Search for R-parity violation at LEP

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L3 Collaboration

- R-parity
- Pair-production of gauginos, sleptons and squarks
  - topologies and selections
  - results and limits
- Sneutrino single production
  - effects in fermion pair production
  - direct RPV decays
- Spontaneous R-parity breaking
- Conclusions

R-parity: multiplicative discrete symmetry in SUSY:

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

$R_P = 1$ for standard particles $R_P = -1$ for supersymmetric particles

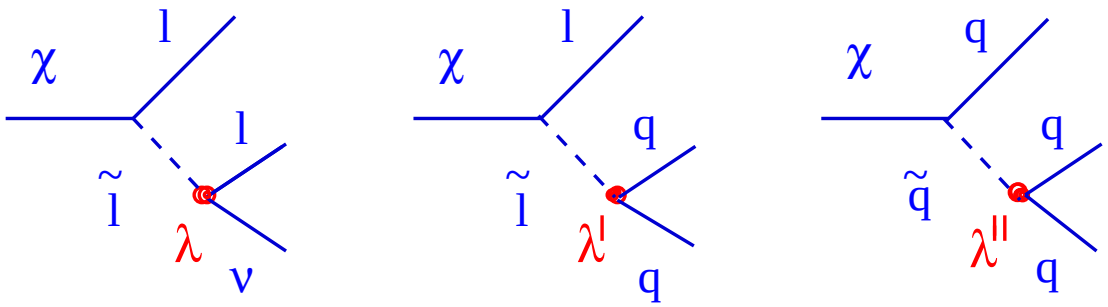
The most general MSSM superpotential has also L- and B-violating terms:

$$W_R = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \varepsilon_i L_i H_2$$

48 new coupling constants (9 + 27 + 9 + 3)

***i*, *j*, *k*: generation indices**

giving rise to LSP decays:



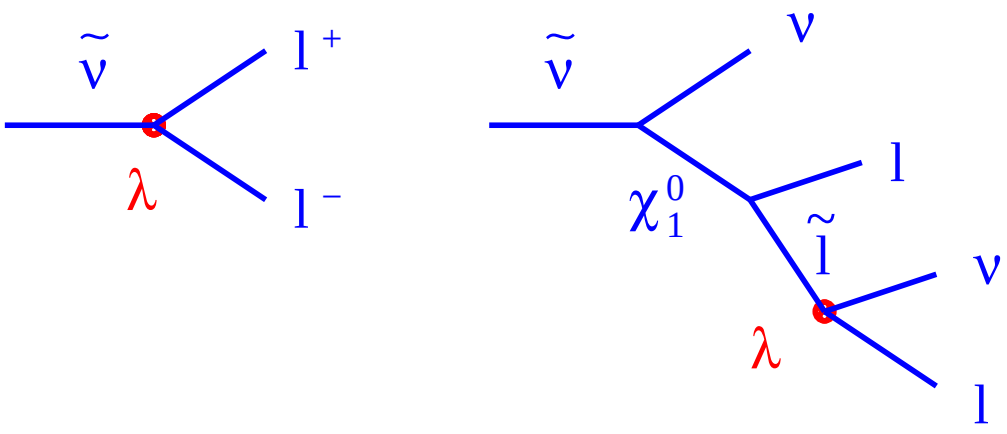
R-parity conserved:

- **SUSY particles are pair-produced (the initial state e^+e^- has $R_P = 1$) and decay in cascade to the LSP**
- **the LSP is stable $\rightarrow$ $\not{E}$**
- **LSP = $\tilde{\chi}_1^0$ (neutral and colourless)**

R-parity violated:

- **single production of SUSY particles is allowed (ex. $e^+e^- \rightarrow \tilde{\nu}$)**
- **LSP decays**
- **LSP can be any particle: $\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}, \tilde{\ell}_R$, ...**

Direct and indirect decays:



Motivations

RPV not excluded by experimental data:

$\lambda_{133} < 0.003$	ν_e mass	$\tilde{m} = 100$ GeV
$\lambda'_{111} < 0.00035$	$(\beta\beta)_{0\nu}$	$\tilde{m} = 100$ GeV
$\lambda_{13k} < 0.06$	R_τ	$\tilde{m} = 100$ GeV

$\lambda'_{11k}\lambda''_{11k} < 10^{-22}$ **and** $\lambda'_{ijk}\lambda''_{lmn} < 10^{-10}$ **(at $\tilde{m} = 100$ GeV)**
to avoid a fast proton decay $p \rightarrow \pi^0 e^+$

Less stringent limits on other couplings

Test the validity of SUSY limits also in the RPV scenario

Assumptions:

- **Only one λ (λ', λ'') $\neq 0$**
- **LSP decay length below 1 cm:**
  - **λ (λ', λ'') $> 10^{-5}$ for gauginos**
  - **λ (λ', λ'') $> 10^{-7}$ for sfermions**

Data and MC Samples

Results based on:

Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1}) / Exp.
1996	161–172	20
1997	183	55
1998	189	180
1999	192–202	230
2000	200–208	220

About 700 pb^{-1} per experiment

Sensitivity to cross sections of 0.02-0.05 pb per experiment (with $\varepsilon \sim 30\% - 40\%$)

Results are preliminary

Data and MC samples

Cross section values at $\sqrt{s} = 206$ GeV

Signal events

Process	σ (pb) for $\tan\beta = 1$	
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	1	$m_0 = 50$ GeV
($M_{\tilde{\chi}_1^0} = 40$ GeV)	0.02	$m_0 = 500$ GeV
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.15	$m_0 = 50$ GeV
($M_{\tilde{\chi}_1^\pm} = 103$ GeV)	0.25	$m_0 = 500$ GeV
$\tilde{\mu}_R^+\tilde{\mu}_R^-$	0.1	$m_0 = 50$ GeV
($M_{\tilde{\mu}_R} = 85$ GeV)		

Background events

Process	σ
$\mu^+\mu^-, \tau^+\tau^-$	7 pb
$q\bar{q}$	80 pb
$e^+e^-f\bar{f}$	20 nb
W^+W^-	20 pb
$We\nu$	3 pb
ZZ	1 pb

RPV Decays and Topologies

Particle	Direct decays			Indirect decays
	λ_{ijk}	λ'_{ijk}	λ''_{ijk}	via $\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$	$\ell_i^- \nu_j \ell_k^+$, $\nu_i \ell_j^+ \ell_k^-$	$\ell_i^- u_j \bar{d}_k$, $\nu_i d_j \bar{d}_k$	$\bar{u}_i \bar{d}_j \bar{d}_k$	–
$\tilde{\chi}_1^+$	$\nu_i \nu_j \ell_k^+$, $\ell_i^+ \ell_j^+ \ell_k^-$	$\nu_i u_j \bar{d}_k$, $\ell_i^+ \bar{d}_j d_k$	$\bar{d}_i \bar{d}_j \bar{d}_k$, $u_i u_j d_k$, $u_i d_j u_k$	$W^* \tilde{\chi}_1^0$
$\tilde{\ell}_{kR}^-$	$\nu_i \ell_j^-$, $\nu_j \ell_i^-$	–	–	$\ell_k^- \tilde{\chi}_1^0$
$\tilde{\nu}_i$, $\tilde{\nu}_j$	$\ell_j^- \ell_k^+$, $\ell_i^- \ell_k^+$	$d_j \bar{d}_k$, –	–	$\nu_i \tilde{\chi}_1^0$, $\nu_j \tilde{\chi}_1^0$
$\tilde{u}_{iR}$	–	–	$\bar{d}_j \bar{d}_k$	$u_i \tilde{\chi}_1^0$
$\tilde{d}_{jR}$, $\tilde{d}_{kR}$	–	$\bar{\nu}_i d_j$, $\ell_i^- u_j$	$\bar{u}_i \bar{d}_k$, $\bar{u}_i \bar{d}_j$	$d_j \tilde{\chi}_1^0$, $d_k \tilde{\chi}_1^0$

