LEP constraints on Susy Dark Matter

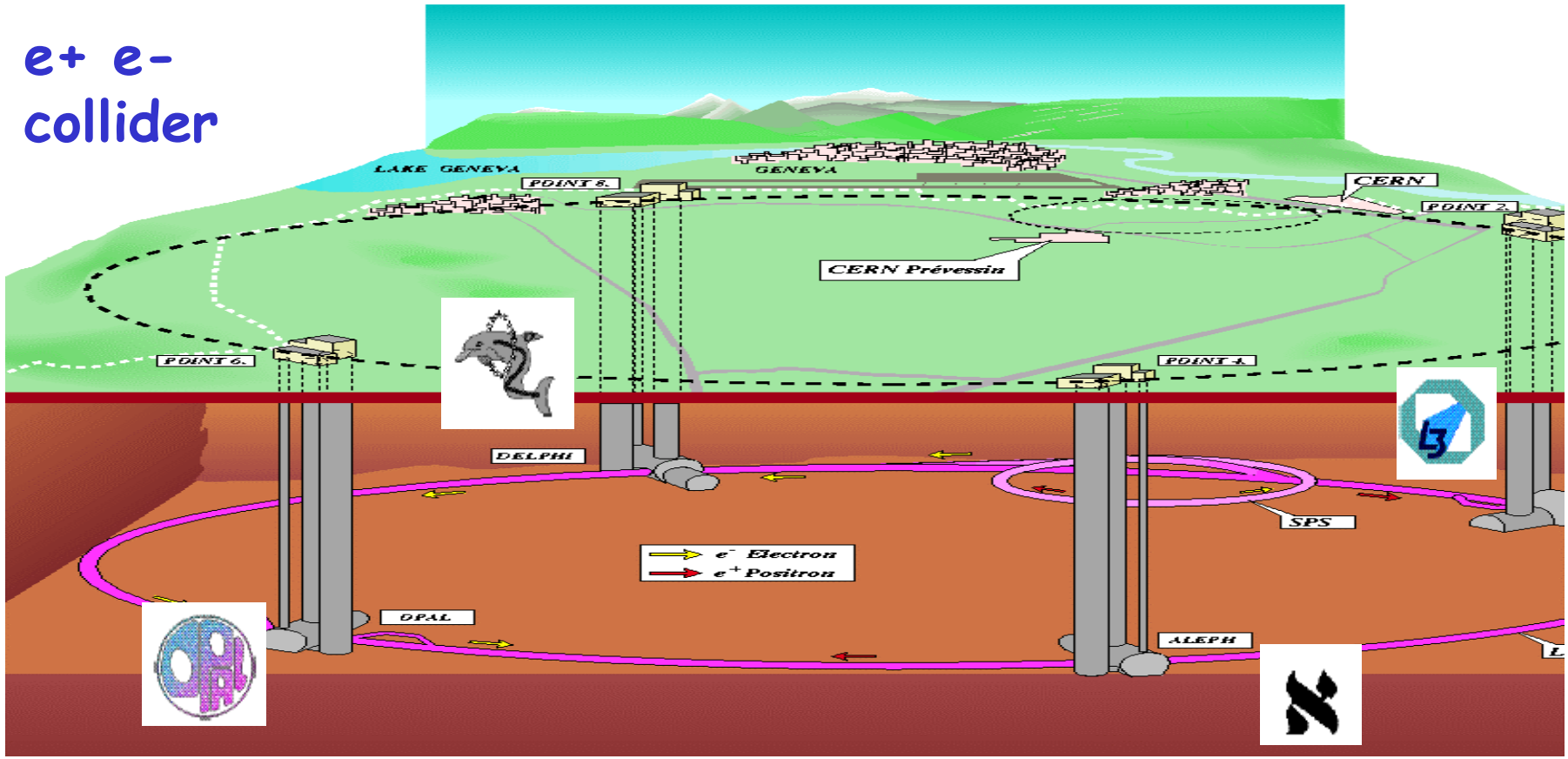
Outline

- Introduction
- Interpretation in the Cmssm Framework
  - Large m_0
  - Low m_0
  - Including Higgs search constraints
  - Stau mixing effects
- Robustness of the limits in less constrained scenarios (unification of gaugino masses at GUT scale relaxed)
  - LEP constraints and relic density constraints
- Summary

LEP since 1989

E_{cm} (GeV)	91	130-136	161-172	183	189	192	196	200	202	204-208
Luminosity (pb^{-1}) (per exp.)	175	5	22	55	160	30	80	80	40	200
Year	1994	1995	1996	1997	1998	1999	1999	1999	1999	2000

e+ e- collider

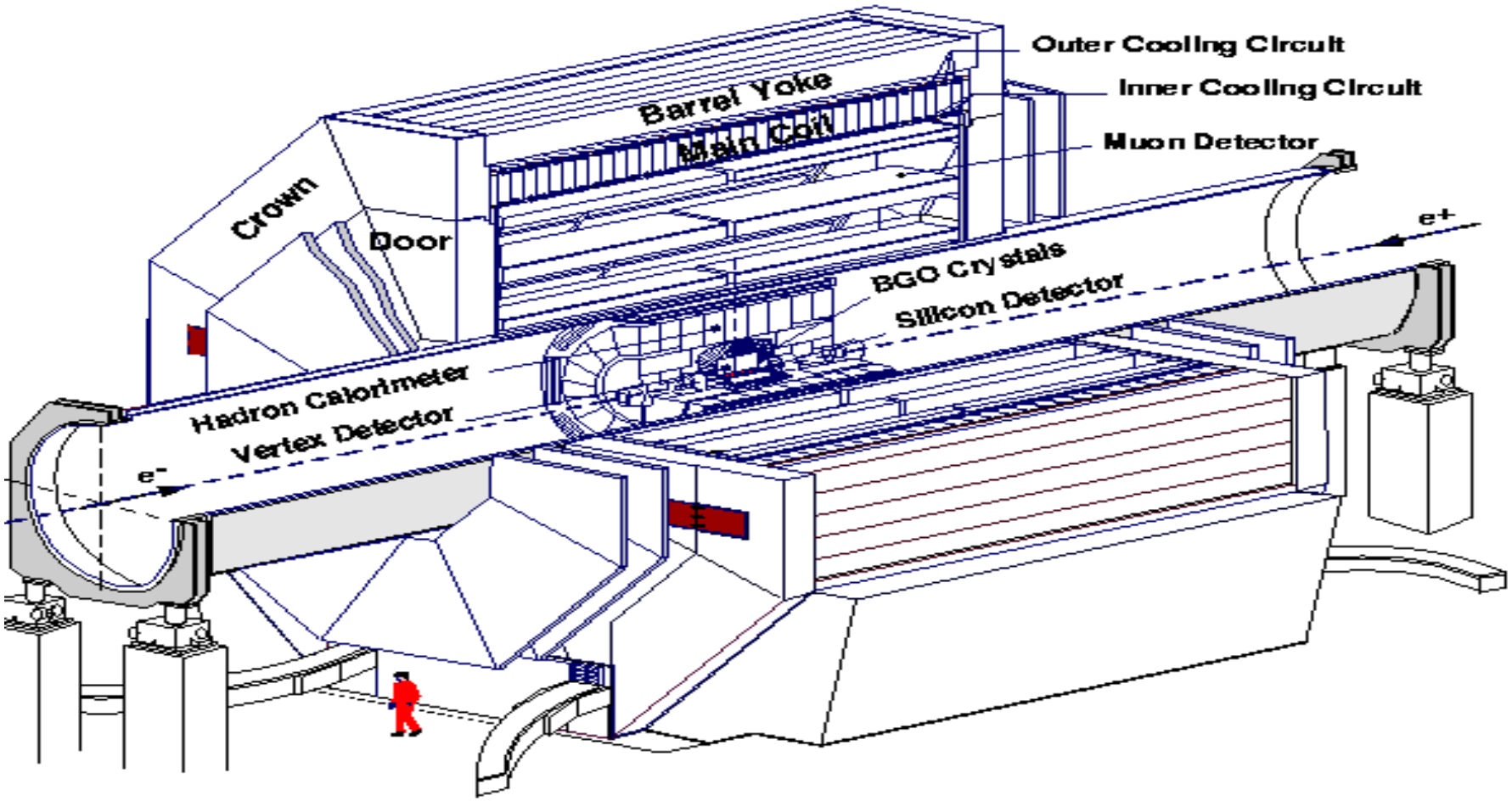


Susy search features at LEP

- Within the Rparity conservation assumption:
  - -The Lightest Susy Particle (LSP) is stable,
  - -each Sparticle are produced by pair,
  - -each Sparticle decays into the LSP
- If Sparticle Mass < Ecm/2 (kinematic limit)
  - -Chargino pairs $e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$
  - -Neutralino pairs $e^+e^- \to \tilde{\chi}_j^0 \tilde{\chi}_i^0$
  - -Slepton pairs $e^+e^- \to \tilde{l}^+ \tilde{l}^-, \quad \tilde{l} = \tilde{e}, \tilde{\mu}\ \tilde{\tau}$
  - -Stop and Sbottom quark pairs $e^+e^- \to \tilde{b}\ \tilde{b}, \tilde{t}\ \tilde{t}$
- The Lightest Neutralino $\tilde{\chi}_1^0$ is a favourite LSP candidate

  Neutral and interacting weakly ->

  the LSP is invisible and escapes detection

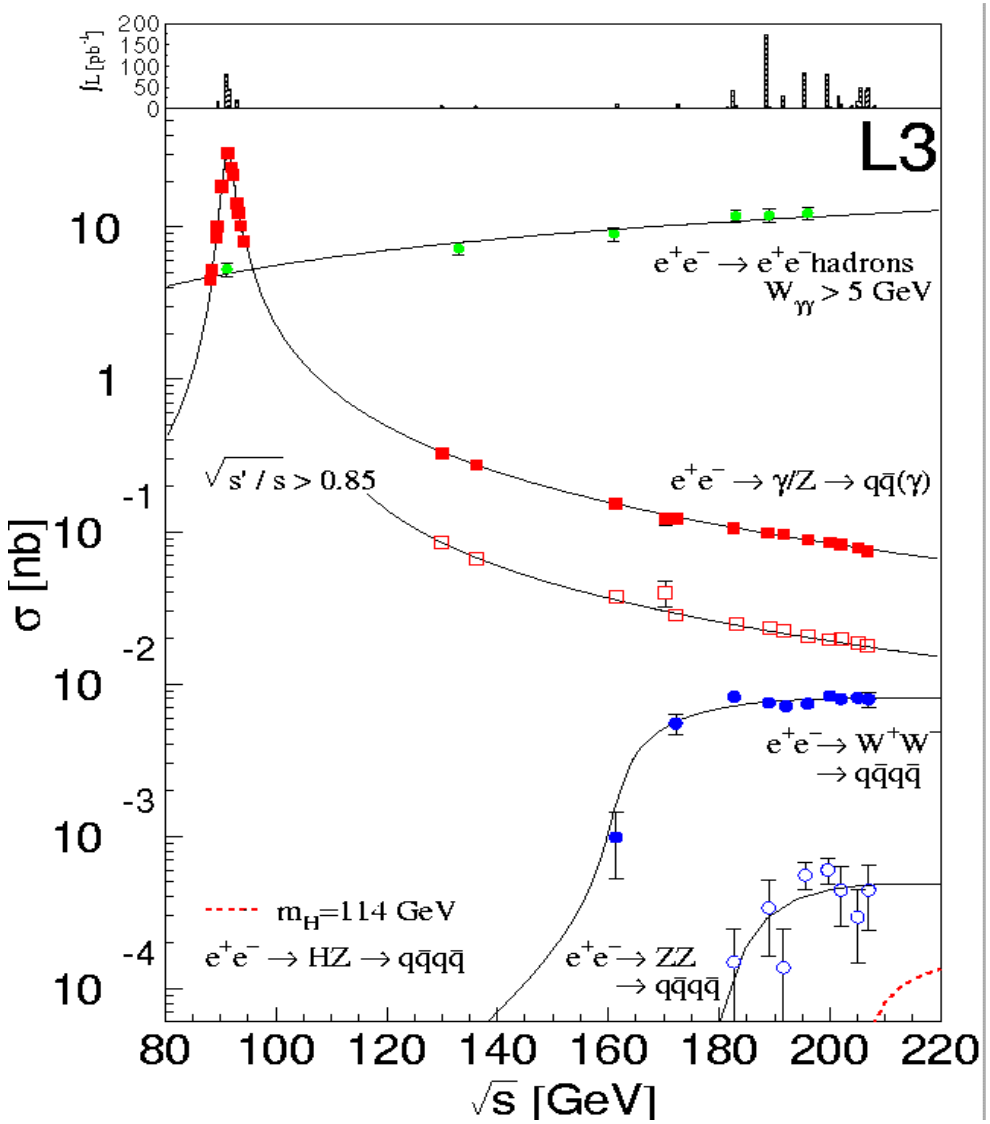


SUSY particle topologies are characterised by missing energy and missing mass carried out by the $\tilde{\chi}_1^0$

Key point : Hermetic Detector

Susy searches at LEP - Background

particle multiplicity and energy seen $\propto \Delta M \Rightarrow$ **Sensitivity**
background contributions vary with ΔM **depends on ΔM**



$$\Delta M = M\tilde{p} - M\tilde{\chi}_1^0$$

Low $\Delta M \leq$ 3-4 GeV

Medium $\Delta M \approx$ 20-30 GeV

Large $\Delta M >$ 50 GeV

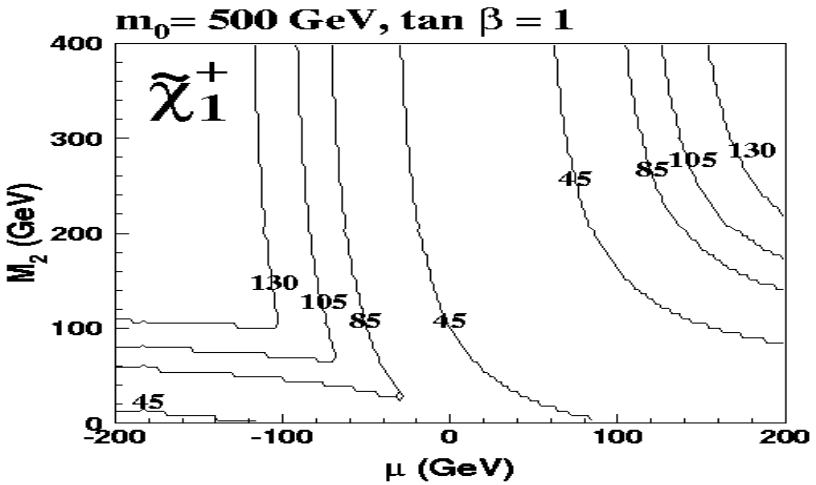
:

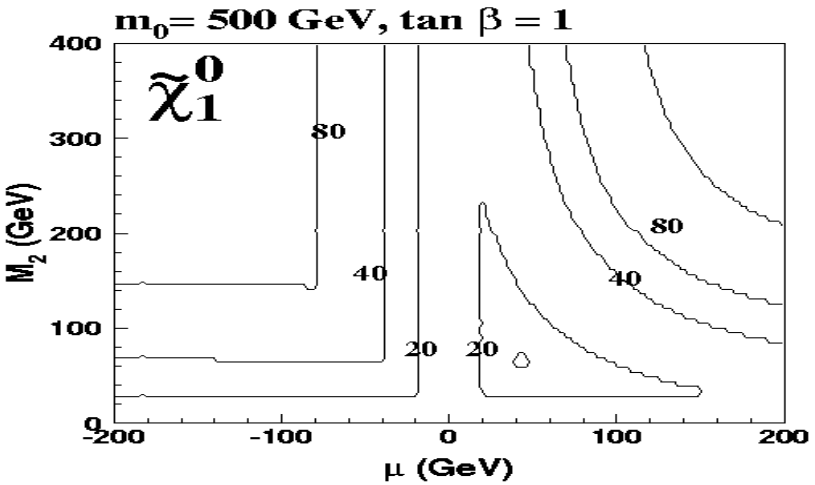
Neutralino LSP

$\tilde{\chi}_1^0$

LSP escapes detection -> limits will be indirect:

- Large m_0 values: sleptons non accessible
  - Chargino and heavy Neutralino
- Low m_0 values: sleptons accessible
  - Chargino, heavy Neutralinos and sleptons



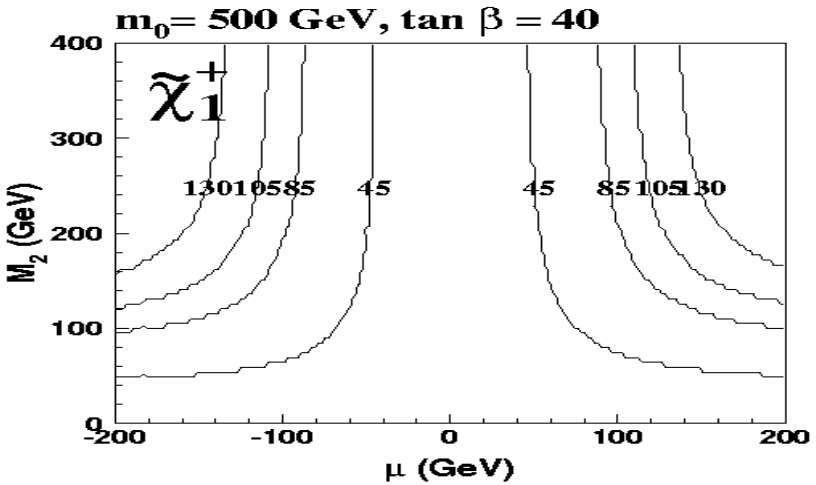


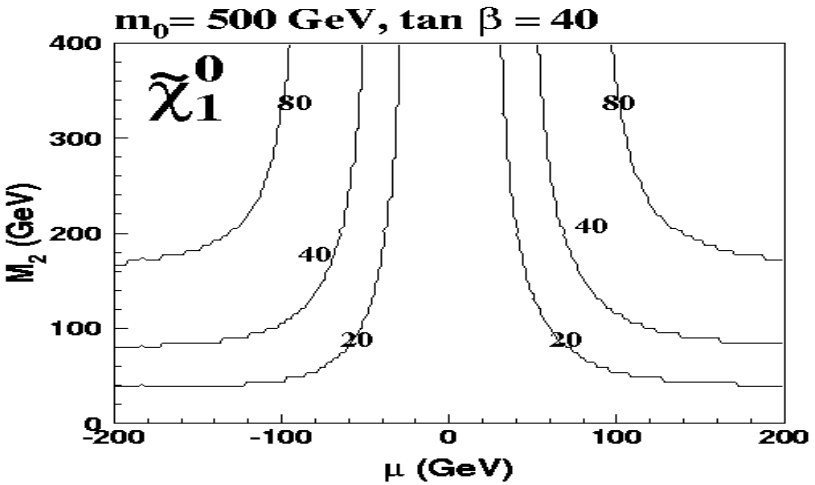
Chargino mass depends on

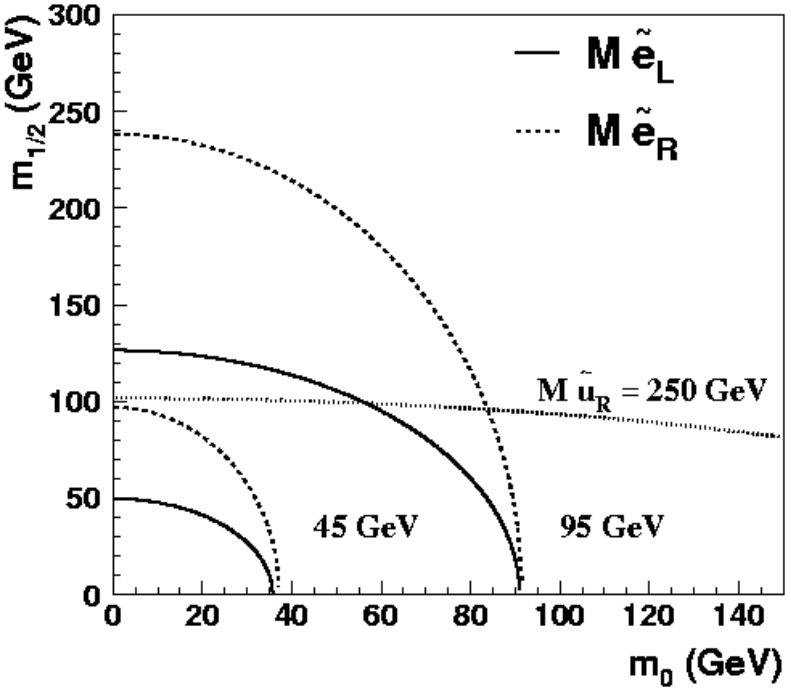
μ, M_2 and tan(β) parameters

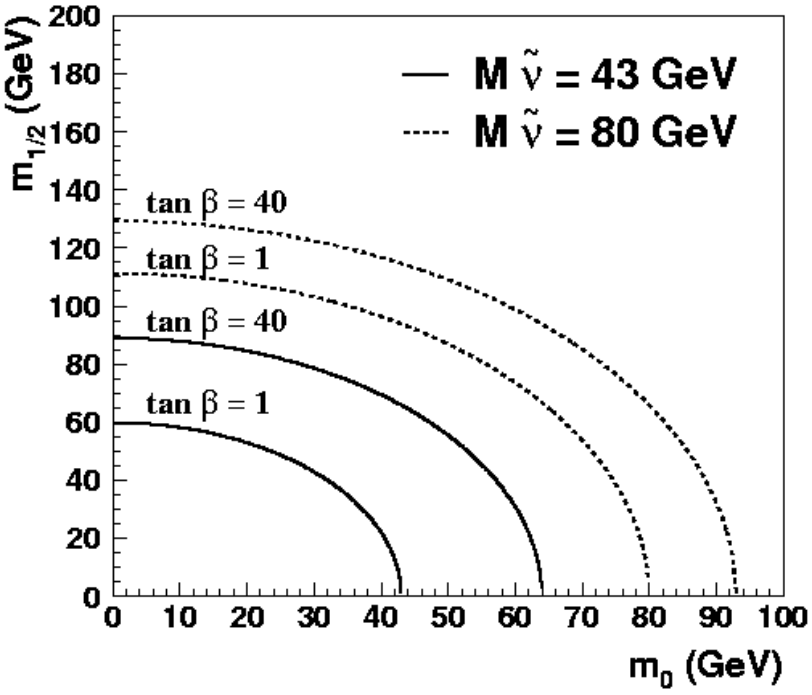
LSP mass depends on

μ, M_1 ($M_1 \approx 0.5 M_2$) and tan(β) parameters









M2≈0.8m1/2

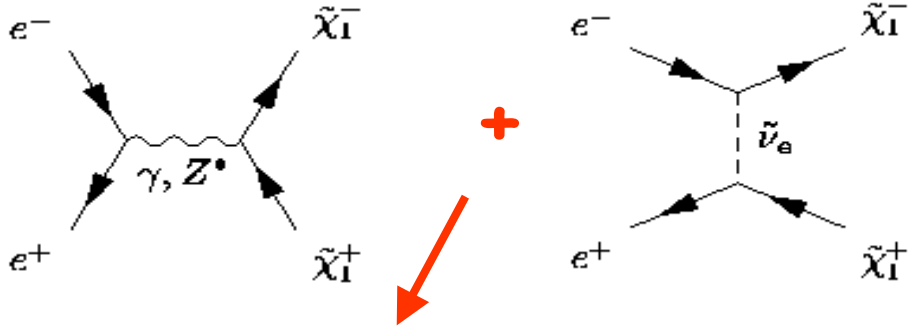
$m^2_{\tilde{l}_R} = m_0^2 + 0.15 m_{1/2}^2 - \sin^2\theta_W \, m_Z^2 \cos 2\beta$

$m^2_{\tilde{\nu}} = m_0^2 + 0.52 m_{1/2}^2 + 1/2 \, m_Z^2 \cos 2\beta$

A mass limit on slepton could be translated into a constraint in the mo-M2 plane

charginos/neutralinos pair productions

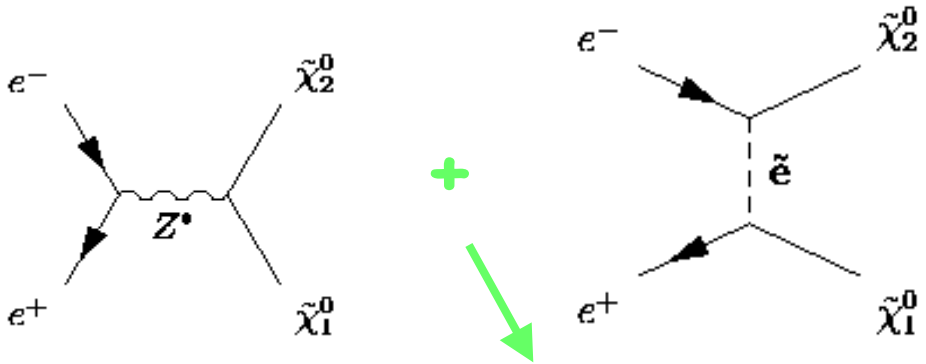
$\tilde{\chi}_1^+ \tilde{\chi}_1^-$



Higgsino Region : $\mu \ll M_2$ no contribution in the t-channel exchange

Destructive interference for light $\tilde{\nu}$

$\tilde{\chi}_{j\geq 1}^0 \tilde{\chi}_{k>1}^0$



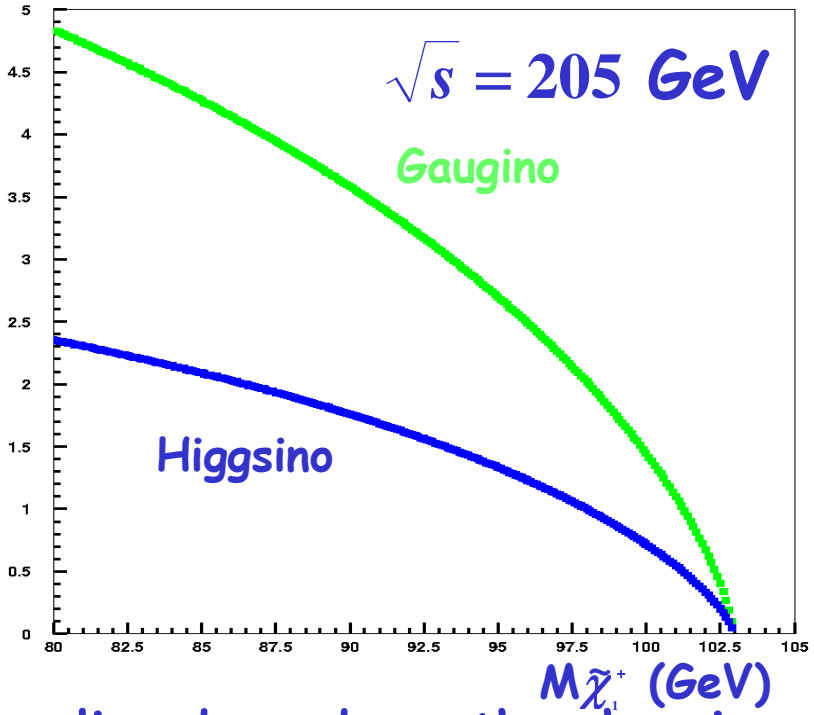
Gaugino region $\mu \gg M_2$, large m0 no t-channel exchange contribution

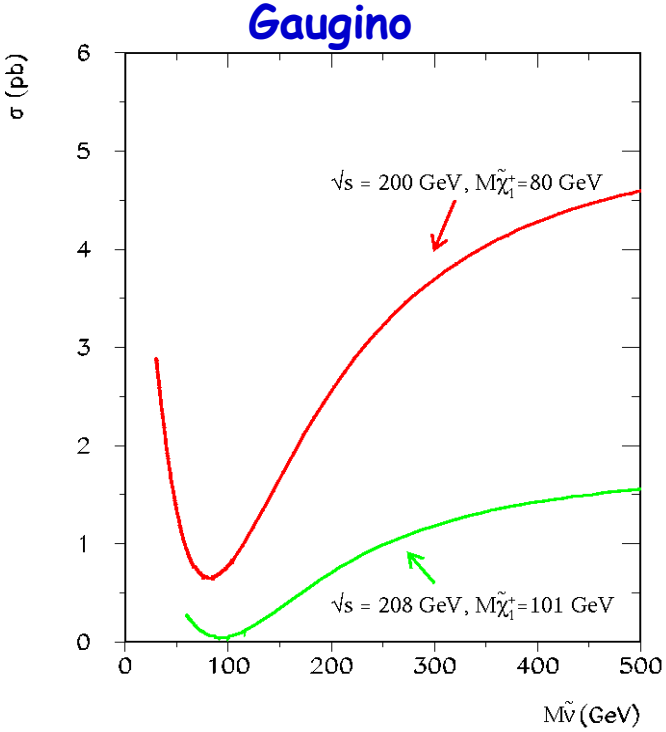
Gaugino region : $\mu \gg M_2$, low m_0 t-channel contribution

Constructive interference for light $\tilde{e}$

Chargino pair production

σ (pb)





