Search for MSSM Sfermions and Gauginos

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On behalf of the LEP experiments

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Outline

- “Standard” SUSY framework at LEP
- Search for Sfermions
- Search for Charginos and Neutralinos
- Summary

All results are preliminary.

Searches for SUSY Particles

"Standard" SUSY model at LEP2

gravity mediated $\Rightarrow$ $\tilde{\mathrm{G}}$ is heavy.

R-parity (SM particles: even / SUSY: odd)

$\Rightarrow$ conserved

$\Rightarrow$

- Lightest SUSY Particle (LSP) is stable.
  $\Rightarrow$ Darkmatter candidate
- Pair production of SUSY particles
- LSP in the final decay products

SUSY particles

	Spin 0	Spin 1/2	Spin 1
Sleptons $\Rightarrow$	$\left.\tilde{\ell}^{\pm}_{\mathrm{L,R}}\right\}\tilde{\ell}^{\pm}_{1,2}$	$\ell^{\pm}_{\mathrm{L,R}}$	
	$\tilde{\nu}_{\mathrm{L}}$	ν_{L}	
Squarks $\Rightarrow$	$\left.\tilde{\mathrm{q}}_{\mathrm{L,R}}\right\}\tilde{\mathrm{q}}_{1,2}$	$\mathrm{q}_{\mathrm{L,R}}$	
		$\tilde{g}$	g
		$\tilde{\gamma}$	γ
Neutralinos $\Rightarrow$	$\mathrm{h, H, A}$	$\left.\begin{matrix}\tilde{\gamma}\\ \tilde{\mathrm{h}}, \tilde{\mathrm{H}}\\ \tilde{\mathrm{Z}}\end{matrix}\right\}\tilde{\chi}^0_j$	
$m_{\tilde{\chi}^0_1} < m_{\tilde{\chi}^0_2} < \ldots < m_{\tilde{\chi}^0_4}$		$\tilde{\mathrm{Z}}$	Z
Charginos $\Rightarrow$	$\mathrm{H}^{\pm}$	$\left.\begin{matrix}\tilde{\mathrm{H}}^{\pm}\\ \tilde{\mathrm{W}}^{\pm}\end{matrix}\right\}\tilde{\chi}^{\pm}_i$	$\mathrm{W}^{\pm}$
$m_{\tilde{\chi}^{\pm}_1} < m_{\tilde{\chi}^{\pm}_2}$			

$\boxed{\text{LSP is } \tilde{\chi}^0_1 \text{ or } \tilde{\nu}_{\mathrm{L}}}$

SUSY Framework at LEP2

General MSSM

105 new parameters....

$\Downarrow$

Unification of masses 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!

LEP Data

- Luminosity/experiment

	$\sqrt{s}$ (GeV)	L (pb^{-1})
1998	189	50
1999	192, 196, 200, 202	29, 79, 82, 39
2000	$\sim$206	220
	($>$207.5	9)

- Luminosity varies with searches as well as with experiment.

ADLO

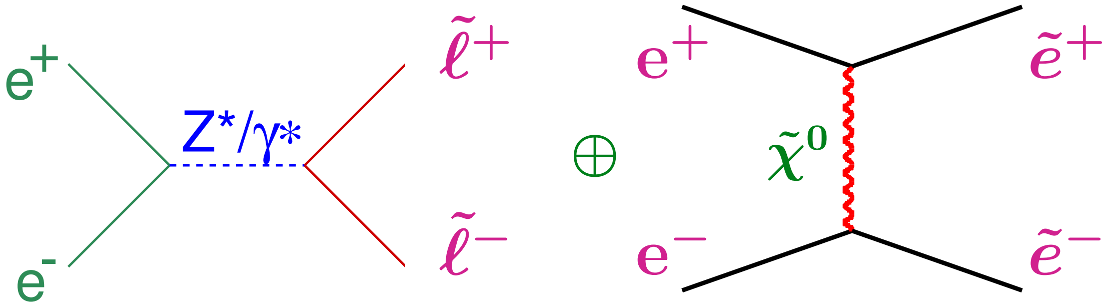
- Whenever possible, combined results of LEP experiments are shown

References

ALEPH http://alephwww.cern.ch/
DELPHI http://delphi.web.cern.ch/Delphi/Welcome.html
L3 http://l3www.cern.ch/welcome.html
OPAL http://opal.web.cern.ch/Opal/PPwelcome.html
LEP SUSY WG: http://lepsusy web.cern.ch/lepsusy/

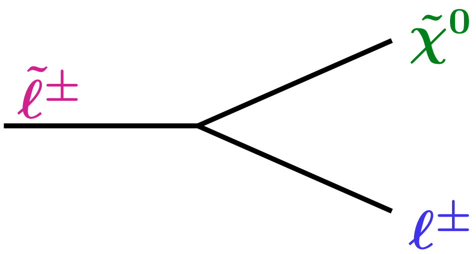
Slepton Production and Decay

- **Slepton pair production**



t-channel

- **Slepton decay**



Event topologies depending on $\Delta M_{\tilde{\ell}}$;

$$\Delta M_{\tilde{\ell}} = m_{\tilde{\ell}^\pm} - m_{\tilde{\chi}_1^0}$$

- **Background**

large $\Delta M_{\tilde{\ell}}$: $W^+W^- \longrightarrow \ell^+\nu\ell^-\bar{\nu}$

small $\Delta M_{\tilde{\ell}}$: $e^+e^- \longrightarrow e^+e^-\ell^+\ell^-$

$(\tilde{e}_L, \tilde{e}_R)$
$(\tilde{\mu}_L, \tilde{\mu}_R)$ **are almost mass eigenstates**

Large mixing of $(\tilde{\tau}_L, \tilde{\tau}_R)$ at large $\tan\beta$

$\Rightarrow$ **Large mass splitting $(\tilde{\tau}_1, \tilde{\tau}_2)$**

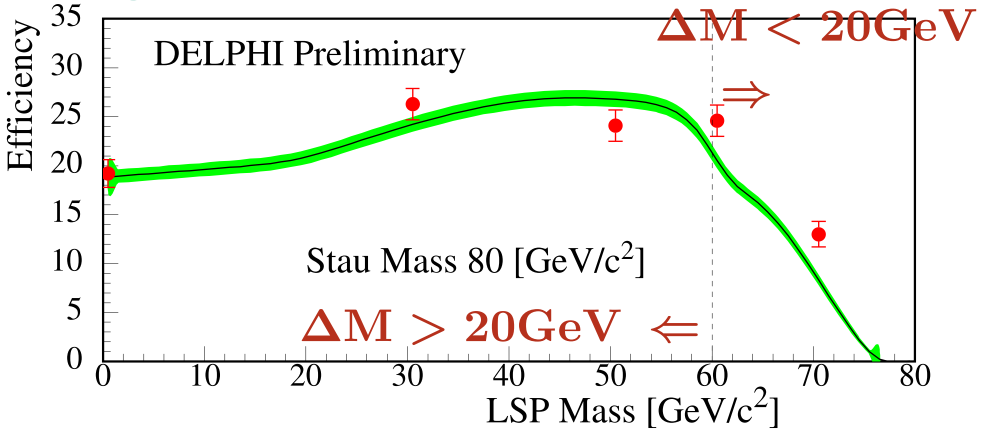
$\tilde{\tau}_1$ can be light

$\Rightarrow$ **minimise $\sigma_{\tilde{\tau}}$ at $\theta_{\tilde{\tau}} = 52^\circ$**

Slepton Selection

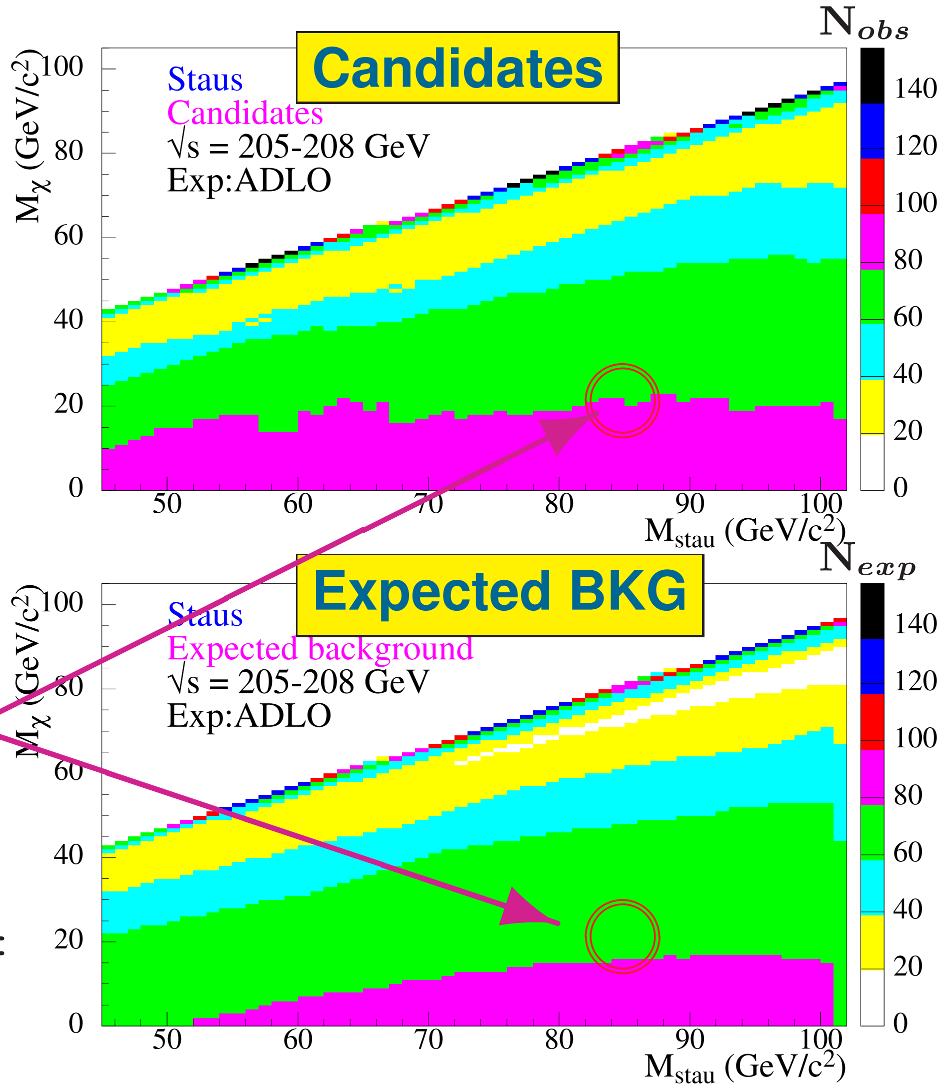
- Selection strongly depends on ΔM
  $\Rightarrow$ Several dedicated selections

