Chargino, Neutralino, Higgsino at LEP

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On behalf of all four LEP experiments

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Outline

- "Standard" SUSY framework at LEP
- "Standard" chargino and neutralino searches
- Searches in Small mass difference region
- The impact of LEP higgs search
- Summary

This talk only includes data up to 1999.

$\Rightarrow$ New data from 2000 will be shown tomorrow.

SUSY framework at LEP2

General MSSM

105 new parameters....

$\Downarrow$

Unification of mases and couplings at GUT scale

$\Downarrow$

Constrained MSSM

M_2	$SU(2)$ Gaugino mass parameter at EW-scale
m_0	Common scalar mass at GUT-scale
$\tan\beta$	v_2/v_1, ratio of VEV's of two Higgs doublets
μ	Mixing parameter of two Higgs doublet field
A_0	Common trilinear coupling
M_A	Mass of the CP-odd Higgs A

Six new parameters.

masses
cross sections
branching ratios

$\Rightarrow$calculable!

Searches for SUSY Particles

"Standard" SUSY model at LEP2

R-parity conserved

$\Rightarrow$ **Lightest SUSY particle (LSP) is stable.**

$\Rightarrow$ **Darkmatter candidate**

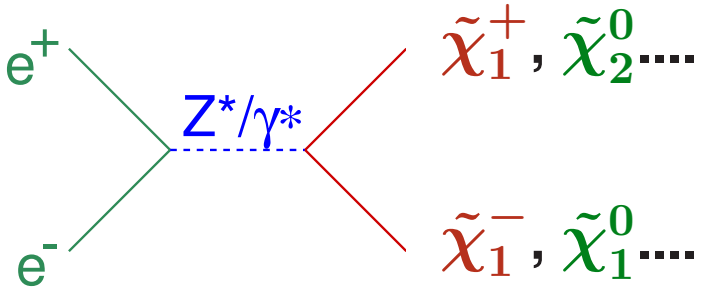
SUSY particles are pair-produced and decay with SUSY particles.

SUSY particles

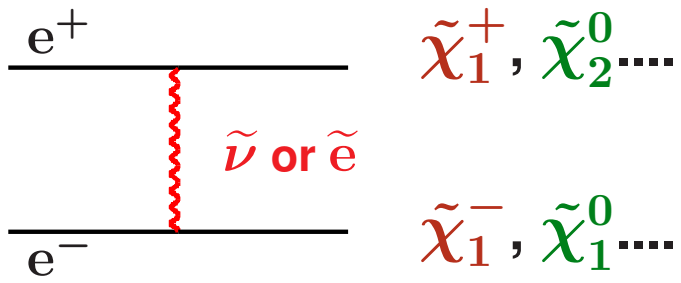
Spin 0	Spin 1/2	Spin 1
$\tilde{\ell}^{\pm}_{L,R}\}\tilde{\ell}^{\pm}_{1,2}$	$\ell^{\pm}_{L,R}$	
$\tilde{\nu}_L$	ν_L	
$\tilde{q}_{L,R}\}\tilde{q}_{1,2}$	$q_{L,R}$	
	$\tilde{g}$	g
	$\tilde{\gamma}$	γ
Neutralino $\Rightarrow$ h, H, A	$\tilde{h}, \tilde{H}$ $\}\tilde{\chi}^0_j$	
$m_{\tilde{\chi}^0_1} < m_{\tilde{\chi}^0_2} < \ldots < m_{\tilde{\chi}^0_4}$	$\tilde{Z}$	Z
($m_{\tilde{\chi}^0_1}$ is LSP.)		
Chargino $\Rightarrow$ $H^{\pm}$	$\tilde{H}^{\pm}$ $\}\tilde{\chi}^{\pm}_i$	
$m_{\tilde{\chi}^{\pm}_1} < m_{\tilde{\chi}^{\pm}_2}$	$\tilde{W}^{\pm}$	$W^{\pm}$

Chargino $\tilde{\chi}^{\pm}$ and Neutralino $\tilde{\chi}^{0}$ production

- **Chargino and Neutralino can be produced at LEP2 mainly via**



If $m_{\tilde{\nu}}$ or $m_{\tilde{\ell}}$ is small (small m_0 case), t-channel is enhanced.



The interference between t- and s-channel,

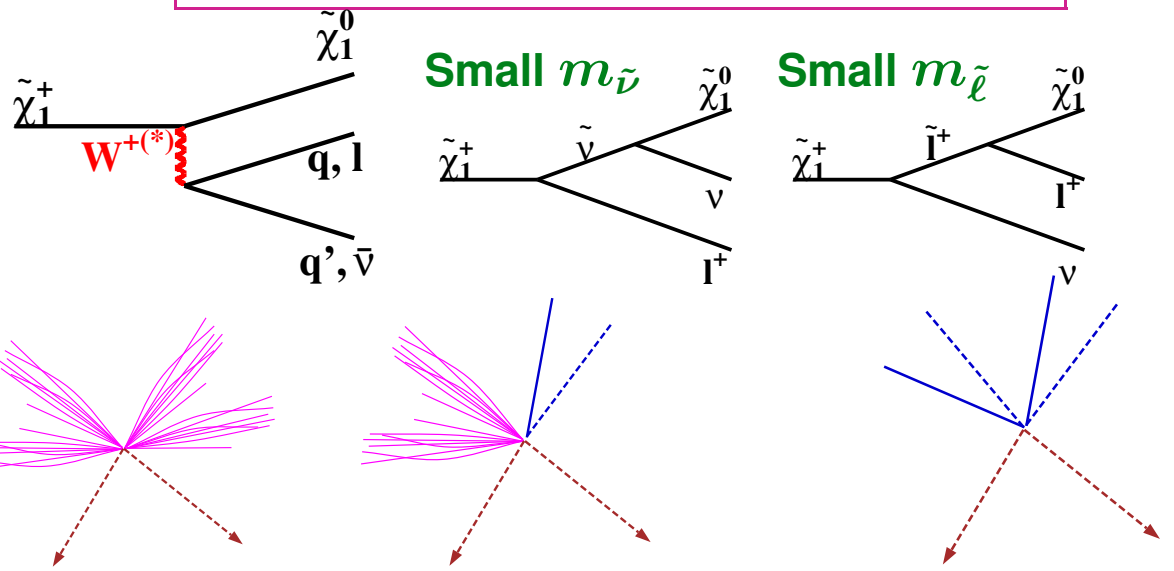
$\tilde{\chi}^{\pm} \Rightarrow$ "destructive"
$\tilde{\chi}^{0} \Rightarrow$ "constructive"

However, cross section of $\tilde{\chi}^{\pm}$, $\sigma_{\tilde{\chi}^{\pm}}$ is large enough to discover it.