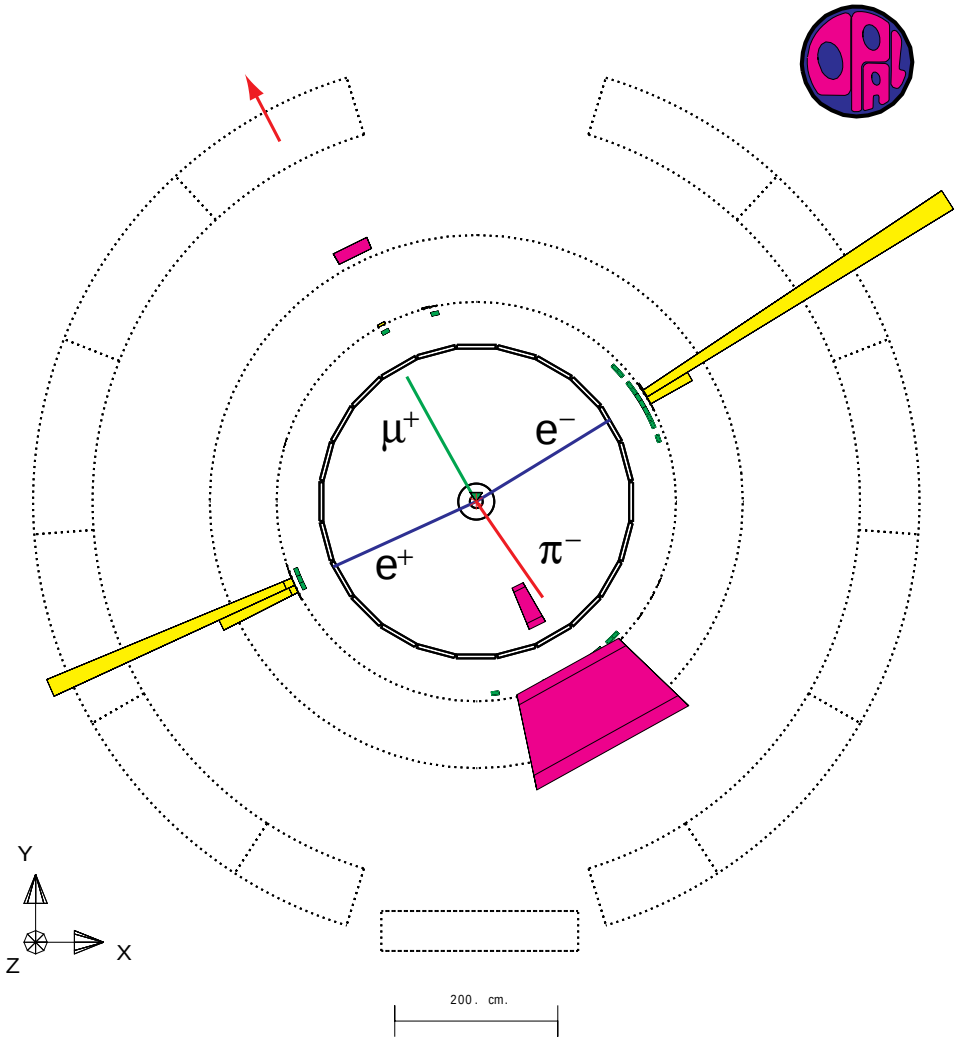
Main selections:

Coupling	Topologies	Eff. (%)
λ	$2\ell + \not{E}$	10-40
	4ℓ	30-50
	$4\ell + \not{E}$	20-50
	leptons + jets	20-70
λ'	4 jets	15-65
	4 jets + $\not{E}$	20-60
	jets + leptons	15-75
	jets + leptons + $\not{E}$	30-50
λ''	multijets + $\not{E}$	30-50
	multijets + leptons	15-55
	multijets (up to 10 q)	25-50

RPV detectable: leptons, leptons and jets, jets

Candidates

OPAL, $\sqrt{s} = 183$ GeV, selected by $4l + \not{E}$
Compatible with $e^+e^- \rightarrow ZZ \rightarrow e^+e^-\tau^+\tau^-$



Number of selected events

$\sqrt{s}$ = 189 – 208 GeV

Overlap not taken into account!

Experiment	Coupling	Data	SM exp.
ALEPH	λ	752	800
	λ'	2810	2981
	λ''	1108	1090
DELPHI	λ	65	69
	λ''	1100	1124
L3	λ	72	71
	λ' (189 GeV only)	382	391
	λ''	6070	6203
OPAL	λ	1025	1112
	λ' (no 192–202 GeV)	170	158
	λ'' (189 GeV only)	167	155

No significant excess of data events

$\rightarrow$ cross section upper limits

$\rightarrow$ limits on MSSM parameters

$\rightarrow$ lower limits on masses

All limits are at 95% C.L.

Cross section upper limits

L3, 95% C.L. upper limits on pair-production cross sections, indirect decays

189–208 GeV data

Coupling	Process	σ limit (pb)
λ	$\tilde{\chi}_1^0\tilde{\chi}_1^0$	0.02 –0.07
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.08 –0.15
	$\tilde{e}_R^+\tilde{e}_R^-$	0.06 –0.08
	$\tilde{\mu}_R^+\tilde{\mu}_R^-$	0.05 –0.06
	$\tilde{\tau}_R^+\tilde{\tau}_R^-$	0.06–0.07
	$\tilde{\nu}\tilde{\nu}$	0.07–0.08
λ''	$\tilde{\chi}_1^0\tilde{\chi}_1^0$	0.11 –0.18
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.14 –0.16
	$\tilde{e}_R^+\tilde{e}_R^-$	0.05 –0.18
	$\tilde{\mu}_R^+\tilde{\mu}_R^-$	0.05 –0.10
	$\tilde{\tau}_R^+\tilde{\tau}_R^-$	0.13–0.16
	$\tilde{\nu}\tilde{\nu}$	0.12–0.15
	$\tilde{q}\tilde{q}$	0.15–0.17

Limits derived for the coupling with the lowest sensitivity: final states with taus, no b-tagging

