LEP searches in R-parity Violation scenarios

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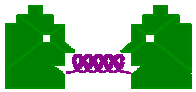


Outline

- Introduction
- RPV Superpotential
- Decays via trilinear RPV Couplings
- Search strategies
- Review of Updated Analyses Results
- Exclusion plots and limits
- Summary
- Conclusion
- As an Epilogue

- **What is Rp and why go beyond ?**

➢ **a discrete multiplicative symmetry in SUSY models connected to matter parity**

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

R_p = 1 **for SM particles**

R_p = -1 **for SUSY particles**

- **SUSY particles produced in pairs**
- **LSP is stable**
- **experimental signature of SUSY E_T miss**

⟶ **fast proton decay is suppressed**

RpV Superpotential

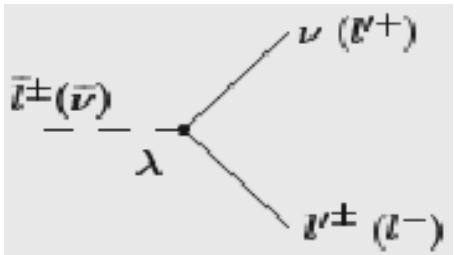
- Rp can be explicitly broken by trilinear terms in the superpotential

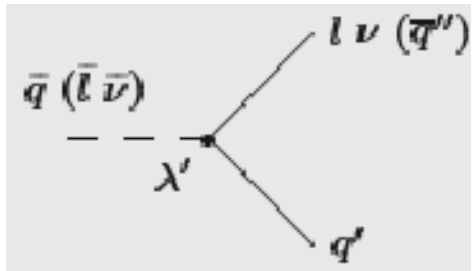
$$W = \lambda_{ijk}\, L_i L_j \bar{E}_k + \lambda'_{ijk}\, L_i Q_j \bar{D}_k + \lambda''_{ijk}\, \bar{U}_i \bar{D}_j \bar{D}_k$$

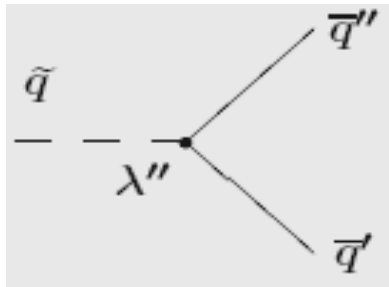
$\Delta L \neq 0$ 9 Couplings $(i \neq j)$

$\Delta L \neq 0$ 27 Couplings

$\Delta B \neq 0$ 9 Couplings $(j \neq k)$







- **single sparticle production** via a $\Delta L \neq 0$ or a $\Delta B \neq 0$ operator
- **Unstable LSP !**
- **Signature of multilepton or multijet events in excess**

→ **fast proton decay is suppressed if Lepton and Baryon number Violating Couplings are not simultaneously present**

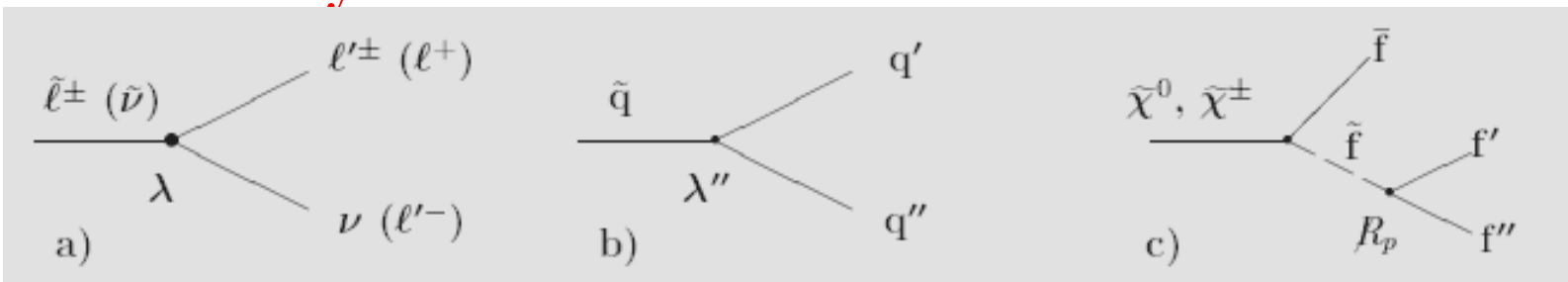
Decays via trilinear RPV Couplings

Decay topologies

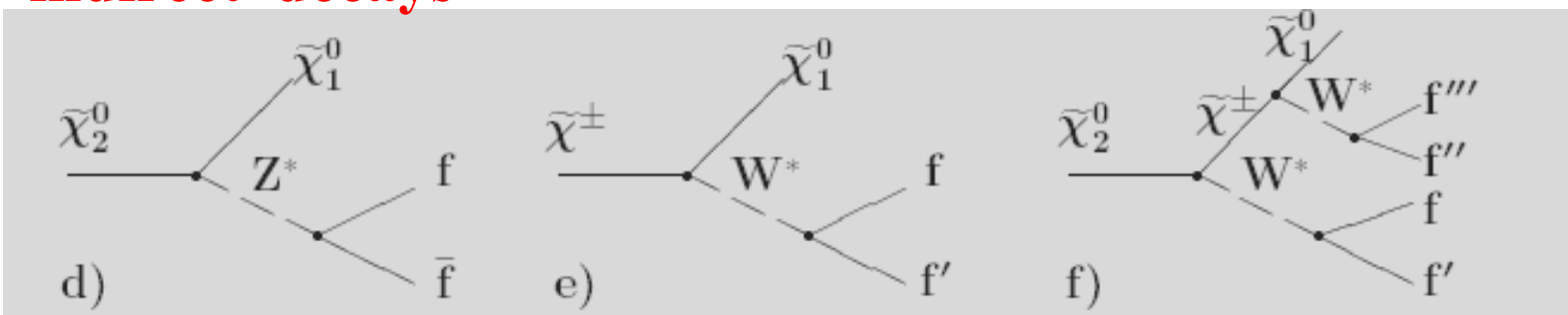
$9\,\lambda_{ijk} + 27\,\lambda'_{ijk} + 9\,\lambda''_{ijk} = 45$ **new couplings**

Hierarchies in RpV Couplings expected (as for Yukawa Couplings generating fermion masses)

