EPS – HEP 97
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CERN–OPAL

Search for R-parity violation and Leptoquark signature at LEP

- Leptoquarks
  - Pair Production
  - Single Production
  - t-channel exchange
- R-Parity violation
  - Production Mechanisms
  - Gauginos
  - Slepton and Sneutrinos
  - Squarks
- Summary

Leptoquarks

Leptoquarks appear in many unification theories beyond the standard model

Leptoquarks (LQ)

- carry lepton and quark quantum numbers
- have fractional charge
- have spin 0 (scalar LQ) or 1 (vector LQ)
- couple either to left– or right–handed quarks
- couple family diagonal
- conserve B and L

Under these assumptions, 9 scalar and 9 vector leptoquarks exist, classified according to spin, weak isospin and charge.

Leptoquarks decay via

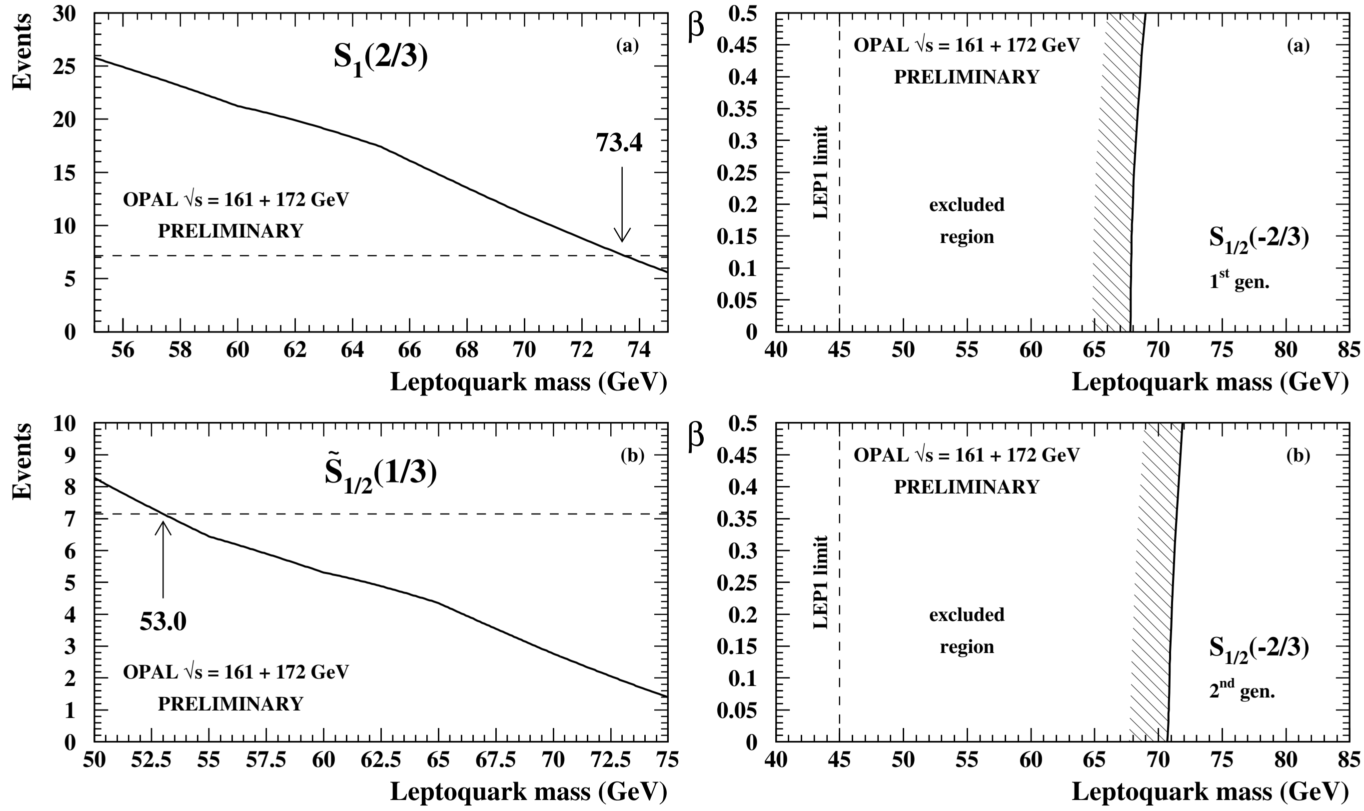
$$\begin{array}{lll} \text{LQ} \rightarrow & \ell + q & (\beta = 1) \\ \text{LQ} \rightarrow & \nu + q & (\beta = 0) \end{array}$$

Leptoquark pairproduction

Scalar leptoquarks with masses below the LEP2 beam energies are excluded from CDF and D0 for $\beta > 0.5$.

Searches for leptoquarks with $\beta < 0.5$ have been performed, assuming leptoquark multiplets are not mass degenerated

OPAL preliminary

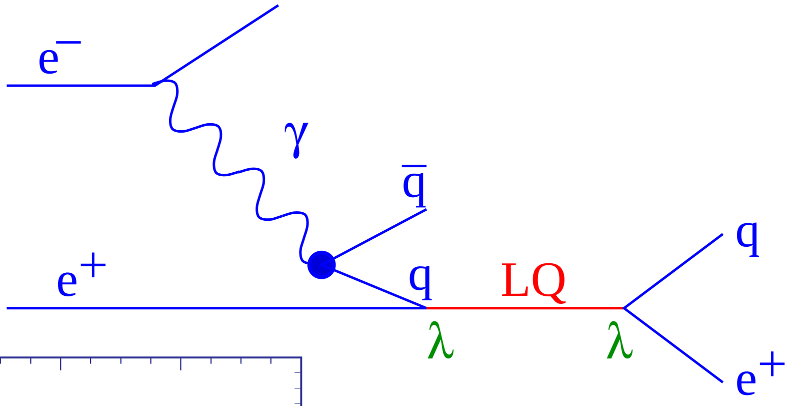


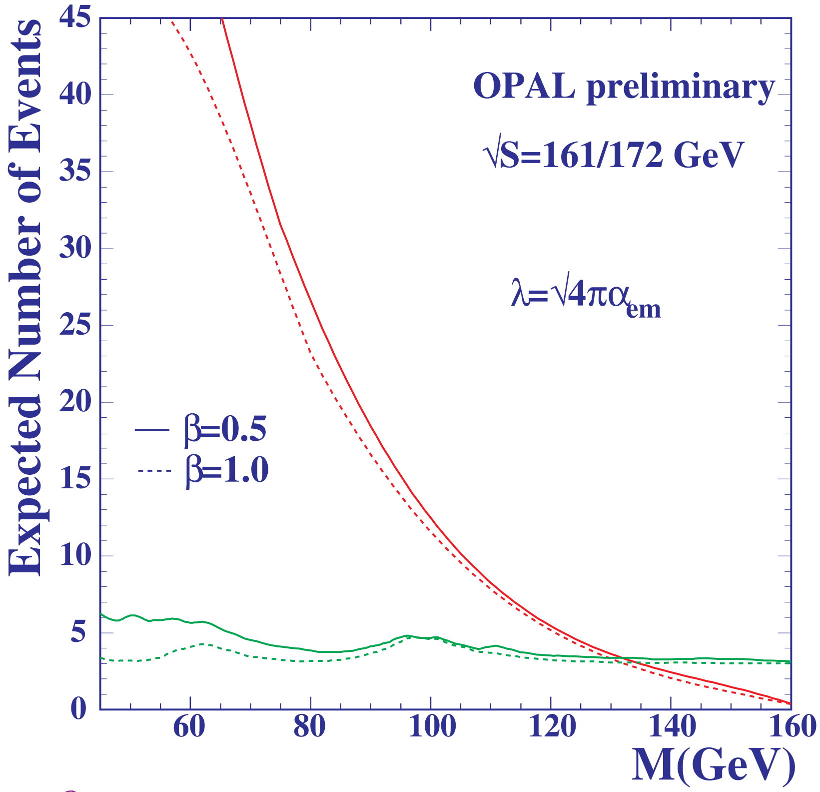
Limits well above those of LEP 1 have been achieved.

