"SUSY Searches at LEP"

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1 - The four LEP experiments

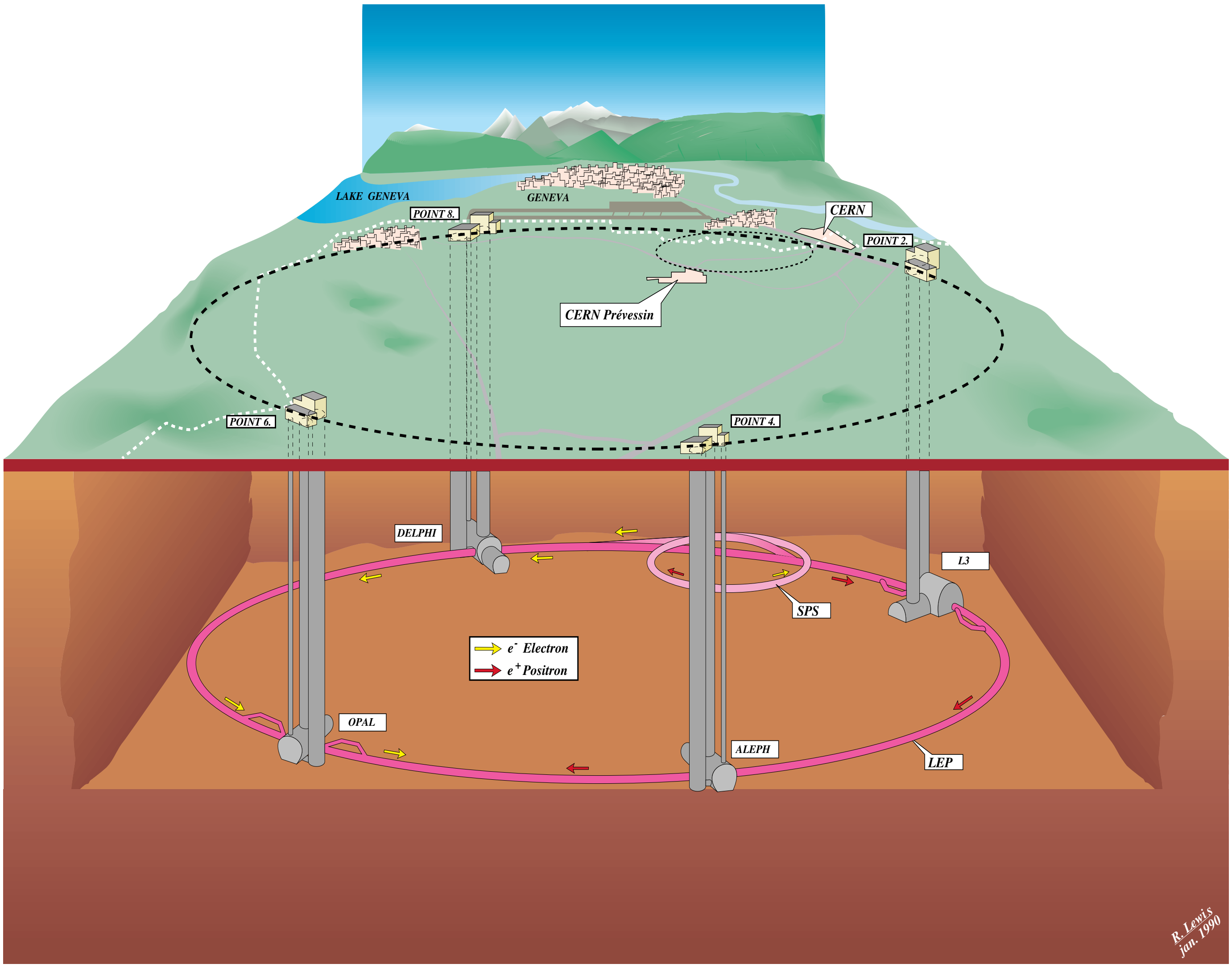
2 - Beyond the Standard Model : Motivations for Supersymmetry

3 - M.S.S.M. / C.M.S.S.M.

4 - R-parity violation

5 - G.M.S.B.

6 - Summary and concluding remarks



LEP is a 27 km e^+e^- collider

There are 4 experiments : ALEPH, DELPHI, L3 and OPAL

Some Results are PRELIMINARY

Problems in the Standard Model

- **Hierarchy problem : the radiative corrections to the Higgs mass are proportional to the cut-off value $\Lambda^2_{NP} = M_{Planck}$ and can be very large**
- **The 19 parameters of the Standard Model can only be derived by experiment**
- **The Gravity cannot be easily included in the Standard Model**

An extension of the S.M. : Supersymmetry

- **SUSY solves the hierarchy problem**
- **The spectrum of particles is doubled wrt the S.M.**
- **New particles are in principle accessible to actual and/or next colliders**
- **Now, the Gravity can be included in the theory**

The Minimal SuperSymmetric Model

Particles introduced by the two-Higgs doublet S.M.		Partners introduced by the Minimal SUSY Model			
$\mathrm{R_p}$ = + **1**		$\mathrm{R_p}$ = **- 1**			
	Mass eigenstates	Fields		Mass eigenstates	
Fermions	$l = e\ \mu\ \tau$ $\nu_l = \nu_e\ \nu_\mu\ \nu_\tau$ $q = u\ d\ c\ s\ t\ b$	**Sleptons** **Sneutrino** **Squarks**	$\tilde{l}_L\ \tilde{l}_R$ $\tilde{\nu}_l$ $\tilde{q}_L\ \tilde{q}_R$	**Sleptons** **Sneutrino** **Squarks**	$\tilde{l}_1\ \tilde{l}_2$ $\tilde{\nu}_l$ $\tilde{q}_1\ \tilde{q}_2$
Charged Bosons	$W^\pm$ $H^\pm$	**Wino** **Higgsino** **Higgsino**	$\tilde{W}^\pm$ $\tilde{H}_1^+$ $\tilde{H}_2^-$	**Charginos**	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_2^\pm$
Neutrals Bosons	γ Z^0 H^0 A^0 h^0	**Photino** **Zino** **Higgsino** **Higgsino**	$\tilde{\gamma}$ $\tilde{Z}^0$ $\tilde{H}_1^0$ $\tilde{H}_2^0$	**Neutralinos**	$\tilde{\chi}_1^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_4^0$
Gluons	$(g_i)_{i=1,\dots,8}$	**Gluinos**	$(\tilde{g}_i)_{i=1,\dots,8}$	**Gluinos**	$(\tilde{g}_i)_{i=1,\dots,8}$

MSSM parameters

Gaugino masses	M_1 M_2 M_3
Higgs mass parameter	μ
v_2/v_1	$\tan\beta$
Mass of CP-odd Higgs A	m_A
Masses of sleptons and squarks	$m_{\tilde{\mathrm{l}}}$, $m_{\tilde{\mathrm{q}}}$
Trilinear coulings	$A_{\tilde{\mathrm{l}}}$, $A_{\tilde{\mathrm{q}}}$

Constrained MSSM

At the GUT scale, one assumes:

Unification of the gaugino masses	$m_{1/2}$
Unification of the scalar masses (except Higgs)	m_0
Unification of the trilinear couplings	A_0

Remaining free parameters :

$$\boxed{m_{1/2},\ m_0,\ \tan\beta,\ \mu,\ A_0,\ m_A}$$

mSUGRA

Unification of all the scalar masses $\Longrightarrow$ m_A not free

Dynamic EWSB $\Longrightarrow$ $|\mu|$ is fixed

Remaining free parameters :

$$\boxed{\tan\beta,\ m_0,\ m_{1/2},\ A_0,\ \mathrm{sign}(\mu)}$$

Standard SUSY Searches

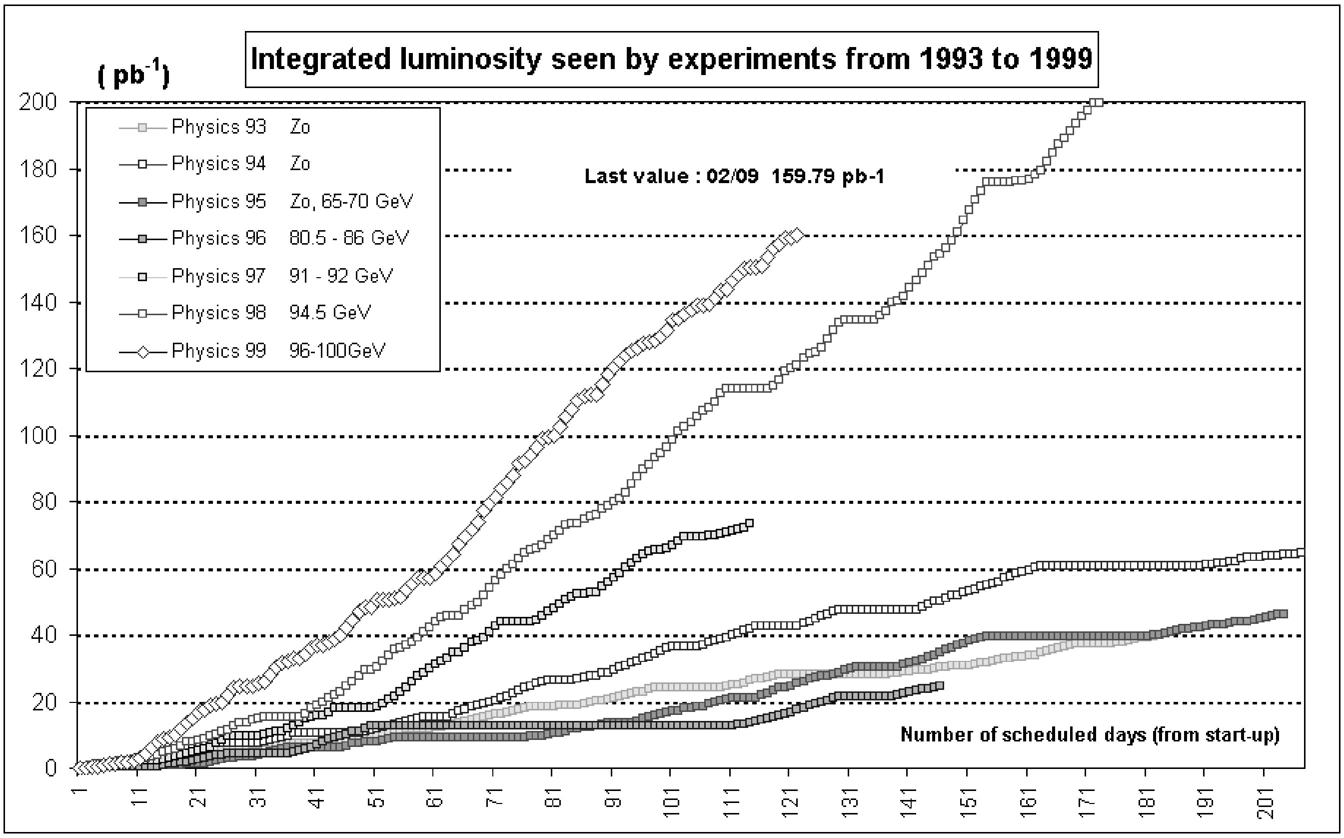
- **Constrained M.S.S.M. hypothesis**
- **R-parity conservation :**
  $\Longrightarrow$ $R_{\mathrm{P}} = (-1)^{3B+L+2S}$
  $\Longrightarrow$ $R_{\mathrm{P}} = +1$ for S.M. particles and -1 for SUSY partners
- **The masses of the $\tilde{\ell}^{\pm}_{\mathrm{R}}$ are expected to be lower than the masses of the $\tilde{\ell}^{\pm}_{\mathrm{L}}$**
- **The L.S.P. is the lightest Neutralino $\tilde{\chi}^0_1$**
  $\Longrightarrow$ the SUSY particles are pair-produced at LEP
  $\Longrightarrow$ they decay into their S.M. partners and the L.S.P.
  $\Longrightarrow$ the L.S.P. is stable and weakly interacting so it escapes detection

Missing energy is the main signature of SUSY

LEP

ALEPH DELPHI L3 OPAL

Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ per Exp (pb^{-1})
1989 to 1995	Z-peak	$\simeq$ 160
1995	130-136	$\simeq$ 6
1996	161-172	$\simeq$ 20
1997	181-184	$\simeq$ 55
1998	189	$\simeq$ 175
1999	192-196-200	$\simeq$ 140 ...
2000	*200 or more*	



At LEP we look for N.L.S.P. production where the NLSP is decaying in one S.M. particle + L.S.P.

$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \quad \text{with} \quad \tilde{\chi}_1^\pm \rightarrow W^\star\tilde{\chi}_1^0$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^0 \qquad \tilde{\chi}_2^0 \rightarrow Z^\star/\gamma^\star\tilde{\chi}_1^0$$
$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \qquad \tilde{\chi}_2^0 \rightarrow Z^\star/\gamma^\star\tilde{\chi}_1^0$$

$$e^+e^- \rightarrow \tilde{\ell}_R^\pm\tilde{\ell}_R^\pm \qquad \tilde{\ell}_R^\pm \rightarrow \ell^\pm\tilde{\chi}_1^0$$

$$e^+e^- \rightarrow \tilde{q}_R\bar{\tilde{q}}_R \qquad \tilde{q}_R \rightarrow q\tilde{\chi}_1^0$$

Typical production cross-sections at 189 GeV :

$$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp : \sigma \simeq 1 \text{ to } 5\ pb$$
$$\Longrightarrow N_{\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp} \simeq \mathbf{200} \text{ to } 900$$

$$\tilde{e}_R\tilde{e}_R : \sigma \simeq 0.4\ pb \text{ for } M_{\tilde{e}_R} = 90 \text{ GeV}$$
$$\Longrightarrow N_{\tilde{e}_R\tilde{e}_R} \simeq 70$$

$$\tilde{\mu}_R\tilde{\mu}_R : \sigma \simeq 0.15\ pb \text{ for } M_{\tilde{\mu}_R} = 90 \text{ GeV}$$
$$\Longrightarrow N_{\tilde{\mu}_R\tilde{\mu}_R} \simeq 20$$

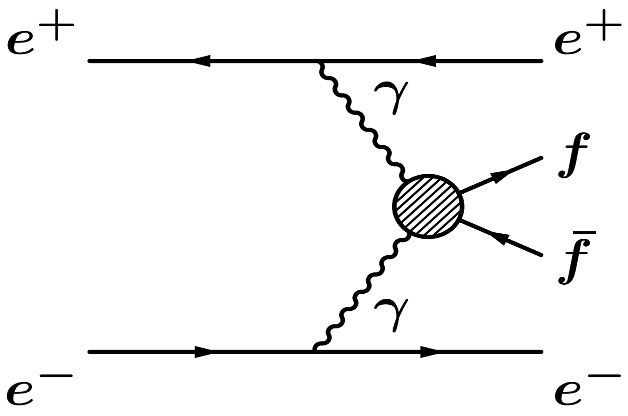
The mass difference $\Delta M = M_{NLSP} - M_{LSP}$ is related to the Visible Energy in the detector. In principle 3 ΔM ranges are considered.

low ΔM :	$\Delta M \lesssim 15$ **GeV**
medium ΔM :	**15 GeV** $\lesssim \Delta M \lesssim 70$ **GeV**
high ΔM :	$\Delta M \gtrsim 70$ **GeV**

For each selection and each ΔM,
the best combination of cuts
(means Maximum SIGNAL/BACKGROUND)
is used to get the highest sensitivity

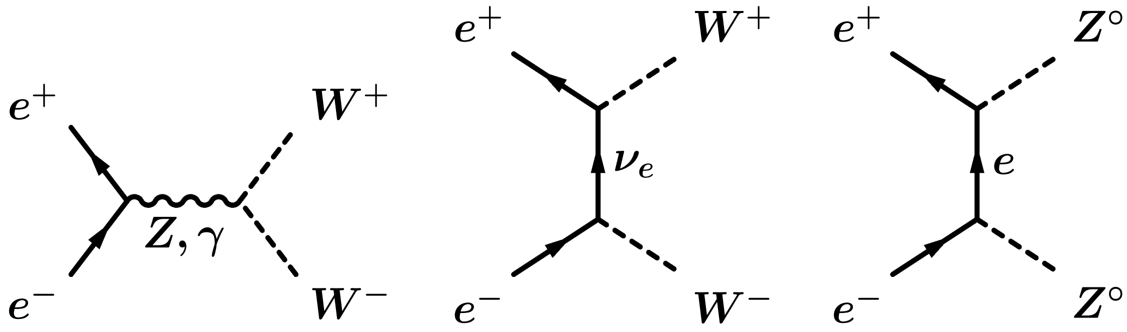
S.M. Background processes

- $e^+e^- \longrightarrow \gamma\gamma \longrightarrow (e^+e^-)f\bar{f}$



Very large cross-sections (a few nb)
The Visible Energy is very low
Dominant only for low ΔM selections

- $e^+e^- \longrightarrow W^+W^-$or $Z^\circ Z^\circ$



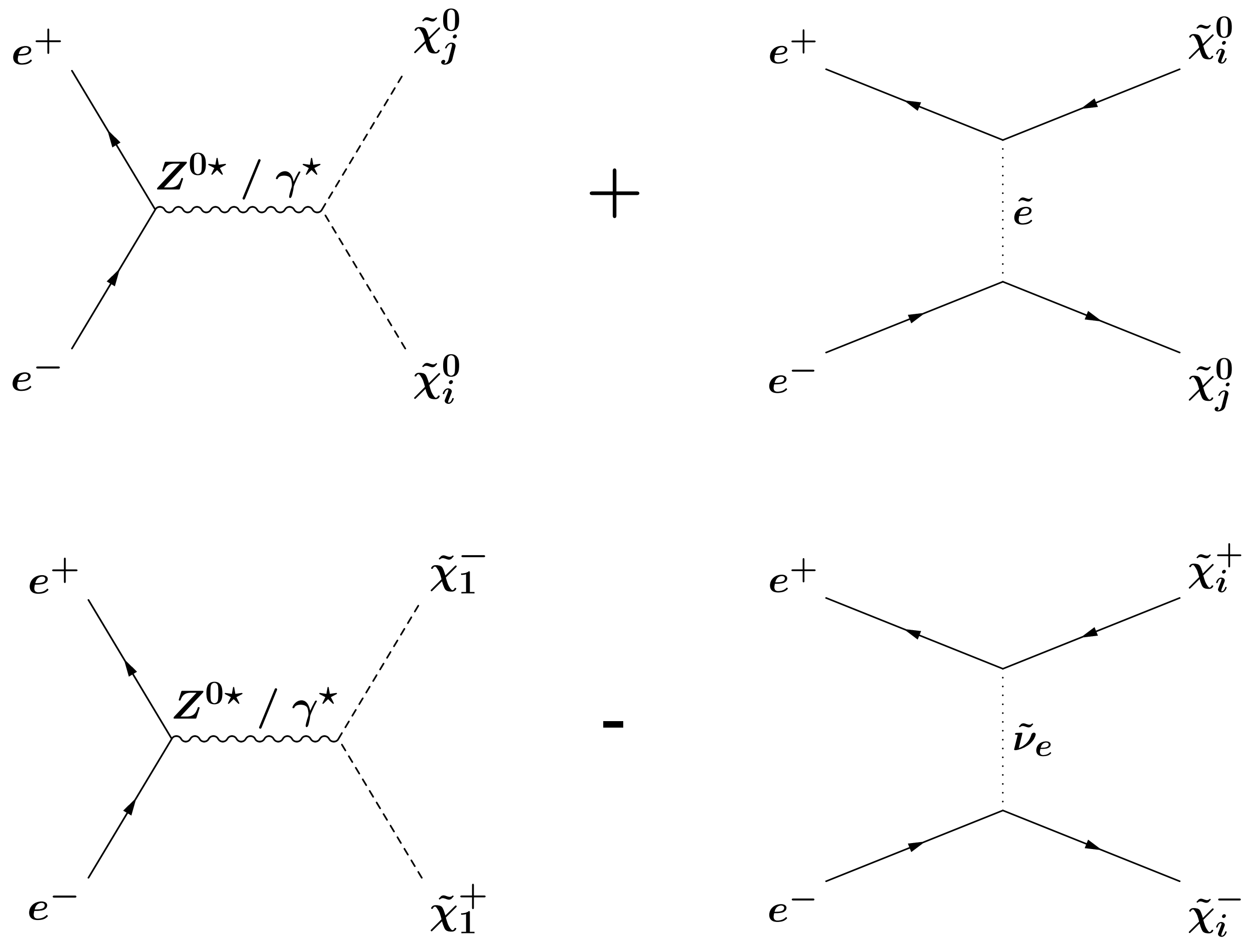
Large cross-sections (around 20 pb)
Large $\not{P}_T$ and $\not{E}$
Large $\not{M}$
Irreducible background for medium/high ΔM

