Search for Supersymmetric Particles at LEP2 with the L3 Detector

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CERN / L3

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- Introduction
- Production, Decays and Signatures of Susy Particles
- Chargino, Neutralino and Sleptons
- Photon(s) and Missing Energy
- Results and Limits
- Interpretation in the MSSM
- Conclusion

Introduction

- Extraordinary experimental confirmation of the STANDARD MODEL validity
- SUPERSYMMETRY provides one of the most attractive extensions of the S.M.
- Fundamental role of SUSY searches at high center of mass energies (LEP2)

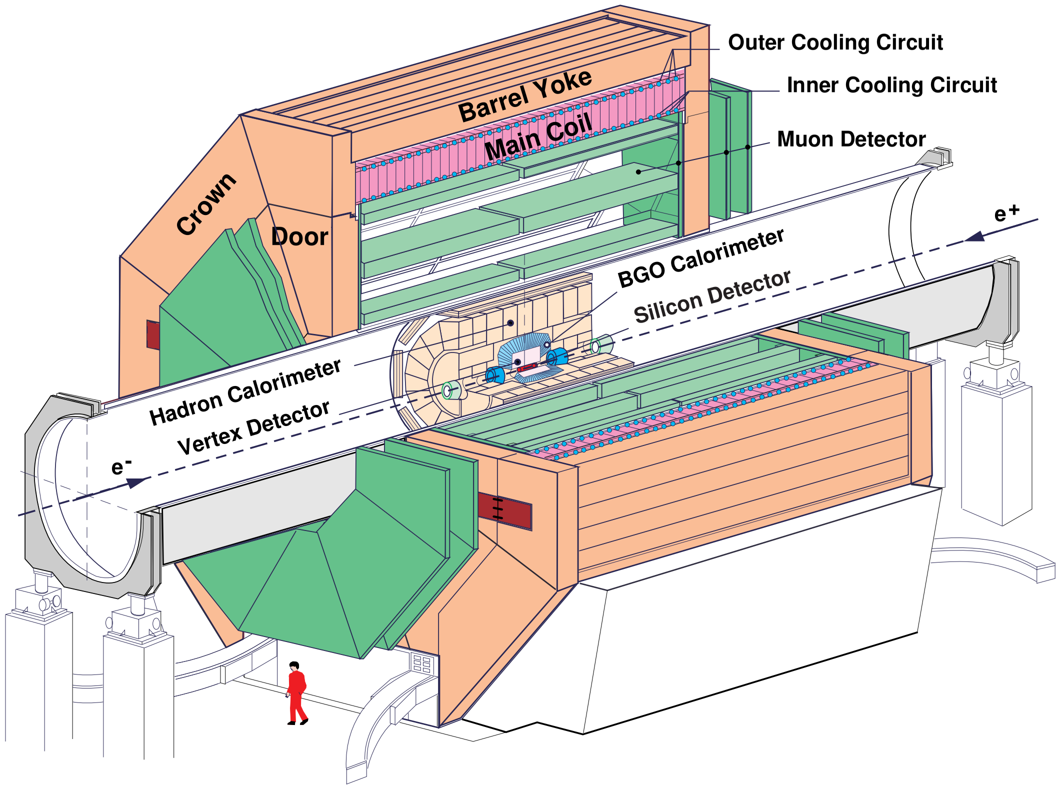
Results from 1996 run

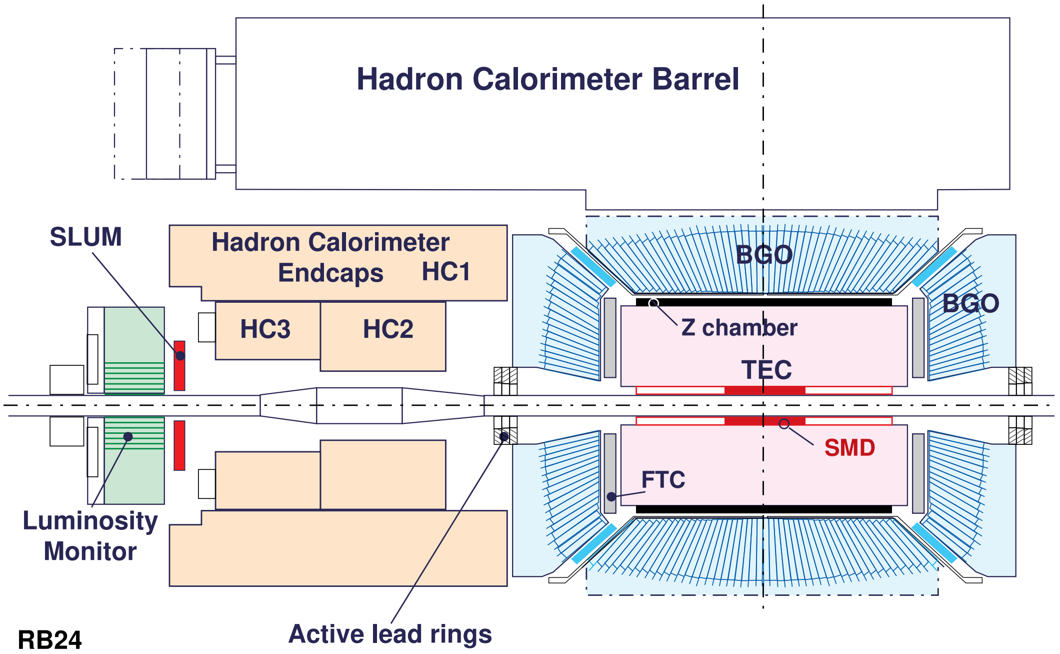
$\sqrt{s}$	$\int \mathcal{L}$ dt
161 GeV	10.5 pb^{-1}
172 GeV	10.7 pb^{-1}

Preliminary Results from 1997 run

$\sqrt{s}$	$\int \mathcal{L}$ dt
183 GeV	36 pb^{-1}

The L3 Detector





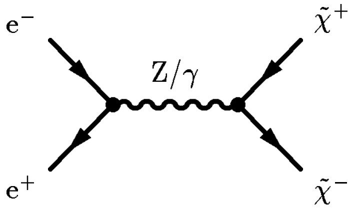
SUSY Production and Decay

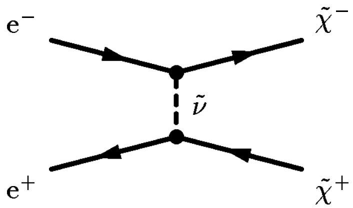
Chargino Production

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

Chargino Decay

$$\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_i^0 q\bar{q}', \tilde{\chi}_i^0 l\nu$$





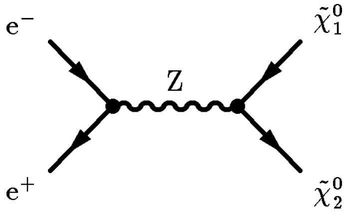
LL/HH/LH

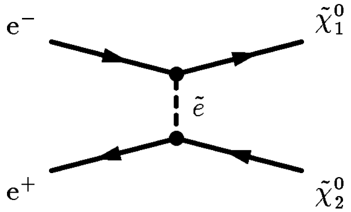
Neutralino Production

$$e^+e^- \rightarrow \tilde{\chi}_i^0\tilde{\chi}_j^0$$

Neutralino Decay

$$\tilde{\chi}_l^0 \rightarrow \tilde{\chi}_k^0 f\bar{f}$$





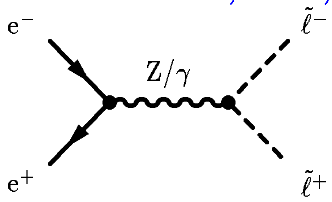
LL/HH

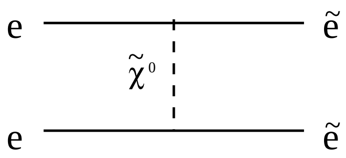
Slepton Production

$$e^+e^- \rightarrow \tilde{\ell}_{R,L}^+\tilde{\ell}_{R,L}^-$$

Slepton Decay

$$\tilde{\ell}^+ \rightarrow \ell^+\chi_1^0$$





LL

R-Parity Conservation

R parity conserved

$\Rightarrow$ **Susy particles are produced in pairs**

$\Rightarrow$ **Susy particles decay in Susy particles**

$\Rightarrow$ **The lightest Susy particle (LSP) is stable**

χ_1° is the LSP

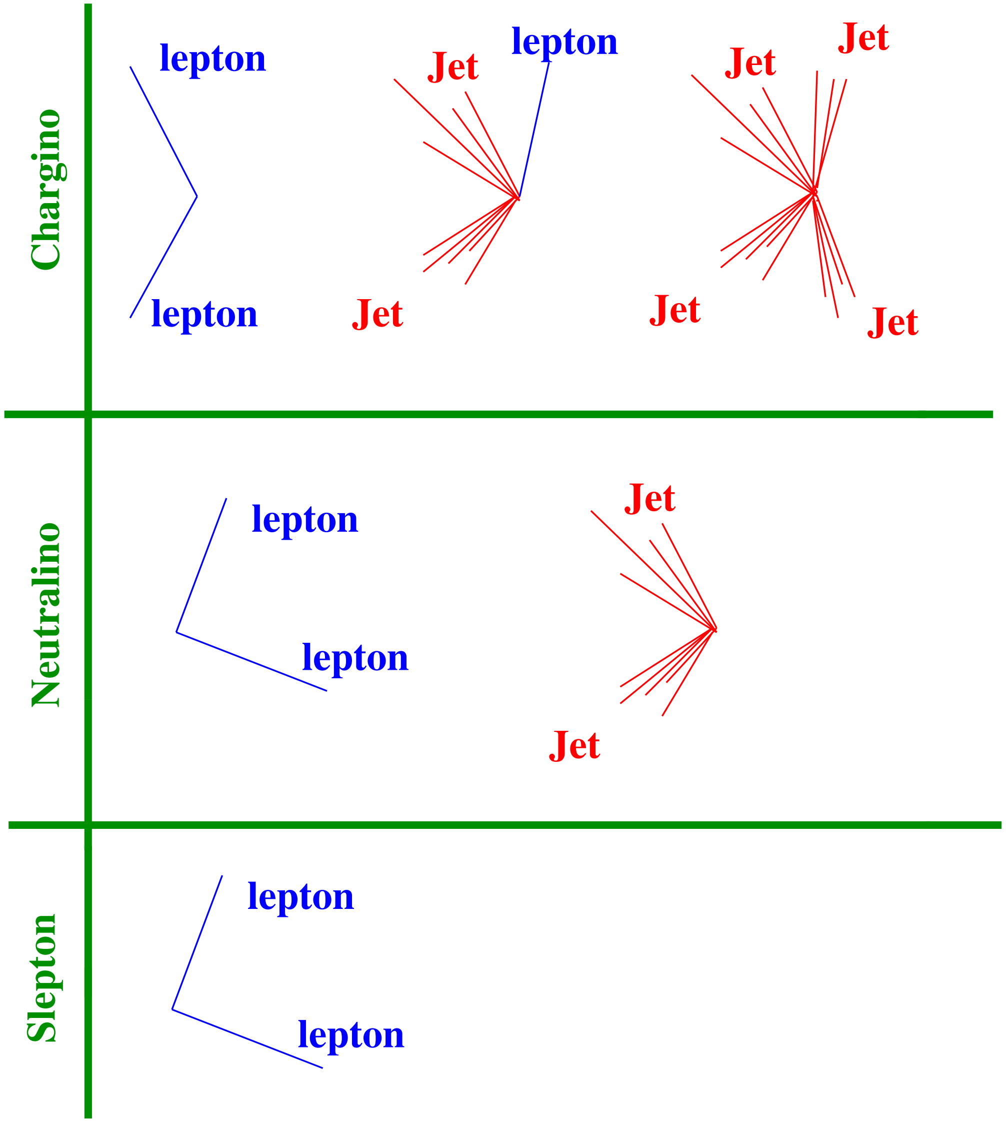
$\Rightarrow$ χ_1° **escapes the detection**

Missing Momentum and Energy

is the Susy footprint.

