LEP SUSY searches at LEP2
in the context of the constrained MSSM

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SUSY99 - Fermilab

June 13-19, 1999

OUTLINE

Introduction

- SUSY framework(s)
- Dataset
- Phenomenology

Mass limits in the CMSSM framework

- Constraints assuming large m_0
- Constraints assuming low m_0
- Higgs constraints

mSUGRA Constraints

Summary

Introduction

Dataset ALEPH DELPHI L3 OPAL

Year	$\sqrt{s}$ (GeV)	L/Exp (pb^{-1})
1989-1995	Zpeak	$\sim$ 160
1995	130-136	$\sim$ 6
1996	161-172	$\sim$ 20
1997	181-184	$\sim$ 55
1998	189	$\sim$ 175
1999	192-200	$\sim$ 25 ...
2000	200+ϵ	

Presented here Results up to 189 Gev

Phenomenology with R-parity conservation assumption

$\longrightarrow$ Sparticles are produced in pairs and decay to their SM partner and LSP

$\longrightarrow$ LSP is stable and weakly interacting :
LSP escapes detection leading to
signal final states with missing energy

SUSY Framework-MSSM

MSSM parameters

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

Constrained MSSM

At the GUT scale, one assumes:

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

Remaining parameters: $m_{1/2}$, m_0, $\tan\beta$, μ, A_0, m_A

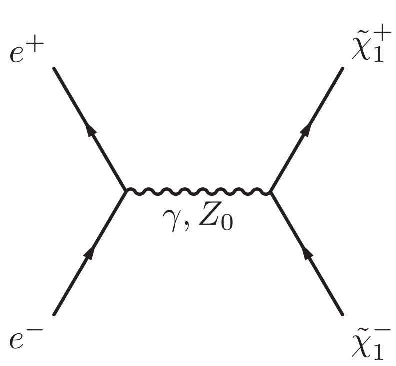
At the EW scale, RGE used $\longrightarrow$ $M_2 \approx 0.8 m_{1/2}$,$M_1 \approx 0.5 M_2$
$m_{\tilde{\mathrm{f}}(m_0,M_2,\tan\beta)}$, $m_{\tilde{\chi}_1^\pm}(M_2,\mu,\tan\beta)$, $m_{\tilde{\chi}_j^0}(M_1, M_2,\mu,\tan\beta)$

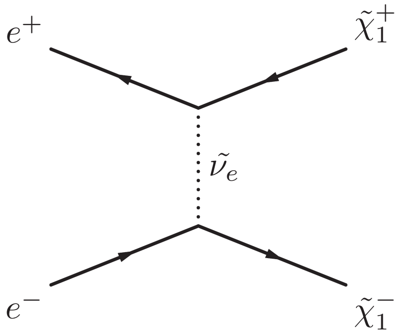
mSUGRA

Unification of all the scalar	$\longrightarrow$ m$_A$ is no more
masses Higgs Bosons included	a free parameter
Dynamic EWSB	$\longrightarrow$ $\lvert\mu\rvert$ is fixed

Remaining parameters: $\tan\beta$, sign(μ) m_0 $m_{1/2}$ A_0

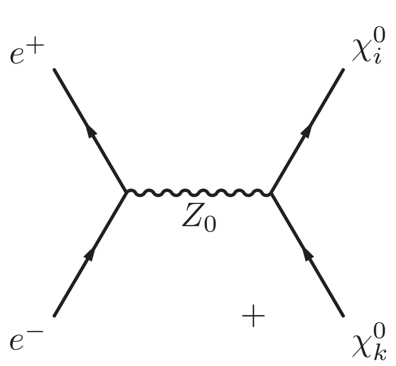
Chargino and Neutralino pair productions

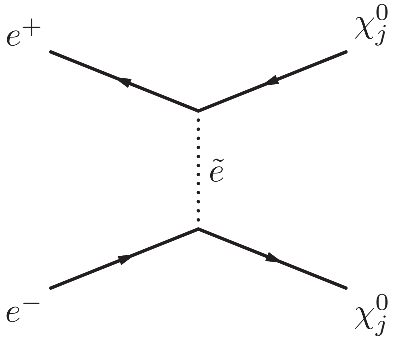




$\tilde{\chi}_1^\pm \to \mathrm{W}^{*\pm}\tilde{\chi}_1^0, \tilde{\nu}l^\pm, \tilde{l}^\pm\nu$

Destructive interference if $\tilde{\chi}_1^\pm$ is gaugino like





$\tilde{\chi}_j^0 \to \mathrm{Z}^*\tilde{\chi}_1^0, \tilde{\nu}\nu, \tilde{l}^\pm l^\mp$

Constructive interference if $\tilde{\chi}_j^0$ is gaugino like

Signal topologies: Jets+$\not{E}$, leptons+jets+$\not{E}$, acoplanar lepton pair $+\not{E}$

Higgsino region $|\mu| << M_2$

No t-channel contribution

Gaugino region $|\mu| >> M_2$ high m_0

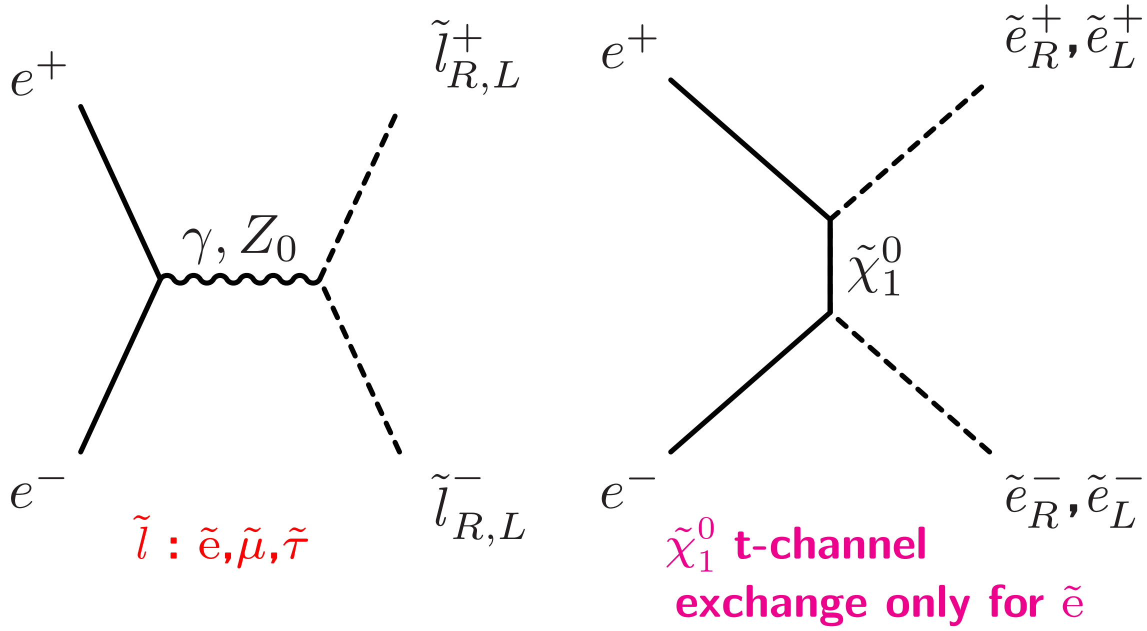
No t-channel contribution

Gaugino region $|\mu| >> M_2$ low m_0

t-channel contribution important

two-body decays enhanced

Scalar lepton pair production



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

Signature: Acoplanar lepton pair plus $\not{E}$

$$\begin{aligned}
m^2_{\tilde{l}_R} &= m_0^2 + 0.15 m^2_{1/2} - sin^2\theta_W M_Z^2 cos2\beta \\
m^2_{\tilde{l}_L} &= m_0^2 + 0.52 m^2_{1/2} - \tfrac{1}{2}(1 - 2sin^2\theta_W) M_Z^2 cos2\beta \\
m^2_{\tilde{\nu}} &= m_0^2 + 0.52 m^2_{1/2} + \tfrac{1}{2} M_Z^2 cos2\beta
\end{aligned}$$

Constraints on $m_{\tilde{l}}$ $\rightarrow$ constraints on (m_0,$m_{1/2}$,$\tan\beta$)

Interpretation of LEP results
Procedure

From $\tilde{\chi}_1^{\pm}, \tilde{l}^{\pm}, \tilde{\chi}_j^0$ inclusive searches

N_{obs}	N_{exp}	L3
198	207	@ 189 GeV

NO excess (ADLO) $\rightarrow$

- **Upper limits on cross section production are set in the ($m_{\tilde{\chi}_1^0}$,m_{SP}) plane**
  Independent of the model.