- **direct decays**



- **indirect decays**



multileptons - multijets

LSP Decay Length

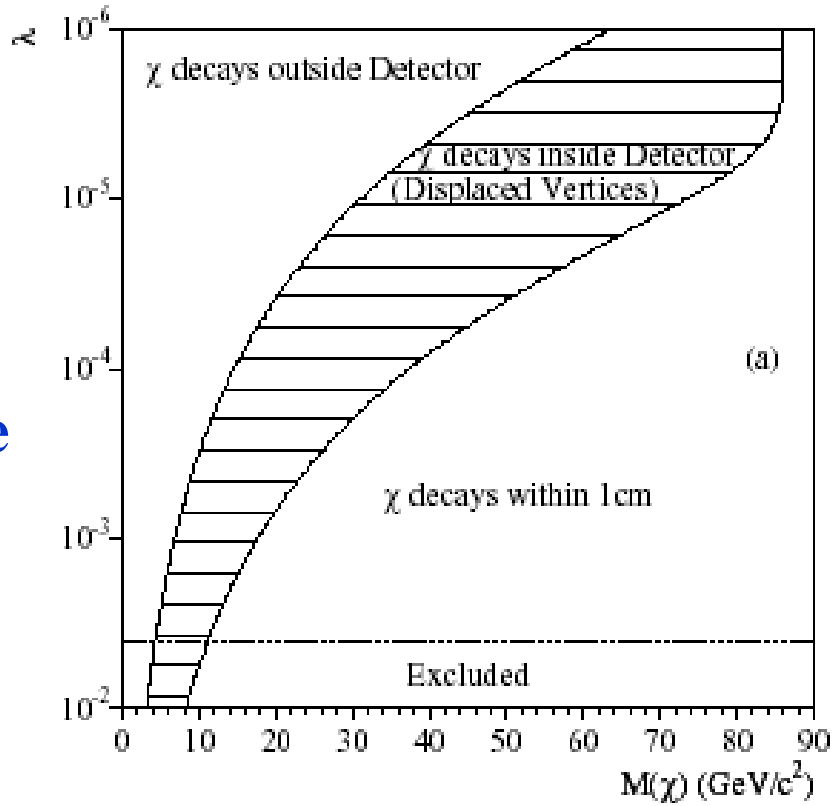
Decay Length of $\tilde{\chi}_1^0$

$$L \approx \frac{1}{\lambda^2}\left(\frac{m_{\tilde{f}}}{100GeV}\right)^4\left(\frac{1GeV}{m_{\tilde{\chi}}}\right)^5$$

- **LEP analyses are sensitive only if the LSP has a negligible lifetime (L < 1 cm)**

➢ $m_{\tilde{\chi}} > 10\ GeV$

$\sim 10^{-5} < \lambda < 10^{-2}$ up to 1



Displaced Vertices < λ < indirect SM bounds

Search strategies

- **Suppose one Coupling** $\lambda_{ijk}^{(' '')} \neq 0$
- **Consider that many channels have to be combined**
- **Optimize Signal selection on various topologies**

  --with sequential cuts : ALEPH, OPAL, L3, DELPHI $(LL\bar{E})$

  --using lepton identification and lepton isolation criteria $(LL\bar{E}\ ,\ LQ\bar{D})$

  -- with neural network methods : DELPHI $(\bar{U}\,\bar{D}\,\bar{D})$

  -- using jet algorithm, b tagging $(LQ\bar{D}\,,\,\bar{U}\,\bar{D}\,\bar{D})$

- **Calculate signal reconstruction efficiency**

  -- optimization on different mass combinations depending on the decays and the kinematics

- **If no significant deviation from the SM, set 95 % CL limits on:**

***cross-sections * couplings and sparticle masses * exclusion plots in the MSSM regions**

Minimal SUSY scenario :

- Topologies predicted in a Constrained MSSM => ***CMSSM***
- gaugino mass unification ($M_1 \approx 0.5\, M_2$) at EW scale
- Mass universality at GUT scale => ***μ, tanβ, m_0***
- Trilinear terms are set to 0 => $A_{b,t,\tau} = 0$
- Mixing angles for stop and sbottom => $\phi_{\tilde{t}}$, $\phi_{\tilde{b}}$

Bounds on RpV Couplings at EW scale:

λ : ~ $5.\ 10^{-2}$ λ' : ~ $2.\ 10^{-2}$ (131) up to 0.56 (232)

λ'': ~ 0.5 up to ~1.23 (except $\lambda''_{112} = \lambda''_{121} \sim O(10^{-9})$, $\lambda''_{131} = \lambda''_{113} = 10^{-4}$)

(for a sparticle mass of 100 GeV/c^2)

LEP 2 Data

- **LEP 2 : 5 years of data taking**

  E_{cm} up to 209 GeV

  ~ 714 pb^{-1} per experiment

Year	E_{cm}	<L/Exp>
	GeV	pb^{-1}
1996	161-172	~ 20
1997	183	~ 55
1998	189	~170
1999	192-202	~230
2000	204-209	~227

- **Backgrounds :**

  * **Four fermions (ZZW^+W^-)**

  $f\bar{f}$ (γ)

  $\gamma\gamma$

- **Signal :**

  generated using

  SUSYGEN 2.2 (3.0)

No evidence for a significant signal observed in all the RpV searches
MANY LIMITS (at 95 %) are derived

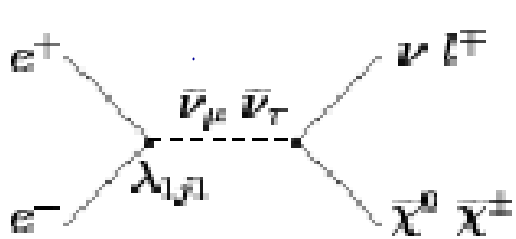
Single sneutrino production

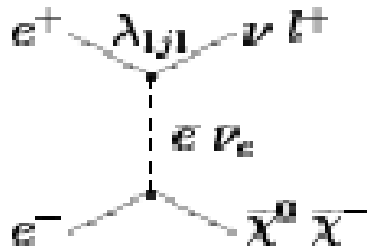
- Resonant sneutrino $\tilde{\nu}_\mu$, $\tilde{\nu}_\tau$ production $\sigma \propto \lambda^2_{ijk}$

→ probes masses up to E_{cm}

DELPHI

- Single gaugino production



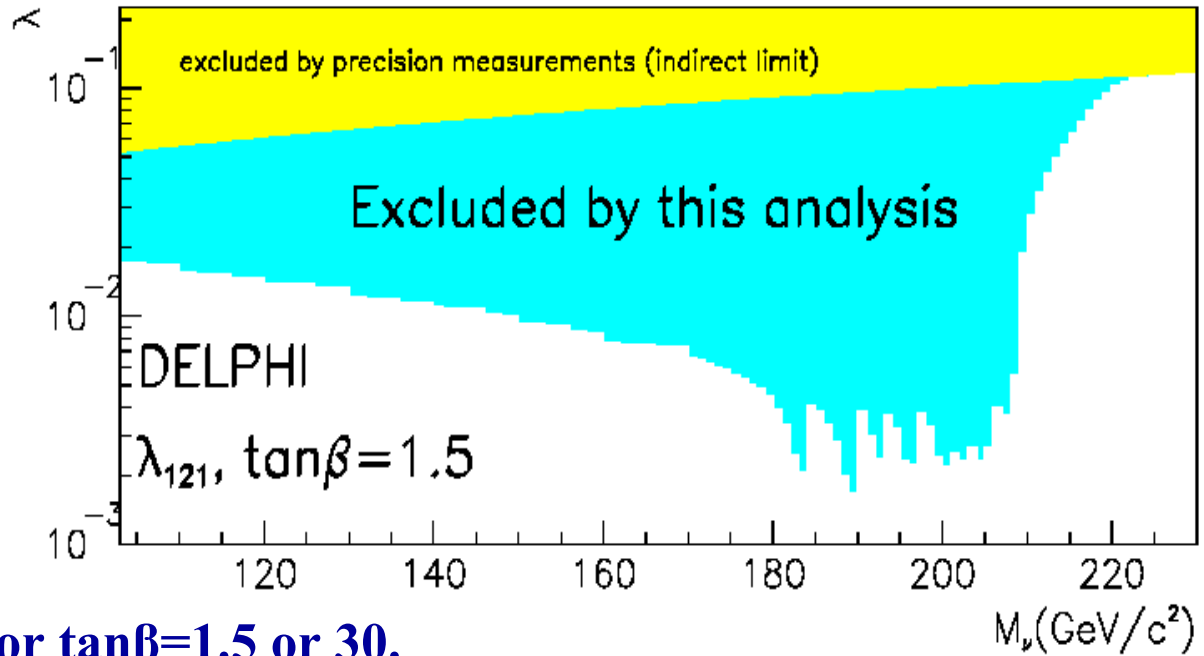


Analysis of final states : 3 topologies

- ➢ 2 leptons and E_{miss}
- ➢ 4 or 6 leptons (with or without E_{miss})
- ➢ leptons + jets