Definition: $\Delta M \equiv M_{sp} - M_{lsp}$

Topologies

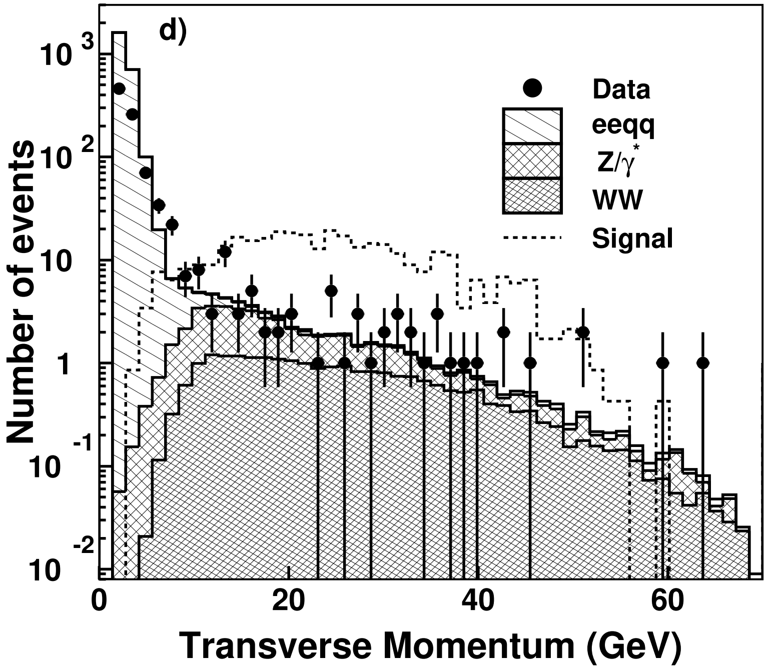

Chargino
lepton
lepton
Jet
lepton
Jet
Jet
Jet
Jet
Jet
Neutralino
lepton
lepton
Jet
Jet
Slepton
lepton
lepton

Signatures and Backgrounds

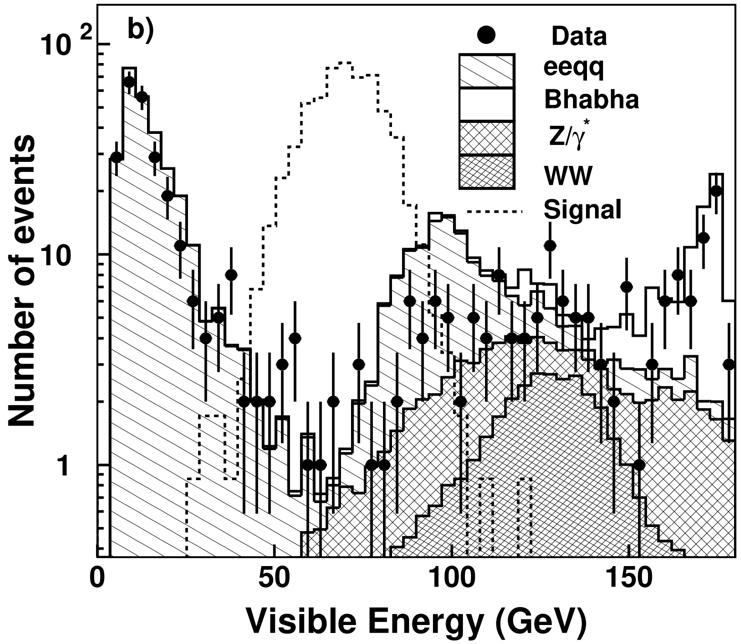
ΔM (≃ Visible Energy)	Background	Discriminating Variables
$>$50 GeV	WW ($\uparrow \sqrt{s}$ Weν	visible energy hadronic mass lepton momentum
$\simeq$ 30 GeV	Z/$\gamma^* \rightarrow f\bar{f}(\gamma)$	
3-10 GeV	Gamma-Gamma Physics	transverse missing momentum direction of missing momentum missing mass acoplanarity

Analysis

Hadronic Channel

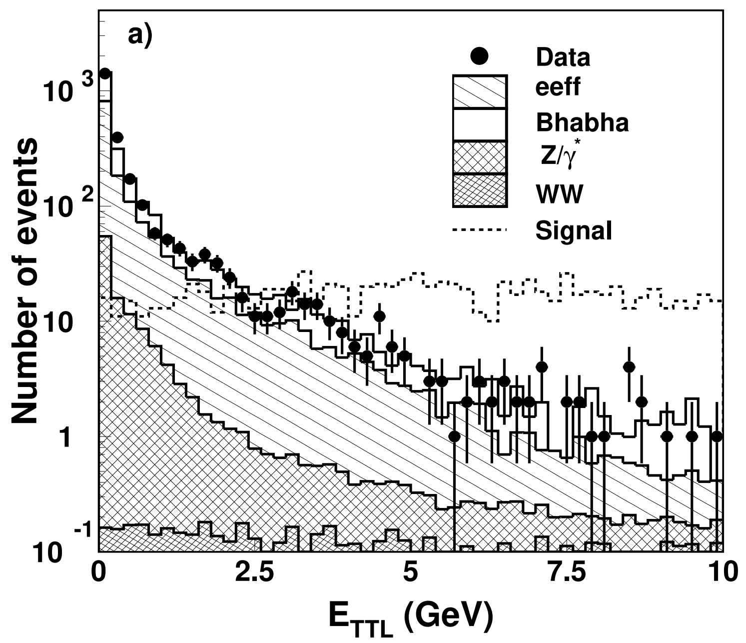


Lepton Hadron Channel



Analysis

Leptonic Channel



Results from 1996 Data

Channel	N_{exp}^{bckg}	N^{data}
Selectron	1.3	3
Smuon	1.3	0
Stau	1.2	1
Chargino Neutralino	4.5	5
Total	7.6	8

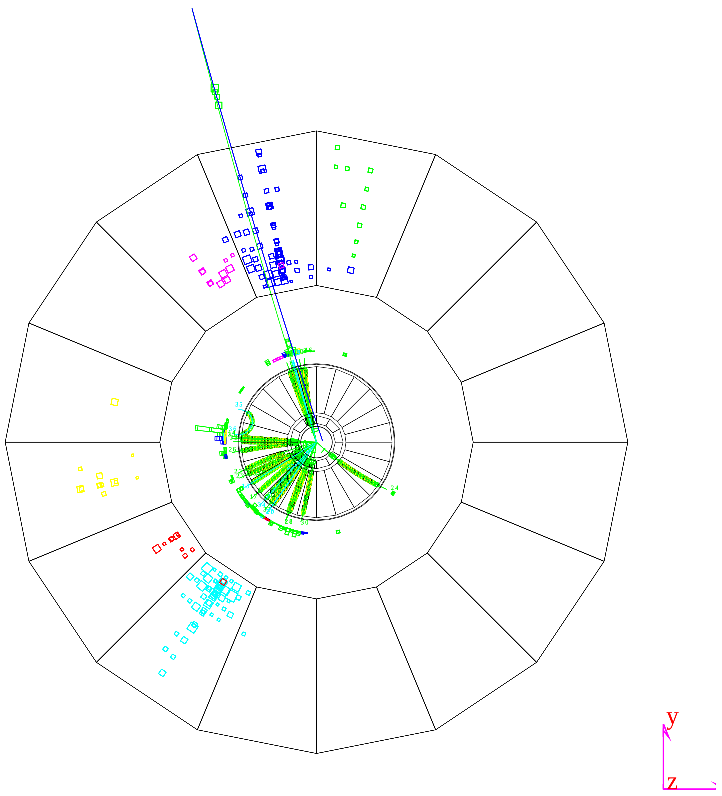
NO EVIDENCE OF EXCESS

ΔM	Typic. Efficiency
50 GeV	30%
30 GeV	60%
5 GeV	10%

Candidate Event

Candidate for Hadrons + Missing Energy $\sqrt{s}$ =172 GeV

Run # **663205** **Event #** **904** Total Energy : 85.44 GeV

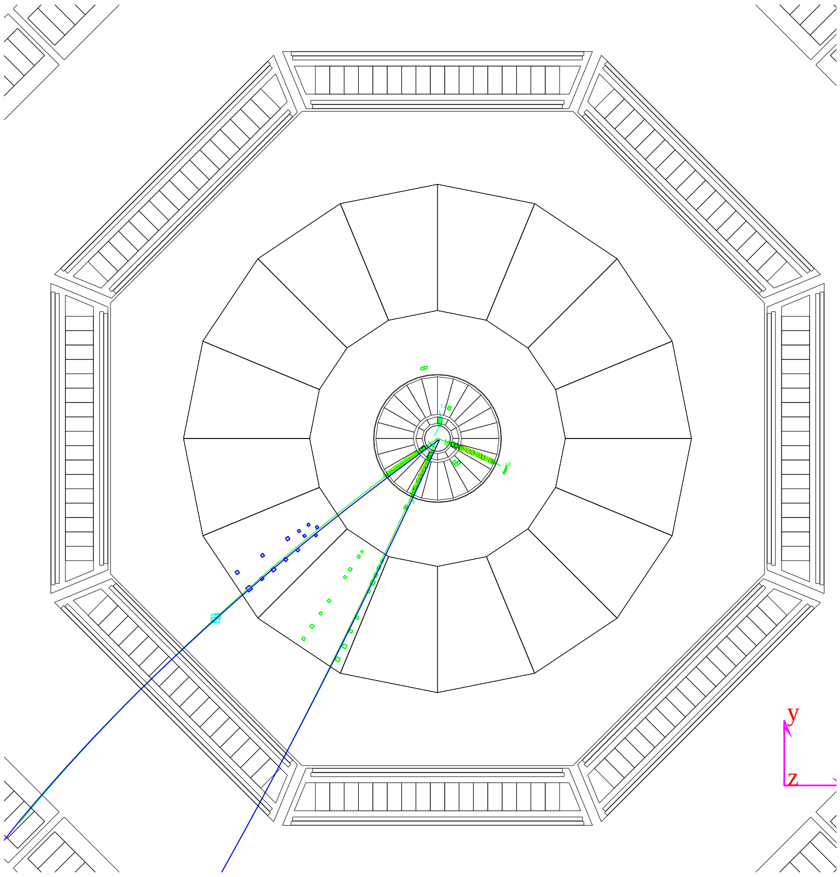


Transverse Imbalance : .4551		**Longitudinal Imbalance :** -.2554	
Thrust : .7783	**Major :** .4587		**Minor :** .1547
Event DAQ Time : *961019 163747*			