	S_1(2/3)	$\tilde{S}_{1/2}$(1/3)	$S_{1/2}$(-2/3) 1st	$S_{1/2}$(-2/3) 2nd
Limit	73.4 GeV	53.0 GeV	67.9 GeV	70.8 GeV

increasing integrated luminosity will improve limits

Single Leptoquark Production



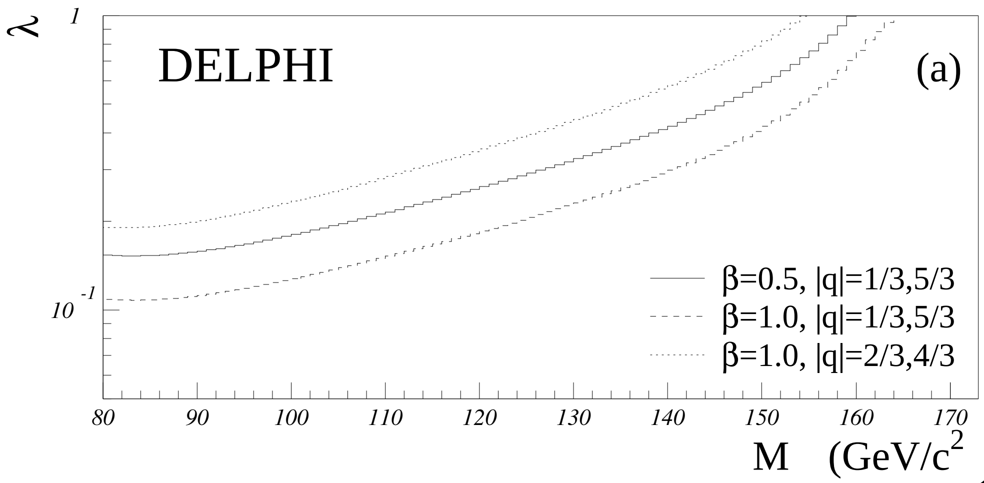


	$\beta = 1.0$
OPAL	**131 GeV**
DELPHI	**142 GeV**
	$\beta = 0.5$
OPAL	**131 GeV**
DELPHI	**129 GeV**

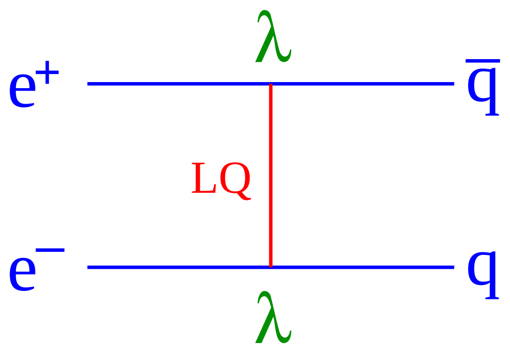
for $\lambda = \sqrt{4\pi\alpha_{em}}$

good sensitivity for low values of β

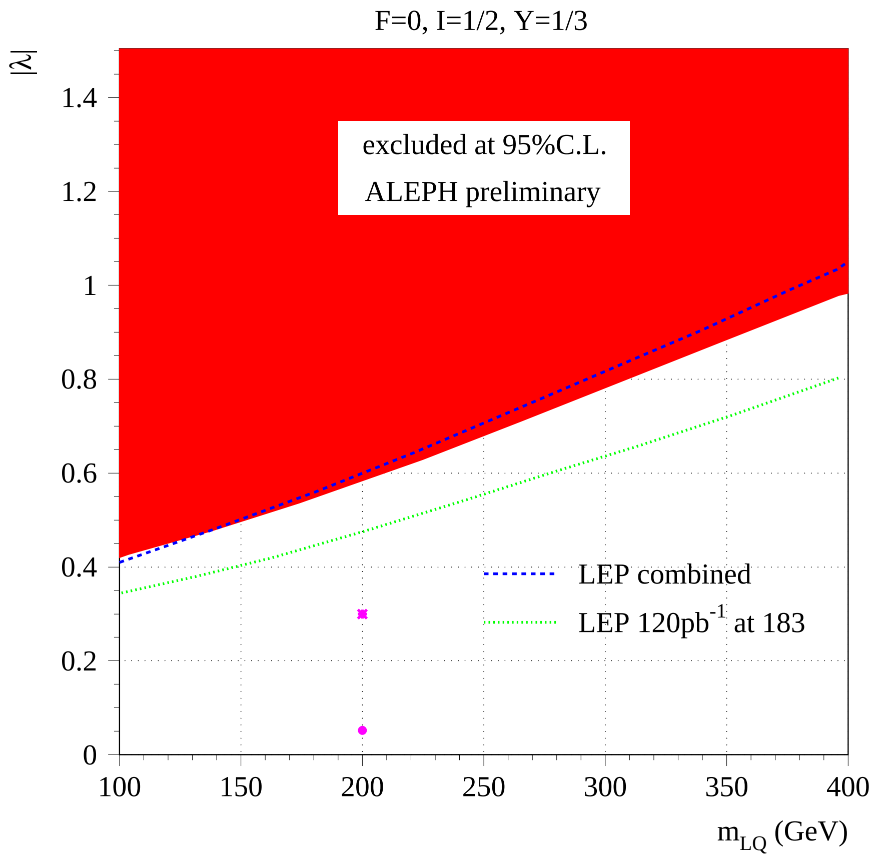
- $\beta = 1$: limits from the Tevatron cannot be reached
- $\beta = 0.5$ limits similiar to Tevatron for large values of λ.



t–channel Leptoquark exchange



cross section for $q\bar{q}$ final states modified by t–channel exchange of leptoquarks

