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MSSM SUSY Searches at LEP2

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For the LEP Collaborations

Outline

- Introduction
- Sfermion searches
- Chargino/Neutralino searches
- Limits on MSSM parameters and sparticle masses
- Conclusion

SUSY framework

❑ Constrained MSSM

M_2	SU(2) gaugino mass at EW scale
m_0	common scalar mass at GUT scale
$tan\beta$	$= \frac{v_2}{v_1}$
μ	Higgs mass parameter
A_0	common trilinear coupling
m_A	Mass of CP–odd Higgs A

❑ R–parity conservation assumed

- ➨ Sparticles are produced in pairs and decay to their SM partner and the LSP
- ➨ LSP is stable and weakly interacting
  - ➥ Lightest neutralino is LSP
  - ➥ LSP escapes detection ➨ missing energy signature
  - ➥ Candidate for cold dark matter

Searched Sparticles

- Sleptons

  $\tilde{e}^+\tilde{e}^-, \quad \tilde{\mu}^+\tilde{\mu}^-, \quad \tilde{\tau}_1^+\tilde{\tau}_1^-$

- Squarks

  $\tilde{t}_1\tilde{t}_1, \; \tilde{b}_1\tilde{b}_1$

- Charginos and Neutralinos

  $\tilde{\chi}_1^+\,\tilde{\chi}_1^-, \quad \tilde{\chi}_i^0\,\tilde{\chi}_j^0$

❑ Mostly decaying directly to LSP:

$\tilde{f} \longrightarrow f\tilde{\chi}_1^0,$ except for stop $\tilde{t} \longrightarrow c\tilde{\chi}_1^0,$

$\tilde{\chi}_1^+ \longrightarrow W^*\tilde{\chi}_1^0 \longrightarrow f\bar{f}'\tilde{\chi}_1^0$

$\tilde{\chi}_i^0 \longrightarrow Z^*\,\tilde{\chi}_1^0 \longrightarrow f\bar{f}\tilde{\chi}_1^0$

❑ Cascade decays can also be important:

$\tilde{f} \longrightarrow f\tilde{\chi}_2^0, \quad \tilde{t} \longrightarrow b\ell\tilde{\nu}$

$\tilde{\chi}_1^+ \longrightarrow W^*\tilde{\chi}_2^0, \quad \tilde{\chi}_1^+ \longrightarrow \tilde{\ell}\nu(\ell\tilde{\nu}),$

$\tilde{\chi}_i^0 \longrightarrow Z^*\,\tilde{\chi}_2^0, \quad \tilde{\chi}_i^0 \longrightarrow \tilde{\ell}\ell, \quad \tilde{\chi}_i^0 \longrightarrow \tilde{\nu}\nu$

