Chargino and Neutralino Searches at LEP

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On behalf of ALEPH, DELPHI, L3 & OPAL Collaborations

Higgs&SUSY
Orsay
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OUTLINE

- $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ production in RP-conserving SUSY
- MSSM decays of $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$
- Final state topologies
- Search results
- Cross-section limits
- $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ mass limits in Constrained MSSM

MSSM Particles

Spin

0	1/2	1
$\tilde{\nu}_L$	ν_L	
$\tilde{\ell}^{\pm}_{L,R} \rightarrow \tilde{\ell}^{\pm}_{1,2}$	$\ell^{\pm}_{L,R}$	
$\tilde{\mathrm{q}}_{L,R} \rightarrow \tilde{\mathrm{q}}_{1,2}$	$q_{L,R}$	
	$\tilde{\mathrm{g}}$	g
$\mathrm{h, H, A}$	$\left.\begin{array}{c}\tilde{\mathrm{h}}, \tilde{\mathrm{H}} \\ \tilde{\gamma}/\tilde{\mathrm{B}}^0 \\ \tilde{\mathrm{Z}}/\tilde{\mathrm{W}}^0\end{array}\right\} \boxed{\tilde{\chi}^0_j}$	$\left.\begin{array}{c}\gamma \\ \mathrm{Z}\end{array}\right\} \left\{\begin{array}{c}\mathrm{B}^0 \\ \mathrm{W}^0\end{array}\right.$
$\mathrm{H}^{\pm}$	$\left.\begin{array}{c}\tilde{\mathrm{W}}^{\pm} \\ \tilde{\mathrm{H}}^{\pm}\end{array}\right\} \boxed{\tilde{\chi}^{\pm}_i}$	$\mathrm{W}^{\pm} \Leftrightarrow W^{1,2}$

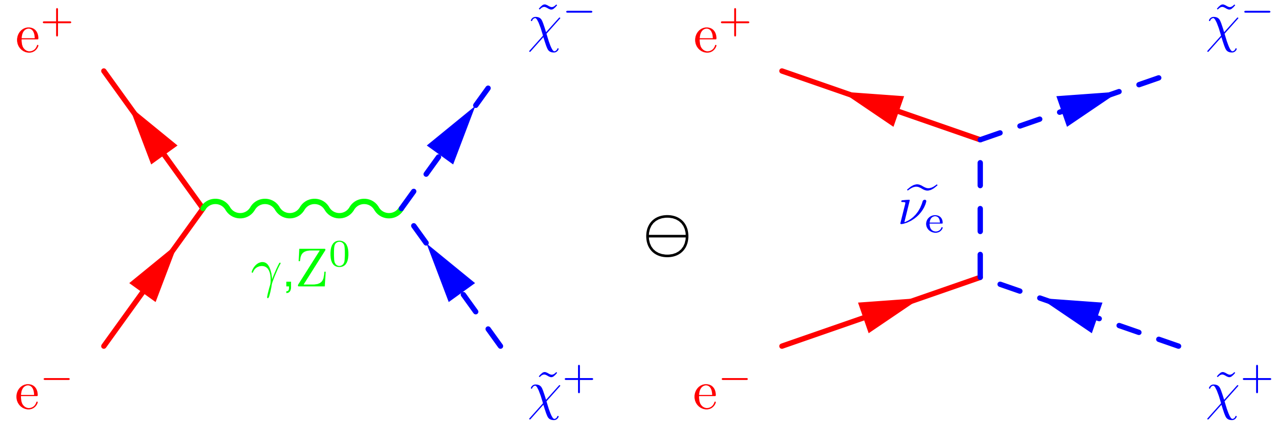
- 4 Neutralinos: $m_{\tilde{\chi}^0_1} < \boxed{m_{\tilde{\chi}^0_2}} < m_{\tilde{\chi}^0_3} < m_{\tilde{\chi}^0_4}$
- 2 Charginos: $\boxed{m_{\tilde{\chi}^{\pm}_1}} < m_{\tilde{\chi}^{\pm}_2}$

$\boxed{\tilde{\chi}^0_1 \text{ (or lightest } \tilde{\nu}\text{) is the LSP}}$

MSSM $\Rightarrow$ RP-conserving $\Rightarrow$ SUSY particles produced in pairs; all decay chains end with stable undetectable LSP.

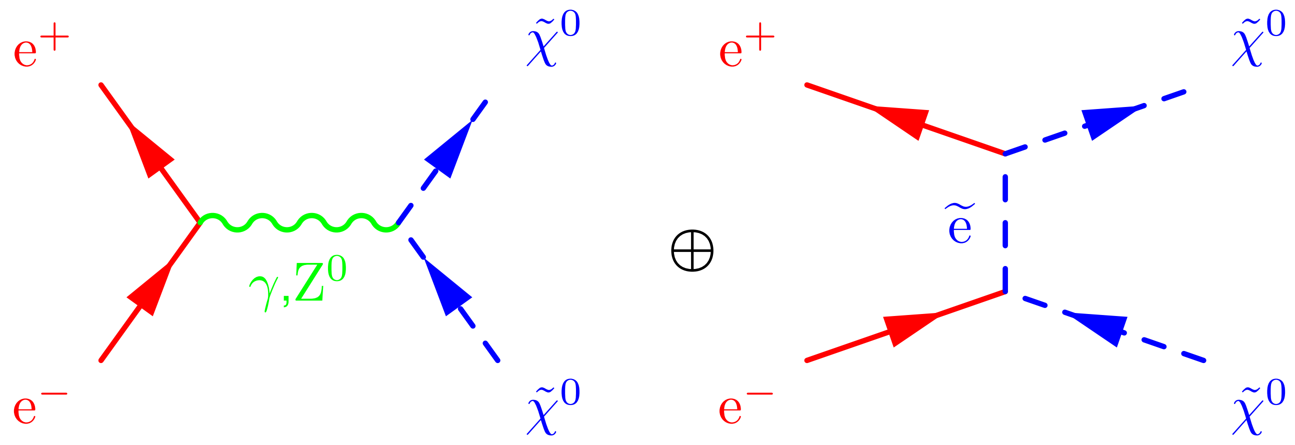
$\tilde{\chi}^{\pm}$ & $\tilde{\chi}^{0}$ Production in RP-conserving SUSY

Chargino Production:



$\longrightarrow$ **destructive interference**

Neutralino Production:



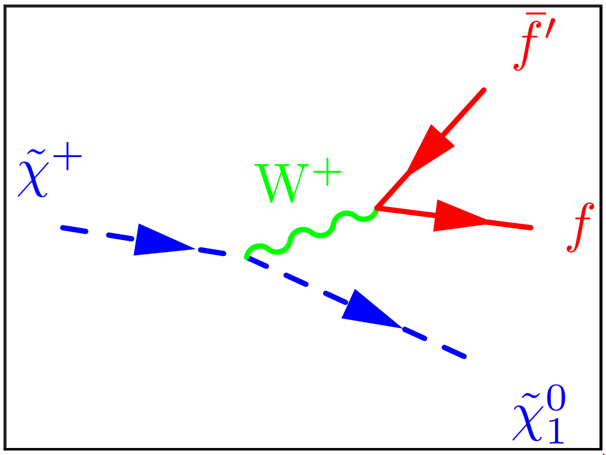
$\longrightarrow$ **constructive interference**

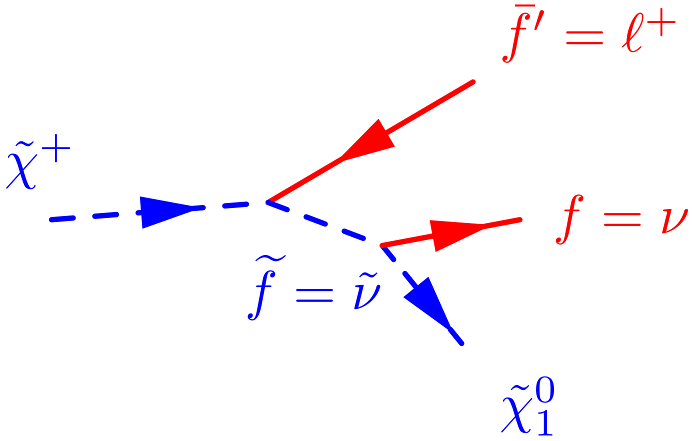
t-channel contribution normally small;

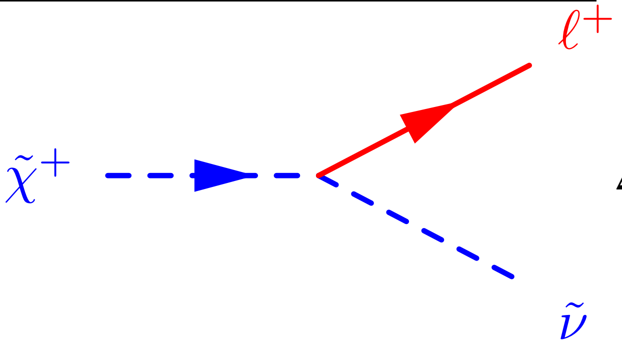
enhanced if m_0 ($\longrightarrow m_{\tilde{\nu}_e}, m_{\tilde{e}}$) small

Chargino and Neutralino Decay in MSSM

Chargino Decay:

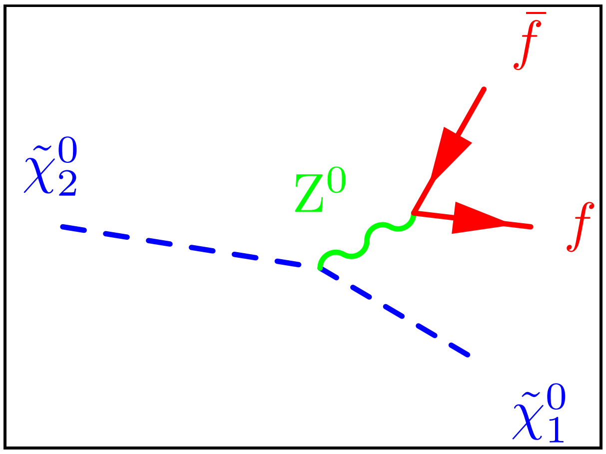


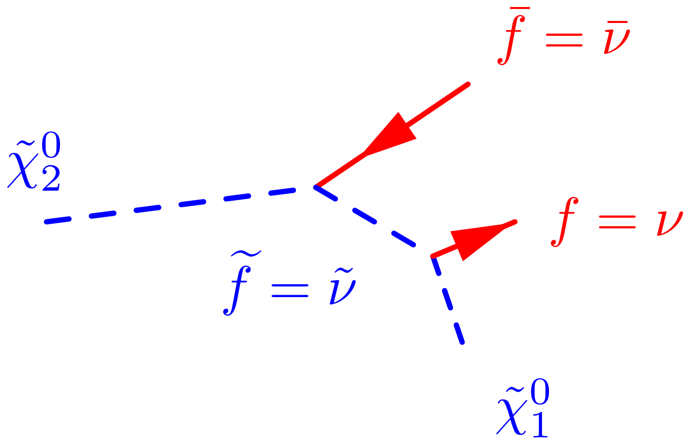


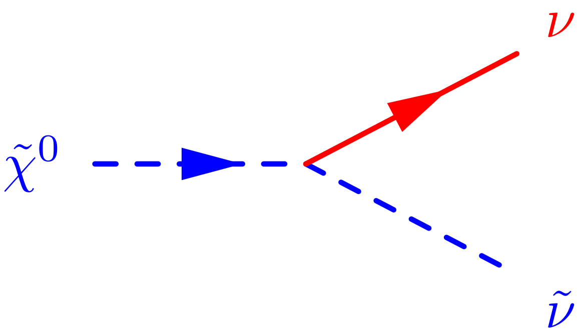


$$\Delta M_+ \equiv M_{\tilde{\chi}^\pm} - M_{\tilde{\chi}^0_1}$$

Neutralino Decay:







