Division of Particles and Fields Conference

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Chargino-Neutralino Searches at LEP

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For the LEP Collaborations

- Introduction
- Final states and search strategies
- Limits on production X-sections and masses
- MSSM parameter space mapping
- Conclusions and perspectives

SUSY Framework

MSSM

Gaugino masses M_i, $M_1 : M_2 : M_3 = \alpha_1 : \alpha_2 : \alpha_3$

Universal scalar mass at GUT scale m_0

Higgsino mass term μ

tanβ = $< H_2^0 > / < H_1^0 >$

Universal trilinear coupling A

Scanned parameter space

0 $\leq M_2 \leq$ 3000 GeV

10 GeV $\leq m_0 \leq$ 500 GeV

1 $\leq tan\beta \leq$ 50

– 500 GeV $\leq \mu \leq$ 500 GeV

(0.5 $\leq M_1 : M_2 \leq$ 5)

$R = (-1)^{3B+L+2S}$ conservation assumed

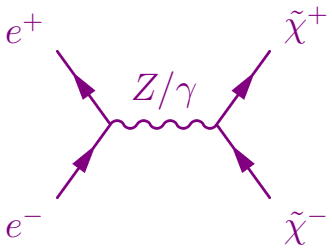
- sparticles are produced in pairs
- LSP is stable
- NLSP $\longrightarrow$ LSP + SM particle(s)
- most plausable LSP is weakly interacting

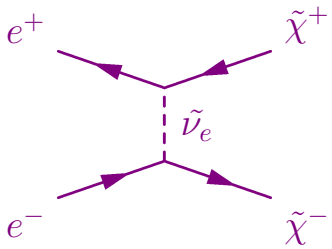
  lightest neutralino $\tilde{\chi}_1^0 \Longrightarrow \not{E}$ signature

In the MSSM gaugino-higgsino mixing gives
two charginos $\tilde{\chi}^{\pm}_{1,2}$ and four neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$

Production mechanisms at LEP

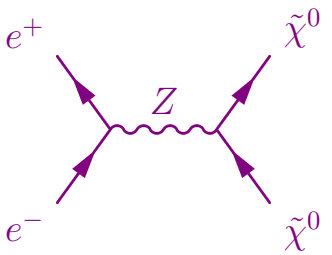
$$\sigma = \sigma(M_2, \mu, m_0, tan\beta)$$

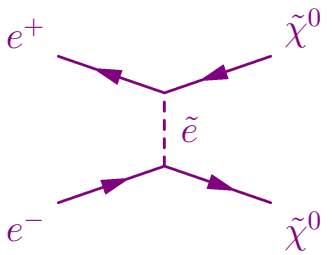




$\sigma_{\tilde{\chi}^+_1\tilde{\chi}^-_1}$ up to $\sim$ 6 pb

destructive interference
if gaugino-like





$\sigma_{\tilde{\chi}^0_1\tilde{\chi}^0_2}$ up to $\sim$ 2 pb

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
  indirect limits from scalar lepton searches

Decays / Topologies

- **Chargino**

$\underset{M(W^{\pm})}{\tilde{\chi}_1^{\pm}} \rightarrow \tilde{\chi}_1^0\, W^* \rightarrow \tilde{\chi}_1^0 f \bar{f}'$ **dominant if** $M(\tilde{l}, \tilde{\nu}, H^{\pm}) >>$

$\rightarrow \tilde{l}\nu\ (l\tilde{\nu}) \rightarrow \tilde{\chi}_1^0 l\nu$ **may enrich leptonic final states**

4 jets + $\not{E}$, 2 jets + ℓ + $\not{E}$, 2ℓ + $\not{E}$

- **Neutralinos**

$\tilde{\chi}_i^0 \rightarrow \tilde{\chi}_1^0 Z^* \rightarrow \tilde{\chi}_1^0 f \bar{f}$ **dominant if** $M(\tilde{l}, \tilde{\nu}, h, A) >> M(Z)$

$\rightarrow \quad \tilde{l}\, l \quad \rightarrow \tilde{\chi}_1^0 l^+ l^-$ **may enrich leptonic final states**

4 (2) jets + $\not{E}$, 2 jets + 2 ℓ + $\not{E}$, 4 (2) ℓ + $\not{E}$

- **Cascade decays**

$\tilde{\chi}_i^0 \rightarrow \tilde{\chi}_1^{\pm} f \bar{f}'$

$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_i^0 f \bar{f}'$

many jets and / or ℓ's + $\not{E}$

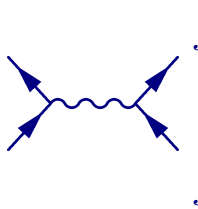
- **Higher order processes**

$\tilde{\chi}_i^0 \rightarrow \tilde{\chi}_j^0 \gamma$

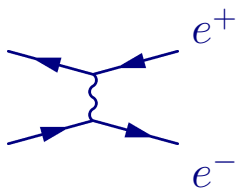
jets and / or ℓ's + photon + $\not{E}$

Backgrounds — X-section at $\sqrt{s}$= 189 GeV

- **Fermion pair production**

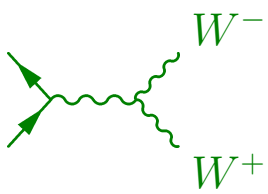


$f\bar{f}$ $\sigma(f\bar{f}) = 0.12$ nb

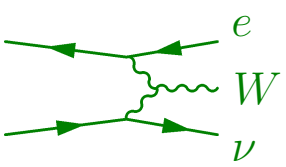


$Bhabha$ $\sigma(e^+e^-) = 1.1$ nb

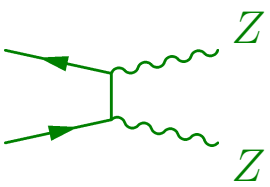
- **Four fermion production**



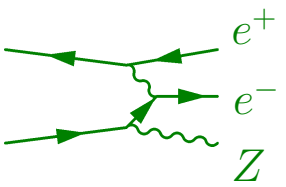
W^+W^- $\sigma(W^+W^-) = 17$ pb



$We\nu$ $\sigma(We\nu) = 2.9$ pb

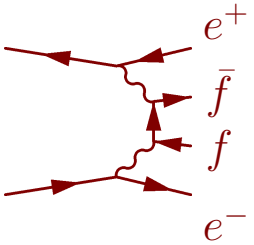


ZZ $\sigma(ZZ) = 0.97$ pb



Zee $\sigma(Ze^+e^-) = 3.4$ pb

- **Two-photon interaction**



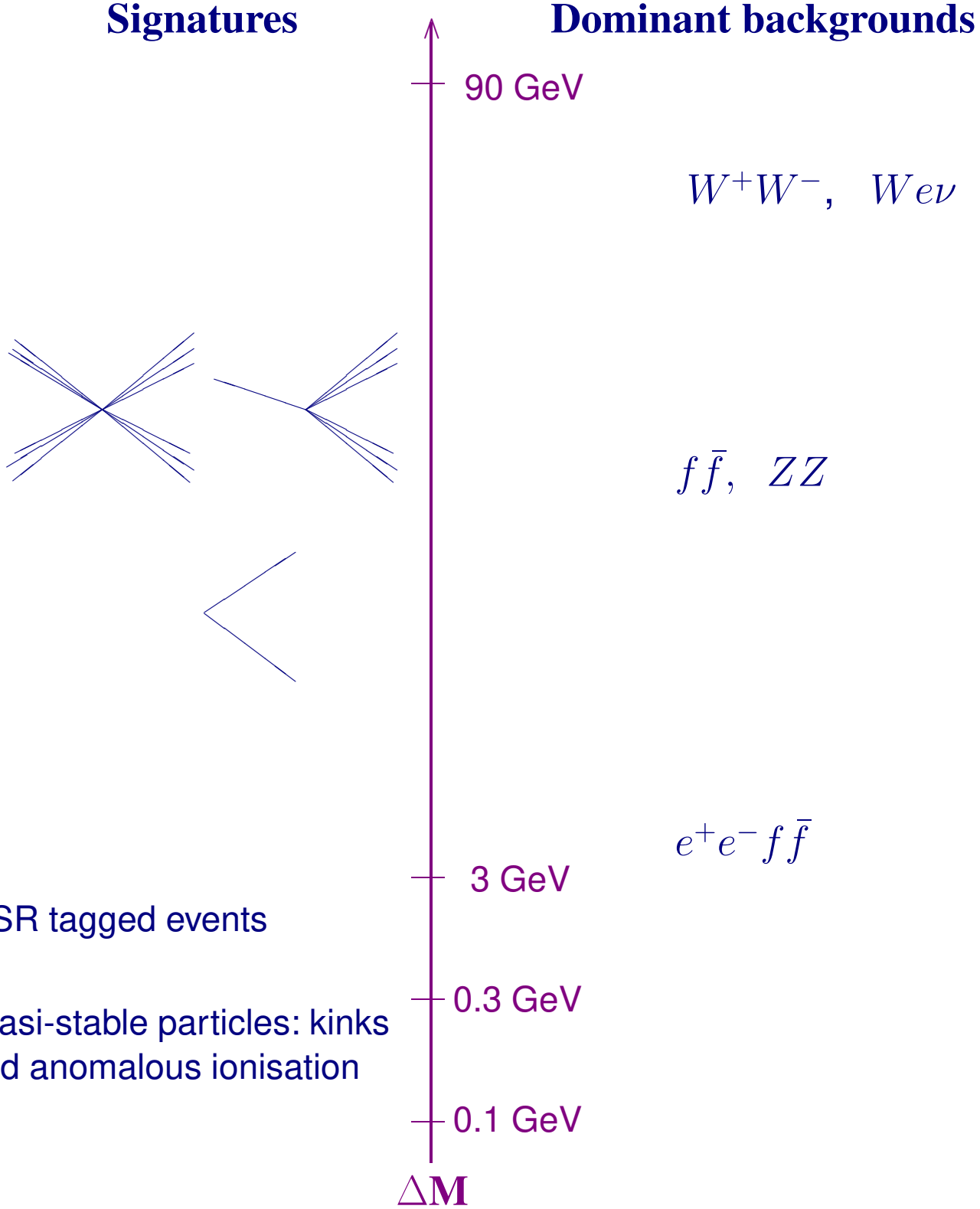
$e^+e^-f\bar{f}$ $\sigma(e^+e^-f\bar{f}) = 17$ nb