- **Model predictions for masses and couplings are used to derive limits on sparticle masses and parameters (interplay of all the channels)**

Parameter scan ranges ($\sim$ADLO)

-2 TeV $< \mu < 2$ TeV	0.7$< \tan\beta <$ 60
$0 < M_2 < 2$ TeV	$0 < m_0 < 1$ TeV
$0 < \lvert A_t \rvert < 4$ TeV	$0 < m_A < 2$ TeV

High m_0

Sleptons are heavy

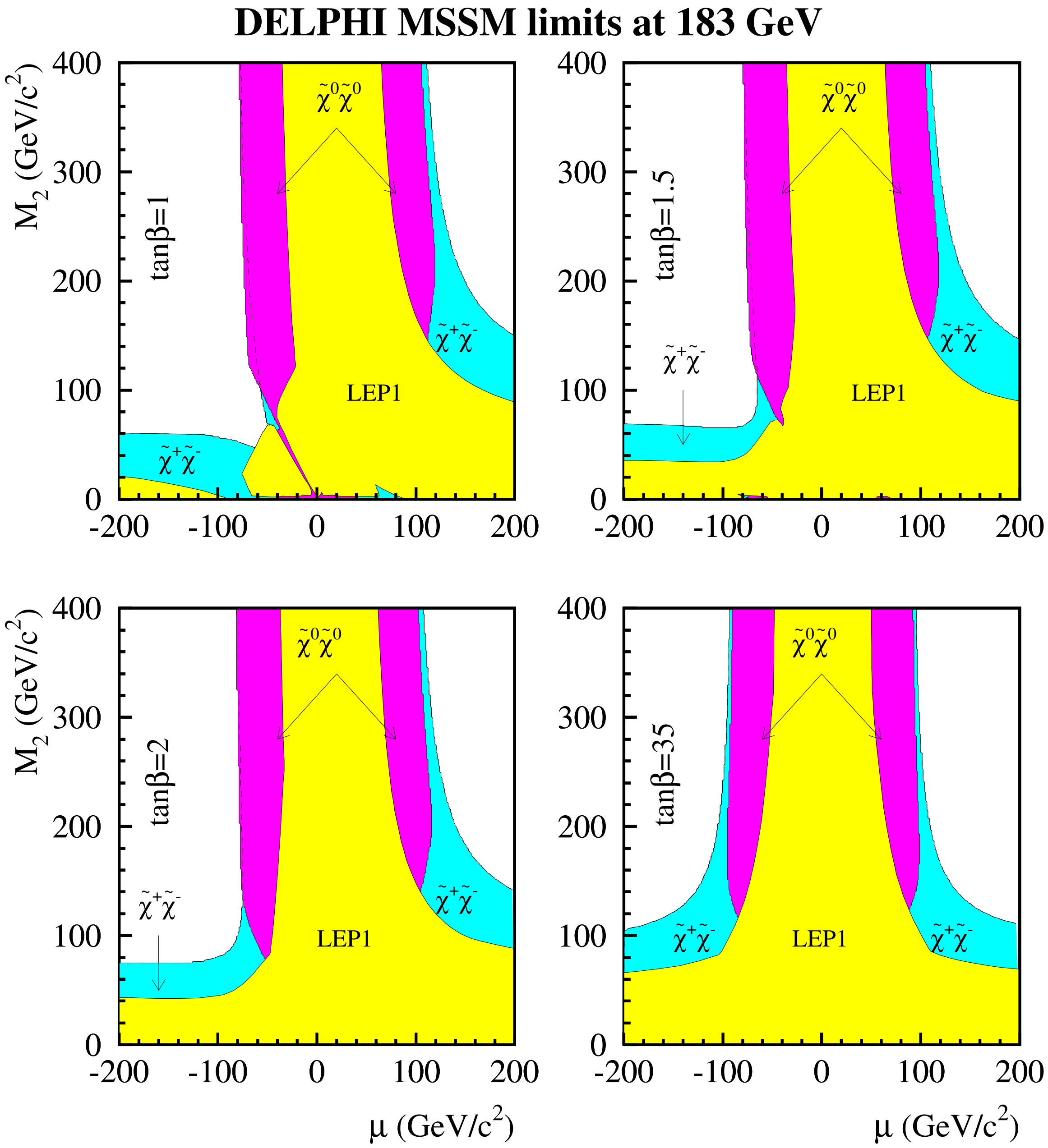
$-$ **Sleptons are not at the kinematic reach**

$+$ $\tilde{\chi}_1^\pm$ **cross section high**
$\tilde{\chi}_1^\pm \to W^* \tilde{\chi}_1^0$ **dominates**

$+$ **Pair production cross section high for higgsino like** $\tilde{\chi}_j^0$
$\tilde{\chi}_j^0 \to Z^* \tilde{\chi}_1^0$ **dominates**

$m_{\tilde{\chi}_1^\pm}$ **(**M_2**,**μ**,**$\tan\beta$**),** $m_{\tilde{\chi}_2^0}$ **(**m_2**,**μ**,**$\tan\beta$**) Limits translated into (**M_2**,**μ**) exclusion contours for** $\tan\beta$ **fixed or into indirect limit on** $m_{\tilde{\chi}_1^0}$