- Couplings λ_{121} , λ_{131}

limits on λ → 1. – 3. 10^{-3}

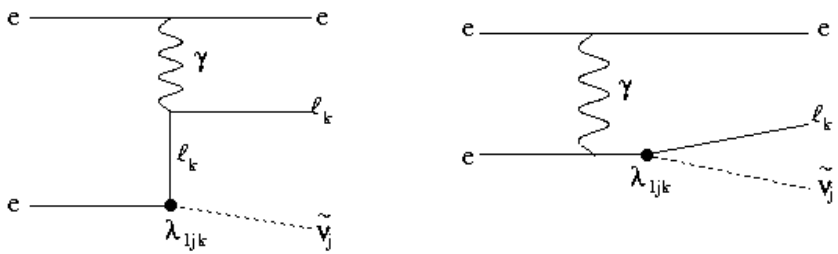


for tanβ=1.5 or 30.

Single sneutrino production

- single sneutrino $\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$ production : $e\,\gamma \rightarrow \tilde{\nu}_j\, l_k$

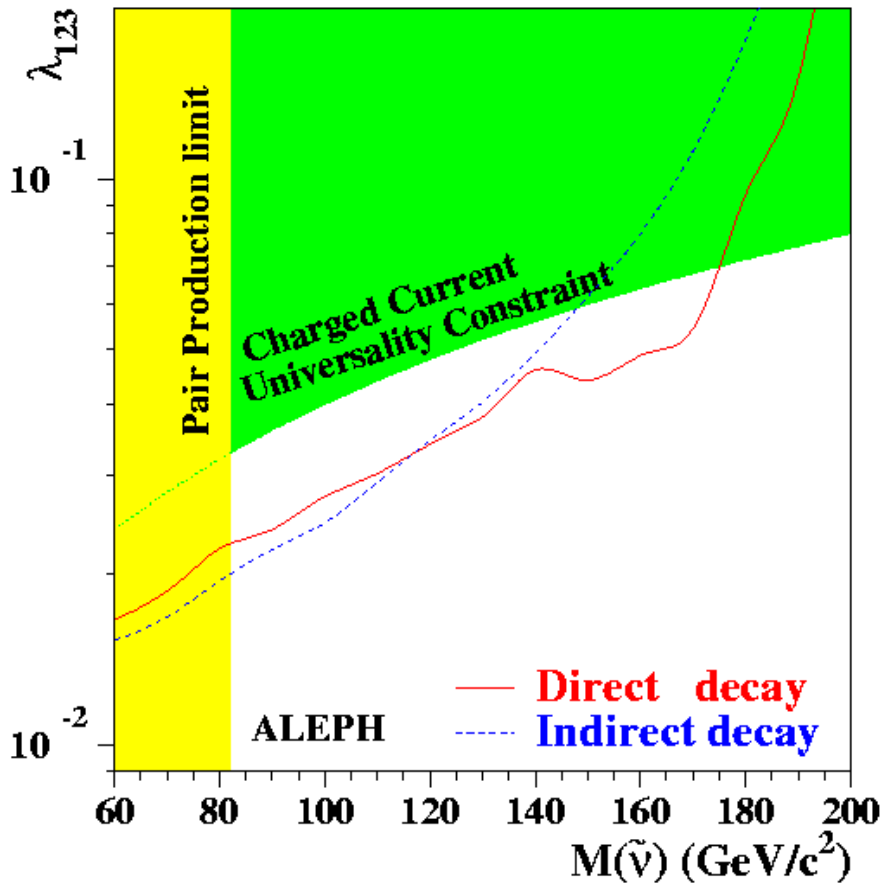
ALEPH



- Couplings λ_{1jk} and λ_{231}
- multi – lepton final states

  (direct / indirect)

  → 6 analyses



Upper limits on λ
~ 7. 10^{-3} - 3. 10^{-2}

(for a sneutrino mass of 100 GeV/c^2)

Gaugino pair production

λ	λ'	λ''
2, 4 and 6 leptons (+ Emiss)	2, 4 jets +lepton(s) (+ Emiss)	multijets + leptons (+ Emiss)

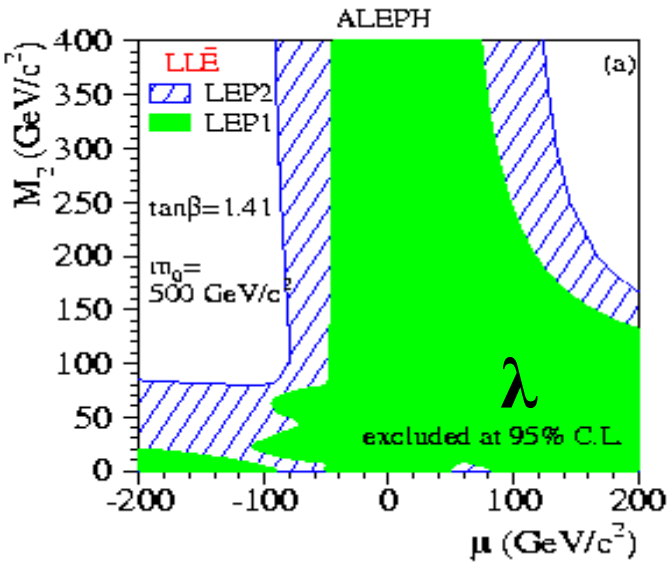
- **Final states**

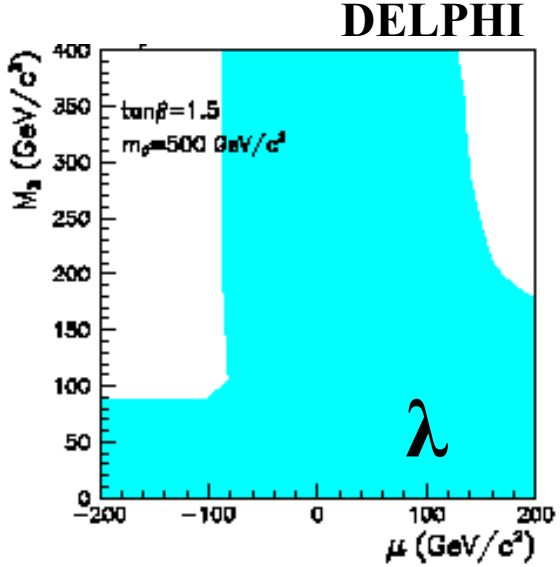
	LL$\bar{E}$	LQ$\bar{D}$	$\bar{U}\bar{D}\bar{D}$
$\tilde{\chi}^0\tilde{\chi}^0$	$4l+\not{E}$	$1,2l+4j+\not{E}$ $2l+4j$	$6j$
$\tilde{\chi}^\pm\tilde{\chi}^\pm$ $(dir.)$	$2,4,6l+\not{E}$	$1,2l+4j+\not{E}$	$6j$
$\tilde{\chi}^\pm\tilde{\chi}^\pm$ $(ind.)$	$\tilde{\chi}^0\tilde{\chi}^0+WW$ $\geq 4l+nj+\not{E}$	$\tilde{\chi}^0\tilde{\chi}^0+WW$ $\geq 4j+nl+\not{E}$	$\tilde{\chi}^0\tilde{\chi}^0+WW$ $\geq 6j+nl$

