LEP Susy Legacy

Outline

- Introduction
- Experimental Searches with RPC:

  Charginos, Sleptons, Squarks

  SUGRA and GMSB scenarios
- Constraints on the SUSY cold dark matter candidate $\tilde{\chi}_1^0$

Advanced Study Institute – Physics at LHC

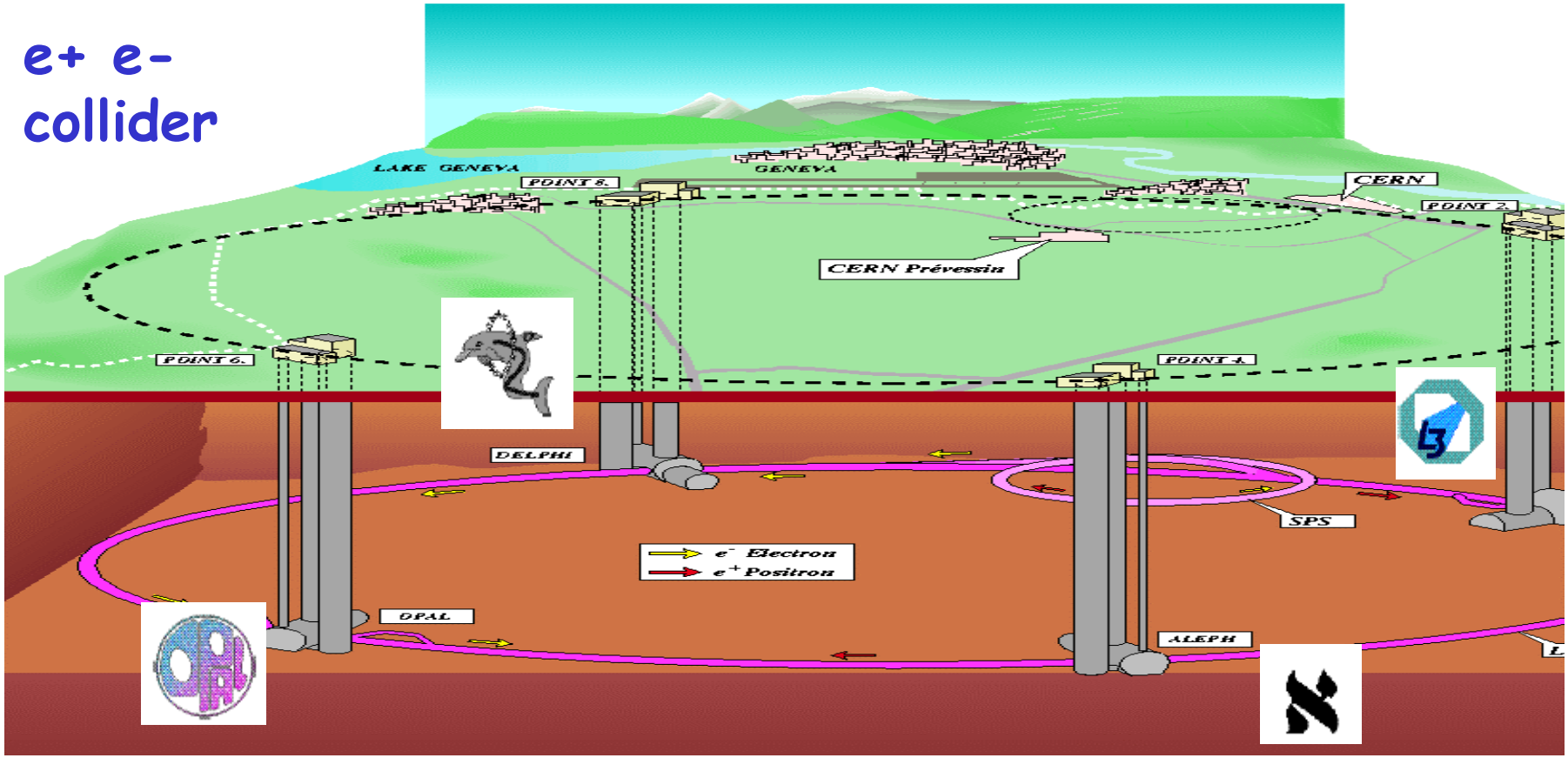
6-12 July 2003, Prague

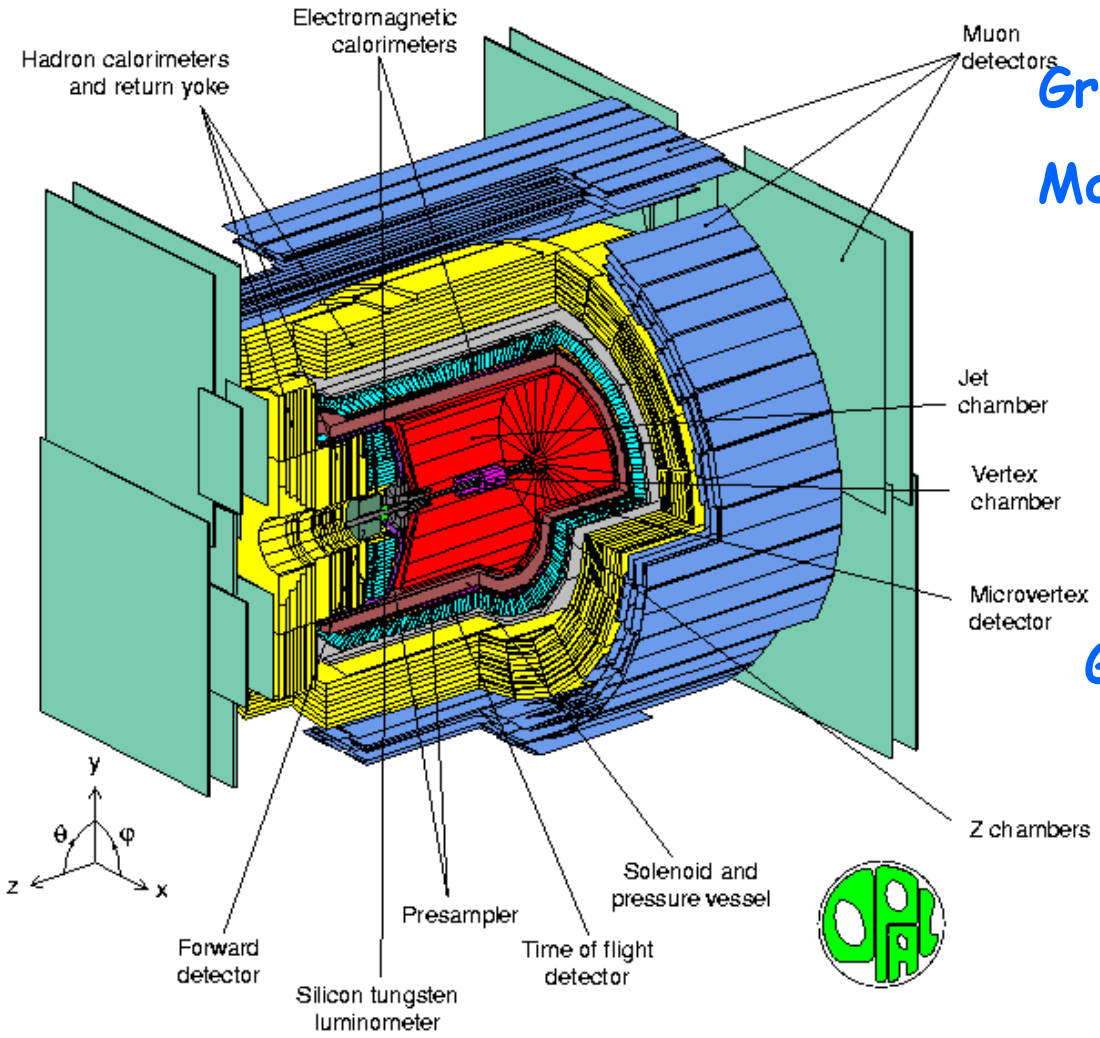
S.Rosier.Lees (LAPP-in2p3)

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





Gravity mediation with RPC

Main SUSY particle topologies

acoplanar objects

missing mass, $\not{E}$

carried out by the $\tilde{\chi}_1^0$

Gauge mediation with RPC

$\tilde{\chi}_1^0$ or $\tilde{l}$ NLSP

lifetime signature,

N γ or N leptons + $\not{E}$

carried out by the gravitino

Key point : Hermetic and redundant detector

Susy search features at LEP

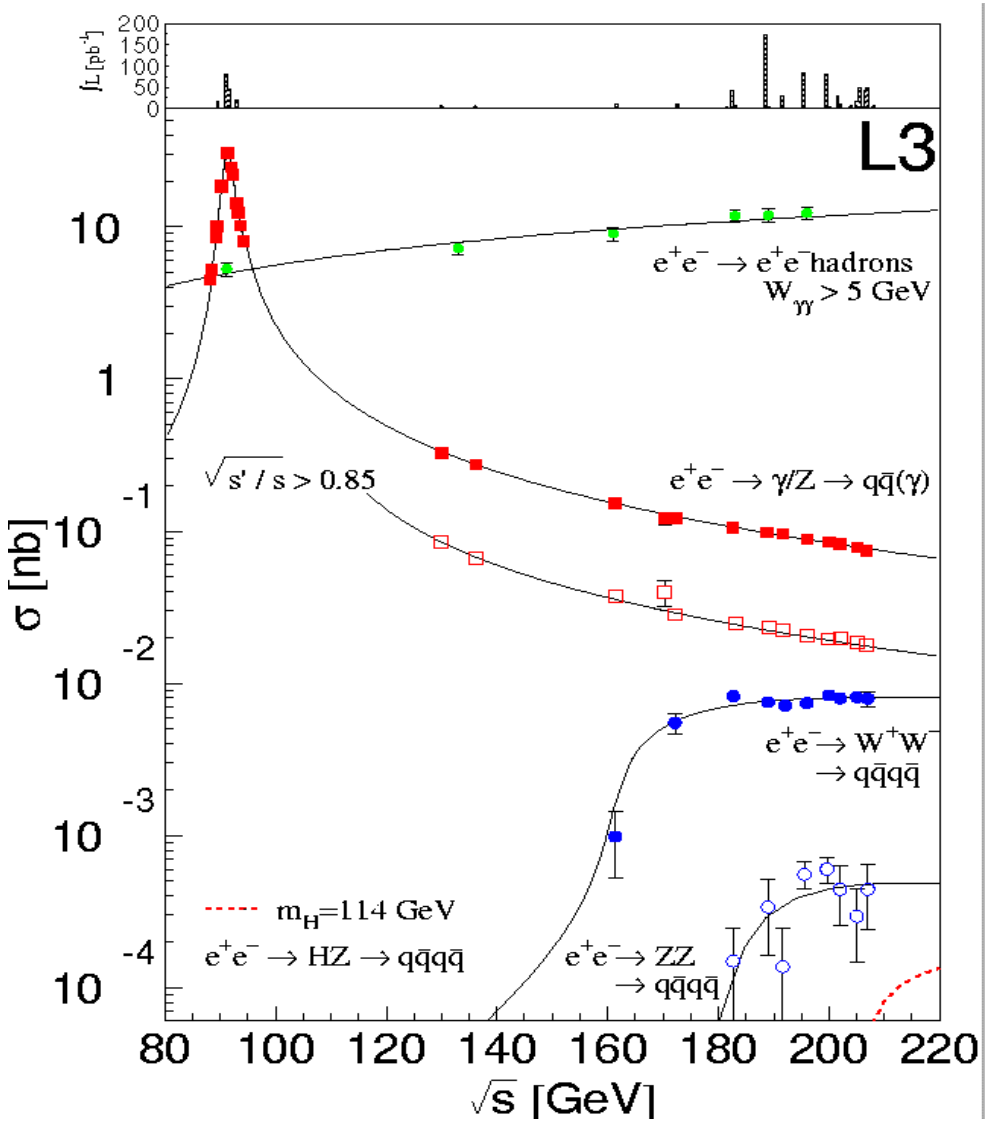
- Within the Rparity conservation assumption*:
  - -The Lightest Susy Particle (LSP) is stable,
  - -each Sparticle are produced by pair,
  - -each Sparticle decays into the LSP
- If Sparticle Mass < Ecm/2 (kinematic limit)
  - -Chargino pairs $e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$
  - -Neutralino 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 is $\tilde{\chi}_1^0$ a favorite LSP candidate

Neutral and interacting weakly: LSP is invisible, escapes detection

*not reported in this talk but Susy searches have been performed assuming RPV also at LEP.

Susy searches at LEP - Background

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

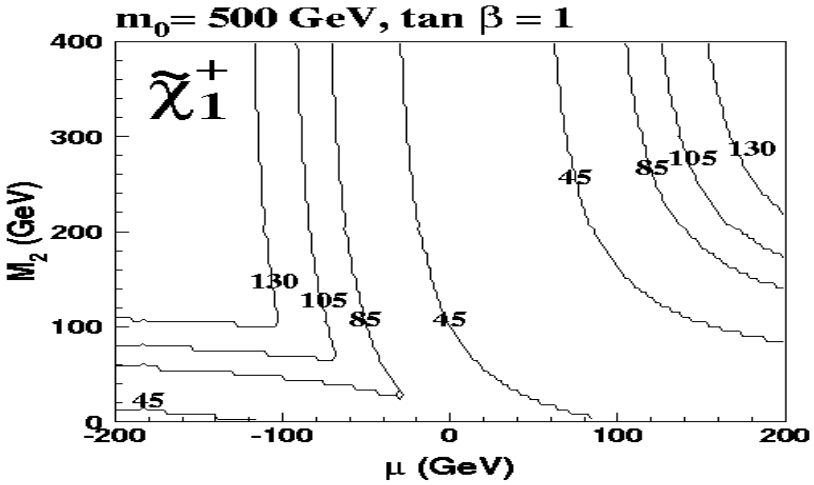


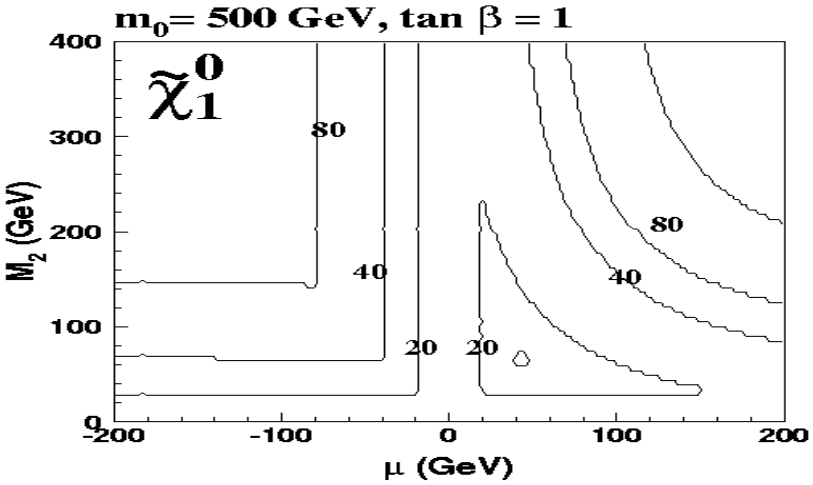
$$\Delta M = M_{\tilde{P}} - M_{\tilde{\chi}^0_1}$$

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

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

Large $\Delta M >$ 50 GeV

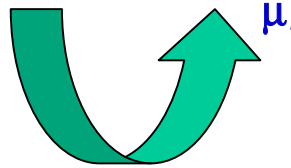




Chargino mass depends on

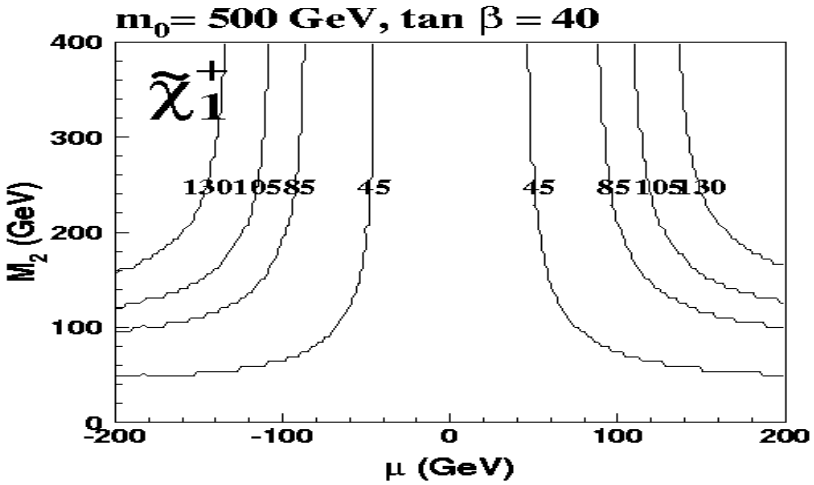
μ, $M_{,2}$ and tan(β) parameters

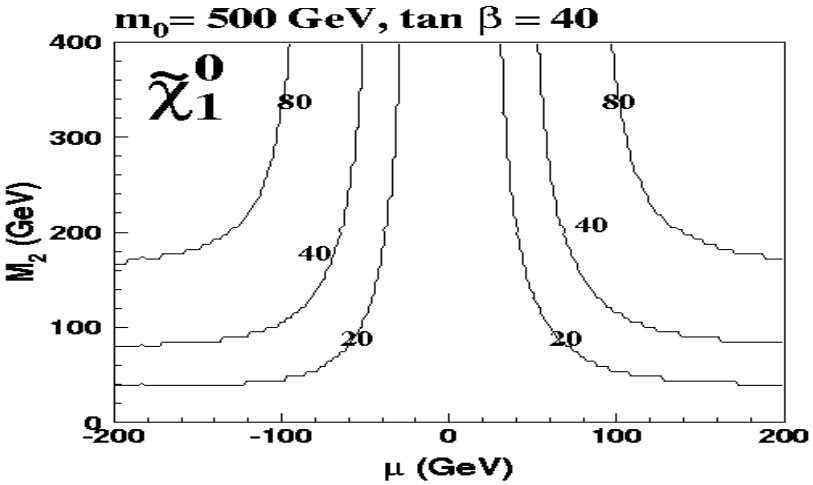
M2≈0.8m1/2

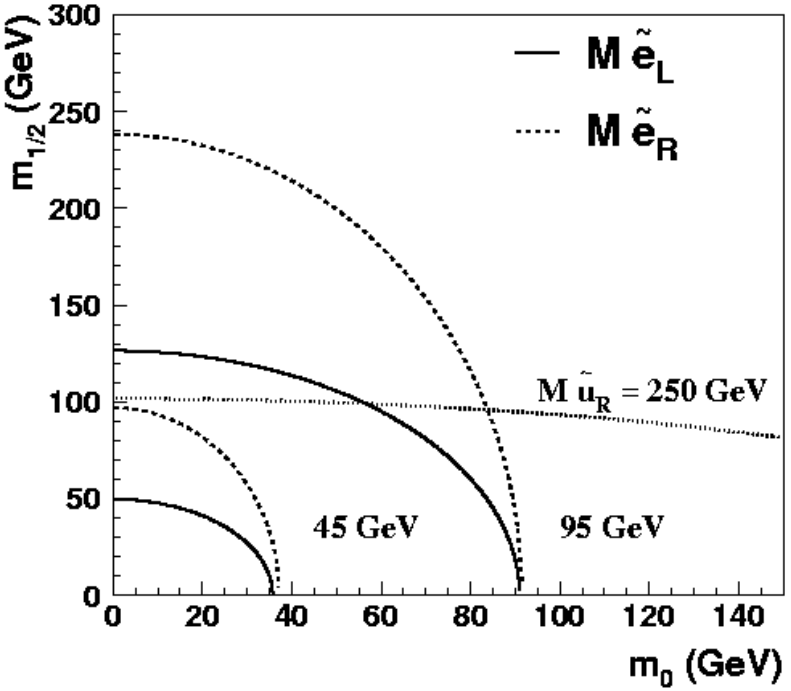


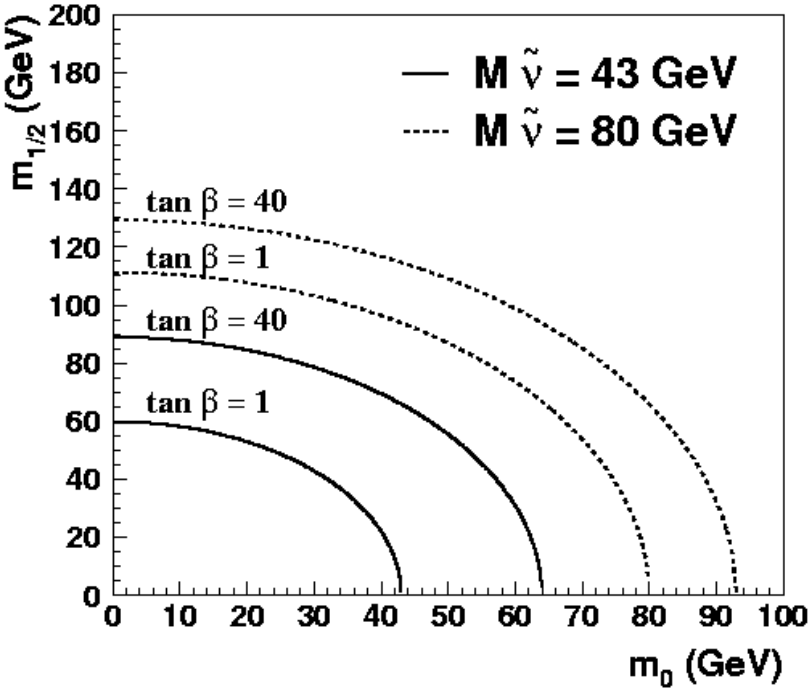
LSP mass depends on

μ, $M_{,1}$ (M_1≈0.5M_2) and tan(β) parameters









M2≈0.8m1/2

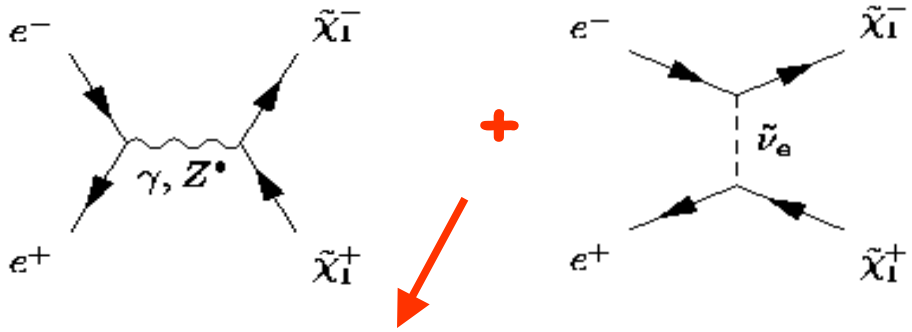
$m^2_{\tilde{l}_R} = m_0^2 + 0.15 m_{1/2}^2 - \sin^2\theta_W \, m_Z^2 \cos 2\beta$

