R-parity violation searches at LEP

Ivor Fleck

University of Freiburg

July 28, 2000

PA-11

- R-parity violating superpotential
- indirect limits on couplings
- experimental results
  - trilinear terms
    - gauginos
    - sleptons
    - sneutrinos
    - squarks
  - bilinear terms
- conclusions and outlook

Introduction of R-parity

new discrete multiplicative symmetry in SUSY models

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

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

$$R_p = 1 \quad \text{for SM particles}$$
$$R_p = -1 \quad \text{for SUSY particles}$$

	R_p	$\not{R}_p$
SUSY particles produced in	pairs	pairs or singly
the LSP	is stable	decays
experimental signature	$\not{E}_T$	E_T

Exclusion limits under assumption of R_p-conservation are not valid under R_p-violation.

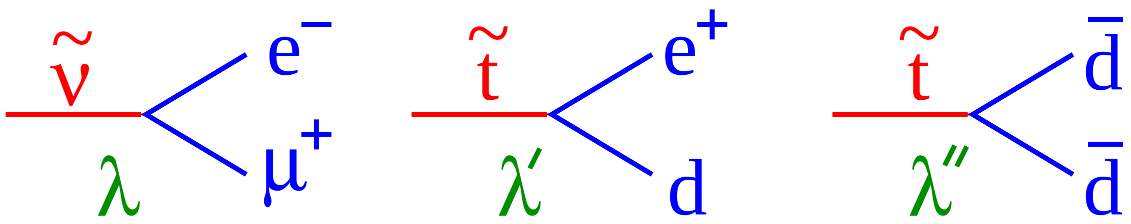
The R-parity Violating Superpotential

$$\mathbf{W} = \lambda_{\mathrm{ijk}} \mathbf{L}^{\mathrm{i}}_{\mathbf{L}} \mathbf{L}^{\mathrm{j}}_{\mathbf{L}} \overline{\mathbf{E}}^{\mathrm{k}}_{\mathbf{R}} + \lambda'_{\mathrm{ijk}} \mathbf{L}^{\mathrm{i}}_{\mathbf{L}} \mathbf{Q}^{\mathrm{j}}_{\mathbf{L}} \overline{\mathbf{D}}^{\mathrm{k}}_{\mathbf{R}} + \lambda''_{\mathrm{ijk}} \overline{\mathbf{U}}^{\mathrm{i}}_{\mathbf{R}} \overline{\mathbf{D}}^{\mathrm{j}}_{\mathbf{R}} \overline{\mathbf{D}}^{\mathrm{k}}_{\mathbf{R}}$$

$$+ \epsilon_{\mathrm{i}} \mathbf{L}^{\mathrm{i}}_{\mathbf{L}} \mathbf{H}_{\mathbf{u}}$$

with

$\mathbf{L_L}(\mathbf{Q_L})$:	lepton (quark) doublet superfield
$\mathbf{E_R}$:	electron singlet superfield
$\mathbf{D_R}(\mathbf{U_R})$:	down- (up-) quark type singlet superfield
$\mathbf{H_u}$:	Higgs field coupling to up-quarks
λ , λ' , λ'' :	Yukawa couplings
ϵ:	effective coupling
$\mathbf{i}, \mathbf{j}, \mathbf{k}$:	generation indices



L violation B violation

Due to symmetrie $i < j$ for λ_{ijk}

$j < k$ for λ''_{ijk}

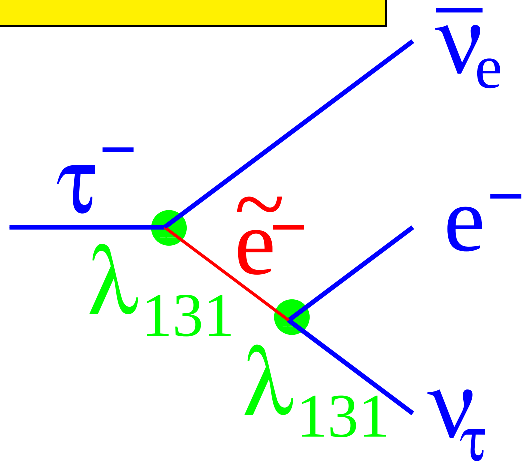
$\rightarrow$ 48 (9 + 27 + 9 + 3) independent couplings

Limits for R-parity Violation

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

- lepton universality violation
- fast proton decay

Non observation of these effects sets limits on the size of the λ-couplings



λ	λ'			λ''
(121) 0.05	(111) 0.0005	(211) 0.06	(311) 0.1	(121) 10^{-15}
(122) 0.05	(112) 0.02	(212) 0.06	(312) 0.1	(131) 10^{-4}
(123) 0.05	(113) 0.02	(213) 0.06	(313) 0.1	(132) 1.23
(131) 0.06	(121) 0.04	(221) 0.18	(321) 0.52	(221) 1.23
(132) 0.06	(122) 0.04	(222) 0.21	(322) 0.52	(231) 0.5
(133) 0.006	(123) 0.04	(223) 0.21	(323) 0.52	(232) 0.5
(231) 0.07	(131) 0.02	(231) 0.18	(331) 0.45	(321) 0.5
(232) 0.07	(132) 0.3	(232) 0.56	(332) 0.45	(331) 0.42
(233) 0.07	(133) 0.001	(233) 0.15	(333) 0.45	(332) 0.42

2σ limits for sparticle mass of 100 GeV

red numbers indicate couplings excluded at 2σ from a global fit to hadronic Z decays

More stringent limits on product of two λ–couplings

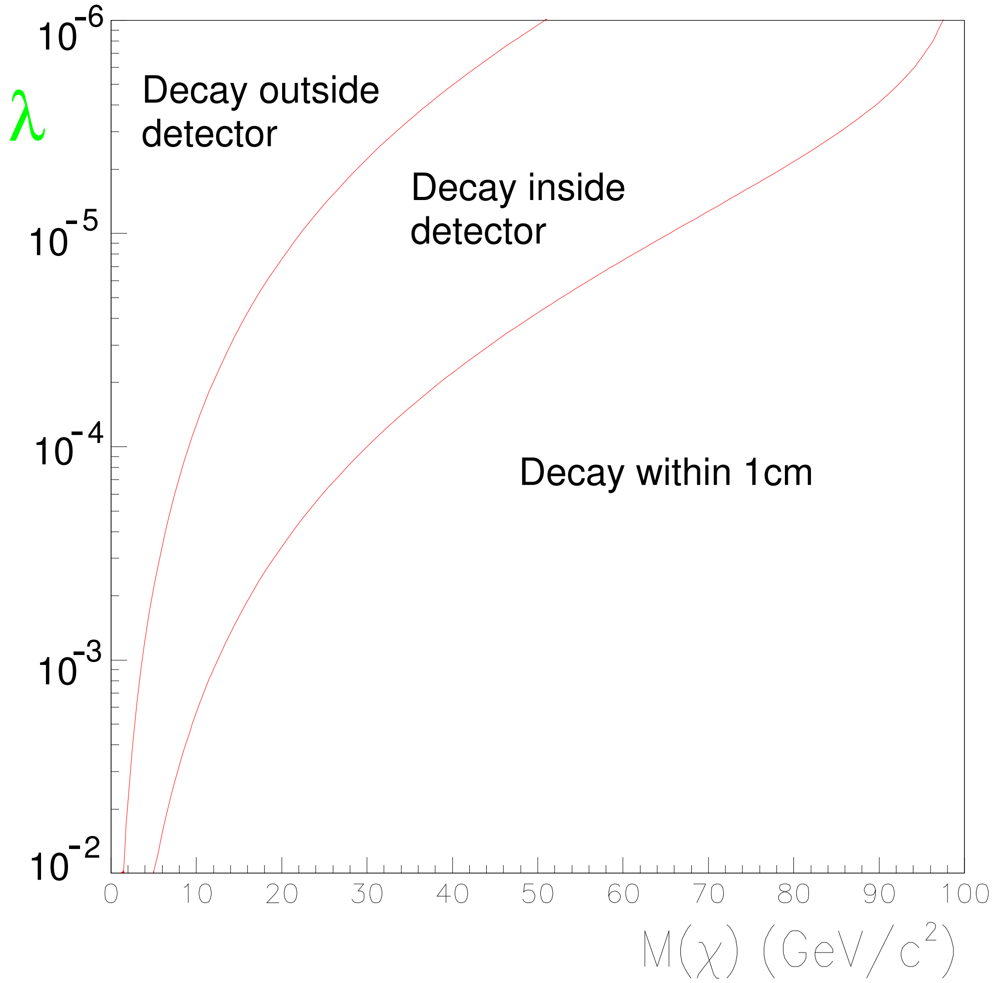
– non observation of proton decay:

$$\lambda'_{11k} \times \lambda''_{11k} < 10^{-24}$$

$\rightarrow$ assume exactly one λ-coupling is different from 0

Decay Width of Gauginos

Decay width of photino like $\tilde{\chi}_1^0$ from pair-production of $\tilde{\chi}_1^0$



$$\Gamma = \lambda^2 \frac{\alpha}{128\pi^2} \frac{(m_{\tilde{\chi}_1^0})^5}{(m_{\tilde{f}})^4}$$