- $\tilde{\chi}^\pm$ **indirect decay is the dominant decay channel in almost all the MSSM parameter space**

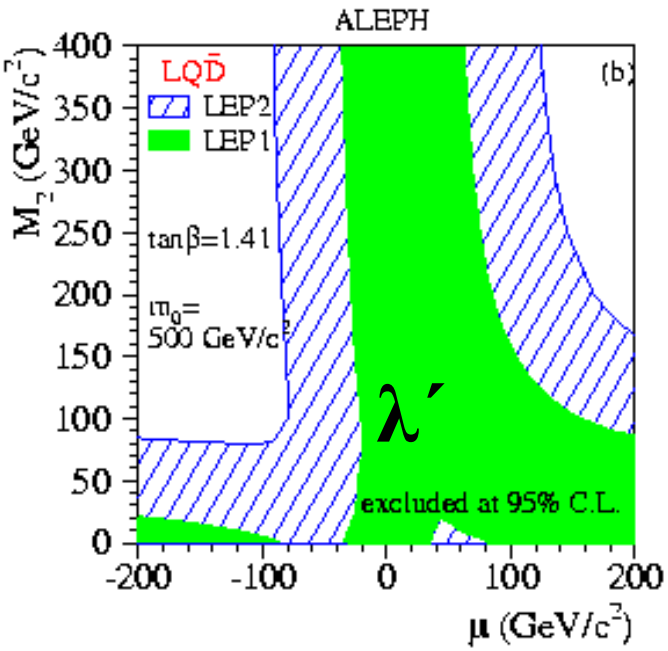
Limits from Gaugino searches

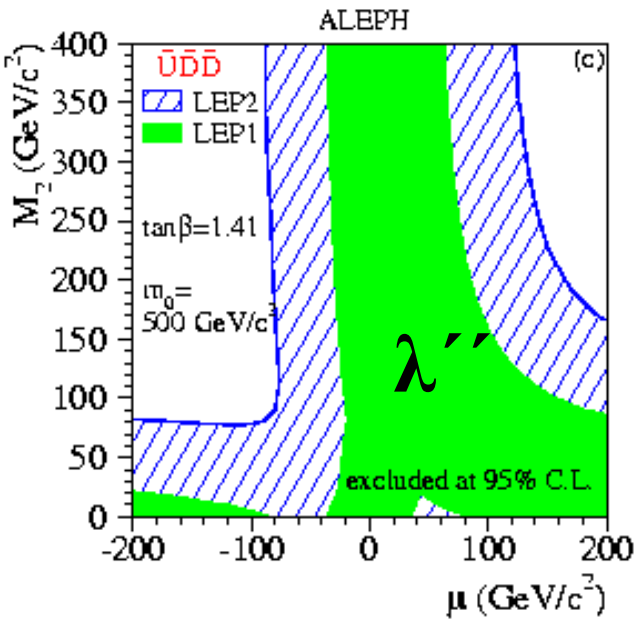
- **Limits in MSSM parameter space**





Scans in μ , M_2 for different values of m_0 and tanβ





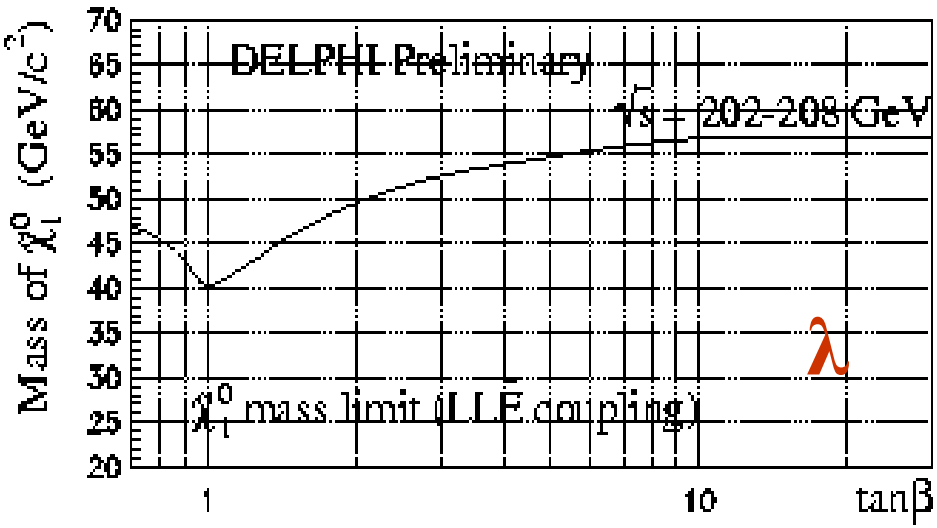
Gaugino mass limits

NEW

- **Mass limits**
  at 95 % CL in GeV/c²

		λ	λ′	λ′′
$\tilde{\chi}_1^0$	L	40.2	—	39.9
	D	39.5	—	38.0
$\tilde{\chi}_2^0$	L	84.0	—	80.0
$\tilde{\chi}_3^0$	L	107.2	—	107.2
$\tilde{\chi}_1^\pm$	A	103	103	103
	D	103		102.5
	L	103.0	—	102.7

DELPHI



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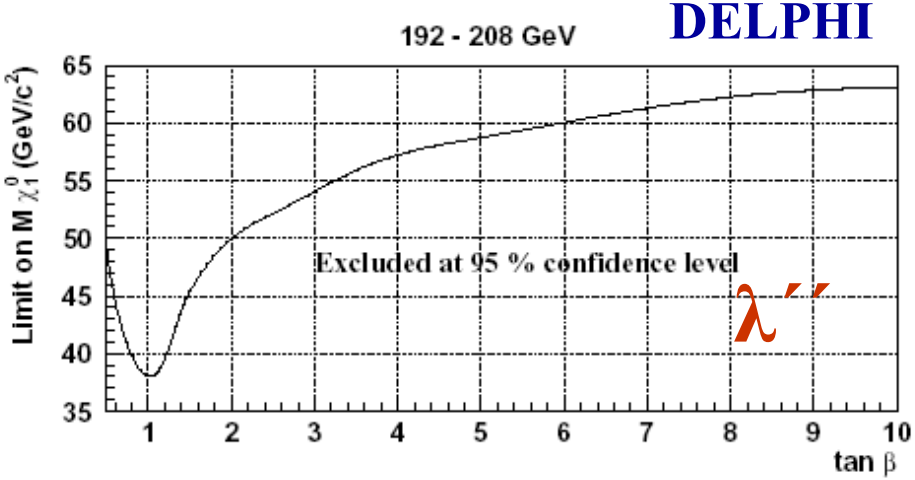
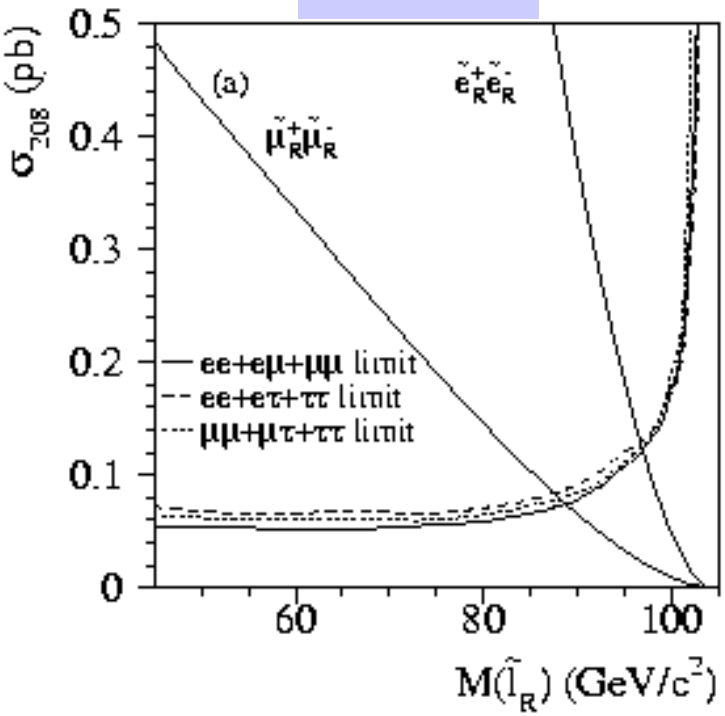


