MSSM SUSY Searches at LEP2

- preliminary results from the final run in 2000 -

- Introduction
- Results on searches for Sfermions
  - Sleptons
  - Squarks
- Chargino and Neutralino searches
- Limits on the Lightest SUSY particle (LSP)

Karl Jakobs
University of Mainz
55099 Mainz, Germany

LEP2 Data set

Integrated luminosity per experiment:

year	$\sqrt{s}$ (GeV)	$\int \mathcal{L}dt$ (pb^{-1})
1997	183	55
1998	189	170
1999	$\sim$ 192	28
	$\sim$ 196	80
	$\sim$ 200	80
	$\sim$ 202	40

All results presented include the data from the year 2000

Jahr	$\sqrt{s}$ (GeV)	$\int \mathcal{L}dt$ (pb^{-1})
2000	$\sim$ 203	10
	$\sim$ 205	75
	$\sim$ 207	120
	$\sim$ 208	9

still preliminary

Limits are quoted at 95% C.L.

Thanks to members of the SUSY working groups and LEP combined group,
in particular: S.Braibant, F.Cerutti, B.Clerbaux, M.Espirito Santo, A.Favara, P.Giacomelli, J.F.Grivaz, A.Lipniacka, M.Maggi, L.Pape, A.Perrotta, S.Rosier-Lees and G.Taylor

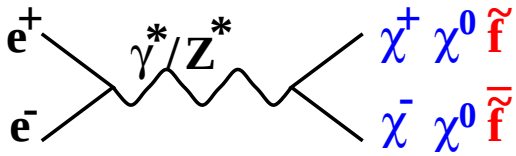
SUSY framework

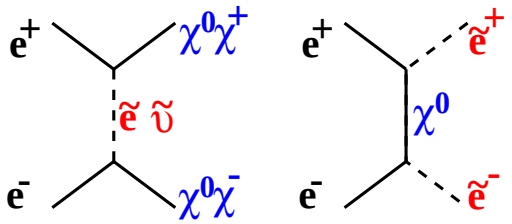
- Minimal supersymmetric extension of the Standard Model
- Gravity mediated supersymmetry breaking
- General assumptions:
  - R parity conservation
  - LSP is neutral, stable and weakly interacting
    LSP is assumed to be the lightest neutralino
  - Universal parameters at a high mass scale (GUT scale)
    - M_2: Gaugino mass term
    - m_0: scalar mass parameter (sleptons, squarks)
    - A_0 (A_t, A_b, A_τ) : trilinear couplings,
      (mass mixing in third family)
    - $\tan\beta$: ratio between v.e.v. of Higgs doublets
    - μ: Higgs mass parameter
  - For interpretation of results:
    unification relation $M_1 = \frac{5}{3} \tan^2\theta_W \; M_2$ is assumed

    (important for fixing the masses and field content of charginos and neutralinos)

SUSY particle production and decays

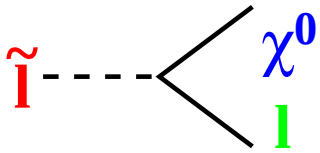
- s- and t-channel production





t-channel: dependence on SUSY parameters (mass spectrum)

- in general: assume decays into SM-partner and LSP



⇒ Events with missing energy

- Decay kinematics (visible energy in the detector) depends on

$$\Delta M = m_{(\tilde{l},\tilde{\chi})} - m_{\tilde{\chi}^0_1}$$

Analysis for different regions of ΔM

cascade decays may become possible in some regions of the parameter space (light SUSY particles)

- Main backgrounds:
  - WW production (high ΔM)
  - $\gamma\gamma$ background (low ΔM)

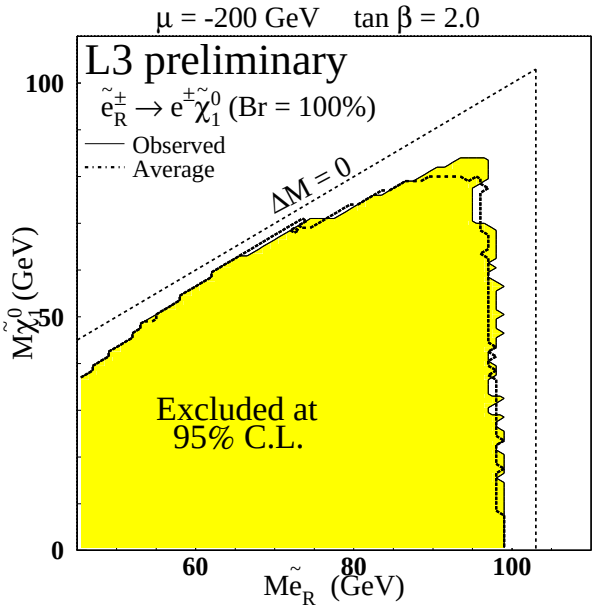
Search for Sleptons

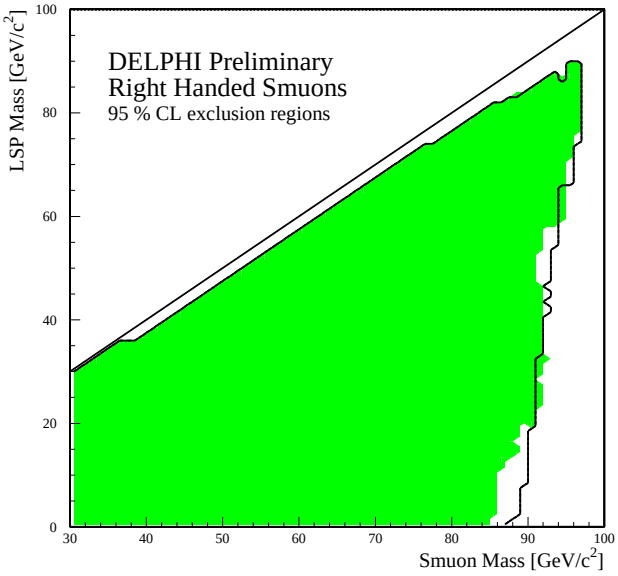
- pair production of $\tilde{l}_R$ and $\tilde{l}_L$

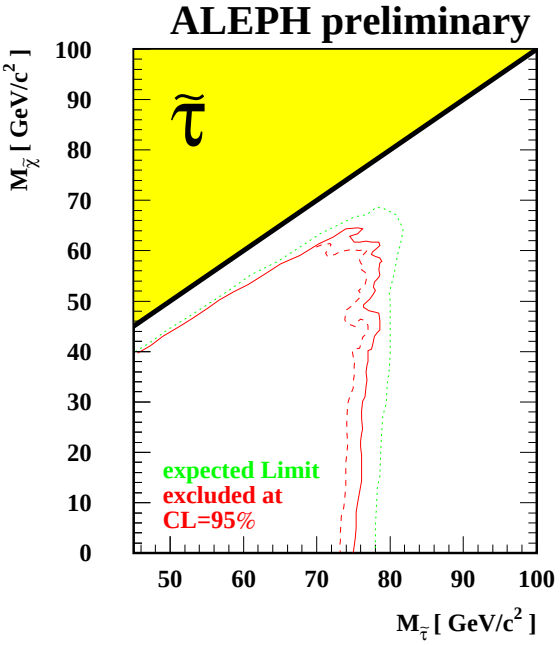
  (t-channel contribution for $\tilde{e}$)

- Stau cross section depends on mixing angle
  (minimal coupling to Z for $\theta_\tau = 52°$)