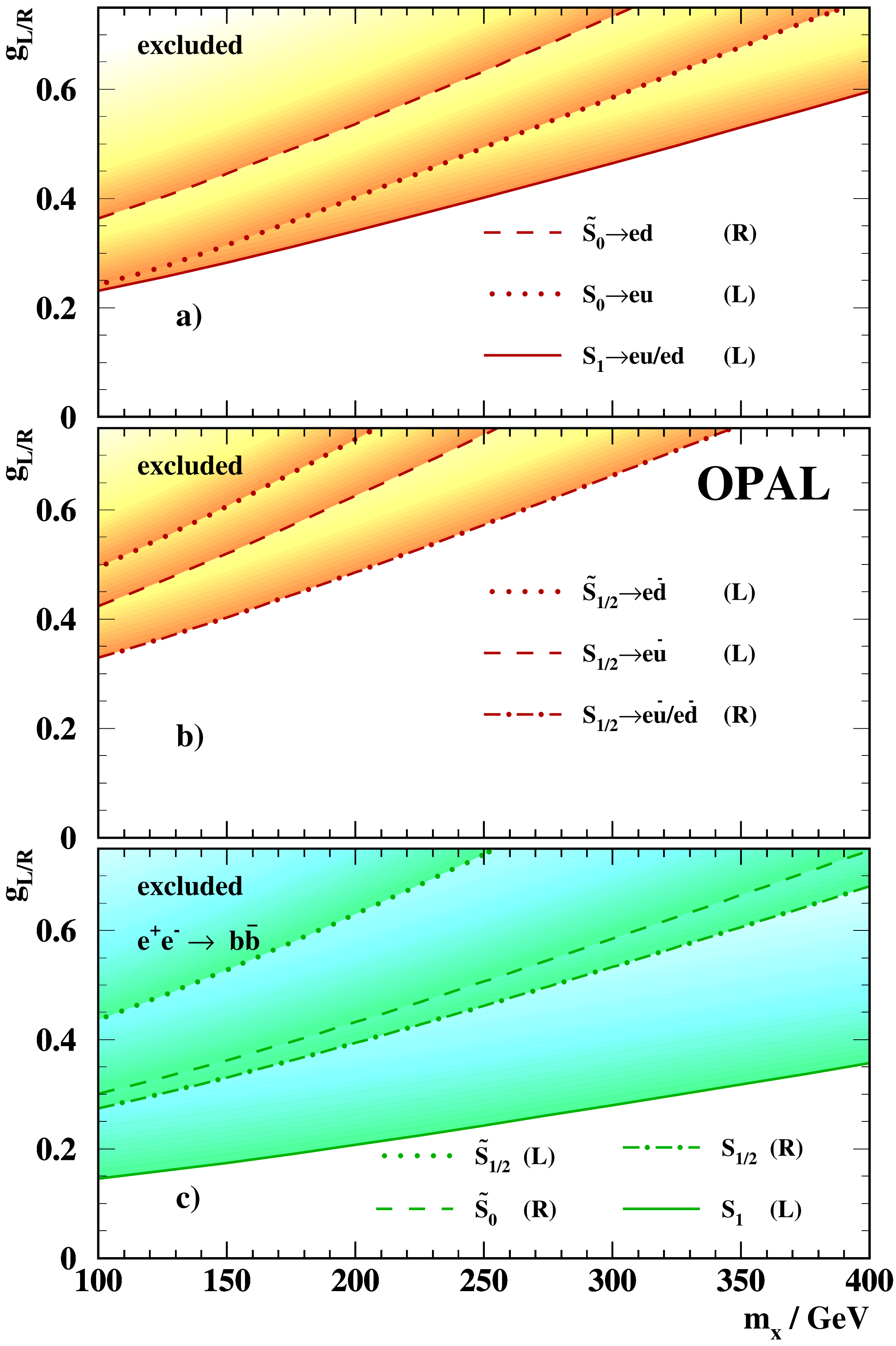


The exclusion limits from the Tevatron of ~ 230GeV and $\lambda > 10^{-7}$ can be extended with LEP for large couplings.

The limits can be improved, when using b-tagging in the final state.

$\rightarrow$ OPAL plot

Limits on the coupling for Scalar Leptoquarks



Results consistent with contact interaction analysis

Introduction to R-parity Violation

R-parity is a discrete multiplicative symmetry in SUSY models

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

S: spin, B: baryon number, L: lepton number

R_p = 1 for SM particles
R_p = -1 for SUSY particles

	R_p	$\not{R}_p$
SUSY particles produced in	pairs	pairs or singly
the LSP is	$\tilde{\chi}_1^0$	any sparticle
the LSP	is stable	decays
experimental signature	$\not{E}_T$	E_T

Exclusion limits from R_p conservation are not valid under R_p violation.

The R-parity Violating Superpotential

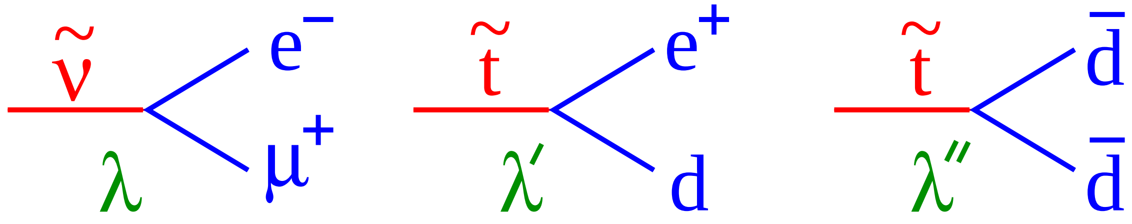
R-parity violating super–potential:

$$W = \lambda_{ijk} L_L^i L_L^j \overline{E}_R^k + \lambda'_{ijk} L_L^i Q_L^j \overline{D}_R^k + \lambda''_{ijk} \overline{U}_R^i \overline{D}_R^j \overline{D}_R^k$$

(after the term $\kappa_i L_i H_2$ has been rotated away)

with

L_L:	lepton doublet superfield
Q_L:	quark doublet superfield
D_R:	down-quark type singlet superfield
U_R:	up-quark type singlet superfield
E_R:	electron singlet superfield
λ , λ' , λ'' :	Yukawa couplings
i, j, k :	generation indices

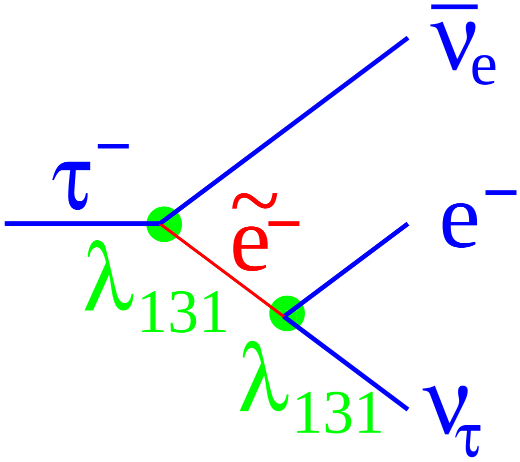


L violation B violation

Due to symmetrie $\lambda_{ijk} = -\lambda_{jik}$ and
$\lambda''_{ijk} = -\lambda''_{ikj}$.
$\rightarrow$ 45 (9 + 27 + 9) independent couplings

Limits for R-parity Violation

R_p–violation leads to several measurable effects e.g. lepton universality violation



Non observation of these effects sets limits on the size of the Yukawa couplings λ , λ' , and λ'' .

λ	λ'			λ''
(121) 0.04	(111) 0.0004	(211) 0.012	(311) 0.012	(121) 10^{-6}
(122) 0.04	(112) 0.012	(212) 0.012	(312) 0.012	(131) 10^{-5}
(123) 0.04	(113) 0.012	(213) 0.012	(313) 0.012	(132) 1.25
(131) 0.06	(121) 0.012	(221) 0.012	(321) 0.012	(221) 1.25
(132) 0.06	(122) 0.012	(222) 0.012	(322) 0.012	(231) 1.25
(133) 0.001	(123) 0.04	(223) 0.18	(323) 0.26	(232) 1.25
(231) 0.06	(131) 0.012	(231) 0.012	(331) 0.012	(321) 0.43
(232) 0.06	(132) 0.04	(232) 0.39	(332) 0.012	(331) 0.43
(233) 0.06	(133) 0.001	(233) 0.39	(333) 0.26	(332) 0.43

limits for sparticle mass of 100 GeV

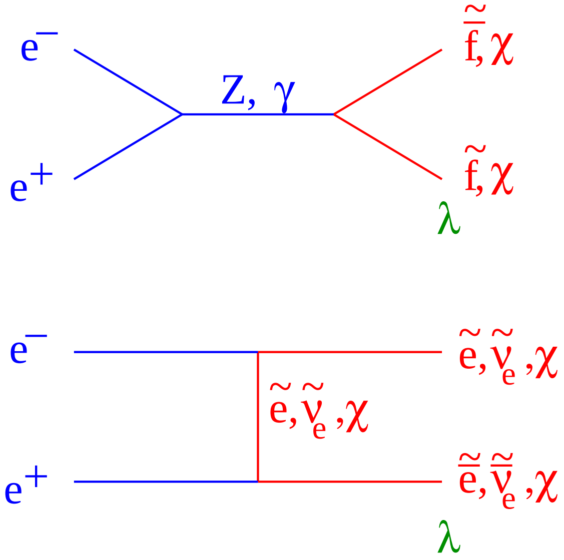
At LEP couplings down to 10^{-7} can be probed for
- sparticle masses up to the beam energy and
- decays at or close to the interaction point

More stringent limits exist on the product of two λ (λ' λ'') couplings. For example the non observation of the proton decay gives $\lambda' \times \lambda'' < 10^{-24}$.

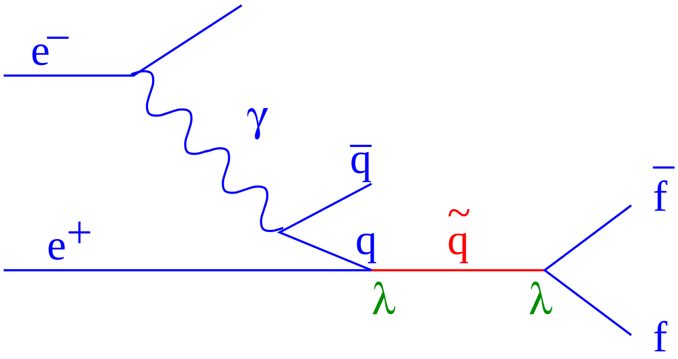
Therefore we assume most of the time that exactly one of the couplings is different from 0.