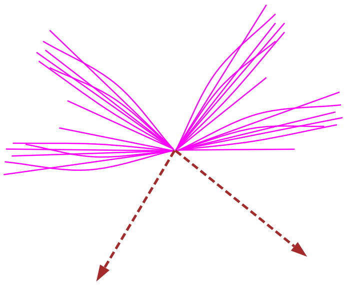
$$\Delta M_0 \equiv M_{\tilde{\chi}^0_2} - M_{\tilde{\chi}^0_1}$$

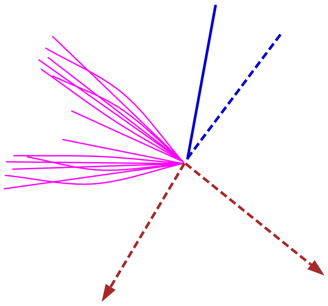
Chargino and Neutralino Decay Topologies

Acoplanar events

$\tilde{\chi}_1^+\tilde{\chi}_1^- \quad \longrightarrow \quad W^{+*}\tilde{\chi}_1^0 W^{-*}\tilde{\chi}_1^0$

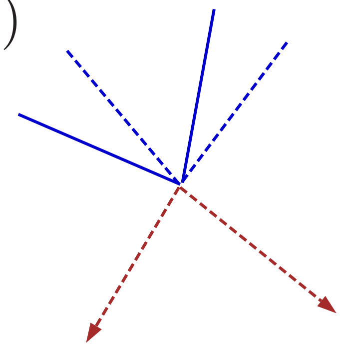
$\hookrightarrow q\bar{q}' \quad \hookrightarrow q\bar{q}'(46\%)$





$\hookrightarrow q\bar{q}' \quad \hookrightarrow \ell^-\bar{\nu}(44\%)$

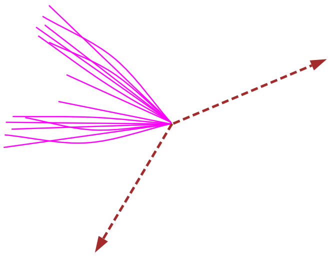
$\hookrightarrow \ell^+\nu \quad \hookrightarrow \ell^-\bar{\nu}(11\%)$



or $\quad \longrightarrow \quad \ell^+\tilde{\nu}\ell^-\bar{\tilde{\nu}}$

or $\quad \longrightarrow \quad \ell^+\tilde{\nu} \qquad \ell^-\bar{\tilde{\nu}}$

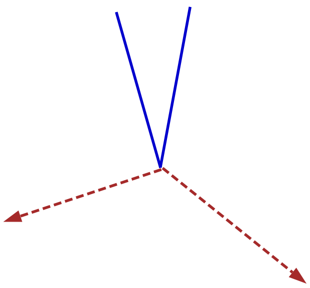
$\hookrightarrow \bar{\nu}\tilde{\chi}_1^0 \quad \hookrightarrow \nu\tilde{\chi}_1^0$



$\tilde{\chi}_2^0\tilde{\chi}_1^0 \quad \longrightarrow \quad Z^{0*}\tilde{\chi}_1^0\tilde{\chi}_1^0$

$\hookrightarrow q\bar{q}(70\%)$

$\hookrightarrow \ell^+\ell^-(10\%)$



$+$invisible final states(20%)

Event Selection Strategy

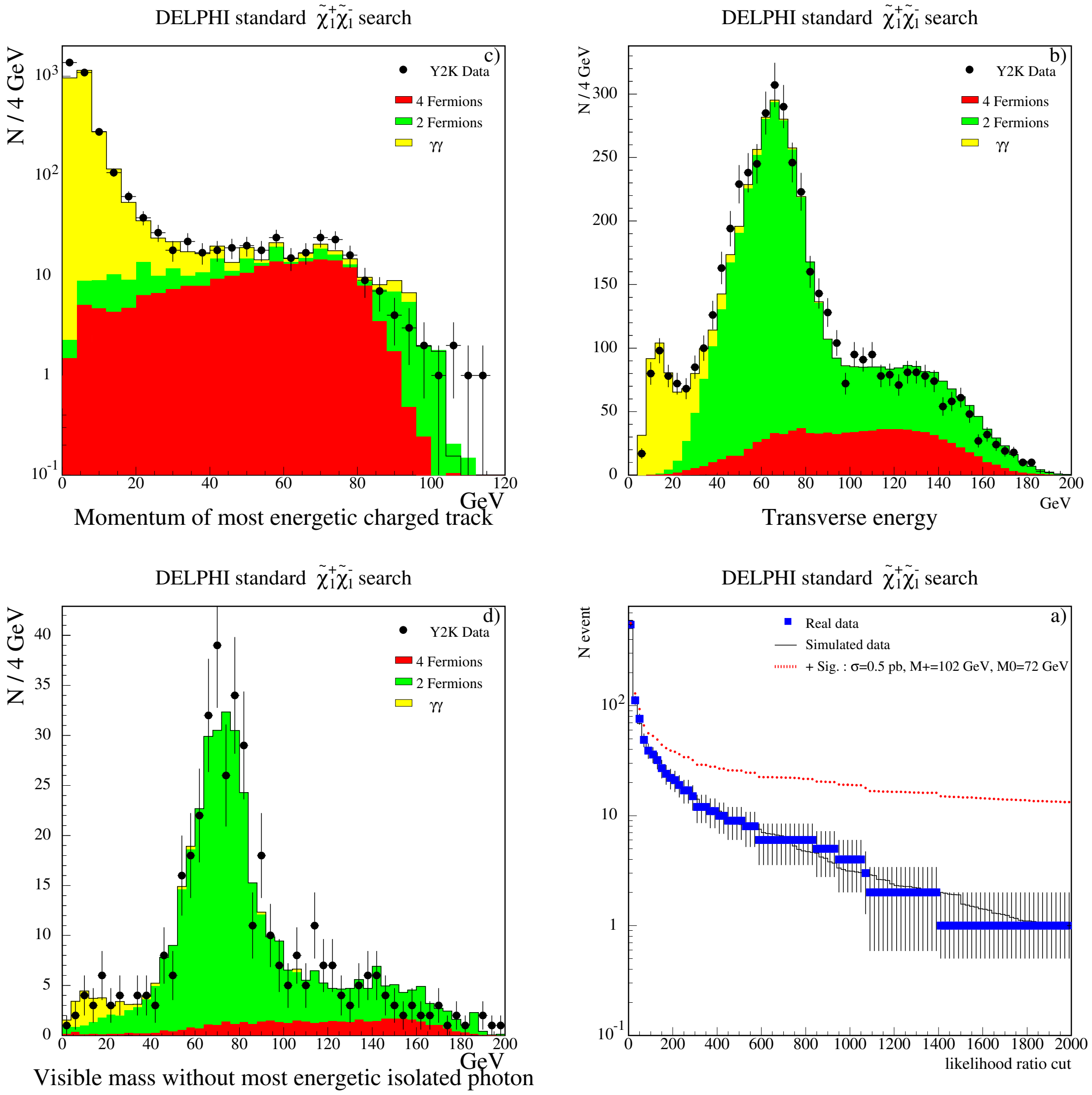
Cut-based or likelihoods; depend on $(M, \Delta M)$...

Backgrounds vary with ΔM

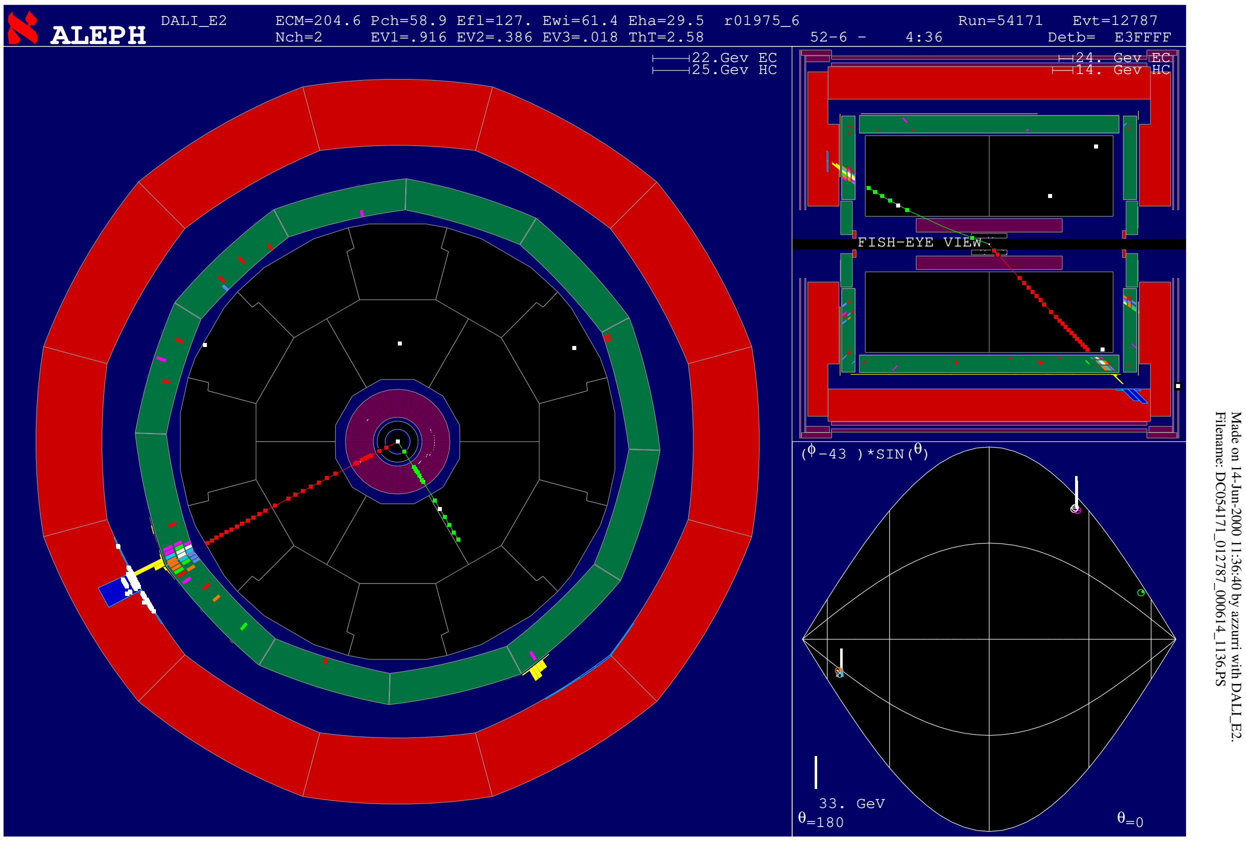
Small ΔM	$\Leftrightarrow$	Large ΔM
2-photon		4-fermion
$\sigma \sim \mathcal{O}(\mathrm{nb})$		$\sigma \sim 20$ pb