slepton pair production

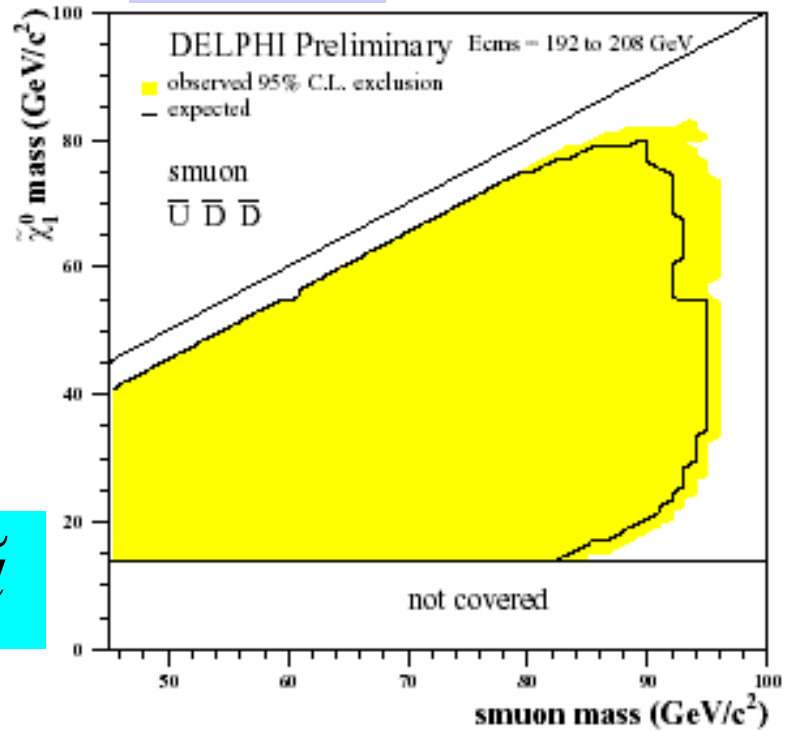
$\tilde{e}, \tilde{\mu}, \tilde{\tau}$

- **Direct decay :** $e^+ e^- \rightarrow \tilde{l}^+ \tilde{l}^- \rightarrow 4$ *fermions*
- **Indirect decay :** $e^+ e^- \rightarrow l^+ l^- \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow 8$ *fermions*

ALEPH λ



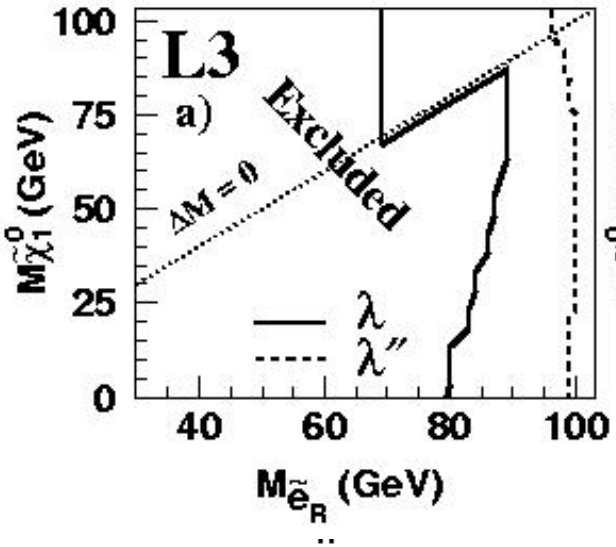
DELPHI λ''