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

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

charginos/neutralinos pair productions

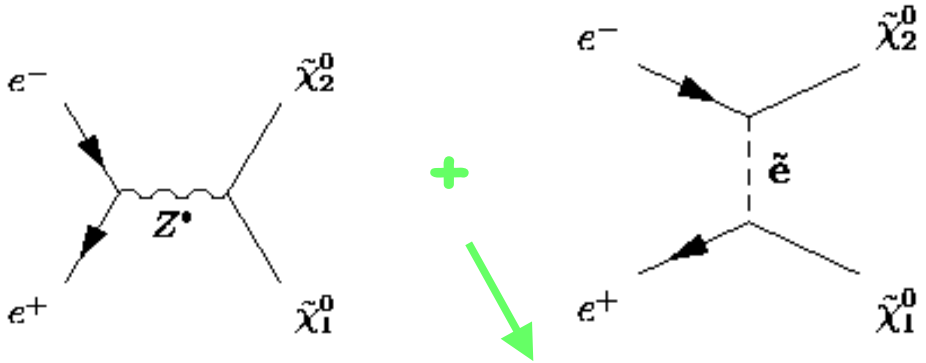
$\tilde{\chi}_1^+ \tilde{\chi}_1^-$



Higgsino Region : $\mu << M_2$ 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 $\mu >> M_2$, large m0

no t-channel exchange contribution

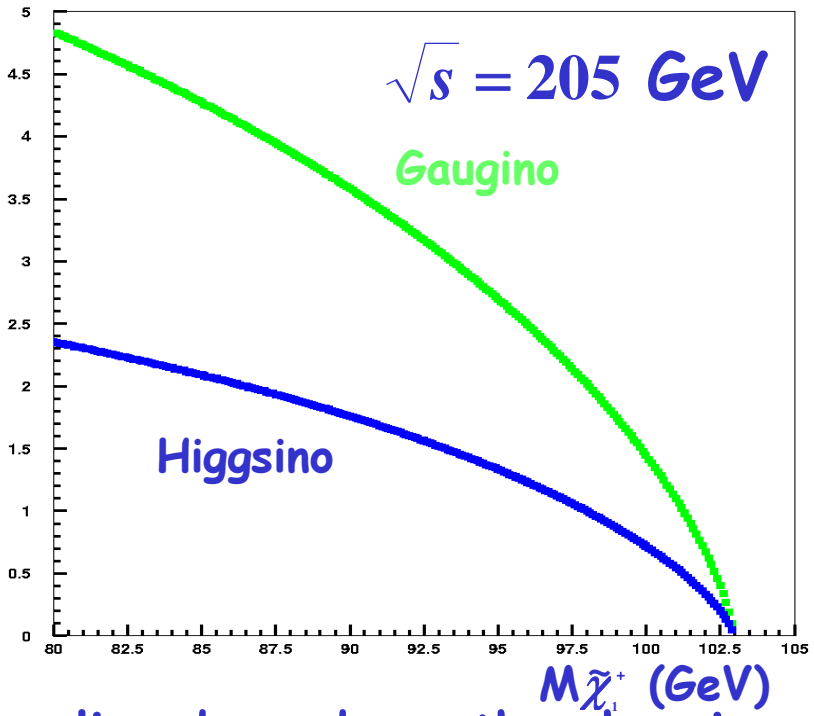
Gaugino region : $\mu >> M_2$, low m_0

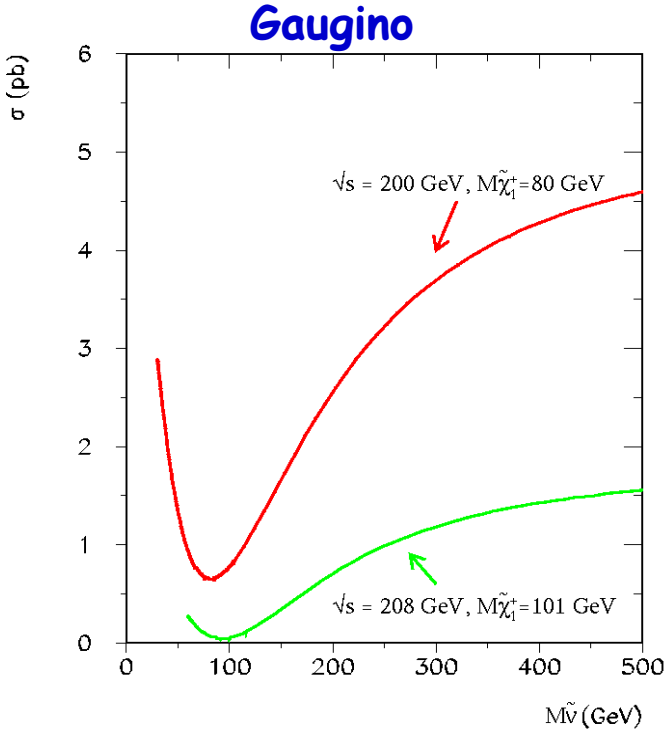
t-channel contribution

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

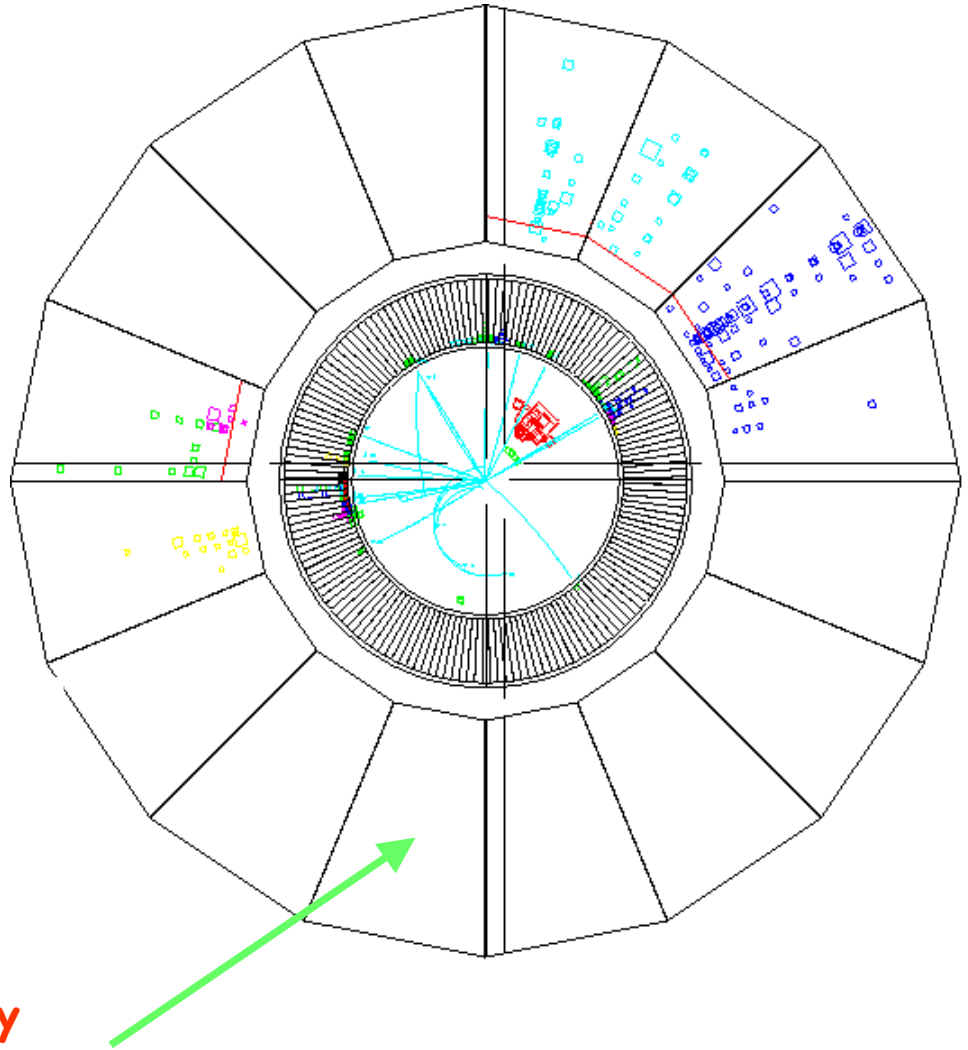
Chargino candidate

compatible with Weν 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:

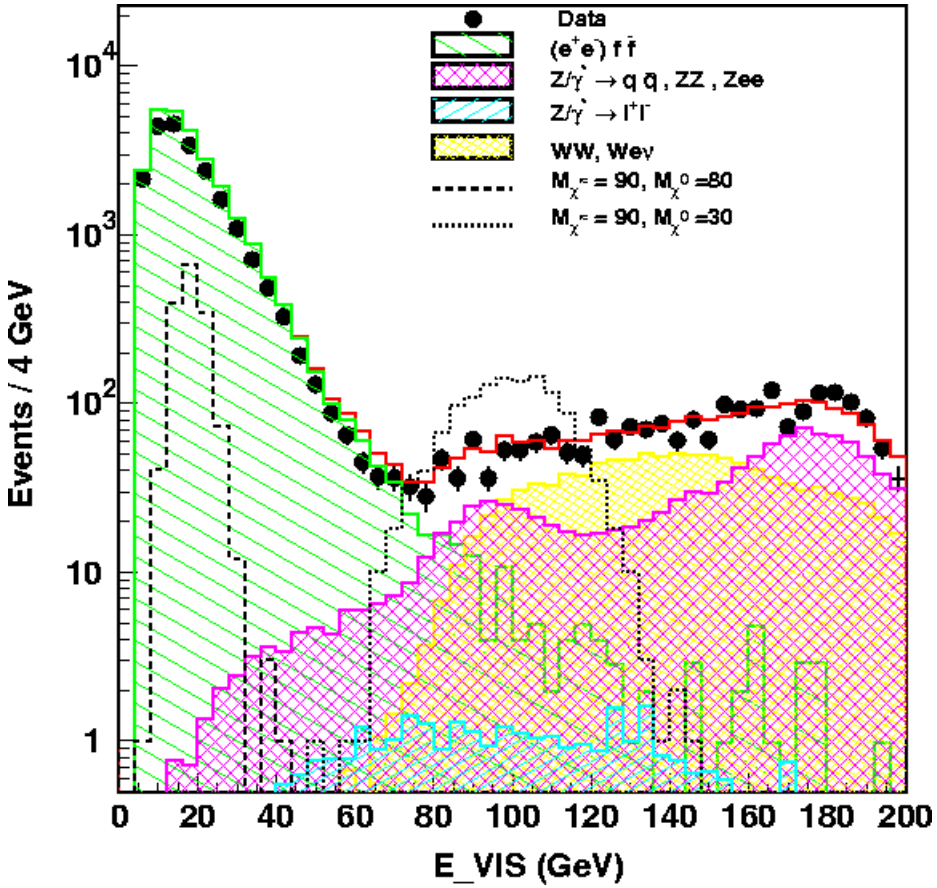
-Leptons plus missing energy

-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

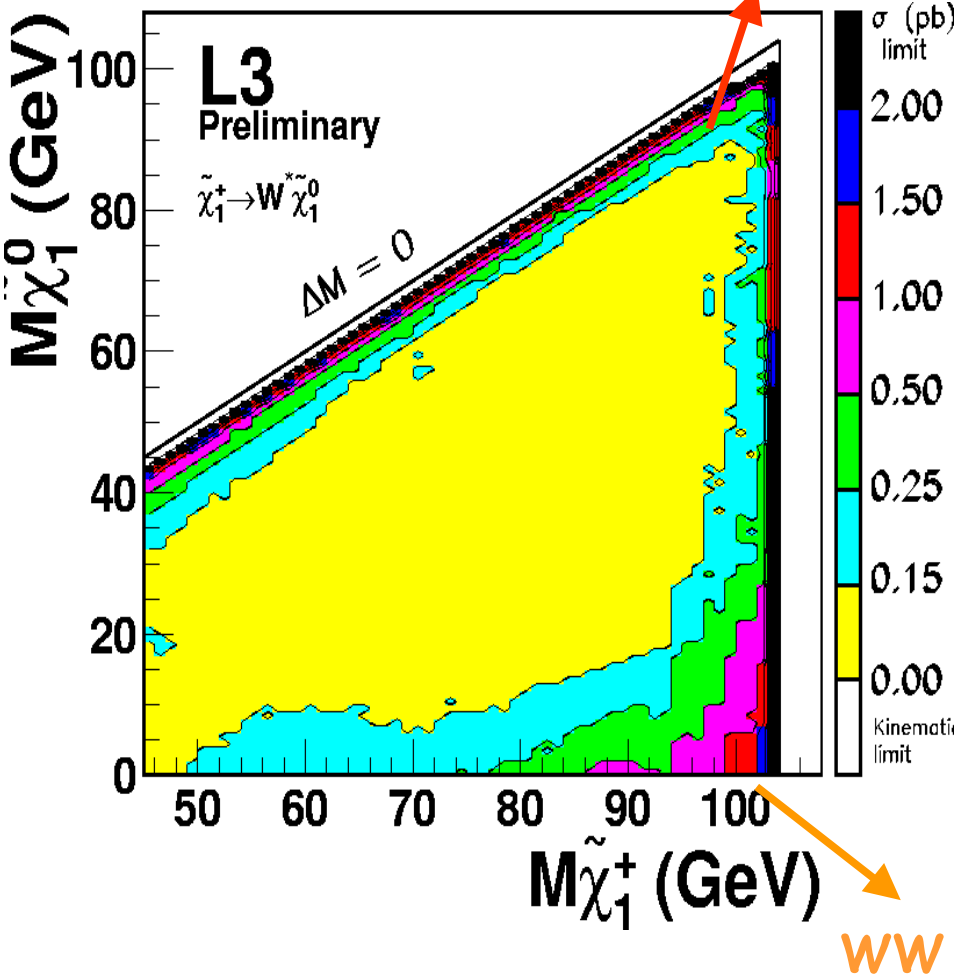
Visible energy: one typical discriminating variable preselection level

No Sensitivity for ΔM<3 GeV

No excess → Upper Limit on the cross section production

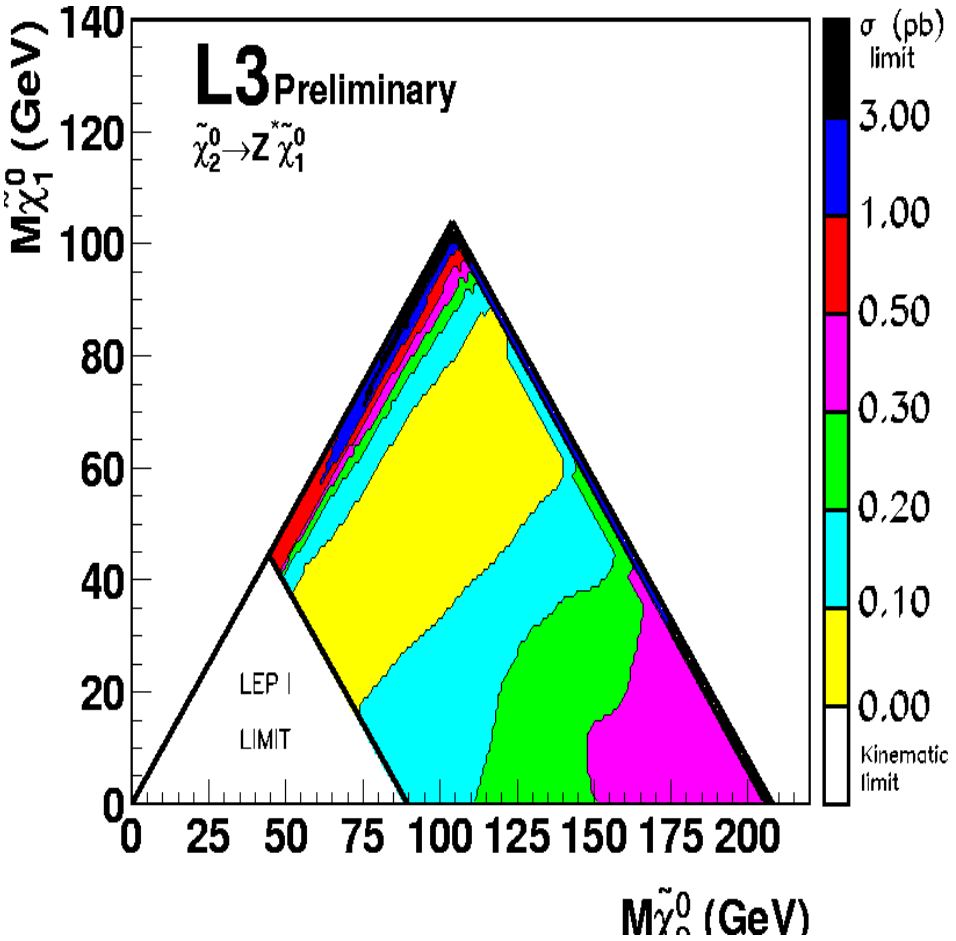
charginos

$\tilde{\chi}_1^+$



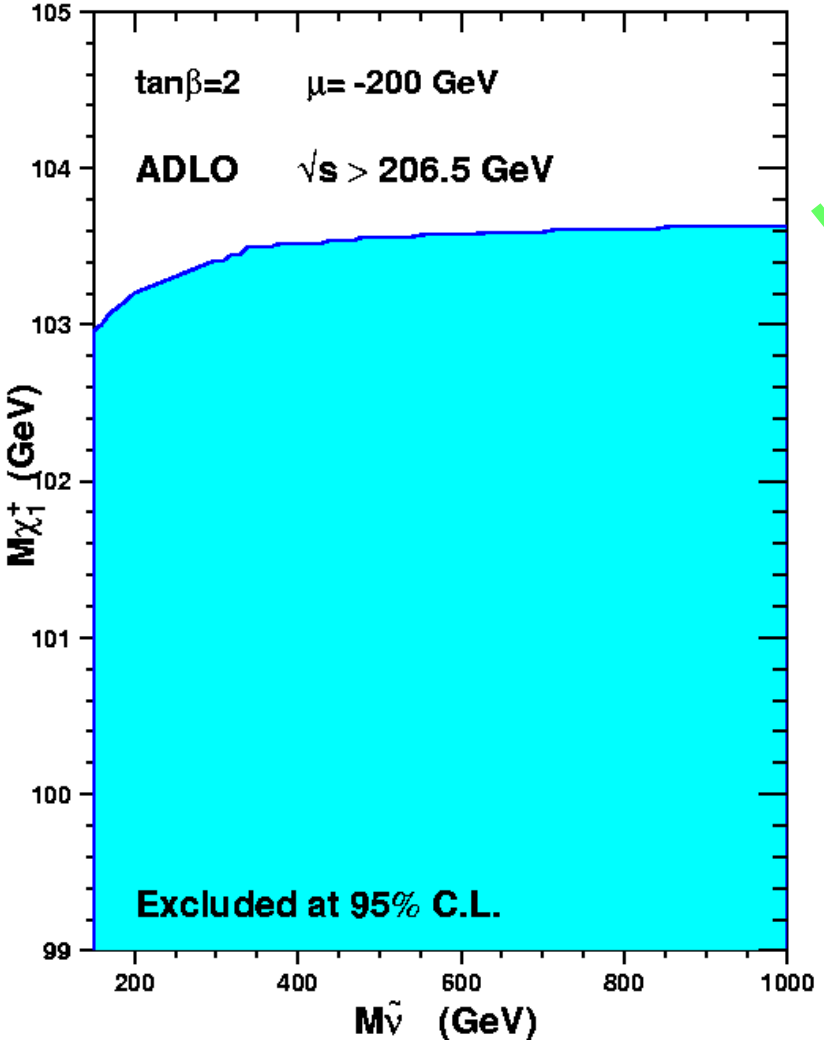
neutralinos

$\tilde{\chi}_2^0$



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

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



Large m_0 (i.e large sneutrino mass)