- Other sources of background are negligible

Production at LEP

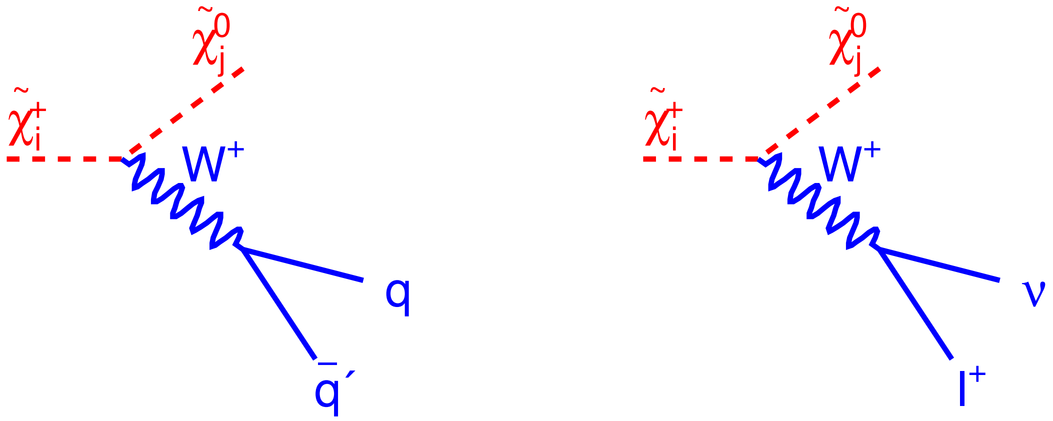
The Production Cross-sections depends on 4 parameters :

$$\sigma(\mathrm{M}_2, \mu, \tan\beta, \mathrm{m}_0)$$

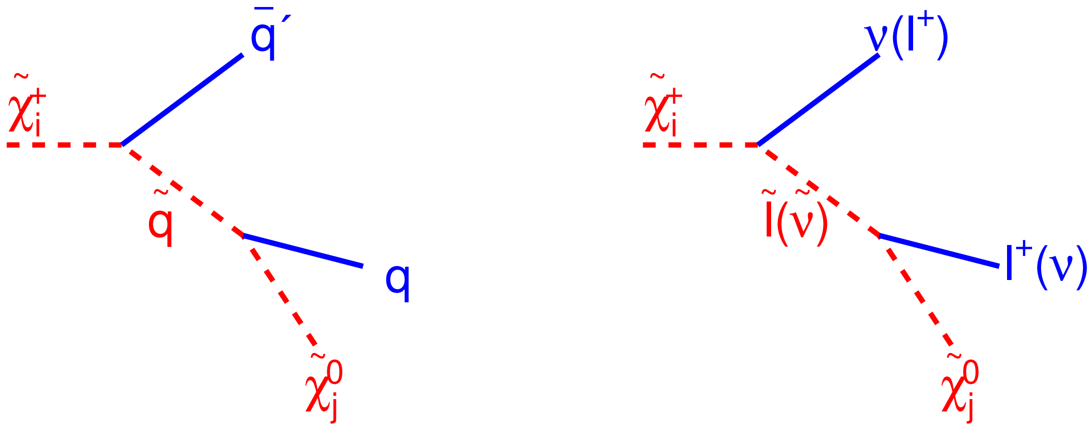


Higgsino region	Gaugino region
$\mathrm{M}_2 >> \|\mu\|$	$\mathrm{M}_2 << \|\mu\|$
no t-channel	**Important t-channel for small m_0**

Chargino $\tilde{\chi}_i^\pm$

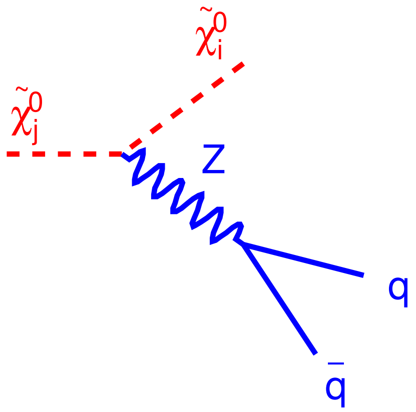


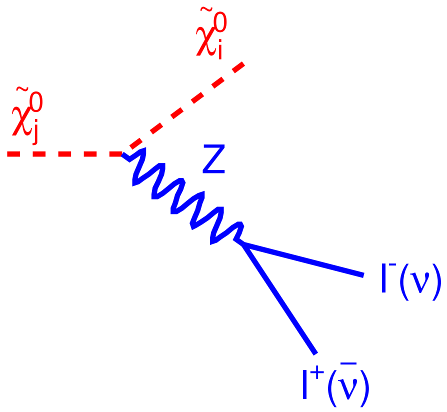
Dominant for large m_0 values



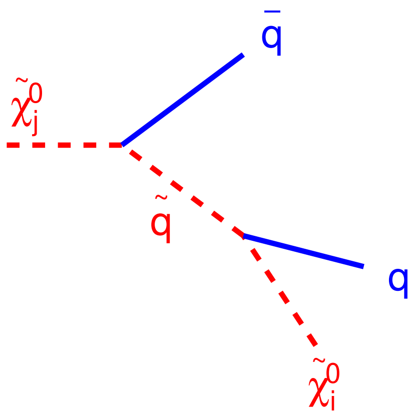
Contribute for small m_0 values

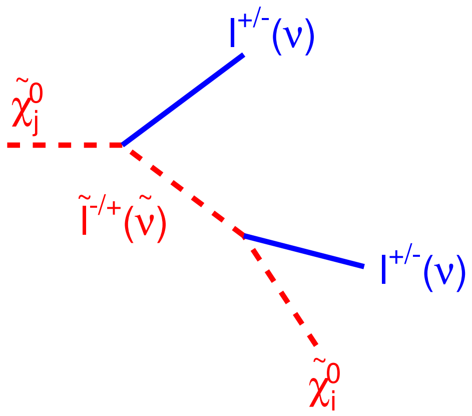
Neutralino $\tilde{\chi}_i^0$



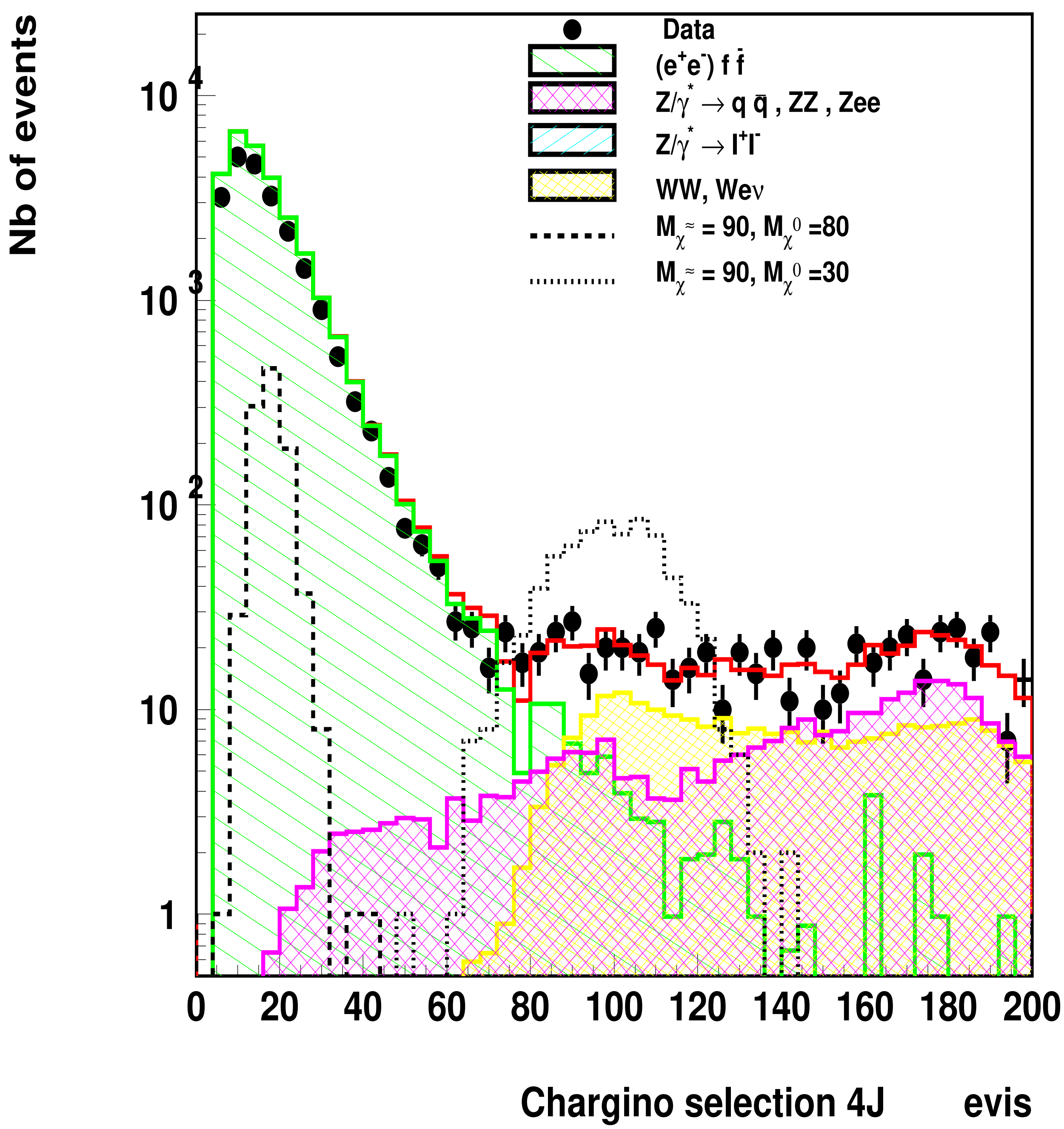


Dominant for large m_0 values

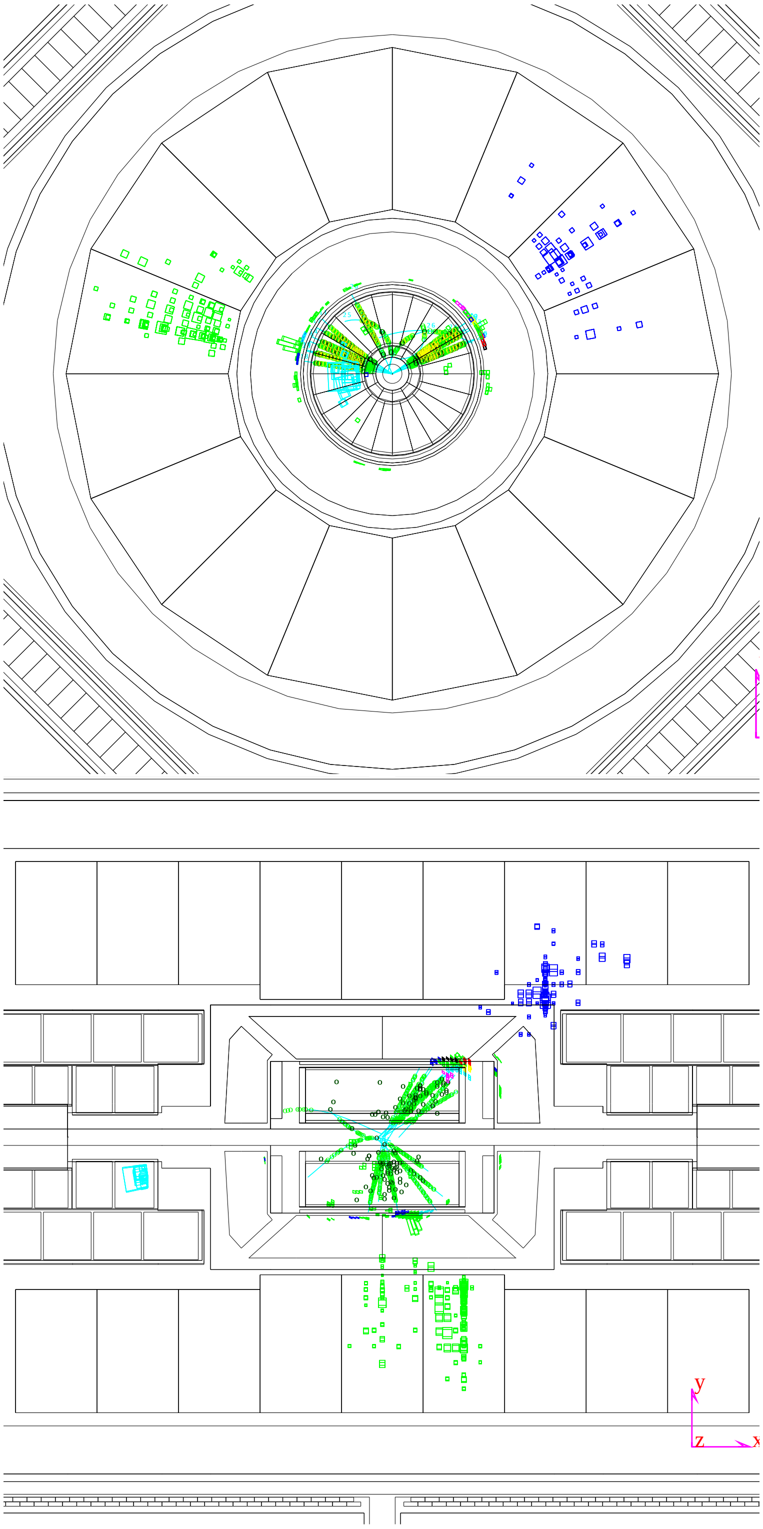




Contribute for small m_0 values


Nb of events
Data
(e⁺e⁻) f f̄
Z/γ* → q q̄ , ZZ , Zee
Z/γ* → l⁺l⁻
WW, Weν
M_χ̃± = 90, M_χ⁰ =80
M_χ̃± = 90, M_χ⁰ =30
10⁴
10³
10²
10
1
0
20
40
60
80
100
120
140
160
180
200
Chargino selection 4J
evis

$e^+e^- \longrightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ candidate at 200 GeV



Results

For example :

30 Selections for Charginos, Neutralinos, Sleptons

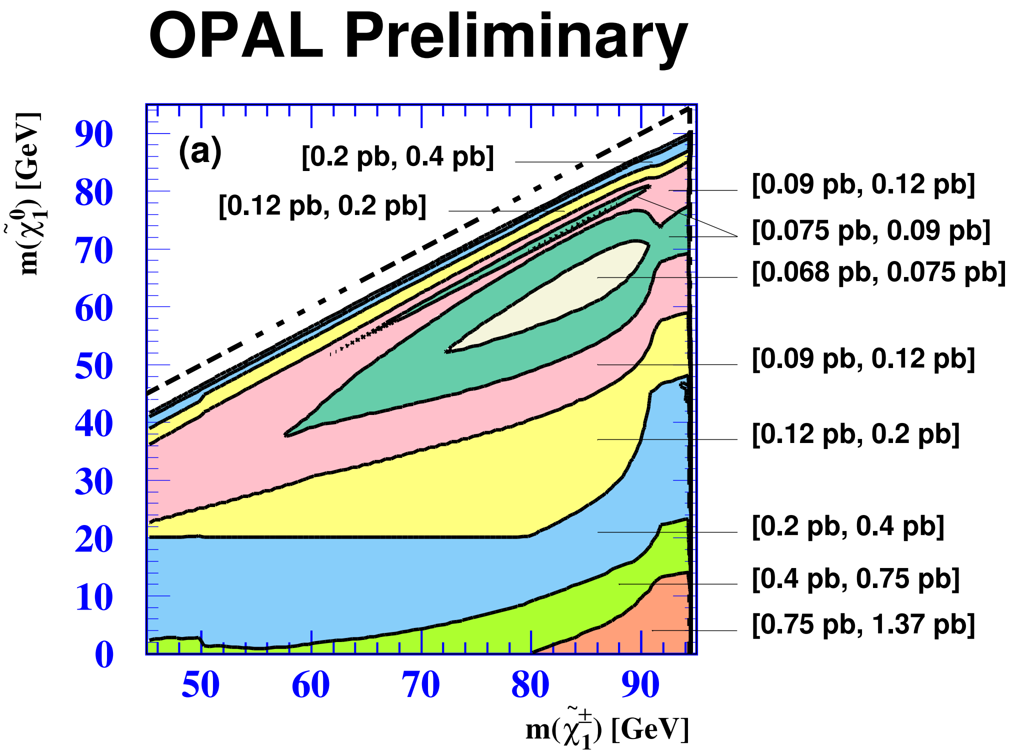
$$\mathcal{L} = 31.0\ pb^{-1} \qquad \sqrt{s} = 196\ \text{GeV}$$