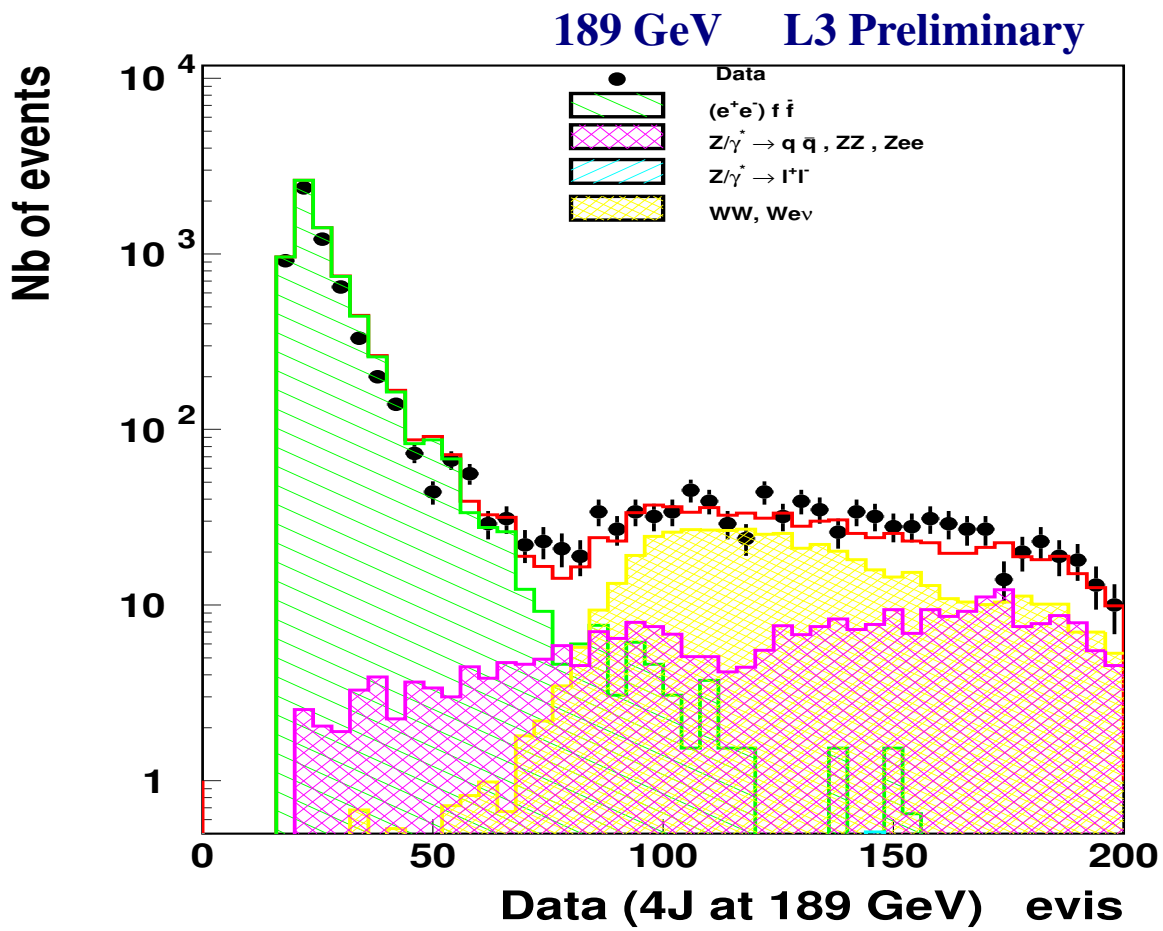
Search Strategies

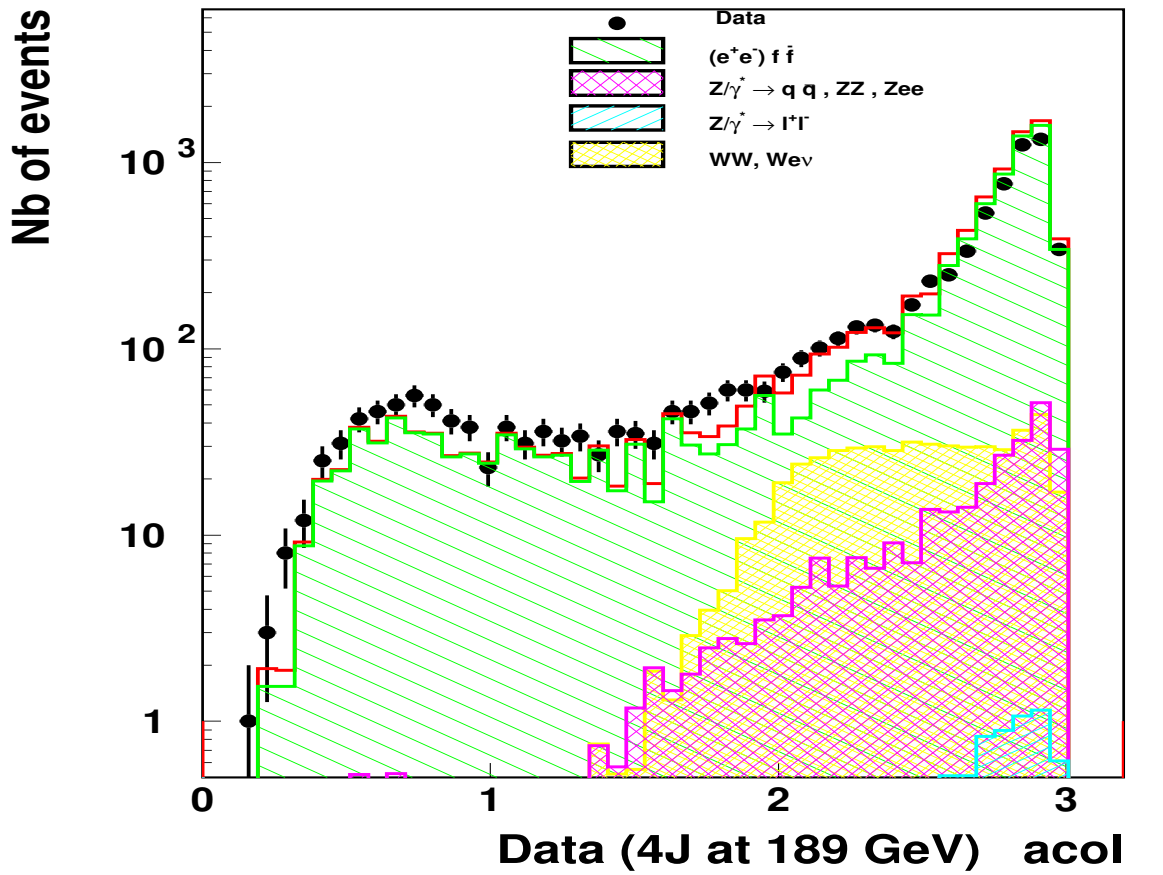
Δ M = $M_{\tilde{\chi}}$ - M_{LSP} $\Longrightarrow$ Visible energy