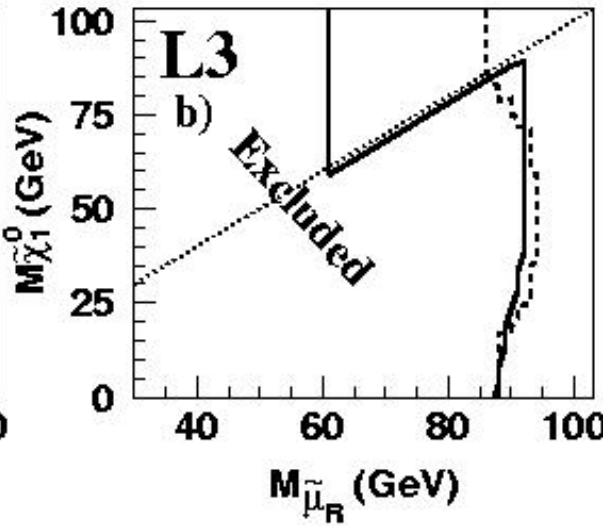


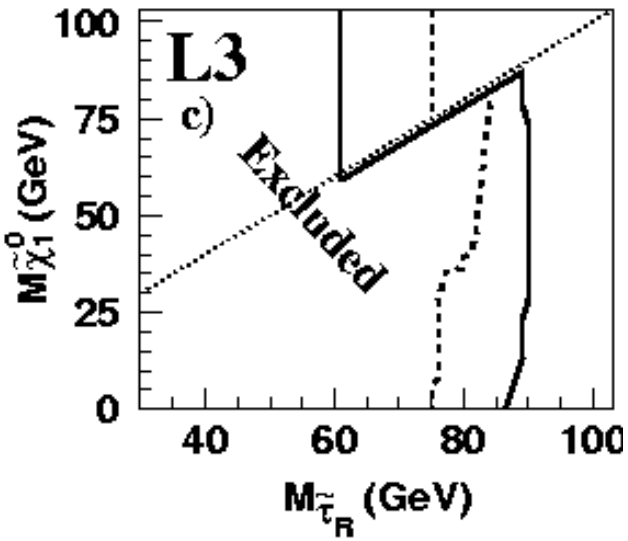
$\tilde{\mu}$

μ=200 GeV/c², tanβ=1.5, BR=1

slepton pair production

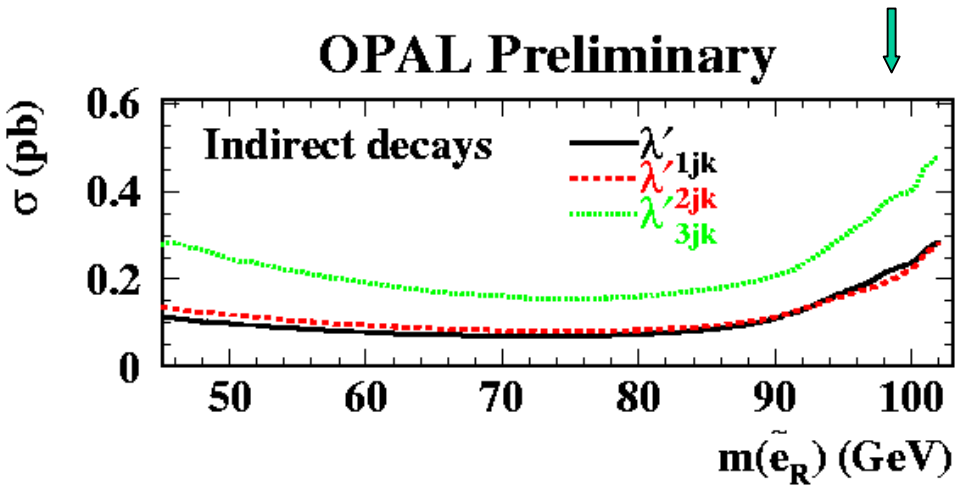






- MSSM exclusion contours, at 95 % C.L.

- Cross-section upper limits, at 95 % C.L.

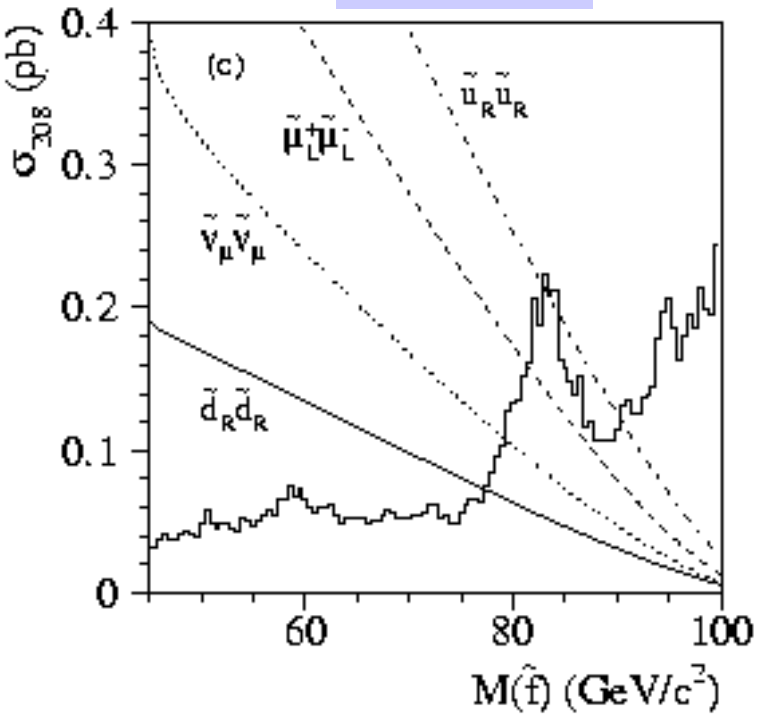


Sneutrino pair production

$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$

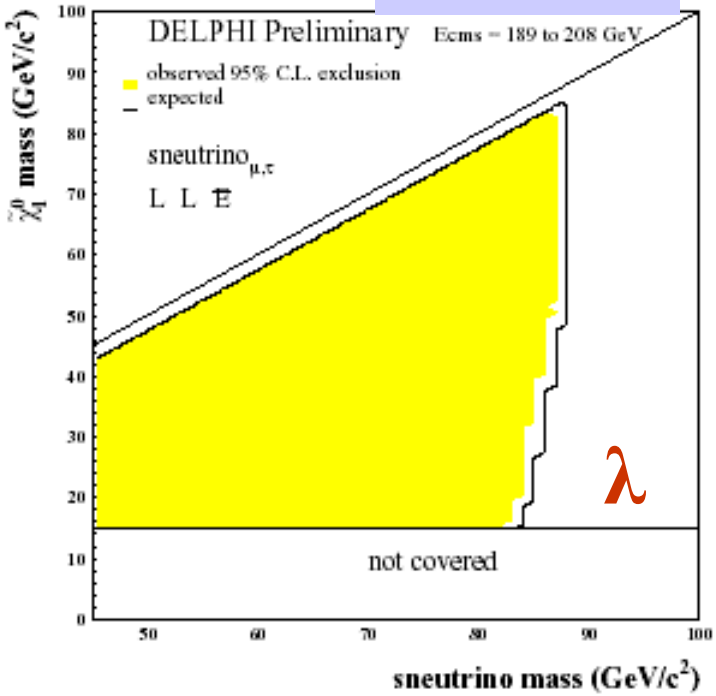
- **Direct decay :** $e^+ e^- \rightarrow \tilde{\nu}\,\bar{\tilde{\nu}} \rightarrow 4\ fermions$
- **Indirect decay :** $e^+ e^- \rightarrow \nu\bar{\nu}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0 \rightarrow 8\ fermions\,(2\nu)$

ALEPH



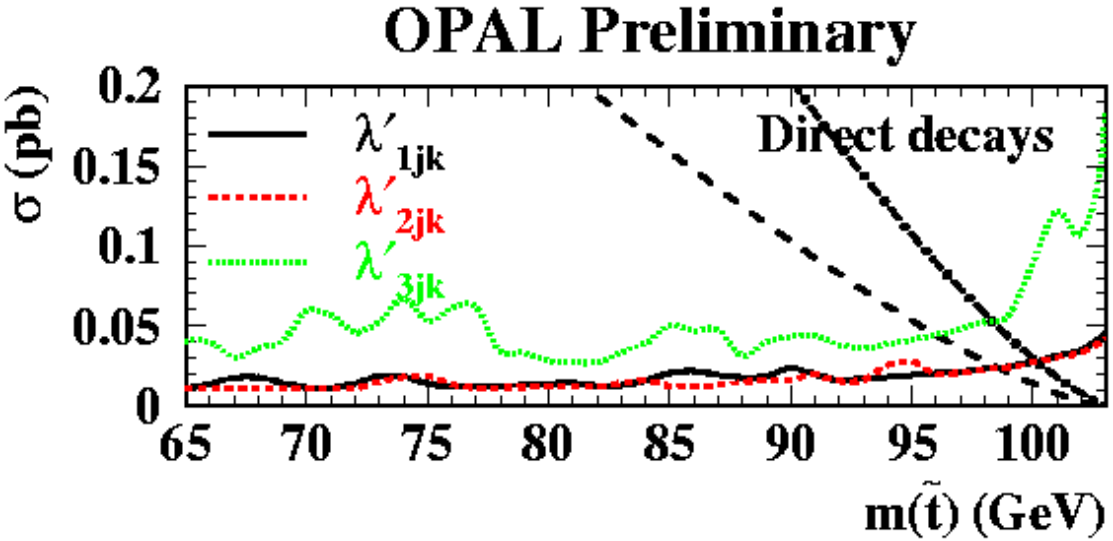
Excluded $\tilde{\nu}\,\bar{\tilde{\nu}}$ cross-section (4 jets)

DELPHI



Excluded contour , at 95% CL for $\tilde{\nu}_\mu, \tilde{\nu}_\tau$ for indirect decays

