XXXIst Rencontres de Moriond
QCD and Hadronic Interactions
29/3/96

Limits at LEP at $\sqrt{s}$=130-136 GeV

Paolo Giacomelli

UCR

- **Introduction**
- **Supersymmetric particles**
- **Heavy Leptons**
- **Excited Leptons**
- **Conclusions**

What I will not treat (see other talks at this conf.):

4-jet final states

4-fermion processes

Introduction

- **Three weeks of running time in November 1995 (LEP 1.5)**
- **Highest energy available at an e^+e^- collider, $\sqrt{s}$ = 130, 136 and 140 GeV**
- **Total integrated Luminosity 5.1-5.7 pb^{-1} (per experiment)**
- **Good opportunity to extend to a new frontier a lot of Searches**
- **Event topologies that could originate from New Physics signals**
  - Isolated Leptons (particle id.)
  - Photons (calorimetry)
  - Acoplanar Jets (tracking, calorimetry)
  - Missing Energy (hermeticity)

Introduction

- **Backgrounds for Searches**
  - Great reduction compared to LEP 1
  - σ ($e^+e^- \rightarrow q\bar{q}\gamma$) ~ 300 pb
  - σ ($e^+e^- \rightarrow l\bar{l}\gamma$) ~ 90 pb
  - Four fermion processes, small cross section but difficult to eliminate
  - Two photon processes $\gamma\gamma \rightarrow q\bar{q}$, $l\bar{l}$ large cross-section (σ ~ 40 nb) but can be greatly reduced
  - LEP 2 backgrounds (WW, ZZ) still small
    - σ ($e^+e^- \rightarrow W^+W^-$) ~ 0.2 pb

SUSY

In SUSY models all "normal" particles are accompanied by their supersymmetric partners, whose spin differs by 1/2.
A new multiplicative quantum number, R, is generally assumed to be conserved:

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

Conservation of R implies that SUSY particles must be produced in pairs, that a sparticle decays down to the lightest SUSY particle (LSP) and that the LSP is stable.

Particles, $R = +1$			Sparticles, $R = -1$			
Particle	Spin	Charge	Sparticle	Spin	S-name	Mass eigenstates
e	1/2	- 1	$\tilde{e}_L, \tilde{e}_R$	0	selectron	
μ	1/2	- 1	$\tilde{\mu}_L, \tilde{\mu}_R$	0	smu	
τ	1/2	- 1	$\tilde{\tau}_L, \tilde{\tau}_R$	0	stau	
$\nu = \nu_e, \nu_\mu, \nu_\tau$	1/2	0	$\tilde{\nu}$	0	sneutrino	
q = u,d,s,c,b,t	1/2	2/3, -1/3	$\tilde{q}_L, \tilde{q}_R$	0	squark	
g	1	0	$\tilde{g}$	1/2	gluino	
γ	1	0	$\tilde{\gamma}$	1/2	photino	neutralinos $(\tilde{\chi}^0_1 - \tilde{\chi}^0_4)$
Z^0	1	0	$\tilde{Z}^0$	1/2	zino	
$H^0_1,\ H^0_2$	0	0	$\tilde{H}^0_1,\ \tilde{H}^0_2$	1/2	neutral Higgsinos	
$H^\pm$	0	± 1	$\tilde{H}^\pm$	1/2	charged Higgsino	charginos $(\tilde{\chi}^\pm_1,\ \tilde{\chi}^\pm_2)$
$W^\pm$	1	± 1	$\tilde{W}^\pm$	1/2	wino	
G	2	0	$\tilde{G}$	3/2	gravitino	

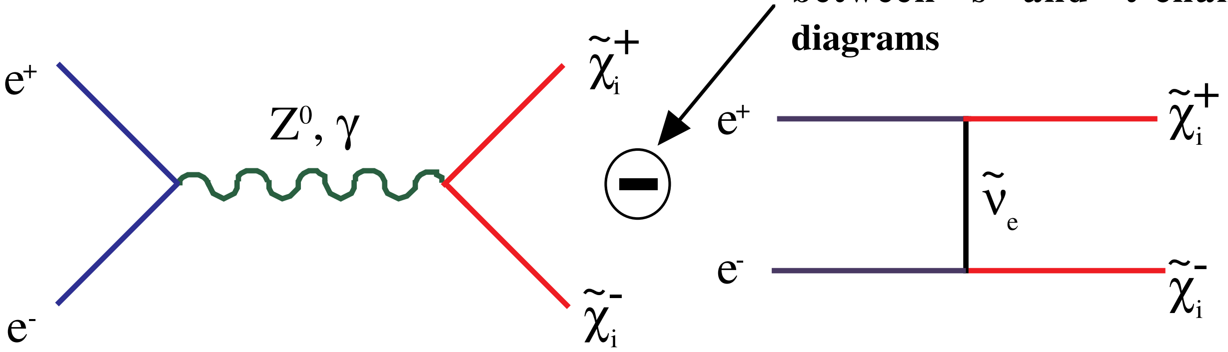
	Spin		
	0	1/2	1
Particles and Sparticles	$\tilde{l}$ $\tilde{q}$ H^0_1, H^0_2 $H^\pm$	l q $\tilde{\chi}^0_1 - \tilde{\chi}^0_4$ $\tilde{\chi}^\pm_1,\ \tilde{\chi}^\pm_2$	$\gamma,\ Z^0$ $W^\pm$

Charginos

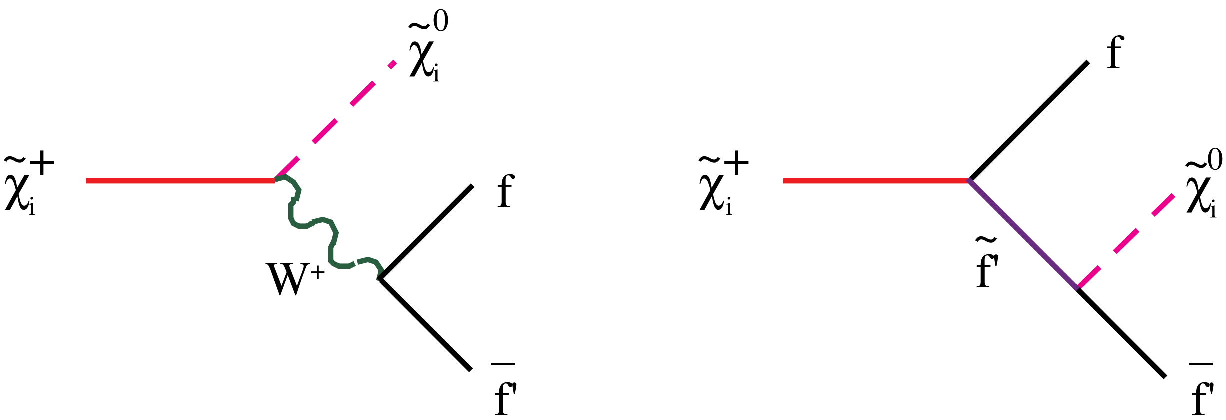
Mixtures of $\widetilde{W}^{\pm}$ e $\widetilde{H}^{\pm}$

