilde{\chi}^{\pm} \longrightarrow \tau^{\pm}$ J (massless Majoron) D

Gaugino pair production

Direct decay

	λ	λ'	λ''
$\tilde{\chi}^0$	$\nu\ell\ell$	ℓqq or νqq	qqq
$\tilde{\chi}^\pm$	$\ell\ell\ell$ or $\ell\nu\nu$	ℓqq or νqq	qqq
$\tilde{\chi}^0\tilde{\chi}^0$	$4\ell + \not{E}$	2ℓ+4 jets $(1\ell+)$4 jets$+\not{E}$	6 jets
$\tilde{\chi}^+\tilde{\chi}^-$	2 or $4\ell + \not{E}$ or 6ℓ	id	id

Indirect decay

$\tilde{\chi}^0_j \to \tilde{\chi}^0_1 Z^* \Longrightarrow$ same final states + $2Z^*$ decay products

$\tilde{\chi}^\pm \to \tilde{\chi}^0_1 W^* \Longrightarrow$ same final states + $2W^*$ decay products

Results

No significant excess

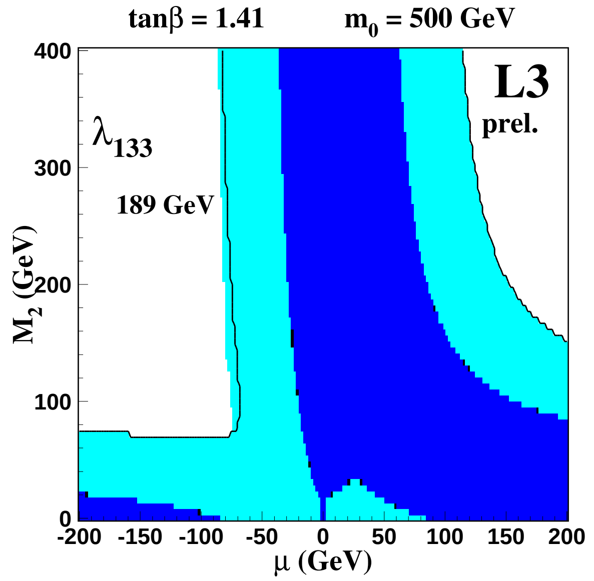
Cross section upper limits

Excluded area in MSSM parameter space

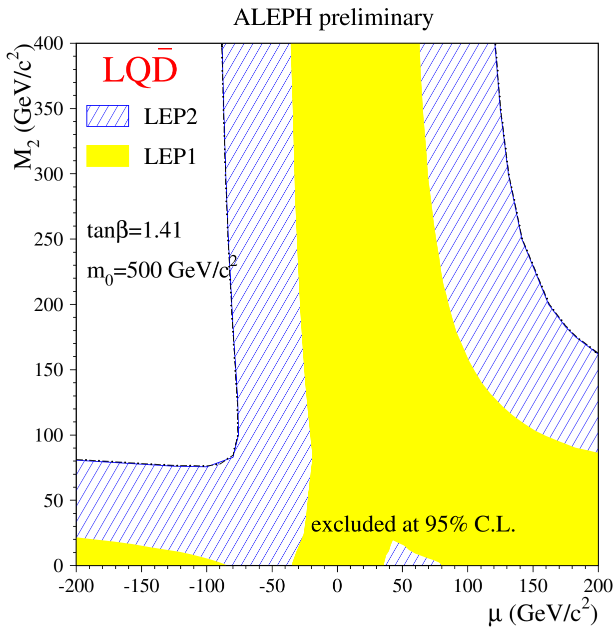
Lower limits on sparticle masses

Gaugino pair production

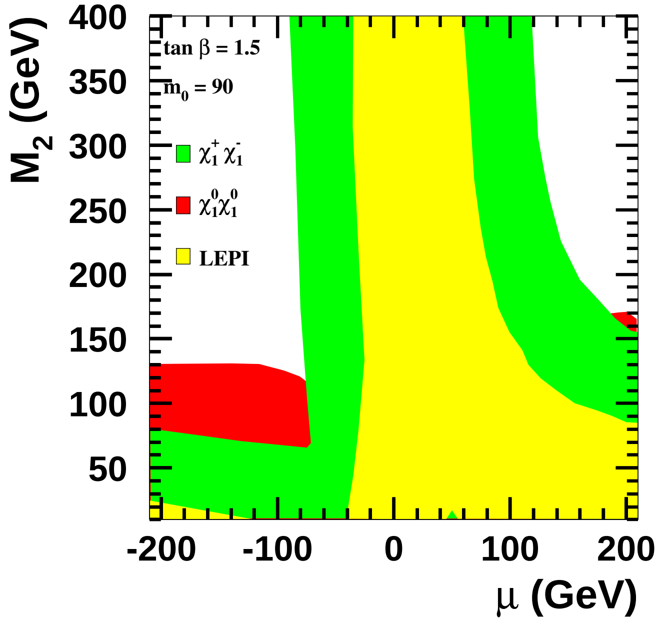
L3 λ



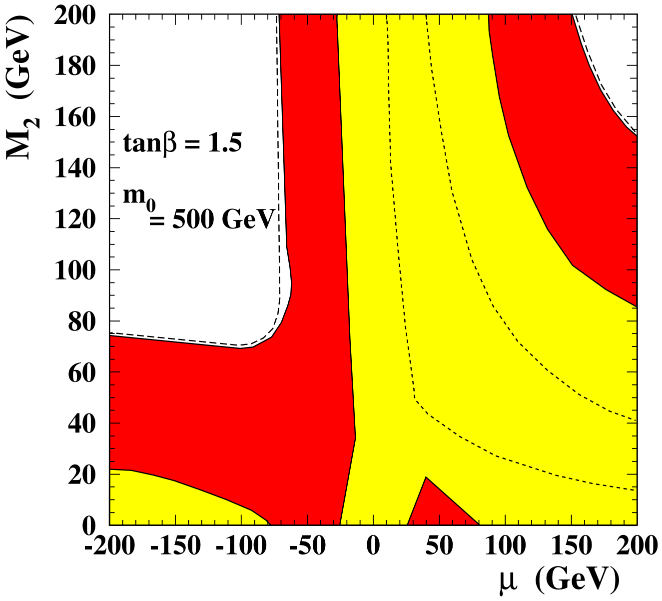
ALEPH λ'