$$(\sigma_{\tilde{\chi}^{\pm}} \gtrsim 1\mathrm{pb})$$

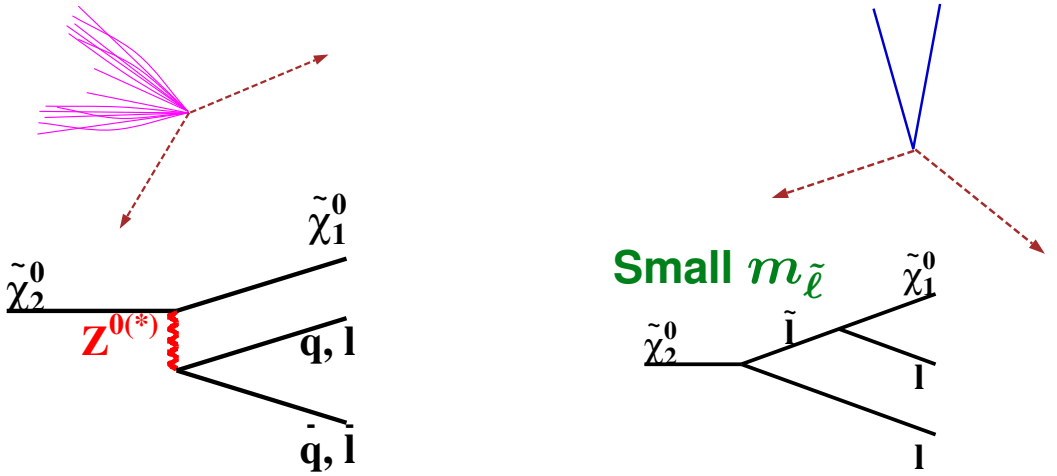
Chargino $\tilde{\chi}^{\pm}$ and Neutralino $\tilde{\chi}^{0}$ decay

$$\tilde{\chi}^{\pm}: \Delta M_{+} \equiv m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$$



Large $\Longleftarrow$ ΔM $\Longrightarrow$ **Small**

large E_{vis} **small** E_{vis}



$$\tilde{\chi}^{0}: \Delta M_{0} \equiv m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

Large missing energy due to LSP.

Acoplanar events

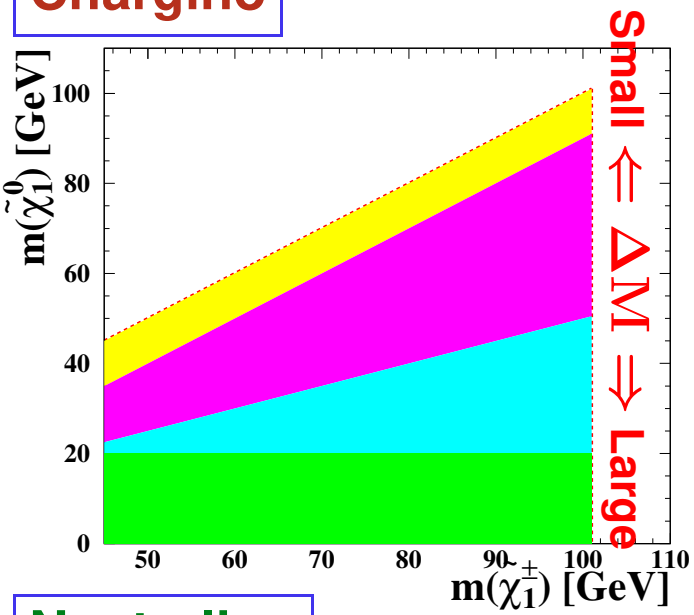
Selection strategy

The analysis is categorised by event topologies;

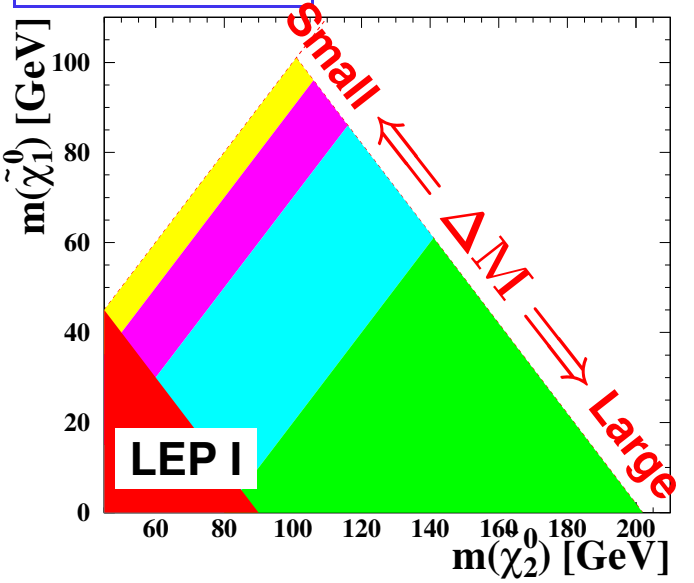
example in OPAL
- $N_{ch} > 4$ without isolated leptons
- $N_{ch} > 4$ with isolated leptons
- $N_{ch} \leq 4$

and ΔM.

Chargino



Neutralino



Background

Small ΔM

two photon processes

$\sigma \approx \mathcal{O}(\mathrm{nb})$

⇕

four-fermion processes

$\sigma \approx 20\mathrm{pb}$

Large ΔM

Chargino cross section limit

Luminosities (pb^{-1}) in plots:

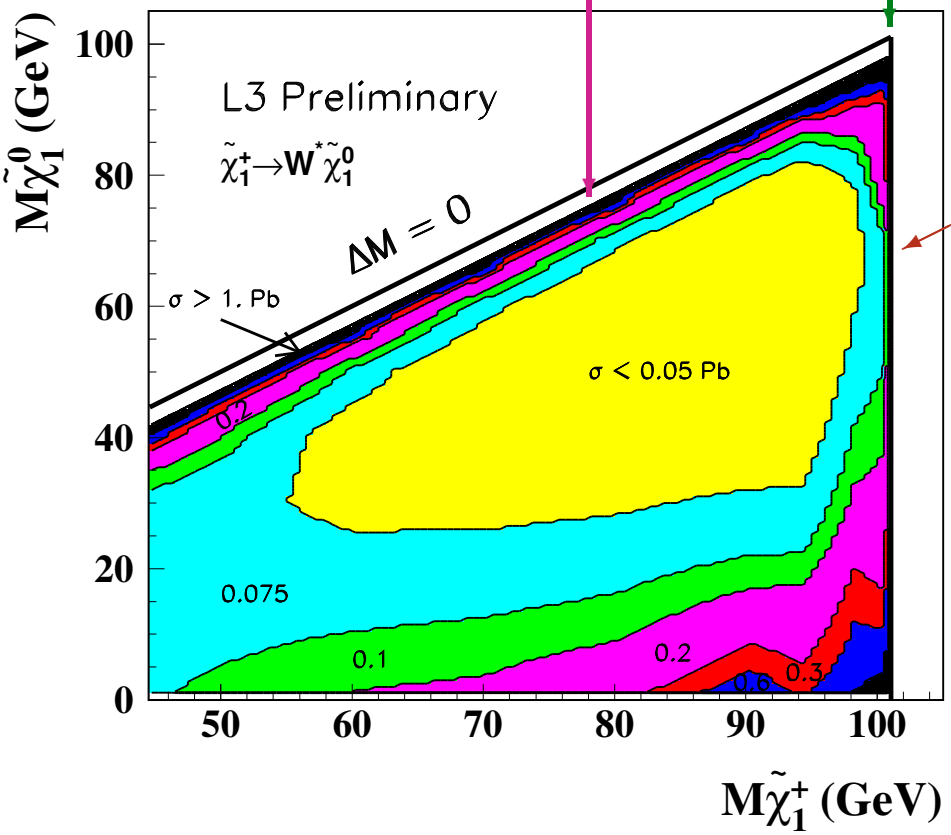
$\sqrt{s}$ (GeV)	192	196	200	202
ALEPH	29	80	86	42
DELPHI	26	77	83	40
L3	30	84	83	37
OPAL	29	73(74)	66(75)	11(38)

difference at kinematic limit

Full of 1999 data are combined with one in 2000

Small ΔM region
No sensitivity

kinematic limit

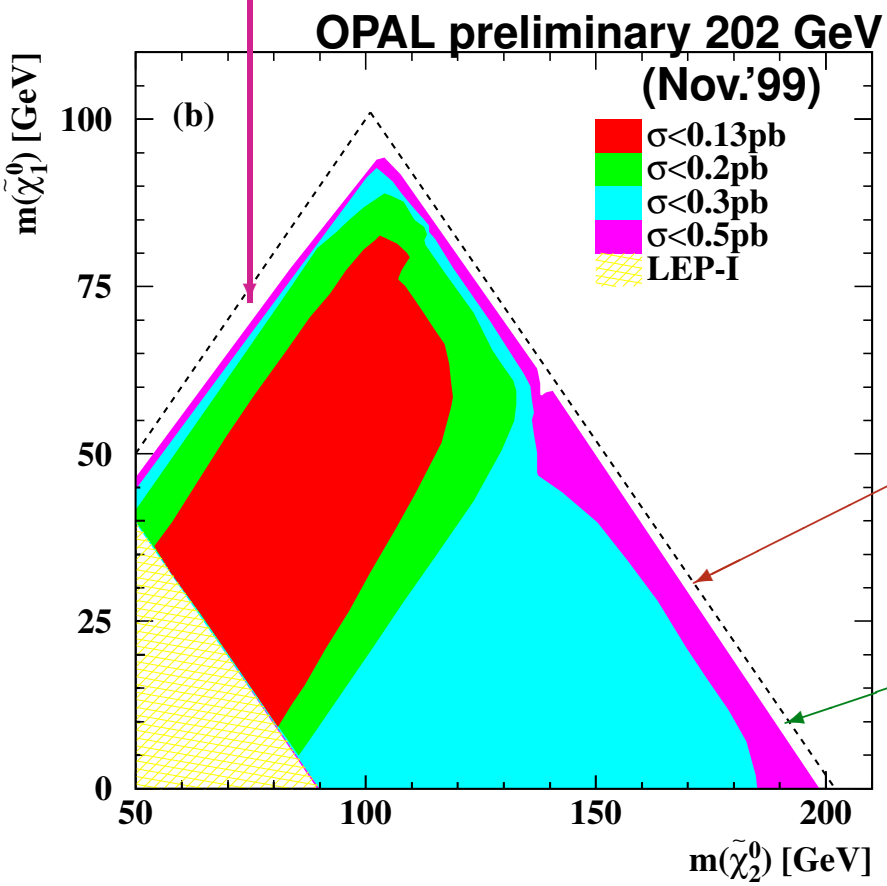


limit is set up to the kinematic limit

Neutralino Cross-section Limit

Small ΔM region
no sensitivity

$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^{(*)}) = 100\%$
is assumed.