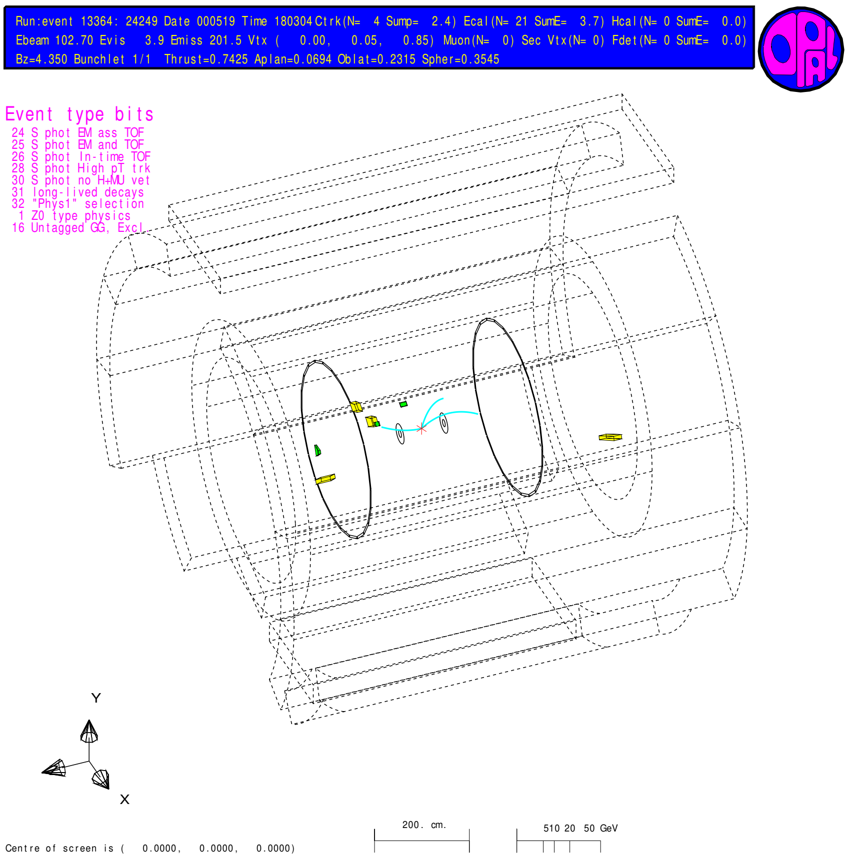
Too many analyses to show separately!

Example: DELPHI $\tilde{\chi}^+\tilde{\chi}^-$ variables after preselection



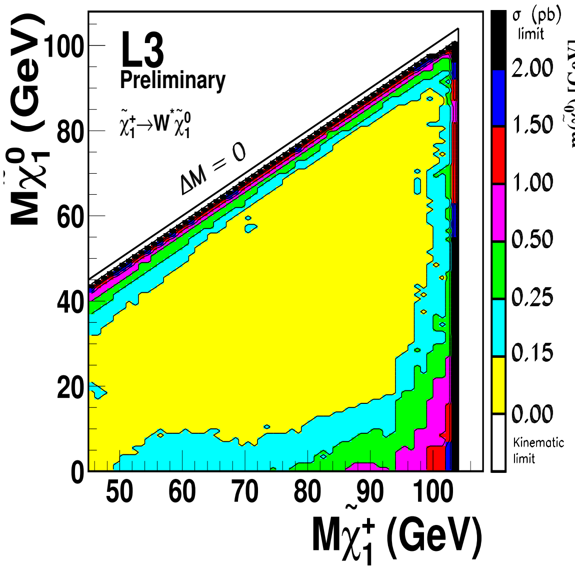
Typical Events

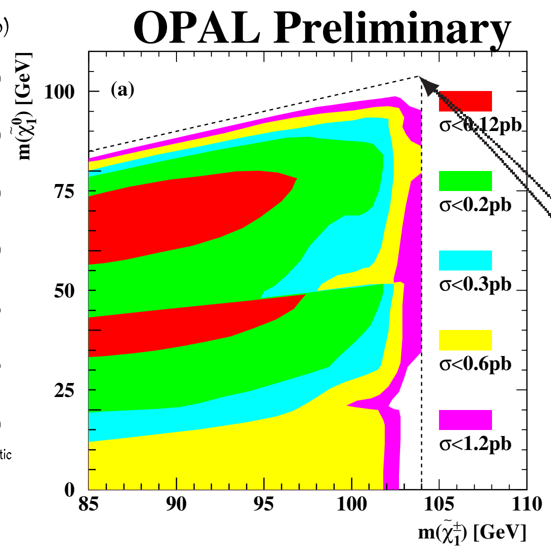




Cross-section Limits: $\tilde{\chi}^{\pm}$

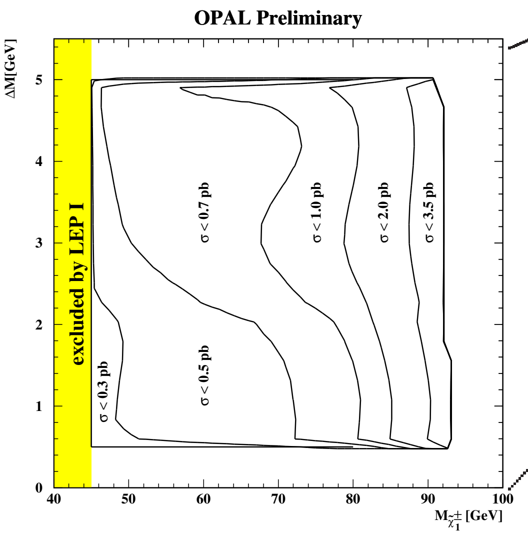
Assuming 100% $\tilde{\chi}^{\pm} \to W^{\pm *}\tilde{\chi}^0_1$ BRs





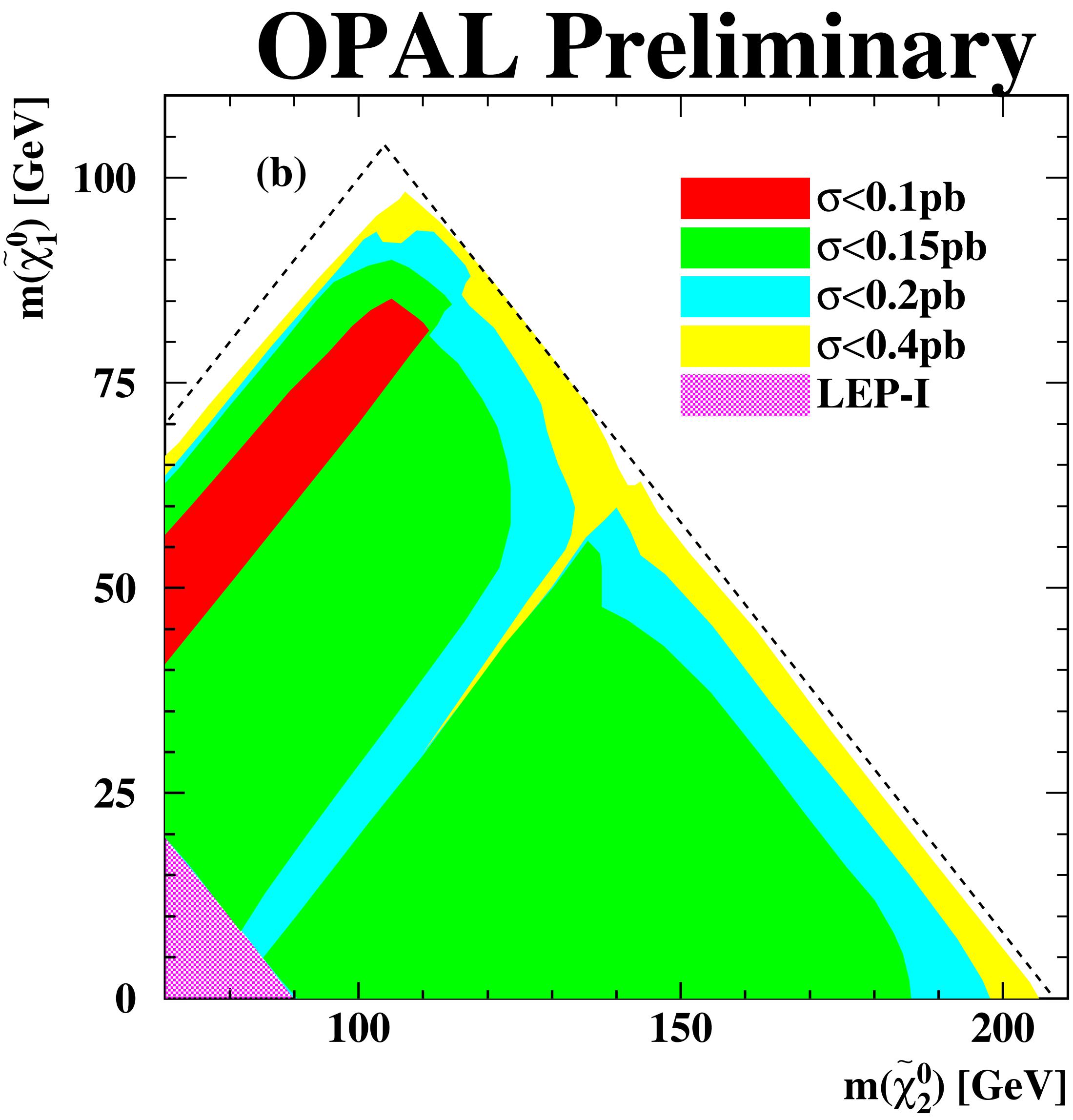
Exclusion to kinematic limit for $\Delta M_{+} > 10$ GeV

Small ΔM Region - ISR Analysis



Cross-section Limits: $\tilde{\chi}^0_1\tilde{\chi}^0_2$

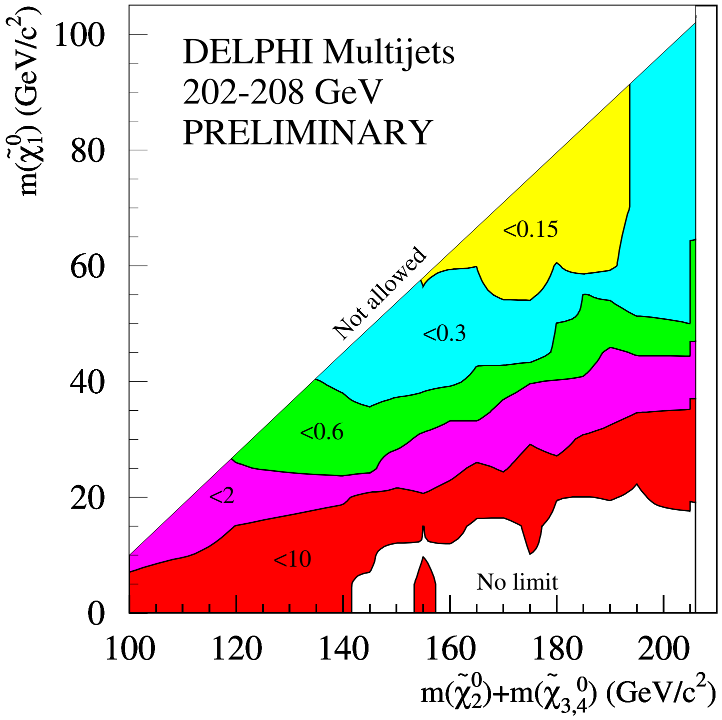
Assuming 100% Z^0 BRs:



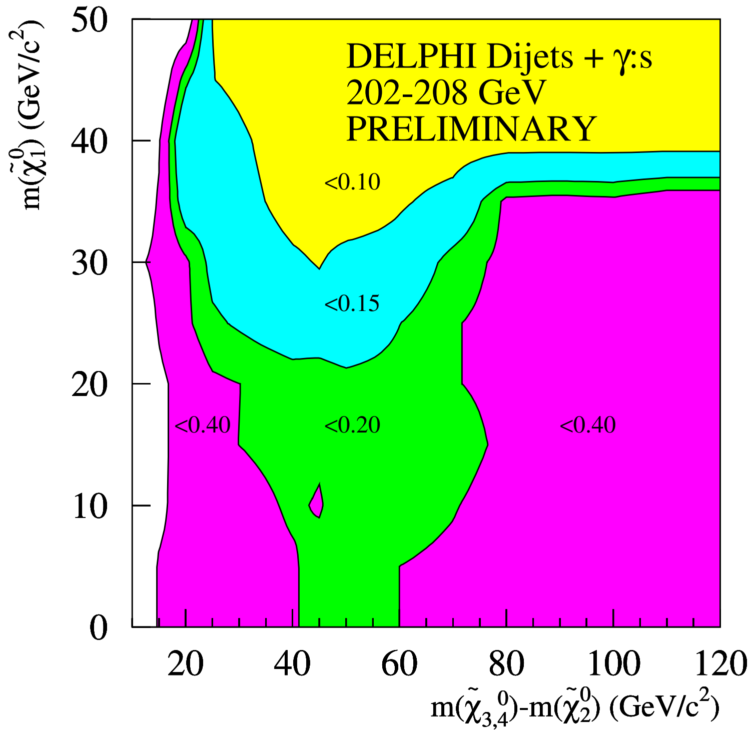
Exclusion to kinematic limit for $\Delta M_0 > 10$ GeV

Cross-section Limits: $\tilde{\chi}^0_i\tilde{\chi}^0_j$

$\boxed{\tilde{\chi}^0_{3,4}\tilde{\chi}^0_2 \rightarrow q\bar{q}q'\bar{q}'\tilde{\chi}^0_1\tilde{\chi}^0_1}$ Used in LSP computations...



$\boxed{\tilde{\chi}^0_{3,4}\tilde{\chi}^0_2 \rightarrow q\bar{q}\gamma\gamma\tilde{\chi}^0_1\tilde{\chi}^0_1}$



$\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1\gamma$: 1-loop process; important only in corners of phase space where usual decays suppressed.

SUSY framework at LEP2

MSSM

105 new parameters

(cannot interpret data in such a complicated framework!)

$\Downarrow$

SUGRA-inspired Constrained MSSM

only 6 new parameters:

m_0	common scalar mass at Planck scale
M_2	$SU(2)$ gaugino mass parameter at EW scale
$\tan\beta$	v_2/v_1 VEV ratio of two Higgs doublets
μ	mixing parameter of Higgs doublet fields
A_0	common trilinear sfermion/Higgs coupling
m_A	pseudoscalar Higgs mass at EW scale

With these, can calculate cross-sections, BRs, etc.

$\Downarrow$

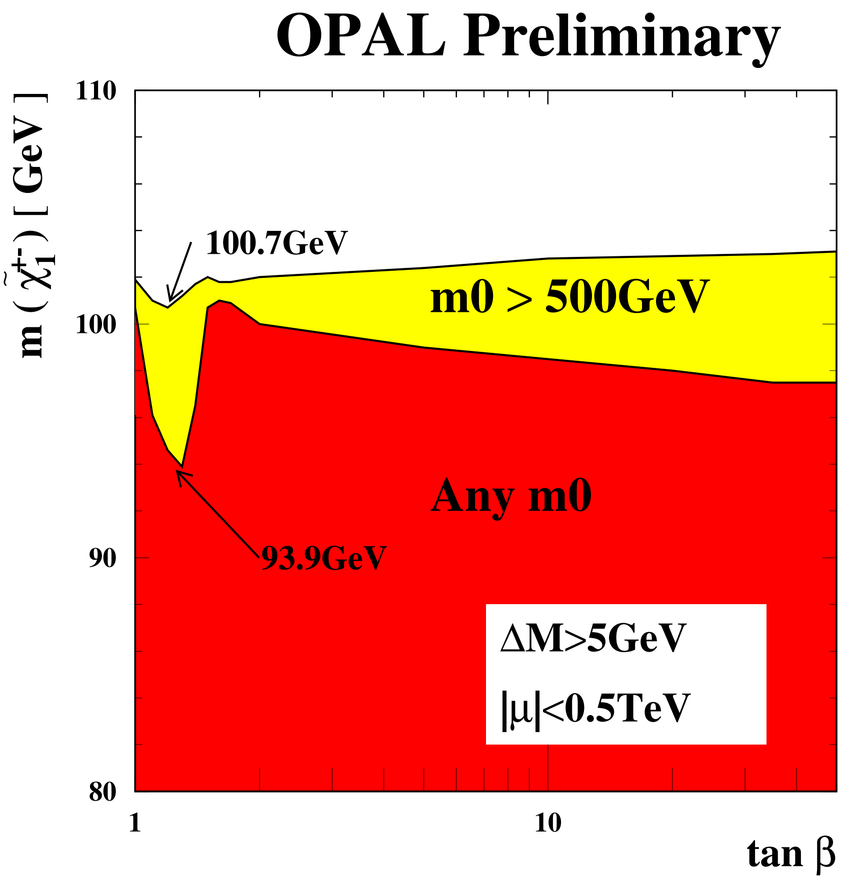
"Standard" LEP2 SUSY model

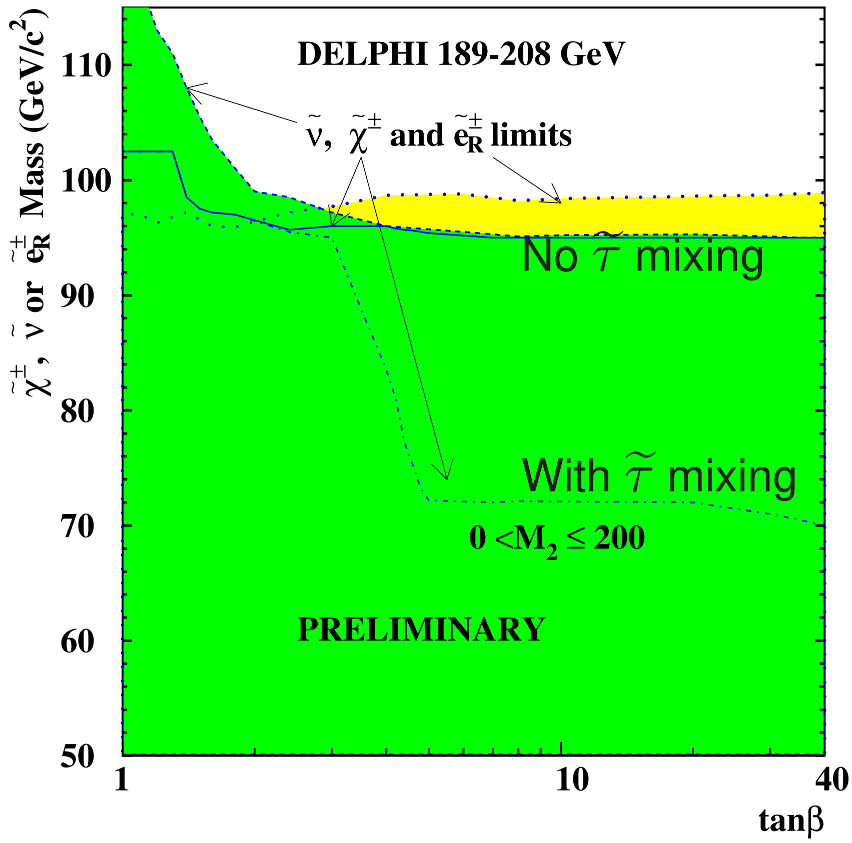
R-parity conserved

$\Rightarrow$ Lightest SUSY Particle (LSP) is stable

$\Rightarrow$ SUSY particles pair-produced; decay with $\tilde{\chi}^0_1$ LSP.