DELPHI λ''



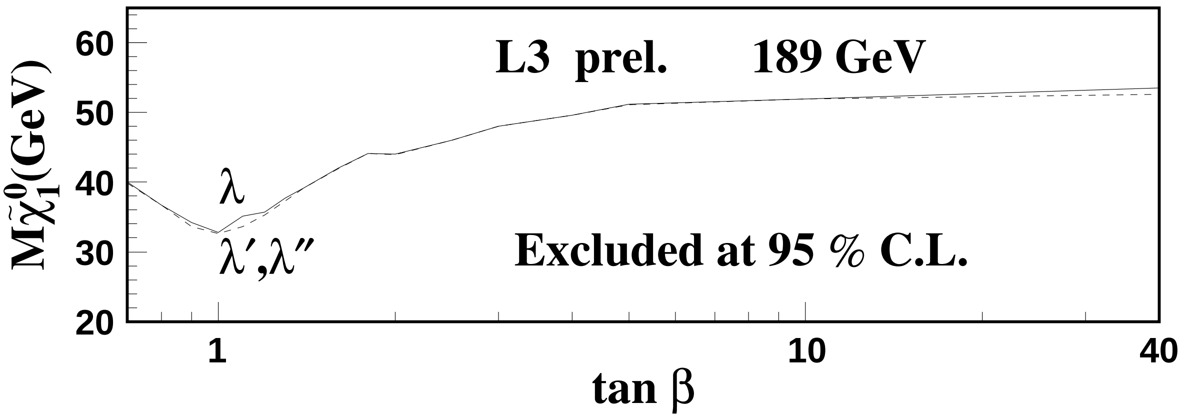
OPAL 189 GeV λ''



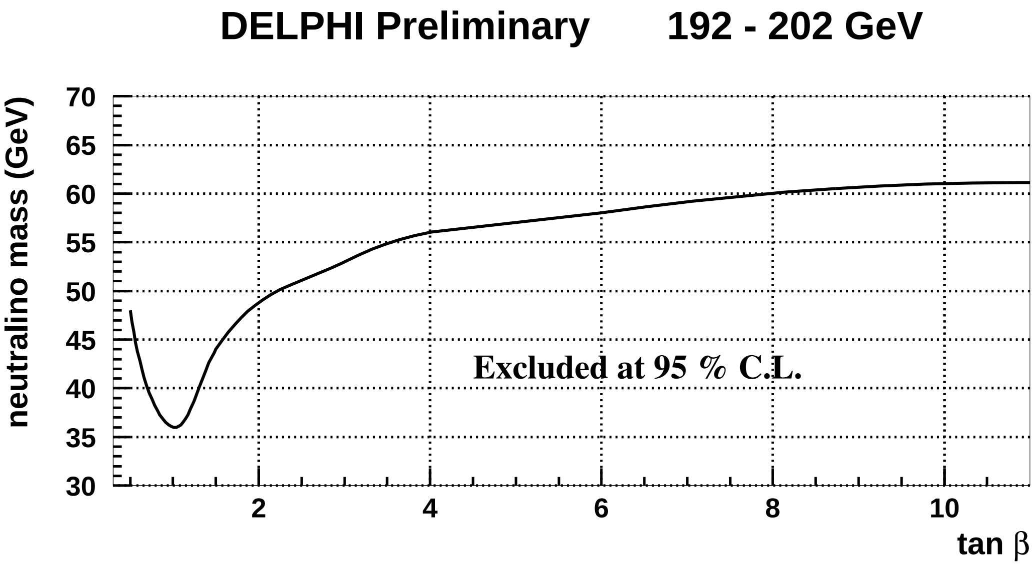
Gaugino pair production

Scan over M_2, μ, $\tan\beta$, m_0 $\Longrightarrow$ limits on masses

189 GeV



λ'



$\tilde{\chi}_1^0$: 36 to 37.5 GeV

$\tilde{\chi}_1^{\pm}$: almost kinematic limit

Sfermion pair production

Direct decay

	λ	λ'	λ''
$\tilde{\nu}$	$\ell\ell$	qq	-
$\tilde{\ell}$	$\nu\ell$	qq	-
$\tilde{q}$	-	νq or ℓq	qq
$\tilde{\nu}\tilde{\nu}$	4ℓ	4 jets	-
$\tilde{\ell}^+\tilde{\ell}^-$	$2\ell+\not{E}$	4 jets	-
$\tilde{q}\tilde{q}$	-	2ℓ +2 jets or 2 jets+$\not{E}$	4 jets

Indirect decay

$\tilde{\nu} \rightarrow \nu\tilde{\chi}^0_1$ $\tilde{\ell} \rightarrow \ell\tilde{\chi}^0_1$ $\tilde{q} \rightarrow q\tilde{\chi}^0_1$