Different analysis for different Δ M regions

Signatures **Dominant backgrounds**




189 GeV L3 Preliminary
Nb of events
Data
(e+e-) f f̄
Z/γ* → q q̄ , ZZ , Zee
Z/γ* → l+l-
WW, Weν
Data (4J at 189 GeV) evis


Nb of events
Data
(e+e-) f f̄
Z/γ* → q q , ZZ , Zee
Z/γ* → l+l-
WW, Weν
Data (4J at 189 GeV) acol

Statistics

$\sqrt{s}$	$\mathcal{L}$/exp.
Z peak	$\simeq$ 160 pb^{-1}
130-136 GeV	$\simeq$ 6 pb^{-1}
161-172 GeV	$\simeq$ 22 pb^{-1}
183 GeV	$\simeq$ 55 pb^{-1}
189 GeV	$\simeq$ 175 pb^{-1}

Number of candidates is in good agreement with the SM expectation

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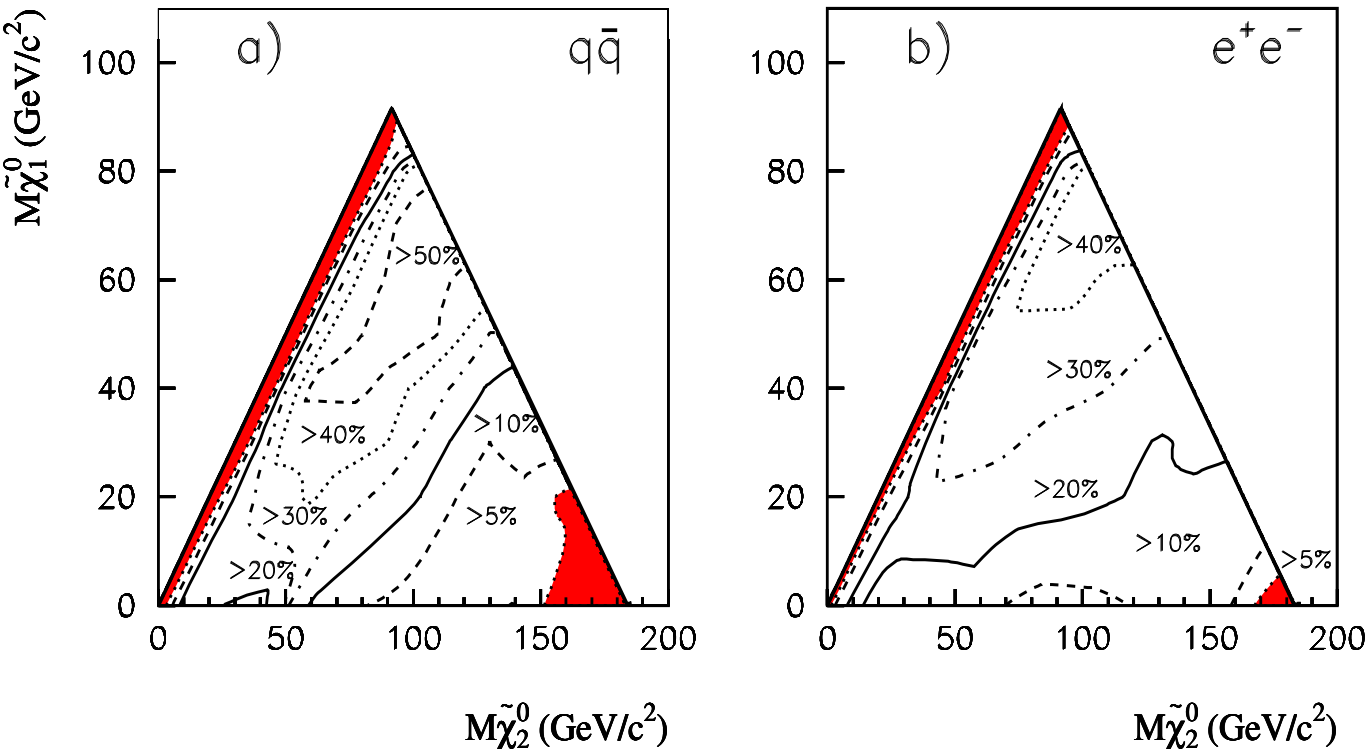
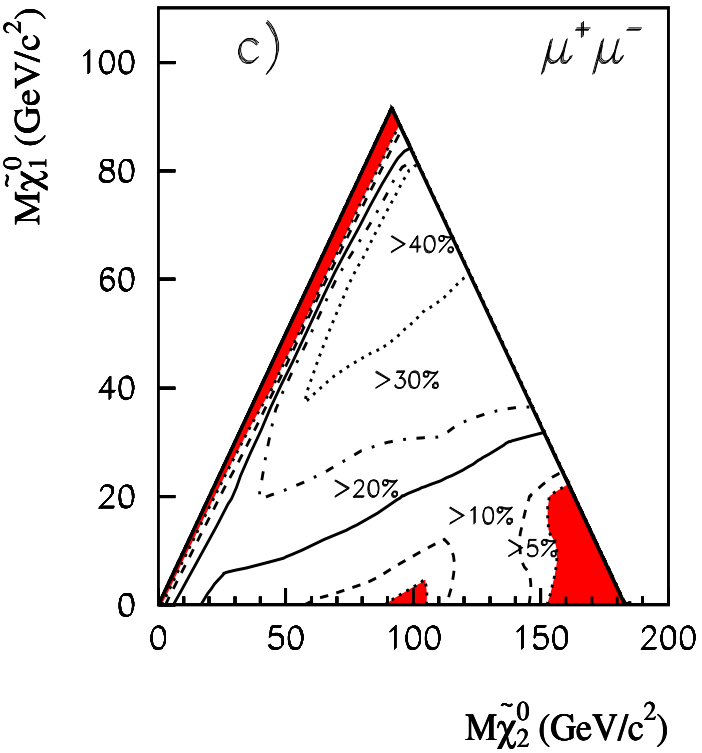
Limits derived

- Model-independent upper limits on X-sections $\sigma = \frac{N}{\varepsilon\mathcal{L}}$ in $(\mathrm{M}_{\tilde{\chi}}, \mathrm{M}_{\mathrm{LSP}})$ plane
- MSSM parameter space regions excluded
- Lower limits on sparticle masses as a function of SUSY parameters
- Model-independent limits on sparticle masses

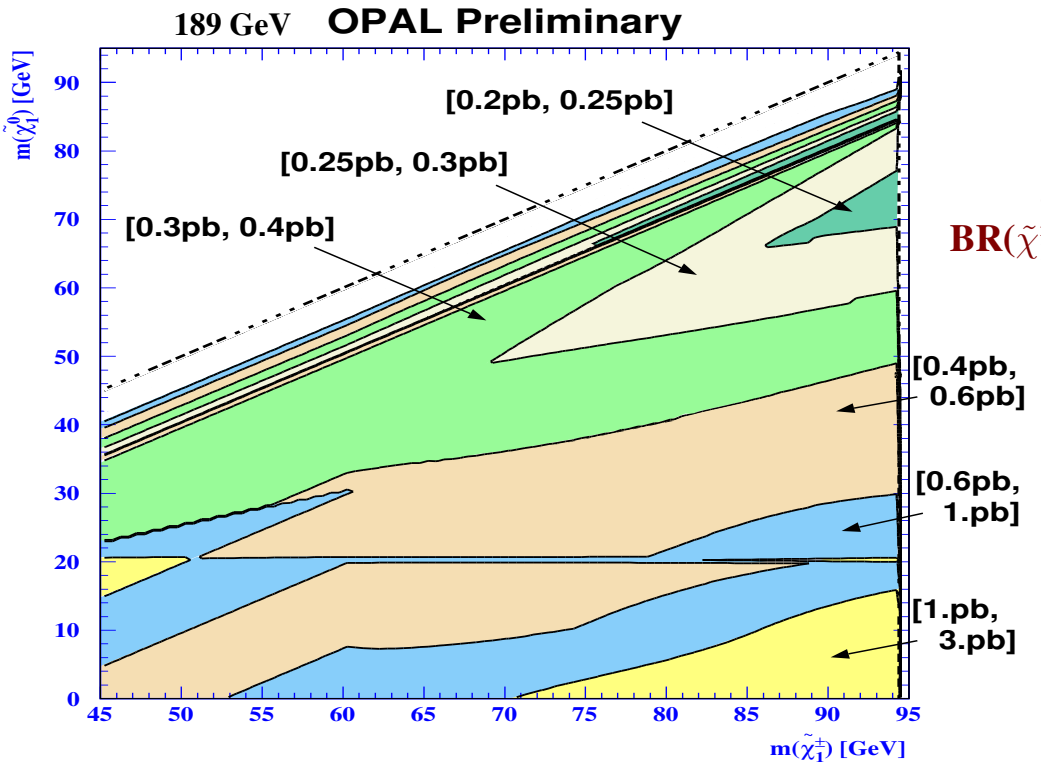
DELPHI $\tilde{\chi}_1^0\tilde{\chi}_2^0$ efficiencies (183 GeV)