Model-Dependent $\tilde{\chi}^{\pm}$ Mass Limits

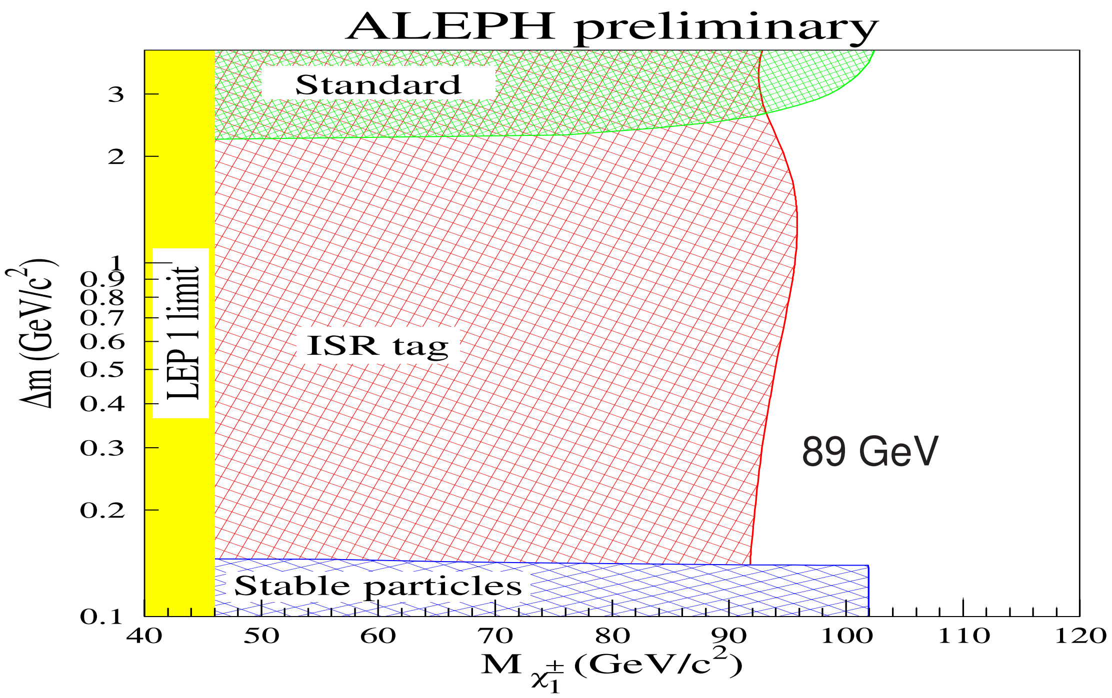




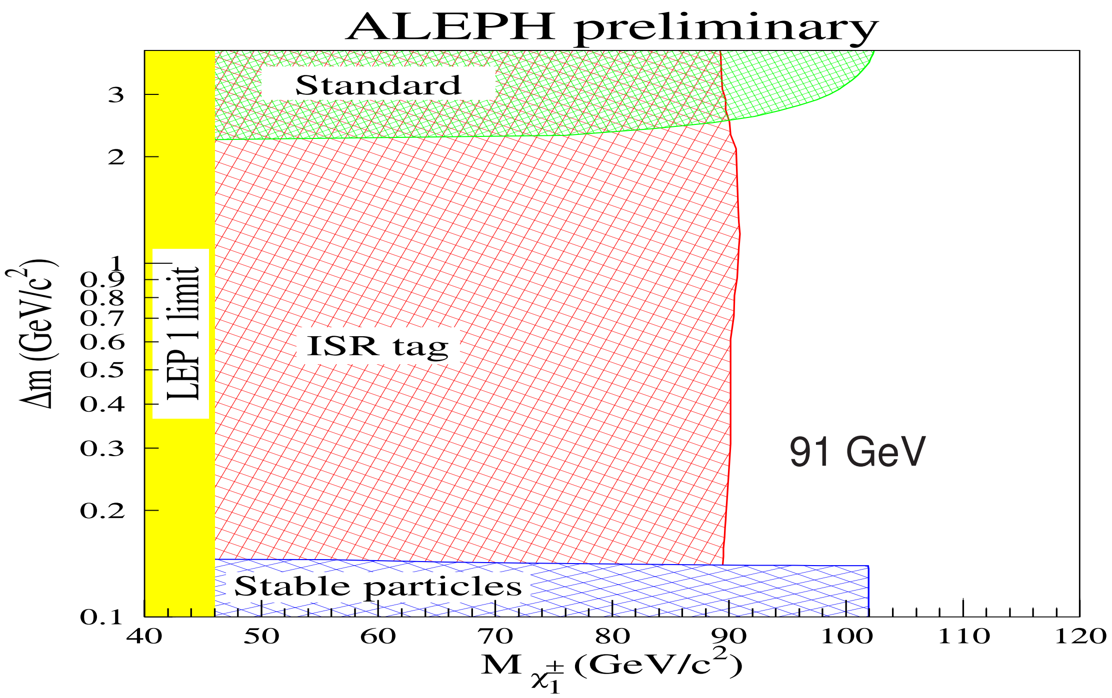
Small ΔM_+: nearly degenerate $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$

ISR analysis now done by all 4 experiments.

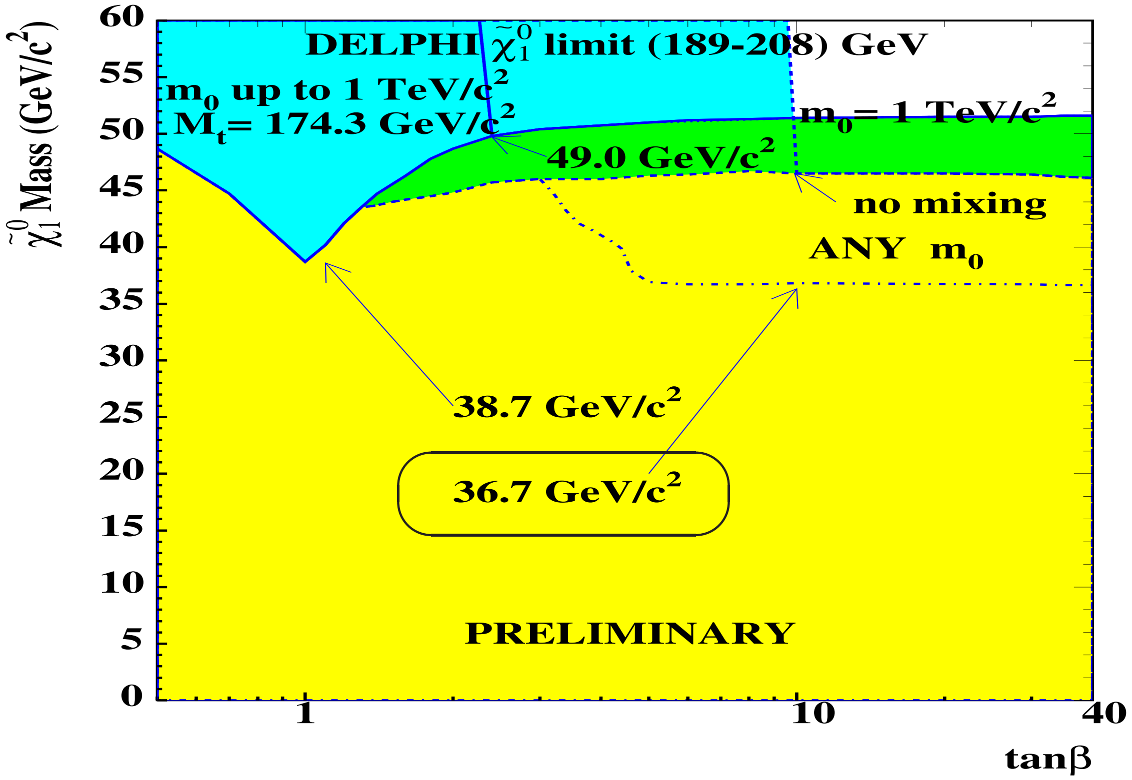
Higgsino scenario:

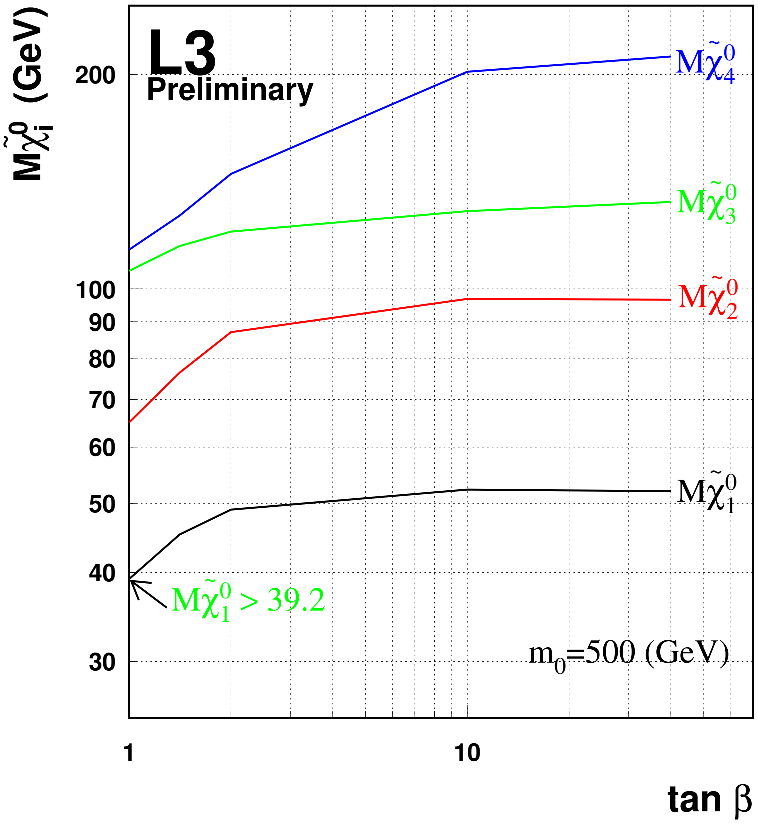


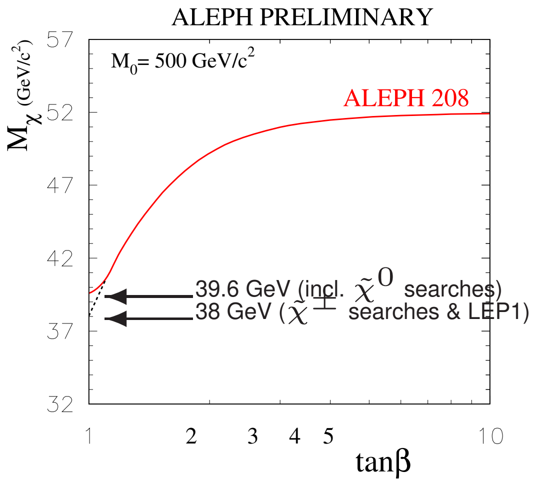
Gaugino scenario:



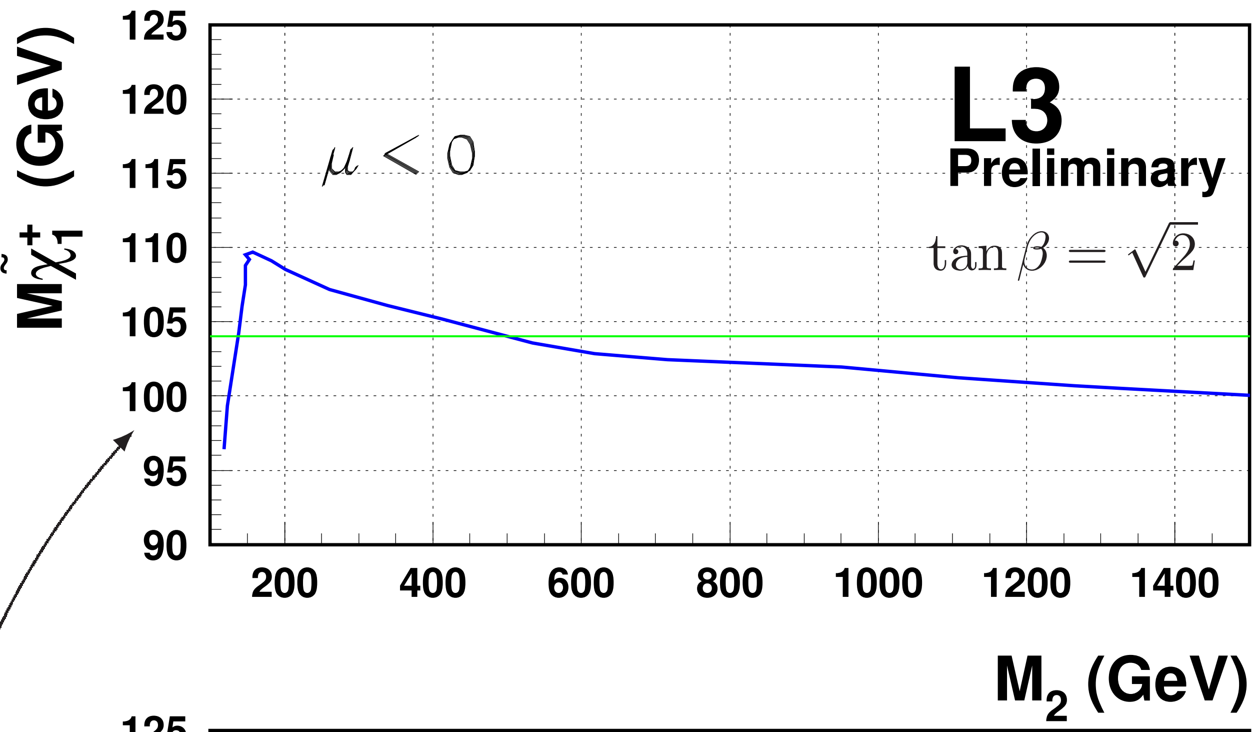
Model-Dependent $\tilde{\chi}^0_1$ Mass Limits