Production

Destructive interference between s and t-channel diagrams



Decays



Large cross-sections at LEP 1.5, σ ~5-18 pb

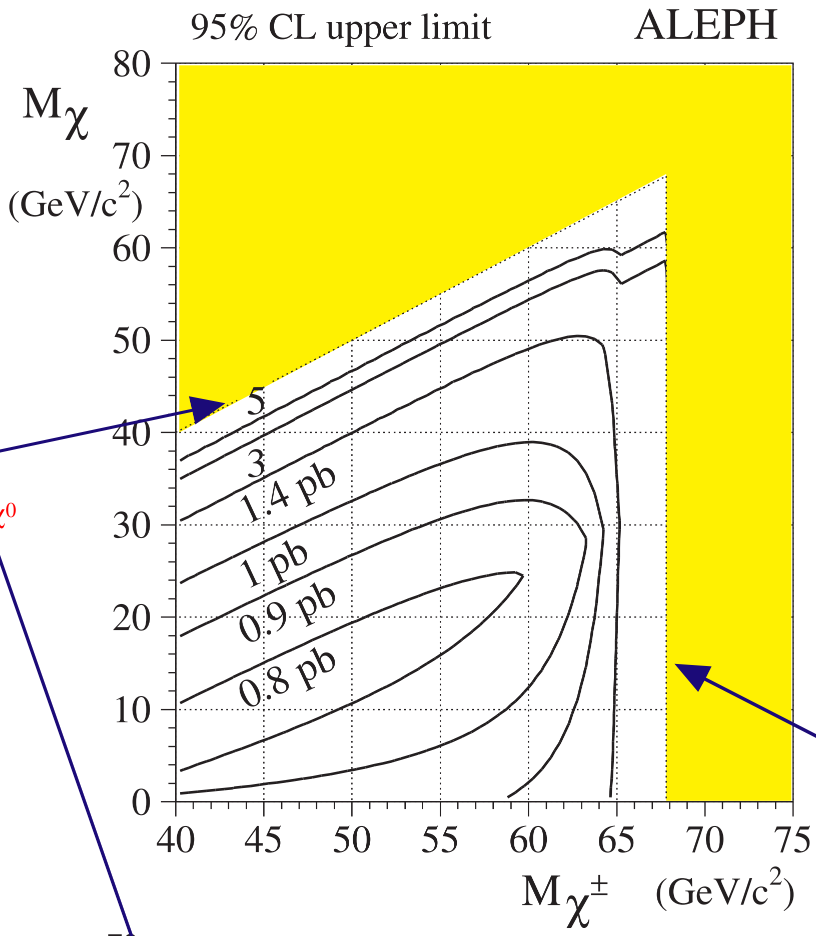
Topologies

Acoplanar jets and missing energy

Jet and isolated lepton plus missing energy

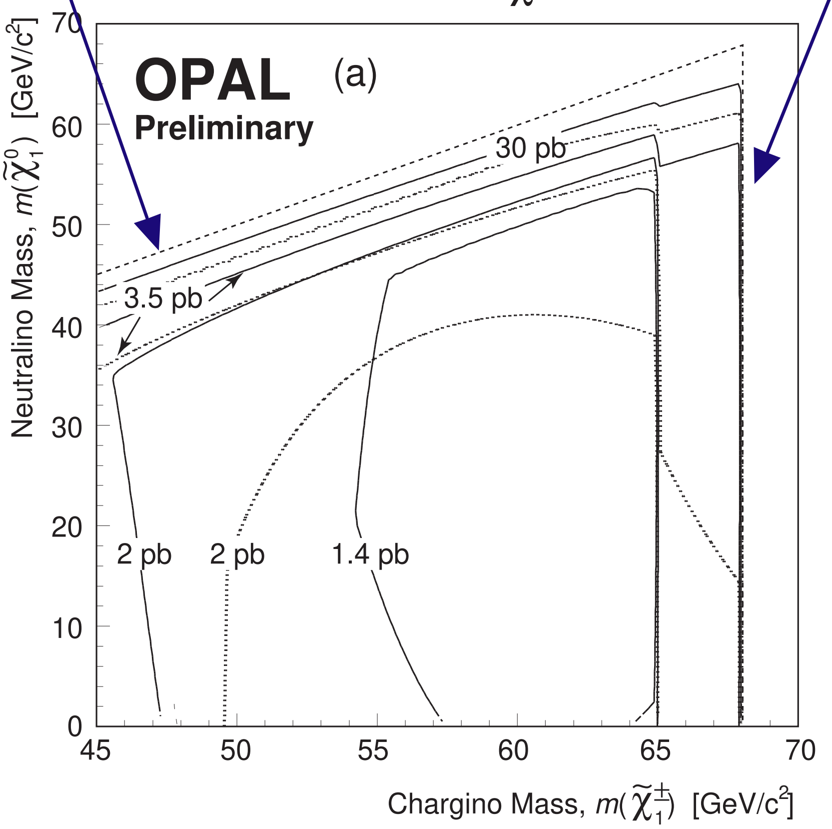
Acoplanar leptons and missing energy

Charginos (model ind. limits)



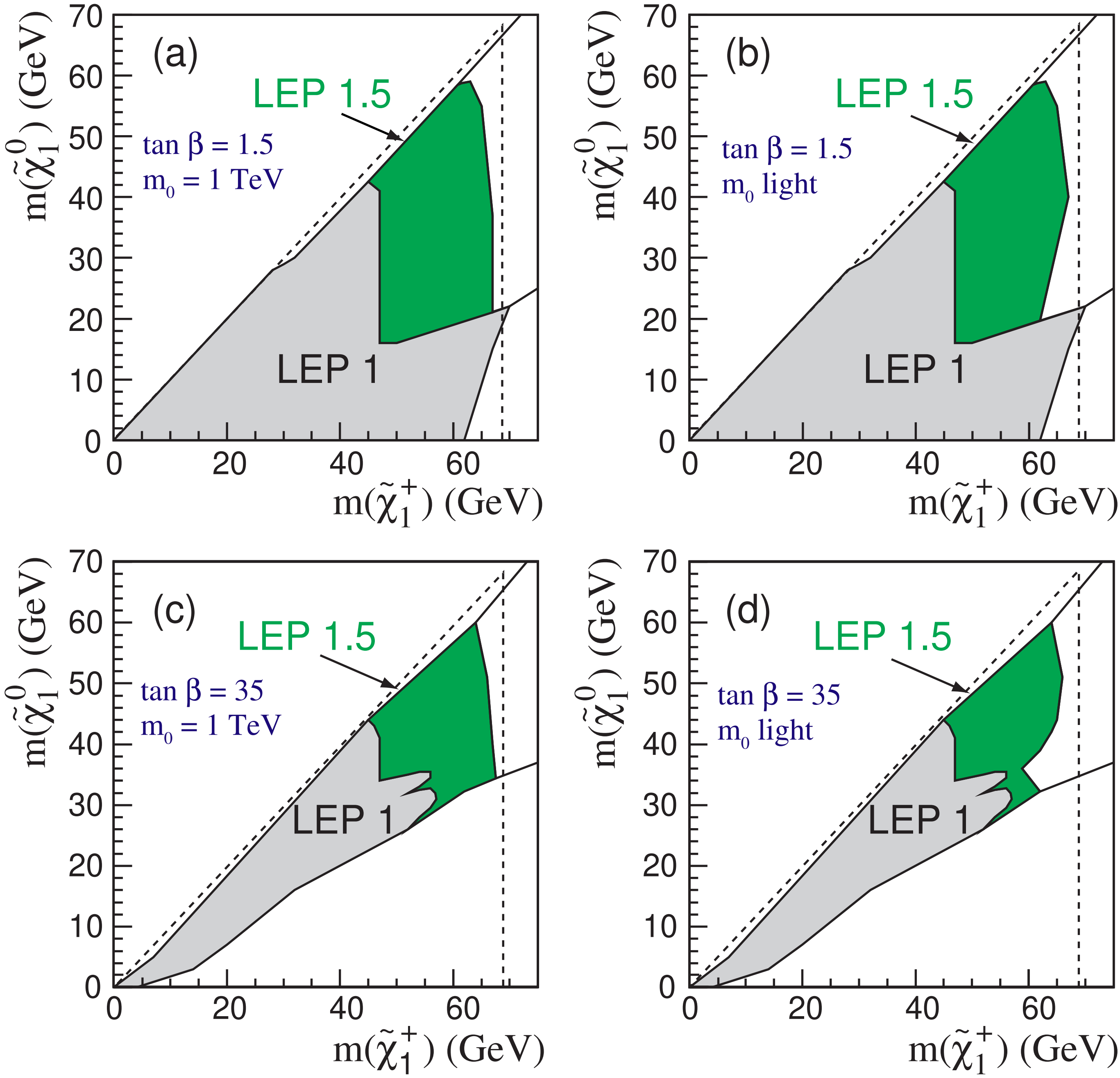
$m_{\chi^\pm} = m_{\chi^0}$

Kin. limit
($\sqrt{s}$ = 136 GeV)



Charginos

OPAL



<u>Chargino mass limits (GeV)</u>

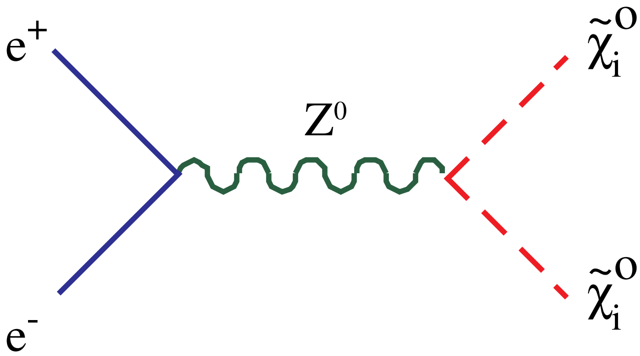
For a heavy $\tilde{\nu}$ and $(m_{\chi^+} - m_{\chi^0}) > 10$ GeV

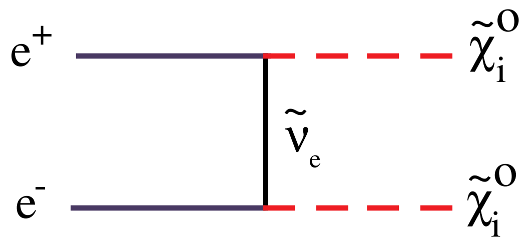
ALEPH	67.8
DELPHI	66.8
L3	65.0
OPAL	65.4

Charginos

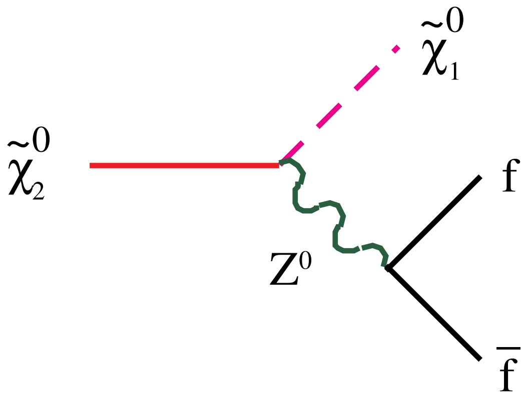
Neutralinos

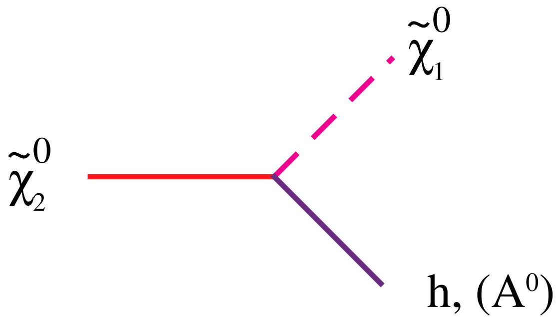
Production

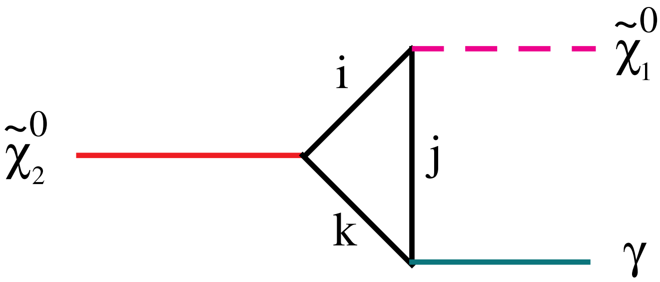




Decays







$$e^+e^- \to \tilde{\chi}^0_2\tilde{\chi}^0_1 \to \tilde{\chi}^0_1\tilde{\chi}^0_1\, f\bar{f}$$
$$\to \tilde{\chi}^0_1\tilde{\chi}^0_1\, \gamma$$