Limits on M_2,μ parameters for large m_0

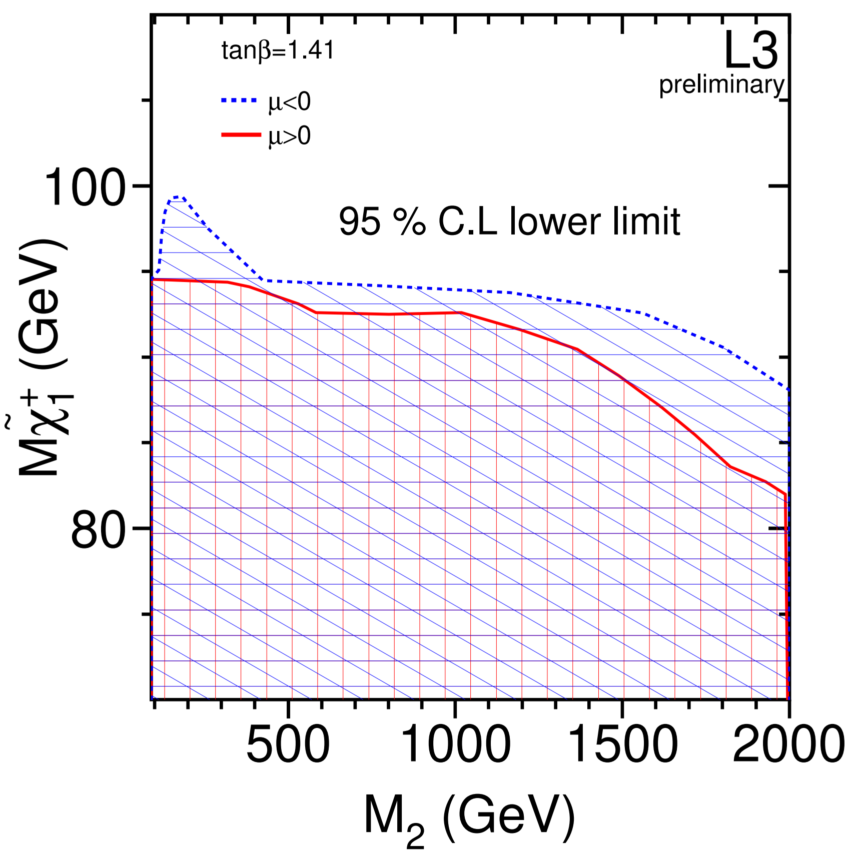


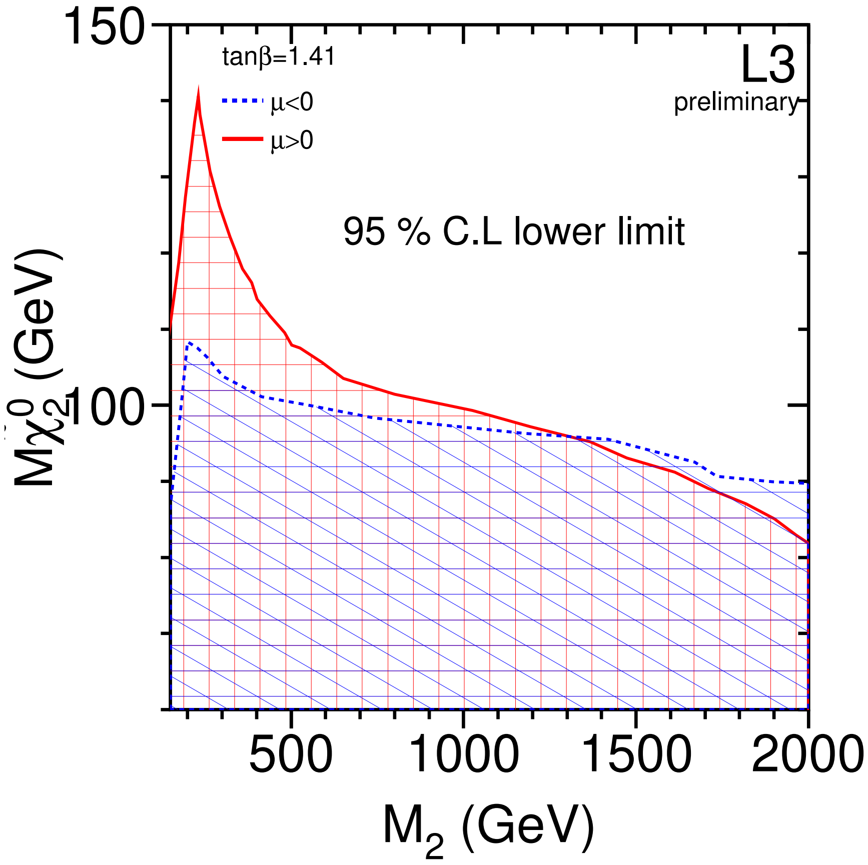
Complementarity of the Chargino and the Neutralino searches at low $\tan\beta$

Main contribution to exclusion contour from Chargino searches

Limits on $m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_2^0}$ for large m_0

Gaugino Like $\tilde{\chi}_1^\pm$: $\sim$at the Kinematic Limit 94.3 GeV

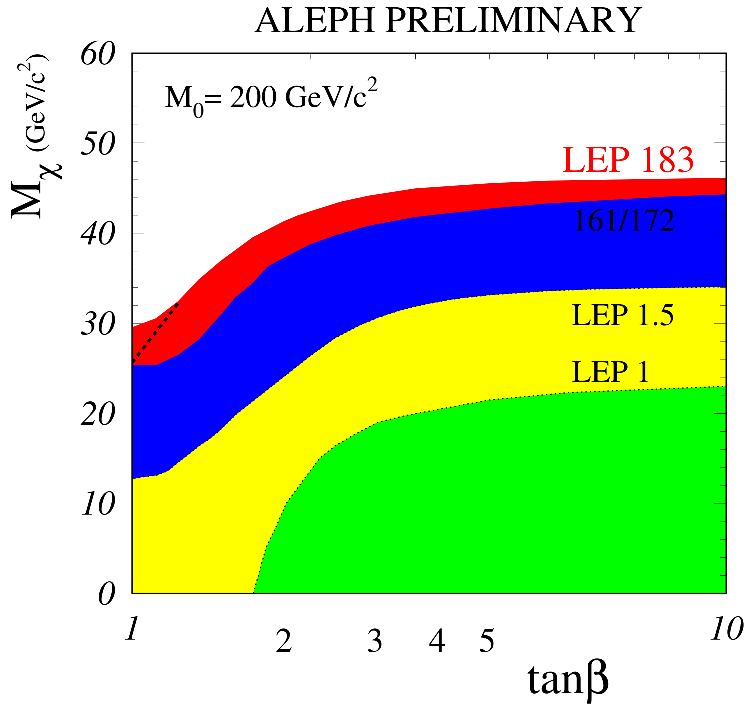


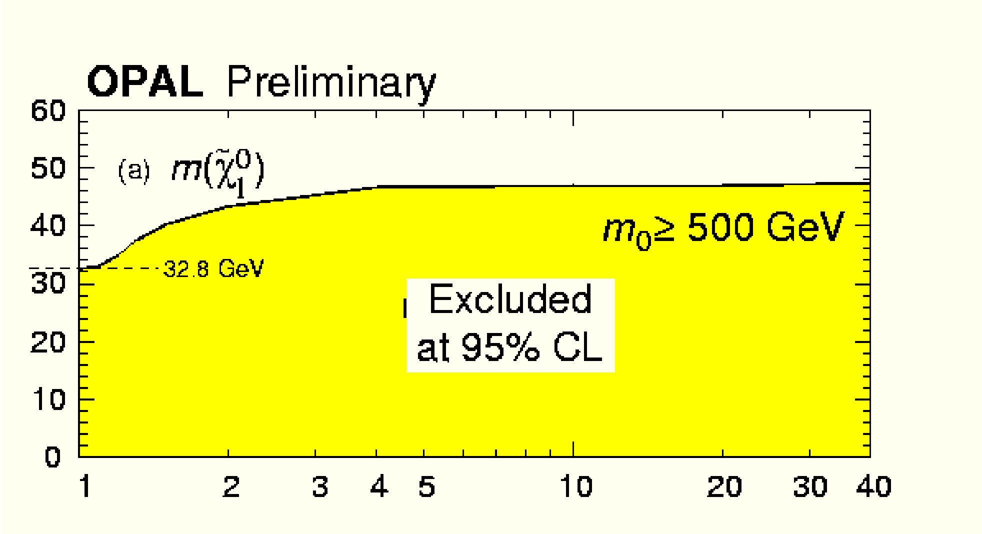


ΔM = $m_{\tilde{\chi}_1^\pm}$-$m_{\tilde{\chi}_1^0}$ (resp. $m_{\tilde{\chi}_2^0}$-$m_{\tilde{\chi}_1^0}$) decreases for increasing M_2

M_2=2 TeV corresponds to ΔM $\sim$ 2-3 GeV

Limits on $m_{\tilde{\chi}_1^0}$ and M_2 for high m_0





A	$m_{\tilde{\chi}_1^0} >$	32.3 GeV	@ 189 GeV
D	$m_{\tilde{\chi}_1^0} >$	31.2 GeV	@ 189 GeV
L	$m_{\tilde{\chi}_1^0} >$	32.5 GeV	@ 189 GeV
O	$m_{\tilde{\chi}_1^0} >$	32.7 GeV	@ 189 GeV

Low m_0

Sleptons are light

$+$ **Sleptons are at the kinematic reach**

$-$ $\tilde{\chi}_1^{\pm}$ **cross section smaller due to the destructive interference of s-t channels.**

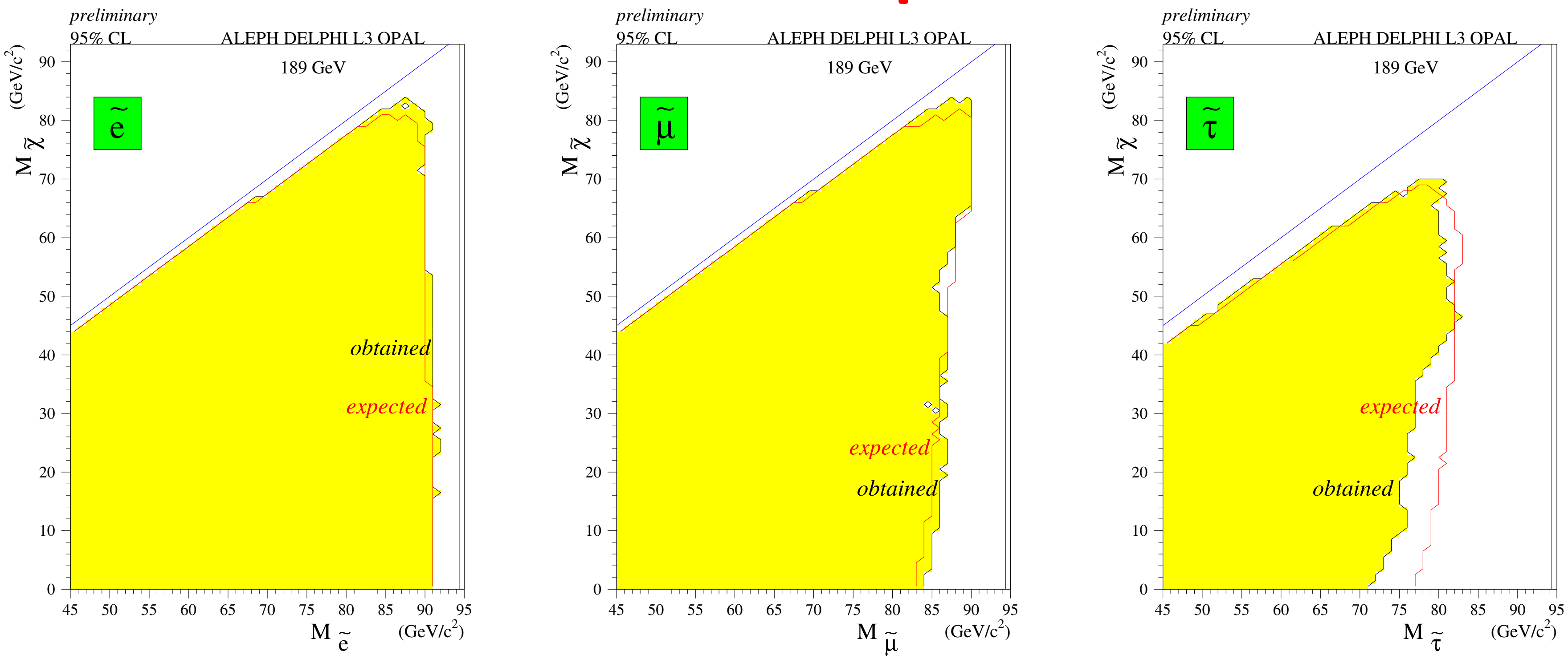
$-$ $\tilde{\chi}_1^{\pm}$ **leptonic branching ratio is enhanced**

