SUSY search

with photonic events at LEP

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

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

Generally, the supersymmetry breaking mechanism is supposed to occur at very high energy.
The gravitino is too heavy to be produced at LEP

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

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

Next to Lightest Susy Particle (NLSP):

- right handed scalar lepton $\tilde{\ell}_R^\pm$
- neutralino $\tilde{\chi}_1^0$

Search for $\tilde{\ell}, \tilde{\chi}^\pm, \tilde{\chi}^0$ optimized for $\tilde{\chi}_1^0$ decay

$$BR(\tilde{\chi}_1^0 \to \gamma \tilde{G}) \simeq 100\%$$

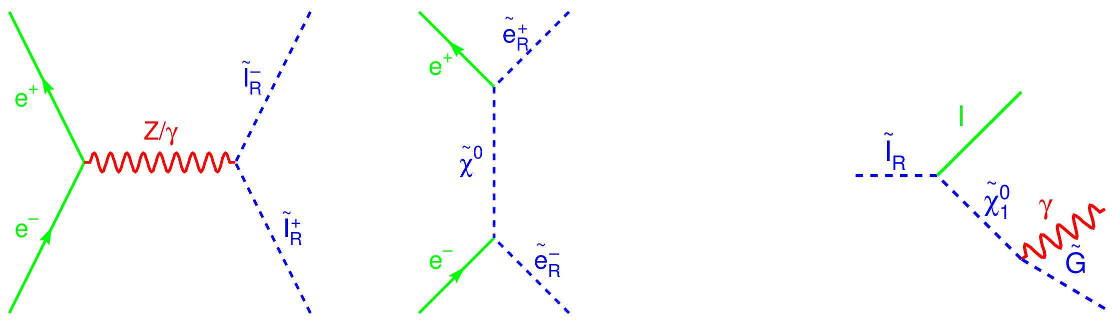
$$D.L. \simeq \ (17\mu\text{m})\ \frac{1}{\kappa} \sqrt{\frac{E^2_{\tilde{\chi}_1^0}}{m^2_{\tilde{\chi}_1^0}}} \left(\frac{m_{\tilde{G}}}{1\ \text{eV}} \right)^2 \left(\frac{m_{\tilde{\chi}_1^0}}{100\ \text{GeV}} \right)^{-5}$$

Unless otherwise stated, $\tilde{\chi}_1^0$ is short lived

slepton A
chargino DO
neutralino ADLO

Main results from $\sqrt{s}$=183 GeV
Preliminary updates at $\sqrt{s}$=189 GeV

slepton search ALEPH



$\sqrt{s}$=161 (11.1 pb^{-1}) 172 (10.6 pb^{-1}) 183 GeV (57.0 pb^{-1})

- **Acoplanar leptons + photons**

e, μ: At least 2 photons and 2 identified leptons
$E_\gamma > 3$ GeV
anti Bhabha cut

τ: At least 2 photons and τ tagging
$E_\gamma > 1$ GeV

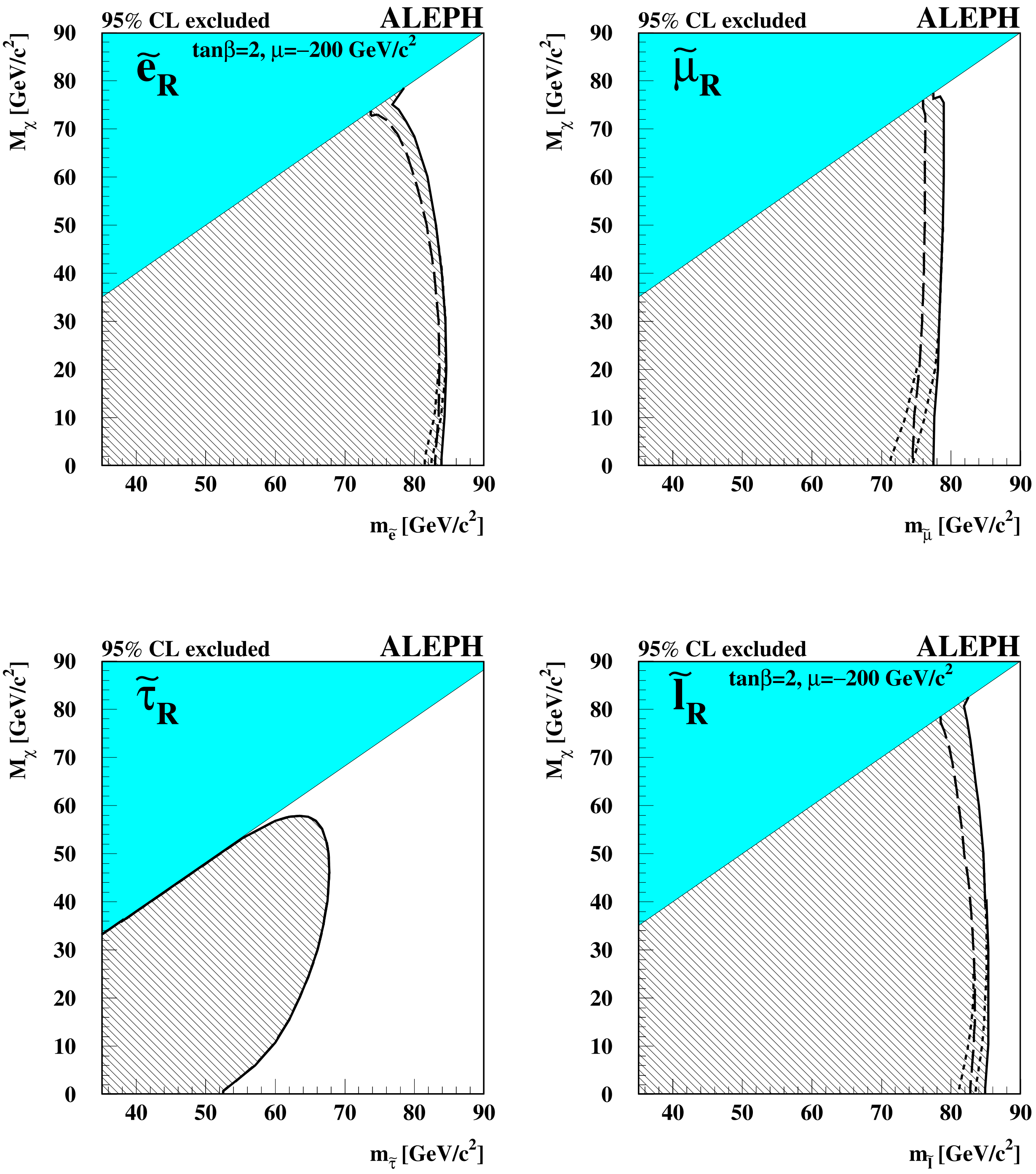
- **Acoplanar photons + X** (when $m_{\tilde{\ell}}$ - $m_{\tilde{\chi}^0_1} < 1$ GeV)
At least 2 photons $E_\gamma > 3$ GeV
Cuts on M_{inv} from tracks and photons