Efficiency depends on $\tilde{f}$ and $\tilde{\chi}^0_1$ masses

Results

No significant excess

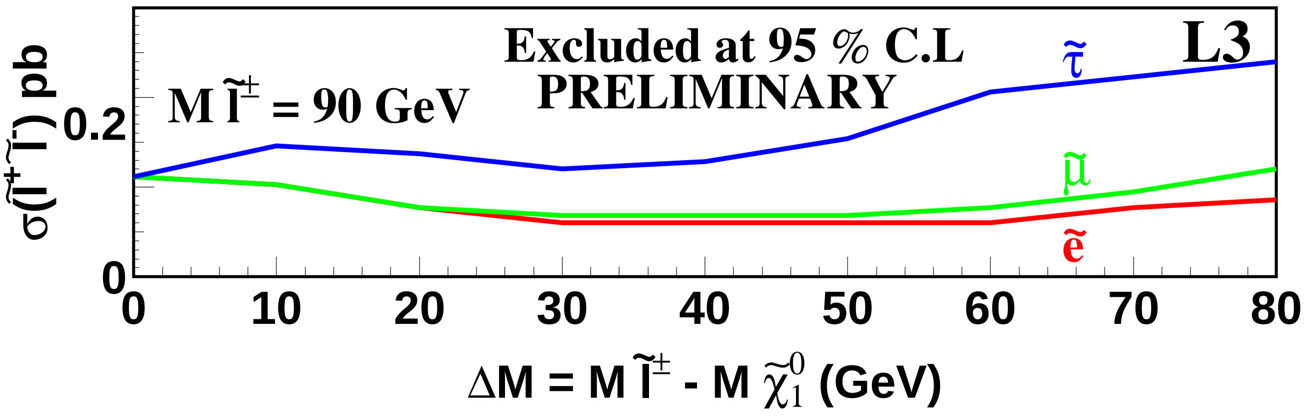
Cross section upper limits as a function of $m_{\tilde{f}}$ (direct)

Excluded area in $m_{\tilde{\chi}^0_1}$ vs $m_{\tilde{f}}$ plane (indirect)