Production Mechanisms

pair production

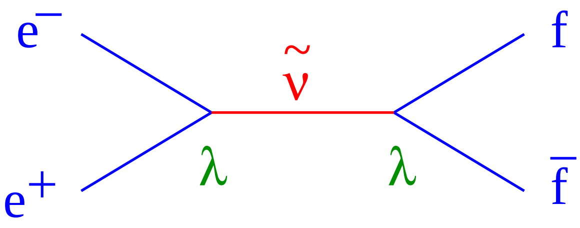


single production

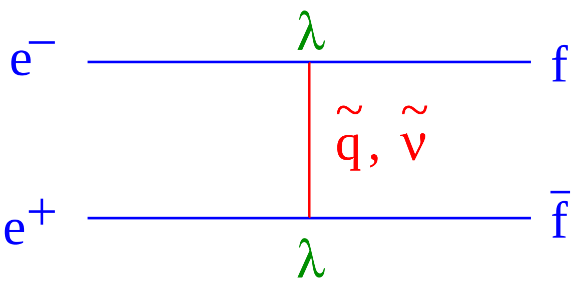


mass limit	beam energy	centre of mass energy
λ limit	10^{-7}	10^{-2}

s–channel resonance



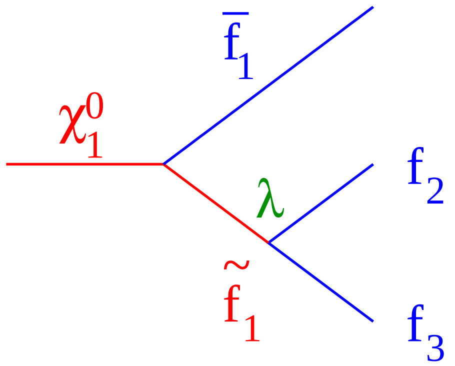
t–channel exchange



mass limit	centre of mass energy	$\sim 2 \times \sqrt{s}$
λ limit	10^{-3}	10^{-2}

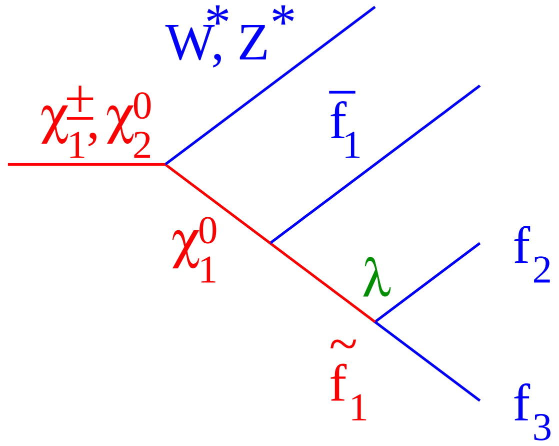
Gauginos

direct



3 fermion final state

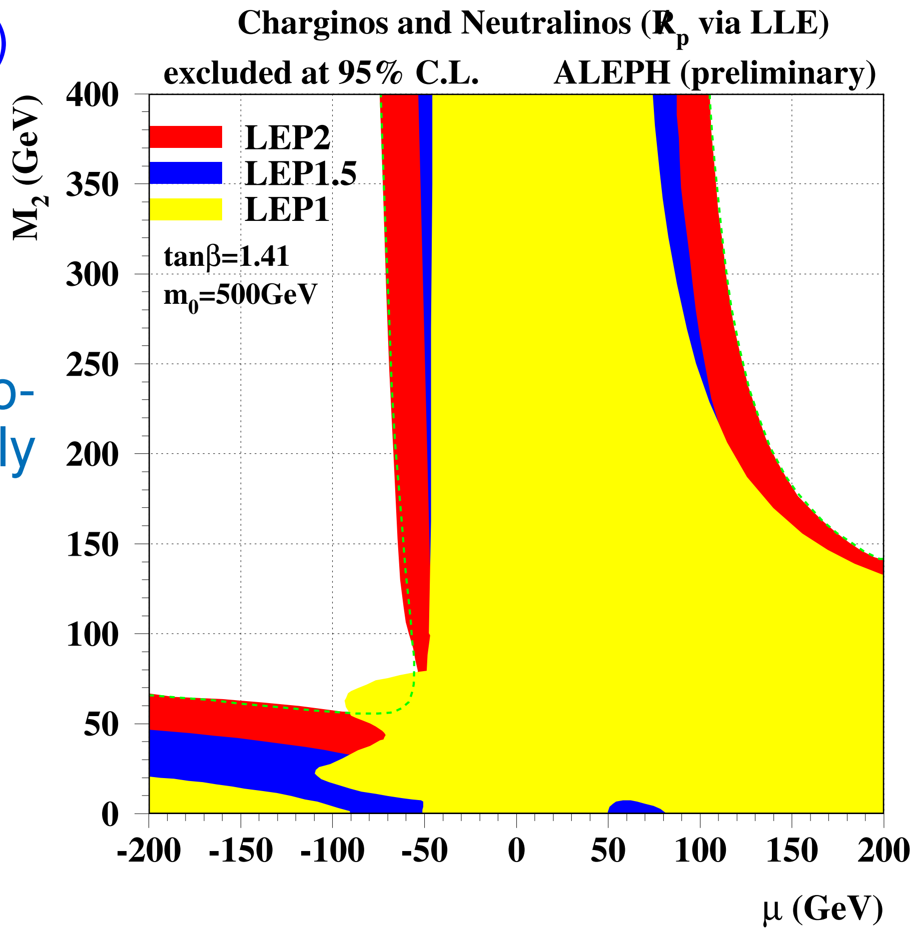
indirect



5 fermion final state

λ dominace :

exclude $\tilde{\chi}_1^\pm$ up to the kinematic limit for any λ coupling assuming indirect decay mode of $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^0\tilde{\chi}_2^0$. (ALEPH)