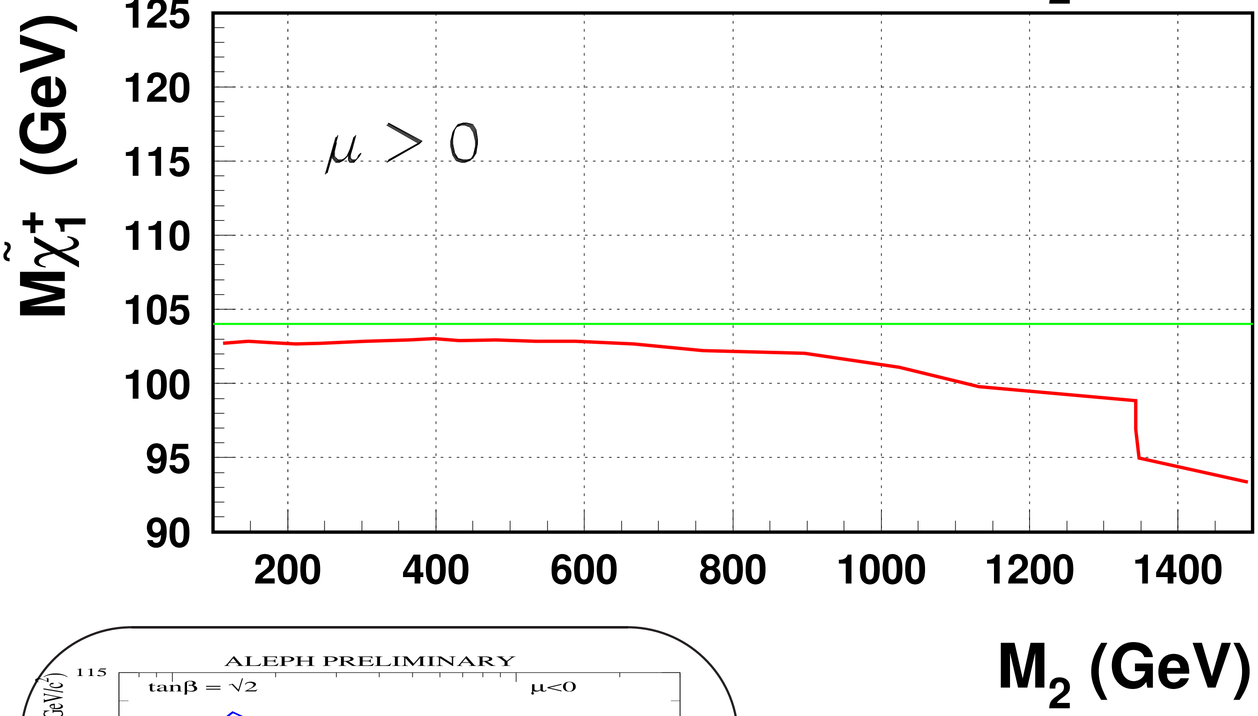


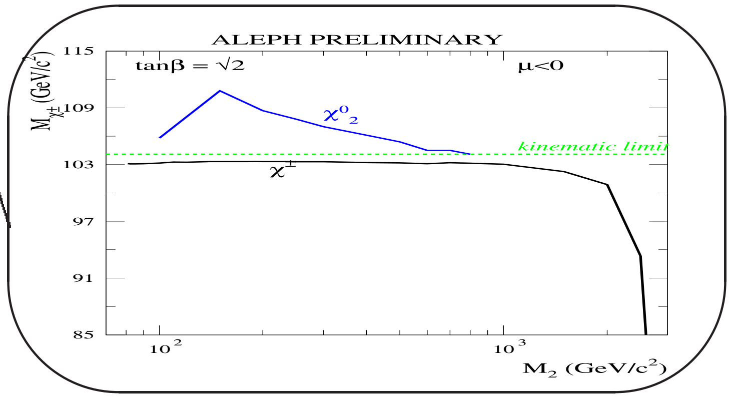




CMSSM Mass exclusion dependence on M_2, μ

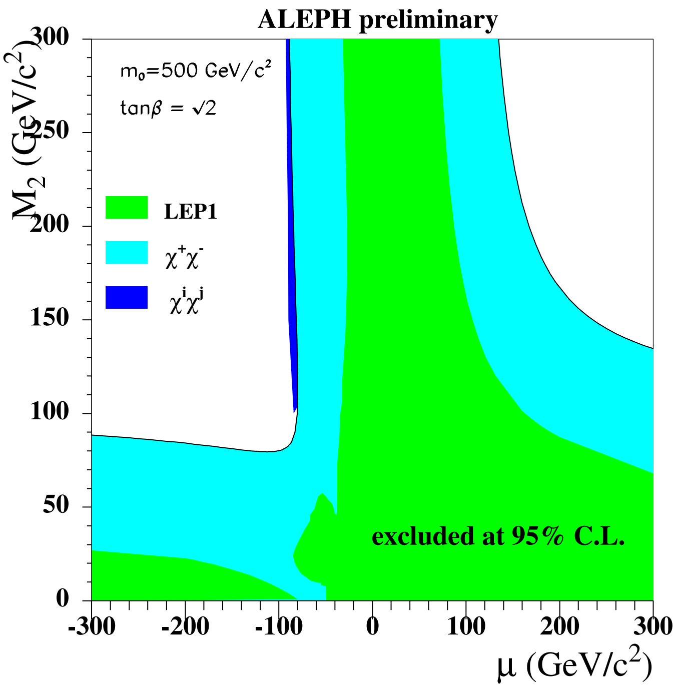






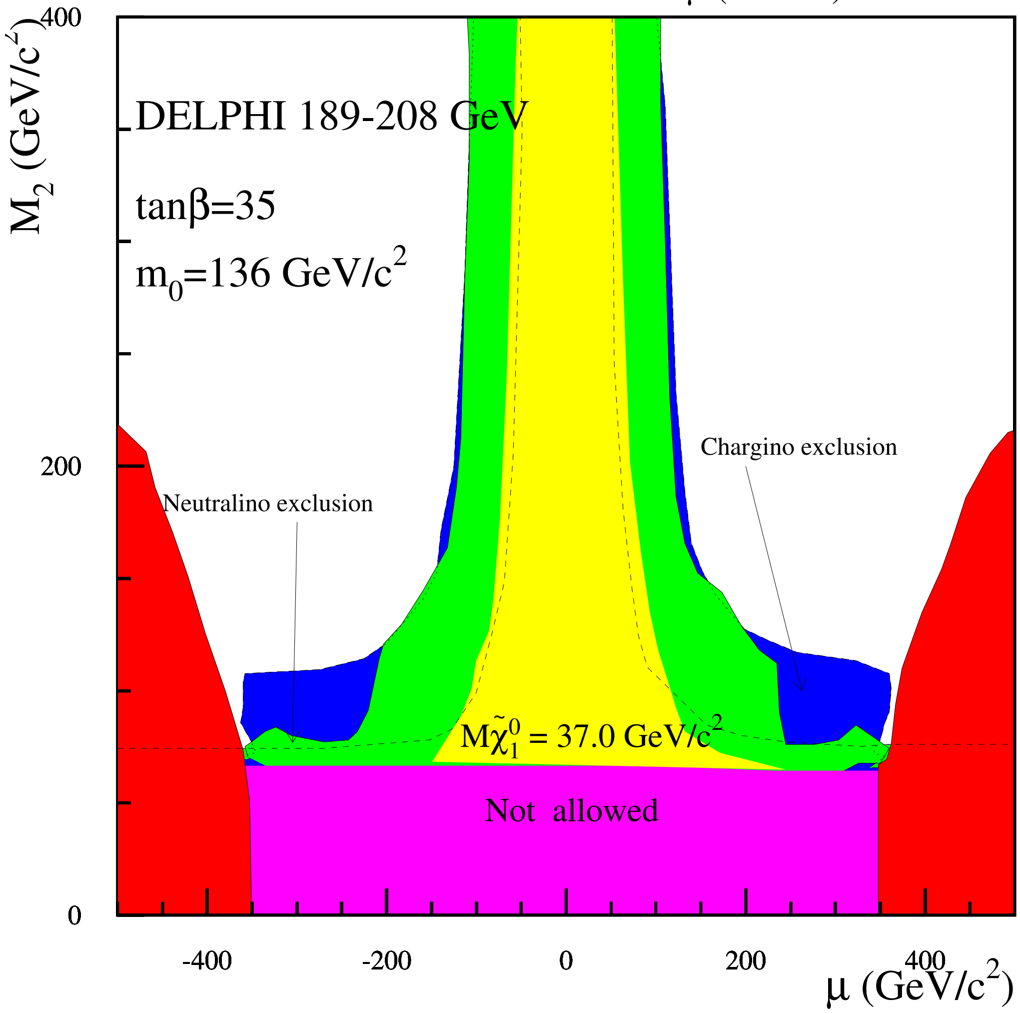
Limits on $\tilde{\chi}^\pm$ beyond kinematic limit, derived from $\tilde{\chi}^0$ search (higgsino scenarios).