- search for acoplanar lepton pairs (low and high ΔM)
  no excess of events above SM background
  $\Rightarrow$ exclusion limits for $\tilde{l}_R$







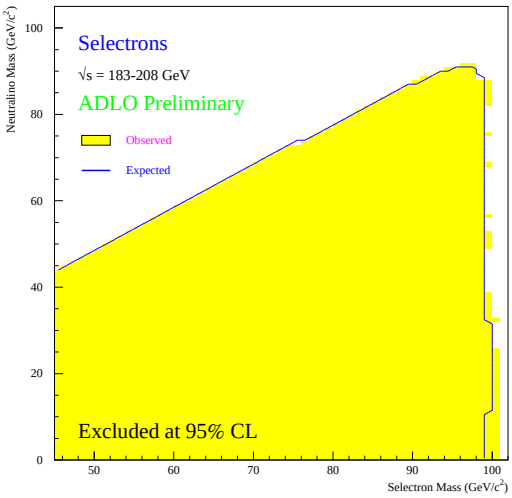
[redacted]

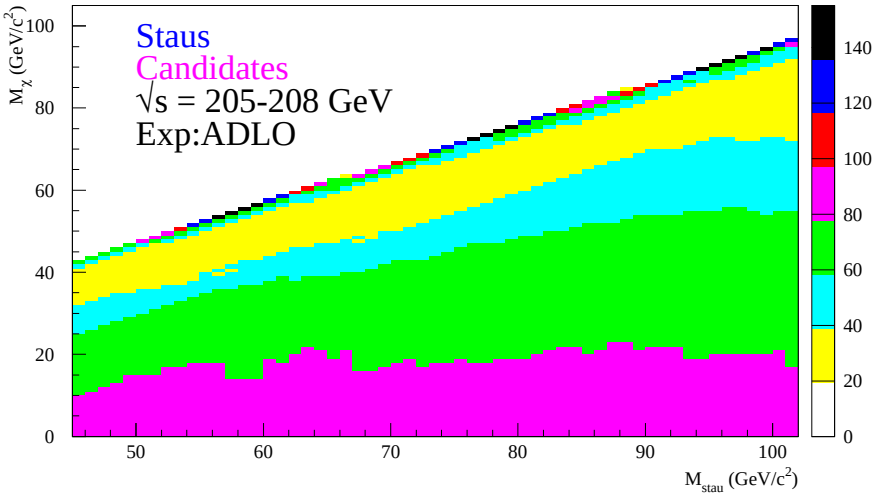
$m_{\tilde{\mu}} > 86$ GeV, $\Delta M > 10$ GeV

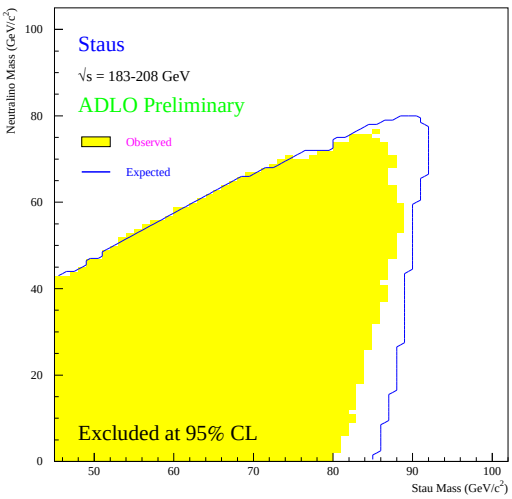
$m_{\tilde{\tau}} > 73$ GeV, $\Delta M > 10$ GeV

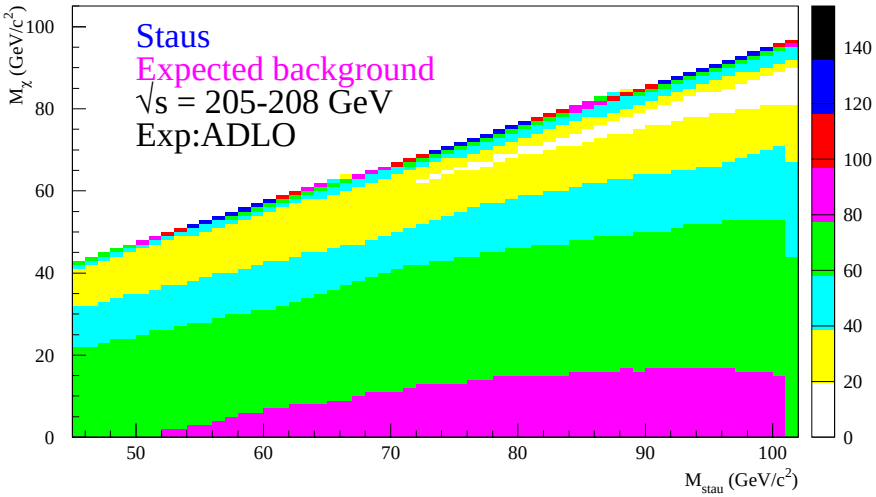
Stau (ALEPH) $\sqrt{s}$: 204 - 208 GeV	High ΔM	low ΔM
# evts. observed:	17	19
# evts. expected:	20.1	18.3

Slepton limits, LEP combined







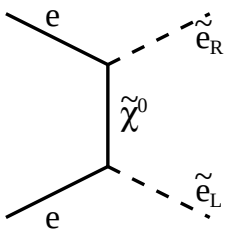


Limits on slepton masses (all data up to $\sqrt{s} = 208$ GeV):

	$m_{\tilde{e}}$ (GeV)	$m_{\tilde{\mu}}$ (GeV)	$m_{\tilde{\tau}}$ (GeV)	
Obs. Limit	99.4	96.4	87.1	$m_{\tilde{\chi}_1^0} = 40$ GeV
Exp. Limit	99.3	91.7	89.3	

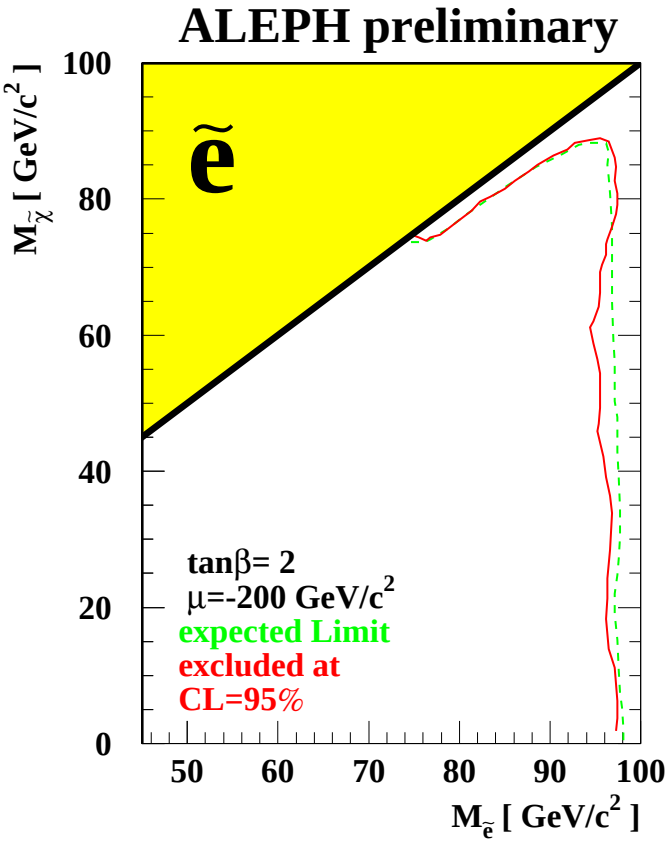
Sleptons at low ΔM

- ALEPH search for $\tilde{e}_R - \tilde{e}_L$ - Production



- $m_{\tilde{e}_L} > m_{\tilde{e}_R}$
  low ΔM between $m_{\tilde{e}_R}$ and $\tilde{\chi}_1^0$