Results:

	ϵ (%)	data	background
$\tilde{e}$	30 - 50	0	0.6
$\tilde{\mu}$	45 - 70	0	0.8
$\tilde{\tau}$	20 - 35	1	1.1
γ + X	15 - 50	3	2.7 ($\nu\bar{\nu}\gamma(\gamma)$)

slepton search ALEPH

Exclusion:



Mass limits in GMSB models with $\tilde{\chi}^0_1$ NLSP and $\tilde{G}$ LSP:

$m_{\tilde{e}_R}$: 77 GeV, $m_{\tilde{\mu}_R}$: 77 GeV, $m_{\tilde{\tau}_R}$: 52 GeV

$m_{\tilde{\ell}_R}$: 82 GeV

chargino search OPAL DELPHI

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

- $\tilde{\chi}_1^- \to \tilde{\chi}_1^0 \, W^{(*)-}$
  - $W^{(*)-} \to q\bar{q}'$ or $\ell^-\bar{\nu}_\ell$
  - $\tilde{\chi}_1^0 \to \gamma \, \tilde{G}$
- $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \, W^{(*)+}$
  - $W^{(*)+} \to q\bar{q}'$ or $\ell^+\nu_\ell$
  - $\tilde{\chi}_1^0 \to \gamma \, \tilde{G}$

$\sqrt{s}$=183 GeV data (OPAL: 56.8, DELPHI: 50.6 pb^{-1})

DELPHI: $\gamma\gamma$ + X (jjℓ, jets, $\ell\ell$)
At least 1 photon: $E_\gamma > 5$ GeV, $15° < \theta_\gamma < 165°$
At least 1 track
Cuts on $\not{p}_t$, E_{vis}, acoplanarity dependent on ΔM

OPAL: 2 different topologies:

- high multiplicity ($N_{tracks} > 4$)
  At least 1 photon with $E_\gamma > 15$ GeV
- low multiplicity ($2 < N_{tracks} \leq 4$)
  At least 1 photon with $E_\gamma > 5\%$ E_{beam}(~ 9 GeV)

Cuts on p_t, E_{vis}, acoplanarity, γ isolation

chargino search OPAL DELPHI

Results:

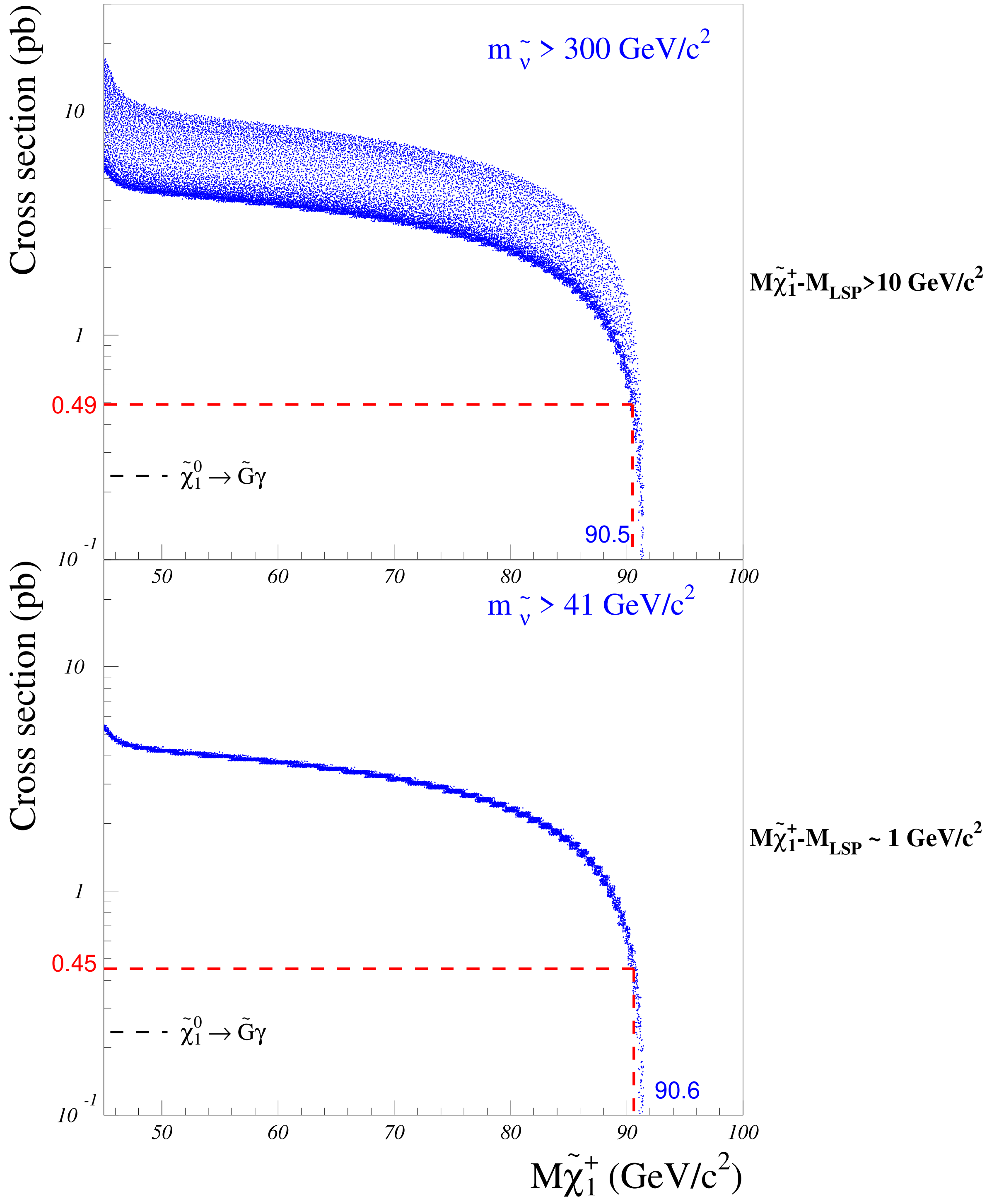
	ϵ (%)	data	backgr.
DELPHI			
ΔM >10 GeV	35 - 45	3	4.9
5< ΔM < 10 GeV	40 - 55	0	0.9
ΔM <5 GeV	40 - 50	1	0.5
total		4	6.3
OPAL			
high mult.	15 - 70	2	2.1
low mult.	40 - 65	4	4.9
total	30 - 50	6	7.0