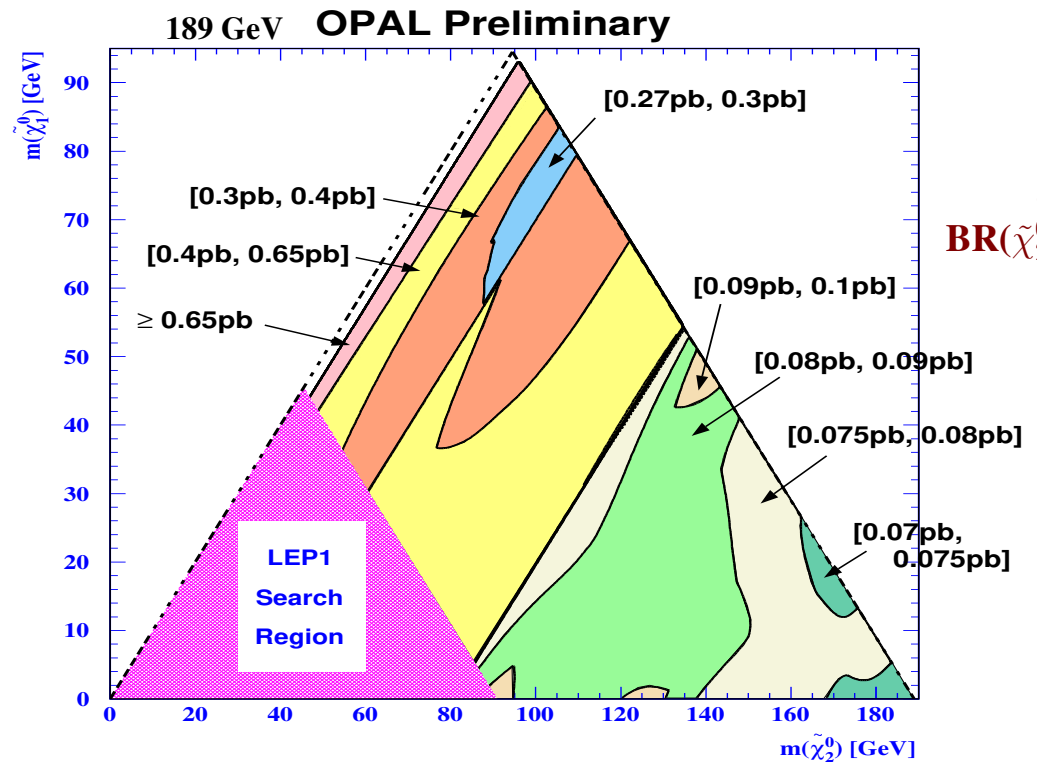


At low ΔM chargino efficiencies are higher thanks to larger visible energy

Cross-section limits

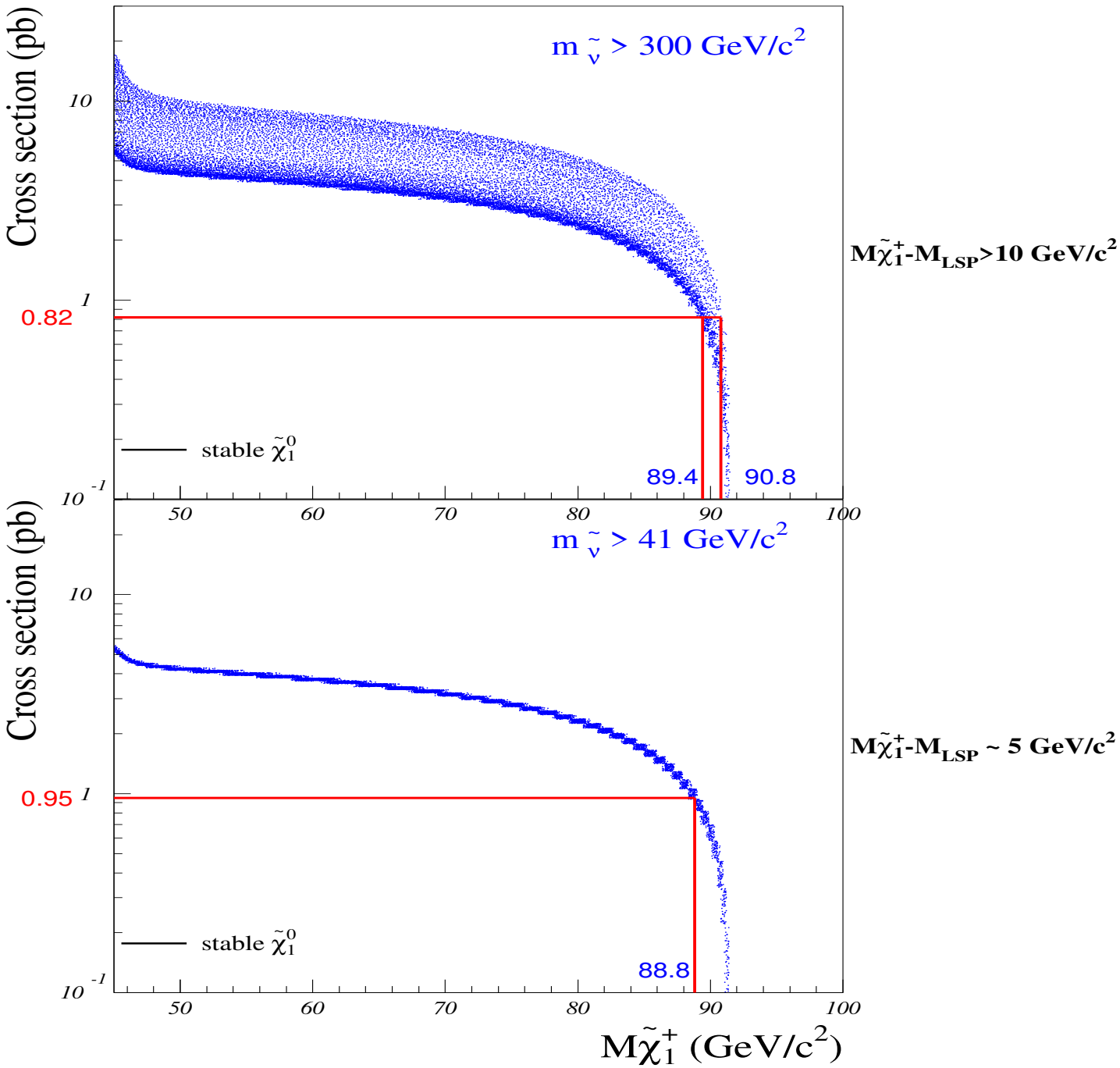


assuming
BR($\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^*$) = 100 %



assuming
BR($\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^*$) = 100 %

DELPHI $\tilde{\chi}_1^+\tilde{\chi}_1^-$ limits at 183 GeV