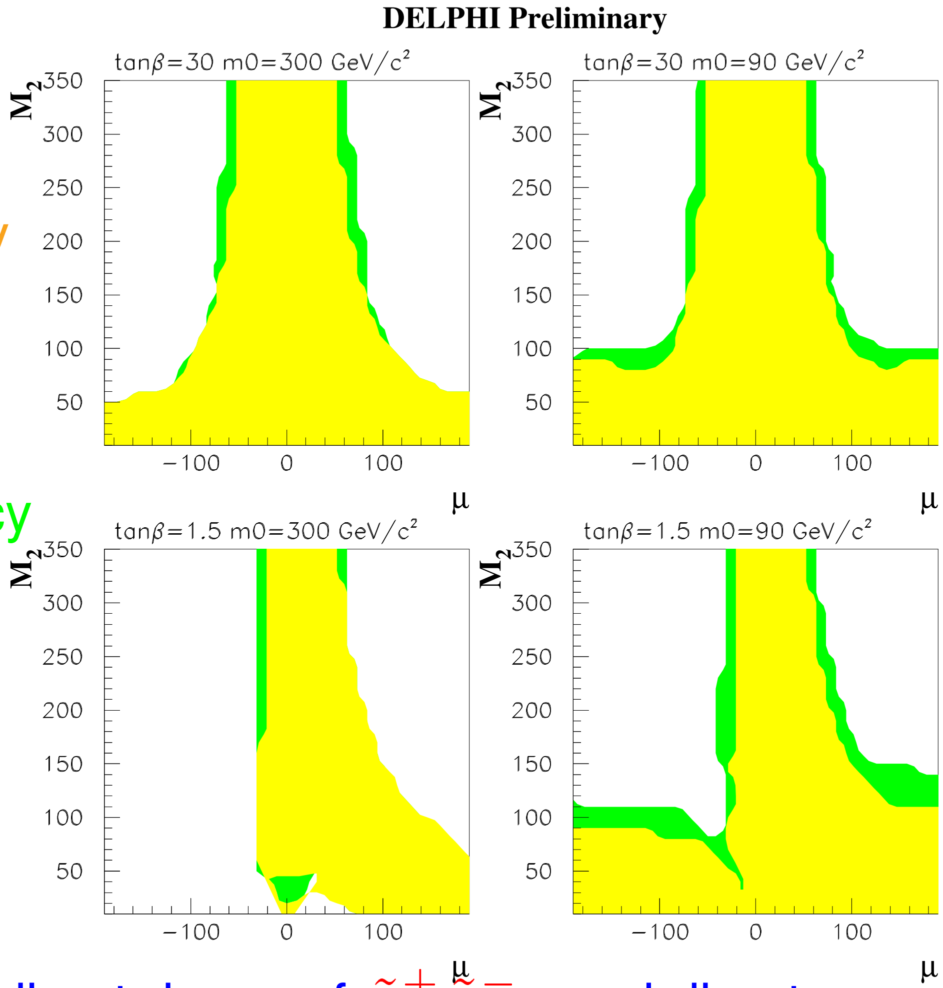


direct decay mode gives slightly worse limits

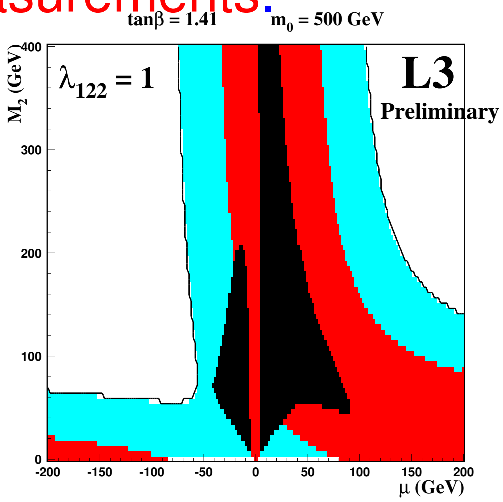
DELPHI limits from $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_1^0$, and $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production in pure leptonic final state from both direct and indirect decays with fixed values of λ .

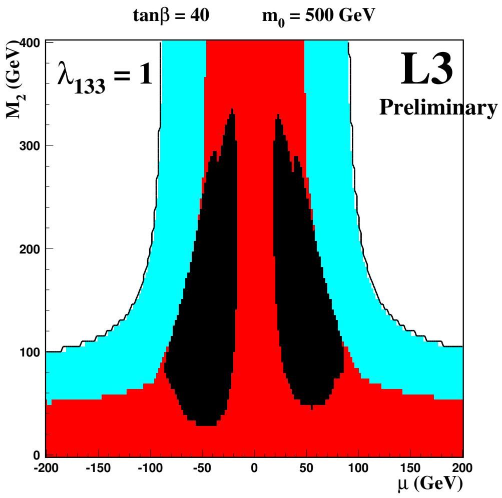
lowest efficiency from λ_{133}

highest efficiency from λ_{122}



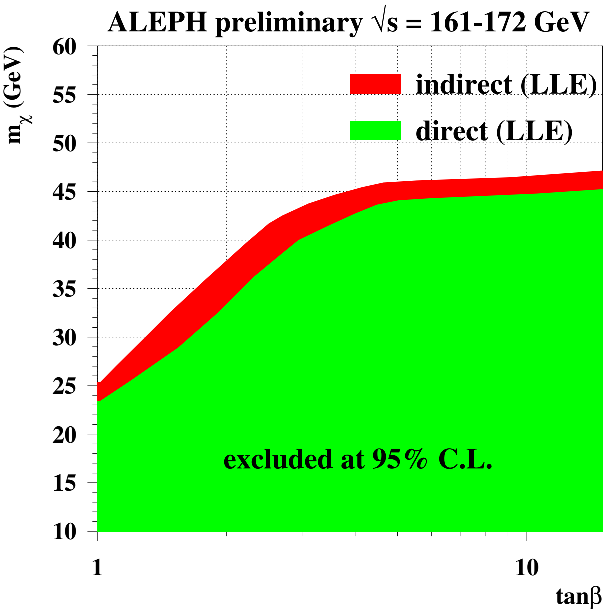
L3 limits from indirect decay of $\tilde{\chi}_1^+\tilde{\chi}_1^-$, and direct decay of $\tilde{\chi}_1^0\tilde{\chi}_1^0$. Exclusion limits are set from chargino searches, neutralino searches, and LEP 1 line shape measurements.

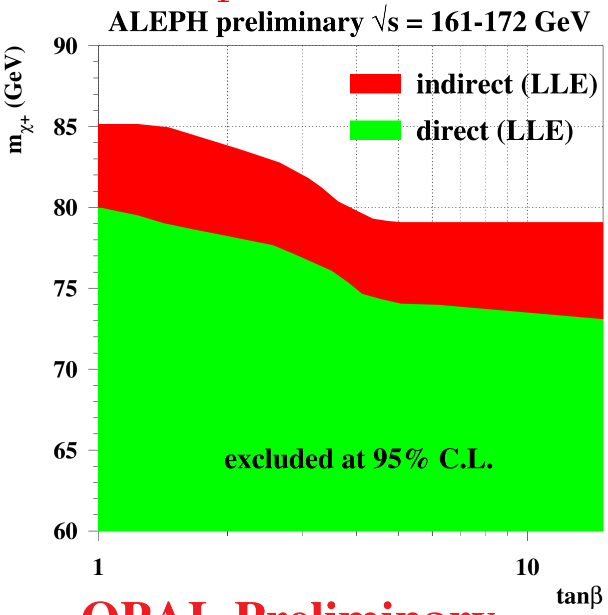




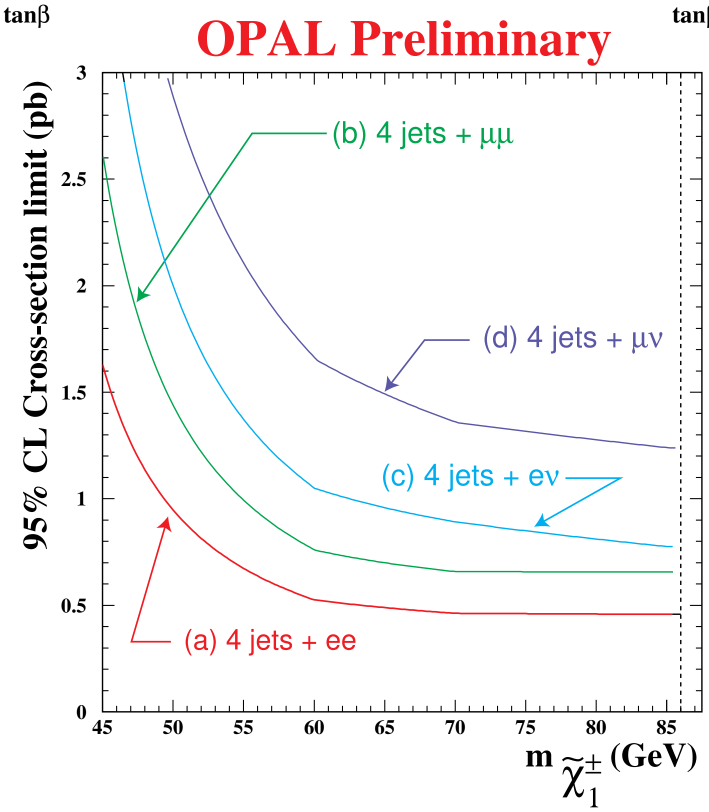
For λ (leptonic coupling) absolute mass limits:

$m_{\tilde{\chi}_1^0} > 23$ GeV $m_{\tilde{\chi}_1^\pm} > 73$ GeV





For a dominant λ' coupling exclude $\tilde{\chi}_1^\pm$ for the following cross sections in direct decay mode (OPAL)



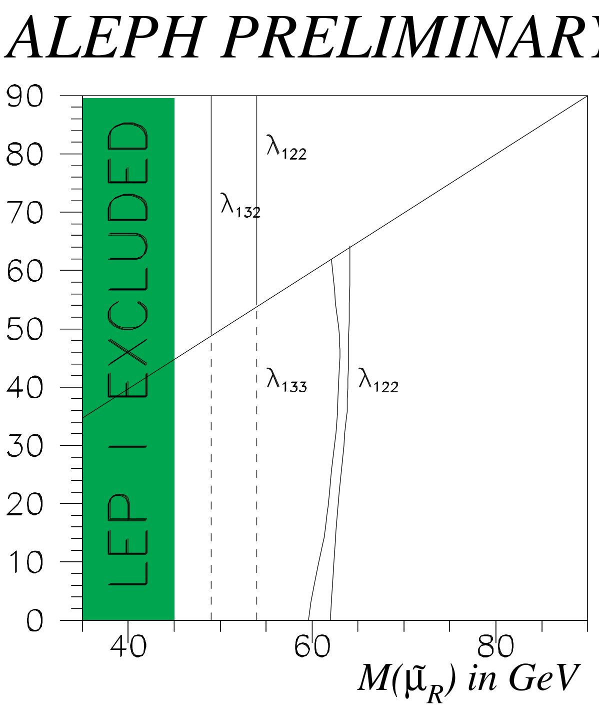
ALEPH excludes a $\tilde{\chi}_1^\pm$ in the indirect decay mode for m_0 =500 GeV/c^2 and $\tan\beta = \sqrt{2}$ with mass lower than 83 GeV.