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

« Good » ΔM

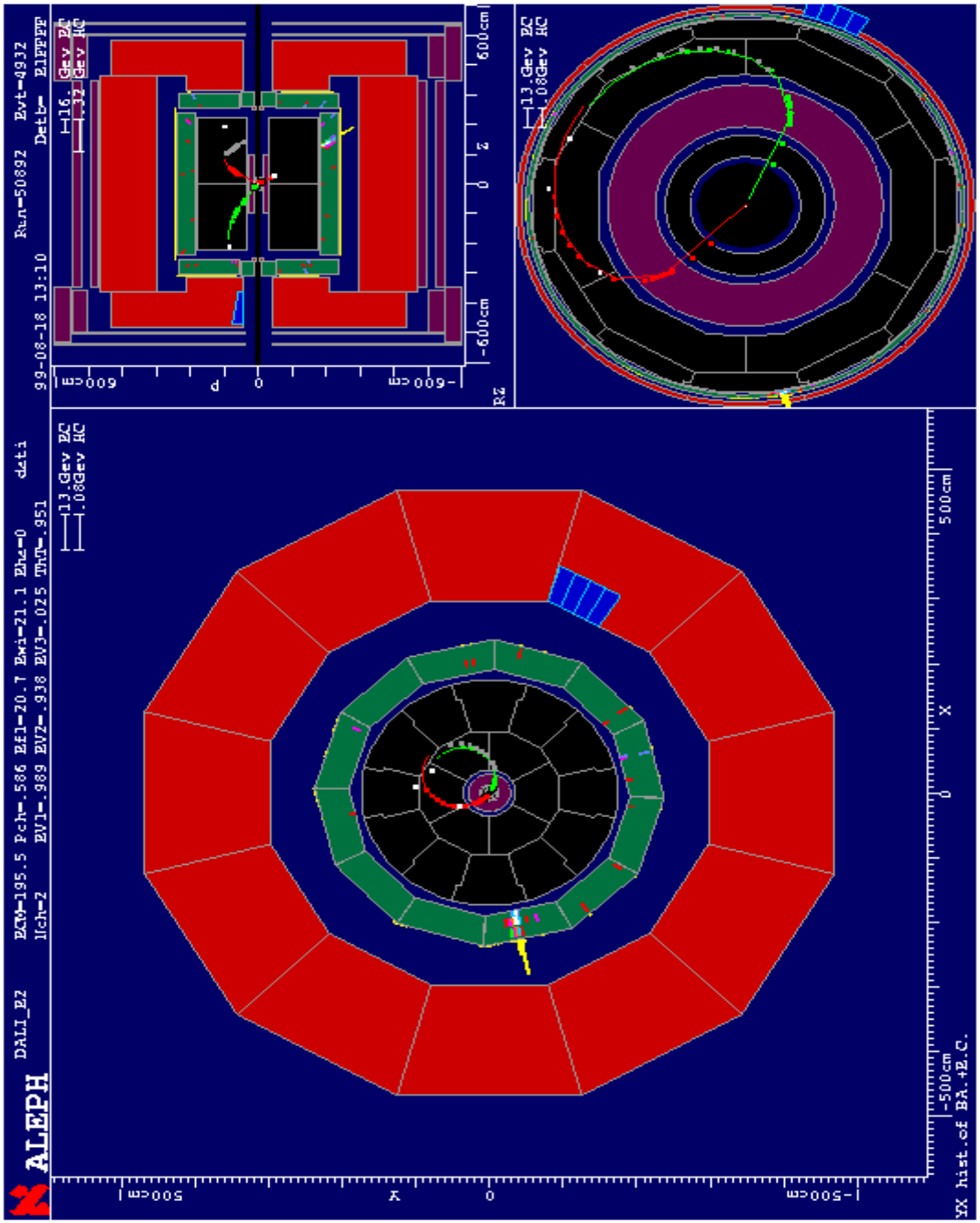
$M\chi^+$>103.5 GeV

⇓

(Assuming M1/M2 ≈ 0.5)

⇓

$$M\,\tilde{\chi}_1^0 \geq 52\ \text{GeV}$$

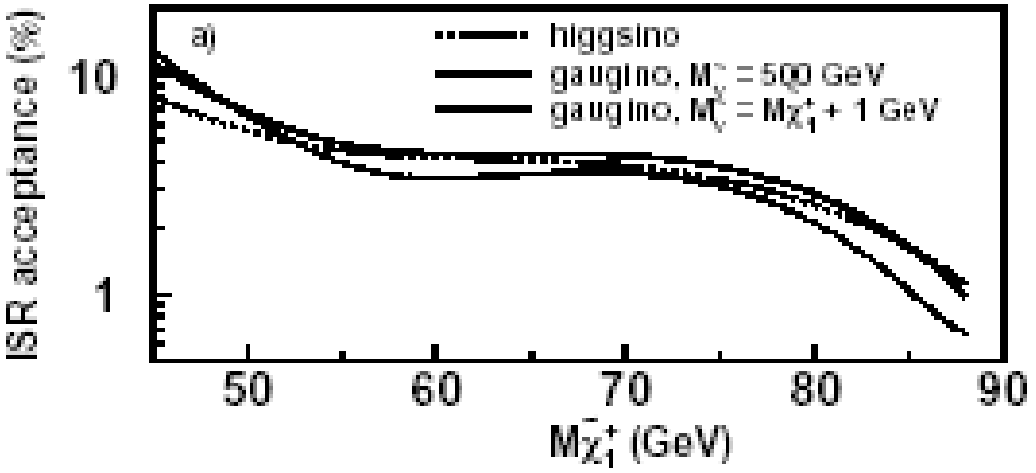


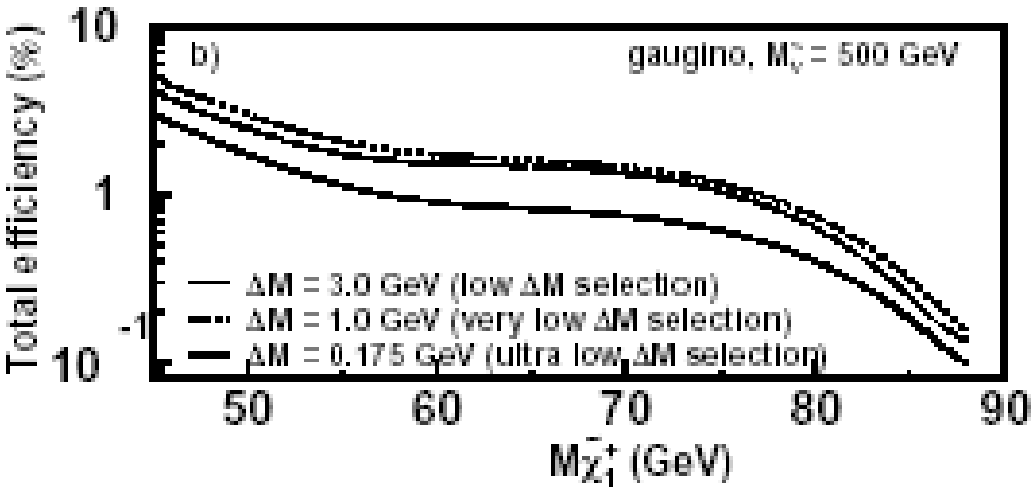
$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- (\gamma_{ISR})$$

Initial State Radiation γ

to recover sensitivity in the very low ΔM regions

$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- (\gamma_{ISR})$$

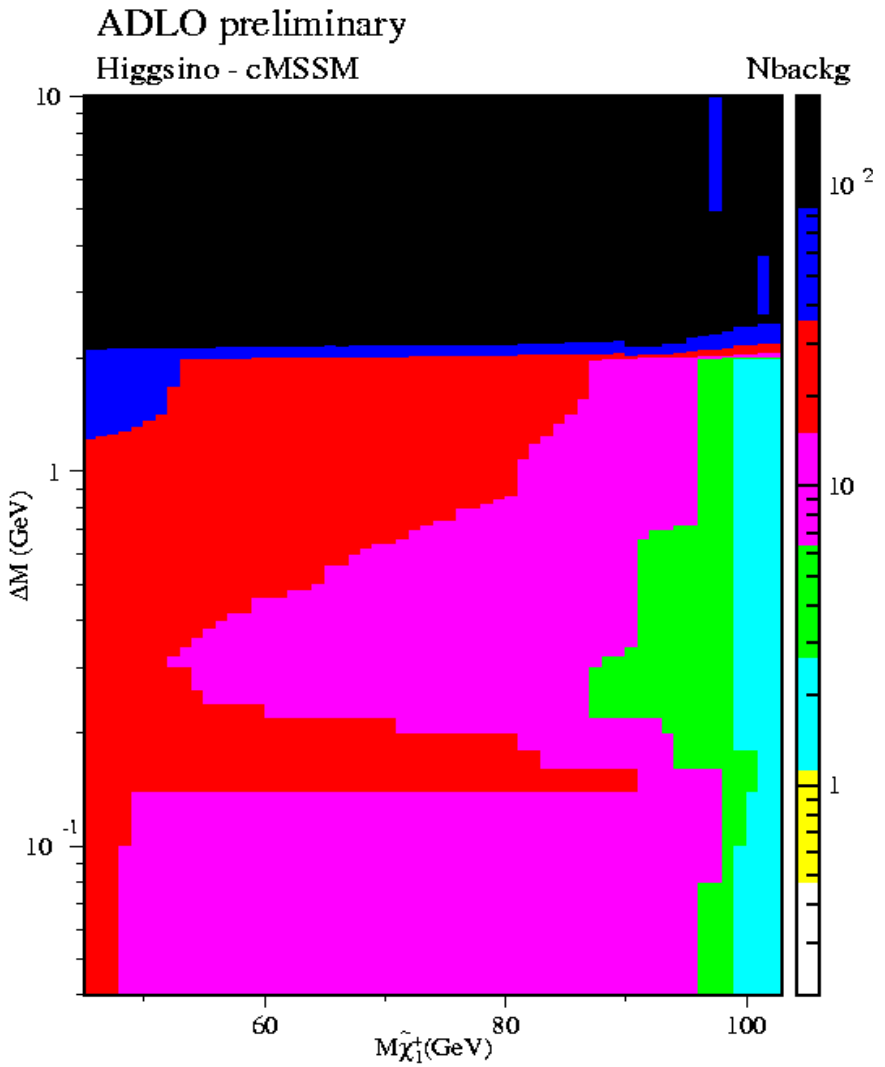


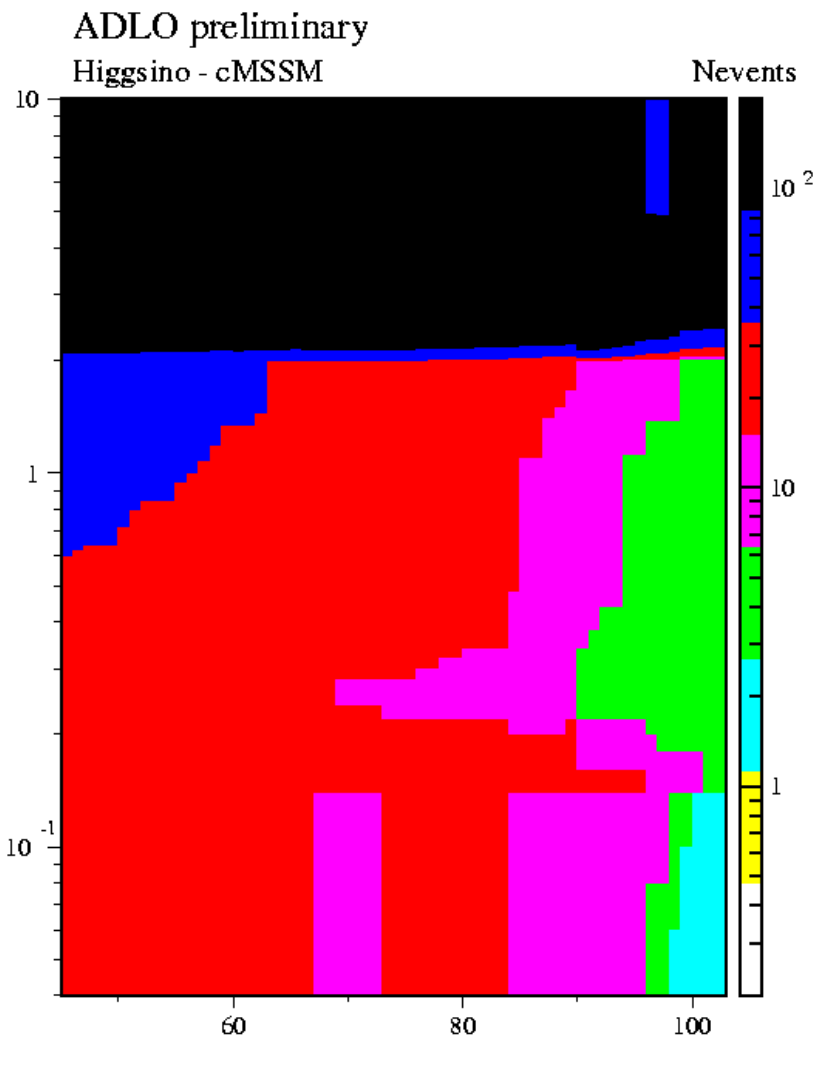


Efficiency ≈ 1-2 %

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

LEP $M_{\tilde{\chi}_1^+}$ Limit independent on ΔM $\tilde{\chi}_1^+$

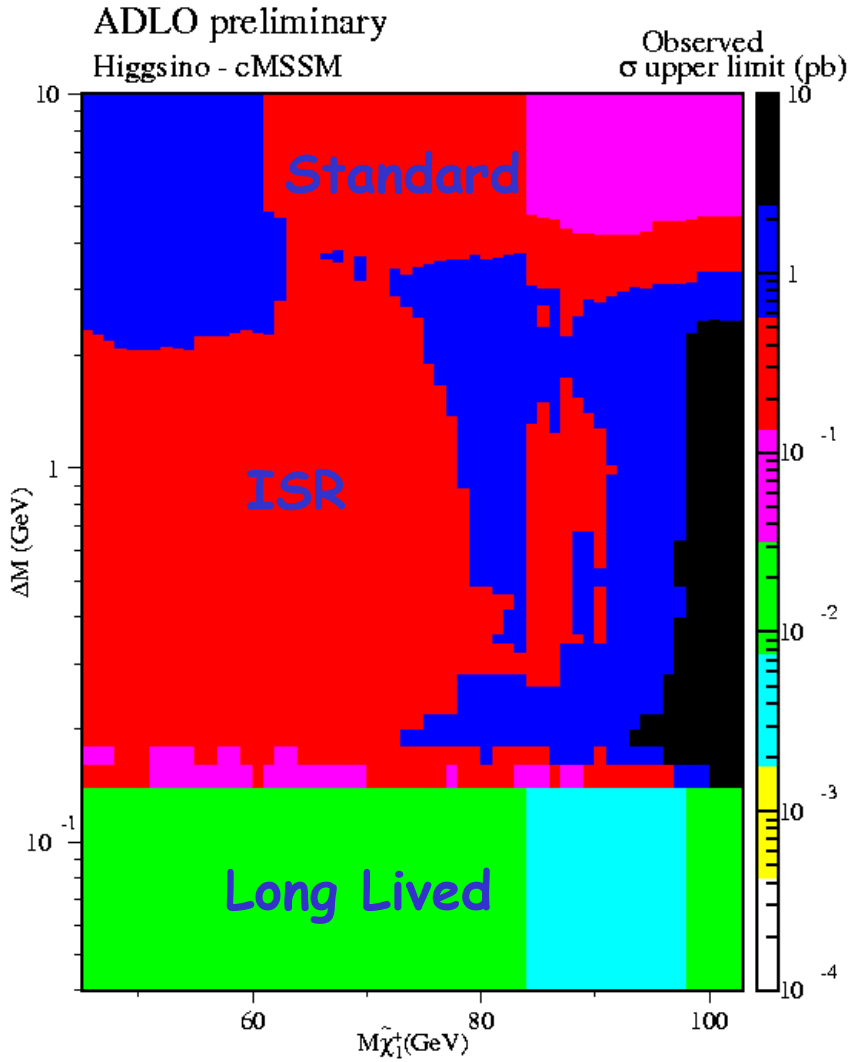


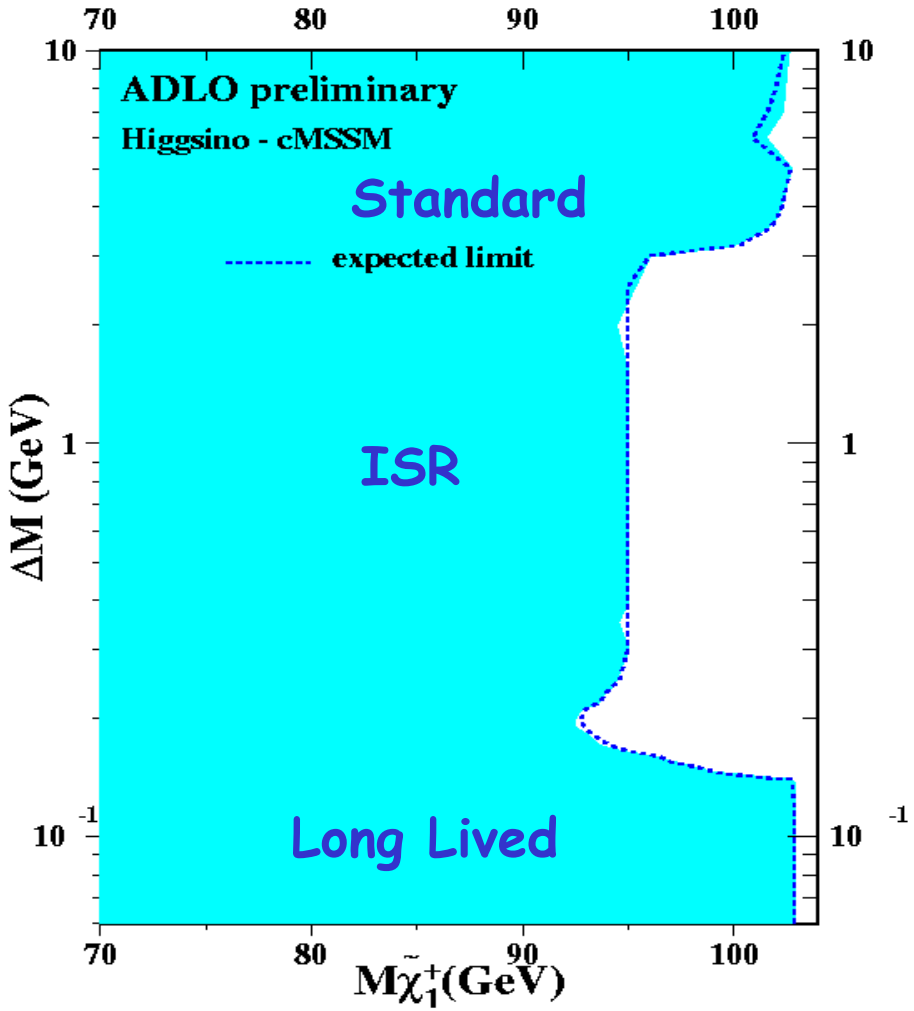


LEP $M\tilde{\chi}_1^+$ Limit independent on ΔM

$\tilde{\chi}_1^+$

Higgsino Cmssm ADLO

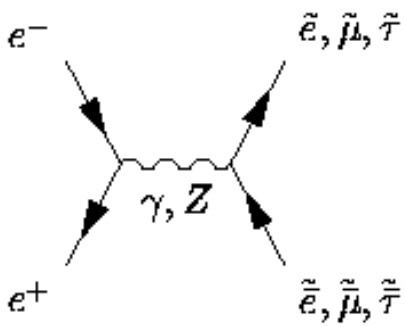




Interpretations also AMSB, assuming Non universality for gaugino masses at GUT

$M\tilde{\chi}_1^+ \geq 92.8$ GeV (exp 92.4)