Lower limits on $m_{\tilde{f}}$

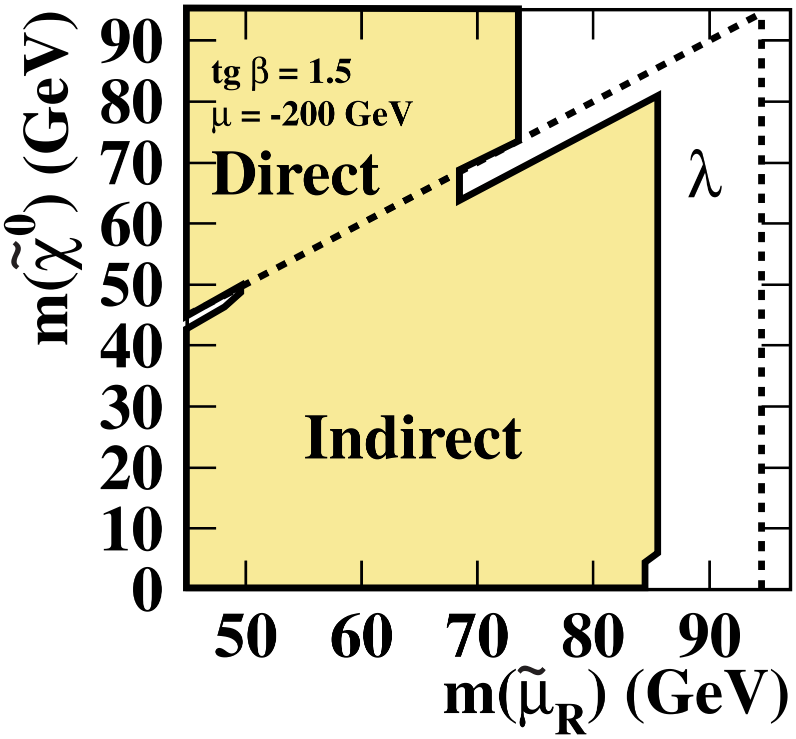
Sfermion pair production

L3 λ'' 192-202 GeV



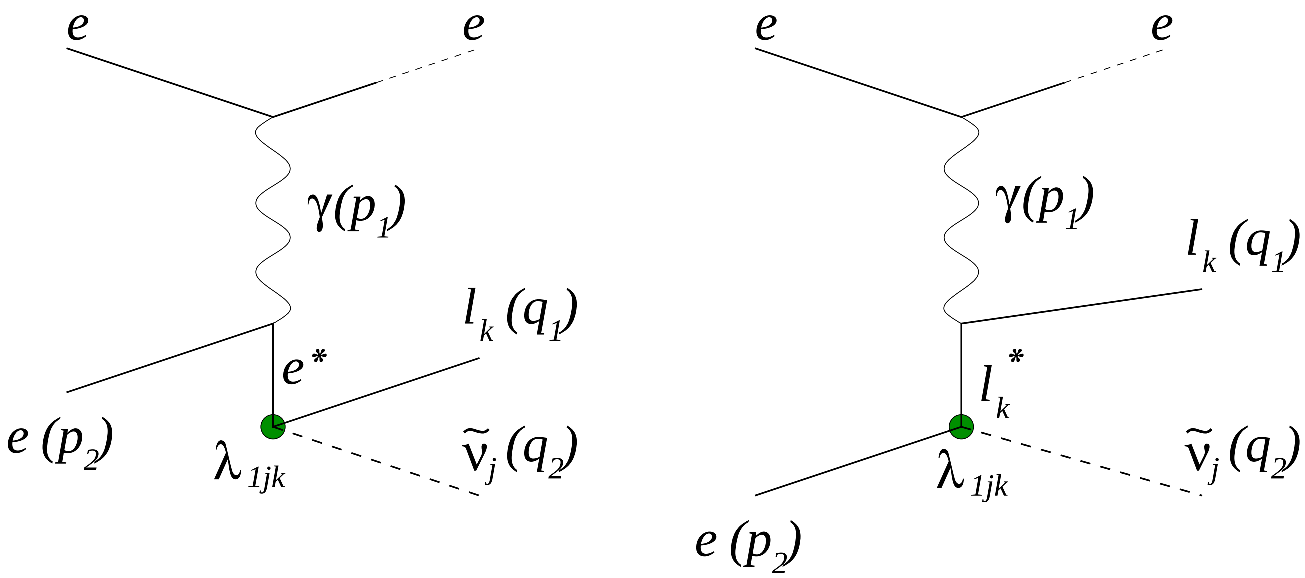
OPAL λ 189 GeV

$e^+e^- \longrightarrow \tilde{\mu}\tilde{\mu}$



Single sparticle production

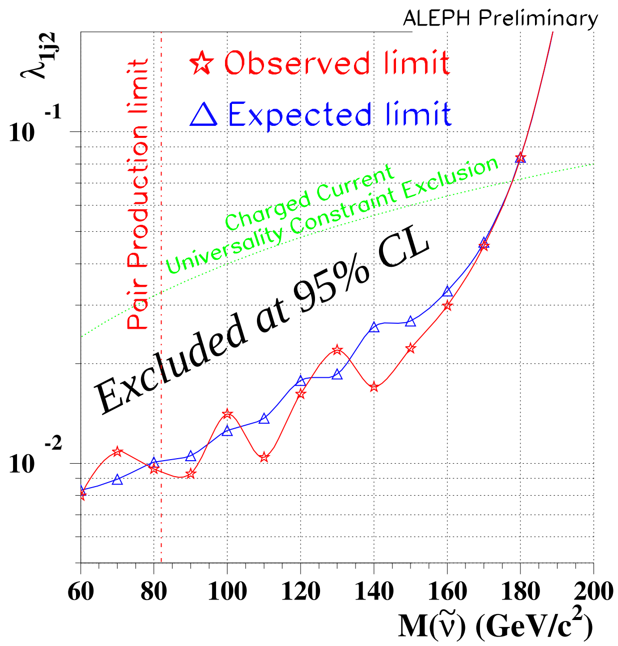
Single sneutrino production: $e\gamma \longrightarrow \tilde{\nu}\ell$ A



Production and decay through λ_{1j2}: $\tilde{\nu} \longrightarrow e\mu$

$\Longrightarrow$ final state: $e\mu^+\mu^-$

Excluded area in $m_{\tilde{\nu}}$ vs λ_{1j2} plane



Single gaugino production:

$e^+e^- \longrightarrow \tilde{\nu} \longrightarrow \nu\tilde{\chi}^0$ or $\ell^{\mp}\tilde{\chi}^{\pm}$ D

GMSB phenomenology

In gravity mediated Susy Breaking (SUGRA):
The gravitino is too heavy to be produced at LEP

Gauge Mediated Susy Breaking (GMSB) models:
breaking scale $\sqrt{\mathbf{F}}$ at much lower energy
gravitino $\tilde{\mathbf{G}}$ Lightest Susy Particle (LSP)

$$\mathbf{m}_{\tilde{\mathbf{G}}} = \frac{\mathbf{F}}{\sqrt{3}\,\mathbf{M_P}} \simeq \mathbf{2.5\ eV} \left(\frac{\sqrt{\mathbf{F}}}{\mathbf{100TeV}} \right)^{2}$$

Next to Lightest Susy Particle (NLSP):

- right handed scalar lepton $\tilde{\ell}^{\pm}_{R}$
- neutralino $\tilde{\chi}^{0}_{1}$

NLSP decay length:

$$D.L. \simeq (17\mu\mathrm{m}) \sqrt{\frac{\mathbf{E}^2_{\mathbf{NLSP}}}{\mathbf{m}^2_{\mathbf{NLSP}}} - 1} \left(\frac{\mathbf{m}_{\tilde{\mathbf{G}}}}{\mathbf{1\ eV}} \right)^{2} \left(\frac{m_{\mathbf{NLSP}}}{\mathbf{100\ GeV}} \right)^{-5}$$

Very different topologies
depending on the NLSP type and decay length

$\tilde{\mathrm{G}}$ LSP $\quad \tilde{\ell}$ NLSP

NLSP decay:

$\tilde{\ell}^{\pm} \longrightarrow \tilde{\mathrm{G}}\ell^{\pm}$

Direct searches:

$\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \tilde{\ell}^{+}\tilde{\ell}^{-} \longrightarrow \tilde{\mathrm{G}}\tilde{\mathrm{G}}\, \ell^{+}\ell^{-}$

D.L. (cm)	Signature	Experiments
	acoplanar lepton pair	ADLO
1		
	large impact parameter or kinks	AD
10^2		
	heavy stable charged particles	ADLO
10^4		
$D.L.(\mathrm{cm})$ ↓		

Indirect searches:

$\tilde{\chi}^0_1 \longrightarrow \tilde{\ell}\ell$

$\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \longrightarrow \tilde{\mathrm{G}}\tilde{\mathrm{G}}\ell^{+}\ell^{-}\ell'^{+}\ell'^{-}$ ADLO

$\tilde{\chi}^{\pm} \longrightarrow \tilde{\ell}\nu_{\ell}$

$\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \tilde{\chi}^{+}\tilde{\chi}^{-} \longrightarrow \tilde{\mathrm{G}}\tilde{\mathrm{G}}\nu_{\ell}\nu_{\ell'}\ell^{+}\ell'^{-}$ AD

$\tilde{\ell} \longrightarrow \ell\tilde{\tau}\tau$

$\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \tilde{\ell}^{+}\tilde{\ell}^{-} \longrightarrow \tilde{\mathrm{G}}\tilde{\mathrm{G}}\tau^{+}\tau^{-}\tau^{+}\tau^{-}\ell^{+}\ell^{-}$ ADLO