  $\Rightarrow$ Single electron visible in the detector



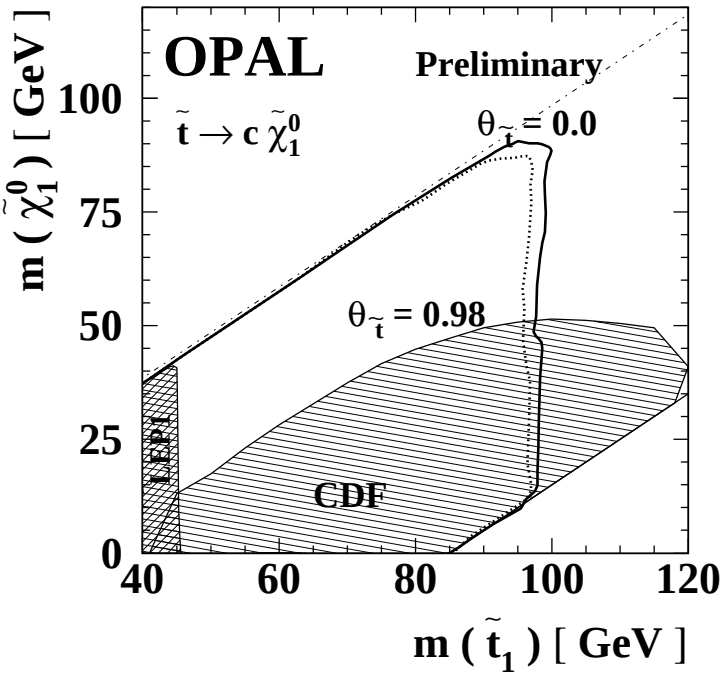
Squarks

- Stop ($\tilde{t}$) may be light,
  large mixing due to large top quark mass

  $\tilde{t}_1 \;=\; \tilde{t}_L \cos\theta_{\tilde{t}} \;+\; \tilde{t}_R \sin\theta_{\tilde{t}}$

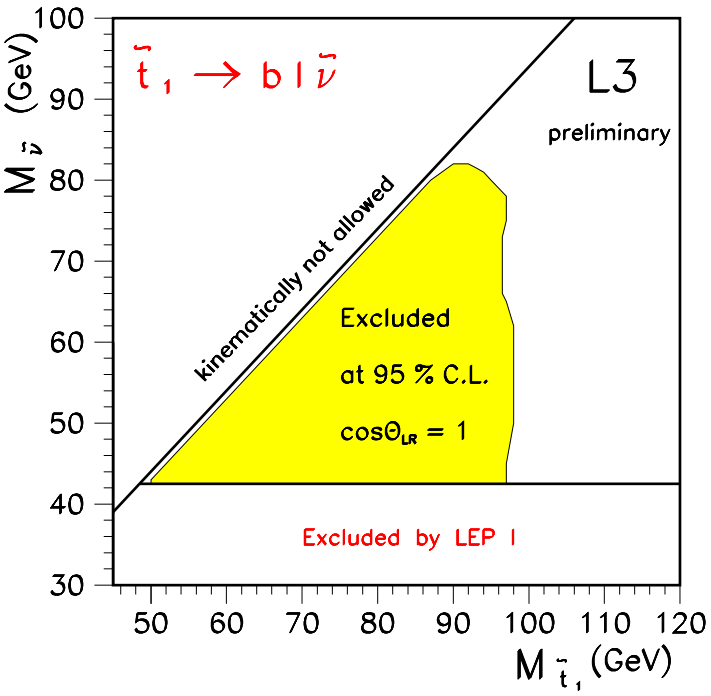
- production cross section depends on mass and mixing angle (decoupling from the Z for $\theta_{\tilde{t}} = 56°$)

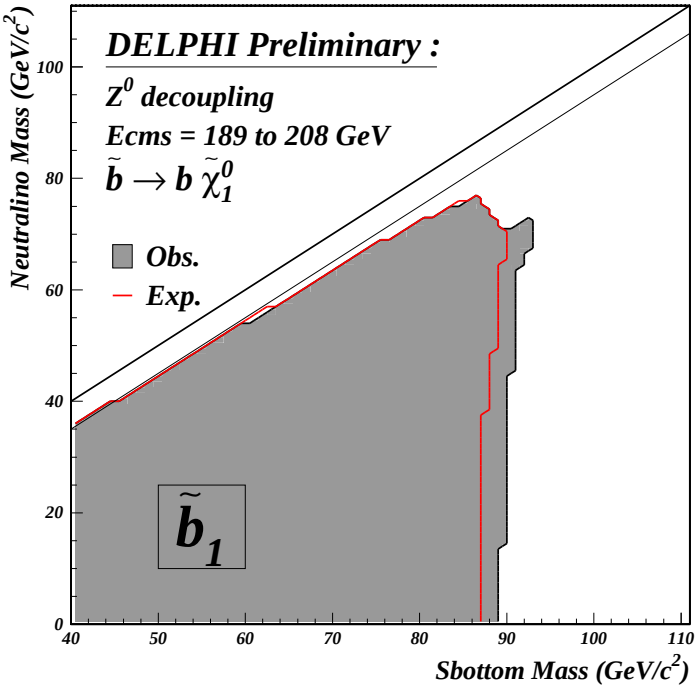
- Search for the decays:
  - $\tilde{t} \to c\ \tilde{\chi}_1^0$ (acoplanar jets + missing energy)
  - $\tilde{t} \to b\ l\tilde{\nu}$ (2 jets + 2 leptons + missing energy)
  - $\tilde{b} \to b\ \tilde{\chi}_1^0$ (acoplanar jets + missing energy)



High ΔM Analysis:
evts. observed: 9
evts. expected: 10.4

$m_{\tilde{t}} > 95.7$ GeV, $\Delta M > 10$ GeV





LEP combined limits (ADLO) for all $\tilde{t}$ and $\tilde{b}$ channels

	$\tilde{t} \to c\tilde{\chi}_1^0$	$\tilde{t} \to b\ l\tilde{\nu}$	$\tilde{b} \to b\tilde{\chi}_1^0$
Comb. limit	95 GeV	97 GeV	95 GeV
95% CL	$\Delta M = 40$ GeV	$\Delta M = 40$ GeV	$\Delta M = 20$ GeV