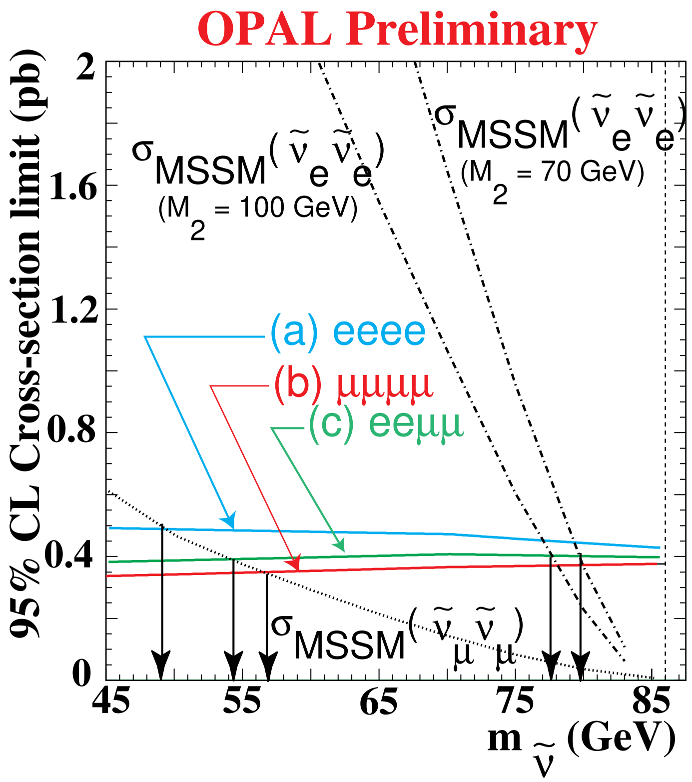
For λ'' (hadronic coupling) exclude cross sections greater than 1.4 pb for $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ for masses between 45 and 60 GeV in direct decay mode (DELPHI).

Sleptons and Sneutrinos

λ dominance

	sleptons	sneutrinos
direct decay	$\longrightarrow$two acoplanar leptons	four leptons
indirect decay	$\longrightarrow$six leptons	four leptons





Exclusion limits valid for any λ coupling:

limits	e_R	μ_R	τ_R	ν_e	ν_μ, ν_τ
ALEPH indirect	63	62	56	72	49
DELPHI direct	70	58	52	62 (λ_{122})	
OPAL direct	56	–	–	79 ($\lambda_{121}, \lambda_{122}$)	49 (λ_{12k})

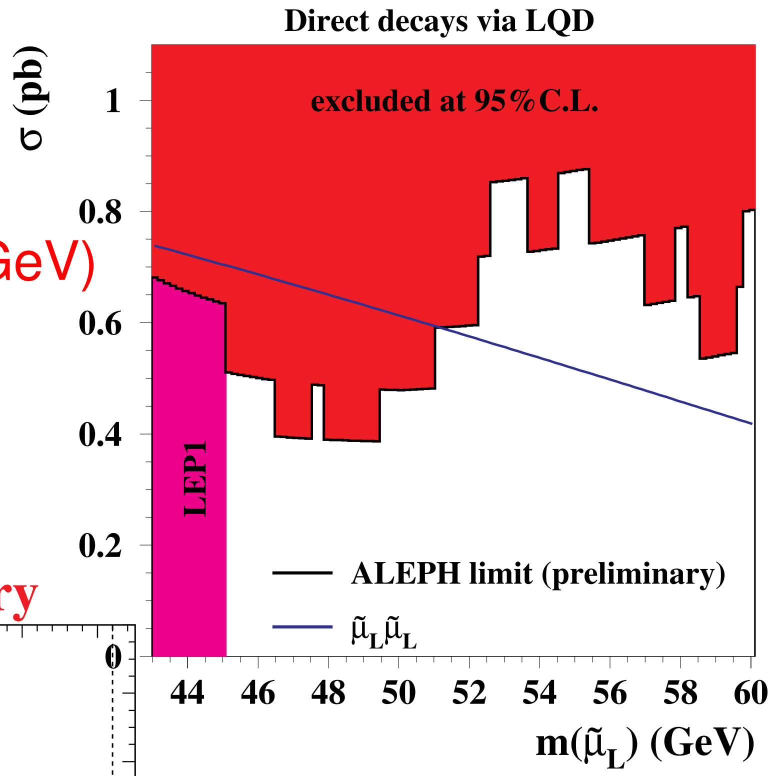
Limits for 1st generation sparticles should not be compared, as they have been calculated for different points in the MSSM parameter space.

λ' dominance

		sleptons	sneutrinos
direct decay	$\to$	four jets	four jets
indirect decay	$\to$	jets plus leptons	jets plus leptons

Only direct decays have been analysed

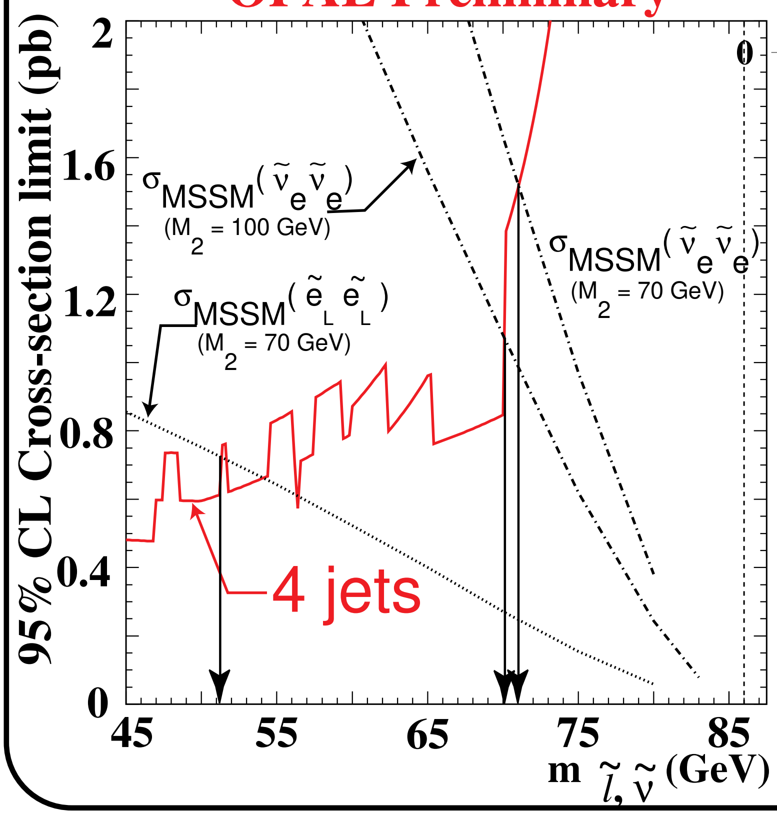
ALEPH preliminary



Mass limits ∼ 50 GeV

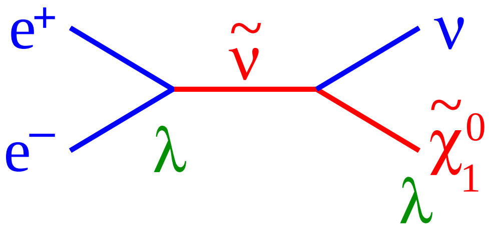
(first generation ∼ 70 GeV)