Candidate Event

Candidate for Leptonic Channel

Run # 659107 Event # 2755 Total Energy : 14.05 GeV

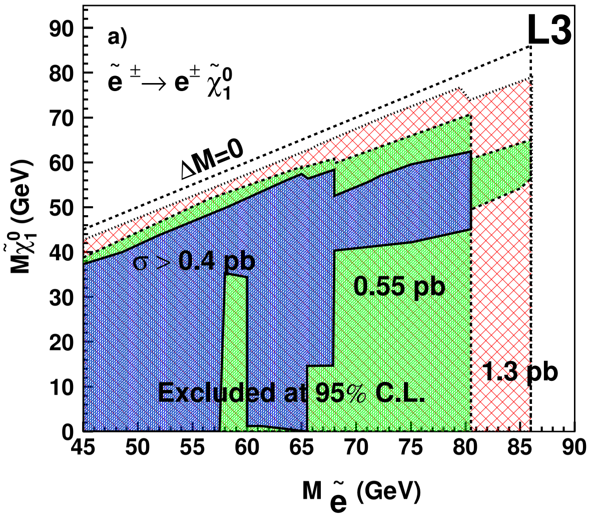


Transverse Imbalance : .7217		Longitudinal Imbalance : -.5845	
Thrust : .9375	Major : .2461		Minor : .0625
Event DAQ Time : 960724 152459			

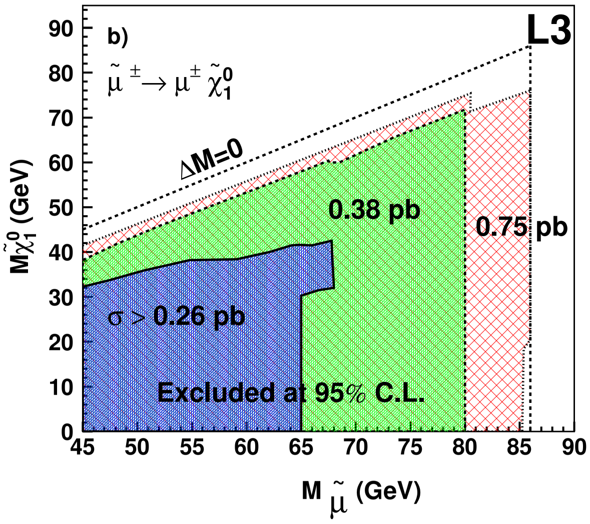
Results - Sleptons

Upper Limits on Production Cross Sections:

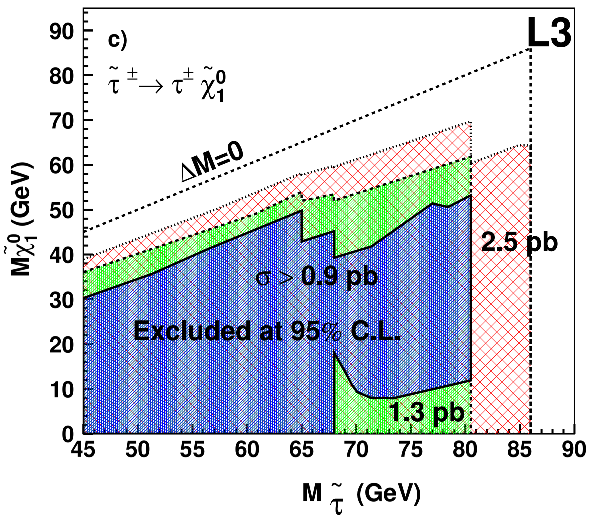
Selectron



Smuon



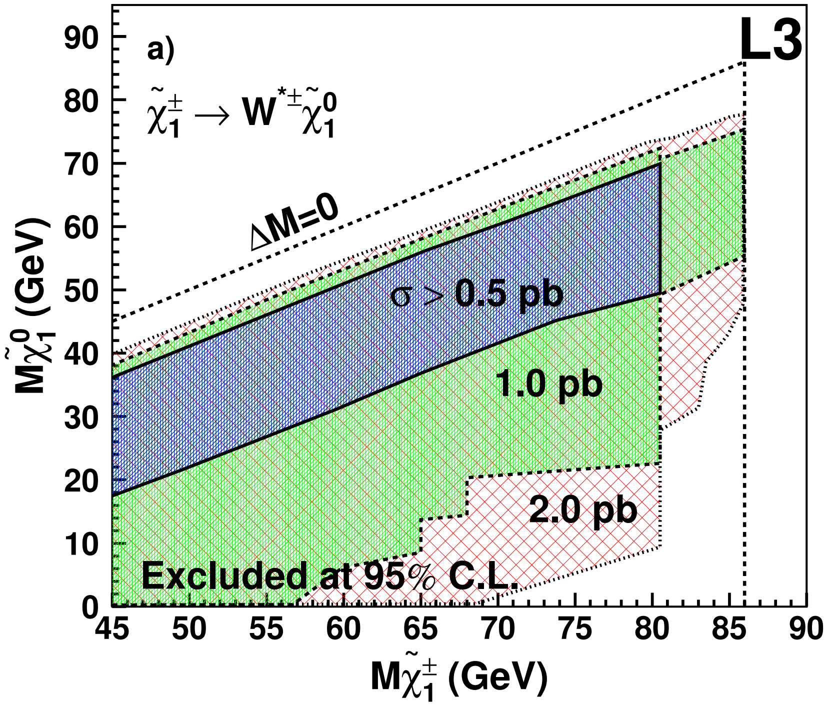
Stau



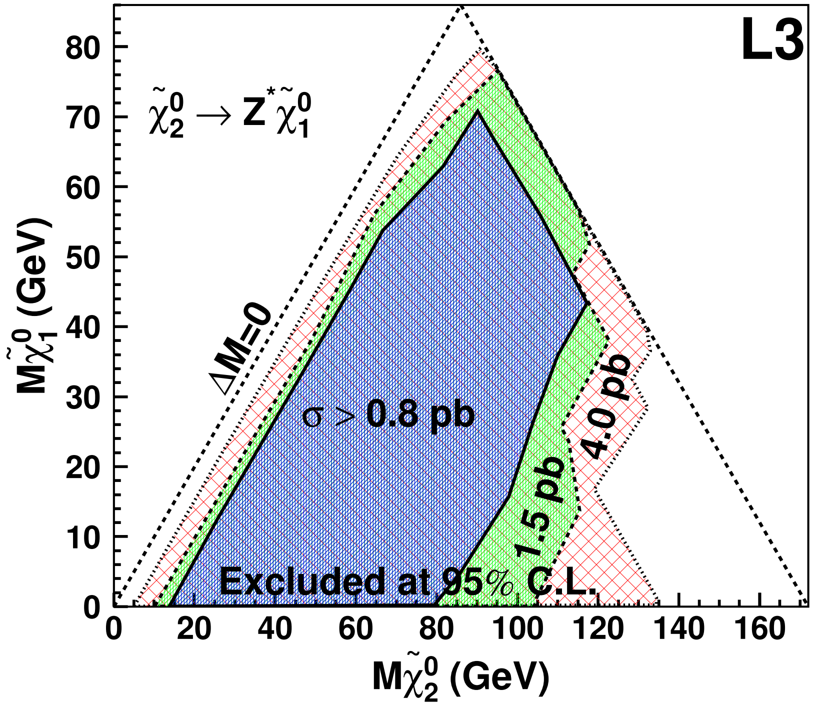
Results - Chargino and Neutralino

Upper Limits on Production Cross Sections:

Chargino



Neutralino



MSSM

All masses and couplings of the Supersymmetric particles are dependent on the free parameter of the MSSM:

- M_1, M_2, M_3 – the SUSY breaking masses associated to $U(1)$, $SU(2)$, $SU(3)$;
- μ – the supersymmetric higgsino mass term;
- $\tan\beta = v_2/v_1$ – the ratio of the vacuum expectation values of the two higgs field;
- m_0 – the common sfermion mass at the GUT scale.

The GUT relation between the gaugino mass parameters

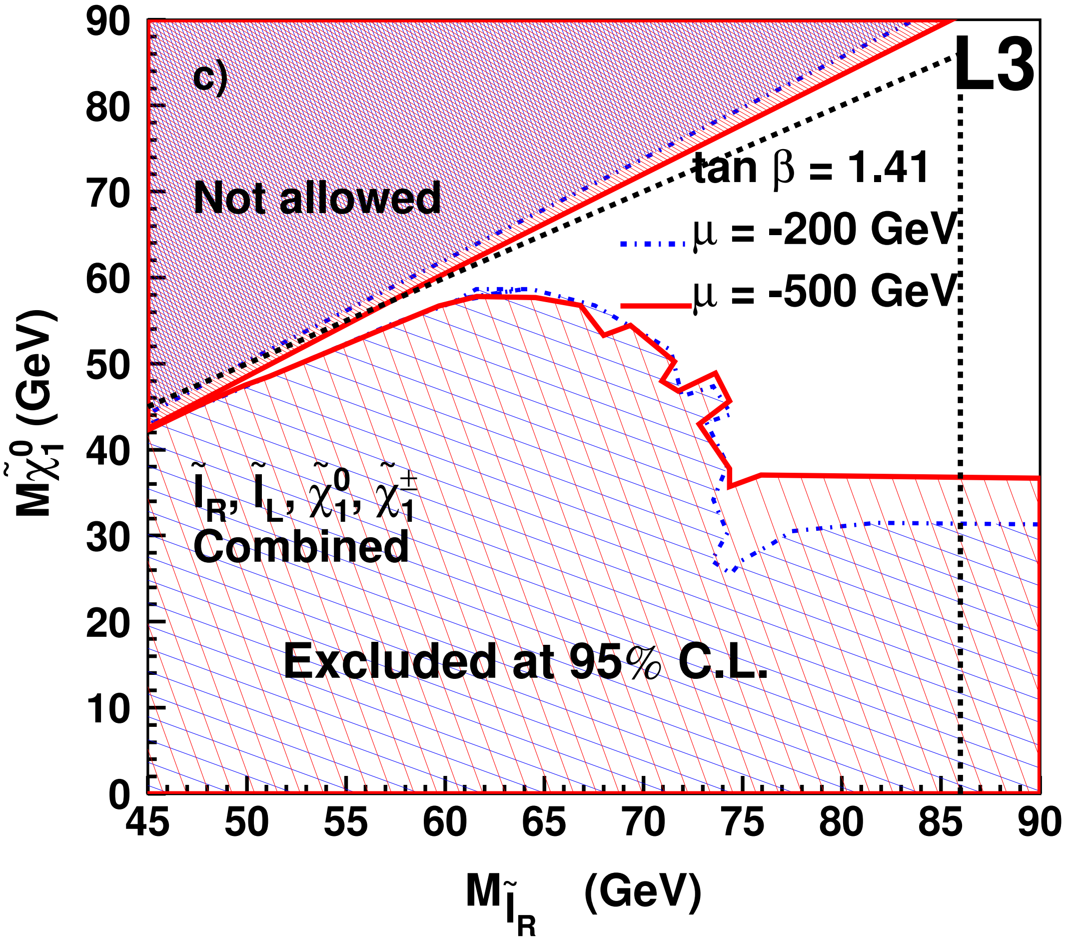
$$M_1 = \frac{5}{3} M_2 \tan^2\theta_W$$

is assumed at the electroweak scale.

The sfermion masses are dependent on the parameter m_0.