Large cross-sections at LEP 1.5,
could be $\sigma \sim 7$ pb

Topologies

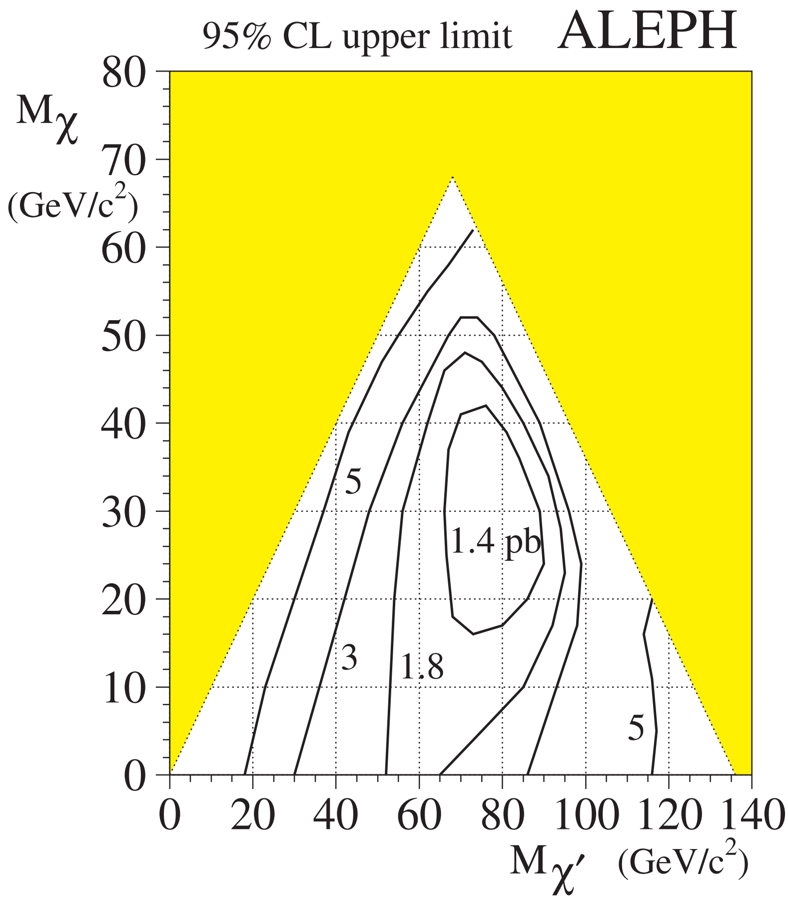
Acoplanar jets and missing energy

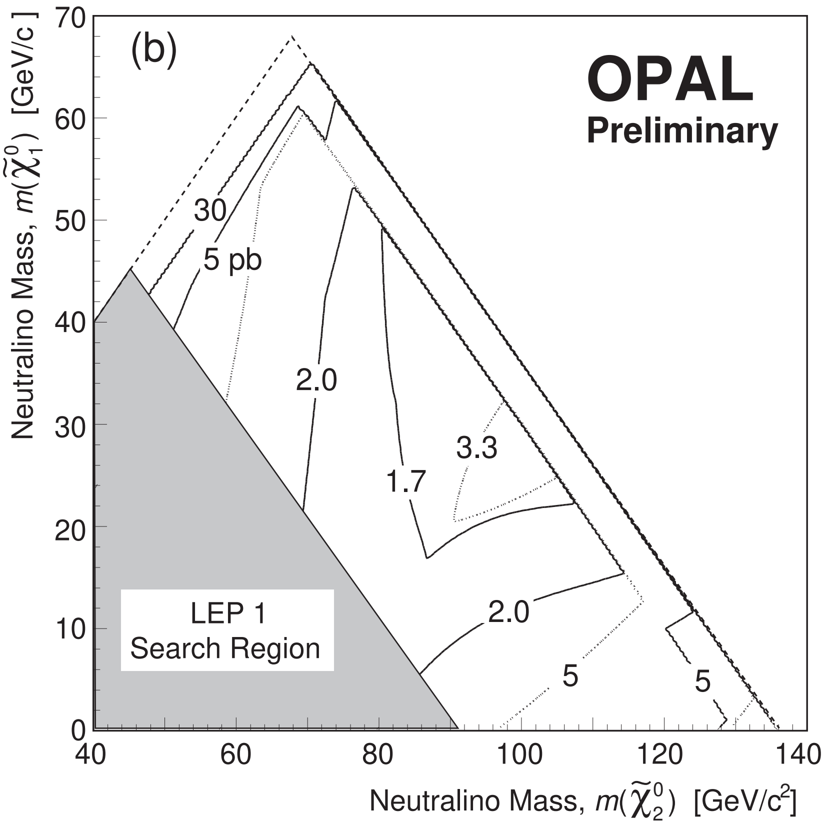
Jet and isolated lepton plus missing energy

Acoplanar leptons and missing energy

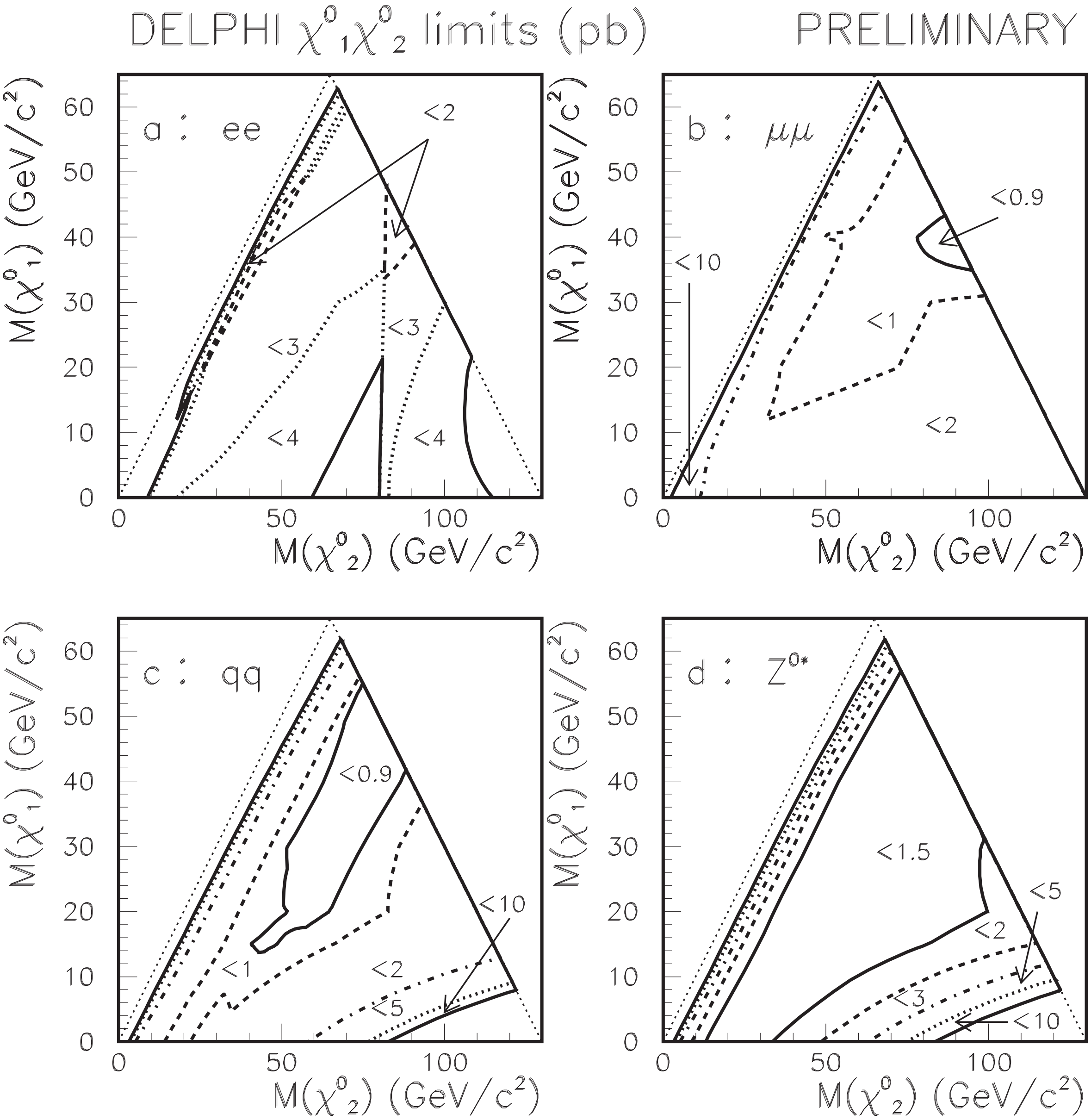
single photon events

Neutralinos (model ind. limits)





Neutralinos (model ind. limits)