Excluded regions of CMSSM (M_2, μ) space

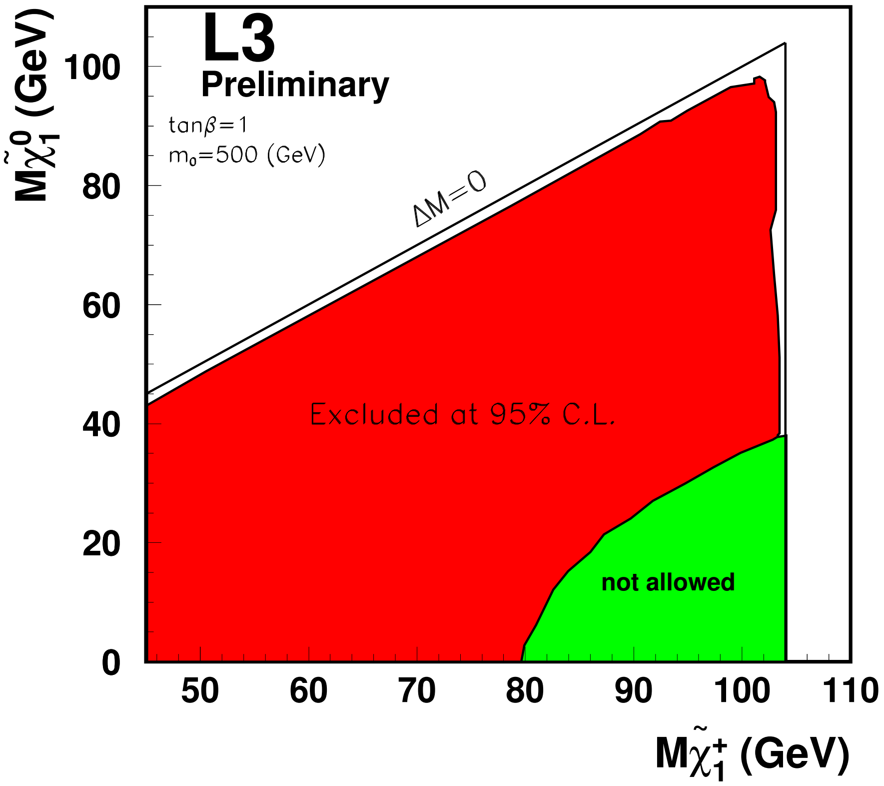


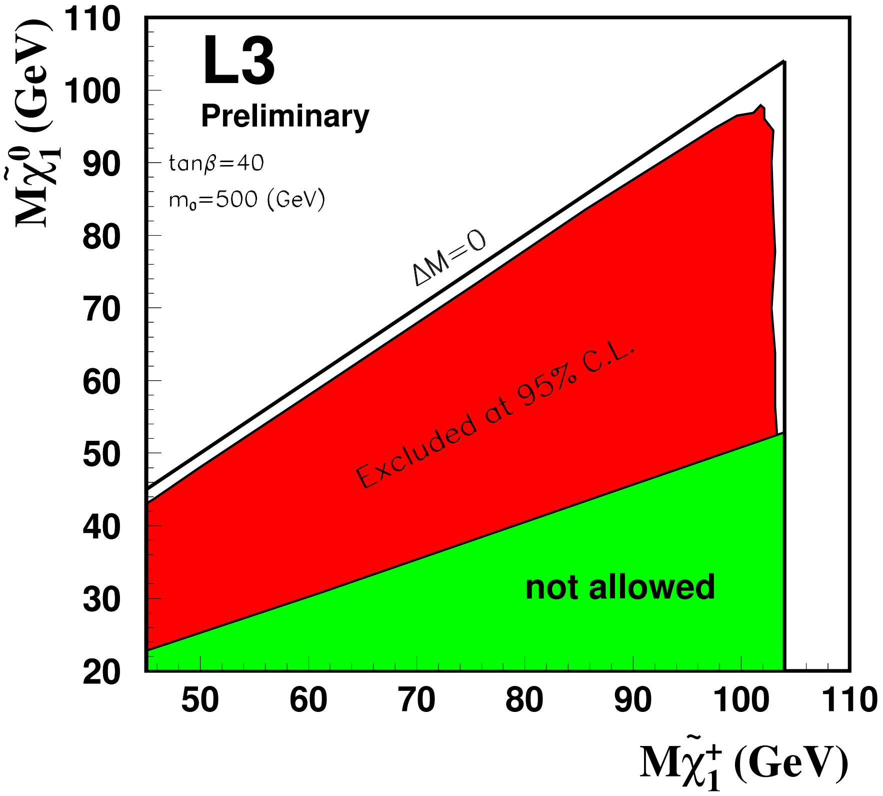
$\Leftarrow \tan\beta = \sqrt{2}$

$\Downarrow \tan\beta = 35.$



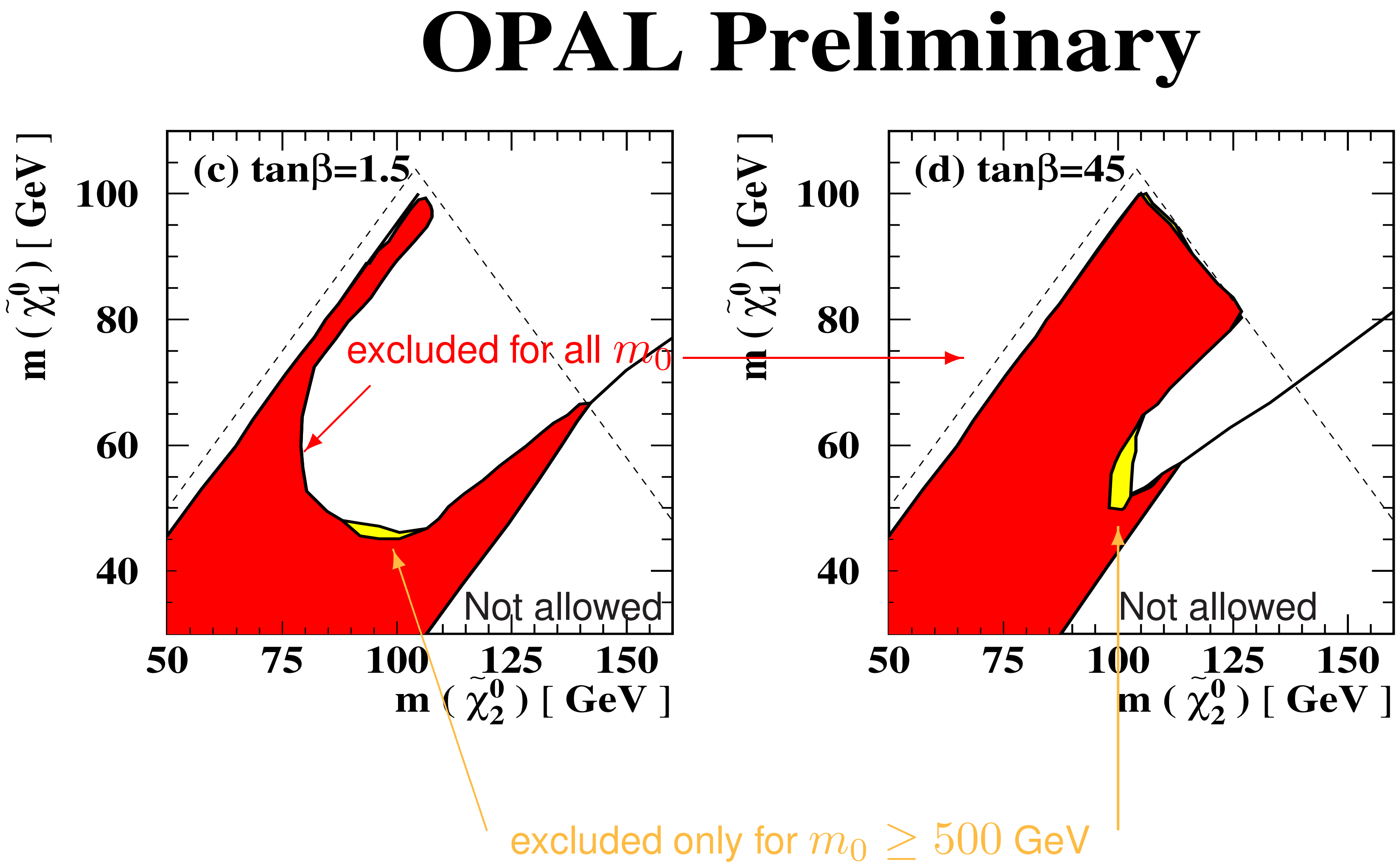
CMSSM scan: $\tan\beta$ influence on mass exclusion



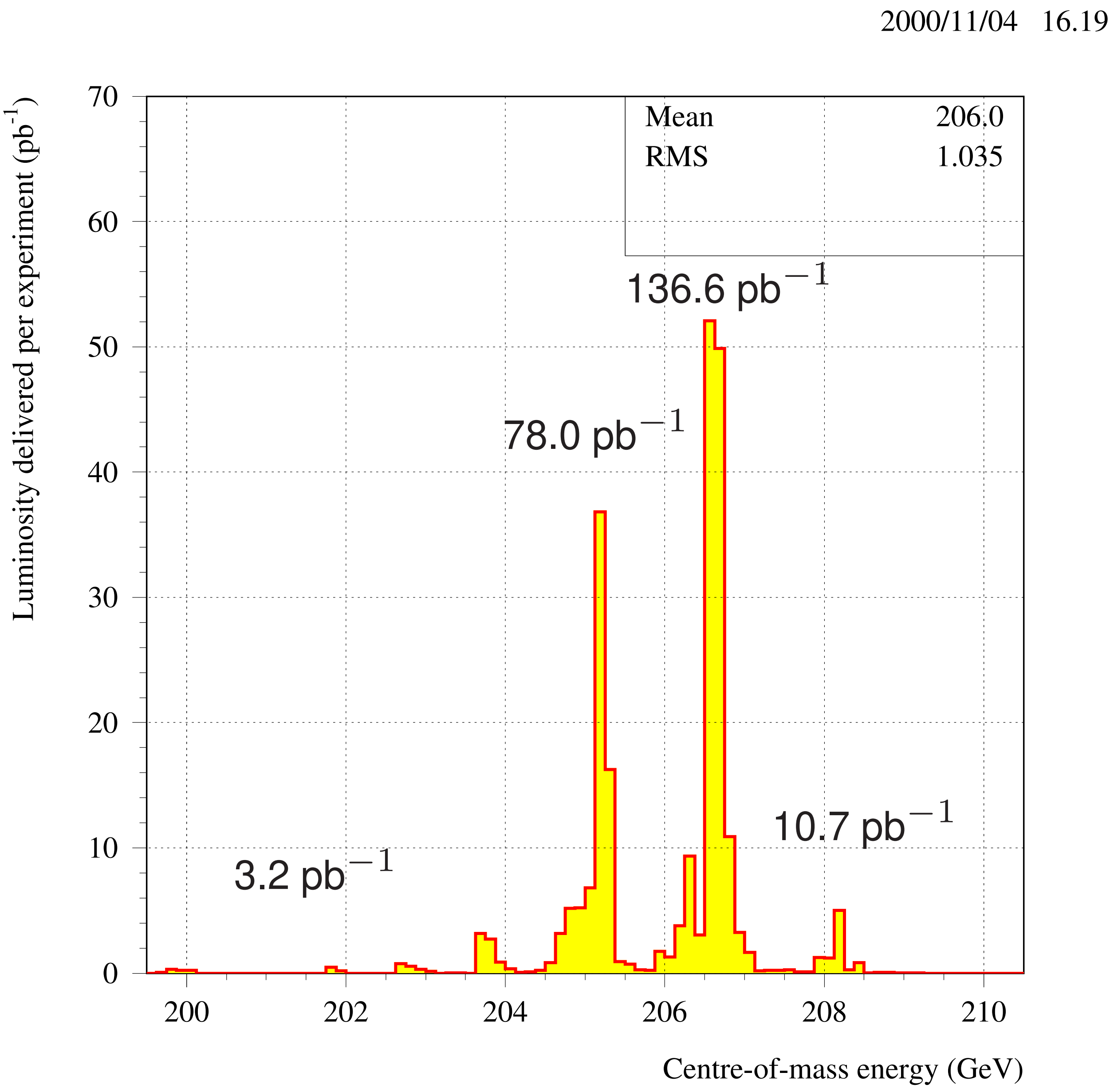


Scan mass plane; see if points are 95% CL excluded for ALL theoretically allowed values of $\tan\beta, M_2, m_0, \mu, m_A, A_0$.