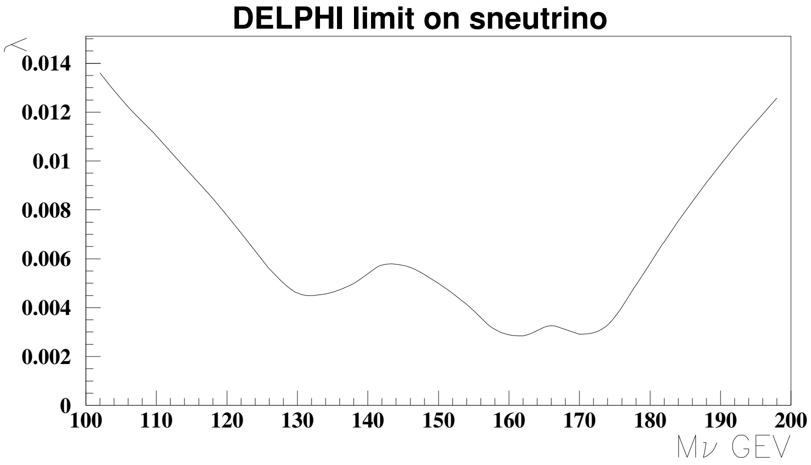
OPAL Preliminary



Masses around the W mass are difficult to exclude due to the same final states.

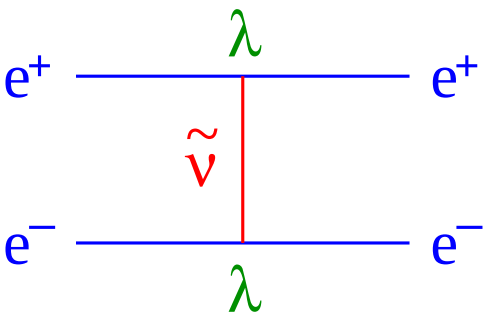
s–channel resonance production of sneutrinos

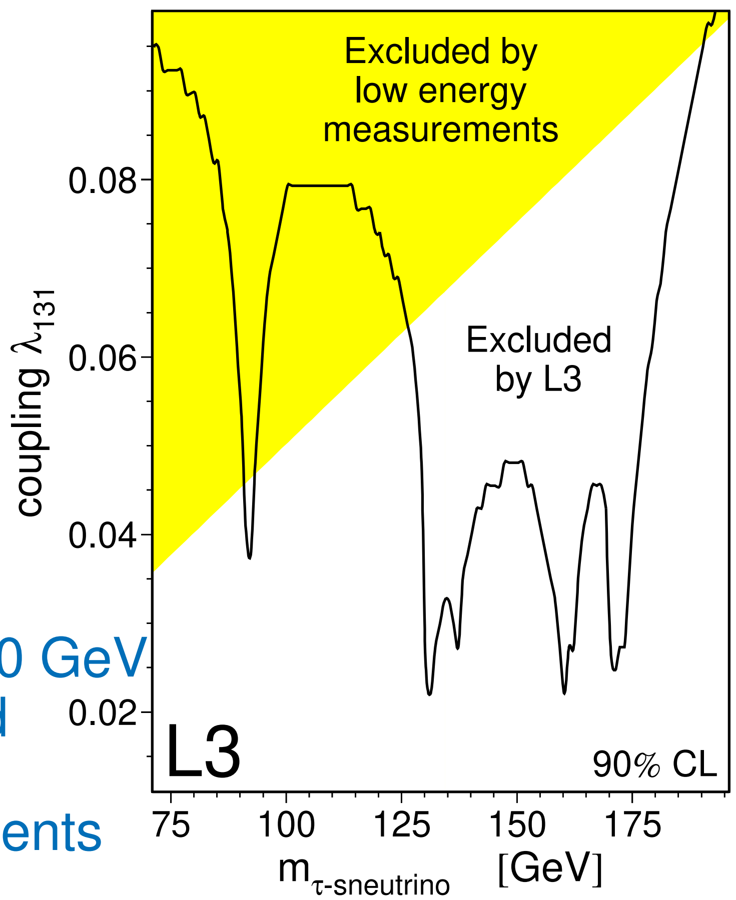




exclude $\lambda_{121} > 5 \times 10^{-3}$
for 130 GeV$< m_{\tilde{\nu}} <$ 170 GeV in indirect decay

sneutrino s– and t-channel exchange





exclude
$\lambda_{131} > 5 \times 10^{-2}$
for
130 GeV$< m_{\tilde{\nu}_\tau} <$ 170 GeV
from cross section and
forward backward
asymmetry measurements

(similiar analysis by DELPHI)

peak structure related to
LEP centre of mass energies

Squarks

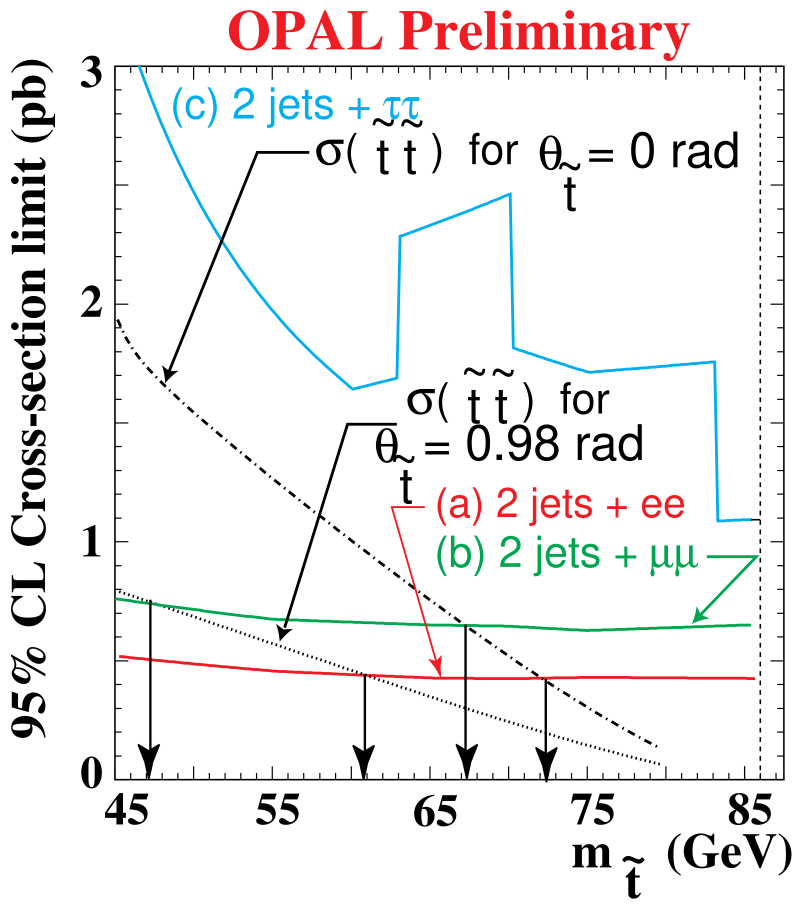
Due to the large t–quark mass and the mixing of the left- and right handed scalar t-quarks the $\tilde{t}_1$ could become very light.