⇓

lepton(s) + E^{miss}

lepton(s) + jets + E^{miss}

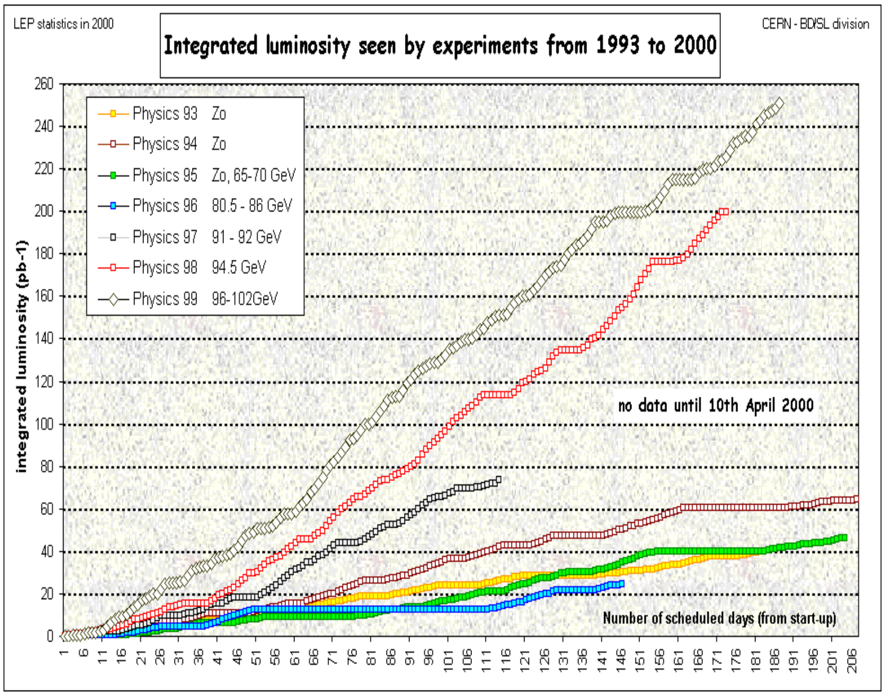
jets + E^{miss}

Kinematics depend on $\Delta M = M_{sparticle} - M_{LSP}$

LEP2 Dataset

ALEPH, DELPHI, L3, OPAL

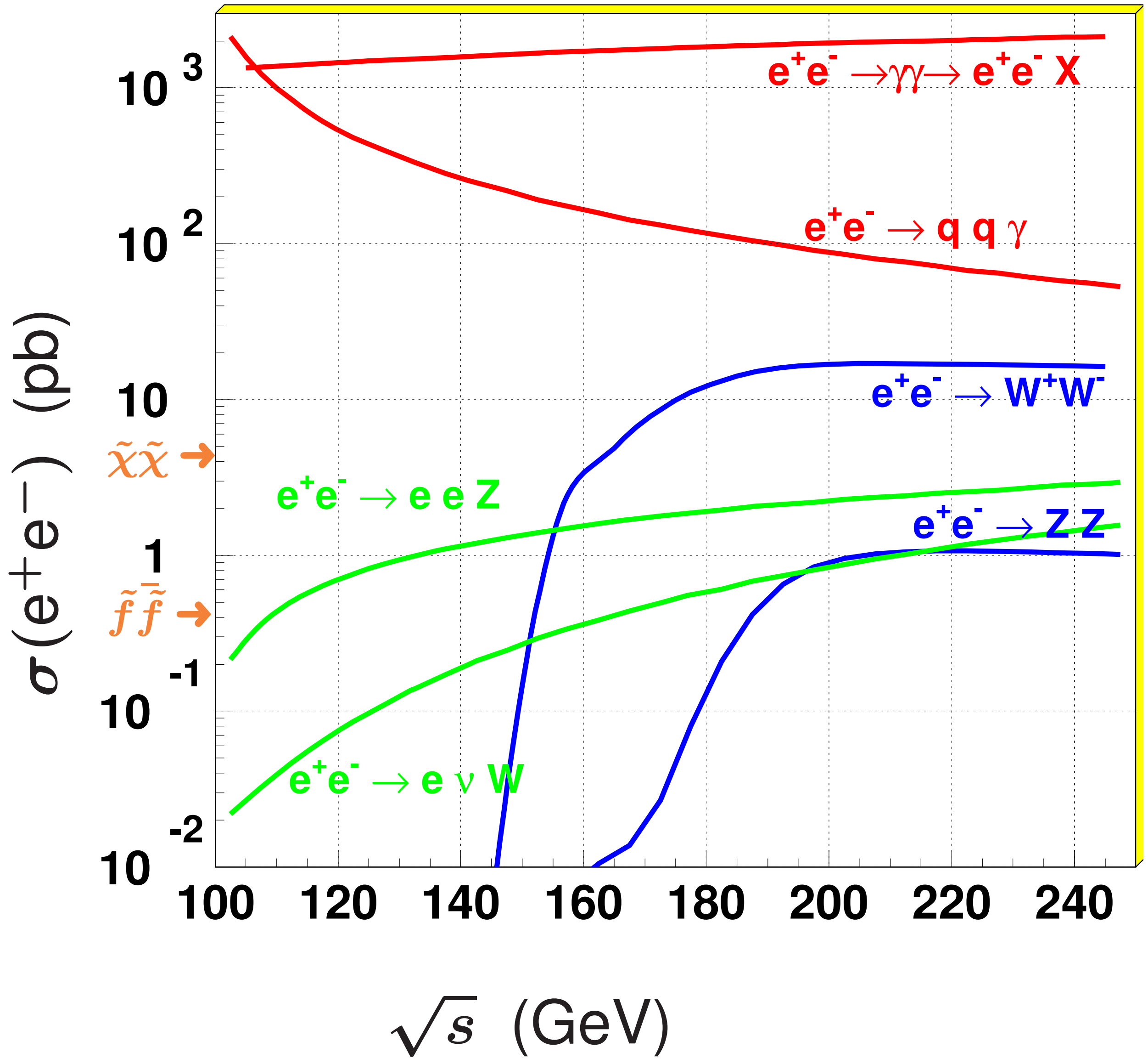
Year	$\sqrt{s}$	$\mathcal{L}$ / Experiment
1995	130–136 GeV	$\approx 6\ \mathrm{pb}^{-1}$
1996	161–172 GeV	$\approx 21\ \mathrm{pb}^{-1}$
1997	181–184 GeV	$\approx 56\ \mathrm{pb}^{-1}$
1998	189 GeV	$\approx 170\ \mathrm{pb}^{-1}$
1999	192–202 GeV	$\approx 240\ \mathrm{pb}^{-1}$



All results are obtained with 1999 data and are PRELIMINARY

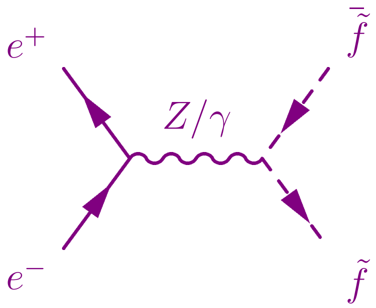
Limits are quoted at 95% C.L.

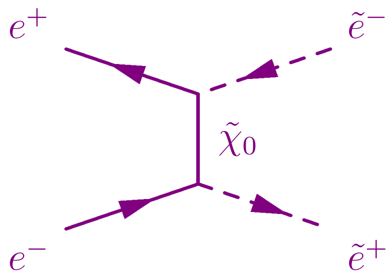
SM Background Processes



- $e^+e^- f\bar{f}$ is most severe background at low ΔM.
- WW and Weν are the dominant backgrounds at high ΔM.

Sleptons



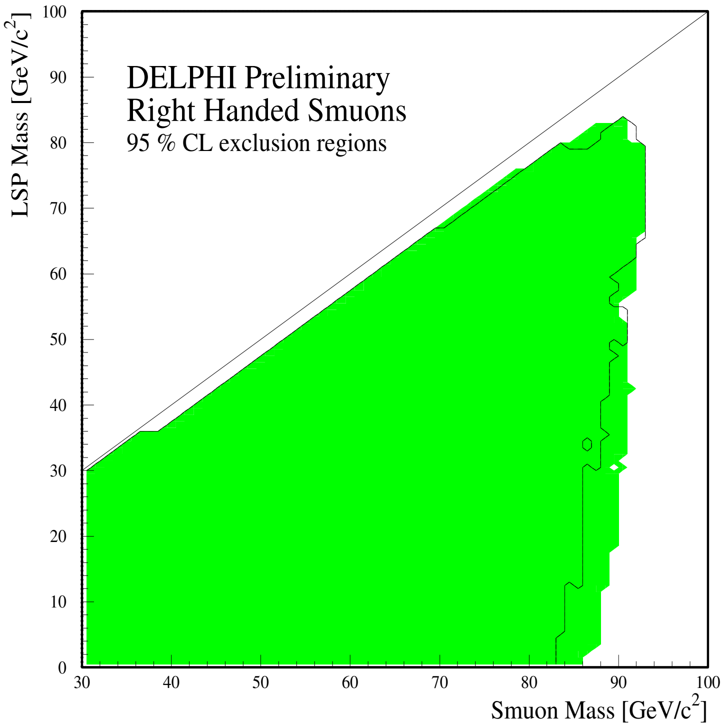


$$\boldsymbol{\sigma = \sigma\big(M_2, \mu, \tan\beta, m_0, (A_0)\big)}$$

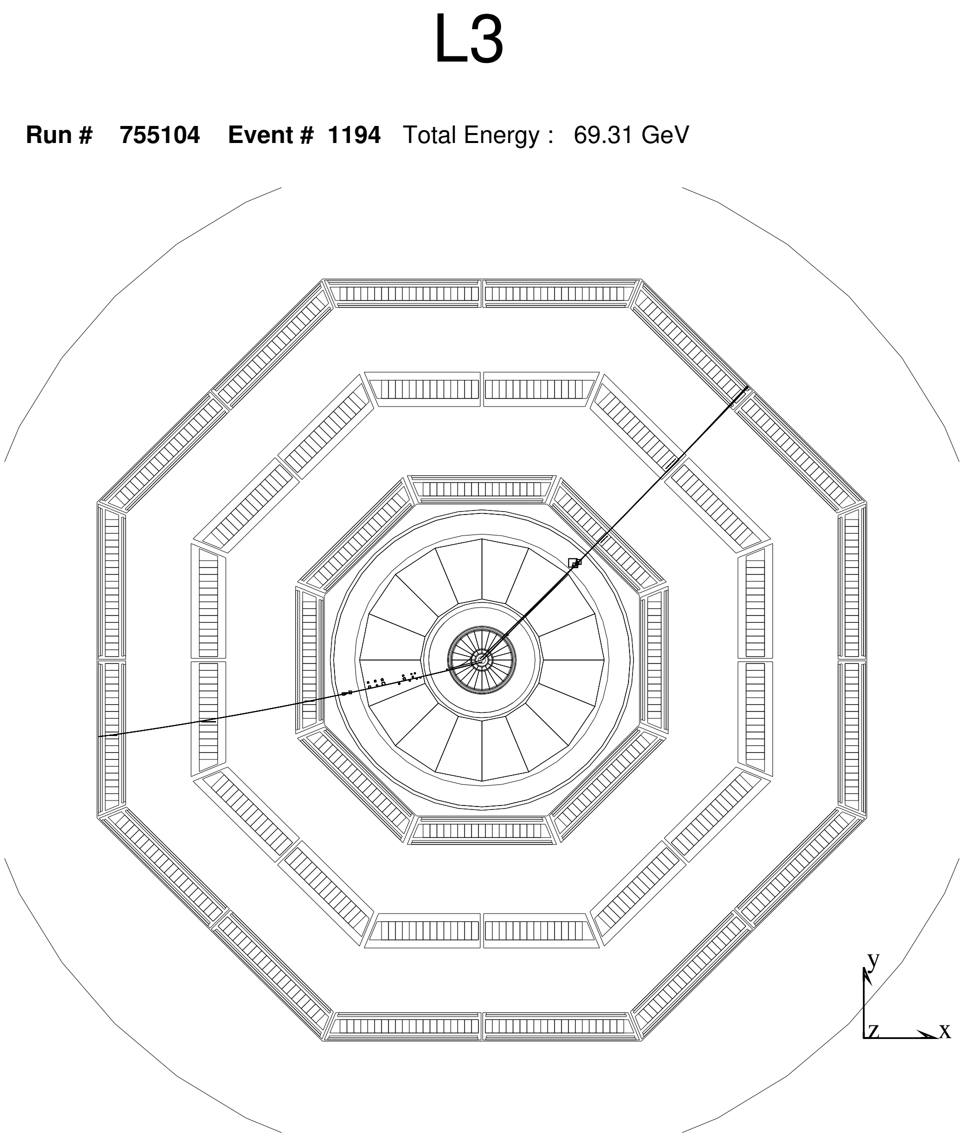
$\tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^- + \mathrm{E}^{\mathrm{miss}}$