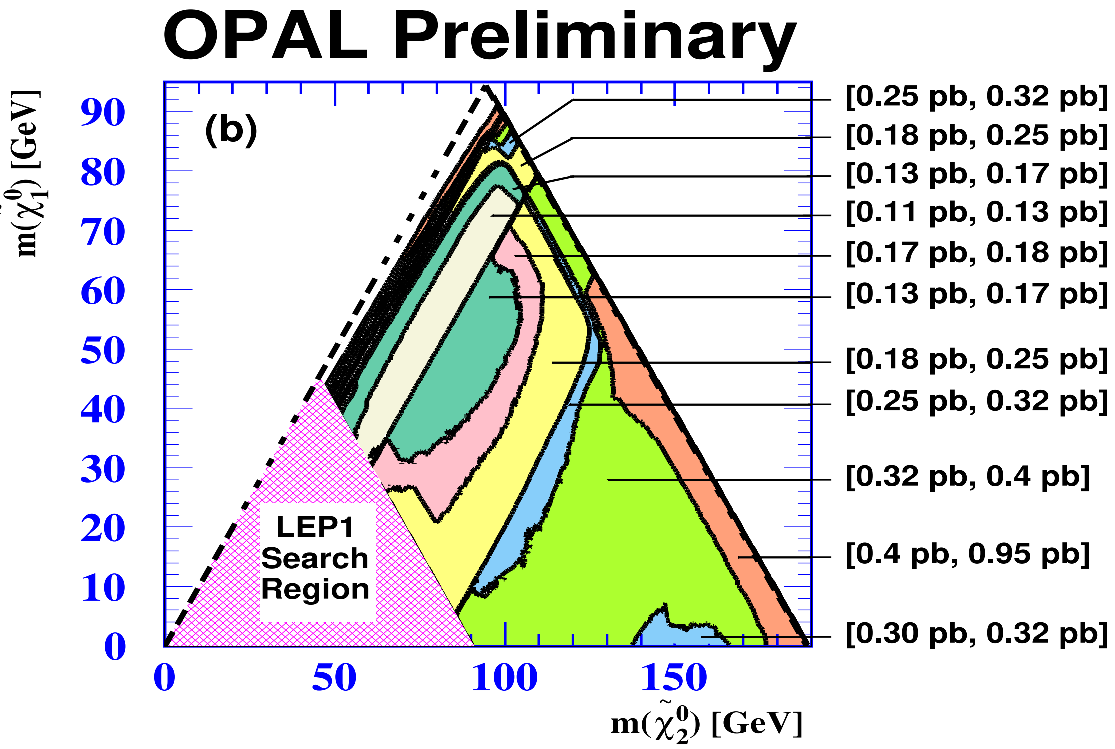
	Low ΔM		Medium ΔM		High ΔM		Combined	
	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}
$\tilde{e}$	2	1.0	2	0.8	4	2.2	8	4.0
$\tilde{\mu}$	0	2.0	0	0.2	0	1.6	0	3.7
$\tilde{\tau}$	2	0.5	3	1.5	4	2.1	6	2.7
$\tilde{\chi}_1^{\pm}$	11	11.7	3	1.9	13	13.4	24	25.9
$\tilde{\chi}_1^0$	9	69	0	1.4	1	0.4	10	8.4
Combined	19	16.9	4	4.4	20	17.6	38	36.2

For $M_{\tilde{\chi}_1^{\pm}} \simeq 96$ GeV $N_{\text{signal}} \simeq 20$
Efficiencies : 30% to 60%

No EXCESS is observed in Data :

- **Upper limit on production cross sections**
- **This allows exclusions in C.M.S.S.M. parameter space**
- **$\Longrightarrow$ Lower limit on the masses of the sparticles**


OPAL Preliminary
(a)
[0.2 pb, 0.4 pb]
[0.12 pb, 0.2 pb]
[0.09 pb, 0.12 pb]
[0.075 pb, 0.09 pb]
[0.068 pb, 0.075 pb]
[0.09 pb, 0.12 pb]
[0.12 pb, 0.2 pb]
[0.2 pb, 0.4 pb]
[0.4 pb, 0.75 pb]
[0.75 pb, 1.37 pb]
m($\tilde{\chi}_1^0$) [GeV]
m($\tilde{\chi}_1^\pm$) [GeV]


OPAL Preliminary
(b)
[0.25 pb, 0.32 pb]
[0.18 pb, 0.25 pb]
[0.13 pb, 0.17 pb]
[0.11 pb, 0.13 pb]
[0.17 pb, 0.18 pb]
[0.13 pb, 0.17 pb]
[0.18 pb, 0.25 pb]
[0.25 pb, 0.32 pb]
[0.32 pb, 0.4 pb]
[0.4 pb, 0.95 pb]
[0.30 pb, 0.32 pb]
LEP1
Search
Region
m($\tilde{\chi}_1^0$) [GeV]
m($\tilde{\chi}_2^0$) [GeV]

Limits on the parameters

- **At LEP we put 95% Confidence Level upper limits on the production cross-sections of the $\tilde{\chi}_i^{\pm}$ and $\tilde{\chi}_i^0$. Those limits depend on the Masses of the particles so depend on the parameters**

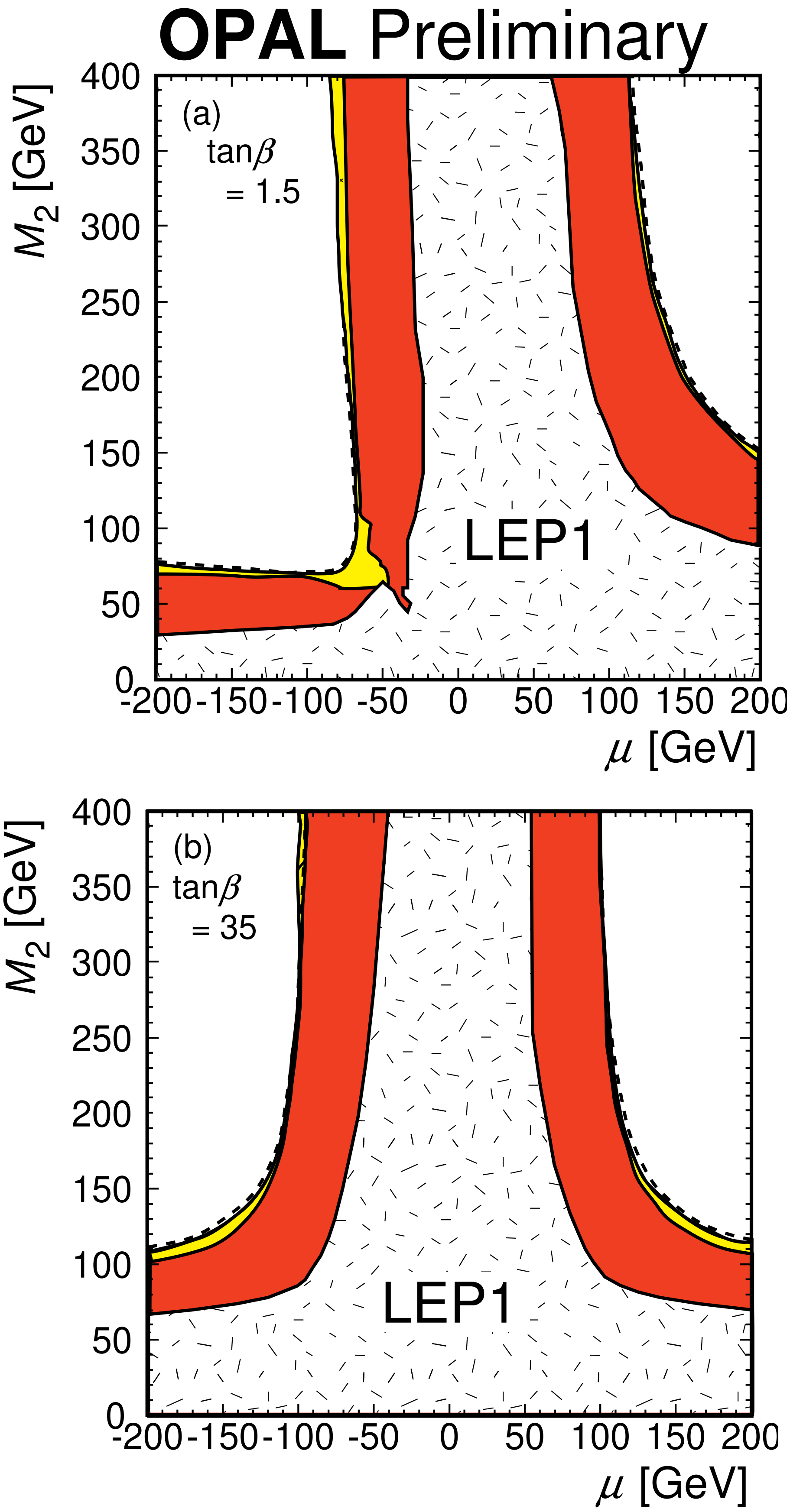
$$\boxed{\mathrm{M}_2, \mu, \tan\beta, \mathrm{m}_0}$$

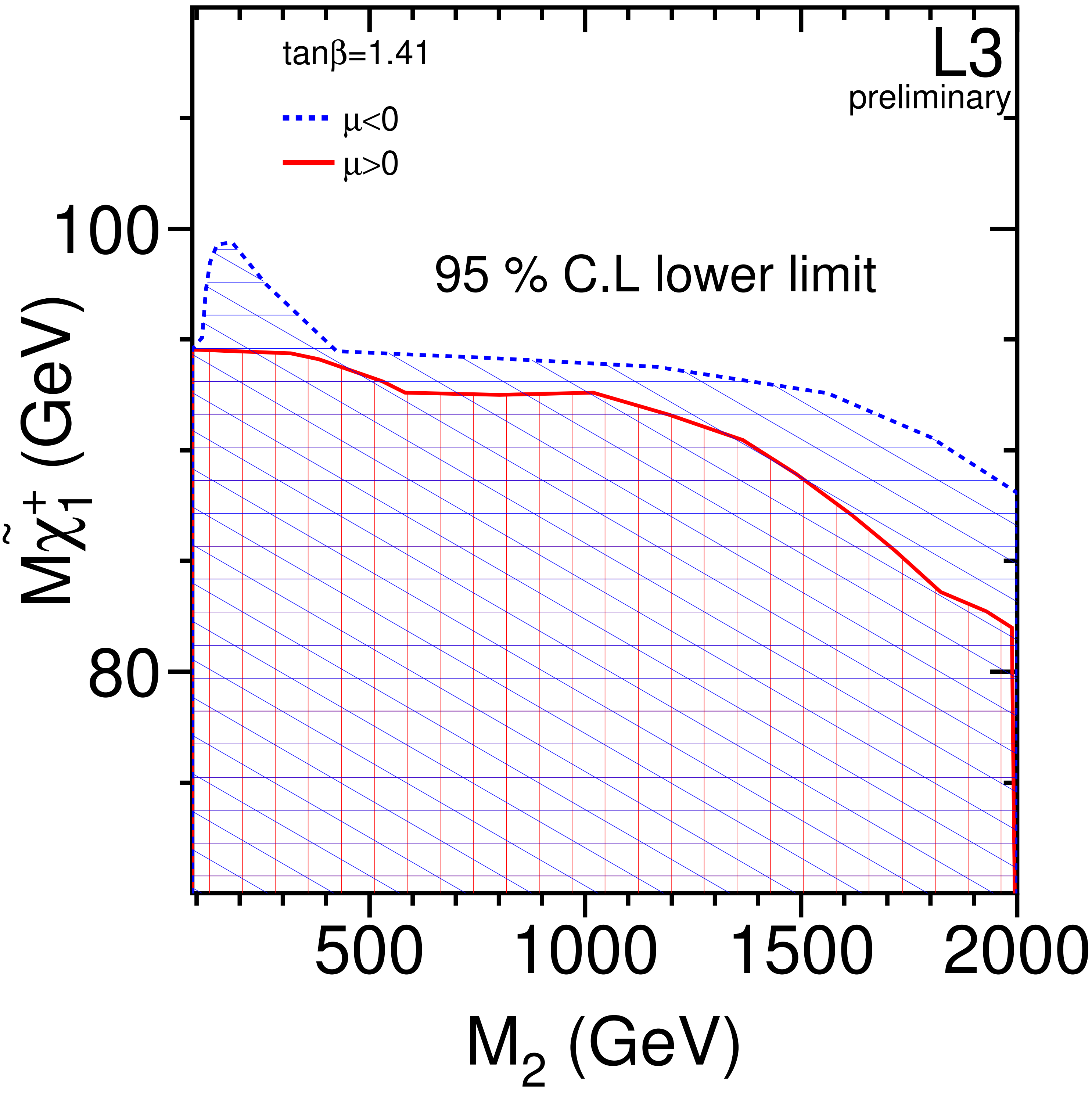
- **The C.M.S.S.M. gives for a given mass the theoritical cross-section. When the theoritical cross-section is higher than the upper limit, the mass point is**

$$\boxed{\textbf{EXCLUDED}}$$

- **The limits on the parameters of the Model allow an indirect limit on the mass of the L.S.P. ($\tilde{\chi}_1^0$)**
- **For the exclusion analysis, the following parameter space has been scanned :**

$$0 \leq \mathrm{M}_2 \leq 2000 \text{ GeV} \qquad 10 \leq m_0 \leq 500 \text{ GeV}$$
$$1 \leq \tan\beta \leq 60 \text{ GeV} \qquad -2000 \leq \mu \leq 2000 \text{ GeV}$$


OPAL Preliminary
(a)
tanβ
= 1.5
LEP1
M2 [GeV]
μ [GeV]
0
50
100
150
200
250
300
350
400
-200
-150
-100
-50
0
50
100
150
200
(b)
tanβ
= 35
LEP1
M2 [GeV]
μ [GeV]
0
50
100
150
200
250
300
350
400
-200
-150
-100
-50
0
50
100
150
200

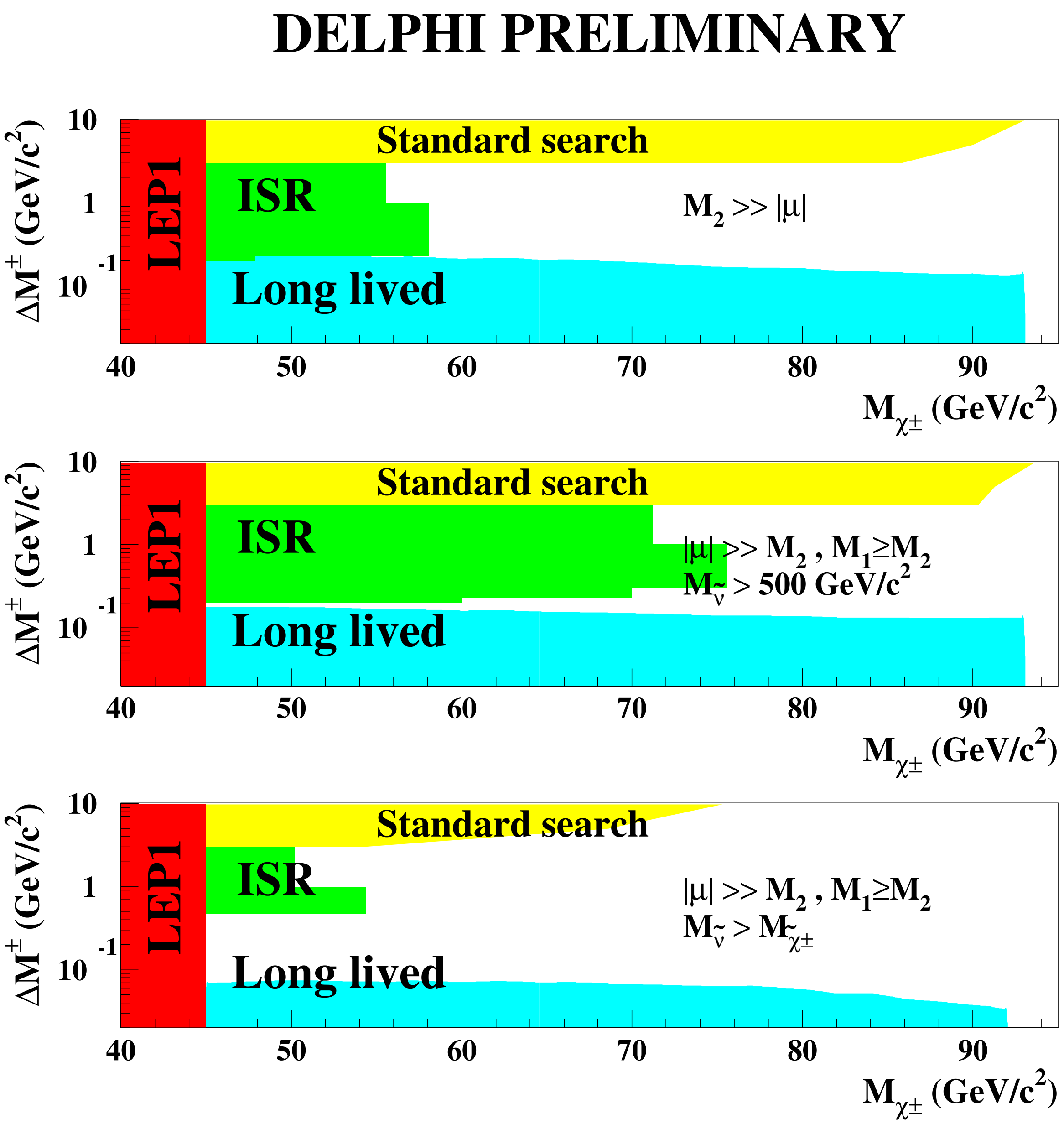

tanβ=1.41
L3
preliminary
μ<0
μ>0
95 % C.L lower limit
100
80
$M_{\tilde{\chi}_1^+}$ (GeV)
500
1000
1500
2000
M_2 (GeV)