Squark pair production

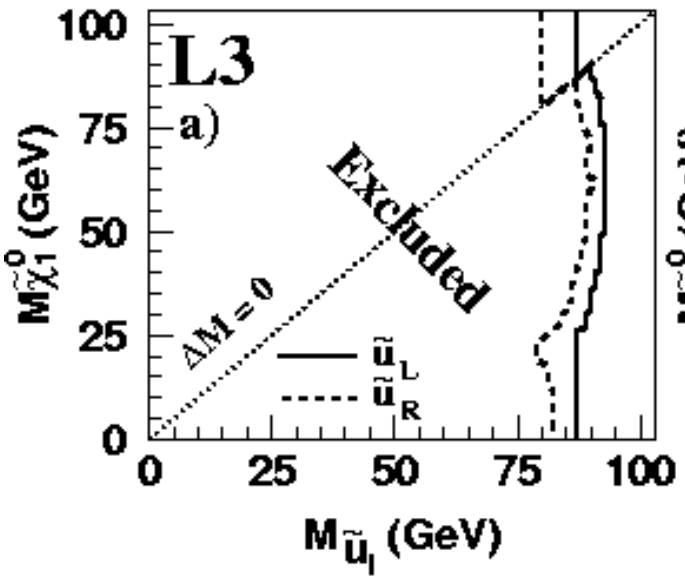


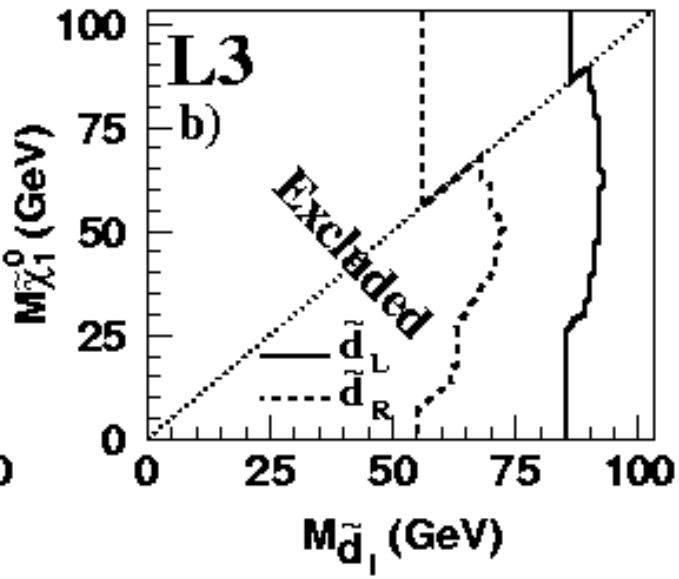
- **Direct decays :**

  => $\tilde{q}\,\tilde{\bar{q}}$ => 4 fermions

- **Indirect decays :**

  => $q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$ => 8 fermions





λ′′

MSSM

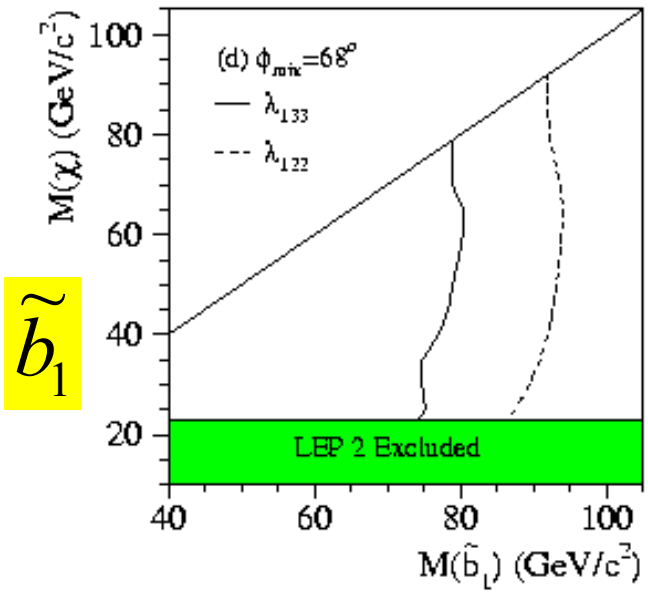
Exclusion contours, at 95% CL

Squark pair production

$\tilde{t}$, $\tilde{b}$

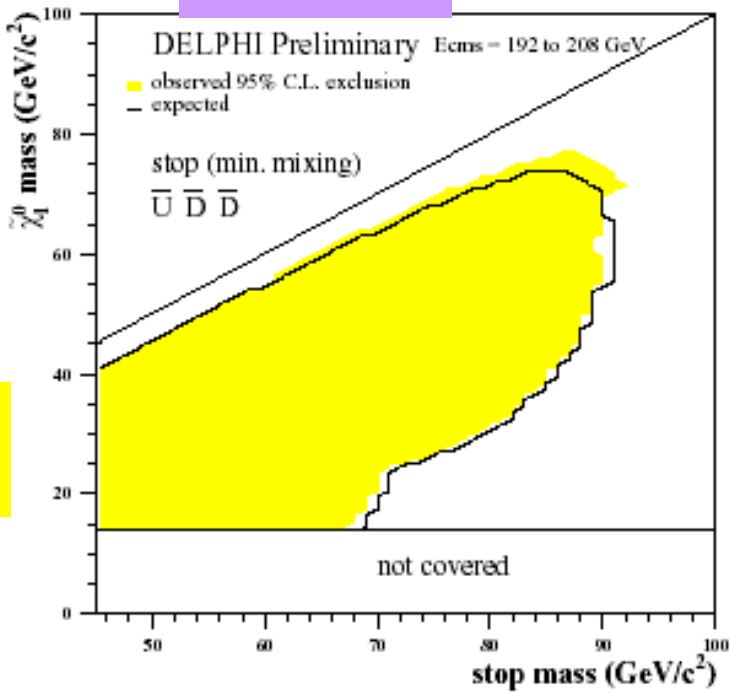
• **Mixing :** $\tilde{t}_1 = \tilde{t}_L \cos\phi_{\tilde{q}} + \tilde{t}_R \sin\phi_{\tilde{q}}$

ALEPH λ



$\tilde{b}_1$

DELPHI λ''



$\tilde{t}_1$

$\phi_{\tilde{b}} = 68^0$ • **Exclusion contours at 95% CL** $\phi_{\tilde{t}} = 56^0$

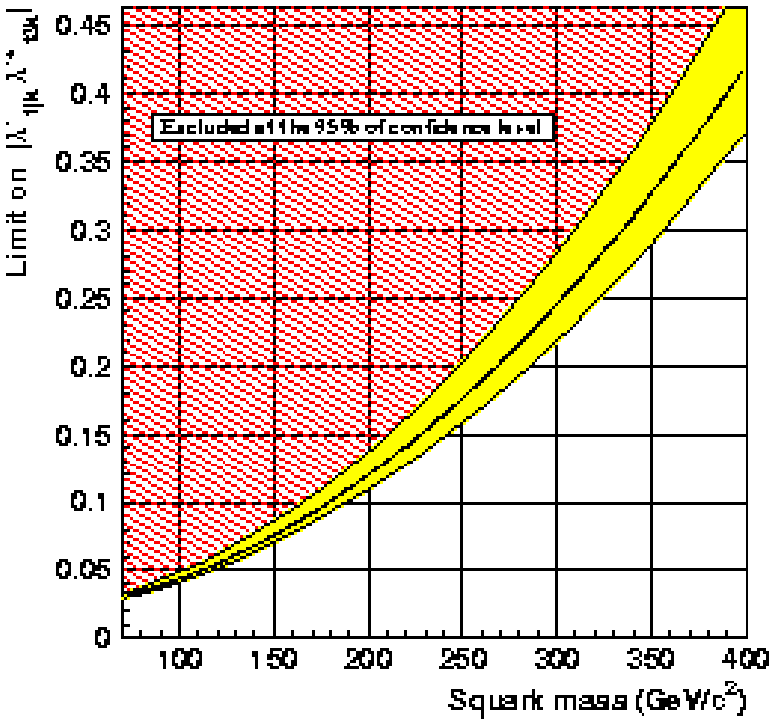
Mixing angle for vanishing coupling to Z for $\tilde{t}$, $\tilde{b}$ **=> σ min**