Effect of low luminosity used in this plot

kinematic limit

Cross section limit for Chargino

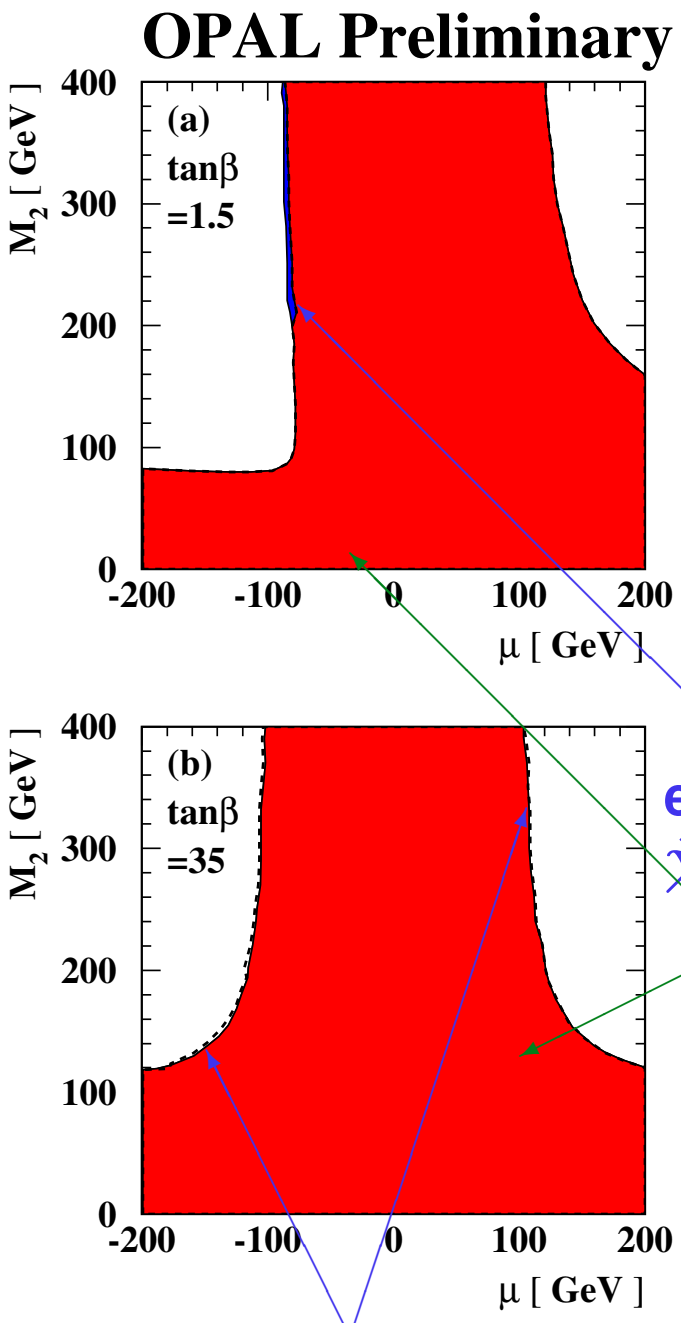
Neutralino

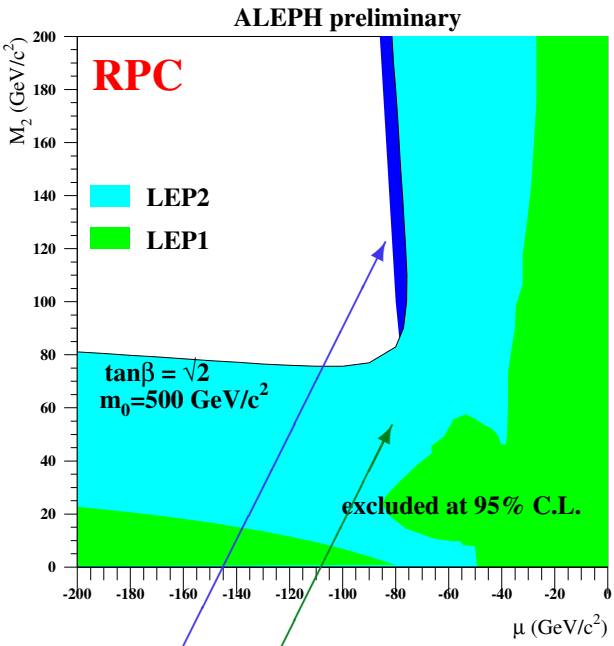
⇓

CMSSM interpretation

MSSM parameter scan (μ, M_2) with large m_0

The production of $\tilde{\chi}_3^0\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0\tilde{\chi}_2^0$ are also taken into account





extention due to the direct $\tilde{\chi}^0$ search

excluded by the direct $\tilde{\chi}^{\pm}$ search

Almost the whole region has been excluded at 95%CL.

the kinematic limit of $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production(dashed curve)