$m_{\tilde{f}}$: virtual sfermion mass (set to 100 GeV)

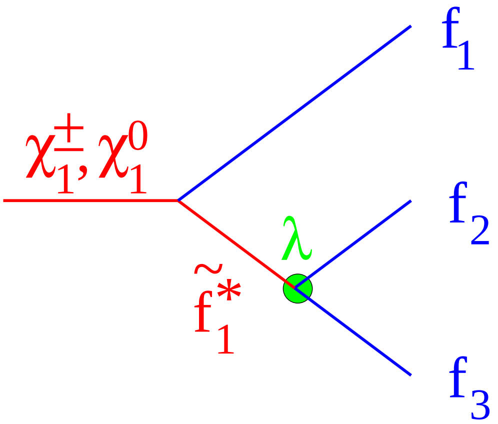
$\rightarrow$ sensitive to $\boldsymbol{\lambda}$-values of $\mathcal{O}(10^{-5})$

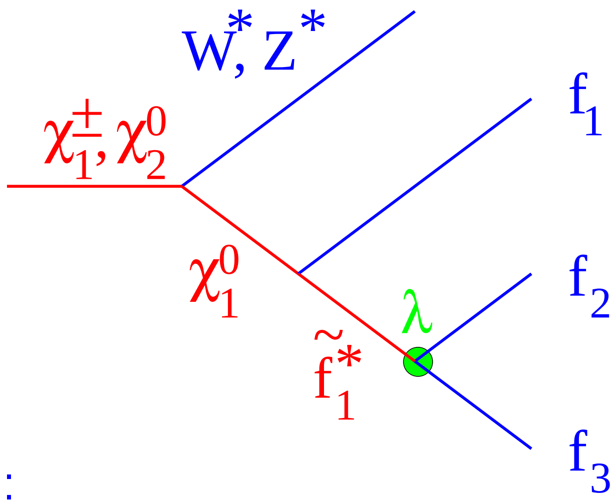
decay width depends strongly on $\tilde{\chi}_1^0$ matrix

Gauginos

two different decay modes:

R_p violating = **direct** $\qquad$ R_p conserving + R_p violating = **indirect**





final states from pair-production:

	direct	indirect
gauginos	6 fermions	10 fermions

direct: λ

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow 4\ \ell + \not{E}$

$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow 2\ \ell + \not{E}$

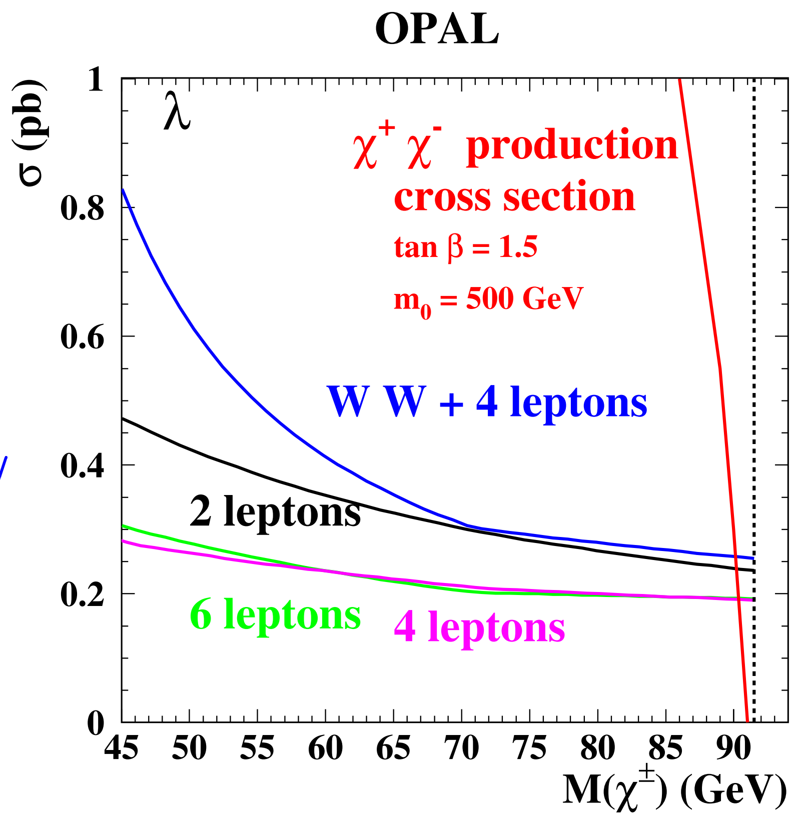
$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow 4\ \ell + \not{E}$

$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow 6\ \ell$

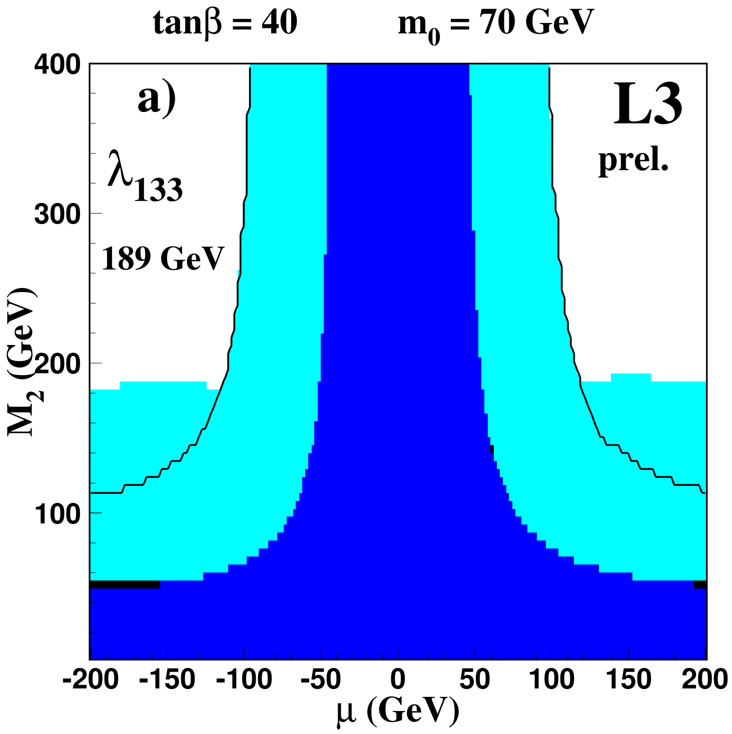
indirect: λ

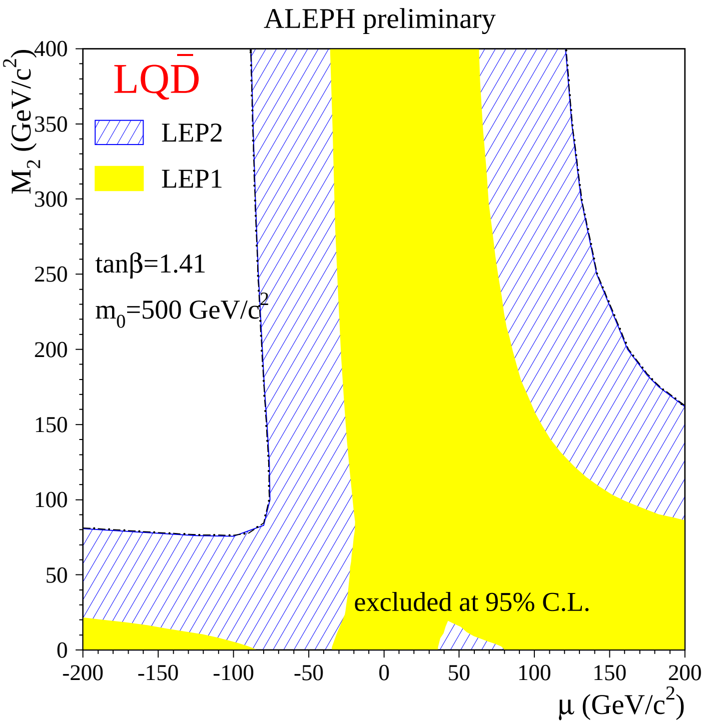
$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W\ W + 4\ \ell + \not{E}$