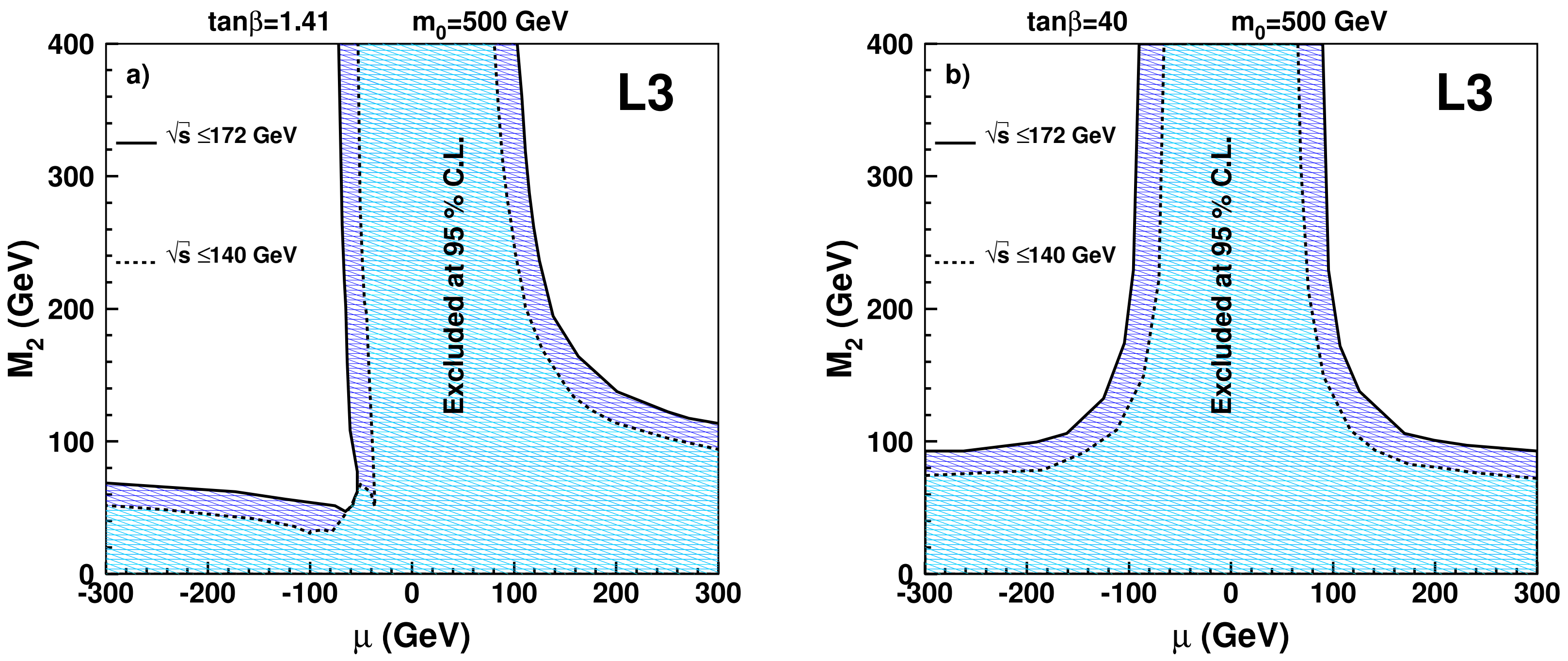
Interpretation in the MSSM - Slepton

$M_{\tilde{\ell}^{\pm}} > 73.9$ GeV for $M_{\tilde{\chi}_1^0} \leq 47.7$ GeV, $|\mu| \geq 200$ GeV and $\tan\beta \geq 1.41$;



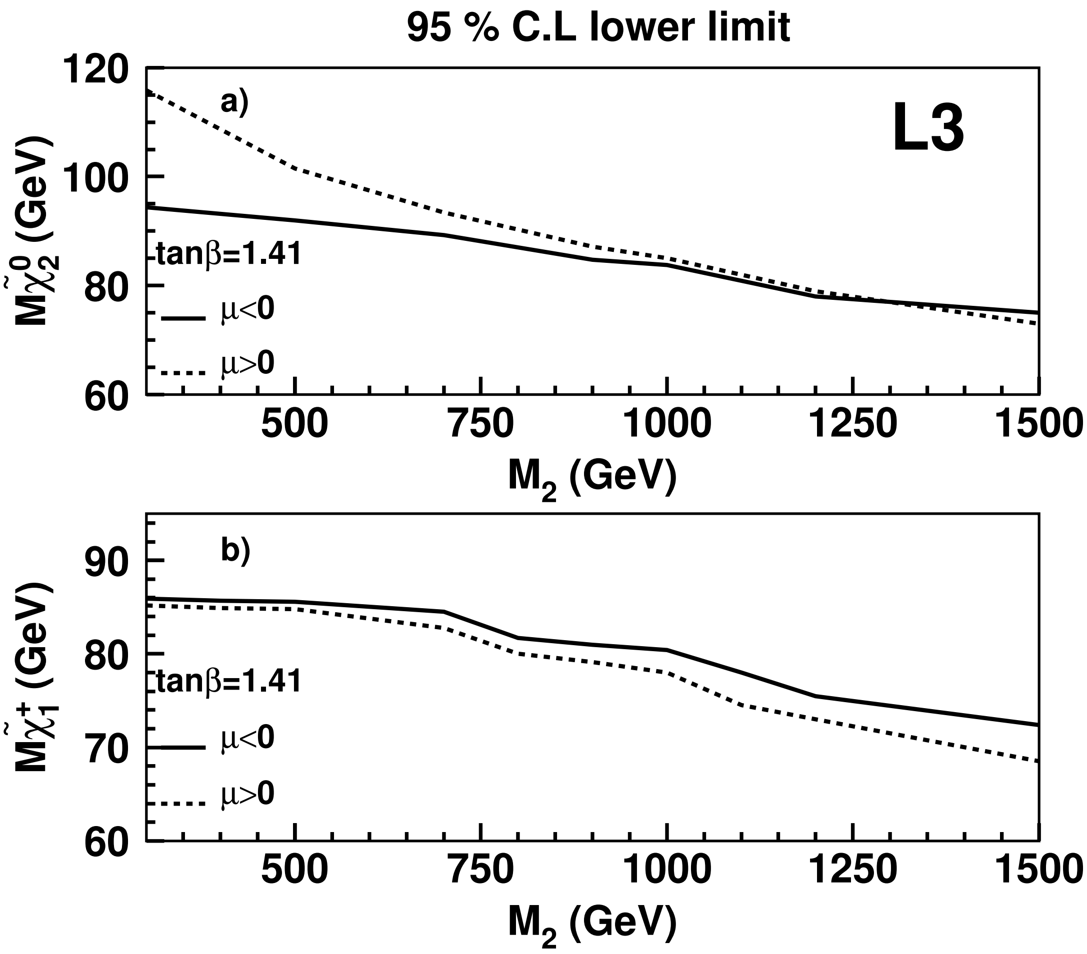
Interpretation in the MSSM

Chargino and Neutralino Searches:



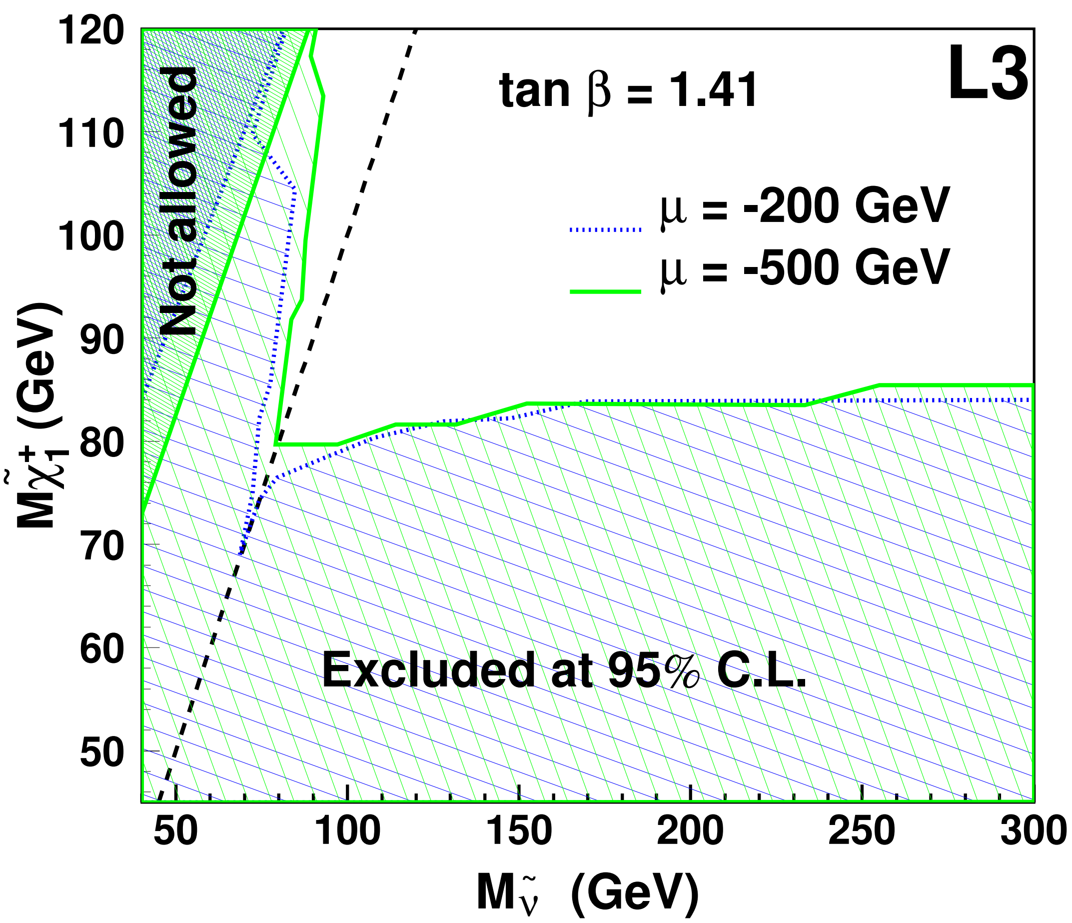
Results: Chargino and Neutralino Masses

Higgsino-like Chargino and Neutralino
$M_{\tilde{\chi}_1^\pm} > 85.0$ GeV for $M_2 \leq 500$ GeV and $\tan\beta = 1.41$
$M_{\tilde{\chi}_2^0} > 92.0$ GeV for $M_2 \leq 500$ GeV and $\tan\beta = 1.41$