$\tilde{\tau}$ NLSP direct search

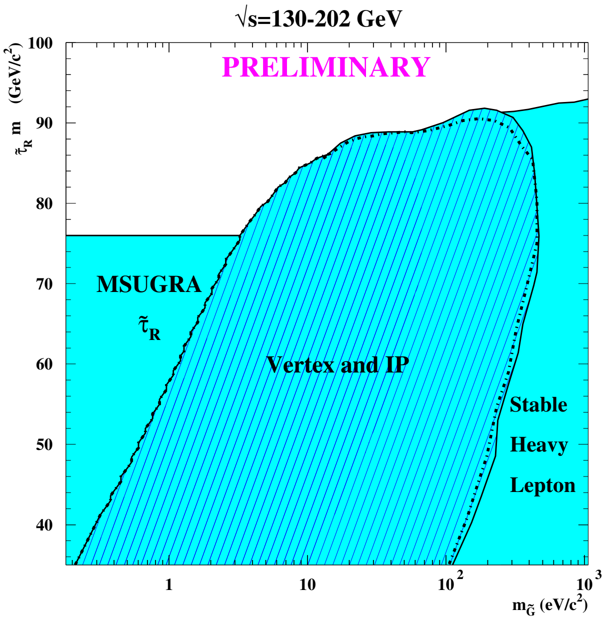
$$e^+e^- \longrightarrow \tilde{\tau}\,\tilde{\tau}$$

$$\tilde{\tau} \rightarrow \tilde{G}\,\tau$$

$$\tilde{\tau} \rightarrow \tilde{G}\,\tau$$

No excess observed

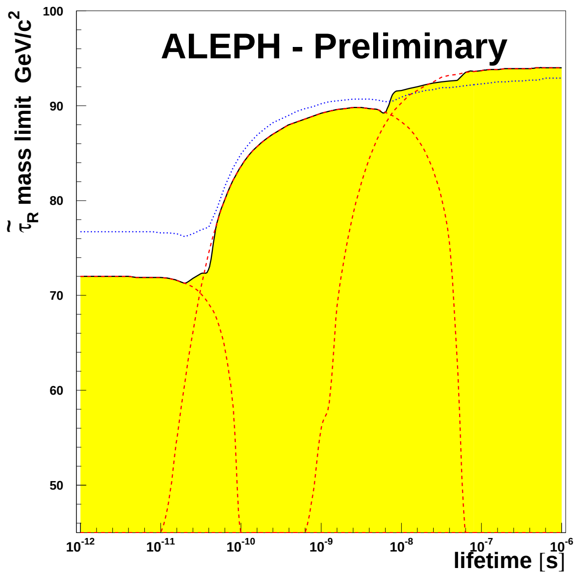
Excluded regions in the plane $m_{\tilde{\tau}}$ vs $m_{\tilde{G}}$ or $\tilde{\tau}$ lifetime



DELPHI

$m_{\tilde{\tau}} > 76$ GeV

for any decay length



ALEPH

$m_{\tilde{\tau}} > 71.3$ GeV

for any decay length

$\tilde{\tau}$ NLSP indirect search

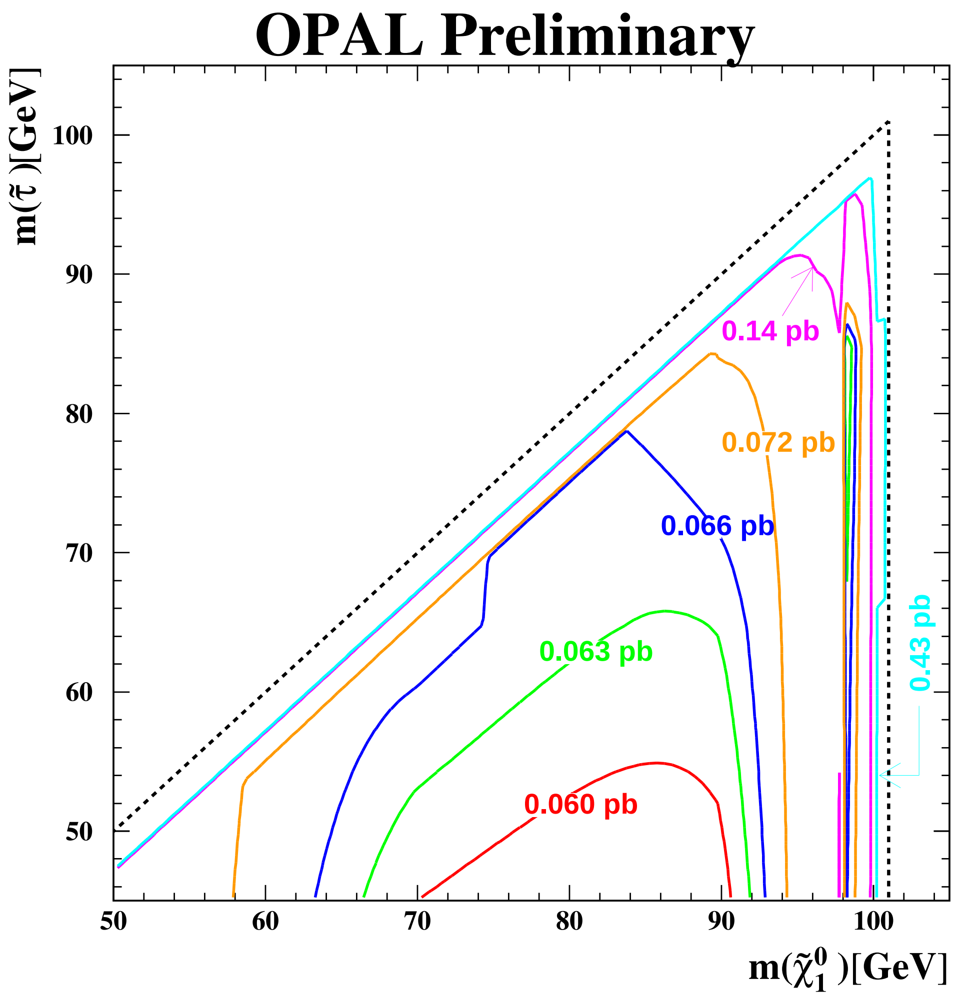
$$e^+e^- \longrightarrow \tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