- Efficiency in transition of two ΔM regions in $\tilde{\tau}$ search



$\sqrt{s}$ = 205–208 GeV

- Result for $\tilde{\tau}$ search (2000, ADLO)



Excess'99

Consistent with SM background $\Leftarrow$

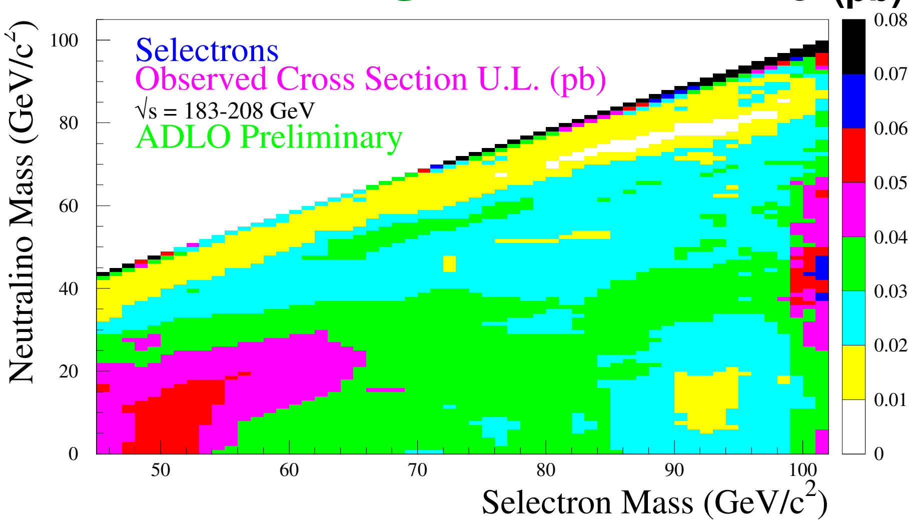
$\tilde{e}$ / $\tilde{\mu}$ are not found, either.

Model Independent Cross Section Limit

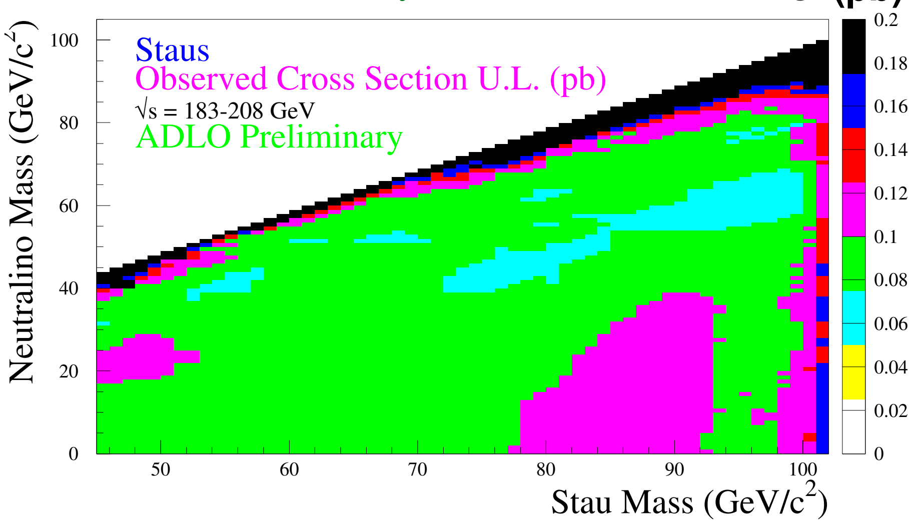
σ limit in mass plane ($m_{\tilde{\chi}^0}$ vs $m_{\tilde{\ell}}$)