Single top production

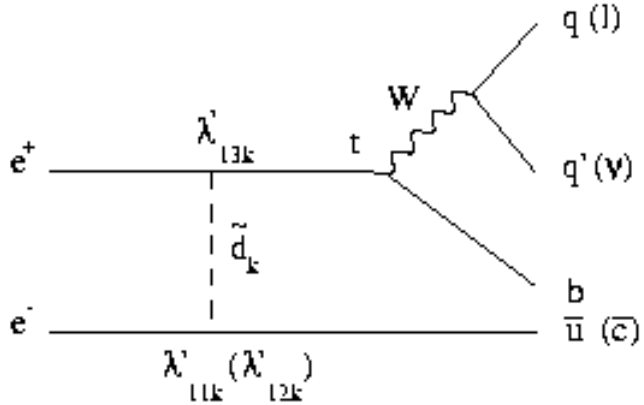
$$e^+e^- \to t\bar{c}(\bar{u}) \to q\,q'b\bar{c}(\bar{u})$$

$$e^+e^- \to t\bar{c}(\bar{u}) \to l\,\nu\,b\bar{c}(\bar{u})$$

DELPHI Preliminary



λ′



- **Analysis with neural network method**
- **b tagging used**

$$\sigma_{\text{upper limit}} = 0.11\ pb$$

(σ upper limit at 95 % CL)

LSP Mass Limit with RpV

LSP $\tilde{\chi}_1^0$

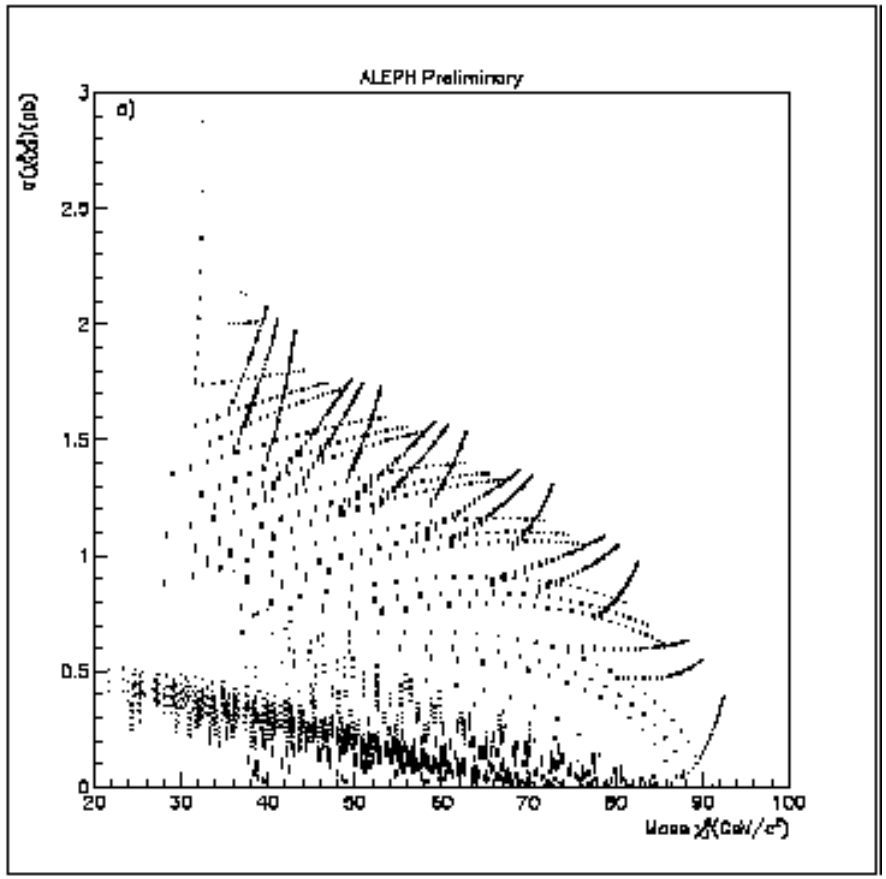
Mass limits

- **Limits are set at 95 % CL via a dominant Coupling**

$LL\bar{E}$ $LQ\bar{D}$ $\bar{U}\bar{D}\bar{D}$

λ_{133} or λ'_{311} or λ''_{223}

60.2 **44.2** **42.2** **(GeV/c²)**



ALEPH PRELIMINARY

- **production cross-section of** $\tilde{\chi}_1^0$ **vrs mass in all μ , all M_2 tanβ(2-4), m_0(200-500) GeV/c²**

New lower mass Limits (GeV/c^2)

ADLO

sfermion	λ (dd)	λ'(dd)	λ''(dd)	λ (id)	λ'(id)	λ''(id)
$\tilde{e}_R\,(\tilde{e}_L)$	96 69 (89)	(89)	96	96 79 99 95	93 92	94 96 92
$\tilde{\mu}_R\,(\tilde{\mu}_L)$	87 61 (74)	(81)(77)	86	96 87 92 90	90 87	85 86 87
$\tilde{\tau}_R,(\tilde{\tau}_L)$	87 61 (74)	(76)	75	95 86 90 90	76 -	- 75 -
$\tilde{\nu}_e$	100 95 90	90	99	98 99 95 98	91 88	88 99 -
$\tilde{\nu}_\mu$	90 65 76	79 75	70	89 78 81 85	78 -	65 70 -
$\tilde{\nu}_\tau$	- 65 76	75	70	89 78 81 85	78 -	65 70 -
$\tilde{t}\ (\tilde{t}_L)$	- - -	(97)	-	(91) (92)	(85)	(71.5) (87)
$\tilde{b}\ (\tilde{b}_L)$	- - -	-	-	(90)	(80)	(71.5) (78)
$\tilde{u}_R\,(\tilde{u}_L)$	- - -	-	(82.5) 80 (87)	-	-	79 (87)
$\tilde{d}_R\,(\tilde{d}_L)$	- - -	-	(77) 56 (86)	-	-	55 (86)

Conclusions

- RpV has inspired new interesting scenarios of SUSY searches
- RpC and RpV are two complementary ways of SUSY searches
- Searches for SUSY with RpV performed by all LEP collaborations (ADLO) in …many channels ….
- No evidence for SUSY with RpV so far at LEP
- Limits on SUSY particles and RpV Couplings are set at 95% CL
- Limits from RpV searches are comparable with the RpC ones!

….. Many papers and … many searches on SUSY !

….. but there is NO evidence up to now

➢ **SUSY with RpV**

predicts very clear signatures especially for couplings

with $\Delta L \neq 0 \quad (LL\bar{E}, LQ\bar{D})$

→ all hopes are shifted

towards future colliders !