limits shown for λ–coupling resulting in worst cross-section limit



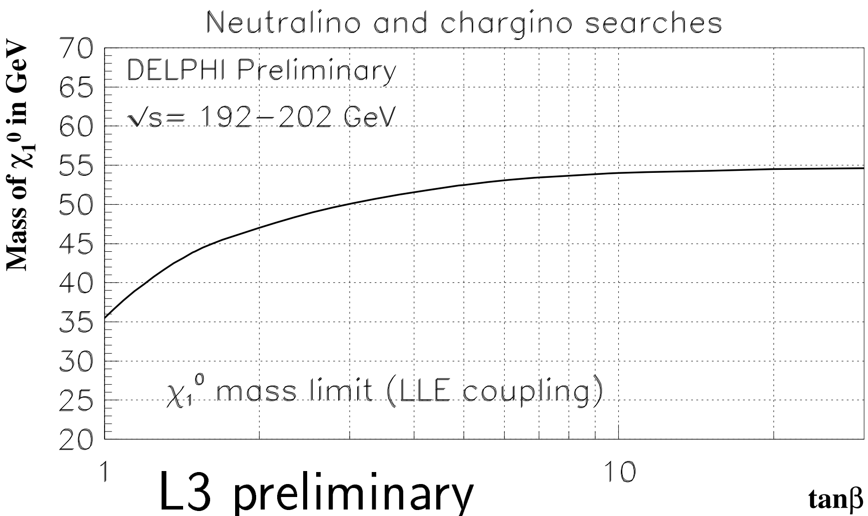
Limits from Gaugino Searches

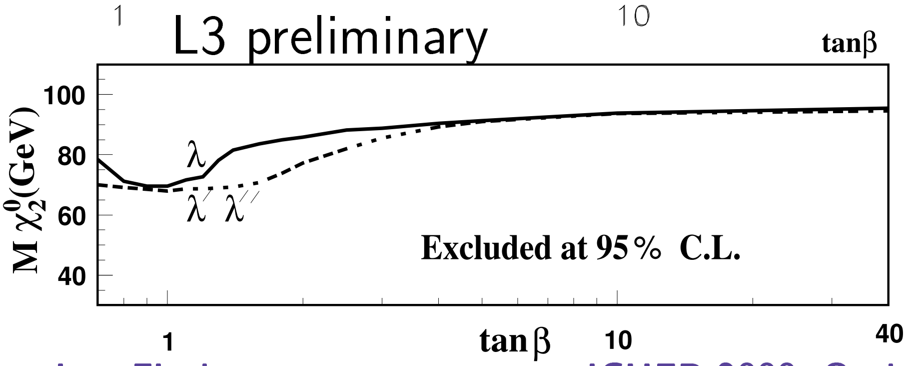




exclusion up to kinematic limit of $\tilde{\chi}_1^{\pm}$ pair production

extended sensitivity due to $\tilde{\chi}_1^0$ pair production





exclusions:

$\mathrm{M}(\tilde{\chi}_1^0) > 35$ GeV

$\mathrm{M}(\tilde{\chi}_2^0) > 68$ GeV

$\mathrm{M}\left(\tilde{\chi}_1^{\pm}\right) > 99$ GeV

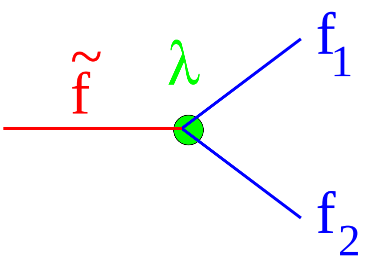
independent of

$\tan\beta, m_0, M_2, \mu$

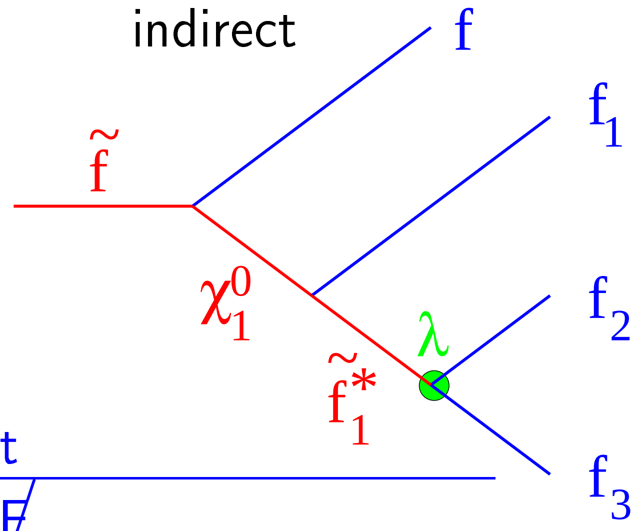
$\lambda, \lambda', \lambda''$

Sleptons

direct



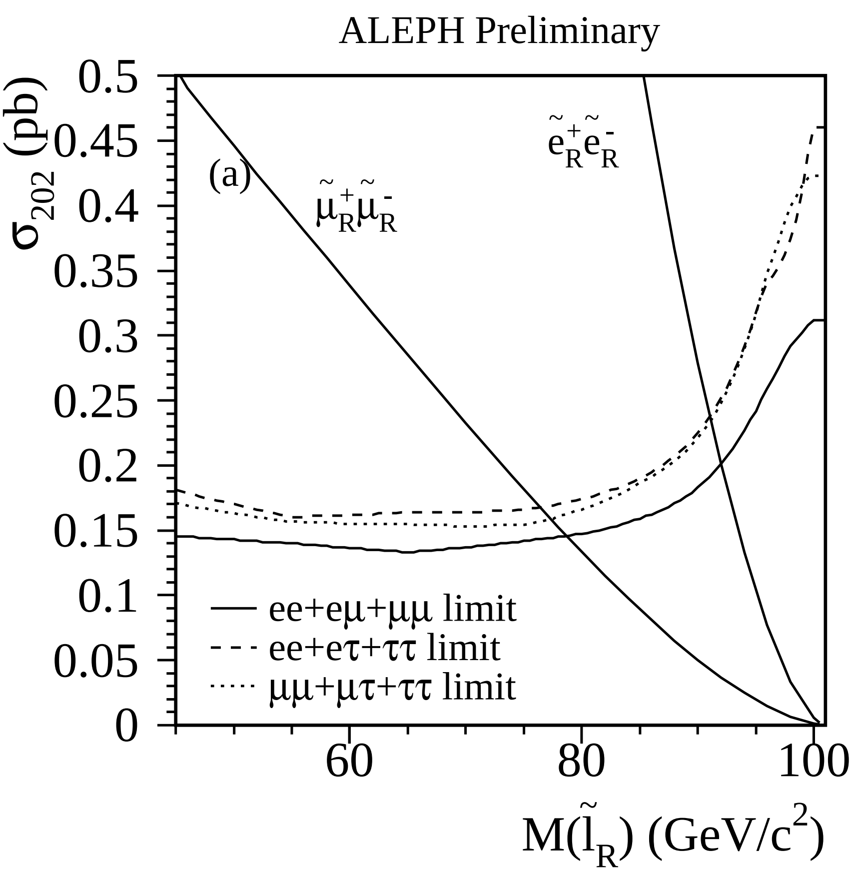
indirect



final states:

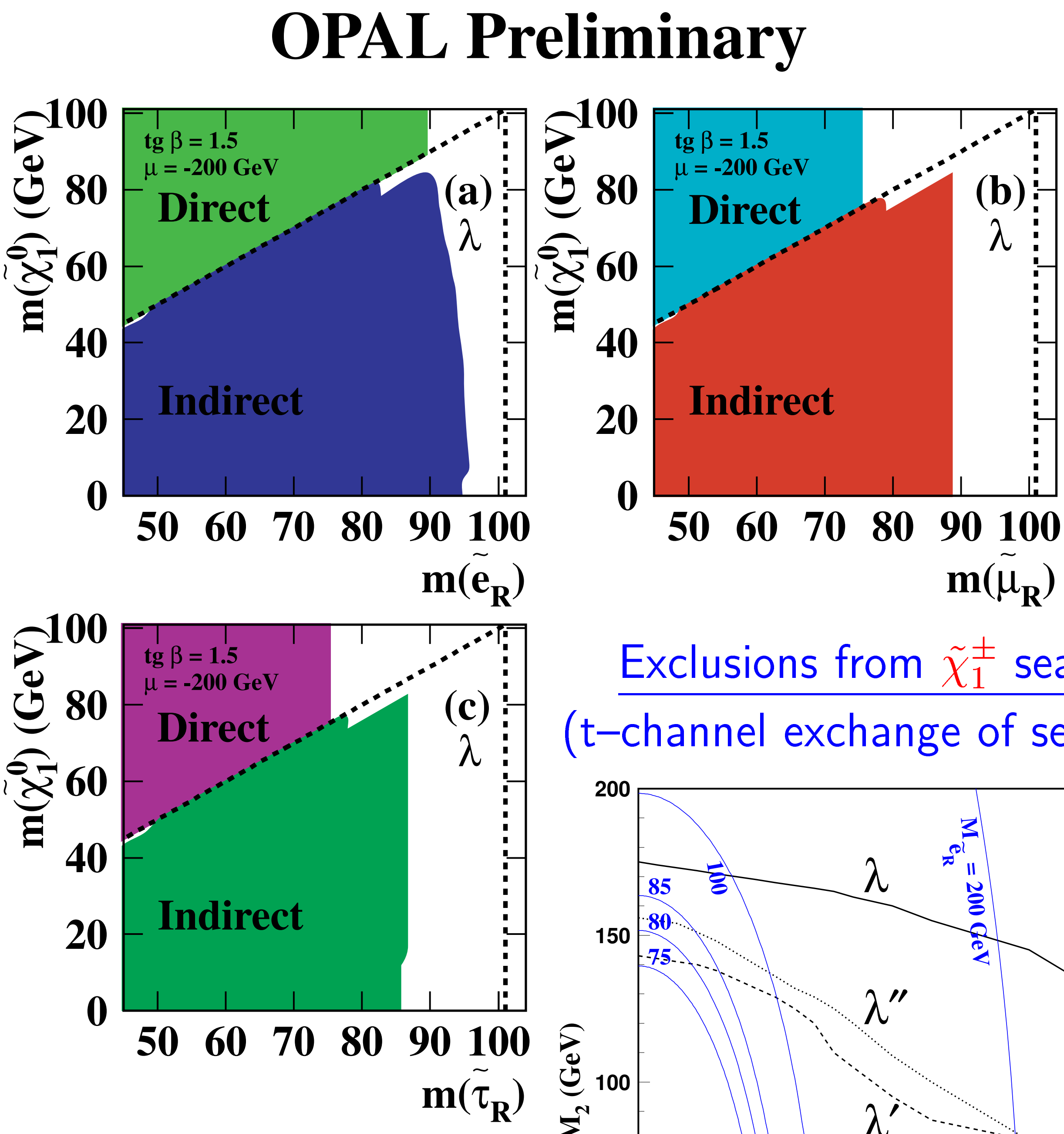
	direct	indirect
λ	$2\ \ell + \not{E}$	$6\ \ell + \not{E}$
λ'	4 jets	$(2+x)\ \ell$ + 4 jets (x=0,1,2)
λ''	–	$2\ \ell$ + 6 jets

upper cross-section limits for $2\ \ell + \not{E}$ final states



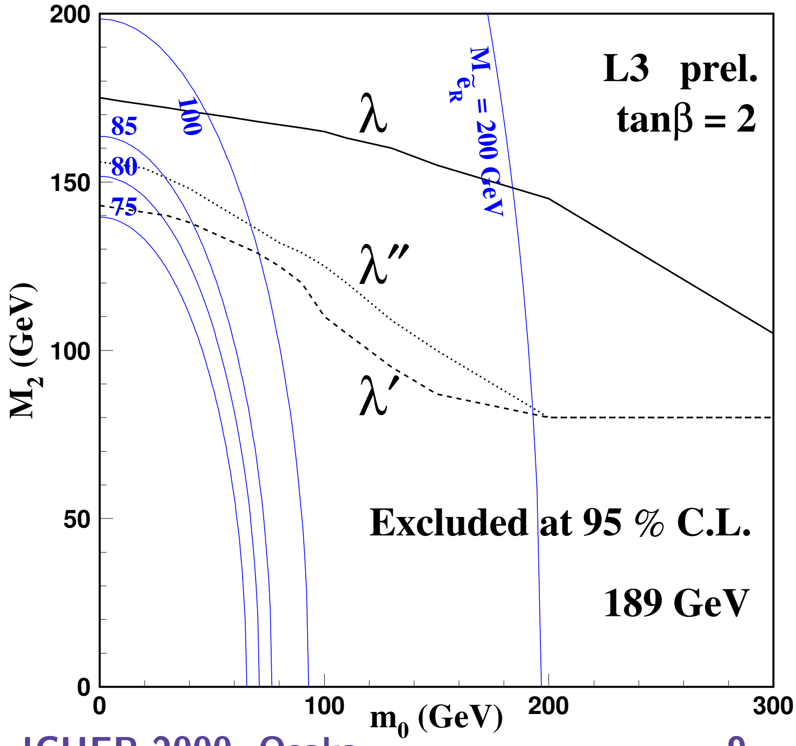
Limits from Slepton Searches

Exclusions from slepton searches: (e.g. λ)



Exclusions from $\tilde{\chi}^{\pm}_1$ searches:

(t–channel exchange of selectron)



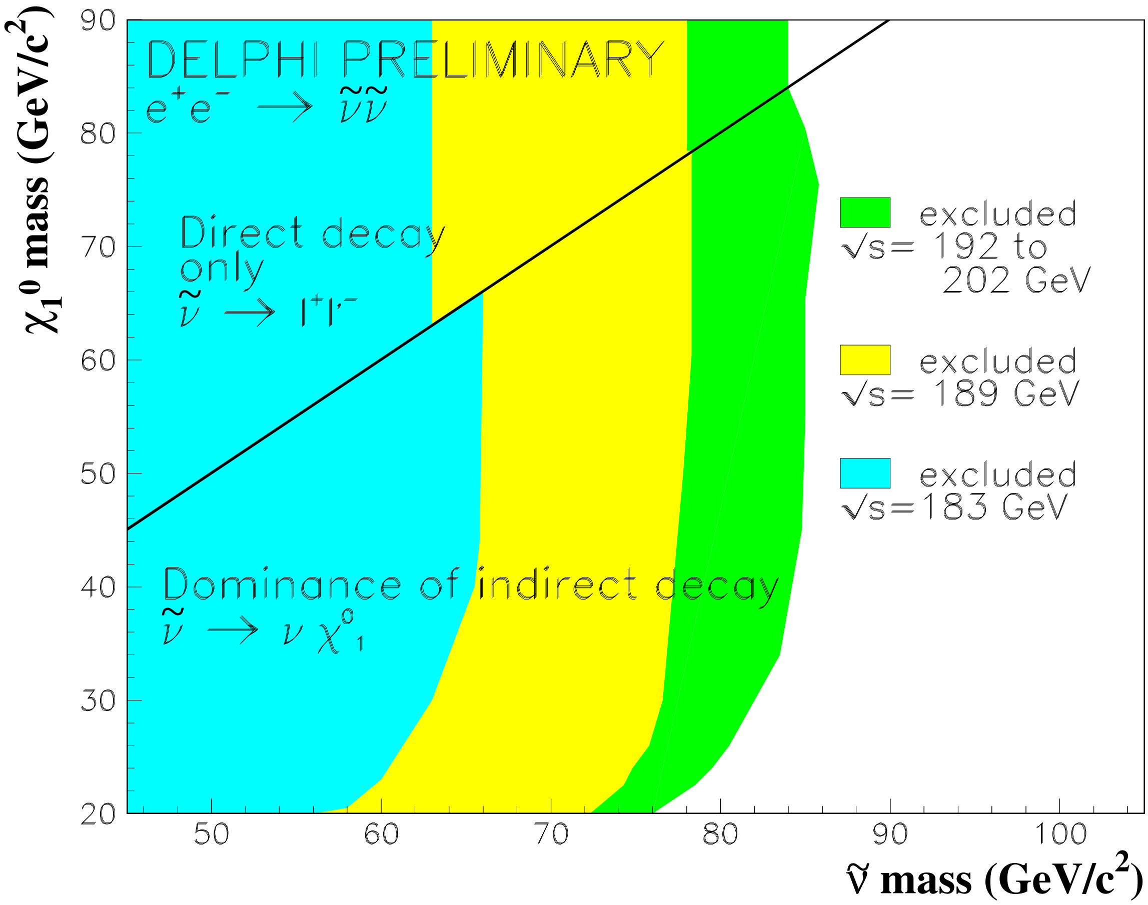
Sneutrinos

final states:

	direct	indirect
λ	$4\ \ell$	$4\ \ell + \not{E}$
λ'	4 jets	$x\ \ell + 4$ jets $+ \not{E}$ (x=0,1,2)
λ''	–	6 jets $+ \not{E}$