Sleptons pair production



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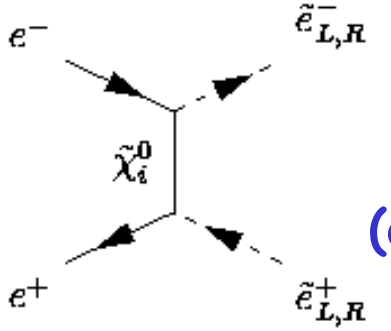
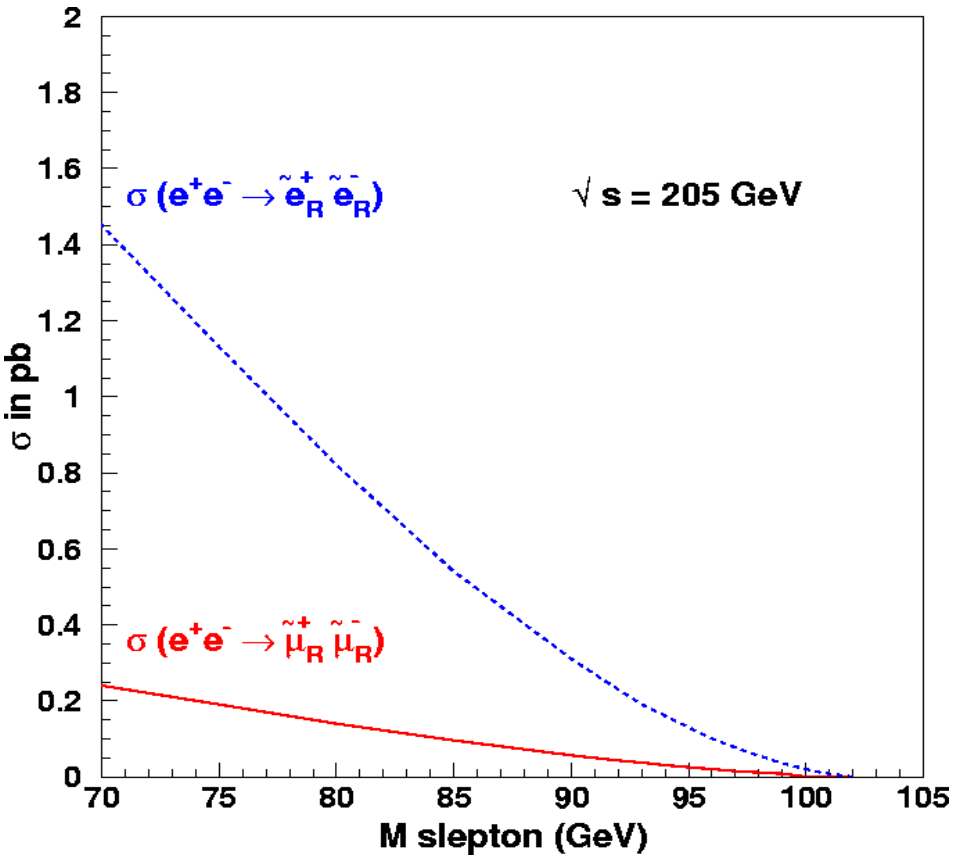


(only $\tilde{e}$)



Cross section production (σ)

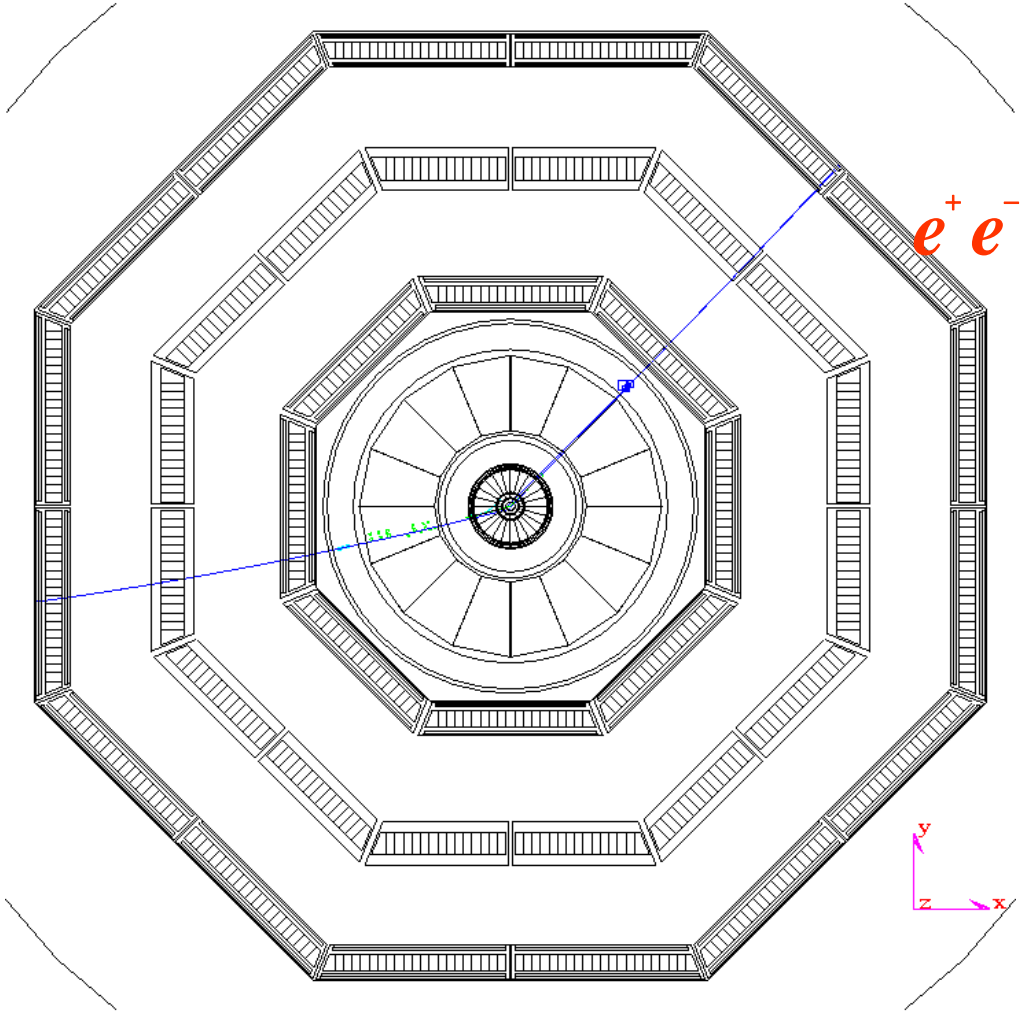
varies as β^3/s -> no sensitivity at the Kinematic Limit

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*				

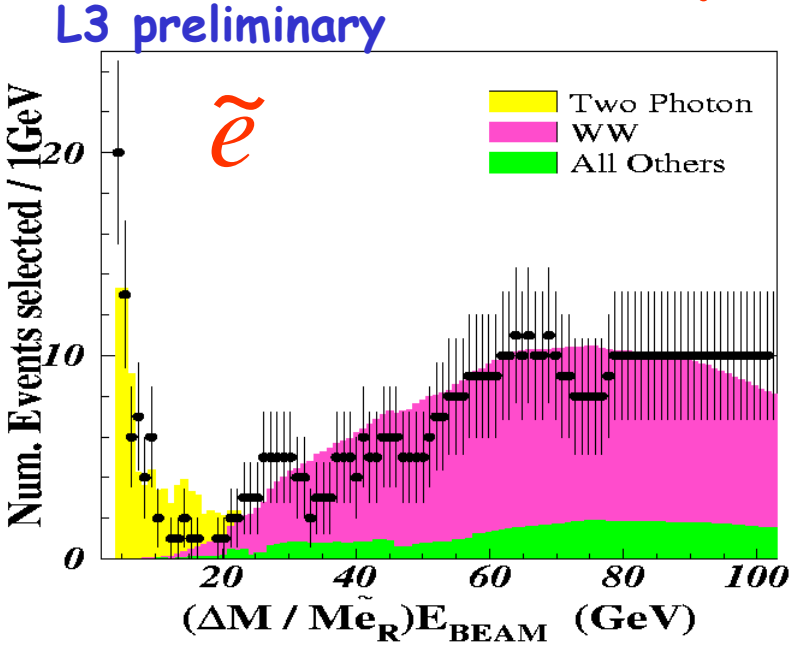
$$e^+e^- \rightarrow \tilde{l}^+\tilde{l}^- \rightarrow (\tilde{l}^+\tilde{\chi}_1^0)(\tilde{l}^-\tilde{\chi}_1^0)$$

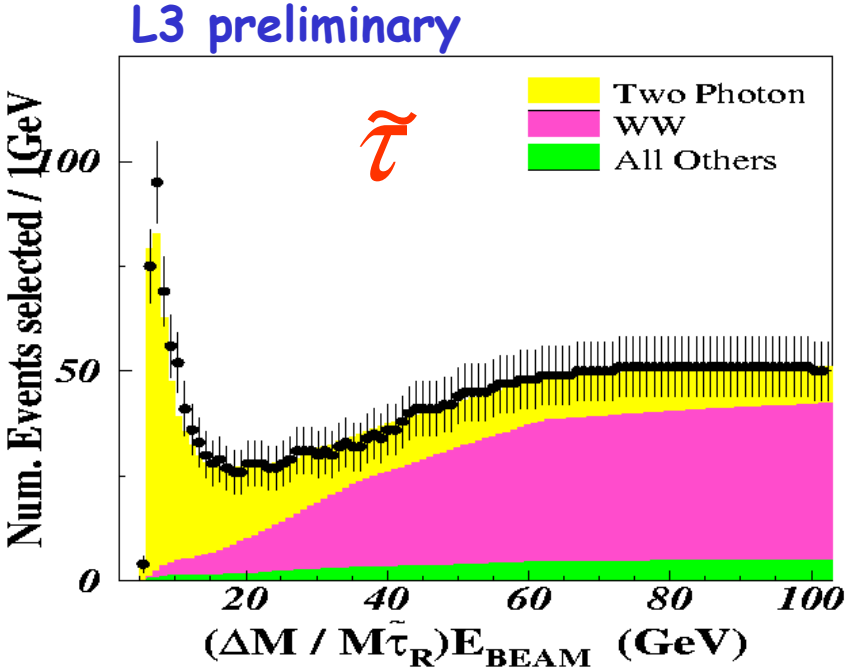
invisibles

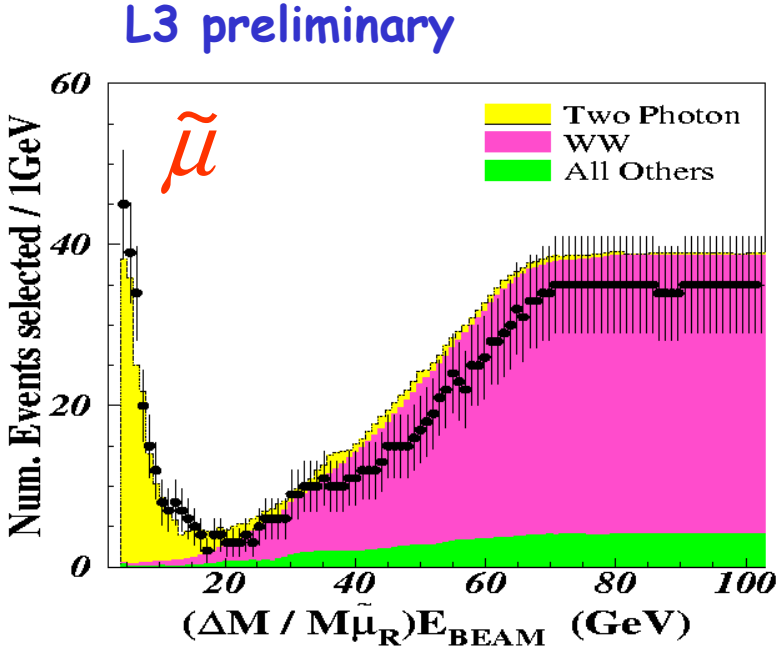
Acoplanar lepton pairs with missing energy

Analysis Method

$\tilde{l}$





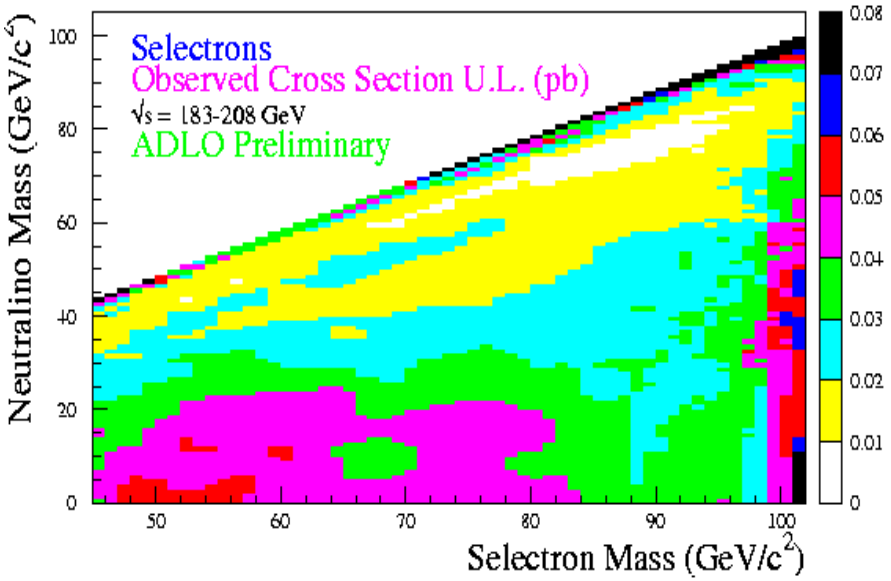


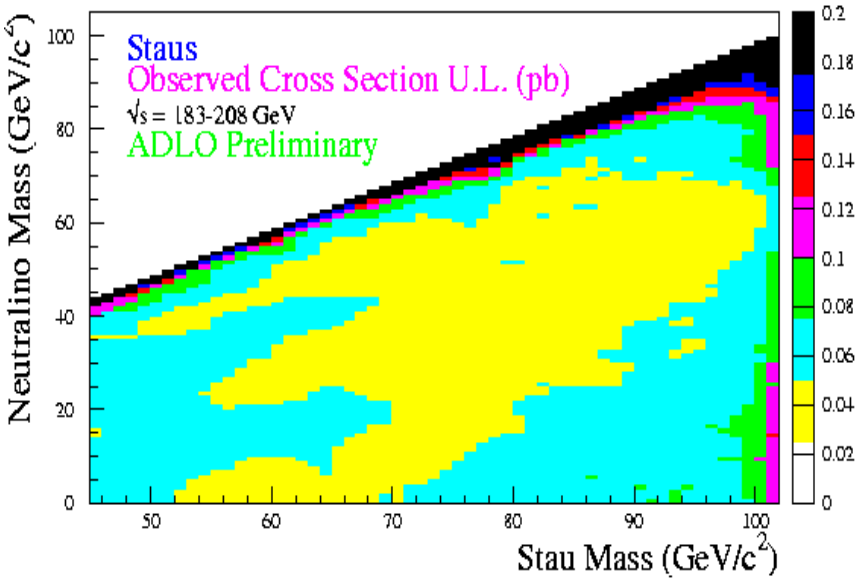
	# obs	# exp	Eff(%)
selectron	48	57.9	53
smuon	47	46.6	55
stau	80	82.1	39

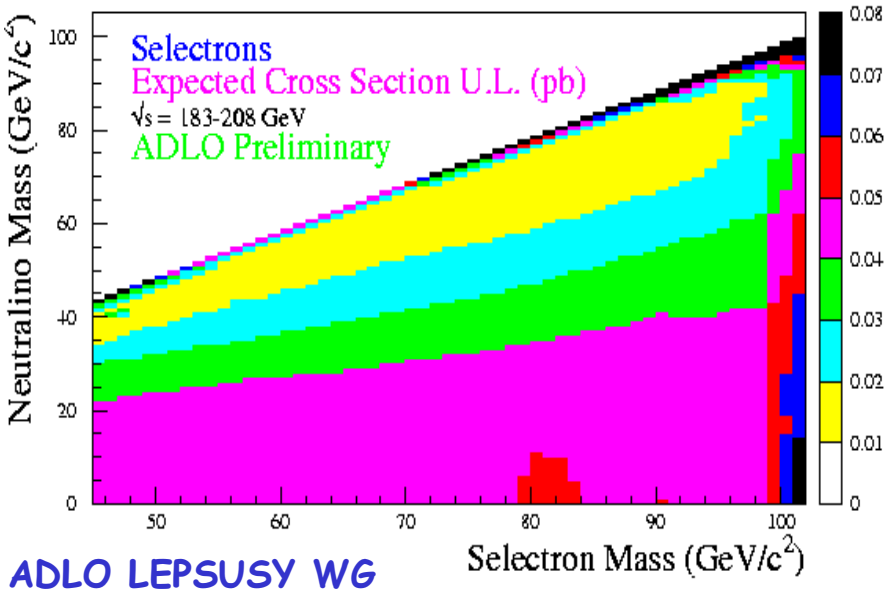
$(M_{\tilde{l}}, M_{\tilde{\chi}^0_1}) = (85, 22)$ GeV

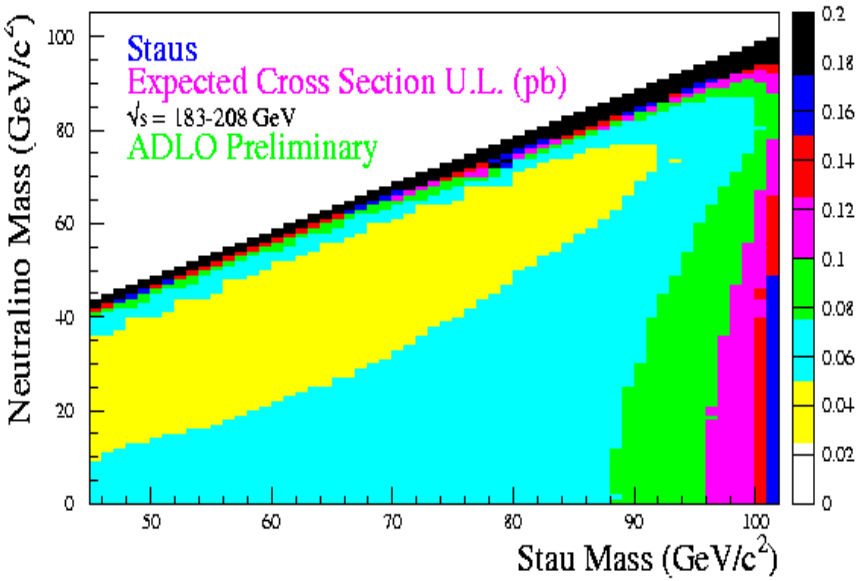
ADLO, Y2K L=585 pb^{-1}

$\tilde{e}$ Cross section Upper limits $\tilde{\tau}$







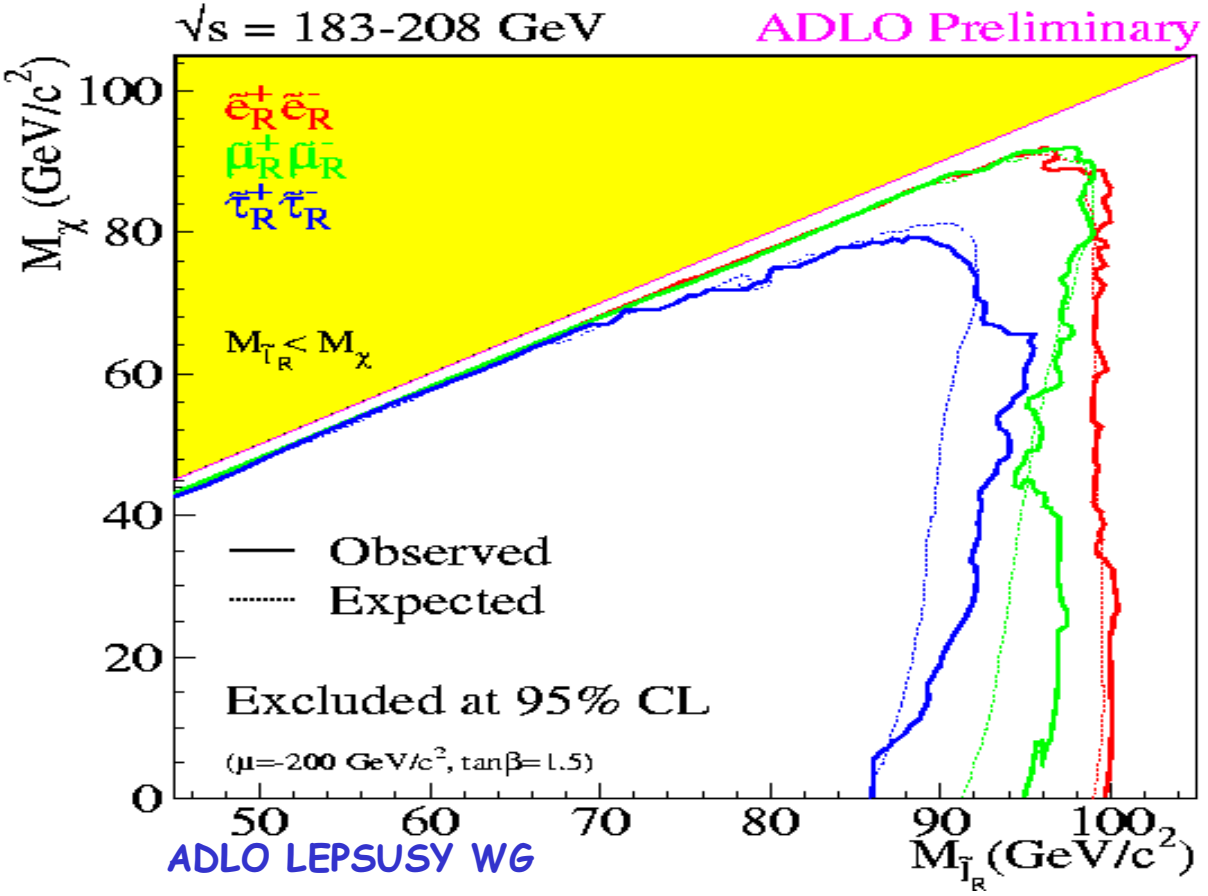


ADLO LEPSUSY WG

$\tilde{e}_R \; \tilde{\mu}_R \; \tilde{\tau}_{1,R}$

Channel	Mass Limit $M\chi^0$=40 GeV
selectron	99.4 GeV (exp 99.4)
smuon	96.5 GeV (exp 94.7)
stau	91.7 GeV (exp 88.8)