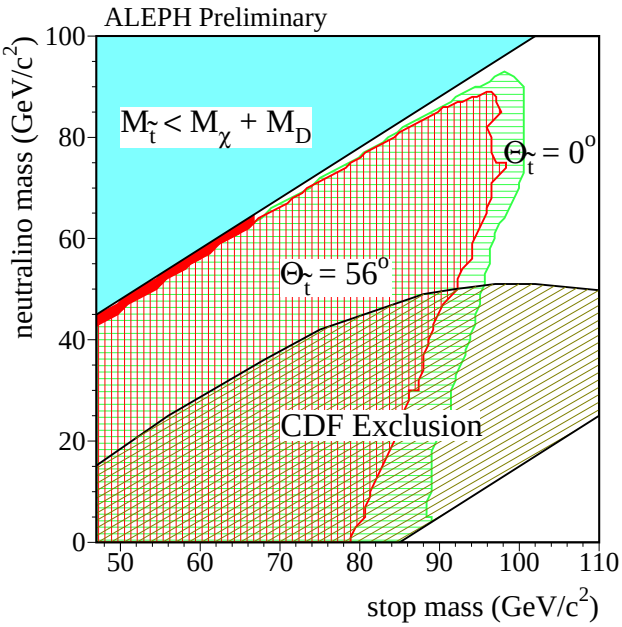
independent of mixing angle

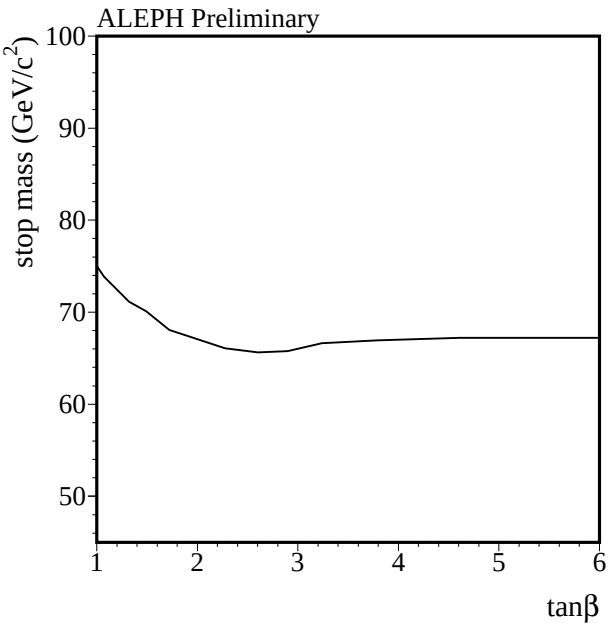
Squarks at low ΔM

- For low ΔM the stop lifetime becomes sizeable (FCNC decay $\tilde{t} \to c\ \tilde{\chi}_1^0$)
  $\Rightarrow$ use impact parameter measurement

- $\Delta M < 1.5$ GeV, dominant decay mode: $\tilde{t} \to u\ \tilde{\chi}_1^0$,
  $\to$ stop can be considered as stable, heavy hadron

  ALEPH:Long living hadron analysis:
  # evts. observed: 0
  # evts. expected: 0.6





Combination of the various analyses:
MSSM interpretation (scan over parameters):

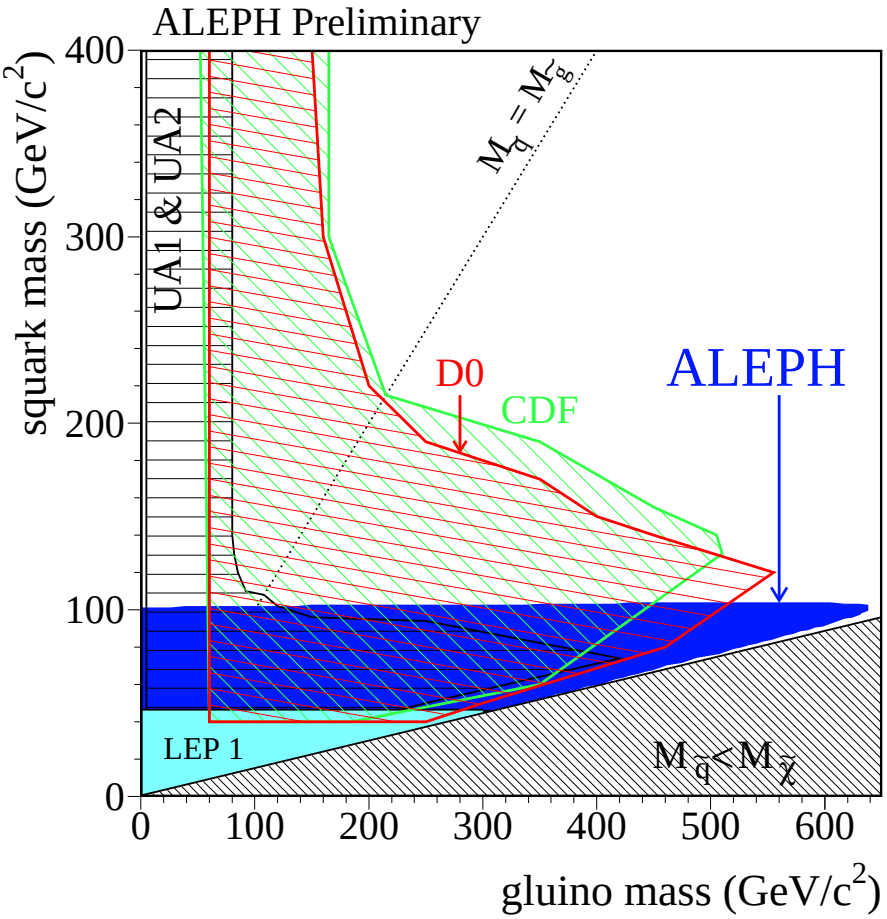
Absolute limit on stop mass:

$m_{\tilde{t}} > 65$ GeV (at $\tan\beta = 2.7$)

Limits for degenerate squarks

- Negative results of acoplanar jet search can be used to set a limit on the mass of degenerate squarks

- ALEPH analysis:
  - assume degenerate mass $m_{\tilde{q}}$ for left- and right-handed $\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{b}$
  - GUT relations between gaugino mass terms (M_i)
  - $\tan\beta = 4$, μ = -400 GeV
    (for consistency with TeVatron analyses)



Improvements on TeVatron exclusions for small mass differences

Charginos and Neutralinos

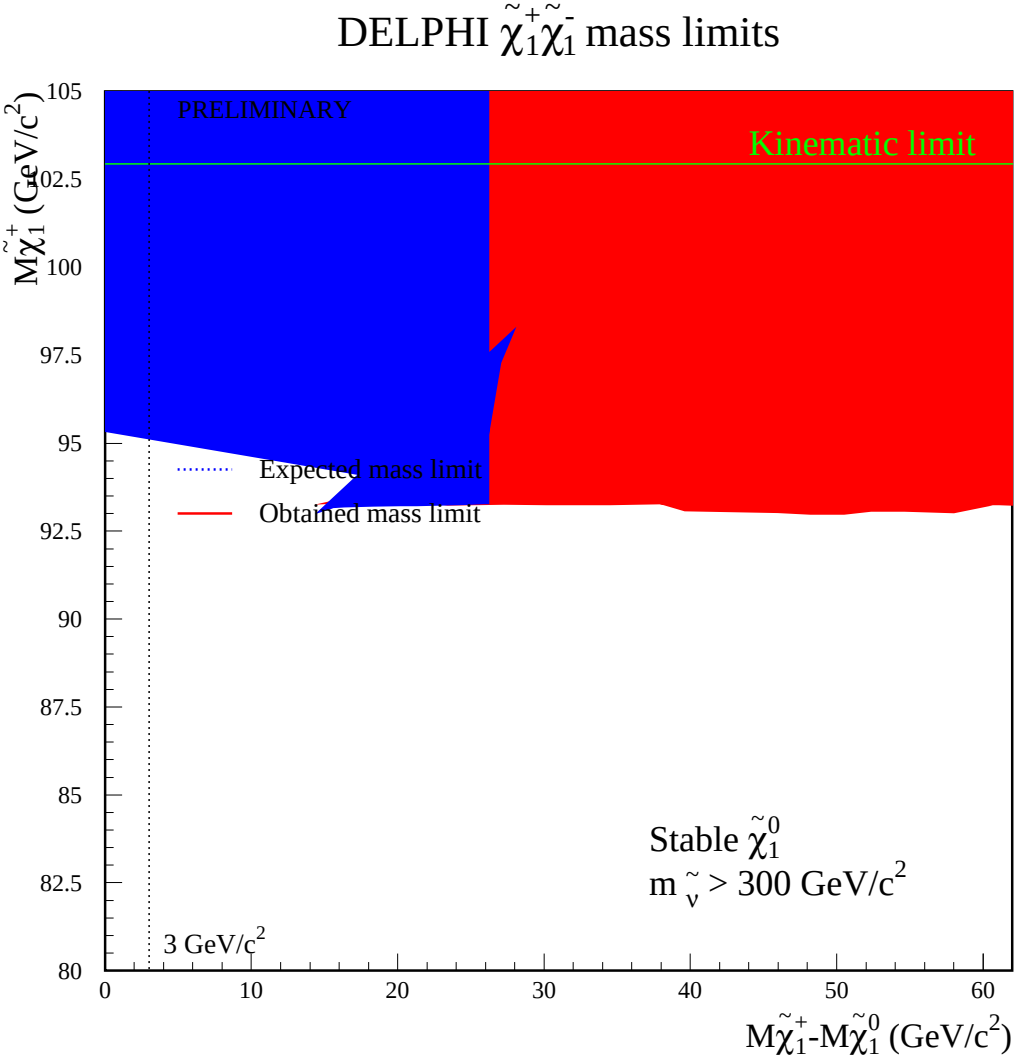
- Mass spectrum of charginos and neutralinos depends on three parameters: M_2 , μ and $\tan\beta$