CMSSM scan: $\tan\beta$ influence on mass exclusion



LEP Combinations: Year 2000 Data Set



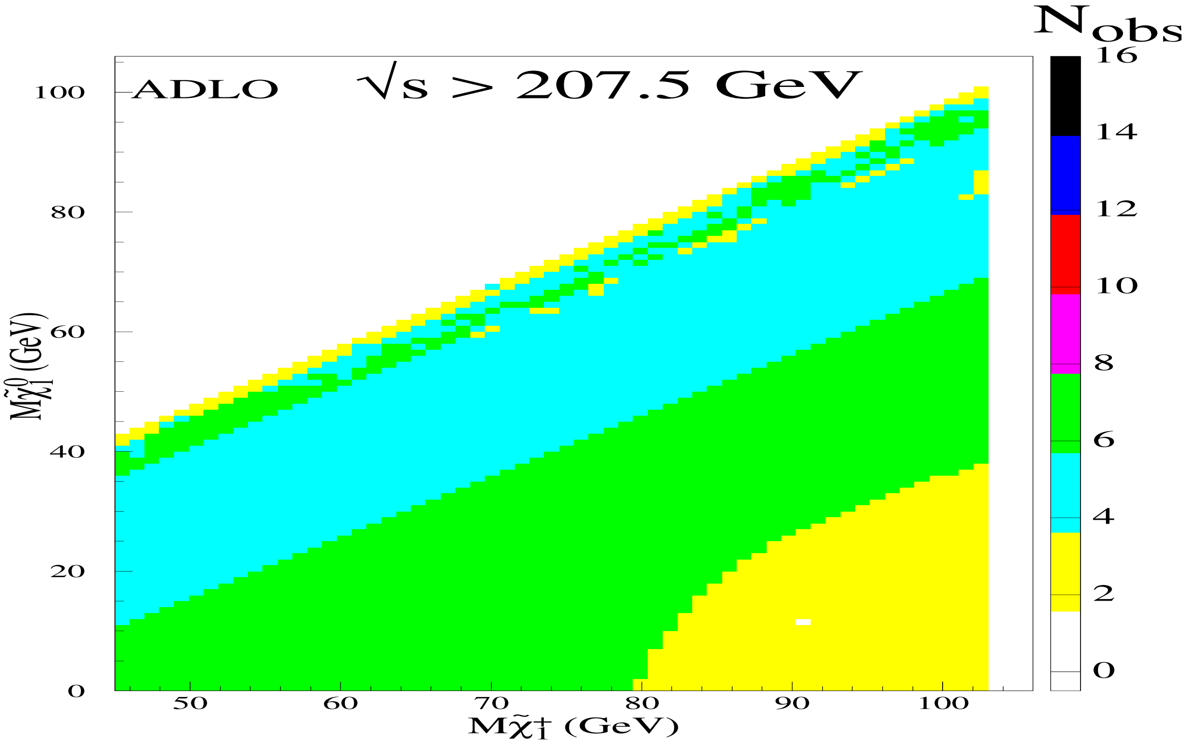
Total data in 2000 with $\sqrt{s} \geq 200$ GeV: $\sim 220\,\mathrm{pb}^{-1}/\mathrm{exp't}$
Total data in 2000 with $\sqrt{s} \geq 207.5$ GeV: $\sim 9\,\mathrm{pb}^{-1}/\mathrm{exp't}$

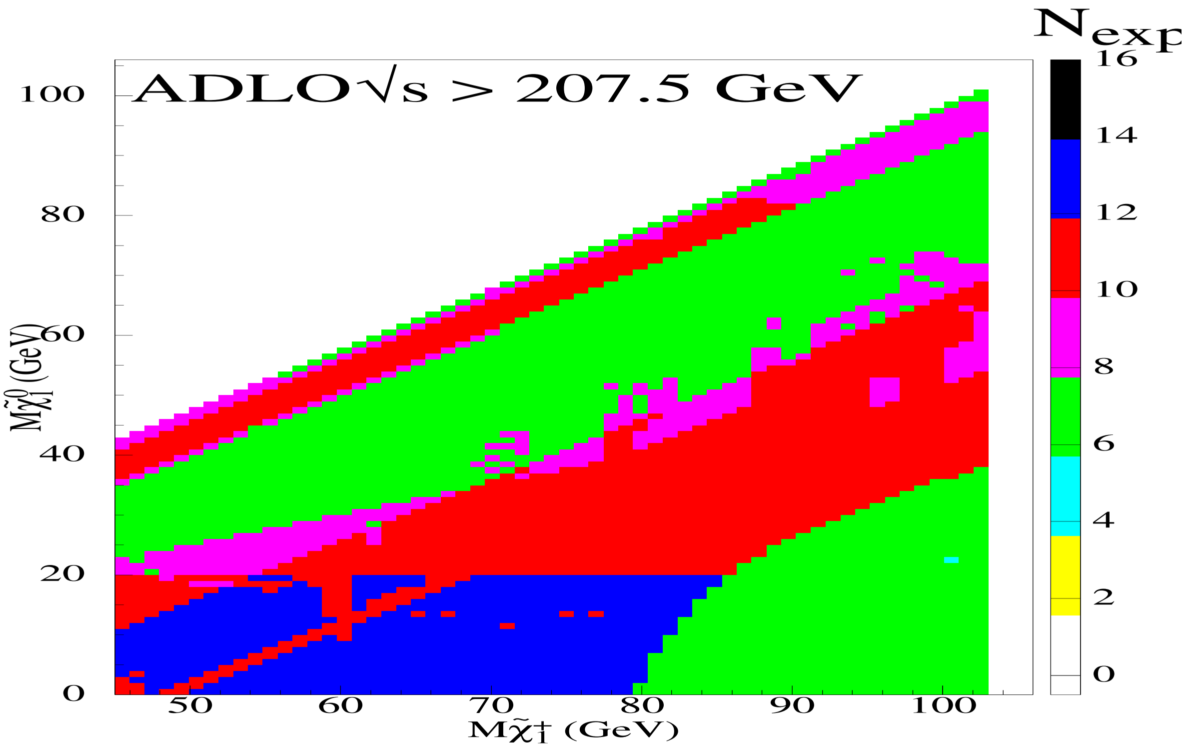
$\tilde{\chi}^{\pm}$ Combination at the highest $\sqrt{s}$

Chargino cross-section expected to be **large** (> 1 pb)

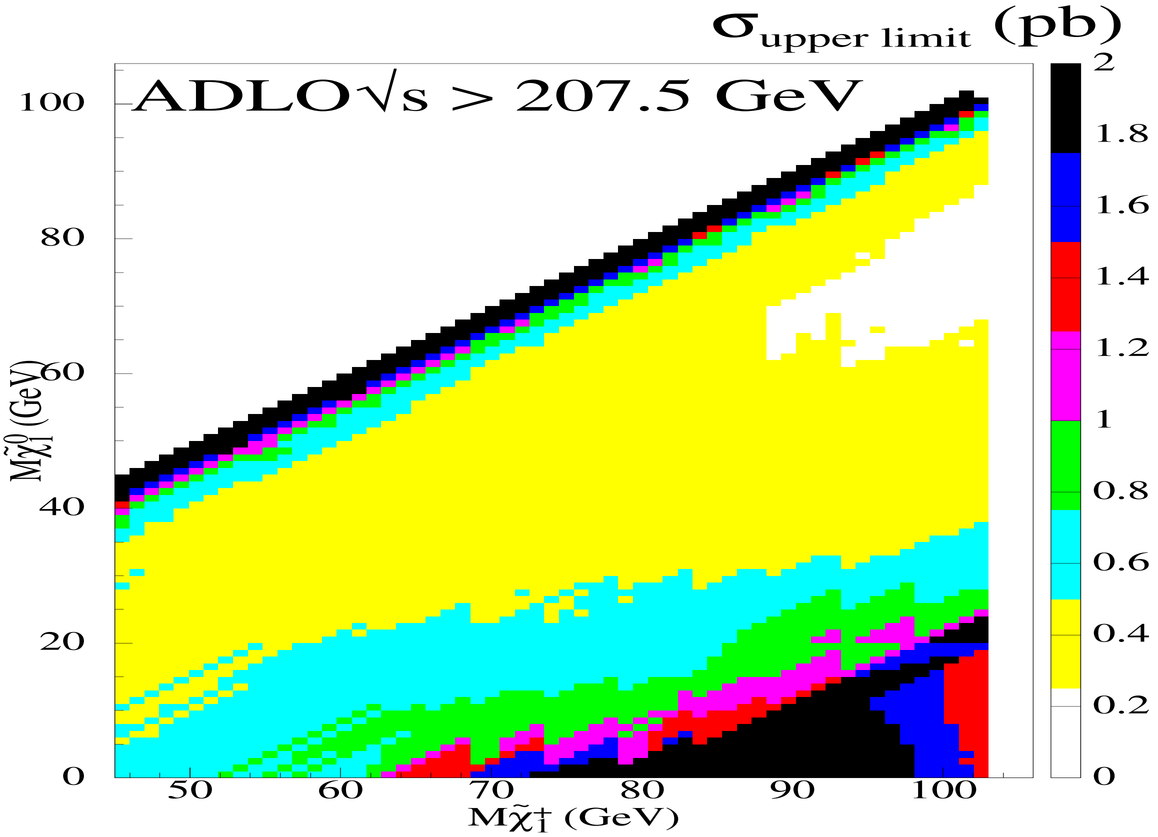
but ~ 9 pb^{-1} not enough for $\tilde{\chi}^{+}\tilde{\chi}^{-}$ at kinematic limit

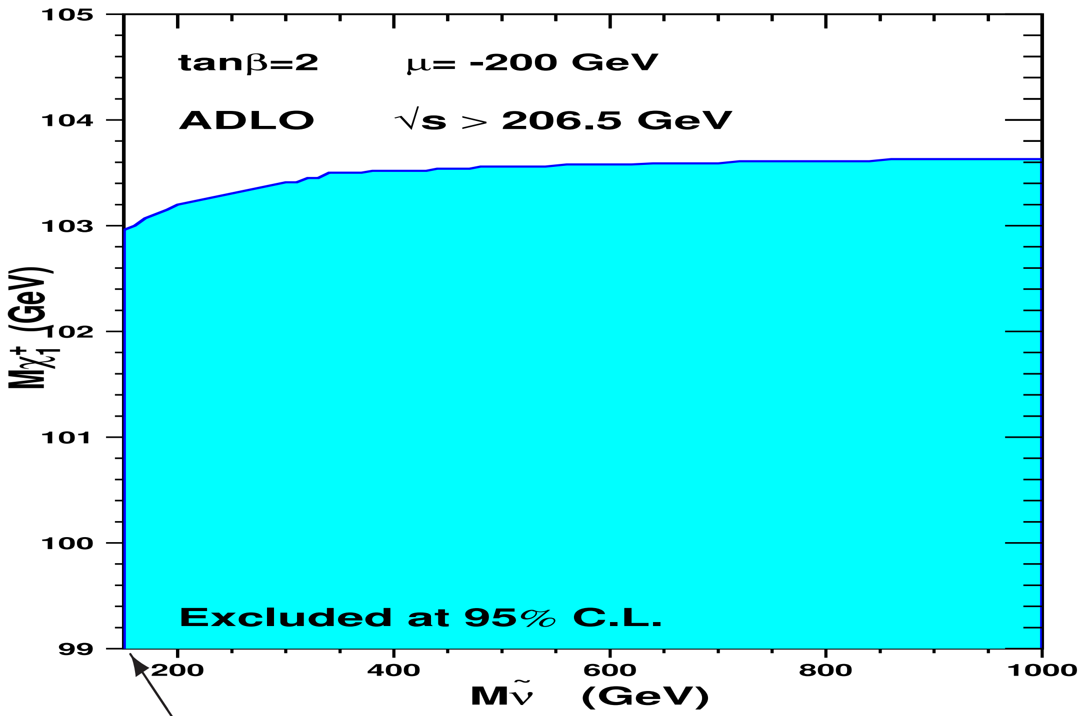
$\Rightarrow$ combine experiments $\Rightarrow$ ~35 pb^{-1} at $\sqrt{s} > 207.5$ GeV





LEP combination $\tilde{\chi}_1^\pm$ mass limit





Valid for **large** m_0 **only**! (A snapshot, not a full scan.)

Conclusions

- $\tilde{\chi}_1^{\pm}$ excluded at 95% CL in almost full kinematically accessible region at LEP2
- LSP mass > 36.7 GeV

  (for all m_0, allowing $\widetilde{\tau}$ mixing, $A_\tau = A_b = A_t = 0$)
- Still unexcluded parameter space in full MSSM
- Final analyses will be more general & sensitive, so wait a few months. . .

References:

- ALEPH 2001-009 CONF 2001-006, 28 Feb. 2001

  & ALEPH 2001-004 CONF 2001-001, 5 Mar. 2001
- DELPHI 2001-010 CONF 451, 8 Mar. 2001
- L3 note 2644, 7 Mar. 2001
- OPAL Physics Note PN470, 27 Feb. 2001