$$\longrightarrow \tilde{\tau}\,\tau$$

$$\longrightarrow \tilde{\tau}\,\tau$$

NLSP decay: $\tilde{\tau} \longrightarrow \tilde{G}\tau$

final state: $4\ \tau + \not{E}$



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

NLSP decay:

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

Direct searches:

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

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

Indirect searches:

$\tilde{\chi}^\pm \rightarrow \tilde{\chi}^0_1 W^*$

$e^+e^- \rightarrow \tilde{\chi}^+\tilde{\chi}^- \rightarrow \tilde{G}\tilde{G}\gamma\gamma + 2W$ decay products DO

$\tilde{\ell} \rightarrow \ell\tilde{\chi}^0_1$

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

$\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 Z^*$

$e^+e^- \rightarrow \tilde{\chi}^0_2\tilde{\chi}^0_1 \rightarrow \tilde{G}\tilde{G}\gamma\gamma + Z$ decay products O

acoplanar photon pair ADLO

1

non pointing photon AD

10^2

heavy standard chargino

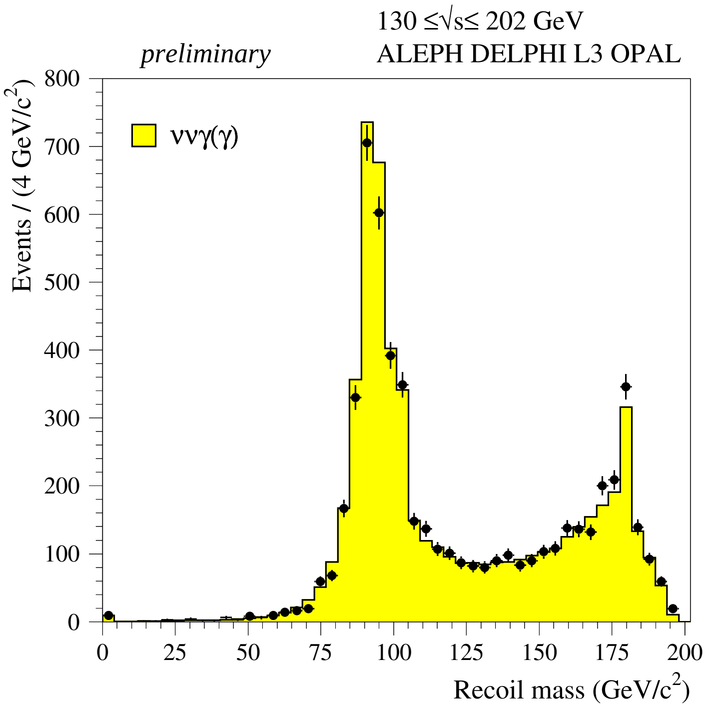
and slepton searches ADLO

10^4

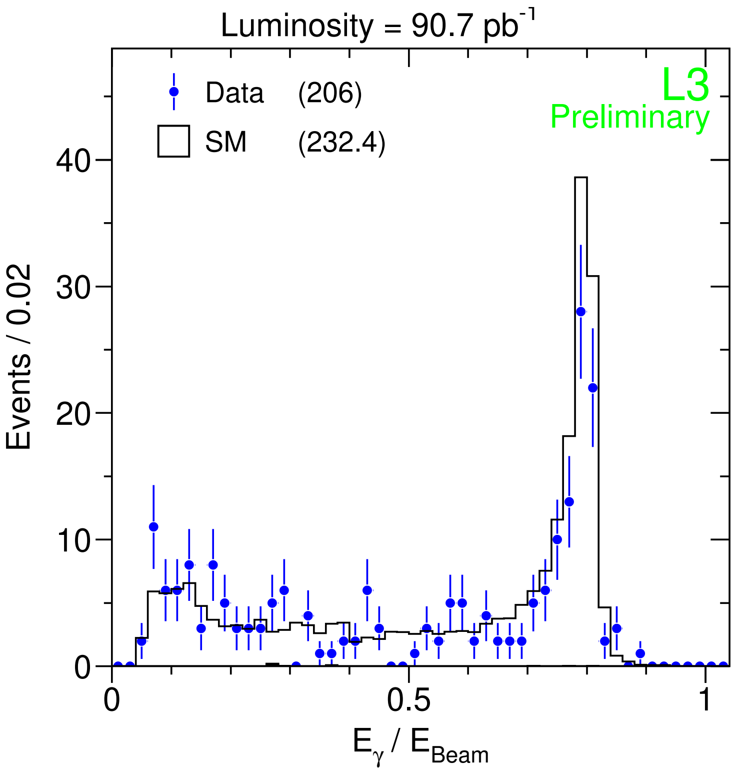
$D.L.$(cm)