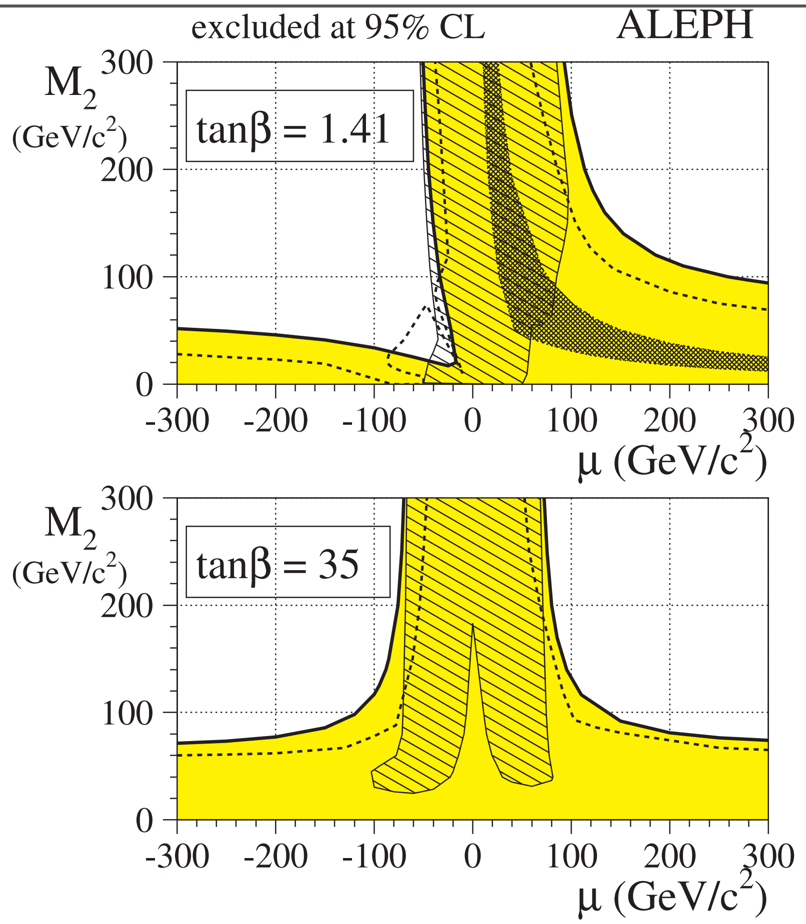


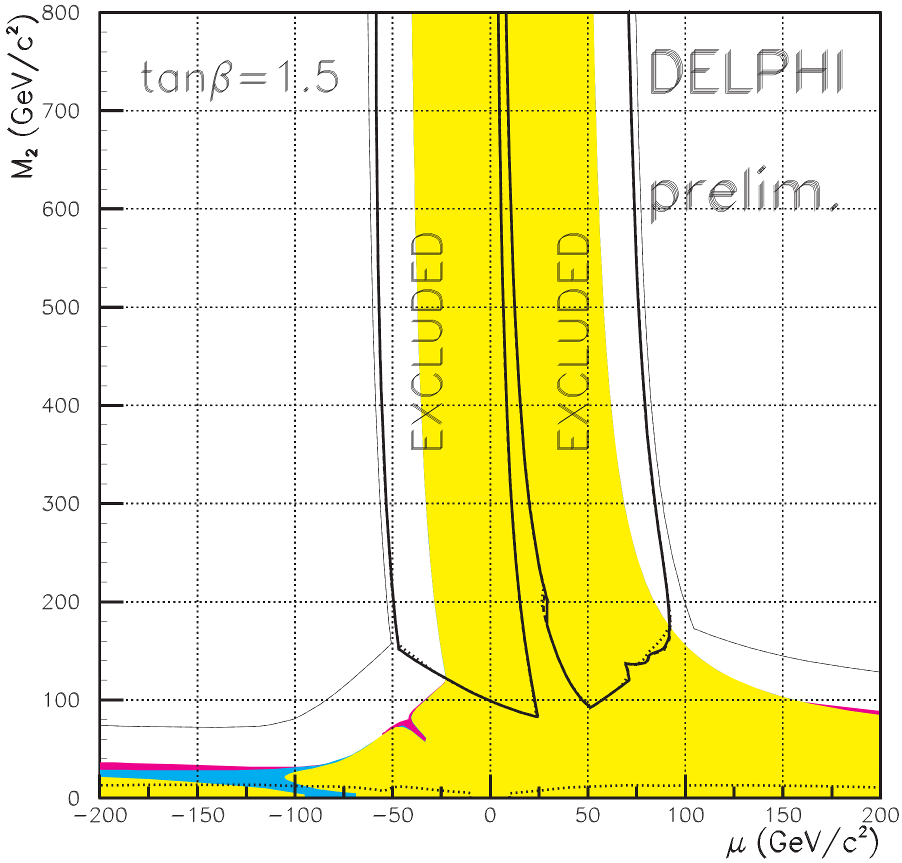
For tan β > 1.5 $m_{\chi^0_1} > 21.4$ GeV

$m_{\chi^0_2} > 47.5$ GeV

For any tan β value $m_{\chi^0_1} > 12.8$ GeV

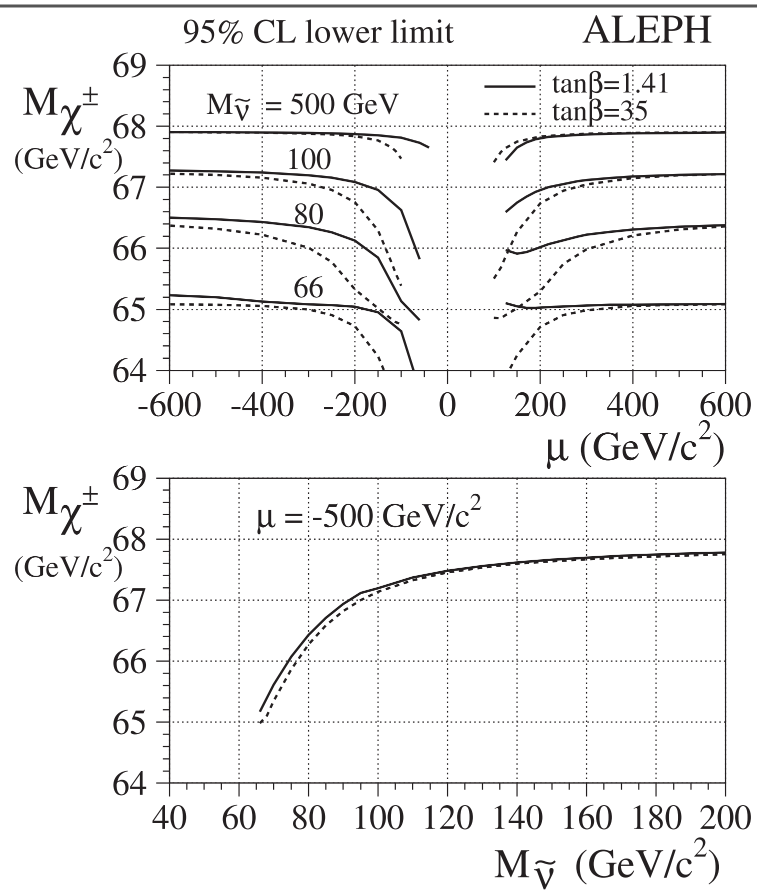
Neutralinos



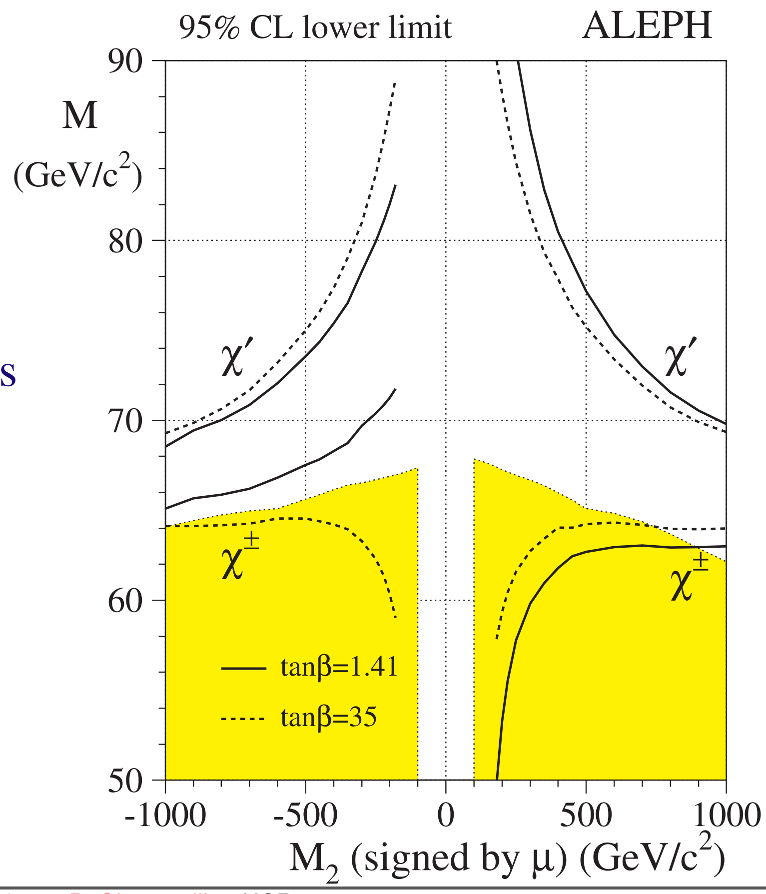


Sparticles

Chargino mass limits



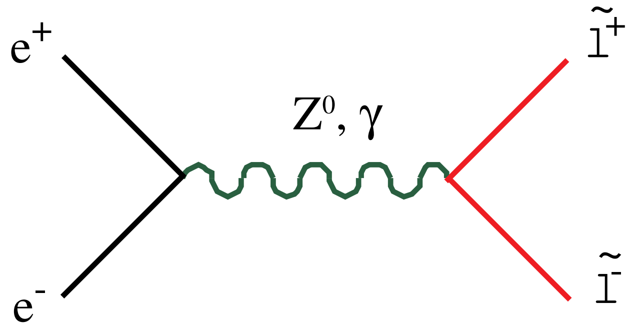
Chargino and Neutralino mass limits as a function of M_2

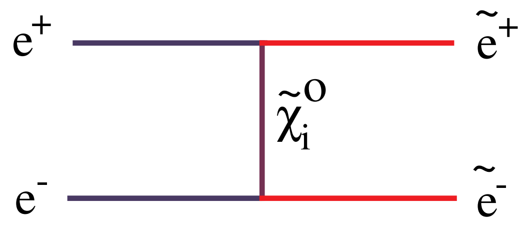


Sleptons

Production

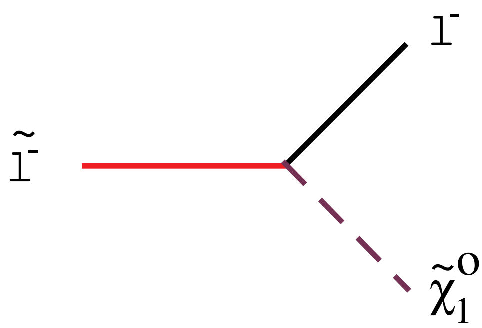
$e^+e^- \rightarrow \tilde{l}^- \, \tilde{l}^+$





If R-parity is conserved : pair production

Decays



Topology

Two acoplanar leptons of the same family and missing energy

Assume that $\tilde{\chi}_1^o$ is the LSP.
If R-parity is conserved: $\tilde{\chi}_1^o$ does not decay

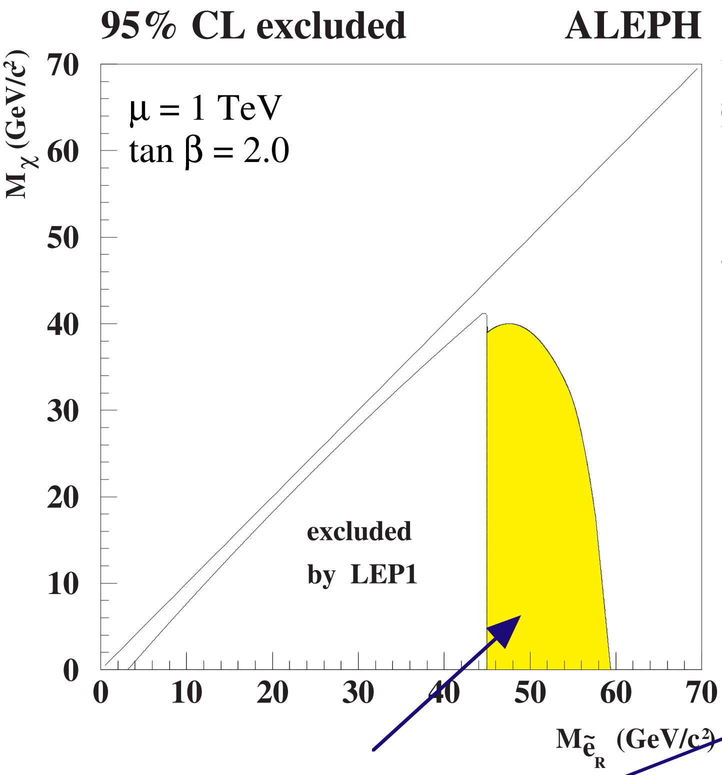
At LEP 1.5 the expected the cross-section are:

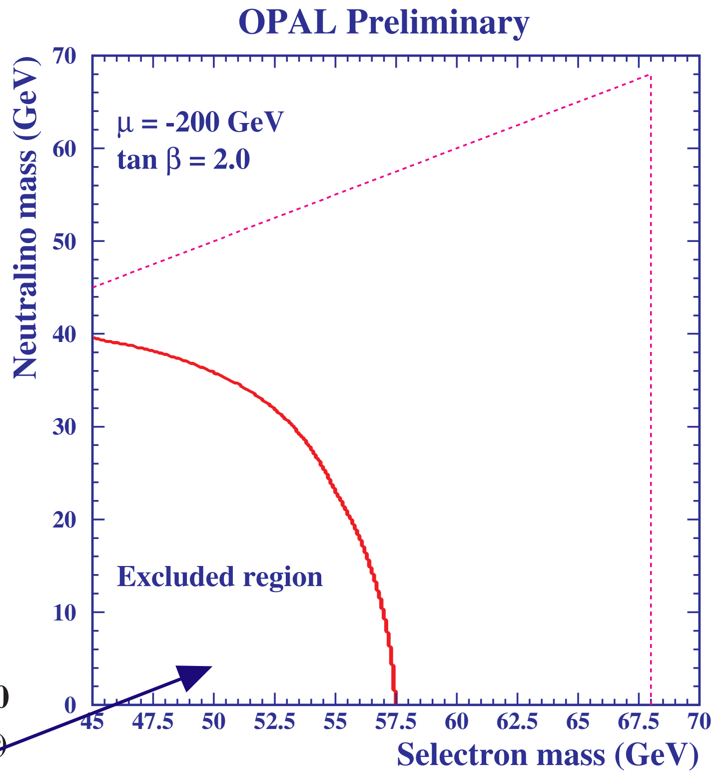
$\sigma\ (e^+e^- \rightarrow \tilde{e}^+\tilde{e}^-) \sim 0.4 - 3$ pb

$\sigma\ (e^+e^- \rightarrow \tilde{\mu}^+\tilde{\mu}^-) \sim 0.1 - 0.5$ pb

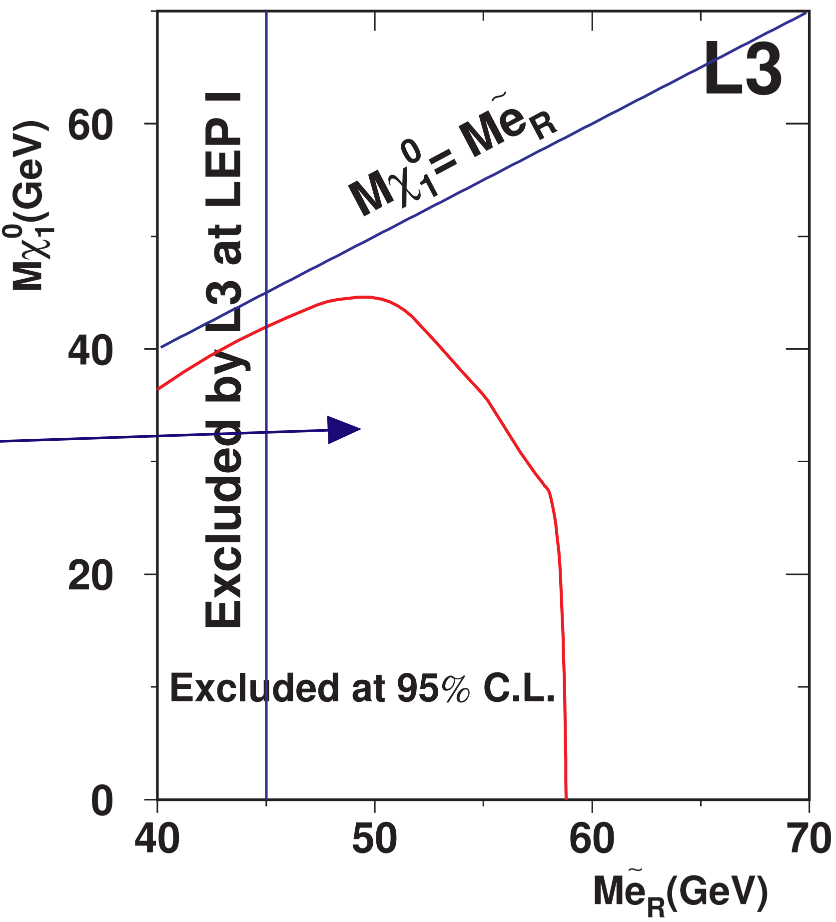
$\sigma\ (e^+e^- \rightarrow \tilde{\tau}^+\tilde{\tau}^-) \sim 0.1 - 0.5$ pb

Sleptons





σ ($e^+e^- \rightarrow \tilde{e}_R^+\tilde{e}_R^-$) only

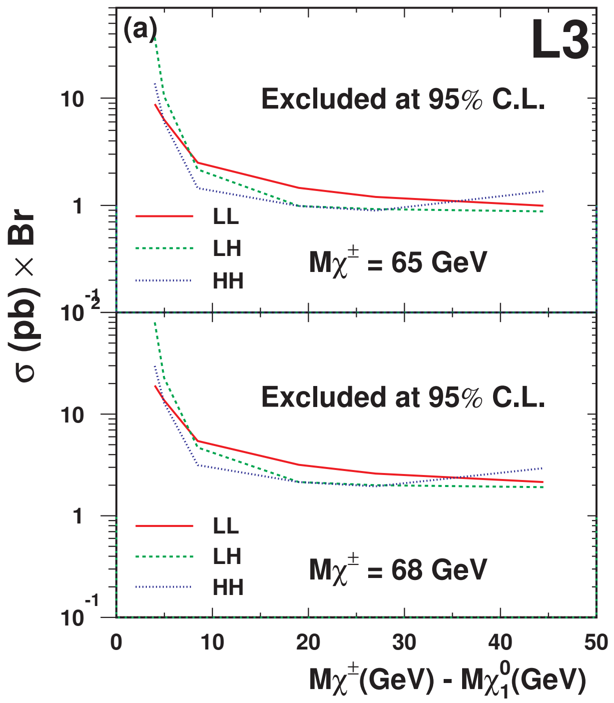


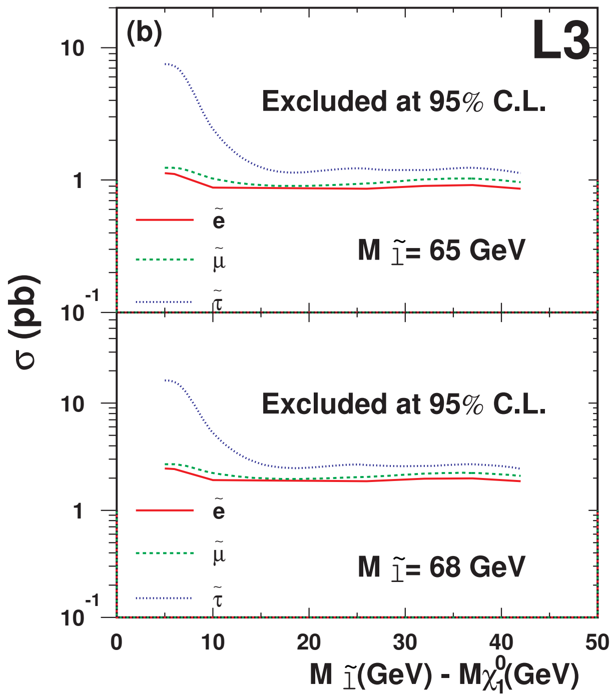
Obtained summing
$\tilde{e}_R\tilde{e}_R$ and $\tilde{e}_L\tilde{e}_R$
cross-sections

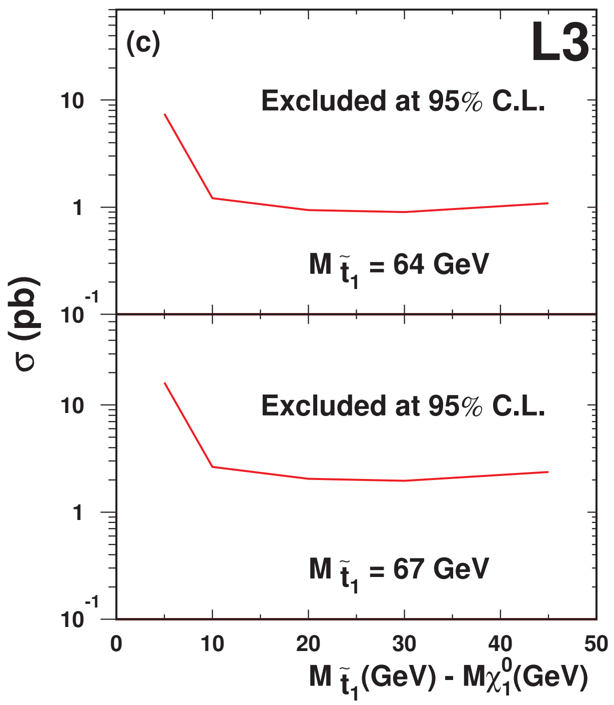
For tan β > 2 and
|μ| > 200 GeV

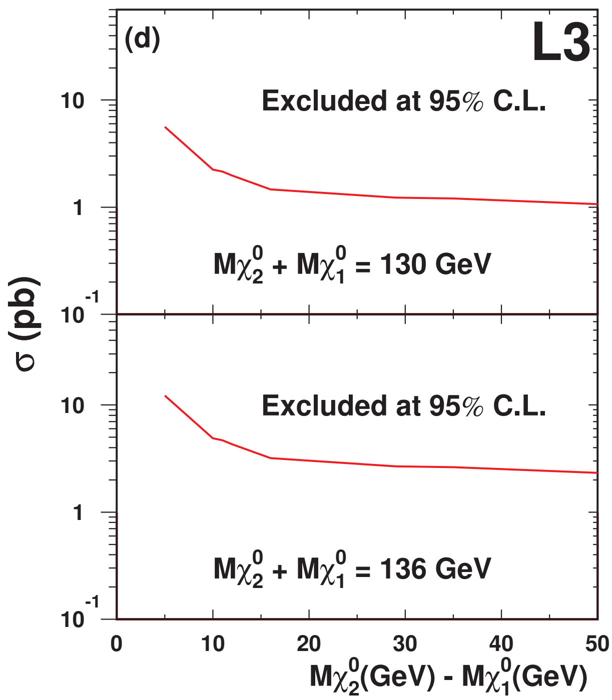
$m_{\tilde{e}_R}$ > ~ 55 GeV

Sparticles


(a)
L3
Excluded at 95% C.L.
LL
LH
HH
Mχ± = 65 GeV
Mχ± = 68 GeV
σ (pb) × Br
Mχ±(GeV) - Mχ⁰₁(GeV)