Data 13

MC 19.2



Smuon Candidate



Transverse Imbalance :	.6543	**Longitudinal Imbalance :**	.1887

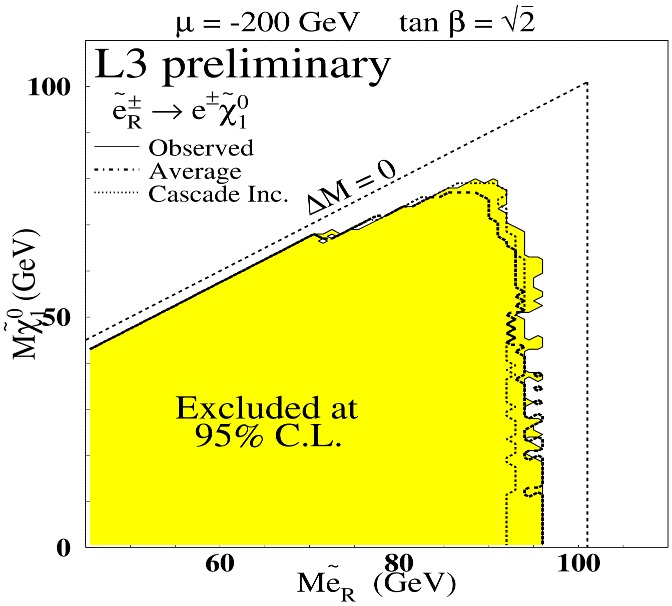
Thrust :	.9814	**Major :**	.1428	**Minor :**	.0013
Event DAQ Time :	*990708 84421*				

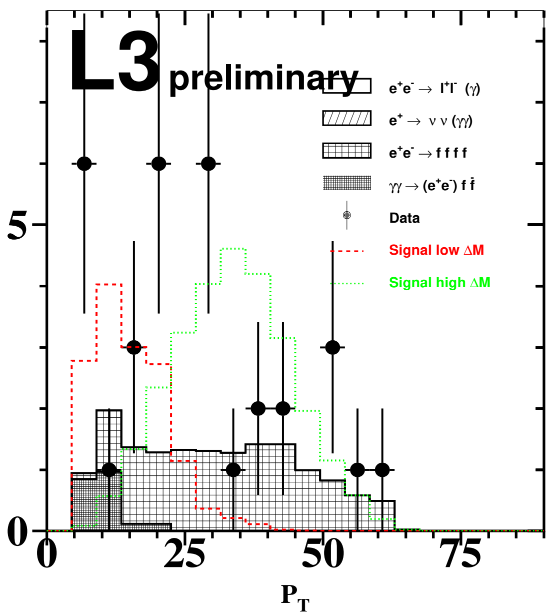
Sleptons

$\tilde{e}_R^+ \tilde{e}_R^- \rightarrow e^+ e^- + \mathrm{E}^{\mathrm{miss}}$

Data 76

MC 68.9





$\tilde{e}_L^+ \tilde{e}_R^- \rightarrow e^+ + soft\ syst. + \mathrm{E}^{\mathrm{miss}}$

Important to cover low $\Delta M = M_{\tilde{e}_R} - M_{\tilde{\chi}_1^0}$ region

Data 32

MC 15.2

Sleptons

$$\mathcal{M}^2_{\tilde{f}} = \begin{pmatrix} m^2_{\tilde{f}L} & a_f m_f \\ a_f m_f & m^2_{\tilde{f}R} \end{pmatrix}$$

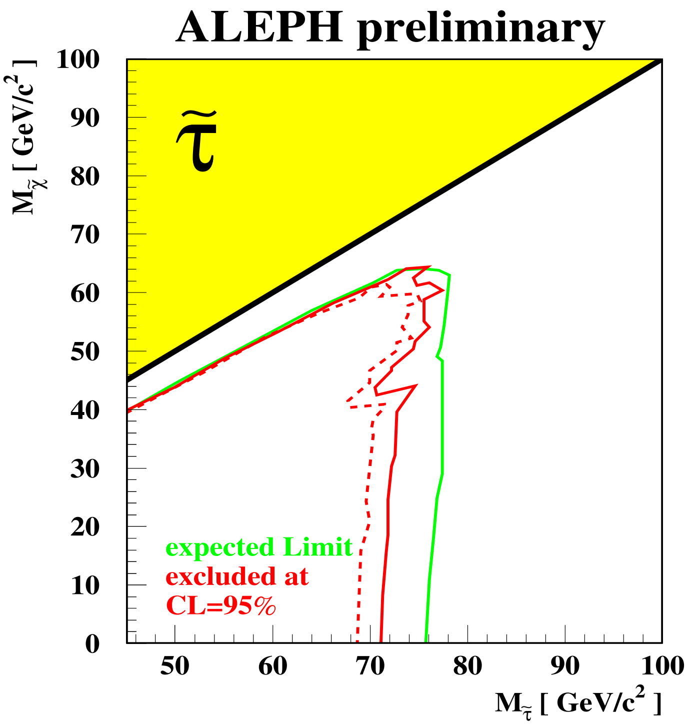
$$a_f = A_0 - \mu(\tan\beta)^{-2I_3^f}$$

➥ Mixing can be sizable for the third generation sfermions ➜ large mass splitting between the two mass eigenstates $\tilde{f}_1$ and $\tilde{f}_2$