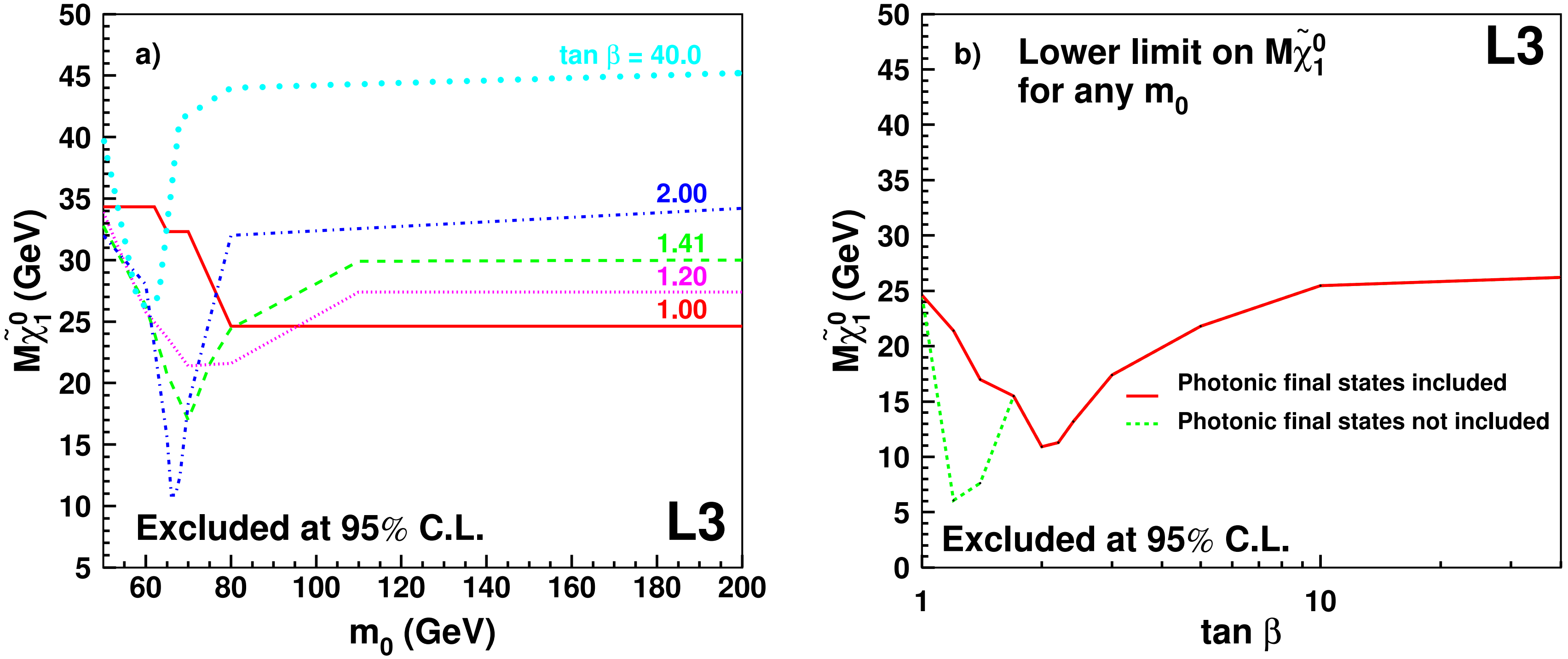
Results: Chargino Mass

$M_{\tilde{\chi}_1^\pm} > 85.5$ GeV for a Gaugino-like chargino with $M_{\tilde{\nu}} \geq 300$ GeV and $\mu = -500$ GeV ;
$M_{\tilde{\chi}_1^\pm} > 79.8$ GeV for any $M_{\tilde{\nu}}$, $\tan\beta \leq 1.41$ and $\mu = -500$ GeV;



Neutralino: Good Dark Matter Candidate

Strong Contribution from Photon(s) + Missing Energy



$M_{\tilde{\chi}^0_1} > 24.6$ GeV for $m_0 \geq 200$ GeV and $\tan\beta \geq 1$

$M_{\tilde{\chi}^0_1} > 10.9$ GeV for any m_0

Photons and Missing Energy

SUSY Searches in the Final State:
$\gamma(\gamma)$ + Missing Energy

Signature for

- **χ_1° is the LSP**
  - $e^+e^- \rightarrow \tilde{\chi}_2^\circ\tilde{\chi}_1^\circ \rightarrow \gamma\tilde{\chi}_1^\circ\tilde{\chi}_1^\circ$
  - $e^+e^- \rightarrow \tilde{\chi}_2^\circ\tilde{\chi}_2^\circ \rightarrow \gamma\gamma\tilde{\chi}_1^\circ\tilde{\chi}_1^\circ$
- **$\tilde{G}$ is the LSP**
  - $e^+e^- \rightarrow \tilde{G}\tilde{\chi}_1^\circ \rightarrow \gamma\tilde{\chi}_1^\circ\tilde{\chi}_1^\circ$
  - $e^+e^- \rightarrow \tilde{G}\tilde{G} \rightarrow \gamma\gamma\tilde{\chi}_1^\circ\tilde{\chi}_1^\circ$

Topologies

- **1 Photon + Missing Energy**
- **2 Photons + Missing Energy**

Main Background
$e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$

Analysis: High Energy Photons

- At least one photon with $E_\gamma > 10 GeV$
- Veto other sub-detectors

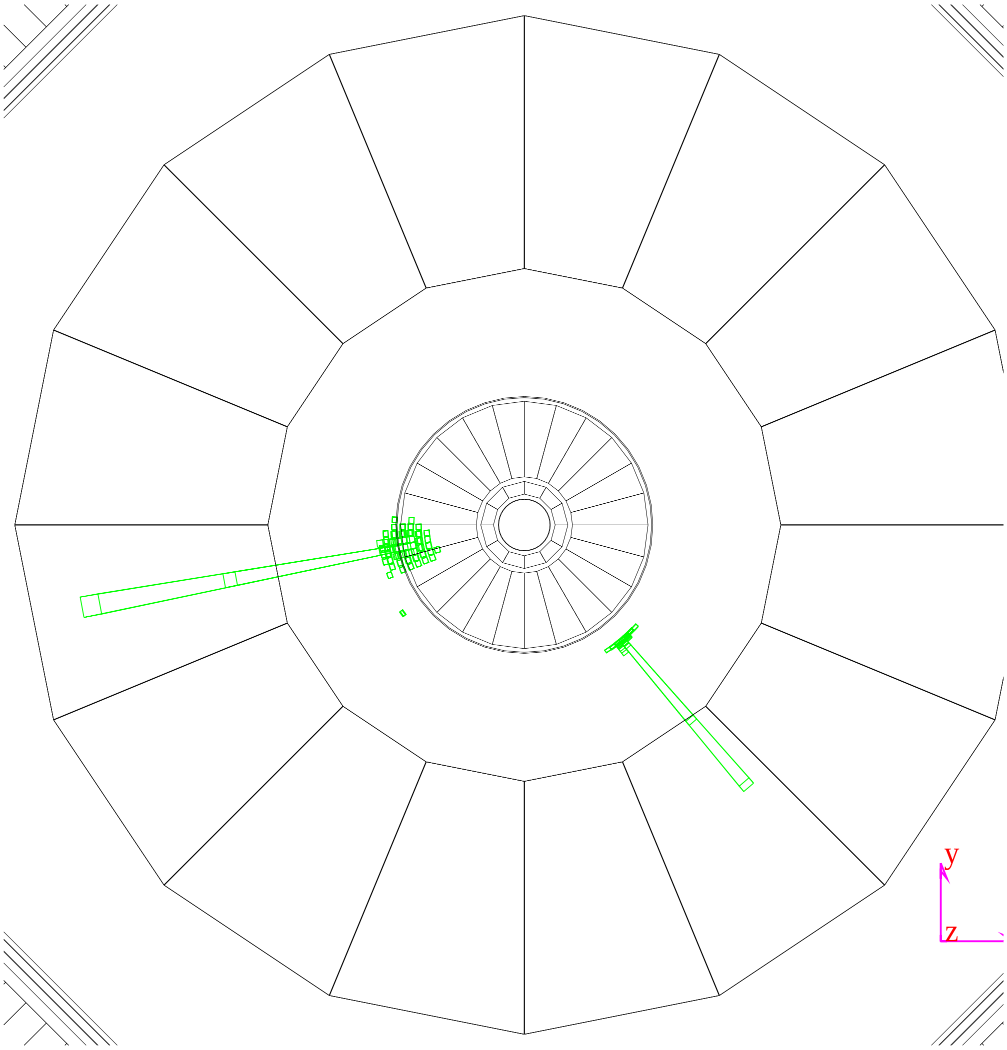
- total transverse momentum of photons $>$ 6 GeV
- opening angle between two jets $<$ 177.6°

If $E_{\gamma,2} > 5$ GeV

- opening angle $\gamma_1, \gamma_2 <$ 177.6°
- total tranverse momentum $>$ 3 GeV
- real solution for the recoil mass $\sqrt{s + M_{\gamma\gamma}^2 - 2\sqrt{s}E_{\gamma\gamma}}$

Two Photons Candidate

Run # **659911** **Event #** **1205** Total Energy : 54.25 GeV



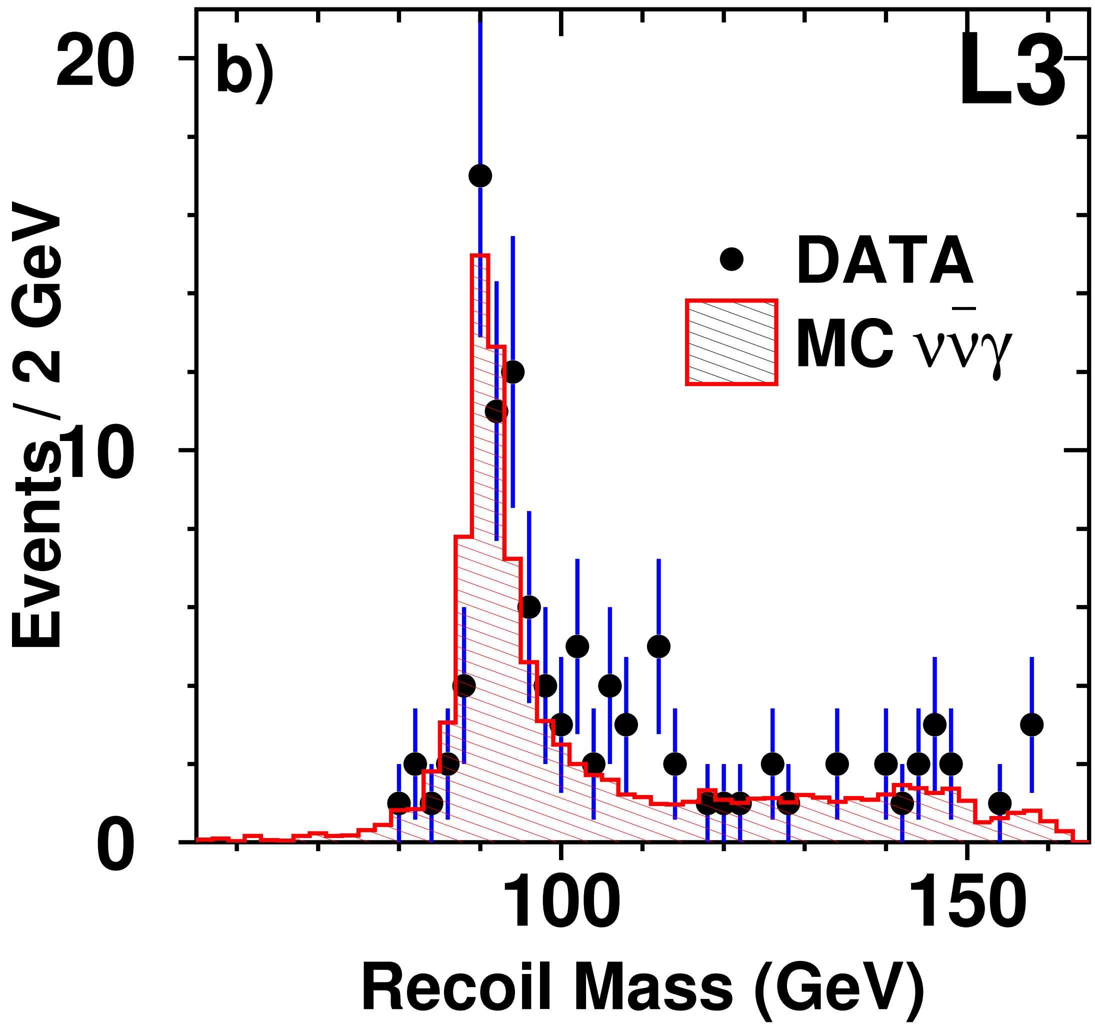
Transverse Imbalance :	.3179	**Longitudinal Imbalance :**	.7705