Using data at $\sqrt{s}$= 183–208 GeV

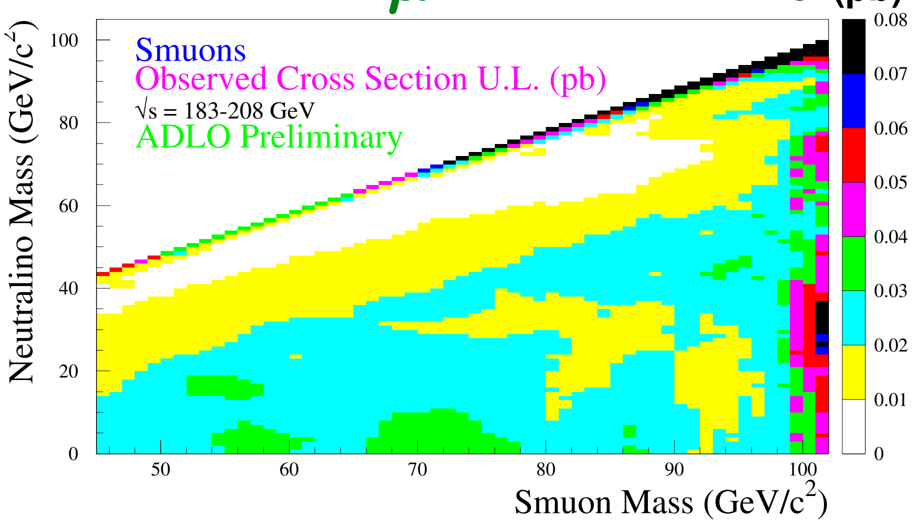
$\tilde{e}$



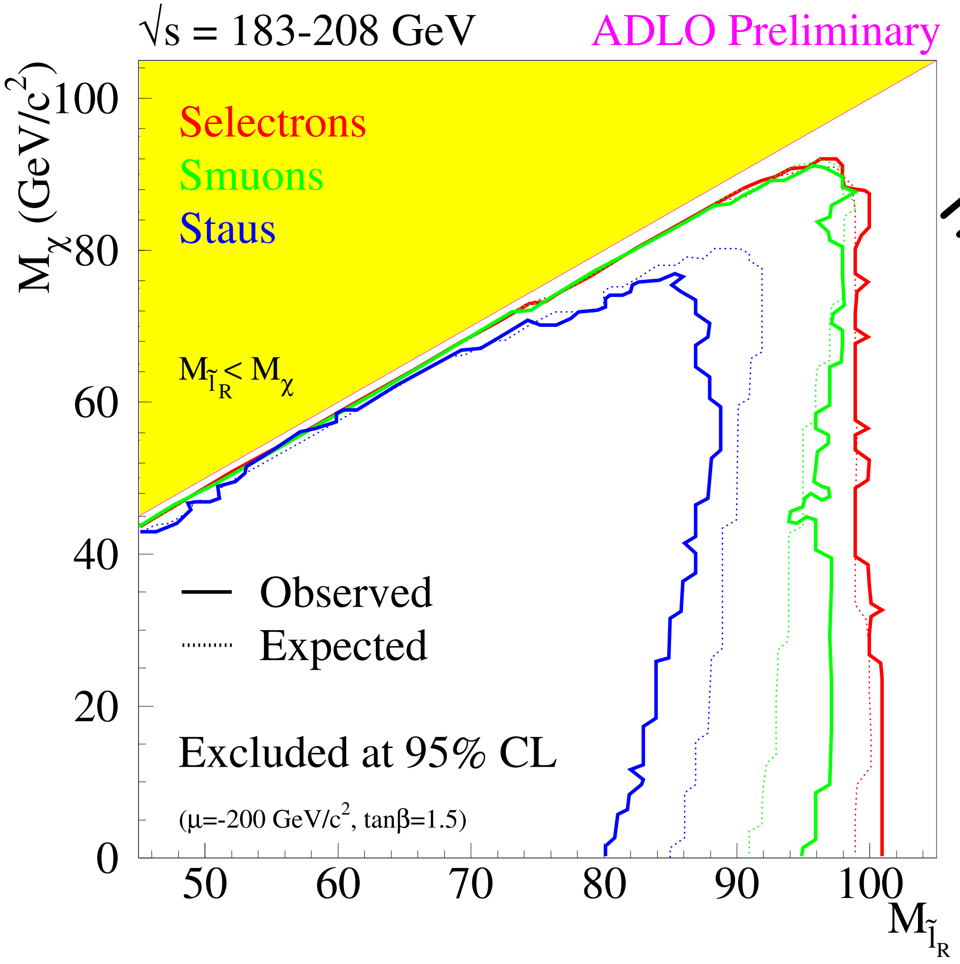
$\tilde{\tau}$



$\tilde{\mu}$



Slepton Exclusion Limit



$\Delta \mathrm{M} > 10\mathrm{GeV}$

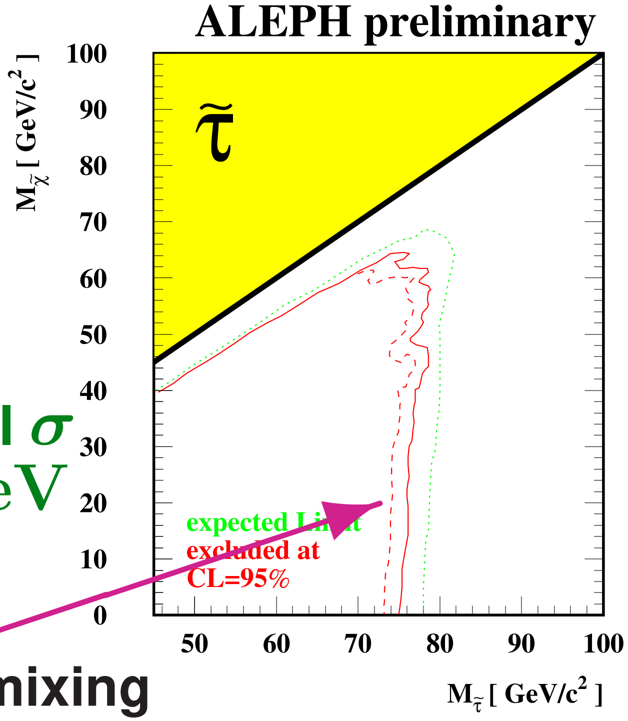
ADLO

	$m_{\tilde{e}_R}$	$m_{\tilde{\mu}_R}$	$m_{\tilde{\tau}_R}$
Obs. (GeV)	99.	95.	80.
Exp. (GeV)	99.	91.	85.

$\tilde{\tau}$-mixing

$\Rightarrow$ minimal σ

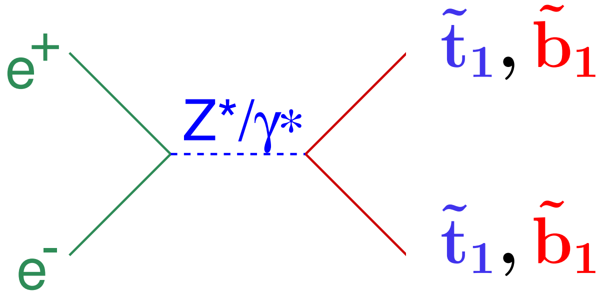
$\sim -2\mathrm{GeV}$



With $\tilde{\tau}$-mixing

Squark Production and Decay

- **Stop/sbottom production**

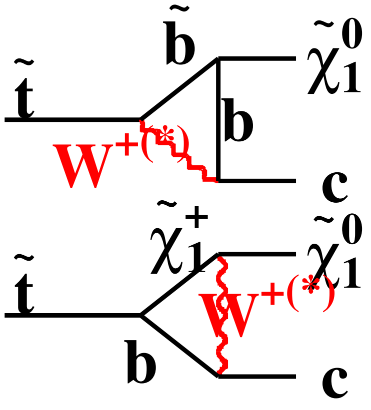


$\tilde{t}_L$ and $\tilde{t}_R$ are mixing
$\Rightarrow$ $\tilde{t}_1$ and $\tilde{t}_2$

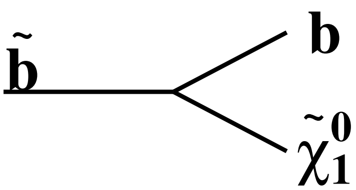
$\tilde{b}_L$ and $\tilde{b}_R$ also mix,
if $\tan\beta$ is large

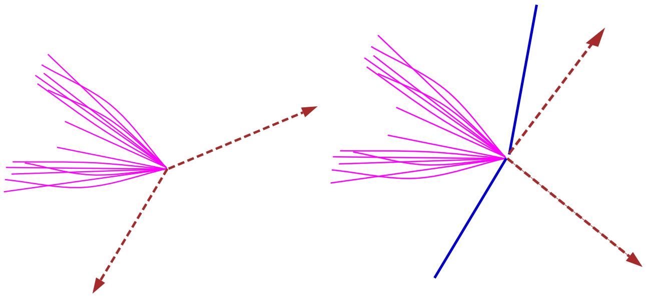
- **Stop/sbottom decays**

$\tilde{t}_1 \rightarrow \tilde{\chi}^0 c$

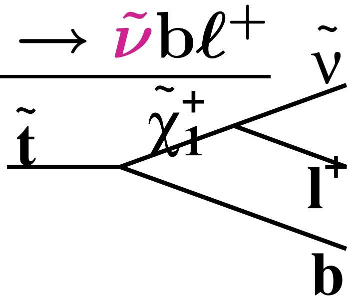


$\tilde{b}_1 \rightarrow \tilde{\chi}^0 b$





$\tilde{t}_1 \rightarrow \tilde{\nu} b \ell^+$



$\Leftarrow$ dominant if it's allowed

$m_{\tilde{\nu}} < (m_{\tilde{t}} - m_b - m_{\ell^+})$

- **The event topologies depend on ΔM;**

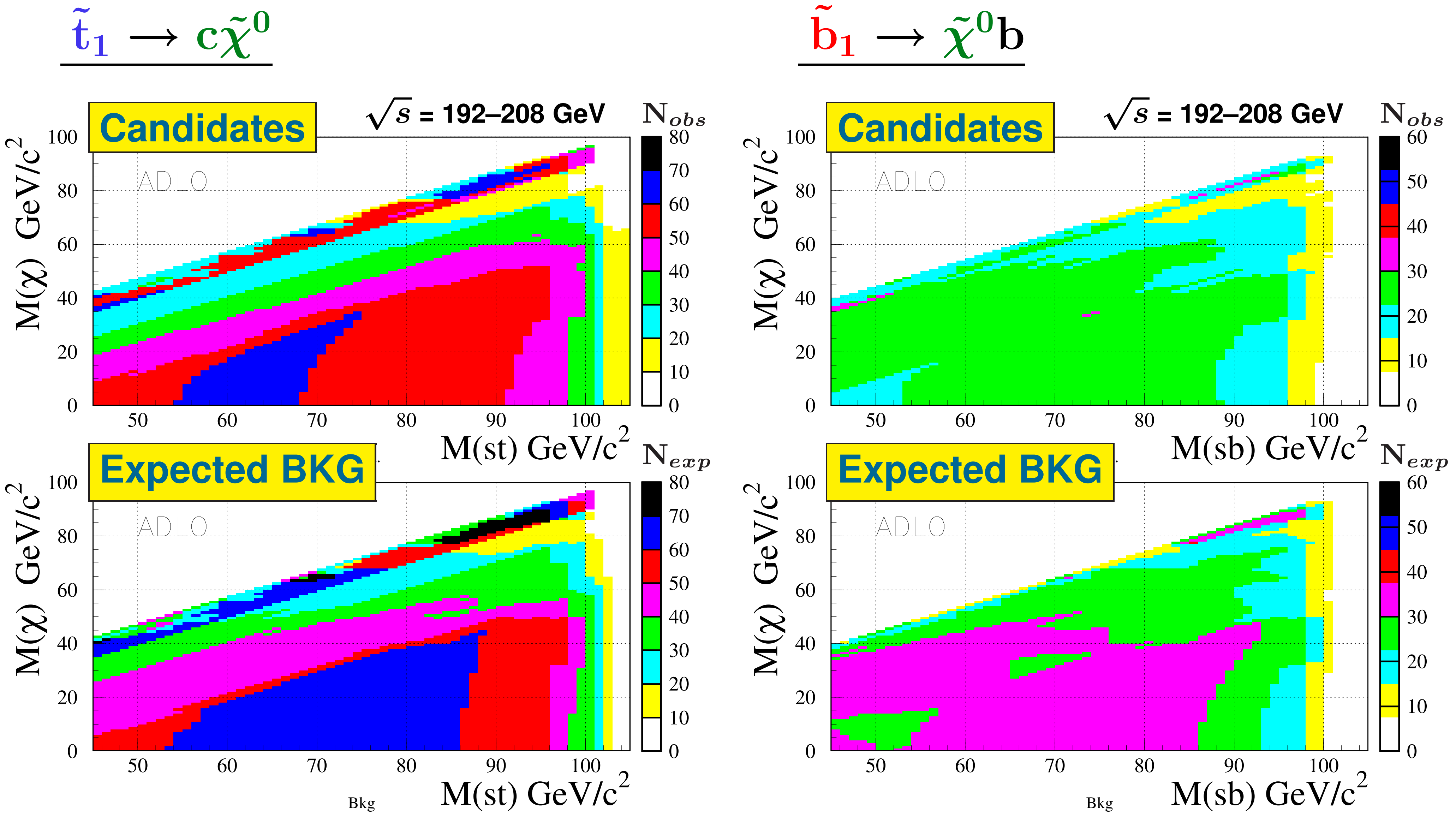
$$\Delta M_{\tilde{q}} = m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$$