- Dominant decays for heavy sfermions (large m_0):

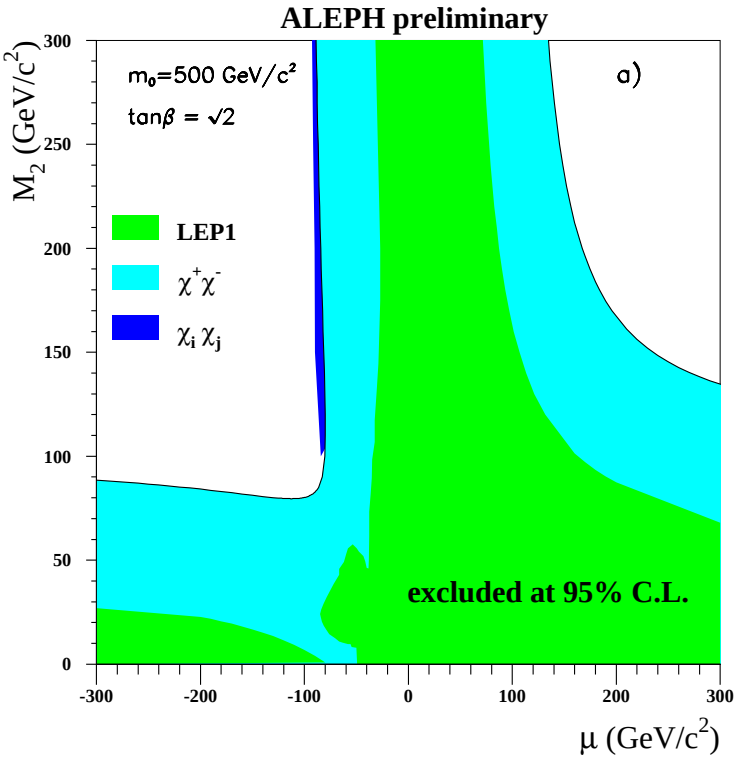
  $\tilde{\chi}^+ \to W\tilde{\chi}^0_1 \to qq'\tilde{\chi}^0_1, \quad l\nu\tilde{\chi}^0_1$
  $\tilde{\chi}^0_2 \to Z\tilde{\chi}^0_1 \to qq\tilde{\chi}^0_1, \quad ll\tilde{\chi}^0_1$

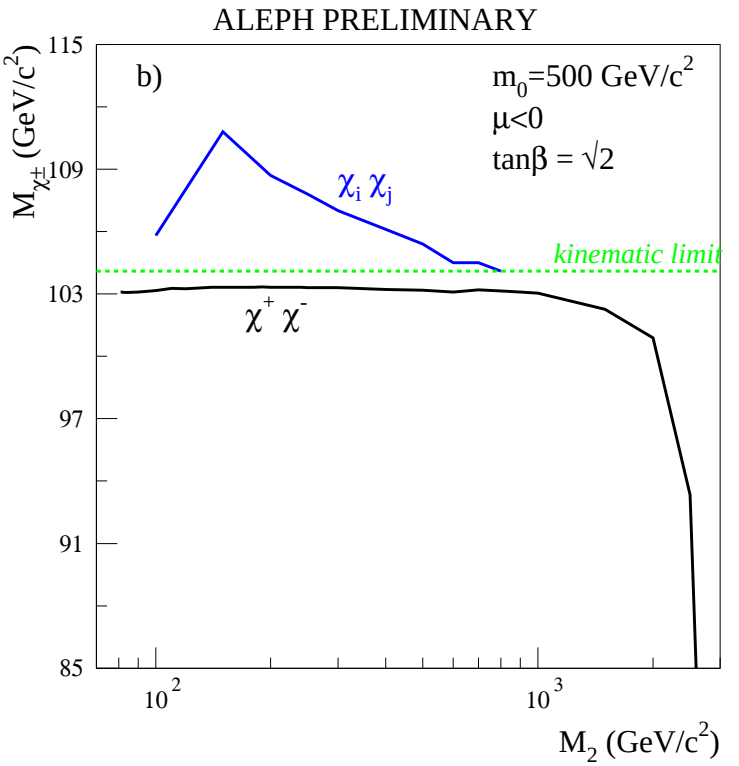
- Search for $\chi^+\chi^-$, $\chi^0_2\chi^0_1$, $\chi^0_3\chi^0_1$, $\chi^0_4\chi^0_2$ ... production