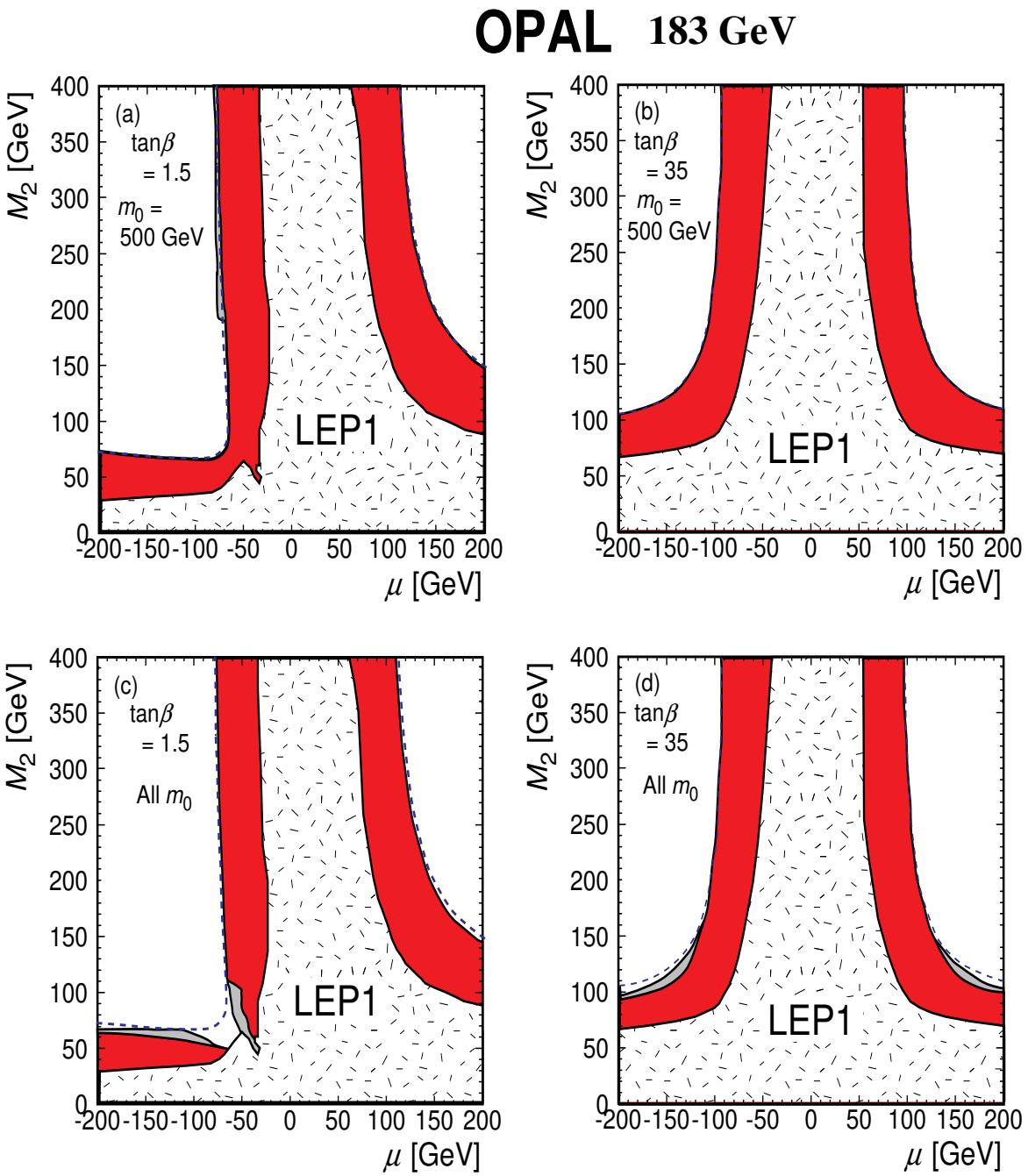
MSSM parameters varied randomly in the ranges:

$0 \leq M_2 \leq 3000$ GeV

-400 GeV $\leq \mu \leq 400$ GeV

$\tan\beta$ =1, 1.5, 35

Limits on the MSSM parameters

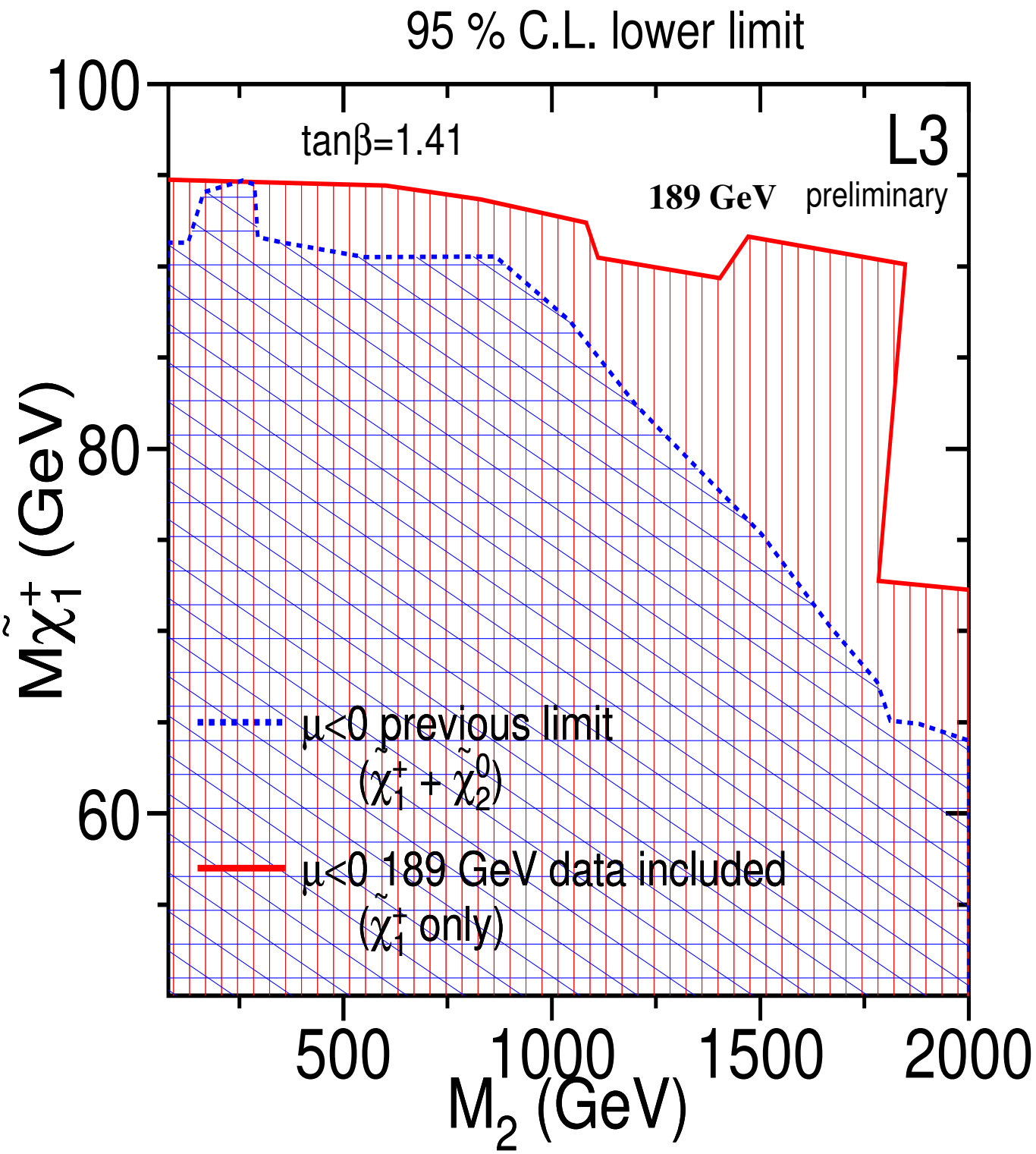


Regions excluded from non-observation of

$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$, $\tilde{\chi}_1^0\tilde{\chi}_3^0$ **events**