Thrust : .8535	**Major :** .4160	**Minor :** .0082
Event DAQ Time :	*960806 33453*	

Analysis: Single and Multi Photon

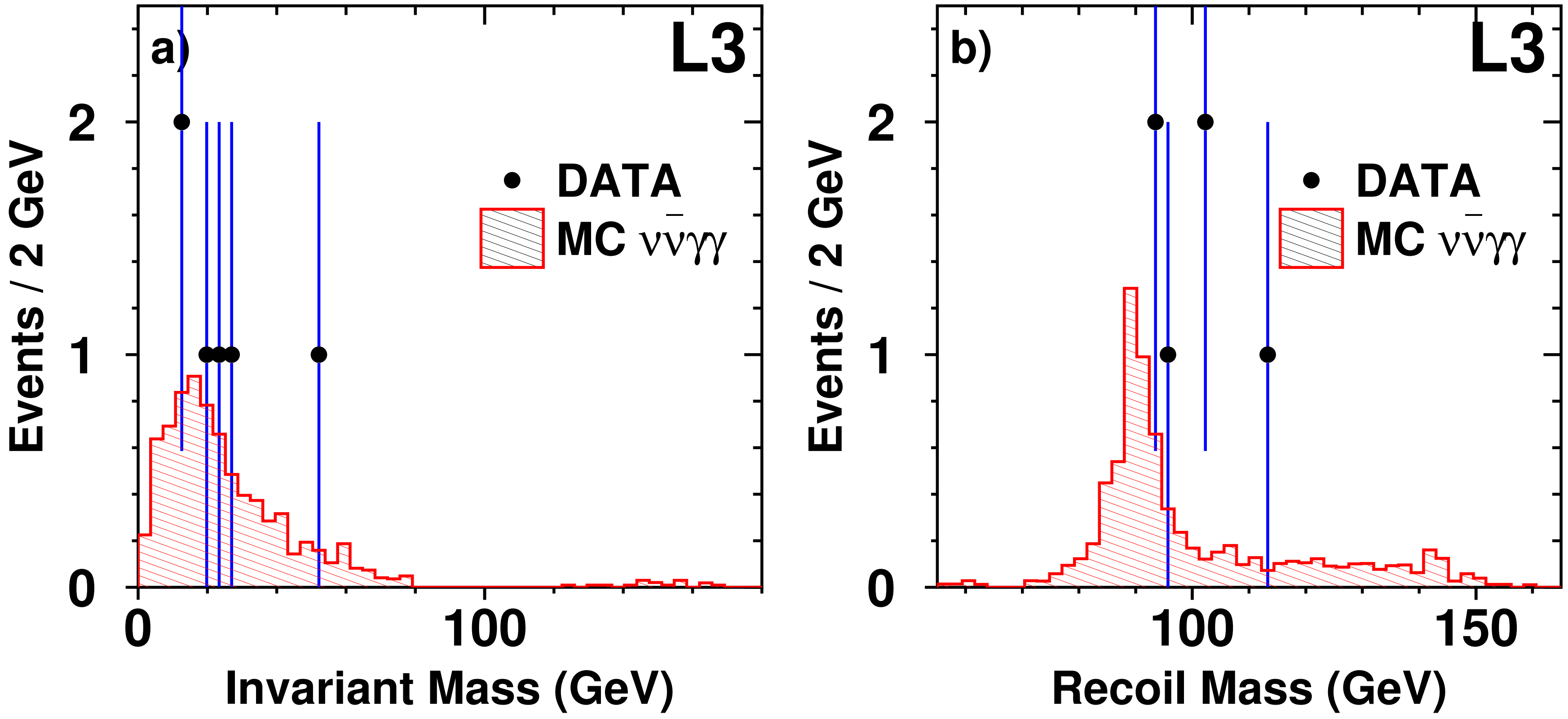
N_{exp}^{bckg}	N^{data}
100.1	106

$14^\circ < \theta < 166^\circ$

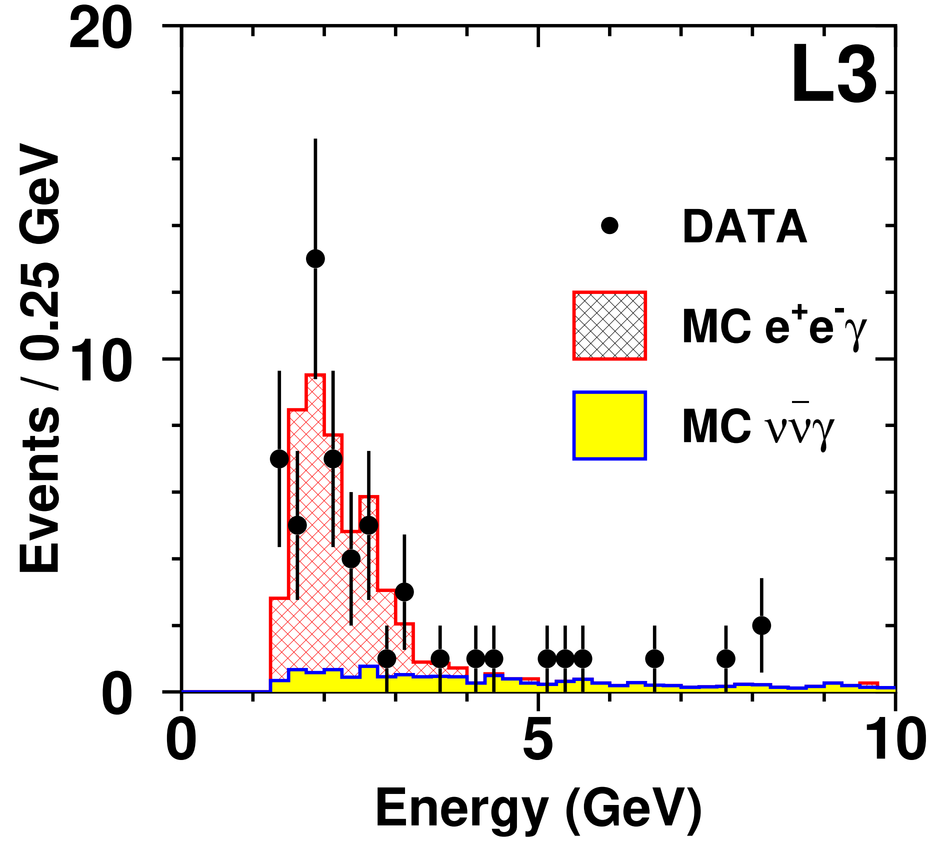


Analysis: Two Photons

	N^{bckg}_{exp}	N^{data}
	7.8	6
Recoil Mass $>$ 100 GeV	2.4	3



Low Energy Photons



Results

Single Photons

$\sqrt{s}$	N^{bckg}_{exp} Barrel+Endcap	N^{data} Barrel+Endcap
161	26.7+27.2	35+22
172	21.7+24.5	25+24