Coupling depends on the chargino field content

best sensitivity obtained for large m_0 et Gaugino type

Mass (GeV)	80	101
Gaugino large m_0	975	330
Gaugino low m_0	172	10
Higgsino	490	150

event number per exp. @√s=205 GeV

Chargino pair signatures

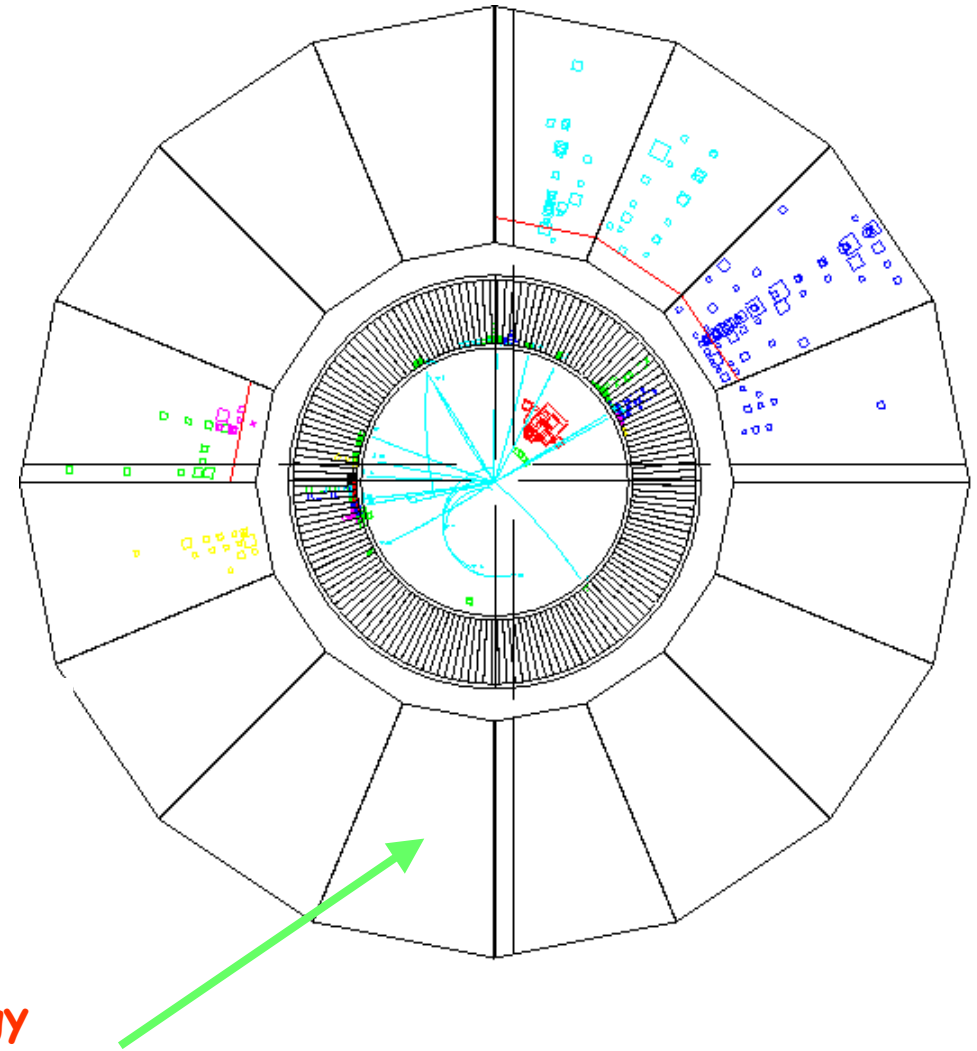
Chargino candidate

compatible with Wεν ou WW

$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$$

$$\tilde{\chi}_1^+ \rightarrow W^+ \tilde{\chi}_1^0$$

$$W \rightarrow l\nu, q'q$$



3 topologies:

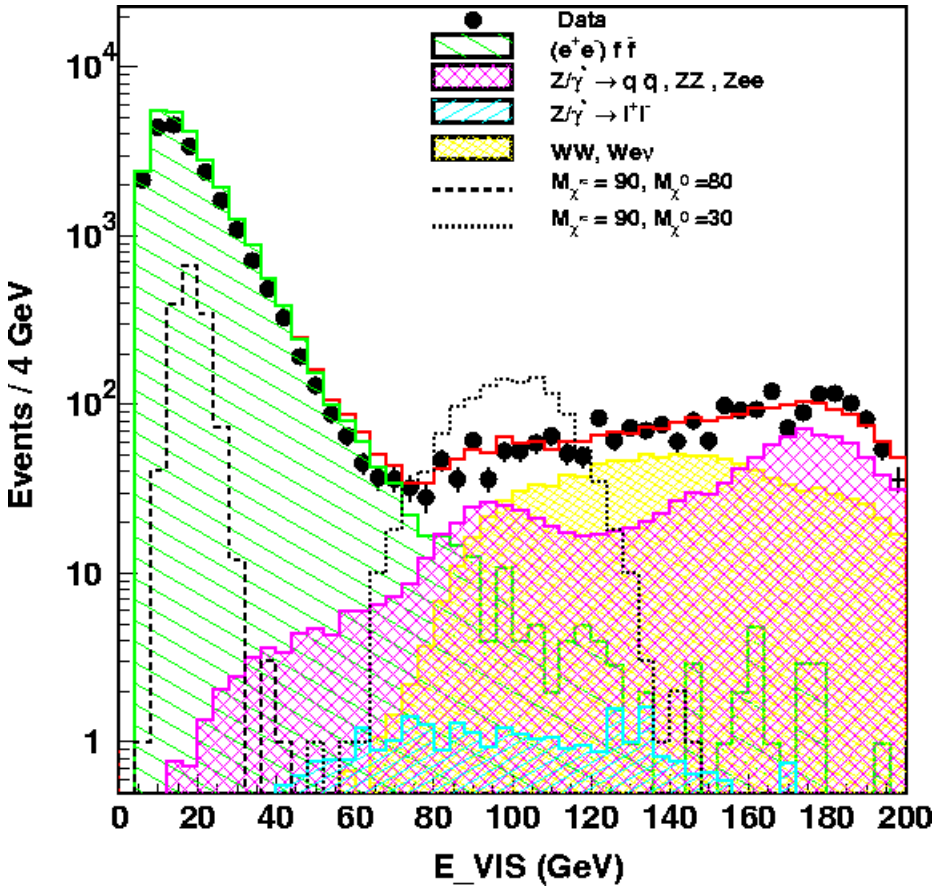
-Leptons plus missing energy

-Leptons hadrons plus missing energy

-Hadrons (jets) plus missing energy

Analysis method

$\tilde{\chi}_1^+$



ΔM (GeV)	5	30	80
Efficiency (%)	10	60	40
Background	20	16	11
Event number			

$\sqrt{s}$ = 205 GeV

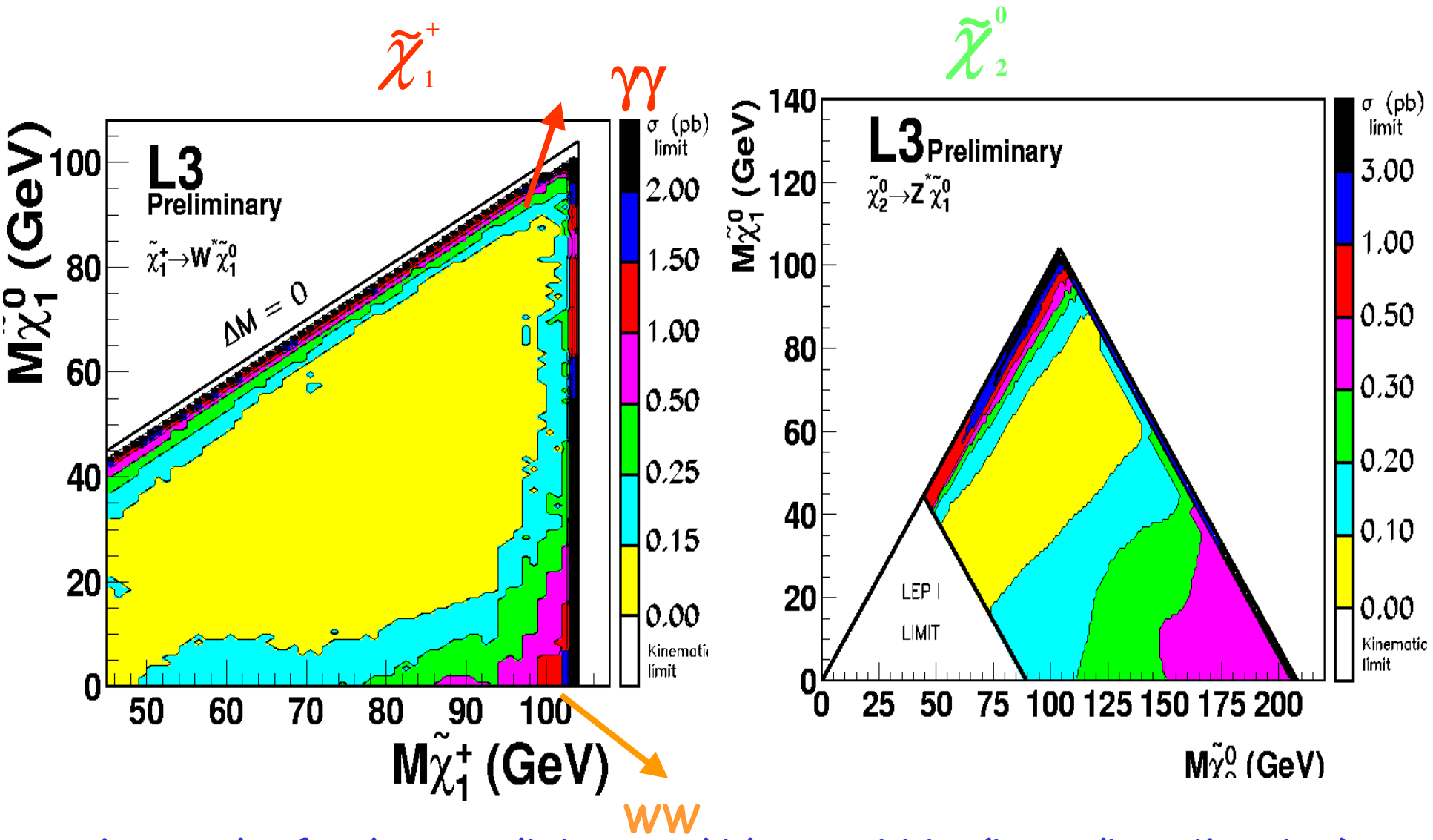
Visible energy: one typical discriminating variable preselection level

No Sensitivity for ΔM<3 GeV

No excess → Upper Limit on the cross section production

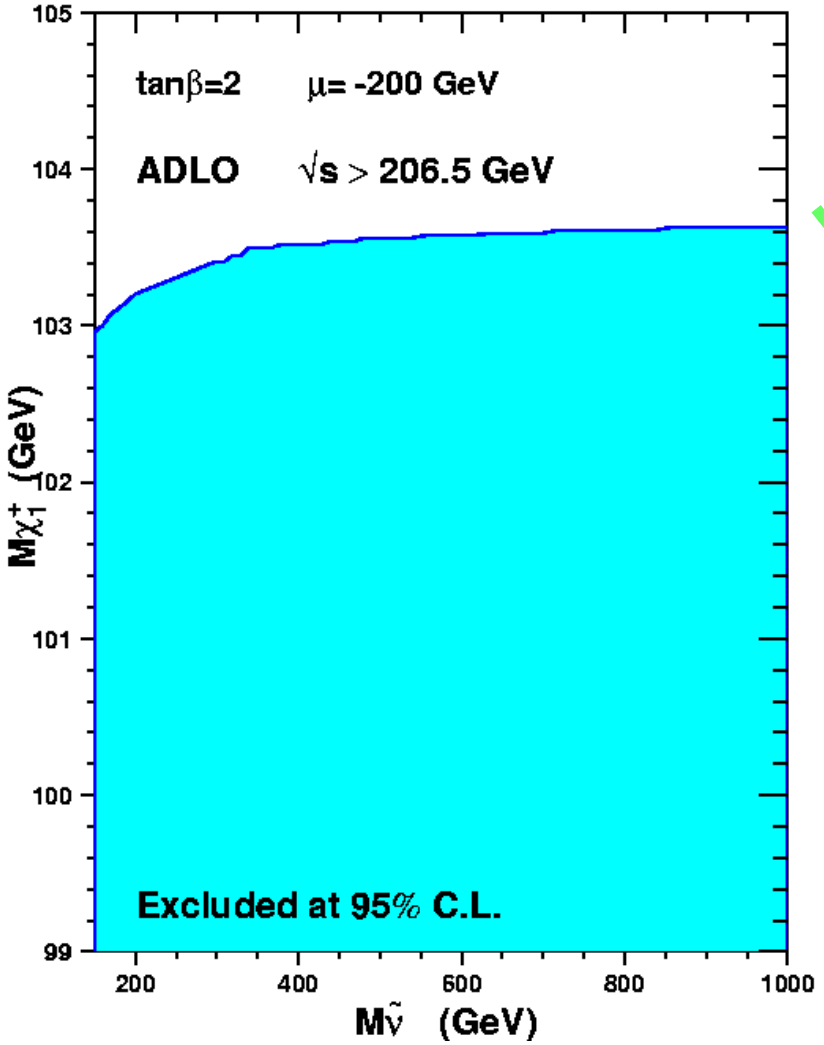
charginos

neutralinos



Lower value for the upper limit means higher sensitivity (i.e medium ΔM regions)

Best Mχ+ LEP Limit - most optimistic scenario $\tilde{\chi}_1^+$



Large m_0 (i.e large sneutrino mass)

Deep Gaugino-like ($|\mu|$>200 GeV)

« Good » ΔM

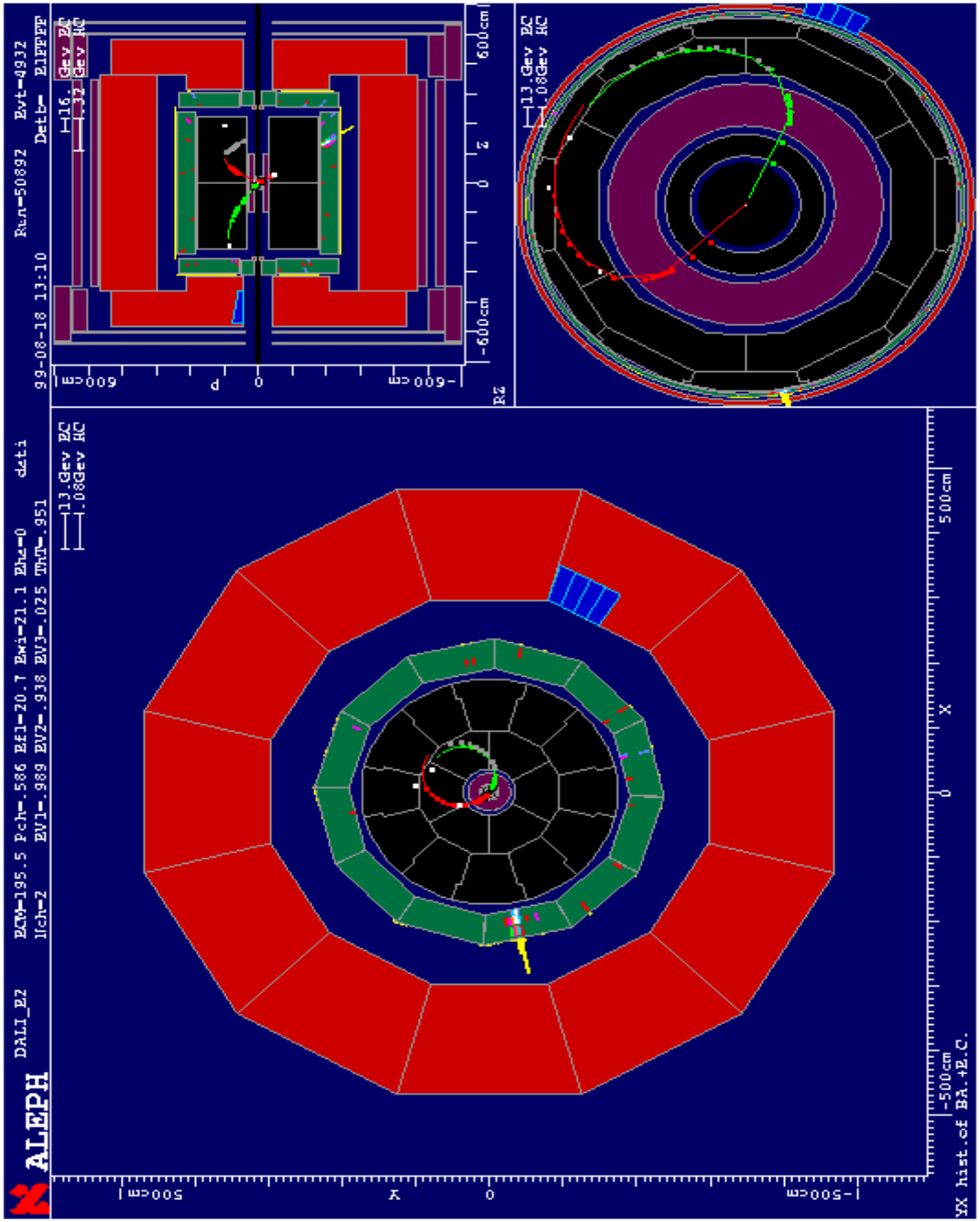
$M\chi^+ > 103.5$ GeV

⇓

(Assuming M1/M2 ≈ 0.5)