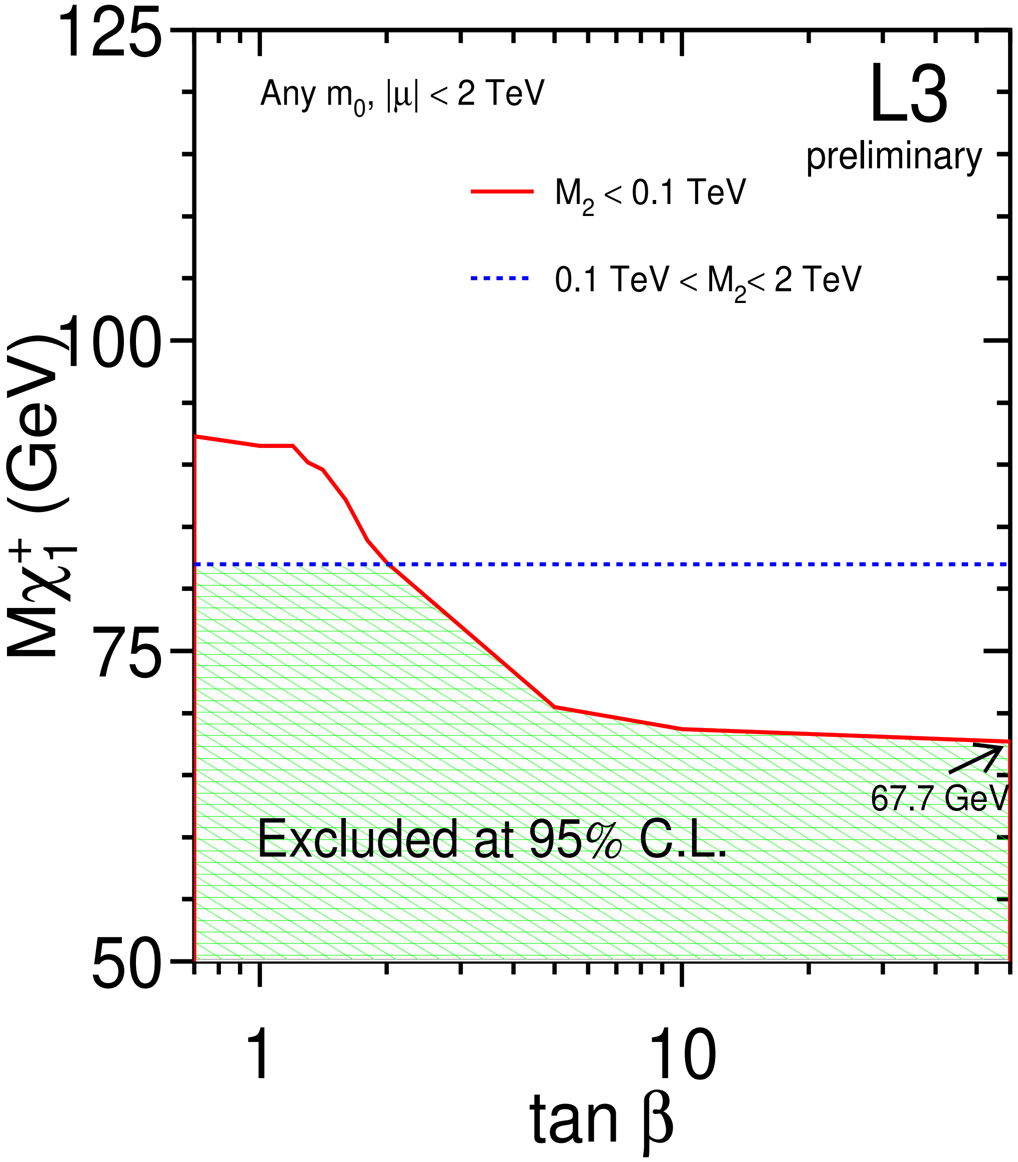
Low m_0 values ($\Longrightarrow$ low masses of s-fermions)

New diagrams are included s-t interference $\Longrightarrow$ $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ cross-section smaller and leptonic branching ratio of the $\tilde{\chi}_1^\pm$is enhanced. But $e^+e^- \rightarrow \tilde{\chi}_i^0\tilde{\chi}_j^0$ becomes larger

- **Efficiency of detection is smaller**
- **(Quasi-)invisible decays :**
  $\tilde{\chi}_1^\pm \rightarrow \tilde{\ell}_R^\pm \nu$ **for small** $\Delta M = M_{\tilde{\chi}_1^\pm} - M_{\tilde{\nu}}$ **or** $\tilde{\chi}_i^0 \rightarrow \nu\tilde{\nu}$
- **Need to include many new processes** $e^+e^- \rightarrow \tilde{\chi}_3^0\tilde{\chi}_2^0$, **cascade decays...**
  for example : $\tilde{\chi}_3^0 \rightarrow \tilde{\chi}_2^0 f\bar{f} \rightarrow \tilde{\chi}_1^0 f\bar{f} f\bar{f}$

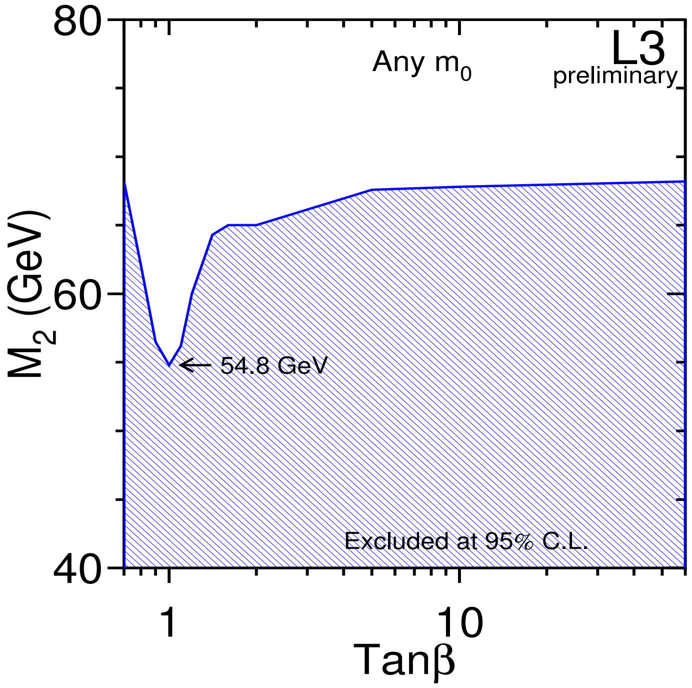
In this case, the visible energy is very small $\Longrightarrow$ trigger efficiency is lower
Need to combine with Long-lived particles searches for very small ΔM and with Initial State Radiative events for the intermediate values of ΔM

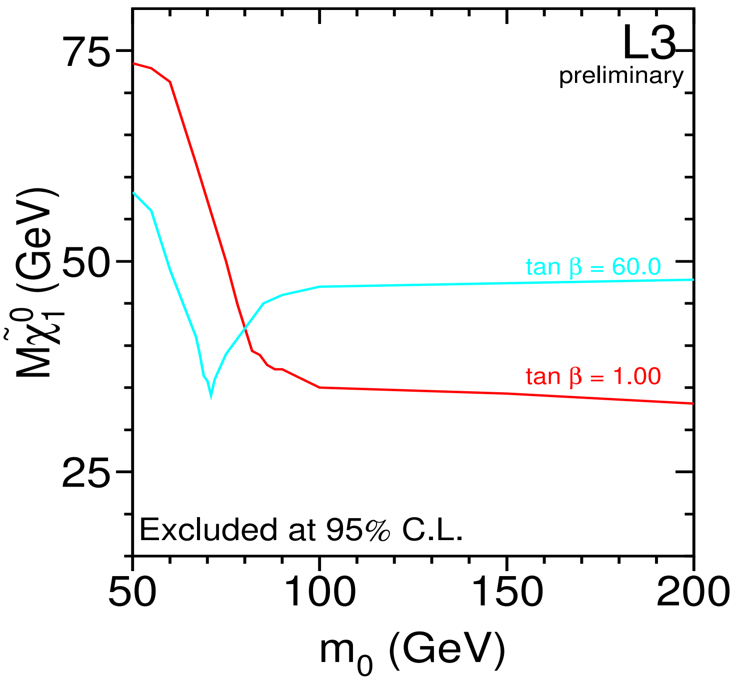




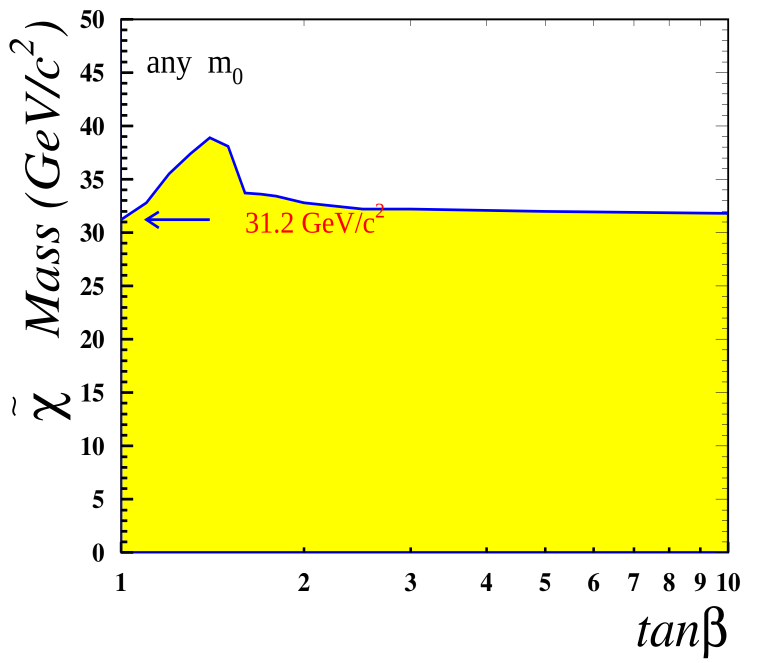
125
100
75
50
1
10
tan β
$M_{\tilde{\chi}_1^+}$ (GeV)
Any m_0, $|\mu|$ < 2 TeV
L3
preliminary
M_2 < 0.1 TeV
0.1 TeV < M_2 < 2 TeV
67.7 GeV
Excluded at 95% C.L.

Indirect limit on the L.S.P. mass up to 189 GeV CM energy

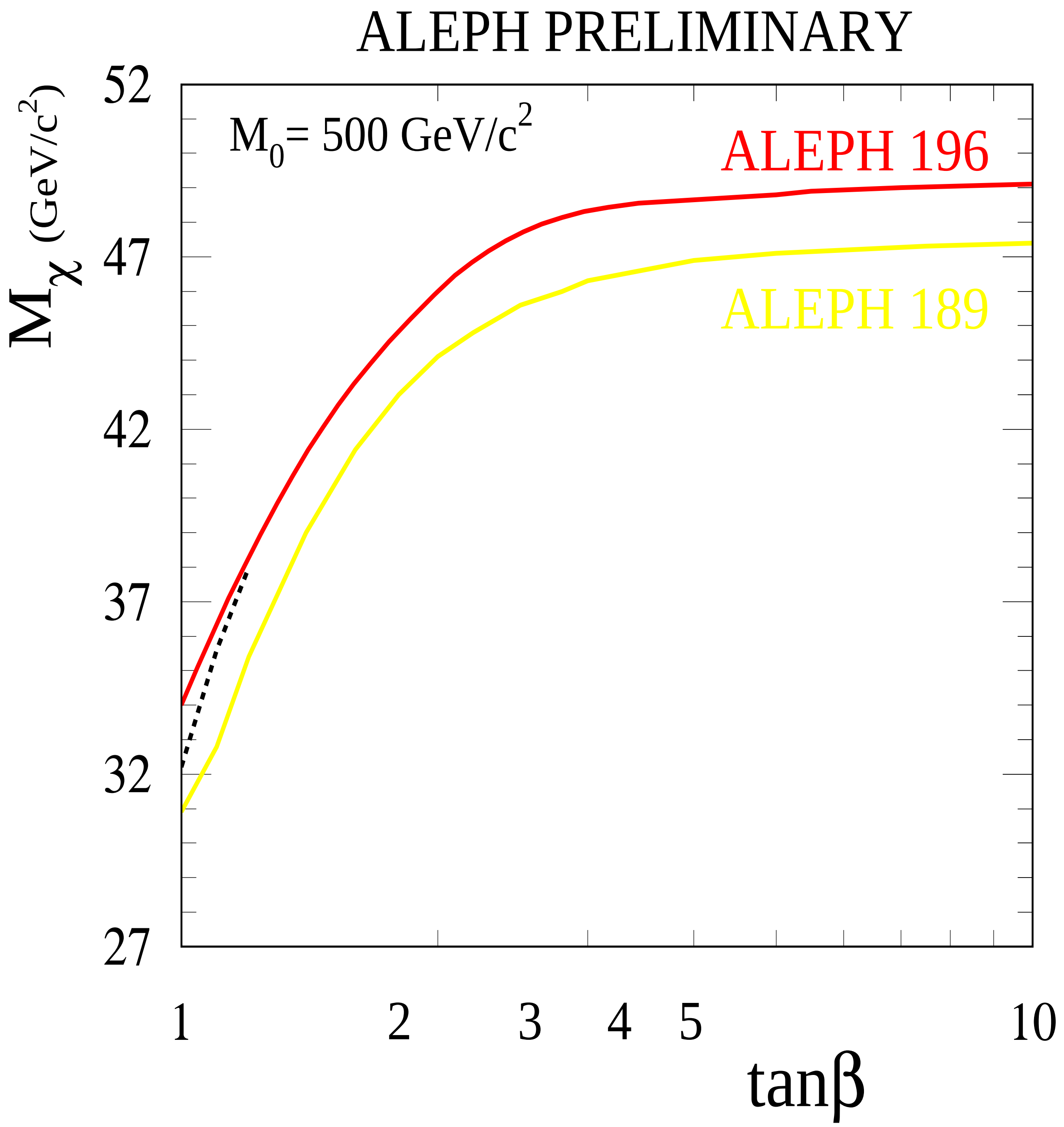




Preliminary DELPHI LSP limit at 189 GeV



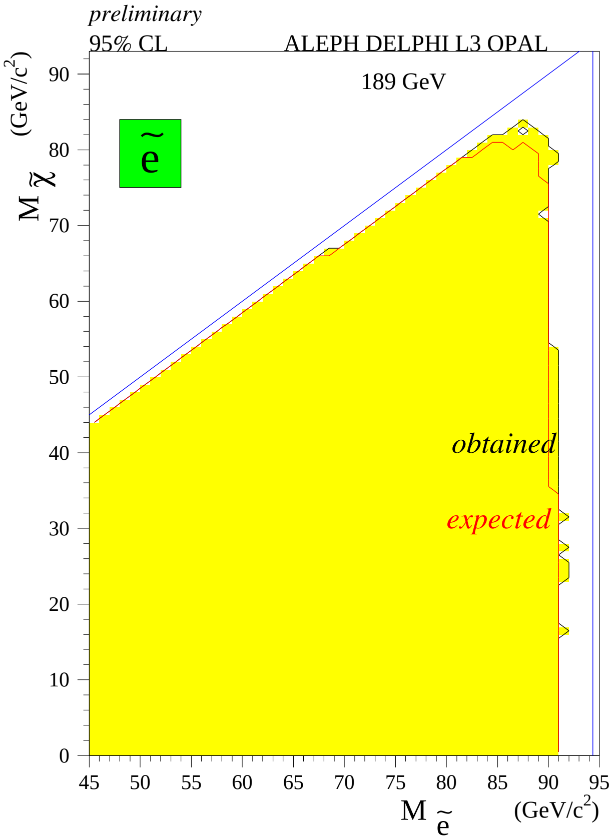
$\sqrt{s}$=189 GeV	A	D	L	O
$M_{\tilde{\chi}_1^0}$ (GeV)	**32.3**	**31.2**	**32.5**	**27.9**

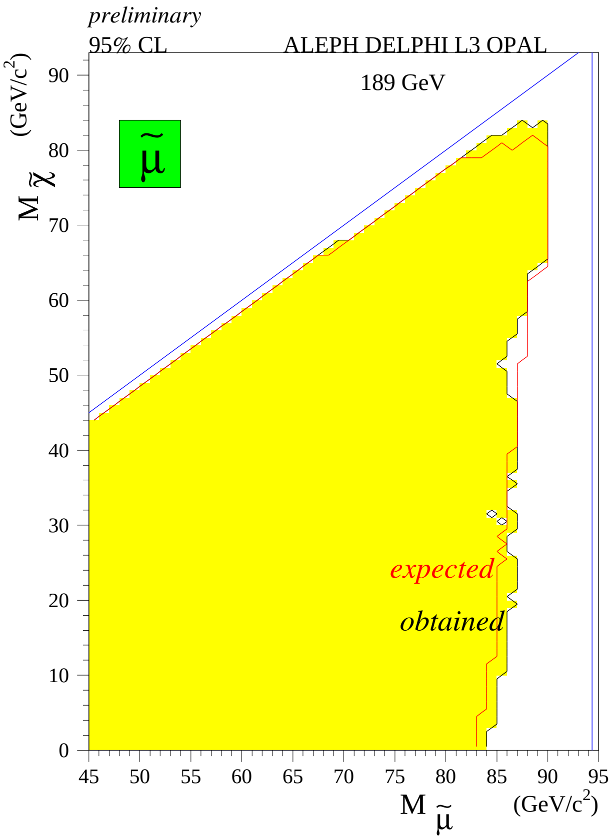

ALEPH PRELIMINARY
M_0= 500 GeV/c^2
ALEPH 196
ALEPH 189
M_χ (GeV/c^2)
52
47
42
37
32
27
1
2
3
4
5
10
tanβ

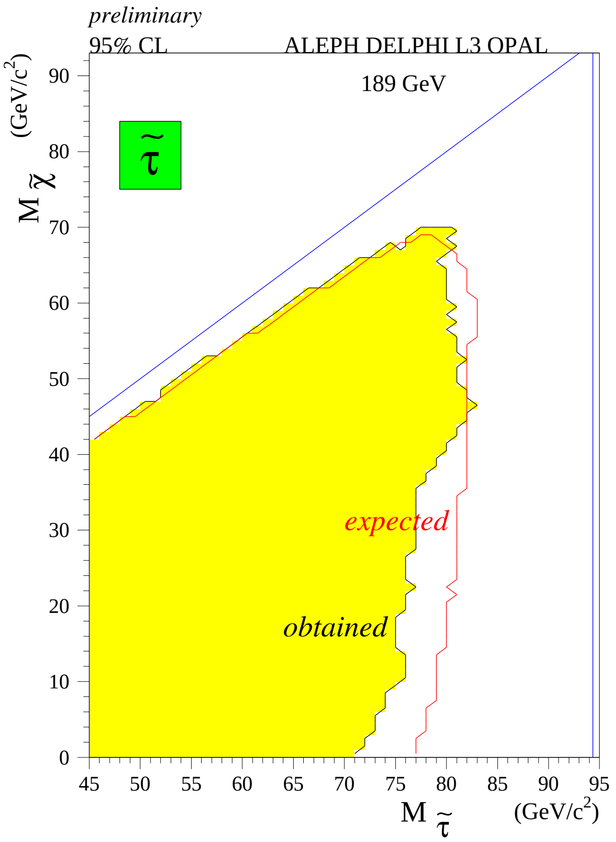
$$e^+e^- \longrightarrow \tilde{\ell}_R\tilde{\ell}_R \longrightarrow \ell\ell\tilde{\chi}^0_1\tilde{\chi}^0_1$$