smaller detection efficiency if $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}\nu$
depends on (A_t**,**μ**,**$\tan\beta$**)**
$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\mathrm{l}}\nu$ **and small** $|m_{chargino} - m_{\tilde{\nu}}|$

$+$ $\tilde{\chi}_j^0\tilde{\chi}_k^0$ **cross sections larger**

Many processes included
Cascade decays all included such as
$\tilde{\chi}_{3,4}^0 \rightarrow \tilde{\nu}\nu$ **with** $\tilde{\nu} \rightarrow \tilde{\chi}_1^+ l^-$ **or** $\tilde{\chi}_2^0\nu$

Limits on Scalar lepton masses



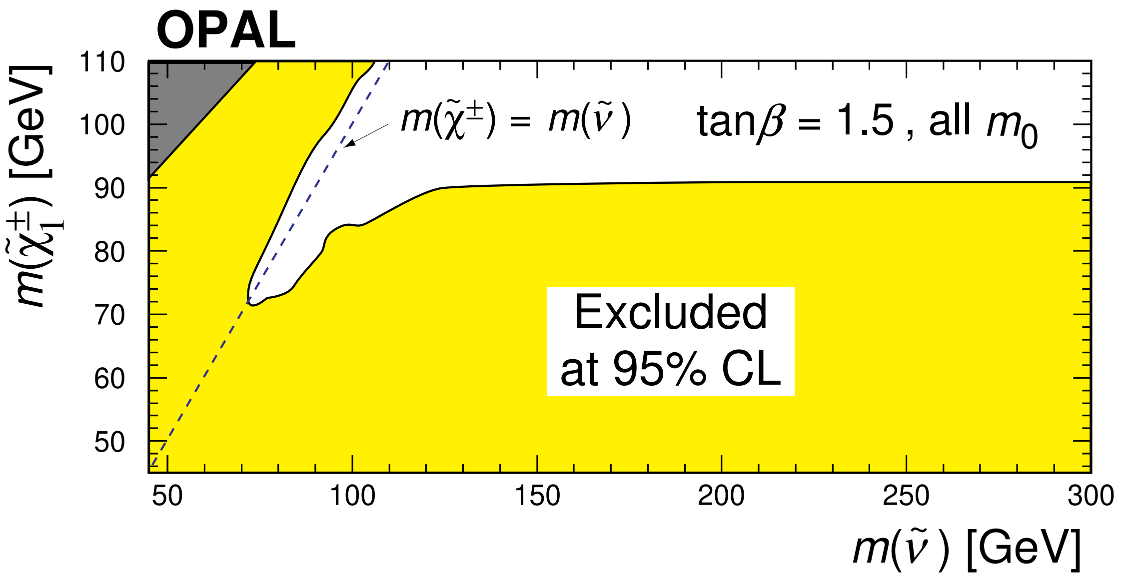
	ADLO @189 GeV	ALEPH @189 GeV
	$\Delta m >$ 15 GeV	any Δm
$m_{\tilde{e}_r} >$	89 GeV	70* GeV
$m_{\tilde{\mu}_r} >$	84 GeV	
$m_{\tilde{\tau}_r} >$	71 GeV	

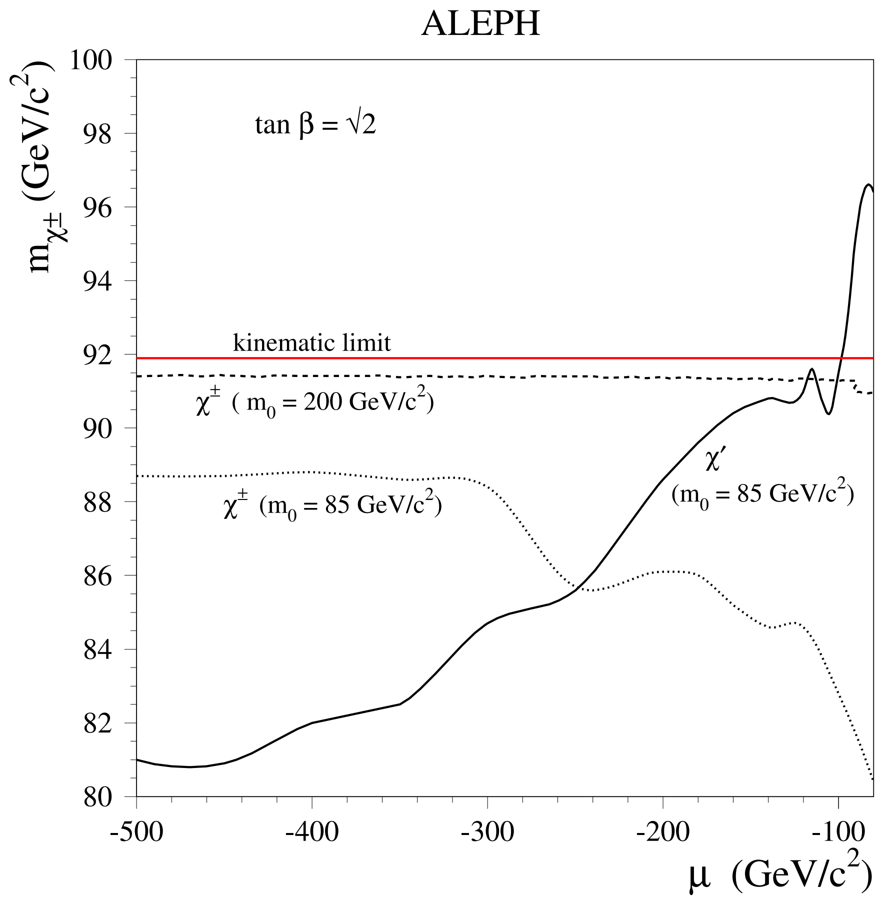
* with single e from $e^+e^- \longrightarrow \tilde{e}_R\tilde{e}_L$ process for $\tan\beta = 2$