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

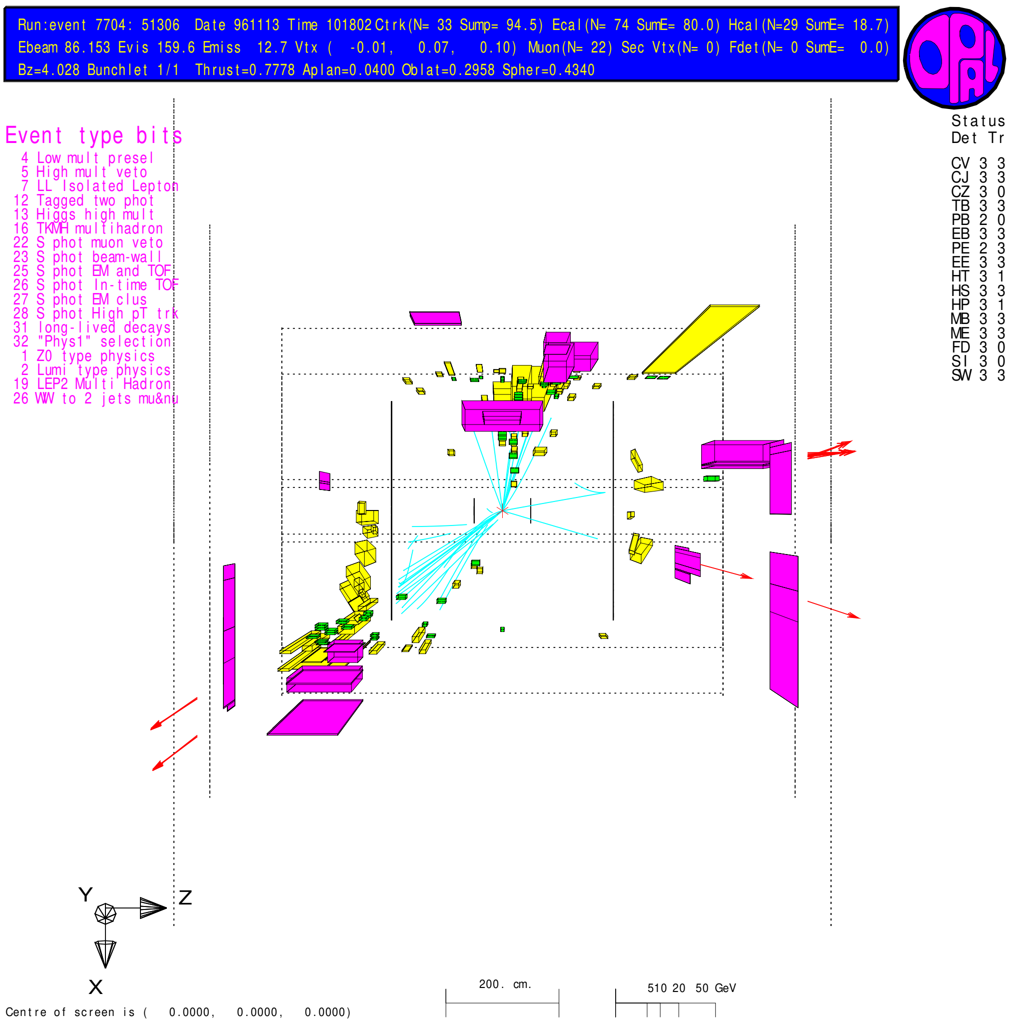
For $\theta_{\tilde{t}} = 0.98$ the $\tilde{t}_1$ decouples from the Z^0 and the production cross section becomes minimal.

For λ', $\lambda''> 1.9 \times 10^{-4}$ the direct $\tilde{t}_1$ decay is dominant over the indirect decay.

direct decay with λ' dominance



LIMITS	$\tilde{t}_1 \to e + q$	$\tilde{t}_1 \to \mu + q$	$\tilde{t}_1 \to \tau + q$
$\theta_{\tilde{t}} = 0$ rad DELPHI	66.9 GeV	69.5 GeV	59.3 GeV
$\theta_{\tilde{t}} = 0$ rad OPAL	72.0 GeV	67.0 GeV	–
$\theta_{\tilde{t}} = 0.98$ rad DELPHI	50.0 GeV	58.7 GeV	–
$\theta_{\tilde{t}} = 0.98$ rad OPAL	61.0 GeV	47.0 GeV	–



direct decay with λ'' dominance

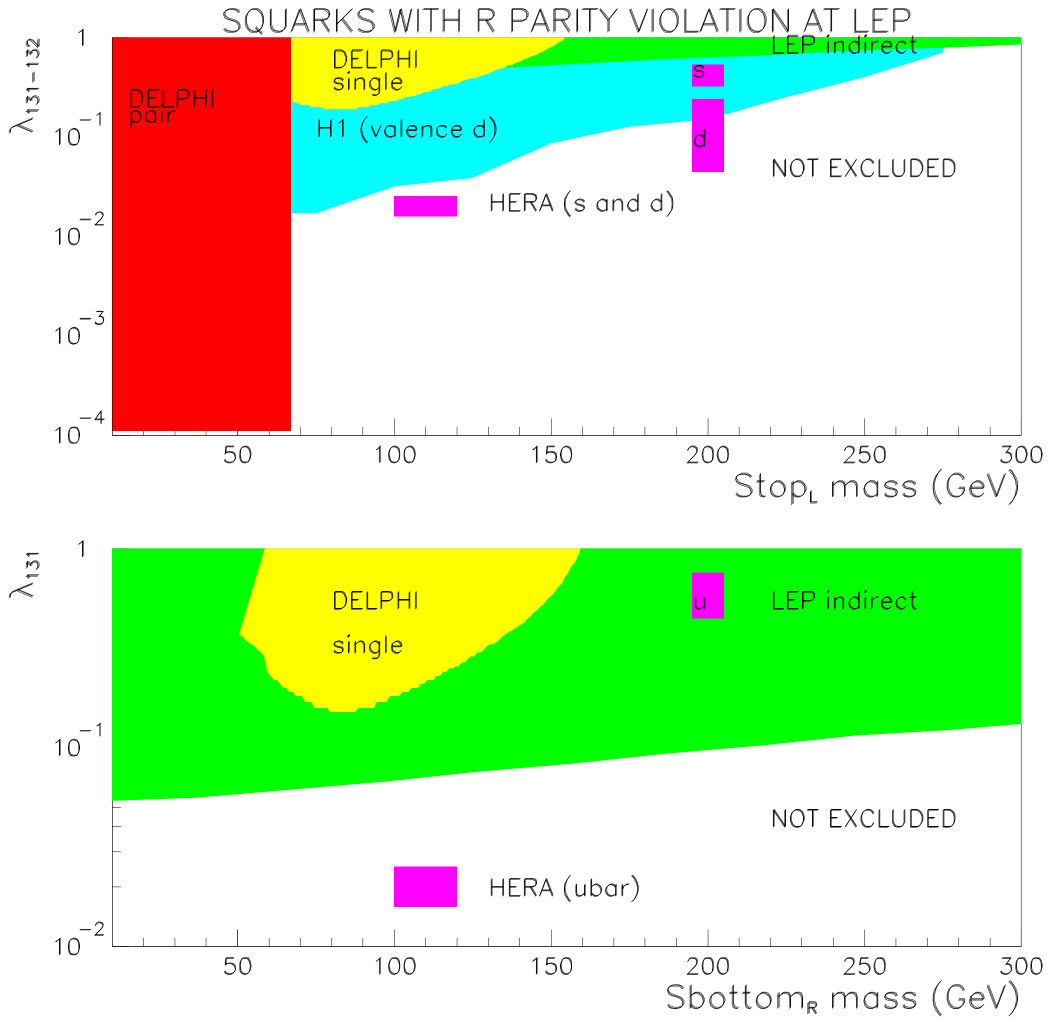
direct decay: $\tilde{t} \rightarrow$ 2 jets
same final state as for sneutrinos and sleptons with λ' coupling

	$\theta_{\tilde{t}}$ = 0 rad	$\theta_{\tilde{t}}$ = 0.98 rad
OPAL	61 GeV	47 GeV
DELPHI	61 GeV	–

Exclude $\tilde{t}_L > 59$ GeV for λ', $\lambda'' > 1.9 \times 10^{-4}$.

Squarks at LEP and HERA

Single production and t-channel contributions allow exclusion limits over a large mass and λ range



Squark production via a dominant λ' coupling is one possible solution of the HERA effect.

The boxes show 'solutions' to the HERA effect.

Summary

- Searches for $R_p$violating production and decay of SUSY particles are complementary to searches with $R_p$conservation
- Searching for both scenarios has extended discovery potential
- Under the assumption of $R_p$violation searches have been performed at LEP for gauginos, sleptons, sneutrinos and squarks for all Yukawa couplings λ , λ' , λ'' .
- No evidence for SUSY with $R_p$violation or leptoquarks so far at LEP
- the further running at LEP has a discovery potential to sparticle masses up to the beam energy for couplings as small as 10^{-7}