Signal Efficiencies

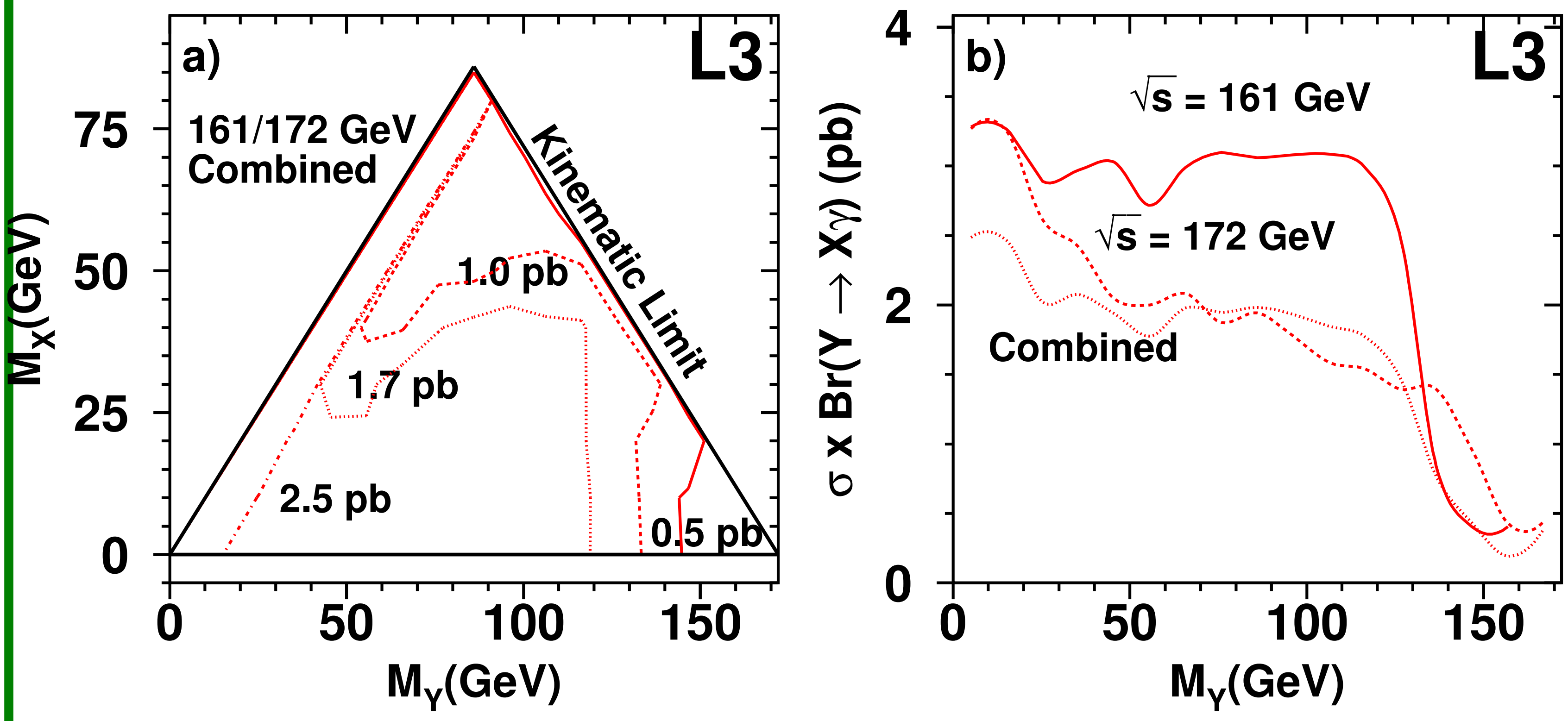
Two Photons

$\sqrt{s}$	N^{bckg}_{exp}	N^{data}
161+172	7.8	6
Recoil Mass $>$ 100 GeV	2.4	3

Signal Efficiencies

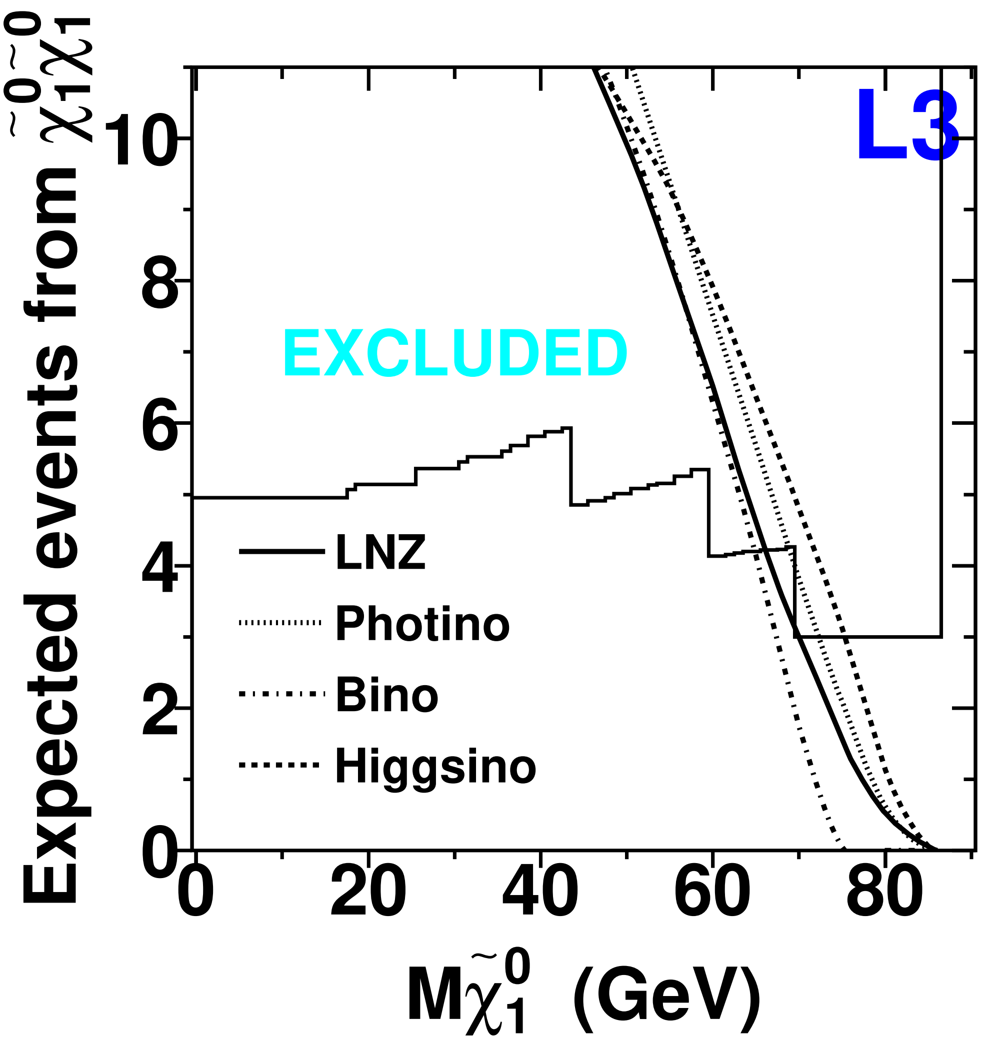
Results on Cross Sections

Limits for the process $e^+e^- \to XY \to \gamma XX$



Result in Specific Models

Number of two photons expected events



LNZ	$M_{\tilde{\chi}^0_1} > 66.1$ GeV;
Photino	$M_{\tilde{\chi}^0_1} > 68.6$ GeV;
Bino	$M_{\tilde{\chi}^0_1} > 64.8$ GeV;
Higgsino	$M_{\tilde{\chi}^0_1} > 75.3$ GeV.

Results from 1997 Run

Preliminary Results from 1997 Run - $\sqrt{s} = 183$ GeV

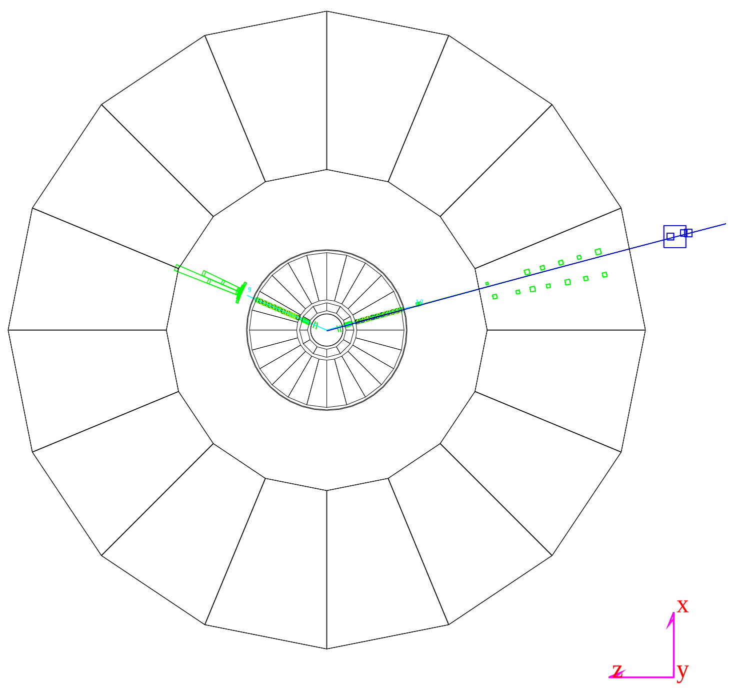
Center of Mass Energy	183 GeV
Luminosity analyzed	36 pb^{-1}

Very Preliminary Results on:

- Chargino
- Neutralino
- Photons and Missing Energy

Candidate Event

Run # 678401 Event # 2252 Total Energy : 42.09 GeV



Transverse Imbalance : .4407		**Longitudinal Imbalance :** .5869	
Thrust : .8433	**Major :** .4333	**Minor :** .0000	
Event DAQ Time : *970913 170245*			