- **Background**

W^+W^-, $We\nu$ and $q\bar{q}(\gamma)$ for large ΔM

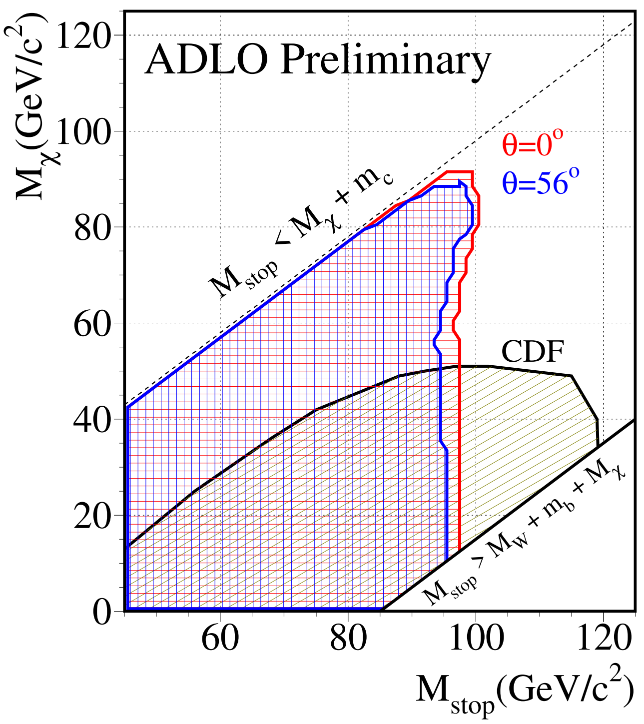
two photon processes for small ΔM

Results from Squark Search(1)

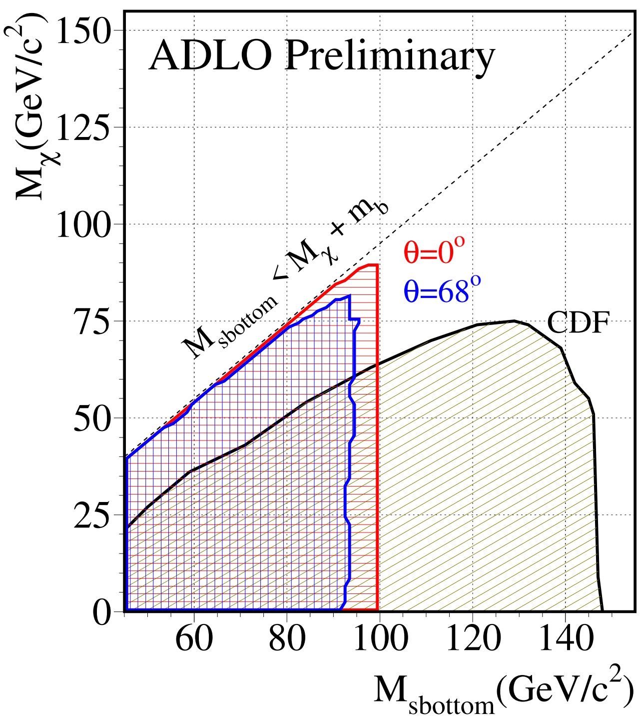


Squark Exclusion Limit

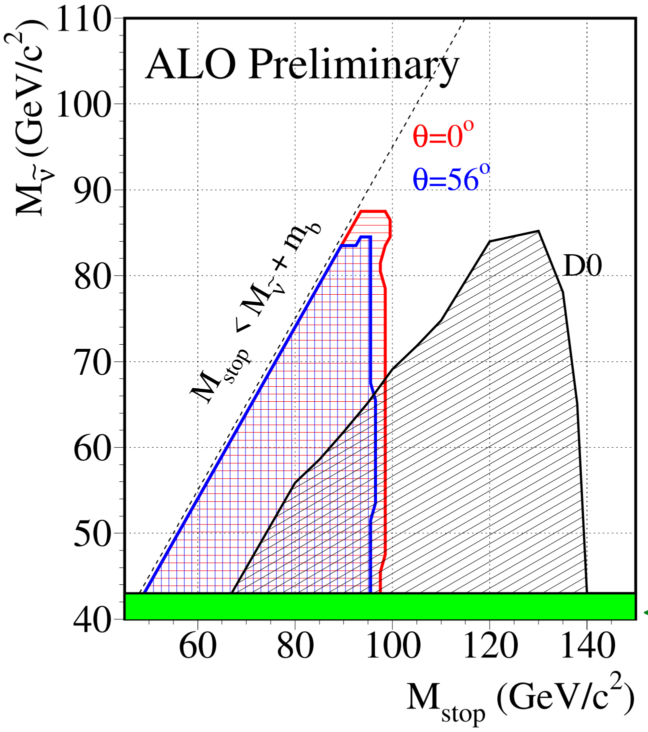
$\tilde{t}_1 \longrightarrow \tilde{\chi}^0 c$



$\tilde{b}_1 \longrightarrow \tilde{\chi}^0 b$



$\tilde{t}_1 \longrightarrow \tilde{\nu} b \ell^+$



Excluded by LEP1

Effect of $\tilde{q}$ mixing

Red: no mixing

Blue: $\sigma_{\tilde{q}}$ minimum

$\Rightarrow$ $\tilde{q}$ decouples with Z

at mixing angle

$\theta = 56^\circ$ for $\tilde{t}$

$\theta = 68^\circ$ for $\tilde{b}$

Another Comparison with Tevatron

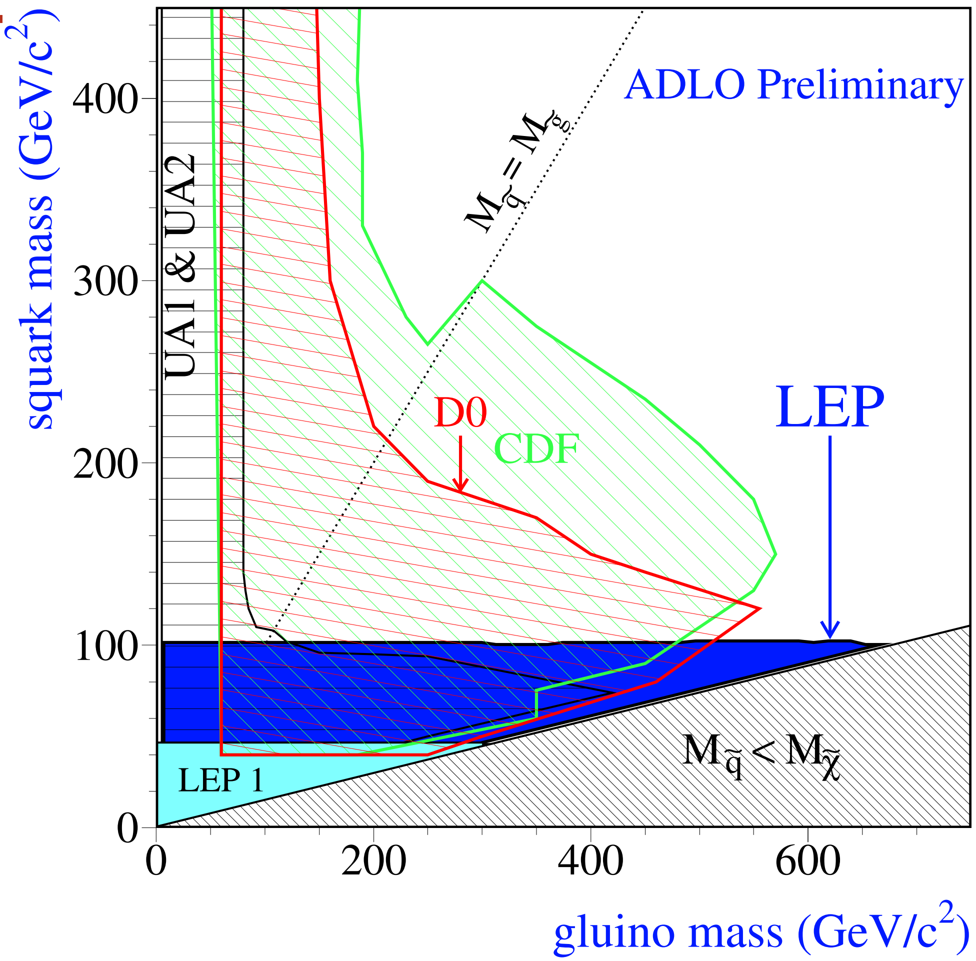
Tevatron has good sensitivity for $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{g}$ production as well as for $\tilde{q}\tilde{q}$.

In order to compare LEP limits with those from Tevatron,
LEP results are translated into

an exclusion limit in $(m_{\tilde{g}}, m_{\tilde{q}}) \Rightarrow$

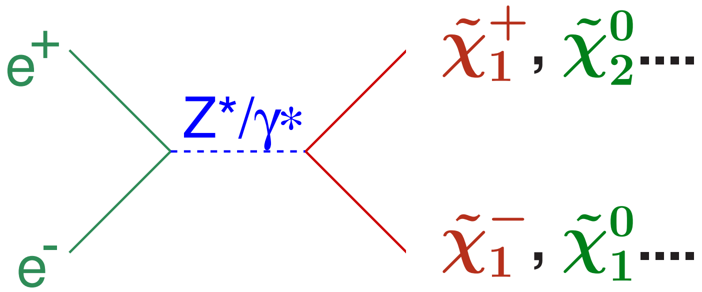
under following assumptions:

- a degenerate mass $m_{\tilde{q}}$ for $\tilde{u}_{R,L}, \tilde{d}_{R,L}, \tilde{c}_{R,L}, \tilde{s}_{R,L}, \tilde{b}_{R,L}$
- GUT relation among the M_1, M_2 and M_3, relating with $\tilde{\chi}^0$ and $\tilde{g}$ masses
- $\tan\beta = 4$ and $\mu = -400\mathrm{GeV}$

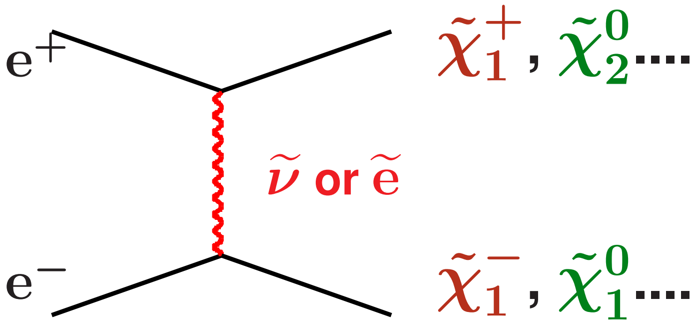


Chargino $\tilde{\chi}^{\pm}$ and Neutralino $\tilde{\chi}^{0}$ Production

- Charginos and Neutralinos 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"

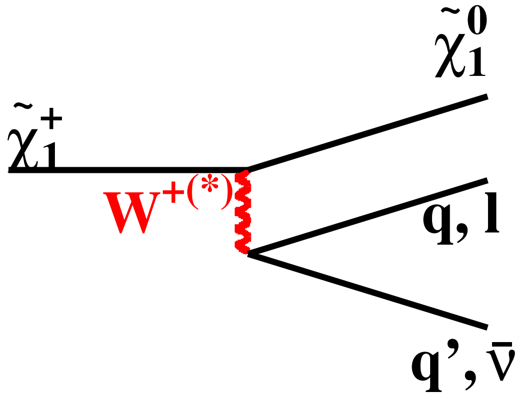
However, cross section of $\tilde{\chi}^{\pm}$,

$\sigma_{\tilde{\chi}^{\pm}}$ is large enough to discover it.