⇓

$M\chi^0 > 52$ GeV



$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \gamma$$

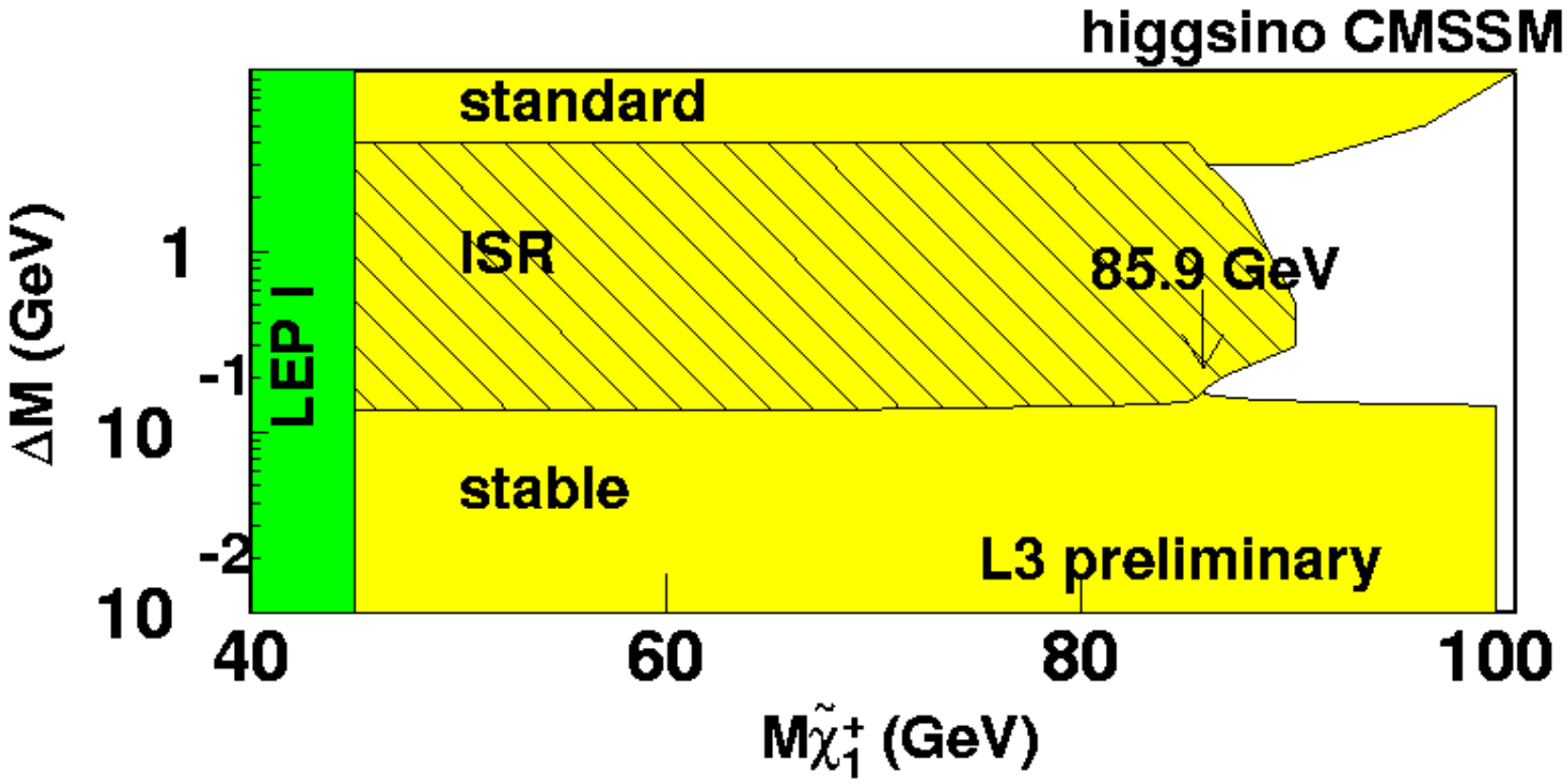
γ_{ISR} to recover sensitivity in the very low ΔM regions

Efficiency ≈ 1-2 %

with 10 back. evts/200 pb^{-1}

LEP Mχ+ Limit independent on ΔM

$\tilde{\chi}_1^+$



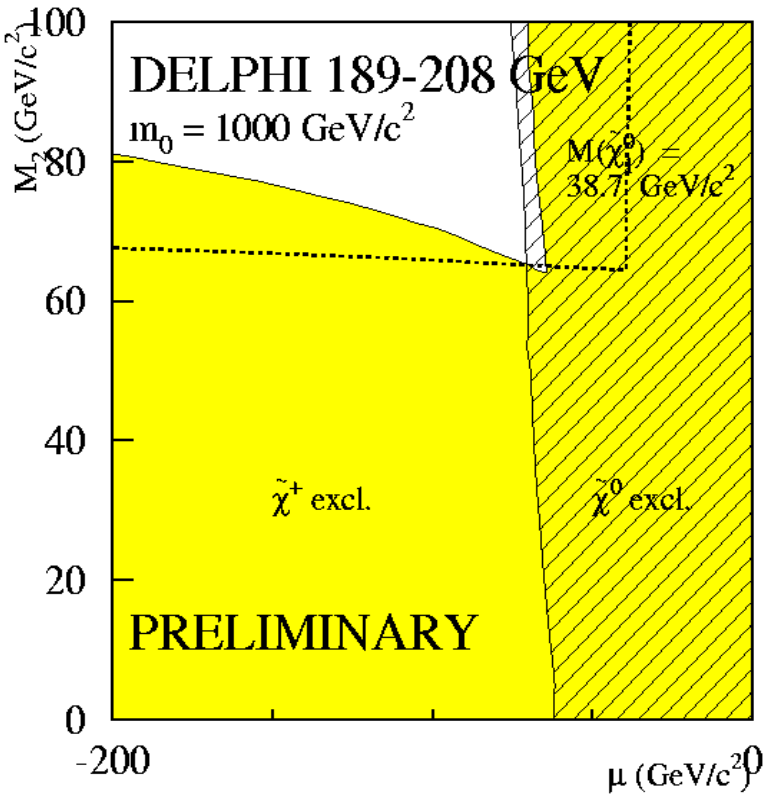
Higgsino Cmssm

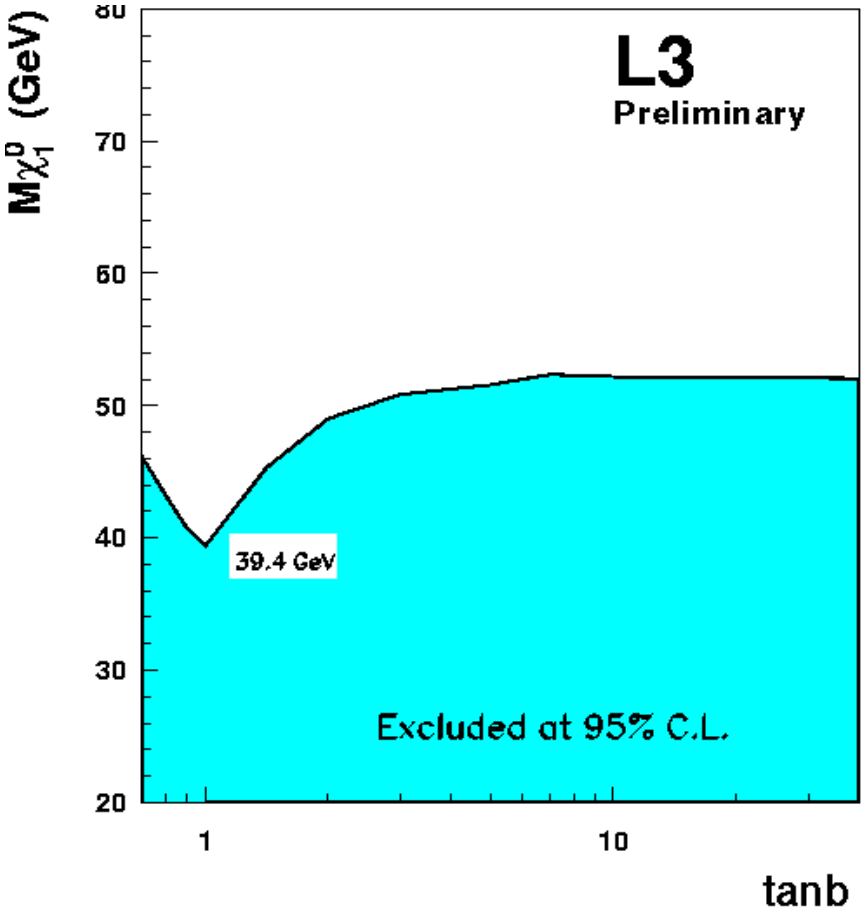
$M\chi^+ > 85.9$ GeV $\Rightarrow$ $M\chi^0 > 85.7$ GeV

Sensitivity improvement with ADLO data future combination

LSP mass limit from LEP- scan over M2,tanβ,μ $\tilde{\chi}_1^0$

Large m_0

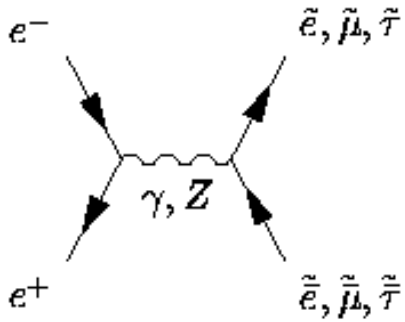




Exploit the complementarity of the chargino and neutralino searches

$M\tilde{\chi}_1^0 > 37-39.6$ GeV $\sqrt{s} \geq 200$ GeV

Sleptons pair production



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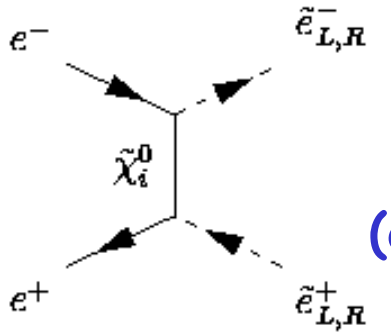
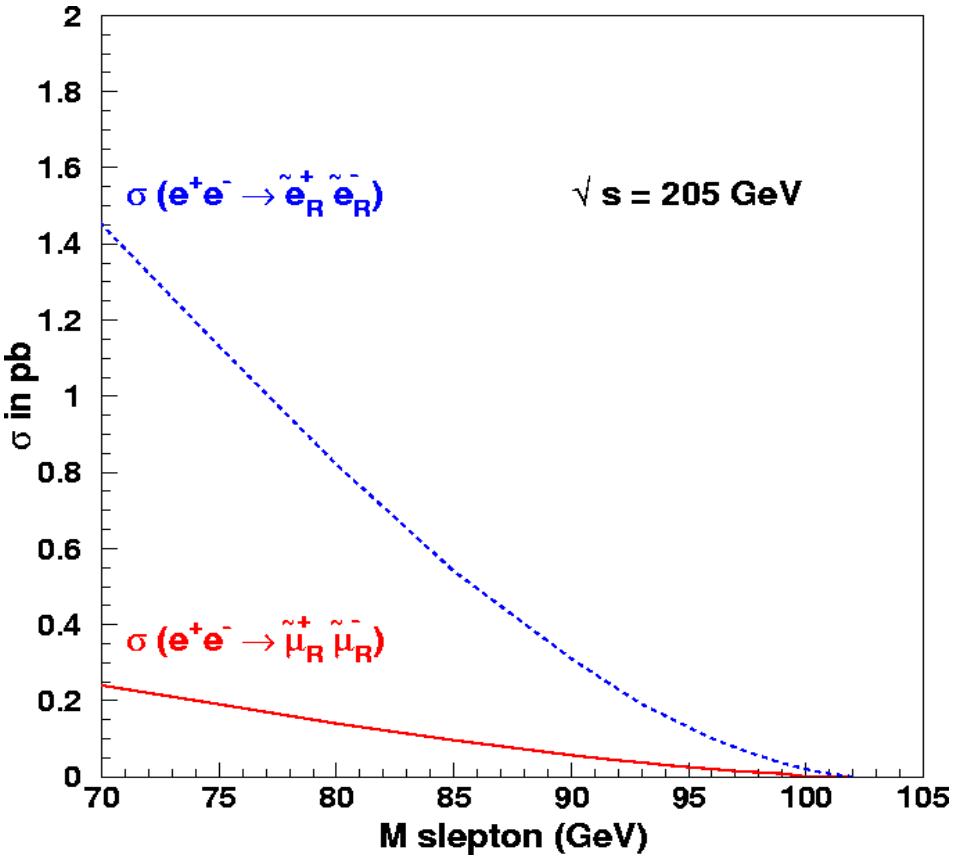


(only $\tilde{e}$)



Cross section production (σ)

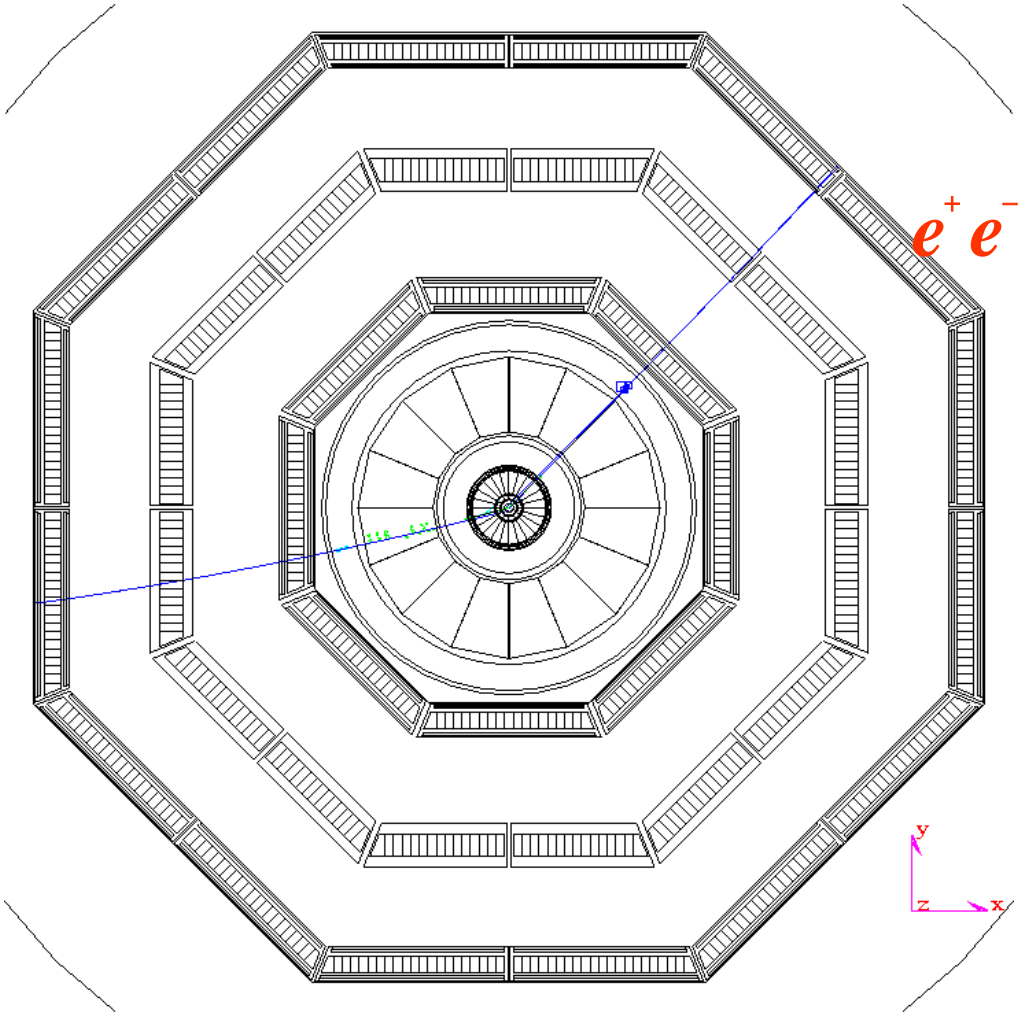
varies as β^3/s -> no sensitivity at the Kinematic Limit