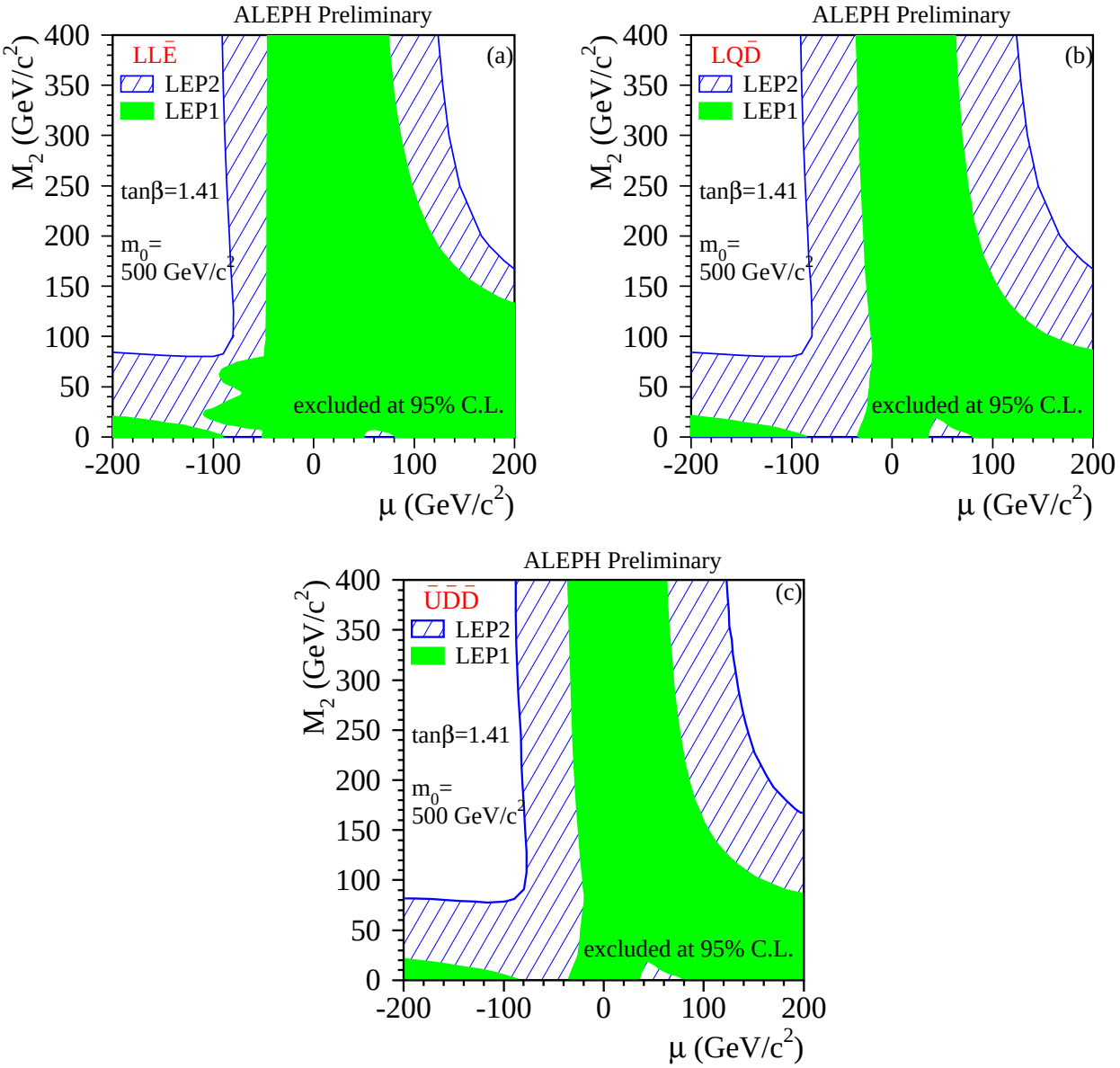
Limits on MSSM parameters

5 free parameters in the CMSSM:

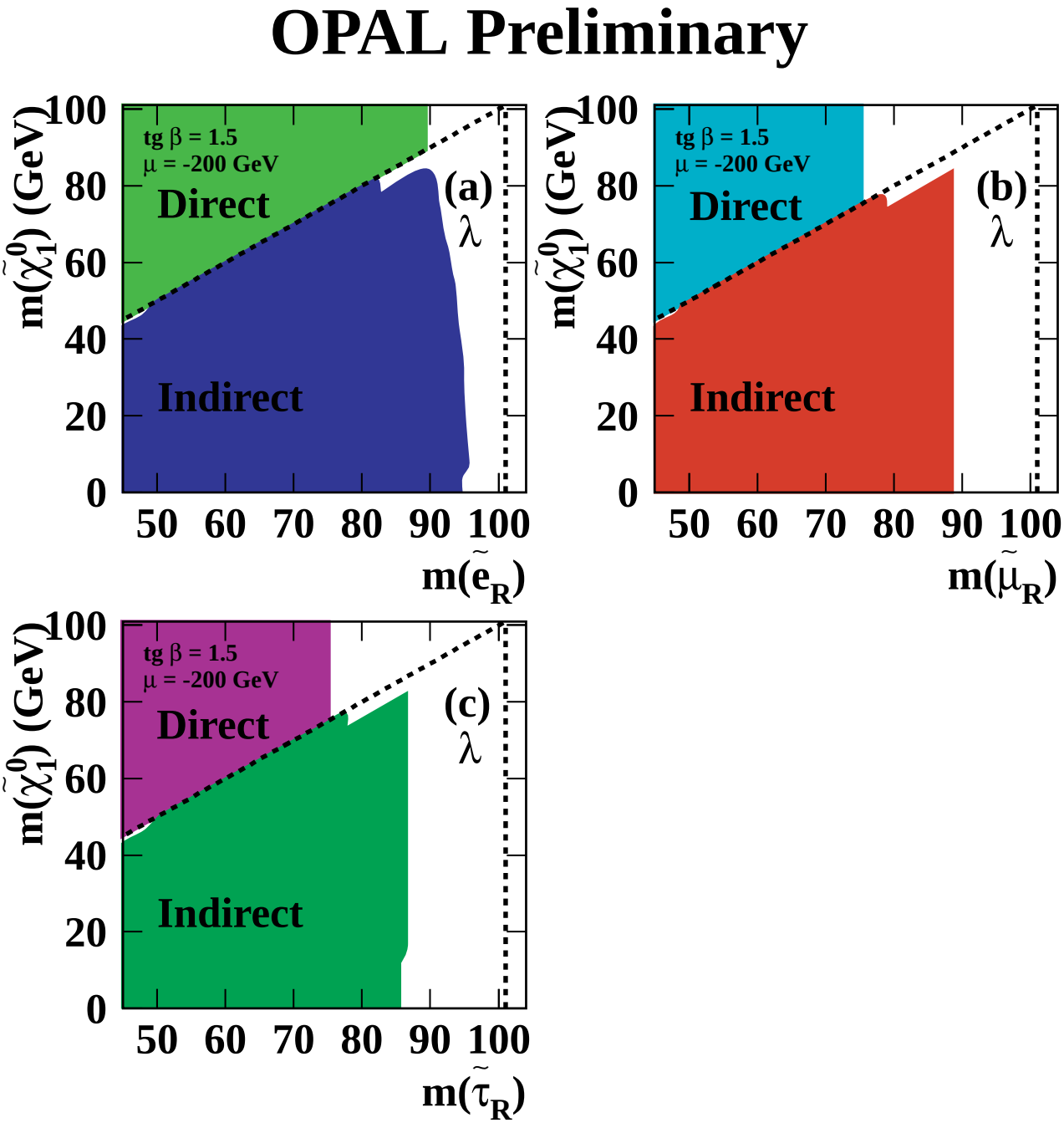
M_2, μ, tan β, m_0, A

Cross sections and masses depend on them

ALEPH, 189-208 GeV



OPAL, $\sqrt{s}$ = 192 – 202 GeV λ



Scalar Fermion Mass Limits

Mass (GeV)	λ_{ijk}		λ'_{ijk}		λ''_{ijk}		Exp.
	Dir.	Ind.	Dir.	Ind.	Dir.	Ind.	
$M_{\tilde{e}_R}$	69-89	79-96		93	96	92-96	ADLO
$M_{\tilde{\mu}_R}$	61-75	87-96		90	86	85-86	ADLO
$M_{\tilde{\tau}_R}$	61-75	86-95		76	75	75	ADLO
$M_{\tilde{\nu}_e}$	94-95	98-99		91	99	88-99	ADL
$M_{\tilde{\nu}_{\mu,\tau}}$	65-95	78-89		78	70	65-70	ADL
$M_{\tilde{u}_R}$					80	79	L
$M_{\tilde{d}_R}$					56	55	L
$M_{\tilde{t}_1}$		87-91		85	77	72-77	ADL
$M_{\tilde{b}_1}$		90		80	55	48-72	ADL