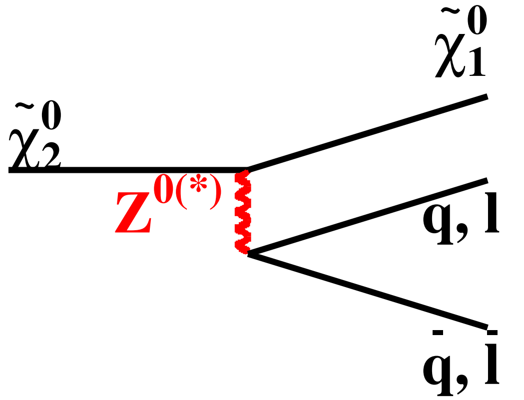
$$\sigma_{\tilde{\chi}^{\pm}} \gtrsim 1\text{pb}$$

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

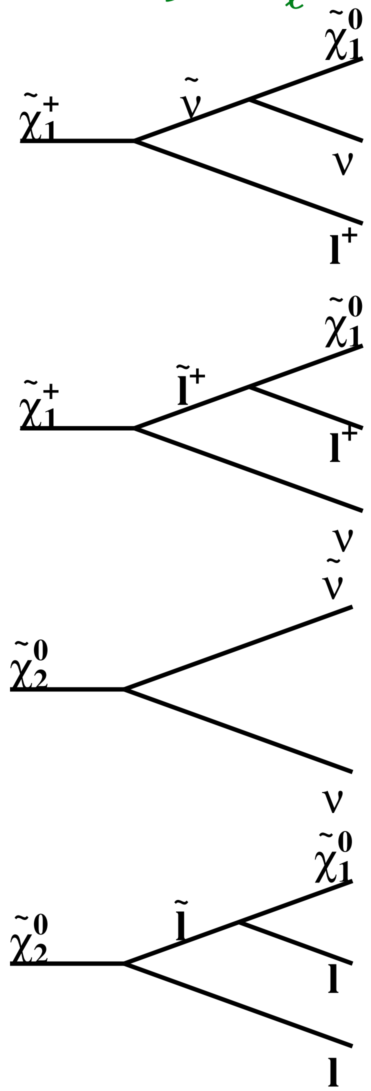
Chargino Decay:



Neutralino Decay:



Small $m_{\tilde{\nu}}$ / $m_{\tilde{\ell}}$

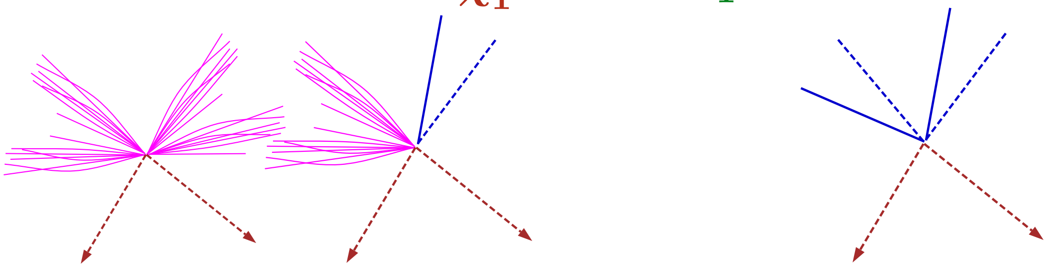


- Large missing energy due to LSP.
  - $\Rightarrow$ Acoplanar events
- In case of small $m_{\tilde{\nu}}$ / $m_{\tilde{\ell}}$, decay BR's of $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$ change.
  - $\Rightarrow$ Sensitivity of analyses change, too.

Event Topologies and Selection Strategy

- The event topologies are depending on $\Delta\mathrm{M}$;

$\tilde{\chi}^{\pm}$: $\Delta\mathrm{M} \equiv \mathrm{m}_{\tilde{\chi}_1^+} - \mathrm{m}_{\tilde{\chi}_1^0}$



Large $\Longleftarrow$ $\Delta\mathrm{M}$ $\Longrightarrow$ Small

$\tilde{\chi}^0$: $\Delta\mathrm{M} \equiv \mathrm{m}_{\tilde{\chi}_2^0} - \mathrm{m}_{\tilde{\chi}_1^0}$

- Backgrounds also vary with $\Delta\mathrm{M}$:

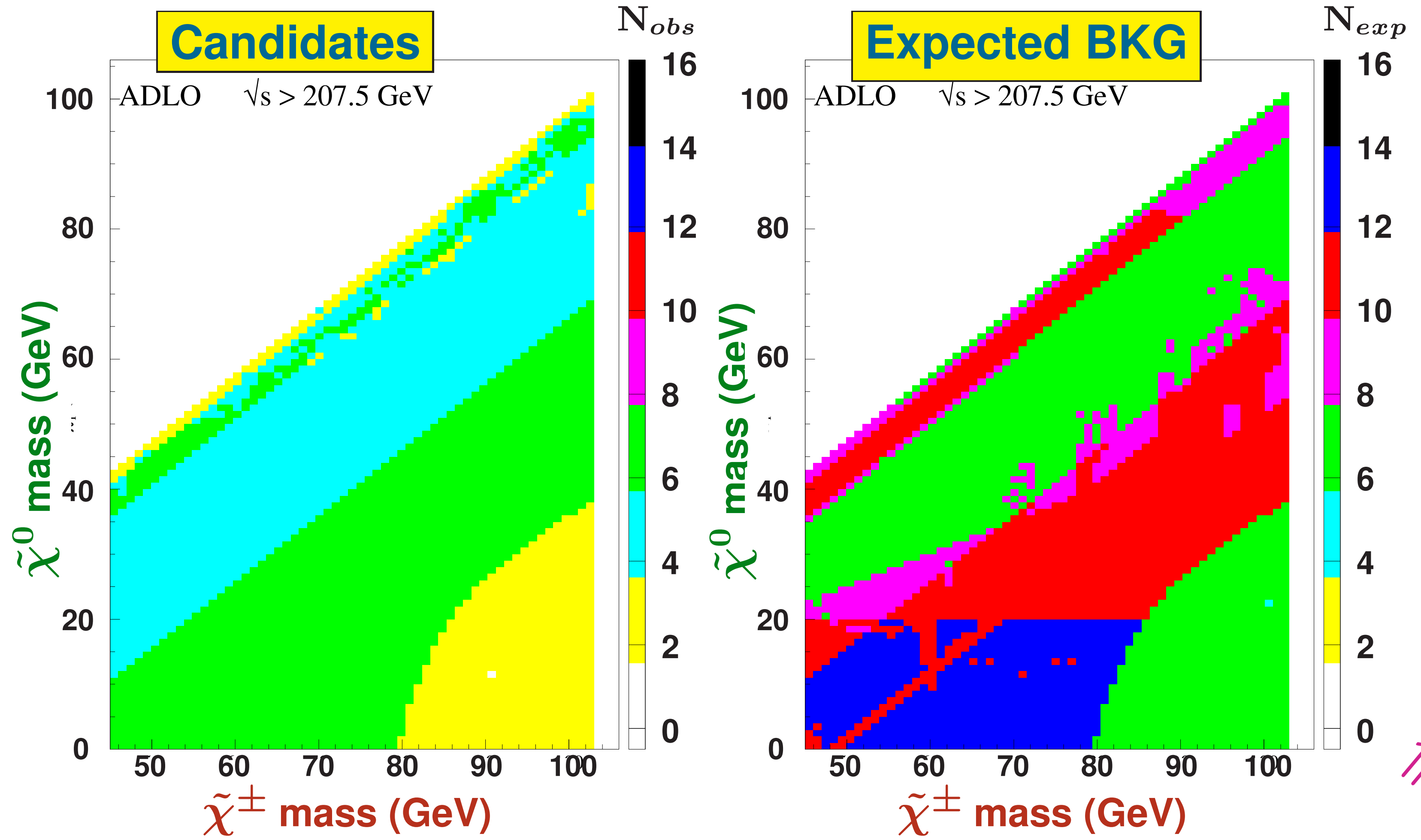
four-fermion $\sigma \approx 20\mathrm{pb}$ $\Longleftrightarrow$ two photon $\sigma \approx \mathcal{O}(\mathrm{nb})$

$\Longrightarrow$ Several categories of analyses depending on $\Delta\mathrm{M}$ and topologies, using cut-based or likelihood method

The key words of searches are again "acoplanar events" and "missing p_T"