$\tilde{\chi}^0_1$ NLSP single photon

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



LEP SUSY
working group

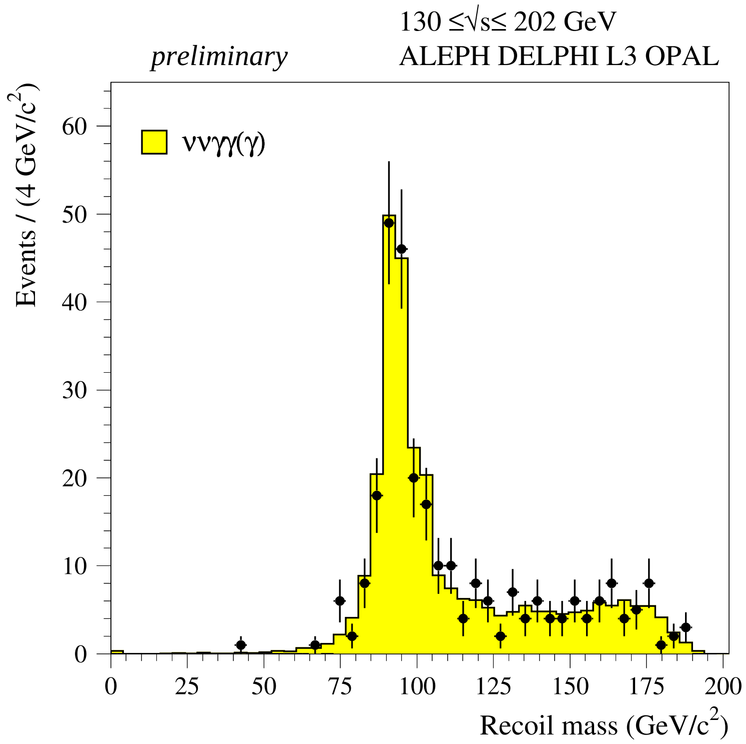


Update
$\sqrt{s} \approx 205$ GeV

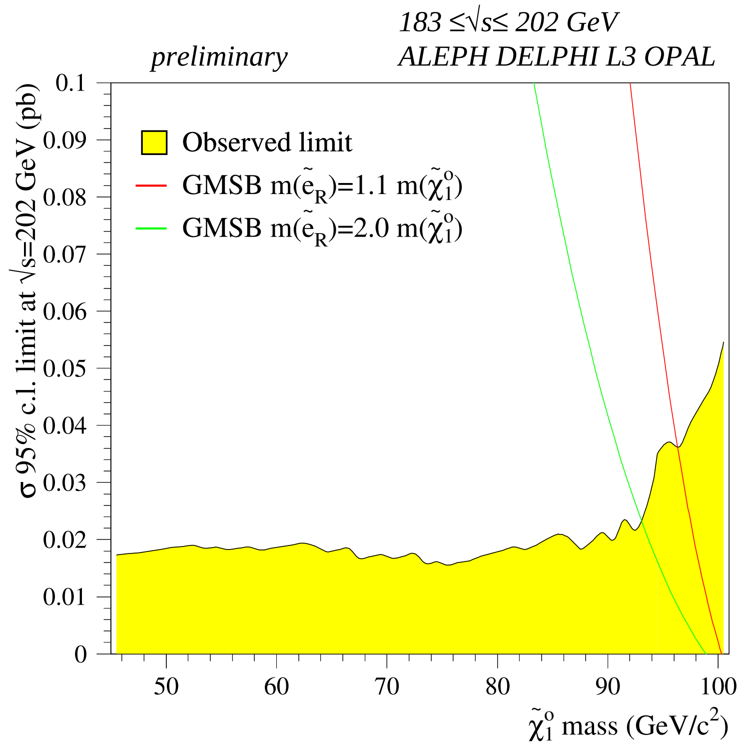
$\tilde{\chi}_1^0$ NLSP acoplanar photon pair