$\sqrt{s}$=189 GeV update

	data	backgr.
DELPHI 34 pb^{-1}		
ΔM >10 GeV	2	3.0
< ΔM < 10 GeV	0	0.5
ΔM <5 GeV	1	0.5
OPAL 32 pb^{-1}		
high mult.	2	2.2
low mult.	2	2.6

chargino search DELPHI

DELPHI $\tilde{\chi}_1^+\tilde{\chi}_1^-$ limits at 183 GeV

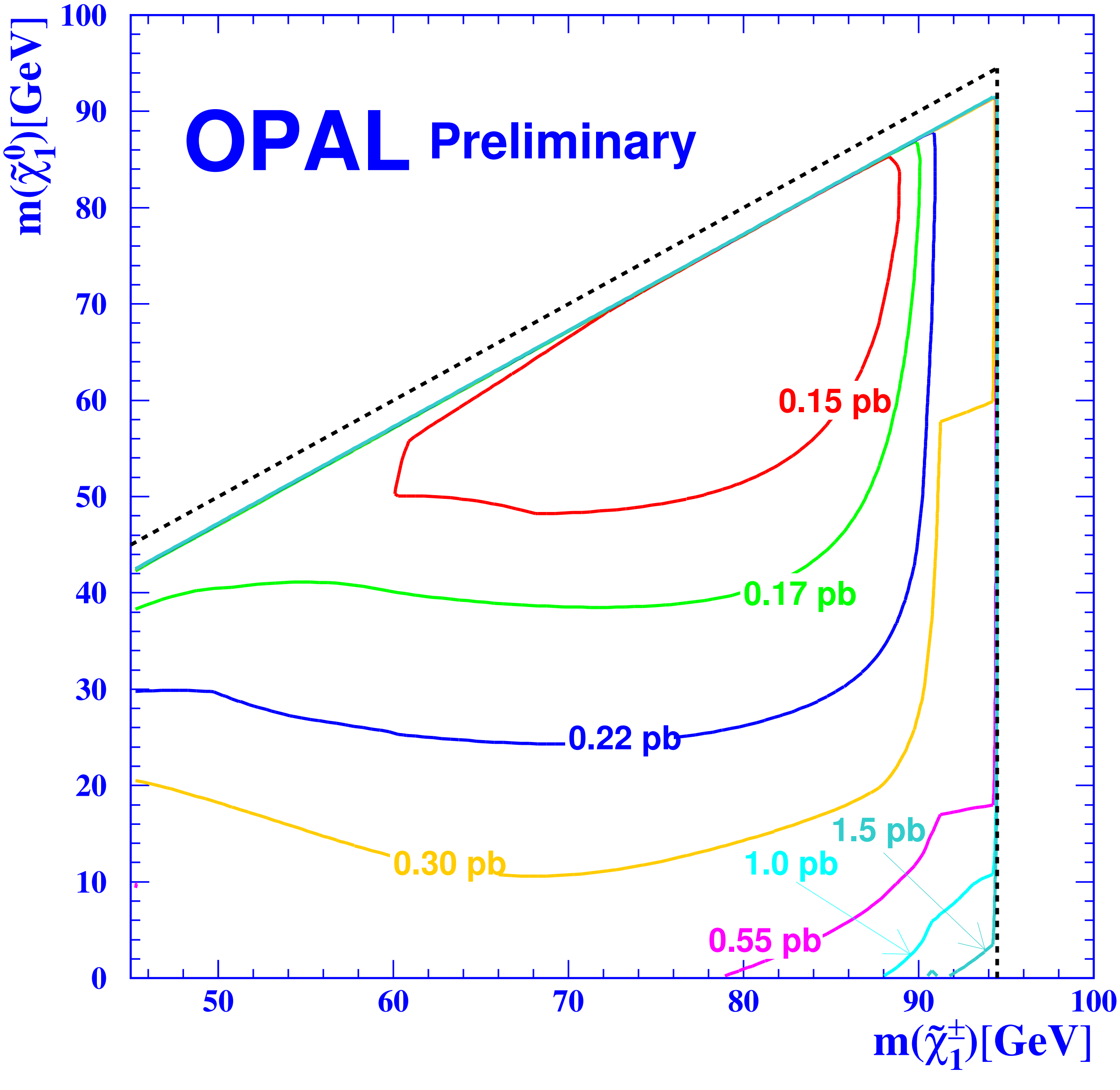


mass limits		prelim.
non-degenerate case	90.5 GeV	93.6 GeV
degenerate case	90.6 GeV	93.7 GeV

chargino search OPAL

Limits:

189 GeV update

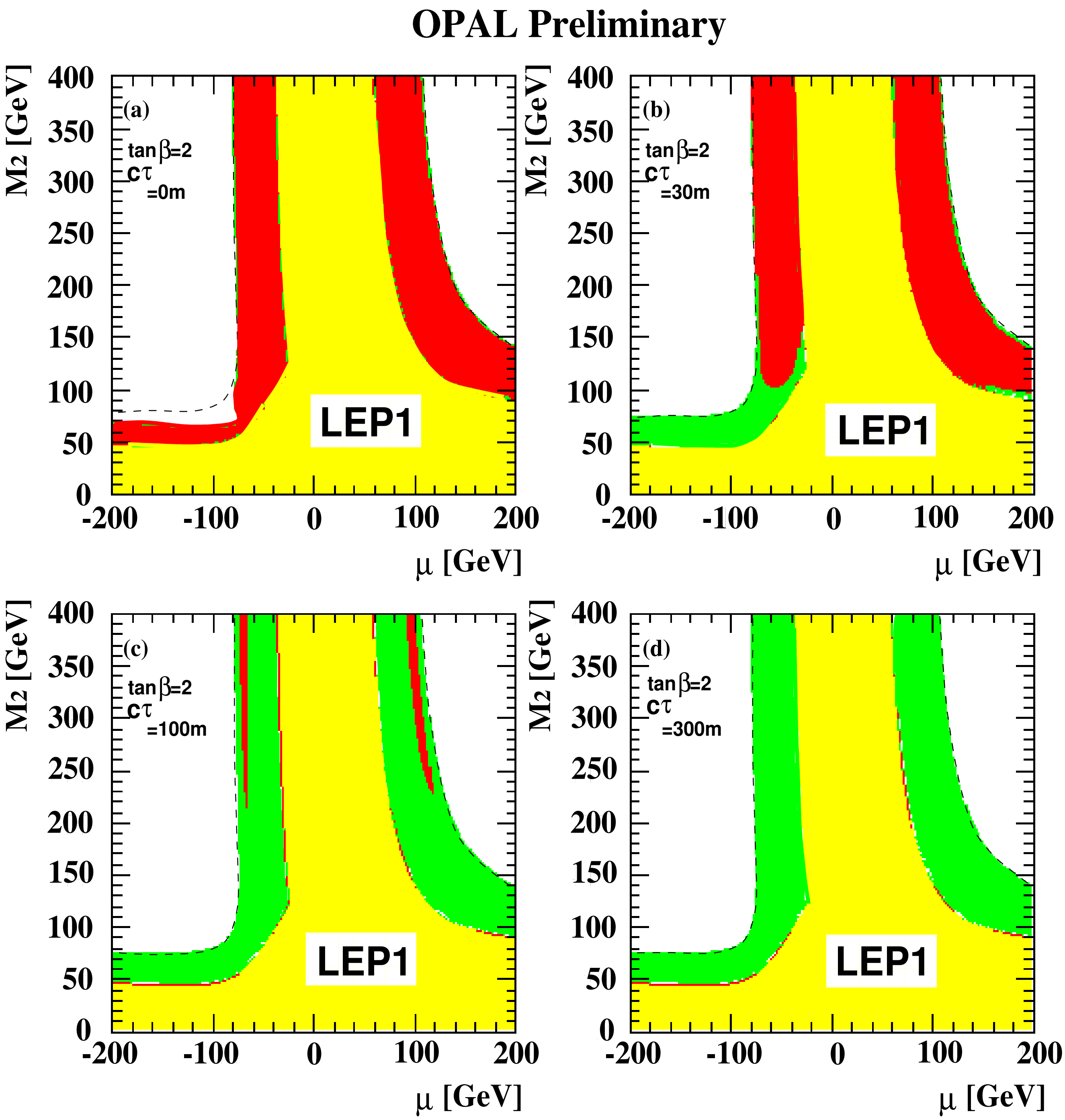


chargino search OPAL

Arbitrary $\tilde{\chi}_1^0$ lifetimes

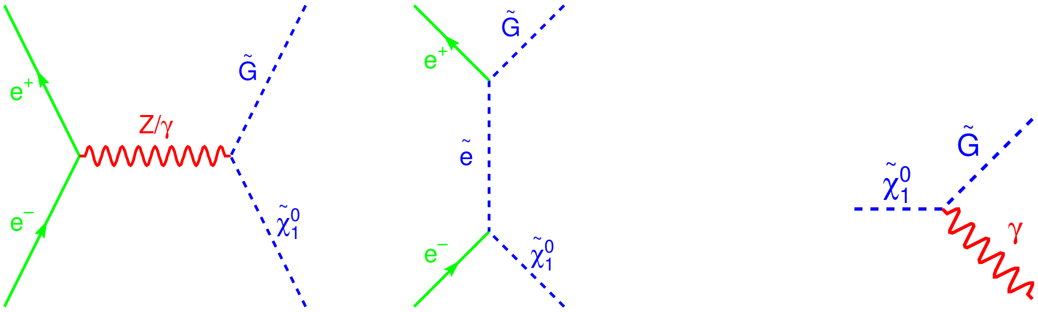
one or both $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ decays can occur outside the detector and escape detection.

Exclusion:

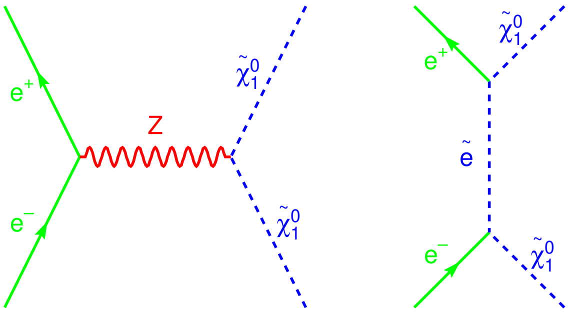


One and two photon final states

GMSB models also predict final states with
1 γ + missing energy:



2 γ + missing energy:



Also in a no-scale supergravity model (LNZ)

- $\sqrt{\mathrm{F}}$ **at high energy (MSSM)**
- $\tilde{\mathrm{G}}$ **LSP (GMSB)**
- $\tilde{\chi}_1^0$ **NLSP and mainly bino**
- $\tilde{\mathrm{G}}$ **mass and 1 parameter ($\mathrm{M}_{\tilde{\chi}_1^0}$)**

All 4 experiments make these searches
Combination by LEP SUSY working group

One photon final states

183 GeV Data:

	ALEPH	DELPHI			L3		OPAL
Luminosity (pb^{-1})	58.5	50.2	44.3	52.0	55.3		54.5
θ_γ range (°)	18 - 162	45 - 135	11 - 30 150 - 169	3.8 - 8 172 - 176.2	43 - 137 14 - 36 144 -166	45 - 135	15 - 165
Energy cuts (GeV)	$p_t > .0375\sqrt{s}$	$E_\gamma > .06\sqrt{s}$	$E_\gamma > .2\sqrt{s}$	$E_\gamma > .6\sqrt{s}$	$E_\gamma > 5$	$10 > E_\gamma > 1.3$ $p_t > 1.3$	$E_\gamma > .05E_{beam}$
Data	195	54	58	28	195	144	191
		140					
MC $\nu\bar{\nu}\gamma(\gamma)$	187	59.5	48.1	24.7	203.2	28.2	201.3
		132.3					
MC $e^+e^-\gamma$	0	0	3.1	2.2	1.2	107.4	0
		5.3					