Limits on $m_{\tilde{\chi}_1^\pm}$ as a function of $M_{\tilde{\nu}}$

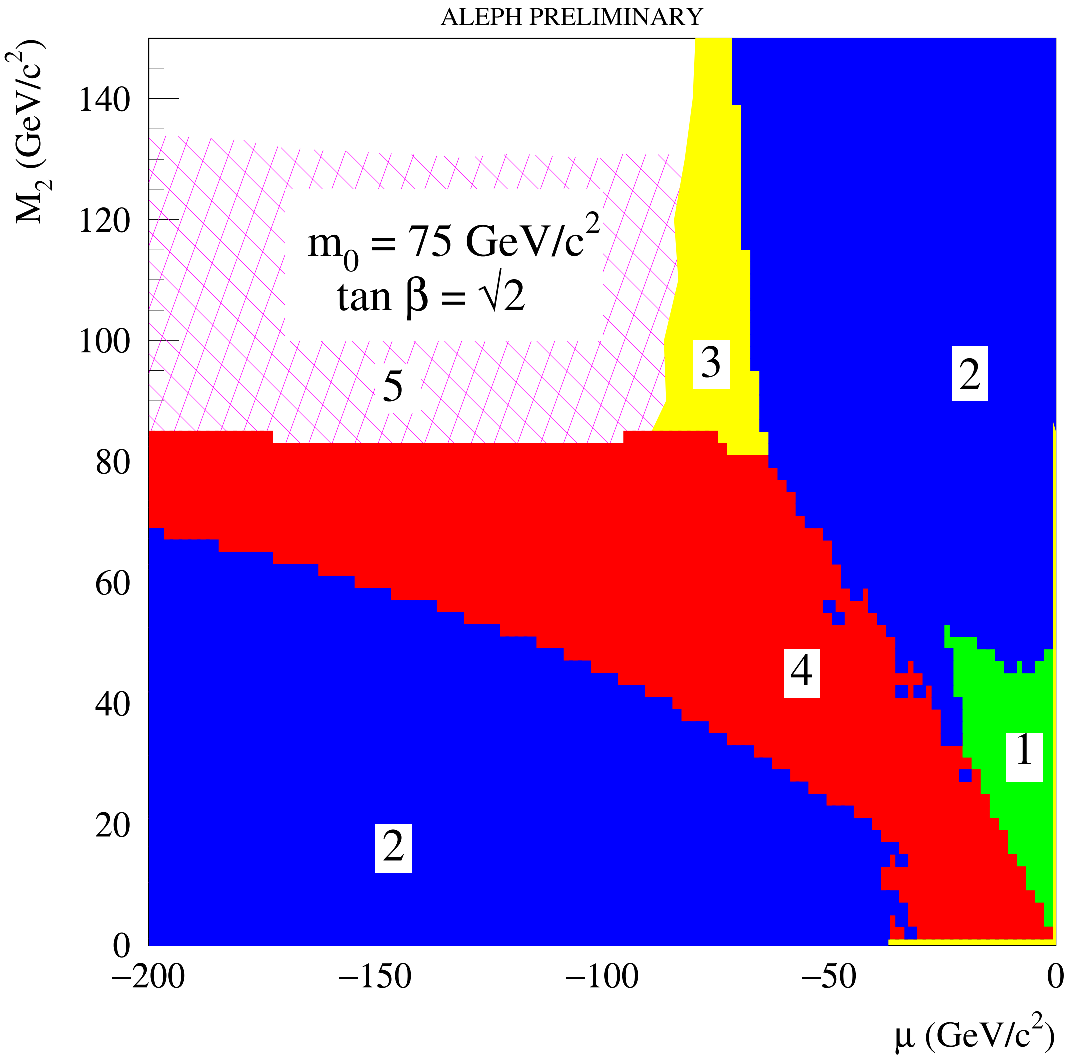
For large $m_{\tilde{\nu}}$, $\tilde{\chi}_1^\pm$ is at the Kinematic Limit

For lower $m_{\tilde{\nu}}$, $\sigma_{e^-e^-\to\tilde{\chi}_1^+\tilde{\chi}_1^-}$ decreases and $\tilde{\chi}_1^\pm$ remains invisible as soon as $0 < m_{\tilde{\chi}_1^\pm} - m_{\tilde{\nu}} < 3$ GeV





Contributions to M_2-μ exclusions



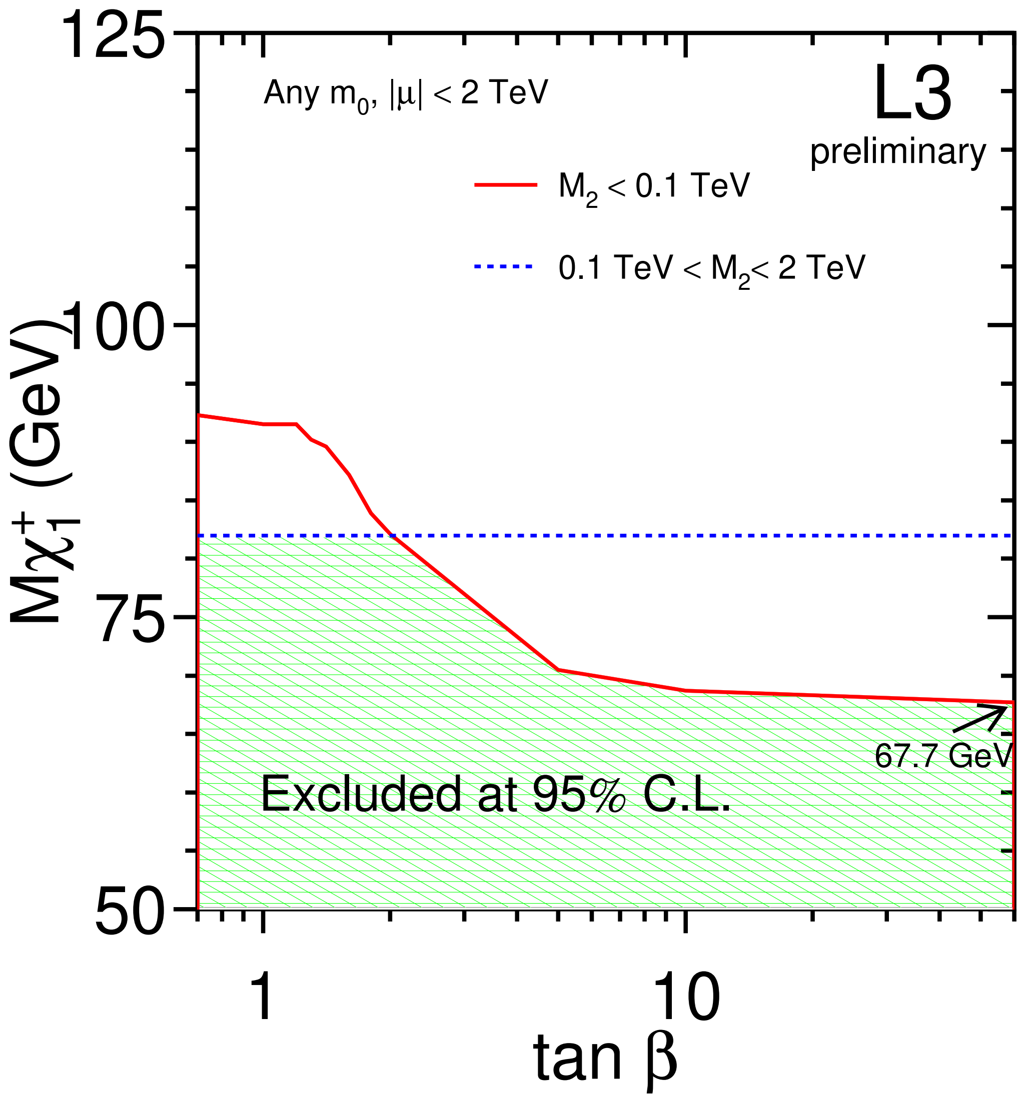
4: $\tilde{l}$

2: $\tilde{\chi}_1^{\pm}$

3: $\tilde{\chi}_j^0$

1: $\tilde{\chi}_j^0$ **LEP1**

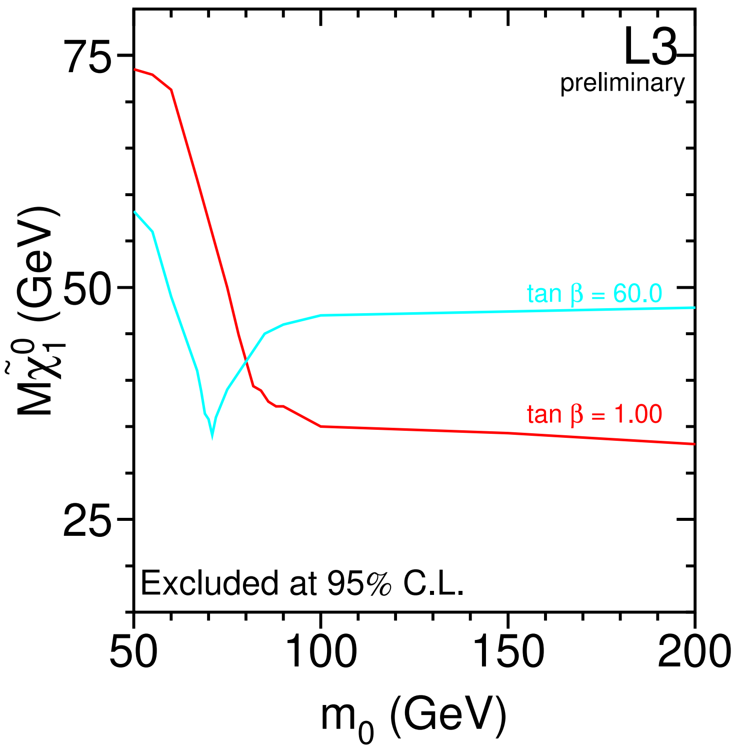
Absolute limit on $m_{\tilde{\chi}_1^\pm}$