ADLO 189 GeV
$\Delta M \geq 15$ GeV

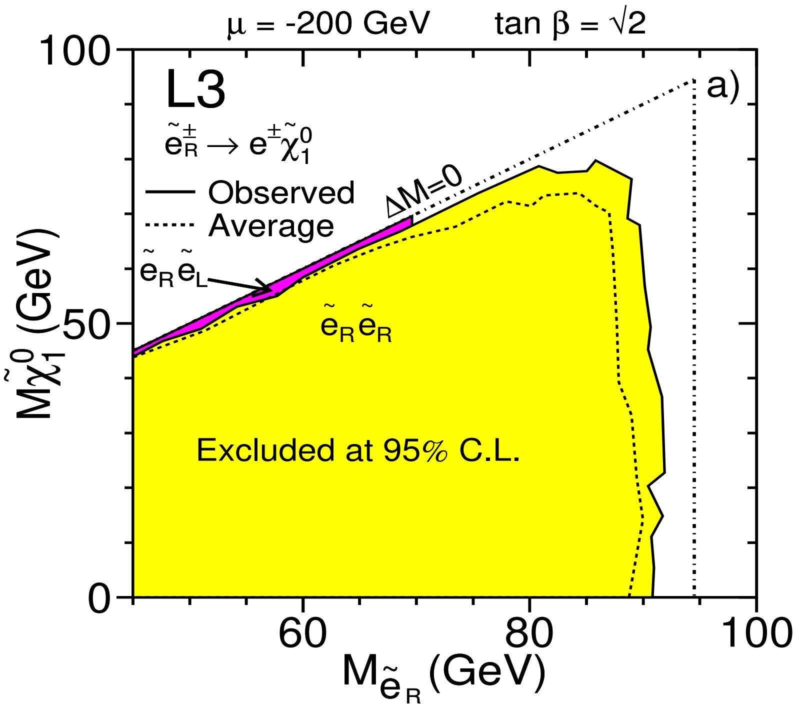
$M_{\tilde{e}} \geq 89$ GeV (exp. 90)
$M_{\tilde{\mu}} \geq 84$ GeV (exp. 83)
$M_{\tilde{\tau}} \geq 71$ GeV (exp. 77)

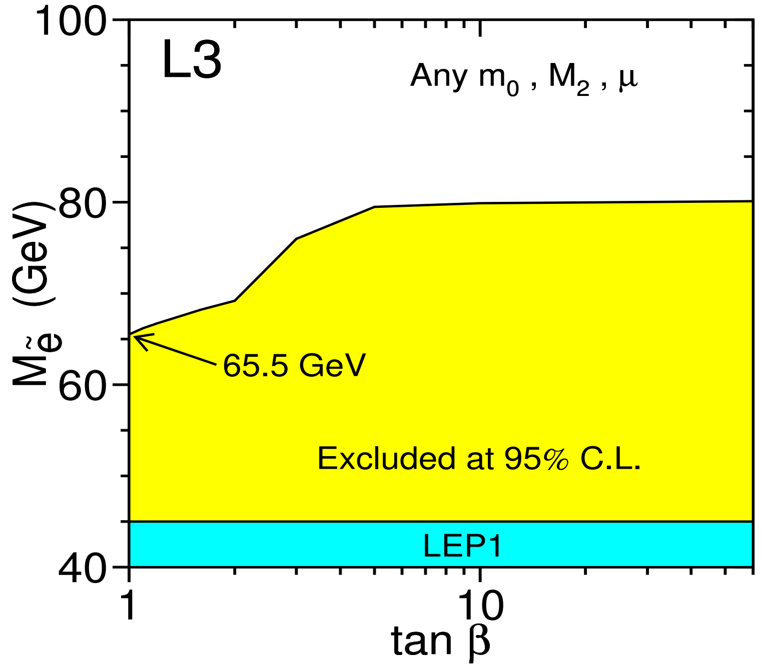






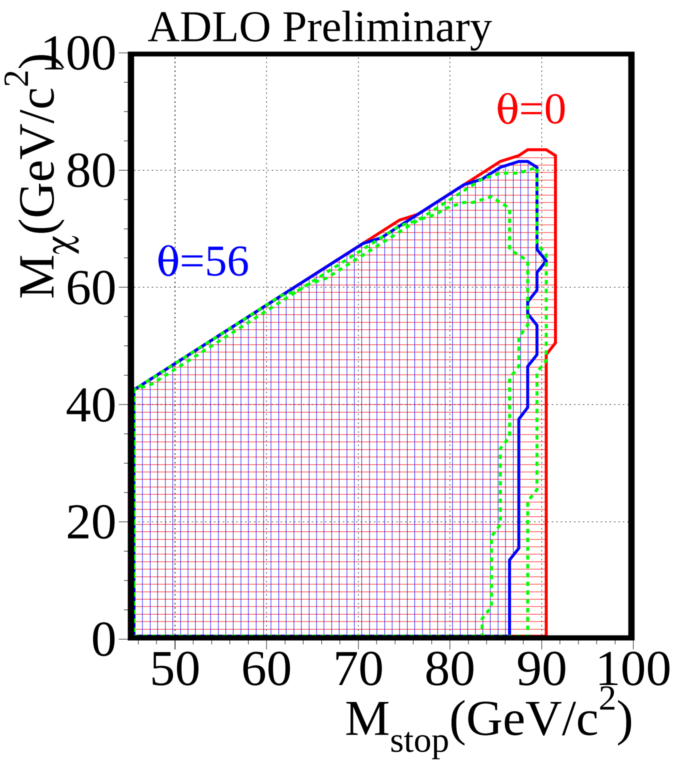
New analysis of $e^+e^- \longrightarrow \tilde{e}_R\tilde{e}_L \rightarrow (e)e\tilde{\chi}^0_1\tilde{\chi}^0_1$





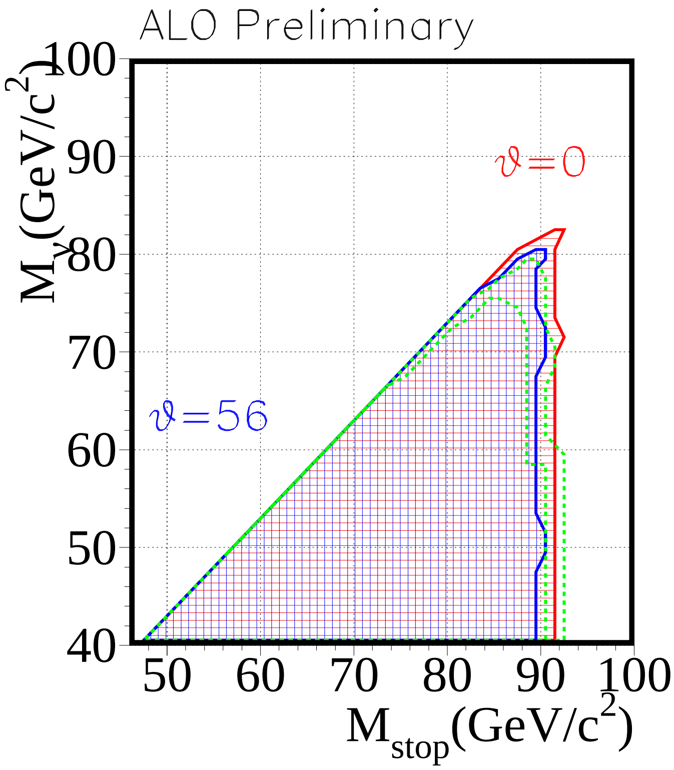
$e^+e^- \longrightarrow \tilde{t}_1\tilde{t}_1$ and $e^+e^- \longrightarrow \tilde{b}_1\tilde{b}_1$

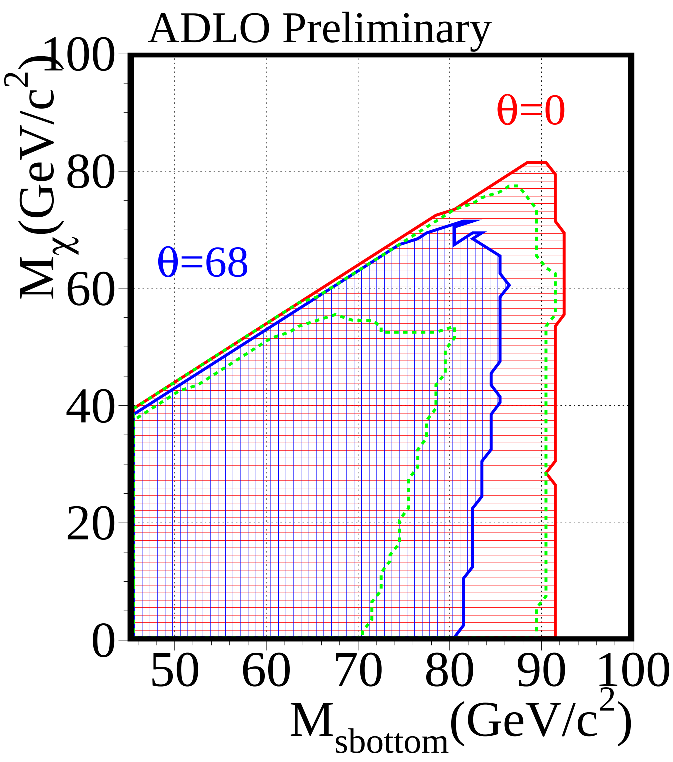
$\tilde{t}_1 = \tilde{t}_L \cos\theta + \tilde{t}_R \sin\theta$
$\tilde{b}_1 = \tilde{b}_L \cos\theta' + \tilde{b}_R \sin\theta'$
Minimal cross-section at
$\cos\theta \simeq 0.57$ (0.39) for $\tilde{t}_1(\tilde{b}_1)$

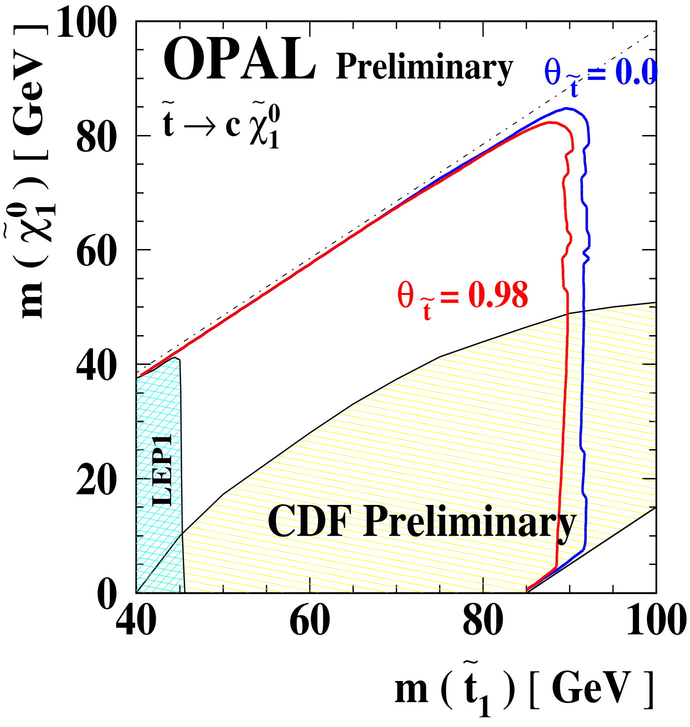


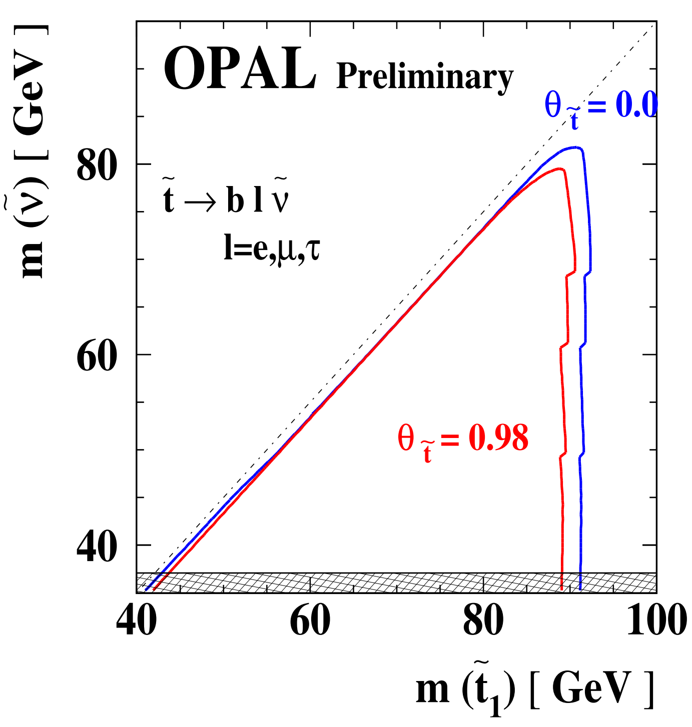
ADLO 189 GeV in case of minimal cross-section

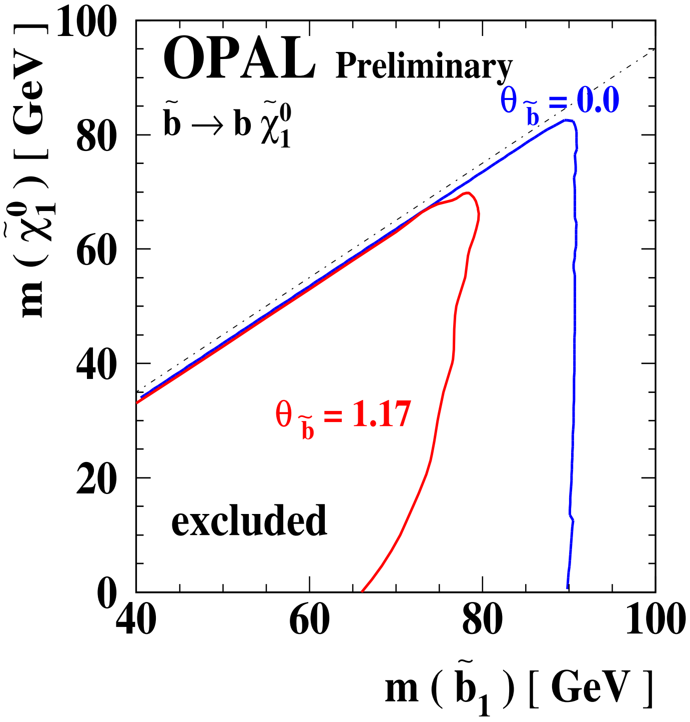
$M_{\tilde{t}}^{\tilde{t}\to c\tilde{\chi}_1^0} \geq$ **87 GeV (exp. 84)**
$M_{\tilde{t}}^{\tilde{t}\to b\ell\tilde{\nu}} \geq$ **90 GeV (exp. 91)**
$M_{\tilde{b}}^{\tilde{b}\to b\tilde{\chi}_1^0} \geq$ **81 GeV (exp. 71)**






OPAL Preliminary
$\tilde{t} \rightarrow c\,\tilde{\chi}^0_1$
$\theta_{\tilde{t}} = 0.0$
$\theta_{\tilde{t}} = 0.98$
LEP1
CDF Preliminary
$m(\tilde{\chi}^0_1)$ [GeV]
$m(\tilde{t}_1)$ [GeV]


OPAL Preliminary
$\tilde{t} \rightarrow b\, l\, \tilde{\nu}$
$l = e, \mu, \tau$
$\theta_{\tilde{t}} = 0.0$
$\theta_{\tilde{t}} = 0.98$
$m(\tilde{\nu})$ [GeV]
$m(\tilde{t}_1)$ [GeV]


OPAL Preliminary
$\tilde{b} \rightarrow b\,\tilde{\chi}^0_1$
$\theta_{\tilde{b}} = 0.0$
$\theta_{\tilde{b}} = 1.17$
excluded
$m(\tilde{\chi}^0_1)$ [GeV]
$m(\tilde{b}_1)$ [GeV]

Framework

- If R-parity is not conserved, some new terms in the Super-potential have to be considered

$$\boxed{\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}$$

- Those terms violate Lepton and Baryon number conservation
- So we have 45 new parameters in the M.S.S.M. :

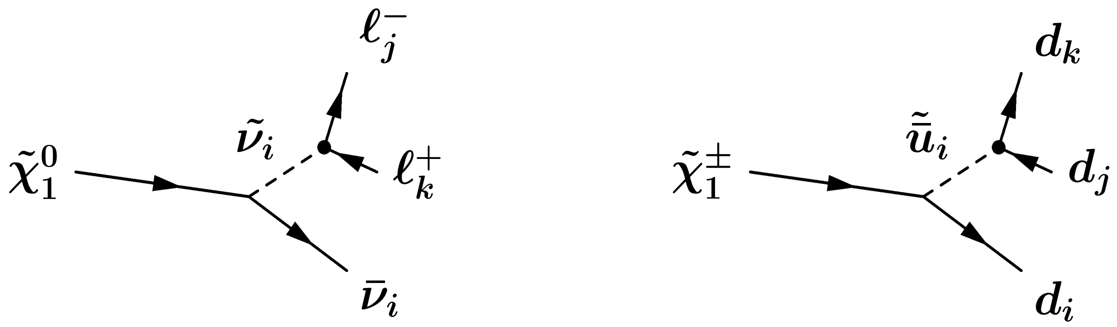
$$\boxed{9\lambda_{ijk} \quad 27\lambda'_{ijk} \quad 9\lambda''_{ijk}}$$

- In principle in the analysis 1 coupling constant only is assumed to be non-zero
- The interpretations of experimental results are made in the C.M.S.S.M. framework with 5 parameters :

$$\boxed{\tan\beta, \mu, \mathrm{M}_2, m_0, \mathrm{A}_0}$$

Topologies

- The L.S.P. (id est $\tilde{\chi}_1^0$) is no longer stable
- Full energy events in the detector, except if there are neutrinos
- Direct decays via R-parity non-conserving vertices



- Indirect decays id est cascade decays via R-parity conserving and non-conserving vertices

- There are many final states combining leptons and/or hadronic jets

Gauginos $\tilde{\chi}_i^0 \tilde{\chi}_i^{\pm}$

- **Same production modes with respect to the R-parity conserved scenario**
- **No problem with the small m_0 case because $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ is VISIBLE**
- **Many decay possibilities**

	$\tilde{\chi}_1^0 \tilde{\chi}_1^0$	$\tilde{\chi}_1^+ \tilde{\chi}_1^-$
λ_{ijk} direct	$4\ell + \not{E}$	$6l$ $4l + \not{E}$ $2l + \not{E}$
λ_{ijk} indirect		$4j + 4l + \not{E}$ $2j + 5l + \not{E}$ $6l + \not{E}$
λ'_{ijk} direct	$4j + 2l$	$4j + (0 \text{ or } 1 \text{ or } 2l) + \not{E}$ $4j + 2l$
λ'_{ijk} indirect		$4 \text{ to } 8j + 0 \text{ to } 4l + \not{E}$
λ''_{ijk} direct	$6j$	$6j$
λ''_{ijk} indirect		$10j$ $8j + 1l + \not{E}$ $6j + 2l + \not{E}$

Limits in the C.M.S.S.M.