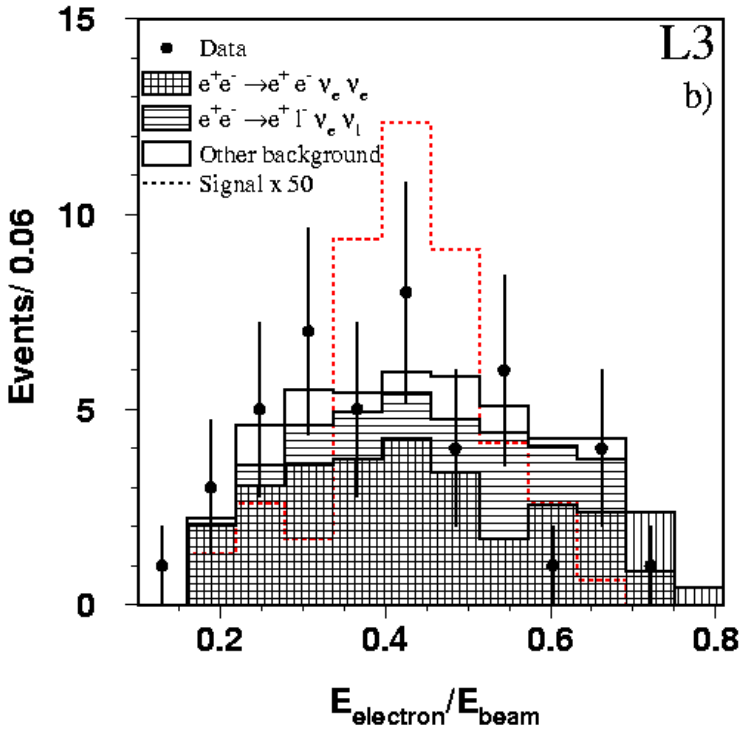
mass limits

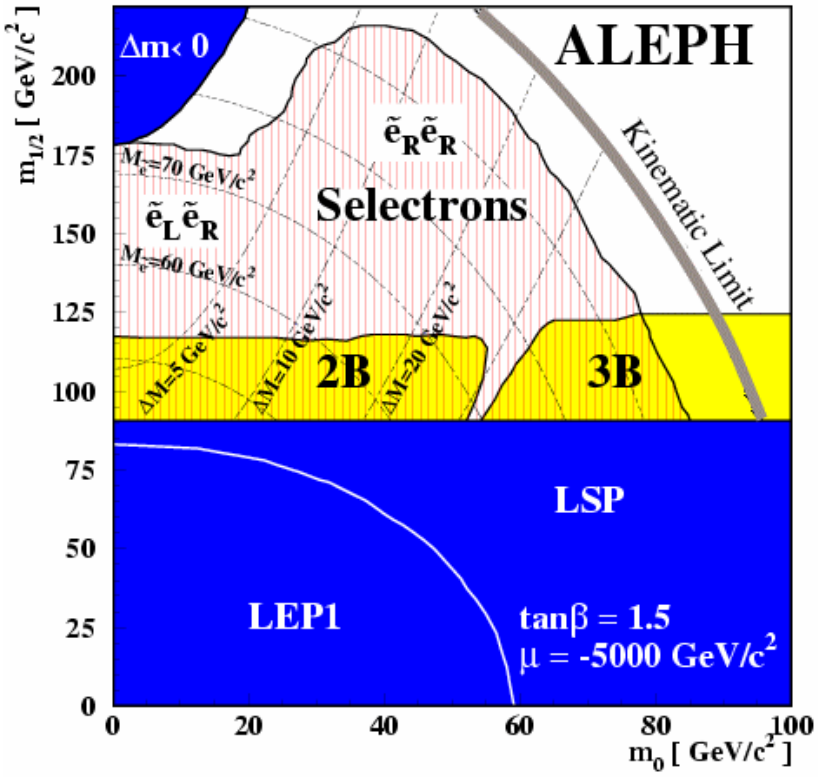


Absolute Mass limits on $\tilde{e}_R$ $\tilde{e}_L$ $\tilde{\nu}_l$

$e^- e^+ \to \tilde{e}_L \tilde{e}_R$ $\quad m_{\tilde{e}_R} \approx m_{\chi_0^1}$

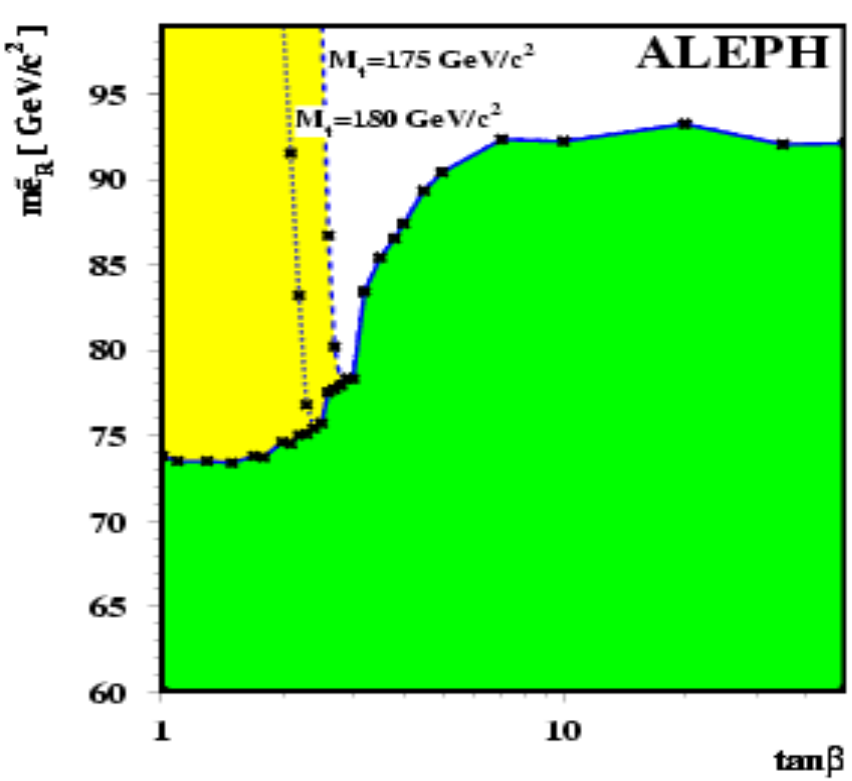
Single electron analysis

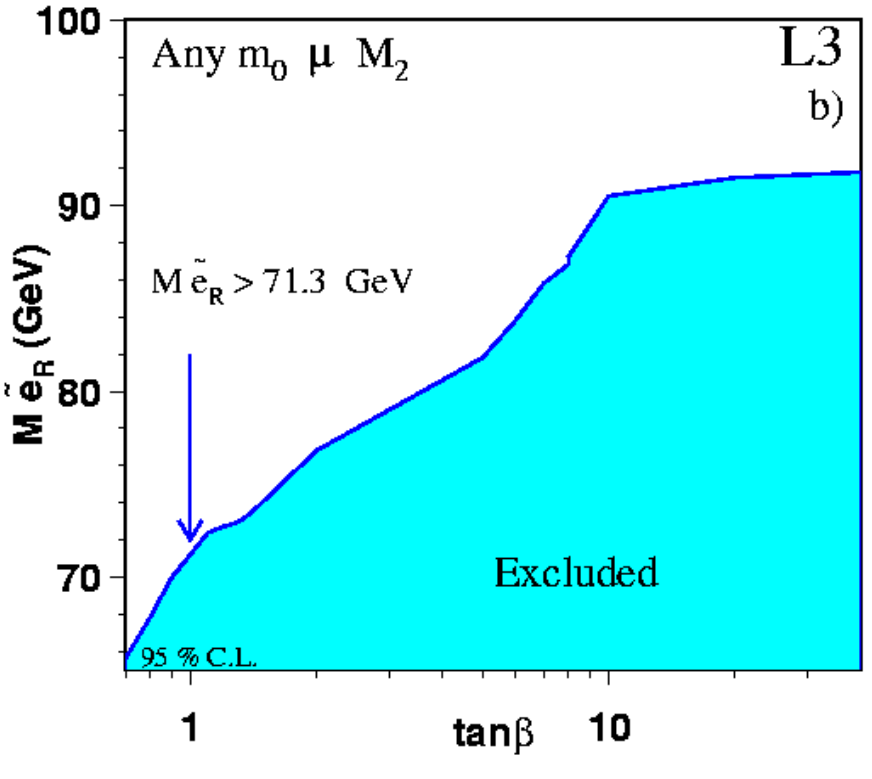




Complementarity of the selectron and chargino searches

Cmssm: Absolute Mass limits on $\tilde{e}_R$ $\tilde{e}_L$ $\tilde{\nu}_l$



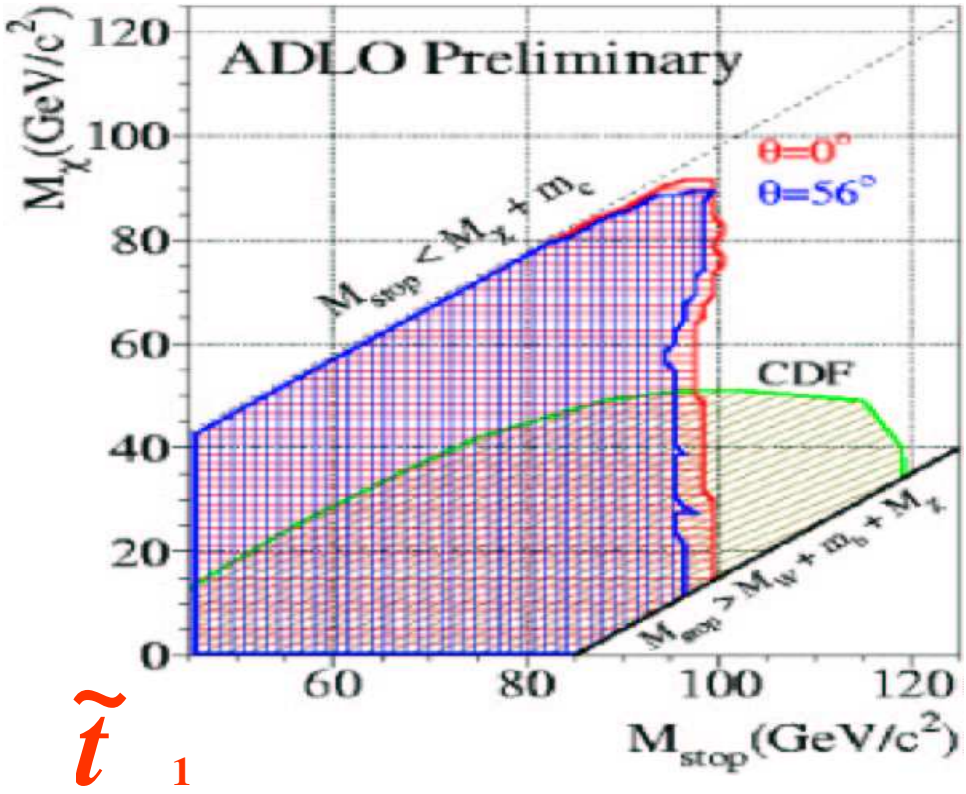


Aleph:

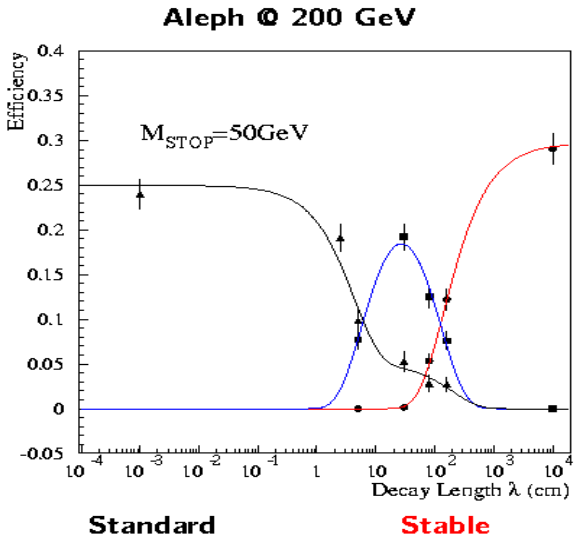
$M_{\tilde{e}_R} \geq 73\,GeV$ $M_{\tilde{e}_L} \geq 104\,GeV$ $M_{\tilde{\nu}_L} \geq 83\,GeV$

Squarks

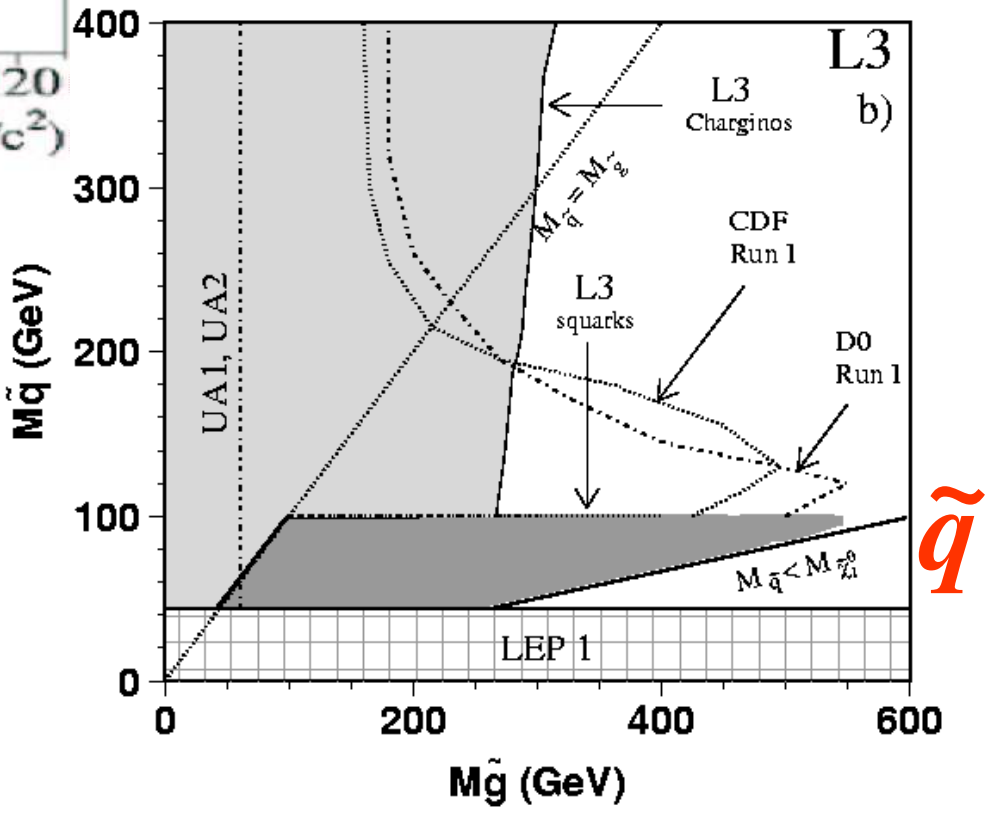
Channel	Mass Limit $M\chi^0$=40 GeV	
stop → cχ	98 GeV	(max mixing 95)
Sbottom → bχ	99 GeV	(max mixing 95)
stop → bl snu	99 GeV	(max mixing 97)



$\tilde{t}_1$

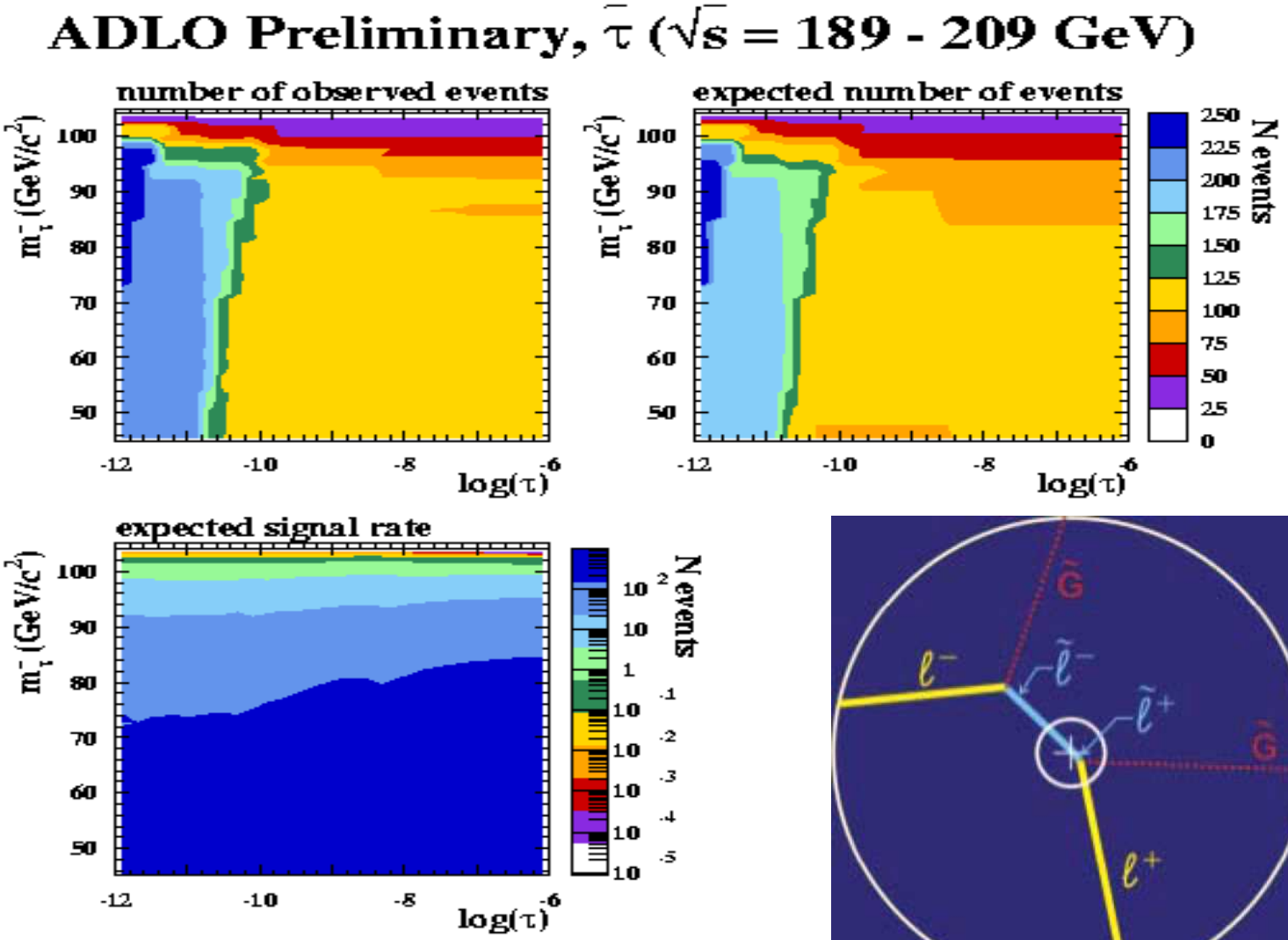


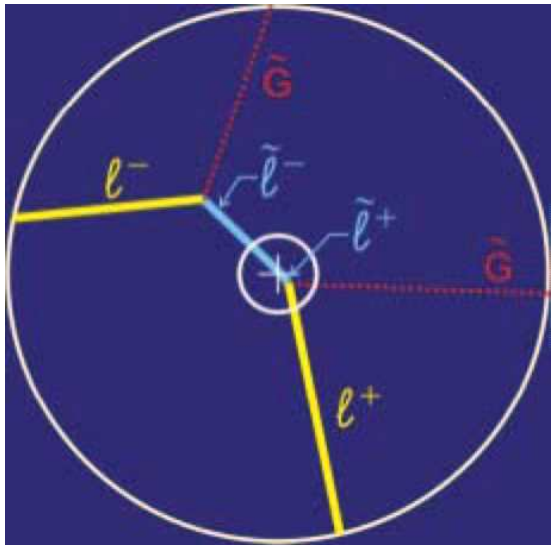
Absolute M stop > 63 GeV



$\tilde{q}$

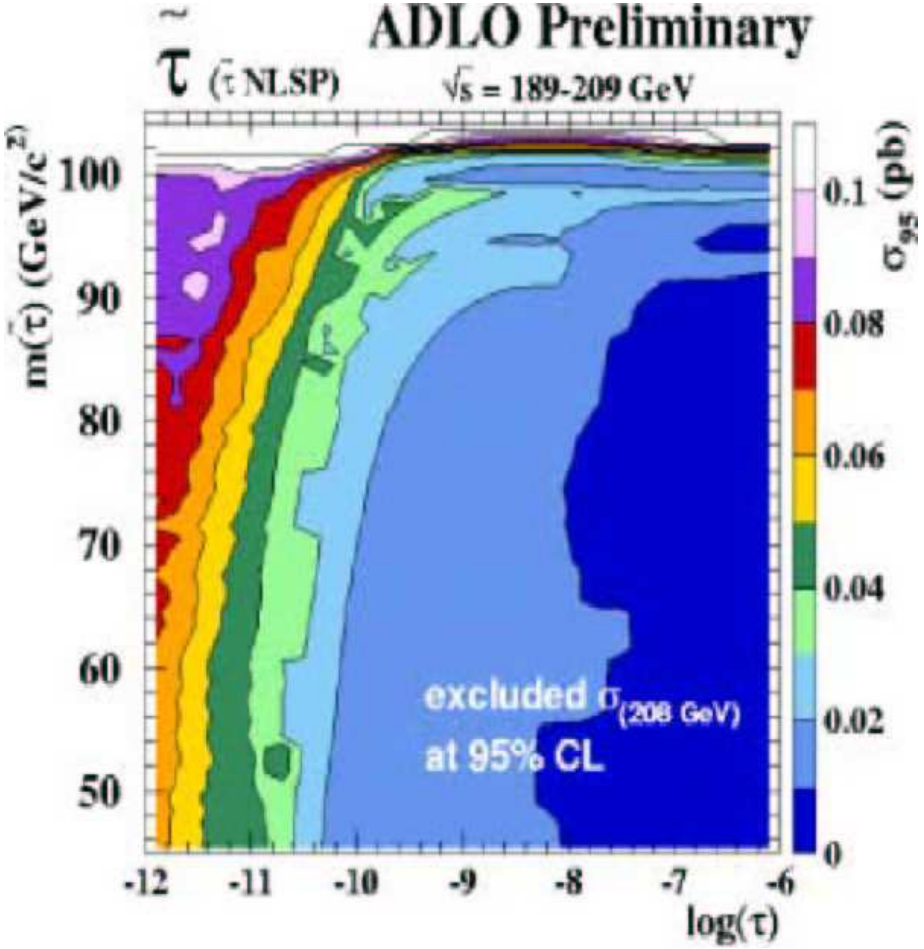
GMSB: slepton Next to ligthest Sparticle