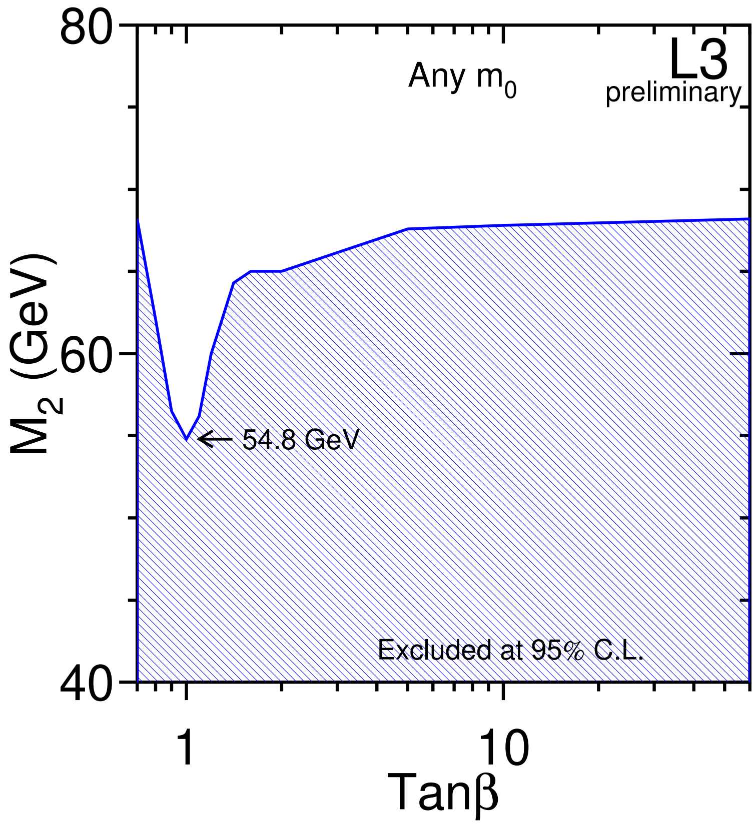


- $\tan\beta < 2$: **minimum found in the deep Higgsino region $|\mu| << M_2$**

$\tan\beta > 2$: **minimum found in the mixed or the gaugino region for $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\nu}}$, the indirect limit is given by the sleptons**

Limits on $m_{\tilde{\chi}_1^0}$ and M_2 for any m_0





A $m_{\tilde{\chi}_1^0} >$ 32.3 GeV @ 189 GeV

D $m_{\tilde{\chi}_1^0} >$ 31.2 GeV @ 189 GeV

L $m_{\tilde{\chi}_1^0} >$ 32.5 GeV @ 189 GeV

O $m_{\tilde{\chi}_1^0} >$ 27.9 GeV @ 189 GeV

$M_2 >$ 54.8 GeV any m_0

Including Higgs and Stop constraints

M_h^2

$M_Z^2 cos^2(2\beta)$ **)** **Large** m_A

$\rightarrow$ **constraints on** $\tan\beta$

$+\ m_t^4/m_W^2 Log(m_{\tilde{\mathrm{t}}}^2/m_t^2)$ **no mixing**

$\rightarrow$ **constraints on** $\tan\beta$**,**$m_{\tilde{\mathrm{t}}}$

$+\tilde{\mathrm{t}}$ **sector mixing**

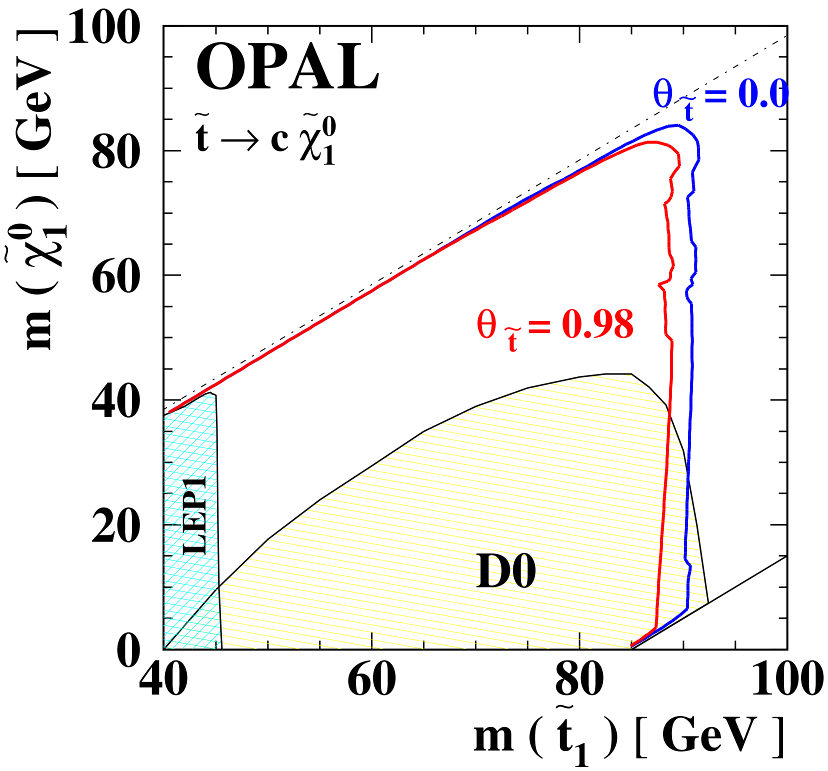
$\rightarrow$ **constraints on** $\tan\beta$**,** $m_{\tilde{\mathrm{t}}_{1,2}}$

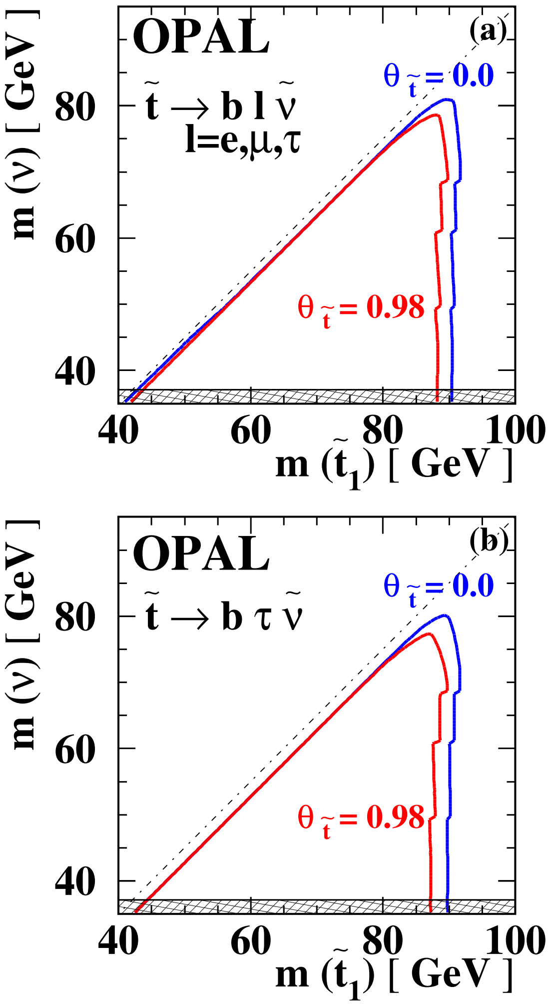
LEP constraints on $m_{\tilde{\mathrm{t}}_1}$ **are also included**

Limits on Stop mass

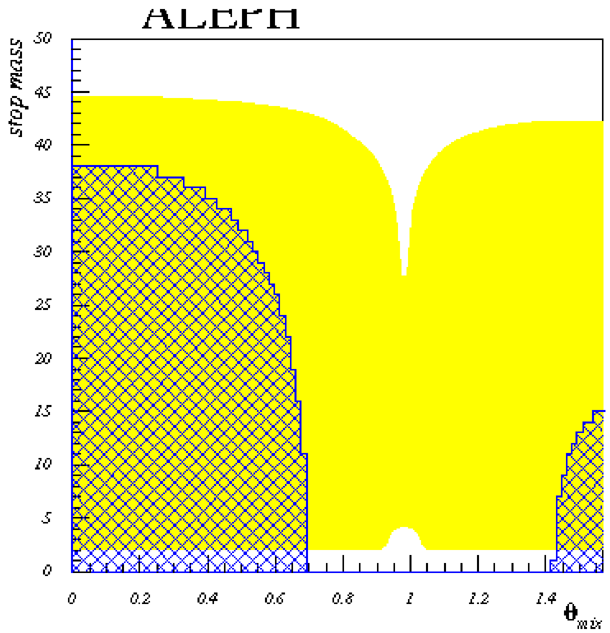
$\tilde{t}_1 \rightarrow c\tilde{\chi}^0_1$