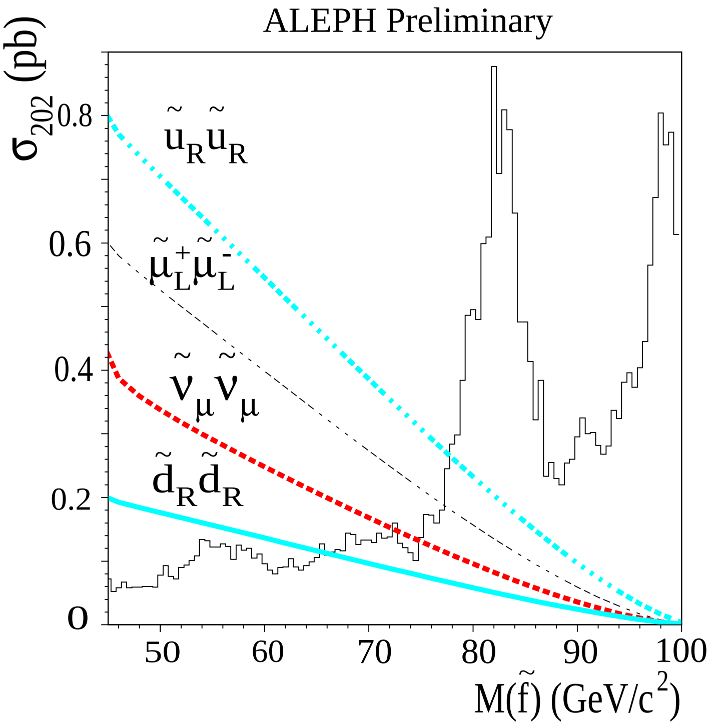
decays via λ:

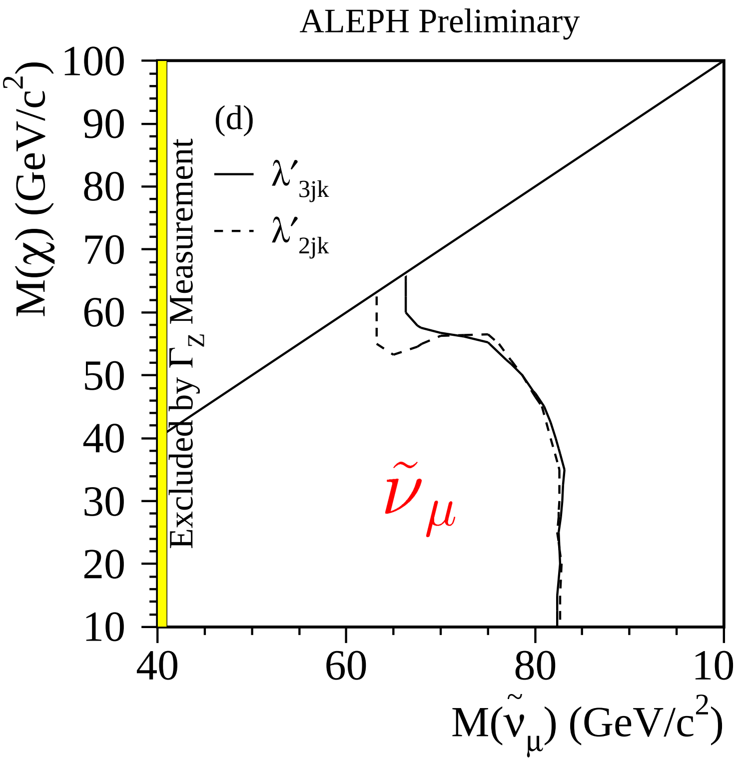
sneutrino limits from different centre-of-mass energies



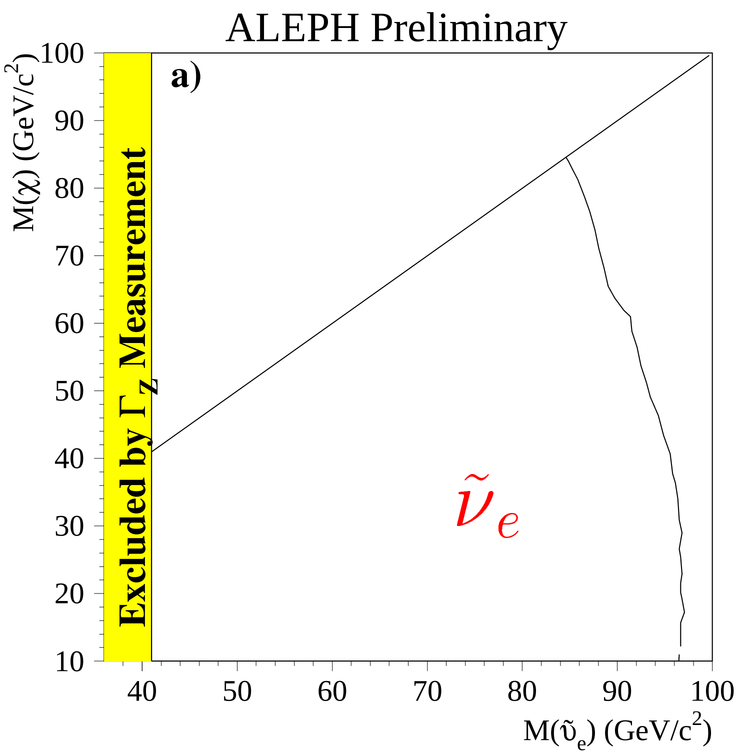
Sneutrino limits

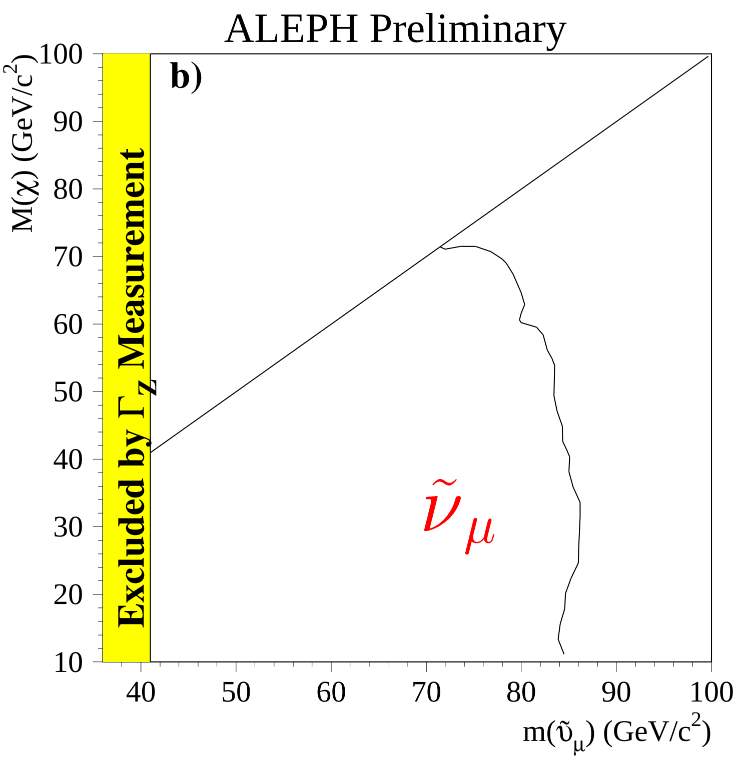
limits from decays via λ':





limits from decays via λ'':