Example of small m_0 case at 183 GeV

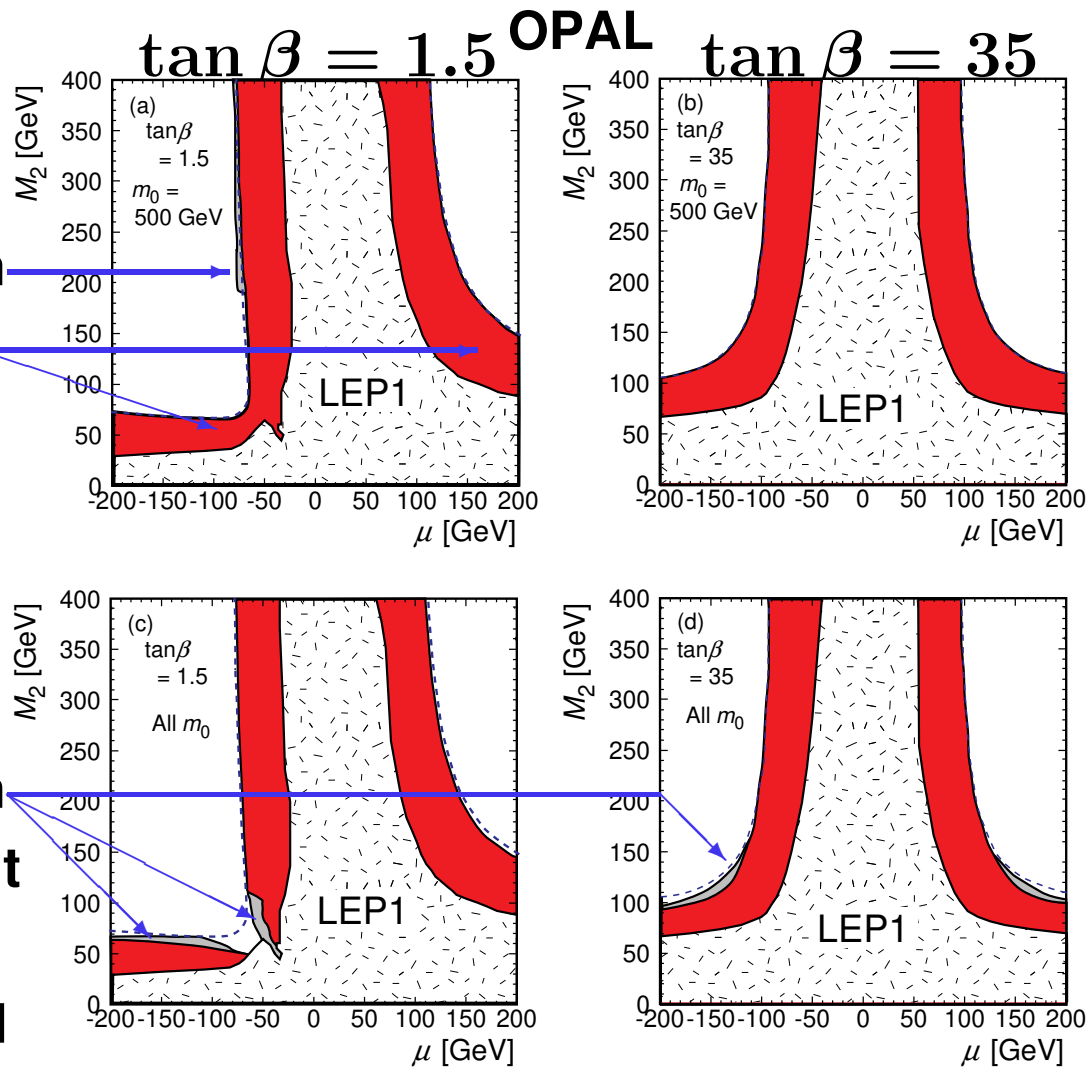
Large m_0 $\Rightarrow$

Neutralino search

Chargino search

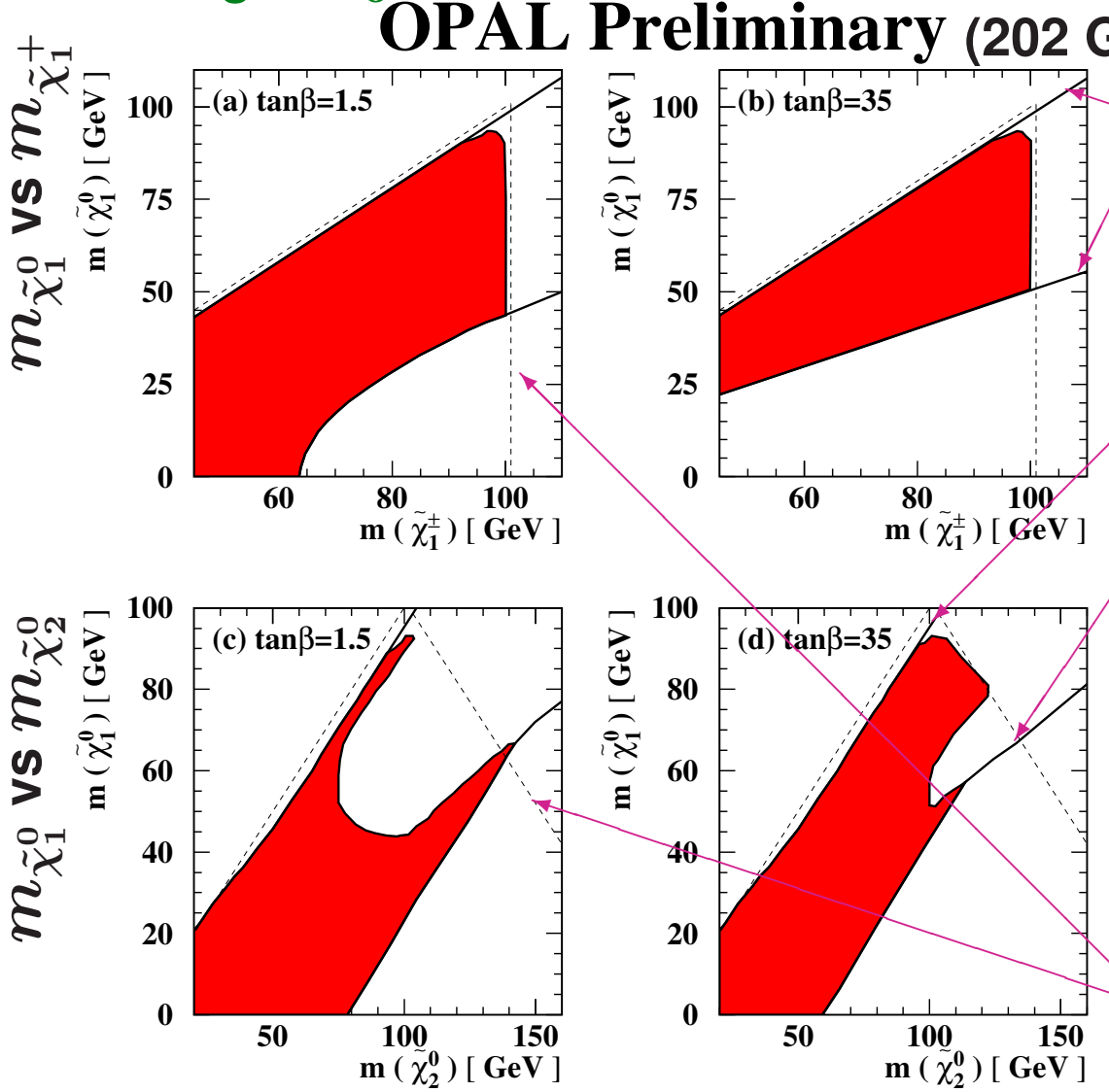
Small m_0 $\Rightarrow$

Neutralino search become important due to cross section increased



Exclusion in mass planes

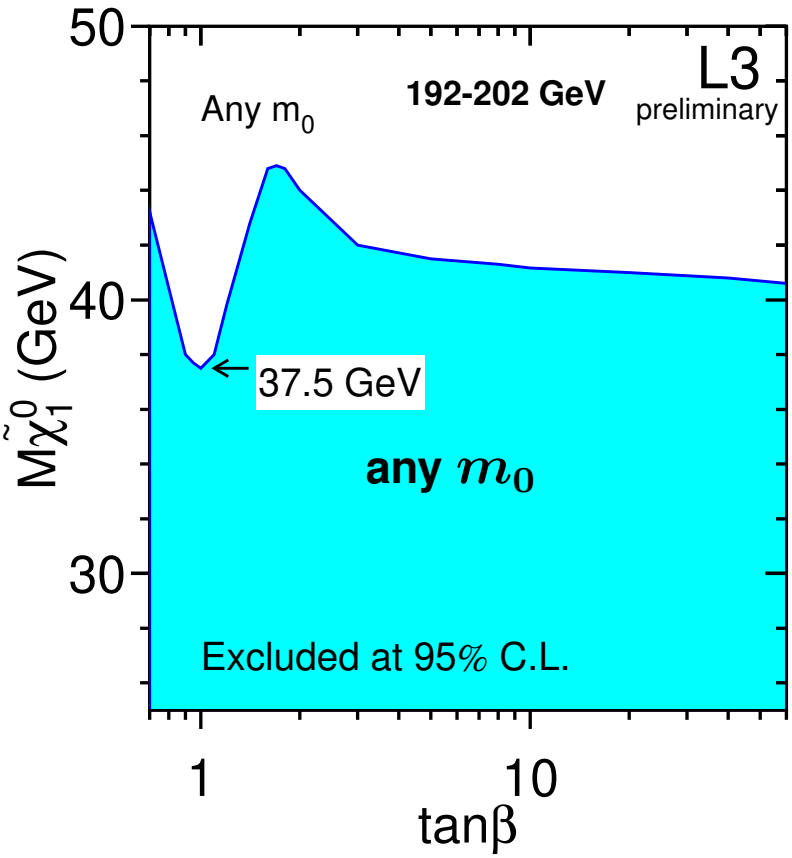
Large m_0 case



Theoretical bounds of CMSSM (solid curves)