$\tilde{\tau}^+\tilde{\tau}^- \rightarrow \tau^+\tau^- + \mathrm{E}^{\mathrm{miss}}$

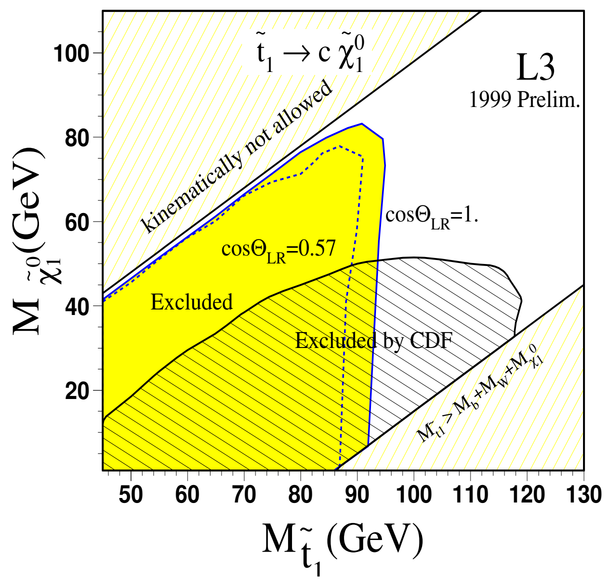
Data 46

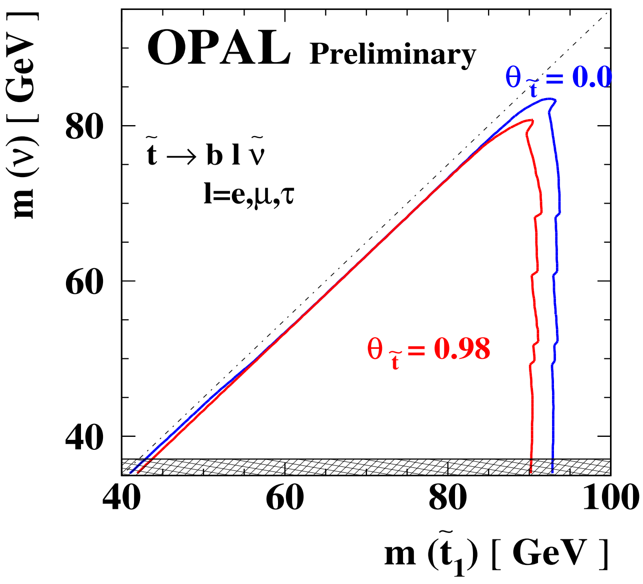
MC 34.2

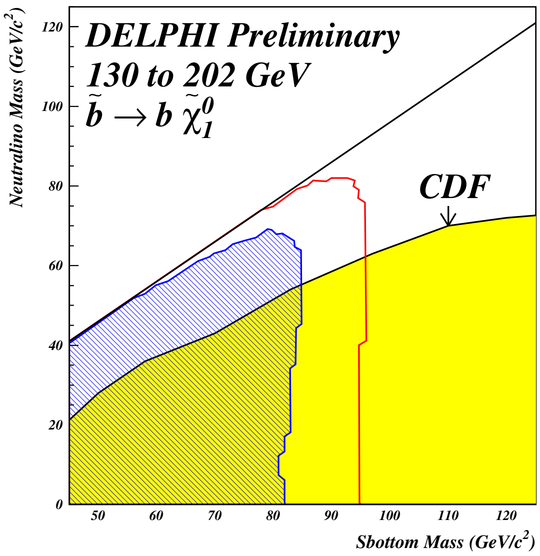


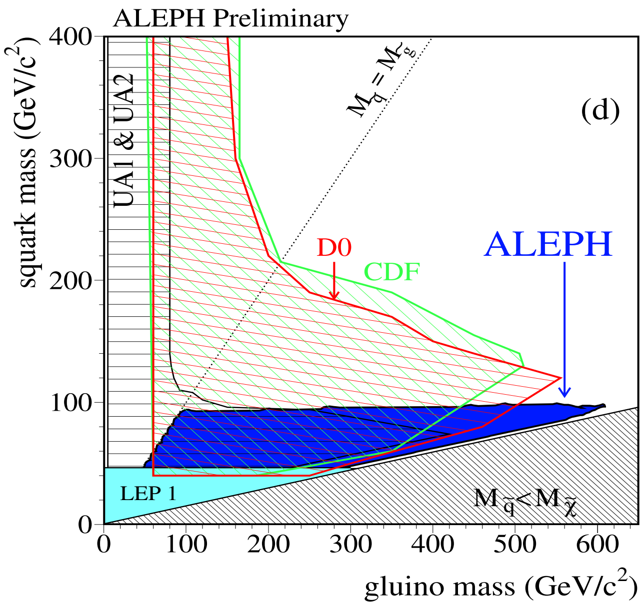
Squarks

Stop and Sbottom exclusion contours for minimal and maximal cross-sections









↑
Squarks of the first two generations

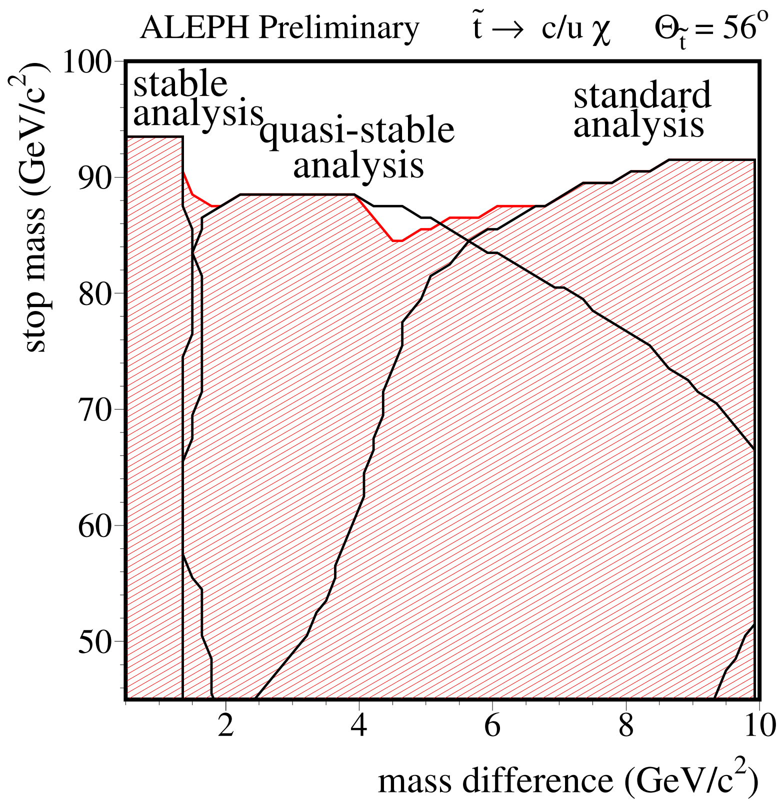
Stop mass degenerate with LSP

$\tilde{t} \to c\tilde{\chi}_1^0$ if $\Delta M \gtrsim m_c$
$\tilde{t} \to u\tilde{\chi}_1^0$ if $\Delta M \lesssim m_c$