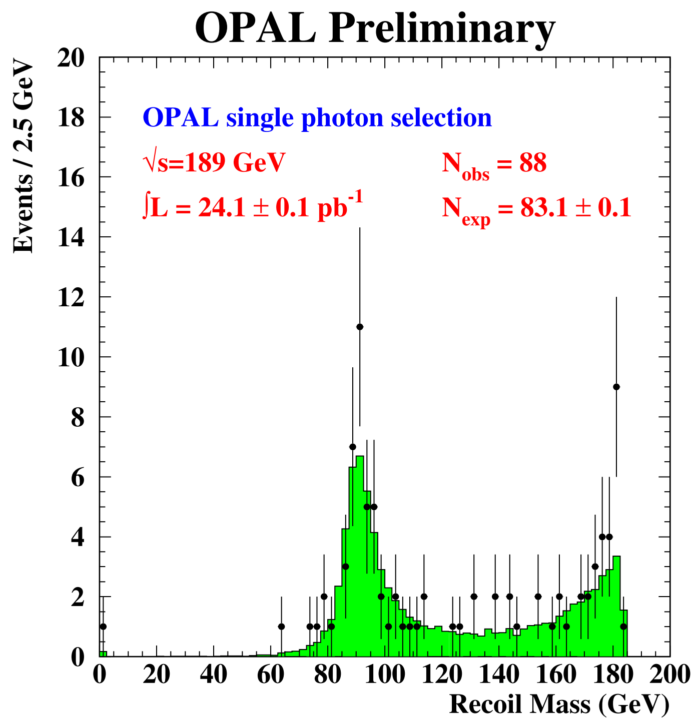
Other backgrounds ($\gamma\gamma(\gamma)$, $\mu\mu\gamma$, $\ell\ell\nu\bar{\nu}\gamma$) negligible

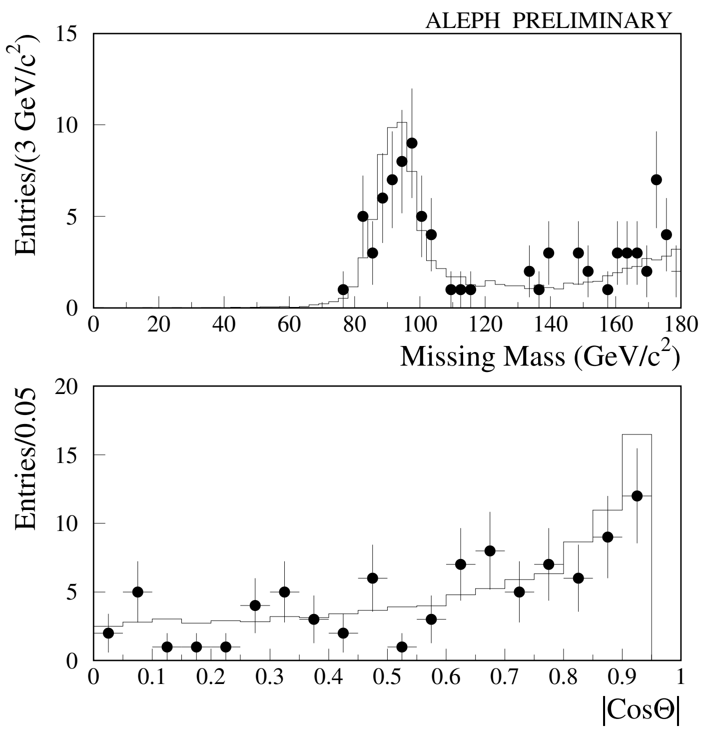
Estimation of the cosmics contamination

One photon final states

Results:

189 GeV update

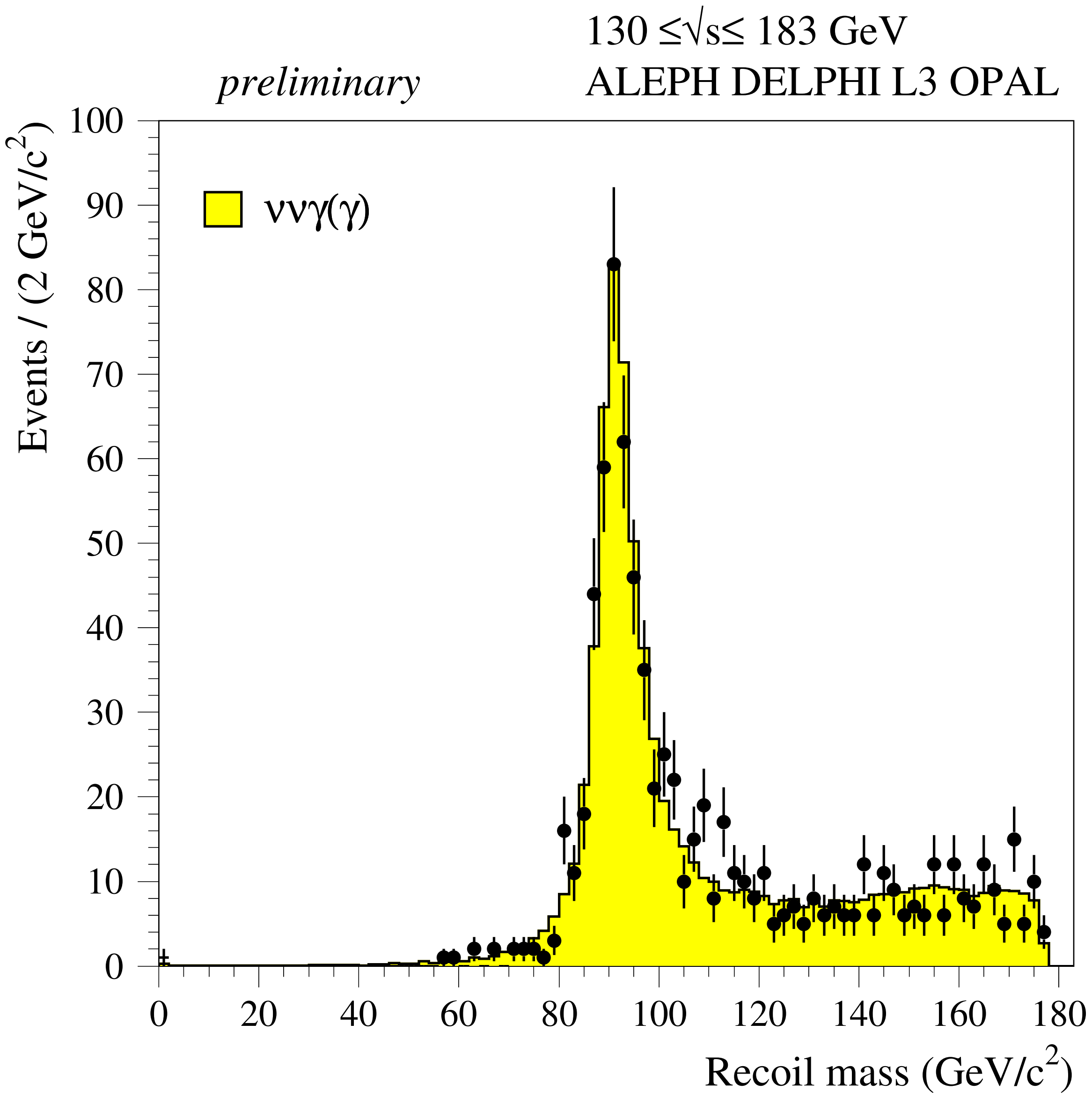




One photon final states

Results:

LEP SUSY working group



One photon final states

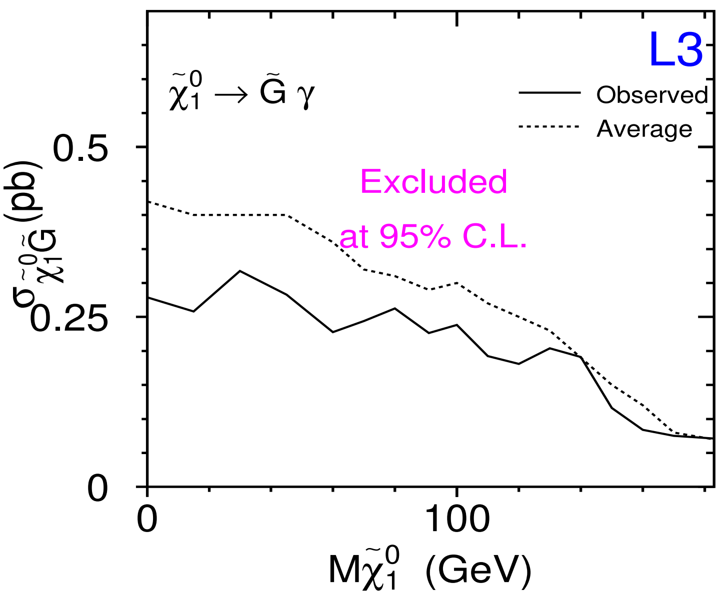
Limits:

Additional cut:

E_γ consistent with kinematics from $\tilde{\chi}^0_1$ mass

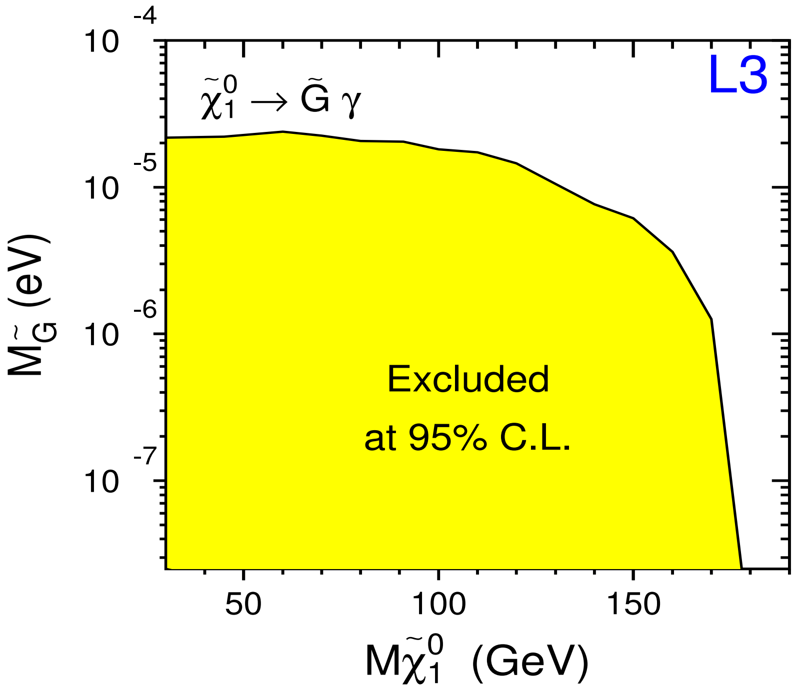
$e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{G} \rightarrow \gamma\tilde{G}\tilde{G}$ cross section limit

DLO



Exclusion region (LNZ)

L



One photon final states

Superlight gravitino:

Process: $e^+e^- \to \tilde{G}\tilde{G}\gamma$
All other SUSY particles too heavy to be produced
Specific model (BFZ):

$$\sigma = \frac{\alpha\ s^3}{320\pi^2|F|^4}\ \mathrm{I}(E_{\gamma,\mathrm{min}}, |\cos\theta_\gamma|_{\mathrm{max}})$$

Integral I dependent on the photon characteristics

Cross section dominated by ISR
Irreducible SM background: $e^+e^- \to \nu\bar{\nu}\gamma$

$$m_{\tilde{G}} > 3.8\ 10^{-6}\mathrm{eV} \left[\frac{\sqrt{s}(\mathrm{GeV})}{200}\right]^{\frac{3}{2}} \left[\frac{\mathrm{I}}{\sigma_{\mathrm{exp}}(\mathrm{pb})}\right]^{\frac{1}{4}}$$

Mass limits ADL

	$m_{\tilde{G}}$ (eV)
ALEPH	$8.3\ 10^{-6}$
DELPHI	$6.6\ 10^{-6}$
L3	$8.0\ 10^{-6}$

Two photon final states

Data:

ALO:183 GeV **D:130-183 GeV data (84.3 pb^{-1})**

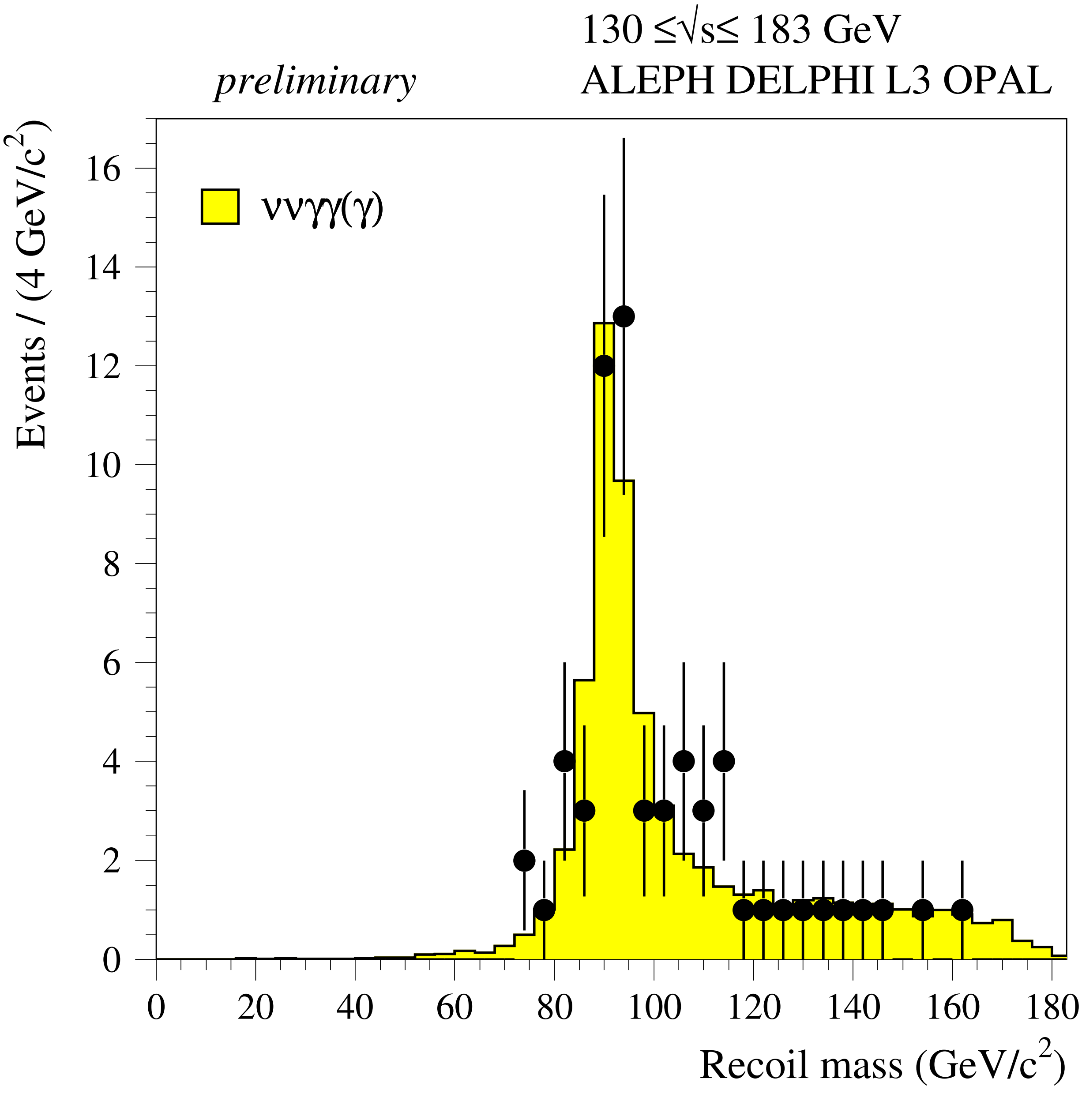
	ALEPH	DELPHI	L3	OPAL
$\theta_\gamma$range ($^\circ$)	18 - 162	γ_1 : 10 - 170 γ_2 : 25 - 155	43 - 137 14 - 36 144 -166	15 - 165
Energy cuts (GeV)	$E_\gamma > 1$	$E_\gamma > .05E_{beam}$	$E_\gamma > 1$	$E_\gamma > .05E_{beam}$ $E_\gamma > 1.5$ if $\lvert\cos\theta\rvert < 0.8$
Acopl. ($^\circ$)	3.	3.	2.4	2.5
Data	9	10	14	9
MC ($\nu\bar{\nu}\gamma\gamma$)	10.8	10.2	13.3	8.2

KORALZ used for $\nu\bar{\nu}\gamma\gamma$ MC
Other backgrounds negligible

Two photon final states

Results:

LEP SUSY working group



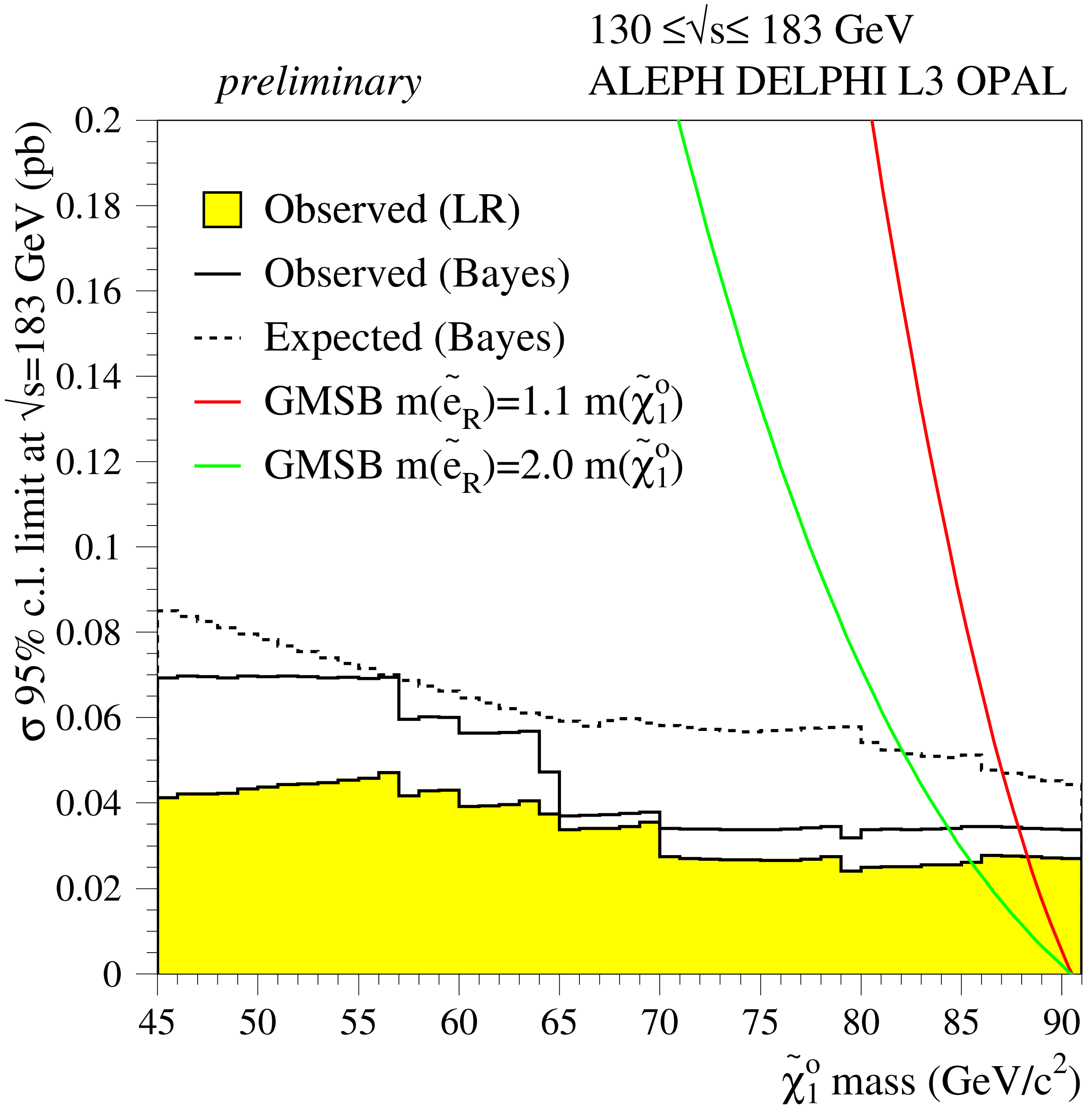
Two photon final states

Limits:

Additional cuts to improve S/B

$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \gamma\gamma\tilde{G}\tilde{G})$ **Upper Limit** **ADLO**

LEP SUSY working group



Two photon final states

Exclusion:

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

Exclusion region **ADL**

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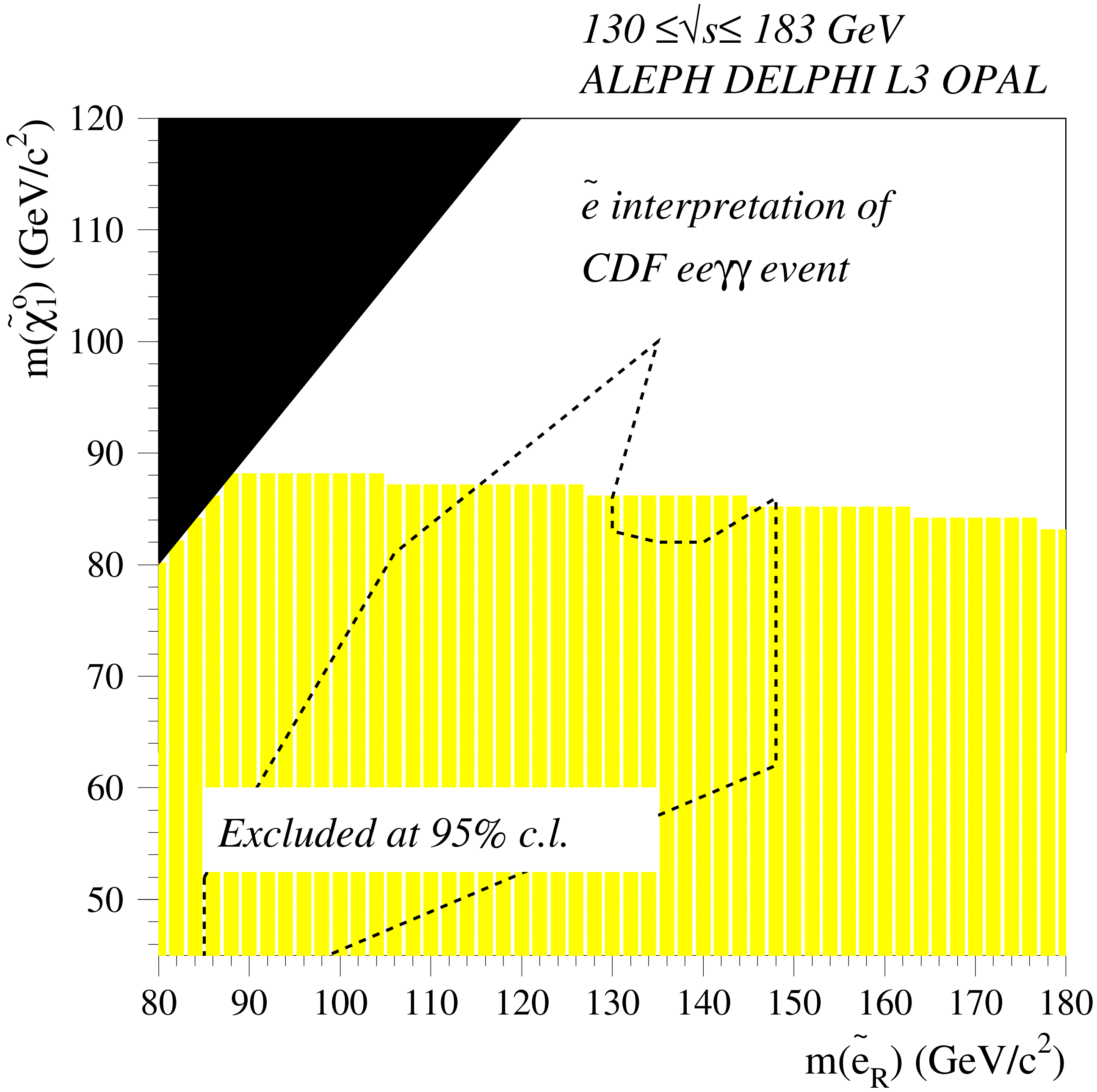

Concluding remarks

- **No evidence for production of events compatible with Supersymmetric models predicting a $\tilde{G}$ as LSP and $\tilde{\chi}_1^0$ as NLSP has been reported by any of the four LEP experiments.**

- **CDF event interpretation in $\tilde{e}\ \tilde{e}$ almost ruled out.**

- **LEP energy now reaches 189 GeV.
Integrated luminosity will be $\sim$ 3 times the one accumulated in 1997.**

- **Still higher energy and luminosity in the 2 coming years.**