$m_{\tilde{t}_1} > 87$ **GeV** $\Delta M > 10$ **GeV**



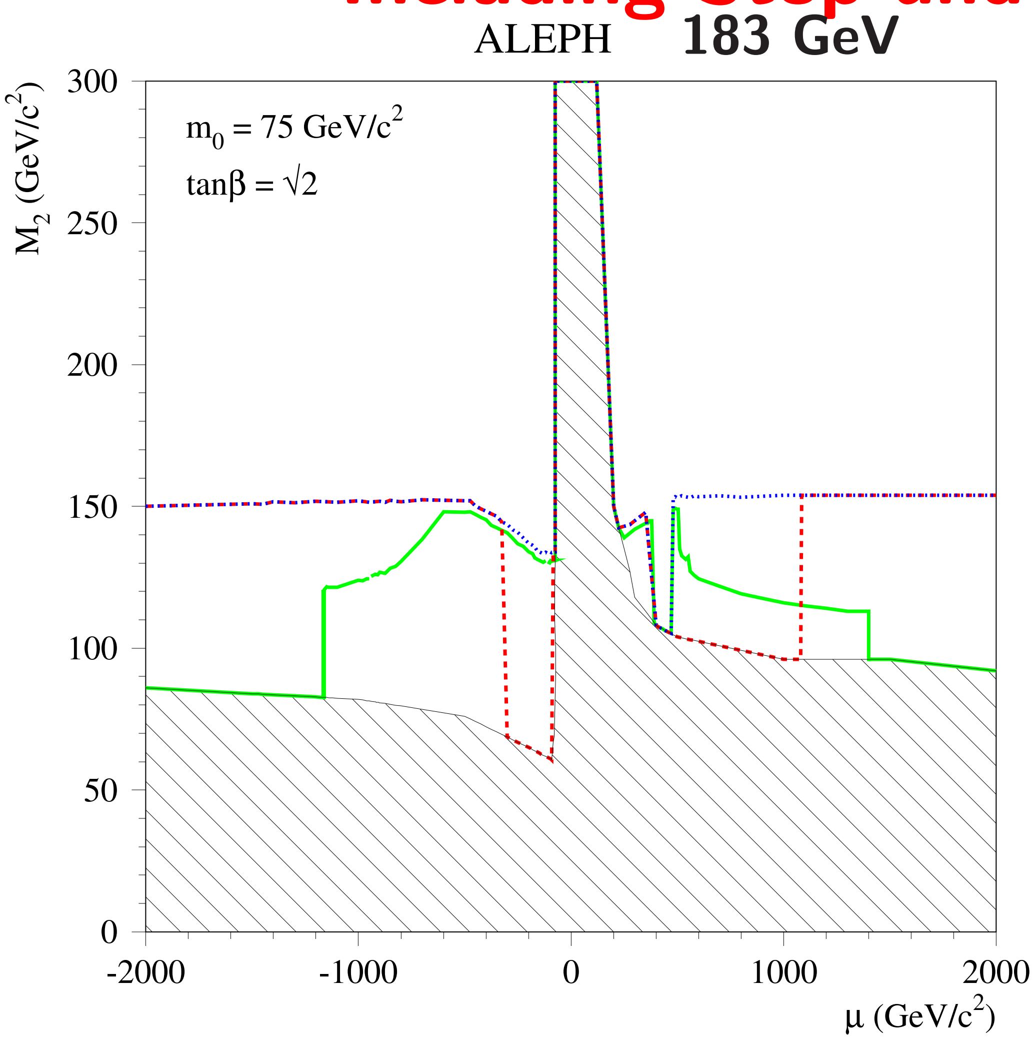


LEPI constraints
$\Delta M > 2$ **GeV**



(a) $\Delta m \geq 2$ GeV/c^2

Including Stop and Higgs Searches



..... m_A=1 TeV, scan on A_t and Higgs limits

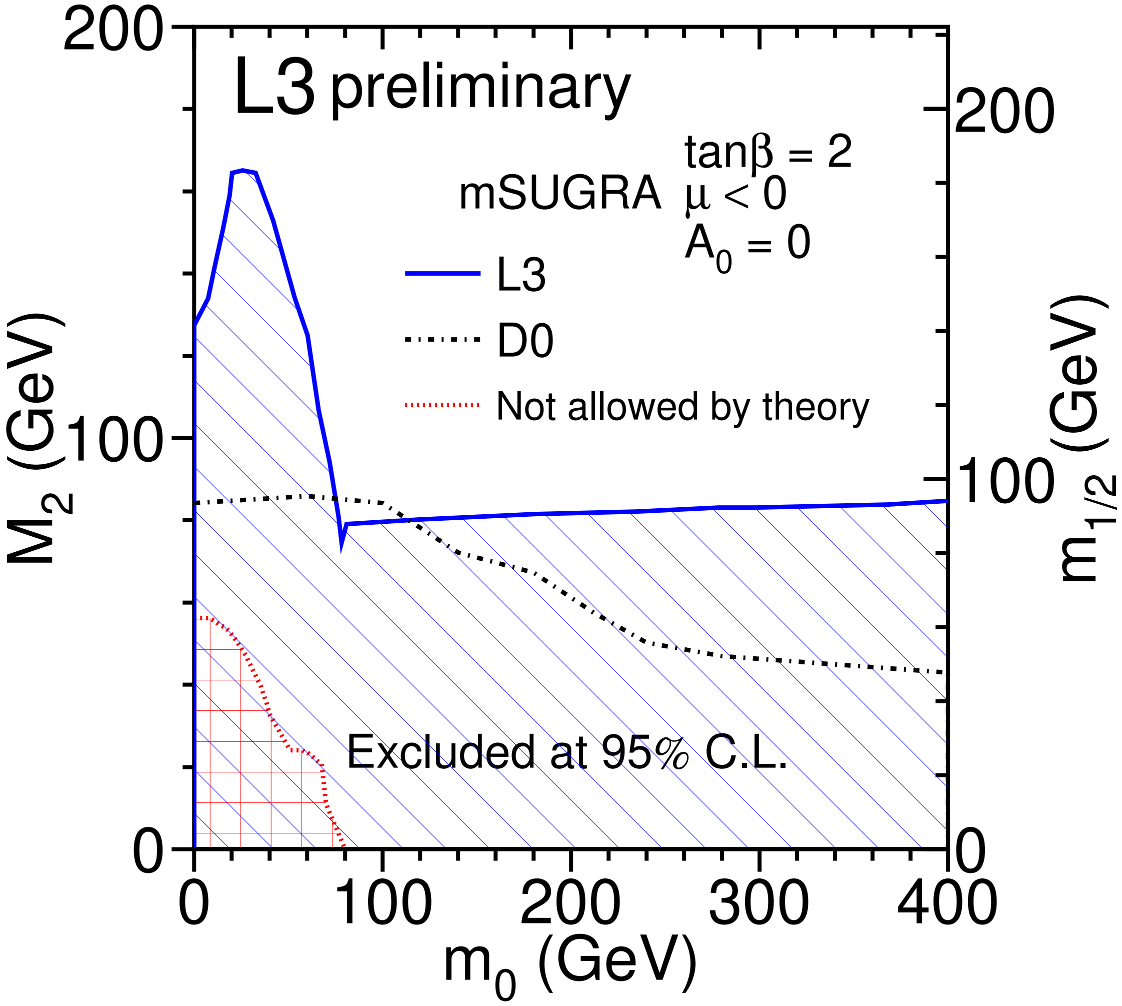
- - - m_A=1 TeV, scan on A_t, Higgs limits and constraints from Stop limits assuming $m_{\tilde{t}} > m_{\tilde{\chi}_1^0} + 2$

— Scan on m_A, scan on A_t, Higgs limits and constraints from Stop limits assuming $m_{\tilde{t}} > m_{\tilde{\chi}_1^0} + 2$

But Higgs contribution $\searrow$ for larger m_0 or larger $\tan\beta$
$\rightarrow$ no effect on $m_{\tilde{\chi}_1^0}$ limit @ 189 GeV