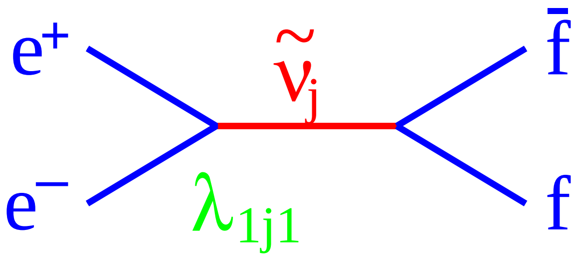




Single Sneutrino Production

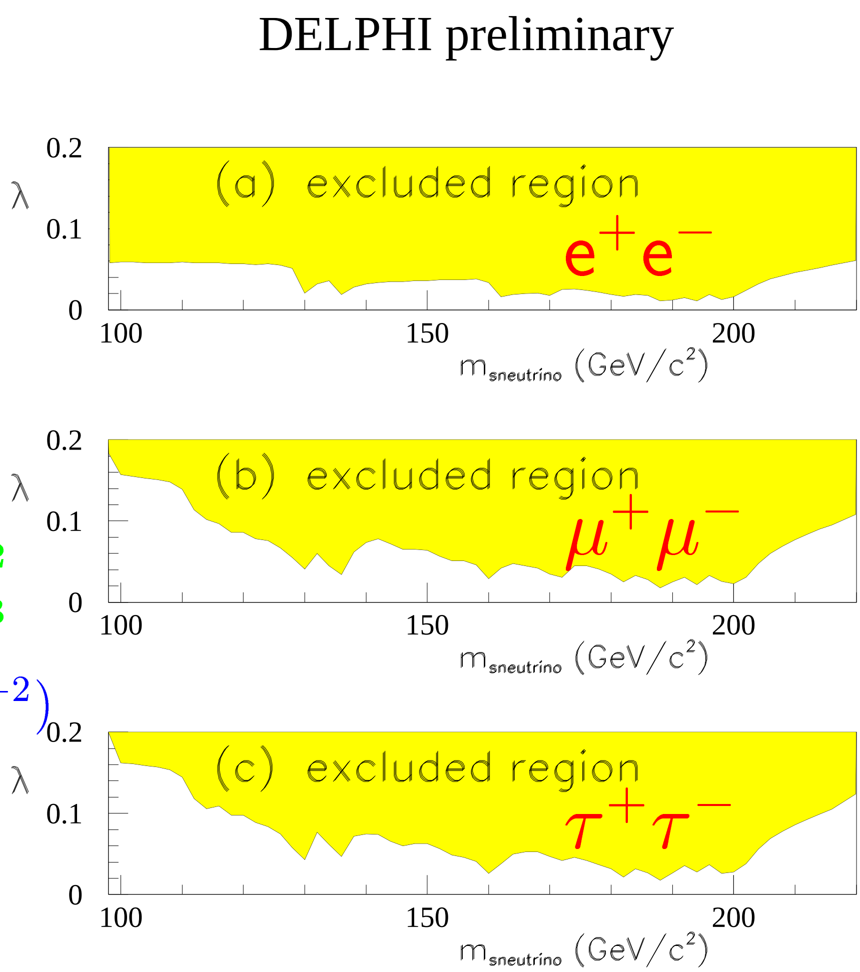
direct decay:

2 fermion final states:

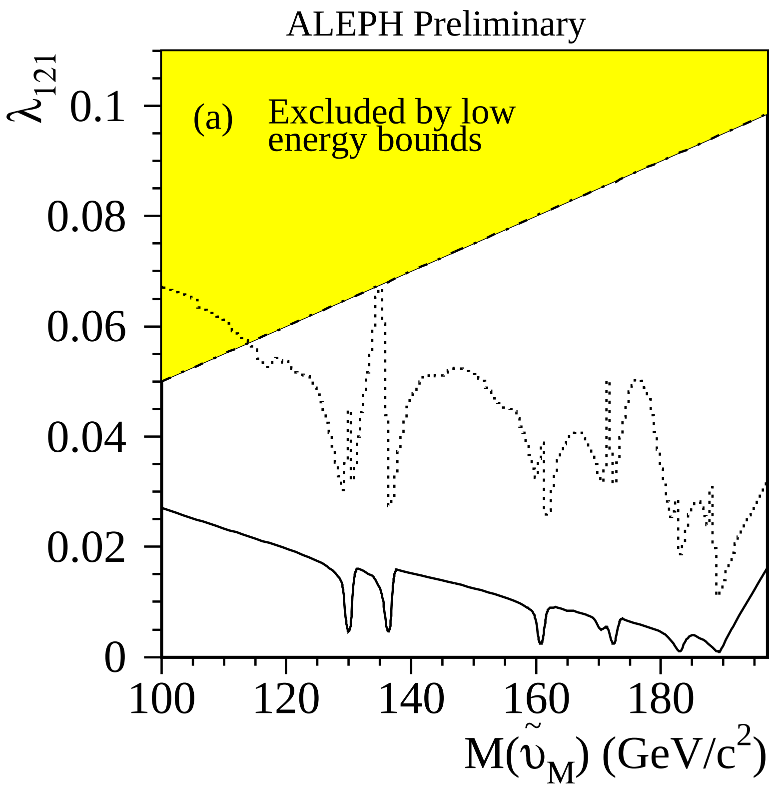


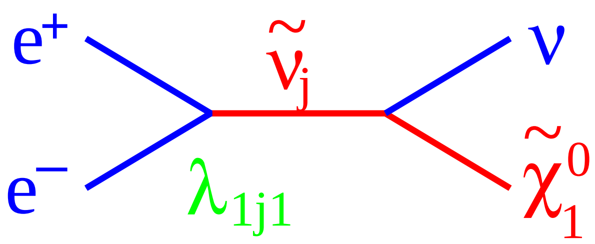
$\mu^+\mu^-$: $\lambda_{131} = \lambda_{232}$
$\tau^+\tau^-$: $\lambda_{121} = \lambda_{323}$

sensitivity for $\lambda > \mathcal{O}(10^{-2})$



indirect decay:





sensitivity for
$\lambda > \mathcal{O}(10^{-3})$
for masses
up to $\sqrt{s}$

Squark Decays

mixing of left- and right handed scalar squarks

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

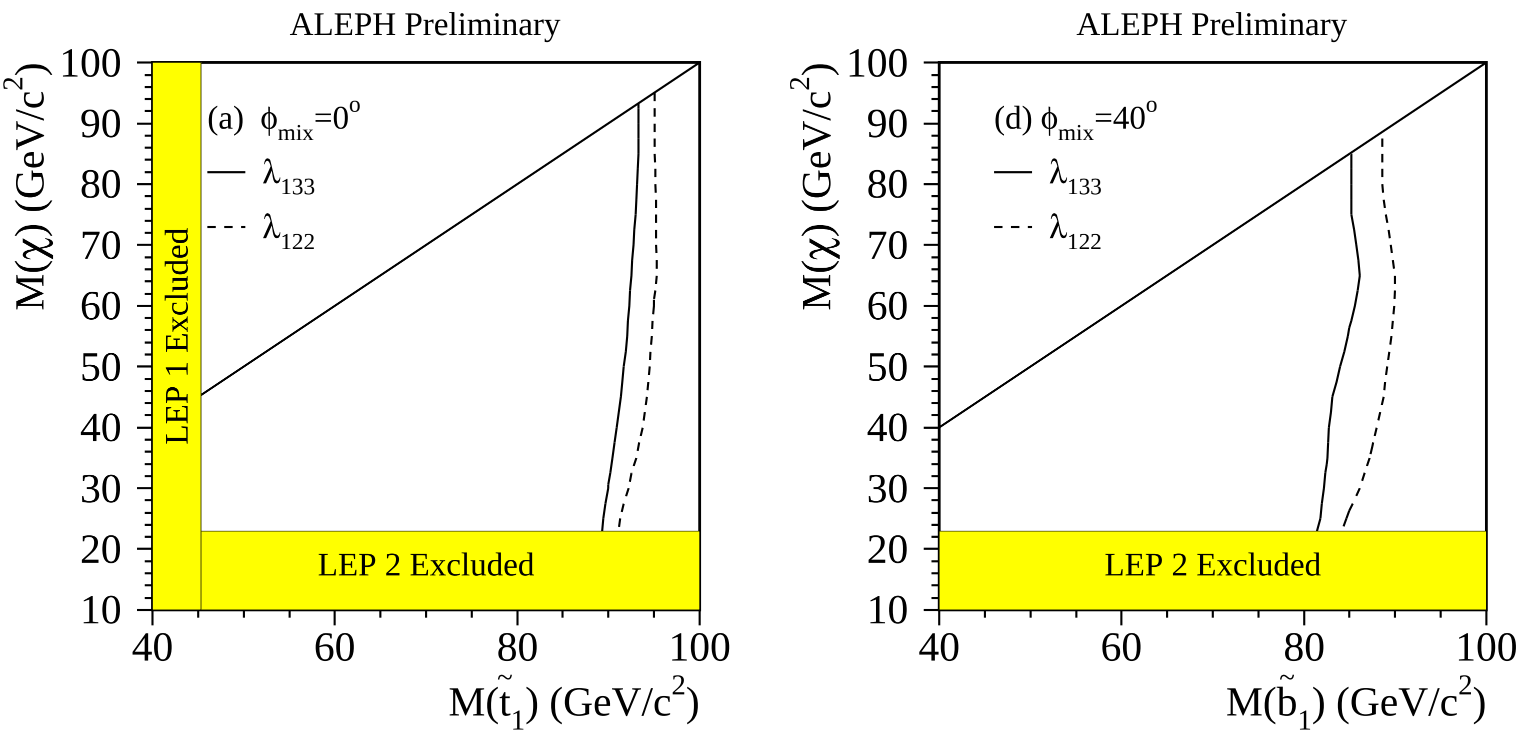
For $\theta_{\tilde{t}} = 0.98(1.17)$ the $\tilde{t}_1$ $(\tilde{b}_1)$ decouples from Z^0 and the production cross section becomes minimal.