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

LEP SUSY
working group



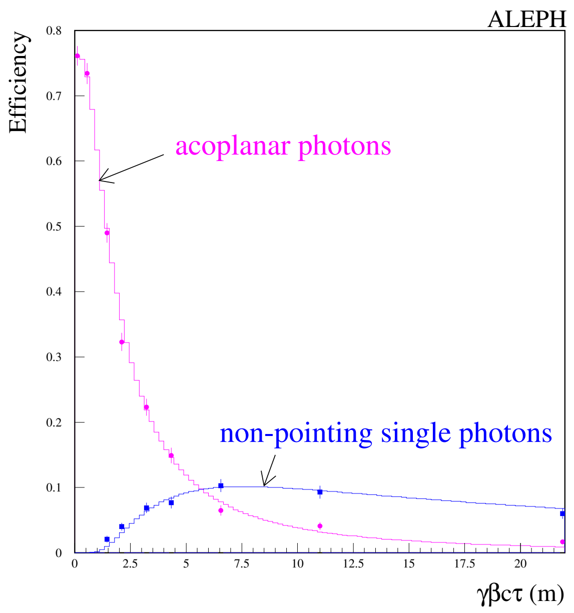
Cross section
upper limit



$\tilde{\chi}^0_1$ NLSP non-zero lifetime

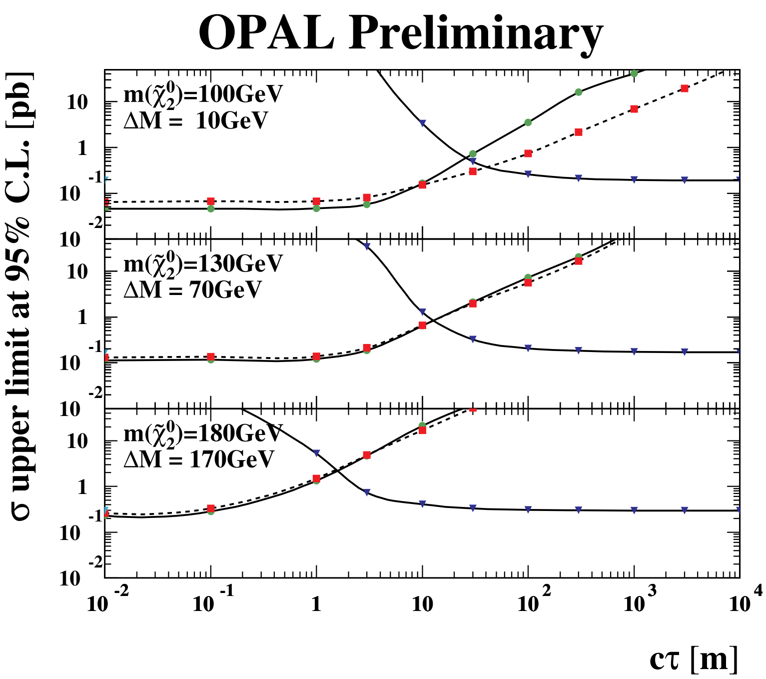
$$e^+e^- \longrightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \longrightarrow \tilde{G}\tilde{G}\gamma\gamma$$

Only 1 photon with a large impact parameter



cascade decay

$$e^+e^- \longrightarrow \tilde{\chi}^0_2\tilde{\chi}^0_1 \qquad \tilde{\chi}^0_2 \longrightarrow \tilde{\chi}^0_1 Z^* \qquad \tilde{\chi}^0_1 \longrightarrow \tilde{G}\gamma$$



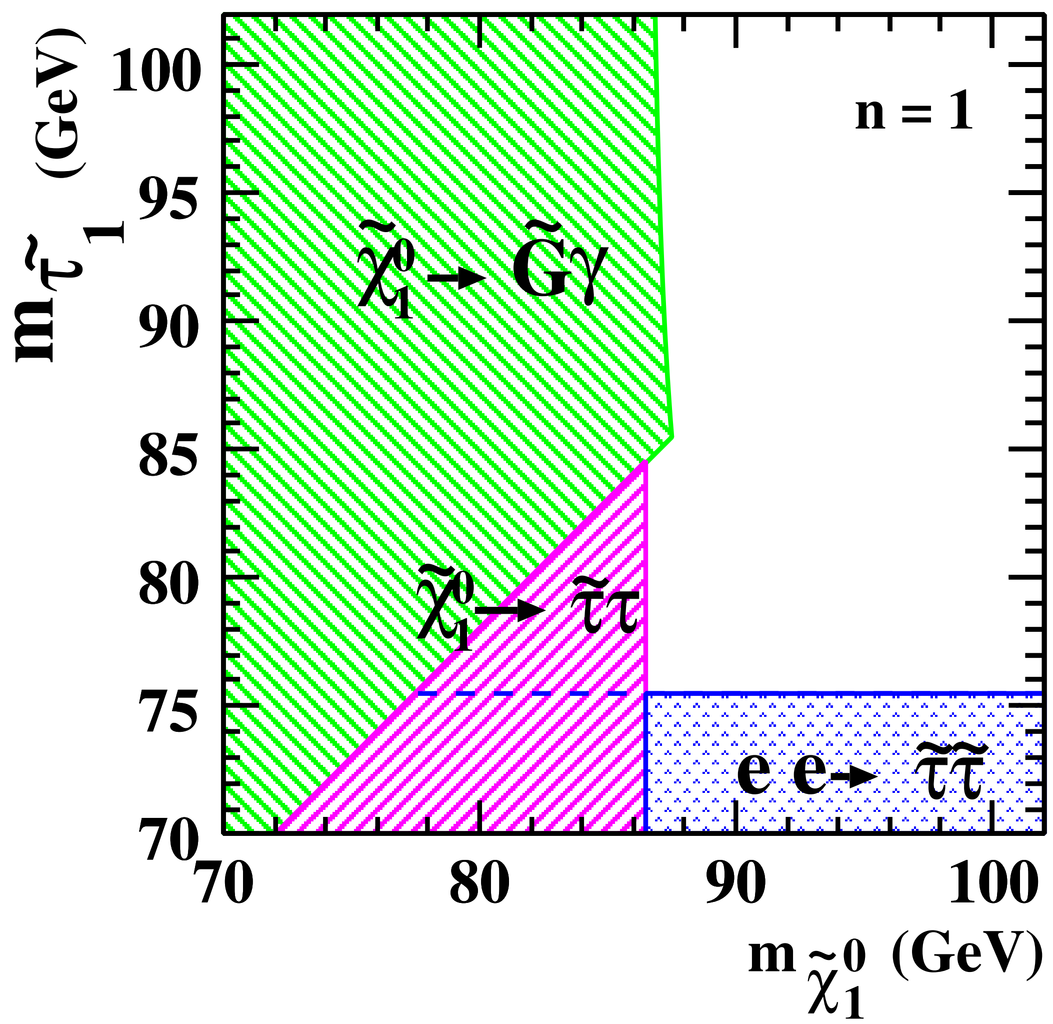
GMSB interpretation

Scan over the parameters of GMSB model

AD

use both $\tilde{\chi}_1^0$ and $\tilde{\tau}$ NLSP

DELPHI $\sqrt{s}$ = 161-202 GeV preliminary



Conclusions

Many searches for events predicted by SUSY

- with R-parity violation
- or GMSB

performed by the 4 LEP experiments

No significant excess found

new limits have been set

$\tilde{\chi}_1^0$ NLSP acoplanar photon pair

CDF event ($q\bar{q} \longrightarrow \tilde{e}\tilde{e} \longrightarrow e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0 \longrightarrow e^+e^-\gamma\gamma\tilde{G}\tilde{G}$)

$\tilde{e}_R$ exchange dominates

$\tilde{\chi}_1^0$ mainly bino

Exclusion region

ADL