Overall MSSM Mass Limits

Take into account different processes at the same MSSM point

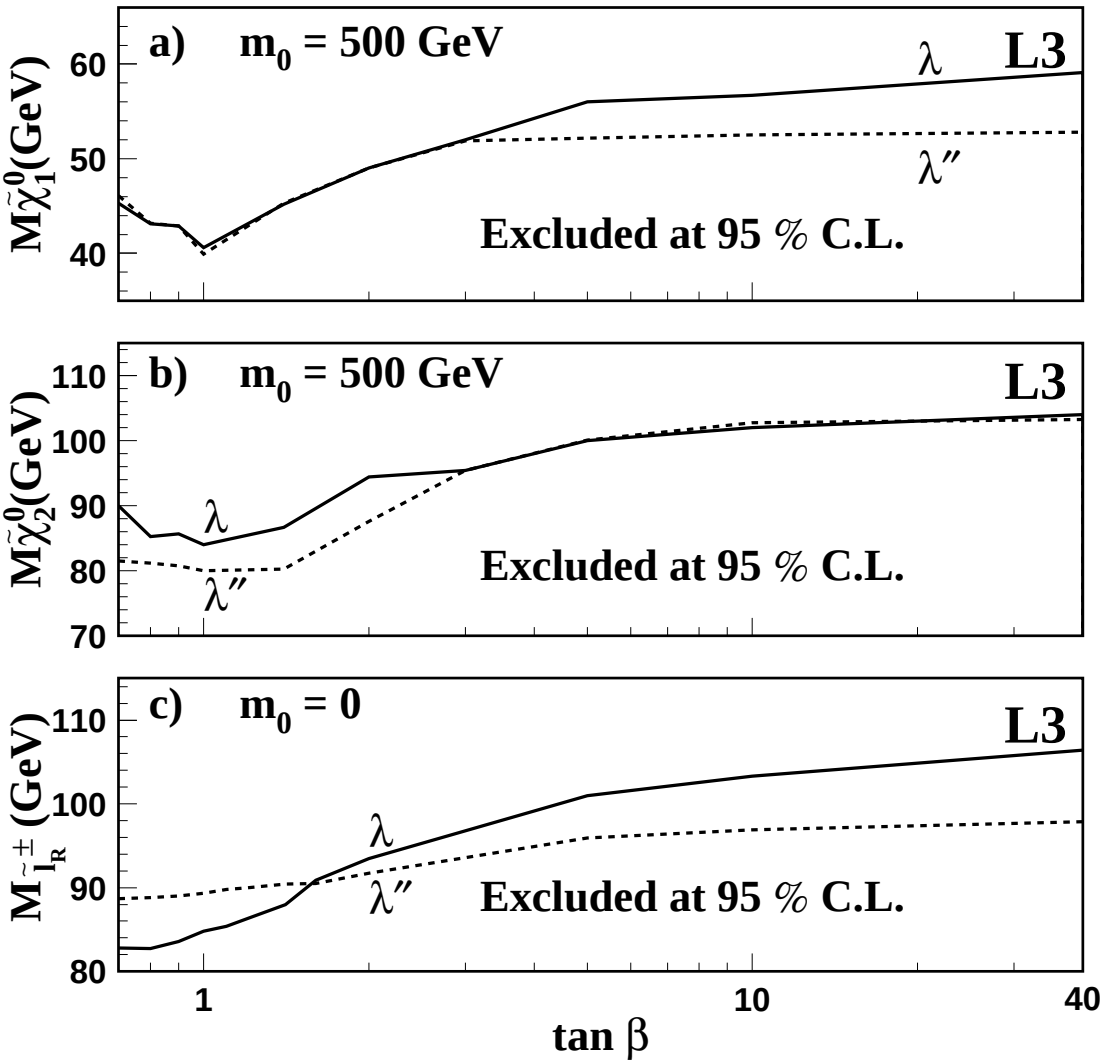
Mass (GeV)	λ_{ijk}	λ'_{ijk}	λ''_{ijk}	Exp.
$M_{\tilde{\chi}_1^0}$	34-40		38-40	ADL
$M_{\tilde{\chi}_2^0}$	84		80	L
$M_{\tilde{\chi}_1^\pm}$	103	103	103	ADL
$M_{\tilde{\ell}_R}$	83		89	L
$M_{\tilde{\nu}}$	153		149	L

$\tilde{\chi}_1^\pm$ **kinematic limit reached for every** $\lambda,\ \lambda',\ \lambda''$

Overall MSSM Mass limits

L3, $\sqrt{s}$ = 189 – 208 GeV

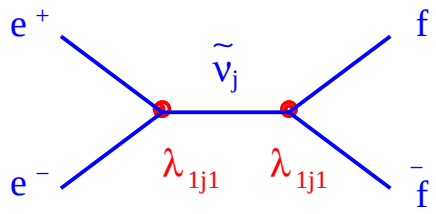
λ, λ''