(b)
L3
Excluded at 95% C.L.
ẽ
μ̃
τ̃
M l̃ = 65 GeV
M l̃ = 68 GeV
σ (pb)
M l̃(GeV) - Mχ⁰₁(GeV)


(c)
L3
Excluded at 95% C.L.
M t̃₁ = 64 GeV
M t̃₁ = 67 GeV
σ (pb)
M t̃₁(GeV) - Mχ⁰₁(GeV)

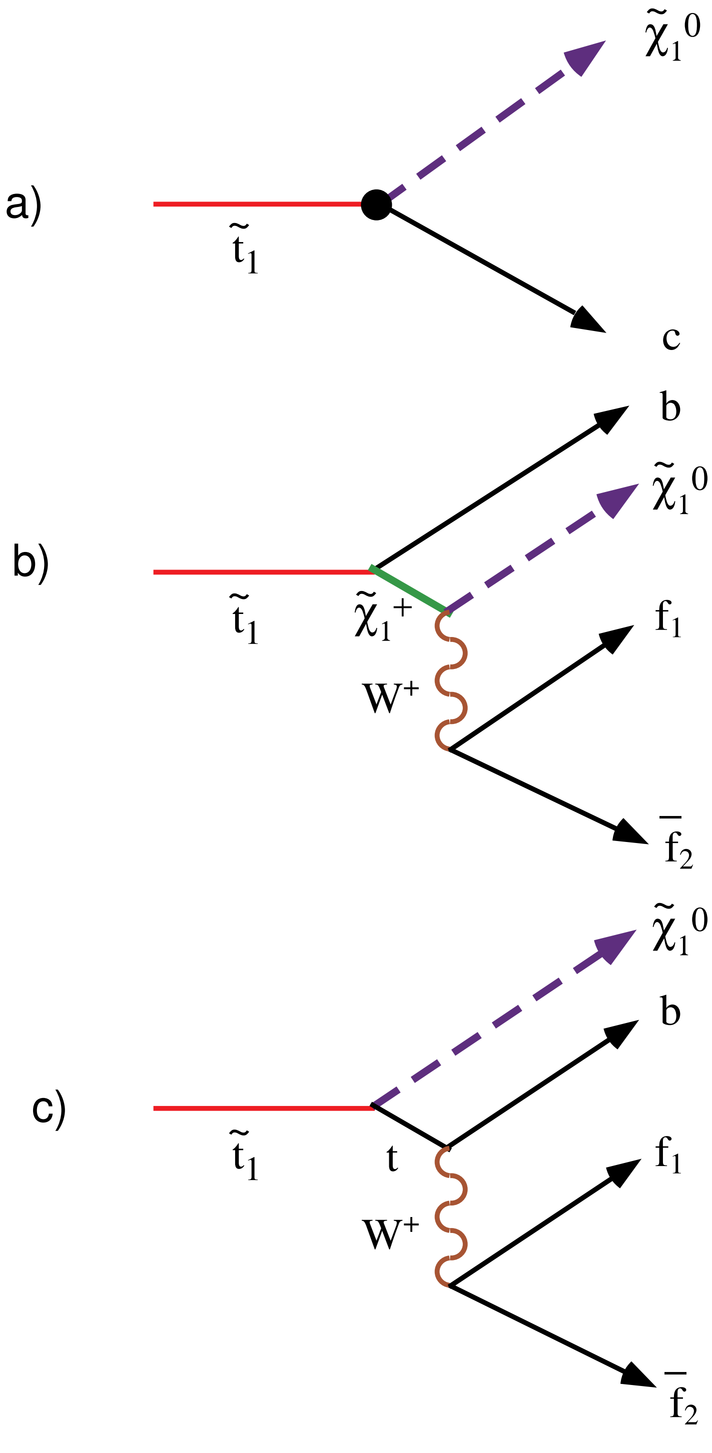

(d)
L3
Excluded at 95% C.L.
Mχ⁰₂ + Mχ⁰₁ = 130 GeV
Mχ⁰₂ + Mχ⁰₁ = 136 GeV
σ (pb)
Mχ⁰₂(GeV) - Mχ⁰₁(GeV)