final states:

	direct	indirect
λ	–	2 jets + 4 ℓ + E
λ'	2 jets + 2 (1,0) ℓ	6 jets + 2 (1,0) ℓ
λ''	4 jets	8 jets

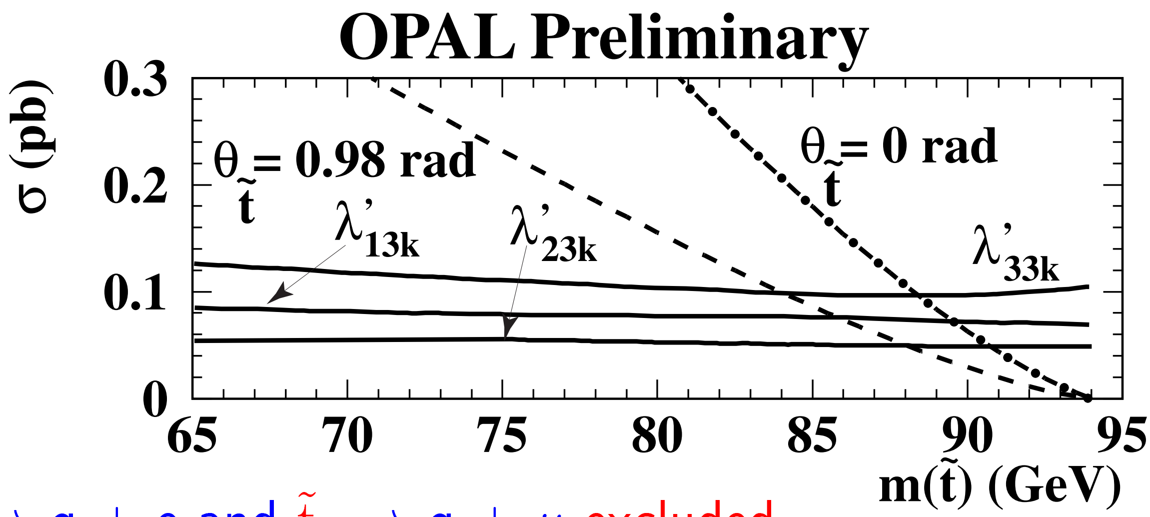
indirect decay via λ :

$$\tilde{q} \rightarrow q + \tilde{\chi}_1^0$$



Squark Decays via λ'

for $\lambda' > 10^{-4}$ direct $\tilde{t}_1$ decay dominant : $\tilde{t}_1 \rightarrow q + \ell$
2 jet + 2 lepton final states:

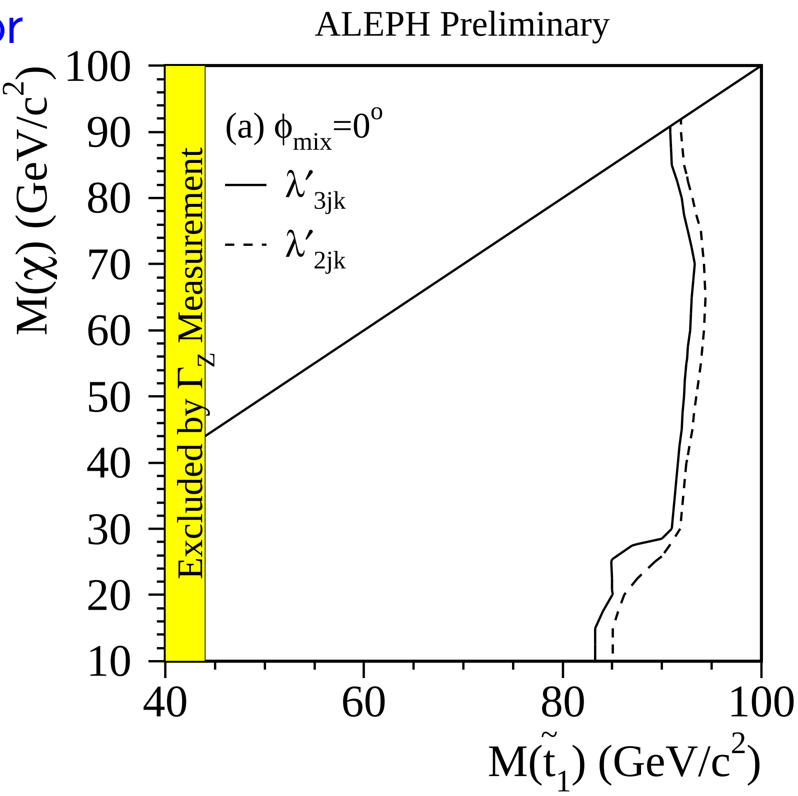


$\tilde{t}_1 \rightarrow q + e$ and $\tilde{t}_1 \rightarrow q + \mu$ excluded
from CDF and D0 for $M(\tilde{t}_1) < 200$ GeV

but $\tilde{t}_1 \rightarrow q + \tau$ not excluded

LEP: lower mass limits for any mixing angle

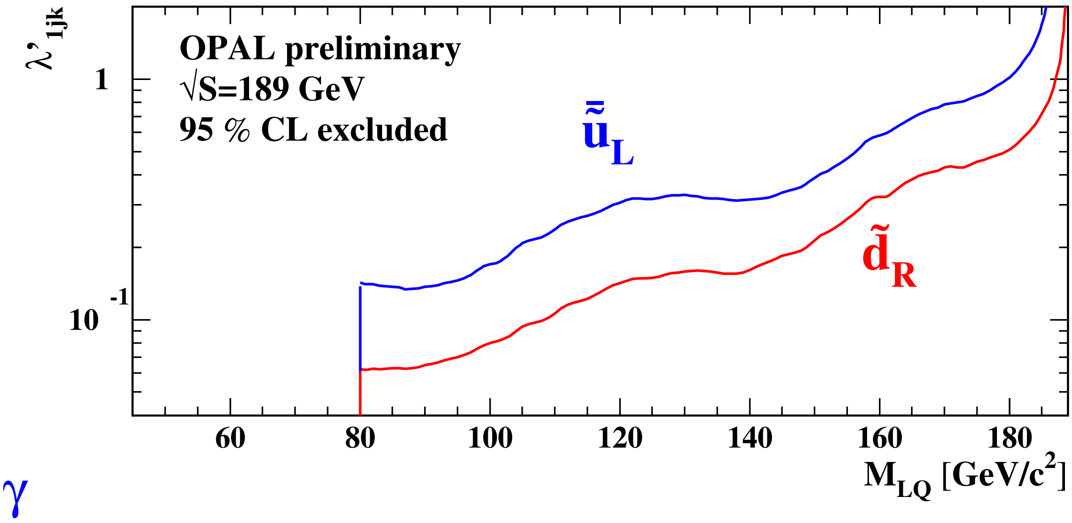
$M(\tilde{t}_1) > 91$ GeV

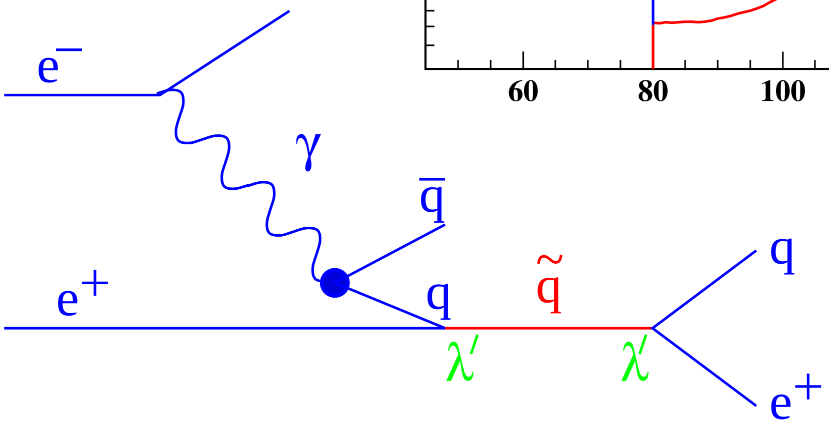


indirect decay via λ' :