Results from 1997 Run

1997 Run $\sqrt{s} = 183$ GeV: Int. Luminosity 36 pb^{-1}

Chargino - Neutralino Searches

ΔM	N^{bckg}_{exp}	N^{data}
Low	6	4
Medium	6	2
High	4	1

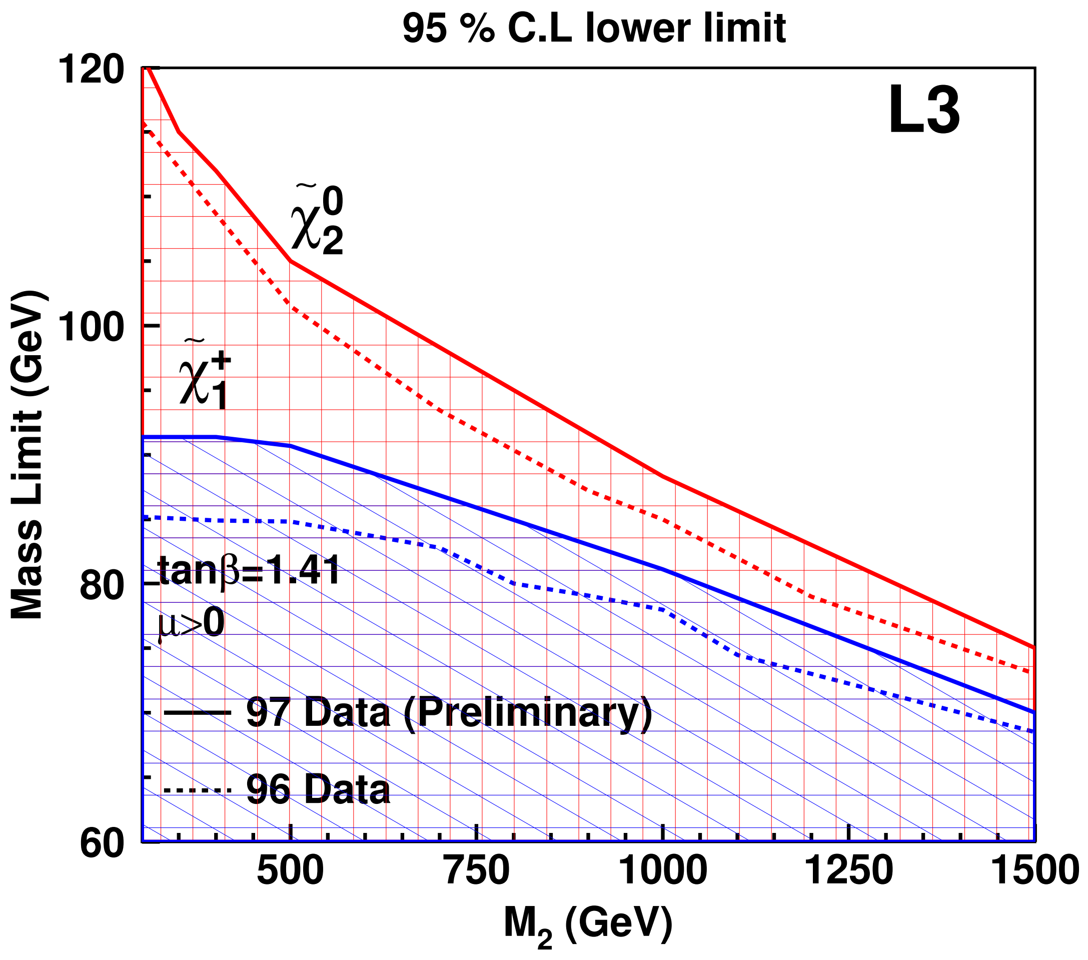
Photons and Missing Energy

	N^{bckg}_{exp}	N^{data}
Single and Multiphoton	122.3	98
Multiphoton	8.1	8

Neutralino and Chargino: 1997 Run

Higgsino-like Region

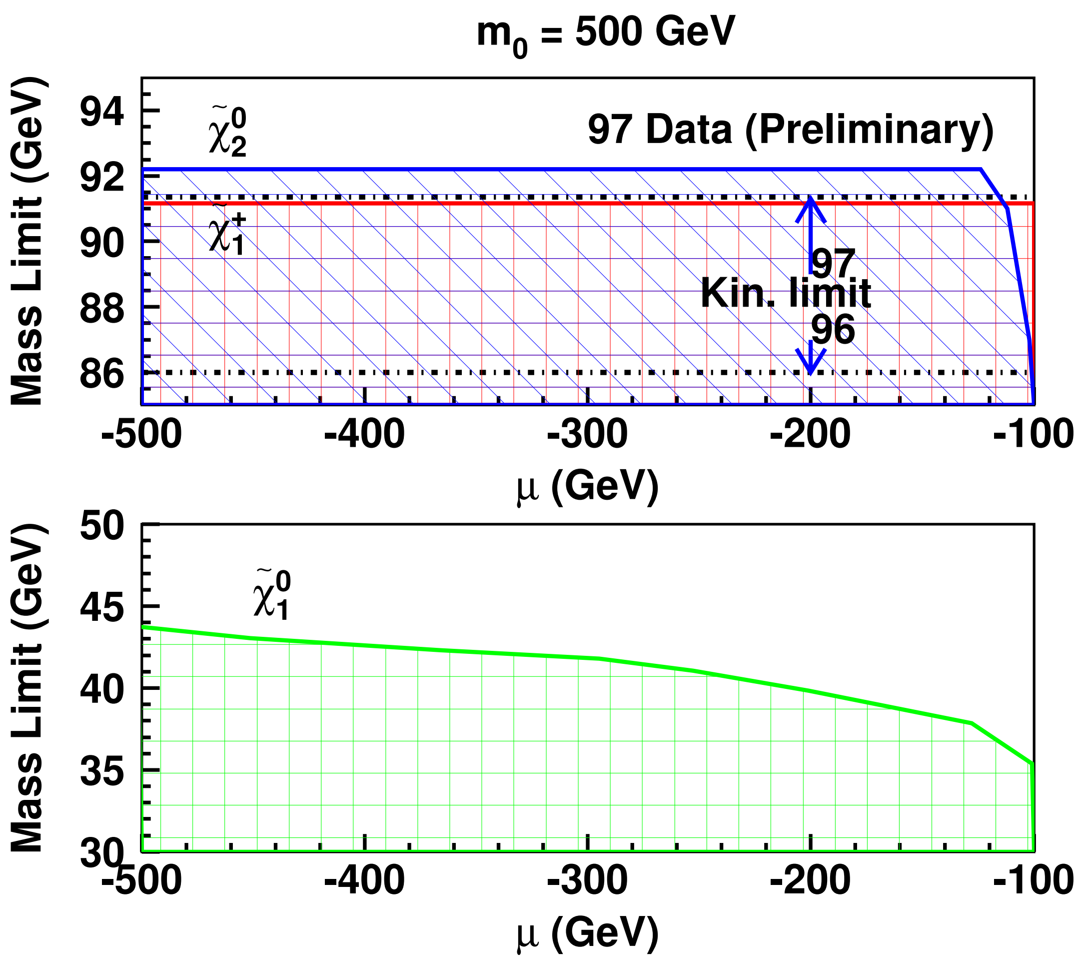
PRELIMINARY 97



Neutralino and Chargino: 1997 Run

Gaugino-like Region

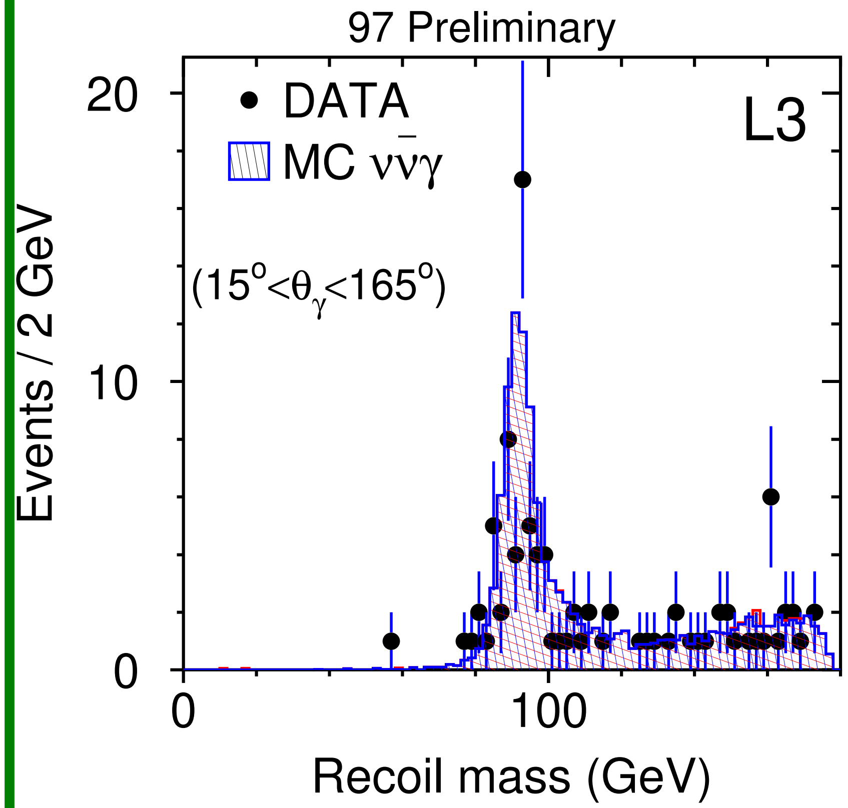
PRELIMINARY 97

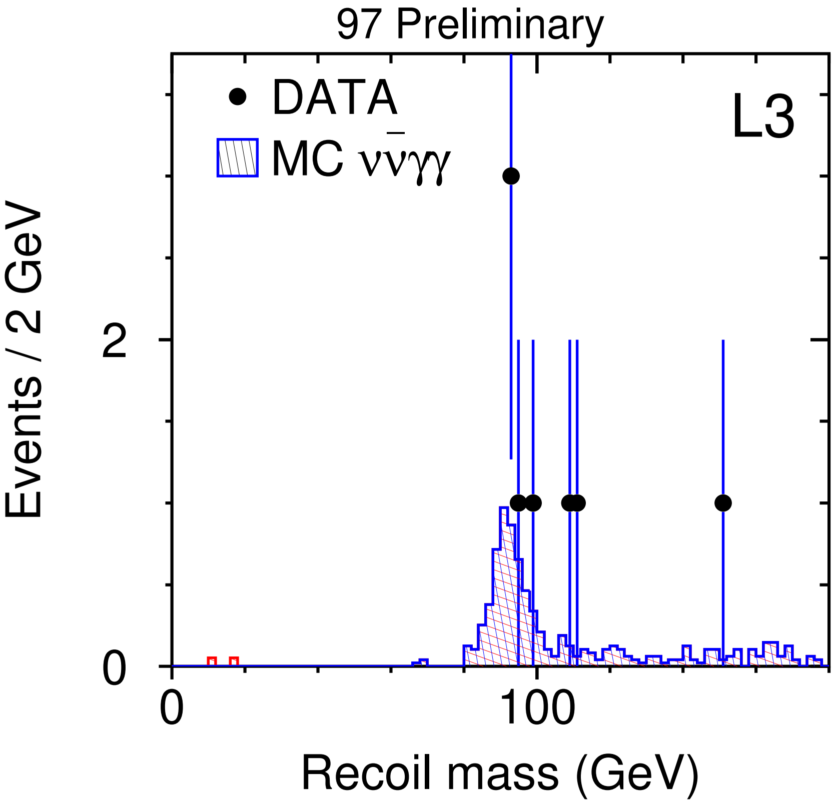


Photons and Missing Energy: 1997 Run

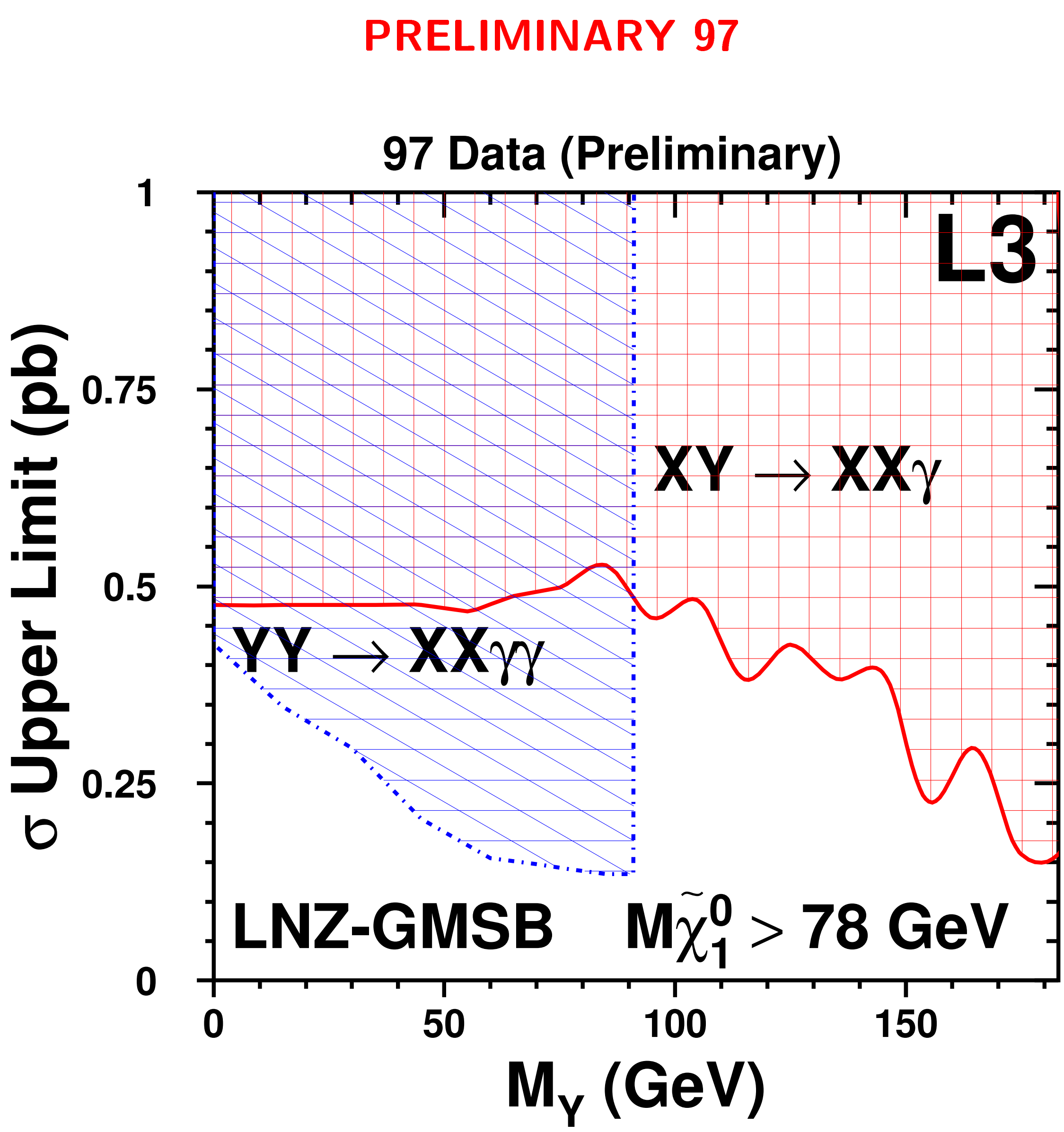
PRELIMINARY 97

Single Photon - Recoil Mass **Multi Photon - Recoil Mass**





Photons and Missing Energy: 1997 Run



Conclusions

Data collected by the L3 experiment at LEP2 show no evidence of Supersymmetric particles.

- Model independent limits on the production cross sections
- Improved limits on mass of SUSY particles
- New excluded regions in the parameter space

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- Run at $\sqrt{s} = 182$ GeV not finished
- Higher energies and higher luminosities in next years

Susy

One partner for each ordinary particle - spin different by 1/2 Symmetry is broken because the partners have not the same mass.

Particle	Spin	S–particle	Spin	Name
$\ell = e, \mu, \tau, \nu$	1/2	$\tilde{\ell}_R, \tilde{\ell}_L$	0	slepton
$q = u, d, s, c, b, t$	1/2	$\tilde{q}_R, \tilde{q}_L$	0	squark
g	1	$\tilde{g}$	1/2	gluino
γ	1	$\tilde{\gamma}$	1/2	photino
$W^\pm$	1	$\tilde{W}^\pm$	1/2	wino
Z	1	$\tilde{Z}$	1/2	zino
H_1°, H_2°	0	$\tilde{H}_1^\circ, \tilde{H}_2^\circ$	1/2	higgsino
$H^\pm$	0	$\tilde{H}^\pm$	1/2	higgsino

Gaugino and Higgsino Mass Eigenstates

- Super–partners of the $W^\pm$ and the charged Higgs bosons mix to form two charged fermion mass eigenstates:

Charginos: $\tilde{\chi}^\pm_{1,2}$

- Super–partners of the Z, γ and the neutral Higgs bosons give four neutral fermion mass eigenstates:

Neutralinos: $\tilde{\chi}^\circ_{1,2,3,4}$