Masse (GeV)	90	95
Selectron $\tilde{e}$	65	20
Smuon $\tilde{\mu}$	20	7

Event numbers per exp. @√s=205 GeV

Slepton pair signature

Run # 755104 Event # 1194 Total Energy : 69.31 GeV



Transverse Imbalance :	.6543		Longitudinal Imbalance :	.1887	
Thrust :	.9814	Major :	.1428	Minor :	.0013
Event DAQ Time :	*990708 84421*				

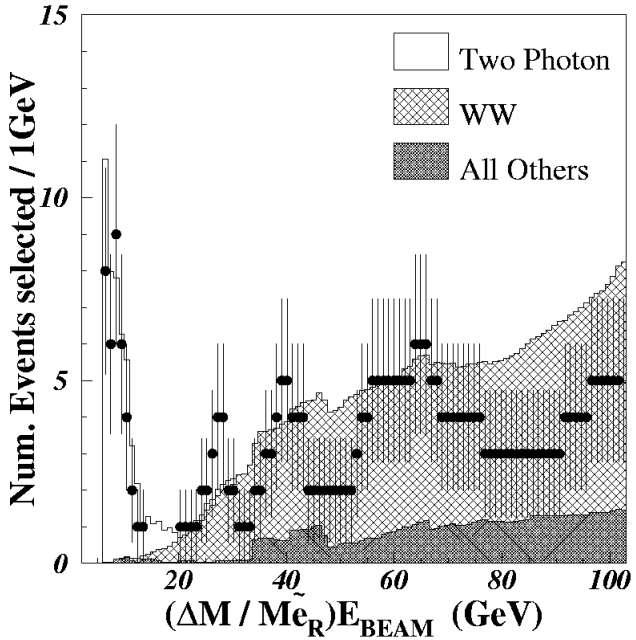
$$e^+e^- \rightarrow \tilde{l}^+\tilde{l}^- \rightarrow (\tilde{l}^+\tilde{\chi}_1^0)(\tilde{l}^-\tilde{\chi}_1^0)$$

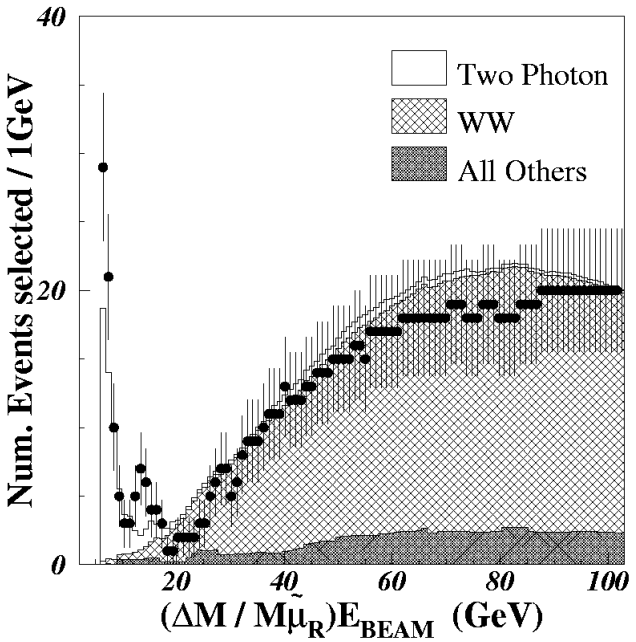
invisibles

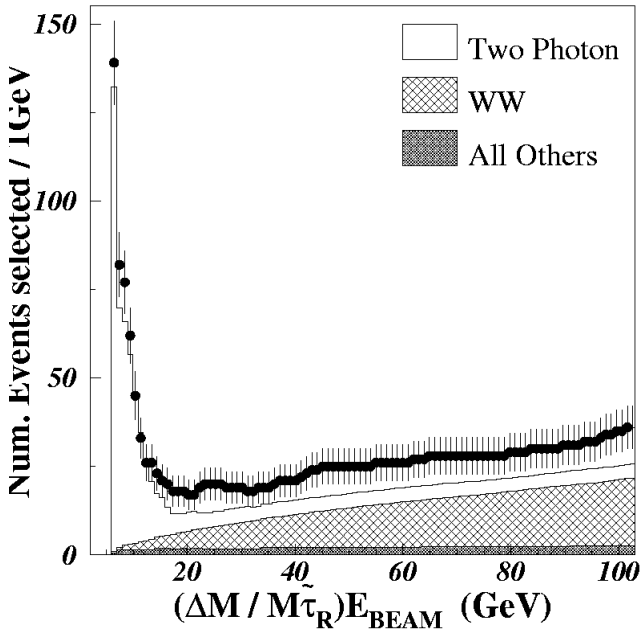
Acoplanar lepton pairs
with missing energy

Analysis Method

$\tilde{l}$





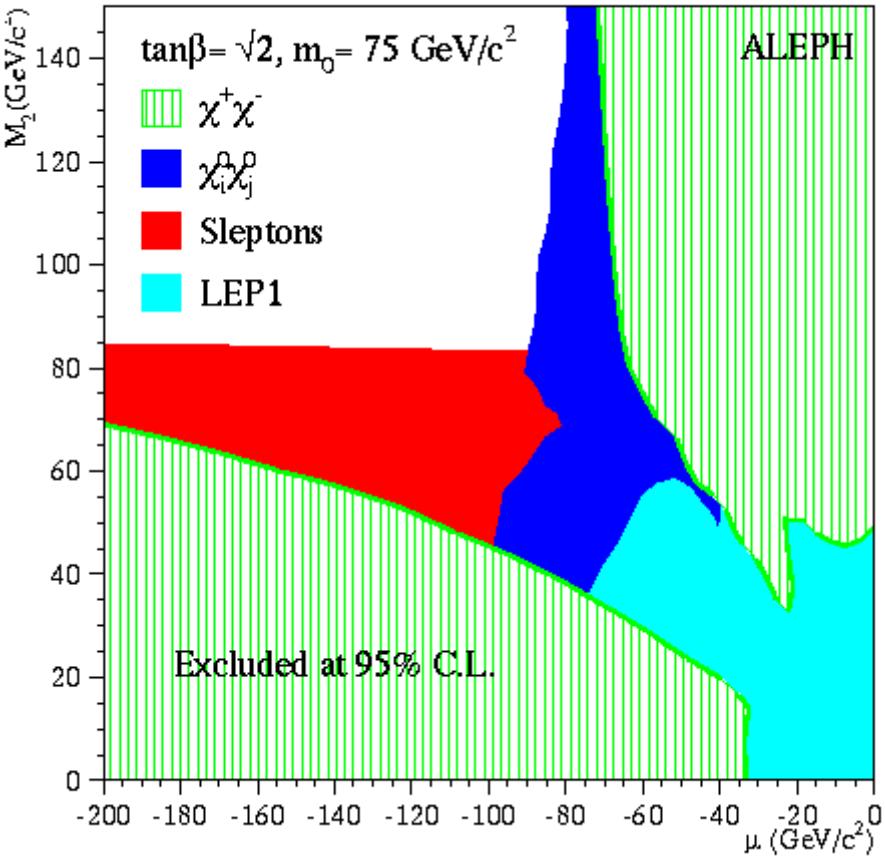


	# obs	# exp	Eff(%)
selectron	48	57.9	53
smuon	47	46.6	55
stau	80	82.1	39

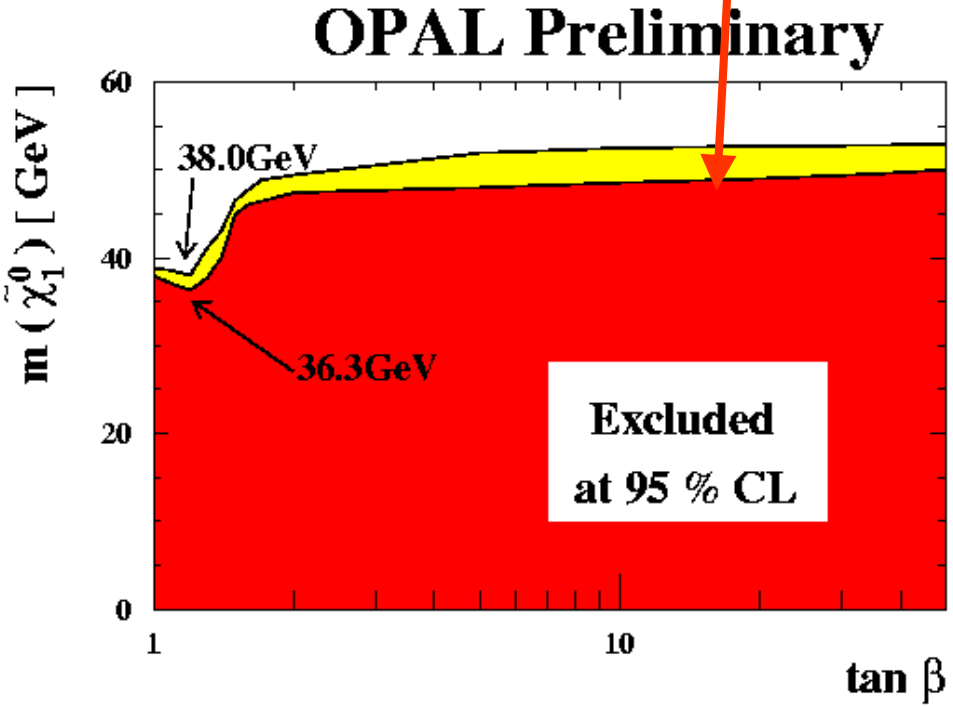
$(M\tilde{l}, M\tilde{\chi}_1^0) = (85, 22)$ GeV

ADLO, Y2K L=585 pb^{-1}

Combination of Slepton, chargino and heavy neutralino searches



For any m_o LSP mass limit given by the slectron mass limit when $|M\chi - M\nu| < 3$ GeV

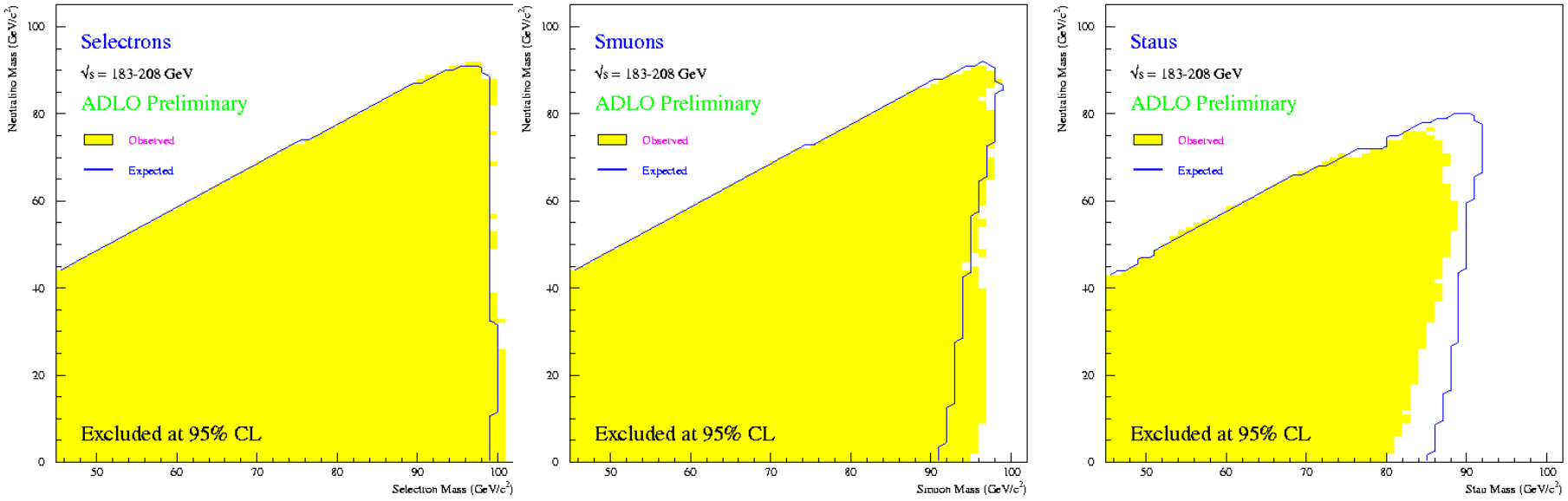


Slepton mass limits

Channel	Mass Limit $M\chi^0$=0 GeV	Mass Limit $M\chi^0$=40 GeV
selectron	100.5 GeV	99.4 GeV
smuon	95.4 GeV	96.4 GeV
stau	80.5 GeV	87.1 GeV