Scalar top quark

$\tilde{t}_1 = \tilde{t}_L \cos\theta_{mix} + \tilde{t}_R \sin\theta_{mix}$

$\tilde{t}_1$ could be the lightest charged SUSY particle

Decays



flavour changing

If Chargino is heavy then only the first decay type can be considered

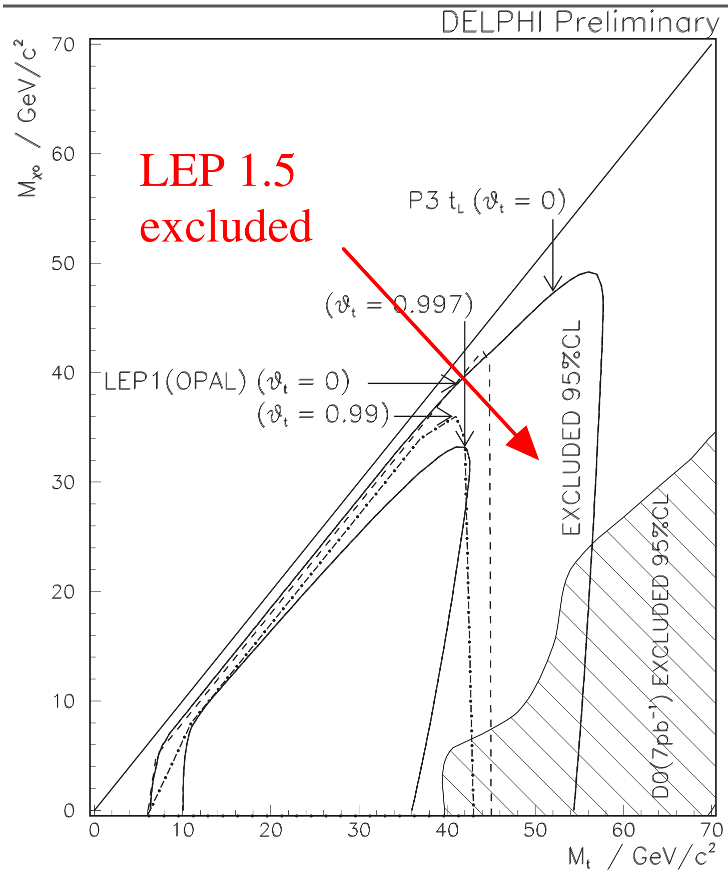
weak decay

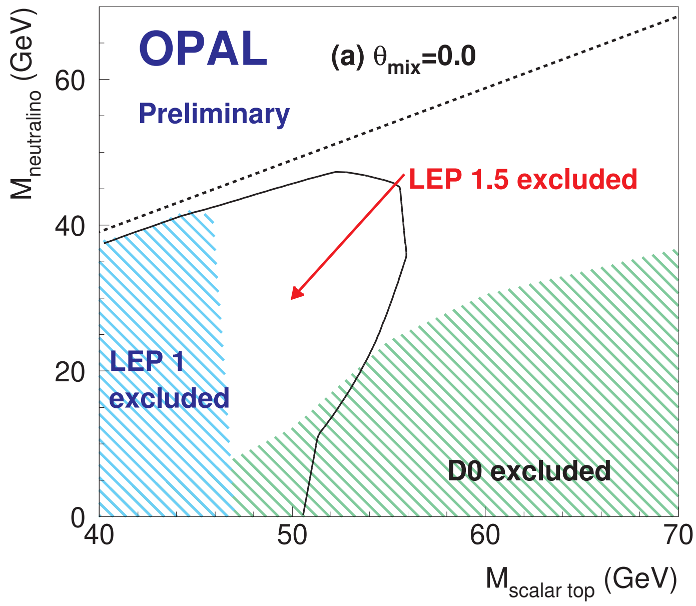
cascade decay

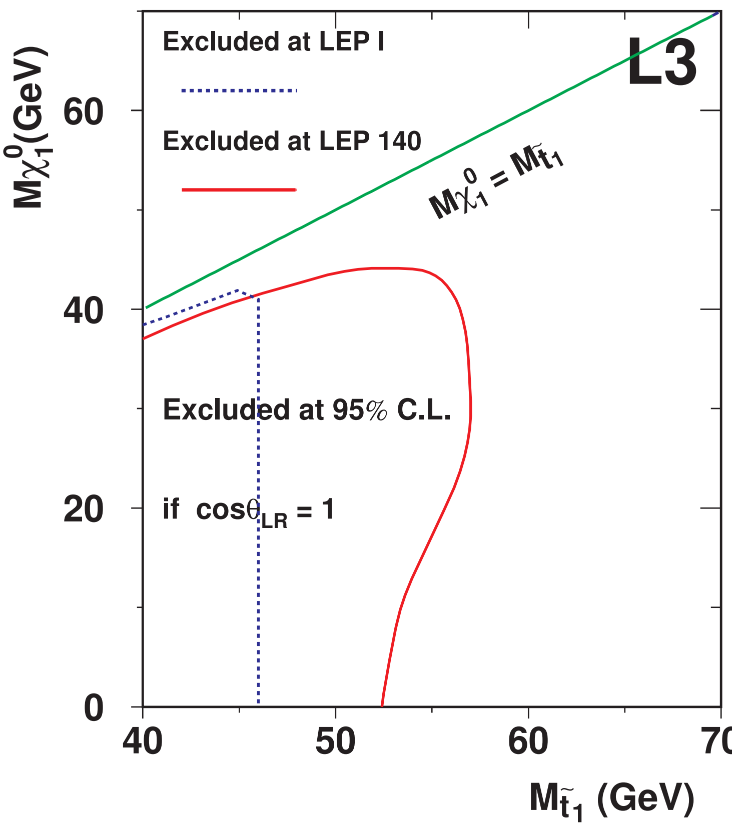
Topology

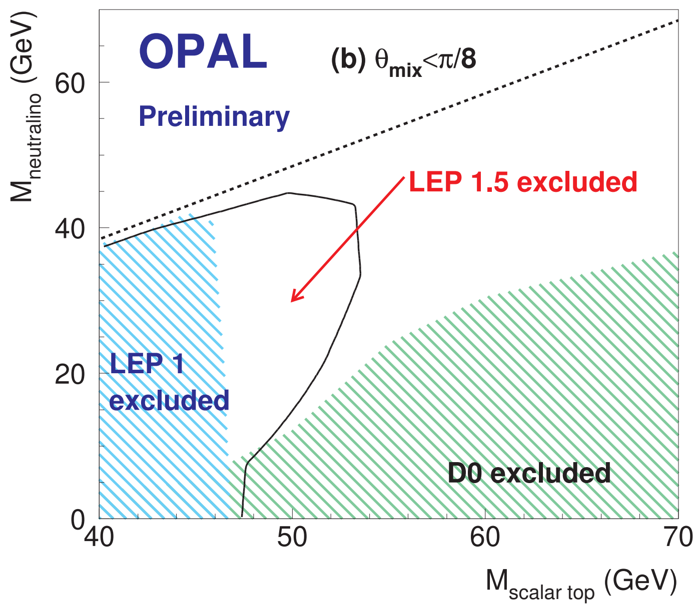
Two acoplanar jets and missing energy (1st decay)

Stop


DELPHI Preliminary
LEP 1.5
excluded
P3 t_L (ϑ_t = 0)
(ϑ_t = 0.997)
LEP1(OPAL) (ϑ_t = 0)
(ϑ_t = 0.99)
EXCLUDED 95%CL
D0(7pb^{-1}) EXCLUDED 95%CL
M_{χ^0} / GeV/c^2
M_t / GeV/c^2


OPAL
(a) θ_{mix}=0.0
Preliminary
LEP 1.5 excluded
LEP 1
excluded
D0 excluded
$M_{neutralino}$ (GeV)
$M_{scalar\ top}$ (GeV)

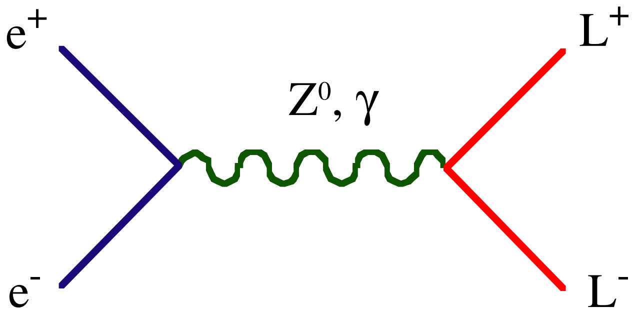

Excluded at LEP I
Excluded at LEP 140
L3
$M\chi^0_1 = M_{\tilde{t}_1}$
Excluded at 95% C.L.
if $\cos\theta_{LR} = 1$
$M\chi^0_1$(GeV)
$M_{\tilde{t}_1}$ (GeV)


OPAL
(b) θ_{mix}<π/8
Preliminary
LEP 1.5 excluded
LEP 1
excluded
D0 excluded
$M_{neutralino}$ (GeV)
$M_{scalar\ top}$ (GeV)

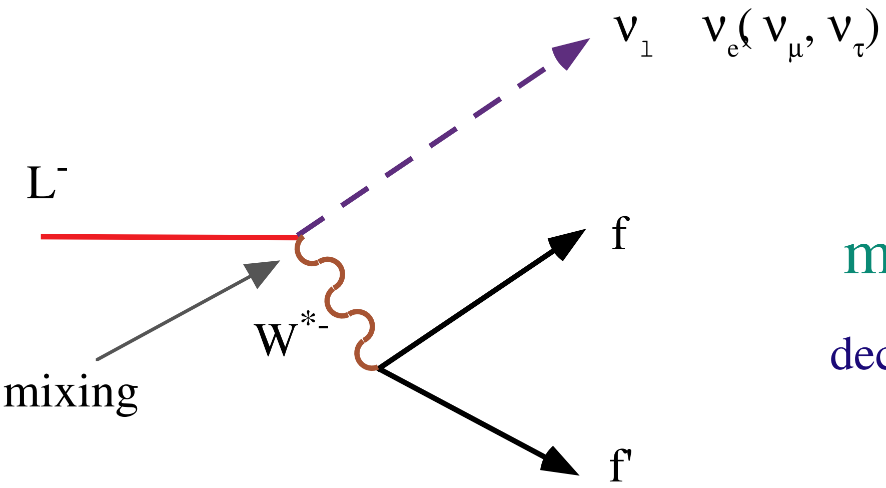
Heavy Leptons

Production

$e^+e^- \rightarrow L^+L^-$

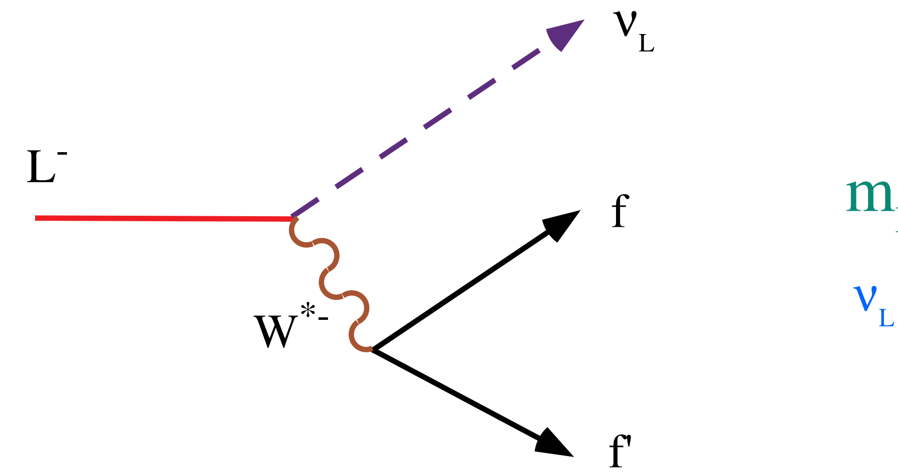


Decay



$m_L < m_{\nu L}$

decays through mixing



$m_L > m_{\nu L}$

ν_L stable

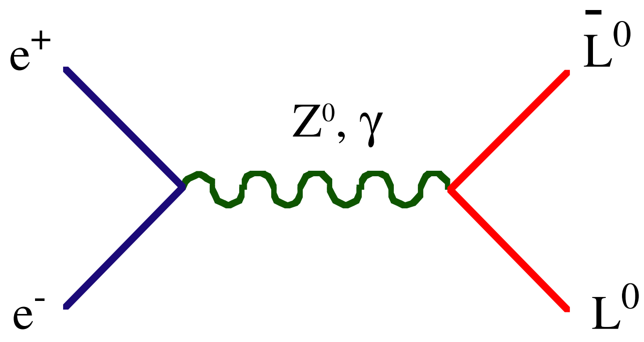
Topology

Two acoplanar jets and missing energy, in the second case there is less visible energy.