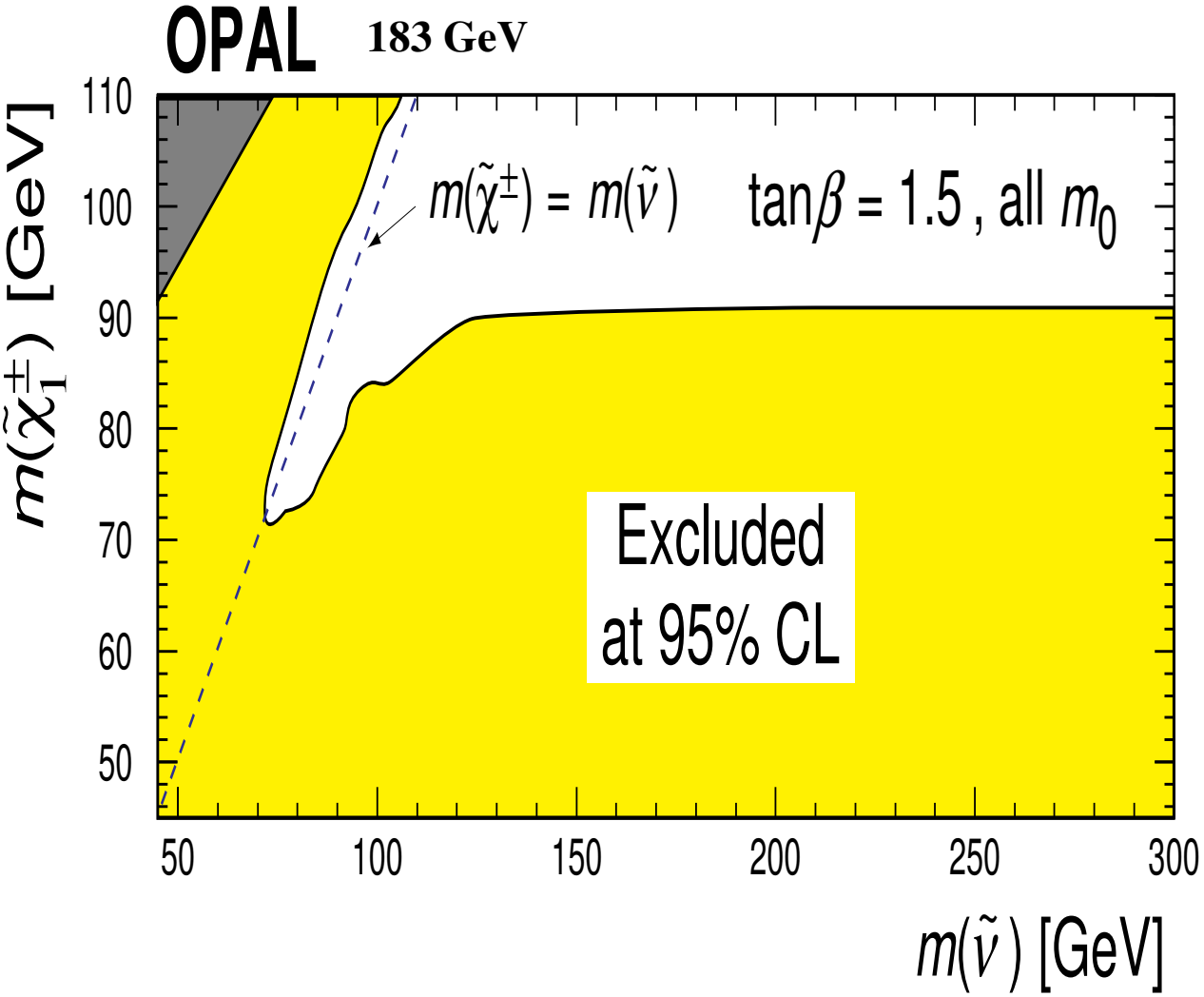
Limit on Chargino mass

Higgsino region



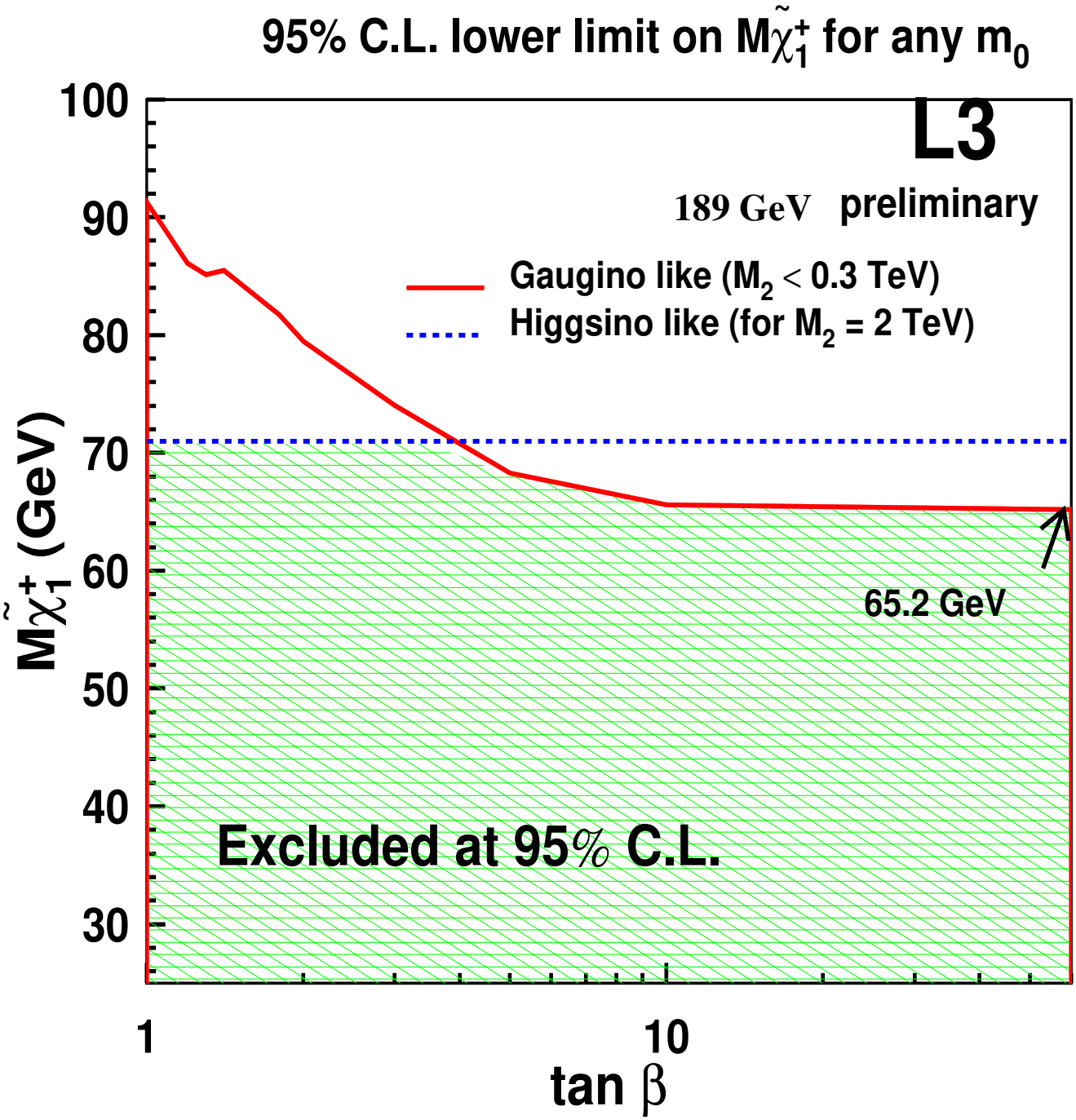
Limit on Chargino mass

Gaugino region

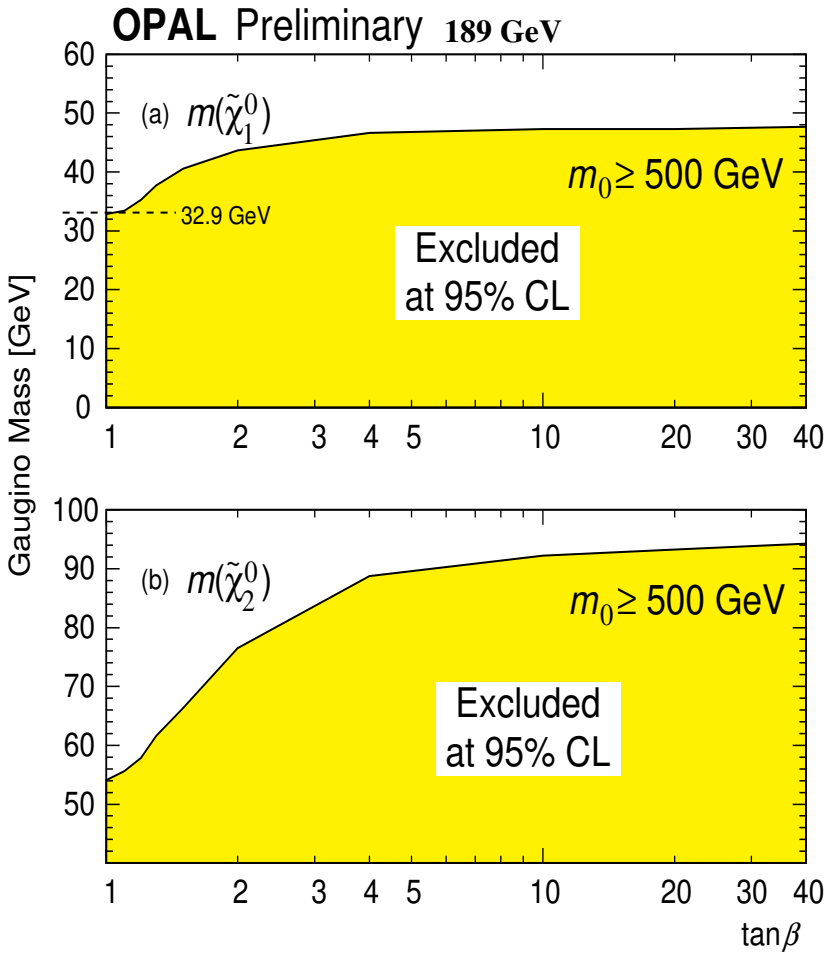


- **m($\tilde{\nu}$) $>$ 120 GeV — limits from direct chargino searches**
- **m($\tilde{\nu}$) $\simeq$ m($\tilde{\chi}_1^{\pm}$) — indirect limits from the slepton searches**
- **m($\tilde{\nu}$) $<$ m($\tilde{\chi}_1^{\pm}$) — indirect limits from slepton searches with a contribution from neutralino production**