DELPHI Chargino analysis: $m_{\tilde{\nu}} > 300$ GeV



For large ΔM: Exclusion nearly up to the kinematic limit



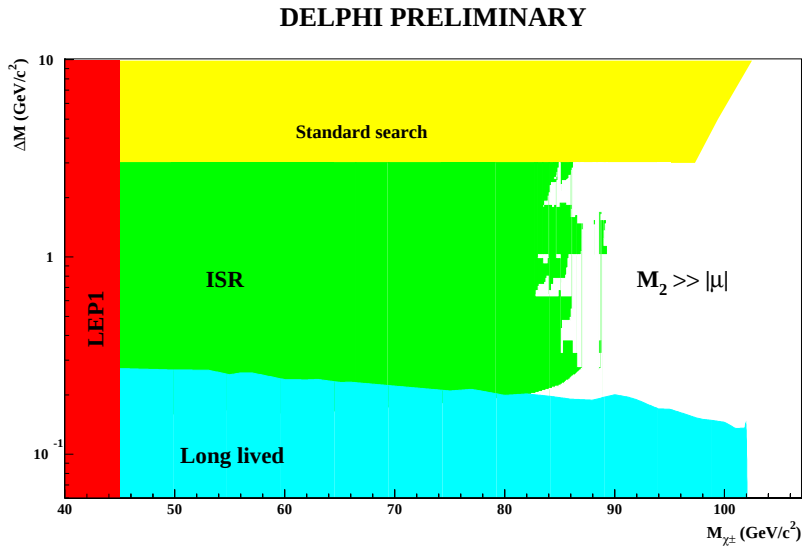


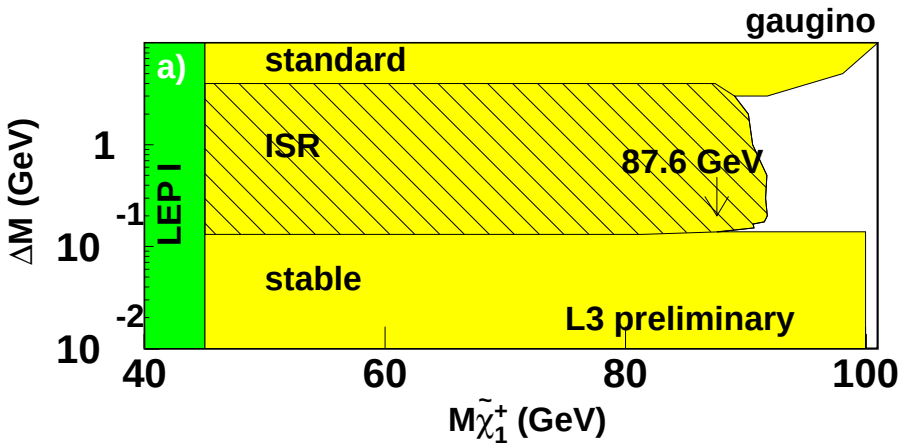
Limits in the Higgsino region can be improved beyond the kinematic limit by neutralino searches

Chargino limits for small ΔM

Combination of the standard analysis with:

- Search for heavy long living charged particles
- Search for a high-P_T photon (ISR photon) accompanied by low momentum particles



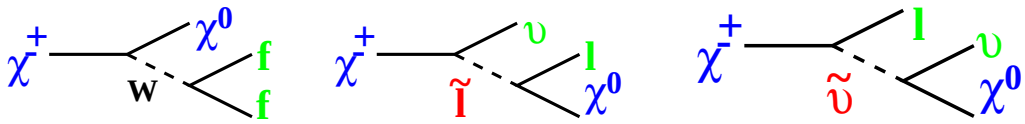


	$M_{\tilde{\chi}^+}$ limit higgsino region	$M_{\tilde{\chi}^+}$ limit gaugino region	
ALEPH	89 GeV	91 GeV	large m_0
DELPHI	82 GeV		$m_{\tilde{f}} > M_{\tilde{\chi}^+}$
		74 GeV	large m_0
L3	85.9 GeV	87.6 GeV	large m_0
OPAL	91 GeV		$m_0 = 1000$ GeV $0.5 < \Delta M < 5.0$ GeV

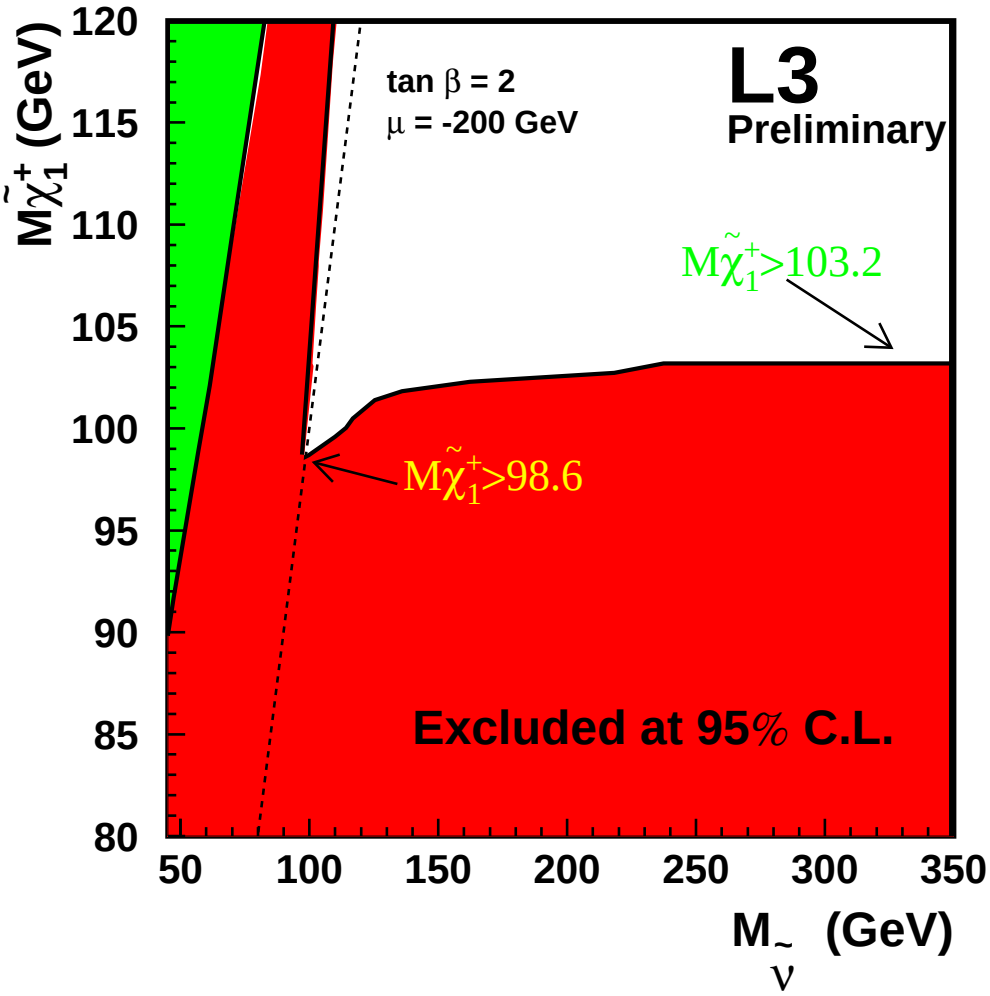
Chargino limits at small m_0

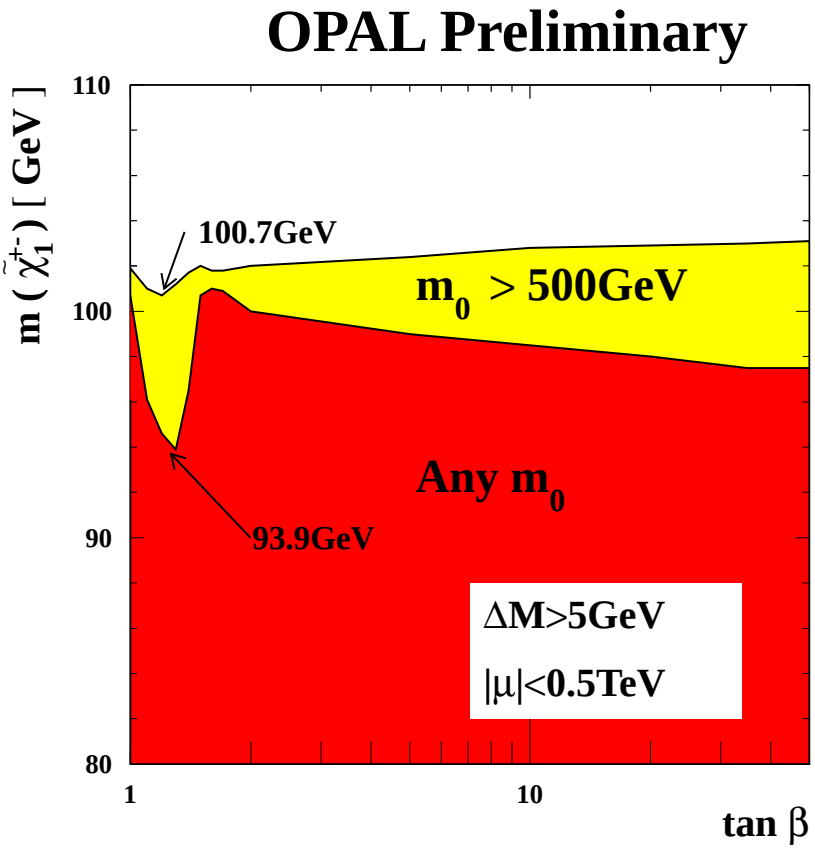
Light sfermions:

- smaller chargino production cross section
  increased neutralino production cross section
- increased leptonic branching ratios
  decays via light SUSY particles



Combination with slepton searches
(example: L3, gaugino region)





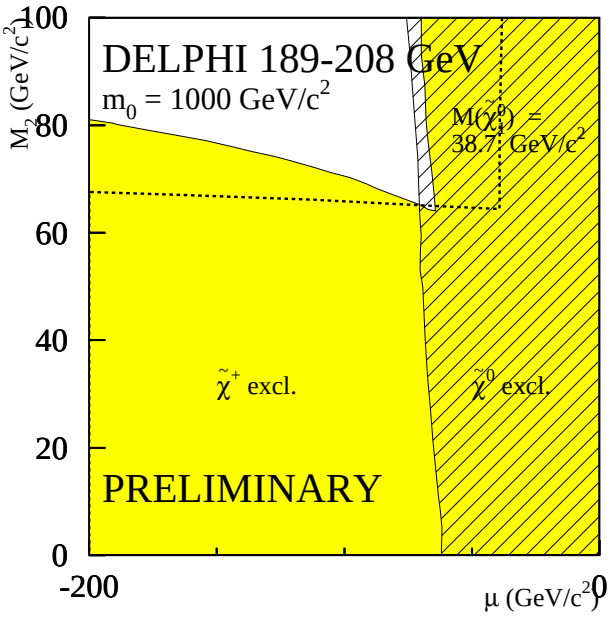
$0 < M_2 < 2000$ GeV
$|\mu| < 500$ GeV
$A = \pm M_2, \pm m_0$ and 0

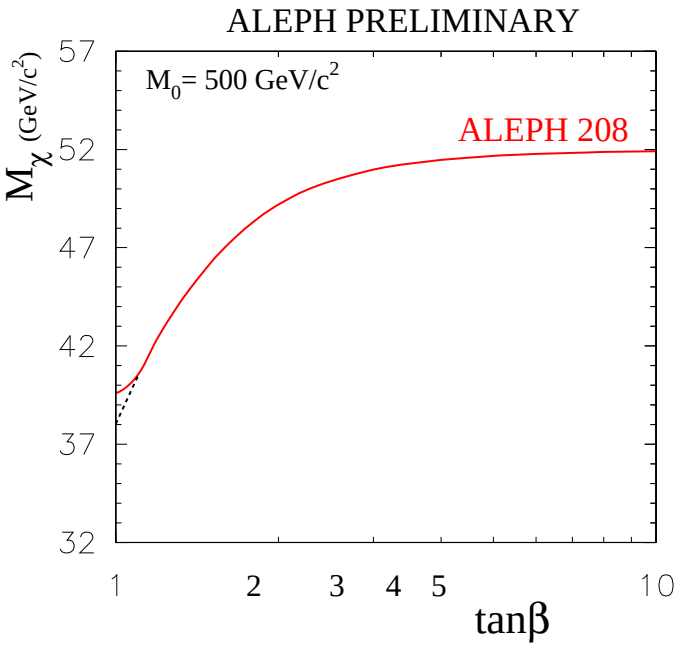
$\Delta M > 5$ GeV

Limits on the mass of the LSP

Large m_0

Combination of chargino and neutralino searches:





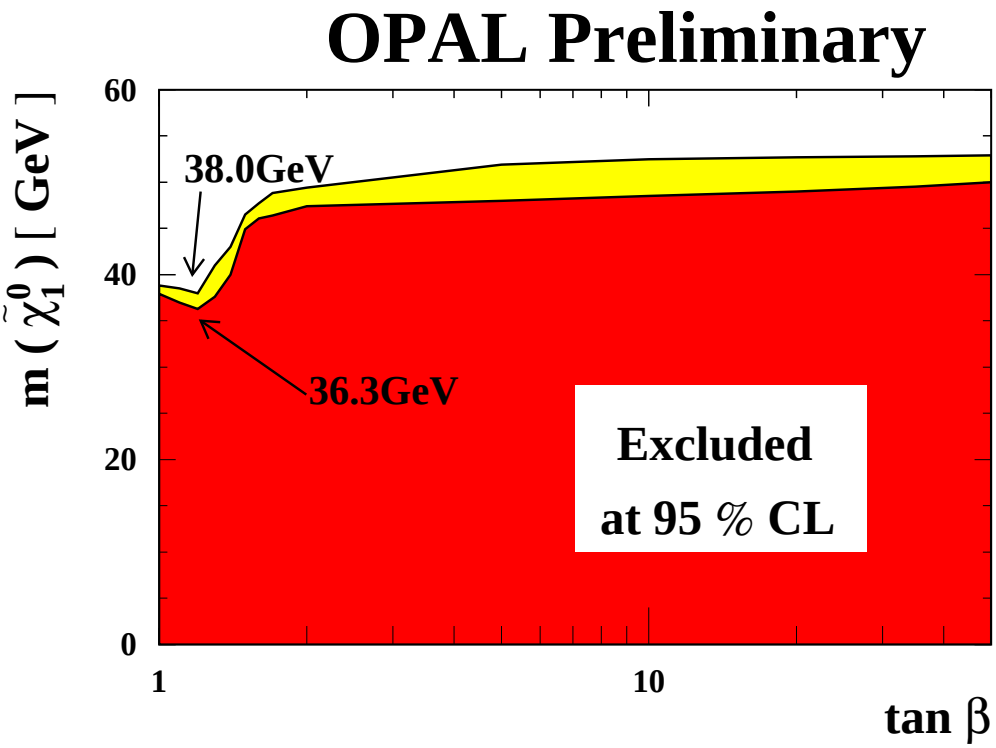
LSP limits (large m_0:)

	$M_{\tilde{\chi}_1^0}$ limit
ALEPH	39.6 GeV
DELPHI	38.7 GeV
L3	39.2 GeV
OPAL	38.0 GeV