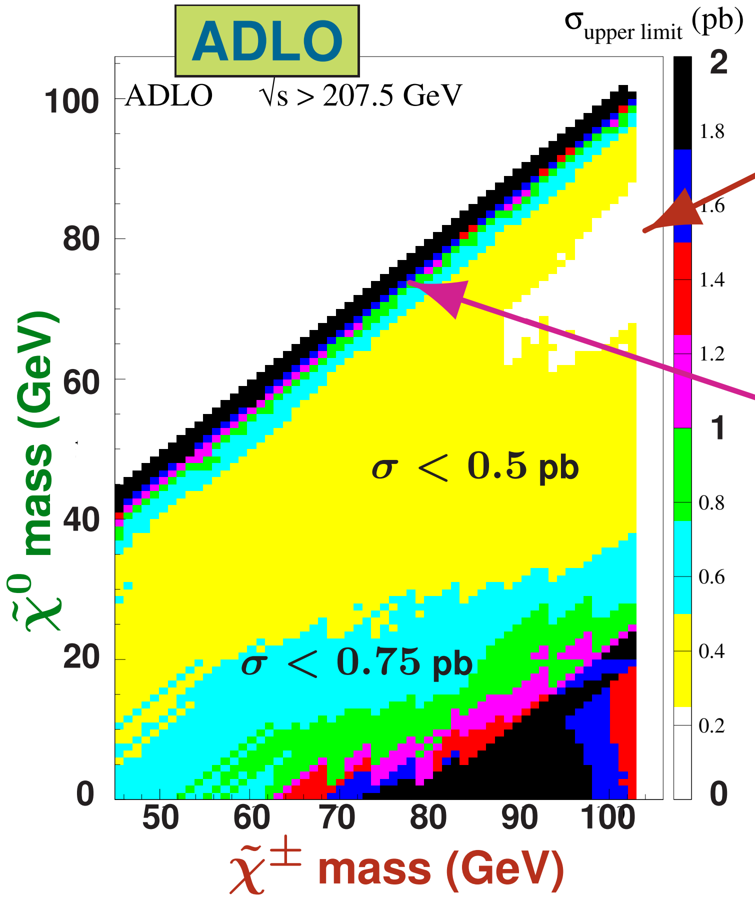
Chargino Candidates and Expected Background

- Results at $\sqrt{s} > 207.5$ GeV from ADLO are combined to obtain good sensitivity at kinematic limit. $\Rightarrow \sim 35\ \mathrm{pb}^{-1}$



$\Rightarrow$ No excess was found.

Chargino Cross Section Limit



limit is set up to the kinematic limit, assuming

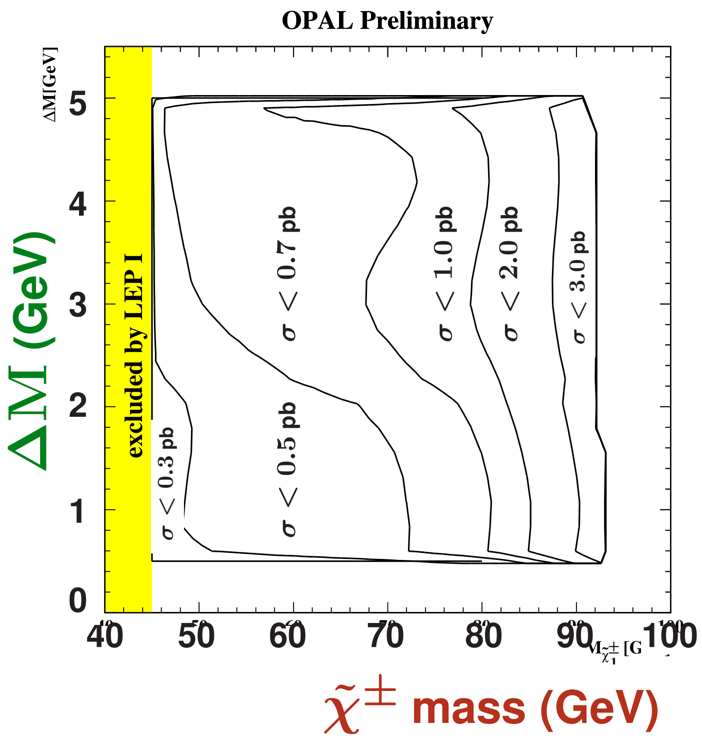
$BR(\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 W^{(*\pm)}) = 100\%$

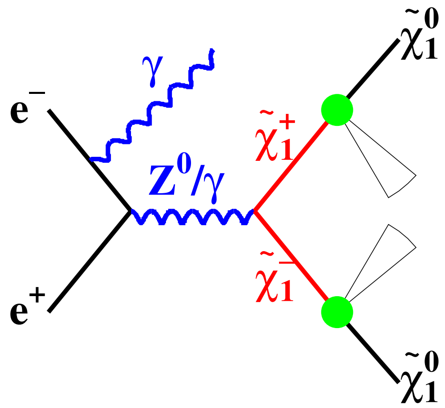
ΔM ($<$ 5 GeV)
No sensitivity

$\Downarrow$

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

"Special search" for small ΔM region



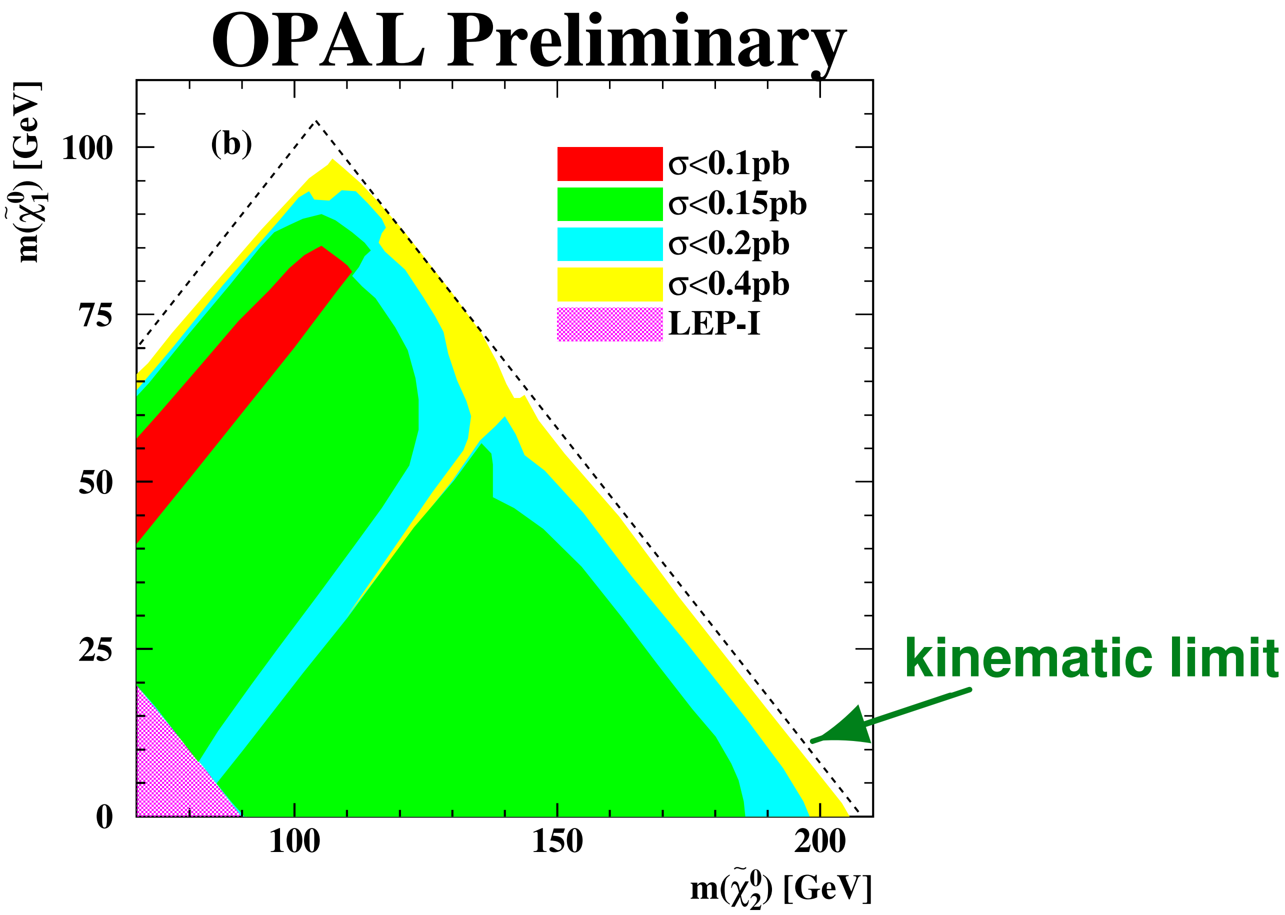


$\Rightarrow$ Events accompanied by ISR photons

$\Rightarrow$ Life time and BR are depended on ΔM decay in detector

Neutralino Crosss Section Limit

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



Cross section limit for $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ and $\tilde{\ell}$