ADLO Combination

LEP SUSY WG



M_h^2 depends on

$M_Z^2 cos^2(2\beta)$ Large m_A

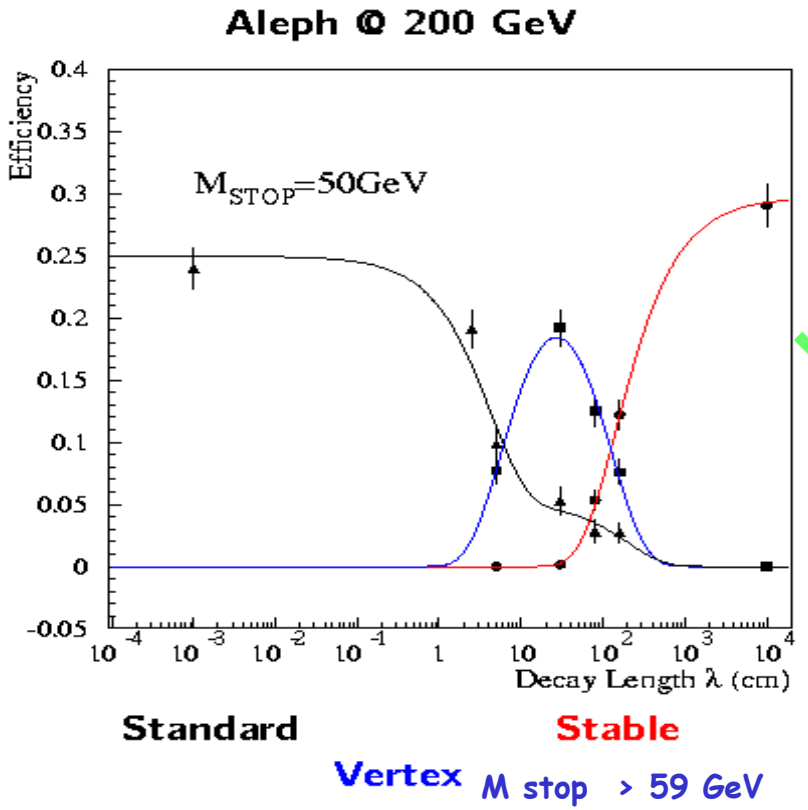
→ constraints on $\tan\beta$

$+ m_t^4/m_W^2 Log(m_{\tilde{t}}^2/m_t^2)$ no mixing

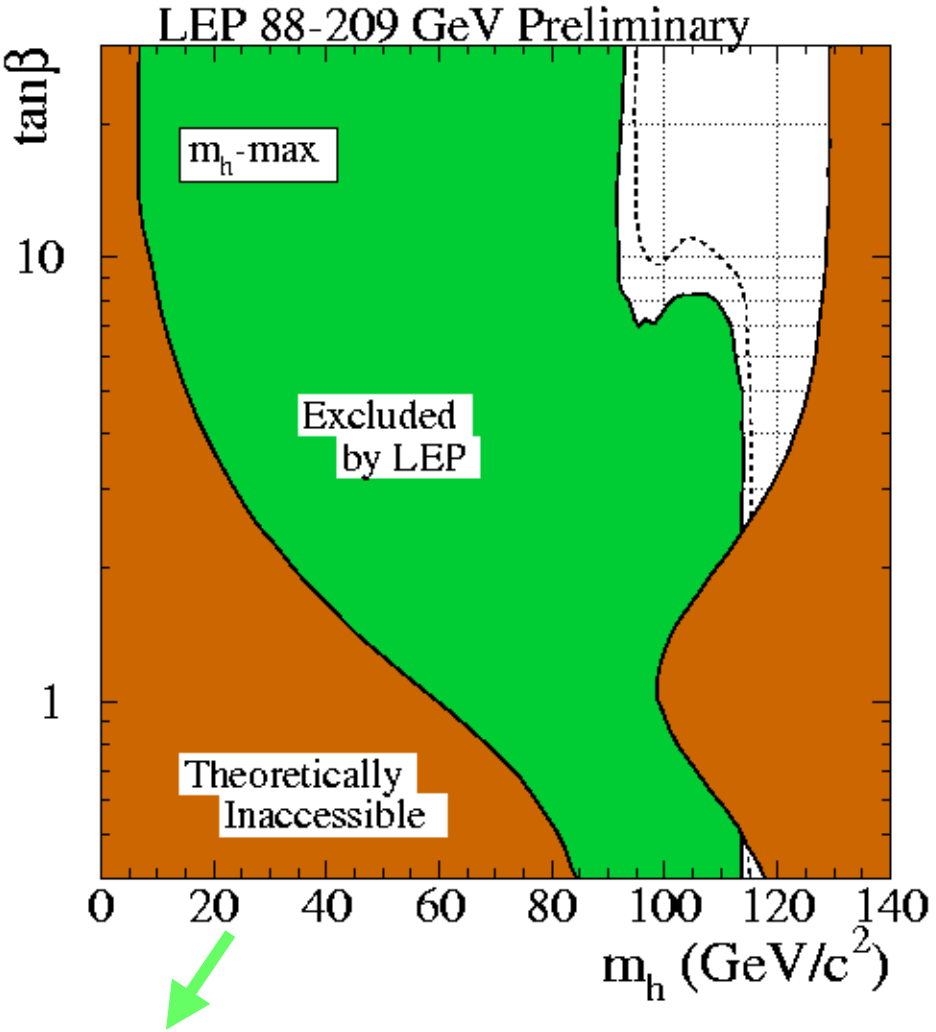
→ constraints on $\tan\beta$,$m_{\tilde{t}}$

$+\tilde{t}$ sector mixing

→ constraints on $\tan\beta$, $m_{\tilde{t}_1}$ or $m_{1/2}$



M stop > 59 GeV



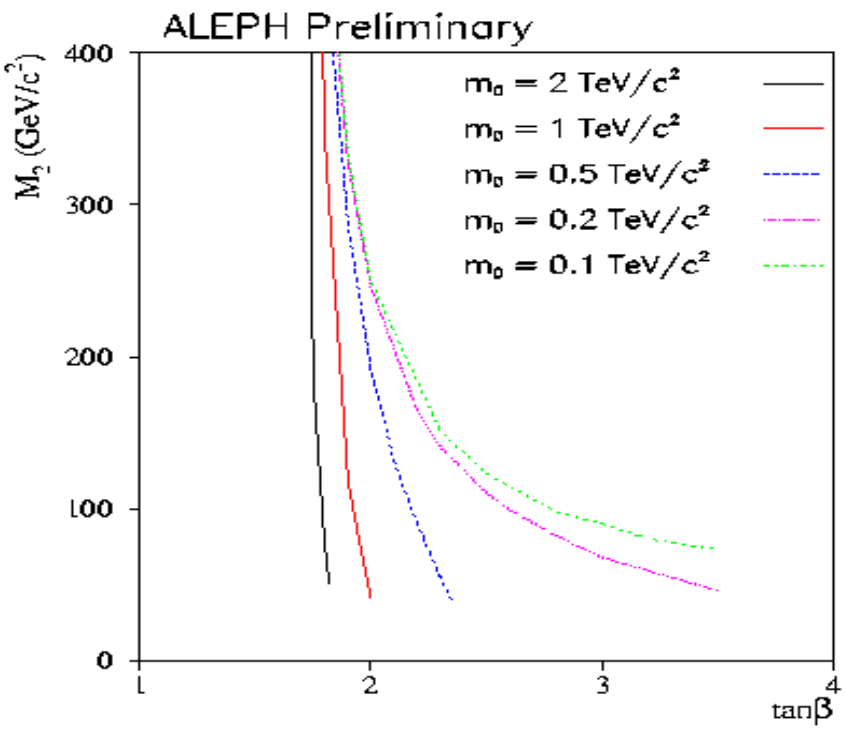
+ Stop mass absolute limit

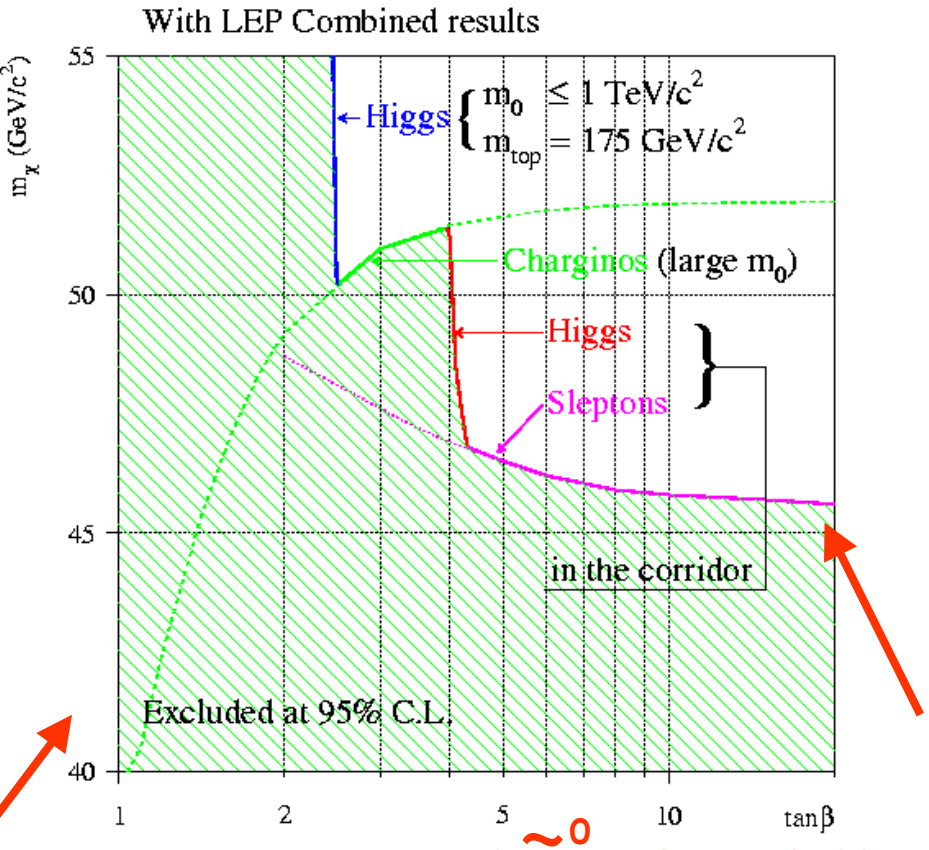
$h \to \tilde{t}\tilde{t}$ closed

+ including HZ and invisible channel

Higgs constraint is robust

Higgs and Stop constraints





Selectron LEP SUSY WG

LEP HIGGS WG

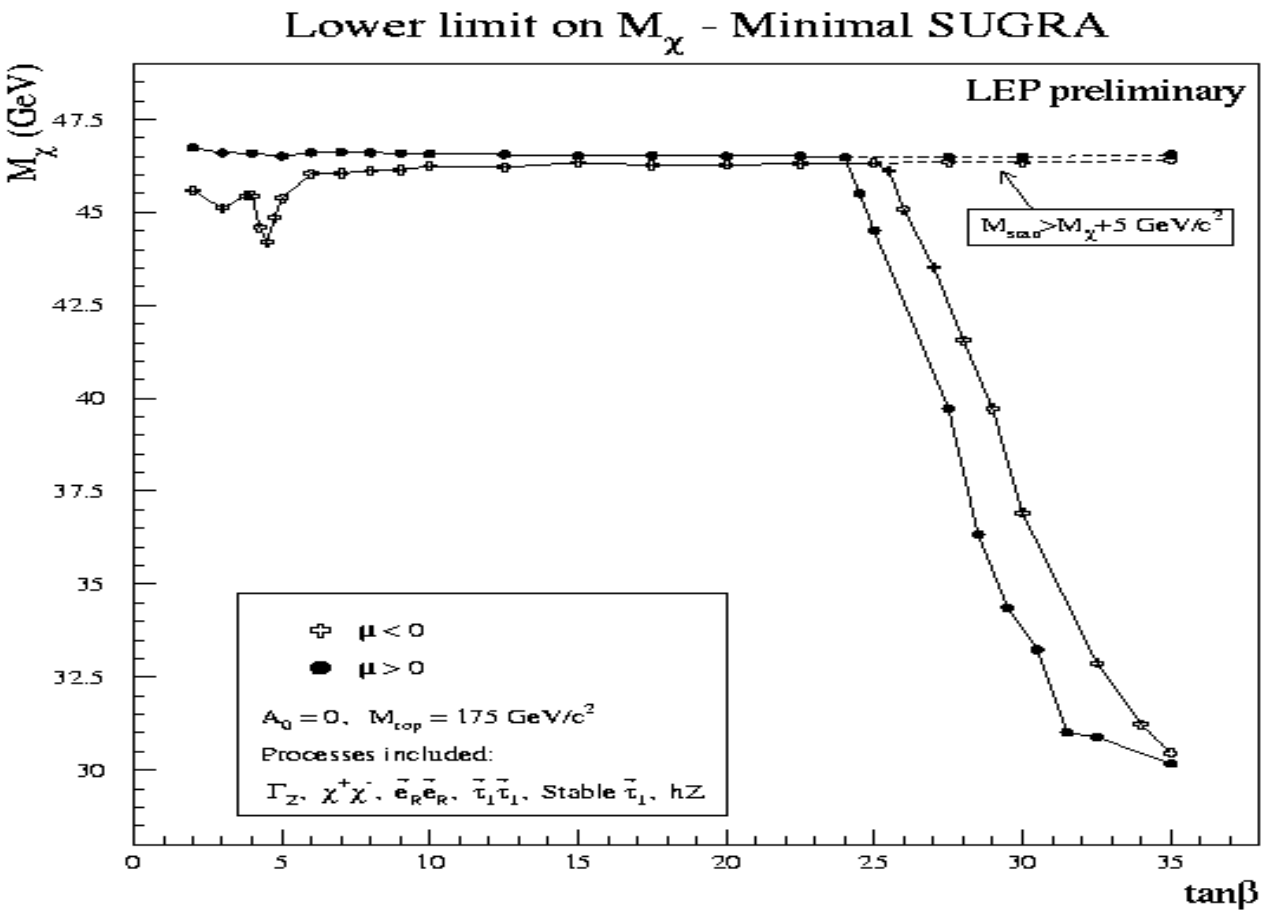
Chargino searches from Aleph

$M\tilde{\chi}_1^0 \geq 47$ GeV

(Mtop = 175 GeV)

Stau mixing effect

$\tilde{\chi}_1^0$



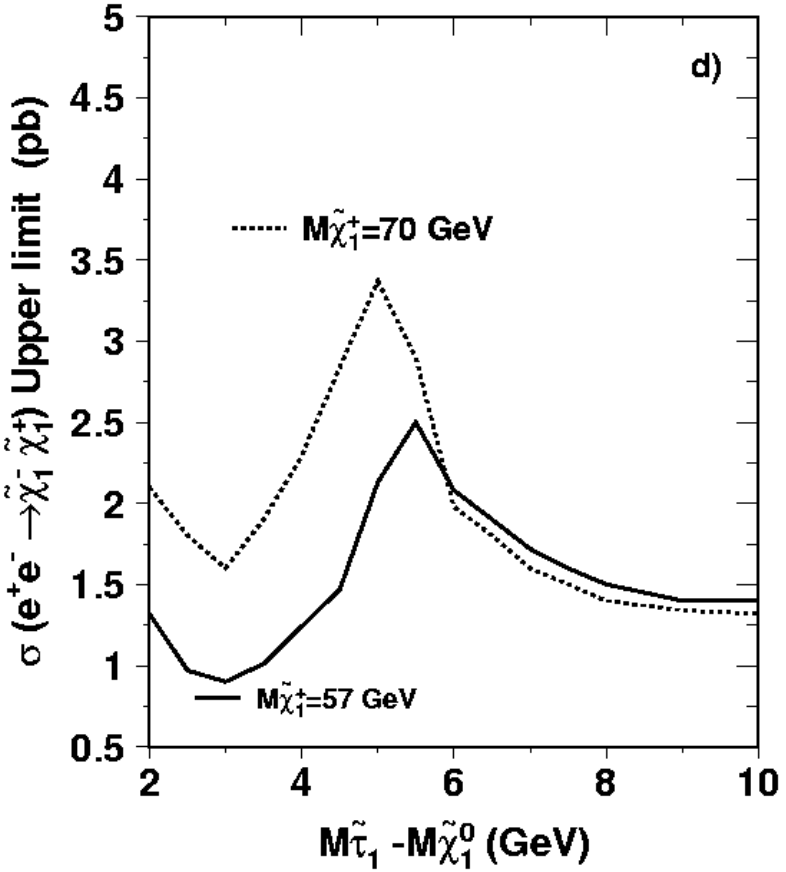
$\tilde{\chi}_1^\pm \to \tilde{\tau}\nu$ and almost invisible when $M_{\tilde{\tau}} \sim M_{\tilde{\chi}^0}$

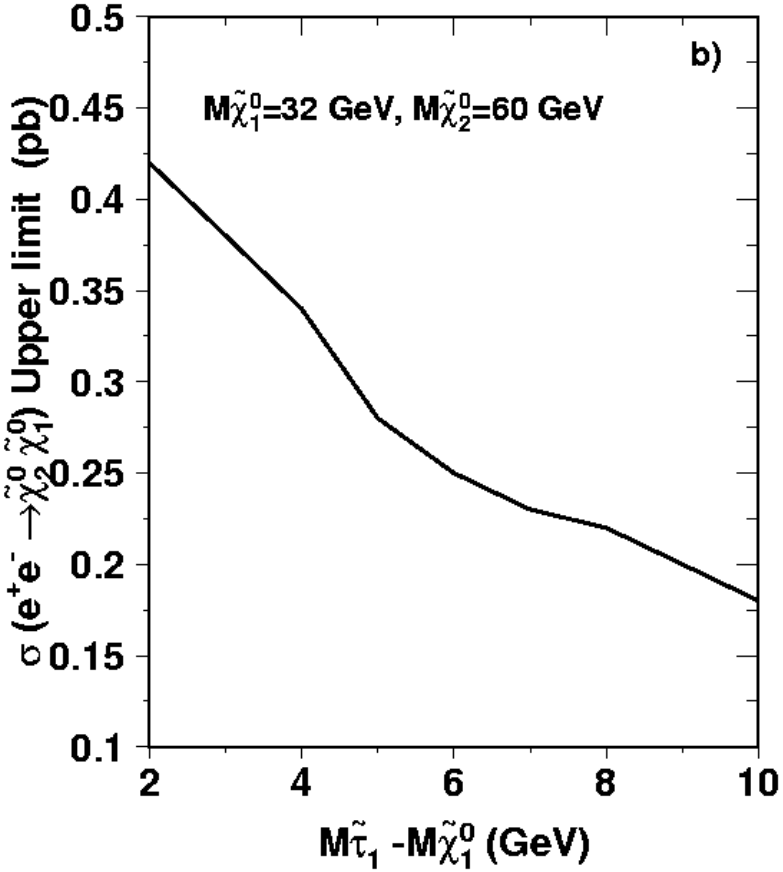
Can we recover some sensitivity ?