LEP results within mSUGRA

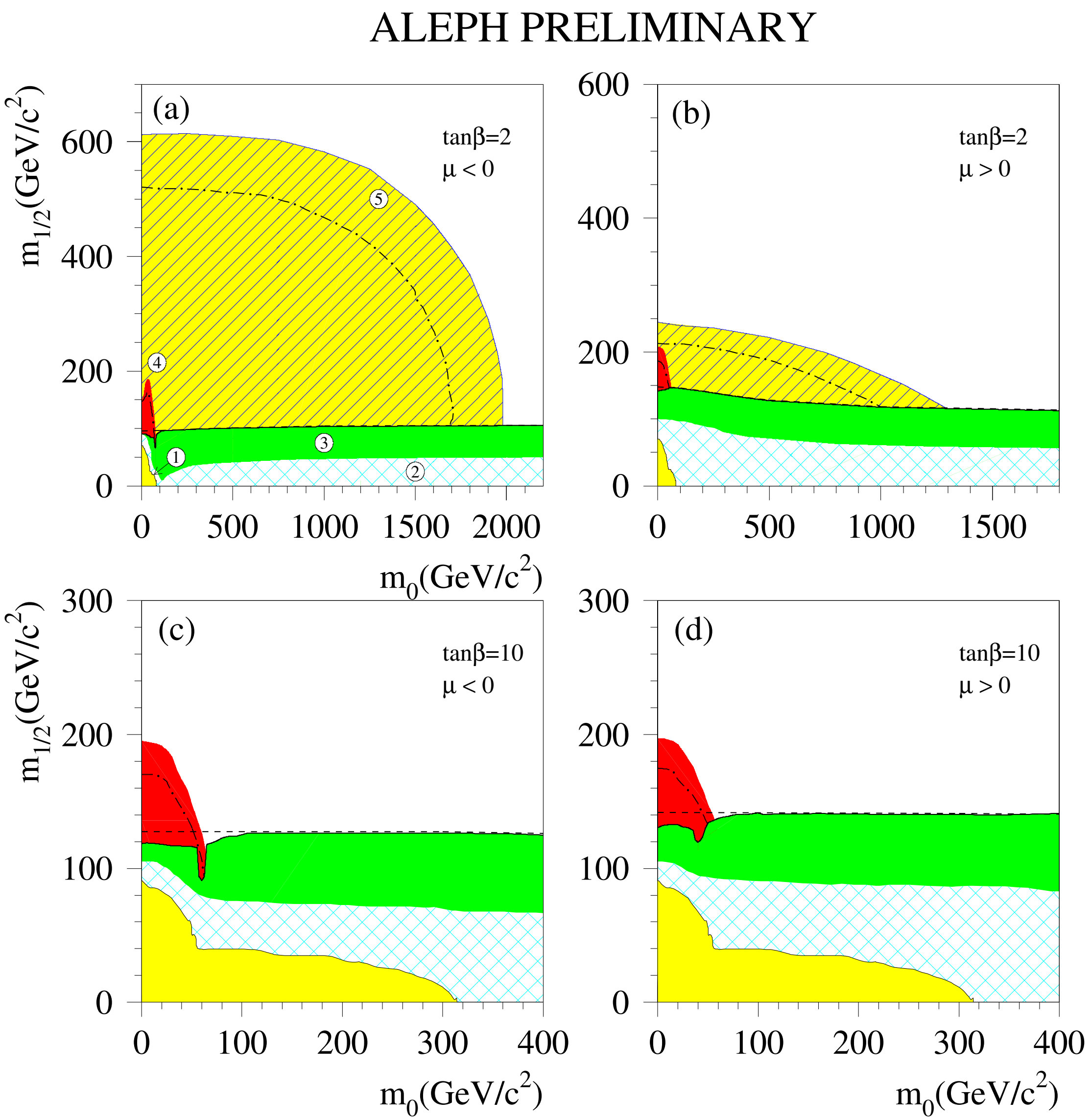
Remaining parameters: $\tan\beta$, **sign**(μ) m_0 $m_{1/2}$ A_0



Slepton limit, essentially an ellipse at low m_0 **and** $m_{1/2}$

Chargino limits at the K.L for large m_0 **up to** m_0 **values corresponding to low** $\Delta M = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\nu}}$

LEP results within mSUGRA including Higgs searches



$A_0 = 0$

Higgs limit effective at low $\tan\beta$ and for negative μ

5: Higgs searches

4: $\tilde{l}$ searches

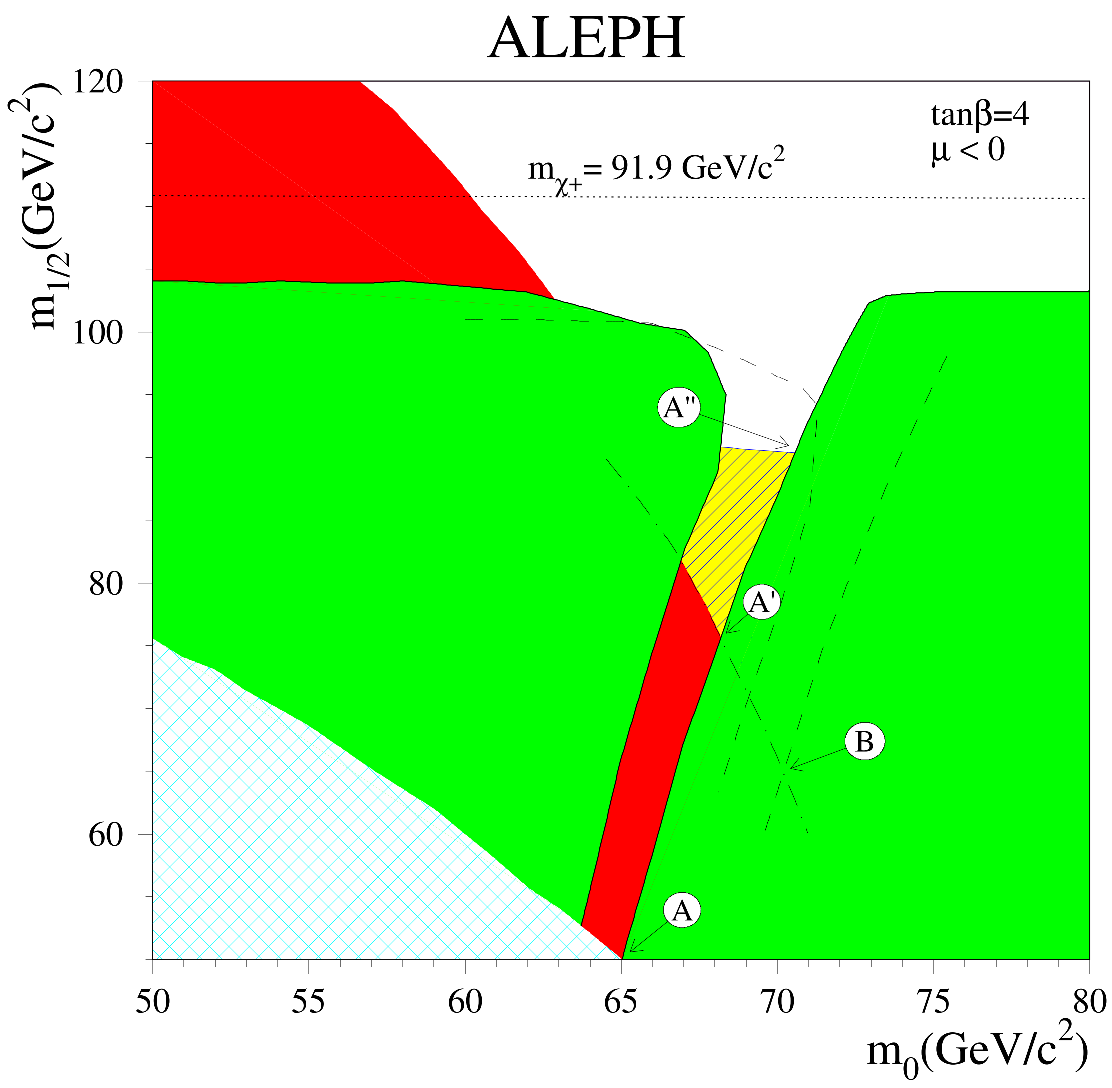
3: $\tilde{\chi}_1^{\pm}$ searches

2: Z width @ LEP1

1: not allowed by theory

LEP results within mSUGRA including Higgs searches

For A_0=-230 GeV



Limits are not improved by Higgs bosons searches in this case

Summary

Wide range of searches are performed at LEP2 but no excess is observed

All results are combined since the searches are complementary and all channels are exploited

Absolute limits are derived within CMSSM or mSUGRA models

$m_{\tilde{\chi}^0_1} >$ 32.5 GeV any m_0

$m_{\tilde{\chi}^\pm_1} >$ 67.7 GeV any m_0

$m_{\tilde{\mathrm{e}}^\pm >}$ 70.0 GeV $\tan\beta > 2$

But searches are not yet over at LEP2 ...
LEP200 sensitivity up to $m_{\tilde{\chi}^0_1} \sim$ 40 GeV