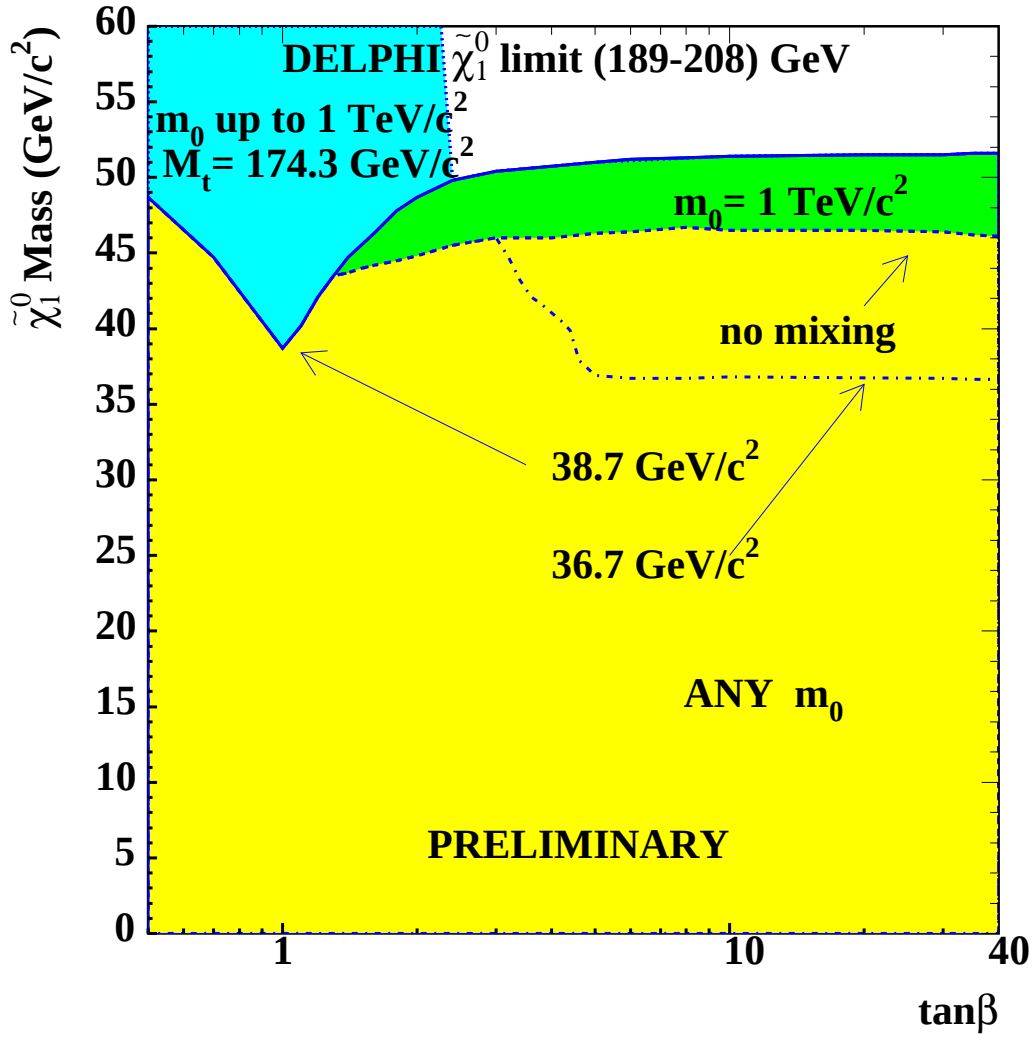
Moriond 2000 value: ~ 36 GeV

All m_0

Chargino, Neutralino and Slepton searches



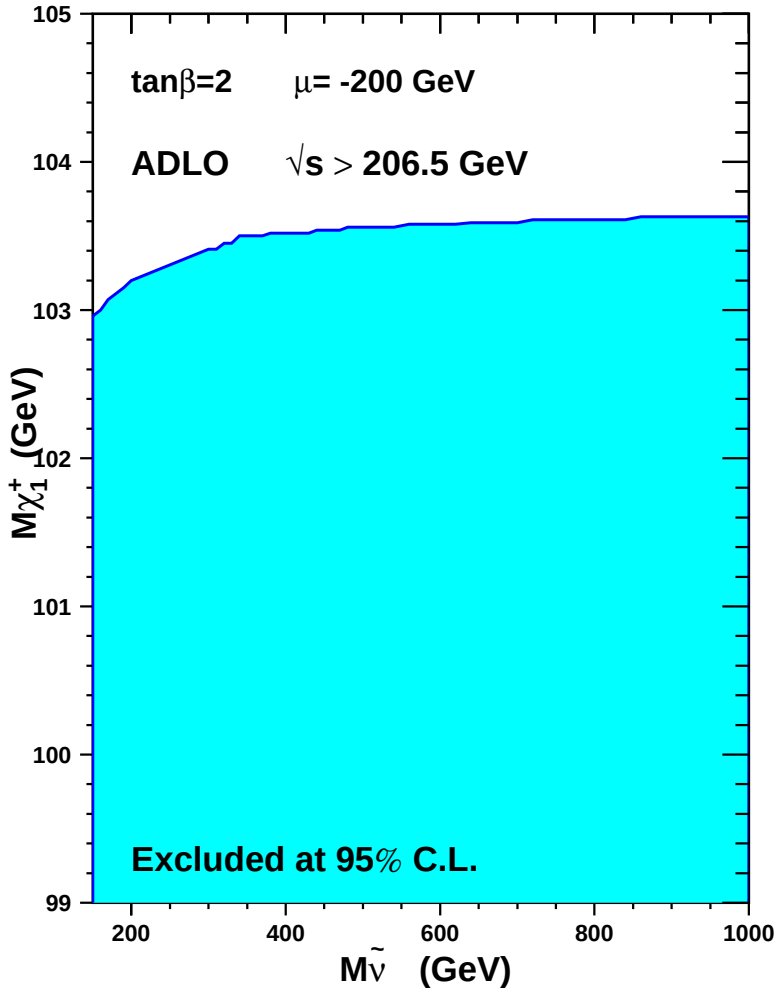
Including slepton and Higgs searches:



Delphi Neutralino limits:

$\tilde{\chi}^+$, χ^0	Large m_0	38.7 GeV
incl. h^0 constr.	m_{top} = 174.3 GeV	49.0 GeV
	m_{top} = 179 GeV	48.5 GeV
$\tilde{\chi}^+$, χ^0, $\tilde{l}$, h^0	any m_0 $A_\tau = \mu \tan\beta$ (no mixing case)	45.0 GeV
$\tilde{\chi}^+$, χ^0, $\tilde{l}$	any m_0 $A_\tau = 0$	36.7 GeV

LEP combined (ADLO) limit on gaugino-like charginos



$m_{\tilde{\chi}^+} > 103.5$ GeV

(for $m_{\tilde{\nu}} > 300$ GeV, $\tan\beta = 2$, $\mu = -200$ GeV)

Conclusions and Outlook

LEP2 has made significant contributions in the exploration of the SUSY landscape

- Up to the highest LEP2 energies no evidence for the production of SUSY particles (MSSM, R-parity conservation) has been found.

- Limits on the masses of sfermions and charginos have been set:
  For $\Delta M > 10$ GeV (mass difference to the LSP):

$m_{\tilde{e}}$	> 99 GeV	$m_{\tilde{t}}$	> 95 GeV
$m_{\tilde{\mu}}$	> 96 GeV	$m_{\tilde{b}}$	> 95 GeV
$m_{\tilde{\tau}}$	> 80 GeV	$m_{\tilde{\chi}^+}$	> 103.5 GeV

- Analyses are well advanced

  - Low ΔM regions are covered by dedicated analyses

  - Absolute limits are being extracted

    Example: $m_{\tilde{t}} > 65$ GeV

  - Limit on the mass of the LSP: $m_{\tilde{\chi}^0_1} > \sim 37$ GeV

- Future analysis will concentrate of more complete interpretaions (including stau mixing, ...)
  $\Rightarrow$ LSP limit
  $\Rightarrow$ More absolute limits (selectrons,...)
  ...
  $\Rightarrow$ LEP combined results

The search for SUSY will continue

Good luck at the TeVatron and at the LHC