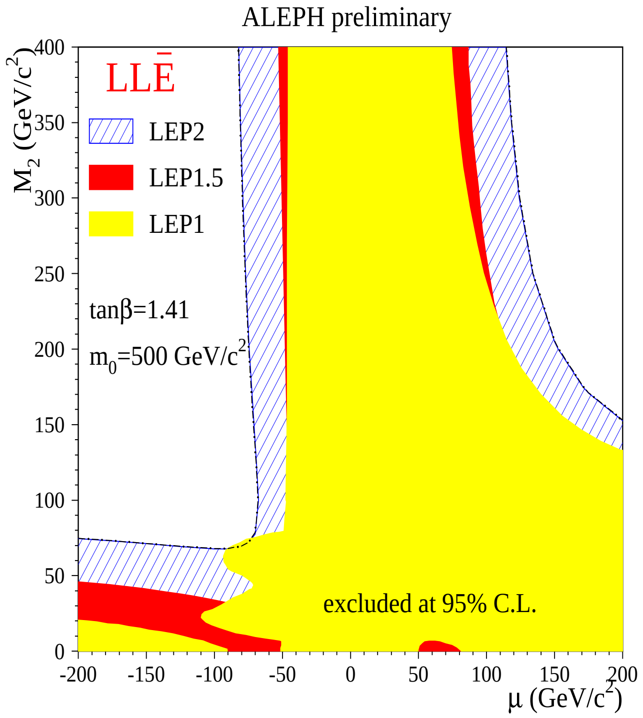
- **Limits on Chargino and Neutralino masses are interpreted in the ($\tan\beta-\mu-\mathrm{M}_2$) space and include LEP1 constraints**

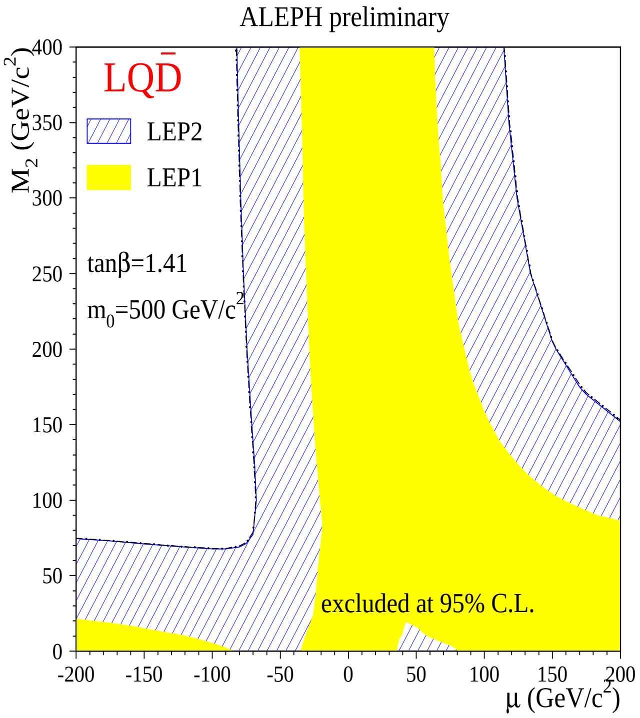
- **In case of large m_0 the limit is derived mainly from $\tilde{\chi}_1^{\pm}$ searches**

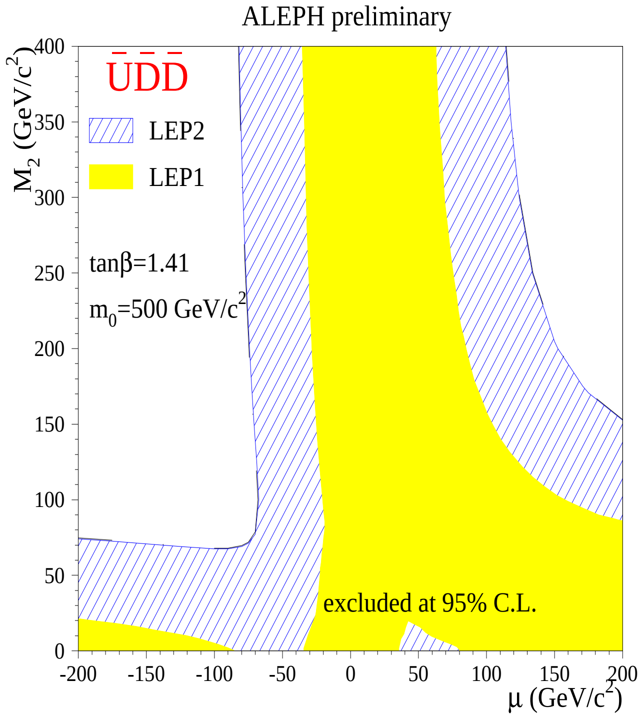
- **For low m_0 (light s-fermions) the gauginos can decay into s-fermions and the selection efficiency depends much stronger on the λ coupling value**

Limits at high m_0

Excluded regions derived from $\tilde{\chi}_i^0$ and $\tilde{\chi}_i^{\pm}$ searches





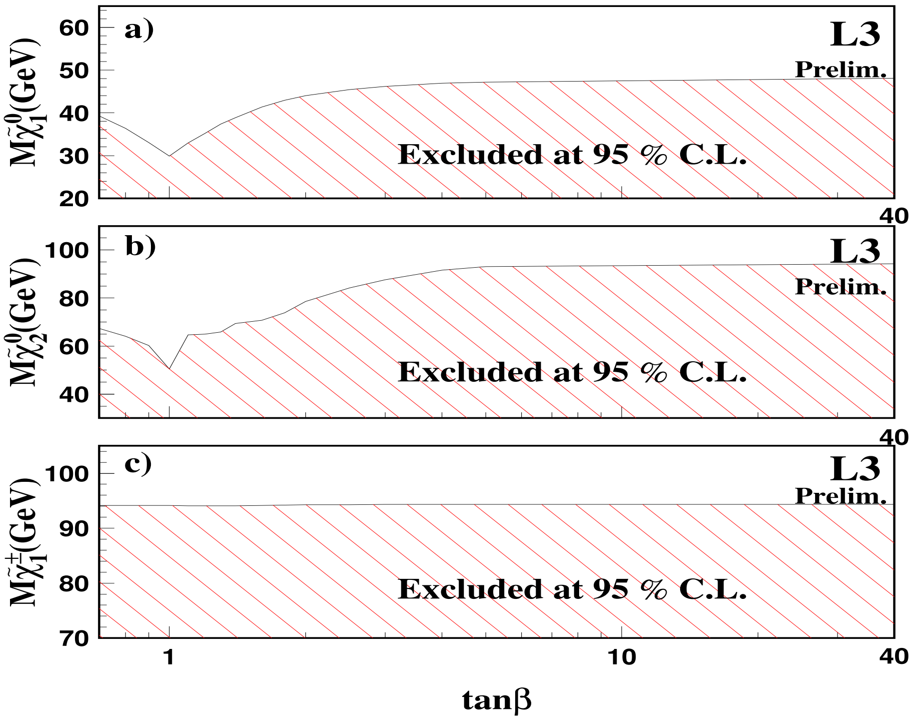


High s-fermions masses

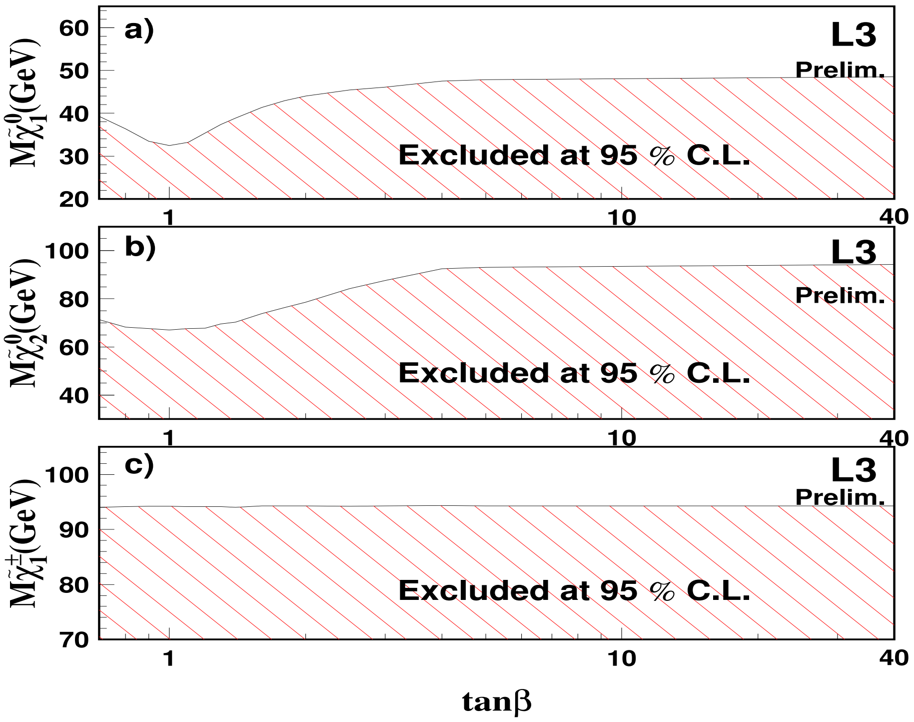
$$\sqrt{s} = 189 \text{ GeV}$$

The limit on $M_{\tilde{\chi}_1^{\pm}}$ reach kinematical limit

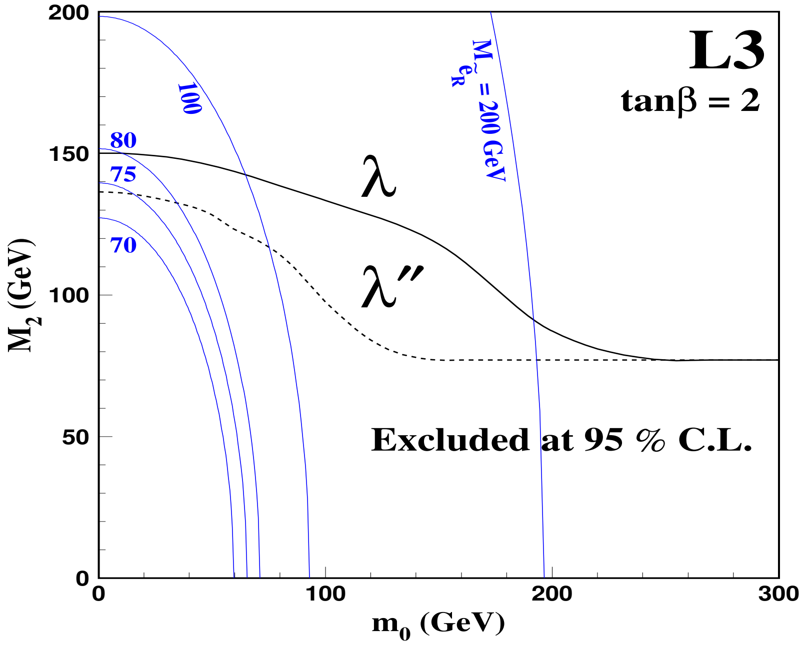
λ'

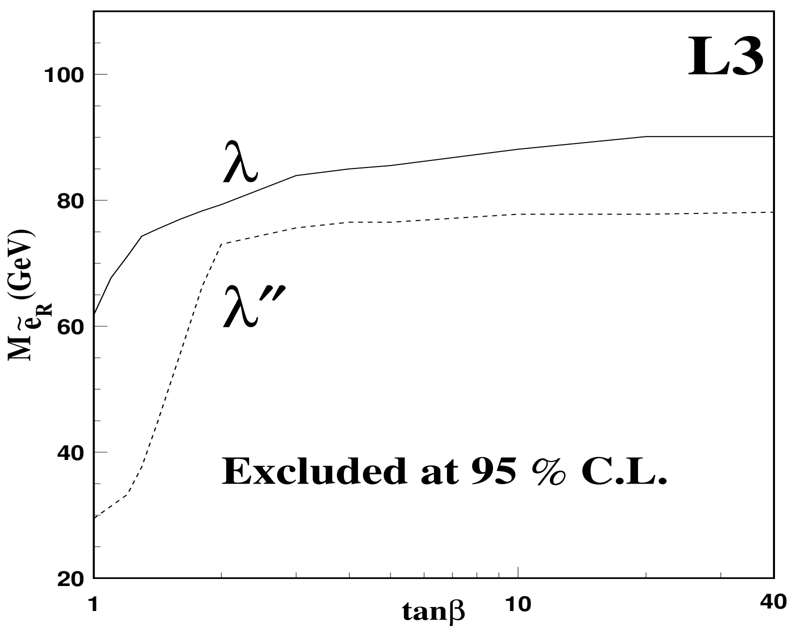


λ''

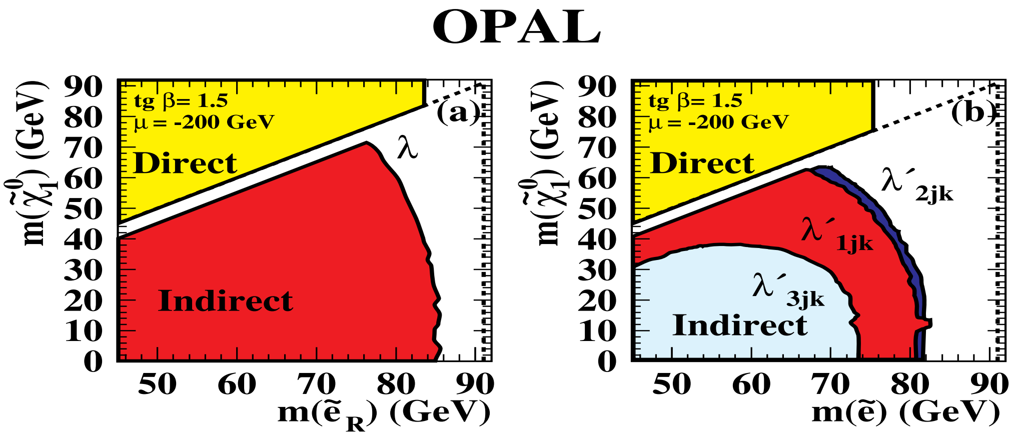


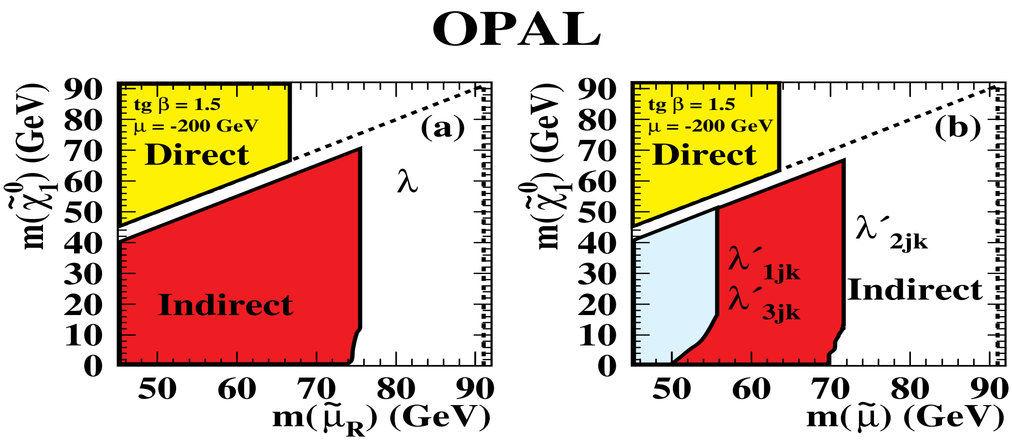
Indirect limits on s-fermion masses can be derived from exclusions in the $M_2 - m_0$ plane

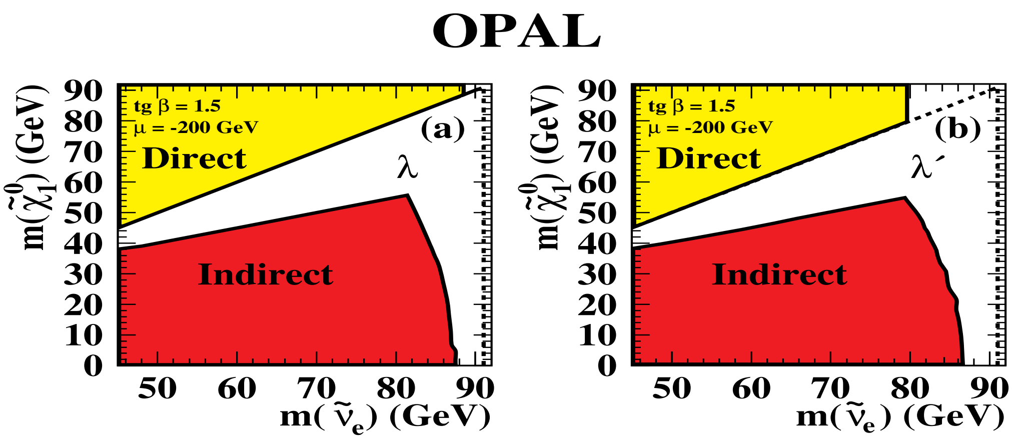




$e^+e^- \longrightarrow \tilde{\ell}_R\tilde{\ell}_R$ via direct/indirect decays (λ and λ')

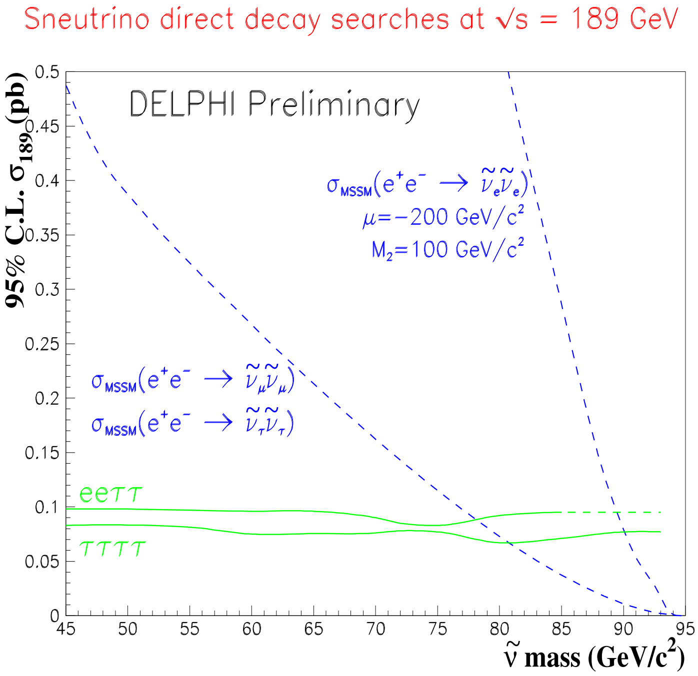




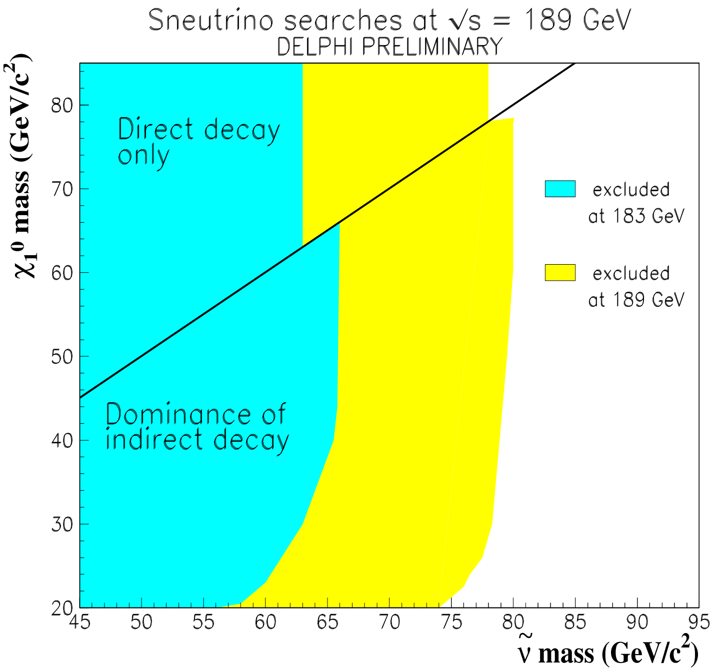


$e^+e^- \longrightarrow \tilde{\nu}\tilde{\nu}$ via direct/indirect decays (λ and λ')