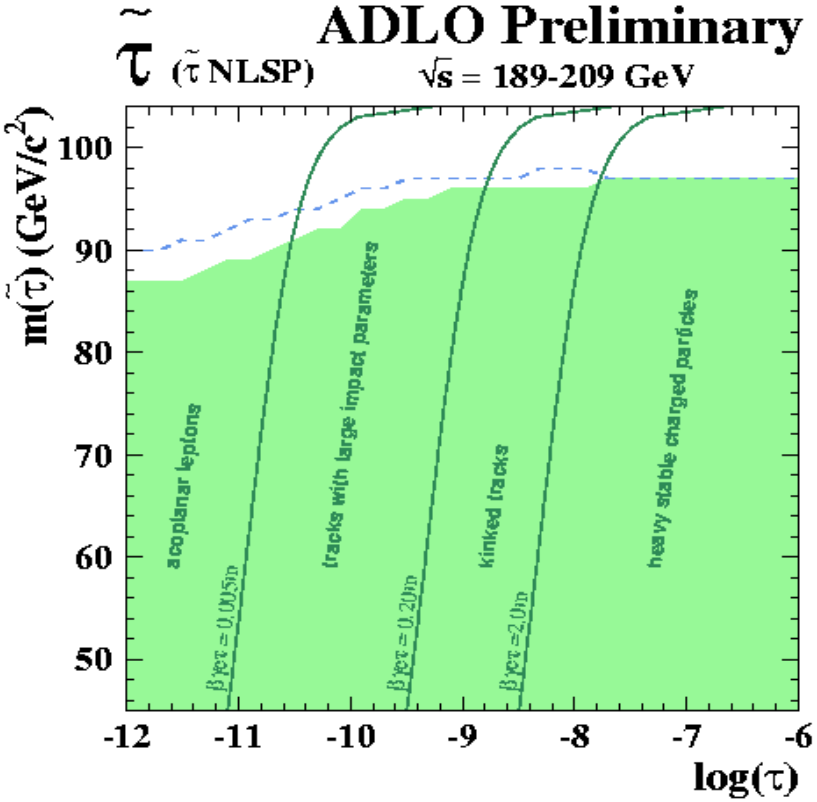




Lifetime signature

GMSB: slepton Next to ligthest Sparticle





ADLO LEPSUSY WG

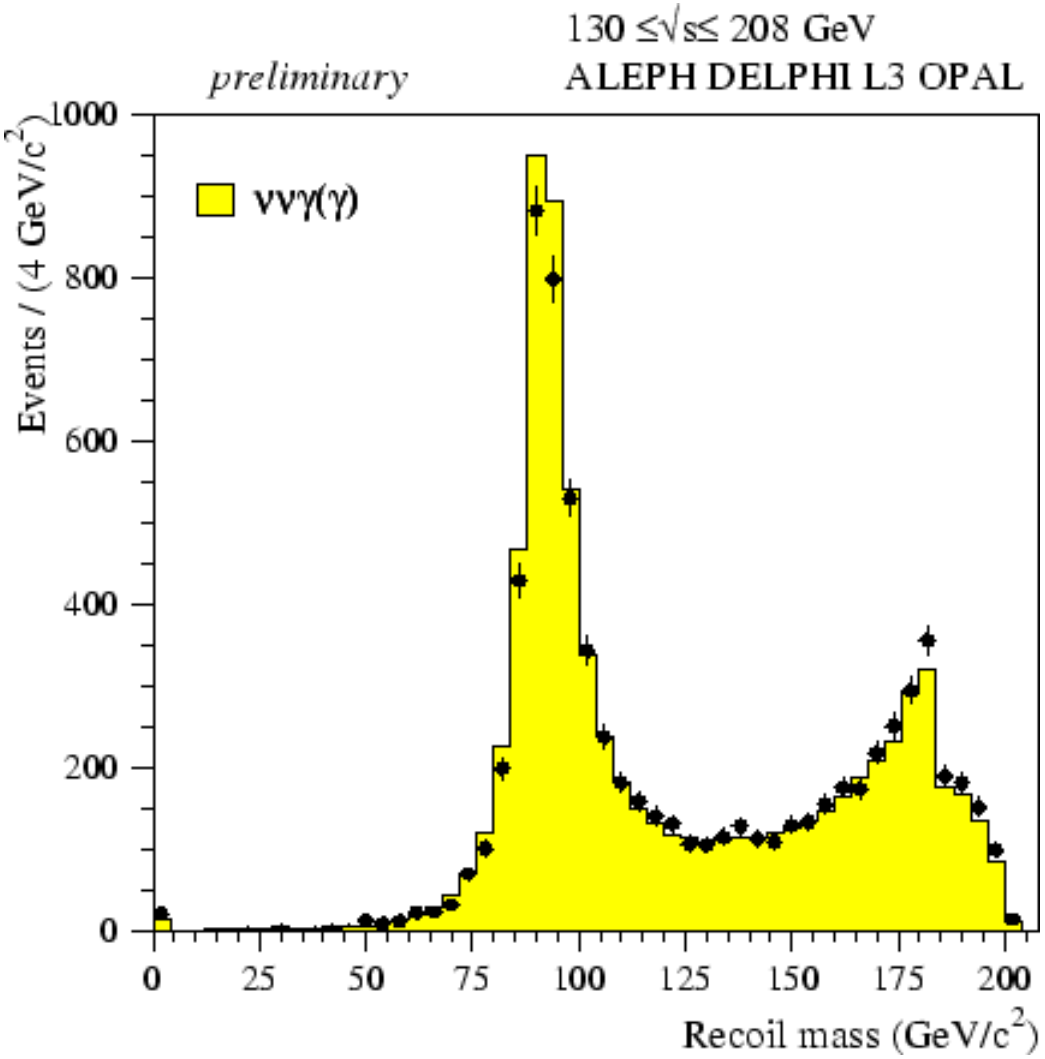
GMSB: Lightest neutralino is the NLSP $\gamma + \not{E}$

$$e^+ e^- \to \chi_1^0 \tilde{G} \to (\tilde{G}\,\gamma)\,\tilde{G} \ \ldots$$

Delphi:

$$M_{\tilde{G}} \geq 1.12 \times 10^{-5}\ eV$$

$$\sqrt{F} \geq 217\ GeV$$

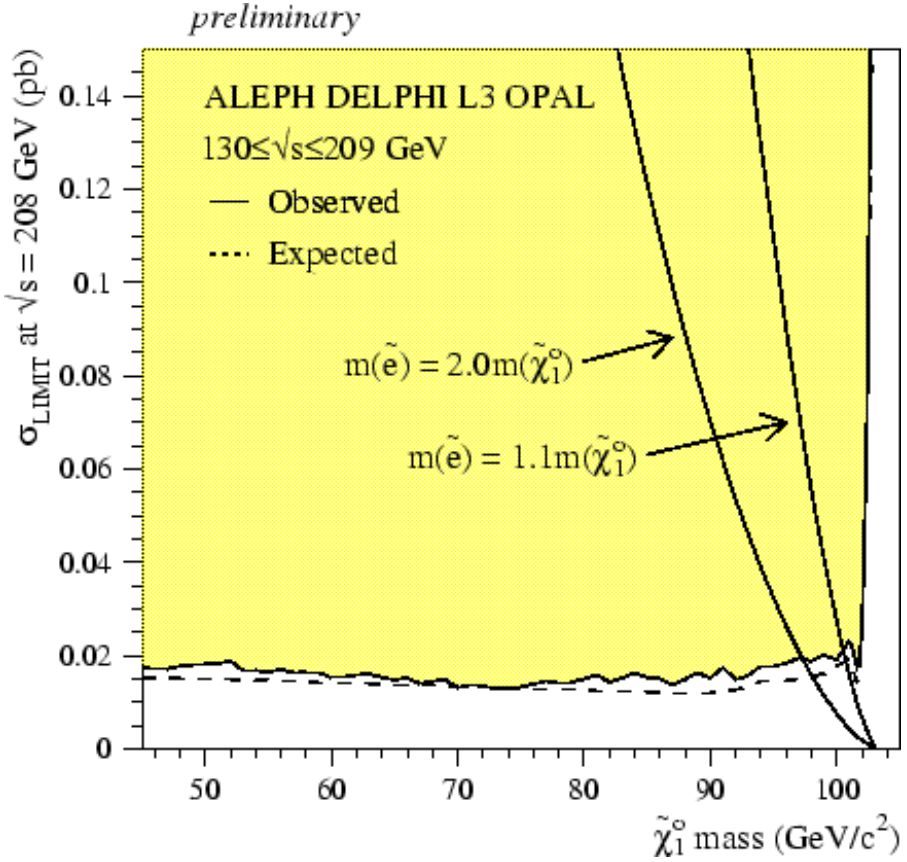


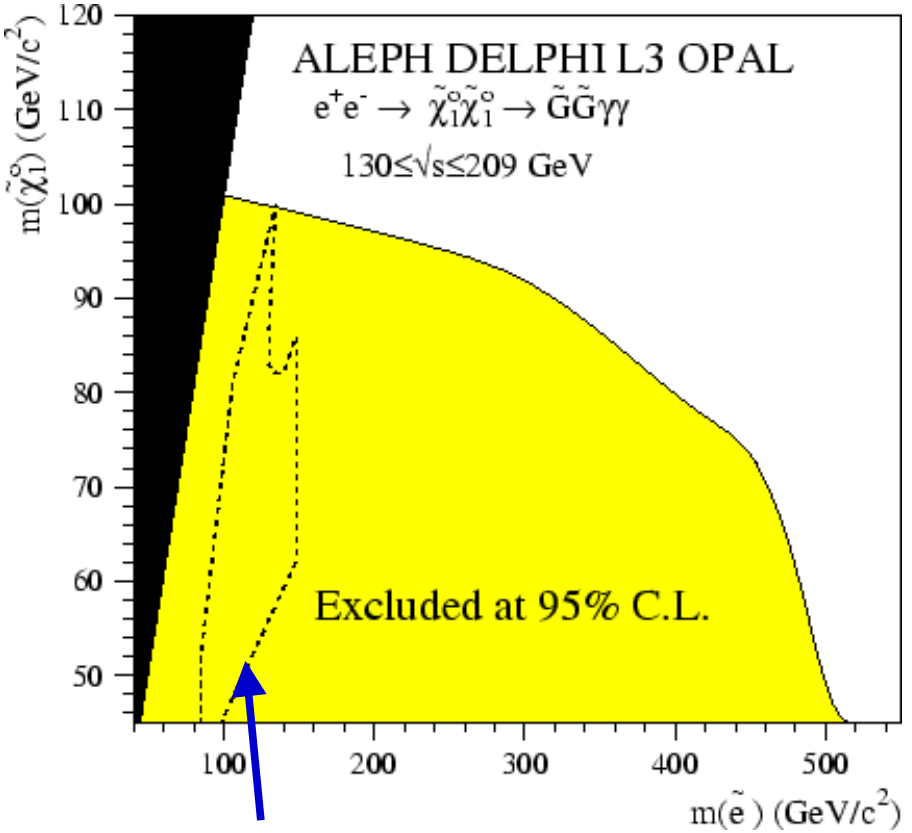
ADLO LEPSUSY WG

GMSB: Lightest neutralino NLSP

$\gamma\gamma+\not{E}$

$$e^+ \; e^- \to \chi_1^0 \chi_1^0 \tilde{G} \to (\tilde{G}\gamma)(\tilde{G}\gamma)$$

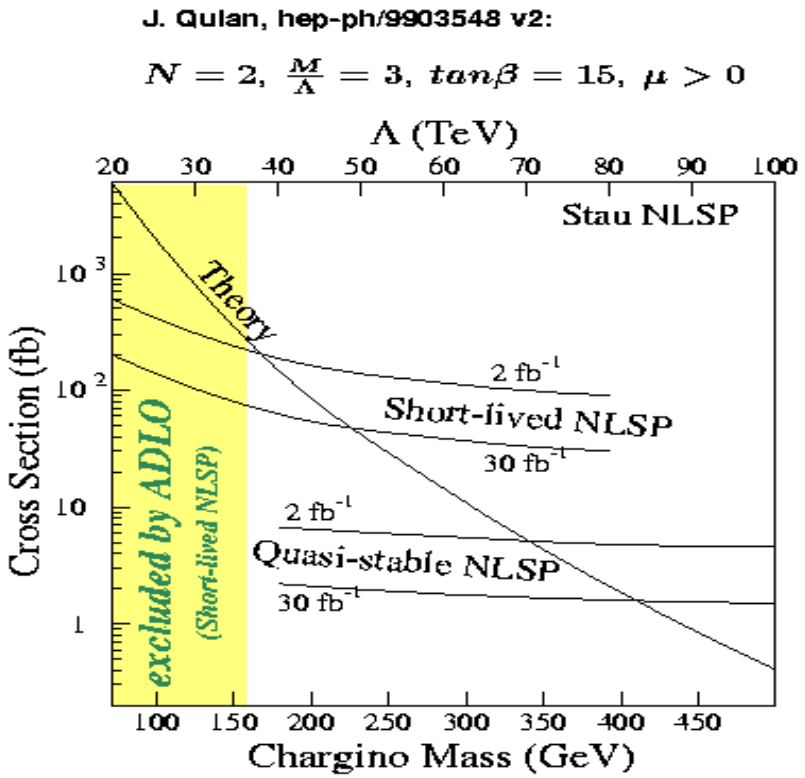


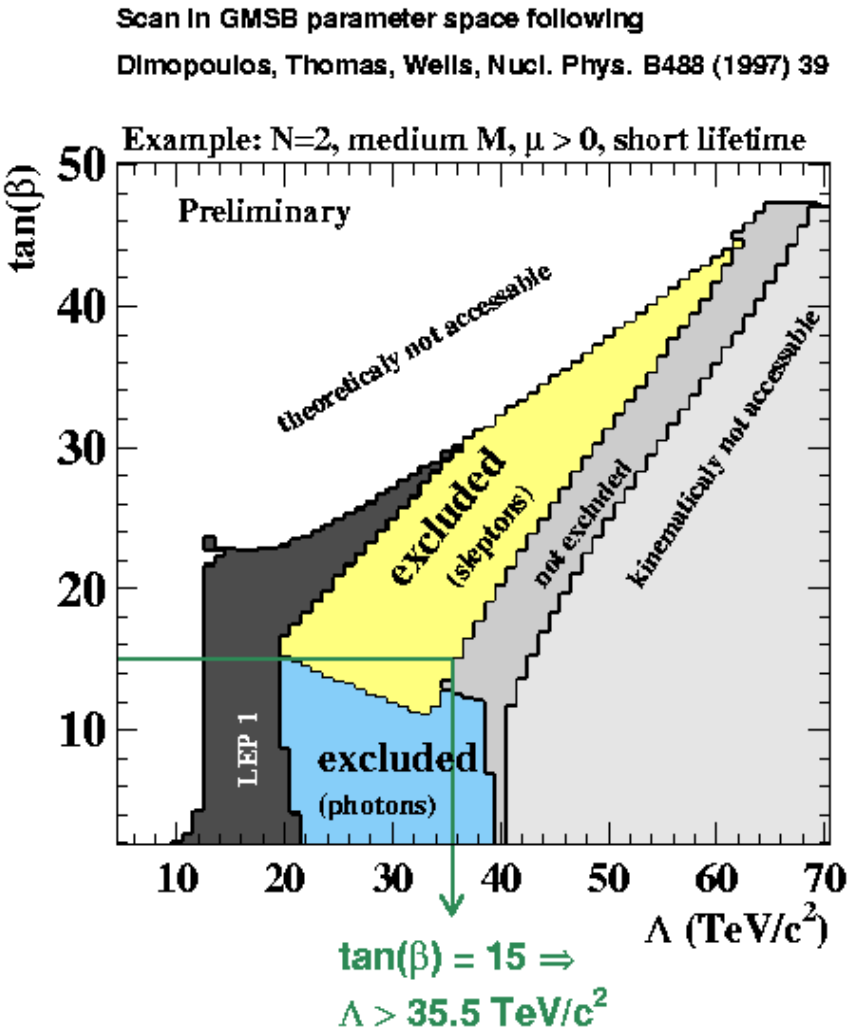


ADLO LEPSUSY WG

CDF eeγγ event

GMSB comparison with the Tevatron





ADLO LEPSUSY WG

Neutralino LSP

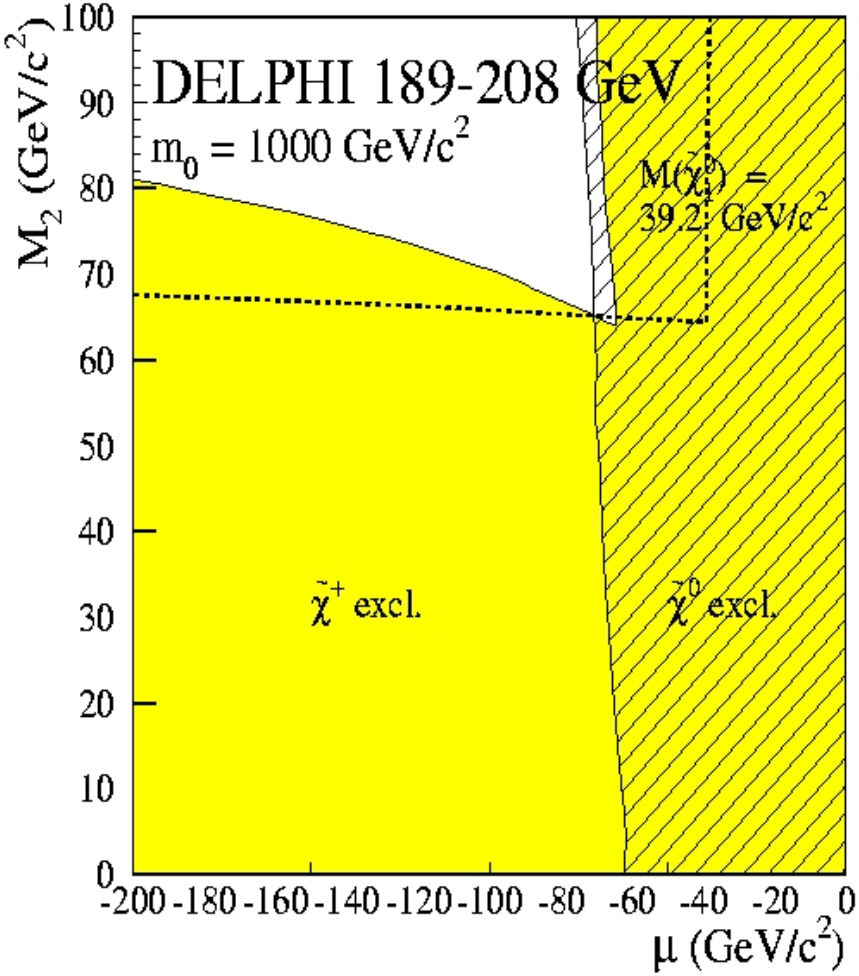
$\tilde{\chi}_1^0$

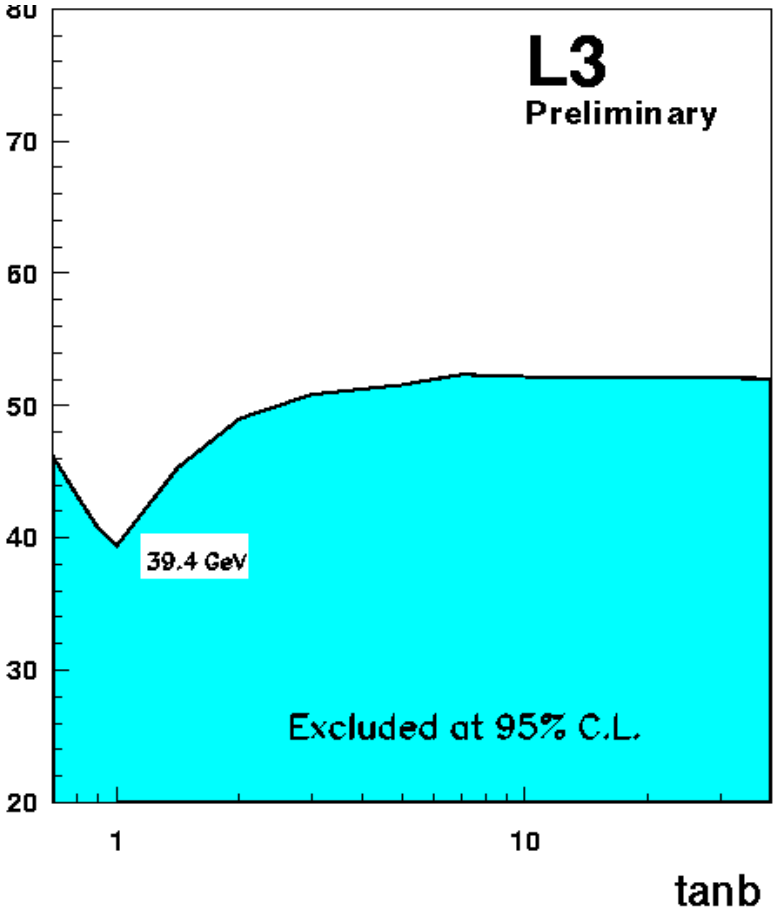
LSP escapes detection -> limits will be indirect:

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

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

Large m_0





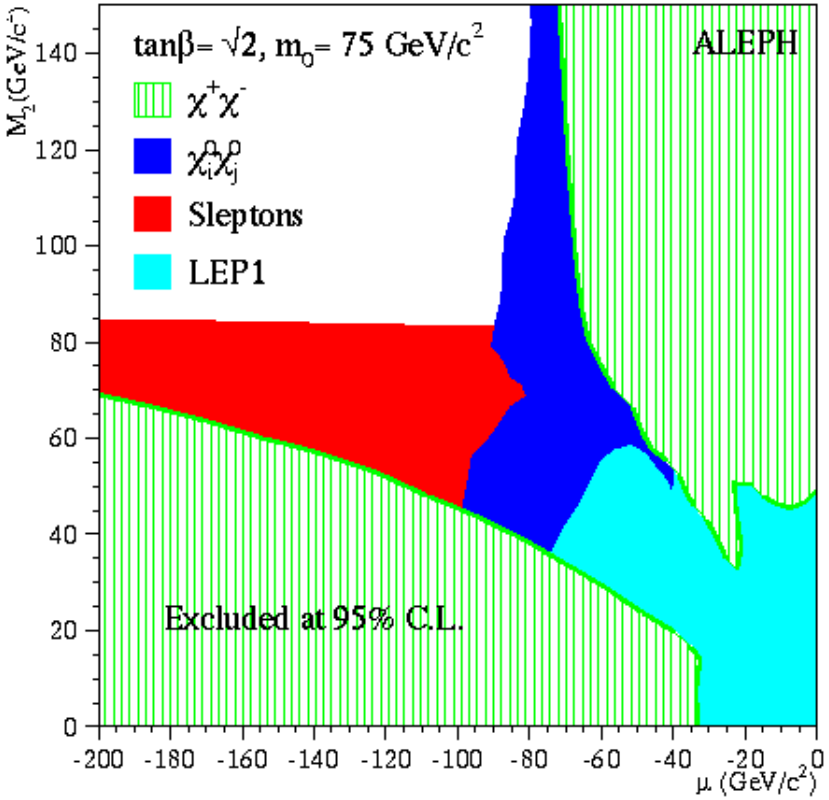
chargino and neutralino search complementarity

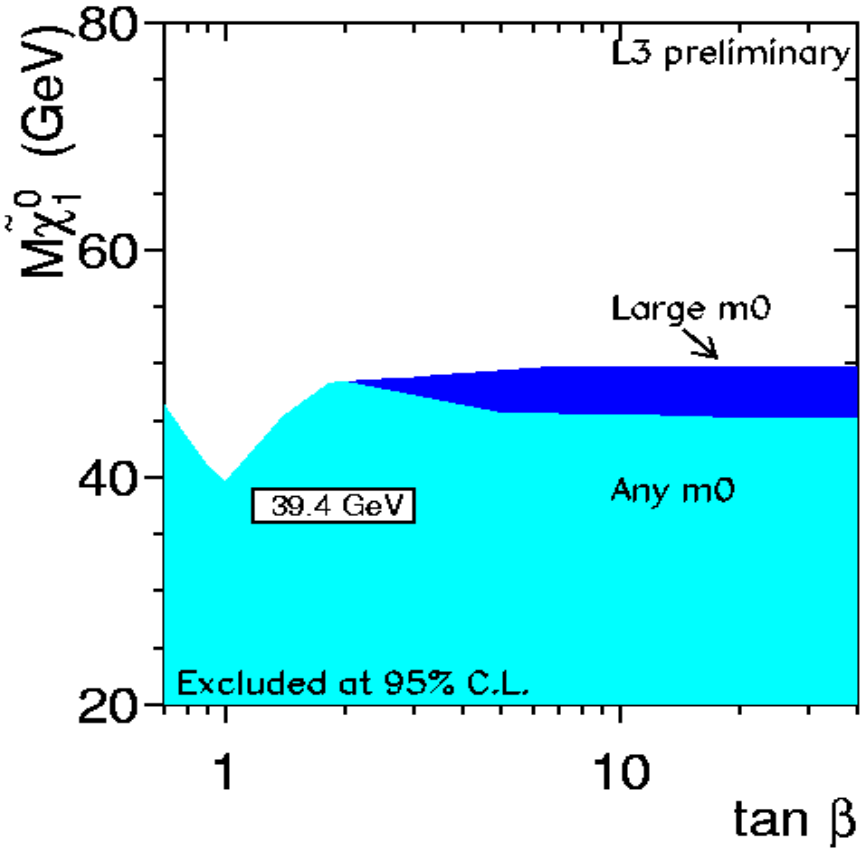
$m_{\tilde{\chi}_1^0} > 37 - 39.6$ GeV $\sqrt{s} \geq 200$ GeV

Combination of Slepton, chargino heavy neutralino searches

For any m_0 LSP mass limit given by the slectron mass limit for

$$|M\tilde{\chi}_1^+ - M\tilde{\nu}| \leq 3 \text{ GeV}$$





M_h^2 depends on

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

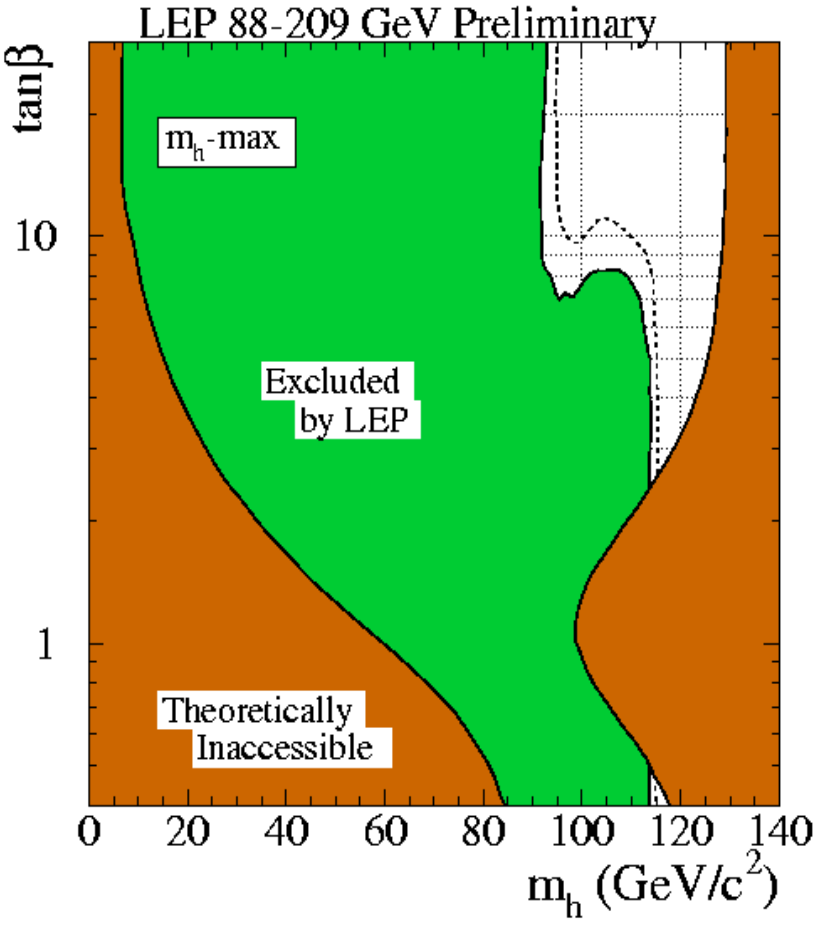
$\rightarrow$ constraints on $\tan\beta$

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

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

$+\tilde{t}$ sector mixing

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



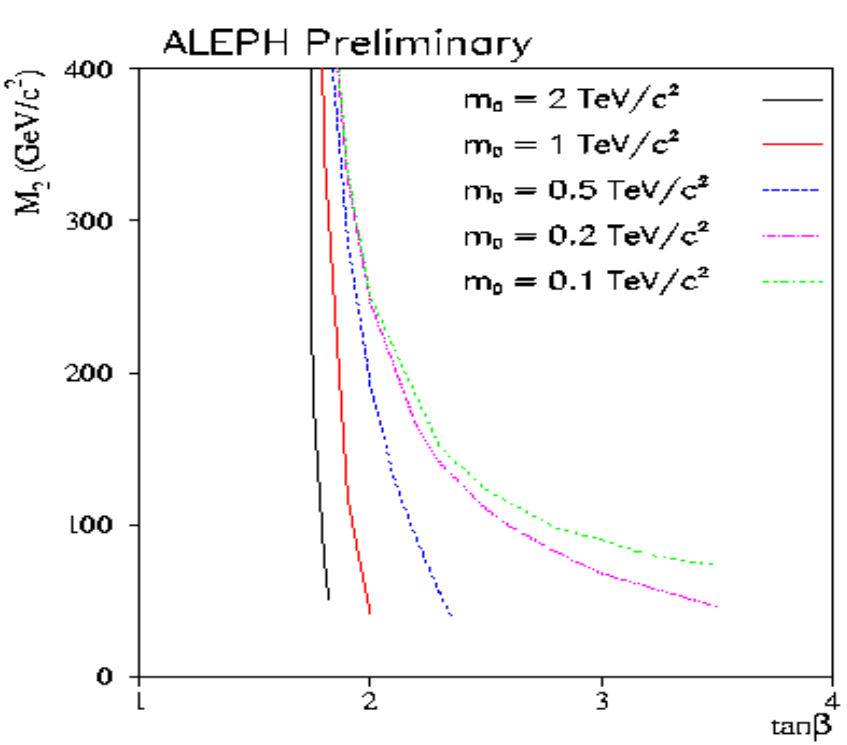
+ **Stop mass absolute limit**

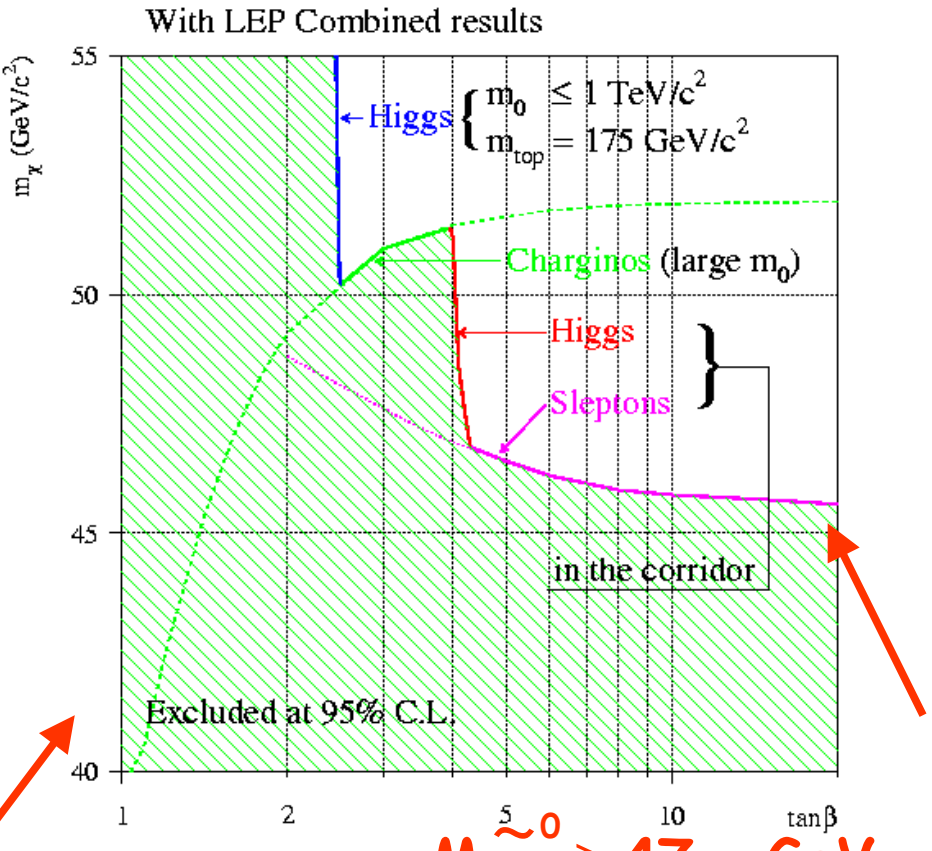
$h \rightarrow \tilde{t}\tilde{t}$ **closed**

+ **including HZ and invisible channel**

Higgs constraint is robust

Higgs and Stop constraints





Selectron LEP SUSY WG

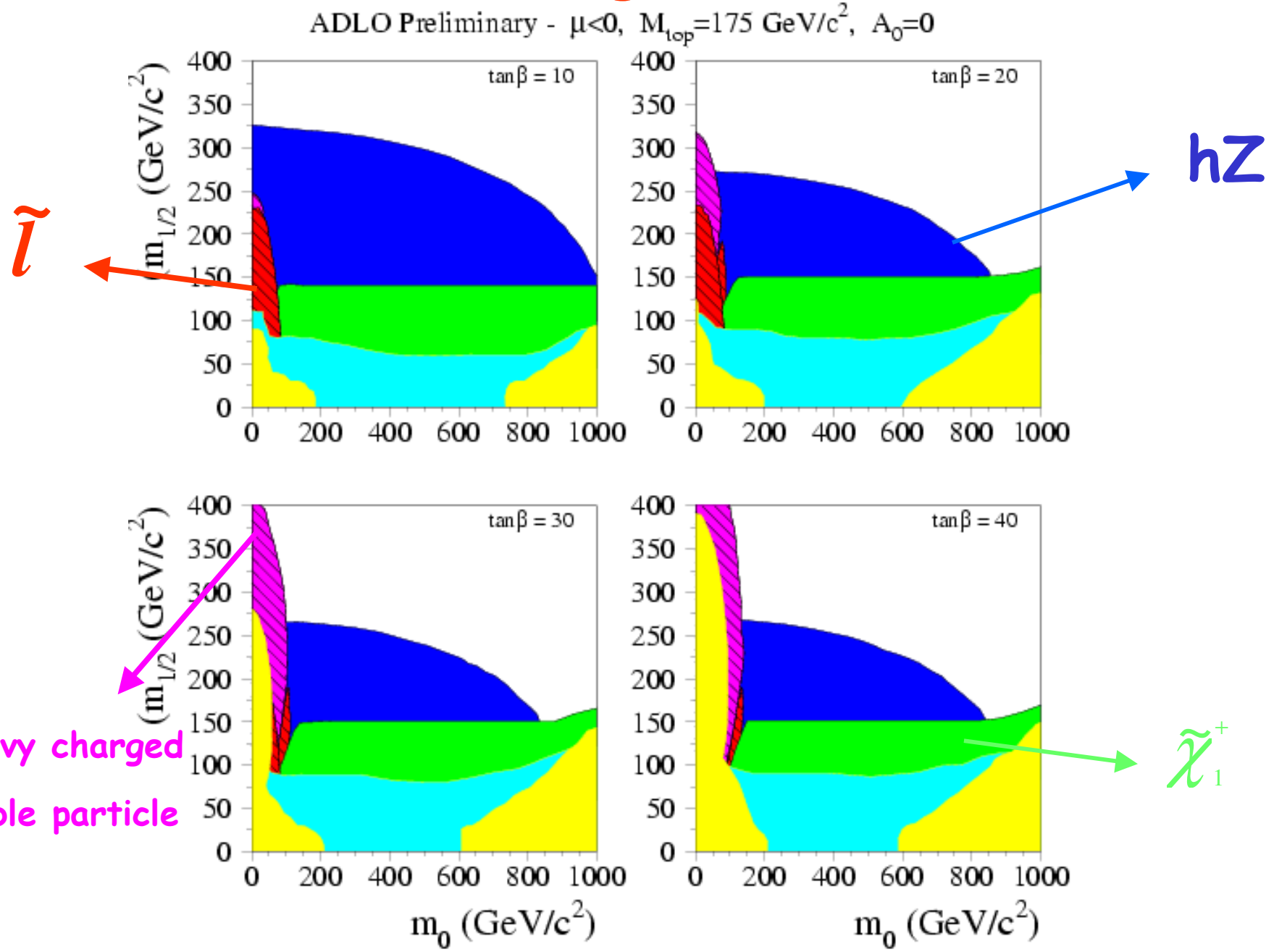
LEP HIGGS WG

Chargino searches from Aleph

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

(Mtop = 175 GeV)