Kinematical boundaries

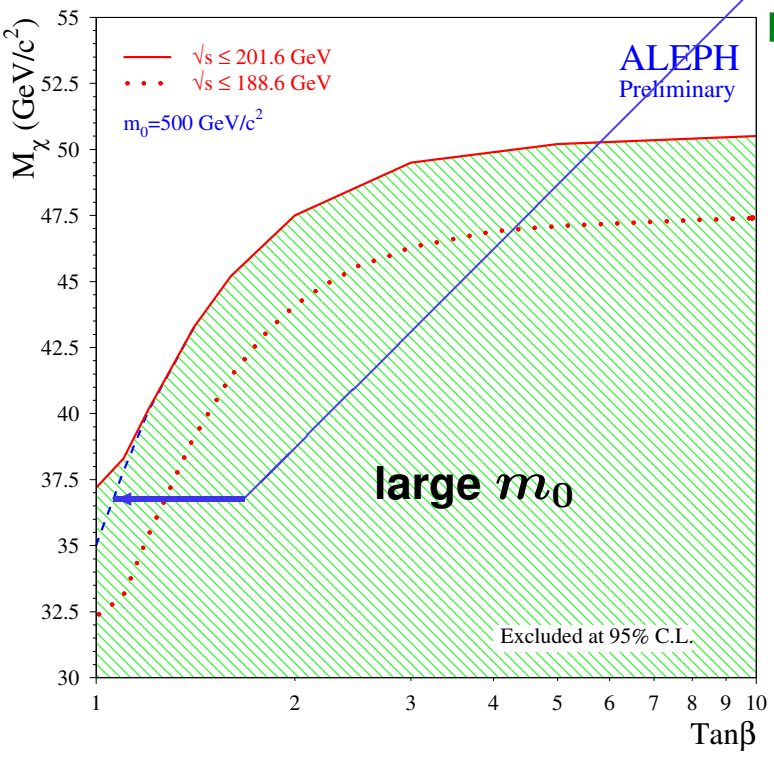
Neutralino mass limits



Chargino, neuralino and slepton results are combined.

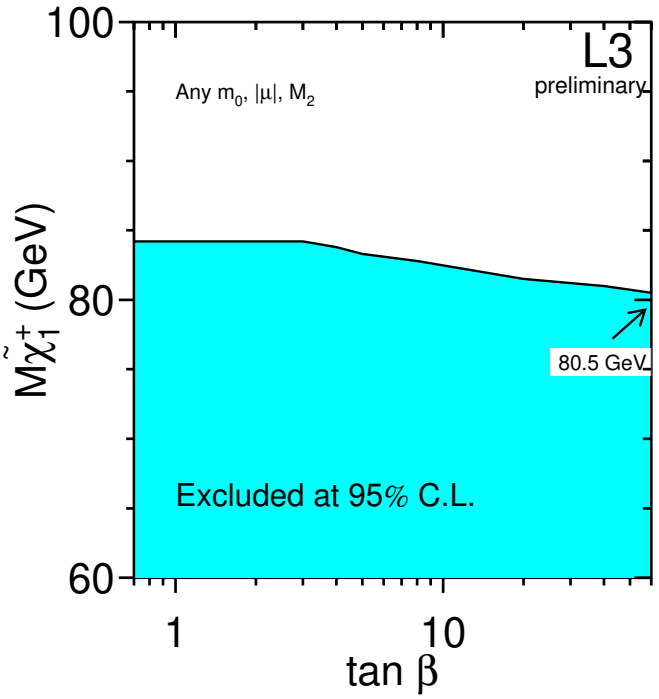
slepton results are importnat for small m_0 at large $\tan\beta$:
2 body decays of $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$

No constraint from neutralino search

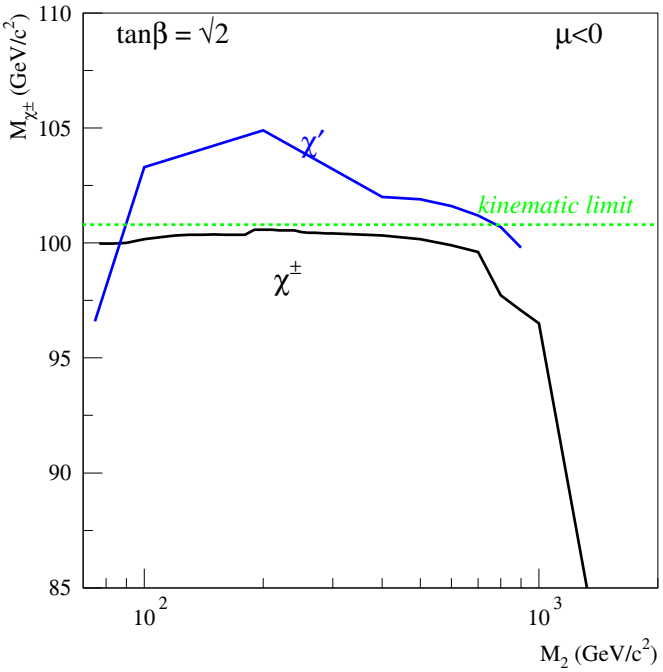


	LSP mass limit (GeV)	
	large m_0	any m_0
ALEPH	37	37
DELPHI	36.7	36.3
L3		37.5
OPAL	35.7	31.6(189)

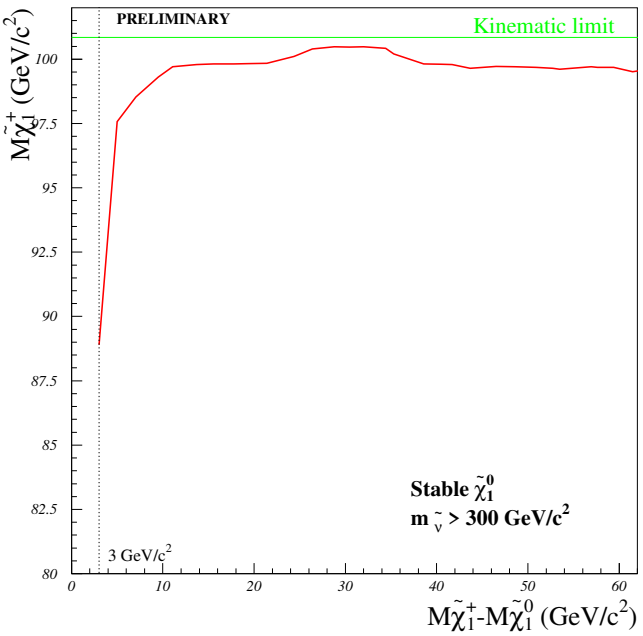
Chargino mass limits



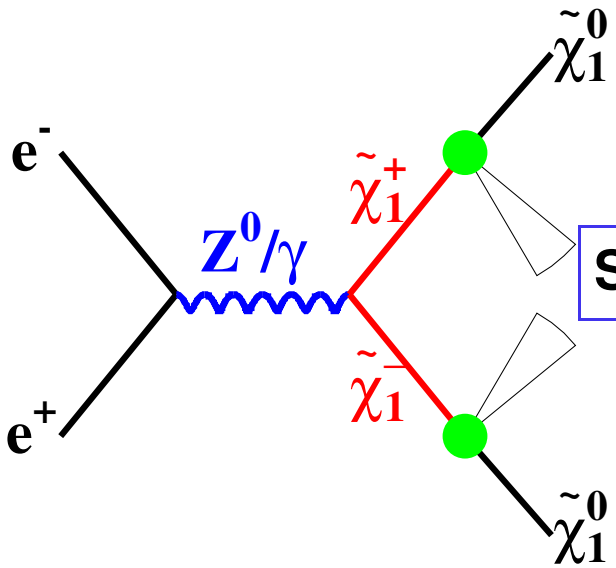
ALEPH PRELIMINARY



DELPHI $\tilde{\chi}_1^+\tilde{\chi}_1^-$ limits at 202 GeV



Searches in Very Small ΔM region



Small $\Delta M_{\pm}$ ($\lesssim 5$ GeV)