Sneutrino direct decay via λ or λ'



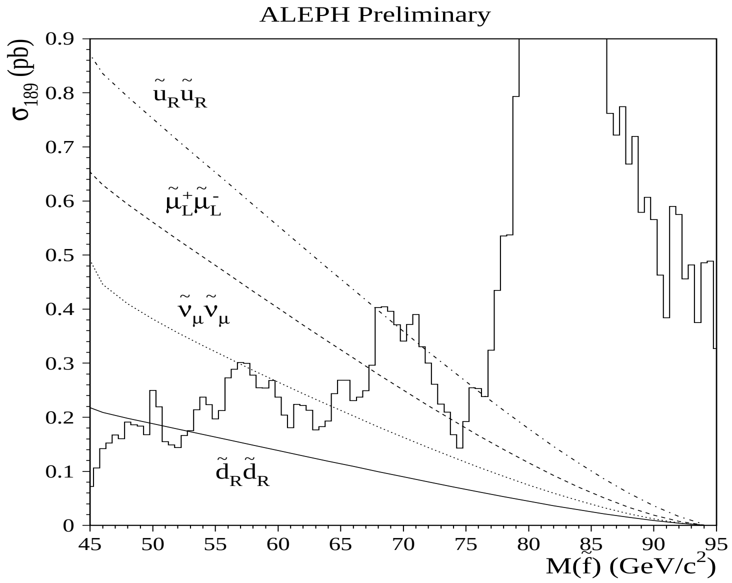
Example of excluded mass region for λ_{133}



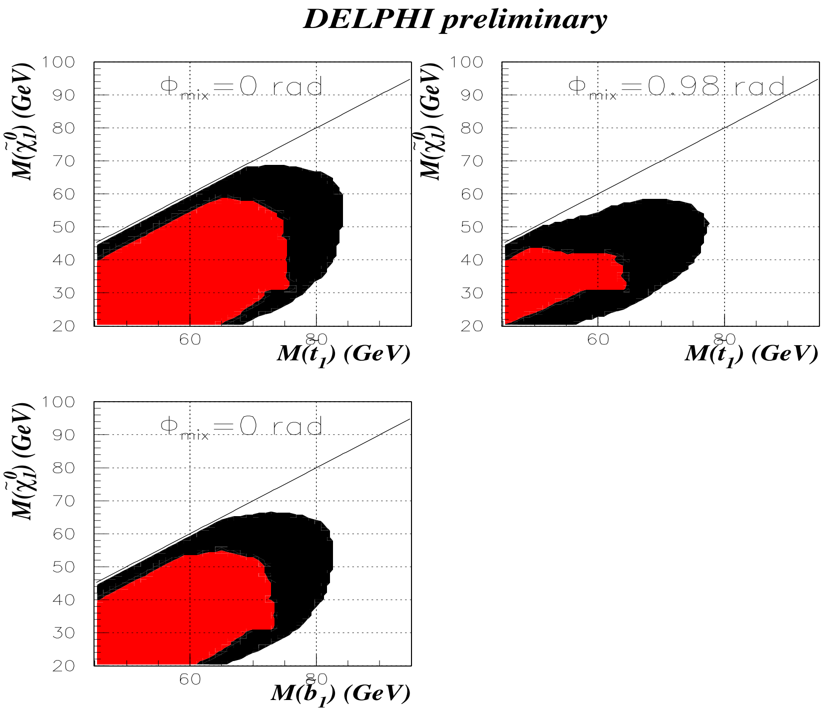
Limits on light s-quarks

$e^+e^- \longrightarrow \tilde{t}_1\tilde{t}_1$ and $e^+e^- \longrightarrow \tilde{b}_1\tilde{b}_1$ via λ' direct and λ'' direct/indirect decays

Direct s-quark decays



Indirect s-quark decays



G.M.S.B. Framework

- Soft SUSY breaking ($M_{SUSY} \lesssim 1$ TeV) mediated by gauge interactions
- Framework is M.S.S.M. with $R-$parity conservation
- The mass spectrum is defined by 6 parameters :

$$\boxed{\tan\beta, \mu, M, F, N, A_0}$$

$\sqrt{F}$	SUSY breaking scale
$\Lambda = \frac{F}{M}$	universal mass scale
M	messenger mass scale
N	number of messenger generations
μ	Higgs mixing parameter
$\tan\beta$	ratio of Higgs doublet v.e.v.

- The gravitino mass is expected to be small

$$\boxed{m_{\tilde{G}} = \frac{1}{k}(\sqrt{F}/100 \text{ TeV})^2 * 2.4 \text{ eV}}$$

$$\boxed{10^{-3} \text{ eV} \lesssim m_{\tilde{G}} \lesssim 10^{3} \text{ eV}}$$

In GMSB models $\tilde{G}$ is the L.S.P.

Phenomenology

$\tilde{\chi}^0_1$ **is the N.L.S.P.**
$\Longrightarrow \tilde{\chi}^0_1 \longrightarrow \gamma\tilde{G}$

Photons and $\not{E}$

Charged slepton N.L.S.P. (in principle $\tilde{\tau}$ due to L-R mixing)
$\Longrightarrow \tilde{\ell} \longrightarrow \ell\tilde{G}$

Leptons and $\not{E}$

- **The decay length of the N.L.S.P. depends on the Gravitino mass and it can be non-negligible**

- **Search mainly for production of slepton or neutralino pair**

$$\mathrm{e^+e^-} \rightarrow \tilde{\ell}\tilde{\ell} \quad \mathrm{e^+e^-} \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1$$

Most important processes :

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

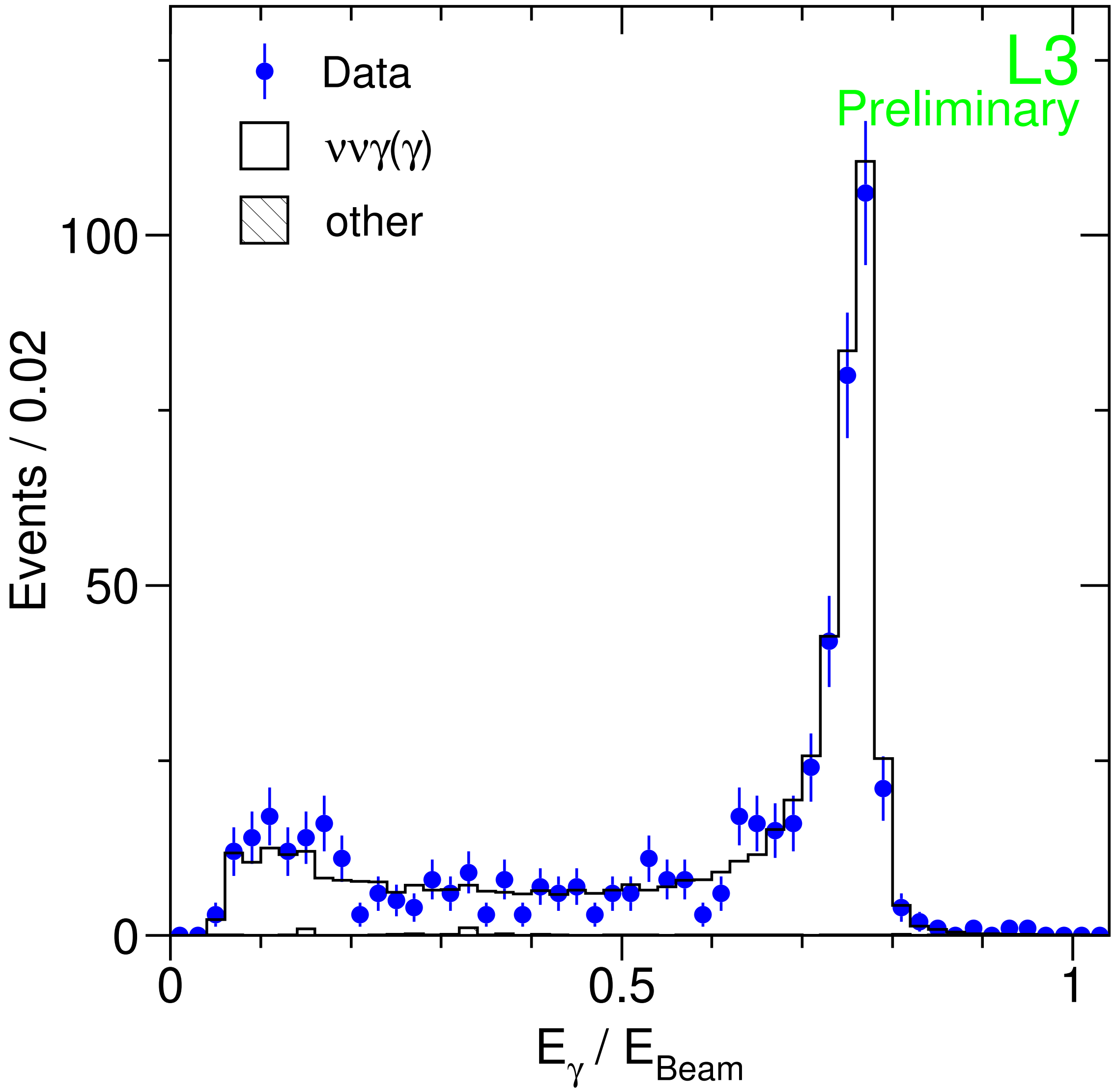
$\Longrightarrow$ single-photon

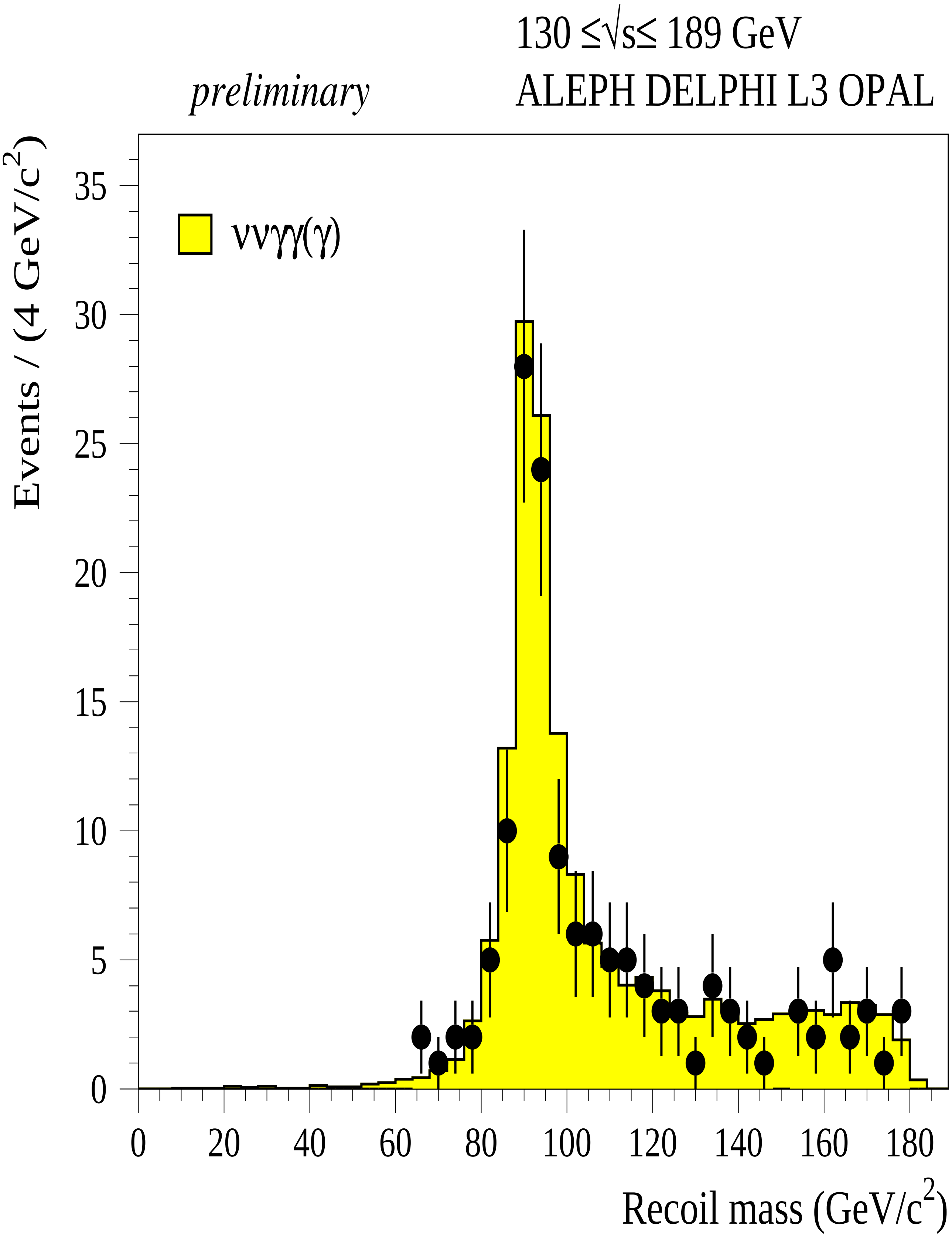
$$e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow \gamma\gamma\tilde{G}\tilde{G}$$

$\Longrightarrow$ two acoplanar γ and $\not{E}$

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

$\Longrightarrow$ two acoplanar leptons with photons and $\not{E}$

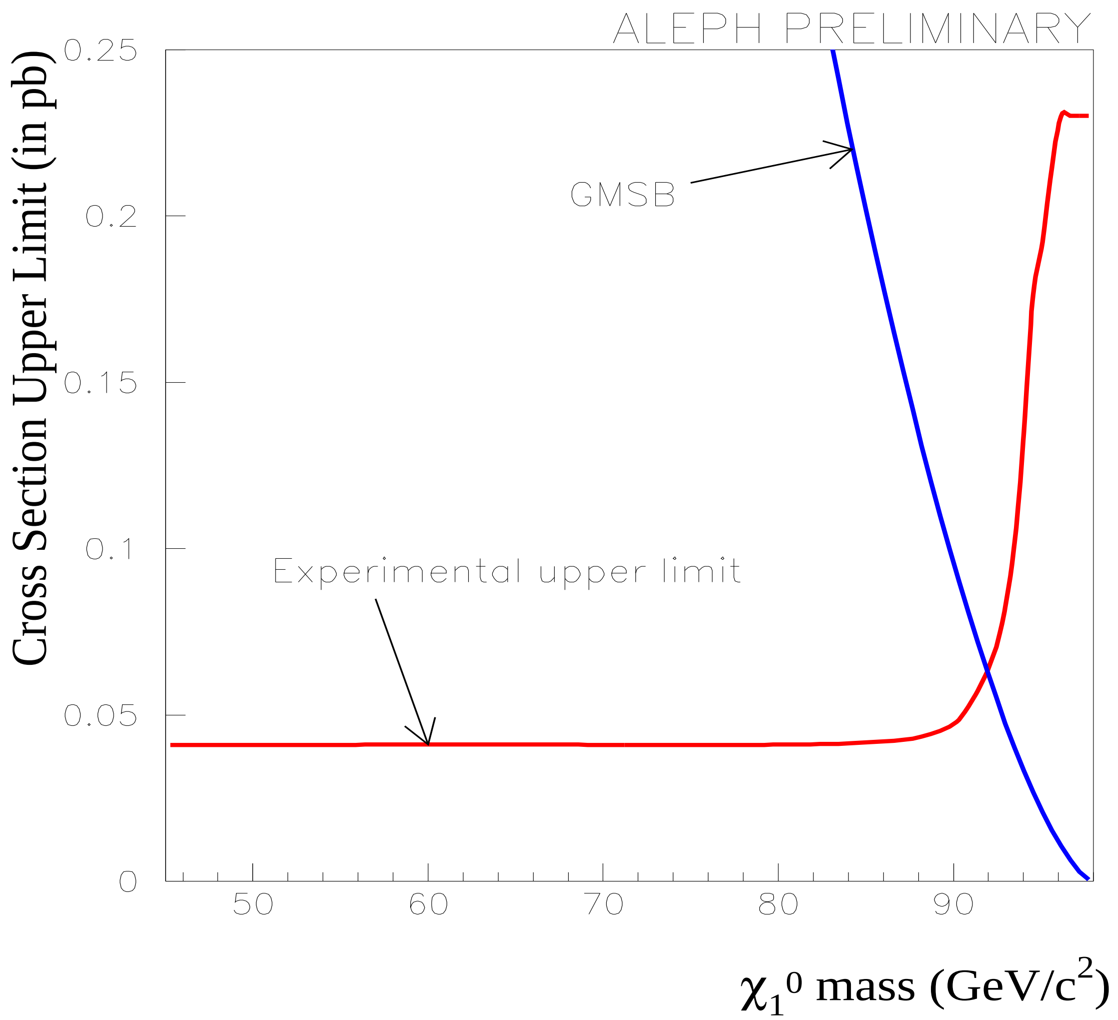




130 ≤√s≤ 189 GeV
preliminary
ALEPH DELPHI L3 OPAL
Events / (4 GeV/c^2)
νν γγ(γ)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160
180
Recoil mass (GeV/c^2)