$\Downarrow$

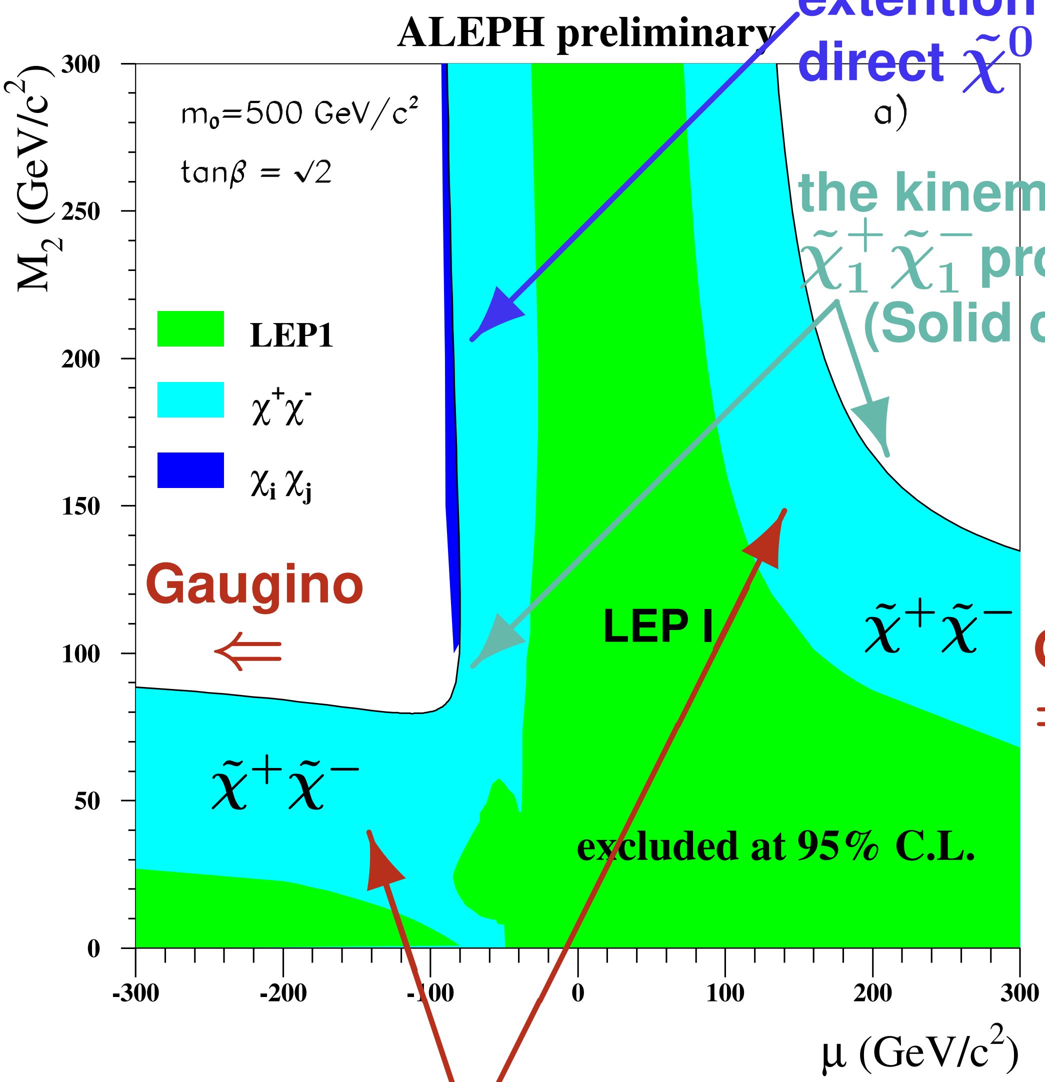
CMSSM interpretation

MSSM Parameter Scan (μ, M_2) with Large m_0

Higgsino

$\Uparrow$

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



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

Gaugino $\Leftarrow$

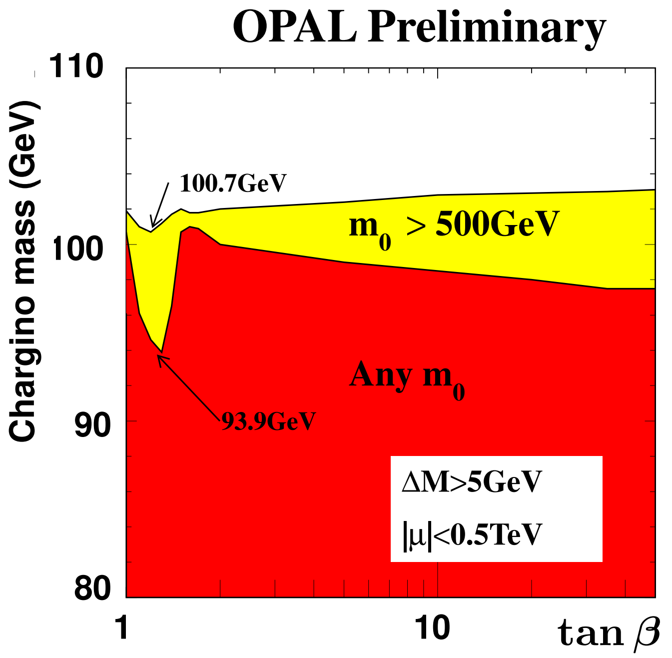
Gaugino $\Rightarrow$

excluded by the direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ search

$\tilde{\chi}_3^0\tilde{\chi}_1^0$ and $\tilde{\chi}_4^0\tilde{\chi}_2^0$ are also taken into account

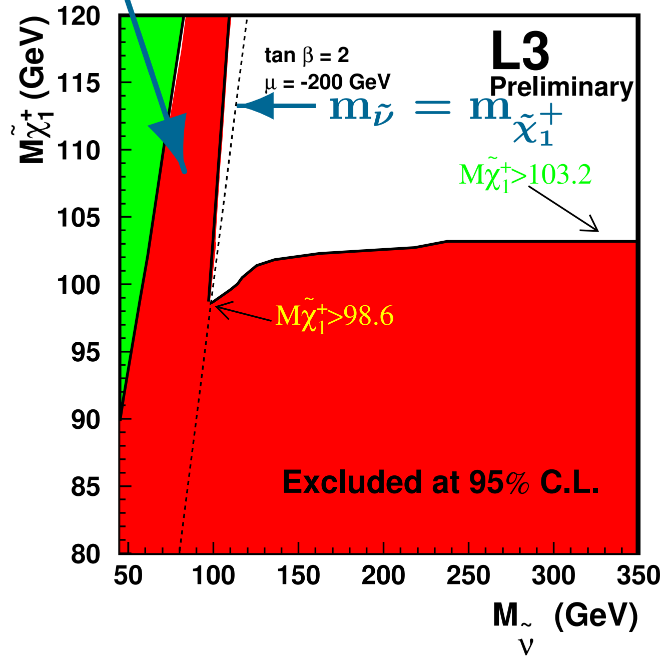
Almost the whole region has been excluded at 95%CL.

Chargino Mass Limits



Slepton results exclude

$m_{\tilde\nu} < m_{\tilde\chi_1^+};\ \tilde\chi_1^\pm \to \ell^\pm \tilde\nu$



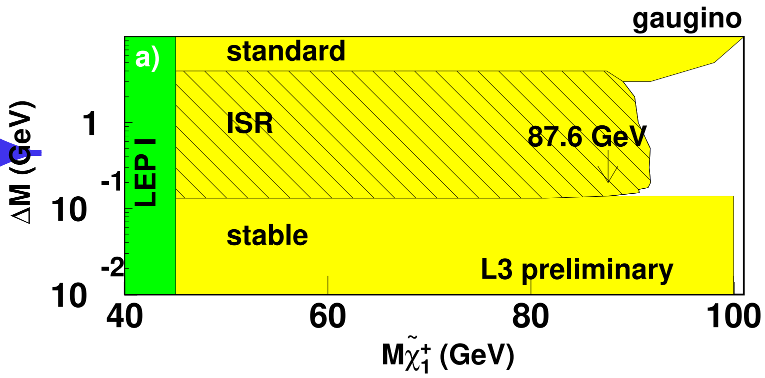
Small ΔM regions

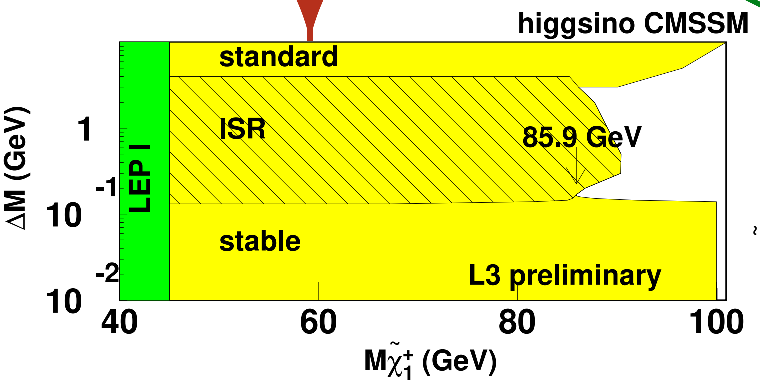
$\boxed{\Delta M < 5\ \text{GeV}}$

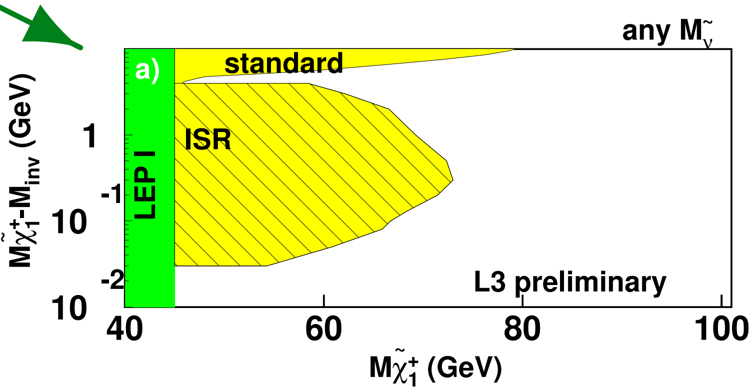
Gaugino-like + heavy $\tilde\nu$

Gaugino-like + light $\tilde\nu$

Higgsino-like







Neutralino Mass Limits

Chargino, neuralino and slepton results are combined.