FCNC decays

Lifetime (depends on MSSM parameters) can be long ➜ displaced vertex or decay outside detector

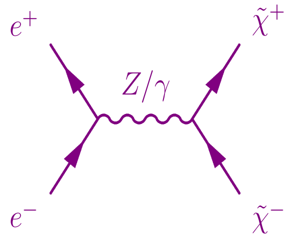
- ❑ $\Delta M \gtrsim$3 GeV "standard searches"
- ❑ 1.5 GeV $\lesssim \Delta M \lesssim$3 GeV Impact parameter measurement
- ❑ $\Delta M \lesssim$1.5 GeV anomalous ionization measurement

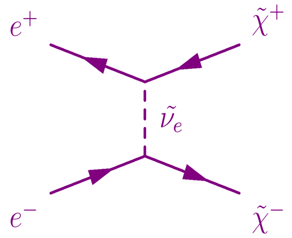


$\mu = -100$ GeV
$\tan\beta = 1.5$

In MSSM $M_{\tilde{t}_1}$ >63 GeV

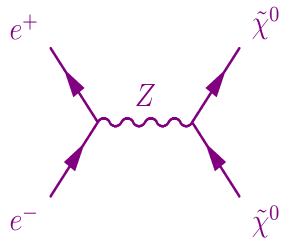
Charginos and Neutralinos

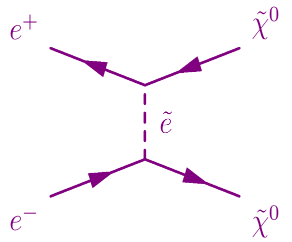




$$\sigma = \sigma(M_2, \mu, \tan\beta, m_0)$$

destructive interference
if gaugino-like





$$\sigma = \sigma(M_2, \mu, \tan\beta, m_0)$$

constructive interference
if gaugino-like

MSSM scenarios

- Higgsino region $M_2 >> |\mu|$

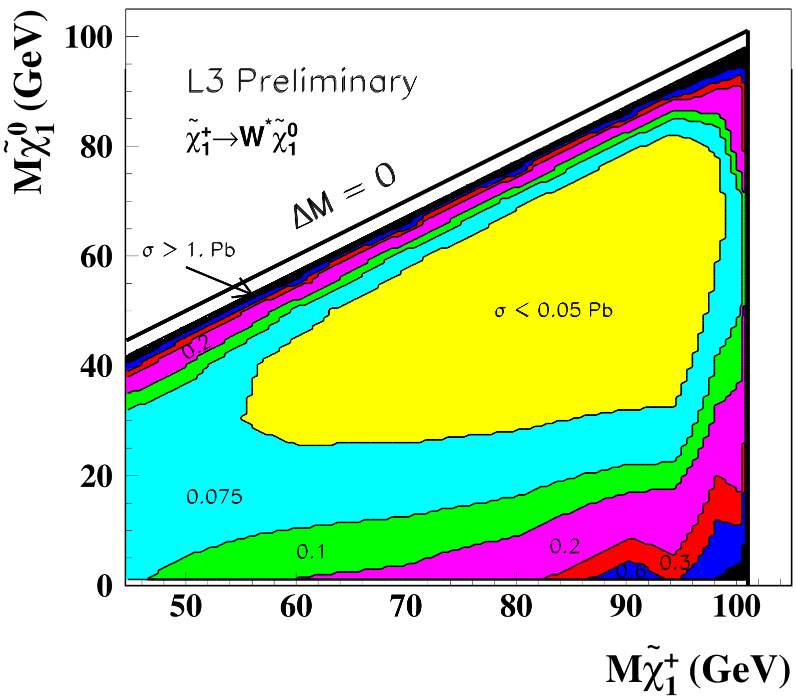
  no t-channel contribution
- Gaugino region $M_2 << |\mu|$ with high m_0

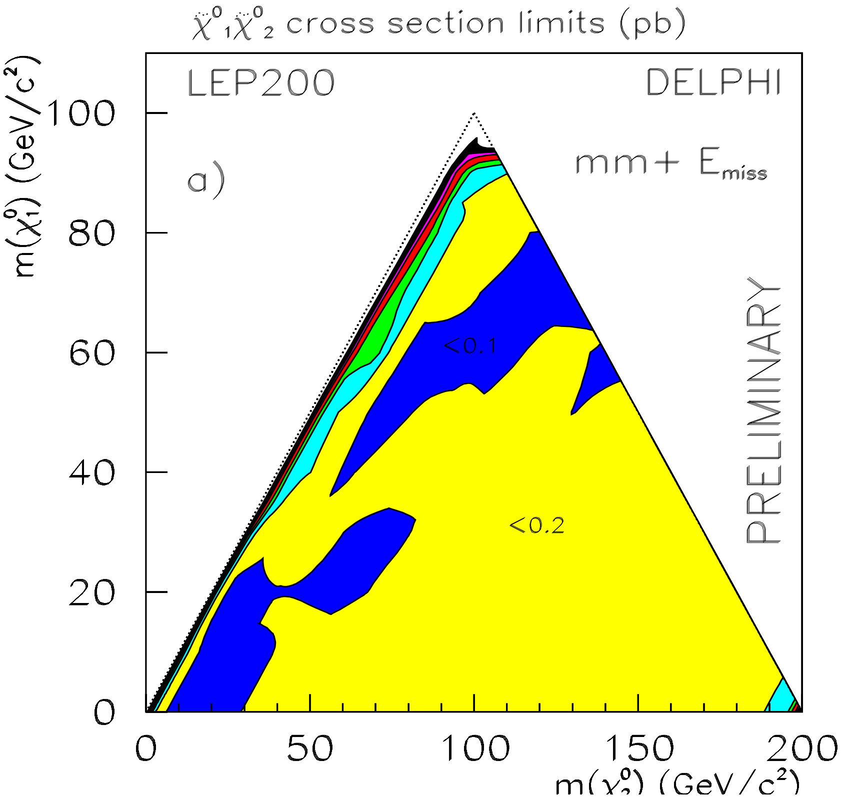
  no t-channel contribution
- Gaugino region $M_2 << |\mu|$ with low m_0