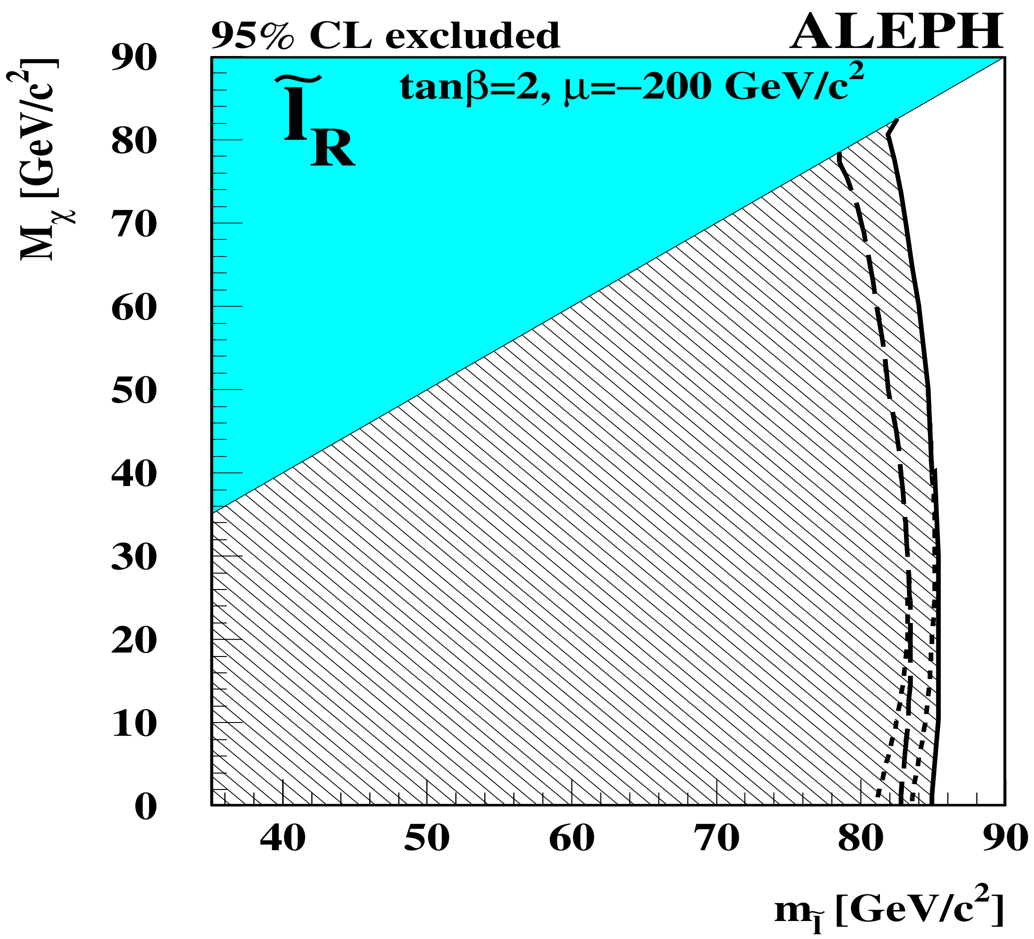
2-γ allows limit on $M_{\tilde{\chi}_1^0} \gtrsim 92$ GeV (short-lived)
One can also derive limit on $m_{\tilde{G}}$
(assuming that only $\tilde{G}$ can be produced at LEP)

A	D	L
$1.1.10^{-5}$ eV	$9.1.10^{-6}$ eV	$8.9.10^{-6}$ eV



ALEPH - $\sqrt{s} = 184$ GeV

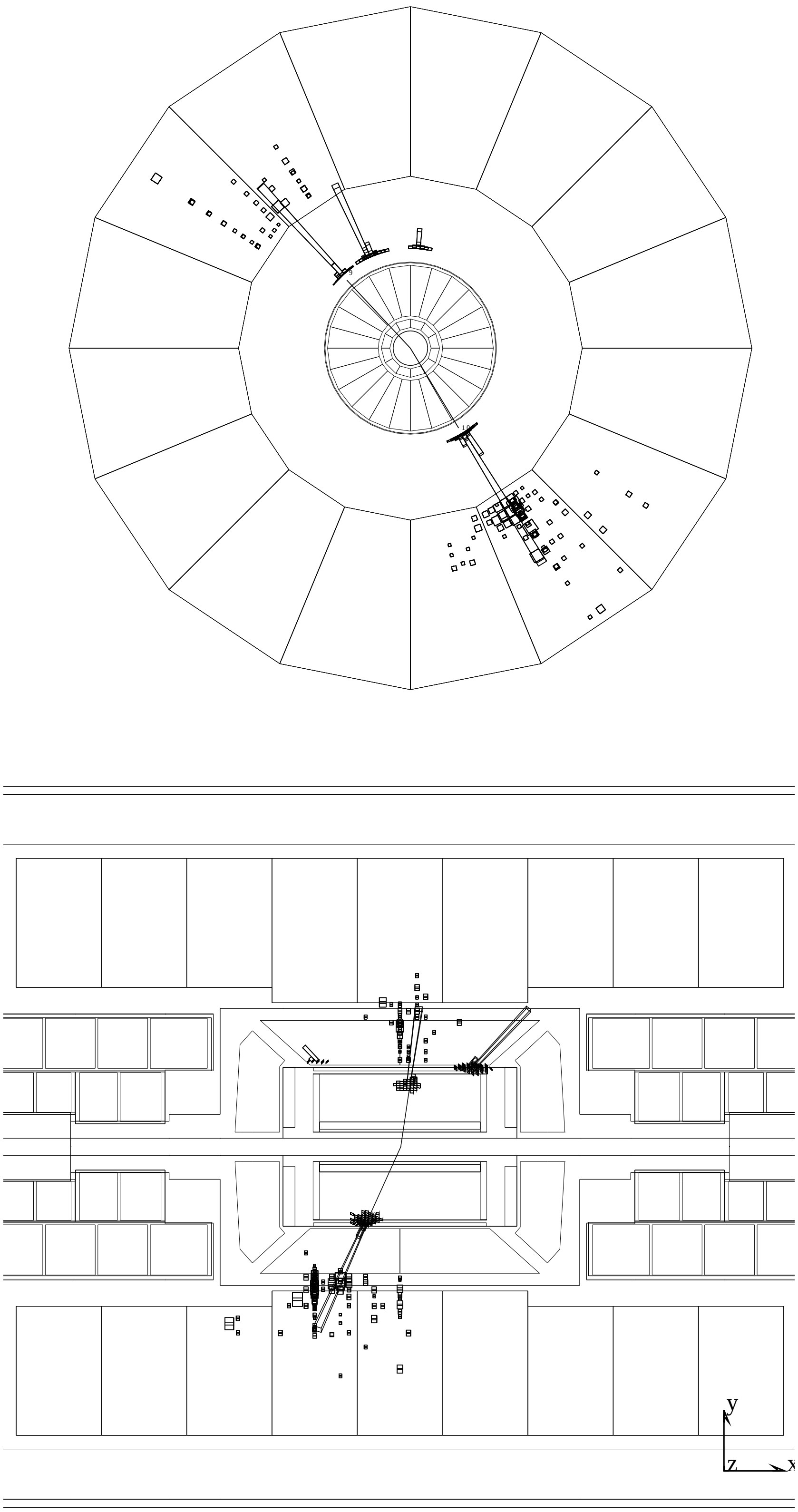
d)



Update at 189 GeV by L3 :

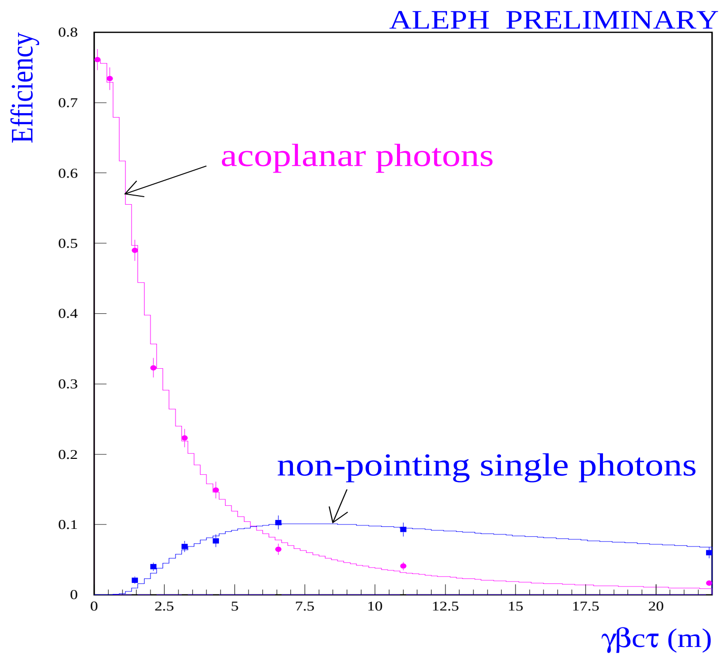
- **Limit on $\tilde{e}_R$ mass (s-channel only) :**
  - **High ΔM : $M_{\tilde{e}_R} \geq 87.5$ GeV**
  - **Low ΔM ($\Delta M \geq 1$ GeV) : $M_{\tilde{e}_R} \geq 87.0$ GeV**
- **Limit on $\tilde{\mu}_R$ mass :**
  - **High ΔM : $M_{\tilde{\mu}_R} \geq 84.9$ GeV**
  - **Low ΔM ($\Delta M \geq 1$ GeV) : $M_{\tilde{\mu}_R} \geq 82.4$ GeV**
- **Limit on $\tilde{\tau}_R$ mass :**
  - **High ΔM : $M_{\tilde{\tau}_R} \geq 83.4$ GeV**
  - **Low ΔM ($\Delta M \geq 2$ GeV) : $M_{\tilde{\tau}_R} \geq 57.0$ GeV**

Candidate $\mathrm{e^+e^-} \to \tilde{\tau}\tilde{\tau} \to \tau\tau\gamma\gamma + \not{E}$

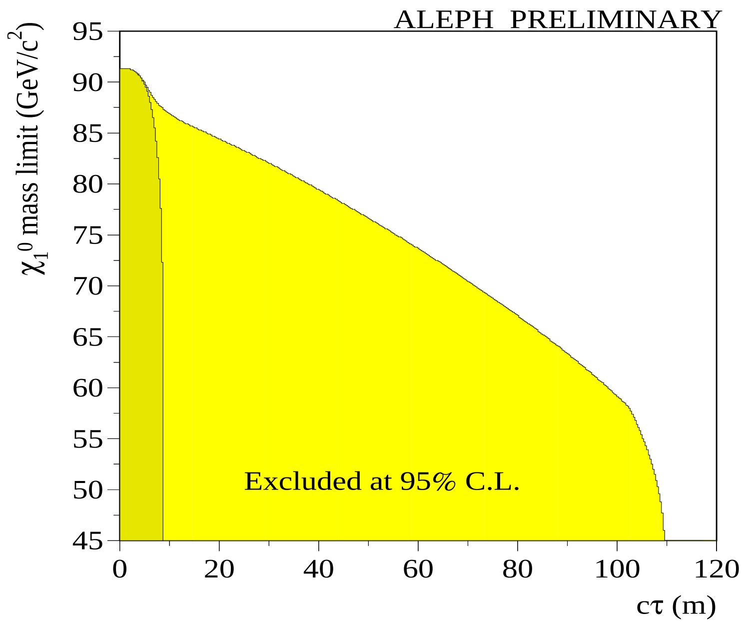


Long-lived $\tilde{\chi}_1^0$ (10 m $<$ L $<$ 1000 m)

Search for non-pointing photons



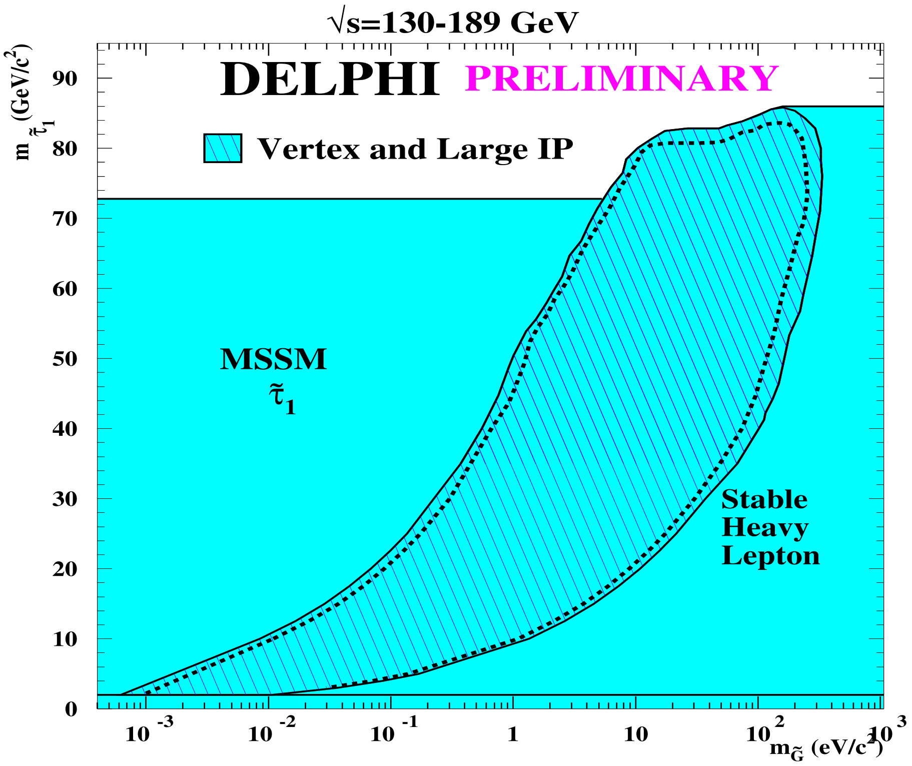
ALEPH $\sqrt{s} = 189$ GeV



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

- **Searches for acoplanar $\tilde{\tau}$-pair in M.S.S.M.**
- **Kinks or large impact parameters events**
- **Search for Stable charged particles**

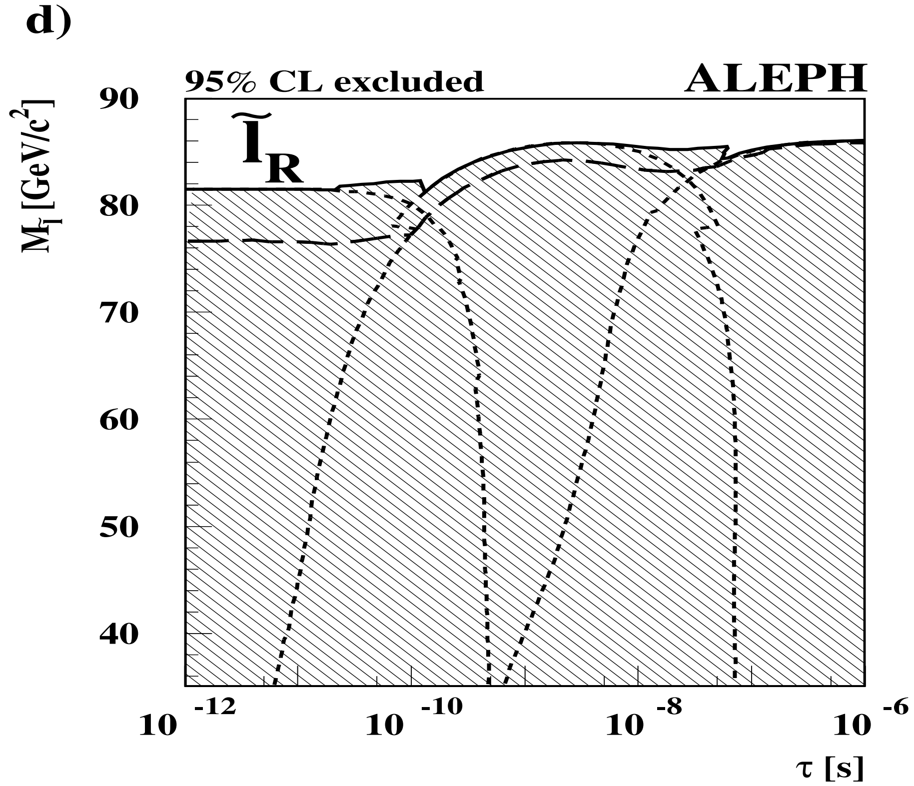
$\tilde{\tau}$ for any $m_{\tilde{G}}$

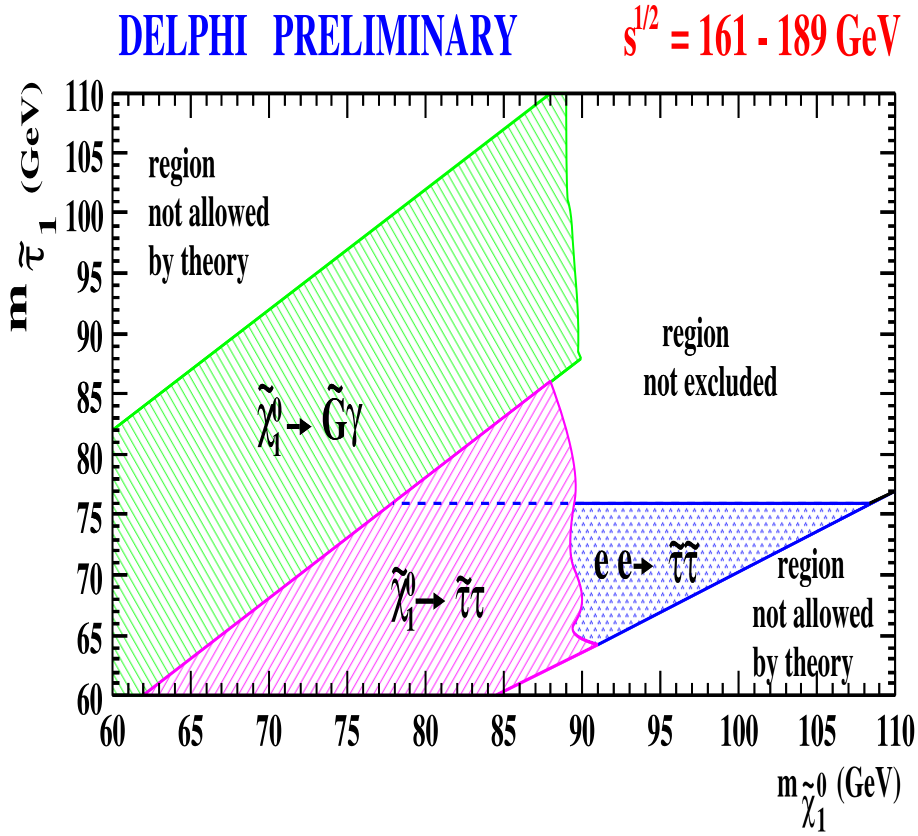


Limit on the $\tilde{\tau}$ mass for any $m_{\tilde{G}}$:

$$M_{\tilde{\tau}} > 71 \text{ GeV (ADLO)}$$

3 mass-degenerate $\tilde{\ell}_R$





At LEP all the possible productions and decays of Supersymmetric particles are investigated

The results are interpreted in the Constrained M.S.S.M. framework, assuming R-parity conservation ar not, but also in Gauge Mediated SUSY breaking Models

As NO EVIDENCE for any signal has been observed yet :

$$\boxed{\textbf{the parameter space is more constrained}}$$

Most important result :

$$\boxed{\mathbf{M_{L.S.P.} \gtrsim 30\ GeV}}$$

Discovery is still possible at LEP200...