$e^+e^- \to \tilde{\chi}_i^0\tilde{\chi}_2^0$

$e^+e^- \to \tilde{\chi}_1^\pm\tilde{\chi}_1^\pm\gamma$

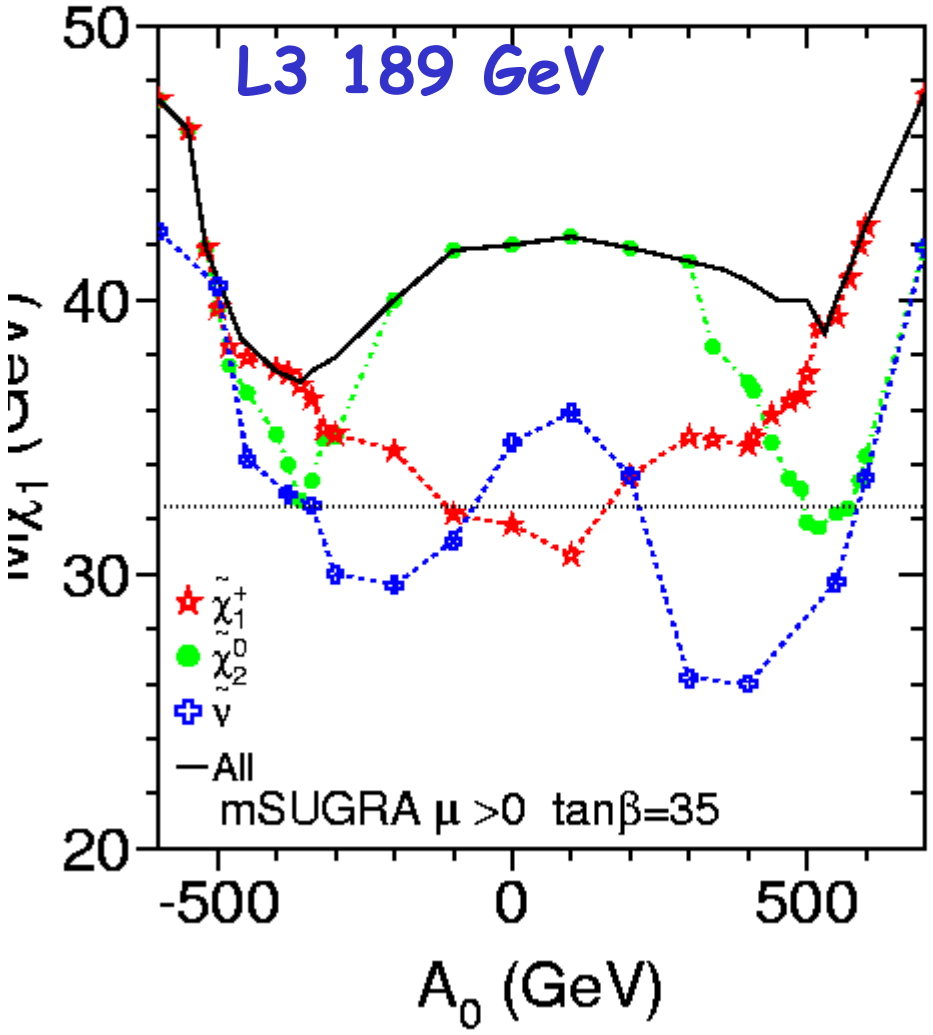
Stau mixing effect

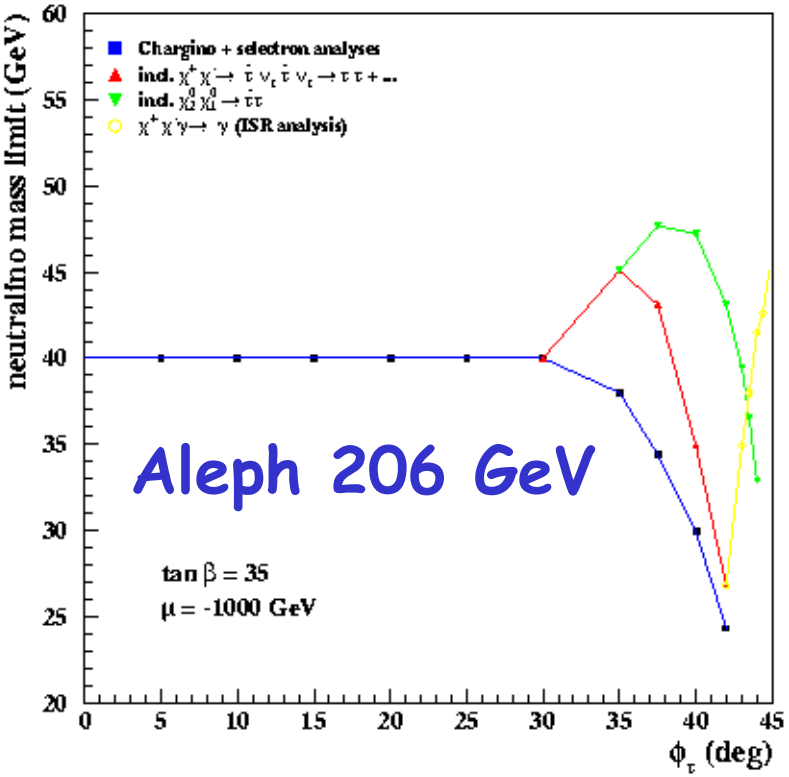




L3 data @ 189 GeV , exploiting the (χ^0_1 χ^0_2) ,(χ+ χ+ γ)

Stau mixing effect

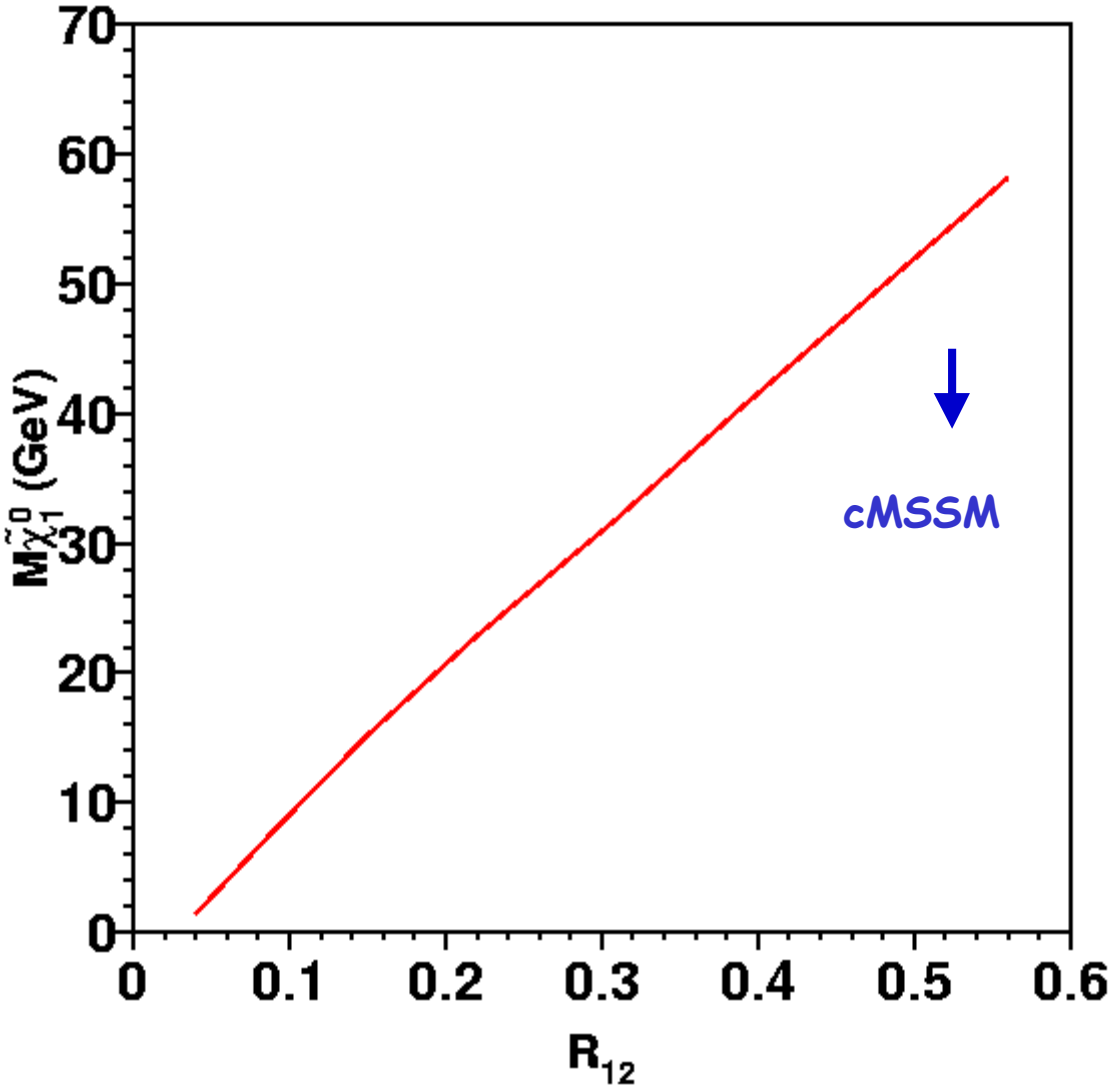




The LSP mass limit remains robust

Towards non gaugino mass unification

Large m_0



M_1/M_2=R12 decreases↓ the ΔM ↑ and the LSP mass decreases with M_1

⇓

NO more constraint from LEP chargino searches

⇓

Relic density of the LSP

should be included

micrOMEGAS package from
G.Belanger F.Boudjema
A.Pukhov and A.Semenov

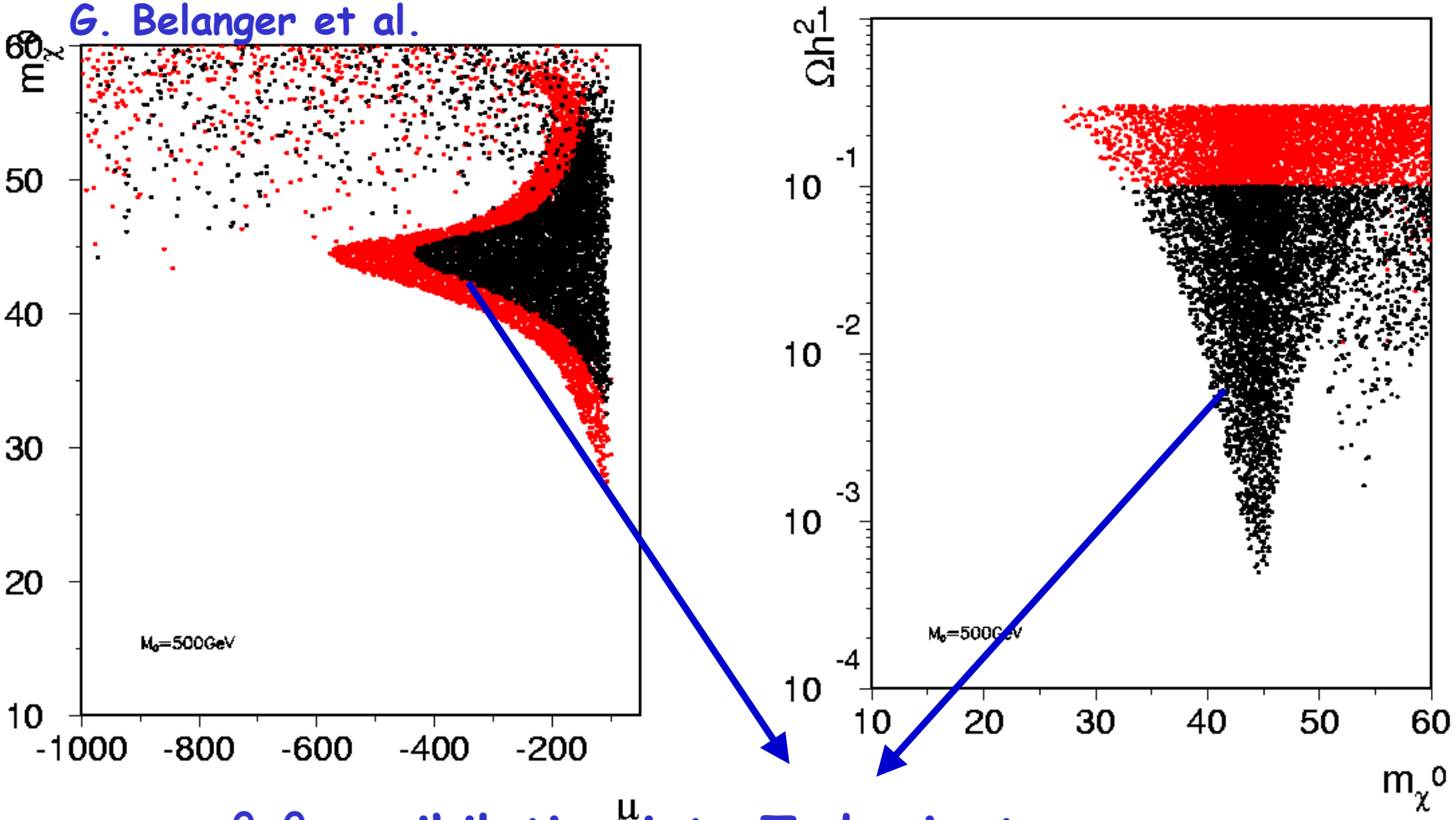
hep-ph/0112278

Towards non gaugino mass unification

Relic density constraint:

$\Omega h^2 < 0.3$ (red dots) or 0.1 (black dots)

G. Belanger et al.

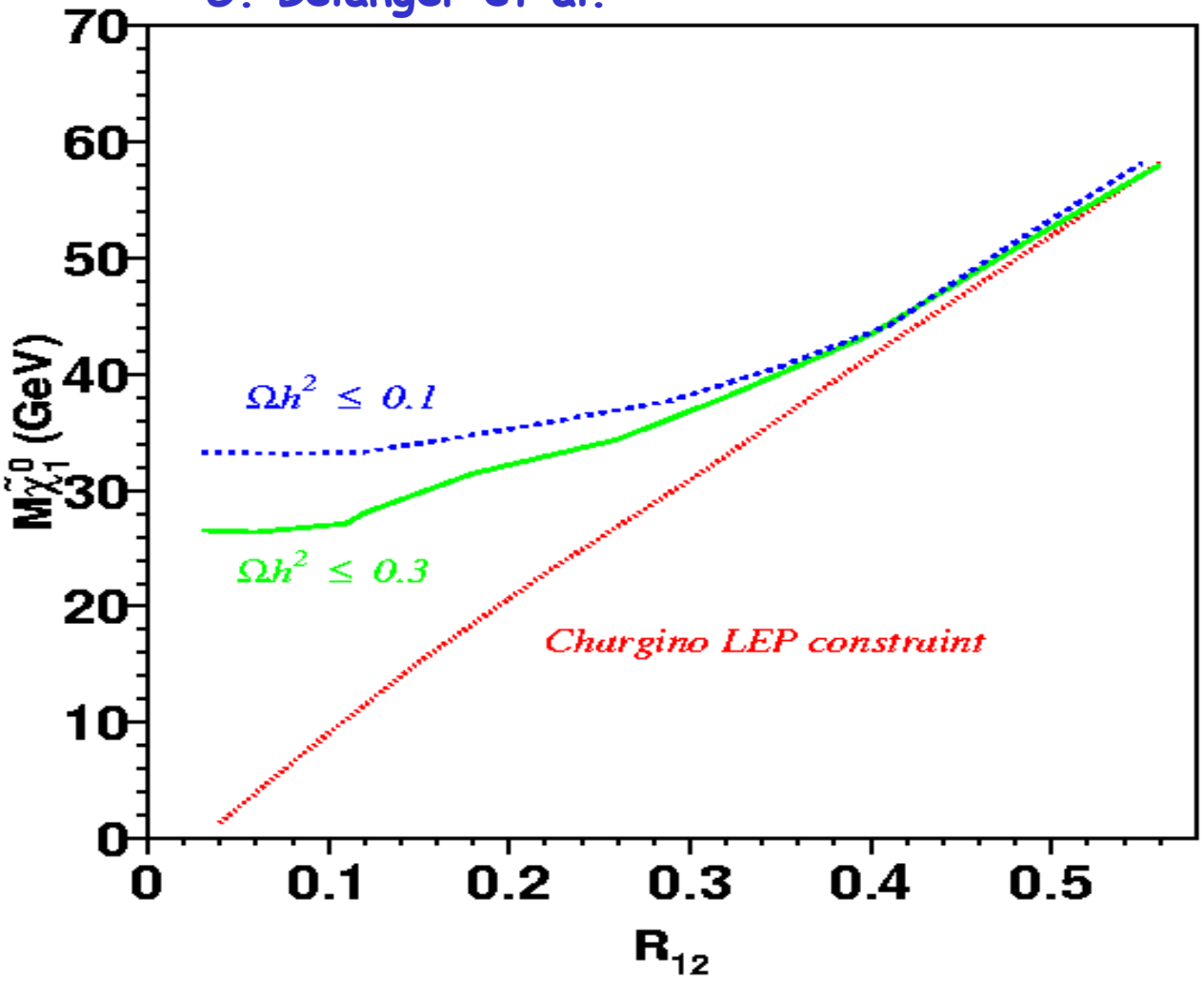


$\chi^0\chi^0$ annihilation into Z dominates

Towards non gaugino mass unification

Large m_0

G. Belanger et al.



$M\,\tilde{\chi}_1^0 \geq 28$ GeV

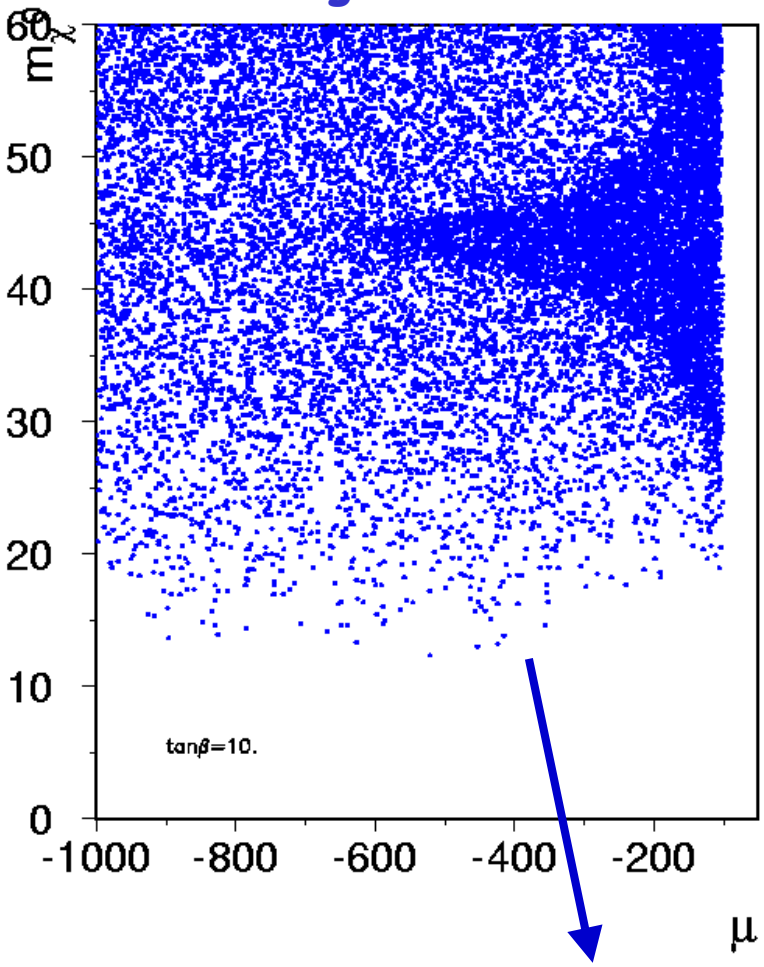
$(\Omega\, h^2 \leq\leq 0.3)$

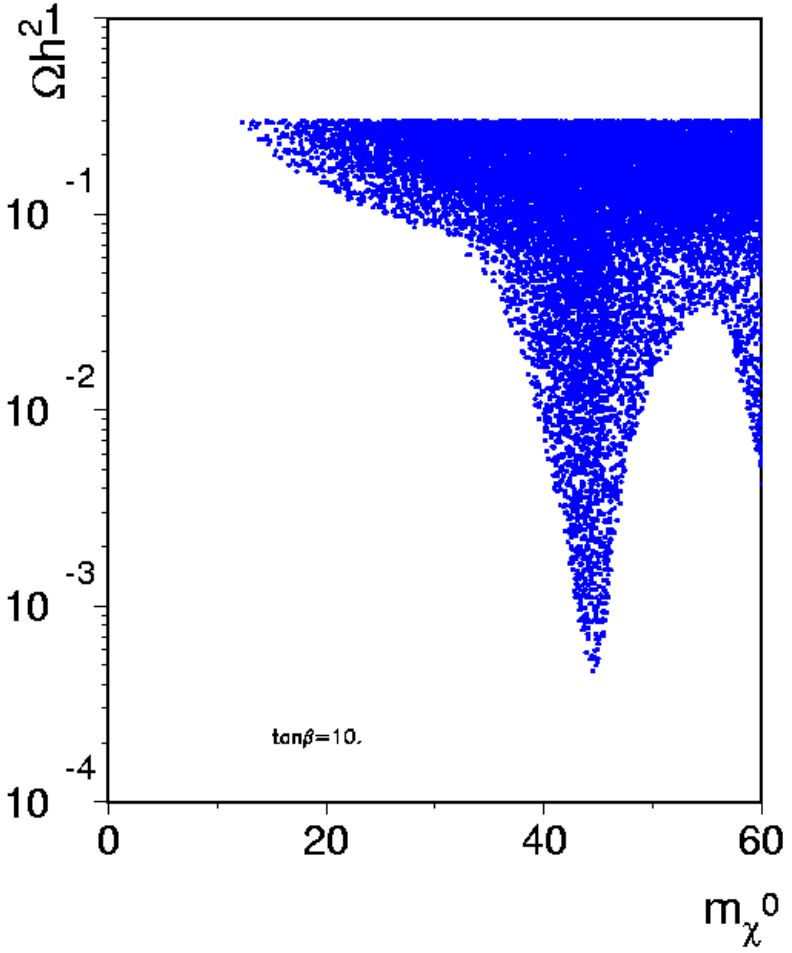
Any tanβ

Towards non gaugino mass unification

$\tan\beta$=10 any m_0

G. Belanger et al.





slepton t-channel contribution in the $\chi^0\chi^0$ annihilation

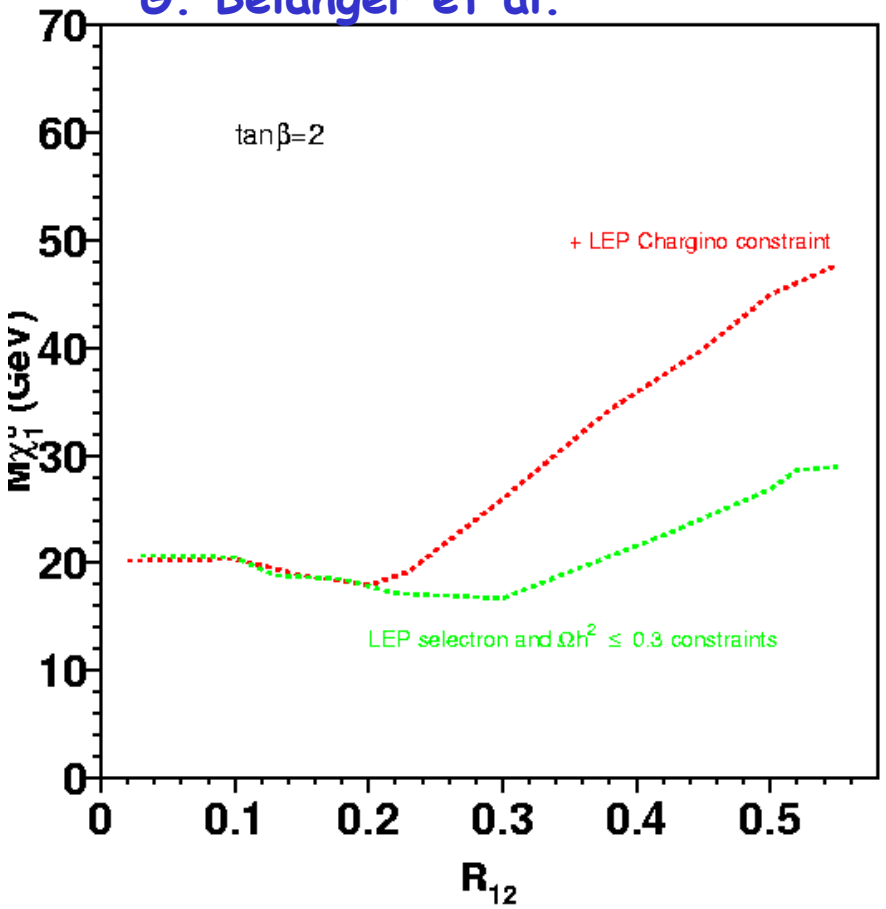
Towards non gaugino mass unification any m_0

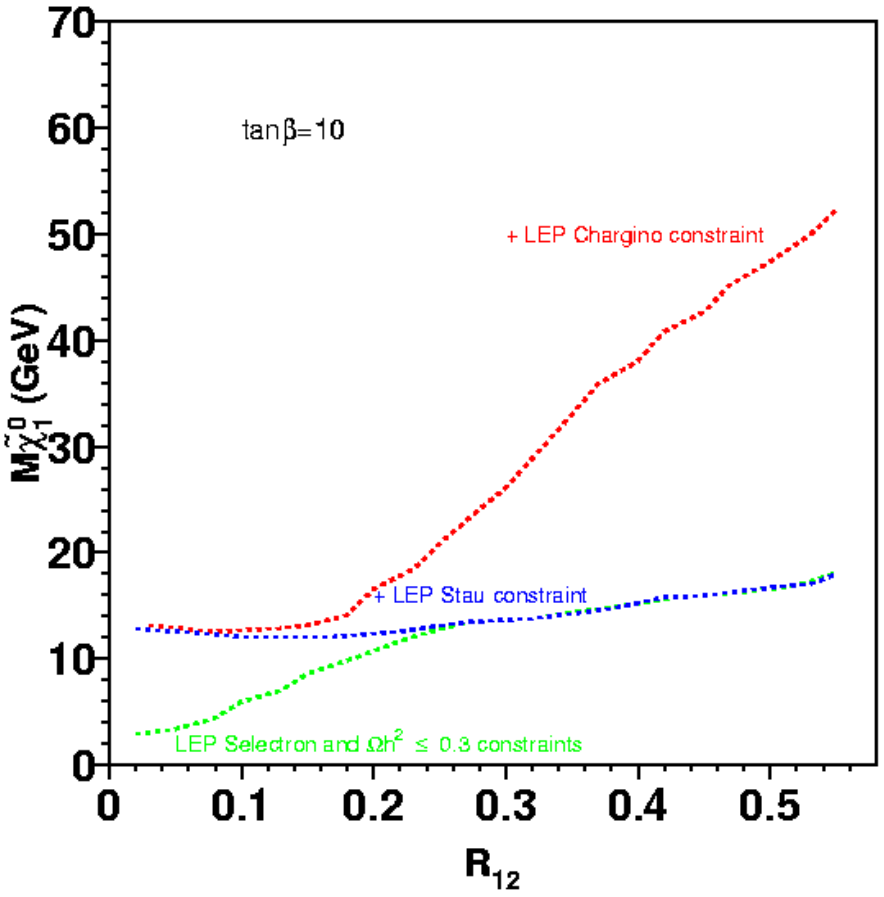
Contribution of τ,slepton, chargino LEP results and LSP Relic density

$M\,\tilde{\chi}_1^0 \geq 12$ GeV

$(\Omega h^2 \leq \leq 0.3$

G. Belanger et al.





Conclusions

A very wide range of searches have been performed at LEP

All the accessible processes are exploited since the sensitivity at LEP was large (good detector performances and low background)

->The absolute LSP mass limit is 39.6 GeV

in the Cmssm framework and is independent on the Stau mixing

It becomes 47 GeV when including Higgs constraints

- When relaxing the gaugino mass unification in the cMSSM

the LSP mass limit becomes 12 GeV when decreasing M1/M2 ↓
using the LSP relic density constraint and LEP constraints