  t-channel interference becomes important

  Slepton searches important

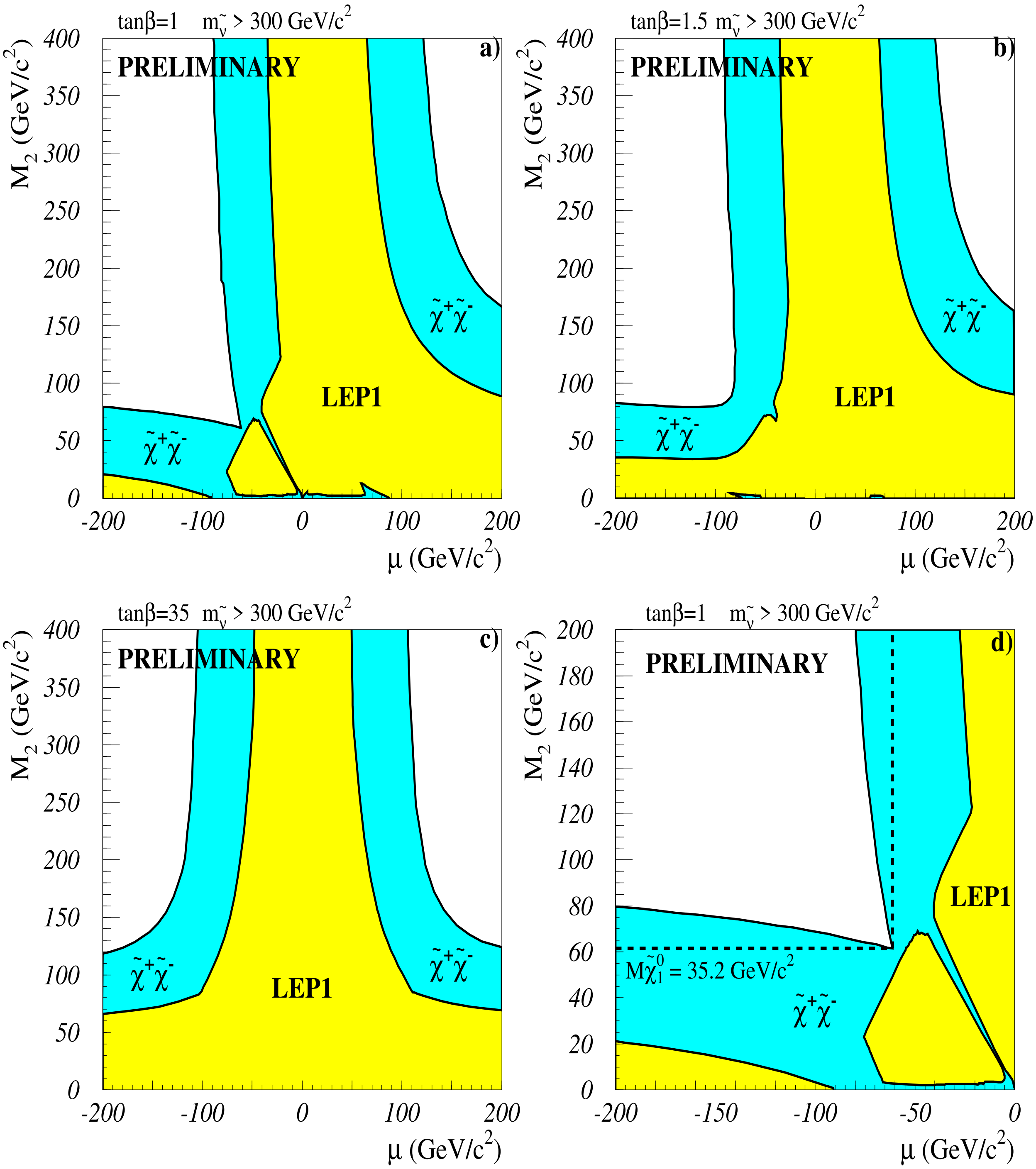
Charginos and Neutralinos





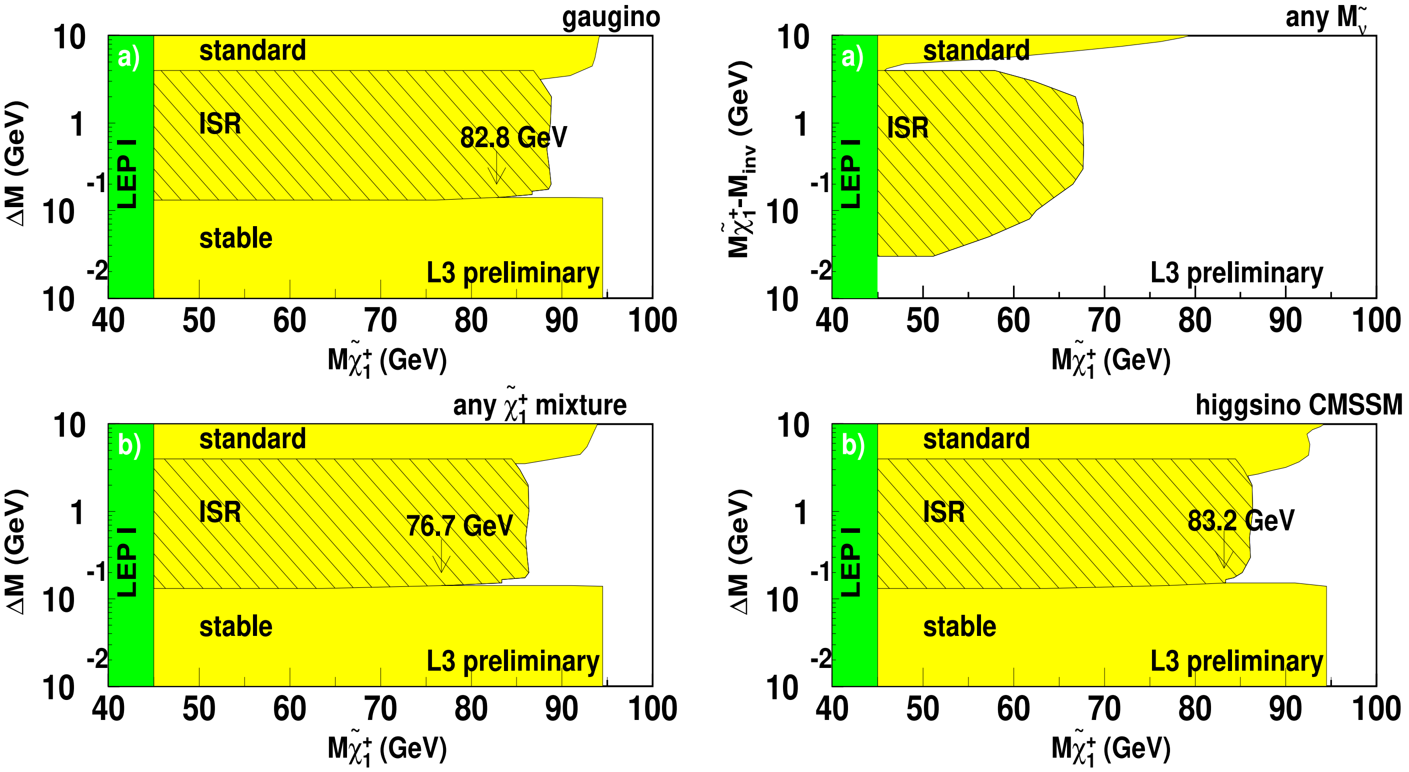
Limits on the MSSM Parameters

DELPHI MSSM limits at 202 GeV



Mass Degenerate Chargino

- Chargino can be mass degenerate with LSP in case of:
  - $|\mu| \gg M_2$ and $M_1 \gtrsim M_2 \longrightarrow M(\tilde{\chi}_1^{\pm}) \simeq M(\tilde{\chi}_1^0) \sim M_2$
  - $|\mu| \ll M_2 \longrightarrow M(\tilde{\chi}_1^{\pm}) \simeq M(\tilde{\chi}_1^0) \sim \mu$ (includes CMSSM case)
  - Any composition of $\tilde{\chi}_1^{\pm}$ and $M_1 \gtrsim 4M_2$
- Search strategies:
  - $\Delta M \lesssim$ 200 MeV — search for stable heavy charged particles.
  - 150 MeV $\lesssim \Delta M \lesssim$ 3 GeV — tag events with ISR photon and E^{miss}