Limit on Chargino mass



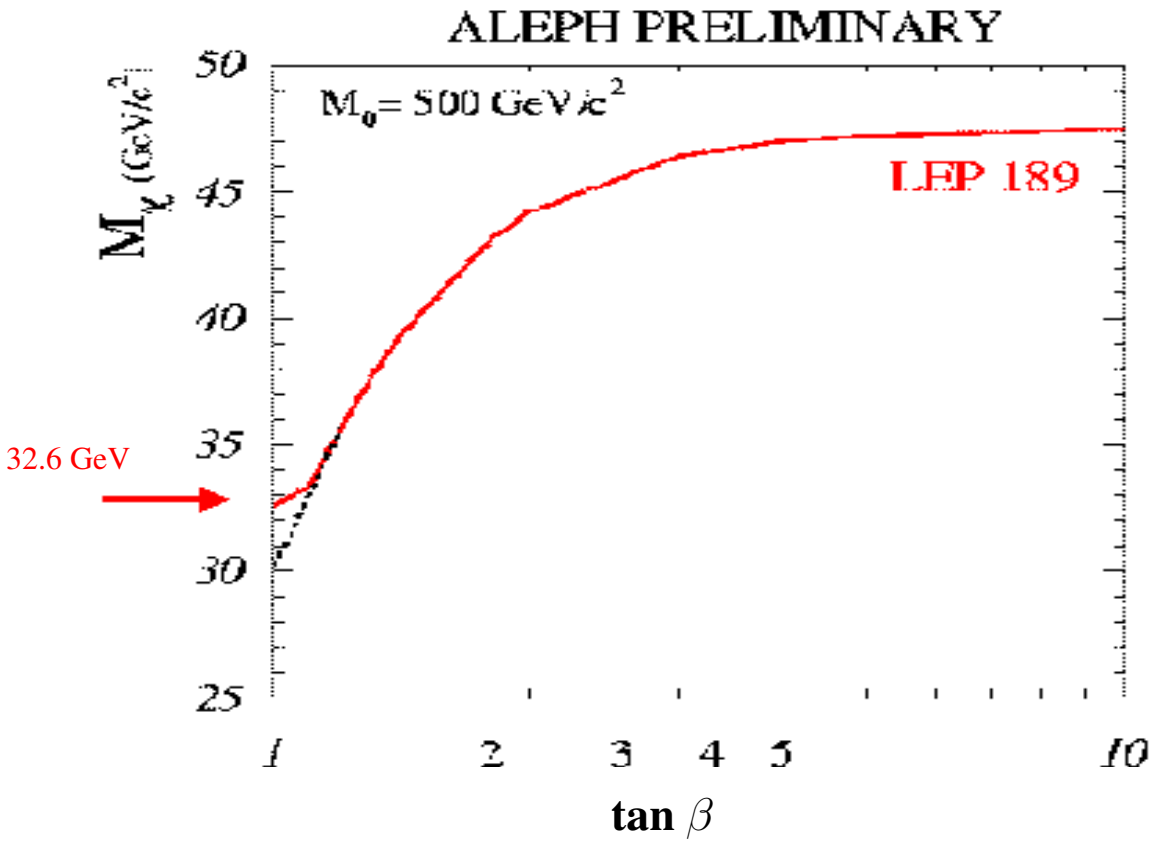
$\tilde{\chi}^+, \tilde{\chi}^0$ Mass Limits

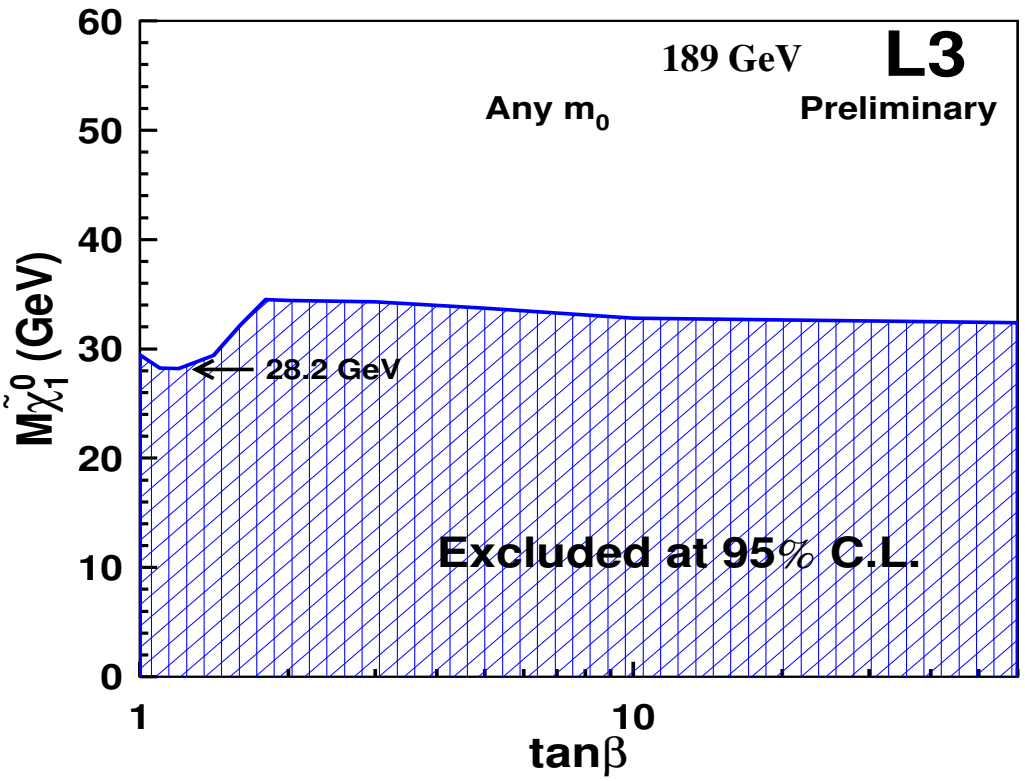


	$\tan\beta = 1.5$	$\tan\beta = 35$
$\Delta M_+ \geq 10$ GeV	$m_{\tilde{\chi}_1^+} > 93.2$ GeV	$m_{\tilde{\chi}_1^+} > 93.7$ GeV
No ΔM_0 restriction	$m_{\tilde{\chi}_1^0} > 40.4$ GeV	$m_{\tilde{\chi}_1^0} > 48.0$ GeV
$\Delta M_0 \geq 10$ GeV	$m_{\tilde{\chi}_2^0} > 66.9$ GeV	$m_{\tilde{\chi}_2^0} > 94.1$ GeV
	$m_{\tilde{\chi}_3^0} > 105.7$ GeV	$m_{\tilde{\chi}_3^0} > 123.6$ GeV

$$m_0 \geq 500 \text{ GeV}$$

LSP mass limit





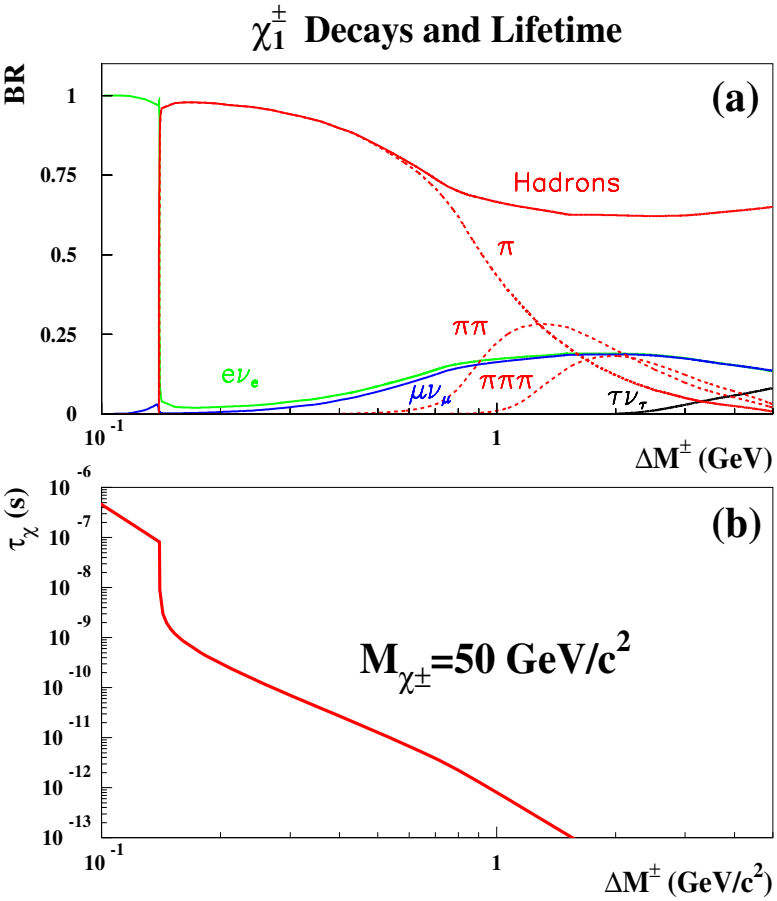
Extremely mass-degenerate scenarios

Chargino can be mass degenerate with LSP in case of:

- Low μ, large M_2
  $M(\tilde{\chi}_1^{\pm}) \simeq M(\tilde{\chi}_1^0) \sim \mu$
- Large μ, low M_2 and no GUT relation ($M_1 : M_2 \neq \alpha_1 : \alpha_2$)
  $M(\tilde{\chi}_1^{\pm}) \simeq M(\tilde{\chi}_1^0) \sim M_2$

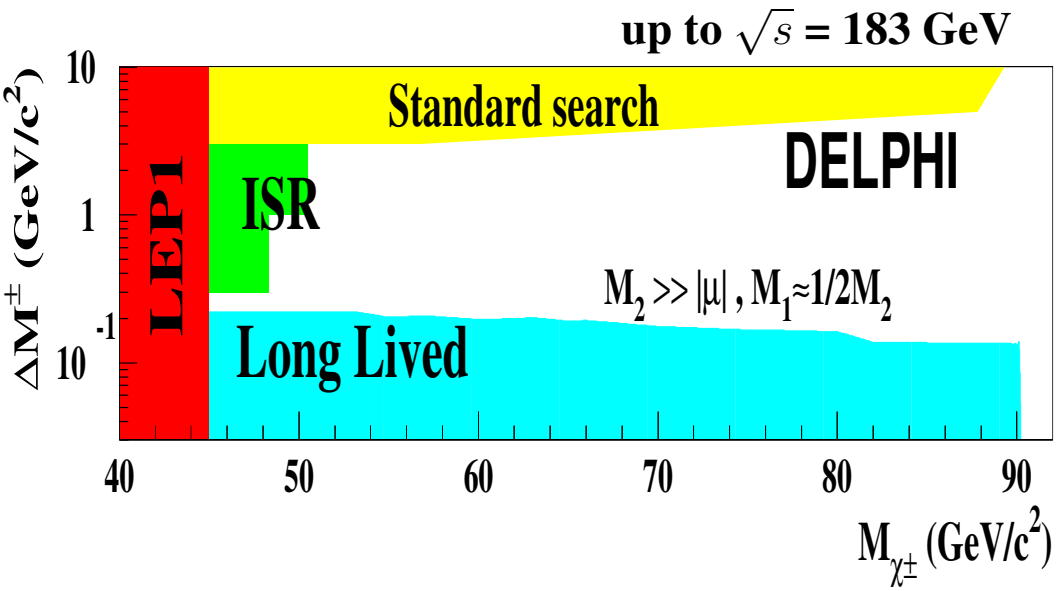
Search strategies:

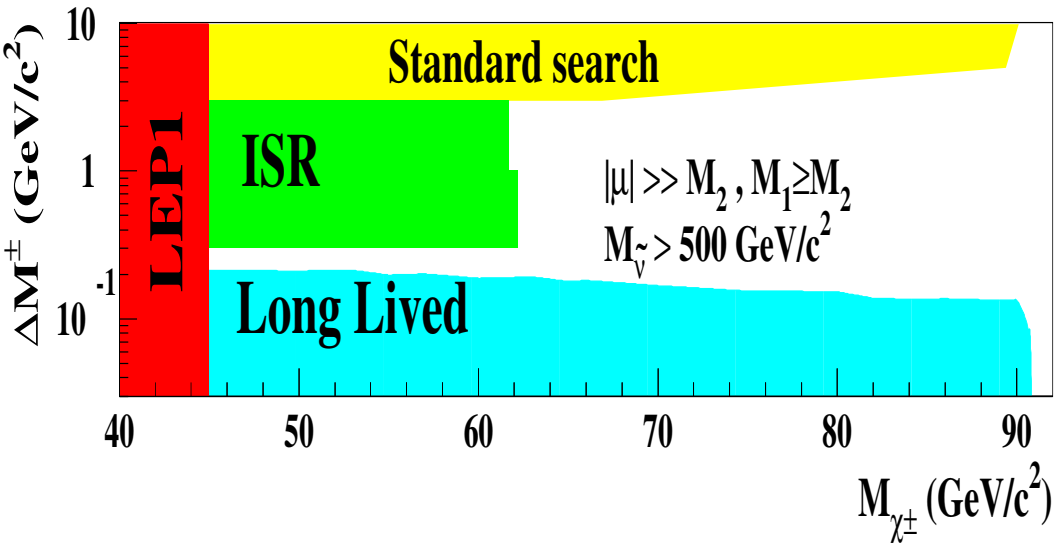
- Δ M $<$ 200-300 MeV — search for quasi-stable particles: kinks and anomalous ionisation
- 300 MeV $<\Delta$ M $<$ 3 GeV — tag events with ISR photon and missing energy

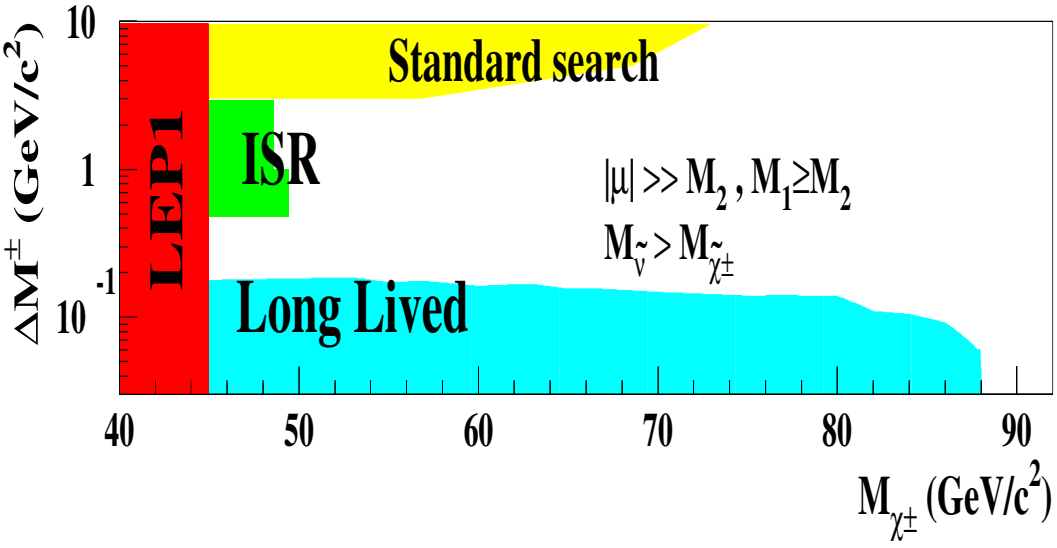


⟸ higgsino-like chargino (gaugino-like chargino has a similar lifetime for heavy $\tilde{\nu}$).

Extremly mass-degenerate scenarios







Conclusions and Perspectives

No evidence for Charginos or Neuralinos found up to now at LEP

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New (preliminary) limits are set

In the Standard SUSY scenario with RPC:

- **Lower limit on the LSP mass m$_{\tilde{\chi}_1^0} > 28.2$ GeV is obtained for tan$\beta > 1$ and any m_0.**

- **Lover limit on the lightest chargino mass m$_{\tilde{\chi}_1^\pm} > 65.2$ GeV is obtained for tan$\beta > 1$ and any m_0.**

- **Lightest chargino has been excluded up to the kinematical limit in most of the parameter space. LEP200 would allow to probe the chargino up to 100 GeV in most of the parameter space.**