- Large contribution from two photon processes
  $\Rightarrow$ poor sensitivity
- Small visible energy from $\tilde{\chi}^{\pm}$ decay
  $\Rightarrow$ inefficient trigger

Several MSSM scenarios

- $|\mu| \gg M_2$:
  $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$ are Higgsino-like.
- $|\mu| \ll M_2$:
  $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$ are Gaugino-like.
  large $m_{\tilde{\nu}} \Rightarrow$ No t-channel and BR with $\tilde{\nu}$
  small $m_{\tilde{\nu}} \Rightarrow \sigma$ and BR affected by $\tilde{\nu}$

$\Delta M < 200 MeV$

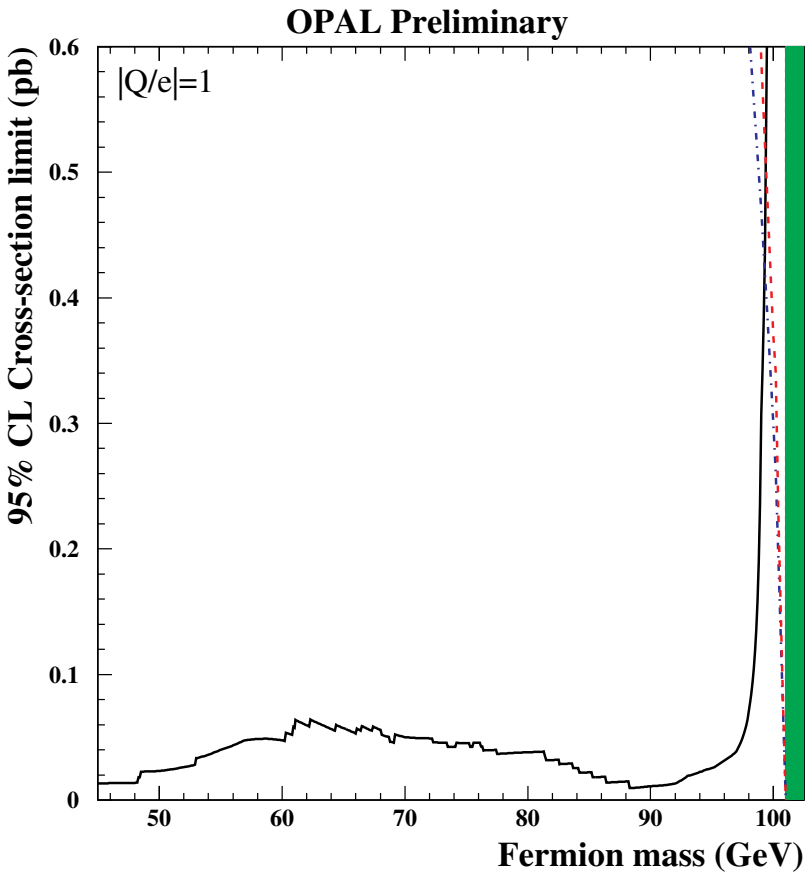
- $\tilde{\chi}^{\pm}$ won't decay in a detector

  $\Rightarrow$ Stable heavy charged particle

  with $|Q/e| = 1$ and spin $= 1/2$

- Analysis has been done on low multiplicity events, using particle ID information

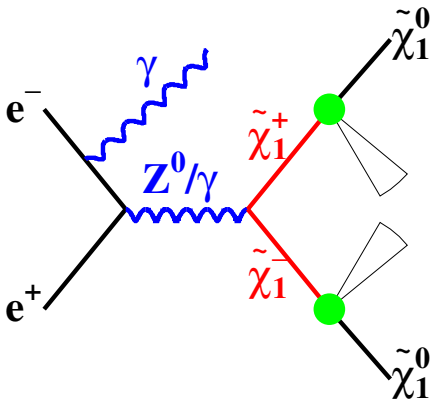
  $\Rightarrow$ dE/dx and others



Limits will be translated into MSSM parameter space.

$200\mathrm{MeV} < \Delta M < 4\mathrm{GeV}$:

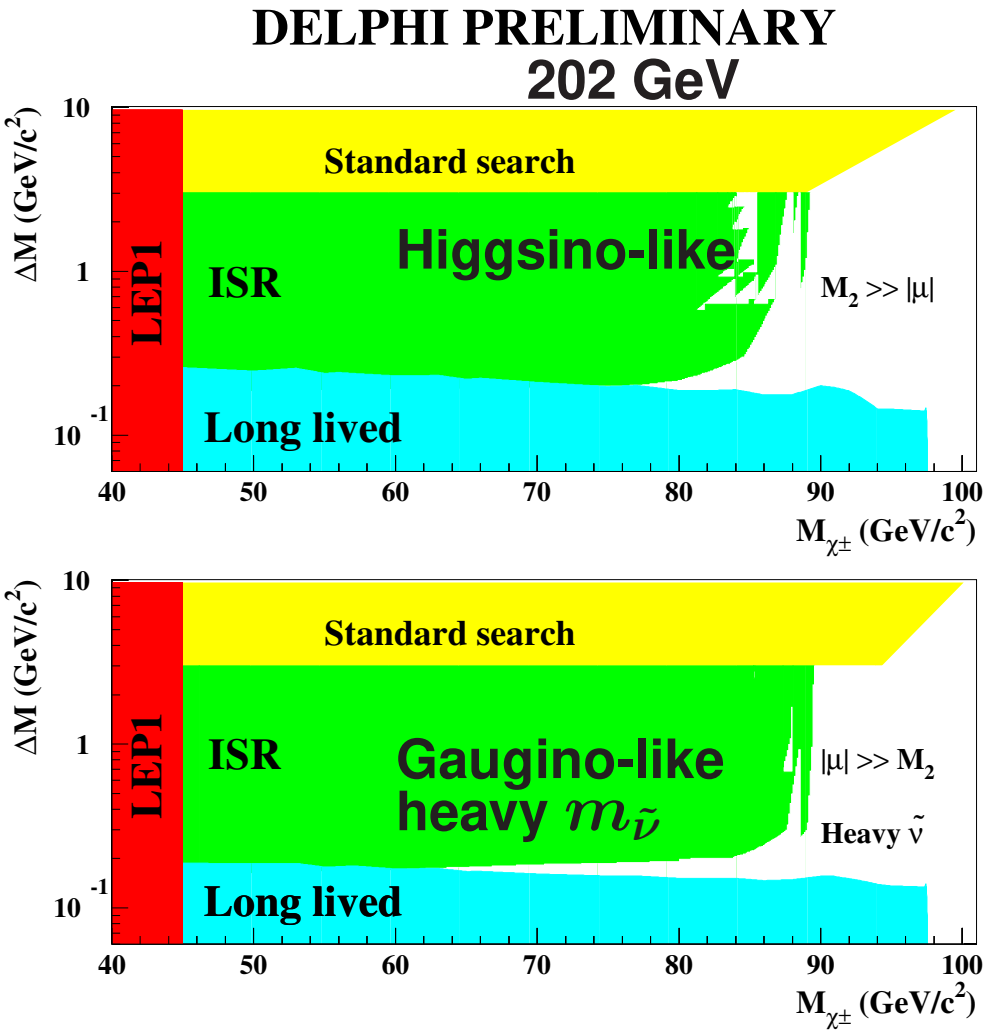
- Topology of $\tilde{\chi}^{\pm}$ is like "two photon process".