Allows to set limit on $M(\tilde{\chi}_1^{\pm})$ for any ΔM

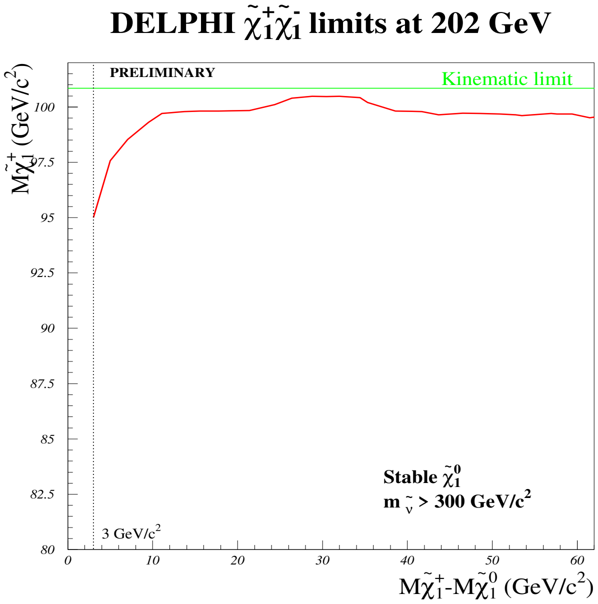
in case of heavy selectrons.

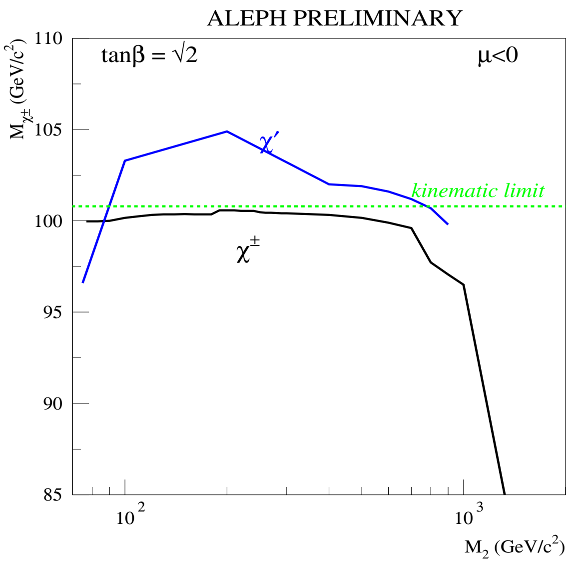
Limits on Gaugino Masses

DELPHI

$\tilde{\chi}_1^{\pm}$ mass limit versus ΔM

for heavy sneutrino





ALEPH

$\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2$ mass limits versus M_2

in higgsino region

OPAL

$\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2$, $\tilde{\chi}_3$ mass limits

for $m_0 > 500$ GeV

		tanβ=1.5	tanβ = 35
$M_{\tilde{\chi}_1^{\pm}}$	$>$	100.0 GeV	100.1 GeV
$M_{\tilde{\chi}_2^0}$	$>$	75.4 GeV	100.1 GeV
$M_{\tilde{\chi}_3^0}$	$>$	110.9 GeV	129.4 GeV

Chargino Mass Limit

Employing chargino and slepton searches

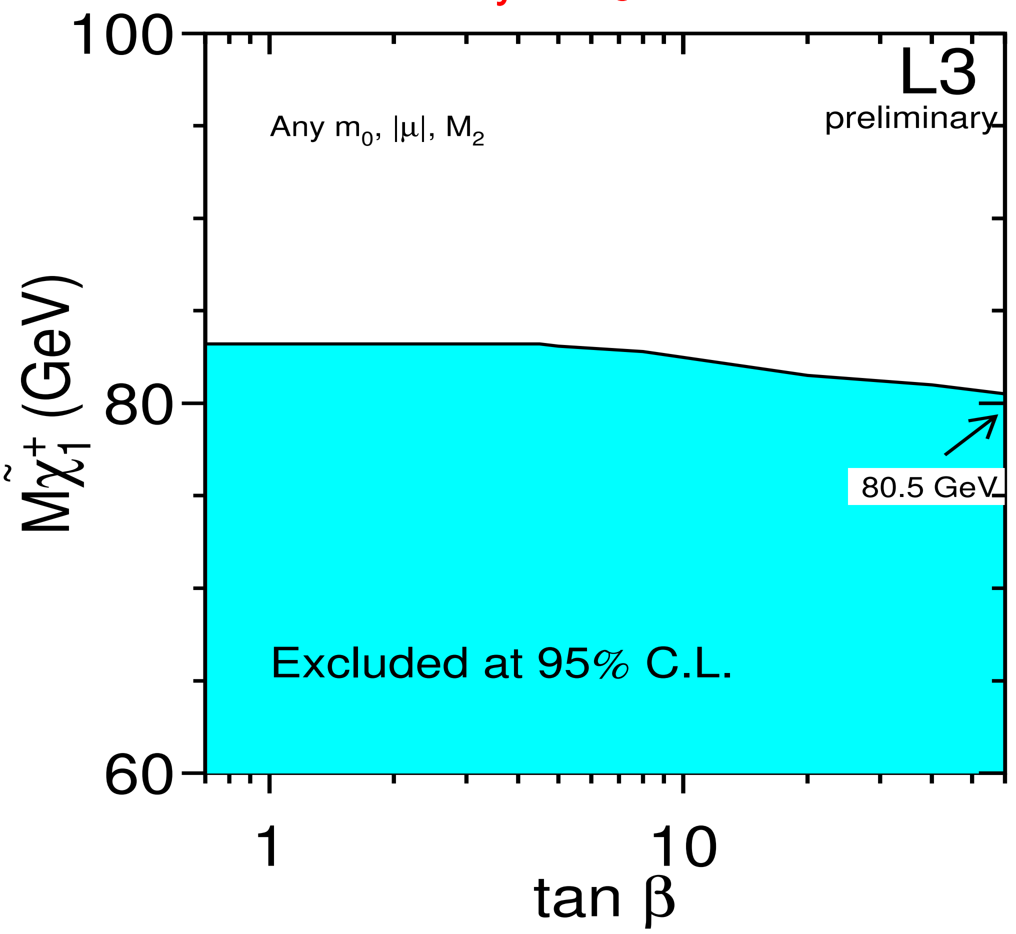
Parameter scan:

any M_2

-2 TeV $<$ μ $<$ 2 TeV,

0.6 $< tan\beta <$ 60,

any m_0



Model parameter independent limit on chargino mass

$$\boxed{M_{\tilde{\chi}_1^{\pm}} > 80.5 \text{ GeV}}$$

LSP Mass Limit

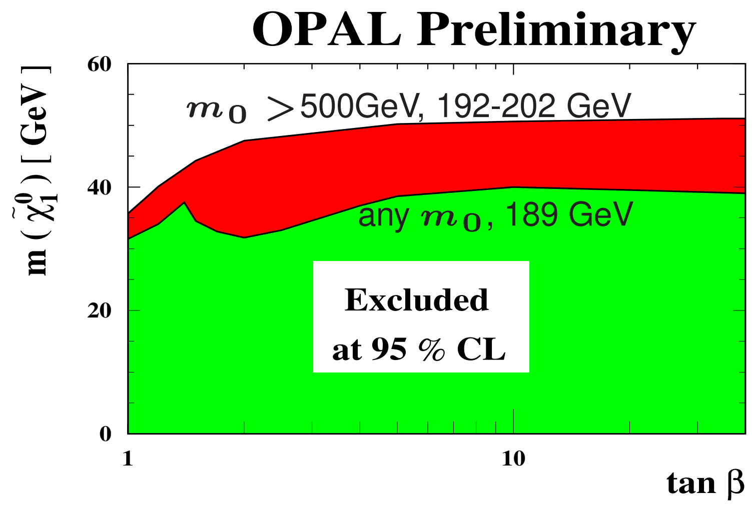
OPAL

Employing $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\chi}_1^0\tilde{\chi}_3^0$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$ searches

Parameters scanned:

$$0 < M_2 < 2\text{ TeV},$$
$$-500\text{ GeV} < \mu < 500\text{ GeV},$$
$$1 < tan\beta < 40$$

m_0 >500 GeV assumed



DELPHI

Employing $\tilde{\chi}_1^+\tilde{\chi}_1^-$ searches

Parameters scanned:

$$0 < M_2 < 3\text{ TeV},$$
$$-200\text{ GeV} < \mu < 200\text{ GeV},$$
$$tan\beta = 1, 1.5, 35$$

$M_{\tilde{\nu}}$ >300 GeV assumed

$M_{\tilde{\chi}_1^0}$ >35.2 GeV

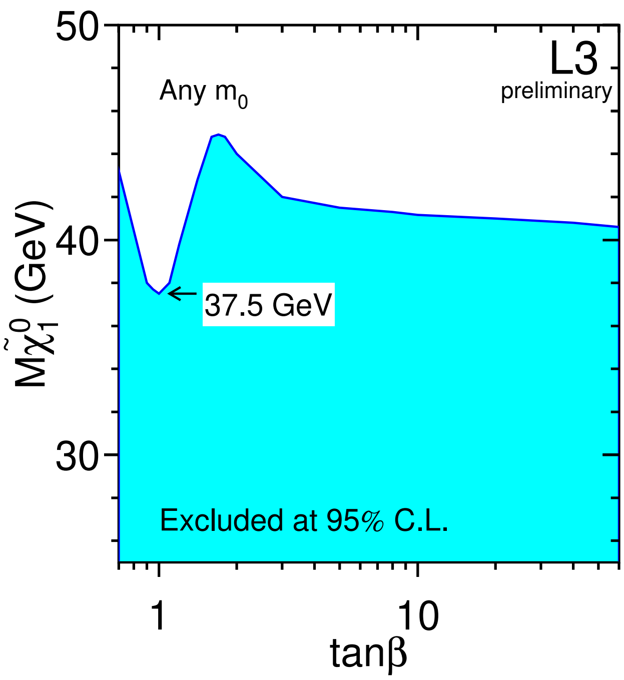
LSP Mass Limit

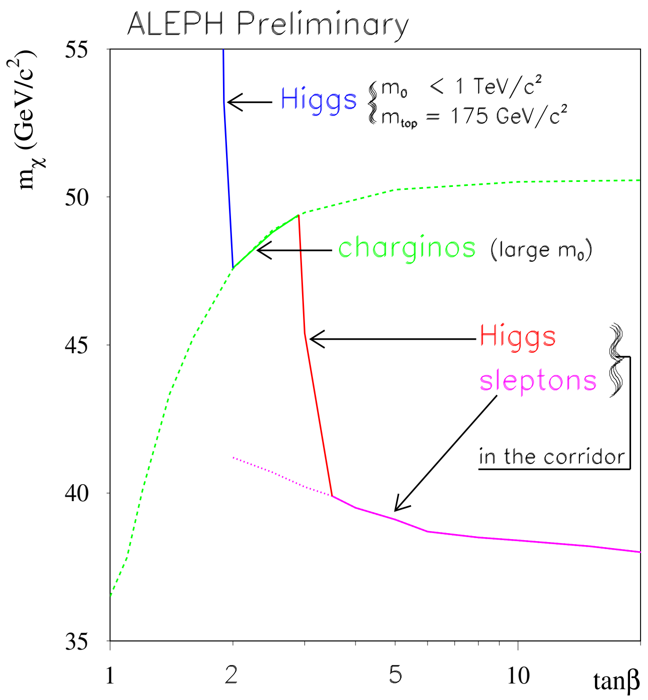
L3

Employing $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_2^0\tilde{\chi}_4^0$ and slepton searches

Parameters scanned:

$$\begin{array}{rcccl} & \text{any} & M_2 & & \\ \text{-2 TeV} & < & \mu & < & \text{2 TeV,} \\ 0.6 & < & tan\beta & < & 60, \\ & \text{any} & m_0 & & \end{array}$$





ALEPH

Employing $\tilde{\chi}_1^+\tilde{\chi}_1^-$, slepton and Higgs searches

Parameters scanned:

$$\begin{array}{rcccl} 0 & < & M_2 & < & \text{1 TeV,} \\ \text{-2 TeV} & < & \mu & < & \text{2 TeV,} \\ 1 & < & tan\beta & < & 50, \\ & & m_0 & < & \text{1 GeV} \\ & & M_A & = & \text{2 TeV} \end{array}$$

very sensitive to the M_t

Conclusion

- Production of charginos, neutralinos, sleptons and squarks has been searched for in various scenarios of CMSSM. Novel experimental signatures have been investigated.

- No evidence for SUSY particle production has been found and new limits have been set on sparticle masses and the model parameters.

- Limit on $\tilde{\chi}_1^0$ – LSP mass:

ALEPH	$m_{\tilde{\chi}_1^0} >$38 GeV	for $m_0 \leq$1 TeV, M_t=175 GeV
DELPHI	$m_{\tilde{\chi}_1^0} >$35.2 GeV	for $M_{\tilde{\nu}} >$300 GeV
L3	$m_{\tilde{\chi}_1^0} >$37.5 GeV	
Opal	$m_{\tilde{\chi}_1^0} >$35.7 GeV	for $m_0 \geq \mathbf{500}$ GeV

Y2K is the last and the best year of LEP