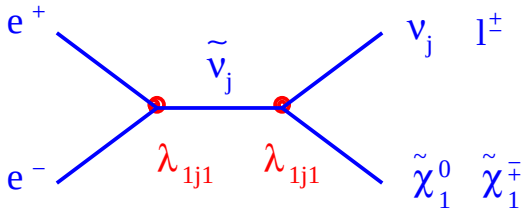
Sneutrino exchange

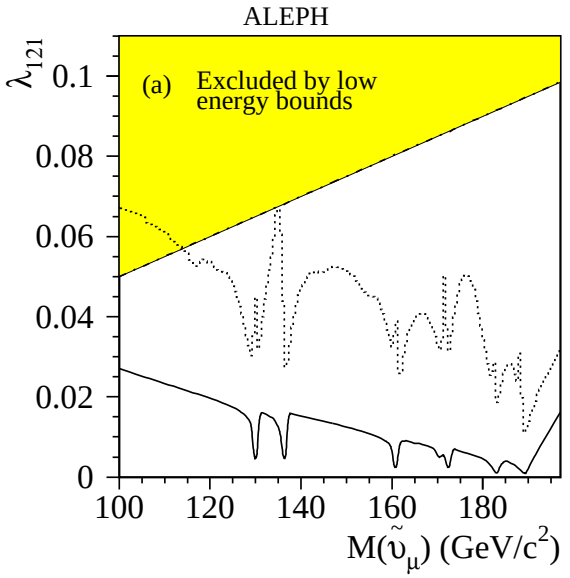
Sensitivity to high $\tilde{\nu}$ masses up to $\sqrt{s}$. Limits on $|\lambda|$

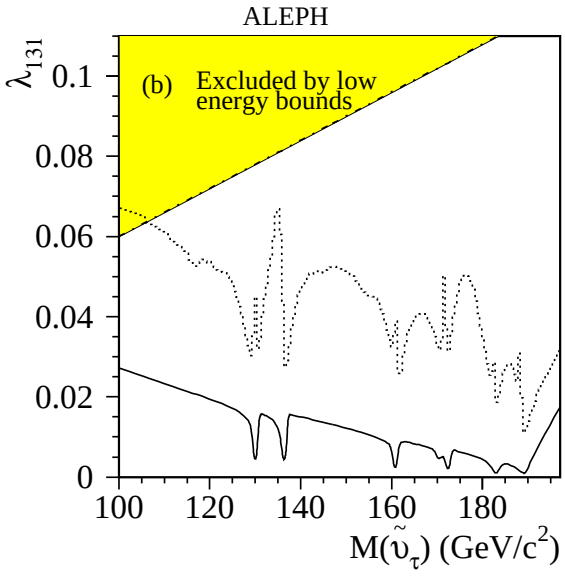
- **Additional contributions to σ and A_{fb} from $\lambda_{ijk} L_i L_j \overline{E}_k$**
  Fit SM + possible new physics effects
  No deviations found



- **Study of $e^+e^- \to \tilde{\nu} \to \nu \tilde{\chi}_1^0$, $\ell \tilde{\chi}_1^{\pm}$**



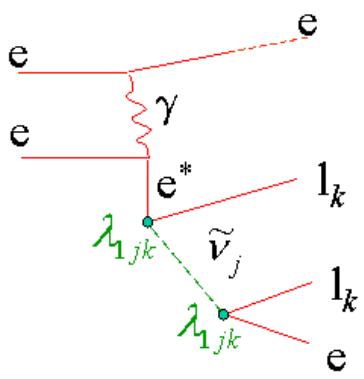


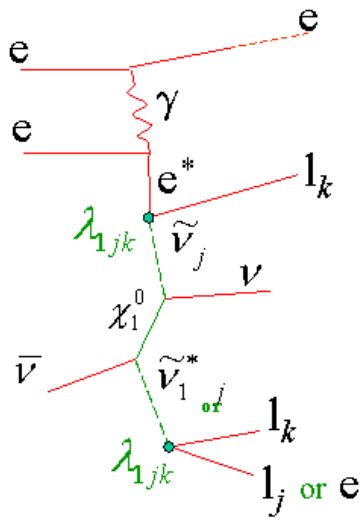


More sensitivity with $\nu \tilde{\chi}_1^0$, $\ell \tilde{\chi}_1^{\pm}$ than with SM fits