Msugra



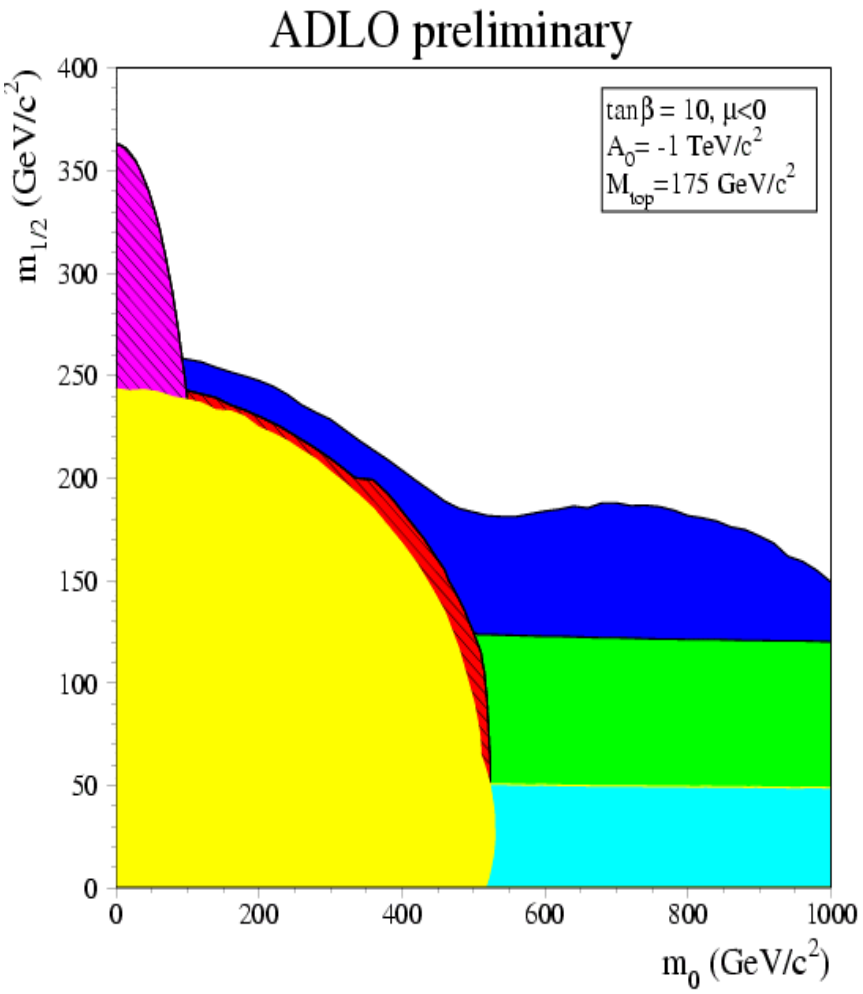
$\tilde{l}$

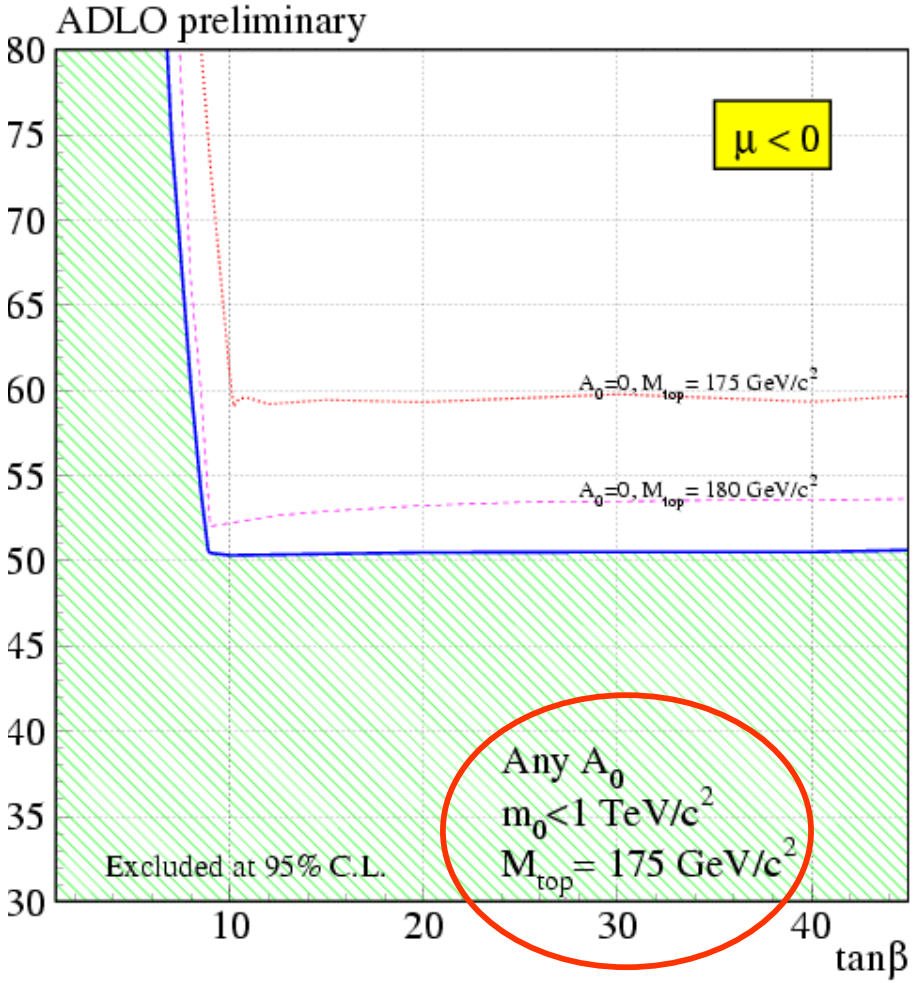
hZ

Heavy charged stable particle

$\tilde{\chi}_1^+$

Msugra





LEP exclusions sensitive to the chosen values of A_0

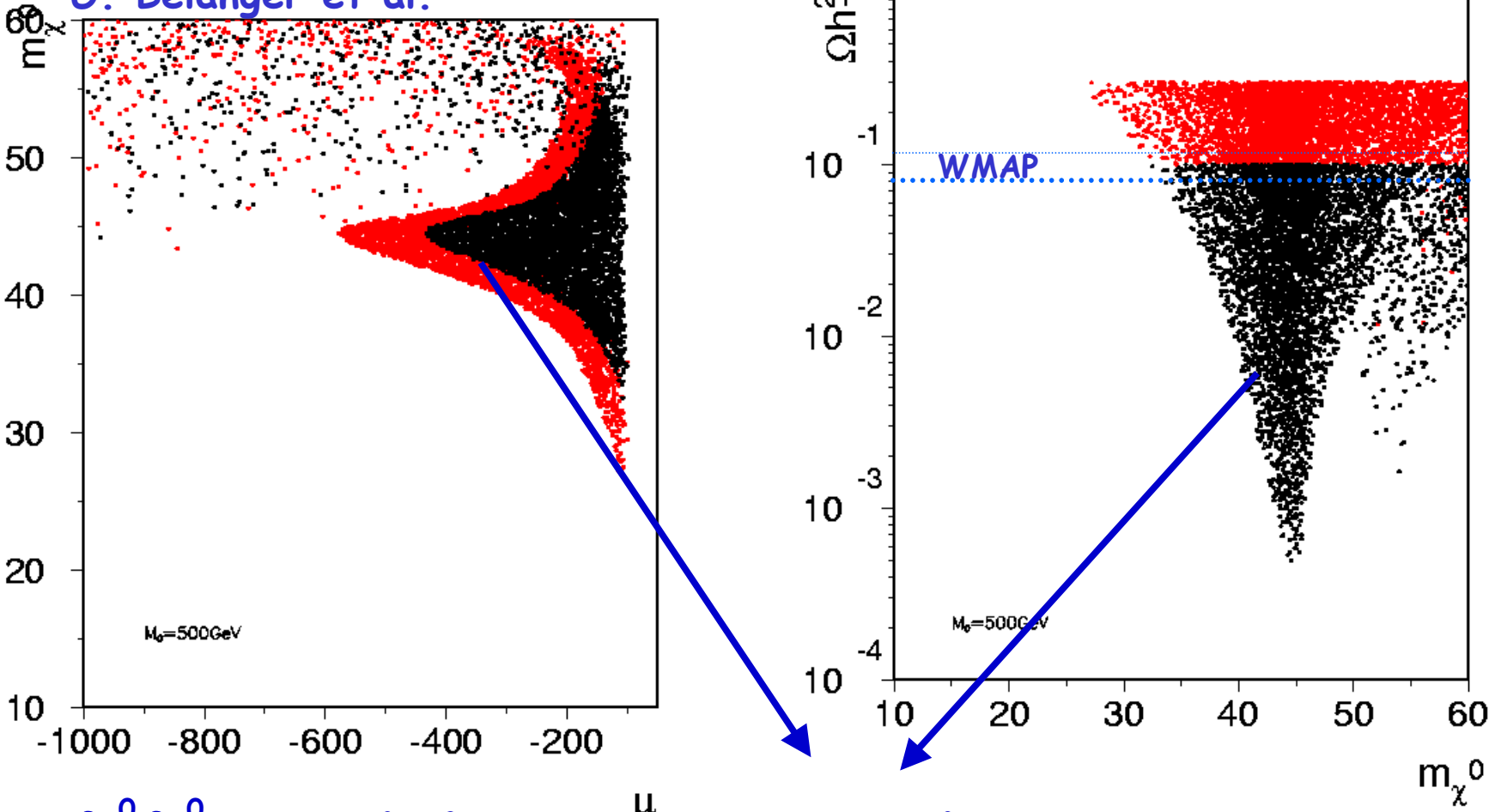
$M\tilde{\chi}_1^0 \geq 50.3$ *GeV*

Towards non gaugino mass unification

Relic density constraint

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

G. Belanger et al.

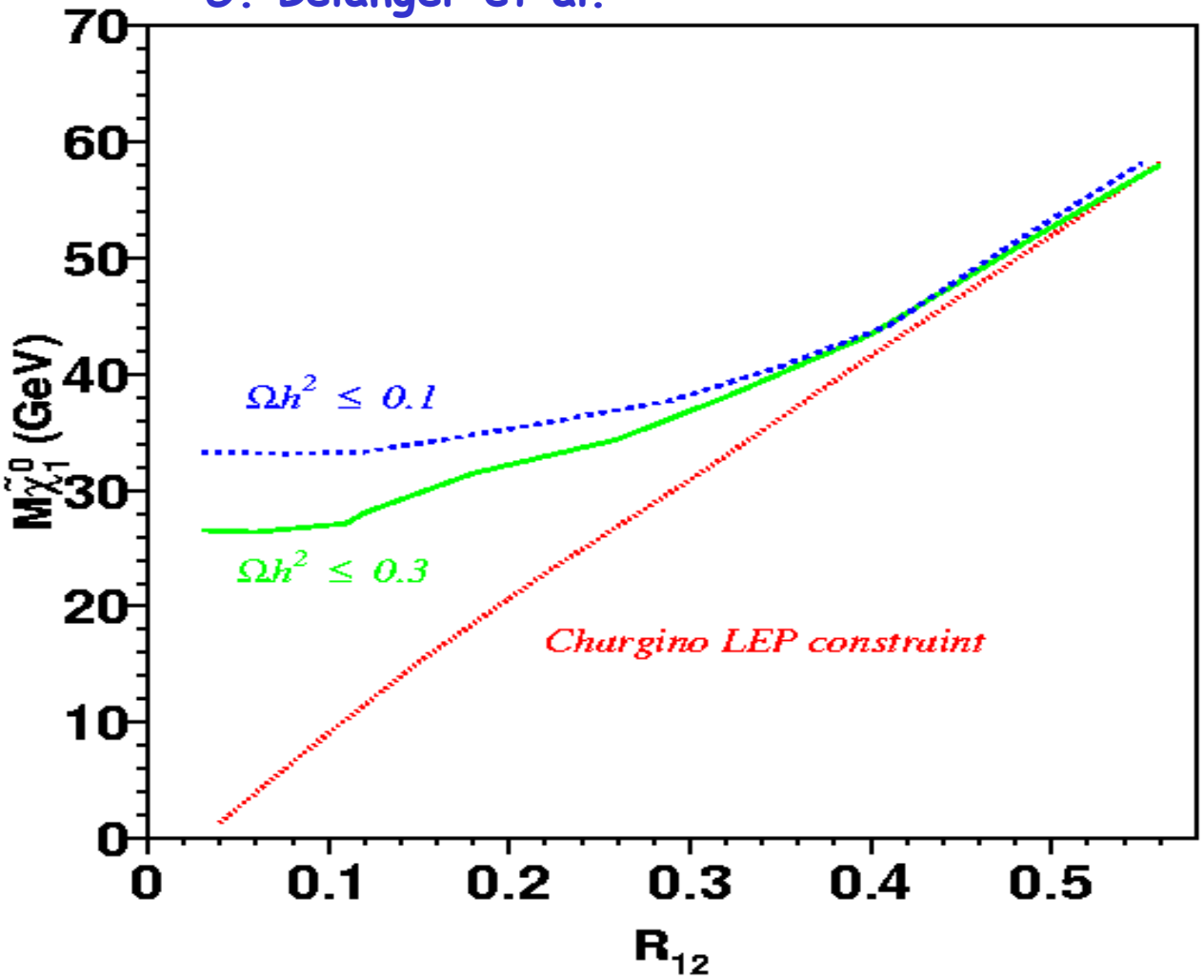


$\tilde{\chi}_1^0 \tilde{\chi}_1^0$ annihilation into Z dominates

Towards non gaugino mass unification

Large m_0, $R_{12}=M_1/M_2$

G. Belanger et al.



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

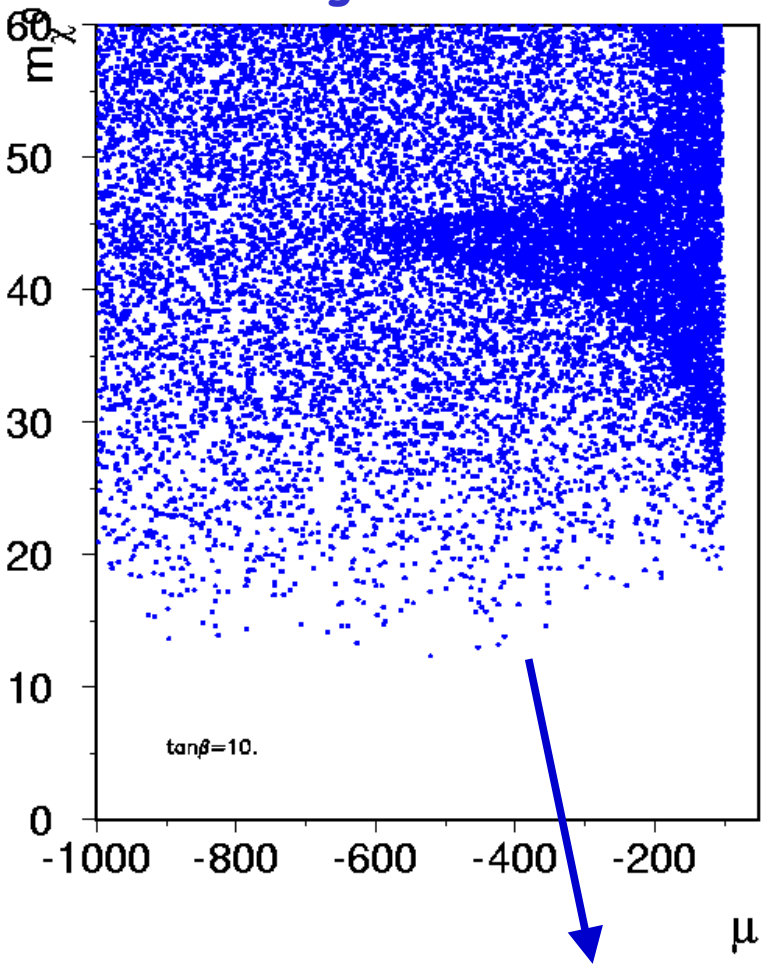
$(\Omega h^2 \leq\leq 0.3)$

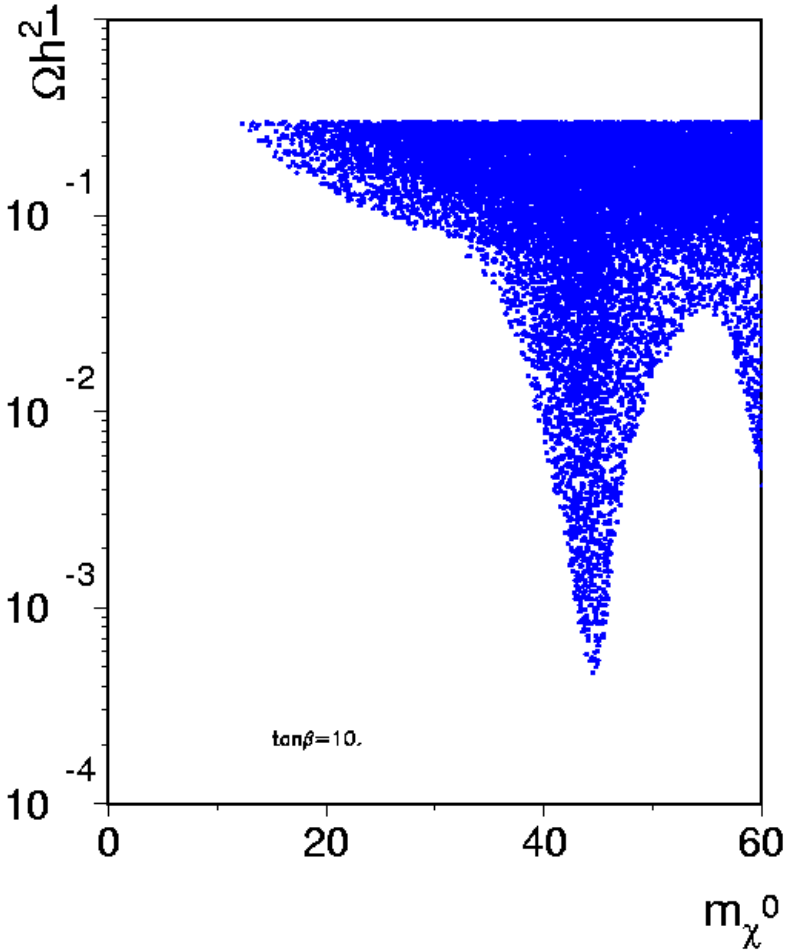
Any tanβ

Towards non gaugino mass unification

$\tan\beta$=10 any m_0

G. Belanger et al.





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

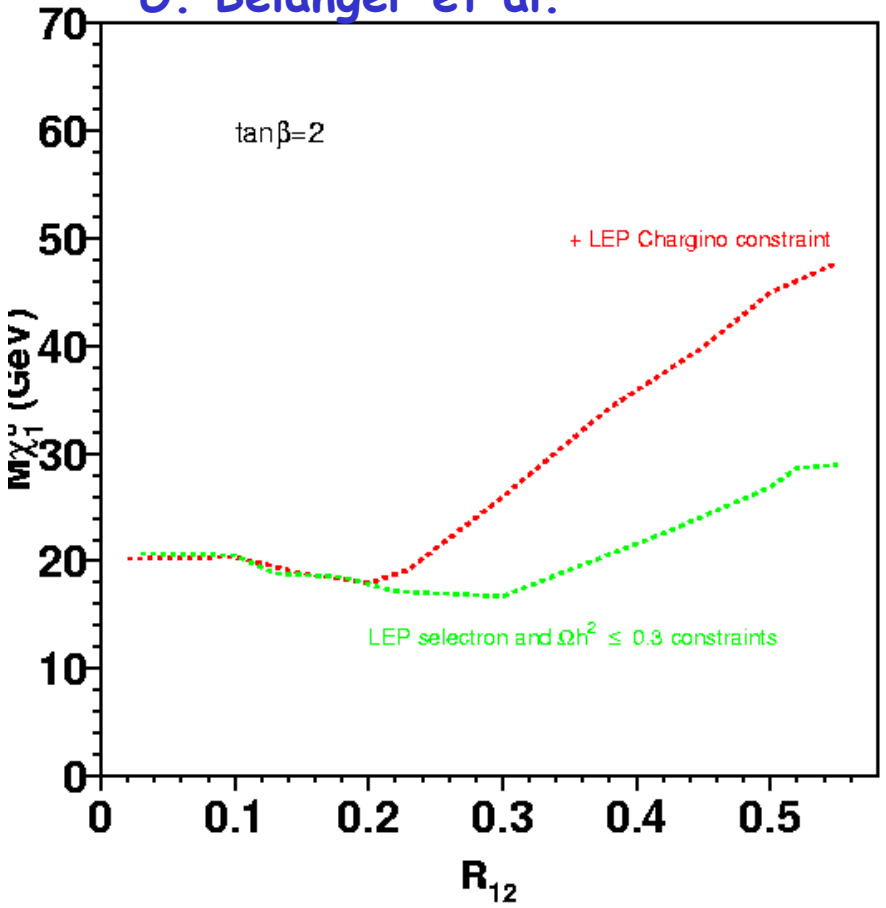
Towards non gaugino mass unification

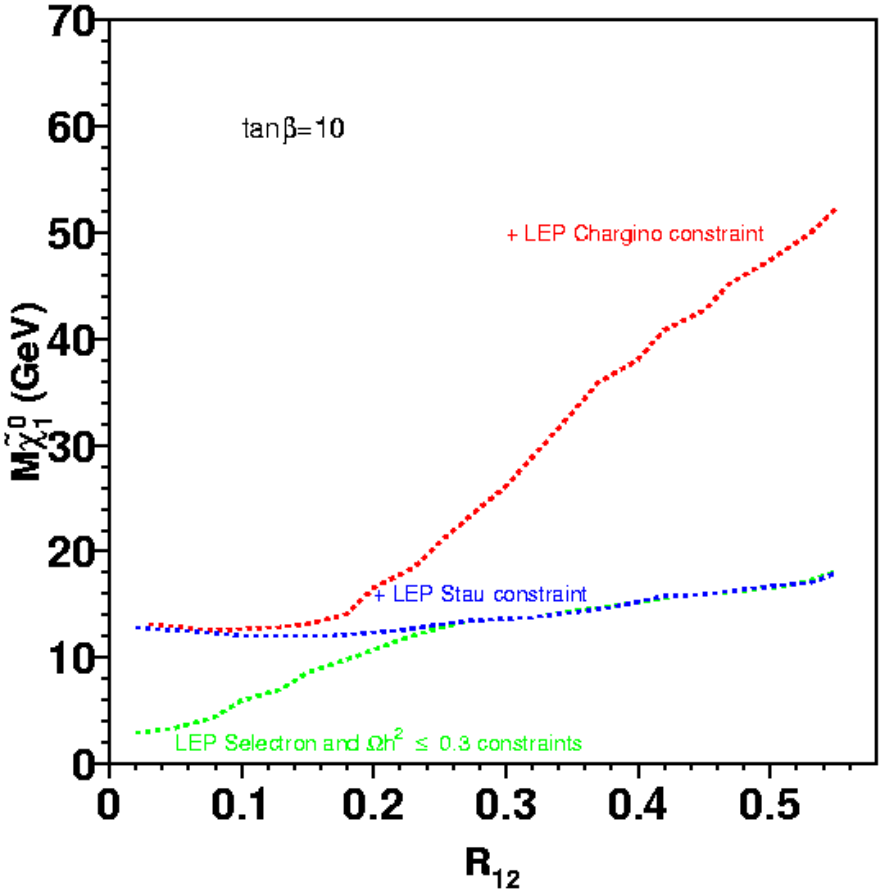
Any m_0 Contribution of stau,selectron and chargino LEP results and Relic density

G. Belanger et al.

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

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





Conclusions

A very wide range of searches have been performed at LEP:

Open triggers and all decay modes are studied

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

The complementarity of the searches allows to set robust limits and to relax the mass universality assumptions

The absolute LSP mass limit is 39.6 GeV in the Cmssm framework and becomes 47 GeV when including Higgs constraints (50.3 GeV, Msugra)