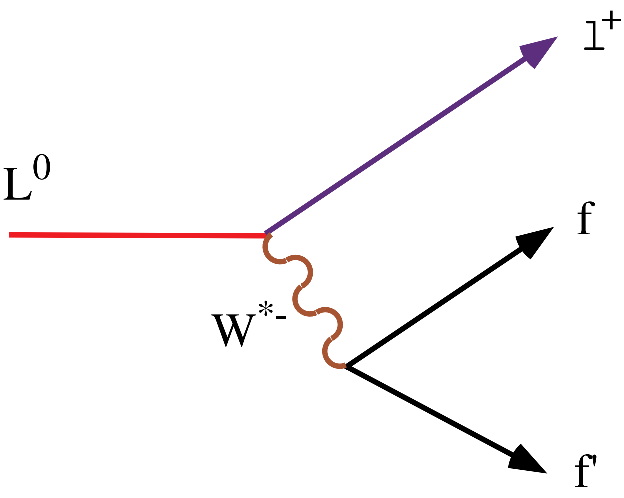
Neutral Heavy Leptons

Production

$e^+e^- \rightarrow L^0 \bar{L}^0$



Decay

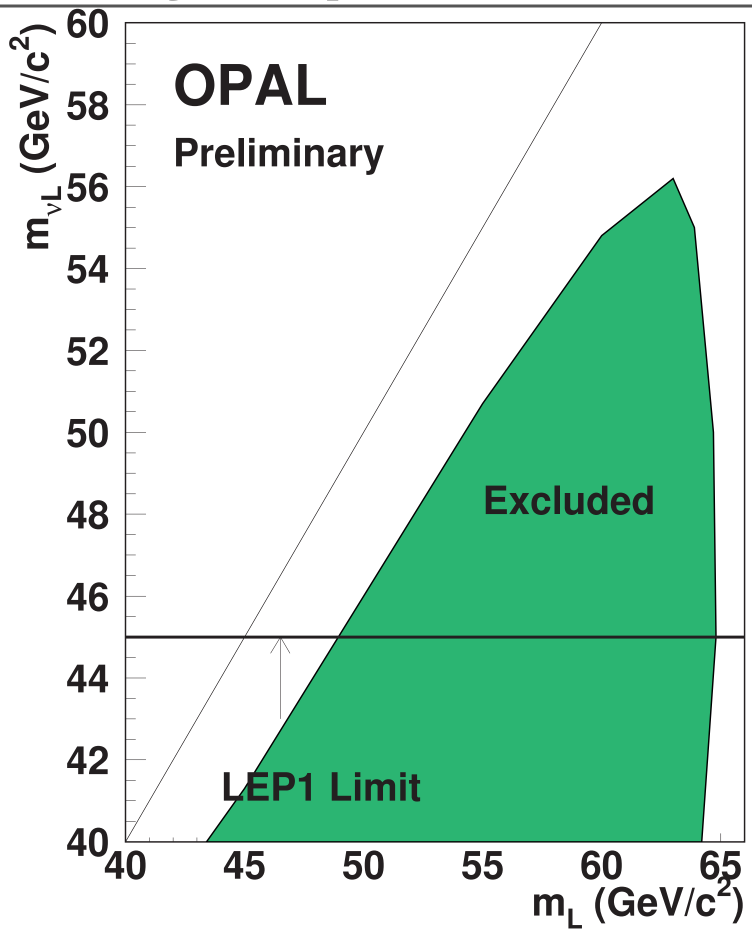


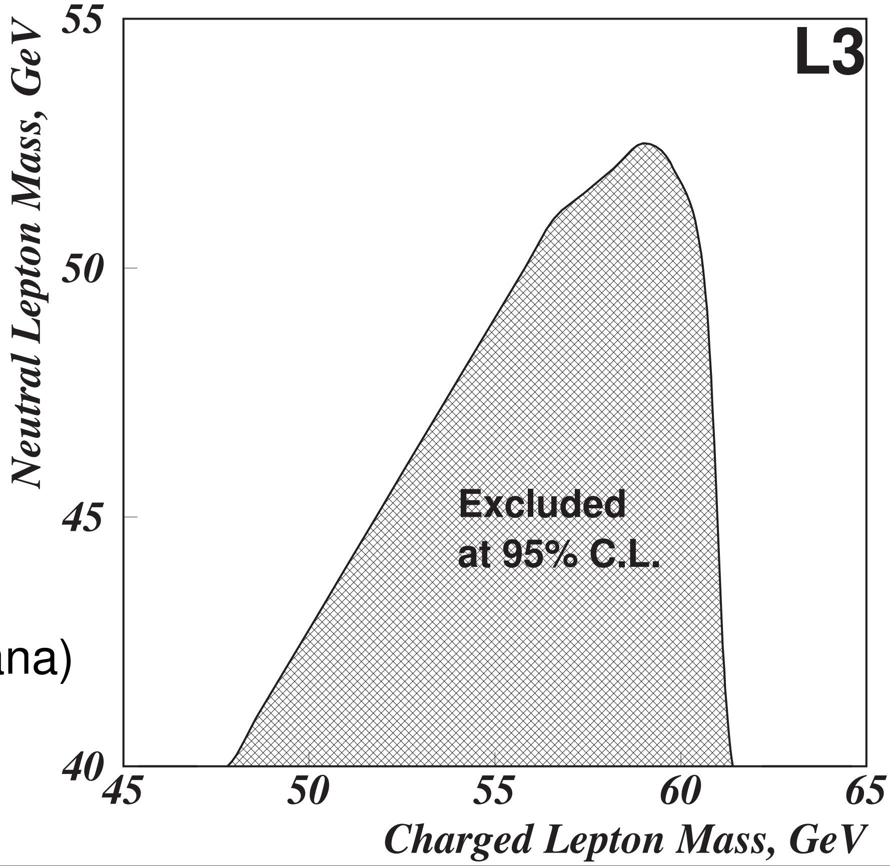
Topology

Isolated leptons plus jets.

Heavy Leptons

$m_{L^+} > 62.9$ GeV





$m_{L^0} > 57.9$ GeV (Dirac)

$m_{L^0} > 47.2$ GeV (Majorana)

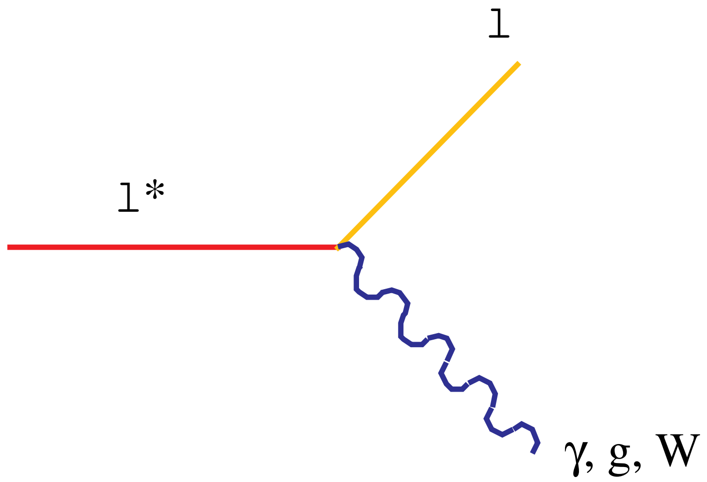
Excited Leptons

The existence of three families of quarks and leptons is a strong motivation for substructures.
In composite models, quarks, leptons and gauge bosons are composite with an associated energy scale Λ.
At $E_{c.m.} << \Lambda$, one could get manifestations of these new constituents through anomalous decay modes, anomalous electric and magnetic multipoles, excited fermions, leptoquarks and contact terms.

Production

Excited leptons can be pair produced in e^+e^- collisions, $e^+e^- \rightarrow l^* l^*$ or singly produced, $e^+e^- \rightarrow l\, l^*$.

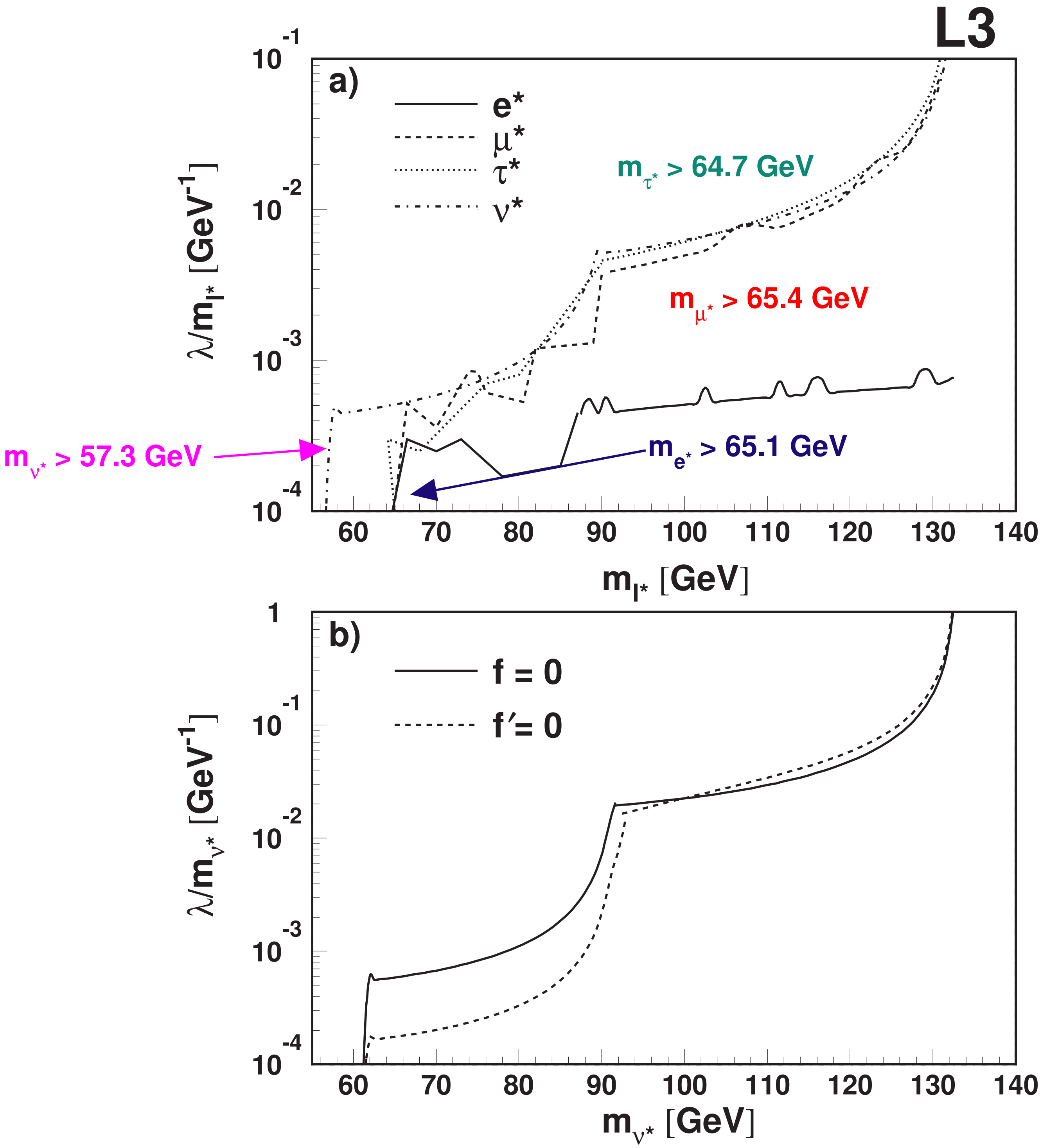
Decay



Topologies

$ee\gamma\gamma$, $\mu\mu\gamma\gamma$, $\tau\tau\gamma\gamma$, $eeWW$, $\nu\nu\gamma\gamma$ (pair production)
$ee\gamma$, $\mu\mu\gamma$, $\tau\tau\gamma$, νeW and $\nu\nu\gamma$ (single production)

Excited Leptons



Limits on coupling → compositeness scale, λ.

Conclusions

- **No new particles yet! $\rightarrow$ Limits improved**
- **SUSY**
  - $m_{\chi^\pm} > 67.8$ GeV
  - $m_{\chi^0_1} > 12.8$ GeV
- **Heavy Leptons**
  - $m_{L^+} > 62.9$ GeV
  - $m_{L^0} > 57.9$ GeV (Dirac)
  - $m_{L^0} > 47.2$ GeV (Majorana)
- **Compositeness**
  - $m_{e^*} > 65.1$ GeV
  - $m_{\mu^*} > 65.4$ GeV
  - $m_{\tau^*} > 64.7$ GeV
  - $m_{\nu^*} > 57.3$ GeV
- **At LEP 2 all these searches will be significantly improved in a few weeks of running time**