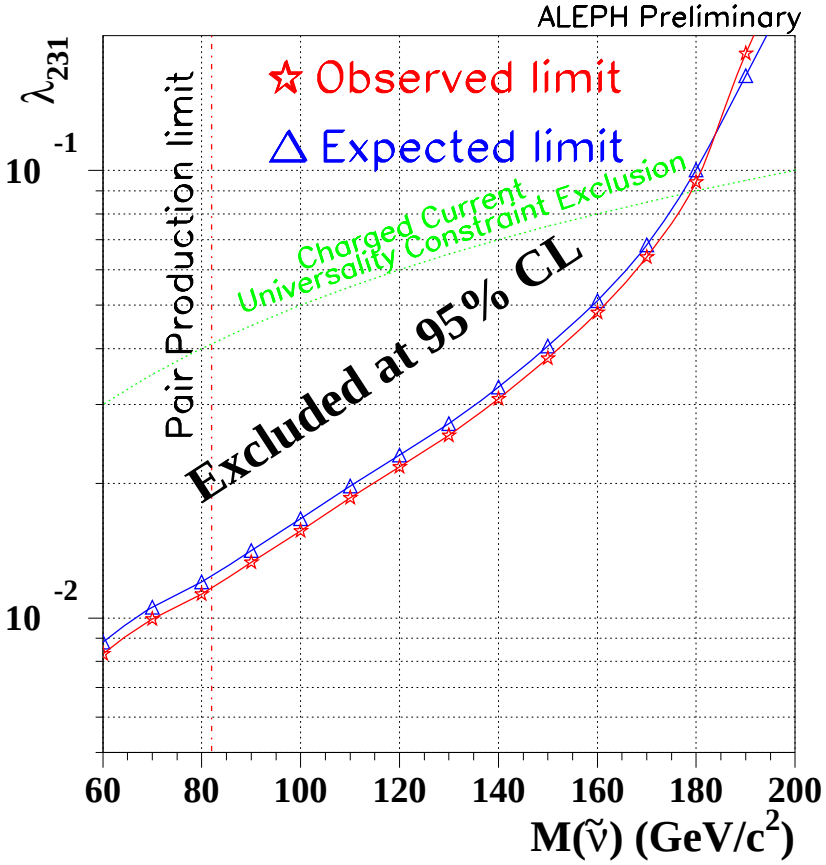
Sneutrino exchange

ALEPH, 189-208 GeV $e\gamma \rightarrow \tilde{\nu}_j \ell_k$ via λ_{1jk} or λ_{231}





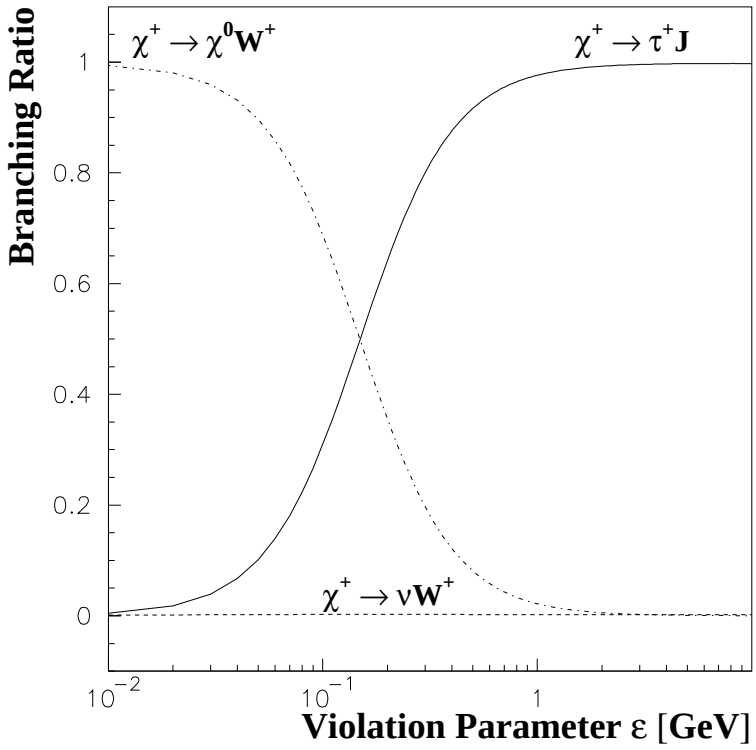
Three-lepton final states. No excess of events



Spontaneous R-parity breaking

Possible additional bilinear term $\varepsilon_i L_i H$ giving rise to:
$\tilde{\chi}_1^{\pm} \rightarrow \tau^{\pm} J$ (J massless Majoron)

DELPHI, 183-202 GeV



Two acoplanar taus + $\not{E}$
40 events found, 45 expected from SM
95% C.L. upper limit on $\tilde{\chi}_1^{\pm}$ prod. cross section: 0.14 pb
Mass limit: 101 GeV

Conclusions

- **RPV searches at LEP cover almost every SUSY process**
- **Same sensitivity as in standard searches: SUSY results do not depend on assumptions of R-parity conservation**
- **New limits with about 700 pb^{-1} for experiment, at different $\sqrt{s}$ values up to 208 GeV**
- **New lower mass limit on lightest neutralino: $M_{\tilde{\chi}_1^0} > 40$ GeV at 95% C.L., for every m_0 and $\tan\beta$**