⇒ Events accompanied by ISR photons

⇒ Life time and BR are depended on $\Delta\mathrm{M}$ decay in detector

⇒ pioneered by DELPHI. followed by L3.



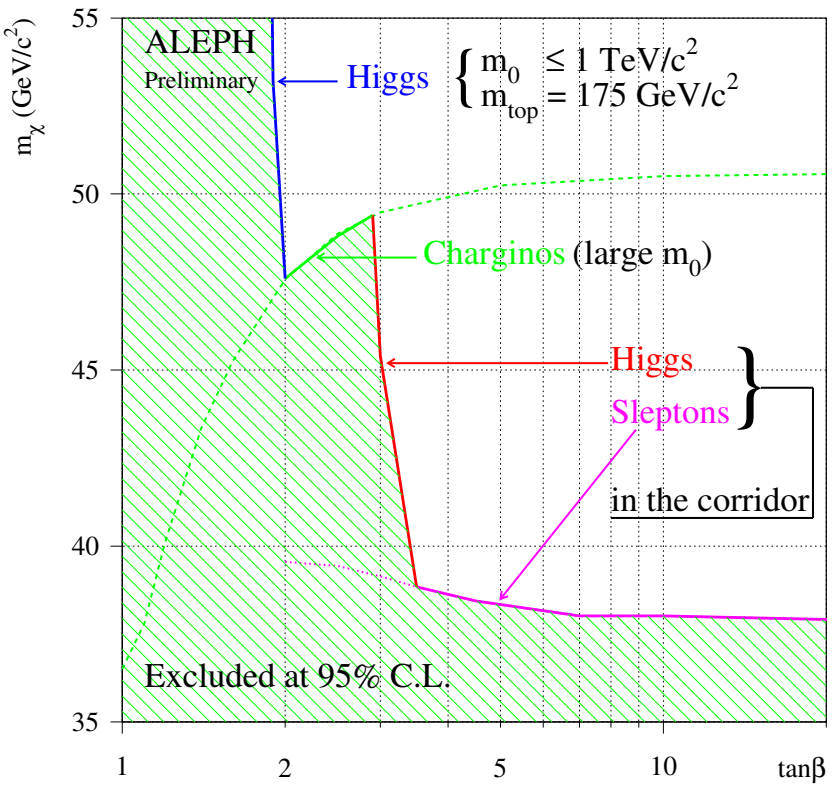
Impact of LEP MSSM Higgs search

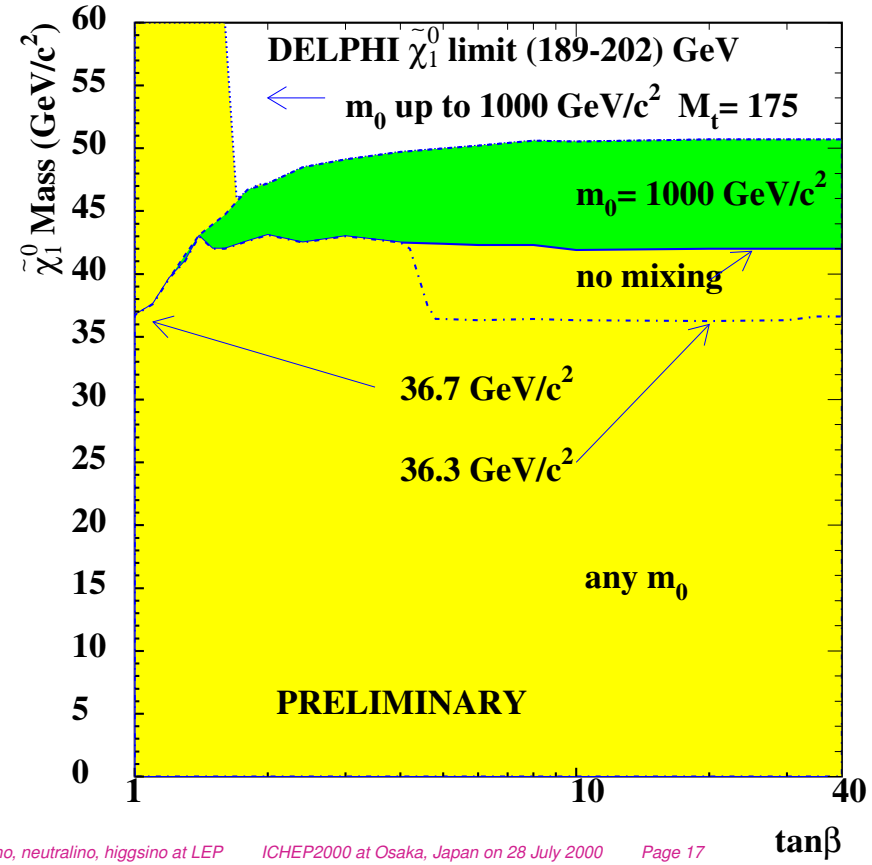
Higgs searches start to exclude low $\tan\beta$ region

$1.8 > \tan\beta > 0.7$ @ 95% CL.(LEP combined)

$\Rightarrow$ included in neutralino mass limit by ALEPH and DELPHI.

$\tilde{\tau}$ mixing is considered in DELPHI.





Summary

"Standard" searches

The analysis method has been established:

$\Rightarrow$ Categorised by ΔM's and topologies

In $\Delta M > 10 GeV$ area, the analyses have good sensitivities up to the kinematic limit.

Searches in small ΔM region

Some scenarios in MSSM are considered.

A new analysis with tagging ISR has been introduced to cover the gap between "Standard" searches and searches for heavy charged lepton

Data in Y2K

If at least each experiment has data of $\approx 10 pb^{-1}$ at the highest energy, LEP-combined results can have good sensitivity close to final LEP kinematic limit.