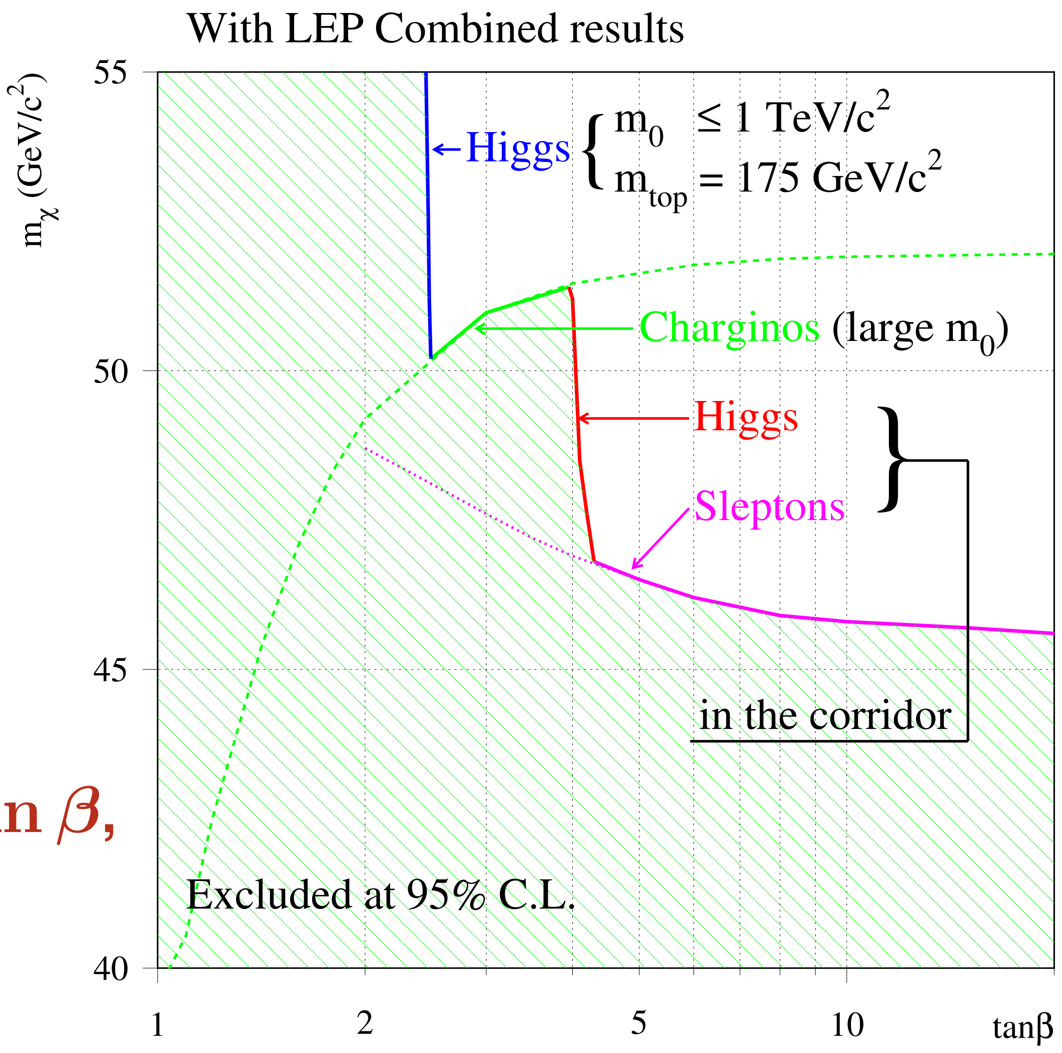
Recent results from Higgs searches;
exclusion of $2.4 \geq \tan\beta \geq 0.5$
are translated into CMSSM.

$\tilde{\ell}$: important role at small m_0 / at large $\tan\beta$:
$\Rightarrow$ decay mode and production cross section of $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$

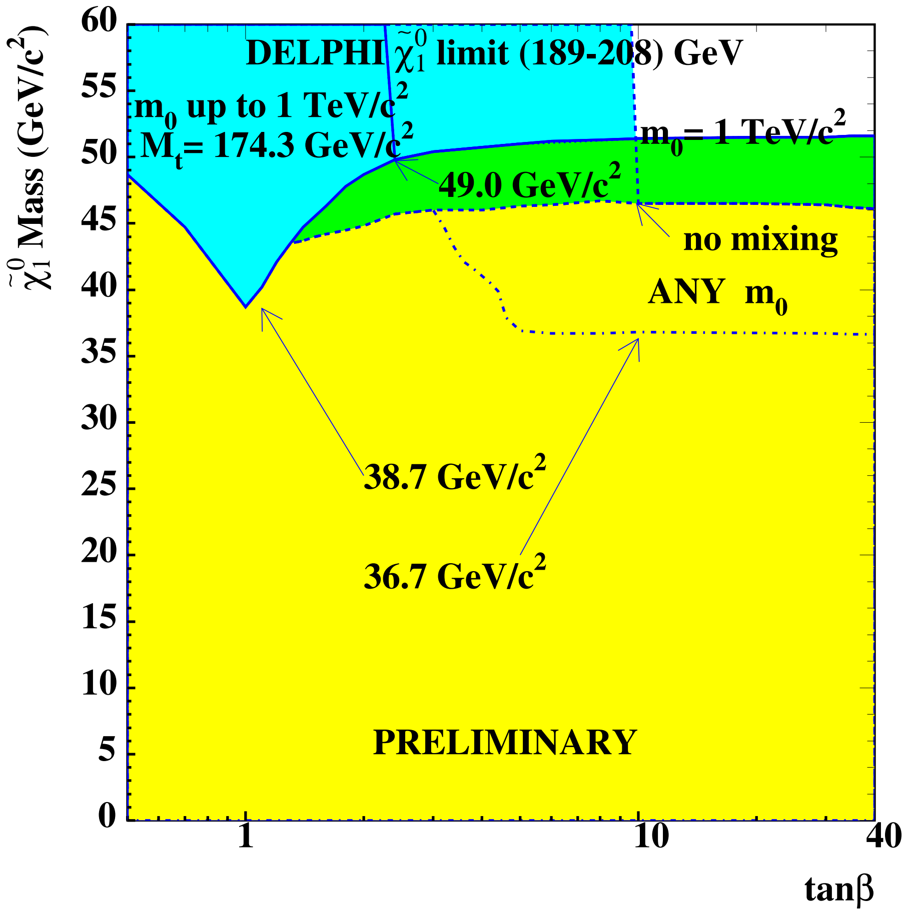
LSP mass limit is obtained at high $\tan\beta$,

$$m_{\tilde{\chi}^0} \gtrsim 45\mathrm{GeV}$$

(no mixing)



Impact of $\tilde{\tau}$ Mixing



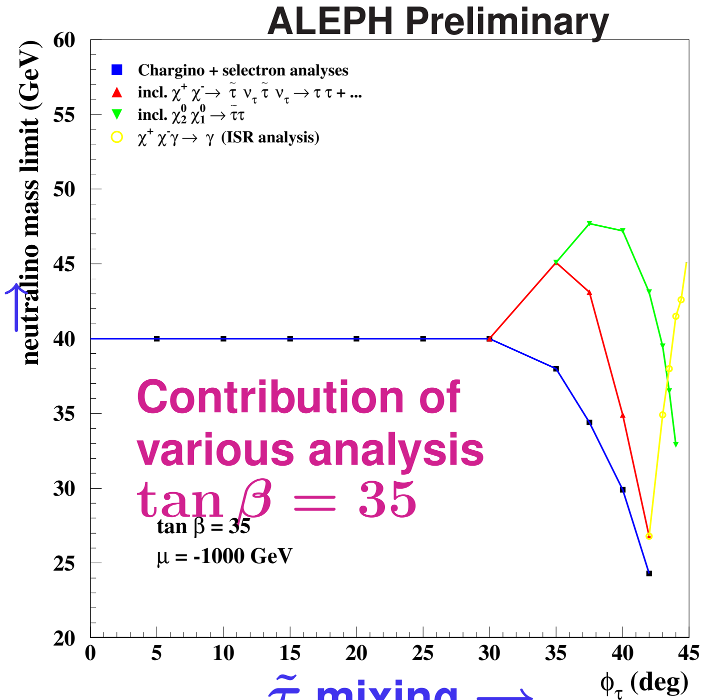
LSP Mass limit

$\Rightarrow$ 49 GeV (Large m_0)

$\tilde{\tau}$ mixing at high $\tan\beta$ region

$\Rightarrow$ 36.7 GeV (Any m_0)

$m_{\tilde{\chi}_1^0} \uparrow$



Contribution of
various analysis
$\tan\beta = 35$

$\tilde{\tau}$ mixing $\longrightarrow$

Summary

Searches Results

Analyses with all LEP2 data show

no evidence of SUSY particles.

Preliminary cross section limits on production processes have been derived.

MSSM Interpretation

Charginos

excluded up to nearly the kinematic limit

$$\mathrm{M}_{\tilde{\chi}^{\pm}} \gtrsim 94\mathrm{GeV}\ \text{(Any } m_0\text{)}$$

$$(\Delta\mathrm{M}_{+} > 10\mathrm{GeV})$$

LSP Mass

$$\mathrm{M}_{\tilde{\chi}^{0}} \gtrsim 37\mathrm{GeV}\ \text{(Any } m_0\text{)}$$

including results from Higgs searches and $\tilde{\tau}$-mixing

Dedicated analysis of final states with staus improve this limit.