Single Squark production

single production:



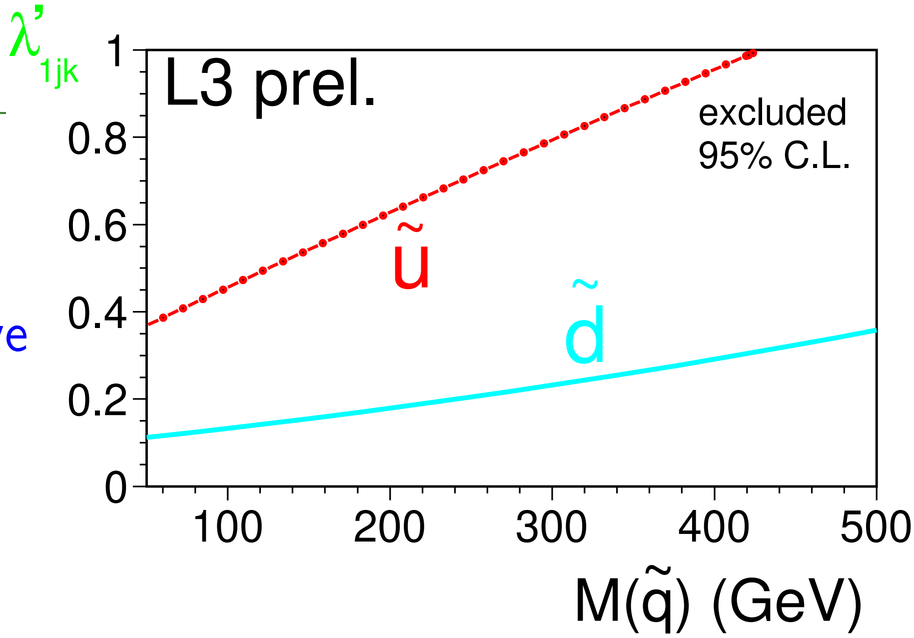


$\tilde{q}$ masses up to $\sqrt{s}$ accessible for $\lambda' > 10^{-1}$

t-channel exchange:

final state: 2 jets

$\tilde{q}$ masses even above $\sqrt{s}$ accessible for $\lambda' > 10^{-1}$



Spontaneous R-parity violation

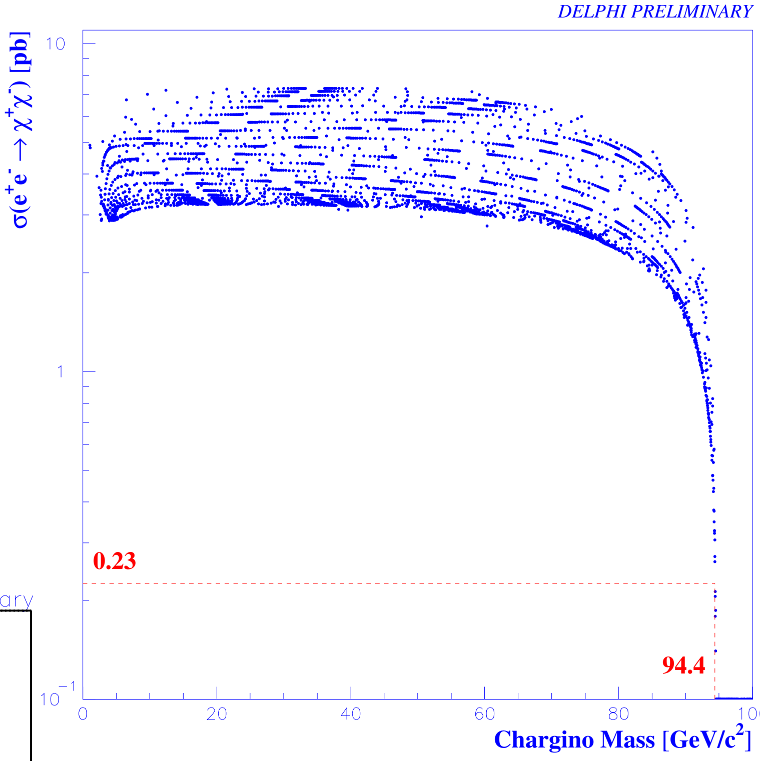
spontanous breaking of Supersymmetry:

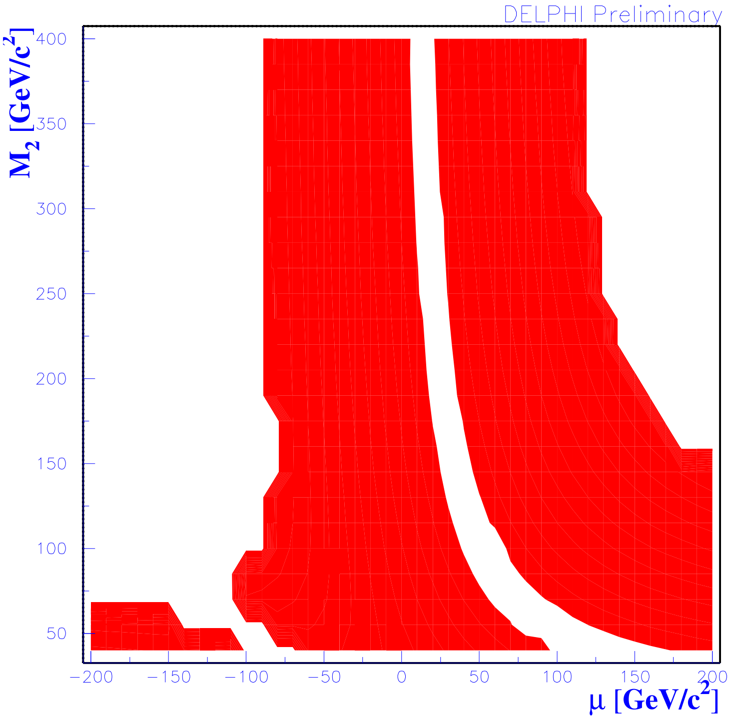
- massless Majoron (J)
- $\boldsymbol{R_p}$ violating superpotential $\boldsymbol{\epsilon_i}\ L_i H_u$
- mixing between lepton and gaugino sector (3. generation)
- leading to neutrino masses

- additional decays:

$$\tilde{\chi}_1^\pm \to \tau^\pm J$$

signal signature:
two acoplanar taus





at $\sqrt{s} = 183$ and 189 GeV

15 events observed with

15.8 events expected

m$(\tilde{\chi}_1^\pm) > 94.4$ GeV

for m$(\tilde{\nu}) > 300$ GeV

Conclusions and Outlook

- Searches for $\boldsymbol{R_p}$-violating production and decay of SUSY particles are complementary to searches with $\boldsymbol{R_p}$-conservation
- Searching for both scenarios has extended discovery potential
- in case of $\boldsymbol{R_p}$-violation sparticles masses up to $\sqrt{s}$ can be probed
- Under the assumption of $\boldsymbol{R_p}$-violation searches have been performed at LEP for $\sqrt{s} \leq 202$ GeV gauginos, sleptons, sneutrinos and squarks for all Yukawa couplings $\boldsymbol{\lambda}$, $\boldsymbol{\lambda'}$, $\boldsymbol{\lambda''}$ and for bilinear terms ϵ
- No evidence for SUSY with $\boldsymbol{R_p}$-violation so far at LEP
- neutrino masses can be explained with $\boldsymbol{R_p}$-violation
- results from this years data will be presented on Saturday
- $\boldsymbol{R_p}$-violating scenarios have to be considered at future colliders like LHC or NLC